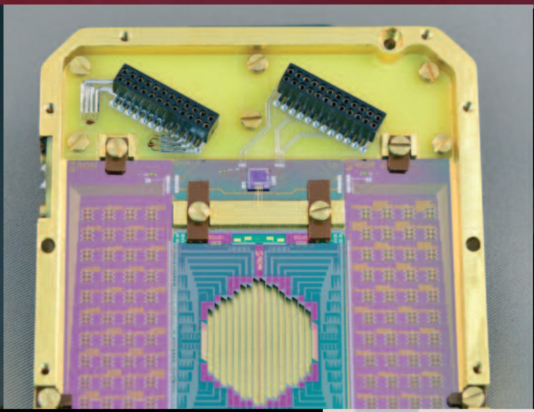
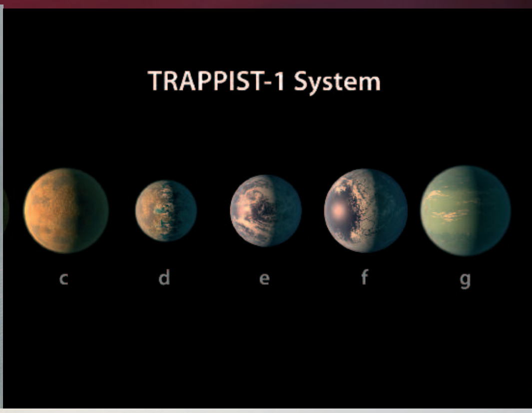
SRON

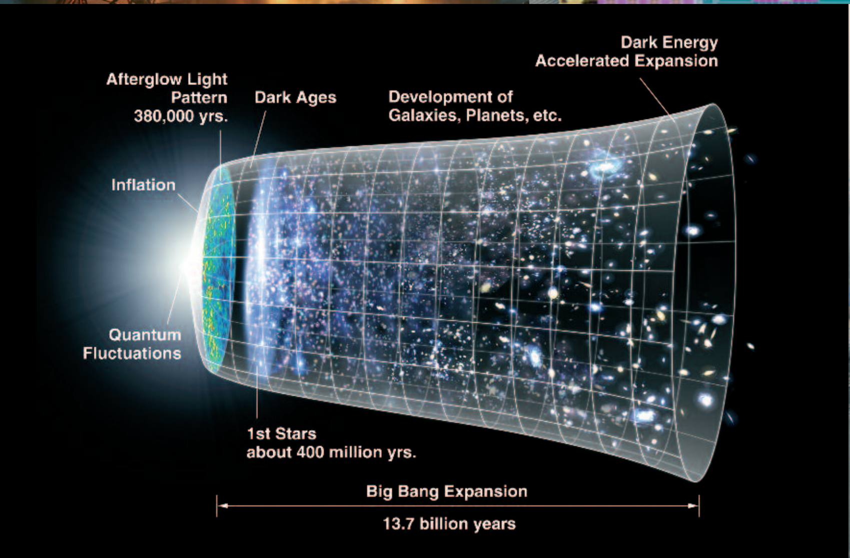
Netherlands Institute for Space Research

Strategy

2017-2023



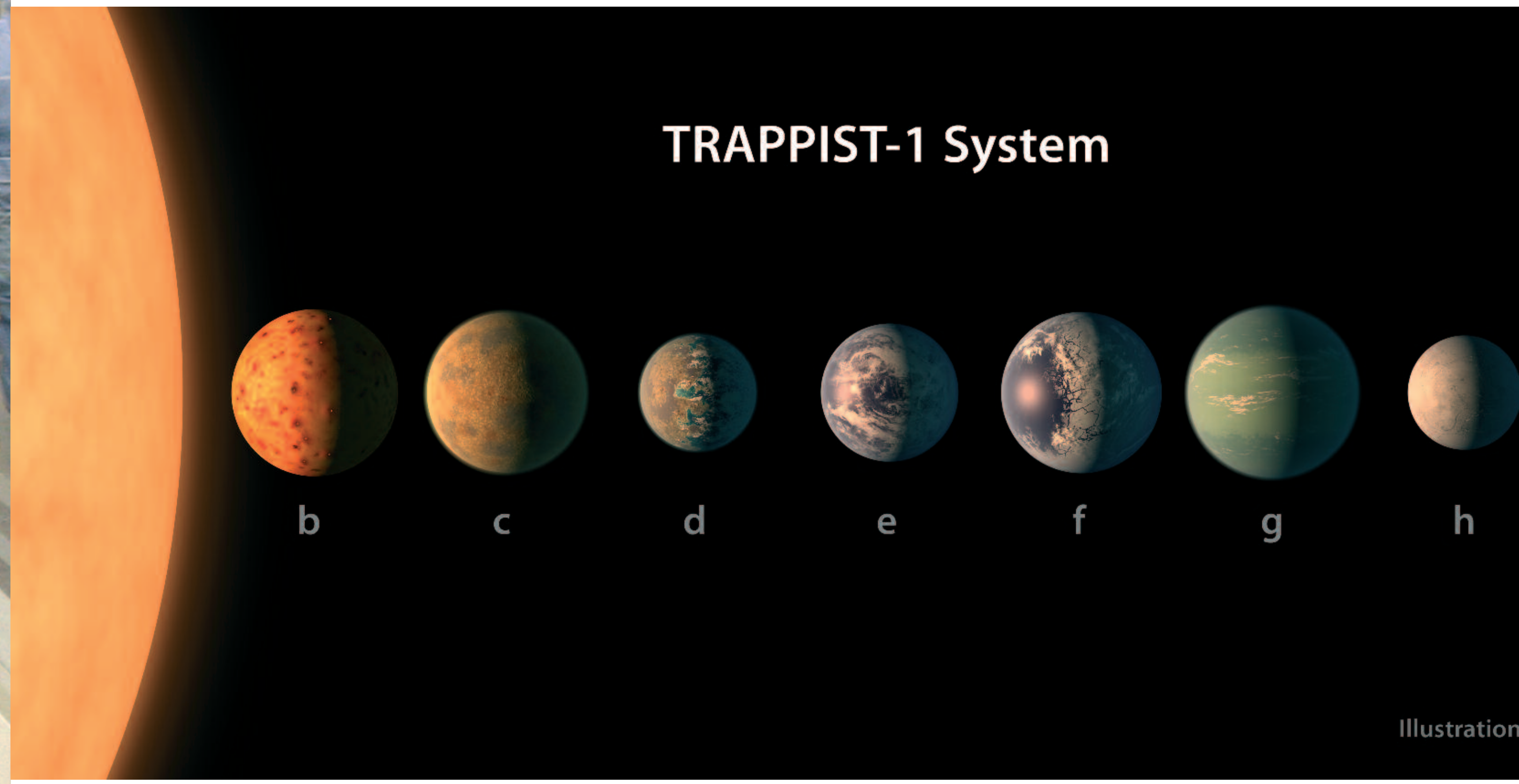




Content

1 Preamble

For the first time in history space missions are being planned that will study the conditions favourable for life on Earth-like planets orbiting other stars, search for the first black holes and galaxies in the universe, and detect gravitational waves from space when massive black holes merge. Other missions monitor with unprecedented accuracy the impact of human activity on the Earth's climate and air quality, which may have a strong impact on the future of mankind. The SRON programme is aimed at these frontiers. Building on more than 55 years of leading roles in international space research, we have charted an ambitious course together with our national and international partners. We develop new key technologies and instruments to enable this research. The transfer to society of the scientific and technological knowledge gained is an integral part of the SRON strategy.



▲ *SRON will study the conditions for life on Earth-like exoplanets. Here we see a size comparison of the planets of the TRAPPIST-1 system, lined up in order of increasing distance from the host star. The planetary surfaces are portrayed with an artist's impression of their potential surface features, including water, ice, and atmospheres. Credit NASA/R. Hurt/T. Pyle.*

◄ *The cleanroom of SRON Utrecht.*

Building on more than 55 years of leading roles in international space research, we have charted an ambitious course.

SRON's mission, vision, and strategy

Space research appeals at the fundamental human desire to explore the unknown and learn more about the world around us. The excitement of discovery is unquestionably connected to space and requires overcoming huge technical challenges. Therefore, worldwide the most innovative countries invest in space research. It attracts students that are educated to provide technical and scientific expertise to society.

SRON's mission is to bring about breakthroughs in international space research
Therefore, the institute develops pioneering technology and advanced space instruments, and uses them to pursue fundamental astrophysical research, Earth science and exoplanetary research. As national expertise institute SRON gives counsel to the Dutch government and coordinates – from a science standpoint – national contributions to international space missions. SRON stimulates the implementation of space science in our society.

SRON is the Dutch national expertise institute for scientific space research. Since the foundation of the institute by university groups, in the early 1960s, we have, often in a leading role, provided key contributions to instruments of missions of the major space agencies, ESA, NASA, and JAXA. These contributions have enabled the national and international space-research communities to explore the universe and to investigate the Earth's atmosphere and climate. As a national expertise institute, we stimulate collaboration between the science community, technological institutes, and industry.

Vision
In our vision the institute continues to belong to the international forefront in search for answers to some of the most fundamental existential and societal questions of mankind: What is the origin of the universe and what is it made of? Is there life elsewhere in the universe? What is the future of the Earth's climate? What are the atmospheric processes that govern changes in the Earth's climate and air quality. What role does human activity play?

Strategy
Our strategy is to develop science cases, key enabling technologies, prototypes/demonstrators, space-qualified instrumentation, and data-analysis tools that will define the next generation of space missions, to be launched in the 2020s and 2030s. This enables us to lead major contributions to answering the fundamental questions of our time. The institute has made sharp choices in its programme based on its strengths, the priorities of the national science community, and the opportunities in international space research. Driven by the Netherlands commitment to the ESA charter, it is our strategy to be principal investigator (PI) or co-PI institute for major instruments on ESA missions.

▼ SRON engineers working on the "molecule hunter" HIFI, the Heterodyne Instrument for the Far-Infrared, one of the three scientific instruments of the Herschel space telescope. Credit Ivar Pel.

► SRON takes part in the search for answers to fundamental existential questions like What is the origin of the universe and what is it made of? Credit NASA.

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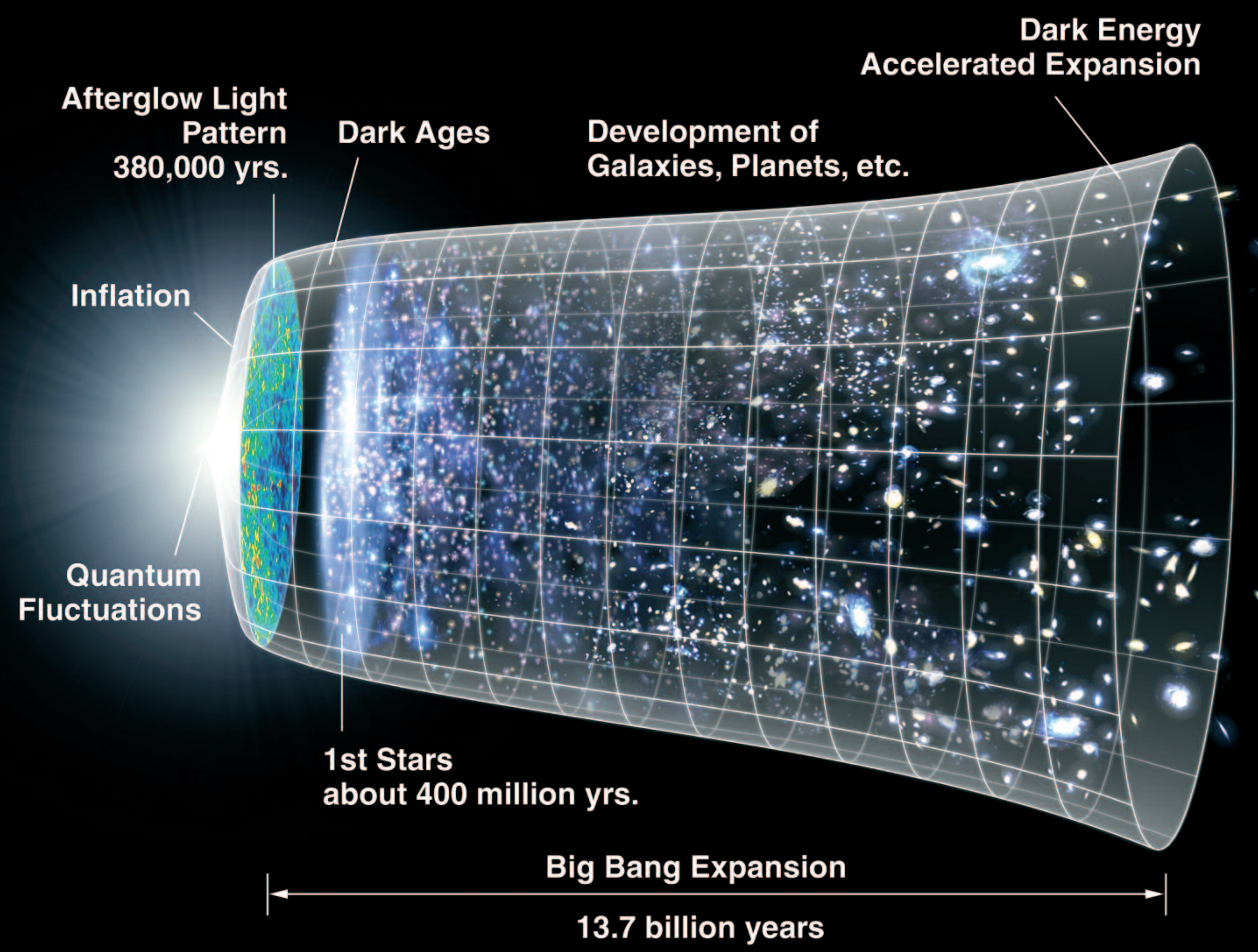


3 SRON's position in space research

3.1 International role

Our playing field is the international big science arena, which is a vibrant national and international interdisciplinary network of space agencies, universities, knowledge institutes, large companies and SMEs. Space agencies such as ESA, NASA, and JAXA provide launch opportunities for selected missions following calls to the science community. SRON helps to shape these costly missions, especially those of the European Space Agency (ESA), by defining science cases, by developing and proto-typing enabling technologies, and by implementing space-qualified instrumentation and data analysis tools.

The Dutch government contributes directly to the mandatory ESA Science Programme (which focuses on astrophysics and solar system exploration) through its ESA membership fee. ESA Member States also provide scientific payloads (instruments) as national contributions to the missions. The ESA Science Programme for 2015-2035, called Cosmic Vision, has large (L, ~1 B€), medium (M, ~500-550 M€), small (S, ~50 M€) class missions and missions of opportunity as its building blocks. The Dutch government also contributes to ESA's optional Earth science programmes. Contrary to the Science Programme the instruments are funded by ESA and are acquired in European competition.

Contributions to international missions

The institute decides to be involved in (ESA) missions (preferably as co-PI or PI) that have a scientific/technological match with the strengths and priorities of Dutch space research. This has proved to be a successful strategy in the past, and we will continue to build on it. Below we give some recent examples.

In 2014 ESA selected Athena as the second flagship (L2) mission of the Cosmic Vision programme. SRON scientists provided compelling examples of science cases for this X-ray observatory based on their work with missions such as XMM-Newton and Chandra (for which SRON provided instruments as PI institute). In addition, the SRON sensor development programme was one of three key enabling technologies in Europe on which ESA based the technical feasibility of the one billion euro Athena mission. SRON is co-principal investigator for Athena's most complex instrument, the X-IFU integral field spectrograph.

Similarly, building on its heritage with ISO and Herschel, SRON has been awarded the international lead in the SPICA proposal for ESA's M5 mission. In this mission, more than ten institutes in Europe, Asia, the US, and Canada, supported by the Japanese Space Agency JAXA, have joined forces.

Building on its track record in SCIAMACHY and TROPOMI, SRON scientists specified the science cases for the near-infrared instrument module for the ESA/EC Sentinel-5 series of instruments. We are directly involved in the definition of the space segment, Sentinel-7, of the first European CO_2 observing system.

3.2 National role

SRON is the main institute for Dutch contributions to the scientific payload of missions in the mandatory ESA Science Programme. As national expertise institute SRON gives counsel to the Dutch government and coordinates – from a science standpoint – national contributions to international space missions. The SRON general director leads the Dutch delegation in the ESA Science Programme Committee (SPC), which decides on the mandatory science programme of the agency, and is an advisor to the Dutch delegation in the ESA Council. SRON is also represented in the advisory structure to the ESA Earth Observation programme board. The NWO executive board has mandated SRON to carry out an advisory role to the Dutch government (the Ministries and Netherlands Space Office, NSO) in the area of scientific space research.

National priorities in astrophysics and exoplanetary science, both from the ground and in space, are discussed and decided within the Netherlands Committee for Astronomy (NCA), in which all universities, SRON, and ASTRON are represented. In Earth-oriented science, SRON and KNMI have taken an initiative to form a similar structure. As a national institute, we collaborate with Dutch SMEs, and larger companies, through co-development and consultancy. SRON also helps SMEs to participate in ESA contracts.

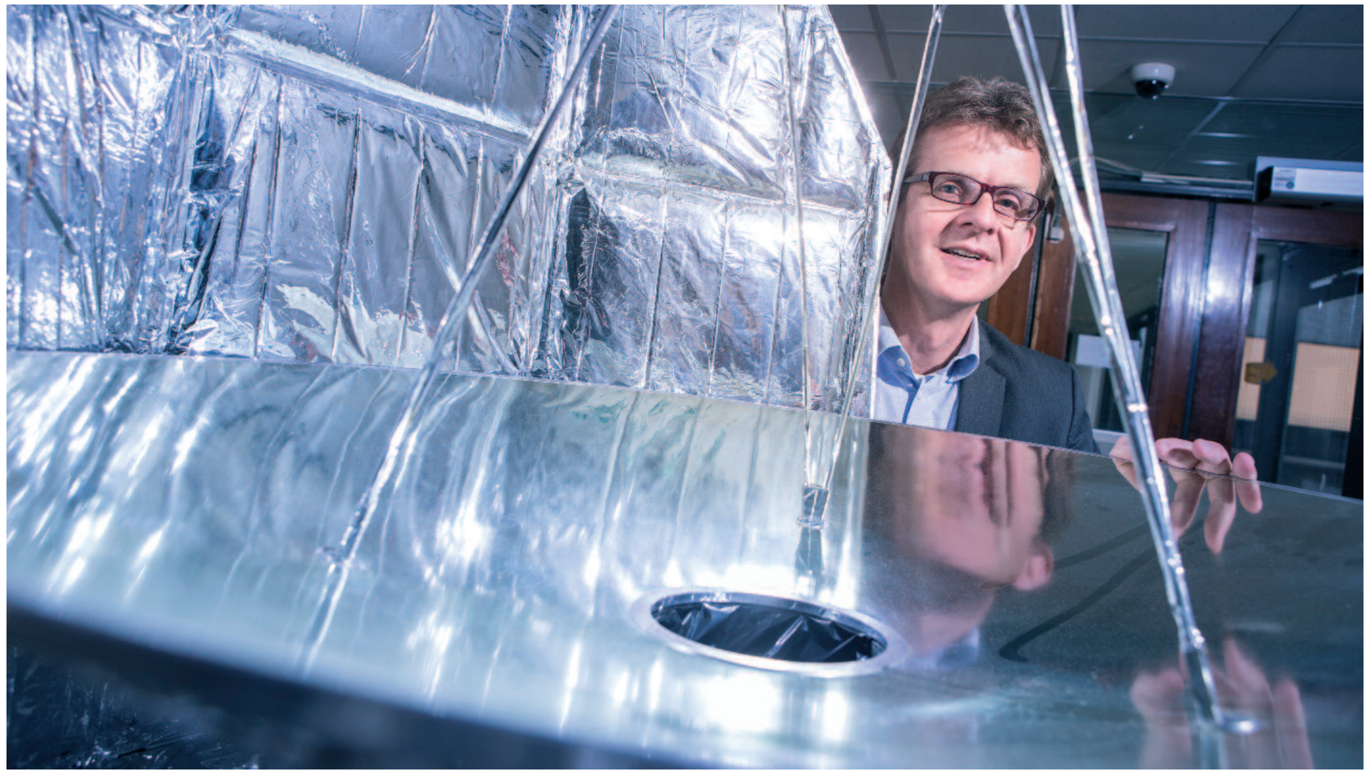
National embedding

The stable embedding as an NWO institute is crucial for accommodating the long timescales in space research (25 years from first idea to launch is no exception). Involvement in space research requires long-term commitments that can build on a track record of quality, reliability and stability. Our involvement in missions of the current and coming decades follows from our track record with precursor missions in past decades, and gives the Netherlands a highly visible role in the international space research arena.

► Artist's impression of the Athena X-ray space telescope. SRON is co-principal investigator for Athena's most complex instrument, the X-IFU integral field spectrograph. Credit MPE and Athena Team.

Our playing field is the international big science arena: a vibrant national and international interdisciplinary network of space agencies, universities, knowledge institutes, industry and SMEs.

In return to SRON's investments Dutch scientists obtain early and/or preferred access to data from international missions.



▲ *The technology contributions and international network of SRON have enabled Dutch scientists to steer scientific capabilities of missions of ESA and other agencies. Credit: Ivar Pel.*

Our scientists and instrument scientists are embedded in general and technical universities, and contribute to research and Master/PhD teaching. They enable, integrate, and coordinate the analysis of mission data with the Dutch scientific community. SRON scientists and scientists at universities are members of science teams and/or advisory groups of missions that SRON is involved in. In return for SRON's investments, these scientists obtain early and/or preferred access to data from these missions, they contribute to the definition of the scientific programme of these missions, and based on that they are well positioned to attract funding. The technology contributions and international network of SRON have enabled Dutch scientists to steer scientific capabilities of missions of ESA and other agencies. Within the ESA Living Planet programme, SRON staff co-steer scientific capabilities of Earth observation missions through their Mission Advisory Group memberships.

National Research Agenda and Top Sectors

The focal points of SRON's research are part of the Dutch National Research Agenda. This agenda, compiled by a bottom-up process initiated by the Dutch government, describes focus areas of Dutch science. SRON scientists are actively involved in shaping this National Research Agenda. SRON coordinates Route 4, The Origin of Life on Earth and in the Universe. A key element in the National Research Agenda is collaboration in interdisciplinary teams because it is often at the interfaces of disciplines that new discoveries are made. SRON is closely connected to the Dutch Top Sectors policy, in which scientific institutes and companies collaborate; our technology and expertise also fits to multiple areas in the recently proposed inventory of Dutch Key Enabling Technologies. As such we are well equipped for interdisciplinary research.

► *What is the future of climate and air quality on Earth? SRON's science and technology focus for the coming decade is also inspired by societal issues. Credit Shutterstock.*

SRON is closely connected to the Dutch National Research Agenda and the Top Sectors policy.

4 Science and technology focus, and its societal relevance

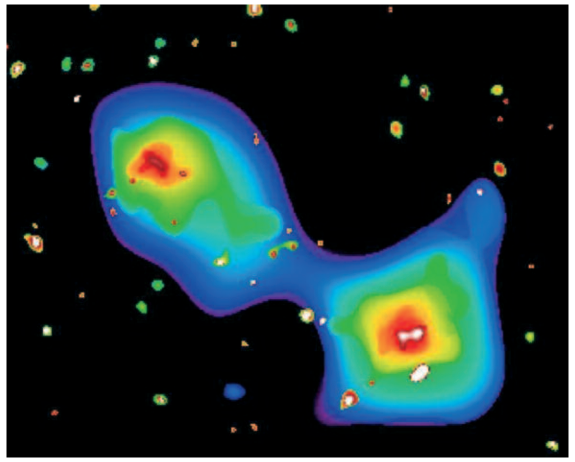
SRON's science and technology focus for the coming decade is inspired by some of the most important curiosity driven and societal questions: What is the origin and evolution of the universe? What is the origin of life? What is the future of climate on Earth?

The societal relevance of our programme has two main components: first the climate and air quality research, and second the development and transfer of scientific and technological knowledge to society. These are intimately linked to the SRON research programme and therefore described in tandem. Plans for the coming years are elaborated in the sections below.

Project portfolio

The project portfolio (an overview is presented in Table 1) reflects our main ambitions and strategy. In the *Astrophysics* programme, we will shift our focus from studies in the local universe to the distant universe and we will address fundamental physics (black holes and gravitational waves). We have a new *Exoplanets* programme, which is ultimately aimed at the search for conditions on exoplanets favourable for extra-terrestrial life, and in our *Earth* programme we will further enhance our efforts to assess the anthropogenic impact of trace gases and aerosols on the Earth's climate and air quality.

The new Exoplanets programme connects the fields of astrophysics and Earth atmosphere. It builds on our track record in deducing the abundance of trace gases (called retrieval) and measuring light scattering and absorption by small particles (aerosols) in



▲ *X-ray image of the sky area around the cluster of galaxies Abell 3128 obtained with the XMM Newton satellite. The bright spot on the right originates from hot gas in this cluster. The spot on the left is hot gas in a recently discovered more distant cluster. Credit ESA/XMM Newton/EPIC/SRON.*

clouds or hazes. Both are key diagnostics of planetary atmospheres anywhere in the universe. An important common diagnostic is (high-resolution) spectroscopy, which is used in all programmes. These efforts are enabled and supported by a vigorous *Technology* programme. We have made several sharp choices for the coming period. Athena will be the top priority in the Astrophysics programme. In the Exoplanets programme, we will focus on the missions PLATO and ARIEL, that will study atmospheres of exoplanets. In de Earth programme we will strengthen aerosol research (for studies of air quality and climate).

► *Launch of the Hitomi satellite. Credit JAXA.*

Table 1: *Overview of the SRON project portfolio for the coming 10-15 years. The magnitude of the SRON contribution ranges from (co-)leading (PI or co-PI), to intermediate and small.*

Mission/instrument	Programme SRON	Launch date	Agency	Contribution SRON
Sentinel-5P/TROPOMI	Earth	2017	ESA (approved)	co-leading
Sentinel-5	Earth	2021	ESA (approved)	intermediate
XARM	Astrophysics	2021	JAXA/ESA (close to selection) [2)]	small
SPEXlite	Earth	2025	Under discussion (NASA,ESA)	(co-)leading
PLATO	Exoplanets	2026	ESA (M3, adopted)	small
ARIEL	Exoplanets	2026	ESA (M4, candidate)	intermediate
Athena/XIFU	Astrophysics	2028	ESA (L2, selected)	co-leading
SPICA/SAFARI	Astrophysics	2030	ESA/JAXA (M5, candidate)	(co-)leading
LISA	Astrophysics	2034	ESA (L3, selected)	intermediate
Demonstrators [1)]	All	–	Ground, aircraft, balloon	(co-)leading

1) Demonstrators are a crucial intermediate step to raise technology readiness while advancing to instruments in space; they allow early science and secure the visibility of the institute's capabilities during the long development tracks. Recent examples are STO-2 and SPEX Airborne.
2) Approval of missions in the ESA Science Programme is done in two steps: selection followed by adoption.

SRON's science and technology focus for the coming decade is inspired by some of the most important curiosity driven and societal questions.

An increase in budget would allow us to take a much more leading role in science and technology development for future missions.

▲ *SRON Groningen will move to the Feringa Building, a new accommodation at the University of Groningen. Credit Ector Hoogstad Architecten.*

Funding
These plans are based on current annual levels of base funding (about 15 M€) and our track record in securing additional funding (adding on average about 5 M€ per year) at constant purchasing power. The additional funding is used for out-of-pocket costs (e.g. involving companies) and the costs of temporary staff. For the Dutch role in Athena (total Dutch investment ~61 M€) a 19.5 M€ application to the National Roadmap for Large Research Infrastructure was submitted in June 2017. An increase in the institute's budget would allow us (1) to take a much more leading role in science and technology development for future exoplanet missions and for the LISA gravitational-wave mission, and (2) develop prototypes for an aerosol space instrument.

Scientific collaboration
Scientists, instrument scientists, and engineers at SRON work closely together in teams. Within several years they will do so in new, state of the art facilities. The Groningen branch will move to a new accommodation at the University of Groningen. Plans for new housing of the Utrecht branch in the coming 4-5 years are being developed.

To achieve our goals, we closely collaborate with universities, knowledge institutes, and companies. The importance of this approach will continue to grow, especially with the rise of new opportunities (e.g. in the fields of exoplanets and gravitational waves) that require resources and new investments. SRON also intends to set up or strengthen strategic collaborations with institutes abroad, in order to be in a competitive position for future projects.

Human capital
The most important asset of our institute is its staff. Our programme offers an attractive challenge to young people and experienced staff alike. The new organizational structure of the institute provides the opportunity for giving close attention to personal development within the science groups attached to our programme lines and the expertise groups. In particular, the new Instrument science group harbours now all our physicists involved in technology and instrument development, like the Engineering group harbours all our engineers for many years already.

SRON will continue to develop its human capital, with special attention to diversity. For instance, we are taking part in the NWO 'talent naar de top' and 'WISE' programmes that are aimed at an increase of the number of female (senior) scientists in the permanent staff. We also pay attention to the development of skills that are needed to meet the institute's goals in the context of our collaboration with national and international partners (such as project-management skills). Of course we also follow the opportunities that are offered by the newly formed NWO-I Institutes Organisation.

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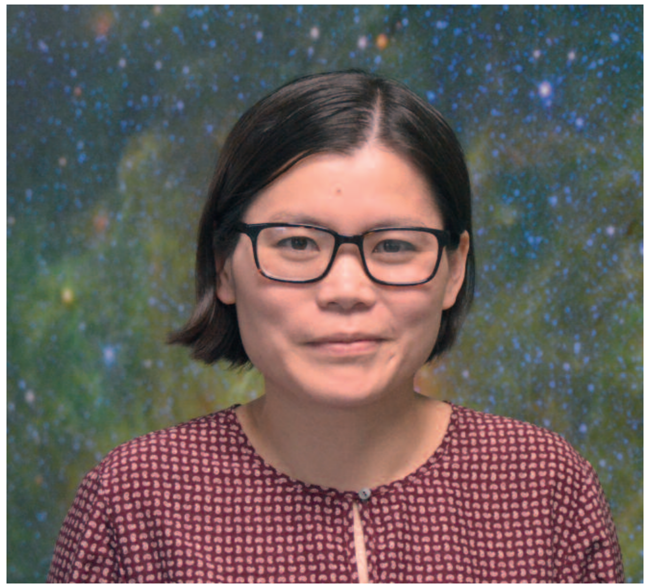


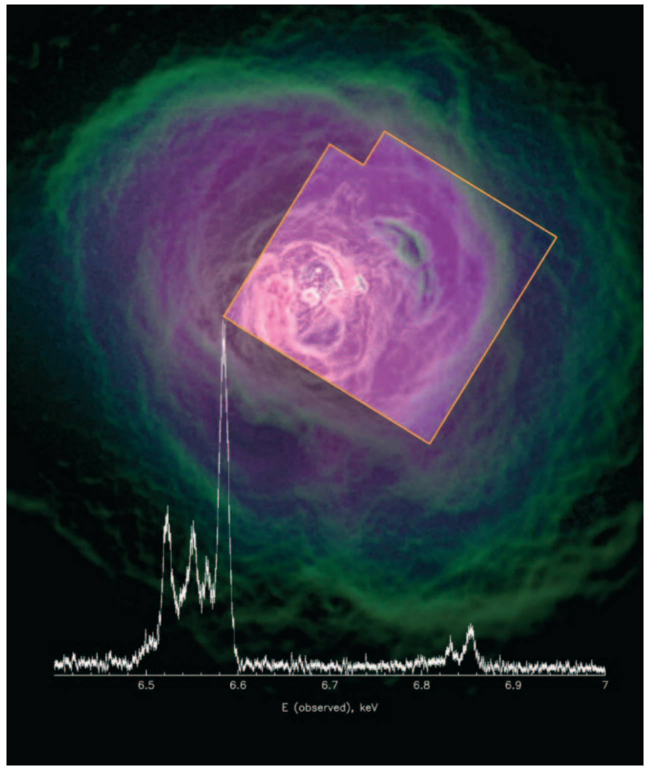
▲ *Our programme offers an attractive challenge to young people and experienced staff alike. Credit Ivar Pel.*

4.1 Origin of the universe

Research focus
A focal point of our research programme is understanding the largest structures in the universe, i.e. clusters of galaxies. Clusters of galaxies have a profound effect on the way individual galaxies have evolved, on the star formation history of the universe, and on the present-day morphology of galaxies. The formation and evolution of supermassive black holes and the formation of their host galaxies are intimately linked to that of the clusters of galaxies in which they are situated.

With integral field spectroscopy, we can derive the physical properties of hot intra-cluster gas (densities, temperatures, turbulence). This provides us with clues as to how the clusters evolve and the role of the supermassive black holes. With Peter Jonker's ERC Consolidator Grant the importance of intermediate mass black holes is studied. The areas where massive stars in starburst galaxies actually produce the new elements that enrich the intracluster gas are hidden from view by large amounts of interstellar dust. Therefore, spectroscopic observations at infrared and submm wavelengths (both ground-based and space-based) are essential. Such observations allow us to draw up a full map of the star-formation history of the universe, and establish where in the universe conditions for rocky planet formation, which requires metals, are favourable. The interpretation of spectroscopic data needs spectroscopic databases and radiative transfer codes, such as SPEX, RADEX, and RATRAN. SRON is playing an active role in developing and maintaining this infrastructure.

Societal relevance
One of the most fundamental curiosity-driven questions is the origin of the universe and the physical laws that govern it. The Astrophysics programme contributes to increasing our understanding of the world around us, and through outreach this knowledge is shared with the general public. The advanced technology needed to answer these fundamental questions is beneficial to industry (through co-development, by increasing technical knowledge) and by the spin-off to non-science areas it offers (see also Section 4.5).



▲ *The Perseus cluster of galaxies is filled with a hot X-ray-emitting gas, as seen in this image from the Chandra X-ray Observatory. Astronomers using the Soft X-ray Spectrometer aboard the Hitomi satellite have, for the first time, mapped the motion of this gas and determined its velocity structure across a large part of the cluster. The square overlay shows the area observed by Hitomi, leading to the spectrum shown at the bottom. Credit NASA/CXO (image) and Hitomi collaboration/JAXA, NASA, ESA, SRON, CSA (spectrum).*

Future
Our top priority is to prepare scientifically and technically for Athena, the L2 mission of ESA's Cosmic Vision programme, scheduled for launch in 2028. SRON is the co-PI of the X-IFU instrument. This will provide spatially resolved spectra of unprecedented quality and energy resolution of the early universe, thus charting its chemical evolution. It will also map the

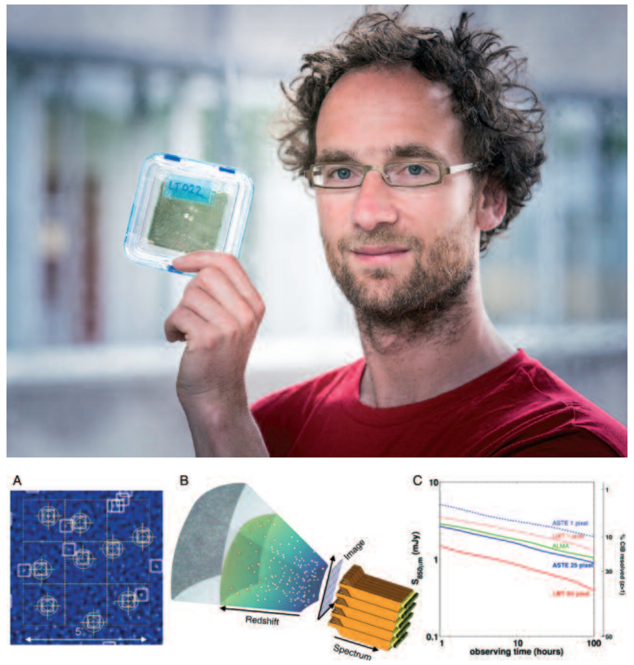
A focal point of our research programme is understanding the largest structures in the universe, i.e. clusters of galaxies.

formation and evolution of supermassive black holes in the centres of galaxies. Our hardware contribution to X-IFU will be the focal plane assembly including its cold electronics. As a precursor mission to Athena, SRON will also contribute to the X-ray spectroscopic instrument on board of the Japanese XARM mission, scheduled for launch in 2021. XARM is a re-fly of the Hitomi satellite, for which SRON provided similarly.

SRON leads the large international consortium that submitted a proposal for SPICA, the next large cryogenic far-IR observatory, for the M5 competition of the ESA Cosmic Vision programme. If selected, the Japanese space agency JAXA will provide major elements to the mission. It has top priority within the Japanese Space Science Programme. SPICA will study the obscured star formation and black-hole activity of thousands of individual galaxies. It will also study cradles of planetary systems, providing a full inventory of their water content. Besides leading the proposal consortium, SRON is the PI institute for SAFARI, the far-infrared grating spectrograph/ polarimeter.

A new opportunity for SRON is gravitational wave science. ESA has selected this topic for its third flagship mission (L3), to be launched in 2034. Many of the science goals of LISA align with those of Athena, making SRON involvement a logical choice. A large international consortium that SRON is a member of has proposed the LISA interferometer concept for L3. The Dutch astroparticle community is already strongly involved in gravitational-wave science using ground-based based detectors (LIGO, VIRGO). SRON will bring together the Dutch scientific and technology expertise at SRON, NOVA, TNO, and the NWO institute Nikhef. The goal is to provide a Dutch contribution to the electronics for the photoreceivers and possibly the actuators on the optical benches of the LISA interferometer. The required technology connects well with Dutch expertise.

SRON is making good progress in the advancement of the large format Kinetic Inductor Detector (KID) sensor-array development for applications in its Astrophysics programme. The ultimate goal is an application of KIDS in a next generation space mission. As a stepping stone towards this, we are developing ground-based applications. A first example is the AMKID continuum camera at the APEX telescope in Chile, which is in its final stages of commissioning. Secondly, Jochem Baselman's ERC Consolidator-Grant project MOSAIC aims to develop a novel KID-based spectrometer on a chip to map the distribution of obscured high redshift galaxies.



▲ *With his ERC Consolidator Grant, SRON researcher Jochem Baselmans aims to develop a novel KID-based spectrometer on a chip to map the distribution of obscured high-redshift galaxies. Credit Ivar Pel.*

4.2 Origin of life: exoplanets

Research focus

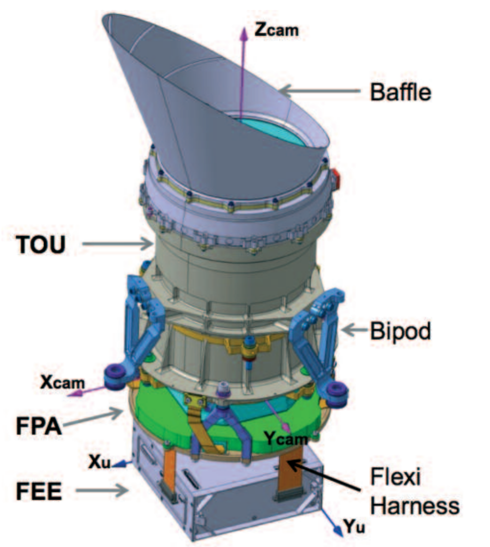
More than 3000 exoplanets are now known, which exhibit a fascinating diversity in their properties. New classes of planets such as hot Jupiters and super-Earths have been discovered that have no counterpart in the solar system. A growing number of rocky planets in the habitable zone has been discovered, with possibly liquid water on their surface. A rapidly developing field is the characterization of exoplanetary atmospheres (both ground-based and space). This is a natural area for SRON to focus on, given the strong position of SRON in Earth atmospheric science, and its track record in star- and planet formation. The long-term goal is to work towards the characterization of Earth-like planets in the habitable zone of Sun-like stars in search of biomarkers.

Societal relevance

As for the Astrophysics programme, the Exoplanets programme addresses a fundamental curiosity driven question: the origin of the Earth and life as we know it. Our rapidly increasing knowledge in this area is a great topic for public outreach. The technical challenges associated with the detection of the weak exoplanet signal against its bright host star can only be solved in close collaboration with knowledge institutes and industry. See also Section 4.5.

SRON is co-principal investigator for Athena's most complex instrument, the X-IFU integral field spectrograph.

For the timeframe beyond 2030, SRON has the ambition to become co-PI or PI on a mission to characterize the atmospheres of Earth-like planets.



▲ *Schematic figure of the PLATO spacecraft. SRON will perform cryogenic tests of a subset of its 24 telescopes. Credit PLATO Mission Consortium.*

Future

We will invest in contributions to instruments for the ESA M-class missions PLATO (M3) and ARIEL (M4). The PLATO mission (launch 2026) will make accurate photometric measurements of a huge sample of stars to provide planetary transits and phase curves. SRON will perform cryogenic tests of a subset of the 24 telescopes on board PLATO. Scientifically, we will focus on phase-curve observations that provide detailed information on cloud structures and atmosphere dynamics.

The ARIEL mission is candidate for the M4 slot of the ESA Cosmic Vision programme. ARIEL is designed to take detailed infrared transmission spectra of a large sample (over 500) of mostly gas giant exoplanets to reveal the chemical composition of the atmospheres. If ARIEL is selected, with a European detector as baseline, SRON will provide sensor read-out electronics. We might also perform detector characterization.

Science preparation for these missions, and for the upcoming JWST/MIRI mission, is underway. State-of-the-art 3D planetary atmosphere radiative transfer model codes and retrieval algorithms (e.g. SPARC, SRON Planetary Atmosphere Retrieval Code) are available.

For the timeframe beyond 2030, SRON has the ambition to become co-PI or PI on a mission to characterize the atmospheres of Earth-like planets. We have therefore initiated technology development in the area of high-contrast imaging and we investigate the possible use of KID sensors to characterize Earth-like exoplanet atmospheres.

4.3 Earth's atmosphere: climate and air quality

Research focus

SRON's Earth atmosphere research focuses on the global carbon cycle (in particular CH_4, CO_2, and CO) and aerosols and their impact on climate and air quality. In particular, we concentrate on the retrieval of atmospheric abundances and the inference of sources and sinks. In its most recent (4th) assessment, the International Panel on Climate Change (IPCC) identifies aerosols as the largest uncertainty in anthropogenic radiative forcing. There is also a clear link between aerosols and the hydrological cycle, as aerosols affect cloud formation and precipitation. The aerosol focus will enhance our understanding of how climate and air quality are connected by cloud (aerosol) emission interactions.

Societal relevance

Our climate and air-quality research addresses one of the most fundamental current challenges of society and contributes to the scientific basis on which governments base their climate policy. The importance of climate research has been amplified by the recent climate agreement of Paris, with far-reaching consequences for investments in sustainable energy and the reduction of greenhouse gases in the Earth's atmosphere. At the same time, air-quality issues can be found almost daily on the front page of newspapers, because this affects people's everyday life and health. Atmospheric monitoring from space provides essential data to assess climate change and air quality. We focus on the careful analysis of raw satellite data to derive trace gas abundances and aerosol properties. Companies traditionally have a large role in developing the innovative instrumentation needed for Earth observation. SRON plays an active role in the early development stages, thereby strengthening the position of Dutch companies. See also Section 4.5.

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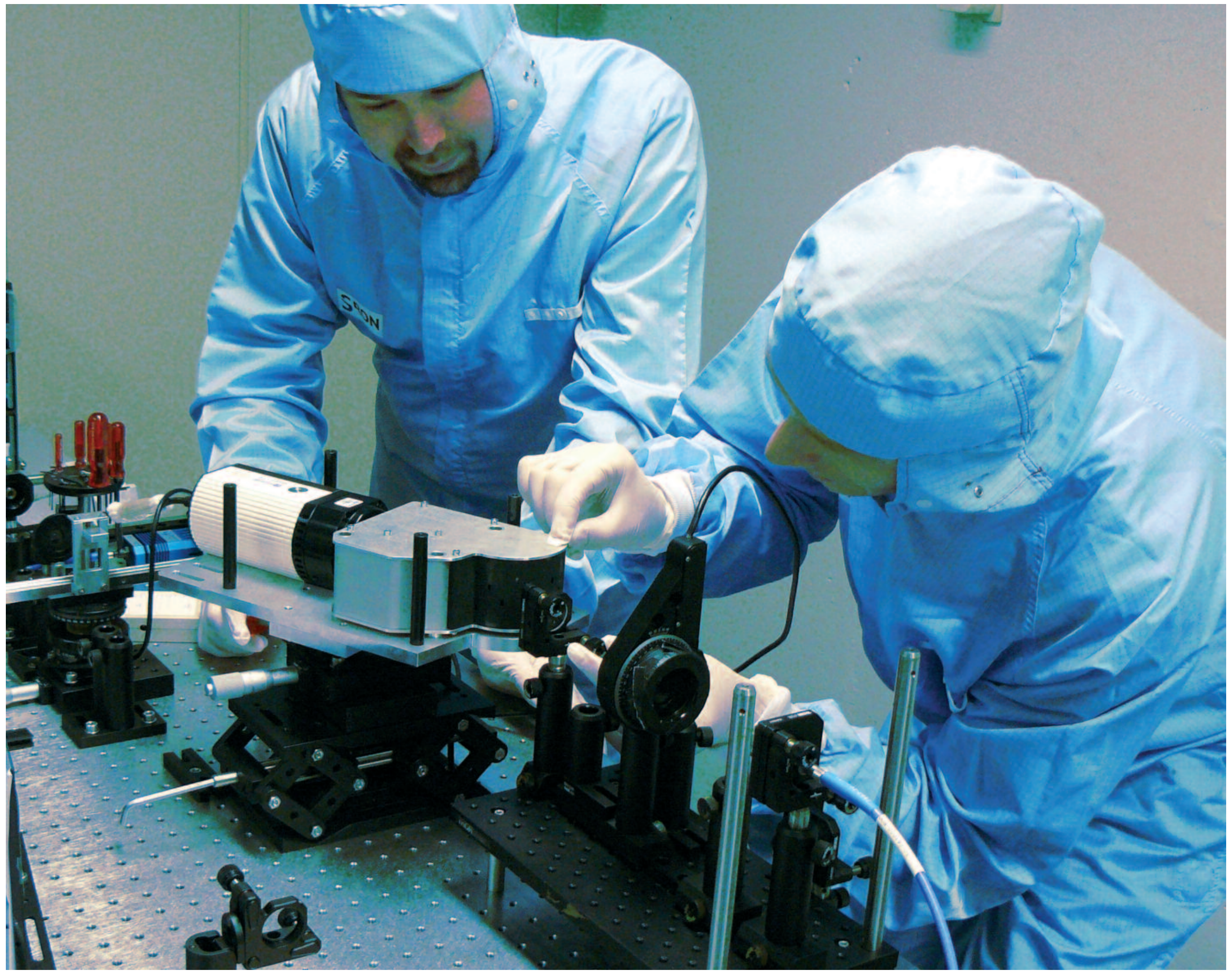


▲ *Working on the SPEX instrument. Credit Ivar Pel.*

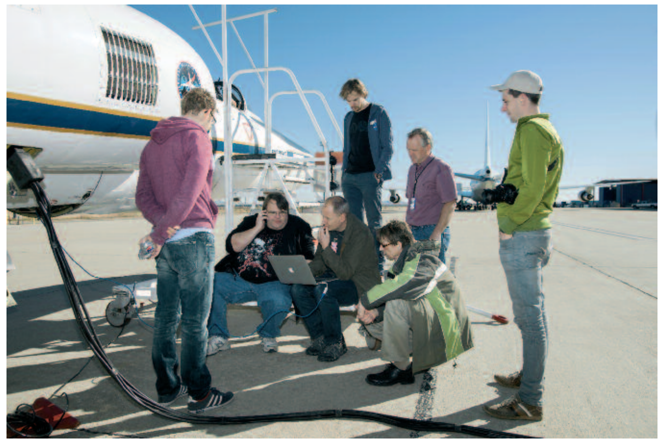
Future

In the coming years, we will give high priority to harvesting the Sentinel-5P/TROPOMI results (launch in 2017). This involves inflight calibration and retrieval processing of the Short-Wave IR (SWIR) module operational data for CO and CH_4, and for the experimental products HDO/H_2O and solar-induced fluorescence. Together with our partners we will derive the global distribution and evolution of sources and sinks by means of atmospheric modelling, including the quantification of emissions from anthropogenic evolution of point sources. Similarly, we will deduce carbon concentrations and surface fluxes from atmospheric modelling of the greenhouse-gas missions GOSAT (JAXA), OCO-2 (NASA), and Merlin (D-Fr). In addition, we will actively pursue new opportunities to collaborate with China.

SRON has obtained contracts from the EU and ESA to provide CO_2 and CH_4 data products as part of the Copernicus Atmospheric Monitoring Services (CAMS), the Copernicus Climate Service (C3S) and the ESA Climate Change Initiative (CCI) programme. A Dutch company has chosen SRON as a sub-contractor to provide prototypes for the processors of the ESA/EC Sentinel-5 data products. In addition, in 2018 we will deliver immersed gratings for Sentinel-5 under contract of European industry. We are also directly involved in the definition of the first European dedicated carbon mission (European Commission and ESA). In the coming years, we will try to increase our activities in this field. Together with SMEs and larger companies we will explore possibilities to identify combinations of scientific and commercial applications of data obtained by remote sensing platforms.

We will continue flights with the SPEX aerosol instrument on the NASA ER-2 aircraft and the analysis of SPEX-Airborne data. Furthermore, we will continue the development of the SPEXlite

Our ambition is to put Dutch industry, supported by SRON, in a position where it can win international contracts for space instruments to advance Earth observation.



▲ *We have set our sights on the coming large aerosol science campaign with our SPEX aerosol instrument on the NASA ER-2 aircraft.*

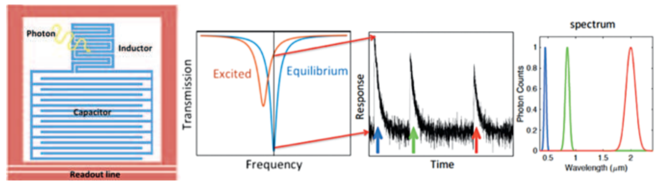
concept and continue our discussions with space agencies for future launch opportunities as a space application of SPEX. This concept was developed with our industrial and institutional partners. In the meantime, SRON is ideally equipped to exploit the ESA 3MI polarimeter on Eumetsat's series of MetOp-SG satellites (2020-2040), thus capitalizing on our scientific expertise.

The international Earth observation community has expressed a clear need for observations with higher spatial and temporal resolution. The European Commission has responded with H2020 calls for new highly-miniaturized optical instrument concepts, to be deployed alongside the large long-term ESA/EC Sentinel series. The Dutch national programme is moving into this direction as well, with a strong focus on commercial services. In addition, the changing political landscape implies that national instruments such as SCIAMACHY and TROPOMI are not likely to happen again in the next decade. This calls for a partial revision of our strategy. The institute will, in collaboration with industry, focus on scientific performance assessment and prototyping of new instrument concepts, including characterisation and calibration. We will pursue options for dedicated measurements with (constellations of) small satellites Our ambition is to put Dutch industry, supported by SRON, in a position where it can win international contracts for space instruments to advance Earth observation. SRON will benefit because of its involvement in the future mission, doing calibrations and developing and exploiting data products for science and society.

4.4 Technology

Research focus

The Technology programme anticipates at contributions to future missions that support the science goals of the Astrophysics, Exo-



▲ *Schematic of the operation of an MKID as a photon counting detector. Left: Schematic MKID pixel. Middle left: the change in the resonance curve upon excitation by a photon. Middle right: simulated time trace in response to photons of different colour. The noise on the MKID signal limits the energy resolution, but does not introduce spurious/dark photon counts. Right: simulated spectrum of a source as a function of wavelength. Credit Pieter de Visser.*

planets, and Earth programmes. It looks therefore many years ahead. Instruments for astrophysical and exoplanet research often require large integral-field spectroscopic capabilities. They are based on large-format cryogenic detector arrays, which achieve extreme sensitivity, in conjunction with read-out electronics. Previous long-term investments in these areas have successfully positioned SRON for contributions to Athena and SAFARI, and will remain an important heritage for the institute.
For the new Exoplanets programme we have embarked on a similar long-term route: investing in high-contrast optics and imaging single-photon spectroscopy using KID sensors in the UV-optical window. For research of the Earth's atmosphere, we focus on the development of key optical elements such as immersed gratings (allowing miniaturisation of instruments) and on the prototyping of accurate spectropolarimetric instruments.
The Technology programme relies on SRON's capabilities in the Engineering and Instrument science groups. Moreover, the Technology programme and instrument developments benefit greatly from our dedicated facilities, such as an in-house cleanroom and cryogenic facilities. This allows for essential short turn-around times in research and provides direct process control over those sensor components that determine performance of future instruments. If possible, we are chosing a co-development route with other companies, i.e. sharing knowledge and jointly working towards new goals beneficial for both.

Societal relevance

To answer current scientific questions requires overcoming huge technical challenges. The institute collaborates with knowledge institutes and companies to overcome these challenges and we are actively seeking applications of our knowledge in other science and non-science areas. See also Section 4.5

Future

The short-term technology development plans have been mentioned in the relevant sections. In the coming years, the require-

In the coming years the requirements for Athena/X-IFU and SPICA/SAFARI will be our first priority.

▲ *Open Door Day at SRON. Credit Samuel van Leeuwen.*

ments for Athena/X-IFU and SPICA/SAFARI will be our first priority. For the next decades, we expect that dedicated optimizations of our cryogenic detector systems (e.g. TES/FDM and KID/microwave read-out) will be able to cover the detector needs of the Astrophysics programme (X-ray and FIR). These detectors reach fundamental physical limits.

The Technology programme anticipates developments with a horizon of 10+ years. While mission details will evolve over that timeframe, the generic requirements for future observatories are generally well known and stable. This makes it possible to determine a development strategy consistent with our research targets. Our development strategy for the Exoplanets programme and our approach in the KID development are examples of this. The Earth programme will be supported by the development and prototyping of critical technology for future miniaturized instrument concepts for high spatial resolution trace-gas and aerosol measurements.

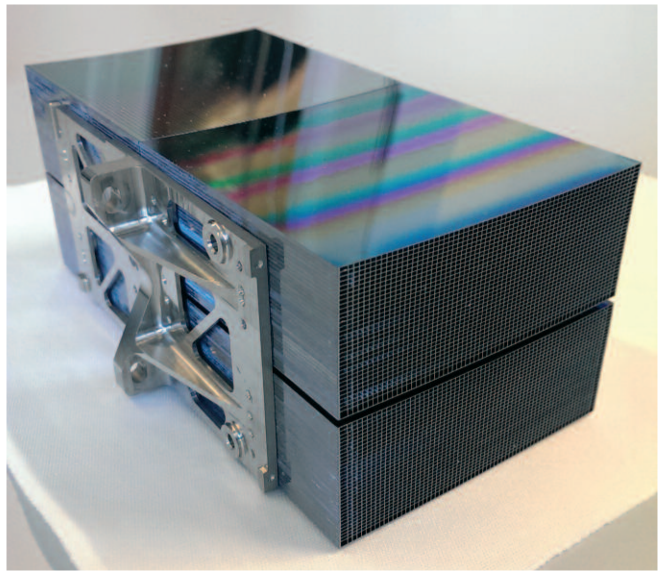
Small (nano/micro) satellites are emerging as interesting alternatives for use in space science. We will investigate which role the institute can play in fostering the application of small satellites within the focus areas of the institute.

4.5 Knowledge transfer to society

Our knowledge-transfer strategy consists of 1) the (early) involvement of SMEs in the development of new technologies and new instrumentation for low technology readiness levels (TRLs), 2) the transfer of our knowledge to other scientific (non-space) applications and non-scientific applications of space technology, and 3) a vigorous outreach programme.

Traditionally, the international big science arena has been an ideal environment for the collaboration with industry. SRON is proud to have a long track record in bringing science and industry together to the benefit of both. Such an approach has been part of generic Dutch government policy since 2011, laid down in so-called Top Sectors. SRON is involved in the Top Sector High-Tech Systems and Materials (HTSM), which has a number of roadmaps for technology development. Apart from the Space roadmap within HTSM, SRON also co-authored the roadmap on Advanced Instrumentation within HTSM, and is well connected to the HTSM roadmap Circuits and Components.

Top Sector funding schemes stimulate the forging of strong partnerships with companies at an early stage of technology development. This enhances the competitiveness of Dutch SMEs and knowledge institutes (including SRON) on the international market for scientific infrastructure. A good example is the involvement of SMEs in the development of technology for the X-IFU instrument for Athena. Conversely, SRON is working under the contract of an SME to support the design of the Athena telescope. Such collaborations enhance the SMEs' technical capa-bilities ("SRON poses challenging questions"), so that these companies are competitive on other (non-science) markets. SRON obviously benefits from being embedded in a competitive SME/industry landscape: the ambitions of the institute cannot be realized without the involvement of SMEs and larger companies.



▲ *The optical system for Athena, manufactured and integrated by Cosine. Credit Cosine.*

Future

We will continue to apply the Dutch Top Sectors approach when possible, within the limited investment possibilities of SMEs. In addition, we will continue to play an active role in setting up regional (provincial) co-development collaboration funding schemes involving SMEs. We will utilize these in the coming years. SRON is already active in the North and the East of the Netherlands. Within the framework of the intended move of SRON Utrecht to the Amsterdam Science Park we were preparing for collaborations with interested SMEs in the Amsterdam area. But now that the Amsterdam accommodation plans have been shelved we will have to rethink our technology-transfer strategy in this area.

In the coming years, we will further stimulate a wider use of technologies developed in the Technology programme, in particular the sensor development and the immersed gratings.

SRON is regularly approached by research institutes that would like to use SRON sensor/read-out technology for their own programme. A first example is NOVA's use of terahertz sensing technologies, developed by SRON and Delft University of Technology for the HIFI instrument on board of ESA's Herschel Space Observatory, in the ALMA array in Chile. Further examples are the use of the same technology for the NASA balloon missions STO-2 and GUSTO (recently approved). In the past few years, SRON has also investigated possibilities to apply terahertz sensing knowledge to the non-science domain. Our TES and KID sensors are applicable in ground-based and space-based scientific instruments (for instance in the area of cosmic microwave background instrumentation), and outside of the field of astronomy as well. We will further explore such possibilities in the coming years to ensure a maximum return on investments and to provide partners in other domains with new possibilities. It was already mentioned that SRON is well-connected to roadmaps in the Top Sector policy. Recently (2017) Dutch Key Enabling Technologies were proposed, including photonics, advanced materials, sensors / detectors / actuators, and micro and nano satellites. These and other technologies are considered essential for science, society, and market and could create opportunities for SRON.

Together with TNO, SRON has developed immersed gratings as an enabling technology for the Sentinel-5P/TROPOMI instrument. Based on that track record, we have won a contract for the development and production of advanced immersed gratings for the ESA/EC Sentinel-5 instruments. There are more opportunities for future Earth science and operational missions. NOVA has approached SRON to provide an immersed grating for the METIS instrument, a first-generation ELT instrument. We will also actively compete for future international contracts to further develop immersed gratings with a large involvement of industry. Our goal is to transfer this knowledge to SMEs or other companies. A relatively new area will be the prototyping of new instrument concepts for Earth observation. In this field knowledge is transferred to industry so that companies can build the flight instrumentation.

Outreach

We give high priority to sharing knowledge with a wider public. With an active new media strategy, the development of accessible communication resources, educational films, open days, trade fairs, and exhibitions, we will cultivate interest in (and support for) space research among all age groups. We make full use of the many links between our programme and the National Research Agenda, which was inspired by the general public.

We aim at the (early) involvement of SMEs in the development of new technologies and new instrumentation for low technology readiness levels.

We will continue to apply the Dutch Top Sectors approach whenever possible within the limited investment possibilities of SMEs.

▲ *SRON's terahertz sensing technology, developed with Delft University of Technology, was used onboard NASA's balloon mission STO-2. Here the STO-2 mission team celebrates a successful final test at Antarctica. See page 19.*

EXHIBITIONS AND OPEN DOOR DAYS

Since 2015, SRON has been involved in the development of an entirely new exhibition at Space Expo about European (and Dutch) space research. This new exhibition will focus much more on "the experience" of space research, with a great many new interactive exhibits. In January 2016, the SRON-sponsored exhibit The Second Earth was opened to the public at the NEMO Science Museum in Amsterdam. The Second Earth specifically focuses on the habitable zone around a star. This exhibit – part of the larger exhibition The Search for Life – will be continued until 2022.

The number of visitors of SRON's open days at Utrecht and Groningen in 2014 (1300), 2015 (1100) and 2016 (1570) reached new heights. We will try to continue this upward trend by intensifying our collaboration with local partners. At both locations visitors will learn about the latest developments in Earth atmospheric and space research, and will be able to take a look in the labs and clean rooms. Children will be able to participate in children's lectures and a fun lab.

SYMPOSIA AND EVENTS

SRON staff regularly present their work to the general public. For instance, in 2017 two so-called mini symposia for the general public are scheduled on the science of the Sentinel-5P/TROPOMI mission and on the first results of the GAIA mission. These will be hosted by the Royal Netherlands Academy of Arts and Sciences (KNAW).

In cooperation with NSO, TNO, Airbus, KNMI, and ESA we have begun preparations for a TROPOMI launch event (fall 2017). At this moment in time the plans converge upon a VIP event at ESA ESTEC and an event for the general public at Space EXPO in Noordwijk.

► *The number of visitors of SRON's Open Door Days at Utrecht and Groningen in 2014 (1300), 2015 (1100), and 2016 (1570) reached new heights. Credit SRON.*

We will cultivate interest in (and support for) space research among all age groups.

5 Concluding remarks

Over the past decades, space research has increasingly contributed to science and society. Nowadays it would be unthinkable to have to do without these contributions, especially in view of the challenges ahead of us. The future is exciting: we will contribute to fundamental science and increase technological capabilities while answering curiosity-driven questions. We will also contribute to a deeper understanding of climate-change related questions that our planet faces. This ambitious programme connects well to Dutch science policy. The track record of the institute shows that we are capable to fulfil a central role in the growing field of international space research. In order to maintain that role in the future and make use of the opportunities ahead, an appropriate level of stable financial support is needed, as well as funding for mission-specific costs that should become available in line with the international decision-making process.

▲ *In 2014 a team with SRON researcher Remco de Kok, led by Dutch scientist Ignas Snellen, found that the exoplanet Bèta Pictoris b is spinning significantly faster than any planet within the solar system. A day only lasts 8 hours. Credit ESO L. Calçada/N. Risinger.*

► *Open Door Day at SRON. Credit Samuel van Leeuwen.*

Over the past decades, space research has increasingly contributed to science and society. Nowadays it would be unthinkable to have to do without these contributions.

Abbreviations

ADS-NL	Airbus Defence & Space NL (formerly Dutch Space)
ALMA	Atacama Large Millimeter Array
AMKID	APEX-Microwave Kinetic Inductance Detector
APEX	Atacama Pathfinder Experiment
ASTRON	ASTRON Netherlands Institute for Radio Astronomy
Athena	Advanced Telescope for High-Energy Astrophysics (ESA L-class mission)
C3S	Copernicus Climate Change Service
CAMS	Copernicus Atmospheric Monitoring Service
CCI	Climate Change Initiative
EC	European Commission
ERC	European Research Council
ESA	European Space Agency
FDM	Frequency Domain Multiplexing
GOSAT	Greenhouse Gases Observing Satellite
GUSTO	Galactic/Xgalactic ULDB Spectroscopic Stratospheric THz Observatory
HIFI	Heterodyne Instrument for the Far Infrared
IPCC	Intergovernmental Panel on Climate Change
ISO	Infrared Space Observatory
JAXA	Japan Aerospace Exploration Agency
JWST	James Webb Space Telescope
KID	Kinetic Inductance Detector
KNAW	Royal Netherlands Academy of Arts and Sciences
KNMI	Royal Netherlands Meteorological Institute
LISA	Laser Interferometer Space Antenna
METIS	Mid-infrared E-ELT Imager and Spectrograph
MIRI	Mid-Infrared Instrument
MKID	Microwave Kinetic Inductance Detectors
MPE	Max-Planck-Institut für extraterrestrische Physik
NASA	National Aeronautics and Space Administration
NLR	Dutch National Aerospace Laboratory
NOVA	Dutch research school for astronomy
NWO	Netherlands Organisation for Scientific Research
NWO-I	NWO Institutes Organisation
NSO	Netherlands Space Office
OCO-2	Orbiting Carbon Observatory 2
PI	Principal Investigator
PLATO	PLAnetary Transits and Oscillations of stars (ESA M-class mission)
SAFARI	SPICA FAR-Infrared Instrument
SCIAMACHY	Scanning and Imaging Absorption Spectrometer for Atmospheric Chartography
SME	Small and Medium Enterprise
SPEX	Spectropolarimeter for Planetary Exploration
SPEX	Atomic code developed by SRON to simulate X-ray emitting plasmas
SPICA	Space Infrared Telescope for Cosmology and Astrophysics
SRON	SRON Netherlands Institute for Space Research (brand name)
STO	Stratospheric Terahertz Observatory
SWIR	Short-wave infrared
TES	Transition Edge Sensor
TNO	Dutch Research Institute for Applied Physics
TROPOMI	Tropospheric Ozone Monitoring Instrument
UV	Ultraviolet
XARM	X-ray Astronomy Recovery Mission
X-IFU	X-ray Integral Field Unit (on Athena)
XMM	X-ray Multi-Mirror Mission (renamed to XMM-Newton after launch)

Colophon

SRON's mission is to bring about breakthroughs in international space research. Therefore the institute develops pioneering technology and advanced space instruments, and uses them to pursue fundamental astrophysical research, Earth science and exoplanetary research. As national expertise institute SRON gives counsel to the Dutch government and coordinates – from a science standpoint – national contributions to international space missions. SRON stimulates the implementation of space science in our society.
SRON is part of the Netherlands Organisation for Scientific Research (NWO).

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Texts and editing
SRON

Design
Studio WW15

Print
Drukkerij Badoux, Houten

Published by
SRON Netherlands Institute for Space Research

September 2017

SRON
Netherlands Institute for Space Research