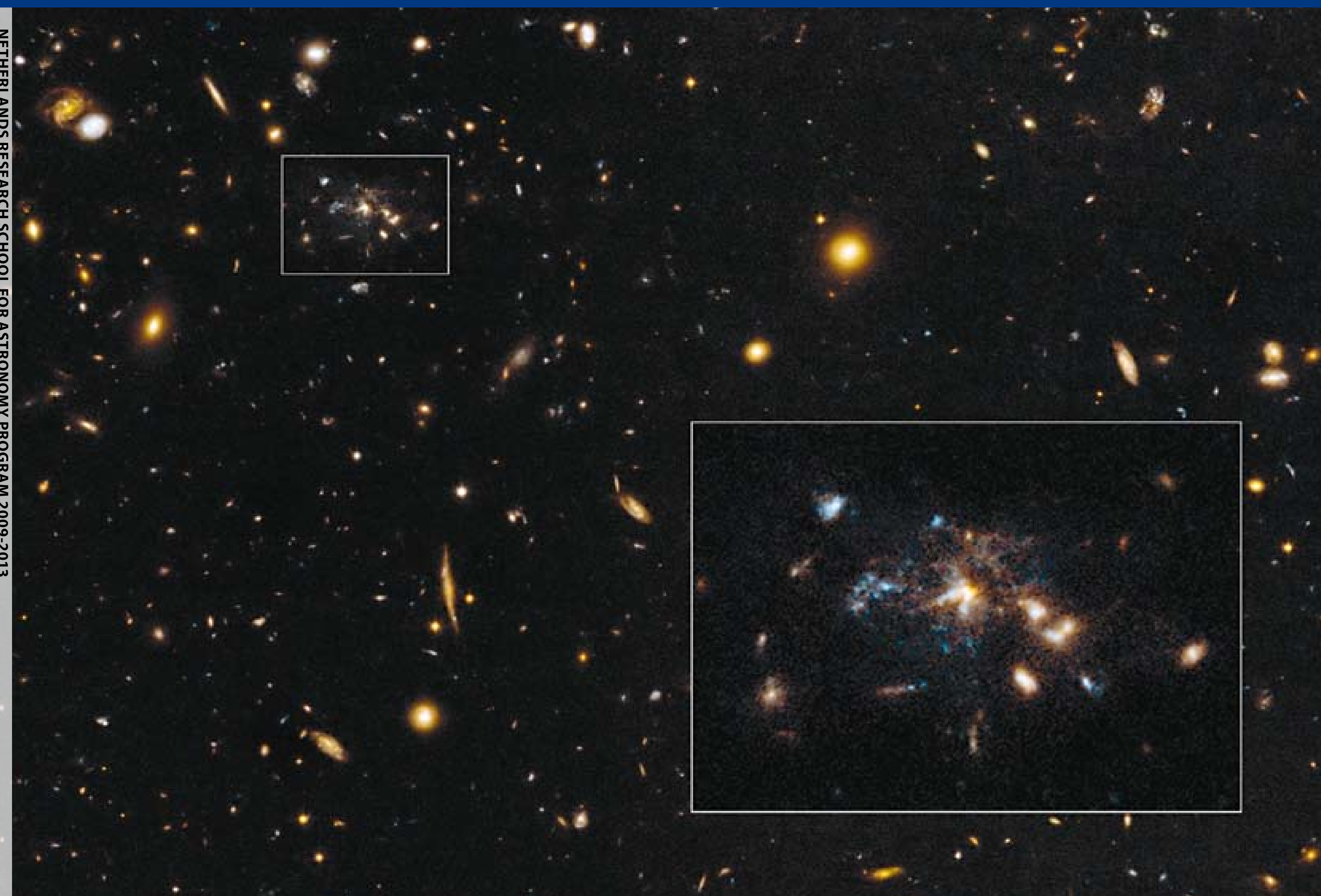
NETHERLANDS RESEARCH SCHOOL FOR ASTRONOMY PROGRAM 2009-2013

Netherlands Research School for Astronomy

Program 2009-2013



NOVA Phase-3 program
2009 - 2013

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NOVA is a federation of the astronomical institutes at the universities of Amsterdam, Groningen, Leiden, Nijmegen and Utrecht, legally represented by the University of Utrecht from 1st September 2007 until 31st December 2012.

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1. Summary

Astronomy is unique among the sciences in its combination of cultural, scientific, technological, and social aspects. Throughout the ages, mankind has been fascinated by the beauty of the night sky, coupled with a deep human desire to understand its own origins and place in the Universe. The Universe is full of mysteries. Only in the last few years has it become clear that the Universe consists for 95% of dark energy and dark matter which leave no directly observable trace; everything we see with the most powerful telescopes comprises the remaining 5%. Galaxies can now be studied at the edge of the Universe from which the radiation takes 13 billion years to reach Earth. Much closer to home an amazing variety of planets circling nearby stars has been found, none of which resembles our own Solar System. The tip of the dusty veils surrounding the birth of galaxies, stars and planets, and perhaps even life itself, is being finally being lifted. New interdisciplinary topics such as astroparticle physics, astrochemistry and astrobiology are emerging worldwide. Astrophysicists study physical and chemical processes under conditions orders of magnitude more extreme than can be found anywhere on Earth: huge densities (e.g., neutron stars, black holes), extreme vacua (interstellar and circumstellar media), immense energies (supernovae, quasars) and intense fluxes of particles and radiation (neutrinos, gamma ray bursts). Dutch scientists, combined in NOVA, are at the forefront in this increasingly exciting research area.

The Netherlands Research School for Astronomy, NOVA, is one of the six national top-research schools established in 1998 under the 'In-Depth Strategy' program initiated by the Ministry of Education, Culture and Science (OCW). The initial program was set up for a period of ten years with a mid-term review carried out by the Netherlands Organization for Scientific Research (NWO) in 2003. NOVA and the other five top-research schools passed this review successfully and the funding for Phase-2 (2005-2008) was confirmed. In 2006 the minister decided to continue the funding for the six schools for the period 2009–2013 and to call for a program review in 2010 which could result in continuation of funding beyond 2013, if excellent quality in comparison with the best foreign institutes in their field of research can be demonstrated. This document describes the NOVA Phase-3 program covering the period 2009–2013.

NOVA is a federation of the astronomical institutes at the universities of Amsterdam, Groningen, Leiden, Nijmegen and Utrecht. When NOVA was established as an inter-university collaboration and officially recognized by the Royal Dutch Academy of Sciences in 1992, it was agreed that its legal representation ('penvoerderschap') should rotate between the participating universities in five year cycles. Accordingly, Leiden University (UL, 1992-1997), University of Amsterdam (UvA, 1997-2002), and University of Groningen (RuG, 2002-2007) have previously held this role. Currently NOVA is legally represented by Utrecht University (UU) for the period from 1 September 2007 until 31 December 2012.

NOVA's mission is to carry out frontline astronomical research in the Netherlands, and to train young astronomers at the highest international level. All graduate astronomy education in the Netherlands is concentrated in NOVA. Dutch PhD students are stimulated to become independent scientists at an early stage. When they graduate, they frequently receive international prize fellowships and challenging research positions at top-ranked astronomical institutes worldwide.

The central theme of the research carried out within NOVA is ***'The life-cycle of stars and galaxies: from high-redshift to the present'***. Modern astronomy requires access to state-of-the-art observations across a wide range of wavelengths. A key component of the NOVA program is therefore to develop and build new astronomical instruments and to carry out technical research and development for the next generation of instruments.

The NOVA research program is organized along the following three interconnected networks:

Network 1: Formation and evolution of galaxies: from high redshift to the present
Network 2: Formation of stars and planetary systems
Network 3: The astrophysics of black holes, neutron stars and white dwarfs

Each inter-university network is led by 5-6 key researchers with strong international reputations. The list of NOVA Key Researchers is given in Appendix A. The entire program enables NOVA researchers to obtain a rich harvest of results from unique ground-based and space-based facilities in conjunction with state-of-the-art theory, numerical modeling, and laboratory astrophysics.

The NOVA program involves about 270 fte scientific staff members spread over the five universities participating in NOVA. This number includes ~60 fte senior staff members in permanent and tenure-track positions, 40 fte postdoctoral fellows, 130 fte PhD students, and ~40 fte staff working on instrumentation projects. NOVA funds about 20% of these positions. It also provides an active workshop and visitors program, and outreach efforts through the NOVA Information Center.

The Phase-3 budget (2009-2013) amounts to 40.4 M€. The revenues match the expenditures (Chapter 5). The expenditures include (1) 14.6 M€ on the research program, (2) 23.6 M€ on the instrumentation program including the ESO-funded program on the ALMA receivers, and (3) 2.2 M€ on the Office, the outreach program and a fund to cover social security obligations for which NOVA has responsibility. A budget overview is presented in Appendix B and in various tables in Chapters 2 and 3. Taken together the NOVA program, presented here, is essential for Dutch astronomy to maintain its status as a premier international center for research and PhD education.

In November 2008, NOVA and its partners including ASTRON, SRON, TNO, Technical Universities and industry received a grant of 18.8 M€ for the national participation in the E-ELT instrumentation program. The allocation is divided into an amount of 8.8 M€ in 2009-2011 to participate in the preliminary design studies and related technological R&D, and 10 M€ to participate in the final design and construction of one E-ELT instrument. This grant for E-ELT instrumentation is additional to the Phase-3 budget as summarized in previous paragraph.

Chapter 2 describes the NOVA research program for Phase-3 and Chapter 3 the instrumentation program. The Office and outreach activities are summarized in Chapter 4, and the financial matters are addressed in Chapter 5.

2. Research Program

The aims of the NOVA research program are to carry out front-line astronomical research in the Netherlands, to train young scientists (PhD, postdocs) at the highest international level, and to scientifically exploit the instrumentation in which the Netherlands has made significant investments, either through the NOVA instrumentation program or through other channels. The research program is organized along the following three interconnected networks:

- Network 1: Formation and evolution of galaxies: from high redshift to the present
- Network 2: Formation of stars and planetary systems
- Network 3: The astrophysics of black holes, neutron stars and white dwarfs

In late November 2007, NOVA issued the guidelines to the general Dutch community to put together the Phase-3 Research Networks and Science Support Program. Within these guidelines each Network was free to use its own internal procedures to put together a program of 2.4 M€, organized by its Network coordinator. The guidelines included that each network should (i) have a number of common themes to ensure a coherent research program; (ii) have a healthy balance between observations, models, theory and laboratory experiments, where relevant; (iii) include a few cross network projects; and (iv) make good use of instrumentation in which the Netherlands has a major involvement. Each PhD student or postdoc should have supervisors or mentors from at least two universities or from one university and ASTRON, JIVE or SRON to strengthen inter-university and inter-institute collaborations.

Each Network organized one or more face-to-face meetings and had several telecons to put its program together. This draft program was subsequently discussed at a face-to-face meeting between the Directorate and the Network coordinators. After iterating on the cross-network proposals, the Network coordinators finalized their Network programs and submitted them to NOVA. The Board subsequently approved the Network program at its May 2008 meeting. A summary of each Network program is provided below. Several projects require only partial funding from NOVA, with the remaining funds provided by the university of the primary supervisor or other sources. In particular, SRON made matching funds available for several Network-2 Herschel-HIFI related projects and a number of Network-3 projects.

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

The question how galaxies formed and evolved is one of the most fundamental problems in current-day astronomy. Most of what we know about the Universe comes from light emitted in galaxies. Before we can make stars or planets, the galaxies have to form in which these objects reside. The study of galaxy formation and evolution has progressed greatly in the last decade due to spectacular advances in observational facilities and improved theoretical modeling. Observationally, galaxies can now be traced to a redshift of 7 and above (corresponding to ages less than 5% of the current age of the Universe). Theoretically, processes can be traced at great detail in very large volumes, allowing the study of rare, bright objects and also the low-mass precursors of 'normal galaxies' in the nearby Universe (Fig. 1). NOVA astronomers have played key roles in the study of galaxy formation and evolution, using observational facilities like the ESO Very Large Telescope (VLT), the Hubble Space Telescope (HST), and additional observatories, and have been making important contributions to the interpretation and modeling of these results.

Network-1 has identified key areas in which it proposes to focus its research with the newly available facilities. The main themes are (1) formation and evolution of galaxies, and specifically the star formation histories of galaxies, and (2) gas in galaxies as related to the processes which drive star formation: the infall of gas, the formation of stars, the feedback on the gas, and the dispersal of gas through winds. These two themes will be addressed with a variety of diagnostics and will be studied from high to low redshifts through a combination of observations, numerical modeling and theory. The projects make heavy use of ESO-VLT (MUSE, X-Shooter, and SINFONI), VST-OmegaCAM, LOFAR, and Herschel, along with other facilities, and prepare for ALMA, JWST, Gaia and SKA. The individual projects are described below.

2.1.1. High redshift galaxies

At high redshifts, the observational and theoretical work will lead to improved descriptions of the evolution of galaxy populations and the build-up of galaxies. Specifically, the newly-built LOFAR telescope will be used to study the very early phase of the Universe in which the neutral hydrogen is ionized by very early galaxies and/or quasars. Koopmans and de Bruyn will lead a study with LOFAR to detect and statistically characterize the hydrogen 21-cm emission line between redshifts 6 and 11.5, giving crucial insight into this very early phase of galaxy formation. Special emphasis will be put on the characterization of possible physical and instrumental contaminants to the Epoch of Reionization signal in the survey, and the isolation of the 'true' detections.

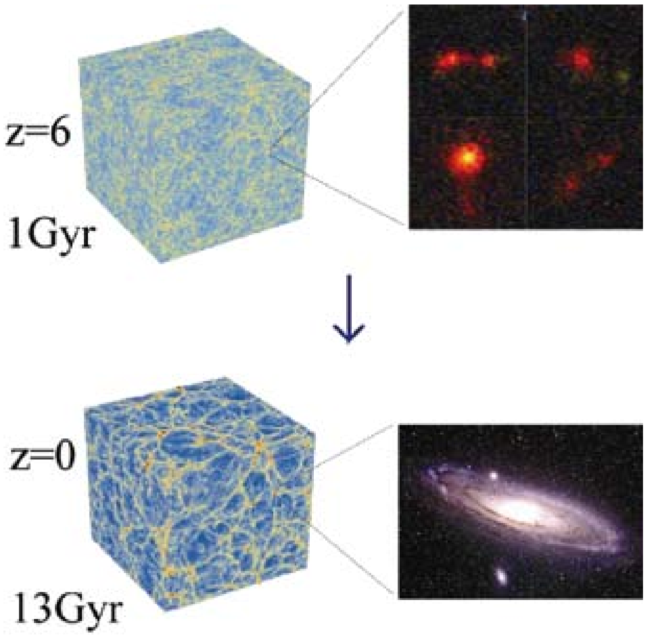

Figure 1: The evolution of galaxies from a redshift of 6, when the Universe was about 1 Gyr old, to a redshift of 0, the current epoch, with an age of about 14 Gyr. The left column shows simulations of the distribution of gas in the Universe in a co-moving box of 140 Mpc (i.e., the expansion of the Universe has been taken out). At a redshift of 6, the gas is already distributed inhomogeneously, but the inhomogeneities have grown strongly by redshift 0. The right hand column shows the observed evolution of galaxies from a redshift of 6 to a redshift of 0. The redshift of 6 galaxies have been observed by the Hubble Space Telescope, and the z=0 galaxy is our large neighbor, the Andromeda galaxy, which is visible by eye. Galaxies at high redshift are significantly smaller and rarer than nearby galaxies, and are more irregular. The Network-1 program focusses on the question how galaxies have grown from high redshift to low redshift, and how star formation progresses in galaxies. It entails both simulations and observational studies. Credits: simulations by Schaye et al.

At slightly lower redshift, the MUSE instrument, built with significant NOVA involvement, will become available. MUSE will be able to detect very faint Ly-α emission from high redshift galaxies. Schaye and Spaans will extend a novel radiative transfer technique recently developed for ionizing radiation to the transfer of Ly-α lines. Numerical simulations of the formation of galaxies will, for the first time, simultaneously solve for the hydrodynamics as well as the radiative transfer of both ionizing and line radiation.

A complementary method to find and study high redshift galaxies is through their rest-frame optical light, i.e., observers' near-IR. These searches are still very difficult at the moment, due to the bright Earth-sky. The near-IR spectrometer on X-Shooter, built by NOVA, will open up a new regime: its high resolution and high efficiency will allow very efficient spectroscopy of z=1.5-3 galaxies in the rest-frame optical. Franx and collaborators will study a mass-selected sample of 100 galaxies with X-Shooter, 10 of which at very high signal-to-noise, the others at high enough signal-to-noise to allow accurate redshifts and SED shape measurements. This will give unique insight into the stellar populations and formation history of these galaxies.

A theoretical study led by Trager and Schaye will address the question how the gas content of galaxies is expected to evolve from z=1 to 0. It has become clear that this interval is quite important, as the number of massive red galaxies in the Universe doubles over that period. This implies a strong evolution in the gas content, which should be observable with future facilities such as ALMA, and later, SKA. Detailed observational predictions will be made of the evolution of the gas content of galaxies for the next generation of cold gas surveys. Current models of galaxy evolution will be extended to understand and predict the molecular gas, neutral hydrogen, and ionized gas components of blue galaxies, where the gas resides, from z=1 to the present.

2.1.2. Local Galaxies in the local Universe

The Herschel satellite will be launched in 2009 and will open up new studies of the gas and star formation regions of galaxies in the local Universe. Of specific importance is the warm, dense interstellar medium in galaxies, which can now be studied for the first time. Van der Werf and Spaans will lead this study and will have access to guaranteed and open time Herschel data. The physical characteristics of the warm interstellar medium will be determined for a variety of galaxies, and a fully documented, web-accessible database of local galaxy spectral line energy distributions will be produced as a local benchmark for the ALMA era.

In addition, Brandl and Spaans will lead a study to create a new predictive tool to interpret the Herschel observations and provide new diagnostics to assist in the analysis of the data by combining existing top-of-the-line photoionization and photodissociation region codes, in a cross-network program with

Network-2. A new code will be developed to provide continuum and line diagnostics to constrain both local and global physical parameters such as gas density, radiation field density, and AGN activity. The existing Dutch expertise in the fields of both ionized, neutral and molecular ISM and star-forming regions and their observations will be utilized.

It is known that the properties of galaxies do not just depend on their mass and size, but also on environment. This environment is best characterized as a 'cosmic web', consisting of filaments, compact clusters, sheet-like walls, amidst large near-empty void regions. The tidal forces which are responsible for the web may leave distinct marks in the properties of galaxies. Van de Weijgaert and Kaastra will test the potential signatures of tidal forces by means of a combined optical, X-ray and radio HI 21 cm observational project focused on the clustering and orientation of late-type gas-rich galaxies, groups of galaxies and clusters in a nearby cluster-rich region selected from the SDSS survey. Particular attention will be paid to morphology of the HI galaxy disks at or near the outskirts of clusters and changes in galaxy population as a function of location along the filaments to the clusters.

The history of star formation in galaxies can be determined from detailed studies of their color-magnitude diagrams. Obviously such studies can only be done on relatively nearby galaxies. Peletier and Larsen will study the stellar populations in the nearby spiral galaxies NGC 2403 and M 81. These galaxies have extensive HST/ACS imaging in multiple passbands, allowing individual stars down to the red giant branch to be resolved and thus model the star formation histories and constrain overall metallicities from the color-magnitude diagrams. In addition, integral-field spectroscopy will give extensive information on sites of recent star formation and velocity fields.

Galaxy centers are the places where supermassive black holes reside, producing active galactic nuclei. The NOVA instrument SINFONI on the VLT has been used to obtain 3-D datacubes of 10 mildly active nearby galaxies. Israel and Spaans will use this spectroscopy to determine the spatial distributions of the stars and the gas. Emission lines will be used to study the distinct components of the interstellar medium: ionized gas, shocked molecular gas, and dust. Galaxies with centers dominated by starbursts or mergers will be studied and the most important sources of energy input with the dominant physical processes will be identified.

2.1.3. The Galaxy

Finally, in our own galaxy the formation history can be studied in exquisite detail, given sufficient information to constrain sophisticated models. ESA's Gaia mission will revolutionize our view of the Milky Way by providing a stereoscopic census

Project	Title	Research leaders	NOVA support
	High redshift galaxies		
nw1-01	Epoch of reionization	Koopmans (RuG), de Bruyn (ASTRON/RuG)	AIO, 2 yrs*
nw1-02	Ly-α emission around galaxies	Schaye (UL), Spaans (RuG)	AIO, 4 yrs
nw1-03	Galaxy evolution at z = 3	Franx (UL) and collaborators	AIO, 4 yrs
nw1-04	Evolution of gas in galaxies	Trager (RuG), Schaye (UL)	AIO, 4 yrs
	Local galaxies in the local universe		
nw1-05	Warm interstellar medium	van der Werf (UL), Spaans	Postdoc, 3 yrs
nw1-06	Modeling Herschel spectroscopy	Brandl (UL), Spaans	Postdoc, 0.5 yr
nw1-07	Galaxies in the cosmic web	van de Weijgaert (RuG), Kaastra (SRON)	AIO, 4 yrs
nw1-08	Resolved stellar populations	Peletier (RuG), Larsen (UU)	AIO, 4 yrs
nw1-09	Galaxy centers	Israel (UL), Spaans	AIO, 4 yrs
	The Galaxy		
nw1-10	Gaia in the Galaxy	Helmi (RuG), Brown (UL)	AIO, 4 yrs
nw1-11	Stars in the KiDS survey	Kuijken (UL), Valentijn (RuG)	AIO, 2 yrs*
	Miscellaneous		
nw1-12	Two Network postdocs	TBD	Postdoc, 2x3 yrs

Table 2.1: Overview of the Network-1 research program in NOVA Phase-3. (*) Network positions nw1-01 and nw1-11 will receive additional funding from their university institutes amounting to 2 yr AIO costs each.

through the measurement of high accuracy astrometry, radial velocities, and multi-color photometry for about 1 billion stars. It is still to be determined how the stellar coordinates from this vast catalog are best used to produce new physical understanding. Sophisticated dynamical models of the Milky Way will be essential for the exploitation, but they are still rudimentary. Helmi and Brown will address this question by extending a well-tested dynamical method for use on the Gaia data set. This method is the Schwarzschild technique, which will be extended to the modeling of discrete datasets containing velocity measurements of individual stars. Two immediate applications will be available: modeling of the internal dynamics of dwarf spheroidal galaxies around the Milky Way, and modeling of the dynamics of stars in the solar neighborhood. In a cross-network project of Helmi, Brown and Tolstoy with Nelemans and Pols of Network-3, they will couple semi-analytical galaxy formation models with stellar evolution codes to simulate stellar populations in the Milky Way halo, their history and chemical evolution.

On a shorter timescale, the KiDS and ATLAS survey will be used to study substructure in the galactic halo and galactic disk. The stellar halo of the Galaxy is its oldest component, containing stars that date back to 1 Gyr or less after the Big Bang. It therefore forms a unique fossil from the epoch at which galaxy formation began, which can be studied in great detail. The VLT Survey Telescope (VST) will start operations in 2009, using the OmegaCAM imager, built in part by NOVA. Two surveys, KiDS and ATLAS, will cover the Southern cap. Kuijken and Valentijn will lead the analysis of these surveys and will study the halo structure in the South and compare it to the North as part of a comprehensive study of the stellar distribution in the galactic halo and thick disk.

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

The origin of stars and planetary systems, and of the Sun and the Solar System, is a central theme in modern astrophysics. It has become clear in the past decade that planetary systems orbiting other stars are common. However, planetary systems similar to the Solar System, with terrestrial planets near the star (in the habitable zone) and gas-giants further out, have still not been found. Observations of young stars have shown that they are surrounded by a disk of gas and dust, believed to be the birthplace of planetary systems. In the coming years new opportunities will allow astronomers to study the process of planet formation and to characterize planetary systems with unprecedented detail. A comprehensive view of the birth and life of planetary systems will be within reach, and the planned NOVA Network-2 program allows Dutch university researchers to stay at the forefront in this rapidly developing field of astrophysics.

Stars form in the cold, dense regions of interstellar space, where gas and dust clouds become unstable against the pull of gravity. In the center of such a collapsing cloud a protostar is rapidly formed, surrounded by a disk of gas and dust. This accretion disk forms because angular momentum in the contracting cloud is preserved, preventing material to fall directly onto the young star. The disk funnels material from the cloud to the growing star and later plays an essential role in the process of planet formation. Planets may form initially through sticking of small dust particles in the disk; once they have grown to a kilometer size, gravity takes over and terrestrial planets (near the star) as well gas-giant planets (further out) can form.

Due to the much shorter timescales involved and their typically large distances from the Sun, the formation and early evolution of massive stars is much less well understood. The strong radiation field that massive protostars develop early on causes a qualitatively different evolution of these stars compared to solar type stars. For instance, it is unclear if the formation of the most massive stars in galaxies is through the gravitational collapse of a single cloud core or through merging of smaller units.

During star and planet formation, the chemical composition of the gas and dust that enters from interstellar space is strongly modified. In protoplanetary disks, ices grow on top of the refractory dust, and chemical reactions within the ice can form new, more complex molecules that evaporate once the dust grains drift closer to the young star. Dust particles grow, settle, crystallize and are chemically modified as their temperature increases. This increase in chemical complexity may be at the basis of the development of life in planetary systems, and can be put into the context of the chemical evolution of the Solar System.

Project	Title	Research leaders	NOVA support
	Water and molecular complexity		
nw2-01	Water in star-forming (SF) regions	van Dishoeck (UL), van der Tak (SRON/RuG)	AIO, 1 yr*
nw2-02	Water in high-mass SF regions	van der Tak, van Dishoeck	AIO, 2 yrs*
nw2-03	Molecular complexity	Dominik (UvA), van der Tak	AIO, 2 yrs*
nw2-04	HIFI, ALMA laboratory studies	Linnartz (UL), Dominik	AIO, 4 yrs; Postdoc, 1 yr
nw2-14	Modeling Herschel spectroscopy	Brandl (UL), Spaans (RuG)	Postdoc, 0.5 yr
nw2-15	HIFI scientific harvest	Tielens (UL), TBD	AIO, 2 yrs
	Disk structure and evolution		
nw2-05	From dust to planets	Spaans, Dominik	AIO, 4 yrs
nw2-06	Disk surface layers	Waters (UvA), Kamp (RuG)	AIO, 1 yr
nw2-07	Inner disk gas models	Kamp, Waters	AIO, 4 yrs
nw2-08	ExPo disk modeling	Keller (UU), Waters	Postdoc, 3 yrs
	Formation and evolution of massive stars		
nw2-09	Disks around embedded YSOs	Hogerheijde (UL), van der Tak	AIO, 4 yrs
nw2-10	Youngest massive stars	Kaper (UvA), TBD	AIO, 4 yrs
nw2-11	Massive stars in LMC	De Koter(UvA), Pols (UU)	AIO, 4 yrs
	Exo-planetary systems		
nw2-12	Red dwarf transits	Snellen (UL), Keller	AIO, 4 yrs
nw2-13	Exo-planets with Corot and Sphere	Waters, Snellen	AIO, 4 yrs

Table 2.2: Overview of the Network-2 research program in NOVA Phase-3. (*) Network positions nw2-01, nw2-02 and nw2-03 are co-funded by SRON with 2 AIO years each.

The following four themes have been identified within the network: (1) Water and molecular complexity; (2) Disk structure and evolution; (3) Massive star formation and evolution; and (4) Exo-planetary systems. An overview of the projects is presented in Table 2.2. The proposed program makes full use of the large investments made by NOVA, NWO, and others (ESO, ESA) in new instrumentation at infrared and millimeter wavelengths, with particular emphasis on the HIFI instrument on board ESA's Herschel Space Observatory, ALMA, and second generation instruments for the ESO VLT (X-Shooter, SPHERE). The Network-2 program will also put Dutch university researchers in an excellent competitive position for the more distant future, with JWST and the ELT on the horizon.

2.2.1. Water and molecular complexity

Theme 1 focuses on the diagnostics that water and complex molecules offer in studies of star and planet formation. Two approaches are used: studies of (many) transitions of a few molecules (e.g. H_2O, CO) in a wide range of objects and a broad spectral scan of a very small number of sources to obtain a full molecular inventory. Four projects have been selected, all with close ties to the unique science potential of the HIFI instrument on board Herschel. Three projects are observational, covering both high- and low mass star formation, and one focuses on laboratory studies of molecular line emission that will be indispensable for the interpretation of HIFI and ALMA data.

Water is a key molecule for determining the physical and chemical structure of star- forming regions because of its large abundance variations between warm and cold regions in both the gas and ice phases. Thus, water acts like a 'switch' that turns on whenever energy is deposited in molecular clouds, highlighting key episodes of stellar birth such as gravitational collapse, outflow injection, and stellar heating of envelopes and disks. Because water cannot be observed from the ground, it is a prime target for HIFI observations with Herschel. A key goal of HIFI is to follow the process of star formation during the various stages and use the water emission as a physical diagnostic throughout the evolution. Because H_2O acts as a natural 'filter' of warm (> 100 K) gas, it provides highly complementary information to that derived from the commonly studied CO molecule.

To use water as a physical tool, its chemistry needs to be fully understood. This chemistry is also interesting in its own right since water is one of the principal reservoirs of oxygen and the main ice component in cold clouds. Thus, studying water chemistry is central to understanding the fundamental chemi-

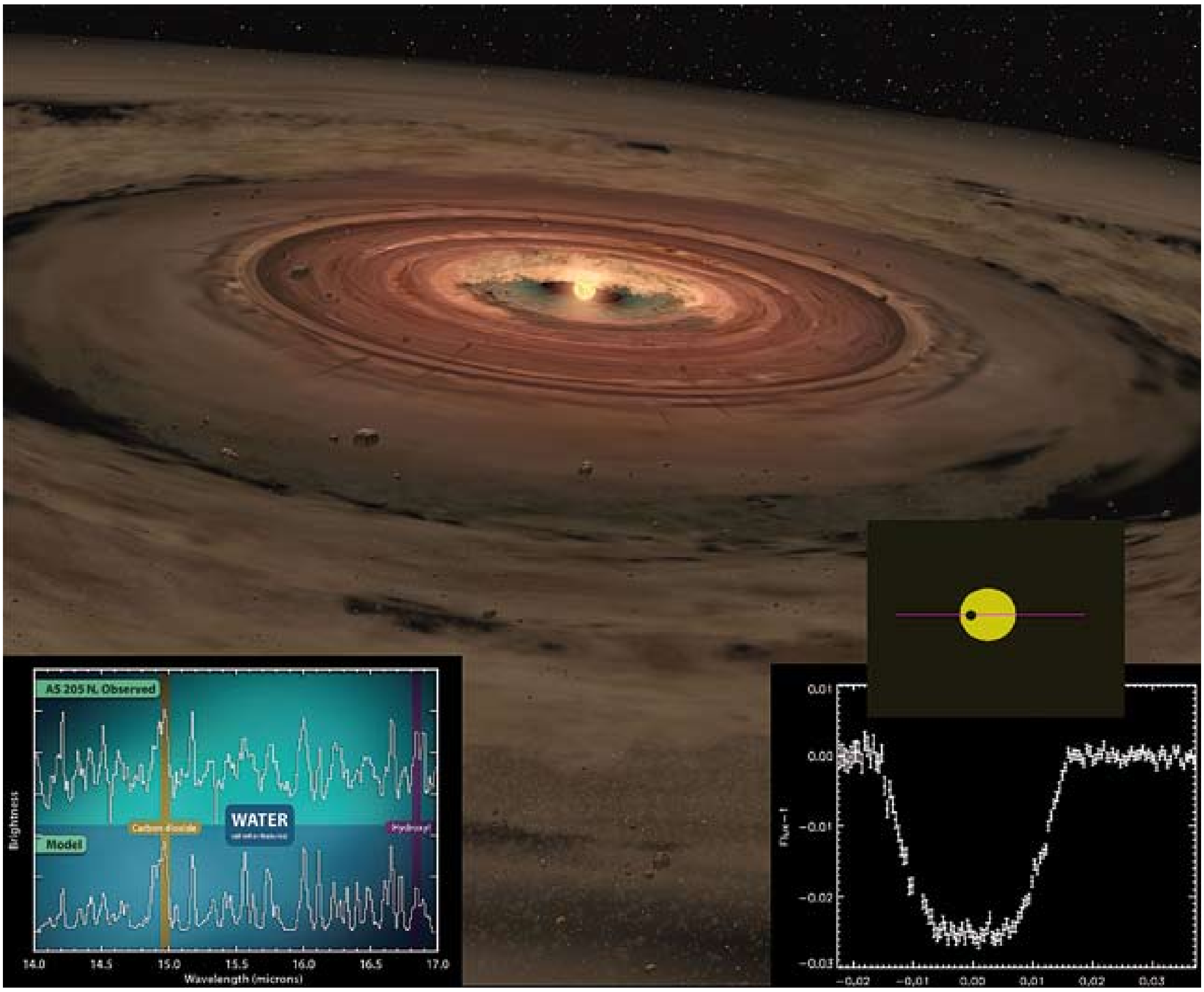

Figure 2: Artist's impression of a proto-planetary disk surrounding a newly born star in which planet formation is taking place. The lower left insert shows infrared spectra with the Spitzer Space Telescope of water and organic molecules detected in proto-planetary disks. The lower right insert shows the light curve of an exo-planet which transits its host star. Credits: NASA/JPL-Caltech, C. Salyk and I. Snellen.

cal processes of freeze-out, grain surface chemistry, and evaporation. Moreover, its level of deuteration provides an important record of the temperature history of the cloud and, in comparison with cometary data, of its evolution from interstellar clouds to Solar System objects. Finally, water also plays an active role in the energy balance: because it has a large dipole moment, its emission lines can be efficient coolants of the gas and thus allow clouds to continue to collapse even at higher temperatures. Van Dishoeck, Tielens, Spaans, Hogerheijde, Van der Tak, Dominik, and Linnartz will use HIFI guaranteed time observations of low- and high-mass stars to study the role of water in star formation, and to investigate the increase in chemical complexity. Laboratory studies will focus on the characterization of the physical and chemical processes in inter- and circumstellar ices with the aim to quantitatively describe solid-state processes that are involved in the formation of complex organic material in space.

2.2.2. Disk structure and evolution

The formation of low- and intermediate mass stars is intimately linked to the formation of an accretion disk early in the collapse of a molecular cloud core. The four Network-2 projects focus on the nature and evolution of this disk in the so-called passive disk phase, when accretion ceases and a planetary system may form in the slowly dissipating disk. Important questions are the way planet formation may proceed through grain growth, and the impact of planet formation on disk structure and composition.

HST and Spitzer observations have revealed the presence of cavities in transition phase disks that could be due to clearing by (proto)planets. Together with VLT, they have also provided a wealth of spatial and spectral information on the gas content in the planet-forming zone of T Tauri and Herbig Ae systems of various ages. The interpretation of the gas observations provides important clues on the mass and distribution of gas that is still available for the planet formation process.

Observations of proto-planetary disks reveal that small grains are lost only gradually and are present at all stages of the planet formation process, from the cloud collapse and protoplanetary disk (T-Tauri) phase, through the transition and clearing stage, to the optically thin debris disk stage. Yet, from a theoretical perspective, removal (particularly coagulation) processes operate on much shorter time scales. This suggests that collisional fragmentation processes play a crucial role in planet-forming disks and planet formation.

Spaans, Kamp, Keller, Dominik, Waters and others will study the structure and composition of protoplanetary disks. Spaans and Dominik will focus on models for the collisional evolution of dust in the disks, including the formation of planetesimals. Kamp, Keller, Waters, Hogerheijde and van Dishoeck will use observations from HST; CRIRES, VISIR, and SPHERE on the VLT; ExPo on the WHT; (e)SMA; and ALMA to study the spatial structure and composition of the gas and the dust in the disk, searching for signposts of planet formation.

2.2.3. Formation and evolution of massive stars

The formation of high mass stars is one of the important unsolved questions in astrophysics. There is an established link with stellar clusters, but it is not clear whether high-mass stars form by accretion like solar-type stars do or through coalescence of lower-mass objects. The existence of accretion disks and bipolar outflows suggests that accretion plays a role for stars up to 20 $M_\odot$, but beyond this mass the situation is unknown. The focus in this theme is on solving the following questions: (i) How are the most massive stars formed? (ii) How does the evolution of massive stars depend on stellar rotation and metallicity?

The presence of disks around protostars is now established up to $M_* = 15\text{-}20\ M_\odot$, but the properties (density, temperature, kinematic structure) of massive protostellar disks are unknown. These properties are fundamental to understand the diversity of final stellar masses. For instance, massive disks may be more unstable and cause a high accretion rate onto the protostar. Unlike the low-mass case, these disks do not survive until the star becomes optically visible, so their properties must be studied at long wavelengths (infrared-radio). Submillimeter interferometry is the only way to obtain high-resolution images of the disk structure, and the connection of JCMT and CSO to the SMA to form the eSMA offers unique high sensitivity and resolution data at 345 GHz to Dutch astronomers. Hogerheijde and van der Tak will study disks in a representative sample of massive stars.

Virtually all massive stars form in clusters. Therefore, in order to understand massive star formation, the cluster mode of star formation must be understood. The earliest phases of massive star formation can be observed at long (far-infrared, millimeter and centimeter) wavelengths, where the star itself can only be detected indirectly. Once the molecular cloud begins to dissipate, extinction in the near-IR drops to values where direct detection becomes feasible. The properties of the youngest massive stars are not well known. For instance, what are their rotation rates and stellar wind properties, and how do these compare to field stars? Can we infer from these stellar or other properties whether or not massive stars form by accretion similar to lower mass stars? How does the environment affect the early evolution of massive stars? Kaper, de Koter and Waters plan to use X-Shooter and SINFONI at the VLT to study the properties of very young massive stars and their environment.

A recent large LMC survey of surface abundances and rotational velocities has identified two new classes of massive main-sequence stars – nitrogen-normal evolved rapid rotators, and nitrogen-enriched intrinsically slow rotators. Both groups of stars are in flagrant contradiction with expectations and in particular challenge the theory of rotational mixing. The direct consequences of this finding may be enormous with essential effects on many fields, from gamma ray bursts and magnetars to first stars in the Universe and the chemical evolution of galaxies. De Koter and Pols will determine the nature of massive stars in the LMC and develop evolutionary models that can account for the chemical diversity of the massive star population in the LMC.

2.2.4. Exo-planetary systems

The radial velocity technique has proven to be very powerful in discovering most of the currently known exo-planetary systems. Unfortunately this indirect detection technique does not give much information about the nature of the planet beyond (a lower limit to) the mass and the orbital parameters. The next step in exo-planetary research is the physical and chemical characterization of these exo-planets using direct detection techniques and the transit method. Both methods allow planetary photons to be detected and the properties of the planetary atmosphere to be mapped.

Planet transits have proven to give unique and extraordinary insights into the physical and atmospheric properties of hot, gaseous giant planets. These studies can now be extended towards terrestrial planets for transits of red dwarf stars. The detection and characterization of terrestrial planets orbiting solar type stars is still a challenge. However, due to their small physical size, red dwarfs are up to two orders of magnitude more sensitive to planet transits than solar-type stars, even down to the sizes of terrestrial planets. Several planets have recently been discovered around red dwarfs, including a super-Earth (possibly within the star's habitable zone), and one transiting hot Neptune. Transit surveys from the ground and from space are ongoing and are sensitive down to the terrestrial planet range. Snellen, Waters, and Keller, in collaboration with Fridlund (ESA) and Aerts (Leuven/Nijmegen) will use ground-based (UKIRT, OmegaCAM) and space-based (COROT) observations to search for planetary transits, and characterize the planetary atmospheres of these transiting systems.

Keller, Waters, Snellen and Stam (SRON) will also use direct detection techniques to search for, and characterize exo-planets. The new instruments ExPo (for the WHT) and SPHERE (for the VLT) are aimed at spatially separating the light of the star and the exo-planet at optical wavelengths, using polarimetry to increase the contrast between star and planet. Both instruments are sensitive to gas-rich giant planets orbiting at several AU distance from the star, i.e., comparable to Jupiter in the Solar System. Such planets are still rarely found from radial velocity observations. Planetary model atmosphere calculations by Stam show that the reflected light from old, cold gas giant planets can be polarized by as much as 50%.

2.3. The astrophysics of black holes, neutron stars and white dwarfs

The main astrophysical setting of Network-3 is the astrophysics of compact objects. Alternative terms are the 'Extreme Universe' or 'High Energy Astrophysics', which are closely related. The scientific challenge that Network-3 has set itself is to understand the formation, evolution, physics, and products of compact objects: black holes, neutron stars and white dwarfs.

Compact objects are, with the exception of supermassive black holes in galactic centers, the end products of stellar evolution. They represent the densest concentrations of matter in the Universe, with the most exotic equations of state and the deepest potential wells. Formation and evolution of these objects are inevitably linked to violent processes such as supernovae explosions or gamma-ray bursts. As a consequence of their nature, compact objects are broad-band emitters and often manifest themselves as sources of high energy radiation, non-thermal emission, highly energetic particles, gravitational waves and short-timescale variations thereof. They are the natural sites to study the physics of strong gravity, extremely high magnetic fields and plasma jets, accretion and particle acceleration. Furthermore, compact objects are quite often found in binary systems, where, due to mass-transfer, they are made 'visible' to the rest of the Universe, and hence stellar and binary evolution is an important aspect as well.

As often in astrophysics all these issues are intimately linked. For example, understanding the neutrino, cosmic ray, or gravitational wave production in the Galaxy requires understanding the physics of compact objects, their formation and populations, as well as the physical processes associated with them. On the other hand, to make a full census of compact objects, one needs to understand the emission mechanisms and appearance of compact objects at the various stages of their evolution.

Network-3 has therefore put together a comprehensive research program to address these issues and has identified four major themes which group the research program, unifying and interconnecting the research pursued at the different groups. The following four themes have been identified within the network: (1) The transient sky, (2) Physics in extreme gravity, (3) Binary populations and stellar evolution, and (4) New windows to the Universe.

To address the full spectrum of the (astro)physics of compact objects a balanced program involving both theory and observations has been constructed. A strong point is the direct interaction between theory, numerical simulations and observations. Examples of these are studies of radiative processes in very hot, dilute plasmas and observations of these processes in compact binaries as well as more galactic settings; stellar evolution calculations, population synthesis and numerical simulations of massive stars and binaries in all settings and the observational efforts to characterize stellar populations in our Galaxy and the study of gamma-ray bursts (GRBs); and the theory of particle acceleration around compact objects and observations of ultra-high energy cosmic rays.

In this research strong use is made of a plethora of world-class facilities, both X-ray and gamma-ray instruments in space, and radio, O/IR, and very high energy gamma and cosmic ray instruments on the ground. This includes instruments built and designed in NOVA Phase-1 and -2 such as the X-Shooter instrument on the VLT, where Network-3

Project	Title	Research leaders	NOVA support
	The transient sky		
nw3-01	Sub-second bursts with LOFAR	Falcke (RU), Wijers (UvA), Wijnands (UvA)	AIO, 4 yrs
nw3-02	Radio-emitting neutron stars and millisecond transients with LOFAR	van Leeuwen (ASTRON), Falcke, van der Klis (UvA), Hessels (UvA), Verbunt(UU), Wijers	AIO, 2 yrs
nw3-03	High-energy follow-up observations of radio transients	Wijnands, Markoff (UvA), Falcke	AIO, 1 yr **
nw3-04	Radio radiation from gamma-ray burst afterglows	Wijers, Icke (UL), Strom (ASTRON)	AIO, 2 yrs
	Physics in extreme gravity		
nw3-05	X-ray timing of stellar mass black holes	van der Klis, Mendez (RuG)	AIO, 4 yrs
nw3-06	Inner accretion flow in neutron-star x-ray binaries	Mendez, Verbunt, van der Klis	AIO, 2 yrs
nw3-07	Jet evolution during accretion outbursts	Markoff, Falcke	AIO, 1 yr **
nw3-08	Burst oscillation mechanism in Type-I x-ray bursts	Levin (UL), Watts (UvA), van der Klis, Wijnands	AIO, 2 yrs
nw3-09	X-ray spectra of binaries with ultra-short periods	Verbunt, Schaye (UL), Vink, Kaastra	AIO, 2 yrs *
nw3-10	X-ray sources in the galactic bulge survey	Wijnands, Jonker (SRON), Nelemans (RU)	AIO, 3 yrs
	Binary population and stellar evolution		
nw3-11	Galactic plane compact binary population	Groot (RU), Nelemans, Verbunt	AIO, 4 yrs
nw3-12	Galactic bulge population of x-ray binaries	Nelemans, Jonker, Wijnands	AIO, 2 yrs Postdoc, 4 months
nw3-13	Evolution of massive stars	TBD	AIO, 4 yrs
nw3-14	Stellar populations in dense systems	Portegies Zwart (UvA), Pols (UU)	AIO, 4 yrs
nw3-15	Progenitors of Type Ia supernovae	Vink (UU), Pols, Nelemans, Kaastra (SRON)	AIO, 2 yrs
nw3-16	X-ray study of local chemical environment	Verbunt and collaborators	AIO, 2 yrs *
	New windows to the universe		
nw3-17	Particle acceleration in intermediate power jets	Achterberg (UU), Markoff, Falcke, Wijers	AIO, 4 yrs
nw3-18	Ultra-high energy cosmic rays with AUGER	Hörandel (RU), Achterberg, Falcke	AIO, 2 yrs
	Miscellaneous		
	Unspent funds from Phase-2: TBD		AIO, 2 yrs

Table 2.3: Overview of the Network-3 research program in NOVA Phase-3. Project nw3-13 will be further specified when the new staff member at Utrecht University has been appointed. * Network positions nw3-09 and nw3-16 are co-funded by SRON with 2 AIO years each. ** Network positions nw3-03 and nw3-07 are co-funded by the EC with 3 AIO years each.

members led and built the near-IR spectrometer of the instrument; the LOFAR radio telescope, where Network-3 members lead two of the four initial Key Science Projects (KSPs); and numerical simulations that are being developed by Network-3. Among the X-ray and gamma-ray telescopes that are central to much of compact object research, SRON has played an important role in Chandra and XMM-Newton and also the Netherlands has started to invest in recent years in the Cosmic Ray Observatory Auger.

2.3.1. The transient sky

A characteristic feature of many compact objects is their high variability on short time scales. This starts with the formation process: essentially most of the stellar-mass compact objects are formed in a short explosive event, which, in the case of supernovae and gamma-ray bursts, can release enormous amounts of energies in a very short time scale. It continues with the further evolution of the sources through accretion and rotation. Variable accretion rates and instabilities in the accretion flow or shocks in the outflowing jet can lead to large variations of the observable energy output. Moreover the fast and stable rotation of the compact object can lead to quasi-periodic oscillations or clear pulsations (as in pulsars) that provide crucial information about the physical processes at work and the state of the system.

Time-domain observations have been very successful in the past, e.g. with pulsar searches and X-ray all-sky monitors, but also very limited. Transient sources, sources which unpredictably appear on and disappear from the sky, are now becoming more and more important at optical and radio wavelengths. The new LOFAR radio telescope will provide unsurpassed capabilities to monitor large areas of the sky and detect transient radio sources. Hence there is a completely new parameter space to explore now and we want to address the following questions, what sources make up the transient (radio?) sky, and what physics governs their behavior and origin?

Van Leeuwen (ASTRON), Falcke, van der Klis, Hessels, Verbunt and Wijers will undertake the first-ever complete census of nearby radio-emitting neutron stars and millisecond transients, using LOFAR. This survey can be the first-ever to map the complete local pulsar population and characterize its low-luminosity tail. The survey will also be highly sensitive to fast radio transients such as the enigmatic, recently discovered millisecond-duration radio bursts. This is complemented by a program to search for sub-second bursts (sparkers) from astrophysical sources with LOFAR by Falcke, Wijers, Wijnands, and van Leeuwen. Here the special techniques to detect fast transients developed for the Cosmic Ray Key Science Project for LOFAR based on data from the transients buffer boards will be used. This allows imaging the entire sky at once for short time scales. These programs are facilitated by a science support program to adapt the PuMa-II pulsar machine and software to LOFAR by van der Klis and collaborators. Furthermore high-energy and multi-frequency follow-up observations of the radio transients found will be conducted by Wijnands, Markoff and Falcke.

Modelling of specific transient sources will be done by Wijers, Icke and Strom (ASTRON) in a cross-network program to understand radio radiation from gamma-ray burst afterglows. On the optical side Wijers and Schaye will investigate high-redshift material illuminated by gamma-ray bursts using X-Shooter in a cross-network program with Network-1. This also connects to research in Theme 3.

2.3.2. Physics in extreme gravity

In addition to understanding where compact objects come from and how many there are (§ 2.3.3), we want to know how they work and which physical processes are important. A major aspect of compact objects is the fact that they are extremely dense concentrations of matter, so they are ideal – in fact the only – laboratories to study physics in extreme gravity. Hence, the question to be answered in Theme 2 is what physical processes happen in and near compact objects?

There are a number of common features and processes that are present in most if not all compact objects with variable strength. The simplest cases

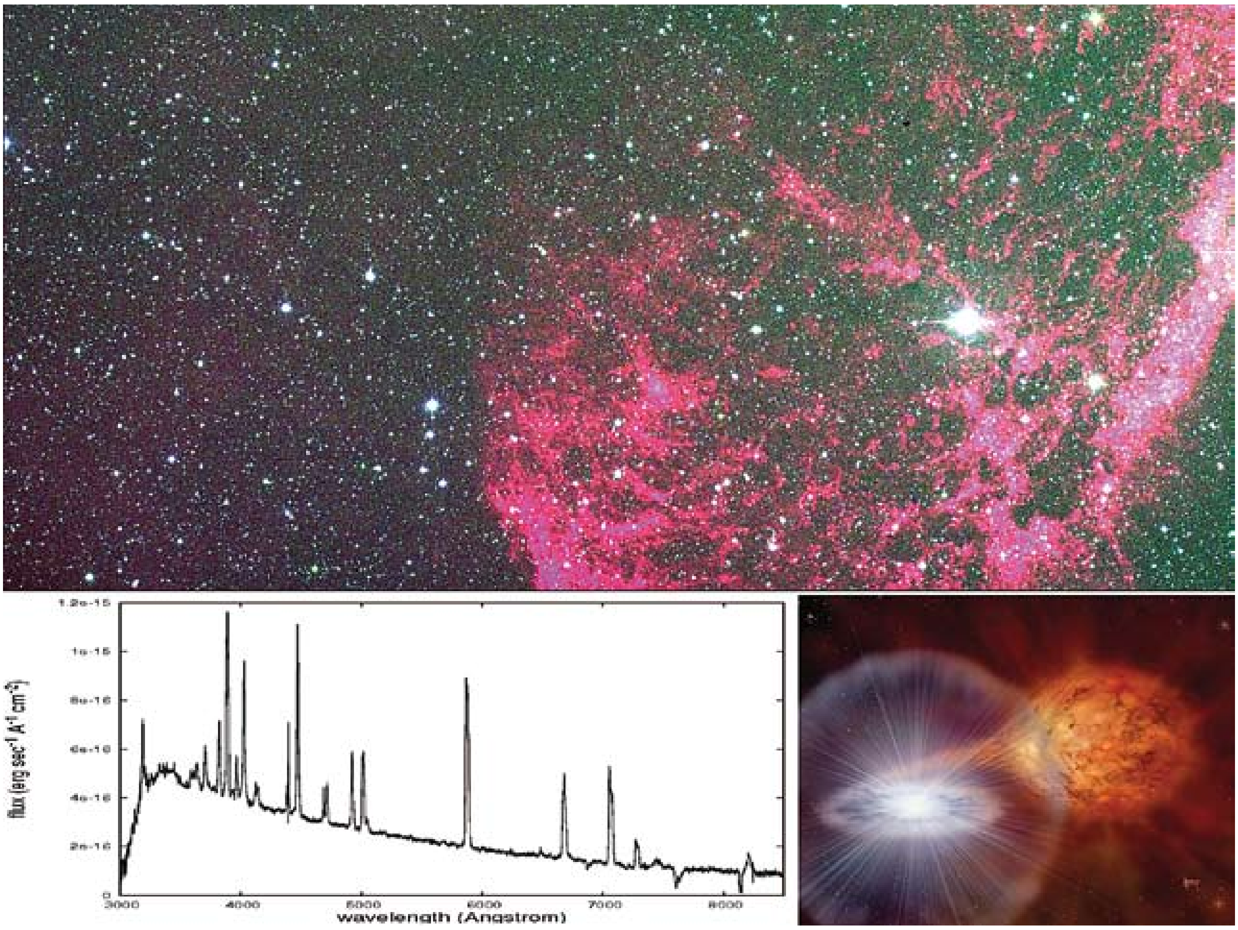

Figure 3: The Crescent Nebula (NGC 6888) in the constellation Cygnus composed from the r', i' and Hα EGAPS filters. The European Galactic Plane Surveys (EGAPS) maps the Northern Galactic Plane in different colors using the 2.5m INT on La Palma and in the future OmegaCAM on the VST. The image shows 11.3x22.5 arcmin. The goal of EGAPS is to find new rare objects like compact binaries. The bottom-left image shows the spectrum of the compact binary V396 Hya with strong helium emission lines. EGAPS will find similar emission objects using narrow helium and hydrogen filters. The bottom-right image shows an artist's impression of an accreting binary: the heavy star at left cannibalizes its neighbor. A clear accretion disk is formed when gravity pulls matter inwards (credit: David Hardy).

are, in a sense, black holes, since there is no surface or internal equation of state to worry about. The activity and appearance of black holes is typically determined by an accretion flow (disk) and a related outflow (jet). The jet is a major source of radio and high-energy emission as well as a site for high-energy particle acceleration. The accretion disk is the power source of the system and emits copious radiation that may have thermal and non-thermal contributions. For stellar-mass black holes the disk is a prominent emitter of X-rays, and, while disks cannot be resolved through imaging, timing observations and spectroscopy provide important clues on their structure.

The situation becomes even more complicated when properties of the object itself have to be taken into account, as is the case for neutron stars or white dwarfs. Here the equation of state of the matter is of essence. The magnetic field and the interaction of the surface with the accretion flow (and outflow) also become important and affect disk and jet structure as well the overall appearance of the object. Again timing observations and spectroscopy in X-rays, optical, and radio (pulsars) are valuable tools to understand this.
This theme primarily makes use of X-ray spectroscopic and timing observations. Van der Klis and Mendez will exploit a novel technique to use CCD data for X-ray timing of stellar mass black holes directly addressing the question of how the geometry of the coronal or jet region of black holes, producing the power law emission, differs from the accretion disk producing the blackbody emission. This is complemented by a project by Mendez, Verbunt and van der Klis to investigate the properties of the inner accretion flow in neutron-star X-ray binaries using a combination of X-ray spectroscopy and timing. To understand the impact of jet outflows in these compact systems, Markoff and Falcke will merge semi-analytical calculations with 3D MHD simulations to understand how the jets evolve during accretion outbursts and predict their spectral features.

The added level of complexity and the opportunity provided by the presence of a surface in neutron stars will be studied by Levin, Watts, van der Klis and Wijnands. They will attempt to understand the burst oscillation mechanism in Type I X-ray bursts, which are thermonuclear explosions triggered by unstable burning on accreting neutron stars. Time-dependent simulations of the burst process will be developed and compared with RXTE data.

Verbunt, Schaye, Vink and Kaastra will investigate the X-ray spectra of binaries with ultra-short periods which must have helium-depleted donors: the former cores of evolved stars. Jonker, Nelemans and Wijnands will constrain the equation of state of neutron stars from eclipsing low-mass X-ray binaries found in the Galactic Bulge survey (link with Theme 3).

2.3.3. Binary populations and stellar evolution

The key question in Theme 3 is where the stellar compact objects actually come from and how many of each type there are in the Galaxy. This is the main topic of Theme 3. More specifically we ask, which progenitor produces which compact remnant?

This requires understanding the formation of compact objects in a stellar setting and the populations in which they form, with a particular emphasis on the binary populations. There are three main open questions: (i) Our ignorance on the progenitor systems of gamma-ray bursts and Type Ia supernovae (strongly connected with Theme 1); (ii) The number and physics of the strongest gravitational wave sources, as well as the equation of state of neutron stars (both tying in with Theme 2); and (iii) The physics of binary evolution, in particular the physics of accretion (tying in with Theme 2) and of the common-envelope phase.
It has become clear in the last decade that in order to answer these questions it is not sufficient to study individual stars or binaries. Rather, one has to obtain a thorough understanding of the populations of objects responsible for the listed phenomena. The study of populations of rare objects (which applies both to compact binaries as well as massive stars) has often been plagued by low-number statistics and very strong observational biases, making a comparison with theory and population synthesis work very difficult or impossible. Network 3 researchers are therefore very actively involved in a number of large surveys that are aimed at obtaining statistically significant samples of rare objects with well-understood selection biases. These efforts include the European Galactic Plane Surveys where Groot, Nelemans and Verbunt investigate the compact binary population and the Galactic Bulge Survey, where Nelemans, Jonker and Wijnands try to obtain a census of the population of X-ray binaries in order to constrain their total Galactic population. This will then be compared to theoretical simulations relating progenitors to compact objects in binaries. The Galactic Halo is also targeted, where the upcoming Gaia mission will deliver an unprecedented wealth of information on stellar populations. Nelemans, Pols and Network-1 researchers (in particular Helmi) will couple semi-analytical galaxy formation models with stellar and binary evolution tools simulating the chemical yields and

stellar properties for a large population in preparation of the Gaia mission in a cross-network project with Network-1.

Portegies Zwart and Pols will use the AMUSE software tools (see § 3.9.1) to model stellar populations in dense stellar systems, where the full physical effects of the evolution of the star, the orbital evolution of the binary, the dynamical evolution of the parent cluster and the global evolution of the galaxy in which the cluster resides will be taken into account in a self-consistent fashion. Among the astrophysical phenomena to be studied are the evolution of (chain) collision products and the formation of intermediate-mass black holes.

In order to understand the birth of black holes and neutron stars, one also needs to understand the evolution of massive stars. Observationally this will be studied with spectra of gamma-ray bursts that act as a light bulb illuminating the circumstellar medium of its predecessor and providing constraints of its nature by Wijers and Schaye in a cross-network project with Network-1.

In an alternative approach, Vink, Pols, Nelemans and Kaastra will address the progenitor histories of Type Ia supernovae by simulating the different progenitor channels and their nucleosynthetic output in a binary population synthesis. They will compare predictions of iron and other elemental abundances to observed abundances of clusters of galaxies and the predicted rates with the observed Type Ia rate in galaxies and clusters of galaxies.

Not only are the late stages of the lives of massive stars leading up to hypernova explosions highly uncertain, but the main-sequence and post-main-sequence stages of massive stars are also poorly understood, as evidenced by recent VLT-FLAMES survey results. Therefore Pols and Network-2 researchers, in particular de Koter and Kaper, will address this issue in a cross-network program. Furthermore Groot and Network-1 researchers will look at stellar clusters in the local Universe, and Verbunt and collaborators will use X-ray absorption spectroscopy to study our local chemical environment.

2.3.4. New windows to the Universe

Technological advances have made it possible to measure high-energy particles (EeV cosmic rays) and photons (MeV-TeV gamma rays) with increasing spectral and spatial resolution from a variety of astrophysical sources. These include supernova remnants, pulsar wind nebulae and micro-quasars in our Galaxy, and sources at cosmological distances such as active galaxies, X-Ray flashes and gamma ray bursts. In the near future the observation of cosmic neutrinos and of gravitational waves will become a reality, opening new windows on the Universe. The neutrino effort in the Netherlands is coordinated by NIKHEF in Amsterdam. Cosmic rays are the subject of one of the Key Science Projects of LOFAR, and the Netherlands has recently joined the AUGER collaboration. The central question we want to focus on is what are the sources and the production mechanisms of the highest energy particles and of gravitational waves?

This assumes that a large fraction of the answer lies with compact objects. Hence, there is a significant overlap between the issues of relevance for this theme, and the research listed under Themes 2 and 3: supernova remnants, pulsar wind nebulae, micro-quasars and gamma-ray bursts are all phenomena associated with the death of massive stars and the compact objects they leave behind. The production of cosmic rays and high energy gamma rays is known to occur in the immediate vicinity of the strong (sometimes relativistic) shocks that occur in the flows (blast waves and jets) that are associated with these objects and phenomena. Gamma rays at high energy provide direct information about the in situ interactions of cosmic rays with ambient matter, and can provide important information about the structure of the circumstellar medium surrounding these sources. Together with existing radio observations this allows one to derive important conclusions about the late evolution of the progenitor systems, such as strength and density of the stellar wind from the progenitor star. This is a young field, where the NL community has a lot to offer, but we initially concentrate on two projects.

First, Achterberg, Markoff, Falcke and Wijers will develop realistic models for particle acceleration in intermediate power jets. Recent observations of some nearby extragalactic jets (such as the jets associated with M87) show that TeV electrons must be present in the source. Also, recent results of Auger point to the jets of Cen A as a potential source of ultra high energy cosmic rays. This requires modelling of the intermediate power jets where the shocks that are presumably responsible for the acceleration are trans-relativistic.

Second, Hörandel, Achterberg and Falcke will work on astronomy with AUGER, trying to better identify the sources of ultra-high-energy cosmic rays using new Auger data on the arrival directions of cosmic rays at the highest energies.

Project	Principal Investigators	Univ	Support
Stellar clusters in the local universe	Groot (NW3), Larsen (NW1), Portegies Zwart (NW3)	RU	AIO, 4 yrs
Illuminating high redshift matter with GRBs	Wijers (NW3), Schaye (NW1)	UvA	AIO, 4 yrs
The Galactic Halo in the Gaia era	Nelemans (NW3), Brown (NW2), Helmi (NW1), Pols (NW3)	RU	AIO, 4 yrs
Massive Stars after the FLAMES Survey	de Koter (NW2), Pols (NW3), Kaper (NW2)	UU	AIO, 4 yrs
Modeling Herschel spectroscopy	Brandl (NW1), Spaans (NW2)	UL	Postdoc, 1 yr

Table 2.4: Overview of the cross-network research projects in NOVA Phase-3.

2.4. Overlap positions

The original proposal for NOVA funding contained a ten-year strategy for overlap positions. This part of the NOVA program intends to recruit and appoint new tenure-track staff members a number of years ahead of the time when a faculty position becomes vacant due to retirement. NOVA pays the salary costs of the new faculty member up to the time when the senior staff member retires and the university takes over the financial commitments from that moment onwards. Two existing overlap positions require extended NOVA funding well into Phase-3 as dictated by the retirement date of the relevant staff member whose replacement is financed by NOVA. Four new retirements will come up during Phase-3 for which overlap positions are planned. In addition some more overlap positions are needed for strategic reasons. One of them is already filled by Hörandel to increase the number of astronomical staff positions at the Radboud University. The overlap positions for Phase-3 are summarized in Table 2.5. The NOVA funding of the overlap positions is conditional on the following terms: (1) NOVA funding is for a limited period up to the retirement date of the relevant staff member whose position is overlapped, or the date on which that person reaches her or his 65th birthday, whichever comes first; (2) If an university is unable to fill an overlap position, the NOVA Board has the right to transfer the unspent overlap funds to another university that is able to meet the conditions that come with the overlap positions; (3) Changes in currently planned overlap positions need the approval of the NOVA Board.

2.5. Science support program

In NOVA Phase-3, the Board decided to create a separate category of Science Support projects within the Research program to optimally exploit instruments in the operational phase. Previously, such projects were part of the instrumentation program. Activities can include software development, implementation and maintenance; data calibration and archiving; and training and support of new users. Each project needs to have a clear management plan and deliverables.

The call for Science Support projects was issued together with that for the Network proposals in November 2007. Proposals were first submitted to, and ranked by, the Networks in competition with Cross Network research proposals. The rankings per Network were subsequently merged in a face-to-face meeting of the Directorate with the NOVA coordinators and consensus was reached, even though the oversubscription was more than a factor of 3. The projects summarized below were approved by the Board at its May 2008 meeting.

2.5.1. Enabling early science with ALMA

ALMA (see also § 3.3) observes the cold and dust enshrouded Universe, and is central to much of the research of NOVA scientists, most notably Network-1 and -2. In late 2011, a sufficient number of antennas will have been commissioned and released to the general community to start Early Science observing. A postdoc will be funded to offer science support to astronomers from the Netherlands

Univ.	Rank	fte	Field	Name	Start	End	Overlap	Network
UvA	UHD	1,0	Protoplanetary disks	Dominik	1-Jan-2006	1-Jul-2014	Henrichs	2
UvA	UD	1,0	Pulsar research		1-Jul-2013	1-Jul-2018	None	3
RuG	UHD	1,0	Black holes and neutron stars	Mendez	1-Sep-2007	1-Feb-2013	van der Hulst	3
UL	UD	1,0	Dark matter, dark energy	Hoekstra	1-Jan-2009	1-Aug-2011	Lub	1
UL	HL	1,0	Theoretical astrophysics		1-Jan-2010	1-Jul-2011	Icke	TBD
UL	UD	1,0	Optical interferometry		1-Dec-2010	1-Aug-2011	Jaffe	TBD
UL	UD	1,0	Nearby galaxies		1-Dec-2010	1-Dec-2011	Israel	1
UU	UD	1,0	Stellar spectroscopy		1-Jan-2010	1-Sep-2013	None	TBD
RU	UD	1,0	Astroparticle physics	Hörandel	1-Jul-2009	1 jul 1012	None	3

Table 2.5: Overlap positions funded in NOVA Phase-3. In addition there are three short continuations of Phase-2 overlap positions which are not listed in the table.

Project	Principal Investigators	Univ	Support
Enabling early science with ALMA	Hogerheijde	UL	Postdoc, 3 yrs
SPHERE-ZIMPOL science support	Waters	UvA	Postdoc, 2.5 yrs
PuMa pulsar data recorder on LOFAR	van der Klis	UvA	Postdoc, 3 yrs
The Herschel harvest	Barthel	RuG	Postdoc, 2.5 yrs
OmegaCEN	Kuijken, Valentijn	RuG	support staff, 9 yrs
			Materials, 75 k€

Table 2.6: Overview of the science support projects in NOVA Phase-3.

enabling them to successfully obtain, calibrate and reduce ALMA early science data. The postdoc will work in the framework of ALLEGRO and will be the essential connection between ALMA and its users in a period when no automated pipeline is yet available and when the frontier of submillimeter interferometry is rapidly expanding.

2.5.2. Science support for VLT-SPHERE-ZIMPOL

The main science goals of SPHERE-ZIMPOL (see also § 3.4.2) are to directly detect giant exo-planets, to image the protoplanetary disks around young stars and to study the environment of evolved stars, topics of prime interest to Network-2 scientists. SPHERE will push the capabilities of the VLT to its limits and its mode of observations will differ from those of other VLT common-user instruments. To make full use of the potential of SPHERE-ZIMPOL, a postdoc will be funded to gain intimate knowledge of calibration and data-reduction techniques and provide support to the Dutch astronomical community.

2.5.3. Enabling PuMa-II for use with LOFAR

The NOVA-funded PuMa-II (Pulsar-Machine II) backend on Westerbork is a flexible, world-class data recorder that allows observations of the radio sky at very high time and frequency resolution. The primary scientific motivation for PuMa-II is the observation of binary and millisecond pulsars, rotating radio transients, and radio-emitting magnetars, of interest to Network-3 scientists. It also has high potential to discover new phenomena. NOVA funding will be provided for a postdoc to prepare and support PuMa-II for use with LOFAR, by extending PuMa-II's suite of reduction, analysis, data calibration, and quality-control monitoring tools to work with LOFAR data.

2.5.4. Maximizing the Dutch scientific harvest from HIFI

The Herschel Space Observatory, to be launched in 2009, will provide the first high angular- and spectral-resolution data in the far-infrared, making possible a wide range of projects related to the formation of stars and galaxies, the interstellar medium, astrochemistry and the Solar System. Network-1 and -2 researchers are well positioned to make excellent use of Herschel through their involvement in, and leadership of, a large number of key programs. The NOVA-funded postdoc will form the liaison between the key program teams and the Herschel HIFI Instrument Control Center, by helping to optimally calibrate the data, developing science pipelines tailored to individual key programs, and providing face-to-face science support.

2.5.5. OmegaCEN

The OmegaCAM 300 Mpixel instrument on the ESO-VST will carry out several large scientific surveys and thus deliver huge amounts of data during NOVA Phase-3. These include KiDS/VIKING for the study of dark matter and dark energy, VESUVIO and UltraVISTA for galaxy evolution, OmegaWhite for study of ultra-compact binaries and SN progenitors, and OmegaTranS for searches for hot Jupiters, involving researchers from all three networks. NOVA funding is provided for the core group of OmegaCEN, which will be the center of expertise for providing software, calibration, and data processing tools for wide-field imaging data, enabling Dutch users to carry out their science effectively and to fulfill their commitment to deliver reduced data and catalogues to ESO.

3. Instrumentation

In the past decades the Netherlands has built up a strong reputation in various areas of instrument design and construction and subsequent science exploitation. This manifests itself not only in scientific and technical publications but also by foreign partners who ask Dutch astronomers to join their instrumentation projects and want to participate in Dutch projects. The strong Dutch track record in astronomical instrumentation includes ASTRON with the observatories for radio astronomy with LOFAR under construction and SKA in development, SRON with space instruments for X-ray and submm spectroscopy with Herschel-HIFI to be launched in 2009, and NOVA with instruments for the ESO observatories with the VLT and VLTI in operation, ALMA under construction, and the E-ELT in its design phase. On a national scale ASTRON, SRON, and NOVA work closely together to implement the 10-year plan as laid down in the national strategic plan for astronomy in the Netherlands.

3.1. National strategy

Modern astronomy requires access to telescopes covering the full electromagnetic spectrum – from the highest-energy gamma- and X-rays to the lowest-energy long radio waves – with the greatest sensitivity. Nowadays most telescope facilities are internationally organized and funded. The aim of the Dutch astronomical community is to secure access to these facilities by partnerships with other countries and by instrument development and construction for international facilities, which in return give Dutch astronomers access to these facilities. Astronomers in the Netherlands have direct access to the most powerful optical and infrared ground-based telescopes through the European Southern Observatory (ESO) and to telescopes in space through the European Space Agency (ESA). Through NWO funding, they also actively use and operate the UK/NL optical telescopes of the Isaac Newton Group at La Palma, and the UK/Canada/NL submillimeter James Clerk Maxwell Telescope on Hawaii. Through ASTRON, they have access to the fully Dutch-owned Westerbork Synthesis Radio Telescope (WSRT) and - in the near future – the LOFAR radio array in the Netherlands together with the multi-national EVN-JIVE facility. LOFAR is expanding into an international partnership including Germany, the UK, France, and Sweden. Through SRON, Dutch astronomers had a head-start for using instruments on the XMM-Newton and Chandra space missions and soon they will have access to the HIFI instrument on the Herschel Space Observatory. Finally, astronomers in the Netherlands have traditionally also been very successful in getting access in open competition to major telescopes world wide not funded by the Netherlands.

3.2. Overview of the Phase-3 instrumentation program

3.2.1. NOVA strategy

NOVA astronomers are actively involved in building instruments to ensure that instruments with the required capabilities for their science are built, to gain expert knowledge of the increasingly complex instruments, and to be in a position to harvest the first scientific fruits, with a focus on instruments related to the ESO telescopes. The incentives for NOVA astronomers to participate in the development of new instruments are the following:
Ensuring scientific capabilities: 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, spectroscopic capability, and polarimetry). Only participation in the design and construction of some of these instruments can ensure that the specific scientific interests of Dutch astronomy are covered;
Guaranteed time: In return for their staff effort contributions observatories 'pay' the institutes via guaranteed time observations (GTO). GTO will provide astronomers with privileged and early access to the telescopes and enables large coherent programs with exclusive data access.

3.2.2. Heritage

NOVA's instrumentation program has a strong focus on ESO, in particular the Very Large Telescope (VLT), the VLT Interferometer (VLTI), the VLT Survey Telescope (VST) and the Atacama Large Millimeter Array (ALMA). Most of the projects in NOVA Phase 1 and 2 were carried out in collaboration with typically 4-6 international partners with each one of the partners being responsible for the design, construction and testing of a component of the instrument and ESO or the leading partner in the consortium being responsible for the overall integration of the instrument. The Dutch investment in the VLT, VLTI and VST instrument programs amounted to 22 M€ over the 1996-2012 period. Major contributions from NOVA (13 M€ excluding in-kind efforts of astronomical staff), ASTRON (8 M€) and NWO-M grants (1 M€) resulted in several first-generation instruments (VISIR, MIDI, SINFONI, OmegaCAM) and second-generation instruments (X-Shooter, MUSE, SPHERE-ZIMPOL) in collaboration with international partners. For the design and construction of the ALMA Band-9 receiver cartridge NOVA invested ~1 M€ in 1999-

2002 and ESO invested ~15 M€ in 2002-2012. In the ALMA case there will be no guaranteed observing time; the NOVA effort was entirely motivated by securing high sensitivity observing capabilities on ALMA at one of the highest frequency bands that can be used routinely from the ground at a 5000m high plateau. The knowledge developed in the PuMa project (NOVA Phase-1 and -2) resulting in a pulsar machine on the WSRT will in Phase-3 be exploited to implement a pulsar observing mode on LOFAR.

3.2.3. Preparation of the Phase-3 instrumentation program

In May 2007 NOVA received 15 proposals for instrumentation projects for its Phase-3 program 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 in Utrecht on 4 July 2007.

The proposals, together with their referee reports and response by the applicants on the referee reports, were reviewed by the Network Key Researchers (KRs) on their scientific merit and their justification within the national astronomy program. The KRs agreed on a motivated ranking of proposals. The proposals were also reviewed by the NOVA Instrument Steering Committee (ISC) on their technical feasibility, financial aspects, project management and risks. At their meeting the ISC was informed of the recommendations of the KRs including the rating on the scientific priorities of the proposals. Final decisions were taken by the NOVA Board at their meeting in November 2007. In total 11 proposals were granted and an additional proposal was supported through the seed funding program. Five projects received approval for an early start in 2008.

3.2.4. Summary of the Phase-3 instrumentation program

In 2009-2013 the focus of the NOVA instrumentation program continues to be on providing instruments for the ESO facilities including ALMA, VLT, VLTI, and the planned E-ELT in collaboration with international partners. For ALMA, ESO entrusted NOVA to build the Band-9 receiver cartridges, and NOVA will undertake technical R&D to explore fruitful options for 2nd generation ALMA receivers. To prepare for the science harvesting, a regional ALMA support node will be established in Leiden. For the VLT, design and construction work continues on the 2nd generation instruments SPHERE-Zimpol and MUSE. For the VLTI, NOVA participates in the preliminary design of Matisse with the option to continue this participation. For the E-ELT, NOVA is currently participating in four Phase-A instrument studies with the aim to continue to work on two instruments in the future. In addition NOVA is involved in two space projects: (1) post-delivery support for the cold optical bench for the MIRI mid-IR spectrometer on board JWST; (2) development of processing software for ESA's Gaia mission. Furthermore NOVA astronomers lead the work packages on the astronomical commissioning of LOFAR and are responsible for the development of the pipeline and data reduction software for the four key projects for this new telescope. In addition there are three small projects named AMUSE, S^{5}T and Matri^{2}ces, and a seed-funding project on Auger radio.

The budget allocations for each of the projects are listed in Table 3.1. The next sections describe each of the projects in more detail with emphasis on the NOVA involvement.

Phase-3 instrumentation program	Allocated budget in k€	
Optical-IR group, including		5.829
SPHERE-Zimpol (MAIT phase)	908	
METIS Phase-A study	414	
Micado Phase-A study	102	
OPTIMOS-EVE Phase-A study	171	
EPICS Phase-A study	88	
Matisse PDR study	196	
ALMA Band-9 production		10.238
ALMA ALLEGRO		547
ALMA technical R&D		517
MUSE		314
MUSE-ASSIST		956
MIRI		1.191
Gaia		424
LOFAR-DCLA		1.773
AMUSE		526
S^{5}T		339
MATRI^{2}CES		458
Seed funding, EC, contingency, new initiatives		2.267
TOTAL INSTRUMENTATION PROGRAM		**25.379**

Table 3.1: Overview of the Phase-3 instrumentation program covering the period 2009-2013. The line item 'Optical-IR instrumentation' is specified in Table 3.2.

3.3. NOVA's strategy towards participation in E-ELT instrumentation

Participation in the design and construction of instruments for the E-ELT is one of the top-priorities in the 'Strategic plan for astronomy in the Netherlands', updated in 2006 in a mid-term review covering the years 2006-2015. NOVA is leading the national efforts on the E-ELT participation in collaboration with ASTRON, SRON, technical universities, TNO, and several industrial partners. NOVA's strategy is to participate in a number for Phase-A studies (4 of the 8 studies selected by ESO) and to reduce the number of instruments in which it participates to one instrument with a leading role (with the aim to be the PI of the international consortium) and one other instrument in a member role. The down-selection is likely to occur in 2010-2011 when ESO decides on the go ahead for the E-ELT and its day-one instrument suite.

In November 2008 the Ministry of OCW and NWO allocated a grant of 18.8 M€ to NOVA and its national partners for work on E-ELT instrumentation projects. The E-ELT was one of the five projects that got national funding out of eight ESFRI projects that were identified as Dutch priorities by the national roadmap committee for large scale research facilities.

The grant includes 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 at least 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 partnership. Payment is spread over the period 2009-2018.

3.3.1. NOVA optical-IR instrumentation group

From the 1st January 2008 onwards NOVA took over the Optical-IR instrumentation group of ASTRON.

NOVA-ASTRON Optical-IR instrumentation group (in k€)						
Staff costs	**Total**	**2009**	**2010**	**2011**	**2012**	**2013**
NOVA Optical-IR group based at ASTRON	**2.716**	843	1.011	862		
Wachtgeld reservation	**175**	78	49	49		
Project staff based at universities	**816**	276	310	230		
Total staff costs	3.708	1.197	1.370	1.140		
Material budget for projects	**Total**					
Material budget for projects	**987**	621	273	93		
Contingency held at NOVA	**1.134**	164	100	120	550	200
Total budget for projects	2.121	785	373	213	550	200
TOTAL costs for NOVA	5.829	1.983	1.742	1.354	550	200
Summary revenues under NOVA responsibility	**Total**	**2009**	**2010**	**2011**	**2012**	**2013**
Direct NOVA contributions	**4.498**	1296	1395	1107	500	200
NOVA contributions through projects	**379**	231	70	77		
Contributions from NOVA partners	**180**	100	80			
ESO funding	**237**	171	66			
EU grants	**150**		30	70	50	
External funding	**385**	185	100	100		
Total revenues	5.829	1.983	1.742	1.354	550	200
Material budget on project basis	**Total**	**2009**	**2010**	**2011**	**2012**	
SPHERE: hardware	**300**	240	60			
SPHERE: travel	**30**	10	10	10		
METIS: Phase-A travel	**47**	47				
Micado: Phase-A travel	**29**	29				
EPICS:Phase-A travel + miscellaneous	**40**	40				
OPTIMOS: Phase-A travel + miscellaneous	**35**	35				
Matisse: PDR travel	**20**	20				
ELT FP7 design studies: travel	**20**	20				
E-ELT technical R&D and prototyping hardware	**162**	80	82			
FP7 OPTICON technical R&D	**170**		30	70	70	
Total material budget for projects	**853**	**521**	**182**	**80**	**70**	

Table 3.2: Overview of the budget for the optical-IR instrumentation projects including SPHERE-ZIMPOL, MATISSE and the Phase-A studies for the E-ELT instruments METIS, MICADO, EPICS and OPTIMOS. NOVA is able to fund the optical-IR projects and the Optical-IR instrumentation group at ASTRON up to the end of 2011. Recently obtained ESFRI funding is not included in the figures presented.

ALLEGRO (in k€) Staff effort	Level	Univ	Total	2009	2010	2011	2012	2013
Technical postdoc: continuation from Ph-2	postdoc	RuG	2,00	1,00	1,00			
Extension Ph-2 technical postdoc	postdoc	RuG	0,40			0,40		
Commissioning postdoc	postdoc	open	0,89	0,39	0,50			
Extension commissioning postdoc	postdoc	open	3,50		0,50	1,00	1,00	1,00
Total staff effort in staff years			6,79	1,39	2,00	1,40	1,00	1,00
Personnel Budget								
Technical postdoc: continuation from Ph-2	postdoc	RuG	134	67	67			
Extension Ph-2 technical postdoc	postdoc	RuG	27			27		
Commissioning postdoc			59	26	33			
Extension commissioning postdoc			233		33	67	67	67
Sub-total Personnel			453	93	133	93	67	67
Material Budget								
Travel			29	6	12	5	4	2
Travel CHAMP+ @ APEX observing			50	40	10			
Computers			15			15		
Sub-total Materials			94	46	22	20	4	2
TOTAL costs ALLEGRO			547	139	156	113	71	69
Funded from Phase-2 budget			261	139	122	0	0	0
Funded from Phase-3 budget			286	0	33	113	71	69
Total funding ALLEGRO			547	139	156	113	71	69

Table 3.3: Budget allocation for ALLEGRO for the period 2009-2013. Figures marked in blue are ongoing commitments from Phase-2. The financial figures are according to guidelines described in § 5.1.

This development occurred after the decision by ASTRON and NWO to concentrate future ASTRON activities on radio astronomy. The group consists of ten experienced people with expertise ranging from optical, mechanical, and cryogenic design, system engineering, CNC and optical production capabilities, instrument integration, and verification. Over the last decade this group carried out the optical-IR instrumentation projects for which NOVA had final responsibility towards ESO, ESA, and international partners.

Current arrangements between NOVA, ASTRON, and NWO concerning the Optical-IR instrumentation group are concluded in a contract that covers the period 2008-2011. NOVA has final responsibility over the work program of the group and has financial liability, ASTRON hosts the group and the infrastructural facilities at their building in Dwingeloo, and NWO employs the staff. ASTRON also provides laboratory instruments, test facilities, and software packages for design and measurement. The financial implications are summarized in Table 3.2.

3.4. Atacama Large Millimeter Array (ALMA)

ALMA is a collaboration between Europe, North America, East Asia, and Chile, to build an aperture synthesis telescope consisting of at least 66 antennas at the 5000m altitude Chajnantor plateau in northern Chile. When complete, ALMA will observe in 7 frequency bands between 30 and 950 GHz (with up to 3 bands more to be implemented later), with a maximum baseline of up to 14 km, offering unprecedented sensitivity and spatial resolution at millimeter and submillimeter wavelengths. First science observations with the ALMA mini-array are expected to start in 2011; the entire observatory will be complete in 2013. ALMA will revolutionize astronomy at (sub)millimeter wavelengths and will have a major impact on many areas of astronomical research. To maximize the science return from ALMA, a node of the European ALMA Regional Center has been established in the Netherlands: ALLEGRO (ALMA Local Expertise GROup). When ALMA becomes fully operational, ALLEGRO will offer general face-to-face user support for novice users, and expert support in the areas of high-

Figure 3.1: First six prototype ALMA Band-9 cartridges manufactured under ESO contract following NOVA funded instrument R&D in Phase-1.

Technical R&D 2nd generation ALMA receiver (in k€) Staff effort	Level	Univ	Total	2009	2010	2011	2012	2013
Instrument scientist / project manager	11	RuG	**2,00**	0,50	0,50	0,50	0,50	
Mechanical designer	9	RuG	**0,80**	0,20	0,20	0,20	0,20	
Technical Postdoc	11	RuG	**2,00**	0,25	1,00	0,75		
Technical PhD student	AIO	SRON	**4,00**	1,00	1,00	1,00	1,00	
Total staff effort in staff years			**8,80**	**1,95**	**2,70**	**2,45**	**1,70**	**0,00**
Personnel Budget								
Instrument scientist / project manager			**133**	33	33	33	33	
Mechanical designer			**46**	11	11	11	11	
Vacancy			**133**	17	67	50		
Vacancy				sron	sron	sron	sron	
Sub-total Personnel			**312**	**61**	**111**	**95**	**45**	**0**
Material Budget								
Materials + travel			**205**	60	61	54	30	
Infrastructure				sron	sron	sron	sron	
Sub-total Materials			**205**	**60**	**61**	**54**	**30**	**0**
TOTAL costs ALMA technical R&D			**517**	**121**	**172**	**149**	**75**	**0**
Funding								
Phase-3 instrumentation program			**396**	61	111	149	75	
Carry-over from Phase-2 R&D project			**121**	60	61			
Total revenues ALMA technical R&D			**517**	**121**	**172**	**149**	**75**	**0**
Total expenditure ALMA project in k€			**1.064**	**260**	**328**	**262**	**145**	**69**
REVENUES			**Total**	**2009**	**2010**	**2011**	**2012**	**2013**
Phase-3 instrumentation program			682	61	145	262	145	69
Carry-over from Phase-2 R&D project			382	199	183	0	0	0
TOTAL REVENUES			**1.064**	**260**	**328**	**262**	**145**	**69**

Table 3.4: Budget allocation for ALMA technical R&D for the period 2009-2013. Part of the costs are funded from a cash transfer of k€ 121 from Phase-2. SRON supports the project with a technical PhD student and providing office and laboratory space and equipment. The financial figures are according to guidelines described in § 5.1.

frequency observing, imaging of wide fields and with high dynamic range, and the use of advanced science analysis tools. The NOVA-funded start-up activities of ALLEGRO aim to consolidate the necessary expertise, to participate in the commissioning of ALMA, and to provide user-support during the early science phase of 2011–2013 when ALMA will still be rapidly developing and the frontier of (sub)millimeter astronomy is quickly expanding. Parallel to the ALLEGRO efforts, an instrumentation R&D program will develop state-of-the-art receiver technology for future ALMA upgrades. Some of this technology can be field-tested and used for astronomy at the APEX telescope.

3.4.1. ALMA R&D and its scientific context

Millimeter and submillimeter astronomy has a strong tradition in the Netherlands, with participation in the James Clerk Maxwell Telescope, development of the CHAMP+ array for the Atacama Pathfinder Experiment (APEX), construction of the HIFI instrument for the Herschel Space Observatory, and development and subsequent construction of the Band-9 receivers for ALMA. ALMA will form a powerful instrument for virtually all branches of astronomy in the Netherlands.

3.4.1.1. International partners and collaborations

ALMA is constructed jointly by Europe, North America, and East Asia. The ALMA Regional Centers (ARCs) form the interface between the ALMA project and its users in each of the three continents. In Europe the ARC consists of a core at ESO and a network of six nodes. ALLEGRO is one of the nodes, in addition to Manchester, Onsala, Bonn/Cologne/Bochum, Grenoble, and Bologna. Each of the nodes is responsible for general face-to-face user support for the community and specialist help in a number of well defined expertise areas. The ALMA technical R&D efforts are carried out in collaboration with partners in France (IRAM, LERMA), Germany (MPIfR in Bonn, KOSMA), Spain (Centro Astronómico de Yebes), Sweden (OSO, Chalmers), and the USA (Caltech, NRAO). Part of the development work will be closely connected to EC FP7 funded activities within RadioNet.

3.4.1.2. Science case and prospects

ALMA is scheduled to start full operation in 2013, but in 2011 early science observations will commence with 16 of the ultimate 66 antennas. This will allow Dutch astronomers to start addressing a number of the questions that ALMA can answer.

These include:
The first stages of star formation: how does star formation commence, and how are the circumstellar disks formed around growing stars from which planets later condense?
Transitional disks: originally, circumstellar disks around young stars are rich is gas and fine dust. How do they evolve toward planetary systems? How is the gas and dust cleared out? How do newly formed planets create wakes in the disks?
The Initial Mass Function (IMF) of stars: does the distribution of stellar masses across the Milky Way find its origin in the substructure inside cluster-forming interstellar clouds?
Star forming galaxies: earlier in the Universe's history, galaxies formed stars at a rate as much as 100 times that seen today in the Milky Way. How do the dynamics of the gas inside these galaxies compare to local regions of active star formation?
Local Ultra-Luminous InfraRed Galaxies: What are the properties of the dense and warm gas inside nearby ULIRGs? How are these related to their enormous energy output?
Ionized carbon and CO in high-redshift galaxies: ALMA can uniquely detect and image the emission of gas in high-redshift galaxies. What will the kinematics of the gas in these primitive environments tell us about their dynamics and masses?
Comets: ALMA can probe the gas composition of a wide range of comets passing by the Earth. What does their diversity and (in)homogeneity tell us about the conditions early in the history of the Solar System?

Astronomers in the Netherlands are active in all of these areas, as is reflected in the NOVA research networks 1 and 2. There is strong synergy between ALMA and other instruments with significant Dutch involvement like the VLT, Herschel, JWST, and E-ELT.

In the ALMA early science phase, Dutch astronomers can start to investigate these questions. Even when ALMA has reached its full size however, further development of submillimeter receivers is required to fully explore these topics. Our ALMA technical R&D program aims at developing mixers with increased sensitivity and suppressing noise from the atmosphere, in particular at the highest ALMA frequencies.

3.4.1.3. Impact/context NL situation

ALLEGRO is coordinated by Hogerheijde and supervised by a steering committee consisting of Barthel, Oosterloo, van Langevelde, van Dishoeck, Roelfsema, and Tilanus. The technical R&D activities are coordinated by Spaans and supervised by a steering committee consisting of Baryshev, Boland, Helmich and Hogerheijde. The main benefits of the ALLEGRO and ALMA technical R&D activities for Dutch astronomy include (i) face-to-face user support by ALLEGRO for novice and expert users, based at Leiden Observatory; (ii) world-leading expertise at ALLEGRO on a number of observational applications that serve the needs of Dutch astronomers, such as observing at the Band-9 frequencies (602–720 GHz) where ALMA is pushed to its ultimate performance; (iii) support by ALLEGRO for Dutch astronomers during the critical early science phase when ALMA generates its first data but little is known about the instrumental properties and pipeline software tools are not yet available; (iv) continuation of the leading position in submillimeter receiver design by the ALMA technical R&D program with significant improvements of submillimeter receiver sensitivities for ALMA. Available NOVA funding is specified in Tables 3.3 and 3.4. NWO-EW agreed to financially support the ALLEGRO activities from 2012 onwards.

3.4.1.4. Technical concept and requirements

ALLEGRO is part of the European ALMA Regional Center and as such is part of the ALMA project. It will develop observing and calibration strategies for the ALMA Band-9 receiver and deliver these to the international ALMA project. ALLEGRO will also participate in the on-site commissioning of ALMA, with a focus on Band-9 (commissioning postdoc). Finally, ALLEGRO will facilitate access to science-analysis tools developed by the community, but which are currently not intuitive to use and which are difficult to interface with each other and with ALMA data. The ALMA R&D project will develop innovative technology for a 2nd generation ALMA receiver to significantly improve the observing efficiency and sensitivity for the two highest frequency atmospheric windows (Band-9 and Band-10) and possibly demonstrate the new findings on APEX. One option would be the 'sideband-separating' mixers which are capable of suppressing the (unwanted) noise from one of the observational sidebands. For comparison, a 10% improvement in sensitivity can be regarded equivalent to adding five antennas to the ALMA array. Another approach is the development of new SIS junction technology in collaboration with TU Delft using a different tunnel-barrier material. The project aims to demonstrate the improved performance of a sideband separating (2SB) mixer design in a receiver cartridge, and at the telescope, before the end of 2012. This is in line with the current thinking within the ALMA project, which is starting to explore possible future development needs and upgrade paths during the operations phase beyond 2012. Also, the 2SB mixers are the baseline technology for ALMA band 3-8 receivers already, allowing a potential upgrade of band-9 to the 2SB scheme without system wide modifications.

3.4.2. ALMA Band-9 production

Within the Netherlands, a collaboration of NOVA, the RuG, SRON, and the Kavli Institute of Nanoscience in Delft developed heterodyne receivers for ALMA to operate at frequencies between 602 and 720 GHz. The work is done under a contract between ESO and NOVA. As the highest frequency band in the baseline 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). In the NOVA Phase-3 period ~66 Band-9 receivers cartridges will be produced at RuG/SRON in Groningen by a dedicated production team consisting of ~12 people. This work package is fully funded by ESO on a fixed price basis amounting to 12.5 M€ of which 2.3 M€ is already spent in 2007-2008 and 10.2 M€ is planned for the years 2009-2012.

3.5. Second generation instruments for the VLT and VLTI

3.5.1. MUSE and ASSIST

MUSE, the Multi Unit Spectroscopic Explorer, is a second-generation panoramic integral-field spectrograph for the VLT, developed by a F-NL-D-CH consortium led by CRAL at Lyon and expected to begin operations in 2012. The instrument consists of 24 combined identical integral-field spectrograph units, covering simultaneously the spectral range 480 - 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 AO Facility (AOF), at the heart of which is the development of a Deformable Secondary Mirror (DSM) for the VLT. An important element to ESO's DSM development (and therefore also to MUSE) is ASSIST: Adaptive Secondary Setup and Instrument STimulator. ASSIST has been developed and will be assembled at Leiden Observatory under NOVA responsibility. 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 (GALACSI and GRAAL), and ensuring the DSM operates at specification before being deployed at the VLT. The core of ASSIST is a support infrastructure to integrate the DSM in a compact and stable test setup. A Nasmyth rotator simulator will be provided for attaching the two AO systems, while ASSIST will be fed by a star simulator and turbulence generator for realistic performance measurements of both the DSM as well as the AO system under test. An on-axis high-speed interferometer will be used for additional testing of the functional operation of the DSM. ASSIST is due to start operation at ESO, Garching, early 2011, in time for the DSM delivery.

3.5.1.1. International partners and collaborations

The MUSE consortium consists of 7 core institutes: Astrophysikalisches Institut Potsdam (AIP); Centre de Recherche Astronomique de Lyon (CRAL); ESO; Leiden Observatory (NOVA); Eidgenössische Technische Hochschule (ETH), Zürich; Laboratoire d'Astrophysique Observatoire Midi-Pyrénées (LAOMP), Toulouse; and the University of Göttingen.

3.5.1.2. Science case

The primary mode of MUSE has a wide (1 x 1 arcmin) field of view, which will be used for conducting uniquely sensitive deep-field surveys, with the key goal of understanding the progenitor population of present-day 'normal' galaxies. Through a series of nested surveys of different area and depth, MUSE will detect Lyman-alpha emission from large numbers of (proto-)galaxies up to redshift z ~ 6. The deepest exposures will reveal emission from the gas around galaxies, enabling the study of gas flowing into and out of galaxies. At low redshifts MUSE will allow detailed two-dimensional mapping of the kinematics and stellar populations of a variety of 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.

Implicit in the MUSE project is the development of new enabling technologies that will have an impact on future extremely large telescope facilities. The modular structure of the instrument provides a model for future research-industry partnerships. The integrated role of a multi-laser adaptive optics facility, which will certainly be part of future instrument developments, highlights the challenges in designing, building and managing such complex systems. The development of the DSM itself

MUSE project budget in k€								
Staff effort	**Level**	**Univ**	**Total**	**2009**	**2010**	**2011**	**2012**	**2013**
Postdoc MUSE system support	11	UL	**4,33**	1,00	1,00	1,00	1,00	0,33
Total staff effort in staff years			**4,33**	**1,00**	**1,00**	**1,00**	**1,00**	**0,33**
Personnel Budget								
Postdoc MUSE system support *			**289**	67	67	67	67	22
Sub-total Personnel			**289**	**67**	**67**	**67**	**67**	**22**
Material Budget								
Travel NL MUSE team			**25**	6	5	7	7	
Sub-total Materials			**25**	**6**	**5**	**7**	**7**	**0**
TOTAL costs			**314**	**73**	**72**	**74**	**74**	**22**
REVENUES			**Total**	**2009**	**2010**	**2011**	**2012**	**2013**
NOVA funding			**314**	73	72	74	74	22
TOTAL REVENUES			**314**	**73**	**72**	**74**	**74**	**22**

Table 3.5: Budget allocation for MUSE for the period 2009-2013. The project is fully funded by NOVA. (*) The technical postdoc already started on 1st April 2008 funded from the Phase-2 budget. The financial figures are according to guidelines described in § 5.1.

ASSIST project budget in k€								
Staff effort	Level	Univ	Total	2009	2010	2011	2012	2013
Project manager / AO expert	12	UL	**2,70**	1,00	1,00	0,50	0,20	
Postdoc hardware / tests	11	UL	**1,50**	0,50	1,00			
Postdoc AO control	11	UL	**0,17**	0,17				
Technical support	10	UL	**1,60**	0,60	0,60	0,20	0,20	
Total staff effort in staff years			**5,97**	**2,27**	**2,60**	**0,70**	**0,40**	**0,00**
Personnel budget								
Project manager / AO expert				UL	UL	UL	UL	
Postdoc hardware / tests			**69**	29	40			
Postdoc hardware / tests extension			**21**		21			
Postdoc AO control			**10**	10				
Technical support				UL	UL	UL	UL	
Sub-total Personnel			**99**	**39**	**61**	**0**	**0**	**0**
Materials, travel								
Bench and travel			**22**	3	5	7	7	
Optical components			**550**	470	80			
Optical components			**250**		250			
Electronics			**8**	8				
Mechanical components			**33**	33				
Test equipment			**2**	2				
Transportation			**7**		7			
Shortfall - to be resolved			**-15**		-15			
Sub-total Materials			**857**	**516**	**327**	**7**	**7**	**0**
TOTAL costs ASSIST			**957**	**555**	**388**	**7**	**7**	**0**
REVENUES			**Total**	**2009**	**2010**	**2011**	**2012**	**2013**
Remaining ASSIST budget NOVA Phase-2			**659**	307	338	7	7	
Leiden Observatory			**85**	85				
ESO hardware contribution			**100**	100				
OPTICON FP7			**113**	63	50			
TOTAL REVENUES			**957**	**555**	**388**	**7**	**7**	**0**

Table 3.6: Remaining budget resources for ASSIST for the period 2009-2013. The project is funded from NOVA's Phase-2 budget, Leiden Observatory, ESO and the EC integrated initiatives program OPTICON. The project still has to resolve a predicted shortfall of ~15 k€. NOVA and ESO are working on a solution.

presents significant challenges both in manufacturing and, more importantly, in system control.

3.5.1.3. **Impact/context NL situation**

NOVA's involvement in the MUSE instrument is many-fold, distributed across three inter-related areas of the MUSE project: The MUSE spectrograph scientific impact: coordinating the MUSE science team and Guaranteed Time Observation (GTO) allocation, and providing key operations-based deliverables. 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.
The ASSIST test-bench: facility for testing and integrating the ESO DSM and AO-Facility instruments.

The NOVA participation in items 1 and 2 is provided through Franx, Schaye, and Stuik with support of Dr. Denis Serre who is appointed as technical postdoc on the MUSE project. He is responsible for the development of the operation and calibration plan for MUSE, its exposure time calculator, and he will also participate in the development of the Point Spread Function (PSF) reconstruction and the interface between MUSE and GALACSI. The available NOVA funding for the MUSE project is summarized in Table 3.5.

3.5.1.4. **Technical concept and requirements for ASSIST**

ASSIST is an on-going NOVA commitment to ESO started in Phase-2. It is part of the Adaptive Optics Facility program at ESO aiming at upgrading the 4th unit (UT4) of the VLT into an adaptive telescope. It will include a new 2nd generation M2-unit hosting a Deformable Secondary Mirror, two AO modules feeding the instruments Hawk-I and MUSE (called GRAAL and GALACSI respectively) and four Launch Telescopes mounted on the telescope center piece providing four laser beams for the wavefront sensing by the AO modules. In order to test the whole system in Europe, NOVA designed (2007-2009) and will manufacture and test (2009-2011) the ASSIST Test Bench to provide mechanical and optical interfaces to the DSM and the AO modules GRAAL and GALACSI. A source module will feed this optical setup and provide turbulence altered images of the natural and artificial (LGS) star sources. This will allow a full testing and characterization of the AO modules and DSM in Europe before delivery to Paranal.

3.5.2. SPHERE-ZIMPOL

SPHERE (Spectro-Polarimetric Exoplanet Research) is one of the four second-generation VLT instruments under development. The SPHERE instrument consists of an extreme Adaptive Optics system and three science arms: ZIMPOL, the imaging polarimeter; IRDIS, the near-IR imaging and slit spectrograph; and IFS, the near-IR integral-field unit. SPHERE will push the capabilities of the VLT to its limits, and the survey nature of its routine observations differs from that of other VLT common user instruments. In order to make full use of the potential of SPHERE, intimate knowledge of calibration and data-reduction techniques will be required.

PI of SPHERE is J.-L. Beuzit, and the project manager is P. Puget. The Dutch contribution focuses on ZIMPOL, the Zürich Imaging Polarimeter. This science arm is designed and constructed in close collaboration with the group at ETH Zurich, and led by H.-M. Schmid. The Dutch effort is led by R. Waters (also member of the international SPHERE executive board), and the national project manager is J. Pragt (ASTRON).

3.5.2.1. **International partners**

The SPHERE Consortium consists of 12 members from institutes located in France, Italy, Swiss, Germany and the Netherlands. The Consortium partners are Institut National des Sciences de l'Univers du Centre National de la Recherche Scientifique (INSU/CNRS), acting on behalf of its laboratories: Laboratoire d'Astrophysique de Grenoble (LAOG), Laboratoire d'Astrophysique de Marseille (LAM), Laboratoire d'Etudes Spatiales et d'Instrumentation en Astrophysique, Observatoire de Paris (LESIA), Laboratoire Universitaire d'Astrophysique de Nice (LUAN); Max Planck Institute for Astronomy (MPIA); Instituto Nazionale di Astrofisica (INAF), with activity coordinated by the Osservatorio Astronomico di Padova; Eidgenössische Technische Hochschule Zürich (ETH); Observatoire de Genève (OG); NOVA, representing the involvement of the University of Amsterdam and Utrecht University; Office National d'Etudes et de Recherches Aérospatiales (ONERA); and ASTRON.

3.5.2.2. **Science case**

Since the first discovery of a planet around a solar-type star in 1995, the search for extra-solar planets, or exoplanets, has developed into one of the main goals of astronomy. To date more than 250 exoplanets have been found, a number of them in multi–planet systems. These exoplanets have been found using indirect detection methods, in which not the planet itself is observed, but rather its influence on the star. Indirect detection methods have proved to be very successful in finding extra-solar planets. However, they provide little information on the planet itself, apart from its mass or size, and some orbital parameters. In addition, these methods have generally little sensitivity to exoplanets that are in orbits as wide as those of the giant planets in our own Solar System. To get information on a planet's physical parameters, such as temperature and pressure, chemical composition and atmospheric structure, which provide key information on planet formation and evolution, direct detection of radiation from the planet is required. This method also enables the detection and study of planets in systems like our own Solar System. It thus covers a parameter space that is complementary to that of the radial velocity method, and is important in view of searches for terrestrial-type exoplanets.

SPHERE aims at the direct detection and characterization of Extra-solar Giant Planets (EGPs). The instrument is based on two detection strategies: one is optimized to detect the polarized, reflected light of old, cold EGPs, and the other is optimized to detect the thermal radiation of young, hot EGPs.

Almost all young, low-mass stars appear to have an accretion disk through which matter flows towards the central star. After the accretion stops, a disk of gas and dust remains, that slowly dissipates. There is growing evidence that these disks are the sites of ongoing planet formation. Imaging and imaging polarimetry of proto-planetary disks reveals important information about its structure and of the composition of the dust in the disk surface layers. Both are strongly affected by the process of planet formation. SPHERE has the capability to image the disks to a distance of 0.1 arcsec from the star, which is much better than current instrumentation is able to provide. SPHERE on the VLT will be a very sensitive instrument to detect exo-zodiacal emission in nearby stars, as well as standard debris disks in stars further away from the Sun.

The GTO exoplanet program will focus on establishing the frequency of gas giant exoplanets as a function of stellar mass and age. This approach will leave ample room for substantial exoplanet surveys in the open time. Other topics of the GTO program will be proto-planetary disks and evolved stars. The Consortium will spend ~200 GTO nights on exoplanet searches using the near-IR arms of SPHERE (IRDIS and IFS), 20-25 nights on exoplanet searches using ZIMPOL and ~20 nights on studies of protoplanetary disks.

3.5.2.3. Impact/context NL situation

In the Netherlands Waters (UvA) is the national PI, and Pragt (ASTRON) is the national project manager. The optical design work is done by Rigal (ASTRON) and the mechanical design and thermal analyses by Roelfsema (ASTRON). The national science team consists of Waters, Stam (SRON), Keller (UU), Jeffers (UU), Dominik (UvA), Min (UvA/UU), de Koter (UvA), Tolstoy (RUG), Snellen (UL), and Hovenier (UvA).

Together with the Swiss the Netherlands will design and build the imaging polarimeter arm of SPHERE named ZIMPOL. The funding of the Dutch work package up to commissioning at Paranal is secured with contributions from NOVA (~1020 k€), a NWO-M grant (400 k€), a contribution from the UvA (200 k€), in-kind support from ASTRON (100 k€) and from members of the science team, and technical advice from the UU. The NOVA contribution consists of ~10 years of staff effort within the NOVA-ASTRON Optical-IR instrumentation group and 330 k€ cash for hardware and travel (Table 3.2).

3.5.3. MATISSE

MATISSE (Multi AperTure Mid-Infrared SpectroScope Experiment) is one of the three second generation instruments for ESO's Very Large Telescope Interferometer (VLTI). It is designed to become the ultimate mid-IR instrument that can be operated at the VLTI and the first instrument to use the full power of the four-telescope VLTI. It represents a major technical and scientific advance over the current instrument, MIDI. Its spatial resolution will be 3 milliarcsec, the size of a Euro coin at a distance of 1000 km. Dutch astronomers at Leiden, Amsterdam, Groningen and Nijmegen will use MATISSE to study at this resolution dust and gas structures of Active Galactic Nuclei (AGNs), planet-forming regions around stars, and dust shells around young and old stars. Direct emission from extrasolar planets may also be detected. The instrument is now in the Preliminary Design phase. The instrument will become available for astronomical observation in early 2014.

3.5.3.1. International partners

Matisse is an international collaboration of various institutes in France, Germany and the Netherlands. The international project PI is B. Lopez, and the PM is P. Antonelli. It was approved for development by the ESO Council in December 2007 after completion of its Phase-A studies.

3.5.3.2. Science case

MATISSE will address new questions due to its capability to allow detailed imaging in multiple bands at mid-IR wavelengths. The mid-IR is particularly suited to studies of dust and molecules in disks and winds surrounding stars, including protostars and

AGNs because the temperatures of these regions are typically ~200-1000 K, where emission peaks in the mid-IR. These materials have characteristic absorption and emission lines in the mid-IR: cool H_2 at 9, 12 and 17 μm, HII as Brackett alpha at 4.05 μm (plus many lines of the higher series) and lines of other ionized species such as [Ne II], [Ar III], [SIV], [SIII] [FeIII], CO gas and ice at ~4.7 μm, PAHs (Poly Aromatic Hydrocarbons) at 3.3, 8.6, 11.3 μm, many dust minerals in the N-band, and gas and ice molecules such as OH, H_2O, CO, NH_3,CH3OH,OCN, C_2H_2, HCN, CS, and SiC.

Proto-planetary disks: Current star formation models predict the existence of disks around young stars as a natural consequence of their formation process. The material in these disks comprises the building blocks for future planetary systems. Circumstellar disks evolve from a gas-dominated state (mainly traced by millimeter interferometers), to so-called 'debris disks' with large solid bodies, where a minor amount of small dust grains is produced by collisions of larger bodies, such as planetesimals. Proto-planetary disks have now been imaged from the optical/near-IR to the millimeter wavelength range around low-mass young stars (T Tauri stars), intermediate-mass young stars (Herbig Ae/Be stars), and possibly around massive young stars. The innermost several AU of disks, where planet formation is expected to occur, can only be marginally investigated so far with single telescopes and the limited VLTI facilities MIDI or AMBER. This will remain the case until ALMA will be in operation with its longest baselines (~2013), and high resolution mid-IR images become available with MATISSE (~2014). With the 10-20 milliarcsecond spatial resolution achievable with VLTI in the 8-13 μm atmospheric window, MATISSE will be the ideal instrument to study the inner 10-20 AU of disks, where mid-infrared continuum radiation of hot dust is the dominant emission.

Formation of High-Mass stars: For several reasons, progress in the understanding of high-mass star formation has lagged behind that of low-mass stars. Young high-mass stars are relatively rare in our Galaxy and tend to be more distant, well beyond 1 kpc, while many low-mass YSOs are found at 100-300 pc. Furthermore, massive stars predominantly form in very opaque and highly-clustered environments. It is a characteristic feature of massive star formation that the Kelvin-Helmholtz timescale for the onset of nuclear fusion is shorter than the accretion timescale. Thus the pre-main-sequence phases are deeply embedded within the accreting envelope. The early phases of massive star formation are hidden to current optical and near-infrared cameras because of the high extinction. Observations in the mid-infrared are far more suitable, since the optical depth drops strongly toward longer wavelengths, while emitted energy increases strongly in the mid-IR. Thus high-resolution interferometric mid-IR observations are best suited to investigate massive star formation.

3.5.3.3. Impact/context NL situation

The Netherlands is asked to provide the Cold Optical Bench (COB) for MATISSE, building on the expertise gained on the contribution to MIDI. The design and fabrication will be done at the NOVA/ASTRON optical-IR instrumentation group in Dwingeloo. The required total staff effort is of the order of 20 staff years. The national PI is Jaffe. The NOVA Board approved the participation up to the completion of the preliminary design phase. In the course of 2009 NOVA will decide about its further involvement in this project. If NOVA decides to continue the total Dutch effort amounts to ~17 staff years and ~750 k€ for hardware. This effort is ~25% of the total cost of MATISSE and will be reflected in the guaranteed observing time on the instrument for Dutch projects.

3.6. Preparation of instruments for the E-ELT

In 2008 NOVA signed up to participate in four Phase-A studies for instrument concepts for the E-ELT. All for these studies involve international partners in Europe. The typical lead time for each of the studies is 15-20 months completing by late 2009. Below is a brief description of each of the instrument concepts.

3.6.1. METIS – mid-IR imager and spectrograph

METIS, the Mid-infrared ELT Imager and Spectrograph, covers the mid-IR wavelength range L, M, N and Q band (from 3 μm to 20-25 μm, depending on the transparency of the atmosphere at the E-ELT location). It will provide high angular resolution imaging (6.5 times higher than the JWST), coronography, and medium- and high resolution spectroscopy (R~100,000). It is ideally suited to study a wide range of scientific topics, especially in regions with large obscuration. It is particularly powerful for imaging the kinematics of gas in proto-planetary disks down to 0.1 AU scales and probe departures from Keplerian rotation, as well as image the distribution of water and organic molecules like HCN, C_2H_2 and CH_4, key ingredients for building more complex prebiotic molecules, in the inner planet-forming zones of disks. Dust gaps indicative of young planets can be imaged in the nearest star-forming regions down to 20 AU or less. Jovian exoplanets can be imaged around the nearest stars (within ~6 pc) down to 1 AU and there are many unique diagnostics at mid-IR wavelengths to probe their atmospheres which are complementary to optical/near-IR studies. In the centers of dusty active galactic nuclei, METIS will be able to measure the mass and thus the growth of supermassive black holes. It will also be able to determine directly the origin of the IR luminosity (starburst or AGN) and the location and geometry of the dusty torus feeding the black hole. Furthermore METIS will probe the composition of comets and other minor bodies in the Solar System and thus constrain the temperature profile and large-scale mixing in the disk from which our planetary system formed.

The Netherlands has a long heritage in groundbreaking mid-infrared missions and instruments over the past 25 years, starting with IRAS, and continuing via ISO-SWS, VLT-VISIR, VLTI-MIDI and Herschel-HIFI to ambitious projects for future facilities like JWST-MIRI. Dutch astronomers have been heavily involved in the design and construction of these instruments, as well as their scientific utilization, as reflected in thousands of refereed publications and dozens of PhD theses resulting from this involvement. The original proposal to NOVA to participate in an E-ELT mid-IR spectrometer listed 25 (co-) investigators from seven institutions within the Netherlands, illustrating the strong interest in this project from both astronomical and technical sides. The Dutch contributions to METIS are concentrated on the mid-IR spectrometer, the overall systems engineering, and the organization and management of the international consortium.

METIS is a NOVA-led international consortium consisting of institutions from five European countries: the Netherlands (NOVA), Germany (MPIA), France (CEA Saclay), the United Kingdom (UK-ATC), and Belgium (KU Leuven). The international PI is Brandl (NOVA, Leiden). The METIS team benefits strongly from its experience with numerous successful ground- and space-based instruments built at these institutes, such as VLT-VISIR, VLTI-MIDI, GEMINI-MICHELLE, Spitzer-IRS, and JWST-MIRI. ESO is actively contributing in several crucial areas such as detector technologies.

3.6.2. MICADO – wide field imager

MICADO is a near-infrared (1-2.5 μm) imager for the E-ELT. It samples the focal plane at 2-4 milli-arcsecond resolution and so is suitable for diffraction-limited imaging. It will cover a field of at least 30 arcsec. The science case covers diverse topics including the environment of the central black hole in our own Galaxy, resolved stellar populations in Local Group galaxies and beyond, and high-redshift galaxies. It takes advantage of the combination of high spatial resolution with great sensitivity of the E-ELT. MICADO is a potential first-light instrument.

Dutch interest centers on the study of galaxy formation using the resolving power and sensitivity of MICADO. This includes (i) the imaging of very distant galaxies, which are very faint and small, and whose light is redshifted to the infrared wavelengths; (ii) studying the resolved stellar populations of nearby galaxies, affording a detailed view of the star formation history that cannot be attained from integrated light spectra; and (iii) measuring the internal kinematics of stars in Local Group galaxies in order to derive the orbit structure and hence the dark matter content of these galaxies.

MICADO is a German-Italian-Dutch consortium led by Genzel (MPE) with involvement from USM, MPIA, INAF-Padua, and NOVA. Kuijken (NOVA, Leiden) is the Dutch PI and co-I in the international consortium. In the Phase-A study the main Dutch involvement centers on design work, particularly mechanical and cryogenic, and on design of the data flow software. It builds on expertise developed for the Sinfoni 2K camera and the near-IR arm for X-Shooter (both on the VLT) and for the data-flow and -reduction software for OmegaCAM (on the VST).

3.6.3. EPICS – exoplanet finder

EPICS is optimized to directly image and characterize exoplanets with the E-ELT. It does this by combining extreme adaptive optics with coronagraphic imaging, imaging spectroscopy, and polarimetry at visible and near-infrared wavelengths. This will allow the E-ELT to characterize extrasolar gas giants that have been discovered by indirect methods, to detect and characterize mature cold gas giants like Jupiter at orbital distances between ~5 and 15 AU in the solar neighborhood (< ~20 pc), young gas giants in star forming regions, and Neptune-like planets, massive rocky planets (super-Earths), and ocean planets around nearby stars (< ~10 pc). The ultimate goal of EPICS is to detect and characterize super-Earths and exoplanets with liquid water in the habitable zones of stars. Polarimetry can characterize exoplanets in much more detail than any other technique.

The Netherlands has a long tradition in precise astronomical polarimetry as well as exoplanetary research. Both of these areas have seen dramatic growth in the Netherlands over the last few years with a dedicated exoplanet polarimeter instrument for the William Herschel Telescope (ExPo) seeing first light in October 2008 and the design and participation in the development and construction of the SPHERE planet finder instrument for the VLT. The Dutch contributions to EPICS (as for SPHERE) are focused on polarimetry.

EPICS is an international consortium consisting of ESO and institutions from six European countries: the Netherlands (NOVA), Germany (MPIA), France (LESIA, LAOG, LAM), the United Kingdom (Oxford), Italy (Padova), and Switzerland (ETH). NOVA and ETH together are responsible for the polarimetry part of the instrument. Keller (NOVA, Utrecht) is the Dutch PI and co-I in the international consortium. The EPICS team (with NL members Dominik, Keller, Stam, and Waters) greatly benefits from its experience with SPHERE, the precursor instrument for the VLT that is currently being built by many of the EPICS consortia members.

3.6.4. OPTIMOS - Optical to infrared multi-object spectrograph

OPTIMOS is an optical to near-IR (350 - 1800 nm) spectrograph for the E-ELT at medium spectral resolution (10000 < R < 20000) with high multiplexing (at least 300) and with the highest efficiency possible assuming natural seeing or ground-layer corrected adaptive optics. The field of view should be 5' x 5', with 10' x 10' as a goal (but then partially vignetted). OPTIMOS will be the one-stop solution for all optical spectroscopy on the E-ELT including a sparse fiber bundle, multiple IFUs and a large IFU that can serve as a pseudo long-slit spectrograph. The E-ELT Science Working Group emphasizes the very strong science case of such an instrument, noting that JWST will have no capability in this domain. The science case includes two out of the three key science drivers for the E-ELT: (i) the resolved stellar populations in the Local Universe and (ii) the formation of the earliest galaxies and the end of the epoch of reionization. In addition, the science team (with NL members Groot, Kaper, Koopmans, Stam, and Tolstoy) has prepared science cases on galactic haloes at high redshift, lensed galaxies, IGM tomography, redshift surveys, transients, star formation, gaseous exoplanets, and trans-Neptunian objects.

The phase A study will consider two concepts: (i) a multi-slit concept led by Le Fevre (LAM Marseille) and Dalton (RAL Oxford) and (ii) a multi-fiber concept led by Hammer (GEPI Paris) and Kaper (NOVA, Amsterdam). The latter consortium merges the expertise of designing and constructing the multi-object spectrograph VLT/FLAMES (GIRAFFE, PI Hammer) and the highly efficient optical/near-IR spectrograph VLT/X-shooter (PIs included Kaper), the first 2nd generation VLT instrument with expected start of science operations in 2009. The NL contribution to the multi-fiber concept study of OPTIMOS will concentrate on overall project management and documentation, optical and mechanical design of the near-infrared spectrograph(s), cryogenics, thermal stability, and the science case.

3.7. Participation in space missions

3.7.1. JWST-MIRI

3.7.1.1. Summary

The Mid-Infrared Instrument (MIRI) is a combined imager and integral-field spectrometer with a spectrum resolution of R ~3000 covering 5-28 μm infrared wavelength range aboard the James Webb Space Telescope (JWST), the successor of HST to be launched late 2013. The Netherlands, led by NOVA, is responsible for the dispersion/camera optics of the spectrometer. With its unprecedented sensitivity and spatial resolution, MIRI will provide an immense discovery space and will have tremendous power for studying the mid-infrared sky. The main aims of the NOVA project are to

- design, build and deliver the Dutch part of the spectrometer to the European consortium according to specifications;
- ensure strong Dutch participation in the scientific exploitation of MIRI;
- maintain and develop mid-infrared scientific and technical expertise in the Netherlands.

With the main hardware delivered in mid-2008, the Dutch emphasis in NOVA Phase-3 is on analysis of ground-test and calibration data, development of data-reduction software, and preparation of in-flight calibration and commissioning plans.

3.7.1.2. Scientific interest in the Netherlands

Owing to the successes of IRAS and ISO, and more recently the Spitzer Space Telescope and VLT-VISIR, there is widespread interest and expertise in mid-infrared observations within the Dutch astronomical community, both in imaging and spectroscopy. This ranges from studies of cosmology and high-redshift galaxies (Franx, Röttgering, Miley, Spaans), active galactic nuclei (Barthel, Jaffe), starbursts (van der Werf, Brandl) and nearby galaxies (Israel) to observations of late-type stars (Tielens, Waters), the formation of massive (Kaper, de Koter, van der Tak, van Langevelde) and low-mass (Hogerheijde, van Dishoeck) young stars in our own Galaxy as

MIRI project budget in k€ Staff effort in fte	Level	Place	Total	2009	2010	2011	2012	2013
Instrument calibration scientist	12	SRON	4,00		1,00	1,00	1,00	1,00
Postdoc	11	UL	0,50	0,25	0,25			
Total staff effort in fte			4,50	0,25	1,25	1,00	1,00	1,00
Personnel Budget								
Instrument calibration scientist			310		78	78	78	78
Postdoc			33	17	17			
Sub-total Personnel in k€			343	17	94	78	78	78
Material Budget								
Contracts hardware			400	400				
Hardware post delivery support			205	125	30	20	20	10
Travel NL team			140	40	40	30	15	15
Postdoc test/calibration			41		41			
PhD student			61	22	22	17		
Sub-total Materials in k€			847	587	133	67	35	25
TOTAL costs MIRI in k€			1191	604	227	144	113	103
REVENUES			**Total**	**2009**	**2010**	**2011**	**2012**	**2013**
NOVA funding			443	17	134	108	93	93
NWO-G			850	850				
NOVA Phase-2 funding			-103	-263	93	37	20	10
TOTAL REVENUES in k€			1191	604	227	144	113	103

Table 3.7: Overview of the budget for the MIRI project for the period 2009-2013. The Netherlands already invested 9.5 M€ in their contribution to MIRI in NOVA Phase-1 and -2.

well as the proto-planetary disks surrounding them (Waters, van Dishoeck, Dominik, Kamp, Lahuis) to icy Solar System objects (Hogerheijde) and exoplanetary atmospheres (Waters). The project is led by van Dishoeck and Brandl.

3.7.1.3. International partners and collaborations

The MIRI instrument is designed and built by a joint US/European consortium. The scientific oversight occurs through the MIRI Science Team, led by G. Rieke and G. Wright, including Brandl as instrument scientist. On the U.S. side, JPL is the lead institute for MIRI, whereas Goddard has the prime responsibility for the integration of all instruments. JPL will procure and deliver the detectors with the associated electronics, software and testing. The European consortium is led by the UK (PI G. Wright), with Germany, France, The Netherlands, Belgium, Spain, Switzerland, Ireland, Denmark, and Sweden as partners. Europe will design and build the entire camera/spectrometer unit.

3.7.1.4. Science case

MIRI will make key contributions to science themes ranging from 'first light' in the Universe to the assembly of galaxies, the birth of stars and proto-planetary disks, and the evolution of exoplanetary systems and the organic material contained within them. Specific projects of interest to Dutch astronomers include:

The distant Universe: MIRI will be critical to identify the youngest objects in the Universe, including the first sources of light after recombination, and distinguish them from objects that have a longer history of star formation.

Obscured star formation and AGNs: MIRI is essential to observe the luminosity as well as diagnostic PAH features and fine-structure lines from starburst galaxies and obscured AGNs. Extreme starbursts in high redshift galaxies may be responsible for much of the stellar populations of present-day galaxies. Milder bursts may occur later in the evolution as a result of mergers, perhaps leading to the formation of AGNs. During these episodes, galaxies evolve rapidly in stellar and gas content, in spectrophotometric properties, in metallicity, in luminosity, and often also in morphology. Such starbursts are totally dust-enshrouded and emit most their energy in the mid-infrared, making MIRI key to their study. MIRI will also detect the important rest-frame 2 μm region (at z>2), which is dominated by an evolved stellar population with mean age >50-100 Myr that cannot be isolated at shorter wavelengths, but which would trace previous episodes of star formation.
Deeply-embedded protostars: MIRI, in combination with ALMA, will be particularly powerful to provide insight into the physical processes in the deeply-embedded protostellar phase when the star is still being assembled through accretion of material from the circumstellar disk and when fragmentation into binary or multiple systems can occur.
Evolution of proto-planetary disks and exoplanetary systems: MIRI will contribute hugely to our understanding of the processes by which disks turn into planets. Indeed, the first few Myr of disk evolution may well be responsible for the wide variety of observed exoplanetary systems, none of which resemble our own Solar System. Spatially resolved images with MIRI and ALMA down to ~10 AU or less will allow dust growth and settling, as well

as the relative settling of the dust versus the gas to be determined as a function of radius and thus the onset of planetesimal formation. Comparison of MIRI spectra of disks with each other and with spectra from Kuiper Belt objects and distant comets allow changes in mineralogy and the raw materials for life (water, hydrocarbons, PAHs) to be traced down to planet-forming zones. The main ingredient for building giant gaseous planets, H_2, can only be traced in the mid-IR.
Exoplanetary atmospheres: Exciting new Spitzer data of transiting giant planets show the potential of mid-IR data to probe exoplanetary atmospheric composition and processes. MIRI will likely be the only instrument capable of pushing these studies down to the (super)-Earth regime. The spatial resolution and sensitivity of MIRI will also allow direct detection of Jupiter-like giant planets in wide (> 5 AU) orbits around the nearest stars and characterization of their atmospheres.

3.7.1.5. Impact/context NL situation

The Dutch contribution to MIRI is led by NOVA (PI van Dishoeck; deputy-PI Brandl; PM Jager). The hardware has been built at ASTRON, with TNO as sub-contractor for the optical design, and SRON as consultant. Strong technical and scientific expertise has been contributed by NOVA astronomers Pel, Brandl, and de Graauw. The main benefits for Dutch astronomers are (i) ensuring that JWST-MIRI will have a proper spectrometer with the desired capabilities; (ii) obtaining a fraction of the JWST guaranteed time; (iii) gaining intimate knowledge of the instrument and its data reduction, essential as a head start for subsequent open-time proposals; (iv) maintaining unique mid-infrared technical expertise in the Netherlands and (v) providing an essential scientific complement to other Dutch projects in the same time frame, in particular ALMA, VLT/VLTI, Herschel, and the E-ELT. Participation in MIRI is also on the scientific and technology path necessary to achieve the next mid- or far-infrared space mission. The funding for this project is specified in Table 3.7. The NOVA Phase-2 funding includes 92 k€ remaining from the NWO-G grant.

3.7.1.6. Technical concept and requirements

The overall optical concept for MIRI is a functional split between the imager and spectrometer instruments. The medium resolution (R~3000) integral field spectrometer has a FOV of 3.7"x3.7" to 7.7"x7.7" with 0.2" to 0.65" slice width. The Dutch contribution is in the dispersion/camera optics of the spectrometer, with the UK providing the IFU's. The spectra from pairs of gratings are imaged by two cameras onto two 1Kx1K Si:As detector arrays. Full wavelength coverage is obtained in three settings of the gratings and corresponding dichroics. The MIRI spectrometer hardware has been delivered to RAL in the summer of 2008.

The NOVA Phase-3 program will fund one 4-yr scientist and a part-time postdoc to participate in the instrument tests in Europe (test procedures, execution, data analysis, calibration products, commissioning plans, calibration plans) and development of data reduction software (framework, data reduction algorithms, calibration and science analysis tools), with a focus on the IFU spectrometer. The scientist will be located at SRON-Groningen, to benefit from the SRON expertise on software development for the ISO and Herschel missions.

3.7.2. Gaia: a three-dimensional map of the Milky Way

3.7.2.1. Summary

Gaia is an ESA cornerstone mission scheduled for launch in 2012. Gaia will provide a stereoscopic census of our Galaxy through the measurement of high accuracy astrometry, radial velocities and multi-color photometry. Over the course of its five year mission it 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. Gaia 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 by means of low-resolution spectro-photometry at wavelengths between 330 and 1000 nm. 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 will achieve the complete all-sky survey to its limiting magnitude via real-time on board detection.

The main aims of the NOVA project are to
design, develop, and deliver the Dutch contribution to the European Gaia Data Processing and Analysis Consortium (DPAC);
ensure strong Dutch participation in the scientific exploitation of the Gaia catalogue;
develop and maintain in the Netherlands scientific and technical expertise with complex data processing systems for large astronomical surveys, in order to ensure a future Dutch role in such surveys.

3.7.2.2. Scientific interest in the Netherlands

There is a long tradition in the Netherlands of research into the structure and formation history of the Milky Way and other galaxies, and the investigations that can be undertaken with Gaia data fit in perfectly with this tradition. However the science case for Gaia is much broader as illustrated by the studies that will be carried out with the Gaia data: assembly history of the Milky Way (Helmi, Brown); the nature and distribution of dark matter (Helmi); the link between dwarf galaxies and the stellar content of the halos of giant galaxies in the local group (Tolstoy, Helmi, Trager); fundamental stellar parameters and binaries (Pols, Nelemans, Portegies Zwart, Levin, Trager); and the formation of stars, star clusters, and planets (Kaper, Brown, Portegies Zwart, Snellen).

3.7.2.3. International partners and collaborations

The Gaia spacecraft and scientific payload are built by the industrial company EADS-Astrium and the data processing will be undertaken by the scientific community in Europe which has organized itself into the Gaia DPAC. The data processing activities will be structured around nine 'coordination units' and six data processing centers. The Dutch contribution forms part of the photometric coordination unit, which is responsible for the design, development and operation of the photometric processing pipeline for DPAC. The partners in this coordination unit are groups in the UK, Spain, and Italy. Brown is member of the Gaia science team.

3.7.2.4. Science case

The primary scientific aim of the mission is to map the structure of the Galaxy and unravel its formation history. Current cosmological models envisage the formation of large galaxies through the merging of smaller structures.

Deciphering the assembly history of our Galaxy requires a detailed mapping of the structure, dynamics, chemical composition, and age distribution of its stellar populations.
Ideally one would like to 'tag' individual stars to each of the progenitor building blocks of the Galaxy. The Gaia mission is designed to provide the required fundamental data in the form of distances (through parallax), space velocities (through proper motions and radial velocities), and astrophysical characterization (through multi-color photometry) for massive numbers of stars throughout most of the Galaxy. Additional scientific products include fundamental stellar data across the Hertzsprung-Russell diagram, unique samples of variable stars of nearly all types (including key cosmological distance calibrators), detection and orbital classification of tens of thousands of extra-solar planetary systems, a comprehensive survey of objects ranging from huge numbers of minor bodies in our Solar System, through galaxies in the nearby Universe, to some 500,000 distant quasars. Gaia will also provide a number of stringent tests of general relativity.

3.7.2.5. Impact/context NL situation

The Dutch contribution to DPAC is led by NOVA (PI Brown) and the project is carried out by groups

Gaia project budget in k€								
Staff effort	**Level**	**Univ**	**Total**	**2009**	**2010**	**2011**	**2012**	**2013**
Postdoc 1 (software design)	11	UL	**3,75**	1,00	1,00	1,00	0,75	
Postdoc 2 (software design)	11	UL	**2,08**	1,00	1,00	0,08		
Total staff effort (in fte)			**5,83**	**2,00**	**2,00**	**1,08**	**0,75**	**0,00**
Personnel Budget								
Postdoc 1 (software design) *			**250**	67	67	67	50	
Postdoc 2 (software design)			**139**	67	67	6	0	
Sub-total Personnel (in k€)			**389**	**133**	**133**	**72**	**50**	**0**
Material Budget								
Travel NL team			**35**	15	10	10		
Sub-total Materials (in k€)			**35**	**15**	**10**	**10**	**0**	**0**
TOTAL costs Gaia (in k€)			**424**	**148**	**143**	**82**	**50**	**0**
REVENUES			**Total**	**2009**	**2010**	**2011**	**2012**	**2013**
NOVA funding			**424**	148	143	82	50	0
TOTAL REVENUES			**424**	**148**	**143**	**82**	**50**	**0**

Table 3.8: Overview of the budget for the Gaia project. Postdoc 1 started on 1 April 2008. Staff costs in that year amounting to 39 k€ were funded from the Phase-2 budget.

in Leiden (photometric instrument algorithms) and Groningen (ground-based preparations). The main benefits for Dutch astronomers are (1) the detailed knowledge of the scientific instruments and the data delivered by Gaia will provide significant advantages in the science exploitation of the final Gaia catalogue and any intermediate data releases, both in terms of time and quality; (2) expertise will be built up regarding the setting up of a very large and complex data processing system, including the development of a complex calibration pipeline. This expertise can be transferred to other large ground or space-based observing programs or facilities in which the Netherlands is involved; and (3) experience with a complex and highly demanding astronomical survey mission employing a large focal plane detector array can be exploited to ensure a prominent Dutch role in technically similar future space missions such as EUCLID and PLATO. Table 3.8 provides an overview for the allocated NOVA funding.

3.7.2.6. Technical concept and requirements

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. Both prisms have appropriate broad-band filters for blocking unwanted light. The dispersion of the prisms ranges from 3 to 29 nm/pixel for BP and from 7 to 15 nm/pixel for RP. These simultaneous photometric measurements of the spectral energy distribution yield key astrophysical information, such as temperatures, gravities, metallicities, and reddenings, for each of the vast number of stars observed. As illustrated in Fig. 3.2 the raw data from the photometric instrument will consist of dispersed images from which the low resolution spectra are to be extracted. NOVA is responsible for developing the definition, design, validation, and provision of a complete software package for the processing of the dispersed images. The main challenges are the treatment of the effects of radiation damage to Gaia's detectors, the disentangling of overlapping images in crowded fields, and the calibration of the point spread function.

3.8. LOFAR for Astronomy

3.8.1. Summary

LOFAR, the Low Frequency Array, is a next-generation radio telescope presently being constructed in the Netherlands. It will operate at frequencies from 15 to 240 MHz (corresponding to wavelengths from 20 to 1.2 m). Its superb sensitivity, high angular resolution, large field of view and flexible spectroscopic capabilities will be a dramatic improvement over previous facilities at these wavelengths. As such, LOFAR will carry out a broad range of fundamental astrophysical studies.

The main aim of the NOVA project the 'Development and Commissioning of LOFAR for Astronomy (DCLA)' consists of the development of essential software capabilities and commissioning tasks to enable the four key astronomical projects to accomplish their goals and at the same time the provision of a first version of general LOFAR user software.

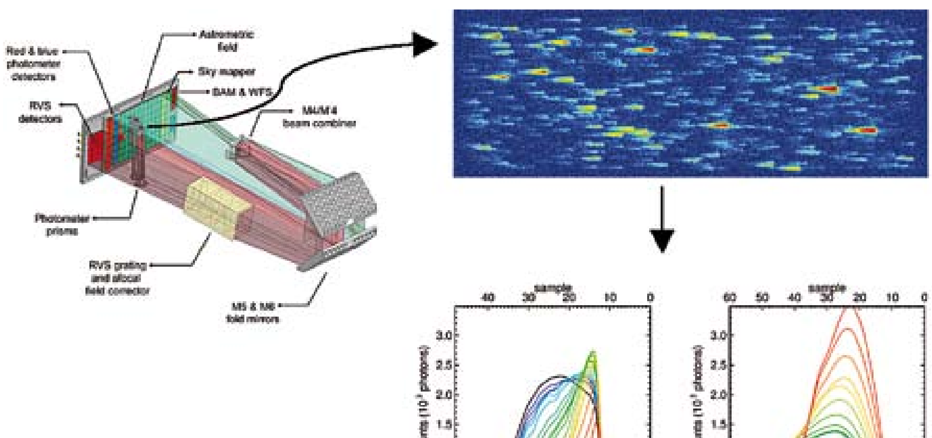

Fig. 3.2: The aim of this NOVA project is to develop data processing algorithms that take the raw dispersed images (top right) as measured with Gaia's photometric instrument (left) and extract the BP and RP prism spectra (bottom right) from which the astrophysical parameters of stars observed by Gaia will be derived. The BP/RP spectra are shown for main sequence stars from 0V (black) to M5V (red). Credit: EADS-Astrium and A. Brown.

3.8.2. Scientific interest in the Netherlands

The science potential of LOFAR is an excellent match to the expertise and scientific interests of a large fraction of the Dutch astronomical community. The University of Groningen has long been the world leader in the field of radio spectroscopy and is leading LOFAR studies of the Epoch of Reionization (de Bruyn (PI), Koopmans, Zaroubi). At Leiden University astronomers have successfully conducted radio surveys with the WSRT for more than three decades, and pursued numerous follow-up programs to study galaxy and cluster evolution. The LOFAR survey project is led by Röttgering (PI), Miley, and Snellen, together with Barthel (Groningen) and Morganti (ASTRON). The University of Amsterdam hosts top research groups in (transient) gamma-ray bursts and pulsars, has successfully exploited the Pulsar Machine-2 (PuMa-2) on the WSRT, and is now in charge of the LOFAR Transient Key Project (Wijers (PI), Fender, Stappers). The group at the Radboud University in Nijmegen has extensive expertise in plasma astrophysics and coherent emission processes. It is now leading the study of high energetic cosmic rays with LOFAR (Hörandel (PI), Falcke, Kuijpers). The NOVA project is led by Röttgering and managed by Wise.

3.8.3. International partners and collaborations

Although LOFAR initially started as a Dutch project, it has now become an international project. In all the four original Dutch key projects, there are in total more than 80 foreign-based astronomers involved. Two new international key projects have been set up, one related to magnetism (PI Zensus, MPIfR, Bonn, Germany) in the Universe and one to solar studies (PI Mann, AIP, Potsdam, Germany). Further LOFAR stations on a European scale are currently being pursued by a number of European countries, including Germany, UK, Sweden, Poland, France, Austria and Italy and it is expected that in addition to the 36 stations distributed over the Netherlands at least 8 European stations will be operational in 2010.

3.8.4. Science case

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 drivers are

- *Epoch of reionization*: One of the most exciting applications of LOFAR will be the study of the as yet unobserved epoch in the history of the Universe when the bulk of the gas in the Universe made the transition from neutral to ionized. Key questions that LOFAR will address include (i) what is the redshift and spatial distribution of heated and still cold gas during that epoch, and (ii) what is the nature of the first objects heating and ionizing the cold gas?
- *Deep extragalactic surveys*: Deep LOFAR surveys will provide unique catalogues of radio sources for investigating several fundamental questions in astrophysics, including the formation of massive black holes, galaxies, and clusters of galaxies. Because the LOFAR surveys will probe unexplored parameter space, it is likely that new phenomena will be discovered.
- *Transient Sources*: LOFAR's large instantaneous beam will make it uniquely suited to efficiently monitor a large fraction of the sky, allowing sensitive unbiased surveys of many classes of radio sources, including gamma-ray bursts, Galactic black-hole/neutron-star systems, and exoplanets.
- *Cosmic Rays*: LOFAR has the capacity to measure the composition and energy of high-energy cosmic rays at energies between 10^{15} - $10^{20.5}$ eV. Together with its high directional accuracy, LOFAR studies will be very important for our understanding of both the source origin and the acceleration processes of these particles.

3.8.5. Impact/context NL situation

LOFAR will fulfill an important strategic function in Dutch astronomy. First, as a largely Dutch telescope of world-class, LOFAR will be a search engine for several international mega-facilities (like Fermi, OmegaCAM and ALMA) in which the Netherlands is only a financially minor (<5%) partner. Second, LOFAR will exploit the technical expertise in radio astronomy that the Netherlands has built up during the past half a century and provide a visible platform for securing a prominent role in the next international large radio facility, the Square Kilometer Array (SKA). Third, as a world-class astronomical facility in the Netherlands, LOFAR will provide astronomy with a unique tool for education, outreach and political visibility.

3.8.6. Technical concept and requirements

LOFAR's revolutionary design makes use of phased array technology that gives the critical advantage of delivering an affordable telescope with the needed large effective aperture. LOFAR will have low frequency antennas optimized for the 30 - 80 MHz range and high frequency antennas which have their maximum sensitivity between 115 and 240 MHz. These antennas are grouped together in 'stations'. The electric signals from the antennas are digitized and appropriate delays applied so that station beams on the sky can be formed. In the standard observing mode up to 8 beams are available simultaneously. 36 stations will be spread in and around the province of Drenthe, with maximum baselines of 100 km and will have a 10 Gb/s connection to the IBM Blue/Gene supercomputer, named Stella, in Groningen. The ten additional European stations will have distances of up to 700 km from the LOFAR core, increasing the angular resolution by almost an order of magnitude.

The design and construction of LOFAR, as a general sensor array, is funded from the national Dutch BSIK subsidy (M€ 52), the contribution (M€ 22) of the three Northern Dutch provinces through SNN (Samenwerkingsverband Noord Nederland), from in-kind contributions of ASTRON, and from investments of partners with an interest outside astronomy. The project entitled the Development and Commissioning of LOFAR for Astronomy (DCLA) was subsequently initiated to enable LOFAR to perform its astronomical science. The DCLA project consists of two main elements.

1. Commissioning and Optimization: Every new large facility undergoes a commissioning process in which the facility is optimized for the intended scientific goals. This requires close interaction between scientists and engineers over a prolonged period. LOFAR commissioning will be particularly important and time-consuming because of (i) the novel calibration procedures, (ii) the high dynamic range needed to attain some of the scientific goals, and (iii) the large range of required exposure times, ranging from nanoseconds for cosmic rays to months for the EOR observations. Basic questions that will need to be addressed concern the acceptable and optimal observing conditions for achieving each of the astronomical goals.

2. Enabling LOFAR for Astronomy: Enabling LOFAR to carry out each of the four key projects requires a set of capabilities to be developed. They include the development of observing modes and procedures, detection algorithms, and software pipelines.
For the EOR project, the main challenge is to produce a software pipeline that is capable of producing high dynamic range maps out of a Petabyte of data. For the transient project, a software system is needed that is capable of detecting and characterizing transient radio sources from a large data stream of images and UV data. The goal of the survey project is to create an extensive catalogue of up to 10^8 sources at a range of frequencies. Also for this extensive software tools need to be developed. The cosmic rays need to be detected by cross correlating data from nano-second sampled time series taken at the antenna level. For this a pipeline is needed capable of detecting, cataloguing, and characterizing the cosmic rays.

3.8.7. NOVA budget

During the years 2009-2011 NOVA will fund 23.6 staff years of postdocs and computer programmers spread over the four key LOFAR projects. Total NOVA funding amounts to 1773 k€ including travel funds and the carry over from the remaining Phase-2 project funds and commitments.

3.9. Miscellaneous projects

3.9.1. AMUSE

3.9.1.1. Summary

The aim of the AMUSE (Astrophysical MUltipurpose Software Environment) project is to develop a multipurpose software environment for astrophysical applications in which different existing numerical codes will be incorporated into a single framework. This component library will provide easy access to individual packages and allow scientists to use combinations of codes to solve coupled problems (such as hydrodynamics and radiative transfer or stellar evolution and stellar dynamics) without the need to write new codes or significantly alter existing codes. The generic, homogeneous library that provides this interface will be developed and made publicly available. In order to test the robustness of the framework and the scientific results (at least) two methodologies for each domain will be supported. Initial development will be for four domains, which include: stellar dynamics, stellar evolution, hydrodynamics, and radiative processes. Experts in each of these techniques are involved in the development and software engineers will be hired to develop a professional, robust, flexible, and easy to use instrument.

3.9.1.2. Scientific interest in the Netherlands

The proposed project will play an important role in focusing theoretical and computational astrophysics in the Netherlands. Researchers from all universities with an astrophysics curriculum collaborate: Portegies Zwart (PI), Groot, Icke, Kaper, Levin, Nelemans, Pols, Spaans, Tolstoy, and van den Weijgaert.

The development of the framework requires regular communication between the parties, and collaboration on a large scale. However, in applying the framework to large-scale astrophysical simulations researchers can maintain their own individual projects without having to share resources or being forced to collaborate on individual projects. Although large-scale collaboration will be encouraged, it is not required for making this project a success. A virtual organization of Dutch computational astrophysics is of crucial importance for the future of theoretical and computational astrophysics in the Netherlands.

The unique diversity of computer languages and numerical techniques within the framework enables astronomers and apprentices to actively participate in research with AMUSE without having to ascend the steep learning curve of other large software projects. The diversity of the proposed framework therefore also provides an excellent backbone for teaching computational astrophysics at the MSc level.

3.9.1.3. **International partners and collaborations**

The PI and co-PIs participate actively in an international network of numerically oriented astronomers. They are members of larger collaborations like the starlab team (see http://sns.ias.edu/starlab.html), the MODEST consortium (see http://manybody.org), and MUSE (see http://muse.li). These endeavors are world-wide, which is also reflected in the list of foreign experts with a direct interest and advisory role in this project. It is envisioned to couple the instrument to the Meta Institute for Computational Astrophysics (MICA, http://www.physics.drexel.edu/mica/index.php/Main_Page).

The excellent national computer facilities and advanced grid infrastructure, developed as part of the DAS-3 project in which the UvA, VU, TU Delft, and Leiden University collaborate, are unique in the world. The DAS-3 is a novel wide-area cluster computer across the Netherlands with light paths between sites providing extremely high-speed networking. Other computer resources are provided by the collaboration between Amsterdam, RIT, and Heidelberg.

3.9.1.4. **Science case**

The Universe is a multi-physics environment, in which Newton's laws, radiative processes, nuclear reactions, and hydrodynamical effects interact mutually. Generally astrophysical problems span many orders of magnitude in time scales and length scales involved. For example in the Galaxy the smallest scales, of the order of 10^4 meter and 10^{-10} year are coupled to the largest scales of the order of the system's size (10^{20} m) and age 10^{10} year). Small isolated environments within the Galaxy, like planetary disks or close binary stars, also involve a broad range of physical phenomena. The combination of a multi-physics and multi-scale environment guarantees a fabulous challenge for modern science. While observational astronomy fills important gaps in our knowledge by harvesting ever-wider spectral coverage with continuously increasing resolution and sensitivity, our theoretical understanding lags behind dramatically and continues to lose distance.

Computational astronomy is situated between observations and theory. The calculations generally cover a wider range of physical phenomena, whereas purely theoretical studies are often tailored to a relatively limited range of spectral coverage. On the other hand, extensive calculations can support observational astronomy by mimicking observations, interpretation, and by studying parameter spaces. They can elucidate complex consequences of physical theories. But extensive computer simulations in order to deepen our knowledge of the physics require large programming efforts and a good fundamental understanding of the underlying physics.

3.9.1.5. **Impact/context NL situation**

The proposed framework is unique for computational astrophysics in the Netherlands. The efforts are led by Portegies Zwart (PI) with co-investigators Groot, Icke, Kaper, Levin, Nelemans, Pols, Spaans, Tolstoy, and van den Weijgaert, which makes this a general effort of theoretical and numerical astronomy in the Netherlands.

AMUSE will fulfill an important strategic function in Dutch computational astrophysics, as expertise from all the astronomy departments in the Netherlands will be used. A successful framework will also open up new roads to larger and more complicated software developments. AMUSE will provide computer scientists and astrophysicists with a unique environment for education and further research. The expertise that we will build is unique and can bring the Netherlands computational astrophysics internationally to the forefront. The budget for the AMUSE project is summarized in Table 3.9.

3.9.1.6. **Technical concept and requirements**

AMUSE's revolutionary design makes use of a high level scripting language (Python) to realize the communication between the application domains, which are written in low-level compiled languages. The technical innovation mainly comes from the development of a general purpose interface between astronomical (and other) domain-specific applications.

Other technical challenges lay in the organization

AMUSE: budget 2009 - 2013 Costs in k€								
Staff effort	Level	Univ	Total	2009	2010	2011	2012	2013
Technical postdoc	11	UvA	**2,00**	0,67	1,00	0,33		
Software engineer	11	UvA	**2,00**	0,67	1,00	0,33		
Programmer(s)	10	UvA	**4,00**		2,00	2,00		
Total staff effort			8,00	1,33	4,00	2,67	0,00	0,00
Personnel Budget								
Technical postdoc			**133**	44	67	22		
Software engineer			**133**	44	67	22		
Programmer(s)			**229**	0	115	115		
Sub-total Personnel			496	89	248	159	0	0
Material Budget								
Bench and travel			**20**	3	10	7		
Materials			**10**		5	5		
Sub-total Materials			30	3	15	12	0	0
TOTAL costs			526	92	263	171	0	0
REVENUES			**Total**	**2009**	**2010**	**2011**	**2012**	**2013**
NOVA funding			**526**	92	263	171		
TOTAL REVENUES			526	92	263	171	0	0

Table 3.9: Overview of the budget for the AMUSE project.

of the numerical framework, the embedding within a grid environment and the use of special-purpose hardware in combination with machine-specific applications. The unit conversions between modules and the generalization of input and output will require an innovative and flexible approach to the framework, but by no means poses a technical challenge. The most technically challenging aspect is related to the inter-module communication of large data sets. The transfer of large volumes of data cannot be done efficiently through the top Python layer, but such information has in some way to tunnel from one domain to another. At this point we have no ready solution for this, but we emphasize that this only becomes important if we perform simulations of astrophysical systems where the specific domains are not well separated.

3.9.2. S^5T: Small Synoptic Second Solar Spectrum Telescope

3.9.2.1. Summary

The Small Synoptic Second Solar Spectrum Telescope (S^5T) will study the temporal variation of the weak turbulent magnetic field that covers the entire solar surface but is invisible to traditional magnetic field measuring instruments. While this turbulent field is weak compared to magnetic fields in sunspots, the total magnetic flux emerging through the solar surface in the turbulent field is orders of magnitude larger than the amount of flux emerging in sunspots, even at the peak of the solar activity cycle. Understanding the origin and dynamics of this turbulent field and its interaction with the sunspot cycle is not only important to solve the enigma of the 11-year solar cycle and the variations of the Sun's energy output that ultimately affect life on Earth, but it is also crucial for our understanding of magneto-hydrodynamic turbulence in an astrophysical plasma with applications to much larger scales, such as the galactic magnetic field whose origin has also not yet been established.

By measuring the linear polarization parallel and close to the solar limb as a function of wavelength, the properties of the weak, turbulent field can be deduced via the Hanle effect, even without spatially resolving the characteristic length scales of this field. Daily measurements with high sensitivity and accuracy with the same instrument during at least one solar cycle (11 years) in combination with advanced radiative MHD numerical simulations will reveal the nature of the ubiquitous weak magnetic field and its relation to the strong fields observed with traditional methods.

The key component of the S^5T is the theta cell, which converts linear polarization with an azimuthal (or radial) symmetry in the focal plane into a uniform linear polarization pattern, which in turn can be analyzed by a regular polarimeter. This allows for a 'one-shot' observation of the entire solar limb polarization by channeling all the relevant light through the theta cell, the precision polarimeter, and finally into a fiber- (bundle-) fed spectrometer, which integrates the signal from the entire limb into a single spectrum. Therefore there is no need for a large-aperture telescope to achieve the required signal-to-noise ratio for highly sensitive spectro-polarimetry. A variety of calibration routines ensure the required polarimetric accuracy and stability.

3.9.2.2. Scientific interest in the Netherlands

The S^5T will study a basic astrophysical process, the generation of magnetic fields by the turbulent motion of a plasma. In the case of the Sun, convection drives the plasma motions. Because of the small scale of the S^5T project, the full instrument development will occur within the Netherlands. Design,

S^{5}T project budget in k€ Staff effort	Level	Univ	Total	2009	2010	2011	2012	2013
Technical PhD student	PhD	UU	3,17	1,00	1,00	1,00	0,17	
Total staff effort			3,17	1,00	1,00	1,00	0,17	0,00
Personnel Budget								
Technical PhD student			159	50	50	50	8	
Sub-total Personnel			159	50	50	50	8	0
Material Budget								
Procurement materials and tools			100	100				
Engineering and construction (at UU-IGF)			60	40	20			
Extra travel: visits Kitt Peak Observatory			20	5	5	5	5	
Sub-total Materials			180	145	25	5	5	0
TOTAL costs			339	195	75	55	13	0
REVENUES			Total	2009	2010	2011	2012	2013
NOVA funding			339	195	75	55	13	0
TOTAL REVENUES			339	195	75	55	13	0

Table 3.10: Overview of the budget allocation for the S^{5}T project. The PhD student started on 1 March 2008. Her staff costs in that year amounting to 40 k€ were funded from the Phase-2 budget. Utrecht University agreed to contribute an additional 60 k€ to the material budget.

construction, assembly and testing will take place at the Sterrekundig Instituut Utrecht. The S^{5}T is scientifically supported by the institutes in Utrecht (Keller (PI), Vögler, Achterberg) and Amsterdam (Spruit) and technically by Utrecht University and the NOVA-ASTRON Optical Instrumentation Group.

3.9.2.3. International partners and collaborations

The instrument will be commissioned at the existing SOLIS synoptic facility at Kitt Peak, Arizona, USA, and will be operated there for at least ten years by the US National Solar Observatory (NSO). Harvey at NSO is a Co-I. Institutes around the world have expressed their interest in the project and scientists working on turbulent magnetic fields and polarized-light generation are eagerly awaiting the first data.

3.9.2.4. Science case

Polarimetric observations of the Sun during the last few decades provided a large amount of information about the nature of solar magnetism. The Zeeman effect in suitable spectral lines is the primary workhorse to derive the magnitude and the direction of the average magnetic flux within a given spatial resolution element on the Sun. Yet, as the longitudinal Zeeman effect is linear in average magnetic field strength, it is virtually blind to weak magnetic fields, particularly to those with a turbulent (mixed-polarity) topology within the spatial resolution element. Therefore, we have to resort to other polarization effects in the solar atmosphere to diagnose the weak magnetic field, which is expected to be ubiquitous on the Sun. Next to the transverse Zeeman effect, the other main process to linearly polarize a spectral line is by coherent large-angle scattering. Such scattering polarization is observed near the limb of the Sun. The scattering polarization can be (partly) destroyed by magnetic fields. This effect is called the Hanle effect and constitutes a sensitive diagnostic for weak magnetic fields. Moreover, the Hanle depolarization only depends on the absolute vertical magnetic field strength and therefore the Hanle effect can also diagnose fields with opposite polarities within a resolution element.

The linearly-polarized spectrum observed several arcseconds inside the limb of the Sun in regions free of strong magnetic fields is called the Second Solar Spectrum, because of the lack of similarity with the intensity spectrum. This by itself implies that a large amount of information about physical processes in the solar atmosphere is hidden in this Second Solar Spectrum. It is a challenge to extract and disentangle all this information, even more so because of the small degrees of polarization which are observed in the Second Solar spectrum: from 1% down to 10^{-4} of the intensity.

The following science questions will be addressed by the S^{5}T:

- What is the origin of the weak, turbulent magnetic field in the solar photosphere: the global dynamo or local dynamo action by the granulation?
- What is the magnetic flux budget of the Sun and how does it change in time?
- How and where are different spectral lines formed?

3.9.2.5. Technical concept and requirements

The goal of the S^{5}T is to deliver daily observations of the Second Solar Spectrum from 420-465 nm, with a polarimetric sensitivity of 10^{-5} and a polarimetric stability of 1%, for more than 10 years. A compact instrument design is obtained by the use of a theta cell. This allows for integration over the entire solar limb, thereby reducing the need for a large aperture to yield the large photon flux required for precision spectro-polarimetry. The S^{5}T telescope with its 5 cm objective lens is fully optimized for its polarization properties and feeds the polarimeter, which is

Figure 3.3: The S[5]T prototype operated at the IRSOL facility in Locarno, Switzerland by PhD student Helena Becher.

based on a rapidly switching liquid crystal retarder. After the polarimetric analysis, the light is fed into a spectrometer by means of a fiber bundle. The 8192x96 pixel line scan camera at the focal plane of the spectrograph can be operated with full binning in the spatial direction, which integrates the signal from the entire limb into a single spectrum. Calibration procedures guarantee the long-term stability of the instrument.

3.9.3. MATRI²CES

3.9.3.1. Summary

MATRI²CES – Mass Analytical Tool of Reactions in Interstellar ICES – is a setup that will be constructed at the Sackler Laboratory for Astrophysics at Leiden Observatory with the aim to characterize reaction schemes in inter- and circumstellar ice analogues. The new setup will be capable of studying laser-desorbed ice particles mass selectively in an interaction-free environment by combining proton transfer mass spectrometry and time-of-flight detection. MATRI²CES will be worldwide unique and is expected to exceed the sensitivity of regular techniques – RAIRS and TPD - by several orders of magnitude. The setup will offer the possibility to study reaction products in situ and on line under conditions as typical for inter- and circumstellar matter (ICSM) yielding rate constants that put a quantitative basis to interstellar surface chemistry. The latter is necessary to interpret observational data and will link gas-phase and solid-state astrochemical processes. The focus of MATRI²CES will be on the solid-state astrochemical formation of complex molecules in space.

3.9.3.2. Scientific interest in the Netherlands

The results obtained with MATRI²CES are important to interpret Dutch observational programs and ongoing research within the Netherlands on complex molecules in space (Cazaux, Cuppen, Dominik, Helmich, Hogerheijde, Kamp, Spaans, van der Tak, Tielens, van Dishoeck, Waters). In particular, a large fraction of the Herschel-HIFI guaranteed time program is devoted to spectral surveys of young stellar objects, whose spectra are expected to be full of lines of complex organic molecules. Complementary ground-based programs on submillimeter telescopes like JCMT and IRAM 30-m are already in progress. Such surveys form the basis for future ALMA line surveys of these regions in which the Netherlands are heavily involved. Currently, interpretation of these data is limited to providing an inventory of species in different regions. The more fundamental questions of how these molecules are formed, why they are seen only under specific conditions, and what the limits to molecular complexity are can only be addressed if complementary laboratory data become available. The project is led by Linnartz.

3.9.3.3. International partners and collaborations

Interstellar ices are currently a hot topic. There is much interest in quantitative results from observers, modelers and laboratory astrophysicists/chemists. The Sackler Laboratory for Astrophysics is member of an EU network application LASSIE (Laboratory Astrophysics Surface Science In Europe) in which all leading European laboratory groups are involved. Good contacts exist towards the groups of McCoustra (Heriot-Watt University, UK), Price (UCL, UK), Lemaire (Paris Observatory, F), Palumbo (Catania Observatory, I), Hornekaer (Aarhus, DK), Henning (MPIA Heidelberg, D), and Fraser (Strathclyde University, UK) which is reflected in active collaborations and common projects. The research in the laboratory is strongly guided by the need of observers and modelers, which includes the HIFI guaranteed time consortium (in particular Tielens, Ceccarelli, Schilke), Herbst (Ohio, USA) and infrared observers (Pontoppidan, Boogert, Blake at Caltech, USA), in addition to Dutch observers.

3.9.3.4. Science case

The availability of laboratory data on fundamental properties of atomic and molecular processes is one of the basic pillars on which modern astrochemistry is built. In the last decades the focus has been on gas-phase processes and a large variety of complementary spectroscopic and dynamical studies has been reported. In recent years, following astronomical observations (e.g. ISO and Spitzer), laboratory studies and astrochemical models, it has become clear that icy dust grains play a key role in the formation of more complex molecules. A typical reaction scheme starting from hydrogenation reactions in CO ice, originally proposed by Tielens, is shown in Fig. 3.4.

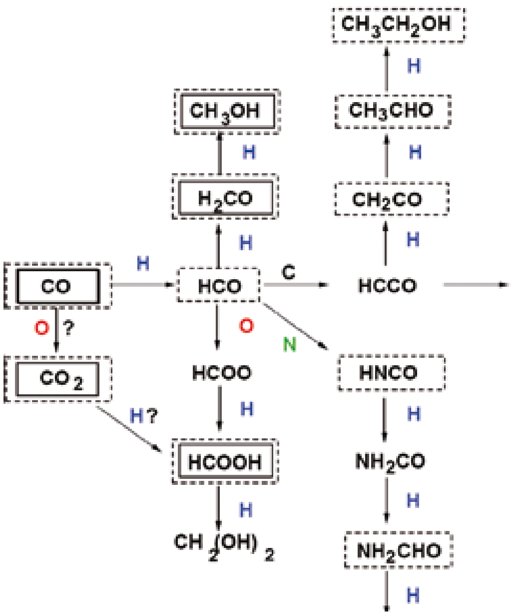

Figure 3.4: A typical reaction scheme starting from hydrogenation reactions in CO ice.

The goal of MATRI²CES is to quantitatively characterize such reaction schemes in full dependence of relevant parameters, such as temperature, ice composition and morphology, UV irradiation and/or atom-bombardment. For this, ices are grown under fully controlled laboratory conditions and subsequently processed by UV light and/or atom beams. A special ablation scheme is used to bring ice particles into the gas phase, which are monitored by a state-of-the-art time-of-flight detection scheme. The setup allows an *in situ* and online detection of molecules produced in the ice and with a sensitivity that is known to be very high.

As the measurements are performed time-dependent it will be possible to derive reaction rates for specific reaction channels and moreover to determine formation ratios. Implementation of these results in a matrix of physical dependencies (temperature, flux, mixing ratios, etc.) and combining the outcome with, for example, Monte Carlo simulations extends the conclusions far beyond typical laboratory timescales and allows a resolution of chemical processes in space, in which both gas-phase and solid-state astrochemical processes are involved.

3.9.3.5. Impact/context NL situation

MATRI²CES will be constructed in the Sackler Laboratory for Astrophysics (PI Linnartz) with help of the local instrument machine shop, which has considerable experience in constructing ultra-high vacuum setups. Scientific-technical expertise is furthermore provided within ongoing collaborations with the Laser Centre at the Free University in Amsterdam and the FOM Institute for Plasma Physics in Nieuwegein. The main return to the Dutch community is the ability to analyze and interpret data from a variety of high-profile new observational facilities in much more depth than possible otherwise. Several collaborations within NOVA Network-2 exist to realize this goal. The NOVA funding for MATRI²CES is summarized in Table 3.11. Additional funding is secured from various resources including Leiden Observatory.

3.9.3.6. Technical concept and requirements

The central unit of MATRI²CES is an ultra-high vacuum chamber in which ices are grown with mono-layer precision and thermal processing, photo-processing and atom bombardment are used to initiate reactions. At this stage the ice is monitored spectroscopically using a Fourier-transform infrared spectrometer. A pulsed laser is used for soft ablation of the ice and to lift ice molecules (both precursors and reaction products, including radicals) into the gas phase. These molecules are picked up by a pulsed molecular-beam expansion that is generated by expanding helium through a special piezo valve in a separately pumped beam chamber. The seeded beam enters the ionization chamber in which the ice molecules are ionized either by regular electron impact ionization or by proton transfer reactions. Electrostatic optics is used to guide the ions into the detection chamber which consists of a commercial time-of-flight mass system. A special trigger scheme is used for time gated detection.

3.10. Seed funding projects

The NOVA instrumentation program also includes a funding line to explore new opportunities that might develop towards 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 to one of the astronomical institutes participating in NOVA.

MATRI²CES project budget in k€								
Staff effort	**Level**	**Univ**	**Total**	**2009**	**2010**	**2011**	**2012**	**2013**
PhD student started in Phase-2	PhD	UL	**1,00**	0,60	0,40			
PhD student	PhD	UL	**2,40**	0,60	0,60	0,60	0,60	
Postdoc	PD	UL	**0,60**		0,60			
Technician	8	UL	**1,25**	0,25	0,25	0,25	0,25	0,25
Total staff effort (in fte)			**5,25**	**1,45**	**1,85**	**0,85**	**0,85**	**0,25**
Personnel Budget								
PhD student started in Phase-2			**45**	27	18			
PhD student			**121**	30	30	30	30	
Postdoc			**47**		47			
Technician			**45**	9	9	9	9	9
Sub-total Personnel			**258**	**66**	**104**	**39**	**39**	**9**
Material Budget								
Equipment			**180**	75	75	25	5	
Software tools			**15**	5	5	5		
Materials			**5**	5				
Sub-total Materials			**200**	**85**	**80**	**30**	**5**	**0**
Total costs			**458**	**151**	**184**	**69**	**44**	**9**
REVENUES			**Total**	**2009**	**2010**	**2011**	**2012**	**2013**
NOVA Phase-3 funding			**408**	101	184	69	44	9
NOVA Phase-2 funding			**50**	50				
TOTAL REVENUES			**458**	**151**	**184**	**69**	**44**	**9**

Table 3.11: Overview of the budget allocation for the MATRI²CES project.

One seed funding project is already approved. It is described below. It addition the seed 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).

3.10.1 Auger-Radio

3.10.1.1. Summary

The nature and origin of ultra-high energy cosmic rays (UHECRs) is one of the burning questions in high-energy astrophysics today. What are the physical processes that accelerate atomic nuclei beyond energies of 10^{19} eV, many orders of magnitudes above the best accelerators at CERN and how are they related to the known sources commonly studied in radio, X-ray and gamma-ray emission? This can finally be addressed by the Pierre Auger Observatory (PAO) collaboration. The PAO covers an unprecedented effective area of 3000 km^2 and has achieved a major breakthrough recently in showing that UHECR are in fact extragalactic, pointing back to their sources at the very highest energies. A new technique, using digital low-frequency radio antennas, has the potential to extend Auger even further and to determine the nature of these particles (e.g. distinguish between protons, iron nuclei, photons, and neutrinos). The seed funding amounting to 100 k€ will be used to develop a first prototype of a smart, low-power antenna that can be mass-produced and installed in the Auger observatory over a large area.

3.10.1.2. Scientific interest in the Netherlands

Astroparticle physics is a newly emerging field combining the questions and skills of astronomer and particle physicists alike. The astronomy community is currently building the LOFAR radio telescope which is also able to measure UHECRs. At the same time particle physicists and astronomers in the Netherlands jointly participated in the PAO project, which has just become operational and is the leading UHECR observatory in the world. Through LOFAR the radio technique for detecting UHECR has been pioneered by NL researchers led by Falcke (see also § 3.8) who have now taken the lead to establish this technique at the AUGER site as well. In addition the project allows cross-calibration between the Auger observatory and the LOFAR UHECR experiment. Hence, the proposed project will maximize the science output of both projects, foster synergies between astronomers and particle physicists, and maintain the leading positing of Dutch researchers in this area of research.

3.10.1.3. International partners and collaborations

The overall project is a collaboration between astronomers at the universities of Nijmegen, Groningen, Amsterdam, and Utrecht, the NWO institute ASTRON, and particle physicists at the universities of Groningen and Nijmegen and the NWO/ FOM institute NIKHEF (Nijmegen/ Amsterdam), as well as members of the Auger collaboration. The NOVA contribution will be matched by a FOM-funded postdoc position at the Radboud University of Nijmegen. The project team is part of the international Pierre Auger collaboration and the radio project is one of the three enhancement projects for the southern site of the PAO agreed upon by the collaboration board of the Auger Observatory. The Nijmegen group is also leading the LOFAR cosmic ray key science project and the LOPES experiment. The LOPES experiment is collaboration with the KASCADE Grande collaboration at the Forschungszentrum Karlsruhe, Germany, which has a major involvement in PAO as well.

3.10.1.4. Science case

Although Hess detected the existence of cosmic rays already in 1912, and while 50 years later the first hit with energy of 10^{20} eV was recorded, the very origin of cosmic rays at the highest energies and their nature remains unclear. Compact objects in the cosmos, which have an extreme energy density, are believed to be one of the possible sources for production and acceleration of UHE cosmic rays. Several initiatives worldwide to study cosmic rays at the highest energies, far beyond the energy available at any human-made accelerator, are presently in operation or under construction. These initiatives bring together various well-known detection techniques and theoretical efforts. To understand the nature of the cosmic rays one must determine their energy spectrum, their composition (e.g. being a neutrino, lepton or hadron, the mass and the charge), and their initial direction or celestial anisotropy. In the case of cosmic rays at energies beyond 10^{19} eV, the deflection of the rays in the intergalactic space is small and therefore the arrival direction can be used to study the correlation of the arrival directions with astronomical objects, such as Active Galactic Nuclei (AGN's) or gamma-ray bursts (GRBs). This opens the field of cosmic-ray astronomy: for the first time, particles hitting the Earth will be traced back to astronomical objects; i.e. very similar to other astronomical observations. The detection of cosmic rays will thus open a new window which is outside the electromagnetic spectrum.

When a high-energy particle hits the atmosphere of the Earth, a cascade of interactions takes place in which copious amounts of particles are created during subsequent collisions of high-energy particles with atmospheric nuclei. This cascade is called an extensive air shower. The standard and presently well-established techniques for the detection of UHE cosmic rays rely either on extensive air-shower detectors which are located on the Earth's surface over large areas (many square kilometers) or on imaging techniques where fluorescence light from excited air molecules are detected with optical telescopes. For the very high energies, large-area detectors are needed. For example, the energy-integrated flux beyond 10^{20} eV yields only one event per km^2 per century. The covered area of the southern site of the Pierre Auger Observatory in the Mendoza Province in Argentina is 3000 km^2 - significantly larger than any previous experiment.

To understand the nature of the particle further improvements have to be made. Here the radio technique which we have developed in recent years will become important. The currently used optical fluorescence technique has some severe limitations: it only operates 10% of the time, during clear moonless nights. This means that only 10% or less of the events are seen by two techniques (so called hybrid events): these have the highest quality of reconstruction and allow one to get a good handle on the nature of the particle. Radio on the other hand can operate 24 hours a day and achieve the same duty cycle as surface particle detectors, while providing the necessary precise information of shower energy and development that allow one to determine the nature of the primary particle. Hence, there is the possibility to increase the number of high-quality hybrid events (radio + surface detectors) in Auger by an order of magnitude and answer the questions on the nature of UHECRs.

3.10.1.5. Impact/context NL situation

The project builds on the NL experience in LOFAR and AUGER. It will allow us to transfer some of the knowledge of antenna design developed in LOFAR to the university groups, and help the NL community to maintain their lead in the radio detection technique that is now attempted worldwide. The project also demonstrates the commitment of astronomers to joint instrumental developments together with particle physics in the newly emerging astroparticle physics field.

3.10.1.6. Technical concept and requirements

The goal of the development is a self-sufficient, solar-powered, self-triggering prototype antenna for later mass production. The antenna will operate in the frequency range from ~30-80 MHz and have a broad acceptance. The electronics requires buffering, smart triggering, and interference rejection on the antenna level. There needs to be wireless communication, synchronization and trigger coincidence detection between different antennas. Low-power consumption requires a high level of integration of all electronic components.

3.11. Instrument Steering Committee

Progress on the NOVA instrument projects are reviewed twice a year. On behalf of the NOVA Board, the Instrument Steering Committee (ISC) carries out these reviews. 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 on the release of such funds and/or on 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. The ISC also played a key role in reviewing the technical and managerial aspects of the instrument projects which constitute the present Phase-3 instrumentation program.
The ISC meets normally in September and March, about 3-4 weeks before the Board meetings. The ISC chair attends the Board meetings as an observer and reports orally on ISC matters. In addition, the Board receives a written report of the ISC meetings including its findings and recommendations. The composition of the ISC is listed in Appendix A3.

Each project PI provides the ISC with a written progress report to be submitted two weeks before the ISC meeting. The report has to address a number of pre-defined issues. At the request of the ISC chair a project PI will report orally at the ISC meeting and will be questioned by the ISC.

4. Organization, office and public outreach

4.1. Organization and office

The NOVA program is governed by the NOVA Board consisting of the directors of the five university astronomical institutes (see also Appendix A2) that are federated in NOVA. The NOVA Directorate is appointed by the university in charge of the legal representation of NOVA after being advised by the NOVA Board. These appointments are for a period of five years. Since the 1st September 2007 the Directorate consists of Prof. Ewine van Dishoeck (scientific matters) and Dr. Wilfried Boland (executive matters). The Directorate is supported by Mrs. Kirsten Groen (office, financial control). The Science Faculty of Leiden University provides the day-to-day financial administration and Utrecht University manages the NOVA bank account.

4.2. NOVA Information Center (NIC)

The NOVA Information Center (NIC) based at the University of Amsterdam has been established to popularize astronomy and astrophysics in the Netherlands. NOVA has a responsibility to report its frontline research in the widest sense. Popularization of astronomy is also an excellent vehicle for stimulating interest in the natural sciences in general, which is of great importance at a time when the interest in university studies in some of these disciplines is declining. The NIC has different target groups for its outreach efforts: (1) the press, (2) students and teachers, (3) policy makers, and (4) the general public. The NIC is managed by Mrs. Marieke Baan (0.6 fte), with administrative support for maintaining the public outreach website (0.2 fte). The NIC is overviewed and advised by the Minnaert Committee.

In Phase-3 the public outreach activities are extended with a program to bring astronomy into classrooms. Since 1st October 2008 an experienced mathematician teacher with a strong interest in astronomy, Mr. Jaap Vreeling (0.5 fte), has been hired to implement this program. He is responsible for developing educational programs for different age groups and corresponding training programs for teachers and volunteer astronomers, and he will actively promote and supervise these programs at schools nationwide.

5. Finance

An overview of the expenditures and revenues for the NOVA Phase-3 program is provided in Appendix B. The total budget for the period 2009-2013 amounts to 42.6 M€. The revenues consist of the following components: (1) ministerial grant for the top-research school of 24.4 M€, (2) a cash carry over on the NOVA bank account from Phase-2 of 5.3 M€; (3) external revenues amounting to 11.3 M€ (including ESO payments for the ALMA Band-9 production amounting to 9.8 M€), (4) cash contributions from the universities for participation in some projects of 0.3 M€, (5) contributions from various instrumentation projects to the costs of the NOVA-ASTRON Optical-IR instrumentation group amounting to 0.4 M€, and (6) a final NWO payment of 0.85 M€ for the MIRI project.

The expenditures include (1) 14.8 M€ on the research program, (2) 25.4 M€ on the instrumentation program including the ESO funded work on the ALMA receivers, (3) 2.1 M€ on the Office and the outreach program, and (4) a reserve fund of 0.3 M€ to guarantee social benefits for staff working on the ALMA and Optical-IR instrumentation projects in case they are unable to find a new job at the time that their project is completed. This fund will grow in 2009-2011 through contributions from the projects concerned.

Further budget information is provided in various tables in Chapters 2 and 3. The research budget includes 1.2 M€ for unforeseen circumstances and/or to allow support for new research initiatives. The instrumentation program includes 0.9 M€ for general contingency.

The financial figures do not yet include the recently allocated ESFRI grant of 18.8 M€.

5.1. Financial arrangements for the Phase-3 program

Staff expenditure for NOVA positions at the universities will be reimbursed on the basis of notional cost figures differentiated by rank as specified in Table 5.1. These figures are based on the actual staff costs per 1st January 2009. Each year they will be adjusted to the actual staff cost figures for that year if NOVA receives financial compensation for inflation which is current practice since 2007. In addition each NOVA research position comes with a bench/travel fee of 15 k€ per year for a professor position, 12 k€ per year for a faculty position at UHD or UD level or for a postdoc position, and 9 k€ per year for a PhD (AIO) position. For the instrumentation projects the NOVA allocation for bench and travel is determined on a case by case basis depending on the needs for the project.

NOVA staff will be appointed at the universities according to local employment conditions. It is assumed that universities, through their local procedures, will cover possible costs when temporary appointment research staff is unable to find a new job immediately after completion of their term and hence call on a support arrangement. For the ALMA hardware projects and the NOVA Optical/IR instrumentation group hosted at ASTRON part of the project budget is reserved by NOVA to cover costs in case staff working on these projects call on social arrangements when they are unable to find a new job after the project is completed. A similar arrangement under NOVA responsibility is in place for the staff working at the NIC.

Reimbursements of costs for staff working on the NOVA program outside the universities federated in NOVA are according the contractual arrangements that describe the collaboration between NOVA and the other party.

Rank *Annual staff costs in k€*	**Scale**	**Salary** *per 1 Jan 2009*	**Opslag**	**Gross** *+ opslag*	**Mat.** *Costs*	**Total**
HL	16 - 9	85.704	1,3962	119,660	15,0	134,660
UHD	14 - 5	63.852	1,4115	90,127	12,0	102,127
UD	12 - 6	54.516	1,4218	77,511	12,0	89,511
Postdoc	11 - 6	46.464	1,4340	66,629	12,0	78,629
AIO				41,284	9,0	50,284
OBP/Proj.manager	11 - 6	46.464	1,4340	66,629		66,629
OBP/Soft.engineer	11 - 6	46.464	1,4340	66,629		66,629
Junior project scientist	10 - 8	39.780	1,4394	57,259		57,259
OBP/Technician	9 - 8	41.064	1,4389	59,087		59,087
OBP/adm support	7 - 5	28.548	1,4432	41,200		41,200
OBP/Director	15 - 9	83.484	1,4006	116,928		116,928

Table 5.1: Summary of the budget guidelines for the NOVA reimbursement of staff costs at the universities for Phase-3. The staff cost figures (in k€) are applicable for 2009 and will be adjusted for inflation each year on a best effort basis.

5.2. NOVA policy on project contingency

The policy for use of contingency funds is to have PI's to make their cases in writing to the NOVA Directorate. The ISC will be asked to review the case and to make a recommendation about the amount of funding required. The NOVA Board makes the final decision.

Appendix A. Organization

Appendix A1: NOVA key-researchers for Phase-3 Each of the three research Networks consists of 5-8 key researchers with one in the role of coordinator. The coordinators are appointed by the NOVA Board for the duration of Phase-3 (2009-2013). The key-researchers were appointed by the NOVA Board in June 2007. They had an active role in preparing the Phase-3 research and instrumentation programs with the following exceptions: * Tielens was appointed to key-researchers were he arrived in the Netherlands in January 2009, and ** Keller (Network-2) was key-researcher until 1st January 2009 when he was appointed to member of the NOVA Board. Langer was Board member and as such key-researcher at large in the period of the preparation of the Phase-3 program until 1st January 2009.

Members of the NOVA Board and the scientific director are key researchers at large.

Naam	University	Network		Naam	University	Network	
Barthel	RuG	1		Achterberg	UU	3	
Franx	UL	1	**Coordinator**	Falcke	RU	3	**Coordinator**
Koopmans	RuG	1		Portegies Zwart	UvA	3	
Larsen	UU	1		Verbunt	UU	3	
Peletier	RuG	1		Wijers	UvA	3	
Röttgering	UL	1		Wijnands	UvA	3	
Schaye	UL	1					
Tolstoy	RuG	1		**Board and directorate**			
				van Dishoeck	UL	at large	
Hogerheijde	UL	2		Van der Hulst	RuG	at large	
de Koter	UvA	2		Groot	RUN	at large	
Spaans	RuG	2		van der Klis	UvA	at large	
Tielens *	UL	2		Kuijken	UL	at large	
Waters	UvA	2	**Coordinator**	Keller **	UU	at large	

Appendix A2: NOVA Board and Directorate Composition of NOVA Board, Directorate, Office and NOVA Information Center from 1st January 2009 onwards.
*) In first half of 2009 Groen combined the tasks for financial control and management support.

Board		
Van der Hulst	RuG	
Groot	RUN	
van der Klis	UvA	Chair
Kuijken	UL	
Keller	UU	
Directorate		
van Dishoeck	scientific matters	
Boland	executive matters	
Office		
Groen	financial control	
vacancy *	management support	
NOVA Information Center (NIC)		
Baan	public outreach	
Vreeling	astronomy in schools	
Lensen	website/support	

Appendix A3: membership Instrument Steering committee Membership of the NOVA Instrument Steering Committee since 1st January 2009.

Name	Affiliation
Prof.dr. R. Bacon	Univ Lyon, F
Dr. B. Brandl	UL
Dr. M. Casali	ESO
Prof.dr. L. Kaper	UvA
Dr. H.J. van Langevelde	JIVE
Dr. G. Nelemans	RU
Prof.dr. P. Roche, chair	Univ Oxford, UK
Dr. M. Verheijen	RuG
Dr. M. de Vos	ASTRON
Dr. W. Wild	ESO

Appendix B: Overview of the NOVA Phase-3 budget

EXPENDITURE ASTRONOMICAL RESEARCH	Total	2009	2010	2011	2012	2013
Overlap Appointments	2.443	576	660	605	376	225
Research Funding						
Network Galaxy Formation & Evolution	2.540	423	692	647	535	243
Network Birth & Death of stars	2.628	450	786	586	467	339
Network Final Stages of Stellar Evolution	2.669	491	732	691	528	226
Cross network research projects	883	114	267	201	201	101
Science Support	1.948	564	362	409	327	287
Miscelleneous research projects	116	10	5	0	50	50
Total Research Funding	10.784	2.052	2.844	2.533	2.108	1.247
Workshops & Visitors	300	60	60	60	60	60
New initiatives	1.213	0	0	0	0	1.213
TOTAL ASTRONOMICAL RESEARCH	14.740	2.688	3.564	3.199	2.544	2.745
NOVA INSTRUMENTATION PROGRAM in k€	**Total**	**2009**	**2010**	**2011**	**2012**	**2013**
Optical-IR group	5.829	1.983	1.742	1.354	550	200
ALMA Band-9 production	10.238	2.713	2.821	2.527	2.178	0
ALMA ALLEGRO	547	139	156	113	71	69
ALMA technical R&D	517	121	172	149	75	0
MIRI	1.191	604	227	144	113	103
Gaia	424	148	143	82	50	0
LOFAR-DCLA	1.773	677	798	297	0	0
MUSE	314	73	72	74	74	22
MUSE-ASSIST	957	555	388	7	7	0
S5T	339	195	75	55	13	0
AMUSE	526	92	263	171	0	0
MATRI2CES	458	151	184	69	44	9
Seed funding / Miscelleneous projects	228	91	27	10	100	0
Contingency for specific projects	715	0	0	0	500	215
General contingency and new initiatives	1.028	0	0	0	0	1.028
EU projects	297	297	0	0	0	0
TOTAL INSTRUMENTATION	25.379	7.838	7.070	5.052	3.774	1.645
OFFICE and OUTREACH						
NOVA Office	1.380	338	299	254	234	254
Outreach	737	163	155	140	140	140
Expected call on Wachtgeld funds	324	0	0	0	150	174
Total Office and Outreach	2.441	501	454	394	524	568
TOTAL EXPENDITURE	42.560	11.028	11.088	8.645	6.842	4.958
REVENUES	**Total**	**2009**	**2010**	**2011**	**2012**	**2013**
OCW grant NOVA	24.260	4.852	4.852	4.852	4.852	4.852
Late payments 2008	126	126				
Interest	100	100	0	0	0	0
Contributions NOVA institutes	265	185	80	0	0	0
Contributions NOVA projects	379	231	70	77		
Various external funding resources	395	195	100	100		
Actual NOVA bank account at end 2008	5.340	5.340				
Expected NOVA bank account at end 2009		-4.155	4.155			
Expected NOVA bank account at end 2010			-1.142	1.142		
Expected NOVA bank account at end 2011				-123	123	
Expected NOVA bank account at end 2012					-106	106
ESO	10.513	3.176	2.887	2.527	1.923	0
EC	323	123	80	70	50	
NWO-Groot for MIRI	850	850				
OCW: astronomy olympic	10	5	5			
Total NOVA Phase-3 revenues	42.560	11.028	11.088	8.645	6.842	4.958

The table below summarizes the NOVA budget for Phase-3 covering the period 2009-2013. The salary costs are calculated according the guidelines described in § 5.1.

C: List of abbreviations

2SB	Sideband Separating
ACS	Advanced Camera for Surveys (on the HST)
AGN	Active Galactic Nuclei
AIO	Assistant-in-opleiding - PhD student
AIP	Astrophysical Institute Postdam (Germany)
ALLEGRO	ALMA Local Expertise GROup
ALMA	Atacama Large Millimeter / Submillimeter Array
AMBER	Astronomical Multiple BEam Recombiner (VLTI instrument)
AMUSE	Astrophysical MUltipurpose Software Environment
AO	Adaptive Optics
AOF	Adaptive Optics Facility
APEX	Atacama Pathfinder EXperiment
ARC	ALMA Regional Center
ASSIST	Adaptive Secondary Setup and Instrument STimulator
ASTRON	ASTRON - Netherlands Institute for Radio Astronomy
ATLAS	Astronomical survey planned for VISTA
AU	Astronomical Unit
AUGER	see PAO
Caltech	California Institute of Technology
CCD	Charge-Coupled Device
CDM	Cold Dark Matter
CfA	(Harvard-Smithsonian) Center for Astrophysics
CFHT	Canada France Hawaii Telescope
CHAMP+	CHAMP+ is a dual-frequency heterodyne submillimeter array receiver on APEX
Chandra	NASA's X-ray space observatory
CMB	Cosmic Microwave Background
CNC	Computer Numerical Control
COB	Cold Optical Bench
COROT	French led astronomical space mission to search for extrasolar planets and stellar seismology
CRAL	Centre de Recherche Astronomique de Lyon (Fr)
CRs	Cosmic Rays
CSO	Caltech Submillimeter Observatory
DCLA	Development and Commissioning of LOFAR for Astronomy
DPAC	Data Processing and Analysis Consortium (Gaia)
DSM	Deformable Secondary Mirror (for ESO's VLT)
EC	European Commission
E-ELT	European Extremely Large Telescope
EGAPS	European GAlactic Plane Surveys
EGP	Extra-solar Giant Planet
EoR	Epoch of Reionization
EPICS	Exoplanet Instrument in study for the E-ELT
ESA	European Space Agency
ESFRI	European Strategy Forum on Research Infrastructures
ESKAC	European SKA Consortium
eSMA	extended SMA
ESO	European Southern Observatory
ETH	Eidgenössische Technische Hochschule (Zürich)
EU	European Union
EUCLID	Possible ESA Cosmic Vision mission to map the dark universe
eV	electron Volt
EVN	European VLBI Network
ExPo	Exoplanet Polarimeter (on WHT)
FIRES	Faint Infrared Survey (at the VLT)
FLAMES	Fibre Large Array Multi Element Spectrograph (at the VLT)
FOM	Fundamenteel Onderzoek der Materie (NWO institute for physics)
FoV	Field of View
FP	Framework Program (of the European Commission)
FWHM	Full Width at Half Maximum
Gaia	Gaia - ESA's astrometric cornerstone mission
GALACSI	Ground Atmospheric Layer Adaptive Corrector for Spectroscopic Imaging (for MUSE)
GHz	Giga Herz
GRAAL	Ground layer Adaptive optics Assisted by Lasers
GRB	Gamma Ray Burst
GTO	Guaranteed Time Observations
HECRs	High Energy Cosmic Rays
Herschel	Herschel Space Observatory (ESA mission for far-IR astronomy)
HI	Hydrogen 21 cm line
HIFI	Heterodyne Instrument for the Far-Infrared (instrument on Herschel)
HII	inonized hydrogen
HST	Hubble Space Telescope
IAC	Instituto de Astrofisica de Canarias (Spain)
IAP	Institut d'Astrophysique de Paris (France)
ICSM	Inter- and CircumStellar Matter
IFS	near-IR integral Field unit (part of SPHERE)
IFU	Integral Field Unit
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
IoA	Institute of Astronomy (in Cambridge, UK)
IR	Infra-Red
IRAM	Institut de Radio Astronomie Millimétrique (Grenoble, France)
IRAS	InfraRed Astronomical Satellite
IRDIS	near-IR imaging and slit spectrograph (part of SPHERE)
IRS	InfraRed Spectrometer
ISAAC	IR (1 - 5 μm) imager and spectrograph on ESO's VLT
ISC	Instrument Steering Committee (NOVA)
ISM	InterStellar Medium
ISO	Infrared Space Observatory (ESA)
JCMT	James Cleck 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)
KNVWS	Koninklijke Nederlandse Vereniging voor Weer- en Sterrenkunde
KOSMA	submillimeter telescope on Gornergrat near Zermatt in Switzerland
KRs	Key Researchers (leaders of the NOVA research networks)

KSP	Key Science Project
LAM	L'Observatoire Astronomique de Marseille-Provence (France)
LERMA	Laboratoire d'Etude du Rayonnement et de la Matière en Astrophysique (Part of Observatoire de Paris)
LGS	Laser Guide Star
LISA	Laser Interferometer Space Antenna
LMC	Large Magellanic Cloud
LOFAR	LOw Frequency ARray - new radio observatory under construction by ASTRON
MATISSE	Multi AperTure Mid-Infrared Spectroscopic Experiment (2nd generation VLTI instrument)
MATRI2CES	Mass Analytical Tool of Reactions in Interstellar ICES (NOVA laboratory astrophysics project)
METIS	Mid-infrared ELT Imager and Spectrometer in study for the E-ELT
MHD	magnetohydrodynamics
MICADO	Near-infrared wide-field imager in study for the E-ELT
MIDI	MID-Infrared instrument (first instrument for the VLTI)
MIRI	Mid Infra-Red Instrument (on board of JWST)
MIT	Massachusetts Institute of Technology
MPA	Max-Planck-Institut für Astrophysik (Garching, Germany)
MPE	Max-Planck-Instituts für Extraterrestrische Physik (Garching, Germany)
MPI	Max-Plank-Institut
MPIA	Max-Planck-Institut für Astronomie (Heidelberg, Germany)
MPIfR	Max-Planck-Institut für Radioastronomie (Bonn, Germany)
MUSE	Multi Unit Spectroscopic Explorer (2nd generation instrument for VLT)
NASA	National Aeronautics and Space Administration (USA)
NIC	NOVA Information Center
NIKHEF	Nederlands Instituut voor Kern- en Hoge Energie Fysica (part of FOM)
NIR	Near Infrared Spectroscopy
NL	Netherlands
nm	nanometer
NOVA	Nederlandse Onderzoekschool Voor Astronomie (Netherlands Research School for Astronomy)
NRAO	National Radio Astronomical Observatory (in USA)
NSO	US National Solar Observatory
NWO	Nederlandse organisatie voor Wetenschappelijk Onder-zoek (Netherlands Organization for Scientific Research)
NWO-EW	NWO department for Physical Sciences
NWO-M	NWO-medium sized (investment grant)
O/IR	Optical to InfraRed
OCW	Dutch ministry for Education, Culture and Research
OG	Observatoire de Genève
OmegaCAM	Wide-field camera for the VLT Survey Telescope
OmegaCEN	OmegaCAM data center
OPTIMOS	OPTical to Infrared Multi-Object Spectrograph
OSO	Onsala Space Observatory (in Sweden)
PACS	Photodetector Array Camera and Spectrometer (on Herschel)
PAH	Polycyclic Aromatic Hydrocarbon molecule
PAO	Pierre Auger Observatory (international cosmic ray observatory in Argentina)
pc	parsec
PDR	Preliminary Design Review
Ph	Phase
PI	Principal Investigator
PLATO	PLAnetary Transits and Oscillations of stars (ESA mission in preparation)
PM	Project Manager
PSF	Point Spread Function
PuMa	Pulsar Machine (in use on WSRT)
R&D	Research and Development
RAIRS	Reflection Absorption InfraRed Spectroscopy
RU	Radboud Universiteit (Nijmegen)
RuG	Rijksuniversiteit Groningen
RXTE	Rossi X-Ray Timing Explorer
S5T	Small Synoptic Second Solar Spectrum Telescope
SDSS	Sloan Digital Sky Survey
SED	Spectral Energy Distribution
SF	Star Formation
SINFONI	Spectrograph for Integral Field Observations in the Near Infrared (VLT instrument)
SIS	Superconductor Insulator Superconductor; detector technology for (sub)-mm and far-IR
SKA	Square Kilometer Array
SMA	SubMillimeter Array (on Mauna Kea, Hawaii)
SMC	Small Magellanic Cloud
SNN	Samenwerkingsverband Noord Nederland
SNR	SuperNova Remnant
SPHERE	Spectro-Polarimetric High-contrast Exoplanet REsearch (2nd generation VLT instrument)
SPIRAS	Supersonic Plasma InfraRed Absorption Spectrometer
Spitzer	NASA's far-infrared space observatory
SRON	SRON - Netherlands Institute for Space Research
SWS	Short Wavelength Spectrometer (on ISO)
TBD	To Be Decided
TNO	Research Institute for applied physics in the Netherlands
TPD	Temperature Programmed Desorption
TU	Technical University
TUD	Technical University Delft
UHECR	Ultra-High Energy Cosmic Rays
UK	United Kingdom
UKIRT	United Kingdom Infrared Telescope
UL	Universiteit Leiden
ULIRG	Ultra Luminous Infra-Red Galaxy
Ultra-VISTA	Ultra deep near-IR imaging with VISTA
UT	Unit Telescope (VLT)
UU	Universiteit Utrecht
UV	ultra violet
UvA	Universiteit van Amsterdam
UVES	Ultraviolet and Visual Echelle Spectrograph (instrument on VLT)
VESUVIO	Observing program with VST-OmegaCAM to study galaxy populations
VIKING	VIsta Kilo-degree INfrared Galaxy survey

VIMOS	VIsible MultiObject Spectrograph (instrument on VLT)
VISIR	VLT-Imager and Spectrometer for mid InfraRed (instrument on VLT)
VISTA	Visible and Infrared Survey Telescope for Astronomy (ESO)
VLBI	Very Long Baseline Interferometry
VLT	Very Large Telescope (ESO)
VLTI	Very Large Telescope Interferometer (ESO)
VST	VLT Survey Telescope
WFC	Wide Field Camera
WHT	William Herschel Telescope (part of ING)
WMAP	Wilkinson Microwave Anisotropy Probe
WSRT	Westerbork Synthesis Radio Telescope
XMM-Newton	ESA's cornerstone X-ray observatory
X-Shooter	Single target optical and near-IR spectrometer (2nd generation VLT instrument)
YSO	Young Stellar Object
ZIMPOL	Zurich IMaging POLarimeter - part of SPHERE

Illustration on the front cover

The Spiderweb Galaxy, a forming massive galaxy at the centre of a protocluster at z = 2.2, a time when the Universe was about 3 Gyr old. This ultra-deep image made with 19 orbits using HST/ACS demonstrates the importance of hierarchical merging processes in the formation and evolution of massive galaxies. The white clumps in the insert are satellite galaxies that are merging with the massive host galaxy: 'flies' being captured by the spiderweb. The Ly-α ionized gas halo (not shown) extends over the entire spiderweb (size ~ 200 kpc) and is one of the largest known objects in the Universe. The insert image shows a 33" x 23" region rotated 10º from north (from: Miley et al. 2006, Astrophys. J. 650, L29).