NOVA Report

1999 - 2000

Illustration on the front cover:

Part of a mosaic of Hubble Space Telescope images of galaxy cluster MS 1054-03 at z = 0.83.This is one of the moste distant clusters known; its redshift corresponds to the time when the Universe was only 45 % of its present age.The cluster has been investigated in detail by NOVA researchers van Dokkum, Hoekstra and Franx, and their collaborators.

Illustration on the back cover:

Photograph of a prototype waveguide mixer for the ALMA band 9 (600 to 720 GHz) developed at SRON and University of Groningen.The mixer consists of a feed horn with integrated magnet pole shoes (left), and a mixer element holder (right).The sensitivity of the mixer depends critically on the machining accuracy and the relative alignment, both of which need to be on the order of a few microns.The research and development work is one of the NOVA instrumentation programs.

NOVA Report

1999 - 2000

NOVA
Nederlandse Onderzoekschool voor Astronomie
Netherlands Research School for Astronomy

Postal address
P.O. Box 9513
2300 RA Leiden, The Netherlands

Phone: +31 (0)71 527 5852
Fax: +31 (0)71 527 5743
E-mail: nova@strw.leidenuniv.nl
Web: http://www.strw.leidenuniv.nl/nova

Address
J.H. Oort building
Niels Bohrweg 2
2333 CA Leiden, The Netherlands

Public outreach
NOVA Information Center
Web: http://www.astronomy.nl

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

Table of contents

1. Introduction

In 1997 the Dutch government initiated a ten-year research program, the so-called 'Bonus Incentive Scheme for Research Schools' to identify and stimulate national focus points of excellent scientific research. To meet the selection criteria, such focus points were compared with the best foreign institutes in their field of research. They had to have the potential to develop even further and become centers of excellence of world-class repute. The training of outstanding young scientists was also one of the main objectives of the program. Out of the 34 proposals covering all academic disciplines, six National Research Combinations were selected by the Netherlands Organization for Scientific Research (NWO) in April 1998. The Netherlands Research School for Astronomy, NOVA, was ranked highest among the six, and received an initial grant from the Minister of OCW of 46 Mfl in order to carry out its proposed innovative research program entitled 'The Life-Cycle of Stars and Galaxies'. It combines key investments in permanent and temporary personnel in three related areas of research with a strong program of instrumentation development.
Despite the requirement that the spending profile could ramp up only gradually to full strength by 2002, the NOVA program had a vigorous start, with many new appointments on the permanent and temporary research staff coordinated in three networks, an active workshop and visitor program, and the launch of an ambitious and multi-faceted instrumentation program which is strengthening the technical expertise of the University groups. This report covers the activities in 1999 and 2000.

Highlights include:

– A total of 42 PhD degrees in astronomy awarded at the four NOVA institutions, with cum laudes for van Dokkum, Galama, Groot, Helmi, Hoekstra and Koopmans.
– The award of the Christiaan Huygens Prize to Galama for his research on gamma-ray bursts, with honorable mentions for van Dokkum and Hoogerheijde.
– The AAS Bruno Rossi Prize and the Physica Prize of the Netherlands Physica Society awarded to van Paradijs for his discovery of the first optical afterglow of a Gamma-ray Burst.
– The Spinoza Award 2000 to van Dishoeck for her work in molecular astrophysics.
– The founding and inauguration of NEVEC, the joint NOVA-ESO Expertise Center for Interferometry with the Very Large Telescope.
– The inauguration of the Raymond and Beverly Sackler Laboratory for Astrophysics
– The national NOVA day in fall 1999, which was also attended by the late van Paradijs.
– The ALMA Science and Technology Day in spring 2000.
– The appointment of Langer as full professor in Utrecht.
– A large variety of new astrophysical results summarized in § 3.

The achievements described in this report demonstrate that the entire NOVA program is already strengthening the existing ties between the university institutes and NWO's technical institutes ASTRON and SRON, and with institutions abroad. The program significantly increases the research output, and also enhances the already well-established NOVA graduate education in astronomy. All this has not gone unnoticed, as a number of other countries, both in Europe and elsewhere, are copying the NOVA strategy in order to strengthen their position in world astronomy as well. This is surely a good sign!

2. Mission Statement and Research Program

NOVA is a federation of the astronomical institutes of the universities of Amsterdam, Groningen, Leiden and Utrecht, officially recognized by the Royal Netherlands Academy of Arts and Sciences in 1992, and currently legally represented by the University of Amsterdam.

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 5% of its present age. The goal of the NOVA Program is to unravel the history of star formation in the Universe, and so to understand 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 for the ESO Very Large Telescope, the ESO-VLT Interferometer (VLTI), the VLT Survey Telescope (VST), the Atacama Large Millimeter Array, the Westerbork Synthesis Radio Telescope, and for the Sackler Laboratory for Astrophysics.
The entire program will enable NOVA researchers to obtain a rich harvest of results from the unique ground-based and space-based facilities which will become available during the coming decade, and will allow NOVA to maintain and strengthen its status as an international top center for research and education in astronomy.

3. Progress reports from the research networks

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

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

Recent technological developments have made it possible to observe galaxies and quasars out to redshifts beyond 5, corresponding to a time when the Universe was less than 5% of its present age. This shows that they must have formed in less than a billion years. Instead of drawing conclusions about how galaxies are formed and evolve from a combination of theoretical modeling and observations of their present-day structure in the nearby Universe, it is now possible to observe distant galaxies directly, when they were still young. In this way we can measure, rather than predict, their evolution over most of the age of the Universe. The formation process appears to have started with the formation of dark matter halos. Inside these halos gas then cooled and star formation took place, followed by the chemical enrichment of the initially pristine gas. The strong Dutch expertise in studies of galaxies on the one hand, and on stellar evolution on the other, provides an excellent opportunity for collaborative progress in understanding the link between stellar and galactic evolution. The most important facilities for this research area are the VLT, medium-sized optical telescopes equipped with special purpose instrumentation (WHT and VST), the HST, the X-ray observatories Chandra and XMM-Newton, the EVN-JIVE, and the WSRT. The research in network 1 is mainly concentrated in Groningen and Leiden, with additional effort in Utrecht.

The following summarizes the research activity in the main areas of this network. Not all of this work was funded directly by NOVA.

3.1.1. High redshift galaxies

High redshift galaxies have entered the 'observable universe' in the last decade, in the sense that they can now be studied with modern telescopes and instrumentation. NOVA astronomers have access to many facilities, and are using these to find high-redshift objects, and study them with the goal to understand their structural properties, their abundance and their formation history and mechanisms.

3.1.1.1. H_2 and CO emission from high redshift radio galaxies

Van der Werf and Kosters analysed the HST/NICMOS data of the ultraluminous merger NGC 6240 (Fig. 1), as part of a collaboration including Israel and Moorwood (ESO). The results confirm the pres-

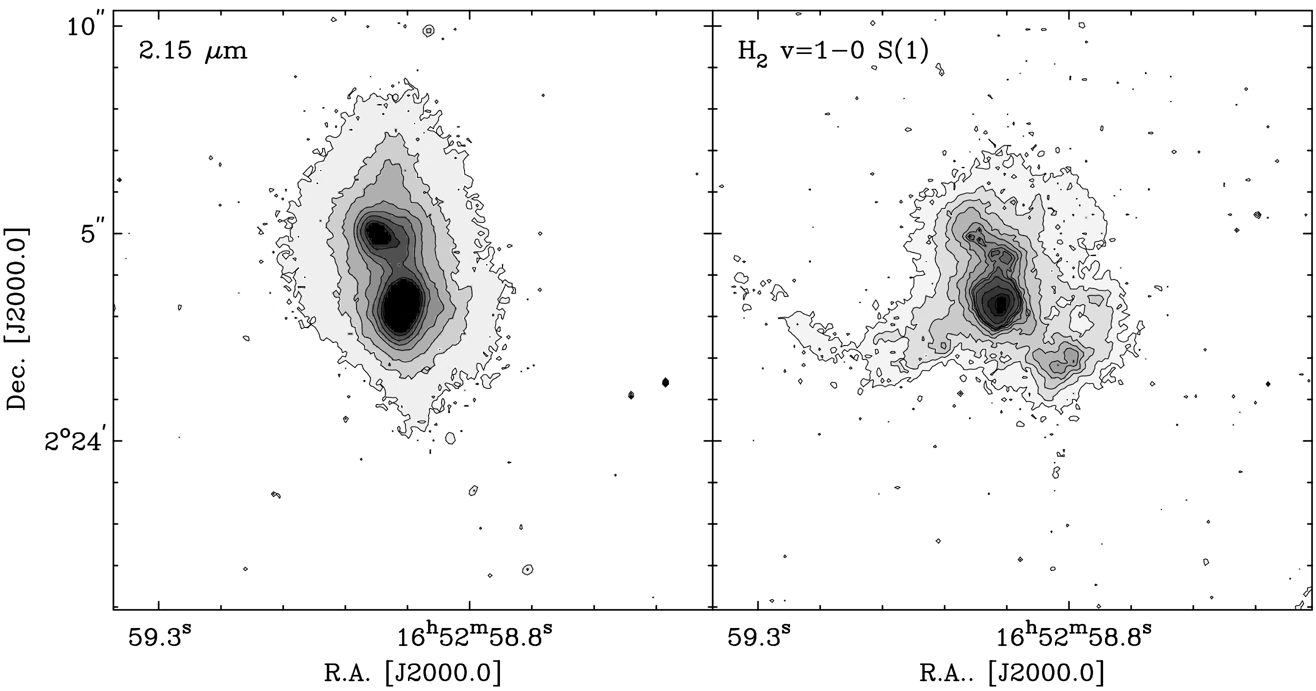

Fig 1: HST/NICMOS images of the ultraluminous merger NGC 6240 (Van der Werf, Kosters, Moorwood, Israel): 2.15 μm continuum (left panel) and $H_2 \nu$=1-0 S(1) emission (right panel).

ence of a molecular gas component between the two nuclei of the merging galaxies, as seen in the $H_2 v=1 \rightarrow 0$ S(1) line. Combined with kinematic information and near- and mid-infrared spectroscopy of other H_2 lines a molecular gas inflow rate of about 260 solar masses per year was inferred, a significant fraction of which towards the central molecular gas component. However, star formation in this component is probably prevented by the large shear in this region.

Papadopoulos, van der Werf and Röttgering, with Omont (IAP), van Breugel (LLNL), Tilanus (JACH) and Guilloteau (IRAM) obtained the first detections of CO emission in two high-z radio galaxies. These galaxies were also detected with SCUBA at the JCMT in the rest-frame far-infrared. The large far-infrared luminosities and gas masses imply that we are witnessing major starbursts in these galaxies, with conditions more extreme than in local ultraluminous infrared galaxies. In one case, the CO emission is extended over more than 30 kpc and spans a velocity range of more than 1000 km/s.

3.1.1.2. Clusters of galaxies and cosmology

Van der Werf, in collaboration with Moorwood and Cuby (ESO) and Oliva (Florence) used the ISAAC spectrograph at the VLT to obtain spectroscopic confirmation of a sample of candidate H_2 emitting galaxies at z~2.2. The candidates were selected based on narrow-band flux excess in the K-band as measured with SOFI at the NTT in an earlier stage of the project. The ISAAC campaign was extremely successful: 6 candidates were spectroscopically confirmed. These objects form the largest homogeneously selected sample of blank-field spectroscopically confirmed star forming galaxies at z~2.2 known to date. Implied star formation rates are in the range 20-35 solar masses per year, significantly higher than in local spiral galaxies. Remarkably, one of the galaxies (the only one observed in good seeing conditions) displays a clear velocity gradient revealing the inner part of a rotation curve. This result implies well-developed massive systems already at z~2.2. When compared to the local B-band Tully-Fisher relation, the system is overluminous by several magnitudes, in agreement with its starburst nature.

3.1.1.3. Active galaxies and star formation

The search for extremely high redshift quasars, carried out by Barthel in a collaborative effort with Neeser and Maza (Santiago), has culminated in lists of such candidate quasars, on the basis of multicolor data for hundreds of thousands of faint stellar objects. VLT spectroscopy will be carried out in 2001. The first result of a study of the ultraviolet emission lines in quasar spectra (with Vestergaard (Ohio) and Wilkes (Harvard)), namely the orientation dependence of the line profiles was published.

Following qualitative studies of IRAS far-infrared continuum emission as orientation indicators and orientation invariants, ESO/RuG graduate student van Bemmel, Barthel, and de Graauw published their ISOPHOT data for samples of quasars and radio galaxies in a quantitative ISO/JCMT/VLA search for such an invariant. Investigation of a wide wavelength range proved essential for discriminating between the various dust components. Barthel and van Bemmel, together with both a scientific and a local organizing committee, organised an international workshop dealing with the Far-Infrared and Submm Spectral Energy Distributions of Active and Starburst Galaxies (see § 7.1).

3.1.1.4. Voronoi tessellations

Van de Weygeart and Icke completed an extensive review on the applications of Voronoi tessellations in diverse branches of science. Using various new techniques for visualizations they confirmed earlier results that had suggested the existence of a self-similar vertex-cluster distribution. The kinematic Voronoi model was meticulously analyzed, and its evolution visualized. Sub samples of clusters selected on the basis of "mass" clearly delineate structures whose size exceeds the cell size proportionally, leading to the conclusion that clustering of clusters on 100 Mpc scales might indeed exist.

3.1.1.5. Galaxy mergers

Van Dokkum and Franx, in collaboration with Fabricant, Kelson, and Illingworth studied the galaxy population in the rich cluster MS1054-03 at a redshift of 0.83. The cluster was observed with the HST, and a large multicolor mosaic of WFPC2 images was obtained. The Keck telescope was used to take 200 spectra of objects in the field. Of these, 80 were cluster galaxies, and combining this with literature data, 81 confirmed cluster members have HST images. A large fraction of these turned out to be mergers. These are either ongoing mergers, or merger remnants, characterized by irregular outer structure. The high merger fraction indicates that many early-type galaxies in clusters have undergone such an event since z=1. Even though it is not certain how typical this result is, it indicates that as many as 50% of the ellipticals may have formed through mergers since z=1. Most of the mergers are not very blue, but rather red. This indicates a rather old stellar population, and is consistent with limits on the mean star formation rate of stellar populations in early-type galaxies in clusters. The merger fraction in MS1054-03 is higher than in other clusters studied until now. Fig. 2 shows the a steep trend of merger fraction with redshift.

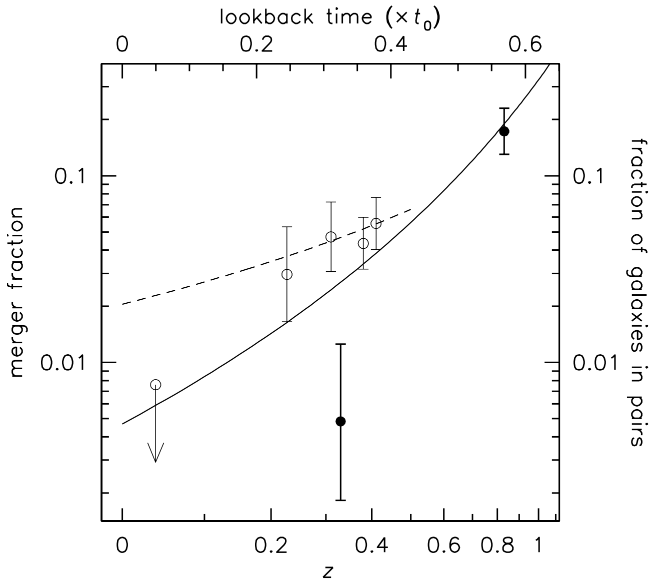

Fig. 2: The merger fraction in rich clusters as a function of redshift. The solid symbols are the clusters MS1358+62 at z=0.33 and MS1054-03 at z=0.83 from van Dokkum, Franx and collaborators. Literature studies of rich clusters are indicated by open symbols. The solid line is a fit to the cluster data. The broken line is a fit to the fraction of field galaxies in close pairs. The merger fraction evolves rapidly in clusters and in the field, possibly even stronger in clusters (van Dokkum, PhD thesis, 1999).

3.1.1.6. FIRES

Labbé and Franx made significant progress on the Faint InfraRed Extragalactic Survey (FIRES): an ultra-deep near-infrared survey of two selected fields, the Hubble Deep Field South (HDFS), and the field around the distant cluster MS1054-03. Over the year all data for the HDFS have been taken, amounting to 100 hours of integration using ISAAC on the VLT. Inspection of the data revealed excellent quality: these are the deepest groundbased observations so far at these wavelengths. Together with the existing space observations in the optical they can address the fundamental issues of galaxy evolution. Work is underway to analyze the images, and the reduced data and catalogues will be made public as soon as possible. The first 20 hours of observations taken on the HDFS were analyzed by Rudnick (MPIA) and Franx. The photometry was completed, and a new photometric redshift technique is under development to estimate redshifts.

3.1.1.7. Searches for high redshift galaxies behind lensing clusters

By combining the magnifying effect of massive galaxy clusters with large telescopes, it is possible to detect very distant, yet intrinsically faint sources. Using the Keck telescope, Ellis, Kneib and Kuijken surveyed several such clusters for isolated emission lines, in the hope to identify high-redshift Lyman-alpha emitters. The search will be continued with the ESO-VLT. This project probes the star-forming galaxy population out to redshift 7, and is sensitive to galaxies with masses of only a few million solar masses. Gravitational lensing provides the only access there currently is to this population.

3.1.1.8. Weak gravitational lensing

Intervening mass distributions between us and distant galaxies cause weak, coherent image distortions through the bending of light by gravitational fields. The distortions can be measured, and used to study the (dark + shining) mass distribution in the intervening redshift interval, principally at redshifts 0.2-0.5. Hoekstra, Franx and Kuijken used weak lensing mosaics of images obtained with the HST to study the mass distribution in three massive galaxy clusters. They found that mass traces light rather well, down to substructure in the dynamically young cluster MS1054-03 at redshift 0.83. Also mass-to-light ratios appear rather constant, appearing to change with redshift only as a result of passive stellar evolution.

A ground-based study of weak lensing by a large ensemble of galaxy groups was carried out with the WHT by Hoekstra, Franx, and Kuijken, in collaboration with the Canadian CNOC team, who identified a number of groups in a deep redshift survey. The weak lensing signal from the groups was clearly detected, and indicates a mass-to-light ratio consistent with $\Omega_M = 0.3$ and no biasing on the scale of groups. As galaxy groups represent the most common environment in which galaxies are found, this result is an important addition to M/L measurements of massive clusters.

Very weak distortions are in principle observable, but these require very accurate techniques in order to overcome systematic effects caused by the atmosphere and by telescope optics. Kuijken developed a new technique which is demonstrably less sensitive to systematic errors than other, widely-used algorithms. It is being applied to the study of the mass distribution at large radii around galaxy clusters, which is where the formation signatures of clusters are expected to be visible.

3.1.1.9. High redshift radio galaxies

There is strong evidence that radio galaxies are amongst the oldest and most massive galaxies in the early Universe, and that they are located in dense cluster environments. As such they place important constraints on the epoch at which the first generation of stars was formed. Particularly relevant questions include: (i) What are the properties of the gas and galaxies of the (proto-) clusters the HzRGs are located in? (ii) What is the origin and fate of the giant (~100 kpc) gas halos associated with HzRGs and what role do they play in the formation of massive galaxies? (iii) At what epoch did the first HzRGs form?

The Leiden 'HzRG-team' (Röttgering, Miley, Jarvis, Wilman, Kurk, Penterricci, Best, de Breuck) conducted a very fruitful multi-wavelength imaging and spectroscopic campaign. Very deep VLT spectroscopy provided a sample of 14 Lyman alpha emitting galaxies in the area of the spectacular radio galaxy 1138-262 ($z = 2.2$) clearly indicating that 1138-262 is at the center of a forming cluster. Deep HST infrared imaging of the highest redshift radio galaxies showed that they are not associated with well-formed ellipticals, unlike their lower redshift counterparts. Deep spectroscopy of powerful $z = 1$ radio galaxies demonstrated that the interstellar medium is dramatically affected by the passage of the radio source shocks. The team also discovered the most distant radio galaxy known to date at $z = 5.2$. This work is continuing with the allocation of a VLT Large Program.

3.1.1.10. Giant and 'double-double' radiogalaxies

Schoenmakers, de Bruyn, Röttgering and van der Laan continued their study of samples of giant (> 1 Mpc) radio galaxies selected from the WENSS survey. A particularly interesting class of sources are the so called 'double-doubles'. These consist of two (pairs) of, aligned, double-lobed radio sources with a common nucleus. The source B1834+62 is considered a prototype; about half a dozen are now known. They shed new light on a range of questions related to the formation and evolution of giant radio sources: such as hot-spot formation, cocoon evolution, lobe expansion speed, and nuclear duty-cycles. The fact that double-doubles have thus far been exclusively found among giant radio sources suggests that age is an important factor in the interruption of nuclear activity. The double-doubles can also be used to set interesting lower limits on the propagation speeds of the inner hot-spots; in B1834+62 this is at least 0.2c.

3.1.1.11. Radio microlensing by galaxy halo dark matter at high redshift

Gravitational lenses can be used to probe the material content and the scale of the Universe and for these reasons have enjoyed tremendous attention during the last decade. The lenses discovered in the CLASS survey have made a major contribution to this area of research. Koopmans and de Bruyn, as Dutch members of the CLASS collaboration, were very active in the use of these lenses, of which about 15 have now been detected at radio wavelengths. Their studies revealed very rapid uncorrelated radio variability in the two components of the gravitational lens source B1600+434. VLA and WSRT observations at frequencies of 1.4, 5.0 and 8.5 GHz provided strong indications that these variations are due to radio microlensing by compact halo objects, and are due to the motion of features in a radio jet (of a quasar at $z = 1.6$) behind a fine-fibered foreground pattern of microlensing caustics. This pattern is due to objects in the halo of the intervening edge-on lens galaxy (at $z = 0.4$). For rapid variations to be detectable there must be extremely compact structure (on a level of 5-10 micro arcseconds) moving at super-relativistic speeds. The discovery was discussed in Science and was one of the highlights in the PhD thesis of Koopmans (RuG, 2000).

3.1.1.12. WSRT's longest and deepest look yet: at the Hubble Deep Field

In the spring of 1999 the WSRT used its new sensitive MFFE's to take a deep look at one of the best studied spots on the sky: the Hubble Deep Field North. Garrett, de Bruyn, Baan and Schilizzi used the WSRT in a 72 hours integration at 1.4 GHz and reached a noise level of about 8 microJy; this is the expected thermal noise level, and is close to the confusion limit (where there is about one source for every 10 beams) at the 15" resolution of the WSRT. They detected more than 200 sources above 45 microJy in a 16x16 arcmin area centered on the 3x3 arcmin HDFN. Eight of these sources fall in the HDFN; two of them had not been seen before. They were not detected by the VLA in a similarly deep survey with 10 times better angular resolution, presumably because of resolution effects. Most of the sources (which approach a density of 1 per square arcmin) are thought to be related to starbursts at moderate redshifts.

3.1.2 Nearby galaxies

The study of nearby galaxies is a fundamental aspect of any investigation of the evolution and formation of galaxies. Present-day galaxies represent a crucial boundary condition that any formation scenario should obey, but more importantly, in nearby galaxies many important aspects of galaxies can be studied that are not accessible (yet) in more distant ones. Particularly details of the stellar population, detailed structure and kinematics, low-luminosity companions, and galactic nuclei, can be studied much better in local galaxies than at great distances. NOVA researchers are using a combination of purpose-built optical instrumentation for 4m-class telescopes with existing multi-wavelength instrumentation on the ground and in space to study nearby galaxies.

3.1.2.1. SAURON

De Zeeuw, Bureau, Copin (NOVA postdoc) and Verolme are members of the SAURON team that has built a panoramic integral-field spectrograph for the 4.2m WHT on La Palma, in a collaboration which involves groups in Lyon (Bacon) and Durham (Davies). The instrument is called SAURON (Spectroscopic Areal Unit for Research on Optical Nebulae), and records 1577 spectra simultaneously, with full sky coverage in a field of 33 by 44'', additional coverage of a small 'sky' field 1.9' away, spatial sampling of 0.94'' x 0.94'', and an instrumental dispersion of 90 km/s. SAURON is funded in part by a grant from NWO, and was built at the Observatoire de Lyon. First light was obtained in February 1999.

SAURON is used for a multi-year program 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 maps reveal significant deviations from axisymmetric kinematics, including minor axis rotation, and s-shaped emission-line gas distributions. Copin developed Fourier-based methods to quantify the rich structure in the kinematic maps.

SAURON observations of the elliptical galaxy NGC4365 (Fig. 3) provided the first full map of a dynamically decoupled core, with the central region of the galaxy rotating approximately around the minor axis, and the bulk of the object rotating around the long axis. The line-strength distributions show that the core and body of the galaxy have had essentially the same star formation history, and suggest that the triaxial structure has been in place for over 12 Gyr.

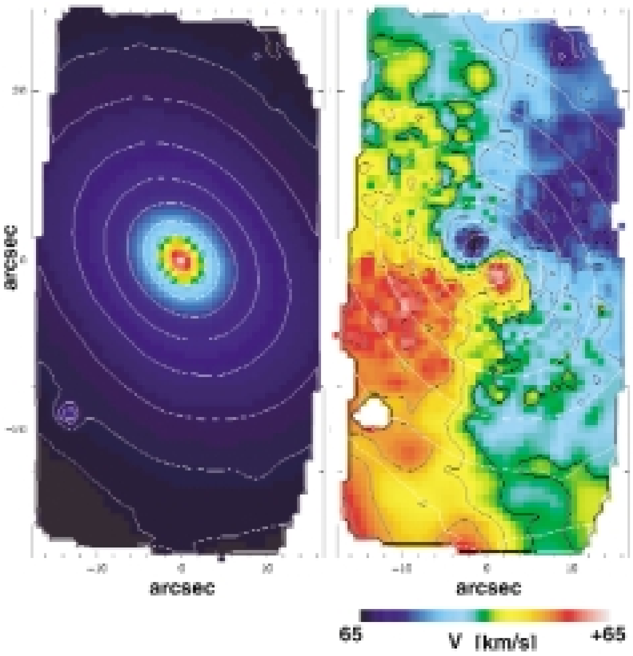

Fig. 3: SAURON observation of the elliptical galaxy NGC4365.The left panel shows the galaxy intensity I, reconstructed from the observed spectra at the lens positions.The right panel is the stellar mean velocity V, with the zero-velocity contour indicated by the thick solid curve. Contours of I are superimposed.

3.1.2.2. Dynamical models

Verolme, Cappellari (Padova), Verdoes-Kleijn and de Zeeuw investigated the nature of the counter-rotating core of the elliptical galaxy IC1459. The dynamical models show that the counter-rotating core is a well-separated structure in phase-space, which comprises about 1% of the stellar mass of the galaxy. The black hole mass inferred from the stellar motions appears to be larger than the one derived by Verdoes-Kleijn and collaborators based on HST/FOS spectra of the gas emission. This highlights the importance of an improved understanding of the various methods that are in wide use to determine black hole masses.

3.1.2.3. Planetary nebulae as tracers of gravitational potentials

With the WHT a new technique was developed by Kuijken, Douglas, Gerssen and Merrifield (Univ. Nottingham) for simultaneous discovery and radial velocity measurement of planetary nebulae in external galaxies, with the aim to measure the stellar kinematics out to large radii where dark matter dominates. These experiments were successful, and this work will be continued starting in 2001 with a purpose-built instrument, the Planetary Nebulae Spectrograph (PNS). This unique instrument is much more efficient, and has a wider field, allowing several galaxies as far as Virgo to be mapped in a night. ASTRON is one of the partners in the international PNS consortium, which is headed by Freeman (ANU, Canberra).

3.1.2.4. Neutral and molecular hydrogen in elliptical galaxies

Van der Hulst, van Gorkom (Columbia University), and Schiminovich (Caltech) studied HI emission from elliptical galaxies with optical shells. These structures are the result of either phase wrapping or spatial wrapping in a minor or major merger. Detailed studies of the galaxies Arp 230 and MCG-5-7-1 were completed. Arp 230 is one of the best candidates in the sample of observed galaxies of spatial wrapping and the HI distribution and kinematics support this idea. The kinematics of the HI in MCG-5-7-1 on the other hand supports the phase wrapping models.

Van der Hulst, Charmandaris (Cornell), and Combes (DEMIRM, Paris) discovered CO emission in the outer HI around the nearby elliptical galaxy Centaurus A (NGC 5128). The implied HI/H_2 ratio is about 1, the same as found for this ratio in the central dust lane of this galaxy. This is rather unexpected if this gas originated from the outer parts of the disrupted satellite galaxy. The presence of CO in the outer HI suggests that the phase wrapping models do apply and that the gas, i.e., the dense and compact cloud component has sufficiently low dissipation to behave similarly as the stars.

3.1.2.5. Kinematics of disk galaxies

Van der Kruit, Kregel, Freeman (ANU, Canberra) and de Grijs (Univ. Virginia) studied a sample of 34 edge-on disk galaxies photometrically and kinematically using the 2.3m ANU telescope at Siding Spring (Australia), the WHT at La Palma, and the VLT on Paranal, Chile. In collaboration with de Blok (ATNF, Sydney) HI synthesis data were also obtained. The goal of the spectral study is to understand the stellar kinematics, and the disk mass distributions of spiral galaxies. Absorption is studied by comparing H-alpha and HI spectra. The thickness of the HI layers will be used to set limits on the vertical velocity dispersions of the stars. Combination of the photometric structural parameters (scale lengths and heights) with kinematics leads to the shape of the velocity ellipsoid, an important parameter in understanding the secular evolution of galaxy disks under the influence of dynamical processes such as heating by molecular clouds or spiral arms, bars, infall etc. The disk flattening can be used to estimate the disk contribution to the maximum rotation velocity. This was determined as 57±22%. At least 20 of the 34 spirals have a radially-truncated light distribution. For small scale length spirals, which are the most numerous in the local universe, the results suggest that the average ration of disk truncation radius to disk scale length is at least four.

3.1.2.6. Faint light around NGC 5907

The edge-on spiral galaxy NGC5907 has attracted interest due to the extended R-band light above its disk plane that is unlike any known thick disk, both in terms of its shallow radial profile and its low surface brightness. The faint light is well fit with a halo-like radial volume density profile $\rho \sim r^{-2.3}$, similar to that inferred for the massive halo from the rotation curve. Subsequent studies confirmed the presence of this light in infrared and optical wavebands from B to K. Suggestions for the origin of the extended light have ranged from a population of low mass stellar objects of varying metallicity, tidal debris from a metal-rich elliptical, and confusion from a thin tidal streamer and an unseen face-on warp of the NGC5907 disk.

To study the stellar population in the extended light, Sackett and colleagues in the US and UK obtained and analyzed HST / NICMOS observations of a field in the halo known to have significant R-band surface brightness. A stellar population of the sort that is suggested by the ground-based surface photometry would yield more than 100 resolved bright giants, but only one candidate was observed in the HST images. Comparison with a variety of stellar models parameterized by their distance, metallicity and IMF slope led the team to conclude that regardless of the origin of the faint light, either: (1) the distance to NGC5907 is larger (at the 5σ level) suggested by other distance indicators, or (2) the giants are so metal-poor ([Fe/H] $\leq$ -1.7) as to escape detection in the IR observations, which is in conflict with ground-based colors, or (3) the mass function of the stellar population is strongly biased toward dwarfs, with an IMF slope $\alpha > 3$.

3.1.2.7. Dust in low surface brightness galaxies

Van der Hulst and Pickering (Steward Observatory) continued their study of dust in low surface brightness (LSB) galaxies. For a sample of galaxies spanning a range of central surface brightness they examined ISO data at λ90, 160 and 200 µm. For a few galaxies they also used JCMT measurements at 850 µm obtained with SCUBA. These data were supplemented where possible with existing IRAS data. The general trend appears to be that the surface brightness in the far-IR/submm follows roughly the optical disk surface brightness. The overall result is that LSB galaxies are still hard to detect in the far-IR/sub- mm: only two of the 10 galaxies observed with SCUBA were detected and none of the very LSBμ_0(B) > 23 mag/arcsec) galaxies observed with ISO were. For a few galaxies there is enough data to estimate the dust temperatures. These fall largely in the normal range of 20-30 K. In the two cases detected with SCUBA, UGC 2936 and UGC 6879, there is a submm excess indicating the possible presence of an additional cold component with T < 15 K.

3.1.2.8. The ISM in M33

Van der Hulst, Higdon, van der Werf and Israel used ISO observations of the 158 µm [CII] line, CO JCMT data, WSRT HI data, IRAS high resolution images in a strip along the major axis of the galaxy M33 to assess the energy balance in the ISM. The data indicates that, except in the central few kpc, most of the [CII] appears associated with the cool, distributed ISM component rather than with PDRs. The data allows the determination of the pressure in the ISM, puts a limit to the CO to H_2 conversion ratio and sets a limit to the HI column density threshold for H_2 formation. Using ANS and UIT UV data to estimate the local radiation field it was possible to determine both the heating and the cooling of the ISM. In the inner 5 kpc heating and cooling balance very well. In the outer parts there is an excess cooling or unexplained [CII] line emission.

3.1.2.9. Warps of galaxy disks

For the first time, an HI survey of nearby edge on galaxies by Garcia-Ruiz, Sancisi and Kuijken has enabled an objective statistical study of the warp phenomenon. A very high percentage of warps is seen: every galaxy with an extended HI disk is warped. A new finding is that almost all warps are quite asymmetric: amplitude differences of a factor of 2 between opposite sides are not uncommon. This is important for the theoretical modelling, which has concentrated (unsuccessfully so far) to find a mechanism to generate ubiquitous symmetric warps. A simulation of the interaction between the Galaxy and its satellites by Garcia-Ruiz, Dubinski and Kuijken showed that, unlike claims in the literature, the tidal interaction is too weak to explain the observed warp of our own Galaxy.

3.1.2.10. Interacting galaxies

Van der Hulst, Hibbard (NRAO), Barnes (IfA, Hawaii) and Rich (UCLA) finished their study of the HI in the interacting galaxy pair NGC 4038/39 (The Antennae). Their new, deep VLA observations revealed a number of interesting features (Fig. 4). The HI in the southern tail is not smooth but has a bifurcated structure, possibly due to a warp in the progenitor disk. The end of the southern tail is believed to entrain a dwarf galaxy, presumably condensed out of the tidal material. There is mild evidence that the concentration of gas and light at the end of the southern tail is a self gravitating entity. This is not the case for other HI concentrations found along the tails. The northern tail lacks HI emission at its base. This can be ascribed to ionization by the numerous massive stars in the disk of NGC 4038 induced by the interaction.

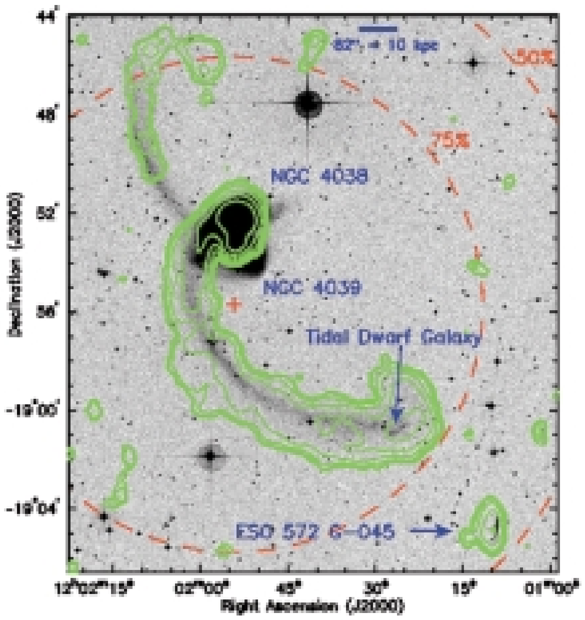

Fig. 4: Integrated emission contoured upon a greyscale representation of the DSS image of "The Antennae". The cross marks the phase center of the VLA observations while the dashed circles represent the 75% and the 50% response points of the VLA primary beam. The two main disks, NGC4038 and NGC 4039, are labelled, as is the location of the putative Tidal Dwarf Galaxy in the southern tail, and the companion galaxy ESO 572-G045. The contours are from the low resolution (40'') data cube, and are drawn at column density levels of (3, 6, 9, 15, 30, 60) x 10^{19} cm^{-2}.

3.1.2.11. Active galaxies

Barthel collaborated with Ho (Carnegie Observatories) and graduate student Filho on a study of the radio properties of LINER galaxies, objects displaying a mild form of nuclear activity. High resolution radio observations (VLA, MERLIN, VLBA, and EVN) were employed to assess the frequency and magnitude of accretion driven energy production in galaxies. Supporting X-ray observations using Chandra were proposed, and it is hoped that kinematical data from SAURON can be used to assess the accretion driving processes.

Barthel and co-workers investigated Seyfert galaxies and low redshift quasars, targeting the interrelation between accretion driven energy production and host galaxy star formation. Radio and optical imaging was combined with molecular gas spectroscopy. A substantial fraction of AGN hosts were found to display vigorous star-formation: the apparent similarity of the star-formation history of the universe and the quasar space density history may not be coincidental. Together with Tielens and ESO/RuG graduate student Spoon, Barthel also investigated the starburst-AGN symbiosis in nearby ultra-luminous IRAS galaxies.

The nature of the class of broad-line radio galaxies, in particular their place in unification schemes, was studied using the VLA, together with Dennett-Thorpe and van Bemmel. This work confirmed the suspected preferred orientation scenario for the broad-line radio galaxy class. Studies of the host galaxies of powerful radio sources, constraining evolutionary models for these objects, are being continued, in collaboration with de Vries (Livermore) and O'Dea (STScI). The VLT proved necessary to extend the redshift baseline for young radio galaxy host identification to redshifts of about one. Transatlantic VLBI observations dealing with the expansion age of a new-born radio galaxy (addressing its "youth") were analysed in a collaborative effort with researchers in Poland (Torun), Bonn (MPIfR) and de Bruyn.

Verdoes-Kleijn, de Zeeuw, and Baum (STScI) studied the nuclei of a complete sample of 21 nearby radio- loud early-type galaxies. They investigated the anisotropy and beaming of the AGN continuum and line emission and the relative orientation of radio jets and the ubiquitous central dust. In collaboration with Carollo and Noel-Storr (Columbia Univ.) they analyzed HST/STIS spectroscopic follow-up survey of the nuclear emission-gas. These observations are primarily aimed at determining black hole masses and constraining the ionization mechanism of the gas.

3.1.2.12. Discovery of the micro-arcsecond quasar J1819+3845

VLBI studies have revealed that the radio nuclei of powerful active galaxies and quasars release their energy in the form of highly collimated jets linked to an unresolved core. The smallest features studied are on a scale of about 0.1-0.5 milli-arcseconds corresponding to a linear scale of typically light years. Higher resolution is needed to understand the collimation process, and what goes on within the radio core. Dennett-Thorpe and de Bruyn set out to find the smallest sources using a radio spectral index criterion. They did find a very small source but via an unexpected route, which required the assistance of the interstellar medium. Due to turbulence in the ISM the planar wavefront of the quasar is distorted such that rays can reach us from a broader range of directions. This scattering and focusing, in fact, provides the extra resolution. But due to the relative motion of source, plasma screen and the earth, transverse to the line of sight, the source intensity will change erratically (this is equivalent to the twinkling of stars by the higher layers in the Earth atmosphere). Using the new MFFE's on the WSRT in a 96hrs campaign in May 1999 they thus discovered unprecedentedly fast and large variations in the quasar J1819+3845. Variations of 5-10% in 1 minute were no exception.

In order to explain these observations the source can not be much larger than 50 micro-arcseconds in size. The lightcurves span more than 1.5 years, and clearly show the predicted annual modulation of the scintillation timescale. The plasma giving rise to the scintillation is at a distance of only 10-20 pc. It has a transverse velocity, relative to the LSR, of about 40 km/sec. The origin of this high level of turbulence in such a local screen is puzzling. The data provide evidence for highly anisotropic density structure in the turbulent plasma. However, the data could also be explained by an elongation of the background quasar. The quasar has maintained its extraordinary high brightness temperature (far in excess of 10^{12} K) for several years, yet shows surprisingly little intrinsic variation.

3.1.2.13. Microlensing of the Andromeda galaxy

The Andromeda galaxy (M31) is, apart from the Magellanic Clouds, the most suitable extragalactic source of microlensing events. It has the advantage that self-lensing dominates, removing some of the ambiguity that affects microlensing studies to date. The shape and mass of the lens distribution can be measured quite directly, and the lensing rate can be mapped over the whole of the galaxy (towards the Large Magellanic Cloud only one narrow line of sight through our dark halo is probed). De Jong, Sackett and Kuijken are part of the `MEGA' collaboration headed by Crotts (Columbia University, New York) which is carrying out a coordinated, multi-year, multi-observatory campaign to study M31 microlensing.

With the construction of the wide-field camera OmegaCAM for the VLT Survey Telescope on Paranal, expected to become operational in 2003, large-scale microlensing surveys of the Galactic Bulge become possible. Every square degree OmegaCAM field will contain an average of 7 on-going microlensing events, which can be used for a range of experiments: searches for circumstellar planets, spatially-resolved spectroscopy of bulge giants, as well as tighter constraints on the low-mass end of the Galactic disk's stellar mass function. Planning for this work is carried out by Kuijken and PhD student Christen (currently at ESO).

3.1.3. The Galaxy

Research on our own Galaxy centers on understanding the mass distribution, its stellar populations and its star formation history. There is a fuzzy boundary with the work of Network 2.

3.1.3.1. Proper motions in the bulge

Together with Rich (UCLA), Kuijken started a program to obtain proper motions of bulge stars in low-extinction fields, using second-epoch HST images. Transverse velocities with accuracies of 20 km/s were obtained for thousands of stars in this way. The first analyses show a clear kinematic distinction between foreground disk stars and the bulge, as well as a direct measurement of the rotation of the bulge stars. A clean color-magnitude diagram of the bulge stars was constructed, and is being used to set limits on intermediate-age stars in our Galactic bulge. Further fields are planned.

3.1.3.2. Microlensing constraints on the abundance of cool Jupiters in the Milky Way

Doppler searches have found a stunning number of massive exoplanets orbiting close (generally within 1 AU) of their parent solar-type stars, but constraints on the presence of longer period 'cool Jupiters' - especially around the most typical of Galactic stars (M dwarfs) - have been lacking. The PLANET team (PI Sackett) provided the first such constraints from its microlensing photometric data covering five years and 43 intensively monitored events in the line of sight toward the Galactic Bulge. In no case were the < 1-day light curve deviations of the sort expected for Jovian-mass planets orbiting the microlens detected. A detailed statistical analysis implies that no more than one-third of Galactic lenses (most of which are likely to M dwarfs near the Bulge) have Jovian-mass companions in the range of semi-major axes 1.5 AU < a < 4 AU. This conclusion assumes circular orbits, but is robust with respect to reasonable assumptions about the size of the background source star. These are the first significant limits on planetary companions of M dwarfs and constrain planets with orbital periods of 3 to 15 years that would be difficult to probe currently with other techniques.

3.1.3.3. The stellar halo

Helmi and de Zeeuw investigated what the next generation of astrometric satellites will reveal by observing the halo of the Milky Way if this were built from disrupted galaxies. They generated artificial DIVA, FAME and GAIA halo catalogues, in which they searched for the signatures left by the accreted satellites. They developed a simple method in integral space which when applied to GAIA data can recover about 50% of the different accretion events, even when the exact form of the Galactic potential is unknown. The recovery rate for DIVA and FAME is much smaller, but these missions, like GAIA, should be able to test the hierarchical formation paradigm on our Galaxy by measuring the amount of halo substructure in the form of nearby kinematically cold streams with for example, a two-point correlation function in velocity space.

3.1.3.4. MACHOs in the dark halo

Kuijken, de Jong and Neeser carried out a small survey to search for high-proper motion stars in the solar neighborhood. These might form an important subpopulation in the Galactic halo, and could be responsible for the microlensing events seen towards the Magellanic Clouds. Several promising candidates were found, using the ESO Imaging Survey data as first epoch, and are being followed up.

Five microlensing teams (EROS, MACHO/GMAN, MPS, OGLE and PLANET) combined their data on one special microlensing event, MACHO 98-SMC-1, a binary lens in the direction of the Small Magellanic Cloud (SMC). With high time-sampling lightcurves of this event, the PLANET collaboration (among whom Sackett, Beaulieu, Naber and Dominic) had already determined that both the physical properties and relative proper motion of the lens make it compatible with a normal stellar binary in the SMC; the small proper motion between the source and lens are highly unlikely to be the result of a lens in the Galactic dark halo. This conclusion was shared by the four other individual teams and with the joint analysis of all data. Although the joint data set covered both caustic crossings, however, two solutions remained, primarily differing in the projected separation between the two lensing components. The excellent coverage by the EROS and PLANET teams of the second caustic crossing in MACHO 98-SMC-1 allowed limb-darkening coefficients for the SMC A-dwarf source star to be derived in the joint analysis. As expected, these progressively decrease with increasing wavelength.

3.1.3.5. Runaway stars

Hoogerwerf, de Bruijne, and de Zeeuw used milli-arcsecond accuracy proper motions and parallaxes from Hipparcos and from radio observations to retrace the orbits of the nearby O- and B-type stars and compact objects (neutron stars). The study resulted in a sample of 56 runaway stars and 9 compact objects; the birth-place (parent group) could be determined for 26 of these. In two cases the formation scenario could be determined with near certainty. The runaway star and the pulsar PSRJ1932+1059 originated about 1 Myr ago in a supernova explosion in a binary in the Upper Scorpius subgroup of the Sco OB2 association. The pulsar received a kick velocity of ~350 km/s in this event, which dissociated the binary, and gave ζ Oph its large space velocity. This case provides conclusive evidence for the so-called binary-supernova scenario proposed by Blaauw in 1961. The study also showed that the runaway-pair AE Aur and μCol, and the massive highly-eccentric binary ι Ori were ejected from the nascent Trapezium cluster ~2.5 Myr ago. These runaways are most likely ejected from the Trapezium cluster as the result of a binary-binary encounter, thus providing evidence for the dynamical-ejection scenario proposed by Poveda in 1967.

3.1.3.6. Hyades

De Bruijne, Hoogerwerf and de Zeeuw determined secular parallaxes for the Hyades open cluster using the observed proper motions of the group members. The resulting color-absolute magnitude diagram of the cluster is three times more precise than any previous one, and shows a very well-defined main sequence which provides the first unambiguous observational evidence of Böhm Vitense's prediction that the onset of surface convection in stars significantly affects their broad-band colors. The precision with which the new parallaxes constrain the location of individual members of the cluster in the Hertzsprung Russell diagram is now limited by (systematic) uncertainties related to the transformations from observed colors and absolute magnitudes to effective temperatures and luminosities.

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, in particular the physical and chemical modifications of the gas and dust as they are expelled into the interstellar medium through the winds from late-type stars and are incorporated into star-forming regions and eventually new solar systems. The projects involve a combination of observations, mostly at infrared and submillimeter wavelengths, and theoretical modeling. In 1999-2000, the emphasis continued to be on the exploitation of the rich harvest of results from the Infrared Space Observatory (ISO). Nine of the ten NOVA-funded positions have been filled in 1999-2000, and the associated research is starting up. In the following, a brief summary of scientific highlights is given, focusing on those projects which involve a direct collaboration between Groningen, Amsterdam and Leiden. Related research carried out by the Sackler Laboratory for Astrophysics is summarized in § 5.7.

Two workshops were organized in 1999 and three workshops in 2000 associated with Network 2 and partly funded by NOVA. All of them took place in the Lorentz Center (see § 7.1)

3.2.1. Evolution of envelopes and disks around pre-main sequence stars

3.2.1.1. Diagnostics of shocks and UV photons

Spectra taken with the ISO Short Wavelength Spectrometer (SWS) and Long Wavelength Spectrometer (LWS) of the gas and dust in the envelopes and disks surrounding young low-mass T Tauri and intermediate-mass Herbig Ae stars were analysed by Waters, Tielens, van den Ancker, Bouwman, Boogert, Wesselius, van Dishoeck and collaborators. In the earliest embedded phase, many gas-phase emission lines are seen due to HI, H_2 and atomic fine structure lines. The spectra also show absorption due to small dust grains - silicates as well as simple ices - and/or emission bands due to Polycyclic Aromatic Hydrocarbons (PAHs). The emission lines arise either in the PhotoDissociation Regions (PDRs) formed in regions where stellar ultraviolet photons dissociate, ionize, and heat the surrounding molecular cloud material, or in shocks driven by the powerful protostellar outflows. Diagnostic lines of these processes were identified. For example, the PAHs are clear indicators of PDRs whereas the [S I] line at 25 μm is a clear diagnostic of shocks. Together, the infrared lines are a powerful tool to determine the physical conditions in star-formation regions and to constrain the relative importance of heating by stellar photons and shock waves in processing the gas and dust in stellar nurseries. A general trend from shock-dominated to PDR-dominated spectra with evolution was found.

3.2.1.2. Crystalline silicates and ices

At a more evolved state of evolution, the envelope has been cleared away and only the disk around the young star remains, showing solid-state emission bands. These bands were compared to laboratory measurements of cosmic analogues, and point to the presence of amorphous and crystalline silicates in some objects, but only amorphous silicates in others. At long wavelengths, evidence for the presence of crystalline water ice were found. Together, these features provide probes of the thermal history of the dust in the disks. Fig. 5 beautifully illustrates the evolution of the spectra with time. The observations are interpreted with radiative transfer models, which are being developed in various institutes.

3.2.1.3. H_2 in disks

A related new result is the first detection of the pure rotational emission lines of H_2 from circumstellar disks around T Tauri and Herbig Ae stars, using the ISO-SWS by Thi, van Zadelhoff, van Dishoeck and collaborators. These lines provide a direct measure of the total amount of warm molecular gas in disks, and complement submillimeter continuum and JCMT CO observations. The mass of warm gas is higher than expected, suggesting more efficient photon- and/or wind-shock heating of gas in disks. Moreover, it was shown that CO is clearly not a good tracer of the disk mass, due to photodissociation in the outer layers and freeze-out in the midplane of the disk. A particularly exciting result is the likely detection of H_2 in debris disks around young stars, including that around β Pictoris. Since H_2 is a necessary ingredient to make gaseous Jupiter-type planets, the detection of H_2 in objects with ages up to 20 Myr implies a longer timescale for giant planet formation than thought before. The presence of gas in the disks can also affect the dust dynamics.

3.2.1.4. Evolution of debris disks

Habing and Dominik, together with a large consortium of ISO colleagues, completed their part of the ISO program on dust around even older main-sequence stars. Their major conclusion is that stars younger than 400 Myr all have dust disks whereas only a minor fraction of older stars do. There are indications that the same is true for the solar system, since in the first 400 million years of its existence the cratering of the surfaces of planets and satellites (e.g. the Moon) was much more frequent.

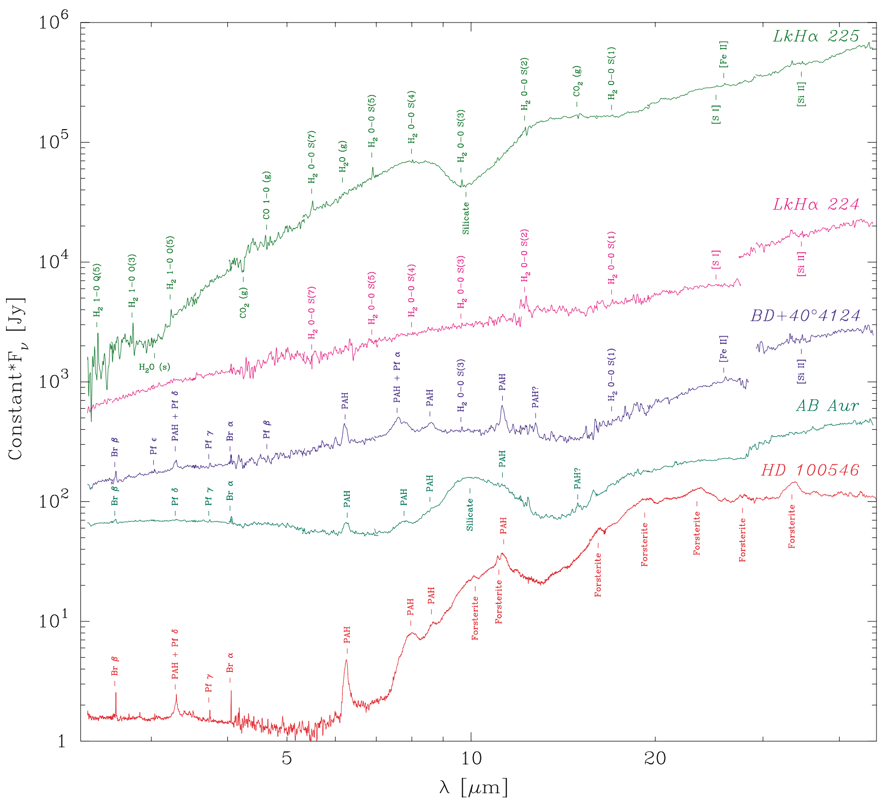

Fig. 5: The ISO-SWS mid-infrared spectra of newly-formed stars in different stages of formation. From top to bottom - in a rough evolutionary sequence - the spectra change from dominated by solid-state absorption features (ices, silicates) and gas (shock) emission lines, to featureless, to PAH features and PDR lines, to amorphous and then crystalline silicates with HI recombination lines (based on van den Ancker et al. 2000).

3.2.1.5. **Future VLTI and SIRTF studies**

The study of the structure and composition of disks surrounding Herbig Ae/Be stars has taken a new direction with the start of the NOVA/ESO PhD project of van Boekel. The aim of the project is to obtain high resolution, spectrally resolved interferometric images of the inner parts of the disks with MIDI on the VLTI starting in mid- 2002. As preparation, a theoretical study is underway to determine the best observing strategy for the VLTI and to select the best targets.

Another new direction comes from the participation by van Dishoeck in the SIRTF legacy program 'From Molecular Cores to Planet-Forming Disks' (PI, N.J. Evans, University of Texas), which was awarded 400 hrs of SIRTF time. About 25 square degrees of molecular cloud area will be mapped from 3.5-70 µm and complete 5-40 µm spectra will be obtained for at least 150 objects ranging from deeply embedded protostars to T Tauri stars with tenuous disks. Pontoppidan started his NOVA PhD research in late 2000 on this topic by collecting a large data base of YSOs in the regions to be mapped as potential targets for spectroscopy.

3.2.2. **Deeply embedded protostars**

3.2.2.1. **Envelopes of massive protostars**

Van Dishoeck, van der Tak, Boonman, Tielens, Keane, Boogert, Lahuis and collaborators continued their studies of deeply embedded massive young stars when they are still surrounded by hundreds of magnitudes of extinction. In contrast with low-mass objects, there is not yet a well-developed scenario linking observational phenomena associated with high-mass star formation, such as luminous infrared sources, ultracompact HII regions, hot molecular cores, and masers into an evolutionary scheme. The combination of ISO-SWS and JCMT submillimeter data provide unique diagnostic tools to probe this very early phase of evolution. The ISO spectra show strong absorption by ices, especially by H_2O, CO_2 and CH_3OH. Comparison with laboratory spectra obtained by Ehrenfeund and Schutte (see § 5.7) shows clear evidence for heating of the ices and ice segregation in the warmest part of the envelope. Both the 15 µm CO_2 bending mode, the $^{13}CO_2$ 4.3 µm stretching mode and the unidentified 6.8 µm feature exhibit shifts with increasing temperature.

The heating of the envelope is also reflected in observations of gas-phase molecules with ISO. Gas-phase C_2H_2, HCN, H_2O and CO_2 were detected and show increases by orders of magnitude in abundance and gas/solid ratios with temperature, providing evidence for ice evaporation and high-temperature chemistry in the warmest sources. Submillimeter observations of hot-core molecules like CH_3OH and HCN show a similar trend and a 'jump' in their abundances at the ice evaporation temperature. Indeed, the recent detection by Boonman and collaborators of the ro-vibrational HCN ν_2=1, J=9-8 line with the new MPIfR/SRON 800 GHz receiver on the JCMT indicates a jump in the HCN abundance of at least a factor of 100 (Fig. 6). Together with the ices, the gas-phase data indicate a 'global warming' of the envelope, which is communicated to both the inner and the outer parts over ranges from < 50 K to 1000 K. This 'global warming' is due to a systematic reduction of the ratio of envelope to stellar mass, which plausibly results from the gradual dispersion of the envelope with time. Thus, the observed features can be used to establish an evolutionary sequence, even in this early phase.

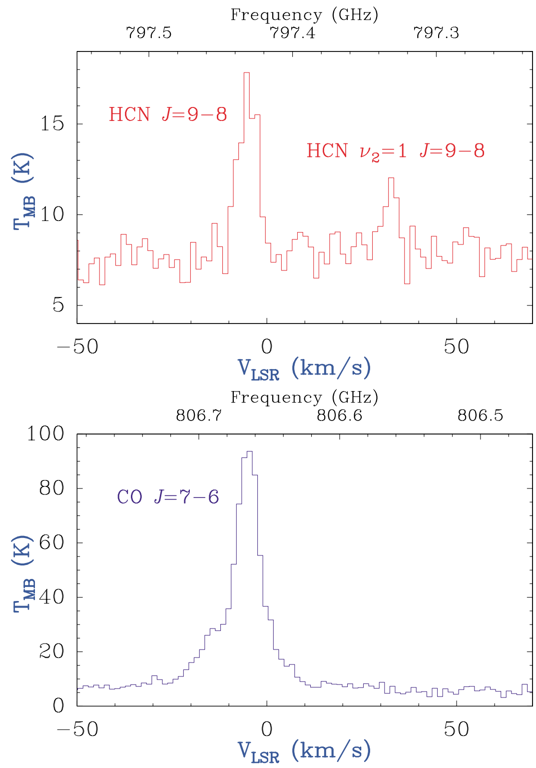

Fig. 6: Spectrum of the ν_2=0 J=9-8 and the vibrationally excited ν_2=1 J = 9- 8 line of HCN at 797.434 GHz and 797.330 GHz, respectively, toward the massive protostar GL2591 obtained with the JCMT by Boonman et al. (Top panel).The CO J = 7-6 line at 806.652 GHz was also observed and is shown for comparison (Bottom panel).The latter spectrum shows clearly the presence of a wing component whereas the HCN J =9-8 lines do not show such a component.

Spaans (NOVA postdoc) and van Dishoeck investigated the thermal and chemical balance of inhomogeneous molecular clouds exposed to intense ultraviolet radiation, with special emphasis on the O_2 and H_2O abundances. It was found that the H_2O and O_2 abundances are lowered by more than an order of magnitude in these clumpy clouds compared with the homogeneous case, and that this mechanism can quantitatively explain the low abundances observed with the SWAS satellite in extended star-forming regions. However, in dense cold cores, additional freeze-out of oxygen onto grains is needed.

3.2.3.2. Envelopes of low-mass protostars

Tielens, van Dishoeck, Jørgensen (NOVA PhD), Schöier and collaborators have started a JCMT program to perform a similar in-depth study of a set of low-mass 'class 0' protostars. As a first example, the environment of the deeply embedded protostar IRAS 16293-2422 in the ρ Oph cloud was studied. Using new multi-transition observations, the abundance of the doubly-deuterated molecule D_2CO is found to be surprisingly high, ~ 5% that of H_2CO. It is concluded that D_2CO is most likely not formed in the gas phase, but has evaporated from the dust grains, where it has been accumulating during the very cold, dense pre-collapse period. The studies of H_2CO and other species are being extended to a sample of low-mass protostars, and analyzed using continuum and radiative transfer codes. Modeling of the grain-surface chemistry was started by NOVA PhD student Cazaux and Tielens.

3.2.3. Massive stars

3.2.3.1. Very young massive stars

Bik (NOVA PhD), Kaper, de Koter and Waters started an observational study of massive stars in ultracompact HII (UC HII) regions, which are believed to be in an early phase in the evolution just after the phase described in the previous section. Due to the large extinction by remnant cloud material, the young massive stars in UC HII regions can only be found by near-infrared imaging. Images taken with the ESO-NTT have resulted in the detection of many individual hot stars. Follow-up spectroscopy with the VLT and ISAAC has shown that some of these stars may have spectral types as early as O3 to O6. So far about 20 stars have been studied spectroscopically, and among these a few apparently are 'cocoon stars' surrounded by dust and molecular material. The origin of this material - expelled by the star or accreting envelope - is not yet clear.

3.2.3.2. Eta Carinae and Gamma Cassiopeia

The ISO spectrum of the peculiar star Eta Carinae was analysed by Waters, Morris, Voors, de Koter, Lamers and collaborators, in combination with ground-based images at 10 and 17 μm. A new, massive and cold dust component at a temperature of about 110 K was discovered, which is probably located in the equatorial regions of the torus, seen in HST images. The total amount of mass in the cold component is about 15 solar masses. It is likely that this massive torus prevented the free equatorial expansion of material ejected in 1840-1860 during the so-called great eruption, resulting in the highly bi-polar structure of the present-day nebula.

3.2.4. Organic molecules in space

3.2.4.1. New PAH features

The ISO-SWS spectra of young and evolved stars are very rich in features due to Polycyclic Aromatic Hydrocarbons (PAHs), which are being studied by Tielens, Waters, Peeters, Hony and van Kerckhoven. A study of the 10-15 μm region shows weak bands at 13.6 and 14.2 μm due to C-H out of plane modes. These bands have not been seen before, and are sensitive probes of the edge structure of their carriers: depending on the number of adjacent C-H bonds, the band shifts from 11.3 μm to longer wavelengths. The observations indicate a strong trend in the strength of the 11.3 μm C-H resonance compared to the bands at 13.6 and 14.2 μm going from planetary nebulae to HII regions. This may indicate selective destruction of large, unstable PAH molecules that are produced in planetary nebulae as they enter the interstellar medium. Also, a plateau of emission in the 15-20 μm region was discovered in the spectra of two Herbig Ae stars, sometimes with a distinct feature at 16.4 μm superposed. The emission is due to C-C-C bending modes which are more molecule-specific than the shorter wavelength bands. The observed variations in the relative strength of these two bands implies a variation in the degree of ionization as well as molecular structure of the emitting PAH families in the sources in this sample. More generally, this wavelength range has great potential for identification of the molecular structures which dominate the PAH family.

3.2.4.2. Diffuse Interstellar Bands

Ehrenfreund and collaborators continued their studies of the diffuse interstellar bands (DIBs), a set of more than 200 lines seen in absorption in diffuse clouds. The first DIBs were discovered in the 1920's, but their identification has remained a mystery for nearly 80 years. Recent research indicates that most DIB carriers are probably large carbon-bearing molecules such as PAHs and their ions which reside ubiquitously in the interstellar gas. O'Tuairisg and Ehrenfreund analysed their spectral survey toward BD+63 1964, a star which shows —to date— the largest number of DIBs in the wavelength range from 3906-6812 Å. Of the 253 measured features, 60 DIBs were until now unrecorded, and the large number of bands allows valuable statistics on the overall DIB population.

3.2.4.3. Extraterrestrial amino acids in the Orgueil meteorite: A cometary origin?

Ehrenfreund and collaborators at UCSD (San Diego, USA) searched for amino acids in meteorites and investigated their parent body. This work is important to understand the link between different small bodies, such as comets, asteroids and meteorites, and helps to reconstruct the origin of our Solar system. Carbonaceous chondrites are of particular interest, since they may have efficiently seeded the early Earth with prebiotic compounds necessary for the origin of life. Analyses of a pristine interior piece of the CI carbonaceous chondrite Orgueil by high-performance liquid chromatography have shown that ß-alanine is by far the most abundant amino acid, followed by glycine. Other a-amino acids, including alanine, are present only in trace amounts. Carbon isotopic measurements of ß-alanine and glycine indicate that these amino acids are extraterrestrial in origin. They are identical to those found in another CI carßonaceous chondrite Ivuna, ßut very different from those found in the CM carbonaceous chondrites Murchison and Murray, suggesting that the CI chondrites come from a different type of parent body, perhaps an extinct comet.

3.2.4.4. The photo stability of amino acids in space

Amino acids are basic components of proteins, essential constituents of all organisms. Ehrenfreund and collaborators at NASA-AMES (USA) tested the stability of amino acids against ultraviolet photolysis. Two biological and two non-biological amino acids were irradiated in frozen Ar, N_2, and H_2O to simulate conditions in the interstellar gas and on grains. The experimental results indicate that amino acids in the gas phase will likely be destroyed during the lifetime of a typical interstellar cloud. In regions with relatively low UV radiation, amino acids may be present as transient gas-phase species. Their survival in interstellar icy grain mantles and on the surface of comets and planets is also strongly limited. These results provide important constraints for the survival and transfer of amino acids in space environments, and thus their possible availability for prebiotic chemistry.

3.2.4.5. Chemistry reviews

Ehrenfreund also compiled the current view on the evolution of organic molecules, and their voyage from molecular clouds to the early Solar System and Earth. Her Annual Reviews paper recapitulates the inventory and distribution of organic molecules in different environments, and their evolution, survival, transport and transformation from interstellar clouds until their incorporation into Solar System material, such as comets and meteorites. Other reviews on aspects of interstellar chemistry and dust were written by van Dishoeck, Tielens, Waters and Schutte.

In addition van Dishoeck and Tielens wrote a major review on space-based spectroscopy of interstellar gas and dust, to appear in the review book 'The Century of Space Science'. The review features many of the results obtained in the Netherlands with the ISO-SWS.

3.2.5. Kuiper Belt objects

Luu and collaborators finished their survey for scattered Kuiper Belt objects using the Canada-France-Hawaii Telescope. The scattered Kuiper Belt at ≥100 AU is found to contain ~10^4 objects with diameters ≥100 km, and contributes a mass of ~0.1 Earth masses. This is comparable in number and mass to the Kuiper Belt inside 50 AU. Another exciting discovery is the detection of water ice in the Centaur 2060 Chiron, believed to be an ex-Kuiper Belt object, suggesting that water ice is ubiquitous in objects originating in the Kuiper Belt.

In 2000, a promising start was made to the investigation of the history of dust in the Kuiper Belt. In collaboration with Moody (ANU), a computer code was written and preliminary results suggest that the Kuiper Belt was indeed as dusty as the ß Pictoris disk at 10^8 yr. Together with Lacerda, the accretion process in the Kuiper Belt was studied, using a high quality, homogeneous database of Kuiper Belt light curves.

3.2.6. Evolved stars

3.2.6.1. Crystalline silicates

The ISO data are particularly rich in results related to the structure and composition of the gas and dust surrounding evolved low mass stars, so-called Asymptotic Giant Branch (AGB) stars, post-AGB stars and planetary nebulae. Waters, Tielens, Molster, Kemper, de Koter and collaborators continued their analysis of the infrared spectra of O-rich AGB and post-AGB objects, which show a rich crystalline silicate forest of features poised upon a 'continuum' due to amorphous silicates (Fig. 7). Comparison with laboratory spectra shows that these crystalline features are due to the magnesium type members of the olivine and pyroxene families: fosterite and enstatite. The relative importance of crystalline to amorphous silicates is highly variable, ranging from a few percent to ~75% crystalline dust. In the outflow sources, the crystalline features seem to appear in the spectra above a certain mass loss rate, suggesting an active crystallization process working in the stellar ejecta. Very strong crystalline silicate features are also observed in sources with associated stable circumstellar disks and this implies crystallization at relatively low temperatures, well below the glass temperatures of these minerals. These objects also show evidence for a population of large, cold grains which likely result from coagulation, a process which eventually leads to planets. A similar low-temperature process may have played a role in the formation of crystalline silicates observed in comets.

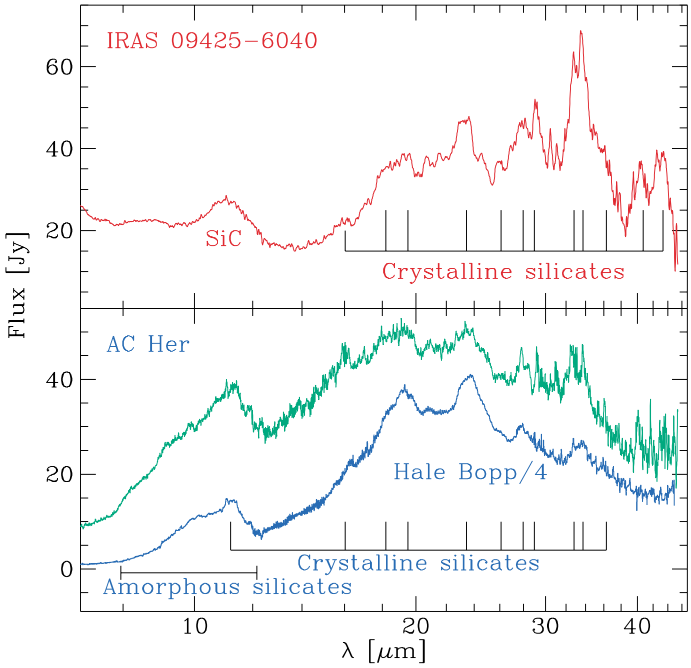

Fig. 7: ISO-SWS mid-infrared spectra of AGB stars, post-AGB stars and planetary nebulae, revealing the enormous richness of features due to crystalline silicates (Molster PhD 2000).

3.2.6.2. TiC nanocrystals

The Low Resolution Spectrometer on board of IRAS discovered a number of objects whose infrared spectra are characterized by a strong emission feature at ~21 μm. These so-called 21 μm objects were later shown to be C-rich post-AGB objects with typical effective temperatures of 5000 K. Various lines of evidence have shown that these stars originate from 1 solar masses, low metallicity progenitors which were formed in the early stages of the formation of the Milky Way - some 10 billion years ago - and which just (~ 500 yrs ago) turned off from the AGB to the planetary nebula phase. The ISO-SWS has obtained high spectral resolution spectra of a large sample of such objects which revealed, that the peak position falls actually at 20.1 μm. Tielens, together with von Helden (FOM/Rijnhuizen), Hony and Waters, have analyzed these observations and identified this band with TiC nanocrystals. Laboratory spectra of TiC nanocrystals obtained with the FELIX laser at FOM revealed a remarkable agreement in peak position and width with the astronomical 21μm feature (Fig. 8). The presence of TiC grains in space has been inferred before from laboratory studies of carbide inclusion in graphite stardust isolated from meteorites. However, this is the first astronomical detection of this material and it places the origin of these stardust grains in low metallicity C-rich AGB and post-AGB objects.

3.2.6.3. Mass-loss history of AGB stars

Dijkstra, in collaboration with Waters, Tielens and de Koter, started his NOVA PhD position in mid-2000 to study the mass loss history of red giants and AGB stars. This mass loss history can be reconstructed by studying the mass, composition and geometry of dust shells surrounding both AGB stars and post-AGB stars. A detailed study of the 40-100 μm ISO spectra of about 20 stars is under way. This region is particularly rich in solid state bands from H_2O ice, carbonates and crystalline silicates. Many of the bands are broad and blended, thus requiring a careful comparison of ISO data with the available laboratory spectra of astrophysically relevant materials for unambiguous identification.

3.2.6.4. AGB stars as probe for mass distribution of our Galaxy

Using AGB stars to trace the dynamics of the inner Galaxy Messineo, in collaboration with Habing and others, started her NOVA PhD project in mid-1999 using AGB stars detected in the 'ISOGAL' project to probe the dynamics of the inner Galaxy. ISOGAL is a survey of ~13 deg^2 of sky, mostly concentrated toward the Galactic Center, performed at 7 and 15 μm using ISOCAM. AGB stars are good tracers

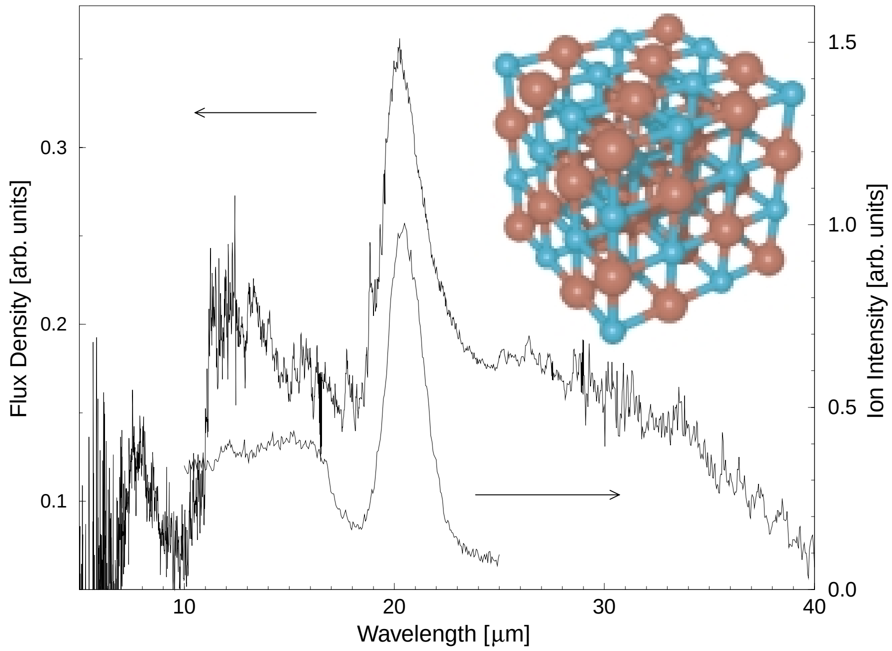

Fig. 8: The emission spectrum from the post-AGB object SAO 96709, taken by the ISO satellite (upper trace, left axis) and the spectra of TiC nanocrystal clusters recorded in the laboratory (lower trace, right axis). Also shown is a pictorial representation of a typical (4x4x4 atom) TiC nanocrystal.

because of their infrared brightness and maser activities that take place in their circumstellar envelopes. To derive stellar radial velocities, searches for the 86 GHz SiO maser emission were started. The main scientific goal is to obtain new data to investigate the triaxial mass distribution of our Galaxy.

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

The compact object research program in NOVA is motivated by the insight that fundamental physical information can be obtained from study of these objects. It focuses on the astrophysics, formation, and evolution of neutron stars, black holes, and their host systems. The following summarizes research highlights in these areas in 1999-2000.

3.3.1. Gamma-ray bursts

3.3.1.1. Gamma ray burst afterglows

Van Paradijs and PhD students Galama, Groot, Vreeswijk and Rol were able in May 1999 for the first time to take spectra of the GRB-afterglows with the ESO-VLT, thus breaking the monopoly held so far by Caltech with the Keck Telescope. They established a redshift of 1.60 for GRB990510 and were for the first time able to detect also the polarization of an afterglow. By the end of 2000, over one quarter of all afterglow redshifts of GRBs had been determined by the Amsterdam group.

Caltech colleagues were able in 1999 to finally measure the redshift of the parent galaxy of the first ever detected optical afterglow of a GRB, discovered by the van Paradijs group on 28 February 1997. The redshift turned out to be 0.69. Going back to the original data of this first afterglow lightcurve, Galama and Reichert (Chicago) discovered in 1999 that the lightcurve of this GRB shows a clear ‘hump’, which exactly fits with the redshifted lightcurve of a type Ic supernova similar to that of SN1998bw which coincided with GRB 980425 (discovered by Galama and Vreeswijk). A third case of such a GRB-SN coincidence was discovered by Bloom (Caltech), so about one quarter of all afterglows found by 2000 showed such a SN hump. This discovery of the GRB-SN connection was ranked by the journal 'Science' among the top-ten breakthroughs of the year 1999.

The GRB-group, together with five other European groups, was awarded an ESO-VLT large program (2 years), starting April 2000 for the study of GRB afterglows. After van Paradijs' untimely death, the PI-ship for this Program was taken over by van den Heuvel.

In collaboration with Fruchter (STScI), Kouveliotou (MSFC, Alabama) and Wijers (Stony Brook), Vreeswijk and Rol obtained new results on GRBs and their host galaxies. For the latter, particularly the HST studies proved extremely useful: it was found that GRBs typically occur in starburst galaxies. An overview of the physics of GRB afterglows and their hosts was given by van Paradijs, Kouveliotou and Wijers in their Annual Review article published in 2000. Presently the GRB group is led by Kaper and van den Heuvel.

3.3.1.2. Soft Gamma-Ray Repeaters

After the discovery in 1998 by Kouveliotou and van Paradijs that the Soft Gamma Ray Repeater SGR 1806-20 is a slowing down single X-ray pulsar (P = 7.476551 sec in 1996), with a slow-down rate indicating a magnetic field strength some thousand times larger than that of the Crab pulsar (10^{15} Gauss), several more of these 'magnetars' were found. On 27 August 1998 the SGR 1900+14 produced a gigantic gamma- and X-ray flare. In collaboration with Hurley (Berkeley) van Paradijs and Kouveliotou measured the slow-down rate of this X-ray pulsar (P = 5.159152 sec), which indicates a magnetic field strength similar to that of 1806-20. They studied the slowdown with ASCA and with BeppoSAX.

3.3.2. Accreting compact objects

3.3.2.1. Accreting black holes

Klein-Wolt, Belloni, Mèndez, van der Klis, and van Paradijs found a way to understand the bewildering variety of behavior of the black hole candidate and superluminal jet source GRS1915+105. They reduced the complex variability of the source to simple transitions between three basic states: a hard state corresponding to a lack of an observable inner accretion disk, and two softer states with a fully observable disk at two different temperatures caused by different accretion rates. The transitions between these states can be extremely fast and occur in certain patterns while avoiding others, giving rise to a relatively large but limited number of variability classes. An intimate correlation was found between hard X-ray dips and radio emission in this object in ~100 simultaneous radio and X-ray observations. The radio emission is produced by synchrotron-emitting relativistic electrons, which are ejected. Klein-Wolt, Fender, van der Klis et al. were able to construct a simple scenario, which explains the complex radio and related X-ray behavior of GRS1915+105 in terms of a clear relation between the inflow of material through the accretion disc close to the black hole, and an outflow or jet.

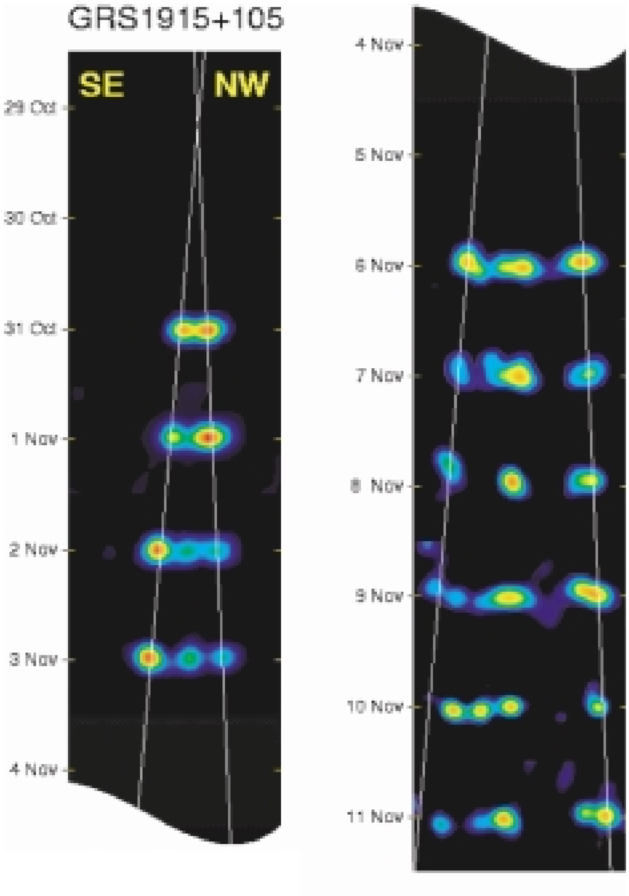

Fig. 9: MERLIN radio observations of the relativistic jet in GRS 1915+105.

Fender published a study of repeated relativistic ejections from GRS 1915+105 with the UK radio

interferometer MERLIN (Fig. 9). This is the most detailed investigation to date of relativistic jets from an X-ray binary, combining daily monitoring observations in radio and X-rays and high resolution radio mapping, including for the first time spatially resolved linear polarization images. The investigation revealed the ejections to possess extremely large velocities (with bulk Lorentz factors possibly >5) and requisite luminosities during their formation (significantly greater than Eddington limit for even a 10 solar mass black hole). The images captured worldwide attention, and were covered in a number of popular magazines and newspapers and made several TV news items.
Fender et al. also reported the first discovery of circularly polarized radio emission from an X-ray binary, a key diagnostic which may be the way forward to determining whether jets from X-ray binaries are comprised of p^+:e^- baryonic material or a e^+:e^- pair plasma. Further radio observations of circular polarization are in progress.

A general property of black hole accretion is the presence of steady radio emission with a flat or inverted spectrum during the 'low hard' X-ray state. This radio emission disappears when the black holes are accreting in 'soft' disc-dominated states. This can be interpreted as an association between the hard states and the production of a quasi-steady outflow. By using the JCMT, Fender et al. were able to show that the self-absorbed synchrotron spectra produced by these jets extend to the millimeter band in both persistent (Cyg X-1) and transient (XTE J1118+480) systems. The total jet power ('hidden' as kinetic energy of the flow) may be comparable to the bolometric radiative luminosity. The radiative luminosity of the jets is probably (≤ 5%, comparable to values estimated for AGN jets.

The black hole candidate LMC X-3 in the Large Magellanic Cloud was for the first time directly observed in the black hole low hard state by Homan et al. This was a surprise, as the source, like its cousin LMC X-1 was thought to be permanently in the high soft state. A study of archival data then showed that the long term behavior of the source is in fact caused by transitions between these two states.

3.3.2.2. The neutron-star black-hole connection

It has been known for more than a decade that the rapid X-ray variability of X-ray binaries containing either a low-magnetic-field neutron star or a black-hole are very similar to each other. However, detailed quantitative study of these similarities only became possible with RXTE. Using data obtained with this satellite, Wijnands, Psaltis, Belloni and van der Klis made the first two such detailed studies allowing a comparison of neutron stars and black hole candidates. They found that the characteristic frequencies of the rapid X-ray variability were well correlated with one another. The most surprising finding was that the correlations were consistent with being the same for the neutron-star and the black-hole systems, with the black holes tending to occupy the lower frequency parts of the correlations. This suggests that the physical mechanisms behind the production of the rapid X-ray variability in neutron star and black-hole systems are identical. The presence of the neutron star surface or the (possible) neutron-star magnetic field apparently does not distort this process. These findings started a vigorous debate about both the implications and the generality of the result, which is still raging.

3.3.2.3. Accreting neutron stars

An exciting recent development was the discovery, with RXTE, of quasi-periodic oscillations at kilohertz frequencies (kHz QPOs) from accreting low-magnetic field neutron stars in X-ray binary systems. These QPOs can reach frequencies of ~1330 Hz, making them some of the fastest signals reaching us from outside the Solar system. They are likely produced within a few kilometers of the surface of the accreting neutron star, where matter moves at half light speed and the time to orbit the star is of the order of a millisecond. The oscillations provide a way to gauge the mass and radius of the neutron star, and thereby obtain information on the fundamental properties of matter at supra-nuclear densities that can not be obtained otherwise. It also allows to study the accretion flow in the ultra-strong gravitational field of the neutron star, and to potentially observe for the first time the predicted effects of general relativity in the strong-field regime, such as the existence of a region near the compact star within which, in qualitative departure from Newtonian physics, no stable orbits are possible. Five years after its discovery, with a review article by van der Klis in the 2000 Annual Reviews of Astronomy and Astrophysics, the phenomenon can be said to have entered the canon of high-energy astrophysics. The precise mechanism producing the oscillations, their relation to slower QPOs, and the question whether similar signals can be observed from accreting black-holes are issues that are currently the subject of vigorous debate.

A number of systematic comparative studies were made of this phenomenon. Mèndez et al. studied the dependence of the frequency of the kHz QPOs upon X-ray intensity and X-ray colors in several low-mass X-ray binaries. They showed that on time

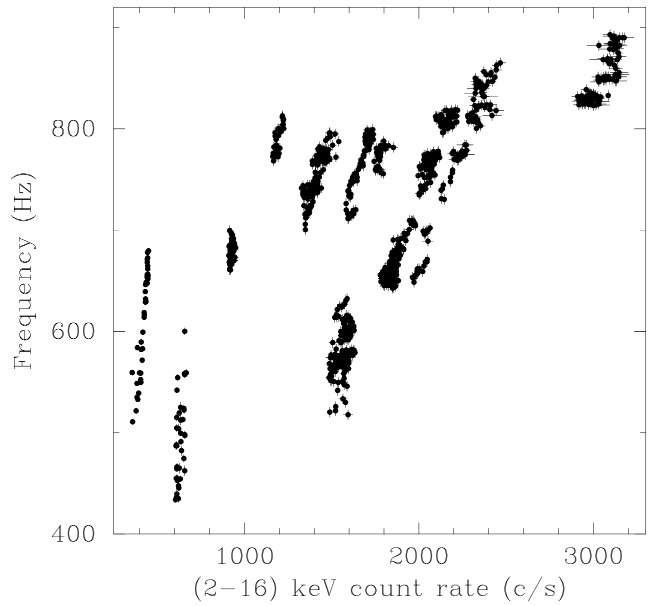

Fig. 10: Relation between the frequency of one of the kHz QPOs in 4U1608-52 and X-ray intensity. Different symbols indicate different observations taken a few days apart.

scales of hours frequency and X-ray intensity are positively correlated, but observations taken a few days apart show the source spanning the same range of frequencies even when the average intensity has changed by a factor of ~3 (see Fig. 10). In a related development, Ford et al. performed a first complete survey of kHz QPO source luminosities and found that the QPO frequencies range from approximately 300 Hz to 1300 Hz, though the sources differ by two orders of magnitude in their X-ray luminosities. Both results indicate we are missing an ingredient in our description of the basic processes in these sources, since the evidence indicates that in an individual source over short timescales the frequency and luminosity are very well correlated.

Two new kHz QPO sources, J2123-058 and EXO 0748-676 were discovered by Homan. Van Straaten discovered the fastest kHz QPO yet, at 1329± 4 Hz, leading to a direct constraint on the equation of state at high densities. Using a new technique that they specially developed for this purpose, Mèndez and van der Klis found that in 4U1728-34 the frequency difference between the two simultaneous kHz QPOs is always significantly smaller than the neutron star spin frequency as inferred from the so-called burst oscillations, contrary to the predictions of one of the leading models for the kHz QPOs. The model has since been amended. However, intriguingly, the frequency difference appears to asymptotically converge to a value that is only just below the spin, suggesting that these two frequencies are indeed related.

Until last year, kHz QPOs were usually seen in doublets, separated in frequency by several 100 Hz. Theoretical expectations were that more than two QPOs should exist in the kHz range, but despite intensive searches none were found. Jonker et al. finally discovered a third kHz QPO, in three sources, located at a frequency 50 to 60 Hz above that of the lower kHz QPO, and now generally referred to as sidebands. This discovery caused a brief flurry of activity on the part of the theorists (the Lamb and Stella teams, as well as Psaltis) and also some press coverage. The central mystery in explaining the sidebands within the framework of existing theories is that its frequency separation from the kHz QPO is not, as was expected before Jonker's discovery, commensurate with one of the known QPOs at lower frequency. Several explanations were proposed. A particularly intriguing one involves Lense-Thirring precession, which would constitute the first direct detection of a strong-field general relativistic effect. However, the Lense-Thirring precession frequency is ~30 Hz at most so this can only be true if a two-fold symmetry in the disk flow allows the phenomenon to manifest itself at twice the fundamental precession frequency (Jonker, Mèndez and van der Klis).

Jonker and Homan discovered a completely new, much slower QPO phenomenon in three different X-ray dip sources with RXTE (4U1323-62, EXO-0748-676, 4U1746-37): QPOs in the X-ray flux with frequencies varying between 0.5 and 2.5 Hz, frequencies not seen in other LMXBs. The amplitude of the oscillations as a fraction of the total flux does not change whether they are observed in or out of the dips, or even during the 10-50 fold increase in flux during X-ray bursts. This clearly demonstrates that unlike other QPOs they are produced by quasi-periodic obscuration of the central emitting regions. So, we now have a fine 'knife-edge' periodically covering up the central regions, one that nearly certainly has a scale that is of the order of the relevant emitting regions.

An important discovery was that of very long X-ray bursts, a phenomenon not previously detected and requiring new theory. The BeppoSAX WFC is used twice a year for the observation of the Galactic Center. Its large field of view then covers more than half of the known low-mass X-ray binaries in a single

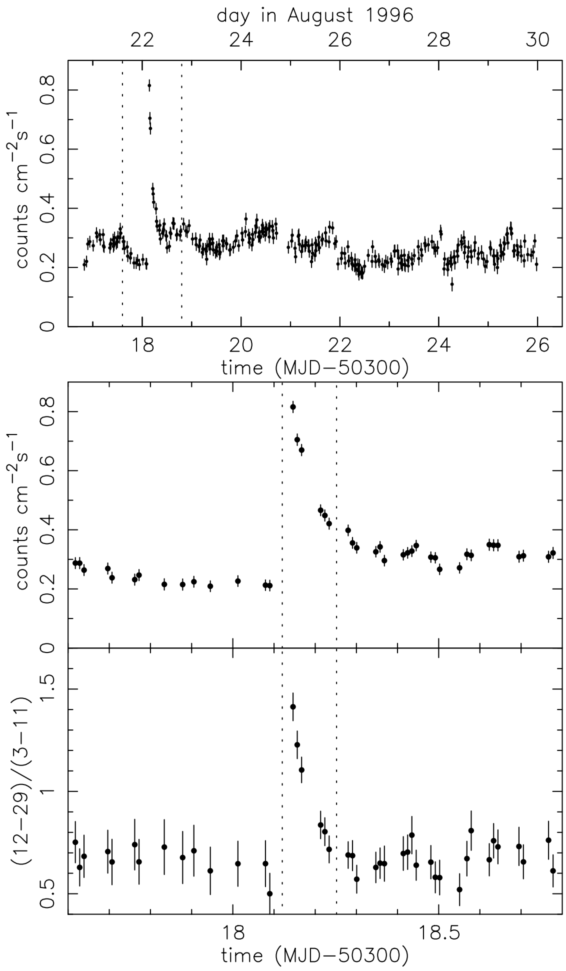

Fig. 11: Light curve (top) and X-ray color (below) of the longest X-ray burst ever (up to then) observed is a new type of burst, corresponding to carbon fusion on the surface of a neutron star.The decline of the burst corresponds to the cooling of the neutron-star atmosphere.

observation thus allowing the discovery of rare events. One such event was the longest X-ray burst by far ever observed, which had a decay time of 86 minutes (Fig. 11). The most probable explanation is that we have observed fusion of a carbon layer on a neutron star (as opposed to fusion of hydrogen and helium in normal bursts). This opens up a new field in the study of nuclear processes on the surface of neutron stars.

O'Brien, observing Cygnus X-1 and Sco X-1 using Keck II simultaneous with RXTE, during 5 nights recorded an optical spectrum covering 3800-9000 Å (~2.5 Å/pix) every 70 milliseconds, producing a vast-dataset of more than 1.2 million optical spectra. Analysis of this data is ongoing but clearly shows significant short-term correlations between the X-ray and optical variability which we hope will eventually allow to image the sources on micro-arcsecond spatial scales using echo-tomography.

Jonker et al. identified the probable infrared counterpart of the bright galactic X-ray source GX5-1. They obtained infrared observations with UKIRT of the field of this bright X-ray source and using very accurate astrometry were able to tie the IR image to an accurate radio position and perform the identification. Narrow-band photometry suggests excess Brγ emission in the counterpart, supporting its association with an accretion-disc source (Jonker, Fender, Hambley and van der Klis).

3.3.2.4. Accreting white dwarfs

In cataclysmic variables a white dwarf accretes matter from a companion, usually via an accretion disk. Dwarf novae are a subclass, in which the accretion onto the white dwarf varies strongly, causing dramatical changes in the overall brightness of the system. Verbunt, in collaboration with Wheatley (Leicester) and Hartmann studied full outburst cycles, from outburst via quiescent interval to outburst, in X-rays with the ROSAT satellite for YZ Cnc and with BeppoSAX for VW Hyi. From these observations the following picture emerges. The X-rays are emitted by an optically thin gas. Changes in the X-ray flux are due to changes in the amount of optically thin gas, the temperature of which changes little throughout. In the beginning of an outburst, as the mass flow through the disk onto the white dwarf increases, most of the gas turns optically thick, and the X-ray flux declines precipitously. During the outburst, the flux continues to drop, as the accretion rate onto the white dwarf, and with it the amount of optically thin gas, gradually declines. At the end of the outburst, a large amount of gas in the disk becomes optically thin again, and the X-ray emission jumps to a high value, which then declines throughout the quiescent interval. This latter observation mimics the decline in ultraviolet and optical flux during quiescence, and just as these is in contrast with theories according to which dwarf nova outbursts are due to instabilities in the accretion disk; supporting instead theories which ascribe the outbursts to enhanced mass transfer from the donor to the disk.

3.3.3. Radio pulsars and isolated neutron stars

3.3.3.1. X-ray and gamma-ray observations

PSR0218+4232, discovered in 1995, is a remarkable recycled radio pulsar that emits detectable radio emission throughout its pulse period. Verbunt, Johnston, and their collaborators Hermsen and Kuiper analyzed BeppoSAX and CGRO-EGRET data of this pulsar, using software developed by Kuiper and Hermsen, which combines spatial and temporal analysis to optimize the pulse detection and analysis. The pulse was detected up to 10 keV with BeppoSAX, and up to 1 GeV with EGRET - the only detection in high-energy gamma-rays of any recycled pulsar. The gamma-ray flux corresponds to about 7% of the total energy lost from the rotation energy of the neutron star (the 'spin-down' energy), and cannot be explained with any of the existing theories for pulsar emission.

3.3.3.2. Optical observations

Van Kerkwijk, together with Kaspi (MIT), Klemola (Lick), Kulkarni (Caltech), Lyne (Jodrell Bank), and Van Buren (IPAC), used HST to detect the optical counterpart of PSR B1718-18, an apparently young pulsar in the globular cluster NGC6342. This pulsar is in a circular orbit with a low-mass companion. The pulsar and its companion are thought to have been initially in an eccentric orbit, which was circularized to produce the present-day highly circular orbit. The optical observations suggest that tidal dissipation in low-mass stars is more efficient than usually thought.

Van Kerkwijk, with Bell (ATNF), Kaspi, and Kulkarni, also used HST to detect, and measure the temperature of, the white-dwarf counterpart of a millisecond pulsar, PSR B1855+09. Since this white dwarf has a mass accurately known from pulsar timing, the temperature can be used to determine a cooling age, given a cooling model. The main uncertainty in the cooling models for such low-mass white dwarfs is the amount of residual nuclear burning, which is set by the thickness of the hydrogen layer surrounding the helium core. The observations show that this layer has to be relatively thin, so that residual burning is not so important; otherwise, the white dwarf would be much older than the pulsar (more than 10 Gyr).

Yet another pulsar, PSR B2303+46, led to a surprise. This pulsar is in a close, eccentric binary, and such pulsars are usually assumed to have another neutron star as a companion. In Keck observations, however, van Kerkwijk and Kulkarni found a faint, blue counterpart. From this, they conclude that most likely the companion is not a neutron star but a massive white dwarf. Given the eccentric orbit, the white dwarf must have formed before the neutron star, from what was originally the more massive star in the binary. Due to mass transfer, the originally less massive star could become sufficiently massive to end its life in a supernova explosion and form the radio pulsar.

Van Kerkwijk used the VLT to obtain an optical spectrum of the isolated neutron star RX J1856.6-3754 (V=25.5 mag), detected a Hα nebula around it, and obtained photometry for a globular cluster in which a transient X-ray source was found with BeppoSAX to be bright. Analysis of these data is underway. Keck data were analyzed by Hulleman to determine an upper limit to the optical flux from the anomalous X-ray pulsar 1E2259+586; these upper limits exclude most models suggested for these mysterious objects, leaving only the single neutron star or the compact binary (with a white dwarf donor) as possibilities. The most likely model now appears the one according to which the anomalous pulsars are single, young neutron stars with extremely high magnetic fields, similar to the fields assigned to soft gamma-ray repeaters.

3.3.3.3. Radio observations

Stappers, Ramachandran and co-workers started an extensive observing program to monitor the times of arrival of pulses from some 30 pulsars once every three weeks. This program takes advantage of PuMa's superior time and frequency resolution to reach timing precision never before possible for a number of pulsars. The program has proved to be very successful even given its limited duration so far. In most cases the timing solutions on known pulsars are already equal to, and for some pulsars better than, those from longer running programs.

Milestones included (i) reaching sub 500 nanosecond timing accuracy for the fastest millisecond pulsar known, PSR B1937+21, confirming that WSRT and PuMa are capable of world-class pulsar timing, and (ii) achieving absolute timing of sufficient quality to allow analyzing X-ray data of the millisecond pulsar PSR J0218+4232 obtained with Chandra.

A further example is the timing of PSR J1518+4904, a member of a double neutron star binary, which confirmed the sum of the masses of the two neutron stars in the system and may allow measuring the orbital period derivative for the first time. This will further constrain the masses, which is important for understanding neutron star evolution along with the equations of state of matter under the highest pressures.

Stappers, Ramachandran and co-workers also modeled the times of arrival of pulses from the extremely steep spectrum MSP J0218+4232 to a root-mean-square accuracy of less than 6 μs. Their observations at 328 MHz of this high dispersion measure pulsar were able to achieve such high accuracy because of the high frequency resolution capability of PuMa. Observations at this low frequency are beneficial as the steep spectral index of the pulsar means it is significantly brighter at low frequencies. Again the timing residuals are much better than those previously published and with continued monitoring in the next year the proper motion of this source should become measurable.

Using the WSRT in combination with PuMa to generate an excellent targeted pulsar search machine, three surveys were carried out.

1. In a collaboration with Chinese astronomers, 30 steep spectrum, strongly polarized, point sources (parameters almost uniquely associated with pulsars) from the WENSS and NVSS northern sky radio surveys were observed at 382 and 1380 MHz. The analysis revealed no positive detection of a new pulsar. This suggests these sources are likely to be steep-spectrum background sources.

2. A survey of known neutron stars detected at X-ray wavelengths, some of which are pulsing and others which are not. The aim of this experiment was not only to see whether these sources pulse in the radio, but if they do not, to determine whether this means that the radio beam points away from us or that there is no radio emission at all from these sources. Preliminary analysis provided excellent upper limits on radio pulsations which are at least an order of magnitude better than any previous observations.

3. A large survey for pulsars in 11 globular clusters, undertaken at 1380 MHz, with a 10-sigma sensitivity of approximately 50-60 micro-Jy which is more than an order of magnitude better than any previous surveys of these clusters. As part of this survey the NOVA funded PhD student Jouteux derived a detailed mathematical analysis of the Fourier response of binary pulsar (both radio and X-ray) signals whose frequencies are modulated by circular orbital motion. The power spectrum of such signals was found to be V_{orb}-periodic over a compact frequency range, where P_{orb} denotes orbital frequency. Subsequently, he considered a wide range of binary systems with circular orbits and short orbital periods, and presented a Partial Coherence Recovery Technique for searching for binary millisecond X-ray and radio pulsars. This uses numerical simulations to investigate how easy it is to detect pulsars in such systems with Porb ≤ 6 hours, using this technique and three widely used pulsar search methods. These simulations demonstrate that the Partial Coherence Recovery Technique is on average always more, and up to 10 times more, sensitive at detecting pulsars in close binary systems when the data span is more than 2 orbital periods. The systems one may find using such a method can be used to improve the constraints on the coalescence rate of compact objects and they also represent those systems most likely to be detected with gravitational wave detectors such as the Laser Interferometer Space Antenna. It has been shown that the technique successfully determines the (already known) orbital period of the accretion powered X-ray millisecond pulsar SAX 1808.4-3658.

Using the highest time resolution mode of PuMa Ramachandran studied propagation effects in the interstellar medium. Radio signals, during their passage through the interstellar medium, are scattered due to the irregularities in the density of free electrons. Signals from distant sources most often undergo multiple scattering, while signals from nearby sources may be only weakly scattered even at meter wavelengths. PuMa observations of PSR B0950+08 at 382 MHz in the highest time resolution mode showed no indication of the presence of discrete scattering events. Ramachandran, Deshpande and Stappers estimated that the minimum measurable delay between the ordinary and scattered ray had to be about 100 nanoseconds. For an electron cloud of size 100 AU, their results place an upper limit to the number density fluctuation of this cloud to be $2x10^{-3}$ cm^{-3}.

Deshpande (RRI), Ramachandran and Radhakrishnan (RRI) examined available data on the known velocities and spin parameters of pulsars for evidence pertaining to mechanisms proposed to explain the origin of their velocities. They found that mechanisms predicting a correlation between the rotation axis and the pulsar velocity are ruled out and that there is no significant correlation between pulsar magnetic field strengths and their velocities. Furthermore if asymmetric impulses are responsible for both the rotation rates and velocities of pulsars, then single impulses of any duration appear ruled out and multiple impulses of long duration are also ruled out.

Stappers, Gaensler (MIT) and co-workers surveyed 27 pulsars to search for radio emission from pulsar powered nebulae. This survey using the VLT and Australia Telescope Compact Array was more sensitive over a wider range of possible nebula sizes than any previous survey. Only one new such nebula was discovered, however the limits on the presence of such nebulae are so strong that the young pulsars in the sample must all be located in the low-density regions of the interstellar medium. For the older pulsars in the sample the radio luminosity of their relativistic winds is less than 10^{-5} of their spin-down luminosity, implying an efficiency at least an order of magnitude smaller than that seen for young pulsars. The same principal investigators with Bock (Berkeley) used limits on the radio emission from the neutron star at the center of the Puppis A supernova remnant to show that the proposed energetic, young X-ray pulsar (based on claimed pulsation detections in the X-rays) was unlikely. This was later confirmed with further X-ray studies.

3.3.4. Populations and evolution

3.3.4.1. X-ray sources in globular and open clusters

Using newly developed software for the analysis of very faint sources whose images overlap, Verbunt analyzed the full globular cluster data in the ROSAT archive, and found five new sources in the cores of four clusters, and three new sources outside the cores, but probably related to the cluster. He furthermore improved positional accuracy for sources in ten clusters, which in several cases exclude previously proposed optical counterparts to the X-ray sources (example in Fig. 12). The homogeneous analysis for the first time allowed a statistical study of the class of low-luminosity sources in globular clusters. From this analysis it follows that; a) the brightest of these sources are too bright to be cataclysmic variables, they must be neutron stars accreting at low rates; the limited information provided by ROSAT on the spectral energy distribution confirms this conclusion; b) the total luminosity is dominated by a few relatively bright, rather than large numbers of low-luminosity sources; c) there is a class of sources in globular clusters outside the cores; d) the mass-to-X-ray-luminosity ratio depends on the cluster concentration when the mass of the cluster core only is used.

Verbunt, Cornelisse, van Kerkwijk, Heise, in 't Zand and Kuulkers in a collaborative effort between SRON and UU detected an outburst of the transient X-ray source in NGC6440 with the BeppoSAX Wide Field Camera. From archival ROSAT data, a position of the quiescent X-ray source was obtained, and used to search for an optical counterpart in VLT and NTT data obtained during the X-ray outburst. A plausible candidate was identified. During the outburst of the source in NGC6440 several X-ray bursts were detected with BeppoSAX, which is interesting because it proves the emitter to be a neutron star (as opposed to a black hole): an X-ray burst is thermonuclear fusion of hydrogen and/or helium accreted onto the surface of a neutron star. This leaves Terzan 6 as the only globular cluster source for which no such burst has been seen, and implies that 11 of the 12 (permanently or transiently) bright X-ray sources in globular clusters are neutron stars. These observations support the theory that black holes are removed by dynamical two- and three-body interactions in the early history of a globular cluster.

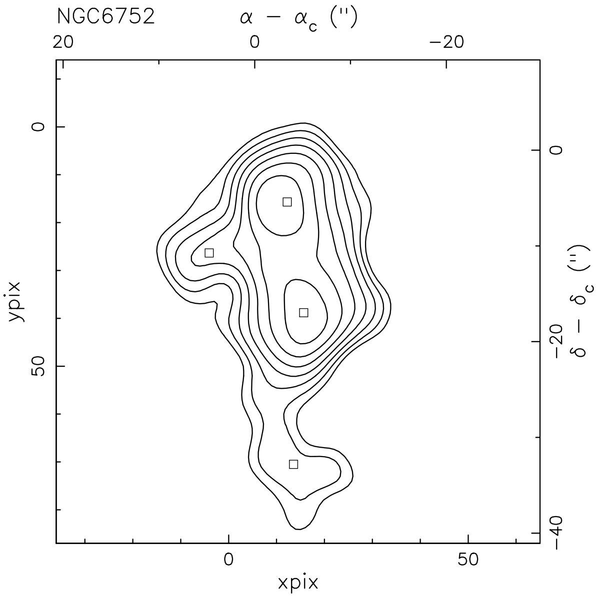

Fig 12: X-ray contours of the central region of the globular cluster NGC6752, obtained with the ROSAT HRI. The source locations determined with the special-purpose software are indicated with squared boxes.

With BeppoSAX an eclipse was observed of the X-ray source in Terzan 6, and analysis of the full set of data from the Wide Field Camera allowed the orbital period to be determined at 12.36 hrs. This period indicates that the mass donor in the binary is larger than a main-sequence star, i.e. it is a subgiant. Of the five X-ray source in globular clusters whose orbital period is now known, only one may have a main- sequence donor.

Old open clusters such as M67 are interesting comparison objects for globular clusters, and have the advantage that study of individual stars, both in X-rays and in optical, are easier. The brightest X-ray sources in M67 are located in the optical Hertzsprung Russell diagram in unusual locations. Van den Berg and Verbunt in collaboration with Mathieu (Wisconsin) obtained high-resolution spectra of stars detected in X-rays, and were able to show that most display signs of coronal activity (e.g.

in the form of Ca H&K emission, and Hα emission). In old stars coronal activity must be due to binary interaction, but several of the binaries are too wide or too eccentric for such interaction to be important. This leaves the cause of the coronal activity, and of the X-rays in these stars a mystery.

3.3.4.2. Studies of X-ray binaries and binary pulsars

Van Paradijs and Ventura organized the two-week NATO Advanced Study Institute "The Neutron Star Black Hole Connection" in Elunda, Crete in June 1999, where many of the leading scientists in the field of neutron star and black hole studies presented lectures. Because of the grave illness of van Paradijs, which prevented him from participating, van den Heuvel led this Institute together with Ventura. The (delayed) proceedings will appear in 2001.

Kaper, van Kerkwijk, van Paradijs and Barziv completed the radial velocity study of the high-mass X-ray binary Vela X-1/HD77581 which resulted in a mass for the neutron star in this system of 1.90 (0.20, 99% confidence error) solar masses, higher than that of any other known neutron star.

Postdoc Liu (Nanjing University, China), together with van Paradijs and van den Heuvel completely revised and updated van Paradijs' 1995 Calalogues of High- and Low-Mass X-ray Binaries. Since 1995 the number of High-Mass X-ray Binaries doubled and that of Low-Mass systems increased by about 30 per cent.

Nelemans, van den Heuvel and Tauris found, from the runaway velocities of the black hole X-ray binaries, that in the formation of stellar mass black holes at least several solar masses of matter are ejected.

Tauris, Savonije and van den Heuvel conceived a new model for the formation of binary radio pulsars with massive white dwarf companions and orbital periods of 1 to 2 weeks. They showed that in the formation of these systems the occurrence of a common-envelope phase can be avoided. This work was presented by van den Heuvel at the Santa Barbara Workshop on 'Spin and Magnetism in Young Neutron Stars', in November 2000.

Savonije and PhD student Witte obtained revolutionary new results on the tidal evolution of close binaries taking into account the occurrence of forced non-adiabatic oscillations. They calculated the tidal evolution of binaries with massive and low-mass stars and discovered that near the many resonances that occur during this evolution the tidal effects in these binaries become enormous and may rapidly synchronize and circularize the orbits.

3.3.4.3. Binary and stellar evolution

Nelemans and Verbunt, in collaboration with Yungelson (Moscow) and Portegies Zwart (MIT) studied the evolution of binaries into double white dwarfs. Such double white dwarfs are interesting as possible targets for gravitational wave detectors, in particular LISA, and as possible progenitors of type Ia supernovae. First they reconstructed the past evolution of three double (helium) white dwarfs. The mass estimates of the currently observed white dwarfs enables the determination of the radii of their giant progenitors through the core-mass-radius relation for giant stars. From these radii strong constraints on the orbital separations of these binaries during their previous evolution could be obtained because the orbital separations must have been comparable to the radii of the giants to allow mass transfer. Combining this information with the two standard scenarios for the formation of double white dwarfs it was found that neither scenario could explain the first phase of mass transfer in these binaries. It was therefore argued that in mass transfer between stars of almost equal mass does not lead to large changes in the orbital period - in contrast to previous views.

Using this new scenario the same authors simulated the present total Galactic population of double white dwarfs and found better agreement with the observed sample of double white dwarfs than before. Complementing this model population of double white dwarfs with a model of the present population of all other Galactic binaries containing compact objects (white dwarfs, neutron stars or black holes) they calculated the expected gravitational wave signal of these binaries in the low-frequency domain where LISA will be sensitive. They concluded that below ~2 mHz the double white dwarf population forms an unresolved background. Above this frequency a few thousand double white dwarfs and a few tens of binaries containing neutron stars will be resolved.

Langer's research on the evolution of massive close binary systems, as part of a large scale parameter study, determined which systems can evolve up to the first supernova explosion without encountering contact. One surprise of this study was that, for the most massive systems, those with the shortest initial periods (so called Case A systems) have indeed the best chance to avoid contact. This finding has immediate consequences for the limiting initial stellar mass separating neutron star and black hole formation, as determined from massive X-ray binaries. He furthermore studied the effect of stellar wind mass loss on the late evolution, collapse, and final compact remnant mass of massive Wolf-Rayet stars formed through close binary mass transfer, and ways to avoid strong stellar wind mass loss in these objects, in order to understand the origin of the observed black hole binary population in our Galaxy and the Magellanic Clouds.

The study of low and intermediate mass single and binary stars has focused on two topics. First, Langer and collaborators investigated the influence of rotational mixing on AGB stars, and found the possibility to self consistently obtain a neutron source for the s-process nucleosynthesis through shear mixing of protons into the helium burning shell source. Pursuing these models into the post-AGB stage, they also found hydrogen-poor surface compositions to arise from a late (i.e., post-AGB) thermal pulse in a natural way. Secondly, they studied the evolution of accreting white dwarfs in binary systems, to investigate which binaries can evolve into Type Ia supernovae. They found that shear mixing in the spun-up accreting white dwarf has an essential effect in suppressing the violent shell instabilities which otherwise dominate the evolution of most of these objects.

The evolution of massive stars from their birth until the supernova stage was modeled for the first time including the effects of global and differential rotation, i.e. in particular the transport of chemical species and angular momentum due to rotationally induced mixing processes. This allowed to predict the surface enrichment of massive stars by nucleosynthesis products, for all evolutionary stages, yielding important constraints on uncertainties in the description of these mixing processes when compared with observations. Langer and collaborators showed that life times, evolutionary tracks, and even the final fate of massive stars depend sensitively on their initial rotation rate. Their models allow the first quantitative prediction of the spin rates of new born pulsars, and of which stars can retain enough angular momentum in their cores to produce Gamma ray bursts when their core collapses into a black hole. They also considered the effect of cosmic ray production from various types of supernovae.

3.3.5. Particles and shocks

3.3.5.1. Relativistic shocks

Achterberg and Gallant, together with Kirk and Giesseler (Max Planck Institut für Kernphysik, Heidelberg), considered particle acceleration near the ultra-relativistic shocks thought to occur in the relativistic jets associated with Active Galactic Nuclei, and in the powerful explosions associated with Gamma Ray Bursts. Using two different approaches, namely numerical simulations and semi-analytical calculations employing an eigenfunction method, they were able to show that the spectrum of accelerated particles is a power-law whose slope depends only weakly on the precise conditions ahead of the shock. This shows that particle acceleration in relativististic shocks is a very robust mechanism.

3.3.5.2. Ultra-high energy cosmic rays

Achterberg and Gallant, in a collaboration with Norman (STScI, Baltimore) and Melrose (University of Sydney), completed a theoretical and numerical study of the propagation of Ultra-High Energy Cosmic Rays (UHECRs) through the intergalactic medium. They treated the effects of energy losses of cosmic ray hadrons on the Cosmic Microwave Background through photo-pion production and pair production in conjunction with the deflection of these particles caused by a weak, random intergalactic magnetic field. The most important conclusions are: (1) the most energetic particles, with an energy of $\sim 10^{20}$ eV, can reach the Earth from a distance up to ~50 Mpc. The sharp cut-off due to pion production losses, predicted for the cosmic ray spectrum at this energy by earlier studies which use only a simple model for the energy losses of cosmic ray hadrons, becomes much less pronounced if one takes the Poisson statistics of the photon-hadron interactions and the kinematics of photo-pion production into account. (2) The delay in arrival time of UHECR protons with respect to photons produced at the same instant as a result of magnetic deflection can be large: up to 10^4 yr. This means that the number of observed UHECR events above 10^{20} eV could be supplied by Gamma Ray Bursts occurring in the local Universe (volume $\sim 10^5$ Mpc^3), provided the rms amplitude of the intergalactic magnetic field exceeds 0.1 nG.

3.3.5.3. Cosmic rays and supernova remnants

Van der Swaluw, Achterberg and Gallant studied the hydrodynamics of Pulsar Wind Nebulae (PWNs) which are present around young, rapidly rotating pulsars. These nebulae, presumably consisting of a relativistically hot plasma, have been seen in radio and in X-ray observations, and in exceptional cases such as the Crab Nebula, also optically. Together with the supernova remnant (SNR), in which these nebulae are located -left over from the explosive birth of the pulsar- they form the class of the Plerionic Supernova Remnants. Using the Versatile Advection Code (VAC) they studied the evolution of the expansion of PWNs, and have shown that a supersonic early expansion becomes a slow subsonic expansion after the SNR enters the so-called Sedov-Taylor Phase (Fig. 13). This phase starts when the blast wave which surrounds the remnant like a bow-shock has swept up an amount of mass from the surrounding interstellar gas equal to the mass which was ejected explosively as a result of the supernova explosion. In the Sedov-Taylor phase the expansion of the remnant decelerates. At the transition between supersonic and subsonic expansion the PWN radius undergoes strong oscillations. They also studied the case where a large proper motion of the pulsar (typically V 1000=km/s brings the PWN to the edge of the decelerating blast wave, and breaks out of the remnant. In this case the pulsar wind nebula is surrounded by a bowshock, not unlike the bowshock which surrounds the Earth's magnetosphere due to the presence of the tenuous Solar Wind. A number of observed SNR-pulsar systems such as CTB 80 and G5.4-1.2, have a morphology which suggests that such a situation occurs.

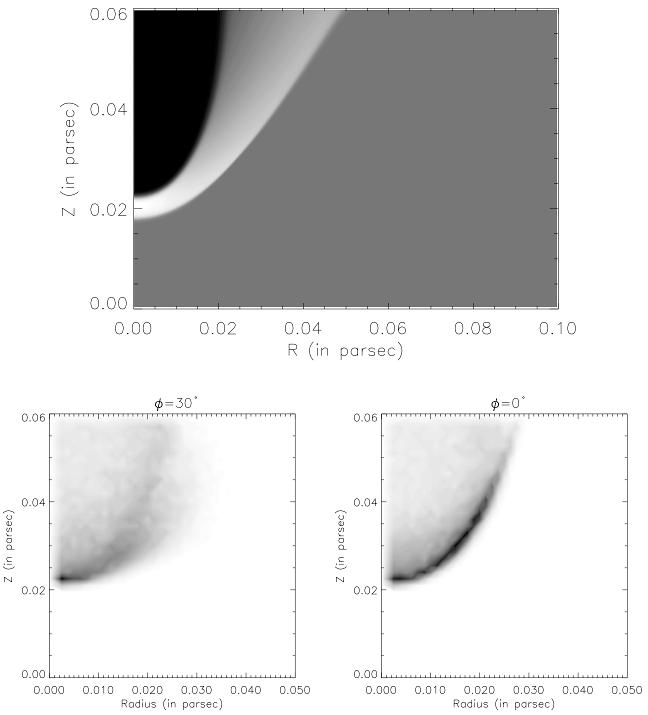

Fig. 13: Hydrodynamical simulation (top panel) and simulated synchrotron map (bottom two panels) of a pulsar wind bow shock due to a pulsar moving with a velocity of three times the sound speed in a supernova remnant.The two synchrotron maps correspond to a different viewing angle (between the line of sight to the observer and the direction of the magnetic field ahead of the shock.

In addition to their study of the hydrodynamics, they also considered the acceleration of Cosmic Rays near the shock waves associated with the SNR. In particular they were able to show that young supernovae remnants (age ≤ 700 years) can accelerate electrons up to energies of ~ 10 TeV. These electrons produce X-rays by synchrotron radiation in the weak (B ~ 3 - 30 μG magnetic fields present in these SNRs. The simulations also produce roughly the right distribution for the energies of the accelerated electrons (a very steep distribution due to synchrotron losses: $N(E)\, dE \,\alpha\, E^{7}\, dE$), close to the one inferred from recent observations of non-thermal X-ray synchrotron emission from a number of young supernova remnants.

3.3.5.4. Accretion disks

Nauta and Kuijpers, in collaboration with Zimmerman (Institute of Meteorological and Atmospheric Physics - at Utrecht University), investigated the dynamics of large-scale vortices in accretion disk. On the basis of numerical simulations they concluded such vortices can persist for several rotation periods in an accretion disk, and will lead to weak shocks in the accretion flow. Vortex- vortex interaction (vortex merging) can also be an important process. The presence of vortices does lead to a loss of angular momentum of disk material, as required in the theory of thin accretion disks. The effective viscosity generated in this manner remains rather small however, and is not appreciably larger than competing mechanisms leading to an increased disk viscosity such as magnetically driven instabilities in the disk.

Kuijpers, in collaboration with Pavlidou, Vlahos and Isliker (University of Thessaloniki) constructed a 'cellular automaton' model for magnetic activity in accretion disks. This model uses a probabilistic method to simulate the magnetic activity due to a large collection of magnetic loops in an accretion disk corona. It calculates the mass transport induced in the disk due to magnetic stresses due to the loops, the dynamical evolution of single loops and interaction between loops due to the process of magnetic reconnection, and the generation of energy ('flares') which results from these processes. They can simulate the temporal behavior of the magnetic energy release using this model, constructing power spectra for the radiation flux that results from the disk as a whole.

4. PhD's in astronomy awarded in 1999 - 2000

In 1999 a total of 23 PhD's in astronomy were awarded in the Netherlands, and another 19 were awarded in 2000. The table below lists all PhD's in astronomy over 1999-2000 specified for each university.

Name	PhD date	Employer	Promotor	Thesis title
UvA				
R.A.D. Wijnands	16-02-1999	PIONIER, UvA	van der Klis	Millisecond Phenomena in X-ray Binaries
M.E. van den Ancker	14-09-1999	NWO-GBE	Tielens, Waters	Circumstellar material in young stellar objects
J.Th. van Loon	23-09-1999	UvA, ESO	de Jong	Mass loss and evolution of asymptotic Giant Branch Stars
C. Schrijvers	16-11-1999	UvA	van Paradijs	Spectroscopic diagnostics of pulsations in rotating stars
P.J. Groot	07-12-1999	UvA	van Paradijs	Optical variability in Compact Stars
T.J. Galama	08-12-1999	NWO-GBE	van Paradijs	Gamma-ray burst afterglows
P.A. Zaal	12-01-2000	UvA	van den Heuvel	Observations and Analysis of early-type stars at infrared wavelengths
J.A. de Jong	08-02-2000	NWO-GBE	van den Heuvel co: Henrichs	On the origin of cyclical variability in the winds of massive stars
F.J. Molster	15-06-2000	NWO-GBE	Waters, de Jong	Crystalline silicates in circumstellar dust shells
RuG				
A.C.A. Boogert	05-03-1999	RuG	Tielens	The interplay between dust, gas, ice, and protostars
P.D. van Dokkum	21-06-1999	RuG	Franx, Illingworth	Formation and evolution of early-type galaxies
W.H. de Vries	25-06-1999	RuG	Briggs	Host galaxies of powerful extragalactic radio sources
R.H.M. Schoenmakers	02-07-1999	RuG	van Albada	Asymmetries in spiral galaxies
R.A. Swaters	15-10-1999	RuG	van Albada, Sancisi	Dark matter in late-type dwarf galaxies
L.V.E. Koopmans	07-02-2000	NWO-GBE	de Bruyn	A study of radio-selected gravitational lenses
J. Gerssen	14-07-2000	RuG	Kuijken, Merrifield	Stellar kinematics in disk galaxies
H. Hoekstra	22-09-2000	RuG	Franx, Kuijken	A weak lensing study of massive structures: looking at the dark side of the universe
W.M. Lane	09-10-2000	RuG	Briggs	HI 21 cm absorbers at moderate redshifts
M.A. Zwaan	16-10-2000	RuG	Briggs	Atomic hydrogen in the local universe
R.A. Jansen	28-11-2000	RuG	Franx, Fabricant	The nearby field galaxy survey: a spectro-photometric study of 196 galaxies in the local field
UL				
R.B. Rengelink	17-02-1999	NWO-GBE	Miley, De Bruyn	The Westerbork Northern Sky Survey; the cosmological evolution of radio sources
E.T. Chatzichristou	15-06-1999	External funds	co: Jaffe	Imaging and bi-dimensional spectroscopy of active and interacting galaxies
N. Cretton	09-09-1999	UL, Swiss, NUFFIC	de Zeeuw, Rix co: van der Marel	Dynamical models of early-type galaxies
J.M. Stil	09-09-1999	UL	Habing co: Israel	Dwarf Galaxies: dynamics and star formation
C.P. Dullemond	22-09-1999	UL	Icke co: Turolla	Radiative transfer in compact circumstellar nebulae
L. Pentericci	28-10-1999	UL	Miley co: Röttgering	The most distant radio galaxies: probes of massive galaxy formation
J.H.J. de Bruijne	25-05-2000	UL	de Zeeuw / Perryman co: Blaauw	Astrometry from space
R. Hoogerwerf	25-05-2000	NWO-GBE	de Zeeuw / Perryman co: Blaauw	Hipparcos and the nearby OB associations: Space astrometry and high-mass star formation
A. Helmi	28-06-2000	UL	de Zeeuw / White	The formation of the Galactic halo
F. van der Tak	20-09-2000	NWO-GBE	van Dishoeck / Evans	The embedded phase of massive star formation
P.M. Veen	27-09-2000	UL	Habing	Intriguing variability of WR 46 and of "dusty" Wolf-Rayet stars
C. De Breuck	08-11-2000	UL/Livermore	Miley/ Röttgering / Van Breugel	Very distant radio Galaxies: search techniques and emission line properties

Name UU	PhD date	Employer	Promotor	Thesis title
J. Vink	19-04-1999	SRON	Bleeker co: Kaastra	The spectral X-ray morphology of the supernova remnants Cas A, RCW 86 and SN 1006
H.C. Hagenaar	10-05-1999	UU	Kuperus co: Schrijver, Rutten	Flows and magnetic patterns on the solar surface
R.H.M. Voors	11-05-1999	UU	Lamers co: Waters	Infrared studies of hot stars with dust
H.W. Hartmann	13-09-1999	SRON	Heise co: Verbunt	Models for hot high-gravity atmospheres applied to soft X-ray sources
A.P. Schoenmakers	4-10-1999	NWO	van der Laan, de Bruyn	A population study of giant radio galaxies
M.L. van den Berg	05-10-1999	SRON	Bleeker co: de Korte, Luiten	Development of a high resolution X-ray spectrometer based on superconductive tunnel junctions
M.D. Nauta	10-01-2000	UU	Kuijpers	Two-dimensional eddies in accretion disks
M. Kouwenhoven	09-10-2000	UU, NOVA	Verbunt	Pulsar observations with the Westerbork Synthesis Radio Telescope
J. van Gent	06-11-2000	UU	Lamers	The Baldwin-effect in Wolf-Rayet stars
J. S. Vinck	20-11-2000	NWO-GBE	Lamers, de Koter	Radiation-driven wind models of massive stars

5. Instrumentation Program

5.1. ALMA high-frequency mixer development

ALMA, the Atacama Large Millimeter Array, is a joint project of Europe (led by ESO), North America (led by NRAO) and possibly Japan (led by NOAJ) to build a millimeter/submillimeter interferometer at 5000m altitude on the Chajnantor highlands of Chile.

The aim of the NOVA - ALMA project is to develop a high sensitivity 600-720 GHz (Band 9) prototype mixer and receiver for ALMA. It is a collaboration between the mixer team located at SRON-Groningen and the SIS device experts at the Technical University of Delft (TUD). There is a close interaction with the Herschel-HIFI team at SRON-Groningen, led by de Graauw. The NOVA - ALMA project also investigates the possible contribution of Dutch industry to the eventual construction of the ALMA receivers.

Wild started his job as the manager for this project on May 1, 1999. On November 1, 1999, Baryshev started as the mixer scientist, and Hesper joined the team at SRON as project physicist on September 1, 2000. In Delft, Zijlstra (junction scientist) and Zuiddam (junction engineer) started on June 1, 2000, under supervision of Klapwijk.

5.1.1. The ALMA project

An important ALMA milestone in 1999 was the signing of the MoU between North America and Europe on a joint Design and Development Phase I (1999-2001). A joint North America - Europe Alma Coordinating Committee (ACC) was established. On the European side, the ALMA organization is through the European Coordinating Committee (ECC) in which ESO and various other European countries, including the Netherlands, are represented. In October 2000, Japan formally announced its intention to join ALMA as a third partner.

The ACC and ECC are advised by the ALMA Science Advisory Committee (ASAC) on many aspects of the projects. The first ASAC meeting was held in Leiden in March 2000; van Dishoeck represents the Netherlands on the ASAC. She was appointed vice-chair in 2000.

Van Dishoeck organized a national ALMA 'Science and Technology Day' in Leiden on April 7, 2000. The purpose of this meeting was to discuss the ALMA science case from the Dutch perspective, stimulate science with (sub)millimeter arrays in general, inform the community at large on the status of the project and the technical developments for ALMA in the Netherlands, and to stimulate interaction between Dutch scientists and technical groups. The meeting was attended by more than 60 participants from the universities and technical institutes.

At the technical level, several joint North America-Europe working groups were established by the ACC/ECC. The receiver working group is led by Wild on the European side and Payne on the North American side. As team managers, they organized several international receiver and optics team meetings during 1999-2000 to work out the overall receiver concepts. In addition, a joint receiver work plan for Phase I was established, and the division of labor during the construction Phase II is being investigated. In late November 2000, an agreement between NOVA and ESO was signed, specifying the NOVA R&D contribution to ALMA and providing ESO reimbursement to NOVA for Wild's efforts as the ALMA European receiver team manager.

5.1.2. ALMA activities at SRON-Groningen

A number of activities were carried out at SRON-Groningen in 1999-2000. Two different mixer designs were developed, one being a balanced waveguide mixer using a magic-T hybrid, the other a quasi-optical design with various antenna structures on the SIS chip. Fig. 13 shows the two different approaches for a 650 GHz SIS mixer. Fabrication of both designs was started, and they are expected to be available for testing in early 2001. In particular, SIS devices for both designs were manufactured at TUD, and first tests were promising.

Intensive work was carried out on the optics design for the ALMA band 9 receiver. The present solution is a two mirror scheme, maximizing performance and at the same time opting for simplicity.

During 2000, the ALMA laboratory at SRON-Groningen was equipped with the necessary optical and measurement setup, with support from

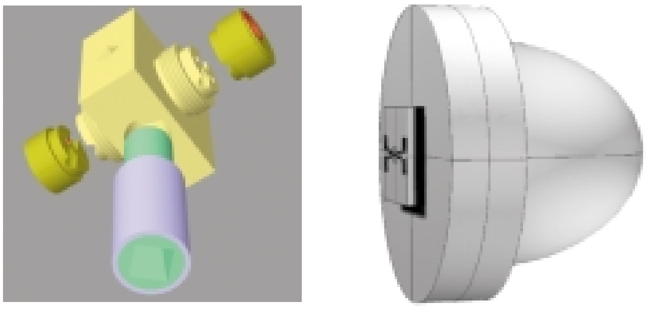

Fig. 14: Design of a balanced waveguide SIS mixer (left) and quasi-optical mixer (right) for ALMA.

SRON. A collaboration was started with NRAO on IF amplifiers. NRAO supplied a 4-12 GHz IF amplifier, which will be interfaced and tested with the SRON mixers.

Representatives from NOVA, SRON and the RuG Transfer & Liaison Group developed ideas and scenarios for the series production of 64 receivers for ALMA following the current design & development phase. Detailed budget and manpower estimates were developed. Many of the Dutch ideas are being incorporated into the overall North America-Europe-Japan ALMA receiver planning.

5.1.3. ALMA activities at DIMES,TU Delft

To achieve high sensitivity heterodyne operation, superconducting junctions and tuning elements are essential components of the receivers. The principal challenge is to improve the technology such that it meets the specifications for ALMA and to make it available to ALMA in a way that long-term commitments can be accommodated and integrated with the scale of ALMA. In 1999-2000, the main focus was on the transfer of equipment from the small university laboratory environment at the RuG to the broader technology-based environment at the Department of Applied Physics at the University of Delft. The transfer also implied training of new personnel, with the advantage of being able to attract people on longer term contracts. This transfer and training round caused delay in realizing mixing elements for ongoing projects, but it has created a much more solid base for the requirements set by the ALMA-project.

Mixing elements were realized and delivered to the receiver group at SRON-Groningen by the end of 2000. In addition, a new design was realized and transferred in a mask-set to be used for new devices. While first results are promising, the yield and accuracy of fabrication to specifications needs further improvement. In the future, a person with a PhD in technology development of superconducting devices needs to be added to the team to allow quicker identification of crucial steps where improvement can be reached.

5.2. Dutch Open Telescope (DOT)

The DOT on La Palma is an innovative optical solar telescope which achieves high angular resolution. Its open structure avoids internal seeing not through telescope evacuation but through wind flushing of the mirror and telescope interior. An open support tower avoids the excitation of local turbulence by wind blocking. The trade winds on La Palma are often sufficiently strong for telescope flushing and keeping the ground-heated boundary layer of turbulent convection all day below the 15m DOT tower height. The science niche that the DOT should fill is to be the premier high-resolution tomographic imager of the magnetic fine structure, topology, and dynamics of the photosphere, low chromosphere, and high chromosphere of the Sun.

The DOT project is currently funded by the Astronomical Institute of the University of Utrecht, NWO, NOVA, and EU-TMR in a three-year ‘initial science validation’ program which started in September 1998. Its aim is to expand the DOT from its initial STW-funded technology demonstration configuration into a facility for front-line solar physics research through: (i) installation and scientific exploitation of a three-channel proxy-magnetometry filter imaging G band, Ca II K, and in rapidly tuned Hα); (ii) software development of phase-diverse and/or speckle restoration.

At the start, item (ii) was thought the hardest and to be explorative only, but it actually became a success very quickly after the hiring of EU-TMR funded postdoc Sütterlin. He brought German speckle expertise to the project and it turned out that speckle restoration was feasible even with the simple analog video camera and 8-bit digitization of the initial DOT configuration. Spectacular movies of solar active regions were taken in 1999 and 2000 using speckle reconstruction techniques. They prove that the combination of the La Palma site, the open tower principle, the DOT optics and mechanical stability, and speckle processing make the DOT one of the sharpest solar telescopes worldwide. The DOT movies received much acclaim at conferences, and have figured on the ‘Astronomy Picture of the Day’ website. They are available at http://dot.astro.uu.nl, as are reprints and preprints of numerous conference presentations. Science analysis of DOT image sequences includes studies of penumbral fine structure and umbral dynamics. Astronomers from Stockholm, Ondrejov, and the IAC at La Laguna are also analyzing DOT image sequences.

An unforeseen but exciting extension to the multi-channel system originated from a test of a tunable Lyot filter. This filter, built by Skomorovsky and Domishev at Irkutsk, selects a very narrow pass-band tuned to and across the Ba II 455.4 nm resonance line. The combination of filter and line turns out to deliver Dopplergrams of unprecedented resolution and sensitivity. The test was performed at the Swedish Vacuum Solar Tower shortly before its demise because the filter is very large and not easily accommodated in the DOT. The results (available on the DOT website) are so promising that the decision was taken to add this filter to the multi-wavelength system, as optional replacement of the blue continuum channel.

5.3. MID-infrared Interferometer (MIDI)

A fundamental goal of the ESO VLT program is the combination of the radiation from the four constituent 8m telescopes and several smaller auxiliary telescopes into the VLT Interferometer (VLTI), giving a spatial resolution of a few tens of milli-arcsec at 10 µm to 1 milli-arcsec in the visible. The NOVA participation in the VLTI program aims to exploit the strengths of Dutch astronomy and to build up the expertise which will optimize scientific use of the facility. Specifically, it consists of (i) participation in MIDI, described here, and (ii) the foundation and development of NEVEC (see § 5.4)

MIDI is a prototype fringe detector system that will operate in the 10 micron window at the VLTI. This project is a largely experimental effort to develop the techniques of multi-telescope synthesis imaging at near- and mid infrared wavelengths. MIDI will provide up to 20 milli-arcsecond angular resolution at a spectral resolution of 200-300. MIDI is a collaboration of MPIA (Max Planck Institut für Astronomie at Heidelberg, Germany, project-PI Leinert), NOVA (universities of Amsterdam and Leiden, NOVA-PI Waters), ASTRON, ESO, and other partners in France and Germany. Delivery to Paranal is planned for Summer 2002.

ASTRON is responsible for the production of the 'cold optics' at the heart of the instrument. The two beams coming from the delay lines are re-imaged, spatially filtered, combined, dispersed and imaged by the detector. The rest of the instrument, warm optics, cryostat, cooling system, detector unit and electronics, will be produced by MPIA.

The project started officially when the Conceptual Design Review was passed successfully in December 1998, though MPIA had been working on the concept of MIDI since 1997. At the end of February 2000, MIDI successfully passed the Final Design Review. Delivery of the 'cold optics' to MPIA is scheduled for Spring 2001.

5.3.1. Optical design

The optical design underwent many changes in the first part of 1999. The angle of the beam combiner was changed from 45° to 30° in order to minimize polarization effects. The space between elements was increased to allow for baffling, mechanisms and structures. The camera lenses were optimized to produce sharp images and to reduce the absorption of radiation longer than 12 micron within the lenses. Both a tolerance analysis and a ghost analysis were performed. The full N-band grism was designed and ordered and preliminary design for the low-resolution prism was completed. All of this led to an optical design that was frozen in November 1999.

The optical laboratory at ASTRON developed a way of polishing aluminium mirrors. This meant that all the flat mirrors could be made in house at ASTRON with a very high optical quality, superior to that achieved by diamond cutting. Four of the camera lenses were also made at ASTRON.

5.3.2. Mechanical design

The mechanical design started in June 1999 with the arrival of the first mechanical designer, supplemented by a second one in November. It proved extremely useful that the two main partners for the hardware (MPIA and ASTRON) work with the same software for optical design (ZEMAX) and mechanical design (Pro-Engineer). This greatly facilitated exchange of designs, checks of interfaces and general communication. A nice example is given in Fig. 15 which shows MIDI as it will be at Paranal with details designed at different places.

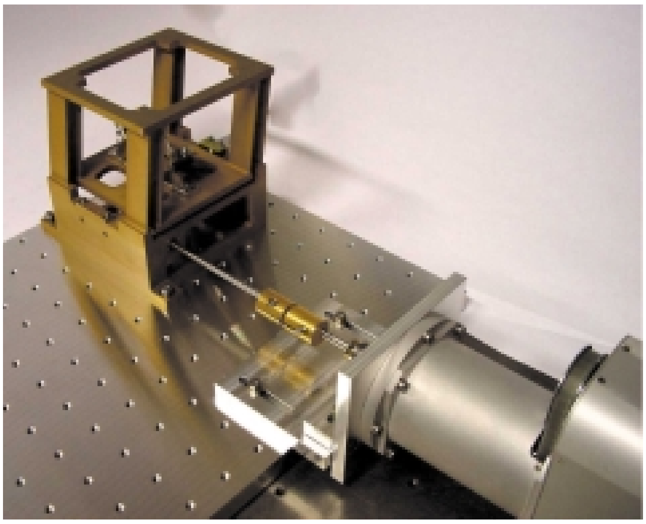

Fig. 15: The MIDI cold bench. MIDI M1 focus unit undergoing testing. It is attached to the motor unit in a test set-up and is not yet mounted on the real base plate.

In 2000, both the optical and mechanical design were completed. Also production and assembly began. The base plate was assembled and placed on its dummy feet. The real feet were sent to MPIA for cryogenic testing. A dummy sliding mechanism was designed and manufactured in order to test the accuracy of the mechanical positioning which removes the need to accurately transfer the encoder positioning into the vacuum vessel. The dummy slider was tested at room temperature and was found to have a repeatability of better than 0.6 microns.

The spectroscopic camera lenses were found to be very difficult to manufacture as they are made up of toroidal and aspheric surfaces. After several months of searching for a manufacturer, it was discovered that Philips could make them with their diamond cutting machine. A mistake was found in the optical design of the beam combiner unit. A small redesign was needed, however the design of this subsystem had not yet been completed so manufacturing was not affected.

5.3.3. Science preparation

There is a well-developed science program available for MIDI, which is split into 3 sections. The first is on active galactic nuclei, the second on young stellar objects, and the third on asymptotic giant branch stars. There is a large overlap with scientific activities for VISIR, benefiting both instruments. Details of MIDI research programs will be tested in 2001 using the MIDI simulator to estimate the amount of observing time required per object. A list of calibrators for MIDI was made and several observing proposals were submitted to ESO in 2000, to obtain photometric and spectroscopic data for the calibrators. The angular sizes of about 100 calibration sources are already known; work is continuing to obtain sizes for the remainder calibrators. A list of filters for the N-band has to be decided and a consortium of several instrument groups, including MIDI and VISIR, was formed to purchase the filters at a reduced cost.

5.4. NOVA-ESO VLTI Expertise Center (NEVEC)

To be an official partner in the VLTI program with guaranteed observing time requires a contribution to the ESO program additional to the normal annual membership fee. On 31 May 1999, a MoU was signed by NOVA and ESO formalizing the additional Dutch contributions to the VLTI project and providing for Dutch membership of the VLTI Steering Committee, presently the VLTI Implementation Committee. NOVA committed to set up and fund a new expertise center in optical/infrared interferometry in astronomy as a joint venture with ESO, called NEVEC and based at Leiden. The goals of NEVEC are: a) development of instrument modelling, data reduction and calibration techniques for VLTI, concentrating on optimizing VLTI for studies of faint objects; b) accumulation of expertise relevant for a second-generation VLTI instrument; c) education in VLTI.

Besides providing an infrastructure for NEVEC, NOVA guaranteed funding for a minimum of 18 staff years of scientists and software engineers to work at NEVEC during the period from 1999 to 2005. At least 10 staff years will be devoted to carrying out a set of tasks defined jointly by NOVA and ESO. The relevant work-packages and management structure for NEVEC were developed in mutual agreement between NOVA and ESO. Selection of NEVEC staff is carried out in consultation with ESO.

5.4.1. Staff

During 1999 and 2000, six appointments were made (see § 6). Three technical astronomers with PhD's in optical interferometry were recruited: Percheron, who came from a position in US industry, Meisner, an optical engineer who obtained his PhD from the University of Minnesota in 1995, and Mennesson, who left in August 2000 to accept a position at NASA/JPL to work on the Terrestrial Planet Finder project. Two software engineers were involved in NEVEC activities. De Jong combines a 50% NEVEC appointment with a position in industry. Hartmann consults on development of components of the MIDI software package. Bakker, who came from TNO, took over project management in late 2000, after a period as interim project manager.

In addition to the NEVEC paid staff mentioned above, Cotton (NRAO) made valuable contributions to the development of VLTI expertise in NOVA. He is an experienced radio interferometerist and one of the chief architects of the image processing package AIPS, and spent a 1 year sabbatical at Leiden. His stay was partially funded by NWO. SRON based d'Arcio, who works on space interferometry, contributes to NEVEC activities for a 3 year term starting early 2000. In addition, substantial contributions to the NEVEC efforts were provided by the following university staff members from Leiden and Amsterdam: Miley (10%), Le Poole (75%), Jaffe (70%), Röttgering (20%), and Waters (20%). Two graduate students carry out research work related to the NEVEC activities, Heijligers (UL) and van Boekel (UvA/ESO). The position of van Boekel is partially funded by ESO and by the NOVA research program of Network 2.

5.4.2. **Software contribution to MIDI**

NEVEC leads the development of the software for MIDI, and has committed 3 staff years to this effort. Jaffe manages the entire MIDI software effort including work at Heidelberg, Leiden and Paris.

Observing and reduction scenarios were developed. These scenarios in turn generate the requirements for observing and reduction software, as well as the ESO 'templates' which encode the user's instructions to the instrument. The Near Real Time System was designed and coded. This does on-line reduction of detector data, computes Delay Line offsets, produces Quality Control data, and prepares data for archiving.
The Expert Workbench System was designed and coded. These are IDL routines for offline interactive analysis and processing of MIDI data. This constitutes roughly 45% of the MIDI software effort. The other components are Observing Software, Instrument Control Software and Detector Control Software (all Heidelberg) and Data Reduction Software (non-interactive offline reduction: Paris).

5.4.3. **Other activities**

A contribution was made to the text for the Call for Tender from ESO regarding Phase Referenced Imaging and Micro-arcsecond Astrometry (PRIMA). The possible use of a Super Conduction Tunnel Junction (STJ) device as fringe detector unit in future instrumentation was investigated.

A VLTI calibration program was defined in collaboration with ESO and the instrument teams.

An improved model of the atmosphere was developed for incorporation into ESO's VLTI end-to-end model. Graduate students van Boekel and Heijligers were involved in modelling of VLTI observations of galactic and extragalactic targets respectively. Meisner studied fringe tracking algorithms, and presented his work at the SPIE conference in 2000.

A proposal was made to ESO on how to define FITS format for VLTI data. This proposal was accepted and is now implemented as ESO standard.

Preparations were made for the participation of NEVEC staff in VLTI commissioning of the various VLTI instruments, VINCI, MIDI and AMBER.

An international interferometric summer school (18 to 22 September 2000 at Leiden) was organised with established lecturers from the interferometric community and about 70 attendants (see § 7.1).

5.4.4. **Collaborations**

Optical interferometry is of interest to several groups at Delft. Le Poole and Röttgering are collaborating on research on an investigation on phase shifting for nulling interferometers for ESA's forthcoming IRSI/Darwin satellite with the optics group of the Technical Physics Department of the TU Delft led by Braat. The optics group of the space-engineering department of TNO/TPD (Hoekstra, Snijders, Braam and others) is also involved.

Röttgering, in his role as IRSI-Darwin Science Team member, organized several meetings to explore possible collaborative projects involving the synergy between VLTI and space interferometry, including a workshop to bring together the various groups involved in optical interferometry in the Netherlands under the umbrella of an informal working group, the Dutch Joint Aperture Synthesis Team (DJAST). Besides participants from NEVEC and Leiden Observatory, representatives were present from SRON, TNO/TPD, Fokker Space, ESA TU Delft, TNO/FEL, SRON and NIVR. A particularly valuable participant at the workshop was Nobel laureate Townes (Univ. of California at Berkeley), who gave the first Sackler Lecture at Leiden, on February 11, 1999 titled 'Stellar interferometry at mid-infrared wavelengths'.

5.4.5. **Oversight of Dutch VLTI activities**

Dutch participation in VLTI is being guided by a national team which meets twice per year, consisting of De Graauw (SRON-Groningen), Jaffe (Leiden), van Kerkwijk (Utrecht), Le Poole (Leiden), Miley, (Leiden - Chair), Noordam (ASTRON), Röttgering (Leiden), Pel (Groningen), Schilizzi (JIVE) and Waters (Amsterdam). NOVA has appointed Miley and Waters to be members of the new Quadripartite VLTI Implementation Committee (CNRS, MPI, ESO, and NOVA).

5.5. OmegaCAM

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 will be covered with 32 2048 x 4096-pixel CCD detectors for a total of about 16000 x 16000 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 with 0.2 arcsec per pixel.

OmegaCAM and the VST are expected to have an operational lifetime of at least 10 years. By way of payment for the instrument, ESO will grant guaranteed observing time: for NOVA this will be about 4 weeks of VST time per year, over the lifetime of the instrument. Towards the end of the development phase of the project, a data center, OmegaCen, is planned to be set up at the RuG, in order to 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, are being designed.

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. 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.

5.5.1. Staff

The universities of Groningen and Leiden provide the collaborative efforts for the Dutch commitments to OmegaCAM. The NOVA-financed project teams at both locations were built up in 1999. Valentijn (RuG) is archive scientist and project manager of the Dutch software efforts. Boxhoorn (RuG) and Rengelink (UL) are software specialists.

The following university staff members are actively involved in the project: Kuijken (RuG, 50%, PI of the NOVA funded work, and PI of the international OmegaCAM consortium), and Deul (UL, 10%, expert on software pipeline and database systems). Pel, Sackett (RuG), and Franx (UL) provide frequent scientific advice.

5.5.2. Software development

Apart from financially contributing to the purchase of the CCD's for the detector array, the technical NOVA input to the OmegaCAM project lies mainly in the data analysis software, one of the most challenging aspects of the project. Software tools are being developed which allow for (semi-)automatic calibration of the images, combination of exposures, extraction of sources, and measurement of source properties. The Netherlands is fortunate to have several key experts in the field of astronomical pipeline processing who are working on the OmegaCAM project. A further key aspect of the work being done by the NOVA OmegaCAM team is an integrated approach to the data reduction and data archiving - this is intended to make it as straightforward as possible for individual users or small groups to handle the huge volumes of OmegaCAM data without getting bogged down in tedious data management. The result will be a precursor to a true Virtual Observatory, a goal being worked towards on many fronts world-wide.

5.5.3. Other activities

In 1999 the full funding of the project (~Mfl 13, of which about 1/3 from the NOVA Instrumentation program) was committed by the partners, and tasks were divided among the consortium institutes. Much preliminary design work was carried out. An MoU between the OmegaCAM Consortium and ESO was signed at the end of the year. The project kick-off was held on April 7-8, 2000, in Groningen.

During 2000 the design work proceeded at an intensive pace. A Conceptual Design Review was held at ESO in July, and a Preliminary Design Review in December - both identified no serious problems with the design, despite serious space constraints. Detailed design work will lead to a Final Design Review in mid-2001, and completion of the instrument is expected by mid-2003. Construction of the telescope is proceeding along a similar schedule. Meanwhile the preparation for the very high data rates to be expected from the instrument (10s of Tbytes per year) is underway. A network of data centers spread throughout ESO member countries is planned, which will operate a common system dubbed ASTRO-WISE. It will be centered around a modern federated database containing raw data, processed data, calibration data and recipes. A significant funding request to the European Commission for development work related to ASTRO-WISE was prepared at the end of 2000 (and turned out to be successful).

5.6. Pulsar Machine (PuMa-2)

During 1999 the scientific operation of PuMa provided much experience which is valuable for the development of PuMa-2. Lessons learned regarding integration within an observatory environment, calibration and how to deal with the massive data rates translated directly into improvements in the plans for PuMa II. The recording of scientific data, especially in the extreme high time resolution modes (i.e. baseband recording), has also highlighted areas where PuMa-2 will be able to improve on the capabilities of existing pulsar hardware anywhere in the world.

The external taping solution which made up Work Package 1 of Module 1 was commissioned in May 2000. This package, which consists of a high-speed Exabyte tape drive and a Linux PC combined with improved archiving software significantly increased the observing capacity of PuMa. Assembly and testing of the second phase of Module 1, the replacement of the work stations by more powerful PowerPCs and the expansion of the recording disk capacity, started later in 2000 after the arrival of all necessary components.

The software and hardware developments for Module II also proceeded apace in 2000. Software for the coherent dedispersion of large bandwidths of PuMa data which could also be easily accessed by all potential users neared completion. Consideration of both the use of general purpose processors and digital signal processors (DSP) continued. This is an important decision as the plan is to use the same hardware type for Module 4 as for Module 2, which thus serves as a prototype for the bigger machine to be completed later. The initial assessment seemed to rule out DSPs however the advance technology associated with the DSP based THEA project at ASTRON meant that a full investigation of its capabilities was necessary. A final assessment will be made early in 2001. Monitoring of advances in GPP capabilities was also instigated.
Late in 2000 benchmarking of the speed of possible hardware for Module 3 of PuMa-2 was well under way. As it turns out, with the fastest of the new generations of processors the main bottleneck is not processor floating point speed anymore, but memory bandwidth. Because of this, Compaq (formerly DEC) Alpha's are vastly superior in price/performance over Athlon's, whereas SPARC's and PA's appear too slow and/or too expensive. The concepts for the core software responsible for the deacceleration was completed and coding of the algorithm had begun. A final hardware decision was planned for early 2001.

5.7. Sackler Laboratory for Astrophysics

The research activities at the Raymond & Beverly Sackler Laboratory for Astrophysics at Leiden Observatory consisted of two components: continued experiments with existing equipment and development of two new ultra-high vacuum set-ups (SURFRESIDE and CRYOPAD). The research is closely linked with the Network 2 research described in § 3.2. A highlight was the dedication ceremony of the laboratory on October 11, 1999, by Raymond and Beverly Sackler. It was preceded by a one-day international symposium on 'Highlights of Laboratory Astrophysics' attended by about 50 scientists, and followed by a four-day workshop on 'Interstellar Ices' in the Lorentz Center, organized by Tielens (§ 7.1).

5.7.1. Research summary

5.7.1.1. Ice segregation toward high-mass protostars

The current view of interstellar ice chemistry was strongly influenced by recent data from ISO. Data from this space observatory and ground-based results have shown that the most abundant ices in warm regions close to massive protostars are H_2O, CO_2, and CH_3OH. Ehrenfreund, Schutte and collaborators presented a systematic set of laboratory infrared spectra of these ice mixtures which have been exposed to thermal processing. It was shown that the infrared bands of CO_2 and CH_3OH are particularly sensitive to the ice composition, temperature and applied ultraviolet irradiation. The laboratory data suggest partial crystallization of interstellar ices in the warm parts of the protostellar envelope. Detailed analysis of bands shows that their profiles can be effectively used to trace the line-of-sight conditions and the origin and evolution of the ice composition in dense clouds. A database containing 325 experiments on the thermal processing of H_2O:CH_3OH:CO_2 ice mixtures in the wavelength range 6000-400 cm^{-1} was posted on the WWW at http://www.strw.leidenuniv.nl/~lab.

5.7.1.2. Low-temperature crystallization

Schutte investigated the viability of the so-called low temperature crystallization phenomenon. This effect was observed at NASA-Goddard in samples which are deposited on fluffy structures of dust particles composed of material similar to amorphous quartz, which were aggregated on top of a 10 K substrate. A possible problem in these experiments is the low thermal conductivity between the particles, which could result in temperatures in the aggregates, which are considerably in excess of the temperature of the substrate. To test whether similar phenomena could occur under controlled conditions, Schutte used an amorphous quartz glass plane-parallel window as a substrate and investigated by infrared spectroscopy whether the deposited ices have crystalline characteristics. In contrast with the Goddard experiments, the ices produced on the quartz substrate were consistently amorphous in structure. This shows that the low temperature crystallization phenomenon will not occur on dust particles in interstellar space. These experiments are relevant to the interpretation of ISO data on crystalline ices and silicates obtained by the group of Waters.

5.7.1.3. **Inventory of ices towards the embedded young stellar object W33A**

Schutte, Ehrenfreund, Tielens and van Dishoeck, in collaboration with the Rensselaer Polytechnic Institute (Troy, USA), analyzed the infrared spectrum of the high mass embedded young stellar object W33A. This object has a huge quantity of ice in the line-of-sight, which presumably is located in the circumstellar envelope around the protostar. Thus, this source has been used as a template to obtain an inventory of ices and information on the chemical conditions in star-forming regions. An analysis of the saturated 3 µm H_2O ice feature and the weak H_2O ice combination band around 4.5 µm produced for the first time a reliable measurement of the column density of water ice. Since water is the most abundant component of ices, this information is essential as a normalization for the other species. Solid NH_3 appears to be an abundant component, but no convincing evidence is found for nitriles. The results for W33A were compared with those toward other low- and high-mass protostars. Some species such as CH_3OH and OCN- show more than an order of magnitude variations from source to source, whereas other species like CO_2 and CH_4 are very similar. The variations appear linked to heating and energetic processing of the ices, also seen in other features (see § 5.7.1.1 and § 5.7.1.4).

5.7.1.4. **The origin of the 6.85 µm feature**

A strong absorption band at 6.85 µm was detected by Keane and Tielens in the ISO spectra of most protostellar sources. The carrier of this band has so far remained unidentified, but possible suggestions in the literature include the ammonium ion and carbonates. To test this hypothesis, Schutte, in collaboration with colleagues from NASA-Goddard (USA), studied the processing of H_2O-CO_2-NH_3-O_2 ice mixtures by ultraviolet and MeV proton irradiation. In both cases a strong infrared feature due to NH^+_4 was produced at 6.85 µm, which matches well the interstellar feature. The implied NH^+_4 abundance is typically ~10% relative to H_2O. The negative counter ions, including the carbonate ions, do not produce any significant infrared structure and can therefore not be detected. The ubiquitous presence of the 6.85 µm feature toward protostars indicates that the ices in their surroundings have been energetically processed. The high implied abundance of NH_3 - the precursor of NH^+_4 - indicates that the gas that gave rise to the ices contained a high fraction of atomic nitrogen.

5.7.2. Development of new equipment

5.7.2.1. **SURFRESIDE**

The Surface Reaction Simulation Device (SURFRESIDE) was conceived and designed to study chemical reactions occurring on interstellar ice grain 'mimics'. The experiments identify the key barrierless reactions and desorption pathways in the solid state that generate simple molecular species in the interstellar gas. When completed, the experiment will provide kinetic and thermodynamic data that are directly relevant to gas-grain systems in the interstellar medium. Such experiments will enhance our understanding of chemical processes occurring in dense molecular clouds and highlight the importance of chemical timescales in star formation.

The SURFRESIDE project was started by Schutte and van Dishoeck in mid-1999, and received a significant boost when Fraser joined it in mid 2000. The experiment combines Ultra High Vacuum (UHV) surface science techniques with atomic and molecular beams. Forgoing a collection of unforeseen equipment failures, the construction of the experiment is now nearing completion.

A number of design modifications were incorporated into the experiment during 2000, including a redesign of the pumping system and molecular dosing lines, modifications to the 'grain - mimic' sample, installation of the main mass spectrometer, infrared windows, temperature control system and sample thickness monitoring system, modifications to the cryostat such that it is fully UHV compatible, and a redesign of the cryogenic shield on the sample. These modifications allow the system to reach base pressures around 2×10^{-10} Torr (only 1000 times greater than the pressure in many dense molecular clouds, and a 1000 times better than the existing old equipment in the laboratory). The first results are expected in 2001.

5.7.2.2. **CRYOPAD**

Schutte, together with Fraser, van Broekhuijzen and de Kuiper from the Huygens mechanical workshop, started the design phase of the second new set-up, the CRYogenic Photoproduct Analysis Device (CRYOPAD). This set-up is meant to analyze in detail the volatile molecules that are produced by energetic processing (i.e., ultraviolet radiation or charged particles) of ices with a composition analogous to ices in space. These data will be of great value for understanding the origin of the molecules found in warm star-forming regions and 'hot cores', where molecules are evaporating off the grains.

The experience gained with the design of SURFRESIDE proved very valuable. Construction will start in 2001.

5.8. SINFONI

SINFONI (SINgle Faint Object Near-infrared Investigation) is a collaboration between ESO, the Max-Planck-Institut für Extraterrestrische Physik (MPE) and NOVA. SINFONI consists of a cryogenic near-infrared (JHK-band) integral-field spectrograph (SPIFFI) developed by MPE (PI Thatte) fed by an adaptive optics unit developed by ESO. Installation of SINFONI at UT4 (Yepun) of the VLT will be in early 2004, when the telescope will be equipped with a laser guide star (LGS) system, so that essentially the whole Paranal sky will be available to SINFONI with diffraction-limited resolution and full spectral multiplexing.

5.8.1. The NOVA part of SINFONI

The NOVA contributio to SINFONI consists of two parts:

1. Development of a number of software components for adaptive optics. This includes a package for point-spread-function (PSF) reconstruction based on the wavefront sensor (WFS) data, and software for simulating adaptive optics performance in order to evaluate for instance performance with a laser guide star. NOVA will also develop the SINFONI exposure time calculator. Validation of these components at ESO/Garching and during commissioning at Paranal will form an integral part of these efforts. In addition, NOVA will participate in the commissioning and scientific validation of the SINFONI instrument as a whole in Garching and on Paranal.

2. Participation in the enhancement of the SPIFFI spectrograph with a 2048x2048 array and higher spectral resolution (R~10000). These enhancements will be carried out jointly by NOVA, MPE, and ESO. NOVA will carry 50% of the hardware costs, and will supply 2 years of manpower at the postdoc level for implementation of these enhancements.

The NOVA-SINFONI project has gone through a definition stage in 1999 and 2000, in various discussions with MPE and ESO. It is now fully defined and budgeted, and a first round of recruitment was completed, which resulted in the appointment of Brown in Leiden to carry out the AO simulation workpackage, starting in 2001. Glazenborg at ASTRON will carry out the PSF reconstruction workpackage. Project management until mid-2001 is being carried out by van der Werf. The NOVA-SINFONI effort will ramp up significantly in the period 2001-2002 with the appointment of further staff and the preparation of scientific utilization of SINFONI.

5.8.2. Strategic importance

The combination of adaptive optics and integral field spectroscopy in the near-infrared (where adaptive optics performs best), including full K-band capability (made possible by the cryogenics), makes SINFONI a very powerful instrument. It will allow fully spectrally multiplexed imaging at a spatial resolution equal to the HST optical resolution (3 times better in both dimensions in K-band) and vastly more sensitive in K-band. The SINFONI project is a natural next step beyond the SAURON and OASIS projects on the WHT (see § 3.1.2.1), and prepares for the next generation of integral-field spectrographs on the road to OWL.

5.8.3. Science team

Scientific applications of SINFONI cover every aspect of near-infrared astronomy, including high-z galaxies, dynamics of galactic nuclei, stellar populations in nearby galaxies, starburst and ultraluminous galaxies, super-star-clusters and proto- globular clusters, circumstellar disks, ultracompact HII regions, protoplanetary disks, atmospheres of solar system satellites such as Titan.

In the Netherlands, a broad science team was set up to harvest the full potential of SINFONI. Members include van der Werf (NOVA PI), Brown, Franx, van der Hulst, Kaper, Katgert, Lamers, Pel, Tolstoy and de Zeeuw. The science team will oversee all scientific aspects of the NOVA involvement in SINFONI. This will include establishing procedures for arriving at a coherent program for the Dutch guaranteed VLT time resulting from this project. In addition, the science team will provide input on the scientific specifications of instrument, requirements for software, etc. The amount of guaranteed time will be approximately 18 nights.

6. Personnel funded by NOVA

The tables in this chapter list all research and technical support staff whose employment was - partially - funded through the NOVA program in 1999 and 2000.

NOVA funded Astronomical Research

Project	Title	Project leader	Univ	Researcher	Yrs	Starting data
Network #1						
10.10.1.01	Radio galaxies at high redshift	Miley	UL	Drs. Bram Venemans	4	Oct 1, 2000
10.10.1.03.1	Mass distribution of galaxies from weak lensing	Kuijken	RuG	Drs. Fabrice Christen	2	Sep 12, 2000
10.10.1.04	Nuclei of elliptical galaxies	de Zeeuw	UL	Drs. Davor Krajnovic	4	Sep 1, 2000
10.10.1.07	Galaxy formation and evolution	Kuijken	RuG	Dr. Annette Fergusson	3	Dec 1, 2000
Network #2						
10.10.2.01	Interaction of Young Stellar Objects with their environment	Tielens	RuG	Drs. Stephanie Cazaux	4	Nov 1, 1999
10.10.2.02	Studies of complex organic molecules	van Dishoeck	UL	Dr. Pascale Ehrenfreund	2	July 1, 1999
10.10.2.03	Envelope structure and formation of circumstellar disks	van Dishoeck	UL	Drs. Jes Jorgensen	4	Nov 1, 2000
10.10.2.04	Formation of most massive stars in the Galaxy	Kaper/Waters	UvA	Drs. Arjan Bik	4	May 1, 2000
10.10.2.05.1	Evolution of gas/dust ratio in circumstellar disks	van Dishoeck	UL	Drs. Klaus Pontoppidan	2	Nov 1, 2000
10.10.2.06	Solid-state features in circumstellar disks	Waters	UvA	Drs. Roy van Boekel	3	May 1, 2000
10.10.2.08	Physics and chemistry of AGB outflows	Tielens	RuG	Dr. Marco Spaans	2	Sep 1, 2000
10.10.2.09	Radiative transfer models of atmospheres of evolved stars	Waters	UvA	Drs. Rien Dijkstra	4	July 1, 2000
10.10.2.10	Stellar population studies of AGB stars	Habing	UL	Drs. Maria Messineo	4	Nov 1, 1999
Network #3						
10.10.3.02	Radio pulsar studies using PUMA on the WSRT	van der Klis	UvA	Drs. Stephane Jouteux	4	Oct 1, 1999
10.10.3.05	Massive X-ray binaries with XMM, AXAF and the VLT	van den Heuvel	UvA	Drs. Arjan van der Meer	4	Dec 1, 2000
Overlap appointments						
10.20.3.01	Laboratory astrophysics		UL	Dr. Willem Schutte 50%	6.5	Jan 1, 1999
10.20.4.01	Evolution of massive stars		UU	Prof. Norbert Langer	5	Jan 1, 2000

Instrumentation Program

Project/job description	Project leader	Univ	Researcher	Yrs	Starting date
ALMA R&D mixers					
Project manager	Van Dishoeck	RuG	Dr. Wolfgang Wild	5.7	May 1, 1999
Mixer scientist	Wild	RuG	Dr. Andrey Baryshev	5.2	Nov 1, 2000
Receiver physicist	Wild	RuG	Dr. Ronald Hesper	3	Sep 1, 2000
Junction scientist	Klapwijk	TuD	Tony Zijlstra (50%)	4.4	Jun 1, 2000
Junctions engineer	Klapwijk	TuD	Mark Zuiddam (50%)	4.4	Jun 1, 2000
NEVEC					
Technical astronomer	Miley	UL	Dr. Isabelle Percheron	3	Sep 1, 1999
Technical astronomer	Miley	UL	Dr. Jeff Meisner	3	Sep 1, 1999
Physicist	Miley	UL	Dr. Bertrand Menneson	0.6	Jan 1, 2000
Physicist/project manager	Miley	UL	Dr. Eric Bakker	4.25	Oct 1, 2000
Software specialist	Miley	UL	Dr. Jeroen de Jong 50%	2	Feb 1, 2000
OmegaCAM					
Calibration software scientist	Kuijken	RuG	Dr. Edwin Valentijn	4	Apr 1, 1999
Programmer calibration software	Kuijken	RuG	Danny Boxhoorn	3	Apr 1, 1999
Programmer database and pipeline software	Deul	UL	Dr. Roeland Rengelink	3	Oct 1, 1999
PUMA					
Study and search for pulsars using PUMA-1	Verbunt	UU	Drs. Marco Kouwenhouwen	1	Sep 1, 1999
R&D to improve the present PUMA capabilities	van Haren	UU	Drs. Roel van der Kraats	1	Sep 1, 1999
Sackler Laboratory for Astrophysics					
Postdoc	van Dishoeck	UL	Dr. Helen Fraser	2	May 1, 1999
PhD student	van Dishoeck	UL	Drs. Fleur van Broekhuizen	4	Oct 1, 2000

7. Workshops & Visitors

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

7.1. Workshops in 1999-2000

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.

	Organizer	Subject	Location	Duration In days	Start 1999
W-01	van Dishoeck	Radiative transfer in molecular lines	UL/Lorentz	7	17/05/99
W-02	Waters	Low mass WR stars: Origin and Evolution	UvA	2	02/09/99
W-03	Kuijken, de Zeeuw	Galactic Dynamics	UL/Lorentz	20	05/07/99
W-04	Tielens	Origin and Evolution of Interstellar Ice	UL/Lorentz	7	10/11/99
					2000
W-05	Barthel	The far infrared and submillimeter spectral energy distributions of active and starburst galaxie	RuG	3	27/04/00
W-06	Israel	J.H.Oort centenary Symposium "Looking Ahead in Wonder"	UL	3	27/04/00
W-08	van Dishoeck	Oort Workshop	UL/Lorentz	4	17/04/00
W-09	Tielens	Origin and evolution of interstellar PAH's	UL/Lorentz	5	19/06/00
W-10	Röttgering	School on Optical/Infrared Interferometry	UL/Lorentz	5	18/09/00
W-11	Habing	ISOGAL workshop	UL/Lorentz	5	10/04/00
W-12	van Dishoeck	Star and planet formation with SIRTF	UL/Lorentz	5	10/07/00
W-13	Dominik	Herbig Ae/Be stars	UvA	2.5	25/10/00
W-14	de Bruyn	Compact sources and pulsars	ASTRON	2	21/09/00
W-15	van Dishoeck	Modeling Interstellar Chemistry	UL/Lorentz	7	16/10/00

W-01:Radiative transfer in molecular lines

Molecular lines are excellent probes of interstellar clouds, protostellar envelopes and circumstellar shells around AGB stars, but a good and self-consistent interpretation of such lines often relies heavily on the use of sophisticated line radiative transfer programs. The workshop was attended by ~30 international experts, presenting different aspects of the problem and participating in lively discussions. The workshop also led to the establishment of a set of test problems, against which various codes can be tested. Details of the results and a report of the workshop can be found at http://www.strw.LeidenUniv.nl/~radtrans/.

W-02: Low mass WR stars: Origin and Evolution

The workshop was attended by 40 astronomers, 25 of whom were from outside the Netherlands. Much of the work concentrated on new observations with ISO and HST. These shed new light on the origin of WR stars, which have gone through a very rapid chemical evolution, resulting in a hydrogen-poor atmosphere. Talks by Bloecker and Herwig proposed new ways to evolve stars on the Asymptotic Giant Branch including efficient mixing. This may result in the removal of all hydrogen in the outer layers of the star. Cohen showed convincingly that a significant fraction of the cool dust confirms the rapid chemical evolution from oxygen-rich to carbon-rich.

W-03: Dynamics of Galaxies

Amongst the about 30 participants were many members of the teams involved in the building of new instrumentation for the WHT on La Palma, the Planetary Nebula Spectrograph (Groningen-München-Napels-Canberra) and a panoramic integral-field spectrograph, SAURON (Leiden-Lyon-Durham). In the first week the emphasis was on nuclei of galaxies. The SAURON team presented the first results, and had intensive work-discussions.

The second week had a more general character, highlighting our own Milky Way. In the third week the outer halos of galaxies were discussed. The SAURON and PNS projects are scientific complementary and discussion between both groups was very effective.

W-04: Interstellar Ices

The scientific program covered an in-depth discussion of both ground-based and ISO observations of interstellar ices, as well as the complementary submillimeter observations of hot cores where ices have evaporated. The workshop also provided an opportunity for team meetings concerning the analysis of the ISO programs as well as planning for future VLT observations.

W-05:The far-infrared and submillimeter spectral energy distributions of active and starburst galaxies (FIRSED 2000)

During the workshop recent progress was discussed on the issue of the FIR-submm spectral energy distributions of active and starburst galaxies, and to address possible further astrophysical progress in this field. A Legacy Project was submitted to NASA's SIRTF.

W-06: J.H. Oort Centenary Symposium 'Looking Ahead in Wonder'

A total of 36 speakers reviewed present and future developments in the astronomical topics to which Oort's name is specifically connected. One session was devoted to Oort's life and work. The symposium was attended by 160 participants from 20 countries. During the symposium the exhibition 'Jan Oort Astronomer' was opened in the Leiden University Library.

W-08: Oort Workshop 'Black Holes: evidence, evolution and future prospects'

The workshop was attended by many experts in the field and had an interdisciplinary character. Topics included (1) evidence for massive black holes near the center of galaxies, with a beautiful overview talk by Genzel (Oort Professor at UL in 2000); (2) evidence and theory of stellar mass black holes such as observed in X-ray binaries; (3) physics near black holes; and (4) importance of X-ray observations of iron lines to probe the accretion disks around black holes. A specific highlight of the workshop was the review talk by Nobel prize winner 't Hooft on 'Black Holes and Particle Physics'.

W-09: Origin and evolution of interstellar PAH's

The topics ranged from new observational results on PAHs (largely ISO) and diffuse interstellar bands, to laboratory spectroscopy of PAHs and carbon clusters, quantum chemical calculations of PAHs and modeling of the PAH ionization balance and chemistry.

W-10: School on Space and Ground Based Optical/Infrared Interferometry

The main aim of the school was 'Contributing to the formation of the young generation of scientists, that will design and use the existing and future optical/IR stellar interferometers'. The workshop was attended by about 70 participants, and included a much-appreciated introduction to the principles of interferometry as well as an overview of the IRSI-DARWIN project.

W-11: ISOGAL-Workshop

The purpose of the workshop was coordination of the research on the results of the ISOGAL project with ISO. The ISOGAL survey will be published in 2 catalogs: the grand catalog and the first, or preliminary catalogue, to be ready in winter 2000/2001. The grand catalog will be the final and complete date base, containing: (1) All the single measurements and the observational data; (2) quality flags, that have still to be defined; and (3) cross-correlation information with the 2MASS and MSC catalogues.

W-12: Star and planet formation with SIRTF

The workshop was organized to discuss studies of the formation of stars and planets using SIRTF. The resulting proposal was one of the 6 Legacy programs selected by NASA in November 2000.

W-13: Herbig AeBe stars

This meeting established that Ae and Be stars are really two different classes of objects. While Herbig Ae stars really can be seen as the high temperature counterparts of T Tauri stars/disks, the structure and evolution of Be stellar disks is much more influenced by the luminous and hot central star. The evolution of these disks was central to the meeting. The gas component can be removed on timescales of typically 10^7 - 10^8 years by the stellar radiation field, interstellar radiation or by the stellar wind. The removal times for cool stars are much longer. One of the highlights was the contribution by van Dishoeck on the gas content of several young Vega-like stars, which have disks so far presumed gas-poor or free. It also became clear that the disks of Herbig AeBe stars are in an evolved state. Several minerals which are being seen in the spectra of these disks require extensive processing of the material in the disks.

W-14: Compact sources and pulsars

The purpose of the meeting was to present some of the first scientific results from the WSRT pulsar machine, PuMa, and to discuss recent developments in the field of compact objects. Talks ranged from radio pulsars to the nature of X-ray binaries with black holes and neutron star companions, gamma ray bursts and high energy observations of radio pulsars.

W-15: Modeling of Interstellar Chemistry

The workshop was organized by Millar (UMIST, UK), with participation from several Network 2 staff, postdocs and PhD students. The topics included laboratory studies, future observational instrumentation, radiative transfer, computational techniques, bi-stability in chemical models, hydrodynamics of reactive flows, gas-grain interactions and theoretical chemistry. Discussion groups were aimed on issues ranging from the chemistry of oxygen to the provision of codes and fundamental data to the wider community. Also, test calculations were set up during the meeting to investigate the consistency among different codes.

7.2. Visitors in 1999 - 2000

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	Visitor	Location	Duration	Start 1999
V-01	van Albada	Prof.dr. M.W. Feast	RuG	5 m	01/04/99
V-03	van den Heuvel	Prof.dr. H. Dickel	UvA	1 y	01/09/99
					2000
V-02	van Dishoeck	Prof.dr. N.J. Evans	UL	6 m	15/01/00
V-04	van Dishoeck	Dr. D. Johnstone	UL	6 w	23/07/00
V-05	R.J. Rutten	Dr. G. Domishev	UU	2 w	07/07/00
V-06	Achterberg, Kuijpers	Prof.dr. D. Melrose	UU	1.5 m	15/05/00
V-07	de Zeeuw	Dr. M-A. Jalali	UL	1.5 m	25/06/00
V-08	van der Kruit	Dr. R. Allen	RuG	2 w	June 00
V-10	Fender	Dr. M.A. Hendry	UvA	2 d	01/11/00
V-11	van den Heuvel	Dr. L. Yungelson	UvA	1 m	18/10/00

V-01: Visit of Prof. dr. M.W. Feast

The grant covered an extension of a working visit by Feast (University of Capetown), but he was unable to extend his stay for personal reasons, and no funds were used.

V-02: Visit of Prof.dr. N.J. Evans

Evans (University of Texas, Austin) worked with van Dishoeck and her students on analysis of spacecraft data, as well as continuing analysis of ground-based data. Together, Evans and Van Dishoeck hosted a meeting of the ALMA Scientific Advisory Committee in Leiden. Evans visited other institutes with astronomy programs in the Netherlands, and gave several talks at other European institutes. During the Leiden visit 8 papers were written.

V-03: Visit of Prof.dr. H. Dickel

Dickel (University of Illinois) collaborated with Kaper, de Koter and Waters on various projects related to the evolution of dense cores in giant molecular clouds and the interaction between the new born massive stars and the remainders of the clouds from which they were formed. She frequently visited ASTRON to analyze WSRT data. During her visit, she gave a course at the UvA on 'physical processes in dense molecular clouds and their relations to star formation'.

V-04: Visit of Dr. D. Johnstone

Johnstone (University of Toronto) collaborated with van Dishoeck's group on two areas of research, (i) molecular line studies of clumps in Orion A (with Boonman), and (ii) The production of H_2 emission from disks. Along with these previously planned projects a number of unexpected collaborations were started. Together with Klessen and Spaans a comparison was begun between the properties of numerical collapse models and thermal dust continuum observations of star-forming regions, aiming to differentiate between a variety of techniques for injecting energy into molecular clouds and stabilizing collapse on particular size scales. A collaboration with Papadopoulos concentrated on the gas-dust ratio within nearby disk galaxies. Talks were given at Leiden and Groningen on submillimeter observations of the star-forming regions within the Orion and Ophiuchus molecular clouds using SCUBA at the JCMT. In Utrecht a colloquium was given on the destruction of disks around young stars.

V-05: Visit of Dr. G. Domishev

The visit by Domishev (Institute of Solar Terrestrial Physics, ISZF, Irkutsk) was organized to test the double breaking Lyot-filter he had manufactured on the Swedish telescope on La Palma, in order to establish whether this could be of value for the DOT. The filter was designed for narrow band observations in the Ba II 4554 Å spectral line of the Sun. An official research agreement was signed to make the export of the filter possible for use at the DOT, initially for three years.

V-06: Visit of Prof.dr. D. Melrose

Melrose (University of Sydney) worked with Kuijpers on understanding models for conservation of magnetic helicity when solar magnetic flux tubes reconnect. A three day visit to the Observatoire de Meudon in Paris was made, which included a talk 'Large scale currents and solar flares'. Talks were also given in Utrecht and at JIVE. Major progress was made in the writing of a book on 'Quantum Plasmadynamics'.

V-07: Visit of Dr. M-A. Jalali

Jalali (Institute for Advanced Studies, Zanjan, Iran) and de Zeeuw reinvestigated the so-called curvature condition for the existence of self-consistent scale-free galaxy models, originally developed by Zhao for elongated disks. They showed that a slight modification of this condition was warranted, and then allows rapid identification of the region in parameter space (density slope and axis ratio) for which equilibrium models are ruled out. They extended the formalism to scale-free three-dimensional axisymmetric models, and also investigated the separable Shridhar -Touma models.

V-08: Visit of Prof.dr. R. Allen

Allen (STScI, Baltimore) and van der Kruit started a collaboration to study in detail the relationship between the Far UV (150 nm) and HI (21 cm) morphology in M81. The bulk of this work will be done by a PhD student from Groningen, who will do the data analysis at STScI. A study was started on the opacity of spiral galaxy disks using counts and colors of background field galaxies seen through the disks of nearby spirals. This work involves the use of HST archive data. Various talks were given in Dwingeloo, Groningen and Utrecht.

V-10: Visit of Dr. M. Hendry

Hendry (University of Glasgow) and Fender extended their earlier treatment of the properties of X-ray binary jets, in order to use the statistical properties of a sample of persistent X-ray binary systems to place robust constraints on the Doppler boosting factor of the systems. They showed that the method works, but a larger data set is required before significant measurements can be made.

V-11 visit of Dr. L. Yungelson

Yungelson (Russian Academy of Sciences) worked with Nelemans, Portegies-Zwart, and Verbunt. The galactic population of interacting close binary white dwarfs (AM CVn stars) was studied. Two models were considered: white dwarfs accreting (i) from a helium white dwarf companion, and (ii) from a helium-star donor. Selection effects related to the luminosity of these systems were analyzed and applied to get a model for expected observable population and reasonable agreement with the observed sample was obtained. Furthermore, the gravitational wave signal from the ensemble of galactic binaries with two compact objects was studied, using results of population syntheses for binary stars. It was confirmed that at the frequencies below about 2 MHz the population of double white dwarfs produces a background which cannot be resolved by the low-frequency gravitational wave detectors (LISA, OMEGA).

8. NOVA Information Center (NIC)

Public interest in astronomy is immense. This is evident in media coverage and in the steady stream of requests for information. Many high school students approach the astronomy institutes for materials for their science projects. Popularization of astronomy is an excellent vehicle 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. For this reason, NOVA has founded NIC, the 'outreach' office for Dutch astronomy. NIC is located at UvA, and its staff consists of Jaspers (0.6 fte) and Visser (0.5 fte). Operations started in January 2000, and the first months were largely devoted to developing an outreach strategy, establishing contacts within NOVA and with ASTRON, SRON, ESO and the Dutch amateur astronomical community. Three main goals were identified: production of promotional and educational material, development of a NOVA-website and better news service to the media.

8.1. Promotional material

A 16-page glossy brochure rolled off the press in July 2000, providing a full-color overview of NOVA's research and instrumentation programs. The old NOVA-logo was redesigned, and now serves as NOVA's highly characteristic visual mark on the website, on business-cards, letterheads, envelopes and virtually all printed NOVA-matter.

8.2. Educational material

A folder containing supplementary educational material for teachers of general science (Algemene Natuurwetenschappen, ANW) was prepared in 2000. NIC supports this project by providing NOVA-brochures for the folder, designing the cover and advising on publicity.

8.3. Astronomical press service

The 'Astronomische Persdienst' distributes astronomical news with a Dutch component by e-mail to the media and other subscribers. This service was set up in 1998 by some editors of Zenit. NIC took it over in June 2000, in order to gather information more actively and increase frequency and exclusivity of the news releases. Astronomers show a growing awareness of the service, and media-response indicates that the Astronomische Persdienst is considered a useful instrument.

8.4. Web-site and Kennislink

The NOVA-website (www.astronomy.nl) went on line in September 2000. It was created in co-operation with a commercial web-design company, Tribute. This versatile site in Dutch - an English version will follow later - aims to be of interest to astronomers as well as to journalists and the general public. It is used to announce public events, presents news and research-highlights, and features an 'e-mailbox' where anyone can post astronomical questions that need answering by an expert. Much work was done on developing the 'NOVA-tour of the Universe'. This is a popular scientific presentation of modern astronomy, which will be published on CD-ROM as well.
Kennislink (linking knowledge) is a government-supported national project to help schools use the internet more effectively. Once operational, it will explore and select websites that provide useful and reliable science information for school-students. Kennislink will be a portal as well as a thesaurus, a database with tailor-made search-tools. The NOVA-website will be one of those sites.

8.5. Other activities

NIC participated in the annual Nederlandse Astronomen Conferentie in Dalfsen, by presenting itself and its mission with a poster and by distributing leaflets.

NIC helped organizing the NEVEC-inauguration in Leiden on May 26, 2000. Generous support by the ESO outreach office and last moment contributions by TNO-TPD and Fokker Space resulted in a successful day for astronomers, officials from Leiden University, NWO and the ministry of OCW. The scientific activities of NEVEC were subsequently covered in a number of local and national publications.

'Observe your own pulsar' was the name of NIC's contribution to the National Science Day on October 8, 2000. On this day, the WSRT pointed one of its dishes to a strong pulsar and transformed its signal into audio. NIC coordinated the installation of web cams and two-way video links via the internet to enable visitors of scientific institutes in Amsterdam, Leiden, Groningen, Nijmegen and Utrecht to see the telescope, listen to the signal and talk to scientists.

More than a hundred VIP's from Dutch science, business, the arts and government congregated in the Ridderzaal in The Hague on November 8, 2000 to promote interdisciplinary contacts. NIC coordinated links between an invited astronomer and people at Fokker space working on delay lines, resulting in a small exhibition on the VLTI in the room next to the Ridderzaal and distribution of NOVA-brochures to politicians and members of government.

9. Organization

Board

Prof. dr. E.P.J. van den Heuvel (chair)	UvA
Prof. dr. P.C. van der Kruit	RuG
Prof. dr. J.W. Hovenier	VU
Prof. dr. A. Achterberg	UU
Prof. dr. G.K. Miley	UL
Prof. dr. H. Butcher (observer)	ASTRON
Prof. dr. J. Bleeker (observer)	SRON

International Advisory Board

Prof. dr. J.N. Bahcall (chair)	IAS, Princeton, USA
Prof. dr. R. Ekers	ATNF, Epping, Australia
Prof. dr. K.C. Freeman	ANU, Canberra, Australia
Prof. dr. M.J. Rees	IoA, Cambridge, UK
Prof. dr. F. Shu	UC Berkeley, USA
Prof. dr. R. Sunyaev	MPA, Garching, Germany

Key Researchers

Prof. dr. A. Achterberg	UU
Prof. dr. F.H. Briggs	RuG
Prof. dr. E.F. van Dishoeck	UL
Prof. dr. M. Franx	UL
Prof. dr. H.J. Habing	UL
Prof. dr. M. van der Klis	UvA
Prof. dr. P.C. van der Kruit	RuG
Prof. dr. K. Kuijken	RuG
Prof. dr. H.J.G.L.M. Lamers	UU
Prof. dr. N. Langer	UU
Prof. dr. G.K. Miley	UL
Prof. dr. A.G.G.M. Tielens	RuG/SRON
Prof. dr. F. Verbunt	UU
Prof. dr. L.B.F.M. Waters	UvA

Coordinators research networks

Prof. dr. K.H. Kuijken	RuG	Network 1
Prof. dr. E.F. van Dishoeck	UL	Network 2
Prof. dr. M. van der Klis	UvA	Network 3

Instrument Principal Investigators

Dr. W. Wild	RuG/SRON	ALMA mixer
Dr. R.J. Rutten	UU	DOT
Prof. dr. L.B.F.M. Waters	UvA	MIDI
Prof. dr. G.K. Miley	UL	NEVEC
Prof. dr. K.H. Kuijken	RuG	OmegaCAM
Prof. dr. M. van der Klis	UvA	PuMa-2
Prof. dr. E.F. van Dishoeck	UL	Sackler Lab
Dr. P.P. van der Werf	UL	SINFONI

Instrument Steering Committee

Prof. dr. M.A.C. Perryman (chair)	ESA/UL
Ir. A. van Ardenne	ASTRON
Prof. dr. F.H. Briggs (from 1-12-2000)	RuG
Prof. dr. M. Franx	UL
Dr. M.W.M. de Graauw	SRON
Prof. dr. H. Ford (until 30-11-2000)	JHU, Baltimore, USA
Prof. dr. M. van der Klis	UvA
Prof. dr. G. Monnet	ESO
Dr. J.W. Pel	RuG
Dr. R.J. Rutten	UU
Dr. R.G.M. Rutten (from 1-12-2000)	ING, La Palma, Spain

Research Committee

Prof. dr. A. Achterberg (chair)	UU
Prof. dr. W.B. Burton	UL
Prof. dr. A.G. de Bruyn	RuG/ASTRON
Prof. dr. G. Gilmore	IoA, Cambridge, UK
Prof. dr. R. Sancisi	RuG
Prof.dr. H. Spruit	MPA, Garching, Germany
Prof dr. L.B.F.M. Waters	UvA

Education Committee

Dr. P.D. Barthel (chair)	RuG
Dr. G.J. Savonije	UvA
Prof. dr. V. Icke	UL
Prof. dr. J. Kuijpers (secretary)	KUN
Dr. H.J. van Langevelde	JIVE
Drs. E.K. Verolme	UL

Minnaert Committee

Prof. dr. H.J.G.L.M. Lamers (chair)	UU
Dr. P.D. Barthel	RuG
Prof. dr. V. Icke	UL
Dr. A. de Koter	UvA
Prof. dr. J. Kuijpers	KUN

NOVA Information Center (NIC)

A. Jaspers	NOVA
Jac. Visser	NOVA/UvA

Office

Prof. dr. P.T. de Zeeuw (director)	UL
Dr. W. Boland (deputy director)	NOVA
R.T.A. Witmer (finance and control)	UL
M.A. Zaal (management assistant)	NOVA

10. Financial report 1999 - 2000

In kfl	1999	2000
ASTRONOMICAL RESEARCH		
Overlap Appointments	**93**	**386**
Network Research Funding		
Galaxy Formation & Evolution	0	86
Birth & Death of stars	108	492
Final Stages of Stellar Evolution	20	79
Total Network Research Funding	**128**	**657**
Workshops & Visitors	**23**	**46**
TOTAL ASTRONOMICAL RESEARCH	**244**	**1,089**
INSTRUMENTATION		
ALMA mixer development	127	523
DOT	92	92
VLTI	729	809
OmegaCam	255	1,075
PUMA - 2	52	106
Sackler Laboratory for Astrophysics	194	217
SINFONI	0	9
New Initiatives	5	0
TOTAL INSTRUMENTATION	**1,454**	**2,831**
OVERHEAD		
NOVA Office	165	171
Outreach	11	81
TOTAL OVERHEAD	**176**	**252**
SPENDING PROFILE	**1,874**	**4,172**
TOTAL GRANT	**1,876**	**3,756**
EXTERNAL FUNDING		**42**
PREFINANCING/REPAYMENT	**(2)**	**374**

11. List of abbreviations

AGB	Asymptotic Giant Branch
AIPS	Astronomical Image Processing System
ALMA	Atacama Large Millimeter Array
AMBER	Astronomical Multiple Beam Recombiner
AM CVn	Interacting close binary white dwarfs
ANS	Astronomische Nederlandse Satelliet
ANU	Australian National University
AO	Adaptive Optics
ASAC	ALMA Science Advisory Committee
ASTRON	Stichting Astronomisch Onderzoek in Nederland (Netherlands Foundation for Research in Astronomy)
ATNF	Australia Telescope National Facility
AU	Astronomical Unit
AXAF	Advanced X-ray Astronomy Facility (Chandra Observatory)
CCD	Charge-Coupled Device
CGRO	Compton Gamma-Ray Observatory
CNOC	Canadian Network for Observational Cosmology
CNRS	Centre National de la Recherche Scientifique
CRYOPAD	Cryogenic Photoproduct Analysis Device
DIB	Diffuse Interstellar Band
DIMES	Delft Institute of Microelectronics and Submicron Technology
DIVA	Small German astrometry satellite
DJAST	Dutch Joint Aperture Syntheses Team
DOT	Dutch Open Telescope
DSS	Digital Sky Survey
ECC	European Coordinating Committee
ESA	European Space Agengy
ESO	European Southern Observatory
EVN	European VLBI Network
FAME	Full-sky Astrometric Mapping Explorer
FELIX	Free Electron Laser for Infrared eXperiments
FIRES	Faint InfraRed Extragalaxtic Survey
FIRST	Far Infrared submm Telescope (ESA Cornerstone 4)
FOM	Stichting voor Fundamenteel Onderzoek der Materie (Organisation for Fundamental Material Research)
FOS	Faint Object Spectrograph on HST
GAIA	ESA's Cornerstone 6 Mission
HDF	Hubble Deep Field
HST	Hubble Space Telescope
IAC	Instituto de Astrofisica de Canarias
IAP	Institut d'Astrophysique, Paris
IAS	Institute for Advanced Study, Princeton
IF	Intermediate Frequency
ING	Isaac Newton Group (of the Roque de los Muchachos Observatory on La Palma)
IoA	Institute of Astronomy, University of Cambridge, UK
IRAM	Institut de RadioAstronomie Millimetrique
IRAS	InfraRed Astronomical Satellite
IRSI/Darwin	Infrared Space Interferometer
ISAAC	Infrared Spectrometer And Array Camera
ISM	Interstellar Medium
ISO	Infrared Space Observatory
ISOCAM	Infrared Space Observatory - Infrared Array Camera
ISOGAL	Mid Infrared Survey of the Inner Galaxy with ISO
ISOPHOT	ISO Imaging Photo-Polarimeter
ISZF	Institute of Solar Terrestrial Physics
JACH	Joint Astronomy Center, Hilo, Hawaii
JCMT	James Clerk Maxwell Telescope (on Mauna Kea, Hawaii)
JHU	Johns Hopkins University
JIVE	Joint Institute for VLBI in Europe
JPL	Jet Propulsion Laboratory
KLM	Koninklijke Nederlandse Luchtvaartmaatschappij (Royal Dutch Airlines)
KUN	Katholieke Universiteit Nijmegen (Catholic University Nijmegen)
LINER	Low Ionization Nuclear Emission Region
LISA	Laser Interferometer Space Antenna
LLNL	Lawrence Livermore National Laboratories
LMXB	Low-Mass X-ray Binary
LWS	Long Wavelength Spectrometer
2MASS	2 Micron All Sky Survey
MERLIN	Multi-Element Radio-Linked Interferometry Network
MFFE	Multi Frequency Front Ends
MHz	MegaHertz
MIDI	Mid-Infrared Interferometry Instrument for ESO's VLTI
MoU	Memorandum of Understanding
MPA	Max Planck Institut für Astrophysik
MPE	Max Planck Institut für Extra Terestrische Physik
MPIA	Max Planck Institut für Astronomie
MPIfR	Max Planck Institut für Radio Astronomie
MSC	Most Supernova remnant Catalogue
NASA	National Aeronautics and Space Administration
NEVEC	NOVA-ESO VLTI Expertise Center
NIC	Nova Information Center
NICMOS	Infrared Camera on HST
NIVR	Nederlands Instituut voor Vliegtuigontwikkeling en Ruimtevaart (Dutch Institute for Aeroplane development and Space flight)
NOVA	Nederlandse Onderzoekschool Voor Astronomie (Netherlands Research School for Astronomy)
NOAJ	National Astronomical Observatory of Japan
NRAO	National Radio Astronomy Observatory (USA)
NTT	(ESO) New Technology Telescope
NUFFIC	Netherlands Organization for International Cooperation in Higher Education
NVSS	NRAO/VLA Sky Survey
NWO	Nederlandse organisatie voor Wetenschappelijk Onderzoek (Netherlands Organization for Scientific Research)
OASIS	Integral Field Spectrograph
OCW	(Ministerie van) Onderwijs, Cultuur en Wetenschap (Ministery for Education, Culture and Science)
OmegaCam	Wide-field camera for the VST
OWL	Over-Whelmingly Large optical telescope
PAH	Polycyclic Aromatic Hydrocarbon
PDRs	Photon Dominated Regions
PI	Principal Investigator
PIONIER	Persoonsgerichte steun vorm van NWO
PLANET	Probing Lensing Anomalies NETwork
PNS	Planetary Nebula Spectrograph

PRIMA	Phase Referenced Imaging and Micro-arcsecond Astrometry
PSF	Point spread function
PUMA	PUlsar MAchine (for the WSRT)
PWN	Pulsar Wind Nebulae
RRI	Raman Research Institute
RuG	Rijksuniversiteit Groningen (University of Groningen)
RXTE	Rossi X-ray Timing Explorer
SAX	Satellite per Astronomia in Raggi X
SAURON	Spectrographic Areal Unit for Research on Optical Nebulae
SCUBA	Submillimeter Common User Bolometer Array
SED	Spectral energy distribution
SINFONI	Single Faint Object Near-infrared Investigation
SIRTF	Space Infrared Telescope Facility
SIS	Submillimeter Infrared Survey
SOFI	Infrared Imager on the NTT
SOHO	Solar and Heliospheric Observatory
SPIFFI	Spectrometer for Infrared Faint Field Imaging
SRON	Stichting Ruimte-Onderzoek Nederland (Space Research Organization in the Netherlands)
STJ	Super Tunnel Junction
STScI	Space Telescope Science Institute
STW	Stichting Technische Wetenschappen (Organisation for Technical Sciences)
SURFRESIDE	Surface Reaction Simulation Device
SWS	Short Wavelength Spectrometer
TiC	Typical Carbonrich Nanocrystals
TMR	Training and Mobility of Researchers
TNO-TPD	Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderwijs (Dutch Organisation for Education in Applied Physics)
TUD	Technische Universiteit Delft (Technical University Delft)
UC	University of California
UCSD	University of California at San Diego
UHV	Ultra High Vacuum
UIT	Ultraviolet Imaging Telescope
UL	Universiteit Leiden (Leiden University)
UMIST	University of Manchester Institute of Technology
UU	Universiteit Utrecht (Utrecht University)
UV	Ultra Violet
UvA	Universiteit van Amsterdam (University of Amsterdam)
VINCI	VLT INterferometer Commissioning Instrument
VISIR	VLT Imager and Spectrometer for the mid-Infrared
VLA	Very Large Array
VLBI	Very Long Baseline Interferometry
VLT	Very Large Telescope (ESO)
VLTI	Very Large Telescope Interferometer (ESO)
VST	VLT Survey Telescope
VU	Vrije Universiteit van Amsterdam (Free University of Amsterdam)
WENSS	Westerbork Northern Sky Survey
WFPC2	Wide Field and Planetary Camera 2 on HST
WFS	Wave front sensor
WHT	William Herschel Telescope (part of ING)
WR	Wolf-Rayet
WSRT	Westerbork Synthesis Radio Telescope
YSOs	Young Stellar Objects
XMM	X-ray Multi-mirror spectroscopy Mission
ZEMAX	Software for optical design

Name	PhD date	Employer	Promotor	Thesis title
UvA				
R.A.D. Wijnands	16-02-1999	PIONIER, UvA	van der Klis	Millisecond Phenomena in X-ray Binaries
M.E. van den Ancker	14-09-1999	NWO	Tielens, Waters	Circumstellar material in young stellar objects
J.Th. van Loon	23-09-1999	NWO, ESO	de Jong	Mass loss and evolution of asymptotic Giant Branch Stars
C. Schrijvers	16-11-1999	NWO	van Paradijs	Spectroscopic diagnostics of pulsations in rotating stars
P.J. Groot	07-12-1999	NWO	van Paradijs	Optical variability in Compact Stars
T.J. Galama	08-12-1999	NWO-GBE	van Paradijs	Gamma-ray burst afterglows
P.A. Zaal	12-01-2000	NWO	van den Heuvel	Observations and Analysis of early-type stars at infrared wavelengths
J.A. de Jong	08-02-2000	NWO-GBE	van den Heuvel co: Henrichs	On the origin of cyclical variability in the winds of massive stars
F.J. Molster	15-06-2000	NWO-GBE	Waters, de Jong	Crystalline silicates in circumstellar dust shells
RuG				
A.C.A. Boogert	05-03-1999	RuG	Tielens	The interplay between dust, gas, ice, and protostars
P.D. van Dokkum	21-06-1999	RuG	Franx, Illingworth	Formation and evolution of early-type galaxies
W.H. de Vries	25-06-1999	RuG	Briggs	Host galaxies of powerful extragalactic radio sources
R.H.M. Schoenmakers	02-07-1999	RuG	van Albada	Asymmetries in spiral galaxies
R.A. Swaters	15-10-1999	RuG	van Albada, Sancisi	Dark matter in late-type dwarf galaxies
L.V.E. Koopmans	07-02-2000	NWO-GBE	de Bruyn	A study of radio-selected gravitational lenses
J. Gerssen	14-07-2000	RuG	Kuijken, Merrifield	Stellar kinematics in disk galaxies
H. Hoekstra	22-09-2000	RuG	Franx, Kuijken	A weak lensing study of massive structures: looking at the dark side of the universe
W.M. Lane	09-10-2000	RuG	Briggs	HI 21 cm absorbers at moderate redshifts
M.A. Zwaan	16-10-2000	RuG	Briggs	Atomic hydrogen in the local universe
R.A. Jansen	28-11-2000	RuG	Franx, Fabricant	The nearby field galaxy survey: a spectro-photometric study of 196 galaxies in the local field
UL				
R.B. Rengelink	17-02-1999	NWO-GBE	Miley, De Bruyn	The Westerbork Northern Sky Survey; the cosmological evolution of radio sources
E.T. Chatzichristou	15-06-1999	External funds	co: Jaffe	Imaging and bi-dimensional spectroscopy of active and interacting galaxies
N. Cretton	09-09-1999	UL, Swiss, NUFFIC	de Zeeuw, Rix co: van der Marel	Dynamical models of early-type galaxies
J.M. Stil	09-09-1999	UL	Habing co: Israel	Dwarf Galaxies: dynamics and star formation
C.P. Dullemond	22-09-1999	UL	Icke co: Turolla	Radiative transfer in compact circumstellar nebulae
L. Pentericci	28-10-1999	UL	Miley co: Röttgering	The most distant radio galaxies: probes of massive galaxy formation
J.H.J. de Bruijne	25-05-2000	UL	de Zeeuw / Perryman co: Blaauw	Astrometry from space
R. Hoogerwerf	25-05-2000	NWO-GBE	de Zeeuw / Perryman co: Blaauw	Hipparcos and the nearby OB associations: Space astrometry and high-mass star formation
A. Helmi	28-06-2000	UL	de Zeeuw / White	The formation of the Galactic halo
F. van der Tak	20-09-2000	NWO-GBE	van Dishoeck / Evans	The embedded phase of massive star formation
P.M. Veen	27-09-2000	UL	Habing	Intriguing variability of WR 46 and of “dusty” Wolf-Rayet stars
C. De Breuck	08-11-2000	UL/Livermore	Miley/ Röttgering / Van Breugel	Very distant radio Galaxies: search techniques and emission line properties

Name	PhD date	Employer	Promotor	Thesis title
UU				
J. Vink	19-04-1999	SRON	Bleeker co: Kaastra	The spectral X-ray morphology of the supernova remnants Cas A, RCW 86 and SN 1006
H.C. Hagenaar	10-05-1999	UU	Kuperus co: Schrijver, Rutten	Flows and magnetic patterns on the solar surface
R.H.M. Voors	11-05-1999	UU	Lamers co: Waters	Infrared studies of hot stars with dust
H.W. Hartmann	13-09-1999	SRON	Heise co: Verbunt	Models for hot high-gravity atmospheres applied to soft X-ray sources
A.P. Schoenmakers	4-10-1999	NWO	van der Laan, de Bruijn	A population study of giant radio galaxies
M.L. van den Berg	05-10-1999	SRON	Bleeker co: de Korte, Luiten	Development of a high resolution X-ray spectrometer based on superconductive tunnel junctions
M.D. Nauta	10-01-2000	UU	Kuijpers	Two-dimensional eddies in accretion disks
M. Kouwenhoven	09-10-2000	UU, NOVA	Verbunt	Pulsar observations with the Westerbork Synthesis Radio Telescope
J. van Gent	06-11-2000	UU	Lamers	The Baldwin-effect in Wolf-Rayet stars
J. S. Vinck	20-11-2000	NWO-GBE	Lamers, de Koter	Radiation-driven wind models of massive stars