/17

ANNUAL REPORT

Research Institute Leiden Observatory

Onderzoeksinstituut Sterrewacht Leiden

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Sterrewacht Leiden

Universiteit Leiden
The Netherlands

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Foreword

Dear **reader**,

In front of you is the annual report of the Leiden Observatory for the year 2017. This is the third 'new'-style annual report. The comments we have received remain very positive and we are sure that you will enjoy reading this annual report as well. It again contains beautiful images of large telescopes, forming stars, distant galaxies and numerical simulations.

Scientifically the observatory was extremely active and almost 500 refereed papers were published. To showcase some of our diverse research efforts a number of our astronomers wrote overviews of the projects they are leading. Elena Rossi describes her hunt for stars with extreme velocities that enable her to constrain the shape of the gravitational field of our Galaxy. Reinout van Weeren informs us on the most energetic events in the Universe: the collisions of galaxy clusters. How to locate and study water in galaxies is addressed by Paul van der Werf. And finally, Leo Burtscher discusses how dust shapes our view of the activity at the centres of nearby galaxies. It was a good year for our education program. We are proud of our 300 BSc and MSc students that are an integral part of the research atmosphere of our institutes. Whether they continue to do a PhD or start a career outside academia, they certainly have a bright future.

In our calendar of events, important highlights of the year are given. For our somewhat more distant future, the most important event was the official laying of the foundation stone of the ELT by the President of the Republic of Chile, Michelle Bachelet Jeria and 'our' Tim de Zeeuw, as director general of ESO. An important cornerstone of the institute are our young excellent researchers. Hence, I am very happy that Jordy Bouwman and Reinout van Weeren received VIDI awards and Yannick Bahé, Marcel van Daalen, and Matthieu Schaller received VENI awards. Also, our 'young at heart' researchers are doing well. George Miley continues to be an important driving force for UNAWE – a large international educational program to inspire young children with the wonders of our Universe. We were all very proud when he received an honorary doctorate from Trinity College Dublin in December 2017. The ceremony (see p. 15) was completely held in Latin – it was a privilege to attend this event among George's family and friends. A more frivolous but also inspiring event was the building of ESO's Paranal mountaintop and VLT telescopes in LEGO. It took Frans Snik and students a long weekend, but the results were impressive (see page 13). And finally, at the end of the year, the NWO board announced that the national space research institute, SRON, will be moving to the Leiden University Science Campus. While some of us saw this as a bad outcome for our spacious parking lot, it is clear that this will give a significant boost to our collaboration with SRON on space missions. Due to the proximity of major players in space research and instrumentation (Delft University, TNO space, Airbus), moving SRON to Zuid Holland will help with realizing the ambitious national space research agenda.

Huub Röttgering, Scientific Director

Leiden **Observatory**

The mission of **Leiden Observatory** is to carry out world class astronomical research, provide education at the bachelors, masters, and PhD level, and inform the general public about the most exciting astronomical results and the beauty of the Universe. Our research is wide ranging, with a particular emphasis on observational and theoretical studies of galaxies and the structures in which they are embedded, on exoplanets, and on star and planet formation.

The **Observatory** and its **people**

Sterrewacht Leiden was founded by the Leiden University in 1633 to house the quadrant of Snellius, making it the oldest operating university observatory in the world. While originally located at the main Faculty Building of the university, a purpose-built observatory was constructed in the university's botanical gardens in 1860. Since the mid-1970s the institute has been located within the campus of the Faculty of Science. A long list of eminent astronomers has populated the Sterrewacht, including Profs. Willem de Sitter, Ejnar Hertzsprung, Jan Oort, Adriaan Blaauw, and Henk van de Hulst. Currently, Leiden Observatory is proud to be one of the largest and top astronomical research institutes in Europe. It has 25 scientific staff members, about 80 postdoctoral researchers, 90 PhD students, and 250 undergraduates. Among its professors are three Dutch Spinoza Prize winners. Prof. Tim de Zeeuw was the Director General of the European Southern Observatory – the largest observatory in the world, and Prof. Ewine van Dishoeck is the president elect of the International Astronomical Union (2018-2021).

Research & Technology

Leiden Observatory is part of the Netherlands Research School for Astronomy (NOVA). Scientific research at Leiden Observatory ranges from studying how the Earth and the Solar System have formed and how this compares to other planetary systems, to the origin and evolution of the Milky Way and the Universe as a whole. Observations play a central role in astronomical research, and the state-of-the-art instrumentation is almost exclusively built and operated through international collaborations. Optical and infrared ground-based observations are mostly conducted with telescopes from the European Southern Observatory (ESO) in Northern Chile, and from the Isaac Newton Group (ING) on La Palma (Canary Islands, Spain). Flagship telescopes at other wavelength regimes are the Atacama Large mm/sub-mm Array (ALMA) in Chile and the international Low Frequency Array (LOFAR), which has its core in the north of the Netherlands. Other observations can only be conducted from space, meaning that Leiden astronomers also frequently use the NASA Hubble Space Telescope. A second pillar of astronomical research is theoretical and astrochemistry modeling. Large-scale numerical simulations and big data are key ingredients of astronomical research. Leiden Observatory hosts the Sackler Laboratory for Astrophysics, which carries out unique experiments to simulate inter- and circumstellar conditions in a controlled environment.

Leiden Observatory is also focused on driving the development of key technologies that will enable future astronomical discoveries. Close collaborations with Dutch partners are crucial, such as the NOVA optical group at ASTRON, TNO Delft, the Netherlands Institute for Space Research (SRON), and Dutch Space. Ultimately, most instruments are built in international consortia under the umbrella of ESO or the European Space Agency (ESA). In this way, Leiden astronomers play important roles in the development and operation the ESA’s GAIA and EUCLID missions. Leiden professor Bernhard Brandl is the NOVA principal investigator of METIS, one of the first light instruments of the future Extremely Large Telescope (ELT).

Bachelor & **Master** education

Leiden Observatory is part of the Faculty of Science and hosts both the Bachelor and Master studies in astronomy of Leiden University. The three year bachelor in astronomy is currently followed by about 200 students, and provides a broad basis in astronomy, with important components in physics, mathematics, and informatics. The two year masters in astronomy is currently followed by about 50 students. Since it is fully taught in English it is also very popular among non-Dutch students. The master not only prepares students for a scientific path, but also launches careers in business or industry.

In collaboration with ESTEC in Noordwijk, Leiden Observatory organises the year Leiden/ESA Astrophysics Program for Summer Students (LEAPS), in which talented students from all over the world conduct a summer research program at the Observatory.

Public **Engagement**

An important task of Leiden Observatory is to engage the general public with the wonders of the universe, and share the scientific, technological, cultural, and educational aspects of astronomy with society. It operates a modern visitor centre at the historic observatory building in the centre of town, where the astronomy student club L.A.D.F. Kaiser conducts about two hundred guided tours per year of the antique telescopes.

Leiden Observatory also hosts the international office of the Universe Awareness programme, UNAWE, which harnesses the excitement of astronomy to interest young children in science and technology and to use the perspective and enormity of the Universe to foster tolerance and a sense of world citizenship at an age when their value systems are forming. UNAWE is active in 60 countries with teacher training and production of educational materials.

Calendar of **Events 2017**

January

- **[10]** Anthony Brown is 3rd place in the Leiden Science Faculty "Discoverer of the Year" 2016.
- **[12]** Jorryt Matthee and David Sobral discover that giant halos of so-called Lyman alpha photons are located around all early galaxies.
- **[12]** Huib-Jan van Langevelde and collaborators have identified fast radio bursts with a low luminosity active galactic nucleus.
- **[20]** NWO Dutch Astrochemistry Network receives 2,4 million euro for 12 projects including several in Leiden Observatory.
- **[27]** H2020 Marie Curie Individual Fellowships for Yannick Bahé, Livia Vallini, Andreas Riedo.

February

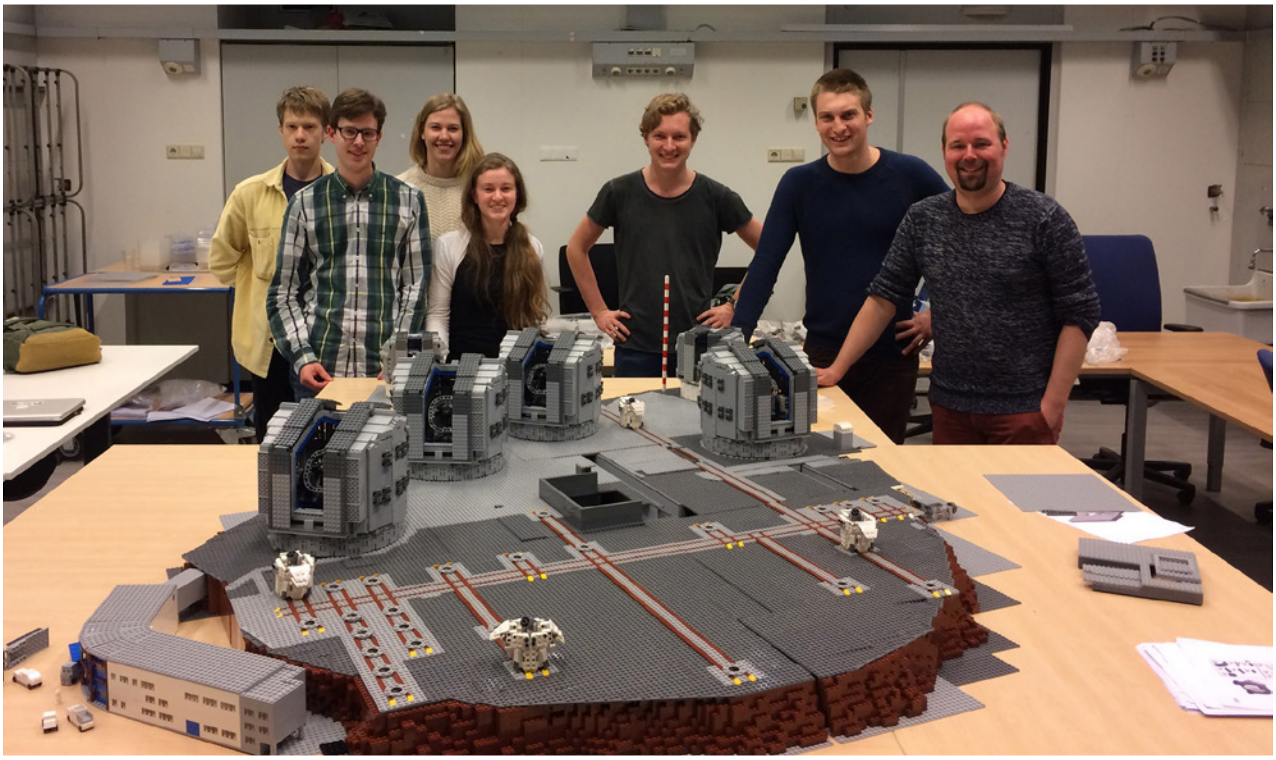
- **[21]** First light for the Beta Pictoris b Ring (bRing) observatory, searching for rings around an extrasolar planet from the Sutherland Observatory in South Africa.

March

- **[22]** The March for Science walk is in Amsterdam.

April

- **[5]** Making use of graphic cards, Jeroen Bédorf and collaborators build and use a supercomputer with the computing power of 10,000 desktop computers, called Little Green Machine II.
- **[6]** Corentin Schreiber and Ivo Labbé discover a galaxy less than 1.6 billion years after the Big Bang with old stars in it.
- **[23]** Construction of Paranal mountain top and telescopes in LEGO at ESO Garching.



LEGO Paranal project team

May

- **[2]** MOU signed with Tsinghua Astronomy department in Bejing, China and NWO-M awarded to Ignas Snellen.
- **[27]** Foundation stone of ELT is laid by President of the Republic of Chile, Michelle Bachelet Jeria and Tim de Zeeuw, director general of ESO.
- **[30]** Two VIDIs awarded for Jordy Bouwman and Reinout van Weeren.

June

- **[8]** ALMA observes stars like the Sun at a very early stage in their formation and finds traces of methyl isocyanate.
- **[16]** Adrian Hamers receives dissertation award from the International Astronomical Union.
- **[22]** Elena Rossi presents LISA as the gravitational wave mission of the European Space Agency (ESA).
- **[22]** Gleb Fedoseev leads team to make glycerol in conditions similar to dark interstellar clouds.
- **[26]** Tommaso Marchetti and Elena Rossi use Artificial Intelligence to search for hypervelocity stars.
- **[27]** Simon Portegies Zwart and collaborators show a new way to form black hole binaries.

July

- **[7]** The MASCARA instrument publishes its first transiting exoplanet discoveries.
- **[13]** Michiel Hogerheijde made Professor by special appointment of Instrumental Astronomy at University of Amsterdam.
- **[17]** Schuyler Wolff awarded the Oort Fellowship.
- **[28]** 3 Veni's awarded to Leiden Observatory researchers Yannick Bahé, Marcel van Daalen and Matthieu Schaller.

August

- **[21]** Leiden team observes Solar Eclipse from Rexburg in the USA.
- **[25]** Henk Hoekstra appointed professor of Observational Cosmology.
- **[31]** 120 year old Astrograph Telescope renovated at Old Leiden Observatory.

The Chinese People's Political Consultative Conference visiting the Old Observatory in November.

September

- **[21]** Evaluation of NOVA shows Dutch astronomy departments amongst best in the world.

October

- **[2]** Niels Ligterink and Ewine van Dishoeck detect methyl chloride in the gas around a young binary star.
- **[21]** Science Run with 3 teams from Leiden Observatory.
- **[27]** Educational programme Universe Awareness (UNAWE) announces as one of HundrED's 100 Global Inspiring Innovations in Education.

November

- **[8]** Ewine van Dishoeck receives Albert Einstein Award of Science in 2015.
- **[22]** Unveiling of Leiden Wall Formulae featuring Jan Oort.

Ewine van Dishoeck

December

- **[5]** SRON space research institute to relocate to Leiden.
- **[8]** George Miley receives an honorary doctorate from Trinity College Dublin.
- **[15]** Observatory Christmas Lunch.
- **[19]** Alessandro Patruno and Mihkel Kama show that habitable planets exist around pulsars.


George Miley receiving his honorary doctorate from Trinity College Dublin

Research Highlights

The **Velocity-Extreme Galactic Astrometry Project** (VEGA P) @Leiden: probing our Galaxy from the Centre to the halo with hypervelocity stars

Elena Rossi

Supermassive black holes —nearly ubiquitous at the centre of galactic nuclei — and ***dark matter*** — dominant in galactic halos — are vital ingredients in the making of a galaxy and in its cosmological evolution: there are observed correlations between the central black hole mass and the stellar properties of the hosting bulges, and dark matter is the main constituent of a galaxy. However, these two “dark” objects and their role are difficult to observe, quantify and describe. A special place to attempt their assessment is in the Milky Way, thanks to our vantage point.

The Galactic Centre

The Galactic Centre (GC) is the only place in the Universe where we can directly image the nearby surroundings of a quiescent supermassive black hole (called Sgr A*). The existence of young stars within a parsec from Sgr A* (**Fig.1**) challenges our knowledge of how stars form, as molecular clouds should not survive tidal forces. More broadly, the nuclear star cluster within the central few parsecs has a debated origin, as both multiple mergers of star clusters and in situ formation as a result of gas inflow could have played a major role. The answer sheds light on the formation and growth of supermassive black holes as they swallow gas and/or stars. Currently, however, dust obscuration and stellar crowding limit our ability to observe individual stars in the GC. The net result is that the vast majority of individually studied stars in the GC are early B-type stars (> 10 solar masses) returning a biased view of its stellar population.

The dark matter halo

On a larger scale, up to several tens of thousands of parsecs the mass distribution of our Galaxy is still mostly unknown. Measurements of the halo mass differ by more than a factor of 2.5, and they are affected by systematics. In combination with measurements of the halo lumpiness (see **Fig.2**), the determination of the halo mass within this range would settle the debate on whether the current model for the content and evolution of the universe (a.k.a. ΛCDM) is as successful

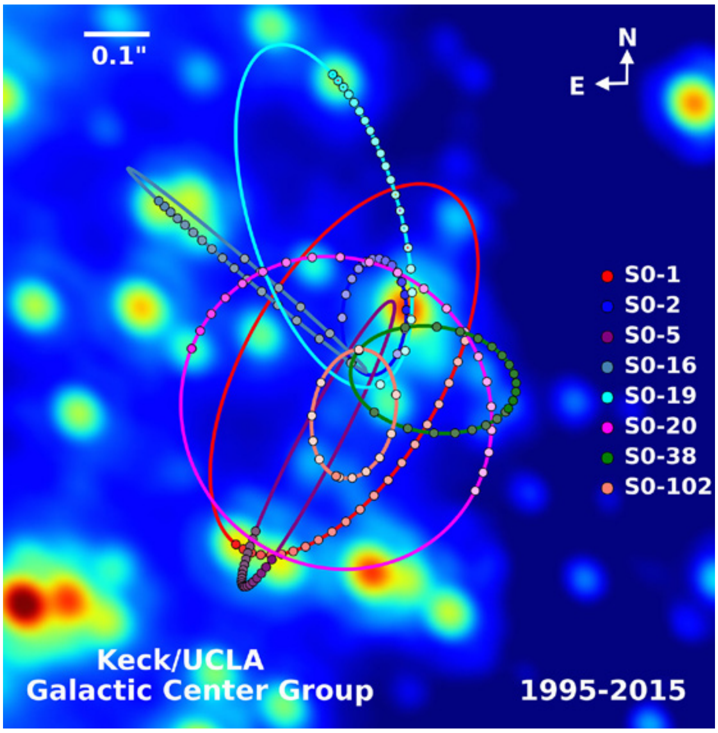


Fig.1: Orbits of stars around the supermassive Black Hole SgrA*

Fig.2: What are the properties of the dark matter halo, important benchmark for simulations?

at galactic scales as it is in reproducing (for example) the observed cosmic microwave background. The halo shape is also debated and currently it is unclear how it compares with a halo assembled in ΛCDM. However, despite the uncertainties, these comparisons between cosmological simulations of the Milky Way and observations show that Galactic studies are essential for understanding galactic mass assembly.

The above seemingly unbridgeable fields can be connected via a unique class of objects called - ***hypervelocity stars*** (HVS see **Fig.3**). These are detected in the Milky Way's halo with radial velocities comparable to or exceeding the Galactic escape speed. Currently, there are ~20 HVSs, discovered in the SDSS catalogue with a spectroscopic strategy that targets late B-type stars in the outer halo, not expected in the local population. Observations strongly support the view that HVSs were ejected in gravitational interactions taking place close to Sgr A*, and, experiencing a huge "kick", escaped into the halo. In the leading ejection model, HVSs were originally members of binary stars, tidally torn apart by Sgr A*, but alternatives have been proposed that involve, for example, an intermediate mass black hole, a cluster of stellar mass black holes or the tidal disruption of young stellar clusters.

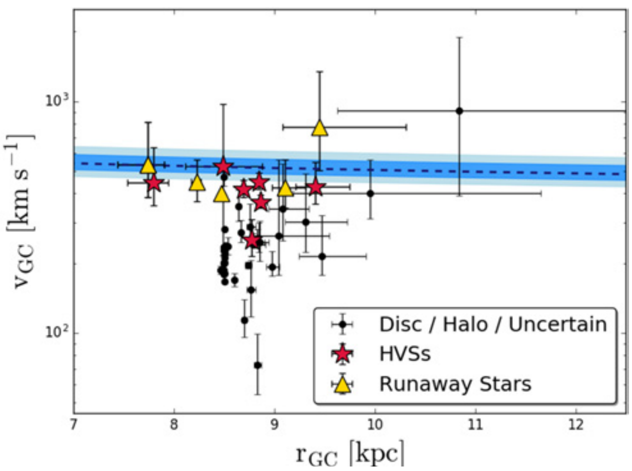


Fig.3: Hypervelocity stars (HVSs, red stars) and runaway stars (yellow triangles) found with our machine learning algorithm, involving an artificial neural network. The blue strip is the observed Galactic escape speed. Adapted from Marchetti, Rossi et al. 2017.

Hypervelocity stars allow us to circumvent the difficulties of direct Galactic Centre observations, as they *are* Galactic Centre stars *but* placed in far more telescope- accessible parts of the sky. On the other hand, as they pervade the whole halo, they can consistently trace the dark matter component over all Galactic scales.

In 2017, with an application to current SDSS data, Dr Rossi and collaborator delivered *the first proof of concept* that HVSs can be exploited to simultaneously constrain the Galactic Centre and the dark matter halo. We found that a ΛCDM dark matter halo is possible but only under specific and in some aspects unusual assumptions for the stellar population around the supermassive black hole. We also showed that the low-velocity tail of the hypervelocity stars velocity distribution is mostly sensitive to the Galactic potential deceleration (and therefore to dark matter) while the high- velocity tail is shaped by the mechanism that ejects stars from the Centre. This feature allows us to disentangle parameters pertaining either to the Galactic mass distribution or the Galactic centre and SgrA*, if a sufficient number of stars (>100) spread over a large velocity range are available. Currently, this ability is limited by paucity and biases of the SDSS sample so far gathered.

The game changer here —that will unprecedentedly address the issue of data paucity in the halo—is the upcoming ***Gaia*** data releases (2018-2022). Notably, Gaia will deliver the largest sample of halo dynamical tracers ever produced with accurate kinematics, including 10^7 halo stars and hundreds of streams. Dr Rossi and her team anticipate that hundreds to a thousand HVS with precise proper motion measurements should be found in the final Gaia catalogue. Thus, Gaia can deliver a HVS sample that represents a huge

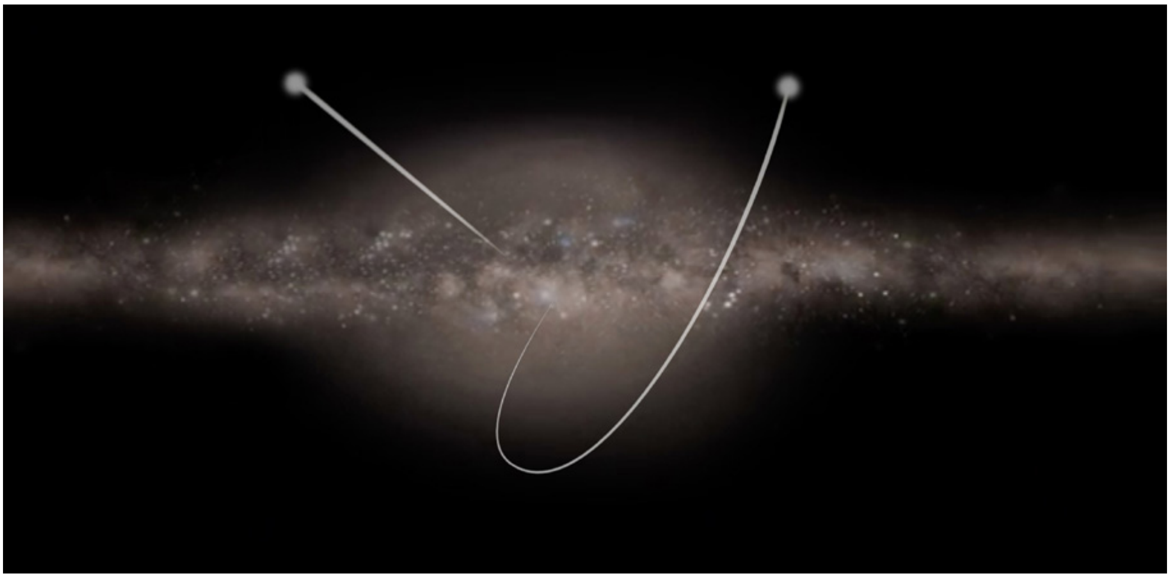


Fig.4: Hypervelocity stars are GC stars escaping into the dark matter halo, following an encounter with the supermassive black hole Sgr A*. [From the ESA press release for Marchetti, Rossi et al. (2017)].

leap in data quality and quantity with respect to the current sample of HVSs, but building it requires careful data mining.

Dr Rossi's team is developing *an original astrometric discovery method*, suited to the data from the Gaia satellite. The implementation of this method involves the development of an artificial *neural network* algorithm, that learns "by experience" as the human brain does: we have been supplying millions of examples of hypervelocity stars in the sky and the algorithm has eventually learnt to recognise a hypervelocity star even if different in e.g. mass and velocity with respect to all the supplied examples. Our application to the Gaia first catalogue (September 2016) published in 2017 was successful, yielding *the first* Gaia HVS candidates (**Fig.3**), together with other very fast stars "running away" from the disc of the Galaxy. Our results were the subject of an ESA press release[1] (**Fig.4**).

Having demonstrated the feasibility of our modelling and data mining procedure in 2017, we are now in a special moment, waiting for the upcoming data releases starting from April 2018, where the bulk of these exciting speeding objects will be found, in a frantic and exciting preparation to be ready to extract the secrets out of the Galaxy's most darkest sides.

1 The ESA press release can be found here: http://www.esa.int/Our_Activities/Space_Science/Gaia/Artificial_brain_helps_Gaia_catch_speeding_stars

Studying cosmic **ray acceleration** in **merging galaxy** clusters with **LOFAR**

Reinout van Weeren

Galaxy clusters are the largest gravitationally bound objects in our Universe. Elongated filaments of galaxies, located between clusters, form even larger unbound structures, making up the cosmic web, with galaxy clusters as the spiders sitting at the nodes.

Clusters typically contain up to several thousands of galaxies. However, most of their baryonic mass is contained in a hot 10-100 million Kelvin ionized intracluster medium, held together by the clusters' strong gravitational pull. This dilute magnetized plasma (~10^{-3} particles cm^{-3}) emits thermal Bremsstrahlung at X-ray wavelengths, permeating the cluster's volume (**Fig.1**).

Galaxy clusters grow by accretion of gas

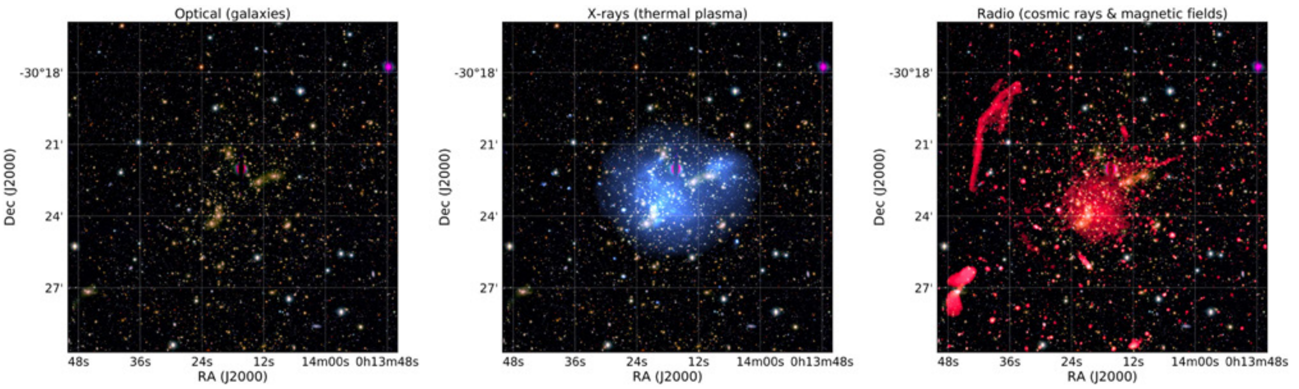


Fig.1: Optical (left), X-ray (middle), and radio (right) images of the massive merging galaxy cluster Abell 2744. These images were taken with the Subaru telescope, Chandra satellite, and Very Large Array (Pearce et al. 2018; Medezinski et al. 2016). The X-ray emission comes the hot intracluster medium. The radio image traces synchrotron emission from energetic particles spiraling around magnetic fields.

from the surrounding medium and through a sequence of mergers with other clusters and galaxy groups. Cluster mergers are the most energetic events that happen in our present day Universe. However, cluster mergers take a very long type to complete, typically several billion years. The energy from the merger events is dissipated through low Mach number shocks and turbulence, heating the intracluster medium. Evidence is mounting that cluster merger shocks and turbulence can also accelerate particles to highly relativistic energies. In the presence of magnetic fields, these so-called cosmic rays then emit synchrotron radiation which can be detected with radio telescopes. An important question that astronomers want to answer is by which mechanism cosmic rays are accelerated.

LOFAR

Researchers at Leiden Observatory play an important role in the study of galaxy clusters at radio wavelengths in particular through their work on the LOFAR Surveys Key Science Project (PI: Röttgering). LOFAR is a revolutionary next-generation radio telescope that operates between 10 and 250 MHz. It is the world's most powerful low frequency telescope and it employs phased array technology, where signals from small low cost antennas are combined in a supercomputer to emulate a giant telescope. The sensitivity and angular resolution of LOFAR are more than an order of magnitude better than any other radio telescope operating in the low-frequency band. However, producing high-quality LOFAR images is also very challenging because of the enormous data rates, complex beam shapes, and distorting effects of the Earth's ionosphere which severely blur the radio images. These challenges were overcome with novel calibration techniques (**Fig.2**; van Weeren et al. 2016a; Tasse 2014) and through processing on grid facilities by the LOFAR group in Leiden (e.g. Mechev et al. 2017).

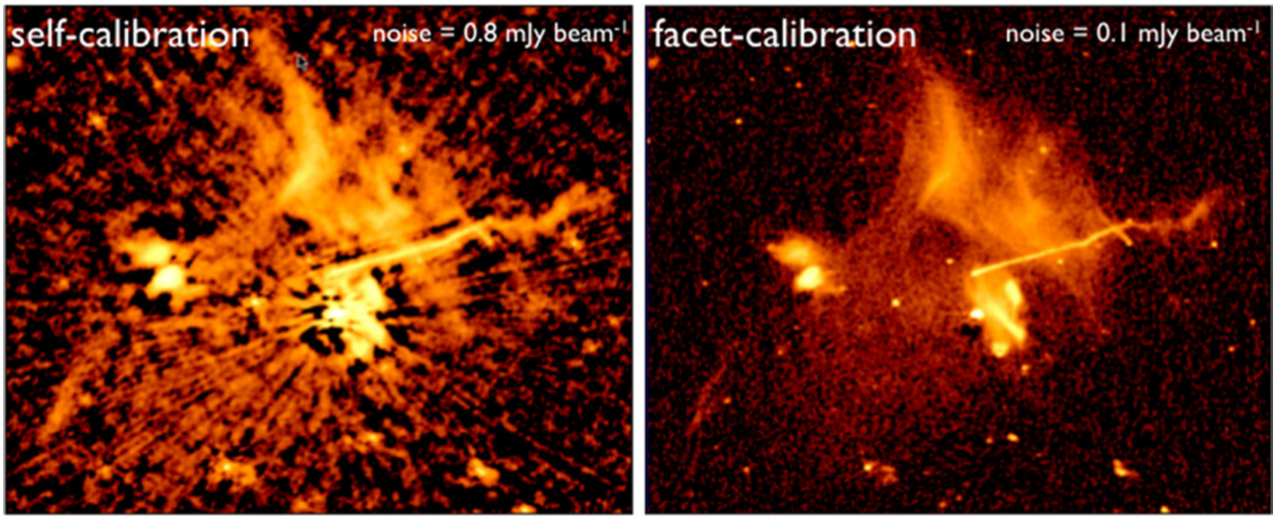


Fig.2: LOFAR 150 MHz images of the galaxy cluster Abell 2256 with old (left) and new (right) calibration techniques. These new techniques correct for ionospheric distortions and complex phased-array beams, enabling deep LOFAR survey images.

The main reason why LOFAR is such a powerful instrument to study galaxy clusters is that the radio synchrotron emission from cosmic rays becomes much brighter at low radio frequencies. In addition, low-frequency observations are sensitive to "fossil" cosmic rays. These are older cosmic rays that were accelerated a long time ago (up to 10^8 yrs) and already lost most of their energy. This provides a fossil record of the galaxy cluster's past activity. Finally, LOFAR's enormous survey speeds allows studying many clusters at unprecedented depth.

Toothbrush and Sausage

The first galaxy clusters that were studied in detail with LOFAR are the so-called 'Toothbrush' and 'Sausage' clusters. These clusters got their name from elongated Mpc-size radio structures that look like a sausage and toothbrush (**Fig.3**). The LOFAR data were taken with the high-band antenna stations at 120-170 MHz. These observations complement higher frequency radio data and X-ray observations from NASA's Chandra satellite. For the Toothbrush, it was revealed that the radio structure traces a weak shock wave traveling through the intracluster medium generated by a cluster merger event. A still unsolved problem is how such a weak shock can accelerate cosmic rays. Theoretical models predict that only strong shocks are efficient particle accelerators. One proposed solution involves a supply of old fossil cosmic rays from a nearby radio galaxy. For the Sausage, LOFAR allowed a detailed study of how a binary merger event resulted in cosmic ray acceleration on the scale of the entire cluster.

In other galaxy clusters, LOFAR revealed a plethora of radio structures that only emit at low frequencies (e.g., Shimwell et al. 2016; Wilber et al. 2018). Although further confirmation is needed, it suggests that fossil cosmic ray populations are rather common in clusters. Another exciting discovery was the identification of a new but still poorly understood mechanism capable of slowly re-energizing cosmic rays in the intracluster medium (de Gasperin et al. 2017).

Future studies

The first LOFAR studies have focussed on individual clusters. A goal for the upcoming years is to extend studies to a much larger sample of clusters. This will allow us to address important questions such as: How common are cluster radio sources? What are their statistical properties? How do these relate to the cluster mass and merger state? How do diffuse cluster radio sources evolve over cosmic time, up to the epoch when the first massive clusters formed? The data to answer these questions is currently being obtained as part of the LOFAR Two-metre Sky Survey (LoTSS; Shimwell et al. 2017). Another goal is to extend clusters studies to even lower frequencies by using LOFAR's low- band antenna stations, although the ionospheric calibration will be more challenging. This would enable us to probe even further back into the cluster's merger history. Opening up another radio window also holds the exciting potential for some unexpected discoveries.

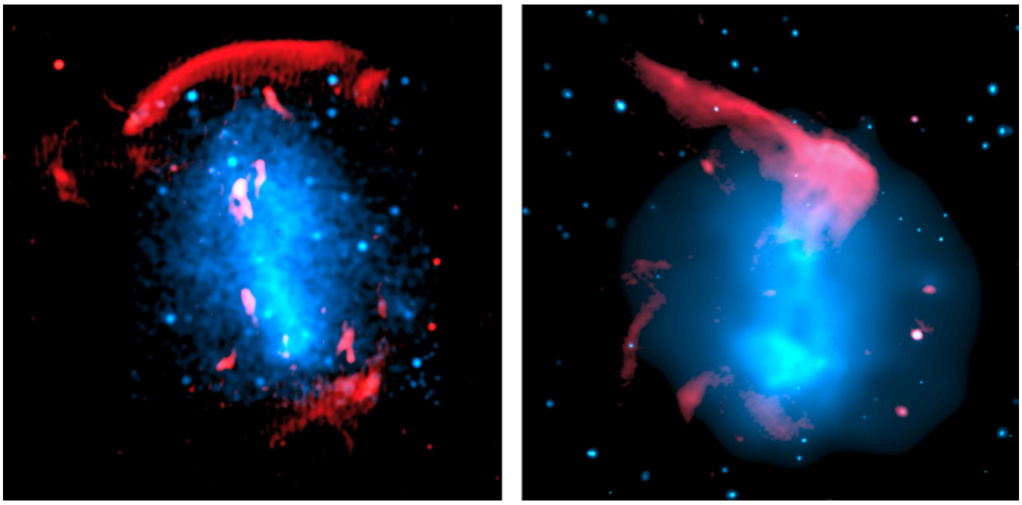


Fig.3: Composite Chandra (blue) and LOFAR (red) images of the Sausage (left) and Toothbrush (right) galaxy clusters (van Weeren et al. 2016b; Hoang et al. 2017; Di Gennaro et al. in prep). Both clusters are undergoing north-south merger events as indicated by the elongated X- ray emission from the intracluster medium. The radio emission traces cosmic rays accelerated at merger induced shock fronts.

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Extragalactic **water**

Paul van der Werf

Water is expected to be one of the most abundant molecules in the interstellar medium (ISM) of galaxies. While in cold interstellar clouds, water is expected (and observed) to be frozen onto the surfaces of dust grains, in warm molecular gas it will be released into the gas phase. Because of its abundance, and because it has a large number of strong spectral lines in the infrared (IR) and submillimeter part of the electromagnetic spectrum, gas-phase water may strongly affect the properties of the molecular medium, and in particular provide a prominent cooling channel.

However, due to the very fact that our Earth's atmosphere is so wet, observations of interstellar water have been extremely sparse until the advent of the Herschel Space Observatory. I summarize a number of key lessons learned from extragalactic H_2O observations made by Herschel, then describe first results of an ongoing program to use H_2O lines as a probe of high-redshift galaxies, using the Atacama Large Millimetre Array (ALMA).

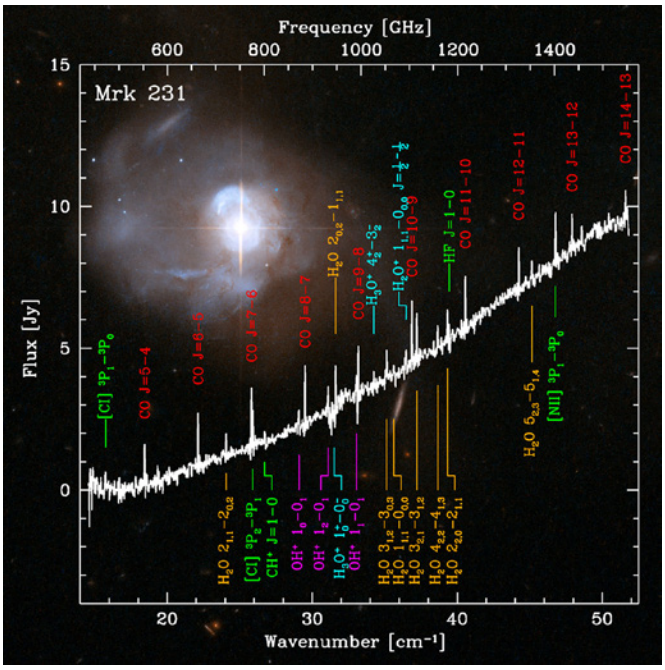

Fig. 1: Herschel SPIRE/FTS spectrum of the nearby QSO Mrk231 (overlaid on the HST/ACS image of the same object). Only the strongest detected lines are indicated. H_2O lines are marked in orange (from Van der Werf et al., 2010, A&A, 518, L42).

Herschel's view of extragalactic H2O: Mrk231 as a case study

The first comprehensive view of the extragalactic H_2O spectrum was provided by the Herschel SPIRE/FTS spectrum of the nearby IR-luminous QSO Mrk231 (**Fig.1**). Eight H_2O lines were readily detected, and the most luminous lines are as bright as the bright CO lines, showing the promise of these lines as cosmological probes. The most remarkable result however is the relative strength of the H_2O lines, showing very weak low-excitation lines (e.g., the $1_{1,1} \rightarrow 0_{0,0}$ line indicated in Fig.1), while lines with upper level temperatures of several 100K are very luminous; the highest transition detected (the $5_{2,3} \rightarrow 5_{1,4}$ line) has an upper level energy of over 600K! Collisional excitation of these levels would require not only very high temperatures and densities, but also strongly overproduce the lines originating from lower energy levels. Collisional excitation is therefore ruled out. Instead, radiative excitation by the absorption of IR photons appears to be responsible for the observed excitation. This process is illustrated by the energy level diagram in **Fig.2**, and the observed level population, with a radiative excitation model is shown in **Fig.3**.

This result is easy to understand. The H_2O molecule, with its bent structure, has a large number of rotational lines, with large Einstein A values, and therefore high critical densities. Collisional excitation therefore requires very high densities. However, the large Einstein A values, and the high abundance of the molecule, also make it couple easily to the IR radiation field. Since in these IR luminous galaxies the local IR radiation field is intense, radiative excitation is efficient.

The upshot of this is that H_2O as a probe is totally different from molecules such as CO, HCN, HCO^+ etc, which are collisionally excited and therefore probe combinations of temperature, density and column density. Water on the other hand is a probe of the local IR radiation field, measuring both its colour (or temperature) and its local intensity. A corollary is that, contrary to naïve expectations, H_2O does not act as a coolant for the warm molecular gas.

The radiative excitation of H_2O has an interesting and powerful application. Since the temperature and the intensity of the radiation field can be derived from multi-line H_2O observations, the derived intensity of the local IR radiation field can be compared to that of a blackbody of the same temperature. It turns out that in several of the objects investigated in this way, the intensity of the local IR radiation field approaches the blackbody limit. This implies significant optical depth in the IR continuum. This has an important physical effect: high optical depth implies that IR photons will be readily absorbed and multiply scattered, and therefore constitute a source of radiation pressure. Since the IR radiation fields in these dusty objects are so intense, IR radiation pressure in this situation becomes an important dynamical effect.

In Mrk231 and other ultraluminous objects, the IR radiation pressure measured in this way exceeds local thermal pressure and turbulent pressure, indicating that IR radiation pressure plays a fundamental role in the nuclear gas dynamics. Whether IR radiation pressure can also drive the molecular outflows often observed from these objects is an open question, which is being actively investigated in Prof. van der Werf's group.

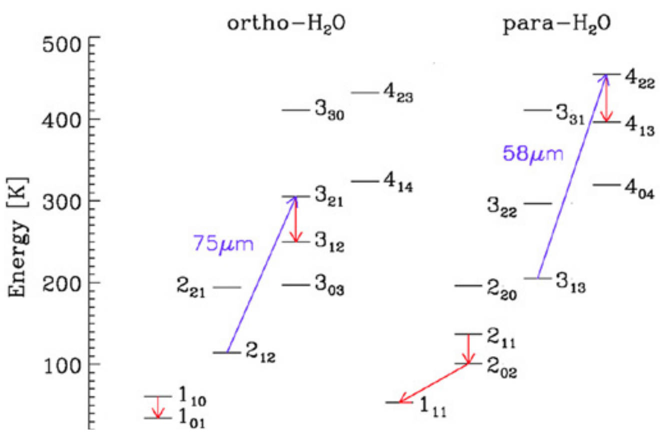

Fig. 2: Partial energy level diagram of H_2O, illustrating observed transitions (red downward arrows), and pumping paths by the absorption of IR photons (purple upward arrows).

Water in the distance: high redshift observations with ALMA

Given the high luminosity of the brightest H_2O lines, they can be detected out to very high redshifts, making use of the cosmological expansion to redshift the lines into transparent spectral windows of the Earth's atmosphere. With the advent of ALMA, this is a new window on the physical conditions in IR-luminous high/redshift galaxies. ALMA for the first time offers the possibility to spatially resolve the H_2O emission (albeit, ironically, only in very distant galaxies), and we are conducting an active program to apply this diagnostic to star forming galaxies and active galactic nuclei at high redshift. A first result is presented in **Fig.4**, which shows high resolution ALMA observations of the famous Cloverleaf Quasar at z=2.560. The Cloverleaf Quasar is gravitationally lensed, giving rise to four images of the same quasar nucleus. The 350 GHz continuum image shown in Fig.4 clearly shows the four images, but also shows diffuse emission connecting the images, which presumably originates in circumnuclear regions, and had not been detected before. The CO 9→8 image, tracing warm, dense molecular gas, roughly follows the continuum, although the contrast between the nuclei and the diffuse emission between the nuclei in the line is lower than in the continuum. The four H_2O emission lines shown in Fig.4 show a remarkable trend in morphology as the excitation level increases. The lowest excitation line (the $2_{0,2} \rightarrow 1_{1,1}$ line, top right panel in Fig. 4) shows fairly diffuse emission, with clear emission from between the four images, but no clear peaks at the four images of the quasar nucleus. However, as lines of higher excitation are observed, this morphology changes, and the highest excitation line (the $4_{2,2} \rightarrow 4_{1,3}$ line, bottom middle panel in Fig.4) shows only prominent emission from the four images of the nucleus and not a trace of diffuse emission. This directly shows that the quasar nucleus plays a dominant role in the radiative excitation of the H_2O molecules. Furthermore, it is directly apparent that local line ratios can deviate significantly from integrated line ratios. Spatially resolved observations thus imply even more extreme conditions than already derived from spatially integrated observations. Our group is currently analyzing spatially resolved H_2O observations of three high-redshift galaxies, in order to determine local conditions in these extreme objects, and their relation to radiative and mechanical feedback processes in these obscured active regions.

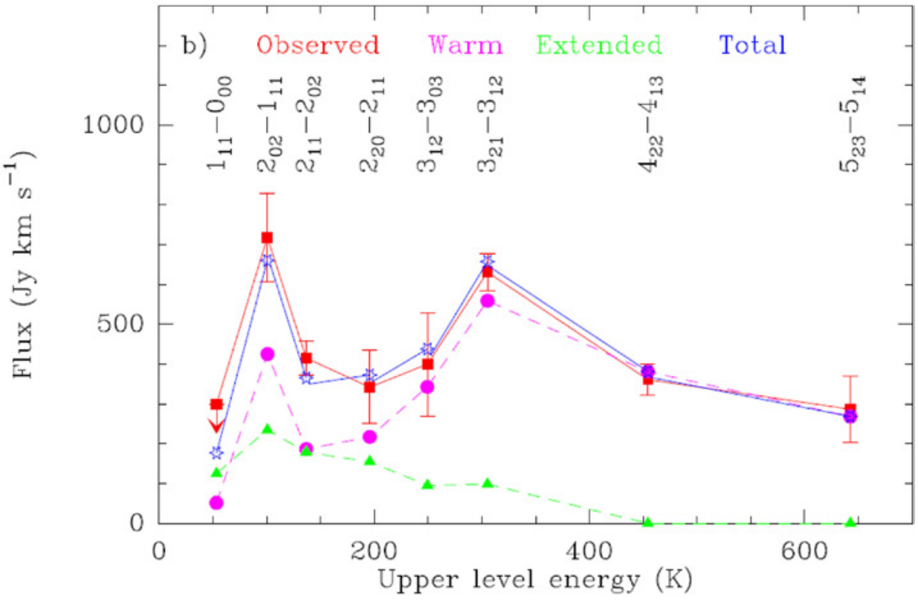

Fig. 3: Observed H_2O level populations in Mrk231. Two peaks represent two excitation components, dominated by IR radiation fields of different temperatures. In the low excitation component, collisional excitation may also play a role (from González-Alfonso et al., 2010, A&A, 518, L43).

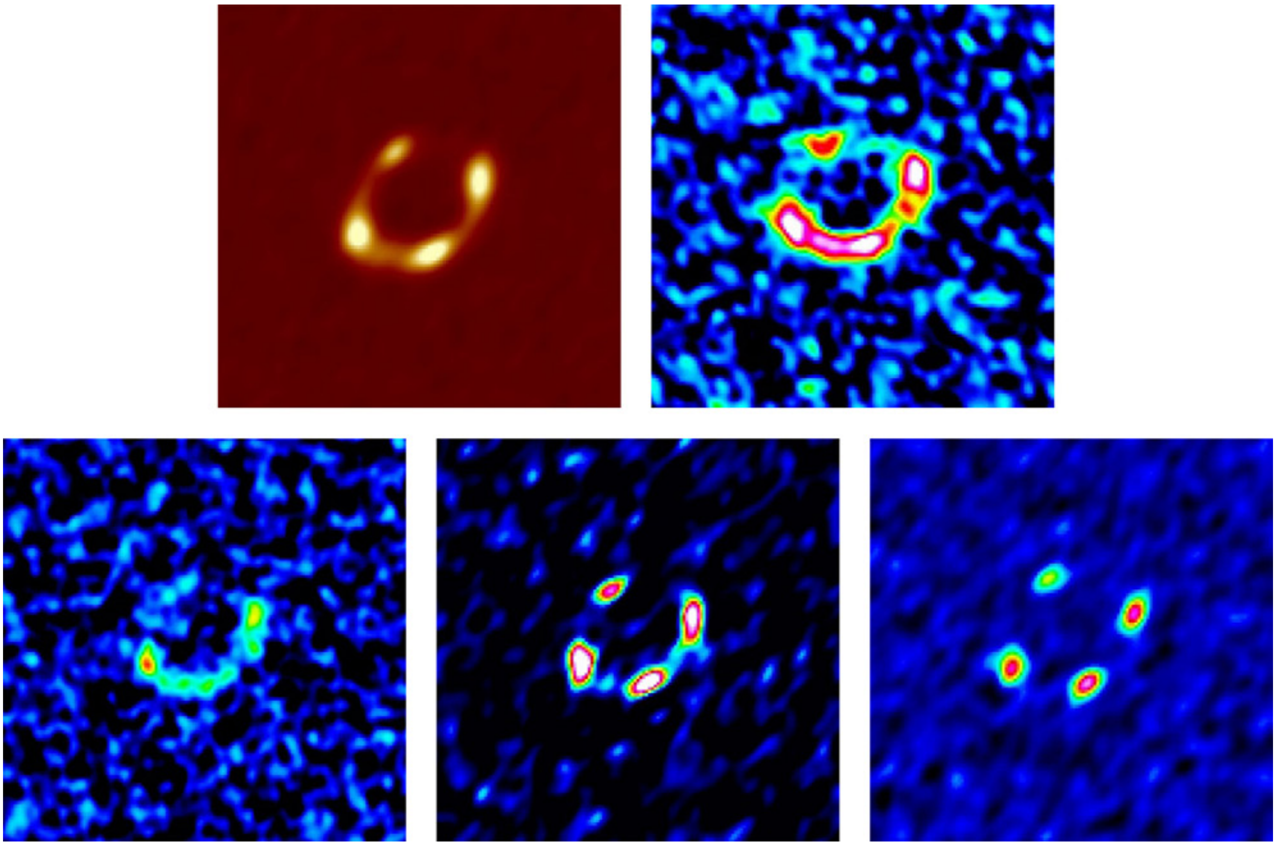

Fig. 4: ALMA images of the Cloverleaf Quasar (z=2.560). The images show: upper left: 350 GHz continuum; upper right: CO 9→8; bottom left: H_2O $2_{0,2} \rightarrow 1_{1,1}$; bottom middle: H_2O $3_{2,1} \rightarrow 3_{1,2}$; bottom right: H_2O $4_{2,2} \rightarrow 4_{1,3}$. The H_2O lines are presented in order of increasing excitation. The angular resolution is ≈0.2" and the size of each image is ≈4".

What is the **AGN torus**?

Leonard Burtscher

Active Galactic Nuclei (AGNs) are among the most energetic phenomena in the universe. In these galaxies, the central supermassive black hole accretes a significant amount of matter. By doing that, it appears to always create an equatorial distribution of gas and dust, commonly referred to as the AGN torus. Historically the torus has been seen as mostly relevant for understanding the dichotomy in the spectral appearance of AGNs, i.e. to unify the sub-classes of broad-line ("type 1") and narrow-line ("type 2") AGNs as one and the same, but seen from a different line of sight relative to this torus.

More recently, however, the torus has become more than a phenomenological gimmick. It is now perceived as an important link in the staggered accretion flow spanning from kiloparsec (host galaxy) to milliparsec (accretion disk) scales. Its relevance stems from the fact that it is clearly linked to the accretion flow of active galaxies, while also being connected to host galaxy activities such as star formation and inflow through bars or spiral arms. Most of this inflow, however, is expelled and the resulting outflows may or may not have a profound effect on the evolution of the AGN host galaxy. These outflows may also contribute to the obscuration originally prescribed to the torus.

Since AGN activity is very likely intermittent on timescales that correspond to the dynamical times at radii of just a few parsec, we can hardly hope to understand the link between accretion / outflow and the host galaxy in detail unless we resolve the relevant scales. There are a number of open questions in the wide field of galaxy evolution that pertain to the nuclear region of AGNs:

- What regulates the growth of super-massive black holes?
- How do AGN outflows actually interact with the surrounding interstellar medium?
- Is the AGN torus a natural by-product of efficient accretion onto the central super-massive black hole?

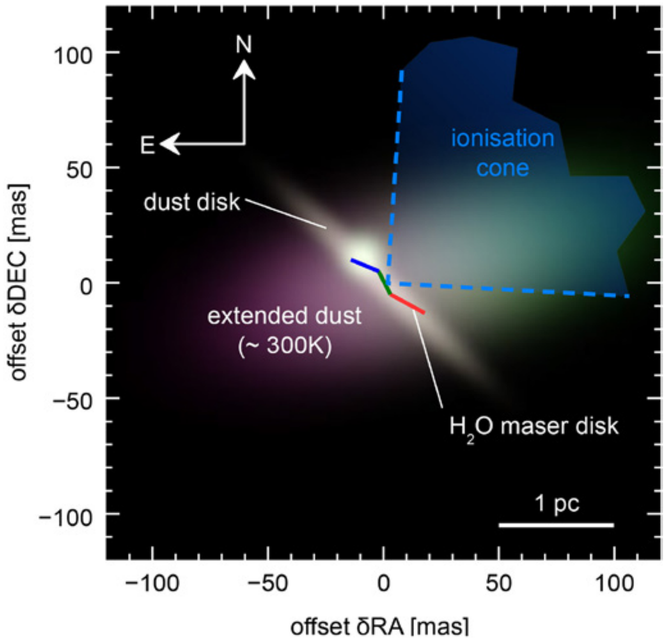

Fig. 1: The best fit model image for the dusty torus of the Circinus galaxy, one of the closest AGNs (Tristram et al. 2014). The dust continuum emission detected by VLTI/MIDI in the thermal infrared is decomposed into a thin disk, coincident with a water maser disk (blue-green-red lines) and a much larger component, more or less coincident with the outflow region, as identified by the ionisation cone. Note the scale bar of 1 pc.

We aim to answer these questions by observing nearby AGNs, where we can resolve the relevant scales, and in the infrared, where we can peer through the host galaxy all the way into its nucleus. A particular emphasis in our group lies on the observation of circum-nuclear dust as it is a readily observable tracer of the in- and outflowing gas and because the torus is brightest at thermal infrared wavelengths (3-20 μm).

In order to achieve high spatial resolutions despite the relatively long wavelengths, we combine the light from several telescopes at the Very Large Telescope Interferometer (VLTI) optically (i.e. with mirrors and beam combiners). The resultant interference signal allows us to obtain a detailed view of the parsec-scale dust distribution in one of the nearest AGNs, the Circinus galaxy (**Fig. 1**). Most remarkably it shows that the majority of the dust emission on parsec scales is not oriented in a thick toroidal

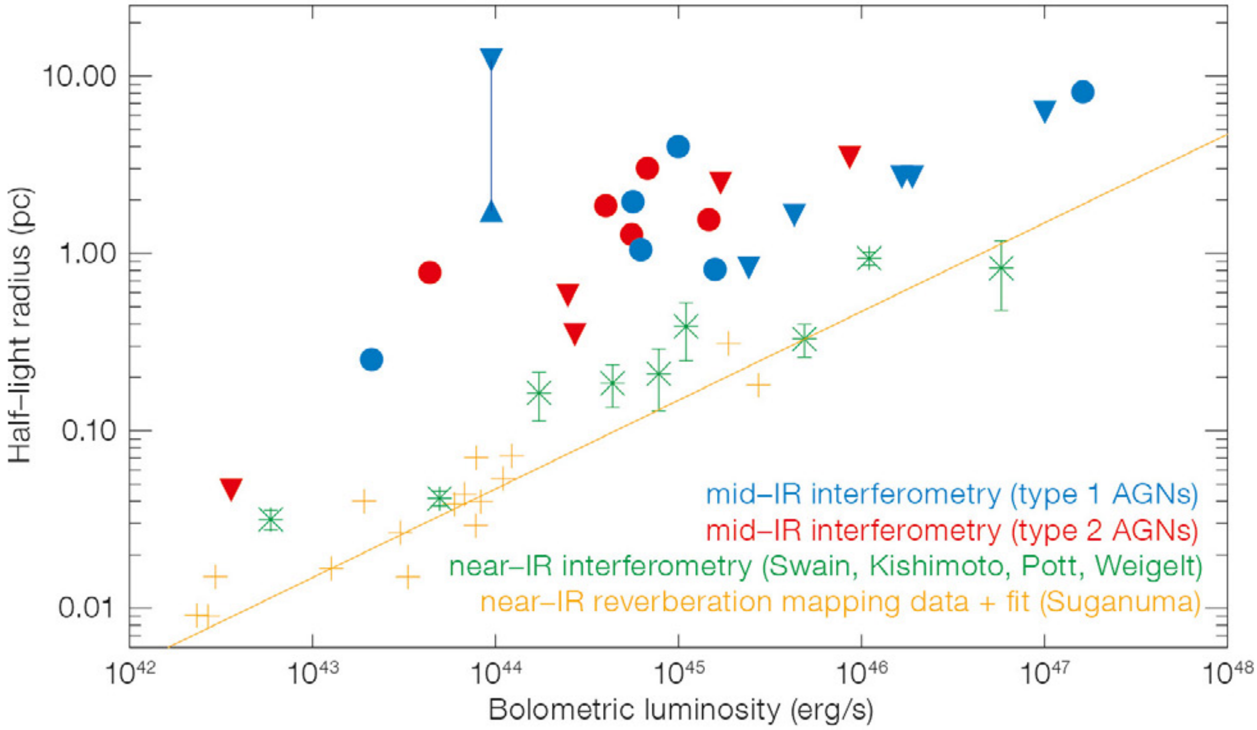

Fig. 2: Sizes (half light radii) of about two dozen tori in mostly nearby AGNs as derived in the mid-infrared (circles and arrows/limits) and in the near infrared (yellow and green crosses).The mid-infrared (12 µm) sizes are on average ~ 20x larger tan the near-infrared (2 µm) sizes, but the scatter in the former is considerably larger. Adapted from Burtscher et al. (2013).

structure (such as in the cartoon often showed to explain the components of AGNs).

This solves one of the long-standing questions about the dynamical stability of the torus. From a theoretical point of view it was always hard to explain the large geometrical thickness (large height / radius ratio) for the "torus": If the dust were distributed continuously, the implied dispersion velocities / temperatures would immediately destroy the dust. But if the dust is distributed in a two-phase medium (cold clumps in a hot environment) then there needs to be a fine balance between collapse of the whole structure into a thin disk (if there isn't enough energy input) and blowing out the entire structure (e.g. if radiation pressure is dominant). Observations with the VLTI instrument MIDI have shown for the first time that the dust is in fact equatorially distributed on parsec scales, but the majority of the dust was found to be in the polar direction of the AGN, coincident with the ionisation cone or narrow-line region of the AGN.

Interferometry has also allowed us to measure sizes of the nuclear dusty structures in about two dozen mostly nearby AGNs (**Fig. 2**). It has not yet, however, allowed us to obtain detailed information from these objects although this would be required in order to test models for the physical nature of the obscuring structure. More specifically, it is still very much unclear where the dust in the nuclear environment originates: is it emitted from a post-starburst nuclear cluster, thus produced as part of the inflow structure (**Fig. 3**), is it created in the outer, colder regions of the disk-wind outflow of the Broad Line Region or is it simply entrained from the surrounding interstellar medium of the host galaxy?

Answering these questions requires more detailed images of the nuclear regions of AGNs than we have previously been able to achieve. This is mostly due to technical limitations, but also because this observing technique is very time demanding (and thus expensive). The new instrument MATISSE, parts of which have been built by NOVA, marks a next big step in optical interferometry and is currently being commissioned at Paranal with first science observations expected for later in 2018. By combining the light of four (rather than previously two) telescopes and enlarging the wavelength range by more than an octave, MATISSE will both provide more detailed information (phases in addition to visibility amplitudes) and have access to a wider range of temperatures and spectral features. At the same time, it will also be more efficient in observing as it records fringes from all six combinations of the four VLTI telescopes at a time, producing observations to answer our questions.

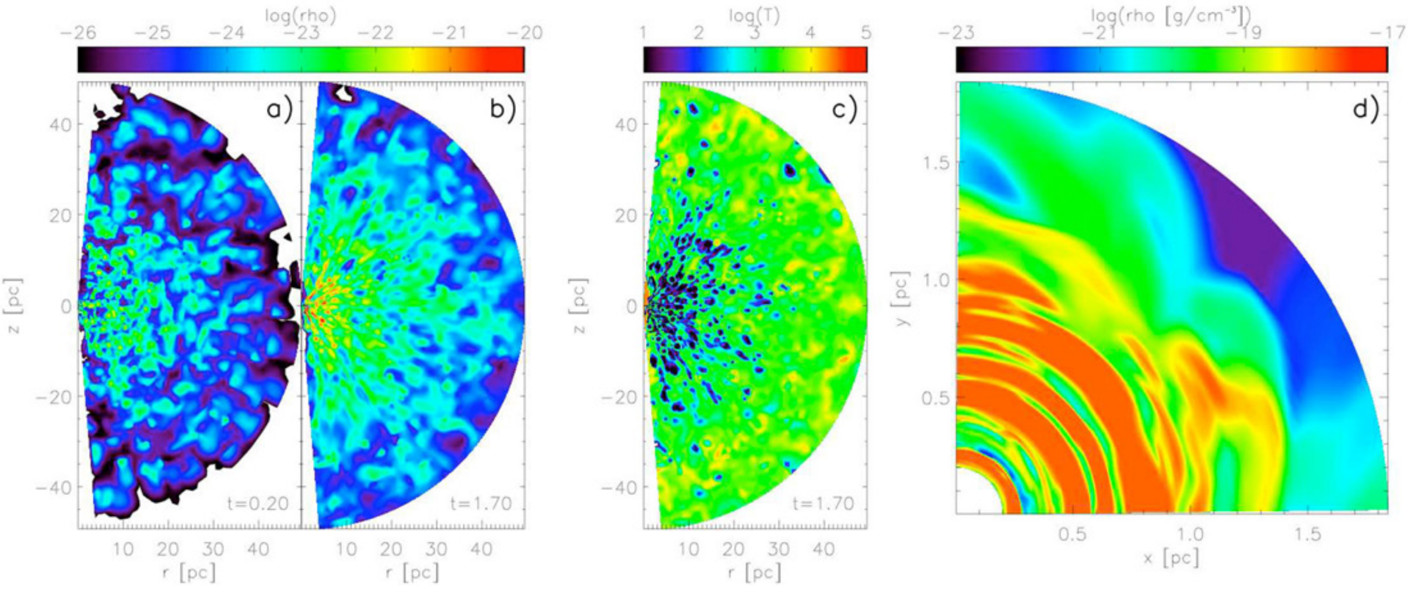

Fig. 3: Meridional density distribution of a simulation to model the stellar mass loss from the nuclear star cluster in the nearby Seyfert galaxy NGC 1068 after an evolution time of (a) $7x10^4$ yr and (b) $6x10^5$ yr. Panel (c) shows the corresponding temperature distribution of the large scale component, whereas panel (d) displays a zoom-in into the central 2 pc region, where a dense disk builds up, similar in size and mass to the one observed by MIDI (Fig.1). Figure adapted from Schartmann et al. (2010).

PhD Degrees

List of **PhD degrees awarded** at Leiden Observatory in **2017**.

Name	Date	Supervisor	Thesis Title
M.M. Brouwer	12-20	Kuijken	Studying Dark Matter using Weak Gravitational Lensing: from Galaxies to the Cosmic Web
N.F.W. Ligterink	12-18	Linnartz/van Dishoeck	The Astrochemical Factory: A solid base for interstellar reactions
V.N. Salinas Poblete	12-18	van Dishoeck	Linking simple molecules and grain evolution across planet-forming disks
B.I.F. Clauwens	12-06	Achucarro/Kuijken	Resolving the building blocks of galaxies in space and time
M. Segers	11-28	Schaye	Galaxy formation traced by heavy element pollution
H.J. Hoeijmakers	11-23	Snellen	Spectroscopic characterization of exoplanets: from Loupe to Sinfoni
N. Murillo Mejias	11-01	van Dishoeck	Multiple Star Formation: Chemistry, physics and coevality
C. Bonnerot	10-05	Rossi	Dynamics and Radiation from Tidal Disruption Events
R.T.L. Herbonnet	09-26	Henk Hoekstra	Unveiling dark structures with accurate weak lensing
A.H. Streefland	09-20	van Lunteren	Jaap Kistemaker en uraniumverrijking in Nederland 1945-1962
D.J. Carton	06-29	Schaye / Brinchmann	Resolving gas-phase metallicity in galaxies
H.E. Andrews Mancilla	06-07	Tielens	Shining light on PAHs in space
H. Schwarz	06-01	Snellen	Spinning Worlds
F.D.M. Mernier	05-31	Röttgering	From supernovae to galaxy clusters: Observing the chemical enrichment in the hot intra-cluster medium
B.C. Sliggers	03-30	van Lunteren	De verzamelwoede van Martinus van Marum (1750-1838) en de ouderdom van de aarde

Publications

Over the year 2017, scientists at Leiden Observatory have published a total of 473 articles in international refereed journals. Astronomy and Astrophysics (139 articles), the Astrophysical Journal and Letters (107 articles), and the Monthly Notices of the Royal Astronomical Society (170 articles) published together 88% of all the papers. The complete list can be found at https://local.strw.leidenuniv.nl/annual-reports/annualreport.php

Interview with Tim de Zeeuw: **'Do something for the broader astronomy community as well'**

Iris Nijman

As Director-General of ESO for the past ten years, Leiden University astronomer Tim de Zeeuw had 'the best astronomy job in the world'. To mark the end of his mandate, he has been appointed Knight in the Order of the Dutch Lion on 14 May 2018. Back at the Leiden Observatory, de Zeeuw is focusing on the structure and dynamics of galaxies, including the Milky Way.

The **European Southern Observatory (ESO)** is busy building the best telescopes in the world for astronomical research, including the **Extremely Large Telescope (ELT)**, under construction in Chile.

What was it like being Director-General of ESO?

'Incredible! It is the best astronomy job in the world. I was responsible for the entire international organisation, from the scientists to the telescope technicians in Chile. My goal was to optimise the **Very Large Telescope**, complete the construction of the **Atacama Large Millimetre/submillimetre Array (ALMA)** and carry out the first observations. In addition, I was responsible for completing the design of the **Extremely Large Telescope**, finding a mountain in Chile to set it up, the donation of the mountain to ESO by Chile, the funding for the construction of the ELT, and the signature of nearly all the main construction contracts. I am really pleased that Leiden University gave me 10 years of special leave so that I could concentrate on this job for ESO.'

What do you think is most unique about ESO?

'That it is an intergovernmental organisation. At the moment, there are fifteen member countries, including the Netherlands. With that kind of partnership, you are able to achieve far more than a single country on its own, and it offers stability in the long run. That's unique in astronomy and it ensures that ESO can realise massive international projects.'

What ESO discoveries were highlights for you?

'Two that stand out are **the discovery of the earth-like planet orbiting the star Proxima Centauri: the closest star from our sun**. And the extremely precise observations of the properties of the super-massive black hole at the centre of the Milky Way.'

Four out of eight ESO directors were Professors at Leiden Observatory. What makes Leiden special?

'Leiden astronomer Jan Hendrik Oort, one of the greatest astronomers of the 20th century, played a big role in establishing ESO. Moreover, the Netherlands has a very strong astronomical tradition. Amongst the ESO member states, the Netherlands has a good strategic position because it is not one of the biggest, but also not the smallest country.'

What is the transition back from Director to Professor like?

'It is a big transition, I don't have as many meetings and I travel less. But I am happy to be back in Leiden, which is an internationally renowned institute and has grown significantly in the last ten years. It is not my goal to start a new research group, but I keep supervising students and I work with an international science team to study the evolution of galaxies in the Fornax Cluster using the MUSE instrument of the Very Large Telescope (VLT).'

'I also recently accepted a position as Blaauw Professor. This is a visiting professorship at the Faculty of Science and Engineering at Groningen University. This is very special for me, because Adriaan Blaauw was ESO Director from 1970 to 1974 and I followed his lectures in 1975 when I was a second-year astronomy student and I did research with him. For this position, I will be at the Kapteyn Astronomical Institute for approximately one month and will give some lectures.'

What are you going to focus on in the coming years?

'I study the structure of our Milky Way and other galaxies. When you look up to the starry sky from the Earth, it is difficult to perceive depth. You don't know which stars are near or further away. The **Gaia space telescope** is like a 3D pair of glasses for astronomical observations: for the first time, we can explore the structure of our galaxy in three dimensions.'

'In the past few years at ESO, I didn't have much time for research, so that's what I am looking forward to focusing on more in the coming years. I am also working on a book about the structure and dynamics of galaxies. I am doing that at the Leiden Observatory and at the **Max-Planck Institute for Extraterrestrial Physics** in Garching, Germany.'

In your opinion, what should the European and Dutch astronomy community focus on in the coming years?

'ESO should build the ELT. As I said in the September 2017 issue of ESO messenger: "The ELT will no doubt produce discoveries that we simply cannot imagine today, and it will surely inspire numerous people around the world to think about science, technology and our place in the Universe."'

'The Dutch astronomy community should focus more on a coherent national programme instead of more and more small research teams. We should keep working together to stay at the frontline of international astronomical research. Furthermore, I think that the Netherlands Research School for Astronomy (NOVA), which is a collaboration of the Dutch university astronomy institutes, should get structural funding. NOVA's instrument group will build the instruments for the ELT and it is important for the whole community that it is also involved in the technical developments of new facilities.'

What would you like to impart to the next generation of astronomers?

'Don't just focus on competition, but do something for the broader astronomy community as well. For example, you can join ESO committees or become engaged in an international project. It may not directly benefit your own research, but it's a way of giving something back to your community.'

Colloquia and Lectures

Scientific Colloquia at Leiden Observatory

19 Jan: Dainis Dravins, *Lund Observatory*
Intensity Interferometry and Imaging of Stellar Surfaces.

09 Feb: Peter Schilke, *University of Cologne*
High-Mass Star Formation - Status and Challenges.

16 Feb: Imke de Pater, *University of California, Berkeley*
Peering through Jupiter's Clouds with Keck and the VLA.

21 Feb: Reinout van Weeren, *Harvard-Smithsonian Center for Astrophysics*
Exciting Physics with Merging Galaxy Clusters.

23 Feb: Yuri Levin, *Monash University, Melbourne*
The secret life of magnetars.

02 Mar: Mario Tafalla, *Observatorio Astronomico Nacional, Madrid.*
ALMA observations of protostellar jets. Trying to understand the mechanism of outflow acceleration.

09 Mar: Sebastiano Cantalupo, *ETH Zürich*
A 3D View of the Dark Universe: Illuminating intergalactic gas with fluorescent Lyman-alpha emission.

16 Mar: Amélie Saintonge, *University College London*
The role of gas flows in regulating galaxy evolution.

23 Mar: Lennart Lindegren, *Lund University*
Towards Gaia DR2: The astrometric solution.

30 Mar: Pratika Dayal, *Kapteyn Institute, University of Groningen*
The first billion years of galaxy formation in Cold and Warm Dark Matter Cosmologies.

09 Apr: Roland Wester, *Inst. fuer Ionenphysik, Uni Innsbruck*
On the coming and going of interstellar negative ions.

20 Apr: Jean-Michel Désert, *Universiteit van Amsterdam*
Characterizing Exoplanets' Atmospheres to Reveal Planetary Origins, Climate and Habitability.

04 May: Stephen Pompea, *NAOA*
Astronomy Public Engagement: Six Essential, But Not Easy Lessons.

18 May: Roberto Capuzzo-Dolcetta, *Dep. of Physics, Sapienza, University of Roma, Italy*
Compact Massive Objects in galaxies.

01 Jun: Paola Caselli, *Max Planck Institute for Extraterrestrial Physics, Garching*
Chemistry at the dawn of star formation and links to our Solar System.

22 Jun: Stella Offner, *University of Massachusetts, Amherst*
Towards a Unified Model for Star Formation: Forging Order from Randomness.

07 Aug: Wolfgang Gieren, *Universidad de Concepcion*
Towards a 1% Hubble constant: a sub-percent distance scale from binaries and Cepheids.

07 Sep: Susanne Pfalzner, *Max Planck Institute for Radio Astronomy, Bonn*
Disk destruction processes in young star clusters.

14 Sep: Michiel Brentjens, *ASTRON*
Aperture holography with phased array telescopes.

21 Sep: Peter Gallagher, *Trinity College Dublin, the University of Dublin*
The Causes and Consequences of Solar Storms.

28 Sep: Dario Izzo, *ESA*
Machine learning for interplanetary trajectories.

12 Oct: Andrea Ferrara, *Scuola Normale Superiore*
The Interstellar Medium of High Redshift Galaxies.

19 Oct: Maria Lugaro, *Konkoly Observatory, Budapest*
Radionuclides from cosmochronology to habitability.

09 Nov: Thomas Henning, *MPIA*
From Protoplanetary Disks to Exoplanet Atmospheres.

23 Nov: Hans van Winckel, *KU Leuven*
Protoplanetary discs around evolved binaries.

30 Nov: Raymond Pierrehumbert, *University of Oxford*
Climate dynamics of lava planets.

07 Dec: Peter Barthel, *RUG*
Fireworks in the young universe: extreme star-formation in extreme AGN.

14 Dec: Duncan Farrah, *Virginia Tech*
The Role of the most luminous AGN in galaxy assembly at z=2.

Endowed **Lectures**

The **Oort Lecture**

The Oort Lecture is an annual event, in memory of the famous Dutch astronomer, organized by the Jan Hendrik Oort Foundation and Leiden Observatory. The lecture covers an astronomical subject of current interest and is intended for a mixed audience with a general interest in astronomy. This year's lecture was presented by **Prof. Imke de Pater** and took place in the Academy Building in Leiden on May 11.

Prof. Imke de Pater is the world's leading expert in planetary sciences, using premier ground-based and Earth-orbiting telescopes at visible, infrared and radio wavelengths. She started her career at Leiden Observatory by observing and modelling Jupiter's radio (synchrotron) emissions, observed with the Westerbork Synthesis Radio Telescope (WSRT) - she received her PhD cum laude for this work. As a postdoctoral Fellow in Tuscon, Arizona, she did detailed investigations of all giant planets' thermal radio emissions. Over the past years, she exploited sophisticated adaptive optics techniques in the infrared range to obtain high angular resolution data of volcanic activity on Io, weather on Titan, planetary rings, and the giant planets; she observed with the airborne observatory SOFIA, and used the recently upgraded Very Large Array to map the atmospheres of the giant planets below their visible cloud deck. Imke is a Professor in the Departments of Astronomy, and Earth and Planetary Science at the University of California at Berkeley; she chaired the Astronomy Department from 2010-2015. She wrote two books together with Jack Lissauer: "Planetary Sciences" (2001) and "Fundamental Planetary Science: Physics, Chemistry and Habitability" (2013). Both books were published with Cambridge University Press. She received a number of prestigious awards during her career, amongst which are the 2007 AAS Chambliss Award for Writing for "Planetary Sciences", and the URSI John Howard Dellinger Gold Medal, and is a member of many international committees.

Her lecture was titled "What wonderful worlds: A journey through our Solar System". She began with discussing how our solar system consists of a diverse and dynamic collection of bodies, ranging in size from tiny dust grains to giant planets and serves as a prototype for other planetary systems in our Galaxy. By talking about the remarkable "zoology" of our Solar system, from giant planets down to tiny asteroids and comets, the information gained from these studies can piece together the story of the formation of our planets and their subsequent evolution and apply this to other planetary systems. More specifically she talked about Jupiter's satellite Io, which has some of the largest volcanic eruptions ever seen in our solar system. As such, Io provides a window into what Earth may have looked like soon after its formation and its own intense volcanic activity.

The **Sackler Lecture**

Prof. Re'em Sari,
Hebrew University

The Raymond and Beverley Sackler Lecture 2017 was held on 22nd September and given by **Professor Re'em Sari**. Re'em Sari received his PhD in 1998 from the Hebrew University in Jerusalem. Afterwards he moved to Caltech (Pasadena, CA), where he first held a Sherman Fairchild Senior Research Fellowship before becoming Associate Professor of Astrophysics and Planetary Science in 2003. Finally, in 2007 he went back to his country of origin and the Hebrew University where he is currently Professor in Astrophysics. Prof. Sari is a theoretician who has significantly contributed to the advance of an impressive broad range of topics from Solar system objects over extrasolar planets and star dynamics to extreme high energy phenomena such as gamma ray bursts and supernovae.

Prof. Sari's lecture was entitled "Dynamical Processes in the Galactic Centre", focusing on the variety of dynamical processes that shape the density of stars and gas in our Galactic Centre. He emphasized the role of binary stars dissolving in the tidal field of the super massive black hole, subsequently producing hypervelocity stars which are observed to escape our Galaxy. He talked about how they also play a role in setting the stellar cusp around the central black hole. He then went on to how stars spiraling into the black hole generate gravtiational waves and how their suqsequent signal can detail the internal properties of the star.

PhD Colloquia

13 Apr: François Mernier
From supernovae to galaxy clusters: Observing the chemical enrichment in the hot intra-cluster medium.

30 May: Heather Andrews
Shining Light on PAHs in Space.

12 Jun: Margot Brouwer
From galaxies to the cosmic web: Studying dark matter with gravitational lensing.

15 Jun: Clément Bonnerot
Dynamics and Radiation from Tidal Disruption Events.

05 Sep: Jens Hoeijmakers
Characterizing exoplanet atmospheres.

19 Sep: Nadia Murillo
Multiple star formation: Chemistry, physics and coevality.

26 Sep: Marijke Segers
Galaxy formation traced by heavy element pollution.

14 Nov: Jos de Boer
Protoplanetary disk imaging in scattered light.

16 Nov: Bart Clauwens
Resolving the building blocks of galaxies in space and time.

21 Nov: Vachail Salinas
Linking simple molecules to grain evolution across planet-forming disks.

28 Nov: Niels Ligterink
The astrochemical factory: A solid base for interstellar reactions.

Education

Bachelor and Master in Astronomy

Teaching and training of students is a major priority of Leiden Observatory, which offers both a university bachelor (BSc) and master (MSc) programme in astronomy. The BSc programme is 3 years and is partly taught in Dutch, with combinations of lectures, problem classes, and practicals. In addition to astronomy courses, the programme consists in the first year of a significant fraction of courses in mathematics, physics, and informatics. First year students conduct their first astronomical observations with the modern LUF/Gratama telescope on the roof of the historic observatory building in the centre of Leiden, and learn about coordinate systems during a lecture at the planetarium in Artis, Amsterdam. In years two and three the emphasis is increasingly on astronomy.

Highlights include observations at the 2.5m Isaac Newton Telescope on La Palma (Canary islands) carried out and analysed by the students, and the 6-month research project at the end of their BSc. The MSc programme is 2 years and taught fully in English, attracting many foreign students. The Observatory has a strongly international flavour, with close ties with other astronomy institutes in Europe and the U.S. Many students, postdocs and staff come from abroad, and the institute hosts regular visitors from all over the world. Education and research focus on three major themes: (i) the formation and evolution of galaxies, (ii) the birth of stars and planets, and (iii) cutting-edge instrumentation. The astrochemistry and optics laboratories, and high performance computing facilities also function as training grounds for students, and are used for student's research projects. Students graduate with a broad knowledge of astronomy and astrophysics, but may specialise in various fields.

The MSc programme in Astronomy offered seven specialisations:

1. Astronomy Research
2. Astronomy and Cosmology
3. Astronomy and Instrumentation
4. Astronomy and Data Science
5. Astronomy and Education
6. Astronomy and Science-Based Business
7. Astronomy and Science Communication and Society

Student Numbers

Student numbers, which have been increasing since several years, continue to rise. In 2017, an exceptionally high number of 136 freshmen started their studies in the Astronomy BSc. Of this number, 44 (32%) were women, and 65 (48%) pursued a combined astronomy/physics or astronomy/mathematics/computer science degree. The Observatory registered a total number of 231 BSc students at the end of the year, of which 91 (40%) aimed at a combined astronomy/physics degree or astronomy/mathematics degree; 31% of all BSc students is female. In 2017, the inflow of master students has grown to 38 students. In total there were 70 MSc students, including 23 (33%) women and 27 (39%) of foreign nationality.

Organisation

The entire teaching program is organized and supported by the Education Office Astronomy (EOA), which deals with all aspects of the curriculum, including organization, student support, outreach and internationalisation. The EOA team currently consists of a Director of Education, Head of Education Office Astronomy & Programme Coordinator, Study Advisor, PR Education Coordinator, Internationalisation PR Officer, Education & Student Affairs Officer and a Secretary.

In addition to counseling by the student adviser, incoming students were assigned to small groups meeting at regular intervals with a staff mentor and a senior student mentor. In the tutor programme, physics and astronomy freshman students were provided on a voluntary but regular basis with coaching by senior students. In the BSc programme, students in the 2nd and 3rd year write a Study Plan, which must be approved by the Study Advisor. The astronomy curriculum is monitored by the 'Education committee' (Opleidingscommissie), which advises the Director of Studies on all relevant matters, and which was chaired by Linnartz. Under the authority of the Education Committee, the lecture course monitoring system was continued. In this system, students provide feedback to lecturers during and after the course.

Quality control of all aspects of the exams is the responsibility of the Board of Examiners (Examencommissie) chaired by Snellen. Admission to the master-curriculum for students without a BSc in astronomy from a Netherlands university requires a recommendation by the 'Admissions committee' (Toelatingscommissie) chaired by Schrier and having Portegies Zwart, Kuijken, Hogerheijde and Kenworthy as members.

Academic **courses** and **pre-university Programmes**

BSc Courses

Title	Lecturer
Planetenstelsels	Hogerheijde
Inleiding Astrofysica	Hoekstra
Praktische Sterrenkunde	van Langevelde
Modern Astronomical Research	Russo
Astrobiology	Fridlund
Astronomical Lab & Observing Project	Brinchmann
Keerpunten in de Geschiedenis van de Natuurwetenschappen	van Lunteren
On Being a Scientist	van Lunteren/Haring/Smeets
Astronomical Observing Techniques	Keller
Galaxies & Cosmology	Hodge
Stars	Snellen
Astronomical Relativity	van der Werf
Radiative Processes	Rottgering/van Daalen
Bachelor Research Project	Linnartz

MSc Courses

Title	Lecturer
Astronomical Telescopes and Instruments	Kenworthy
Computational Astrophysics	Portegies Zwart
Data Bases and Data Mining in Astronomy	Brinchmann
Origin and Evolution of the Universe	Bouwens
Astronomy from Space	Fridlund
Project management For Scientists	Keller
High Contrast Imaging	Kenworthy
Astrochemistry	Van Dishoeck
Compact Objects and Accretion	Rossi
Deep Learning Course	Portegies Zwart
Detection of Light	Brandl
Galaxies: structures, dynamics and evolution	Franx
Interstellar Medium	Tielens
Large Scale Structure and Galaxy Formation	Schaye

Degrees **awarded** in **2017**

BSC DEGREES

A total of **32 students** obtained their **Bachelor's degree**:

Name	Date	Present Position
Eva van Weenen	31/01/17	MSc Astronomy, Leiden
Lennart Prins	31/05/17	MSc Astronomy, Leiden
Marit Mol Lous	30/06/17	MSc Astronomy, Leiden
Tom Sweegers	30/06/17	MSc Astronomy, Leiden
Erik Weenk	30/06/17	MSc Astronomy, Leiden
Olivier Aartsen	31/07/17	MSc Astronomy, Leiden
Joey Braspenning	31/07/17	MSc Mathemetical and Theoretical Physics, Oxford
Robbie Brooymans	31/07/17	MSc Astronomy & Particle Physics, Barcelona, Spain
Auke Bruinsma	31/07/17	MSc Aero Space Engeneering, Spaceflight, T.U. Delft
Christian van Buchem	31/07/17	MSc Astronomy, Leiden
Lisa Dombrovskij	31/07/17	MSc Astronomy, Leiden
Bart Eggen	31/07/17	MSc Mathematics, Leiden
Fedde Fagginger Auer	31/07/17	MSc Astronomy, Leiden
Daniel Gomon	31/07/17	MSc Mathematics, Leiden
Len Hartsuiker	31/07/17	MSc Astronomy, Leiden
Hidde Jense	31/07/17	MSc Astronomy, Leiden
Bouke Jung	31/07/17	MSc Physics, Amsterdam
Margot Leemker	31/07/17	MSc Astronomy, Leiden
Michelle Mertens	31/07/17	MSc Physics, Leiden
Jelle Mes	31/07/17	Msc Astronomy, Leiden

Name	Date	Present Position
Jessamy Mol	31/07/17	MSc Particle Physics, Lund, Sweden
Erik Osinga	31/07/17	MSc Astronomy, Leiden
Lisa Pothoven	31/07/17	MSc Mediatechnology, Leiden
Youandi van der Tang	31/07/17	MSc Aero Space Engeneering, Spaceflight, T.U. Delft
Jonah Wagenveld	31/07/17	MSc Astronomy, Leiden
Joost Wardenier	31/07/17	MSc Astronomy, Leiden
Rosalie van Wetten	31/07/17	MSc Astronomy, Leiden
Martijn Wilhelm	31/07/17	MSc Astronomy, Leiden
Joris Witstok	31/07/17	MSc Astrophysics, Cambridge, UK
Daan Fuldner	31/08/17	MSc Physics, Oxford, UK
Roel Knol	04/09/17	Job searching
Paul Couzy	29/09/17	MSc Astronomy, Leiden

MSC DEGREES

The following **20 students** were **awarded Master's degrees**:

Name	Date	Present Position
Vikram Radhakrishnan	31/01/17	PhD at Leiden Observatory
Alex Pietrow	30/06/17	PhD at Lund, Sweden
Patrick Dorval	30/06/17	PhD at Leiden Observatory
Andrew Barr	31/07/17	PhD at Leiden Observatory
Aswin Payyoor Vijayan	31/07/17	PhD at the University of Sussex in United Kingdom
Bas Zoutendijk	31/07/17	PhD at Leiden Observatory
Christine Wilson-Rogers	31/07/17	Job searching
Dieuwertje van der Vlugt	31/07/17	PhD at Leiden Observatory
Dilovan Serindag	31/07/17	PhD at Leiden Observatory
Eimear Oreilly	31/07/17	Job searching
Gonzalo Fernandez	31/07/17	Consultant European Patent Office
Hiddo Algera	31/07/17	PhD at Leiden Observatory
Iva Laginja	31/07/17	Research and Instrument Analyst at Space Telescope Science Institute
Jurrien Huisman	31/07/17	Job searching
Louis Cheung	31/07/17	Job searching
Martijn Oei	31/07/17	MSc Applied Mathematics Cambridge
Olivier Burggraaff	31/07/17	PhD at Leiden Observatory
Omar Contigiani	31/07/17	PhD at Leiden Observatory
Steven Bos	31/07/17	PhD at Leiden Observatory
Tom Warmerdam	31/08/17	Job searching

Outreach and popularisation

Pre-university programme

LAPP-Top, the Leiden Advanced Pre-University Programme for Top Students, is aimed at enthusiastic and ambitious high school students from the 5th and the 6th grade. Candidates are selected on the basis of their high school grades and their enthusiasm to participate, as shown by a letter of motivation. Students that are selected then take part in 6 to 8 meetings from January till May, following the programme of their own choice.

The Sterrewacht has been participating in the LAPP-TOP programme since its start in 2001. In that pilot year 5 students participated, growing to an average of 28 students over the years. In eight sessions the following subjects were covered: The Milky Way and other galaxies, Extrasolar planets, Building molecules and planets in the universe, Practicum I + II, Black Holes, Cosmology and an excursion to the radio telescopes in Westerbork and Dwingeloo.

After successfully completing the programme participants have been awarded a certificate from the University of Leiden. High school students are allowed to use this project as part of their final exams.

Contact.**VWO**

Contact.VWO (Contact-punt-VWO) is the liaison between pre-university education and the Departments of Astronomy and Physics at the University of Leiden. It supports both teachers and their students with various activities. Since the start in 2008, Contact.VWO has built a significant network of more than 500 teachers over the entire country, through which a multitude of high school students is reached. Various activities are defined through which this network is fed:

- **Teacher meetings:** These meetings are organized three times per year, according to a fixed format: Start at 17:00, end at 20:30. The meetings start with a plenary session, a scientific contribution from one of the staff members. This is followed by a dinner. The evenings continue with a plenary session with many smaller contributions. Meetings are attended by seventy participants on average.
- **Einstein's Birthday:** We celebrate Einstein's birthday (March, 14th) with a seminar for both teachers and their best students. We welcome our visitors with challenging scientific contributions from the staff, followed by lab visits (30 teachers; 80 students).

- **HiSPARC:** This is the Dutch project for high-energy physics and cosmology education which is an optional subject in the new physics curriculum for pre-university levels. Contact.VWO is a regional partner for this project. We support more than ten schools in our network.
- **Profielwerkstuk support:** For their final assignment (profielwerkstuk) high school students spend 80 hours researching a field of their interest. Highly motivated students can apply for our support. Yearly we coach about 50 high school students with a subject in physics or astronomy.
- **Experiments for Quantum-world:** Recently, the physics curriculum for pre-university level has been renewed. It now includes sections on quantum-world and astronomy, including radiation processes. We designed a set of fifteen challenging experiments to support these new subjects. We use professional equipment that is not generally available for high schools. The experiments can be performed by individual students, or by a visiting class.
- **Visits of school classes:** Contact.VWO has two programs in which visiting school classes can perform a practical assignment. “Discover Exoplanets” and “Quantum World”. We include a lunch seminar in these visits. These seminars are given by PhD students. This year more than twenty schools visited these programs.
- **Posters:** Twice a year 250 schools in our region receive two posters. The posters highlight a research novelty and announce upcoming events.

Astronomy & Society Activities

The aim of the Astronomy & Society Group is to foster Leiden Observatory's mission to engage the Dutch, European and global audiences with the wonders of the Universe and share the scientific, technological, cultural and educational aspects of astronomy with society.

Leiden Observatory - Visitor Centre

The visitors center of the Leiden Observatory is open 3 days a week: Wednesdays, Saturdays and Sundays.

The visitors center, along with the historic telescopes available in the building, were also opened during several nights in 2017 for special events such as Museumnacht, Midzomernacht, and De Nacht van Kunst & Kennis. These events drew large crowds, averaging one thousand visitors per night.

During the open day on October 29th, more than one thousand people came to the Old Observatory to enjoy talks, tours and workshops. Compared to previous years, a number of new activities were introduced. These included a radio play by journalist Maartje Duin and talks by Astronomy on Tap.

The historic building has also maintained a strong presence on the social media platform Facebook, reaching a total of 1513 likes[1], a 30% increase compared to 2016.

1 As of December 31st, 2017.

Universe Awareness

Universe Awareness engages with children aged 4 to 10 years (particularly those from underprivileged communities). The program provides educational resources, teacher trainings and student ambassador programs in more than 63 countries worldwide.

In 2017, Universe Awareness became one of the most innovative programmes in Education Worldwide. At the HundrED Innovation Summit in October 2017, Universe Awareness (UNAWE) was officially announced as one of the HundrED's 100 Global Inspiring Innovations in Education.

HundrED's mission is to help schools evolve by seeking and sharing inspiring innovations in K12 education. Without inspirational innovators, such as Universe Awareness, education wouldn't continue to improve and thrive, often in the face of adversity. UNAWE uses the beauty and the enormity of the Universe to inspire young children. The aim is twofold: to show children that science and technology are exciting and to foster the spirit of world citizenship.

To announce the 100 innovations, HundrED organised a high profile, invitation only summit in Helsinki, Finland, for the world's leading education innovators. Universe Awareness uses an innovative approach to ensure that that teachers and parents around the world will have excellent educational material available for making children aware of the Universe in which we live and achieving its two goals.

On 1-2 April 2017, Universe Awareness organised workshops at Rabobank Westelijke Mijnstreek in Sittard (Limburg) for 70 children between the ages 4 to 13 by invitation of a non-profit in the south of the Netherlands. The workshops were given in celebration of the Global Money Week (GMW). In addition, more than 30 parents and visitors were reached with the topics of space and astronomy.

Space Scoop, a news service about astronomy for children, published 29 articles ('Space Scoops') on www.SpaceScoop.org, www.unawe.org and www.space-awareness.org. Space Scoops were published in 23 languages by more than 40 volunteers.

Space Awareness

The science education project Space Awareness engaged 230,000 people in 68 countries with the excitement and challenges of space sciences and technologies. After three years, the project coordinated by Leiden Observatory came to an end in March 2018 and has now been evaluated by the European Commission.

The project aimed to raise the interest of young people in science, technology and career opportunities offered by the space industry. Space Awareness created and implemented 160 activities, such as local teacher trainings, Massive Online Open Courses (MOOCs), an international Space Education Conference and 2 summer schools. Partners from 23 countries across Europe and Africa participated in the project.

In total, the Space Awareness team developed and distributed 305 high quality educational resources. Some examples include:

The Climate Box: a low cost, hands-on educational toolkit that teaches children about our climate, climate change and the habitability of other planets.

The Journey of Ideas: a toolkit that showcases the history and accomplishments in the fields of science and technology from several cultures from the ancient Islamic World. This innovative tool tells the story of a shared history based on creativity, tolerance and respect for other cultures. Furthermore, it provides hands on educational resources to familiarise teenagers with the immensely important contributions that scientists from North Africa and the Middle East made to the field of science and culture. The Journey of Ideas is an important tool in fulfilling one of the goals of the project: to stimulate European and global citizenship.

Four Massive Online Open Courses (MOOCs) were organised to train teachers. The team delivered the MOOCs to more than 2,400 educators from 68 countries.

Space Awareness hosted a 5-day International Space Education conference in 2016, in collaboration with the European Space Agency and the Galileo Teacher Training Programme. This event brought together almost 100 professional educators, engaging them through presentations and workshops.

Space Awareness has shown that space is an extremely effective tool for motivating and educating children and teenagers, fostering fundamental values of tolerance and engaging the public in science, technology and innovation. Such public engagement also helps to inform the public that support for scientific research and technological innovation are important for the future of our society.

IAU astroEDU

During 2017, astroEDU went through a major revamp with the recruitment of a new editor-in-chief for the project. The call for editor-in-chief position received 20 top applications from around the world, making for a competitive selection process. Since the appointment of the editor-in-chief, the project improved its activity submission process and review methods, which helped to increase the quality of the content. astroEDU collaborated with the Space Awareness project and Europlanet to review their activity sets. The topics included planetary science, earth science, geology, among others. This wider scope of topics beyond astronomy gathered more traffic and experts to the project. The platform had 44,968 views, while 80 experts scientists and educators joined as volunteers to support the peer review process.

Open Science Hub

In July 2017, the Astronomy & Society Group opened the first Open Science Hub to engage rural communities with science, Technology and Innovation.

The first location of the Open Science Centre network, Plataforma de Ciência Aberta, opened during the StixCamp workshop 2017 in Figueira de Castelo Rodrigo, Portugal. The Portuguese Minister of Economy, Manuel Caldeira Cabral and the State Secretary of Science, Technology and Higher Education, Fernanda Rollo, inaugurated the Platform, which is a collaboration between Leiden University and the municipality of Figueira de Castelo Rodrigo. On 6 July, in Figueira de Castelo Rodrigo in Portugal, local citizens, scientists, science communicators and educators gathered with representatives of local and national governments, to discuss the role of science, technology and innovation on the development of rural communities at StixCamp workshop 2017.

The 4 day programme offered panel discussions with engaging speakers working in the areas of science, technology and innovation and informal 'unconference sessions'.

Plataforma de Ciência Aberta maintains the historic architecture of the former school building.

On 7 July 2017, the Portuguese Minister of Economy, Manuel Caldeira Cabral, officially opened Plataforma de Ciência Aberta, the first Open Science Centre. The minister added: "This important infrastructure generates value for tourism, a key sector for this region, and creates impact in the surrounding communities through innovation." The Open Science Centre shares the vision of Universe Awareness of "inspiring every child with our Wonderful Universe." The OSC are equipped with UNAWE resources, like Earth Balls and Universe in a Box.

Plataforma de Ciência Aberta is located in an upcycled school building in Barca d'Alva, next to the Douro river, and combines modern design with historic architecture. The Open Science Centre will support the surrounding schools and their communities in co-creating solutions for local challenges using Science, Technology, Engineering, Arts and Mathematics (STEAM).

During the opening, visitors explored the new building, a temporary exhibition on Insect classification and identification, and the new makerspace of the Open Science Centre. During the panel discussion at the end of the day, the Secretary of State of Science, Technology and Higher Education, Maria Fernanda Rollo, expressed her support of the project and announced the intention to allocate additional resources to stimulate Open Science practices on a national level through local initiatives.

Plataforma de Ciência Aberta fosters collaboration between schools, local government, enterprises, research institutes, civil society and community at large to tackle local challenges. According to Figueira de Castelo Rodrigo mayor Paulo Langrouva, "Projects like these add value to the community of Figueira by bringing science, technology and education to the local communities, creating a sustainable environment for future generations."

The Plataforma de Ciência Aberta is part of the international Open Science Centre network of STEAM learning spaces in rural communities, coordinated by Leiden University (through Leiden Observatory, Astronomy & Society Group). Plataforma de Ciência Aberta is a collaborative project of Leiden University (the Netherlands) and the municipality of Figueira de Castelo Rodrigo in Portugal.

Social
Networking

L.A.D. **"F. Kaiser"**

The Leidsch Astronomisch Dispuut "Frederik Kaiser" is the society for Leiden astronomy students, named after the founder of the historic observatory building in the centre of Leiden. It is part of De Leidsche Flesch, the student association for Physics, Astronomy, Mathematics, and Computer Science. Kaiser strives to promote integration between students and staff at the Leiden Sterrewacht by organising social activities. In addition, Kaiser facilitates practical observing sessions using the historic telescopes of the old observatory, and is active with outreach events.

Social events

Very popular is the annual football tournament, which includes teams from both observatory staff and students. Kaiser also organizes student dinners, movie nights, excursions, and a series of lunch talks like a lecture by VO-S to get closer ties between students and alumni and to give students an opportunity to think about what they want to do after their studies.

Kaiser also organises very successful observing events at the Old Observatory with the historic telescopes. This is done by the Observing Committee, who organises as many observing nights as the weather will allow.

Outreach

L.A.D. 'F. Kaiser' trains the students that perform tours through the historic observatory. In order to keep the tours up to date and find new material, Kaiser also has a Historical Committee, who studies the institute archives and interviews older Astronomers to find more information about the history of the observatory. The tour guides, along with other members, also form the backbone of the organisation of major public events at the observatory, such as the annual Nationale Sterrenkijkdagen (National Stargazing Nights), and the Nacht van Kunst en Kennis (Night of Art and Knowledge).

The Kaiser Spring Lecture Committee also organised the fifth edition of their annual public lecture series, de Kaiser Lente Lezingen, also at the Old Observatory. The lectures were given by Prof. dr. Malcolm Fridlund, Dr. Fred Jansen, Drs. Arno Wielders and Dr. Angelo Vermeulen, and over 300 tickets were sold. The Committee consisted of Dennis Vaendel (president), John Hefele (treasurer), Michelle Willebrands (assessor PR) and Vikram Radhakrishnan (assessor Speakers).

The 2016/17 board consists of Olivier Burggraaff (chairman/treasurer), Joey Braspenning (secretary), Lennart van Sluijs (assessor Old Observatory) and Cameron Mackie (assessor Outreach). The 2017/18 Kaiser board consisted of Julia Wasala (chairman/assessor Old Observatory), Kira Strelow (vice chairman/assessor Old Observatory), Rutger Rijnenberg (secretary), John Hefele (treasurer) and Vikram Radhakrishnan (assessor Outreach).

The Kaiser board of 2017.

VO-S, the Leiden Observatory **Alumni Association**

The Vereniging van Oud-Sterrewachters ("VO-S") is the Leiden Observatory alumni association. In 2017 several events have been organised, including our annual meeting at Anton Pannekoek Institute and mentoring students who consider a career outside astronomy.

Studying or working at Leiden Observatory is an unforgettable experience to many with the exciting discoveries of astronomy on one side, and the strong social aspects on the other. Fuelled by the early participation of students in astronomical research and the lively social interaction in this relatively small, international community then it should come as no surprise that when (under)graduates or staff leave Leiden Observatory to pursue (career) life elsewhere, good memories often remain of this special period in life.

The alumni association VO-S aims at bringing our alumni together and keeping these ties alive, both on the social level as well as feeding the general interest in scientific research. As such it serves as a network between alumni and the institute. Activities comprise of the both social and science-related events. The association has nearly 150 members, with membership open to all Leiden Observatory alumni and staff.

Social events

2017 has been another busy year with a variety of activities for alumni organised by our organisation. In May, some 15 alumni joined for drinks at café Barrera, prior to the Oort lecture by Prof. Imke de Pater. At the Academy building, she shared the latest research developments in planetary science.

In early July, some our alumni convened in front of the Oort building to join the annual Observatory barbeque event and mingled with students and staff.

Our annual meeting was held at the Anton Pannekoek Institute at the Science Park in Amsterdam. We were welcomed by the institute director and Leiden alumnus, prof. Ralph Wijers. He looked back on the history of his institute and the life of its founder. After that, three staff members presented their research, specifically on fast radio bursts.

Erwin van Soest was thanked for his contributions over many years, when he stepped down as member of the VO-S board. Afterwards we enjoyed conversations over drinks in the autumn sun at a nearby pub.

Other activities

We proceeded with our mentoring of individual students. The sizeable VO-S network serves here as a source of inspiration for those who consider a career outside astronomy.

Communication with our members on the latest research in astronomy and our upcoming activities took place via www.vo-s.nl, our newsletter and by e-mail. We thank the Marcom team of the Faculty of Science for their ongoing support in updating our website and preparing our newsletters.

Join the VO-S

For contact and membership of our alumni association: visit our website: www.vo-s.nl or send an email to: vo-s@strw.leidenuniv.nl.

VO-S Committee:

Chair: Niels van Weeren
Secretary: Gerben Zwart
Treasurer: Yuen Ng
Liaison: Anthony Brown

VO-S annual meeting

Organization

Observatory **Staff**

Full professors

Prof.dr. B.R. Brandl
Prof.dr. E.F. van Dishoeck
Prof.dr. M. Franx
Prof.dr. C.U. Keller
Prof.dr. K.H. Kuijken
Prof.dr. H.V.J. Linnartz
Prof.dr. F.H. van Lunteren
Prof.dr. S.F. Portegies Zwart
Prof.dr. H.J.A. Rottgering
Prof.dr. J. Schaye
Prof.dr. I.A.G. Snellen
Prof.dr. A.G.G.M. Tielens
Prof.dr. P.P. v.d. Werf
Prof.dr. P.T. de Zeeuw

Affiliate professors

Prof.dr. D. van Delft
(Stichting tot beheer Museum boerhaave, Directeur Museum Boerhaave)

Prof.dr. N.J. Doelman
(J.H. Oortfonds, TNO)

Prof.dr. P. Ehrenfreund
(CEO, German Aerospace Center)

Prof.dr. M. Fridlund
(J.H. Oortfonds, staff scientist ESTEC/ESA)

Prof.dr. M.A. Garrett
(Jodrell Bank Centre for Astrophysics)

Prof.dr. J.S. Kaastra
(Senior scientist SRON)

Prof.dr. H.J. van Langevelde
(JIVE Dwingeloo)

Associate and **Assistant** Professors, **Senior** Researchers

Dr. R.J. Bouwens
Dr. J. Brinchmann
Dr. A.G.A. Brown
Dr. M.P. van Daalen
Dr. J.A. Hodge
Dr. H. Hoekstra
Dr. M.R. Hogerheijde
Dr. M.A. Kenworthy
Dr. A. Patruno
Dr. E.M. Rossi
Dr. P.M. Rodrigues Dos Santos Russo
Dr.ir. F. Snik
Dr. R. Stuik
Dr. R.P.J. Tilanus
Dr. R.J. van Weeren

Emeriti

Dr. A.M. van Genderen
Prof.dr. H.J. Habing
Prof.dr. V. Icke
Prof.dr. F.P. Israel
Prof.dr. W.J. Jaffe
Dr. J. Lub
Prof.dr. G.K. Miley
Drs. R.S. le Poole

Postdocs / Project **personnel** / longterm **visiting** Scientists

Dr. F.J. Alonso Floriano
Dr. J.I. Bailey III
Dr. J. Bedorf
Dr. M.A. Bilicki
J. de Boer MSc
Dr. J. Bouwman
Dr. H. Buddelmeijer
Dr. M. Cacciato
Dr. X. Cai
Dr. A. Candian
Dr. Y.A. Contreras Morales
Dr. C.A. Correa
Dr. E. Costantini

Dr. G. Costigan

P. Dabhade MSc

Dr. C.R. D'Angelo

Dr. M.N. Drozdovskaya

Dr. K.J. Duncan

Dr. M.B. Eriksen

Dr. V. Van Eylen

Dr. T.A. Fernandes Gomes Da Costa

Dr. M. Fumagalli

Dr. C.J. Garcia Vergara

Dr. F. de Gasperin

Dr. C. Ginski

Dr. I.R. Guerra Aleman

Dr. S. Guha Niyogi

Dr. L. Guzman Ramirez

Dr. A. Hacar Gonzalez

Dr. D.S. Harsono

Dr. A.N. Heays

Mr. E.M. Helmich

E.C.J. Hendriks MSc

Dr. B.W. Holwerda

P.W. Hoogendoorn

Dr. A.P. Hypki

Dr.ing. H.T. Intema

Prof.dr. C.A. Jackson

Dr. L. Jilkova

Dr. S. Jin

Dr. J.T.A. de Jong

Dr. M. Kama

Dr. J.K. Katgert-Merkelijn

Dr. M. Kazandjian

Dr. A. Kannawadi Jayaraman

Ing. J.N.M. Kommers

Dr. I.F.L. Labbé

Dr. A. Lesage

Dr. N. Lopez Gonzaga

Dr. S.I. Loubser

Dr. L.T. Maud

Dr. J.A. Meisner

Dr. E.P. Monaghan

Dr. S. Muzahid

Dr. G.P.P.L. Otten

Dr. J.B.R. Oonk

Dr. D.M. Paardekooper

Dr. M.V. Persson

Dr. A. Petrignani

Dr. P.A. Pinilla Ortiz

Dr. S. Plöckinger

Prof.dr. S.M. Pompea

Dr. E.E. Rigby

Dr. A.J. Rimoldi

Dr. K.J. Rosdahl

Dr. D.R. Serrano Goncalves Sobral

Dr. C. Schreiber

Dr. T.W. Shimwell

Dr. J.F.P. Spronck

Dr. M. Stefanon

Dr. I.M. Stewart

Dr. L.A. Straka

S. Sultan

Dr. V.D.F. Taquet

Dr. J.J. Tobin

Dr. S.G.M. Toonen

Dr. M.C. Toribio Perez

Dr. M. Velliscig

Dr. M. Viola

Dr. C. Walsh

Dr. I. Yoon

Dr. J. Zhen

Promovendi

A.S. Abdullah MSc

J. Albert MSc

H.E. Andrews Mancilla MSc

X. Bacalla MSc

C.R. Barber MSc

R.E. v.d. Berg MSc

J. de Boer MSc

E.G. Bogelund MSc

C.A. Bonnerot MSc

L.A. Boogaard MSc

A.D. Bosman MSc

S. v.d. Broek MSc

M.M. Brouwer MSc

G.E. Calistro Rivera MSc

M.T. Carney MSc

P. Castellanos Nash MSc

P. Cazzoletti MSc
Guest

K. Chuang MSc

B.J.F. Clauwens MSc
Guest, LION/STRW

F.A. Concha Ramirez MSc

V. Cordeiro de Sousa Santos MSc
Externally funded

P. Dabhade MSc
Guest

Di Gloria MSc

D.S. Doelman MSc

K.D. Doney MSc

G.C. Dufour MSc

A. Dvornik MSc

C.L. van Eck MSc

C. Eistrup MSc

Ir. A.K. van Elteren

K.L. Emig MSc

M.C. Fortuna MSc

B.E. Fournier MSc

J. Franse
Guest, LION/STRW

C. Georgiou MSc

C. Giese MSc

S.Y. Haffert MSc

S. Heikamp MSc

E. v.d. Helm MSc

E. v.d. Helm MSc

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Dr. D. Harsono

Science policy functions and University Committee Memberships

Dr. R.J. Bouwens

- SOC member for the Rise and Shine Meeting, Strasbourg, France
- Member, BUFFALO team
- Member, MUSE GTO team
- Member, XDF team
- Deputy Coordinator, Euclid Science Ground Segment, OU-NIR

Prof.dr. B.R. Brandl

- Member of the ESO's ELT Project Science Team
- Principal investigator (PI) of E-ELT/METIS
- Chair, SOC, "Science Enabled by Novel Infrared Instrumentation"

Dr. J. Brinchmann

- Co-chair, Euclid Galaxy & AGN Evolution Science Working Group
- Co-chair, Euclid Consortium: Legacy science
- Member, Euclid COMS Group
- Member, Euclid Calibration Working Group
- Member, Euclid Archive User Group
- Member, Euclid Diversity Committee
- Member, Euclid Editorial Board
- Member, MUSE Science Team
- Chair, MUSE Data management group
- Member, James Webb Space Telescope Data Processing Working Group
- ATLAS spectroscopic survey telescope project (proposed to NASA)
- Leids Kerkhoven-Bosscha Fonds: Secretary/treasurer
- Leids Sterrewacht Fonds: Secretary/treasurer
- Leiden University Funds International Student Grant board: member
- Examencommissie, Leiden Sterrewacht: member

Dr. A.G.A. Brown

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- Member, Gaia Science Team
- Principal Investigator, Gaia/Netherlands
- President, IAU Commission A1
- Member, Steering Committee IAU Division A
- Associate Member, International Earth Rotation and Reference Systems Service
- Member, Executive Board GENIUS FP7-Space Collaborative Project
- Member, NOVA Instrument Steering Committee
- Faculteitsraad

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- Scientific Director, Netherlands Research School for Astronomy (NOVA)
- President-elect, IAU
- Co-Editor, Annual Reviews of Astronomy & Astrophysics
- Member, National Committee on Astronomy (NCA)
- Chair, A-ERC PE9 panel
- Co-PI, European JWST-MIRI consortium
- Coordinator, Fundamentals of Science profile area Leiden University

Prof.dr. M. Franx

- Member, KNAW
- Member, Nova Research Committee
- Member, NWO Middelgroot beoordelings commissie Exacte Wetenschappen
- Member, NIRSPEC/JWST Instrument Science Team
- Member, Lega-C team
- Co-PI, Ultravista Survey
- Member, MUSE Science Team
- Director, Leids Kerkhoven Bossche Fonds

Prof.dr. M. Fridlund

- Member, CHEOPS Science Team

Dr. J.A. Hodge

- Member, NL-LAC
- Member of SOC for SMG20 conference
- Member of SKA Extragalactic Spectral line working group
- JCMT Large Proposal Referee
- Member, Origins Space telescope Galaxy Evolution Science Working Group
- Member, Next Generation Very Large Array (ngVLA) High-redshift Universe working group
- Member, ESO OPC
- Member of Diversity committee

Dr. H. Hoekstra

- Member, NWO Vidi committee
- NOVA NW1 deputy coordinator
- Euclid Cosmology Coordinator
- Member, Euclid Consortium Coordination Group
- Member, Euclid Consortium Editorial Board
- Chair Lorentz Center Astronomy Advisory Board

Dr. M.R. Hogerheijde

- Member, MATISSE Science Group
- Member, European ALMA Regional Center Coordinating Committee
- Program Director, Allegro, European ALMA Regional Center node in the Netherlands
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- Member, Board of Directors, Leids Sterrewacht Fonds
- Member, Board of Directors, Jan Hendrik Oort Fonds

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- Chair, Skepsis Foundation
- Vice-chair Editorial Board `Mare'

Prof.dr. W.J. Jaffe

- Member. VENI selection committee

Prof.dr. J.S. Kaastra

- Principal Investigator, XMM-Newton Reflection Grating Spectrometer (ESA)
- Principal Investigator, Chandra Low Energy Transmission Grating Spectrometer (NASA)
- Chair, Athena science working group WHIM
- Member, Athena XSAT team
- Lead, AGN Science team Arcus
- Member, KRISM Science team
- Editorial board member, Astrophysics & Space Science
- Member, SOC 'ICAMDATA 2018'

Prof.dr. C. U. Keller

- Member of the Board, Isaac Newton Group of Telescopes
- Member, ELT Project Science Team, ESO
- Member, EPA Network Task Group on Citizen Science, European Environmental Agency, Copenhagen, Denmark
- Member, NWO VIDI grant selection committee
- Member, editorial board of the journal Astronomische Nachrichten
- Member of the Board, Europhysics News
- Member of the Board, Isaac Newton Group of Telescopes
- Co-Coordinator NWO program on Planetary and Exoplanetary Science (PEPSci)

Dr. M.A. Kenworthy

- Coronagraph design lead for ERIS
- High Contrast Imaging Lead for METIS
- NASA and NSF reviewer
- Principal Investigator, bRing Project

Prof.dr. K.H. Kuijken

- Scientific Delegate from the Netherlands, ESO Council
- Chair, ESO contact committee
- Member and Vice-chair, Netherlands Committee for Astronomy
- Chair, NWO Exact/Natural Sciences advisory committee for astronomy
- Board member, SRON
- Member, steering committee National Science Agenda, Route “Building Blocks of Space, time and matter”
- Member, KNAW Council voor Natural and Technical Sciences
- Board Member, Physics Society Diligentia (the Hague)
- Lead, Euclid Consortium “Complimentary Observations Group”
- Principal Investigator, ESO KiDS Survey
- Principal Investigator, OmegaCAM project
- Co-investigator, ESO VIKING Public Survey
- Co-investigator, Planetary Nebulae Spectrograph project
- Member of Leiden Latin America/Caribbean Committee

Prof.dr. H.J. van Langevelde

- Member consortium board of directors European VLBI Network
- Member, EC project RadioNet Board
- Member, EC project ASTERICS Board
- Member, EC project AENEAS Board
- Coordinator, EC project JUMPING JIVE
- Member of the Dutch URSI committee
- Member, SKA klankbordgroep NL
- Member, ALMA Scientific Advisory Committee (ASAC)
- Member of the ALMA European Scientific Advisory Committee (ESAC)
- Member, SKA Science Working Group “Cradle of Life”
- Chair, SKA Consortium Board for Signal and Data Transport (SaDT)
- Chairman board of directors Leids Kerkhoven Bosscha Fonds
- Member board of directors Leids Sterrewacht Fonds
- Member board of directors Jan Hendrik Oort Fonds

Prof. dr. H. Linnartz

- Chairman OC Astronomy (Leiden)
- Coordinator 'Solid state theme' NWO-EW/CW 'DAN' (Dutch Astrochemistry Network) / since 2012
- Coordinator 'Detection of Extraterrestrial Biosignatures and Organics' (PEPSci)
- Workgroup leader, FOM group FOM-L-027
- Member, NWO-CW 'Spectroscopy and Theory'
- Member, HRSMC research school / since 2005
- Board member, IAU division 'Laboratory Astrophysics'
- Board member, SOC 'Molecular high resolution spectroscopy symposium'
- Editorial board member 'Journal for Molecular Spectroscopy'
- Co-PI 'Ice Age' – JWST ERS DD program
- International advisory committee ECOSS 2018
- Board member ECLA2019
- Reviewer for numerous Journals and Science Organizations

Prof.dr. F.H. van Lunteren

- Voorzitter bestuur Stichting Historische Commissie voor de Leidse Universiteit
- Voorzitter bestuur Octavie Siegenbeek van Heukelom Stichting, Leiden
- Voorzitter Stevin Centre for the History of Science and the Humanities, Amsterdam
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- Gastschrijvercommissie Universiteit Leiden
- Studium Generale-commissie Universiteit Leiden
- Bestuur Stichting Vrienden van de Leidse Universiteitsbibliotheken
- Advisory editor Isis
- Redactie Nederlands Tijdschrift voor Natuurkunde
- Descartes Centre Utrecht
- Koninklijke Hollandse Maatschappij van Wetenschappen
- Teylers Tweede Genootschap
- Woensdagavond Gezelschap Utrecht
- Historisch Genootschap Amsterdam
- History of Science Society
- Koninklijk Nederlands Historisch Genootschap
- Leescommissie en oppositiecommissie Friso Hoeneveld, Utrecht
- Leescommissie & oppositiecommissie Thomas Mougey, Maastricht

Prof.dr. G.K. Miley

- Member, South African Astronomy Advisory Council
- Trustee, Associated Universities Inc. (Governing body of US NRAO)
- Member, European Research Commission Advisory Panel
- Co-Chair, IAU European Regional Office of Astronomy for Development
- Chair, Greenberg Foundation
- Chair, Organising Committee, Visit to Leiden University and Oort Professorship for South African Minister of Science and Technology, H.E. Naledi Pandor

Prof.dr. S.F. Portegies Zwart

- Member, KHMW
- Chair, AMUSE development team
- Visiting prof. RIKEN, Japan

Dr. P.M. Rodrigues Dos Santos Russo

- President, IAU Commission C2: Communicating Astronomy with the Public
- Member, IAU Division C Education, Outreach and Heritage
- Member, IAU Working Group: IAU 100
- Advisor to Nederlands Space Office about European Commission's Space Programme Committee.
- European Commission's H2020 Expert

Dr. E.M. Rossi

- European leader of the LISA consortium's work package "multimessenger astrophysics"
- Member of the CAN (committee for astroparticle physics in the Netherlands)
- Co-leader of the XIPE's "tidal disruption event" working group

Prof.dr. H.J.A. Rottgering

- PI, LOFAR surveys: Opening up a new window on the Universe.
- Member, Curatorium of the professorship at Leiden University "Experimental Astroparticle physics"
- Member, Science Advisory Committee ASTRON
- Member, LOFAR's NL-LAC, national LOFAR steering committee
- Member, Board LOFAR International Telescope
- Member, Netherlands Committee for Astronomy
- Chair, Board of the Netherlands Research School for Astronomy
- Member, SKA Science working group on radio continuum surveys
- Member, NL-SKA contact committee
- Member, Board Holland Space Cluster
- Member, ALMA Proposal Review panel for Cosmology

- Member advisory board Delft University Space Institute
- Chair, Euclid (ESA's dark energy satellite mission) consortium board
- Member, Leiden university wide committee on the promotion of scientific excellence and talent policy
- Member, Steering Group relocation SRON to Zuid-Holland

Prof.dr. J. Schaye

- Principal Investigator, MUSE QuBES (Quasar Blind Emitter Survey)
- Principal Investigator, EAGLE collaboration (Evolution and Assembly of GaLaxies and their Environments)
- Scientific Editor, Monthly Notices of the Royal Astronomical Society
- Scientific Editor, Scientific Reports
- Member of the steering committee, Virgo Consortium for cosmological supercomputer simulations
- Member of the executive board, MUSE (Multi Unit Spectroscopic Explorer)
- Builder, MUSE GTO team
- Core member, LOFAR Epoch of Reionization science team
- Member, Athena X-IFU science team
- Member, EUCLID cosmological simulations working group
- Member, WEAVE QSO science team
- Member of the board, "Stichting Studiefonds J.C. Kapteyn"
- Member of the board, Pastoor Schmeits prize
- Member, SOC, "What matter(s) around galaxies"
- Member, SOC, "Frontiers of astrophysical modeling"
- Member, SOC, "A Decade of the Star-Forming Main Sequence"
- Member, SOC, "European Week of Astronomy and Space Science"
- Member, SOC, "Intergalactic Interconnections"
- Member, SOC, "IAU Focus Meeting #2: Warm and Hot Baryonic Matter in the Cosmos"
- Member, WeCo (Permanent Committee for Academic Practice)

Prof.dr. I.A.G. Snellen

- Principal Investigator, Multi-site All-Sky CAmeRA (MASCARA)
- Dutch Co-PI, HARPS3 at the INT
- EU FP7 Network progress reviewer
- EU ERC grant proposal referee
- Member, board of Dutch Astronomy Society (NAC)
- Member, METIS Science Team
- Member, PLATO consortium
- Member, HIRES/E-ELT consortium
- Member, NWA, Route 4 committee
- Member of Editorial Board, Zenit

Dr. F. Snik

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- Member, Time Allocation Committee Isaac Newton Group
- Member, De Jonge Akademie

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- Member of the European Space Sciences Committee
- Member KNAW

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- Astronomy board Lorentz Center

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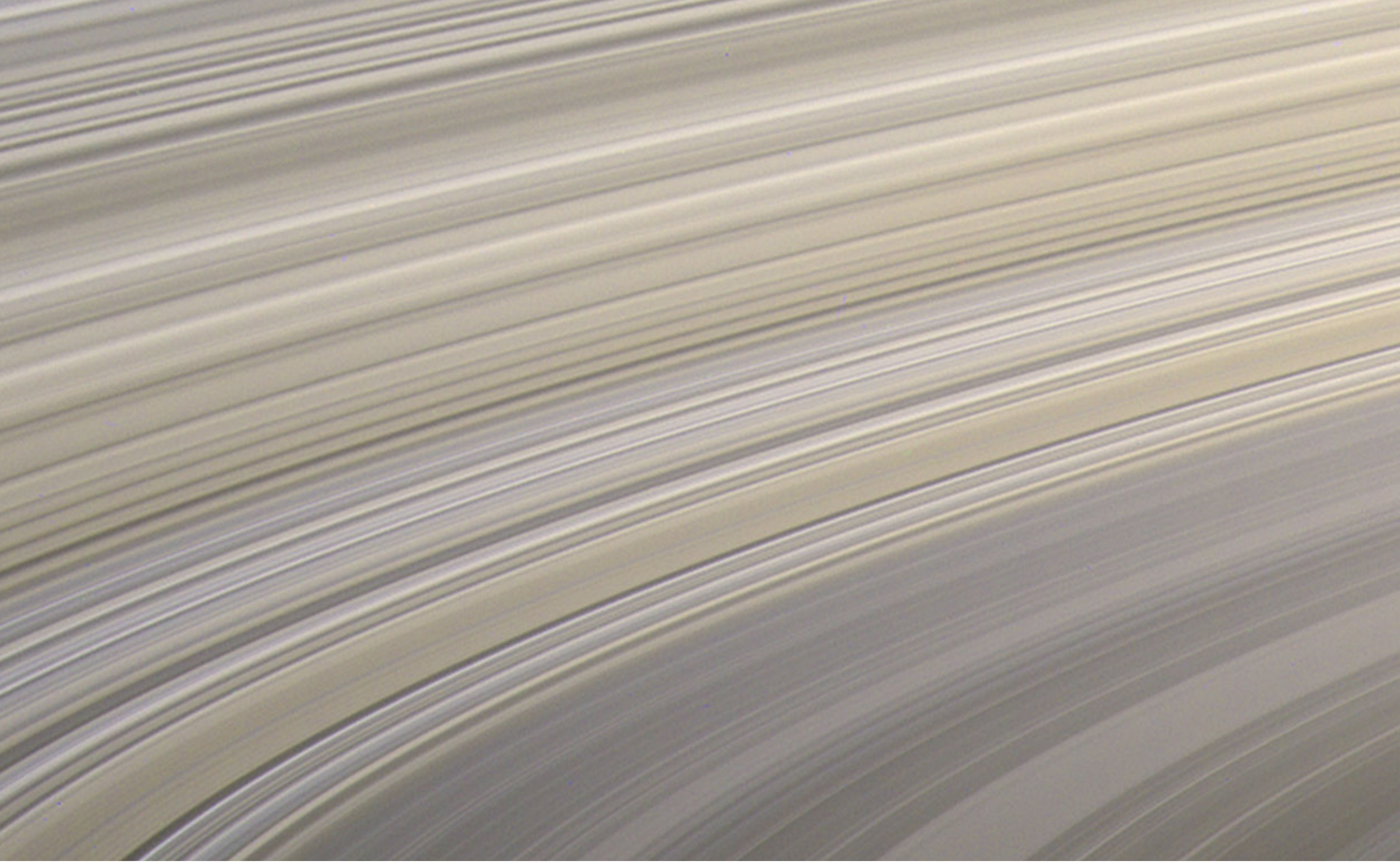
- Co-investigator, MIRI
- Member, METIS Science Team
- Member, STFC Herschel Oversight Committee
- Project Scientist, AMKID submillimeter camera
- Principal Investigator, DESHIMA spectrograph
- SOC Member, Conference "20 Years of Submillimetre Galaxies", Durham (UK)

Grants

P.I.	Funder	Proposal Title	Grant
H. Linnartz	NWO	Molucular Complexity in Insterstellar Ices	212 k€
M. Hogerheijde	NWO	Circumstellar ice and snow lines - Photochemistry at the edge	170 k€
X. Tielens	NWO	Photo-processing, reactivity and spectroscopic characteristics of large PAHs and their derivatives	118 k€
E. van Dishoeck	NWO	Protostellar and protoplanetary disk chemistry: from basic data to astrochemical models	212 k€
C. Keller	NWO	Development of an athermal multi-fiber spectrograph for astronomy and air-quality monitoring	90 k€
J. Bouwman	NWO	Hydrocarbon chemistry under exotic conditions: the case of (exo)planetary atmospheres	800 k€
R. van Weeren	NWO	A Quest to Understand the Universe's Largest Particle Accelerators	784 k€
M. van Daalen	NWO	Cosmic remodelling: How galaxies change the structure of the universe	250 k€
Y. Bahe	NWO	Uncovering the Mechanisms that Drive Galaxy Formation in Massive Clusters	250 k€
M. Schaller	NWO	Evaluating the effect of baryons on cosmological probes with next-generation simulations	250 k€
P. Russo	NWO	Zwaartekracht - een nieuwe ontdekkingsreid	122 k€
R. van Weeren	NWO	Unraveling the mystery of cosmic ray acceleration in galaxy clusters with ultra-low frequency radio observations	260 k€
E. van Dishoeck	NWO	Chemistry from clouds to planet-forming zones of disks with JWST-MIRI	690 k€
S. Portegies Zwart	NWO	Machine learning for accelerating planetary dynamics in star clusters	73 k€
P. Russo	Municipality Figueira/Portugal	Partnership for the promotion of scientific and technological culture for the development of human capital	65 k€
P. Russo	SPIE/USA	International Year of Light	13 k€
M. Rodenhuis	Ministerie van Defensie	Feasibility Study for Optical Tracking of Optical Satellites	35 k€
L. Burtscher	DFG	Towards a comprehensive understanding of the interstellar medium in the extreme environment of Active Galactic Nuclei	55 k€
A. Riedo	EU	Detection of bio-signatures in space research using a new and innovative measurement technique based on laser desorption ionisation mass spectrometry	177 k€
Y. Bahe	EU	Investigating the mechanisms that shape galaxies in and around massive clusters	177 k€
L. Vallini	EU	Deep Investigation on Molecular Processes At early Cosmic Times	165 k€
H. Hoekstra	ESA	Correcting radiation-induced charge transfer inefficiency in CCDs in the context of the Euclid Mission	80 k€
H. Hoekstra	EU	Enabling Weak lensing Cosmology	28 k€
F. Snik	EU	Multiscale Observation Networks for Optical monitoring of Coastal waters, Lakes and Estuaries	498 k€
A. Riedo	ESA	Enhancement of Analytical Protocols for Mars Analogue Aliquots	15 k€



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