NOVA REPORT 2003-2005

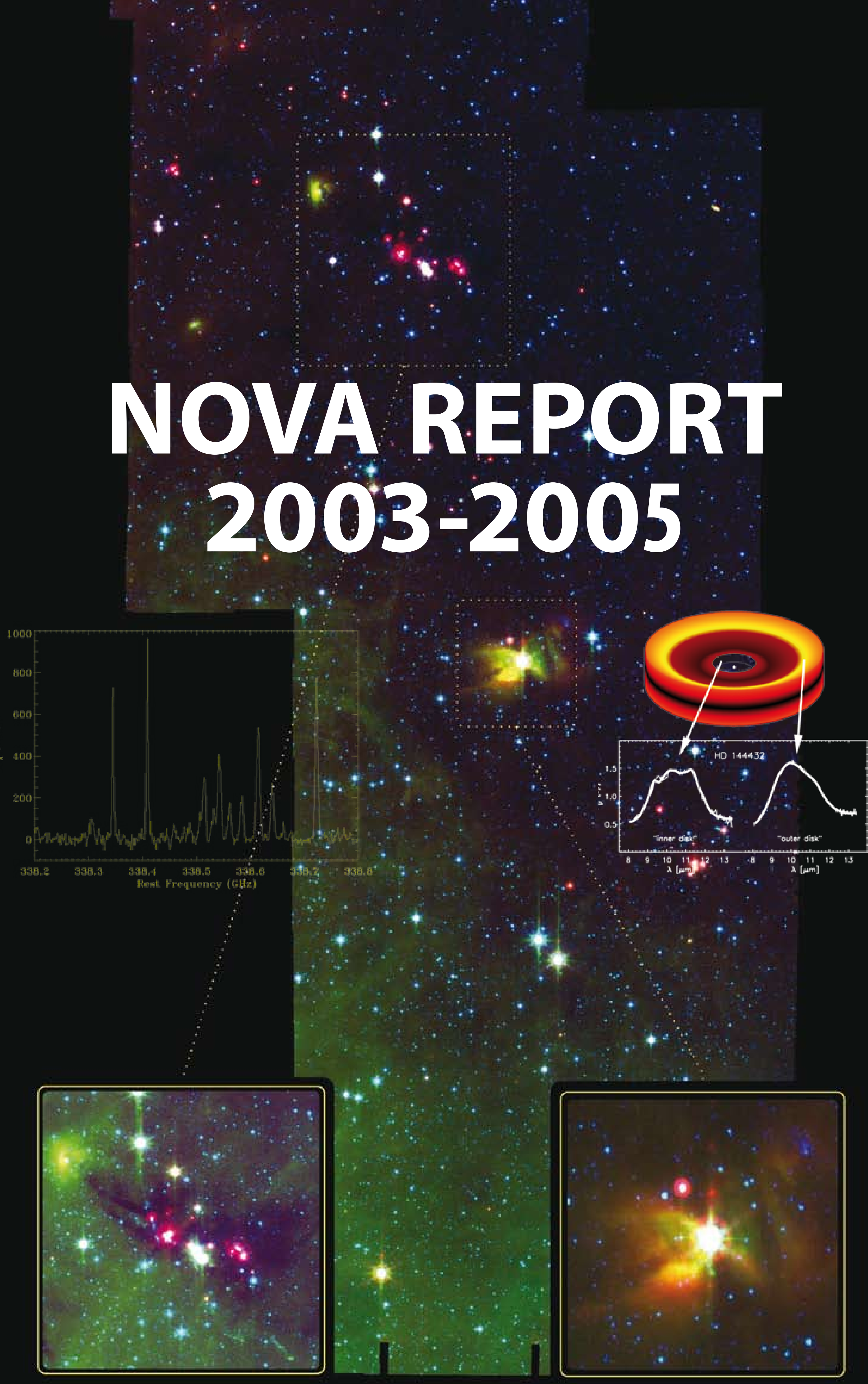

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Illustration on the front cover

Spitzer image of the Serpens molecular cloud mapped by the 'Cores to Disks' Legacy program combining data at 3.6, 8 and 24 µm. The inserts show a newly-discovered cluster of young stars as well as the young star VV Ser with its shadow disk. Follow-up IRS spectroscopy shows that the newly discovered sources cover a range of evolutionary stages, from deeply embedded YSOs to young stars with optically thin disks (based on Pontoppidan, Geers, Merin, van Dishoeck et al. 2006). Superposed is a schematic view of a flaring circumstellar disk and the VLTI-MIDI spectra observed of the inner and outer regions of a Herbig Ae disk (van Boekel, Waters et al. 2005). Also superposed is part of the JCMT 345 GHz spectral survey of the low-mass protostar IRAS 16293-2422, showing strong lines of gaseous methanol (Tielens, Helmich et al. 2006).

Illustrations on the back cover

Clockwise starting at upper left.

1. First ALMA Band 9 receiver cartridge.

2. MIRI qualification model mirrors support structure

3. The 2K camera for the SINFONI integral field spectrograph

4. PuMa for the WSRT.
   Netherlands Research School for Astronomy

NOVA Report

2003 - 2004 - 2005

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NOVA is a federation of the astronomical institutes at the universities of Amsterdam, Groningen, Leiden, Nijmegen and Utrecht, legally represented by the University of Groningen.

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1. Introduction

In 1997 the Ministry of Education, Culture and Science initiated a ten-year program, the so-called 'In Depth Strategy' to identify and stimulate national focus points of excellent scientific research, which also train outstanding young scientists. To meet the selection criteria, such focus points were compared with the best foreign institutes in their field of research. The Netherlands Organization for Scientific Research (NWO) selected six such National Research Combinations from 34 proposals covering all academic disciplines. The Netherlands Research School for Astronomy, NOVA, was ranked highest among the six, and received an initial grant of 21 M€ to support its proposed innovative research program entitled 'The Life-Cycle of Stars and Galaxies' through mid 2005.

The NOVA program started in 1999, with a budget profile that ramped up to full strength by 2002. The current report describes activities in 2003, 2004 and 2005. This period saw many new appointments on the permanent and temporary research and technical staff, and continuation of a strong instrumentation program. NOVA funds nearly 25% of the research and technical positions at the five participating universities, an active workshop and visitor program, and outreach efforts. The ambitious instrumentation program is on track, and has generated substantial additional funding. As a result, the quality and quantity of the research output of Dutch astronomy, and of the graduate education, continues to increase.

In 2003 NWO carried out a mid-term review of the achievements of the program, and of the plans through 2008, which had been developed with input from NOVA's International Advisory Board. The resulting very positive recommendation led to a further allocation of nearly 15 M€ to support the program through 2008. Sadly, the chair of the International Advisory Board, professor John Bahcall of the Institute for Advanced Study, and one of the most distinguished astronomers anywhere in the world, passed away in August 2005, well before his time.

The year 2005 also saw the retirement of van den Heuvel, who had served on the NOVA Board since 1992, and chaired it for many years. He helped shape Dutch astronomy over many decades, and had a key role in the development of the entire NOVA program. His new-found freedom to concentrate on research again is eminently deserved.

Highlights for the period 2003-2005 include:

- A tremendous variety of new astrophysical results which are summarized in chapter 3 of this report;

- A total of 58 PhD degrees in astronomy awarded at the five NOVA institutions (chapter 4), with cum laude for van de Ven;

- The excellent performance of MIDI on ESO's VLTI, SINFONI on ESO's VLT and PuMa on the WSRT. MIDI is the first NOVA instrumentation project for which hardware and software delivery was completed. It is the first common-user interferometric instrument on the VLTI entering into its routine mode of science operations. SINFONI combines the strengths of adaptive optics and integral field spectroscopy in the near-infrared. PuMa provided the WSRT with a state-of-the-field pulsar timing facility;

- Many awards and honors for NOVA researchers, including
  - A Royal Academy of Arts and Sciences (KNAW) Professorship to Miley
  - Election to the KNAW for Lamers
  - The very prestigious NWO Spinoza Award to van der Klis
  - The Physica Prize to van Dishoeck
  - Appointment to the Jacobus C. Kapteyn Chair for van der Kruit
  - The Annie Jump Cannon award of the American Astronomical Society for Ferguson
  - An honorary doctorate from the Université Claude Bernard in Lyon to de Zeeuw, and from the Observatoire de Paris to Blaauw
  - The Christiaan Huygens Award to Helmi for the best PhD dissertation in space sciences in the period 2000-2003

- Co-winner of the EU Descartes prize for Stappers as member of the European PULSE collaboration for research into the use of radio pulsars to study the most extreme physical conditions in the universe and test its most fundamental laws
- An Excellence Grant from the European Union to Schaye.

- NWO awarded VIDI grants to Helmi (2003), Fender (2003), Hogerheijde (2004), Vink (2005), and Koopmans (2005), and VICI grants to Wijers (2003) and Keller (2005);

- Award of most of the construction funds for a new international radio observatory, LOFAR, with its headquarters at ASTRON in Dwingeloo through the BSIK scheme;

- The visit in May 2005 by her excellency Maria van der Hoeven, the Minister of Education, Culture and Sciences, to the ESO Very Large Telescope at Paranal and the ALMA project near San Pedro de Atacama in Chile. Van der Kruit, van Dishoeck and de Zeeuw accompanied her, together with highly-ranked officials from the Ministry.

2. Mission statement and research program

NOVA is a federation of the astronomical institutes of the universities of Amsterdam, Groningen, Leiden, Nijmegen and Utrecht, officially recognized by the Royal Academy of Arts and Sciences in 1992. When NOVA was founded as an inter-university collaboration, it was agreed that its legal representation ('penvoerderschap') should rotate between the participating universities. Accordingly, Leiden University (UL) was penvoerder in the 1992-1996 period, and the University of Amsterdam (UvA) was penvoerder for the following five years ending on 1st September 2002. Since that date NOVA is legally represented by the University of Groningen (RuG), for a term of five years.

2.1. NOVA's mission

NOVA's mission is to carry out frontline astronomical research in the Netherlands, and to train young astronomers at the highest international level. All graduate astronomy education in the Netherlands is concentrated in NOVA.

2.2. The NOVA program: The life-cycle of stars and galaxies

Stars form in galaxies from interstellar material, and at the end of their lives return chemically-enriched material to the interstellar medium from which new generations of stars and planets form. The most massive and luminous stars evolve fastest, and leave neutron stars and black holes. This life cycle causes evolution in the stellar population of a galaxy as a whole. Recent technological advances make it possible to observe this evolution all the way back to epochs when the Universe was less than 4% of its present age. The theme of the NOVA Program is to unravel the history of the universe and to further develop the understanding of the life cycle of stars and galaxies. This requires full knowledge of astronomy and astrophysics, and state-of-the-art observations.

The NOVA research program concentrates on the following three areas:

- Formation and evolution of galaxies: from high redshift to the present
- Birth and death of stars: the life-cycle of gas and dust
- Final stages of stellar evolution: physics of neutron stars and black holes

The research is carried out in three interuniversity networks, each led by 4-6 key researchers with international reputations.

The NOVA instrumentation program is carried out in collaboration with the NWO institutes ASTRON and SRON, and institutions abroad. The aim is to strengthen the technical expertise at the universities, and to develop and construct new instrumentation and high-level software for world-class observatories. These include the ESO Very Large Telescope, the ESO-VLT Interferometer (VLTI), the VLT Survey Telescope (VST), the Atacama Large Millimeter Array (ALMA), the Atacama Pathfinder Experiment, the James Webb Space Telescope, the Westerbork Synthesis Radio Telescope (WSRT), the LOw Frequency ARray LOFAR, and the Sackler Laboratory for Astrophysics.

The entire program enables NOVA researchers to obtain a rich harvest of results from unique ground-based and space-based facilities, and will allow NOVA to maintain and strengthen its status as a premier international center for research and education in astronomy.

3. Progress reports from the research networks

This chapter summarizes the research highlights of the three research networks. More information can be found in the annual reports of the five university astronomical institutes.

3.1. Formation and evolution of galaxies: from high redshift to the present

The aim of the research of Network 1 is to study the formation and evolution of galaxies from our local neighborhood at redshift 0 to the first observable objects at redshifts just under 7 (a look back time of more than 90% of the history of the universe). This overview only gives the highlights and is not meant to be an exhaustive summary of all research that has been carried out.

3.1.1. The Galaxy and galaxies in the Local Group

3.1.1.1. Substructures in the Galaxy

Helmi (NOVA overlap) demonstrated that the kinematics of old debris from the Sagittarius dwarf galaxy can be used to determine the shape of the Galactic dark halo. Radial velocities for M giants from the 2MASS catalog, selected to be part of the Sgr dwarf leading and trailing streams, were compared to the model predictions of the Sgr dwarf orbiting Galactic potentials, with halo components of varying degrees of flattening and elongation. She showed that the leading stream contains sufficiently old debris that its kinematics provide for the first time direct evidence that the dark-matter halo of the Galaxy has a prolate shape with an average density axis ratio within the orbit of Sgr close to 5/3 (Fig 3.1).

Battaglia and Helmi together with the Spaghetti survey team (PI: Morrison, Case Western) compiled a new sample of 241 halo objects with accurate distance and radial velocity measurements, including globular clusters, satellite galaxies, field blue horizontal branch stars and red giant stars from the Spaghetti survey. The new data led to a significant increase in the number of known objects for Galactocentric radii beyond 50 kpc, which allows a reliable determination of the radial velocity dispersion profile out to very large distances, and a more precise measurement of the Milky Way mass. The radial velocity dispersion shows an almost constant value of 120 km/s out to 30 kpc and then continuously declines down to 50 km/s at about 120 kpc. This fall-off puts important constraints on the density profile and total mass of the dark matter halo of the Milky Way. For a constant velocity anisotropy, the isothermal profile is ruled out, while both a dark halo following a truncated flat model of mass $1.2^{+1.8}_{-0.5}\times10^{12}$ $M_\odot$ and an NFW profile of mass $0.8^{+1.2}_{-0.2}\times10^{12}$ $M_\odot$ are consistent with the data.

In collaboration with Navarro (Victoria) and Freeman (ANU), Helmi reanalyzed the group of stars associated kinematically with Arcturus, and confirmed that they constitute a peculiar grouping of metal-poor stars with similar apocentric radius, common angular momentum, and distinct metal abundance patterns. These properties are consistent with those expected for a group of stars originating from the debris of a disrupted satellite. Arcturus, together with some of the brightest stars in the night sky, may have formed beyond the confines of the Galaxy.

Helmi led the search for signatures of past accretion events in the Milky Way in the recently published catalogue by Nordström and collaborators, containing accurate spatial and kinematic information as well as metallicities for 13240 nearby stars. To optimize this quest, she devised a new technique: stars with a common progenitor are expected to show distinct correlations between their orbital parameters; in particular, between the apocenter A and pericenter P, as well as their z-angular momentum (L_z). In the APL-space, such stars are expected to cluster around regions of roughly constant eccentricity. Indeed, the APL space for the Nordström catalogue exhibits a

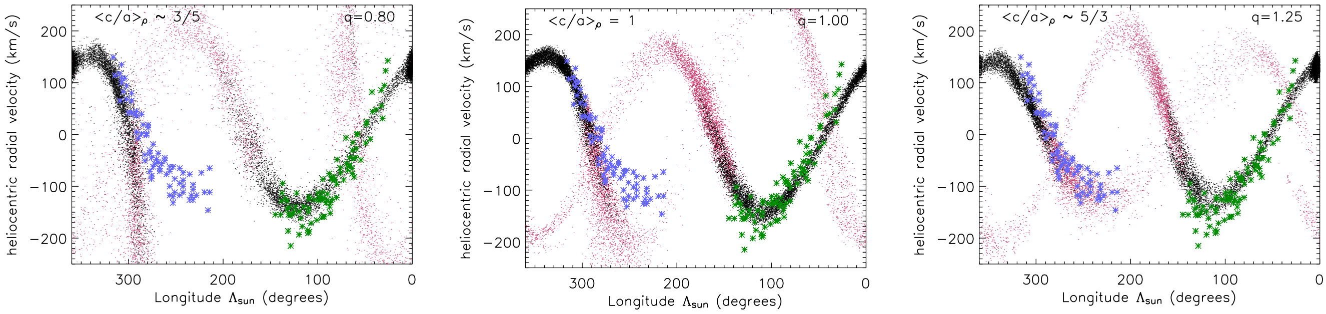


Fig 3.1: Comparison of the velocities of stars in the Sagittarius dwarf streams (from Law et al. 2004) to those predicted in numerical simulations of the evolution of Sgr in a Galactic potential with different dark halo flattenings: oblate, spherical and prolate (first, second and last panel respectively). The best match corresponds to the prolate halo case (right panel).

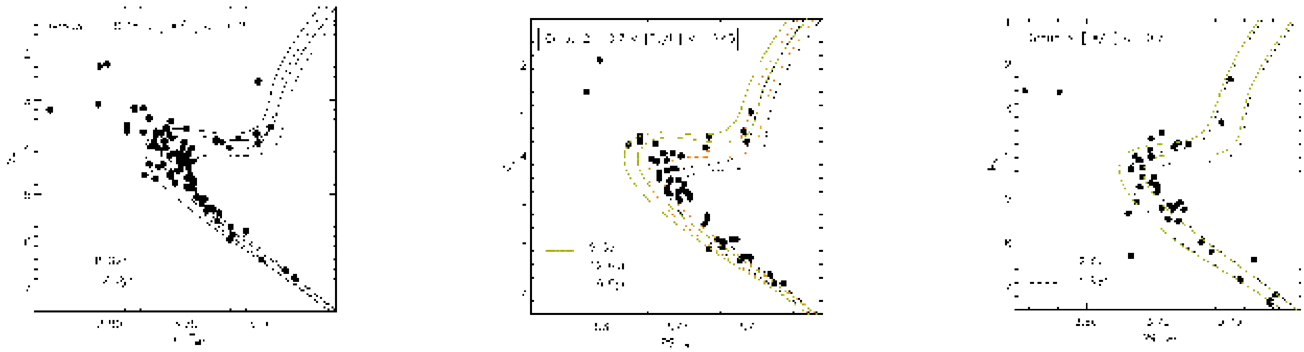


Fig 3.2: Hertzsprung-Russell diagram of the stars associated to the overdensities found in the APL-space. It is possible to identify three coherent Groups (first, middle and last panels) among these stars on the basis of their metallicity. The well-defined HR diagrams bare a striking resemblance to those of present-day dwarf satellites of the Milky Way, with the provision that they correspond to stars distributed all across the sky! These are in all likelihood the remains of satellites disrupted more than 8 Gyr ago.

statistically significant excess of stars on orbits of common (moderate) eccentricity, analogous to the pattern expected for merger debris. Besides being dynamically peculiar, the 274 stars in these substructures have very distinct metallicity and age distributions, providing further evidence of their extra-Galactic provenance (Fig. 3.2). The identification of substantial amounts of debris in the Galactic disk, whose origin can be traced back to more than one satellite galaxy, provides direct evidence of the hierarchical formation of the Milky Way.

3.1.1.2. Surveys of the Galaxy

Helmi is a partner of the RAVE (Radial Velocity Experiment, PI: Steinmetz at Potsdam): an ambitious program to conduct an all-sky survey to measure the radial velocities, metallicities and abundance ratios of 1 million stars using the 6dF multi-object spectrograph on the 1.2-m UK Schmidt Telescope of the AAO, over the period 2003 - 2010. The survey will represent a giant leap forward in our understanding of the Milky Way galaxy, providing a vast stellar kinematic database an order of magnitude larger than any other survey proposed for this coming decade. RAVE started in the Spring of 2003 and so far has delivered 80,000 spectra in the Ca-triplet region (8410-8790 Å) for southern hemisphere stars in the magnitude range $9<I<12$ at a resolution of R=8000-10000. The radial velocities measured in this survey are accurate to a few km/s. The first scientific highlights include the determination of the local escape velocity (led by Smith and Helmi together with Ruchti and Wyse at Johns Hopkins), the measurement of the local mass density (led by Bienayme in Strasbourg), and the use of the diffuse interstellar band at 8620 Å as a reddening tracer (led by Munari at Padova).

3.1.1.3. Nearby Dwarf Galaxies

Tolstoy, Cole and collaborators study the properties of large numbers of individual stars in Local Group Dwarf Galaxies. This employs both high resolution spectroscopy using FLAMES and UVES on the VLT and high resolution imaging using the HST ACS. The imaging provides multi-color photometry of the stars and enables identifying individual stellar populations groups using HR diagrams, while the spectroscopy provides detailed information about the stellar types and more importantly, the elemental abundances of the stars. The latter enable a study of the metallicity of the stars on connection with their kinematic characteristics. In the Sculptor, Fornax and Sextans dwarf spheriodal galaxies there appears to be segregation between the metal rich and the metal poor stars, the latter being more centrally concentrated.

Tolstoy leads an ESO Large Program entitled “Dwarf galaxies: remnants of galaxy formation and corner stones for understanding galaxy evolution”. This program also involves Helmi and RuG PhD students Battaglia and Letarte and a large number of colleagues around the world who call themselves the Dwarf Abundances and Radial velocities Team (DART). Their goal is to use spectroscopic and photometric data of stars in the Local Group dwarf galaxies to trace back the star formation history of these systems and understand galaxy formation from this end rather than looking back in time by going to more and more distant objects. This program found evidence for two distinct ancient stellar components in the Sculptor dwarf spheriodal galaxy. Both components are > 10 Gyr old. The team used the ESO Wide Field Imager together with the VLT/FLAMES spectrograph to study the properties of the resolved stellar population of Sculptor out to and beyond the tidal radius. They found that the two components are discernible in the spatial distribution of horizontal branch stars and in the [Fe/H] and velocity distributions for their large sample of spectroscopic measurements. They can be generally described as a "metal-poor" component ([Fe/H] ≤ –1.7) and a "metal rich" component ([Fe/H] ≥ –1.7). The metal-poor stars are more spatially extended than the metal-rich stars, and they also appear to be kinematically distinct. These results provide insight into the formation processes of small systems in the early universe. Even this simplest of galaxies appears to have had a surprisingly complex early evolution (Fig. 3.3). Similar results were obtained for the Fornax and Sextans dwarf galaxies which form a large part of the PhD thesis of Battaglia.

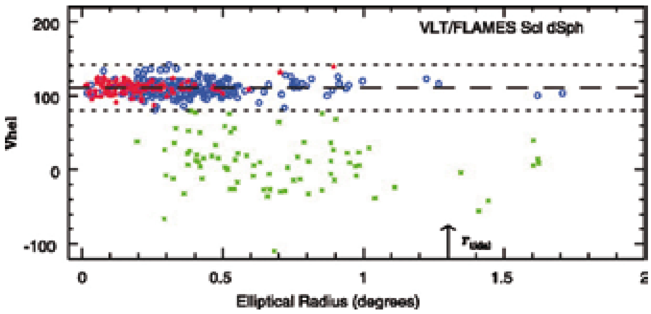


Fig. 3.3: Heliocentric velocities as a function of elliptical radius for stars in the Sculptor dwarf spheriodal galaxy with spectra satisfying a signal-to-noise ratio > 10. The 308 stars that are potential members are plotted as red asterisks ([Fe/H] > –1.7) and blue open circles ([Fe/H] < –1.7), while the 93 green crosses are assumed to be non-members. The systemic velocity of Sculptor, at 110 km/s, is plotted as a dashed line. The dashed lines are the 3σ velocity limits for membership of stars in Sculptor dwarf spheriodal. The position of the tidal radius is also marked.

Part of this large program also includes high resolution spectroscopy of large samples of individual stars in nearby dwarf galaxies. This is the PhD project of Letarte carried out in close collaboration with Hill (Observatoire de Paris). Previous spectroscopic samples in dwarf galaxies contain 3-5 stars per galaxy, with FLAMES this is dramatically increased to nearly 100 stars in each of 4 different nearby galaxies (Sculptor, Fornax, Sextans and Carina). This proved unambiguously that stars in dwarf galaxies and all components of the Milky Way have significantly different abundance patterns which mean that the Milky Way can not be built up of building blocks which are like the dwarf galaxies we see around the Milky Way today. This is clearly illustrated in Fig. 3.4.

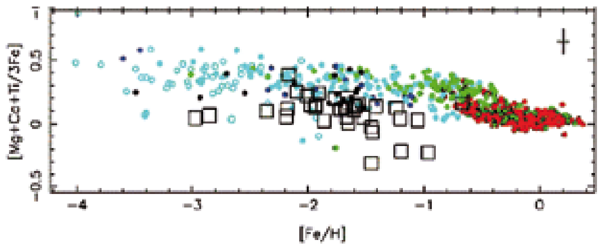


Fig. 3.4: [α/Fe] versus metallicity for the mean of individual α elements Mg, Ca, Ti. The Milky Way thin disk (red), thick disk (green), halo (cyan), an extreme retrograde component (black) and a high velocity Toomre component (blue). Data are from Venn et al. 2004.

Cole, Tolstoy and collaborators obtained HST/ACS imaging data to look at the Leo A dwarf irregular galaxy, which is an extremely low metallicity (~3% solar) star-forming dwarf galaxy in the Local Group. It is the best nearby candidate to be a redshift zero analogue to the major building blocks of the Milky Way. These new data provide the first opportunity to measure the complete star-formation history of a potential "living fossil" analogue to the building blocks of the Milky Way using color-magnitude diagram analysis. The data show a clear old (but not ancient) main sequence turnoff which proves that the majority of stars in Leo A were formed in the last few Gyr, although it also contains ancient stars (as evidenced by the faint blue horizontal branch sequence of stars in the color-magnitude diagram. It is not clear why this galaxy formed most of its stars relatively recently.

3.1.1.4. Molecular gas in the Magellanic Clouds

From 1988 to 1995, an ESO-Swedish Key Program mapping CO in the Magellanic Clouds was carried out on the SEST in Chile under the co-leadership of Israel and Johansson (Onsala). In 2003, Israel, Johansson, Rubio, Garay (latter two Univ. Chile) and collaborators finished the analysis of the last parts of the survey. The distribution of molecular gas in the N 11 complex, the second brightest star forming complex in the LMC, is highly structured. In the south-western part of N 11 molecular clouds form a shell surrounding the OB star association LH 9. In the north-eastern part, a chain of molecular clouds follows the rim of a supergiant shell. The individual clouds have diameters of 25 pc or less. In those clouds where physical parameters could be modeled, the gas is warm (T_{kin} = 60 – 150 K) and moderately dense (n_{H2} = 3000 cm^{-3}). The northeastern chain of CO clouds lacks diffuse intercloud emission, but is otherwise similar to the more quiescent regions of the LMC. The clouds in the southwestern shell have all the characteristics of an extreme photon-dominated region (PDR). Throughout molecular clouds in the LMC, the isotopic ratio ^{12}CO /^{13}CO is typically about 10, twice higher than common in Galactic star-forming complexes. Lower ratios apply to relatively dense and cold molecular gas in cloud centers, whereas higher ratios mark CO photo-dissociation zones at the cloud edges.

Israel, Bolatto, Leroy (both Berkeley) and Jackson (Boston) determined the CO-to-H_2 conversion factor in the N83/N84 starforming complex in the low metallicity (~1/9 solar) SMC. Comparison of the CO luminosities of clouds in this complex with their virial masses suggested local values for the CO-to-H_2 conversion factor X_{CO} which are only a factor two larger than those obtained in a similar manner for clouds with solar metallicity in the Milky Way and M33. However, comparison of CO, neutral hydrogen and far-infrared measurements yielded a global factor fifty times higher than found in the Milky Way. These results fit into the pattern that CO observations with high linear resolution invariably suggest nearly Galactic values of X_{CO} independent of environment.

By combining J=4-3 CO submillimeter emission data from the SMC and the LMC obtained with the AST/RO telescope located at the South Pole with lower transition data from the SEST survey Israel, Bolatto and Martin (Berkeley) concluded that the relatively high gas temperatures measured in N11 are in fact pervasive throughout the sample. This may be a consequence of the low metallicities and the associated dearth of gas coolants but more information is needed to uniquely determine the cause.

3.1.1.5. Microlensing in the Andromeda galaxy

The nature and distribution of dark matter in galaxies is still an unsolved mystery in astronomy. The microlensing results towards the Magellanic Clouds indicate that at most 20 percent of the Galactic dark matter can be in compact objects. The Andromeda galaxy (M31), being the nearest large spiral galaxy to the Milky Way, provides a way of studying another dark matter halo, independent of our own Milky Way halo. Because of the high inclination of M31 a microlensing halo will induce a clear signal in the spatial distribution of the microlensing events. The MEGA (Microlensing Exploration of the Galaxy and Andromeda) collaboration, consisting of de Jong and Kuijken and international co-workers Crotts, Uglesich, Alves, Czjernes (Columbia University), Sackett (Mt. Stromlo), Sutherland (Cambridge), Baltz (Stanford), Gyuk (Chicago), and Widrow (Queens) performed a survey of two large fields in M31, using special techniques to detect microlensing of unresolved stars. Several telescopes were used for several years including the INT on La Palma. In 2005 the results of the INT program were published as part of de Jong's PhD thesis. A total of 14 microlensing events were detected. This number is fully consistent with the microlensing expected from the known stellar populations in M31. Formally, at most 20% of the dark halo can consist of microlensing objects, but the most likely solution is that the halo does not consist of dark, star-mass objects at all.
In a follow-up project, HST observations of five of the events were obtained, and in three cases the source star could be unambiguously assigned. Their colors and magnitudes indicate that the stars are unlikely to be variable stars, confirming the microlensing interpretation of the events.

3.1.2. Nearby Galaxies

3.1.2.1. Formation and disruption of star clusters in galaxies

Star clusters are ideal chronometers to determine the evolution of nearby galaxies, because they can be observed in galaxies of distances up to about 20 Mpc, and their age can be determined from their energy distribution. Therefore the age distribution of clusters provides a record of the star formation history of galaxies. However, star clusters are also destroyed by internal and external effects. Hence, the study of the star formation history of galaxies has to be combined with a study of the cluster destruction. Boutloukos and Lamers derived an empirical method for determining the disruption time of star clusters in different galaxies, based on the mass and age distributions of unbiased cluster samples. This method was applied to star clusters in a number of galaxies.

From HST imaging of star clusters in M82 Bastian (NOVA PhD), Lamers, and de Grijs (IoA, Cambridge) revealed a population of "intermediate age" star clusters, which fill the gap in evolutionary phase between the tradition "old" globular clusters, and the "young massive clusters" observed today in starbursts and even in some normal spiral galaxies. The mass function of these young massive clusters is a power-law increasing towards low-mass clusters, whereas the mass function of the globular clusters shows a distinct turnover at a few x10^5 $M_\odot$. The cluster population in M82, although young, also shares this turnover in its mass function, which is thought to come from the preferential disruption of low mass clusters, as the population evolves.

Lamers, Gieles (NOVA PhD student), Bastian, and Portegies-Zwart in collaboration with Baumgardt (Bonn) and Karchenko (Kiev, Ukraine) studied the formation rate and its history of clusters in the solar neighborhood using a new and complete cluster sample within 600 pc from the sun. They found that the disruption time of star clusters in the solar neighborhood is five times shorter than predicted by N-body simulations. The present star formation rate in bound clusters is about half that derived from the study of embedded clusters. The difference suggests that about half of the stars in the solar neighborhood are born in clusters that become unbound within about 10 Myr.

Gieles, Bastian, Lamers, Scheepmaker and Mout together with de Grijs studied the cluster population and the cluster formation history in M51 using HST-observations of 1152 clusters. Just like in the solar neighborhood, the cluster destruction time is a factor five shorter than predicted. There is clear evidence for an increase in the cluster formation rate by a factor 3 during the two encounters of M51 with its companion NGC 5195, about 70 and 400 Myr ago. The ratio of the numbers of clusters younger and older than 10 Myr indicates that most of the clusters, about 70%, do not survive as bound clusters after 10 Myr in M51.

Young star clusters do not form in isolation, but instead tend to form in larger groupings or complexes. Bastian, Gieles, Lamers and Efremov (Moscow) used HST broad and narrow band images (from both WFPC2 and ACS), along with BIMA-CO observations to study the properties and to investigate the origin of these complexes in the interacting galaxy M51. They found that the complexes are all young (<10 Myr), have sizes between ~85 and ~240 pc, and have masses between 3 and 30 x 10^4 $M_\odot$. Unlike isolated young star clusters, there is a strong correlation between the complex mass and radius, which is similar to that found for giant molecular clouds. By comparing the mass-radius relation of GMCs in M 51 to that of the complexes they derived a star formation efficiency of 50 ± 20%. The complexes have the same surface density distribution as individual young star clusters and GMCs. If star formation within the complexes is proportional to the gas density at that point, then the shared mass-radius relation of GMCs and complexes is a natural consequence of their shared density profiles. Many of the complexes show evidence for merging of star clusters in their centers, suggesting that larger star clusters can be produced through the merging of smaller clusters.

The destruction time of star clusters appears to differ very strongly from galaxy to galaxy. Lamers, Gieles and Portegies-Zwart derived and compared the dissolution times of star clusters in four galaxies: the solar neighborhood of our Galaxy, the SMC and in selected regions of M 51 and M 33, with theoretical predictions based on N-body simulations. In all four galaxies the empirically derived lifetimes of clusters depends on their initial mass as ~ $M_i^{0.6}$, in excellent agreement with N-body simulations. The disruption times of star clusters in M 51 within 1-5 kpc from the nucleus, are shorter than predicted by about an order of magnitude. This discrepancy is most likely due to the strong tidal field variations in M 51, caused by the strong density contrast between the spiral arms and inter-arm regions, and to the disruptive forces from giant molecular clouds.

3.1.2.2. Stellar Content of Nearby Galaxies

Trager in collaboration with Worthey (WSU), Faber (UCSC), and Dressler (OCIW) probed for the presence of hot, evolved stars in elliptical and lenticular (so-called "early-type") galaxies in the Coma Cluster using extremely high signal-to-noise optical spectra. Such hot stars have been proposed to corrupt the measurement of ages of early-type galaxies. Their ages are crucial to better understand how they formed. Determination of galaxy ages is based on the strength of the absorption lines of hydrogen, which are sensitive to hot—young or old—stars in galaxies. If the stars contributing to the lines are hot but old, the measured ages are meaningless, because the lines will be misinterpreted as coming from young stars. The study of Trager et al., using different lines that are sensitive to giant -and therefore old - hot stars, found that while hot, evolved (old) stars are certainly present in these galaxies, they actually have little effect on the measured ages, even without correcting for their presence. However, they do affect the measured chemical compositions and must be taken into account if a careful census of the chemical make-up of galaxies is desired.

3.1.2.3. The SAURON project

De Zeeuw, Peletier, Cappellari (VENI fellow), Damen (NOVA PhD), Falcón-Barroso (EU fellow/NOVA postdoc), Krajnović (NOVA PhD), McDermid (NOVA postdoc), van de Ven (UL/NOVA PhD), Fahti, Ganda and Weijmans are members or associates of the SAURON team that built a panoramic integral-field spectrograph for the 4.2 m WHT on La Palma, in a collaboration which involves groups in Lyon (Bacon) and Oxford (Davies). SAURON (Spectroscopic Areal Unit for Research on Optical Nebulae) records 1577 spectra simultaneously, with full sky coverage in a field of 33'' by 44'', with additional coverage of a small 'sky' field 1.9' away, spatial sampling of 0.94'' by 0.94'', and an instrumental dispersion of 105 km/s.

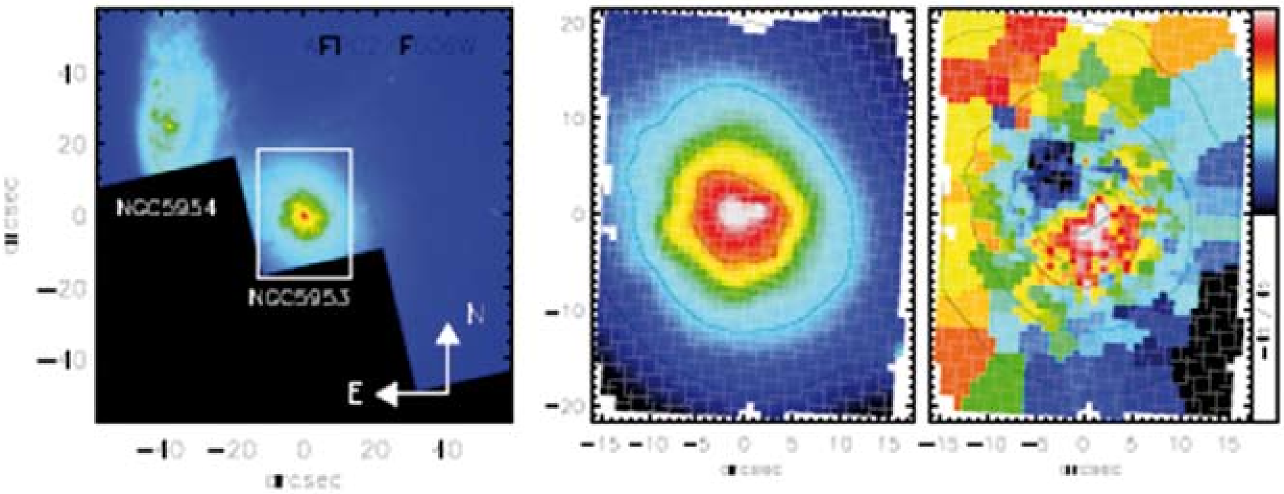


Fig 3.5: Interacting pair NGC5953/NGC 5954. From left to right: i) HST/ WFPC2 image of the pair of galaxies. Overlaid on NGC5953 is the SAURON field-of-view. ii) SAURON reconstructed intensity image of NGC5953, iii) stellar radial velocity of NGC5953.

SAURON was used to measure the kinematics and line strength distributions for a representative sample of 72 nearby early-type galaxies (ellipticals, lenticulars, and Sa bulges, in clusters and in the field). The entire survey was completed in 2003. In parallel with the data taking, the team developed a number of tools that are key to analyze all the resulting maps. The team built an elaborate software pipeline to reduce and analyze the data to produce full 2D velocity maps from both stellar absorption lines and ionized gas emission lines (for example Fig. 3.5), and maps of velocity dispersion and of line ratios. In general, the gas maps display regular motions with smooth variations in angular momentum. In the majority of the galaxies, the gas kinematics is decoupled from the stellar counterpart, and less than half displays signatures of recent acquisition of gaseous material. The presence of dust features is always accompanied by gas emission while the converse is not always true. Finally, a considerable range of values for the [OIII]/Hβ ratio was found both across the whole sample and within single galaxies. Absorption line maps in four strong absorption lines were derived for the elliptical and S0 galaxies of the sample. The metal line strength maps generally show negative gradients with increasing radius, consistent with the morphology of the continuum light. For 40% of the galaxies, however, the ones displaying significant rotation show Mg b isoindex contour maps that are flatter than the continuum isophotes. This implies that these fast-rotation components feature a higher metallicity and/or an increased Mg/Fe ratio as compared to the galaxies as a whole. Apart from these surveys a number of galaxies (NGC 7332 and NGC 4321) were studied in detail.

Peletier, Ganda and the SAURON team extended the SAURON database to include a sample of 18 late type spiral galaxies. These data allow a study of the internal kinematics of gas and stars for the objects, as well as their stellar populations, following the methods already developed within the SAURON team. The stellar kinematics permits a distinction between spiral galaxies possessing thick and hot bulges in their centers and galaxies without bulges. The connection between the presence of a bulge and the stellar population in the galaxies will be used to understand the bulge-formation process.

Peletier and Falcón-Barroso, together with Sanchez-Blazquez (Lausanne), Gorgas, Cenarro (both UCM), Jimenez (Granada) and Selam (Ankara) developed a stellar library for population synthesis, named MILES, consisting of 1000 stars, and covering a large range in wavelength at a resolution of 2 Å. The coverage of stellar parameters (gravity, temperature and metallicity) is much larger than in previous libraries. The accurate flux-calibrated spectra make it possible to significantly improve models for galaxy population synthesis.

Morganti, de Zeeuw, Oosterloo, McDermid, Krajnovic, Cappellari and Weijmans used the WSRT to carry out deep observations of the neutral hydrogen in a sample of 12 elliptical and lenticular galaxies selected from a representative nearby sample already studied at optical wavelengths with SAURON. They detected HI in or near 70% of the galaxies. This detection rate is much higher than in previous, shallower surveys, and is similar to that for the ionized gas. The observed total HI masses range between a few times 10^6 $M_\odot$ to just over 10^9 $M_\odot$. The HI morphologies include regular disks as well as offset HI clouds and tails. Galaxies with HI disks tend to also have strong emission from ionized gas. In these cases, the neutral hydrogen and the ionized gas appear to be part of the same structure (Fig. 3.6). The kinematical axis of the stellar component is however nearly always misaligned with respect to that of the gas. There is no clear trend between the presence of HI and the age of the stellar population or the dynamical characteristics of the galaxies: HI detections are found uniformly spread through fast- and slow rotating galaxies. Therefore, if these two types of galaxies represent the relics of different formation paths, this does not appear in the presence and distribution of the HI.

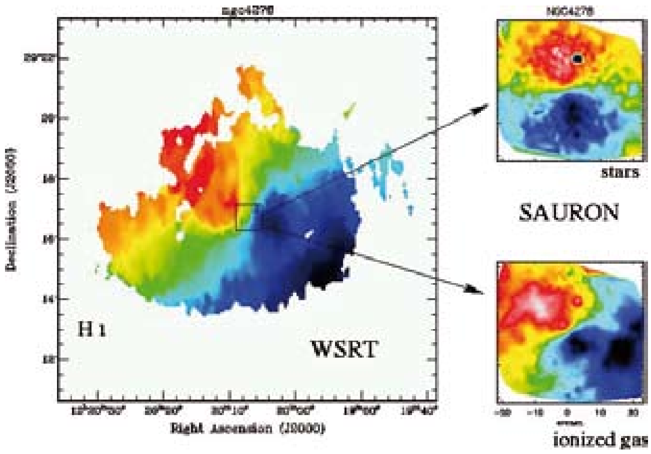


Fig 3.6: Velocity fields of the HI, ionized gas and stars of the galaxy NGC 4278.

Cappellari, together with van den Bosch, Damen, Falcón-Barroso, Krajnović, McDermid, van de Ven and de Zeeuw, investigated the well-known correlation between the dynamical mass-to-light ratio of galaxies and the corresponding velocity dispersion σ of the stars. They found a tight correlation, of the form $(M/L) \sim \sigma_e^\beta$, between the M/L measured from the dynamical models and the luminosity-weighted second moment of the line-of-sight velocity σ_e within the half-light radius. The comparison of the observed accurate correlation with the similar one derived using simple virial estimates of M/L and with estimates of the M/L of the stellar population, showed that (i) the 'tilt' of the Fundamental Plane of early-type galaxies is almost exclusively due to a real M/L variation, while orbital and photometric non-homology has a negligible effect on it; (ii) galaxies are likely not to be dark-matter dominated within R_e; (iii) the virial mass, which is generally used in high-redshift studies, is a good estimator of the galaxy mass.

Cappellari, in collaboration with the other SAURON team members in Leiden, analyzed the orbital distribution derived from the Schwarzschild modeling of the sample of 24 early-type galaxies described previously, and found that a revision may be needed of the conventional interpretation of the (V/σ)-ε diagram, which relates the observed flattening of early-type galaxies to their amount of rotation. The models reveal that the slowly-rotating elliptical galaxies are generally quite round and not far from isotropic inside R_e. The anisotropy of the flatter ellipticals is either due to the presence of disk-like components, which tend to be radially anisotropic (heated?), or due to counter-rotating stellar components, which produce tangential anisotropy, or in some cases to strong triaxiality and the presence of barred components.

3.1.2.4. HI in nearby galaxies

Boomsma, van der Hulst, Sancisi, Oosterloo and Fraternali (Oxford) made a detailed study of the vertical structure and kinematics of HI gas in the spiral galaxies NGC 6946 and NGC 253. The starburst galaxy NGC 253 turns out to have an HI halo similar to NGC 891 and NGC 2403, but also plumes of gas extending to 8 kpc from the disk. A starburst in the center of NGC 253 is ejecting a superwind. This superwind has probably brought up the HI from the halo layer, producing the plumes. From the data it is also clear that the HI disk of NGC 253 is much smaller than the stellar disk.

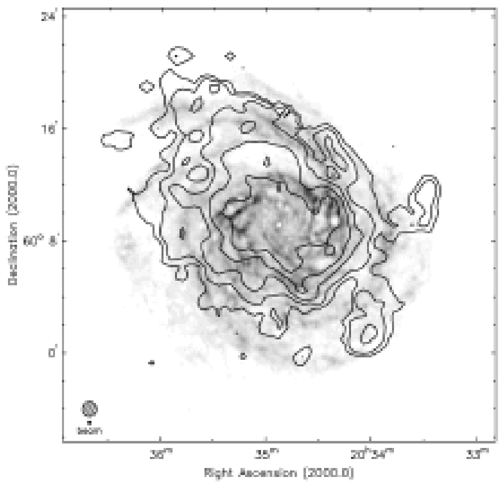


Fig 3.7: An image of the HI distribution in NGC 6946. The contours show where HI is found with velocities anomalous to normal galactic rotation.

Sensitive HI observations of the nearby face-on spiral galaxy NGC 6946 (Fig 3.7) reveal the presence of large complexes of kinematically anomalous HI as well as many HI holes. Both are believed to be produced by the massive star formation in the disk.

Noordermeer, van der Hulst, Sancisi, van Albada and Swaters (Maryland) studied the mass distribution in early-type disk galaxies. A major part of their study involved the imaging, with the WSRT, of the neutral hydrogen component in 68 galaxies of type S0 to Sab. Rotation curves were derived from the HI velocity fields, complemented by long-slit optical spectra for the inner regions. The rotation velocities are found to rise extremely fast in the central regions, and reach maximum values of up to 400 km/s. At intermediate radii, they often decline, but usually flatten out again in the outer parts. To study the dark matter properties of these galaxies, work continued on a careful modeling of the stellar mass distribution. Deep optical images were decomposed into bulge and disk components, and the 3D density distribution in each component was carefully measured. The bright bulges were found to dominate the gravitational potential in the inner regions of these galaxies and are responsible for the steep rise and subsequent decline in the rotation curves; their mass-to-light ratios are tightly constrained by the observed rotation curves. The stellar disks can explain the rotation velocities at intermediate radii, but the shape of the rotation curve in the outer parts can only be understood if a substantial amount of dark matter is present in these galaxies. The neutral gas is found to have little dynamical impact in these systems. There is a degeneracy between the contributions of the stellar disk and the dark matter, but these early-type disks seem less dark matter dominated than most late-type and dwarf galaxies.

Kovač, Oosterloo and van der Hulst used the WSRT to survey a region of 86 square degrees in the Canes Venatici groups of galaxies in HI to study the faint end of the HI mass function (HIMF) in order to test the predictions of the Cold Dark Matter (CDM) theory on the number density of objects with small (dark) masses. The neutral hydrogen is a much better tracer of the underlying mass distribution compared to the luminous matter and can be used to test the existence of a population of small galaxies in which the star formation has been partially or completely suppressed during cosmic evolution. Due to technical limitations, the existing HI surveys are not very sensitive on masses below 10^8 HI $M_\odot$. They detected 70 objects, 21 of them for the first time in HI. All new HI detections fall in the lower part of the mass-histogram, confirming our ability to detect galaxies with small HI masses. The fitted HIMF has a flat slope (~ 1.1), different from the steep rise predicted by CDM models.

3.1.2.5. Molecular gas in compact galaxies

Israel used published data and new observations of eleven compact (dwarf) galaxies in the J=2-1 and J=3-2 transitions of CO to construct accurate line ratios in matched beams, suitable for the modelling of physical parameters. Fits with a single gas component did not produce physically realistic results; in all cases much better results were obtained by modelling two distinct gas components. These show that typically in these compact galaxies, molecular gas is warm (50-150 K) and moderately dense (n = 3000 cm^{-3}). The gas-phase carbon is mostly in atomic form; only 5% is locked up in carbon monoxide. Although beam-averaged CO column densities are low (10^{16} cm^{-2}, H_2 column densities are high (10^{22} cm^{-2}) confirming large CO-to-H_2 conversion factors of 10^{21}-10^{22} cm^{-2}/K km/s found for low-metallicity environments by other methods. The CO measurements allow the compact galaxies to be divided into three different types: type I (high rotational and isotopic ratios) corresponds to hot and dense molecular clouds dominated by star-forming regions; type II has lower ratios, similar to the mean found for infrared-luminous galaxies in general, and corresponds to environments engaged in, but not dominated by, star-forming activity; type III, characterized by low CO (2-1)/(1-0) ratios, corresponds to mostly inactive environments of relatively low density.

3.1.2.6. Gas and dust in the whirlpool galaxy M51

Meijerink, Israel, Van der Werf, Tilanus (JAC Hawaii) and Dullemond (MPA, Garching) used SCUBA on the JCMT to obtain a submillimeter map of dust emission from the whole of M51, readily showing dust following the spiral pattern. Quite surprisingly, however, most of the dust emission was found to originate in a smooth exponential disk with a scale length of 5.5 kpc, the first time such a component is observed at (sub)millimeter wavelengths. The disk has both a radial temperature gradient and a column density gradient, and a canonical gas-to-dust ratio of about 100. Data on the central region of M51 in various CO, ^{13}CO and [CI] lines showed that the very center of M51 is poor in but not devoid of molecular gas.

Rapidly rotating material close to the nucleus represents inner spiral arms which are very rich in molecular gas rather than the often assumed circumnuclear disk. Unlike the dust, most of the molecular gas resides in the spiral arms. In the center, dense

(1000 cm^{-3}) gas at a temperature of 100 K is accompanied by either a less dense (100 cm^{-3}) gas at the same temperature, or a denser (3000 cm^{-3}) gas at a much lower temperature of 20 K. Only a small fraction of all carbon is in CO, most of it is ionized carbon (C^+). Emission from a major starforming region in the inner NW arm likewise comes from two different gas components. One is modestly dense (1000 cm^{-3}); the other is tenuous (100 cm^{-3}) and more widespread. Both must be at temperatures of 100 -150 K. The center of M51 has a face-on gas mass density of 40 $M_\odot pc^{-2}$, and a well-established CO-to-H_2 conversion factor 4-5 times lower than the standard Galactic value, in line with similar results for other galaxy centers.

3.1.3. Distant Galaxies

3.1.3.1. HI in distant galaxies

Verheyen and Szomoru in collaboration with van Gorkom (Columbia University), Poggianti (Padua) and others used the wide band (~30,000 km/s) capabilities of the WSRT to observe the Butcher-Oemler clusters Abell 963 and Abell 2192. These clusters are known to be very different in their dynamical state and star formation properties. Abell 963, at z=0.206, is one of the nearest Butcher-Oemler clusters with an unusual high fraction (19%) of blue galaxies. This massive, X-ray luminous cluster, is in a sample of X-ray selected clusters currently being studied at many wavelengths (Chandra, HST and INT). Lensing studies showed that 70% of the X-ray luminous clusters at z=0.2 are dynamically immature. Abell 963 is, however, unusually relaxed with less than 5% substructure. Abell 2192, at z=0.188, is less massive and much more diffuse with significant substructure. So far it has not been detected in X-rays. So far 20x12 hours were spent on observing Abell 963 and 15x12 hours on Abell 2192. More observing time has been allocated to push the sensitivity limits deeper. The HI mass limit in the present observations is 7.4 x 109 $M_\odot$.

Up to the end of the reporting period 20 HI selected galaxies were identified with optical counterparts in Abell 963 and 21 in Abell 2192. In the case of Abell 963 nearly all of these are located to the NE of the cluster, while in the case of Abell 2192 the distribution is more diffuse, although some clumping seems to be present to the SW. These data were used to map the large scale structure in which these clusters are embedded. Abell 963 is particular interesting because significant substructure was found. Although the core of this cluster is relaxed, it seems that this Butcher-Oemler cluster is, or soon will be, accreting a large group of gas-rich galaxies from its surroundings.

Fig 3.8 shows examples of detected galaxies in the clusters and some fore- and background galaxies. The data show that many optical counterparts have disturbed morphologies. The data show spatially resolved kinematic information. It allows to derive a Tully-Fisher relation for the galaxies at z=0.2.

3.1.3.2. Stellar Content of Distant Galaxies

Trager in collaboration with Dressler, Oemler and Shectman (OCIW), Poggianti (Padova), Smail Durham), Couch (UNSW), and Ellis (Caltech) examined the evolution of the absorption lines of hydrogen and the emission lines of oxygen to quantify the amount of star formation in cluster galaxies at different epochs. They found that a very strong decrease in the star formation rate in cluster galaxies - with strong starbursts in a much higher fraction of galaxies than seen in any environment locally - is required to explain the evolution of the spectral features, suggesting that cluster galaxies were being transformed from star-forming galaxies to “passive” galaxies at intermediate redshifts.

3.1.3.3. Distant radio galaxies and Quasars

Röttgering, together with Wilman (Durham), Jarvis (Oxford), and Binette (UNAM, Mexico) obtained VLT-UVES echelle spectra of the Ly α emission and absorption in five radio galaxies at redshifts z = 2.55 to 4.1. Two groups of HI absorbers were identified: strong absorbers with $N_{HI} = 10^{18}$ to 10^{20} cm^{-2} and weaker systems with $N_{HI} = 10^{13}$ to 10^{15} cm^{-2}. There is none at intermediate N_{HI}. The strong absorbers are suggested to be a byproduct of massive galaxy formation or could instead represent material cooling behind the expanding bow shock of the radio jet. It is argued that the weaker absorbers are part of the Ly α forest, as their rate of incidence is within a factor of 2 - 4 of that in the intergalactic medium at large. Such column densities are consistent with models of a multiphase proto-intracluster medium at z > 2.

Röttgering, Cohen (NRL, Washington) and Jarvis finished a deep survey carried out with the new 74 MHz system at the VLA. High-resolution VLA follow-up observations of the sources with the steepest radio spectrum were carried out and show that these are excellent candidates for high-redshift radio galaxies. Subsequent near-infrared K-band imaging using UKIRT confirmed that a number of the highest-redshift (z > 5) radio galaxies should be contained in this sample.

3.1.3.4. Radio properties of LINER galaxies

Barthel, Ho (Carnegie) and Filho (Porto) studied the radio properties of LINER galaxies, objects displaying a mild form of nuclear activity. High resolution

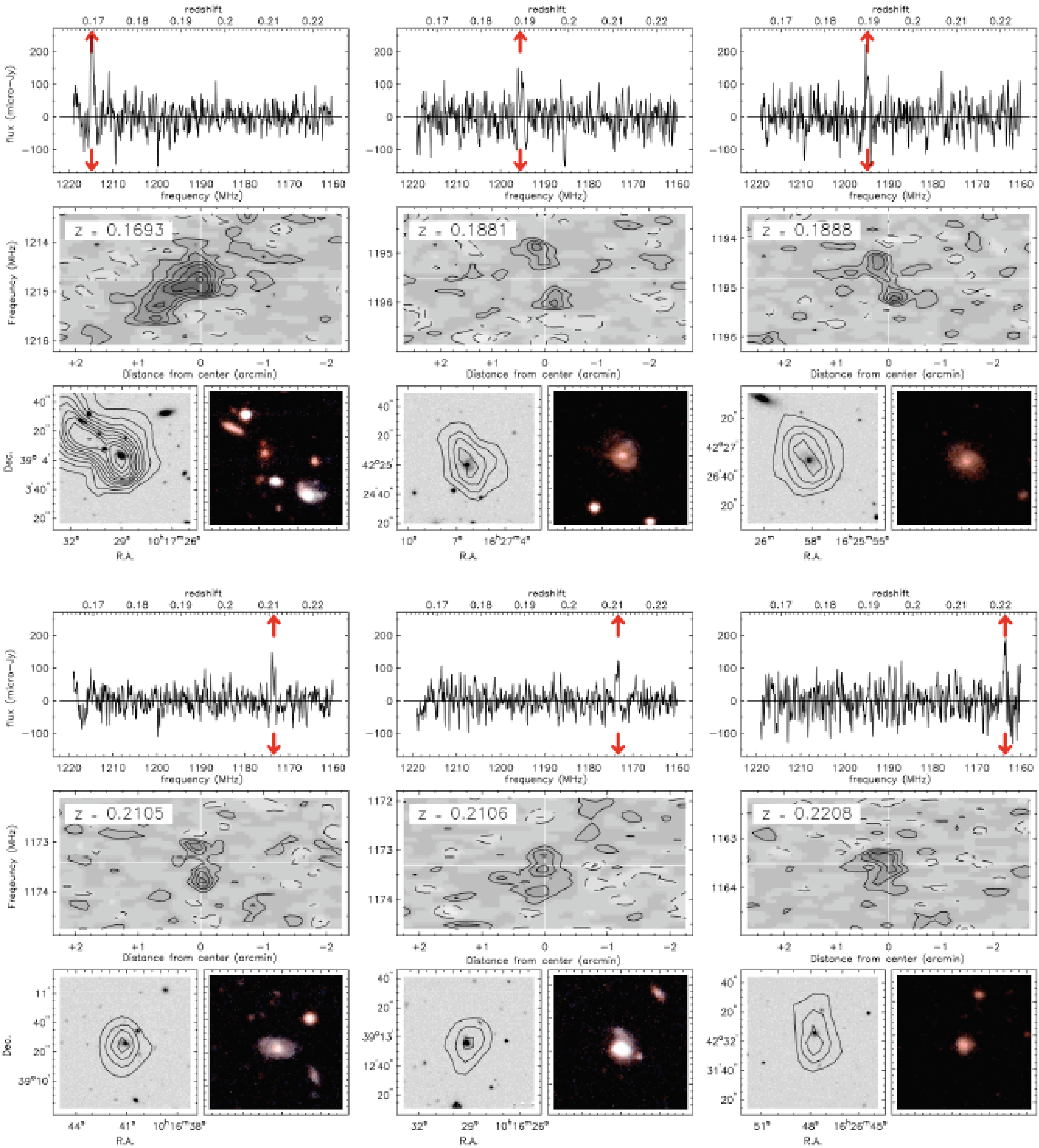


Fig. 3.8: Examples of six galaxies at intermediate redshifts detected in HI with the WSRT. For each galaxy, the upper panel shows the entire HI spectrum with red arrows indicating the redshift and frequency of the HI signal. The middle panel shows the position-velocity diagram along the major axis of the galaxy. The lower left panel shows the integrated HI map on top of an optical image. The lower right panel shows a blow-up color image of the HI detected galaxy.

radio observations (VLA, MERLIN, VLBA, and EVN) were used to assess accretion driven energy production in galaxies, which is likely to be widespread. The radio data were supplemented with X-ray as well as optical data. A collaborative effort with Peletier and the SAURON group (de Zeeuw et al) found an intriguing trend between accretion and circumnuclear gas properties: this trend is being pursued further, focusing on the possibility of mass loss from star clusters.

3.1.3.5. Orientation of quasars and radio galaxies

Barthel and co-workers studied the far-IR properties of AGN. IRAS and ISO data will be supplemented with data which are planned to be obtained with the Japanese ASTRO-F mission: Barthel is taking part in a British-Groningen consortium collaborating with the Japanese Space Agency JAXA. ASTRO-F will be launched in early 2006. Some data using the new VISIR infrared instrument on the VLT were obtained (in collaboration with Pel); this work will continue, and will eventually culminate with guaranteed time on the Herschel satellite. Aim of these studies is to constrain evolutionary models for the galaxies which host the compact powerful radio sources.

3.1.3.6. Fast neutral outflows in powerful radio galaxies

Morganti, Oosterloo, Emonts and Tadhunter (Sheffield) discovered fast (~1000 km/s), massive outflows of neutral gas in a number of radio-loud AGN. These outflows are observed as 21-cm HI absorption against the strong radio continuum. The neutral outflows occur, at least in those cases where the location could be determined, at kpc distance from the nucleus. They are most likely driven by the interactions between the expanding radio jets and the gaseous medium enshrouding the central regions. The estimated mass outflow rates are up to ~50 $M_{\odot}$/yr, comparable (although at the lower end of the distribution) to the outflow rates found for starburst-driven superwinds in Ultra Luminous IR Galaxies (ULIRG). This suggests that massive, jet-driven outflows of neutral gas in radio-loud AGN can have as large an impact on the evolution of the host galaxies as the outflows associated with starbursts. A radio-loud phase of the AGN is likely a relatively common, albeit short, phase in the life of many (or even all) massive elliptical galaxies. Jet-driven neutral outflows may represent one of the main feedback mechanisms controlling the evolution of these galaxies.

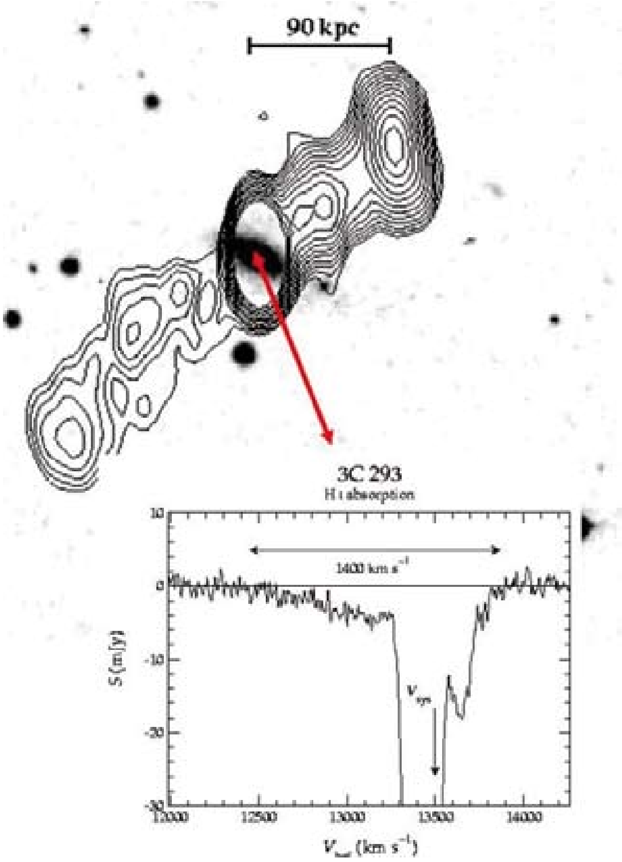


Fig 3.9: The radio galaxy 3C293 observed with the WSRT: (top) radio continuum (contours) superimposed to an optical image, (bottom) the HI profile observed against the central region. The newly discovered broad (1400 km/s) blue shifted wing is clearly visible (Morganti et al.).

3.1.4. The high redshift universe

3.1.4.1. Red galaxies at high redshift

Franx led the Faint Infrared Survey (FIRES), a large program at the VLT which consisted of very deep near-IR imaging of two fields. Based on these data, Franx, van Dokkum (Yale), Labbé, Förster-Schreiber, and the FIRES team discovered that a large population of red galaxies exists at redshifts larger than 2. The galaxies, dubbed 'Distant Red Galaxies', or DRGs, can be selected by the simple color criterion J-K > 2.3. Spectroscopic follow-up confirmed that most of the galaxies selected in this way are indeed at redshifts higher than two.

Franx, Förster-Schreiber and the FIRES team studied the stellar populations and spectral energy distributions of the DRGs. They generally have old ages (~1 Gyr) and high extinction. They are red because they are old and dusty. Some are best fit by population models with little if any star formation. They constitute the most massive galaxies at high redshift, and their average star formation rates are high (more than 100 $M_{\odot}$/yr). The DRGs can be contrasted to Lyman-break galaxies, which are generally much bluer, less dusty, and younger (Fig. 3.10). Their contributions to the stellar mass density are very similar to the limit to which these galaxies are observed.

Several of the DRGs are detected in Hα using IR spectroscopy; the emission line widths indicate high masses. The data show a correlation between line width and rest frame V band flux, indicating the possible presence of a Tully-Fisher relation at $z > 2$.

The star formation rates of the DRGs were also derived from deep X-ray imaging of one of the fields,

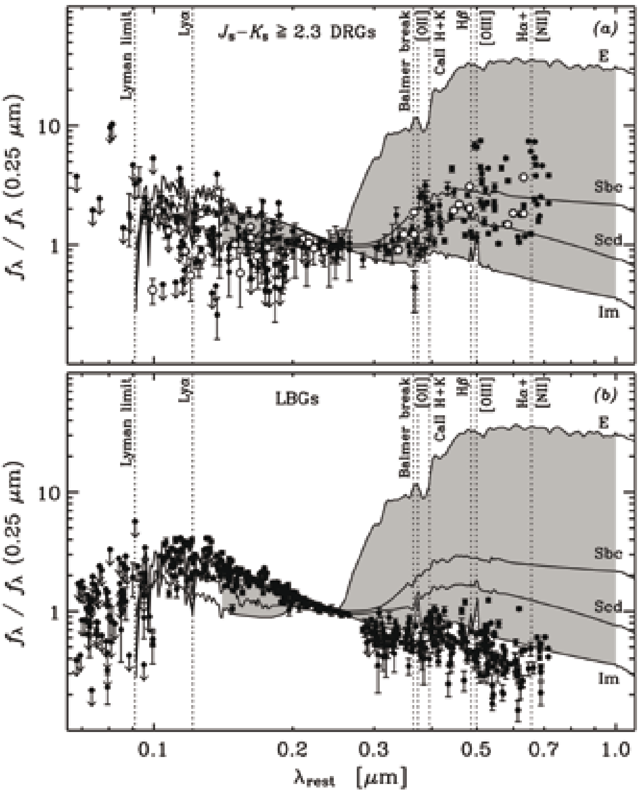


Fig. 3.10: The spectral energy distributions of Distant Red Galaxies (top), contrasted with that of Lyman-Break galaxies (bottom). As can be seen, the Distant Red Galaxies have much redder colors than the Lyman-Break galaxies, and they have very similar redshift distributions. The colors of the Distant Red Galaxies are similar to those of spiral galaxies in the nearby universe, whereas the Lyman Break galaxies are typically bluer than the blue irregulars. The two populations are very complementary, with very little overlap. Their contributions to the mass density at redshifts between 2 and 3.5 are very comparable (Franx et al.).

and from deep sub-mm SCUBA imaging taken at the JCMT. When it is assumed that the emission originates from star formation, the derived star formation rates are consistent with star formation rates estimated from SED fitting, and have an average above 100 $M_{\odot}$/yr. The sizes of galaxies at $z = 2$ to 3.5 were studied by Franx, Trujillo, and the FIRES collaboration. They found that the sizes are smaller, given the luminosity of the galaxies; but that the sizes remain fairly constant as a function of mass. This is inconsistent with most of the models of galaxy formation.

Labbé, Franx and the FIRES team studied the DRGs at 3.6-8 μm using IRAC on the Spitzer satellite, and confirmed that many are indeed star forming, but some are nearly 'red and dead'. These nearly 'red and dead' galaxies must have formed when the universe was much younger.

3.1.4.2. The highest redshift galaxies

Franx, in collaboration with Bouwens and Illingworth (Santa Cruz, USA) and collaborators studied galaxies at the highest redshifts. In a series of papers, galaxies at redshift 6, 7-8, and 9-10 were studied based on very deep images taken with the HST. The highest redshift galaxies were selected from very deep near-IR imaging taken by this group with the HST. The work indicates that at higher redshifts bright galaxies become rarer. We may have reached the epoch in which the first bright galaxies formed.

3.1.4.3. Damped Ly α systems

Kanekar and Chengalur (NCRA-TIFR) used the GMRT to search for HI absorption in a sample of high redshift damped Ly α systems (DLAs). They obtained several strong upper limits on the 21 cm optical depth and the detection of 21 cm absorption at $z \sim 3.39$ towards PKS0201+113. This is the highest redshift at which 21 cm absorption has been found in a DLA. Besides this, Kanekar, Chengalur, Lane (NRL) and Ellison (ESO) used the GBT to search for HI 21 cm absorption in another DLA sample, with two detections at $z \sim 2.4$. These observations suggest the majority of high redshift DLAs have high spin temperatures, with small fractions of gas in the cold phase. These high values for the spin temperature are consistent with the absorbers being small, low metallicity objects, rather than dwarf galaxies. The results also hint at evolution in the relative fraction of the cold and warm phases from high redshifts to today.

Kanekar, Smette (ESO), Briggs (ATNF, ANU) and Chengalur used VLT-UVES observations to measure the metallicity [Zn/H] of a sample of high redshift damped absorbers with measured spin temperatures T_s. These resulted in the detection of an anti-correlation between T_s and [Zn/H] in a sample of 15 DLAs, clearly implicating gas metallicity is important in determining the temperature of the neutral ISM. It is plausible that the high spin temperatures of DLAs arise because the ISM in small galaxies is inefficiently cooled due to the lack of metals, resulting in a lack of radiation pathways.

3.1.4.4. Dusty galaxies at high redshift

Knudsen and Van der Werf completed their work on distant sub-millimeter galaxies with the construction of the cumulative 850 μm source counts shown in Fig. 3.11. Source counts at 850 μm in the 1 mJy regime are of interest because the integrated background at 850 μm is dominated by sources at this flux density level. However, probing the 1 mJy sources directly is prohibited by confusion. Knudsen and Van der Werf circumvented this problem by using gravitationally lensed cluster fields, which magnify the source plane, hence alleviating the confusion problem. This project resulted in the first substantial source count at flux density levels fainter than 2 mJy (the blank-field confusion limit of the JCMT at 850 μm), reaching levels as faint as 0.1 mJy. These source counts confirm that 50% of the 850 μm background is produced by sources with flux densities between 0.5 and 2 mJy. A key result is the first indication of a flattening of source counts at lower flux levels, which is necessary in order to not overproduce the integrated 850 μm background, and is here detected for the first time.

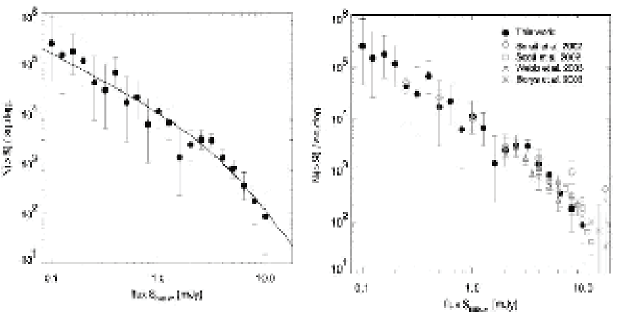


Fig 3.11: Cumulative source counts from the Leiden-SCUBA Lens Survey. A flattening of the counts towards the faint end is evident.

A further result is the detection in the survey by Knudsen and Van der Werf of a triple-image lensed ultraluminous infrared galaxy (ULIRG), which is gravitationally lensed by the foreground cluster Abell 2218 into three discrete images, as shown in Fig. 3.12. Subsequent follow-up investigations using deep optical and near-infrared (near-IR) images identified a faint counterpart to each of the three images, with similar red colors and HST morphologies. The morphological and photometric similarity of these three objects suggests that they are all images of the same background source.

The combined images of this galaxy are magnified by a factor of ~ 45 implying that this galaxy would have unlensed magnitudes K_s = 22.9 and I = 26.1, and an unlensed 850 μm flux density of only 0.8 mJy. Moreover, the highly constrained lens model predicted the redshift of the source to be z = 2.6 ± 0.4. This estimate was confirmed using deep optical and near-IR Keck spectroscopy, measuring a redshift of z = 2.516. This object is the faintest sub-mm selected galaxy so far identified with a precise redshift. Interestingly, there are two other highly amplified galaxies at almost identical redshifts in this field (although neither is a strong sub-mm emitter). The three galaxies lie within a ~100 kpc region on the background sky, suggesting this sub-mm galaxy is located in a dense high-redshift group.

The triply-imaged object was the subject of intense follow-up. A highlight is the detection of CO emission from all three components, with both the Owens Valley interferometer and the IRAM Plateau de Bure interferometer. These results show that this system is much less luminous and massive than other high-redshift submillimeter galaxies studied to date, but it bears a close similarity to luminous, dusty starburst galaxies resulting from lower-mass mergers in the local Universe.

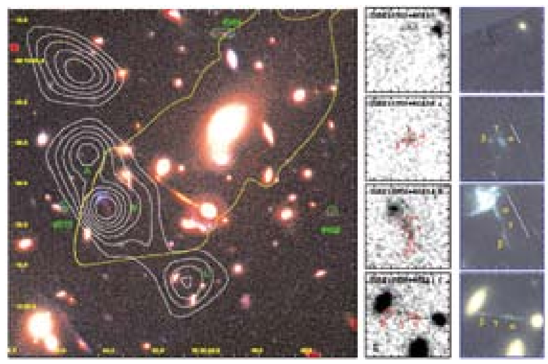


Fig 3.12: Montage showing on the left-hand side a true-color HST image of the core of A2218. The 850 μm sub-mm image from SCUBA is overlayed as white contours. The three images of the multiply imaged sub-mm galaxy are annotated as A, B and C. The yellow line shows the critical line at z=2.515. The right-hand side shows 10″ x 10″ images of the INGRID Ks-band (left column) and HST of the four sub-mm sources in the core of A2218. The contours on the Ks frames show the morphologies of the galaxy in the F814W pass band at the resolution of the Ks-band frame.

3.1.4.5. **Protoclusters of galaxies**

Miley, Röttgering, Venemans (NOVA PhD), Overzier, and collaborators found convincing evidence that the most luminous radio galaxies are excellent tracers of distant protoclusters. In his thesis Venemans presented the results of a Large Program carried out with the VLT. He showed that all seven radio galaxies investigated (at z = 2.2, 2.9, 2.9, 3.1, 3.2, 4.1 and 5.2) to sufficient depth are surrounded by an overdensity of Ly α emitters. The galaxy overdensities are in the range of 5 - 15 with velocity dispersions between 300 - 1000 km/s. The structure sizes are > 3 Mpc, and the masses are estimated to be $>10^{14}$ - 10^{15} $M_{\odot}$, comparable to the mass of present day rich clusters of galaxies. A highlight of the follow-up was the detection of a probable Lyman break population in the protocluster 1338-19 at redshift z ~ 4.1, discovered previously by Venemans et al. based on an over density in Ly α emission galaxies.

A large multi-year project was commenced to study the evolution of the most distant protoclusters and their constituent galaxies. The PROtoCluster Evolution Systematic Study (PROCESS) is investigating the spectral energy distributions and morphologies of galaxies in 4 key targets (z = 4.1, 3.1. 2.3 and 1.2). Carefully selected filters are used to disentangle the history of star formation from that of structure assembly in protocluster galaxies.

3.1.4.6. **Formation of massive galaxies**

Distant luminous radio galaxies are among the brightest known galaxies in the early Universe and the likely progenitors of dominant cluster galaxies. For these reasons, high-redshift radio galaxies (HzRGs) are unique laboratories for studying massive galaxy formation. Miley led a project within the HST/ACS GTO Team to use HzRGs as probes of massive galaxy formation. A highlight was the acquisition of deep images of the rest-frame UV continuum emission of the radio galaxy MRC 1138-262 at z = 2.2. These images reach > 2 magnitudes fainter and provide spectacular evidence that tens of satellite galaxies were merging into a massive galaxy, 11 Gyr ago.

3.1.4.7. **Ultra-steep spectrum radio sources**

Two classes of objects with ultra-steep radio spectra are unique probes of galaxy and cluster evolution, namely distant luminous radio galaxies and diffuse radio emission. Intema (NOVA PhD), Röttgering, Miley and Snellen commenced a project to study the nature of both these classes of objects by combining the angular resolution of the GMRT at 150 MHz with the spectral sensitivity of the new Low Frequency Front End (LFFE) receivers at the WSRT. The resulting maps are among the deepest ever taken at these frequencies and show interesting diffuse emission associated with a well-known cluster of galaxies A2256.

3.1.5. Large scale structure

3.1.5.1. **The power spectrum at small scales**

Zaroubi, in collaboration with Nusser (Haifa), Viel, Haehnelt and Kim (Cambridge) measured the matter power spectrum on small scales from 33 Ly α spectra spanning the redshift range of 1.5–3.5. The optical depth for Ly α absorption of the intergalactic medium, obtained from the flux using the inversion method of Nusser & Haehnelt, is converted to density by using a simple power law relation. The authors find that the CDM power spectrum amplitude is $0.6 < \sigma_8 < 0.8$ (with 3σ confidence level) consistent with previous measurements. This result is somewhat low relative to the concordance model. The data support a non-adiabatic temperature evolution at certain stages, consistent with full helium reionization at about z = 3. On the density and velocity correlation functions Zaroubi and Branchini (Roma) introduced a simple linear equation relating the line-of-sight peculiar-velocity and density contrast correlation functions. Estimation of the cosmological density parameters with this equation from the Point Source Catalogue Redshift (PSCR) survey and the SEcat catalogue of peculiar velocities is consistent with $\Omega = 0.3$.

Zaroubi, Erdogdu (Cambridge), Lahav (UC London) and the 2dF collaboration, reconstructed the underlying density field of the Two-degree Field Galaxy Redshift Survey (2dFGRS) for the redshift range $0.035 < z < 0.200$ using the Wiener filtering method. They identify all major superclusters and voids in the survey. In particular, they found two large superclusters and two large local voids.

Van de Weygaert and Aragon Calvo applied a filtering method for galaxy classification based on the local geometry of the density field. This method was used in computer vision and medical imaging and is now applied to models of the large scale structure and large volumes sampled by the Sloan Digital Sky Survey. The method promises to be very powerful for locating and describing the large scale structure filaments, clusters and walls and was developed further for this purpose.

3.1.5.2. **Formation and evolution of galaxy clusters**

Van de Weygaert and Araya Melo studied the formation and evolution of clusters within the context of the surrounding large scale structure. Clusters are

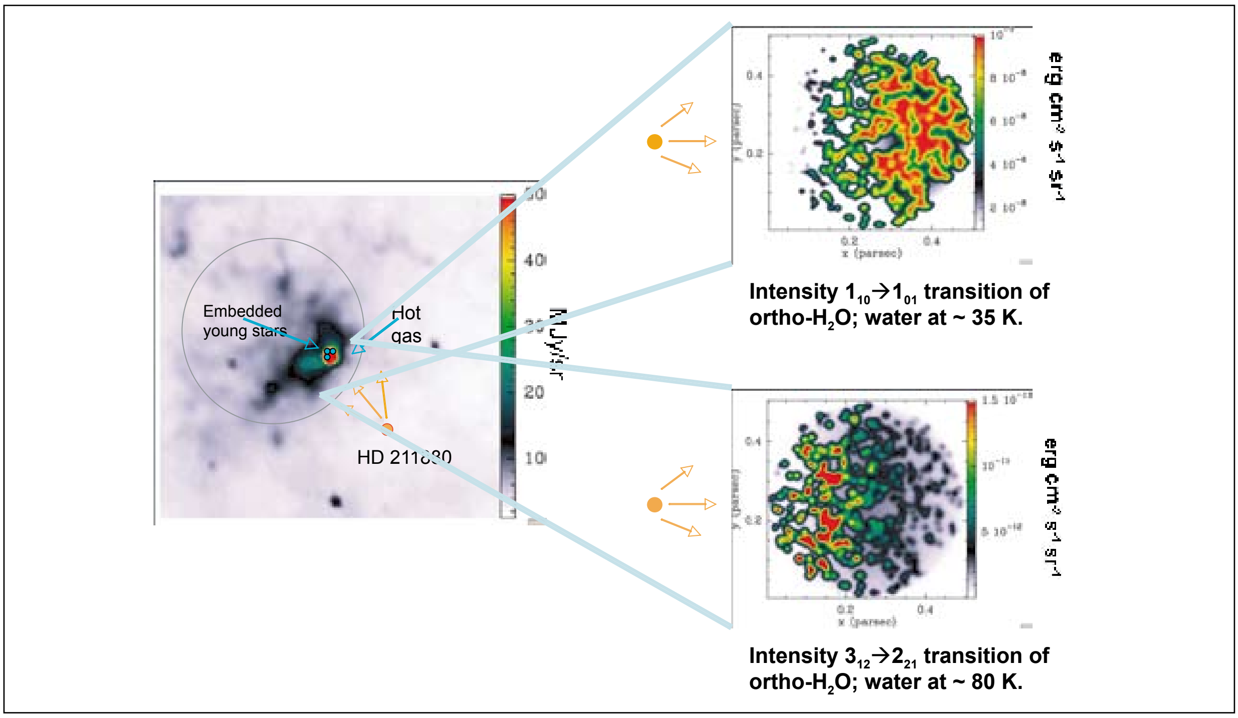


Fig. 3.13: Predicted emission in two transitions of the water molecule for the S140 molecular cloud. UV photons from the star HD 211880 heat the gas in this cloud and cause water to be warm. The HIFI instrument on the Herschel satellite will observe many water transitions in the far infrared.

forming at the intersections of filamentary features in the large scale matter distribution. Matter is transported towards the clusters via these filamentary extensions. Simulations with GADGET, (Springel et al. 2001) were used to study how properties such as mass of the cluster, shape, tidal shear and power spectrum shape set the large scale environment. To this end they used the Constrained Random Field code (from van de Weygaert and Bertschinger 1996). The code was extended by Araya Melo and Aragon Calvo in order to be able to achieve a much higher dynamical range by enabling hundreds of constraints. Of crucial importance is the unbiased resolution of hierarchy of substructures and the anisotropic geometry of the surrounding matter distribution. The aim of their computations are to study the dynamics, flow patterns and thermodynamics of the infall regions, the precise morphology of filamentary structures and the virialization of the dark matter as well as the gas inside the cluster itself.

3.2. Birth and death of stars: the life-cycle of gas and dust

The aim of the research of Network 2 is to study the origin and evolution of stars and planetary systems, using spectral features from gases and dust as the main tracers. The projects range from studies of the most deeply embedded protostars to dying stars which are in the process of returning a significant fraction of their material to the diffuse interstellar medium. They involve a combination of observations, mostly at infrared and submillimeter wavelengths, theoretical modeling and laboratory astrophysics (see also sections 5.9 and 5.12.1). Eight NOVA funded graduate students obtained their PhD in 2004-2005. All of them found excellent post-doc positions abroad.

In the following, a brief summary of scientific highlights is given. Regular network meetings were held every six months.

3.2.1. Interstellar clouds

3.2.1.1. H_2

The most abundant interstellar molecule, H_2, is generally thought to form by recombination of H atoms on grain surfaces. Cazaux (NOVA PhD), in collaboration with Tielens, developed a model for H_2 formation on surfaces of astrophysical relevance. This model solves the time-dependent kinetic rate equation for atomic and molecular hydrogen and their isotopes, taking the presence of physisorbed and chemisorbed sites, as well as quantum mechanical diffusion and thermal hopping, into account. The results show that the time evolution of this system is mainly governed by the binding energies and barriers against migration of the adsorbed species. The model results are benchmarked against laboratory experiments on the formation of HD on silicate and carbonaceous surfaces under irradiation by atomic H and D beams at low and at high temperatures. Implications for the formation of H_2 in the interstellar medium were assessed and it was demonstrated that H_2 formation can be efficient even at elevated dust temperatures. Together with Spaans, the model results were applied to high-redshift galaxies where the dust abundance and dust properties are different from those in the local universe.

3.2.1.2. Water

The water molecule plays a key role in the oxygen chemistry and thermal balance of interstellar gas, and has great diagnostic potential as a tracer of gas density, temperature and kinematics. Poelman and Spaans studied the excitation of water in the star-forming cloud S 140, which contains young stellar objects (YSOs) and UV irradiated molecular gas. With the use of a three-dimensional multi-zone escape probability method and a Monte Carlo code the emissivity of ortho- and para-water was computed for temperatures of 20-500 K and gas densities of 10^3-10^8 cm^{-3}. Different line profiles were found for the compact embedded protostellar sources (self-absorbed) and the extended irradiated molecular gas (single-peaked) (Fig. 3.13). The constructed models will allow detailed interpretation of water observations of spatially resolved clouds with HIFI on the Herschel Space Observatory.

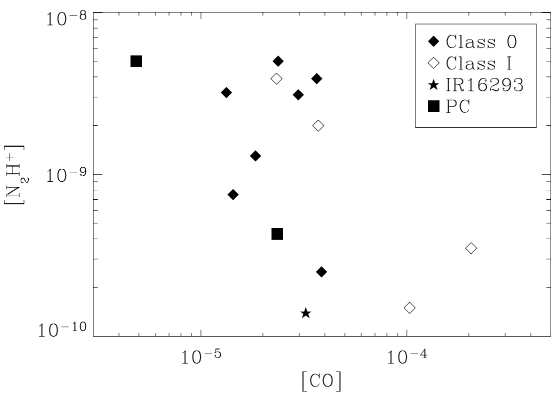
3.2.1.3. Dust in the interstellar medium

Min, Waters, Hovenier, de Koter and co-workers performed a detailed investigation of the composition of interstellar silicate dust. In previous studies, oversimplified dust models were employed, resulting in flawed conclusions concerning the composition. Building on previous work to compute the optical properties of complex grains, it was possible to derive the composition of interstellar silicates in detail. In particular the magnesium content of the dust is about 90%, much higher than previously thought. This has major implications for the interpretation of dust evolution from its formation to the incorporation into planetary systems.

3.2.2. Deeply embedded low-mass protostars

3.2.2.1. Chemical survey of low-mass protostars

Jørgensen (NOVA PhD), Schöier, van Dishoeck and Tielens, together with Ceccarelli (Bordeaux), Maret and Caux (Toulouse) completed their large JCMT and IRAM 30-m survey for submillimeter emission lines from a sample of low-mass protostars. The physical structure of the envelopes was established using radiative transfer modelling of SCUBA dust continuum observations, which was then subsequently adopted to determine molecular abundances using a line radiative transfer code. The large sample allowed empirical correlations between species to be derived and basic chemical networks to be tested. For example, it was found that the HCO^+ and CO abundances are linearly correlated, both increasing with decreasing envelope mass, whereas N_2H^+ and CO are anti-correlated (Fig. 3.14). Species such as CS, SO and HCN show no



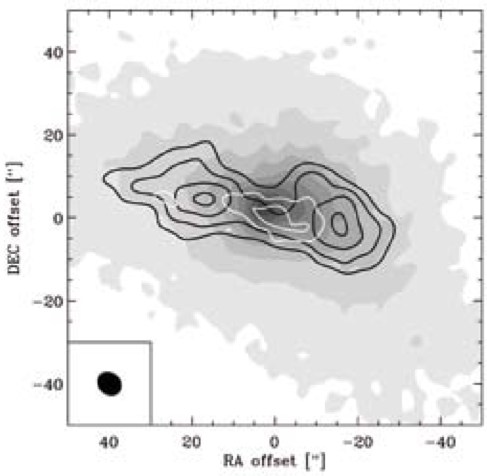


Fig. 3.14: Left: Anti-correlation of N_2H^+ and CO abundances found in the JCMT single dish survey of protostellar envelopes, caused by freeze-out of CO in the coldest parts. Right: OVRO interferometer maps of the L483 protostar, revealing the spatial anti-correlation between N_2H^+ (thick black line) and $C^{18}O$ (thick white line) emission. The grey-scale map indicates the SCUBA 800 µm emission due to cold dust (From: Jørgensen et al. 2004).

trend with envelope mass. In particular no relation is seen between "evolutionary stage" of the objects and the abundances of the main sulfur- or nitrogen-containing species.

One tracer of protostellar evolution is CO itself. In the outer part of the envelope, the timescales for freeze-out are longer than the lifetimes of the cores, whereas in the inner warm part heated by the protostar ices are rapidly evaporated. The heavy depletions found for CO and other species are thus limited to an intermediate cold high density zone in the envelope, with the size of this freeze-out zone related to the evolutionary stage. Fits to single-dish observations of molecules such as CO, HCO^+ and H_2CO indicate short timescales of only ~10^5 years from the time when a dense pre-stellar core has formed until a protostar emerges. The ice evaporation in the innermost envelope (<300 AU) is seen in jumps in the abundances of complex organic molecules such as CH_3OH.

Tielens, Helmich and van Dishoeck, in collaboration with Ceccarelli and Caux, performed a complete 330-365 GHz spectral survey with the JCMT of one class 0 object, IRAS16293-2422. Complementary surveys at lower frequencies are nearly finished at the IRAM 30-m. Together they form the first unbiased overview of the chemical composition of a low-mass protostar, not only important in itself but also as preparation for ALMA and Herschel. This object turns out to be remarkably rich in complex organic molecules (Fig. 3.15). Their origin is still debated, in particular whether they are first generation evaporated ices or second generation molecules produced by high-temperature gas-phase reactions.

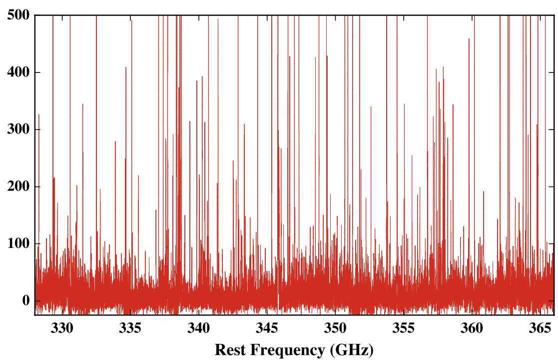


Fig. 3.15: The 330-365 GHz spectrum of the low-mass protostellar object IRAS 16293-2422 obtained with the JCMT, showing a wealth of lines from complex organic molecules. A blow-up of the 338 GHz section containing CH_3OH is included on the cover (Tielens et al.).

3.2.2.2. High-resolution imaging of low-mass protostars

Some of the chemical characteristics discussed above were further explored by Jørgensen through imaging of the molecular emission at ~500 AU resolution using millimeter interferometry data from OVRO and BIMA, in collaboration with Hogerheijde and Blake (Caltech) (Fig 3.14). The envelope model derived from single-dish data is used as a starting point for the analysis of the continuum visibilities seen by the interferometer. For some sources, a point source is revealed by the interferometer, presumably due to a cold disk with a mass of typically 0.01 $M_\odot$. N_2H^+ is seen to be closely correlated with dust concentrations where CO is frozen out.

A new window on the innermost warm and dense parts of the envelopes and disks was opened up by the SMA. Interferometry at 345 GHz at <2" resolution of the Class 0 source NGC 1333 IRAS 2A by Jørgensen, van Dishoeck and co-workers revealed complex organic molecules such as CH_3OCH_3 and CH_3OCHO on scales of <200 AU. The continuum data show a compact but resolved component, presumably a disk with 200-300 AU diameter providing some of the first accurate constraints on disk properties in the earliest phase.

Van Kempen, van Dishoeck and Hogerheijde in collaboration with Güsten (MPIfR, Bonn) used the newly commissioned APEX telescope during science verification to observe high excitation CO J=4-3 and 7-6 lines in the protostellar envelope of IRAS 12496-7650. The J=7-6 line is much stronger than expected based on an envelope model, but does not show the high velocity wing seen prominently in J=4-3. Combined with lower-J and isotopic lines, these data put constraints on the temperature and kinematics of the outflow gas.

3.2.2.3. Chemical models of protostellar envelopes

Together with Doty (Denison) and Schöier (Stockholm), van Dishoeck continued her studies of the time- and space-dependent chemistry in protostellar envelopes, focussing on the low-mass protostar IRAS 16293 -2422. A new feature is the use of a radiative transfer model to translate the model abundances into line strengths and compare them directly with observations. The best fit is for times in the range of $3x10^3$ – $3x10^4$ yrs and requires only minor modifications to a model for the high-mass YSO AFGL 2591. The ionization rate for the source may be higher than previously expected - either due to an enhanced cosmic-ray ionization rate, or, more probably, to the presence of X-ray induced ionization from the protostars. Predictions of the abundances and spatial distributions of other species which could be observed by future facilities (e.g. Herschel-HIFI, SOFIA, millimeter arrays) were made.

Together with Stäuber and Benz (ETH), van Dishoeck, Doty and Jørgensen started an observational and modeling program to search for molecular probes of high-energy ultraviolet radiation and/or X-rays in the inner envelopes of deeply-embedded YSOs. Because of the high extinction in protostellar regions, ultraviolet radiation and X-rays cannot be detected directly from these objects, but they can selectively enhance molecules due to photodissociation and ionization processes. Time- and depth-dependent chemical models containing ultraviolet and X-ray chemistry were developed by extending the models of Doty et al. described above. The main difference between UV radiation and X-rays is the much greater penetration depth of X-rays, up to at least 1000 AU from the central source.

The X-ray models were also used to investigate the water abundance in low-mass YSO envelopes. Water is found to be destroyed by X-rays on relatively short timescales ($<10^4$ yr) for realistic X-ray fluxes. The average water abundance in Class I sources with $L_X>10^{27}$ erg s^{-1} is less than 10^{-6}. This model prediction can be tested by Herschel-HIFI observations. Van Kempen, van Dishoeck and Hogerheijde also started an extensive radiative transfer study of the rotational emission lines of water in the outer regions of solar-mass protostars for a range of model abundances.

3.2.2.4. VLT-ISAAC 3-5 µm survey of low- and intermediate mass YSO's

Pontoppidan (NOVA PhD), van Dishoeck, Thi, Tielens and Fraser (NOVA postdoc), in collaboration with Dartois and d'Hendecourt (IAS, Paris) finished their large ESO VLT-ISAAC program to observe ices and gases around a large sample of low-mass young stellar objects (YSOs) in nearby star-forming regions at unprecedented S/N and spectral resolution. In total, spectra of about 50 sources were obtained covering the 3-5 µm atmospheric windows with resolving powers up to $\lambda/\delta\lambda \sim 10^4$. The goal of the project is to search for broad absorption features from ices (for example CO, H_2O, OCN^-, CH_3OH) and for CO gas through its ro-vibrational transitions around 4.7 µm. Most of the targets are low- and intermediate mass protostars, to complement previous ISO-SWS studies on high-mass YSOs.

The most recent analysis focused on the famous XCN band at 4.62 µm. In a study led by van Broekhuizen (NOVA PhD), it was shown that the XCN band consists of at least two components, of which only one can be ascribed to OCN^-. The other component is likely due to CO directly adsorbed on the silicate surface, studied in the laboratory by Fraser and Bisschop. The typical OCN^- abundance in low-mass YSOs is less than 0.85% with respect to H_2O ice, somewhat lower than that toward high-mass YSOs. Abundances are found to vary by at least a factor of 10-20, even within the same star-forming cloud complex on scales down to 400 AU. Comparison with laboratory data indicates that the inferred abundances are quantitatively consistent with a photochemical formation of OCN^-, but the large abundance variations are not easily explained in this scenario unless local radiation sources or special geometries are invoked. Surface chemistry should therefore be considered as an alternative formation mechanism of OCN^-.

Thi and collaborators finished an analysis of the VLT-ISAAC spectra of a set of intermediate mass YSOs in Vela. One source, LLN 17, shows an extremely broad CO ice feature accompanied by strong OCN^- and CH_3OH ice, whereas its lower mass companion at a few thousand AU has a narrow CO ice profile. This provides direct evidence for local thermal processing of the ice close to the protostar.

A new development, led by Pontoppidan, is to produce high-resolution ice maps through VLT-ISAAC observations toward a number of closely-spaced infrared sources. A small region of the Serpens cloud core was mapped in water and methanol ice absorption. Abundant methanol ice was previously detected in this region, but is now shown to be extended over a larger area. Furthermore, a sharp increase in the abundance of water ice compared to the normal cloud abundance was detected in the cold outer envelope of the class 0 source SMM4, confirming the indirect evidence from submillimeter line data (section 3.2.2.1). This work demonstrates that the sensitivity of current infrared instrumentation is now sufficient to map small, well-defined regions in ices with angular resolutions similar to those of maps in rotational gas-phase lines.

3.2.2.5. First Spitzer spectroscopy results

Pontoppidan, van Dishoeck and Lahuis, in collaboration with Noriega-Crespo, Blake, Boogert (all Caltech), analyzed the first mid-infrared spectroscopic data obtained with the Spitzer Space Telescope, launched on 25 August 2003. The southern low-mass protostar HH 46 was targeted and revealed very strong ice absorptions, including clear features by solid CO_2 and CH_4. Together with ground-based VLT-ISAAC data at shorter wavelengths, an initial ice inventory of this low-mass protostar was made and compared with that found in high-mass YSOs studied by ISO. The CO_2 abundance with respect to H_2O ice is high, ~35%. Toward this and other protostars observed in the context of the Spitzer 'Cores to Disks' (c2d) legacy survey, the CO_2 15 μm band shows little evidence for thermal processing at temperatures above 50 K. Signatures of lower temperature processing are present in the CO and OCN^- bands, however. Clearly, Spitzer spectra are essential for studying ice evolution in low-mass protostellar environments and for eventually determining the relation between interstellar and solar system ices (for example Fig. 3.16).

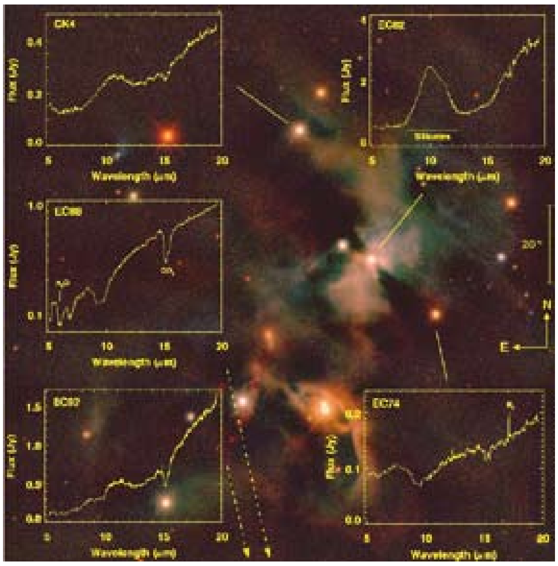


Fig. 3.16: Spitzer-IRS spectra of low-mass young stellar objects in the Serpens core obtained in the c2d Legacy program. Note the variety of spectral features: embedded sources show silicates and ices in absorption, whereas young stars with disks have silicate features in emission. Some sources show gaseous emission lines such as that of H_2 (from Geers et al.).

Spitzer also has the sensitivity to obtain mid-infrared spectra of stars that lie behind dense molecular clouds. Together with Knez (Texas), van Dishoeck, Pontoppidan, Lahuis and the c2d team obtained complete 5-20 μm spectra of three stars behind the Serpens and Taurus clouds, providing the first complete inventory of solid-state material before star formation begins. Remarkably, the spectra show strong 6.0 and 6.8 μm features as well as strong CO_2 ice bands. Thus, the production of the carrier of the 6.85 μm band does not require energetic input of a nearby source. Models of star formation should begin with dust models already coated with a fairly complex mixture of ices.

3.2.2.6. Database for analysis of submm line observations

Schöier, van der Tak (Bonn), Black (Chalmers) and van Dishoeck summarized available atomic and molecular data for transitions of astrophysically interesting species, including energy levels, Einstein-A coefficients and collisional rate coefficients. The latter were extrapolated to higher temperatures, up to 1000 K. The data are essential input for non-LTE radiative transfer programs and are made publically available through the WWW. This database should form an important tool for analyzing data from current and future submillimeter telescopes, in particular APEX, Herschel and ALMA.

3.2.3. Very young massive stars

Massive stars have the greatest impact on the Galactic environment of all the varieties of stars within our Galaxy.

3.2.3.1. High mass pre-stellar cores

The earliest stages of the formation of massive stars remained elusive due to their large distances and rapid evolution. Frieswijk, Shipman and Spaans identified potential sites of massive star formation by searching for extremely cold (~10 K) and opaque (A_V > 100 mag) molecular cloud cores within the Galaxy, combining infrared and submm observations. In directions toward the inner Galaxy, these cores can be seen by their extinction of the diffuse mid-infrared Galactic radiation. Toward the outer Galaxy, they are detected via their near-infrared extinction of background stars.

Follow-up observations made at the JCMT with SCUBA and heterodyne receivers confirm many of these cores as sites of high-mass or cluster formation. Indeed Ormel, Shipman, Ossenkopf and Helmich concluded through JCMT and Spitzer photometry that star-formation is correlated with the turbulent spectrum that the forming stars induce in the surrounding gas-clouds. These data place fundamental constraints on the evolution of the earliest stages of high mass star formation and a new catalogue is close to being published.

3.2.3.2. Deeply embedded young massive stars

Bik (NOVA PhD), Lenorzer, Kaper, de Koter, Waters, and others studied the photometric and spectroscopic properties of the youngest massive stars, deeply embedded in their natal cloud. With the ESO 3.5-m NTT deep near-infrared images were obtained of the well-known Flame Nebula (NGC 2024) in Orion in which many massive members of the young (~1 Myr) embedded stellar cluster could be identified thanks to the excellent spatial resolution of the images. Follow-up K-band spectroscopy with the VLT resulted in the discovery and definite identification of the ionizing source of the Flame Nebula (IRS2b) with spectral type O8V.

With the discovery of IRS2b, the nature of the bright infrared source IRS2 remains unclear. IRS2 is associated with the ultra-compact radio source G206.543-16.347 and is a classical example of a massive YSO. However, Lenorzer et al. demonstrated that much of the mid- and far-infrared emission does not originate in the direct surroundings of IRS2, but instead from an extended molecular cloud. Using simple gaseous and/or dust models of prescribed geometry, strong indications are found that the infrared flux originates from a dense gaseous disk with a radius of about 0.6 AU.

3.2.3.3. Spectroscopy of UC HII regions

Bik, Kaper and collaborators obtained high-resolution K-band spectra with VLT/ISAAC of candidate young massive stars deeply embedded in (ultra-) compact H II regions. These objects were selected from a near-infrared survey of 44 fields centered on IRAS sources with UCHII colors. The near-infrared counterpart of the IRAS source is often a young embedded cluster hosting massive stars. Several of them show normal photospheric OB-type spectra, a few of them of very early type (O3 - O4V) consistent with the young age of the cluster. Other objects have broad Br-γ and CO band head emission and no photospheric absorption lines, characteristic of massive YSOs (Fig. 3.17). Even very hot water was detected. Modelling of the CO profiles by Bik and Thi shows that this emission is produced by a dense circumstellar disk. Bik, Kaper and Waters argued that these circumstellar disks are the remnant of the accretion process rather than the result of rapid rotation and mass loss such as in Be/B[e] stars.

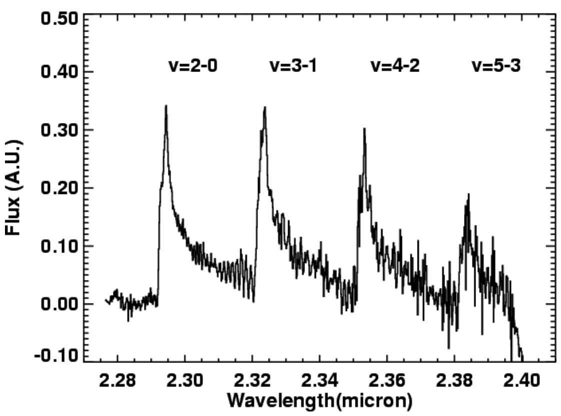


Fig. 3.17: Continuum subtracted CO band head emission toward the massive YSO 51 Oph obtained with VLT-ISAAC. Modeling of the profile indicates hot (2000-4000 K) and dense (>10^{10} cm^{-3}) gas located in the inner AU of a dust free Keplerian disk viewed nearly edge-on. This disk may be in a rare transition state toward a small debris disk (Thi, Bik et al. 2005).

3.2.3.4. Diagnostics of embedded young massive stars

Together with Martin-Hernandez, Tielens, and Hanson (Cincinnati), Bik and Kaper performed a spectroscopic study of the ultra-compact HII region G29.96-0.02 with the VLT. This cometary-shaped compact nebula contains a hot massive star of spectral type O5-O6V. Although the central star is likely a very young object, its spectrum does not show obvious deviations from that expected for a "normal" main sequence star. The high spatial and spectral resolution of the K-band spectrum allowed a critical evaluation of models explaining the cometary shape of the nebula. Neither the wind bow shock model nor the champagne flow model provide a satisfactory description of the observations. The nebular spectrum is in good agreement with the derived spectral type of the central massive star.

3.2.4. Protoplanetary disks around pre-main sequence stars

3.2.4.1. Spatially resolved silicate emission from disks

Van Boekel (NOVA PhD), Min, Waters, Dominik (NOVA postdoc), de Koter and co-workers obtained VLT-MIDI interferometric spectra of the dust in the inner regions of proto-planetary disks surrounding three intermediate mass pre-main-sequence stars known as Herbig Ae/Be stars (see cover). The stars are at typical distances of 100-200 pc, which gives a spatial resolution of about 1-2 AU using a baseline length of 100 meters at a wavelength of 10 µm. For the first time, the composition of dust in the terrestrial regions of proto-planetary disks could be measured. The dust in these inner disk regions turns out to be highly crystalline, much more so than in the outer disk regions. The MIDI data show that the crystals most likely form in the inner disk by thermal annealing of amorphous grains that enter the disk from the surrounding clouds, and by chemical equilibrium reactions with the gas. They also suggest a gradient in the chemical composition of the crystals, with more forsterite in the innermost regions, and more enstatite further out. This gradient in chemical composition was predicted by disk chemical models.

3.2.4.2. Grain growth in disks

A study of ground-based 10 µm spectra by van Boekel, Waters, Dominik, and de Koter, in collaboration with Bouwman and Dullemond (Heidelberg), demonstrated a clear correlation between the strength and the shape of the 10 μm silicate feature from disks around Herbig stars (Fig. 3.18). Weaker features suggest that the average grain size has increased to about 2 μm. Since the process of gravitational settling of grains in disks should remove the large grains first, these results indicate that vertical stirring is active in these disks and constantly replenishes the large dust grains in the disk surface. This implies that the dust in the disk surface is chemically and crystallographically much more representative of the mid-plane dust than previously believed.

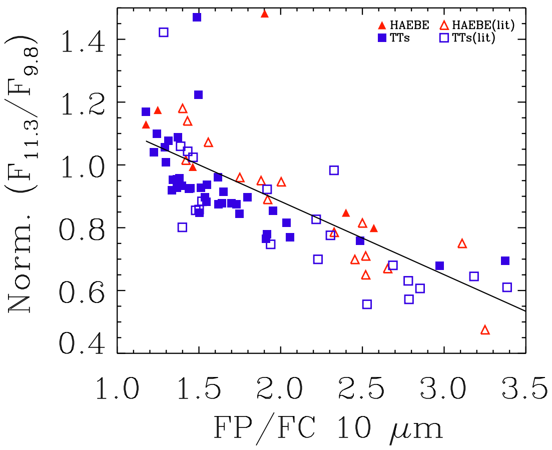


Fig. 3.18: The degree of processing of the broad silicate 10 μm emission in Herbig Ae/Be and T Tauri stars versus the absolute strength of this feature. The correlation reflects the growth of dust grains in the visible surface layer of proto-planetary disks (van Boekel et al. 2003, Kessler et al. 2005).

A further investigation of the 10 μm feature of a large sample of Herbig stars was performed by van Boekel, Min, Waters, de Koter, Dominik and co-workers. It was found that none of the disks have fully pristine dust comparable to that found in the interstellar medium. In addition, all sources with a high fraction of crystalline silicates are dominated by large grains. The disks around relatively massive Herbig stars have a higher fraction of crystalline silicates than those around lower mass stars, which may be a selection effect. The present data favor a scenario in which the crystalline silicates are produced in the innermost regions of the disk, close to the star, and transported outward to the regions where they can be detected by means of 10 μm, and that the final crystallinity of these disks is reached very soon after active accretion has stopped.

In a related study, the infrared spectrum of the Herbig star HD 100546 was compared with that of comet Hale Bopp. The spectral energy distribution (SED) of HD 100546 differs remarkably from that of other Herbig stars. The weak near-IR excess indicates significant removal of material from the inner disk regions, while the very strong mid-IR excess is indicative of a gap in the disk which might have been cleared by a planet. HD 100546 contains a large amount of crystalline forsterite, and much of this material is cold and therefore located in the outer disk. This requires either very efficient radial mixing, or a local production of such processed material, for example by the destruction of large planetesimals in this older disk.

Another example is provided by the ISO spectrum of the disk around HD 100453, which shows very little structure in the 10-30 μm wavelength range, and at the same time a rather prominent 33.5 μm forsterite band. This can be understood if the silicate dust grains in this disk have grown to sizes of several microns. Independent evidence for grain growth also comes from the correlation of the slope of the millimeter dust spectra with the shape of the mid-infrared spectra for a large sample of sources, in a study led by Acke, van Boekel and Waters. Flat millimeter slopes typically occur in disks with steep mid-infrared spectra.

Ormel, Spaans and Tielens developed a dust coagulation model that allows the incorporation of porosity, i.e., the extended nature of dust grains, into the complex collisional processes that occur between dust particles in disks. Grains grow and are compacted depending on the collisional frequency and energetics. It is found that inclusion of this internal (fractal) structure of dust grains delays the onset of settling until much larger grain sizes have been reached. With disk turbulence included, aggregates grow to mm or even cm size for a fractal dimension of 2.1 at 1 AU from the gas disk center. Compact coagulation models yield much smaller grains. The large mm/cm aggregates found in the models are typical of the sizes of chondrules observed in chondritic meteorites.

Kessler-Silacci (Texas), Augereau, Geers, and van Dishoeck, in collaboration with the c2d team, are involved in the interpretation of the Spitzer c2d survey of disks around solar-type T Tauri stars, i.e., young pre-main sequence stars which are less massive than the Herbig stars. A large fraction of the observed spectra have a flat and boxy 10 μm silicate emission feature and a flat spectrum beyond 20 μm. Only a small fraction of sources have a rising mid-infrared spectrum with a PAH feature at 11.3 μm. There is clear evidence for grain growth up to a few μm in a large fraction of these sources (Fig. 3.18). At least half of the sources show evidence for crystalline silicate emission.

Lommen (NOVA PhD), Jørgensen and van Dishoeck, together with collaborators in Australia and the USA, used the Australia Telescope Compact Array (ATCA) to observe 14 of the c2d T Tauri sources in Chamaeleon and Lupus at mm wavelengths. Nine sources were detected at 3 mm, giving disk masses of order 0.01 $M_\odot$. Combined with 1 mm fluxes from the literature, the submm spectral slope was found to be shallower than that of interstellar medium grains, confirming the conclusion from the infrared data that the grains have grown to micron, and even mm, size.

A theoretical study of dust coagulation in disks by Dullemond and Dominik showed that this process very rapidly depletes small grains. If turbulence is present, the entire inner disk is cleared of small grains on timescales irreconcilable with the observed properties of disks. Dullemond and Dominik suggest that the fragmentation of larger grains may be an important process, leading to a steady state abundance of small grains while large grains still continue to grow.

Paszun and Dominik studied the process of grain aggregation in a Monte-Carlo simulation, including for the first time grain rotation into the computation. The rotation leads to significant structural changes in the resulting aggregates which are much more elongated, with fractal dimensions of only 1.4 instead of 1.9 indicated by previous computations. This finally solves a long standing puzzle, brought up by experiments which produced unexpectedly elongated aggregates.

3.2.4.3. Disks around brown dwarfs

Merin, Augereau, and van Dishoeck, in collaboration with the c2d team, discovered several new brown dwarf candidates with disks in the Lupus star-forming region as part of the Spitzer c2d program. Spectroscopic follow up with the IRS shows that one of the objects (Lupus BD2) has spectacular silicate emission bands at 10 and 20 μm as well as several features from crystalline silicates, in particular forsterite. The analysis of the SED suggests a passive disk with (small) dust grains and a mass fraction of crystalline material of 30%, which is among the highest found to date.

3.2.4.4. Structure and evolution of disks

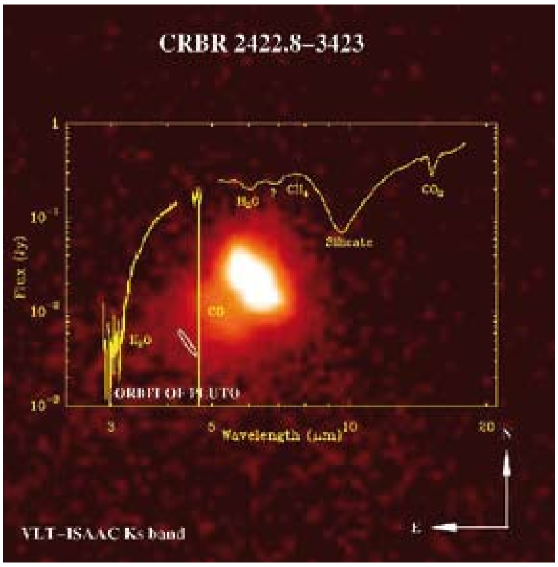
Dominik, Dullemond and Natta (Arcetri) developed a model to describe the structure of a circumstellar disk with an inner hole where the dust has evaporated to explain the strong near-infrared emission. Together with Waters and de Koter, this model was used to reproduce the SEDs of a sample of Herbig Ae stars. Overall, the fits turned out quite successful: large disks with flaring outer parts (class I) require relatively flat distributions of the surface density. Disks with limited or no structure in the 10 μm region can be matched with models containing only large grains or, alternatively, with an exceptionally high inner rim of the disk. SEDs with low mid-infrared fluxes (class II) require small disks with a fine-tuned outer radius. Preliminary analysis of MIDI data by van Boekel et al. of a small number of sources indeed suggests that this is the case.

Dullemond and Dominik have subsequently analyzed the dependence of disk structure on dust mass and the radial distribution of dust grains. If the outer disk dust opacity decreases below a threshold value, the outer disk will cease to flare, i.e. it will no longer expose an optically thick surface to the stellar light. These disks are called self-shadowed, and show SEDs consistent with the so-called class II sources. The effects of grain settling on disk structure and SED have also been investigated. The gravitational field of the star causes grains to settle toward the mid-plane, unless this settling motion is countered by turbulent mixing. Significant mixing appears to be a requirement to explain the observed SEDs. Settling can cause the outer disk to switch from flaring to self-shadowed, once the settling dust has receded below the shadow caused by the optically thick inner disk. This effect that can render a disk undetectable in scattered light.

An important question in disk evolution is the gas content. Van Kempen, van Dishoeck, Brinch and Hogerheijde performed a JCMT CO J=3-2 survey of 21 class II sources in Lupus. One new large gas-rich disk was found, IM Lup, which will be an excellent target for future studies. For all other targets, the single-dish data are dominated by extended cloud emission, pointing to the need for interferometry in the southern sky.

3.2.4.5. Edge-on disks

Pontoppidan and Dullemond, in collaboration with the c2d Spitzer team, carried out a detailed study of the edge-on disk CRBR 2422.8-3423 in Ophiuchus. This object is known for showing deep absorption features due to ices, such as water, CO and CO_2. A two-dimensional Monte Carlo radiative transfer code was used in combination with Spitzer-IRS data and VLT-ISAAC near-infrared imaging to construct a physical model for the disk. While much of the ice observed along the line of sight is located in



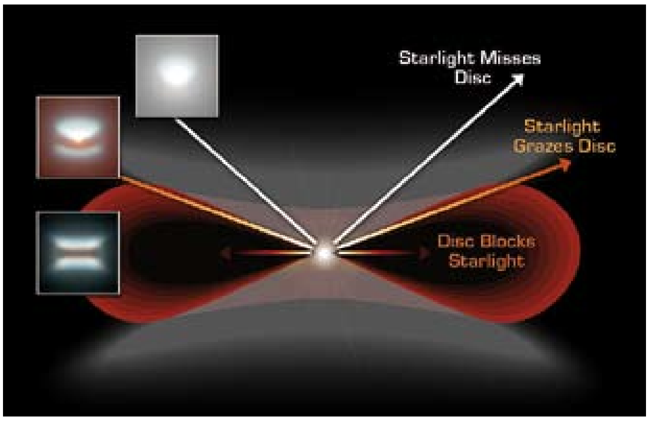


Fig. 3.19: Left: Spitzer-IRS and VLT-ISAAC spectra of the edge-on disk CRBR 2422.8-3423, superposed on the VLT near-infrared image of the source. A fraction of the deep ice absorptions arises in warm surface layers of the disk. Right: Model images of the CRBR 2422.8-3423 disk viewed under various inclinations (Pontoppidan et al. 2005).

a foreground molecular core, a significant fraction of the ice is likely present in the outer disk. This is supported by the shape of the 6.85 μm band, attributed to NH_4^+ ice, which shows indications of heating of ~50% of the ice. This is the first - and arguably the strongest - evidence for the presence of ices in circumstellar disks surrounding young solar-type stars.

Pontoppidan and collaborators also obtained a deep mid-infrared spectrum with Spitzer-IRS of the edge-on disk "The Flying Saucer" (2MASS J16281370-2431391). The shape of the spectrum shows that the emission from the object is dominated by photons scattered on the disk surface out to wavelengths of 20 μm. Radiative transfer modeling shows that this requires grains that have grown to at least 5 μm in size. The presence of large grains in the upper layers puts significant constraints on models of grain growth and dust-mixing in planet-forming disks.

3.2.4.6. PAHs in disks

Geers and Augereau, in collaboration with the c2d team, analyzed Spitzer spectra of a handful of T Tauri stars which show PAH emission. Considerable care was taken to prove that the emission arises from the source itself and not from the general surrounding cloud. The detections indicate that PAH molecules receive sufficient UV radiation from the central star to be excited, suggesting an additional source of UV radiation above the stellar photosphere, most likely associated with the accretion process. Visser, in collaboration with Augereau, van Dishoeck and Geers, developed a PAH chemistry and infrared emission model. This was subsequently coupled with Dullemond's radiative transfer disk models in order to constrain the characteristics (abundance, size, charge, hydrogenation state) of the PAHs observed with Spitzer and ISO.

Geers and collaborators also detected spatially resolved, extended emission from PAHs in the circumstellar disk around the old pre-main sequence Herbig Ae star HD 100546 using VLT-ISAAC. The 3.3 μm PAH emission feature was found to have an extent of around 30 AU. This is much larger than the typical extent of crystalline silicate emission, indicating that ultraviolet excitation of these molecules can continue out to large distances.

3.2.4.7. Disk shadows

Pontoppidan and Dullemond studied the phenomenon of a small (~50 AU) disk casting a large shadow extending over more than 10,000 AU on a large reflection nebulosity surrounding the central star-disk system. It was shown that disk shadows are likely common and may form a variety of morphologies in reflection nebulae. The shape of a disk shadow can thus be used to obtain unique constraints on the physical structure of disks. A number of disk shadow candidates were identified including EC 82 -the illuminating source of the Serpens reflection nebula- and Ced 110 IRS 4 in Chamaeleon. These objects were modeled using a two-dimensional Monte Carlo radiative transfer code and compared to VLT-ISAAC near-infrared images and mid-infrared spectroscopy from ISAAC, ISO and Spitzer.

One particularly interesting case is formed by the UX Orionis star VV Ser studied by Pontoppidan, Dullemond and co-workers. This young star is surrounded by an extended (over 4′) mid-infrared nebulosity interpreted as being due to PAHs and very small grains that have been transiently heated by stellar UV photons. Additionally, the nebulosity is intersected by a dark wedge-shaped band indicative of a shadow cast by a much smaller, inclined disk (see cover). The Spitzer and complementary data, including near-infrared interferometric visibilities, were modeled successfully by adapting the Monte Carlo code to treat transiently heated grains. The relative abundance of PAH molecules is constrained to 3±1% of the total dust mass. The relatively high inclination of the system is consistent with the interpretation of UX Orionis variability as being due to dust clumps in Keplerian orbits in the innermost part of the disk.

3.2.4.8. Chemistry in disks

Lahuis, van Dishoeck, Pontoppidan, together with the c2d team, detected surprisingly strong absorption due to the gaseous organic molecules C_2H_2 and HCN toward the low-mass YSO IRS 46 in Ophiuchus using Spitzer-IRS. Only 1 out of 100 sources shows these features. Analysis of the data combined with Keck spectra shows temperatures of at least 350 K and abundances up to 10^{-5} with respect to H_2, orders of magnitude higher than in the surrounding cloud. The most plausible origin of this hot gas rich in organic molecules is in the inner (<6 AU radius) region of the disk, either the disk itself or a disk wind. These data provided a first look at chemistry in the planet-forming zones of disks.

Brinch, Hogerheijde, Crapsi, and Jørgensen used available single-dish molecular line data to construct a detailed model of the L1489 IRS disk. The model describes the circumstellar structure by a flattened density profile with a Keplerian velocity field. It also provides good agreement with near-infrared scattered light and millimeter interferometry imaging. The inferred abundances in the outer disk are significantly lower than found in molecular clouds, consistent with freeze-out in the cold midplane and photodissociation in the upper layers.

Thi, van Zadelhoff and van Dishoeck performed a JCMT and IRAM 30m search for gas-phase molecules in disks around two T Tauri stars and two Herbig Ae stars. Simple molecules such as CO, ^{13}CO, HCO^+, CN, HCN, H_2CO and CS are detected, but no CH_3OH is seen. Line ratios indicate that the emission arises from dense and moderately warm intermediate height regions of the disk atmosphere between the midplane and the upper layer, in accordance with predictions from chemistry models. CN is strongly detected in all disks, and the CN/HCN abundance ratio toward the Herbig Ae stars is even higher than that found in galactic PDRs, testifying to the importance of photo processes.

Hogerheijde and Bergin (Michigan) performed a series of simulations of the expected line strengths of water in protoplanetary disks, in preparation for the upcoming Herschel mission. Line strengths are found to be generally weak, and detecting a few objects with Herschel will be challenging but doable.

3.2.4.9. Deuterated molecules in disks

Deuterated molecules have long fascinated astrochemists because of the enormous fractionation observed in cold clouds, where the D/H ratios in molecules can be as large as 0.1, more than four orders of magnitude above the overall [D]/[H] abundance ratio of 10^{-5}. This chemical enrichment is an excellent probe of the chemistry that occurs in cold clouds, envelopes and circumstellar disks. Van Dishoeck, Thi and co-workers detected for the first time a deuterated species (DCO^+) in the gas phase in the disk surrounding the young star TW Hya. The high DCO^+/HCO^+ ratio is consistent with disk models which consider gas-phase fractionation processes within a realistic two-dimensional temperature distribution and which include the effects of freeze-out onto grains.

The midplane gas in disks is very difficult to observe, because most molecules including CO are frozen onto grains and the main species H_2 has no strong spectroscopic signatures. Deuterated molecules are unique tracers of this cold gas, especially the deuterated isotopes of H_3^+, which can be enhanced in abundance by factors up to 10^{14}. A search for H_2D^+ in the DM Tau and TW Hya disks by Ceccarelli (Grenoble), Dominik and collaborators using the JCMT successfully detected this molecule, providing the first tracer for the cold midplane gas in such disks and its ionization fraction.

Another key molecule in disks is water (H_2O), not observable from the ground because of the bad atmospheric transmission. However, the deuterated variant HDO can be observed. Ceccarelli, Dominik and collaborators discovered an absorption line associated with this molecule in DM Tau, indicating that there may be a layer of HDO in the disk above the continuum-producing midplane. This was initially a surprise since temperatures in the outer disk are so low that water should be frozen out everywhere. However, in a follow-up study, Dominik, Ceccarelli, together with Hollenbach and

Kaufman (NASA Ames), showed that the interstellar UV radiation can release molecules from ice mantles, leading to a layer of water and HDO molecules above the midplane.

3.2.4.10. Gas temperature of (flaring) disks

Jonkheid, van Dishoeck, Kamp and Dullemond performed calculations of the gas temperature of the outer regions in flaring circumstellar disks. Previous models assumed that the gas and dust temperature are equal, which is only valid in the midplane. The gas temperature was calculated explicitly by balancing the various gas heating and cooling processes and was shown to be significantly higher than the dust temperature. The effects of dust settling on the temperature structure and on important emission lines were also examined. It was found that relatively high-lying lines, such as the high-J CO, [C II] 158 μm and [O I] 63 and 145 μm lines, are much stronger when the gas temperature is calculated explicitly instead of taken to be equal to the dust temperature. The high temperatures may also lead to outgassing of the disk.

Hogerheijde, in collaboration with Qi, Wilner (both CfA) and other US collaborators, modeled the submillimeter interferometric line emission of two protoplanetary disks, TW Hya in CO J=6-5 and HD169142 in CO J=3-2. For both disks, the SED provides a template for the disk's structure, and the molecular line data were used to probe the chemical composition of the disk, as well as its velocity field (Keplerian in both cases, with very little turbulence) and inclination. The J=6-5 data indicate that the gas is hotter than the dust, consistent with heating by UV or X-rays.

In collaboration with Augereau and Kamp, Jonkheid and van Dishoeck developed chemical and thermal models of the circumstellar disk around the Herbig Ae star HD 141569. The disk around this object is in an interesting transitional state between the optically thick gas-rich phase and the optically thin debris phase. The dust distribution as imaged by HST and other telescopes shows that the dust is concentrated in two rings, probably shaped by an external object with a large inner hole. CO has also been detected by single-dish telescopes and interferometers. The best fitting model has a total gas mass of about 80 Earth masses, with some gas present in the inner hole of the dust disk.

3.2.4.11. Debris disks

In collaboration with Waelkens and Decin (Leuven), Dominik and Waters undertook a re-investigation of the dust masses and ages determined for stars with debris disks found in various ISO studies. In these disks, the gas has been cleared out and the small dust grains are thought to be produced by collisions of planetesimals. It was found that the maximum dust mass observed at a given age is independent of age, which excludes a simple power law relation between the two quantities suggested in earlier studies. Furthermore, there do not seem to be any young sources with intermediate amounts of dust. A detailed analytical model was used to study the time behavior of such collisional cascades. The results favor a scenario in which the disks in different systems enter the cascade phase at different times, determined by the amount of gravitational stirring by (hypothetical) planets embedded in the disk.

Using a particle-in-a-box method, Thébault (Stockholm), Augereau and Beust (Grenoble) addressed the problem of conflicting solid mass estimates in the inner β Pictoris disk. The collisional activity between km-sized planetesimals is found to very rapidly erode the more massive planetesimal disk, leading to an upper limit of 0.1 Earth mass for the total disk in the inner 10 AU after 10 Myr, consistent with the lower mass estimates deduced from modeling of the SED. They also addressed the problem of conflicting gas mass estimates in the inner disk of β Pictoris. Specifically, the effect of gas drag on the dynamics of the dust particles was modeled to derive an upper limit on the gas mass of about 0.4 Earth masses and a gas-to-dust mass ratio smaller than 1.

Radiation pressure in the β Pictoris system is important because of the large luminosity of the central star (A-type star). This is not the case for AU Mic, the first M-type star for which a debris disk was spatially resolved in scattered light. Nevertheless, the edge-on disk shows a very similar brightness profile to that of β Pic. Augereau and Beust showed that the dynamics of the grains are very similar to that of the grains in the β Pic system if the star possesses a stellar wind with a mass loss rate of a few 10^{-12} $M_\odot$ per year.

3.2.5. Large organic molecules in space

3.2.5.1. Diffuse interstellar bands in the LMC and beyond

Ehrenfreund and Cox (NOVA PhD) led an international consortium to study the properties of the Diffuse Interstellar Bands (DIBs) in a large sample of galactic and extragalactic regions. DIBs were observed toward SN2001el in the spiral galaxy NGC1448 and are very similar to those in galactic diffuse clouds that are edge dominated, i.e., subject to a relative intense interstellar radiation field

(Fig. 3.20). A detailed study in collaboration with Kaper of the highly reddened line of sight toward a high-mass X-ray binary at a distance of 5 kpc revealed a wealth of DIBs of unprecedented strength.

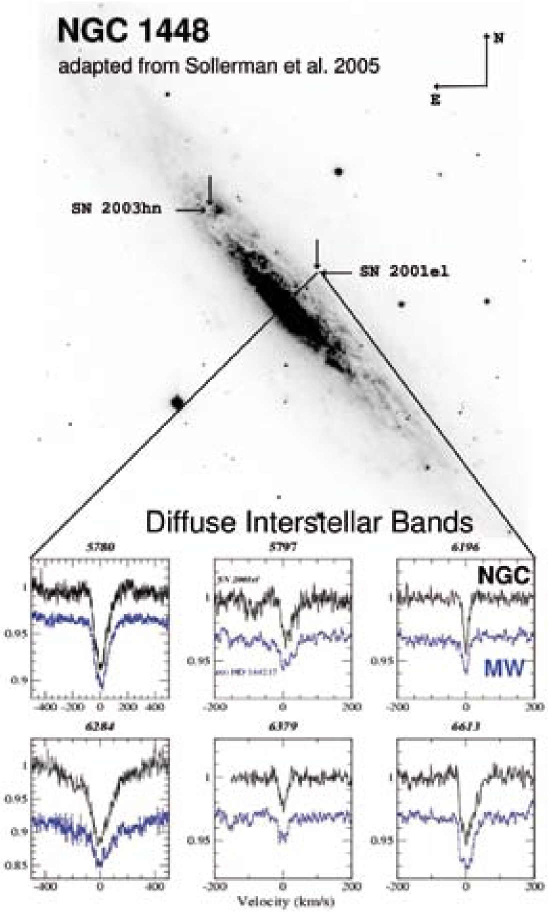


Fig. 3.20: First detection of strong narrow diffuse interstellar band profiles outside the Local Group, towards SN2001el in NGC1448. Comparison with Galactic lines of sight indicates that the local ISM conditions must resemble closely those observed for Galactic diffuse clouds exposed to an intensive UV radiation field (from Sollerman, Cox et al. 2005).

A comprehensive study of LMC targets was performed with VLT-UVES and the local conditions of the interstellar clouds in the Large Magellanic Cloud could be related to the behavior of the DIBs. The data showed that the UV radiation field and/or metallicity are the most decisive parameters governing the behavior of the DIB carriers.

The physical origin of the DIBs is still unknown. The hypothesis that the DIB carriers are complex organic molecules, like fullerenes and PAHs, is being tested through comparison with models and laboratory data. In collaboration with Spaans, diffuse cloud models were developed including a simple PAH chemistry and the resulting absorption spectrum was constructed using theoretical calculations of electronic transitions in the visible spectral range by Ruiterkamp. The model was expanded to include different types of PAH molecules (e.g. fullerenes, chains, peri-condensed, cata-condensed). With this model, the Milky Way translucent cloud HD147889 was investigated and the charge state fractions of different PAHs calculated as functions of depth into the cloud and for different internal symmetry groups of the PAHs. Small PAHs with less than 50 carbon atoms provide a good fit to the HD147889 data. Cox and Spaans subsequently extended the models to the physical conditions that pertain in the LMC and SMC. For these low metallicity (0.25 - 0.10 of the solar abundance) environments, PAHs remain positively charged because recombination with electrons is suppressed. As a consequence, DIB strengths in the LMC are comparable to those in the Milky Way. Moreover, the models can explain DIBs of Galactic strength observed towards the SMC wing, as well as the absence of DIBs towards the SMC bar.

3.2.5.2. PAHs as tracers of star formation

Together with Peeters and Spoon, Tielens finished a large survey of the infrared emission features from UV-pumped polycyclic aromatic hydrocarbon (PAH) molecules in a variety of regions (Fig. 3.21). ISO data on Galactic massive star-forming regions

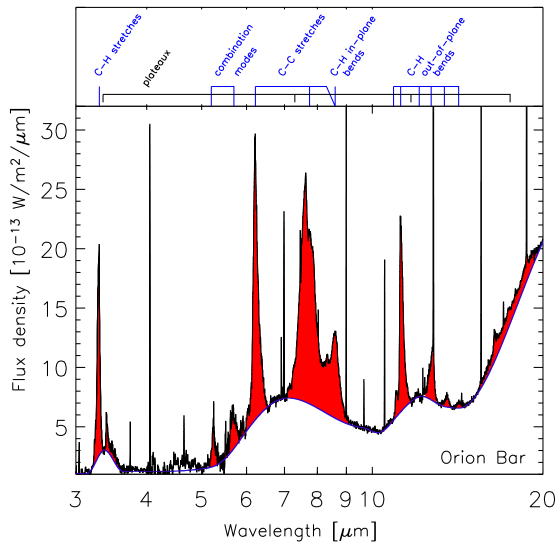


Fig. 3.21: ISO SWS spectrum of the Orion Bar PDR, illustrating the richness of PAH features. Various atomic and molecular lines are seen as well, originating in the PDR and in the Orion H II region along the line of sight (Peeters et al. 2004).

and of normal and starburst galaxies, AGNs and ultra-luminous infrared galaxies were summarized. A new mid-infrared/far-infrared diagnostic diagram was developed based on the Galactic sample. Comparison with the extragalactic sample revealed an excellent resemblance for normal and starburst galaxies to exposed PDRs. While Seyfert 2 galaxies coincide with the starburst trend, Seyfert 1 galaxies are displaced by at least a factor of 10 in 6.2 μm continuum flux, in accordance with general orientation-dependent unification schemes for AGNs. ULIRGs show a diverse spectral appearance. The observed variation in the Galactic sample was explained in terms of the evolutionary state and the PAH/dust abundance ratio. The use of PAHs as quantitative tracers of star formation activity was established. It appears that PAHs are better suited as tracers of B-type stars, which dominate the Galactic stellar energy budget, than of massive star formation (O stars).

3.2.5.3. Testing grain-surface astrochemistry

Bisschop (NOVA PhD), van Dishoeck and Jørgensen performed deep searches for complex molecules using the JCMT in a small sample of low- and high-mass protostars. Molecules that are thought to originate through grain surface chemistry by successive hydrogenation and oxidation of CO (cf. the models by Tielens and co-workers) were targeted. The aim was to derive abundances and abundance ratios for these species and compare them with grain-surface and gas-phase chemical models. Interestingly, initial data show that some molecules like CH_3OCHO are present only in the colder environments, whereas others like CH_2CH_3OH are more abundant in warmer gas.

3.2.6. Exoplanets

Most exoplanets found to date have been detected by the radial velocity technique, which measures the wobble of the star induced by one or more unseen planets through small changes in the star's spectral features. Accurate astrometry is an alternative method to detect these wobbles, and is applicable to stars of all masses and ages with the advantage that it can determine all orbital parameters (inclination, mass, orientation). The VLTI in its astrometric mode will have a precision of 10-30 microarcsec, and will have the sensitivity to detect massive rocky planets (~10 M_{Earth}) around the nearest stars. Preparations for a long term survey by Quirrenbach and co-workers to monitor ~200 stars with VLTI-PRIMA were started.

The VLT with adaptive optics may allow direct detection of the more massive exoplanets and a rough physical characterization of their atmospheres. Stam, Waters, de Koter and co-workers developed models to probe exoplanetary atmospheres by opto-infrared polarimetry and spectroscopy.

Paardekooper and Mellema adapted their hydrodynamical codes to model the interaction of massive planets with protoplanetary disks. A new aspect of this method is the two-fluid approach, which allows separate treatments of the gas and dust. In particular, only planets more massive than 1 M_{Jup} can open a gap in the gas disk, but planets with 0.1 M_{Jup} already create a gap in the dust disk. This will facilitate detection of lower-mass planets through dust continuum observations with ALMA.

3.2.7. Comets

Hogerheijde, as member of a team of US astronomers, observed molecular lines from two comets that approached the Sun in May 2004, LINEAR

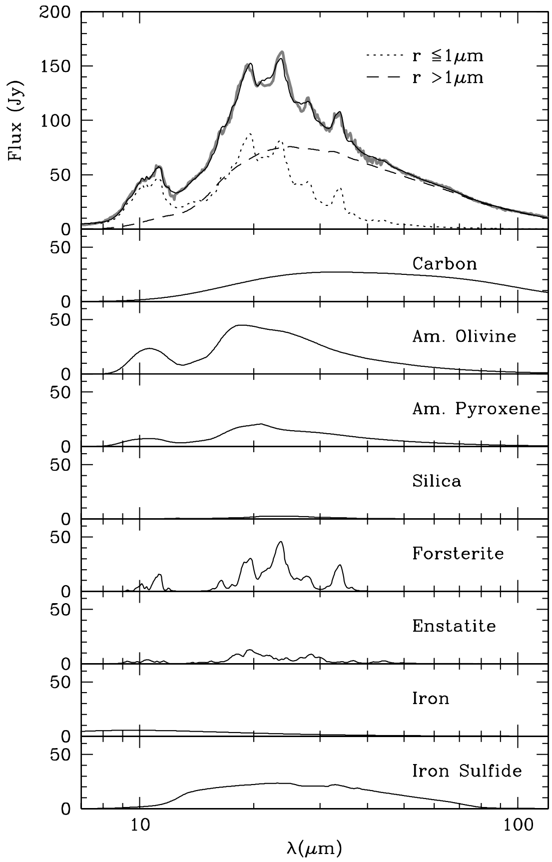


Fig. 3.22: The ISO spectrum of comet Hale-Bopp, together with a decomposition of the dust species that contribute to the observed emission (grey line). The small (large) grain component is denoted with a dotted (dashed) line in the upper panel. The black line indicates the best fit model. The contributions of the various solid state components are displayed in the lower panels (from: Min et al. 2005).

(C/2002 T7) and NEAT (C/2001 Q4), using millimeter interferometers. Clear detections of HCN and CS using both BIMA and OVRO lead to abundances which can be interpreted in the framework of evaporation of the parent ices and photochemistry in the expanding coma. The effects of solar infrared fluorescent pumping on the millimeter lines of HCN were modeled.

The composition and size distribution of the dust in the coma of Comet Hale-Bopp was studied by Min, Hovenier, de Koter, Waters, and Dominik (Fig. 3.22). For the first time spectroscopy was combined with polarimetry. The infrared spectrum at long wavelengths reveals that large grains are needed in order to fit the spectral slope. The ratios of the strength of various forsterite features show that the crystalline silicate grains in Hale-Bopp must be sub-μm sized. Large crystalline grains in the coma can be excluded. Combined with the need for large amorphous grains, this implies that only approximately 4-8% of crystalline silicates by mass (forsterite and enstatite) need to be present to account for the observed spectral features. This is in sharp contrast to previous studies, where 20-30% of this material was deduced. It is concluded that the crystallinity observed in Hale-Bopp is consistent with the production of crystalline silicates in the inner Solar System by thermal annealing and subsequent radial mixing to the comet forming region at about 30 AU.

3.2.8. The most massive stars

3.2.8.1 The VLT-FLAMES survey of massive stars

Smartt, Evans, de Koter, Mokiem and co-workers obtained spectra of an unprecedented sample of 800 massive stars in open cluster fields in the Magellanic Clouds and Milky Way, primarily with the multi-fibre FLAMES instrument (Fig. 3.23). The survey addresses the role of environment, via stellar rotation and mass-loss, on the evolution of the most massive stars, which are the dominating influence on the evolution of young, star-forming galaxies.

De Koter and Puls (München) lead the analysis of all O- and early B-type stars secured in the FLAMES project, featuring prominent stellar winds. In view of the large number of objects – about 100 targets (doubling the number of such stars known) – an automatic fitting method for quantitative spectroscopy was developed to allow for a homogeneous analysis. The method is robust, fast, and accurate and was tested for consistency on seven O-type stars in the young cluster Cygnus OB2 and five other Galactic stars for which previous studies exist. The derived spectroscopic masses agree with those derived from stellar evolutionary models. This indicates that the improved spectral fitting resolves (part) of the long-standing mass problem in massive star research.

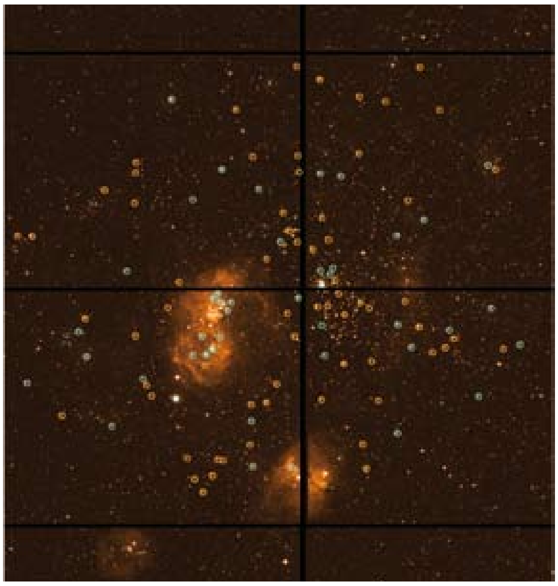


Fig. 3.23: V-band WFI image of FLAMES targets in N11 in the LMC. O-type stars are marked as open blue circles, B-type stars by yellow circles. The solid black lines are the gaps between CCDs in the WFI mosaic array. The image covers 34′ x 33′ (Evans et al. 2005)

Mokiem, de Koter, Langer, Young, and co-workers investigated a sample of 31 massive stars, mostly located in the young cluster NGC 346 in the SMC. The automated spectral analysis method allowed for a detailed determination of the projected rotational velocities of the 21 dwarfs in the sample that are expected to be NGC 346 members. This distribution is consistent with an underlying rotational velocity distribution with a mean velocity of about 160 -190 km/s and an effective half width of 100 - 150 km/s. The distribution must include a small percentage of slowly rotating stars. If predictions of the time evolution of the equatorial velocity for SMC circumstances are correct, the young age of the cluster must imply that this underlying distribution is representative for the initial rotational velocity distribution. This would be the first derivation of this distribution for massive stars, essential for understanding the initial conditions of the evolution of these objects.

3.2.8.2. Resolving the stellar wind and sub-arcsecond dusty environment of η Carinae

Van Boekel, de Koter, Waters and co-workers obtained high angular resolution observations at near-IR wavelengths of the core of η Carinae, using

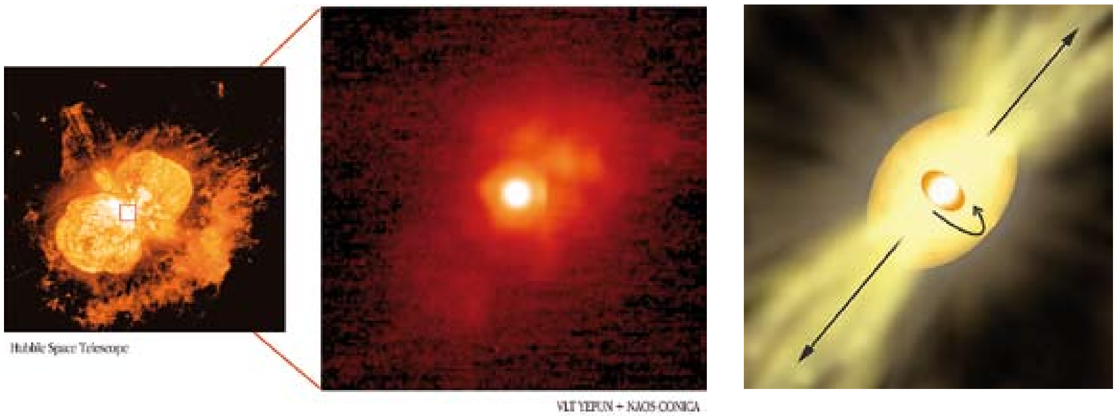


Fig. 3.24: Left: HST optical image of the massive star η Carinae, together with the VLT NACO near-infrared image revealing the structure of the star's immediate surroundings. Right: Artist's impression of the star, based on the new VLT-NACO and VLTI-VINCI data (van Boekel et al. 2003).

NAOS-CONICA at the VLT and VINCI at the VLTI (Fig. 3.24). The latter data provide spatial information on a scale of 5 milli-arcsec or ~11 AU at the distance of the star. The present-day stellar wind of η Carinae is resolved on a scale of several stellar radii and the object is elongated with a de-projected axis ratio of approximately 1.5; the major axis is found to be aligned with that of the large bi-polar nebula that was ejected in the 19th century. The most likely explanation is a counter-intuitive model in which stellar rotation near the critical velocity causes enhanced mass loss along the rotational axis. This rapid rotation results in a large temperature difference between pole and equator of such stars: η Carinae must rotate in excess of 90% of its critical velocity to account for the observed shape. The data provide strong support for the existence of a theoretically predicted rotational instability, known as the Ω limit.

The core of the nebula surrounding η Carinae was observed with the VLT-NACO and with VLTI-MIDI by Chesneau, Min, Waters, de Koter and co-workers. These data constrain spatially and spectrally the warm dusty environment and the central object. Narrow-band images at 3.74 and 4.05 μm reveal the butterfly-shaped dusty environment close to the central star with unprecedented spatial resolution. An inner hole whose radius corresponds to the expected dust sublimation radius was discovered around the central source. A large amount of corundum (Al_2O_3) was found, peaking at 0."6 - 1."2 south-east from the star. The dust content of the blobs is dominated by silicates.

3.2.8.3. Maximum mass-loss rates of line-driven winds of massive stars

Lamers, in collaboration with Aerts and Molenberghs (Leuven) studied the effect of rotation on the maximum mass-loss rate due to an optically-thin radiatively-driven wind using a formalism which takes into account the possible influence of any extra force (apart from gravity and radiation pressure) at the base of the wind. The maximum surface-integrated mass that can be lost from a star by line driving was determined as a function of rotation for a number of relevant stellar models of massive OB stars. Comparison with literature data showed that inclusion of the extra force leads to extreme mass loss at much lower rotation rates. A scaling law to predict maximum mass-loss rates was derived and applied to η Carinae.

3.2.8.4. Luminous blue variable stars

Smith, in collaboration with de Koter investigated the distribution of luminous blue variable stars (LBVs) in the Hertzsprung-Russell diagram using numerical simulations. There appears to be a deficiency of these massive post-main sequence stars at luminosities between 400,000 and 630,000 solar luminosities. The upper boundary, interestingly, is also where the temperature-dependent S Doradus instability strip intersects the bi-stability jump at 21,000 K. Because of increased opacity, winds of early-type supergiants are slower and denser on the cool side of the bi-stability jump, and this may trigger optically thick winds that inhibit quiescent LBVs from residing there.

3.2.8.5. The metallicity dependence of Wolf-Rayet winds

Vink and de Koter performed a pilot study of mass loss predictions for late-type Wolf-Rayet stars as a function of metal abundance, over a range between 10^{-5} and 10 times the Galactic metal abundance. The winds of nitrogen-rich Wolf-Rayet stars are dominated by iron lines, with a mass-loss dependence on metal content similar to that of massive O and B-type stars. The winds of more evolved, carbon-rich Wolf-Rayet stars also depend on the chemical environment of the host galaxy, but with a mass loss metallicity dependence that is less steep than for OB stars. This discovery has important consequences for black hole formation and X-ray population studies in external galaxies. For C-rich WR stars the mass loss no longer declines once the metal abundance drops below 10^{-3}. In combination with rapid rotation and/or proximity to the Eddington limit – likely to be relevant for massive population III stars - this effect may indicate a role for mass loss in the appearance and evolution of these objects, as well as a potential role for stellar winds in enriching the intergalactic medium of the early Universe.

3.2.9. Evolved stars

3.2.9.1. Dust in outflows of low-mass evolved stars

All low and intermediate mass stars end their life with a phase of very high mass loss (up to 10^{-3} $M_\odot$ per year) through a cool, dusty and slowly expanding stellar wind. Kemper, de Koter, Waters, Dijkstra (NOVA PhD) and co-workers analyzed submillimeter observations of CO for a sample of AGB stars and red supergiants to determine their mass loss history. A physical structure with a variable mass-loss rate and/or a gradient in stochastic gas velocity is required to reproduce the data. A case study of WX Psc shows that the CO line strengths may be explained by variations in mass loss on time scales similar to those observed in the separated arc-like structures present around post-AGB stars.

ISO-SWS and LWS spectra for a large sample of AGB and post-AGB stars were analyzed by Dijkstra, Dominik, de Koter and Waters. The composition of the dust provides vital clues on the physical conditions and mass loss history and geometry in these sources. The study focused on the 40-60 μm region which includes water ice. A model was developed which studies the condensation of water ice in the circumstellar envelope on the surfaces of pre-existing silicate grains. A critical process governing ice formation turned out to be mechanical sputtering: efficient ice formation only occurs in high-density winds which are able to couple the dust grains well to the gas.

A detailed study of the envelope of the post-AGB star HD 56126 was performed by Hony, Tielens, Waters, and de Koter in order to derive the dust composition and mass, and the mass-loss history of the star. The mid-infrared imaging and spectroscopy is best reproduced by a single dust shell from 1.2 to 2.6 arcsec radius, originating from a short period during which the mass-loss rate exceeded 10^{-4} $M_\odot$ per year. The stellar spectrum shows a pronounced feature at 21 μm which may be due to titanium carbide. To explain hydrocarbon features at 3.3 - 3.4 and 6-9 μm relative to those at 11-17 μm, it was proposed that these particles are transiently heated to high temperatures. The 30 μm feature was suggested to be due to MgS, which fits well with the measured atmospheric abundances of Mg and S.

Chesneau, Waters, de Koter and co-workers studied the famous OH/IR star OH 26.5+0.6 using VLTI-MIDI. Emission of the dusty envelope, spectrally dispersed from 8 to 13.5 μm, appears to have an angular diameter which increases strongly within the silicate absorption band. The star itself was not detected in interferometric mode which provides significant constraints on the opacities in the inner regions of the dust shell or in the close vicinity of the star.

3.2.9.2. OH/IR stars as tracers of the inner Galaxy

Messineo (NOVA PhD), Habing, Menten (MPIfR), Omont (IAP) and Sjouwerman (NRAO) compiled a catalogue of 1-25 μm photometry by DENIS, 2MASS, ISOGAL, MSX and IRAS for a sample of 441 late-type stars that were previously searched for 86 GHz SiO maser emission using the IRAM 30-m telescope. The comparison of the DENIS and 2MASS J and K_s magnitudes showed that most of the sources are variable stars. Since variable AGB stars, in particular the sub-class of Mira variables, obey a period-luminosity relation, variability is a key ingredient to measure the distance to the stars. The MSX colors and the IRAS [12]-[25] colors of the SiO maser stars were found to be consistent with those of Mira-type stars with a dust silicate feature at 9.7 μm in emission, indicating only a moderate mass-loss rate. Stellar bolometric magnitudes were computed by direct integration of the observed energy distribution. The luminosity distribution peaked at M_{bol} = -5.0 mag, which coincides with the peak also shown by OH/IR stars in the Galactic Centre, suggesting similar initial masses for the two samples.

3.3. Final stages of stellar evolution: physics of neutron stars and black holes

The aim of NOVA Network 3 is to study the physics of neutron stars and black holes, including processes related to their formation, such as supernovae and Gamma Ray Bursts. These compact stellar fossils are objects of fundamental physical importance. Neutron stars contain the densest form of bulk matter known, whose equation of state is as yet undetermined. Gravity near neutron stars and black holes is sufficiently strong so that general relativistic effects dominate the dynamics, rather than providing small corrections to the classical laws of motion; in this extreme regime the theory of relativity has not been tested yet. Network 3 concentrates on the astrophysics, formation and evolution of compact objects and their host systems by (1) direct observation of neutron stars and black holes and the processes around them, in particular of radio pulsars, X-ray binary systems and gamma-ray bursts, (2) population studies, and (3) theoretical work on formation and evolution of compact objects and host systems as well as on physical processes near them.

3.3.1. Gamma ray bursts, shocks and particles

The study of these cosmic explosions vastly expanded since the discovery in 1997 of long-wavelength afterglows in GRBs. The Amsterdam group and their colleagues at SRON/Utrecht played a key role in this breakthrough via their involvement in the Italian-Dutch BeppoSAX satellite as well as via the discovery of the first optical afterglow. During the reporting period the Amsterdam group continued to play a leading role in GRACE, an international collaboration for observing GRB afterglows at the VLT, and is PI of the EU-funded Research and Training Network on GRBs (funding 9 postdoctoral fellows in 8 countries) which had its successful mid-term evaluation in October 2004.

The study of Gamma Ray Bursts continues to generate considerable excitement. Progress was made both in revealing what the sources and mechanisms are of these most energetic events, and in using their bright presence in the early, distant Universe to study the history of star formation at times as early as half a billion years after the Big Bang, when the Universe had only 4% of its current age.

3.3.1.1. GRBs, observational studies

"Long" Gamma- Ray Bursts.
A highlight in 2003 was the discovery of a very energetic type Ic supernova associated with GRB030329 at redshift z=0.17. This supernova (Fig. 3.25) showed outflow velocities up to 15% of the speed of light. It was an almost identical twin copy of supernova 1998bw discovered in 1998 by Amsterdam astronomers to be associated with the nearby and intrinsically faint GRB980425. Since GRB030329 is a genuine cosmological (distant) gamma ray burst, the discovery of its association with a very energetic

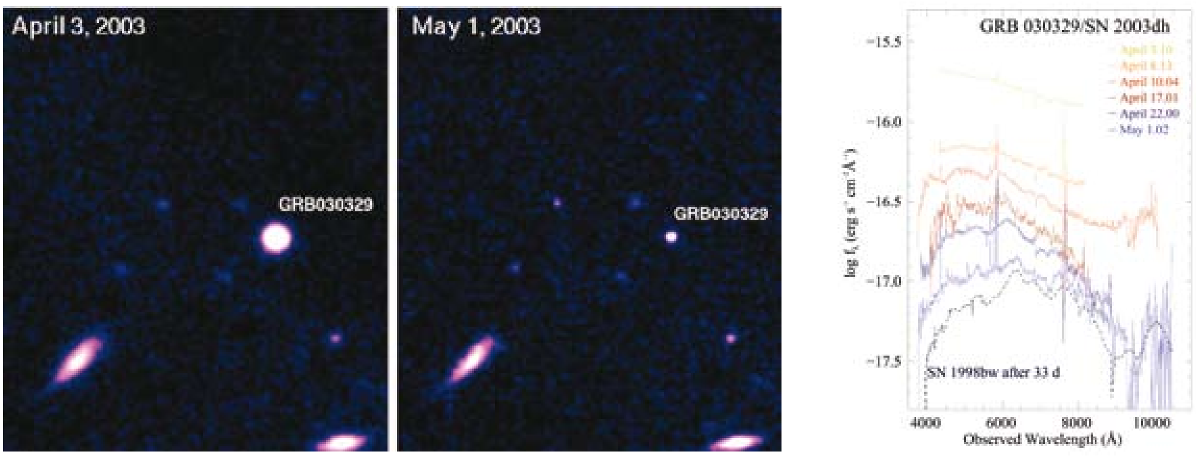


Fig. 3.25: ESO-VLT images of the afterglow of the Gamma-Ray burst of 29 March 2003 and its supernova SN2003dh, at redshift 0.17, taken on 3 April 2003 (left) and 1 May 2003 (middle). The figure right shows the discovery spectra of a type Ic supernova in the afterglow of this gamma-ray burst. The spectra are shown in real intensity, the brightest and earliest ones on top, and fainter downwards as time proceeds from 4 days after the burst to more than one month later. The early spectra show a fairly smooth and featureless continuum of the very fast explosion that made the gamma-ray burst. As this fades, another spectrum becomes apparent, which is identified as that of a very energetic type Ic supernova, caused by the explosion of a massive star. This confirms that (at least a class of) gamma-ray bursts are caused by the deaths of very massive stars (2003, Nature paper of Hjorth et al. involving Kaper, Rol, Van den Heuvel and Wijers).

supernova provided the definitive proof that the "long" GRBs (duration > 2 seconds) are connected with these very energetic type Ic supernovae, which mark the end of life of a 6-13 $M_\odot$ carbon-oxygen star -remnant of a star initially more massive than about 40 $M_\odot$- which presumably collapsed to a black hole.

Vreeswijk, Wijers, Kaper, Van den Heuvel and international collaborators demonstrated that the high-redshift GRB030323 at z= 3.37 had the strongest damped Lyman-alpha absorption ever observed in an astronomical object. Both this burst as well as GRB020124 at redshift z=3.20 turned out to share the property of a very high hydrogen column density together with a perfectly dust free environment. A very low dust content of the environment appears to be a general property of high-redshift GRBs. Starling and Wiersema (NOVA PhD) discovered that the very-high redshift GRB050730 at z= 3.96 also has a very large damped Lyman-alpha absorption, which is larger than seen in any quasar. They demonstrated for the first time, from the study of the evolution of the afterglow spectrum, that there is clear evidence for dust destruction in the burst environment. This finally provides an explanation for the puzzling almost dust-free nature of GRB environments.

"Short" Gamma-Ray Bursts.
Untill May 2005, nothing was known about the origin of the "short" GRBs, which constitute some 30% of all bursts, having duration of less than 2 seconds and showing a considerably harder gamma-ray spectrum than the "long" bursts. On 9 May 2005 the SWIFT satellite detected an X-ray afterglow of a short burst, GRB050509B, yielding a precise arc-second location of this burst. This enabled Starling, Wiersema and Wijers, together with the European GRACE team, to identify this burst with a bright elliptical galaxy of moderate redshift using the ESO-VLT. Subsequently, on 9 July 2005 the HETE-2 satellite detected the X-ray afterglow of another short burst, which was found by an Italian team to show a brief optical afterglow. This allowed Amsterdam astronomers and the GRACE team, using the WHT, to find its host galaxy: a faint irregular galaxy with clear signs of massive-star formation. A third X-ray afterglow of a short burst was detected by SWIFT on 24 July 2005. Caltech colleagues demonstrated that this burst coincides with an elliptical galaxy at redshift z=0.257. The identification of two short bursts with elliptical galaxies in which there has not been any star formation for billions of years indicates that, contrary to the "long" bursts, the short ones clearly are not related to the deaths of short-lived massive stars. Most likely, they are related to the mergers of two compact objects, such as a double neutron-star binary or a neutron star and a black hole (as was suggested in 1988 by Paczynski and Piran). The orbital decay by gravitational wave losses of binary systems with orbital periods of ten hours or more may take many billions of years. Therefore, one expects a reservoir of such binaries to be present in old elliptical galaxies, dating from the time that these galaxies still contained massive stars. On the other hand, systems born with orbital periods of only a few hours will merge within a few tens of millions of years, such that such merger events (and thus: short bursts) will also occur in galaxies in which massive-star formation is taking place. This may explain the nature of the host galaxy of the burst of 9 July 2005.

3.3.1.2. Theoretical studies

Wiersma (NOVA PhD) and Achterberg studied the physics of ultra-relativistic shocks. Such shocks are believed to be present in Gamma Ray Bursts, and are responsible for the afterglow emission from these objects. They have shown that the Weibel (current filamentation) Instability in a shock develops first in the electron/positron component of plasma. This creates hot electron-positron plasma that, paradoxically, prevents the ion-driven version of the Weibel instability to develop to a sufficient level to disrupt the flow of the incoming ions. The merging of current filaments that follows this instability stalls rapidly due to screening effects. This means that another collisionless dissipation mechanism for the ions in relativistic shocks needs to be found, and that the magnetic fields generated by current filamentation are too weak to explain the afterglow observations.

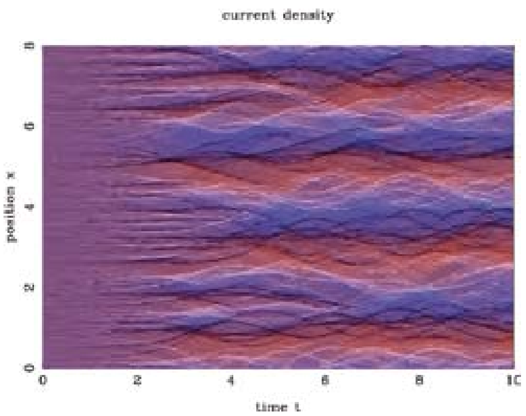


Fig 3.26: A numerical simulation of the current filamentation instability, and the subsequent current merging. Currents are shown in grayscale, with white positive and black negative currents, while the magnetic fields are color-coded with blue a positive field, red a negative field and purple no net field.

Van der Swaluw and Achterberg showed that the non-thermal continuous diffuse X-ray emission (photon energies ~1-20 keV) that is observed in a number of young supernova remnants can be explained as synchrotron emission from shock-accelerated electrons with an energy of ~100 TeV. This emission, however, is short-lived: as the remnant ages, the speed of the supernova blast wave falls and the energy of the electrons produced near the blast wave falls below the energy needed to radiate in the X-ray range. Typically, remnants larger than a few parsecs in diameter should not show diffuse synchrotron X-Ray emission above a few keV.

How massive stars die - what sort of explosion and remnant each produces - depends chiefly on the masses of their helium cores and hydrogen envelopes at death. For single stars, stellar winds are the only means of mass loss, and these winds are a function of the metallicity of the star. Langer (NOVA overlap) with Heger and Fryer (Los Alamos), Woosley (Santa Cruz) and Hartmann (Clemson) worked out how metallicity, and a simplified prescription for its effect on mass loss, affects the evolution and final fate of massive stars. They mapped, as a function of mass and metallicity, where black holes and neutron stars are likely to form and where different types of supernovae are produced. Integrating over an initial mass function, they derived the relative populations as a function of metallicity. Provided that single stars rotate rapidly enough at death, they discussed stellar populations that might produce gamma-ray bursts and jet-driven supernovae (Fig. 3.27).

Recent models of rotating massive stars that include magnetic fields have shown that it is difficult for the cores of single stars to retain enough angular momentum to produce a collapsar, and the associated gamma-ray burst. At low metallicity, even very massive stars may retain a massive hydrogen envelope due to the weakness of the stellar winds, posing an additional obstacle to the collapsar model (Fig. 3.27). Langer and collaborators studied the behavior of massive, magnetic stars, where rapid rotation induces almost chemically homogeneous evolution. In this case the requirements of the collapsar model are rather easily fulfilled if the metallicity is sufficiently small. The numerical results indicate that (1) rapidly rotating helium stars are formed without the need to remove the hydrogen envelope, avoiding mass-loss induced spin-down, and (2) that angular momentum transport from the helium core to the hydrogen envelope by magnetic torques is insignificant. They demonstrated this by calculating evolutionary models of massive stars with various metallicities, and derive an upper metallicity limit for this scenario based on currently proposed mass loss rates.

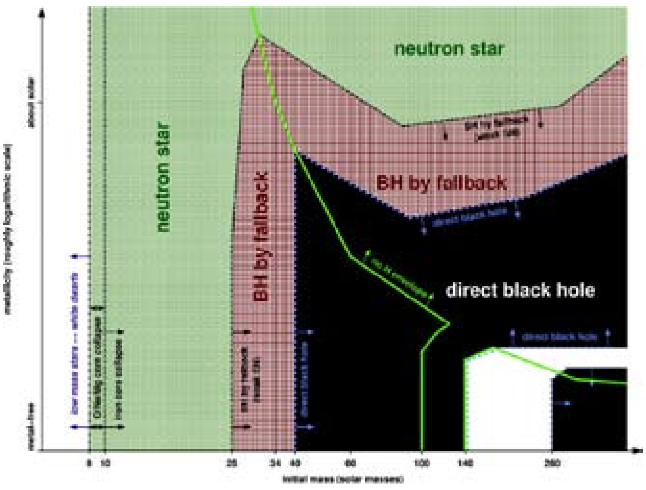


Fig. 3.27: Remnants of massive single stars as a function of initial metallicity (y-axis; qualitatively) and initial mass (x-axis). The thick green line separates the regimes where the stars keep their hydrogen envelope (left and lower right) from those where the hydrogen envelope is lost (upper right and small strip at the bottom between 100-140 $M_{\odot}$. The dashed blue line indicates the border of the regime of direct black hole formation (black). This domain is interrupted by a strip of pair-instability supernovae that leave no remnant (white). Outside the direct black hole regime, at lower mass and higher metallicity, follows the regime of BH formation by fallback (red cross-hatching and bordered by a black dot-dashed line). Outside of this, green cross-hatching indicates the formation of neutron stars. The lowest mass neutron stars may be made by O-Ne-Mg core collapse instead of iron core collapse (vertical dot-dashed lines at the left). At even lower mass, the cores do not collapse and only white dwarfs are made (white strip at the very left).

Long GRBs are thought to be caused by a subset of exploding Wolf-Rayet stars. Van Marle, Langer and Garcia-Segura (Ensenada) showed that the circumstellar absorption lines in early supernova and in GRB afterglow spectra may allow one to determine the main properties of the Wolf-Rayet star progenitors that can produce those two events. This is demonstrated by first simulating the hydrodynamic evolution of the circumstellar medium around a massive star up to the time of the supernova explosion. Knowledge of density, temperature, and radial velocity of the circumstellar matter as function of space and time then allowed the computation of the column density in the line of sight to the center of the nebula, as a function of radial velocity, angle, and time. These column density profiles indicate the possible number, strengths, widths, and velocities of the absorption line components in the spectra of supernova and GRB afterglows.

Langer and Norman (Baltimore) explored the consequences of new observational and theoretical evidence that long GRBs prefer low-metallicity environments. Using recently derived mass-metallicity correlations together with the mass function from SDSS studies, and adopting recently proposed average cosmic metallicity evolution, they derived expressions for the relative number of massive stars formed below a given fraction of solar metallicity, ε, as function of redshift. They demonstrated that about 10% of all stars form with $\varepsilon < 0.1$. Therefore, a picture where the majority of long GRBs form with $\varepsilon < 0.1$ is not inconsistent with an empirical global SN/GRB ratio of 1/1000. It implies that (1) GRB's peak at a significantly higher redshift than supernovae (Fig. 3.28); (2) massive star evolution at low metallicity may be qualitatively different and; (3) the larger the low-metallicity bias of GRBs the less likely binary evolution channels can be significant GRB producers.

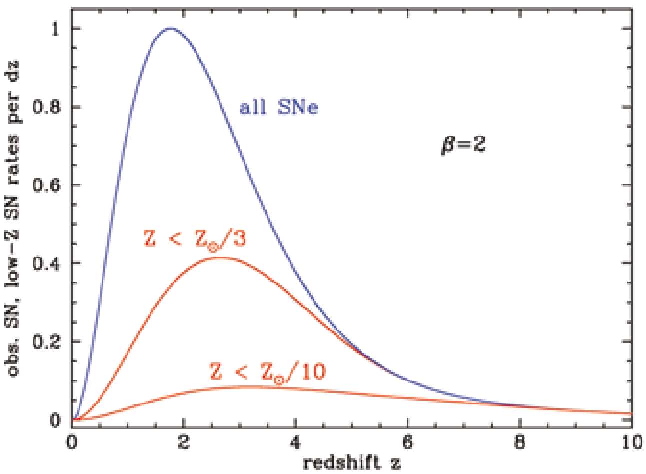


Fig. 3.28: Perceived differential and cumulative supernovae rate of stars with metallicity less than $z/z_{\odot} = \varepsilon$, for ε=0.3 and 0.1 as indicated, compared to that of all core collapse supernovae, as a function of redshift. A galaxy mass-metallicity exponent of β=2 is adopted.

3.3.1.3. Gravitational Waves and GRBs

Moortgat (NOVA PhD investigated the coupling between Gravitational Waves (GWs) and Magnetohydrodynamic (MHD) waves. The subject is important for our understanding of binary mergers and GRBs, and for indirect detection of GWs with LOFAR. Inverse Compton scattering of the relativistic wind on MHD waves excited by the GWs leads to radiation at frequencies in the LOFAR observing band. The coupling efficiencies between a plane monochromatic GW and a MHD was derived for arbitrary polarization of the incoming GW and applied to the relativistic Poynting flux dominated outflow from a merging neutron binary star. Although direct linear coupling between GWs and Alfvén waves was found to exist, in the wind of a binary merger the coupling between GW and fast MHD wave is much stronger. Moortgat also showed that the GW becomes a mixed wave in a magnetosonic plasma with a group speed slightly smaller than the speed of light in vacuum.

3.3.2. X-ray binaries

3.3.2.1. Accretion-powered X-ray pulsars

New and exiting results continue to be published about the accreting millisecond pulsars. This field was opened up in 1998 by the discovery of the first object of this type, SAX J1808.4-3658, by Wijnands (NOVA overlap) and van der Klis. Accreting millisecond pulsars are important for our understanding of binary evolution, especially the link between accreting neutron stars and the millisecond radio pulsars. Seven accreting millisecond pulsars are now known, with spin periods ranging between 1.67 and 5.41 milliseconds.

In 2003 Wijnands, van der Klis and co-workers published an article in Nature reporting the discovery of twin kHz quasi-periodic oscillations in the 2002 October outburst of SAX J1808.4-3658. This was the first time that a clear relation was found between the neutron-star spin frequency and the frequencies of the Quasi-Periodic Oscillations (QPO) of the X-ray emission of low-mass X-ray binaries. This established definitely that the QPO bear a direct physical relation to the spin of the accreting neutron star, as had long been suspected but so far could not be proven. This discovery also led to the rejection of the up to then dominant 'spin-orbit beat-frequency models' because the frequency separation between the two kHz peaks was inconsistent with the neutron star spin frequency (it was consistent with half that frequency).
In 2005, Linares and van der Klis reported the discovery of twin kilohertz quasi-periodic oscillations in a second accreting millisecond pulsar, XTE J1807-294, where the separation between the kHz QPOs *was* consistent with the pulse frequency. This confirmed for the first time from pulsation measurements the inference that the slower millisecond accreting pulsars (with spin frequencies below 400 Hz) are fundamentally different from the faster ones in this respect.

Together, these two results imply that the neutron star spin must be directly affecting the motions of the material in the accretion disk, presumably by a resonant interaction. The observed link between kHz QPO and spin frequencies is very intriguing as it strongly constrains the remaining models. The only viable alternatives to beat frequency models that have been found (as already proposed by Wijnands et al. in their 2003 Nature paper, and later examined further by two theoretical groups, Kluzniak/ Abramowicz and Lamb/Miller) involve resonant interactions between the spin and the general relativistic epicyclic motions in the disk.

Chakrabarty (MIT), Wijnands, van der Klis and co-workers reported the discovery of burst oscillations in SAX J1808.4-3658. An indication for the existence of burst oscillations had previously been seen with BeppoSAX in the archival data of the 1996 outburst. The work on the burst oscillations in the millisecond pulsars led to greater confidence in how to estimate the spin frequency in non-pulsating neutron stars. More than 15 spins have now been determined, and Chakrabarty et al. argue that the observed spin distribution cuts off near 780 Hz, well below breakup, supporting theoretical predictions that gravitational radiation losses limit the spin rate of accreting neutron stars. If true, accreting millisecond pulsars are strong coherent sources of gravitational waves of known frequency, which can in principle be detected with future gravitational-wave antennas such as LIGO, VIRGO and GEO.

Van Straaten, van der Klis and Wijnands made a systematic study of the aperiodic X-ray time variability and X-ray spectral hardness behavior of four of the new accreting millisecond pulsars using large data sets obtained since their discovery with the Rossi X-Ray Timing Explorer. The accreting millisecond pulsars have timing properties very similar to those of non-pulsing neutron stars, and that their variability frequencies follow the same universal scheme of correlations. However, intriguingly, in two of the pulsars the relations are shifted by a factor close to 1.5. This result was later also found for XTE J1807-294 in the work of Linares and van der Klis already mentioned above. Some of the resonant interaction (spin-disk) models that were proposed include 2:3 frequency ratios as an ingredient, and 2:3 frequency ratios are also observed in black hole accretion disk oscillations.

3.3.2.2. Mass-determinations of neutron stars in high and low mass X-ray binaries

Van der Meer (NOVA PhD), Kaper and van den Heuvel continued their VLT-UVES high-resolution studies of the optical companions of the accreting X-ray pulsars in the high-mass X-ray binaries SMC X-1, Cen X-3, LMC X-4 and 4U1223-64. The unique high resolution of the UVES spectra allows a much more accurate determination of the radial velocity curves of the optical stars, yielding more accurate determinations of the masses of the neutron stars in these systems. The resulting masses for these neutron stars are: 1.06 (+0.11, -0.10), 1.25 (+0.11, -0.10) and 1.34 (+0.16, -0.14) $M_\odot$ for SMC X-1, Cen X-3 and LMC X-4, respectively.

Jonker and collaborators performed a similar analysis of the low-mass X-ray binary 2S 0921-630 and concluded the systems contains either a high mass neutron star or a low mass black hole.

3.3.2.3. Comparative studies between black holes and low-magnetic field neutron stars

A recurrent theme in the research into accreting neutron stars and black holes over the last years was that of comparative studies between black holes and low-magnetic field neutron stars. A neutron star is only about three times as large as its Schwarzschild radius, so if there is no strong magnetic field disrupting the accretion flow, in both types of object the accretion disk is expected to extend down all the way into the strong field gravity region. Observations confirmed this, and many similarities were found in the phenomenology of the accretion process onto these two types of object. Finding either differences or similarities between neutron stars and black holes by comparative studies can strongly constrain the interpretation of the phenomena. A phenomenon that is seen in both neutron stars and black holes can't depend on any property that is unique to either neutron stars or black holes, such as the presence or absence of a solid surface or a horizon. Conversely, a phenomenon that seems to only occur in either neutron stars or black holes likely does require such a unique neutron star or black hole property. The eventual aim of this line of research is the 'definitive' proof of the existence of black holes by the identification of a unique black hole phenomenon, in conjunction with a compelling interpretation for the phenomenon relying on a unique predicted physical black hole characteristic. The constant-frequency QPOs in black holes with frequencies up to 450 Hz are a candidate for such a unique black hole phenomenon, whereas the variable-frequency twin kHz QPOs with frequencies up to 1300 Hz appears to be unique to neutron stars.

In the area of QPOs and other forms of rapid X-ray flux variability van Straaten showed that in neutron stars with a low magnetic field the variability frequencies follow a universal scheme of correlations. This scheme covers both luminous and dim objects, and also extends to the accreting millisecond pulsars. Building on this work, Klein-Wolt presented the first systematic extension of this scheme to black hole candidates since the exploratory works of Wijnands and van der Klis (1999) and Psaltis, Belloni and van der Klis (1999). Klein-Wolt suggested that the universal scheme, for most of the frequencies, also extends to the black holes.

Yu, van der Klis, Fender and Klein-Wolt performed comparative studies of black hole and neutron star X-ray outbursts. In these outbursts, which last for weeks to months, a flare of soft X-rays comes days to weeks after the initial flare in hard X-rays. The similarity between black holes and neutron stars was found to be remarkable. Surprisingly, it turned out to be possible to predict the flux of the soft X-ray flare from that of the preceding hard X-ray flare. Yu and co-workers concluded that this implies that X-ray outbursts are determined by processes that take place in the outer parts of the accretion disk, even though the outbursts themselves occur in the inner parts of the disk.

Di Salvo, Mendez, van der Klis and co-workers discovered a broad iron K line in the neutron star 4U 1705-44. This is of particular interest as it can provide a link with similar Fe lines seen from the strong field gravity region around black holes, and because 4U 1705-44 is a known producer of kHz quasi-periodic signals, which are also thought to arise in the strong field region.

Homan (MIT), Wijnands, Fender, di Salvo, van der Klis and co-workers studied the correlation between X-ray and radio flux of the neutron star GX 13+1. A delay of 40 minutes was found between X-ray and radio variations, similar to what was previously seen in black holes, strongly suggesting a similar production mechanism of the radio flux, namely, in a jet.

Migliari, Fender, van der Klis and co-workers compared correlations between radio luminosity and X-ray timing features in seven low magnetic field neutron stars, among which two millisecond pulsars, with those in black holes. In the neutron star systems the radio luminosity correlated with the characteristic frequency of a variability component detected in the power spectrum following a power law fit with similar index in both cases. As the variability component arises in the accretion disk and the radio flux in the jet, this is further evidence for disk-jet coupling in neutron stars that is very similar to that in black holes.

3.3.2.4. Low magnetic field neutron stars

Wijnands and co-workers focused on studies of the X-ray characteristics of accreting neutron stars in X-ray transients (systems which accrete only sporadically at high level). In their "quiescent states", during which no or hardly any accretion occurs, these objects can still be detected in X-rays but at very low levels. The origin of this quiescent X-ray emission is not yet clear; it could be due to residual accretion down to the surface of the neutron star or the magnetospheric boundary, or to the cooling of the accretion heated neutron star. Wijnands and collaborators studied the enigmatic neutron star X-ray transient MXB 1659-29 during its quiescent state. This system is one of the rare neutron-star X-ray transients which accretes matter at a very high rate for several years to several decades (instead of weeks to months which is more usual) before turning off again. In such systems, the long period of active accretion will have heated up the neutron-star crust to very high temperatures and the crust should be considerably out of thermal equilibrium with the core. Wijnands et al. observed MXB 1659-29 on several occasions with Chandra after the 2.5 years accretion episode of the source. They unexpectedly found that the crust of the neutron star in this system cooled down rapidly on a time scale of only 1.5 years. These results indicate that the neutron-star crust has high heat conductivity, suggesting an iron crystalline composition with very few impurities caused by other elements. Furthermore, these results also indicate that the neutron star core is much colder than expected from the standard core cooling models, requiring extra cooling processes to occur in the core.

Using Chandra, Jonker, Wijnands and van der Klis studied the neutron-star X-ray transient, SAX J1810.8-2609, in its quiescent state. They found that the source was very weak in quiescence with a X-ray luminosity of only $\sim 10^{32}$ erg s^{-1}, which is at the low end of the luminosity range seen for other quiescent neutron-star X-ray transients. This detection supports the suggestion that there exists a previously unidentified group of faint quiescent neutron star systems with lower luminosities and different spectral characteristics compared to the brighter systems. Jonker (CfA), Mendez, van der Klis and co-workers observed the neutron star soft X-ray transient RX J170930.2-263927 after an outburst during return to quiescence with the Chandra satellite. The X-ray flux observed at a level 10^5 below that during the outburst could be due to the cooling neutron star surface, in which case the neutron star would have a mass of about 1.7 $M_\odot$, or be associated with low-level accretion. Also by these authors observations of the eclipsing low-mass X-ray binary MS 1603.6+2600 with Chandra led to the suggestion that this object is an accretion disk corona source.

Studies of the quasi-periodic oscillations (QPOs) at frequencies up to more than a kiloHertz in low-magnetic field neutron stars continued apace. Altamirano (NOVA) et al. studied these kHz QPOs in 4U 1820-30 and found shifts are similar to, but smaller than those reported for some accreting millisecond pulsars (3.3.2.2). 4U 1820-30 is the first non-pulsing source discovered to have such a shift in the frequency correlations. Jonker, Mendez and van der Klis further studied the sidebands to these QPOs discovered by them. The sidebands remain enigmatic although explanations involving Lense-Thirring precession are still under consideration. Lommen, van Straaten and van der Klis studied the X-ray variability of a so-called dipping X-ray source and found similar variability as in other sources. As dipping sources are seen at high inclination this implies that the viewing angle dependence of the variability is small, rejecting most occultation mechanisms as a viable explanation.

Kuulkers (ESA), van Straaten, Altamirano (NOVA PhD), van der Klis and co-workers studied the properties of a so-called 'superburst' in the source 4U 1636-53. The burst (due to thermonuclear burning of carbon in the neutron star's lower atmosphere) provides the strongest constraints so far on the effect of such an explosion on the more ordinary hydrogen/helium burning bursts. These bursts were suppressed by the superburst and were first seen again 23 days after its occurrence, providing further insight in the sensitivity of the burst phenomenon to the physical circumstances in the bursting layer of the neutron star's atmosphere.

Evidence for a redshifted X-ray line in a transient low-mass X-ray binary was presented by Tiengo and co-workers, and a broadened iron line in the neutron star binary 4U 1705-44 found by di Salvo et al. indicates relativistic effects similar to those found in iron lines seen in black holes. Continuum spectroscopy of three other neutron star low-mass X-ray binaries led to the detection of a time variable hard tail in GX 17+1 (indicative of the formation of a hot corona at lower mass accretion rates), a soft excess in Cir X-1 (leading to a revised distance estimate of this source), and a similarly revised distance for GX 9+1.

O'Brien (UK), van der Klis and co-workers performed simultaneous X-ray and optical spectroscopic observations of the neutron star system Cygnus X-2 using the Rossi X-ray Timing Explorer satellite and the 10-m meter Keck II. This project involved the analysis of 220,000 optical spectra of the source, each integrated over 72 msec. A linear increase was observed in optical flux with mass accretion rate as inferred from X-ray hardness measurements, whereas the X-ray flux shows a more complex relation to accretion rate.

Nelemans (IoA Cambridge, UK, presently at Nijmegen), van der Klis and co-workers performed optical spectroscopy of a number of ultra-compact neutron star X-ray binaries, with very short orbital periods. No evidence was found for hydrogen or helium emission lines, as are seen in classical X-ray binaries, but carbon and oxygen lines were seen. This provides evidence for the donor stars in these systems being carbon-oxygen white dwarfs.

Migliari, Fender, Klein-Wolt, van der Klis and co-workers discovered - finally - the first quantitative evidence for disc-jet coupling in an 'atoll'-type X-ray binary (the most numerous class of low-mass X-ray binary), 4U 1728-34. Correlations were found not only between X-ray luminosity and radio luminosity, as in black holes, but also between the frequencies of X-ray timing features and X-ray luminosity. The importance of comparing the jet formation processes in black holes and neutron stars derives from the insights it provides us into the roles of processes specific to one or either class, namely advection, black hole spin, surface magnetic fields. Fender was further involved in the development of X-ray synchrotron jet models for black hole binaries by Markoff et al. and published a paper demonstrating that current observations cannot be used to place a constraint on the Lorentz factor of the jets from such sources.

Fender, van der Klis and co-workers published an article in Nature reporting the discovery of an ultra relativistic jet from a neutron star X-ray binary, Cir X-1, the fastest-moving bulk flow ever observed within our galaxy. Fender and Belloni further completed a prestigious 47-page review for Annual Reviews of Astronomy & Astrophysics, on the disc-jet coupling in accreting black holes systems. This in turn led to a further paper, together with Gallo, putting forward a 'unified' model for the disc-jet coupling in black hole X-ray binaries. Fender was involved in several other papers on this topic, and also wrote a review chapter on jets from galactic binaries a book setting out the science case for the Square Kilometer Array.

The Galactic Center Region was observed for a total of 7 million seconds, spread over 6 years, with the Wide Field Cameras of BeppoSAX. Cornelisse et al. studied the behavior of the nine sources that most frequently emit X-ray bursts, and found that at luminosities above about 2 10^{37} erg s^{-1} X-ray bursts are a factor five less frequent (see for example Fig.

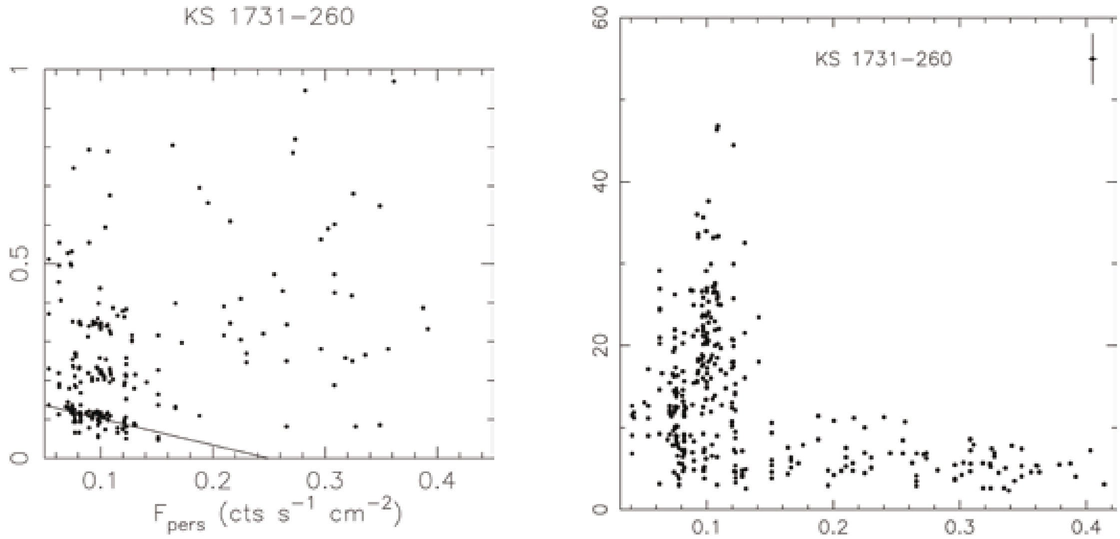


Fig. 3.29: Left: interval between successive bursts (in days) as a function of persistent count rate for the low-mass X-ray binary KS 1731-260. At fluxes below 0.13 counts per sec per cm^2 the interval between bursts decreases linearly with the count rate. The relation is given by the solid line; due to limited satellite coverage the measured time interval can also be an integer multiple of this line. At higher fluxes the time intervals are erratic. Right: the exponential decay time of the burst (in seconds) as a function of count rate. Above the same critical count rate where burst intervals become erratic, the long bursts disappear.

3.29), are irregularly spaced in time, and are all short (i.e. hydrogen-poor). This transition is identified with the onset of stable hydrogen fusion. It occurs at a luminosity that is ten times higher than what theory predicts. These observations explain another puzzle: the decrease of burst frequency with increasing luminosity. These results were made possible by the large size and the homogeneity of the BeppoSAX WFC data set.

These properties also allowed In 't Zand (NOVA postdoc) and co-workers to determine the average waiting time between a new class of X-ray bursts, the super bursts: about 0.5 per year for a persistently bright burst source. This constrains possible models for super bursts, by implying that the bursting matter contains no hydrogen but some helium. This excludes carbon-oxygen white dwarfs as donor stars for the accreting material.

Boirin et al. used the high sensitivity of XMM-Newton to study the X-ray spectra of the low-mass X-ray binary 4U 1323-62 in detail (Fig. 3.30). They found that lines of Fe XXV and Fe XXVI are both present, and change in strength with the orbital variation in flux. This implies that absorption of X-rays within the system is due to partially ionized gas above the accretion disk, and that the relative importance of the two ionization states (24+ and 25+) changes with orbital phase. In previous models, only absorption by neutral material was taken into account; such models require partial eclipses, and therefore a large dimension of the X-ray source. In the new model with partial ionization all X-rays undergo the same (phase-dependent) absorption, and the X-ray source is compact.

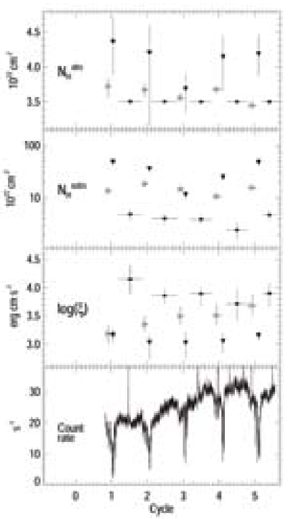


Fig. 3.30: The count rate of the low-mass X-ray binary 4U 1323-62 (lower panel) with a measure ζ for the average ionization level of the absorbing gas in the binary, in phases of maximum flux (filled rectangles), moderate absorption (open triangles) and strong absorption (filled triangles). The top panels give the column density of ionized (xabs) and neutral (abs) material.

3.3.2.5. **Black Holes**

Significant progress was made in both observations and interpretation of relativistic jets in X-ray binaries and their relation to those in Active Galactic Nuclei. A power-law relation was discovered by Gallo (NOVA PhD), Fender and Pooley between the radio and X-ray luminosities of black hole X-ray binaries in 'low/hard' X-ray states: L_{radio} : $L_X{}^{0.7.}$ A natural implication of the non-linearity of this relation is the existence of 'jet-dominated states', which Fender, Gallo and Jonker argued must correspond to all quiescent black hole X-ray binaries and may naturally explain the difference between their luminosities and those of quiescent neutron star X-ray binaries. This difference had previously been attributed to advection across event horizons. This non-linear relation was in fact found to describe a part of a 'universal' plane of black hole activity which, with the inclusion of a mass term, extends the relation to Active Galactic Nuclei. Maccarone (NOVA postdoc), Gallo and Fender investigated this further, and found evidence that AGN undergo jet suppression ('quenching') in the same range of Eddington ratio X-ray luminosities as X-ray binaries, further indicating parallel physics across a range of 10^8 in black hole mass.

Gallo, Fender and co-workers discovered a large-scale, relativistic jet from the Galactic stellar black hole GX339-4. In 2002 May, the source displayed a dramatic outburst in X-ray luminosity, contemporaneously exhibiting a very bright radio flare. With the Australia Telescope Compact Array a collimated structure was observed extending to about 12 arcsec, with apparent velocity greater than 0.9 times the speed of light. These observations confirm that transient large-scale jets are likely to be common events triggered by X-ray state transitions in black hole X-ray binaries.

A remarkable discovery made by Gallo and co-workers using the WSRT is a large arc-minute-scale ring like radio source that is perfectly aligned with the milli-arcsecond radio jet of the black-hole X-ray binary Cygnus X-1 (Fig. 3.31). The discovery that Cygnus X-1 blows such a relativistic bubble into the Interstellar Medium was published in 2005 in Nature with the map of this radio-bubble on its cover.

Miller (MIT, CfA), van der Klis, Wijnands and co-workers reported on X-ray spectroscopic observations with the Chandra, XMM-Newton and Rossi XTE satellites of X-ray outbursts in the transient black hole candidates XTE J1550-564 and GX 339-4. A skewed, relativistic Fe K emission line profile and ionized disk reflection spectrum were found in both black holes. In GX 339-4, self-consistent spectral models applied to these data rule out an inner disk radius compatible with a Schwarzschild black hole, and suggest that GX 339-4 instead harbors a black hole with Kerr rotation parameter 0.8-0.9 (the theoretical maximum is 1.0). The extreme red wing of the line requires a centrally concentrated source of hard X-rays that can strongly illuminate the inner disk. They argued that hard X-ray emission from the base of a relativistic jet (see 3.3.2.2), enhanced by gravitational light-bending effects, could create the concentrated hard X-ray emission.

Using NASA's X-ray observatory Chandra, in 2003 Fender, Wijnands (NOVA overlap) and collabora-

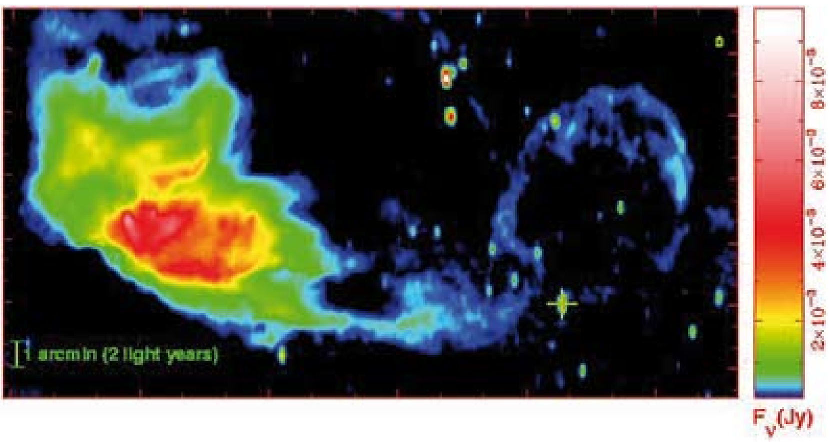


Fig 3.31: WSRT wide-field radio image (at 1.4 GHz) of the environment of the black hole system Cygnus X-1. The cross marks the location of the black hole. The bright region to the left (East) of the black hole is a dense cloud of gas existing in the space between the stars. The action of the jet from Cygnus X-1 has 'blown a bubble' in this gas cloud, extending to the north and west of the black hole. The image was made at a frequency of 1.4 GHz with the WSRT.

tors discovered X-ray emission from two quiescent black-hole X-ray transients and also discovered the X-ray jet emission from the black hole X-ray binary XTE J1550-564. Migliari et al. discovered rapid (days to hours) variability in high resolution X-ray images of the jets in the well known relativistic jet source SS 433 which they interpret as evidence of a propagating shock wave related to a jet flow moving much faster than the well known velocity of 26% of the speed of light characterizing the jets in this object.

Homan (MIT), Klein-Wolt, van der Klis and co-workers discovered high frequency quasi-periodic oscillations (QPOs) in the X-ray flux of a new black hole candidate, XTE J1650-500. Interpreting the 250 Hz frequency of the oscillations as the orbital frequency at the innermost stable orbit around a Schwarzschild black hole led to a mass estimate of 8.2 $M_\odot$ for this case. Homan et al. also studied the high frequency QPOs in H1743-322 and conclude that high inclination black holes have more prominent high frequency QPOs, which suggests interception or localized emission of flux by the disk may be related to their generation.

Belloni, Homan, van der Klis, Mendez and co-workers studied in detail a complete, densely sampled outburst of the black hole transient GX 339-4 leading to a much better understanding of the phenomenology of black hole transient outbursts in general and providing a template to which all other black hole outbursts are now being compared (Fig. 3.32). Radio observations indicate the ejection of a large amount of plasma at relativistic speeds, and different types of high-frequency variability (referred to by different symbols in Fig. 3.32) show that complex inhomogeneities in the flow occur down to very close to the event horizon. After this phase the disk emission fades by more than an order of magnitude. Then there is another sudden transition, back to the hard, corona-dominated state and after that the holes fades from view – until the next outburst in a few years. This big sequence of coordinated X-ray spectral and variability observations has provided the best view of what a black hole does during a transient outburst to date (Belloni et al. 2005). The 'squareness' of the track, indicating very sudden changes in the character of the hole's evolution was an unexpected discovery and is shaping current thinking on the nature of black hole states as described above.

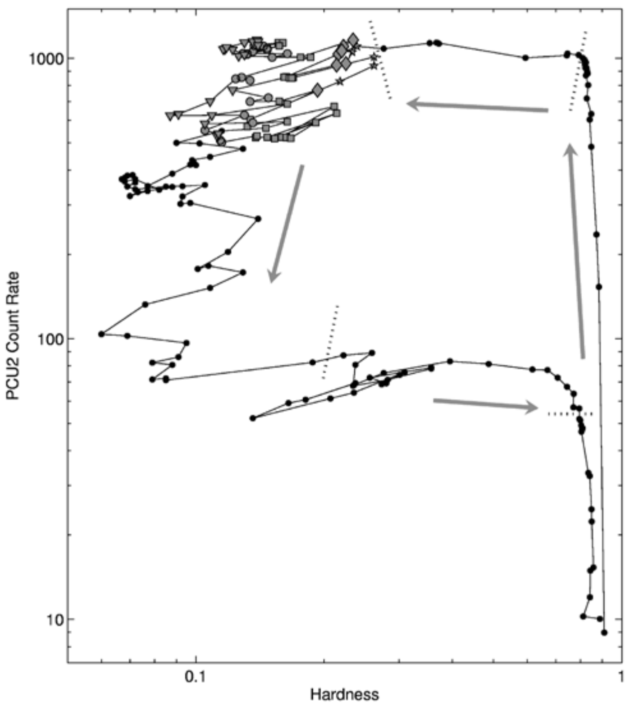


Fig. 3.32: Behavior of the X-ray flux of the black hole GX 339-4 as function of the X-ray spectral hardness during its X-ray outburst. Arrows indicate the time sequence, starting at the bottom right. The entire track took several months to complete. Initially there is only hard X-ray emission from a corona of hot electrons (100 million K). After the coronal emission has become brighter by a factor 100, the hole suddenly begins to emit progressively softer X-rays indicating that the emission of the cooler (a few million K) accretion disk becomes stronger and that of the corona weaker. During this hard-soft transition a major reconfiguration is thought to take place in the geometry of the emission regions surrounding the hole.

3.3.3. Binary and single compact objects in stellar systems: populations and their evolution

3.3.3.1. Ultra-short-period X-ray binaries and degenerate donors

Hydrogen and/or helium accreted by a neutron star accumulates in an ever thickening layer, until pressure and temperature in the layer allow nuclear fusion, and all accumulated hydrogen and helium is fused to carbon. The energy released in this manner is emitted as a burst of X-rays. If the X-ray luminosity reaches the Eddington limit, the surface layers of the neutron-star atmosphere are lifted, and the apparent radius of the neutron star expands. Kuulkers and co-workers investigated X-ray expansion bursts from sources in globular clusters observed with the Wide Field Cameras of BeppoSAX and with the Proportional Counter Array of RXTE, and showed that the Eddington limit of about half of the sources points to an absence of hydrogen. Such an absence is expected if the donor is degenerate (e.g. is a white dwarf), and thus half of the bright X-ray sources in globular clusters have degenerate donors. Verbunt and Lewin (MIT) demonstrated that the same conclusion is obtained from the visual magnitude of the optical counterparts (faint for degenerate donors) and from the lengths of the bursts (short for degenerate donors). Van der Sluys (NOVA PhD) and collaborators investigated a popular model for the formation of binaries with degenerate donors, in which a main-sequence companion to the neutron star expands a little before mass transfer begins, after which strong magnetic braking drives donor and neutron star to ever shorter orbital periods. Their detailed evolutionary calculations show that the initial conditions required for this scenario are so restrictive that this model cannot explain that a significant fraction of all X-ray sources has degenerate donors.

3.3.3.2. Compact object binary populations in our Galaxy

The Nijmegen Compact Binaries group (led by Groot/Nelemans) is studying the Galactic binary population containing a compact object. A major goal of the research is to better understand the process of binary evolution by obtaining homogeneous samples of post common-envelope compact binaries in our Galaxy. In 2003 Morales-Rueda (postdoc from the NWO-VIDI grant to Groot) joined the group and in 2004 Nelemans joined on a personal NWO-VENI grant.

Considerable effort has gone into proposing a set of surveys that will map the complete Galactic Plane (10x360 degrees) in u', g', r', i' and H-α colors down to 20th magnitude. This will be the first ever digital, multi-color optical survey of the Galactic Plane. In the Northern Hemisphere the survey includes IPHAS and UVEX. The IPHAS r', i', and H-α survey (Drew et al., 2005) was granted more than 200 nights. It started in 2003 and reached 60% completeness at the end of 2005. The blue complement of IPHAS is the UV-Excess (UVEX) survey (PI Groot) which will observe the same area in the blue colors (u', g', r') in semester 2006A. Both IPHAS and UVEX are combined UK/NL/E surveys using the Wide Field Camera on the INT. In the Southern hemisphere the VPHAS+ proposal was granted 96 nights on the ESO Public Survey using the new VST-OmegaCAM combination to map the Southern Galactic Plane in (u', g', r', i', H-α). Combined the VPHAS+/IPHAS and UVEX surveys will obtain optical colors for ~1 billion objects.

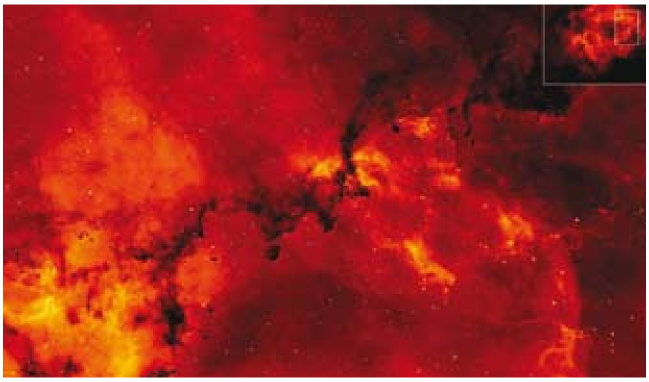


Fig 3.33: A detail of the Rosette Nebula as imaged by the IPHAS survey, showing the dark dust lanes in this star forming region. The image size is 10′ by 20′. The Hα strength is indicated in color with yellow being the highest intensity (figure made by N. Wright).

As a start-up to these major surveys the Sloan Digital Sky Survey (SDSS) was used to identify rare classes of white dwarf binaries. The research on AM CVn stars by Roelofs and Groot concentrated on discovering new systems and determining population characteristics. AM CVn stars are mass-transferring close binaries with orbital periods between 5 and 65 minutes. They most likely consist of a white dwarf primary and either a white dwarf secondary or a semi-degenerate helium star as a secondary. They are a very distinct outcome of binary stellar evolution involving at least one common-envelope evolution phase, but most likely two of these phases (in the case of a double white dwarf system transferring mass). The known population of AM CVn stars has been growing quite rapidly over the last few years, increasing from 7 to 17 in the last five years. The SDSS was important in increasing the number of systems. Roelofs and collaborators found the first SDSS AM CVn (SDSSJ1240-01) from a helium emission line search of all the publicly available SDSS spectra. Follow-up spectroscopy with the VLT showed it to have an orbital period of 37 minutes, but more importantly, it showed a double bright spot feature in the accretion disk, which has not been seen before in hydrogen rich systems. It also shows the mysterious ‘central spike’ in its line profiles. This feature is a very narrow emission spike in the line core of AM CVn stars that has been seen before in GP Com and CE 315, the long period systems. Currently no satisfactory explanation for the origin of this spike is known, although Steeghs and colleagues demonstrated from VLT-UVES spectra that it originates on or near the white dwarf. SDSSJ1240-01 is also the first system to convincingly show that the underlying continuum is dominated by the primary white dwarf, as evident from the broad absorption features underlying the strong helium emission lines from the disk. This opens the possibility to directly study the white dwarf primary, e.g. (in slightly hotter systems) by asteroseismology.

For the prototype system AM CVn Roelofs, Groot and co-workers obtained high time resolution spectra on the WHT. AM CVn is predicted to be in a permanent super hump state where the resonance between the secondary star and the disk causes the disk to precess slowly in the binary frame. This precession should cause the hot spot to change in radial position in the disk (the mass stream is hitting the disk either on the 'long' side, or on the 'short' side), causing also velocity changes of the hot spot. This is testable with phase resolved spectroscopy covering the full precession period. The more than 3000 spectra taken so far allow a detailed study of any orbital variation in the system. This allowed to identify a very weak, but clearly detected central spike emission. Combined with the known hot-spot emission this allows to determine the component masses in AM CVn, which, combined with the HST results (see below) are quite surprising.

On the space density side of the AM CVn work Groot et al. used the HST to measure the parallax for the brightest AM CVn systems, with the surprising result that AM CVn itself is much further away (at 660 pc, and therefore much brighter) than so far assumed, which lead to the conclusion (in combination with the WHT spectra) that AM CVn must contain a fairly massive white dwarf (~1 $M_\odot$) and a semi-degenerate helium star secondary.

Understanding the variability of sources down to very faint limits was the main aim of the Faint Sky Variability Survey by Groot, Morales-Rueda and co-workers. This analysis showed that between 2-4% of all point-sources in the sky with magnitudes in the $17<V<22$ range is photometrically variable with a strong concentration to short timescale variability (<1 hour) and a strong concentration of variable object towards the blue end of the main sequence (which, for a general galactic population is located near early F-type stars) and beyond, including white dwarf binaries of all types and quasars that overlap in color space.

The ongoing effort to map the Galactic population of double white dwarfs resulted in papers by Morales-Rueda, Nelemans and collaborators on six new binaries, two of which have high mass white dwarf components and by Nelemans, Roelofs and co-workers on five new double white dwarfs, substantially enlarging the number of known orbital periods for these systems. The results strengthen the conclusion reached in 2000 by Nelemans, Verbunt, Portegies Zwart and Yungelson, that application of the standard common-envelope formalism is incorrect.

To better understand the evolution of sdB stars in particular the importance of the preceding binary evolution, Groot started a project in collaboration with Aerts (Leuven) and Jeffreys (Armagh). Binary and stellar evolution calculations were combined with theoretical and observational studies of non-radial pulsations of sdBs in general and NY Vir in particular.

3.3.3.3. Galactic gravitational wave sources

Galactic ultra-compact binaries are important sources for the upcoming ESA/NASA gravitational wave detector LISA. In order to prepare for this mission and to investigate the potential for gravitational wave astronomy both observational and theoretical studies of ultra-compact binaries are needed. Nelemans, Portegies Zwart and co-workers modeled the population of short period AM CVn binaries, for the first time including detailed simulation of optical and X-ray emission. It was found that possibly half of the individually resolved sources are AM CVn stars (the other half are detached double white dwarfs).

Nelemans started collaborations with gravitational wave experts from the group of Tinto (JPL) and the group of Vecchio (Birmingham). Edlund, Tinto, Nelemans and co-workers modeled the galactic gravitational-wave background in detail using massive parallel computing. They found that the background is variable during the year and its cyclo-stationary nature allows extraction of more information on this background from the data. Stroeer, Vecchio and Nelemans investigated the details of the detection of individual binaries with LISA by focusing on two fiducial sources. It was concluded that the amount of astrophysical information that can be extracted is greatly increased if complementary observations (e.g. with GAIA or the VST) are available.

Marsh, Barros (both Warwick), Groot, Nelemans, Roelofs and co-workers looked in detail at current models for two binaries: RX J0806.3+1527 and V407 Vul, with periods of 5.4 and 9.5 min respectively, which might be the strongest Galactic gravitational wave sources. Barros et al. concluded that the proposed "Electric star" model, in which the observed X-ray emission is generated through unipolar induction in a magnetic double white dwarf, has severe problems explaining the X-ray light curve. Marsh and Nelemans showed that, contrary to common belief, this model is inconsistent with the observed period derivatives and that the interpretation of these sources as short-period AM CVns is still viable.

3.3.3.4. Globular cluster X-ray sources

Pooley (MIT), Portegies Zwart, van der Klis, Verbunt and co-workers investigated the number of close encounters in globular clusters from an extensive survey of X-ray sources with Chandra, and used the virial theorem to express this number in terms of density and size of the cluster core. They presented conclusive observational evidence of a link between the number of close binaries observed in X-rays in a globular cluster and the stellar encounter rate of the cluster. This finding is in line with theories predicting that such close binaries are formed by stellar encounters.

Bassa (UU), Verbunt, van der Klis and co-workers performed observations of the Galactic globular cluster M4, down to a limiting luminosity of 10^{29} erg/sec. This is the deepest X-ray observation of a globular cluster. 12 X-ray sources were detected inside the core and another 19 further out the cluster. Comparison of M4 with the globular clusters 47 Tuc and NGC 6397 suggested a scaling of the number of active binaries in these clusters with the cluster (core) mass.

Bassa and collaborators dramatically improved the accuracy of astrometry of HST-WFPC2 images of globular clusters, by comparing stellar positions in these images with positions in the UCAC-2 catalogue, via intermediate images obtained with the Wide Field Imager of the ESO 2.2m telescope. The search area for optical counterparts of radio pulsars or X-ray sources is reduced by an order of magnitude, and secure identifications were made of three companions to radio pulsars (one each in NGC6752, M30 and NGC6397) and of 16 X-ray sources in M4.

3.3.3.5. Dynamical evolution of dense star clusters

Hurley (CSPA, Monash University, Australia), Pols (NOVA overlap) and co-workers in the UK investigated the effect of metallicity on the dynamics of star clusters. The shorter evolution timescales of low-metallicity stars lead to increased cluster mass loss and postponed core collapse compared to high-metallicity clusters. On the other hand earlier core collapse in metal-rich clusters results in an increased stellar escape rate. These effects nearly cancel out so that the overall cluster dissolution time only weakly depends on metallicity. However, metallicity has a much more important effect on the appearance of a cluster in the CMD and on its underlying stellar and binary population.

The same group presented the first complete, direct N-body model for the old open cluster M67, using a realistic binary fraction and taking full account of cluster dynamics as well as stellar and binary evolution. The model is evolved from zero age to 4 Gyr, the age of M67, at which point its overall properties (such as the mass and half-mass radius of luminous stars in the cluster) are a good match to observations (Fig. 3.34). The stellar mass and luminosity functions are significantly flattened by preferential escape of low-mass stars. M67 is dynamically old enough that information about the initial mass function (IMF) is lost, both from the current luminosity function and from the current mass fraction in white dwarfs. The model contains 20 blue stragglers at 4 Gyr, nine of which are in binaries, again a good match to observations (28 blue stragglers are observed in M67). The blue stragglers were formed by a variety of means and formation paths are found for the whole variety observed in M67. Both the primordial binary population and the dynamical cluster environment play an essential role in shaping the population.

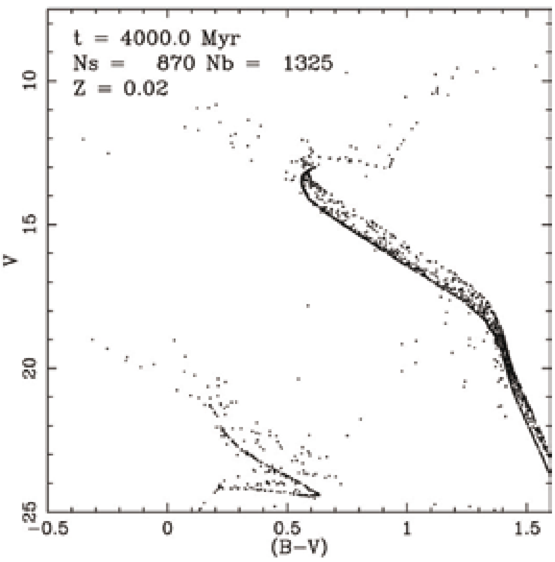


Fig 3.34: Color-magnitude diagram of the M67 cluster model at 4.0 Gyr. Of the initial 36000 stars (12000 singles and 12000 binary systems) about 10% remain; the rest – predominantly low-mass stars - have escaped from the cluster. The cluster at this age contains 20 prominent blue stragglers.

Pols and Portegies Zwart collaborated on self-consistent modelling of stellar collisions in the framework of the dynamical evolution of dense star clusters. This work is done in the context of the international MODEST collaboration. Physical collisions between stars are common in such clusters and can result in exotic objects such as blue stragglers and, through runaway collisions, extremely massive stars and intermediate-mass black holes. These serve as important tracers of dynamical processes operating inside dense clusters.

The study of the dynamical evolution of dense star clusters with numbers of stars approaching those of globular clusters (of order one million stars) requires dedicated computer hardware. Portegies Zwart is a driving force in the MODEST (MOdelling DEnse STellar systems) collaboration, with other members in Tokyo, Princeton, Pittsburgh, Edinburgh, Cambridge (UK) and Santa Barbara. In addition to the N-body code Portegies Zwart and his colleagues developed a code for the realistic computation of the evolution of binary systems produced in star clusters by dynamical interactions. The numerical results indicate that during the early evolution of very dense young globular star clusters (first few million years of the cluster) many collisions of massive stars may occur, leading to the rapid build-up of a "super-massive" star with a mass between 800-3000 $M_\odot$ in the cluster center. Such stars are expected to be very short-lived and it seems hard to avoid the (speculative) conclusion that at the end of their lives

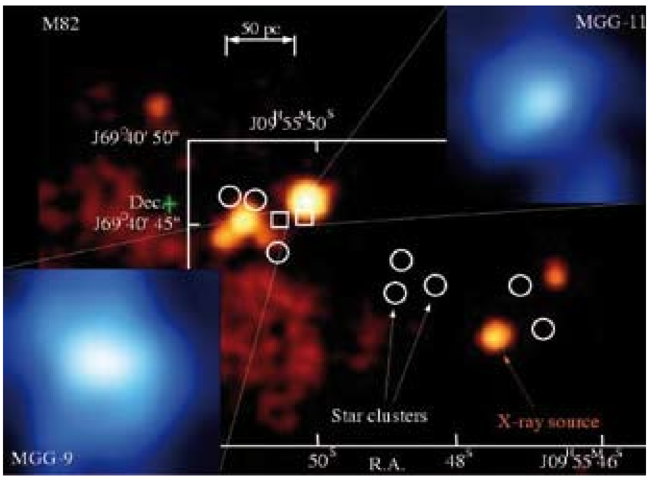


Fig. 3.35: Chandra X-ray image of the relevant part of the starburst galaxy M82 with the observed star clusters indicated. The image is from the 28 October 1999 X-ray observation by Matsumoto et al, (2001), with about arcsec positional accuracy. The brightest X-ray source (M82 X-1) is near the centre of the image. The star clusters are indicated by circles. The positions of the two star clusters MGG-9 and MGG-11 are indicated with squares. The magnified infrared images of these star clusters from the McCrady et al observations are presented in the upper right (MGG-11) and lower left (MGG-9) corners.

these "superstars" will collapse to black holes with masses of order 100-1000 $M_\odot$. CHANDRA observations of ultra luminous point X-ray sources in external "starburst" galaxies, having X-ray luminosities of order 10^{40} to 10^{41} erg/sec, support the presence of accreting black holes in these systems with masses of order 100-1000 $M_\odot$.

A particularly striking case is the 10^{41} erg/sec X-ray source M82 X-1 in the starburst galaxy M82, which within the positional uncertainty coincides with the young globular cluster MGG-11 in that galaxy (Fig. 3.35). Portegies Zwart and collaborators pointed out in a Nature paper (2005) that the density and velocity dispersion of the cluster MGG-11 indeed fulfill the conditions for the occurrence of runaway stellar collisions and the formation of a "superstar" in the cluster center, whereas the other young globular cluster MGG-9 in that same galaxy does not fulfill these conditions. That cluster indeed does not contain an ultra luminous X-ray source.

Numerical simulations of Portegies Zwart and McMillan showed that a population of very dense and rich young star clusters in the Galactic Center region will cause dynamical friction in the galactic bulge resulting into some clusters spiraling in towards the center and to deposit its black hole in the galactic center black hole within the life-time of our Galaxy. They demonstrated that galactic-center cluster IRS-16 is such an example. They suggested that black holes with masses of a few million solar masses in the centers of spiral galaxies may have been built up by the coalescence of intermediate mass black holes, formed in dense clusters and transported towards the galaxy centers by dynamical friction in the dense bulges.

Portegies Zwart and McMillan studied the formation of the recently discovered ''hot Jupiter'' planet orbiting the primary component of the triple star system HD188753. The current outer orbit of the triple is too tight for a Jupiter-like planet to have formed elsewhere and migrated to its current location, the binary may have been much wider in the past. They postulated that the planetary system formed in an open star cluster, the dynamical evolution of which subsequently led to changes in the system's orbital parameters and binary configuration. They calculated cross sections for various scenarios that could have led to the multiple system currently observed and concluded that component A of HD188753 with its planet was most likely formed in isolation, to be swapped into a triple star system by a dynamical encounter in an open star cluster. They estimate that within 500 pc of the Sun, there are about 1200 planetary systems that, like HD188753, have orbital parameters unfavorable for forming planets but still have a planet, making it quite possible that the HD188753 system was indeed formed by a dynamical encounter in an open star cluster.

Gualandris, Portegies Zwart and Sipior investigated the interplay between the super-massive black hole in the center of the Milky-way Galaxy and its local stellar cluster. They simulated the interactions between the black hole and other stars to study the possibility that the hypervelocity star SDSS J090745.0+024507 found in the halo was initially ejected from this region. The star currently has a velocity exceeding 700 km/s moving away from the Galactic center. With the measured radial velocity and the estimated distance to the star, they traced its trajectory backward in time in the Galactic potential. Assuming it was ejected from the center, they found that a proper motion of about 2 mas/yr is necessary for the star to have come within a few parsecs of the SMBH. They concluded that this star is most likely ejected in a strong dynamical interaction between the super-massive black hole and a tight binary, of which the currently observed star once was a component. Such events should occur frequently enough that the Galactic halo should be populated with more than a hundred hyper velocity stars.

3.3.4. Radio pulsars

Radio pulsars are famous for their stable average pulse profiles; however it is the fluctuations in intensity, shape and polarization of each individual pulse which provides us with the best insight into the way in which radio pulsars shine.

3.3.4.1. Pulsar emission processes

Stappers and Strom with collaborators in Ireland reported on simultaneous high time resolution radio and optical observations, made with PuMa at the WSRT and the WHT respectively, to study the relationship between the giant radio pulses (GPs) from the Crab pulsar and the optical emission. They found that optical pulses coincident with the GPs were on average 3% brighter than those coincident with normal radio pulses providing the first ever direct link between the individual radio pulse properties and emission at any other wavelength. It was argued that the mutual brightening is associated with an increase in the electron-positron plasma density in the pulsar magnetosphere.

Pulsar PSR B1937+21 also emits GPs and studies by Hermsen, Kuiper, Stappers and co-authors showed, using the high-precision timing solution obtained at the WSRT with PuMa, that the X-ray pulse profile and the average radio pulse profile are aligned with high accuracy. This alignment showed that the X-ray pulses are closely aligned in phase with the GPs suggesting that they originate in the same region of the magnetosphere due to a high and fluctuating electron density that occasionally emits coherently in the radio band.

Comparison of the radio and high-energy pulse profile was also carried out for PSR J0218+4232. Using the high precision timing solution from the WSRT-PuMa timing program absolute phase alignment and accurate folding of the high energy data were possible. The two non-thermal pulses in the X-ray profile were found to be aligned with two of the three pulses visible at radio-frequencies and more importantly with the two gamma-ray pulses seen in the EGRET 100-1000 MeV pulse profile improving its significance to 4.9 σ.

Drifting subpulses and nulling (complete cessation of emission) are closely linked to the emission process. By studying PSRs B0809+74 and B0818-13 van Leeuwen, Stappers, Ramachandran, Rankin (NOVA visitor) and Janssen showed how these phenomena interact. In some models the subpulses correspond to emitting entities which rotate about the magnetic pole like a carousel. In PSR B0809+74 they found that the carousel must rotate very slowly which is inconsistent with the expectation of these models. In PSR B0818-13 they showed that the long nulls are actually a series of rapidly alternating nulls and pulses. Sometimes only the nulls coincide with the pulse window, resulting in the apparently long nulls occasionally seen. They also showed that the carousel likely rotates in 30 seconds or less, making it the fastest found to date.

Using a novel approach Edwards (NOVA postdoc) and Stappers studied a large sample of millisecond pulsars and were able to determine the presence and properties of the pulse-to-pulse intensity variations in this distinctly different class of pulsars for the first time. For two pulsars they found that the modulation appears as drifting subpulses

The same technique was used to study the individual pulse behavior ~180 pulsars using WSRT-PuMa. From the observations Weltevrede (NOVA PhD), Stappers and collaborators found that at least 55% of all pulsars show the phenomenon of regularly “drifting” subpulses. This very high incidence of the phenomenon of “drifting” subpulses suggests that this is rule rather than exception among all radio pulsars, and the drifting subpulse phenomenon likely provides a tool to study the physical mechanism by which radio pulses are generated.

An analysis of the drifting subpulses of PSR B0320+39 by Edwards and Stappers indicated a sudden step of ~180° in subpulse phase near the center of the pulse profile. The phase step, in combination with the attenuation of the periodic subpulse modulation at pulse longitudes near the step, suggests that the patterns arise from the addition of two superposed components of nearly opposite drift phase and differing longitudinal dependence. They argued that the drift components must be associated with a kind of "multiple imaging" of a single polar cap "carousel" spark pattern.

Weltevrede, Stappers, van den Horn and Edwards studied the effects of refraction in the pulsar magnetosphere. They demonstrated that some models are less realistic due to a focusing effect and cannot be used to fit (typical) multi frequency pulsar observations. Fung and Kuijpers studied the concept of the free-electron laser to understand the high brightness temperature of pulsar radio emission. They numerically examined the case where a transverse electromagnetic wave is distorting the motion of a relativistic electron beam while traveling over one stellar radius. For different sets of parameters, coherent emission is generated by bunches of beam electrons in the radio domain, with bandwidths of 3 GHz. brightness temperature of 10^{30} K and tens of nanosecond duration. In the context of pulsar radio emission, these results indicate that the laser can produce elementary bursts of radiation which build up the observed microstructure.

3.3.4.2. Polarization of radio pulses

Edwards and Stappers used WSRT-PuMa to study the polarization of single pulses from PSR B0329+54. Using a new analysis and visualization technique they concluded that the distribution of polarization orientations in the central component of the pulse profile diverges strongly from the standard picture of orthogonal polarization modes. They argued that this can be understood in terms of birefringent alterations in the relative phase of two elliptically polarized propagation modes in the pulsar magnetosphere (i.e. generalized Faraday rotation). Using PuMa data Rankin and Ramachandran showed that the average polarization properties of some pulse profiles directly reflect the polarization-modal structure of the emission beams that produce them. Some pulse component pairs exhibit large fractional linear polarization on their inside edges and virtually complete depolarization on their outside edges, whereas profiles resulting from sight-line encounters with the outside edge are usually very depolarized.

3.3.4.3. X-ray observations of radio pulsars

Stappers, van der Klis and co-workers, using the CHANDRA X-ray observatory, in 2003 discovered an X-ray nebula around the "black widow' millisecond binary pulsar B 1957+20 which is evaporating its companion star. This result was published in Science.

3.3.4.4. Free electron laser pulsar emission

Fung adapted a numerical code for Free Electron Lasers (FELs) in the laboratory to conditions occurring in atmospheres of radio pulsars. Together with Kuijpers she showed that a high-gain single-pass inverse Compton FEL can exist in the outer parts of the pulsar magnetosphere. They used Gaussian modes and relativistic electron-positron bunches scattering off magnetic wigglers. The radio emission from such a FEL can reach extremely high brightness temperatures. It comes in short pulses of broad bandwidth and has narrow opening angles, all in agreement with typical pulsar observations.

3.3.4.5. Explanation of drifting sub-pulses

Fung and collaborators showed that the challenging phenomenon of drifting sub-pulses can be understood as a result of a diocotron (or 'electrostatic Kelvin-Helmholtz') instability above the pulsar polar caps. The instability operates in a differentially rotating relativistic wind of electrons and positrons such as is ejected from the pulsar polar caps. Typical azimuthal wave numbers are in the range 2-30 as is observed. This result is a breakthrough in our understanding of pulsar electrodynamics, and allows usage of drifting sub-pulses to determine the detailed spatial profiles of the relativistic particle beams from pulsars.

3.3.4.6. Single neutron stars and Magnetars

Single neutron stars were supposed to be steady X-ray sources, and one of them was observed regularly by XMM as a calibration source. De Vries et al. used the stability of the Reflection Grating Spectrometer to show that the spectrum of this source, RXJ 0720-3125, is variable on a time scale of months, and suggest that precession of the neutron star is the cause of this. Such precession before has only been detected in long-term variations in the pulse period of one radio pulsar. It implies that the neutron star is not spherical, and the required amplitude of the deformation excludes the (too) popular model for glitches as due to vortex pinning (the tying of rotation vortices of the super-fluid interior to atomic nuclei in the solid crust).

Since the 1998 discovery by Kouveliotou and van Paradijs that the Soft Gamma-ray Repeaters (SGRs) are Magnetars, single neutron stars with magnetic fields of 10^{14} to 10^{15} Gauss, the anomalous X-ray pulsars were recognized to be a similar type of single neutron stars with extremely large magnetic fields. The X-ray emission of both these types of objects is thought to be due to the crustal heating of the neutron star produced by the dissipation of the very strong electric currents associated with their magnetic fields. The soft gamma-ray outbursts of the SGRs are most probably due to crustal "star quakes", produced by rearrangements of inhomogeneities of their very strong surface magnetic fields. Van der Klis, Kouveliotou and collaborators studied the cooling behavior of the SGR 1627-41 following its 2003 outburst. Using the Chandra X-ray observatory they also studied in 2003 the X-ray spectrum of the anomalous X-ray pulsar 4U0142+61.

Van der Klis participated in a large collaboration performing several target of opportunity observations with the Integral gamma ray satellite of the soft gamma ray repeater SGR1806-20. This object is thought to be a magnetar: a neutron star with an ultra-strong magnetic field occasionally producing large numbers of soft gamma ray bursts through electromagnetic processes. More than 100 bursts were detected.

3.3.5. Binary and stellar evolution

Dessart, Langer and Petrovic investigated to what extent the radiation and stellar wind momenta in a massive close binary system can remove part of the matter flowing from one towards the other star during a mass transfer phase. They performed radiation-hydrodynamics simulations in the co-rotating frame of a massive close binary system and studied the interaction of the winds of both stars, and of their photons, with the accretion stream originating from the Roche-lobe filling component. These simulations show that, even for moderate mass transfer rates, the wind and radiative momenta do not alter the dynamics of the accretion stream. Therefore, they cannot be responsible for the non-conservative nature of mass transfer events.

Type Ia supernovae are essential tools for cosmology, and are recognized as major contributors to the chemical evolution of galaxies. The construction of detailed supernova progenitor models, however, was prevented until recently by various physical and numerical difficulties in simulating binary systems with an accreting white dwarf component. Yoon and Langer performed the first binary evolution calculation which includes both stellar components and the binary interaction, and where the white dwarf mass grows up to the Chandrasekhar limit by mass accretion (Fig. 3.36). Although the supernova production rate through the computed channel is not well known, and this channel cannot be the only one as its progenitor life time is rather short (~10^7 - 10^8 yr), these results indicate that helium star plus white dwarf systems form a reliable route for producing Type Ia supernovae.

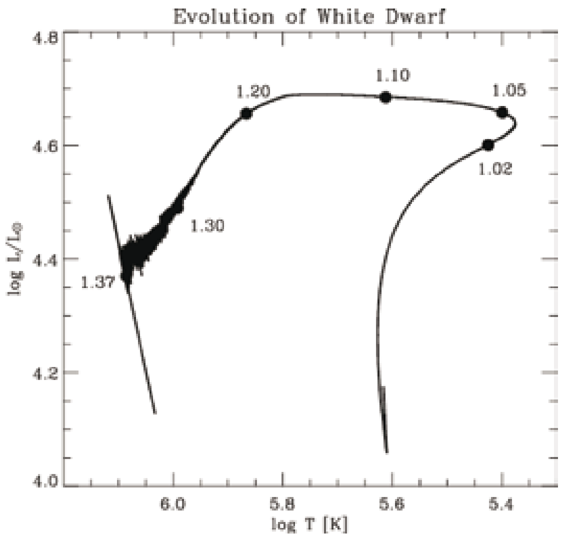


Fig. 3.36: Evolution of the CO white dwarf in the HR diagram, from the onset of mass accretion up to its explosion as Type Ia supernova. The high surface temperature of the white dwarf makes it appear as a super soft X-ray source during the accretion phase. The numbers at the filled circles denote the white dwarf mass in the unit of solar mass at the given points.

Yoon and Langer computed evolutionary models of helium-accreting carbon-oxygen white dwarfs, taking into account the effects of the spin-up of the accreting star induced by angular momentum accretion, rotationally induced chemical mixing and rotational energy dissipation. Initial masses and accretion rates that are typical for the sub-Chandrasekhar mass progenitor scenario for Type Ia supernovae were chosen. It was found that the helium envelope in an accreting white dwarf is heated efficiently by friction in the differentially rotating spun-up layers. As a result, helium ignites much earlier, and under much less degenerate conditions than in the corresponding non-rotating case. Consequently, a helium detonation was found to be avoided, which questions the sub-Chandrasekhar mass progenitor scenario for Type Ia supernovae. In a separate study, Yoon and Langer found that differentially rotating white dwarfs have critical masses for thermonuclear explosion or electron-capture induced collapse that significantly exceed the canonical Chandrasekhar limit. They constructed two-dimensional differentially rotating white dwarf models with realistic rotation laws, and provided the first rapidly rotating progenitor models for Type-Ia supernovae and electron-capture induced collapse of rotating CO and O-Ne-Mg white dwarfs. These results lead to a new paradigm of a variable mass of exploding white dwarfs, at values well above the classical Chandrasekhar mass.

Podsiadlowski (Oxford), Langer, Poelarends, and coworkers systematically examined how the presence in a binary affects the final core structure of a massive star, and its consequences for the subsequent supernova explosion. Interactions with a companion star may change the final rate of rotation, the size of the helium core, the strength of carbon burning, and the final iron core mass. Stars with initial masses larger than about 11 $M_\odot$ that experience core collapse will generally have smaller iron cores at the point of explosion if they lost their envelopes through a binary interaction during or soon after core hydrogen burning. Stars below ~11 $M_\odot$, on the other hand, can end up with larger helium and metal cores if they have a close companion, since the second dredge-up phase that reduces the helium core mass dramatically in single stars does not occur once the hydrogen envelope is lost. It is found that the initially more massive stars in binary systems with masses in the range 8-11 $M_\odot$ are likely to undergo an electron-capture supernova, while single stars in the same mass range would end as O-Ne-Mg white dwarfs. This work suggests that the core collapse in an electron-capture supernova (and possibly in the case of relatively small iron cores) leads to a prompt or fast explosion, rather than a very slow, delayed neutrino-driven explosion. This naturally produces neutron stars with low-velocity kicks, and leads to a dichotomous distribution of neutron star kicks, as inferred previously, where neutron stars in relatively close binaries attain low kick velocities.

Dewi and Pols studied the formation of double neutron-star (DNS) systems through the so-called standard evolution scenario that involves a Be/X-ray binary as an intermediate stage. The final stages of this evolution path, involving mass transfer from a helium star to a neutron star companion, were studied with a detailed stellar evolution code. These calculations were used to trace back the evolution of observed DNS systems, and to constrain the kick velocity received by the second neutron star at its birth. Furthermore they found that under certain conditions a second common envelope phase occurs, which may produce double neutron stars in very tight orbits with merger times less than 1 Myr. If such a fast-merging population exists it may significantly increase the DNS merger rate above that derived from the observed population.

Dewi and Pols together with Podsiadlowski (Oxford) investigated the relation between the pulsar spin period and the orbital eccentricity observed among the eight Galactic double neutron stars. Using a simple model for spin-up of the first-born pulsar by accretion from a helium star companion, they showed by means of population synthesis that this relation can only be produced if the second neutron star received a kick that is substantially smaller than the standard large kick received by a single radio pulsar. This shows that the kick mechanism depends on the evolutionary history of the NS progenitor, which has implications for estimating the birth-rates of NS-NS mergers and short-duration gamma-ray bursts.

Van den Heuvel also analyzed the properties of these double neutron stars. He found that in 5 out of the 8 systems the mass of the second-born neutron star is very low, between 1.18 - 1.30 $M_\odot$. Just all these five systems have a very low orbital eccentricity, between 0.09 - 0.25, indicating that the second-born neutron star cannot have received a large kick velocity (a few hundred km/sec) at its birth, as was so far always assumed to be the case. Based on the finding that these "low-kick-velocity" neutron stars always have a small mass (~ 1.24 $M_\odot$) he suggested that these neutron stars were formed by the electron-capture collapse of the degenerate Oxygen-Neon-Magnesium cores of stars with initial main-sequence masses in the range 8 to 13 $M_\odot$. At the time of collapse the cores of these stars have a mass of 1.44 $M_\odot$ and after losing the gravitational binding energy of a neutron star (~ 0.20 $M_\odot$) these will produce a neutron star of ~1.24 $M_\odot$. On the other hand stars with initial masses above about 13 $M_\odot$ will develop a collapsing iron core. It is suggested that these collapses produce the high-kick-velocity neutron stars, as the core collapse of these more massive stars is expected to proceed less symmetric than the collapse of the degenerate O-Ne-Mg core.

Regös, Tout (both IoA Cambridge, UK), Pols and coworkers investigated the role of edge-lit detonations (ELD) of sub-Chandrasekhar-mass white dwarfs. From population synthesis they found that such explosions must be common, even though they are no longer favored as progenitors of Type Ia supernovae. The results also indicate possible systematic effects of their explosion properties with metallicity. If any distant Type Ia supernovae can be identified as ELDs, they should not be used as cosmological standard candles.
Izzard (IoA Cambridge, UK; currently UU), Tout,

Karakas (Monash) and Pols presented a new synthetic model for the evolution of asymptotic giant branch (AGB) stars. They constructed analytic fits to detailed stellar models of this evolution phase, and an algorithm to follow the nucleosynthesis during thermal pulses. The model is calibrated against various observational constraints such as the carbon-star luminosity functions in the Magellanic Clouds. The model can be used in population synthesis studies of single as well as binary stars. Bonacic and Pols made some additional improvements to the synthetic model. They applied it in a binary population synthesis of the formation of barium stars. They found disagreements between the observed and predicted distributions of orbital periods and eccentricities of barium stars, and discussed various possible solutions which will be explored in subsequent studies.

Stancliffe (IoA Cambridge, UK), Tout and Pols computed detailed models of thermally-pulsing AGB stars. This evolution phase is notoriously difficult to model and there are large differences between results obtained with different codes, particularly regarding the depth of convective dredge-ups. All detailed AGB models so far have failed to reproduce the observed carbon-star luminosity functions in different stellar environments, most notoriously in the Magellanic Clouds. Stancliffe et al. use, for the first time in such models, a fully implicit and simulta neous method for solving for the stellar structure, nuclear burning and convective mixing. They find deep dredge-up after a few thermal pulses in all their models, occurring (in the case of a 3 $M_\odot$ star) at significantly smaller core masses than in any previous calculation. In a follow-up study with the same code, Stancliffe, Tout and Izzard computed detailed AGB models for the Magellanic Clouds. Again they found dredge-up at smaller core masses than before, which for the first time brings agreement between the predicted and observed LMC carbon-star luminosity function. However, such agreement is still lacking for the SMC carbon stars.

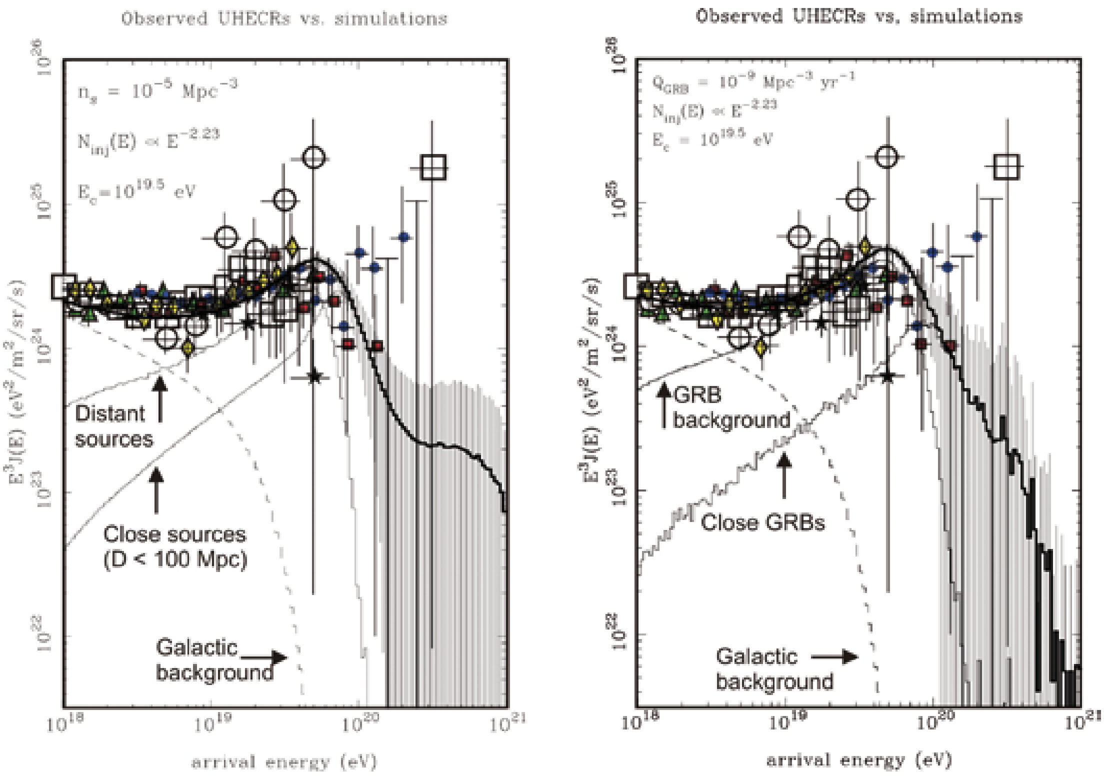


Fig.3.37: The simulated all-sky arrival spectrum of ultra-high energy cosmic rays from due to bursting sources (left) and due to continuously radiating sources (right). Shown is the flux in the energy range 10^{18} - 10^{21} eV. The spectrum shown is the mean spectrum obtained from a large number of independent realizations of the spatial distribution of close-by sources. The vertical error bars show the range of expected spectra for a single realization of the source distribution. This flux consists of three contributions: the Galactic background, the flux of distant (>100 Mpc) sources, and the flux due to sources closer than 100 Mpc. These last sources contribute most of the flux above $10^{19.7}$ eV. The data points show the experimentally determined cosmic ray flux spectrum as obtained by various experiments.

Sipior, Nelemans and Portegies Zwart constructed a new scenario for a class of still unobserved black holes in tight binaries with a recycled pulsar. In this scenario a high mass star is stripped of its envelope in an early stage of its evolution. This causes the star to collapse to a neutron star. The companion star, which accreted part of the primaries envelope subsequently collapses to a stellar mass black hole after yet another episode of mass transfer. The resulting binary consists of a (mildly) recycled pulsar around a relatively low mass black hole.

Lommen, van den Heuvel and collaborators studied Cyg X-3 and found that the observations are consistent with either a black hole accreting from the wind of a massive helium star or a low-mass helium star transferring matter to a neutron star. Through population synthesis it was found that of either type there should be about 1 currently existing in the Galaxy.

3.3.6. Ultra-high energy cosmic rays

Achterberg, together with Gallant, Rachen, Norman (STScI), Melrose (University of Sydney) completed their study of the propagation of ultra-high energy cosmic rays (UHECRs) in intergalactic space. They considered several scenarios for the production of these enigmatic particles (energy $E > 10^{18.5}$ eV): continuous production in active galaxies and explosive production in Gamma Ray Bursts. Their simulations show that in both scenarios the arrival spectrum at Earth shows a distinct break at an energy $E \sim 10^{19.7}$ eV. This break was predicted forty years ago, and is the result of catastrophic energy losses of UHECR nuclei due to pion production on the Cosmic Microwave Background Radiation. Even though the break in the spectrum is not as strong as suggested by previous studies, it is clearly observable (Fig. 3.37). Currently available experimental data are inconclusive: one experiment (AGASA} suggests that the UHECR spectrum continues well beyond energy of $10^{19.7}$ eV, and another (HiRes) suggests a clear break in the spectrum. The experimental situation will improve considerably in the near future as the data from the much more sensitive AUGER experiment become available.

4. PhD's in astronomy awarded in 2003 - 2004 - 2005

In 2003 a total of 13 PhD's in astronomy were awarded in the Netherlands, 24 in 2004 and another 21 were awarded in 2005. Of these PhD's 16 were obtained through funding from NOVA. The table below lists all PhD's in astronomy over 2003-2005 specified for each university.

	PhD date	Funding	Promotor	Thesis title
UvA				
J. Dewi	28-03-2003	NWO	van den Heuvel	From Be/X-ray binaries to double neutron star systems
A. Lenorzer	14-01-2004	UvA/NWO	Waters co: de Koter, Kaper	Near-infrared spectroscopic analysis of hot massive stars
E. Rol	29-01-2004	UvA/NWO	van den Heuvel co: Kaper	The physics of gamma-ray burst afterglows
J. Braithwaite	08-04-2004	MPA, Germany	Spruit	Stable and unstable magnetic fields in stars
S. van Straaten	22-04-2004	NWO	van der Klis	Timing similarities among accreting neutron stars
A. Bik	27-09-2004	NOVA	Waters co: Kaper	The stellar content of high-mass star-forming regions
M. Klein-Wolt	30-09-2004	UvA	van der Klis	Black hole X-ray binaries
R. van Boekel	21-10-2004	NOVA	Waters co: Pel	High spatial resolution infrared studies of proto-planetary disks
C. Dijkstra	23-11-2004	NOVA	Waters	Silicates and water ice around evolved stars
M. Min	12-05-2005	UvA	Hovenier, Waters	Optical properties of circumstellar and comentary grains
S. Migliari	21-09-2005	NWO	Van der Klis	Disc-jet coupling in neutron star and black hole binaries
E. Gallo	23-09-2005	NOVA/EC	Van der Klis	Relativistic jets from stellar black holes
RuG				
M. Beijersbergen	06-01-2003	RuG	Van der Hulst	The galaxy population in the Coma Cluster
J. Bernard Salas	30-09-2003	SRON/ RuG	Tielens co: Wesselius	Physics and chemistry of gas in planetary nebulae
A.C. Gonzalez Garcia	28-03-2003	RuG	Van Albada	Elliptical galaxies: merger simulations and the fundamental plane
M.E. Filho	09-05-2003	Ubbo Emmius	Van der Hulst co: Barthel, Ho	Nuclear activity in nearby galaxies
M. Kregel	17-11-2003	RuG	Van der Kruit co: Freeman	Structure and kinematics of edge-on galaxy disks
H.W.W. Spoon	20-10-2003	ESO/RuG	Tielens	Mid-infrared spectroscopy of dusty galactic nuclei
S.M. Cazaux	06-01-2004	NOVA	Tielens co: Spaans	Grain surface chemistry in astrophysical objects: from H_2 to complex molecules
H.R. Klöckner	19-03-2004	RuG/ ASTRON	Van der Hulst co: Baan	Extragalactic Hydroxyl
E. Romano-Diaz	08-10-2004	Ubbo Emmius	Van der Weijgaert, Sanders	Probing cosmic velocity flows in the Local Universe
L.K. Hunt	15-10-2004	Foreign funding	Van der Kruit	Building galaxies: from low-metallicity compact dwarfs to active galactic nuclei
K. Fathi	17-12-2004	RuG co: Peletier	Van der Kruit	Morphology and dynamics in the inner regions of spiral galaxies
B.W. Holwerda	17-06-2005	STScI/ RuG	Van der Kruit Allen	The opacity of spiral galaxy disks
J.T.A. de Jong	23-09-2005	RuG	Kuijken, Sackett, Crotts	Microlensing in Andromeda. A search for baryonic dark matter
UL				
G.M. Muñoz Caro	05-02-2003	NWO	Van Dishoeck co: Schutte	From photo-processing of interstellar ice to amino acids and other organics
A.M.S. Gloudemans-Boonman	05-03-2003	NWO	Van Dishoeck co: Doty	Spectroscopy of gases around massive young stars
E.K. Verolme	21-05-2003	UL	De Zeeuw	Dynamical models of axi-symmetric and tri-axial stellar systems

	PhD date	Funding	Promotor	Thesis title
J.D. Kurk	22-05-2003	UL	Miley co: Röttgering	The cluster environment and gaseous halos of distant radio galaxies
M. Messineo	30-06-2004	NOVA	Habing	Late type giants in the inner galaxy
K. Kraiberg Knudsen	06-10-2004	NWO	Franx co: van der Werf	Deep submillimeter observations of faint dusty galaxies
D. Krajnovic	12-10-2004	NOVA	De Zeeuw	On the nature of early-type galaxies
I. Labbé	13-10-2004	NWO	Franx co: van Dokkum	Deep infrared studies of massive high redshift galaxies
J.K. Jørgensen	14-10-2004	NOVA	Van Dishoeck	Tracing the physical and chemical evolution of low-mass protostars
K.M. Pontoppidan	14-10-2004	NOVA	Van Dishoeck	Fire and ice
R. Ruiterkamp	28-10-2004	NWO/SRON	Ehrenfreund	Aromatic molecules in space: laboratory studies and applications to astrochemistry
K.C. Steenbrugge	02-02-2005	SRON	Schilizzi co: Kaastra	High-resolution x-ray spectral diagnostics of active galactic nuclei
D. van Delft	10-02-2005		Visser, van Lunteren	Heike Kamerlingh Onnes, een biografie
P.B. Lacerda Cruz	17-02-2005	NWO	Habing	The shapes and spins of kuiper belt objects
M.A. Reuland	24-02-2005	UL/foreign	Miley	Gas, dust, and star formation in distant radio galaxies
F.I. Pelupessy	16-03-2005	NWO	Icke co: van der Werf	Numerical studies of the interstellar medium on galactic scales
B.P. Venemans	27-04-2005	NOVA	Miley co: Röttgering	Protoclusters associated with distant radio galaxies
F.A. van Broekhuizen	29-06-2005	NOVA/Spinoza	Van Dishoeck Schlemmer co: Fraser	A laboratory route to interstellar ice
A. van der Wel	29-09-2005	NOVA/UL	Franx Van Dokkum	Setting the scale. Photometric and dynamical properties of high-redshift early-type galaxies
P.M. van de Ven	01-12-2005	NOVA/UL	de Zeeuw	Dynamical structure and evolution of stellar systems
E.J. Rijkhorst	06-12-2005	NWO	Icke co: Mellema	Numerical nebulae
UU				
R. Cornelisse	15-01-2003	UU	Verbunt co: Heise	A wide field view of the population of X-ray bursters in the galaxy
F. Hulleman	14-04-2003	UU	Verbunt co: van Kerkwijk	Anomalous X-ray pulsars at optical and infrared wavelengths
K.J. van der Heyden	02-02-2004	SRON	Bleeker	High-resolution X-ray spectral diagnostics of shell type Supernova Remnants
W.M. Bergmann Tiest	01-03-2004	SRON	Bleeker co: Hoevers	Energy resolving power of transition-edge X-ray micro-calorimeters
S.C. Yoon	22-04-2004	NWO	Langer	On the evolution of accreting white dwarfs in binary systems
A.G.J. van Leeuwen	10-05-2004	NWO	Verbunt	Radio pulsars
J. Petrovic	27-10-2004	UU	Langer	On the evolution of massive close binary systems
N.J. Bastian	21-04-2005	NOVA	Lamers co: Kissler-Patig	Studies on the formation, evolution and destruction of massive star clusters
D.J. Nickeler	10-06-2005	UU	Goedbloed, Fahr co: Neukirch	MHD equilibria of astrospheric flows
P.K. Fung	12-09-2005	UU	Kuijpers	Pulsars: magnetosphere and radio emission UU
C. Wang	23-11-2005	FOM	Goedbloed	Study of plasma channels for use in laser wakefield accelerators
TU Delft				
B.D. Jackson	08-06-2005	SRON/TuD/NOVA	Klapwijk de Graauw	NbTiN-Based THz SIS Mixers for the Herschel Space Observatory
A. Baryshev	09-03-2005	SRON/TuD/NOVA	Klapwijk co: Koshelets	Superconductor-Insulator-Superconductor THz Mixer Integrated with a Superconducting Flux-Flow Oscillator.

5. Instrumentation Program

5.1. ALMA high-frequency prototype receiver

The NOVA-ALMA group at RuG and SRON is involved in three projects: the development and prototype production of 600-720 GHz receiver cartridges for the ALMA project; the development and production of receiver mixers operating at 600-720 and 780-950 GHz for the CHAMP+ heterodyne array receiver being refurbished at the Max Planck Institute für Radioastronomie (MPIfR) at Bonn, Germany, for use on the APEX telescope; and the development of 600-720 GHz side-band separating mixers. The first project is discussed here, while the others are discussed in sections 5.2 and 5.3.

5.1.1. The NOVA-ALMA Band-9 project

The ALMA project is a collaboration between Europe, North America, and Japan to build an aperture synthesis telescope consisting of at least 50 12-m antennas located at 5000 m altitude in Chile. In its full configuration, ALMA will observe in 10 frequency bands between 30-950 GHz, with a maximum baseline of up to 10 km. This will provide astronomers with unprecedented spatial resolution at millimeter and sub-millimeter wavelengths. Additionally, ALMA's large collecting area and the quantum-limited sensitivities of its cryogenic receivers will combine to offer a significant improvement in sensitivity relative to contemporary (sub)millimeter observatories. Within the Netherlands, a consortium of NOVA, RuG, SRON, and TU Delft is developing heterodyne receivers for the ALMA project covering the 600-720 GHz atmospheric window. As the highest frequency band in the baseline ALMA project, these so-called ALMA Band-9 receivers will provide the observatory's highest spatial resolution. In addition they will probe higher temperature scales that will complement observations in the three lower-frequency bands in the baseline project (covering 84-116, 211-275, and 275-370 GHz). The SIS mixers that are being used in the ALMA Band-9 cartridge were developed within the framework of a NOVA phase-1 instrumentation project.

5.1.2. The ALMA Band-9 cartridge

The ALMA Band-9 cartridge is a compact unit containing the core of a 600-720 GHz receiver, which can be easily inserted into and removed from the cryostat in the ALMA receiver. It combines high-sensitivity, broadband SIS mixers as the eyes of the receiver; a high-power, electronically-tunable local oscillator that drives the mixers at their operating frequency; and low-noise intermediate frequency amplifiers that amplify the mixers' weak outputs before they leave the cryostat. These components are built into a rigid opto-mechanical structure that includes a compact optical assembly that combines the astronomical and local oscillator signals and focuses them into the two SIS mixers. Fig. 5.1 depicts the cryogenic portion of the Band-9 cartridge.

5.1.3. The NOVA-Band 9 Group

While earlier development efforts were supported by a combination of NOVA phase-1 and ESO funds, work on the Band-9 cartridges has been fully funded by a contract with ESO since the start of 2003. NOVA is the contracting partner with ESO; the majority of the group is employed via the University of Groningen; SRON provided critical infrastructure, design heritage, and technical support; and TU Delft developed the SIS junctions at the core of the cartridge's mixers. The NOVA-ESO contract covers the design, production and testing of eight prototype units of the Band-9 receiver cartridge, as well as further development of SIS junctions.
Prior to 2003, a group of four (Wild, Baryshev, Hesper, and Gerlofsma) had focused on the development of the SIS mixers at the heart of the cartridge, in addition to contributing to the preliminary design of the ALMA front end. With the signing of the contract with ESO to develop the Band-9 cartridge and produce the first eight units, the group has expanded substantially – Adema, Jackson, and Koops joined in 2003, Barkhof and Mena in 2004, and Bekema and Keizer in 2005. Additionally, the group of Klapwijk and Zijlstra at TU Delft was strengthened by PhD student Lodewijk and post-doc Loudkov. Wild left the project in 2003 for a position within SRON, but remains in a line management role.

The Band-9 project is critically dependent upon several partners within the ALMA project – ESO, NRAO (USA), RAL (UK), Centro Astronomico de Yebes (Spain), HIA (Canada), and IRAM (France). Close relationships were also developed with commercial partners who will produce the majority of the Band-9 cartridge hardware components.

5.1.4. Progress and achievements in 2003-2005: ALMA Band-9 receiver cartridge

Over the course of 2003-2005, significant progress was made in the design of the Band-9 cartridge, in the production of prototypes of critical components and the cartridge itself, and in the development of test equipment. A preliminary design review was successfully passed in March 2004. The year 2003 was marked by the development of a preliminary design of the cartridge by Baryshev and Hesper, with the support of a Dutch design company (Mecon). One key decision was to take advantage of modern CNC machining capabilities to manufacture the cartridge's five-mirror optical assembly out of two blocks of aluminum (Fig. 5.1). In this way, the sur-

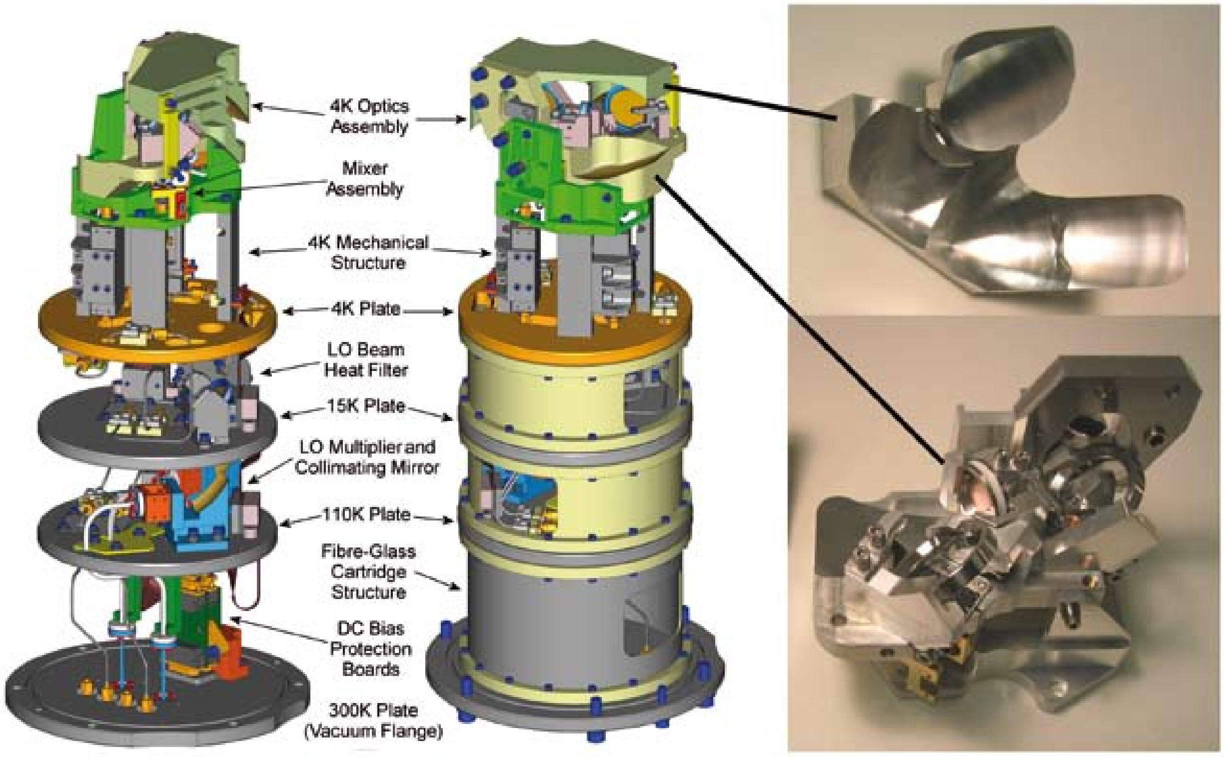


Fig. 5.1: (left) Cryogenic portion of the ALMA Band-9 cartridge, with and without the fiberglass rings that separate the cartridge's four temperature levels; (right) the 4K optics assembly. The surface and relative alignment accuracies of the five mirror surfaces (four in the upper block and one in the lower block) are typically several microns, or better. This allows the system to be assembled without need for mechanical alignment.

face quality and relative alignment of the mirrors are defined by machining accuracy alone, which will greatly simplify the assembly of the cartridge. A prototype of this concept was tested in late 2003. The results proved that tolerance specifications were met.

During 2004, the group focused on detailing the cartridge design, manufacturing components for the first cartridge, and developing equipment for testing the integrated cartridges. 2005 was highlighted by the assembly and testing of the first cartridge (see Fig on the back cover of this annual report), including the continued development of cartridge test equipment and test procedures, and trouble-shooting of critical cartridge components. In parallel with this test effort, experience gained with the first cartridge was used to redesign the cartridge in 2005, with the goal of easing manufacturing and assembly during the eventual series production phase of the project.

In parallel to the development of the cartridge, work on SIS mixers also continues. The results of SIS development until mid-2005 are described in the report on the CHAMP+ project (section 5.2). Since mid-2005, SIS junction work focused on optimizing the center frequency of the SIS mixers' frequency response to optimally cover the 600-720 GHz band.

5.1.5. NOVA-ESO contract

In January 2004 NOVA and ESO signed a contract on the development of the ALMA Band-9 cartridge and the fabrication and testing of eight pre-production Band-9 cartridges. This contract for 3969 k€ covers all project costs from January 2003 until mid-to-late 2006. An extension to this contract to cover all project costs until mid-2007 is being negotiated with ESO.

5.2. CHAMP+

CHAMP+ is a 14-element SIS heterodyne array receiver for the 600-720 GHz (same as ALMA Band 9) and 790-950 GHz (same as ALMA Band 10, large overlap with HIFI band 3) atmospheric windows to be exploited on APEX at the Chajnantor site in Chile. The project is a collaboration between the Netherlands and MPIfR. In the Netherlands the NOVA-ALMA group and TU Delft extended their collaboration to also build the mixer receivers for CHAMP+, the upgraded CHAMP receiver of MPIfR, using the experience and technology devel-

oped for the ALMA Band-9 and HIFI band 3 receivers. This NWO funded project (653 k€), for which NOVA holds formal responsibility, provides astronomers in the Netherlands 42 guaranteed observing nights on APEX spread over six years in access to the open competition time available through ESO. The formal contract between NOVA and MPIfR on CHAMP+ was signed in April 2003.
During the reporting period the design of both CHAMP+ mixers was completed for both frequency bands. In addition effort was spent on improving the sensitivity of the 600-720 GHz receiver through optimizing the design of the SIS junction and the choice for junction materials. Noise temperatures as low as 100K double side band at 690 GHz were achieved (Fig. 5.2). At the end of 2004 all hardware components for the low band sub-array were manufactured through commercial outsourcing and integration of the first mixer began. The low band mixer array was delivered to MPIfR in August 2005.

Assembly of the high band array block commenced in 2005. Unfortunately the SIS batches produced for HIFI didn't provide enough good SIS junctions for the CHAMP+ high band. Hence a new batch design was made to get a SIS junction better optimized for the CHAMP+ frequency band dictated by the transparency of the Earth atmosphere. Good quality devices for the mixer were received at the end of 2005. The best mixer noise temperature is 250 K at 850 GHz (Fig. 5.2). The high band mixer array with five mixers was delivered to MPIfR to facilitate receiver tests. The rest of the mixers will be delivered in the beginning of 2006 – in time for the year 2006 observing season at APEX in Chile.

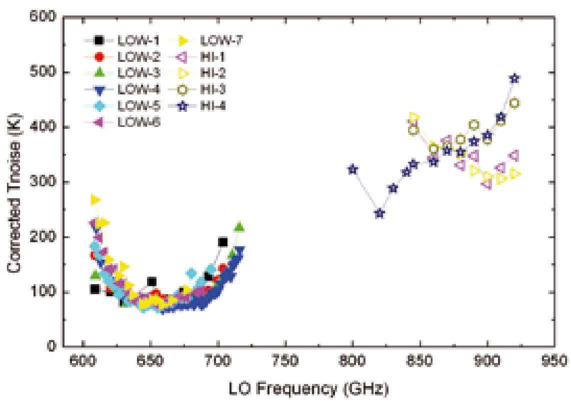


Fig 5.2: Double side band noise temperature for the CHAMP+ low and high band mixer as a function of frequency. Mixers of similar design will also be used in the ALMA Band-9 receiver.

5.3. ALMA R&D phase-2 and ALLEGRO

The main advantage of a sideband-separating (2SB) receiver compared with double sideband (DSB) receiver is that it cuts out the atmospheric noise of the unwanted image sideband, which is significant at submillimeter wavelengths even at the best observing sites. Improvements in observing speed of up to a factor of two can be achieved under typical weather conditions at the ALMA site. This NOVA phase-2 project aims for building a 2SB mixer at 650 GHz after several technical concept studies to be applied for the ALMA Band-9 receiver. The possibilities include (a) a waveguide hybrid 2SB mixer, (b) a quasi-optical 2SB mixer, and (c) two single-ended mixers combined quasi-optically. Wild (SRON-RuG) is PI of the project.

The design of a 2SB mixer for the ALMA Band-9 receiver started in 2003 with working visits of Kooi (Caltech) and contributions from experts working on HIFI and ALMA Band-9 and the hiring of Mena in September 2004. The electromagnetic design of the mixer block was finished late 2004. Assessment of possible fabrication techniques resulted in a number of options which need further exploration. A very first trial of direct machining a hybrid prototype gave promising results.

In 2005, several milestones were met. Key people for this work were Baryshev, Mena, Gerlofsma, and Adema (all of them are members of the ALMA Band-9 group and shared between the 2SB and ALMA Band-9 projects).The electrical and detailed mechanical design (Fig. 5.3) of the 2SB block finished, including the fabrication feedback from a fine mechanical company. Final drawings were produced and the 2SB mixer block and input horn were ordered with a delivery date of March 2006.The elec-

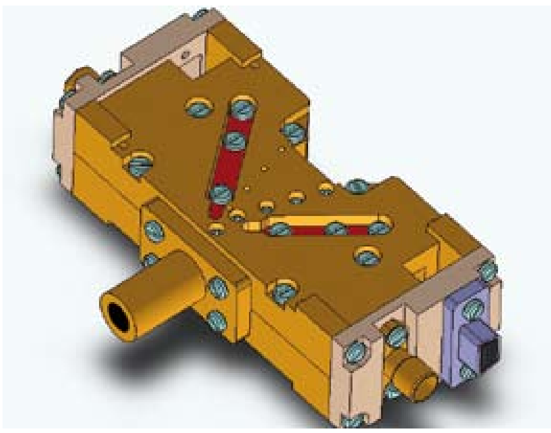


Fig. 5.3: Mechanical design of the 2SB mixer prototype.

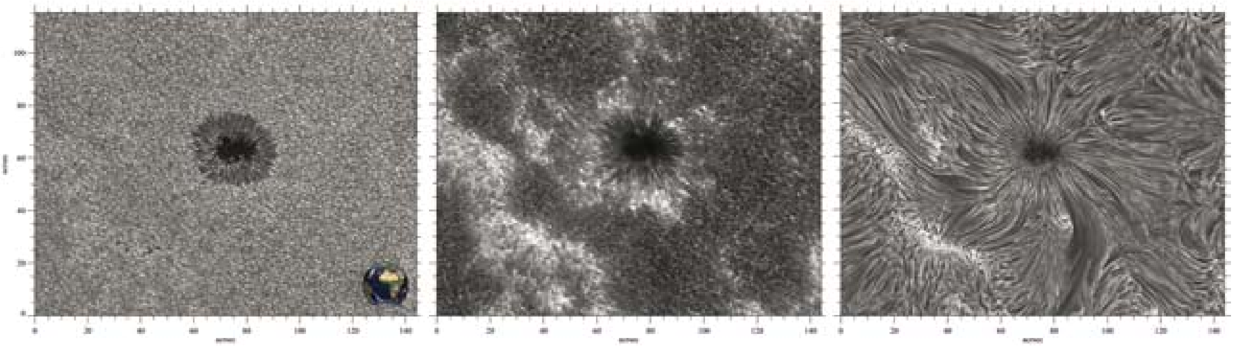


Fig 5.4: Narrow-band imaging in selected spectral lines permits sampling solar phenomena simultaneously in multiple layers. These DOT image mosaics taken on 29 September 2004 show three such slices through a sunspot about as large as the Earth (inset). The G band (first image) shows the photospheric solar surface covered by convective granules and tiny bright magnetic elements between these. The sunspot has a dark umbra containing small bright umbral dots and surrounded by a filamentary penumbra. The strong Ca II H line (second image) samples the low chromosphere, a few hundred km higher up. At that height the granulation appears reversely and the magnetic elements appear considerably brighter. The Hα line (third image) shows fibrils in the high chromosphere that lie at a few thousand km height and are obviously controlled by magnetic fields. They show that many (but not all) field lines originate in the spot and in the intergranular magnetic elements, and span wide distances to where they connect back to the surface.

tromagnetic design of the junction structures was finalized in close collaboration with the Kavli group at TU Delft. A few junction runs (batches) were done at the TU Delft facilities one of which resulted in useable junctions according to a DC test.

During 2005, the design and performance calculations of the 2SB mixer were presented at the 16th International Symposium on Space Terahertz Technology (May 2005, Gothenburg, Sweden, Mena), the FP6 RadioNet-AMSTAR meeting in June 2005 at SRON (Baryshev), the Infrared and Millimeter wave conference (Mena), and the AMSTAR meeting of FP6 RadioNet in Köln (December 2005, Mena).

5.3.1. ALLEGRO

During NOVA phase-2 a dedicated ALMA Local Expertise Group (ALLEGRO) is being established to build up hands-on experience in (sub)millimeter interferometry and to contribute to the development of data analysis tools for ALMA. Following a response to the "call for statements of interest for participation in the European ALMA Regional Centre Network" (ARC), issued by ESO in 2004, a seven-node network was established by ESO in February 2005. Leiden Observatory will host the node for the Netherlands. Other nodes are at Jodrell Bank, Onsala, Grenoble, Bonn/Köln/Bochum, Portugal, and Bologna; ESO/Garching will form a central node. Regular discussions on ARC-node activities and staffing were conducted throughout 2005; hiring of an ESO/ARC manager and first local node staff is planned for 2006. ALLEGRO activities in the Netherlands are led by Hogerheijde and van Dishoeck, and coordinated also by van Langevelde, Baan, Oosterloo, Roelfsema, and Barthel.

5.4. Dutch Open Telescope (DOT)

The DOT at the Observatorio del Roque de los Muchachos on La Palma is an innovative optical telescope for high-resolution imaging of the solar atmosphere. It successfully achieves diffraction-limited image quality (0.2 arcsec angular resolution at the 45 cm diameter of the primary mirror) due to the combination of the excellent site, the wind-flushed open construction, and post-detection image restoration through speckle reconstruction.
During the reporting period the DOT project made a successful transition from open-telescope technology demonstration to full science utilization through the realization of an elaborate multi-channel speckle imaging and processing system. Solar-atmosphere tomography using different spectral features to sample different layers in the solar photosphere and chromosphere (Fig. 5.4) became operational in early 2003. A large tunable Lyot filter for the Hα line was installed in 2004 and produces spectacular images. The opto-mechanical design and hardware for the final filter (a Lyot filter from Irkutsk for Doppler grams and magnetograms using the Ba II 455.4 nm line as well as Hβ imaging) was completed in 2005.
Another important technical advance has been the completion of the DOT Speckle Processor, an NWO-funded advanced parallel computer cluster which was installed in a nearby building on La Palma and is connected to the DOT control room with optical fibers. The speckle processor speeds up the image processing by two orders of magnitude, to a capacity as large as 1.6 Terabyte/day, and effectively removes the dataflow bottleneck which so far limited the production of DOT movies to less than a dozen per year.

The UU Department of Physics and Astronomy decided in the spring of 2003 to guarantee the DOT operation and science harvesting until 2008, with continuation of NOVA's financial contribution for the same period. The secured resources cover operational costs, and include a considerable amount of Utrecht workshop manpower and support for onsite education. At the end of 2005, the EC awarded an EST grant to start the "USO-SP Graduate School in Solar Physics", a joint undertaking of the solar groups at Utrecht, Oslo, and Stockholm.

The UU Department of Physics and Astronomy also decided during 2004 to expand the solar physics program at Utrecht through a full professorship, which is initially funded by NOVA as overlap. Keller (NOVA overlap) started in this chair in July 2005. He aims to start an instrumentation program targeting polarimetry in both solar physics and night time astronomy (for which he was awarded a VICI grant by NWO).

5.5. MID-infrared Interferometer (MIDI)

MIDI is a two-element beam combiner for the ESO VLT Interferometer (VLTI). MIDI was built by a German/Dutch/French consortium led by the Max-Planck-Institut für Astronomie (MPIA) in Heidelberg, with PI Leinert. The Dutch hardware contribution to MIDI was provided by NOVA and ASTRON. The NOVA team (NL PI Waters) contributed to MIDI in two main areas: (a) the optical and mechanical design and construction of the cold optical bench (collaboration with ASTRON), and (b) design and implementation of instrument control and data analysis software (through NEVEC, see section 5.6).

MIDI was the first NOVA instrumentation project completed. It received first light at the UTs on Paranal in December 2002. The instrument was commissioned in 2003. Its scientific capabilities were successfully demonstrated during a first science run in June 2003. Regular observations by astronomers from the ESO community started in April 2004.

5.5.1. First scientific results

Being the first mid-infrared long baseline interferometric instrument for large apertures to become available at ESO, MIDI had broken ground in high angular resolution studies of warm dust in circumstellar disks and in galactic nuclei. MIDI demonstrated in its early stages of operation that the VLTI concept is powerful and able to deliver challenging scientific results. The impact of MIDI is also on a different level: being a common user instrument, it brings optical interferometry into the realm of 'standard observing techniques' and moves it away from 'experts only' set-ups that have characterized most optical interferometers so far. One example of early scientific results obtained with MIDI is described in section 3.2.4.1 and another is given below.

Jaffe and collaborators obtained the first optical/infrared fringes ever detected in an extragalactic object, the Active Galactic Nucleus (AGN) NGC1068. One of the puzzling questions on the nature of AGN cores is the structure and origin of their circumnuclear torus. The torus is considered to be a key ingredient in the unification of different types of AGN, whose spectral differences can be explained in terms of different orientations on the sky of a massive black hole surrounded by an accretion disk and a dusty torus. Several models have been

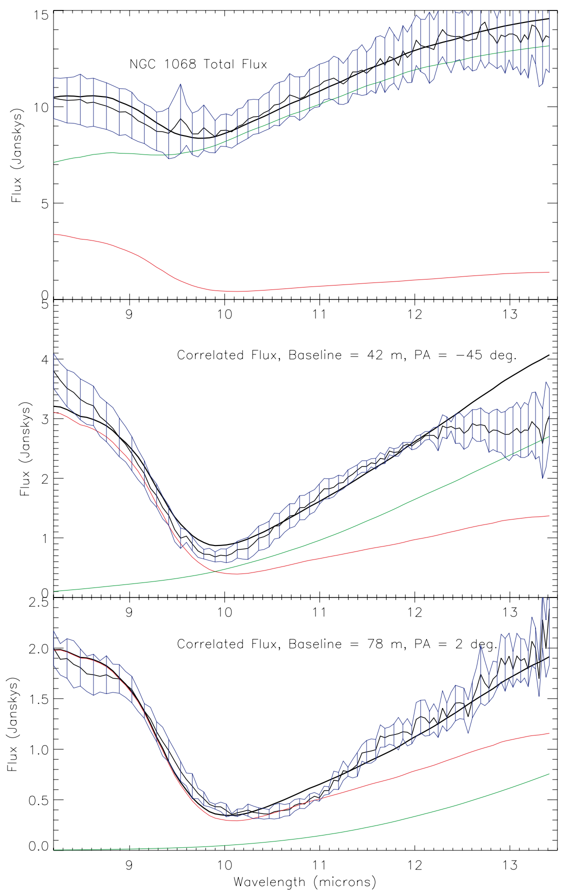


Fig. 5.5: Single telescope (top panel) and interferometric spectra taken with MIDI of the core of NGC1068 (Jaffe et al. 2004). The red and green lines represent the contribution from a compact hot component (red line) and a more extended, cooler component (green line). The black wiggly line indicates the MIDI measurements and the smooth black line is the best fit to the MIDI data.

proposed for the geometry of the torus, the main difference between these models being the spatial extent of the mid-IR emission the torus produces. The MIDI observations (Fig 5.5) favor a compact torus with a fairly large scale-height, which may not be easily explained in terms of a disk in hydrostatic equilibrium.

5.6. NOVA-ESO VLTI Expertise Center (NEVEC)

The NOVA-ESO VLTI Expertise Center in optical/infrared interferometry was funded by NOVA as a joint venture with ESO. The objectives of NEVEC are:

- development of instrument modelling, data reduction and calibration techniques for VLTI, concentrating on optimising VLTI for studies of faint objects and astrometry;
- accumulation of expertise relevant for a second-generation VLTI instrument;
- training and education related to the use of the VLTI for science.

The NEVEC project under NOVA's Phase-1 program was successfully completed in September 2005. ESO confirmed receipt of all NEVEC deliverables under the NOVA-ESO agreement on VLTI enhancement. The total NEVEC staff effort amounted to 20 staff years over the 1999-2005 period.

5.6.1. (Inter)national context and collaborations

During the reporting period NEVEC was involved in a number of international collaborative projects. It had direct links with ESO in order to execute its mission and to identify and perform studies relevant for optimising the scientific performance of the VLTI. NEVEC had a leading role in the software development for the data acquisition for the MIDI instrument. It acted as coordinator for the OPTICON FP6 network activity on optical interferometry and it was one of the three partners that initiated the PRIMA project for the VLTI and the related Astrometry Planet Search Consortium (PI Queloz, Geneva).

5.6.2. Progress and achievements in 2003-2005

In 2003 NEVEC staff successfully completed the software for the MIDI data acquisition and data reduction. NEVEC delivered the following two software modules: (1) the near real-time system, which allows a quick look display, and (2) the expert workbench station, which process the detector data to extract the scientific information. During commissioning at Paranal they contributed to the overall testing of the instrument. As a result Jaffe et al obtained high quality interferometric observations of the extragalactic object NGC 1068 (see section 5.5.1).

Other NEVEC staff participated in the conceptual design study of the PRIMA differential delay lines and in various other studies to analyse and improve astrometric software packages for applications in PRIMA. For PRIMA the activities focused on two work packages: (1) the pre-PRIMA survey and (2) the PRIMA planet search consortium program.
Adaptive optics and phase referencing in interferometry mode require a bright point source as reference object within the isoplanatic patch of the science object. Because of the small size of the isoplanatic patch, the number of reference objects around a science object is limited. To prepare for PRIMA observations without a laser guide star system NEVEC staff selected reference objects first and than searched for suitable science objects within the isoplanatic patch.
The PRIMA planet search consortium prepared a successful proposal to ESO to build the PRIMA Differential Delay Lines (DDL) for the VLTI including the PRIMA astrometric operations tools and software packages. Activities which took place after the kick-off of the PRIMA DDL consortium in February 2004 are described in section 5.6.5.

5.6.3. NEVEC staff

Staff involved in the NEVEC project are Quirrenbach (UL, PI), Waters (UvA, co-PI), Le Poole (UL, project scientist hardware), Jaffe (UL, project scientist software), Röttgering (UL, liaison with space interferometry), Glindemann (ESO, liaison ESO), and Bakker (UL, project manager).
The scientific and engineer postdoc staff included Meisner, Percheron, Tubbs, Reffert, and de Jong (further details are given in chapter 6). Participating PhD students were Heijligers, Albrecht, and Gori, funded by Dutch Space, OPTICON, and TNO/TPD, respectively. In addition other postdocs were working on projects closely related to the NEVEC program. Additional funding for NEVEC activities was secured through participation in the FP6 OPTICON program, an arrangement with TNO to supervise a PhD student, through the NWO VICI grant of Quirrenbach, and through the successful application of two Marie Curie fellows.

5.6.4. PRIMA

In 2004 a consortium of Dutch (NOVA/Leiden, ASTRON), German (MPIA Heidelberg), and Swiss (Geneva and Lausanne) institutes reached an agreement with ESO to develop the VLTI into a high precision astrometric facility. The agreement included the construction and delivery of four Differential Delay Lines (DDL) which would allow the overall PRIMA system to reach the astrometric accuracy needed for a planet search program. Searching for and direct detection of planets is the main science driver of the consortium partners to conduct this project. The intention was that the Netherlands would play a leading role in the software development (Leiden), the hardware construction (ASTRON), as well as in the planet search program (NOVA). The required funding was secured from a grant from the NOVA phase-2 instrumentation program, from the NWO-VICI grant to Quirrenbach and in-kind contributions from ASTRON and Leiden Observatory.

Two DDL designs based on flexure bearings were produced by ASTRON and the University of Neuchatel, respectively. Prototypes of the two DDL translation mechanism designs were tested extensively against all specifications. At the time of the PDR both designs were nearly compliant with all specifications; the non-compliances were deemed to be resolvable. A sub-contract was given to TNO-TPD for the investigation of an alternative solution based on magnetic bearings; this was presented as a possible back-up at the PDR. Continued work on the two flexure bearing prototypes led to substantial improvements; the Neuchatel prototype became fully compliant with all specifications, while ASTRON stopped the activities due to lack of funding. The project tentatively selected the Neuchatel design for the implementation of the DDL translation mechanisms.

The Dutch contribution to PRIMA also involved the analysis of the astrometric errors, and construction of a formal error budget. A two-pronged approach was adopted: various individuals worked on the detailed analyses of specific areas (e.g. dispersion effects, air flow in the light ducts, fringe sensing, polarization effects), while Quirrenbach maintained a "Top Worries" document, which listed difficulties that could be potential showstoppers if not addressed properly.

Jaffe contributed to the extensive documentation about the design of the PRIMA astrometry software. The overall plan, which includes the delivery of calibrated data to the end user (a novelty for ESO!), was accepted by the review board.

The PDR for the DDL and the Astrometry Operations and Software (AOS) was conducted in June 2005 at ESO. It was passed successfully contingent upon the completion of a few action items. By mid-2005 Quirrenbach decided to move to Heidelberg to accept the position of Director of the Landessternwarte in Heidelberg. With the departure of the national PI for PRIMA the NOVA Board decided to terminate the Dutch contribution to this project.

5.7. OmegaCAM / OmegaCEN

5.7.1. The OmegaCAM project

OmegaCAM is the wide-field camera for the VLT Survey Telescope (VST). Its focal plane contains a 1x1 degree, fully corrected field of view, which is tiled with 32 2048x4096 pixel CCD detectors for a total of about 16,000 x 16,000 pixels – a quarter of a giga-pixel. The camera and telescope are designed specifically for good image quality, and the detector array will sample the excellent seeing on Paranal well with 0.2 arcsec per pixel. The total cost of the instrument is of the order of 6 M€. NOVA leads the project, and contributes about 1/3 of the funding.

OmegaCAM and the VST are expected to have an operational lifetime of at least 10 years. By way of payment for the instrument, ESO grants guaranteed observing time. For NOVA its share is about four weeks of VST time per year, over the lifetime of the instrument. Towards the end of the development phase of the OmegaCAM project, the OmegaCEN data center will enable the Dutch user community to work with the OmegaCAM data as efficiently as possible. Facilities for processing raw data into calibrated images, and for extracting and measuring sources from these images, have been designed and implemented.

Scientific use of OmegaCAM will include simultaneous monitoring of millions of stars for variations in brightness, which can be caused by gravitational microlensing, occultation by faint companions (perhaps planets), intrinsic variability or transients such as distant supernovae or gamma-ray bursts. Tracking object positions over a timescale of years allows faint nearby stars to be recognized through their motion on the sky. Measurement of the systematic alignments of distant galaxies, caused by gravitational lensing, will map the intervening mass distribution in galaxy clusters. NOVA leads a large 1500 square degree, ESO, public survey (named KIDS) tuned to trace this cosmic sheer. Multi-filter observations will allow photometric redshift determinations for distant galaxies, which form the basis for deep mapping projects with spectrographs on the larger telescopes.
The period 2003-2004 saw the effective completion of the instrument, ready for tuning and acceptance tests by the NOVA partners in München, Göttingen, Bonn, Padua and Naples. In April 2004 the NOVA team at the University of Groningen delivered to ESO the data flow software, needed for pipeline processing of OmegaCAM data by ESO. A key part of the project, the detector mosaic with its cooling system and readout electronics, was assembled by

ESO's optical detector team, and produced "first laboratory light" in November 2004 (Fig. 5.6). At the end of 2004 the complete instrument was integrated at ESO-Garching.

From March to November 2005 the integrated OmegaCAM instrument was extensively tested in the laboratory at ESO-Garching, including the software suite to calibrate and monitor the instrument. Photometric calibration terms at <1% level could be well traced. The instrument shows excellent stability and the CCDs are cosmetically very clean. In December 2005 the tests for Preliminary Acceptance Europe (PAE) were completed and the instrument was packed for shipment to Paranal. Meanwhile preparations continue at the OmegaCEN data center for the commissioning and the operations phase of OmegaCAM, expected to start in 2006-2006 once the VST is ready to host OmegaCAM.

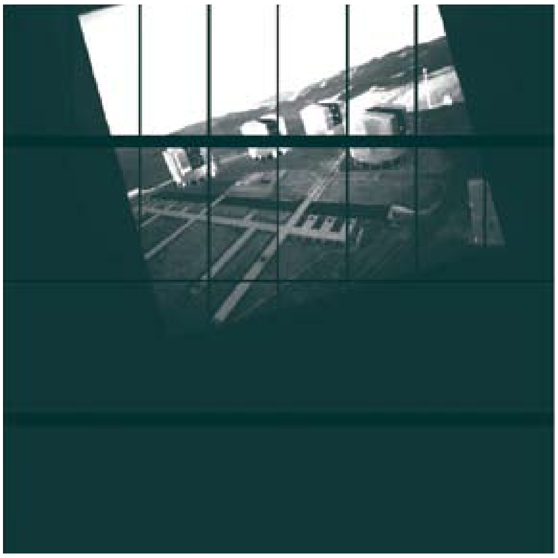


Fig. 5.6: "First laboratory light" for the OmegaCAM detector system.

5.7.2. Science exploitation: preparing for wide field surveys with OmegaCAM

In the summer of 2003 a workshop was held at the Lorentz Center in Leiden, at which NOVA astronomers presented proposals for the use of the NOVA guaranteed time (GT). As a result of this, and in collaboration with German and Italian astronomers who have access to their own GT, a coordinated set of surveys was defined which ensure that OmegaCAM will be scientifically very productive.

At the end of 2004 several very large observing proposals were submitted to ESO for consideration as large 'public surveys' with VST/OmegaCAM. After evaluation and coordination of the survey proposals, ESO selected the KIDS program (Kilo-Degree Survey), PI Kuijken, as the largest and most demanding survey to be done on OmegaCAM. A total of 4300 observing hours were allocated to the survey, which will be completed over a four year period by a European team involving astronomers from Leiden, Groningen, Paris, Bonn, München, Edinburgh, Imperial College London, and Cambridge. The main aim of KIDS is to provide an imaging survey of about 1/6th the sky coverage of the Sloan imaging Survey, but some two magnitudes deeper. By scheduling the time according to observing conditions, the survey should be particularly suitable for massive-scale weak lensing measurements, enabling masses of galaxies, groups, clusters and large-scale structures to be determined from lensing. A KIDS consortium meeting was held at the Kapteyn Institute in December 2004.
A second-largest public survey, the Galactic Plane Survey VPHAS+, significantly involves the Nijmegen astronomy institute (co-PI Groot).

The largest Dutch guaranteed time project on OmegaCAM is VESUVIO, a study of the galaxy population in nearby superclusters. Staff of the Kapteyn Institute (Heraudeau, Trager, Valentijn, Peletier, and van de Weijgaert) designed an extensive observing program of nearby superclusters. This program will start with a deep 12 square degree survey of the Hercules supercluster and extending this later with a large 100 square degree survey of the Horologium supercluster. For this multispectral study also X-ray XMM-Newton observations (Bohringer, Kaastra) and HI observations (Valentijn, van Gorkom) are planned. VESUVIO was designed within the framework of the EU RTN network SISCO (Spectroscopic and Imaging Surveys for Cosmology), in which OmegaCEN participated. It involves collaboration with Italian colleagues (Busarello, Merluzzi) at the Observatorio di Capodimonte. PIs are Capaccioli and Valentijn. Joint meetings were held at Napoli (June 2004) and Groningen (September 2004). Schneider (PhD student Groningen) started her project on the Hercules supercluster. She obtained broad band wide field images at the MDM telescope of a long strip in the supercluster, as a preparation for the large survey. Sikkema (also PhD student Groningen) used the wide field imager at ESO's 2.2m telescope to obtain broad band image data for a large area in the 2dF south regions, which also contains supercluster filamentary structure. The data will be used to study galaxy evolution and structural properties over very large areas. Both the MDM and the WFI data sets were reduced using the new OmegaCEN/AstroWise system.

5.7.3. The OmegaCEN data center

OmegaCEN is a Dutch astronomical data center supporting wide field astronomical imaging located at the Kapteyn Astronomical Institute of the University of Groningen. The center builds and supports a unique advanced survey information system for astronomy: the virtual survey telescope. At the center, staff is involved in research and development of data basing and processing of very large data sets. The OmegaCEN information system provides a dynamic imaging archive, for use as a survey system and data mining. The system will be filled with 100's of Terabyte of imaging data from VST/OmegaCAM and other wide field imaging instruments. By ingesting all 'raw'/observational data into a single database, different 'after the fact' surveys and projects can be carried out. OmegaCEN expertise is focused on scalable information systems, connecting distributed processing, data basing, archiving, storage and web services. The integrated approach to the data reduction and data archiving is intended to make it as straightforward as possible for individual users or small groups to handle huge volumes of data without getting bogged down in tedious data management. The result will be a precursor to a true Virtual Observatory (VO), a goal being worked towards on many fronts worldwide. Nationally, OmegaCEN supports users at the Universities of Groningen, Leiden, Nijmegen and Amsterdam. Internationally, OmegaCEN leads the EU ASTRO-WISE consortium, a network of wide field imaging data centers spread throughout ESO member countries which will operate a common system. The technology developed at the center will also serve as a first prototype for other large survey projects, such as planned for LOFAR and GAIA. About 15 scientists (Postdocs, PhD students and scientific programmers) work at the center.

OmegaCEN developed a paradigm characterized by "target processing" or "on-the-fly-reprocessing". The system is initiated by complex queries that trigger image processing pipelines and produce tailor-made images and/or source lists. The user asks for results which are either stored from previous runs and retrieved or computed on-the-fly. Computations, on parallel clusters, main-frames or other applicable nodes, are done exclusively on-demand by the end-user, giving the raw data an important status in the archive. Both the volume of data (dozens of Tbytes) and the size of the computing problem at both database and image processing levels require dedicated hardware and an integrated approach. To this end local compute-GRIDs and storage-GRIDS are developed, supervised by a database and file-server. OmegaCEN is well connected to the international IT service networks, such as EURO-VO (EU funded virtual observatory).

In the reporting period the center developed and qualified the AstroWise information system and performed first 'stress-tests' by ingesting about 15.000 wide field images obtained with the ESO 2.2m telescope into the system. In total 225,000 2k*4k CCD readouts were ingested, of which about half of the data serve calibration purposes. Also, the OmegaCAM test data taken at the ESO instrument laboratory were successfully ingested, reduced, archived and distributed with the system.

OmegaCEN also collaborated with the University of Groningen Computing Center visualization group on a program to develop multidimensional tabulated data (Astro-Vis). This program aims to facilitate visual feature extractions out of lists of up to billions of (astronomical) sources characterized with to up to hundreds of parameters. It will use SLOAN, WSRT, and OmegaCAM datasets and serves as pathfinder for missions like GAIA which will characterize a billion stars.

In collaboration with the LOFAR/Bsik consortium OmegaCEN designed and implemented prototype GRID and web services for end users for use on LOFAR. To continue this activity OmegaCEN received a grant of 960,000 € from the LOFAR/Bsik consortium (as part of a larger grant from the "Samenwerkingsverband Noord Nederland, SNN) to develop software tools for distribution and dissemination of very large data sets.

5.7.4. AstroWise

OmegaCEN leads the EU-funded program AstroWise. In 2004-2005 the prototype of the AstroWise system was further developed and prepared for mass production following the recommendations set at the AstroWise workshop held in November 2003. As a test 10 Terabyte of data of a smaller imaging camera (WFI@2.2m) were successfully ingested into the system.

In November 2004 an AstroWise workshop was held at the Kapteyn Institute to define the work plan for the remaining part of the project. The consortium had to face the late delivery of VST/OmegaCAM. The remaining work packages include (1) introduction of context/privileges, (2) design for distributed processing, (3) distributed archiving, and (4) quality control. The AstroWise resources also allowed for upgrading of the OmegaCEN hardware disk storage capacity to 10 Terabyte in 2004 and 24 Terabyte in 2005. A new way to handle catalogues of astronomical data (named Sourcelists) and methods to

associate catalogues (Associate) were implemented by Begeman. Boxhoorn further developed the AstroWise database system while Tempelaar built and improved a web based advanced viewer to the database.
On 14 November 2005 a milestone was reached by the public release of the web and grid services, announcing the internet portal: www.astro-wise.org/portal. The portal bundles, documentation, code-base distribution, code-base viewer, database viewer, and active user participation through web services for calibration file validation and target processing.

5.7.5. Towards a Virtual Observatory

OmegaCEN organized several meetings at the Kapteyn Institute to further develop the ideas on an European Virtual Observatory for astronomy: one aimed to strengthen the European collaboration and involved representatives of the German GAVO, European AVO (now called Euro-VO), UK AstroGrid and ASTRON/LOFAR (6-7 May 2004) while the other dealt with technical aspects on large databases and involved experts from CWI and ASTRON/LOFAR (September 2004).

Valentijn served as the national point-of-contact for the European Virtual Observatory initiative named Euro-VO. He attended several meetings including the Science Working Group meeting in Strasbourg and the Euro-VO Data Center Alliance board. The latter is a new consortium in which OmegaCEN participates. Its goal is to coordinate the connection of the European Virtual Observatory infrastructure to national institutions.

5.8. Pulsar Machine (PuMa-2)

The original Pulsar Machine (PuMa) in combination with the first and third module of PuMa-2 became a workhorse for pulsar studies at the WSRT in the past few years. This state-of-the-art backend, conceived, designed, and built at the Universities of Utrecht and Amsterdam, is uniquely equipped to use the capabilities of the WSRT systems for pulsar searches and timing studies, and pioneered interactive remote operations of the WSRT.

During the period 2003-2005 the main focus of work was on the fourth, and largest, module of the PuMa-2 project. The aim of this module is to coherently dedisperse as much of the available bandwidth of the WSRT as possible. Based on previous experience, it was decided to go for a system where the data were stored and then processed 'offline' in General Purpose Processors (GPPs). Early 2003 work begun on designing a prototype signal chain consisted of an ADC (as at this time only analog signals were available), a direct memory access (DMA) card, banks of RAM and finally an IDE RAID system of 1 Terabyte all controlled by a data acquisition computer (DAQ; dual Pentium). Once this system was assembled extensive testing was carried out at the end of 2003 and early in 2004, and, crucially, it was established that the combination of ADC, DMA and IDE RAID was able to transfer data to hard disk at a rate of 80 Mbytes/s. This very large transfer rate meant that one signal chain and DAQ combination is capable of handling a dual polarisation, 20 MHz WSRT band recorded at 8 bits. This excellent combination of throughput and high bit resolution, improving greatly the robustness to interference, meant that with 8 DAQ systems the full 160 MHz bandwidth available from the WSRT could be acquired, making this system the largest bandwidth pulsar recorder in the world.

Early in 2004 the final design phase begun. This design included improvements made during the testing process and combination of all features into a single board. It allowed for the replacement of the ADC with a digital input system which was not planned to be in place until after the time frame of the PuMa-2 project. A cost-effective way was found to expand the disk space available to each of the DAQs. This meant that the total observing time (at the maximum data rate) was increased from 3 hours to 14 hours. A redesign of the PuMa interface card (PiC, Fig. 5.7) allowed for direct access to the digital inputs already available at the WSRT. This had three clear advantages: the extra cost of building two separate sets of input cards could be avoided, there would be no need for analog components to be placed inside the DAQ PCs (thus reducing interference problems) and the system would no longer need to be modified in the future. Furthermore it would make higher quality data directly available and it was realised that with the new digital inputs a simpler circuit design was possible for determining accurately the synchronisation, thus again making the system more robust. The new design was finalised in November 2004 and was sent out for production just prior to the end of the year. All components and boards were delivered by March 2005 and the boards were assembled and placed inside the DAQ PCs by July 2005.

Work continued in parallel on the data acquisition and processing systems. Once leaving the RAM on the DAQ the data is passed to high access-speed disk arrays. The penultimate component of the PuMa-2 Module 4 is the offline processing component. This is in the form of a Beowulf cluster of GPPs. A benchmark was carried out on a number of different Linux-based platforms looking at raw processing speed, input/output performance, memory bandwidth and network performance. The AMD Opteron processor was identified as a clear winner in terms of performance. During the tendering process proposals from seven different Beowulf cluster suppliers were considered. The cluster was delivered in January 2005 and was immediately available for software testing and analysis of PuMa-2 data. It was also used to process a large amount of existing pulsar survey data obtained with the existing PuMa. It was realized that by clever use of software and the power of the cluster PuMa-2 would be able to carry out some real time processing as well as baseband recording for later processing. This mode is now implemented thereby expanding significantly its observing capacity.

The final component of Module 4 is the offline storage unit. Based on a detailed study of the expected output data requirements of PuMa-2 a total storage capacity of 20 Terabytes per year was planned. The significantly lower data management overhead, investment and running costs associated with tape technology meant that this was considered a viable alternative to disk. By using an autoloader and modern tapes of approximately 400 GB capacity, more than a few Terabytes could be available in almost real time. Experience from the use of the present PuMa archive indicated that this would be sufficient to serve all archive requests. In order to provide data security a mirror copy will be kept at the University of Amsterdam with the original either at the WSRT site or at ASTRON.

PuMa-2 including the complete coherent dedispersion module was handed over during a ceremony at the WSRT on 16 December 2005. The state-of-the-art nature of PuMa-2 in combination with the sensitivity and frequency agility of the WSRT make a world class facility for pulsar observations. The full system is now available for use by the Dutch and international astronomical communities. It provides the widest bandwidth (160 MHz) of any fully coherent dedispersion capable pulsar machine in the world, which implies both exquisite sensitivity and a maximum time resolution of a mere 3 nanoseconds. The fact that the input data is kept in digital format and with 8-bit resolution means that the sensitivity is significantly improved compared to the current pulsar machine as is the robustness to interference. The large processing power means that for a large number of pulsar observations the data can be analysed in real or close to real time while for more complicated and computationally costly analysis schemes there is sufficient hard disk space to record more than 14 hours of data. The sophisticated processing chain allows for the formation of many data products from each observation which can be archived in the large data storage system.

The high time resolution and sensitivity will impact strongly on all pulsar research currently being undertaken in the Netherlands but it will also facilitate other possibilities. One particular example where it will have a large impact is in the field of high precision timing. It will enable up to an order of magnitude improvement in timing precision. When combined with a long timing baseline of at least five years with the WSRT with PuMa-2 it in turn brings the goals of the European Pulsar Timing Array of measuring gravitational waves from the early universe within reach and will also allow greatly improved tests of theories of gravity.

Some PuMa-2 science highlights are given in section 3.3.4.

Fig. 5.7: The PuMa Interface Card (PiC) is the hardware component that connects PuMa-2 to the WSRT. It takes the optical, digital signals supplied and synchronizes and reformats them in a format suitable for subsequent recording. It is built around the PCI 9080 interface chip from PLX Technologies, and Altera ACEX FPGA. The card also has a daughter board (shown) to de-multiplex serial data from the Tied Array Adder Module. Board control, error detection, synchronization and status monitoring are basic tasks done in the FPGA. The PCI interface is used to communicate with the upper layer application software. The board and associated software were developed principally by Ramesh Karrupasamy (NOVA PhD) with able assistance from the staff in the Digital Laboratory at ASTRON and initial outlines from Stappers.

5.9. Raymond & Beverly Sackler Laboratory for Astrophysics

The work in the Sackler Laboratory for Astrophysics at Leiden Observatory aims at the construction of state-of-the-art experiments in which inter- and circumstellar processes are simulated under laboratory controlled conditions. The research comprises both solid state experiments – SURFRESIDE, CRYOPAD, HV-SETUP and CESSS – and gas phase experiments - LIRTRAP, SPIRAS and LEXUS - that support the analysis of new observational data. Much of the 2003-2005 effort was put in the construction of CRYOPAD, which was completed in 2005 and provides new results on a daily basis, and SURFRESIDE, which is expected to be fully operational in 2006. The HV-SETUP is running continuously. LIRTRAP was brought to Leiden in 2003 with Schlemmer's appointment and was used successfully at FOM Rijnhuizen, before being moved to Cologne. With the appointment in 2005 of Linnartz, three new setups SPIRAS, LEXUS and CESSS were brought to Leiden.

5.9.1. Staff

The Sackler laboratory has undergone several significant personnel changes during the reporting period. Schlemmer was appointed as its head in 2003, but left in late 2004 to become full professor at the University of Cologne. Linnartz took over as its leader in mid-2005, partly on a NOVA overlap position. The NOVA-funded postdocs Fraser (-2004) and Fuchs (2004-) were crucial for the design, construction and maintenance of CRYOPAD and SURFRESIDE. Other postdocs and PhD students involved include Asvany, van Broekhuizen, Bisschop, Edouard, Öberg and Verbraak, with funding from a variety of sources including NOVA, NWO-Spinoza, NWO-EW, EU, FOM, DFG and Leiden University. The laboratory also benefited from Greenberg fellow Acharyya and undergraduate students Groot and Alsindi. Linnartz furthermore maintains close connections with the Laser Centre Vrije Universiteit in the supervision of two PhD projects in collaboration with Ubachs and Stolte.

The laboratory group is integrated with the research in the molecular astrophysics group of van Dishoeck and that of NOVA network 2, particularly through collaborations with Tielens. Many projects profit from close collaborations with theoretical chemistry groups, particularly with that of Kroes (Leiden) through joint postdocs Andersson and Al-Halabi.

5.9.2. Solid state experiments

5.9.2.1. CRYOPAD – CRYOgenic Photo-product Analysis Device

This instrument is specifically designed to study the formation of volatile complex organic molecules from interstellar ice by solid state chemistry in 'hot cores' such as found around massive protostars by heating and by irradiation of ices with intense UV irradiation. Ultra-high vacuum conditions (5 x10^{-11} mbar) are routinely achieved and sensitive detection techniques such as TPD (temperature programmed desorption) and RAIRS (reflection absorption infrared spectroscopy) are used to characterize interstellar ice analogues. The ices are grown with mono-layer precision and the spectroscopic and thermal properties of pure, layered and mixed ices were studied.

Systematic studies were performed on CO-N_2 and CO-O_2 ices with a view to understand the differential gas-phase chemistry of CO and N_2 observed in dense pre-stellar cores and to explain the low abundances of oxygen in interstellar clouds by possible freeze out on interstellar grains. In addition, a systematic study of the photodesorption of CO in pure CO-ices was carried out.

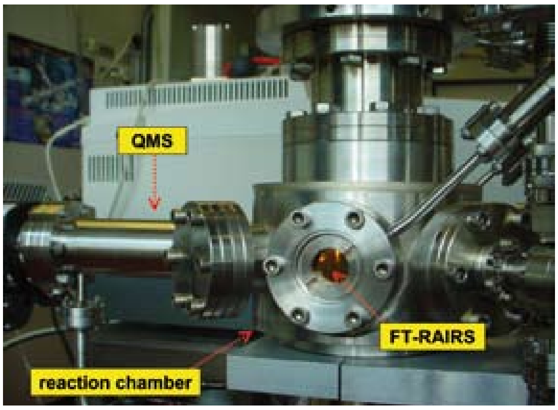


Fig. 5.8: The heart of the CRYOPAD setup. It is fully operational and spectroscopic and thermal data of interstellar ice analogues are obtained routinely.

5.9.2.2. SURFRESIDE – SURFace REaction SImulation DEvice

The goal of this setup is to study atom-molecule reactions on surfaces under simulated interstellar conditions. As in CRYOPAD, interstellar ice analogues are grown with mono-layer precision under UHV conditions and monitored using TPD and RAIRS. Details of the basic setup and first results using TPD to study the desorption kinetics of CO trapped in methanol ice were published. During the last two years most effort focused on the atomic beam sources to produce H, O and N atoms. Substantial efforts were put in optimizing a low-flux microwave driven atomic beam source from Oxford Scientific that did not meet its specifications. These problems were solved, resulting in a unique source with an unprecedented cracking capacity in operation. In parallel a second H-only source was contracted and successfully tested at the manufacturer.

This system will be incorporated into SURFRESIDE in the course of 2006.

5.9.2.3. **HV-SETUP – High Vacuum setup**

The HV-setup was used for a number of temperature dependent spectroscopic experiments on interstellar ices. These studies often involved (visiting) undergraduate students. The spectroscopic characteristics and thermal desorption behavior of CO and CO_2 in mixed and layered ice configurations were studied in detail. These experiments were triggered by VLT/Keck IR spectra of solid CO at 4.67 µm and Spitzer data of solid CO_2 at 15 µm that indicate that CO-CO_2 mixtures may well be present in space. Another successful project was the systematic study of the desorption behavior of CO in a variety of ice systems, i.e. HCOOH, CO_2, CH_3OH and CH_4, all of which are found in roughly equal abundances in a variety of high and low mass young stellar objects. Recent VLT-ISAAC observations suggest that more than 60% of CO ice is present in its pure form, probably in a layer segregated from other ice species. The laboratory experiments show that CO spectroscopy and desorption from layers and mixed ices is significantly different as the temperature of the ice increases. Some of the CO is able to migrate into the under- or over-lying layers, where it is trapped. This means that a fraction of interstellar CO may remain in the solid state beyond its expected desorption temperature, thereby being available for subsequent chemistry on or in the ice in regions where the ices are already warming or evaporating.

Another highlight is the spectroscopic study of CO on grain analogs to understand an unidentified solid-state band observed at 2175 cm^{-1} in VLT-ISAAC data. Laboratory data of CO chemisorbed to a zeolite surface were shown to give an excellent fit to the observational spectra, including a component of OCN^- (see also section 3.2.2.4). This constitutes the first direct evidence for grain-gas interactions in interstellar and protostellar regions.

5.9.2.4. **CESSS – Cavity Enhanced Solid State Spectrometer**

CESSS is currently in the phase of construction and combines the expertise available from the HV-SETUP with an optical detection scheme that became recently available from gas phase spectroscopy: IBBCEAS = Incoherent BroadBand Cavity Enhanced Absorption Spectroscopy. So far spectroscopy of interstellar ices has been mainly limited to the IR (i.e. vibrational). Here the aim is to extend the techniques into optical (i.e. electronic) spectroscopy of interstellar ices. The technique is sensitive, fast and covers large frequency regimes in a short time, i.e. is ideally suited to study in situ and online reaction products following UV bombardment of interstellar ice analogues.

5.9.3. Gas phase experiments

5.9.3.1. **LIRTRAP – Laser Induced Reactions TRAPping device**

LIRTRAP consists of a low temperature 22-pole ion trap designed to determine rate coefficients for gas phase ion-molecule reactions under interstellar conditions and to measure infrared spectra of astrophysically interesting ions. In a collaboration with the free electron laser facility FELIX at FOM Rijnhuizen, it was possible to study a cloud of cold, trapped and mass selected ions in the (far)infrared. In these experiments the laser induced formation of product ions (e.g. C_2H^+) is used to monitor an excitation of the parent ion ($C_2H_2^+$). This method serves as a new tool for both spectroscopy and for determining state-to-state rate coefficients for astrophysically relevant reactions, also including deuterated species, e.g. H_3^+ deuteration reactions. A recent highlight was the interpretation of the spectral features of the protonated methane, CH_5^+ (Fig. 5.9).

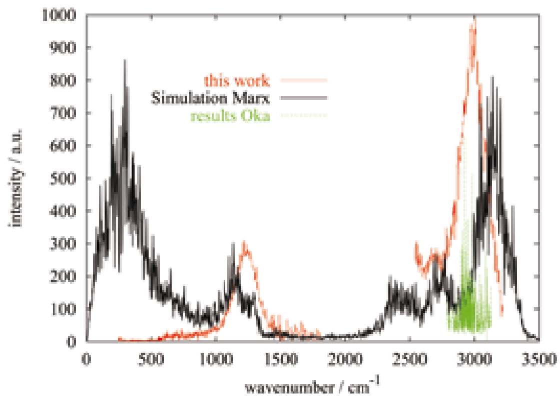


Fig. 5.9: Spectrum of CH_5^+ obtained with LIRTRAP using the free electron laser facility FELIX at FOM Rijnhuizen (A). The simulated spectra using ab initio calculations are shown in (B) and (C) for different temperatures and give insight in the molecular structure of CH_5^+ (Asvany et al. 2005).

5.9.3.2. **SPIRAS – Supersonic Plasma InfraRed Absorption Spectrometer**

Many gas phase species observed in space are open shell species, particularly molecular radicals and ions. SPIRAS offers the unique possibility to study such species at high resolution (< 0.001 cm^{-1}) in the frequency region of 1000-3000 cm^{-1} by combining sensitive tunable diode laser spectroscopy and special supersonic planar plasma expansions under mass spectrometric controlled conditions. Such an expansion offers a Doppler free environment at low final rotational temperatures and is ideally suited to obtain structural information from fully resolved spectra. So far the setup was used to characterize fundamental properties in the interaction of ion-neutral interactions by studying strongly bound ionic complexes - some of which (e.g. $(CO)_2^+$) might be of astrophysical relevance - and an extension to infrared studies of highly unsaturated linear carbon chain radicals of (possible) astrophysical interest – e.g. the linear HCCCCCCCH chain - is planned for nearby future. For this a new plasma source has to be constructed. The set-up is fully operational after its move to Leiden.

5.9.3.3. LEXUS – Laser EXcitation setup for Unstable Species

LEXUS is a recently constructed setup capable of detecting optical spectra of very small gas amounts without a serious loss in sensitivity by applying time gated fluorescence spectroscopy. Plasma discharge techniques were developed in which low rotational excitation is coupled with high vibrational temperatures. The setup is particularly suited to study gases that come in small supply; isotopes (e.g. deuterated species) and species that are dangerous in large amounts, e.g. PAHs. Experiments are in preparation to link laboratory spectra to emission features as observed in the Red Rectangle.

5.9.4. Theoretical studies

All studies described here benefited substantially from interaction with theoretical groups.

5.9.4.1. Molecular dynamics simulations of CO adsorption on H_2O ice

With a view to understand the processes governing the growth and destruction of icy mantles on interstellar grains classical trajectory calculations were performed on the adsorption of thermal CO to the surface of amorphous and crystalline water ice, for a range of energies. At low temperatures relevant for interstellar conditions, the calculations predict a high adsorption probability (~1). In all adsorbing trajectories CO sits on top of the surface; no surface penetration is found. Geometry minimizations suggest that the maximum potential energy of adsorbed CO occurs when CO interacts with a 'dangling OH' group, attributed to the secondary (weaker) CO band seen in solid-state infrared laboratory spectra at 2152 cm^{-1}. CO also interacts with 'bonded OH' groups, which is attributed to the primary (stronger) band of solid CO at 2139/2136 cm^{-1}. Only the latter bands are observed in space.

5.9.4.2. Molecular dynamics simulations of H_2O ice photo dissociation

A new set of programs was developed to calculate the photodissociation dynamics of a water molecule in an ice layer at 10K, using classical molecular dynamics. Both crystalline and amorphous ices were studied. Photodissociation in the first bi-layer leads mainly to H-atoms desorbing (65 %), while in the third bi-layer trapping of H and OH dominates. The H-atoms move on average 11 Å in the ice before becoming trapped, while the OH radicals move typically 2 Å. Thus, in interstellar space these radicals will be available for further reactions in the ice with other species. The models predict a low photodesorption rate of H_2O ice of less than 0.1%; this can be tested by future CRYOPAD experiments.

5.10. SINFONI

SINFONI (Spectrograph for INtegral Field Observations in the Near-Infrared) is a collaboration between the ESO, MPE and NOVA. SINFONI combines a cryogenic near-infrared (J, H and K-bands) integral field (image slicer) spectrograph (spectral resolution R~3000) with an adaptive optics unit. A laser guide star facility will enable nearly diffraction-limited imaging over the whole sky. A seeing-limited mode is also available.

The power of SINFONI is based on two features. The combination of adaptive optics and integral field spectroscopy in the near-infrared (where adaptive optics performs best) allows fully spectrally multiplexed imaging at a spatial resolution equal to the HST optical resolution (three times better in both dimensions in K-band) and vastly more sensitive in K-band. Contrary to most other integral field spectrographs, SINFONI is cryogenic and thus allows full K-band capability.

Staff effort associated with SINFONI is provided at Leiden Observatory and at ASTRON. In Leiden these are Van der Werf (NOVA-SINFONI PI and project manager), Brown (NOVA postdoc, laser guide star simulations), Van Starkenburg (NOVA PhD, scientific utilization) and Reunanen (NOVA postdoc, data reduction pipeline, scientific utilization). Staff involved at ASTRON included: Pragt (project manager), Schoenmaker (optical design), Kroes (mechanical design), Elswijk (optical testing), Kragt (mechanical analysis), Glazenborg (PSF reconstruction) and Rigal (PSF reconstruction).

5.10.1. NOVA role in SINFONI

The NOVA contributions to SINFONI consisted of four parts:

5.10.1.1. SINFONI 2K camera and detector

NOVA had a key role in producing the spectrograph camera and procuring the 2048^2 detector for SIN-

FONI. While originally conceived with a 1024^2 detector, the implementation of a 20482 detector greatly enhances SINFONI's performance. This modification to the original design required (in addition to the procurement of a 2048^2 detector and associated electronics, and related software modifications) the development of a new spectrograph camera. This camera was developed and constructed by ASTRON, under contract with NOVA. Principal technical challenge of this camera was the fact that very large (17cm diameter) lenses are involved, and that some of the lens materials (e.g. CaF_2) are very difficult to handle. A particular difficulty was the fact that during cooldown to operating temperature, the lenses do not shrink as much as the lens mounts. Hence a lens mount was developed that compensates for the difference in coefficient of thermal expansion. The camera (see back cover of this report) was successfully completed and delivered to ESO in early 2004.

5.10.1.2. Performance of Laser Guide Star adaptive optics

NOVA developed a number of software components for SINFONI. Two of these components are related to adaptive optics and have a wider range of applicability than just SINFONI. This concerns first of all the development and use of a simulation tool that analyses the performance of adaptive optics in the case of a laser guide star. This tool, which was completed in 2004, takes into account the various effects which are present with laser guide star adaptive optics but not with natural guide star adaptive optics. The simulation tool allows the possibility to vary the height and thickness of the sodium layer, the distance between the laser beacon and the natural tip-tilt star, and the zenith distance of the science target. Detailed modeling of laser beacon generation, launch and propagation are included, as well as the cone effect, the 3D effect at the curvature sensor, tip-tilt management, and static errors in focussing on the sodium centroid altitude. The results were used to generate optimisation tables that list the predicted adaptive optics module performance as a function of various system and observing parameters. This work package was carried out in Leiden by Brown.

5.10.1.3. Adaptive Optics Point Spread Function reconstruction

The second NOVA-supplied software component is a package for reconstruction of the adaptive optics corrected point-spread-function based on the SINFONI wavefront sensor data. The scope of this package was revised in 2004 by dropping the goal of also studying the pyramid wavefront sensor (as used in MAD, the Multi-conjugate Adaptive optics Demonstrator, currently under development at ESO), and it was decided instead to concentrate the effort on the curvature wavefront sensor used in SINFONI. This work package was carried out at ASTRON, under contract with NOVA, by Glazenborg and Rigal. A prototype of the reconstruction tool was delivered to ESO and, and final delivery is foreseen before the summer of 2006.

5.10.1.4. SINFONI performance analysis and commissioning

Finally, NOVA supplied manpower for assisting with SINFONI commissioning at Paranal and for validating and commissioning the Point Spread Function reconstruction tool. This task started in 2005 with the appointment of Reunanen as NOVA/SINFONI postdoc in Leiden.

5.10.2. First light and scientific utilization of SINFONI

SINFONI is a mainstream instrument, catering to a large fraction of the NOVA community. A national SINFONI science day, to discuss scientific utilization of SINFONI in NOVA guaranteed time (18.5 nights in total) was organized in June 2004.This led to the formulation of a number of programs which will be carried out in NOVA guaranteed time. Most of the time will be devoted to two large programs: one aimed at spectroscopy of distant galaxies and one at the nuclei of nearby (quiescent and starburst) galaxies. A smaller amount of time is kept in reserve for small programs. This philosophy ensures maximum scientific impact.

SINFONI achieved first light on 9 July 2004 on VLT UT4 (Yepun). This was followed by an extremely smooth commissioning run, which was so successful that it was decided to offer SINFONI for proposals by the community at large as of April 2005 onwards. This success was the reward for several years of hard work by the entire SINFONI team.

Scientific utilization of SINFONI by the NOVA community began in 2005 with observations of a number of nearby galaxies (partly with adaptive optics), and of several samples of high redshift galaxies. Much of these data was fed into existing or new PhD projects, notably by Van Starkenburg (kinematics of high redshift galaxies), Kriek (spectroscopy of high redshift galaxies), Snijders (nearby starburst galaxies) and Vermaas (ultraluminous infrared galaxies).

A scientific highlight (from the first night of NOVA guaranteed time on SINFONI) concerns the super massive black hole in the obscured nucleus of the nearby elliptical galaxy Centaurus A. Using a nearby bright star, the nuclear region of Cen A was observed with SINFONI in adaptive optics mode, with a pixel scale of 0.1". The spectrum is dominated by bright hydrogen and helium recombination lines, [FeII] lines and H_2 lines. Fig 5.10 shows the richness of the spectra. A number of high-ionization lines (so-called coronal lines) are clearly visible originating from individual areas. This is a remarkable discovery, since these lines were not detected in Cen A before.

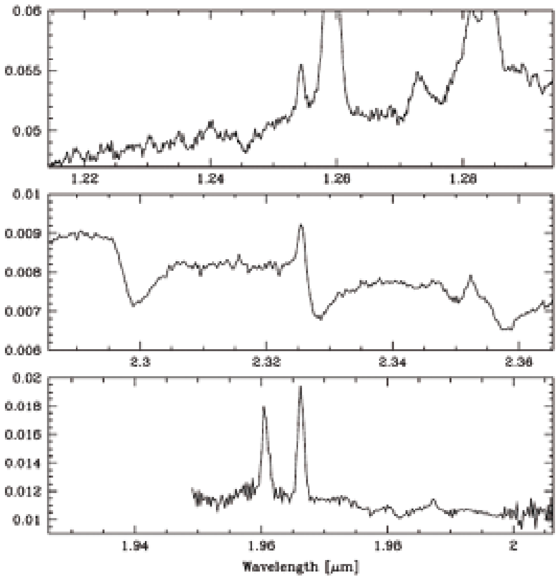


Fig. 5.10: Blow-ups of selected parts of the SINFONI spectra of Cen A, centred on the coronal lines (top), [CaVIII line] (middle) and [SiVI line] (bottom).

The SINFONI data reveal for the first time the full detail of the spatial distribution and kinematic properties of the lines. A remarkable example is shown in Fig. 5.11 showing the flux distribution and velocity field of S(1) molecular hydrogen line. The flux distribution shows a number of features which can be characterized as arcs or bow-shocks, and which may be related to the outflowing ionized gas traced in [SiVI]. The velocity field can be modeled as a thin warped sheet of gas, with smoothly varying inclination, position angle and circular velocity. These data give a mass for the nuclear black hole in Cen A of about $6x10^7$ $M_\odot$. Another remarkable result concerns the velocity fields of stars and gas: the gas in the nuclear region rotates in opposite sense to the stars: a counter rotating core. This corroborates the hypothesis of a recent merger for the origin of the gas and dust lane in Cen A.

5.11. JWST-MIRI

The Mid-Infrared Instrument (MIRI) is a combined imager / integral field spectrometer covering 5-28 μm on board the ~6m James Webb Space Telescope (JWST), the successor of HST to be launched around 2013. The Netherlands, led by NOVA (PI: van Dishoeck, deputy-PI: Brandl) with ASTRON and TPD as subcontractors, is responsible for the camera and dispersion optics of the spectrometer. With its unprecedented sensitivity and spatial resolution, MIRI will provide a huge discovery space and will have tremendous power for studying the mid-infrared sky. It will make key contributions to science themes ranging from the 'first light' in the Universe to the assembly of galaxies, the birth of stars and proto-planetary disks, the evolution of planetary systems and the organic material contained within them, and exo-planetary atmospheres.

The main aims of the NOVA project are:

- design, build and deliver the Dutch part of the spectrometer to the European consortium according to specifications;
- ensure strong Dutch participation in the scien-

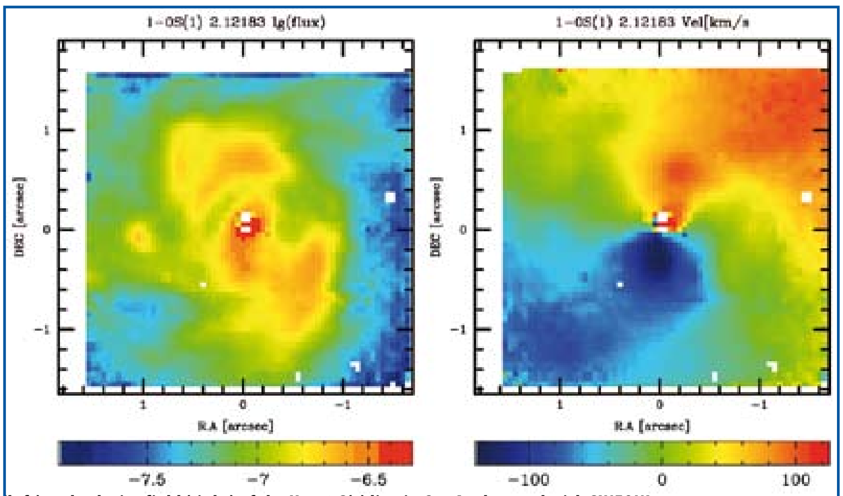


Fig. 5.11: Flux distribution (left) and velocity field (right) of the H_2 1-0 S(1) line in Cen A, observed with SINFONI.

tific exploitation of MIRI;
- maintain and develop mid-infrared scientific and technical expertise in the Netherlands, also important for securing a Dutch role in future infrared missions.

The MIRI instrument is designed and built by a joint US/European consortium. The European consortium is led by the UK (PI Wright), with Germany, France, The Netherlands, Spain, Switzerland, Ireland, Sweden and Belgium as partners. Europe will design and build the entire camera/ spectrometer unit, the so-called Optical Bench Assembly (OBA). Scientific oversight is through the joint NASA-ESA MIRI Science Team (co-chairs: G. Rieke, G. Wright), of which van Dishoeck is a member.

The Dutch project office is located at ASTRON, with Jager as the Dutch project manager. ASTRON leads the optical and mechanical design of the Dutch part of MIRI, and will do the end-to-end modeling, as well as the prototyping, testing and construction. TPD's contribution was in the optical design. SRON has a consultancy role, and provides support in the area of space qualified design, and PA/QA.

Funding for the Dutch contribution of MIRI was secured in 2003 by commitments from NOVA, a NWO-Groot grant and in-kind contributions from the universities, ASTRON and SRON. The ESA-SPC confirmed the European contribution to JWST and the MIRI consortium in late 2003, and NOVA signed the formal agreement with ESA on behalf of the Netherlands. A European MIRI steering committee was formed in spring 2003, with representatives from the various agencies contributing financially to MIRI. Boland (NOVA) chaired this committee till mid 2005.

Internationally 2005 was dominated by the re-negotiation of the JWST budget at NASA, including an assessment of the scientific capabilities of JWST by an independent panel. MIRI was strongly endorsed by the panel and JWST obtained the green light forward.

5.11.1. Technical progress in 2003-2004-2005

The overall optical concept for MIRI is a functional split between the imager and spectrometer instruments. The MIRI optical design is all reflective and fully diffraction limited. The spectrometer can obtain simultaneous spectral and spatial data on a few arcsec region by using four integral field units (IFUs) constructed of image slicers. The Netherlands contribution is in the dispersion/camera optics of the spectrometer including all collimator-, grating- and camera-optics. The UK provides the IFUs, Germany the grating mechanisms and the US is responsible for the detector arrays. The resolving power of the spectra is R~2000-3700 and the FOV ranges from 3.6"x3.6" at 5 μm to 7.7"x7.7" at 28μm with 0.2 to 0.7" slice widths.

Within the spectrometer, light from the JWST focal plane is split spectrally into four paths by sets of dichroic filters mounted in a wheel. The resulting four passbands are fed into four IFUs where the images are sliced and re-assembled to form the entrance slits for the spectrometers. The light from each IFU is separately collimated and dispersed. The spectra from pairs of gratings are then imaged by two cameras onto two 1024x1024 Si:As detector arrays cooled to 7 K. This design with two cameras instead of one was found to result in a more compact instrument with a much smaller total mass. The spectrometer design therefore has two arms, one for the short-wavelength range (5.0-11.9 μm) and one

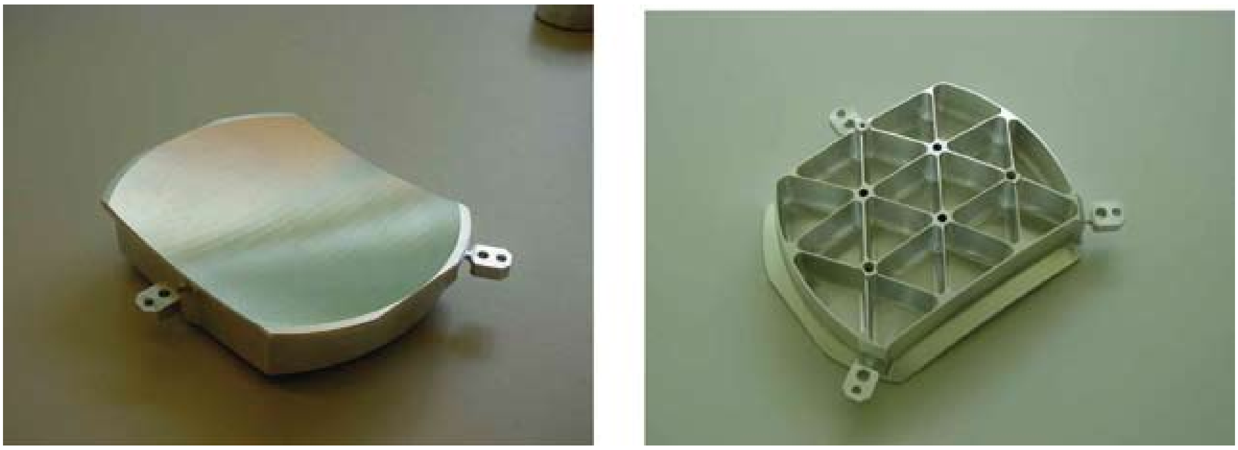


Fig. 5.12: MIRI Mirror Engineering Qualification Model (front and rear). Note the lightweighting of rear of mirror.

for the long-wavelength range (11.9-28.3 μm). Each arm has its own camera optics and detector array. By arranging two spectral ranges onto each detector simultaneously the efficiency of the spectrometer is doubled. Full wavelength coverage is obtained in three settings of the gratings and corresponding dichroics. The optical design, developed at TPD with significant input by Pel (RuG) and ASTRON, was frozen in 2003.

The (opto-)mechanical design work is led by Kroes (ASTRON), the concept study was completed and documented and the detailed design almost completed. The Structural-Thermal Model was designed, built, tested and delivered in 2004 to RAL in the reporting period. The design culminated in the successful VM Manufacturing Readiness Review in July 2005. Other activities include design and engineering models of the mirrors and grating wheel assembly, and procurement of the gratings.

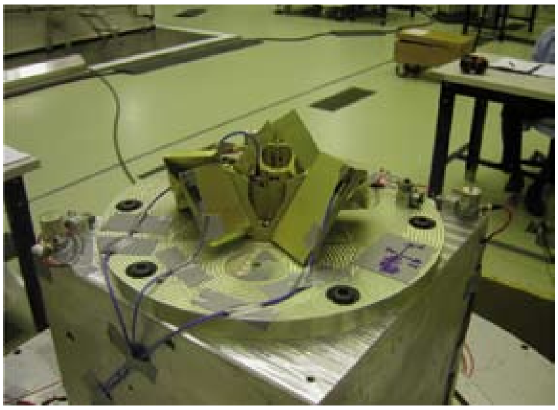


Fig. 5.13: MIRI Grating wheel Engineering Qualification Model on the vibration table.

The MIRI-OBA passed its Systems Requirements Review in early 2004 and its Preliminary Design Review in late 2004. The requirements baseline was frozen. All optical, mechanical and thermal interfaces were extensively discussed within the consortium and are well documented. Phase C/D started at ASTRON in September 2004.

Planning for integration, testing and calibration on the ground and in-orbit has started within the European Consortium. Brandl is involved in the MIRI calibration working group, led by Meixner (StScI), and is composing the strategy with stellar calibrators based on experience from ISO-SWS and Spitzer-IRS. The Dutch team has stressed the general need for a well characterized relative spectral response function before launch, and first steps were been made to incorporate such measurements in the Flight Model test plan at RAL.

5.12. Miscellaneous seed funding projects

5.12.1. The Amsterdam Light Scattering Facility

Dust in space is usually observed by the light it scatters and absorbs in the visible part of the spectrum, and by the thermal radiation it emits at infrared and millimeter wavelengths. The scattering properties of dust constitute an important diagnostic tool which contains essential information about the nature of the grains. The long-term goal of the Light Scattering Facility (LSF) at the University of Amsterdam is to study the size, shape, structure and composition of dust particles in a variety of astronomical environments, such as the atmospheres of planets orbiting the Sun and stars, comets and circumstellar disks in which planets are born. For that purpose, several theoretical and experimental studies of single and multiple light scattering were conducted.

The LSF at the UvA focused its experiments on measuring the full, polarization resolved scattering matrix of micron-sized particles in random orientation, covering a scattering angle range from about 5° (near forward scattering) to about 173° (near backward scattering).

The group worked on an extensive measurement program including irregular particles of high interest for planetary atmospheres and other astronomical environments. The program included measurements for several volcanic ashes, hematite and palagonite dust particles relevant for Mars, and three types of forsterite particles relevant for comets and circumstellar material. NOVA seed funding allowed the group consisting of Waters (PI), Volten and Hovenier to demonstrate early scientific results attracting structural support from the University of Amsterdam for laboratory infrastructure and from NWO and NASA for project grants.

The interpretation of infrared spectra of dusty astronomical objects requires complex calculations of the optical properties of dust particles (e.g. the absorption and scattering cross sections) as functions of wavelength for various materials. Min, Hovenier and de Koter studied the so-called statistical approach, using a broad distribution of fairly simple dust grain shapes and successfully applied this method to obtain information on the characteristics of cometary and circumstellar dust grains, such as their sizes and composition. Comparing their modeling results with data of the bright comet

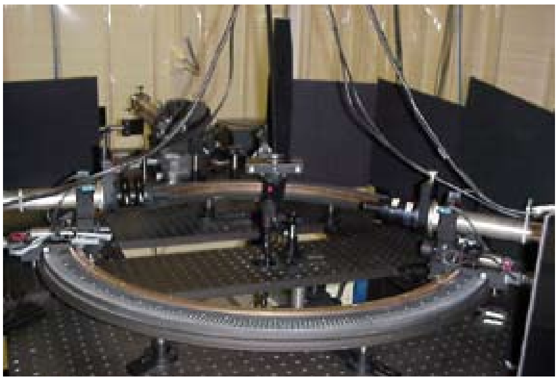


Fig 5.14: The Light Scattering Facility at the University of Amsterdam. Light from a laser is scattered by particles in the center of a goniometric ring and then detected by two photomultipliers. One of these can be moved on the ring to vary the scattering angle. The other one is used as a monitor to account for fluctuations in the number of particles.

Hale-Bopp let to the conclusion that the amount of crystalline silicates in this comet - which are products from grain processing - is much lower than expected from earlier studies. Min, Dominik, and Waters studied the emission spectra of very large dust grains. Resonances at certain wavelengths in the bulk refractive index of the dust material lead to corresponding emission enhancements in the spectra when the dust grains are very small, which allows to identify the dust materials. It is generally assumed that the emission spectrum of a very large grain is a smooth function of wavelength and shows no diagnostic for the mineralogy. Min et al. showed that for arbitrarily large particles, detectable spectral structure is still visible. Model simulations for the dust around Vega let to the prediction that the infrared spectrometer onboard the Spitzer space telescope should be able to determine the mineralogy of the dust around Vega.

5.12.2. Preparation for Gaia photometric data analysis

Gaia is an approved ESA space astrometry mission which will measure accurate positions, parallaxes and proper motions for all stars to a limiting magnitude of V=20. To complement the astrometric information photometry will be obtained in 15-20 broad and medium wavelength bands and radial velocities will be collected for stars brighter than V=17. The primary scientific aim of the mission is to map the structure of the Galaxy and unravel its formation history by providing a stereoscopic census of 1 billion stars throughout the Milky Way. This census can only be interpreted properly if one can accurately characterize the constituent stars by their age and chemical composition. Ideally one would like to 'tag' individual stars to each of the progenitor building blocks of the Galaxy. This requires the stereoscopic data to be supplemented by highly accurate multi-color photometric measurements, which will be provided by Gaia as well. The mission will provide a wealth of data on all stages of stellar evolution, including the latest stages through transient sources and the earliest stages by providing a complete and a very detailed map of Gould's Belt, the largest nearby star-forming complex.

This project is aimed at preparing for the Gaia mission by taking the lead in pursuing the photometric data analysis. It encompasses all steps from the raw treatment of the photometric data coming directly from the satellite to the delivery of the final mission-averaged fluxes and magnitudes for each observed object and for each photometric filter. The study of the photometric data analysis will lead to the design and development of algorithms that will be used during the operational phase of the mission. The national project team is collaborating with various institutes throughout Europe, notably in the UK, Spain, Denmark and Lithuania.

NOVA seed funding for this project was used to fund the postdoc position of Brown in Leiden for a period of 8 months starting in April 2004. During that period Perryman, de Zeeuw, and Brown were awarded an NWO-M grant of 365 k€ to continue the Gaia photometric data analysis effort in The Netherlands. This funding was used to appoint Brown for a further 3 years (2005–2008) and to hire postdoc Marrese to work with Brown. Their aim is to explore the possibility of using the Grid framework (developed by Dutch Space) for the photometric data processing.

In 2004 two groups in the UK joined the photometric data analysis effort. A group in Leicester had taken on calibration tasks and will carry out laboratory studies of CCDs operated in time-delayed integration mode. The outcome will be fed into the photometric data analysis study. The other group in Cambridge will implement the results of the exploratory studies defined by Brown as actual production software for the Gaia mission. Brown also joined the Gaia Data Access and Analysis System Steering Committee. This group will investigate the scientific data processing tasks, plans to implement a prototype system, and will develop procedures to examine the data including algorithms for data calibration and source extraction. Brown is responsible for overseeing all photometry related activities.

In 2005 Leiden was added as a node to the GaiaGrid infrastructure. The photometric algorithm tests will make use of GaiaGrid both for simulating the data and for retrieving the data from a central database and processing them remotely. In the Netherlands the following groups offered support in the development of data processing tools for Gaia: (1) in Leiden Brown and co-workers will contribute to the development of algorithms for the core and shell tasks of the photometric data analysis (in collaboration with groups in Barcelona and Cambridge, UK); (2) Dutch Space and its partners (TNO/TPD, SRON) expressed interest to provide quality control mechanisms for the CCDs; (3) the OmegaCEN group offered to share its expertise with handling very large data sets; (4) in Nijmegen Groot and Nelemans are interested to contribute to the development of algorithms that allow for robust science alerts; (5) in Groningen Trager, Helmi, Tolstoy and Douglas plan to carry out extensive testing of the Gaia photometric filter system through ground based observations This will facilitate the calibration of the photometric systems of Gaia; (6) in Delft the department of earth observation and space systems will contribute to the core astrometric processing. Van der Marel and co-workers will look into options to use methods from the Hipparcos great circle reduction software package to develop an independent scheme to verify the results from Gaia's main data reduction package.

5.12.3. CHEOPS - SPHERE

Characterizing Extrasolar planets by Opto-infrared Polarimetry and Spectroscopy (CHEOPS) aims at the direct detection and characterization of faint planetary companions in the vicinity of bright guide stars, using high order AO in combination with polarimetric and spectral differencing techniques. The instrument is a single conjugate AO system, aiming for very high Strehl ratios on 7-11 magnitude stars, feeding a near-IR integral-field spectrometer plus a visible-light polarimeter. Detection feasibility is focused on young, contracting planets for the near-IR instrument, while the visible-light polarimeter is also sensitive to older gas giants. Inherent in the differencing methods are diagnostic capabilities of planetary atmospheres, including polarization signatures: detection of each planet is already a partial physical characterization. The project complements other high-angular resolution programs (MIDI for VLTI, and SINFONI for VLT), and connects with exo-planet studies, theory, laboratory light-scattering experiments, and other instrumentation (JWST-MIRI for the physical studies, VLTI-PRIMA for the dynamical studies).

In reply to a call for proposals for a planet finder instrument for the VLT by ESO two consortia started an independent feasibility study. NOVA collaborated in a consortium led by MPIA involving ETH Zurich and Padova as well.

In 2003-2004 the Dutch contribution was threefold. Waters (PI NL work packages), Dominik, Hovenier, Quirrenbach and Stam contributed to the science case, both by performing physical studies of planetary atmospheres to determine scattering and thermal infrared emission properties of exo-planetary systems, as well as in the description of the secondary science case. Tinbergen played a strong role in the specification and design of the polarimetric arm (ZIMPOL) of CHEOPS, especially in finding novel methods to maximize the polarimetric contrast of the instrument and stimulating awareness within the consortium on the importance of taking polarimetry into account in the full instrument concept from the start. Together with MPIA staff, NOVA and ASTRON researchers Flicker, Quirrenbach, Stuik and Venema worked on the specification of the corrective elements and simulations of the performance of the CHEOPS AO system. Several measurements were performed on existing corrective optics to determine the effects of the physical limitations of these devices on the AO performance.

In December 2004 the CHEOPS Phase A review took place at ESO, where the two competing Planetfinder consortia presented the results of their study. ESO selected the French consortium as preferred choice. In 2005 the SPHERE consortium was formed as a result of the merging of two competing consortia. The planned Dutch contribution to SPHERE was in the design and scientific exploitation of the imaging polarimeter arm ZIMPOL. This effort was headed by the ETH at Zurich. Main activity in the Netherlands in 2005 focused on writing proposals to obtain funding for the project.

5.12.4. Mid-InfraRed Instrument for the ELT (MIDIR)

The huge technological progress over the last decade in almost all relevant areas, from detector technologies to adaptive optics, and from lightweight mirrors to complex active computer controls, enabled the next generation of optical "Extremely Large Telescopes" (ELTs), with primary mirror sizes of 30 – 60 meters. Coordinated by the OPTICON FP6 framework and ESO, numerous European institutions begun investigating the scientific and technical requirements on such a challenging project, and contracts for concept studies of the telescope and its scientific instruments have been issued.

One out of eight instruments currently under investigation is MIDIR, an imager/spectrograph for the 3 – 27 μm wavelength range. MIDIR has many scientific objectives; its main scientific goals are to study:

- the conditions under which planetary systems formed and evolved
- the centers of active galaxies and the feeding of super-massive black holes
- the most energetic gamma-ray bursts in the very early Universe.

With unsurpassed diffraction-limited spatial resolution at mid-IR wavelengths of a few tens of milliarcseconds, and very high spectral resolution (R~50,000) it will be complementary and competitive to other future ground- and space-based facilities with similar science objectives, such as ALMA or JWST.

The MIDIR consortium is an international team led by the PI (Brandl, Leiden) and co-PI (Lenzen, MPIA, Germany), the project engineer (Venema, ASTRON), and partners from ESO and ATC (UK). The technical team from Dutch universities involves: Pel, Peletier, Stuik, Keller, Quirrenbach, de Graauw, Tinbergen and Hallibert (NOVA optical designer), and received valuable scientific input from van Dishoeck, van der Werf, Tolstoy, Barthel, Waters, Tielens, and Wijers. This list of names illustrates how heavily MIDIR is based on the large expertise that Dutch astronomers acquired over many decades in projects like IRAS, ISO-SWS, VISIR, HIFI, and MIRI.

The MIDIR concept study (originally called T-OWL) started in January 2005 and produced a detailed 200-page study document which was formally presented at ESO in September 2005. Thereafter the work continued in the second phase. Because of its good progress and perspective MIDIR has an excellent chance to be selected as one of the 3-5 first generation ELT instruments.

5.13. Multi Unit Spectroscopic Explorer (MUSE)

MUSE is a panoramic integral-field spectrometer for the wavelength range 0.5-1.0 µm with a 1'x1' field of view, providing 90,000 simultaneous spectra with a spatial resolution between 0".05 and 0".2. An adaptive optics system will provide improved image quality so that MUSE is uniquely suited to study both distant as well as nearby galaxies. The Fr-NL-Ger-CH consortium led by CRAL at Lyon is developing innovative AO concepts, optimized for correction over a wide field-of-view and for operation at short wavelengths. Starting as a NOVA seed funding project in 2003-2004, continuation of the Dutch participation in MUSE was secured through funds from the NOVA phase-2 instrumentation program with support from an EU-FP6 OPTICON grant. Significant additional funding is needed to continue the involvement during its construction phase.

Together with the ESO adaptive optics group, NOVA laid down the requirements of the AO system and simulated the performance of the conceptual design of MUSE and the AO system. During the reporting period two designs of the MUSE AO system (GALACSI) were started. The first option uses a novel approach based on the Deformable Secondary Mirror (DSM) at the VLT, currently under development by ESO. This option is expected to give the highest throughput as in the baseline design the AO system will not have any optical components within the field of view of the MUSE spectrographs. The second option consists of an AO system internal to MUSE, on the platform. In December 2005 ESO chose for the development of the VLT Adaptive Telescope Facility (ATF), which includes the DSM. Unless serious problems are encountered in the further design phases, this means that MUSE will be using the DSM, as was investigated in the first option. GALACSI will use the 4 laser guide stars of the VLT ATF and 1 natural guide star (Fig. 5.15). Extensive simulations were performed on the expected performance of the AO system, the sky coverage, fratricide and spot elongation effects.

MUSE successfully completed its preliminary design study (Phase A) and, after approval by the ESO Council in April 2004, started its Preliminary Design Phase (PDP) in January 2005. The consortium working on this study now consists of 6 core institutes: Astrophysikalisches Institut Potsdam (AIP), Potsdam; Centre de Recherche Astronomique de Lyon (CRAL, overall project PI Bacon), Lyon; ESO; NOVA; ETH Zürich; Institut für Astrophysik Göttingen; and Laboratoire d'Astrophysique Observatoire Midi-Pyrénées (LAOMP).

The main contribution of NOVA to MUSE in the preliminary design phase is the design, construction and implementation of a test set-up called ASSIST (Adaptive Secondary Simulator and InStrument Testbed) where GALACSI - and possibly the full MUSE instrument - can be tested in Europe. This test bed is essential in the case that a DSM will become available for use by MUSE/GALACSI: other than on the sky, there is no method for testing GALACSI before the actual operation, which is both time consuming as well as expensive. A preliminary design of ASSIST was presented for the VLT ATF review and the design is now being further developed by NOVA. The second contribution will be in the development and testing of the high-order (ground layer) AO algorithms required for GALACSI. A dedicated AO set-up is being built at Leiden Observatory to perform high-order AO reconstruction experiments, with first closed loop operation expected in early 2006. This AO set-up has also proven to be an excellent opportunity for students to familiarize themselves with optical set-ups in general and Adaptive Optics set-ups in particular and get involved in instrumentation projects.

In the Netherlands the following staff members contributed to MUSE: the science team involved Brandl, McDermid (deputy instrument scientist), Franx (instrument scientist), Quirrenbach, Schaye, van der Werf and de Zeeuw (NL Co-I on the international MUSE consortium). The AO work packages are being carried out by Brandl (system scientist), Flicker (software), Hallibert (optical design), Quirrenbach (system scientist), Stuik (hardware and national project manager) and Vink (opto-mechanical design). Falcon Barroso contributed to the development of data analysis software.

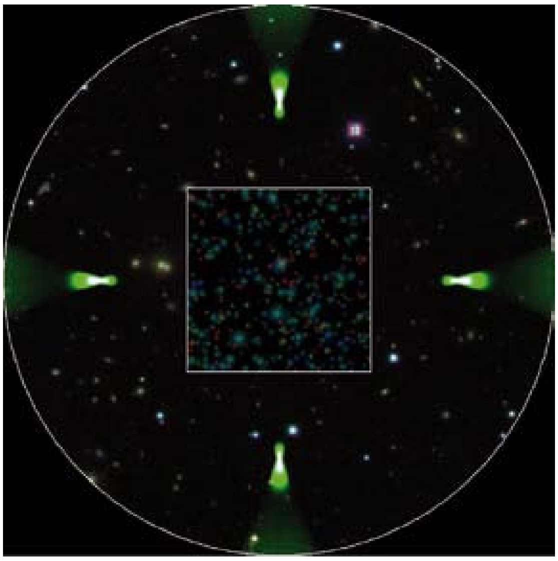


Fig. 5.15: Simulated MUSE Wide Field Mode view. The central area of 1'x1' is the scientific FoV, in the above image containing a simulated galaxy field. Four Laser Guide Stars surround this field at a distance optimized for AO performance and minimized scatter in the science field. A single Natural Guide Star can be picked up anywhere within a FoV of 3-4'.

5.14. X-SHOOTER

X-SHOOTER is a single target spectrograph for the Cassegrain focus of one of the UTs of the ESO VLT, covering in a single exposure the wide spectral range from 300 to 2500 nm (from the UV to the K band). It is designed to maximize the sensitivity by directing the light to three wavelength-optimized spectrograph arms (Fig 5.16). X-SHOOTER is intended to become the most efficient medium-resolution (R = 4000 - 14000) wide-band spectrograph in the world. The capability to observe faint sources with an unknown flux distribution in a single shot inspired the name of the instrument. The science drivers for X-SHOOTER are numerous, ranging from brown-dwarf atmospheres, star formation, compact objects and close binary systems to supernovae, lensed high-redshift galaxies and gamma-ray bursts, serving a large user community.

A consortium with partners in the Netherlands, Denmark, Italy, France and involving ESO was selected by ESO Council in 2003 to design and build the instrument, based on a feasibility study financially supported with NOVA seed funding. X-SHOOTER will be the first second-generation VLT instrument to be installed on the VLT, and offered to the community in 2008. The Dutch contribution to X-SHOOTER is one of the three spectrographs: the near-infrared arm, designed, constructed and tested at ASTRON and its cryogenic enclosure at the Radboud University in Nijmegen. Funding of the NL work packages is fully secured with contributions from the NOVA Phase-2 instrumentation program (1000 k€), a NWO-M grant (744 k€), and a grant from the University of Amsterdam (300 k€). The UvA contribution will cover the construction costs of some hardware components for the near-IR spectrograph (carried out by the section Mechanical Construction at the UvA) and a postdoc for the development of data reduction software. The Radboud University supports the project with an in-kind contribution of 60 k€. Kaper is the Dutch PI and member of the International Consortium Board, Groot is co-PI and chair of the Science Team, and Navarro (ASTRON) is the national Project Manager.

The preliminary design review of X-SHOOTER was held at ESO in December 2004, and passed with success. The review board concluded that many areas in the project were already exceeding PDR requirements. It was recommended to extend the near-IR wavelength coverage to the K band, requiring a redesign of the near-IR camera and an upgrade of the detector. During the review it became clear that ESO wanted to avoid to further use of closed-cycle coolers on the telescope platforms to reduce possible interference with VLTI observations. This implied a complete redesign of the cooling system for which the Dutch consortium obtained financial compensation (129 k€). The final design review is planned for February 2006.

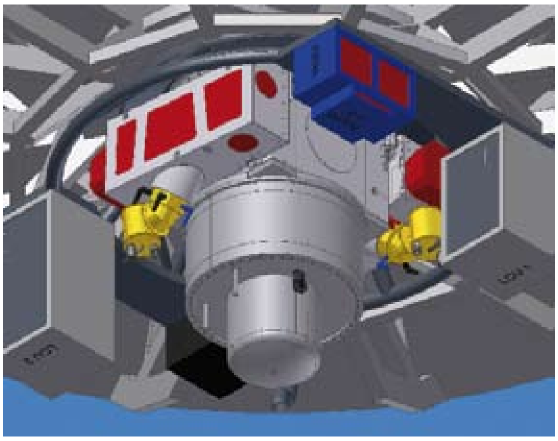


Fig 5.16: View of X-SHOOTER attached to the Cassegrain focus of the VLT. The electronics boxes are supported by a co-rotating ring, reducing flexure and improving access. The near-IR spectrograph is mounted below the backbone; the two other spectrographs are mounted to the side.

5.15. LOFAR Development and Commissioning

LOFAR, the Low Frequency Array, is a next-generation radio telescope currently being constructed in the Netherlands. The initial array will comprise 45 stations distributed over an area of diameter of 100 km and observe in the frequency range 10-240 MHz. The array is planned to be operational in 2009. The design of LOFAR has been driven by four astrophysical applications that fit excellently with the expertise and scientific interests of the four participating Dutch university astronomy groups. These key LOFAR drivers are:

Epoch of Reionization (PI de Bruyn): One of the most exciting applications of LOFAR will be the search for redshifted 21cm line emission from the Epoch of Reionization (EoR). LOFAR will address a number of key questions related to the EoR, including: (i) what is the redshift range in which the bulk of the neutral hydrogen became ionized? (ii) What is the spatial distribution of heated and still cold IGM during the era of reionization? (iii) Which objects (Pop III stars, galaxies, quasars) or processes are responsible for re-ionizing the Universe?

Deep Extragalactic Surveys (PI Röttgering): LOFAR surveys will provide unique catalogues of radio sources for investigating several fundamental questions in astrophysics, including the formation of massive black holes, galaxies and clusters of galaxies. Because the LOFAR surveys will probe unexplored parameter space, it is likely that they will discover new phenomena. Classes of extragalactic objects are of particular interest including (i) $z>6$ radio galaxies, (ii) diffuse radio emission in galaxy clusters, and (iii) distant star forming galaxies.

Transient Sources (PI Wijers): LOFAR's large instantaneous beam will make it uniquely suited to efficiently monitor a large fraction of the sky, allowing a sensitive unbiased survey of variable radio sources on a variety of time scales ranging from seconds to many days. The angular resolution attained will be sufficient for the crucial task of rapid optical and X-ray identifications. Classes of object known or expected to exhibit variable radio emission include Gamma-Ray Bursts, Galactic black-hole/neutron-star Systems and exo-planets.

High Energy Cosmic Rays (HECRs, PI Kuijpers): LOFAR offers a unique possibility for studying the origin of high-energy cosmic rays (HECRs) at energies between 10^{15} - $10^{20.5}$ eV. The uniqueness of LOFAR as a CR detector lies in its capacity to measure: (i) the composition of CRs via the Gerasimova-Zatsepin effect; (ii) point sources of high energy CRs via the detection of energetic neutrons; (iii) high-energy neutrinos in horizontal showers as well as from the lunar surface regolith. These studies will be very important for our understanding both the source origin and the acceleration processes of these particles.

5.15.1. Development & Commissioning of LOFAR for Astronomy - DCLA

The LOFAR radio telescope is being built by a Dutch consortium led by ASTRON. The DCLA project is being carried out at the four participating universities (Amsterdam, Groningen, Leiden, and Nijmegen). The DCLA project consists of the development of algorithms and software pipelines that are necessary to make the four key programs possible, as well as crucial commissioning tasks that are essential for optimising the observations and calibration techniques to enable the four key programs to be carried out. Partial funding of the DCLA project was obtained from NOVA, NWO-M and SNN (Samenwerkingsverband Noord Nederland, a collaboration of the three Northern Provinces of the Netherlands). In addition, the DCLA was supported by grants allocated to individual astronomers as VIDI, VICI, FOM and KNAW awards, and ASTRON provides the program management.

5.15.2. Organization of DCLA

The DCLA management team (DMT) is responsible for the DCLA budget and for ensuring that the DCLA achieves its objectives. Members of the DMT are the PI (Röttgering), the PIs of each of the Key Project Teams (KP-PI's) or their designated replacements (Braun, De Bruyn, Snellen, Stappers), the DCLA Program Manager (van Haarlem) and the LOFAR International Project scientist (Falcke). The Astronomy Research Committee (ARC) represents the interest of the astronomy community and overviews all aspects of the project that are relevant in making LOFAR a success as a radio observatory. Currently it has as its members: Boland, Braun, de Bruyn, Kuijpers, Koopmans, Röttgering (chair), Schilizzi and Wijers and observers: van Enst (LOFAR Director Science), Falcke (International Project Scientist), van Haarlem (Technical Project Scientist) and Miley (Chair LOFAR Interdisciplinary Research Committee). The ARC reports both to the LOFAR Directorate and the ASTRON Board.

The ARC has set up a committee to review the DCLA project on the following aspects: (i) technical progress, (ii) organization and planning, (iii) funding and budgets, and (iv) human resources.

5.15.3. Progress of key DCLA projects

Epoch of Reionization: Yatawatta (RuG, NOVA postdoc) commenced work in July 2005. He worked within Noordam's (ASTRON) group and developed code to incorporate aspects of wide field imaging within the calibration imaging packages. Thomas (RuG, PhD student of Zaroubi) and Pawlik (UL, PhD student of Schaye and Röttgering) joined the EOR key project. They worked on theoretical aspects of the EOR signal and simulations on how the foregrounds and instrument response affect the signal. In April 2005 a 10x10 degree area in the North Galactic Pole was observed at 150 MHz using the WSRT for 6x12h. This data set was used to investigate ionospheric Faraday rotation at these long wavelengths which is one of the challenging issues related to LOFAR calibration. In late June 2005 an international conference was held at the University of Groningen about the 'Epoch of Reionization and the Physics of the IGM'. About 120 people attended the meeting which was a great success.

Extragalactic Surveys: Members of the survey team carried out a number of observing projects using the GMRT and WSRT at 150 MHz and the VLA at 74 MHz. As part of the thesis of Intema (UL, PhD student partly funded by NOVA) a rudimentary calibration scheme was implemented within the classic AIPS radio reduction software package. Furthermore, in collaboration with the long-term visitors Dharam Vir Lal (GMRT) and Cohen (Naval Research Laboratory, Washington DC) structure functions of the ionosphere were measured using data from these low-frequency observing projects. Mohan (NOVA Postdoc) started on the development of a pipeline for the detection and characterization of LOFAR sources.

Transient Sources: Spreeuw started his PhD project on LOFAR transients (jointly funded by NOVA and Wijers VICI Grant) in November 2005. He used a variety of data from the WSRT, VLA and the LOFAR test station to study a number of variable radio sources, with the aim of developing methods of robust source identification and characterization. Miller-Jones (Postdoc) took a complementary approach by developing algorithms for 'interrogating' imaging of transients, applying methods of 'map comparison'. As a test imaging data set, the WENSS/WSRT survey (250,000 sources at 325 MHz) was used to search for variable sources. Scheers, a second PHD student started in November 2005 (also jointly funded by NOVA-2 and Wijers' VICI Grant). He will work on the compilation of a catalogue of variable radio sources.

Cosmic Rays: Due to the combined effort of Bahrens, Nigle, LaFebre (PhD students) and Horneffer (NOVA postdoc) significant progress was obtained in the implementation of algorithms for triggering and recognition of cosmic rays taking into account man made radio frequency interference. Special attention was paid to methods for absolute calibration of the signals. The Monte Carlo simulation gave deeper insight into the development of the radio showers resulting from CRs penetrating the Earth atmosphere. An important highlight of the CR project was the Nature paper of Falcke et al. (2005) with decisive observational proof of the working principle on which LOFAR as a CR detector is based.

6. Personnel funded by NOVA

The tables in this chapter listed all research and technical support staff whose employment was – partially – funded through the NOVA program in 2003 -2005.

NOVA funded astronomical research

Project	Title	Project leader	Univ	Researcher	Yrs	Start	End	Remarks
Network #1								
10.1.1.01	Radio galaxies at high redshift	Miley	UL	Drs. Bram Venemans	4,0	Oct 1, 2000	Sep 30, 2004	
10.1.1.02	Gas through the galaxy formation epoch	De Bruyn	RuG	Dr. Nissim Kanekar	2,0	Sep 1, 2001	Aug 31, 2003	
10.1.1.03.2	Mass distribution of galaxies from weak lensing	Franx	UL	Drs. Arjen van der Wel	2,0	Sep 1, 2001	Aug 31, 2003	a
10.1.1.04	Nuclei of elliptical galaxies	De Zeeuw	UL	Drs. Davor Krajnovic	4,0	Sep 1, 2000	Aug 31, 2004	
10.1.1.05	Structure and evolution of elliptical galaxies	De Zeeuw	UL	Drs. Glenn van de Ven	2,0	Oct 1, 2001	Sep 30, 2003	a
10.1.1.06	Triggered star formation in nearby mergers	Lamers	UU	Drs. Nathan Bastian	4,0	Mar 1, 2001	Feb 28, 2005	
10.1.1.09	Network postdoc position	Kuijken	RuG	Dr. Andrew Cole	2,0	Sep 23, 2002	Sep 22, 2004	
10.1.1.10	Network postdoc position	Lamers	UU	Dr. Amina Helmi	1,2	Jul 1, 2002	Aug 31, 2003	
10.1.1.11	Triggered star formation in interacting galaxies	Lamers	UU	Drs. Mark Gieles	1,0	Nov 1, 2002	Oct 31, 2003	b
10.1.1.11	Triggered star formation in interacting galaxies	Lamers	UU	Drs. Mark Gieles	1,2	Nov 1, 2004	Dec 31, 2005	b
10.1.1.12	Network postdoc position	Miley	UL	Dr. Tracy Webb	2,0	Sep 1, 2002	Aug 31, 2005	
10.1.2.02.1	Diffuse radio emission in clusters	De Bruyn	RuG	Drs. Roberto Pizzo	1,5	Jul 1, 2005		a
10.1.2.03	2D spectroscopy of distant galaxies	Franx	UL	Drs. Maaike Damen (50%)	4,0	Sep 12, 2005		a
10.1.2.04	Void hierarchy and cosmic web	Van de Weygaert	RuG	Drs. Erwin Platen	2,5	Mar 1, 2005		a
10.1.2.05	Infant mortality rate star clusters	Lamers	UU	Drs. Remco Scheepmaker	2,0	Jun 1, 2005		a
10.1.2.09	Network postdoc position	Franx	UL	Dr. Kim-Vy Tran	3,0	Oct 1, 2005		
10.1.2.10	Network postdoc position	Van der Hulst	RuG	Dr. Spyros Basilakos	0,5	Sep 1, 2005		
Network #2								
10.2.1.01	Interaction of Young Stellar Objects with their environment	Tielens	RuG	Drs. Stephanie Cazaux	4,0	Nov 1, 1999	Oct 31, 2003	
10.2.1.03	Envelope structure and formation of circumstellar disks	Van Dishoeck	UL	Drs. Jes Jorgensen	4,0	Nov 1, 2000	Oct 31, 2004	
10.2.1.04	Formation of the most massive stars in the Galaxy	Kaper/Waters	UvA	Drs. Arjan Bik	4,0	May 1, 2000	Apr 30, 2004	
10.2.1.05	Evolution of gas/dust ratio in circumstellar disks	Van Dishoeck	UL	Drs. Klaus Pontoppidan	4,0	Nov 1, 2000	Oct 31, 2004	
10.2.1.06	Solid-state features in circumstellar disks	Waters	UvA	Drs. Roy van Boekel (50%)	4,0	May 1, 2000	Apr 30, 2004	c
10.2.1.09	Radiative transfer models of atmospheres of evolved stars	Waters	UvA	Drs. Rien Dijkstra	4,0	Jul 1, 2000	Jun 30, 2004	
10.2.1.10	Stellar population studies of AGB stars	Habing	UL	Drs. Maria Messineo	4,0	Nov 1, 1999	Oct 31, 2003	
10.2.1.11	Search for large carbonaceous molecules in space	Kaper	UvA	Drs. Nick Cox	2,0	May 1, 2002	Apr 30, 2004	
10.2.1.12	Early phases of planet formation in Herbig Ae/Be stars	De Koter, Waters	UvA	Drs. Joke Meijer	3,0	Jan 1, 2003	Dec 31, 2005	a
10.2.1.13.2	Network postdoc position	Van Dishoeck	UL	Dr. Inga Kamp	0,6	Sep 1, 2003	Feb 29, 2004	
10.2.1.14	Triggered star formation in interacting galaxies	Lamers	UU	Drs. Mark Gieles	1,0	Nov 1, 2003	Oct 31, 2004	b
10.2.2.01	Probing the inner envelopes of protostars	Van Dishoeck	UL	Drs. Dave Lommen	2,7	May 1, 2005		e
10.2.2.06	Search for large carbonaceous molecules in space	Kaper	UvA	Drs. Nick Cox	2,0	May 1, 2004		
10.2.2.07	Models of protoplanetary disks	Waters	UvA	Dr. Carsten Dominik	2,0	Jan 1, 2004	Dec 31, 2005	
10.2.2.09	Mass loss during the AGB phase	Tielens	RuG	Drs. Christiaan Boersma	3,0	Feb 1, 2005		
10.2.2.11	Network postdoc position	Waters	UvA	Dr. Michiel Min	1,0	Apr 1, 2005		
Network #3								
10.3.1.01	Gamma-ray bursts	Wijers	UvA	Drs. Klaas Wiersema	2,0	Oct 1, 2003	Sep 30, 2005	f
10.3.1.02	Radio pulsar studies using PUMA on the WSRT	Van der Klis	UvA	Drs. Patrick Weltevreden	4,1	Dec 1, 2002		
10.3.1.03.1	Evolution of neutron stars	Verbunt	UU	Drs. Marc van der Sluys	4,0	Sep 1, 2001	Aug 31, 2005	
10.3.1.04.1	Neutron stars & black holes	Van der Klis	UvA	Drs. Diego Altamirano	3,1	Nov 1, 2003		
10.3.1.04.2	Neutron stars & black holes	Van der Klis	UvA	Dr. Tiziana di Salvo	1,8	Mar 1, 2002	Dec 31, 2003	
10.3.1.04.3	Neutron stars & black holes	Van der Klis	UvA	Dr. Wenfei Yu	0,2	Jan 1, 2004	Feb 29, 2004	

Project	Title	Project leader	Univ	Researcher	Yrs	Start	End	Remarks
10.3.1.05	Massive X-ray binaries with XMM-Newton, Chandra and VLT	Van den Heuvel	UvA	Drs. Arjen van der Meer	4,0	Dec 1, 2000	Nov 30, 2004	
10.3.1.06	Physics of ultra-relativistic shocks	Achterberg	UU	Drs. Jorrit Wiersma (80%)	5,0	Feb 1, 2001		
10.3.1.07.1	Pulsar wind & pulsar emission	Achterberg	UU	Dr. David Khechinashvili	1,0	Oct 1, 2003	Sep 30, 2004	
10.3.1.07.2	Pulsar wind & pulsar emission	Achterberg	UU	Dr. Jeroen Bergmans	0,5	Jan 1, 2004	Jun 30, 2004	
10.3.1.07.3	Pulsar wind & pulsar emission	Achterberg	UU	Drs. Pui-Kei Fung	0,5	Jan 1, 2004	Jun 30, 2004	a
10.3.1.08	Binary population synthesis	Verbunt, Van den Heuvel	UU	Dr. Jean in 't Zand	2,8	Sep 1, 2002	Jun 30, 2005	
10.3.1.09	Jets from neutron stars in X-ray binaries	Fender	UvA	Drs. Elena Gallo	4,0	Sep 1, 2001	Aug 31, 2005	
10.3.2.01	X-rays from accreting compact objects	Langer	UU	Drs. Laurens Keek (50%)	4,0	Nov 15, 2004		a
10.3.2.02	Realistic GRB light curves and the GRB environment	Wijers	UvA	Drs. Hendrik van Eerten	4,0	Oct 1, 2005		
10.3.2.03	Relation between radio and non-radio emission from pulsars	Van der Klis	UvA	Drs. Eduardo Rubio Herrera	4,0	Oct 1, 2005		
10.3.2.10	Network postdoc position	Verbunt	UU	Dr. Jean in 't Zand	1,0	Jul 1, 2005		
Miscellaneous projects								
10.4.1.01	Postdoc NOVA Director	De Zeeuw	UL	Dr. Michelle Cappellari	4,0	Mar 1, 2001	Feb 28, 2005	d
10.4.1.03	PhD student NOVA Chair	Van den Heuvel, Henrichs	UvA	Drs. Roald Schnerr	2,0	Dec 1, 2002	Nov 30, 2004	a
10.4.1.04	Research stimulation at Radboud University in Nijmegen	Kuijpers	RU	Drs. Joachim Moortgat	3,0	Jan 1, 2002	Dec 31, 2004	a
10.4.2.01	Postdoc NOVA Director	De Zeeuw	UL	Dr. Jesús Falcon-Barroso	2,5	Jul 1, 2005		
Overlap appointments								
10.5.1.01	Birth and death of stars	Van den Heuvel	UvA	Prof. Rens Waters	4,8	Jan 1, 2001	Oct 31, 2005	
10.5.1.02	Computational astrophysics	Van den Heuvel	UvA	Dr. Rudy Wijnands	1,7	Jan 1, 2004	Aug 31, 2005	
10.5.2.01	Evolution of galaxies	Van der Kruit	RuG	Dr. Amina Helmi	5,3	Sep 1, 2003		
10.5.2.02	Astronomical instrumentation	Van der Kruit	RuG	Dr. Reynier Peletier	5,2	Sep 1, 2003		
10.5.3.01	Laboratory astrophysics	Van Dishoeck	UL	Dr. Willem Schutte (50%)	4,5	Jan 1, 1999	Jun 30, 2003	
10.5.3.01	Laboratory astrophysics	Van Dishoeck	UL	Dr. Stephan Schlemmer (50%)	1,2	Jul 1, 2003	Aug 31, 2004	
10.5.3.01	Laboratory astrophysics	Van Dishoeck	UL	Dr. Harold Linnartz (50%)	3,0	Sep 1, 2005		
10.5.3.02	Optical-infrared instrumentation	Miley	UL	Prof. Andreas Quirrenbach	5,0	Sep 1, 2002		
10.5.3.03	Optical-infrared instrumentation	Miley	UL	Dr. Bernhard Brandl	5,0	Jul 1, 2003		
10.5.4.01	Evolution of massive stars	Achterberg	UU	Prof. Norbert Langer	4,8	Jan 1, 2000	Oct 31, 2004	
10.5.4.02	Infrared-radio astronomy	Achterberg	UU	Dr. Onno Pols	4,5	Sep 1, 2001		
10.5.4.03	Astronomical instrumentation	Langer	UU	Prof. Christoph Keller	2,0	Jul 1, 2005		

Remarks

- a Additional funding up to 4 year in total is covered by the university
- b Position jointly funded by networks #1 and #2
- c Additional 2 years funding through ESO PhD fellowship
- d With support of external funding
- e Addional funding from NWO Spinoza grant
- f Addional funding from NWO VICI grant

Instrumentation Program

Project/job description	Project leader	Inst	Researcher	Yrs	Starting date	Ending date
ALMA Band-9 development and prototyping, CHAMP+, ALMA phase-2 technical R&D						
Project Manager	Wild	SRON	Dr. Brian Jackson	P	Oct 1, 2003	
Manager industry contracts	Jackson	RuG	Drs. Joost Adema	Pw	Mar 1, 2003	
Instrument scientist	Jackson	RuG	Dr. Andrey Baryshew	Pw	Nov 15, 1999	
Front-End scientist	Jackson	RuG	Dr. Ronald Hesper	Pw	Sep 1, 2000	
Front-End technician	Jackson	RuG	Gerrit Gerlofsma	Pw	Oct 10, 2001	
Documentalist	Jackson	RuG	Albert Koops	Pw	Dec 1, 2003	
Receiver scientist	Jackson	RuG	Dr. Patricio Mena	3,0	Sep 1, 2004	
Receiver scientist	Jackson	RuG	Jan Barkhof	3,0	Mar 16, 2004	
Assembly technician	Jackson	RuG	Marielle Bekema (40%)	2,5	Jan 1, 2005	
Assembly technician	Jackson	SRON	Klaas Keizer	1,8	Mar 1, 2005	
Various staff University of Delft	Klapwijk	TUD				
NEVEC, VLTI						
Technical astronomer	Quirrenbach	UL	Dr. Isabelle Percheron	3,4	Sep 1, 1999	Jan 31, 2003
Technical astronomer	Quirrenbach	UL	Dr. Jeff Meisner	4,0	Sep 1, 1999	Aug 31, 2003
Technical astronomer	Quirrenbach	UL	Dr. Brian Tubbs	0,5	Nov 1, 2003	Apr 30, 2004
Physicist/project manager	Quirrenbach	UL	Dr. Eric Bakker	5,0	Oct 1, 2000	Sep 30, 2005
Software engineer	Quirrenbach	UL	Dr. Jeroen de Jong	5,0	Feb 1, 2000	Feb 28, 2005
Support astronomer	Quirrenbach	UL	Dr. R. Köhler	1,0	Jan 1, 2005	Dec 31, 2005
OmegaCAM, OmegaCEN						
Calibration software scientist	Kuijken	RuG	Dr. Edwin Valentijn	Pw	Apr 1, 1999	
Programmer calibration software	Valentijn	RuG	Danny Boxhoorn	Pw	Apr 1, 1999	
Programmer database and pipeline software	Valentijn	UL	Dr. Roeland Rengelink	4,5	Oct 1, 1999	Mar 31, 2004
Postdoc commissioning	Valentijn	RuG	Dr. John McFarland	3,8	Apr 1, 2005	
PUMA						
Science postdoc	Van der Klis	UvA	Dr. Russell Edwards	3,3	Apr 1, 2001	Jul 31, 2004
Technical PhD student	Stappers	ASTRON	Drs. Ramesh Karrupasamy (60%)	5,0	Jan 1, 2003	
Sackler Laboratory for Astrophysics						
Technical PhD student	van Dishoeck	UL	Drs. Fleur van Broekhuizen	4,4	Oct 1, 2000	Feb 28, 2005
Postdoc	van Dishoeck	UL	Dr. Helen Fraser	3,3	May 1, 2000	Aug 31, 2003
Technical PhD student	van Dishoeck	UL	Drs. Suzanne Bisschop	1,0	Sep 1, 2003	Aug 31, 2004
Postdoc	van Dishoeck	UL	Dr. Guido Fuchs	1,5	Sep 1, 2005	a
SINFONI						
WP2: AO performance simulation	Van der Werf	UL	Dr. Anthony Brown	3,3	Apr 1, 2001	Jun 30, 2004
Emission line studies of high-z galaxies	Van der Werf	UL	Drs. Lottie van Starkenburg	3,0	Oct 1, 2002	Sep 30, 2005 b
MIRI						
NL project manager	van Dishoeck	SRON	Ir. Rieks Jager	P	Jun 1, 2003	
Several ASTRON staff	Jager	ASTRON				
MUSE						
Project manager, AO scientist	de Zeeuw	UL	Dr. Remko Stuik	4,0	Dec 1, 2003	c
Opto-mechanical designer	Stuik	UL	Ramon Vink	1,6	Jan 1, 2005	
Opto-mechanical designer	Stuik	UL	Pascal Hallibert	3,8	April 1, 2005	
X-Schooter						
NL project manager	Kaper/Groot	ASTRON	Dr. Lars Venema (parttime)	P	Mar 1, 2003	Sep 30, 2005
NL project manager	Kaper/Groot	ASTRON	Ramon Navarro (parttime)	P	Mar 1, 2005	
Several ASTRON staff	Venema/Navarro	ASTRON				

Project/job description	Project leader	Inst	Researcher	Yrs	Starting date	Ending date
LOFAR-DCLA						
Postdoc reionization calibration software	de Bruyn/Koopmans	RuG	Dr. Sarod Yatawatta	3,0	July 1, 2005	
PhD student transient calibration software	Wijers	UvA	Drs. Hanno Spreeuw (50%)	2,0	Dec 1, 2005	d
PhD student transient calibration software	Wijers	UvA	Drs. Bart Scheers (50%)	2,0	Dec 1, 2005	d
Postdoc cosmic rays calibration software	Kuijpers	RU	Dr. Andreas Horneffer	2,5	May 1, 2005	
Postdoc surveys data reduction software	Röttgering	UL	Dr. Niruj Mohan Ramanujam	3,0	June 15, 2005	
Seed funding projects						
Adaptive optics for MUSE and Cheops	Quirrenbach	UL	Dr. Remco Stuik	1,0	Dec 1, 2002	Nov 30, 2003
Light Scattering	Waters	UvA	Dr. Hester Volten	1,0	Feb 1, 2003	Jan 31, 2004
GAIA photometric system	de Zeeuw	UL	Dr. Anthony Brown	0,5	Jul 1, 2004	Dec 31, 2004

a Addional funding from NOVA overlap program
b Additional funding up to 4 year in total is covered by the university
c Funded through OPTICON FP6 JRA1
d Co-funded with VICI grant Wijers
P Permanent position
Pw Permanent position for duration of project funding

7. Workshops and Visitors

The NOVA workshops & visitors program enables researchers to invite foreign experts to the Netherlands for collaborative projects.

7.1. Workshops in 2003-2005

The table below lists the workshops which received financial support from NOVA. The table is followed by a description of each meeting. In addition the university astronomical departments in Amsterdam, Groningen, Leiden, Nijmegen and Utrecht received NOVA funding up to 3400 € per institute per year to strengthen the local colloquium program through inviting more foreign speakers. A common approach is to co-ordinate the colloquium programs in various places in such a way that foreign speakers visit two or more institutes during their stay in the Netherlands.

Organizer	Organizing	Institute	Subject	Duration in days	Start
W-25	Fender	UvA	Circular polarisation from relativistic jet sources	3	17/07/02
W-34	Fraser	UL/LC	Solid state chemistry in star forming regions	4	14/04/03
W-35	van Dishoeck	UL	Oort workshop 2003	3	07/04/03
W-36	van den Heuvel	UvA	BeppoSAX Symposium	4	05/05/03
W-37	Mellema	UL/LC	Dutch Astrophysics Days 2003	2	13/03/03
W-38	Israel	UL	Harm Habing emeritus symposium	2	10/04/03
W-39	Olthof	UU	KNVWS symposium 2003	1	04/10/03
W-41	Franx	UL/LC	Workshop FIRES project	6	02/06/03
W-42	Kuijken	UL/LC	OmegaCAM's first surveys	5	30/06/03
W-43	Reuland	UL	Workshop on Emission line halos	1	16/06/03
W-44	Waters	UvA	Retirement of Joop Hovenier	2	15/12/03
W-45	Schilizzi	UL	Science with the SKA	5	10/11/03
W-46	Van Dishoeck	UL	Benchmarking of PDR models	4	05/04/03
W-47	Groot	KUN	Dutch Astronomer Conference 2003	3	21/05/03
W-48	de Jong	UvA	2nd Regensburg Workshop on Babylonian Astronomy: From Observation to Theory	3	26/05/04
W-49	Hogerheijde	UL	Radiative Transfer Modelling of Water	3	22/03/04
W-50	Röttgering	UL	LOFAR and the epoch of reionization	1	07/11/03
W-51	Röttgering	UL	The structure and composition of Active Galactic Nuclei: Optical Interferometry and adaptive optics of NGC 1068	3	12/01/04
W-52	van de Weijgaert	RuG	NAC 2004 conference	3	26/05/04
W-54	Barthel	UU	Summer School of the European Association for Astronomy Education	6	19/07/04
W-55	Fender	UvA	From X-ray Binaries to Quasars: Black Hole Accretion on all Mass Scales	3	13/07/04
W-56	Habing	UL/LC	Near-and Mid-IR studies of galaxies in or near the Local Group	5	03/05/04
W-58	Katgert	UL/LC	Magnetic Fields in Galaxies: Observations and Models	4	05/07/04
W-59	Moortgat	RU	Dutch Astrophysics Days IV	2	01/04/04
W-60	Portegies Zwart	UvA	MODEST-b4	3	06/06/04
W-61	Kuijken	UL	Oort Workshop	3	26/04/04
W-62	Olthof	UL	KNVWS/NOVA Symposium	1	25/09/04
W-63	de Bruyn	RuG/ ASTRON	Interstellar Scintillation of Extragalactic Radio Sources	3	05/04/04
W-64	De Zeeuw	UL/LC	The nuclei of Galaxies Meeting	5	25/07/04
W-65	Van Dishoeck	UL/LC	From Molecular Cores to Protoplanetary Disks	19	07/07/05
W-66	Kuijpers	RU	Drifting subpulses: new challenges for the theory and observations	2	28/06/04
W-67	Langer	UU	Equation-of-State and Phase-Transition issues in models of Ordinary Astrophysical Matter	10	02/06/04
W-68	Franx	UL/LC	The Study of Near-IR selected high redshift galaxies	5	13/09/04
W-69	Portegies Zwart	UvA	Summerschool 2005	5	24/07/04
W-70	Groot	KUN	Studiereis Zuid Afrika	21	04/10/05

Organizer	Organizing	Institute	Subject	Duration in days	Start
W-71	Pols	UU	Nucleosynthesis in Binary Stars	12	04/04/05
W-72	Barthel	RUG/LC	QSO Hosts:evolution and environment	5	22/08/05
W-73	Zaroubi	RuG	Reionizing the Universe	5	26/06/05
W-76	Van der Kruit	RuG	Island Universes:The structure and Evolution of Disk Galaxies	5	03/07/05
W-79	Douglas	RuG	WINT weekend in Groningen	2	08/04/05
W-80	Olthof	Delft	KNVWS: Op reis langs Mars, Saturnus en Titan	1	10/01/05
W-81	Groot	RU	FIRST Nijmegen Workshop on AM CVn stars	7	07/03/05
W-82	Van Dishoeck	UL/LC	Protoplanetary disk evolution	2	07/07/05
W-83	Peletier	RuG/LC	The outer edges of disk galaxies: a truncated perspective	4	04/10/05
W-84	Kaper	UvA	A Life with Stars	5	22/08/05
W-88	van Dishoeck	UL/LC	Star and planet formation with the Spitzer Space Telescope	5	14/11/05

W-25: Circular polarisation from relativistic jet sources

The workshop was held in Amsterdam from July 17 until 19, 2002 and attracted 35 attendees from around the world. It covered the observations, the techniques as well as the theoretical interpretation of the circular polarisation of relativistic jet sources (i.e. X-ray binaries and Active Galactic Nuclei). It holds the tantalising promise of distinguishing between baryonic (e^-:p^+) or 'antimatter' (e^-:e^+) jets from active galactic nuclei and 'microquasars'. The published proceedings should represent the definitive text on this subject for years to come.

W-34: Solid state astrochemistry of star forming regions

This workshop was held from April 14 until 17, 2006 in the Lorentz Center in Leiden and brought together over 60 scientists from Europe, USA and Japan, split around 50:50 between astronomers and physicists / chemists. It was organized to bring together observational and theoretical astronomers working on star forming regions, and experimental and theoretical physical scientists working on surface reactions and processes. The workshop highlighted four major questions (1) data needs and validation; (2) H_2 formation on astronomically relevant surfaces; (3) ices in star forming regions, and (4) chemical reactions (not H_2) on grain / ice surfaces. As a result of the interdisciplinary approach the chemists gained a clearer view on the prevailing physical conditions in interstellar regions. The astronomers on the other hand obtained requirements that help select laboratory experiments and were informed about limitations on the interpretation of their results and their most suitable applications to astronomy.

W-35: Oort workshop 2003

At the initiative of the Oort professor 2003, Prof. Alexander Dalgarno, a workshop on 'X-rays in the Solar System' was held in Leiden from April 7 until 9, 2003. In this highly interdisciplinary topic, 22 atomic- and astro-physicists closely interacted to interpret the latest X-ray observational results, like the presented X-ray spectra taken with Chandra and XMM-Newton. The motivation for this workshop came from the surprising discovery of X-ray emission from comets. As these objects are very cold, the emission is unexpected. (The probable mechanism is electron capture by highly stripped ions impacting the neutral material from the cometary atmosphere.) The fact that models developed by various groups require information on basic atomic processes has stimulated close and fruitful interactions with laboratory physicists.

W-36: BeppoSAX symposium

The second BeppoSAX symposium titled 'The Restless High-Energy Universe' was held in Amsterdam from May 5 – 8, 2003 and attended by about 180 persons. The aim of the symposium was to highlight the areas of research in which the Italian-Dutch satellite has made major contributions to our understanding of the High-Energy Universe during its 6 year active lifetime. The unique capabilities of BeppoSAX for X-ray spectroscopy over a wide spectral range have led to a number of scientific breakthroughs, including (1) the solution to the mystery of the places of origin of Cosmic Gamma-Ray Bursts, they originate in high-redshift galaxies in the early Universe and represent the most violent cosmic explosions since the Big Bang; (2) the discovery of a new type of very long thermonuclear X-ray Bursts from neutron stars; (3) many discoveries on spectroscopic properties of AGN and Clusters of Galaxies and in the field of neutron stars and black holes in binary systems in our Galaxy. The symposium was also devoted to the follow-up of these discoveries with the newest generation of X-ray observatories in space, particularly CHANDRA and XMM. Finally, the first results from ESA's INTEGRAL satellite were presented.

W-37: Dutch Astrophysics Days 2003

The third edition of the Dutch Astrophysics Days was organized by Garrelt Mellema on March 13 and 14 , 2003. The meeting was attended by 31 scientists from all Dutch universities with astronomy institutes or groups, as well as FOM Rijnhuizen. The program reflected the wide interests of the Dutch astrophysical community. There was time scheduled for discussion on education and contact between the different theoretical groups.

W-38: Harm Habing's emeritus symposium "Insight and Wonder"

On the occasion of Harm Habing's 65th birthday and the completion of his monumental compendium on AGB stars a two day symposium was held on April 10 and 11, 2003. The symposium, held in Leiden, was attended by 140 national and international astronomers. The meeting was considered inspiring since the speakers were mainly young, promising scientists and there was an informal atmosphere.

W-39: KNVWS Symposium

On October 4, 2003 the 'Koninklijke Nederlandse Vereniging voor Weer- en Sterrenkunde' (KNVWS) held a symposium in Utrecht on 'Regarding the earth'. The central topics were the environmental issues and humanity's influence on the global climate. (Four experts spoke about the current state of scientific knowledge and also indicated in which cases very little is yet known.) The meeting was attended by 240 participants.

W-41: Workshop FIRES project

The workshop titled 'Deep Infra Red Studies in the Distant Universe: FIRES project' was held in Leiden from June 2 until 7, 2003. This workshop brought together 14 participants from all over the world to discuss a large number of aspects concerning the FIRES project. This project is based on very deep Near-Infrared imaging of 2 fields taken with ESO's VLT and it aims to determine the rest-frame optical properties of galaxies in the early universe. Surprisingly, these properties seem very similar to those of galaxies in the nearby universe. Moreover very massive galaxies have been found at high redshift and in combination with a strong correlation of the red galaxies this suggests that they are 'massive galaxies taking form'. The aim of the workshop was to discuss the latest results of the FIRES team, and to present and analyse the general scientific context of this research area.

W-42: OmegaCAM's first surveys

OmegaCAM is a new wide-field imaging camera for astronomical surveys, (currently being built with NOVA funding and international partners. NOVA has guaranteed access to almost 10% of the observing time.) The workshop took place at the University of Leiden from June 30 to July 4, 2003 and was attended by 23 participants from Germany, Italy, France, the Netherlands and the UK. The aim of this workshop was to bring together those groups that will have guaranteed access to observing time with OmegaCAM, in order to discuss the scientific programs being considered in these different communities, and to try to distill a coherent, coordinated Guaranteed Time Program for the first few years of operation.

W-43: Workshop on Emission line halos

One of the exciting discoveries of the last few years was the existence of very extended (> 100 kpc) emission line halos. This extended gas could provide important clues on how galaxy formation takes place. To help better understand these halos the workshop 'Emission Line Halos: recent observations and modeling' was organized. It took place in Leiden on June 16, 2003 and was attended by 25 scientists and graduate students (from Germany, England, Australia, USA and the Netherlands). The workshop consisted of 13 presentations, with mostly 15-20 minute talks from young researchers and some longer review talks from more senior scientists. The blend of observers and theorists with different levels of experience resulted in many open and exciting discussions and stimulating new ideas.

W-44: Retirement of Joop Hovenier

On December 15 and 16, 2003, the workshop titled 'Light on Planetary Atmospheres, from the Solar System to Exoplanets' was held at the University of Amsterdam. It marked the retirement of Hovenier and was attended by about 50 international participants. The workshop focused on the prospects of using spectroscopy and polarimetry methods proven in the solar system for the study of exoplanetary atmospheres. In contrast to the indirect technique with which the extrasolar planets are detected, these methods can be used to obtain information about the composition and structure of the atmospheres of these planets.

W-45: Science with the SKA

The Square Kilometer Array will be a revolutionary new instrument at centimeter and meter radio wavelengths. With its exquisite sensitivity it will be able to survey large-scale structure in the very early universe as well as pinpoint the details of radio emission near massive black holes in active galactic nuclei. The workshop was held from November 10 – 14, 2003 at the University of Leiden. It brought together 45 astronomers from around the world who are engaged in revising the science case for the Square Kilometer Array. The goals were two-fold: organize and write chapters of the science case, and secondly, select key science projects for the telescope. Consensus was achieved on five key projects, and these have been subsequently been submitted to the International Square Kilometer Array Steering Committee for approval.

W-46: Benchmarking of PDR models

From April 5 until April 8, 2004, a workshop was held at the Lorentz Center in Leiden, which aimed at testing and benchmarking models of Photo-Dominated Regions (PDR). About 30 people from Europe and USA attended the workshop: most of the participants were presenting a PDR code but observers were also invited to participate. Six major questions on PDR codes were addressed and discussed within groups. Large parts of the afternoon were spent performing benchmarking tests. The results of the benchmarking effort were published in a refereed journal.

W-47: NAC 2003 Conference

The Dutch Astronomer Conference 2003 was held in Kleve, Germany from May 21 - 23, 2003. With over 120 national and international participants this conference has contributed to the consistent high level of Dutch astronomy. Special contributions came from the NOVA speakers Greg Tucker (Brown University) on the microwave background radiation and from Bernard Schutz (Max-Planck Institut für Gravitationsphysik) on gravitational waves. The evening lecture was given by Barendregt.

W-48: 2nd Regensbrug Workshop on Babylonian Astronomy: From Observation to Theory

About 10 participants attended the workshop titled 'From Observation to Theory'. This 2nd workshop in the series of workshops on Babylonian Astronomy that started in October 2002 in Regensburg was held at the University of Amsterdam from May 26 – 28, 2004. Topics included (1) lunar observations and theory, and (2) planetary observations and theory.

W-49: Radiative Transfer Modeling of Water

Water is one of the most important molecules in star-forming interstellar clouds. Its abundance variation is more than 10 000-fold from cold molecular clouds to regions heated by newly formed stars and the water emission- and absorption line spectrum thus offers a unique probe of the physical structure of star-forming clouds and the fundamental interaction between gas and grains in such regions. Astrophysical sources with water spectra will be prime targets of the Herschel Space Observatory and HIFI. The workshop was held at the University of Leiden on March 22 - 24, 2004 and was attended by 28 experts. The workshop addressed two themes: testing and benchmarking of computer codes used to simulate the line formation of water in astrophysical environments, and the exploration of the diagnostic capabilities of the water spectrum.

W-50: LOFAR and the epoch of reionization

In collaboration with the EU network "the Physics of the Inter Galactic Medium", Leiden Observatory organized a one-day workshop on "LOFAR and reionisation". The aim of this workshop was to discuss models and present constraints on characteristics of the reionisation epoch in the early universe, the design of LOFAR and issues related to LOFAR's experiment to study the epoch of reionisation. Highlights of the program included: (i) Spergels presentation of the results from the WMAP satellite, which possibly indicates an extended period during which reionisation takes place, (ii) Ferrara's review of our present theoretical understanding of the first stars, with an emphasis on the emerging acceptance that these objects are more massive than present day stars, (iii) The presentations by Ciardi, Miniati and di Matteo on the various foreground that have to be removed during the analysis of LOFAR data before the reionization signal is apparent. A lively discussion led by Katgert ended the workshop.

W-51: The structure and composition of Active Galactic Nuclei: Optical Interferometry and adaptive optics of NGC 1068

This workshop took place at the University of Leiden from January 12 - 14, 2003 and attracted 39 participants. The varying importance of energetic phenomena in active galactic nuclei (AGNs) result in a complex classification of AGNs. This diversity seems caused by orientation effects: from certain viewpoints, circumnuclear dust clouds block the view of the central accretion disk and jets. The dust re-radiates the absorbed energy at infrared wavelengths, but even the largest telescopes have not resolved the dust structures. Recent mid-infrared interferometric spectral observations of NGC 1068 prove the existence of a compact dust structure only a few parsec across. The workshop programme included (1) an overview of the new recent results of multi-wavelength observations of nearby AGNs, (2) a detailed discussion of the VLTI data obtained together with a comparison of the various reduction models, (3) a first confrontation of the various models with the data obtained in 2002.

W-52: NAC 2004 conference

The 59th annual conference took place from May 26 until 28, 2004. In honour of the 90th birthday of Adriaan Blaauw the University of Groningen had organized a special programme titled 'Star Formation: from small to large scales'. For this special programme a number of international speakers were invited, including amongst others Shu (Tsianghua University, Taiwan / University of California, Berkeley), Lada (CfA) and Scoville (Caltech). This attracted an exceptional number of 213 participants. Another special element was the presentation of the pastoor Schmeits award to Van Dokkum for his work on the evolution of galaxies from redshifts 0 to 3.

W-54: Summer School of the European Association for Astronomy Education

This annual summer school was held from July 19 until 24, 2004 and attended by 70 participants from 15 different countries. Goal of the summer school is to offer teachers access to specific research, to new educational materials and methods and the opportunity to exchange experiences. This was achieved as the programme included 3 lectures, 13 workshops on various (didactical) aspects of astronomy in high school education and 3 excursions (to the Sonnenborgh Observatory Museum, the ESA/ESTEC testcenter, Noordwijk, and to the Radio Observatory, Dwingeloo/Westerbork). Participants were also provided with specialized information and concrete lecturing materials.

W-55: From X-ray Binaries to Quasars: Black Hole Accretion on All Mass Scales

The workshop was held at the University of Amsterdam from July 13 - 15, 2004 and was attended by approximately 50 people. Some topics addressed were: (1) whether the spectral state phenomenology seen in X-ray binaries is also seen in AGN, (2) whether quasi-periodic oscillations are seen in AGN, and what might be the best strategies for finding them, (3) how the observations of disk-jet coupling in AGNs and X-ray binaries can be used in a complementary manner to gain a fuller understanding of jet formation, (4) whether some of the high-resolution spectral features most commonly associated with one type of source (e.g. the non-relativistic outflows in AGN) are observed in the other type, and (5) strategies for finding intermediate black holes, especially those making use of our knowledge of supermassive and stellar mass black holes.

W-56: Near-and Mid-IR studies of galaxies in or near the Local Group

From May 3 until May 7, 2004 a workshop was held at the Lorentz Center of the University of Leiden. The workshop brought together about 30 active researchers in the field of infrared observations of red giants in Local Group Galaxies. During this workshop many informal meetings took place between people form very different locations. Most participants arrived with questions and (sometimes) answers of great value to the other participants. The informal style of the workshop was very much appreciated by the participants.

W-58: Magnetic Fields in Galaxies: Observations and Models

A 4-day workshop was held at the University of Leiden from July 5 – 8, 2004, bringing together 36 people. The main driver for this workshop was to bring together the theorists and observers working on galactic magnetic fields, to discuss the outstanding questions, to sort out apparent contradictions and to define new approaches to, sometimes old, problems. One session dealt with the large-scale (or mean) magnetic field in galaxies. Another central theme was the relation between the large-scale and small-scale fields. In the last session, future observational facilities and the next generation of models were discussed, with an attempt to define some crucial observational tests for the applicability of the models.

W-59: Dutch Astrophysics Days 2004

The fourth edition of the Dutch Astrophysics Days was held at the University of Nijmegen on April 1 and 2, 2004 and attended by 31 participants. The 15 oral contributions gave a good overview of the current theoretical astrophysics research in the Netherlands including numerical codes that handle items like relativistic magnetohydrodynamics, shocks, radiative transfer and N-body/SPH simulations. Apart from the numerical work a new model for pulsar radio emission was presented and there were several presentations on non-electromagnetic astrophysics. A general discussion on education and research in astronomy from a 'national' point of view covered the idea of having an 'Interacademiaal expertise college' in addition to the traditional 'Interacademiaal college'. Spinoza laureate professor Cutler gave a lecture on 'Flexibility and inflexibility of speech perception'.

W-60: MODEST-b4 satellite

This informal workshop about MOdeling DEnse STellar systems was held at the University of Amsterdam, from June 6 until 8, 2004. The main aim of the workshop was to bring together a number of experts from the fields of stellar dynamics and stellar evolution, in order to discuss and coordinate efforts toward realistic simulations of star clusters. The workshop attracted some 16 experts in parallel and direct N-body integration on dedicated computer platforms. During the workshop interesting new algorithms for solving the high precision N-body problem were found, several novel parallelization schemes were designed and the future of dedicated hardware was discussed. One of the major achievements during the meeting was the startup of collaborations and the development of a self-regularizing N-body timing scheme.

W-61: Oort Workshop

The Oort workshop was held at the University of Leiden from April 26 until 28, 2004, and was titled 'The CMB and first objects in the end of the dark ages: Observational signatures of reionisation'. This subject currently enjoys great attention, mainly due to the results of the first year of observations with the WMAP satellite, the slightly older data of a Gunn-Peterson absorption in the highest redshift quasars from the Sloan Survey and the now frequent announcement of newly discovered galaxies at very high redshifts. The 44 participants that attended the workshop examined these first sources and their observable characteristics. Oort professor Rashid Sunyaev gave a lecture on 'CMB observations and the production of chemical elements at the end of the dark ages'.

W-62: KNVWS/NOVA Symposium

On September 25, 2004, the KNVWS/NOVA syposium titled 'Een dynamische blik op onze Melkweg' was held in Leiden and attracted about 260 people. The new view of our Galaxy is one of dynamics, birth, evolution and death. At the end of their lives stars expel part of their metal enriched material, which will be incorporated in the next generation of stars. On larger scales the Milky Way itself expels and accretes material. Lectures were given by (1) De Zeeuw, on expanding OB-associations, runaway stars and pulsars, (2) Waters, on interstellar dust, (3) Van Woerden, on high velocity clouds of hydrogen gas in the Galaxy, and (4) De Bruijne, on the Gaia satellite and its goal to determine the formation history, evolution and structure of the Milky Way.

W-63: Interstellar Scintillation of Extragalactic Radio Sources

The aim of this workshop was to provide a forum for discussion of current problems relating to scintillation, in particular of intraday variable (IDV) quasar, BL Lac and Gamma-Ray Burst (GRB) sources. The workshop was held at ASTRON/JIVE, Dwingeloo from April 5 until 7, 2004. The following topics were covered: (1) radio IDV in quasars/BL Lacs, (2) scintillation in GRB afterglows, (3) characteristics of interstellar turbulence, and (4) future telescopes. The workshop was attended by 19 foreign visitors and about 10 local astronomers.

W-64: Nuclei of Galaxies

The nuclei of Galaxies Meeting ran from July 26 through July 30 and was attended by 20 people. The meeting was focused on understanding and comparing data on nuclei of galaxies obtained recently by the two large groups working on the problem: The Nuker Group (using high spatial resolution HST data) and the Sauron Group (using lower resolution but full area coverage data obtained with an Integral Field Spectrometer). Many members of both groups and a few additional investigators attended. The meeting roughly followed the plan of joint session in the morning, with two groups meeting separately in the afternoon. The joint sessions concentrated mostly on a comparison of dynamical modeling methods. The joint sessions also included talks on, and considerable discussion of the core-scouring paradigm. During the private meetings both teams worked on papers concerning this subject.

W-65: From Molecular Cores to Protoplanetary Disks

The three week workshop, held in July 2005, brought together 40 participants in the Legacy program of Spitzer Space Telescope, "From Molecular Cores to Planet-forming Disks", known by the nickname, c2d. The project has recently received the bulk of its data from the spacecraft, and attention at the meeting was on the implications of the data. The first two weeks of the meeting concentrated on the large molecular cloud, integrating the lessons learned from the imaging with those from the spectroscopic work. The last week was devoted to the dense cores and the weak-line T Tauri stars, though work continued on issues raised in the first two weeks. While the primary goal of the meeting was to accelerate the working group agendas, many other goals were also achieved.

W-66: Drifting subpulses: new challenges for the theory and observations

The meeting took place on June 28 and 29, 2004, at the University of Nijmegen and was attended by a small group of 18 specialists. Its aim was to focus on drifting subpulses in radio pulsar emission, their interpretation and remaining problems. The talks presented on the first day covered various, mostly theoretical, aspects of pulsar electrodynamics and emission mechanisms. The second day was completely dedicated to the recent observational results on drifting subpulses. Discussions were essential elements of this meeting and they were in most cases intensive and lively.

W-67: Equation-of-State and Phase-Transition Issues in Models of Ordinary Astrophysical Matter

The workshop took place from June 2 through June 11, 2004 at the Lorentz Center of the University of Leiden. The aim of this workshop was to bring together physicists and astronomers with an interest in the interdisciplinary field of equation-of-state physics. The highest promise lies in the possibility not only to model astrophysical objects, but to use these models to improve our knowledge of basic physics. The topics of the workshop could be classified in three groups: astrophysics of hot dense plasmas and the application of laboratory diagnostics; astrophysics of solid-state objects and links to high-pressure experiments; and fundamental theory of the equation of state and phase transitions. During the last day of the workshop a plenary session was held to discuss what had emerged. The principal outcome of the workshop was that it had allowed two different research communities to meet. The interactions during the lectures, as well as the additional personal contact established outside the formal program, were extremely useful for all 28 participants.

W-68: Workshop "FIRES: The Study of Near-IR selected High Redshift Galaxies", 2004

This workshop was coordinated by Franx, Van Dokkum and Rix in order to bring together investigators studying the high redshift universe through deep Near-IR imaging, and related techniques. The workshop brought together 17 astronomers from various specialities, and allowed for extensive exchange of information and ideas. The workshop focused on the evolution of galaxies, as measured in several ways: from detailed analysis of photometry, through emission line kinematics, through analysis of (very recent) imaging taken with the Spitzer telescope. The program was left open for ample discussion in small groups, with general discussion sessions at the end. The success of the workshop can be measured by the large number of new projects spawned by this meeting.

W-69: MODEST-5c Summer School on Modeling Dense Stellar Systems

In order to fill in some gaps in the knowledge of our young researchers with regard to the MODEST activities a summer school was organized with as main aim to allow the students some hands-on expertise in modeling dense stellar system. MODEST stands for Modeling Dense Stellar systems, and it is a loosely knit collaboration between various groups in Europe, the USA, Canada and Japan working in stellar dynamics, stellar evolution, and stellar hydrodynamics. See also the website: http://www.manybody.org/modest/. The school was held for the duration of one week, during which the 48 students and 7 teachers were hosted by the Astronomical Institute 'Anton Pannekoek' and the Sectional Computational Science, both of the University of Amsterdam.

W-70: Studytrip to South Africa, Marie-Curie, Nijmegen

In the period from October 4 until 24 students, accompanied by scientific supervisor. P. Groot, visited South Africa. On the route from Kaapstad to Johannesburg, several institutes involved in research in astronomy and/or physics, were visited. Although these visits were the main theme of the trip, there was also time for cultural activities and the South African flora and fauna. The trip was a great success. The organizing committee and the scientific supervisor are very content with the scientific level and the smooth proceedings of the trip. Also, the excellent and active involvement of the students has made this trip into a valuable experience to all.

W-71: Nucleosynthesis in Binary Stars

From April 4 until 15 a workshop on the nucleosynthesis in binary stars was held at the Lorentz Center, University of Leiden. The aim of this workshop was to assess the contribution that binary stars make to the synthesis of elements in the Universe. The workshop brought together 35 astrophysicists working in the diverse fields of stellar nucleosynthesis, binary star evolution, novae and supernovae, stellar abundances and presolar grains from meteorites. In a series of review talks the present state of affairs in these fields was discussed and in particular, the currently open questions were addressed. The program and length of two weeks of the workshop allowed for plenty of informal discussion between talks and for the participants to work on many of the problems discussed. A summary article on the highlights of the workshop was submitted to a leading astronomical journal.

W-72: QSO Host Galaxies: Evolution and Environment

From August 22 until 26, 2005 a workshop on QSO host galaxies was held at the University of Leiden. The interest in the workshop exceeded the expectations of organizers greatly. In stead of the expected

30-40 participants, 62 astronomers applied from all over the world. All research components (observation, interpretation, theory and modeling) were present. Twelve invited reviews, 26 contributed talks and 18 posters were considered. A Proceedings-paper will be published by Elsevier, in the series New Astronomy Reviews.

W-73: Reionizing the Universe Conference

The conference was held from June 26th – July 1st, 2005 at the University of Groningen and was visited by 132 participants. The conference was one of the first conferences that is completely focused on the newly emerging field that studies the Epoch of Reionization of the Universe. The program attempted to cover most of its theoretical and observational aspects of this epoch, the conditions prevailing in the intergalactic medium prior to it and its ramification on structure formation and the properties of intergalactic medium after it. The program was divided into three parts: the pre-reionization Universe, the reionization process itself and the post-reionization intergalactic medium.

W-76: Island Universes: The structure and Evolution of Disk Galaxies

The Island Universe: Structure and Evolution of Disk Galaxies conference was held on the island of Terschelling from 3-8 July, 2005. It was attended by 125 registered participants coming from 23 different countries. A total of 50 oral papers were presented including a conference summary. Furthermore, more than 50 posters were presented, which were summarized in two short presentations. The reason for the conference was the appointment of Prof. Piet van der Kruit on a new honorary chair -the Jacobus C. Kapteyn Professorship in Astronomy. We would orginanize the meeting to celebrate Piet's achievements in astronomy and thank him fot his generous contributions to astro-politics and administration. Thetopiuc of the conference had to be a tribute to Piet's life long science interests: the properties of disk galaxies. The goal of the meeting was to take inventory of our current knowledge of the structure and content of disk galaxies, to present models of formation and evolution leading to disk galaxies, and to bring together observers and theorists to investigate paths for future research.

W-79: WINT weekend Groningen

On Friday April 8 and Saturday April 9 the four winners of the INT Observation contest visited the Kapteyn Institute. Under leadership of Douglas and students Starkenburgh and van Bethlehem the winners worked on observational data. A report of the visit was made by journalist Rene Fransen, for the June 2005 issue of the popular-scientific magazine "Natuurwetenschap & Techniek".

W-80: Report KNVWS symposium "A trip to Mars, Saturn and Titan"

On October 1, 2005 the KNVWS organized, in collaboration with NVR and the TU Delft, a symposium on planetary research. During the last couple of years Europe has made a formidable contribution to knowledge about Mars, Saturn and its moons, in particular Titan. The Mars-express mission has provided us with impressive images of the surface of Mars, which lead to new insights on the developments of Mars. The Cassini/Huygens mission has mapped the rings and moons of Saturn in great detail. The Huygens capsule landed successfully on Titan and has made fascinating measurements of the composition and condition of the atmosphere. Radio astronomers have determined the trajectory of the Huygens capsule through the atmosphere with staggering accuracy. The scientific and industrial interest in planetary research has strongly increased in the Netherlands. The Nationaal Platform voor Planeetonderzoek (National Platform for Planetary Research) gives shape to this purpose. The lectures were held on these subjects and with 275 people attending, the symposium was a great success.

W-81: First Nijmegen Workshop on AM CVn stars

From July 3 until 9 the department of astronomy of the University of Nijmegen organized the first international workshop on AM CVn stars. A total of 26 people attended the workshop, which was more than expected. This astronomy field is experiencing a revival and some older participants were delighted to see the attention AM CVn star nowadays receive. The format of the workshop was successful, with talks by all participants (including all students) in the morning and the "free" afternoons, which were filled with heated discussions in the offices of the participants. Later in the afternoon a general 'reconvene' session was held to discuss the topic of the day. A conference photo and a number of talks can be found on: http://www.astro.ru.nl/en/amcvn2005/intro.html

W-82: Protoplanetary disk evolution

On July 7and 8, 2005 a two-day workshop took place associated with the 2005 J.H. Oort professor, Anneila Sargent from the California Institute of Technology. The topic chosen Sargent was "Protoplanetary disk evolution". About 30 experts from Europe and the US gathered in Leiden to discuss various new results in this rapidly developing field. The workshop focused on three aspects of disk evolution: (i) disks in the embedded phase; (ii) grain growth and grain settling, and (iii) mixing processes in disks. These topics were particularly timely because of exciting new data from the Spitzer Space Telescope, large ground-based optical telescopes, infrared interferometers, and millimeter interferometers was just becoming available. The Lorentz Center setting stimulated ample discussion among the participants, both during the formal sessions as well as during a delightful outing.

W-83: The outer edges of disk galaxies: A truncated perspective?

A workshop on the outer edges of disks was held from October 4 until 7, 2005 at the Lorentz Center. The workshop brought together 50 experts from all over the world to discuss issues concerning the outer parts of spiral galaxies. The discussion forums, in which all the participants were involved, were centered on the origin of the distribution of matter in the outer parts of disk galaxies. There were five discussion sessions. One of the results from the first three sessions, on the radial distribution of disks, was the unanimity on the fact that the gas in the outer parts is not primordial.

There was also a wide discussion on the origin of dust and metals. There was agreement that understanding the dust in the outer parts will help us to understand the origin of the breaks in the radial profiles. It became clear that the intergalactic UV background cannot be the only ingredient to produce the break in the galaxy radial distribution. It must; however, certainly play a role.

Furthermore, the session on the vertical distribution put into the picture the merging and internal processes in the disk as shapers of the outer disk. And finally, when discussing the role played by the interactions, it was obvious that one has to be careful, again, when defining a disk, since the accreted matter has different properties than that of the outer disk and there is evidence that there are no breaks in the radial profile when there are signatures of debris in the outskirts of galaxies.

In summary, this field is becoming very active and multi-wavelength studies are necessary to understand the distribution of matter in the outer parts of disk galaxies.

W-84: A Life with Stars

From the 22nd to the 26th of August 2005 a conference was held in Amsterdam in honour of Van den Heuvel. With 197 participants of which more than 75% came from abroad, including many renowned scientists, the conference was a big success. The talks covered with subjects like: stellar evolution, compact objects (neutron stars and black holes), and GRBs. Some new discoveries for the first time presented at this symposium found their way into the science sections of several newspapers. The science talks themselves will be published in a special edition of New Astronomy Reviews.

W-88: Star- and planet formation with the Spitzer Space Telescope

From November 14 until November 18, 2005 a meeting was held on recent results obtained with the Spitzer Space Telescope. The EU-RTN PLANET network meeting provided the first opportunity for the European groups involved in the Spitzer Space Telescope legacy programs “From Cores to Disks” (c2d) and the “Formation and Evolution of Planetary Systems” (FEPS) to jointly discuss results. The c2d program is focused on the early evolutionary sequence from pre-stellar cores to protoplanetary disks (up to few Myr), whereas the FEPS program is aimed at the later stages when stellar accretion from the disk terminates and when planets achieve their final masses via coalescence of solids and accretion of remnant molecular gas. The school contained both introductory lectures as well as in-depth presentations of unpublished results. One emerging result from both programs is that the evolution from massive gas-rich disks to tenuous debris disks happens very quickly but unpredictably: age of the system is not the only important parameter. Grain growth starts at an early stage and is inferred from the shape of the infrared silicate features and the millimeter spectral slopes. Both PAHs and crystallinity provide unique diagnostics of disk shape and energetic processing. The school included a brief tutorial on the use of Spitzer data.

7.2. Visitors in 2003 – 2004

The table in this section lists the foreign visitors who received financial support from NOVA to visit the Netherlands for collaborative projects with NOVA researchers. The table is followed by a description of each activity.

	Host	Visitors	Location	Duration	Start
V-49	De Koter	Dr. J.S. Vink	UvA	3d	31/01/03
V-50	Tolstoy	Prof. dr. K. Venn	RuG	2w	12/04/03
V-51	Van der Hulst	Prof. dr. E. Skillman	RuG	2w	12/04/03
V-52	Portegies Zwart	Prof. dr. D.C. Heggie	UvA	1d	25/02/03
V-53	H. Lamers	Dr. T. Nugis	UU	1m	01/04/03
V-54	De Koter	Dr. C. Dullemond	UvA	4d	06/03/03
V-55	Van den Heuvel	Dr. A. Fruchter	UvA	1m	01/04/03
V-58	Van Dishoeck	Dr. D. Johnstone	UL	2m	05/05/03
V-59	Portegies Zwart	Prof. dr. D.C. Heggie	UvA	1d	03/06/03
V-60	Van den Heuvel	Dr. D. Frail	UvA	9d	26/04/03
V-61	Röttgering	Prof. dr. M.A. Dopita	UL	3w	01/06/03
V-62	Portegies Zwart	Dr. M. Freitag	UvA	3d	13/08/03
V-63	Röttgering	Dr. R. Windhorst	UL	1m	20/06/03
V-65	Henrichs	Dr. E. Verdugo	UvA	1w	18/08/03
V-66	Fender	Dr. A. Merloni	UvA	1w	16/07/03
V-67	Portegies Zwart	Prof. dr. D.C. Heggie	UvA	1d	21/08/03
V-69	Hogeveen	Prof. dr. F. Halzen	NAC	1d	23/01/04
V-70	Röttgering	Dr. W. Breugel	UL	1w	20/11/03
V-71	Kaper	Dr. J.Th. van Loon	UvA	4d	13/01/04
V-72	Fender	Dr. J. Malzac	UvA	3d	04/02/04
V-73	Fender	Dr. C. Brocksopp	UvA	5d	23/02/04
V-74	Van den Heuvel	Prof. dr. P. Gosh	UvA	5d	23/02/04
V-75	Portegies Zwart	Dr. B. Elmegreen	UvA	1d	27/02/04
V-76	Fender	Dr. T.Belloni	UvA	6d	29/03/04
V-77	Portegies Zwart	Prof. dr. S. McMillan	UvA	3d	23/03/04
V-78	Van den Heuvel	Dr. L. Yungelson	UvA	3m	12/04/04
V-79	Franx	Dr. G. Rudnick	UL	7d	32/05/04
V-80	Van den Heuvel	Prof. dr. J. Narlikar	UvA	8d	24/04/04
V-81	Volten	Dr. O. Munoz	UvA	3w	25/04/04
V-82	Johnston-Hollitt	Drs. M. Fleenor	RuG/UL	2w	23/06/04
V-83	Fender	Dr. A. Celloti	UvA	6d	28/06/04
V-84	Portegies Zwart	Prof. dr. D.C. Heggie	UvA	1d	27/07/04
V-86	Portegies Zwart	Prof. dr. R. Spurzem	UvA	6d	09/12/04
V-88	De Koter	Dr. J. Vink	UvA	5d	29/11/04
V-89	Dominik	Dr. B. Parise	UvA	2d	18/12/04
V-91	Van den Heuvel	Dr. W. Sutantyo	UvA	3m	27/02/03
V-92	Zaroubi	Prof.dr. N. Sugiyama	RuG	2w	29/01/05
V-93	Rutten	Dr. G. Tsiropoula	UU	8d	11/01/05
V-94	Waters	Dr. O. Munoz	UvA	2w	22/01/05
V-96	Portegies Zwart	Drs. E. Mamikonyan	UvA	9d	16/03/05
V-99	Portegies Zwart	Dr. H. Baumgardt	UvA	4d	15/03/05
V-100	Hogerheijde	Dr. I. de Pater	UL	8d	05/06/05
V-101	Portegies Zwart	Prof. dr. Heggie & Dr. R. Klessen	UvA	2x2d	may/jun 05
V-102	Lamers	Dr. M. Borges Fernandes	UU	6w	10/06/05
V-103	Hogerheijde	Dr. D. Johnstone	UL	2w	25/07/05
V-104	Portegies Zwart	Prof. dr. S. McMillan	UvA	1w	16/07/05
V-108	Henrichs	Prof. S. Owocki	UvA	4d	16/07/05
V-110	De Zeeuw	Dr. R. Hoogerwerf	UL	5d	19/09/05
V-113	Lamers	Prof. M. Perinotto	UU	2w	02/10/05
V-114	Portegies Zwart	Prof. dr. D. Merritt	UvA	3d	06/10/05

V-49: Visit of Dr. J.S. Vink

Vink (Imperial College, London) visited the Astronomical Institute of the University of Amsterdam in the period from January 22 until 24, 2003 as part of an ongoing long term collaboration with de Koter, in order to work on a project concerning the predictions of the mass loss of massive stars in the upper part of the HR-diagram. The predictions focus on (1) the mass loss of the first generations of very massive stars having extremely low metallicities, and (2) the transition of mass loss properties from Of/WN to full blown Wolf-Rayet stars. Vink and De Koter performed these predictions by means of Monte-Carlo simulations in realistic stellar atmospheres, this allowed them to study the mechanism of radiative line driving and the corresponding properties of the winds. A paper addressing the effects of metal content on the mass-loss behaviour of Wolf Rayet-stars was submitted.

V-50: Visit of Prof. dr. K. Venn

Venn (Macalester College, USA) visited Tolstoy at the University of Groningen from April 12 – 27, 2003. They collaborated on several papers and spent time planning their FLAMES observations for an ESO Large Programme and the data reduction and analysis strategy. The aim of that project is to determine detailed abundances and kinematics of a sample of stars in several nearby dwarf galaxies. During her stay in the Netherlands Venn gave colloquia in Groningen and Utrecht.

V-51: Visit of Prof. dr. E. Skillman

Skillman (University of Minnesota) visited Van der Hulst at the University of Groningen from April 14 – 25, 2003. Van der Hulst showed him several of the new observational results from the upgraded 21 cm receivers at Westerbork. Skillman had discussions with several people, amongst others he discussed possible projects for the Spitzer Observatory with Van der Hulst and with Spoon and stellar populations in dwarf galaxies with Tolstoy and Cole. Tolstoy and Skillman also finished a paper. Skillman gave two colloquia in Dwingeloo and Groningen, and also visited the University of Utrecht to talk with Langer.

V-52: Visit of Prof. D.C. Heggie

Heggie (University of Edinburgh) visited Portegies Zwart on February 25, 2003 to discuss and work on the self organization of the dynamical evolution of star clusters. His visit resulted in the development of the McScatter package, an educational program for integrating SeBa binary evolution with simple stellar dynamics. The dynamics is based on binary scattering in a multi-mass field of stars with uniform density and velocity dispersion, using the scattering cross section of Giersz.

V-53: Visit of Dr. T. Nugis

From the 1st to the 29th of April 2003, Nugis (Tartu Observatory, Estonia) collaborated with Lamers at the Astronomical Institute of Utrecht University. Computations of optically thick winds of WNE stars were started by using the inward integration method. The full modeling of these winds consists of three steps: sonic point analysis, outward integration and inward integration. In order to solve this task the opacity run (or velocity run) has been investigated. In Utrecht the evolutionary models of WNE stars (from E. Petrovic) were used to compute subsonic wind models with the empirical scaling method. Different variants for the additional opacity were checked and it was concluded that the solutions, which are in agreement with the internal structure of evolutionary models, can be achieved with the additional opacity proportional to velocity gradient. However, this method is in conflict with CAK-type theory assumptions. Therefore a new method was used whereby the additional opacity is given according to the Gayley (1995) formula. The principal new point here is that additional opacity below and around the sonic point is provided by the velocity gradient of turbulent (convective) flows.

V-54: Visit of Dr. C. Dullemond

Dullemond (MPIA) visited the University of Amsterdam on March 6 and 7 and on April 28 and 29, 2003, as part of a ongoing long-term collaboration with De Koter, Dominik and Waters to work on a project addressing the structure and composition of disks surrounding young intermediate mass Herbig Ae/Be stars. These disks are believed to be the sites of on-going planet formation. To find out why there are two types of these Herbig Ae/Be disks SEDs of the disks were modeled, including a detailed description of their solid state constituents and a self-consistent treatment of the (vertical disk structure). The visit was extremely beneficial voor the PhD work of Meijer (supervised by De Koter), and will be reflected in two thesis chapters.

V-55: Visit of Dr. A. Fruchter

The visit of Fruchter (STScI) to Wijers in April 2003 occurred at a special time, just after GRB030329 went off, and while the supernova associated with it was being discovered and characterized using observing programs of which they both are principal investigators. Consequently, they discussed this burst and coordinated between HST and VLT observations of it. With the obtained HST grism data, Fruchter discovered the underlying host galaxy, an SMC-like underluminous object with unexpectedly strong emission lines. Besides this other ongoing projects were discussed and papers were prepared.

V-58: Visit of Dr. D. Johnstone
Jonhstone (University of Victoria, Canada) visited the Astrochemistry Group from Van Dishoeck from May 5 to June 26, 2003, deciphering the chemical and physical properties of protostellar envelopes. Coupling the submillimeter continuum mapping and molecular line observations with the envelope modelling capabilities of the Leiden group, allowed for determinations of the envelope density and temperature structure along with abundance estimates of key molecules. The collaboration has worked extensively on the submillimeter sources within the Orion Integral Shaped filament and a highlight of this visit was the recognition that the intense radiation field in the Orion region produces a much warmer envelope ~ 30 K than traditional models provide. This collaboration has resulted in a published paper. Additional time was spent in discussions with Papadopolous on the formation of molecular clouds across the Galaxy and the importance of CO as a coolant.

V-59: Visit of Prof. D.C. Heggie
Heggie (University of Edinburgh) visited Portegies Zwart on June 3, 2003, to continue the discussion on the project started with NOVA grant V-52. The 3-body encounter cross sections derived by Giersz were discovered to be wrong. During this visit a correct 3-body encounter cross section was derived and implemented into the simulation program McScatter together with exchange cross sections.

V-60: Visit of Dr. D. Frail
Frail (VLA, Soccoro) visited the University of Amsterdam from April 26 to May 5, 2003, to collaborate on afterglow studies of interesting new Gamma-Ray Bursts for which both had Westerbork observations. Rol , whose research is focused on the radio afterglows of GRBs, profited enormously from the discussions with Frail. Van den Heuvel and Frail also discussed a new model for the GRB jets.

V-61: Visit of Prof. M.A. Dopita
Dopita (ANU) visited the Leiden Observatory from June 1 until 23, 2003, to attend the informal workshop held with NOVA grant W-43, to work with Reuland and to give NOVA colloquia in Leiden and Groningen. Reuland has analyzed the date consisting of SCUBA, XMM and KECK imaging and spectroscopy of several emission line nebulae and during his visit Dopita collaborated with him on several more theoretical aspects relating to these objects. One of the aspects is the energetics and dynamics of the observed outflows.

V-62: Visit of Dr. M. Freitag
Freitag (Astronomisches Rechen-Institut, Heidelberg) visited Portegies Zwart from August 13 -15 , 2003 to couple Freitag's stellar dynamics code with Portegies Zwart's stellar evolution program. The two codes were successfully linked, but the code appeared to be considerably slower than expected.

V-63: Visit of Dr. R. Windhorst
Windhorst (Arizona State University) visited the University of Leiden from June 20 to July 18, 2003. He worked with Röttgering and others in the group of Miley on understanding objects at redshifts $z \approx 6$ that caused reionization. This required a better definition of the luminosity function and the clustering of dropout candidates at $z \approx 6$, which directly constrains the conclusion of the reionization epoch. A study of the properties of (dusty) objects at $z > 5$-6 is also needed and therefore Röttgering and Windhorst wrote a VLT proposal. Finally they determined that dwarf galaxies were most likely the main source of the reionizing flux by using the luminosity function to determine the total reionizing flux in the universe at the end of the reionization epoch. In addition Windhorst gave 7 talks on his recent research at Dutch institutes.

V-65: Visit of Dr. E. Verdugo
Verdugo (ESA, Madrid) visited the University of Amsterdam from August 18 until 24, 2003, to discuss with Henrichs and Schnerr the reduction and interpretation of recent observations of stars with a potential magnetic field. In particular they worked on software corrections of unwanted fringe patterns that influence the values of the resulting magnetic field. This was also done for the magnetic star beta Cephei and preparations were started for an article on this star. A first new conclusion seems to be that the pulsation behaviour of this star varied due to the magnetic field which led to an explosion, similar to those in B emission stars, in 2001.

V-66: Visit of Dr. A. Merloni
Merloni (MPIA, Garching) visited Fender at the University of Amsterdam from August 27 – 31, 2003. Merloni had extensive discussions with Fender, Gallo, Maccarone and Migliari. This resulted in a combined Chandra and VLA observing proposal which was approved, observations will take place in August 2005. Merloni also gave a talk at the University of Amsterdam.

V-67: Visit of Prof. D.C. Heggie
Heggie (University of Edinburgh) visited Portegies Zwart on September 3, 2003. His visit resulted in finalizing the development of the McScatter package started with NOVA grant V-52.

V-69: Visit of Prof. dr. F. Halzen
Halzen (University of Wisconsin, Madison) visited the annual NAC meeting at the University of Nijmegen, on January 23, 2004. The scientific theme of the programme was 'High(est) Energy Astrophysics' and professor Halzen held a lecture titled 'High Energy Neutrino Astronomy: Results from the South Pole'. Only neutrino's can directly convey astrophysical information from the edge of the Universe and from deep inside its most cataclysmic high-energy region near black holes. His observations with the Antarctic Muon and Neutrino Detector Array (AMANDA) led to a proof of concept for an expandable technology with which to build the ultimate kilometer-scale neutrino observatory, IceCube. Halzen made appointments for further collaborations with Achterberg and Falck.

V-70: Visit of Dr. W. van Breugel
Van Breugel (LLNL) visited the Leiden Observatory from November 17 – 21, 2003, as part of an ongoing collaboration using distant radio galaxies to study the formation and evolution of the most massive galaxies and their proto-clusters at high redshift. Van Breugel's observational program at Keck Observatory has provided input for the work of several Leiden promovendi. These ongoing collaborations were discussed with Miley and Röttgering and their promovendi. In addition Van Breugel discussed plans for laboratory astrophysics experiments on interstellar dust materials in high energy density environments at LLNL with Schlemmer (Sackler Laboratory for Astrophysics).

V-71: Visit of Dr. J.Th. van Loon
Van Loon (School of Chemistry and Physics, Keele University, UK) visited the University of Amsterdam from January 13 – 16, 2004 to work with Kaper on HST spectra of the High-Mass X-ray Binary LMC X-4. During the visit the code to model these spectra was adapted to include a more realistic description of the ionization zone in the wind of the massive star in this binary. Different aspects of the analysis of the data were discussed and a plan was agreed upon for the publication of the results. Van Loon also gave a seminar in Amsterdam and Utrecht on 'Mass Loss from Red Giants in Globular Clusters'.

V-72: Visit of Dr. J. Malzac
Dr. J. Malzac (University of Cambridge) visited the University of Amsterdam from February 4 until 6, 2004. He discussed his new model for the disc-jet coupling in black hole systems with Fender, Maccarone and Gallo. Malzac also presented a colloquium

V-73: Visit of Dr. C. Brocksopp
Brocksopp (Mullard Space Science Laboratory, UCL, UK) visited the University of Amsterdam from February 23 – 27, 2004. The main reason for her visit was to work with Fender and Stappers on a large data set obtained from the Australia Telescope Compact Array, on a bright and poorly understood black hole transient. The data reduction is complex (due to a nearby supernova remnant) but highly significant since the target was one of the brightest black hole transients in recent years and no detailed study has yet been made. The work has resulted in a successful ongoing observing proposal and a journal paper has been published.

V-74: Visit of Prof. dr. P. Gosh
Gosh (Department of Astrophysics and Space Research of the Tata Institute of Fundamental Research in Bombay, India) visited the University of Amsterdam from February 20 until 27, 2004. He discussed with Van der Klis and Wijers and their team the formation of the accreting millisecond X-ray pulsars and their relation to the QPO-phenomenon. With Van den Heuvel he discussed the scientific program of the 2005 COSPAR colloquium on 'Spectra and Timing of Accreting X-ray Binaries'. During his visit professor Gosh also gave a talk on 'Neutron Star Spin-up and Spin-down'.

V-75: Visit of Dr. B. Elmegreen
Elmegreen (T.J. Watson Research Center, New York) visited the University of Amsterdam on February 27, 2004. He visited the Netherlands in relation to the LOFAR project and he presented his latest results on the evolution of Young Dense Star Clusters in the form of a colloquium. In addition he discussed the use of IBM supercomputers for N-body stellar dynamical research.

V-76: Visit of Dr. T. Belloni
Belloni (Merate, Italy) visited the University of Amsterdam from March 29 to April 4, 2004. He collaborated with Fender and Gallo. This resulted in the completion of a major review for the Annual Reviews of Astronomy and Astrophysics titled 'GRS 1915+105 and the disc-jet coupling in accreting black hole systems' and in the conception of a further major paper which was subsequently published, titled 'Towards a unified model for the disc-jet coupling in accreting black hole systems' (MNRAS 2004).

V-77: Visit of Prof. Dr. S. McMillan
McMillan (Department of Physics, Drexel University, Philadelphia) visited the University of Amsterdam from March 22 until24, 2004. His visit was directly related to the building of the MODESTA GRAPE-6 special purpose platform in Amsterdam. He collaborated with Portegies Zwart on the finalization of three papers and on the starlab software environment and they discussed possible future collaborations. With the support from several graduate students they were working on various aspects of the formation and evolution of the Galactic bulge.

V-78: Visit of Dr. L. Yungelson
Yungelson (Astronomical Institute of the Russian Academy of Sciences) visited the University of Amsterdam for 3 months starting April 12, 2004. Together with Portegies Zwart and Van den Heuvel they studied the evolution of very high mass stars. According to N-body simulations by Portegies Zwart these stars can form in the clustercenter of young, dense starclusters. Their formation is due to the 'runaway' collisions of massive stars and takes place during the first 5 to 10 million years of existence of the cluster. Yungelson succeeded to modify his evolutionary program such that he was able to calculate the evolution of stars up to 600 solar masses up to late phases of hydrogen burning. Beyond that the code becomes unstable; further work on the code is going on in Moscow.

V-79: Visit of Dr. G. Rudnick
Rudnick (MPIA) visited the University of Leiden for a week starting May 31, 2004. During his visit he collaborated with Franx on a paper describing the growth of the stellar mass density of the Universe at redshifts z=0 – 3. The specific goal of this work was to combine the stellar mass density estimates from different fields on the sky to control the effects of cosmic variance. They also studied systematic effects in the construction of their comparison estimates of the local mass density using the Sloan Digital Sky Survey.

V-80: Visit of Prof. Dr. J. Narlikar
Narlikar (Inter University Institute for Astronomy and Astrophysics, Puna, India) visited the University of Amsterdam from April 24 to May 1, 2004. During his visit he discussed the question of the use of Gamma Ray Bursts (GRBs) for cosmology with the GRB group led by Wijers and Van den Heuvel. On April 29 he gave a colloquium titled 'The Quasi Steady-State Cosmology: A Status Report', in which he presented the pro's and con's of the Quasi Steady State Cosmology.

V-81: Visit of Dr. O. Munoz
Munoz (Instituto de Astrofisica de Andalucia, Granada, Spain) visited the University of Amsterdam from April 25 to May 14, 2004. During her visit she has tested the experimental light scattering facility. She has checked and calibrated the electronics of the setup. Furthermore, she performed test measurements needed to check the connection between the hardware and the software, working in parallel with Volten. In addition they had discussions about joint papers.

V-82: Visit of Drs. M.C. Fleenor
Fleenor (University of North Carolina) visited the Universities of Groningen and Leiden for two weeks, starting June 26, 2004. He collaborated with Johnston-Hollitt on two projects involving the synthesis of optical redshifts of galaxies with radio continuum emission to better understand the dynamical environment of the Horologium-Reticulum Supercluster (HRS). They also discussed the ramifications of their future involvement in the VESUVIO/OmegaCAM project which relates to the HRS. In addition Fleenor collaborated with Van de Weygaert and Romano Díaz towards the quantitative comparison of observational datasets with cosmological simulations. Finally he presented his observational research on the large-scale structure in the HRS at the weekly colloquium.

V-83: Visit of Dr. A. Celloti
Celloti (Scuola Internazionale Superiore di Studi Avanzati, Italy) visited the University of Amsterdam from June 28 until July 3, 2004. She collaborated with Gallo on some aspects of theoretical astrophysics as a part of her PhD. The visit was successful and has resulted in an ongoing collaboration.

V-84: Visit of Prof. Dr. D.C. Heggie
Heggie (University of Edinburgh) visited Portegies Zwart at the University of Amsterdam on July 27, 2004. They continued to work on their Monte-Carlo N-body simulation method, finalized the paper about this work and started to work on a a new concept of integrating N-body systems. In their 'democratic algorithm' each N-body particle (star) has some limited knowledge of time and is able to decide whether or not it has to take an integration step. The method has similarities with a discrete event simulation, but with a self organized scheduler.

V-86: Visit of Prof. Dr. R. Spurzem
Spurzem (Astronomisches Rechen Institut) visited Portegies Zwart at the University of Amsterdam from December 9 – 14, 2004. They have been working on parallelisation algorithms for high preci-

sion N-body simulations, such as NBODY6++. In Amsterdam there are somewhat simpler codes, but they have a nice implementation of both the ring and the copy algorithm. Spurzem and Portegies Zwart have compared performances and scale-ups with their expectations. The copy algorithm fails if the memory of one node is not sufficient to keep the entire system's particle data. Another advantage of the ring algorithm is its ability to use non-blocking communication. They have discussed large scale distributed computing on European and international grids, plans for common projects and their papers and preprints on the subject.

V-88: Visit of Dr. Vink

Vink (Imperial College, London, UK) visited the Astronomical Institute of the University of Amsterdam in the period from November 29 until December 3, 2004 as part of an ongoing long-term collabo ration with De Koter concerning predictions of the mass loss of massive stars in the upper part of the HR-diagram. Two studies were worked on: 1) The results of the graduation research project of Bonsee were assessed. The project was on the automation of a method of mass-loss predictions. This automation was applied to study several aspects of the physics of line driven winds. 2) A pilot study was started investigating the role of metallicity in Wolf-Rayet stars. The main results of this study are that the winds of N-rich WR stars are driven by a myriad of Fe lines, with a dependence of mass loss on Z similar to that of massive OB stars. For more evolved, carbon-rich, WR stars, the winds are also dependent on the Fe abundance, so that they do depend on their chemical environment, albeit with a mass loss metallicity dependence that is less steep. A paper on this topic was published in Astrononmy & Astrophysics, entitled "On the metallicity dependence of Wolf-Rayet winds".

V-89: Visit of Dr. B. Parise

Parise (Toulouse, France) visited the University of Amsterdam for preliminary discussions with Dominik on a project on deuterium chemistry as a tracer of mixing processes in circumstellar disks. This visit also served as a first meeting of Parise with the other group members of the project.

V-92: Visit of Prof. Dr. N. Sugiyama

Sugiyama (National Astronomical Observatory of Japan) visited the Kapteyn Astronomical Institute from January 29th to February 12th. During his visit he gave a colloquium at the Institute on "Cosmological Reionization". He also interacted with a few members, postdocs and students at the Institute. During his visit progress was made on two specific research projects. The first project was concerned with introducing a semi-analytical approach for simulating the Epoch of Reionization. The second project was concerned with the effect of hard photons secondary ionizations on the spin temperature, i.e., the influence of the collisional excitation and ionization due to the electrons that were ionized by x-ray photons.

V-93: Visit of Dr. G.Tsiropoula

Tsiropoula, an associate professor from the Institute for Space Applications and Remote Sensing (ISARS) visited the Sterrekundig Instituut Utrecht for 8 days for scientific collaboration. This collaboration was mainly focused on: (1) Study of chromospheric fine structures on the limb of the Sun; (2) Study of the cooling of a coronal loop; (3) Umbral flashes and running waves; (4) Line inversions of absorbing cloud-like structures. The visit of Tsiropoula at SIU provided the opportunity to work on several questions of ongoing common research programs and discuss ways of further enforcing the existing strong scientific collaboration between ISARS and SIU.

V-94: Visit of Dr. O. Munoz

Munoz (Instituto de Astrofisica de Andalucia, Granada, Spain) visited Volten from January 22 until February 5, 2005. The collaboration with Munoz, who is an expert in light scattering measurements and calculations, is a long standing one and this one is a continuation of the previous visit (V81). The main purpose of this visit was to discuss two joint papers in preparation. These two papers deal with the results of light scattering measurements performed in Amsterdam during previous measurement campaigns. Apart from these papers we have discussed our contributions to the upcoming light scattering conference in Salobrena, Spain, May 16-20, and Munoz was able to give advise about the acquisitions we are currently making for "the color of polarization project" and about new LabView software developed in Spain that may also be used for the experiment in Amsterdam.

V-96: Visit of Drs. E. Mamikonyan

Mamikonyan (Drexel University, Philidelphia, USA) visited the University of Amsterdam from March 16 to March 24. He collaborated with Portegies Zwart. Progress was made on two main items: 1) chart out detailed plans for the upcoming paper on the formation of intermediate-mass black holes in dense nuclear star clusters, and 2) Discuss the parallelization effort for time-critical sections of Starlab. After discussing various aspects extensively, a preliminary draft for an article was written. Furthermore, in collaboration with Vermin (SARA) Mamikonyan and Portegies Zwart discussed in detail his strategy for parallelizing direct N-body integrators. Furthermore, a test code was constructed.

V-99: Visit of Dr. H. Baumgardt

Baumgardt (Sternwarte Bonn) visited the astronomical institute "Anton Pannekoek" from March 15 – 18, 2005 to collaborate with Portegies Zwart and his team on the dynamical evolution of dense star clusters, such as MGG-11 in M82. The work done in 2004 on the runaway merging of stars in MGG-11 to explain the ultra luminous X-ray source was extended. This paper was published in Nature. A new Nature publication was also worked on. This paper discusses a self consistent theoretical model for the inner 100 pc of the Milky-Way galaxy. Future collaborative projects were discussed, in particular together with Hopman (PhD student at the Weizmann institute). This work discusses the possibility of tidal capture of stellar objects by an intermediate mass black hole.

V-100: Visit of Dr. I. de Pater

In the week June 5 - 11, De Pater (UC Berkeley) visited Leiden University, where she worked with Hogerheijde on CARMA observations of comets. They finished the data reduction of the combined BIMA/OVRO array observations of comet LINEAR. Furthermore, they started to adapt the Monte Carlo radiative transfer code from Hogerheijde and Van der Tak (2000) to cometary emissions. Most of the code was finished and work was started on deriving production rates for HCN. Also, a first draft for a paper was written. De Pater also gave a talk in Nijmegen, where she discussed science with Nigl, and in Amsterdam where she discussed science with Hovenier and his group.

V-101: Visit of Professors D.C. Heggie (Edinburgh) and R. Klessen (Potsdam)

Icke and Portugies Zwart organized the Interacademial Lectures for the 2005 curriculum (see http://www.strw.leidenuniv.nl/~icke/html/IAC2005.html). In order to give the students some direct exposure to two of the world leading experts in the field Heggie (University of Edinburgh, expert in stellar dynamics by means of direct N-body integration) and Klessen (IPA Potsdam, expert in star formation via smoothed particles hydrodynamics) were invited. Both guests gave 2 to 3 hours of lectures to our IAC (master) students in astronomy. Both lectures (Heggie 11 May 2005; Klessen 8 June 2005) were timed at such a moment at the course that the students would be able to follow the technical details and theoretical complications discussed by the two guest speakers. Both lectures were of high quality and the students (after evaluations) liked this approach very much. Inviting guest speakers for the Interacademial Lectures is considered to be a great success.

V-102: Visit of Dr. M. Borges Fernandes

Borges Fernandez (Observatorio do Valongo, Rio de Janeiro, Brasil) visited Utrecht from June 10 to July 18, 2005. He collaborated with Lamers. Together they worked on B[e] stars with emphasis on observations, mainly high-resolution optical spectroscopy. The aim of the visit was to combine the newest results gained with Borges Fernandez' observations and the theoretical models made by Lamers. In addition, a new project was started that dealt with infrared data from some B[e] stars. The timing of the visit was set up by the opportunity for Borges Fernandes to attend the worksop "Stars with B[e] Phenomenon" on Vlieland, 10-16 July, 2005, and present some of the results.

V-103: Visit of Dr. D. Johnstone

In July and August 2005 Johnstone and Kirk (Herzberg Institute for Astrophysics, University of Victoria) visited Leiden University. Johnstone and Kirk attended the c2d Spitzer Legacy team meeting. They shared the details of their analysis of the Ophiuchus and Perseus clouds, which were obtained as part of the COMPLETE Survey of Molecular Clouds. Through presentations during the main meetings and small group discussions work was done on the connections between the two important data sets and how to best further analyze the data sets. As a second component to the visit Johnstone collaborated with Hogerheijde to further define the Internediate Mass Protostar project for the HIFI Key Water Project.

V-104: Visit of Prof. S. McMillan

Mc Millan (Drexel University, Philadelphia, USA) visited Portegies Zwart (UvA) from July 16 to July 22, 2005, During his visit, they worked on the preparation of the MODEST-5c summer school, of which a separate report follows. It was our intention to work also on building a better leapfrog for performing direct N-body integrations; however, we were sidetracked by the discovery of the planet around the primary star of a triple star system HD188753. In the one week of McMillan's visit we analyzed the observational problem, came up with a theoretical explanation, performed the numerical calculations, analyzed the data and wrote the paper. The paper has been published in ApJ Letters.

V-108: Visit of Prof. S. A. Owocki

From July 16 until 20, 2005 Owocki (University of

Delaware, USA) visited the Anton Pannekoek Institute. The main purpose of the visit of Owocki was to discuss the results and detailed plans for the further collaboration between our research groups on the influence of magnetic fields on the outflow of stellar winds in massive stars. This is one of the topics of the PhD work of Schnerr, and Owocki will be invited to be on his thesis committee as he is the world-leading expert on theoretical calculations on stellar wind outflows. A first draft of a paper by Schnerr et al. on the enigmatic time dependent behavior of the stellar wind of the magnetic star beta Cephei was discussed. A colloquium on his recent work by Owocki was held on July 18, which was in particular very inspiring for our group. Furthermore, detailed plans were made about the format of the meeting in Japan (Aug 2005), chaired by Owocki, as HFH is a member of the IAU working group on active B stars, which was supervising this meeting.

V-110: Visit of Dr. R. Hoogerwerf

Hoogerwerf (CfA, Cambridge, USA) visited Leiden Observatory from September 19 - 23, 2005. The goal of this visit was to make together with De Bruijne (ESTEC), Brown and De Zeeuw a first assessment of the data quality of the new, on-going reduction of the Hipparcos Catalogue by Van Leeuwen (Cambridge)and to possibly apply these data to update the results from the De Zeeuw et al (1999) article: "A Hipparcos Census of the Nearby OB Associations". A detailed comparison of the new and old parallaxes showed that the new formal parallax errors are indeed significantly smaller. However, the new parallaxes did not move away from the originally published parallaxes, in the reduction process, as one would expect from the error analysis. After consultation with Le Poole, it was decided to suspend the project until these issues have been solved.

V-113: Visit of Prof. M. Perinotto

Perinotto (Firenze-Arcetri, Italy) visited the University of Utrecht from October 2 until 15, 2005. He collaborated with Lamers on an improved radiative transport program. This program will calculate the profiles of the visual and infrared spectral lines of H and He in stellar winds in the central stars of planetary nebulae. This program will also interpret the new observations of extra-galactic planetary nebulae. On 12 October Perinotto gave a colloquium entitled "The chemical abundances of the planetary nebulae".

V-114: Visit of prof. D. Merritt

Merritt (Rochester Institute of Technology, USA) visited Portegies Zwart from October 6 to 8, 2005. Merritt is the head of an active group which studies the dynamics of dense star clusters and Galactic nuclei using special purpose GRAPE hardware. Merritt's hardware setup is inspired by our MODESTA computer for MOdeling DEnse STar clusters in Amsterdam (http://modesta.science.uva.nl). Merritt and Portegies Zwart discussed how to coordinate research between these two special purpose super computers. They worked on a paper about the performance of special purpose hardware in a parallel environment with high-speed network. In subsequent projects they plan to couple their currently separate computers in a GRID environment to be able to perform joined very large scale simulations of galactic nuclei. This may allow simulation of the sphere of influence of the super massive black holes in active galaxies. Merritt also gave a nice overview of his work at RIT in the form of a colloquium.

8. NOVA Information Center (NIC)

Popularization of astronomy is an excellent manner for stimulating interest in the natural sciences in general, which is of great importance at a time when the interest in university studies in some of these disciplines is declining. The strategy of NIC is to inform journalists through press releases, and to issue news letters to school teachers aiming that they pass the information to the broader public. NIC staff and members of the Minnaert Committee produced multimedia material, maintained the NOVA website for public outreach (www.astronomie.nl) and organized special media events. They also explored various opportunities to increase the visibility of astronomy in various science museums like Artis Planetarium, NEMO and Museon, and explored options to promote a new initiative named Astronomium. The lessons learnt include the observation that museums are enthusiastic about the idea to exhibit more astronomy oriented materials but suffer from financial resources to implement such plans.

In 2003-2004 NIC staff member Visser made an inventory of existing astronomy activities in the Netherlands for primary and secondary schools. Materials gathered were made available for further distribution through the NIC website. It was concluded that a lot of materials exist but teachers have lack of time to search for projects they can use at their school. Subsequently, in collaboration with the Nederlandse Astronomen Club, the Koninklijke Nederlandse Vereniging Voor Weer- en Sterrenkunde and teachers, new ideas were developed for practical methods for education in natural sciences. These activities also led to closer collaboration with biologists and meteorologists who developed similar initiatives. Through Barthel the Ministry of Education, Culture and Science was informed about the initiatives. The ideas were well received and the Ministry encourages the group to develop a focused proposal that could be considered for support.

NIC staff was completely renewed during the re porting period. Jaspers (0.6 fte) left per October 2004 and Visser (0.5 fte) retired per September 2005. Baan (0.6 fte) started in April 2005. With financial support of ASTRON and SRON NIC staff amounted to 1.1 fte up to the end of 2004. Thereafter it dropped to 0.6 fte because external support disappeared.

8.1. Astronomical press service & astro-newsletter

Press releases to the media via the NIC electronic news service named 'Astronomische Persdienst' produced a steady stream of information about national highlights of new astronomical discoveries to journalists. Through this channel NIC informed the media about 20 times per year, not counting simple 'forwards' from other organizations. Some press releases were issued in close collaboration with outreach officers at ESO and ESA when appropriate. In a number of cases the press releases got prime media attention, for instance at national TV stations (twice in 2005) and national newspapers. Until his departure Jaspers was leading this effort and Baan took over when she arrived.

Jaspers was also responsible for the astronomy pages on the website of 'Kennislink'. This website is a national initiative sponsored by the Ministry of Education, Culture and Science to distribute scientific information among the general public. Through this medium he published news articles about astronomy and special events on the nightly sky on a weekly basis.

In 2005 Baan initiated a campaign at the university astronomical institutes to increase the awareness under NOVA staff to inform the general public about results of their astronomical research. The overall aim of this action was to improve the balance in the news media between reporting on national results and those from abroad.

8.2. Special events

NIC co-organized or participated in the following outreach-events:

- Submission of the ESA-ESO astrophysical exercises in the Dutch language and distribution among high school teachers in physical sciences (2003);
- Participation in Hi-Sparc (high school project on astrophysical research with cosmic rays) during the science week in October 2003. This project allowed high school students to observe high-energy cosmic rays using a detector at their school. Demonstrations were also given at the astronomical and physics institutes at the universities of Amsterdam, Groningen, Leiden, Nijmegen and Utrecht and at ASTRON in Dwingeloo during the national science days on 18-19 October;
- Major media attention including TV for the Venus transition on 8 June 2004. The special website got over half a million visitors. As part of a special project high school students and other persons interested were guided to calculate the distance between the Sun and the Earth using accurate timing measurements of the Venus transition. The result obtained was accurate within 0.007%;
- Four high school students supported by Barthel

and Douglas observed with the INT on La Palma on 24-25 February 2005. Their proposals were selected out of 42 ideas received in a national contest organized by NIC. Their class mates participated in the observations through an internet connection;
- Mailing of the HST15 DVD with NOVA logo to ~580 high schools in the Netherlands highlighting astronomical results obtained with the Hubble Space Telescope at the occasion of the 15th year in orbit;
- Education project for 10-12 year old kids at the elementary school, in collaboration with ESA and SRON at the occasion of the launch of ESA's Venus Express (October 2005). NIC coordinated the special activities and website for the Netherlands.

9. Organization

9.1 Board

Prof. dr. E.P.J. van den Heuvel (chair)	UvA, until October 2005 (chair till September 2003)
Prof. dr. P.C. van der Kruit (chair)	RuG, Chair since September 2003
Prof. dr. M. Franx	UL, since October 2003
Prof. dr. J.M. van der Hulst	RuG, since November 2005
Prof. dr. M. van der Klis	UvA, since October 2005
Prof. dr. J. Kuijpers	RU
Prof. dr. N. Langer	UU, since April 2004
Prof. dr. G.K. Miley	UL, until October 2003
Prof. dr. F. Verbunt	UU, until April 2004

9.2 International Advisory Board

Prof. dr. J.N. Bahcall † (chair)[1]	IAS, Princeton, USA
Prof. dr. R. Ekers	ATNF, Epping, Australia
Prof. dr. K.C. Freeman	ANU, Canerra, Australia
Prof. dr. M.J. Rees	IoA, Cambridge, UK
Prof. dr. F. Shu	National Tsing Hua University, Taiwan
Prof. dr. R. Sunyaev	MPA, Garching, Germany

9.3 Key Researchers

Prof. dr. A. Achterberg	UU
Prof. dr. P.D. Barthel	RuG
Prof. dr. E.F. van Dishoeck	UL
Prof. dr. M. Franx	UL
Prof.dr. E.P.J. van den Heuvel	UvA
Prof. dr. J.M. van der Hulst	RuG
Prof. dr. M. van der Klis	UvA
Prof. dr. K.H. Kuijken	UL
Prof. dr. H.J.G.L.M. Lamers	UU
Prof. dr. N. Langer	UU
Prof. dr. G.K. Miley	UL
Prof. dr. A. Quirrenbach	UL
Prof. dr. A.G.G.M. Tielens	RuG/SRON, until March 2006
Dr. E. Tolstoy	RuG
Prof. dr. F. Verbunt	UU
Prof. dr. L.B.F.M. Waters	UvA
Prof. dr. R. Wijers	UvA

9.4 Coordinators research networks

Prof. dr. J.M. van der Hulst	RuG	Network 1
Prof. dr. E.F. van Dishoeck	UL	Network 2
Prof. dr. M. van der Klis	UvA	Network 3, until April 2004
Prof. dr. A. Achterberg	UU	Network 3, since April 2004

9.5 Instrument Steering Committee

Prof. dr. M.A.C. Perryman (chair)	ESA/UL	Until June 2003
Dr. R.J. Rutten (chair)	ING, La Palma	Since June 2003, director ING
Ir. A. van Ardenne	ASTRON	Until March 2005, head ASTRON Lab
Prof. dr. M. Franx	UL	Until Nov 2003
Prof. dr. M.W.M. de Graauw	SRON	IR/submm; HIFI
Dr. P. Groot	RU	Spectroscopy
Dr. H.J. van Langevelde	JIVE	Since Sept 2005, interferometry
Prof. dr. C. Keller	UU	Since Sept 2005, Solar, AO
Prof. dr. M. van der Klis	UvA	Until Oct 2005, X-ray timing, pulsars
Prof. dr. K.H. Kuijken	UL	Wide-field imaging
Prof. dr. G. Monnet	ESO	Head VLT Instrumentation ESO
Dr. J.W. Pel	RuG	Until April 2003, optical, near IR
Prof. dr. A. Quirrenbach	UL	Interferometry, Adaptive Optics
Prof. dr. P .Roche	Oxford	Infrared Instrumentation
Dr. R.J. Rutten	UU	Until March 2004, solar
Dr. B. Stappers	ASTRON, UvA	Since Nov 2005, pulsars
Dr. E. Tolstoy	RuG	User of various VLT Instruments
Dr. M. de Vos	ASTRON	Since Nov 2005, director ASTRON Lab

9.6 Phase-2 Instrumentation Advisory Committee

Members of the Instrument Steering Committee plus

Dr. R. Fender	UvA
Prof. dr. H.J. Habing	UL
Prof. dr. J.M. van der Hulst	RuG
Dr. A. de Koter	UvA
Dr. P.P. van der Werf	UL
Dr. J. in 't Zand	SRON

9.7 Education Committee (check Peter Barthel)

Prof. dr. P.D. Barthel (chair, until Oct 2005)	RuG
Prof. dr. J. Kuijpers (chair since Oct 2005)	RU
Dr. G.J. Savonije	UvA
Prof. dr. F.P. Israel	UL
Prof. dr. R.J. Rutten	UU
Dr. H.J. van Langevelde	JIVE
Drs. A. Weijmans (from Oct 2005)	UL
Drs. K. Wiersema	UvA
Drs. J. Moortgat	RU
S. Rieder	UU
E. Starkenburg	RuG

9.8 Minnaert Committee

Prof. dr. A. de Koter (chair, since Oct 2004)	UvA

[1] Deceased August 17, 2005

Prof. dr. P.D. Barthel	RuG	
Prof. dr. V. Icke	UL	
Prof. dr. H.J.G.L.M. Lamers	UU	
(chair, till Oct 2004		
Dr. P. Groot	RU	
Dr. W. Boland (observer)	NOVA	

9.9 Instrument Principal Investigators

Dr. A. Brown	UL	GAIA
Prof. dr. E.F. van Dishoeck	UL	ALMA Band-9. MIRI, Sackler Lab
Prof. dr. L. Kaper	UvA	X-Shooter
Prof. dr. M. van der Klis	UvA	PuMa-2
Prof. dr. K.H. Kuijken	UL	OmegaCAM/CEN
Prof. dr. A. Quirrenbach	UL	NEVEC, Prima
Dr. R. Röttgering	UL	LOFAR
Dr. R.J. Rutten	UU	DOT
Prof.dr. L.B.F.M. Waters	UvA	MIDI, LSE, CHEOPS-SPHERE
Dr. P.P. van der Werf	UL	SINFONI
Dr. W. Wild	RuG/SRON	ALMA mixers phase-2
Prof. dr. P.T. de Zeeuw	UL	MUSE

9.10 NOVA Information Center (NIC)

A. Jaspers	NOVA, until Sept 2004
J. Visser	UvA/NOVA, until Sept 2005
Drs. M. Baan	UvA, from April 2005

9.11 Office

Prof. dr. P.T. de Zeeuw (director)	UL
Dr. W.H.W.M. Boland (Deputy director)	NOVA
R.T.A. Witmer (finance & Control)	UL, until Sept 2005
C.W.M. Groen (management assistant)	NOVA/UL

10. Financial report 2003 - 2004 - 2005

In k€	2003	2004	2005
ASTRONOMICAL RESEARCH			
Overlap Appointments	**850**	**1036**	**704**
Research Funding			
Network Galaxy Formation & Evolution	433	215	143
Network Birth & Death of stars	324	180	339
Network Final Stages of Stellar Evolution	312	436	298
Other research	218	144	54
Workshop and Visitors	28	79	27
Total Research Funding	**1315**	**1054**	**861**
TOTAL ASTRONOMICAL RESEARCH	**2165**	**2090**	**1565**
INSTRUMENTATION (NOVA funded)			
ALMA mixer development	125	0	0
DOT	42	42	45
VLTI (MIDI, NEVEC)	266	116	161
OmegaCAM / OmegaCEN	285	157	0
PUMA - 2	95	86	601
Sackler Laboratory for Astrophysics	153	26	92
SINFONI	305	73	316
MUSE			239
X-Shooter			357
LOFAR DCLA			93
New Initiatives	189	92	13
TOTAL instrumentation NOVA funded	**1460**	**592**	**1917**
INSTRUMENTATION (external funded)			
ALMA Band-9 prototype receiver	404	805	797
CHAMP+	34	212	37
JWST - MIRI	906	1027	1309
TOTAL instrumentation externally funded	**1344**	**2044**	**2143**
TOTAL INSTRUMENTATION	**2804**	**2636**	**4060**
OVERHEAD			
NOVA Office	184	163	156
Outreach	92	90	60
TOTAL OVERHEAD	**276**	**253**	**216**
TOTAL EXPENDITURE	**5245**	**4979**	**5841**

11. List of abbreviations

2dF	Two-degree Field
2dFGRS	Two-degree Field Galaxy Redshift Survey
2SB	Sideband-Separating (submm) receiver
AAO	Anglo-Australian Observatory
ACS	Advanced Camera for Surveys (on the HST)
ADC	Analog to Digital (signal) Convertor
AGN	Active Galactic Nuclei
AIPS	Astronomical Image Processing System
ALMA	Atacama Large Millimeter Array
AMP	Accreting Millisecond Pulsar
ANU	Australian National University
AO	Adaptive Optics
APEX	ALMA Pathfinder Experiment
ASSIST	Adaptive Secondary Simulator and InStrument Testbed
AST/RO	Antarctic Submillimeter Telescope and Remote Observatory
ASTRO-F	Japanese satellite for IR studies
ASTRON	Stichting Astronomisch Onderzoek in Nederland (Netherlands Foundation for Research in Astronomy)
ATCA	Australia Telescope Compact Array
ATF	Astrometric Telescope Facility
AU	Astronomical Unit
c2d	cores to disks (Spitzer Legacy proposal)
Caltech	California Institute of Technology
CCD	Charge-Coupled Device
CDM	Cold Dark Matter
CESSS	Cavity Enhanced Solid State Spectrometer
CfA	(Harvard-Smithsonian) Center for Astrophysics
CHAMP+	CHAMP+ is a dual-frequency heterodyne submillimeter array receiver built by MPIfR and NOVA/SRON/TuD for APEX
CHEOPS	CHaracterizing Extrasolar planets by Opto-infrared Polarimetry and Spectroscopy
CMB	Cosmic Microwave Background
CRAL	Centre de Recherche Astronomique de Lyon
CRs	Cosmic Rays
CRYOPAD	CRYOgenic Photo-product Analysis Device
CWI	Centrum voor Wiskunde en Informatica
DAQ	Data Acquisition Computer
DART	Dwarf Abundances and Radial velocities Team
DCLA	Development and Commissioning of LOFAR for Astronomy
DDL	Differential Delay Lines (component of the VLTI)
DFG	Deutsche Forschung Gemeinschaft
DIB	Diffuse Interstellar Band
DLAs	Damped Ly-α systems
DMA	Direct Memory Access
DMT	DCLA Management Team
DOT	Dutch Open Telescope
DRGs	Distant Red Galaxies
ELD	Edge-Lit Detonations
EoR	Epoch of Reionization
ESA	European Space Agency
ESO	European Southern Observatory
EU	European Union
EURO-VO	EU funded virtual observatory for astronomy
EVN	European VLBI Network
FEL	Free Electron Laser
FIRES	Faint Infrared Survey (at the VLT)
FLAMES	Fibre Large Array Multi Element Spectrograph (VLT Instrument)
FOM	Fundamenteel Onderzoek der Materie (NWO division for physics)
FoV	Field of View
FP6	Framework Program 6 (EU)
Gaia	ESA's Cornerstone mission on astrometry
GALACSI	Ground Layer Adaptive Optics System (for MUSE)
GBT	Green Bank Telescope
GMC	Giant Molecular Cloud
GMRT	Giant Metrewave Radio Telescope (in India)
GPP	General Purpose Processor
GRB	Gamma Ray Burst
GT	Guaranteed Time
GTO	Guaranteed Time Observations
GWs	Gravitational Waves
HECRs	High Energy Cosmic Rays
Herschel	Far-infrared Submillimeter satellite (see also HSO)
HIFI	Heterodyne Instrument for the Far-Infrared for HSO
HR	High Resolution
HSO	Herschel Space Observatory, ESA's cornerstone 4 mission
HST	Hubble Space Telescope
HV-SETUP	High Vacuum setup
HzRGs	High-redshift Radio Galaxies
IDE RAID	Integrated Drive Electronics - Redundant Array of Inexpensive Disks
IGM	Inter galactic matter
ING	Isaac Newton Group of the Roque de los Muchachos Observatory on La Palma
INT	Isaac Newton Telescope (part of ING)
IoA	Institute of Astronomy (in Cambridge, UK)
IRAS	InfraRed Astronomical Satellite
ISAAC	IR (1 - 5 μm) imager and spectrograph on ESO's VLT
JCMT	James Clarck Maxwell Telescope
KBO	Kuiper Belt Object
KIDS	Kilo-Degree Survey (planned for VST/OmegaCAM)
KNVWS	Koninklijke Nederlandse Vereniging voor Weer- en Sterrenkunde
LEXUS	Laser EXcitation setup for Unstable Species
LFFE	Low Frequency Front End (new receiver on WSRT)
LGS	Laser Guide Star
LINER	Low Ionization Nuclear Emission line Region
LIRTRAP	Laser Induced Reactions TRAPping device
LMC	Large Magellanic Cloud
MDM	Michigan-Dartmouth-MIT Observatory
MEGA	Microlensing Exploration of the Galaxy and Andromeda
MERLIN	Multi-Element Radio Linked Interferometer Network
MHD	Magnetohydrodynamic
MIDI	MID-Infrared instrument (for the VLTI)
MIT	Massachusetts Institute of Technology
MODEST	MOdelling DEnse STellar systems collaboration
MPA	Max-Planck-Institut für Astrophysik
MPI	Max-Plank-Institut
MPIA	Max-Planck-Institut für Astronomie
MPIfR	Max-Planck-Institut für Radioastronomie

MUSE	Multi Unit Spectroscopic Explorer (2nd generation instrument for VLT)
NAC	Nederlandse Astronomen Club
NCRA-TIFR	National Centre for Radio Astrophysics - Tata Institute of Fundamental Research
NEVEC	NOVA ESO VLTI Expertise Center
nm	nanometer
NOVA	Nederlandse Onderzoekschool Voor Astronomie (Netherlands Research School for Astronomy)
NWO	Nederlandse organisatie voor Wetenschappelijk Onderzoek (Netherlands Organization for Scientific Research)
NWO-EW	NWO department for Physical Sciences
NWO-M	NWO-middelgroot
OCIW	Observatories of the Carnegie Institution of Washington
OmegaCAM	Wide-field camera for the VLT Survey Telescope
OmegaCEN	OmegaCAM data center
PAH	Poly Aromatic Hydrocarbon molecule
PDR	Photon-Dominated Region
PI	Principal Investigator
PIC	PuMa Interface Card
PRIMA	Phase Referenced Imaging and Micro-arcsecond Astrometry (facility in development for the VLTI)
PuMa	Pulsar Machine (in use on WSRT)
RAIRS	Reflection Absorption InfraRed Spectroscopy
RAVE	RAdial Velocity Experiment
RTD	Research and Technical Development (an EU program)
RTN	Research and Training Network (an EU program)
SAURON	Spectroscopic Areal Unit for Research on Optical Nebulae
SCUBA	Submillimetre Common-User Bolometer Array (on JCMT)
SDSS	Sloan Digital Sky Survey
SEST	Swedish-ESO Submillimeter Telescope
SIS	Superconductor Insulator Superconductor (mixer)
SISCO	Spectroscopic and Imaging Surveys for Cosmology (EU-RTN network in astronomy)
SMA	Submillimeter Array (on Mauna Kea, Hawaii)
SMC	Small Magellanic Cloud
SNN	Samenwerkingsverband Noord Nederland
SPHERE	Spectro-Polarimetric High-contrast Exoplanet Research
SPIRAS	Supersonic Plasma InfraRed Absorption Spectrometer
SRON	Netherlands Institute for Space research
SURFRESIDE	SURFace REaction SImulation DEvice
TNO	Nederlandse organisatie voor Toegepast Natuur-wetenschappelijk Onderzoek (Research Institute for applied physics in the Netherlands)
TPD	Temperature Programmed Desorption
TU	Technical University
TUD	Technical University Delft
UCSC	University of California, Santa Cruz
UKIRT	United Kingdom Infrared Telescope
ULIRG	Ultra Luminous Infra-Red Galaxy
UNAM	Universidad Nacional Autónoma de México
UNSW	University of New South Wales (Australia)
UT	Unit Telescope
UV	ultra violet
UvA	Universiteit van Amsterdam
UVES	Ultraviolet and Visual Echelle Spectrograph (on VLT)
VLA	Very Large Array
VLBA	Very Long Baseline Array
VLT	Very Large Telescope (ESO)
VLTI	Very Large Telescope Interferometer (ESO)
VST	VLT Survey Telescope
WFI@2.2m	Wide Field Imager on ESO's 2.2m telescope
WHT	William Herschel Telescope (part of ING)
WMAP	Wilkinson Microwave Anisotropy Probe
X-Shooter	single target spectrograph for the VLT
YSO	Young Stellar Object
ZIMPOL	Zurich IMaging POLarimeter