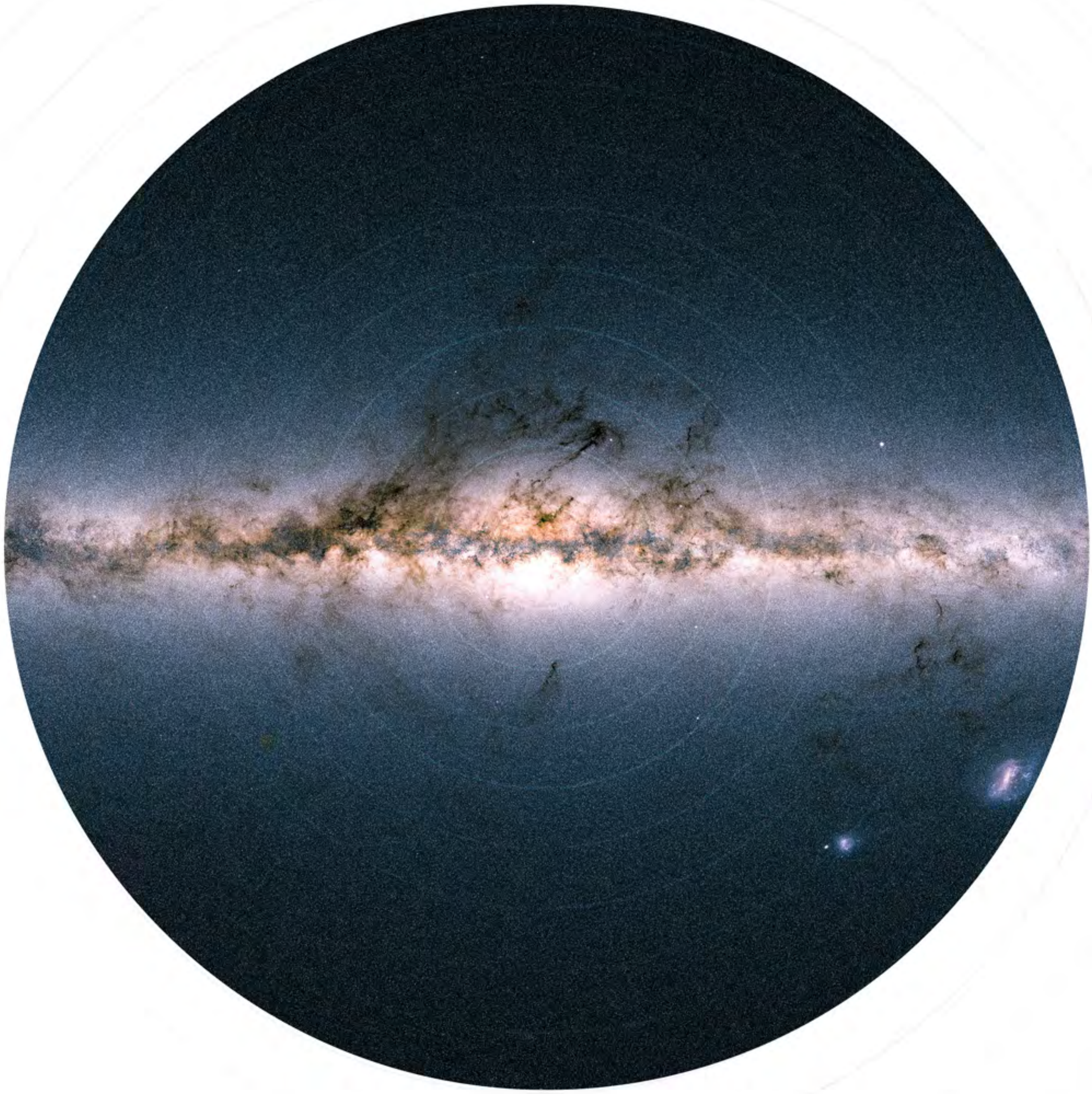
NOVA REPORT



2016 – 2018

NEDERLANDSE ONDERZOEKSCHOOL
VOOR ASTRONOMIE

NETHERLANDS RESEARCH
SCHOOL FOR ASTRONOMY

POSTAL ADDRESS
P.O. Box 9513
2300 RA Leiden, The Netherlands

PHONE
+31 (0)71 527 5852

E-MAIL
nova@strw.leidenuniv.nl

WEB
www.nova-astronomy.nl

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

PUBLIC OUTREACH
NOVA Information Center Web: www.astronomie.nl

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

Photo Front cover: Gaia's sky in colour. Gaia's all-sky view of our Milky Way Galaxy and neighboring galaxies, based on measurements of nearly 1.7 billion stars. The map shows the total brightness and colour of stars observed by the ESA satellite between July 2014 and May 2016. Spectacular progress in our understanding of the Milky Way has been made because the projected sky motions of 1.3 billion of these stars have also been measured by Gaia.

NOVA REPORT

2016 - 2018

Table of Contents

01 Introduction

Introduction and major developments of the NOVA program 2016 – 2018

Astronomy is a unique discipline which combines top science, cutting-edge technology and education while inspiring and exciting the general public. Progress in astronomy is driven by the combination of new facilities, big data streams and critical thinking, with discoveries continuing at an amazing pace. Close to home a surprising variety of planets circling nearby stars has been found, with characteristics very different from those in our own Solar System. The dusty birthplaces of galaxies, stars and planets, and perhaps even life itself, are being revealed with new facilities. Gravitational waves from the merging of black holes, predicted more than a century ago by Einstein, have been seen for the first time. Galaxies are now found at the edge of the Universe from which the radiation takes 13 billion years to reach Earth. Even more remarkable is the fact that all visible objects comprise only 5% of the Universe, with the remaining 95% consisting of mysterious dark energy and dark matter which leave no directly observable trace and whose nature is not understood. The desire and curiosity to understand this fascinating Universe is shared between astronomers and the general public, and astronomy presents an excellent vehicle to enhance appreciation for the natural sciences and technology to children and students.

The Netherlands Research School for Astronomy (NOVA) is the alliance of the astronomical institutes of the universities of Amsterdam, Groningen, Leiden, and Nijmegen, founded in 1992. Since 1999, NOVA receives funding as a top-research school. All university researchers in astronomy are part of NOVA. The research within NOVA is focused around the theme "The life-cycle of stars and galaxies: from high-redshift to the present". This theme consists of three research 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: **Astrophysics in extreme conditions**

These three research themes are inter-university, dynamic and inter-connected and have been chosen strategically. The Netherlands has a tradition of excellence in these research areas and they are part of the five big European research themes within the Strategic Plan for European Astronomy, ASTRONET.

The top research school grant enables NOVA to keep its position at the world-top with a quality that is at the same level as that of prime institutes in the USA and the UK and Max Planck Institutes in Germany. Of vital importance for the success of the research programs is the development and construction of advanced instrumentation for Big Science and Big Data(science). There is a large synergy between astronomical research and high-tech R&D in the Netherlands. NOVA's instrument program enables university astronomers to participate in big international instrumentation projects. It is mainly focused on optical, infrared and submillimeter instrumentation for the European Southern Observatory (ESO), thereby functioning as its homebase and having international impact through national coordination.

Major developments of the NOVA program 2016 – 2018

The reporting period 2016-2018 concludes the final part of the top-research school Phase-4 funding cycle of NOVA which was running from 2014 to the end of 2018. The interrelated science and instrumentation program is described below. Future instrumentation is becoming increasingly focused on ESO's Extremely Large Telescope (ELT) for which first light is foreseen in 2027. The NOVA flagship project is the mid-Infrared imager and high-resolution spectrometer METIS, a first-generation ELT instrument, of which NOVA has the prestigious role as the Principal Investigator leading an international consortium. NOVA is co-Investigator in the ELT first light instrument MICADO, a near-infrared camera with unprecedented sharpness and low-resolution spectrometer capabilities. In addition, NOVA participates in the design study of the second-generation multi-object spectrometer MOSAIC as well as in R&D studies of a future ELT instrument for high-contrast polarimetric imaging of exoplanets, EPICS.

NOVA had its 5-year review in November 2016. The main findings of the international evaluation board (EB) were:

NOVA has performed at an exemplary level in all the key areas of its mission: research, instrumentation, PhD education, and education and outreach. These exemplary standards hold across all of the institutes, with NOVA greatly enhancing existing institutional strengths. The very high degree of integration between research and instrumentation strategies is a key element in NOVA's ability to punch well above its weight' in astronomy within Europe and the world. The EB emphasizes that the NOVA-led PhD program in astronomy and astrophysics is of the world-wide highest quality in all respects. The NOVA coordinated outreach activities set a standard that is exemplary for comparable astronomy and education outreach programs world-wide.

Early 2016 the ministry OCW announced that the NOVA funding would be extended after Phase-4 by five years until the end of 2023, but that the top-research school funding line would end then. NOVA has since been searching actively for future ways to continue its funding after 2023, given its long-term commitment to instrumentation projects of typically 10-20 years duration.

Dutch university astronomy continues to be highly productive with more than a thousand unique refereed papers per year in 2016-2018, most of them led by young PhD students and postdocs and several of them among the most highly cited of that year. A significant fraction is joint between NOVA institutes. In this period a total of 109 PhDs in astronomy were awarded.

Selected science highlights in the 2016-2018 period include:

- NOVA scientists used data from ESA's Gaia mission to map the 3D motions of stars in our own Milky Way. This led to their discovery of a major merger of the Milky Way with another galaxy, Gaia-Enceladus. This collision had a profound influence on the evolution and appearance of the Milky Way.
- With the MUSE instrument on the VLT, co-built by NOVA, faint Ly alpha and CIII lines were measured, indicating that the reionization of the early Universe could be caused by the light of stars in low mass galaxies.
- With the LOFAR radio telescope now in full swing, NOVA astronomers have performed a large survey of the Northern Sky detecting hundreds of thousands of previously undetected radio galaxies, shedding new light on many research areas, including the physics of black holes and how clusters of galaxies evolve.
- NOVA scientists have detected the prebiotic gas methyl isocyanate (CH3NCO) on solar system scales (~50 AU) with ALMA and demonstrated the formation of such peptide bonds under cold conditions in the laboratory. Freon-40 (CH3Cl) was also found by ALMA in the same source and by ESA's Rosetta mission to comet 67P/C-G. On Earth this molecule is only formed by biological processes, something which is clearly not the case in space – making it less suitable as a so-called biomarker gas.
- The new exoplanet imager on ESO's Very Large Telescope co-built by NOVA, called SPHERE, has driven many new discoveries. One highlight has been the detailed observations of changes in a planet-forming disk on time-scales of less than a year. The images show a beautiful circumstellar disk with spiral arms and dark patches caused by the inner disk casting long shadows on the outer part.
- Measurements of the binarity of massive stars in 30-Doradus, a region of very high star formation in the Large Magellanic Cloud, with VLT X-shooter co-built by NOVA revealed that that most very young stars are single, or only weakly bound to another star. This is surprising since most mature stars are mostly found in pairs. It implies that many of the stars will acquire a companion later in their life – an important aspect in understanding the evolution of massive stars.
- NOVA has been at the forefront in the new field of Fast Radio Bursts (FRBs) which are extragalactic millisecond duration bursts of unknown origin. NOVA scientists have been instrumental in the discovery of new FRBs, including the first repeating FRB and the fact that its emission is nearly 100% linearly polarized, requiring a strong and dynamic magneto-ionic environment.
- The direct detection of gravitational waves due to the merging of compact objects has been one of the greatest achievements of the 2016-18 period. For the first black hole merger, GW150914 and the first neutron star merger GW170817, NOVA scientists played a key role in the astrophysical interpretation and searches for an electromagnetic counterpart.
- Simulations on the Blue Waters supercomputer, using the world's fastest GPU-accelerated general relativistic magnetohydrodynamical code, have shown that the jets of supermassive black holes are aligned with the disk's rotation axis rather than the black hole's spin axis. This allows jets to precess, something that fits with new results from NICER on the International Space Station.

The instrumentation program saw the completion of the NOVA contribution to the MATISSE instrument (2018) for the ESO-VLT Interferometer. In 2018 the APERTIF frontends on ASTRON's Westerbork Synthesis Radio Telescope were declared open, and at that time also the partly NOVA-funded ARTS became operational in its science commissioning. The NOVA submm group delivered its last two Band 5 cartridges to ESO for use in the ALMA telescopes in 2018. The upgrade of the CRYOPAD instrument in the Laboratory for Astrophysics, CRYOPAD2, was also completed in the reporting period.

In addition, NOVA researchers received awards and honors for their work. A small selection is given here:

- Van Dishoeck received the prestigious Kavli Prize and the James Craig Watson Medal in 2018
- The RU Gravitational Wave Group was part of the team that received the Special Breakthrough Prize and the Gruber Prize for Cosmology in 2016
- Helmi became member of the KNAW in 2017
- Hessels became member of De Jonge Akademie in 2016
- Snik became member of De Jonge Akademie in 2017
- de Mink received the MERAC prize in 2017 and Smit in 2018
- Van den Heuvel received the 2018 Viktor Ambartsumian International Science Prize
- Hamers received the Christiaan Huygens prize in 2018
- De Zeeuw received Royal Knighthood in 2018

GRANT	2016	2017	2018
ERC Advanced	Snellen		Hörandel
ERC Consoli-dator	Caputi	Haverkorn Levan	
ERC Starting	Dayal De Mink		Birkby Van Weeren
NWO -VICI	Hoekstra Nelemans		Van Leeuwen
NWO -VIDI	Hodge Nissanke	Bouwman Meerburg De Mink Van Weeren	Dayal Désert
NWO-VENI	Hacar Russell Toonen Zhou	Van Daalen Bahe Schaller Schmidt	Blagorodnova Mushtukov Petroff Rosotti
NWO-TOP1	Bouwens De Koter	Van Dishoeck Haverkorn	
NWO-TTW			Keller, Snik
NWO-Groot	Kuijken, Valentijn		
NWO-M	Berge Portegies Zwart	Helmi Hessels Snellen	

INTRODUCTION

02 Mission and Landscape

NOVA is the alliance of the four university astronomy institutes in the Netherlands: in Amsterdam, Groningen, Leiden and Nijmegen.

NOVA's mission and objectives

NOVA's mission is to carry out front-line astronomical research, to train young astronomers at the highest international levels, and to share discoveries with society. NOVA coordinates all of Dutch university astronomy research, instrumentation, PhD education and outreach activities in a coherent and collaborative national program called "The lifecycle of stars and galaxies".

NOVA's objective is to ensure a front-line role in the next generation of astronomical discoveries and to share our new knowledge with society. The first part of its strategy is to foster a stimulating scientific atmosphere which allows astronomers to pursue their scientific dreams and push boundaries, and in which young scientists can develop and grow. To enable these dreams, new observations, instruments and technology – together with theory and models – are essential. The second part of NOVA's strategy is therefore to design and build advanced instrumentation for state-of-the-art observing facilities, in particular for ESO, which provide priority access to observations of particular importance for Dutch astronomy. This strategy maximizes the science return of major telescopes in which the Dutch government has invested. NOVA also stimulates development of specialized data reduction software, numerical modelling and laboratory astrophysics at the universities. NOVA thereby empowers the university astronomers in several key areas, providing them with a longer-term planning horizon and a higher impact than would otherwise be possible.

Research and instrumentation are strongly interlinked in the NOVA program. NOVA astronomers use a wide variety of telescopes and instruments, but new breakthroughs often come from a close involvement in instrumentation itself: by developing and building new instruments, astronomers define their functionality, steer their science capabilities towards Dutch interests, and safeguard them throughout the complete instrument building cycle. Through guaranteed time awarded as compensation for this investment, NOVA astronomers are among the first to use the instrument and harvest the most exciting early science. Leading or being part of the instrument team is key to doing modern frontline astronomy.

NOVA is fully committed to share its knowledge with people from all walks of society. Its activities are grouped around three main pillars: (i) outreach and education; (ii) pushing technology boundaries and spin-offs with industry; and (iii) human capital development. In outreach the NOVA Information Centre strategy is (a) to inform the general public in the Dutch language about new astronomical discoveries with a focus on results in which NL astronomers had a leading role, through the widest possible range of (social) media; (b) to identify within and to engage with society on astronomical developments, and (c) to stimulate and support education in astronomy (and sciences in general) in primary and secondary schools through providing compelling and exciting material for school books, training and coaching for teachers, and operating three mobile planetariums to visit schools. Each of the university institutes also has a wide range of outreach activities, often centered around their own small telescopes. They complement the NIC activities by being aimed at their local and regional communities (typically thousands of people), but they join forces with the NIC when appropriate to reach broader audiences at the national level (up to millions of people).

The NOVA research program: The life cycle of stars and galaxies

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

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

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

Network 3: **Astrophysics in extreme conditions**

Each network consists of 15-30 active staff researchers with strong international scientific records. The networks have regular face-to-face meetings two to three times a year with scientific presentations, mostly by PhD students and postdocs. Subgroups of researchers from different universities focusing on more specialized topics also meet regularly.

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

Network 1 studies the formation and evolution of galaxies across time and space, from the Milky Way to the first observable objects in the Universe. Its main themes for the coming 5-10 years are: (i) The dawn of the Universe (ii) The nature of the main constituents of the Universe: putting constraints on dark matter and dark energy; (iii) The process of galaxy assembly: towards a theory of galaxy evolution.

Network 2: Formation and evolution of stars and planetary systems

Network 2 studies the physics and chemistry of the interstellar medium, its collapse to form new stars and protoplanetary disks, the formation of planets, and the subsequent evolution of those stars and planets. Its main themes for the coming 5-10 years are: (i) Massive stars: how do they form and shape their environment and the Universe? (ii) Planet formation in disks: what determines the architecture of planetary systems? (iii) Extrasolar planets: towards characterization of Earth-like planets; (iv) The molecular Universe: inventory, chemical pathways and diagnostic applications.

Network 3: Astrophysics in extreme conditions

Network 3 investigates the extremes of physics, as encountered at the highest temperatures, densities and energies in objects with the strongest gravitational potentials: neutron stars (NS), white dwarfs (WD) and black holes (BH). Its main themes for the next 5-10 years are (i) Extreme physics with compact objects and in their mergers; (ii) Accretion, ejection and particle acceleration; (iii) Formation and evolution of (binary) BHs, NSs and WDs in diverse environments.

Instrumentation

NOVA's instrumentation program is focused on the European Southern Observatory (ESO). The top-level strategy of the program is therefore that it will be (at any given time) Co-Principal Investigator on at least one ESO instrument. For the coming decade, this will be the PI-ship on the METIS instrument for the ELT. The NOVA instrumentation program also invests in smaller scale instrumentation and R&D projects where new concepts and technologies will be developed, implemented and matured before being deployed in new instrumentation. Two areas of R&D focus have been chosen for the coming years: (i) high contrast imaging; and (ii) multi-pixel submillimeter instrumentation.

The central part of the LOFAR International Telescope is the so-called Superterp, an elevated area of 320m diameter, with many receivers for measuring the shortest baselines. Credit: ASTRON

Landscape

Astrophysics uses knowledge from all corners of the physics community – from cosmology to solid state physics. Because of its large data streams in theory and observations, astronomy is additionally very well connected to computer science and mathematics. Astrochemistry is a vivid research branch within NOVA, and exoplanetary research connects well with planetary and geosciences. Astronomy is therefore a valuable binding theme in the Dutch scientific landscape.

Within the Netherlands there are strong ties with the NWO institutes ASTRON and SRON. ASTRON is doing research and development for radio observatories like the SKA and maintaining the radio observatories in the Netherlands, LOFAR and WSRT. SRON concentrates on instruments for scientific research from space in Earth Observation and Astronomy in the X-rays, optical/near-IR and far-IR wavelength regimes. More recently, a tighter collaboration with NWO institute NIKHEF (the institute for nuclear and high energy physics) has started, a focal point for instruments in gravitational wave detection and astroparticle physics.

Artist's impression of ESA's Herschel satellite, designed to study the formation of galaxies and stars. Credit: ESA/AOES Medialab

03 Diversity and Inclusiveness

The reporting period 2016-18 falls just after the middle of a decade in which our community has become quite a bit more gender-diverse. The fraction of female PhDs graduating has approximately doubled from just over 20% in 2010 to about 40% in 2015; it fluctuates around that value thereafter. In that same period, the absolute number of PhDs graduating grew by 70%, so another way of phrasing this result is that the number of male PhDs grew slightly (30%), whereas the number of female PhDs became 2.5 times higher.

The fraction of female permanent staff lags behind, more so in the higher ranks. But still, it grew from 15% to 25% between 2011 and 2020, which is about double the rate of growth of female faculty nationally. It ranges considerably between institutes though, from 13% to 44%, partly due to the rates of faculty replacement having been quite different: in recent times, the fraction of new female faculty hires is approaching 50% in all NOVA institutes. This puts NOVA in a leading position among hard natural sciences, certainly in the Netherlands, which lags among EU countries in female participation in STEM. Our community has also become more international, with overall membership share of Dutch nationality decreasing from 50% to 30% (counting PhDs, postdocs, and faculty).

NOVA recognizes that there is still more work to do. Representation of women among students of Dutch origin is still poorer, with typically about 1 in 4-5 incoming BSc students being women. Also, among faculty women are more often of foreign background than men. This means more work has to be done to engage with girls at primary and secondary school level and entice them to STEM. The same holds for students with minority backgrounds, e.g., immigrant backgrounds, which are underrepresented in all of academia including STEM. At the time of writing of this report (end 2020), the Dutch Astronomy Council, of which NOVA is part, is preparing to launch new initiatives towards making ours a more inclusive environment, such as a national astronomy statement of values and code of conduct.

04 NOVA Networks

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

NOVA Network 1 (NW1) focusses on fundamental questions related to the constituent components of our Universe and how it came to be as we see it around us today. Its core question is: "How do galaxies form and evolve, and how can they be used as tracers of the evolution of the Universe and its (dark) constituents?"

Recent years have seen spectacular progress with NOVA NW1 researchers playing leading roles in key discoveries. This has been possible thanks to long-term preparations and investments from earlier in this decade, particularly through the NOVA instrumentation program. Examples are the key roles in ESA's Gaia space mission, whose datasets are driving a revolution in our understanding of the Milky Way. The use of ALMA, MUSE, and ultra-deep imaging of the Hubble Space Telescope, together with the LOFAR telescope, have provided new insights into the galaxies and the Universe at the earliest times. Studies of dark matter and dark energy using ESO's VLT Survey Telescope in Chile as part of the Kilo-Degree Survey (KiDS) have confirmed surprising tensions in the cosmological model. In short, NOVA NW1 researchers have tackled very important questions in the evolution of galaxies throughout cosmic time and have also used galaxies to probe the fundamental physics of the cosmos (e.g. dark matter and dark energy). These selected highlights that illustrate the enormous progress of NOVA NW1 are described in more detail below.

Deciphering the Milky Way with Gaia

ESA's Gaia cornerstone mission has been charting the Milky Way to unveil its composition, formation and evolution. Two data releases took place in the 2016-2018 period, and particularly the 2nd data release has revolutionized our understanding of the Galaxy because of the enormous improvement in quality and quantity of kinematical, photometric and positional information. The Gaia Processing and Data Analysis Consortium, whose leadership is in the hands of a NOVA researcher, producing arguably one of the most impactful astronomical datasets in history. Using Gaia DR1 in combination with HST, NOVA NW1 made the first measurement of the 3D internal motions of stars in the nearby dwarf galaxies, critical to understand their mass distribution. Among the top science with Gaia DR2, was the NOVA led discovery that the Milky Way underwent a major merger with another galaxy called "Gaia-Enceladus" some ten billion years ago, which dominates the halo near the Sun and also shaped the thick disc of the Milky Way. The flagship paper that produced a catalogue of the 3D motions of dwarf galaxies and globular clusters, also a NOVA NW1 led effort, has allowed among other things, NOVA researchers to associate globular clusters to not only Gaia-Enceladus but also to different building blocks of the Milky Way.

Gaia – Our Milky Way shaped by a merger with Gaia-Enceladus

NOVA scientists found in the data from ESA's Gaia satellite a tell-tale sign of a major collision event in the history of the Milky Way. The merger with another galaxy, named Gaia-Enceladus, altered the shape, content and evolution of our Milky Way. Left panel: the dynamical picture of the two galaxies merging. Right panel: The Versailles gilt-bronze of Enceladus, son of Gaia, is merging with the Milky Way, depicting the major merging event.

Galaxies under construction

A study led by NOVA researchers using ALMA has resolved star formation within galaxies present when the Universe was only a fraction of its current age. They discovered compact (≤ a few kiloparsecs) dust disks within more extended and chaotic unobscured stellar distributions, suggesting that major mergers may be responsible for driving the formation of the compact dust disks. The extreme morphological contrast also indicates that the current bursts of dusty star formation have the potential to transform both the observed galaxy sizes and overall light profiles.

NOVA astronomers have also used the MUSE instrument on the VLT to obtain new insights of galaxies in the early universe, particularly about mergers, galactic winds and star formation processes. They have detected and characterized faint Lyman alpha and CIII emitters, and found that low-mass galaxies at $3 < z < 6$ are forming stars at higher rates than seen locally or in more massive galaxies. This is consistent with a scenario where low mass galaxies reionise the Universe.

In other efforts led by NOVA researchers, very deep observations of the Hubble Space Telescope have revealed galaxies at $z \sim 11$, and hundreds of thousands of galaxies only 1/2 billion years after the Big Bang. These observations have been used to obtain precise measurements of the (primeval) galaxy luminosity function up to a redshift of $z \sim 10$, probing deep into the Epoch of Reionization and approaching the Cosmic Dawn.

Hubble View of the Universe

This Hubble-picture shows part of the Hubble Legacy Field. The image is a combination of thousands of exposures, taken over 16 years for various Hubble-Deep-Field Surveys. The mosaic contains 200,000 galaxies up to 500 million years after the Big Bang. Observations such as these have been used by NOVA researchers to obtain precise measurements of the galaxy luminosity function deep into the Epoch of Reionization and approaching the Cosmic Dawn. Credit: NASA, ESA

New views from the Low-Frequency Array (LOFAR): the radio sky and the epoch of reionisation

The Low-Frequency Array, the largest low frequency array with baselines from tens of meters to thousands of kilometers, has finally started routine observations. An international team led by NOVA astronomers has carried out a low frequency survey of the northern sky. The first phase of the survey has revealed hundreds of thousands of previously undetected radio galaxies, shedding new light on many research areas, including the physics of black holes and how clusters of galaxies evolve. A special issue of the scientific journal Astronomy & Astrophysics was dedicated to the first 26 research papers describing the survey and its first results, based on work done over the past several years.

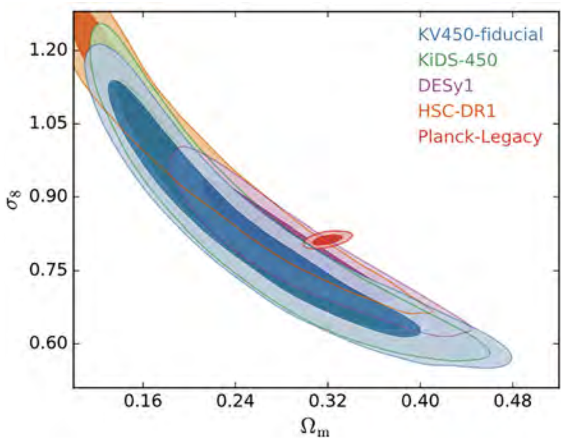
During the first one billion years the Universe was pervaded by neutral hydrogen, which was (re)ionized rapidly in the Epoch of Reionization. This epoch forms the foundation of most of what we see around us today: the first stars, galaxies, black holes and metals were formed, transforming the pristine Universe into a complex astrophysical system. Using LOFAR data, NOVA researchers have been able to place the deepest limits on the feeble 21-cm signal of neutral hydrogen from the EoR at redshift z=8-11.

LOFAR

The core area of LOFAR, showing the High-Band Antennas (square boxes) and Low-Band Antennas (individual receivers). In the period 2016-2018, NOVA astronomers have used LOFAR to produce not only the deepest low-frequency radio images of the radio sky from the LOTTS survey but also to obtain the first and thus far deepest limits on the 21-cm signal of neutral hydrogen from the Epoch of Reionization.

Cosmography via Weak Lensing

The ESO-VST survey KiDS has come to fruition over the past few years. An exciting result from its weak lensing survey, led by NOVA researchers, has been the measurement of the cosmic shear power spectrum over a range of redshifts, using 450 square degrees of sky. The results confirm the recently reported tension between local universe measurements and measurements from the Cosmic Microwave Background. This same tension was reported from strong lensing and measurement of the Hubble Constant from local and CMB observations.



KiDS Parameters

Tomographic cosmic shear analysis of the Kilo-Degree Survey (KiDS) combined with the VISTA Kilo – Degree Infrared Galaxy Survey (VIKING). The unprecedented dataset (KV450), spanning 450 deg2, allows to improve significantly the estimation of photometric redshifts, and hence of cosmological parameters using weak lensing. This figure shows the constraints obtained by NOVA astronomers in the Ωm vs. σ8 plane from KV450 cosmic shear tomography (blue), and the KiDS-450 optical-only cosmic shear measurement (green) in comparison to those derived from other experiments, and reveals the tension with the Planck-Legacy CMB results. Credit: ESO, KiDS Collaboration

Quotes of Amina Helmi,
based on an interview published in NRC Handelsblad,
4 June 2018

Amina Helmi is professor of astronomy at the University of Groningen. She analyzes the data from the space telescope Gaia ("1 billion starmapper")

How did you, as an Argentinian, actually end up in the Netherlands?

"There are two reasons for this. One is that my mother is originally from the Netherlands. As a result, I have a Dutch passport and I also had family here. I thought the switch to the Netherlands would be easy. The other reason was that the Netherlands is very highly regarded in astronomy."

At the University of Groningen you have followed in the footsteps of Jacobus Kapteyn, who made a name for himself with his research of the Milky Way – the theme of your own thesis...

"Yes, that is interesting. I think people find my work so interesting because I have linked the traditional astrometric exploration of our Milky Way – which in itself is often seen as very boring – with cosmology. And I did that at a time when cosmology had increasing predictive power to understand how galaxies evolve. That's how "galactic archeology" came into being, which people are very excited about because it is about our origins."

Is Gaia going to solve all outstanding problems?

"When I look at my own research, I do have the feeling that Gaia is going to solve a lot. I am particularly interested in the history of the Milky Way and in what is dark matter. "We are already starting to get a good picture of that history. Moreover, galaxies were long seen as self-contained „universe islands," but now it appears that our Milky Way is very sensitive to interactions with other galaxies. As a result, the disk of stars that our sun is also part of shows a lot of structure. Understanding what is dark matter issue will need a little more time, I think. We need to map the force field around the Milky Way using the movements of the stars. That way you can determine if there really is such a thing as dark matter or if we need to adjust our theory of gravity."

Network 2: Formation and evolution of stars and planetary systems

Research in NOVA Network 2 focuses on the formation and evolution of stars and planetary systems. It touches upon fundamental and existential questions about mankind and our place in the Universe. It seeks answers to the origin and evolution of our Solar System and the Earth in the context of star and planet formation processes, and the diverse architectures of other planetary systems in the Milky Way.

We live in an exciting time. Circumstellar disks, from which ultimately planets and their moons form, are being studied in detail. Exoplanets are found in their thousands, for which the chemical make-ups are being deciphered. The most massive stars, which produce the bulk of the chemical elements in the universe (essential ingredients for the formation of Earth-like planets and life), can be studied in a wide range of environments. In addition, increasingly complex molecules are found in interstellar space, and their formation processes can now be simulated in state-of-the-art astrochemical laboratory set ups. The science of NW2 is at the heart of all these exciting developments.

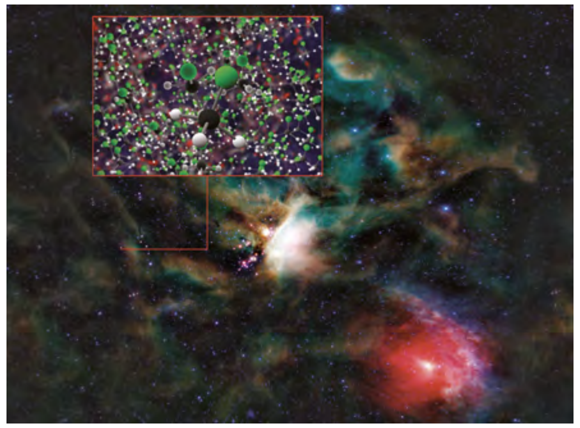
Giant steps forward with ALMA

In the 2016-2018 period, the Atacama Large Millimeter/submillimeter Array (ALMA) provided exciting new pathways to study the formation of stars and their planets. New ALMA observations reveal a wealth of beautiful and often surprising structures on solar system scales, with gas and mm-sized dust not following each other. Some of the observed gaps and cavities are caused to forming protoplanets, whereas other structures are may be related to snowlines. Rings purely due to chemistry have also been found. The unexpectedly weak observed CO (and H_2O, from *Herschel*) emission implies the transformation of the bulk of CO into other carbon-bearing species and locking up of ices into larger pebbles. It remains a challenge to understand how small dust grains over time can grow to larger sizes, from mm to cm size, meter size, and eventually km-size planetesimals. NOVA astronomers have used relatively simple molecules, such as H_2CO, DCO^+, DCN, and N_2D^+ to trace how grain growth and radial drift affects the disk chemistry.

The unprecedented power of ALMA now also allows large samples of disks to be studied at ~20 AU resolution, often with integration times as short as one minute. Disk demographics of hundreds of sources in nearby star-forming regions show that typical dust mass distributions are very similar from cloud to cloud but that the median value is not enough to form a giant planet core by the T Tauri stage. In contrast, disks in the embedded stage have 5-10 times higher dust masses. Thus, planet(esimal) formation must start early, shortly after the collapse of the cloud to form a new star. Taken together, these ALMA data allow a completely new view on the structure and evolution of protoplanetary disks.

A unique NOVA quality is the combination of state-of-the-art astronomical observations with laboratory measurements, allowing a deeper level of understanding not possible otherwise. Of particular interest is the study of pre-biotic molecules – chemical species that may play a role in the formation of life. As part of the ALMA PILS-survey of the IRAS16293-2422 solar-mass protostar, NOVA scientists found the gas methyl isocyanate on solar system scales (~50 AU), a building block for biologically important molecules and studied its formation in the laboratory. Freon-40 (CH_3Cl) was also found by ALMA in the same survey and by ESA's Rosetta mission to comet 67P/C-G. On Earth this molecule is only formed by biological processes, something which is clearly not the case in space – making it less suitable as a so-called biomarker gas. Excitingly, NOVA scientists managed to produce the biologically important compound glycerol in the Leiden Laboratory for Astrophysics, under circumstances that are very similar to those in cold interstellar clouds – letting CO ice react with hydrogen atoms at a temperature of only 10 K. The ice laboratory data will be important for analysis of the JWST-MIRI GTO data on protostars and disks, and also formed the basis for the award of a JWST Early Release Science program to search for complex organic molecules in the solid state.

Advanced modelling is a crucial aspect of NOVA NW2 astrophysical research. An exciting highlight involves simulations of how water at a microscopic level can be incorporated in dust grains. It shows that water can be trapped efficiently in small silicate grains in the early stages of planet forming disks near the water snowline, forming a viable way to incorporate significant amounts of water into objects that could later form planets like our Earth.

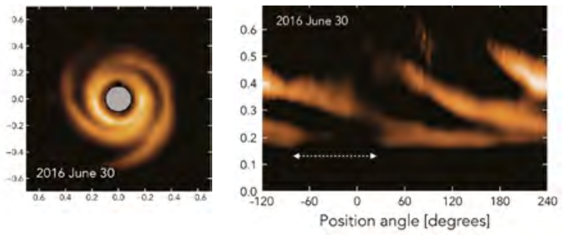


ALMA and Rosetta Detect Freon-40 in Space

Organohalogen methyl chloride (Freon-40) discovered by ALMA around the infant stars in IRAS 16293-2422. These same organic compounds were discovered in the thin atmosphere surrounding Comet 67P/C-G by the ROSINA instrument on ESA's Rosetta space probe. The combination of measurements from ground and space with laboratory data and chemical modelling is typical for how NOVA's researchers work. Credit: B. Saxton (NRAO/AUI/NSF); NASA/JPL-Caltech/UCLA

The sharpest views with SPHERE

In the scientific world of exoplanets, it has been the new exoplanet imager on ESO's Very Large Telescope co-built by NOVA, called SPHERE, that has driven many new discoveries. One highlight has been the detailed observations of changes in a planet-forming disk on time-scales of less than a year. The images show a beautiful circumstellar disk with spiral arms and dark patches caused by the inner disk casting long shadows on the outer part of the disk. In another great example, NOVA scientists detected for the first time a planet in polarized light outside a disk surrounding two binary stars. The polarization signal suggests seeing reflected light coming off a disk or dusty envelope around the planet – a new and exciting view of a planet in formation.

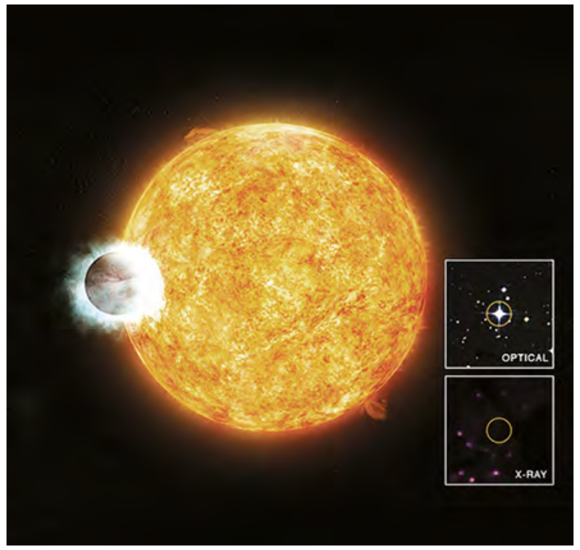


Transition disk of HD 135344B

ALMA Shadows cast on the transition disk of HD 135344B as seen by ESO's SPHERE instrument on the Very Large Telescope. SPHERE has been co-developed by NOVA's instrumentalists and astronomers. Credit: Stolker et al. 2016

Novel probes of gas giant planets

NOVA astronomers detected for the first time the absorption from H-, atomic hydrogen with an extra electron, in an exoplanet atmosphere, showing that ultra-hot giant exoplanets atmospheres have different properties and opacity sources than their cooler counterparts. Their chemical and dynamical properties are found to be governed by H – and molecules that have fallen apart.



WASP18b

The large exoplanet WASP-18b is found 410 light years from Earth. It rotates around its star in a very close orbit, always showing the same side to the star. NOVA has expanded its work on exoplanets considerably in the 2016-2018 period. Credit: X-ray: NASA/CXC/SAO/I.Pillitteri et al; Optical: DSS; Illustration: NASA/CXC/M.Weiss

Another highlight has been the measurement of the reflex motion of a young star, β Pictoris, due to the gravitational pull of its planet, using the transformational *Gaia* satellite from the European Space Agency. This allowed for the first time a direct mass measurement of the infant planet – an important step towards testing planet formation and evolution theories, in particular how young planets evolve in temperature and size over time.

New insights into massive stars

For the first time, NOVA astronomers have conducted a detailed VLT-X-Shooter survey of a region of very high star formation in our satellite galaxy – the Large Magellanic Cloud. They were able to map precisely when and at what rate the stars in the 30 Doradus region are being formed. Surprisingly, stars significantly more massive than our Sun form much more often than expected. Another highlight involves new measurements of the binarity of massive stars. While mature stars are mostly found in pairs, it turns out that very young stars are mostly single, or only very weakly bound to another star. It implies that many of the stars will acquire a companion later in their life – an important aspect in understanding the evolution of massive stars.

Tarantula Nebula

This image shows the central region of the Tarantula Nebula in the Large Magellanic Cloud. The young and dense star cluster R136 can be seen at the lower right of the image. This cluster contains hundreds of young blue stars, among them the most massive star detected in the Universe so far. A team of astrophysicists, including NOVA scientists, discovered that the binarity of the most massive stars was surprisingly low. Credit: NASA, ESA, P. Crowther (University of Sheffield)

Powerful new impulse to NOVA exoplanet research

The exoplanet field in the Netherlands has been strengthened very much with the arrival of two new staff members at the University of Amsterdam, Jean-Michel Désert and Jayne Birkby. Both have experienced a flying start with large grants from the European Research Council. A dual mini – interview.

What is your research about?

Désert "The main goal of my research is to answer questions about the formation and evolution of exoplanets, to understand the nature and diversity of exoplanet atmospheres, and to explain the origin and characteristics of our Solar System and the Earth. I conduct comparative exoplanetology observational programs. Ultimately, my work provides techniques that will be used to characterize potentially habitable exoplanets with future capabilities such as JWST and Extremely Large Telescopes."

Birkby "My ultimate research goals are similar, but I focus on a special technique with very high resolution spectroscopy to find out what is in the atmospheres of these planets and how they gathered these materials from their natal protoplanetary disk environment. The technique relies on the orbital motion of the planet, and its unique spectral fingerprint to detect the photons coming from the planet atmosphere."

What attracted you to continue your career in the Netherlands, and what do you think of NOVA?

Birkby "I did my first postdoc at Leiden University where I learnt and developed the techniques I use today. The Netherlands is the PI in building METIS for the Extremely Large Telescope. This very high resolution integral field spectrograph is going to help us find biomarkers on the very nearest exoplanets and was a key attractor for me to return to the Netherlands. While the Netherlands is a relatively small community in astronomy by comparison to other countries, with NOVA it is well organized which helps makes us very competitive on the international stage."

Désert "Yes, I agree. NOVA definitely played a major factor for me to come to the Netherlands, and more generally the way Dutch astronomy is conducted. I found that approach unique, with a lot of potential. In particular, the NOVA contribution to JWST/MIRI was an important factor for me to make my decision to come here. I was also impressed by NWO and the Veni, Vidi, Vici schemes, as well as the TOP and Groot grants, and I found them very appealing. I was also aware of initiatives like PEPSci (Planet and Exoplanet Science Network), and NWA (Nationale WetenschapsAgenda), which are particularly interesting for my field."

What do you hope to achieve in your research over the next year, and what role could NOVA play?

Birkby "Over the next years, with my NOVA PhD student, we aim to develop a technique that can monitor exoplanet atmospheres over time and potentially map their features. This is a new technique that will open new doors on exoplanet properties, and is enabled by NOVA's support."

Désert "I have half of a PhD candidate supported by NOVA working with me (the other 0.5 is with SRON), and so NOVA helps me to develop research components that are not directly supported by my grants. Over the coming years, we will be developing a framework that connects exoplanet chemistry to disk chemistry by looking at specific tracers of planet formation."

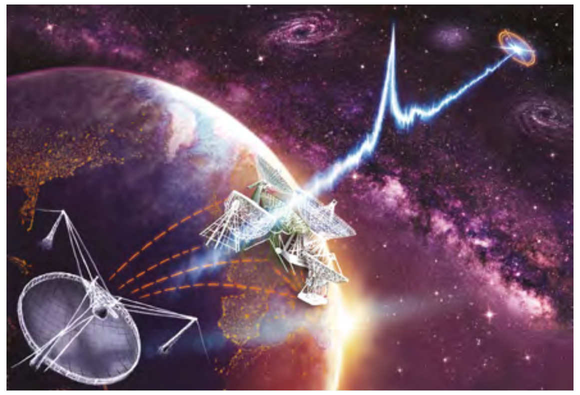
Network 3: Astrophysics in extreme conditions

Research in NOVA Network 3 focuses on the physics of compact objects, their evolution and the interaction with their environment. These compact objects are natural sites to study the physics of strong gravity, dense matter, extremely high magnetic fields, accretion processes, and particle acceleration.

Stellar compact objects, such as white dwarfs, neutron stars, and stellar-mass black holes are the end products of stellar evolution and are often found in binaries. Super-massive black holes in the centres of galaxies have a very different formation history, but share similar physics and allow the study of the physics of black holes and the process of accretion on different scales. Compact objects manifest themselves as sources of high-energy radiation, non-thermal emission, highly energetic particles, gravitational waves, and high time variability, which we can measure and model with rapidly increasing precision. NW3 is at the heart of these developments.

Extreme astrophysical transients

The last decade has seen a revolution in the use of transients in multi-messenger astronomy to study extreme conditions in the universe. NOVA has been at the forefront of this effort, in particular in the new field of Fast Radio Bursts (FRBs)) which are extragalactic millisecond duration bursts of unknown origin. NOVA scientists have been instrumental in discovering new FRBs, including the first repeating FRB and of the fact that its emission is nearly 100% linearly polarized, requiring a strong and dynamic magneto-ionic environment. We have developed new techniques for transient discovery, such as real-time mining of Gaia data, and are also working on the theory that underpins extreme transients: exploring how the disruption of stars in orbit around a supermassive black hole can give rise to tidal disruption events; and whether the tearing instability in a neutron star magnetosphere is a viable mechanism for magnetar giant flares.

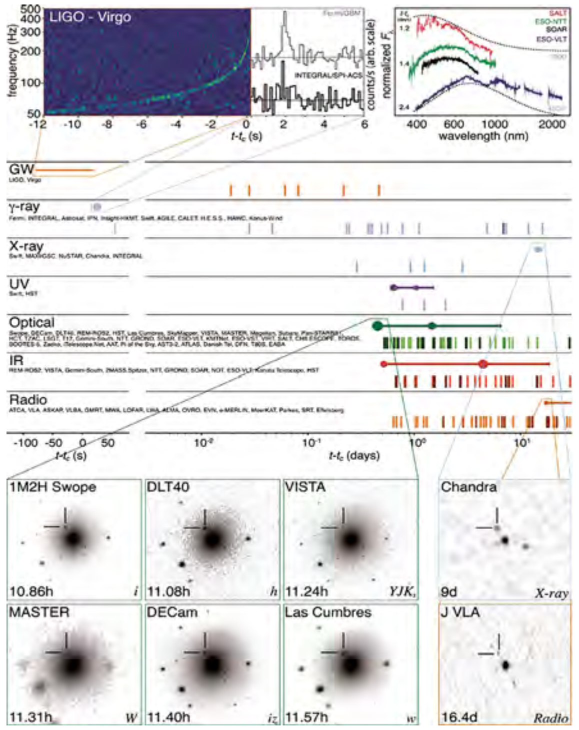


Astronomers find an extra-galactic source of mysterious fast radio bursts

Artist's impression of the globally distributed dishes of the European VLBI Network. They are linked with each other and the 305-m William E. Gordon Telescope at the Arecibo Observatory in Puerto Rico. Together they have localized FRB121102's exact position within its host galaxy.

GW counterparts and source modelling

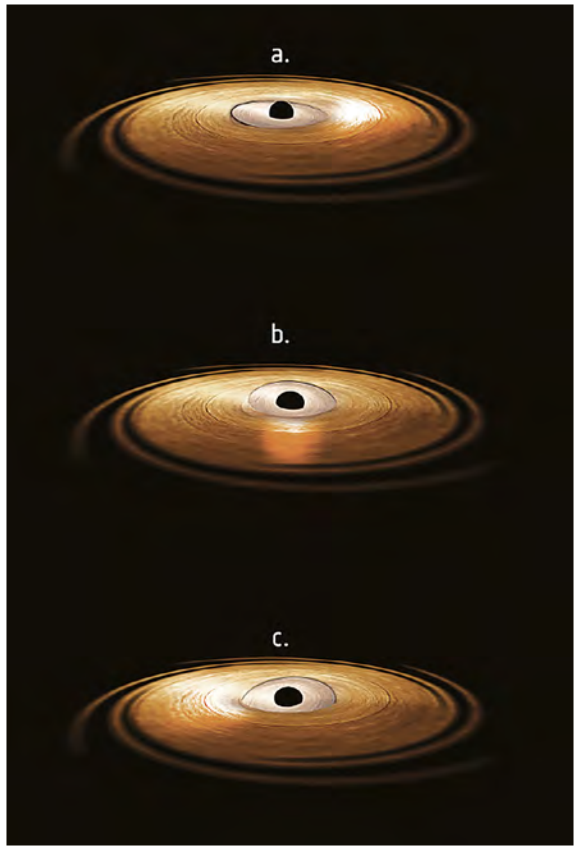
The direct detection of gravitational waves due to the merging of compact objects has been one of the greatest achievements of the 2016-18 period. For the first black hole merger, GW150914, NOVA scientists played a key role in the astrophysical interpretation and searches for an electromagnetic counterpart. This was followed by the discovery of the first double neutron star merger and its associated kilonova, with leading roles in the work on the counterpart [Figure 1] and the progenitor. A protocol developed by NOVA scientists is now being used for the open LIGO-VIRGO Consortium alerts that let observers know whether events are thought to be NS-BH systems or NS-NS mergers.



Timeline of multimessenger observations of the first binary neutron star merger seen in gravitational waves NOVA scientist Dr Samaya Nissanke was responsible for coordinating the multiwaveband electromagnetic follow-up campaign, and many other NOVA scientists contributed to this effort.

Fundamental physics: strong gravity and dense matter

NW3 scientists use black holes and neutron stars to probe the strongest gravitational fields in the Universe. Timing of the radio pulsar PSR J0337+171, which is in a hierarchical triple system with two white dwarfs, enabled the strongest test of the universality of free fall to date. Meanwhile X-ray observations the black hole binary H1743-322 led to the first measurement of the Lense-Thirring effect in the strong gravitational field close to a black hole. NOVA scientists are also heavily involved in efforts to constrain the nature of ultradense matter in the cores of neutron stars, with detailed studies on basic principles of dense matter, reviews defining the dense matter science case for anticipated large-area X-ray timing telescopes, and a leading role in the first constraints on dense matter to come from gravitational wave observations of neutron star mergers.



Black Hole

Artist's impression of a black-hole system exhibiting the Lense-Thirring effect, using XMM-Newton of the black hole binary H1743-322. NOVA astrophysicists have a tradition on the interpretation of timing d ta from X-ray and radio telescopes. Credit: ESA/ATG media

Accretion and outflows around compact objects

Accreting compact objects across the mass and compactness scales, allow us to probe our physical understanding of the most extreme conditions in the universe, via the behaviour of astrophysical plasmas moving under the influence of the strong gravitational and (possibly strong) magnetic fields close to the compact objects. NOVA scientists are trying to understand how jets from supermassive black holes generate their multi-wavelength emission, and have developed state of the art general relativistic magnetohydrodynamical models to explore the parameter space. Progress has also been made on the jet-launching problem: simulations on the Blue Waters supercomputer, using the world's fastest GPU-accelerated general relativistic MHD code, have shown that the jet is aligned with the disk's rotation axis rather than the black hole's spin axis. This allows the jet to precess, something that fits with new results from NICER on the International Space Station. NOVA teams have also been able to show that the ultra-strong magnetic fields around some neutron stars do not impede jet formation. Meanwhile high time resolution UV and X-ray spectral-timing studies of outflowing winds from the accretion disks around supermassive black holes have also shed light on their complex phenomenology.

Neutron star heating and cooling

The fate of material accreted onto the neutron star surface, in particular the unstable thermonuclear burning that leads to X-ray bursts, is another active area: NOVA scientists have shown that the burning layer where the rp process is active is underabundant in hydrogen by a factor of at least five with respect to cosmic abundances; that there is a relation between ignition location and the onset of marginally stable burning; and that the most promising mechanism to explain burst oscillations fails when applied to carbon-triggered superbursts. Intensive effort also continues on the cooling of accretion heated neutron stars, homing in on the mysterious shallow crustal heating mechanism that is required to explain many of their properties.

Endpoints of stellar evolution

Supernovae, and the formation of the observed population of compact objects remains an active area of research with many open questions. Technically challenging low frequency radio observations of the supernova remnant Cassiopeia A with the NOVA-supported LOFAR telescope have shown that the ejecta need to be very clumped or the temperature in the cold gas needs to be as low as 10 K. NOVA scientists have identified serious flaws in previous studies of the velocity distribution of young neutron stars (a critical parameter in determining whether they remain in a globular cluster or in a binary), and shown that at least some black holes get relatively large natal kicks. Understanding the evolution of multiple star systems is vital to explain many open astrophysical problems, from the formation routes of the binary black holes detected in gravitational waves, to the cause of the giant outburst of Eta Carinae in the mid-nineteenth century, to discrepancies in the distribution of supernova remnants.

Interview with Dr Abigail Stevens, PhD student at University of Amsterdam 2013-18

As part of your PhD you published one of the first scientific results from NICER. Can you tell me about what you discovered?

"We used NICER data from the new black hole transient MAXI J1535-571 taken in the autumn of 2017. We discovered a weak "Type B" low-frequency QPO that was hidden in a disk-dominant state and we applied "spectral-timing" analysis techniques that consider the spectral and temporal information simultaneously. Our results indicate that the QPO signal is being produced in a small compact region very close to the black hole. My thesis was the first PhD thesis to be published with NICER data!"

What was it like to work on data from a telescope on the International Space Station?!

"It's so cool! There are more than 200 science experiments happening right now on the International Space Station, and it's very fun to be a part of that. The NICER team sends a weekly summary of science to the astronauts, and I've written two of these (one on the work from my thesis and one on another black hole). It's really exciting to know that astronauts in the space station know about my research!"

You finished your PhD in 2018 – where are you now?

"I've moved back to the US (my home country) and have a National Science Foundation Astronomy and Astrophysics Postdoctoral Fellowship at Michigan State University and the University of Michigan. I have a post-bachelors research trainee working with me at Michigan State on NICER and NuSTAR data of black holes and neutron stars, and I'm branching out in my own research to study optical data of accreting compact objects."

Interview with Jordy Davelaar, Master student Physics and Astronomy from 2013-2016, PhD student from 2016-2020 both in Nijmegen

Your research webpage is full of beautiful Virtual Reality images – not what you might expect from an astrophysicist!

"Virtual Reality is a great way to inspire and engage with the general public. During my Ph.D. we got the idea that we could use our state-of-the-art black hole simulations to render VR movies, this resulted in a series of movies that allow you to see the direct environment of these objects in the most immersive way possible. The movies have been watched more than one million times on multiple channels and are used during many outreach events. Besides fun, they also are very useful to visualize the data for myself, and they help me understand complex dynamics."

What do you hope to learn about supermassive black holes?

"Black holes are excellent laboratories to test GR and plasma physics. The plasma physics affects the characteristics of the emission we observer, such as near-infrared flares or the extended non-thermal radio emission from jets. Our current models do not capture this physics self-consistently. I would like to gain a deeper understanding of the complex plasma physics and try to combine what happens on the micro-scale to the macro-scale."

You were also selected as one of the KNAW's Faces of Science – tell me about that!

"Being selected by the KNAW was a big honor. The Faces of Science program tries to inspire a new generation of scientists via various activities aimed at elementary and high school children, for example, via blogs, visits to schools, and media appearances we try to show how it is to be a scientist. During these activities Virtual Reality is, of course, also a great way to show them how the universe works and teach them about black holes!"

05 Instrument Development

Developing novel instruments to answer scientific questions is one of the main activities of NOVA. NOVA has two dedicated groups working on

1. Optical/InfraRed (O/IR) instrumentation at NWO-I/ASTRON in Dwingeloo and

2. Submm/ALMA instrumentation at the University of Groningen.

In Leiden, university staff is working on high contrast imaging as one of the focal points for instrumentation R&D, some of it in collaboration with Groningen and SRON. In Nijmegen, radio technology is one of the main activities in the Radboud Radio Lab. In Amsterdam developments for the Cherenkov Telescope Array were done.

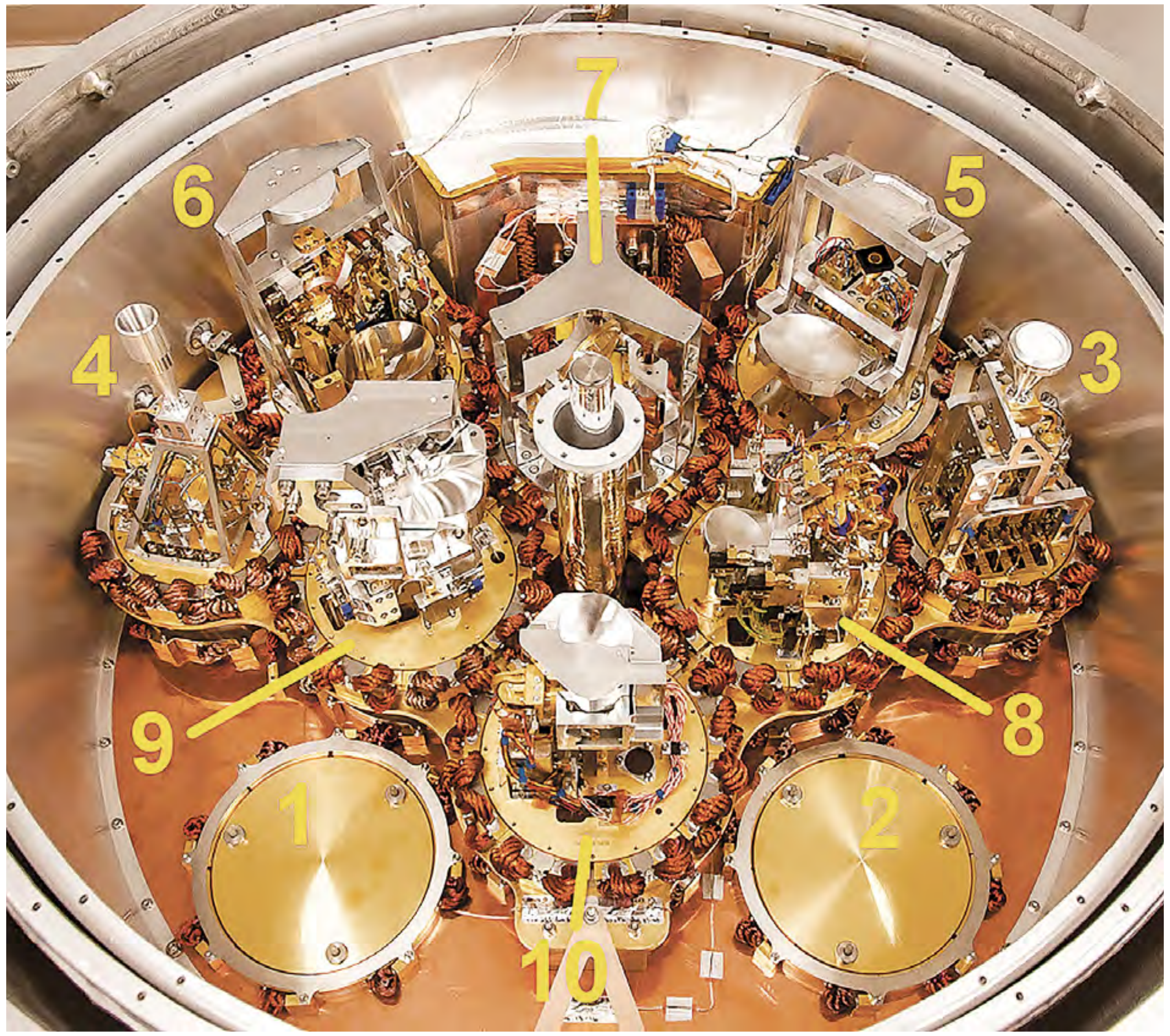
Submillimeter instrumentation

In 2017 the NOVA ALMA team in Groningen completed production of the last Band 5 receiver module for the ALMA telescopes. This achievement follows the completion of the production of the Band 9 receiver modules in 2011. In September 2019 a 4 to 5-year contract for the production of Band 2 receivers for ALMA is expected, providing a sound financial basis to the group and to NOVA.

NOVA is able to lead these production contracts because of the stable nature of the Groningen submm group and continuous investments in new technology in relation to the scientific demands for ALMA, which can be summarized as: development and production of ALMA bands 2, 6, 9 (2SB) and 10 (2SB), developing multipixel arrays and forward integration in the direction of warm electronics and perhaps complete cryostats including receiver systems.

The 66 ALMA antennas on the Chajnantor plateau in the Atacama Desert in northern Chile.

The final antenna for the Atacama Large Millimeter/submillimeter Array (ALMA) project is here seen arriving to the high site at the ALMA Observatory, 5000 metres above sea level. Its arrival completes the complement of 66 ALMA antennas on the Chajnantor Plateau in the Atacama Desert of northern Chile — where they work together as one giant telescope. NOVA has been a strong promotor for this powerful telescope. Credit: A. Marinkovic/X-Cam/ALMA (ESO/NAOJ/NRAO)



ALMA Cryostat

A view into the cryogenic receiver cryostat for the ALMA telescopes with positions of the receiver bands. Bands 9 and 5 were NOVA deliveries. Band 1 will soon be added and Band 2 in a few years. Credit: NOVA/J. Adema

These technology development projects can be ALMA studies but are also often executed in single dish observatories rather than through ALMA itself. Examples of the latter include: The APEX / SEPIA Band 9 2SB and APEX / FLASH Band 10 2SB, EHT Band 6 and maybe Band 2 and LLAMA (Bands 5, 6, 9 and maybe 2). The single dish projects also lead to a faster science return.

The ALMA science demands can be summarized as: Broadening the Intermediate Frequency of the mixers by at least a factor of two: i.e. 32GHz rather than the current 16GHz; Improve the sensitivity by hardware, implying new (difficult) junction fabrication, or through advanced tuning schemes; Increase the baseline distance for the high frequency bands, by advanced phase measurements correcting for the atmospheric effects and multi pixel arrays for larger field-of-view.

The Event Horizon Telescope (EHT) warm electronics boards deserve a special mention. The integration of these boards added experience with warm electronics to the submm group's portfolio, knowledge that will also be used in the production of the Warm Cartridge Assembly of Band 2. The EHT is interested in a group that can supply an entire cryostat including receivers. In principle, this is also one of NOVA's future options.

Optical/InfraRed instrumentation

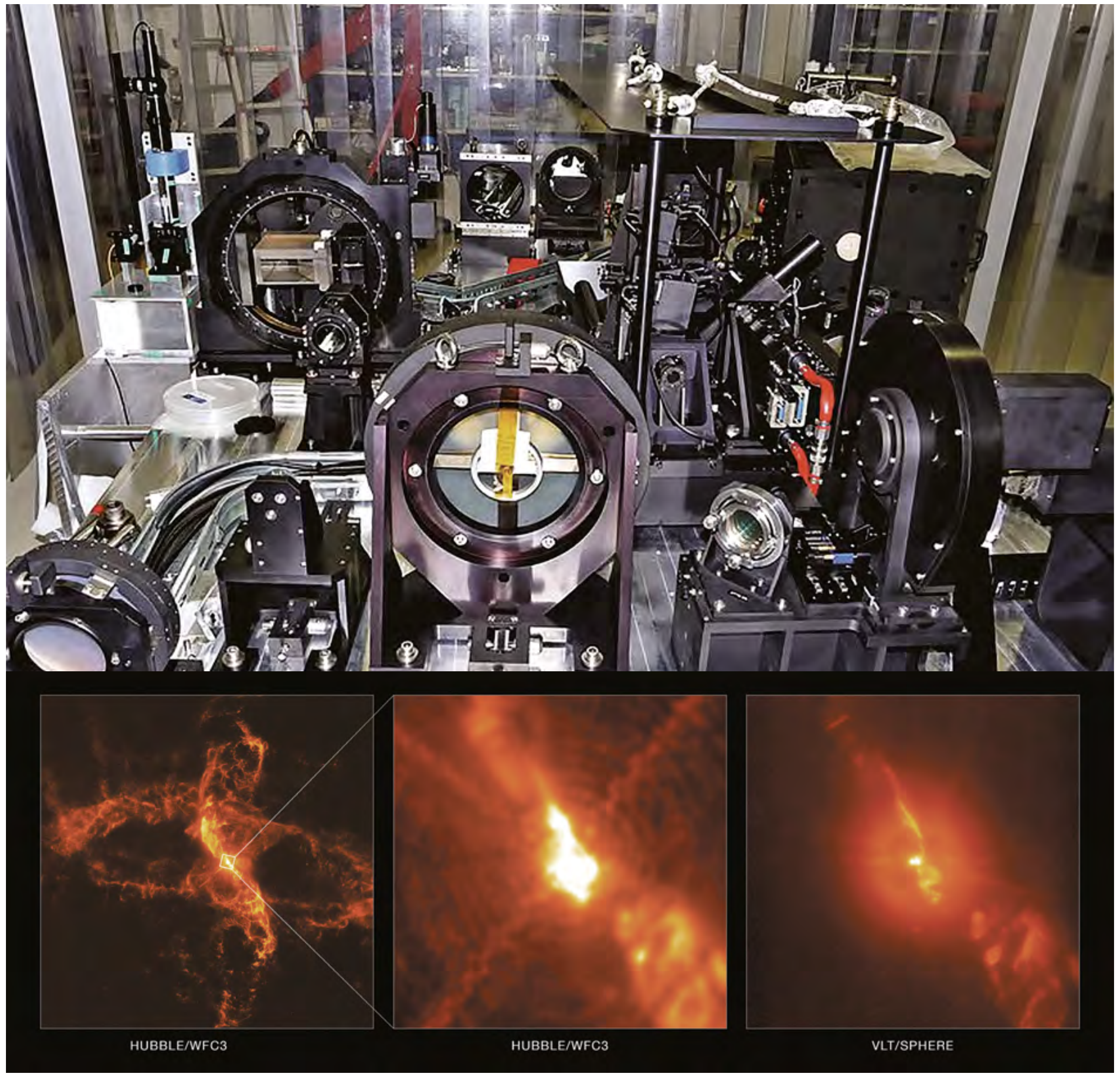
In Dwingeloo, at the premises of NWO-I/ ASTRON, the O/IR group develops subsystems for instruments at the European Southern Observatory and the La Palma Group of Telescopes. NOVA specializes in optical precision components often at cryogenic temperatures. NOVA finances part of the Dutch contribution, jointly with grants of the Dutch funding agency NWO or the European Research Council.

NOVA is involved in instrumentation and science of the major observatories of the world.

NOVA, ESO, ESA, NASA. Instrument consortiums of: Sphere, MATISSE, 4MOST, WEAVE, BlackGEM, Meerlicht, METIS, MICADO, ALMA, MIRI and JWST.

The SPHERE instrument on the VLT delivers crisp images because of the capabilities of extreme adaptive optics. SPHERE has been developed in collaboration with the NOVA O/ IR group. The image of R Aquarii shows the VLT diffraction limited resolution compared to the Hubble Space Telescope.

INSTRUMENT DEVELOPMENT



SPHERE and R Aqu

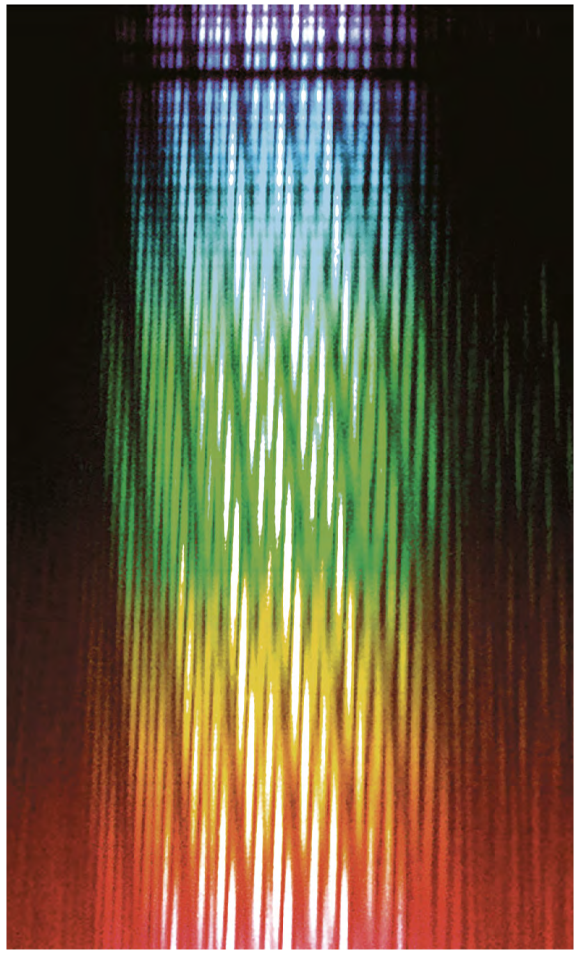
Extreme Adaptive optics on VLT SPHERE generates images with unprecedented resolution, like the image of R Aquarii (lower panel, right). The upper panel shows the SPHERE optics in the laboratory. NOVA contributed to the ZIMPOL instrument in SPHERE. Credit: Upper panel: NOVA, R. Navarro; lower panel: ESO/Schmid et al./NASA/ESA

Even higher resolutions are possible. In 2017 the NOVA O/IR group finished development of the cold optics subsystems for the MATISSE instruments. MATISSE can combine the signals from all 4 VLT telescopes coherently in order to achieve an extremely high resolution, comparable to a virtual telescope of 200-meter diameter.

MATISSE cold bench

The MATISSE cold optical bench in the cleanroom in Dwingeloo, with three people from NOVA's OIR group. NOVA was responsible for the cold optical bench in the MATISSE instrument. Credit: NOVA/R. Navarro

The MATISSE instrument on ESO's Very Large Telescope Interferometer (VLTI) successfully made its first observations at the Paranal Observatory in northern Chile in early 2018. MATISSE is the most powerful interferometric instrument in the world at mid-infrared wavelengths. It will use high-resolution imaging and spectroscopy to probe the regions around young stars where planets are forming as well as the regions around supermassive black holes in the centers of galaxies. NOVA specialists Eddy Elswijk and Felix Bettonvil enjoyed their roles during the installation: "It is great to further expand the capabilities of the most productive observatory in the world."



MATISSE interferogram

This image is a colorized version of the first MATISSE interferometric observations of the star Sirius, combining data from four Auxiliary Telescopes of the VLT. The colors represent the changing wavelengths of the data, with blue showing the shorter wavelengths and red the longer. The observations were made in the infrared, so these are not the colors that would be seen with the human eye. Credit: NOVA/R. Navarro

BlackGEM are three telescopes at the ESO La Silla Observatory project dedicated to monitoring the Southern Sky with large field of view and high cadence.

The main purpose of BlackGEM is follow-up of gravitational wave detections by LIGO and VIRGO, pinpointing the exact location of the optical counterpart of gravitational wave sources. Up to 27 August 2017 this was pure theory, but the detection of the first kilonova showed the huge potential of the combination of gravitational wave and optical detections. Nearly a thousand different institutes were involved in writing the first kilonova detection paper.

THE ASTROPHYSICAL JOURNAL LETTERS, 848:L12 (59pp), 2017 October 20 https://doi.org/10.3847/2041-8213/aa91c9
© 2017. The American Astronomical Society. All rights reserved.
OPEN ACCESS

Multi-messenger Observations of a Binary Neutron Star Merger*

LIGO Scientific Collaboration and Virgo Collaboration, Fermi GBM, INTEGRAL, IceCube Collaboration, AstroSat Cadmium Zinc Telluride Imager Team, IPN Collaboration, The Insight-HXMT Collaboration, ANTARES Collaboration, The Swift Collaboration, AGILE Team, The 1M2H Team, The Dark Energy Camera GW-EM Collaboration and the DES Collaboration, The DLT40 Collaboration, GRAWITA: GRAvitational Wave Inaf TeAm, The Fermi Large Area Telescope Collaboration, ATCA: Australia Telescope Compact Array, ASKAP: Australian SKA Pathfinder, Las Cumbres Observatory Group, OzGrav, DWF (Deeper, Wider, Faster Program), AST3, and CAASTRO Collaborations, The VINROUGE Collaboration, MASTER Collaboration, J-GEM, GROWTH, JAGWAR, Caltech-NRAO, TTU-NRAO, and NuSTAR Collaborations, Pan-STARRS, The MAXI Team, TZAC Consortium, KU Collaboration, Nordic Optical Telescope, ePESSTO, GROND, Texas Tech University, SALT Group, TOROS: Transient Robotic Observatory of the South Collaboration, The BOOTES Collaboration, MWA: Murchison Widefield Array, The CALET Collaboration, IKI-GW Follow-up Collaboration, H.E.S.S. Collaboration, LOFAR Collaboration, LWA: Long Wavelength Array, HAWC Collaboration, The Pierre Auger Collaboration, ALMA Collaboration, Euro VLBI Team, Pi of the Sky Collaboration, The Chandra Team at McGill University, DFN: Desert Fireball Network, ATLAS, High Time Resolution Universe Survey, RIMAS and RATIR, and SKA South Africa/MeerKAT
(See the end matter for the full list of authors.)

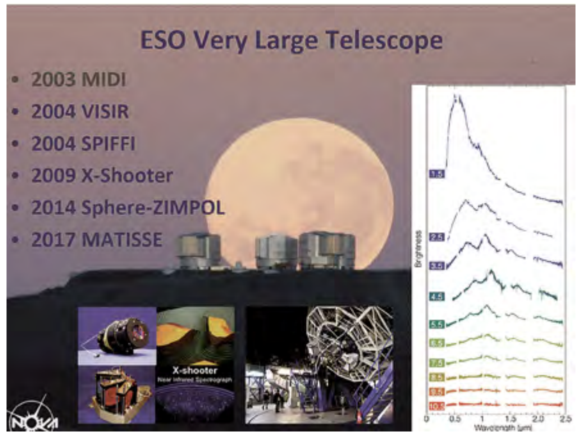
Received 2017 October 3; revised 2017 October 6; accepted 2017 October 6; published 2017 October 16

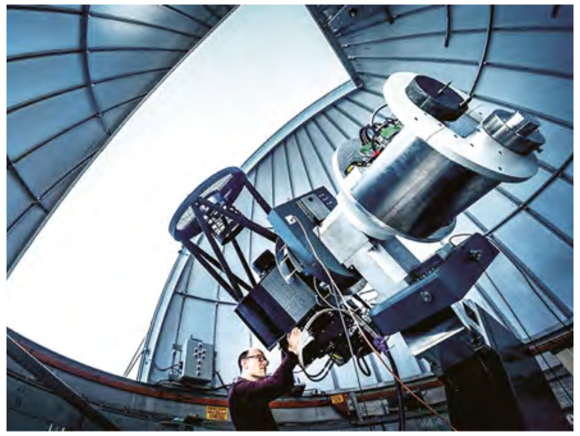
Abstract

On 2017 August 17 a binary neutron star coalescence candidate (later designated GW170817) with merger time 12:41:04 UTC was observed through gravitational waves by the Advanced LIGO and Advanced Virgo detectors. The *Fermi* Gamma-ray Burst Monitor independently detected a gamma-ray burst (GRB 170817A) with a time delay of ~1.7 s with respect to the merger time. From the gravitational-wave signal, the source was initially localized to a sky region of 31 deg^2 at a luminosity distance of 40^{+8}_{-8} Mpc and with component masses consistent with neutron stars. The component masses were later measured to be in the range 0.86 to 2.26 $M_{\odot}$. An extensive observing campaign was launched across the electromagnetic spectrum leading to the discovery of a bright optical transient (SSS17a, now with the IAU identification of AT 2017gfo) in NGC 4993 (at ~40 Mpc) less than 11 hours after the merger by the One-Meter, Two Hemisphere (1M2H) team using the 1 m Swope Telescope. The optical transient was independently

Kilonova

A graphical depiction of the merger of two neutron stars (upper panel) from the detection in gravitational waves with LIGO and the immediate follow-up by telescopes around the world and in space. In the lower panel the title page of the first synthesis of all these data. In the large, world-wide science consortia NOVA astronomers have a very visible role, both in coordination and in science. Credit: LIGO/Virgo Collaboration



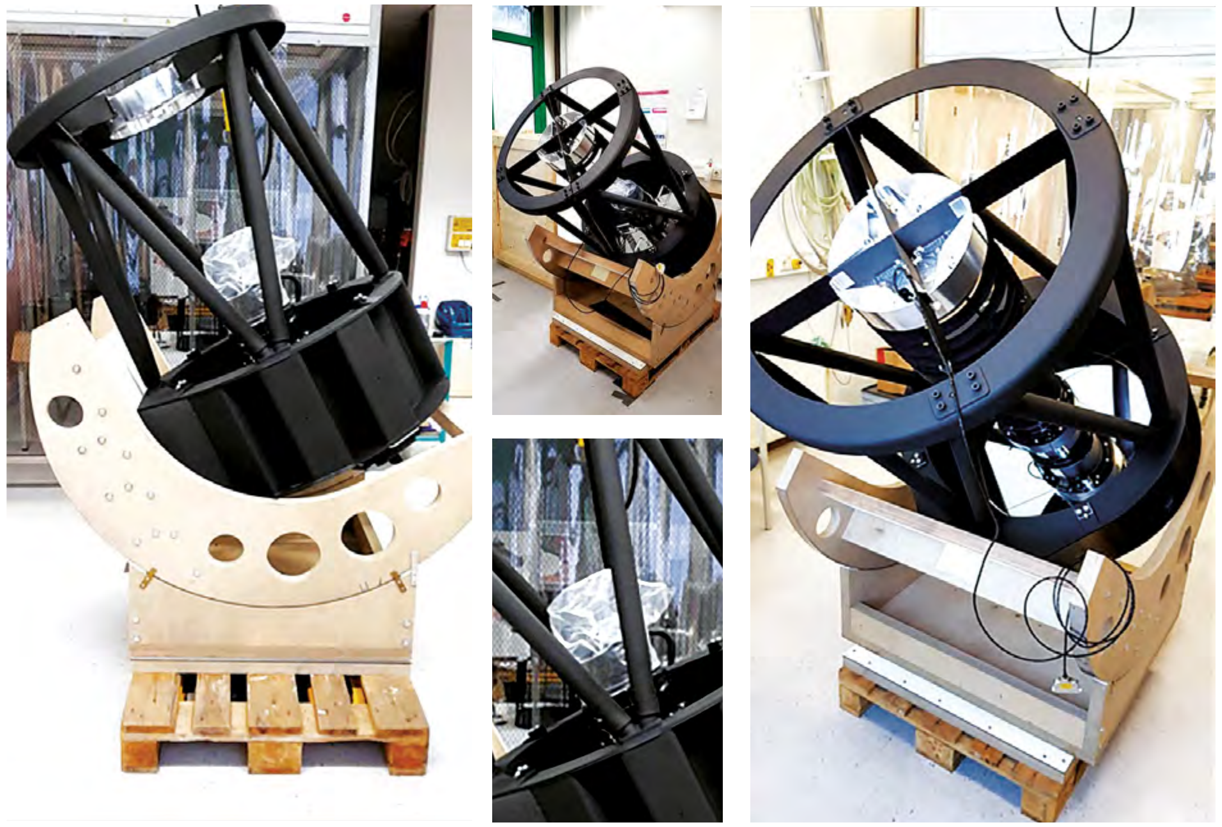


X-shooter follow-up

Follow-up observations of the first kilonova detection were made by virtually any professional telescope in the world, including all instruments that were developed by the NOVA O/IR group. One of the most impressive observations is the one by the X-shooter spectrograph. Credit: NOVA

MeerLICHT and BlackGEM

The Meerlicht telescope is a prototype telescope for the NOVA/RU BlackGEM telescope array. Meerlicht is located in Sutherland, South Africa and is co-pointing with the MeerKAT radio telescope. The main purpose of BlackGEM is follow-up of gravitational wave detections by LIGO and VIRGO, pinpointing the exact location of the optical counterpart of gravitational wave sources. Credit: NOVA

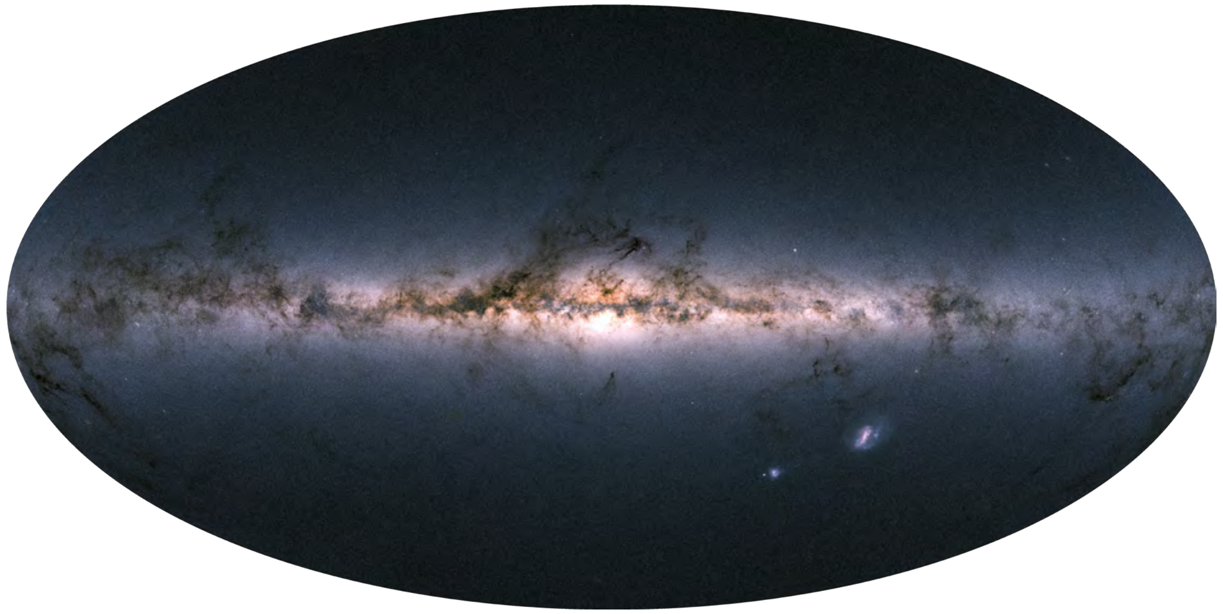


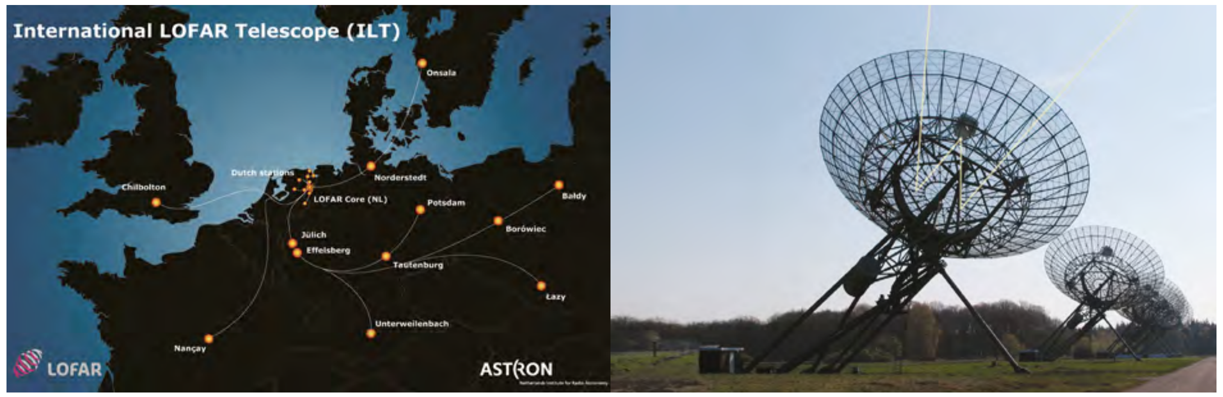
BlackGEM

The first array of 3 BlackGEM telescopes has been integrated in NOVA's submm lab in Groningen before being shipped to La Silla in Chile, where groundwork had started. Control electronics and data processing pipelines have been developed in Nijmegen and mounts and domes are procured abroad. Credit: NOVA

The enormous potential for BlackGEM is underlined by the fact that Virgo detected 6 gravitational wave events in just 4 weeks in 2017 and the expected sensitivity increase would likely result in multiple gravitational wave detections per day in the early 2020s.

WEAVE is a multi-object spectrograph, capable to detect spectra of up to 1000 sources in a single observation. One of the most prominent science cases is to determine radial velocities for millions of stars in order to complement existing Gaia data and complete position and velocity information for all objects, enabling a complete reconstruction of the Milky Way Galaxy. WEAVE will be located at the William Herschel Telescope on La Palma, and because of its location in the Northern hemisphere ideal for follow-up observations of transients detected by LOFAR and Apertif.

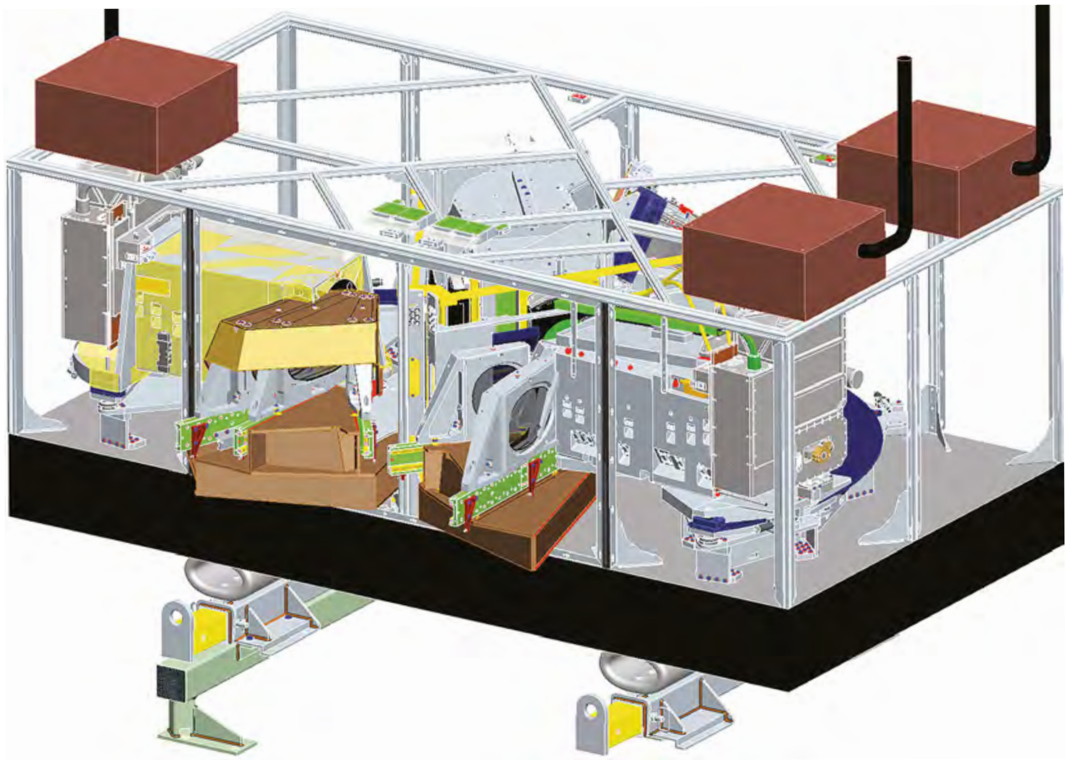




WEAVE, Gaia, LOFAR and Apertif

The northern observatory of La Palma with WEAVE will give access to the same part of the sky as LOFAR and WSRT/APERTIF and can be combined with the space-borne Gaia data. NOVA is one of the major subsystem providers in the WEAVE consortium. Credit: NOVA & Daniëlle Futselaar/ASTRON

WEAVE was in the manufacturing phase in 2016-2018. Development of the WEAVE spectrograph is progressing, although there were a number of issues, mainly involving broken pieces of glass. It proves to be difficult to manufacture, coat and handle really large and heavy lenses, even by the most specialized companies in the world. The WEAVE spectrograph consists of more than 30 large pieces of optics, varying in size from 25cm to 90cm.



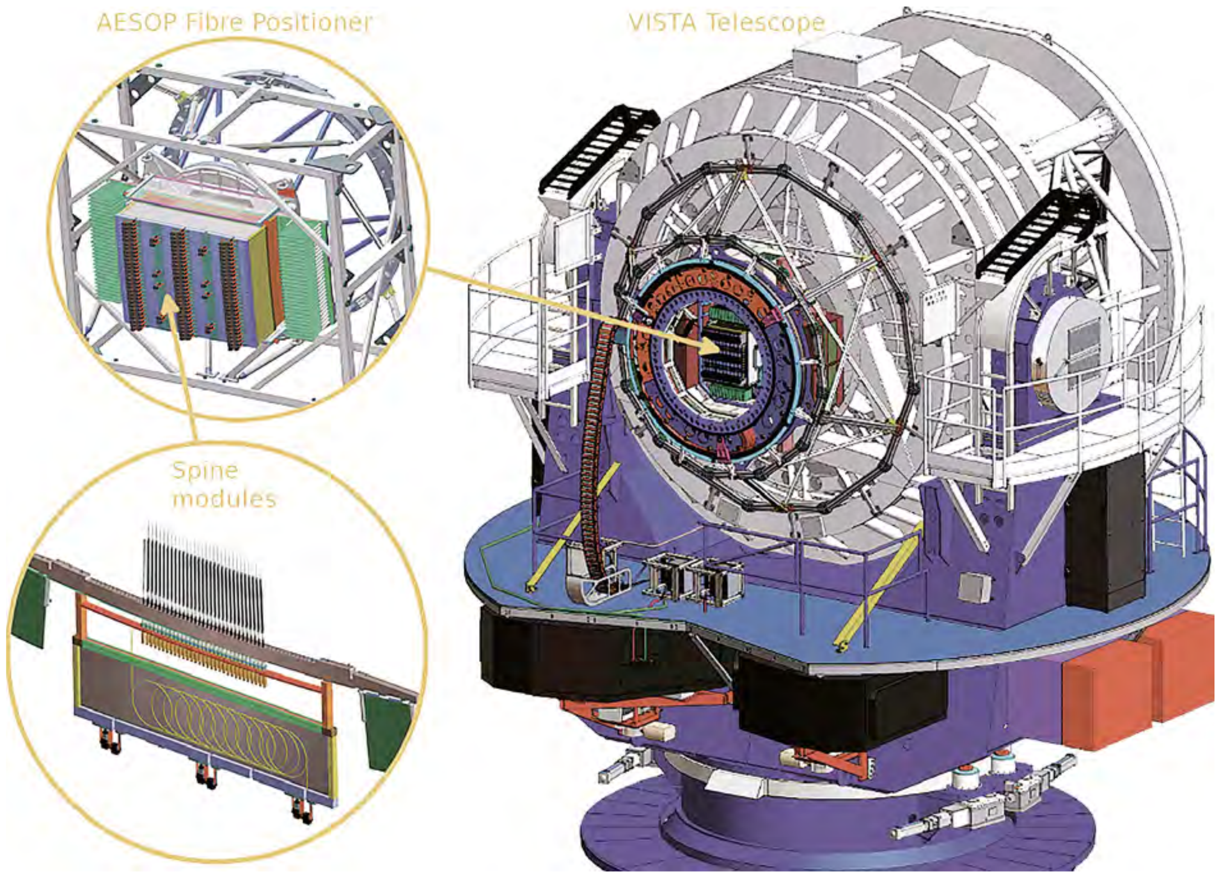
WEAVE

The WEAVE spectrograph consists of more than 30 large pieces of optics, varying in size from 25cm to 90cm. Credit: NOVA/R. Navarro

Related projects include 4MOST and HARPS3. 4MOST is the multi-object spectrograph for the VISTA telescope in Paranal, capable to observe spectra of 2400 objects simultaneously. It will carry out an all sky survey, serving several science cases at once, e.g. Gaia follow-up observations. NOVA develops the calibration system for 4MOST.

WEAVE assembled

The WEAVE spectrograph being assembled in the cleanroom at the NOVA-lab in Dwingeloo. Credit: NOVA/R. Navarro



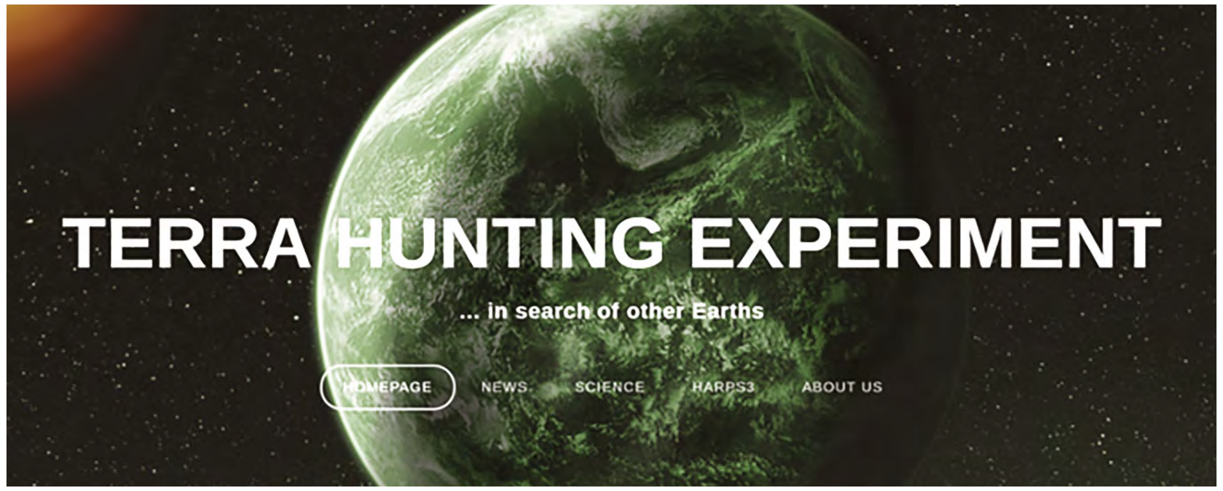
4MOST

4MOST is the multi-object spectrograph for the VISTA telescope in Paranal, capable to observe spectra of 2400 objects simultaneous. It will do an all-sky survey, serving several science cases at once, e.g. Gaia follow-up observations. NOVA develops the calibration system for 4MOST. Credit: NOVA/R. Navarro

The Terra Hunting Experiment is developing a 3rd HARPS instrument for the Isaac Newton Telescope. The goal is to detect earth – like exoplanets.

Terra Hunting Experiment

NOVA contributes the Cassegrain Fibre Adapter Unit, the Calibration Unit, the Control Electronics, and the Control Software for these elements.



The most exciting development of the last years is the go ahead for the European Extremely Large Telescope (E-ELT or ELT in short). The ELT with a primary telescope mirror of 39m will be one of the most powerful infrastructures ever made for astrophysics. It will give unprecedented sharp images, spectra of very faint sources at the edge of the visible universe or a combination of these.

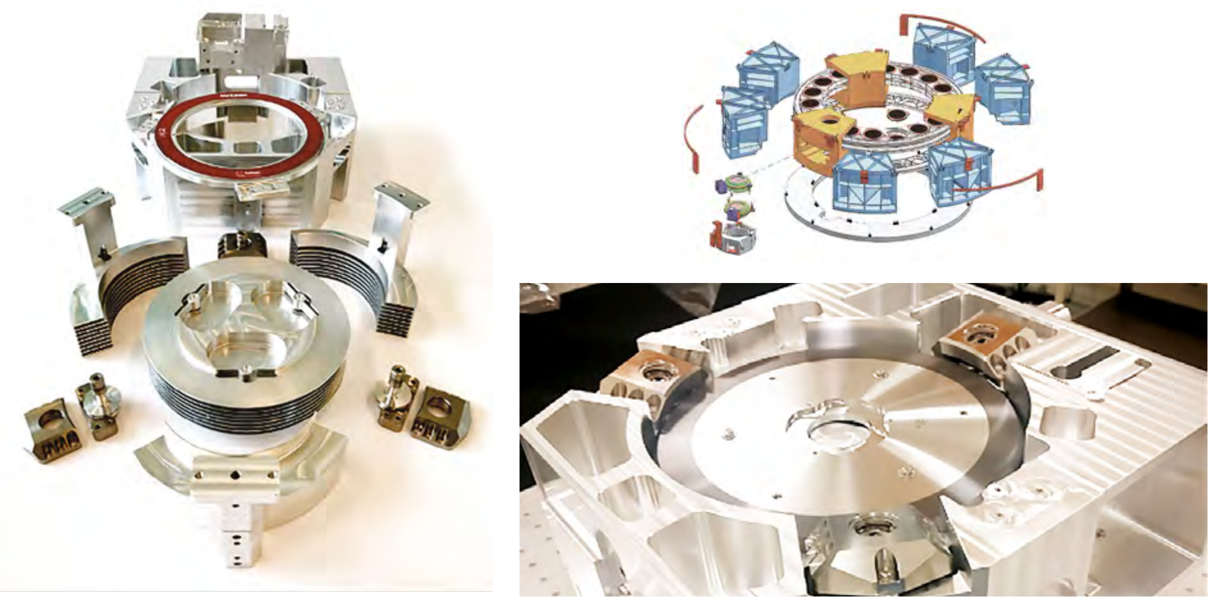
Extremely Large Telescope

Artist impression of the E-ELT opening up to the sky. NOVA is involved with 4 scientific instruments for the ELT. Credit: ESO

NOVA is involved with 4 scientific instruments for the ELT. They are listed here with their main observing mode:

- **MICADO** Near Infrared Diffraction Limited Camera
- **METIS** Mid Infrared Camera & Spectrograph
- **MOSAIC** Multi Object Spectrograph
- **EPICS** Planet Imager and Spectrograph

NOVA has a prominent role in the first light instrument MICADO. It leads three work packages: development of the Science case, the Data Flow System and the Central Wheel Mechanism. A prototype Atmospheric Dispersion Corrector mechanism (ADC) has been developed in order to test the performance of this mechanism under operational (vacuum cryogenic) conditions and in order to assess the impact of this mechanism on the astrometric precision of the instrument.

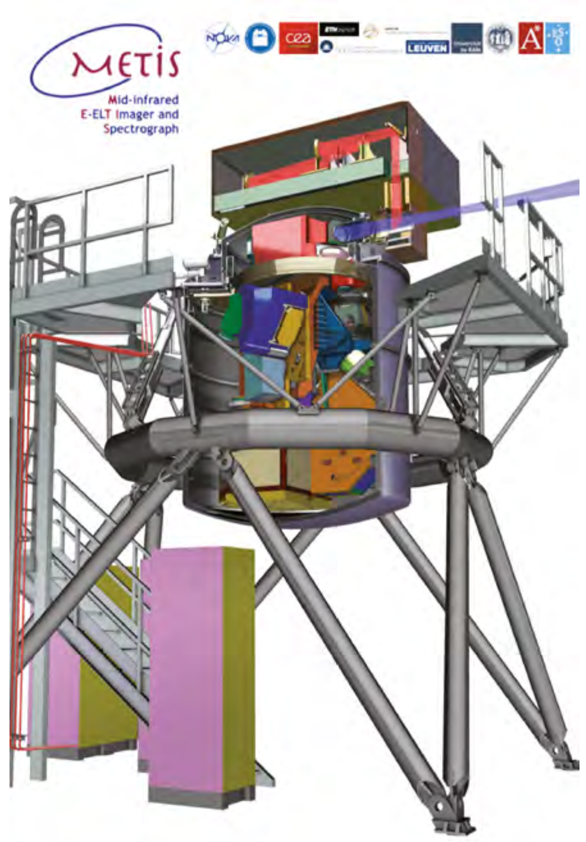


MICADO ADC

CAD drawing of the MICADO Central Wheel Mechanism, housing filter wheels, pupil wheel and Atmospheric Dispersion Correction mechanism (lower panel). The actual prototype has been built in the O/IR Group of NOVA and can be seen in the upper left panel with the housing in the upper right panel. Credit: NOVA/R. Navarro

METIS is the flagship project for NOVA. NOVA is the PI institute, leading the consortium of 11 institutes in 7 different countries. METIS has a long heritage, as first proposals for a thermal infrared instrument on a next generation ground based telescope date back to 2004. METIS is preparing for its preliminary design review in May 2019. There are discussions to extend the consortium to include new institutes, also from non-ESO member states. The NOVA O/IR group is expanding both in size and in competencies.

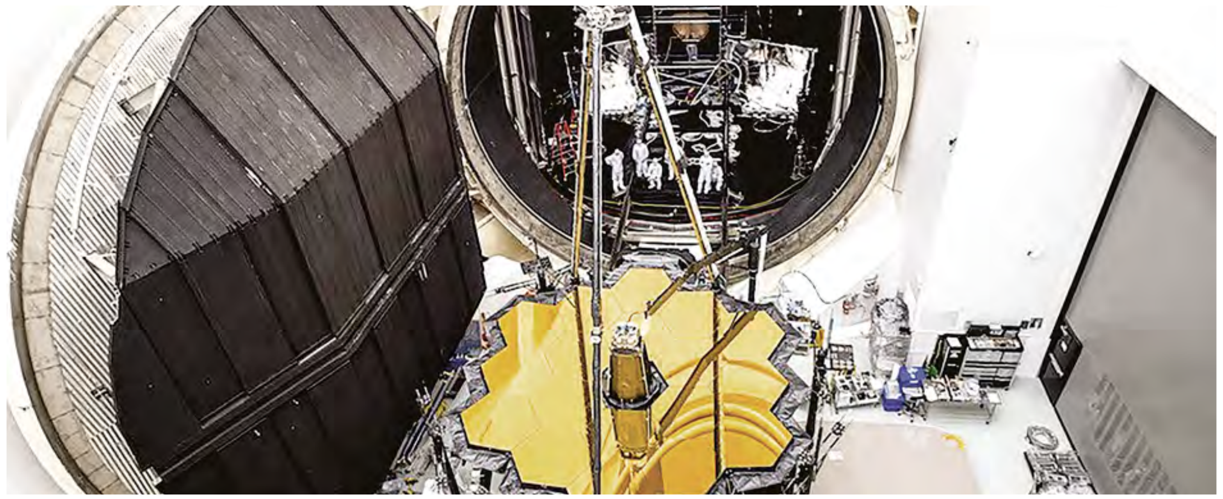
Of the second or third generation ELT instruments, MICADO has completed its Phase A study, or concept study early 2018 and is waiting for the goahead for the development phase, while EPICS is in the stage of technology developments.



METIS Mid-infrared ELT Imager and Spectrograph

The whole METIS system on its warm support structure (WSS). The beam from the ELT is shown in blue on the right-hand side. NOVA is leading the science and development of the whole instrument, as well as providing the Cold Front Optics and the Cold Central Structure. NOVA is responsible for systems engineering and assembly, integration and verification of the whole instrument.

The James Webb Space Telescope is progressing slowly to its intended launch date in 2021. Cryogenic vacuum tests of the telescope and the Integrated Scientific Instruments Module have been completed successfully in historic Chamber A in the NASA Johnson space complex. NOVA was responsible for the cold optics of the MIRI instrument and is now involved in the calibration, software and science for this instrument.

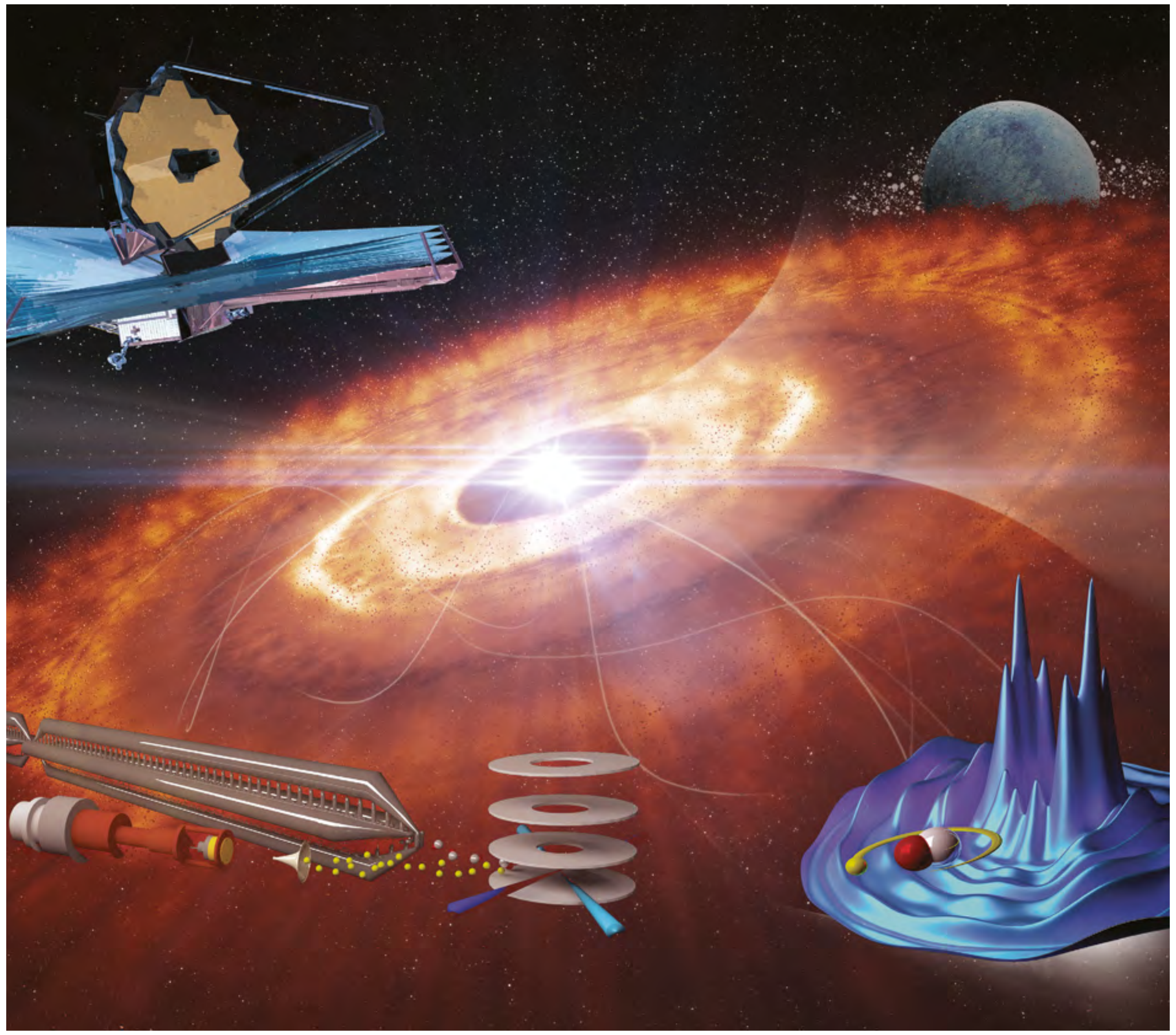


JWST and MIRI

The James Webb Space Telescope is progressing slowly to its intended launch date in 2021. Cryogenic vacuum tests of the telescope and the Integrated Scientific Instruments Module have been completed successfully in historic Chamber A in the NASA Johnson space complex in 2017. NOVA provided the MIRI spectrometer main optics. Credit: NASA/ESA

06 Building Bridges

"All physics is astrophysics" is a well-known saying that perfectly describes how astrophysics needs all of physics to describe the Universe. At the same time the importance of chemistry, geo – and planetary sciences as well as data science and multi messenger approaches have become more important. NOVA astronomers and instrument builders are forging new collaborations to observe and explain more and more aspects of the Universe.

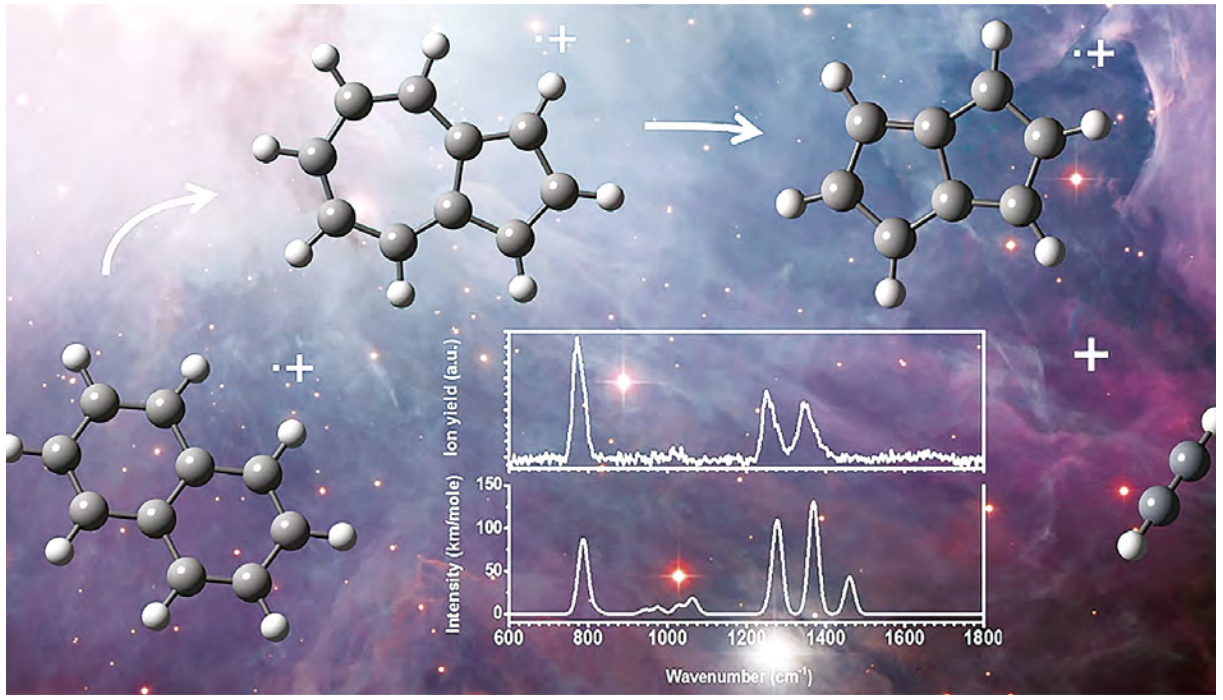


Dutch Astrochemistry Network (DAN)

Overview of of the DAN-II gas-phase theme. The JWST-MIRI will provide unique data to the Dutch community (upper left), especially on the planet-forming zones of disks (center). The analysis of the observations will make use of molecular data obtained from quantum theoretical calculations (lower right). The theory will be tested against laboratory collision experiments making use of Stark decelerator controlled molecular beams and advanced molecular imaging techniques (lower left). The star emits copious UV photons resulting in photodissociation of molecules, whose rates and product branching ratios will be measured and put into models. Credit: PPD ESO/L. Calçada; JWST: NASA

The Dutch Astrochemistry Network

The Dutch Astrochemistry Network (DAN) is a highly interdisciplinary network combining the astronomical and chemical expertise in the Netherlands with the goal of understanding the origin and evolution of molecules in space and their role in the Universe. DAN is funded by the Dutch Research Council, NWO, as an integrated and coherent program of astrochemical and astrophysical experiments, quantum chemical calculations, and laboratory spectroscopy of astronomically relevant species in combination with an active program on modeling and observations of astronomical sources. DAN was initiated in 2010 and renewed in 2017. DAN II focuses on three major astrochemical themes where Dutch astronomy and chemistry have particular strong expertise and experience as well as access to unique observational or experimental facilities. The three themes are 1) The Gaseous Molecular Universe where formation and destruction as well as the excitation of simple molecules are studied; 2) The Icy Universe where the role of ices is studied in the origin of molecular complexity in the Universe; 3) The Aromatic Universe, which studies the contribution of aromatic species to the molecular inventory and their evolution in space. Each theme consists of four, deeply interwoven projects addressing key aspects of their field. The three themes are complementary with projects addressing common science questions from different perspectives including the photostability of small and large hydrocarbons and their reaction products, the interaction of water with grains and with PAHs, and photodissociation in the gas phase and in ice environments. DAN works closely with NOVA and with the NASA Ames team in the NASA Astrobiology Institute on The Evolution of Prebiotic Chemical Complexity and the Organic Inventory of Protoplanetary Disks and Primordial Planets. In addition, the DAN Aromatic Universe theme is closely aligned with the EUROPAH Marie Curie Initial Training Network. Collaborations and joint projects are fostered through joint meetings and through exchange of students and postdocs.



Breakdown of small Polycyclic Aromatic Hydrocarbon (PAH) molecules

NOVA researchers elucidated the detailed chemical route in the conversion of hexagons into pentagons – a necessary step in converting polycyclic aromatic hydrocarbons into fullerenes; e.g., the soccerbal, C_{60}. The experiments demonstrated that this is a facile process in energetic environments and may play a major role in the processing of interstellar PAHs. Credit: J. Bouwman

NOVA and Geosciences

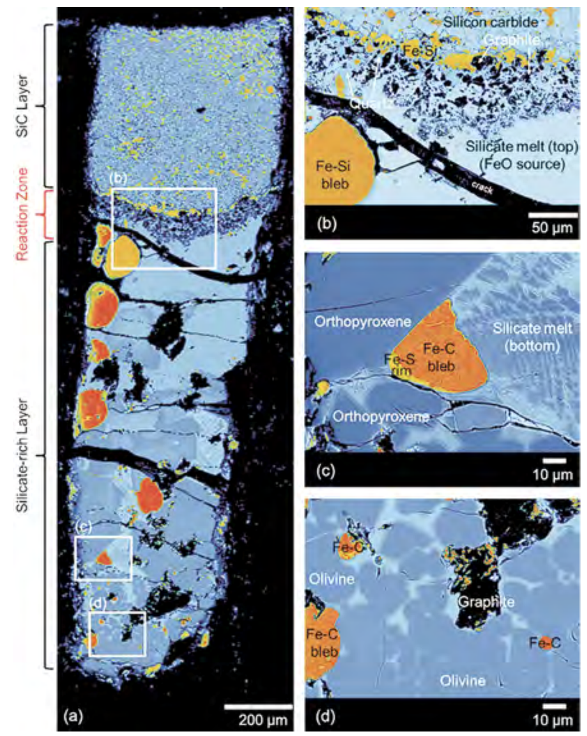
Over the last 25 years, astronomy has made great progress in finding and characterizing exoplanets. About 4000 exoplanets have been discovered, and many of them are solid like the Earth. To make progress in our understanding of the formation, structure and evolution of these rocky exoplanets, knowledge from astronomy needs to be combined with knowledge from planetary science and the geosciences. Of particular interest are the structure and composition of exoplanet interiors and the composition and dynamics of their atmospheres. Increased knowledge on rocky exoplanets can teach us about our own solar system formation; a large variety of exoplanets can be studied at different stages of evolution while we can only directly study our own solar system at a single evolutionary stage.

The interpretation and understanding of exoplanets require the development of new, highly cross-disciplinary and interdisciplinary research approaches. Astronomical studies need to be combined with knowledge from the fields of earth science, biology, and chemistry to provide a coherent framework to understand planetary system formation and evolution – to ultimately answer the question 'Are we alone?'.

The Netherlands have a long tradition of world-leading science in these fields. In 2012, the NWO-funded Planetary and Exoplanetary Science (PEPSci) network was established to foster the collaboration between geoscience and NOVA astronomy to establish an integrated, world-leading (exo)planetary research community in the Netherlands. PEPSci funded 8 cross-disciplinary positions for four years in two themes: 1: Identification, Characterization and Detection of Biomarkers, and 2: Formation, Evolution and Structure of Rocky (Exo)Planets. NOVA was fully involved in five of these projects.

One of the major gains with PEPSci has been the ability of senior scientists to "learn the language" of colleagues in very different research fields. This major gain is not directly visible in the substantial, direct research output of the projects, but the major advantages stem from understanding each other's backgrounds and fields and from knowing where to find the key players. Members of the PEPSci network have played a leading role in the establishment of the Netherlands Origins Center (www.origins-center.nl), a Dutch initiative that aims to bring together a very broad range of scientific disciplines to study the origins and evolution of life, planets, and the universe. This initiative was one of the very few natural science consortia that received substantial (2.5 million euros) seed funding from the Dutch government as part of its new National Science Agenda funding scheme. NOVA staff are Origins Center council members. This heavy involvement was due in no small part to the network activities initiated through PEPSci.

NOVA is looking forward to working with colleagues in the geosciences in the forthcoming PEPSci-2 funding and the Origins Center.



Simulated Exoplanet Interiors

False-color backscattered electron images of laboratory samples of simulated exoplanet interiors. A team of researchers at the VU under leadership of Wim van Westrenen and astronomers at the UvA under leadership of Carsten Dominik studied fundamental reactions in the interior of rocky exoplanets at high pressure and temperature. The figure shows the ongoing reaction between the silicon carbide layer and the silicate-rich layer representing a carbon-enriched rocky exoplanet. Most of the work as well as this figure was carried out by the joint PhD student, Kaustubh Hakim, who defended his thesis in December 2018. Credit: VU/UvA/K. Hakim

Multi-messenger astrophysics and the relation with physics

The interaction between astronomy and physics has always existed but in the past decade has become stronger. The departments in Amsterdam and Nijmegen have formal collaborations in the GRAPPA (since 2011) and IMAPP (since 2005) institutes. While astronomy at the universities is working together in NOVA, the physics community is mainly organised through the National Institute for Subatomic Physics (Nikhef). The astrophysics/physics collaboration has been established particularly strongly around the topics of (the origin of) cosmic rays and gravitational waves and increasingly in dark matter at GRAPPA, cosmology, black hole research and neutrino (astro)physics. Since many years the Committee for Astroparticle physics in the Netherlands (CAN) is fostering and coordinating research in this field.

Gravitational Waves, Black Holes and Cosmology

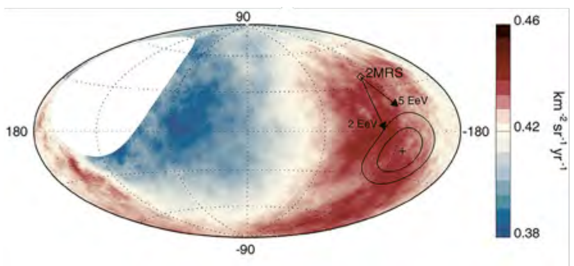
The collaboration in the area of Gravitational Waves (GW) in the Netherlands concentrates around the membership of the Virgo collaboration of both the Radboud Astrophysics department and Nikhef/GRAPPA and preparations for the LISA space mission that in 2016 was selected for launch in 2034. In the reporting period this collaboration has expanded significantly, including astronomers from Amsterdam and Leiden and has delivered spectacularly, with the discovery of the first GW source, the binary black hole merger GW150914, ten more binary black hole mergers plus the neutron star merger GW170817 (see Box 1). With the expected strong increase of detections, the field is expected to develop further, and both in the physics as well as the astronomy community new initiatives are taken and hires are made. Within NOVA the BlackGEM array is specifically designed to do follow-up of GW triggers in order to fully exploit the combination of GW signals with electromagnetic measurements.

On October 3, 2017 (the day the Nobel prize for the discovery of GW was announced) a workshop "Black Holes in the Netherlands" was organised with contributions from astronomy and physics. This has led to more interaction and joint proposals under the umbrella of the national science agenda for joint projects. Less established but clearly in development are collaborations between astronomy and physics in the areas of cosmology and black holes. Strong theoretical Cosmology groups exist in Leiden, Amsterdam, Utrecht and Groningen. Through local connections there is considerable interaction with NOVA astronomers.

The double neutron star merger GW170817, was a true multi-messenger event, where a GW signal was followed within 2 seconds by a gamma-ray detection, within 11 hours by optical and infrared measurements and X-ray and radio following after several days. It was a huge effort, with contributions from many electromagnetic facilities including LOFAR, the Auger Cosmic Ray experiment, neutrino experiments and TeV gamma-ray telescopes. The discovery immediately probed the physics of the merger, the formation of the gamma-ray emission seen already for decades in gamma-ray bursts and the first unambiguous measurement of the electromagnetic emission from the radioactive decay of heavy element produced in the merger, called a kilonova.

Cosmic Rays, TeV gamma-rays and Neutrino's

Since more than a decade physicists and astronomers in the Netherlands work closely together to investigate the origin of high-energy cosmic rays. In particular in the Radboud IMAPP institute the astronomy and high-energy physics departments are collaborating strongly in this area, also together with scientists from Groningen and within Nikhef. The most important development is the establishment of the radio detection technique, where the LOFAR telescope has played a crucial role in characterising the radio emission emitted by cosmic rays that is now used worldwide. The reporting period saw other important results, in particular the establishment of anisotropy in the arrival direction of cosmic rays and multi-messenger follow-ups of the gravitational wave event GW170817 There is currently a large effort led by Nijmegen to install a 3000 km^2 radio detection array at the Pierre Auger site in Argentina. This will strongly improve the performance of the Auger observatory and will help to clarify the origin of cosmic rays at the highest energies. There is a significant involvement from Amsterdam in TeV gamma-ray observations in H.E.S.S. and, in particular, in the preparations for the future Cherenkov Telescope Array (CTA). Through Nikhef the Netherlands have significant involvement in neutrino research through the KM3NeT project.



Cosmic Ray Flux

Map showing the fluxes of particles in galactic coordinates. Sky map in galactic coordinates showing the cosmic-ray flux for E ≥ 8 EeV smoothed with a 45° top-hat function. The galactic center is at the origin. The cross indicates the measured dipole direction; the contours denote the 68% and 95% confidence level regions. The dipole in the 2MASS Redshift Survey (2MRS) galaxy distribution is indicated. Arrows show the deflections expected for a particular model of the galactic magnetic field on particles with E/Z = 5 or 2 EeV. NOVA astronomers work together with the physics community on astroparticle physics. Credit: NOVA

The data science bridge

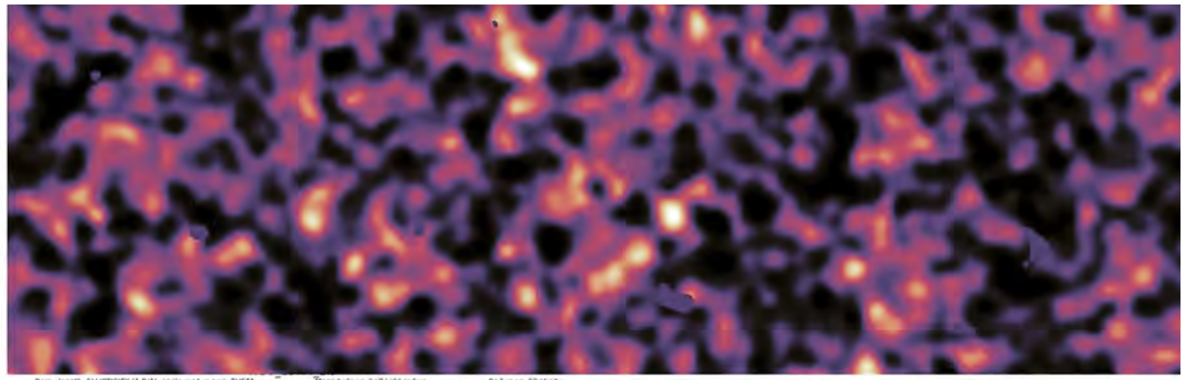
Through its instrumentation program, NOVA invests heavily in a suite of survey instruments that produce very large streams of state-of-the-art raw observational data. They are essential for cutting edge science. NOVA data science teams develop information systems and algorithms which improve their data calibration and scientific analysis of these "oceans" of information. Close collaboration and mutual understanding between design teams of complex instruments and complex software is critical. This is rapidly becoming the only way to achieve the required accuracies leading naturally to the design concept of a single system that consists of "steel, glass and bits". In 2016-2018 NOVA has continued therefore its strategy to have data software system projects as an integral part of its instrumentation programme. Five of these projects are detailed below.

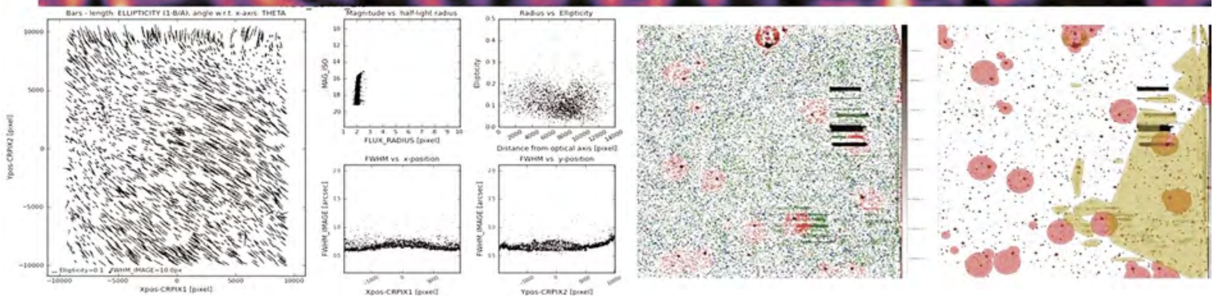
OmegaCEN is NOVA's largest expertise center for astronomical information technology and data science since the early 2000s. In this period, it pooled its human expertise, its WISE software technology and its hardware park at the University of Groningen computing centre in seven projects. OmegaCEN coordinated the survey operations for:

1. The Kilo-Degree Survey and Fornax Deep Survey with Astro-WISE, using four of its nodes in The Netherlands, Germany and Italy.

2. The MUSE Guaranteed Time surveys with MuseWISE using seven nodes in The Netherlands, France, Germany and Switzerland.

Both WISE systems are a platform for Data Science. An example is the SUNDIAL project, a collaboration between computer scientists and astronomers centered around the Fornax Deep Survey and Kilo-Degree Survey. The WISE technology has also been a bridge for data science collaborations with researchers in artificial intelligence and medicine porting the WISE technology to these domains. Lastly a specific example of data science algorithms is the application of Convolutional Neural Networks to Kilo-Degree Survey data.





KiDS dark matter map

KiDS dark matter map and quality control examples of image quality and the masking of bright sources. NOVA has been instrumental in the planning, data reduction and interpretation of the data from this large international collaboration. Slowly the Hubble tension arises from the KiDS data. Credit: Kilo-Degree Survey Collaboration/H. Hildebrandt & B. Giblin/ESO

The BlackGEM Array of three wide-field telescopes will be looking for optical transients and variable sources A real-time data processing pipeline has been developed to find transients in each image within 20 minutes after it has been taken. The software is being deployed in the Google Cloud environment and a new datalink to the La Silla Observatory was installed to make real-time transfer possible. Building on the heritage of LOFAR, a database system was developed to perform source association and to build and analyze light curves. This archive will amount to 300TB after five years. As a result of this software development, a spin-off company of CWI called DataSPEX was created, which further develops the software and markets it for other project in and outside astrophysics. The collaboration with a commercial cloud provider is a pilot to test the use of massively scalable resources and cloud technologies in an astrophysical context.

ARTS, the Apertif Radio Transient System, is arguably the nation's largest data generator. It continually searches 3.7 TB/s of data, more than the internet of the entire Netherlands. Twelve steel Westerbork dishes are connected through 1000 km of glass to the central hybrid FPGA/GPU supercomputer that searches the bits for pulsars and Fast Radio Bursts. The acceleration required for this mammoth task was developed in a collaboration between NOVA, ASTRON and the Netherlands eScience Center. The data science innovations needed to search through millions of fast transient candidates per hour include an open-source deep learning solution developed at ASTRON and UvA, through the NOVA ARTS program.

Gaia and Data Science

While the data volume collected by the Gaia mission over the past five years is modest and amounts to a data rate of just 8 MB/s, it does represent 1.5 trillion individual CCD measurements collected for over 1.7 billion stars and other sources on the sky. From this data, the positions, proper motions, and parallaxes, as well as radial velocities and hundreds of astrophysical parameters, are determined for each source observed by Gaia. One of the daunting challenges faced by the Gaia Data Processing and Analysis Consortium (DPAC) is how to validate all this information before making it public. To this end the group in Groningen has developed sophisticated statistical tools that can be run on large subsets of the Gaia catalogue to automatically spot potential problems. This effort was greatly aided by the visualization and data analysis tool Vaex, also developed in Groningen. With Vaex, tables with over a billion rows of information can be manipulated and visualized within seconds, a real asset in the era of big data. The Vaex development led to the commercial spin-off vaex.io. The Gaia catalogue and archive are excellent playing grounds for students interested in machine learning and/or data mining. The skills they learn put them in high demand on the data science labour market.

07 Nationale Wetenschapsagenda (NWA) – The Dutch Research Agenda

In 2015 the general public in the Netherlands could ask questions to be solved by scientists, and the response was overwhelming – more than twelve thousand questions were sent in. Scientists bundled these 12,000 questions into 140 cluster questions and these were attached to 25 routes. Two of these Routes are important in research conducted by NOVA scientists: "Bouwstenen van materie en fundamenten van ruimte en tijd" and "Oorsprong van het leven: op aarde en in het heelal" (also called the Origins Center). Loosely speaking, the first route connects with Networks 3 and 1 of NOVA and the second one with Network 2 of NOVA. In the years 2016 and 2017 astronomers actively participated in the matchmaking activities with other disciplines, such as physics, mathematics, computer science, biology, geosciences, planetary sciences. The two routes were amongst the eight that received a "Startimpuls" from the ministry of science and education, 2.5 M€ to be spent in three years. Dutch astronomers were active in defining these and further programs under the umbrella created by the Routes.

In 2018 the first call for Research for Consortia (NWA-ORC) was released. While the requirements are such that medical and societal research have an advantage, the NWA itself remains important because it emphasizes interdisciplinary research. The route organizations are now in the process of obtaining money elsewhere: e.g. NWO-Zwaartekracht funds were made available for the "Bouwstenen" Route to be invested in a Dutch Institute for Emergent Phenomena. The Origins Center looks at a variety of funding possibilities.

08 Communication, Education and Public Outreach

The NOVA Information Centre (NIC, located in Amsterdam) has been established by NOVA and its four university astronomical institutes to execute, promote and coordinate activities in public outreach in the Netherlands on discoveries in astronomical research in general and results obtained by astronomers in the Netherlands in particular.

The four institutes at the Universities of Amsterdam, Groningen, Leiden and Nijmegen also have local outreach officers and outreach and educational activities. The vision and strategy which is outlined below is also applicable to the local and regional public outreach and education activities. Examples of local outreach are stargazing nights, open days and organizing activities with schools in the region.

Vision & strategy

In 2018 NOVA/NIC redesigned their communication vision and strategy in the document NOVA Information Centre Vision and Strategy 2025.

Vision:

1. Engage society in modern astronomical research and share the thrill of scientific discovery;
2. Foster enthusiasm for astronomy in particular, and other beta sciences and technology in general through education;
3. To reach as many members of the general public and school youth as possible and to be inclusive in this process.

Strategy:

NOVA/NIC acts as initiator, innovator, expertise center and national hub of nationwide outreach activities in astronomy. These activities include development of education materials and teaching tools, modern internet – based communication to the general public, and press communication to the media. NOVA/NIC aims to consolidate and, where feasible and desired, further strengthen its position as the national coordinator and the main connector for astronomical news in the Netherlands, on behalf of NOVA, and also ESO and IAU.

To realize its vision, NOVA makes the following strategic choices:

1. Actively stimulate innovation and share best practices;
2. Foster connections, partnerships and alliances in the field of astronomy and outreach;
3. Continuously monitor and pro-actively benefit from and adapt to the fast-changing media landscape;
4. Reach children by means of the innovative and interactive mobile planetarium project 'Bringing Astronomy into Classrooms';
5. Participate in *Ministerie van Onderwijs, Cultuur en Wetenschap* commissioned curriculum and exam program evaluation in primary and secondary schools;
6. Continued effort in primary and secondary school astronomy education;
7. Expand activities in (electronic) teacher training in primary and secondary schools.

Goals and target groups

The main target groups are (1) press & media, (2) school children & educators, and (3) the general public.

Prime goals of the NOVA/NIC outreach efforts are to (1) inform the public about astronomy and involve them in astronomy, (2) identify and engage with societal developments where astronomy can contribute, and (3) contribute to the teaching of the astronomy curriculum in schools.

It aims to reach these goals by communicating to selected target groups using those media and platforms that are most efficient in reaching these groups. The sizes of such target groups range from very large (e.g., the general public) to small (e.g., engineers specialized in detector technology). Communication to specific groups is both direct and indirect – and both one-way and interactive. Examples of the former are outreach via the press, social media presence, and contributing to writing high school textbooks. Examples of the latter are public events, science fairs, and school visits with the mobile planetariums.

Press & Media

As part of its communication effort, NOVA/NIC issues about 50 press releases (in the Netherlands and abroad) and announcements annually, on behalf of all the four NOVA astronomy institutes, highlighting Dutch science results of (inter-)national importance and linking these to societal and technological developments where appropriate. A similar number of ESO press releases is translated and disclosed to the Dutch public. These efforts contribute to the many hundreds of astronomy news items and features that are reported on in regional and national newspapers, internet sites, radio, television and social media every year, in the Netherlands and abroad.

Press releases are issued in close collaboration with the NOVA institutes, but also with ESO, ESA, ESA, SRON, ASTRON, NWO, JIVE, NSO, UNAWE, and institutes abroad. The NIC also acts proactively towards media and journalists by pitching ideas for reports on a regular basis, and by organizing press visits to the big observatories and other press events.

Since 2017 the NIC offers annual media training sessions at all NOVA institutes, for PhD students, post docs and staff. The NIC is also the Dutch national communication and press hub for the European Southern Observatory (ESO) and the International Astronomical Union (IAU).


Nederland bouwt ondersteuningsstructuur hoofdspiegel reuzentelescoop ELT

donderdag 19 april 2018, 15:00 Print Delen

(c) ESO

VDL ETG Projects, onderdeel van VDL Groep, gaat de ondersteuningsstructuur bouwen voor de hoofdspiegel van de Extremely Large Telescope (ELT) in Noord-Chili. De Europese Zuidelijke Sterrenwacht (ESO) heeft 's werelds grootste optische/infraroodtelescoop in aanbouw op een ruim 3000 meter hoge bergtop nabij de Paranal-sterrenwacht. De ondersteuningsstructuur bestaat uit 798 draagstructuren voor spiegelsegmenten, die samen de hoofdspiegel (met een diameter van ruim 39 meter) van de telescoop vormen. Met de order, die een looptijd heeft van ongeveer vijf jaar, zijn enkele tientallen miljoenen euro's gemoeid.

Press release on www.astronomie.nl about the contract for building the support structure of the ELT. NOVA fosters its relation with the high tech industry in the Netherlands.

Mobile Planetarium

NOVA runs three mobile planetariums since 2010. The sets were upgraded in 2017 with the latest Evans and Sutherland software. NOVA/NIC has a unique position in the mobile planetarium world, having direct access to the large community of NOVA scientists and their datasets. There is an increasing trend in bringing cutting-edge science data into the dome. This can be in the form of imagery and films, the most basic way of utilising science data in a planetarium show, or data can be used in e.g. visualisations to connect the visitor to current science.

Two domes (the NOVA dome and the Leiden dome) are operated by the NIC, the third (Groningen) is operated locally. All three domes are equipped with the same software and hardware and are run under the same licenses. The NIC coordinates and negotiates the licenses, advises about and implements upgrades, produces and renders planetarium movies, and takes care of daily maintenance.

The NIC organized approximately 270 show days per year in the period of 2016-2018, including school visits and special events. In this period, an increased interest developed from event organizers, including the International Short Film Festival, Royal Concertgebouw and several museums (e.g. the Copernicus exposition in Zutphen in 2018). At the end of 2018, a grand total of 282,900 people (the majority of which are school children) visited an interactive planetarium show since the start of the project. This converts to 1/6th of the total annual cohort of students in the Netherlands. Schools pay a minimum contribution for covering transport and personnel costs.

Other educational projects involve development and distribution of materials, organizing teacher trainings, and coauthoring textbooks.

NOVA's Mobile Planetarium

NOVA's Mobile Planetarium at the Expedition Next festival of NWO in 2018 in Rotterdam. Credit: NOVA/M. Baan

Teacher training

As part of the new physics curriculum in high schools, the NIC organized six Astronomy courses at the NOVA institutes. Over 200 teachers were trained in modern astrophysics and were offered new materials for their lessons. In 2018 the NIC started with a new approach to teacher trainings by collaborating with a company specialized in online programs (e-Wise). Development of the first course finished at the end of 2018 and will be offered to teachers August 2019.

Networks

The NIC officers maintain strong connections with, and play important roles in, national press communication and education organizations, like board membership of the Platform Wetenschapscommunicatie (PWC), members of the Vereniging van Wetenschapsjournalisten (VWN). Baan is the ESO media representative in the Netherlands, member of the editorial board of the website natuurkunde.nl and member of the advisory committee for the science program of the Allard Pierson Museum. Baan joined in 2018 the Local Organizing Committee for the PCST (Public Communication of Science and Technology) science communication conference that will be held in the Netherlands in 2023. Vreeling is chair of the Dutch/Belgium planetarium society Planed and board member of the International Planetarium Society IPS. In 2018 Baan was appointed National Outreach Coordinator for the IAU and chair of the Dutch national steering committee which oversees and manages the activities in the Netherlands celebrating 100 years of IAU.

Textbooks

The NIC continued the collaboration with one of the major educational publishers in the Netherlands. The NIC, in collaboration with was involved in writing and producing the astronomy chapters in a text book series for high school children (13-15 years old).

Channels

A broad range of channels is used for communicating and interacting with press, schools and the general public. Examples include press releases, media pitches, website (news, phenomena in the night sky, agenda for talks and events, all on a daily basis), newsletter with over 3000 people subscribed, mainly working in education, annual direct mailing to high schools with materials, posters, social media, Q&A e-mail service, and events (science fairs, movie festivals, star gazing activities).

Website

In 2018 preparations started for a restyling of the NOVA website for the general public **www.astronomie.nl.**

This project will conclude in 2019.

COMMUNICATION, EDUCATION AND PUBLIC OUTREACH

09 NOVA organization

Board

Prof. dr. P. Groot	*chair*	RU	to 01 01 2017
Prof. dr. G. Nelemans		RU	from 01 01 2017
Prof. dr. R.F. Peletier		RuG	to 01 01 2017
Prof. dr. S. Trager		RuG	from 01 01 2017
Prof. dr. H.J.A. Röttgering	*chair*	UL	
Prof. dr. R.A.M.J. Wijers		UvA	

Supervisory Board

Prof. dr. S. Gielen	*chair*	RU	to 01 09 2016
Prof. dr. L.M.C. Buydens		RU	from 01 09 2016
Prof. dr. J. Knoester	*chair*	RuG	
Prof. dr.ir. K. Maex		UvA	to 01 01 2017
Prof. dr. P.H. van Tienderen		UvA	from 01 01 2017
Prof. dr. G. de Snoo		UL	

International Board

Prof. dr. R.C. Kennicutt	*chair*	University of Cambridge, UK
Prof. dr. C.J. Cesarsky		Saclay, France
Prof. dr. H-W. Rix		MPIA, Heidelberg, Germany
Prof. dr. A. Sargent		Caltech, Pasadena, California, USA
Prof. dr. B. Schmidt		The Australian National University
Prof. dr. D.N. Spergel		Princeton University, USA
Prof. dr. W.J. van de Zande		ASML, NL

Minnaert Committee

Prof. dr. A. de Koter	*chair*	UvA
Prof. dr. R. vd Weijgaert		RuG
Dr. M. Klein Wolt		RU
Prof. dr. I. Snellen		UL
Dr. W.H.W.M. Boland	*(observer)*	NOVA

NOVA Information Center

M. Baan MSc	Head of NIC
D. Redeker MSc	Press and information officer
J. Vreeling	Education and public outreach officer

NIC is supported by 15 freelancers on a project-by-project basis. The NOVA outreach activities are monitored by the Minnaert Committee.

NOVA Office

Prof. Dr. E.F. van Dishoeck	Scientific Director
Dr. W.H.W.M. Boland	Executive Director
Dr. Ir. M. Rodenhuis	Instrumentation coordinator
C.W.M. Groen	Finance and control
J.T. Quist	Management assistant

Current lists of NOVA staff, engineers, emeriti, postdocs and PhD students can be found at: **https://nova-astronomy.nl/people/**

Instrument Steering Committee

Prof. dr. M.W.M. de Graauw	*chair*	ALMA, Chile	to 01 11 2008
Prof. dr. G. Wright	*chair*	ATC, UK	from 01 11 2018
Dr. T. Augusteijn		NOT, La Palma	
Dr. F. Bettonvil		UL	to 01 05 2016
Dr. B. Brandl		UL	to 01 05 2016
Dr. A. Brown		UL	
Dr. J. M. Desert		UvA	
Dr. F.P. Helmich		SRON	
Dr. T. Herbst		MPIA, Heidelberg	
Dr. J. Hörandel		RU	
Dr. W. Jellema		RuG	
Prof. dr. L. Kaper		UvA	to 01 05 2016
Dr. G. Kruithof		ASTRON	
Dr. Ir. M. Rodenhuis	*secretary*	UL	
Dr. G. Verdoes Klein		RuG	
Prof. dr. W. Wild		ESO	

10

PhDs in Astronomy 2016 – 2018

A total of 109 PhD's in astronomy were awarded in the Netherlands in 2016, 2017 and 2018. The table below lists all PhD's in this period.

NAME	PhD DATE	PROMOTOR	THESIS TITLE
K. Hakim	18 12 2018	Dominik	Diving Deep into Rocky Exoplanets
S. Straal	12 12 2018	Van der Klis, co: Van Leeuwen	Young Hidden Pulsars
R.R. Kooistra	10 12 2018	Zaroubi	Large-scale filaments and the intergalactic medium
Y. Wang	03 12 2018	Mendez	Disc reflection in low-mass X-ray binaries
E. Zapartas	07 12 2018	De Koter, co: De Mink	The Deaths of Massive Stars in Binary Systems
J. van Roestel	27 11 2018	Groot, Prince	Optical Variability with the Palomar Transient Factory
M.J. Wilby	27 11 2018	Keller	Painting with Starlight Optical techniques for the high-contrast imaging of exoplanets
Y.M. Welling	27 11 2018	Kuijken	Spectroscopy of two-field inflation
A.R. Ridden-Harper	21 11 2018	Snellen, Keller	Inferno Works
C.R. Barber	20 11 2018	Schaye	Monsters in the Deep: Using simulations to understand the excess baryonic mass in the centres of high-mas, early type galaxies
A. Savino	02 11 2018	Tolstoy	On the complex stellar populations of ancient stellar systems
S. Zeegers	01 11 2018	Tielens	X-ray spectroscopy of interstellar dust: From the laboratory to the Galaxy
S.S. Sridhar	29 10 2018	Van der Hulst	Non-thermal emission and magnetic fields in nearby galaxies: A low-frequency radio continuum perspective
K. Mikhailov	23 10 2018	Van der Klis, co: Van Leeuwen	The radio lighthouse from afar: in search of distant pulsars
C. Eistrup	16 10 2018	Van Dishoeck, co: Walsh	From Midplane to Planets: The Chemical Fingerprint of a Disk
A.J. Greenwood	15 10 2018	Kamp	The future of protoplanetary disk models: Brown dwarfs, mid-infrared molecular spectra, and dust evolution
V.A. Allen	12 10 2018	Van der Tak	Organic chemistry around young high-mass stars: Observational and theoretical
L. Klarmann	04 10 2018	Dominik, co: Waters	The inner regions of protoplanetary disks
M.C. Ramirez Tannus	28 09 2018	Kaper, co: De Koter	The outcome of massive star formation

NAME	PhD DATE	PROMOTOR	THESIS TITLE
A. Borghese	27 09 2018	Van der Klis, co: Rea	Hunting for High Magnetic Fields in Different Neutron Star Classes
J.J.A. Matthee	19 09 2018	Röttgering	Identifying the origins of galaxy formation
D. Michilli	14 09 2018	Van der Klis, co: Hessels	Discovery and Characterisation of Fast Radio Transients
A.S. Bak-Nielsen	13 09 2018	Portegies Zwart, co: Patruno	Spin evolution of accreting and radio pulsars in binary systems
E. Aranzana Martez	07 09 2018	Groot, co: Kördíng	Exploring rapid variability of accreting compact sources
G. Kokotanekov	06 07 2018	Wijers, co: Wise	Joint Radio and X-ray Analysis of Powerful Feedback Systems
P. Castellanos Nash	28 06 2018	Tielens	Breaking & entering: PAH photodissociation and top-down chemistry
S. Vats	23 06 2018	Wijers, co: Wijnands, Van den Berg	X-ray diversity in old star clusters
S. Hernandez Orta	22 06 2018	Groot, Trager, co: Larsen	Tales told by Galaxies: Clues to chemical enrichment and the Epoch of Reionization
K. Chuang	20 06 2018	Linnartz, Van Dishoeck	The formation of complex organic molecules in dense clouds – sweet results from the laboratory
K.D. Doney	20 06 2018	Linnartz	Infrared spectroscopy of astrophysically relevant hydrocarbons
P. Salkia	14 06 2018	Falcke, co: Kördíng	Disc-jet coupling in supermassive black holes
J. Mao	07 06 2018	Kaastra	Astrophysical plasma modeling of the hot Universe: Advances and challenges in high-resolution X-ray spectroscopy
F. Santoro	01 06 2018	Morganti	The multi-phase ISM of radio galaxies: a spectroscopic study of ionized and warm gas
J.J.F.J. Jansen	22 05 2018	Van Lunteren	The ornithology of the Baudin expedition (1800-1804)
C. de Jesus Silva	25 04 2018	Wijers, co: Uttley, Costantini	A spectral-timing approachto the study of AGN outflows
J. Mentz	20 04 2018	Peletier	Kinematics and stellar populations of dwarf elliptical galaxies
A. Stevens	19 04 2018	Van der Klis, co: Uttley	New techniques for understanding rapid X-ray variability from compact objects
A.R. Hill	18 04 2018	Franx	Some assembly required: the structural evolution and mass assembly of galaxies at z < 5
M. Dries	06 04 2018	Trager	Unravelling the stellar Initial Mass Function of early-type galaxies with hierarchical Bayesian modelling
J.C. Mackie	29 03 2018	Tielens	The anharmonic infrared spectra of polycyclic aromatic hydrocarbons
M. Brienza	23 03 2018	Morganti	The life cycle of radio galaxies as seen by LOFAR

NAME	PhD DATE	PROMOTOR	THESIS TITLE
A. Miotello	07 03 2018	Van Dishoeck	The puzzle of protoplanetary disk masses
C. Elenbaas	23 02 2018	Wijers, co: Watts	On magnetar burst mechanisms
J. Boer, de	10 01 2018	Keller	High-contrast imaging of protoplanetary disks
A. Igoshev	21 12 2017	Verbunt	Neutron stars as fragmentary records of supernova explosions
M.M. Brouwer	20 12 2017	Kuijken	Studying Dark Matter using Weak Gravitational Lensing: from Galaxies to the Cosmic Web
N.F.W. Ligterink	18 12 2017	Linnartz, van Dishoeck	The Astrochemical Factory: A solid base for interstellar reactions
V.N. Salinas Poblete	18 12 2017	Hogerheijde, Van Dishoeck	Linking Simple Molecules and Grain Evolution Across Planet-Forming Disks
L. Rivera Sandoval	14 12 2017	Wijers, co: Wijnands, Van den Berg	Multi-wavelength studies of compact binaries
B.I.F. Clauwens	06 12 2017	Kuijken, Achucarro	Resolving the building blocks of galaxies in space and time
T. Wevers	30 11 2017	Nelemans, Jonker	Searching for quiescent black holes
R. Connors	30 11 2017	Wijers, co: Markoff	Accretion and jets from stellar-mass to supermassive black holes
M. Segers	28 11 2017	Schaye	Galaxy formation traced by heavy element pollution
H.J. Hoeijmakers	23 11 2017	Snellen	Spectroscopic Characterization of ExoPlanets: From LOUPE to SINFONI
L. Bisigello	13 11 2017	Caputi	Assessing the performance of forthcoming Infrared telescopes
N. Murillo Mejias	01 11 2017	Van Dishoeck	Multiple Star Formation: Chemistry, physics and coevality
M.A. Ramatsoku	17 10 2017	Verheijen	A Westerbork blind HI imaging survey of the Perseus-Pisces filament in the Zone of Avoidance
C. van Eck	09 10 2017	Falcke, co: Haverkorn	Exploring the Threefold Invisible Universe: Low-Frequency Spectropolarimetry with LOFAR as a Probe of Galactic Magnetism
T. Wijnen	05 10 2017	Portegies Zwart, Groot, co: Pols	Face-on accretion onto protoplanetary discs
C. Bonnerot	05 10 2017	Schaye, Rossi	Dynamics and Radiation from Tidal Disruption Events
F.M. Maccagni	18 09 2017	Morganti	Cold gas in the center of radio-loud galaxies: New perspectives on triggering and feedback from HI absorption surveys and molecular gas
T. Stolker	09 09 2017	Dominik	Protoplanetary disks and exoplanets in scattered light
R.T.L Herbonnet	26 09 2017	Hoekstra	Unveiling dark structures with accurate weak lensing
A.H. Streefland	20 09 2017	Van Lunteren	Jaap Kistemaker en uraniumverrijking in Nederland 1945-1962

NAME	PhD DATE	PROMOTOR	THESIS TITLE
H. Tian	04 07 2017	Helmi	Hide and Seek in the Halo of the Milky Way: Substructure Recovery
D.J. Carton	29 06 2017	Schaye, Brinchmann	Resolving gas-phase metallicity in galaxies
S. Rapisarda	28 06 2017	Van der Klis	Mass accretion rate fluctuations in black hole x-ray binaries
H. Andrews Mancilla	07 06 2017	Tielens	Shining light on PAHs in space
H. Schwarz	01 06 2017	Snellen	Spinning worlds
F.D.M. Mernier	31 05 2017	Kaastra	From supernovae to galaxy clusters: observing the chemical enrichment in the hot intra-cluster medium
D. Punzo	26 05 2017	Van der Hulst	3D Visualization and analysis of HI in and around galaxies
B.C. Sliggers	30 03 2017	Van Lunteren	De verzamelwoede van Martinus van Marum (1750-1838) en de ouderdom van de aarde
R. Coppejans	23 03 2017	Falcke	Into the depths: the radio hunt for the youngest and most distant AGN
M.K. Yildiz	19 03 2017	Peletier	The impact of neutral Hydrogen on the current evolution of early type galaxies
A. Ponomareva	24 02 2017	Verheijen	Understanding disk galaxies with the Tully-Fisher relation
K.M.B. Asad	23 01 2017	Koopmans	Polarization leakage in epoch of reonization windows
L.M.P.V. Boschman	06 01 2017	Hoekstra, Spaans	Chemistry and photophysics of polycyclic aromatic hydrocarbons in the interstellar medium
J. Franse	20 12 2016	Kuijken, Achucarro	Hunting dark matter with X-rays
E.G.P. Bos	05 12 2016	Weygaert	Clusters, voids and reconstructions of the cosmic web
G.P.P.L. Otten	29 11 2016	Kenworthy, Keller	Suppressing a sea of starlight: enabling technology for the direct imaging of exoplanets
A.H. Patil	22 11 2016	Zaroubi	LOFAR Epoch of reionization. Statistical methods and first results
P. Podigachoski	24 10 2016	Barthel	Star formation and AGN activity in distant massive galaxies
D. Carbone	21 10 2016	Wijers	Exploring the transient sky: from surface to simulations
W. Karman	21 10 2016	Caputi	A spectroscopic study of the high-redshift universe
C. van Borm	17 10 2016	Spaans	Matter of life and death. The impact of environmental conditions on the origins of stars and supermassive black holes
M. Drosdovskaya	06 10 2016	Van Dishoeck	Inextricable ties between chemical complexity and dynamics of embedded protostellar regions

NAME	PhD DATE	PROMOTOR	THESIS TITLE
L.D. di Gesu	04 10 2016	Kaastra	Winds in the AGN environment: new perspectives from high-resolution X-ray spectroscopy
D. Coppejans	03 10 2016	Groot, Woudt, co: Kording	Multi-wavelength accretion studies of cataclysmic variable stars
S. MacFarlane	28 09 2016	Groot, co: Woudt, Ramsay	The Search for Galactic Short-period Variable Stars in the Omega White Survey
S. Repetto	28 09 2016	Nelemans, co: Jonker	The formation of black holes derived from X-ray binaries
F. Köhlinger	28 09 2016	Kuijken	Weighing the dark: cosmological applications of gravitational lensing
A. Feldmeier-Krause	13 09 2016	De Zeeuw	The assembly history of the milky way nuclear star cluster
L. Morabito	13 09 2016	Röttgering	Radio galaxies at low frequencies: high spatial and spectral resolution studies with LOFAR
C.J. Sifon Andalaft	07 09 2016	Hoekstra	The connection between mass and light in galaxy clusters
D.M. Paardekooper	05 07 2016	Linnartz	Shining light on interstellar matter
M. Lyu	27 06 2016	Mendez	Spectral and timing properties of neutron-star low-mass X-ray binaries
T.K. Starkenburg	24 06 2016	Helmi	The impact of dark satellites on dwarf galaxies in a ΛCDM universe
A.S. Hamers	21 06 2016	Portegies Zwart	Hierarchical systems
E. Koumpia	14 06 2016	Van der Tak	Far and mid-infrared studies of star forming regions: Probing their thermal balance, chemistry and evolution
P. van Oers	09 06 2016	Wijers, co: Uttley	Exploring radio and jet properties across the black hole mass scale
D. Kiawi	09 06 2016	Waters, co: Buma, Oomens	Infrared studies of astronomically relevant metallic clusters and their interactions with simple molecules
A. Skuladottir	18 04 2016	Tolstoy, Salavdori	Sulphur, zinc and carbon in the Sculptor dwarf spheroidal galaxy
C.A. Martinez Barbosa	13 04 2016	Brown	Tracing the journey of the sun and the solar siblings
N. Lopez Gonzaga	12 04 2016	Jaffe	The structure of the dusty cores of active galactic nuclei
A.J. Rimoldi	29 03 2016	Portegies Zwart	The influence of dramatic stellar events on their environment
C.M.S. Straatman	29 03 2016	Franx, co: Labbé	Early death of massive galaxies in the distant universe
S. Antonellini	04 03 2016	Kamp, Spaans	Water in protoplanetary disks: Line flux modeling and disk structure
T. van Putten	16 02 2016	Wijers, co: Watts	Modeling the atmosphere of a magnetar during outburst
J. Schulz	11 02 2016	Falcke, co: Horandel	Cosmic Radiation. Reconstruction of Cosmic-Ray Properties from Radio Emission of Extensive Air Showers

www.nova-astronomy.nl