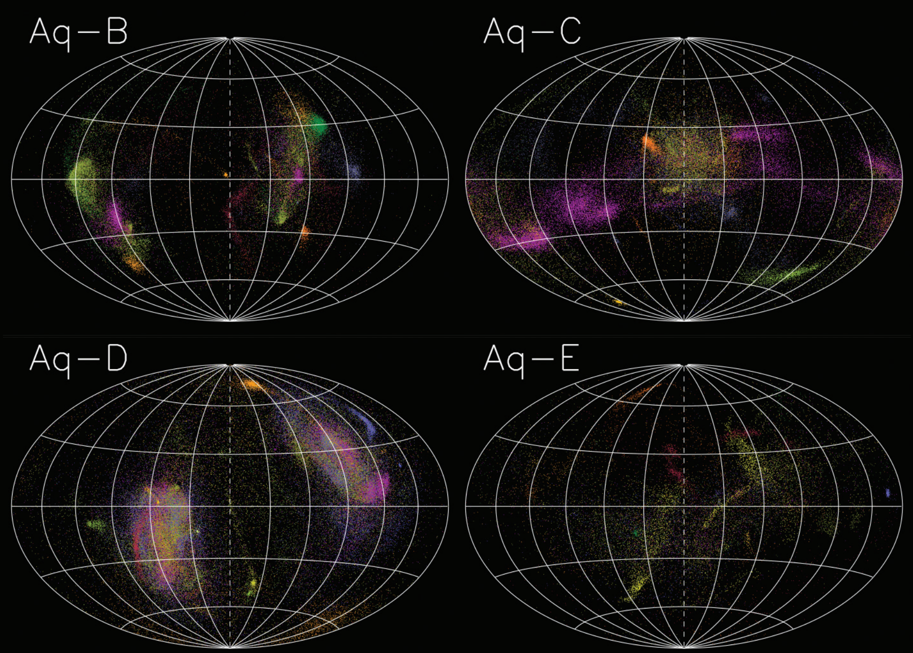
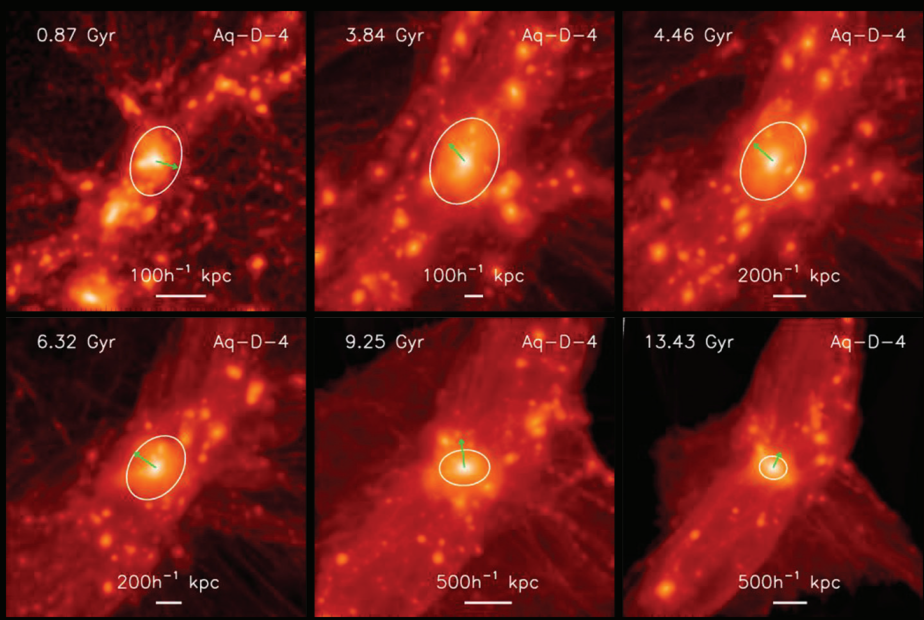
NOVA REPORT

2010 - 2011 - 2012





Ilustrations on front cover

Top: Distribution of model 'stars' in the halo of an N-body Aquarius simulation of the formation of our Milky Way including the disruption of satellite galaxies. The different colors correspond to stars originating in different progenitors. The stars are located at 30-50 kpc from the model 'Sun' and show a wide variety of features. Even more distant substructures are distributed anisotropically and this should. Even more distant substructures are distributed anisotropically, and this should become apparent in the next generation of photometric surveys (Helmi et al. 2011).

Lower: Time sequence of the formation of one of the Aquarius dark matter halos. Its shape evolves continuously with time, in response to the infall of matter. This illustrates the complexity involved in the build up of the present day dark halos (Vera-Ciro et al. 2011).

Ilustrations on back cover

In the reporting period NOVA has strengthened its collaboration with industry. Examples are given in section 5.6. The following figures are presented at the back cover.

Top: The prototype chopper for METIS developed in a collaboration between Janssen Precision Engineering, NOVA, SRON, RUG and TNO.

Middle: Laboratorium setup at UTwente for sorption cooling experiments. The project is a joint effort of UTwente, DutchSpace and NOVA.

Bottom: Test samples of coated composite materials, a collaborative project of Airborne Composites, TNO and NOVA.

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

Table of contents

1. Introduction

Astronomy is the study of the formation and evolution of objects in the Universe, including galaxies, stars and planets as well as the tenuous matter in between these objects. Discoveries in astronomy continue at an amazing pace. Close to home a wide variety of planets circling nearby stars has been found, with characteristics very different from those in our own Solar System. The dusty veils surrounding the birth of galaxies, stars and planets, and perhaps even life itself, are being lifted with new facilities. Galaxies are now detected at the edge of the Universe from which the radiation takes 13 billion years to reach Earth. Even more remarkable is the fact that all the objects that we see with the most powerful telescopes comprise only 5% of the Universe, with the remaining 95% consisting of mysterious dark energy and dark matter which leave no directly observable trace. This report covers the numerous scientific and technical achievements by the university astronomical community united in NOVA in the years 2010-2012.

Astronomy spans a wide range of disciplines, including physics, chemistry, mathematics, and informatics, and now even biology and geology. New interdisciplinary topics such as astroparticle physics, computational astrophysics, astrochemistry and astrobiology are emerging worldwide, with the Netherlands having a leading position in several of these areas. Astrophysicists study phenomena involving enormous scales of length and mass (the entire Universe), huge densities (e.g., neutron stars), enormous gravitational fields (black holes), ultra-high vacua (interstellar and circumstellar media), and immense energies and intense fluxes of particles and radiation (gamma ray bursts and supernovae, accreting neutron stars and black holes). The desire and curiosity to understand this fascinating Universe is shared between astronomers and the general public, and astronomy presents a unique opportunity to enhance appreciation for the natural sciences to the younger generation.

The Netherlands Research School for Astronomy (NOVA) carries out astronomical research at the highest international levels centered around the theme 'The Life-Cycle of Stars and Galaxies: from high-redshift to the present' and trains the next generation of astronomers in this area (Chapters 3+4). Essential for the success of the research program is access to state-of-the-art observational facilities. An integral component of the NOVA program is therefore to build and develop new astronomical instruments, often in concert with industry, and smart software pipelines to analyze large data streams (Chapter 5). NOVA shares the excitement of astronomical discoveries with the general public through its outreach program, the NOVA Information Center (NIC) (Chapter 8).

Major developments of NOVA program

During the reporting period 2010 – 2012 the NOVA program had several major up and downs. Starting on the positive side: on 1st July 2011 the Ministry of OCW announced the continuation of the top-research grant for NOVA for another period of five years for 2014-2018. This decision followed a number of reviews and recommendations.

In April 2010 the NOVA International Review Board (IRB) visited NOVA and the individual university astronomical departments to assess the quality of the research conducted in the period 2003-2009. The IRB concluded that the Netherlands, through NOVA, makes contributions to world astronomy far disproportionate to its population or GDP. These contributions include important scientific discoveries, development of forefront instrumentation, production of scientific leaders, training of young astronomers, outreach and public education.

In summer 2010, the funding agency NWO carried out an independent evaluation at the request of the ministry of OCW of the six top-research school financed by the 'Bonus incentive scheme' – the official name for the Dutch government program that started in 1999 - and called here the 'NOVA grant'. The NWO committee concluded that NOVA had used the top-research grant to create a coherent and compelling program, allowing the Dutch astronomical community to maintain and enhance its already excellent international standing. The NOVA grant had been instrumental in rejuvenating the leadership in the astronomical community. The implementation of a new and ambitious instrumentation program obtained special praise and it was recognized such an activity needs of stable, long-term funding given the long term nature of these projects. In the overall rating by this committee NOVA was qualified as 'exemplary'. Two out of the six top-schools reviewed received this 'top' qualification (NOVA and Zernike) while the four other schools were rated as 'excellent'.

The final decision of the Ministry of OCW in summer 2011 was to extend the top-research grant for NOVA and Zernike up to end 2018 and to terminate the funding of the other four top-research schools by end 2013. Furthermore, based on a recommendation by the Royal Dutch Academy of Sciences (KNAW), it was decided to replace the 'Bonus incentive scheme' by a new program called 'Zwaartekracht' ('Gravity') with a different set of conditions.

On the down side: on 1st June 2011 NOVA received the message from the University Utrecht (UU) that it had decided to refocus its program for the Science Faculty. This included the regrettable choice not to continue astronomy in spite of its excellent performance. In the winter of 2011-2012 all scientific staff of the Astronomical Institute in Utrecht and their research groups were transferred to the universities of Amsterdam (2 staff), Leiden (1 staff) and Nijmegen (4 staff). On 5 April 2012, on the final day of the symposium to celebrate the scientific achievements of 370 years of astronomical research at the UU, the Astronomy Department was officially closed.

Overview and highlights

Dutch astronomy continues to be highly productive, with many refereed papers in 2010-2012, most of them led by young PhD students and postdocs. Scientific highlights include the discovery of the most distant galaxies that were formed less than 0.5 Gyr after the Big-Bang; the detection of extremely metal-poor stars in Milky Way satellites, providing insight into their origin; the rich harvest from Herschel-HIFI including the lifecycle of water from clouds to disks; the first direct detection of exoplanets and their atmospheres through measurements of their orbital velocities; the identification of the most massive neutron star to date ruling out exotic equations of state; and the observation of the shortest period white dwarf binary, providing a guaranteed detection target for gravitational wave searches.

The NOVA instrumentation program attracted special attention of both the IRB and the NWO evaluation committee. The IRB noted the depth and variety of astronomical instruments developed by NOVA scientists and engineers, and the remarkable achievement that most of these instruments were delivered on time and on budget. The instrumentation projects completed in the reporting period include the design, prototyping and construction of 72 ALMA Band-9 receiver cartridges covering the atmospheric window between 610 and 720 GHz, the commissioning of X-Shooter on the VLT, the ground-based testing and delivery of the MIRI instrument on JWST to NASA with a NOVA contribution to the mid-infrared spectrometer, the NOVA part of the development of software data-reduction packages for the four LOFAR key projects, and the NOVA start-up support for AMUSE and ALLEGRO. Further information is presented in Chapter 5.

In the reporting period the NOVA program involved ~290 fte scientific staff members spread over the universities participating in NOVA. This number includes ~60 fte senior staff members in permanent and tenure-track positions, 50 fte postdoctoral fellows, 145 fte PhD students, and ~35 fte staff working on instrumentation projects. NOVA funds about 19% of these positions, as well as an active workshop and visitor program (Chapter 7), and outreach efforts through the NOVA Information Center (Chapter 8).

In the period 2010-2012 a total of 84 PhD degrees in astronomy were awarded at the five NOVA institutions. Several PhD students received prestigious fellowships abroad, including 4 Hubble fellowships (Chapter 4).

Many astronomers in the Netherlands received prestigious research grants during the reporting period. The table below gives an overview.

In addition many NOVA researchers received awards and honors, including

- Academy professorship for Van der Klis (2010)
- Academy professorship for Van Dishoeck (2012)
- Election to the Royal Dutch Academy of Sciences (KNAW) for Tielens (2012)
- Election to the Young Academy of the KNAW for Haverkorn (2012)
- Pastoor Schmeits price for Helmi and Schaye (2010)
- Royal knighthood to Icke (2012) and Miley (2012)
- WiF best science publication for Hekker (2012)
- National academy public price to iSPEX team led by Snik (2012)

Major grant	2010	2011	2012
Spinoza prize	Franx	Falcke	Tielens
Advanced ERC grant		van Dishoeck	Morganti
		van der Hulst	
Starting ERC grant	Koopman	Schaye	
		Hoekstra	
VICI	Linnartz	Zaroubi	Snellen
VIDI	Cazaux		Körding
VENI	Hekker	Deller	Sobral
	de Kok	Glebbeek	Hu
	Oppenheimer	Jin	Salvadori
	Serra		

Major personal research grants obtained in 2010 - 2012.

2. Mission statement and research program

NOVA is a federation of the astronomical institutes of the universities of Amsterdam, Groningen, Leiden and Nijmegen, consisting now of four universities since the closure of Utrecht in 2011. In November 2012 the four universities have signed a new NOVA Agreement in which the new NOVA organization is described. In this agreement the University of Leiden is assigned as the legal representative of NOVA.

2.1. NOVA's mission and objective(s)

NOVA's mission is to carry out front-line astronomical research in the Netherlands and to train young astronomers at the highest international levels.

NOVA's objectives for the next decade are 1) to continue scientific innovation in the three main lines of NOVA's coherent research program maintaining its high quality; 2) to further strengthen NOVA's instrumentation program by having a leading role in designing and realizing cutting-edge instrumentation for Europe's Extremely Large Telescope; 3) to keep attracting very talented PhD students and educating them to levels where they compete successfully for the best positions in science and elsewhere; 4) to share enthusiastically our increased understanding of the Universe with the general public; and 5) to secure continued, long-term access to direct government funding for NOVA to make all of this possible.

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

The research program carried out by NOVA 'The lifecycle of stars and galaxies: from high-redshift to the present' is organized along the following three interconnected thematic programs (also referred to as 'networks'):

- Network 1: Formation and evolution of galaxies: from high redshift to the present

- Network 2: Formation and evolution of stars and planetary systems

- Network 3: The astrophysics of black holes, neutron stars and white dwarfs

Each network consists of 15-25 active staff researchers with strong scientific records. The list of NOVA network researchers is given in section 9.3. The networks have regular (one to two times per year) face-to-face meetings with scientific presentations, mostly by PhD students. Subgroups of researchers from different universities focusing on more specialized topics also meet regularly.

Network 1: Formation and evolution of galaxies: from high redshift to present

Galaxies contain billions of stars, as well as interstellar gas and dust, and are embedded in dark halos of unknown constitution. Astronomers are able to look back in time, by observing galaxies at ever greater distances to a redshift of 8 and above (corresponding to ages less than 5% of the current age of the Universe). How did galaxies form? Can we look back to the epoch of re-ionization? What processes have occurred between high redshift and the present? Do evolved galaxies contain relics which are clues to their formation? What are the influences of the environment, of nuclear activity, and of the original large-scale distribution of dark matter? What is the role of massive black holes in galactic nuclei? What are the physical conditions in galaxies and what controls their star-formation activity?

Network 2: Formation and evolution of stars and planetary systems

New stars continue to be born deep inside molecular clouds in galaxies. The birth process leads to a circumstellar disk of gas and dust from which planets and comets may subsequently form. What are the physical processes that lead to these new solar systems, and how do they evolve? What is the origin of the large diversity in observed planetary architectures? How is the chemical composition of the gas and dust involving water and complex organic molecules modified during the collapse from the cold, tenuous interstellar medium to the dense protoplanetary material? What is the nature of exo-planets orbiting other stars? Massive stars are important in driving the chemical evolution and energetics of the interstellar medium in galaxies. Do massive stars form in a similar way as solar type stars, and are they capable of forming planetary systems? How important are chemical composition, rotation and mass loss for the evolution of massive stars?

Network 3: the astrophysics of black holes, neutron stars and white dwarfs

At the end of its life, a massive star explodes and ejects its outer layers. The stellar core collapses to form a neutron star or a black hole; lower mass stars become white dwarfs. These are the densest objects that exist, and the ones with the strongest gravitational fields. What are the properties of matter at the extreme density in the interior of a neutron star? What are the observational signatures of black holes? Can we observationally verify the extraordinary predictions of General Relativity for the properties of curved space-time near these objects? How do particles and radiation behave near these compact objects? What happens when two compact objects orbiting each other eventually merge? Is this the origin of the most powerful explosions we know, the enigmatic gamma-ray bursts? What is the origin of the highest energy cosmic rays observed throughout the Universe? What are the prospects for detection of gravitational waves?

NOVA Grant

The NOVA Grant stimulates the university research program through funding of PhD and postdoc positions and through ‘overlap’ appointments for permanent staff, which make it possible to appoint successors to retiring faculty several years early. A significant number of projects are joint with the NWO astronomical institutes SRON and ASTRON and the Joint Institute for VLBI in Europe (JIVE), which co-fund positions.

Modern astronomy requires access to state-of-the-art observations across a wide range of wavelengths. The NOVA Grant stimulates this access through the design and building of selected new astronomical instruments, through technical research and development for the next generation of instruments, and through development of specialized data reduction and analysis software. The integrated research and instrumentation program enables Dutch astronomers to obtain a rich harvest of results from ground-based and space-based facilities provided by NOVA and others, in conjunction with strong theory, numerical modeling, and laboratory astrophysics efforts. Over the last decade NOVA has revitalized optical-infrared astronomical instrument-building in the Netherlands, involving many university astronomers in the program, and has positioned itself well for participation in future major projects.

The aim of the NOVA instrumentation program is to develop, construct and exploit new instrumentation and high-level software for world-class observatories, with a focus on instrumentation for the European Southern Observatory (ESO), and to increase technical expertise at the universities. The program is carried out in collaboration with the NWO institutes ASTRON and SRON, and institutions abroad. Current projects include instrumentation for the ESO Very Large Telescope, the ESO-VLT Interferometer (VLTI), the VLT Survey Telescope (VST), the European Extremely Large Telescope (E-ELT), the Atacama Large Millimeter/submillimeter Array (ALMA), the James Webb Space Telescope (JWST), the ESA astrometric Gaia mission, the LOw Frequency ARray (LOFAR) and the Sackler Laboratory for Astrophysics (Chapter 5).

As part of its graduate education program, NOVA organizes an annual 5-day NOVA fall school in Dwingeloo with the aim to broaden the astrophysical background of starting PhD students and improve their presentation skills. Monitoring of the actual graduate research is carried out on behalf of NOVA by the 'Graduate Student Review Committee' at each of the NOVA institutes which meets annually with each of the graduate students to discuss progress, problems and future career prospects.

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

3. Scientific highlights

3.1 Formation and evolution of galaxies

NOVA researchers in Network 1 used several new instruments in 2010-2012 to obtain more insight in the evolution and structure of galaxies as well as to test cosmological models. They used a wide variety of instruments and computer simulations to obtain their results. The Hubble Space Telescope, with the newly installed Wide Field Camera 3 played an important role, as did new instrumentation on the VLT (e.g., X-Shooter which was partly built by NOVA). The studies ranged from cosmological weak lensing studies, to galaxies in the nearby and distant universe, to theoretical computer simulations to understand the physics driving the observed galaxy evolution and for comparison with the latest observational surveys. We present a number of the highlights below.

Cosmology and weak lensing

Schrabback, Hoekstra, Kuijken, Hildebrandt, Semboloni (PhD), and Velander (PhD) completed a comprehensive analysis of the large-scale mass distribution in the HST map of the COSMOS field, together with collaborators in the EU-funded DUEL network. A key development was the inclusion of accurate photometric redshifts for large numbers of galaxies, allowing a measurement of the evolution of the growth of large-scale structure and a 3-D tomographic lensing analysis. For the first time, they could show that the weak shear of distant galaxies scales with redshift as expected in the standard ΛCDM model. This established the combination of weak lensing and photometric redshifts as a cosmological probe. The results of the 1.6-square degree survey confirmed the accelerated expansion of the universe, and demonstrated the potential of all-sky space-based weak lensing and photometric redshift surveys for precise measurements of the properties of dark energy (Fig. 1.1).

The Highest Redshift Galaxies

Bouwens, Franx, Labbé and collaborators used the new Wide Field Camera 3 on the Hubble Space Telescope to identify 73 z~7 and 59 z~8 candidate galaxies in the reionization epoch. This enabled them derive very deep luminosity functions to less than -18 AB mag and the star formation rate (SFR) density at z~7 and z~8 (just 800 Myr and 650 Myr after recombination, respectively). The application of strict optical non-detection criteria ensures the contamination fraction is kept low (just ~7% in the HUDF). The faint-end slopes α at z~7 and z~8 are uncertain but very steep at α = -2.01 ± 0.21 and α = -1.91 ± 0.32, respectively (Figure 1.2, left). Such steep slopes contrast to the local values of α shallower than ~ -1.4 and they may even be steeper than that at z~4 where α = -1.73 ± 0.05. With such steep slopes, lower luminosity galaxies dominate the galaxy luminosity density during the epoch of reionization. The SFR densities derived from these new z~7 and z~8 luminosity functions are consistent with the trends found at later times (lower redshifts). In addition, Bouwens et al (2011, Nature) identified one candidate galaxy at a redshift of 10 in the Hubble Ultra Deep Field (Figure 1.2, right). This galaxy is detected only in 1 band (the H band), and not in the bluer bands, consistent with a galaxy at a redshift of 10. Deep spectroscopy with the James Webb Space Telescope is needed to confirm this candidate.

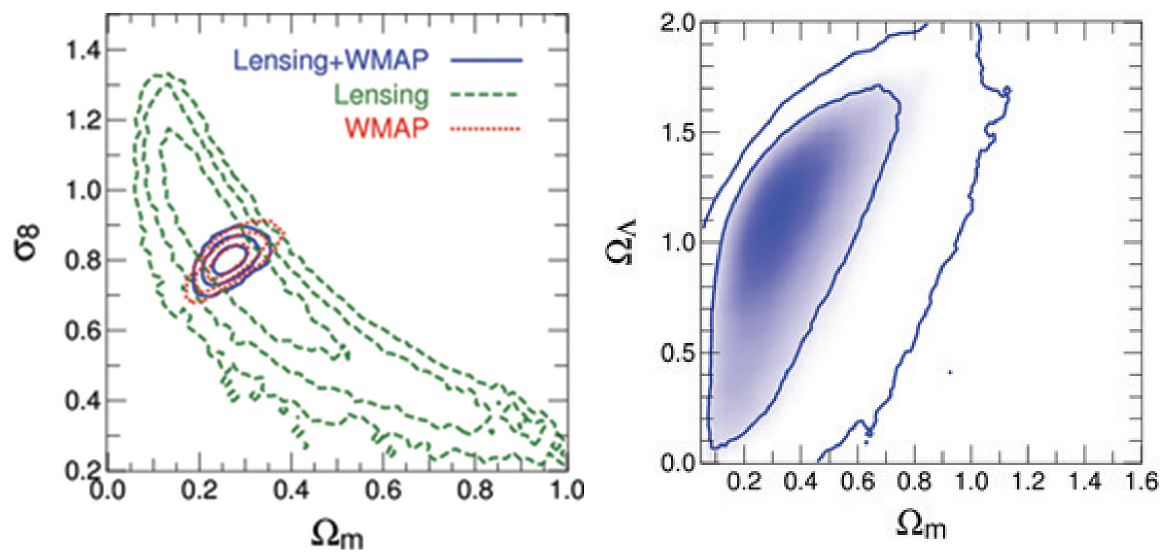


*Figure 1.1. Constraints on cosmological parameters from the three-dimensional analysis of weak gravitational lensing distortions in the Hubble Space Telescope COSMOS Survey. The contours indicate the 68%, 95% (and 99.7%) confidence regions. **Left:** Constraints on the matter density Ω_m and amplitude of matter fluctuations σ_8 for a standard, spatially flat ΛCDM cosmology. The COSMOS lensing constraints are nearly orthogonal and hence complementary to WMAP5 results from the cosmic microwave background. **Right:** Constraints on the density of matter Ω_m and vacuum energy Ω_Λ for a ΛCDM cosmology with curvature from COSMOS. From these constraints a 96% probability for cosmic acceleration is computed, providing further support for the presence of dark (or vacuum) energy (Schrabback et al. 2010).*

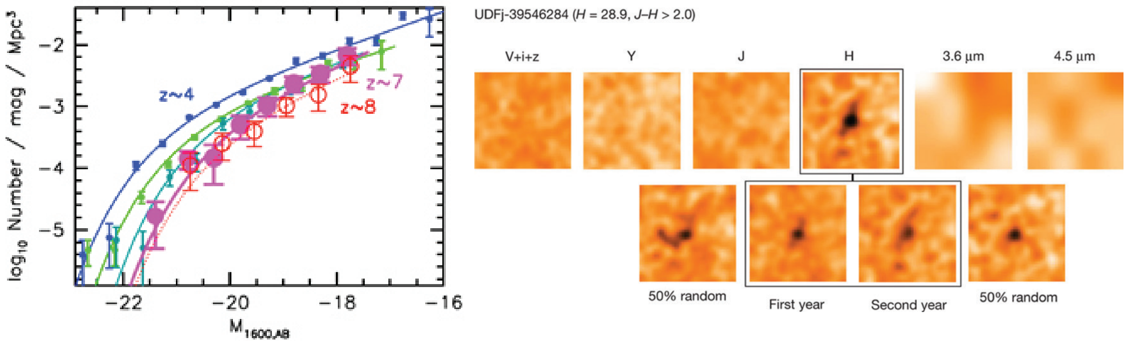


***Figure 1.2. Left:** The evolution of the luminosity function of galaxies from a redshift of 4 to a redshift of 8 (Bouwens et al 2011a). The brightest galaxies evolve the fastest, and the slopes are very steep. **Right:** The candidate z=10 galaxy from Bouwens et al (2011b). The galaxy is detected only in the H band, and not in any other bands.*

Massive galaxies at z=1.5-2.5

Szomoru (PhD), Franx and collaborators used very deep imaging with the Wide Field Camera 3 on the Hubble Ultra Deep Field to study the intensity profiles of very compact, quiescent galaxies. These galaxies had been found previously to be very small, but it was thought by some to be due to the missed flux in the outer parts of the galaxies. The Hubble Ultra Deep Field imaging is so sensitive that it can detect the faint outer envelopes of these galaxies. Their analysis showed that the galaxies are truly compact, and do not have extended envelopes (Fig. 1.3, left).

Van de Sande (NOVA PhD), Franx and collaborators took a spectrum of a bright, compact galaxy at a redshift of 1.8, using the X-Shooter spectrograph on the VLT (Fig. 1.3, right). The individual absorption features can be clearly seen, and result in an accurate measurement of the velocity dispersion of 294 ± 51 km/s. The stellar mass of 1.5×10^{11} M⊙ agrees well with the implied dynamical mass of $(1.7 \pm 0.5) \times 10^{11}$ M⊙. This is direct proof that the stellar masses are reliable.

Cosmological simulations

Schaye and collaborators completed the suite of OverWhelmingly Large Simulations (OWLS), which consists of more than fifty large, cosmological simulations of the formation of galaxies and the evolution of the intergalactic medium. The parameters of the model are systematically varied to determine which physical processes are most important for a variety of phenomena, ranging from the growth of galaxies and black holes to the chemical enrichment of the intergalactic medium, as summarized in a series of papers. Among the most remarkable findings is the strong effect that outflows driven by accreting supermassive black holes have on cosmological observables (Fig. 1.4, van de Voort (PhD)). Together with McCarthy (Cambridge) it was shown that ejection of gas at high redshift by winds from growing black holes allows the OWLS models to solve the overcooling problem and to reproduce, for the first time, both optical observations of stars and detailed X-ray observations of gas in groups of galaxies. The resulting redistribution of baryons improves the agreement with a variety of observables and has dramatic consequences for the structure of dark haloes (which expand rather than contract, cf. Duffy et al.) and for the power spectrum of the matter distribution (which is reduced out to the scales on which groups cluster, cf. van Daalen (PhD) et al.). These surprisingly strong feedback effects will be the factor limiting our ability to translate upcoming weak lensing surveys into constraints on cosmological parameters, as shown together with Sembolini, Hoekstra and Kuijken.

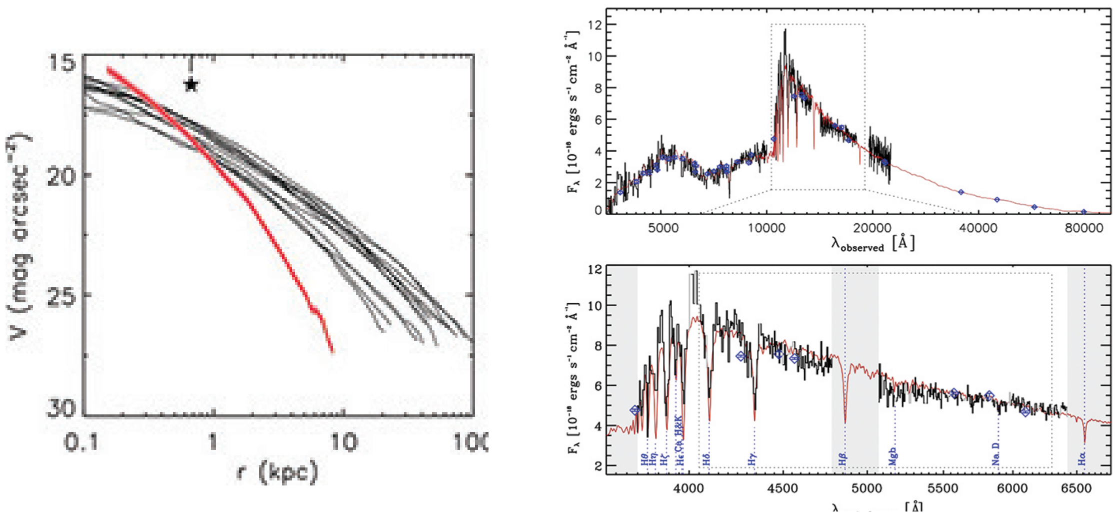


***Figure 1.3: Left:** Intensity profile (red) of a compact galaxy at z=1.9 in the Hubble Ultra Deep Field. The surface brightness profile has been shifted vertically to represent the galaxy as it would be at z=0 (due to passive evolution). It is clearly very small compared to Virgo galaxies of the same mass (black curves), and is measured to the similar surface brightness (Szomoru et al. 2010). **Right:** VLT X-Shooter spectrum of a bright compact galaxy at z=1.8, indicating a velocity disper sion of 294 ± 51 km/s. The corresponding dynamical mass agrees with the stellar mass (Van de Sande et al. 2011).*

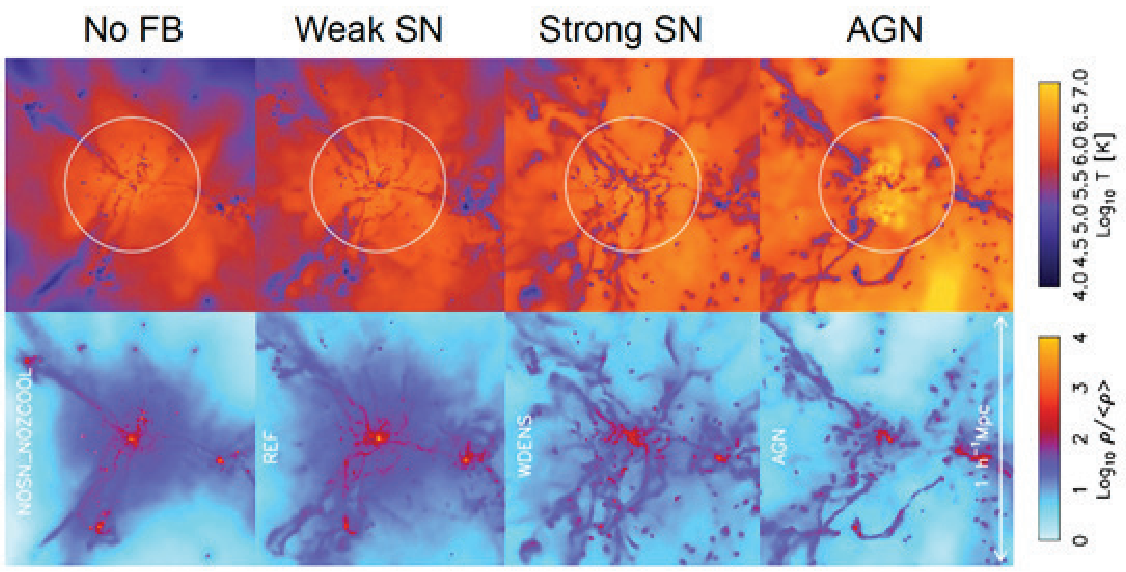


Figure. 1.4: *The effect of feedback from galaxy formation. Shown are the gas temperature (top row) and density (bottom row) in a 1 comoving Mpc/h volume centred on a halo of 10^{12} solar masses at redshift z=2. The white circles indicate the virial radius. The columns show four OWLS models of the same galaxy, from left to right: no feedback, weak winds from star formation, strong feedback from star formation, strong feedback from star formation plus outflows driven by supermassive black holes. Cold gas streams in through filaments. Efficient feedback disrupts the inner filaments and heats gas out to large radii (van de Voort et al. 2011).*

Structure of early-type galaxies

Spiniello (PhD), Koopmans, Trager and collaborators are studying the mass distributions of massive early-type galaxies combining gravitational lensing, stellar dynamics and stellar-population analyses of more than fifty Sloan Lens ACS (SLACS) early-type lenses. This can be used to constrain the Initial Mass Function of the early-type galaxies since it puts a firm upper limit on the total stellar mass. With help of a deep X-Shooter spectrum they could constrain the slope of the IMF of the galaxy shown in Fig. 1.5 to have $\alpha < 3.0$ (90% confidence limit; $dn/dm \sim m^{-\alpha}$), consistent with a Salpeter IMF.

Merging clusters and shocks

Galaxy clusters grow by mergers with other clusters or galaxy groups, as well as through the accretion of gas from the intergalactic medium (IGM). Both these two processes shock the intercluster medium. Cluster relics are large elongated diffuse structures at the periphery of clusters. van Weeren (PhD), Röttgering and collaborators have discovered a spectacularly long and narrow relic with a size of 2.0 Mpc × 50 kpc (Fig. 1.6), located at a distance of 1 Mpc from the centre of the merging cluster CIZA J2242.8+5301 (z=0.19). The relic displays highly aligned magnetic fields and a strong spectral index gradient due to cooling of the synchrotron emitting particles in the post shock region. These observations provide conclusive evidence that shocks in merging clusters produce extremely energetic cosmic rays. Detailed modelling of the morphology, polarization properties and variations of the radio spectrum allows determination the strength of the magnetic field (5 μG) and the Mach number ($4.6^{+1.3}_{-0.9}$) of the shock. The numerical simulations indicate that the impact parameter of the cluster collision was about zero and the mass ratio of the colliding clusters was 2:1.

Properties of galaxies in voids

Beygu (PhD), van de Weygaert, van der Hulst and collaborators are carrying out the Void Galaxy Survey, an extensive multiwavelength (optical, infrared, ultraviolet, radio) campaign to study the morphology, star formation rates, gas content, mass distributions and environment of a set of 60 void galaxies. The selection of the sample is uniquely based on a pure (tessellation-based) geometric procedure, guaranteeing an objective census of the void galaxy population in the nearby Universe. The galaxies are located in the deepest troughs of voids that were identified from the SDSS DR7 survey sample. The aim of the project is to compare the intrinsic physical properties of void galaxies and to assess in how much

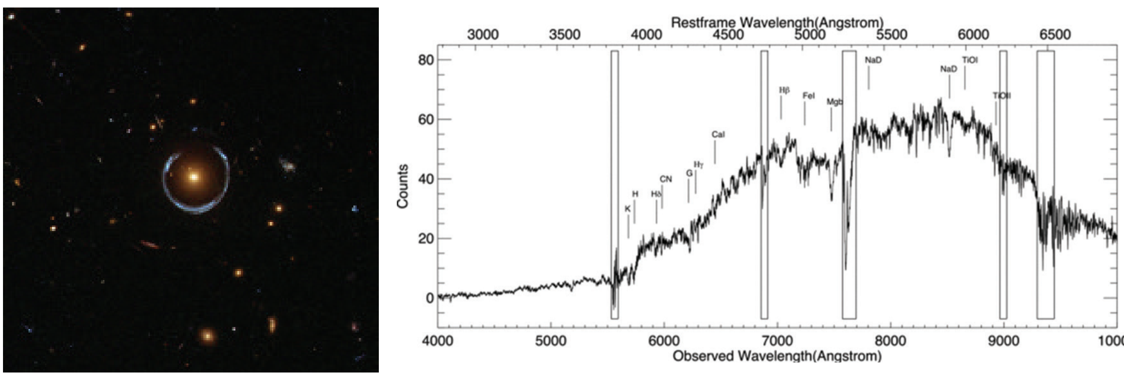


Figure 1.5: Left: *Hubble Wide Field Camera 3 optical/infrared image of the SLACS lens LRG 3-757 at z=2.379, one of the sources in the sample. The field of view is approximately 2.6 arcminutes. Credit: http://www.spacetelescope.org/images/potw1151a/.* ***Right:*** *Luminosity-weighted X-Shooter spectrum of the galaxy SDSS J1148+1930 at z=0.444 used to derive the stellar mass distribution. Telluric features are masked in the spectral regions indicated by the boxes (Spiniello et al. 2011).*

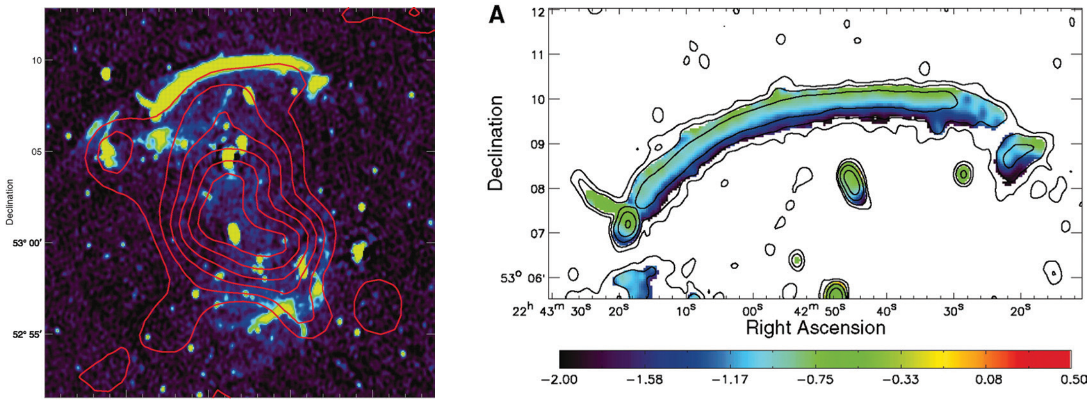


Figure 1.6: *Radio relics in the merging cluster CIZA J2242.8+5301 (z=0.19).* ***Left:*** *1400 MHz WSRT image with ROSAT X-ray contours overlaid.* ***Right:*** *spectral index map using observations at 1400, 610 and 325 MHz (van Weeren, Röttgering et al. 2010, Science).*

they differ from the regular field population in terms of morphology, brightness, colour, star formation activity and (HI) gas content and morphology. In the pilot survey (15 galaxies) it was found that the void galaxies are generally gas rich, low luminosity, blue disk galaxies, with optical and HI properties that are not unusual for their luminosity and morphology. They also appear to be somewhat smaller than their peers in the field and have an uncommonly active star formation rate with respect to their hydrogen mass. The survey shows many examples of void galaxies with strongly disturbed HI morphologies and kinematics, evidence for on-going gas accretion in these systems. Also, the high abundance of faint companions, non-interacting as well as merging events, suggests that void galaxies are actively building up as shown in Fig. 1.7.

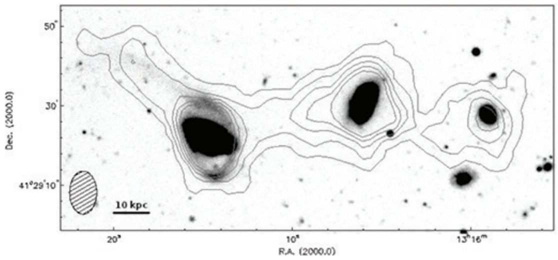


Figure 1.7: *Neutral hydrogen intensity map of the galaxy VGS31 at z=0.021 from the Void Galaxy Survey. The contours indicate the neutral hydrogen column density intensity obtained with WSRT. Note that members of the VGS31 group are aligned along a neutral hydrogen filament and appear to be embedded in a common envelope (Beygu et al. 2013).*

The interplay between star formation and black hole activity

Barthel and colleagues obtained new insight into the interplay of star-formation and accretion activity in galaxies. At the high luminosity end, vigorous optically obscured star-formation was discovered in the ultra-massive hosts of 3C radio galaxies at high redshift. Herschel observations in a guaranteed time program yielded complete FIR-submm spectral energy distributions, which imply star-formation rates of several hundreds to a thousand $M_{\odot}$/yr. At the faint end, weak AGN activity was discovered in the distant star-forming galaxy population in the HDF-N. Using deep, wide-field VLBI, Chi (PhD), Barthel, and Garrett reported the discovery of high brightness temperature radio cores in a dozen faint galaxies in the central 100 square arcmin of the well-studied HDF-N/GOODS-N field, demonstrating a unique technique to assess the occurrence of faint AGN (Fig. 1.8).

Far IR spectroscopy of nearby galaxies

Van der Werf, Meijerink, Loenen, Israel and collaborators obtained Herschel SPIRE FTS spectra within the context of the Herschel Comprehensive (U)LIRG Emission Survey (HerCULES) of 29 (U)LIRGs led by van der Werf. The first spectrum of the relatively nearby ultra-luminous infrared galaxy Markarian 231 turned out to be surprisingly rich (Fig. 1.9). At least 25 lines were detected, including the CO J=5-4 through J=13-12 transitions, 7 rotational lines of H_2O, 3 of OH^+ and H_2O^+, and one line each of CH^+, and HF. The excitation of the lower CO rotational levels can be accounted for by the UV radiation from newly formed luminous stars, but the approximately flat intensity distribution of the higher CO transitions requires the presence of a separate source of excitation. The team explored X-ray rather than UV-photon heating by the accreting super-massive black hole in Markarian 231 as a source of excitation for these lines, and found that this mechanism can reproduce the observed intensities. This widely cited result, together with spectra for other sources, demonstrates the usefulness of the CO ladder to separate star formation and black hole accretion

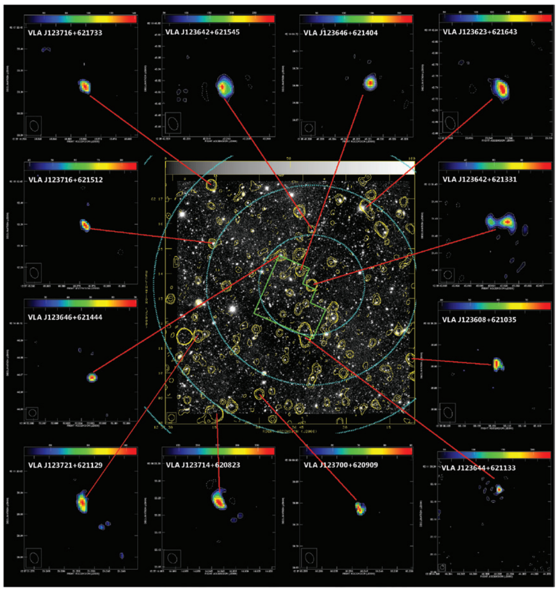


Figure 1.8: *Composite of the WSRT (center) and the VLBI (individual panels) studies, overlaid on the HST image of HDF-N, demonstrating a unique technique to assess the occurrence of faint AGN (Chi et al. 2013).*

as power sources for galaxy nuclei, providing also a crucial local benchmark for high redshift observations with ALMA.

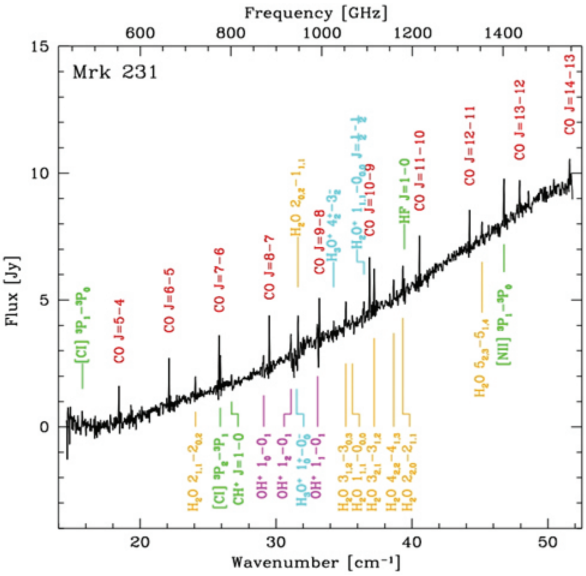


Figure 1.9: *SPIRE-FTS spectrum of the AGN Mrk 231, revealing a remarkably rich molecular spectrum including CO, H_2O and new species OH^+ and H_2O^+ indicative of a low density H_2 poor phase of the interstellar medium. Line identifications are given (van der Werf et al. 2010).*

The lowest metallicity stars in the satellites of the Milky Way

Starkenburg (PhD), Tolstoy, Helmi and collaborators have developed a new powerful calibration for the derivation of the metallicity of stars in Milky Way satellites. The lowest metallicity stars that still exist today probably carry the imprint of very few generations of supernovae. A comparison of these stars in the Milky Way and surrounding dwarf galaxies can teach us about the earliest phases of star formation and its dependence on environment and the mass of the galaxy. Specific very broad absorption lines, the Ca II triplet feature, can be used as an efficient tool to search for these stars in the satellite dwarf galaxies. To really get down to the lowest metallicities, a new calibration method using the widths of these Ca lines had to be made. With the aid of this new technique shown in Fig.1.10 many new extremely metal-poor candidates could be uncovered and followed up using higher resolution spectrographs. In one follow-up effort seven extremely metal-poor stars in the Sculptor dwarf spheroidal galaxy have been found, using X-Shooter. These spectra confirm the (non-linear shape of the) new calibration directly from the measurement of iron lines and allow measurement of many other elements. The abundance ratios of many elements show comparable patterns to those found in Galactic extremely metal-poor stars, an agreement that is not present for the later chemical evolution stages and that suggests a more universal early epoch of star formation across galaxies of various masses.

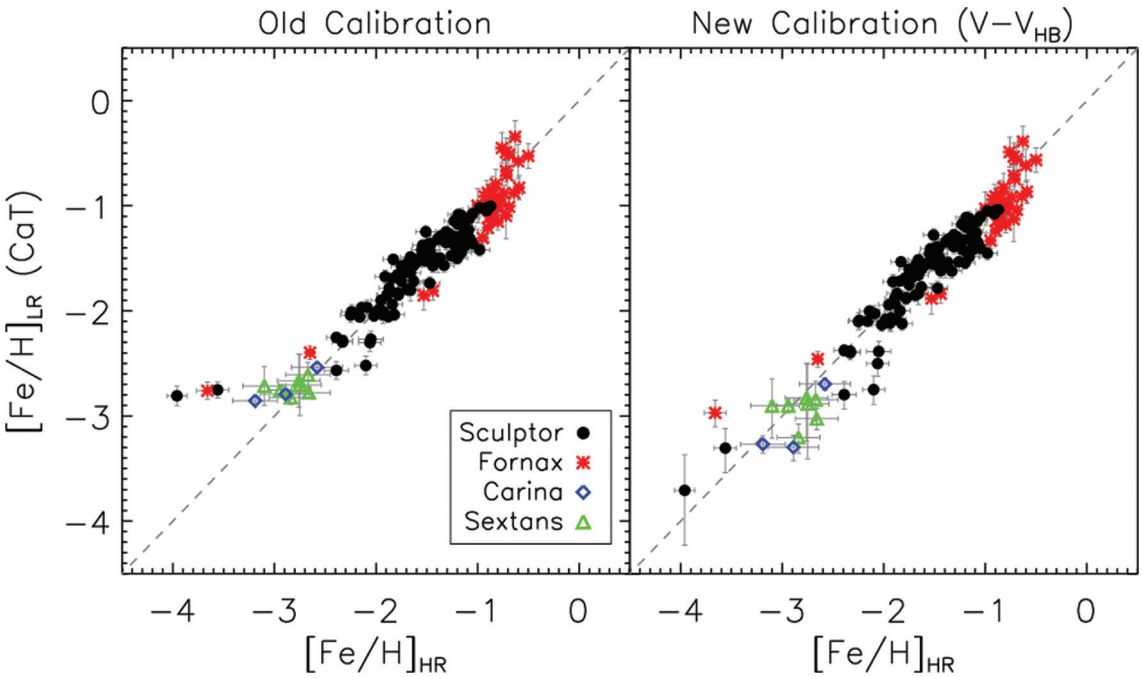


Figure 1.10: *The predictions for metallicities of individual red giant branch stars in nearby classical dwarf galaxies from the Ca II triplet lines, using the linear calibration by Battaglia et al. (2008) in the left panel and the new non-linear calibration by Starkenburg et al. (2010), in the right panel, compared to high-resolution [Fe/H] data. To uncover the extremely metal poor stars with [Fe/H] < -3, one clearly needs to use the new calibration. The old linear calibration predicts no stars below [Fe/H]~ -2.7, while in reality stars with [Fe/H] as low as -4 are present in the sample. The high-resolution data on the plot are taken from various efforts within the Dwarf Abundances and Radial velocities Team (DART, P.I. E. Tolstoy) (Starkenburg et al. 2010).*

Dark matter & stellar halos of Milky Way

Helmi and collaborators from the VIRGO consortium have modeled the assembly of dark matter and stellar halos using the Aquarius cosmological N-body simulations combined with phenomenological models of galaxy formation. Stellar halos result from the disruption of satellite galaxies and an important question is whether this is also how our Milky Way's halo formed. As shown in the figure on the cover, the model halos exhibit a wealth of tidal features: broad overdensities and very narrow faint streams akin to those observed around the Milky Way. The amount of substructure appears to be systematically larger compared to the Milky Way, and this is partly due to contamination by foreground or background sources, but could also imply that ~10% of the Milky Way halo stars have formed in-situ.

Using the same simulations, Vera-Ciro (PhD), Sales, Helmi and the VIRGO consortium found that the shape of individual dark matter halos evolves from a typically prolate configuration at early stages to a more triaxial/oblate geometry at the present day. This evolution in shape correlates well with the distribution of infalling material as shown on the cover. At redshift z=0, this history is imprinted in the shape at different radii, which are prolate in the inner regions and triaxial/oblate in the outskirts.

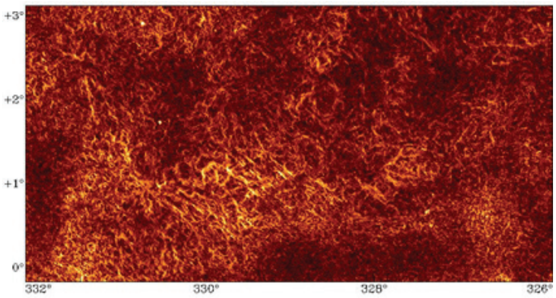


Figure 1.11: *Gradient of the complex polarization vector in a field in the Galactic plane, which shows high polarization gradients in filamentary structures (Gaensler, Haverkorn et al, Nature, 2011).*

Turbulence in the ionized Galactic interstellar medium

Haverkorn and collaborators developed a method to directly image turbulence in the Galactic magneto-ionized interstellar medium. Faraday rotation of the linearly polarized radio synchrotron background in the Milky Way provides a very sensitive probe of fluctuations in magnetic field and ionized gas density. Mapping the gradient of the complex polarization vector provides the first direct image of turbulence in the ionized interstellar medium, manifested as a complex filamentary web of sharp jumps in the Stokes vector (Q,U). Statistical properties of the filament maps, as compared to numerical magneto-hydrodynamical simulations, show that the turbulence in the ionized interstellar gas is subsonic or transonic. The simulations also indicate that the high gradients in polarization are mostly caused by magnetic field fluctuations as opposed to density fluctuations (Fig. 1.11).

Other projects

Zaroubi and collaborators investigated Lyman-α emission from the first galaxies and the consequences for imaging neutral hydrogen on large scales at the epoch of recombination with LOFAR. Although challenging, low resolution images should show very large pockets of neutral regions in the intergalactic medium, reflecting the clustering of the large-scale structure, which stays strong up to scales of ~120 h^{-1} comoving Mpc (≈1°). Verheijen and collaborators continued their ultra-deep Westerbork survey for H I at z~0.2. Initial results suggest that the fraction of detections is significantly affected by environment: by the time group galaxies fall into a cluster, they are already devoid of H I.

Larsen and collaborators showed that 4 of 5 globular clusters in the Fornax dwarf spheroidal galaxy are very metal poor, challenging conventional theories of self-enrichment and loss of first generation stars during the early evolution of the clusters. Peletier and collaborators from IAC (Tenerife) improved their MILES stellar spectra library and stellar population models and Peletier continued his studies on the formation and evolution of early type dwarf galaxies. Shirazi (PhD) and Brinchmann used a very large sample of emission line galaxies with strong nebular HeII 4686 emission due to Wolf-Rayet stars in SDSS7 data, and discovered that at lower metallicities a steadily increasing fraction of galaxies lacks signs of Wolf-Rayet emission, a finding that is not yet understood.

Brandl and collaborators used VLT-VISIR and SINFONI to investigate galaxies with circumnuclear rings of starburst activity that lead to the formation of massive clusters. Rather than inflow of interstellar gas along the bars to the nuclear region, the physical conditions prevalent in the local environment appear to trigger the starburst ring. Meijerink, Spaans, Khazandjian (PhD), Pelupessy and Israel have shown the importance of turbulent heating for the interpretation of the observations and understanding the physical properties of galaxy centers, in any case where it exceeds 1% of the UV luminosity of the starburst region.

3.2 Formation and evolution of stars and planetary systems

NOVA network 2 studies the formation and evolution of stars and planets. In 2010-2012, new pioneering observatories and instruments became available, especially the Herschel Space Observatory launched in 2009 with the SRON-built Heterodyne Instrument for the Far Infrared (HIFI). Network 2 researchers have been heavily involved in many Key Programs using both HIFI and the other two instruments, PACS and SPIRE. Other important results have been obtained with the VLT, in particular the new X-Shooter spectrograph. On the experimental side, the Sackler Laboratory for Astrophysics continues played an important role underpinning our understanding of the physical and chemical processes that occur during stellar and planetary formation.

Water near protostars: a WISH come true

The 'Water In Star-forming regions with Herschel' (WISH), led by van Dishoeck and involving a large international team including Dominik, Hogerheijde and van der Tak as co-Is, is the largest Herschel-HIFI guaranteed time program and is designed to probe the physical and chemical structures of young stellar objects using water and related molecules and to follow the water abundance from collapsing clouds to planet-forming disks. About 80 sources have been targeted, covering a wide range of luminosities and evolutionary stages. The bulk of the WISH data were been obtained in 2010-2011 and many WISH papers have been published. For low mass protostars, Kristensen, van Dishoeck, Yildiz (PhD), Karska (PhD) and the WISH team found that the H_2O line profiles are surprisingly complex, with a mix of broad and narrow emission revealing the dynamics of the envelope (Fig. 2.1). Both inverse P Cygni and regular P Cygni profiles indicative of infall and outflow are seen, as well as high-velocity bullets associated with jet shocks. From the line profiles alone, it is clear that the bulk of the water emission arises from shocks. The H_2O/CO abundance ratios range from 0.1-0.5 corresponding to H_2O abundances of a few times 10^{-5} with respect to H_2, lower than expected and indicative of a new class of UV irradiated shocks. Dissociative J-type shocks produce bright OH and [O I] emission in dense gas close to the protostar. The different H_2O profile components show a clear evolutionary trend: in the younger Class 0 sources the emission is dominated by outflowing gas from an infalling envelope. When large-scale infall diminishes during the Class I phase, the outflow weakens, the envelope expands and H_2O emission all but disappears.

Probing cold water reservoir of disks

Icy bodies may have delivered the oceans to the early Earth, yet little is known about water in the ice-domi

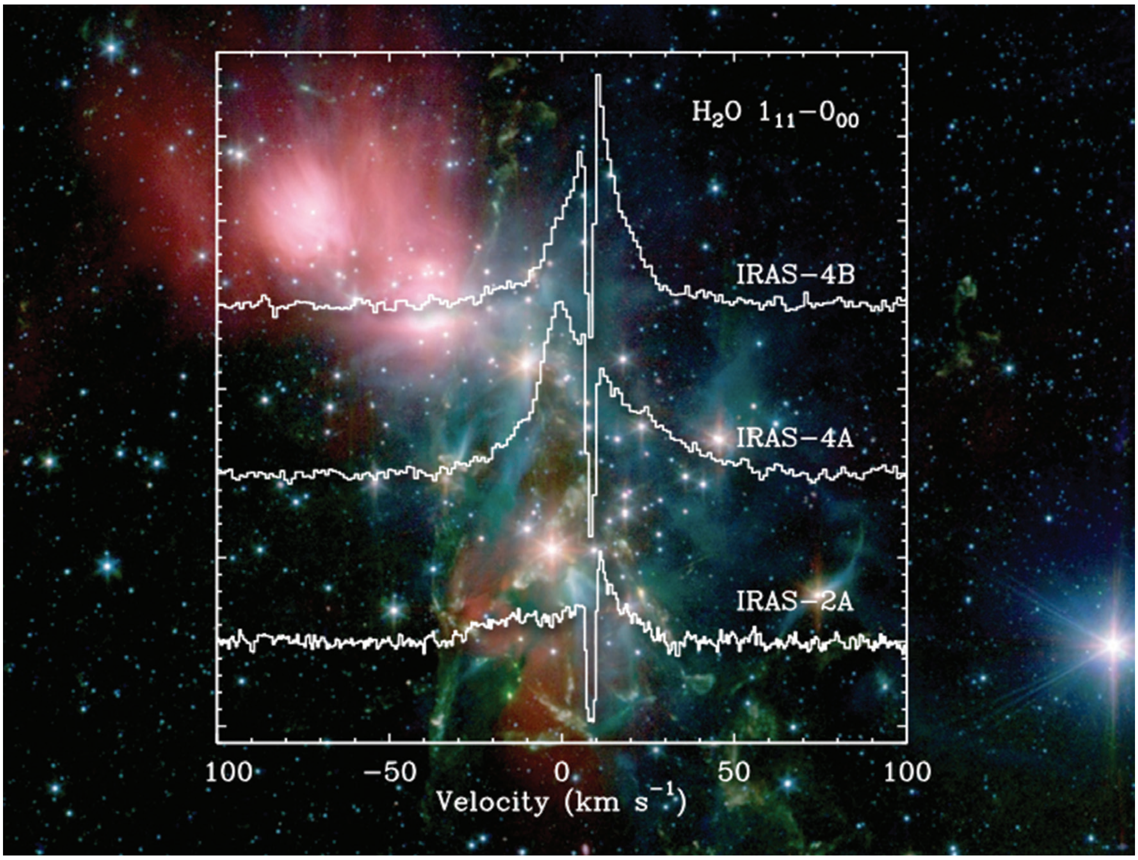


***Figure 2.1:** Herschel-HIFI spectra of the p-H2O 1113 GHz line toward three low-mass protostars in the NGC 1333 star-forming region obtained in the WISH key program (Kristensen et al. 2010). The line profiles provide new insight into the dynamics of the gas in the collapsing envelope as well as the water chemistry. Background: Spitzer image of the NGC 1333 region (credit: NASA/JPL-Caltech, R. Gutermuth).*

nated regions of extrasolar planet-forming disks. Using Herschel-HIFI as part of WISH, Hogerheijde and collaborators detected the rotational ground-state emission lines from both spin isomers of cold water vapor from the disk around the young star TW Hydrae (Fig. 2.2). These lines required a total observing time of 17 hours, illustrating the weakness of the features. Detailed model calculations indicate that the detected lines probe a thin layer containing 0.005 Earth oceans of water vapor coating the surface of the disk (1 ocean = 1.5×10^{24} gr of water). This cold water vapor likely originates from ice-coated solids near the disk surface, where UV photons liberate individual water molecules from the ice mantle. Using photodesorption probabilities determined in the lab and by theory (see below), the detected amount of water vapor can be used to infer the underlying water ice reservoir, which is equivalent to several thousand Earth oceans in mass. Interestingly, the ortho-to-para ratio of water is much lower than commonly observed in solar system comets. One hypothesis is that comets contain heterogeneous ice mixtures that they collected across the entire solar nebula during the early stages of planetary birth. This implies that primitive volatiles can be mixed across large distances in planet-forming disks.

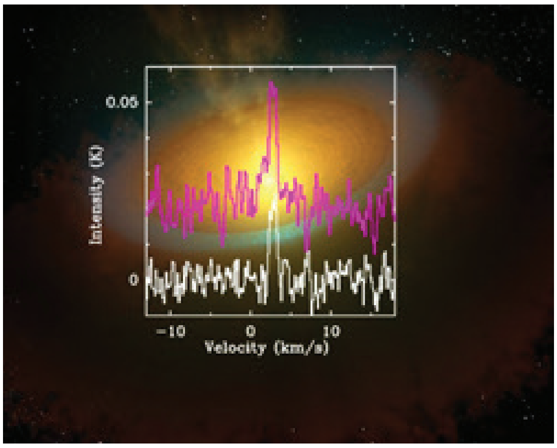


Figure 2.2: *Detection spectra of the ground-state rotational transitions of ortho-water (white) and para-water (pink, shifted for clarity) toward the protoplanetary disk around the young star TW Hya, obtained with HIFI on the Herschel Space Observatory (Hogerheijde et al. 2011, Science). The background image is a cartoon of the TW Hya disk showing the water vapor ring (ESA/NASA-JPL/R. Hurt).*

Water chemistry in space

A key question is how the water that is observed in space by Herschel is actually formed. Since gas phase reactions are not efficient enough to explain the observed abundances in cold dense clouds, solid state reactions schemes provide alternative pathways, proposed originally by Tielens. Linnartz, Cuppen, Ioppolo (NOVA PhD), Romanzin, Lamberts (PhD) and van Dishoeck have used the NOVA-financed experiment SURFRESIDE in the Sackler laboratory for Astrophysics to prove that subsequent hydrogenation reactions of oxygen-containing ice results in the efficient formation of water ice, even at temperatures as low as 12 K. Dedicated experiments combined with theoretical modeling have characterized the full reaction network that is illustrated in Figure 2.3. Subsequent detections of the reaction intermediates H_2O_2 and HO_2 by millimeter observations by other groups are fully consistent with the network proposed here. Follow-up experiments by Isokoski (PhD), Bossa and Linnartz have shown that water ice in space may be more porous than assumed so far, providing additional surface for reactions.

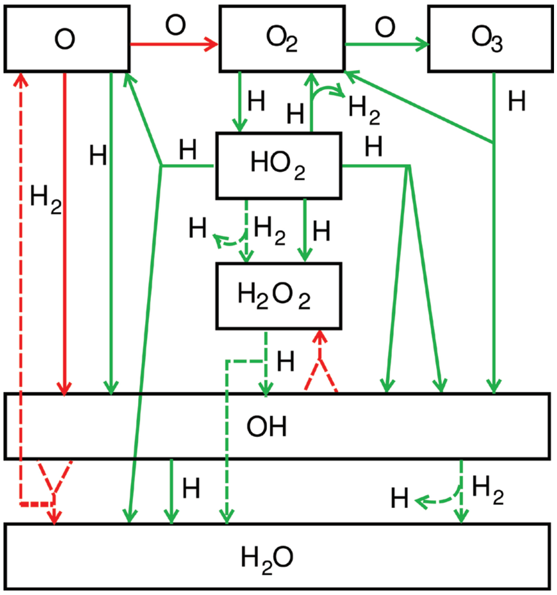


Figure 2.3: *A schematic representation of the solid state water reaction network as obtained from the NW2 laboratory program. Green arrows refer to reactions that have been characterized by experiments or through simulations of experimental data. Red arrows refer to reactions that have not yet been studied experimentally or for which the experimental data are inconclusive. Four cases are distinguished. (i) efficient, effectively barrierless (<500 K) reactions (green), (ii)reactions with a barrier above 500 K (dashed-green), (iii) reactions not studied experimentally (red), and (iv) reactions studied experimentally but for which results are inconclusive (red-dashed). Credit: Tielens and Hagen (1982), Cuppen et al. (2010), Lamberts et al. (2013).*

Another critical parameter in the models is the photodesorption efficiency for water ice, which has been studied both experimentally in the Sackler laboratory using CRYOPAD by Öberg (NOVA PhD), Linnartz and van Dishoeck, and modeled using classical dynamics by Arasa, Cuppen and van Dishoeck in collaboration with Kroes (Leiden, chemistry). Efficiencies for H_2O, HDO, and D_2O in water ice as function of ice temperature have been determined, together with branching ratios to OH.

Warm and dense gas towards W49A: starburst conditions in our Galaxy?

The star formation rates in starburst galaxies are orders of magnitude higher than in local star-forming regions, and the origin of this difference is not well understood. Nagy (PhD), van der Tak, Spaans and collaborators used JCMT Spectral Legacy Survey maps to characterize the physical conditions of the molecular gas in the luminous Galactic star-forming region W49A. Maps of H_2CO and HCN line ratios over a 2' × 2' (6.6 × 6.6 pc) field with an angular resolution of 15'' (~0.8 pc) reveal an extended region (1' × 1' = 3 × 3 pc) of warm (>100 K) and dense (> 10^5 cm^{-3}) molecular gas, with a mass of 2 × 10^4 - 2 × 10^5 $M_\odot$. These temperatures and densities in W49A are comparable to those found in clouds near the center of the Milky Way and in starburst galaxies. The highly excited gas is likely to be heated via shocks from the stellar winds of embedded O-type stars or alternatively due to UV irradiation, or possibly a combination of these two processes. Cosmic rays, X-ray irradiation and gas-grain collisional heating are less likely to be the source of the heating in the case of W49A.

The 'soot line' in protoplanetary disks

Presolar polycyclic aromatic hydrocarbons (PAHs) can be destroyed by chemical processes in the planet-forming regions of disks. Tielens has been working with Kress (SETI) and others to determine the region in which PAHs are attacked by H and OH radicals. At a given temperature, PAHs will be stable for timescales below the line marked "PAH-line" in Fig. 2.4. The dashed lines indicate calculated temperatures in the mid plane at 1, 2, and 5 AU for a typical model for the evolution of the early Solar nebula. It is concluded that PAHs are rapidly destroyed in the inner regions of disks. This 'soot line' has received much less attention than the snow line in disks, but is equally important for astrobiology.

Tomography of a disk using dust emission feature

Mulders (NOVA/SRON PhD), Min (NOVA PD), Waters, and Dominik used dust observations taken by the Herschel DIGIT key program to probe the vertical structure of the transitional disk around the Herbig star HD 100546. Herschel- PACS spectra reveal the detailed profile of a crystalline dust emission feature due to forsterite (Mg_2SiO_4) near 69 μm (Fig. 2.5). The shape and strength of this feature is strongly dependent on the temperature and iron content of the forsterite crystals present in the disk. Using sophisticated radiative transfer models and comparing this feature with others at shorter wavelengths from Spitzer data, they were able to show that most if not all of the crystals are concentrated in the inner wall of the disk, located around 13 AU from the star. Optical depth effects are crucial to the relative strengths of short and long wavelength features. The observations only scratch the surface of the disk at wavelengths below 20 μm, but at 69 μm the full interior of the disk contributes to the observed radiation.

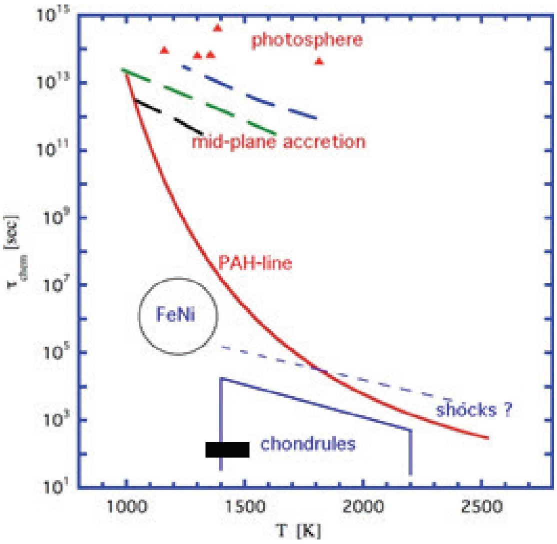


__Figure 2.4:__ Chemical timescale for the breakdown of PAHs through chemical attack by H and OH radicals as a function of the temperature of the gas. For comparison, other determinations of gas temperature in disks and in the solar nebula are shown (Kress, Tielens et al. 2010).

The Fomalhaut debris disk

Acke (Leuven), Min, Dominik and collaborators obtained Herschel-PACS far-infrared images of the well known debris disk around the young star Fomalhaut. These images (Fig. 2.6) reveal an amazingly smooth ring of dust at large distances from the star (~150 AU). The high color temperature of this material, derived from comparing images at different wavelengths, shows that this material absorbs starlight so efficiently that it will be blown out of the system on very short timescales, which means it has to be replenished similarly fast. A dynamical model of colliding planetesimals in the ring was constructed to derive the replenishment timescale of the small dust particles: about 2000 comets need to be destroyed by collisions every day. Computations

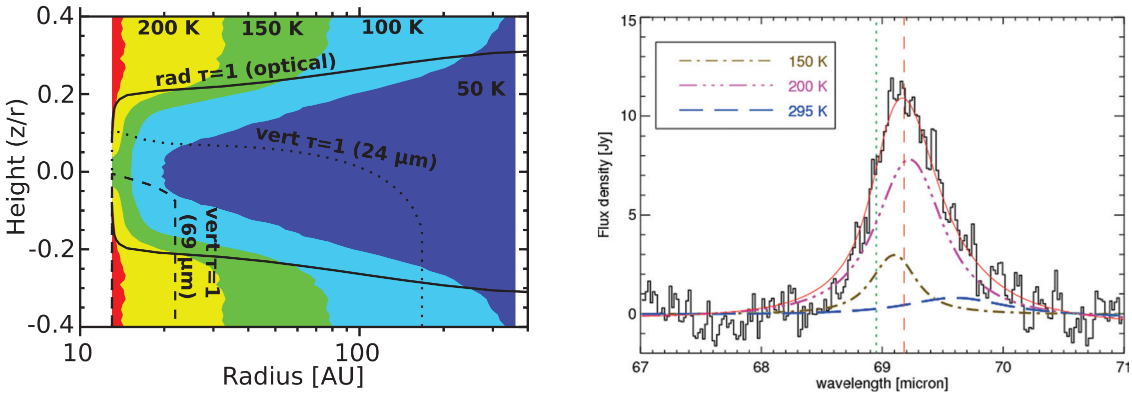


__Figure 2.5: Left:__ The temperature and optical depth structure of the disk around HD100546. The colors show the dust temperatures in the different regions of the disk. The solid, dotted, and dashed lines show the location of the optical depth equal to 1 in the V band, at 2 and 33 μm, respectively (Mulders et al 2011). __Right:__ Herschel-PACS spectrum of the forsterite band at 69 μm and its sensitivity to temperature (Sturm et al. 2010).

of the cometary reservoir required to obtain this extremely high rate compare well to estimates of our own primordial Kuiper belt. This demonstrates that this system is truly quite similar to what our Solar system looked like in her childhood.

Line diagnostics of gas in protoplanetary disks

New observing facilities such as Herschel and ALMA are excellent tools to study the gas in a large – statistically meaningful – sample of protoplanetary disks. Kamp, in collaboration with Woitke (St. Andrews), Thi (Grenoble) and others performed a first pioneering study based on large grid of disk models to investigate the potential of the classical PDR tracers [OI] 63 and 145 μm and the CO submm lines in estimating disk gas masses. The DENT grid of 300000 disk models (Disk Evolution with Neat Theory) demonstrates the predictive power of individual gas lines, line ratios, and continuum tracers. The most powerful diagnostic for estimating gas masses that are accurate to within an order of magnitude appears to be a combination of the [OI [63] μm line flux and the [OI] 63/CO 2-1 line ratio (Fig. 2.7)

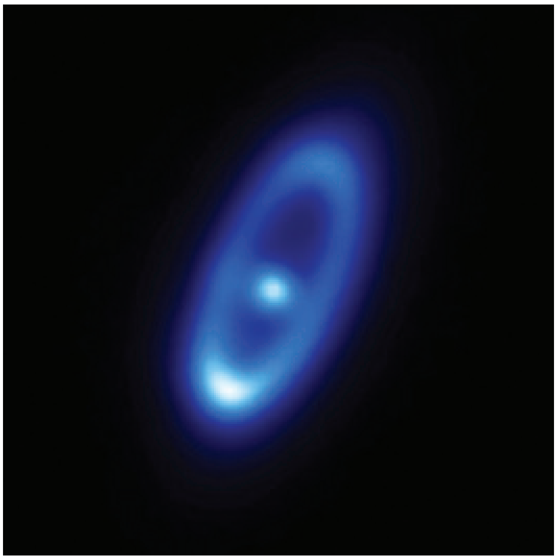


Figure 2.6: *The debris disk in the Fomalhaut system at 70 μm observed with Herschel/PACS. The disk is eccentric, with a semi major axis of 141 AU. An eccentricity of e=0.11 causes the center of the disk to be offset by 15 AU from the star, so that the southern part of the ring is closer and warmer (Acke et al. 2012).*

First detection of exoplanet orbital velocity and atmospheric winds

During a planetary transit a very small part of the stellar radiation passes through the planet atmosphere leaving an imprint of the molecular gas content. Snellen, de Mooij (PhD), de Kok (SRON) and collaborators were the first to observe this effect from the ground at high spectral resolution using VLT-CRIRES targeting HD209458b in carbon monoxide. These measurements reveal the change in the radial component of the orbital velocity of the planet, allowing for the first time to solve for the masses of both planet and star (1.00±0.22 $M_{\odot}$ and 0.64±0.09 M_{Jup} for this system). In addition, evidence is found for a strong wind blowing from the hot dayside to the cooler night side of the planet (Fig 2.8).

Brogi (NOVA PhD), Snellen, de Kok, Birkby and collaborators have also for the first time detected molecular absorption in the atmosphere of a non-transiting hot Jupiter. Using VLT-CRIRES they measured carbon monoxide in the thermal emission spectrum of exoplanet τ Bootis b while it orbits its star with a velocity of 140 km/sec. In this way, the orbital inclination and the true mass of this planet could be determined to 5.95±0.28 M_{Jup} (Brogi et al. 2012, Nature).

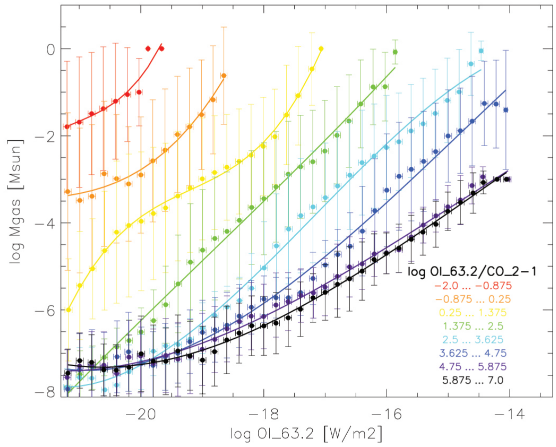


Figure 2.7: *Correlation between the gas mass in the disk and the [OI] 63 μm line. The second relevant parameter, the average gas temperature, is color coded through the [OI] 63/CO 2-1 line ratio. A selection is made for CO 2-1 fluxes greater than 10^{-23} W m^{-2}. The colored lines are polynomial fits of 3rd order to the data (Kamp et al. 2011).*

Detection of the planet in the β Pictoris system using an APP Coronograph

Kenworthy with collaborators at ETH Zurich successfully detected the extrasolar planet β Pictoris b using the Apodizing Phase Plate (APP) Coronagraph developed by Kenworthy on the VLT with NaCo (Fig. 2.9). The detection confirms both the position and photometry published at the same time by Lagrange et al. The coronagraph reduced the exposure time needed from two hours to 20 minutes, demonstrating the utility of coronagraphs on AO systems with high Strehl ratios. The design of the coronagraph means that it is insensitive to pointing errors in the telescope and AO system, and allows for observing as efficient and as simple as direct imaging and beam switching.

Evaporating exoplanet stirs up dust

Brogi (NOVA PhD), Keller, de Juan Ovelar (NOVA PhD), Kenworthy, de Kok, Min and Snellen modeled the star KIC 12557548 observed by the exoplanet-hunting Kepler satellite. This star exhibits a very strange behavior: at very regular intervals of 15.7 hours, its light decreases by up to ~1% but in contrast to normal exoplanet transits, the transit depth is highly irregular. Early in 2012 a group led by Rappaport (MIT) qualitatively explained the observations in terms of

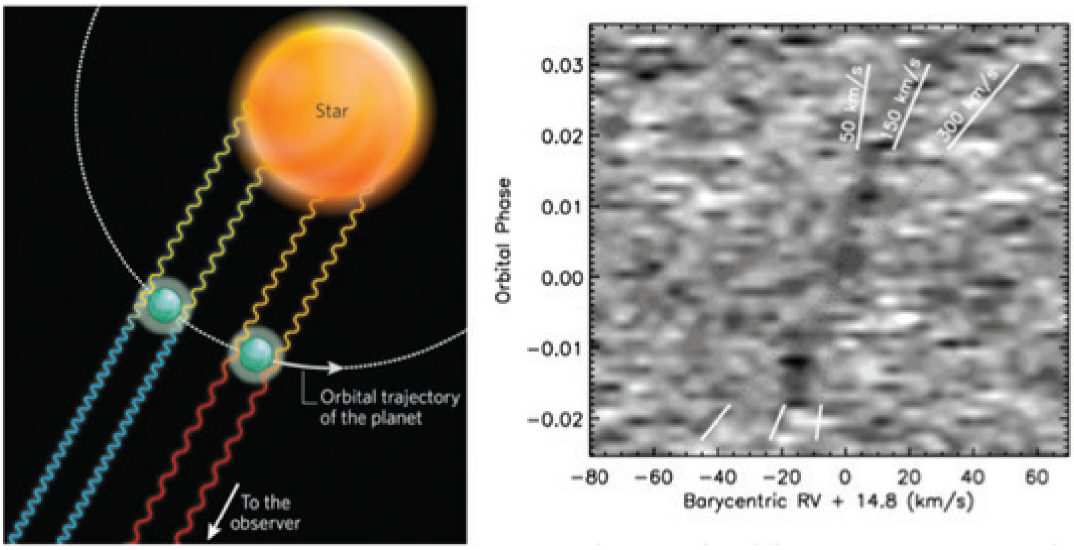


Figure 2.8: Left: *Orbital trajectory of exoplanet HD209458b during transit showing the expected change in the radial component of its orbital velocity.* ***Right:*** *The change in Doppler shift as observed in carbon monoxide using CRIRES on the VLT (Snellen et al. 2010 Nature).*

a disintegrating, rocky planet that has a trailing dust tail created and constantly replenished by thermal surface erosion. The variability of the transit depth is then a consequence of changes in the tail's size (Fig. 2.10). The team led by Keller quantitatively modeled the observed, average transit light curve and reproduced the observations down to minute details. The brightening in flux just before the beginning of the transit is explained by forward scattering, and an asymmetry in the transit light curve shape is reproduced by an exponentially decaying distribution of optically thin dust, with a typical grain size of 0.1 μm. This quantitative analysis supports the hypothesis that the transit signal is due to a variable dust tail, most likely originating from a disintegrating object, KIC 12557548b. This work opens the exciting possibility to directly study solid (and/or molten) material from the surface and/or inside of a rocky exoplanet. If this exoplanet has been losing mass for a substantial amount of time, these data may indeed probe the core of an originally much larger planet.

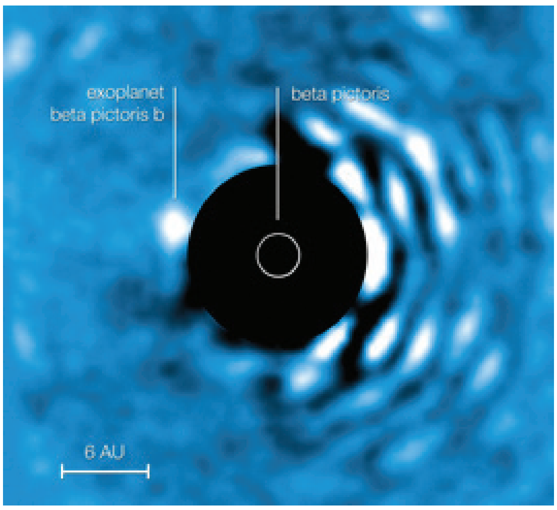


Figure 2.9: *The planet β Pictoris b imaged at a wavelength of 4.05 μm with VLT-NaCo using the Apodising Phase Plate (APP) coronagraph on 3 April 2010. The "bad" (bright) side of the image is seen to the right while the central bright regions of the central star (β Pictoris) have been masked out to enable the viewer to see clearly the planet to the left of the star. At its current projected position the planet is roughly 6.5 AU away from its host star. The planet's mass is estimated to be roughly nine times that of Jupiter (Kenworthy et al. 2010).*

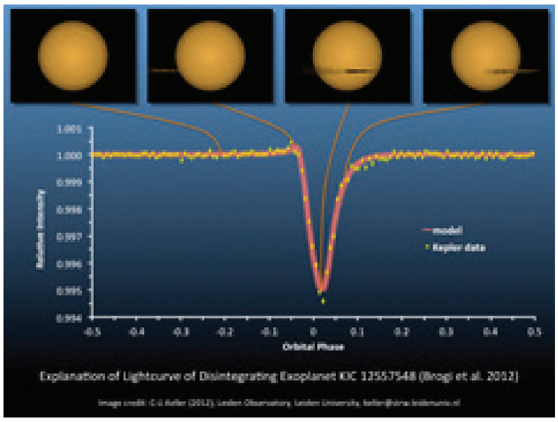


Figure 2.10: *Comparison between the light curve of the star KIC 12557548 as observed by the Kepler satellite and the model developed by Brogi et al. (2012) along with artist's impressions of four different phases of the light curve.*

The VLT-FLAMES Tarantula Survey

The VLT-FLAMES Tarantula Survey (VFTS) is an ESO Large Program that has obtained multi-epoch optical spectroscopy of over 800 massive stars in the 30 Doradus region of the Large Magellanic Cloud (LMC). Scientific goals of this Europe-wide project – of which the analysis of O-type stars is coordinated by De Koter and Sana – include a census of the nearest "mini-starburst"; establishing the binary fraction and multiplicity properties of the 30 Doradus population; testing single and binary evolution, including effects of mass-loss and rotation, and studying cluster dynamics, mass segregation and infant mortality. A particularly interesting result is the discovery of the WNh star VFTS682 (Bestenlehner, de Koter, Sana and co-workers) at a projected distance of 29 parsecs away from the dense central star cluster dominating the 30 Doradus region (Fig. 2.11). Such WNh objects are the most massive stars known and so far have been found only in the very centers of dense star clusters. Analysis of the spectrum constrains the present-day mass to about 150 $M_\odot$ and points to an initial mass of about 200 $M_\odot$. If this object is formed at or near its present location – which is in the line-of-sight of an active star forming region – it poses a very interesting challenge for the theory of massive stars formation. If, on the

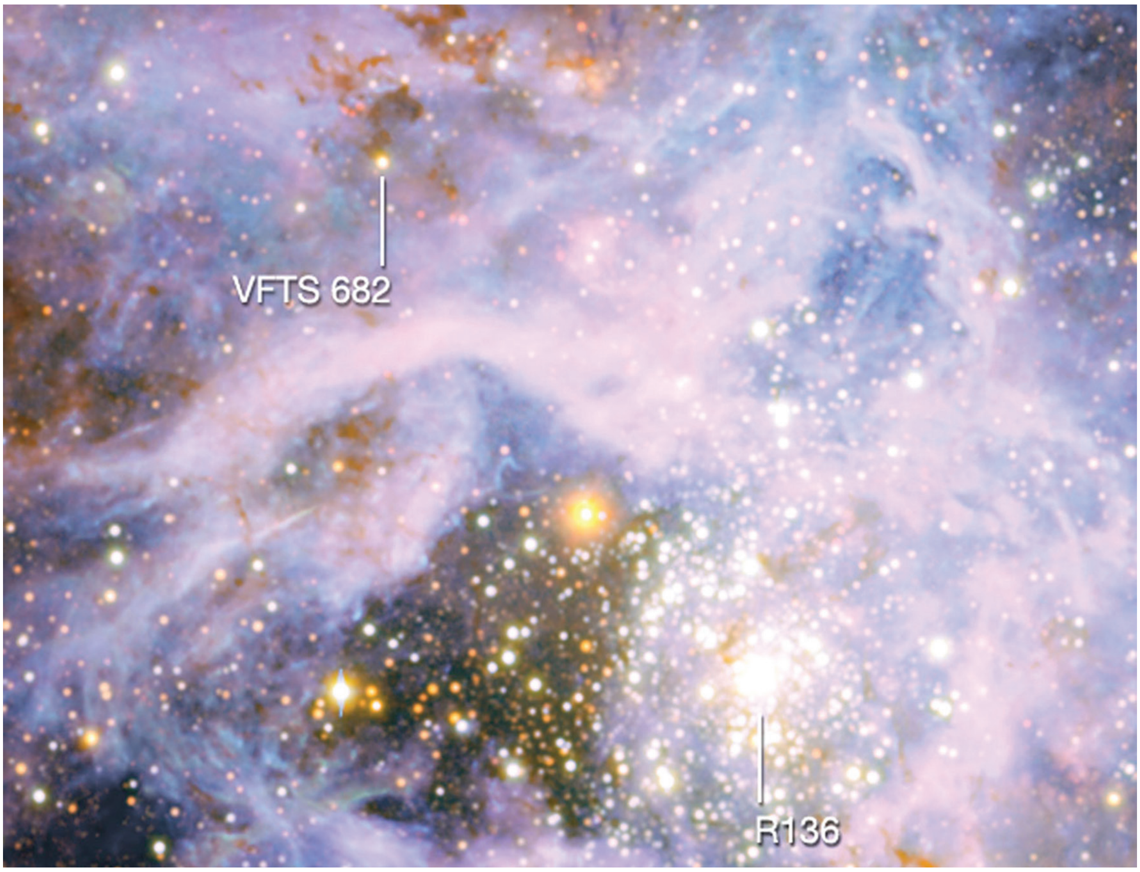


Figure 2.11: *VLT images of part of Tarantula Nebula in the Large Magellanic Cloud, one of the largest active star-forming complexes in the Local Group of galaxies. The ~1 million year old central cluster, R136, is visible in the lower right corner. The extremely massive WNh star VFTS682, at a projected distance of 29 pc from the central cluster, is in the upper left corner. At birth this star had a mass of about 200 $M_{\odot}$ and it is the first ever extremely massive star to be found outside of a dense stellar cluster (Bestenlehner et al. 2011).*

other hand, VFTS682 is formed in the core cluster and is subsequently ejected from the cluster through dynamical interaction with cluster members, it poses a big challenge for dynamical ejection scenarios.

Disk-jet system in a massive YSO

Ellerbroek (NOVA PhD), Kaper and collaborators present observations of the embedded massive young stellar object (YSO) candidate 08576nr292, obtained with X-Shooter and SINFONI on the VLT (Fig. 2.12). The X-Shooter spectrum (300-2500 nm) includes over 300 emission lines, but no (photospheric) absorption lines, and is consistent with a reddened disk spectrum. The Hα and Ca II triplet lines are very strong, with profiles indicative of outflow and - possibly - infall, usually observed in accreting stars. The He I and metal-line profiles are double peaked, with a likely origin in a circumstellar disk. The forbidden lines, associated with outflow, have a single blueshifted emission component centered at -125 km/s, coinciding with the absorption components in Hα and Ca II. SINFONI H- and K-band integral-field spectroscopy of the cluster environment demonstrates that the [Fe II] emission is produced by a jet originating at the location of 08576nr292. Because the spectral type of the central object cannot be determined, its mass remains uncertain, but the system is argued to have a high accretion rate. These observations demonstrate the potential of X-Shooter and SINFONI to study in great detail an accretion disk-jet system, rarely seen around the more massive YSOs.

Massive stars prefer to be in close binary pairs

The presence of a nearby companion alters the evolution of massive stars in binary systems, leading to phenomena such as stellar mergers, X-ray binaries, and gamma-ray bursts. Sana, de Koter and collaborators simultaneously measured all relevant binary characteristics in a sample of Galactic massive O stars and quantified the frequency and nature of binary interactions. It was found that more than 70% of all massive stars will exchange mass with a companion, leading to a binary merger in one-third of the cases (Fig. 2.13). These numbers greatly exceed previous estimates and imply that binary interaction dominates the evolution of massive stars, with implications for populations of massive stars and their supernovae. The suggestion that a sizeable fraction of observed O stars in the Galaxy and beyond are actually merger products is intriguing and is now spurring the search for signatures of such violent histories in the known population of objects.

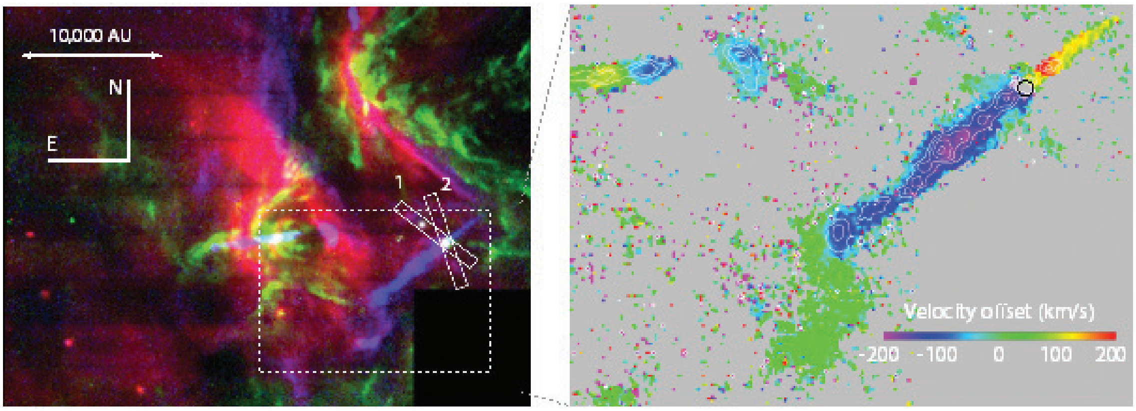


__Figure 2.12: Left:__ Detail of VLT/SINFONI image of RCW36 in Vela (0.7 kpc) showing H_2 (green), Br γ (red) and [Fe II] (blue). The X-Shooter slits are indicated. __Right:__ the [Fe II] 1644 nm velocity offset map, showing emission of the jet produced by the massive YSO candidate 08576nr292 (Ellerbroek et al. 2011).

Other highlights

Van der Tak and collaborators reported the first detection of interstellar HF emission toward the Orion Bar using Herschel-HIFI. HF is a useful tracer of cold H_2 but is usually seen in absorption. Models indicate that the appearance of HF in emission is due to the high abundance of free electrons in this region caused by the strong UV radiation field. The same conditions may apply to the nuclei of some active galaxies, where HF also appears in emission.

In a collaboration with the KVI nuclear physics lab (Groningen), Boschman (PhD), Cazaux and Spaans have experimentally studied the hydrogenation of the PAH coronene and its role in the interstellar formation of H_2. The results imply highly hydrogenated forms of PAH cations, as well as neutrals, in the ISM. Furthermore, PAH cations and neutrals appear to contribute equally to H_2 formation. Chaparro-Molano (PhD) and Kamp showed that the impact of the CR induced UV radiation field in the optically thick interior of protoplanetary disks where direct UV or X-rays cannot reach is a factor of 15 higher than previously thought due to grain growth. These UV photons generated close to the disk midplane drive an interesting active chemistry that is largely controlled by the OH radical.

Krijt (MSc) and Dominik found that the dynamics of planetesimal populations embedded in a disk that also contains a migrating planet from 20AU toward the star are such that very high inclinations can be reached by a special combination of resonance trapping followed by direct scattering. This process could be a source of spherically distributed, halo-like dust clouds that have been indicated in a number of observations. Jeffers (PhD), Min, Keller and co-workers have obtained polarimetric images of the highly variable star R CrB using ExPo at the WHT during its current dramatic minimum where it decreased more than 9 mag due to obscuration by ejected dust clouds. The new polarimetric observations reveal another scattering dust cloud at approximately 1.3'' or 2000 AU from the star, which, combined with the measured obscuration suggests that the grains have a very low albedo of approximately 0.07% and may be very large (140 nm).

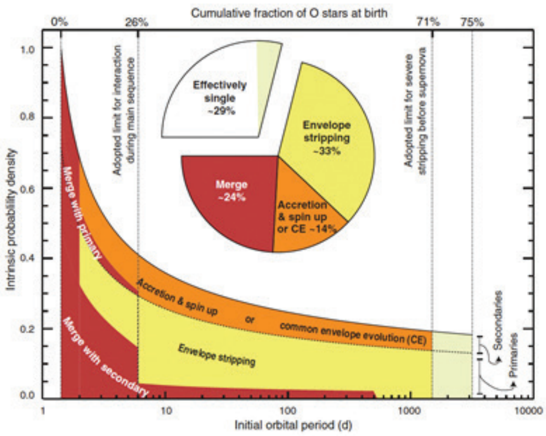


__Figure 2.13:__ Schematic representation of the relative importance of different binary interaction processes. All percentages are given in terms of the fraction of all stars born as O-type stars, including the single O stars and the O stars in binaries, either as the initially more massive component (the primary) or as the less massive one (the secondary). The solid curve gives the best-fit intrinsic distribution of orbital periods. For the purpose of comparison, the ordinate value is normalized to unity at the minimum period that was considered. The dotted curve separates the contributions from O-type primary and secondary stars. The colored areas indicate the fractions of systems that are expected to merge (red), or experience stripping (yellow) or accretion/common envelope evolution (orange). The pie chart compares the fraction of stars born as O stars that are effectively single (i.e., single (white) or in wide binaries with little or no interaction effects (light green)), with those that experience significant binary interaction (Sana et al. 2012, Science).

3.3 Astrophysics of black holes, neutron stars and white dwarfs

NOVA Network 3 focuses on the physics of compact objects, such as white dwarfs, neutron stars, and black holes. These objects are the end products of stellar evolution and are often found in binaries. Strong analogies exist with massive black holes in the centers of galaxies, which are increasingly the topic of NW3 study. They often manifest themselves as sources of high-energy radiation, non-thermal emission, highly energetic particles, gravitational waves, and high time variability. They are also natural sites to study the physics of strong gravity, dense matter, extremely high magnetic fields, accretion processes, and particle acceleration. Consequently the network has defined a number of themes, such as 'Binary population and stellar evolution: which progenitor produces which compact remnant?', 'Physics in extreme gravity: what physical processes happen in and near compact objects?', 'The transient sky - into the unknown: what sources make up the transient sky?', and 'Astroparticle physics: what are the sources and production mechanisms of the highest energy particles and gravitational waves?'.

Over the 2010-2012 period, VLT X-Shooter has been very important in many projects, together with the WHT (and soon VST) European Galactic Plane and the Galactic Bulge survey. Palomar Transients Factory (PTF) and Kepler data are being used to study white dwarfs and asteroseismology. Excellent use is being made of RXTE, Chandra, XMM-Newton, Swift and Suzaku data. The Auger Observatory continues to be scientifically very productive. A first small array of radio antennas, AERA, has been deployed, which detected the first signals from cosmic rays in coincidence with Auger surface detectors. LOFAR is starting to produce scientific results, especially on pulsars. Finally, the AMUSE project, providing an integrated software environment to combine various astrophysical codes (stellar evolution, cluster evolution, hydro codes, etc.), has started to show first results for NW3 science.

Pulsars – a two solar mass pulsar and pulsars with LOFAR

Hessels and collaborators discovered a pulsar, PSR-J1614-2230, that made a splash in 2010, producing one of the most cited papers in astrophysics in that year. Using the strong Shapiro delay signal for this source, a mass of twice that of the Sun was found for the neutron star, the most massive one known to date (Fig. 3.1). Neutron stars are composed of the densest form of matter known to exist in our Universe, the composition and properties of which are still theoretically uncertain. Measurements of the masses or radii of these objects can strongly constrain the neutron star matter equation of state and rule out theoretical models of their composition. The observed range of neutron star masses, however, was so far too narrow to rule out many predictions of 'exotic' non-nucleonic components. The Shapiro delay is a general-relativistic increase in light travel time through the curved space-time near a massive body. For highly inclined (nearly edge-on) binary millisecond radio pulsar systems, this effect allows one to infer the masses of both the neutron star and its binary companion to high precision. For the binary millisecond pulsar J1614-2230, the calculated pulsar mass is (1.97±0.04) $M_{\odot}$, which rules out almost all currently proposed hyperon or boson condensate equations of state. Quark matter can support a star this massive only if the quarks are strongly interacting and are therefore not 'free' quarks.

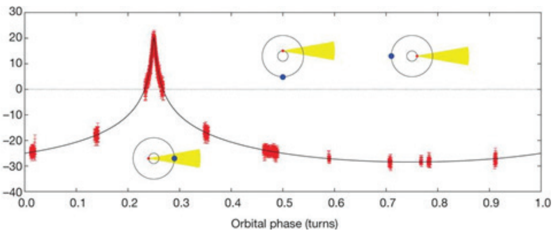


Figure 3.1: *Time delay of the arrival of the radio pulses from PSR J1614-2230 in micro-seconds showing the Shapiro delay, which is caused by the potential well of the companion star (illustrated in the artist impression above). The measurement of the Shapiro delay allows determination of both masses in the binary system (Demorest, Hessels et al. 2010)*

Hessels, van Leeuwen, Wijers, Falcke, Markoff and the LOFAR Pulsar team have presented the first high-time-resolution observations made with the LOFAR radio telescope, which demonstrate powerful techniques for observing pulsars and other rapidly varying sources of transient radio emission (Fig. 3.2).

Discovery of the first eclipsing accretion-powered millisecond X-ray pulsar

Altamirano, Cavecchi, Patruno (NOVA PD), Watts, Degenaar (NOVA PD), Kalamkar (NOVA PhD), van der Klis, Armas Padilla, Kaur, Yang, Soleri, Wijnands and colleagues discovered and performed a timing analysis of the first eclipsing accretion-powered millisecond X-ray pulsar (AMXP): SWIFT J1749.4-2807. The neutron star rotates at a frequency of ~517.9 Hz and is in a binary system with an orbital period of 8.8 hr. Assuming a neutron star mass between 0.8 and 2.2 $M_{\odot}$ and using the mass function of the system and the eclipse half-angle, they constrain the mass of the companion and the inclination of the system to be in the range of 0.46-0.81 $M_{\odot}$ and ~ 74-77°, respectively. To date, this is the tightest constraint on the orbital inclination of any AMXP. As in other AMXPs, the pulse profile shows harmonic content up to the third overtone. However, this is the first AMXP to show a first overtone with rms amplitudes between ~6% and ~23%, which is the strongest ever seen and which can be more than two times stronger than the fundamental. The fact that SWIFT J1749.4-2807 is an eclipsing system that

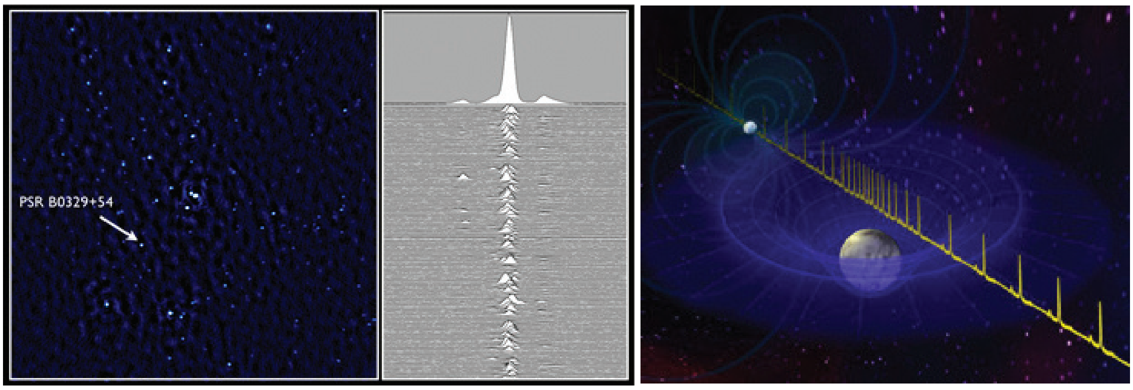


Figure 3.2: *LOFAR is capable of simultaneously creating high angular resolution images (left) as well as high time resolution snapshots for detecting rapidly varying sources like pulsars (right). Here, the bright pulsar B0329+54 was localized in the imaging data (left) and its individual, sub-second pulses were also recorded (middle).*

shows uncommonly strong harmonic content suggests that it may be the best source to date to set constraints on neutron star properties including compactness and geometry.

White Dwarf binaries: the shortest period binary and guaranteed gravitational wave source

HM Cancri is a candidate ultracompact binary white dwarf with an apparent orbital period of only 5.4 minutes, as suggested by X-ray and optical lightcurve modulations on that period, and by the absence of longer-period variability. Groot, Nelemans, and collaborators presented Keck-I spectroscopy of this source showing clear modulation of the helium emission lines in both radial velocity and amplitude on the 5.4 minute period and no other. This strongly suggests that the binary is emitting He I 4471 from the irradiated face of the cooler, less massive star, and He II 4686 from a ring around the more massive star (Fig. 3.3). They conclude that the observed 5.4 minute period almost certainly represents the orbital period of an interacting binary white dwarf. Thus, they confirm that HM Cnc is the shortest period binary star known, providing a unique test for stellar evolution theory. More importantly, however, in the long run, this source is one of the strongest known sources of gravitational waves for space-based gravitational wave detectors and it is essentially guaranteed to be detected if our understanding of gravitational waves is correct.

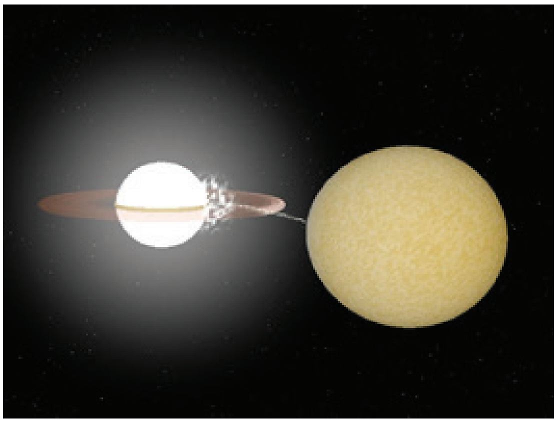


Figure 3.3a: *Artist impression of the ultra-compact binary HM Cnc, which has an orbital period of only 5.4 min. The system consists of two white dwarfs and matter is transferred from one to the other. The object is the strongest know source of detectable Gravitational Wave emission (Nelemans et al. 2010).*

Young massive clusters

Portegies Zwart and colleagues published an extensive review on young massive clusters (YMCs), which are dense aggregates of young stars that form the fundamental building blocks of galaxies. Several examples exist in the Milky Way Galaxy and the Local Group, but they are particularly abundant in starburst and interacting galaxies. They are younger than ~100 Myr, more than a few current crossing times old, and more massive than ~10^4 $M_\odot$; the size of the cluster and its environment are considered less relevant as distinguishing parameters. The few YMCs that are close enough to resolve are of prime interest for studying the stellar mass function and the ecological interplay between stellar evolution and stellar dynamics. The distant unresolved clusters may be effectively used to study the star-cluster mass function, and they provide excellent constraints on the formation mechanisms of young cluster populations. YMCs are expected to be the nurseries for many unusual objects, including a wide range of exotic stars and binaries. So far only a few such objects have been found in YMCs, although their older cousins, the globular clusters, are unusually rich in stellar exotica.

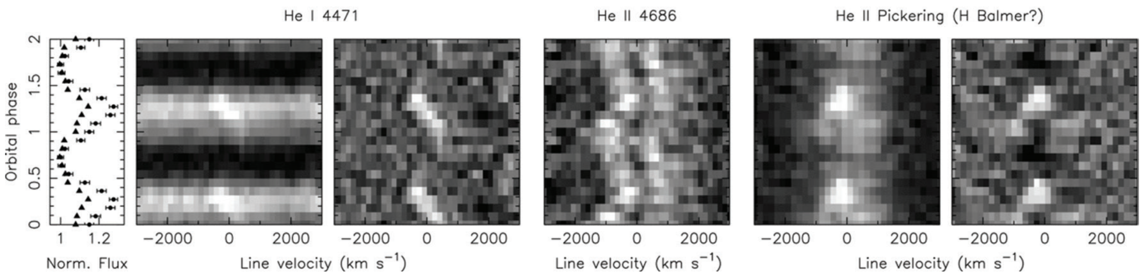


***Figure 3.3b**: Radial velocity curves of the strongest HeI and HeII lines of HM Cnc folded on the 5.4 min photometric period. After correcting for the strong flux variability the anti-phase sine waves in the two lines are clearly visible, showing the movement of the two white dwarfs. The measurement confirms that the photometric period is the orbital period and establises HM Cnc as the shortest period binary known (Roelofs et al. 2010).*

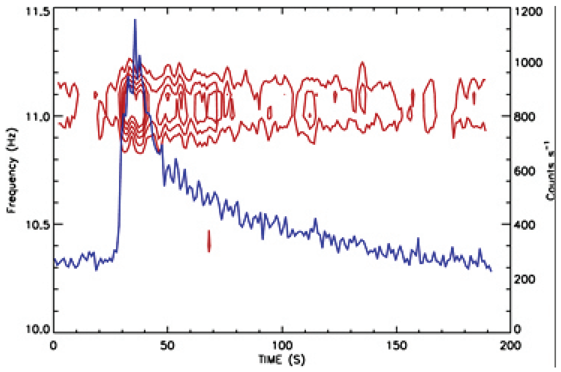


Figure 3.4: *Light curve (blue) and dynamical power spectrum (red) showing the spin frequency of the neutron star for the 2010 October 13 thermonuclear burst of IGR J17480-2446 (Cavecchi et al. 2011).*

Ultra-High Energy Cosmic Rays

The Auger collaboration, including Hörandel, Falcke, Jiraskova (PhD), Horneffer, and Kelley (NOVA PD) has published their first results on the composition of ultra-high energy cosmic rays. This is based on measurements of the depth of the shower maximum, X_{max}, of the longitudinal development of air showers induced by ultra-high energy cosmic rays when they collide with the earth atmosphere. Almost 4000 events above 10^{18} eV were observed by the fluorescence detector of the Pierre Auger Observatory in coincidence with at least one surface detector station and were selected for the analysis. The average shower maximum was found to evolve with energy at a rate of (106^{+35}_{-21})g/cm^2/decade below 1018.24±0.05eV, and (24±3) g/cm^2/decade above this energy. The measured shower-to-shower fluctuations decrease from about 55 to 26 g/cm^2. Comparisons with predictions from Monte Carlo simulations of showers indicate that the composition moves from proton-like particles towards iron-like particles at higher energies. This result is rather puzzling, since most models had assumed that UHECRs are mainly protons at the highest energies. Also, the previously found cutoff in the UHECR spectrum would be at different energies for iron-like particles, if interpreted as the GZK-cutoff, which is due to interactions of UHECRs with the cosmic microwave background. Hence, the interpretation of the new results is part of a lively discussion, which may indeed involve a different composition of UHECRs, but could also be due to a change of particle physics cross sections at these energies, or some other explanation.

IGR J17480-2446: a unique system

IGR J17480-2446 is a system in the globular cluster Terzan 5 that hosts an 11-Hz X-ray pulsar implying a young neutron star. Degenaar (NOVA PD) and Wijnands found clear evidence for cooling of the accretion-heated crust of the neutron star, implying that crust cooling is even observable after short accretion episodes (months instead of years). Cavecchi, Watts, van der Klis, Wijnands and colleagues show that Type I X-ray bursts from this source display oscillations at the same frequency as the stellar spin (Fig. 3.4). IGR J17480-2446 is the first secure case of a slowly rotating neutron star which shows Type I burst oscillations, all other sources featuring such oscillations spin at hundreds of Hertz. The low-frequency oscillations rule out two of the most popular models for burst oscillations (global oscillation modes and a hot spot on the surface confined by the Coriolis force). The most likely scenario is that the oscillations are produced by a hot spot confined by hydromagnetic stresses, the first time that such a mechanism has been suggested. Patruno, van der Klis and van den Heuvel consider the evolution of this enigmatic system and conclude that it is very likely a mildly recycled pulsar. They suggest that it has started a spin-up phase at an exceptionally recent time, that has lasted less than a few 10^7 yr.

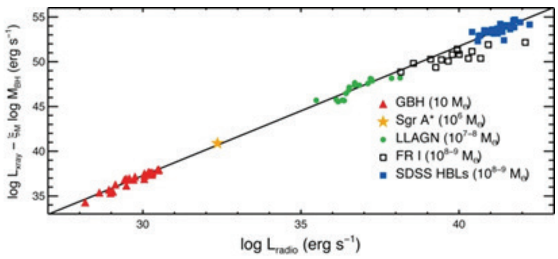


Figure 3.5: *Fundamental plane of black hole activity showing the tight relation between the radio luminosity, the X-ray luminosity and the mass of the black hole for a large range of black hole masses (ranging from stellar mass around 10 solar mass to super-massive, more than 100 million solar mass) (Markoff et al. 2011).*

Black holes on all scales: the fundamental plane

Plotkin, Markoff, Körding and collaborators published the best study of the Fundamental Plane of Black Hole accretion to date (Fig. 3.5). It is a physical relation linking black hole radio and X-ray luminosity to black hole mass, and holds over 8 orders of magnitude in black hole mass. The study includes the new and largest uniform SDSS-selected BL Lac sample, and provides the strongest evidence yet that black holes in the compact jet dominated state regulate their power output similarly regardless of mass. Soleri and Fender have investigated radio-quiet stellar mass black holes, i.e. outliers in the fundamental plane of black holes, and suggest that they may be neutron stars or neutron-star-like.

Formation of the millisecond pulsar J1719-1438 with a planetary companion

Van Haaften (PhD), Nelemans, Jonker and Voss show that the planetary object discovered around the millisecond pulsar J1719-1438 (Fig. 3.6) is not naturally explained as the late time phase of the standard evolution of ultra-compact X-ray binaries, i.e., systems in which a neutron star accretes from a white dwarf companion. The orbital period would be reached only over a time much larger than the age of the Universe. However, independent observations suggest that the evolution of these systems is accelerated, possibly by emission of a small stellar wind from the white dwarf companion. In that case, the planet – pulsar system actually fits very nicely as the final fate of these X-ray binaries.

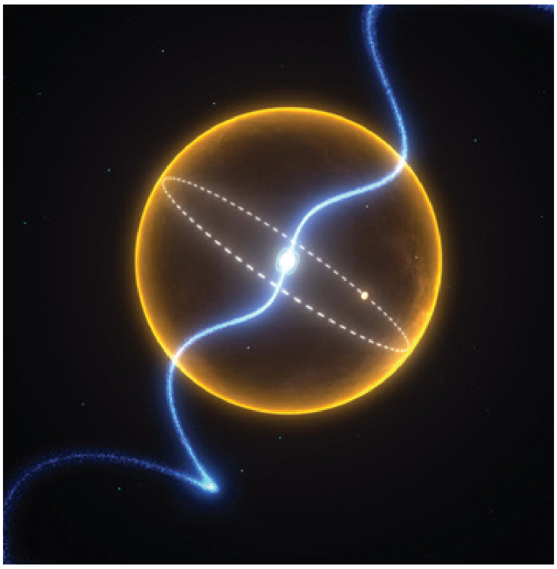


Figure 3.6: Impression of the Pulsar – Planet system PSR J1719-1438 The pulsar at the centre of the image is orbited by an object that is about the mass of Jupiter and composed primarily of carbon; effectively a massive diamond. The orbit, represented by the dashed line, would easily fit inside our Sun, represented by the yellow surface. The blue lines represent the radio signal from the pulsar, which spins around 175 times every second (van Haaften et al. 2012).

Low frequency QPO in Terzan 5: not frame dragging

Altamirano, Ingram, van der Klis and colleagues discovered low-frequency quasi-periodic oscillations in the X-ray light curves of the 11 Hz pulsar in Terzan 5 (Fig. 3.7). The fact that the 11 Hz spin period is more than an order of magnitude slower than that seen in other similar systems led to the conclusion that the X-ray oscillations are not due to special precession of the accretion disk as Einstein predicted ('frame dragging'). This work has ended a 15 years debate of whether these X-ray oscillations are the result of the Lense-Thirring precession.

Simulations of GRB afterglows

Van Eerten, Leventis, Wijers and collaborators performed accurate calculations of gamma-ray burst afterglows at late stages, when the blast wave causing them slows down to mildly relativistic speeds and when its jet-like shape becomes more spherical. These two physical events leave traces in the form of breaks in their power-law like light curves from which one can observationally deduce important physics, such as the initial opening angle and total energy of the gamma-ray burster explosion. They show that the actual behaviour is richer, and that both energy and opening angle can be considerably underestimated by simplified modeling. Subsequently, van Eerten, van der Horst, and colleagues used the results of this modeling to provide observers with a toolset to efficiently fit data with sophisticated numerical-simulation based models, and derive accurate physical parameters of gamma-ray bursters.

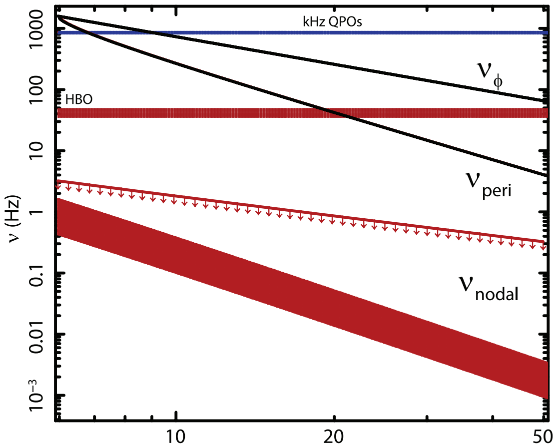


Figure 3.7: Comparison of the measured QPO frequencies (horizontal bands oscillations, HBO) with the different characteristic frequencies expected in General Relativity. The HBO in other sources have been interpreted as Lense-Thirring precession that would show up as the nodal frequency. For IGR J17480-2446 this is clearly not the case as the expected frequency (diagonal band) is much lower than the observed HBO frequency. Indeed even the maximum frequency for extreme assumptions (line with arrows) falls short of the observed frequency. This results calls the interpretation of the HBO oscillations as Lense-Thirring precession in other systems also in doubt (Altamirano et al. 2012).

More Highlights

Linares, van der Klis and many others were able to show that the famous and much debated source Cir X-1 is indeed a neutron star through the detection of a thermo-nuclear burst from its surface. Markoff and Russell with colleagues have detected strong evidence that the broad-band spectrum of the black hole accretor XTE J1550-564 may be entirely dominated by jet-emission, thereby further challenging the old paradigm of disk-only models. Hiemstra, Mendez, Altamirano, and colleagues have found the strongest iron line in a newly discovered accreting black hole, probing gas in a highly relativistic environment. Scaringi, Körding, Uttley and Groot and co-workers discovered that the well-known rms-flux relation found in accreting neutron and black hole systems binaries also appears in an accreting white dwarf system, suggesting a common physical origin for the broad-band variability, independent of source type, mass or size of the compact accretor. Portegies Zwart, van den Heuvel, van Leeuwen, and Nelemans were able to explain the formation of the eccentric-orbit millisecond Pulsar (MSP) J1903+0327 using a triple system, thereby also suggesting a new way to form single MSPs in the Galaxy. Jonker, Nelemans, Groot, Mendez, Verbunt, Wijnands and others presented the first source list of the Galactic Bulge Survey (GBS); among the goals of the GBS are constraining the neutron star (NS) equation of state and the black hole (BH) mass distribution via the identification of eclipsing NS and BH low-mass X-ray binaries. A team involving Nelemans found a faint type of supernova from a white dwarf with a helium-rich companion, confirming an earlier prediction of a new type of supernova from an old remnant. Finally, Rossi and others have studied the coalescence of supermassive black hole binaries analytically, finding that previous dimensional estimates have underestimated the kinetic energy gained by the surrounding disk gas by an order of magnitude and predicting prompt emission during the process.

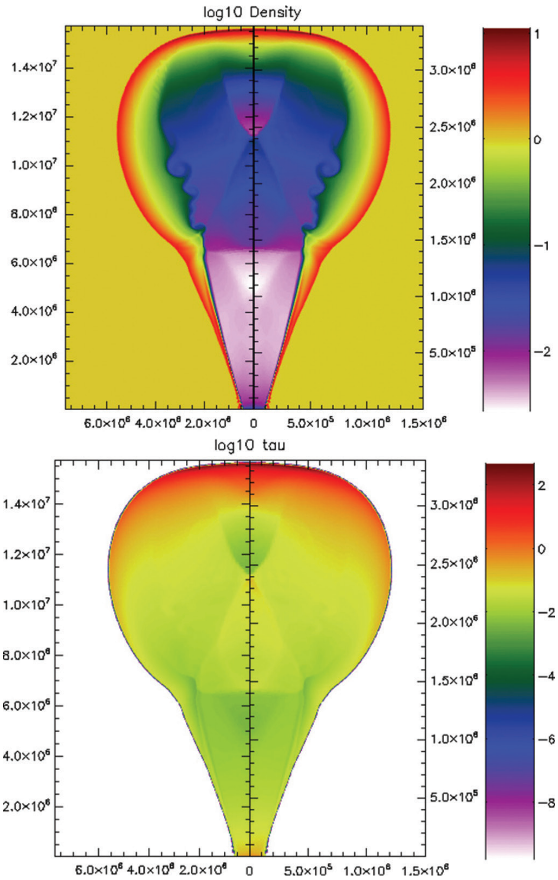


Figure 3.8: *Color-coded images (top: density; bottom: energy density) showing two different jet-GRB afterglow simulations with the same opening angle and external density, but initial energies differing by a factor 100. By scaling the simulation time by* $100^{1/3}$*, the two become identical, demonstrating that by analytical scaling one can use a very small number of expensive numerical simulations to fit a wide range of afterglows, making the fitting of accurate simulations to data feasible (van Eerten et al. 2012). The code and method are freely available at http://cosmo.nyu.edu/afterglowlibrary.*

4. PhD's in astronomy awarded in 2010 -2011 - 2012

In 2010 a total of 33 PhD's in astronomy were awarded in the Netherlands, 34 in 2011 and 17 in 2012. Of these 84 PhD's 18 were obtained through funding or co-funding from NOVA. The table below lists all PhD's in astronomy over 2010-2012 specified for each university.

	PhD date	Funding	Promotor	Thesis title
UvA				
R. Karuppusamy	13 11 2009	NOVA	van der Klis; co: Stappers	A Study on giant radio pulsars
R. Moll	28 01 2010	MPA Garching	Spruit	Magnetic acceleration and instabilities of astrophysical jets
H.J. van Eerten	26 02 2010	NOVA/NWO	Wijers	Gamma-ray burst afterglows from jet simulation to light curve
V.M. Tudose	10 03 2010	NWO	van der Klis; co: Fender	Jets at different scales
E.A. Rubio Herrera	04 05 2010	NOVA	van der Klis; co: Stappers	Galactic and extragalactic searches for pulsars and radio transients
P. Soleri	11 05 2010	NWO	van der Klis; co: Fender	Accretion/ejection coupling in X-ray binaries
J.N. Spreeuw	18 06 2010	NWO	Wijers	Search and detection of low frequency radio transients
L.E. Muijres	12 11 2010	NOVA	de Koter, Langer; co: Vink	The physics of line-driven winds of hot massive stars
D.J. Groen	16 11 2010	NWO	Portegies Zwart, co: Sloot, van den Heuvel	High Performance N-body Simulation on computational grids
G. van der Plas	07 12 2010	ESO/UvA/NOVA	Waters	Warm gas in proto-planetary disks
N.D. Degenaar	08 12 2010	NWO	van der Klis; co: Wijnands	Exploring subluminous X-ray binaries
L.H.A. Scheers	20 01 2011	NOVA	Wijers	Transient and variable radio sources in the LOFAR sky
M. Serylak	18 02 2011	ASTRON/NOVA	van der Klis; co: Stappers	Modulation properties of radio-emitting neutron stars
C.R.M.X. D Angelo	03 03 2011	MPA Garching	Spruit	Truncated accretion discs around stellar mass objects
P.D. Meerburg	27 09 2011	NWO	Wijers; co: van der Schaar	Exploring the early universe through the CMB sky
RUG				
A. Popping	29 01 2010	NWO	van der Hulst; co: Braun	Diffuse neutral hydrogen in the local universe
E. Kutdemir	05 02 2010	RUG / other	Peletier co: Ziegler	The evolution of spiral galaxies in clusters
R.F. Pizzo	19 02 2010	NOVA /RUG	de Bruyn	Tomography of galaxy clusters through low-frequency radio polarimetry
S. Vegetti	26 03 2010	NWO	Koopmans	Quantifying mass substructure in early-type galaxies
V. Jelic	07 05 2010	RUG	Zaroubi, Koopmans, de Bruyn	Cosmological 21cm experiments : searching for a needle in a haystack
J. Sansa	21 05 2010	Nuffic	van der Hulst; co: Rai	Measuring and modeling the performance of high-speed data transport protocols
P. Lampropoulos	17 09 2010	RUG	Koopmans; co: Zaroubi, de Bruyn	The Lofar epoch of reionization experiment data model
F.A. Gomez	27 09 2010	RUG	Helmi	Milky Way archaeology and the dynamical signatures of mergers
J.P. Pérez-Beaupuits	10 08 2010	NOVA	Spaans	Chemical fingerprints of star forming regions and active galaxies
M. Arrigoni	29 10 2010	RUG	Trager; co: Somerville	Galactic chemical evolution in hierarchical formation models
C. Struve	12 11 2010	EU / RUG	van der Hulst; co: Morganti, Oosterloo	The Role of Neutral Hydrogen in the Evolution of Nearby Radio Galaxies
C. Llinares	24 01 2011	Others	Sanders	On the linear and non-linear cosmological evolution of dust density perturbations with MOND

	PhD date	Funding	Promotor	Thesis title
N. Wehres	18 03 2011	EU / NOVA	Tielens, Linnartz	Optical spectroscopy of interstellar and circumstellar molecules
M.H.D. van der Wiel	16 05 2011	RUG	Spaans; co: van der Tak	Molecular gas and dust influenced by massive protostars : spectral surveys in the far-infrared and submillimeter
A. Monachesi	23 05 2011	NOVA	Trager	The resolved stellar populations of M32
H. Buddelmeijer	04 07 2011	NWO	Valentijn, Trager, Roerdink	Query driven visualization of large scale multi-dimensional astronomical catalogs
M.A. Latif	16 09 2011	others	Zaroubi, Spaans	Cosmological simulations of the first galaxies
G. van der Wolk	28 10 2011	NOVA / RUG	Barthel, Peletier	Mid-infrared imaging of dust in galaxies
S. Hocuk	21 11 2011	RUG	Spaans	The origin of stars: tales from the unexpected in extreme environments
E. Starkenburg	01 12 2011	NWO	Tolstoy, Helmi; co: Hill	Galactic archaeology in and around the Milky Way
T.P.K. Martinsson	12 12 2011	RUG	Verheijen	The distribution of mass within spiral galaxies: unique solution
B. Hiemstra	10 02 2012	RUG	Méndez	A walk through the different spectral states of low-mass X-ray binaries
T.J.L. de Boer	20 04 2012	NWO-VICI	Tolstoy; co: Saha	The Star Formation & Chemical Evolution timescales of two nearby dwarf spheroidal galaxies
M. den Brok	14 05 2012	NWO	Peletier, Valentijn	Dynamics and stellar populations of small stellar systems
A. Aykutalp	21 09 2012	RUG	Spaans	Enlightenment of the Universe: the interplay between dark energy, the first stars, and black holes
J.B. Mwebaze	30 11 2012	other	Valentijn	Extreme data lineage in ad-hoc astronomical data processing
G.Aresu	10 12 2012	NWO	Kamp, Spaans; co: Meijerink	High energy irradiated protoplanetary disks : the X-rays and FUV role in thermo-chemical modeling
J.D. Bregman	14 12 2012	ASTRON	Brouw, Butcher	System design and wide-field imaging aspects of synthesis arrays with phased array stations: to the SKA system design

UL				
P.M. Lopes Beirao	13 01 2010	UL	Israel; co: Brandl	Interstellar medium conditions in starburst galaxies
M.H. Soto	24 03 2010	UL	Kuijken; co: Lub, Rich	3-Dimensional dynamics of the galactic bulge
M.C. Damen	22 06 2010	UL / NOVA	Franx; co: Van Dokkum	The build-up of massive galaxies
R.P.C. Wiersma	22 09 2010	EU / other	de Zeeuw; co: Schaye	Simulating the chemical enrichment of the intergalactic medium
J. Bouwman	12 10 2010	FOM	Linnartz; co: Allamandola	Spectoscopy and chemistry of interstellar ice analoques
D. Salter	25 11 2010	UL / NWO	van Dishoeck; co: Hogerheijde	Millimeter emission from protoplanetary disks
M.R. Haas	07 12 2010	UL	Franx; co: Schaye	Nature and nurture in galaxy formation simulations
S. Ioppolo	09 12 2010	UL / NOVA / NWO	Linnartz, van Dishoeck; co: Cuppen	Surface formation routes of interstellar molecules
I.M. Oliveira	07 06 2011	UL / NWO-Spinoza	van Dishoeck; co: Pontoppidan	Observational constraints on the evolution of dust in protoplanetary disks
E.J.W. de Mooij	28 09 2011	UL	Kuijken; co: Snellen	Ground-based observations of exoplanet atmospheres
J.B.R. Oonk	06 10 2011	UL	Jaffe	Cool gas in the brightest cluster galaxies
R. van Haasteren	11 10 2011	NWO	Portegies Zwart; co: Levin	Gravitational wave detection and data analysis for pulsar timing arrays
C. Kruip	20 10 2011	UL / NOVA	Icke	Connecting the Dots Analysis, development and applications of the SimpleX algorithm
N. Amiri	26 10 2011	JIVE-EU ESTRELA	van Dishoeck; co: van Langevelde, Vlemmings	Developing asymmetries in AGB Stars: occurrence, morphology and polarization of circumstellar masers
T. Prod'homme	22 11 2011	EU / UL	Kuijken; co: Brown	From electrons to stars: modelling and mitigation of radiation damage effects on astronomical CCDs

	PhD date	Funding	Promotor	Thesis title
K. Torstensson	06 12 2011	JIVE-EU ESTRELA / NWO	van Dishoeck; co: van Langevelde	Methanol masers and millimetre lines: a common origin in protostellar envelopes
R.J. van Weeren	20 12 2011	UL / KNAW	Rottgering, Miley	Radio emission from merging galaxy clusters
L. Vermaas	11 01 2012	UL / NOVA	Israel, vd Werf	Spectroscopy and nuclear dynamics of starburst galaxies
E. Kuiper	24 01 2012	NWO	Rottgering, Miley	Growing up in the city: a study of galaxy cluster progenitors z>2
O. Rakic	07 02 2012	NWO	Schaye, Steidel, de Zeeuw	The Intergalactic medium near high-redshift galaxies
M. van Hoven	15 02 2012	NWO / UL	Kuijken; co: Levin, Hopman	Seismology of magnetars >2
A-M. Madigan	16 02 2012	NWO	Kuijken; co: Levin, Hopman	Secular stellar dynamics near massive black holes
F. van der Voort	28 03 2012	NWO / UL	Schaye	The growth of galaxies and their gaseous haloes
E. van Uitert	29 05 2012	EU / UL	Kuijken	Weak gravitational lensing in the RCS2
R. Martinez Galarza	19 06 2012	NOVA / UL	van Dishoeck; co: Brandl	Mid-Infrared spectroscopy of starbursts: from Spitzer-IRS to JWST-MIRI
M. Velander	20 06 2012	EU / UL	Kuijken	Studying dark matter: haloes with weak lensing
UU				
S.E. de Mink	12 04 2010	NOVA / UU	Langer; co: Pols	Stellar evolution at low metallicity under the influence of binary interaction and rotation
K.M. Schure	21 06 2010	NWO	Achterberg; co: Vink	Supernova remnants as particle accelerators and probes of the circumstellar medium
E.A. Helder	28 09 2010	NWO	Verbunt; co: Vink	Cosmic-ray acceleration in supernova remnants
B. van Veelen	19 11 2010	UU	Langer	Supernovae Interacting with their circumstellar medium
N.Vitas	13 01 2011	NOVA	Keller, Rutten	Observational signatures of the simulated solar photospere
I. Brott	28 02 2011	NWO	Langer, de Koter	Modeling populations of rotationally mixed massive stars
C.E. Fischer	09 03 2011	NOVA	Keller	Transient events in the solar photosphere at high spatial and temporal resolution
J.M.D. Kruijssen	06 06 2011	NWO	Lamers, Portegies Zwart, Icke	Formation and evolution of star clusters and their host galaxies
M. Rodenhuis	16 06 2011	NWO	Keller	EXPO: a sensitive imaging polarimeter for observations of scattered light from circumstellar environments
E. Silva Villa	02 09 2011	NWO	Keller; co: Larsen	Tracing galaxy evolution through resolved stellar populations and stars clusters
H. Cánovas Cabrera	23 09 2011	NOVA	Keller	High contrast imaging polarimetry of circumstellar environments
A.L. Chies Santos Santiago	30 09 2011	NWO	Keller; co: Larsen	Globular clusters as probes of the evolutionary histories of E/SO galaxies
S. Chita	06 10 2011	UU	Langer, Achterberg	Models for circumstellar nebulae around red and blue supergiants
R.G. Detmers	06 12 2011	NOVA / SRON	Verbunt; co: Vink	Outflow and feedback in active galactic nuclei: high-resolution X-ray spectroscopy and variability
RU				
A. Obermeier	23 02 2011	Univ Chicago / FOM / NIKHEF	de Jong, Müller; co: Hörandel	A direct measurement of cosmic rays to very high energies
S. Thoudam	12 06 2012	SNN / LOFAR	Falcke; co: Hörandel	Propagation of cosmic rays in the Galaxy and their measurements at very high energies with LORA

4.1. Facts on students and PhDs

The number of bachelor students entering physics and astronomy is growing over the last years as indicated in Fig.1. Universities with an astronomy program (i.e., the universities united in NOVA) show a steeper increase than those without, demonstrating that astronomy helps to attract physics students, a phenomenon also seen in other countries.

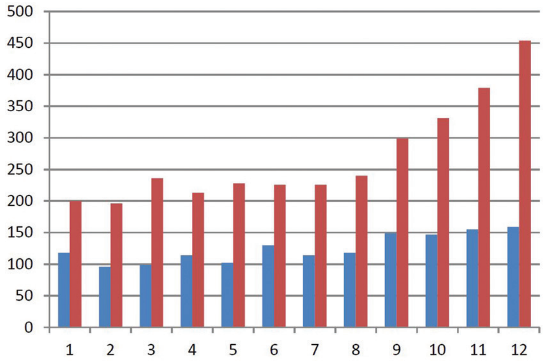


Figure 1: *Number of arriving students in physics and astronomy in the period 2001-2012. The number of new students remains constant for the universities without an astronomy curriculum (in blue) and show an significant increase for the universities with an astronomy bachelors and masters program (in red).*

About 2/3 of the students that have completed their PhD remain in astronomy for their first job (Fig. 2). The statistic is for a sample of 220 students who obtained their PhD in the 2000-2009 period. This fraction has remained relatively constant with perhaps a slight increase over the years. Of those, on average, 32% have their first postdoc in the USA, 34% in Europe, 11% in other countries and 23% stay in the Netherlands. This last group also contains PhDs appointed for a short postdoc position after their PhD defense to finish papers and/or bridge the gap toward their next postdoc position. Overall, the Dutch culture is that students should leave the country after they get their PhD if their ambition is to get a permanent position in astronomy.

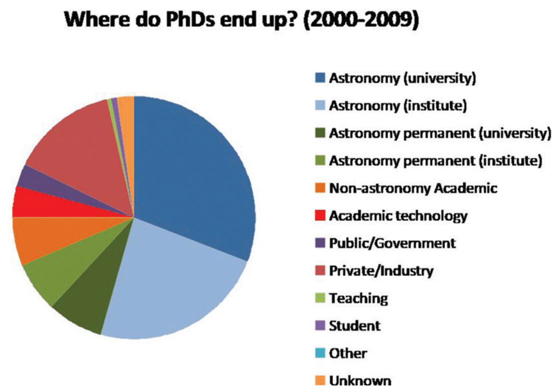


Figure 2: *Types of positions currently occupied by Dutch PhD students that graduated between 2000 and 2009 (220 PhDs total). Here 'institute' means a non-teaching research institute like ASTRON, SRON, ESO or STScI where the PhDs are on an astronomer position. PhDs on non-astronomer positions at these institutes (e.g., software development, detector testing) are in the 'Academic technology' bin.*

The fraction of students that leave astronomy after their first job is close to constant at 5% over 2000-2009, implying that about 70% of today's students can be expected to remain in astronomy in a decade from now (assuming the total number of positions in astronomy stays at a comparable level). This is consistent with, or even slightly higher than, statistics about students that finished a decade ago. Of the PhDs that graduated in 2000-2009 and are now in the Netherlands, 59% are at a Dutch university and 41% at ASTRON or SRON. Young astronomers typically start to get permanent/tenure track positions about five years after their PhD, but statistics for this sample are small.

Of the PhD students that leave astronomy, either immediately after graduation or a few years later, 23% end up in non-astronomy academic (research) positions (e.g., at the national meteorological institute KNMI), 52% in private/industry, 12% in public/government positions, and only 2% as teachers.

One key measure of the PhD training is the success of the PhD students on the international postdoc market: after the US, the Netherlands has the highest number of Hubble, Chandra, Fermi and Jansky fellows (Fig. 3).

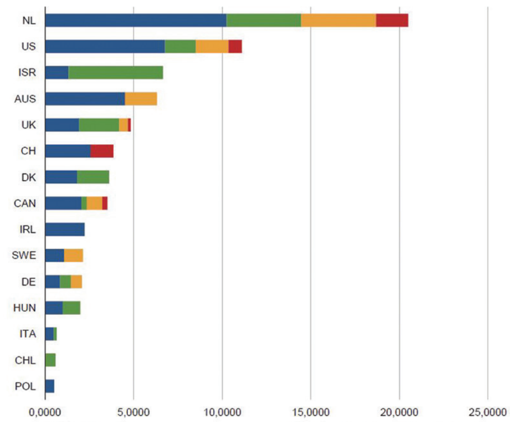


Figure 3: *Numbers of Hubble (blue), Chandra + Einstein + Fermi (green), Jansky (yellow) and Spitzer postdoc fellowships (red) per capita awarded through 2012 to candidates who got their PhD in various countries outside the USA.*

The number of PhD graduations per year in astronomy in the Netherlands is slightly growing over the last 5-7 years (Fig. 4) As the figure shows, the number of graduations per year has remained about constant over most of the period, with a slight rise since 2007. The low number in 2012 is a one-off exception.

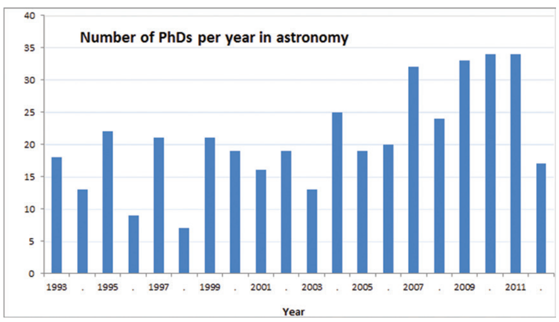


Figure 4: *The number of PhDs in astronomy granted in the Netherlands over the 1993 -2012 period.*

5. Instrumentation

Science and instrumentation are intimately linked. There are three main reasons for NOVA to be actively involved in building instruments. The first reason is to ensure that instruments are built with the required capabilities to address the major scientific questions in the areas of the three networks. There is no 'do-it-all-in-one' instrument. All instruments are specialized for particular measurements (e.g. wavelength range, image quality, field of view, time resolution, and spectroscopic and polarimetric capability) and designed with specific science goals in mind. For some instruments only participation in the design and construction can ensure that they become reality. The second reason is to gain expert knowledge of the increasingly complex instruments, necessary to be among the first to harvest the scientific results and, ultimately, to get the most out of the data. The third very important reason is the guaranteed time: in return for their staff effort contributions, observatories 'pay' institutes with privileged early access to the telescopes. This enables large coherent programs with exclusive data access as well as smaller seed programs preparing for subsequent open time programs. NOVA policy is that the guaranteed time for NOVA-funded projects is available to the entire Dutch community, not just to the groups involved in building the instruments.

Building instrumentation is also an excellent way to capitalize on the Dutch investments in the world-wide facilities made available through ESO and ESA. In fact, both organizations expect the member countries to design, build and finance the instruments that go on the billion-euro telescopes. Thus, a relatively small investment of 1-10 M€ can still have a large impact. Finally, NOVA's involvement in instrumentation strengthens the technical expertise at the universities. This provides an opportunity for existing staff to get 'hands-on' experience with the technical intricacies and project management of instrument building and it allows training of a new generation of instrumentalists. Collaboration with industry and physics groups provides fertile ground for technical innovation.

There is a clear division in technical focus between NOVA and the institutes ASTRON and SRON. NOVA has grown into the national 'home base' for instrumentation on the ESO telescopes including the VLT, VLTI, VST, ALMA and in the future the E-ELT. The NOVA-funded program can effectively be viewed as the national support for the ESO program, similar to what has been in existence for ESA and CERN for decades. The NOVA Optical-Infrared instrumentation group has built up a solid reputation in various areas of optical and infrared instrument design (especially the cryogenic parts), construction and subsequent science exploitation over the past 10+ years. This manifests itself not only in scientific and technical publications, but also by foreign partners seeking collaborations with Dutch astronomers on joint instrumentation projects and on joint programs to harvest the results from new international observing capabilities. NOVA – in some cases in collaboration with ASTRON and/ or SRON – also supports other instrumentation projects led by university PIs, ranging from dedicated software pipelines for various key research programs with LOFAR, to the Cold Optical Bench for the MIRI spectrometer which will fly on JWST, to stimulating laboratory astrophysics in a university setting.

Instrument Steering Committee

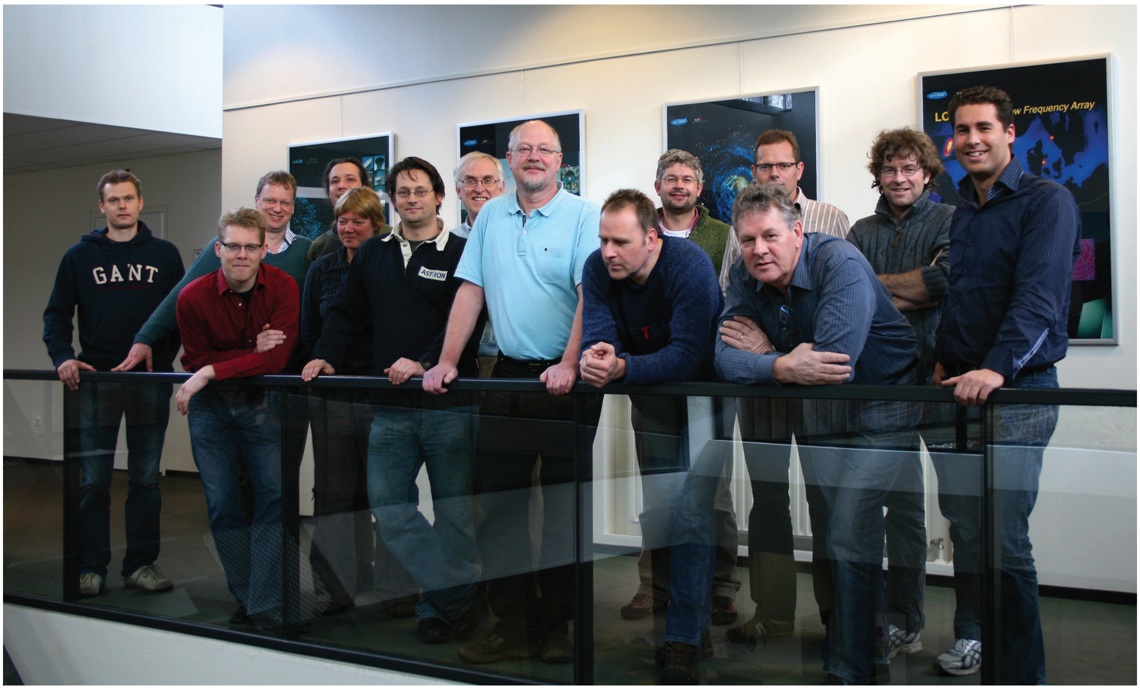
Progress of the NOVA instrument projects is reviewed twice a year by the Instrument Steering Committee (ISC) on behalf of the NOVA Board. The ISC addresses all aspects of the instrumentation projects, including overall quality, progress, achievement of milestones, use of manpower and financial resources, and project risks. It reports on these matters to the NOVA Board and Directorate and recommends actions where necessary. The ISC also reviews the need to release contingency funds when projects call on such a demand and recommends to the NOVA Board and Directorate the release of such funds and/or other measures to keep projects within their budgets. Requests for seed funding are reviewed by the ISC before the NOVA Board and Directorate decide whether they will be granted.

Preparation Phase-4 instrumentation

Preparation of the Phase-4 (2014-2018) program started in 2012. The procedure was divided in two stages: in the first stage all university staff was invited to submit a proposal that included a full science case and a preliminary workplan, a budget estimate and a management plan. Condition was that each proposal must by led by a PI of one of the NOVA institutes. After review and evaluation a selected number of proposals were asked to prepare and submit a full proposal. In the first round in September 2012 NOVA received 16 proposals for instrumentation projects in response to a call for proposals that was issued to the entire astronomical community in the Netherlands. All proposals were presented to the community at an open national instrumentation day held on 25 September 2012. The proposals were reviewed by each of the three Research Networks on their scientific merit and their match to the national astronomy program. Each of the Networks concluded on a motivated scientific ranking of proposals. The proposals were also reviewed by the NOVA ISC on their technical feasibility, financial aspects, project management, and risks. The ISC provided the NOVA Board and Directorate with their findings on the issues they addressed. Final decisions were taken by the NOVA Board at their meeting in November 2012. In total 13 out of the 16 proposals were selected to submit a full proposal in March 2013.

5.1. Optical-IR Instrumentation

The NOVA instrumentation program focusses on projects for the telescope facilities provided by ESO (VLT, VLTI, VST, and in the future the E-ELT) or in part by ESO (ALMA). Hence, in the optical-IR wavelength regime, NOVA takes the responsibility to act as the national home-base for ESO by providing instruments for the Paranal Observatory and the E-ELT. Specific projects will be described in the following section. Key requirements continue to be that the projects are driven by university astronomers and have an integrated science and instrumentation plan. In general each instrument project is a joint effort of four to ten international institutes working together as a Consortium structured under a Memorandum of Understanding (MoU) and a contract with ESO. ESO entrusts the Consortium to design, build and verify the instrument. In return, after delivery, the Consortium receives guaranteed observing time to be the first to use the instrument on one of the ESO telescopes. In parallel the instrument is offered for use by the astronomical communities in the ESO member states.



The NOVA Optical-IR instrumentation group with some co-workers from ASTRON who contributed to the Phase-A feasibility studies for the E-ELT instrument concepts METIS, MICADO, Optimos-EVE and EPICS.

For NOVA the Op-IR instrumentation projects are led by a Principal Investigator (PI) who is a staff member at one of the university astronomical institutes in the Netherlands. The PI is required to spend a significant fraction of time on the project. The PI's main task is to ensure that the scientific objectives of the project will be maintained, to provide leadership for the NL team working on the project, and to represent NOVA in the relations with the consortium partners and with ESO. The design and construction work for the project are usually done by the NOVA Op-IR instrumentation group based in Dwingeloo, with some exceptions where the work is performed by a small team within the university institutes. Collaboration with industry has grown over the reporting period.

NOVA Optical-IR instrumentation group

The Optical-IR instrumentation group works under leadership of NOVA. It is based in the ASTRON institute in Dwingeloo. Staff is employed by NWO. The organizational structure and the relations between the three parties are described in a contractual agreement signed in August 2009. This agreement runs for a period of four years from 1 January 2008. In 2011 the parties started negotiations on a contract extension up to end 2018.

The group consists of 13 experienced people (see Chapter 6 for full list) with expertise including optical, mechanical, and cryogenic design, system engineering, CNC and optical production capabilities, instrument integration, and verification. Over the last decade this group has carried out the optical-IR instrumentation projects for which NOVA had final responsibility towards ESO, ESA, and international partners.

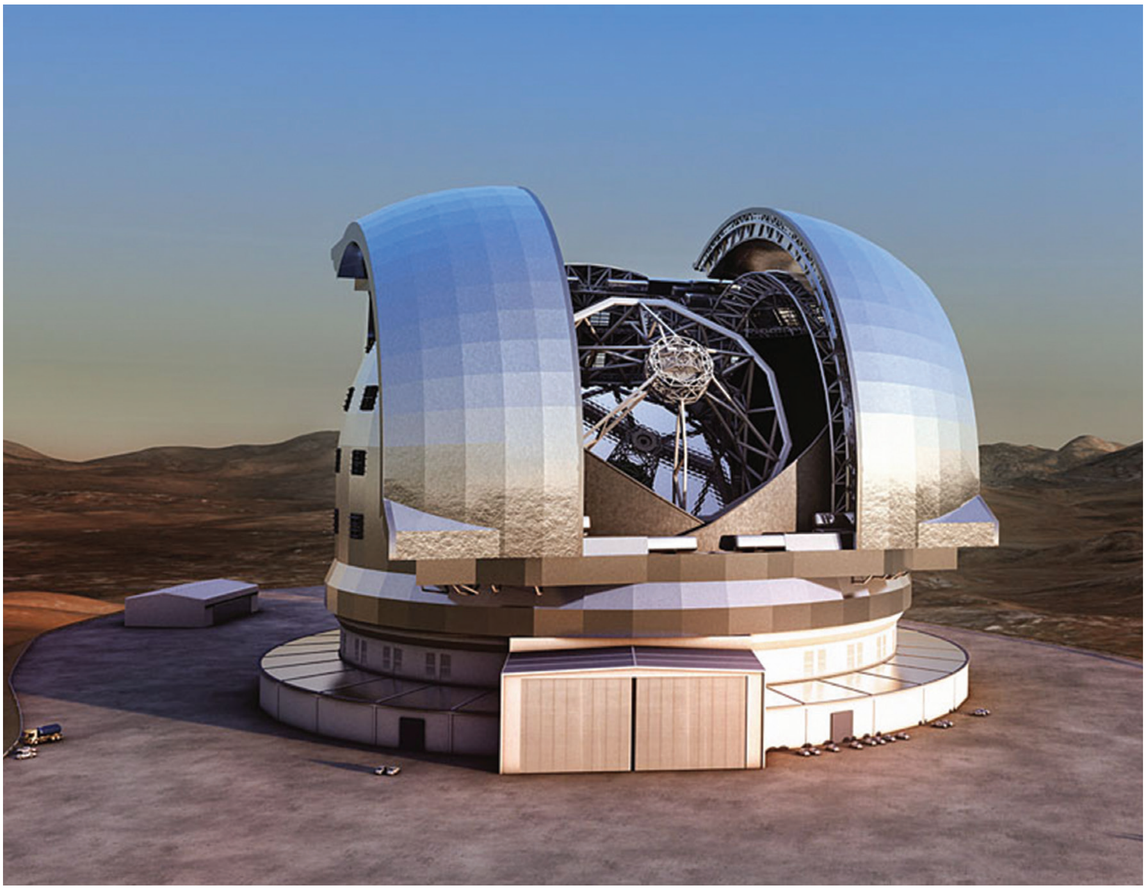
In the reporting period the Op-IR group worked on the following major projects: the VLT 2nd generation instrument SPHERE-Zimpol, the VLTI 2nd generation instrument Matisse, Phase-A feasibility studies and subsequent follow-up work for four E-ELT instrument concepts and some technical R&D for future instrumentation. Navarro is the head of the group. ASTRON provides in-kind systems engineering support through Venema.

Participation in E-ELT instrumentation

NOVA seeks an active role in the design and construction for instrumentation for the European Extremely Large Telescope (E-ELT). This telescope will yield a revolutionary view on the Universe enabling the study of extra-solar planets, of stellar populations in external galaxies, and of faint distant galaxies tracing the early history of the Universe. E-ELT observations will lead to breakthrough results addressing key issues like the origin of the first stars and galaxies, the nature of dark matter and dark energy, galactic evolution and the formation of stars and planets. The large collecting area of the 39m primary mirror and its novel five mirror design make the E-ELT to achieve diffraction limited imaging and spectroscopy down a resolution of 2-4 milliarcsec over a large (up to 10' × 10') field of view.

The Netherlands participated in four of the eight Phase-A feasibility studies for instrument concepts for the E-ELT. These were the near-infrared wide-field imager MICADO, the mid-infrared imager/spectrometer METIS, the multi-object spectrometer OPTIMOS-EVE, and the instrument to characterize exoplanets EPICS. In 2010 ESO selected two first-light instruments, MICADO and the near-infrared spectrometer Harmoni. METIS was assigned to be the third instrument. The international METIS consortium confirmed that NOVA will be their PI organization, with Brandl (NOVA staff member, Sterrewacht Leiden) as PI.

NOVA also leads the national efforts in E-ELT instrumentation in the national roadmap for participation of the Netherlands in large scale international research infrastructures. Funding through the Roadmap program was secured in 2008. Together with industry (Dutch Space, Janssen Precision Engineering), technical universities (Delft, Twente), and technology institutes (ASTRON, SRON and TNO), several technology studies were undertaken in the reporting period to address the chopper mechanism, immersed grating spectroscopy and vibration free sorption cooling technology for METIS. For EPICS the technical R&D studies targeted physical concepts for optical polarimetry in systems with segmented mirrors, hardware and software tools for extreme AO demands, and a testbed for high contrast AO systems. The national Roadmap grant consisted in two parts: 8.8 M€ for conceptual design, Phase A and B studies and technology development, and 10 M€ for participation in the final design and construction of one instrument. The latter part is conditional to ESO's decision to approve the construction of the E-ELT and to select instruments in which NOVA has a leading role. METIS with NOVA as the PI organization will satisfy this condition. Payment of the Roadmap grant is spread over the period 2009-2018.



Artist impression of the E-ELT

5.1.1. E-ELT METIS

Project PI
Brandl

NL Co-Is
Caputi
Van Dishoeck
Helmich
Hogerheijde
Jaffe
Kamp
Kaper
Keller
Kenworthy
De Koter
Dominik
Larsen
Peletier
Roelfsema
Snellen
Spaans
Stam
Stuik
Van der Tak
Tielens
Trager
Waters
Van der Werf

Project team
Kroes
Molster (NL PM)
Stuik
Venema

The Mid-infrared E-ELT Imager and Spectrograph (METIS) is the only instrument concept for the E-ELT that covers the thermal IR wavelengths from 2.9 - 14 μm. It contains a diffraction limited imager and an IFU high resolution spectrometer. METIS is scheduled to be the third instrument on the E-ELT. The instrument will be developed by a European consortium led by NOVA. The science case for METIS encompasses a broad range, from Solar System objects to luminous IR galaxies at high redshift, but the main breakthroughs are expected in the fields of exoplanets and proto-planetary disks.

METIS is a European project to design and construct a thermal infrared instrument for the E-ELT. Originally starting as a three-party consortium to study T-OWL (thermal infrared instrument for a 100 meter telescope), the consortium now includes most of the mid-IR expertise in Europe, embodied by the seven institutes: NOVA, CEA Saclay (F), ETH (CH), KU Leuven (B), MPIA (D), UK ATC (UK) and U Vienna (A). NOVA has the lead role in this consortium and provides the Principal Investigator, Project Manager and Systems Engineer.

From May 2008 to December 2009 the consortium successfully ran the phase A study for METIS. From 2010 to 2012 the consortium continued working on several important aspects of the instrument. The recent focus has been on the development of critical technologies necessary for METIS, reducing the technical and schedule risks later in the project. In the same period METIS has been formally identified as the third instrument on the instrumentation roadmap for the E-ELT.

Technical concept

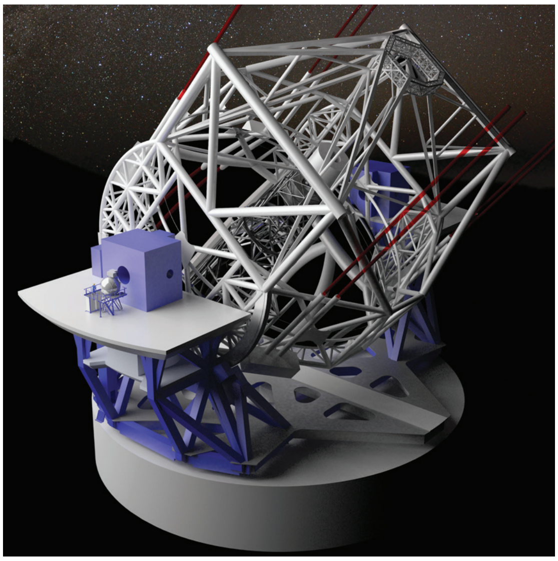
METIS will have two main instrument modes:

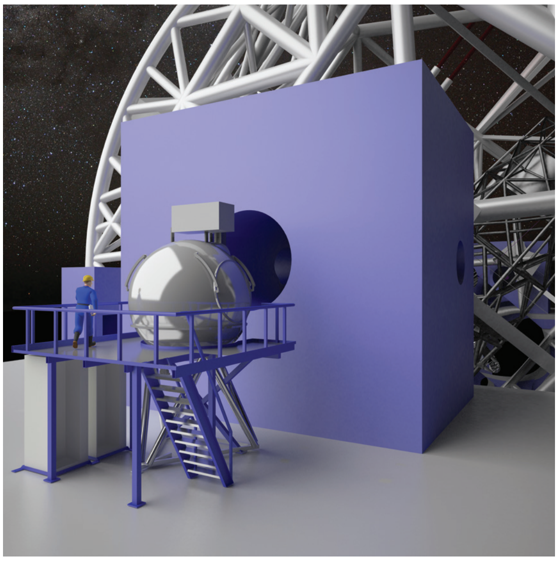
1. A diffraction limited imager at L/M, and N band with an approximately 18"x18" wide field of view. The imager includes the following observing modes: coronagraphy at L/M and N-band, low-resolution (900 $\leq$ R $\leq$ 5000) long slit spectroscopy at L/M and N band, and polarimetry at N-band;
2. A high resolution (R ~ 100,000) spectrometer at L/M (2.9 - 5.3μm) band, fed by an Integral Field Unit (IFU) with a field of view of about 0.4"x1.5".

All modes require adaptive optics (AO) correction, unless the atmospheric conditions are very favourable, in which case METIS will be able to achieve quasi-diffraction-limited images at 10 μm resolution without AO. It will achieve diffraction-limited performance with the corrective E-ELT mirrors M4/M5, and does not require additional adaptive mirrors. METIS AO follows a two step approach: first, an internal wavefront sensor (WFS) for on-axis, self-referencing targets, will be used; second, and probably not implemented from the start, a laser guide star (LGS/LTAO) system will be constructed to provide full sky coverage.

The optical system of METIS uses all-reflective optics (with the exception of the spectral filters and dichroic beam splitters) to simplify testing and integration and to minimize chromatic aberrations. The optical system provides superb diffraction-limited performance. The main optical modules of METIS are:

- The wavefront sensor module, which hosts the internal wavefront sensor, an atmospheric dispersion corrector, field selector and derotator;
- The warm and cold calibration units, which provide a set of important calibration sources, including an integrating sphere as absolute flux reference;
- The common fore-optics, which is the central part of the optical system. It splits the beam between the AO/calibration modules and the science modules. In addition, it includes two essential optical components: (i) the chopper, which can provide fast, two-dimensional chopping (±5") and residual tip/tilt beam stabilization, (ii) the image derotator to provide a stable focal plane for the science modules;
- The L/M/N band imager consists of two very





Left: *the E-ELT with METIS on its Nasmyth platform A;* **Right:** *Zoom-in to show details of the cryostat, the detached service platform, and the location of the electronics racks.*

similar, parallel channels for L/M band and N band. These include a reimaging system with slit, filter and grism wheels, as well as pupil imaging optics. Coronagraphy can be performed by inserting masks in either the entrance focal plane or pupil plane;

- The L/M band high resolution IFU spectrograph cuts the image in 24 slices, rearranges the slices and sends the light to an Echelle grating spectrometer. Tilting of the grating allows selecting the spectral range within the preselected diffraction order.

The modules are mounted to a common 'backbone' structure, which acts as a mechanical and thermal interface. The cold system is surrounded by a spherical cryostat, with a diameter of approximately 2.5m, made of stainless steel.

Progress in 2010-2011-2012

Work has focussed on technology developments for METIS. These include the METIS Cold Chopper Demonstrator, the sorption coolers and the immersed grating.

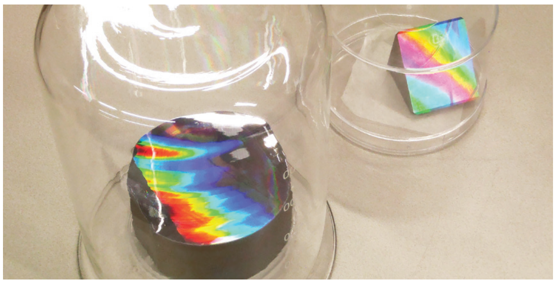
METIS Cold Chopper Demonstrator

The METIS Cold Chopper Demonstrator development, in collaboration with JPE and SRON, demonstrates the feasibility of a 2D movable mirror in a cryogenic environment (80K), performing fast (within 5msec from one chop position to the other) and very stable (movements of the mirror in a stable position of less than 1.7 µrad) movements. A design was made of the mechanism. The most critical part turned out to be the position sensors to detect the movement of the mirror. After several breadboard tests and two different sets of sensors, the complete system was designed and successfully reviewed at the end of 2012. The first tests of the complete system will be done in 2013.

Sorption Coolers

Closed cycle coolers cause vibrations, have fluctuations in the temperature and cannot be operated in all orientations. The sorption coolers technology promises to be vibration free, have high temperature stability at the cooling tip, and be rather flexible in design. However, apart from a study for ESA, these coolers have not yet been manufactured and are not yet ready to be implemented in an instrument. During the last three years UTwente and Dutch Space BV, in collaboration with NOVA, have worked on a sorption cooler design that will be suitable for METIS and other instruments.

At the end of 2012 there was a conceptual design for a cooler, including cooling levels and selection of suitable cooling gases that would fulfil the requirements of METIS. At the same time the preliminary Design and Development Plan was completed, describing the steps needed to be taken toward an industrial product. All these steps together were promising enough that, at the end of 2012, the consortium started with the preparations for the manufacturing of a sorption cooler demonstrator.



Small size immersed gratings

Immersed Grating

Another development that showed significant progress in the last three years is the development of the immersed grating. This project, which is a collaboration between NOVA, SRON, ASTRON, TNO and industry (Philips), aims to use the internal reflection of an in silicon etched grating, reducing the size of the grating and therefore the surrounding optics by roughly the index of refraction. In the period 2010-2012 first a study was made to investigate the different methods that could be applied to manufacture this challenging large grating and compare the problems encountered here with the problems and difficulties of manufacturing standard gratings. After this analysis, which showed promising results for the immersed grating, the team applied the selected techniques individually to determine what worked best. In May 2012, an international review board reviewed the results and came to the conclusion that it is still difficult but very promising. The review board recommended the manufacture of a real size demonstrator. Since June 2012 the team has been working to get the demonstrator immersed grating made and tested.

Other developments

Besides the three projects mentioned above, NOVA was also involved in the VISIR upgrade, which houses the AQUARIUS detector also envisioned for METIS at N-band. During commissioning in 2012 it became clear that the performance of this detector dit not completely meet expectations. NOVA is participating in a rigorous program to investigate the source of the low frequency excess noise and to mitigate it.

A METIS end to end instrument simulator is being built by NOVA. The goals of this project are threefold. (i) to calculate reliable system sensitivities to guide the science case and related top-level requirements, (ii) to enable performance checks for different design options, which can be used to find the optimal design solution, (iii) to provide realistic data products, which can be used as a basis for the data pipeline development. The first results of this simulator helped to refine the METIS sensitivity limits, allowing better comparison to other instruments.

5.1.2. E-ELT MICADO

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MICADO is the Multi-AO Imaging Camera for Deep Observations. It is a high profile European-wide project to build the First Light adaptive optics camera and spectrograph for the E-ELT. It will be optimized for the multiconjugate adaptive optics (MCAO) module MAORY, but it will also allow a phased approach, and thus be able to work with any adaptive optics system, and it includes its own separate module to provide a single conjugate adaptive optics (SCAO) capability during the earliest operational phase. This simple on-axis, natural guide star mode system sets relatively low requirements on the telescope's AO performance (no lasers), but still provides excellent performance over small fields of view.

Instrument specifications

Building a large aperture telescope brings with it dramatically increased spatial resolution only if it can work at or close to its diffraction limit. MICADO is designed to make use of both SCAO and MCAO adaptive optics facilities to regularly obtain diffraction limited images of unparalleled sensitivity. Right from the start of E-ELT operations, MICADO will be at the forefront of high spatial resolution sensitive optical/infrared imaging and spectroscopy in the new era of extremely large telescopes.

The design of MICADO is compact, and it will be supported underneath the AO modules so that it rotates in a gravity invariant orientation (see Figure). It will be able to take diffraction limited images through a large number of wide- and narrow-band filters ranging from red-optical (starting from at least 800nm) to K-band in the near-IR over a large (53 arcsec) field of view using fixed mirrors for superior stability, thus optimizing astrometric precision. There will be a high throughput imaging camera with a 3 mas pixel scale, and a camera with a finer 1.5 mas pixel scale over a smaller field of view, as well as a long-slit capability for simple, medium resolution (at least R~5000) spectroscopy covering a long wavelength range (at least 0.8 – 2.5 μm).

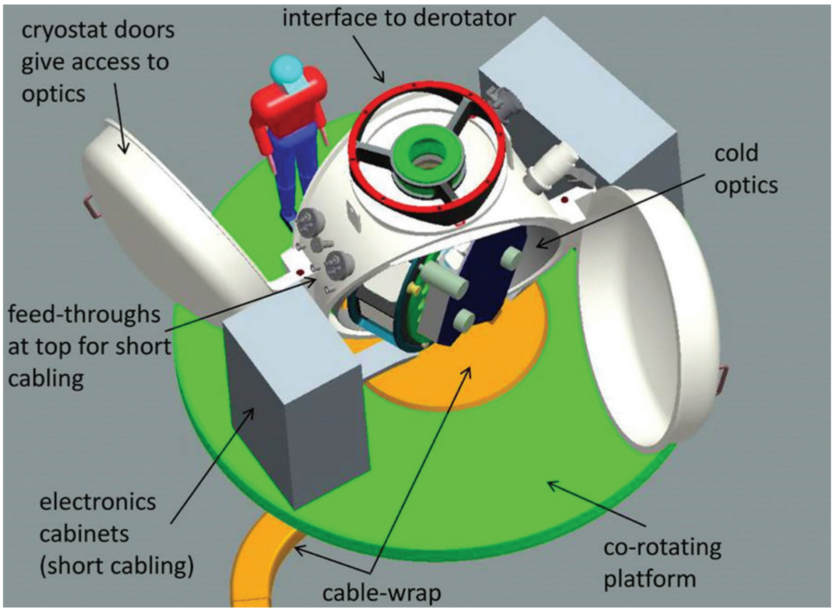
International Consortium

MICADO will be designed and built by a consortium of European institutes led by the Max Planck Institute for Extraterrestrial Physics (MPE) with PI Ric Davies. The participating institutes are located in Germany, the Netherlands, France, Austria, Italy and ESO.

NOVA Contribution in 2010-2012

The NOVA contribution to the large international consortium has been chosen to be that which makes the best use of Dutch expertise. The largest item is one of the key components of MICADO, the Atmospheric Dispersion Corrector (ADC), which is required to obtain diffraction limited images, and thus accurate and sensitive photometry and astrometry. A pre-study of the ADC started in September 2012. Preliminary results show that this component is complex but feasible and can be built by the NOVA Op-IR instrumentation group. Two key issues for MICADO's design phase have surfaced from the Phase A study on calibration strategy and data flow (led by NOVA-OmegaCEN) followed by the astrometry and ADC performance pre-study led by NOVA Op-IR instrumentation group:

- The design of MICADO hardware and the design of its calibration strategy are fully intertwined;
- Wide-field astrometric requirements on MICADO can only be accurately assessed after the E-ELT, MAORY and MICADO designs have been analyzed as a single system.



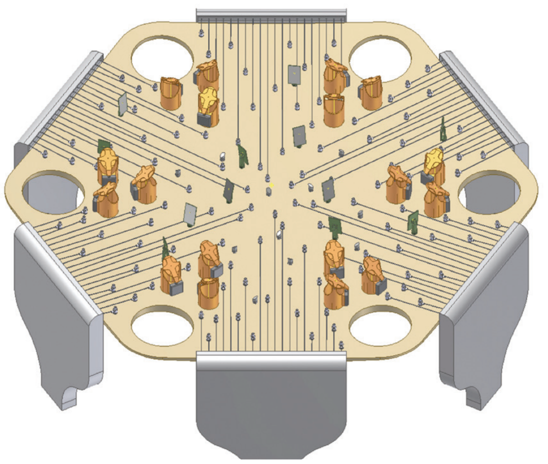
Schematic view of the MICADO instrument as made for the Phase A feasibility study.

5.1.3. E-ELT MOSAIC

Astronomers in the Netherlands aim to participate in the E-ELT/MOS definition process, following the successful completion of the Phase A study on the fiber-fed multi-object spectrograph called OPTIMOS-EVE in March 2010, building on the NOVA expertise with VLT/X-Shooter. Discussions between the OPTIMOS-EVE and EAGLE (another Phase A E-ELT/MOS concept operating with IFUs and dedicated adaptive optics) teams have resulted in updated science and technical requirements for the E-ELT/MOS, evaluating both a "high definition" and a "high multiplex" mode using a common focal plane. Several national meetings (UK, NL, F, and Brazil) have been organized to define these requirements, as well as an international E-ELT/MOS workshop in October 2012 in Amsterdam. The outcome has been presented in a "white paper" and the new instrument concept is called MOSAIC: Multi-Object Spectrograph for Astrophysics, Intergalactic-medium studies and Cosmology.

Instrument specification

The workhorse instruments of the 8-10m class observatories have become their multi-object spectrographs (MOS), providing comprehensive follow-up to both ground-based and space-borne imaging. With the advent of deeper imaging surveys from, e.g., the HST and VISTA, there are already a plethora of spectroscopic targets beyond the sensitivity limits of current facilities; this will continue to grow even more rapidly, e.g., with the completion of ALMA, LOFAR, the launch of the JWST and SKA. Therefore, one of the key requirements underlying plans for the next generation of ground-based telescopes, the ELTs, is for even greater sensitivity for optical and infrared (IR) spectroscopy.

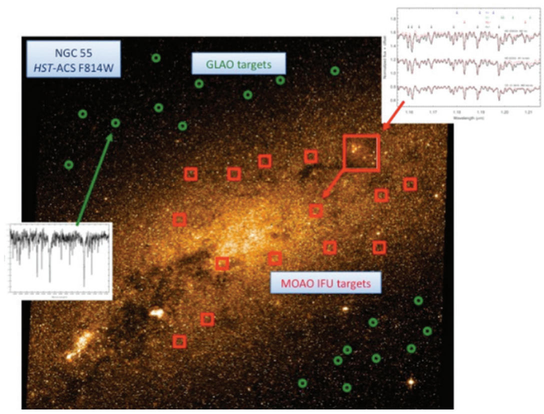


Mixed Architecture Design (MAD) of the movable pick-off mirrors (relaying to MOAO systems) and fibers (working at GLAO resolution) in the focal plane of one of the Nasmyth foci of the E-ELT. The up to 7' x 7' field corresponds to an area of about 2 m².

MOSAIC will be designed with the following two top-level science requirements in mind:

- High definition: observations of tens of channels at fine spatial resolution, with MOAO providing high-performance AO for selected sub-fields in the focal plane;
- High multiplex: integrated-light (or coarsely resolved) observations of >100 objects at the spatial resolution delivered by GLAO.

The two modes of observations for MOSAIC on the E-ELT are leading to two options for the instrument concept, based on the combined requirements driven by the science cases. The first is the "Fibers Only Option" and the second concept is the "Mixed Architecture Design" is based both on fibers and IFUs. There is no obvious show-stopper in these two options. A trade-off study will have to be performed with respect to science requirements on the one hand and technical and cost aspects on the other. The Netherlands will be in charge of the optical and mechanical design of the fiber-fed spectrographs, as was the case for the Phase-A study of OPTIMOS-EVE which was completed in March 2010.



An example scenario for observations of the stellar populations in NGC 55 (Sculptor group, distance 2 Mpc). The green circles correspond to fibers, the red squares to IFUs exploring the much better spatial resolution (~40 milliarcsec) in areas of higher target density.

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5.1.4. E-ELT EPICS

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The E-ELT will obtain the first direct images of rocky exoplanets in the habitable zone and search for atmospheric biomarkers using the EPICS instrument. However, the required technologies are not yet at a level where construction could begin. During 2010-2012 a number of feasibility and technology R&D studies have been done in the Netherlands to maintain a leading position in the direct polarimetric imaging and spectroscopy of exoplanets. The aim is to reach contrasts of 10^{-9} at optical wavelengths and beyond to image rocky exoplanets from the ground. A series of individually optimized subsystems cannot succeed; rather, entire combinations of subsystems must be optimized together.

Instrument concept

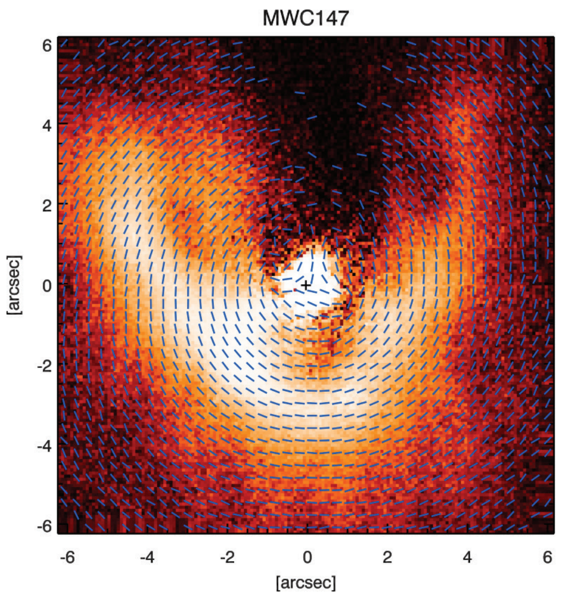
The key to achieving the highest imaging contrast and sensitivity from the ground is a superb correction of the dynamic and quasi-static wavefront aberrations introduced by the Earth's atmosphere and the telescope/instrument, respectively, with an extreme Adaptive Optics (XAO) system. In conjunction with a coronagraph and a system for non-common path calibrations, EPICS will achieve a high quasi-static PSF contrast of better than 10^{-6}. Spectral deconvolution, differential polarimetry, and angular differential imaging will further increase the sensitivity. Most importantly, systematic errors need to be understood and minimized by designing the complete instrument including the data reduction as a system. The biggest risk, unexpected systematic errors, can only be mitigated by using laboratory setups and testing at telescopes.

Progress in 2010-2011-2012

Significant progress has been made with the R&D efforts funded under the national Roadmap program for E-ELT instrumentation. The E-ELT instrumental polarization analysis has been completed by de Juan Ovelar, Snik and Keller. The first imaging polarimetry observations of exoplanets have been obtained with VLT/NACO and Subaru by Snik and de Juan Ovelar, and the first monochromatic prototype of a vector-apodizing phase-plate has proven the basic concept in the laboratory. Furthermore, sensing wavefront aberrations behind an apodizing phase plate coronagraph have been demonstrated by Otten, Kenworthy and Snik with actual telescope data.

Rodenhuis, de Juan Ovelar, Snik, Keller et al have been following an evolutionary path for high-contrast, visible-light polarimetry for circumstellar disk and exoplanetary research. They had three successful observation campaigns using the ExPo instrument at the William Herschel Telescope. The observations have initially focused on stars known to or suspected of harboring protoplanetary disks as well as some debris disks. Later observations revealed linearly polarized light from the dust and gas surrounding Herbig Ae/Be stars (see Fig).

Keller and Korkiakoski have developed a new focal-plane wavefront sensing and reconstruction approach for optical systems with deformable mirrors that dramatically reduces the optical and computational complexity to the level where a single PC and existing cameras could control the EPICS eXtreme Adaptive Optics system. The approach has been tested with computer simulations and with a low-order AO system. ESO has invited the NOVA team to test the approach on their HOT setup. The request is to carry out and analyze the HOT tests, experimentally verify the approach in a laboratory setup with 10.000 to 100.000 actuators, and explore industrial applications with the ultimate goal to solve one of the two biggest risks for EPICS.



ExPo observation in linearly polarized light of MWC147. This Herbig Ae/Be star is surrounded by the circumstellar cloud of dust and gas from which it formed and is still accreting material. The figure shows the intensity of the polarized light scattered by the cloud, overlaid with blue vectors (not scaled) indicating the polarisation direction. The '+' marks the star position.

5.1.5. MOS studies for 4-8m telescopes

One of the top-ranked recommendations in the Astronet Science Vision report of 2007 was to equip some 4m class telescopes with a Multi Object Spectrometer (MOS) having at least a few thousand individual fiber elements covering a wide field of view on the sky. The main science drivers are (1) a spectrometric follow-up of the Gaia mission to study the evolution of our Galaxy, and (2) a spectroscopic survey of millions of galaxies to provide further knowledge about the nature and distribution of dark matter and dark energy. In the following years three initiatives have been started in Europe to study the feasibilities and science cases for a MOS instrument on different 4-8m telescopes. NOVA astronomers and the Op-IR instrumentation group participated in three of these studies with the intention to decide later on which project continuation is most fruitful.

WEAVE

WEAVE is a wide-field multi-object and integral-field spectrograph facility for the ING's WHT on La Palma, Spain. At the focal plane, WEAVE will have three observing modes, 1000 individual fibers (MOS) and 20-30 small (~8"x12") integral-field units (IFU's) that can be placed over a 2º diameter field and a ~2 square arcminute integral-field unit, all located at prime focus, behind a new prime-focus corrector. WEAVE is designed to be as low-cost as possible given its desired capabilities, using wherever possible off-the-shelf components or well-developed designs. Significant technical challenges include the large prime-focus corrector needed to achieve a flat, 2º diameter field on the WHT providing good images over a wide wavelength span and the implementation of the high-resolution (R=20,000) mode with the same camera as used for the moderate-resolution (R=5000) mode. WEAVE is intended to complement the 4MOST design study for ESO and shares a common spectrograph design. The project is a partnership between the ING communities of the UK, the Netherlands, and Spain, together with France. Partners include RAL-Space (PI institute), Oxford University, and Liverpool John Moores University (UK), University of Groningen and NOVA (NL), IAC (Spain), GEPI and Observatoire Côte d'Azur (France) and the ING. For astronomers in the Netherlands WEAVE is also of particular interest because it offers spectroscopic follow-up at optical wavelengths for objects detected at radio frequencies with the WSRT and LOFAR. The project was initiated in early 2010 with the aim of bringing WEAVE to the telescope by the end of 2016, not long after the release of the first preliminary Gaia catalog in late 2015. The Netherlands is providing the project scientist and a major part of the spectrograph. The instrument design is heading towards an international PDR scheduled for early 2013.

4MOST

This project is initiated from two key all-sky, space-based observatories of prime European interest: Gaia and eROSITA. 4MOST is a wide-field multi-object spectrograph for ESO's 4m VISTA. It will have 1500-3000 fibers feeding 2-4 moderate-resolution two-beam high-throughput spectrographs at R=5000 over the wavelength region 390-950 nm, and 150-300 fibers feeding a separate high-resolution two-beam high-throughput spectrograph at R=20,000 over the wavelength regions 395-457 nm and 586-674 nm. The field of view is 3º diameter. Major technical challenges include the fiber positioner system, which needs to fit into the small volume and mass envelopes of the back Cassegrain mount, and the large wide-field corrector required on the telescope. 4MOST is complementary to the WEAVE spectrograph for the WHT, covering the crucial Southern Hemisphere, where the inner disk and bulge of our Milky Way are most easily reached, and sharing a common (low-resolution) spectrograph design. The project is a partnership between the Leibniz Institute Potsdam (PI institute), MPE, LMU, ZAH and LSW (Germany), IoA and RAL/Oxford (UK), GEPI (France), RUG and NOVA (NL), Lund and Uppsala Universities (Sweden), and ESO. The Netherlands is contributing the design of the low-resolution spectrograph (LRS) and leading the telescope Trade-Off studie. The instrument design is heading towards an ESO Phase-A review in early 2013.

MOONS

The Multi-Object Optical and Near-infrared Spectrograph (MOONS) for the VLT aims to be fully operational by 2018. It combines a large multiplex (1,024 fibres), and a large wavelength coverage (0.8 to 1.8 μm) on a field of view of 500 square arcmin. MOONS will enable the ESO community to study a wide range of Galactic, extragalactic and cosmological science cases. It will study galaxy formation and evolution over the entire history of the Universe, from stars in our Milky Way, through the redshift desert, and up to the epoch of re-ionization at z>8-9. In 5 years of observations, MOONS will provide high quality spectra for > 3 million stars and 1-2 million galaxies at z >1. In addition to a low resolution mode (R>4000) covering the whole spectral range (0.8-1.8μm), MOONS covers i) the Calcium triplet region (0.8μm-0.9μm) and ii) selected windows in the H (1.17μm-1.26μm) and J (1.52μm-1.63μm) bands at higher resolution, respectively 8,000 and 20,000. MOONS is complementary to WEAVE as it will be located in the Southern Hemisphere. Thanks to its near-infrared capabilities, it will be the only instrument able to provide the spectra of large numbers of stars in the Galactic Bulge and inner disk. The project is a partnership between the UK Astronomy Technology Centre in Edinburgh (PI Institute), IfA (Edinburgh, UK), AIUC (Chile), CAAUL (Portugal), GEPI (France), NOVA (Netherlands), INAF (Italy), USM (Germany), ETH (Switzerland). The Netherlands are also involved in the science team. ESO has invited the consortium to define the Statement of Work and a MoU with the aim to officially kick-off the project before the end of 2013.

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5.1.6. VLT SPHERE-ZIMPOL

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Direct detection and spectral characterization of extra-solar planets is one of the most exciting but also one of the most challenging areas in modern astronomy. One of the second generation instruments for ESO's VLT under construction is SPHERE. It combines a powerful adaptive optics system (SAXO), various coronagraphs, an infrared differential imaging camera (IRDIS), an infrared integral field spectrograph (IFS) and a visible differential polarimeter (ZIMPOL). The ZIMPOL focal plane instrument is a technology development at the group of ETH in Zürich (Switzerland), the NOVA Op-IR instrumentation group, and the astronomical institutes at UvA and UU. ZIMPOL is a complex system that was built in collaboration with several other groups: instrument software by INAF in Padova (Italy), data reduction software by MPIA in Heidelberg and the detector system by ESO.

Instrument concept

ZIMPOL is a high-precision imaging polarimeter working in the visual wavelength range between 600 and 900 nm. It is based on a differential comparison of two images by fast modulation with a ferro-electric liquid crystal. Two different polarization directions are measured on the same pixel, allowing for a star-planet contrast of 10^{-7} to 10^{-8}. Achieving this contrast also requires the use of a coronagraph with clever calibration and dither procedures. Planets with atmospheres are revealed, because their reflected light is polarized, while starlight is not polarized. Proto-planetary disks and debris disks will also be observed with this polarization technique.

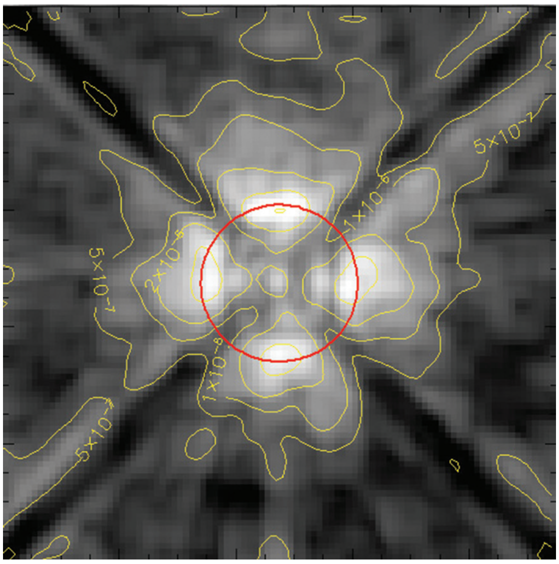

Figure 1: *Differential polarization image measured with the SPHERE-ZIMPOL system in the laboratory at Grenoble. Polarimetric contrast map (5σ confidence level) for coronagraph 5λ/D.*

Progress in 2010 - 2011- 2012

In 2010 and 2011 a number of critical, risky and technically challenging parts of the project were successfully completed. After FDR (Final Design Review) was passed in early 2010, the manufacturing, assembly, integration and testing work started. During this period a number of technical issues had to be solved: unstable new motor controllers, the new generation detector controller and gluing issues with the microlens array in front of detector required significant efforts. Other challenges were the instrument alignment, the alignment of the coronagraphs, setup of polarimetric and non-polarimetric pre-optics, instrument characterization and evaluation, and the development of the instrument software. The instrument evaluation was done in close cooperation with the team at the ETH Zürich and required several visits of the Zürich team to Dwingeloo. The instrument was validated and accepted just before Christmas 2011. In January 2012, the instrument was transported to Grenoble. After a standalone test it was integrated onto the SPHERE bench on 16 January 2012, alongside the two other focal plane instruments IFS and IRDIS. During 2012 there were about three weeks of testing of SPHERE-ZIMPOL, in the first quarter with passive AO, and in the second half of 2012 with active AO. During 2012 several remote test runs were done where the instrument was controlled from Dwingeloo, to test the software. In cooperation with INAF the data reduction software was further developed. Together with work on the documentation the instrument was prepared for the Technical Readiness Review, planned in January 2013. For 2013 the final two test weeks are foreseen in order to prepare for Preliminary Acceptance Europe (PAE, scheduled for Sep. 2013). Shipment to Paranal is expected by end 2013.

SPHERE as a whole also went through critical periods over the reporting period. Just like ZIMPOL, SPHERE struggled with the new motor controllers. Two other critical work packages were related to the adaptive optics system: the WFS unit and its detector controller, and the extreme AO mirror (41x41 actuators). The AO mirror produced for SPHERE does not have the full performance values due to a few slow or limited actuators. Corrective steps in hardware and controller software will still allow SPHERE to enter science mode with limited performance loss. Eventually the mirror may be replaced at a later stage.

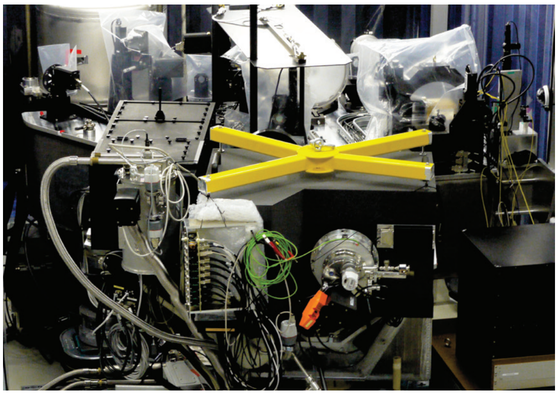

Figure 2: *ZIMPOL (with yellow hoist tool) integrated onto the SPHERE bench. ZIMPOL is located underneath its black cover with the detector cryostat sticking out.*

5.1.7. VLT MUSE-ASSIST

MUSE, the Multi Unit Spectroscopic Explorer, is a second-generation panoramic integral-field spectrograph for the VLT, due to start commissioning on the telescope in 2013. The instrument consists of 24 combined identical integral-field spectrograph units, covering simultaneously the spectral range 465 – 930 nm. MUSE will have two modes of operation, both of which are explicitly designed to exploit a complex multi-laser guide star (LGS) Adaptive Optics (AO) system, called GALACSI (Ground Atmospheric Layer Adaptive Corrector for Spectroscopic Imaging), envisioned as part of the approved VLT Adaptive Optics Facility (AOF), at the heart of which is the development of a Deformable Secondary Mirror (DSM) for the VLT.

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Critical to ESO's DSM development (and therefore also to MUSE) is ASSIST: Adaptive Secondary Setup and Instrument STimulator. This facility will act as the primary test-bench for ESO's DSM development, used for verifying control algorithms and hardware, functional validation of AO-Facility instruments, and ensuring the DSM operates at specification before being deployed at the VLT. Furthermore, ASSIST will be used to verify the full closed-loop operation of the AO systems for MUSE (GALACSI) and the IR imager HAWK-I (GRAAL). ASSIST has been developed and assembled at NOVA in Leiden and is due to start operation at ESO, Garching, in spring 2013, given by the delivery of the DSM.

Instrument specifications

The primary mode of MUSE has a wide (1 x 1 arcmin) field of view. It is able to operate with or without the AOF, and will be used for conducting uniquely sensitive deep-field surveys with the key goal of understanding the progenitor population of present-day 'normal' galaxies. The second mode of MUSE aims to provide the unique capability of near-diffraction limited spatial resolution at optical wavelengths over a large 7.5 x 7.5 arcsec field. This will be used for a variety of science goals, including monitoring solar-system bodies; studying the complex emission regions of Active Galactic Nuclei (AGN), and studying young stellar objects.

NOVA's involvement in the MUSE instrument is many-fold, distributed across three inter-related areas of the project:

- The MUSE spectrograph scientific impact: participation in the MUSE science team and Guaranteed Time Observation (GTO) allocation, providing key operations-based deliverables, like the MUSE Exposure Time Calculator (ETC), and estimating the achievable sensitivities in the different instrumental and target configurations.
- Put in place a data management structure for the MUSE GTO program using AstroWISE.
- The Interface Control Document: controls all aspects of interfacing MUSE with the GALACSI AO system and VLT AO Facility. This also involves the development of tools required for optimal use of the AO system for scientific use and the development of the Slow Guiding System – a system that maintains the (optical) interface stable between MUSE and GALACSI by monitoring faint stars just outside the MUSE scientific field.
- The ASSIST test-bench: facility for testing and integrating the ESO DSM and AO-Facility instruments.

International Consortium

The MUSE consortium consists of six core institutes: Astrophysikalisches Institut Potsdam (AIP), Potsdam; Centre de Recherche Astronomique de Lyon (CRAL), Lyon; ESO, Garching; NOVA; Eidgenössische Technische Hochschule (ETH), Zürich; Laboratoire d'Astrophysique Observatoire Midi-Pyrénées (LAOMP), Toulouse; and the University of Göttingen, Göttingen. Bacon (CRAL) is the overall instrument PI.

Progress in 2010 - 2011 - 2012

The MUSE team in the Netherlands is led by Schaye together with Franx. Furthermore, Serre worked as a full-time NOVA Postdoc on MUSE, developing, among other things, the MUSE Exposure Time Calculator and the data calibration and de-convolution procedures. He was succeded by Martinsson, also a NOVA Postdoc, for integrating the MUSE GTO data reduction in AstroWise. Further contributions to the MUSE science were made by Brinchmann (also member of the MUSE Science Team), Bouwens, Van de Voort (PhD, virtual deep Ly-alpha fields and cosmological simulations) and Rakic (PhD, explored what MUSE can do to study the interaction between galaxies and the intergalactic medium), and Turner (PhD, target selection).

During 2010-2012 MUSE was fully in its manufacturing and integration phase. At the end of 2011 first light for the first complete path (of the twenty four) through a single spectrograph was obtained, allowing for a first demonstration of the performance of MUSE. Preliminary acceptance Europe is now expected for Sep 2013. MUSE will operate several years before the AO system will be installed, opening up its full potential.

Brinchmann is in charge of a group to put in place a data management structure for the MUSE GTO program. This is done with support of LAOMP, Toulouse and AIP, Potsdam. During 2011 the decision was taken to use AstroWISE for managing the data from the MUSE GTO program. The MUSE data reduction pipeline has now been successfully integrated into the AstroWISE structure and a review of this system was undertaken in October 2011. The full integration of the MUSE pipeline has been significantly aided by the appointment of Martinsson (NOVA post-doc) and, in parallel, Toulouse with the assistance of Brinchmann are now expected to design a quality assurance framework for MUSE GTO data.

ASSIST

ASSIST is entirely designed and built by NOVA, with strong ties to ESO and ADS/Microgate, the manufacturers of the DSM. Furthermore, the participation within the European 7th Framework Program together with other European institutes on Adaptive Optics for the next generation of telescopes ensures a good connection with other European institutes working on Adaptive Optics. Within NOVA, Stuik is the PM for ASSIST. He was supported by Molster (NOVA), Deep (NOVA Postdoc), and in a later stage by de Haan (NOVA Op-IR group) during the integration at Leiden and ESO. Ter Horst (NOVA Op-IR group) supported Stuik in the acceptance tests of the optical components at both AMOS and Winlight.

During 2010 and 2011, all components for ASSIST have been manufactured at several companies spread out through Europe. The main components for ASSIST are the mechanical structure (Boessenkool, Almelo, the Netherlands), the 1.8m diameter ASSIST Mirror 1 (AM1, AMOS, Liege, Belgium), ASSIST Mirror 2 (AM2, NOVA Op-IR group) and the integrated optical modules (Winlight, Pertuis, France). Integration and testing of the ASSIST Star Simulator and Turbulence Generator (SSTG) and the VLT focus simulator at Leiden Observatory was done by Stuik, de Haan (NOVA Op-IR group) and Deep (NOVA postdoc), from end-2010 until mid-2011. The performance of these modules of ASSIST was found to be well within the specifications. After Temporary Acceptance Leiden (TAL), the ASSIST SSTG and VFS were moved to ESO and integrated by Stuik and de Haan with the DSM tower, the mechanical structure that will hold the Deformable Secondary Mirror during testing. Final alignment for ASSIST was completed early 2012, with the integration with the DSM taking place by the end of 2012.

Both the MUSE and ASSIST projects are governed by their individual agreements with ESO. The two projects together will yield a total of 255 nights of GTO time for the MUSE consortium on MUSE, to be used mainly for a coordinated set of deep surveys. In parallel with the development of the MUSE instrument, preparations have started for the use of the GTO time and required preparatory observations. Furthermore, the science team has been keeping a close eye on the impact of the design of MUSE with regards to the scientific performance of MUSE.

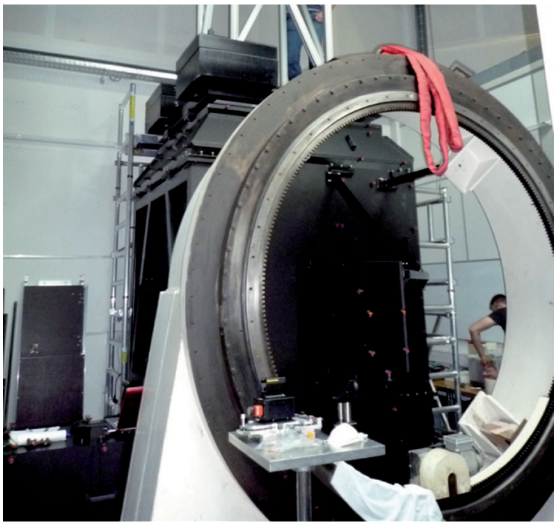
Preparing for science

Three PhD students working with Schaye at Leiden have been supporting the investigations into the optimal use of MUSE GTO time. Van de Voort has written software for the creation of virtual deep fields from cosmological simulations. Rakic has used both numerical simulations and real data to investigate what the data requirements are for studying the connection between galaxies and the intergalactic medium by targeting fields that contain bright background QSOs or gamma-ray bursts. PhD student Turner has continued the work of Rakic. She will also be involved in the processing and analysis of the data. Together with postdoc Bertone (UC Santa Cruz) and van de Voort, Schaye has worked on predictions for MUSE regarding emission from the intergalactic medium. Brinchmann has helped with simulations of datacubes based on real data from the Hubble Ultra-Deep Field with particular emphasis on the intermediate redshift galaxy population. Three papers have been published with methods/predictions for MUSE.

For the dry run process, Brinchmann has been responsible for creating input data cubes for galaxies in the Hubble Ultra Deep Field. These have been adopted as reference simulations for testing part of the MUSE data reduction pipeline. During a 2 month stay as a invited professor in Lyon (May-July 2011), Brinchmann has improved these and used them to quantify the expected number of [O II] emitters in MUSE data and their properties.

Alignment and testing of ASSIST at ESO Garching was concluded with a successful Preliminary Acceptance in October 2012. Following initial system test on the DSM itself, ASSIST was integrated with the DSM in January 2013. After the testing of the DSM, ASSIST will be used to test GRAAL and GALACSI. Finally, ASSIST will be shipped to Paranal for final tests before the DSM is installed on the UT4 of the VLT.

Schaye was awarded an ERC starting grant that included funding for one PhD student (from 1/9/2013) and one postdoc (from 1/9/2013) to work on MUSE data. Brinchmann was awarded a PhD position (starting 1/9/2012) in the NWO open competition to work on MUSE.



ASSIST during its final integration at ESO, Garching. The instrument rotator (large ring in the front) will hold the AO systems under test (GALACSI and GRAAL). The DSM will replace the alignment tower (light gray aluminum struts) and dummy weights (~2000 kg square blocks on the top of ASSIST). All of ASSIST is covered to minimize stray light into the system.

5.1.8. MATISSE

MATISSE is a 4-telescope, 6-baseline interferometer for ESO's VLTI whose goal is to image galactic and extragalactic mid-infrared sources on milliarcsec spatial scales with spectral information. The primary scientific targets are protoplanetary disks around young stars and the dusty accretion disks of AGNs. Additional scientific targets are the dusty structures around young massive stars, the winds from evolved stars, solar system objects, and possibly exoplanets.

Instrument concept

MATISSE will operate as a "camera" at the VLTI, combining the light from either four of the 8m Unit Telescopes, or four of the 1.8m Auxiliary Telescopes, or possibly combinations of both. In this way, at any time visibilities on six baselines can be measured simultaneously, and a large number of "UV-points" can be measured in one day by the Earth-rotation technique familiar to radio astronomers. The Auxiliary Telescopes can also be moved on the ground to access more UV-points. MATISSE will operate simultaneously at N-band (8-13 μm), M-band (4-5 μm) and L-band (3-4 μm), and the visibilities will be measured with spectral resolutions of 30, 300, 1000, or 5000. Atmospheric phase fluctuations can be corrected by internal tracking for stronger sources, or with an external tracker to be built by ESO.

The chief technical challenge is the complexity of combining four infrared signals in a stable, calibratable way simultaneously over such a wavelength range, in addition to the extreme stability and accuracy necessary to achieve IR interferometry at 100 meter baselines. No other facility is available in the world for imaging infrared interferometry at the wavelengths and baselines covered by MATISSE.

International consortium

The project is being developed by an international consortium in cooperation with ESO. The primary consortium partners are: the Observatoire de Cote de Azur (UNS-CNRS; PI Bruno Lopez and PM Pierre Antonelli), Max Planck Institute for Astronomy (Heidelberg), Max Planck Institute for Radio Astronomy (Bonn), and NOVA. The work at NOVA is done at the Op-IR instrumentation group in Dwingeloo and at Leiden Observatory. Each of these four partners has its own technical specialty and contributes approximately one quarter of the resources necessary for MATISSE. ESO contributes the detector system and funding for hardware procurement.. Minor partners in the consortium include ITAP (Kiel), Vienna University, and Konkoly Observatory (Budapest).

The principal contributions of the Netherlands to the instrument are the design and construction of the Cold Optical Bench (NOVA Op-IR group), fringe tracking software (Leiden Observatory), and participation in the international effort as project scientist (Jaffe).

Progress 2010 – 2011 - 2012

2010 was fully spent on the detailing of the PDR design. The original Matisse design required extreme tolerances and was considered not manufacturable against reasonable cost. The new design resolved these issues with a reduction in complexity and in the number of components and passed successfully delta-PDR in mid December 2010. The new design consists of an imager, a beam shaper that creates the required anamorphism and combines the four input beams, followed by a filter, polarizer, disperser wheel and camera that focuses the four beams on the detector.

On January 14, 2011, a national NL science day was organized to probe the Dutch interest in Matisse. The conclusions were that there is strong Dutch interest to use the instrument for observations of proto-planetary disks, characterization of exoplanets and AGNs. Matisse and ALMA were found to be complementary and there is also synergy between Matisse and METIS.

The science day was followed a few days later by a NOVA initiated mini review meeting to verify the Dutch contributions in the MATISSE project, consisting of panel members Pel, Le Poole and Bettonvil with the task to review how solid the work package is, how much personnel effort is needed and whether resources are available. The overall impression of the Dutch contribution to MATISSE was very good. The panel concluded that the state of the MATISSE design was mature and reliable and several points beyond PDR level. The advice was given to investigate an arrangement where the Dutch team takes a stronger, more leading role in the overall instrument system engineering. The recommendations resulted in a by NOVA increased contingency to the level of 20%, and arranging a role for Venema as consortium wide system engineer for all internal interface issues. Mid 2011 the NOVA Board gave final approval for the full Dutch contribution to Matisse.

As of February 1, 2011, Bettonvil was appointed as project manager for Matisse and co-PM in the consortium. In the following months the optical design was detailed, characterized and frozen, followed by the Warm Optics, Cold Optics and Cryogenics final design review in September 2011. This FDR was passed successfully with compliments for management and system engineering and working well together. Completion of this milestone initiated the start of the optics procurement.

NL project PI
Jaffe

NL co-I's
Hogerheijde
Dominik
Snellen

Project team
Agocs
Bettonvil (NL PM)
Elswijk
de Haan
ter Horst
Jasko (Hungary)
Kragt
Kroes
Navarro
Schuil
Tromp
Venema

The MATISSE project passed its mechanical FDR in April 2012. No major issues appeared. The review took place in a very collaborative way. ESO gave the consortium a green light to go ahead with construction of the instrument. For the remaining part of 2012 the consortium worked on the preparation of final drawings, manufacturing of instrument parts and integration and testing of first sub-assemblies. The project entered one of its busiest phases with a major fraction of the mechanical design and production capacity in the NOVA Op-IR group working on MATISSE.

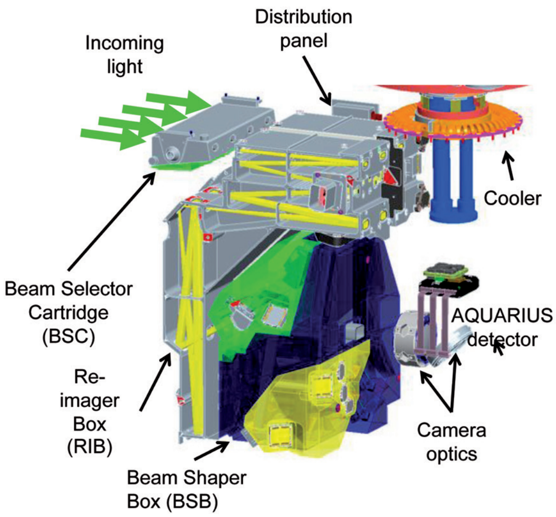
Hungary, the newest partner in the MATISSE consortium, provided ~1 staff year manpower contribution in mechanical design of the cold optics, which ended on August 28, 2012, when the engineer (Jasko) left the Op-IR group in Dwingeloo, after 10 months of being member of this group. As part of the start-up of an instrumental group in Hungary, Jasko returned to Hungary to continue his study and work in the group at Konkoly Observatory.

High spectral resolution module

Hogerheijde (NL co-PI) joined the team and strengthened the connection between MATISSE and ALMA. The international consortium science team ramped up its activities by validating the final MATISSE design and starting preparation of the GTO program. As this develops, a national Dutch team will be organized to provide input to the two Dutch members of the consortium team. Addition of a high-resolution (R=5000) mode for observation in the CO-line (4.7µm) and Br-alpha line (4.05 µm) was discussed in detail within the consortium. A technical feasibility study was carried out and the science motivation further developed. The study concluded that this extra mode could be integrated in MATISSE, within acceptable constraints, as long the development can be done in parallel with the current work plan of MATISSE, avoiding extensive delays. A high-resolution grism will be accommodated in an existing free slot in the disperser wheel. The science justification of a higher resolution mode was recognized by ESO at the FDR, and the HR grism option was subsequently introduced to ESO directly after the FDR meeting and further discussed during SPIE in Amsterdam in July 2012.

Preparing for science

The Dutch astronomical institutes are entitled to a fraction of the Guaranteed Observing Time (GTO) on MATISSE in proportion to their contribution to the project, ~22.2%. The GTO is expected to be 37.5 nights using 4 Unit Telescopes at Paranal, and 7.2% of the available time on the Auxiliary Telescopes over 8 years. The MATISSE organization includes a Science Group whose duty is to plan for the scientific use of MATISSE, particularly the GTO time. Each major partner has two members on this team, and some of the minor partners have one member. The Dutch members are Jaffe (AGN) and Hogerheijde (protoplanetary disks). As the actual operation of MATISSE approaches, the Science Group will draw up a detailed GTO plan, respecting the proportional contributions of the consortium members. The Dutch Science Group members will organize the Dutch contribution by assembling the Dutch MATISSE Science Team, communicating to them the capabilities of the instrument and assessing the specific desires of the Dutch astronomical communities. This input will be used to steer the Dutch participation in the international MATISSE Science Group.



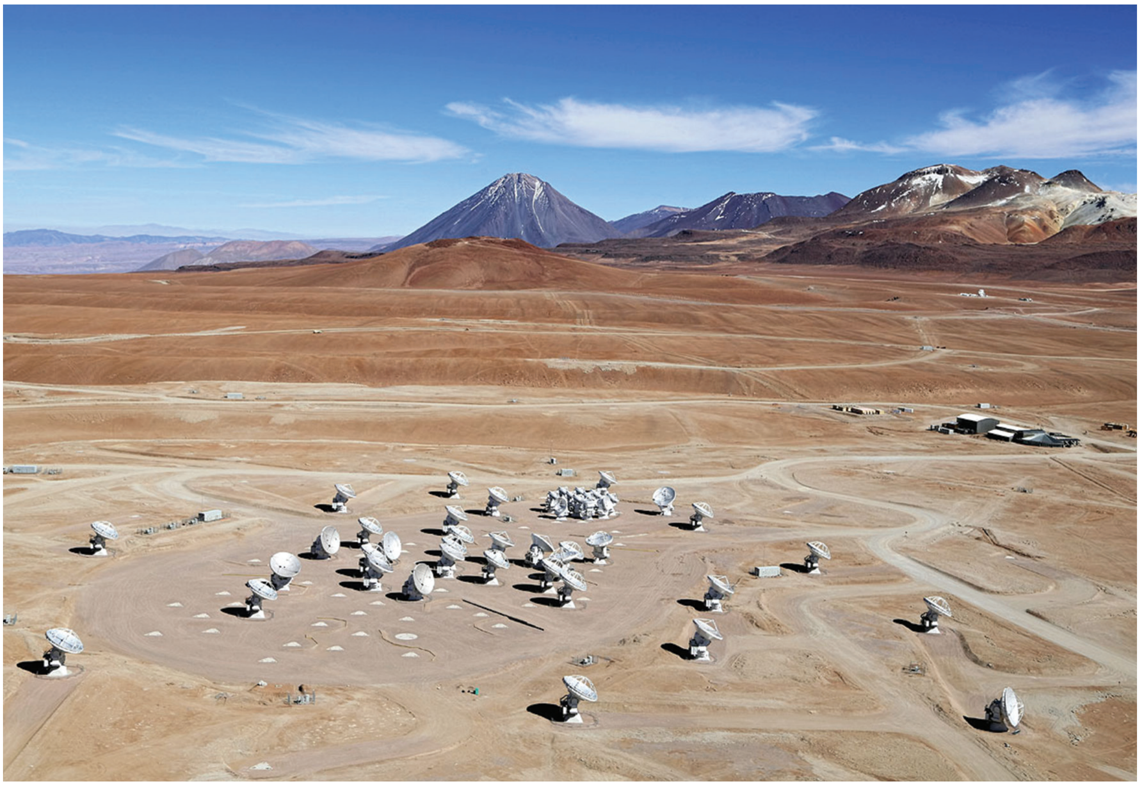
Schematic view of the Cold Optical Bench, the Dutch contribution to the MATISSE instrument. The COB combines the light of 4 telescopes into one high angular resolution image. It consists of over 200 optical components. All optical paths together have a length of 56m, multiply-folded to fit into two cryostats of 1x1x0.5m each.

5.2. ALMA related projects

NOVA is involved in the development and production of receivers for ALMA and in its science support by providing a node of the European ALMA Regional Center (Section 5.2.1). In 2000-2012 the NOVA-ALMA group located at the Kapteyn Institute of the RUG and working within SRON Groningen developed and manufactured the Band-9 receiver cartridges, optimized for the atmospheric window at the frequency range of 602-720 GHz (equivalent to wavelengths around 0.4 mm, Section 5.2.2). In 2011 the NOVA-ALMA group also participated in a study for the series production of the Band-5 receivers for ALMA in collaboration with GARD in Sweden and RAL in the UK.

The Atacama Large Millimeter/submillimeter Array (ALMA), an international astronomy facility, is a partnership of Europe, North America and East Asia in cooperation with the Republic of Chile. ALMA is funded in Europe by ESO, in North America by the U.S. National Science Foundation (NSF) in cooperation with the National Research Council of Canada (NRC) and the National Science Council of Taiwan (NSC) and in East Asia by the National Institutes of Natural Sciences (NINS) of Japan in cooperation with the Academia Sinica (AS) in Taiwan. ALMA construction and operations are led on behalf of Europe by ESO, on behalf of North America by the National Radio Astronomy Observatory (NRAO), which is managed by Associated Universities, Inc. (AUI) and on behalf of East Asia by the National Astronomical Observatory of Japan (NAOJ). The Joint ALMA Observatory (JAO) provides the unified leadership and management of the construction, commissioning and operation of ALMA. ALMA will be a single instrument composed of 66 high-precision antennas located in Region II of Chile, in the district of San Pedro de Atacama, at the Chajnantor altiplano, 5,000 meters above sea level. ALMA's primary function is to observe and image with unprecedented clarity the enigmatic cold regions of the Universe, which are optically dark, yet shine brightly in the millimeter part of the electromagnetic spectrum. When complete, ALMA will observe in 10 frequency bands between 30 and 950 GHz, with a maximum baseline of up to 18 km. By moving telescopes to different platforms it will be able to observe in a wider field of view mode or in a close up mode with highest angular resolution in the range of milliarcseconds.

At the end of 2012 about two-thirds of the ALMA array construction was completed. Early science operations involving an array of up to 16 telescopes in a configuration with longest baselines of ~500 m started in September 2011. An example of an early science result obtained with ALMA with the NOVA built Band-9 receivers is described in Section 5.2.1.



The core of the ALMA array in operation on the 5000m altitude Chajnantor plateau in the Chilean Andes.

5.2.1. Allegro

NL project PI
Hogerheijde

NL co-I's
Barthel
Hogerheijde
Van Dishoeck
Dominik
Van Langevelde
Oosterloo
Roelfsema

Project Team
Brinch (until 8/2011)
Frieswijk (until 12/2010)
Juhasz
Van Kempen
Klaassen (from 2011)
Kospal (2011)
Schleicher (until 5/2011)
Schmalzl
Tilanus (from 5/2012)
Torstensson (until 4/2012)

Allegro is one of the nodes of the European ALMA Regional Center. It assists ALMA users with proposal preparation and calibration, reduction, and analysis of their ALMA data. Furthermore, Allegro aims to provide expert advice on high-frequency observing with ALMA, future (sub)mm Very Long Baseline Interferometry (mmVLBI), synergy with radio techniques, and the use of advanced science-analysis software. In order to build up the necessary expertise, Allegro staff is actively involved in the analysis of ALMA Science Verification observations. Allegro staff has been pivotal in ensuring the science return from ALMA Cycle 0. One Allegro staff member was stationed with the ALMA project in Chile for a period of two years (2010–2012) as a full member of the ALMA Commissioning and Science Verification team.

Allegro is part of the European ALMA Regional Center (ARC), a network of seven nodes (Allegro, Netherlands; Bonn, Germany; Bologna, Italy; Grenoble, France; Ondrejov Czech Republic; Onsala, Sweden; and Manchester, UK) with a core at ESO. Each of the nodes provides face-to-face user support and hosts one or more unique expertise areas. The ESO ARC core provides coordination of the activities and offers centralized support for proposal handling and data storage. It also functions as the main interface with the ALMA project in Chile and the two other ARCs in North America and East Asia.

Allegro is hosted by Leiden Observatory and coordinated by Hogerheijde. Allegro employed three postdocs in 2010–2012 on NOVA instrumentation funding and four more postdocs on additional funding. Allegro activities started in 2004 when an ARC node in the Netherlands was proposed to ESO. It was formalized in 2008 with the signing of a Memorandum of Understanding (MoU) between ESO and the nodes. In 2011 a further MoU was signed between NOVA, NWO/EW, and Leiden Observatory. The European ARC network commenced full operations in 2011 with the start of ALMA Early Science observations.

Allegro contributes unique expertise to the ARC network in the areas of high-frequency observing (in particular to support the receivers supplied by the Netherlands to the ALMA observatory) and more recently has started supporting efforts towards global mmVLBI with ALMA. It is exploiting the synergy between ALMA and existing techniques at radio wavelengths (via collaborative work with ASTRON and JIVE, and in connection with other nodes) and science analysis software (via the development of a dedicated web site, planned training schools, and in collaboration with the Bonn and Onsala nodes as well as an ASTRONET-funded development project).

Progress in 2010 - 2011 – 2012

The ALMA project made tremendous progress in 2010 - 2012. Where early 2010 saw the first few antennas in place on Chajnantor, by late 2012 more than 25 antennas were routinely operational at the site and the first cycle of science observations was successfully concluded. Commissioning and Science Verification (CSV) dominated during 2010-2011, delivering several Science Verification data sets to the community, including for a project proposed by Hogerheijde. Allegro postdoc van Kempen joined the ALMA CSV team in October 2010 for a period of 2 years and focused on ALMA calibration, imaging, and especially high-frequency observing strategies. Throughout, he reported regularly to the other Allegro staff, and returned to Leiden in October 2012.

In spring 2011 focus shifted to Early Science observing with the issuance of a call for Cycle 0 proposals, even as CSV continued unabated. The response to the Cycle 0 call for proposals was overwhelming, with a total of close to 1000 proposals submitted worldwide representing an oversubscription factor of ~10. Within Europe, the oversubscription factor was even higher at ~14, showing the great scientific demand for ALMA, and also illustrating the effectiveness of the ARC network in generating interest. Of the submitted proposals, 25 had PIs with a Netherlands affiliation, including 65 co-Is from the Netherlands. Three proposals with PIs from the Netherlands were accepted (led by van Dishoeck, Kospal, and Falcke), and a further 22 Netherlands co-Is were listed on accepted proposals.

In the run-up for the Cycle 1 deadline (July 2012), further preparatory workshops and institute visits were organized by Allegro. Out of a worldwide number of 1133 submitted proposals for Cycle 1, 34 were NL-led, and 87 unique co-Is were involved. Of the 196 proposals selected for observation, 4 were NL-led including 30 co-Is from the Netherlands.

Early Science: The expertise areas of Allegro were further developed in 2010 through 2012. van Kempen's secondment to ALMA CSV focused on high-frequency observing with exploratory work on identifying suitable calibrators. Torstensson was hired for a 6-month period on a joint appointment with JIVE to explore the wide-field imaging aspects of ALMA. For the third expertise area, namely support for science analysis tools, Allegro postdoc Klaassen and ESO COFUND-fellow Schleicher (hosted by Allegro) developed a dedicated web site. To assist with the interpretation of the groundbreaking, but often complex, ALMA observations Juhász released ARTIST, which enables comprehensive multi-dimensional radiative transfer calculations of the dust and line emission.
In addition to these expertise areas, all Allegro staff have contributed to ALMA data Quality Assurance and face-to-face user support of ALMA users.

ARC node network: Hogerheijde is a member of the ARC Coordinating committee, which meets at least once a year in Garching or at another node location. Monthly telecons are conducted between the ARC nodes and Garching, in addition to more frequent in-depth sessions on selected topics. A yearly all-hands meeting (since 2011) further improves the cohesion in the network and offers valuable training opportunity for all Allegro staff. For its user support activities Allegro put in place a dedicated fast computing infrastructure able to handle the large ALMA data volumes, a project overseen by Allegro postdoc Schmalzl.

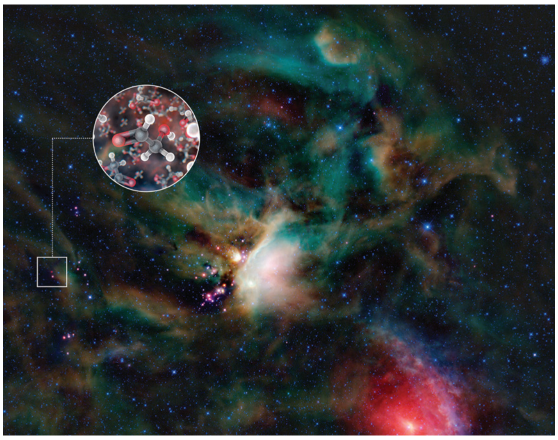
Future developments: With ALMA nearing completion in 2013, NWO/Physical Sciences has approved an application for longer term funding (at the level of several postdocs, one senior fellow, and a Program Manager position) for 2013 and beyond. A MoU between NOVA, NWO, and Leiden Observatory was signed in November 2011 to formalize the establishment of Allegro. The ramp-up of the NWO-funded activities was reviewed in late 2012, and 2012's activities were reviewed in March 2013 by the Allegro Steering Committee instituted in the NOVA/NWO/Leiden Observatory MoU.

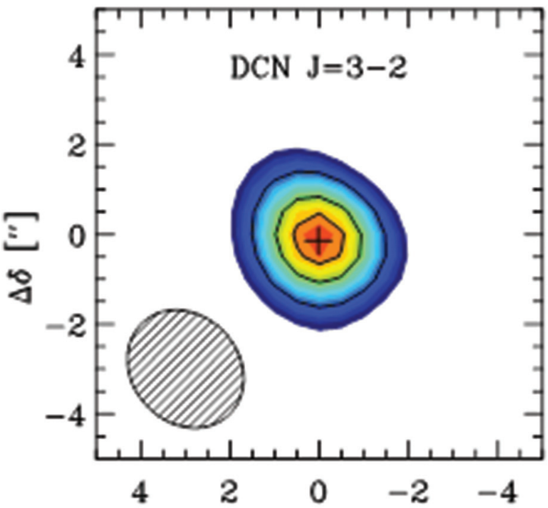
Building out the user support and further development of Allegro's expertise areas will be the main focus of the new Program Manager, Tilanus, who took up this position at the end of 2012. Allegro staff is expecting to take a leading role in the development of long-baseline and high-frequency observing with ALMA, as well as exploring innovative capabilities, such as dual-frequency observations. In this context it has started collaborations with SRON (Groningen) and the University of Cambridge (UK). Tilanus is actively involved in the development of a future network for mmVLBI with ALMA, an associated research group at the Radboud Universiteit, and user-support through Allegro.

First science results

Unlike other instrumentation projects, ALMA does not have Guaranteed Observing Time. Many of Allegro's activities are directed at developing a user base in the Netherlands, and optimally supporting potential users in proposal preparation. For approved projects, Allegro plays a pivotal role in the preparations of the observations, and in the calibration and imaging of the results.

Alongside the role of Allegro in assisting proposers in writing their proposals and, if approved, designing their observing programs, and in carrying out Quality Assurance of completed projects, Allegro staff have played important roles in realizing the early science output of ALMA. In 2012, the first 19 papers appeared in the refereed literature containing ALMA observations. This includes three papers with involvement from Dutch astronomers, including Allegro and its staff: Jørgensen et al. (2012, ApJ 757 L4; see Figure) report the finding of a simple sugar molecule (glycoldehyde) in the warm material surrounding a forming star. This Band-9 results was accompanied by considerable press attention. Allegro postdoc van Kempen was co-author on Pineda et al. (2012, A&A, 544, L7) that describes the kinematics around the two young stars in the same data set. Allegro Program Director Hogerheijde was involved in Öberg et al. (2012, ApJ, 749, 162) that presented evidence for multiple routes of deuteration in the disk around TW Hya, a Science Verification project originally suggested by Hogerheijde (among others). Throughout 2012, Allegro assisted PIs in the Netherlands with preparing, calibrating, imaging, and analyzing ALMA data for several projects that were published in 2013.





__Left:__ Artist's impression of the detection by ALMA of glycoaldehyde, a simple sugar molecule, in the warm gas around the forming solar mass star (Jørgensen et al. 2012); __Right:__ Detection of DCN in the disk around TW Hya, suggesting a high(er) temperature route towards deuteration of disk gas (Öberg et al. 2012).

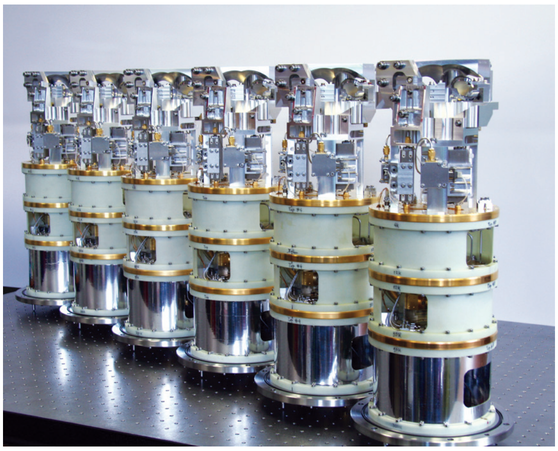
5.2.2. ALMA receivers

Band-5 team

Adema (PM)
Barkhof
Bekema
de Haan
Hesper
Koops

Band-9 receivers

Within the Netherlands, a collaboration of NOVA, RUG, SRON, and the Kavli Institute of Nanoscience in Delft has developed heterodyne receivers for ALMA to operate at frequencies between 602 and 720 GHz, the Band-9 receivers. The work is built on the heritage at SRON and the Kavli Institute of technical R&D, design and construction of the HIFI instrument for the Herschel satellite. The ALMA Band-9 work was done under a contract between ESO and NOVA. As one of the highest frequency bands in the ALMA project, the Band-9 receivers will provide the observatory's highest spatial resolutions and probe higher temperature scales to complement observations in the lower-frequency bands (between 84 and 500 GHz). A dedicated production team of ~12 people lead by NOVA and based at RUG/SRON in Groningen has produced and tested 72 Band-9 receiver cartridges between 2005 and 2011. The last cartridge was delivered in December 2011. In 2012 the work changed to production of spare parts sufficient to guarantee a 20 years operational lifetime of the Band-9 receivers.



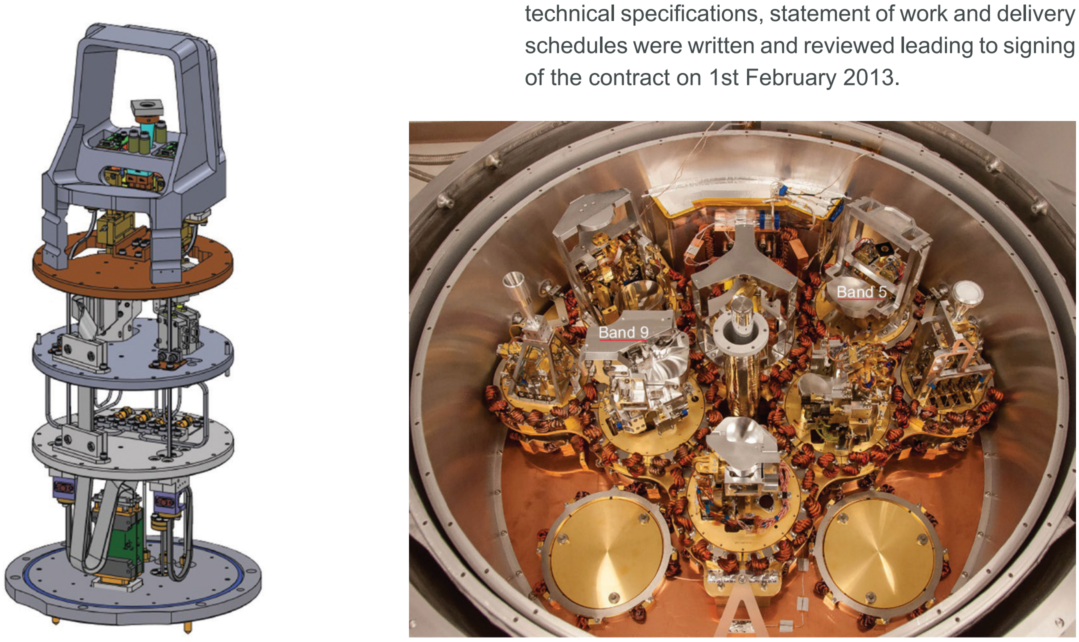
ALMA Band-9 production receivers

Band-5 receivers

In 2011 NOVA, GARD (Group for Advanced Receiver Development of the Onsala Space Observatory, Sweden) and RAL (Rutherford Appleton Laboratory, UK) studied various options for the production of 67 ALMA Band-5 receiver cartridges enabling ALMA to observe in the atmospheric window between 163 – 211 GHz with the full array from 2017 onwards. The study has shown that this work is feasible and financially affordable if Europe and North America work together with NOVA-GARD under contract with ESO to produce and integrate the heterodyne receivers and the cartridge assembly, and NRAO delivers the local oscillators, as was done for the other receiver bands in ALMA. The project builds on the technology development at GARD and RAL for the design and pre-production of six ALMA Band-5 receiver cartridges funded within the European Commission FP6 program. In October 2011 the first pre-production cartridge was integrated in one of the ALMA Frontends and had its first light from an astronomical source on an ALMA antenna at Chajnantor in Chile soon thereafter.

In the Band-5 collaboration NOVA provided the experience of cartridge integration and testing in a series mode. This involvement led to a mechanical redesign of the Band-5 cartridge to ease assembly and to allow better access to critical components for maintenance and repair, an important aspect for a receiver intended to be in operation for a period of 20 years.

In May 2012 ESO finance committee approved the proposal by NOVA and GARD for the production and delivery of 67 ALMA Band-5 receiver cartridges. Work began thereafter on a reassessment of the technical specifications and mechanical redesign of the cartridge body. In parallel, contract documents, technical specifications, statement of work and delivery schedules were written and reviewed leading to signing of the contract on 1st February 2013.



Left: *drawing of the redesign of the Band-5 receiver cartridge;* **Right:** *top-view of the ALMA frontend with reference to the locations of the Band-9 and Band-5 receiver cartridges.*

5.3. OmegaCAM and OmegaCEN

OmegaCAM is the wide-field camera at ESO's VLT Survey Telecope which started operations in 2011. OmegaCEN is the partly NOVA funded national datacenter for wide-field imaging and the expertise center for astronomical information technology. It is situated at the Kapteyn Astronomical Institute of the RUG. It brings together astronomers and astronomical IT experts. About 15 persons (scientific staff, postdocs, PhD students and scientific programmers) work at OmegaCEN and jointly conduct astronomical research and R&D for astronomical information systems. OmegaCEN is partner in international optical, near-infrared and radio surveys, ESA space missions, ground-based wide-field imagers and spectrographs. The technology and data flow components developed by OmegaCEN are ported to market applications and scientific disciplines dealing with Big Data. This is done in the framework of Target, a public private partnership in which OmegaCEN has a leading role.

Commissioning of OmegaCAM

The one square-degree optical OmegaCAM imager at the VLT Survey Telescope (VST) was commissioned successfully at ESO Paranal in 2011. In total four commissioning runs were executed between March and August 2011. OmegaCEN (PI Valentijn) led the data flow operations for commissioning on Paranal with a real-time 'back-office' in Groningen. The instrument produces very good image quality (up to 0.6 arcsec resolution) over the full field of view, exploiting its own wavefront sensing system. The handling of eight Terabytes of OmegaCAM commissioning data and dry runs for surveys went smoothly. It represented a good test for the data flow system at OmegaCEN and commissioned its team in performing end-to-end survey operations.

Weak-lensing survey KiDS+VIKING: *survey production, early science pilots*

Regular survey operations with OmegaCAM at the VST commenced in October 2011. OmegaCEN leads the European survey production team that handles the Kilo Degree Survey (KiDS, PI Kuijken) using the Astro-WISE survey system (see below). KiDS is the largest (440 nights) of ESO's Public Surveys with OmegaCAM. It is a 1500 square-degree survey through 4 optical filters (u,g,r,i). OmegaCEN coordinated several team-internal deliveries of KiDS survey products (images, masks and catalogs) in 2012 and delivered to ESO the first public release, published by ESO in 2013. The KiDS team combines in Astro-WISE its survey data with VIKING, the near-infrared counterpart of KiDS using VIRCAM at the VISTA telescope. The VIKING survey products (images and catalogs) are delivered by CASU/WFAU in the UK. KiDS+VIKING main science driver is the nature of dark matter and dark energy as a function of redshift through weak-lensing tomography. KiDS data has many more scientific applications including for example galaxy evolution in superclusters, discovery of large samples of high redshift QSOs, extreme brown dwarfs and strong lenses and the study of the Milky Way halo stars. OmegaCEN is involved in many of these science projects.

OmegaCAM GTO science

In exchange for providing the OmegaCAM instrument for ESO's VST, NOVA was granted a significant amount of guaranteed observing time: nearly 9% of all VST science time until 2021. OmegaCEN provides for this period to the Dutch astronomical community the environment and infrastructure in which science teams with Guaranteed Time Observing (GTO) projects can efficiently generate their science-grade data. The teams, distributed over the Netherlands, can collaborate in a common environment provided within Astro-WISE for the calibration, science data production, quality assessment and their public data releases. The GTO science projects have been ramping up since 2011 and include currently the ultracompact stellar dwarf survey OmegaWHITE, the Hercules supercluster survey, a survey of Local Group dwarf galaxies and the Fornax Ultradeep Cluster Survey.

Multi-survey system Astro-WISE

Astro-WISE is the workhorse for both survey production and also scientific research for KiDS/VIKING and the OmegaCAM GTO projects. It is a unique, advanced survey information system that supports in similar fashion over a dozen additional optical and near-infrared imagers. Astro-WISE was designed and developed in-house and is coordinated by OmegaCEN. Over 2010-2012 OmegaCEN has continued to coordinate Astro-WISE. The system connects in real-time databases, compute and storage grids available at national datacenters and satellite nodes across Europe. Geographically-spread survey teams collaborate in this single virtual research environment

The Hercules galaxy cluster (also known as Abell 2151) lies about 500 million light-years away in the constellation of Hercules observed with VST-OmegaCAM. It is unlike other nearby galactic assemblies in many ways: as well as being rather irregular in shape, it contains a wide variety of galaxy types, particularly young, star-forming spiral galaxies, and there are no giant elliptical galaxies. The data were processed at OmegaCEN using the Astro-WISE software system.

OmegaCAM

NL project PI
Kuijken

OmegaCEN

NL project PI
Valentijn

Project team
Begeman
Boxhoorn
Helmich
McFarland
Verdoes Kleijn

accessing these resources to calibrate astronomical wide field imaging data up to the Petabyte regime and to do research analysis and publish the results.

Astro-informatical and visualization research

Two PhD projects in these research fields were completed at OmegaCEN. 'Query-driven visualization of large scale multi-dimensional astronomical catalogs', by Buddelmeijer (2011) and 'Extreme data lineage in ad-hoc astronomical data processing' by Mwebaze (2012). They were focused on enabling astronomers to efficiently run their mining algorithms, specialized processes and to visualize and publish results for a Petabyte-sized ocean of data. This is achieved by imposing extreme data lineage ('Data about Data') to all processing steps via datacentric models that keep track of the processing configuration and propagation of pixel and metadata via databases. Mwebaze (Nuffic PhD student) worked on extreme data lineage in a distributed environment. His work exploited data lineage in scientific pipelines to the sub-image level and to couple eventually applied methods and programs to the data in a database. Query-driven visualization of very large catalogues was developed by PhD student Buddelmeijer in collaboration with the Scientific Visualization and Computer Graphics research group of the Mathematics and Computer Science department in the NWO-STARE program AstroVIS. The goal was to give within the visualization process direct access to multi-dimensional 10-100 Tb datasets, which current visualization techniques cannot handle alone. This work is an emerging domain called 'query driven visualization'. A first prototype for query-driven visualization was designed and implemented in Astro- WISE. Follow-up research projects have been awarded a NWO e-Visualization grant in 2012.

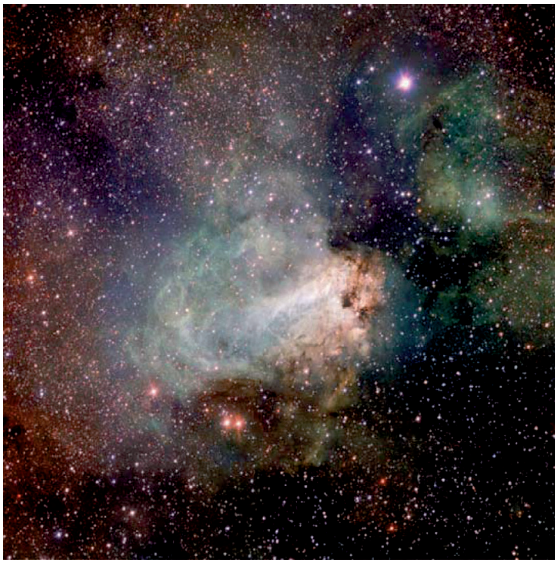
Target: LOFAR, Euclid, MUSE

As a leading partner in the Target program, OmegaCEN coordinates and supports the development of several very large-scale information systems for astronomy and beyond. This program was triggered by the unique generic e-science aspects of the Astro-WISE system. Target is a public-private partnership coordinated by Valentijn in which five public research groups (OmegaCEN-NOVA, LOFAR-ASTRON, RUG Artificial Intelligence, Donald Smits Center for Information Technology (RUG-CIT) and University Medical Center Groningen) collaborate with five high-tech business enterprises (including IBM and Oracle). The Target partners are executing a 32 M€, five-year R&D program which started in September 2009 performing pioneering work in the field what has now become known as Big Data.

OmegaCEN designed and supports together with ASTRON and CIT the long-term archive for LOFAR. Target also participates in the EU EGI grid project and collaborates with the National Big Grid program. Target operates a 10+ Petabyte testbed with dedicated connections to compute clusters and database clusters at the CIT.

Target-OmegaCEN is involved in the Euclid Consortium (EC) for the development of its huge Science Ground Segment. OmegaCEN had an important role in the data-handling study for Euclid, which led to the Euclid Definition Study Report in July 2011. Euclid was selected as an ESA M class mission in 2011 with a projected launch date of 2019. The NL contribution to the EC involves major data handling research and development. OmegaCEN leads the development of the Euclid Archive System (EAS, Williams, Belikov, Valentijn) in close collaboration and partnership with ESA. Together with MPE OmegaCEN leads the Organizational Unit (OU-EXT, Verdoes Kleijn) that will design and implement the handling of external ground-based data handling for the space mission, including KiDS-VIKING and the Dark Energy Survey data. The Dutch Science Data Center (SDC, Williams) is located at Target-RUG and will host the External data pipeline and the Euclid infrared imaging pipeline (latter being developed by Leiden Observatory).

Target-OmegaCEN has developed the data-handling system MUSE-WISE for the Multi-Unit Spectroscopic Explorer (MUSE). Prototypes of the MUSE pipeline have been successfully embedded in an environment based on existing WISE technology. The current version of the MUSE-WISE system is being used to support MUSE simulations and the system is rolled out at Leiden, Groningen, Potsdam, Toulouse, Lyon and Zurich.



The first released OmegaCAM-VST image shows the spectacular star-forming region Messier 17, also known as the Omega Nebula. This vast region of gas, dust and hot young stars lies in the heart of the Milky Way in the constellation of Sagittarius. The VST field of view is so large that the entire nebula, including its fainter outer parts, is captured and retains its superb sharpness across the entire image. The data were processed at OmegaCEN using the Astro-WISE software system.

5.4.1. Participation in MIRI

Following the construction of the Spectrometer Main Optics of the Mid-InfraRed Instrument (MIRI) for the James Webb Space Telescope (JWST) in the Netherlands in 2002-2009, the Flight Module (FM) has been integrated, tested and delivered to ESA and NASA in May 2012. After instrument delivery, the MIRI European Consortium (EC) continues to be responsible for the instrument and is contractually required to deliver major parts of the instrument characterization and calibration, support Integrated Science Instrument Module (ISIM) testing, and co-lead software development and mission preparation. The Dutch MIRI team has played an important role in the MIRI consortium during all of the project phases, from making the initial science case and conception of the instrument to the design and development of the Spectrometer Main Optics by the NOVA Op-IR instrumentation group, support of the instrument tests at Rutherford Appleton Laboratory and the analysis of the test data, to leading the MIRI EC software development and supporting mission preparation at STScI (the JWST operations center). During the design phase the Dutch team has been instrumental in safeguarding the spectroscopic capabilities of MIRI and is now the driving force in exploiting the unique science potential of the integral field unit (IFU) spectrometer within the EC. The Dutch MIRI team aims to maintain its strong role in the continued MIRI EC activities. In particular, the NL co-leads the EC software developments and IFU characterization and is heavily involved in the preparation of the MIRI GTO science program.

Instrument concept

MIRI (European Consortium PI Wright) is a collaborative effort between NASA and ESA to provide mid-infrared imaging and spectroscopy on the JWST. The instrument development is shared between the partners of a nationally funded European Consortium (EC) and JPL, with oversight from ESA and NASA. Routine operations of the JWST and its instruments will be provided through the Space Telescope Science Institute (STScI) in Baltimore.

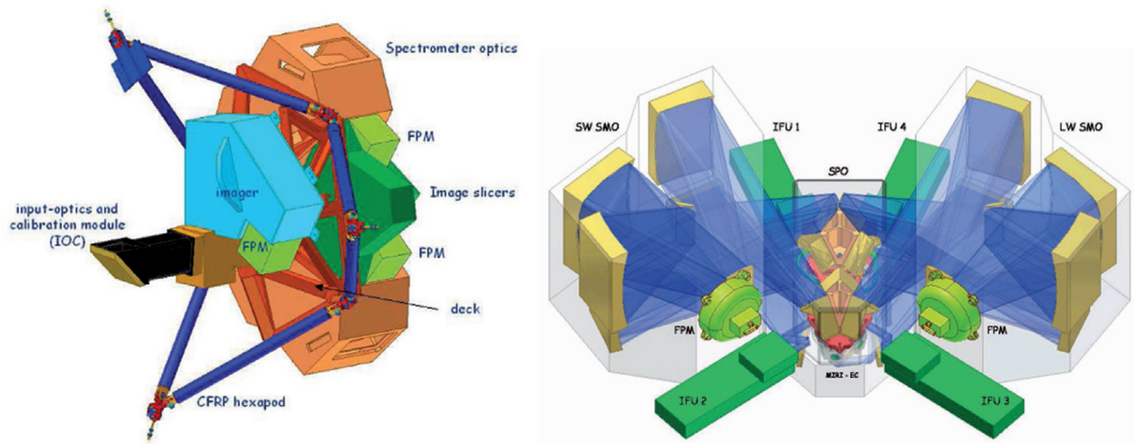
MIRI consists of a camera and an R ~3000 IFU spectrometer that will operate in the 5−28.5 μm wavelength range. The 6m JWST will have unprecedented sensitivity in the infrared. MIRI will be three orders of magnitude more sensitive than any existing ground-based instrument in the 5−30 μm range, a large part of which (>50 %) is completely blocked by atmospheric features from the ground. Compared with Spitzer (85 cm diameter telescope in space), MIRI will have more than an order of magnitude increase in sensitivity and almost an order of magnitude increase in spatial resolution. Moreover, its R ~3000 spectral resolving power is much higher than that of Spitzer, which had only low resolution spectroscopy R = $\lambda/\delta\lambda$ = 50−100 in the important 5−10 μm range, and only R = 600 in the 10−38 μm range. MIRI complements Herschel and ALMA, which observe at wavelengths >50 μm.

MIRI in the vibration test facility during the Flight Model AIV testing at Rutherford Appleton Laboratory in 2010.

Dutch context

The Dutch participation in MIRI consists of

- Ensuring that MIRI has an excellent and well characterized high resolution integral field spectrometer;
- Gaining intimate knowledge of the instrument characteristics and data reduction, essential for the science harvest;

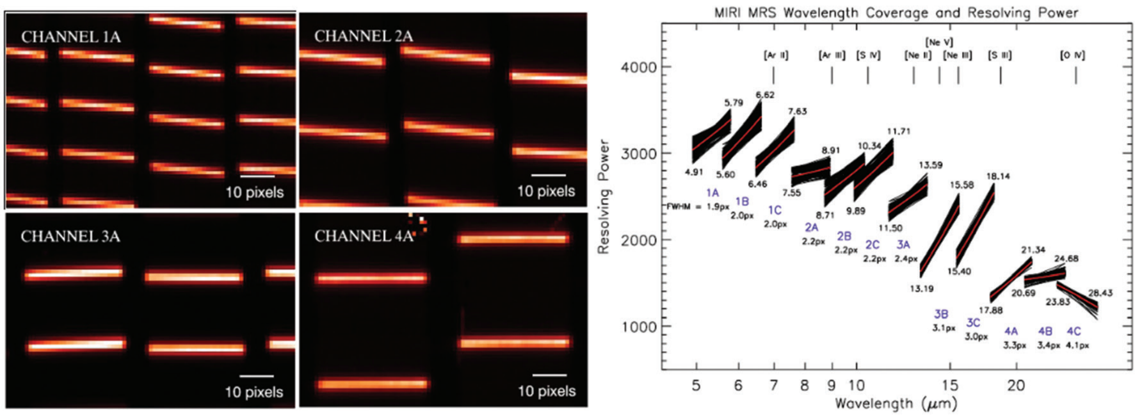


Graphical overview of the MIRI instrument (left) and the MIRI spectrometer (right).

NL project PI
Van Dishoeck

NL co-I's
Van Dishoeck
Brandl
Caputi
Kamp
Roelfsema
Waters
Van der Werf

Project staff
Kroes
Lahuis (NL PM)



Left: *Zoomed-in images of unresolved etalon line observations obtained with the MIRI Flight Model IFU during testing at RAL. These images illustrate the excellent optical performance of the IFU.* ***Right:*** *Measured spectral resolving power, exceeding requirements across the entire MIRI range. These results have been part of the work of NOVA PhD student J. Rafael Martínez-Galarza.*

- Having leading roles in the MIRI guaranteed time program;
- Retaining mid-infrared scientific and technical expertise in the Netherlands, relevant for the METIS instrument for the E-ELT.

The 2010-2012 period was dominated by the integration, testing and delivery of the MIRI FM. At the heart of this was a three month performance test campaign from May to August 2011 in which the Dutch team took more than its fair share. The overall test campaign was highly successful with a working instrument and no failures. The Dutch team had the main responsibility for the FM analysis for the IFU wavelength and fringing characterization (see Figure above).

The tests did reveal a lower than expected instrument sensitivity and a reduced throughput of the MRS channel 4. The reduced sensitivity was resolved with additional detector characterization tests at JPL and analysis by the MIRI team. The MRS channel 4 throughput issue was traced back to a limitation in the manufacturing process of the gratings. Because of the high risk of changing gratings and the modest science impact, the gratings were accepted by ESA/NASA. Overall the performance of the MIRI instrument is of a very high standard with very good optical properties and a high fidelity IFU spectrometer.

The MIRI team presented the MIRI datapack, consisting of 1000+ documents, at ESTEC on Dec 8 2011. After a thorough review the instrument was accepted by the ESA/NASA review board on May 3 2012 and formally delivered on May 9 2012. This makes MIRI the first JWST instrument delivered, a major achievement for the MIRI consortium. Science activities ramped up in this period as well. In 2010-2011 the MIRI science team prepared a set of GTO science proposals, which were discussed with US colleagues. The MIRI software team set up a working collaboration with the STScI pipeline development team and the MIRI consortium has a strong involvement in all calibration and mission preparation activities.

MIRI in the "Envirotainer", its shipping container, in front of the British Airways plane taking MIRI from London to Washington for its delivery to the NASA Goddard Space Flight Center in May 2012.

5.4.2. Gaia mission

Photometric instrument algorithms

ESA's Gaia mission is the next European breakthrough in astrophysics, a cornerstone space mission scheduled for launch in the last quarter of 2013 aimed at producing the most accurate 3D map of the Milky Way to date. The resulting stereoscopic census of our Galaxy will represent a giant leap in astrometric accuracy complemented by the only full sky homogeneous photometric survey with an angular resolution comparable to that of the HST, as well as the largest spectroscopic survey ever undertaken. The scientific bounty will be immense, not only unraveling the formation history and evolution of our Galaxy but also revealing and classifying thousands of extra-solar planetary systems, minor bodies within our solar system and millions of extragalactic objects, including some 500,000 quasars.

Over the course of its five year mission Gaia will measure parallaxes and proper motions for every object in the sky brighter than magnitude 20, amounting to about 1 billion stars, galaxies, quasars and solar system objects. It will achieve an astrometric accuracy of 12–25 µas, depending on color, at 15th magnitude and 100–300 µas at 20th magnitude. Multi-color photometry will be obtained for all objects. In addition radial velocities with a precision of 1–15 km/s will be measured for all objects to 17th magnitude, thus complementing the astrometry to provide full six-dimensional phase space information for the brighter sources. Gaia's photometric instrument consists of two low-resolution fused-silica prisms dispersing all the light entering the field of view. One disperser - called BP for Blue Photometer - operates in the wavelength range 330–680 nm; the other - called RP for Red Photometer - covers the wavelength range 640–1050 nm.

Unlike other ESA missions both the spacecraft and science instruments are built by industry and paid for by the agency. The ESA member states contribute to Gaia through the on-ground processing of the Gaia measurements. To this end the European scientific community has organized itself into the Gaia Data Processing and Analysis Consortium (DPAC). The data processing activities are structured around nine 'coordination units' (CUs) and six data processing centers. Each CU is responsible for delivering a specific part of the overall data processing system for Gaia. DPAC currently consists of some 460 members (representing about 210 fte) throughout Europe with the biggest contributions coming from France, Italy, United Kingdom, Spain, ESA through their team at ESAC, Germany, Belgium, and Switzerland.

NOVA Contributions

The work of NOVA staff for the Gaia mission is part of the photometric Coordination Unit and they are carried out by a dedicated team at Leiden University led by Anthony Brown. The photometric CU is led from the United Kingdom and includes partners from Italy, Spain, and the Netherlands. The NOVA-led team consists of Brown, Busso, and Risquez. Their work includes the definition, design, validation and provision of a complete software package for the initial treatment (extraction of clean images from the raw BP/RP data) of the dispersed images from Gaia's photometric instrument. The algorithms will be delivered to DPAC as software modules to be integrated in the photometric processing pipeline which will be used during the operational phase of the Gaia mission. These algorithms are crucial to the success of the mission and are essentially an instrument in themselves. The Dutch contribution forms part of the core processing algorithms for both the photometric and astrometric measurements of Gaia.

Progress in 2010-2011-2012

A major effort was made to redesign the pipeline infrastructure for the photometric processing pipeline. The result is a much more robust and maintainable pipeline infrastructure which also has much better performance (processing speed, I/O throughput) than the previous version. As a consequence the NOVA-provided algorithms had to be overhauled completely in order to fit into the new pipeline infrastructure. This process obviously caused delays in the further scientific development of the algorithms. The delay was kept manageable by organizing four one-week workshops where the NOVA-led team and the Cambridge team sat together to work intensively on the pipeline code.

Busso (NOVA postdoc) and Brown have finished the basic versions of modules that deal with the sky background removal and with the source color estimation from the BP/RP data. These modules are implemented in the Initial Data Treatment pipeline running at ESAC (the first pipeline to deal with the daily telemetry from Gaia) and in a slightly modified version in the pipeline at Cambridge. Risquez has finished the first versions of the algorithms that run within the First Look pipeline, also running at ESAC. These algorithms provide a daily quick health check of the BP/RP instruments and will be used in that role also during the commissioning phase of the Gaia mission. During 2012 two operations rehearsals were conducted in which the algorithms contributed by NOVA were run successfully and during which both Busso and Brown had the opportunity to gain experience in working with a consortium in operational mode.

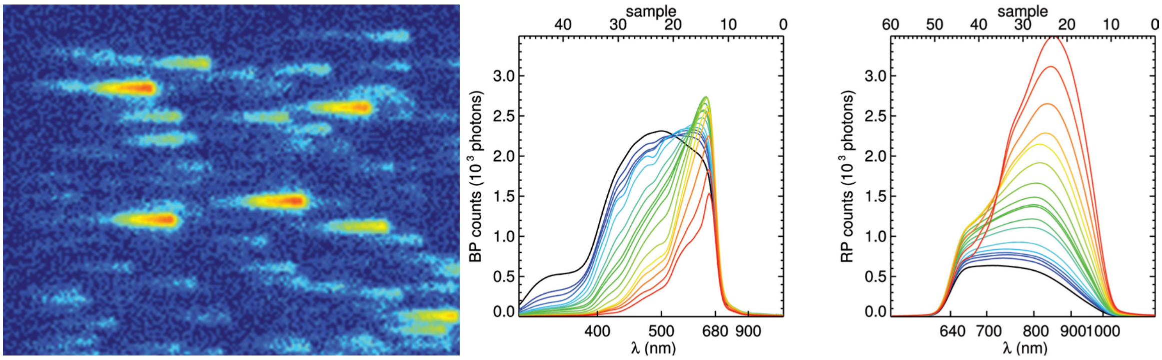
Other contributions

The highest-quality attitude information is required in order for Gaia to meet its astrometric accuracy targets. It is thus important to incorporate a complete physical understanding of the dynamics of a continuously rotating space platform into the attitude modelling for Gaia. Risquez (EU and NOVA-funded postdoc) developed

NL project PI
Brown

NL Co-Is
Brown
Helmi
Jonker
Kaper
Nelemans
Portegies Zwart
Tolstoy
Trager
Valentijn

Project team
Busso
Risquez
Prod'homme



Photometric data processing: *The left hand side shows simulated raw data from the BP/RP instrument. The stellar images have all been smeared out into little spectra by the prisms. The right hand side shows simulated examples of what the extracted clean spectra will look like for a variety of main sequence stellar types, varying from O and B stars (black and blue lines) to M stars (red lines). The spectra on the right are from the blue (BP) channel while on the left they are from the red (RP) channel. The detailed shapes of the spectra will allow the astrophysical characterization of every source seen by Gaia.*

in this context detailed simulations of Gaia's attitude, incorporating all of the relevant physical effects. This model was developed in collaboration with van Leeuwen (Cambridge) and Keil (Bremen). Risquez improved and finished the model during 2011 and used it to provide realistic simulated data to the Gaia community. These data enabled a study of the effect of different perturbations on the astrometry, and it was also used to assess in detail the effect of not having access to the instantaneous attitude on the Gaia spacecraft due to the finite integration time of the observations. The latter will lead to unmodelled noise in the reconstructed attitude and to differences in the measured spacecraft attitude for bright and faint stars. Risquez developed criteria to optimize the attitude modeling parameters used in the astrometric data processing.

A major concern for the Gaia mission is the effect of radiation damage to the CCDs (due to Solar wind and cosmic ray protons). The consequence will be an increased level of charge transfer inefficiency (CTI), which will cause a loss of signal as well as a distortion of the image. The latter will cause systematic errors in the astrometry if not carefully controlled. In this context Prod'homme (EU-funded) completed his PhD research on the theoretical and empirical modelling of radiation damage effects. Prod'homme, Holl (Lund), Lindegren (Lund), and Brown conducted detailed studies to demonstrate that the astrometric performance of Gaia can still be achieved in the presence of CTI.

Role in international coordination

In 2010-2012 Brown was a member of the Gaia Science Team and had a leading role in the international working groups that are preparing the commissioning phase of the Gaia mission. He has coordinated the planning of the Gaia payload commissioning from the DPAC side and the planning of the rehearsal campaigns that will be held in 2012 and 2013 in order to prepare the various data processing teams for dealing with the massive daily telemetry volume from Gaia and with any problem situations that may occur.

In 2012 Brown was appointed chair of the Gaia Data Processing and Analysis Consortium Executive (DPACE) and as such will be in charge of overall coordination of DPAC. Specific responsibilities include convening, preparing, and chairing the DPACE meetings; monitoring the overall progress of the DPAC; coordinating the preparation and submission of material for DPAC-wide reviews (conducted by ESA); and acting as the main contact point between DPAC and ESA. The DPACE chair is also a member of the Gaia Science Team.

Preparing for science

The preparation for the scientific exploitation of the Gaia mission has accelerated greatly over the past two years through the initiation of various projects within the European astronomical community. National staff members who are actively involved are listed in the column under PI and co-I's.

The GREAT (Gaia Research for European Astronomy Training) network funded by the ESF has partly funded 12 workshops, 2 conferences, 1 summer school, and 14 exchange visits. These activities were all aimed at stimulating the scientific research in preparation for the exploitation of the Gaia mission results. This has resulted in a very active community working alongside DPAC but focused on the science of Gaia. In particular a GREAT initiated Marie Curie ITN (of which Brown and Portegies Zwart are members) is preparing a generation of PhD students for using the Gaia data. The GREAT network has also successfully pushed for three important projects complementary to Gaia, namely the WEAVE and 4MOST instruments, and the Gaia-ESO survey.

Spectroscopy at resolutions R = 20,000–40,000 (not obtained by Gaia) will be needed for precision Galactic archaeology studies. To this end the GREAT network stimulated the organization of a European consortium with the aim of carrying out a large spectroscopic survey using ESO facilities. The goal of this survey is to obtain spectroscopy for about 100,000 stars in the thin disk, thick disk and halo of the Milky Way, as well as in selected open clusters. The survey will make use of the Giraffe and UVES instruments and will also exploit the ESO archive. Helmi, Tolstoy, Jonker, Nelemans, and Brown have all contributed to putting together the proposal and the survey program.

5.5.1. LOFAR for Astronomy

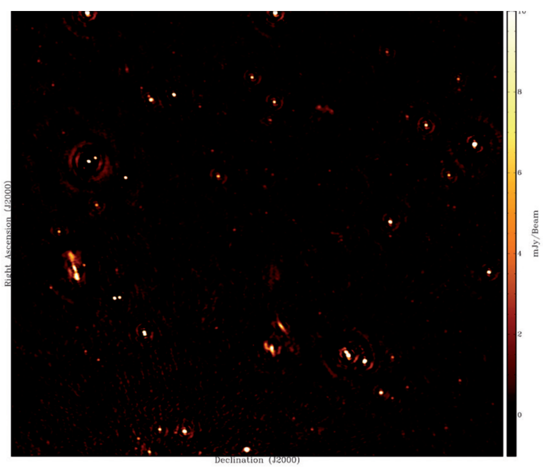
LOFAR, the Low Frequency Radio Array, is a pan-European radio telescope that will open the ultra-low frequency radio sky for astronomical research. At the end of 2012 the Dutch part of the array consisted of 40 stations out to ~100 km and the international part comprises 8 stations, distributed over Germany, France, Sweden and the United Kingdom. Optimized to operate at frequencies from 30 to 200 MHz, LOFAR will provide enormous improvements over previous facilities in four regions of parameter space:

- **Very low frequencies, with 2-3 orders of magnitude improvement in both sensitivity and angular resolution. This is a mostly unexplored spectral region that is uniquely sensitive to ultra-steep spectrum z > 6 radio galaxies, diffuse emission from clusters and the oldest 'fossil' synchrotron electrons;**
- **Size of the instantaneous field of view, of many tens of square degrees. This will deliver a transformational increase in speed to survey the radio sky, crucially important for the quest for rare transient objects;**
- **Low-frequency radio spectroscopy, facilitating studies of redshifted neutral hydrogen at the Epoch of Reionization;**
- **Nanosecond time resolution, enabling detection and characterization of high energy cosmic rays.**

Key science projects

The design of LOFAR has been driven by four astrophysical applications that fit excellently with the expertise and scientific interest of the four participating Dutch university astronomy groups. These Key LOFAR Science Projects (KSPs) are:

Epoch of Reionization (de Bruyn, Koopmans, Zaroubi and Brentjens): one of the most exciting applications of LOFAR will be the search for redshifted 21cm line emission from the Epoch of Reionization (EoR). LOFAR will address a number of key questions related to the EoR, including: (i) what is the redshift range in which the bulk of the neutral hydrogen became ionized? (ii) What are the characteristics of the spatial distribution of heated and still-cold IGM and what is their evolution? (iii) What is the nature of the first objects that ended the Dark Ages and reionized the IGM?



A deep 150 MHz image of the North Celestial Pole (NCP) field using the highband antennas (HBA) showing the power of the LOFAR system. The noise level is 0.1 mJy, the lowest ever attained at low frequencies. Using the longest Dutch baselines, the angular resolution obtained is 5 x 8 square arcsec (courtesy: Yatawatta)

Deep extragalactic surveys (Röttgering, Barthel, and collaborators): Deep LOFAR surveys of the sky will provide unique catalogues of radio sources for investigating several fundamental questions in astrophysics, including the formation of massive black holes, galaxies and clusters of galaxies. Because the LOFAR surveys will probe unexplored parameter space, it is likely that new phenomena will be discovered. The design of the surveys has been driven by 3 important topics: radio galaxies in the early universe (z > 6), diffuse radio emission in galaxy clusters, and distant star forming galaxies.

Transient sources (Wijers, Fender and Stappers): LOFAR's large instantaneous beam will make it uniquely suited to efficiently monitor a large fraction of the sky, allowing sensitive unbiased surveys of radio transients for the first time. Averaging the data will provide information on a variety of time scales, ranging from seconds to many days. The resolution attained will be sufficient for the crucial task of rapid identification of bursts at optical and X-ray wavelengths. Classes of objects known or expected to exhibit variable radio emission include Gamma-Ray bursts, Galactic black-hole/neutron-star systems and exoplanets.

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

Project PI's

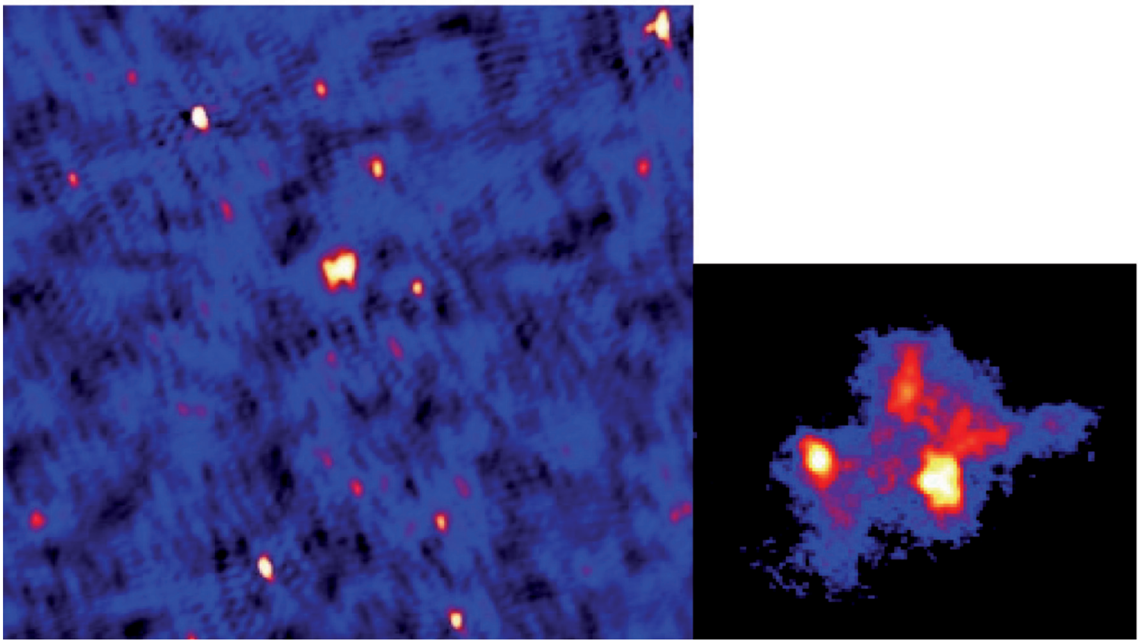
EoR
De Bruyn

Surveys
Röttgering

Transients
Wijers

Cosmic rays
Falcke

Project team
See section 6



Left: *The first image ever at 19.5 MHz. Shown is 10% of the inner area of LOFAR in a 10x10 degree image centered on the rich cluster of galaxies A2256 at z = 0.058 with a noise level of 250 mJy/beam and a resolution of 110 arcsec.* **Right:** *A 60 MHz LOFAR image of part of the same cluster with a noise level of 10 mJy/beam and a resolution 30 arcsec. Note that only 25 stations and 4 MHz out of 48 MHz of BW were used. The full LOFAR will go two orders of magnitude deeper (Courtesy: van Weeren).*

Progress of the LOFAR project

At the end of 2012, the LOFAR array was in place and routinely used for commissioning and science observations. Within the Netherlands, 40 stations were online. With the completion in 2011 of the Jülich and Onsala stations, all 8 international LOFAR stations were complete and took part in commissioning tests and science observations. An issue was the failure of hardware components in an increasing number of highband antennas tiles. An intensive repair effort has been carried out to replace the components and was successfully concluded at the end of 2011. In addition to the station roll-out itself, the final deployment of computing hardware at the LOFAR central processing facility (CEP) was completed in 2011. After some initial hardware issues following installation, the CEP Phase II processing cluster and network hardware came online and are functioning smoothly. Development of the science processing pipelines progressed steadily with an initial release of the full operational system in early 2012. This initial release features a variety of LOFAR's initial observing modes including standard interferometry, a variety of high time resolution beam-formed modes, and direct storage modes utilizing the transient buffer boards (TBBs).

Development and Commissioning of LOFAR for Astronomy (DCLA)

The DCLA project is being carried out at the four participating universities (Amsterdam, Groningen, Leiden, and Nijmegen). It consists of two main tasks that need to be accomplished in order to enable LOFAR to perform its science. These tasks are:

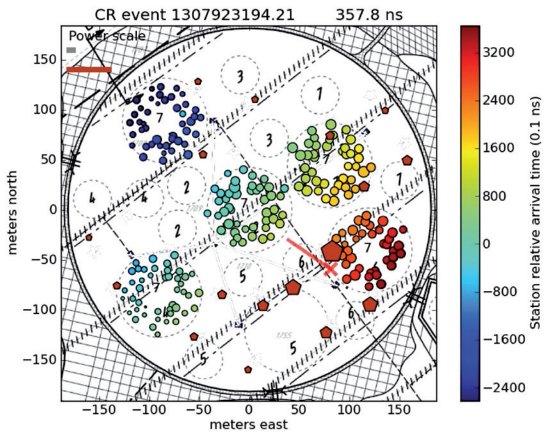
1. Optimizing the observation and calibration techniques needed to do LOFAR science;
2. Developing the algorithms and software pipelines necessary to make astronomy possible.

In the reporting period, the four teams of the key projects made significant progress:

Epoch of Reionization: The main challenge of the EoR project is to detect the extremely faint EoR signals in the very complex data taking and reduction chain of the LOFAR telescope. To this end, the EoR team has carried out a large end-to-end simulation of the reduction pipeline that includes the majority of the critical elements. To address issues that are crucial for the required high dynamic range imaging, Pandey (NOVA postdoc) worked on reliable fitting of relevant calibration parameters taking spectral index variation into account. He was also involved in designing, debugging and verifying diagnostics tools. Martinez Rubi (NOVA research assistant) has developed LEDDB, the LOFAR EoR Diagnostics DataBase. This system will administer and handle the large number of EoR observations and will be an invaluable help in monitoring LOFAR data quality. One of the major issues is the modeling of station beams and their direction, frequency and time dependent effects. Yatawatta (NOVA postdoc) developed the SAGEcal approach which solves for the direction-dependent calibration parameters for all stations in more than 100 directions. Using this approach Yatawatta has generated the deepest LOFAR 140 MHz image thus far with a noise level of 100 microJy after about 10h effective integration. A tiny part (1%) of this image is shown on p. 58. Labropoulos (NWO postdoc) has achieved a similar noise level in the 3C196 field. As 3C196 is a very bright sources (80 Jy), this corresponds to an enormous dynamic range of 700,000:1. Regular EoR observations started in late 2011.

Surveys: The survey team has played a leading role in the development, implementation and testing of many algorithms that are crucial to make reliable low frequency images. These include (i) the implementation of the demixing method developed by van der Tol (NOVA postdoc) that enables efficient and effective subtraction of extremely bright sources many tens of degrees away from the pointing center. This removal allows for frequency- and time-averaging of the visibility data set, reducing the amount of data by a factor of 100, (ii) the implementation of the SPAM method into the LOFAR pipeline to remove ionospheric corruptions, (iii) an imager (based on NRAO's AWimager) that maps and deconvolves visibility data taking the varying LOFAR beams into account. Mohan and Rafferty (NOVA postdocs) developed PyBDSM, a software package that finds and characterizes radio sources, taking the varying angular resolution of the maps into account. All these efforts enabled Van Weeren (PhD) to make the deepest maps ever at frequencies below 100 MHz (Figure on p. 59) from which the flux measurements can be carried out with an accuracy of 10-15%.

Cosmic rays: For the cosmic ray key science project the hardware for the LOFAR Radboud Air Shower Array (LORA), which consists of five stations of four particle detectors each, was installed at the LOFAR superterp in the last quarter of 2010. The system is fully operational since 2011 and has been regularly used to trigger dumps of the transient buffer boards (TBB). At first, this was done in a standalone mode, with LOFAR dedicated to these cosmic ray observations. Observing in the "piggy back" mode on imaging and other observations, was successfully tested and many possible cosmic ray events were collected this way. Thoudam (NOVA postdoc) and others developed a first software pipeline (pycrtools) to analyse these TBB dumps. The analysis of ~1200 recorded TBB dumps resulted in ~50 'good' candidates, with the cosmic ray pulse visible in the time series of at least one LOFAR station. Using the large number of antennas of LOFAR, the lateral distribution function of cosmic rays can be measured with an unprecedented accuracy (Figure below).



Detection of a cosmic ray shower by the LOFAR antennas located at the central 'superterp'. The color circles denote cosmic ray detections. The sizes correspond to the signal strength, while the colors indicate the relative arrival times according to the color bar. The pentagons show the location of the LORA particle detectors.

For the FRATS project (search for Fast RAdio TransientS), James (NOVA postdoc) was involved in the development of a method to collect and analyse beam formed data parallel to standard imaging observations. Using a trigger algorithm on these beam-formed data has successfully led to the detection of known pulsars and issued a trigger of the TBBs.

Transients: The major products worked on and delivered by the TKP (including the pulsar group) to date have been the pipeline framework for the design of all LOFAR pipelines, detailed data formats for the various modes of LOFAR (both definition and implementation for imaging and beam-formed data), components of the transients imaging pipeline (which takes raw visibilities and processes them into calibrated images), and a functioning basic version of the transients pipeline (which takes images and produces light curves of the detected sources and alerts for transients). Swinbank (partly NOVA funded) has developed the LOFAR Transients Pipeline. Rol (partly NOVA funded postdoc) worked on parts of the transients pipeline and was testing the pipeline framework itself, including its separate components: flagging, calibration and imaging. As a result of all these efforts, there is now a test version of a pipeline that is capable of analysing raw LOFAR data to detected transients in an automated fashion. The first candidate transients have been detect. The performance of the transients pipeline is still limited by the quality of images that are ingested by it, but the great improvement of the LOFAR imaging pipeline now means realistic tests of transient searches are being done for the first time. Preparation of LOFAR for real-time response has now started, as well as research on making a near-real time imaging pipeline for transient searches.

5.5.2. Laboratory Astrophysics

Project PI

Linnartz

Project team

Bossa

Ioppolo

Isokoski

Website

www.laboratory-astrophysics.eu

In the Sackler Laboratory for Astrophysics solid state chemical processes are simulated under astrophysical conditions. Three experimental setups have been constructed with NOVA funding. CRYOPAD, CRYOgenic Photoproduct Analysis Device, and SURFRESIDE, SURface Reaction SImulation Device, are part of the NOVA Phase-1 and -2 instrumentation program and MATRI^{2}CES, Mass Analytical Tool for Reactions in Interstellar ICES, has been constructed in the reporting period. CRYOPAD and SURFRESIDE have been routinely producing data for years. MATRI^{2}CES produced its first results in 2012.

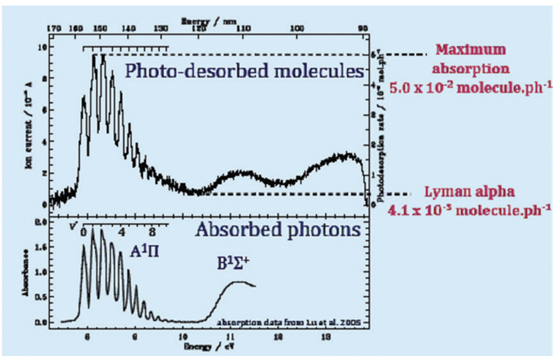
The aim of the laboratory setups is to characterize the solid state astrochemical processes that take place on icy dust grains in the inter- and circumstellar medium. Cold grains in space act as micrometer sized cryopumps, accreting up to tens of monolayers of molecules from the gas phase, providing a solid state molecule reservoir. It is here that molecules can 'meet, greet and react'. External triggers – like vacuum UV irradiation and/or atom bombardment – subsequently trigger processes that provide solid state formation routes to molecules that have been unambiguously identified in space, but could not possibly have been formed in gas phase reactions only. Experiments simulating these processes are performed under fully controlled conditions and provide accurate parameters needed to quantify the solid state processes that govern the physical and chemical evolution of ice in space, particularly around young stellar objects. Dedicated experiments put a physical-chemical base under these processes and allow an in-depth interpretation of astronomical observations. They also provide data needed to guide new observational runs. In the reporting period three key questions have been answered: 1) how does water form in space, 2) why is it possible to observe species in the gas phase at temperatures well below their freeze-out value, and 3) how can larger organic species form in the interstellar medium? A breakthrough has been realized in wavelength dependent UV irradiation studies of interstellar ice analogues providing for the first time details of the molecular excitation processes at work. Furthermore, the results hint at chemical processes in space that may depend on the spectral energy distribution of the impacting radiation field.

Laboratory setup

All three setups operate under ultra-high vacuum (10^{-10}-10^{-11} mbar) conditions. Cryostats are used to grow ices with monolayer precision on a substrate at temperatures as low as 12 K. In CRYOPAD the ice is processed through vacuum UV irradiation using a microwave driven hydrogen discharge lamp, producing Ly-α radiation, and in SURFRESIDE H- or D-atom bombardment is applied using a thermal cracking source. Chemical processes in the ices are monitored spectroscopically in situ and in real time, using Fourier transform RAIRS (reflection absorption infrared spectroscopy) and quadrupole mass spectrometry applying TPD (temperature programmed desorption). In 2011 SURFRESIDE has been fully reconstructed and extended with a second atomic beam line, based on a microwave plasma source, suited to generate H/D and high fluxes of N and O atoms. This now allows ice bombardments with different atoms simultaneously (e.g., H/O, H/N, or H/D). CRYOPAD and SURFRESIDE are optimized to study complex species with typically up to 10 atoms; for larger species the spectroscopic information is not fully unambiguous. MATRI^{2}CES, however, continues where CRYOPAD and SURFRESIDE stop. A soft laser ablation technique is combined with ultra-sensitive time-of-flight mass spectrometry to study the solid state formation of substantially larger molecular systems (e.g., amino acids). The detection sensitivity is orders of magnitude higher than RAIRS and TPD. Reactions in the ice are induced thermally by UV irradiation or H-atom bombardment.

SURFRESIDE

Experiments by Ioppolo (NOVA postdoc) and Cuppen (now Radboud University Nijmegen) in collaboration with PhD students Fedoseev (EU-LASSIE) and Lamberts (NWO – Dutch Astrochemistry Network) demonstrated that water in space can be formed through hydrogenation (i.e., H-atom addition reactions) of O, O_2 and O_3 ice as proposed in the 1980's by Tielens and Hagen. A comparison with CO hydrogenation experiments, known to form formaldehyde and methanol, showed that the O_2+H reaction path is more efficient than CO+H. In a mixed CO:O_2 binary ice, in addition, CO_2 was found as an additional reaction product. In 2011 Fedoseev and Ioppolo extended this work to the hydrogenation of NO ice. They showed that it is possible to form hydroxylamine, NH_2OH, an important nitrogen containing ingredient in the formation of amino acids through subsequent H-atom addition reactions. The extension with a second atomic beam line makes it possible to study surface reactions in which different atoms are involved simultaneously,



A fully wavelength dependent desorption spectrum of CO ice irradiated by tunable vacuum UV light from the DESIRS beamline at the synchrotron facility SOLEIL. The desorption pattern (upper trace) follows the rovibronic CO absorption pattern (lower trace) which shows that desorption is induced by electronic excitation.

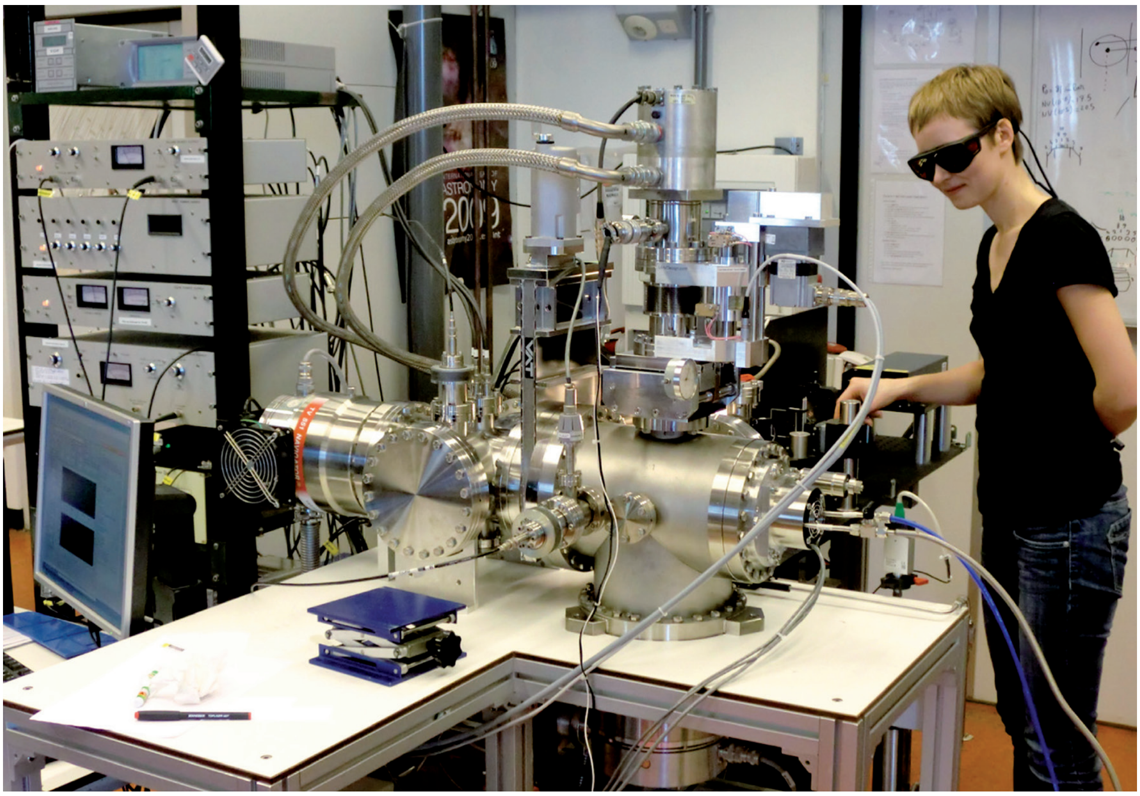
e.g., H/D to study deuteration effects or H/O or H/N addition reactions. The main chamber was replaced and the whole setup was moved, as a new Fourier transform infrared spectrometer could be purchased with NWO-VICI money. This made it possible to uncouple CRYOPAD and SURFRESIDE from a shared radiation source. The new SURFRESIDE setup is ready for the next generation of atom impact induced ice experiments.

CRYOPAD

Experiments by Fayolle (NOVA PhD) in collaboration with the research group of Prof. Fillion (UPMC-Paris) at the vacuum UV beamline DESIRS of the French synchrotron facility SOLEIL showed that the photodesorption of interstellar ice is highly dependent on wavelength. The photodesorption efficiency of CO-ice follows directly the electronic absorption pattern of CO, a mechanism that is known as DIET (desorption induced by electronic transition). Moreover, it was shown that only the upper 2-3 monolayers desorb and that the excitation mechanism involves molecules in the layers directly below. This hints at indirect desorption processes in which molecules can also be evaporated that are not directly excited. Such an efficient and non-thermal desorption process offers a pathway for molecules to participate in gas phase reaction schemes for temperatures well below their freeze-out temperature.

MATRI^{2}CES

Isokoski (NOVA PhD) and Bossa (partially NOVA postdoc) designed and constructed MATRI^{2}CES in 2010-2012, in close collaboration with Witlox of the Leiden fine mechanical workshop, and in parallel have worked on the characterization of ice porosity combining laser interference and FTIR spectroscopy. First mass spectra were produced in 2011. The challenge has been to transport newly formed complex ice constituents from the ice into the detection zone of a large and sensitive time-of-flight (TOF) mass spectrometer. Most notable was the design of an optical ablation system and the incorporation of a highly precise and fully computer controlled (x,y) UHV translation system to move the ice surface with respect to the desorbing laser, an extra cold shield, and a new compressor for the cryostat. Meanwhile it has become possible to study a sample ice comprising larger species (i.e., methanol or methylformate) in real time with full mass resolution. The next step is to monitor reaction products that are formed upon irradiation or bombardment of the ice for different ice temperatures and ice morphologies. In 2012 Paardekooper (NWO-VICI PhD) delivered experimental proof for the first time that amorphous solid water in space is highly but not fully compact, in contradiction to what is generally assumed. In 2011 Bossa obtained a prestigious IEF grant within the EU peoples program and will stay involved in this project for the next 2.5 years.



NOVA PhD student Karoliina Isokoski aligning the ablation laser at MATRI^{2}CES. The laboratory projects are ideal for obtaining real hands-on experience in instrumentation.

5.5.3. AMUSE

Project PI
Portegies Zwart

Co - I's
Spaans
Groot
Kaper
Nelemans
Pols

Project team
van Elteren (PM)
Marosvölgyi
Pelupessy
de Vries

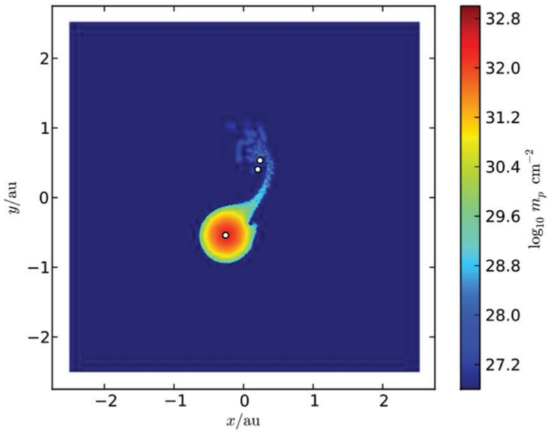
The Astronomical Multi-purpose Software Environment (AMUSE) is a software instrument for astrophysical multi-scale and multi-domain simulations. This project aims to provide a transparent, homogeneous interface to codes of different astrophysical domains. Implementation of code for the following domains is available: hydrodynamics, stellar evolution, gravity and radiative transfer. Target applications are simulations of compound objects with widely differing length scales and physical regimes. The software and codes are publicly available at www.amusecode.org.

The development of multi-physics software is relatively new for computational astrophysics. Such simulation environments are often plagued by a series of problems, many of which are rather basic for software engineers but new to computational astronomy. To name a few, the development of large computer codes requires the programmers to make a careful study of the applicability, the user base, the exact scope, the level of interactions between the various physical domains, and the interaction with the user. Limited planning therefore often results in the uncontrolled growth of the number of code lines, which eventually causes the program to become unmanageable. Maintainability of the resulting code is of prime importance. Instead of writing a new large numerical environment from scratch, AMUSE intends to combine existing packages in a homogeneous and multi-functional framework. In this approach, each package (legacy code) is embedded in an interface layer which realizes the communication between the framework and the scientific software. The project utilizes the user interface and communication library to interface with a wide variety of numerical solvers. The conversion of units and the setting of application-dependent parameters are largely taken care of by the framework, as is the acquisition of simulation data and its mining. The homogeneity of the environment will make it rather easy to perform numerical experiments with a wide variety of codes and quickly assess the results. Comparing the results of different codes within the same application domain is almost trivial, and for relatively weakly coupled problems the communication overhead is negligible.

Multiple applications will be able to use all of these resources simultaneously and exchange data from one to the other. With this hybrid simulation environment it will become possible to study the multi-physics processes that operate on a wide range of size and time scales in stellar environments. Such a resource could be used many times by different researchers to address a wide variety of problems, but could also be used for educational purposes, like the training of master students, educational research projects or for demonstration purposes at advanced schools.

Progress in 2010-2012

The project has reached its production state of AMUSE with several results published in this reporting period. These publications included a wide variety of physical domains. One example of a result is the work of de Vries et al. on the evolution of the triple star ξ Tau. Such triples are quite common. In about 1% of the triples in the solar neighborhood, the tertiary star will overflow its Roche lobe at some time in its evolution, before any of the inner stars leave the main sequence. For two of these systems, ξ Tau and HD97131, AMUSE was used to simulate this phase of mass transfer, during which stellar evolution, gravitational dynamics and hydrodynamics all play an important role. The resulting evolution, mass transfer and the effects on the inner as well as on the outer orbit are profound, although it is not trivial to predict the eventual consequence of the phase of mass transfer and the appearance of the resulting system.



Simulation of the evolution of the triple star system ξ Tau 92 days since the onset of Roche lobe overflow of the outer star. The column density along the line of sight is indicated in a color coding. The two white dots (near the top) represent the inner binary stars of ξ Tau, whereas the white dot in the colored blob represents the core of the giant star. Credit de Vries et al. 2013.

This study would have been impossible with any mono-physics simulation code. Stellar evolution is crucial for acquiring the proper structure of the giant, the outer star in the triple system. The gravity has to be resolved accurately due to the chaotic dynamics of the triple star system, whereas the hydrodynamics is needed to resolve the mass transfer between the stars. The complex interactions needed to be able to simulate the evolution of this system requires a tight coupling between the various numerical solvers. Such a tight coupling can only be realized via the AMUSE framework.

5.5.4. Seed funding projects

The NOVA instrumentation program also includes a funding line to explore new opportunities that may develop into full instrumentation projects in the future. Proposals that get funded should fulfill several criteria, including (1) a challenging science goal that fits within the strategic plan for astronomy in the Netherlands, (2) technical and managerial feasibility, (3) perspective on an attractive Dutch role (like PI or co-PI), and (4) the PI has to be affiliated with one of the astronomical institutes participating in NOVA.

Three seed funding projects are described below. This funding line also provides a financial contribution to pay for the membership of the European SKA Consortium (ESKAC) to allow university astronomers in the Netherlands to participate in the organization and design studies of the next generation observing facility for radio astronomy, the Square Kilometer Array (SKA).

Auger Engineering Radio Array

The Auger Engineering Radio Array (AERA) is an extension of the Pierre Auger Observatory, a high-energy cosmic ray experiment in Argentina. AERA utilizes very-short-timescale radio-frequency emissions from cosmic ray air showers to detect, localize, and characterize cosmic rays as they interact in the atmosphere, supplementing the existing particle and fluorescence detectors. The scientific goals of AERA are (a) to fully characterize and calibrate the radio emission from cosmic ray air showers, including sub-dominant effects; (b) to demonstrate that the radio emission can be used to measure fundamental properties of cosmic rays, such as energy, direction, and mass composition, and to quantify its potential as a technique for future cosmic ray observatories; and (c) to understand the Galactic to extragalactic cosmic ray transition at energies of 10^{17} to 10^{18} eV.

AERA is an international collaboration of universities and research institutions in Germany, France, and the Netherlands, and is organized as a task within the larger scientific collaboration of the Pierre Auger Observatory. Construction of the array has proceeded in three stages, with ongoing physics data acquisition at the completion of each stage. Stage 1 construction was completed in 2010; Stage 2 construction was completed in 2012; and Stage 3 construction will be completed in 2013. The Dutch institutions involved include Radboud University Nijmegen (Falcke, Hörandel), the University of Groningen (van den Berg, Scholten), Nikhef-RU (Timmermans) and ASTRON. The Netherlands contributed significant hardware and software development to the project, including the station electronics designed at Nikhef, RU Nijmegen, and KVI Groningen, wireless communications development, and theoretical work in air shower physics and simulation. Kelley (NOVA postdoc) made important contributions to the systems electronics.

Cherenkov Telescope Array (CTA)

The Cherenkov Telescope Array (CTA) will be the next generation very high energy gamma ray telescope array (~20 GeV-300 TeV). Construction of CTA is foreseen to start in 2016 and to be completed by 2020. It is considered the successor to the successful H.E.S.S. (Namibia), MAGIC (La Palma) and Veritas (Arizona) telescope arrays. CTA will improve the sensitivity of current small-scale arrays (2-4 telescopes) by an order of magnitude by employing many more telescopes (up to 80), with various diameters (4m, 12m, 20m). The smallest diameter telescopes will target the bright, but rare events from the highest energy gamma-rays (>5 TeV). The use of a large quantity of telescopes allows for a better coverage of the atmosphere, and thereby increases the effective area. Moreover, the reconstruction of the direction of the primary photon by triangulation will also be improved. The use of different types of telescopes will improve the spectral coverage. The broad coverage and order of magnitude improvement in sensitivity will greatly improve the capacity for detecting faint sources and transient sources, for a broad range of Galactic and extragalactic high energy sources. The telescopes have typically arcminute resolution, suitable for imaging the air showers.

The NOVA seed project led by Vink and Markoff has prepared the Dutch contribution to CTA, as well as raised the Dutch profile within the CTA consortium. In 2012 two staff members in astronomy joined the national CTA design efforts: Berge as new arrival at the UvA and Hörandel at the RU. CTA related technology R&D is selected to be one of the NOVA Phase-4 instrumentation efforts. The project aims to (1) co-develop a camera for the small-sized telescopes aimed at detecting the highest energy gamma-rays, (2) develop new detector types and (3) develop a new type of precise (5") pointing reconstruction system for the telescopes.

MASCARA

The Multi-site All-Sky CAmeRA (MASCARA) aims to find the brightest transiting planet systems in the sky. It will consist of several stations across the Earth, each monitoring the near-entire sky using a battery of CCD-detectors plus wide-field lenses, targeting stars in the V = 4-8 magnitude range. MASCARA is expected to discover up to a dozen bright transit systems which will be extremely valuable for spectroscopy follow-up studies. The project started in early 2012. It is led by Snellen with support of Stuik and two postdocs arriving in 2013. The NOVA seed funding allowed an early start and a NWO-VICI grant secured full cost coverage.

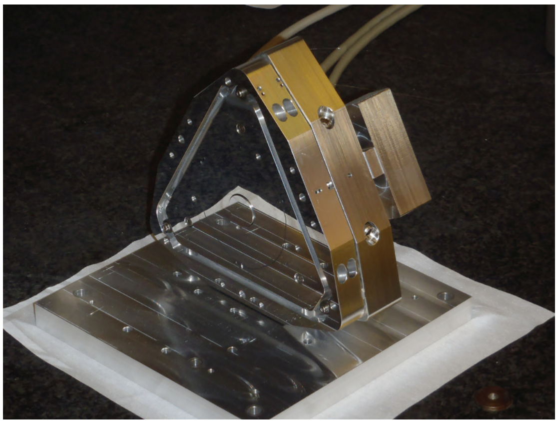
The MASCARA camera system will have no moving parts, except the opening/closing of the dome. Due to the near all-sky nature of the observations, there is no need for tracking to compensate for the Earth rotation. The first station, which will be located on La Palma, will consist of five Atik 11,000 CCD cameras, each with 4k×2.67k 9μm pixels, and equipped with a 24mm F/1.4 wide-field Canon lens. The cameras will be pointed in such way that at each site most of the sky at airmass <3 will be covered. Exposure times will be kept short, to 6 seconds (matching the total read-out time of the interline CCD arrays), to avoid trailing of the stars on the CCD. The use of short exposures implies that the data rate will reach 1 terabyte per night per station, meaning that a significant part of the data reduction needs to be done on site in real time. The current schedule allows for operations on the La Palma site from April 2014 onwards. Later that year two more stations, one at the ESO sites in Chile and one in South Africa, will be completed as well.

5.6. Collaboration with industry

The national Roadmap funds for E-ELT instrumentation have strengthened the collaboration between NOVA, the NWO institutes ASTRON and SRON, the technology organization TNO, technical universities and industry in the area of technology development for future scientific instrumentation. Five examples of NOVA-industry collaboration in the reporting period are described below. In 2010 NOVA also took on the task of Industrial Liaison Officer to improve and coordinate the relations between ESO and industry in the Netherlands. The aim is to achieve a good economic return to the Netherlands for the investments ESO will make for the construction of the E-ELT.

High precision mechanical control

One of the most crucial elements within the E-ELT METIS instrument is a small and fast tip-tilt mirror, the chopper. This mirror has to perform in a high vacuum environment at a temperature of 77 K. Even though similar mirrors have been made previously, the required positional accuracy and stability are beyond the capabilities of current 'state-of-the-art' technologies. Therefore, a development project, involving Janssen Precision Engineering (JPE, in Maastricht), NOVA, SRON, RUG-DTPA, and TNO, has been initiated to demonstrate the feasibility of the chopper.

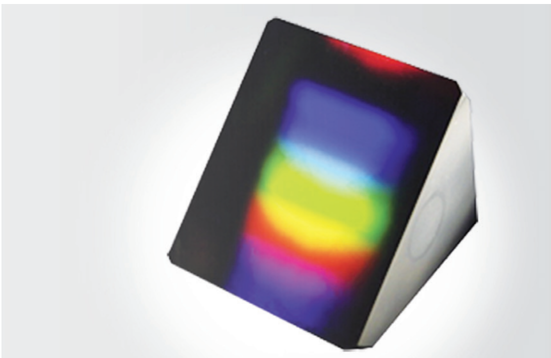


The prototype chopper for METIS

All bread board tests have been finalized at JPE and reviewed. Based on the test results a minor modification has been made to the actuators. Moreover, the initial inductive displacement sensors were rejected and replaced by a fiber-coupled laser interferometer system with customized retro-reflectors. The knowledge gained in the project enabled JPE to obtain at least two contracts for technology development from large international companies.

Immersed grating

METIS needs a grating that operates at the diffraction limit and will have a spectral resolution of 100.000 in mid-infrared wavelengths. Conventional gratings, which would fulfill these requirements, are large and therefore difficult to make according to specifications. Compared to a conventional grating, the immersed grating drastically reduces the beam diameter and thereby the size of the spectrometer optics. As diffraction takes place inside the high-index medium, the optical path difference and angular dispersion are boosted proportionally to the index of refraction, thereby allowing a smaller grating area and a smaller spectrometer size.



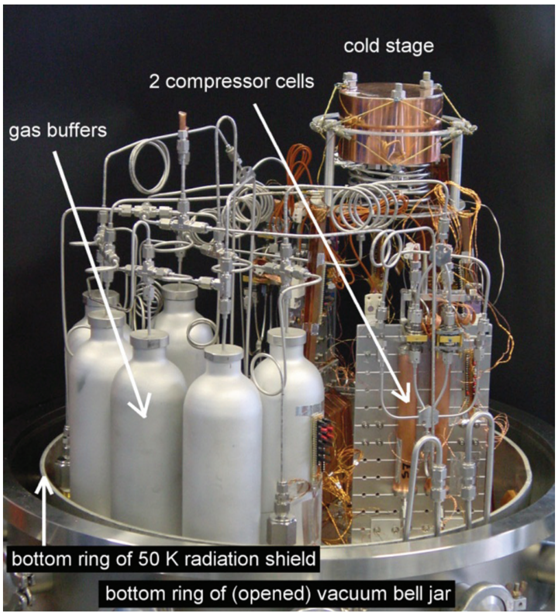
Demonstration of immersed grating

In this technical R&D project SRON, NOVA, TNO, and Philips Innovation Services worked together to make the optical-mechanical design and manufacture a prototype immersed grating to evaluate the critical technology, which has passed in critical review in May 2012. The project is now in its last phase working on a real-size demonstrator model which will be tested to confirm performance requirements. For Philips the economic benefits will be applications of immersed gratings in medical instruments.

Sorption coolers

The specifications of current astronomical and space instruments require addressing all internal sources for vibrations and temperature fluctuations. While standard coolers have improved significantly, they still cause disturbances that limit the accuracy of the measurements. Sorption coolers can provide very good temperature stability combined with practically no vibrations and very long lifetimes without maintenance. However, the cooling power of sorption coolers is of order a few mW while cooling capacities of a few W are required for cryogenic instruments. In principle the cooling capacity of sorption coolers is scalable. Optimizing the pressure, gas and number of cells should lead to a concept that is affordable, practical and fulfills the requirements of future instruments.

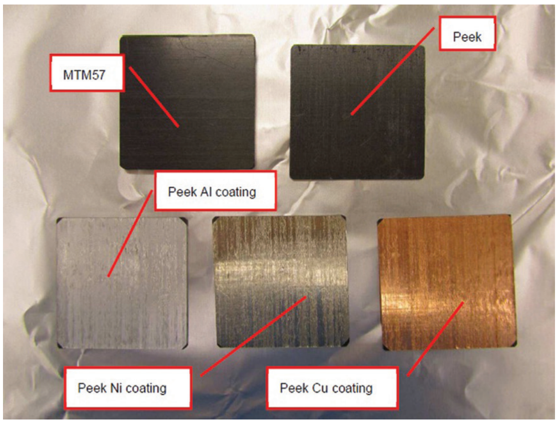
At the UTwente the most suitable combination of pressure, gas and number of cells has been investigated and based on this outcome a strawmen design has been made for a METIS cooling system based on sorption coolers in collaboration with Dutch Space and NOVA. To boost the technical readiness level of the system a number of demonstrator models have been defined and are being made after which they will be tested. For Dutch Space the long-term economic benefits are in applications in space equipment.



Laboratorium setup at UTwente for sorption cooling experiments

Composites in cryo-vacuum

Use of composite materials will reduce the weight and/or increase the performance of instruments. For astronomical and space applications where (cryo-) vacuum conditions are often encountered, this implies that the composite materials need to be coated against outgassing. Airborne Composites, TNO and NOVA have identified potential coatings which were applied on test samples to verify gas-tightness, cryo-resistance and fixation. Manufacturing techniques are assessed for larger sizes and more difficult shapes. Initial results are promising but further prototyping is needed to better understand which coating can best be applied to composite materials. Economic benefits for Airborne Composites lie in cryogenic applications in the oil and gas industry and for Dutch Space in space equipment and structures.



Test samples of coated composite materials

Target and OmegaCEN
high performance information systems

Target is a public-private partnership in which OmegaCEN, ASTRON, IBM, Oracle and six other partners do R&D for information systems for very data intensive ('Big Data') projects and operate them. The software architecture and technology originally developed for handling and analysis of the optical astronomical data from OmegaCAM has been made applicable for projects in other disciplines. Examples are

- radio astronomy: the LOFAR long-term archive
- medicine: both the Lifelines study of the health course of 165000 citizens for a period of 30 years and GLIMPS the novel image-based classification project for accurate and early diagnosis of Idiopathic Parkinson's Disease
- cultural heritage: the MONK artificial intelligence system capable of searching words and phrases in handwritten historical collections, also used at the Nationaal Archief.

To host such projects Target has built one of the largest publicly-known data and metadata storage systems worldwide at the Computing Centre of the University of Groningen. It serves as a testbed to investigate Oracle's and IBM's hardware under extremely demanding conditions. Partner Target Holding creates business out of Target components and services.

6. NOVA-funded research and instrumentation positions

The tables in the chapter list all research and instrumentation positions whose employment was - partially - funded through NOVA in 2010-2011-2012.

Project	Title	Project leader	Univ	Researcher	Yrs	Start	End	Notes
Network #1								
10.1.2.06	Sinfoni study starburst galaxies	Van der Werf	UL	Drs. Liesbeth Vermaas	2,00	Feb 1, 2008	Jan 31, 2010	a
10.1.3.1	Epoch of reionization	Koopmans/ Bruyn	RUG	Dr. Panagiotis Lam-propoulos	2,00	Aug 1, 2010	Jul 31, 2012	
10.1.3.2	Ly-α emission around galaxies	Schaye	UL	Drs. Alireza Rahmati	4,00	Sep 1, 2009		
10.1.3.3	Galaxy evolution at z=3	Franx	UL	Drs. Jesse van de Sande	4,00	Nov 1, 2009		
10.1.3.4	Evolution of gas in gal-axies	Trager	RUG	Drs. Gergo Popping	4,00	Sep 1, 2010		
10.1.3.5	Warm interstellar medium	Van der Werf	UL	Dr. Edo Loenen	3,00	Dec 1, 2009	Nov 30, 2012	
10.1.3.7	Galaxies in the cosmic web	Van de Weijgaard	RUG	Drs. Patrick Bos	4,00	Sep 1, 2010		
10.1.3.8	Resolved stellar popula-tions	Peletier	RUG	Drs. Sofia Meneses-Goytie	4,00	Dec 1, 2009		
10.1.3.9	Galaxy centers	Israel	UL	Drs. Marissa Rosenberg	4,00	Sep 27, 2010		
10.1.3.10	Gaia in the galaxy	Helmi	RUG	Drs. Maarten Breddels	4,00	Feb 1, 2009		
10.1.3.11	Stars in the KIDS survey	Kuijken	UL	Drs. Pila Diez	2,00	Oct 11, 2010		a
10.1.3.12	Network 1 postdoc	Tolstoy	RUG	Dr. Stefania Salvadori	3,00	Dec 1, 2009	Nov 30, 2012	
10.1.3.12	Network 1 postdoc	Franx	UL	Dr. Ben Oppenheimer	1,08	Aug 1, 2009	Aug 31, 2010	
10.1.3.12	Network 1 postdoc	Rottgering	UL	Dr. David Sobral	1,92	Sep 1, 2011	Aug 31, 2012	
Network #2								
10.2.2.03	Gas-grain chemistry	Linnartz	UL	Drs. Sergio Ioppolo (40%)	4,00	Sep 1, 2006	Aug 31, 2010	a
10.2.2.04	Massive young stars	de Koter	UvA	Drs. Lianne Muijres	4,00	May 1, 2006	Apr 31, 2010	
10.2.2.10	AGB puls dust formation	Icke	UL	Drs. Chael Kruip (80%)	2,80	May 1, 2007	Apr 31, 2010	a
10.2.3.1	Water in star-forming regions	Van Dishoeck	UL	Drs. Daniel Harsono (25%)	4,00	Sep 1, 2010		a, b
10.2.3.2	Water in high mass SF regions	Van der Tak	RUG	Drs. Yunhee Choi	4,00	Sep 1, 2010		b
10.2.3.3	Molecular complexity	Dominik	UvA	Drs. Gijs Mulders (50%)	4,00	Feb 1, 2009		b
10.2.3.4	HIFI, ALMA laboratory studies	Linnartz	UL	Drs. Edith Fayolle	4,00	Aug 1, 2009		
10.2.3.4	UHV-HIFI and ALMA related lab. studies	Linnartz	UL/ SRON	Dr. Herma Cuppen (40%)	0,50	Apr 1, 2010	Sep 30, 2010	b
10.2.3.4	UHV-HIFI and ALMA related lab. studies	Linnartz	UL/ SRON	Dr. Sergio Ioppolo (40%)	0,50	Sep 1, 2011	Dec 31, 2011	b
10.2.3.4	UHV-HIFI and ALMA related lab. studies	Linnartz	UL/ SRON	Dr. Joseph Guss (40%)	1,50	Apr 1, 2010	Dec 31, 2011	b
10.2.3.5	From dust to planets	Spaans	RUG	Dr. Rowin Meijerink	2,50	Nov 1, 2011		
10.2.3.6	Disk surface layers	Waters	UvA	Drs. Gerrit van der Plas	1,00	Aug 1, 2009	Jul 31, 2010	a
10.2.3.7	Inner disk gas models	Kamp	RUG	Drs. Rosina Bertelsen	4,00	Oct 1, 2010		
10.2.3.9	Disks around embedded YSOs	Hogerheijde	UL	Drs. Kuo-Song Wang	4,00	Oct 1, 2009		
10.2.3.10	Youngest massive stars	Kaper	UvA	Drs. Lucas Ellerbroek	4,00	Mar 1, 2010		
10.2.3.11	Massive starts in LMC	de koter	UvA	Drs. Frank Tramper	4,00	Nov 15, 2010		

Project	Title	Project leader	Univ	Researcher	Yrs	Start	End	Notes
10.2.3.12	Red Dwarf transients	Snellen	UL	Drs. Matteo. Brogi	4,00	Jun 1, 2010		
10.2.3.13	Exo-planets with Corot and Sphere	Dominik	UvA	Drs. Rik van Lieshout	4,00	Oct 15, 2011		
10.2.3.14	ExPo disk modeling	Keller	UU/UvA	Dr. Michiel Min (86%)	3,00	Apr 1, 2009	Sept 30, 2012	
10.2.3.15	Star formation with Herschel observations	Tielens	UL	Msc. Koen Maaskant	2,00	Jul 1, 2010		
Network #3								
10.3.2.09	HE CR detection with LOFAR	Hörandel	RU	Drs. Sarka Jiraskova	2,00	Aug 15, 2008	Aug 15, 2010	
10.3.3.1	Sub-second bursts with LOFAR	Falcke	RU	Drs. Pim Schellart	4,00	Apr 15, 2010	Dec 31, 2011	
10.3.3.2	Radio-emitting neutron stars & millisecond transients with LOFAR	Van der Klis	UvA	Drs. Thijs Coenen	2,00	Apr 1, 2009	Mar 31, 2011	
10.3.3.3	High-energy follow up observations of radio transients	Wijnands	UvA	Msc. Yi-Jung Yang	1,00	Jul 1, 2012		
10.3.3.4	Radio radiation from gamma-ray burst afterglows	Wijers	UvA	Drs. Kostadinos Leventis	2,00	Oct 1, 2010	Sep 30, 2012	
10.3.3.5	X-ray timing of stellar mass black holes	Van der Klis	UvA	Drs. Maithili Kalamkar	4,00	Aug 1, 2009		
10.3.3.6	Inner accretion flows in neutron-star x-ray binaries	Mendez	RUG	Drs. Andrea Sana	2,00	Jul 1, 2009	Jun 30, 2011	
10.3.3.8	Burst oscillation mechanism in Type-I x-ray bursts	Levin	UL	Drs.Yuri Cavecchi (50%)	4,00	Jul 1, 2009	41274	a
10.3.3.9	X-ray spectra of binaries with ultra-short periods	Verbunt	UU/RU	Drs. Oliwia Madej	4,00	Sep 1, 2009		b
10.3.3.10	X-ray sources in the Galactic Bulge Survey - X-ray observations	Wijnands	UvA	Dr. Nathalie Degenaar	1,17	Oct 1, 2010	Nov 30, 2011	
10.3.3.11	Galactic plane compact binary population	Groot	RU	Drs. Thomas Kupfer	4,00	May 1, 2011		
10.3.3.12	Galactic budge population of x-ray binaries	Nelemans	RU	Drs. Serena Repetto	2,00	Oct 1, 2011		
10.3.3.14	Stellar populations in dense systems	Portegies Zwart	UL	Msc Edwin van der Helm	4,00	Sep 1, 2012		
10.3.3.15	Progenitors of Type Ia supernovae	Pols	UU/RU	Drs. Joke Claeys	2,00	Sep 1, 2009		
10.3.3.17	Particle acceleration in intermediate power jets	Achterberg	UU/RU	Drs. Sander Walg	4,00	Mar 1, 2010		
10.3.3.18	Ultra-high energy cosmic rays with AUGER	Hörandel	RU	Drs. Johannes Schulz	2,00	Feb 15, 2012		
Cross Network								
10.CN.3.2	Illuminating high redshift matter with GRBs	Wijers	UvA	Drs. Olga Hartoog	4,00	Dec 1, 2010		
10.CN.3.3	The Galactic Halo in the Gaia era	Nelemans	RU	Drs. Pim van Oirschot	4,00	Sep 1, 2011		
10.CN.3.4	Massive stars after the FLAMES survey	de Koter	UvA	Drs. Oscar Ramirez Aguledo	2,00	Mar 1, 2011		

Project	Title	Project leader	Univ	Researcher	Yrs	Start	End	Notes
10.CN.3.5	Modeling Herschel spectroscopy	Brandl	UL	Dr. Brent Groves	1,00	Nov 1, 2009	Oct 31, 2010	
Science Support								
10.SS.3.1	Early science with ALMA	Hogerheijde	UL	Dr. Markus Schmalzl	2,00	Apr 1, 2011		
10.SS.3.2	SPHERE science support	Dominik	UvA	Dr. Christian Thalmann	2,50	Jan 1, 2011		
10.SS.3.3	PuMa pulsar data recorder LOFAR	Wijers	UvA	Dr. Anastasia Alexov	3,00	May 15, 2009	May 14, 2012	
10.SS.3.4	The Herschel harvest	Barthel	RUG	Dr. Max Avruch	2,50	Dec 1, 2009	May 31, 2012	
10.SS.3.5	OmegaCEN, calibration software scientist	Peletier	RUG	Prof.dr. Edwin Valentijn (50%)	1,00	Jan 1, 2011	Dec 31, 2011	
10.SS.3.5	OmegaCEN, database	Valentijn	RUG	Danny Boxhoorn	5,00	Apr 1, 1999		
10.SS.3.5	OmegaCEN, Surveys	Valentijn	RUG	Dr. John McFarland	4,90	May 1, 2005	Mar 31, 2010	
10.SS.3.5	OmegaCEN photometry	Valentijn	RUG	Dr. Gijs Verdoes Kleijn (80%)	5,75	Dec 1, 2006		
10.SS.3.5	OmegaCEN, commissioning support	Valentijn	RUG	Drs. Ewout Helmich	3,25	Jan 1, 2009	Mar 31, 2012	
Overlap appointments								
10.OA.3.1	Proto planetary disks	Wijers	UvA	Prof.dr. Carsten Dominik	5,00	Jan, 1, 2009		
10.OA.3.2	Black holes and neutron stars	Peletier	RUG	Prof.dr. Mariano Mendez	4,08	Jan 1, 2009		
10.OA.3.3.1	Dark matter, dark energy and galaxy clusters	Kuijken	UL	Dr. Henk Hoekstra	2,67	Jan 1, 2009	Aug 31, 2011	
10.OA.3.3.2	Computational astrophysics	Kuijken	UL	Prof.dr. Portegies Zwart	1,50	Jan 1, 2010	Jun 30, 2011	
10.OA.3.3.3	Formation and evolution of super-massive black holes	Kuijken	UL	Dr. Elena Rossi	1,58	Jan 1, 2011	Jul 31, 2012	
10.OA.3.3.4	High contrast imaging of exoplanets	Kuijken	UL	Dr. Matthew Kenworthy	2,50	Jan 1, 2011		
10.OA.3.5	Astroparticle physics	Groot	RU	Dr. Jörg Hörandel	3,00	Jul 1, 2009	Jun 30, 2012	
10.OA.3.6	Physics of accretion in compact binaries and AGNs	Groot	RU	Dr. Elmar Körding	2,50	Jan 1, 2012		

Notes	
a	Additional funding up to 4 year in total is covered by the university
b	Co-funded by SRON with 2 AIO years

Instrumentation Program

Project/job description	Project leader	Inst	Staff member	Yrs	Start	End	Notes
Allegro							
Technical astronomer	Hogerheijde	RUG	Dr. Wilfred Frieswijk	2,4	Jan 1, 2009	Dec 31, 2010	
ALMA early science	Hogerheijde	UL	Dr. Agnes Kospal	0,8	Dec 1, 2010	Sep 30, 2011	
Technical astronomer	Hogerheijde	UL	Dr. Tim van Kempen	3,0	Jul 1, 2010		
ALMA Band-9 development and construction, ALMA Band 9 technical R&D / ALMA Band 5							
Project Manager	Boland	SRON	Dr. Brian Jackson	P	Oct 1, 2003	Mar 15, 2010	
Project manager	Boland	SRON	Dr. Rieks Jager	0,9	Mar 1, 2010	Jan 31, 2011	
Project Manager	Boland	RUG	Ir. Joost Adema	Pw	Feb 1, 2011		
Manager industrial contracts	Jackson/Jager	RUG	Ir. Joost Adema	Pw	Mar 1, 2003	Jan 31, 2011	
Front-End scientist	Jackson/Jager/ Adema	RUG	Dr. Ronald Hesper	Pw	Sep 1, 2000		
Receiver scientist	Adema	RUG	Jan Barkhof	Pw	Mar 16, 2004		
Front-End technician	Adema	RUG	Gerrit Gerlofsma (80%)	Pw	Oct 10, 2001		
Test Engineer	Adema	RUG	Menno van den Bemt	3,9	Oct 1, 2008	Sep 1, 2012	
Test Engineer	Adema	RUG	Rob de Haan - Stijkel	Pw	Nov 1, 2009		
Test Engineer	Navarro	Op-IR	Menno de Haan (50%)	1,5	Jan 1, 2010	Jun 30, 2011	
Documentalist	Adema	RUG	Albert Koops	Pw	Dec 1, 2004		
Assembly technician	Adema	SRON	Klaas Keizer	7,6	Mar 1, 2005	Sep 30, 2012	
Assembly technician	Adema	RUG	Marielle Bekema (40%)	Pw	Jan 1, 2005		
Test Engineer	Adema	RUG	Jack Koops van het Jagt	4,9	Nov 1, 2007	Sep 30. 2012	
ALMA Band 9 early science harvesting							
PhD student	Van Dishoeck	UL	Drs. Nienke van der Marel	4,0	May 1, 2011		
AMUSE							
Technical postdoc	Portegies Zwart	UL	Dr. Inti Pelupessy	2,4	May 1, 2009	Dec 31, 2011	
Software engineer; project manager	Portegies Zwart	UL	Dr. Arjen van Elteren	2,7	May 1, 2009	Dec 31, 2011	
Programmer	Portegies Zwart	UL	Drs. Marcel Marosvölgyi	2,3	Oct 1, 2009	Dec 31, 2011	
Programmer	Portegies Zwart	UL	Dr. Nathan de Vries	2,1	Dec 1, 2009	Dec 31, 2011	
VLTI 2nd generation Fringe Tracker design							
Postdoc	Jaffe	UL	Dr. Jeff Meisner	0,6	Jan 1, 2010	Aug 15, 2010	
Gaia photometric data reduction							
Software designer	Brown	UL	Dr. Giorgia Busso	5,33	Jan 1, 2009	Dec 31, 2012	
Software designer	Brown	UL	Dr. Daniel Risquez Oneca	3,83	Sep 1, 2010	Sep 30, 2012	

Project/job description	Project leader	Inst	Staff member	Yrs	Start	End	Notes
LOFAR development key projects							
EOR-02b postdoc	de Bruyn	RUG	Dr. Sarod Yatawatta	2,00	Jan 1, 2009	Dec 31, 2010	
EOR-03 postdoc	de Bruyn	RUG	Dr. Vishambar Pandey	2,50	Oct 1, 2008	Mar 31, 2011	
EOR-06 data analyst	de Bruyn	RUG	Drs. Oscar Martinez Rubi	1,50	Dec 1, 2010	May 31, 2012	
SRV-2 P2 postdoc	Röttgering	UL	Dr. David Rafferty	2,00	Aug 1, 2010	Jul 31, 2012	
SRV-2 P3 postdoc	Röttgering	UL	Dr. Bas van der Tol	2,25	Apr 15, 2011		
SRV-04 postdoc	Röttgering	UL	Dr. Niruj Mohan Ramanujam	0,50	Oct 1, 2009	Mar 31, 2010	
SRV-05 data processor	Röttgering	UL	Dr. Laura Rafferty-Birzan	2,00	Aug 1, 2010	Jul 31, 2012	
TRA-06 P2 postdoc	Wijers	UvA	Dr. John Swinbank	0,50	Jan 1, 2010	Jun 30, 2010	
TRA-07b postdoc	Wijers	UvA	Dr. Evert Rol	1,00	Jan 1, 2010	Dec 31, 2010	
TRA-08a data analist	Wijers	UvA	Dr. Kenneth Anderson	2,00	Jan 19, 2009	Jan 18, 2011	
TRA-09 postdoc	Wijers	UvA	Dr. Bart Scheers (50%)	1,00	Feb 1, 2012		
COS-02 + 07b postdoc	Falcke	RU	Dr. Satyendra Thoudam	3,00	Apr 1, 2009	Dec 31, 2011	
COS-09 postdoc	Falcke	RU	Dr. Clancy James (30%)	0,83	Jun 15, 2009	May 30, 2011	
COS-10b +09 + 11 data analist	Falcke	RU	Drs. Martin van den Akker	1,50	Oct 1, 2009	Mar 31, 2011	
Matri2ces							
Surfreside development	Linnartz	UL	Drs. Sergio Ioppolo (60%)	1,00	Jan 1, 2009	Aug 31, 2010	
PhD student	Linnartz	UL	Drs. Karoliina Isokoski (60%)	2,40	Jan 1, 2009	Dec 31, 2012	a
Postdoc	Linnartz	UL	Dr. Jean-Baptiste Bossa	0,60	Jan 1, 2012	Aug 15, 2012	
METIS							
Postdoc instrument modelling	Brandl	UL	Dr. Eva Meyer	1,61	Jun 15, 2011		
Postdoc	Brandl	UL	Dr. Jeff Meisner	0,55	Sep 1, 2012		
MIRI							
Instrument science support	van Dishoeck	UL	Dr. Fred Lahuis (80%)	4,72	Jan 1, 2010		
Postdoc	Brandl	UL	Dr. Eva Meyer	0,50	Dec 15, 2010	Jun 15, 2011	
MUSE							
Postdoc system support	Schaye	UL	Dr. Thomas Martinsson	2,00	Nov 1 , 2011		
Postdoc system support	Schaye	UL	Dr. Denis Serre	2,00	May 1 , 2008	Aug 31, 2010	
Postdoc hardware/Test	Schaye	UL	Dr. Atul Deep (50%)	1,00	Jan 1, 2009	Dec 31, 2010	a
NOVA Optical-IR instrumentation group							
Groups manager	Boland	Op-IR	Ramon Navarro				
System engineer/cryogenic engineer	Navarro	Op-IR	Ronald Roelfsema				
System engineer/project manager	Navarro	Op-IR	Felix Bettonvil		From Feb 1, 2011		
System engineer/mechanical designer	Navarro	Op-IR	Niels Tromp				
Optical engineer	Navarro	Op-IR	Rik ter Horst (0.84)				

Project/job description	Project leader	Inst	Staff member	Yrs	Start	End	Notes
NOVA Optical-IR instrumentation group							
Optical designer		Op-IR	Florance Rigal (0.80)		Until Jul 31, 2011		
Optical designer		Op-IR	Tibor Agocs		From Jun 1, 2011		
Senior mechanical designer		Op-IR	Gabby Kroes				
Mechanical designer		Op-IR	Jan Kragt				
Project manager/system engineer		Op-IR	Johan Pragt (50%)				
Manufacturer/test engineer		Op-IR	Eddy Elswijk				
CNC technician		Op-IR	Menno Schuil				
Manufacturer/test engineer		Op-IR	Menno de Haan				
Project controller		ASTRON	Karin Spijkerman (40%)				
Instrument physicist/Liaison		UL	Remko Stuik (80%)		From Jan 1, 2011		a
SPHERE-Zimpol							
Optical engineer	Boland	UL	Charlotte Groothuis	0,92	Mar 1, 2009	Jan 31, 2010	
S5T							
Technical PhD student	Keller	UU	Drs. Helena Becher	4,0	Mar 1, 2008	Dec 31, 2011	
E-ELT-EPICS; national roadmap funding							
Polarimetry system engineering	Keller	UU/UL	Dr. Frans Snik	4,0	Jul 1, 2009		
EPICS integral field unit development	Keller	UL	Dr. Michiel Rodenhuis	2,5	Jan 1, 2011		
Polarization performance prediction	Keller, Snik	UL	Drs. Maria de Juan Ovelar	4,0	Feb 15, 2010		
High contrast adaptive optics testbed	Kenworthy	UL	Drs. Gilles Otten	4,0	Nov 1, 2011		
E-ELT METIS; national roadmap funding							
Background calibration	Brandl	UL	MSc. Mayuresh Kulkarni	1,0	Sep 1, 2011	Sep 12, 2012	
Background calibration	Brandl	UL	MSc. Stephanie Heikamp	3,0	Oct 15. 2012		
E-ELT Mosaic: national roadmap funding							
Instrument technival trade-offs studies	Kaper	UvA	Dr. Bertrand Lemasle	3,0	Jun 1 , 2012		

Notes
Additional funding by the university
Permanent contract with warning

7. Workshops & Visitors

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

7.1. Workshops in 2010-2011-2012

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

Nr.	1st Date	Applicant	Event	University	# days
W-141	15-03-2010	F. Verbunt	High-resoluiton X-ray spectroscopy	UU	3
W-147	05-10-2010	S. Portegies Zwart	Computational gravitational dynamics	UL/LC	4
W-148	14-06-2010	M. Franx	Oort workshop - highest redshift galaxies	UL	3
W-149	19-04-2010	H. Hoekstra	How to weight clusters of galaxies?	UL/LC	5
W-150	26-07-2010	A. Watts	X-ray bursts and burst oscillations	UvA/LC	5
W-151	10-09-2010	H. Olthof	KNVWS-NVR symposium on planet atmospheres	UU	1
W-152	20-09-2010	G. Nelemans	Observational signatures of type Ia lupernova progenitors	RU/LC	4
W-153	26-04-2010	E. van Dishoeck	Herschel Wish DIGIT	UL	7
W-154	25-08-2010	H. Linnartz	Infrared plasma spectroscopy	UL	3
W-155	21-06-2010	Y. Levin	International pulsar timing array	UL/LC	10
W-156	14-03-2011	S. Markoff	Cosmic ray interactions	UvA/LC	5
W-157	05-01-2011	X. Tielens	Eindhoven astrochemistry meeting of RCS RAS	UL	3
W-158	21-02-2011	H. Röttgering	Probing the radio continuum universe with SKA pathfinders	UL/LC	5
W-159	28-02-2011	F. Israel; X. Tielens	Herschel and the characteristics of dust in galaxies	UL/LC	5
W-160	13-12-2010	N. de Vries	Second AMUSE workshop	UL	5
W-161	20-04-2011	R. vd Weygaert	Quantum universe	RUG	2
W-162	25-07-2011	H. Hoekstra	Groups and clusters of galaxies	UL/LC	5
W-164	11-07-2011	A. Brown	Oort workshop - Gaia and the interstellar medium	UL	4
W-165	01-07-2011	S. de Jong	The arrow of time IMAPP symposium	RU	5
W-166	05-12-2011	E. van Dishoeck	Isotopes in astrochemistry	UL	5
W-168	26 10 2011	A. Watts	LOFT science meeting	UvA	3
W-169	19-11-2011	N. de Kort	KNVWS symposium on the Sun	UU	1
W-170	27-02-2012	R. Meijerink	Exciting CO in the local and high-redshift universe	UL/LC	5
W-171	15-12-2011	E. van Dishoeck	Water in star forming regions with Herschel	UL	2
W-172	08-06-2012	B. Oppenheimer	Dynamic nature of baryons in halos	UL/LC	5
W-173	25-07-2012	J. Hörandel	41th international summer school on Astroparticle Physics	RU	7
W-174	27-01-2012	R. Peletier	Mini-symposium in honor of 80th birthday of Stuart Pottasch	RUG	1
W-175	04-02-2012	H. Lamers	370 year of astronomy in Utrecht	UU	5
W-176	23-05-2012	I. Kamp	Netherlands Astronomers Conference	RUG	3
W-177	04-04-2012	R. vd Weygaert	2nd Quantum Universe symposium	RUG	2
W-178	09-10-2012	S. Portegies Zwart	Compact binaries in globular clusters	UL/LC	4
W-180	07-09-2012	R. Stuik	Adaptive optics tomography	UL	3
W-181	25-10-2012	L. Kaper	Multi-object spectroscopy on the E-ELT	UvA	2
W-182	12-03-2012	T. van Oosterloo	Atlas 3D team meeting	UL/LC	5
W-187	01-12-2012	N. de Kort	KNVWS symposium on exoplanets	UU	1
W-191	06-04-2012	E. van Dishoeck	Spectroscopy of star and planet forming regions with Herschel	UL	10

W-141: High-resolution X-ray spectroscopy: past, present and future

In three full days, results were discussed from high-resolution spectrometers on ESA's XMM-Newton observatory, NASA's Chandra X-ray observatory and NASA/ESA's Hubble Space Telescope. Subjects included measurements of Galactic dust and gas, the warm/hot medium between clusters of galaxies, multi-mission observations of the supermassive black hole in Mrk 509 and results and perspectives of laboratory measurements of cosmic compounds. The mix of the subjects and participant expertise, the large invited component of the program and the atmosphere of the venue and city provided a stimulating environment for discussion among the participants. The conference received national media coverage through an interview with LOC chairman Jelle de Plaa in 'Goedemorgen Nederland' on public television and an interview on public radio in the program 'Noorderlicht'.

W-147: Computational gravitational dynamics

The advanced school and workshop on computational gravitational dynamics was attended by 24 young students and 32 experienced researchers worldwide. Computational astrophysics is a fast growing discipline which covers computational science, astronomy and physics. There is a range of expert fields within computational astrophysics, some of them are related but socially and professionally well separated. The school attempted to bridge gaps between a range of specialized fields in computational astrophysics, in particular focused on those disciplines that simulate gravitational dynamics using N-body techniques. The school grouped the students to work in collaboration with experienced researchers on one of the following topics: orbital dynamics of multi-planet systems, Galactic disk and bar formation, the final parsec problem, exploring galaxy collision products, forming ultra-compact dwarf galaxies and do spiral galaxies contain a dark matter disc?

W-148: Oort workshop – highest redshift galaxies

The workshop was organized around the 2010 Oort professor Richard Ellis in June 2010 with more than 20 participants. The latest developments related to the very highest-redshift galaxies and to moderate redshift galaxies (approximately a redshift of 1) were discussed in a lively atmosphere. Many local students and staff participated as well.

W-149: How to weigh clusters of galaxies?

At the intersections of the cosmic web, clusters of galaxies correspond to the highest-density regions in the universe. They are dark-matter-dominated systems, which complicates a direct measurement of their masses. There are many open questions regarding the measurements of cluster masses. This is because many different methods can be employed, each providing a somewhat different probe of the gravitational potential, and with different systematic biases. Numerical simulations are playing an increasingly important role in understanding biases. From the discussions it became clear that impressive progress has been made in both observations and numerical simulations. Nonetheless a clear picture emerged that no single method provides "all the answers": extensive multi-wavelength data sets are needed. Several of the participants are collecting such data. However, the interpretation of these results requires also a close connection to the simulations. Thanks to this workshop, the necessary connections have been made to allow for a more comprehensive approach to cluster mass determination.

W-150: X-ray bursts and burst oscillations

Though generally understood, there are many aspects of thermonuclear shell flashes on neutron stars (NSs) which are not well understood. These varies from understanding the ignition conditions of carbon flashes to the origin of the millisecond oscillations seen in many flashes. These flashes express themselves as one-minute-long X-ray bursts that were discovered 35 years ago with the first Dutch satellite ANS. This was the first dedicated workshop on this subject, held at the Lorentz Center from 26 to 30 July 2010. 47 researchers participated from 12 countries, most from the USA (15) and the Netherlands (11). The program consisted of 22 plenary invited talks during the mornings, 11 contributed posters, a plenary flash poster session with five-minute oral presentations of the posters, six organized/chaired discussion meetings and three end-of-the day 'wrap-up' sessions where the chairs of the discussion meetings reported back to the whole group.

W-151: KNVWS symposium on planetary atmospheres

The purpose of the annual KNVWS Symposium is to inform the general public and amateur astronomers on developments in topics in the field of astrophysics, meteorology & climatology, and scientific space research. At the 2010 symposium Snellen described the scientific context of exoplanets found via eclipses of their host star. Keller took the audience on a tour in the realm of polarization studies. Stam characterized the differences in the terrestrial planets in our Solar System and detailed the various stages in the evolution of a dusty gas cloud via planetesimals to planets. Stammes presented ongoing studies of the evolution and current composition of the Earth's atmosphere. De Jager gave a very inspiring talk about the relationship between the Sun and our climate. He revealed what might cause such solar variability, as periodically the magnetic fields winds up and releases energy.

W-152: Observational signatures of type Ia supernova progenitors

A total of 50 participants from 10 countries took part in this workshop, which was structured as follows: "assigned" talks in the mornings, giving overviews of the state-of-the-art in the different topics, some "hot" talks, showing new results, and extended discussion sessions in the afternoons. The overview talks gave an excellent setting of the scene, and the discussions were lively and led to many interesting observations. It is clear that type Ia supernovae show great diversity and that improved theoretical modelling now predicts several observable progenitor signatures that can be searched for in existing and future observations. Several new results were presented, such as global delay time distributions, double white dwarf merger simulations and likely progenitor features in the SN spectra. X-ray and radio observations will soon put very tight constraints on the presence of circumstellar material.

W-153: Herschel WISH and DIGIT team meetings

From 26 April to 3 May 2010 two workshops took place in Leiden connected with the Herschel "Water in Star Forming Regions" (WISH; PI E. van Dishoeck) and "Dust, Ice and Gas In Time" (DIGIT; PI N. Evans) key programs. The WISH and DIGIT meetings brought together about 50 and 20 people, respectively, working on the physical and chemical structure of star-forming regions and protoplanetary disks, and the specific role of water in these sources. A significant fraction of the Herschel data had been taken just before the meeting, so the timing was excellent for detailed discussions on data reduction, analysis and interpretation. Based on the workshop results, several talks and posters were presented at the ESTEC Herschel workshop the following week, and a dozen first results letters were submitted to Astron. Astrophys by the end of May 2010.

W-154: Infrared plasma spectroscopy

The fourth Infrared Plasma Spectroscopy meeting was held in Rolduc Abbey, Kerkrade, The Netherlands, 25-27 August, 2010. Seventeen lectures and nine posters were presented, covering topics including the chemical composition of the red rectangle nebula, plasma enhanced chemical vapor deposition, and many applications and techniques related to the new field of quantum cascade lasers. The meeting was notable for the lively discussions that followed every lecture, and continued into the coffee and meal breaks. The after dinner presentation, entitled "FELIX, Polyaromatics and Stardust", by Jos Oomens of the FOM Institute for Plasma Physics, Rijnhuizen, was a highlight in which very impressive experiments with free electron lasers were discussed. The talk focused on the detection of polycyclic aromatic hydrocarbons in space, and also raised the question of the existence of diamandoids in space.

W-155: International pulsar timing arrays

Pulsar Timing Arrays (PTA) are programs developed in order to detect and measure extragalactic gravitational waves using a super-precise timing of an array of millisecond pulsars. These programs are long-term campaigns which have been rapidly growing on 3 different continents: the Parkes PTA in Australia uses the data from the Parkes telescope; the NANOGrav group in North America uses the data from Arecibo and Green Bank telescopes; and the European PTA utilizes 5 telescopes: Westerbork (Netherlands), Jodrell Bank (UK), Effelsberg (Germany), Nancay (France), and Sardinia (Italy). There is a strong need to both educate the young researchers (students and postdocs) in this field, and to coordinate research and exchange ideas across the 3 PTAs. This timely workshop addressed both of these needs.

W-156: Cosmic ray interactions: bridging high and low energy astrophysics

Cosmic rays are an energetically important ingredient of the interstellar medium (ISM), which are an important source of pressure, and ionization, thus affecting the chemistry of molecular clouds. This workshop targeted both the acceleration and transport of cosmic rays, as the effects they have on the ISM. During the workshop the high energy astrophysicists became much more aware of the molecular tracers of cosmic rays interactions, with H3+ being one of the most important molecules. They also became aware of the importance of low energy cosmic rays (up to 10 MeV). Participants also became more aware of the potential diagnostic power of Fe-K fluorescent lines around 6.4 keV, which could be induced by interactions between cold gas and MeV protons. These lines were also discussed during the meeting in the context of cosmic ray interactions in the Galactic Center region.

W-157: Astrophysical chemistry group of the RSC and RAS

This annual meeting was held in Eindhoven on 5 to 7 January 2011 to strengthen existing contacts with the astrochemistry community in The Netherlands and to explore connections with terrestrial plasma chemistry. The meeting, with 74 participants from UK, Netherlands and elsewhere, started with a tutorial session in which the essence of astrochemistry and relevant plasma physical chemistry was introduced. The main subject areas discussed were carbon chemistry, polycyclic aromatic hydrocarbons, cluster and dust growth, and dynamics both in astrochemical and terrestrial plasma environments. Ion processes in molecule formation in astrochemistry and the astronomical observations of molecules with modern instruments, including the ALMA interferometer in Chile, were discussed, followed by surface processes both in astro conditions and in experiments with plasma irradiation of ices. One area common to both communities is the observed similarity in the distributions of ro-vibrationally excited hydrogen molecules in astrochemical conditions and in plasma experiments pointing to a probably related excitation mechanism.

W-158: Probing the radio continuum universe with SKA pathfinders

Several next-generation "SKA pathfinder" radio telescopes and upgrades are under construction around the world, each planning major radio continuum surveys. This workshop was held to bring together expertise in both science and survey techniques, to coordinate developments, to avoid duplication of effort, and to ensure that each project has access to best practice. The workshop included discussion of specific science goals, to ensure cross-fertilization of ideas and optimum survey strategies. The primary outcome was to rethink some aspects of the way we are constructing these telescopes and designing the surveys.

W-159: Herschel and the characteristics of dust in galaxies

The workshop provided a comprehensive overview of the characteristics of dust and the spectral energy distribution of galaxies. It brought together observers, modelers, theoreticians and experimentalists. It covered the physical and chemical processes affecting dust in space, as well as laboratory measurements of astrophysical relevance. New data from the Herschel and Planck space observatories and new insights from laboratory experiments and theoretical work have been combined. The workshop provided the missing communications link between the very different communities involved, producing eye-openers and identifying unjustified prejudices. In particular laboratory results on submillimeter dust emissivity effectively rule out all simple dust-mass estimates, to the surprise (and dismay) of many attendants. As a result of the workshop, a benchmarking effort of modelling SEDs is now in progress.

W-160: Second AMUSE workshop

The workshop was attended by an international group of researchers and students. It consisted of 6 talks detailing needed features, possibilities of AMUSE, coupling of the different physics codes, and new community codes. There was great emphasis on working with AMUSE during this workshop, in order to help the users get acquainted with the software, and to get feedback. Every day ended with a discussion session, surveying the experiences and comments. Work was done on the implementation of three new codes and the possibility of more elaborate close encounter treatments was discussed. Also technical details concerning debugging of codes were discussed and different philosophies were presented.

W-161: Quantum Universe

On 20-21 April 2011, the 1st Quantum Universe symposium has been organized at Zernikeborg, University of Groningen. The symposium included a diverse participation, including experts from theoretical physics, high energy and particle physics, high energy astrophysics and cosmology. The core of the meeting consisted of a few well chosen keynote lectures. Examples were those by De Jong on the hunt for the Higgs particle and LHC, by Schellekens on the string theory landscape and the anthropic principle. Highlight of the conference were the keynotes by Verde on primordial non-Gaussianities, by Delabrouille on the Planck mission and by Tong on string theory. In addition to the keynote and invited lectures, there was a set of contributed talks. One of the strongest points of the meeting was the presentations by four PhD students. The meeting succeeded in establishing a strong link between physicists and astronomers.

W-162: Groups and clusters of galaxies: confronting theory with observations

Groups and clusters of galaxies represent the densest regions in the universe, where a range of physical processes that are relevant for galaxy formation and cosmology can studied in detail. In recent years progress in observations have pushed to lower masses, challenging theoretical predictions, which also appear to have difficulties explaining a range of properties of more massive systems. Discussing the fidelity of the data and how best to compare to theoretical models and how the latter can guide new observations were the main aim of this meeting.

This created an excellent forum to review the tremendous progress made in recent years, but also to identify several fundamental issues that remain. It has become clear that only a multi-wavelength approach will allow us to study the various physical processes involved, although a clean separation may not always be possible. Similarly, an integrated approach is needed to best “confront theory with observations”.

W-164: Oort workshop on Gaia and the interstellar medium

This workshop brought together astronomers with a wide range of expertise: optical and near-infrared photometric surveys of stars; spectroscopic surveys of stars; radio-frequency surveys for masers; observations of radio-frequency and infrared emission by gas and dust; stellar- and gas-dynamical modelling. The participants considered how these data can be combined with the astrometric data from Gaia to determine the three-dimensional structure and dynamics of the interstellar medium in our Galaxy. Various participants have established further collaborative work. Each group learned what insights into the structure of the ISM can be gained by using techniques from other areas. It became clear that the key to decisive progress in the era of Gaia is to fuse all these insights into dynamical models of the ISM whose predictions can be compared with the observational data.

W-165: The arrow of time IMAPP symposium

The IMAPP symposium was held on 1 July 2011, on the occasion of the fifth anniversary of the institute. The theme of the symposium was “The Arrow of Time”. Five excellent speakers had been attracted: Jean Bricmont (Louvain), From the microscopic to the macroscopic world; Misha Katsnelson (Nijmegen), Graphene: CERN on the desk; Robert Kirshner (Harvard), The arc of time’s arrow: from the Big Bang to you; John Morgan (Stonybrook), Ricci flow and the topology of 3-D spaces; Jim Virdee (London), the LHe project: exploring the origin, the evolution and the composition of our universe. They gave beautiful lectures, making the symposium into a great success.

W-166: Isotopes in astrochemistry

The matter comprising the Sun and the planets, well as the comets and asteroids, originated in the dense core of an interstellar cloud over 4.6 billion years ago. The aim of this interdisciplinary workshop was to obtain a clearer picture of the fate of observed interstellar isotopic fractionation patterns (especially those of D, C, N and O) as they were incorporated into the proto-solar nebula. The primary focus was on (1) the contribution of stellar nucleosynthesis to Galactic chemical evolution, (2) observed isotopic fractionation in interstellar clouds and protoplanetary disks, (3) isotopes in comets, (4) isotopic anomalies in meteorites and IDPs (including the Stardust samples), (5) new results from Herschel and prospects for ALMA. More than 50 scientists from 10 different countries gathered to present the state-of-the-art knowledge in their respective areas of expertise, resulting in many lively discussions and plans for future collaborations.

W-168: LOFT science meeting

The program, consisted of a mix of invited and contributed talks and focused on the three main science areas for the LOFT mission: strong gravity, dense matter and observatory science. The discussions that followed each talk were extremely lively and fed into some very productive science working group sessions on the Friday afternoon. The outcomes were scientific, operational and technical. In terms of the science case for the mission the meeting generated new ideas, quantified the scientific advances that can be expect (for example in terms of dense matter physics) and gave first sight of detailed simulations of how well the methods that LOFT intends to use will perform.

W-169: KNVWS Symposium on the Sun

The topic for the 2011 symposium was solar research in an historic context, as well as related to past and future technological developments. Rob Rutten presented the general context of solar research and highlighted several scientific breakthroughs. Joe Zender (ESA) discussed the role of satellites in monitoring the behavior of the sun and illustrated the importance with examples of the PROBA project. Felix Bettonvil gave an overview of ground based solar research facilities, in particular the Dutch Open Telescope and the future European Solar Telescope. Traditionally, an amateur astronomer with a profound track record was invited to present amateur contributions to the research field. This time, Ton Spaninks presented a selection of achievements made by members of the KNVWS working group “Sun”. Finally, Ed van den Heuvel addressed the impact of solar research on the development of knowledge in the characterization of stars. The symposium concluded with a lively discussion between the audience and the speakers about future challenges in solar research.

W-170: Exciting CO in the local and high-redshift universe

This workshop brought together for the first time people from different galactic and extra-galactic programs. They learn about each other’s observations and favorite analysis tools (PDRs, XDRs, and shocks) and make a detailed inventory and comparison of the models. During the workshop observations from various Herschel key programs were discussed including the interpretation of the data with various available models. A hot topic was the comparison of predictions of CO line temperatures for the various transitions in the rotational ladder. Although in some case good agreement between the codes was demonstrated, but many discrepancies were recognized as well. During the workshop the participants discussed the discrepancies, by comparing how different processes were implemented in each other's codes. Consensus was reached to implement key processes in a similar fashion. Observers learned more about using results from modeling, what can be trusted and what not. Modelers learned more about the needs of the observers.

W-171: Water in star-forming regions with Herschel

About 40 members of the program 'Water in Star-forming regions with Herschel' (WISH, PI E.F. van Dishoeck) met in Oegstgeest to discuss the Herschel HIFI and PACS data and analysis from this large guaranteed time key program. Herschel observations of lines of H_2O, OH and CO in sources ranging from pre-stellar cores to low- and high-mass protostars and protoplanetary disks were presented. The data taking has been completed in fall 2011, so this was the first meeting where the entire data set was available. The workshop resulted in the planning of the second and third round of papers as well as further modeling projects. More information on the project can be found on www.strw.leidenuniv.nl/WISH.

W-172: The dynamic nature of baryons in haloes

This meeting brought together leading international astronomers with a diverse range of observational and theoretical expertise, to advance the nascent field of circum-galactic medium astrophysics. A key aim of the meeting was to build awareness of complementary studies in differing observation wavebands, and to build connections between the two guided by insight from numerical models. The meeting was a great success, having initiated new collaborative efforts between research groups that were previously only loosely connected, especially between computational simulators and observers. The discussion-oriented scheduling, which is an essential quality of Lorentz workshops, allowed the flexibility of discussions to enhance contributed talks and invited reviews. A primary goal of the organizers was to involve younger researchers representing the future of the field, and their involvement made the plenary discussions unusually collaborative and active compared to most other meetings.

W-173: 41th international summer school on astroparticle physics

This summer school was attended by 40 students from all over the world and took place from 25 July until 3 August 2012 at the Schloss Gnadenthal at Kleve, Germany. The aim of the school was to educate students in the field of astroparticle physics through lectures given by scientists working at the forefront of this field on various subjects, ranging from the non-thermal universe, dark matter, gravitational waves, cosmology, to the properties of elementary particles. The students judged the lectures and the program of the school to be very good to good.

W-174: Mini symposium in honor of 80th birthday of Stuart Pottasch

Pottasch was appointed professor at the age of 31 to introduce the field of astrophysics. From 1969 to 1982, he was chairman of the Kapteyn Institute. He edited BAN for 6 years and Astronomy and Astrophysics Letters from 1969 to 1999. Pottasch had published ~300 papers and a book on planetary nebulae. His expertise covers infrared spectroscopy and various aspects of planetary nebulae, including their masses, distances, space density and abundances, using IUE, IRAS, ISO and Spitzer data.

W-175: 370 year of astronomy in Utrecht

This conference was held in conference center "de Leeuwenhorst" in Noordewijkerhout and took place from 2 to 5 April 2012. The program consisted of 6 sessions, 19 invited lectures, 40 other speakers and 29 posters and a few historical contributions. There were 171 participants. Most foreign participants had studied or worked at the Utrecht Institute or had strong research ties. At the end of the conference, the reactions of the participants were unanimously very positive.

W-176: Netherlands Astronomers Conference

The conference took place from 23-25 May 2012 on Ameland with 200 participants, among them 91 PhD students and 42 master students. Key-note contributions included the invited lectures by Thijs van der Hulst on "Tracing the evolution of cold gas with HI", by Robert Laing (ESO) on "ALMA: recent progress and early science" and Michael Wise on "Next generation radio astronomy with LOFAR". The last year PhD students had ample opportunity to present their work during parallel sessions. The conference setting provided extensive opportunity to the participants to interact and discuss their research, to network across the institute boundaries, and also across the various areas of research. In total more than 80 posters were presented and a subset of the poster presenters advertised their work in a 1 minute poster flash presentation during one of the plenary session.

W-177: 2nd Quantum Universe symposium

This symposium took place on 4-5 April 2012 at the University of Groningen. It gathered a mixed company of experts from theoretical physics, high energy physics, high energy astrophysics, astrophysics and cosmology. By means of a set of carefully chosen keynote lectures, the meeting succeeded in evoking a genuine dialogue between the various communities. The topics included particle en high energy physics, results from Icecube and other neutrino physics experiments and early results from the LHC search for the Higgs particle. In the field of astrophysics keynote topics were high-energy processes in SgrA and the Center of the Galaxy, cosmological computer simulations, dark energy in relation to DES and the evolution of low mass galaxies. Together with the very good contributions by PhD students and postdocs, the meeting was a success and a motivation to continue with the special series of Quantum Universe symposia.

W-178: Compact binaries in globular clusters

The meeting brought together theoreticians and observers to discuss and better understand the current state of the field and to learn what is needed to achieve further progress. The presentations gave a good overview of the subjects and many of the existing paradigms were challenged both in talks and in the discussions, which also focused on how to test the ideas. Furthermore a number of collaboration projects were set up between small groups of participants, and it was decided to attempt to set up a larger collaboration with the goal of proposing for major observational projects that can lead to large advances in the field.

W-180: Adaptive optics tomography

This workshop took place between 9 and 11 July 2012 at the Old Observatory in Leiden. With a total of 51 participants from 12 different countries the workshop was intense. The emphasis in the program was on learning and collaboration, which was achieved by a number of invited talks, and 6 discussion sessions. On the first day, the interaction between science and adaptive optics was discussed, specifically how to come to a good metric of the performance of the AO system that makes sense from the scientific point of view. The second topic of the day was how and how accurately to simulate a tomographic AO system. On the second day new algorithm and experiments were treated that are required for the new generation of Extremely Large Telescopes. The last day was dedicated to innovative methods which are currently not part of the standard set of techniques, but which might improve tomographic AO systems. Furthermore, techniques, accuracies and improvements of atmospheric characterization techniques were discussed.

W-181: Multi-object spectroscopy on the E-ELT

The meeting was a success, with roughly 60 registered participants. Several UvA PhD students did not register but attended some of the sessions. The PIs and a good portion of the science teams from each of the three E-ELT/MOS concepts (EVE, EAGLE and DIORAMAS) described the technical design and the most important science cases for their respective instruments. The other spectrograph concepts for the E-ELT were also presented. The program covered a large range of topics, including MOS-related technical issues. Most of the relevant science cases, from exoplanets to resolved stellar populations and extragalactic studies in the distant Universe have been presented and the speakers always mentioned the technical requirements. These requirements were summarized in the last two talks and examined in the following plenary discussion. The meeting provided the opportunity to refine the technical requirements and paved the way to future collaborations and possibly merging of the instrument concepts, in the perspective of the ESO call for proposals for an E-ELT MOS instrument expected in 2013.

W-182: Atlas 3D meeting

The goal of this workshop was to bring together a diverse group of observers and simulators to interact on outstanding questions of star formation and mass assembly in early-type galaxies. The workshop was effectively a team meeting of the Atlas3D project, enabling the members of the Atlas3D team to meet and interact. During the meeting observational and theoretical progress were discussed on the star formation process in early-type galaxies, focusing on the ongoing debate as to whether the apparently regular ‘law’ of star formation found in spiral galaxies still holds in the more evolved, early-type galaxies. Furthermore discussions included the results from simulations of galaxy formation using cosmological models re-simulated at high resolution and a new large observing initiative using the Canada-France-Hawaii Telescope combining the data and efforts of two large teams.

W-187: KNVWS symposium on exoplanets

Tielens elaborated on star formation and showed how observations, in particular sub millimeter and infrared, helped to unravel the circumstances in which stars and planets form. De Kort (KNVWS chair) presented an overview of the status quo in discovering and characterizing exoplanets and exoplanet systems. Van der Hucht showed that understanding of the short and long term dynamics in the solar system helps to unravel the evolution of exoplanetary systems. Braam (TNO) revealed different types of technical challenges for the design and operation of detectors, and how these could be resolved. Snik showed that spectral polarimetry in particular offers a great potential to characterize alien worlds. Van Es (ASTRON / CAMRAS) won deep respect for the initiative to restore the Dwingeloo telescope which could be used to locate exoplanets that orbit pulsars. Nieuwenhout (ECN / KNVWS) presented a personal story to make his backyard astronomical equipment suitable for observations of exoplanets.

W-191: Spectroscopy of star and planet forming regions with Herschel

The meeting comprised two parts, extending over two weeks from 4 to 15 June 2012. The first week was a joint meeting of two teams doing key programs with the Herschel Space Observatory, the WISH and DIGIT teams. These two programs are quite closely related, with many personnel in common, but with significant differences in samples and observing modes. Both projects used the PACS and HIFI instruments to study the emission from spectral lines of molecules and atoms in the far-infrared region. In the second week, some members of both WISH and DIGIT remained and members of 14 other Herschel teams joined them. The week began with presentations by representatives of each team, followed by discussions of emerging topics. The relatively unstructured week allowed the formation of numerous working groups that addressed the way forward in many aspects of the subject. Examples of working group topics were the initial conditions for star formation, evolutionary sequences, outflows, complex organic species, chemistry in star forming regions, regions forming massive stars, patterns in disk mineralogy, and disk evolution.

7.2. Visitors in 2010-2011-2012

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.

Nr.	Date	Applicant	Visitor	University	Duration (days)
V-175	Apr-Jun-Sep 2009	A. de Koter	Jorick Vink, Armagh Obs, UK	UvA	3
V-181	20-Jun-2009	E. vd Heuvel	M.M. Verma, IUCAA, Pune, India	UvA	1
V-184	25-Jan-2010	A. Watts	Maxim Priymak, University of Melbourne, Australia	UvA	35
V-186	4-15 Jan 2010	S. Portegies Zwart	Alfred Whitehead, Drexel University, USA	UL	10
V-188	1-7 Mar 2010	S. Portegies Zwart	M. Iwasawa, University of Tokyo, Japan	UL	7
V-189	Jul-Sep 2010	M. Franx	Pieter van Dokkum, Yale, USA	UL	35
V-190	30 May - 17 June 2010	R. Quadri	Rik Williams, Carnegie, USA	UL	18
V-191	20 May 2010	J. Hörandel	Invited NAC conference spreakers	RU	1
V-192	13-16 Jun 2010	E. vd Heuvel	H. Bhadkamkar, Mumbai, India	UvA	3
V-194	20 Oct-27 Nov 2010	M. Verheijen	Visiting Blaauw professor Ron Ekers, CSIRO Australia	RUG	39
V-195	15-18 Nov 2010	R. vd Weygaert	Mike Edmunds, Cardiff University, UK	RUG	4
V-196	25-31 Jan 2011	E. vd Heuvel	Jishnu Dey and Mira Dey, Kalkota, India	UvA	6
V-197	3-11 March 2011	R. vd Weygaert	Franciso Kitaura, Leibnitz Institute, Potsdam	RUG	9
V-199	4 May - 7 June 2011	M. vd Sluys	Mike Politano, Milwaukee, USA	RU	35
V-200	12 - 22 April 2011	R. vd Weygaert	Wojtek Hellwing, Warsaw, Poland	RUG	10
V-201	18 - 20 May 2011	P. Jonker	Invited speakers NAC 2011 conference	SRON	3

Nr.	Date	Applicant	Visitor	University	Duration (days)
V-202	7 June - 7 Dec 2011	E. v. Dishoeck	Shuro Takano, Nobeyama Radio Observary, Japan	UL	180
V-204	16 Sept - 16 Dec 2011	H. Henrichs	Natallia Sudnik, St. Petersburg, Russia	UvA	90
V-205	Nov 2011 - Mar 2012	H. Röttgering	Emma Rigby, Edingburgh, UK	UL	90
V-207	23 Apr - 7 June 2012	H. Henrichs	Natallia Sudnik, St. Petersburg, Russia	UvA	15
V-208	12 - 14 April 2012	R. vd Weygaert	Herbert Edelsbrunner, IST, Austria	RUG	2
V-209	8 - 11 July 2012	R. vd Weygaert	Mark Neyrinck, John Hopkins, USA	RUG	4
V-212	12 - 30 Nov 2012	H. Henrichs	Natallia Sudnik, St. Petersburg, Russia	UvA	15
V-214	16 -21 Dec 2012	R. vd Weygaert	Oliver Hahn, Zurich, Switzerland	RUG	5

V-175: Visit of Jorick Vink

Vink (Armagh Observatory) visited the Netherlands three times for a collaborative research project which became part of the PhD thesis of Lianne Muijres. The thesis is on the prediction of mass-loss rates of early-type massive stars. The stellar winds of these objects are driven by radiation pressure on spectral lines. The standard predictions for this type of mass-loss employ a method developed and applied by De Koter, Vink and co-workers. This method makes a number of assumptions that require further investigation. Moreover, only a limited part of parameter space has so far been probed. Muijres had improved on the method by implementing a detailed solution of the momentum equation, building on work of a postdoc in the group of Vink. This extra physics has revealed the nature of the (long standing) “weak-wind” problem in O-type winds to be connected to an insufficient driving of the wind near the sonic point and that previous predictions did not properly account for the driving in this part of the outflow. The new method allows demarcating the boundary of solutions of line driven winds, not only in terms of stellar luminosity but also in terms of stellar metallicity. This is very relevant for the nature (and presence) of stellar winds of massive stars in the early universe. Moreover, the study of parameter space was extended to objects that are relatively close to the Eddington limit. This allows confronting observations and theory of objects in transition between normal O-type stars and Wolf-Rayet stars. Interestingly, the mass-loss rates scale nicely with the ratio of force due to the gradient in the continuum radiation pressure and the gravitational force, which allows for a fairly straightforward description. Finally, the effect of a clumpy wind on the mass-loss rate has been investigated theoretically. It was shown that for very clumpy and porous winds the mass-loss rates may be strongly reduced. This effect, however, does not explain the above mentioned “weak-wind” problem.

V-181: Visit of M.M. Verma

On 20-21 July 2010 Professor M.M. Verma (IUCAA, Pune, India) visited API for a meeting with Van den Heuvel and several other staff members to discuss the possible alternative causes of dark energy in the Universe. He also gave a colloquium, entitled: “Dark energy and the cosmological constant”.

V-184: Visit of Maxim Priymak

Current models of thermonuclear type-I X-ray bursts require the inclusion of MHD effects in order to explain unsolved phenomena such as double peaked bursts. These are often attributed to stalling of the flame front, although why this should occur is not yet clear. During his visit Maxim Priymak (Univ Melbourne) investigated the effect of equatorial magnetic field compression (which can build a ‘magnetic mountain range’ around the equator) on the propagation of thermonuclear flame fronts. Working with Watts and Cavecchi at Amsterdam he explored how the predictions of this model might be compared to data on double-peaked bursts. The work allowed us to gauge the feasibility of ‘magnetic mountain’ and flame stalling models.

V-186: Visit of Alfred Whitehead

Whitehead is a student of McMillan (Drexel University) with whom Portegies Zwart collaborate quite intensively. Whitehead’s visit was particularly valuable because he brought a small-N N-body integration method in a spatially distributed strategy, named ‘the Gorilla approach’. During his visit he explored the new setup of the AMUSE software environment, an endeavor for the seedless incorporation of multi-physics and multi-scale simulation software. Whitehead’s expertise as an experienced programmer, and an expertly trained stellar dynamicists has been a valuable asset to our AMUSE developments.

V-188: Visit of M. Iwasawa

Iwasawa (Univ Tokyo, Japan) has been visiting the Sterrewacht Leiden to work with Portegies Zwart, Deveccio, Fujii, Groen and Rieder on the dynamics of supermassive black holes (SMBHs) in stellar systems and the stellar structure around SMBHs. During his visit the team worked on mechanisms of rapid loss-cone refilling of merging supermassive black holes. For this purpose the group of Portegies Zwart was in the process of incorporating 6th and 8th order Hermite integration methods in direct N-body codes. The work was quite successful in improving on recent simulations which mainly focused on the binary evolutions after galaxy merging. An important step forward was made by allowing the entire galaxy to participate in the merger process. As a recent of this visit Iwasawa's numerical methods are now incorporated in the AMUSE framework.

V-189: Visit of Pieter van Dokkum

During 6 June and 16 July 2010 Van Dokkum (Yale, USA) and Franx have worked together on a number of collaborative projects, discussed recent work of several master students and PhD's, and reflected on articles and observations. Van Dokkum also participated in a workshop.

V-190: Visit of Rik Williams

Williams (Carnegie, USA) visited the Sterrewacht Leiden from 31 May to 17 June, 2010 to continue his collaborations with Quadri on studies of massive galaxies. The primary goal was to update the K-selected galaxy catalog from the UKIDSS Ultra-Deep Survey initially published by Williams et al. 2009, and continuing work on other projects. Williams and Quadri acquired data in the UKIDSS field, performed image registration and PSF matching across all bands and began performing tests to assess the improvement in data quality since the last catalog release. The remaining tasks (source detection and photometry and noise measurements) can easily be performed from the home institute. Williams also worked with Moein Mosleh (PhD student of Franx) on a paper about the evolution of UV-bright galaxy sizes resulting in a paper in the Astrophysical Journal.

V-191: Invited NAC conference speakers: Martin Pohl and Steven Smartt

The 65th Dutch Astronomy Conference was held from 19 to 21 May, 2010 in Cuijk. It was organized by the department of astrophysics at Radboud University Nijmegen. The meeting has been attended by 144 astronomers from the Netherlands and abroad. There was a balanced mixture of students, PhD students and senior scientists. A total of eight invited talks, 30 contributed talks, and 34 posters have been presented. Among the scientific highlights of the conference were talks about recent results from FERMI (Pohl), the Pan-STARRS1 sky survey (Smartt), LOFAR and the path towards SKA (Garrett), the microwave according to Planck (Bartelmann), the Herschel space observatory (Tielens), self-regulated evolution of galaxies and supermassive black holes (Schaye), and mapping the Milky Way with VLBI astrometry (Brunthaler).

V-192: Visit of H. Bhadkamkar

H. Bhadkamkar (Tata Institute for Fundamental Research, Mumbai, India) gave a colloquium at API on "Understanding the luminosity function of High Mass X-ray Binaries HMXBs" and further discussions with Van den Heuvel, Kaper, Wijnands, Markoff and members of their research groups. He used probability density distributions of primordial binaries – the progenitors of HMXBs -, derived from observations. The resulting distributions are further transformed to obtain luminosity functions using analytical fitting formulae for stellar evolution and models of wind mass loss from massive stars. Properties of luminosity functions and its dependence on model parameters were investigated. Comparison of the results with observationally obtained luminosity functions of HMXBs set limitations on the model and show directions for testing the theoretical calculations.

V-194: Visiting Blaauw professor Ron Ekers

For 2010, Ron Ekers (CSIRO, Australia was the Blaauw professor at the Kapteyn Institute in Groningen. He had plenty of discussions with colleagues in Groningen, Leiden and at ASTRON about the development of radio astronomy, in particular the near-term science opportunities of LOFAR and the longer-term strategic issues of the SKA.

V-195: Visit of Mike Edmunds

Mike Edmunds (Cardiff University) visited the Kapteyn Institute on 14-17 November, 2010. In particular he came to discuss the Antikythera mechanism, the subject of the research of Van de Weygaert and his graduate student Niels Bos. Van de Weygaert and Bos became members of the Antikythera Mechanism Research Project (AMRP), the international team lead by Edmunds that has obtained and is obtaining an imaging and high-energy high-resolution X-ray dataset of the mechanism. In particular during the visit two topics were addressed: the first is an analysis of the mechanical accuracy of the gear house of the mechanism and of its planetarium extensions, via the CAD models that Bos had developed. The second topic is the search for ancient artifacts that may indicate the existence of similar gear works in antiquity. To this end, the initiate was born to write letters to the directors of several European museums of Greek and Roman antiquity. The intention is to get access to the collections and storage places to assess whether there are hitherto unrecognized artifacts.

V-196: Visits of Jishnu and Mira Dey

Professors Jishnu Dey and Mira Dey visited API at the UvA on 25-31 Jan, 2011 to work with Van den Heuvel, Van der Klis, Watts and Wijnands. The visitors had developed a model for strange stars where quarks have masses varying with density and chiral symmetry plays an important part. The pions can couple to quarks unlike the bag model but the coupling decreases with higher density. The quarks are allowed to interact with a potential which has asymptotic freedom and confinement built into it with parameters tested to give right baryon masses and magnetic moments. The model uses the 1/color as an expansion parameter so that quark loops and non-planar gluon diagrams are suppressed and one can use simple Hartree-Fock like self consistency with a Dirac equation to obtain a mean field.

V-197: Visit of F. Kitaura

Kitaura (Leibniz Institute, Potsdam, Germany) visited Van de Weygaert at the Kapteyn Institute from 3-11 March, 2011. Together they wrote a review on large scale structure reconstruction. Kitaura also gave a guest lecture about his Bayesian reconstruction formalism. During the visit, a new collaborative was started to define Bayesian reconstruction techniques on triangulated surfaces, to optimally use the adaptability of tessellations to the sampled galaxy distribution. Although very promising, there are many technical issues to solve.

V-199: Visit of Mike Politano

Politano (Milwaukee, USA) visited the Radboud University from 4 May 4 to 7 June, 2011, as a part of his sabbatical year. During his visit he worked on two main topics in collaboration with Nelemans and Van der Sluys: 1. Upgrade of the jointly developed population-synthesis code, by optimizing the way stellar models are used and by finding a way to improve the treatment of the merger process; 2. Preparing a U.S. National Science Foundation (NSF) proposal that will seek funding for three years to make long-term improvements to the population-synthesis merger code mentioned above.

V-200: Visit of Wojtek Hellwing

The visit was in the context of the international collaboration, with participation of Van de Weygaert for the Netherlands, on the alpha-shape topology of the Cosmic Web, involving cosmologists from Groningen, Warsaw, Durham and KIAS in Seoul, and experts of computational topology (Vegter and Edelsbrunner). Hellwing (Warsaw University, Poland) is leading two papers in which the Groningen topological toolbox is used to determine the Betti numbers - which form the complete specification of the homology of the matter distribution - are applied to cosmological N-body simulations. Jointly the paper on LCDM was written, where the topology of both the dark matter and the dark halo distribution were described in terms of their Betti numbers. In addition to the obtained results on the dark matter distribution, more work is necessary on the dark halo distribution. As a result of the more diluted halo distribution, the errors in the fitting parameters turned out to be larger. The second paper, lead by Changbom Park (KIAS, Seoul), concerned the determination of the theoretical Betti numbers for Gaussian random fields.

V-201: Invited NAC conference speakers: Marten van Kerkwijk and Jean-Loup Puget

The two invited NOVA speakers on 2011 NAC conference Marten van Kerkwijk (Toronto University) and Jean-Loup Puget (CNRS-Université Paris Sud). Van Kerkwijk presented a novel idea explaining SN type Ia as merging binary white dwarfs. A lively discussion took place after his lecture and he was available for the whole NAC meeting for questions and answers. He participated actively in the meeting. Puget presented the first results of the Planck survey and summarized the main science goals of the mission. Furthermore, he explained how interested astronomers would be able to get access to the first release data.

V-202: Visit of S. Takano

Takano (Nobeyama Radio Observatory, Japan) visited Leiden Observatory from 7 June – 7 December, 2011, where he interacted with both galactic and extragalactic millimeter observers. His expertise on molecules in local and distant interstellar clouds was fruitful in discussions of several ongoing projects. He also wrote two papers, presented several seminars on his work, and gave a public talk on radio astronomy to the Japanese community in Leiden.

V-204: Visit of Natallia Sudnik

Sudnik (PhD student from St. Petersburg, Russia) collaborated with Henrichs at the API in Amsterdam in reanalyzing her high-quality spectroscopic dataset of the enigmatic O supergiant lambda Cephei, which was collected at observatories in Russia and South Korea. This star was extensively studied by Kaper in 1990 in He II and UV lines, but no explanation was found for the very strongly variable emission and absorption lines on an hourly timescale. Co-rotating surface magnetic fields were suspected to cause the observed variability. The new dataset included many more optical lines, which allowed us to construct a model with co-rotating magnetic loops on the surface. This model produces line profiles as a function of rotation phase, and a comparison with the observed profiles. A unique solution was found for the H gamma line behavior, which also provided the (unknown) rotation period. A model was developed to explain the behavior of other lines as well.

V-205: Visit of Emma Rigby

Rigby (Edinburgh University, UK) visited Leiden Observatory for 3 months in total in the period 15 Nov 2011 to 1 April 2012 working on a search for protoclusters using Herschel data. Protoclusters, the ancestors of local galaxy clusters, provide a unique opportunity to study both the emergence of large scale structure, and the evolution of galaxies in dense environments. Large field far-infrared observations of eight of the richest known protoclusters have been carried out by the Herschel Space Observatory, as part of the 'Search for Protoclusters with HERschel survey (SPHER)', with the aim of uncovering two key pieces of missing information: their large-scale morphology and the quantity of dust-obscured star formation in their member galaxies (PI Röttering). During her visits to Leiden Rigby fully reduced these data. Preliminary analysis suggests that the protocluster overdensity can be identified in 63% of these fields. Future work will focus on combining the Herschel observations with multi wavelength data (e.g. low frequency radio, sub{mm) to unambiguously identify protocluster members without the need for spectroscopic follow{up, and to constrain their spectral energy distributions.

V-207: 2nd visit of Natallia Sudnik

This second visit of Sudnik (see also V-204 and V-212) was to develop a magnetic-loop model to describe the high-quality spectroscopic dataset of the enigmatic 0 supergiant lambda Cephei. This model is able to represent the observed spectroscopic changes fairly well. Co-rotating surface magnetic loops (like prominences in the Sun) are suspected to cause the observed variability. After fitting a number of optical line profiles on the first night, the same set of parameters can predict and describe the evolution of the features during consecutive nights. This enables to find the rotation period of the star, which appeared to be 2 days. The results were presented at the 6th MiMeS meeting in Paris, 20 - 25 May 2012, and also at the Hot-Star Meeting on 30 May 2012. A joint paper was submitted.

V-208: Visit of Herbert Edelsbrunner

Edelsbrunner (IST, Austria) visited Van de Weygaert at the Kapteyn Institute in Groningen from 12-13 April, 2012. Both work together on a range of projects involving the application of algebraic topology and computational topology on the analysis of the large scale matter distribution in the Universe. The work also involves PhD project Pratyush Pranav, whose thesis project is supervised by prof. Gert Vegter (RUG, Mathematics) and Van de Weijgaert. During the visit, good progress was made on the "methods" paper, the extensive MNRAS publication in which the concept of homology, Betti numbers, and in particular persistence diagrams to a cosmological setting were introduced. By means of several heuristic models as well as LCDM cosmological simulations, the significance of the various measures was explored. Edelsbrunner wrote the text on the topological concepts, while Van de Weygaert was responsible for the part on random fields. Pranav took care of the numerical texts. In addition to the paper, quiet some time was spent on the issue of the topology of Gaussian random fields, the subject of a student project by two Groningen students (FeldbRUGge & Van Engelen). In the meantime, helped by the involvement of Edelsbrunner, their work is in the process of being converted into a scientific paper.

V-209: Visit of Mark Neyrinck

Neyrinck visited the Kapteyn Institute from 8-11 July 2012. During the visit he presented a seminar on his Origami work, which analyzes the full phase-space structure of an evolving cosmological dark matter distribution. This was used to identify filaments and walls. His visit tied in with the 6-month sabbatical visit of Shandarin, who was at the Kapteyn Institute from 25 June until 21 December 2012. Neyrinck has been developing the Origami formalism, which uses the deformation of an initial tessellation to trace the dark matter sheet in 6-D phase space. Independently, Shandarin has been developing a similar technique, the phase space sheet method. Together they wrote a chapter for upcoming book by Van de Weygaert on applications of tessellations. A common project on the study of the dynamics of filaments based on a comparison between the Origami technique, the phase-space sheet method and the Nexus formalism has been discussed.

V-212: Visit of Natallia Sudnik

The goal of her third visit was to further develop the “magnetic-loop model” in collaboration with Henrichs to describe the high-quality spectroscopic dataset of the enigmatic O supergiant lambda Cephei. Co-rotating surface magnetic loops (like prominences in the Sun) produce in this model the observed variability. An earlier version of this model was able to represent the observed spectroscopic changes fairly well in two datasets obtained at the Calar Alto, Kitt Peak and Crimean Observatories. In October 2012 the dataset was extended with spectra of the Hermes spectrograph at the Mercator telescope on La Palma during 7 consecutive nights, as part of a master course project for UvA and Leuven students. During her visit this new dataset was reduced. It appeared that the new observations did not well support the new model with the parameter set which worked with the previous observations.

V-214: Visit of Oliver Hahn

Hahn (Zurich, Switzerland) visited the Kapteyn Institute from 16 to 21 December 2012 to work with Van de Weygaert. During the visit he presented a seminar on his Phase Space Sheet work, which analyzes the full phase-space structure of an evolving cosmological dark matter distribution and uses this to infer a density field of impressively high resolution which can be used to identify filaments and walls. His visit tied in with the 6-month sabbatical visit of Shandarin. Hahn, Shandarin, Van de Weygaert and PhD student Hidding worked together on the implementation of a 2-D N-body code which would enable a systematic comparison of the outcome of adhesion theory based outline of the cosmic web-like structure of the universe. This, in turn, will allow an analysis of small-scale structure formation processes as a function of cosmic environment. As a spin-off PhD student Cautun and Van de Weygaert started a project looking for the evolution of substructure in voids.

8. Public Outreach and Education

An integral part of NOVA's mission is to popularize astronomy and astrophysics in the Netherlands; to report its frontline research in the widest sense, and to play an active role in defining and realizing the astronomy curricula in primary and secondary education. To these ends, it has established the NOVA Information Center (NIC), located in Amsterdam. The fast changing world of information and communications technology requires a pro-active approach to outreach and the NIC strives at being a forerunner in this field. Popularization of astronomy is also an excellent means for enthusing the public interest in the natural sciences in general. Specifically, NOVA aims to stimulate to such interests of young children up to students contemplating their higher education options. The NIC identifies four main target groups for its outreach and education efforts: 1. the general public, 2. students and teachers; 3. the press, and 4. policy makers.

The NIC is managed by Marieke Baan (1.0 fte). Jaap Vreeling (0.6 fte) is responsible for initiating, developing and managing educational programs and Franka Buurmeijer (0.4 fte) is assistant press officer and web-editor. The NOVA outreach and education program is monitored by the Minnaert Committee, chaired by De Koter.

NIC team

Baan

Vreelink

Buurmeijer

Communicating astronomy to public

The NIC presents news & information, and reports on all of its activities, through different types of media, including social media. Central to its communication is the website 'astronomie.nl', that has been revamped in 2012, where news is presented on a daily basis through collaboration with the site www.allesoversterrenkunde.nl by Govert Schilling. The site is linked to a YouTube channel and a presence on Twitter and Facebook, media that are rapidly becoming the main channels through which young people inform themselves. In addition to news, the site includes a news archive, a blog, an interactive sky chart, information on NOVA, an astronomy encyclopaedia, educational material and information for teachers and (prospective) students. In 2008-2010 the site attracted 175.000 annual unique visitors.

Press releases provide the media with news on national highlights of astronomical discoveries and general astronomical phenomena, typically on a weekly basis. Such press releases are issued in close collaboration with outreach officers at ESO, ESA, SRON and ASTRON, when appropriate. In the reporting period, three press visits have been organised to Chile, aimed at informing journalists on the Dutch contributions to the VLT and ALMA observatories. This has resulted in three programs on national television, two by Klokhuis and one by Labyrinth, and a feature on the ALMA inauguration in the NOS evening news. NIC press activities furthermore resulted in hundreds of articles in newspapers and magazines.

The NIC developed a new strategy to inform policy makers, aiming for direct communication. By utilizing its Mobile Planetaria, the ALMA inauguration and through prize nominations of NOVA astronomers and the NIC itself, it was successful in informing successive ministers and secretaries of state of the ministry of OC&W, as well as policy makers of NWO, on the goals and achievements of NOVA on a first-person basis.

Bringing astronomy into classrooms

The NOVA project 'Bringing astronomy into classrooms' initiated by De Koter, Barthel and Baan aims to improve the transfer of astronomical knowledge in schools through the use of innovative methods.

Two (three from 2012 onwards) Mobile Planetaria are used to visit primary and secondary schools. Trained operators apply an interactive didactical method to let students discover the night sky, the solar system and beyond. The program has been nominated for the NOT Innovation Prize 2011 in the category educational tools and methods. The launch of this project received attention of the NOS Jeugdjournaal. The program has reached 75,000 students in the period 2010-2012.

NOS-reporter at the ALMA site covering the inauguration of the telescope facility.

Secretary of state mister Sander Dekker and ESA-astronaut Andre Kuipers in front of the NOVA Mobile Planetarium.

A set of four NOVAlabs, booklets with astronomy projects and exercises, have been developed for groups 7 and 8 of primary schools and juniors in secondary schools. A digibord lesson 'Zon en Planeten' was developed for primary school students and served as a basis for the educational iPad games Planetenreis, for the same target group. The game, a co-production with publisher Moon, has won the third prize in the national Meester App 2012 contest for best ideas and apps on the topic 'learning' in primary schools.

Nieuwe Natuurkunde, the new physics curriculum in secondary education

In 2010 the Nieuwe Natuurkunde (NiNa) committee, including Barthel, for renewal of the physics curriculum in secondary schools advised the minister regarding the astrophysics requirements for HAVO and VWO students. The minister implemented this advice in 2012. NOVA actively participates in designing the new course materials through a collaboration with Noordhoff Publishers, the Dutch market leader in highschool textbooks. The HAVO material has been written by De Koter, Lamers and Van den Heuvel and is currently in the production phase. The NIC coordinates this project and guards the didactical aspects. In collaboration with Microsoft Nederland, the NIC has provided a Dutch translation for the World Wide Telescope software of this company, and practica using this software are included in the astrophysics chapters.

Supplementary to the new curriculum development, the NIC has taken the lead in organising a NiNa teacher training course that will be given at the Woudschoten Natuurkunde Didactiek Conferentie in 2013, where 600 physics teachers will gather. The central theme of this conference will be 'astronomy'. The training will familiarize these teachers with the new astrophysics offered, which is more topical than that offered in previous generations of textbooks.

The NIC in a larger perspective

The NIC collaborates closely with the national coordinator of EU Universe Awareness. UNAWE is a European educational initiative targeted at children in under developed regions of ages up to 10. This age group is complementary to the target groups of the NIC. The NIC takes care of Dutch translations of UNAWE produced SpaceScoops, news items for small children, and operates a joined stand with UNAWE at the Nationale Onderwijstentoonstelling 2012 (NOT) in Utrecht, a fare for professionals in education that attracted 60.000 visitors. Baan is a member of the board of the Platform Wetenschaps Communicatie (PWC), a national intervision platform for communication officers of all universities and scientific institutions. Vreeling chairs Planed, the Dutch-Flemish collaboration of planetaria.

The next generation

The NIC has implemented a training program to transfer its knowledge of public outreach to the next generation of astronomers. As part of this program, Baan offers an annual Science Communication Training at Groningen University, as well as an annual training to improve press communication awareness at the NOVA Autumn School.

The iPad Planetenreis for children six and up, winner of the third prize in the national Meester App contest for best ideas and apps on the topic `learning' in primary schools.

9. Organization

9.1 Board

Prof.dr. M. van der Klis (chair)	UvA, until January 2011 (chair from September 2007 until January 2011)
Prof.dr. P. Groot (chair)	RU (chair from November 2012)
Prof.dr. J.M. van der Hulst	RUG, until September 2011
Prof.dr. K.H. Kuijken (chair)	UL, until November 2012 (chair from January 2011 until November 2012)
Prof.dr. H.J.A. Röttgering	UL, since November 2012
Prof.dr. C.U. Keller	UU, until January 2012
Prof.dr. R.A.M.J. Wijers	UvA, since January 2011
Prof.dr. R.F. Peletier	RUG, since September 2011

9.2 Raad van Toezicht since November 2012

Prof.dr. S. Gielen	chair, RU
Prof.dr. K-J. Schoutens	UvA
Prof.dr. J. Knoester	RUG
Prof.dr. G. de Snoo	UL

9.3 International Advisory Board (2010-2011)

Prof.dr. F.H. Shu (chair)	University of California, San Diego, USA & Academia Sinica Institute of Astronomy and Astrophysics, Taiwan
Prof.dr. R.D. Blandford	Stanford University, California, USA
Prof.dr. R.C. Kennicutt	University of Cambridge, UK
Prof.dr. H-A. Rix	MPIA, Heidelberg, Germany
Prof.dr. A. Sargent	Caltech, Pasadena, California, USA
Prof.dr. R.A. Sunyaev	MPA, Garching, Germany

9.4 NOVA Research Network 1, 2 and 3

Network 1	*Network 2*	*Network 3*
Helmi, RUG, chair from 2013	Dominik, UvA, chair from Sep 2010	Nelemans, RUN, chair from 2012
Franx, UL, chair 2010-2012	Waters, UvA, chair, until Sep 2010	Falcke, RUN, chair 2010-2011
Barthel, RUG	Brown, UL	Achterberg, RUN
Bouwens, UL	Caxaux, RUG	de Koter, UvA
Brandl, UL	de Koter, UvA	den Herder, SRON
Brinchman, UL	Haverkorn, RUN/UL	Groot, RUN
Brown, UL	Helmich, SRON/RUG	Hermsen, SRON/UvA
Caputi, RUG	Henrichs, UvA	Hessels, ASTRON/UvA
de Bruijn, RUG	Hogerheijde, UL	Hörandel, RUN
Garrett, ASTRON/UL	Kamp, RUG	in t Zand, SRON
Haverkorn, RUN/UL	Kaper, UvA	Jonker, SRON/RUN
Hoekstra, UL	Keller, UL	Kaastra, SRON
Koopmans, RUG	Kenworthy, UL	Kaper, UvA
Kuijken, UL	Linnartz, UL	Koerding, RUN
Labbé, UL	Roelfsema, SRON/RUG	Markoff, UvA
Larsen, RUN	Shipman, SRON/RUG	Mendez, RUG

continuation

Network 1	Network 2	Network 3
Morganti, ASTRON/RUG	Snellen, UL	Pols, RUN
Oosterloo, RUG	Spaans, RUG	Portegies Zwart, UL
Peletier, RUG	Stam, SRON	Rossi, UL
Portegies Zwart, UL	Tielens, UL	Uttley, UvA
Rossi, UL	van der Tak, SRON/RUG	van der Klis, UvA
Röttgering, UL	van Dishoeck, UL	van Leeuwen, ASTRON/UvA
Schaye, UL	van Langevelde, JIVE/UL	Verbunt, RUN
Spaans, RUG	Waters, SRON/UvA	Vink, UvA
Tolstoy, RUG		Watts, UvA
Trager, RUG		Wijers, UvA
Valentijn, RUG		Wijnands, UvA
van de Weygaert, RUG		Wise, ASTRON/UvA
van der Hulst, RUG		
van der Werf, UL		
Verdoes Klein, RUG		
Verheijen, RUG		
Zaroubi, RUG		

9.5 Coordinators research networks

Prof.dr. M. Franx	UL Network 1
Prof.dr. L.B.F.M. Waters	UvA Network 2, until September 2010
Prof.dr. C. Dominik	UvA / RU Network 2, since September 2010
Prof.dr. H. Falcke	RU Network 3, until September 2012
Prof.dr. G. Nelemans	RU Network 3, since September 2012

9.6 Instrument Steering Committee

Prof.dr. P. Roche (chair)	Oxford
Prof.dr. R. Bacon	Univ. Lyon
Ing. F. Bettonvil	UL
Dr. B. Brandl	UL
Dr. M. Casali	ESO, until March 2010
Prof.dr. H.J. van Langevelde	JIVE
Prof.dr. L. Kaper	UvA
Prof.dr. G. Nelemans	RU, until September 2012
Dr. J. Hörandel	RU, since September 2012
Prof.dr. M. Verheijen	RUG
Dr. M. de Vos	ASTRON
Prof.dr. W. Wild	ESO
Dr. D. Martin	ESTEC, since September 2011

9.7 Education Committee

Prof.dr. P. Barthel	RUG, until October 2011
Prof.dr. M. Mendez	RUG, since October 2011
Dr. M. Brentjens	ASTRON
Dr. J. Hörandel	RU, until September 2011
Drs. N. Degenaar	UvA, until December 2011
Drs. T. Coenen	UvA, since December 2011
Prof.dr. F.P. Israel	UL, until October 2011
Prof.dr. P.van der Werf	UL, since October 2011
Prof.dr. L. Kaper (chair)	UvA/VU, until February 2011
Dr. A.L. Watts	UvA, since February 2011
Prof.dr. F. Verbunt (chair)	RU
L. Einarsen	UU, until September 2011
P. Bos	RUG, until September 2011
S. Jiraskova	RU
E. Kuiper	UL, until September 2011
MSc N. van der Marel	UL, since September 2011
L.Boschman	RUG, since September 2011

9.8 Minnaert Committee

Prof.dr. A. de Koter (chair)	UvA
Prof.dr. P.D. Barthel	RUG
Prof.dr. V. Icke	UL, until December 2011
Prof. dr. G. Nelemans	RU
Dr. J. Vink	UvA, until July 2012
Prof. dr. I. Snellen	UL, since January 2012
Dr. W. Boland (observer)	NOVA

9.9 Instrument Principal Investigators (PI or NL-PI for international projects)

Dr. B. Brandl	UL	E-ELT METIS
Dr. A.G.A. Brown	UL	Gaia
Prof.dr. E.F. van Dishoeck	UL	MIRI
Prof.dr. J. Schaye	UL	MUSE
Dr. M. Hogerheijde	UL	ALLEGRO
Prof.dr. K.H. Kuijken	UL	OmegaCAM
Prof.dr. E.A. Valentijn	RUG	OmegaCEN
Prof.dr. H.V.J. Linnartz	UL	Laboratory Astrophysics
Prof.dr. H.R. Röttgering	UL	LOFAR/DCLA
Prof.dr. W. Jaffe	UL	MATISSE
Prof.dr. C. Dominik	UvA	SPHERE-Zimpol
Prof.dr. E. Tolstoy	RUG	E-ELT MICADO
Prof.dr. C.U. Keller	UU/UL	E-ELT EPICS
Prof.dr. C.U. Keller	UU/UL	S5T
Prof.dr. L. Kaper	UvA	E-ELT MOSAIC
Prof.dr. S.F. Portegies Zwart	UL	AMUSE

Seed funding

Prof.dr. I. Snellen	UL	Mascara
Prof.dr. H. Falcke	RU	AUGER-radio
Dr. J. Vink	UvA	CTA pilot
Prof.dr. J.M. van der Hulst	RUG	ESKAC

9.10 NOVA Information Center (NIC, located at UvA)

Drs. M. Baan	
Drs. A. Lenssen (0.2)	until July 2010
Dhr. J Vreeling (0.6)	
Msc. F. Buurmeijer (0.2)	since August 2012

9.11 Office (located at UL)

Prof.dr. E.F. van Dishoeck (scientific director)
Dr. W. Boland (executive director)
C.W.M. Groen (finance and control)
J.T.Quist (management assistent)

10. Financial report 2010 - 2011 - 2012

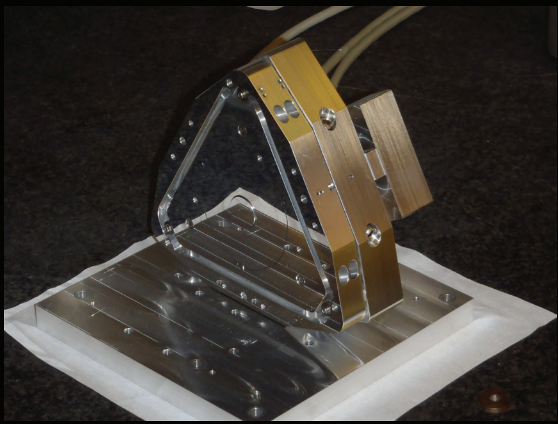
in k€	*2010*	*2011*	*2012*
ASTRONOMICAL RESEARCH			
Overlap Appointments	*564*	*600*	*836*
Research Networks			
Network 1: Galaxy Formation & Evolution	487	651	612
Network 2: Birth & Death of stars	539	672	657
Network 3: Final Stages of Stellar Evolution	414	484	454
Miscellaneous research activities	29	12	48
Cross network research projects	70	109	152
Science Support	327	509	374
Workshops & Visitors	35	43	45
Total research funding	1.902	2.479	2.342
TOTAL ASTRONOMICAL RESEARCH	**2.465**	**3.079**	**3.177**
INSTRUMENTATION (NOVA administrated projects)			
ALMA-ALLEGRO	123	131	97
ALMA Technical R&D Band 9	82	66	55
ALMA Band 5 Production		15	113
ALMA Band 9 Production	1.921	880	1.055
AMUSE	250	235	0
OPTICON, EU funded technical R&D projects	91	13	0
Gaia	98	147	125
LOFAR-DCLA	492	527	199
MATISSE	74	97	688
MATRI2CES	113	60	102
E-ELT METIS	95	54	85
E-ELT MICADO	101	1	0
MIRI	117	182	62
MUSE	56	3	89
MUSE-ASSIST	212	510	8
Optical-IR instrumentation group	1.600	1.115	1.267
S5T	50	137	0
Seed funding / Miscelleneous projects	13	152	93
TOTAL INSTRUMENTATION	**5.489**	**4.325**	**4.039**
SUPPORT			
NOVA Office	331	220	258
Outreach - NIC	267	239	198
TOTAL MANAGEMENT/ OUTREACH	**598**	**458**	**456**
TOTAL EXPENDITURE	**8.552**	**7.863**	**7.672**

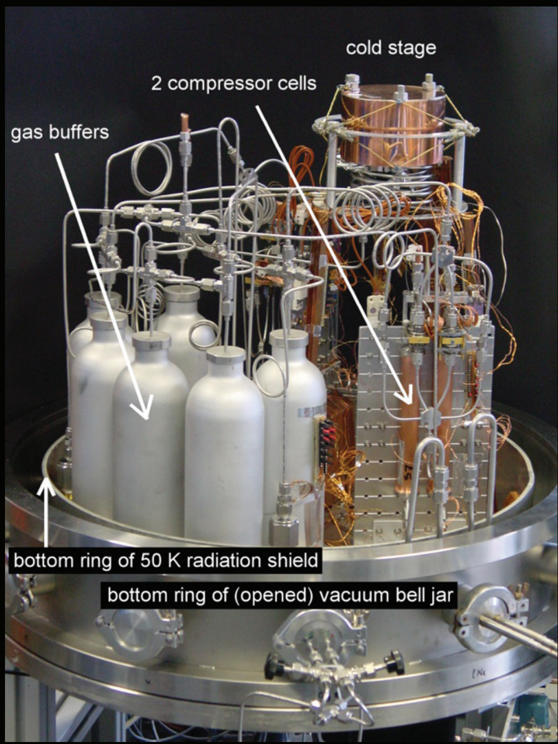
11. List of abbreviations

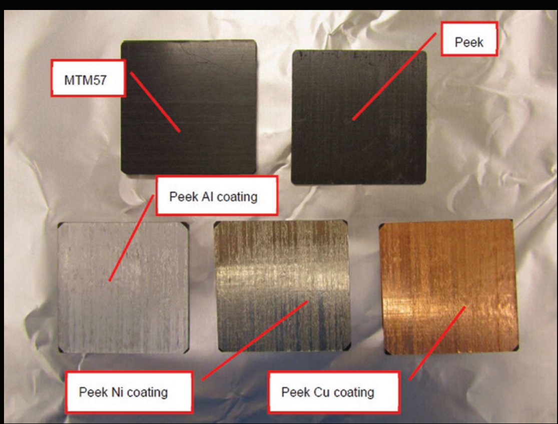
2SB	Sideband Separating
A&A	Astronomy & Astrophysics
AAS	American Astronomical Society
ACS	Advanced Camera for Surveys (instrument on HST)
AGN	Active Galactic Nuclei
AIO	Assistant-in-onderzoek - PhD student
AIP	Astrophysical Institute Postdam (Germany)
AJ	Astronomical Journal
ALLEGRO	ALMA Local Expertise GROup
ALMA	Atacama Large Millimeter/submillimeter Array
AMUSE	Astrophysical Multipurpose Software Environment (NOVA project)
AO	Adaptive Optics
AOF	Adaptive Optics Facility
APERTIF	APERture Tile in Focus (Multi-beam receiver for WSRT)
APEX	ALMA Pathfinder Experiment
API	Astronomical Institute Anton Pannekoek (UvA)
ApJ	Astrophysical Journal
ARC	ALMA Regional Center
ASSIST	Adaptive Secondary Setup and Instrument Simulator (NOVA project)
ASTRON	ASTRON - Netherlands Institute for Radio Astronomy (NWO institute
ASTRO-WISE	Astronomical Wide-field Imaging System for Europe (EU-funded network involving NOVA-RUG)
AU	Astronomical Unit
Auger	see PAO
Band-5	ALMA receiver for the atmospheric window between 163 and 211 GHz
Band-9	ALMA receiver for the atmospheric window between 610 and 720 GHz
Caltech	California Institute of Technology
CCD	Charge-Coupled Device
CDF	Chandra Deep Field
CDM	Cold Dark Matter
CEA Saclay	Commissariat à l' Energie Atomique (institute at Saclay, France)
CERN	European Organization for Nuclear Research
CfA	Center for Astrophysics (Harvard, USA)
CFHT	Canada France Hawaii Telescope
CHAMP+	CHAMP+ is a dual-frequency heterodyne submillimeter array receiver built by MPIfR and NOVA/SRON/TuD for APEX
Chandra	NASA's X-ray space observatory
CMB	Cosmic Microwave Background
COROT	French led astronomical space observatory to search for extrasolar planets and stellar seismology
COSMOGrid	Worldwide super-computer collaboration for astrophysical simulations
CRAL	Centre de Recherche Astronomique de Lyon (Fr)
CRIRES	Cryogenic high-Resolution InfraRed Echelle Spectrograph (instrument on VLT)
CRs	Cosmic Rays
CRYOPAD	CRYOgenic Photoproduct Analysis Device (set-up at Sackler Laboratory at Leiden Obdervatory)
CSO	Caltech Submillimeter Observatory
CTA	Cherenkov Telescope Array
DCLA	Development and Commissioning of LOFAR for Astronomy
DTFE	Delaunay Tessellation Field Estimator
DPAC	Data Processing and Analysis Consortium (on development data processing software for Gaia)
DSM	Deformable Secondary Mirror (for one of the VLT telescopes)
DTFE	Delaunay Tessellation Field Estimator
DUEL	Dark Universe through Extragalactic Lensing (EU Network)
E-ELT	European Extremely Large Telescope
ECDFS	Extended Chandra Deep Field-South
EoR	Epoch of Reionization
EPICS	Exo-Planet Imaging Camera and Spectrograph (Instrument in study for the E-ELT)
EPOL	EPICS Polarometer
ESA	European Space Agency
ESFRI	European Strategy Forum on Research Infrastructures
eSMA	extended SMA
ESO	European Southern Observatory
ETH	Eidgenössische Technische Hochschule (Zürich)
EU	European Union
EU FP7	EU Framework Program 7
EUCLID	Possible ESA Cosmic Vision mission to map the geometry of the dark universe
EUV	Extreme Ultra Violet
eV	electron Volt
EVN	European VLBI Network
ExPo	Exoplanet Polarimeter (instrument on WHT)
Fermi	Fermi Space Telescope for gamma ray wavelengths (NASA)
FIR	Far InfraRed
FIRES	Faint Infrared Survey (large program at the VLT)
FLAMES	Fibre Large Array Multi Element Spectrograph (instrument on VLT)
FOM	Fundamenteel Onderzoek der Materie (NWO institute for physics)
FP	"Framework Program (EU) Fundamental Plane"
Gaia	Gaia - ESA's astrometric cornerstone mission
GALACSI	Ground Atmospheric Layer Adaptive Corrector for Spectroscopic Imaging (for MUSE)
GALEX	Galaxy Evolution Explorer (NASA satellite for UV wavelengths)
GARD	Group Advanced Receiver Development at Onsala Space Observatory, Sweden
GEPI	Galaxies Etoiles Physique et Instrumentation (Division of Observatoire de Paris, France)
GHz	Giga Herz
GMRT	Giant Meterwave Radio Telescope
GRAAL	Ground layer Adaptive optics Assisted by Lasers (ESO facility for instrument tests)
GRAPPA	Astroparticle physics and gravitation initiative (at UvA)
GRB	Gamma Ray Burst
GTC	Gran Telescopio CANARIAS
GTO	Guaranteed Time Observations

GZK	Greisen-Zatsepin-Kuzmin limit (energy cut-off for cosmic rays)
HAWK-I	High Acuity Wide field K-band Imager (instrument on VLT)
HerCULES	Herschel Comprehensive ULIRG Emission Survey
Herschel	Herschel - Far infrared space observatory (ESA)
HI	Hydrogen 21 cm line
HIFI	Heterodyne Instrument for the Far-Infrared for Herschel
HST	Hubble Space Telescope
HV-setup	High Vacuum setup (at Sackler Laboratory at Leiden Observatory)
HzRGs	High-redshift Radio Galaxies
IAP	Institut d'Astrophysique de Paris
IAU	International Astronomical Union
IceCube	Neutrino telescope at South Pole
ICM	Inter-Cluster Medium
IFS	near-IR integral Field unit (part of SPHERE)
IFU	Integral Field Unit
IGM	Inter-Galactic Medium
IMF	Initial Mass Function
INAF	Instituto Nazionale di Astro-Fisica (Italy)
ING	Isaac Newton Group of the Roque de los Muchachos Observatory on La Palma
INSU/CNRS	Institut National des Sciences de l'Universe du Centre National de la Recherche Scientifique (funding agency, Fr)
INT	Isaac Newton Telescope (part of ING)
IR	Infra-Red
IRAM(-PdBI)	Institut de Radio Astronomie Millimétrique (Grenoble, Fr) - Plateau de Bure Interferometer
IRAS	InfraRed Astronomical Satellite
IRDIS	InfraRed Dual Imaging Spectrograph (part of SPHERE)
IRS	InfraRed Spectrometer (instrument on Spitzer Space Telescope)
ISAAC	Infrared Spectrometer And Array Camera (instrument on VLT)
ISC	Instrument Steering Committee (NOVA)
ISM	InterStellar Medium
ISO	Infrared Space Observatory (ESA)
IXO	International X-ray Observatory (under consideration, ESA, NASA, JAXA)
JAXA	Japan Aerospace Exploration Agency
JCMT	James Clerk Maxwell Telescope (on Mauna Kea, Hawaii)
JIVE	Joint Institute for VLBI in Europe
JPL	Jet Propulsion Laboratory, Pasadena, USA
JWST	James Webb Space Telescope (successor of Hubble Space Telescope)
KiDS	Kilo-Degree Survey (planned for VST/OmegaCAM)
KIPAC	Kavli Institute for Particle Astrophysics and Cosmology
KM3NeT	Neutrino telescope in Mediterranean Sea; successor of ANTARES
KNAW	Koninklijke Nederlandse Akademie van Wetenschappen (Royal Academy of Arts and Sciences)
KRP	Key Research Project
KRs	Key Researchers (leaders of the NOVA research networks)
LABOCA	Large APEX Bolometer Camera
LAM	L'Observatoire Astronomique de Marseille-Provence (Fr)
LAOG	Laboratoire d'Astrophysique de l'Observatoire de Grenoble (France)
LAOMP	Laboratoire d'Astrophysique Observatoire Midi-Pyrénées (Fr)
LERMA	Laboratoire d'Etude du Rayonnement et de la Matière en Astropysique (part of Observatoire de Paris)
LESIA	Laboratoire d'études spatiales et d'instrumentation en astrophysique (part of Observatoire de Paris)
LGS	Laser Guide Star
LIGO	Laser Interferometer Gravitational-Wave Observatory (USA)
LIRG	Luminous InfraRed Galaxy
LISA	Laser Interferometer Space Antenna (possible ESA mission to detect gravitational waves)
LLAGN	Low Luminosity Active Galactic Nucleus
LMC	Large Magellanic Cloud
LOFAR	LOw Frequency ARray - new radio observatory managed by ASTRON in collaboration with European partners
LOPES	LOFAR PrototypE Station (at Karlsruhe, Germany)
LRIS	Low Resolution Imaging Spectrometer (Keck Instrument)
LSS	Large Scale Structure Survey (by XMM)
LUAN	Laboratoire Univeritaire d'Astrophysique de Nice (Fr)
M2-unit	Secundary mirror in telescope
MATISSE	Multi AperTure Mid-Infrared Spectroscopic Experiment (2nd generation VLTI instrument)
MATRI^{2}CES	Mass Analytical Tool of Reactions in Interstellar ICES (set-up at Sackler laboratory at Leiden Observatory)
METIS	Mid-infrared ELT Imager and Spectrograph for E-ELT
MICADO	Near-infrared wide-field imager for E-ELT
MIDI	MID-Infrared instrument (instrument on VLTI)
Mid-IR	Mid-InfraRed
MIRI	Mid Infra-Red Instrument (under construction for JWST)
MIT	Massachusetts Institute of Technology
MNRAS	Monthly Notices of the Royal Astronomical Society
MOSIAC	Multi Object Spectrograph instrument concept for E-ELT
MPE	Max-Planck-Institut für Extraterrestrische Physik (Garching, Germany)
MPIA	Max-Planck-Institut für Astronomie (Heidelberg, Germany)
MPIfR	Max-Planck Institut für Radioastronomie (Bonn, Germanny)
MUSE	Multi Unit Spectroscopic Explorer (instrument under construction for VLT)
NAC	Nederlandse Astronomen Club
NASA	National Aeronautics and Space Administration (USA)
NIC	NOVA Information Center
NIKHEF	Nationaal Instituut voor Kernfysica en Hoge-Energiefysica (institute of FOM)
NL	Netherlands
nm	nanometer
NOVA	Nederlandse Onderzoekschool Voor Astronomie (Netherlands Research School for Astronomy)
NRAO	National Radio Astronomical Observatory (USA)
NRL	Naval Research Laboratory (USA)
NSF	National Science Foundation (USA)
NW	NOVA research network
NWO	Nederlandse organisatie voor Wetenschappelijk Onderzoek (Netherlands Organization for Scientific Research)
OCW	Dutch ministry for Education, Culture and Science

OmegaCAM	Wide-field camera for the VLT Survey Telescope
OmegaCEN	OmegaCAM data center (at RUG)
ONERA	Office National d'Etudes et de Recherches Aérospatiales (Fr)
OP/IR	Optical to InfraRed
OSO	Onsala Space Observatory (in Sweden)
PACS	Photodetector Array Camera and Spectrometer (instrument on Herschel)
PAH	Polycyclic Aromatic Hydrocarbon molecule
PAO	Pierre Auger Observatory (international cosmic ray observatory in Argentina)
pc	parsec
PD	Postdoc
PDF	Probability Density Function
Ph	Phase
PI	Principal Investigator
PSF	Point Spread Function
PuMa	Pulsar Machine (instrument on WSRT)
R&D	Research and Development
RadioNet	EU-funded network for radio astronomy
RAL	Rutherford Appleton Laboratory (Didcot, UK)
RM	Rotation Measure
RU	Radboud Universiteit, Nijmegen
RUG	Rijksuniversiteit Groningen
S5T	Small Synoptic Second Solar Spectrum Telescope (NOVA project)
SAFARI	SpicA FAR-infrared Instrument (instrument on Japanese-European SPICA mission)
SINFONI	Spectrograph for INtegral Field Observations in the Near Infrared (instrument on VLT)
SIS	Superconductor Insulator Superconductor; detector technology for (sub)-mm and far-IR
SKA	Square Kilometer Array
SLACS	Sloan Lens ACS Survey
SMA	SubMillimeter Array (on Mauna Kea, Hawaii)
SMC	Small Magellanic Cloud
SMG	SubMillimeter Galaxies
SMO	Spectrometer Main Optics
SNN	Samenwerkingsverband Noord Nederland
SPHERE	Spectro-Polarimetric High-contrast Exoplanet Research (instrument under construction for VLT)
SPICA	SPace Infrared telescope for Cosmology and Astrophysics (likely Japanese mission with European participation)
SRON	SRON - Netherlands Institute for Space Research
SURFRESIDE	SURFace Reactions Simulation Device (setup for Sackler Laboratory at Leiden Observatory)
TNO	Research Institute for applied physics in the Netherlands
TUD	Technical University Delft
UD	Assistant professor
UHD	Associate professor
UHE	Ultra-High Energy
UHECR	Ultra-High Energy Cosmic Rays
UK	United Kingdom
UKIRT	United Kingdom Infrared Telescope
UL	Universiteit Leiden
ULIRG	Ultra Luminous Infra-Red Galaxy
UltraVISTA	Ultra deep near-IR imaging program with VISTA
UNAWE	Universe Awareness (international outreach activity aimed at kids of 4-10 years)
UNESCO	United Nations Educational, Scientific and Cultural Organization
univ	university
USM	Universität-Sternwarte München (Germany)
UU	Universiteit Utrecht
UV	ultra violet
UvA	Universiteit van Amsterdam
VIKING	Vista Kilo-degree Infrared Galaxy survey
VIMOS	Visible Multi-Object Spectrograph (VLT instrument)
VISIR	VLT-Imager and Spectrometer for mid InfraRed (instrument on VLT)
VISTA	Visible and Infrared Survey Telescope for Astronomy (ESO)
VLA	Very Large Array
VLBI	Very Long Baseline Interferometry
VLT	Very Large Telescope (ESO)
VLTI	Very Large Telescope Interferometer (ESO)
VO	Virtual Observatory
VST	VLT Survey Telescope
WFI	Wide-Field Imager (ESO 2.2m instrument)
WFPC	Wide-Field Planetary Camera (instrument on HST)
WHT	William Herschel Telescope (part of ING)
WSRT	Westerbork Synthesis Radio Telescope
XMM-Newton	X-Ray Multiple Mirror (ESA's X-ray observatory)
XRB	X-Ray Binary
X-Shooter	Single target optical and near-IR spectrometer (instrument on VLT)
YSO	Young Stellar Object
ZIMPOL	Zurich IMaging POLarimeter - part of SPHERE




cold stage
2 compressor cells
gas buffers
bottom ring of 50 K radiation shield
bottom ring of (opened) vacuum bell jar


MTM57
Peek
Peek Al coating
Peek Ni coating
Peek Cu coating