NETHERLANDS RESEARCH SCHOOL FOR ASTRONOMY

PROGRAM 2014-2018

COVER ILLUSTRATION

Artist's impression of the highly asymmetric dust distribution in the transitional disk around the young star Oph IRS 48, imaged with ALMA Band-9 by van der Marel et al. (Science, 2013). This asymmetric structure is explained by a dust trap at 60 AU radius where dust particles can grow quickly to planetesimals through coagulation, making it a 'comet' factory. The dust trap is modeled with a vortex triggered by an unseen companion orbiting at 20 AU. In contrast with the mm-sized dust, the micron-sized dust imaged by VLT-VISIR and gas imaged by ALMA show a symmetric distribution across the disk, with gas clearly present inside the dust hole. Image credit: ESO/L. Calçada.

NOVA PROGRAM 2014 - 2018

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1. SUMMARY

Progress in astronomy continues at an amazing pace. Our solar system is now known to be just one of thousands of planetary systems in the Milky Way, each with a different architecture. The nurseries of stars and planets are being revealed through sharper and sharper images of their birthplaces. At the end of their lives, stars give rise to the most energetic explosions known in the Universe - supernovae, gamma ray bursts and binary mergers- with conditions far exceeding anything that can be made in a laboratory on Earth. The resulting black holes, neutron stars, white dwarfs, relativistic jets and cosmic rays provide unique insight into the fundamental properties of space-time and matter, and on the origin of gravitational waves that are on the verge of discovery. There is growing evidence that galaxies, including our own Milky Way, continue to accrete gas and stars from smaller satellites, and that such merging processes shape galaxy evolution. The detection of the first stars and light in the Universe - the epoch of reionization - is observationally within tantalizingly close reach. On the largest cosmic scales, the nature and distribution of the mysterious dark energy and dark matter, which make up 96% the Universe, are being probed by new instruments.

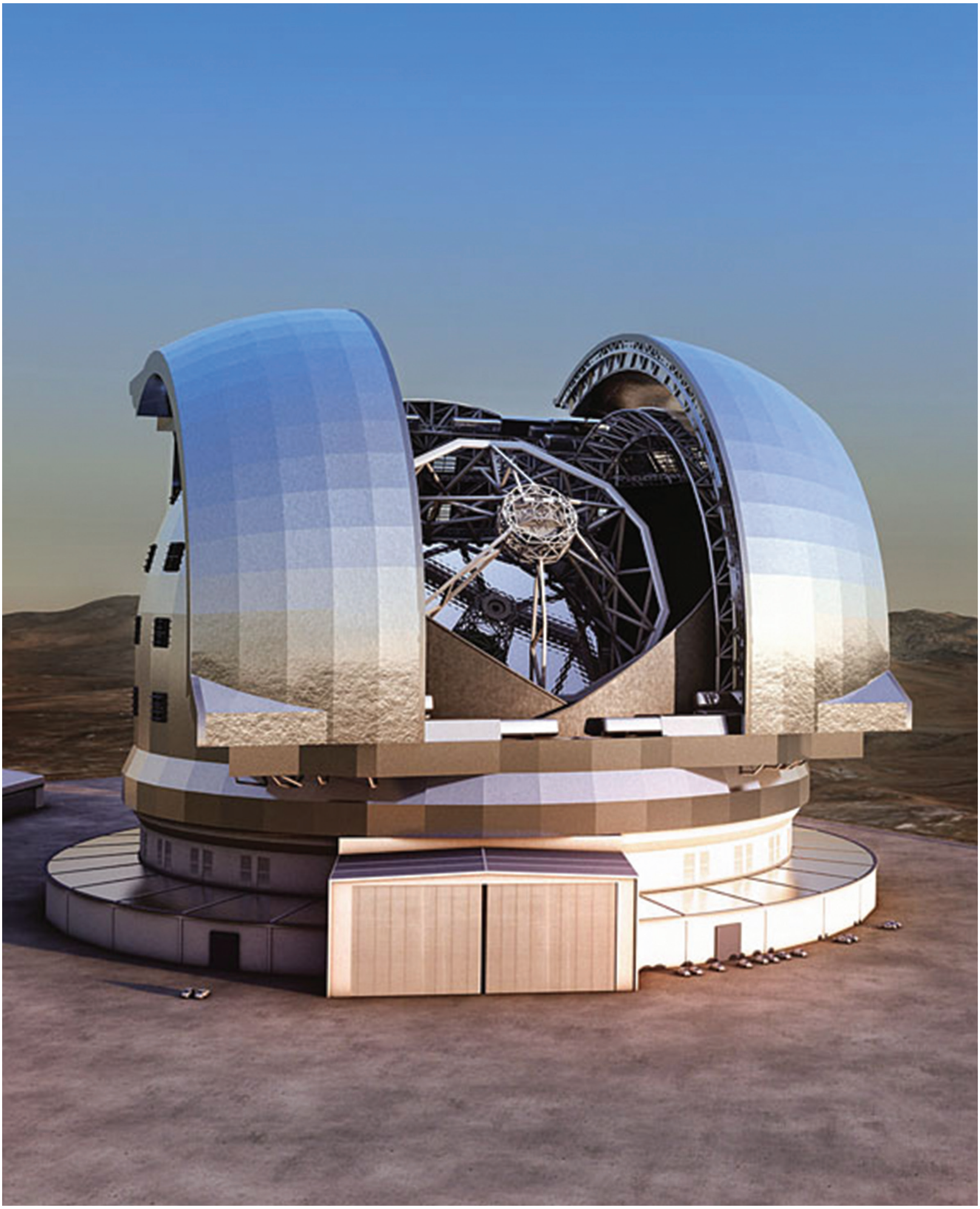
Astronomy is a high-tech, fundamental science with a large public appeal, driven forward by the combination of human ingenuity and technological development. NOVA is the Netherlands top-research school in astronomy, federating the universities of Amsterdam, Leiden, Groningen and Nijmegen. NOVA operates in close collaboration with the NWO institutes ASTRON and SRON. The NOVA mission is to perform scientific research at the highest international levels and to train the next generation of astronomers. To achieve this mission NOVA designs and builds instrumentation, in particular in its function as the national home base for the European Southern Observatory (ESO).

NOVA's central research theme is '***The life-cycle of stars and galaxies***', in which it studies the formation, evolution and structure of stars, galaxies and their environments throughout cosmic time. The 2014-2018 program is structured in three, interlinked, networks, centered on the formation and evolution of galaxies; the process of star and planet formation; and the high-energy Universe. Dutch astronomy is internationally renowned for its research on the youngest galaxies in the Universe; the history of the Milky Way; the astrochemical processes in star-forming regions; the evolution and death of stars and binaries; and high-energy phenomena: gamma-ray bursts, jets, compact binaries and (supermassive) black holes. The NOVA-4 program opens new avenues in studies of the epoch of reionization, stellar populations in our own and other galaxies, the planet-forming zones of disks using the Atacama Large Millimeter Array (ALMA), fast transients and gravitational wave events.

The research program requires observations using a multi-messenger approach. The NOVA instrumentation program focuses on the European Extremely Large Telescope (E-ELT), on the design and construction of receivers for ALMA, on pioneering cameras for the Cerenkov Telescope Array (CTA), and on optical counterparts to gravitational wave events through the BlackGEM telescope array. Astronomical research is high-tech and big data. NOVA works with industry to collect, process, interpret and simulate the extremely weak signals coming to us, requiring the most advanced technologies. The NOVA program is part of the Advanced Instrumentation roadmap of the topsector 'High-Tech Systems and Materials' and the ICT roadmap.

Astronomy addresses the 'big questions' and as such is a shared fascination by all mankind. NOVA drives an outreach program centered on 'scales-of-ten': activities targeting 10, 100 … 1 million people. This ranges from outreach talks, educational material for primary and secondary schools, the mobile planetarium, a state-of-the art website, and TV. Through these activities NOVA not only shares its knowledge of the Universe but also hopes to inspire the next generation of science students.

With this NOVA-4 program, astronomy in the Netherlands will maintain and strengthen its world-leading research position, enable cutting-edge research and technology development in collaboration with industry, train the next-generation of internationally operating researchers, keep top-researchers in the Netherlands, and continue to serve as a flagship of Dutch research.


Artist impression of the E-ELT (credit: ESO)

2. INTRODUCTION

Over the last 50 years, our understanding of the Universe has increased dramatically. The Universe is now thought to be composed almost entirely of dark matter and dark energy, substances so far undetected in Earth's laboratories. Telescopes are so powerful that the history of galaxy formation can be traced back to the earliest times, putting our own Milky Way in the context of the other billions of galaxies in the Universe. Material is being cycled continuously from clouds to stars and back again during stellar birth and death. Planets have been discovered around other stars, and the fingerprints of the building blocks for life are being found throughout the Universe. The elements in our bodies were synthesized through nuclear fusion in the interiors of stars and during powerful supernova explosions. Altogether, the Universe is a fascinating new territory to be discovered; it also provides a unique laboratory for investigating and testing physics and chemistry under conditions far more extreme than can be reached in a laboratory on Earth.

Astronomy and astrophysics have developed into a multidisciplinary research field that uses, and often drives, advances in optics, mechanical engineering, detector technology and computer and network capabilities, in close collaboration with industry. Progress in astronomy requires access to state-of-the-art telescopes and instrumentation on the ground and in space across a wide range of wavelengths and using different types of 'messengers'. The extreme sensitivity and precision needed to answer astronomical questions drive the development of new technologies.

These technological advances affect people's daily life not only in practical terms, but astronomy also provides people with a totally different perspective of the world in which they live. Age-old questions such as 'how did the Universe begin and how will it end?', 'where do we come from?', 'what is our place in this huge universe?' and 'is there a twin sister of our Earth?' continue to fascinate both astronomers and the public at large. Astronomy therefore presents a unique opportunity to enhance appreciation for the natural sciences to society. Black holes, gamma ray bursts (the most energetic explosions in the universe), pulsars and neutron stars (matter at extreme densities) inspire children to pursue a career in the natural sciences.

Astronomy in the Netherlands has a long standing tradition of planning and collaboration in order to make efficient use of resources over the long timescales needed to build major new facilities (typically 20-30 years). This is reflected in a series of Strategic Plans, of which the current version covers the decade 2011-2020. The Strategic Plan is written on behalf of the National Committee for Astronomy (NCA), which is the informal coordination between the key players in Dutch astronomy: the universities, federated in NOVA, the NWO institutes ASTRON and SRON, and the NWO division of Physical Sciences (NWO-EW), which have complementary roles in running or enabling astronomical research. The priorities of Dutch astronomy are also in line with those of the European ASTRONET roadmap.

The NOVA mission is to perform scientific research at the highest international levels and to train the next generation of astronomers. To achieve this mission NOVA designs and builds instrumentation, in particular in its function as the national home base for ESO. All graduate astronomy education in the Netherlands is concentrated in NOVA. Dutch PhD students are stimulated to become independent scientists at an early stage. They frequently receive international prize fellowships and research positions at top-ranked astronomical institutes worldwide. NOVA researchers are leading national and international multi-disciplinary programs on astroparticle physics, computational astrophysics and astrochemistry.

NOVA was first selected in 1997 as one of six top-research schools in The Netherlands for a ten year funding period starting in 1999. After this, the NOVA program was renewed for another period of five years. In 2010 the Ministry of Education, Culture and Sciences (OCW) called for an in-depth review of the top-research schools in the light of the new 'Zwaartekracht' initiative. Out of the initial six top-schools only NOVA and Zernike Institute of Advanced Materials were labeled 'Exemplary' in this evaluation and recommended for up-front renewal due to their established internationally leading role and as flagships of Dutch research. In June 2011 OCW renewed its commitment to NOVA funding as part of their 'Strategic agenda for higher education, research and science', and planning for NOVA Phase-4 started.

This document describes the NOVA Phase-4 program 2014-2018 enabled by the top-research school funding from OCW (called the 'NOVA Grant'). The program was put together by the NOVA researchers through a bottom-up process. The three research networks have identified new research themes, including emerging fields such as the epoch of reionization, exoplanetary atmospheres, and the transient sky. They have made strategic choices in the development and building of instrumentation to confront new astrophysical insight with observational data, at a level that is appropriate for the size and budget available for the astronomical community in the Netherlands. Astronomers from the NWO-funded institutes ASTRON and SRON, many of which have adjunct positions at the universities, have participated in the process. The NOVA Instrument Steering Committee has reviewed the instrumentation projects on technical, managerial, financial and risk matters which were taken into account in the NOVA Board final decisions. The entire Phase-4 program is confirmed by the NOVA Raad van Toezicht (Supervisory Board).

NOVA supports both the research and instrumentation through personnel at all levels, from PhD students to professors, and with observational, theoretical, computational and/or technical expertise to obtain the best science. The NOVA Phase-4 instrumentation program focuses on ESO-related instrumentation projects, in particular the E-ELT, but it also supports a variety of other projects driven by university astronomy, ranging from laboratory astrophysics and specialized back-ends for WSRT-Apertif to gravitational wave follow-up with wide-field telescopes and technical R&D studies on instrumentation for CTA. NOVA also provides services for relations and information exchange between ESO and industry in the Netherlands. Finally, NOVA supports an active workshops and visitors program, and outreach efforts through the NOVA Information Center.

Overall, the program involves about 300 fte scientific staff members spread over the four universities participating in NOVA. This number includes ~60 senior staff members and tenure-track positions, ~50 fte postdoctoral fellows, ~150 fte PhD students, and ~40 fte staff working on instrumentation projects including the NOVA-ALMA team in Groningen and the optical-infrared instrumentation group hosted at ASTRON for which NOVA is fully responsible. NOVA funds ~20% of the university research positions. Strategic investments and choices, in combination with a bottom-up selection process, not only ensure a high quality program from a committed community but also makes that the entire NOVA program acts as a catalyst: it attracts and keeps international top-level researchers in the Netherlands and it enables Dutch astronomers to successfully compete for (inter)national grants, reflected in the total NOVA Phase-4 budget, and for the Netherlands to '… make contributions to world astronomy far disproportionate to its population or GDP' [1].

[1] Quoted from the NOVA International Review Board, in their 2010 report

3. RESEARCH PROGRAM 2014-2018

NOVA's research program 'The lifecycle of stars and galaxies: from high redshift to the present' addresses several of the most fundamental questions on our Universe and consists of three interconnected thematic programs (also called networks):

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

The networks function to focus and channel the research within NOVA, but are not exclusive or disconnected from each other. The unique nature of our Universe makes that studies of one component are inadvertently connected to others and therefore must be studied within the larger context. Figure 3.1 shows the three networks and in particular how and where they overlap and connect. Also in the instrumentational program it is clear that one instrument may serve the needs to more than one network.

The next sections describe a broad introduction and overview of the programs of each of the three research network for the period 2014-2018. Within each Network, there are different themes that are evolving with time. Details of individual projects can be found in Appendix A, including a few cross-network projects. Each project has a responsible principle investigator, whereas each theme has a significant number of co-investigators, spread over the university institutes and ASTRON and SRON. Together, they coordinate the research within the theme and ensure collaboration between the institutes. The network interaction is further stimulated by network-wide meetings taking place twice per year. Researchers at the network boundaries attend meetings of more than one network. In addition, NOVA organizes the NOVA fall school for first-year PhD students, as well as a PhD weekend for third-year PhD students to discuss career options within and outside astronomy. Each of the institutes also provides a wide range of training courses that PhD students take throughout their 4-yr appointment.

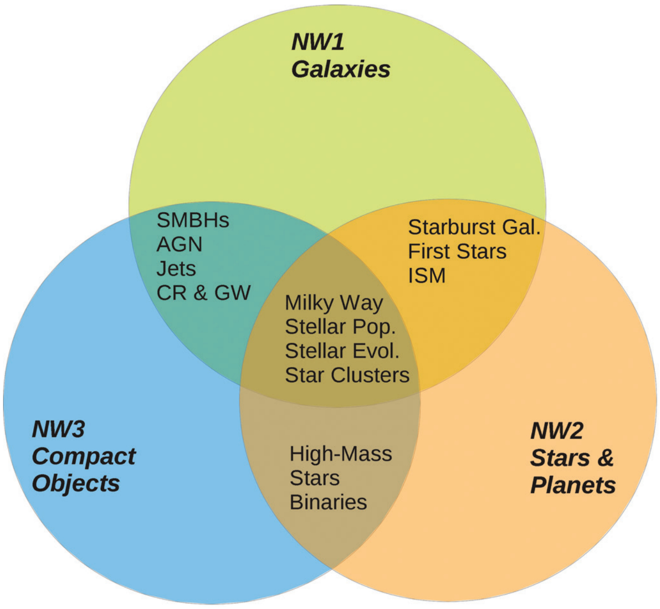


Figure 3.1: *Schematic view of the three research networks and their overlapping themes. SMBH = Supermassive Black Holes; AGN = Active Galactic Nuclei; CR = Cosmic Rays; GW = Gravitational Waves; and ISM - Interstellar Medium*

3.1. FORMATION AND EVOLUTION OF GALAXIES: FROM HIGH REDSHIFT TO THE PRESENT

Research in Network 1 focuses on understanding the evolution of the Universe and its constituents, in particular its dark components, which dominate its dynamics. The formation and structure of galaxies are studied from the earliest epochs, when the first stars were formed in the infant Universe, to the present day, where the fossils from those epochs can be found. The breadth of the research implies that Network 1 researchers study the light from stars (their chemical composition, their motions, their distribution in mass), the interstellar medium (gas and dust, and the associated physical processes, all intimately linked to the evolution of galaxies), as well as the nature of dark matter and dark energy (relating these to fundamental physics). All of these aspects impact our understanding of how galaxies, from small to large, have formed and evolved throughout the history of the Universe (Fig. 3.2).

This breadth is reflected in the research projects that are the focus of the coming period. These projects can be roughly split into three main themes:

- ***The young universe and the earliest galaxies:*** when did the first galaxies form and what were their properties (mass, star formation history, structure)?
- ***The physics of galaxy evolution:*** how do galaxies accrete and retain their fuel (gas) for star formation? How does star formation occur in the smallest systems and how in extreme environments? Do stars form in the same way in different objects and environments (the initial mass function, the role of feedback and AGN)? What is the distribution of mass in galaxies of different types, and how does mass correlate with galaxy properties?
- ***The local Universe and the fossil record:*** what was the assembly history of the Milky Way and the nearest neighboring galaxies? How do we retrieve this from the chemical composition and the motions of stars? What is the detailed mass distribution in the Galaxy, at large distances in the realms of the dark matter halo, and at small radii where the super-massive black hole lurks, and how has it evolved in time?

THEME 1: THE YOUNGEST UNIVERSE AND THE EARLIEST GALAXIES

The earliest epochs will be probed through a series of studies. A key goal is the detection of the signal that occurred when the Universe transited from being largely opaque (the gas was almost completely neutral) to nearly completely ionized (thanks to the radiation emanating from the first light sources), a time referred to as the epoch of reionization. The discovery and characterization of the first galaxies, i.e., the sources of

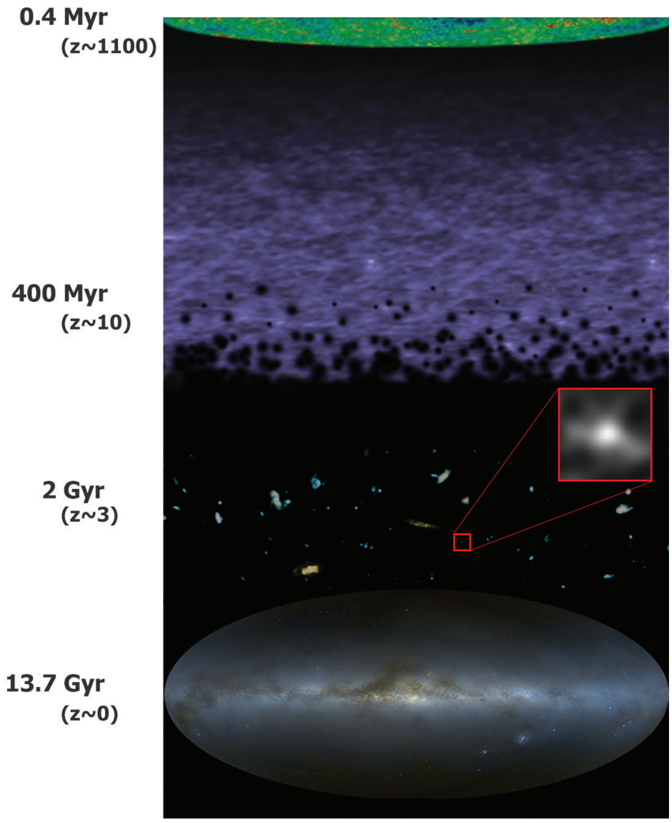


__Figure 3.2:__ The evolution of galaxies in the Universe, from the earliest epochs to the present time. Soon after the Big Bang (at z ~ 1100) the Universe experienced its dark ages. This epoch ended when the first radiating objects formed and the Universe was a few hundred million years old but the exact time or redshift are unknown. This Epoch of Reionization will be determined and studied with LOFAR. An example of the first galaxies formed is shown in the inset, and such systems will be studied and characterized by projects in the first Network-1 theme 'The young Universe and the earliest galaxies'. The second Network-1 theme focuses on the physical processes that have taken place since those earliest epochs and which are crucial to understand galaxy evolution. The galaxies in the nearby Universe are the final product of this process, and are the focus of the third theme in the Network. The Local Universe can be studied in exquisite detail and its fossil record leads to unique insights into the dynamical evolution, star formation and chemical history of systems like the Milky Way, shown in the bottom panel. Credits: LOFAR EoR image by V. Jelić, and high-z galaxies by R. Bouwens et al. (2013).

the photons that led to the reionization of the Universe, is important to understand the physics of this process. At later times, but still within the first two to three billion years of the Universe, there is evidence that star formation occurred in some galaxies at prodigious rates, but the details and importance of these systems in the global galaxy evolution picture is not known. On the other hand, some galaxies even at those epochs appear to have already formed most of their stars, yet their structural properties indicate that they have no local counterpart. Determination of their dynamical mass is crucial to establish what they will turn into at the present time. Even at early times, galaxies show signs of coming together in larger dynamical structures, known as proto-clusters. These galaxy aggregates are important not only for the internal evolution of a galaxy, but also because they represent the highest peaks in the cosmological density field.

PROJECT	TITLE	RESEARCH LEADERS	PLACE	SUPPORT
nw1-01	Growth of galaxies in the early universe	Bouwens, Franx	UL	AIO, 4 yrs
nw1-02	Modes to enhance EoR HI power-spectra measurements	Koopmans, Wijers	RUG	AIO, 2 yrs ***
nw1-03	Ultra-Luminous Infrared Galaxies in the AM-KID E-CDFS survey	Caputi, vdWerf, Baryshev	RUG	AIO, 4 yrs **
nw1-04	Onset of the Red Sequence	Franx	UL	AIO, 3 yrs *
nw1-05	LOFAR study of star forming galaxies in the field and in proto-clusters	Röttgering et al.	UL	AIO, 3 yrs *
nw1-06	Characterizing the low-mass stellar IMF in galaxies	Trager, Koopmans, Peletier	RUG	Postdoc, 3 yrs
nw1-07	Probing feedback in the nuclei of (U)LIRGs using water lines	vdWerf, Spaans	UL	AIO, 3 yrs *
nw1-08	Galaxy halo masses, shapes, and sizes from KiDS+VIKING+GAMA	Kuijken, Hoekstra	UL	AIO, 4 yrs
nw1-09	Simulating the gas around low-redshift galaxies	Schaye et al.	UL	AIO, 3+1 yrs
nw1-10	Star formation at ultra-low levels	Brinchmann et al.	UL	AIO, 4 yrs
nw1-11	Chemical composition of stellar populations beyond the Local Group	Larsen, Trager	RU	AIO, 4 yrs
nw1-12	Hypervelocity stars as a powerful new tool to investigate the Galaxy	Rossi, Brown	UL	AIO, 3 yrs *
nw1-13	Structures and substructures in the Milky Way using Gaia	Helmi, Brown	RUG	Postdoc, 3 yrs
nw1-14	NW-1 fellowship program	TBD	TBD	Postdocs, 6.8 yrs

Table 3.1: *Network-1 research program in NOVA Phase-4.*

* *The positions will be supported for four years with NOVA funding for 3 yrs and university/personal grant support for 1 yr;*

** *Joint project with SRON, 100% funded by SRON;*

*** *Also 2 yr funding from Network-3.*

THEME 2: THE PHYSICS OF GALAXY EVOLUTION

To answer the question how galaxy formation and evolution took place, and why there is such a rich variety of systems in the present day Universe, requires studies of galaxies at all epochs with a sufficiently high level of detail so that the main drivers can be identified. The studies on 'the physics of galaxy evolution' to be carried out in NOVA Phase-4 will lead to a much better characterization of the 'typical' galaxy at any epoch, as well as of the various physical ingredients that enter in the evolution of a galaxy. For example, to sustain the formation of stars at the rate seen in the Milky Way, cold gas must continuously be accreted most likely from the larger circumgalactic environment. There is new evidence that even the stellar initial mass function (the mass spectrum of stars) varies with galaxy mass, but this must be established more firmly with larger samples and new sophisticated modeling techniques. The determination of dynamical masses for galaxies is critical for our understanding of these processes, and techniques based on gravitational lensing (weak and strong) make such measurements possible. The crucial questions that will be addressed by the various projects are therefore what the 'true' galaxy properties are (stellar masses, star formation rates, etc.), how they are related to dark matter halos; and what processes cause the galaxies (large and small) to form and evolve towards what is seen today. State-of-the-art simulations in comparison with observations are a powerful tool to quantify the importance of various processes such as feedback by outflows.

THEME 3: THE LOCAL UNIVERSE AND THE FOSSIL RECORD

Truly complementary to the above themes are studies focusing on the local Universe and the fossil record that nearby stars offer. For example, some of the stars around the Sun contain direct imprints in their atmospheres of the chemical elements produced by the first generations of stars, and so studies of these nearby fossils can tell a detailed story of the formation of a galaxy to a level of detail that is unattainable for the most distant objects. Furthermore their kinematics can serve to determine the present mass distribution and the dynamical history of the galaxies they inhabit.

A large number of the projects proposed for this period capitalize on the investments made in the NOVA Instrumentation Program in previous periods. These new observational facilities will play a crucial role in Network-1 research program in the coming years. This includes space missions such as Herschel which just finished observing, to Gaia which was launched in December 2013. Ground based facilities associated to ESO also feature prominently, including ALMA, which started early operation in 2011, and OmegaCAM on the VST, which is fully functional now. Particularly important are the new instruments on the VLT (X-Shooter, MUSE) which will lead to new fundamental studies on the dynamics and stellar populations of galaxies. LOFAR has begun taking data and is a unique tool to study intergalactic medium around the epoch of reionization. A direct detection of reionization may be feasible in the coming years, within the lifetime of NOVA-4.

NETWORK-1 FUNDING IN 2014-2018

The Network-1 research program for NOVA Phase-4 is summarized in Table 3.1. NOVA funding for this program amounts to 2,829 k€. In addition co-funding of 200 k€ is secured from personal research grants guaranteed by university institutes. Because SRON also co-funds research positions in other networks it was decided – for administrative reasons – that SRON funds and manages the nw1-03 position and NOVA does the same for project nw2-12.

3.2. FORMATION OF STARS AND PLANETARY SYSTEMS

The origin and properties of stars and (exo)planets is one of the central themes of astronomical research today. This field addresses questions about the origin of our and other planetary systems and, ultimately,

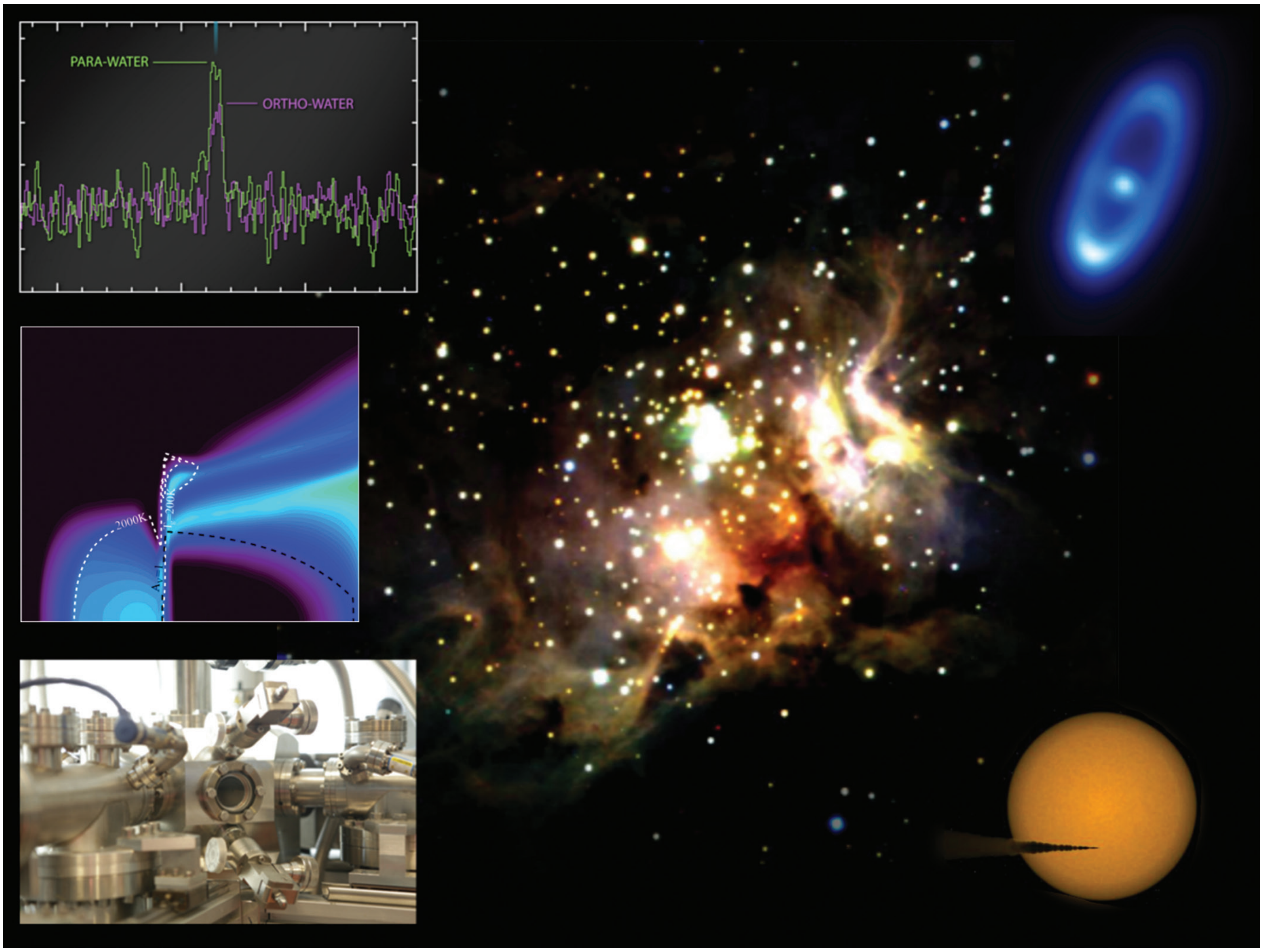


Figure 3.3: *Key results of Network-2 research related to their Phase-4 research program. Background: JHK broadband image of the massive star-forming region RCW 36 in the Vela molecular cloud (Ellerbroek et al. 2013). Left from top to bottom: Discovery of water emission in the TW Hydra disk with Herschel/HIFI (Hogerheijde et al. 2011), model of water vapor distribution in TW Hydra (Kamp et al. 2013), Sackler laboratory setup for the study of water formation (Ioppolo et al. 2010). Right from top to bottom: Herschel/PACS image of the debris disk around Fomalhaut (Acke et al 2012), artist impression of the evaporating planet KIC 12557548 b (Brogi et al 2012).*

of the conditions that allowed the development of life on Earth and possibly on other exoplanets. The Network-2 program is structured along the following three themes:

- Protoplanetary disks
- Characterization of extrasolar planets
- Massive stars and their formation

In addition to these themes, the Network-2 program also supports two cross-network positions, and two positions for instrument support.

THEME 1: PROTOPLANETARY DISKS

Planets form when dust particles in disks surrounding young stars aggregate and slowly grow into pebbles, boulders, and ultimately planetesimals. Gravity will collect these bodies into planetary cores and terrestrial planets. The largest cores of several Earth masses can start to accrete large envelopes of gas and evolve into giant planets. The study of these planet-forming disks links the earlier stages of star formation – including chemical evolution - to the large numbers of exoplanets detected around other stars, and it also connects the different areas of Network-2 research. Under the NOVA

PROJECT	TITLE	RESEARCH LEADERS	PLACE	SUPPORT
	Theme 1: protoplanetary disks			
nw2-01	Disk structure and planet formation across spectral types	Kamp	RUG	AIO, 4 yrs
nw2-02	Mid-IR spectroscopy of protostars and disks	van Dishoeck	UL	AIO, 2 yrs *
nw2-20	MIRI science support	van Dishoeck	UL	Support, 1 yr °
nw2-03	Infrared spectroscopy of carbon chain radicals of astronomical interest	Linnartz	UL	AIO, 2 yrs °°
nw2-04	PAH evolution in disks	Tielens	UL	AIO, 4 yrs
nw2-05	Transport in disks with freeze-out	Dominik	UvA	AIO, 4 yrs
nw2-06	Planet formation: gravity, hydro-, and thermo-dynamics in disks	Spaans	RUG	Postdoc, 1 yr
nw2-07	Observing disk structure with evolving dust	Hogerheijde	UL	AIO, 4 yrs
	Theme 2: characterization of extrasolar planets			
nw2-08	Identifying the brightest transiting planets using MASCARA	Snellen	UL	AIO, 4 yrs
nw2-09	Scientific preparation for transit observations with MIRI	Waters, Stam	UvA	Postdoc, 2 yrs ***
nw2-10.1	Direct imaging techniques with SPHERE-ZIMPOL	Keller, Kenworthy	UL	Postdoc, 2.5 yrs
nw2-10.2	Direct imaging techniques with SPHERE-ZIMPOL support	Keller, Kenworthy	UL	Support, 2.5 yrs
nw2-11	Modelling disks and planets in reflected light	Keller, Dominik, Kenworthy	UvA	AIO, 2 yrs *
	Theme 3: massive stars and their formation			
nw2-12	High mass star formation from Herschel to ALMA	van der Tak	RUG	AIO, 4 yrs **
nw2-13	Formation and early evolution of the most massive stars	Kaper	UvA	AIO, 4 yrs
nw2-14	Episodic mass-loss by massive stars in low metallicity environments	de Koter	UvA	Postdoc, 2 yrs
nw2-15	Resolving the star formation history in the Gould belt with Gaia	Brown, Kaper	UL or UvA	AIO, 4 yrs
nw2-16	Population synthesis of star forming galaxies	de Koter	UvA	AIO, 2 yrs *
nw2-17	The quest for DIB carriers: a Dutch laboratory approach	Linnartz	UL	AIO, 2 yrs *
	Cross network projects			
nw2-18	Diffuse emission in the Galactic plane	Haverkorn, Vink	RU	AIO, 4 yrs
nw2-19	The ISM as calorimeter: how accreting compact objects impact environment	Spaans, Markoff	RUG	Postdoc, 0.5 yr "

Table 3.2: *Network-2 research program in NOVA Phase-4.*

* *The positions will be supported for four years with NOVA funding for 2 yrs and university/personal grant support for 2 yrs;*

** *Joint project with SRON, 100% funded by NOVA;*

*** *Joint project with SRON, 50% funded by NOVA and 50% by SRON;*

ʿʾ *0.5 yr funding from nw-2; 0.5 yr funding from nw-3; 2 yr funding from external grant;*

° *In addition 1 yr funding from MIRI project*

°° *In addition 2 yrs funding from Laboratory Astrophysics project*

Phase-2 and Phase-3 programs, tremendous progress has been made in the study of disks. The progress has been observationally and theoretically and has been strongly supported by laboratory measurements. Two space missions, the Spitzer Space Telescope and the Herschel Space Observatory, provided unique insight in the structure and chemical composition of protostars and disks. From the ground, high resolution spectroscopy at near- and mid-infrared wavelengths on VLT was used to trace the inner disks, while the outer disks were probed with the JCMT and with millimeter interferometers such as SMA. On the theoretical and laboratory side, efforts have focused on understanding the physical structure and chemical composition of disks and on the evolution of the spatial distribution and the size distribution of the dust. The overall picture that emerges is one of a rich diversity of disk morphologies reflecting different evolutionary paths. A significant subset of disks has cleared out inner regions, either because of photo-evaporation of the material, or because planets have dynamically cleared their surroundings. The chemical composition appears strongly coupled to the location of the dust, since the dust regulates the penetration of stellar ultraviolet into the disk. Hints of substantial vertical settling, radial migration, or even non-axisymmetric distributions, of dust are found in the data.

In Phase-4 the pace of discovery is expected to increase: new observational facilities, in particular ALMA, and VLT-SPHERE, and later VLTI-MATISSE and JWST-MIRI will provide a wealth of new data with unprecedented high spatial and spectral resolution, coupled with huge jumps in sensitivity. These data will revolutionize our understanding of disks since they allow the crucial planet forming zones in disks (1-30 AU) to be resolved. Inspired by this flood of information, theoretical models are set to increase in complexity to tackle the new levels of detail. In parallel, laboratory data are needed to interpret spectroscopic surveys at different wavelengths and to provide a better understanding of the chemical richness and evolution during star and planet formation. With these facilities and associated theory development, finding the answer to the question how planets form inside disks and what controls the diversity comes within our reach.

The Network-2 research on disks will focus on the interlinked questions of how dust settles and migrates in disks and grows into planets (nw2-05, nw2-06), what observational consequences this dust evolution has (nw2-07), what ALMA / Herschel / MIRI will learn about disk structure and composition (nw2-01, nw2-02), and how major carbon-bearing compounds evolve in the disk stage (nw2-03, nw2-04).

THEME 2: CHARACTERIZATION OF EXTRASOLAR PLANETS

The discovery of the first extrasolar planets leading up to the ~1000 planets known to date, has opened up a major new field of research. It enables astronomers to study the solar system in the context of many other planetary systems, and they can now begin to answer questions about the origin and evolution of planetary systems in general (Theme 1), and about the uniqueness of the solar system and our own planet Earth in particular. In the more distant future, there is the thrilling prospect of placing the origin and evolution of life on Earth in the context of other life-bearing planets in the Milky Way. Radial velocity and transit surveys (both from space and the ground) are rapidly revealing the general population of extrasolar planets in the Milky Way. They show that 10-15% of sunlike stars have Jupiter-mass planets, and the planet-frequency increases dramatically towards lower mass planets. Even our nearest neighbor star alpha Centauri B likely has an Earth-sized planet. It will not be long before the first Earth-like planets in the habitable zones of their host stars will be discovered, both with transit and with radial velocity measurements. The characterization of extrasolar planets has also taken off in spectacular ways, both using transiting systems and direct imaging techniques. Transmission and secondary eclipse photometry have already revealed the major molecular constituencies of hot Jupiter atmospheres as well as the thermal structure of these planets. Direct imaging techniques are particularly successful in studying massive planets in young stellar systems. Both techniques are undergoing transformational improvements, making them sensitive to smaller and cooler planets.

It is in this area where NOVA plays a leading role, and which forms the focus of this theme in Network-2. In the field of transiting planets, NOVA will prepare itself for making optimum use of future instrumentation, in particular MIRI on the JWST. Funding for one PhD student (nw2-10) will strengthen the discovery of the brightest transiting planets using the Multi-Site All-Sky CAmeRA (MASCARA), and a postdoc (nw2-11) who will develop a realistic instrument model for transit observations with MIRI. The development and utilization of direct imaging techniques is focused on the new, state-of-the-art SPHERE instrument for the VLT, in which NOVA has invested significant resources. Significant Dutch scientific output is ensured through the funding of a 5 year science and science support postdoc (nw2-08), and a PhD student (nw2-09) to model proto-planetary disks and planets in reflected light as will be observed by SPHERE/ZIMPOL.

THEME 3: MASSIVE STARS AND THEIR FORMATION

Massive single stars and massive binaries are spectacular systems and have been among the first objects that formed in the early Universe. Massive stars comprise a particularly important population of extreme objects, strongly impacting their surroundings and host galaxies, ending their lives in supernovae or gamma-ray bursts, and leaving neutron stars and black holes as remnants of their short but energetic lives. Yet massive star formation is not understood and their evolution is only poorly constrained. The formation mechanism of massive stellar objects is one of the most important open questions in modern astrophysics. Several formation scenarios have been proposed, of which competitive accretion and monolithic collapse are considered the most plausible. This discomforting situation is for a large part due to the lack of observations covering the formation and early evolutionary stages of these objects, a situation that is only recently remedied with the advent of a generation of new instruments and observatories, including X-Shooter and VISIR at the VLT, ALMA and the Herschel Space Observatory. In a coherent program, Network-2 will cover the formation and evolution from the first stages to the final result of the formation process of massive stars, using these new facilities on the ground and in space.

The approach is to test theories of massive star formation. The binary fraction among massive stars is large and the majority is part of close binary systems. Multiple star systems are the key end product of massive star formation. Network-2 researchers will take a novel approach and include multiplicity properties as quantitative tests of formation theories. The lifetimes of massive stars are so short that on a cosmic scale the simple presence of these objects is proof for on-going star formation. Populations of massive stars, spatially unresolved in the distant cosmos, are thus diagnostics of the star formation history of the universe as a whole. It is therefore essential to also study massive stars as a population, which will be done both observationally in the context of the Gaia space mission, and theoretically, developing state-of-the-art population synthesis models.

The comprehensive approach proposed here must address the pristine material from which stars are formed. This material is dominated by a gaseous component, however, a small (~1% by mass) but crucial constituent are solid-state (like) particles. These particles, responsible for obscuring star-forming regions at optical and near-infrared wavelengths, also shield material from the intense radiation field of young massive (proto-) stars. Part of this material reveals itself through diffuse interstellar bands (DIBs) in the spectra of background stellar objects. After almost a century of study the nature of the carriers of these DIBs still eludes us. Network 2 researchers will pursue a new laboratory technique in search for the nature of DIBs.

NETWORK-2 FUNDING IN 2014-2018

The Network-2 research program for NOVA Phase-4 is summarized in Table 3.2. NOVA funding for this program amounts to 3,175 k€. In addition co-funding of 520 k€ is secured from personal research grants guaranteed by university institutes. Because SRON co-funds several research positions it was decided – for administrative reasons – that SRON funds and manages the nw1-03 position and NOVA does the same for project nw2-12.

3.3. THE ASTROPHYSICS OF BLACK HOLES, NEUTRON STARS AND WHITE DWARFS

The Network-3 research can be broadly described as 'The physics of compact objects and their interaction with the environment'. Much of it is more traditionally called 'High-energy astrophysics' or 'Astroparticle physics'. Technological developments have recently matured in the fields of fast transients, and cosmic-rays. Network-3 is planning to use these new facilities to study the physics and formation of compact objects (white dwarfs, neutron stars and black holes) and their interaction with the environment on stellar and galactic scales.

The research of Network-3 is evolving over time, but the formation and physics of stellar mass compact objects as the end points of stellar evolution has remained the focal point. These extreme objects not only bear witness to the final and least understood phases of the evolution of stars, they also provide physics laboratories for experiments in strong gravity, high magnetic fields and ultra-dense matter. These often only become available when the compact objects reside in binary or multiple systems. The formation and evolution of these binary systems itself is in many places highly uncertain. In case of accreting black holes, theoretically expected scalings relating to stellar-mass and super-massive black holes can be used to study the physics of accretion and ejection and the role of super-massive black holes in galaxy formation. Cosmic rays likely originate in super-massive black holes as well as in supernova remnants, but their study is hindered by uncertainties in the knowledge of their propagation.

Studying these diverse yet connected topics needs a good balance between observations, theoretical and computational projects as well as strong collaboration between the different research groups within Network-3. The observational work benefits greatly from LOFAR and many of the new projects use this great observatory and exploit earlier ASTRON and NOVA investments. New facilities such as the Fermi Gamma-ray telescope, the optical Palomar Transient Facility, ALMA, Gaia and the MeerKAT SKA pathfinder bring new opportunities to our research. Network-3 continues to use the very successful X-Shooter spectrograph on the VLT, X-ray telescopes such as Chandra, XMM-Newton and soon Astro-H to which SRON has contributed, and the Hubble Space Telescope. The NOVA-funded AMUSE framework for computational astrophysics has been delivered and is currently further extended and will be heavily used in several projects. The NOVA aim of bringing instrumentation expertise to the university groups has worked and several Network 3 researchers are actively pushing new instrumentation efforts, in particular a transient machine for Apertif (ARTS), a dedicated optical gravitational-wave counterpart finder BlackGEM, a contribution to the international Cherenkov Telescope Array (CTA) and a sub-mm VLBI instrument named the Event Horizon Telescope (EHT).

For the upcoming period, Network-3 has grouped its research into five clusters described in detail below. Collaboration within the network is strong, as can been seen from the wide range of co-investigators from different research groups in each of the clusters. Advances in theoretical knowledge, simulation tools and observational facilities have put this network in an excellent position to study fundamental questions and take an active part in new fields that are on the brink of success.

The five themes of Network 3 are:

- Astrophysical transients
- Accretion, ejection and feedback from compact objects
- The physics of compact objects
- From binary star to high-energy phenomenon
- Supernova remnants as particle accelerators

THEME 1: ASTROPHYSICAL TRANSIENTS

Many of the sources related to compact objects reveal themselves through time variable emission. Finding interesting sources is thus often a matter of being capable of monitoring large parts of the sky. With the advent of efficient wide-field optical imagers and clever radio telescopes such as LOFAR, monitoring can be extended from the high-energy wave bands to real multi-wavelength transient studies. This brings fast transients within reach that are currently either extremely rare or undiscovered. Within this theme the aim is to open up the parameter space of fast transients and exploit new facilities such as LOFAR, Apertif, Gaia and MeerKAT for multi-wavelength studies of more traditional transients. The newly discovered sources will be used to study the astrophysics of accretion, magnetic fields and explosions and they may be the electromagnetic counterpart to gravitational-wave sources.

THEME-2: ACCRETION, EJECTION AND FEEDBACK FROM COMPACT OBJECTS

Accretion of matter onto compact objects is the most efficient form of energy generation and is typically accompanied by ejection of material, often in jets. This means that accreting compact objects have a very important (feedback) effect on their environment, both on stellar as well as galactic scales. Yet, both accretion and ejection are poorly understood. The network will study accretion and ejection using different objects (neutron stars versus black holes), different mass scales (stellar-mass and super-massive black holes), different environments (binaries, AGN and clusters) as well as different mass transfer rates. Theoretical models will be combined with unique data sets from LOFAR, Chandra, XMM-Newton and later Astro-H.

THEME 3: THE PHYSICS OF COMPACT OBJECTS

Compact objects (white dwarfs, neutron stars and black holes) are governed by extreme physics: degenerate matter, extremely high densities, extremely high magnetic fields and very strong gravity. It is unclear how matter behaves under these conditions and even after a century, it is untested whether General Relativity is an accurate description of gravity in the strong regime. The existence of black holes is now widely accepted, yet their signature feature, the event horizon, has never been seen. Using X-ray spectroscopy, Fermi gamma-ray and LOFAR radio observations, and dedicated VLBI observations, the physics of highly magnetized neutron stars and stellar as well as super-massive black holes will be studied.

THEME 4: FROM BINARY STAR TO HIGH-ENERGY PHENOMENON

Many stars, in particular massive stars, reside in binary or multiple systems and many star clusters are found in which high-energy sources reside. Often a companion star is needed to make the compact object shine and make the laboratory accessible to astronomers. At the same time, the interactions in the binary systems and clusters alter the properties (mass, spin, magnetic field) of the compact objects. However, the processes in which these interactions take place are poorly understood themselves and the different possible outcomes often confuse the picture of how accretion and other interactions alter the compact object properties. Network-3 researchers will use advances in computing tools (in particular the AMUSE framework) and observational knowledge to model the interactions in binary stars and clusters and the resulting compact object populations. Detailed observational studies of radio pulsars and X-ray sources in and outside clusters will be used to construct observational samples.

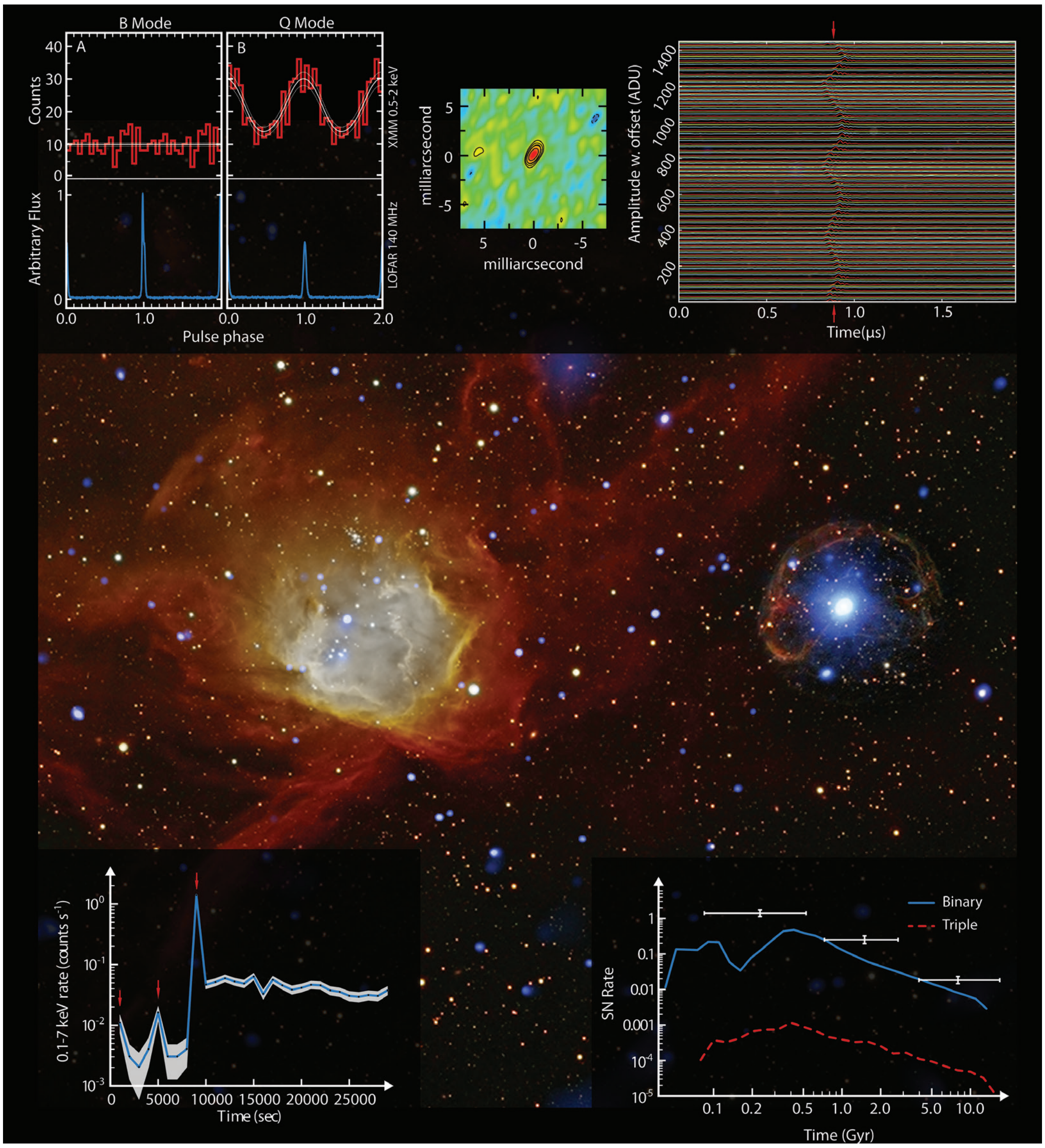


Figure 3.4: *Recent results from NW3 researchers relating to the five NW3 themes shown around a composite X-ray/ optical image of the star cluster NGC602 in the nebula N90 (left) and the X-ray pulsar SXP 1062 in a supernova remnant (right) in the Small Magellanic Cloud.*

Theme-1, bottom left inset: Discovery light curve of a new type of fast X-ray transient (Jonker et al. 2013).

Theme-2, top middle inset: Radio image of a newly discovered ultra-luminous X-ray source in M31 that can be used to probe the physics of the accretion disc - jet connection (Middleton et al. 2013).

Theme-3, top left inset: Discovery of the anti-correlation between X-ray and LOFAR radio brightness of the pulsar PSR B0943+10, challenging the physics of the pulsar emission mechanism (Hermsen et al. 2013).

Theme-4, bottom right inset: Inability of theoretical supernova type Ia rates from binary and triple stars to match the observations (Hamers et al. 2013).

Theme-5, top right inset: LOFAR detection of the time delays between the arrival of the radio emission from an air shower caused by a cosmic ray hitting the Earth that was likely accelerated in a supernova remnant, from the LOFAR overview paper (van Haarlem et al. 2013).

PROJECT	TITLE	RESEARCH LEADERS	PLACE	SUPPORT
	Thema 1: Astrophysical transients			
nw3-01	LOTAAS: LOFAR tied-array all-sky survey for pulsars and fast transients	Hessels	UvA	AIO, 2 yrs **
nw3-02	Fast optical and radio intra-night variables and transients	Groot	RU	AIO, 4 yrs
nw3-03	Fast Gaia transients: a treasure trove to be explored	Nelemans	RU	AIO, 4 yrs
nw3-04	ALERT: the Apertif legacy exploration of the radio transient sky	van Leeuwen	UvA	AIO, 2 yrs **
nw3-05	Detecting the Epoch of Reionization and transients with AARTFAAC/LOFAR	Koopmans, Wijers	RUG	AIO, 2 yrs ***
	Theme-2: Accretion, ejection and feedback from compact objects			
nw3-06	How does Sgr A* relate to other black holes?	Markoff	UvA	AIO, 4 yrs
nw3-07	Black-hole ejecta physics: studying tidal disruption events	Wijers	UvA	AIO, 4 yrs
nw3-08	AGN feedback and super-massive black hole growth with LOFAR	Wise	UvA	AIO, 2 yrs **
nw3-09	Physical origin of low-frequency QPO's in black holes and neutron stars	Uttley	UvA	AIO, 4 yrs
nw3-10	Outflows from supermassive black holes	Costantini, Uttley	UvA	AIO °
nw3-11	The ISM as calorimeter: how accreting compact objects impact environment	Markoff, Spaans	UvA	Postdoc, 0.5 yr "
	Theme 3: the physics of compact objects			
nw3-12	Black hole masses in Galactic black hole X-Ray binaries and X-Ray sources	Jonker	RU	Postdoc, 2.5 yrs °
nw3-13	Q(ED) music: radio bursts from magnetars	Watts	UvA	AIO, 2 yrs *
nw3-14	Imaging the Event Horizon of a black hole with radio telescopes	Falcke	RU	AIO, 2 yrs *
	Theme 4: from binary star to high-energy phenomenon			
nw3-15	Understanding binary mass transfer with AMUSE	Pols	RU	AIO, 4 yrs
nw3-16	From star/binary population synthesis to single/binary neutron stars	Verbunt	RU	AIO, 4 yrs
nw3-17	Formation and evoluton of young stellar clusters	Portegies Zwart	UL/RU	Postdoc, 2 yrs
nw3-18	Faint X-ray source populations in different environments	van den Berg	UvA	AIO, 2 yrs *

PROJECT	TITLE	RESEARCH LEADERS	PLACE	SUPPORT
	Theme 5: Supernova remnants as particle accelerators			
nw3-19	Galactic propagation of energetic cosmic rays and interactions with gas	Achterberg, Hörandel	RU	AIO, 4 yrs
nw3-20	Supernova remnants and pulsar wind nebulae observations with LOFAR	Vink, Haverkorn	UvA	AIO, 4 yrs

***Table 3.3:** Network-3 research program in NOVA Phase-4.*

* *The positions will be supported for four years with NOVA funding for 2 yrs and university/personal grant support for 2 yrs;*

** *Joint project with ASTRON. NOVA and ASTRON each fund 50% of the costs;*

‹› *0.5 yr funding from nw-3; 0.5 yr funding from nw-2; 2 yr funding from external grant;*

° *Joint projects of NOVA and SRON: nw3-10 is funding by SRON and nw3-12 is funded by NOVA.*

THEME 5: SUPERNOVA REMNANTS AS PARTICLE ACCELERATORS

Supernova remnants (SNRs) are the direct witnesses of the interaction of (massive) stars with their environment. They are important for energy input to the interstellar medium and for chemical enrichment. In addition, their structure makes them prime sources for the acceleration of charged particles to cosmic rays that spread through the Galaxy influenced by its magnetic field. When these hit the Earth, they can be studied to find their origin, but they also influence life by mutations and possibly climate. Many SNR in the Galaxy are still unknown. Network-3 researchers will find new SNR and study their role as particle accelerators as well as the propagation of cosmic rays through the Galaxy using theoretical models and state-of-art observations with LOFAR, HESS and later CTA and direct detection instruments such as TRACER.

NETWORK-3 FUNDING IN 2014-2018

The Network-3 research program for NOVA Phase-4 is summarized in Table 3.3. NOVA funding for this program amounts to 3,006 k€. In addition co-funding of 800 k€ is secured from personal research grants guaranteed by university institutes, and co-funding from ASTRON and SRON.

3.4 INVESTMENT IN FACULTY STAFF

Attracting and keeping internationally respected staff at the university astronomical institutes is 'key' to the NOVA program to stay at the forefront worldwide and to provide the best training to the students. For this reason NOVA invests of order 10% of its Grant in funding faculty staff or tenure track positions on the condition that NOVA funds the initial years of the new appointment and the university agrees to guarantee the ongoing support of these staff positions. For the period 2014-2018 an investment of 2.8 M€ is planned of which 0.6 M€ is covered by funds carried forward from Phase-3. This funding allows to overlap with two retirements, create five new staff positions, and to fulfill ongoing commitments from Phase-3 for one position. Further specifications are provided in Table 3.4.

INVESTMENT IN FACULTY STAFF	TOTAL	2014	2015	2016	2017	2018
UvA						
Dr. Selma de Mink	**1.9**	0.2	0.5	0.5	0.5	0.2
Characterization of exoplanets	**4.0**		1.0	1.0	1.0	1.0
Observations of radio transients	**1.5**			0.5	0.5	0.5
RUG						
Dr. John McKean (LOFAR. radio astronomy)	**2.5**	0.5	0.5	0.5	0.5	0.5
Infrared astronomer: SPICA-SAFARI and ALMA	**2.1**	0.1	0.5	0.5	0.5	0.5
Instrumentation liaison with NOVA Op-IR group	**2.2**	0.2	0.5	0.5	0.5	0.5
UL						
Astrophysics of interstellar gas and dust	**4.3**	0.3	1.0	1.0	1.0	1.0
RU						
Dr. Onno Pols	**3.5**	1.0	1.0	1.0	0.5	
Dr. Sören Larsen	**3.5**	1.0	1.0	1.0	0.5	
Dr. Elmar Körding	**0.5**	0.5				
Total staff effort (in staff years)	**26.0**	**3.8**	**6.0**	**6.5**	**5.5**	**4.2**

Table 3.4: *NOVA funded staff positions for the period 2014-2018. The positions colored in yellow will be paid from funds carried over from Phase-3.*

PLANNED INVESTMENTS IN STAFF POSITIONS AT THE INSTITUTES

UVA, ANTON PANNEKOEK INSTITUTE (API)

API is making a number of faculty hires related to its strategic priorities, which are in line with those of NOVA. The institute will invest in strengthening its two key science areas: high-energy astrophysics and star and planet formation, which are central to NOVA networks 3 and 2, respectively.

The MacGillavry Fellowship program of UvA's Faculty of Science for excellent women faculty staff gave API the opportunity to hire Dr. Selma de Mink. She is an expert in the astrophysics of massive stars and stellar populations. The fellowship in combination with API funding and the NOVA investment made it possible to offer her a long-term carrier perspective to return to the Netherlands.

The second position will be used to strengthen the research in exoplanetary science, by hiring an observer who will make optimal use of ESO facilities. This will strengthen the use of, and connection with, NOVA's instrumentation program. This research will also be coordinated with SRON, as part of the arrangement to move the SRON Utrecht institute to Amsterdam. This arrangement will be supported by an additional investment by the universities in two full professor positions by UvA and VU in the larger theme 'Are we Alone?', a collaboration with SRON and the Earth Science Department at VU. The NOVA investment allows an early, more vigorous start of this expansion in the faculty staff, well before the actual move of SRON (~2019), which is essential to get up to speed in this fast-moving field.

A third position partly supported by NOVA investment will be to strengthen API's high-energy astrophysics in the area of radio astronomy. This will be done in the form of two joint positions shared equally between ASTRON and API, further expanding the ASTRON-

API collaboration and ensuring optimal exploitation of the NL strategic priorities LOFAR and SKA for the research in NOVA network 3.

RUG, KAPTEYN ASTRONOMICAL INSTITUTE

To optimally use the proximity of the NWO-institutes ASTRON and SRON, and the NOVA Op-IR instrumentation group, it is important that the science priorities of the Kapteyn Institute are well coordinated and overlap with those of ASTRON and SRON, and that there are sufficient contacts with the Op-IR group. For this purpose in 2013 two SRON-scientists were appointed in endowed faculty positions, and the university and ASTRON jointly hired a new radio-astronomer (Dr. John McKean, Table 3.4)

The second NOVA investment is part of the recent agreement between SRON, the RUG and the Province of Groningen to continue the SRON activities in Groningen for at least ten more years. The plan is the start of two new joint positions; one is for an infrared astronomer who will take on a strong role in the definition of the science case for the SPICA-SAFARI instrument and related ALMA and APEX projects, and the other is for an instrumentation oriented astronomer, who will work closely with the NOVA Op-IR group in Dwingeloo. NOVA funds half of both positions for four years, after which the university takes over the commitments.

UL, STERREWACHT

Understanding the formation and evolution of galaxies, stars and exoplanets is at the core of the research program at Leiden Observatory. It is clear that molecular gas and dust play a crucial and complex role in the processes that shape these very different objects. Observations with the new ALMA observatory and other space and ground based facilities will play an important role for the next decades. Interpreting the observational data using both numerical modeling techniques and laboratory experiments are essential to advance the understanding in this field. With the official retirement of Tielens in 2019-2020, it is important to remain at the forefront in this field. The NOVA funds will be used to appoint a young and ambitious astronomer to strengthen the observatory activities in this field.

RU, ASTRONOMY DEPARTMENT

For the Radboud University the NOVA investment in staff positions has been crucial for an autonomous growth of the astronomy department. In the years up to 2012 NOVA startup funding helped to create three permanent positions (Nelemans, Hörandel, and Körding). For NOVA Phase-4 the investment has been used to allow a substantial part of the Utrecht group to come to Nijmegen. The NOVA investment supports the positions of Larsen and Pols (permanent), and in combination with funding from Utrecht and the Radboud University itself, also allowed Achterberg and Verbunt to transfer to Nijmegen. Through this combined investment the Radboud University department has grown to 10.9 fte permanent staff (until 2018), on par with the other NOVA institutes and in line with the 2010 IRB recommendation.

The long-term investment in retaining Pols and Larsen for NOVA strongly supports the home-base function for ESO on both the observational and theoretical side. Larsen is an observational astronomer specialized in star clusters in the Local Universe. He not only forms a bridge between NOVA networks 1 and 2, but is also part of the E-ELT MOSAIC and MICADO science teams. Pols is a theoretical astronomer who is one of the world-leading experts on stellar evolution in single and binary stars. His work is essential for the interpretation of (ESO) observations on compact binaries, high-mass binaries, peculiar-composition stars in the Galactic halo (Gaia-related) and binary merger products. As such he closely collaborates with observational and numerical groups (Groot, Nelemans, Portegies Zwart, Helmi, Tolstoy, Langer).

4. INSTRUMENTATION

In the past decades the Netherlands has built up a strong reputation through NOVA in various areas of optical/infrared (Op-IR) and millimeter instrument design, construction and subsequent science exploitation. This manifests itself not only in scientific and technical publications, but also by the fact that NOVA is an attractive partner in international collaborations with foreign partners asking Dutch astronomers to join their instrumentation projects and wanting to participate in Dutch projects. This development has recently culminated in ESO and international consortium partners entrusting NOVA to take on the role of Principal Investigator for the mid-infrared instrument for the European Extremely Large Telescope (E-ELT) and to take responsibility for the final design and production of the Band-5 receivers for ALMA in cooperation with the Swedish partner GARD/Chalmers University. This strong NOVA track record in Op-IR and millimeter astronomical instrumentation complements that of ASTRON, which has recently completed the innovative LOFAR radio telescope and is contributing to the development of SKA, and that of SRON which develops novel space instruments for the X-ray and far-infrared domains. On the national scale ASTRON, SRON and NOVA work closely together to implement the 10-year plan as laid down in the 2011-2020 National Strategic Plan for Astronomy in the Netherlands.

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 priority access to these facilities by partnerships with other countries and by instrument development, construction and data handling 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, infrared and millimeter/submillimeter 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. Through ASTRON they have access to the fully Dutch-owned Westerbork Synthesis Radio Telescope (WSRT), the LOFAR international radio telescope and the multi-lateral EVN-JIVE facility. SKA is gaining momentum with support of numerous countries worldwide, a number of technology development projects and prototype stations in Australia, South Africa and the Netherlands (LOFAR). Through SRON, Dutch astronomers have in-depth expertise in using instruments on the XMM-Newton and Chandra space missions with in the near future participation in ASTRO-H, and in the long-term Athena+. In the far-infrared they had guaranteed time on the HIFI instrument on the Herschel Space Observatory, and are looking forward to SPICA-SAFARI. Finally, astronomers in the Netherlands have traditionally also been very successful in getting access – in open competition - to major telescopes worldwide, including those not funded by the Netherlands.

OVERVIEW OF THE PHASE-4 INSTRUMENTATION PROGRAM

NOVA STRATEGY

NOVA astronomers are actively involved in designing and building instruments to ensure the required capabilities for their science, to gain expert knowledge of the increasingly complex instruments and to be in a position to harvest the first scientific results. The focus is on instruments to be used on 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 provides astronomers with privileged and early access to the telescopes and enables large coherent programs with exclusive data access.

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/submillimeter Array (ALMA). Most of the projects in the previous NOVA Phases 1-3 were carried out in collaboration with typically 4-6 international partners with each 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.

In 2010 the NOVA instrumentation program attracted special attention of both the International Review Board (IRB) and the NWO evaluation committee. The IRB noted "*the depth and variety of astronomical instruments developed by NOVA scientists and engineers, and the remarkable achievement that most of these instruments were delivered on time and on budget*".

The instrumentation projects completed in recent years include the design, prototyping and construction of 72 ALMA Band-9 receiver cartridges covering the atmospheric window between 610 and 720 GHz, the X-Shooter spectrometer on the VLT with the near-infrared arm delivered by NOVA, the OmegaCAM panoramic imager and dataflow system (with NOVA leading the instrument consortium), the ground-based testing and delivery of the MIRI instrument on JWST to NASA with an NOVA contribution to the mid-infrared spectrometer, the AMUSE software instrument for astrophysical multi-scale and multi-domain simulations, and the NOVA part of the development of software data-reduction packages for the four LOFAR key projects. In 2008-2010 NOVA researchers made significant contributions to the Phase-A studies of four instrument concepts for the E-ELT: these include the 'first-light' imager MICADO, the mid-infrared imager and spectrometer METIS, the Multi-Object Spectrometer (MOS) OPTIMOS-EVE (now transformed into MOSAIC), and EPICS optimized for high-contract optical studies of exoplanets.

PREPARATION INSTRUMENTATION PROGRAM

In September 2012 NOVA received 16 pre-proposals for instrumentation projects for its Phase-4 program in response to a call for proposals that was issued to the entire university astronomical community in the Netherlands. All proposals were presented to the community at an open national instrumentation day held in Amsterdam on 25 September 2012.

The proposals were reviewed by the network researchers on their scientific merit and their justification within the national astronomy program. Each research network provided a motivated ranking of proposals to the NOVA Board. In parallel the proposals were reviewed by the NOVA Instrument Steering Committee (ISC) on their technical feasibility, financial aspects, project management and risks. At their meeting of 10 December 2012 the NOVA Board invited 13 out of the 16 pre-proposals to submit a full proposal.

In March 2013 NOVA received 12 full proposals which were reviewed by the ISC on technical merits, project organization, financial aspects and project risks. At its meeting of 18 April 2013 the NOVA Board approved all 12 proposals with some projects receiving a firm budget allocation for the entire project and others only start-up funds for a design phase up to PDR or FDR with a provisional budget reservation for the further project costs conditional to successful delivery of the design work and meeting the conditions for passage of the toll-gate.

OVERVIEW PHASE-4 INSTRUMENTATION PROGRAM

The NOVA instrumentation program enables astronomers in the Netherlands to secure guaranteed access to observing capabilities that are essential for their research themes but do not yet exist. The strategy is to design and build auxiliary instruments for existing or new telescope facilities provided by other organizations.

NOVA acts as the national home-base for ESO by providing instruments for the Paranal Observatory, for ALMA and the E-ELT. The projects are led by a Principal Investigator (PI) based at one of the NOVA institutes who is also co-I in the international collaboration. In general each Op-IR instrument project is a joint effort of four to ten international institutes working together as a Consortium structured under a Memorandum of Understanding (MoU) and a contract with ESO. ESO entrusts the Consortium to design, build and verify the instrument. In return, after delivery, the Consortium receives guaranteed observing time to be the first to use the instrument on an ESO telescope. In parallel the instrument is offered for use by the astronomical communities in the ESO member states following the regular ESO proposal process.

In NOVA projects, the PI must spend a significant fraction of his time on the project. His main task is to ensure that the scientific objectives of the project will be maintained, to provide leadership for the NL team working on the project, and to represent NOVA in the relations with the consortium partners and with ESO. The design and construction work for the project are usually done by the NOVA Op-IR instrumentation group based in Dwingeloo, with some exceptions where work is performed by a team within the university institutes. Collaboration with industry has grown since NOVA took over the group in 2008.

In 2014-2018 the focus is on participation in the design and construction of instrumentation for the E-ELT with the mid-infrared imager/spectrometer METIS as the NOVA flagship, including the PI role in the international consortium and an important contribution to the 'first light' camera/spectrometer MICADO. The strategy is to take responsibility for those parts of the instrument that are directly linked to the science questions.

The next sections will describe each of these projects in more detail with the emphasis on the NOVA role and contributions.

4.1. E-ELT INSTRUMENTATION

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

In 2014-2018 NOVA will participate in the design and construction of the mid-infrared imager and spectrometer METIS as consortium lead and PI, and in the 'first-light' instrument MICADO as one of the 4-6 consortium partners. In addition NOVA will work with international partners to develop the science case and the instrument concept for the multi-object spectrometer MOSAIC, and will continue technical R&D for the EPICS instrument that will characterize exoplanets.

4.1.1. MID-INFRARED INSTRUMENT METIS

METIS is the Mid-infrared E-ELT Imager and Spectrometer for the E-ELT. It is the only E-ELT instrument to cover the scientifically important thermal/mid-infrared wavelength range from 3–14 μm. METIS is a combined imager equipped with a medium-resolution spectrometer and a high resolution integral field unit. Mounted on the 39m telescope this instrument will open up discovery space with Spitzer-like sensitivity at optical HST resolution but at thermal infrared wavelengths.

SCIENCE CASE

The E-ELT will surely open up new perspectives for optical/infrared astronomy and enable new kinds of observations in the thermal and mid-IR range which have never been possible before. Contemporary astronomy is more and more focusing on that wavelength range as many objects are intrinsically cool (e.g., Solar System bodies, disks and exoplanets), emit important spectral features in this wavelength range, or have their characteristic features redshifted into the thermal infrared. Based on these considerations and the synergies and complementarity with ALMA and JWST, the international METIS science team has identified five science drivers from which the top level requirements for METIS were derived:

- Discovery and characterization of exoplanets
- Circumstellar disk structure and evolution
- Formation and evolution of stars and star clusters
- Physics and chemistry of the solar system
- Formation and evolution of galaxies.

These science drivers are also at the heart of NOVA Networks 1 and 2. In addition, numerous additional science areas are identified, in which METIS is expected to make substantial contributions. These areas include the Galactic Center, the atmosphere of Mars, the properties of low-mass brown dwarfs, evolved stars and their environments, high-mass star formation and UCHIIRs, the IMF and disk survival in massive stellar clusters, and GRBs as cosmological probes.

The key to the success of METIS will be its superb sensitivity (Fig. 4.1). Although the imaging sensitivity of ground based observations at thermal infrared wavelengths will always be inferior to space, METIS' sensitivity becomes comparable to the sensitivity of the Spitzer Space Telescope but with 45 times (!) higher spatial resolution. To estimate the sensitivity to extended emission, the METIS team has developed an end-to-end instrument simulator, of which some preliminary results are shown below.

The wide range of observing modes ensures that METIS will remain powerful and flexible enough to respond to future challenges in observational astronomy. Two science cases are described in more detail below.

Exoplanets: the two main science questions are (1) which stars have planetary systems?; and (2) what are the physical properties of the planetary systems? The first question is connected to the detection of exoplanets while the second goal is related to the characterization of exoplanets (i.e., their orbital parameters, internal structures, temperature profiles, atmospheric composition, weather and seasons, and signs of life). While METIS is expected to make contributions to both, its unique power will mostly

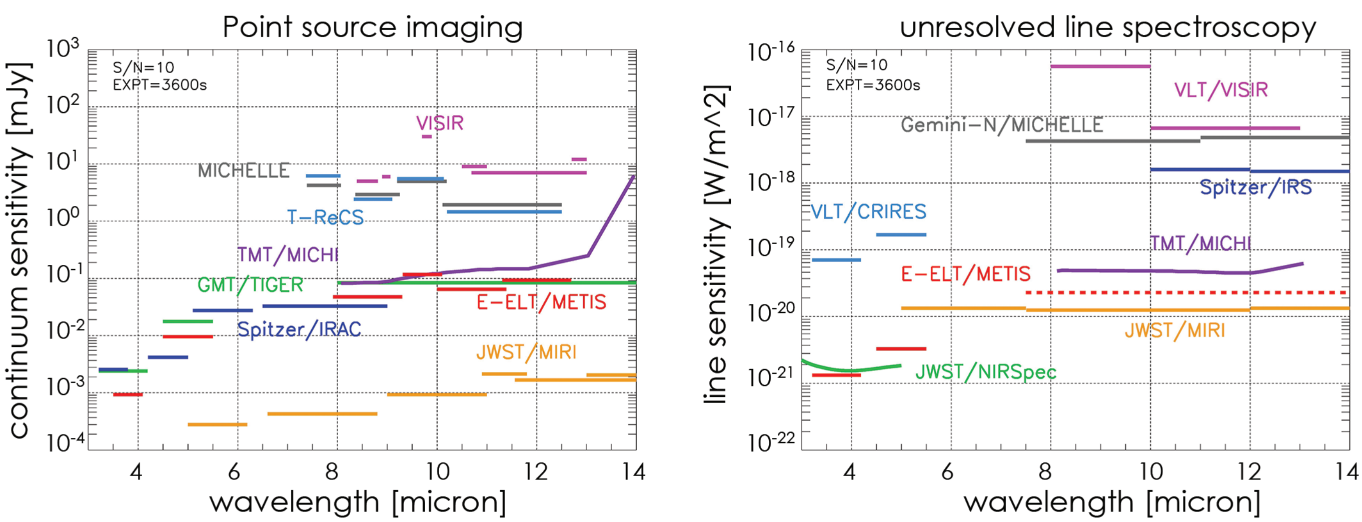


Figure 4.1: METIS point source sensitivity (left) and unresolved line sensitivity (right) compared with other (future) instruments.

be in the characterization. Monte Carlo simulations using the population of known (detected) exoplanets from radial velocity studies and extrapolating their masses and orbital periods to fill a larger parameter space show that METIS will be able to directly detect large numbers of exoplanet systems in comparison to current state of the art facilities (NACO on the VLT). Most importantly, this increase is not just an increase in number, but also expanding the discovery space to lower masses and much smaller separations from the host star. A second simulation using the sample of Kepler-detected exoplanet systems with orbits P < 50 days around stars within 8 parsec from the Sun shows that the near-IR capability of METIS will be unsurpassed in the detection of reflected light; METIS will be unique for studying the thermal emission of planets.

Proto-planetary disks: key questions for the study of proto-planetary disks are (1) the interactions between proto-planet and disk: do observations provide evidence for planetary systems in their formation?; (2) proto-planetary disk evolution: what is the dominant mechanism that disperses the primordial gaseous disk – or what is the likelihood that the inner disk can form a planetary system before it is being photo-evaporated?; and (3) chemical processes in disks: what is the chemical composition of the disk (and hence the basic ingredients out of which planets can form) and how does it evolve with time and distance?

With an angular resolution of ~3.3 AU in nearby (~140pc) star forming regions and its unique high spectral resolution ($R \sim 10^5$) IFU mode, METIS is capable to directly address these questions. While ALMA is unsurpassed for probing the cooler molecular gas in the outer 20 – 100 AU disks, METIS is unique for detecting and resolving the warm gas in the inner disk, where exoplanets are forming, out to 15 AU from the star.

INTERNATIONAL CONSORTIUM AND PROJECT STATUS

The international METIS consortium is led by NOVA (PI: Brandl), with six partners being MPIA (Germany), CEA-Saclay (France), UK-ATC (UK), KU Leuven (Belgium), ETH Zürich (Switzerland), and the University of Vienna (Austria). In addition, ESO will provide the detector systems. The METIS consortium draws heavily from its long-term successful experience with numerous ground- and space-based infrared instruments, including JWST-MIRI, VLT-VISIR, Spitzer-IRS, ISO-SWS, and VLT-NACO. In the E-ELT roadmap ESO has identified the mid-infrared instrument as the 3rd instrument. METIS is the only candidate for this slot. METIS possesses a high level of technology readiness and the consortium partners have already secured a major fraction of the required financial resources. The anticipated commissioning date of METIS at the telescope is in 2026 assuming that all funding for the E-ELT will be secured by mid 2014.

TECHNICAL CONCEPT

METIS is the only instrument on the E-ELT for wavelengths longer than 2.5 microns. It will have two main instrument modes:

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

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

STAFF EFFORT IN FTE	TOTAL	2014	2015	2016	2017	2018
Project manager A	**4.5**	0.5	1.0	1.0	1.0	1.0
Project manager B	**2.5**		0.5	0.5	0.5	1.0
System engineer A	**4.4**	0.4	1.0	1.0	1.0	1.0
System engineer B	**2.1**	0.4	0.5	0.5	0.5	0.2
Instrument scientist	**3.2**	0.2	0.5	1.0	1.0	0.5
Optical design	**4.0**	0.2	0.8	1.0	1.0	1.0
Mechanical design A	**4.3**	0.3	1.0	1.0	1.0	1.0
Mechanical design B	**6.5**		1.5	2.0	2.0	1.0
Procurement. Manufacturing	**1.9**		0.3	0.3	0.3	1.0
Assembly. Integration. Test	**2.1**	0.2	0.2	0.3	0.4	1.0
Electronic Engineer	**0.3**					0.3
Support scientist	**4.0**		1.0	1.0	1.0	1.0
Quality Assurance	**1.2**		0.1	0.4	0.4	0.3
Project Control	**2.0**		0.5	0.5	0.5	0.5
Secreterial support	**1.9**		0.4	0.5	0.5	0.5
Coronograph expert	**0.4**		0.1	0.1	0.1	0.1
Principal Investigator	**3.4**	0.5	0.8	0.7	0.7	0.7
Total staff effort for NL	**48.7**	**2.7**	**10.2**	**11.8**	**11.9**	**12.1**

STAFF COSTS IN K€	TOTAL	2014	2015	2016	2017	2018
Staff costs at OP-IR group	**3304**	130	657	818	840	859
Other staff costs	**1152**	60	242	285	287	278
Outsources work to industry	**700**		200	200	200	100
Total NOVA staff costs in k€	**5156**	**190**	**1099**	**1303**	**1327**	**1237**

MATERIAL BUDGET (IN K€)	TOTAL	2014	2015	2016	2017	2018
Travel	**275**	40	50	60	55	70
Prototyping	**500**	100	200	200		
Hardware procurement	**700**				200	500
Integration facility	**120**			20	50	50
Miscelleneous	**106**	26	20	20	20	20
Total Material costs (k€)	**1701**	**166**	**270**	**300**	**325**	**640**

Total costs METIS (k€)	**6.857**	**356**	**1.369**	**1.603**	**1.652**	**1.877**

Table 4.1.1: *Estimated costs (in k€) for the NOVA contribution to METIS for the period 2014-2018. In addition the costs for NOVA after 2018 up to and including commissioning of the instrument on the E-ELT are budgeted for 7.3 M€ including project contingency.*

NL TEAM

Brandl (UL in-kind contribution) is the elected international Principal Investigator for METIS. Venema (ASTRON in-kind contribution) is the international system engineer. In addition there are 12 Co-I's in the Netherlands from UvA, RUG, UL, TU Delft and SRON.

COSTS AND FUNDING

The costs of the NOVA contribution to METIS are estimated to be of order 14.8 M€ for which full funding is now secured. The costs for the period 2014-2018 amounting to 6,857 k€ are summarized in Table 4.1.1. In addition NOVA has made a project contingency reservation of 600 k€ for this period. Funding contributions come from NOVA (3,000 k€), the national Roadmap for large-scale research infrastructures (4,457 k€), and in-kind staff contributions from ASTRON and Leiden Observatory which are not listed in Table 4.1.1. For work on METIS after 2018 up to and including commissioning of the instrument on the telescope, a funding reservation of 7.3 M€ has been made from the national Roadmap program.

The funding for the project costs in 2014 and 2015 amounting to 1,725 k€ are allocated. These resources allow the project to work together with its international partners and ESO to assess the impact of the change in telescope parameters, achieve a final statement of work, complete technical specifications, a full project costs estimate, and divisions of work among the partners. In preparation of the contract with ESO the NOVA Board will decide on its full funding allocation to the METIS project.

4.1.2. E-ELT OPTICAL/NEAR-INFRARED IMAGING-SPECTROMETER MICADO

MICADO is the Multi-AO Imaging Camera for Deep Observations. It is a high profile European-wide project to build the 'first light' adaptive optics camera and spectrometer for the E-ELT. This instrument will provide the first pictures from the E-ELT. It will be optimized to work at the diffraction limit of the 39m telescope over a wide field of view using the multiconjugate adaptive optics (MCAO) module MAORY. It will also allow a phased approach and thus be able to work with any adaptive optics system, and it includes its own separate module to provide a single conjugate adaptive optics (SCAO) capability primarily for use during the earliest operational phase. This simple on-axis, natural guide star mode system sets relatively low requirements on the telescopes' AO performance (no lasers), but still provides excellent performance over small fields of view. An obvious complement to imaging is spectroscopy, and this additional capability makes MICADO an extremely powerful 'first light' instrument.

SCIENCE CASE

MICADO will address a large number of science topics that span key elements of modern astrophysics and also the broad interests of the Dutch astronomical community. It will open up a new parameter space in both spatial resolution and astrometric precision to trace the movements of individual stars in a range of environments. This means that astronomical sources are no longer static, but they become dynamic entities. This will allow dramatic new insights into the 3-dimensional structure and evolution of a range of different targets.

The Galactic Center is a unique laboratory for exploring strong gravity around the closest massive black hole. The fundamental goal is to measure the gravitational potential in the relativistic regime very close to the central black hole via stellar motions, using very faint stars that cannot be detected or studied with any other facility. These motions can reveal the extended mass distribution from stellar black holes that should dominate the inner region, as well as the dark matter distribution.

Globular clusters are ancient compact stellar systems that surround the Milky Way, and may also host intermediate mass black holes. The presence and masses of these black holes can be derived from detailed measurements of the internal kinematics of a cluster. Deriving the proper motions and thus the orbits of these globular clusters around the Milky Way would enable us to address detailed questions about their formation and evolution, as well as that of our Galaxy. The intriguing multiple populations of these systems that were recently discovered also remains a mystery and more detailed study of the kinematics of globular clusters in the vicinity of the Milky Way will shed light on this issue as well (NL interest: Kuijken, Larsen, Tolstoy).

The internal kinematics of dwarf spheroidal galaxies will be better understood from accurate proper motion studies. This would remove a large degree of degeneracy in the interpretation of velocity dispersion studies and provide an accurate measure of the dark matter content and distribution in these objects, hence testing models of structure formation, and putting very strong limits on the nature of dark matter particles themselves (NL interest: Kuijken, Helmi, Tolstoy).

Resolved stellar populations in the form of color-magnitude diagrams provide uniquely detailed information about the star formation history of a stellar system, tracing the fossil record of the star formation from the present day back to the earliest times. Spatially resolving stellar populations is crucial, since the youngest and brightest stellar population always dominates the integrated luminosity. MICADO will be able to resolve stars for detailed photometric and spectroscopic studies over a wide range of environments, from our Galaxy to >30 Mpc distance, for star clusters and also field stars in a large range of galaxy types, including elliptical galaxies. This is possible due to the combined effects of increased sensitivity and spatial resolution, both of which are fundamental for this science case. MICADO will push the analysis of the stellar populations deeper into the central regions of both nearby and more distant high surface brightness galaxies (NL interest: Tolstoy, Trager, Peletier, Groot, Larsen, and Kaper).

Other topics with an interest from astronomers in the Netherlands include (a) star-forming regions, (b) high redshift galaxy studies, (c) properties of the central regions of galaxies, and (d) strong gravitational lensing.

There are three key capabilities that exemplify the unique features of MICADO at the E-ELT and that will contribute to make it the most powerful optical/infrared instrument available until a telescope with a larger aperture is built. These capabilities lie at the heart of the primary science cases that have driven the design of the camera, and they are:

- Sensitivity and resolution
- Precision astrometry
- High throughput spectroscopy

INTERNATIONAL COLLABORATION

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

INSTRUMENT CONCEPT

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

The NOVA contribution to the international consortium has been chosen to be that which makes the best use of Dutch expertise. The largest planned NOVA contribution to MICADO is the Atmospheric Dispersion Corrector (ADC), which is required to obtain diffraction limited images, and thus accurate and sensitive photometry and astrometry. A pilot study of the ADC started in September 2012. Preliminary results show that this component is complex but feasible and can be built by the NOVA Op-IR instrumentation group. Another NOVA contribution to the project is the development of the calibration strategy and data flow system by the NOVA-OmegaCEN team.

STAFF EFFORT IN FTE	TOTAL	2014	2015	2016	2017	2018
Project management	**1.1**	0.2	0.2	0.2	0.2	0.3
ADC system engineer	**1.4**	0.2	0.3	0.3	0.3	0.3
ADC optical design	**0.8**	0.2	0.2	0.2	0.2	
Mechanical design	**4.1**	0.2	0.6	0.9	1.0	1.4
Procurement, Manufacturing	**0.4**			0.1	0.1	0.2
Assembly, Integration, Test	**0.0**					
Software workplan manager	**1.1**		0.2	0.3	0.3	0.3
Software programmer	**1.0**		0.1	0.3	0.3	0.3
Total staff effort for NL	**9.9**	**0.8**	**1.6**	**2.3**	**2.4**	**2.8**

STAFF COSTS IN K€	TOTAL	2014	2015	2016	2017	2018
Staff costs at Op-IR group in k€	**927**	96	153	201	215	262
Staff costs at Universities in k€	**167**	0	24	47	48	48
Total NL staff costs in k€	**1095**	**96**	**177**	**248**	**263**	**311**

MATERIAL BUDGET (IN K€)	TOTAL	2014	2015	2016	2017	2018
Travel + ICT equipment	**73**	13	13	15	16	16
Hardware Mechanics	**0**				pm	pm
Prototype + test equipment	**19**	0	0	4	5	10
Total Material costs (k€)	**92**	**13**	**13**	**19**	**21**	**26**
Reservation for work beyond 2018	**807**					807
Total costs Micado (k€)	**1.994**	**109**	**190**	**267**	**284**	**1.144**
NOVA funding reservation (in k€)	**1.994**	**109**	**190**	**267**	**284**	**1.144**

Table 4.1.2: *Estimated costs and NOVA funding reservation (in k€) for the participation in the E-ELT 'first-light' instrument MICADO. The expected costs for the completion of the work after 2018 (of order 807 k€) are taken into account.*

NL TEAM

The project team for the Netherlands is led by Tolstoy, who is also project scientist and co-I of the international project team, with support of Navarro (PM; hardware) and Verdoes Klein (software). The NL science team consists of six staff members from RUG, UL and RU.

PROJECT FUNDING

The total costs of the NOVA contribution to the E-ELT 'first-light' instrument MICADO amount to 1,994 k€ excluding the contingency reservation for the Phase-4 period of 125 k€. It is assumed that ESO or a proposal for external funding covers the costs for hardware.

The budget figures shown in Table 4.1.2 are reservations. The Board will decide on the NOVA contribution after the pilot-study on the ADC system is completed and externally reviewed.

4.1.3. E-ELT MOSAIC

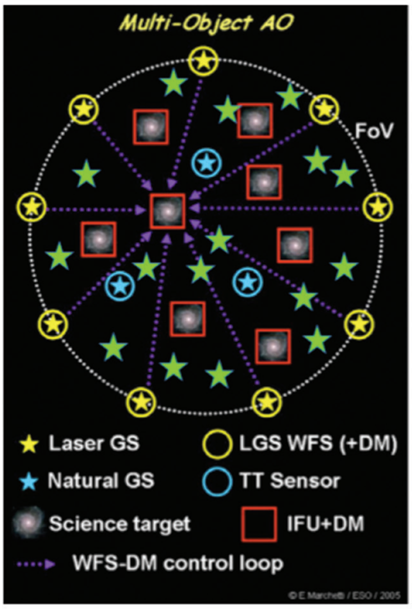
Astronomers in the Netherlands aim to participate in the E-ELT/MOS definition process, following the successful completion of the Phase-A study on the fiber-fed multi-object spectrometer OPTIMOS-EVE, building on the NOVA expertise with VLT/X-Shooter. On a European scale, discussions between the OPTIMOS-EVE and EAGLE (another Phase-A E-ELT/MOS concept) teams have resulted in a merger of the two projects. Science cases and technical requirements for the Multi-Object Spectrometer (MOS) for the E-ELT have been updated, evaluating both a 'high definition' and a 'high multiplex' mode using a common focal plane. The results have been presented in a 'white paper' and the new instrument concept is called MOSAIC: Multi-Object Spectrometer for Astrophysics, Intergalactic-medium studies and Cosmology. The project aims to become the 4th or 5th instrument for the E-ELT after submission of a proposal in response to a call for proposals which ESO plans to issue by mid-2014.

SCIENCE CASES

Six top-level science cases have been identified. They will drive the design of MOSAIC:

1. 'First light' spectroscopy of the most distant galaxies
2. Spatially-resolved spectroscopy of high-redshift galaxies and following the assembly of galaxy mass as a function of look-back time
3. Role of high-redshift galaxies in galaxy evolution
4. Tomography of the intergalactic medium
5. Resolved stellar populations beyond the Local Group
6. Galaxy archeology with metal-poor stars.

The science cases listed here illustrate the huge scientific applications of an E-ELT/MOS, but they are not the full scope of the potential MOS science cases, which also includes distant galaxy clusters, Galactic stellar populations, extragalactic stellar clusters, and the extragalactic distance scale.



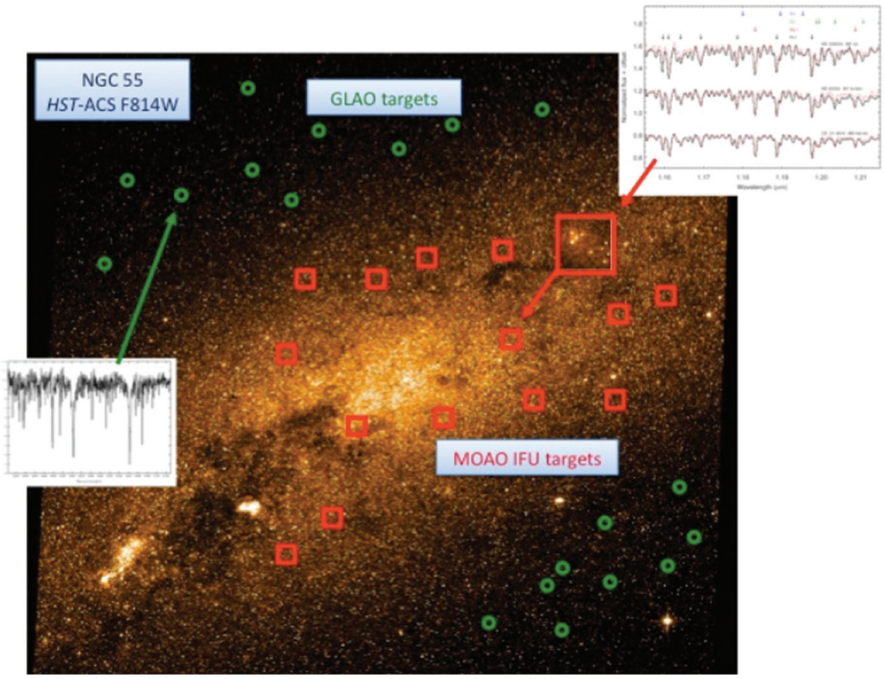


Figure 4.2: *Left: Schematic of MOAO IFU observations (red squares), with example targets for GLAO spectrometry elsewhere in the focal plane (green stars); Right: An example scenario for observations of the stellar populations in NGC 55.*

INSTRUMENT CONCEPT

The top-level instrument requirements are (using the full 7' diameter field of view):

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

These two modes of observations for MOSAIC are leading to two options, currently under evaluation, for the instrument concept. The likely NOVA contribution to the project is the design and construction of the spectrometer similar to the design made for the Phase-A study for OPTIMOS-EVE. The future work for MOSAIC will make use of the heritage at the NOVA Op-IR instrumentation group with the design and construction of the spectrometer for the WEAVE instrument for the WHT on La Palma.

INTERNATIONAL PARTNERS AND NL TEAM

The plan is that the MOSAIC project will be led by France with PI Hammer, with partner institutes in Brazil, France, the Netherlands (NOVA) and the UK. Several new partners have indicated that they would like to join the MOSAIC consortium.

In the Netherlands Kaper is leading the partnership in MOSAIC with 17 national co-I's distributed over all NOVA institutes and SRON. Navarro provides the technical support.

FUNDING

NOVA will provide staff effort at the Op-IR instrumentation group and travel funds in 2014 and 2015 for participation in the project preparations up to the end of its Phase-A study. The total allocation amounts to 150 k€. In addition a funding reservation of up to 1131 k€ including project contingency has been made for further support of MOSAIC or another project on the condition that the instrument is definitely selected by ESO for going to the E-ELT.

STAFF EFFORT IN FTE	TOTAL	2014	2015	2016	2017	2018
Total staff effort for NL	**11.8**	**0.4**	**0.6**	**2.1**	**4.3**	**4.4**
STAFF COSTS AT OP-IR GROUP IN K€	**TOTAL**	**2014**	**2015**	**2016**	**2017**	**2018**
Staff costs at Op-IR group	**1072**	25	52	232	373	391
STAFF COSTS AT UNIVERSITIES IN K€	**TOTAL**	**2014**	**2015**	**2016**	**2017**	**2018**
Subtotal NL staff costs in k€	**175**	0	0	0	87	88
Total staff costs in k€	**1248**	**25**	**52**	**232**	**460**	**479**
MATERIAL BUDGET (IN K€)	**TOTAL**	**2014**	**2015**	**2016**	**2017**	**2018**
Total material costs (k€)	**33**	**3**	**3**	**5**	**10**	**12**
Total costs MOSAIC (k€)	**1,281**	**28**	**55**	**237**	**470**	**491**

Table 4.1.3: *NOVA staff and cash contributions (in k€) reserved for the MOSAIC project.*

4.1.4. E-ELT EPICS

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

INSTRUMENT CONCEPT

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

In the last five years technical R&D has been carried out in the following areas: prediction polarization performance, development of tools for polarization system engineering, high level AO control algorithms, AO control hardware development, high contrast AO testbed, and development of an integral field unit for EPICS. The studies were funded from the grant for E-ELT instrumentation from the national Roadmap program for participation in large-scale international research facilities. Good progress has been made, but further R&D is required to achieve a robust and reliable instrument concept for the E-ELT EPICS instrument.

To reach contrasts of 10^{-9} and beyond, a series of individually optimized subsystems cannot succeed; rather, entire combinations of subsystems must be optimized together. The optimization will be done with laboratory setups, experimental science observations at large telescopes (WHT, GTC) and working with SPHERE at the VLT. The focus of the effort will be on achieving a contrast of at least 10^{-9} in broadband light under realistic, simulated ground-based conditions in the laboratory and to test new approaches at telescopes, in particular achromatic aperture and focal-plane coronagraphs, focal-plane wavefront-sensing and speckle suppression, integral-field polarimetry and high-contrast data reduction algorithms and combinations thereof.

INTERNATIONAL PARTNERS AND NL TEAM

Technology development for EPICS is done in an international collaboration with institutes in France, Germany, Italy, the Netherlands (NOVA), Switzerland, UK and ESO.

In the Netherlands the effort is led by Keller with 20 co-I's from all NOVA institutes, ASTRON, SRON, TNO, ESA and TU Delft.

FUNDING

The costs of the NOVA contribution to the EPICS R&D program are summarized in Table 4.1.4. The NOVA funding contribution amounts to 375 k€. In 2014 and 2015 the project will also use funds from the national Roadmap program, personal grants to Keller from STW and NWO-VICI. Further funding may come from ESO under a program line for technology development for future E-ELT instrumentation.

STAFF EFFORT IN FTE	TOTAL	2014	2015	2016	2017	2018
Project management	**0.40**	0.10	0.10	0.10	0.10	
System engineer	**0.20**	0.05	0.05	0.05	0.05	
Instrument scientist	**0.40**	0.10	0.10	0.10	0.10	
PhD student	**4.00**	0.50	1.00	1.00	1.00	0.50
Total staff effort for NL	**5.00**	**0.75**	**1.25**	**1.25**	**1.25**	**0.50**
STAFF COSTS AT OP-IR GROUP IN K€	TOTAL	2014	2015	2016	2017	2018
Subtotal Op-IR staff costs in k€	**97**	24	24	24	25	0
STAFF COSTS AT UNIVERSITIES IN K€		2014	2015	2016	2017	2018
Subtotal staff costs at Universities (in k€)	**205**	26	51	51	51	26
Total NL staff costs in k€	**301**	**49**	**75**	**76**	**76**	**26**
MATERIAL BUDGET (IN K€)	TOTAL	2014	2015	2016	2017	2018
Travel + ICT equipment	**8**	2	2	2	2	
Hardware	**66**		30	30	6	
Total Material costs (k€)	**74**	**2**	**32**	**32**	**8**	**0**
Total costs for EPICS (k€)	**375**	**51**	**107**	**108**	**84**	**26**
NOVA funding in (k€)	**375**	**51**	**107**	**108**	**84**	**26**

Table 4.1.4: *Expenditures and funding (in k€) for the NOVA contribution to the technical R&D for EPICS.*

4.2. OTHER OP-IR INSTRUMENTATION

Several instruments delivered to ESO for use on the VST and VLT require further support in the area of data mining and archiving to handle the large volume of science data that will be obtained during guaranteed time observations. NOVA will also design and build an array of four optical telescopes to be located at the ESO La Silla Observatory for studies of optical afterglows of gravitational wave events. NOVA also participates in the WEAVE project, a UK, Netherlands, Spain, French and Italian collaboration to equip the 4.2m WHT of the Isaac Newton Group on La Palma with a wide-field multi-object spectrometer for a Northern Hemisphere spectroscopic survey to complement the Gaia mission and to follow up observations obtained with LOFAR and WSRT-Apertif.

4.2.1. DATA MINING AND LONG-TERM ARCHIVING FOR OMEGACAM AND MUSE

NOVA has made significant investments in survey instruments that will produce very large data streams. For the VLT integral-field spectrometer MUSE and the VST wide-field camera OmegaCAM, large allocations of guaranteed observing time (GTO) are the reward, to be used for many science cases. The aim of this project is to provide, to the Dutch astronomical community, the environment and infrastructure in which science teams of the GTO projects can efficiently generate and archive their science data. The teams, distributed over the Netherlands, need to collaborate on calibration, science data production, quality assessment and public data releases in a common environment (via web services and local command-prompt). OmegaCEN designed, implemented and operates such an environment for MUSE and OmegaCAM with the MUSE-WISE and Astro-WISE (Fig. 4.3) survey systems, respectively. Both systems are hosted at the OmegaCEN-CIT-Target datacenter at the RUG. The support work for MUSE-GTO and OmegaCAM GTO will be as follows:

- Provide continuous basic infrastructure support for data ingestion, archiving, back-ups, data processing, database operations and web services for GTO projects over the full NOVA Phase-4 period
- Provide user support to astronomers for GTO specific usage of the WISE survey systems via documentation, helpdesk and tutorials
- Provide technical support to integrate GTO pipelines and significant changes to them into the WISE systems. The required changes to databases and data models can only be carried out by specialists that are part of in the instrument and GTO teams
- Support the incorporation of GTO specific algorithms that are most efficiently run inside the WISE systems
- Incorporate in the WISE systems new instrument modes for MUSE and OmegaCAM.

TEAM

The project team consists of PI's Verdoes Kleijn and Valentijn, and co-I's Schaye and Brinchmann for MUSE-NL and Kuijken for OmegaCAM. The technical and user support is provided by the OmegaCEN team.

GUARANTEED TIME PROGRAMS AND DATA FLOW SUPPORT

ESO does not support the processing and scientific data mining for MUSE and OmegaCAM GTO beyond archiving the raw observational data. Therefore the Dutch instrument teams require support to ensure that the Dutch GTO teams can calibrate and quality control their data, harvest the science and issue data releases.

MUSE: The international consortium will have ~250 nights of GTO, starting in the second half of 2014 and lasting at least five years. The unique nature of the MUSE integral field spectroscopic data, with a wide field of view, high spatial resolution and good wavelength coverage, have led the consortium to develop a coherent GTO plan where the same data will be used by a variety of groups within the consortium

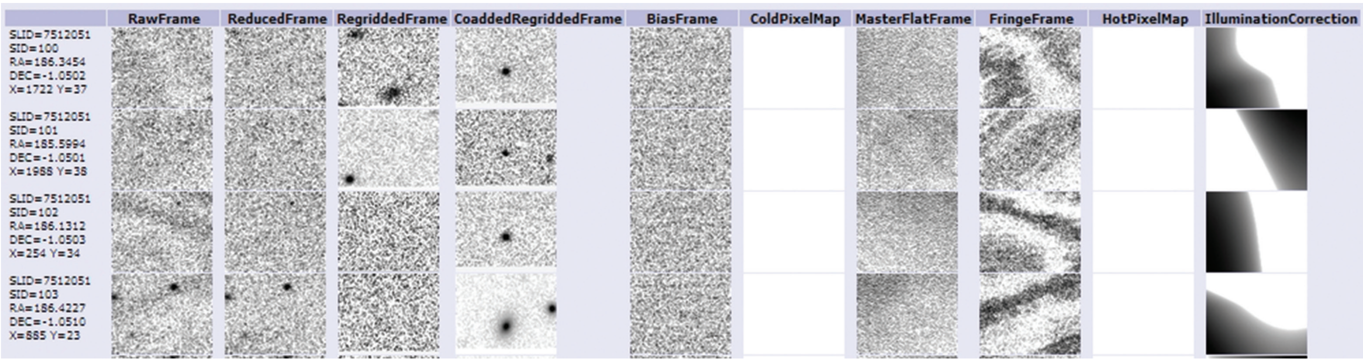


Figure 4.3: *Image cut-outs provided by Astro-WISE. They follow the data chain from raw to final products for individual sources per row. The science images from raw to co-added are shown in the columns on the left side while the corresponding area in calibration images are shown in the right half.*

STAFF EFFORT	LEVEL	TOTAL	2014	2015	2016	2017	2018
Project manager	12	**0.75**	0.25	0.15	0.15	0.10	0.10
OCAM-GTO user support	11	**0.80**	0.20	0.20	0.20	0.10	0.10
MUSE-GTO user support	11	**0.70**	0.20	0.20	0.10	0.10	0.10
OCAM-GTO technical support	10	**1.00**	0.20	0.20	0.20	0.20	0.20
MUSSE-GTO technical support	10	**0.79**	0.27	0.22	0.18	0.09	0.04
Total Staff Effort		**4.04**	**1.12**	**0.97**	**0.83**	**0.59**	**0.54**

PERSONNEL BUDGET	LEVEL	TOTAL	2014	2015	2016	2017	2018
Project manager	12	**62**	21	12	12	8	8
OCAM-GTO user support	11	**57**	14	14	14	7	7
MUSE-GTO user support	11	**50**	14	14	7	7	7
OCAM-GTO technical support	10	**71**	14	14	14	14	14
MUSSE-GTO technical support	10	**56**	19	15	12	6	3
Sub-total Personnel		**295**	**82**	**70**	**60**	**43**	**39**

MATERIAL BUDGET		TOTAL	2014	2015	2016	2017	2018
Hardware		**20**	4	4	4	4	4
Travel		**8**	2	2	2	2	2
Sub-total Materials		**28**	**6**	**6**	**6**	**6**	**6**

Total expenditure Data Mining		**322**	**87**	**76**	**66**	**49**	**45**

NOVA funding Data Mining (in k€)		**322**	**87**	**76**	**66**	**49**	**45**

Table 4.2.1: *NOVA funding (in k€) for the long-term archiving and data mining support for MUSE and OmegaCAM.*

for a range of science studies. This multi-purpose use of the data means that it is imperative to have a single comprehensive data processing system in which the GTO groups collaborate to avoid a proliferation of slightly modified data across the consortium. For this purpose MUSE-WISE has been developed. It is now installed at MUSE nodes in Leiden, Groningen, Potsdam, Toulouse, Lyon and Zürich in preparation for commissioning early 2014.

OmegaCAM: In exchange for providing the OmegaCAM instrument for ESO's VST, the instrument team including NOVA was granted a significant amount of guaranteed observing time: nearly 9% of all VST science time until 2021. To give the public surveys the large share of the telescope time they need for the first few years, the OmegaCAM team has been saving up about half of its GTO, in agreement with ESO. This opens up the possibility for ambitious programs that use a significant fraction of the VST.

Following the first call for such programs a range of OmegaCAM GTO surveys is underway within the Galaxy, the Local Group, nearby galaxy clusters and nearby superclusters. The processing and scientific analysis for these programs is performed by the GTO teams using the Astro-WISE information system. This is operational in Leiden, Groningen and Nijmegen (and several additional nodes across Europe).

FUNDING

The NOVA expenditures and funding revenues are summarized in Table 4.2.1. The support consists of four years staff efforts and 28 k€ material budget. In addition the scientists involved have obtained personal grants to carry out the research and to purchase the required computer systems.

4.2.2. BLACKGEM

From 2015 on the Advanced LIGO and Virgo detectors will open up a completely new window onto the Universe through direct detections of gravitational waves (GW). The expected source populations are mainly merging neutron stars (NS) and black holes (BH). In a ramp-up to their design sensitivities the detection horizon of Ad-LIGO/Virgo will increase from ~50 Mpc during the first science runs (2015-2016) to 400 Mpc at full design sensitivity (2019 and on). Binary evolution population synthesis codes show a realistic detection rate of one event per week when at design sensitivity, with error bar estimates running from a few events a year to ten per day.
Electromagnetic detections of gravitational wave events are required to fully understand their astrophysical settings, and to probe the final stages of massive binary star remnant evolution. This is directly connected to questions on the formation and evolution of massive stars; on which stars leave which remnant; on the survival of towards massive compact binaries (BH/NS systems); on the rate and nature of gamma-ray bursts (both short and long), hypernovae, Wolf-Rayet stars, over/underluminous supernovae and on the production of r-processed elements in the Universe, all part of the Network-3 research focus.

SPH and radiative transfer modelling of binary black hole and neutron star mergers shows that isotropic electromagnetic radiation is expected through a 'macronova' channel caused by neutron star material that is not accreted onto the black hole. This material ($\geq 10^{-2}$ $M_{\odot}$) is heated to >5 GK temperatures and ejected with velocities ~0.2c. The expanding and cooling photosphere causes the 'macronovae' event with peak fluxes in the optical/infrared wavelength regime on a timescale of hours after the merger event.

Ad-LIGO/Virgo will be able to locate gravitational wave events in the sky with an accuracy of 20 to >100 square degrees, depending on the signal strength, location and detector sensitivity. In order to extract optimal electromagnetic information from any related electromagnetic signal with e.g. the VLT, ALMA, HST or other major astronomical facilities, the error box will have to shrink by a factor of one billion, to one square arcsecond accuracy. Additionally, one needs to identify the correct transient from a combination of position, colors, and (multi-color) light curves. The synoptic sky at these faintness levels and time scales is very poorly charted. The scientific aim of BlackGEM-Phase 1 (P1) is therefore twofold:

1. To characterize the multi-color optical transient sky down to a limiting magnitude of m_g ~23 on timescales of ~hours, to identify and understand 'interloper' populations to GW events
2. To make the first detections of optical counterparts to gravitational wave events.

INSTRUMENT CONCEPT

BlackGEM-P1 is the first step to the complete BlackGEM array, which will consist of 20 identical telescopes, creating a field-of-view of 44 square degrees[1]. The full array will be required to follow-up all the possible LIGO/Virgo events, also the lower signal-to-noise ratio ones which will (generally) have the larger error boxes (but occur more often). BlackGEM-P1 will produce a large amount of ancillary science of interest to the NL community. BlackGEM-P1 will work in three 'surveys':

1. The BlackGEM Southern All-Sky Survey: a multi-color (u,g,r,i,z) survey of the full southern sky down to m~22-23. Will be executed during the first year in the two weeks per month around new Moon;
2. The BlackGEM Fast Synoptic Survey: over a period of a week 4.4 square degrees will be covered 150-300 times per night in 3 colors at atmospheric resolution down to 22nd magnitude. The synoptic database will be used for the study of fast supernovae, accreting binaries and AGN, Kuiper Belt Objects, asteroids, flare stars, orphan GRB afterglows and tidal disruption events. The Fast Synoptic Survey will be executed in the two

[1] In 'Fly's-eye' mode; or the equivalent of 4 x 1.5m telescopes in a 'Clustered mode', or the equivalent of a 2.2-square-degree wide-field 3.6m telescope in 'Focus' mode.

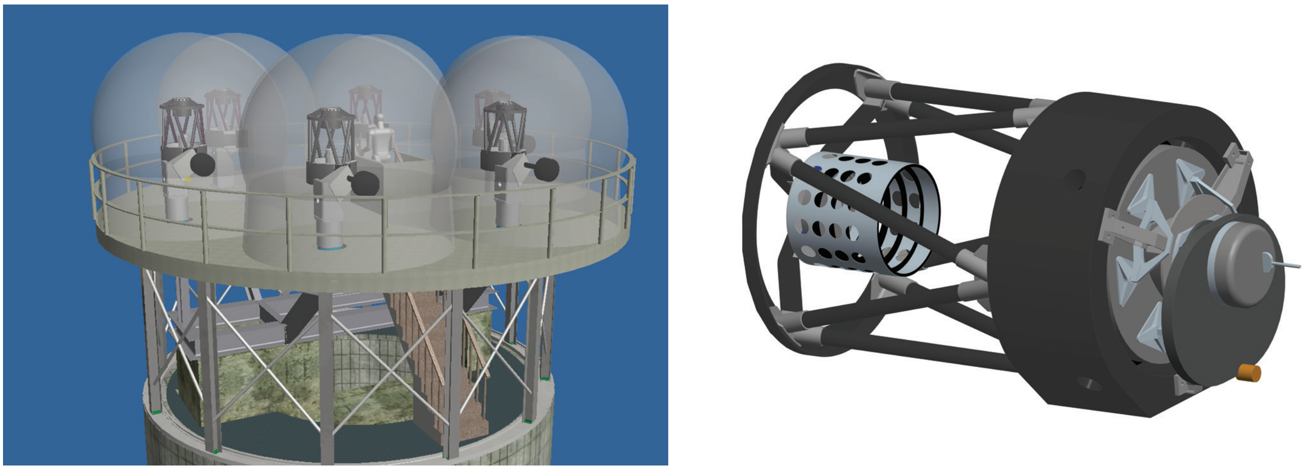


Figure 4.4: *Design of BlackGEM. Left: drawing of a six telescope array on top of the GPO/Marly building at the ESO La Silla Observatory (credit: RU Nijmegen TechnoCenter); right: opto-mechanical design of the 60-cm telescope (credit: NOVA Op-IR group).*

weeks per month around Full Moon. A total of 106 square degrees per year will be covered. This will be a very rich dataset available to the complete NOVA community;

3. The BlackGEM Transient Survey: during science runs of Virgo/LIGO BlackGEM will be in triggered transient mode, meaning it will accept outside triggers to identify and study optical counterparts.

No current facility in the world is set up and dedicated to detect optical counterparts to gravitational wave sources due to the combination of extreme size of the error boxes, required depth and time scales. The BlackGEM project, for which NOVA will fund the telescope design and the construction of a four telescope array, allows astronomers in the Netherlands to pioneer in the EM study of gravitational wave sources. The BlackGEM array will be located on ESO La Silla and is to be operational in late 2015 (Fig. 4.4). The planned work packages cover the complete project: the optical-mechanical design of the telescopes and camera, the design of the housing, the site preparation, manufacturing, testing and operations of the telescopes and the implementation of the data reduction and database software infrastructure. NOVA Network-3 has also allocated a PhD position for the science preparation phase as well as early science with BlackGEM.

TEAM

The core project team consists of Principal Investigator Groot, project scientist Nelemans, project manager Klein-Wolt, instrument scientist Bloemen, and ~20 co-I's distributed over all NOVA institutes, ASTRON, SRON, Nikhef, and several institutes abroad. The work packages are distributed over the RU Nijmegen Techno Center, the NOVA Op-IR instrumentation group and industrial partner Airborne Composites.

FUNDING AND PARTNERS

The BlackGEM project is a project between NOVA (signing partner) and Radboud University, with participation of KU Leuven and the NWO institute for high-energy physics Nikhef. The total budget allocation for BlackGEM is currently at the 2700 k€ level, in which NOVA participates through 100 k€ in 2013 for staff effort at the Op-IR instrumentation group and cash for travel and contractual work to support the opto-mechanical design and organization of the work packages up to and including PDR, scheduled for February 2014. In addition NOVA has made a budget reservation of 1400 k€ and a project contingency reservation of 300 k€ for the final design, construction, verification, commissioning and operations of BlackGEM. Allocation of this budgetary reservation will be made following a successful completion of FDR.

4.2.3. WEAVE

WEAVE is the next-generation wide-field survey facility for the William Herschel Telescope (WHT at La Palma). It will provide the instrument required for full scientific exploitation of the Gaia, LOFAR, and WSRT-Apertif surveys in the Northern Hemisphere. WEAVE is a multi-object and multi-integral field-unit (IFU) facility utilizing a large, new 2° diameter prime focus corrector at the WHT with a pick-and-place fiber positioner system hosting 1000 multi-object fibers or 20 mini-IFUs for each observation, or a single wide-field IFU. The fibers are fed into a dual-beam spectrometer located in the GHRIL enclosure on the telescope's Nasmyth platform. The spectrometer measures 1000 spectra simultaneously at a spectral resolution of R~5000 over an instantaneous wavelength range 370–985 nm. In high-resolution mode this is R~20,000 over two more limited wavelength regions. Three core surveys are envisaged with WEAVE over a period of 5 years, producing more than 30 million spectra of nearly 10 million objects: a survey of our Galaxy, providing radial velocities and stellar abundances for stars too faint for these quantities to be measured by Gaia; a survey probing galaxy evolution and dark energy over cosmic time, providing the needed redshifts and galaxy properties of LOFAR's sources; and a survey of the stellar and gaseous kinematics and physical properties of gas-rich galaxies out to cosmological distances, providing a necessary optical complement to Apertif's neutral hydrogen surveys of the local Universe.

INTERNATIONAL COLLABORATION AND NL TEAM

The WEAVE project is a collaborative effort of the UK, the Netherlands and Spain, the owners of the ING observatory on La Palma of which the WHT is the largest telescope. Additional contributions are expected from France, Italy, Hungary, and possibly also from an institute in Mexico.

The NL part of the WEAVE project is led by Trager with ~ 15 co-I's in the Netherlands distributed over all four NOVA institutes and ASTRON. The spectrometer

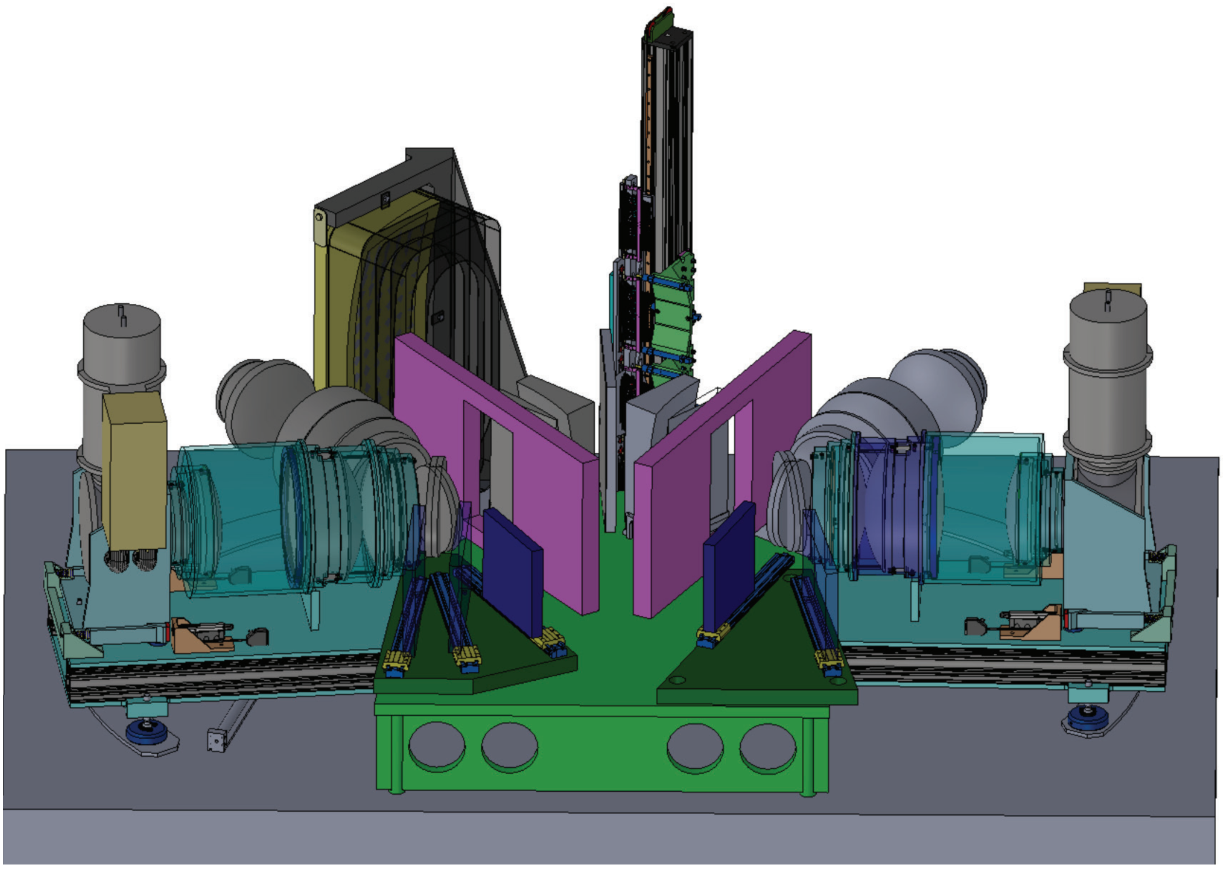


Figure 4.5: *Drawing of the WEAVE spectrometer at PDR.*

is designed and will be built by the NOVA Op-IR instrumentation group.

TECHNICAL CONTRIBUTIONS

The Netherlands is responsible for the design, construction and testing of the spectrometer system for WEAVE (Fig. 4.5), except for the detectors, which will be provided by the UK. WEAVE also plays an important role in the development of 4MOST, a similar facility for ESO's VISTA telescope, providing commonalities in spectrometer design, science software systems, and science objectives. WEAVE has successfully passed its PDR in May 2013 and is now heading to FDR completion in fall 2014. In 2012-2013 staff at the NOVA Op-IR group also made important contributions to the optical design for the new top-end of the WHT.

FUNDING

The costs of the Dutch contributions to WEAVE amount to 3,365 k€ excluding 200 k€ reserved for project contingency (Table 4.2.3). NWO-EW provides most of the funding (2,960 k€); the NOVA contribution is 605 k€ including the contingency reservation and work done in 2011-2012 to enable the project startup. NOVA's position is that work on WEAVE is funded up to the end of FDR. The formal decision to enter into the project construction phase depends on (1) the instrument plan and design being robust and economically feasible as proven at FDR. The project plan must demonstrate that the instrument will be on the telescope and in operation before end 2017; (2) confirmation that all parties in WEAVE together are able to secure the required funding; and (3) the partners in the ING must have confirmed that WEAVE on the WHT can be used for a period of at least five years.

STAFF RESOURCES (IN FTE)	TOTAL	2011	2012	2013	2014	2015	2016	2017
Project Manager	**2.73**	0.04	0.30	0.47	0.60	0.60	0.52	0.44
Systems Engineer	**2.75**		0.15	0.25	0.50	0.55	0.55	0.74
Optical Design/verification	**1.94**	0.05	0.24	0.34	0.35	0.34	0.29	0.33
Mechanical Designer	**3.09**			0.31	1.10	1.00	0.50	0.18
Procurement. Manufacturing	**1.23**			0.02	0.27	0.65	0.22	0.07
Assembly. Integration. Test	**2.32**				0.18	0.60	1.00	0.55
Electronic Engineer	**0.60**				0.10	0.20	0.20	0.10
Project control	**0.19**			0.03	0.05	0.05	0.05	0.01
Total staff effort (in fte)	**15.09**	**0.09**	**0.69**	**1.42**	**3.14**	**3.99**	**3.33**	**2.43**

STAFF COSTS OP-IR GROUP (IN K€)	TOTAL	2011	2012	2013	2014	2015	2016	2017
Project Manager: Johan Pragt	**438**	7	45	66	87	89	77	67
Systems Engineer	**309**		19	27	55	61	62	84
Optical Designer	**227**	4	26	38	41	41	35	41
Mechanical Designer	**344**			35	120	111	56	21
Procurement. Manufacturing	**117**			2	25	62	21	7
Assembly. Integration. Test	**224**				17	57	97	54
Electronic Engineer	**58**				9	19	19	10
Project control	**16**			1	5	5	5	1
Total staff effort (in k€)	**1733**	**11**	**90**	**170**	**359**	**445**	**374**	**285**

MATERIAL BUDGET WEAVE NL PARTS	TOTAL	2011	2012	2013	2014	2015	2016	2017
Travel, meetings	**105**	2	3	9	22	25	25	20
External mechanical designer	**70**				70			
Optics hardware	**808**				404	404		
CNC milling hardware	**69**			2	33	34		
Mechanisms, mechanics hardware	**221**				90	73	33	25
LIFU +MIFU optics and manufacturing	**94**				73	1	2	18
Project scientist - non staff costs	**75**				15	20	20	20
Shipment	**40**						40	
Miscelleneous costs	**150**				31	40	40	40
Total WEAVE material budget (in k€)	**1632**	**2**	**3**	**11**	**738**	**597**	**160**	**123**
Total WEAVE costs NL (in k€)	**3366**	**13**	**93**	**180**	**1097**	**1042**	**534**	**408**

PROJECT REVENUES (IN K€)	TOTAL	2011	2012	2013	2014	2015	2016	2017
NWO-EW contribution	**2000**			1000	500	500		
NWO-M	**960**			765			195	
NOVA Fase-4 excl contingency	**300**					150	100	50
NOVA Fase-3 (in-kind)	**106**	13	93					
Total WEAVE funding NL (in k€)	**3366**	**13**	**93**	**1765**	**500**	**650**	**295**	**50**

Table 4.2.3: *Planned expenditures for the NL contribution to WEAVE (in k€) and the origin of the revenues.*

4.3. ALMA RELATED PROJECTS

In Phase-4 NOVA continues to make contributions to ALMA, the Atacama Large Millimeter/submillimeter Array, in Northern Chili. There are two ongoing projects: one is the final design and construction of the Band-5 receivers covering the frequency range between 163 and 211 GHz, and the other is technical R&D to improve the calibration scheme for high-frequency line observations especially in the extended array with the longest baselines up to 15 km resulting at the highest angular resolution.

4.3.1. ALMA BAND-5 RECEIVER FINAL DESIGN AND PRODUCTION

The project started in 2011 when NOVA, GARD (Group for Advanced Receiver Development of the Onsala Space Observatory, Chalmers University, Sweden) and RAL (Rutherford Appleton Laboratory, UK) made a study considering various options for the production of the ALMA Band-5 receivers enabling ALMA to observe in the atmospheric window between 163 – 211 GHz with the full array from 2017 onwards. The study has shown that this work is feasible and financially affordable if Europe and North America work together with NOVA-GARD under contract with

STAFF EFFORT	TOTAL	2012	2013	2014	2015	2016	2017
Management/procurement	**4.33**	0.08	1.00	1.00	1.00	1.00	0.25
Instrument scientist	**2.67**	0.17	1.00	0.50	0.50	0.50	
Test engineer	**4.50**	0.25	1.00	1.00	1.00	1.00	0.25
Test engineer support	**2.90**	0.25	0.40	0.60	0.70	0.70	0.25
Documentation	**4.33**	0.08	1.00	1.00	1.00	1.00	0.25
QA/PA effort	**1.60**	pm	0.60	0.40	0.30	0.30	
Assembly technician	**1.80**	0.10	0.40	0.40	0.40	0.40	0.10
Financial Control	**0.50**		0.10	0.10	0.10	0.10	0.10
Total FTEs	**22.63**	**0.93**	**5.50**	**5.00**	**5.00**	**5.00**	**1.20**

	TOTAL	2012	2013	2014	2015	2016	2017
Total RUG staff costs (in k€)	**1949**	**0**	**536**	**424**	**437**	**449**	**103**
Industrial support (in k€)							
Redesign	**195**	53	127	10	5		
Mechanical production	**160**		50	50	40	20	
Procurement support	**100**	10	70	20			
QA/PA verification	**70**		30	40			
Total hiring external expertise	**525**	**63**	**277**	**120**	**45**	**20**	**0**
Total costs for Operations	**731**	**22**	**178**	**162**	**170**	**165**	**34**
Spare parts for 2 years	**24**	**0**	**2**	**2**	**2**	**16**	**2**
Total costs fixed price labor + operations (in k€)	**3,229**	**85**	**993**	**708**	**654**	**650**	**139**
ESO funding (in k€)	**3,229**	**0**	**0**	**1,786**	**654**	**650**	**139**

	TOTAL	2012	2013	2014	2015	2016	2017
Component for cartridges	**3,491**	5	868	1,221	873	524	
Test equipment + contingency	**325**	21	129	170	55		
Spare parts for 2 years	**104**			52	52		
Total Costs ALMA Band 5 procurement	**3,970**	**26**	**997**	**1,443**	**980**	**524**	**0**
ESO funding (in k€)	**3,970**	**0**	**0**	**2,466**	**980**	**524**	**0**

Table 4.3.1: *Specification of the costs in k€ of the ALMA Band-5 project at NOVA. Top part of the table specifies the staff costs, support from industry and operations costs amounting to 3229 k€. The bottom parts summarize the expenditures on procurement of 3rd party supplies adding up to 3970 k€.*

ESO to produce and integrate the heterodyne receivers and the cartridge assembly and NRAO to manufacture the local oscillators (as was done for the other receiver bands in ALMA). The project builds on the technology development at GARD and RAL for the design and pre-production of six ALMA Band-5 receiver cartridges funded within the European Commission FP6 program, and the experience at NOVA obtained with the design and series production of the Band-9 receivers.

The official start of the project was on 1st February 2013 with the kick-off meeting and start of the contract signing procedure. NOVA and GARD will jointly carry out the final design of the receiver cartridge including optimization for series production. Thereafter, in 2014-2016, 67 receiver cartridges will be produced and delivered with GARD being responsible for the 2SB heterodyne mixers and IF-hybrid and NOVA for the cartridge integration and verification measurements.

SCIENCE CASE

There are two key science drivers to build the Band-5 receivers: (1) detection and study of the dynamics of the first galaxies (at z~8-10) through their C^+ line emission and (2) imaging water vapor in the Solar System and in protoplanetary disks.

INTERNATIONAL COLLABORATION AND NL TEAM

ESO awarded the NOVA-GARD consortium the final design and production of the Band-5 receivers. The project is fully funded by ESO from the ALMA enhancement budget. The consortium is coordinated by Boland with Belitsky (GARD) as co-I and technical lead. In the Netherlands the work is carried out by the NOVA-ALMA group employed by the RUG, located at SRON Groningen and managed by Adema. Other members of the group are Hesper (instrument scientist), Barkhof (verification measurements), Bekema, de Haan and Koops.

FUNDING

The contract of the ALMA Band-5 project with ESO has a value of 12.66 M€, of which 7.20 M€ will be spent at NOVA and 5.46 M€ at GARD. The NOVA part (Table 4.3.1) consists of a fixed price payment of 3.229 M€ for staff effort and operations, and a payment on the basis of actual costs for third party supplies from industry with an estimated value of 3.97 M€.

4.3.2. ALMA TECHNICAL R&D

ALMA is becoming operational at its full power. It will revolutionize how submillimeter astronomy is done as it provides significant increases in spatial resolution and sensitivity compared to any other submm facility. The ALMA interferometer will employ baselines of up to 16 km. Especially at the higher frequencies, observations will be sensitive to atmospheric effects that attenuate and decorrelate the data. This introduces new challenges both for the calibration and imaging of high-resolution data. At present, little concrete information is available as to the exact nature and severity of these effects: although some commissioning observations have been carried out with a baseline of about 2.5 km, the majority of science observations during the early science phase observations in Cycles 0 and 1 use significantly more compact configurations with baselines of up to 400 m. Also, relatively few high-frequency observations have been made up to now and those typically targeted bright and relatively compact objects.

In the Netherlands, the NOVA-ALMA group has contributed significantly to this success by developing key technology and by developing and producing the Band-9 receiver cartridges. Recognizing the challenge that ALMA is currently facing in calibrating out atmospheric fluctuations in its higher frequency bands and extended baselines, this technical R&D project will develop a dual-frequency atmospheric phase error calibration method and demonstrate it by implementing dual Band-9/6 operation using external optics on a few ALMA baselines using the existing ALMA front-end.

In parallel, a technical development program will be carried out that will lead to significant enhancements in the science output of ALMA at high frequencies and on long baselines. It will include the development of parametric amplifiers that enable future design of multi-pixel and multi-beam receivers.

INTERNATIONAL COLLABORATION AND NATIONAL TEAM

The project results will be shared with ESO and the ALMA team in Chile. Part of the project is to implement the dual frequency Band-9/6 observing mode in three telescopes in the ALMA array to verify the new calibration scheme by measurements. The NL project is co-led by Baryshev (technical R&D) and Tilanus (calibration scheme) with scientific and technical support from Hesper (instrument physicist) and ten other staff members at the NOVA institutes in Groningen and Leiden and at SRON Groningen.

FUNDING

In Phase-4 NOVA has allocated up to 350 k€ for this technical R&D project. Opportunities to obtain additional funding will be explored to broaden the scope for this ALMA enhancement program. The NOVA funding originates from the revenues received for the ALMA Band-9 production project. The detailed spending of the funds is still under discussion.

4.4. PARTICIPATION IN SPACE MISSIONS

4.4.1. PARTICIPATION IN MIRI

Following the construction of the Spectrometer Main Optics of the Mid-InfraRed Instrument (MIRI) for the James Webb Space Telescope (JWST) in the Netherlands under NOVA Phase-2 and -3, the Flight Module (FM) has been integrated, accepted by, and delivered to ESA and NASA in May 2012. After instrument delivery, the MIRI European Consortium (EC) continues to be responsible for the instrument and is contractually required to deliver major parts of the instrument characterization and calibration, support Integrated Science Instrument Module (ISIM) testing at Goddard, and co-lead software development and mission preparation. The Dutch MIRI team has played an important role in the MIRI consortium during all of the project phases, from making the initial science case and conception of the instrument to the design and development of the Spectrometer Main Optics by the NOVA Op-IR instrumentation group located at ASTRON, support of the instrument tests at Rutherford Appleton Laboratory and the analysis of the test data, to leading the MIRI EC software development and supporting mission preparation at STScI (the JWST operations center). During the design phase the Dutch team has been instrumental in safeguarding the spectroscopic capabilities of MIRI and is now the driving force in exploiting the unique science potential of the integral field unit (IFU) spectrometer within the EC. The Dutch MIRI team wants, and has been asked by the MIRI-EC, to maintain its strong role in the continued MIRI-EC activities, in particular in the area of software developments and IFU characterization.

PROJECT OBJECTIVES

The planned work aims for a continued active and visible role for NOVA at the international level in the years until launch in 2018. It ensures that the Dutch community is optimally prepared when JWST becomes operational to guarantee a maximum science return. Specifically, in 2014-2018 the NL team will focus on the following aspects:

Calibration of the medium resolution IFU spectrometer (MRS) following ISIM test campaigns (Fig. 4.6). Similar to the FM testing, the NL team will lead the MRS wavelength calibration and defringing analysis and be involved in the relative spectral response calibration.

Software development: Continue co-leading the MIRI software development to ensure a science optimized software package with a high quality pipeline and a suite of high level interactive analysis (IA) tools in close collaboration with STScI. Development of high-level

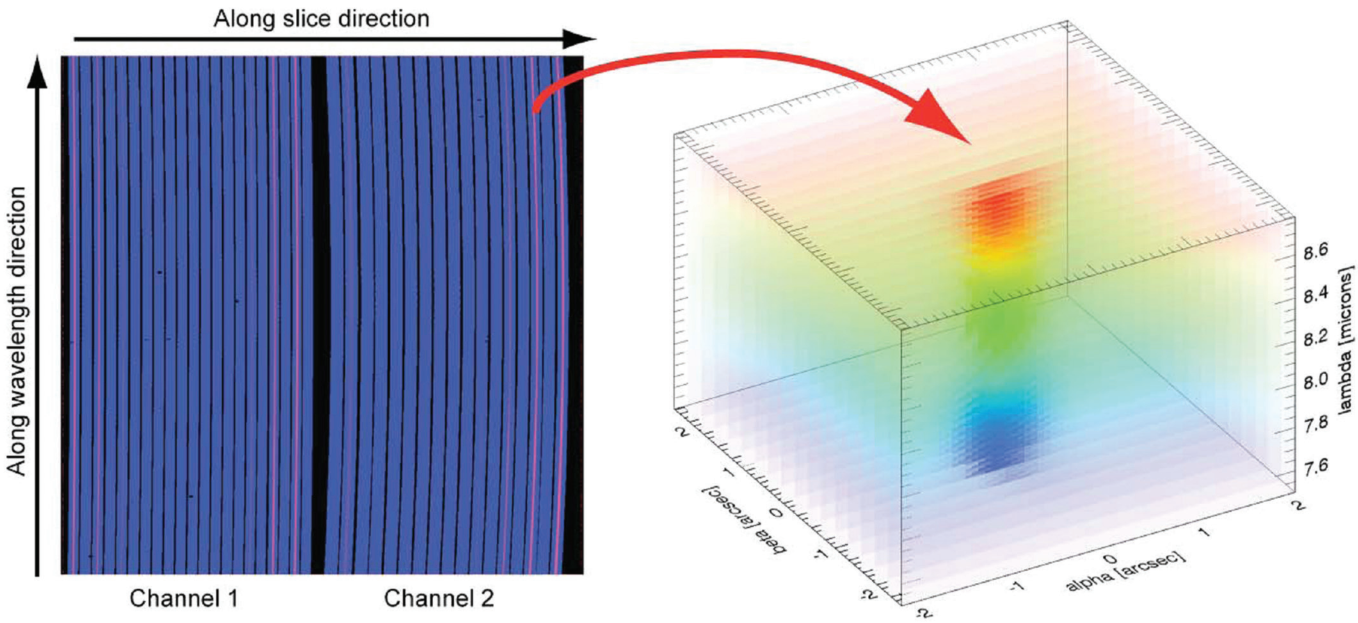


Figure 4.6: *Example of an exposure taken with the MIRI medium resolution spectrometer integral field unit during Flight Model testing at RAL. The left image shows the FM detector data whereas the right image illustrates the challenge for NOVA Phase-4 to develop software to turn these data into reliable reconstructed 3D position-velocity data cubes.*

algorithms and tools for the reduction and analysis of the MRS-IFU data and low resolution spectrometer data on exoplanets.

User support: Mission preparation and assisting Dutch astronomers in preparation of MIRI proposals and data reduction.

These efforts are shared with other MIRI partners, in particular Leuven, Dublin and the UK-ATC.

INTERNATIONAL PARTNERS AND NL PROJECT LEADS

The MIRI instrument is built by a joint US/European consortium as a 50:50 partnership. The scientific oversight occurs through the MIRI Science Team (MST) lead by Gillian Wright (European PI) and George Rieke and containing four members from each continent (with rotating membership from the MIRI-EC). The US has the responsibility for procuring and delivering the detectors with the associated electronics, software and testing, and for the cryo-coolers. On the European side, the consortium is led by Gillian Wright (UK-ATC), together with project manager Faye Hunter from ASTRIUM-UK. Europe has designed and built the entire camera/spectrometer unit. Partners in the European consortium are the UK, Germany, France, The Netherlands, Belgium, Spain, Switzerland, Ireland and Sweden. The NL PI and EC co-PI is van Dishoeck, with Brandl as deputy Co-PI and Lahuis as NL-PM.

The EC has a European science team, consisting of about 40 scientists from the participating countries and institutes. Each country has a maximum of three members in addition to the co-PIs and PM: for the Netherlands these are Kamp, Waters and van der Werf. Moreover, Caputi and test team members are part of the GTO team. As in previous phases, the Dutch team will be heavily involved in the preparation of the MIRI GTO science program.

FUNDING

The NOVA expenditures and funding revenues are summarized in Table 4.4.1. Due to savings in previous years an amount of 180 k€ is transferred on project level from Phase-3 to Phase-4. In addition ESA has agreed to contribute 117 k€ to compensate for project delays caused by developments outside the responsibility of the European MIRI Consortium.

STAFF EFFORT	LEVEL	UNIV	TOTAL	2014	2015	2016	2017	2018
Instrument Science Support Phase-3	10	SRON	**1.13**	0.80	0.33			
Instrument Science Support Phase-4	10	SRON	**2.87**		0.47	0.80	0.80	0.80
Postdoc 1	11	tbd	**1.00**				0.50	0.50
Postdoc 2	11	tbd	**1.00**			1.00		
Total Staff Effort			**6.00**	**0.80**	**0.80**	**1.80**	**1.30**	**1.30**
Sub-total Personnel (in k€)			**446**	**61**	**62**	**135**	**94**	**94**
MATERIAL & TRAVEL BUDGET			TOTAL	2014	2015	2016	2017	2018
Travel			**100**	15	15	20	20	30
Hardware post delivery support			**40**	10	10	10	10	
Miscelleneous			**18**	2	2	4	5	5
Sub-total Materials			**158**	**27**	**27**	**34**	**35**	**35**
Total costs MIRI			**604**	**88**	**89**	**169**	**129**	**129**
REVENUES			TOTAL	2014	2015	2016	2017	2018
NOVA Phase-4 allocation			**307**	-209	89	169	129	129
NOVA-MIRI transfer Phase-3 → 4			**180**	180				
ESA project contingency			**117**	117				
Total revenues MIRI (in k€)			**604**	**88**	**89**	**169**	**129**	**129**

Table 4.4.1: *NOVA expenditures (in k€) on the participation in the MIRI project excluding contingency.*

4.4.2. PREPARATION FOR GAIA SCIENCE HARVESTING

ESA's Gaia mission is the next European breakthrough in astrophysics, a cornerstone mission launched on 19 December 2013 aiming at producing the most accurate 3D map of the Milky Way to date. The resulting stereoscopic census of the Galaxy will represent a giant leap in astrometric accuracy complemented by the only full sky homogeneous photometric survey with an angular resolution comparable to that of the Hubble Space Telescope, as well as the largest spectroscopic survey ever undertaken. The scientific bounty will be immense, not only unraveling the formation history and evolution of our Galaxy but also revealing and classifying thousands of extra-solar planetary systems, minor bodies within our solar system and millions of extragalactic objects, including some 500,000 quasars. Moreover, such a massive survey is bound to uncover many surprises. Over the period 2014-2018 the first Gaia data releases will appear, with the first full astrometric solutions (positions, proper motions, parallaxes) expected in 2017 (launch + 40 months).

SCIENTIFIC OBJECTIVES

In the Netherlands the main scientific objectives for the Gaia mission are: (1) the assembly history of the Milky Way and the link to nearby dwarf galaxies (Helmi, Brown, Tolstoy; Fig 4.7), (2) the nature and distribution of dark matter (Helmi, Kuijken), (3) fundamental stellar parameters and binaries (Groot, Pols, Nelemans, Portegies Zwart, Trager), and (4) the formation of stars, star clusters, planets, and the siblings of the Sun (Kaper, Brown, Portegies Zwart, Snellen).

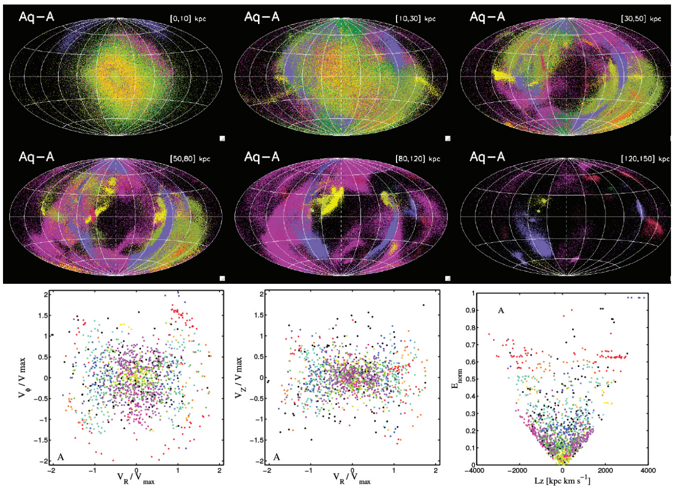


Figure 4.7: *Predictions for the distribution of stars in a stellar halo like that of the Milky Way. The top panels show that the distribution of nearby stars is smooth (first two panels), and that at larger distances substructures become apparent (middle panels). There is however, much substructure hidden in the kinematics, as shown in the bottom panels for stars within 5 kpc from the Sun. This is why multidimensional clustering and visualization techniques are required to exploit the Gaia data and unravel the formation of the Galaxy.*

TEAM

The project is led by Helmi and Brown. The co-I's include Nelemans, Pols, Portegies Zwart, Trager, Tolstoy and Roerdink (RUG computer science).

PROJECT APPROACH

ESA provides the core archive and catalogue hosting and access. The science application tools have to be developed by the research groups themselves. This project will develop interactive visualization tools to explore the very large multi-dimensional datasets. Discovery of new or unexpected phenomena in the Gaia data requires data-driven visualization tools that guide the user to information-rich spaces. The development of such tools forms the Dutch contribution to the Gaia DPAC Coordination Unit (CU9) which is in charge of the data archive and the catalogue tools (handling, mining, visualization), including the task to scientifically validate the Gaia catalogue prior to its public release. Through participation in DPAC in general and CU9 in particular astronomers in the Netherlands will be involved in the development of tools for the exploitation of the Gaia data and in the data release process, thereby obtaining a deep understanding of the Gaia archive prior to its public release. It is beneficial to NOVA at this point in time to switch the funding emphasis of its DPAC contributions from the photometric data processing (CU5, Phase-3 project) to the data publication and archive development activities (CU9).

FUNDING

In Phase-4 the Dutch contribution to the Gaia mission is to lead the visualization work packages on multi-dimensional data sets, and the validation statistical tools. It is estimated that 6.4 staff years are needed for this effort, of which 4.4 are funded through personal grants allocated to Helmi. The NOVA contribution is two staff years (Table 4.4.2). The emphasis capitalizes on local knowledge. The involvement is close to the data and will ensure that the astronomical community in the Netherlands will be ready to exploit the Gaia data releases in an efficient manner.

4.4.3. PARTICIPATION IN THE EUCLID MISSION

Cosmology continues to come up with surprises about fundamental physics, as was spectacularly exemplified by the accelerated expansion of the Universe, whose discovery led to the 2011 Physics Nobel Prize. The main constituents of the Universe, dark matter and dark energy, point to extensions of the standard model of particle physics and/or modifications in our understanding of gravity. Making sense of these discoveries has become a key goal of astronomers and physicists alike. Large ground-based sky surveys are underway to make progress, but it is widely recognized that definitive results will require a space mission. The Euclid satellite, selected in October 2011 by ESA for launch in its Cosmic Vision program after an intense three-year competition, will perform the ultimate study of the expansion history of the universe and the growth of structure within it. This will provide a

STAFF EFFORT	LEVEL	UNIV	TOTAL	2014	2015	2016	2017	2018
Software scientist	10	RUG	**2.00**	0.50	1.00	0.50		
Total Staff Effort			**2.00**	**0.50**	**1.00**	**0.50**	**0.00**	**0.00**

PERSONNEL BUDGET	LEVEL	UNIV	TOTAL	2014	2015	2016	2017	2018
Software scientist		RUG	**129**	32	65	32		
Sub-total Personnel			**129**	**32**	**65**	**32**	**0**	**0**

MATERIAL BUDGET			TOTAL	2014	2015	2016	2017	2018
Travel			**10**	2	5	3		
Travel DPAC chair			**30**	5	10	10	5	
Sub-total Materials			**40**	**7**	**15**	**13**	**5**	**0**
Total Costs Gaia			**169**	**39**	**80**	**45**	**5**	**0**

REVENUES (IN K€)			TOTAL	2014	2015	2016	2017	2018
NOVA Phase-4			**139**	9	80	45	5	0
Transfer Phase 3 → 4			**30**	30				
Total revenues (in k€)			**169**	**39**	**80**	**45**	**5**	**0**

Table 4.4.2: *NOVA contribution (in k€) to the preparation of the Gaia science harvesting. Additional staff effort in this project is funded through a personal grant.*

fundamental test of our cosmological world model, and will probe the nature of the dark matter and dark energy. To achieve its goals Euclid will map a large part of the sky with ultra-stable and sharp image quality in visible light, and measure fluxes and emission-line redshifts for tens of millions of faint sources in the near-infrared. These data will be combined with color measurements from on-going large ground-based imaging surveys. With ultra-sharp images of over a billion galaxies, the Euclid archive will also provide fantastic legacy science opportunities for those able to handle the large volumes of data.

DUTCH SHARE OF THE MISSION PREPARATION

The NL contributions to the Euclid Science Ground System (SGS) form an integral part of the Euclid mission. This scientific collaboration is organized by the Euclid Consortium, which consists of 107 European institutes from 12 European countries: Austria, Denmark, Finland, France, Germany, Italy, Netherlands, Norway, Romania, Spain, Switzerland, and the UK (a number of US scientists and engineers, primarily from the Jet Propulsion and Berkeley laboratories, participate as well). Currently, the consortium encompasses nearly 900 registered members, comprising a staff effort of more than 450 full-time researchers.

The NL EUCLID team will undertake selected work-packages for developing, building and populating part of the mission SGS. This activity centers around the NL Science Data Center (SDC-NL) at the Center for Information Technology (CIT) of the University of Groningen at which the team in the Netherlands, together with partners in the Euclid international consortium, will (1) jointly develop, build and host the Euclid Mission Archive, (2) populate it with a large amount of complementary ground based data from dark matter/energy surveys, and (3) develop a data reduction and calibration pipeline for the infrared

Euclid data. The SDC-NL will be delivered before launch to the international Euclid consortium as part of the missions Science Ground Segment. This in-kind contribution provides membership of the consortium and gives the Dutch astronomy community the opportunity to take a leading role in this high-profile mission. The SDC-NL will also serve as an expertise and service center to the NL astronomical community at large for attaining their science goals.

The designated roles for the Netherlands in the SGS are (1) to host a Science Data Center at the RUG Center for Information Technology (CIT), where the NL activities on the Euclid Mission Archive (EMA) will be centered and all NL processing and storage will be hosted; (2) to co-lead the activities for OU-EXT (collecting and archiving external complementary non-Euclid data); (3) be deputy lead for OU-NIR (near IR reduction software); and (4) to provide important contributions to OU-SHEAR (weak lensing analysis). The contributions to the SDC-NL, EMA, OU-EXT and OU-NIR, count as formal (ESA and Euclid Consortium) contributions to the mission. They are regarded in the same way as contributions in hardware, and entitle the Netherlands to full membership of the Euclid project and involvement in its scientific exploitation.

TEAM AND INTERNATIONAL REPRESENTATION

Kuijken and Valentijn are project PI's for the Netherlands with ~20 co-I's spread over all four NOVA institutes. The NL work packages are led by Valentijn and Williams (SDC-NL), Verdoes-Klein (OU-EXT), Bouwens and Labbé (OU-NIR) and Hoekstra and Kuijken (OU-SHEAR). Valentijn is the national project manager, Röttgering is member of the international EUCLID consortium board and Boland represents NOVA in the international EUCLID steering committee.

FUNDING

The total investment of the Netherlands in the EUCLID space mission amounts to 8.0 M€ of which 1.4 M€ is spent in 2012-2013 and 6.6 M€ is available for use in the period 2014-2020. The revenues are provided from the following sources: 1.6 M€ from TARGET, 1.8 M€ from RUG ICT strategy funds, 1.2 M€ staff contributions from the RUG Kapteyn Institute, 0.9 M€ staff contributions from OmegaCEN, 0.4 M€ staff contributions from the UL Sterrewacht, 1.0 M€ from NOVA (800 k€ as specified in Table 4.4.3 and 200 k€ is kept in reserve for project contingency), 0.4 M€ from NWO-M and 0.7 M€ from SRON.

STAFF EFFORT	FUNDING	TOTAL	2014	2015	2016	2017	2018
Euclid Mission Archive							
Project manager EMA/SDC	RUG	**4.1**	1.0	1.0	0.7	0.7	0.7
System design engineer	RUG	**5.0**	1.0	1.0	1.0	1.0	1.0
Database expert	RUG/NOVA	**4.0**	1.0	1.0	1.0	1.0	
System engineer	RUG	**4.0**	1.0	1.0	1.0	1.0	
Science preparations	RUG	**5.0**	1.0	1.0	1.0	1.0	1.0
System engineer	SRON	**3.0**		1.0	1.0	1.0	
OU NIR pipeline							
Staff UL Sterrewacht	UL	**2.5**	0.5	0.5	0.5	0.5	0.5
Software designer	NOVA	**4.0**	1.0	1.0	1.0	1.0	
OU External ground-based data		**0.0**					
Kapteyn/RUG staff	SRON	**2.5**	0.5	0.5	0.5	0.5	0.5
Technical postdoc	NOVA	**4.0**	1.0	1.0	1.0	1.0	
System engineer SDC	RUG	**5.0**	1.0	1.0	1.0	1.0	1.0
Technical support	RUG	**5.0**	1.0	1.0	1.0	1.0	1.0
NL science data center							
Technical development	RUG	**9.0**	2.0	2.0	2.0	2.0	1.0
Total Staff Effort		**57.1**	**12.0**	**13.0**	**12.7**	**12.7**	**6.7**

NOVA FUNDED STAFF COSTS	UNIV	TOTAL	2014	2015	2016	2017	2018
Database expert	RUG	**216**		70	72	74	
OU-NIR software designer	UL	**248**	60	62	62	64	
Technical postdoc	RUG	**248**	60	62	62	64	
Sub-total Personnel		**712**	**120**	**194**	**196**	**202**	**0**

MATERIAL BUDGET		TOTAL	2014	2015	2016	2017	2018
Database server	RUG	**pm**					
Travel funds	NOVA	**88**	16	18	18	18	18
Sub-total Materials		**88**	**16**	**18**	**18**	**18**	**18**
Total Euclid costs for NOVA		**800**	**136**	**212**	**214**	**220**	**18**

Table 4.4.3: *NOVA funding contribution (in k€) excluding contingency to the Dutch participation in the EUCLID space mission. The different colors indicate the contributions of each of the partners: blue for RUG including the TARGET project and NWO-M , green for UL, red for SRON, and yellow for NOVA.*

4.5. OTHER INSTRUMENTATION PROJECTS

4.5.1. APERTIF RADIO TRANSIENT SYSTEM – ARTS

Apertif is a highly innovative receiver system currently being constructed for the WSRT. Its factor of 30 increase in field-of-view allows astronomers to survey the entire sky at 1.4 GHz with an unprecedented combination of sensitivity and speed. ARTS is an instrument that extends this wide-field Apertif system to high time resolution, enabling unique searches for millisecond transients, and nanosecond neutron-star timing. ARTS also allows for a wholly new approach to Very Long Baseline Interferometry (VLBI) that produces sensitive, wide-area images at milliarcsecond angular resolution.

SCIENCE CASE

ARTS will be built to research radio transients and their likely origin: supernovae, neutron stars, and stellar-mass or supermassive black holes. The extreme energies, densities and gravity in all these sources far exceed what can be produced in terrestrial laboratories. Their study is imperative for fundamentally understanding mass and energy. ARTS will enable to better understand how dense, hot matter is attracted and expelled in extreme gravity, to precisely measure stellar kinematics, and to determine supermassive black-hole energetics.

TECHNICAL APPROACH

The I/O demands and computing power requirements of the instrument are extraordinary. The instrument

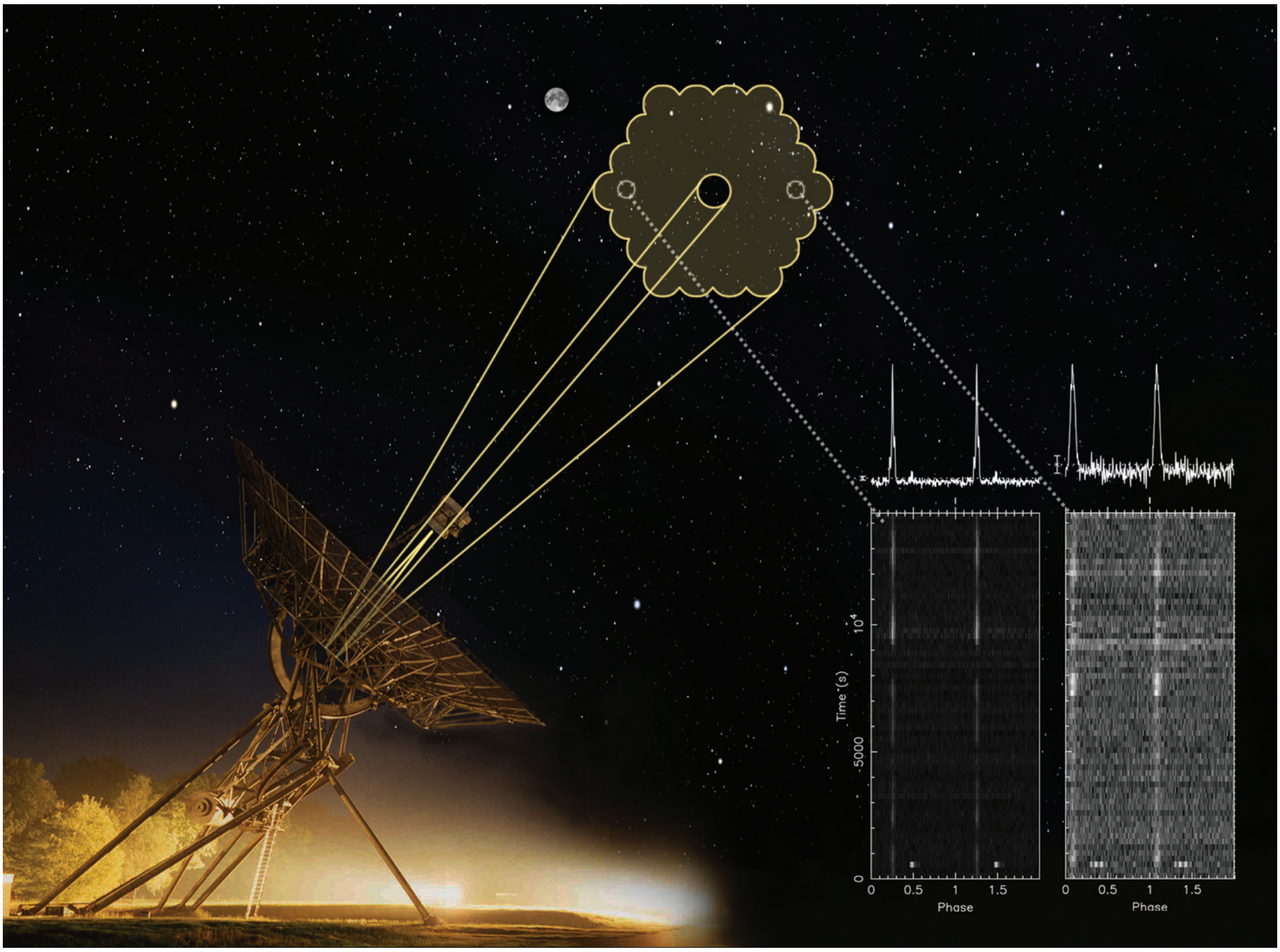


Figure 4.8: *The improvement in field of view from current WSRT beam (central circle; size of the full moon) to that of ARTS (large hexagon). The two cross hairs indicate pulsars B0329+54 and B0355+54, detected with the ARTS test system.*

algorithms, however, map exceedingly well on Graphics Processing Units (GPUs). ARTS will be built as a GPU-based supercomputing instrument that will serve as a unique wide-field VLBI backend; as a pulsar timing machine much more powerful than PuMa-II; and finally, as a cutting-edge fast-transient survey instrument. It is an order of magnitude more sensitive to extragalactic radio bursts than any other experiment in the world, including the Parkes telescope that recently found and confirmed these bursts. ARTS will provide much better localization, essential for discovering the nature of these enigmatic, powerful cosmological events. The demonstrator systems have already successfully detected real-life transients (Fig. 4.8).

TEAM

The ARTS team consists of PI van Leeuwen (UvA/ASTRON), project managers Nijboer (ASTRON) and Bassa (UvA/ASTRON) and 12 co-investigators from NOVA institutes and ASTRON.

STAFF EFFORT	LEVEL	UNIV	TOTAL	2014	2015	2016	2017	2018
Technical postdoc	11	UvA	**1.50**		0.50	0.50	0.50	
Technical PhD 1	AIO	UvA	**2.00**	0.50	0.50	0.50	0.50	
Technical PhD 2	AIO	UvA	**4.00**	1.00	1.00	1.00	1.00	
Project coordinator	11	UvA	**0.80**	0.20	0.20	0.20	0.20	
Total Staff Effort			**8.30**	**1.70**	**2.20**	**2.20**	**2.20**	**0.00**

PERSONNEL BUDGET	LEVEL	UNIV	TOTAL	2014	2015	2016	2017	2018
Technical postdoc	11	UvA	**106**		35	35	35	
Technical PhD 1	AIO	UvA	**86**	21	21	21	21	
Technical PhD 2	AIO	UvA	**171**	43	43	43	43	
Project coordinator	11	UvA	**57**	14	14	14	14	
Sub-total Personnel			**420**	**78**	**114**	**114**	**114**	**0**

MATERIAL BUDGET			TOTAL	2014	2015	2016	2017	2018
Module 1 timing			**20**	20				
Module 2 VLBI			**20**	20				
Module 4 Full searching			**142**		102		40	
Bench & Travel			**68**	14	18	18	18	
Sub-total Materials			**250**	**54**	**120**	**18**	**58**	**0**
Total expenditure ARTS			**670**	**132**	**234**	**132**	**172**	**0**
NOVA funding ARTS (in k€)			**670**	**132**	**234**	**132**	**172**	**0**

Table 4.5.1: *NOVA funding contributions (in k€) to the ARTS project. The other 2 yrs of technical PhD-1 is funded through nw3-04 research project ALERT. In addition the project has secured 2,189 k€ funding from ASTRON and NWO-G and NWO-M grants.*

FUNDING

Significant external funding has been secured from NWO grants and ASTRON. To realize the full ARTS scientific potential, NOVA will fund (Table 4.5.1) part of the hardware and cover staff costs based at UvA to develop and implement the GPU transient-search and pulsar-timing pipelines.

4.5.2. PARTICIPATION IN THE CHERENKOV TELESCOPE ARRAY – CTA

The CTA (www.cta-observatory.org) is a global effort to build northern and southern observatories for γ-ray astronomy at the highest energies (~10 GeV to ~300 TeV). It will dramatically improve on all aspects of performance with respect to the highly successful current generation of Cherenkov telescopes (e.g. H.E.S.S., MAGIC, Veritas) and will outperform the Fermi satellite by 4–5 orders of magnitude in sensitivity for sub-minute timescale transient phenomena such as gamma-ray bursts above ~30 GeV (Fig. 4.9). CTA is a key project in the field of particle astrophysics and high energy astrophysics and is highly ranked in all major European and US astrophysics and astroparticle physics roadmaps. CTA is currently transitioning from an EU-supported preparatory phase to the prototyping phase, with site preparation and construction envisaged from 2016-2020. The construction of CTA will start with construction of a sub-array of small-sized telescopes (SSTs), the most numerous types of CTA telescopes, which target the highest energy gamma-rays (> 5 TeV). The most likely design of the SSTs consists of double mirror telescopes, which allows for a compact camera design. Currently prototypes are being developed in Italy and Paris, with Italy (the ASTRI consortium) considered the front runner. The likely camera design will be that of the Compact High-Energy Camera (CHEC), developed by a UK team.

NL CONTRIBUTION

The project will realize an important share in the prototyping phase of CTA, by a) taking up a major role in developing the CHEC camera, by b) playing an important role in photosensor development and testing for CTA, and by c) designing a novel system for the calibration of the exact telescope pointing position in the sky. A substantial Dutch contribution to CHEC will bring researchers in the Netherlands into a position to also make important hardware contributions to

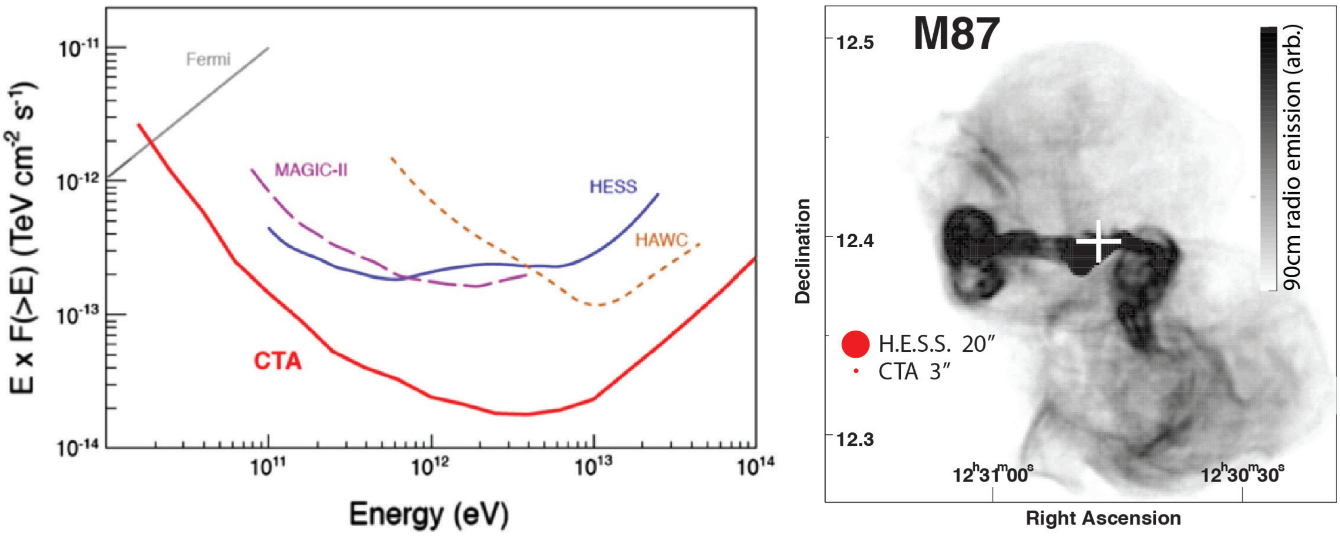


Figure 4.9: Left: *The integral flux sensitivity of CTA in comparison to selected current and planned γ-ray instruments.* ***Right:*** *The radio image of the radio galaxy M87 is shown together with the best-fitting position and uncertainty of the most precise current γ-ray measurement by H.E.S.S. (white cross). Both the central black hole and the relativistic jets could be the source of γ-rays. The H.E.S.S. telescope-pointing uncertainty of this measurement is 20'', and the red solid circles compare the precision of H.E.S.S. to that envisaged for CTA (3'').*

STAFF EFFORT	LEVEL	UNIV	TOTAL	2014	2015	2016	2017	2018
Instrument scientist CHED	11	UvA	**3.00**	1.33	1.00	0.67		
Instrument scientist Photosensors	11	RU	**3.00**	1.25	1.00	0.75		
Instrument scientist SST pointing	11	Op-IR	**1.43**	0.43	0.33	0.33	0.33	
Total Staff Effort			**7.43**	**3.02**	**2.33**	**1.75**	**0.33**	**0.00**

PERSONNEL BUDGET	LEVEL	UNIV	TOTAL	2014	2015	2016	2017	2018
Instrument scientist CHED	11	UvA	**212**	94	71	47	0	0
Instrument scientist Photosensors	11	RU	**212**	88	71	53	0	0
Stuik, R.	11	Op-IR	**101**	31	24	24	24	0
Sub-total Personnel			**526**	**214**	**165**	**124**	**24**	**0**

MATERIAL BUDGET			TOTAL	2014	2015	2016	2017	2018
Hardware CHEC			**196**	196				
Hiring mechanical engineering			**40**	40				
Hardware Photosensors			**330**	200	130			
Travel								
CHEC			**35**	10	10	10	5	
Photosensors			**28**	7	7	7	7	
Pointing			**10**	4	3	3		
Miscelleneous			**16**	3	3	3	4	3
Sub-total Materials			**655**	**460**	**153**	**23**	**16**	**3**
Total expenditure CTA			**1,181**	**674**	**318**	**147**	**40**	**3**
NOVA funding + guarantee CTA (in k€)			**1,181**	**674**	**318**	**147**	**40**	**3**

Table 4.5.2: *NOVA funding contribution (in k€) to the technology development for the NL participation in CTA. The project plans to cover a significant part of the development costs of the photosensor from an external grant.*

the construction of CTA, thereby assuring full Dutch consortium membership, including prioritized access to data and observation time. Moreover, it allows the Netherlands to participate in the construction of the CTA seed array of SSTs, giving access to the first science data of CTA with sensitivities that are potentially already better than those of current experiments at the highest gamma-ray energies. This project will prepare ground for a possible Dutch contribution to the CTA construction.

TEAM

The project joins the major new astroparticle physics initiatives GRAPPA in Amsterdam and IMAPP in Nijmegen with contributions of the University of Groningen. The Dutch CTA project team is also actively looking for collaborations with the particle physics community in the Netherlands interested in CTA. The core team consists of Vink (PI), Berge (lead CHEC camera R&D and telescope pointing calibration), Markoff, Hörandel (lead R&D photosensor), and van den Berg (electronics development at KVI).

TECHNICAL APPROACH

The Dutch share in the CHEC project will be substantial, with the Netherlands contributing the back-end electronics, and substantial contributions to building a full camera prototype with silicon photon multipliers (SiPMs) as light detectors (a first CHEC prototype is based on more conventional multi-anode PMs). An important supplier of SiPMs is Philips, and part of the efforts is geared towards co-developing with Philips a version of their SiPMs that is suitable for CTA. This will be an important partnership with industry. For the telescope pointing calibration, the CHEC cameras will be supplied with additional read-out electronics in order to process the continuous signal from the night sky, which will be used to localize bright stars in order to reconstruct the pointing of the SSTs with an accuracy of better than 7 seconds of arc. The pointing system will be co-developed with the NOVA Op-IR group.

FUNDING

In the CTA project NOVA contributes to technology development and feasibility studies. The funding amounts to 7.4 staff years and 655 k€ material budget. Further specifications are given in Table 4.5.2.

4.5.3. LABORATORY ASTROPHYSICS

During NOVA Phases 1-2 the CRYOPAD instrument – an ultra-high vacuum laboratory setup for cryogenic photoproduct experiments - was designed and constructed. It has been extensively used to study the behavior of interstellar ice analogues upon irradiation with vacuum UV light. The experiments performed with CRYOPAD have provided molecular insights that allow astronomers to interpret their observations in terms of consistent physical-chemical reaction schemes and to make predictions that can be tested with future programs. How is it possible that gas phase molecules can be observed in space at temperatures where all species should be frozen onto dust particles? Why do JCMT, Herschel-HIFI and ALMA observations find complex molecules like glycolaldehyde, dimethylether and methylformate near forming stars, where the observed abundances cannot be due to gas phase reactions? Predictions derived from CRYOPAD data have guided astronomical surveys and the importance of dedicated laboratory experiments to fully exploit the scientific impact of observational data is now generally recognized worldwide. Indeed, the quantitative parameters determined over the last years with CRYOPAD are routinely implemented in astrochemical models and provide the means to visualize the full chemical evolution of the interstellar medium, alongside astronomical observations that normally only provide snapshots in time.

In NOVA Phase-4 an upgrade of CRYOPAD is foreseen for studies of complex nitrogen containing molecules. These are considered building blocks of amino-acids and other biologically relevant species. The outcome will guide astronomical observations to search in the correct environments for molecular species that are a prerequisite for life. Moreover, a simultaneous detection of different species allows constructing chemical networks and deriving physical parameters such as the temperature history or level of UV irradiation, a core topic within the Network-2 program. Other elementary questions that will be addressed are the photo-desorption rate of H_2O ice to accurately model the flood of Herschel-HIFI data on water ranging from cloud cores on the verge of collapse to the cold outer regions of proto-planetary disks, the dependence on the wavelength of the impacting radiation, and the role of photon induced co-desorption processes.

PROJECT PLAN

CRYOPAD is an ultra-high vacuum setup with base pressures lower than 10^{-10} mbar. Interstellar ice analogues are grown with monolayer (ML) precision at thicknesses between a few up to a few hundred MLs by exposing a cold substrate at the center of the vacuum chamber to a steady flow of gas, directed along the surface normal. The substrate is mounted on top of a closed cycle He cryostat generating temperatures that can be controlled with 0.2 K precision between 15 and 200 K. The light of a Fourier transform infrared spectrometer (500-4000 cm^{-1}, 0.5 cm^{-1} bandwidth) is guided through the ice in a reflection-absorption mode (FT-RAIRS) onto a liquid nitrogen cooled InSb infrared detector.

The instrumental objective of this project is to upgrade and extend CRYOPAD, in particular replacing the main ultra-high vacuum chamber; exchanging the turbo pumps; implementing a new type of vacuum UV radiation source, with the option of online monitoring of the emission pattern and a real time quantitative flux determination using a vacuum UV spectrometer; replacing the gas inlet system by a fully automated system using leak valves; and upgrading the 15-year old Fourier Transform IR spectrometer by a new Agilent FTIR 660 system. In order to get access to high quality monochromatic radiation as provided at large beam line facilities the new setup will be constructed on a mobile frame.

TEAM

The project is led by Linnartz with 9 co-Is in the Netherlands and 4 abroad.

FUNDING

The funding allocated for Laboratory Astrophysics is summarized in Table 4.5.3. About half of the funds will be spent on hardware to upgrade the CRYOPAD instrument and the other half will fund staff to do the work. In the last two years of the appointment the PhD student will use the upgraded instrument for astrophysical relevant experiments funded by Research Network-2.

STAFF EFFORT	LEVEL	TOTAL	2014	2015	2016	2017	2018
Technical PhD student	AIO	**2.00**	1.00	1.00	nw2	nw2	
Technician		**0.50**	0.25	0.25			
Total Staff Effort		**2.50**	**1.25**	**1.25**	**0.00**	**0.00**	**0.00**

PERSONNEL BUDGET	LEVEL	TOTAL	2014	2015	2016	2017	2018
Technical PhD student	AIO	**104**	52	52			
Technician (FMD/ELD)		**25**	13	13			
Sub-total Personnel		**129**	**64**	**64**	**0**	**0**	**0**

MATERIAL BUDGET		TOTAL	2014	2015	2016	2017	2018
Travel		**3**	1	2			
Vacuum chamber Hardware equipment		**120**	60	60			
Sub-total Materials		**123**	**61**	**62**	**0**	**0**	**0**
Total costs Laboratory Astrophysics		**252**	**125**	**126**	**0**	**0**	**0**

Table 4.5.3: *NOVA funding (in k€) for the upgrade of the CRYOPAD instrument at the Laboratory Astrophysics group.*

4.6. OPTICAL-INFRARED INSTRUMENTATION GROUP

The Optical-IR instrumentation group of NOVA provides the technical focus of the projects in this wavelength range. It is based in the ASTRON institute in Dwingeloo. The staff are employed by NWO. The organizational structure and the relations between the three parties are described in a contractual agreement renewed in November 2013. The original agreement started on 1st January 2008 and present version runs to end 2018 with the option for further extensions.

The group consists of 13 experienced people with expertise including optical, mechanical, and cryogenic design, system engineering, CNC and optical production capabilities, instrument integration, and verification. Over the last 14 years this group has carried out the optical-IR instrumentation projects for which NOVA had final responsibility towards ESO, ESA, and international partners.

COSTS OF THE OP-IR GROUP

The staffing and costs of the Op-IR instrumentation group are summarized in Table 4.6a. The staff costs are calculated assuming an inflation of 1.5% per year. The annual costs of the group increase from 1.5 M€ in 2014 to 1.8 M€ in 2018. The main reason of the cost increase is the planned three new positions for an instrument scientist, a third optical designer (in a joint appointment with another organization) and a documentalist. These extra staff positions are required when the work on E-ELT instrumentation starts seriously.

The revenues for the Op-IR group are specified in Table 4.6b. As listed in the top-frame of the table the funding comes from the approved and planned NOVA Phase-4 projects (in total 7463 k€), remaining Op-IR contingency from Phase-3 (157 k€) and work for new projects or contractual work (832 k€). These cost figures are totals for the five year period. The middle frame specifies the revenues from work for the various NOVA projects, and the bottom frame lists the options for additional funding resources. Over the Phase-4 period there will be steady baseline NOVA funding for the Op-IR instrumentation group but only on a project basis. The strategy is that NOVA wants to fund instrumentation projects that are directly related to innovative research. Additional income is required to fund innovation and technical R&D to keep the expertise and infrastructure of the group at the competitive level. A risk is that any delay in the start of projects for whatever reason will impact on the revenues for the group and hence will create a cost burden for NOVA. The approach to mitigate this risk is to create internal funding contingency for the group as has been done in Phase-3 (third line in top frame of Table 4.6b) through undertaking contractual work to generate extra revenues that will build up the contingency.

OP-IR PERMANENT POSITIONS	TOTAL	2014	2015	2016	2017	2018
Total Op-IR staff resources (in fte)	**71,46**	**12,89**	**13,59**	**14,99**	**14,99**	**14,99**
Total Op-IR staff costs (in k€)	**7575**	**1336**	**1431**	**1579**	**1602**	**1626**
Maintenance facilities + licences	**60**	12	12	12	12	12
Integration hall + cleanroom	**250**	50	50	50	50	50
Miscelleneous	**100**	20	20	20	20	20
Travel	**125**	25	25	25	25	25
Investments/Education	**95**	15	20	20	20	20
Prototyping hardware	**172**	12	50	50	30	30
Diversen	**75**	15	15	15	15	15
Total general costs (in k€)	**877**	**149**	**192**	**192**	**172**	**172**
Total costs Op-IR group in k€	**8452**	**1485**	**1623**	**1771**	**1774**	**1798**

Table 4.6a: *Staffing and costs (in k€) of the Op-IR instrumentation group for the period 2014-2018. Staff costs are calculated assuming an inflation of 1.5% per year.*

REVENUES OP-IR GROUP	TOTAL	2014	2015	2016	2017	2018
NOVA Phase-4 funding	**0**	0	0	0	0	0
Work for NOVA projects	**7494**	965	1514	1742	1761	1511
Op-IR funds transfer Phase-3 → 4	**126**	126				
Possible new projects / external funding work	**832**	100	132	150	225	225
Total revenues (in k€)	**8452**	**1191**	**1646**	**1892**	**1986**	**1736**

	TOTAL	2014	2015	2016	2017	2018
Op-IR group: Revenues - Costs in k€	**0**	**-294**	**23**	**121**	**212**	**-62**

WORK FOR NOVA PROJECTS	TOTAL	2014	2015	2016	2017	2018
METIS	**3304**	130	657	818	840	859
MICADO	**927**	96	153	201	215	262
EPICS	**97**	24	24	24	25	
MOSAIC	**1072**	25	52	232	373	391
WEAVE	**1463**	359	445	374	285	
CTA	**101**	31	24	24	24	
BlackGEM	**120**	60	60			
OPTICON FP7.2: active optical systems	**90**	30	30	30		
OPTICON FP7.2: AO	**40**	20	20			
MATISSE after delivery support	**250**	160	50	40		
Production ALMA Band-5 mirror blocks	**30**	30				
Total revenues for Op-IR group	**7494**	**965**	**1514**	**1742**	**1761**	**1511**

POSSIBLE NEW PROJECTS / EXTERNAL FUNDING WORK	TOTAL	2014	2015	2016	2017	2018
Extra work paid from project contingencies	**230**	30	50	50	50	50
New projects with funding	**220**			20	100	100
External contractual work	**292**	40	52	50	75	75
Support ALMA Band-5 production/testing	**90**	30	30	30		
Total new projects /external contractual work	**832**	**100**	**132**	**150**	**225**	**225**

Table 4.6b: *Revenues (in k€) for the Op-IR instrumentation group for the period2014-2018.*

4.7. PROJECT CONTINGENCY

Within the instrumentation program NOVA has reserved contingency funds for each project. These reservations are listed in Table 4.7. All contingecy funds are held centrally at Board level. The table only lists nominal reservations for indivitual projects. In addition to the project contingencies amounting to 2121 k€ a reservation of 259 k€ is made for general instrumentation program contingency and new initiatives. For the E-ELT MOS the contingency is still part of the funding reservation for this project.

NOVA POLICY ON PROJECT CONTINGENCY

The policy for use of contingency funds is as follows: PI's have to make their case 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 Boards makes the final decision.

PROJECTS	TOTAL	2014	2015	2016	2017	2018
E-ELT METIS	**600**			100	250	250
E-ELT - MICADO	**125**				50	75
E-ELT MOS	**0**					
E-ELT EPICS	**13**		13			
EUCLID	**200**	40	40	40	40	40
WEAVE	**200**	40	40	60	60	
MIRI	**50**				20	30
BlackGEM	**300**	100	100	100		
CTA	**235**	45	70	70	50	
ARTS	**36**		20	16		
Data-mining and long-term archiving	**48**		24	24		
GAIA	**24**		12	12		
MATISSE contingency	**290**	290				
Total project contingency	**2,121**	**515**	**319**	**422**	**470**	**395**
General contingency and new initiatives	**259**		9	50	100	100
Total contingency Phase-4 instrumentation	**259**	**0**	**9**	**50**	**100**	**100**
Reservation for contingency / new initiatives (in k€)	**2,380**	**515**	**328**	**472**	**570**	**495**

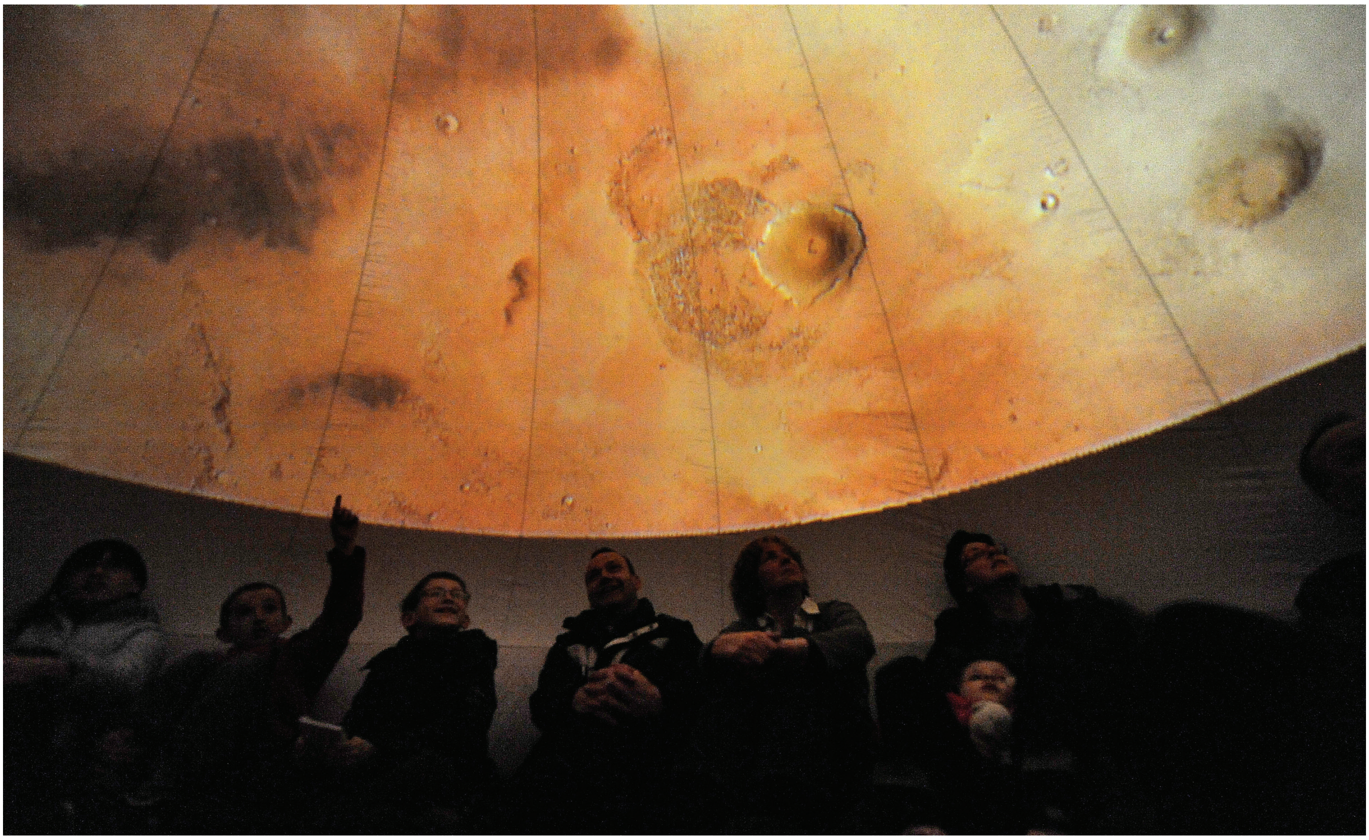
Table 4.7: *Contingency reservations (in k€) for the instrumentation projects. In addition there is 259 k€ available for general instrumentation program commissioning and new initiatives.*

4.8. 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 for contingency funds when projects make 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-4 instrumentation program.

The ISC meets normally in March and September, 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.

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.



One of the three mobile planetaria as seen from the outside (top) and inside (bottom). Each year 300 primary and secondary schools are visited to let scholars discover the night sky and other astronomical phenomena.

5. ORGANIZATION, OFFICE AND PUBLIC OUTREACH

5.1. ORGANIZATION, DIRECTORATE AND OFFICE

In November 2012 the universities of Amsterdam (UvA), Groningen (RUG), Leiden (UL) and Nijmegen (RU) signed a new agreement regarding the ongoing collaboration of their astronomy institutes in the NOVA program. The program is governed by the NOVA Board consisting of the directors of the four university astronomical institutes (see Appendix B) and the Raad van Toezicht (Supervisory Board) consisting of the deans of the faculty in which astronomy resorts. NOVA is legally represented by the UL.

The NOVA Directorate is appointed 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 (financial control) and Mrs. Jacqueline Quist (office management). The Science Faculty of the UL provides the financial administration for NOVA.

5.2. PUBLIC OUTREACH – NOVA INFORMATION CENTER (NIC)

The NOVA Information Center (NIC) has been established to popularize astronomy and astrophysics in the Netherlands. NOVA has a responsibility to report its frontline research in the widest sense. The fast changing world of information and communications technology requires a pro-active approach to outreach and the NIC strives at being a forerunner in this field. It realizes that popularization of astronomy is also an excellent means for stimulating the public interest in the natural sciences in general. Specifically, it aims to contribute to such interests of students contemplating their higher education options. The NIC has different target groups for its outreach efforts: (1) the general public, (2) students and teachers, (3) the press, and (4) the policy makers.

The NIC is managed by Marieke Baan (0.74 fte). Jaap Vreeling (0.6 fte) is responsible for initiating, developing and managing educational programs. Franka Buurmeijer (0.8 fte) is assistant press officer and web-editor. The NOVA outreach and education program is monitored by the Minnaert Committee, chaired by Alex de Koter.

The NIC program includes:

- Close collaboration with the national coordinator of Universe Awareness. UNAWE is a European educational initiative targeted at children of ages up to 10. This age group is complementary to the target groups of the NIC. The NIC takes care of Dutch translations of UNAWE produced promotion materials;
- Communicating astronomy to the public: The NIC presents news and information, and reports on all of its activities, through different types of media, including TV, and social media. Central to its communication is the website 'astronomie.nl';
- Providing press releases to the media with news on national highlights of astronomical discoveries and general astronomical phenomena, typically on a weekly basis. These press releases are issued in close collaboration with outreach officers at ESO, ESA, SRON and ASTRON, when appropriate;
- Using a new strategy to inform policy makers, aiming for direct communication through using the mobile planetarium;
- Bringing astronomy into classrooms. The NOVA

project aims to improve the transfer of astronomical knowledge in schools through the use of innovative methods;

- Use of three Mobile Planetaria to visit primary and secondary schools. Trained operators apply an interactive didactic method to let students discover the night sky, the solar system and beyond;
- Publication of NOVAlabs, booklets with astronomy projects and exercises, for groups 7 and 8 of primary schools and juniors in secondary schools. A digibord lesson 'Zon en Planeten' is developed for primary school students and served as a basis for the educational iPad games Planetenreis, for the same target group;
- Include a chapter on astronomy in the new physics curriculum in secondary education. NOVA astronomers have made a convincing case which is now being implemented. NIC coordinates writing of the astronomy chapters by experienced people with a strong track record in astronomy at university level. Furthermore training of the physics teachers to familiarize them with the new astrophysics education, which is more topical than that offered in previous generations of textbooks.

6. FINANCE

An overview of the expenditures and revenues for the NOVA Phase-4 program is provided in Table 6. The total budget for the period 2014-2018 amounts to 42.280 M€. The revenues consist of the following components: (1) ministerial grant for the top-research school of 25.7 M€, (2) a cash carry over on the NOVA bank account from Phase-3 of 3.5 M€; (3) ESO funding for the ALMA Band-5 production project of 7.2 M€, (4) several grants from the national research funding agency NWO for the WEAVE project amounting to 1.2 M€, (4) funding from the national Roadmap program for METIS of 4.5 M€, and (5) two smaller external contributions adding up to 217 k€.

The expenditures include (1) 13.1 M€ on the research program, (2) 26.5 M€ on the instrumentation program, and (3) 2.7 M€ on the office and the public outreach program.

Further budget information is provided in various tables in Chapters 3 and 4. The research budget includes 450 k€ for unforeseen circumstances and/or to allow support for new research initiatives. The instrumentation program includes 2121 k€ project contingency and 258 k€ for general contingency and/or new initiatives.

REVENUES	TOTAL	2014	2015	2016	2017	2018
OCW grant NOVA phase 4	**25.675**	5.135	5.135	5.135	5.135	5.135
NOVA Bank	**3.537**	3.537				
Interest	**100**	20	20	20	20	20
Roadmaps funds for METIS	**4.457**		200	1.000	1.500	1.756
NWO funds for WEAVE	**1.195**	500	500	195		
ESO funding	**7.199**	4.252	1.634	1.174	139	
MIRI, ESA contribution	**117**	117				
NOVA PHASE-4 revenues (in k€)	**42.280**	**13.561**	**7.489**	**7.524**	**6.794**	**6.911**

Table 6: *Specification of the NOVA Phase-4 program (page on the right) covering the period 2014-2018. Integrated over the period expenditures and revenues (above) are in balance. The salary costs for the positions at the universities are calculated according the guidelines described in section 6.1.*

EXPENDITURE	TOTAL	2014	2015	2016	2017	2018
ASTRONOMICAL RESEARCH						
Overlap Appointments	**2.853**	**642**	**767**	**674**	**448**	**322**
Formation and evolution of galaxies	**2.829**	434	746	839	653	157
Formation of stars and planetary systems	**3.175**	705	763	765	769	173
Astrophysics: black holes, neutron stars, white dwarfs	**3.006**	975	878	710	443	0
Total Research Network Program	**9.010**	**2.114**	**2.387**	**2.314**	**1.865**	**330**
Miscelleneous activities	**100**	20	20	20	20	20
Master Fellows	**400**	80	80	80	80	80
Workshops & Visitors	**275**	55	55	55	55	55
New Initiatives	**450**	10	110	110	110	110
Total Other Research Activities	**1.225**	**165**	**265**	**265**	**265**	**265**
TOTAL ASTRONOMICAL RESEARCH	**13.088**	**2.921**	**3.419**	**3.253**	**2.578**	**917**
INSTRUMENTATION						
E-ELT METIS	**6.857**	356	1.369	1.603	1.652	1.877
E-ELT MICADO	**1.994**	109	190	267	284	1.144
E-ELT instruments EPICS	**375**	51	107	108	84	26
E-ELT instruments MOSAIC	**1.281**	28	55	237	470	491
Datamining related to OmegaCAM and MUSE	**322**	87	76	66	49	45
BlackGEM	**1.400**	536	653	132	63	15
WEAVE	**3.080**	1.097	1.042	534	408	0
NOVA Op-IR instrumentation group	**0**	-294	23	121	212	-62
ALMA Band-5 final design and production	**5.098**	2151	1634	1174	139	
MIRI	**604**	88	89	169	129	129
Gaia	**169**	39	80	45	5	0
Euclid	**800**	136	212	214	220	18
ARTS	**670**	132	234	132	172	0
CTA	**1.181**	674	318	147	40	3
Laboratory for Astrophysics	**252**	125	126	0	0	0
Project contingency	**2.121**	515	319	422	470	395
General contingency and new initiatives	**258**	0	8	50	100	100
TOTAL INSTRUMENTATION	**26.463**	**5.832**	**6.535**	**5.419**	**4.496**	**4.180**
OFFICE AND PUBLIC OUTREACH						
NOVA Office	**1.544**	306	305	337	312	282
NOVA Public Outreach (NIC)	**1.185**	236	236	236	236	241
TOTAL OFFICE and OUTREACH	**2.729**	**542**	**541**	**574**	**549**	**524**
TOTAL EXPENDITURE (in k€)	**42.280**	**9.295**	**10.496**	**9.245**	**7.623**	**5.621**

6.1. FINANCIAL ARRANGEMENTS FOR THE PHASE-4 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 6.1. These figures are based on the actual staff costs per 1st January 2014. Each year they will be adjusted to the actual staff cost figures for that year if NOVA receives financial compensation for inflation.

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 an 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 appointed 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 Optical/IR instrumentation group NOVA has made a reservation to cover such 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.

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	SCALE	MONTH	SALARY	OPSLAG	GROSS + OPSLAG	MAT. COSTS	TOTAL
			per 1 Jan 2014		in k€	in k€	in k€
HL	16 - 9	7.285	87.420	1,4463	126,437	15,0	141,437
UHD	14 - 5	5.428	65.136	1,4652	95,440	12,0	107,440
UD	12 - 6	4.634	55.608	1,4780	82,187	12,0	94,187
Postdoc	11 - 6	3.950	47.400	1,4934	70,789	12,0	82,789
AIO			see table below		42,842	9,0	51,842
Non-scientific academic staff	11 - 6	3.950	47.400	1,4934	70,789		70,789
Technical staff	9 - 8	3.491	41.892	1,4878	62,328		62,328
Support staff 1	7 - 5	2.427	29.124	1,4678	42,747		42,747
Support staff 2	8 - 9	3.037	36.444	1,4807	53,962		53,962

AIO SALARY SCALE				
year		**Gross/year**		**Total/year**
1	2.083	24.996	1,4664	36,655
2	2.427	29.124	1,4678	42,747
3	2.542	30.504	1,4707	44,861
4	2.664	31.968	1,4734	47,103
Average per year				**42,842**

Table 6.1: *Summary of the budget guidelines for the NOVA reimbursement of staff costs at the universities for Phase-4. The staff cost figures (in k€) are applicable for 2014 and will be adjusted for inflation each year on a best effort basis.*

APPENDIX A: DESCRIPTION OF THE NETWORK RESEARCH PROJECTS

A.1. FORMATION AND EVOLUTION OF GALAXIES: FROM HIGH REDSHIFT TO THE PRESENT

As described in Sect. 3.1, Network-1 researchers cover a wide range of expertise, which leads to a wide range of topics within the study of galaxy formation and evolution. The projects described here in detail make optimal use of the observational facilities available to NOVA researchers, and employ the strong expertise in simulations that has been built up. The projects are listed below by decreasing redshift.

CHARACTERIZING THE GROWTH OF GALAXIES IN THE EARLY UNIVERSE (NW1-01)

Bouwens, Franx and collaborators will use the new integral field spectrograph MUSE pointed at the Hubble Ultra Deep Field and lensing clusters as part of the guaranteed time to take deep optical spectra, with integration times up to 80 hours. These spectra will provide accurate redshifts of distant galaxies in the fields (up to z=6.5). The redshifts are crucial to measure the effect of emission lines in the rest frame optical (observed at 3-5 μm). The emission lines need to be (statistically) subtracted to obtain accurate stellar mass estimates for these galaxies using rest frame optical and rest frame UV data, which have already been taken with IRAC on the Spitzer Space Telescope. The combination of these various datasets will allow constructing stellar mass functions, and can be compared to the observed star formation rates to test for consistency.

EPOCH OF REIONIZATION AND TRANSIENTS WITH AARTFAAC/LOFAR (NW1-02,NW3-05)

AARTFAAC will correlate and image all the data from the LOFAR superterp on a per-element basis all the time, in parallel to regular LOFAR data taking. In so doing, it will image the sky on larger scales (>30 Mpc) than LOFAR when observing in the 110-200 MHz EoR band. This will add very significantly to LOFAR's sensitivity to an EoR signal, provided that the AARTFAAC data can be as well calibrated as LOFAR, and that even subtle effects of variables and weak transients can be detected and removed. In this NW1-NW3 cross network project Koopmans and Wijers will conduct these observations, and seek ways to

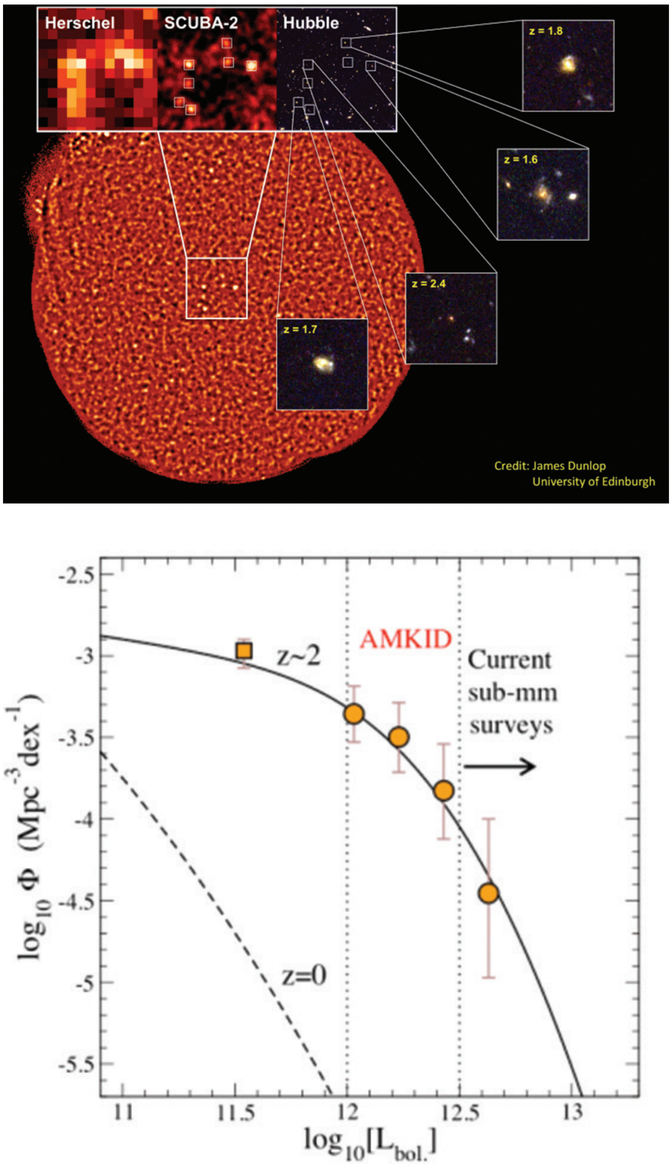


***Figure A1:** The new AMKID submillimeter camera on the APEX telescope will allow mapping the sky at similar wavelengths, and with similar angular resolution, to SCUBA2 (first image, y'z'), but with a larger field of view and mapping speed, making the submillimeter coverage of large areas of the sky more efficient. Since APEX is located at the same site as ALMA, it will be possible to follow up all the newly discovered submillimeter sources with ALMA. The panel on the right shows the bolometric IR luminosity function at z » 2 derived from Spitzer 24 μm data (Caputi et al. 2007). The luminosity ranges probed by current submillimeter surveys and our new AMKID E-CDFS survey are indicated. AMKID E-CDFS will probe the bulk of the ULIRG population at submillimeter wavelengths.*

perform this calibration and transient detection, thus combining the LOFAR and AARTFAAC data to obtain the best possible EoR sensitivity. At the same time, they will obtain a much deeper survey of transient sources than with regular AARTFAAC data, killing two birds with a stone.

TYPICAL ULTRA-LUMINOUS IR GALAXIES IN AMKID E-CDFS SUBMILLIMETER SURVEY (NW1-03)

Submillimeter galaxy surveys are ideal to probe the most intense dust-obscured activity of the Universe at high redshifts, since submillimeter data to probe deeper into the galaxy total infrared luminosity function at high z (Fig. A1). Caputi, van der Werf and Baryshev will use the new AMKID submillimeter camera operational on the APEX telescope. This instrument is unique with a large field of view and fast mapping speed. It will observe simultaneously at 350 and 850 µm, with an angular resolution of 5-6 arcsec at 350 µm. Specifically, the Extended Chandra Deep Field South will be imaged to: (1) constrain the peak of the dust emission in ULIRGs at $1 < z < 3$, which is important to derive reliable dust-obscured star formation rates; (2) compute a pure star-formation IR luminosity function and revise the previously derived cosmic star formation rate density at $z \sim 2$; (3) discover new high-z, submillimeter sources; (4) select a representative sample of ULIRGs for ALMA spectroscopic follow up. The ALMA spectra, in conjunction with the AMKID photometry, will allow Caputi et al. to simultaneously investigate the properties of the dust and molecular gas in ULIRGs, including the dynamics of their interstellar media through the high spatial and spectral resolution ALMA maps.

THE ONSET OF THE RED SEQUENCE (NW1-04)

Franx and collaborators have discovered that 'passive' or quiescent galaxies exist out to redshifts of 2 and above: massive galaxies with relatively little star formation. Surprisingly, they discovered that these galaxies are much smaller than low redshift systems with the same mass. Obviously, strong evolution must have taken place. These results were criticized as they depended on masses which were derived from stellar population modeling. Recent spectroscopy for a small (and biased) sample has shown that the dynamical masses can be measured for these galaxies, and that the evolution is just as strong if dynamical (instead of stellar) masses are used. Much larger samples will be observed by Franx and collaborators using NOVA instruments MUSE and the near-IR spectrograph of X-Shooter. The redshifts taken with MUSE will allow to trace the evolution of the quiescent galaxies with great accuracy. The line dispersions measured with X-Shooter will constrain the masses, and allow determinations of the scaling relations, and their evolution.

LOFAR STUDY OF STAR-FORMING GALAXIES IN THE FIELD AND IN PROTO-CLUSTERS (NW1-05)

Röttgering, Koopmans, Labbé, and Schaye will use LOFAR and Herschel to define unbiased samples of the progenitors of clusters ('proto-clusters'), by using innovative color selection techniques on the combined datasets. The deeper surveys are designed to cover an area large enough to contain 100 $z > 2$ progenitors of clusters of galaxies, sampling the most extreme (and rarest) peaks in the density field. So far, their pioneering searches for proto-clusters were biased towards fields with high redshift luminous radio galaxies. The surveys will allow a characterization of the galaxy properties in protoclusters, and a comparison to the sophisticated simulations by Schaye.

STELLAR MASS IN THE UNIVERSE? CHARACTERIZING LOW-MASS STELLAR IMF IN GALAXIES (NW1-06)

The number of stars formed at a given mass - the initial mass function (IMF) - in a galaxy is crucial for our understanding of the evolution of galaxies and the Universe. The IMF has long been assumed to be universal, simply because it has been nearly impossible to measure outside the Local Group. Trager, Koopmans, Peletier and collaborators will directly measure the low-mass end of the IMF in distant galaxies more accurately and precisely than ever before. This will allow a determination of the possible change of the IMF slope and/or shape over a wide variety of galaxy masses. A variation of IMF shape and/or slope with galaxy mass, hinted at in previous work, will directly impact measurements of the efficiency of star formation in galaxies and of the dark matter content of galaxies, hence are fundamental to a good understanding of galaxy evolution and feedback.

PROBING FEEDBACK IN THE NUCLEI OF (U)LIRGS AT LOW AND HIGH REDSHIFT USING WATER (NW1-07)

Van der Werf, Spaans, and collaborators will use Herschel and ground-based observatories to study feedback in the nuclei of ULIRGs. Herschel has opened a new window into the processes in these galaxies by observing H_2O from their nuclei. The water lines appear to be radiatively excited, and therefore form a completely new probe of local conditions, measuring the local IR radiation field. First H_2O detections at high z, obtained with the Plateau de Bure Interferometer, also reveal ubiquitous IR-excited water lines in IR-luminous galaxies, indicating similar conditions to local ULIRGs. Derived physical conditions are extreme, and remarkably, many objects have P Cygni profiles on various spectral lines, demonstrating a direct relation to feedback processes resulting in the outflow of molecular gas. Van der Werf and collaborators will combine these datasets to determine the local IR radiation field, the local pressure budget and its correlation with source type (starburst/AGN) and luminosities; establish the existence of outflows in these objects, and extend these analyses to higher redshift based on ALMA observations. This will result in a significantly better understanding of local radiative and mechanical feedback processes in these very obscured nuclei, where a significant stellar population as well as a supermassive black hole are building up simultaneously.

GALAXY HALO MASSES, SHAPES, AND SIZES FROM KIDS+VIKING+GAMA (NW1-08)

Weak lensing is the most powerful tool astronomers have to image the dark mark distribution around galaxies. To study this distribution Kuijken, Hoekstra and collaborators will use the KiDS survey in combination with VIKING and GAMA. The combination of accurate photometry and spectroscopic redshifts will lead to much improved determinations

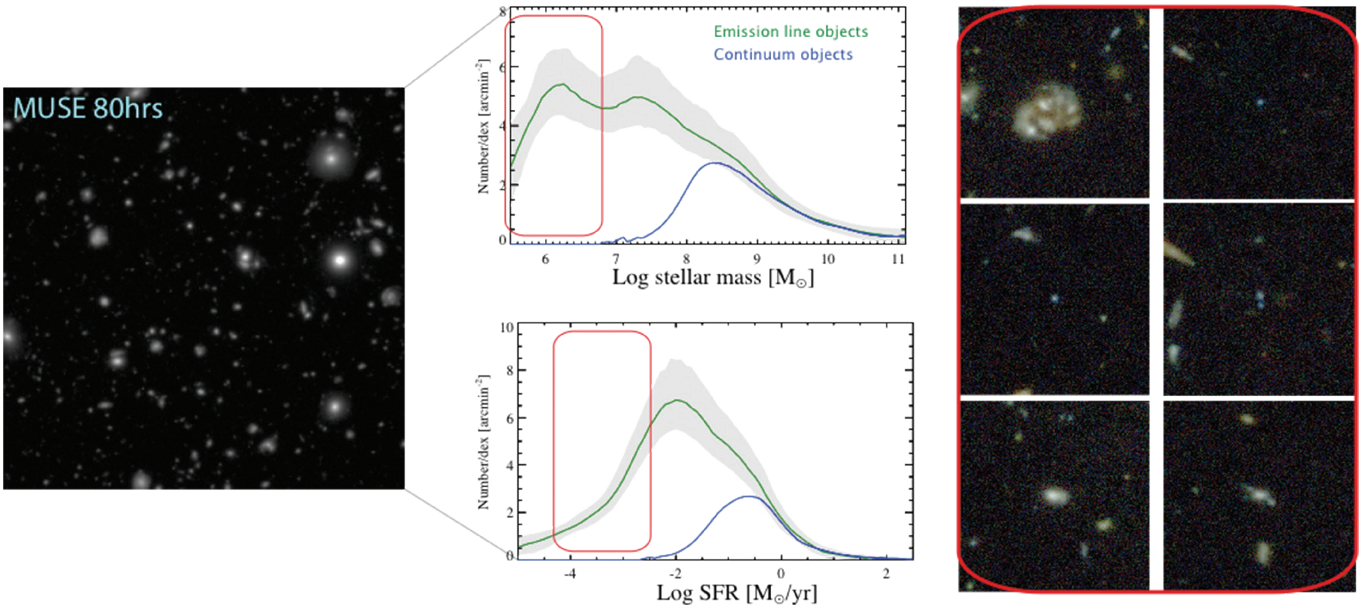


Figure A2: *A deep exposure with the MUSE spectrograph (left, summed over all wavelengths) will lead to the detection of a large number of objects. In many cases these will only be detected as an emission line source, this is illustrated in the middle panel which shows the expected number of objects at different masses and star formation rates per MUSE field of view. The green line shows those that will only be detected as an emission line source while the blue line shows the same for continuum detected sources. However coupling this with the deepest HST images (right, from the Hubble Ultra Deep Field) we can detect the faint emission line sources and compare the star formation rates from the UV to that measured from Ha using MUSE and thence constrain properties of the massive end of the initial mass function in these objects.*

of the dark matter distributions of galaxies and their group environment. The dark matter properties can be measured as a function of galaxy property (mass, star formation, etc.). In addition, the measurements are also useful as fundamental physics probes. For example, a clear measurement of the radial variation of the flattening of the gravitational potential around edge-on disk galaxies would be a direct test for alternative theories of gravity without dark matter.

SIMULATING THE GAS AROUND LOW-REDSHIFT GALAXIES (NW1-09)

Schaye and collaborators will use the EAGLE simulation to model the circumgalactic medium around low-redshift galaxies in order to understand the formation and evolution of such galaxies. Gas accretion is required to feed star formation, while self-regulated growth requires the existence of powerful galactic winds. Thanks to recent and upcoming instruments such as HST/COS, the VLT/MUSE and the Dutch WSRT/APERTIF, the ability to observe the interaction between low-redshift galaxies and the surrounding medium is rapidly improving. EAGLE (Evolution and Assembly of GaLaxies and their Environments) is a massive cosmological simulation, performed by an international collaboration led by Schaye. It can be used to construct virtual observations and therefore will allow detailed comparisons with new observations that are coming in.

STAR FORMATION AT ULTRA-LOW LEVELS (NW1-10)

Brinchmann and collaborators will use VLT-MUSE to study star formation in low-mass galaxies. Existing surveys of star formation are mostly optimized for massive galaxies, leaving star-formation activity in the least massive galaxies poorly characterized. While star formation takes place at a very low level in absolute terms in these objects, the impact on such galaxies can be very significant. Furthermore, the finding that Hα and UV-based star formation indicators give discrepant results at the very lowest rates is a strong indication that star formation in low mass systems behaves differently. This has been argued to be either due to stochastic effects or to a modification of the IMF in these systems. These effects really become significant at star formation rates below 0.001 $M_\odot$/yr, where existing samples are incomplete and very sparse. Therefore, larger samples and observations of different emission lines to derive more physical information about the systems are a must (Fig. A2). To address these issues, > 50 fields with exposure times in excess of 10 hrs with MUSE will be obtained using a significant fraction of GTO time, to measure good diagnostics like Hα and other lines (e.g., [S II] 6716, 6731). In addition, a search for broad Balmer emission line components can put constraints on winds, critical for the evolution of low mass galaxies.

CHEMICAL COMPOSITION OF STELLAR POPULATIONS BEYOND THE LOCAL GROUP (NW1-11)

Larsen, Trager, and collaborators will perform a survey of M83, NGC1313, and NGC 5128 with VLT/X-Shooter to determine elemental abundances of star clusters The detailed mix of chemical elements in stars is a powerful diagnostic of the past histories of their parent galaxies. This is because different elements are produced in different stars on different time scales: the elements (O, Mg, Si, S, Ca) in massive, short-lived stars, iron mainly in Type Ia supernovae originating from longer-lived low-mass stars, etc. Studies of individual elements have generally not been performed beyond the Local Group. Observations of star clusters over the full wavelength range of X-Shooter, combined with advanced modeling, can provide direct constraints on individual element abundances and therefore the (chemical) evolutionary history of these objects (Fig. A3).

HYPERVELOCITY STARS AS A POWERFUL NEW TOOL TO INVESTIGATE THE GALAXY (NW1-12)

Rossi, Brown and collaborators will use Gaia to detect hypervelocity stars, and provide new insights into the Galaxy's mass distribution in the realms of the halo as well as in its very central region. Hypervelocity stars have been discovered in the Milky Way's halo with radial velocities exceeding the Galactic escape speed. The stars were presumably ejected in gravitational interactions taking place close to the supermassive black hole at the Galactic center. However, their origin is still debated, and may point to the presence of a second black hole. Interestingly, their distributions and trajectories provide a new and powerful tool to probe the shape and depth of the Galactic potential, along with the stellar content of the Galactic bulge. The full potential of hypervelocity star observations has not yet been realized, due to the small number of stars so far discovered. However, the new astrometric mission Gaia will deliver 3-dimensional positions and velocities for about one billion stars, enabling the discovery of hundreds of such stars.

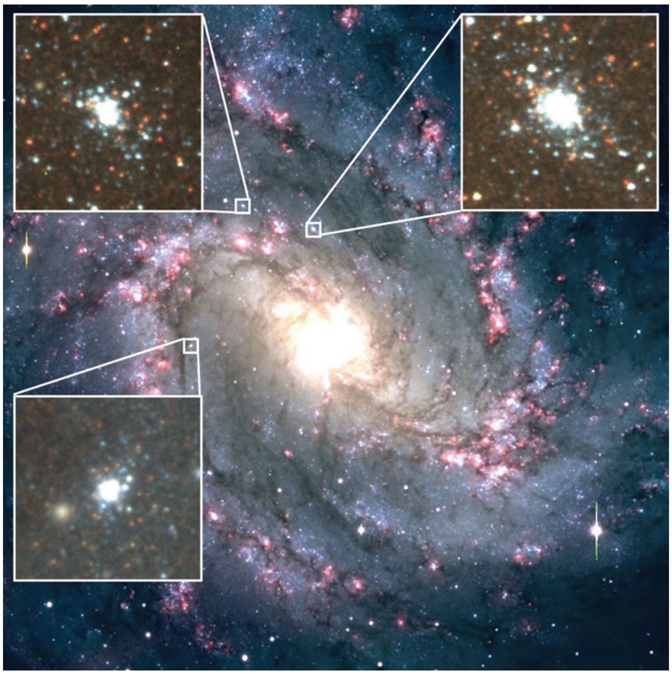


Figure A3: *The image shows the nearby spiral galaxy M83 and is composed from BVR+Ha exposures with VLT/FORS1+FORS2. Also shown are HST close-ups of three young massive clusters, which are part of the sample that will be studied spectroscopically in project nw1-11. The color-magnitude diagrams of the clusters that can be obtained from the HST imaging will help in modelling the integrated-light X-Shooter spectra so that the chemical composition can be accurately determined.*

STRUCTURE AND HISTORY OF THE MILKY WAY: EXPLOITATION OF THE FIRST GAIA DATA (NW1-13)

The Gaia mission will provide a vast catalogue of the spatial distribution, kinematics and properties of stars required to answer fundamental questions about the structure and history of the Milky Way. The satellite's first data release, giving magnitude, color and positions on the sky for a billion stars over the whole sky is expected two years after launch, around end of 2015. Helmi, Brown and collaborators will use this information to unravel the history of the outer Galaxy, where the dynamical timescales are sufficiently long that imprints of the history are directly retrievable on the sky. This will lead to a measurement of the luminosity function of the Milky Way satellites at the faint end, and to the discovery streams originating in objects that have been accreted in the past. The analysis of state-of-the-art cosmological simulations of the formation of Milky Way-like galaxies coupled to realistic Galactic models, and the development of tools to identify substructures and establish the completeness and limitations of the methods in the context of the Gaia dataset, are crucial first steps. Their application to the first Gaia data release, will allow Helmi and collaborators to exploit its full potential and begin to disentangle the full history of the Galaxy.

NETWORK FELLOWSHIP POSITIONS (NW1-14)

Funds for up to 6.8 yrs postdoc positions are reserved for network fellowship positions. During several years open calls for postdoctoral positions will be advertised in the area of Network-1 research. Applicants are invited to propose their own research program and to choose the university institute to work in the Netherlands. The proposals will be ranked on a peer review basis. Each year the top-ranked candidate(s) receive an offer for a 3 year position. It is expected that the network fellows apply for personal research grants after their first year in the Netherlands. When successful, the remaining network funds are usually returned to the program to hire new fellows and maintain the annual call.

DISK STRUCTURE AND PLANET FORMATION ACROSS SPECTRAL TYPES (NW2-01)

Kamp and collaborators aim to address the fundamental question to which extent the diversity in planetary systems is rooted in the difference of protoplanetary disk structure around M dwarfs and more massive stars. With the growing number of detected exoplanets and the widening range of investigated spectral types of host stars, interesting differences in the architecture of planetary systems as a function of spectral type are emerging: more massive stars have a higher frequency of more massive planets. With Spitzer and Herschel data in hand, the study aims to address the mass distribution, temperature structure and chemical composition of disks as a function of the spectral type of the central star. The Herschel key program GASPS and open time data provide an independent assessment of the gas evolutionary timescale in protoplanetary systems. In addition, submillimeter (IRAM, SMA and soon ALMA) observatories will study the sizes of disks and the chemical diversity in ever growing numbers, making it feasible to reveal differences across spectral types.

MID-INFRARED SPECTROSCOPY OF PROTOSTARS AND YOUNG DISKS (NW2-02, NW2-20)

Van Dishoeck and collaborators will develop models of the mid-infrared line emission of embedded protostars to quantify the physical processes that shape the protostar, disk and their immediate surroundings. Herschel and Spitzer have contributed significantly to the statistics of the different phases and phenomena associated with star and planet formation, but not the detailed physics. Infall in the collapsing envelope, formation of the disk, outflows sweeping up and shocking the material, and UV photons heating and dissociating the gas all occur simultaneously on scales of a few thousand AU, processes that determine the final mass of the star(s), the diversity in disk masses, sizes, and chemical composition. The next major steps in the understanding of protostars and disks will be provided by ALMA, JWST and eventually ELT-METIS and SPICA. MIRI's spatial resolution down to 0.2" (15 AU radius in the nearest star-forming clouds) is well matched to the sizes of young disks and envelopes. Combined with mJy sensitivity for IFU spectroscopy, this means that disks and inner collapsing envelopes can be dissected in the mid-infrared for the first time at the relevant scales. This project will use existing data to build a model of the different physical components and make predictions for MIRI that could distinguish between different scenarios. Also, MIRI software analysis tools and model libraries will be developed for the entire Dutch community involved in MIRI.

INFRARED SPECTROSCOPY OF CARBON CHAIN RADICALS OF ASTRONOMICAL INTEREST (NW2-03)

Linnartz and collaborators will use a newly constructed, unique set-up in the Sackler laboratory for Astrophysics in Leiden to scan for carbon chain radicals in the infrared. With HIFI and ALMA producing data, there is more and more need for accurate molecular constants that allow to interpret new and unassigned transitions ('weeds') or to search for new molecular species ('flowers'). Laboratory based THz spectroscopic studies, however, are slow and spectral surveys are very time consuming. A new ultrasensitive and highly precise spectrometer, based on mid infrared continuous wave cavity ring down spectroscopy, has been constructed that allows to tackle this challenge in an indirect way, by exciting strong vibrational modes. Rotational constants are needed to calculate THz line positions with an accuracy that makes a direct comparison with astronomical data possible. Moreover, applications are envisaged particularly for the many species that are 'radio-silent' because of a lacking dipole moment, such as the linear and centro-symmetric carbon chain radicals indirectly via their low-lying bending vibrations. A special (plasma) expansion is used to simulate the conditions in the ISM and to generate (unstable) species at low final rotational temperatures. The setup can also be used to perform 'boring' scans for transitions of abundant species such as CH_3OH and CH_3CN and other species with internal rotations that literally litter the wavelength regimes covered by ALMA and HIFI. The setup offers the possibility to clean up submm spectra.

PAH EVOLUTION IN DISKS (NW2-04)

Tielens and collaborators will undertake a combined observational and modeling study of the chemical evolution of PAHs in protoplanetary disks. The mid-IR spectra of many Herbig AeBe stars show strong IR emission features at 3.3, 6.2, 7.7, 8.6, 11.3 and 12.7 μm, generally attributed to IR fluorescence by UV-pumped Polycyclic Aromatic Hydrocarbon (PAH) molecules containing some 50 C-atoms. Analysis of the many Spitzer spectra reveal variations in the peak position of the 6.2 and 7.7 μm bands linked to the characteristics of the central star and the location of the PAHs. As the 6.2 and 7.7 μm bands probe the C-C bonds, these variations imply a chemical evolution of the carrier in regions of planet formation and a number of possibilities have been suggested, ranging from the predominance of (more labile) aliphatic (rather than aromatic) groups in low effective temperature environments to the incorporation of N-atoms into the C-skeleton. This study combines analysis of Spitzer and VISIR data with model studies of the chemical evolution of PAHs and protoplanetary disks. It draws upon experimental studies of PAHs supported by the ERC and the Dutch Astrochemistry Network in the Leiden laboratory and at the FELIX laser group at Nijmegen. Eventually, JWST-MIRI and ELTs will spatially resolve the emission from PAHs and their spectral variations and from chemical daughter products such as C_2H_2 and CH_4 in disks on ~0.1" scale size and the proposed study will allow for optimizing observing strategies.

TRANSPORT IN DISKS WITH FREEZE-OUT (NW2-05)

Dominik and co-workers will develop disk models that take the physics involved in dust-carrier-generated transport into account. The availability of sub-mm interferometers like ALMA, IRAM, SMA and the current revolution in high-order adaptive-optics imaging with VLT/NACO, Subaru/HiCIAO, SPHERE and optical and infrared interferometers is generating a new area of disk research, where disks become spatially resolved at many different wavelengths. This provides information about both dust and gas in the disk as a function of distance from the star. The dust can lead to the separation of different materials in the disk, including vertical and radial transport. Vertical transport in the gas proceeds via turbulent mixing. Grains settle and limit the space governed by turbulence-triggered motions to a size-dependent range around the midplane. At the same, radial transport of grains let solid matter drift toward high pressure. Currently, only the changes in general metallicity (usually described as the dust-to-gas ratio) due to settling and radial drift are being tracked in this way, but the differential motions between gas and dust will lead to chemical alterations in the disk. Ice condensing onto and evaporating/sputtering from grains will allow specific components of the gas (usually the more volatile ones) travel with the dust for a limited amount of time and/or distance. Observable effects of vertical differentiation can be the depletion of water ice in the upper layers of protoplanetary disks as suggested by Herschel-HIFI data. Radial migration of volatile materials in this way may lead to changes in volatile/refractory materials and to changes isotopic ratios as a function of distance. A global coagulation model will be built that also calculates the vertical distribution of dust particles in a consistent way and will be coupled with chemical codes and applied to explain new observations by network 2 researchers.

PLANET FORMATION: GRAVITY, HYDRO-, AND THERMODYNAMICS IN DISKS (NW2-06)

Spaans and collaborators will perform numerical simulations with the FLASH adaptive mesh refinement code to study the hydrodynamic evolution of proto-planetary disks, with the gas and dust as two distinct yet interacting, fluids. This will allow treatment of the gravitational interactions among planetesimals and their interaction with the gas and dust inside the protoplanetary disk. The FLASH code is well suited for these types of physical problems given its accurate hydro solvers and modularity, which allows it to be extended with user-provided subroutines. The presence of planetesimals in a disk, believed to be the result of dust coagulation and/or global hydro flows, introduces discrete (self-) gravitating bodies (for sizes >1 km). These planetesimals accrete from the gas and dust reservoirs, and interact (viscously) with it. This affects the individual orbits of the planetesimals, as well as their mutual interaction, and thus the formation of larger structures like planet cores.

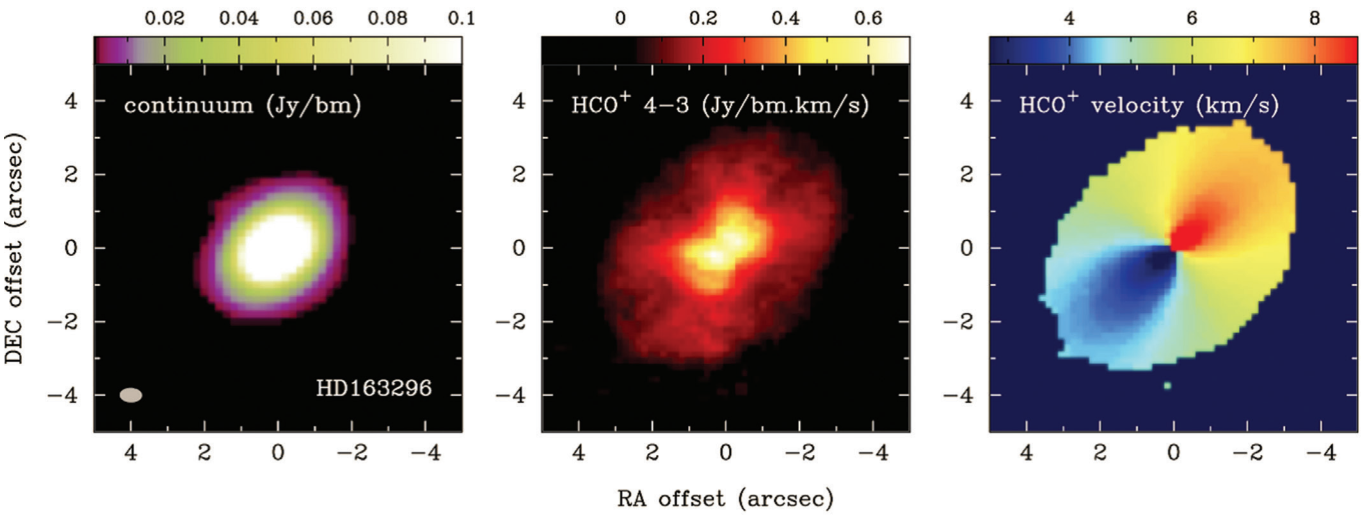


Figure A4: *Science Verification data obtained in 2012 illustrate the power of ALMA. The planet-forming disk surrounding the star HD163296 is seen in 1 mm continuum emission from cold dust (left) and in HCO^+ J=4-3 emission (center). The right panel shows the velocity of the HCO^+ emitting gas, revealing Keplerian rotation in the inclined disk. Credit: Mathews et al. 2013.*

Observing disk structure with evolving dust (NW2-07)

Hogerheijde et al. will use ALMA to probe the structure of disks as their dust evolves. The evolution of the 1% of the disk mass that is taken up by grains dictates much of the disk's structure and evolution. Dust form the major source of opacity, intercepting the stellar radiation to heat the disk and emitting infrared radiation to cool the disk, and attenuating UV radiation that otherwise dissociates many of the molecules. Grains also provide the surfaces on which ice layers form, inside of which more complex chemical species can form. Throughout the disk's lifetime, dust grains coagulate and grow in size, settle toward the disk midplane, and migrate radially inward. By selecting objects with 'pristine' dust distribution to disks with highly 'evolved' distributions, i.e., with high degrees of dust growth, settling, and migration, the effects of the major mass reservoir of the disk will be analyzed: the molecular gas. Using newly obtained and archival ALMA data, the distribution of key gas molecules will be analyzed for carefully selected disks that represent different stages of dust evolution (Fig. A4).

Identifying the brightest transiting planets using MASCARA (NW2-08)

Snellen and collaborators will use MASCARA for finding transiting exoplanets around bright stars. For atmospheric characterization of exoplanets, e.g. through transmission spectroscopy or secondary eclipse measurements, it is absolutely vital that the system is bright enough such that the <0.01% atmospheric signals can be seen above the photon noise. For this reason, most of the impressive results so far (detection of molecular gases, thermal profiles, and even evidence for atmospheric circulation) have been obtained for the two brightest known transiting planet systems HD209458b and HD189733b (both V=7.7). None of the current transit surveys is sensitive in the V=4-8 mag regime, where dozens of transiting planets are expected to be present. For this reason, Snellen et al. built MASCARA, funded through a VICI grant and with NOVA seed funding. The aim is to have the first station up and running by April 2014, with the addition of two more sites later that year. The PhD student will carry out the photometric and spectroscopic follow-up of MASCARA targets to identify true transiting planets. A planet yield on the order of ~5 hot Jupiters, ~5 Neptunes, and ~5 super-Earths is expected – all around the brightest stars in the sky. These will be unique targets for obtaining highly competitive observing time on JWST and E-ELT.

SCIENTIFIC PREPARATION FOR TRANSIT OBSERVATIONS WITH MIRI (NW2-09)

With its launch at the end of NOVA Phase-4, the JWST will become the telescope to perform exoplanet atmospheric characterization through transmission and eclipse spectroscopy. Lahuis, Waters et al. will capitalize on their specific MIRI expertise to maximize the Dutch role in this highly competitive field. A two year postdoc, co-funded through SRON, will prepare for MIRI observations by developing a state-of-the-art instrument model for transit observations, geared towards measuring tiny variations in very bright stars. As Spitzer has shown, this requires a thorough knowledge of the instrumental characteristics such as PSF stability and intra-pixel sensitivity variations. To assess the feasibility of achieving specific science goals, the instrument model will be provided with theoretical transmission spectra of exoplanets calculated by Stam and de Kok. Combining this knowledge will allow careful sensitivity and retrieval studies to be done concerning the composition and structure of the exoplanet atmospheres, crucial for optimizing observations and analyzing future data.

DEVELOPMENT AND UTILIZATION OF DIRECT IMAGING TECHNIQUES WITH SPHERE-ZIMPOL (NW2-10)

The SPHERE instrument on the VLT will become operational in 2014. In light of the significant technical investments of the Dutch community in SPHERE-ZIMPOL over the last decade, it is imperative to optimally benefit from this instrument, concentrating on those aspects in which Dutch astronomers are experts (Fig. A5). A five-year postdoc working together with Keller and Kenworthy will focus on reducing and understanding ZIMPOL observations beyond the standard pipeline – a crucial component for the scientific harvest, since polarimetry will be largely limited by systematic effects. In addition the postdoc will work on improving the high-contrast imaging performance of the near-infrared arm of SPHERE, making use of specific expertise on apodizing phase plate coronagraphs and PSF reconstruction techniques, which will improve its contrast for point-sources by an order of magnitude or more. The long-term appointment will also provide user suppport as well as necessary continuity for a significant part of the guaranteed time program.

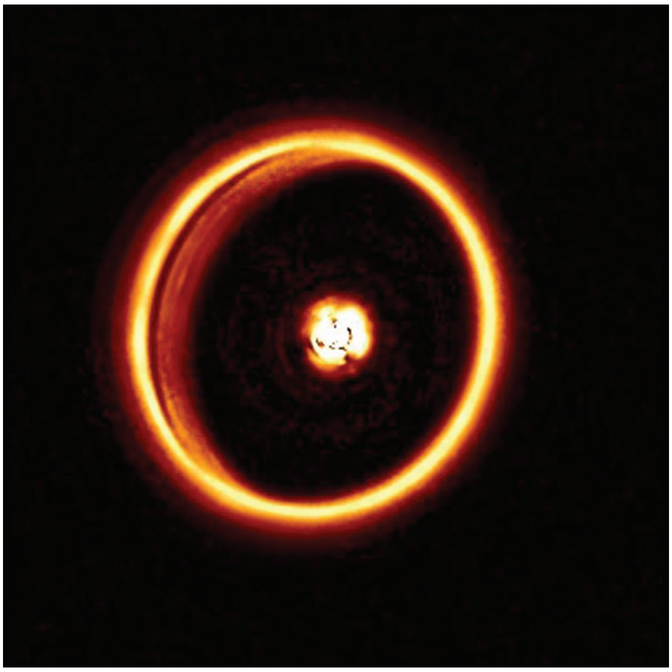


Figure A5: *Simulation of the polarized flux from the disk of the Herbig star HD 142527 as it will be seen by SPHERE-ZIMPOL. This image is the result of a radiative transfer calculation with MCMax (Min et al. 2009) and processed with the ZIMPOL simulator by NOVA science support postdoc Thalmann.*

MODELLING CIRCUMSTELLAR DISKS AND PLANETS IN REFLECTED LIGHT (NW2-11)

Keller, Dominik, Kenworthy and collaborators will develop the polarized radiative transfer codes to analyze the upcoming ZIMPOL measurements of protoplanetary disks and mature/cold gas giant exoplanets. The PhD student will focus on modeling signals by adapting existing models of gas planet atmospheres and (polarized) radiative transfer and polarized spectrum codes, to explain the SPHERE observations as well as spectropolarimetric observations of solar-system gas planets. These codes together will provide a data retrieval package that will allow us to quantitatively understand the structure of protoplanetary disks and the atmospheres of gaseous exoplanets.

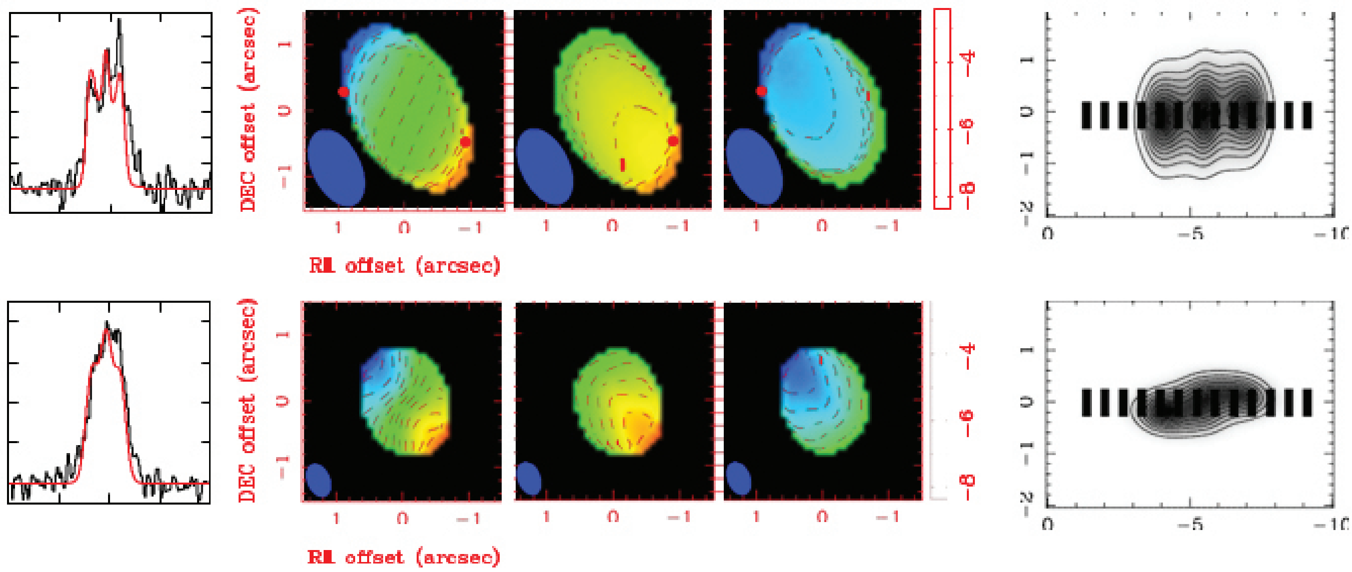


Figure A6: *Velocity field in the inner ~1000 AU around the highmass protostar AFGL 2591, observed in submillimeter HDO (top) and $H_2^{18}O$ (bottom) line emission with the IRAM PdBI interferometer. The left panels show the central line profiles, the middle panels maps of the central velocity, and the right panels the position-velocity diagrams. The best-fit model to these data combines sub-Keplerian rotation with Hubble-like expansion, quite unlike the velocity fields around solartype protostars (Wang et al. 2012). Inspired by these results, project nw2-12 aims to use high-resolution ALMA observations of water-like molecules to understand the accretion process onto deeply embedded high-mass protostars, using Herschel-HIFI legacy data for the source selection.*

HIGH MASS STAR FORMATION FROM HERSCHEL TO ALMA (NW2-12)

Van der Tak et al. will undertake ALMA observations of multiple high-mass star forming regions to study the kinematics of extended luminous circumstellar disks as a function of mass and age – testing solid-body versus Keplerian rotation models – and the onset of bipolar outflows – testing stellar wind versus disk wind driving (Fig. A6). ALMA's high sensitivity and angular resolution will trace the flow of matter from massive cores of ~0.1 parsec in size onto protostars and into disks, jets and outflows with unprecedented precision. These submillimeter (and longer wavelength) spectral regions are the only ones that allow to probe the earliest stages of massive-star formation because of hundreds of magnitudes of extinction at shorter wavelengths. A major new step will be the use of continuum observations to probe low-mass companions to young high-mass stars, which addresses the origin of stellar multiplicity, but also takes existing work on the core mass function to the stellar scale, thus directly addressing the origin of the IMF. Multi-wavelength observations using VLTI-Matisse and ALMA will be essential to localize and disentangle the contributions of free-free emission and dust emission to the observed continuum. A special role is played by observations of isotopologues of water lines with the ALMA Band-5, build by NOVA and GARD. ALMA observations are essential to understand the properties and origin of the water seen with Herschel. Other lines of common tracers of kinematics and physical conditions such as CO, CS and CH_3CN will be observed simultaneously with the multi-band continuum.

FORMATION AND EARLY EVOLUTION OF THE MOST MASSIVE STARS (NW2-13)

Kaper and co-workers will study the physical link between two, likely sequential, phases of massive star formation by combining ALMA and near-IR imaging and spectroscopy of star-forming regions in the Milky Way and Local Group galaxies, in particular the Magellanic Clouds. Recent spectroscopic techniques at near-infrared wavelengths allow for the first time direct detections and quantitative analysis of characteristics of massive proto-stars. These massive Young Stellar

Objects likely represent a later phase of formation than the luminous sources with disks that can be detected at millimeter wavelengths. Such a multi-wavelength approach will allow us to study massive star formation in an environmental context, including aspects of metallicity and cluster mass/density. By establishing the physical properties of the newly formed stars – such as photospheric parameters, binary properties, rotational characteristics, ionizing fluxes, and radiation-driven winds – this project will assess the importance of feedback from this population on the star formation process in general. The project will make use of state-of-the art spectroscopic analysis methods being developed by de Koter et al.

EPISODIC MASS-LOSS BY MASSIVE STARS IN LOW METALLICITY ENVIRONMENTS (NW2-14)

De Koter and collaborators will provide statistical data of episodic mass loss that massive stars may experience, allowing for an assessment of the relative role of stellar wind mass loss and episodic mass loss. A comprehensive and homogeneous study of the properties of dust around evolved massive stars in the Magellanic Clouds will be used, based on mapping surveys done with Spitzer and Herschel. Modeling of the thermal continuum will reveal the properties and amount of dust around these sources and spectroscopy will allow to constrain the dust-to-gas ratio. If episodic mass loss is important in these low metallicity environment, it will, among others, change our view of the evolution of population III stars. If significant, low metallicity massive stars may not produce tens of solar mass black holes, proposed to be a formation channel of Ultra-luminous X-ray sources.

RESOLVING THE STAR FORMATION HISTORY IN THE GOULD BELT WITH GAIA (NW2-15)

Brown and Kaper will disentangle the detailed spatial and kinematical distribution of the young stellar population in the Gould Belt using Gaia, and thus the recent star formation history of this important part of the Milky Way. The Gould Belt is a ring-like structure of stars and gas of about 1 kpc across, tilted toward the Galactic plane by about 20 degrees, and containing essentially all nearby OB associations including Orion and the Sco-Cen region. Most of the ISM in the Solar vicinity is expanding with a mean velocity of 2-5 km/s from a point located near the 50 Myr old Cas-Tau group, a 'fossil' OB association. This expanding ring of gas, with the Sun well inside, appears to be a 30 - 60 Myr old super-shell driven into the local ISM by the Cas-Tau group and the associated α Per cluster. The Gould belt of stars, nearby OB associations, and star forming dark clouds may thus represent secondary star formation in clouds that condensed from the ancient Lindblad's ring super-shell. Note that even in a well-studied region as Orion we essentially do not know the distribution of the stellar population along the line of sight. This complicates cluster membership and age determinations. Gaia will revolutionize our view on the Gould Belt, will provide important information on the triggering and progression of (massive) star formation in the nearby Galaxy, and will give insight into the uniqueness of this environment.

POPULATION SYNTHESIS OF STAR-FORMING GALAXIES (NW2-16)

De Koter and collaborators will develop a new generation of sophisticated population synthesis models for massive stars in galaxies. The VLT-FLAMES Tarantula Survey, the X-Shooter GTO program on massive stars and recent galactic studies provide unprecedented new constraints on the current and initial conditions of the high mass stellar population, particularly their multiplicity properties. These initial conditions reflect the outcome of massive star formation. Massive star populations and the ~100 pc scale Giant Molecular Cloud (GMC) environment which they are part of reflect the largest scale in star formation. Galaxies at distances of (tens of) Mpc may show complex configurations of multiple GMC complexes that individually can no longer be spatially resolved. To study star formation at a galactic scale and to probe star formation throughout cosmological time requires population synthesis models aimed at reconstructing the properties of stellar populations from spatially integrated quantities. A crucial step to achieving such models is the treatment of the main-sequence phase of evolution. The most massive among these stars, the 150-300 $M_\odot$ WNh stars, are dominating the ionizing fluxes of young massive clusters. Main-sequence population synthesis will be used to unravel the nature of these stars, which may be binary merger products.

THE QUEST FOR DIB CARRIERS: A LABORATORY APPROACH (NW2-17)

Linnartz et al. are currently carrying out a survey of reddened sightlines in the Galaxy and Magellanic Clouds with VLT/X-Shooter and VLT/FLAMES to search for DIBs in the optical and near-infrared, covering various interstellar environments. So far, over 300 DIBs have been detected, though only a handful in the near infrared. Recently, the discovery of a dozen new near-infrared DIB candidates has been reported in reddened sightlines towards the Galactic center. High spectral resolution spectra (R ~100,000) of these near-infrared DIBs will be obtained to confirm their DIB nature and study the detailed (sub) structure of the DIBs. A highly sensitive new technique will be developed and implemented to search for DIB carriers in the Sackler laboratory at Leiden: optical shutter-modulated broadband cavity-enhanced absorption spectroscopy. The technique is ultra-sensitive and covers large wavelength regions (comprising the signatures of tens of DIBs) in short time intervals (several seconds). The scientific focus is on the systematic detection of electronic spectra of different families of potential DIB carriers and the subsequent comparison of laboratory spectra with observed absorption bands. The focus is on species that are known or expected to be abundantly present in space and will be produced from hydrocarbon, PAH and H_2 containing plasmas, using acetylene (C_2H_2) and allene (C_3H_5) as precursor species to generate unsaturated species with respectively acetylenic and cumulenic bonds. In addition we will study C_{60}^+, a proposed carrier of two DIBs around λ~960 nm.

DIFFUSE EMISSION IN GALACTIC PLANE (NW2-18)

LOFAR uniquely covers the low frequency radio band. In the next few years, the entire Northern sky will be observed by LOFAR in the frequency range 30-210 MHz in full polarization. Haverkorn and Vink will lead a NW2-NW3 cross-network research project that will analyze these LOFAR Galactic plane data by (1) studying supernova remnants and pulsar wind nebulae (nw3-20), and (2) determining the 3D distribution of various components of the Galactic interstellar medium: the cosmic ray distribution, the ionized gas distribution and the Galactic magnetic field (nw2-18). At low frequencies, HII regions become optically thick and will be seen in absorption against the background of Galactic synchrotron radiation. Absorption measurements constrain the synchrotron emissivity from the region behind the HII region. If enough HII regions with known distances are observed in absorption, one can construct a 3D map of the synchrotron emissivity. This method was proven to work in the direction of the Galactic Center. Using a model of Galactic magnetic fields, one can convert the synchrotron emissivity map into a cosmic ray distribution map. Such a map would be very useful for testing cosmic-ray electron production, diffusion, and aging models. Also, it may help to explain high cosmic ray ionization rates in some diffuse interstellar clouds.

The cosmic ray electrons detected by LOFAR are also detected in the soft gamma-ray regime via bremsstrahlung with interstellar plasma and inverse Compton scattering with the background radiation model. Combined analysis of LOFAR data with available gamma-ray data as obtained by the Fermi (NASA) and AGILE (Italy) satellites will allow Markoff and Spaans to estimate the local magnetic fields and the interstellar ionized gas density. Although this is a complex issue, this is possible as the various radiative processes have different spectral slopes which have different relations to the observed radio spectral index. To close the loop, rotation measure measurements of 35.000 polarized extragalactic sources in the Northern sky will be used as probe of the Galactic magnetic field and electron density distribution. Both of these distributions will also be derived from the sub-projects above, giving a method to bootstrap the reliability of the resulting maps.

THE ISM AS A CALORIMETER (NW2-19, NW3-11)

Markoff, Spaans, Kaper and collaborators will search for diffuse ionized emission around compact objects. The gravitational potential energy of accreted material liberated by black hole X-ray binaries and/or ultra-luminous X-ray sources is converted into several forms of output power: mechanical power carried by the bulk flow of winds and relativistic jets, radiation from the accretion inflow/outflow, and accelerated particles, namely cosmic rays. In fact many of these sources evolve on relatively fast (month/year) timescales, where the power channel will change on timescales much shorter than the recombination time of the surrounding material, making the ISM a calibrator over a longer timeframe than probed from observing the current source emission. While the companion star in high-mass black-hole binaries can produce significant ionization via its UV emission, the binary itself can also both radiatively and collisionally ionize its surroundings, forming ionization nebulae sometimes as large as several hundred parsecs. Understanding the various forms of power dumped by black holes into their surroundings, and the ultimate environmental impact is a very interesting problem, at the heart of topics such as AGN feedback, the epoch of ionization, and general questions of ISM chemistry and pressure balance and the (otherwise not measurable) low-energy cosmic ray role therein. This project thus straddles the Network-1, 2 and -3 research boundary. There are increasingly more ionization nebulae found around compact objects in nearby galaxies, intrinsic source models have been with ionization characteristics for a few well-studied cases such as Cyg X-1 and LMC X-1. For LMC X-1 in particular we found the spectrum of the nebula very difficult to explain with the current output of the black hole as measured by X-ray facilities, meaning either the source had a state change sometime before current observations began, or understanding of the ionization is still not complete. Some potential diagnostics for black hole mass have been found from the ionization, but these results are very preliminary and a proper study is needed.

A.3. THE ASTROPHYSICS OF BLACK HOLES, NEUTRON STARS AND WHITE DWARFS

LOFAR TIED-ARRAY ALL-SKY SURVEY FOR PULSARS AND FAST TRANSIENTS (LOTAAS) (NW3-01)

Hessels and collaborators will work on 'LOTAAS', an all-northern-sky survey for pulsars and fast transients using the LOFAR high-band antennas. LOTAAS will take advantage of LOFAR's unparalleled field-of view and multi-beaming capabilities to perform the deepest all-sky survey ever undertaken for pulsars and any other radio pulses with sub-second durations. The survey is in many ways different from previous pulsar surveys (e.g., much longer dwell times and lower frequency) and the potential for the serendipitous discovery of new source classes and physical phenomena is high, especially because of the unprecedented 'total on-sky' time the survey will achieve. The technical feasibility and scientific potential of LOTAAS have been demonstrated through two pilot surveys performed during LOFAR's commissioning period (Fig. A7). The PhD will be involved in the acquisition and analysis of the data (e.g. searching for periodic signals and evaluating promising candidates) as well as the follow-up of interesting discoveries.

FAST OPTICAL AND RADIO INTRA-NIGHT VARIABLES AND TRANSIENTS (NW3-02)

Groot and collaborators will study intra-night variability and transients at optical and radio wavelengths from compact binary populations in the form of e.g. dwarf nova outbursts in ultra-compact binaries, supernovae Type-Ia and mergers of white dwarf binaries, as well as neutron star and black hole binaries. The last two source populations are also expected to be detected as the first high-frequency gravitational-wave sources with the Advanced VIRGO and LIGO systems. Nijmegen has become a member of Virgo as of 2012 and is the main partner within the consortium for electromagnetic follow-up, in particular through the BlackGEM optical array. Since this parameter space is virtually unexplored one also can expect the unexpected! Groot et al. will start with a systematic exploitation of the PTF databases for fast transients. As soon as MeerKAT/MeerLICHT observations commence (early 2015) the allocated PhD student will focus on transients detected in the MeerLICHT data (a small optical telescope financed by Nijmegen and NWO located at MeerKAT).

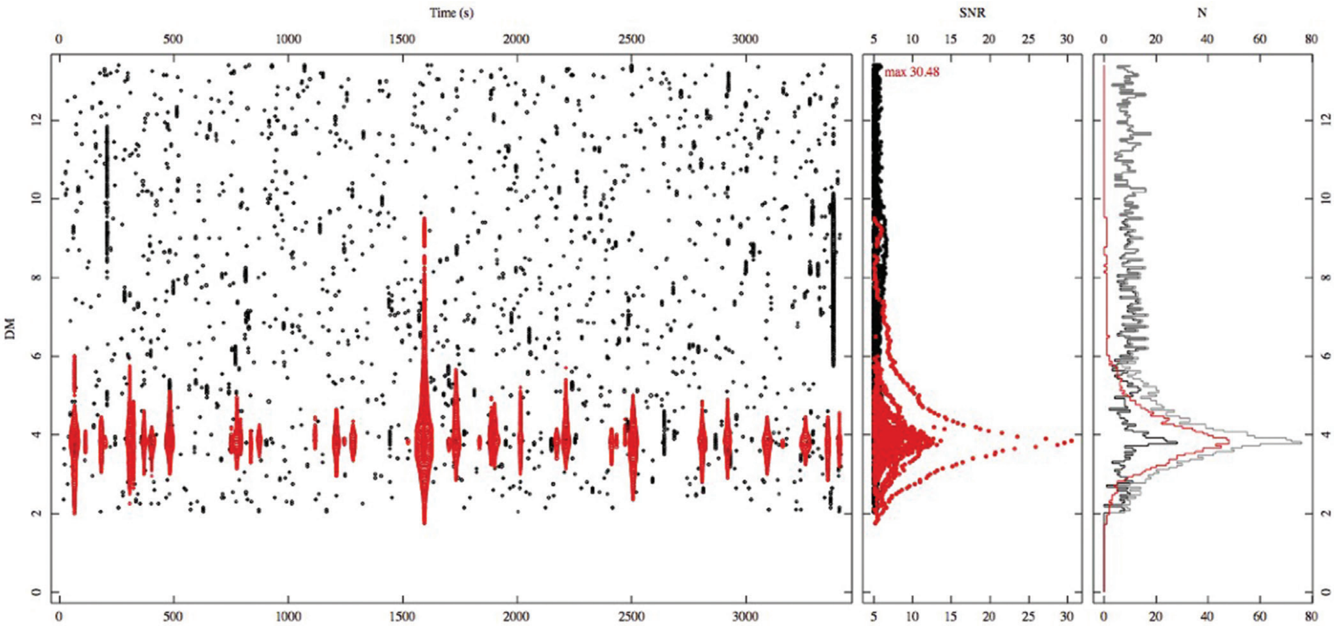


Figure A7: *Blind detection of dispersed single pulses from the LOFAR commissioning searches. Similar searches with LOTAAS will open a large new phase space for neutron stars that emit radio pulsations only intermittently.*

This will evolve into BlackGEM as soon as this gets off the ground. The main issues to be addressed by the PhD student are: What is the rate of fast intra-night transients and variables, as a function of magnitude, Galactic position, galaxy type, color? What is the nature of these fast, intra-night transients? What is the broad-band spectrum (X-rays to radio) of these transients and their spectral evolution? How do these connect to gravitational wave sources?

FAST GAIA TRANSIENTS: A TREASURE TROVE TO BE EXPLORED (NW3-03)

With the launch of Gaia a new way of studying fast transients becomes available. The Gaia team is preparing to release triggers for transients detected immediately, but they are not planning to do any science with them. Because of the complicated scanning pattern, Gaia itself will provide information on several time scales, ranging from hours (or even seconds when individual chip measurements would become available) to weeks and years. In particular the short time scales will cover a parameter range that is largely unexplored. Nelemans et al. will explore this treasure trove and have a suite of follow up possibilities lined-up, in particular using LOFAR. LOFAR can track the northern hemisphere GAIA scans of the sky providing simultaneous optical and low-frequency radio information. The fast transients could be related to black-hole and neutron star mergers, black hole formation or even black hole evaporation. In addition, known events will be harvested such as Galactic black-hole X-ray transients, Galactic (dwarf) novae, sub-luminous supernovae and stellar mergers that may show up as the so-called luminous red novae. For the latter the results of ongoing transient searches will be utilized such as PTF to quickly classify new transients as well as the unique data provided by Gaia itself: photometry, parallax, colors and if bright enough even (short) spectra.

APERTIF LEGACY EXPLORATION OF THE RADIO TRANSIENT SKY (ALERT) (NW3-04)

In the largely constant radio Universe, a highly dynamic component was recently discovered: flashes of bright radio emission that last only milliseconds but appear all over the sky. Some of these short-lived radio bursts can be traced to neutron stars, but the extremely limited activity has so far prevented determination of the origin and formation of this neutron-star population. Other bursts apparently originate far outside our Galaxy, and defy any explanation. Due to great observational challenges the nature of these extragalactic bursts remain a mystery. In ALERT, van Leeuwen and collaborators will carry out by far the deepest all-sky search for radio bursts ever undertaken. Exploiting the novel wide-field Apertif receivers on the WSRT, they will increase by a factor of 10 the exploration volume for fast transients throughout the Universe, and use these data to both map the population of intermittently bursting neutron stars, and characterize and localize extragalactic bursts; to finally, and for the first time, understand the origin of both.

HOW DOES SGR A* RELATE TO OTHER BLACK HOLES? (NW3-06)

The Galactic center is our closest galactic nucleus, harboring the weakest known accreting supermassive black hole, Sgr A*. It has been the driver for many theoretical studies of radiatively inefficient accretion and jet launching, and we are now at a stage where years of semi-analytical models by Markoff and others are converging with predictions from sophisticated MHD simulations. However many questions still exist, particularly about the existence of a fully collimated jet outflow, and the spin of the black hole. Sgr A* also exhibits roughly daily X-ray flares, often simultaneous with the IR, hinting at stochastic plasma processes including magnetic reconnection and particle acceleration events. Sgr A* is thus the ideal testbed for accretion inflow/outflow theory, plasma astrophysics, particle acceleration and general relativity, and an important source for quantifying AGN activity in normal galaxies. NOVA Phase-4 falls at an extremely opportune time, between an unprecedented multi-wavelength campaign in 2012 centered around a 3Msec Chandra X-ray visionary project, and an infalling gas cloud encountered by Sgr A* in mid-2013. The project will focus on semi-analytical models guided by MHD simulations performed within the cluster, in collaboration with Körding, to develop new models that account for time-dependent particle evolution as well as MHD-consistent jet models that link inflow to outflow for the first time. The research builds on the groundwork that allows an unambiguous connection between the jet dynamics and particle acceleration. The Fermi Bubbles and X-ray light echos in the Galactic

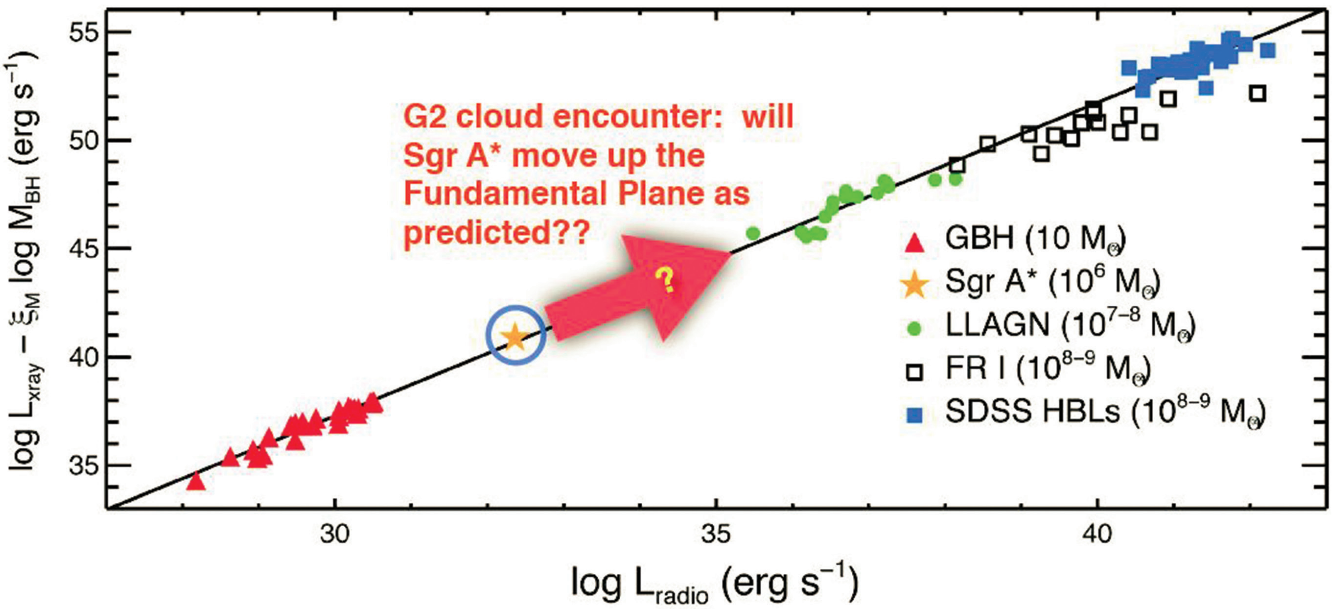


Figure A8: *The 'Fundamental Plane of black hole accretion'. This figure shows a 2D projection of a 3D plane relating black hole mass to radiative output in radio (jets) and X-ray (near black hole, accretion disk corona/jet base), that holds over 8 orders of magnitude in black hole mass for sub-Eddington accreting black holes. Bottom left are stellar mass BHBs and upper right are various classes of AGN. In the middle sits Sgr A* during its flaring state. If Sgr A* shows enhanced AGN activity due to the G2 cloud encounter, one would expect to see it move along the FP in real time, as observed on much faster timescales in BHBs. The physics driving this relation is understood so any potential deviation would also provide important hints about the initiation of AGN activity at the lowest accretion rates.*

center further hint at Sgr A* having been significantly more active in the past, and based on its renewed activity, estimates will also be made for the emission of Sgr A* during the past, and test it against the current limits (Fig. A8).

BLACK-HOLE EJECTA PHYSICS: STUDYING TIDAL DISRUPTION EVENTS (NW3-07)

Relativistic astrophysical jets exist in many guises: from the almost perfectly steady jets of M87 and SS433 to variable jets from Cyg X-3 and other microquasars, to extreme explosive events like gamma ray bursts. There must be common physics to all of these, from the mechanism of launching a jet from near a black hole to the collimation and transport of the ejected energy and mass to the eventual dissipation of the energy into the ambient medium. Very few objects show the full range of phenomena in a well-observable fashion: AGN are too slow to show the time development, GRBs are too small to spatially resolve the phenomena. In some sources the jet and launching region dominate what is seen, in others those are completely hidden, and only the dissipation region is probed. It is therefore difficult to create a unified model for the ejection and dissipation and test it on a single source with only one set of free parameters. Wijers and his group plan to combine GRB and jet expertises to model Tidal Disruption Events in galaxy centers, one of the few phenomena where both the jet launching and jet dissipation phases leave observable signals, and explore whether a single consistent description can explain all the phenomena.

AGN FEEDBACK AND SUPER-MASSIVE BLACK HOLE GROWTH WITH LOFAR (NW3-08)

Wise and colleagues will use exciting new data from LOFAR's first all-sky survey to study open questions such as how black holes grow over cosmic time, how feedback from black holes moderates the growth of galaxies, and how the combined effects of black hole feedback and mergers determine the growth of the observed large-scale structure. As the largest gravitationally bound objects, the hot atmospheres of clusters retain an archaeological record of the integrated effects of these physical processes over a significant fraction of the age of the Universe. Radio sources trace the enormous amount of mechanical energy deposited into the intercluster medium by supermassive black holes and may be the principal agent dispersing chemical elements created by stellar evolution throughout the intercluster and intergalactic medium. Supermassive black holes are now believed to play a central role in galaxy formation through a feedback process that regulates both star formation in the host galaxy and the rate of accretion onto the black hole. Low-frequency radio observations represent a unique and powerful new tool to probe this archaeological record in galaxy clusters. We will use the results of new and ongoing all-sky surveys with LOFAR to study these effects in the largest sample of clusters ever obtained at low radio frequencies. The process of amassing these new data is well underway through LOFAR's first all-sky, pathfinder survey, which will provide the largest and most sensitive catalog of radio observations on clusters ever obtained in this frequency range and down to frequencies that have never been probed before.

PHYSICAL ORIGIN OF LOW-FREQUENCY QUASI-PERIODIC OSCILLATIONS IN BLACK HOLES AND NEUTRON STARS (NW3-09)

Uttley et al. will use quasi-periodic oscillations (QPOs) in the X-ray light curves of black holes and neutron stars as clocks that probe the conditions in extreme gravity close to the compact object. The origin of the QPOs is not yet settled, but could relate to instabilities in the mass-accretion flow, or alternatively, to the precession of the flow in the strongly-curved space-time close to the compact object. Using newly-developed spectral-timing techniques, X-ray observations of black holes and neutron stars allow mapping the structure and motion of matter as it accretes on to the compact object, by measuring time-lags between variations in the emission from the different components of the accretion flow, as they respond to fluctuations in the mass accretion rate and/or changes in the geometry of the system. Neutron stars also generate emission as matter hits the solid surface, so that clear differences in the time-lag behavior between neutron stars and black holes will be seen. This project will combine measurements of the time-lags from X-ray observations of neutron star and black hole X-ray binaries with models for the QPO, to try to finally reveal the origin of these enigmatic signals.

OUTFLOWS FROM SUPERMASSIVE BLACK HOLES (NW3-10)

AGN are powered by supermassive black holes. Costantini, Uttley and collaborators will study the self-sustenance of such galaxies regulated by accretion into the black hole and by ejection of matter, either in the form of relativistic jets or gas outflows, rich in metals. The impact of such matter in the AGN-surrounding environments, the so-called feedback, has been invoked by theoretical models of black hole evolution across cosmic time. However the real contribution of AGNs to feedback has not been quantified yet. The project is focused on the study of the characteristics of the outflowing gas and its impact on the environment outside the black hole system. This gas is mainly studied through high-resolution X-ray spectroscopy and timing using the instruments of existing X-ray observatories, XMM-Newton and Chandra, as well as data from Astro-H, whose launch is foreseen in the spring of 2015. These X-ray data will be combined with complementary information provided by the far-ultra-violet spectroscopy, using the HST instruments (COS and STIS).

BLACK HOLE MASSES IN GALACTIC BLACK HOLE X-RAY BINARIES AND ULTRA-LUMINOUS X-RAY SOURCES (NW3-12)

Jonker and co-workers will use NIR and X-ray spectroscopic observations to obtain in an as-much-as-possible unbiased way the masses of black holes in X-ray binaries and ultra-luminous X ray sources within 10 Mpc and compare them with the predicted mass distributions as derived from supernova calculations. In particular, it will be determined whether black holes in these sources have a higher mass than the black holes in X-ray binaries. The soft-state X-ray spectroscopic observations will also help us to understand the importance of the wind outflow and feedback.

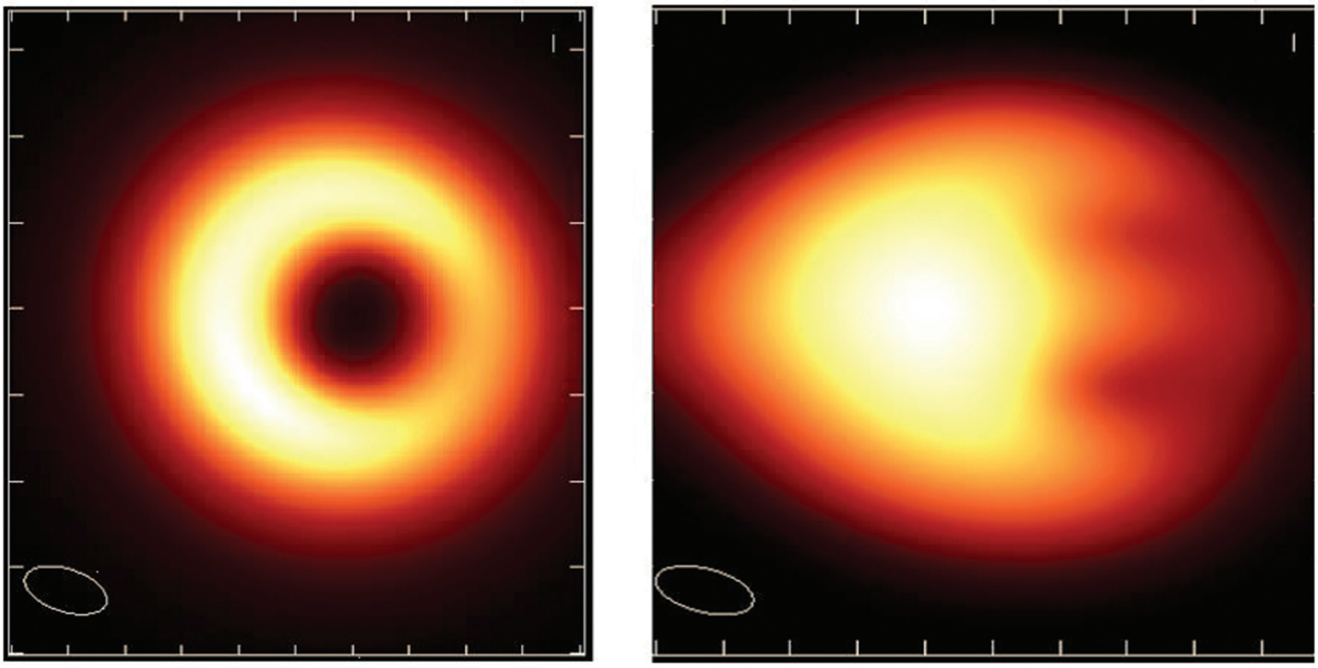


Figure A9: *Simulated images at 345 GHz of the black hole in the Galactic Center using a VLBI array involving ALMA and other telescopes based on relativistic magneto-hydrodynamic simulations of plasma around a Kerr black hole from Móscibrodzka et al. (2009).* ***Left:*** *face-on orientation,* ***Right:*** *edge-on orientation. The black hole shadow and photon ring are much more difficult to detect, but still visible in the edge-on case.*

Q(ED) MUSIC: RADIO BURSTS FROM MAGNETARS (NW3-13)

Highly magnetic neutron stars, known as magnetars, emit regular bursts of gamma-ray emission that are thought to be associated with magnetic reconnection and particle acceleration. The process is similar to that involved in solar flares, although heavily modified by processes unique to such strong magnetic fields. This has led to speculation that magnetar bursts, like solar flares, might be accompanied by radio bursts, which would provide new insight into the trigger process and burst energetics. Watts and collaborators will study prospects for radio emission from magnetar bursts, to determine whether this offers a means of distinguishing competing physical models for burst trigger and emission processes. This theoretical study will support and provide the means to interpret a simultaneous multi-wavelength magnetar burst monitoring campaign using the Fermi Gamma-ray Burst Monitor and the LOFAR and WSRT telescopes.

IMAGING THE EVENT HORIZON OF A BLACK HOLE WITH RADIO TELESCOPES (NW3-14)

Near black holes General Relativity predicts effects such as closed photon orbits, infinite time dilation, and event horizons. These effects, however, have never been experimentally tested, since they are typically seen on scales much smaller than what can be resolved with current telescopes. There is, however, one notable exception, namely the super-massive black hole, Sgr A*, in the center of our own Milky Way. Sgr A* is so large, close, and bright that its event horizon scale could in principle be imaged with a global interferometer, consisting of existing sub-mm-wave radio telescopes reaching tens of microarcsecond resolution. This would allow one for the first time to actually 'see' a black hole and its extreme gravity effects, such as the 'shadow' of the event horizon (Fig. A9). The other source where such scales could perhaps be reached is Virgo A. An international consortium to construct an 'Event Horizon Telescope' or a 'Black Hole Camera' to do very long baseline interferometry (VLBI) at frequencies of 230 and 350 GHz is being built up, supported by a recent ERC synergy grant by Falcke. In the next few years, Falcke and co-workers will support this effort by performing and analyzing upcoming VLBI experiments on Sgr A* and M87 at 230 and 350 GHz. In addition the PhD student will perform VLBI experiments with existing VLBI arrays at lower frequencies and do mm- and submm-observations of Sgr A* and M87 with connected element interferometers (ALMA, CARMA, IRAM, polarization and variability) to advance our understanding of the behavior and properties of the event-horizon scale emission further.

UNDERSTANDING BINARY MASS TRANSFER WITH AMUSE (NW3-15)

Mass transfer is crucial to our understanding of binaries with compact objects. It drives the accretion process observed e.g. in X-ray binaries and cataclysmic variables, as well as the formation and evolution history of these and other compact-object binaries. It also plays a pivotal role in many progenitor channels for Type Ia supernovae. This project aims to improve our quantitative understanding of mass transfer in eccentric binaries by a combination of Roche-lobe overflow and stellar winds. Pols and collaborators will perform detailed simulations using the NOVA-funded AMUSE software framework, in which hydrodynamics, radiative transfer and binary evolution are combined. The research will focus on the following questions: How does the mass-transfer rate vary as a function of orbital phase? Which fraction of the transferred mass is accreted, and how much angular momentum is lost? What is the geometry and structure of the circumstellar material formed by the mass that leaves the system? What are the expected observational signatures, e.g. on the X-ray lightcurves of massive X-ray binaries, ultra-luminous and super-soft X-ray sources? What are the long-term effects on the stability of mass transfer and the orbital evolution of the binary system, e.g. under what circumstances does the orbit shrink or expand, and can the eccentricity grow?

FROM STAR/BINARY POPULATION SYNTHESIS TO SINGLE/BINARY NEUTRON STARS (NW3-16)

The computer code SeBa that describes the origin and evolution of binaries, with emphasis on binaries with compact stars, will be updated by Verbunt et al. with new knowledge about evolution of high-mass stars, and about initial properties of binaries, e.g. the coupled probabilities of primary mass, mass ratio and binary period. The output of this code will be used as input to a second code, Maya, that describes the evolution of pulsars and their observability. This code will be updated by testing it against new, more sensitive pulsar surveys, and the pulsars detected in them.

THE FORMATION AND EVOLUTION OF YOUNG STELLAR CLUSTERS (NW3-17)

Portegies Zwart and collaborators will simulate small ~1000$M_\odot$ star clusters self-consistently from the beginning (only gas) to the moment the cluster dissolves in the tidal field of the parent galaxy. The project will start the simulations with only gas in a turbulent molecular cloud, and continue until the cluster is composed of compact objects and residual gas. With a series of simulations of gradually increasing complexity the formation of small star clusters like Orion to large systems like NGC3603 will be studied. All relevant physical processes will be included in the simulations via the AMUSE framework (Fig. A10); these include gravity, hydrodynamics, stellar evolution, binary evolution, radiative processes and the cluster will be embedded in the larger background potential of the Milky Way Galaxy. This project intends to study a wide range of phenomena that occur in young and older star clusters, including the initial stellar mass function, the effect of stellar wind versus radiation in the ejection of the ambient gas, the effect of supernovae and post-AGB winds on the young stellar cluster, the retention and fate of black holes, neutron stars and white dwarfs and the form of the tidal debris from the cluster in the tidal field of the parent galaxy.

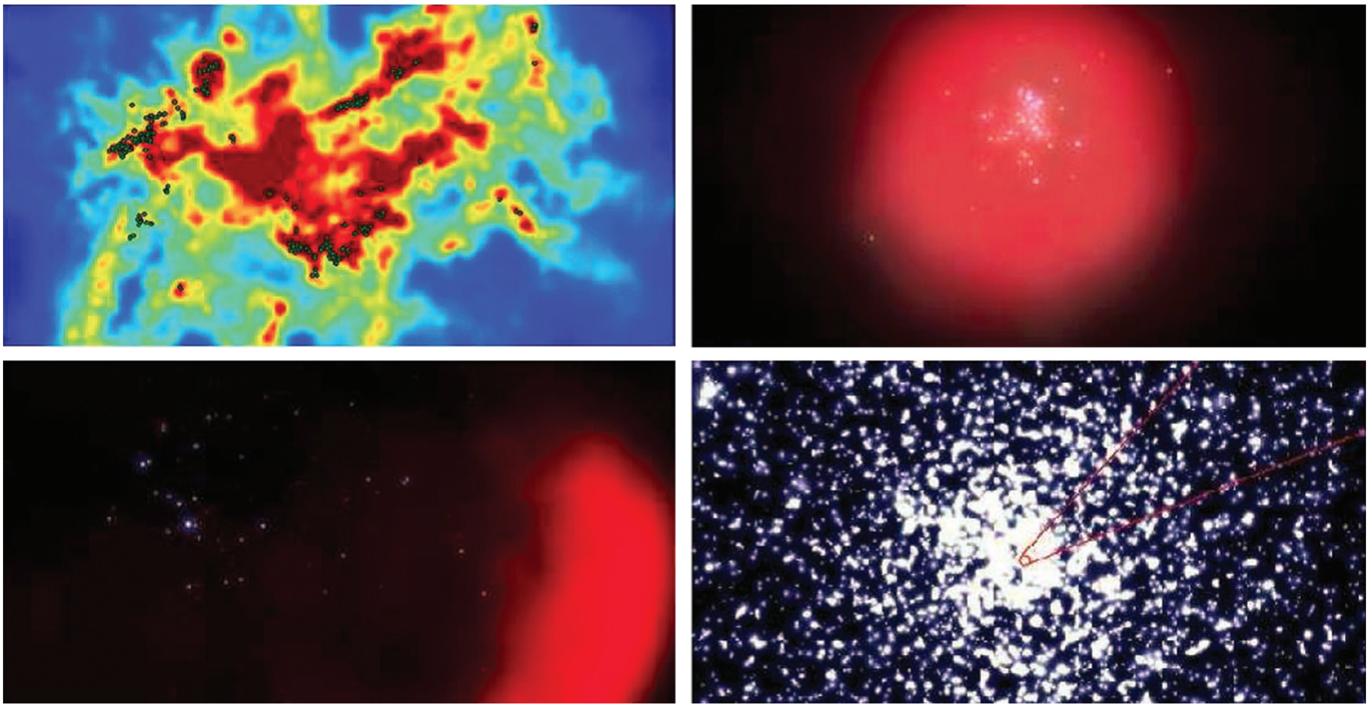


Figure A10: *AMUSE: Top left: snapshot of a smooth particles hydrodynamics simulation of a 1000 $M_\odot$ molecular cloud (in isolation, 1x2 pc, the colors indicate gas density). Top right: Snapshot of a simulation of an embedded star cluster at the moment all stars have arrived on the zero-age main sequence. Bottom left: Snapshot of the same embedded cluster as top right panel, but now after the majority of the gas has been expelled (at an age of about 8 Myr, the first supernova in this cluster occurs at about 10 Myr). Bottom right: Snapshot of an old cluster after all gas has been removed and the cluster is strongly affected by internal dynamical evolution and the external potential of the parent galaxy. With AMUSE these simulations can be combined together to a homogeneous single simulation which includes all relevant physical effects.*

FAINT X-RAY SOURCE POPULATIONS IN DIFFERENT ENVIRONMENTS: FROM THE GALACTIC PLANE TO THE CORES OF DENSE STAR CLUSTERS (NW3-18)

The central regions of star clusters can be so dense (with more than thousand times the stellar density of our local environment) that they affect the way stars evolve. Dynamical encounters between cluster stars can create exotic binaries that are very rare in the field, but they can also lead to binary destruction, resulting in a dearth of certain classes of systems that are typically relatively common. Such interacting binaries are bright sources of X-ray emission. Thanks to the sensitivity and sharp view of the Chandra X-ray Observatory, the balance between forming and dissolving binaries can be studied by comparing the properties of cluster and field binary populations. Van den Berg et al. will take the vantage point of the latter, and focus on those binary classes that so far have received little attention due to their low X-ray luminosities (~10^{32} erg/s or less), including magnetically-active binaries. The work is (initially) mainly observationally oriented using both ground-based and satellite data (e.g. from Chandra and HST), with theoretical models explored in the second part of the project.

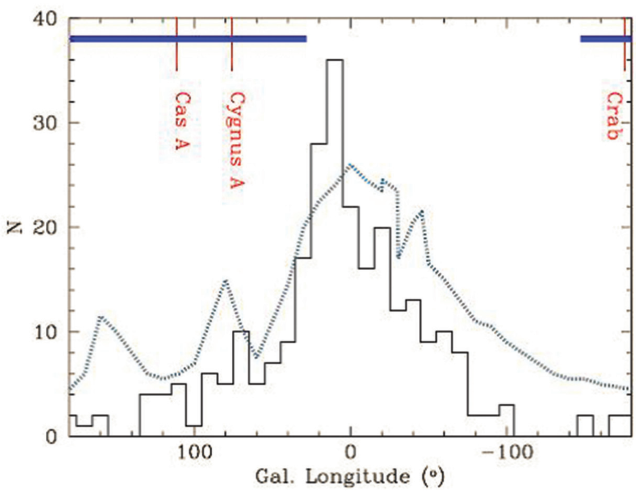


Figure A11: *The SNR distribution as a function of Galactic latitude (solid line). The dotted line shows the distribution of g-ray emission by radio-active Al-26 (courtesy of J. Knödlseder), which is a tracer of the recent star formation (normalized to the SNR peak in the center). The dark blue lines indicate the region of the galactic plane covered by the survey (δ > 0°). Note the absence of SNR peaks where our line of sight is tangential to Galactic spiral arms.*

GALACTIC PROPAGATION OF ENERGETIC COSMIC RAYS AND INTERACTIONS WITH THE INTERSTELLAR (MOLECULAR) GAS (NW3-19)

Supernovae occur mostly in the Galactic spiral arms, the site of recent star formation. The cosmic rays produced in their remnants propagate through the galaxy, guided by the magnetic field and subject to scattering by fluctuations (MHD waves) in the Galactic magnetic field. Cosmic ray electrons produce the diffuse synchrotron glow of the Galaxy, while hadrons contribute to the diffuse gamma-ray emission above 100 MeV due to collisions with the interstellar (molecular) gas. Achterberg, Hörandel and collaborators will build models of cosmic ray propagation in/near spiral arms, using the best available knowledge of the structure of the Galactic magnetic field. In particular, new data from the LOFAR Galactic plane survey will be used. The project aims to improve on existing codes (such as GALPROP) using recent insights into cosmic-ray diffusion in turbulent magnetic fields, and to produce predictions about the cosmic ray-induced diffuse emission from the Galaxy, both in the radio and for gamma-ray experiments, as well as for charged cosmic rays. The latter are measured e.g. with the TRACER instrument, in which one of the PIs is involved. The results of this research are a necessary ingredient for the interpretation of both the diffuse synchrotron radio emission (LOFAR, ...) and the diffuse gamma ray emission (CTA, HESS) from the galactic plane.

SUPERNOVA REMNANTS AND PULSAR WIND NEBULAE OBSERVATIONS WITH LOFAR (NW3-20)

Vink and Haverkorn will use the LOFAR Galactic survey data to search for new supernova remnants (SNRs) and pulsar wind nebulae (PWNe). The estimated number of SNRs in the Galaxy is 1500-3000, whereas the detected number of SNRs is less than 300 (Fig. A11). This means that we have only a very limited view of the Galactic SNR population and its distribution. SNRs are essential for the ecology of the interstellar medium (ISM), as they provide a source of heating and kinetic energy for the ISM, and because they are considered to be the main sources of Galactic cosmic rays. SNRs are expected to trace star formation in the Galaxy, with the exception of Type Ia SNRs. LOFAR is excellently suited for SNR searches as SNR radio spectra are steeper (α~0.5) than most other diffuse Galactic sources. Hence they become more dominant at low frequencies. Indeed a survey at relatively low frequency (330 MHz) with the VLA resulted in the detection of 35 new SNRs. Also from an astrophysical point of view observations at low frequencies of SNRs are interesting, since this has hardly been explored: low frequency radio emission corresponds to low energy electrons, which probe the overall low energy cosmic rays responsible for ionization in dense molecular clouds. For young SNRs searches for signs of non-linear cosmic ray acceleration (steeper spectra at low frequencies) will be made, which are a consequence of the cosmic-ray modified shock structure that is expected if a significant fraction of the shock kinetic energy is being transferred to cosmic rays.

APPENDIX B: NOVA ORGANIZATION

B1. BOARD

Prof.dr. P. Groot, chair	RU
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Prof.dr. H.J.A. Röttgering	UL
Prof.dr. R.A.M.J. Wijers	UvA

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B3. INTERNATIONAL BOARD

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Prof. dr. B. Schmidt	The Australian National University
Prof. dr. D.N. Spergel	Princeton University, USA

B4. MINNAERT COMMITTEE

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Prof.dr. P.D. Barthel	RuG
Dr. M. Klein Wolt	RU
Prof. dr. I. Snellen	UL
Dr. W. Boland (observer)	NOVA

B5. INSTRUMENT STEERING COMMITTEE

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Ing. F. Bettonvil	UL
Dr. B. Brandl	UL
Prof.dr. L. Kaper	UvA
Dr. J. Hörandel	RU
Dr. M. de Vos	ASTRON
Prof.dr. W. Wild	ESO
Dr. D. Martin	ESTEC
Dr. T. Herbst	MPIA, Heidelberg
Dr. T. Augusteijn	NOT, La Palma

B6. NETWORK RESEARCHERS

Each university staff member and tenure tracking is member of one of the NOVA research networks. In addition the table lists the researchers on long-term postdoc contracts which are in practice considered as staff, co-workers from other institutes, in particular ASTRON and SRON, who do research and teaching at the universities for one day per week, and emeriti still active in research.

NETWORK 1	NETWORK 2	NETWORK 3
UNIVERSITY STAFF	**UNIVERSITY STAFF**	**UNIVERSITY STAFF**
Helmi, chair, RuG	Dominik, chair, UvA	Nelemans, chair, RU
Barthel, RuG	Brown, UL	Achterberg, RU
Bouwens, UL	de Koter, UvA	Berge, UvA
Brandl, UL	Haverkorn, RU	Falcke, RU
Brinchman, UL	Henrichs, UvA	Groot, RU
Caputi, RuG	Hogerheijde, UL	Hörandel, RU
Franx, UL	Kamp, RuG	Körding, RU
Haverkorn, RU/UL	Kaper, UvA	Markoff, UvA
Hoekstra, UL	Keller, UL	Mendez, RuG
Koopmans, RuG	Kenworthy, UL	Pols, RU
Kuijken, UL	Linnartz, UL	Portegies Zwart, UL
Larsen, RU	Snellen, UL	Rossi, UL
McKean, RuG	Spaans, RuG	Uttley, UvA
Peletier, RuG	Tielens, UL	van der Klis, UvA
Röttgering, UL	van Dishoeck, UL	Verbunt, RU
Schaye, UL		Vink, UvA
Tolstoy, RuG		Watts, UvA
Trager, RuG		Wijers, UvA
Valentijn, RuG		Wijnands, UvA

NETWORK 1	NETWORK 2	NETWORK 3
UNIVERSITY STAFF	**UNIVERSITY STAFF**	**UNIVERSITY STAFF**
van der Weygaert, RuG		
van der Werf, UL		
Verheijen, RuG		
Zaroubi, RuG		
LONG-TERM POSTDOCS	**LONG-TERM POSTDOCS**	**LONG-TERM POSTDOCS**
Labbé, UL	Cazaux, RuG	van den Berg, UvA
Verdoes-Kleijn, RuG	Min, UvA	Rea, UvA
Oonk, UL/ASTRON		Patruno, UL
CO-WORKERS	**CO-WORKERS**	**CO-WORKERS**
de Blok, ASTRON/RuG	Aerts, RU/Leuven	Costantini, SRON/UvA
Garrett, ASTRON/UL	Baryshev, SRON/RuG	Jonker, SRON/RU
Heald, ASTRON/RuG	Helmich, SRON/RuG	Hessels, ASTRON/UvA
Morganti, ASTRON/RuG	Fridlund, ESTEC/UL	Kaastra, SRON/UL
Oosterloo, ASTRON/RuG	van Langevelde, JIVE/UL	van Leeuwen, ASTRON/UvA
Wise, ASTRON/UvA	Roelfsema, SRON/RuG	Wise, ASTRON/UvA
	Shipman, SRON/RuG	In ‘t Zand, SRON/UvA
Emeriti, still active researchers	van der Tak, SRON/RuG	
de Bruijn, RuG	Waters, SRON/UvA	Emeriti, still active researchers
van der Hulst, RuG		Hermsen, SRON/UvA
Israel, UL		van den Heuvel, UvA
Jaffe, UL		
van der Kruit, RuG		
Miley, UL		
Sanders, RuG		

APPENDIX C: ABBREVIATIONS

AGN	Active Galactic Nuclei
AIO	Assistant-in-onderzoek - PhD student
ALMA	Atacama Large Millimeter/submillimeter Array
AMUSE	Astrophysical Multipurpose Software Environment (NOVA project)
AO	Adaptive Optics
APERTIF	APERture Tile in Focus (Multi-beam receiver for WSRT)
APEX	ALMA Pathfinder Experiment
API	Astronomical Institute Anton Pannekoek (UvA)
ApJ	Astrophysical Journal
ASTRON	ASTRON - Netherlands Institute for Radio Astronomy (NWO institute
ASTRO-WISE	Astronomical Wide-field Imaging System for Europe
AU	Astronomical Unit
Band-5	ALMA receiver for the atmospheric window between 163 and 211 GHz
Band-9	ALMA receiver for the atmospheric window between 610 and 720 GHz
Caltech	California Institute of Technology
CfA	Center for Astrophysics (Harvard, USA)
Chandra	NASA's X-ray space observatory
CRs	Cosmic Rays
CTA	Cherenkov Telescope Array
DPAC	Data Processing and Analysis Consortium for Gaia
E-ELT	European Extremely Large Telescope
EMA	Euclid Mission Archive
EoR	Epoch of Reionization
EPICS	Exo-Planet Imaging Camera and Spectrograph (Instrument in study for the E-ELT)
ESA	European Space Agency
ESO	European Southern Observatory
ETH	Eidgenössische Technische Hochschule (Zürich)
EU	European Union
Euclid	ESA Cosmic Vision mission to map the geometry of the dark universe
eV	electron Volt
EVN	European VLBI Network
Fermi	Fermi Space Telescope for gamma ray wavelengths (NASA)
FLAMES	Fibre Large Array Multi Element Spectrograph (instrument on VLT)
FP	Framework Program (EU)
Gaia	Gaia - ESA's astrometric cornerstone mission
GARD	Group Advanced Receiver Development at Onsala Space Observatory, Sweden
GHz	Giga Herz
GRAPPA	Astroparticle physics and gravitation initiative (at UvA)
GRB	Gamma Ray Burst
GTC	Gran Telescopio CANARIAS
GTO	Guaranteed Time Observations
Herschel	Herschel - Far infrared space observatory (ESA)
HI	Hydrogen 21 cm line
HIFI	Heterodyne Instrument for the Far-Infrared for Herschel
HST	Hubble Space Telescope

IAU	International Astronomical Union
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
IR	Infra-Red
ISC	Instrument Steering Committee (NOVA)
ISM	InterStellar Medium
JCMT	James Clerk Maxwell Telescope (on Mauna Kea, Hawaii)
JIVE	Joint Institute for VLBI in Europe
JWST	James Webb Space Telescope (successor of Hubble Space Telescope)
KiDS	Kilo-Degree Survey (planned for VST/OmegaCAM)
KNAW	Koninklijke Nederlandse Akademie van Wetenschappen (Royal Academy of Arts and Sciences)
LIGO	Laser Interferometer Gravitational-Wave Observatory (USA)
LISA	Laser Interferometer Space Antenna (ESA L3 mission to study gravitational waves)
LMC	Large Magellanic Cloud
LOFAR	LOw Frequency ARray - radio observatory operated by ASTRON with European partners
MATISSE	Multi AperTure Mid-Infrared Spectroscopic Experiment (2nd generation VLTI instrument)
METIS	Mid-infrared ELT Imager and Spectrograph for E-ELT
MICADO	Near-infrared wide-field imager for E-ELT
Mid-IR	Mid-InfraRed
MIRI	Mid Infra-Red Instrument (under construction for JWST)
MNRAS	Monthly Notices of the Royal Astronomical Society
MOSIAC	Multi Object Spectrograph instrument concept for E-ELT
MPE	Max-Planck-Institut für Extraterrestrische Physik (Garching, Germany)
MPIA	Max-Planck-Institut für Astronomie (Heidelberg, Germany)
MPIfR	Max-Planck Institut für Radioastronomie (Bonn, Germanny)
MUSE	Multi Unit Spectroscopic Explorer (instrument on VLT)
NASA	National Aeronautics and Space Administration (USA)
NIC	NOVA Information Center
NIKHEF	Nationaal Instituut voor Kernfysica en Hoge-Energiefysica (institute of FOM)
NL	Netherlands
nm	nanometer
NOVA	Nederlandse Onderzoekschool Voor Astronomie (Netherlands Research School for Astronomy)
NRAO	National Radio Astronomical Observatory (USA)
NW	NOVA research network
NWO	Netherlands Organization for Scientific Research
OCW	Dutch ministry for Education, Culture and Science
OmegaCAM	Wide-field camera for the VLT Survey Telescope
OmegaCEN	OmegaCAM data center (at RUG)
Op/IR	Optical to InfraRed
PAH	Polycyclic Aromatic Hydrocarbon molecule
pc	parsec
pd	Postdoc
PI	Principal Investigator

R&D	Research and Development
RAL	Rutherford Appleton Laboratory (Didcot, UK)
RU	Radboud Universiteit, Nijmegen
RUG	Rijksuniversiteit Groningen
SAFARI	SpicA FAR-infrared Instrument (instrument on Japanese-European SPICA mission)
SDC	Science Data Center
SIS	Superconductor Insulator Superconductor; detector technology for (sub)-mm and far-IR
SKA	Square Kilometer Array
SMC	Small Magellanic Cloud
SMO	Spectrometer Main Optics
SPHERE	Spectro-Polarimetric High-contrast Exoplanet Research (instrument on VLT)
SPICA	SPace Infrared telescope for Cosmology and Astrophysics (possible Japanese/European mission)
SRON	SRON - Netherlands Institute for Space Research
TNO	Research Institute for applied physics in the Netherlands
UD	Assistant professor
UHD	Associate professor
UK	United Kingdom
UL	Universiteit Leiden
ULIRG	Ultra Luminous Infra-Red Galaxy
UltraVISTA	Ultra deep near-IR imaging program with VISTA
UNAWE	Universe Awareness (international outreach activity aimed at kids of 4-10 years)
univ	university
UU	Universiteit Utrecht
UV	ultra violet
UvA	Universiteit van Amsterdam
VLT	Very Large Telescope (ESO)
VLTI	Very Large Telescope Interferometer (ESO)
VST	VLT Survey Telescope
WHT	William Herschel Telescope (part of ING)
WSRT	Westerbork Synthesis Radio Telescope
XMM-Newton	X-Ray Multiple Mirror (ESA's X-ray observatory)
X-Shooter	Single target optical and near-IR spectrometer (instrument on VLT)
ZIMPOL	Zurich IMaging POLarimeter - part of SPHERE