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2024

Observatoire royal de Belgique
Koninklijke Sterrenwacht van België
Royal Observatory of Belgium



Cover illustration: Artist impression of the two PROBA-3 satellites aligned above Earth. Credits: *ESA - P. Carril*. The ORB-KSB hosts the Principal Investigator of ASPIICS onboard PROBA-3 who leads the international science team and prepares data exploitation (see Highlight 'Launch of the PROBA-3 mission').

Foreword

Dear readers,

I am happy to present you with the annual summary report of the Royal Observatory of Belgium (ORB-KSB). As in the previous years, we have decided to only present the highlights of our scientific activities and public services, rather than providing a full, detailed and lengthy overview of all of our work during the year. We hope to provide you, in doing so, with a report that is more interesting to read and gives a taste of life at the ORB-KSB. If you need more or other information on ORB-KSB and/or its activities, contact rob_info@oma.be or visit our website <http://www.observatory.be>.

A list of publications and staff statistics are included at the end. To also suit our international readers & collaborators and to give it an as wide visibility as possible, the report is written in English.

Ronald Van der Linden

Director General

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Brief news of the Royal Observatory of Belgium

Launch of the PROBA-3 mission

PROBA-3 is the most recent mission of the European Space Agency (ESA) in the PROBA (PROject for OnBoard Autonomy) line of small technology demonstration satellites. PROBA-3 is a mission dedicated to the in-flight demonstration of precise formation flying techniques and technologies. The concept of PROBA-3 is to place two small satellites in a highly elliptical orbit around the Earth. The bigger spacecraft (coronagraph spacecraft) hosts the optical telescope, and the smaller spacecraft (occulter spacecraft) carries the circular occulting disk. The two satellites fly in a precise formation, producing a very long baseline solar coronagraph called ASPIICS (Association of Spacecraft for Polarimetric and Imaging Investigation of the Corona of the Sun). During extended periods of time (up to 6 hours), the occulter spacecraft covers the bright solar disk, thus allowing the dimmer corona to be seen by the coronagraph spacecraft, similarly to observations of a total solar eclipse. Such artificial eclipses could be produced regularly (twice per week on average).



Figure 1: The two PROBA-3 spacecrafts are seen mounted on top of the upper stage of the PSLV-XL launcher, in one of the last photos taken before the rocket fairing has been closed, Satish Dhawan Space Centre, Sriharikota, India, 29 November 2024.

Credit: ISRO.

In order to observe the corona, the two spacecrafts must keep the precise position and orientation (i.e. 'fly in formation') with respect to each other and to the Sun. During coronal observations, the distance between the two spacecraft is around 144 metres, and the precision of their alignment is around one millimetre. This allows blocking the bright light of the solar disk to observe the corona in eclipse-like conditions, i.e. close to the solar limb and with very low straylight.

PROBA-3 is also a Mission of Opportunity in the ESA Science Programme. The ASPIICS observations provide data that are crucial to solving several outstanding problems in solar physics, namely the origin of solar wind and mechanism of coronal mass ejections. The ORB-KSB hosts the Principal Investigator of ASPIICS who leads the international science team and prepares data exploitation. The ESA Science Programme funds the ASPIICS Science Operations Centre (SOC) located at the ORB-KSB. The SOC is responsible for daily operations of ASPIICS, i.e. preparing observational commands, processing the downlinked data in the science pipeline, and making the data accessible to the science community.



Figure 2: The PSLV-XL rocket launched the PROBA-3 mission on 5 December 2024 from the Satish Dhawan Space Centre, Sriharikota, India. Credit: ISRO

PROBA-3 was successfully launched on 5 December 2024 from the Satish Dhawan Space Centre in Sriharikota, India, aboard the Polar Satellite Launch Vehicle (PSLV-XL) of the Indian Space Research Organization. The launch was attended by the members of the PROBA-3 Science Working Team, who also held their 10th meeting at the SRM Institute of Science and Technology in Chennai, India, on December 5-6, 2024.

Launch of the Hera mission

To protect Earth from asteroids, the Royal Observatory of Belgium participates in the European Space Agency's [Hera mission](#), which was launched on Monday, 7 October 2024 at 16:52 Belgian time. Targeting the binary asteroid system Didymos, the Hera mission is Europe's contribution to an international experiment in planetary defence to protect Earth against asteroid impacts. It is also a scientific mission focusing on the origin and evolution of our Solar System. It follows on from NASA's DART mission in 2022, which successfully tested an asteroid deflection by impact technique on Dimorphos, the small moon of the Didymos binary system.

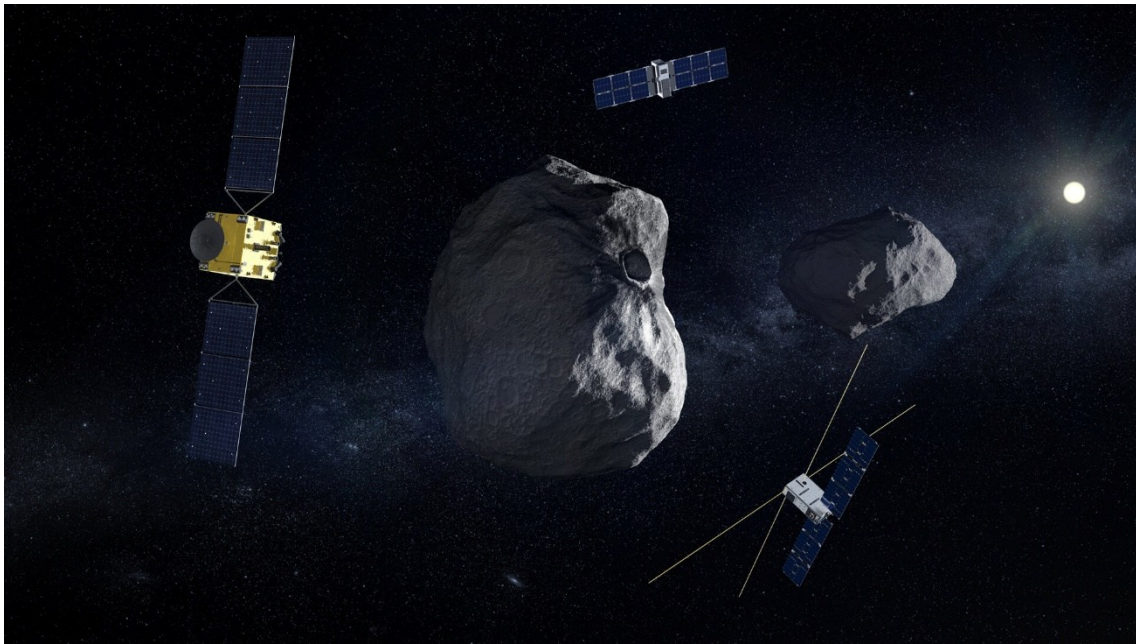


Figure 3: Artist's view of the Hera satellite (left) and its two CubeSats Milani (top) and Juventas (bottom right). Credit: ESA – ScienceOffice.org.

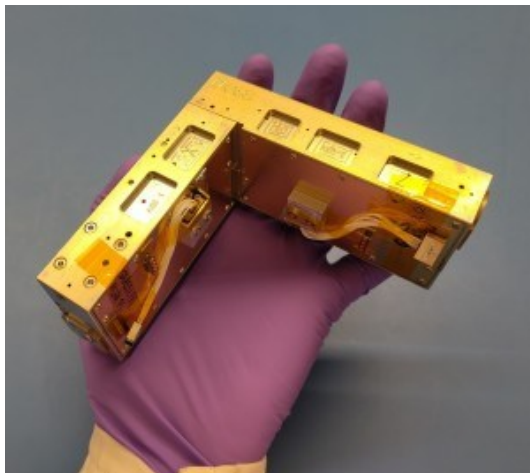


Figure 4: The GRASS instrument, a miniaturised space gravimeter. Credit: ORB-KSB.

The Hera mission is the first European planetary defence mission and the first mission to rendezvous with a binary asteroid. Dimorphos is the smallest asteroid and Didymos the fastest-spinning asteroid ever visited by a space mission. Hera will use advanced imaging tools and deploy two CubeSats, Milani and Juventas, to analyse the asteroids' structure and composition.

The Royal Observatory significantly contributes to Hera, notably by developing one of its onboard instruments, GRASS (GRAVimeter for Small Solar system objects), with the Spanish company [EMXYS](#). GRASS will be the first instrument to directly measure the surface gravity of an asteroid, which is a million times weaker than the Earth surface gravity. Onboard the CubeSat Juventas, GRASS will land on Dimorphos in 2027 and provide detailed

information about the interior structure and dynamics of the binary asteroid system. This information will be used to improve our knowledge of near-Earth objects and to develop future diversion strategies for asteroids that could threaten to collide with the Earth.

The Royal Observatory also contributes to the study and simulations of the landing of Juventas on the asteroid. Touching the asteroid’s surface with the small spacecraft is scientifically very interesting, while the landing itself is extremely challenging because of the particularly low gravitational force. In addition, the Observatory, together with [VITO](#) Remote Sensing, has contributed to the development and analysis of data from the TIRI thermal imager on board the main Hera spacecraft. [TIRI](#) will take images of Didymos and Dimorphos in the mid-infrared spectral range to resolve their surface temperatures and help us understand the thermophysical properties of their surfaces and sub-surfaces.

ESA’s GENESIS Mission Development in 2024, with Key Contributions from the ORB-KSB

In 2024, the European Space Agency’s GENESIS mission marked major milestones with the inaugural GENESIS Science Workshop, the establishment of its official working structure and the successful completion of the System Requirements Review. GENESIS is part of ESA’s optional *FutureNAV* programme and is planned for launch in 2028. A year into preparation, the Royal Observatory of Belgium, in collaboration with the Belgian industry Antwerp Space and academic institutions UCLouvain and Université de Liège contributed significantly to these early mission phases.

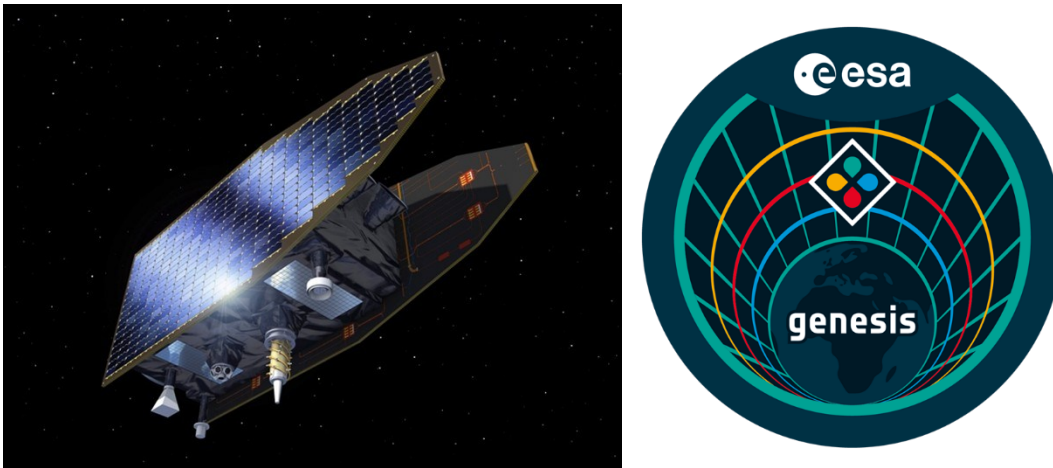


Figure 5: Credit picture on the left: ESA-P.Carril

Over the past year, scientists from the ORB-KSB – responsible for overall science coordination and contributing to various working groups – have played a key role in consolidating the mission’s scientific objectives and requirements. They also provided critical input during the successful System Requirements Review that took place in the fourth quarter of 2024.

GENESIS is designed to be the first mission to co-locate and synchronise the four main space geodetic techniques – GNSS, SLR, DORIS, and VLBI – on a single satellite platform. This integrated ‘Space Tie’ approach aims to enhance the accuracy and stability of the International Terrestrial Reference Frame (ITRF), which is fundamental for both scientific and operational geospatial applications. A notable feature of GENESIS is the inclusion of a Very Long Baseline Interferometry (VLBI) transmitter on the satellite. This

instrument, developed in Belgium by Antwerp Space with antenna design by UCLouvain, will allow Earth-based VLBI telescopes to observe the satellite directly. The joint use of all four geodetic techniques is expected to reduce systematic discrepancies and strengthen the global reference frame.

The ORB-KSB's contributions include refining instrument requirements, ensuring compatibility with VLBI ground stations, developing operational concepts, and performing simulations to support the derivation of a high-precision global reference frame.

The GENESIS mission is expected to benefit a broad range of applications, from precise navigation and autonomous systems to improved modelling in climate science and environmental monitoring. It also supports the United Nations General Assembly resolution calling for a global geodetic reference frame to advance sustainable development.

For more information, visit www.esa.int/Genesis

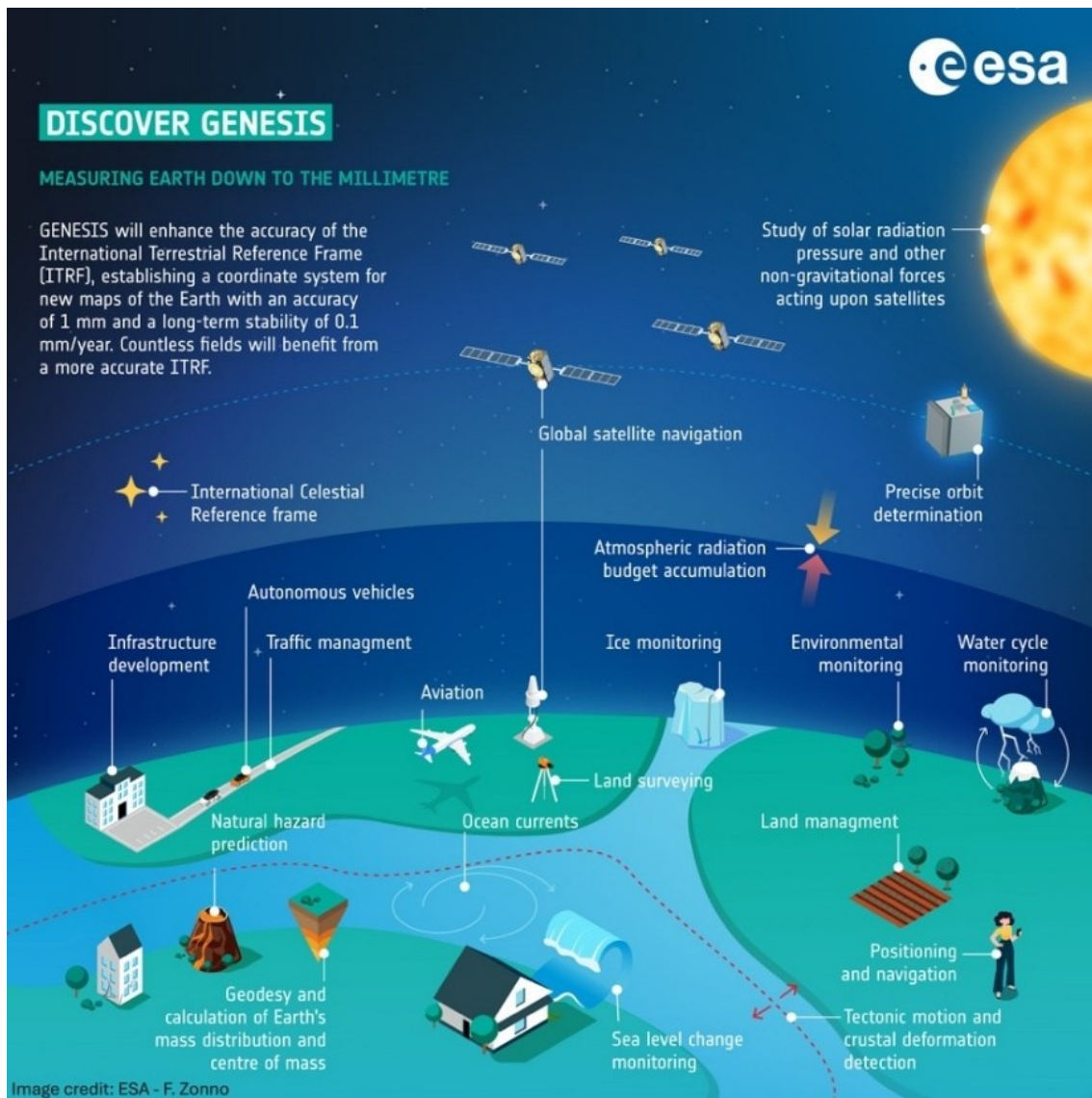


Figure 6: Credit: ESA - F. Zonno

DISCOVER GENESIS

MEASURING EARTH DOWN TO THE MILLIMETRE

GENESIS will contribute to a highly improved reference frame of Earth with an accuracy of 1 mm and a long-term stability of 0.1 mm/year for the most rigorous navigation applications on our planet. The GENESIS satellite will combine the main geodetic techniques, synchronising and cross-calibrating the instruments to determine biases inherent to each technique, allowing to correct them for superior precision.

VERY-LONG-BASELINE INTERFEROMETRY (VLBI)

An artificial radio source on the GENESIS satellite broadcasts signals that are picked up by several ground stations spread across the continents at slightly different times. This time difference can be used to calculate the precise location of the stations relative to one another.

SATELLITE LASER RANGING (SLR)

This technique involves bouncing laser pulses off a retroreflector onboard the GENESIS satellite and measuring the two-way travel time to calculate the distance between the ground-based laser station and the satellite, and consequently the position of both.

GLOBAL SATELLITE NAVIGATION SYSTEMS (GNSS)

GNSS provide accurate positioning information by measuring the time it takes for signals from at least four navigation satellites to reach receivers on Earth. GENESIS will use multiple satellite navigation constellations including Galileo and GPS for added precision.

DORIS

Measures frequency shifts in radio signals emitted by ground beacons and picked up by a receiver onboard the GENESIS satellite. The shift is caused by the satellite's movement and provides information about its location and that of the ground beacon.

ULTRA-STABLE OSCILLATOR

Ensures the instruments are synchronised.

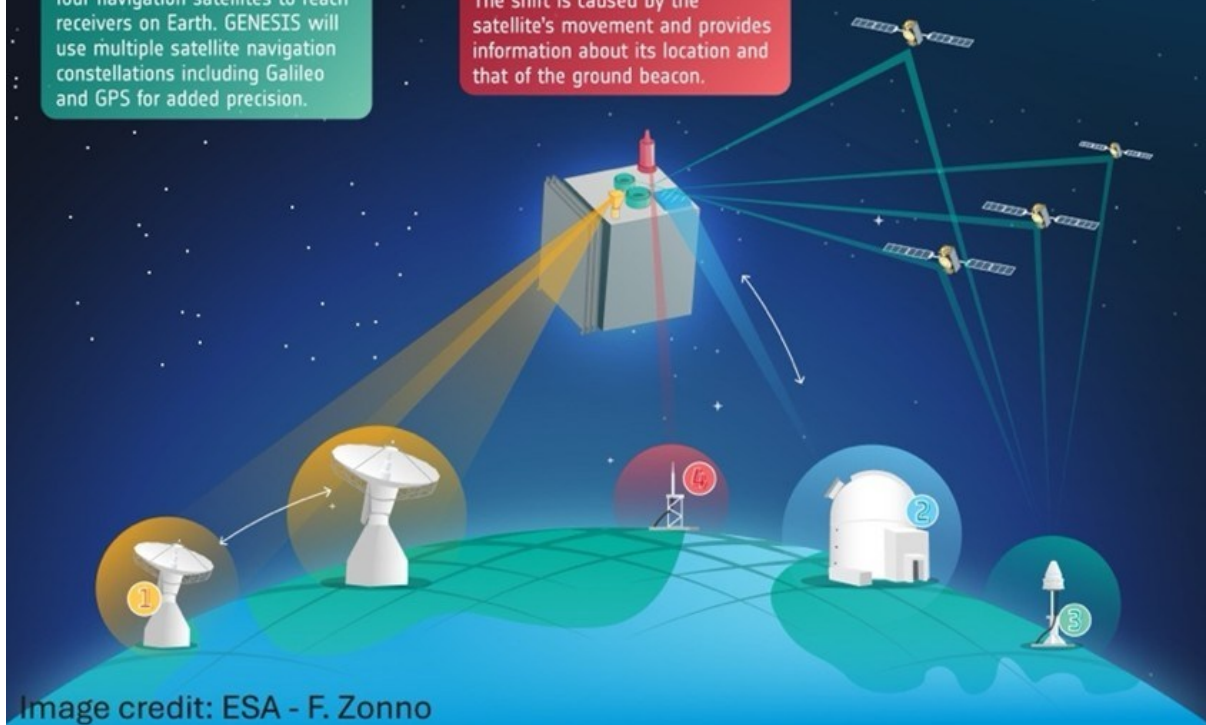


Image credit: ESA - F. Zonno

Figure 7: Credit: ESA - F. Zonno

Publication of the 150th Anniversary of Quetelet's Death



Figure 8: Posthumous portrait of Quetelet. Credit: ORB-KSB.

150 years ago, on February 17, 1874, Adolphe Quetelet, founder and first director of the Royal Observatory of Belgium, passed away. A keen statistician, he is best known as the inventor of the Quetelet index, better known today as the BMI (Body Mass Index). He founded the ORB-KSB in 1826 and was permanent secretary to the Royal Academy for almost 50 years.

In the occasion of the anniversary of his death, a publication was made on social media and the website of the Royal Observatory of Belgium. It was also an occasion to announce the upcoming festivities and special events that will take place in 2026 (see Highlight 'A logo for the 200th anniversary of the ORB-KSB').

The ORB-KSB news publication on Quetelet's 150th death anniversary: <https://www.astro.oma.be/en/150th-anniversary-of-quetelets-death/>

Interview of Fabienne Collin and Sabrina Bechet for the Women and Girls Day in Science

February 11 is the [International Day of Women and Girls in Science](#), a day recognised by UNESCO. According to the [UNESCO Institute for Statistics](#), 33.3% of scientists are women. This percentage is of the same order of magnitude as that of female researchers at the Royal Observatory of Belgium, which is between 30 and 38% among its scientific staff (see Staff Statistics: Analysis by Gender).

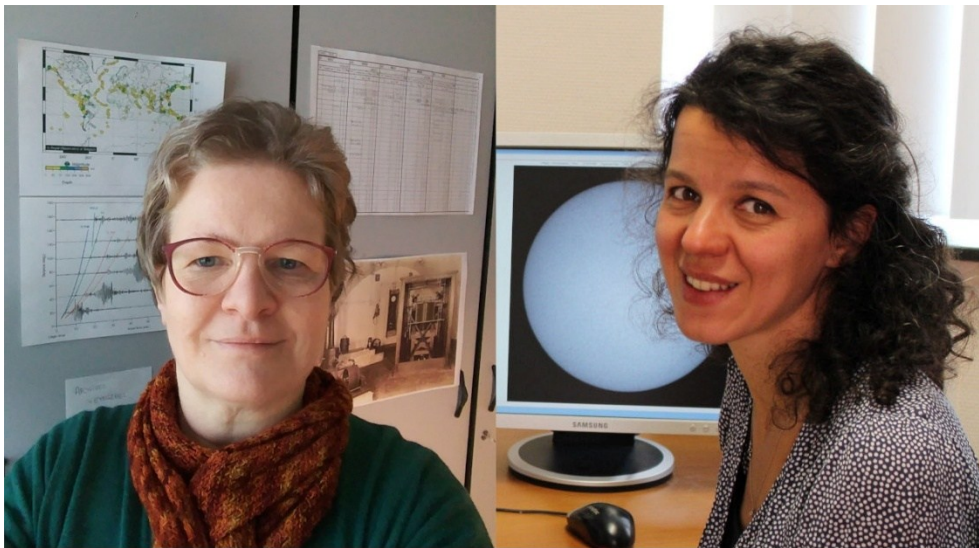


Figure 9: Left: photo of Fabienne Collin; Right: photo of Sabrina Bechet. Credits: F. Collin (first picture), S. Bechet (second picture).

To mark the occasion, the ORB-KSB gave the floor to Fabienne Collin, seismologist, and Sabrina Bechet, solar physicist, who share their experiences of their work at the Observatory.

The interview can be read on the ORB-KSB website: <https://www.astro.oma.be/en/international-day-of-women-in-science-interview-with-fabienne-and-sabrina/>.

Strong solar eruptions and auroras in Belgium

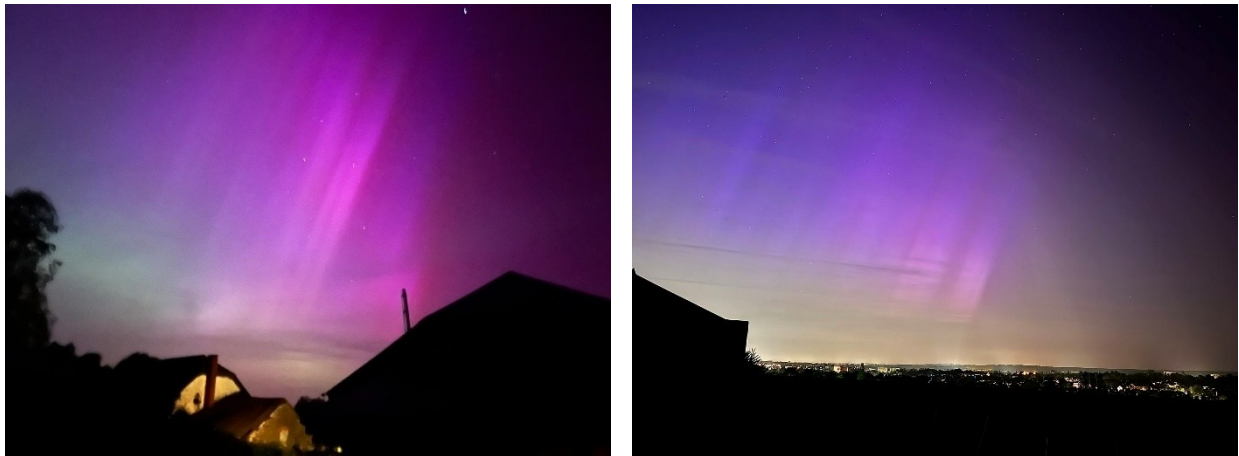


Figure 10: Mobile phone aurora pictures taken by ORB-KSB colleagues during the night between May 10 and 11, 2024. Credit: picture on the left: Koen Van Noten and Charles De Ryck (taken in Neundorf (Sankt Vith)); picture on the right: Brenda Dorsch (taken near Boondael (Brussels)). Note that auroras viewed in photographs are more clearly visible than seen with naked eyes.

2024 was a year of intense solar activity, with a maximum of the solar cycle reached in October 2024 (see Highlight Solar Cycle 25 has reached its maximum). This translates to a higher number of extreme solar flares, some of which causing auroras that were seen in Belgium.

This happens following the extreme X-class solar flares occurring in early May 9, 2024, and October 9, 2024. There are 5 categories of solar flares: A, B, C, M and X. An X-flare is 10 000 (!) times stronger than an A-flare. Each of those solar flares generated a solar cloud, which is a plasma cloud consisting of extremely hot and electrically charged hot gas, that came straight to the Earth.

A solar cloud generated on May 9 came straight to the Earth, causing an extreme geomagnetic storm on May 10–11, causing auroras to be observed as far south as Spain and Italy in Europe. Some people had the chance to observe them in the Belgian territory and some pictures were taken by colleagues of the ORB-KSB. The ORB-KSB published some of them in their social media (see [for example in Facebook](#)). More information and aurora pictures can also be found in the STCE news item: <https://www.stce.be/news/701/welcome.html>.

On October 9, 2024, the Solar Terrestrial Centre for Excellence issue a [press release](#) announcing that the extreme solar flare of this day will impact Earth in less than a day with high probability of seeing auroras in Belgium and warning about the disturbance in the (tele-) communication systems. Due to the cloudy sky, auroras were not seen in most parts of Belgium, but some lucky observers were able to spot them in clearer-sky area of the country.

Publication of historical sunspot drawings made on the day of the liberation of Brussels

On 3 September 1944, the Allies liberated Brussels, and this event was marked by the solar observers of the Royal Observatory of Belgium. At the Observatory, scientific activity did not cease during the war. In particular, the daily drawing of sunspots continued since 1940. Sunspots are dark structures on the Sun's surface indicating the emergence of magnetic fields. These can be the source of geomagnetic storms, giving rise to northern lights or auroras.

Exceptionally, the observer adds a note that is not related to solar activity but to historical events, such as the liberation of Brussels on September 3, 1944, with the comment 'entrée des Alliés en Belgique (Tournai) et à Bruxelles le soir' ('Allied entry into Belgium (Tournai) and Brussels in the evening'), or the Allied victory on May 8, 1945, with the note 'capitulation de l'Allemagne, V pour Victory Day' ('German capitulation, V for Victory Day').

On this occasion, the Royal Observatory of Belgium published sunspots drawing of those two dates in its website and social media. This is a vivid reminder of a tumultuous time when science was trying to survive.

The publication of the ORB-KSB: <https://www.astro.oma.be/en/the-liberation-of-brussels-marked-by-the-suns-observers/>

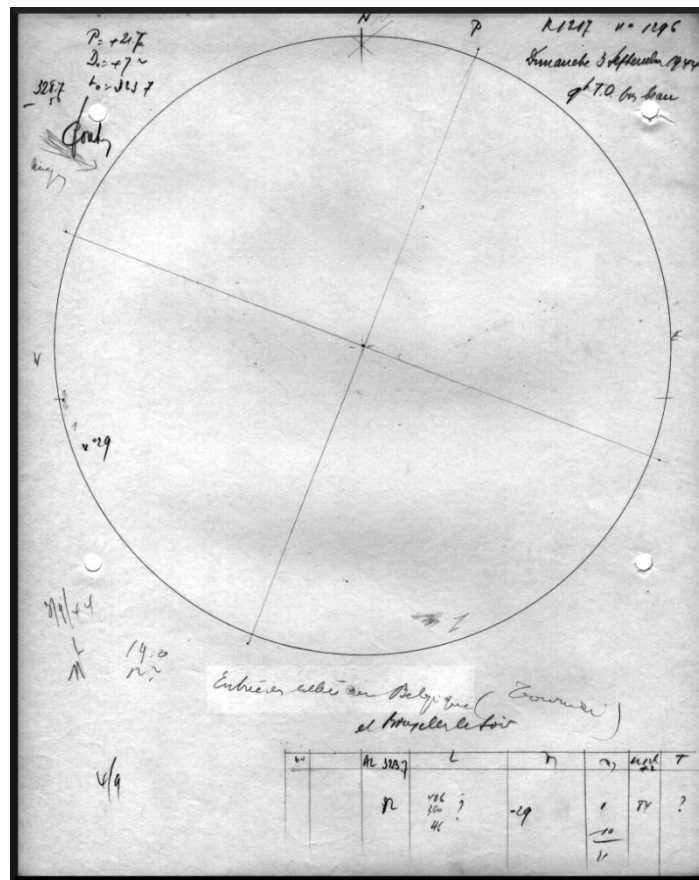


Figure 11: the 3 September 1944 drawing on which it is written 'entrée des Alliés en Belgique (Tournai) et à Bruxelles le soir' ('Allies' entry into Belgium (Tournai) and Brussels in the evening'). Credit: ORB-KSB

PECASUS celebrates its fifth anniversary!



Figure 12: Image courtesy: 'Europe': EUMETSAT; 'Sun': ESA/Proba2

In November 2019, the Solar-Terrestrial Centre of Excellence (STCE) launched an *unprecedented service that alerts pilots and air traffic controllers* when navigation and communication systems may experience problems, or when the health of passengers and crew is at risk due to space weather. This was the very first time such messages have been sent out.

PECASUS is a global civil aviation service drawing on the expertise of the STCE, the Belgian Space Weather Centre. STCE staff have worked hard over the past 5 years to collect the necessary data and models, to put these data into a form that allows experts and scientists to assess the state of space weather and its impacts, to ensure proper coordination with countries that are part of PECASUS and with the other 3 world centres, to enable a 24/7 service.

The STCE is the Belgian Space Weather Centre that closely monitors solar storms. As expected, the number and strength of solar storms are currently increasing. As a consequence, STCE's PECASUS operators have their hands full estimating the impact on the pilot's navigation systems and radio communications and sending out warnings.

It was a huge task and the future promises to be challenging. Therefore, STCE does not wish to just let the 5th anniversary of PECASUS go by; instead we celebrated it together with colleagues and partners.

PECASUS stands for 'Pan-European Consortium for Aviation Space weather User Services' and brings together several European institutes possessing leading expertise in the space weather impact domain. PECASUS is led by the FMI, the Finnish Meteorological Institute under the regulations of ICAO (International Civil Aviation Organisation).

The STCE (Belgium) provides expertise in the domain of solar physics and particle radiation expertise, and is responsible for collecting, formatting and analysing the data and to write the bulletins.

The alerts are available on the website of FMI, the Finnish Meteorological Institute.

First evidence of water frost on the tallest volcanoes of Mars

A [study published in Nature Geoscience on 10 June 2024](#), and to which researchers of the Royal Observatory of Belgium contributed, reveals for the first time the presence of water frost on the peak of Martian volcanoes near the equator.

The presence of frost was observed independently by the Colour and Stereo Surface Imaging System (CaSSIS) and the Nadir and Occultation for Mars Discovery (NOMAD) instruments onboard the European Space Agency's (ESA) ExoMars Trace Gas Orbiter (TGO) spacecraft, as well as by the High Resolution Stereo Camera (HRSC) from ESA's Mars Express mission. Scientists from ORB-KSB analysed data from the [TGO-NOMAD instrument](#), which is led by Royal Belgian Institute for Space Aeronomy (BIRA-IASB). Specifically, the Limb Nadir and Occultation (LNO) spectrometer of NOMAD, originally designed to measure absorptions by the Mars atmosphere of infrared sunlight reflected from the surface, detected an absorption by ice deposits at the summit of Olympus Mons, located at an altitude of 20 km above the surrounding area.

The weather conditions at these high altitudes were simulated by the researchers at the ORB-KSB in order to assess spacecraft observations within a consistent theoretical framework and to better identify the frost composition. Modelling of Martian air circulation at the summit of the caldera, the large depression at the peak of ancient volcanoes, revealed that moist air can indeed condense into water frost at the bottom of the caldera floor during the night and early morning, similar to what can be observed on the Earth.

This discovery provides new insights into Martian climate dynamics, highlighting the importance of ongoing research to understand the Martian water cycle and prepare for future Mars missions and possible human exploration.

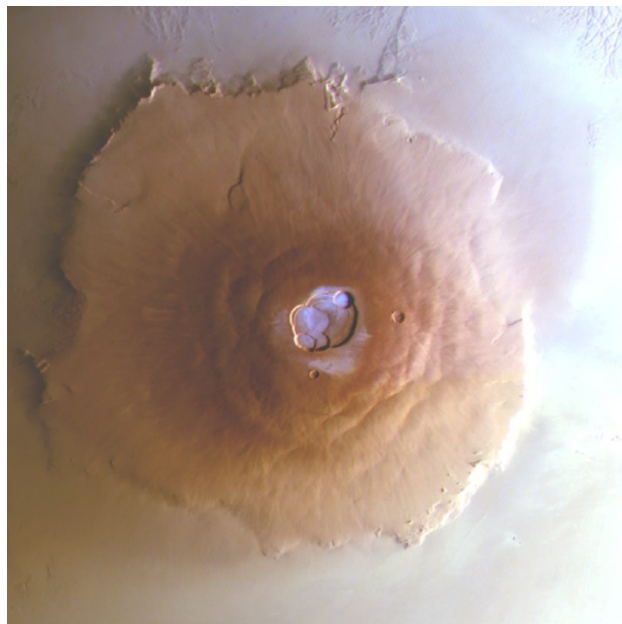


Figure 13: This early morning wide-angle image of Olympus Mons (LST = 7:20 a.m., $L_s = 346.7^\circ$, lat = 18.2°N , lon = -133.2°E) taken by the Mars Express High Resolution Stereo Camera (MEX-HRSC) reveals for the first time the presence of frost on the summit of the volcano, the tallest one on Mars and in the entire Solar System. © ESA/DLR/FU Berlin.

A new research project with the ORB-KSB for dark matter detection with satellites and gravimeters

Scientists from the Royal Observatory of Belgium and the Université libre de Bruxelles (ULB) are involved in the new project named OMMEGANG ('Observing dark Matter and MEteoroids with Gravimeters AND GNSS'). This project aimed at detecting mini black holes passing close to the Earth using data from GNSS positioning satellites (including the GPS and GALILEO systems) and superconducting gravimeters.

A recent hypothesis stipulated that dark matter, the existence of which could explain the anomalies in the movements of the galaxies, could be made up of primordial mini black holes. Although very massive in absolute terms, these mini black holes are virtually undetectable, which therefore presents a challenge. Scientists, including Pascale Defraigne, Bruno Bertrand (ORB-KSB), Michel Van Camp (formerly ORB-KSB, now at the Royal Belgian Institute of Natural Sciences) and Sébastien Clesse (Université libre de Bruxelles) took part in a study to estimate the limits and possibilities of detecting these objects. The first author of the article, Michal Cuadrat-Grzybowski, a student at the time at ULB and ORB-KSB and currently a researcher at TUDelft, is an expert in orbit calculation.

In this [study, published in Physical Review D](#), the scientists estimate that, in the vicinity of the Earth, passages of these mini black holes below the Earth-Moon distance, estimated at at least one per decade for the mass of 10^{14} kg mentioned above, could disrupt the orbits of GNSS (Global Navigation Satellite System) positioning satellites, such as the GPS and Galileo satellites, and create variations in the Earth's gravity field, detectable by superconducting gravimeters.

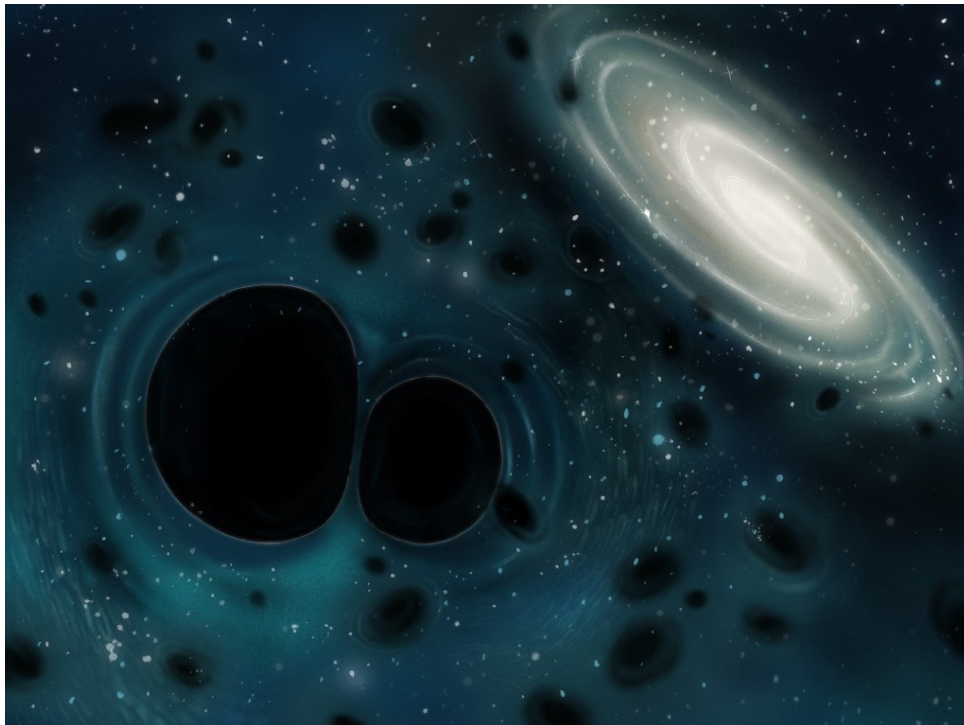


Figure 14: Artist's view of a massive black hole merging into a cluster, probably like GW190521, an observation of gravitational waves by LIGO/Virgo. Credit: Ingrid Bourgault (distributed under a CC BY-SA 4.0 International licence). (Source: https://commons.wikimedia.org/wiki/File:Illu_LIGO-Virgo_20200902_2.jpg)

With its long-standing expertise in [processing GNSS data](#) and [gravimetry](#), the ORB-KSB will bring its contribution to the OMMEGANG project, without the need to build a costly new experiment since the data are already available, while the ULB will provide its expertise in cosmology and fundamental physics. This interdisciplinary project is hence a novel way of doing science, of which the involved scientists expect many fruitful results.

Prizes, Awards and ORB-KSB scientists in the limelight

Cem Berk Senel is a laureate of EOS Pipet 2024

On 23 May 2024, the Flemish popular science magazine EOS Wetenschap presented five young scientists in its contest [EOS Pipet 2024](#). Each was chosen for their significant contribution to scientific research. Among them is Cem Berk Senel, postdoctoral researcher at the Royal Observatory of Belgium, who recently published a [paper in Nature Geosciences](#) that attracted a great deal of media attention.



Figure 15: Photo of Cem Berk Senel in front of a dinosaur statue. Credit: Cem Berk Senel.

After a master's degree at the Technical University of Istanbul, Cem Berk Senel developed his expertise in atmospheric sciences during his post-master's degree at the von Karman Institute, followed by a PhD degree at the ORB-KSB and the Université libre de Bruxelles, which he completed in 2023. During his doctoral thesis, together with Orkun Temel and Özgür Karatekin (ORB-KSB), he developed a model that simulates the Earth's climate just after the Chicxulub impact 66 million years ago. Paleoclimate simulations show that the fine dust generated by the meteorite impact caused a global cooling of the planet and disrupted photosynthesis of the vegetation present at that time.

[The results of this research](#), also carried out in collaboration with researchers from the Vrije Universiteit Brussel (VUB) (Philippe Claeys, Pim Kaskes, Steven Goderis), the KU Leuven and the Royal Belgian Institute of Natural Sciences (Johan Vellekoop), were published in *Nature Geosciences* on October 30, 2023. The publication attracted considerable attention from the Belgian and international media, demonstrating the high level of public and media interest in this significant contribution to research. Featured in a curated collection by *Nature* ([Dinosaur 200th Anniversary Collection](#)), this research was selected for [The Top 10 Dinosaur Discoveries of 2023](#), by *Smithsonian Magazine*.

By becoming one of the five laureates of EOS Pipet 2024, a contest organised in collaboration with the Jonge Academie, he has received further recognition for his scientific achievements from the jury, made up of Flemish science journalists and communicators.

Cem Berk Senel's interview by EOS Wetenschap (in Dutch) can be found on this webpage: <https://www.eoswetenschap.eu/natuur-milieu/cem-berk-senel-ontrafelde-hoe-fijnstof-66-miljoen-jaar-geleden-het-leven-decimeerde>

The Royal Academy awarded two of its prizes to researchers from the Observatory

On Saturday 14 December 2024, Jérémy Requier of the Royal Observatory of Belgium was awarded the Maily Prize by the Royal Academy of Sciences, Letters and Fine Arts of Belgium. His colleague Sébastien Le Maistre, from the same institute, won the prize in the 2024 annual competition of the Class of Sciences.

The Maily Prize to Jérémy Requier

The Édouard Maily Prize is awarded every four years by the Royal Academy to anyone who, through his or her writings or lectures, has helped to spread a taste for and knowledge of astronomy.

Jérémy Requier works in the Reference Systems and Planetology Operational Directorate at the Observatory. He is a specialist in the dynamics of rotating fluids. He has applied this field to the study of the Earth's rotation and its liquid core, as well as to the flow of the oceans of the ice moons of Saturn and Jupiter. In addition to his activities in disseminating and popularising science, for which he was awarded the prize, Jérémy teaches astronomy at UCLouvain.



Figure 16: Jérémy Requier (left) and Sébastien Le Maistre (right) holding their prizes from the Royal Academy of Belgium in front of the Observatory's solar dome. Credit: ORB-KSB.

Sébastien Le Maistre, winner of the 2024 Class of Science competition

Sébastien Le Maistre works in the same Operational Directorate as Jérémy Requier. He specialises in the analysis of radio communications between the Earth and probes placed on the surface of planets, a field known as radioscience. He has used his expertise to prepare and analyse data from space missions, one of the most recent being the [InSight mission](#) on the surface of Mars.

This year, the Class of Science was looking for new research in the field of astronomy and physics. The class asked for 'an original contribution, either experimental or theoretical, concerning the different parts of the planet Mars, whether in terms of its interior, polar caps, atmosphere or potential biosphere, past or present'.

As part of this competition, Sébastien Le Maistre submitted his contribution, entitled The Heart of a Dancer, in which he reports a series of new results on the rotation and deep interior of Mars. He shows, for example, that the existence of a solid core at the very centre of the Red Planet is unlikely, which has

serious consequences for energy dissipation and magnetic field models on Mars. This paper attracted the interest of the jury, who selected the author as the winner of the competition.

Congratulations to Jérémy and Sébastien for their prizes!

The winners and 2024 prizes of the Royal Academy of Belgium: <https://academieroyale.be/fr/actualites-detail/messages/classe-sciences-laureats-prix-decernes-2024/>

Research at the Royal
Observatory of Belgium

Seismology and Gravimetry

Seismic Activity in and around Belgium in 2024

In 2024, 141 earthquakes were located by the Royal Observatory of Belgium to be in or near Belgium. On Belgian territory, no earthquake was large enough to have been felt.

The 141 located earthquakes occurred in a zone between 1° and 8° E longitude and 49° and 52° N latitude (Figure 17). On Belgian territory, 42 natural earthquakes occurred. The largest earthquake occurred on 12 April 2024 in Maaseik and had a local magnitude of 1.8. It was not felt by the local population. The 2024 catalogue of the ORB-KSB is complete for natural earthquakes with a magnitude M_L larger than 1.0. Events with magnitudes lower than 1.0 were also routinely detected where the Belgian seismic network is denser.

During the same period, the ORB-KSB also measured one induced event in Germany, 304 quarry blasts and 10 explosions offshore linked to controlled explosions of WW1 and WW2 bombs by the Belgian, Dutch or French Armies. In Belgium, none of the induced (man-made) earthquakes were large enough to be measured by the Belgian Seismic Network maintained by the ORB-KSB.

In comparison, last year in 2023, 120 earthquakes occurred in and around Belgium.

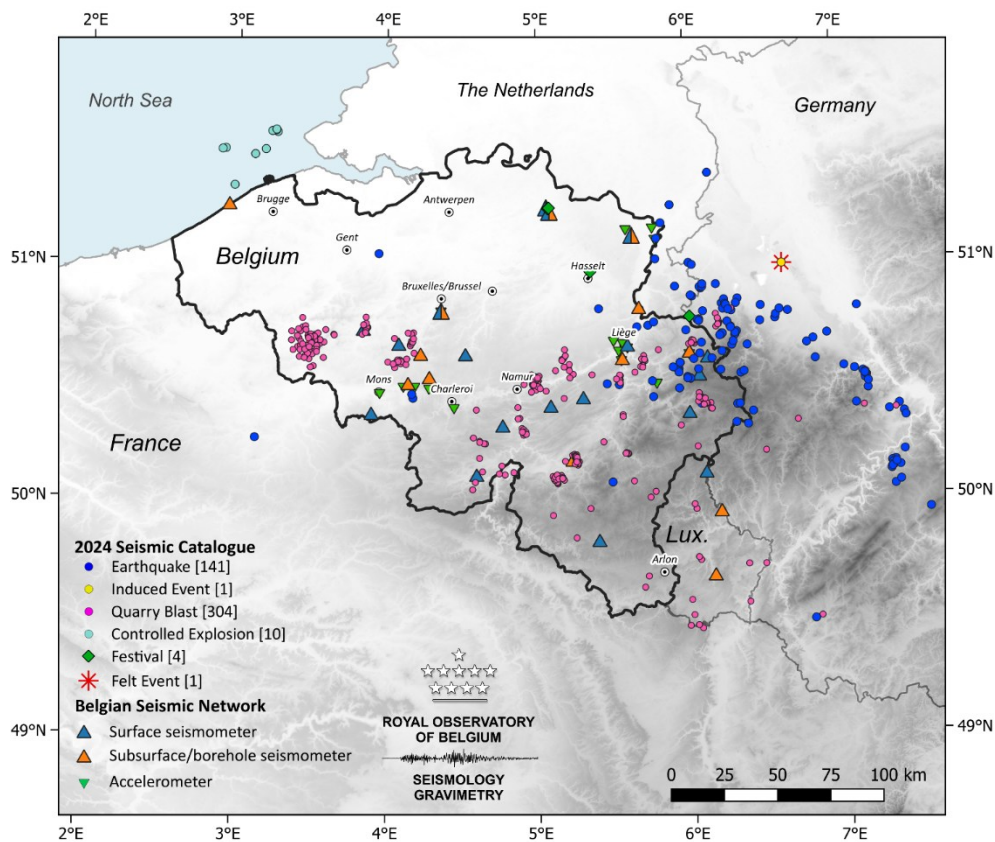


Figure 17: Events recorded in 2024 by the Belgian Seismic Network of the Royal Observatory of Belgium. Credit: ORB-KSB.

A climate-change-triggered landslide caused Earth to vibrate for 9 days – Belgian researchers are involved in a study led by an international multidisciplinary team

In September 2023, a mysterious, globally observed and unprecedented 9-day-long seismic signal was caused by a massive landslide in Greenland. 25 million m³ of rock and ice fell into the Dickson Fjord and, in turn, caused a 200-metre-high mega-tsunami that continued sloshing back and forth – a phenomenon called a seiche – in the narrow fjord for 9 days. That is the conclusion of research published in the journal *Science*. The seismic waves generated by this large mass of moving water were observed around the world. Never before have scientists, including researchers of the Royal Observatory of Belgium, the Flanders Marine Institute (VLIZ) and the Université libre de Bruxelles, observed such an unusual mechanism causing a global seismic signal.

A puzzle solved within a multidisciplinary collaboration

The mysterious 9-day-long seismic signal, which started on 16 September 2023 and was recorded on highly sensitive sensors all over the globe, puzzled seismologists from ORB-KSB and ULB. The signal looked completely different to frequency-rich earthquake recordings – it contained only a single vibration frequency, like a monotonous-sounding hum. At the same time, news of a large tsunami in a remote Northeast Greenland fjord reached authorities and researchers from VLIZ working in the area.

Both teams joined forces with a multidisciplinary international group of 68 scientists from 40 institutions in 15 countries, combining seismometer and infrasound data, unique field measurements, on-the-ground and satellite imagery, and simulations of tsunami waves.

The team also used imagery captured by the Danish military who sailed into the fjord just days after the event to capture the collapsed mountain-face and glacier front along with the dramatic scars left by the tsunami. This unique harmony of local field data and remote, global-scale observations allowed the team to solve the puzzle and reconstruct the extraordinary cascading sequence of events in September 2023. The results are now published in *Science* (Svennevig et al., 2024).

A huge landslide collapsing into a narrow fjord as the origin of the seismic waves

Traditionally, seismology focuses on measuring seismic vibrations arising from earthquakes in the ground. However, seismic records can also contain information about movements of large masses on Earth's surface, such as landslides and water waves.

The local signal was picked up by a real time monitoring network set up in the Kong Oscar Fjord System by VLIZ and Aarhus University, including cameras and oceanographic moorings, to study climate gradients and freshwater dynamics. Oceanographic sensors in Dickson Fjord and near Ella Ø measured anomalous water levels and peak turbidity. The global seismic signal was picked up by a global network of seismometers; sensitive scientific instruments that record vibrations travelling through the ground – called seismic waves.

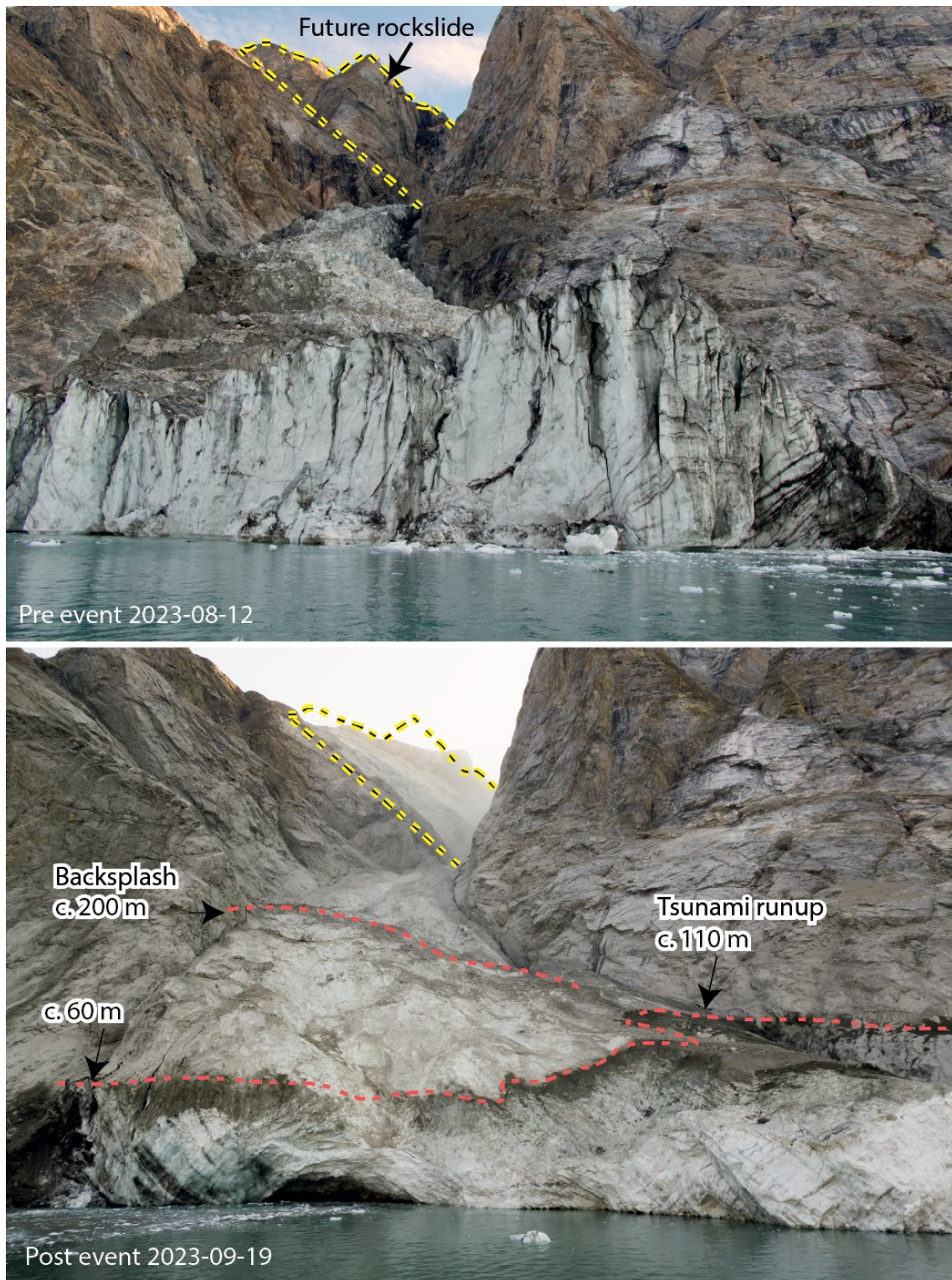


Figure 18: Before (August 2023; above) and after (September 2023; bottom) photos of the mountain peak and glacier, taken from the Dickson Fjord. Source image credits: Søren Rysgaard, Danish Army. GIF animation: Carsten E. Thuesen.

The study found that the landslide was from the collapse of a mountaintop that previously towered 1.2 km above the Dickson Fjord. The volume of material that collapsed was massive – more than 25 million cubic metres – or 27 times the volume of all 20 ft containers on the world’s largest container vessels (circa

24 000 per vessel or 650 000 containers). This collapse was caused by glacial thinning at the base of the mountain over recent decades, ultimately caused by climate change.

The combined signals were so puzzling that one of the scientific team members tried to recreate the long-lived sloshing effect in their bathtub at home. They failed to simulate the same effect, so it was left to detailed mathematical models to show that the landslide direction, together with the uniquely narrow and bendy fjord channel, was the last missing piece of the puzzle of how climate change rang the Earth for 9 days.

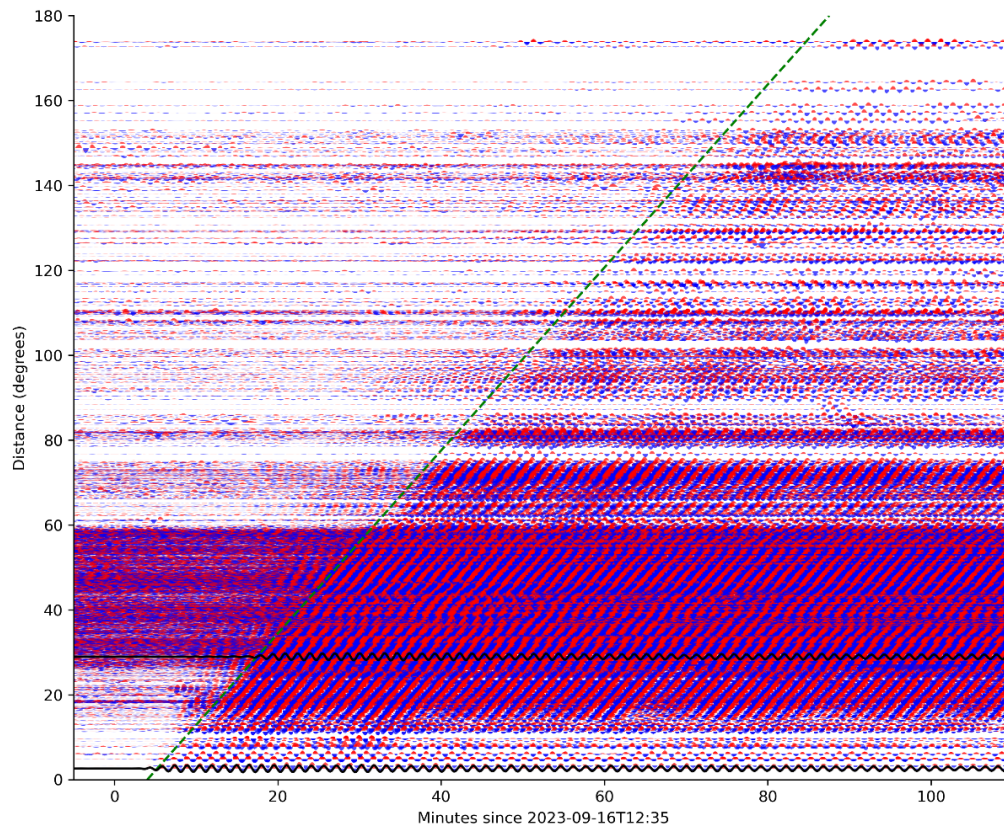


Figure 19: Record section showing the recorded seismic waves plotted against distance from the landslide (1 degree = 110 km; 180 degrees = antipodal to Greenland). The wiggles are filled with red (positive amplitude) and blue (negative amplitude) colours. Credit: ORB-KSB

The predictions showed that water sloshed back and forth every 90 seconds, the same oscillation period observed in the seismic waves. This perfect match shows how the force of the moving water body, generating a distinct oscillation due to the width and depth of the fjord, creates seismic energy in the crust.

The highest tsunami observed in recent history

Numerical simulations, data from a local oceanographic sensor network, satellite and on-the-ground imagery confirm that **the resulting mega-tsunami is one of the highest seen in recent history**. Further out of the fjord, 4 m high tsunami waves damaged a research base at Ella Ø (island) 70 km away and destroyed cultural and archaeological heritage sites across the fjord system. The fjord is on a route commonly used by tourist cruise ships visiting the Greenland fjords.

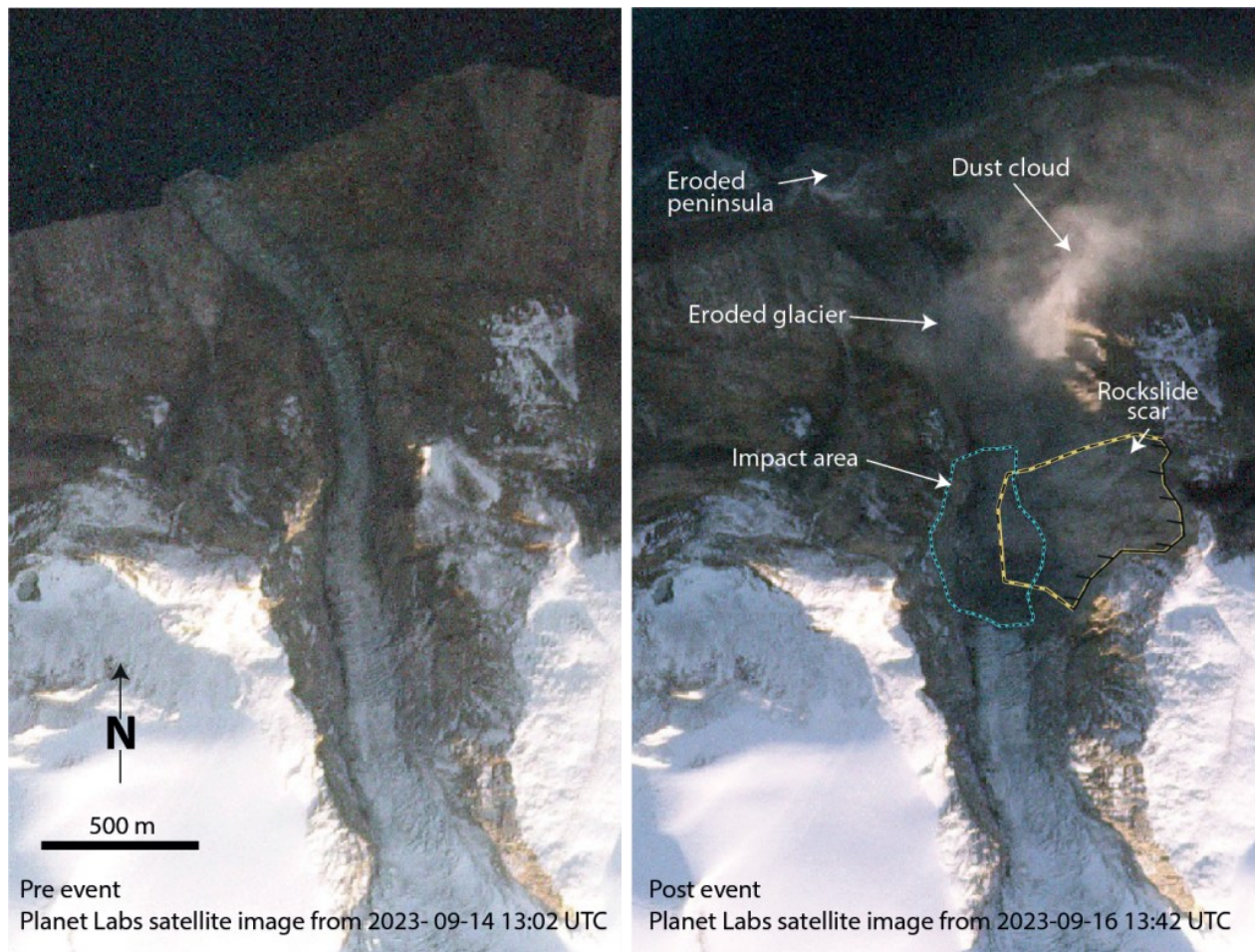


Figure 20: Pre- (30 minutes before) and post-landslide (7 minutes after) Planet Labs satellite image. Credit: Planet Labs

Fortunately, no cruise ships were close to Dickson Fjord on the day of the landslide and tsunami, but if they had been, the consequences of a tsunami wave of that magnitude could have been devastating. With rapidly accelerating climate change, it will become more important than ever to characterise and monitor regions previously considered stable and provide early warning of massive landslide and tsunami events.

Co-author Wieter Boone (Flanders Marine Institute, VLIZ): *'For our research, we established a network of real time under ice oceanographic stations in Northeast Greenland. Last year, we sailed into Dickson Fjord to install instruments close to a glacier and almost right in front of the mountain just weeks before it collapsed. Our instruments survived and we were able to follow the events unravel in real time. The observed destruction of an old trapper hut, never affected by tsunamis for its century-old history, demonstrate the unexpected size of this event. During August 2024, we updated our sensor network, mapped the impact of the tsunami using drones and installed high frequency seismic and water-level sensors in Dickson Fjord.'* VLIZ also installed three seismic instruments from the ORB-KSB in the area, to record future motions there. The sensors are still there and need to be recovered.

Reference paper: Svennevig et al., [A rockslide-generated tsunami in a Greenland fjord rang Earth for 9 days](#), Science, published online on 12 September 2024. DOI: 10.1126/science.adm9247.

Ambient seismic noise campaign to measure site effects of Lixouri and the Paliki peninsula, Kefalonia, Greece

The Royal Observatory of Belgium, the National and Kapodistrian University of Athens and the National Museum of Natural Sciences of Spain (MNCN-CSIC) joined forces in a field campaign to measure earthquakes and ambient seismic noise in the Paliki peninsula of the Ionian Island of Kefalonia in Greece to better understand the subsurface of this area.



Figure 21: Installation of SmartSolo geophones on the Paliki Peninsula, Kefalonia, Greece. Credit: ORB-KSB.

The Ionian Islands Kefalonia and Lefkada in Greece have been repeatedly hit by moderate to large earthquakes and took place in one of the most active seismotectonic zones of the Aegean. In Paliki, the western peninsula of the Island of Kefalonia, large earthquake amplification has been measured due to the presence of a subsurface soft sediment basin, but a geotechnical model explaining these amplifications is currently still lacking.

To develop a new 3D subsurface model and a detailed velocity model, the National and Kapodistrian University of Athens, the ORB-KSB and the National Museum of Natural Sciences of Spain (MNCN-CSIC) joined forces in a field campaign to deploy geophones in cross-profiles through the Paliki Peninsula.

The impetus of this fieldwork activity was initiated during the ‘8th International Conference on Historical Seismology, Paleoseismology and Earthquake Engineering’ held in Lixouri on 17–19/9/2023. Between Friday, 27 September 2024 and Friday, 4 October 2024, we successfully completed an ambient noise field study throughout the Paliki Peninsula.

Using 24 SmartSolo IGU-16HR 3C geophones, 3 SmartSolo IGU-BD3C-5LC broadband devices and two Tromino instruments, ambient noise measurements were carried out at 220 locations all over the Paliki Peninsula which resulted in ~ 3225 hours of ambient noise data. We installed one array and 9 profiles (total profile length of 50 km) crossing the island to detect the variation in bedrock depth and to measure site amplification when an earthquake would occur. Array and cross-correlation techniques, H/V Spectral Ratio analysis, and earthquake relocation techniques will be applied to better understand the impact of earthquakes on this area.

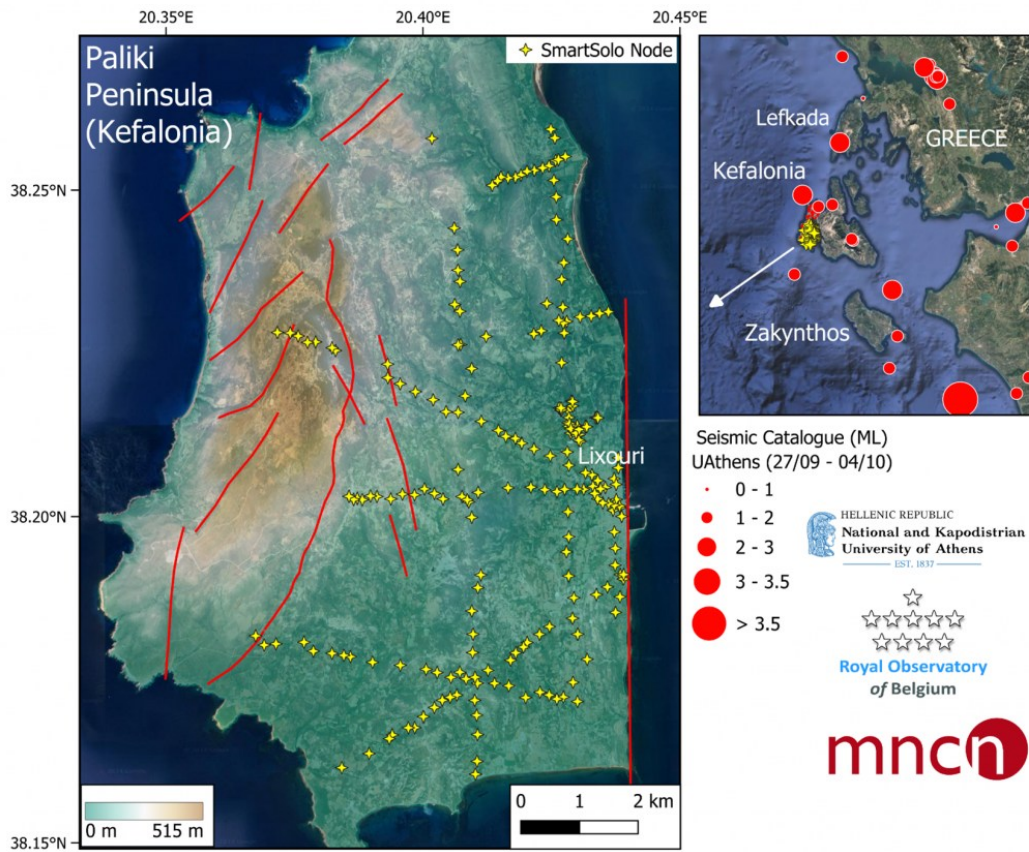


Figure 22: Installed profiles (yellow stars) and seismicity around Kefalonia during the profile installation. Credit: ORB-KSB/MNCN.



Figure 23: Raypaths between simultaneously installed geophones crossing the town of Lixouri and the Paliki Peninsula. Credit: ORB-KSB/MNCN.

To our knowledge, it is the first time that such large-scale fieldwork has been performed on the Ionian Islands and the recorded data will stimulate new research studies and contribute significantly to the seismic protection of the Lixouri municipality on Paliki. A first look at the data already looks very promising as tens of small earthquakes were recorded, which beautifully propagated through the different installed networks, without having been identified by the permanent seismic network.

The field research team included the seismologists Dr Maria Jose Jimenez, Dr Mariano Garcia Fernandez (scientific advisors of the OXE cooperation programmes), and Dr Nikolaos Sakellariou, all at MNCN-CSIC (Spain), Dr Koen Van Noten and Dr Raphael De Plaen from the ORB-KSB and Nikolaos Galanos, our local guide in Lixouri. The project was coordinated by Ms Vasiliki Kouskouna, Em. Professor of Seismology at the University of Athens, and coordinator of the OXE cooperation projects between the University of Athens and the Municipality of Lixouri, under the supervision of the Mayor of Lixouri, Georgios Katsivelis, and, in close collaboration with CSIC, projects PIE 202330E132 and PIE 202330E137. The ORB-KSB provided in-kind contributions to support these projects with their seismic instrumentation.



Figure 24: Installation team. Collaboration between the National and Kapodistrian University of Athens, the Royal Observatory of Belgium and the National Museum of Natural Sciences of Spain (MNCN-CSIC). Credit: ORB-KSB/MNCN.

In the future it will be important to continue this initiative with additional measurements to cover the entire peninsula of Paliki, which eventually will contribute to the understanding of the seismic risk of the area. Together with the study of the building vulnerability that already has been carried out in the framework of the OXE programme, our study will make the assessment of the seismic risk of a future strong earthquake more accurate.

The research team expresses its sincere thanks to the residents of the Municipality of Lixouri, who welcomed us greatly and contributed to the smooth performance of the field campaign.

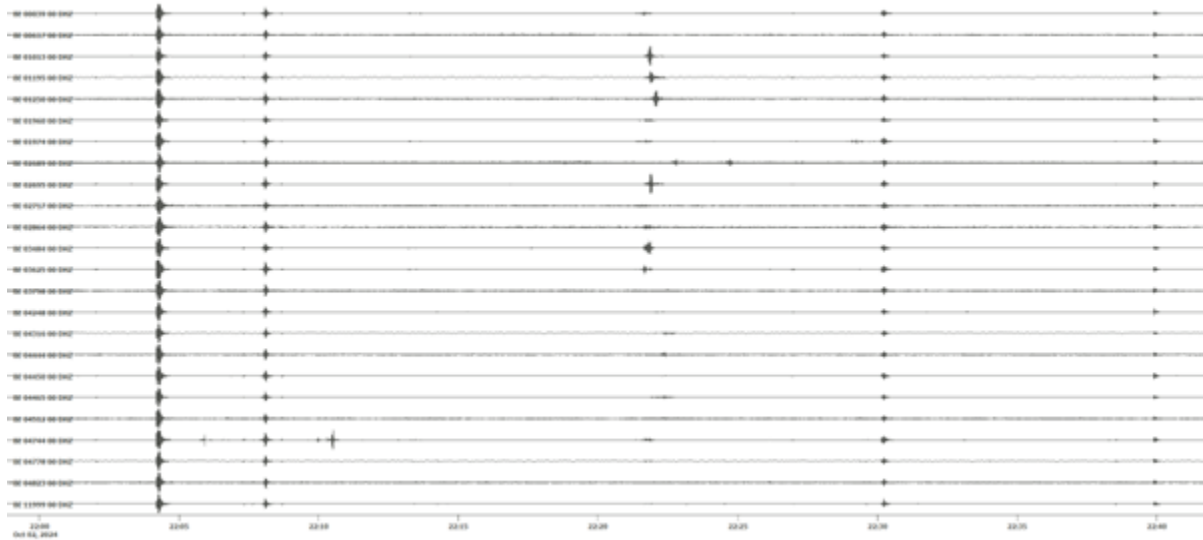


Figure 25: View on four consecutive earthquakes that occurred on the main island of Kefalonia on 2 October 2024 while our overnight array network of 26 stations near Lixouri was running. Credit: ORB-KSB/MNCN.

Evaluation of seismic models using data of earthquakes in the Belgian Hainaut province

In a recently published article in *Bulletin of Earthquake Engineering*, researchers from the seismology department of the Royal Observatory of Belgium evaluate the applicability of existing models to calculate ground motions due to earthquakes in the coal basins of the Belgian Hainaut Province.

During the 20th century, more than 25 earthquakes occurred here with magnitudes between 2.9 and 4.1, presumably triggered by the large-scale coal mining in the region. Due to their shallow depth (only a few kilometres), these earthquakes were strongly felt by the population and even caused damage to buildings. Unfortunately, because these earthquakes all occurred at a time when there was no modern seismic network, no digital records are available. However, it is possible to compare the models via an intermediate step with macroseismic intensity data (= a measure of the shaking at the Earth's surface during an earthquake based on the effects on people, objects and buildings) gathered from the numerous testimonies in a previous study.

For more than 20 models, our researchers calculated the goodness of fit with the data according to various measures, including a self-developed measure to evaluate the distance trend separately. The compilation of intensity data had already shown that intensities in the Hainaut coal basins decrease much faster as a function of distance than elsewhere in north-western Europe. Our analysis shows that no international model really matches the data well, especially in terms of the distance trend, demonstrating the uniqueness of this region. Nevertheless, we were able to select three models that clearly outperform the others (Figure 26). The selection of suitable ground motion models is important to compute new seismic hazard maps and possibly also to generate ShakeMaps (Figure 27) in case of potential future earthquakes in the region.

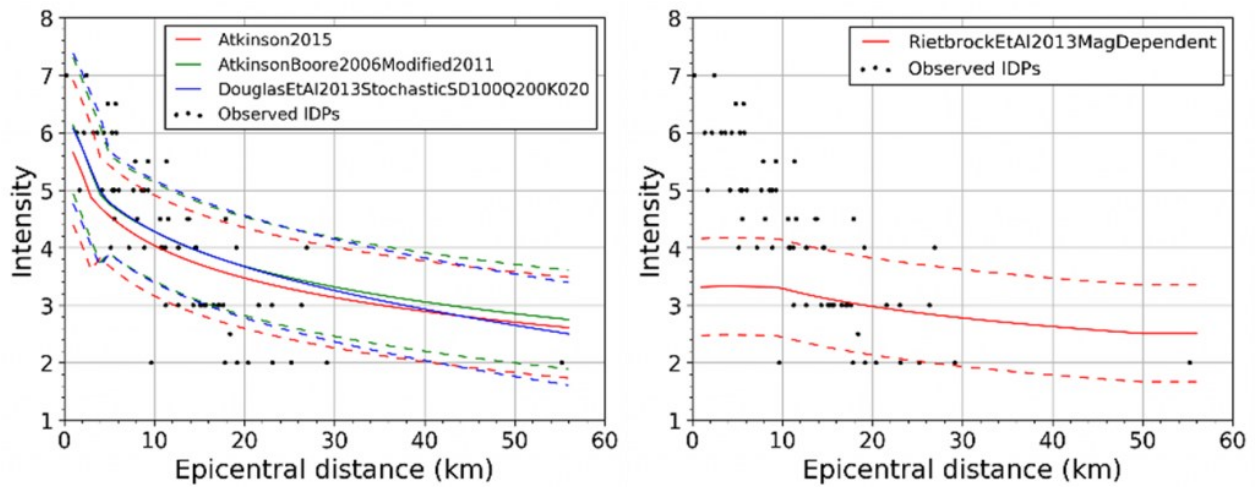


Figure 26: Comparison between observed intensities (black circles) and intensity models (solid lines) with their uncertainties (dashed lines) as a function of distance for the April 3, 1949, Havré earthquake (magnitude 4.1). Left: the three best-fitting models; Right: one of the worst-performing models. Reference paper: [Vanneste et al. \(2024\)](#).

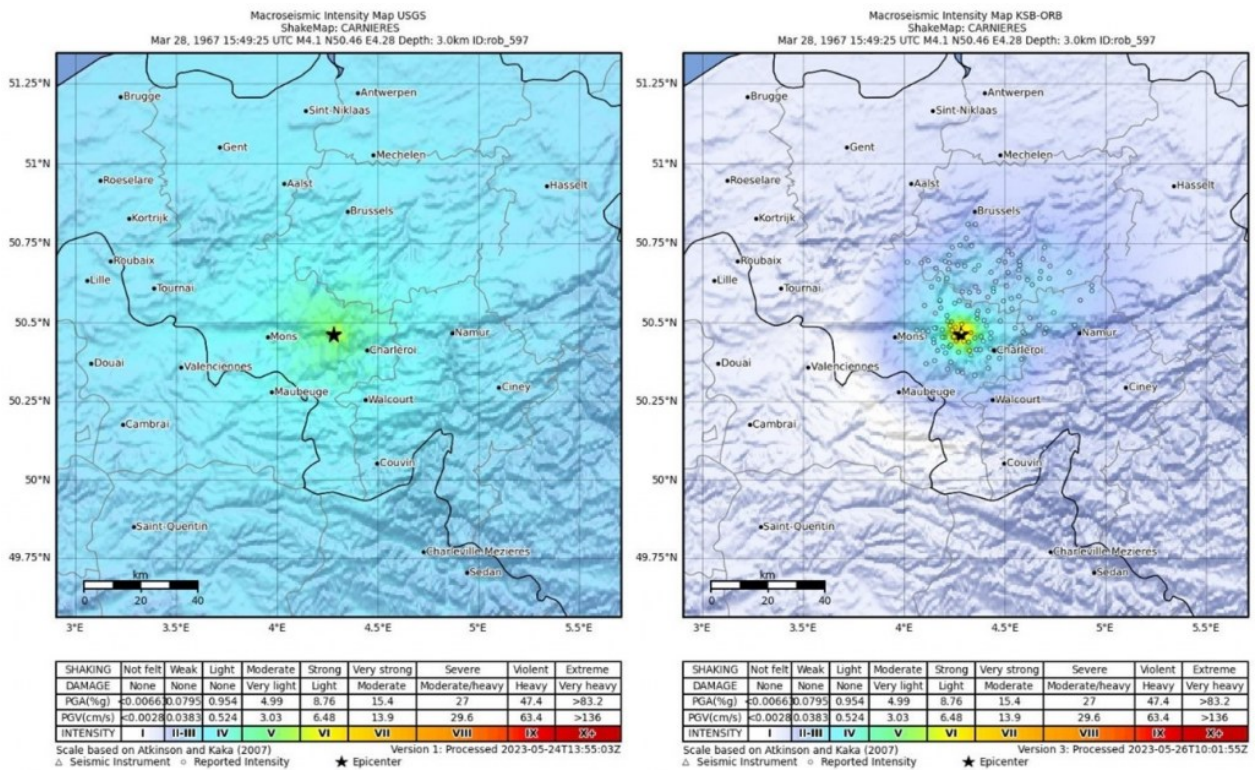


Figure 27: ShakeMap calculated for the March 28, 1967, Carnières earthquake (magnitude 4.1). Left: based on ground motion models developed for stable continental regions; Right: based on the models selected in this study. Reference paper: [Vanneste et al. \(2024\)](#).

Reference paper: Vanneste, K., Neefs, B. & Camelbeek, T. *Testing the applicability of ground motion prediction equations for the Hainaut region (Belgium) using intensity data*. Bull Earthquake Eng (2024). <https://doi.org/10.1007/s10518-024-01958-1>

A new book on historical seismology published by the Observatory

In 2024, the Royal Observatory of Belgium published a new book on historical seismology, written by Pierre Alexandre and Dominique Alexandre-Lamotte. In this work 2,489 critical sources and a catalogue containing 1,507 earthquakes that took place in the Middle Ages and Renaissance are presented. The book is free to download. Prints can be ordered.

This book, entitled in French ‘Les tremblements de Terre en Europe au Moyen Âge et à la Renaissance’ (in English: ‘Earthquakes in Europe and Minor Asia from 284 to 1550’) is a new critical catalogue of earthquakes in Europe from 284 to 1550, as known from the original written sources.



Figure 28: Book covers of the new book in historical seismology. The printed version of the book is divided in four volumes. Credit: ORB-KSB.

The first part of the book is a critical study of the written sources providing information on earthquakes. 2,489 sources have been listed. Most of them (2,117) are narrative sources (annals, chronicles, annotations, etc.), the others (372) are administrative documents, reporting damage caused by the earthquakes. Only two types of texts were preserved: those from original authors, contemporary with the events, and those coming original, lost, sources copied by later authors recognised as trustworthy by historical criticism. Other second-hand texts have been eliminated, either because they are duplicates or because they provide false data or affabulations. In total, 4,641 original texts are provided, of which 1,273 (27%) come from lost sources.

The second part of the book is the actual catalogue of 1,507 earthquakes, classified in chronological order. For each earthquake, the texts are given in their original language, except for those (12%) written in non-Latin characters and for which only translations by other authors are given. Together with the book, a table of 4,702 macroseismic data points (MDPs) is presented including all the localities where each of the 1,507 seismic events has been felt. Some examples of historical seismicity maps have been added, based on this list of MDPs.

The third and last part of the book is a catalogue of 1,585 false earthquakes, where the false earthquakes – and false data on real earthquakes – conveyed by the authors of ‘traditional’ catalogues of historical seismicity are listed.

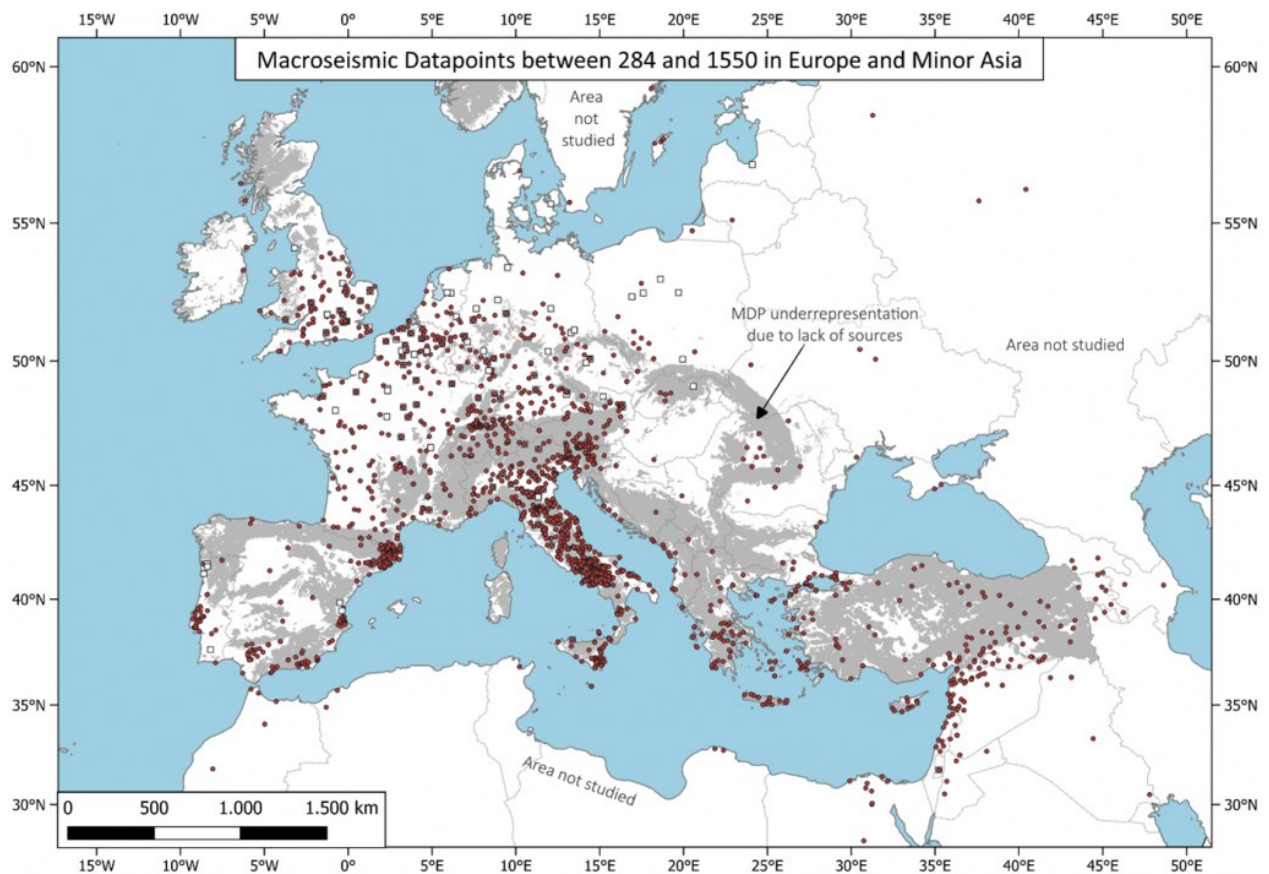


Figure 29: European map with an overview of all macroseismic data presented in the book. Red dots are places where the earthquake has been felt. Squares are negative evidence. Credit: ORB-KSB.

It should be kept in mind that it is an illusion to believe that medieval chronicles allow the creation of continuous and homogeneous series; some regions and periods are not represented in the presented catalogue. Yet, the aim of this book is to provide the most reliable corpus of data possible from medieval and Renaissance sources for seismologists studying seismic hazard in Europe.

This book was edited by Koen Van Noten (ORB-KSB), typeset by Claudia Godinho (Royal Academy for Overseas Sciences), printed by the State Archives of Belgium and funded by the Royal Observatory of Belgium.

A printed copy can be ordered (€65 excl. shipping costs) by contacting Koen Van Noten at [seismo.info\[at\]oma.be](mailto:seismo.info[at]oma.be). The printed book is provided in four volumes.

The book (pdf) and the catalogue (xlsx) can be downloaded for free following the DOI URL in the reference.

Reference paper: Alexandre, P., Alexandre-Lamotte, D. 2024. *Les tremblements de terre en Europe au Moyen Âge et à la Renaissance. Étude critique des sources et catalogue des tremblements de terre en Europe de 284 à 1550* (Koen Van Noten, Ed.). Observatoire royal de Belgique, Bruxelles, Belgique, p. 2074. doi: [10.24414/srvz-2k77](https://doi.org/10.24414/srvz-2k77)

20th century Felt Earthquakes in Belgium – How many earthquakes were experienced in your municipality?

In 2024, the Seismology and Gravimetry section of the Royal Observatory of Belgium published a new paper presenting an overview of a century of felt earthquakes in Belgium. Compiling the seismic impact on Belgium was rendered possible by reviewing all testimonies of the Belgian population to the ORB-KSB on how they experienced various earthquakes throughout a century. The paper is freely available to the public and the data can be consulted online.

This new work, entitled '*The Belgian traditional macroseismic (BTM) database of the twentieth century*' published in the Journal of Seismology, results from the PhD research of Ben Neefs, a PhD funded entirely by an ORB-KSB PhD grant.

Since its origin, the ORB-KSB is responsible for detecting and measuring earthquakes on the Belgian territory. Prior to the existence of a modern seismic network, the people's reports on how they experienced an earthquake were the only information on the impact of an event. The intensity of shaking can be derived from these reports, an important parameter called *macroseismic intensity*, which allows demonstrating the impact of an earthquake to the public and the authorities.

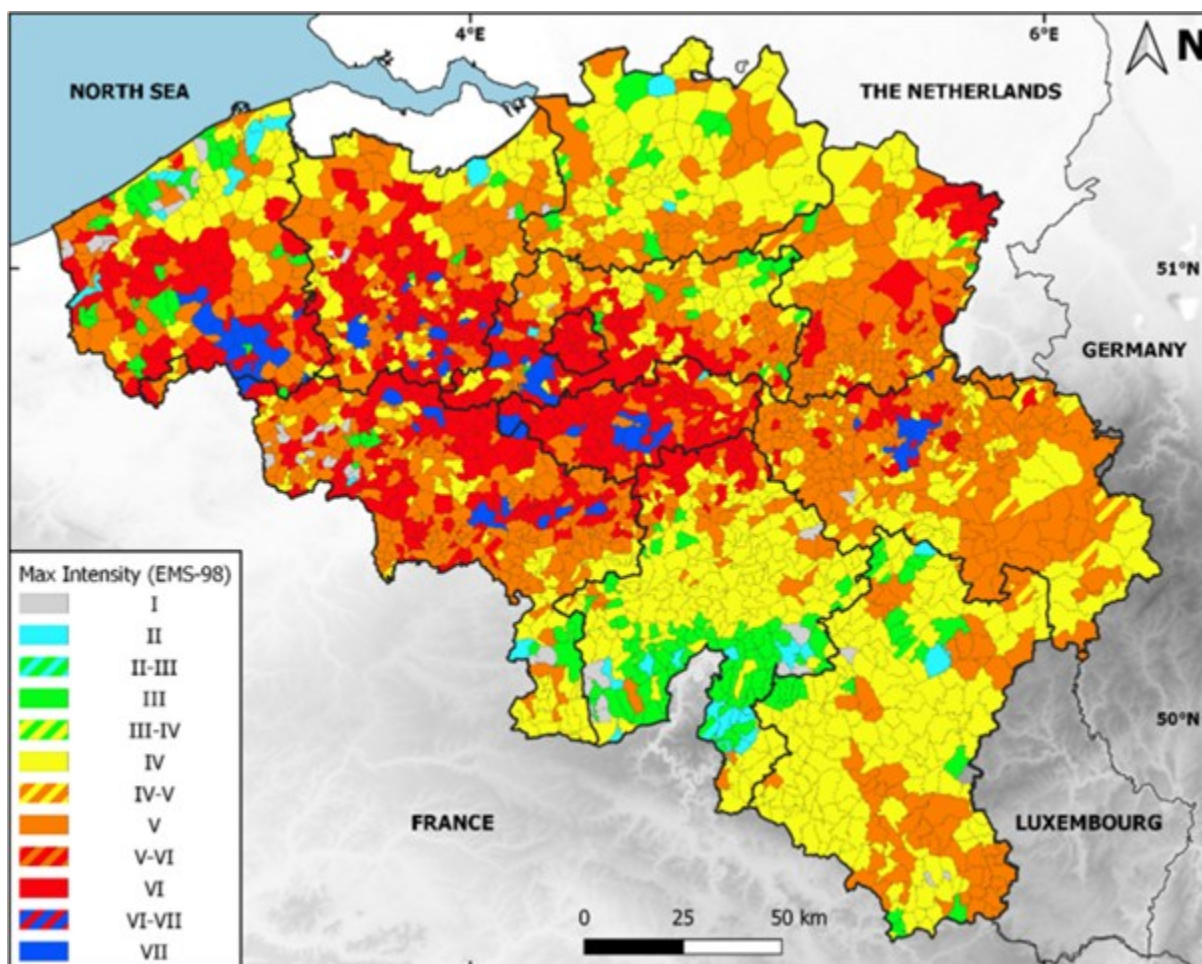


Figure 30: Maximum intensity on the sub-municipal scale for felt earthquakes in and around Belgium presented in the Belgian traditional macroseismic database. Credit: ORB-KSB.

The applied survey practices to gather this macroseismic intensity data, however, evolved significantly over the twentieth century: from small-scale ad hoc improvised surveys to the mass distribution of collective questionnaire versions sent to local authorities. We thoroughly re-evaluated the original source material to create the *Belgian Traditional Macroseismic (BTM) database*, a comprehensive compilation of 20th-century macroseismic data in which all sources are properly referenced.

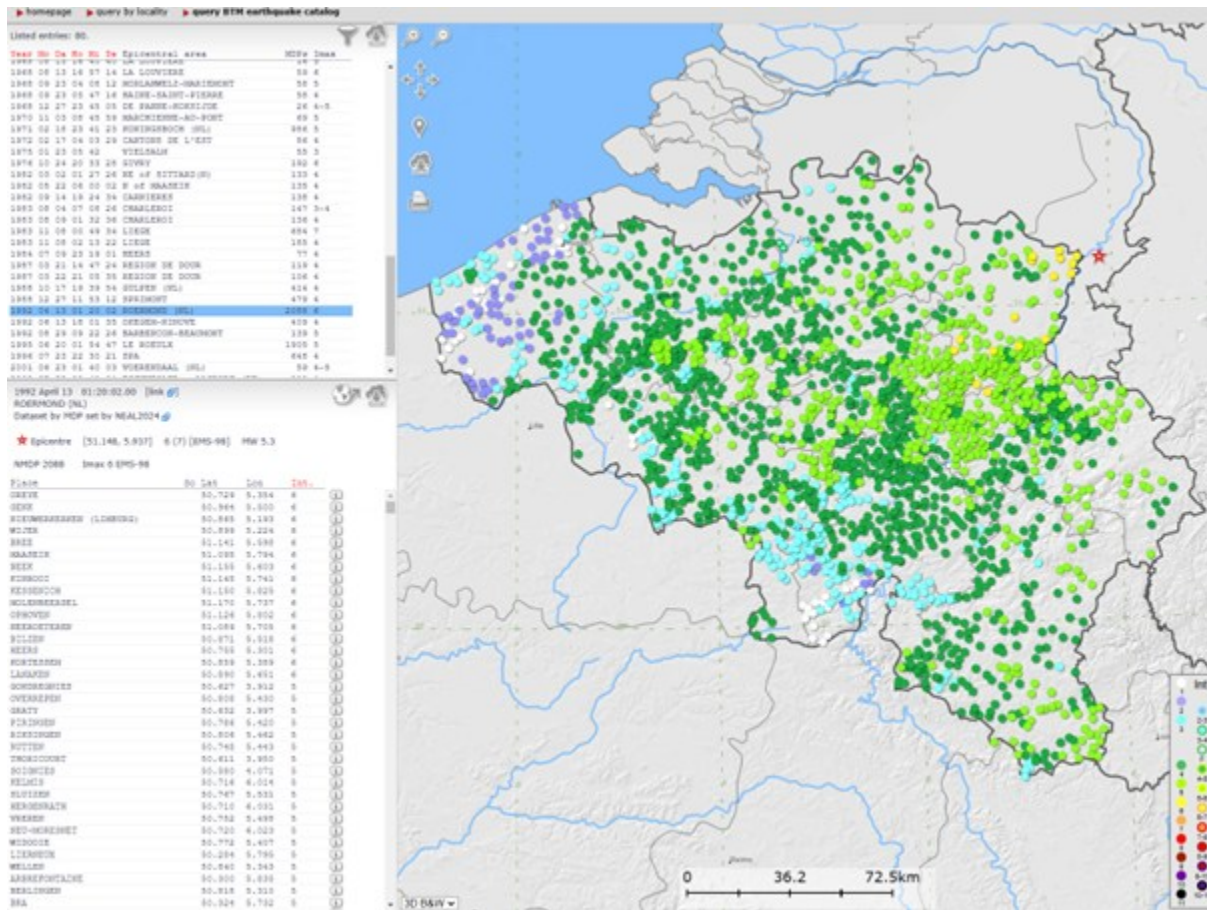


Figure 31: Online MIDOP platform of the ORB-KSB to explore macroseismic intensity data linked to all felt earthquakes in the 20th century. The example shows the 1992 Roermond (NL) earthquake felt all over Belgium. Credit image: ORB-KSB. https://seismology.be/midop/query_eq/index.htm

The BTM database currently consists of 23,950 intensity data points (IDPs) on the European Macroseismic Scale for 80 felt earthquakes in and around Belgium, ranging from 2.4 to 5.8 on the local magnitude (M_L) scale. Each IDP is provided with a source type and each earthquake is attributed a data quality parameter that indicates the level of uncertainty associated with its IDP source quality.

The open publication of the BTM database:

- facilitates the use of Belgian macroseismic data for a variety of seismological purposes
- summarises the overall seismic impact on Belgium for the duration of a century
- allows the Belgian population to consult these data:
 - How many earthquakes were felt in your municipality in the twentieth century?
 - Which earthquake had the largest impact on your municipality?
 - What was the largest magnitude of an event in your region?



Figure 32: Online MIDOP platform of the ORB-KSB to explore macroseismic intensity data linked to all felt earthquakes in the 20th century. The example shows the felt earthquakes and maximum intensity for the Uccle Municipality (Brussels). https://seismology.be/midop/query_place/index.htm Credit image: ORB-KSB.

Reference paper: Neefs, B., Van Noten, K., Vanneste, K. et al. *The Belgian traditional macroseismic (BTM) database of the twentieth century.* J. Seismol (2024). <https://doi.org/10.1007/s10950-024-10266-9>

Reference database (data shared under a CC BY 4.0 license): Neefs B., Van Noten K., Vanneste K., Camelbeek T., *The Belgian Traditional Macroseismic (BTM) Database of the 20th century: online database.* Royal Observatory of Belgium (2024). <https://doi.org/10.24414/2b5w-j029>

Global Navigation Satellite Systems, Time and Reference Systems

Better time and frequency transfer with GNSS



Figure 33: antenna and receiver connected to the atomic clock at the Royal Observatory of Belgium, measuring the GNSS satellite signals. These measurements are then analysed by the Atomium tool for time and frequency comparisons with the clocks of other laborator. Credit: ORB-KSB.

For the maintenance of time scales based on a distributed ensemble of atomic clocks, such as the Coordinated Universal time (UTC) which is an average of about 450 clocks distributed around the world, the time and frequency differences between the different clocks must be precisely determined. One of the different approaches classically used for these clock comparisons (also called time and frequency transfer, TFT) is using the Global Satellite Navigation System (GNSS). Compared to other techniques, GNSS has the advantage of being available everywhere at a reduced cost.

Since more than 20 years, the Royal Observatory of Belgium developed analysis techniques of GNSS measurements for TFT, among them 'Atomium', based on the so-called Precise Point Positioning (PPP). With the recent developments of optical clocks with frequency stabilities reaching below 10^{-17} , the time and frequency transfer techniques must be improved to enable the comparison of these clocks without masking their performances in the noise of the technique itself.

In 2024, the Atomium-PPP was pushed one step further, introducing an additional algorithm to solve for the

integer cycles of carrier phase data. Then, in collaboration with the Wuhan University, who provided specific phase bias products of the satellite clocks needed, we could improve the stability of the GNSS TFT solutions, allowing to compare atomic clocks with a stability of 3×10^{-17} after a sufficiently long averaging time of about 10 days as shown by Figure 34.

As the clocks compared in this study do not have such stability, we show only the stability of the difference between the Atomium solution and the clock difference obtained by optical fibres between two stations in Poland. In this difference, the stability of the clock no longer affects the results, and we get the stability of the techniques themselves. The optical fibre transfer is known to be less noisy than GNSS so that the final stability shown in Figure 34 is the stability of the Atomium result. The figure shows that a given stability can be reached about two times more rapidly with the new approach.

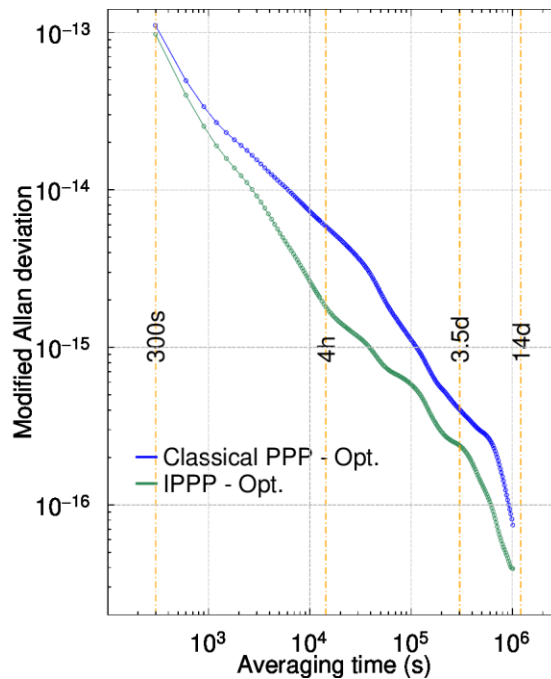


Figure 34: Stability, given by the Modified Allan deviations, of the differences between Atomium results and an optical fibre link solution (blue) for classical PPP, and (green) for the new approach fixing integer cycles of carrier phase data (called IPPP). The vertical orange lines from the left to right mark the averaging times of 5 minutes, 4 hours, 3.5 days and 14 days, respectively. Credit: ORB-KSB.

GNSS Highlights

In 2024, the Royal Observatory of Belgium further reinforced its involvement in geodetic research and innovation through a series of strategic projects and partnerships.

Amongst them, the ORB-KSB was recognised as [Partner of the UN Global Geodetic Centre of Excellence](#) (UN-GGCE) setup for advancing a sustainable Global Geodetic Reference Frame.

The ORB-KSB was also invited to join two new major Horizon Europe initiatives:

- Building on its longstanding role within the European Plate Observing System (EPOS), the ORB-KSB became Partner in the ‘EPOS Optimization and Evolution’ (EPOS-ON) project, dedicated to enhancing the resilience and sustainability of the EPOS research infrastructure and fostering broader international collaborations.
- Based on its leading expertise in applying Open and FAIR (Findable, Accessible, Interoperable, and Reusable) data principles to GNSS observation datasets, the ORB-KSB was also invited to join the EQUIP-G project (European Quantum Infrastructure Project for Gravimetry), which aims to develop and deploy a European network of quantum gravimeters.

The GNSS Open Data Portal (<https://gnss.be/opendataportal>) operated by the ORB-KSB is constructed on top of two data repositories: the Belgian national repository and the EUREF repository. This year, the Belgian repository included new contributions from the Royal Belgian Institute of Natural Sciences and the Agentschap Maritieme Dienstverlening & Kust. The repositories form a data hub that ensures the integration of Belgian and EUREF GNSS data in EPOS. Together, they represent 35% of all GNSS data discoverable through the EPOS-GNSS Data Gateway.

The ORB-KSB also completed a **27-year re-analysis of historical GNSS data** from EUREF network stations as part of the third reprocessing campaign coordinated by EUREF, contributing to the generation of a consistent and accurate long-term dataset of GNSS station positions and velocities across Europe used to provide access to the European reference frame, a cornerstone for all geolocated data and applications.

A **newly tracked usage statistics tool** developed by our team underscored the importance of ORB-KSB's GNSS data, products, and services, revealing that the ORB-KSB's GNSS platforms supported in 2024 more than 25,000 external users, with over 2 million downloads of GNSS station metadata, and 15 million downloads of observation GNSS data files.

Earth and Planetary Science

Exploration of the Galilean moons of Jupiter by the ESA JUICE mission

In 1610, Galileo Galilei discovered the four large moons of Jupiter. The largest of these moons, Ganymede, is larger than the smallest planet, Mercury, and will be the first moon of another planet than Earth that will be orbited by a human-made spacecraft. In its 9-month-long orbital phase around Ganymede, the ESA JUICE (JUper ICy moons Explorer) spacecraft will observe Ganymede in 2035 from close by and in far greater detail than ever done before with a unique suite of 10 instruments. This will enable to obtain unprecedented insight into the moon's interior, from the central regions where a magnetic field is generated to the internal ocean and outer ice shell. Before the orbital phase, between July 2031 and December 2034, JUICE will be orbiting Jupiter and perform close flybys of Ganymede and two of the other large moons of Jupiter, Europa and Callisto. Launched on 14 April 2023, JUICE is currently on its way to Jupiter.

One of the main goals of the JUICE mission is to characterise these moons as planetary objects and as possible habitats. An overview paper, written by the JUICE team and led by the Royal Observatory of Belgium, details how JUICE will advance our knowledge about the interiors of Ganymede, Callisto and Europa. Since accurate geophysical observations about the interior of the moons can only be performed from close distances to the moons, best estimates of signatures of the interior, such as an induced magnetic field, tides and rotation variations, and radar reflections, will be obtained during the flybys of the moons with altitudes of about 1000 km or less and during the Ganymede orbital phase at an average altitude of 500 km and a final orbital phase at an average altitude of 200 km.

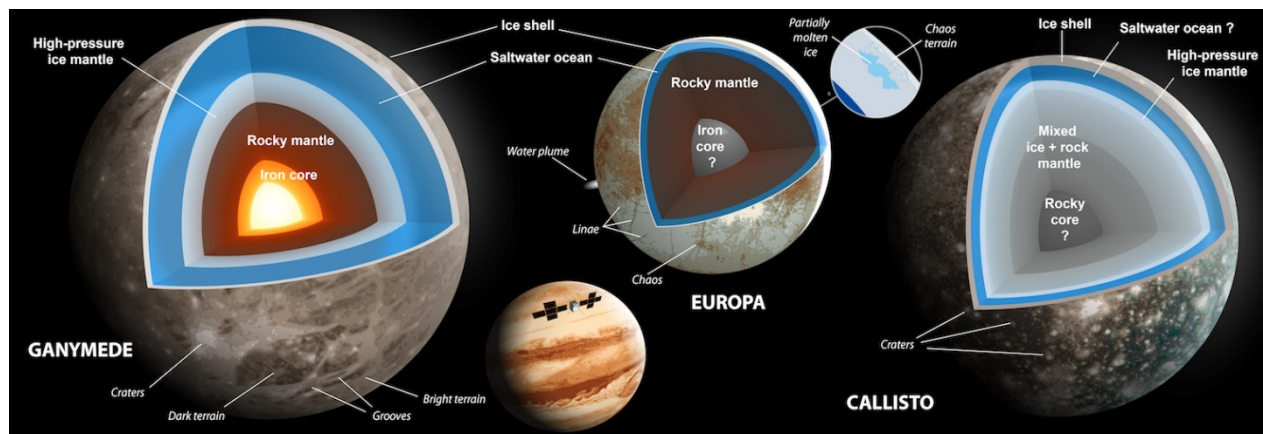


Figure 35: Schematic of possible interior structures of Ganymede, Europa and Callisto based on the Galileo data, and link with surface signatures of internal activity. Ganymede possesses the most differentiated structure with a thick hydrosphere, a rocky mantle and a liquid iron core, while the presence of an iron core inside Europa and the degree of ice-rock separation in the interior of Callisto are still uncertain. The thickness, depth and composition of the saltwater subsurface oceans are still poorly constrained. Galileo data are not fully conclusive about the existence of an ocean in Callisto. Reference : Figure 1 from [Van Hoolst et al. \(2024\)](#).

To better understand the habitability of the Galilean moons, JUICE will probe the ice shell and ocean by combining measurements of the tides, rotation and magnetic field. Properties that will be determined include the average thicknesses of the outer ice shell, ocean and high-pressure ice mantle, the salt content

of the ocean, the deflection of the ice/ocean interface and lateral variations in density. The 3D structure of the ice shell will be determined by measurements of the gravity field and surface topography and by the JUICE radar. An essential component of the JUICE investigations is that different instruments will work together to probe the hydrosphere.

The article also describes how synergies between JUICE instruments will contribute to the assessment of the deep interior of the moons, their internal differentiation, dynamics and evolution. In situ measurements and remote sensing observations will support the geophysical instruments to achieve these goals, but will also, together with subsurface radar sounding, provide information about tectonics, potential plumes, and the composition of the surface, which will help understanding the composition of the interior, the structure of the ice shell, and exchange processes between ocean, ice and surface. Accurate tracking of the JUICE spacecraft all along the mission will strongly improve our knowledge of the changing orbital motions of the moons and will provide additional insight into the dissipative processes in the Jupiter system.

Reference: Van Hoolst, T., Tobie, G., Vallat, C., Altobelli, N., Bruzzone, L., Cao, H., Dirkx, D., Genova, A., Hussmann, H., Iess, L., Kimura, J., Khurana, K., Lucchetti, A., Mitri, G., Moore, W., Saur, J., Stark, A., Vorburger, A., Wieczorek, M., Aboudan, A., Bergman, J., Bovolo, F., Breuer, D., Cappuccio, P., Carrer, L., Cecconi, B., Choblet, G., De Marchi, F., Fayolle, M., Fienga, A., Futaana, Y., Hauber, E., Kofman, W., Kumamoto, A., Lainey, V., Molyneux, P., Mousis, O., Plaut, J., Puccio, W., Retherford, K., Roth, L., Seignovert, B., Steinbrügge, G., Thakur, S., Tortora, P., Tosi, F., Zannoni, M., Barabash, S., Dougherty, M., Gladstone, R., Gurbit, L.I., Hartogh, P., Palumbo, P., Poulet, F., Wahlund, J.-E., Grasset, O., Witasse, O. 2024. *Geophysical characterization of the interiors of Ganymede, Callisto and Europa by ESA's JUpiter ICy moons Explorer*. *Space Science Reviews* 220:54 (73 pages), <https://doi.org/10.1007/s11214-024-01085-y>

The hunt for hidden oceans extends to Uranus' icy moons

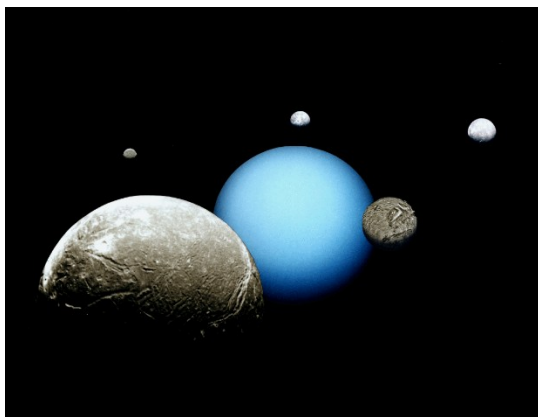


Figure 36: Montage of the Uranian system prepared from images taken by the Voyager 2 spacecraft with Ariel in the forefront. Starting clockwise from Ariel are shown the moons Umbriel, Oberon, Titania, Miranda
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<https://solarviews.com/cap/uranus/urfamily.htm>

With a launch window opening in 2029, the Uranus Orbiter and Probe (UOP) mission has been prioritised as a NASA Flagship mission for the coming decade. This ambitious mission aims to explore Uranus and its five largest moons – Miranda, Ariel, Umbriel, Titania, and Oberon – and to shed light on their composition and potential subsurface oceans. Just as Jupiter's moons Europa and Ganymede and Saturn's moons Titan and Enceladus are thought to contain global liquid water oceans beneath their surfaces, some of Uranus's moons might also harbour hidden oceans.

Two recent studies led by scientists of the Royal Observatory of Belgium and published in *Icarus* and *The Planetary Science Journal*, explore advanced geodetic techniques to detect and characterise these possible internal oceans. Crucial data for this investigation will be obtained by the sophisticated radio telecom system of the

UOP spacecraft, which will help determine the gravity field and rotation of the moons.

The first study focused on modelling the rotation of the moons, examining their obliquity (the tilt of their rotational axis) and librations (small oscillations in their rotation). We examined different possible interior structures that range from a solid, undifferentiated rock-ice body to a layered structure with a rocky core

surrounded by an ice shell, which can be either completely frozen or contain an internal liquid ocean up to 50 km thick. By demonstrating that the libration amplitude differs significantly between the various possible interior structures (see Figure 37 for Ariel), this research suggests that precise rotational measurements can determine whether these moons have differentiated interiors and can detect the presence of an internal ocean. The study also found that, due to gravitational interactions, among the moons, most of them experience significant periodic variations in their obliquity. Accurate obliquity measurements could help rule out the possibility of a completely homogeneous interior. Moreover, if a global ocean exists, it might amplify obliquity variations, making detection easier. However, if no such resonance occurs, the obliquity measurements alone may not be sufficient to distinguish between a solid body and one containing a hidden ocean.

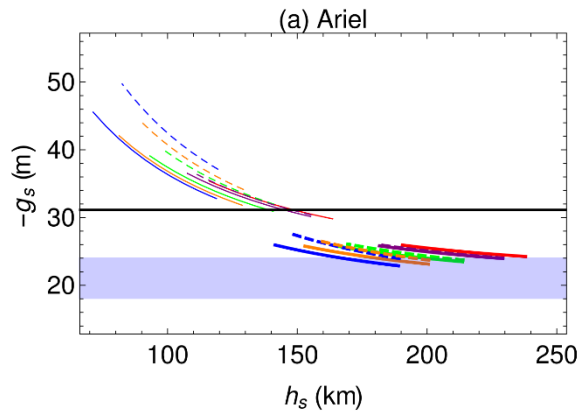


Figure 37: Ariel shell libration amplitude g_s as a function of the shell thickness h_s for a selection of interiors models. The blue region corresponds to the range of possible values for two-layer solid models. The black line corresponds to the libration of a single-layer homogeneous body (Baland et al. 2025).

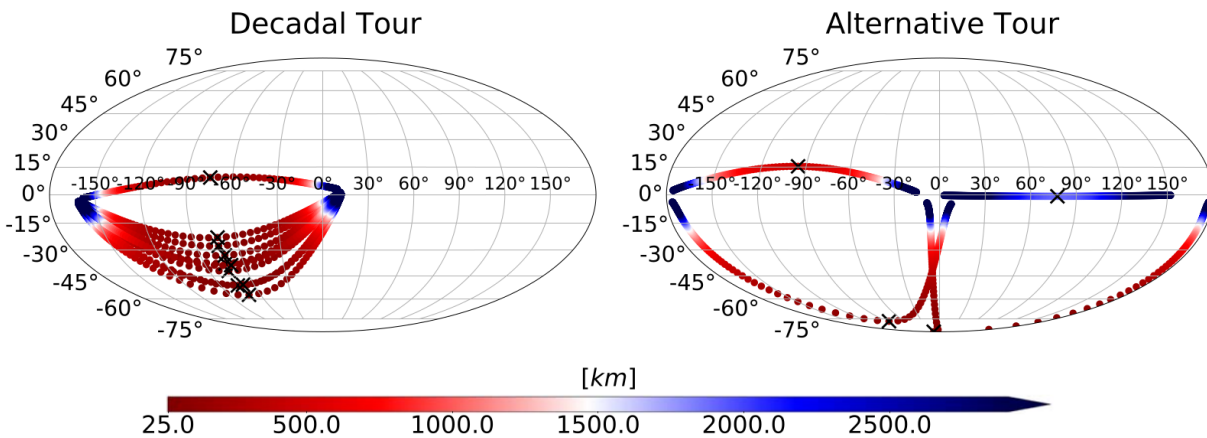


Figure 38: UOP flybys of Ariel (± 30 minutes around closest approach). Colours show the altitude with respect to the moons' surface, whereas the crosses show the point of closest approach (Filice et al. 2025).

A companion study took a different look at how geodesy can help unravelling the interior of Uranian moons by using advanced modelling techniques to determine the best mission design to achieve the scientific objectives. By combining statistical analysis with Precise Orbit Determination methods, the researchers developed a way to directly link the precision of gravity and rotation measurements to the uncertainties in the interior structures of Uranus's moons. They created maps connecting the data collected by the spacecraft to key interior characteristics. This allowed for a rapid assessment of how well different mission designs could constrain these parameters. Their analysis of two potential orbital tours (see Figure 38) and multiple measurement strategies showed that it would be possible to determine Ariel's ice shell thickness with an accuracy of about 15% and estimate its rock-to-ice mass ratio at approximately 30%. However, none of the tested approaches could effectively measure the thickness of a subsurface ocean. This study highlights how mission design can be dynamically adjusted to maximise scientific return, providing a valuable framework for future planetary exploration missions.

Reference papers:

- Rose-Marie Baland, Valerio Filice, Sébastien Le Maistre, Antony Trinh, Marie Yseboodt, Tim Van Hoolst (2025). *Librations and obliquity of the largest moons of Uranus*. Icarus, Volume 426, id.116371. <https://doi.org/10.1016/j.icarus.2024.116371>
- Valerio Filice, Gael Cascioli, Sébastien Le Maistre, Rose-Marie Baland, Antony Trinh, Erwan Mazarico, Sander Goossens (2025). *Informed Design of a Gravity Science Experiment for the Future Geophysical Investigation of the Uranian Moons*. The Planetary Science Journal, Volume 6, Issue 2, id.41, 31 pp. <https://doi.org/10.3847/PSJ/ada7ef>

Solar Physics

Solar Cycle 25 has reached its maximum

In 2019, the Solar Cycle Prediction Panel convened to gather and combine predictions for the still infant Solar Cycle 25. The results of this gathering were published shortly thereafter: the [Solar Cycle Prediction Panel](#) expected the cycle maximum value of the smoothed monthly sunspot number to be in a very narrow range between 105 and 125 with the peak occurring between November 2024 and March 2026.

Six years later, we seem to have finally reached the maximum and the prediction dates from 2019 appear to have been significantly later than reality. Of course, in terms of prediction accuracy, the closer we are to the actual maximum, the more the various prediction methods will converge. Indeed, in September 2024, SILSO predicted a maximum SN between 138 and 161 that would take place sometime between May and October 2024, while [NOAA](#) predicted a similar range between 137 and 164 but within a broader time window between February 2024 and January 2025. The results are now confirmed by SILSO (https://www.sidc.be/SILSO/DATA/SN_ms_tot_V2.0.txt): the maximum value of the monthly smoothed sunspot number for Solar Cycle 25 was reached in October 2024 and is 161 (see Figure 39), versus 159 for September 2024 and 157 for November 2024.

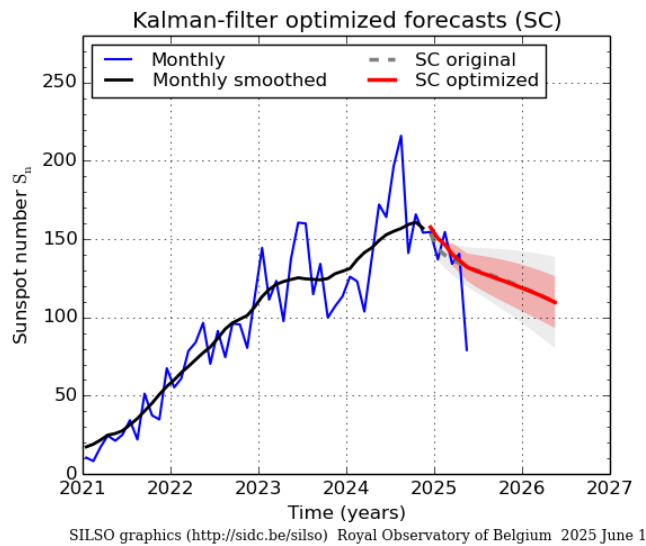


Figure 39: Solar Cycle 25 and its maximum seen in October 2024, as well as the 12-months ahead predictions that show a decreasing trend. Credit: SIDC/ROB.

What this entails for the SIDC team is that, at this stage of the Solar Cycle, the Sun is very active and will remain at a similar level of activity well into 2026. Since the beginning of 2024, many large and complex active regions have crossed the solar disk regularly, driving the daily sunspot number to well above 250 as can be attested by the [SIDC/USET](#) image for 7 August 2024 (Figure 40).

These active regions often were the source of strong solar flares, and the associated solar eruptions, when they are earth-directed, strongly affect the Earth's magnetic field. The important aurorae thus created are sometimes visible from countries further away from the polar regions, such as in May 2024 when the colourful display was also visible from Belgium (see [this news item](#)). While storms of this magnitude occur approximately once every 12.5 years, the length of this specific storm was unusual, expected only once

every 41 years (see S. Elvidge, D. R. Themens, 2025: <https://doi.org/10.1029/2024SW004113>). There were also important storms in October 2024 (<https://sidc.be/article/arrived>). These major solar storms and their impact on Earth help improve the accuracy of Space Weather forecasting as they enable us to sample solar events with the full range of instruments at our disposal today (see the 45th COSPAR General Assembly abstract of de Patoul, 2024: <https://ui.adsabs.harvard.edu/abs/2024cosp...45.2942D/abstract>).

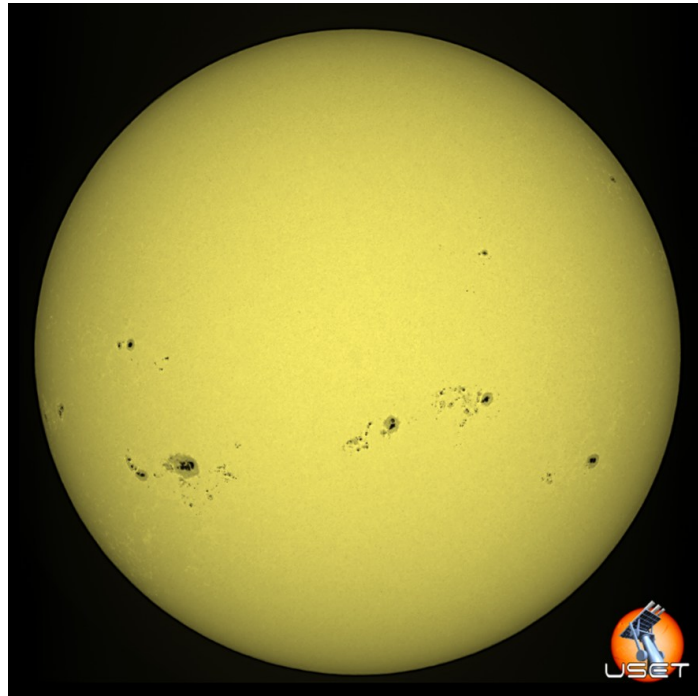


Figure 40: White light image of the photosphere of the Sun taken on August 7, 2024. Credit: USET data/image, Royal Observatory of Belgium, Brussels -- DOI : <https://doi.org/10.24414/nc7j-b391>.

2025 and 2026 thus promise a lot of sunspots to count a lot of activity for the Space Weather team of the SIDC.

ECO: towards first direct measurements of Earth Energy Imbalance from space

On 17 April 2024, the European Space Agency (ESA) selected the Earth Climate Observatory (ECO), a new space mission concept for the measurement of the Earth's energy imbalance, a critical climate parameter, for Phase 0 study. ECO was proposed by an international team of 12 scientists led by the Royal Observatory of Belgium.

Climate change is fundamentally driven by the Earth's energy imbalance (EEI). The measurement of the EEI from space is challenging, but it is needed to get an early indication on how well mankind is doing in the implementation of the Paris Climate Agreement. If the Paris Climate Agreement were respected, the EEI should go to zero, and global temperature rise should stabilise at 1.5 °C. In reality, as illustrated in the Figure 41 below, 2024 was the warmest year on record, and 2025 is expected to be the first year when the Paris Climate Agreement limit of 1.5 °C global warming will be broken.

The EEI is defined as the small difference between two nearly equal quantities: the incoming solar radiation and the outgoing terrestrial radiation (see Figure 42). This small difference – of the order of 1 W/m², to be

compared to an incoming solar radiation of the order of 340 W/m^2 – is accumulated in time within the Earth climate system, in particular in the oceans, which have a high heat capacity. Global temperature rise is proportional to the integral of the EEI, the EEI is proportional to the derivative of global temperature rise. Therefore, if the annual mean EEI can be monitored directly from space, this will result in a significant improvement of the prediction of future climate change.

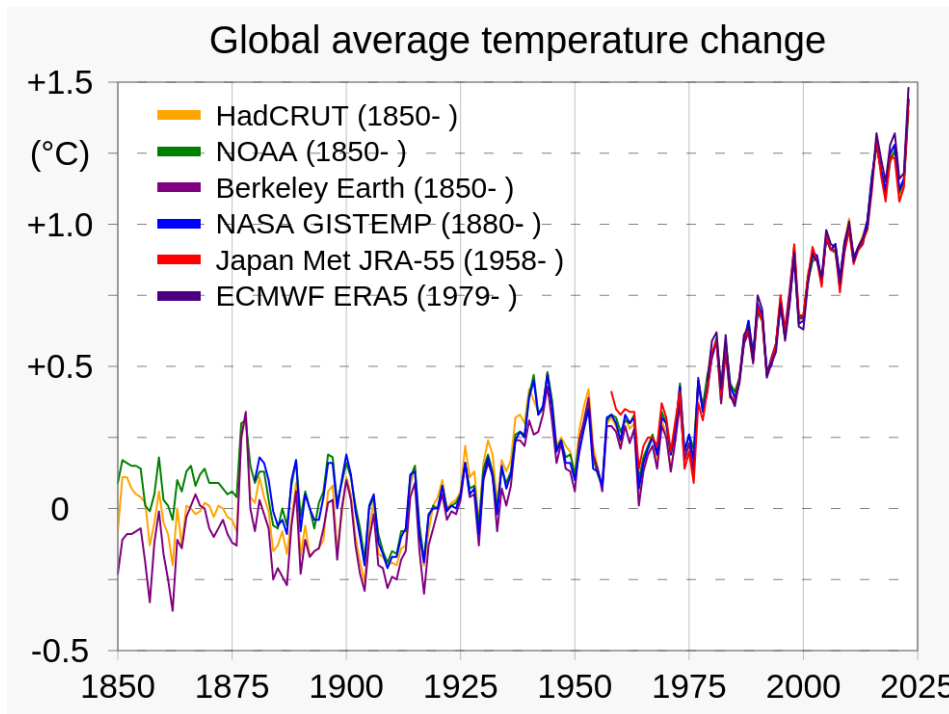


Figure 41: Global temperature rise from 1850 to 2024. Credit: [RCraig09](#), shared under a CC-BY-SA 4.0 license.

In order to measure the EEI with the required accuracy, two fundamental challenges need to be overcome.

The first fundamental challenge is that the EEI is the difference between two opposing terms of nearly equal amplitude. Currently, the incoming solar radiation and outgoing terrestrial radiation are measured with separate instruments, which means that their calibration errors are added and overwhelm the signal to be measured. The current error on the direct measurement of the EEI is of the order of 5 W/m^2 , significantly larger than the signal to be measured of the order of 1 W/m^2 . To make significant progress in this challenge, a differential measurement using identical intercalibrated instruments to measure both the incoming solar radiation and the outgoing terrestrial radiation is needed.

The second fundamental challenge is that the outgoing terrestrial radiation has a systematic diurnal cycle. An adequate sampling can be obtained from two orthogonal 90° inclined orbits, which give both global coverage, and a statistical sampling of the full diurnal cycle at seasonal (3 months) time scale.

For understanding the radiative forcing – e.g. aerosol radiative forcing – and climate feedback – e.g. ice albedo feedback – mechanisms underlying changes in the EEI, and for climate model validation, it is necessary to separate the Total Outgoing Radiation (TOR) spectrally into the two components of the Earth Radiation Budget (ERB), namely the Reflected Solar radiation (RSR) and Outgoing Longwave Radiation (OLR) and to map them at relatively high spatial resolution. This can be achieved by the use of auxiliary visible and thermal cameras.

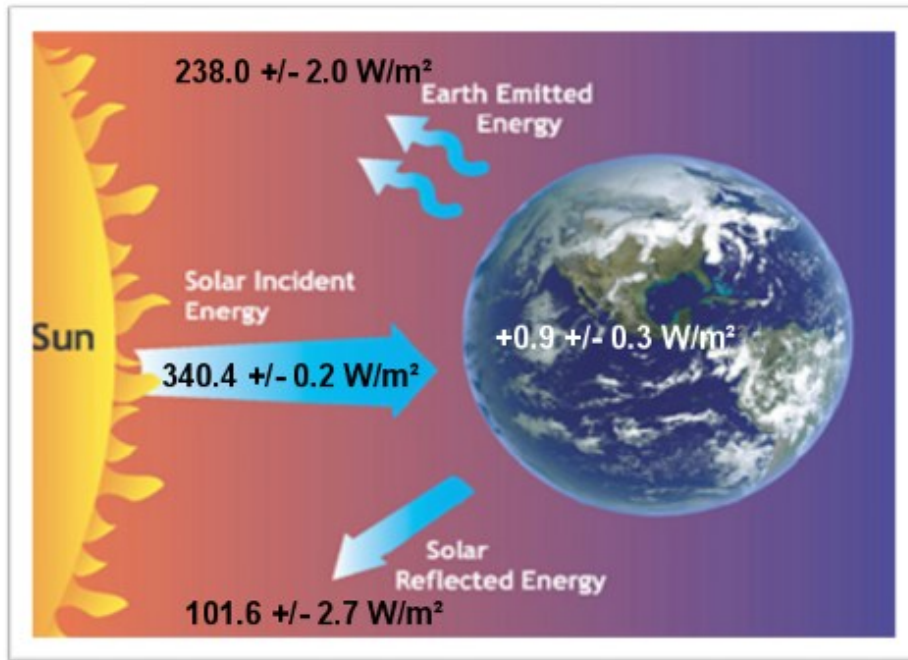


Figure 42: The Earth energy imbalance is defined as the difference between the incoming solar radiation, and the sum of the reflected solar radiation and the emitted thermal radiation. Credit: NASA (modified by Steven Dewitte).

Astronomy and Astrophysics

New Black Hole discovered with ESA's Gaia satellite

The Gaia satellite has been charting the sky since 2014, and its map includes stars that are a million times fainter than can be seen with the naked eye. Published in June 2022, the third version of the most complete and detailed catalogue of stars (Gaia DR3) is a milestone in astrophysical research. Gaia's exceptionally accurate distances, motions, and fundamental parameters of stars, as well as the accurate astrometry of asteroids, are now part of the everyday work and research of most astronomers.

Scientists working on the next version of the Gaia catalogue (Gaia DR4, to be released in 2026) are currently analysing and validating the latest results obtained by the satellite. In this context, scientists from the Gaia Data Processing and Analysis Consortium (DPAC), including scientists from the ORB-KSB, have revealed on 16 April 2024 the identification of a binary star system composed of a giant star and a stellar black hole (now identified as 'Gaia BH3'). Stellar black holes result from the collapse of a massive star at the end of its life, after it has 'burned up' all its fuel. This exotic object is located in the inner halo of the Milky Way, which is a spherical cloud made of older stars surrounding its centre.

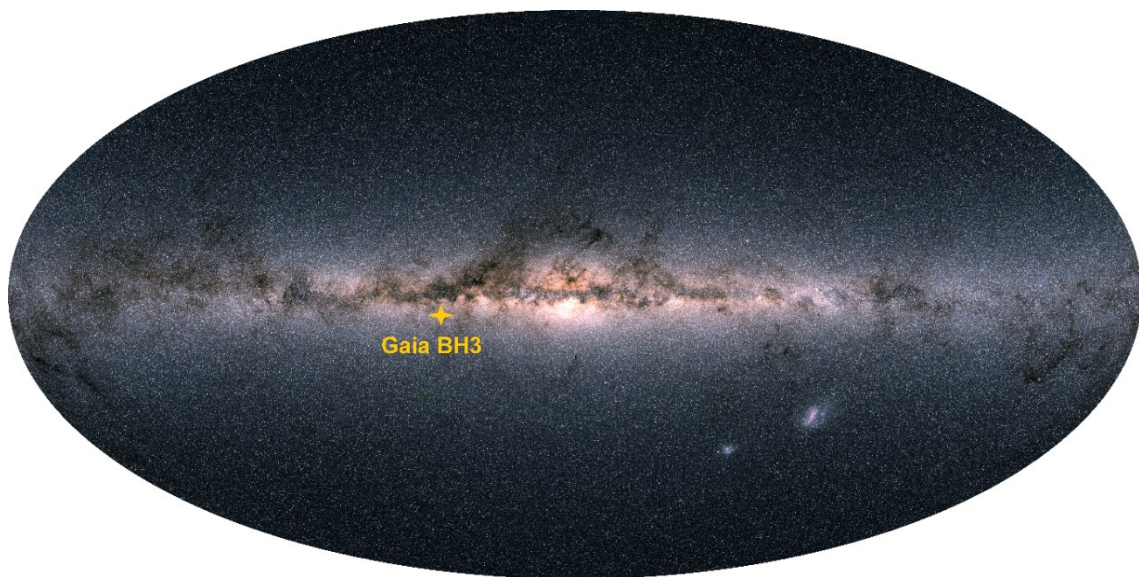


Figure 43: The Milky Way as seen by Gaia. The location of Gaia BH3 is plotted in yellow. Credits: ESA/Gaia/DPAC

Multiple systems are automatically identified at various stages of the Gaia data processing chain, while another part, developed by ULB colleagues, combines all the astrometric and spectroscopic data provided by the satellite to derive parameters such as the mass and luminosity of the system components. During the scientific validation of the pipeline results, Gaia DPAC researchers highlighted a multiple system of which one member has zero luminosity and a mass of 32 solar masses, as expected from a black hole.

To ensure that the algorithms provide correct results, the DPAC teams use data obtained with ground-based instruments. In this case, measurements from the Hermes spectrograph¹ at the Mercator telescope

¹ As a member of the Hermes@Mercator consortium (KULeuven, ORB-KSB, ULB, Geneva), the Astronomy & Astrophysics department of the ORB-KSB played a leading role in the development of the data reduction pipeline of the Hermes spectrograph with the goal of deriving high accuracy radial velocities.

were used. It confirmed that the results are correct and that Gaia BH3 is a stellar black hole of 32.7 solar masses, which is part of a binary system with an 11.6-year period. The detailed analysis of the RVS spectrum of its companion shows that the binary system components formed from interstellar matter containing very little metallic elements. It confirms the theory establishing that the progenitors of massive stellar black holes such as Gaia BH3 have very low metallicities making them more compact with weaker stellar winds.

Further details can be found in [Gaia Collaboration, Panuzzo, et al., A&A 686, L2.](#)

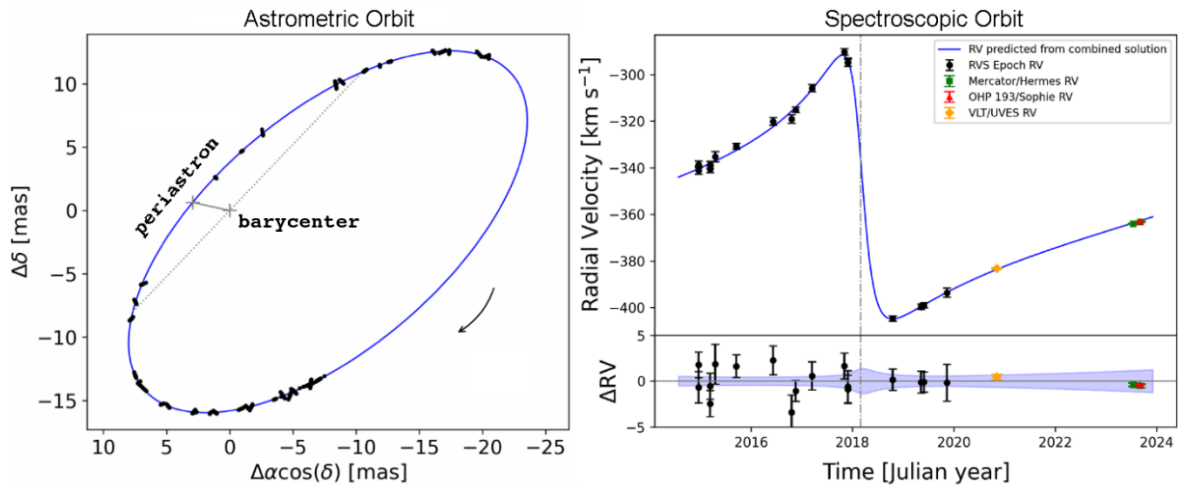


Figure 44: The left panel shows in black the position on the sky of the giant star as measured by Gaia at different moments. The blue line represents the best fitted orbital solution. The crosses locate the barycentre of the system (right) and the periastron (left). The right upper panel shows how the radial velocity varies with time. Black points are the measurements made by the Gaia Single Transit Analysis software which development and coordination are carried out by the A&A department of the ROB. The blue line represents the final best orbit solution. A few measurements made with ground-based instruments (Hermes@Mercator, Sophie@OHP, and UVES@VLT) are used to validate the solution (coloured points). The lower right panel presents the corresponding residuals. Credits: [Gaia Collaboration, Panuzzo et al. 2024 \(AA, 686, 2G, Figs. 2 and 3\).](#)

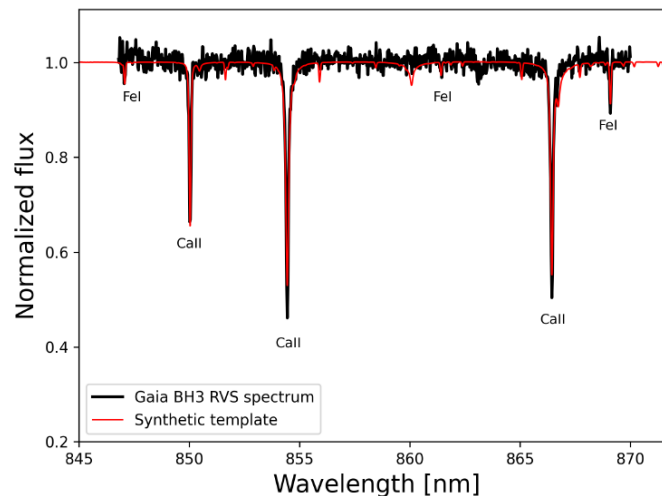


Figure 45: Gaia RVS spectrum of the stellar component of Gaia BH3 (black). The modelling of the spectrum shows that the bright giant companion of the black hole has very weak calcium (Ca II) and iron (Fe I) spectral lines and have a metallicity more than 100 times lower than the Sun. Credits: [Gaia Collaboration, Panuzzo et al. 2024 \(AA, 686, 2G, Fig. 4\).](#)

HD148937: Nebula and magnetic star born from a stellar clash

Most massive stars have a companion close enough to interact via mass transfer or coalescence. Approximately 25% of massive stars will merge at some stage of their evolution, and 10% of them are currently the products of such mergers. One of the outcomes of a merging event is the ejection of mass, visible through the presence of dust and gas around the merger product. The circumstellar material is mainly detectable in the infrared, with some exceptions in the H α imaging.



Figure 46: This image, taken with ESO's VLT Survey Telescope, shows the beautiful nebula NGC 6164/6165. The nebula is a cloud of gas and dust surrounding a pair of stars called HD 148937. Image credit: ESO/VPHAS+ Team/CASU

Observationally identifying and characterising a merger product is challenging, as these stars evolve similarly to single stars of comparable mass. However, some subtle differences can persist, such as over-luminosity, rejuvenation, unusual rotation rates (either exceptionally low or high), or differences in core mass. Notably, stellar mergers have also been proposed as a plausible mechanism for the generation of

magnetic fields. Interestingly, about 7% of massive stars are found to host magnetic fields. For these magnetic stars, the evolutionary implications are significant. A strong magnetic field can suppress stellar mass loss by channelling material, which would otherwise be expelled via stellar winds, back to the equator along magnetic field lines. This reduced mass loss can influence the type of core-collapse supernova a star undergoes and may lead to the formation of high-mass black holes. Furthermore, magnetic stars are linked to phenomena such as magnetars, long-duration gamma-ray bursts, and super-luminous supernovae.

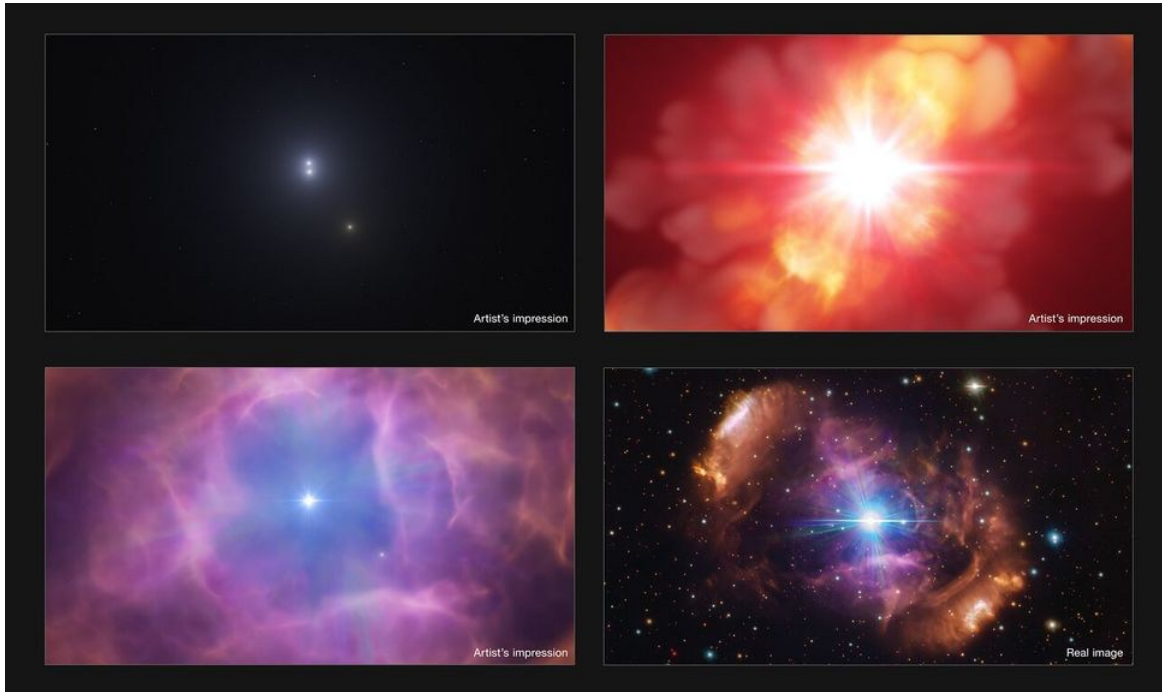


Figure 47: Artist illustration of the evolution history of HD148937. Image credit: ESO/VPHAS+ Team/CASU.

It is not so common to detect a massive star surrounded by such a circumstellar nebula, that is also magnetic. The only star we know of in the Galaxy is HD148937 (Figure 46). Aside from the fact that the star is surrounded by a nebula, and possesses a magnetic field, the star was also discovered to be a binary system in 2014 with an orbital period longer than 10 years. The system, HD 148937, is located about 3800 light years away from Earth in the direction of the Norma constellation.

To analyse this star, we combined high-quality data obtained from the ESO La Silla Observatory and the Very Large Telescope Interferometer facilities at ESO, to observe the star both in interferometry and in spectroscopy. We combined these data with space-based photometry obtained with the TESS instruments.

After a detailed analysis, we could determine that the more massive star appears much younger than its companion. The age difference – one star appears to be at least 1.5 million years younger than the other – suggests something must have rejuvenated the more massive star.

The only explanation for this rejuvenation (Figure 47) is that this system had at least three stars originally forming a hierarchical triple system, i.e. formed by two stars close enough to form an inner system whilst another star was much more distant. The two inner stars have merged in a violent manner, creating a magnetic star and throwing out some material, which created the nebula. The more distant star formed a new orbit with the newly merged, now-magnetic star, creating the binary we see today at the centre of the nebula. This event must have happened 7500 years ago, which corresponds to the age of the nebula. This nebula shows very high amounts of nitrogen, carbon and oxygen. This is surprising as these elements

are normally expected deep inside a star, not outside; it is as if some violent event had set them free. Its shape appears to be helical, which can also suggest a merger origin.

This scenario also explains why one of the stars in the system is magnetic and the other is not – a peculiar feature of HD 148937. At the same time, it helps solve a long-standing mystery in astronomy: how some massive stars get their magnetic fields. While magnetic fields are a common feature of low-mass stars like our Sun, more massive stars cannot sustain magnetic fields in the same way. Magnetic fields in massive stars are particularly interesting because they can drastically change a star's future evolution. HD 148937 represents a fantastic new piece of the puzzle to better understand massive star evolution including magnetic fields. Astronomers had suspected for some time that massive stars could acquire magnetic fields when two stars merge but this is the first time researchers have found such direct evidence of this happening.

Further details can be found in [Frost, Sana, Mahy, et al. 2024, Science 384, 214](#).

The colliding stellar winds of the massive binary HD 168112

Stellar winds

Massive stars (those with a mass above about 8 times the mass of the Sun) are also the hottest and most luminous stars. The radiation they emit is so strong that its pressure pushes the material at the stellar surface away from the star, thus creating a stellar wind. The wind can reach velocities of 1000 to 3000 km/s, and the amount of mass loss can be a few millionths of solar masses per year. As these stars live for only a few million years, the mass loss has an important effect on their stellar evolution.

The stellar wind material surrounding the star also has important observational consequences. In the ionised material of the wind, the free-free radiation mechanism plays an important role. As a free electron passes close to an ion, it can lose some of its energy in the interaction. This energy is then emitted as a photon. Inversely, the electron can also gain energy in the interaction by absorbing a photon. The free-free radiation thus has both an emission and absorption effect.

The free-free radiation depends on the square of the wavelength. At radio wavelengths the absorption effect is so strong that we no longer see the surface of the star. Instead, at radio wavelengths the star looks much larger than at optical wavelengths. We can therefore easily detect the radio emission of such a star, or rather, of its stellar wind. And because the radiation is so strongly related to the stellar wind, we can use it to derive the mass loss rate.

Colliding stellar winds in a binary

The situation becomes even more interesting if we have two stars that form a binary system (see Figure 48). When both stars have a stellar wind, the two winds must collide somewhere between the two stars. Where that collision happens depends on the relative strength of the two winds: the collision will be closer to the star with the weaker wind.

The surface where the two winds meet is called the contact discontinuity. On either side of this discontinuity a shock is formed. Around each shock, the Fermi acceleration mechanism starts to play a

role: electrons can bounce back and forth across the shock, and each time they do so they gain some energy from the shock. In this way, a fraction of the electrons can attain relativistic speeds.

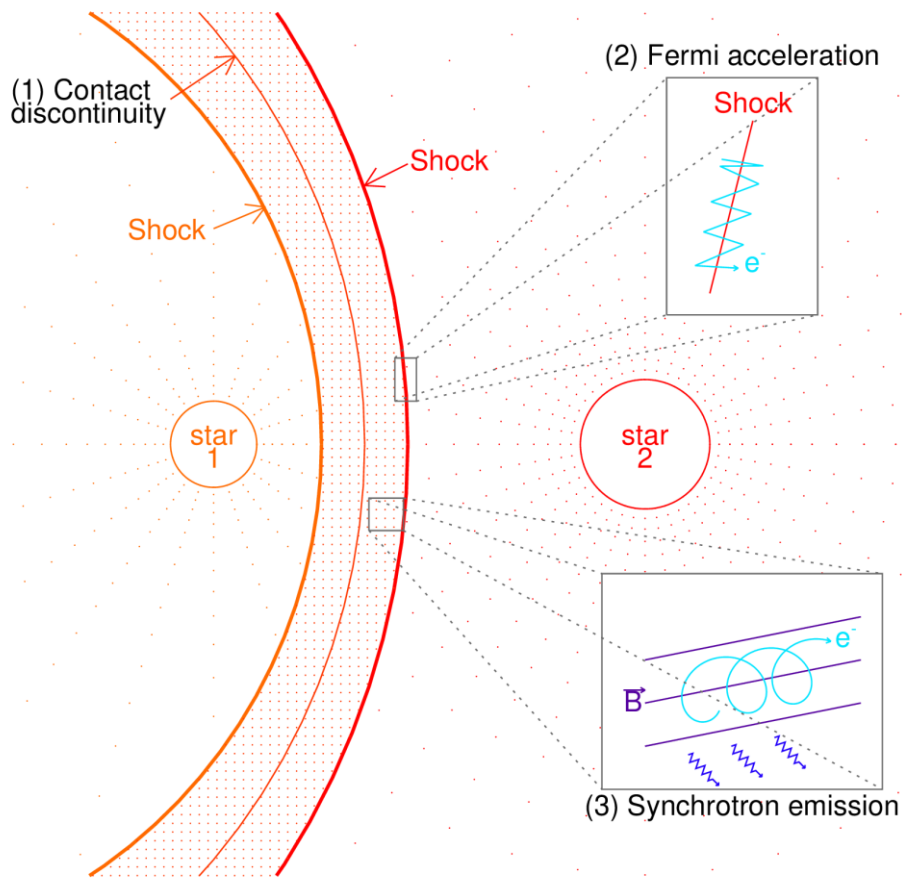


Figure 48: Synchrotron emission in a colliding-wind binary. Each of the two stars has a stellar wind, which collides at the contact discontinuity (1). On each side of this discontinuity, a shock is formed where the Fermi mechanism accelerates a fraction of the electrons up to relativistic speeds (2). These relativistic electrons then spiral in the magnetic field, thereby emitting synchrotron radiation (3). Credit: ORB-KSB.

When these relativistic electrons are present in the magnetic field of the star, they spiral around the magnetic field lines. They thus lose energy, which is emitted as radiation in a process called synchrotron emission. It is important to note that this emission mechanism is quite different from the free-free one. The free-free emission is related to the temperature of the stellar wind and the radiation field of the star, as these are responsible for the ionisation that is needed for free-free emission to occur. The synchrotron emission, on the other hand, is mainly related to the strength of the shocks around the colliding-wind region and the strength of the magnetic field.

HD 168112

HD 168112 was only recently confirmed to be a binary system. But before that, there were already indications that it could be a binary: the radio fluxes are much too high to be explained by only free-free radiation, and the X-ray fluxes are also higher than expected for a single star. Furthermore, an optical interferometry observation showed two stars, but that single observation could, of course, not confirm if these were gravitationally bound.

Finally, [Putkuri et al. \(2023, MNRAS, 525, 6084\)](#) used spectroscopic observations to show that HD 168112 is indeed a binary system with a period of ~ 514 days, and an eccentricity of 0.743.

Spectroscopic data

In our analysis, we used 97 spectra from the HERMES (High Efficiency and Resolution Mercator Echelle Spectrograph) spectrograph on the 1.2 m Mercator telescope at the Roque de los Muchachos Observatory (La Palma, Canary Islands, Spain). The spectra were taken by many observers in an observing campaign covering about 13 years. They were supplemented by 16 spectra from the refurbished HEROS instrument on the 1.2 m Telescopio Internacional de Guanajuato Robótico Espectroscópico (TIGRE), located at La Luz observatory, Mexico.

From these data, we determined the orbital parameters, and we found a period of 512.17 days, a high eccentricity of 0.753, and a mass ratio close to one, thereby confirming the results of Putkuri et al. The comparison of our orbital solution to the observed radial velocities is shown in Figure 49. Combining our data with the optical interferometry detection, we could constrain the inclination angle of the orbit to $\sim 63^\circ$ and the mass of each component to ~ 26 solar masses.

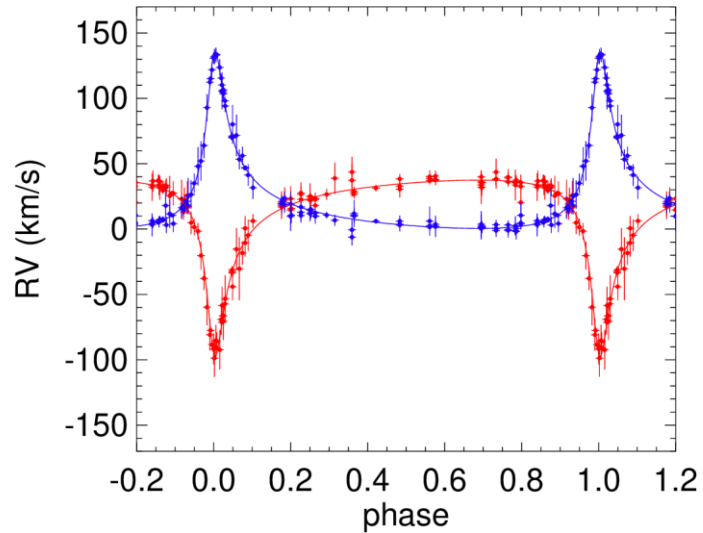


Figure 49: Our orbital solution (solid line) compared to the observed radial velocities (symbols), as a function of the binary orbital phase. Blue indicates the primary component, red the secondary component. Credit: ORB-KSB. Figure adapted from [Blomme et al. \(2024, BSRSL 93, 262\)](#).

Radio data

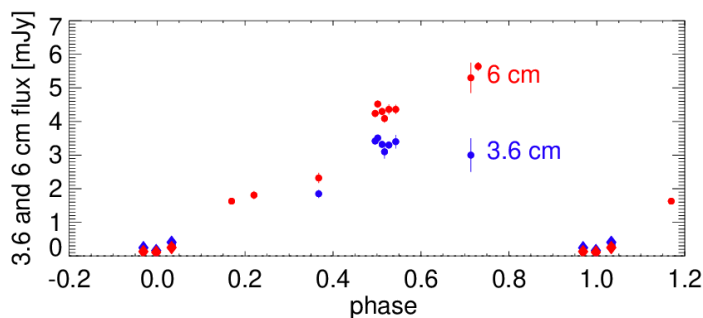


Figure 50: The 3.6 cm (blue) and 6 cm (red) radio fluxes of HD 168112 as a function of the binary orbital phase. Credit: ORB-KSB. Figure adapted from [Blomme et al. \(2024, BSRSL 93, 262\)](#).

We also obtained radio observations of HD 168112 near periastron passage, using the Karl G. Jansky Very Large Array (VLA) of the National Radio Astronomy Observatory (NRAO). Data were obtained at 3.6 cm (X-band) and 6 cm (C-band). Figure 50 shows these new measurements, together with older observations from the literature. Near apastron (phase ≈ 0.5), the 6 cm fluxes are higher than the 3.6 cm ones. This indicates the presence of synchrotron radiation, because for free-free radiation the 6 cm flux would be the lower one.

Near periastron (phase ≈ 0.0), we see that indeed the 6 cm flux is lower than the 3.6 cm one, indicating only free-free radiation. This may seem surprising: in this highly eccentric binary, the stars will be the

closest to one another at periastron and we would therefore expect the collision to be strongest, and hence the synchrotron radiation to be strongest. However, we need to take into account the interaction of the synchrotron emission with the free-free absorption in the stellar winds, as shown in Figure 51. At periastron, the colliding-wind region, and therefore the synchrotron emitting region, is largely inside the denser part of the two stellar winds. Although more synchrotron emission is generated, almost all of it is absorbed by the free-free absorption in the stellar winds. On the other hand, when the two stars are apastron, they are far from each other, and the synchrotron emission no longer suffers substantial absorption by the stellar winds. At that orbital phase, we can therefore detect the synchrotron radiation of the colliding-wind region.

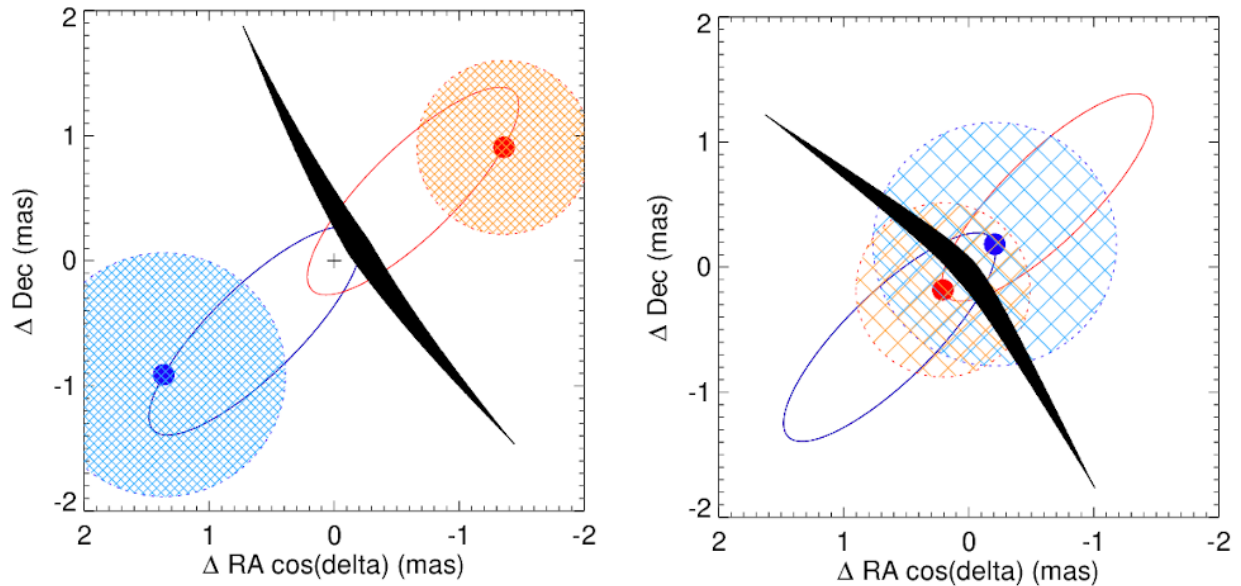


Figure 51: The orbits of both binary components projected onto the sky (blue=primary component; red=secondary component). The circles with the crosshatch pattern indicate the surface where the optical depth at radio wavelengths is one. The position of the colliding-wind region is indicated in black. The left panel shows the situation far from periastron, where the synchrotron photons from the colliding-wind region can easily escape. The right panel shows the situation near periastron, where the synchrotron photons are absorbed in the stellar winds. Credit: ORB-KSB. Figure adapted from [Blomme et al. \(2024, BSRSL 93, 262\)](#).

Whether a colliding-wind binary will show synchrotron emission at periastron therefore depends on the specific orbital parameters of the system in question. Stars that remain at a sufficiently large distance from each other at periastron will indeed show synchrotron emission at the time, while the others will only show the free-free emission of the stellar winds.

Further details about the analysis of the HD 168112 data can be found in Blomme et al. ([2024, A&A 687, A106](#)).

MELCHIORS: Unveiling the Universe through Stellar Fingerprints

Decoding Starlight: The Cosmic Context

Stars are the fundamental building blocks of our universe, each one a cosmic laboratory that tells a unique story through its light. When astronomers capture starlight and split it into its component wavelengths (a spectrum), they reveal a treasure trove of information about the star's temperature, composition, age, and evolutionary stage. These stellar 'fingerprints' are essential tools for unravelling the mysteries of our Galaxy and beyond. For decades, astronomers have relied on stellar spectral libraries – collections of carefully documented stellar spectra – to serve as reference points for their research. However, existing libraries have faced significant limitations that hamper scientific progress: Theoretical libraries offer clean, high-resolution data with excellent parameter coverage but suffer from model assumptions and imperfect atomic and molecular data. These inherent approximations can introduce systematic errors when compared with real observations. On the contrary, observational libraries capture actual stellar light but often compromise on resolution, signal quality, or diversity of stellar types. Many previous libraries could only achieve moderate spectral resolution ($R \sim 2,000-10,000$), limiting the detection of subtle spectral features crucial for precise stellar classification and analysis.

The MELCHIORS library (Mercator Library of High-Resolution Stellar Spectroscopy) represents a significant advancement in this field. With exceptional spectral resolution ($R \sim 85,000$), wide wavelength coverage (380-900 nm), and outstanding signal-to-noise ratios, it offers astronomers unprecedented detail in stellar spectra. As shown in Figure 52, represented in a celestial equatorial projection, the library provides extensive sky coverage, with observations of stars distributed across the full northern hemisphere and partial southern hemisphere. The colour coding indicates the B-V colour index of each star, which is a proxy for the surface temperature, with hotter stars appearing toward the blue end of the scale and cooler stars toward the red end, visually demonstrating the library's coverage of different stellar types across the sky.

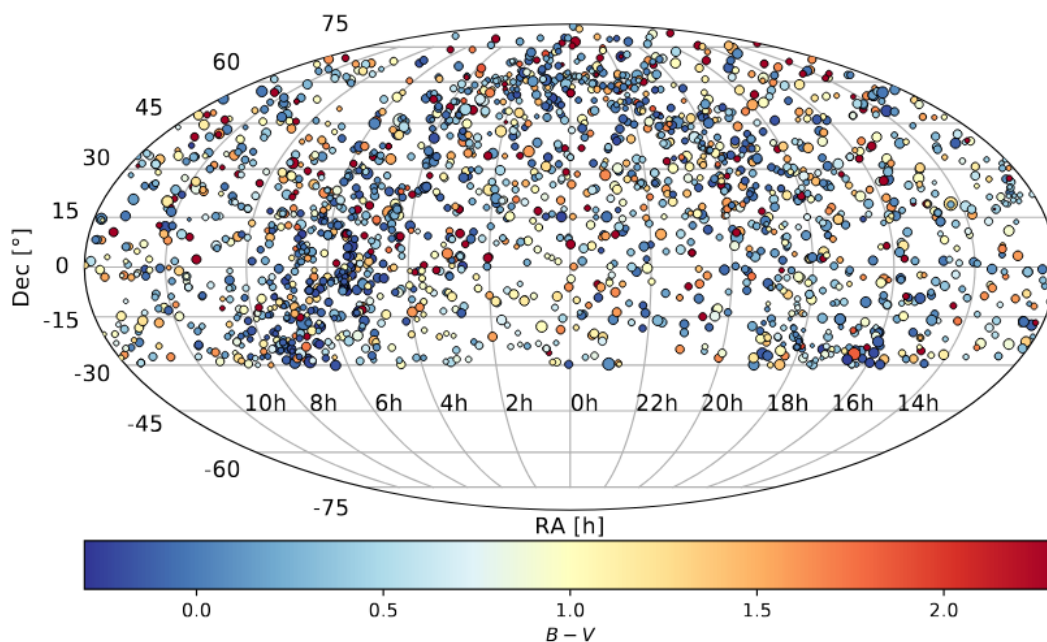


Figure 52: Skymap of the MELCHIORS library. Credit: [Royer et al. \(2024\)](#).

This new spectral library bridges the gap between theoretical ideals and observational limitations, creating a resource that will power the next generation of stellar and galactic research. By recording the exquisite details in stellar spectra with unprecedented clarity, the MELCHORS library enables astronomers to detect subtle features that reveal a star's true nature and history.

A Galactic Showcase: The Stars of MELCHORS

The MELCHORS library represents a comprehensive catalogue of stellar diversity, containing 3,256 high-quality spectra from 2,043 stars observed between 2010 and 2020 with the Mercator-HERMES spectrograph at the Roque de Los Muchachos Observatory in La Palma, Spain. This collection offers a remarkable window into the variety of stars that populate our galaxy.

The library focuses on bright stars ($V < 8$), providing a representative stellar sample across (i) a wide temperature range from hot O-type stars exceeding 30,000 K to cool M-type red giants below 3,500 K; (ii) spanning various evolutionary stages including main sequence stars (like our Sun), giants, supergiants, and other evolved types, and; (iii) exhibiting significant spectral diversity through hundreds of unique spectral subtypes that capture the subtle differences between stars.

Figure 53 showcases this diversity beautifully, displaying spectra from seven different stellar types arranged from hottest (top) to coolest (bottom). The spectral progression reveals how absorption features change dramatically with stellar temperature.

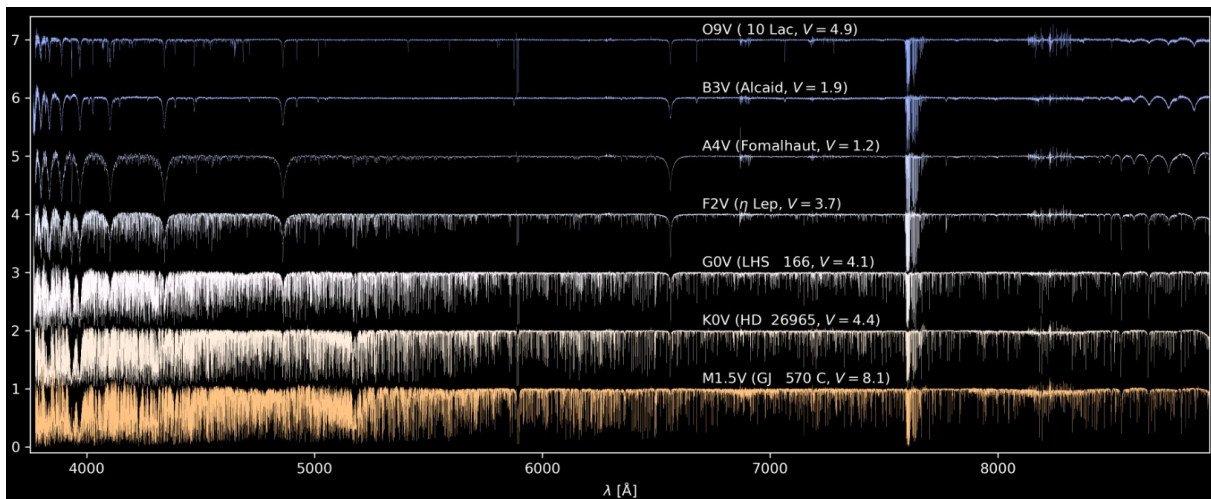


Figure 53: Spectral types on the main sequence from hot (up and bluish) to cool (down and reddish) stars. Credit: [Royer et al. \(2024\)](#).

For many stars, the MELCHORS library includes multiple observations over time, enabling studies of stellar variability, binary star interactions, and other time-dependent phenomena. The library's extensive coverage of the Hertzsprung-Russell diagram ensures that virtually every major stellar type and evolutionary stage is represented. This makes MELCHORS an invaluable reference for stellar classification, population studies, and as a training set for machine learning algorithms that can automatically identify and analyse stellar properties.

Our Sun as a Benchmark: The Gold Standard

The Sun occupies a privileged position in astronomy as the only star we can study in extreme detail. Its proximity allows us to resolve surface features and measure its properties with unprecedented precision,

making it the ultimate reference point for stellar studies. The MELCHORS library recognises this special status by including a meticulously captured **high-fidelity solar spectrum** that serves as a critical benchmark for the entire collection.

Rather than pointing the telescope directly at the Sun (which would damage the sensitive camera), astronomers captured sunlight reflected from asteroids. These small, rocky bodies in our solar system act as natural mirrors, reflecting unaltered sunlight toward Earth. Figure 54 showcases this solar reference, displaying two versions of the solar spectrum from 3800 to 9000 Å. The black line represents the response-corrected spectrum, showing the original signal intensity across wavelengths. The red line shows the normalised version, which has been processed to flatten the continuum to a constant level, making it easier to analyse individual absorption features. The richness of detail is immediately apparent, with thousands of dark absorption lines created by elements in the Sun's atmosphere absorbing specific wavelengths of light.

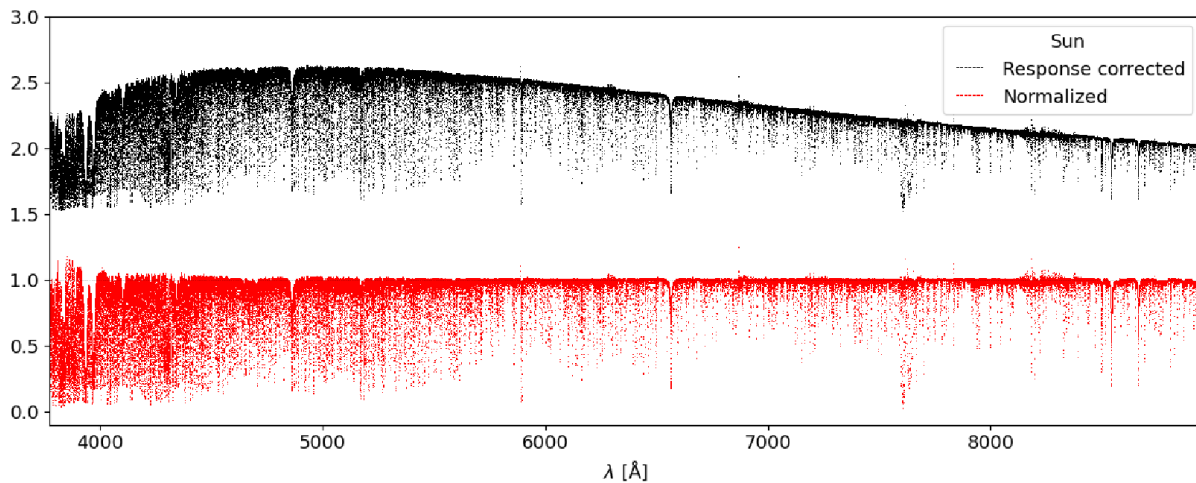


Figure 54: The MELCHORS solar reference spectrum, i.e. the Sun as a star. Credit: [Royer et al. \(2024\)](#).

This solar benchmark serves multiple crucial functions, acting as a calibration reference that ensures consistency in measurements across the entire library while simultaneously serving as an abundance standard where the Sun's known elemental composition helps calibrate measurements of other stars. It enables stellar twin studies by identifying Sun-like stars through direct spectral comparison and significantly contributes to exoplanet research by helping characterise stars hosting planets, as the planetary system formation depends on the host star's properties. Through careful correction for instrumental effects and telluric (Earth's atmosphere) absorption, the MELCHORS solar spectrum achieves exceptional accuracy, enabling astronomers to make direct, meaningful comparisons between our Sun and thousands of other stars in the galaxy.

Illuminating the Cosmos: Scientific Frontiers

The MELCHORS library opens numerous exciting avenues for scientific discovery across multiple astronomical disciplines. Its combination of high resolution, exceptional signal quality, and broad stellar coverage makes it a powerful tool for addressing some of astronomy's most compelling questions.

Stellar Physics: Stars are cosmic laboratories where physics operates at uncommon temperatures and pressures. The detailed spectra in MELCHORS provide stringent tests for stellar atmosphere models, helping refine our understanding of complex processes like convection, rotation, and magnetic activity.

The library also serves as a test-bed for atomic data, identifying inaccuracies in existing line lists and providing constraints for theoretical calculations of atomic transitions.

Galactic Archaeology: Just like archaeologists unearth human history from buried artefacts, astronomers use stellar spectra to reconstruct the Milky Way's past. The chemical compositions of stars – particularly the ratios of different elements – serve as 'fossil records' revealing the galaxy's evolution. MELCHORS' high-resolution spectra enable precise measurement of elemental abundances in thousands of stars, helping to map our galaxy's chemical enrichment history and to identify distinct stellar populations that formed under different conditions or at different times.

Machine Learning Applications: The growth of astronomical data from current and upcoming large surveys requires automated analysis techniques. MELCHORS provides an ideal training set for machine learning algorithms designed to classify stars or detect peculiarities like binarity, pulsations, or chemical peculiarities. These algorithms can then be applied to much larger datasets from missions like Gaia or upcoming spectroscopic surveys.

Exoplanet Characterisation: Understanding planets begins with understanding their host stars. MELCHORS provides detailed information about stellar properties, helping researchers accurately determine the sizes, masses, and potential habitability of orbiting planets. The library's high-resolution spectra also enable precise stellar radial velocity measurements – crucial for detecting exoplanets through their gravitational pull on their host stars.

Public Engagement and Education: The visual richness of stellar spectra makes MELCHORS a valuable resource for education and outreach. The clear progression of spectral features from hot to cool stars (as shown in Figure 53) provides an intuitive demonstration of stellar physics for students and the public, explaining complex astronomical concepts through direct observation.

As large-scale spectroscopic surveys collect data from millions of stars in the coming decade, MELCHORS will serve as a crucial high-resolution reference set, enabling more accurate calibration and interpretation of these massive datasets.

The original article is accessible at https://www.aanda.org/articles/aa/full_html/2024/01/aa46847-23/aa46847-23.html.

The library is freely available through an interactive portal at www.royer.se/melchors.html and through the Centre de Données astronomiques de Strasbourg (CDS) at <https://cdsarc.cds.unistra.fr/viz-bin/cat/J/A+A/681/A107> and

Outreach and Communication

A logo for the 200th anniversary of the ORB-KSB



Figure 55: Credit: ORB-KSB.

On June 8, 2026, the Royal Observatory of Belgium, one of the oldest federal research institutes in our country, will celebrate its 200th anniversary. For this occasion, a team was created to work on various projects to celebrate this jubilee year.

In 2024, following an internal contest with the personnel of the ORB-KSB, logo was selected with different languages version (French, Dutch, and an unofficial English version). This logo will be used to highlight the 200th anniversary festivities.

Permanent exhibition on seismology at Fort Eben-Emael

Thanks to a collaboration with the non-profit organisation [Fort Eben-Emael](#), the staff of the Seismology and Gravimetry service of the Royal Observatory of Belgium were able to open a new fascinating exhibition on seismology on 27 June 2024.

Ever since 1 April 1986, a seismograph (= the combination of a seismometer and a digital recording system) in a hidden room of Fort Eben-Emael has been continuously recording all seismic activity in and around Belgium. This seismometer is known internationally as the station EBN (code BE.BEBN) and its recordings and maintenance are managed by the Royal Observatory of Belgium.



Figure 56: The EBN seismometer exhibited behind a glass. Credit: ORB-KSB.

The station EBN is one of the stations in the Belgian Seismic Network with the longest digital recordings. Before installation of the station EBN, a seismometer was installed in the marl caves in Kanne for several

months. However, the fortress was preferred due to the vision of long-term cooperation between the ROB and the non-profit organisation Fort Eben-Emael (at that time still managed by the army).

EBN's location was chosen because the fort is located close to the Roer Valley Rift System. This rift system stretches across the borders of Belgium, the Netherlands and Germany and is the most seismic active zone around Belgium. Groundbreaking palaeoseismology from the ORB-KSB has shown that the border faults of this rift system have been active for millions of years, with the last major earthquake to breach the surface being about 3,000 years ago. Hence, proper and close monitoring of its activity is needed.

Via a pillar, the EBN seismometer is brought into direct contact with the marl bedrock, in which the fort was excavated. This direct contact is necessary to accurately record vibrations and better 'listen to' the earth. Over time, EBN's seismometer has been changed several times following technological developments. Since January 2024, a TH-120s broadband seismometer has been operating, which is extra sensitive to low-frequency vibrations emitted by distant earthquakes.



Figure 57: Inauguration of the Casemate Maastricht 2 and the seismology exhibition at Fort Eben-Emael. Credit: ORB-KSB.

In 38 years, using the EBN seismometer, no fewer than 1032 local earthquakes in and around Belgium, and more than 5,000 earthquakes worldwide were measured by seismologists of the ORB-KSB. These recordings provide valuable data for scientific research, improving understanding of the seismic activity of the Roer Valley Rift, Belgium and its border regions. Moreover, with the open sharing of global EBN recordings through international platforms, the ORB-KSB contributes to international cooperation in seismology to improve the location and knowledge of global seismic activity. Besides natural earthquakes, earthquakes induced by humans, quarry blasts and sometimes dredging activities on the Meuse are also measured.

Until the end of 2023, the chamber in which the seismometer is installed remained closed to the public, but not anymore. With united efforts of the ORB-KSB seismology staff and volunteers of the Fort Eben-Emael, a new room was set up in which the seismometer will be on permanent display. The visitors can take a unique look at the instrument and learn

about seismology and earthquakes. The Royal Observatory of Belgium expresses its sincere gratitude to the non-profit organisation Fort Eben-Emael for this unique initiative!

Soapbox Science Brussels 2024

On June 29, 2024, the Brussels Local Organisation Committee of [Soapbox Science Brussels](#) organised their fifth edition of their main event (fourth in-person event). The event took place at the Place de la Monnaie between 14:00 and 17:00. Isla Watton of the main organisation team of London also went to the 2024 Soapbox Science Brussels event and met the organisation team.

During the event, speakers took turns talking about their research and interacting with the public passing by for one hour each. Talks were in French, Dutch and English, three languages widely used in Brussels.

There was a good reception from the visitors, from the communication from the institutes of the speakers, and from the press with whom some interviews were done, notably by BX1.

In 2024, Soapbox Science Brussels Sponsors are the VIB, Europlanet Benelux, the King Baudouin Foundation and Belspo, under the Belgian European Presidency of 2024. The ORB-KSB is the host institute of Soapbox Science Brussels, and the IASB-BIRA also contributed to this event for the logistics.



Figure 58: Credit: Soapbox Science Brussels.

WiseNight 2024 Festival and WiseNight at Schools



Figure 59: Credit: BeWiSe.

The Planetarium of the Royal Observatory of Belgium and the Royal Observatory of Belgium participated in the free WiseNight Science Festival on 27 September 2024. WiseNight is a fun and inclusive event that aims to bring science and scientists in contact with the public interactively. [WiseNight](#) is part of the European Researchers' Night, taking place everywhere in Europe simultaneously. The aim is to show that science is about passion, teamwork and for anyone with an insatiable curiosity to discover and change the world.

The WiseNight Festival took place on 27 September 2024 at the Planetarium of Brussels and on 28 September 2024 at the Museum of Natural Sciences of Belgium. The festival is free of charge, but registration is required for practical purpose.

The Planetarium of Brussels hosted a variety of activities:

- Three planetarium movies sessions:
 - 'We are stars' followed by a workshop 'Create your own star chart';
 - 'We are stars' followed by a Q&A session with an astronomer;
 - Earth's Climate followed by a Q&A session with a meteorologist;
- Two activities related to space weather:
 - 'Panic in the Space Weather Room': an interactive tour of the Space Weather office, where the space weather forecast is being prepared;
 - Northern Lights: a spectacular show of the Northern lights;
- Talks given by female scientists organised by Soapbox Science Brussels;

- Meet Marie Curie sessions, where visitors could interact with researchers who received a Marie Skłodowska-Curie Actions (MSCA) grant;
- An EU4U booth highlighting the European Union’s involvement in Research and Innovation,
- A portrait exhibition of scientists.

Personnel of the Royal Observatory of Belgium participate in the activities ‘We are stars’ followed by a Q&A session with an astronomer, the two activities related to Space Weather and the talk organised by Soapbox Science Brussels (see highlight Soapbox Science Brussels 2024).

The WiseNight is organised by BeWiSe (Belgian Women in Science) with the participation of the Planetarium of the Royal Observatory of Belgium, the Museum of Natural Sciences of Belgium, the Von Karman Institute and the associations Ekoli and GoodPlanet Belgium. This project received funding from the European Union.

In addition to the WiseNight festival, the Planetarium and the Royal Observatory of Belgium also participated in the WiseNight at Schools activity in which female scientists visits class to explain their work to the pupils.

Other outreach events



Figure 60: ASGARD 13th balloon launch. Credit: ORB-KSB.

The **ASGARD 13th balloon launch** took place on April 25, 2024. This event is organised by the Planetarium, with participation of the Space Pole institutes (ORB-KSB, IRM-KMI and IASB-BIRA). The ASGARD Contest is geared toward primary and high school classes who proposed an original experiment that will be loaded on a stratospheric balloon. The finalists of the contest spent a day at the Space Pole site, during which the balloon launch of their experiments is the climax.

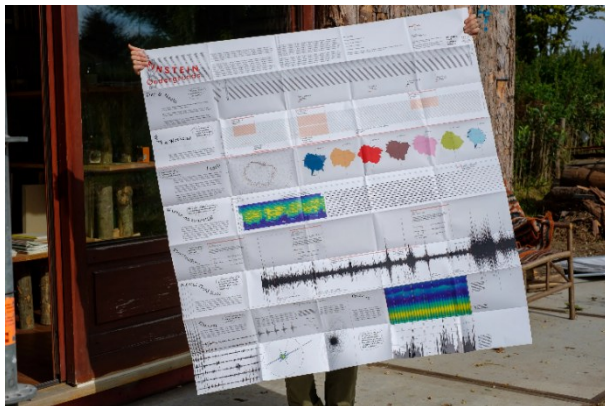


Figure 61: Seismology reveals the secrets of the underground.
Photo © Ward Willems, Institute of Cartopology.

On August 25, 2024, The Seismology and Gravimetry section of the ORB-KSB participate in a **MAPAWAY** festival activity: **Einstein in Tube – What can we measure with a seismometer?** The Einstein Telescope is a future telescope that will be used to detect gravitational waves. In this MAPAWAY activity, they try to re-create an Einstein Telescope in miniature and take seismic measurements on site. Through DIY-expedition, tour and a map artwork, visitors can understand the challenges of the Einstein telescope to neutralise environmental vibrations.

More information:

<https://www.mapaway.eu/theme/theme-einstein/>.

The Planetarium

Daily Activities

Attendance, social media and mobile planetarium

The Planetarium of the Royal Observatory of Belgium welcomed 54,418 paying visitors in 2025, setting a second consecutive attendance record (+157 people compared to 2023). This positive result is due to the combined success of 360° films with the public (including the positive reception of the new film *Birth of the Planet Earth*, see below) on the one hand, and astronomy lessons with teachers and students on the other, complemented by the continued strong performance of the film *The Dark Side of the Moon Planetarium Experience*, which was shown several times in the evenings throughout the year.

The Planetarium's Facebook page had 4,806 followers as of 31 December 2024, an increase of 280 followers (+6%). The Planetarium's Instagram account had 1,379 followers, an increase of 165 followers (+13%) over the year.

The Observatory's mobile planetarium has been used independently by several schools throughout the year, allowing students whose schools were unable to organise a visit to the Planetarium to attend a presentation on the sky and watch educational films. The inflatable planetarium and its accessories are circulated among schools that request them. Teachers are provided with an explanatory guide and lesson plans written by the Planetarium's teacher-facilitators to help them learn how to use the astronomy software and give a structured lesson to their pupils. Given the success and high demand from schools, a decision was made to begin the process of acquiring a second inflatable planetarium, which will allow more schools to benefit from this service.

New film: *The Birth of Planet Earth*

At the end of June, the new planetarium film *The Birth of Planet Earth* was launched. It provides an accessible description of the processes involved in the formation of the solar system, a field at the intersection of astronomy and geophysics. Featuring impressive visual sequences, this 360° film was well received by audiences, with **4,390** people viewing it during its six-month run from July to December.



Figure 62: Copyright: Spitz Creative Media.

Temporarily licensed film *The Dark Side of the Moon Planetarium Experience*



Figure 63: Copyright: NSC Creative.

The special film based on Pink Floyd’s eponymous album continued to be screened in 2024 on 21 evening dates (two screenings per evening). As a result, more than 4,400 spectators were able to enjoy this unique visual and musical experience between January and December. The screening licence expired at the end of 2024.

Astronomy education research

The astronomy education research team led by Jan Sermeus (FED-tWIN researcher affiliated with the Observatory and KU Leuven) welcomes two doctoral students, Judith Vandewiere (in joint supervision with KU Leuven) and Charly Moberg (co-supervised by the University of Mons), who began their research work in education sciences and, at the same time, became increasingly involved in the science education and promotion activities carried out at the Planetarium.

Special Activities

Several events promoting science and scientific, educational and cultural activities were organised in 2024. Participants in these events add approximately 1,500 people for activities and nearly 7,000 people for rentals to the annual number of visitors who frequent the Planetarium during the year.

WiseNight



Figure 64: Credit: BeWiSe

As part of the European Researchers' Night project, the WiseNight 2024 science promotion event took place on September 27 at the Planetarium (see Highlight 'WiseNight 2024 Festival and WiseNight at Schools'). The result of a partnership between BeWiSe (coordinator), the Royal Observatory of Belgium, the Royal Belgian Institute of Natural Sciences, the Von Karman Institute and other partners, this day and evening of activities attracted a large audience who came to watch planetarium films followed by a question-and-answer session with an astronomer from the Observatory, lecture-shows on the Northern Lights and solar weather hosted by colleagues from the Solar-Terrestrial Centre of Excellence, Soapbox Science talks by female scientists, fun physics experiments, educational workshops on fluid mechanics, and more.

Also in 2024

- The finale of the *Girls Leading in Science* competition was co-organised at the Planetarium on March 20. The aim of this project is to promote scientific careers among young people, particularly young girls.

- The *ASGARD project* was hosted from April 24 to 26 at the Space Pole (ORB-KSB, IRM-KMI and BIRA-IASB) and the Planetarium
- The *Brussels Museums Nocturnes* (Nocturnes des Musées de Bruxelles/Nocturnes van de Brusselse Musea) was hosted at the Planetarium on May 23: in addition to the planetarium film, visitors were able to attend an astro-musical lecture given by Arthur Choplin (ULB)
- The meeting of the FNRS Astronomy Contact Group and the *Astronomy Day* of the ORB-KSB took place on May 23
- A new edition of the *Brussels Planetarium Poetry Festival* took place on November 29 and 30, with several poets from all over Europe (European project Urban Travel Machines)



Figure 65: Final of the Girls Leading in Science contest. Credit: BeWiSe.

Rental of rooms in the form of provision of the dome or auditorium in 2024 for various third parties

- Candlelight concerts on January 17 and 31, February 15 and 28, March 21, April 19, June 13, August 29 and 30, and October 11
- Ayming society on February 22
- the National Lottery on February 26
- Performance by an artist as part of the KANAL programme on April 5 and 6
- VRT on April 26
- VVS on May 4
- VTM on May 8
- the Geography Olympiad on May 15
- Dark Trace on June 5
- a concert by a pianist in aid of the Jacques Cox Fund on June 7
- Belnet on September 19
- the anniversary of BIRA-IASB on November 22

- Studio 100 on November 25
- EURid on November 5

Interviews with the media

In response to requests from several radio stations and newspapers: Radio Vivacité on January 9 and July 6 (Planetarium programming), Radio BX1 on June 19 (launch of the new film 'Birth of Planet Earth'), RTL-TVI on August 20 (feature on the 'supermoon').

Annexe 1: Publications

Publications With Peer Review

- [1] Adassuriya, Janaka ; Ganesh, Shashikiran ; De Cat, Peter ; Joshi, Santosh ; Jayaratne, Chandana
Curve of Growth Analysis of SZ Lyn
Bulletin de la Société Royale des Sciences de Liège, 93 issue 2, pp. 470-477 (2024).
<http://dx.doi.org/10.25518/0037-9565.11753>
- [2] Afify, M. S. ; Dreher, J. ; Schoeffler, K. ; Micera, Alfredo ; Innocenti, M. E.
Electrostatic Bursts Generated by the Ion-Ion Acoustic Instability with Solar Wind Plasma Parameters
The Astrophysical Journal, 971 issue 1, pp. 93 (2024). <https://doi.org/10.3847/1538-4357/ad644c>
- [3] Asvestari, E. ; Temmer, M. ; Caplan, R.M. ; Linker, J.A. ; Heinemann, S.G. ; Pinto, R.F. ; Henney, C.J. ; Arge, C.N. ; Owens, M.J. ; Madjarska, M.S. ; Pomoell, J. ; Scolini, Camilla
Coronal Models and Detection of the Open Magnetic Field
The Astrophysical Journal, 971 issue 1, pp. 45 (2024). <https://doi.org/10.3847/1538-4357/ad5155>
- [4] Backs, F. ; Brands, S. A. ; de Koter, A. ; Kaper, L. ; Vink, J. S. ; Puls, J. ; Sundqvist, J. ; Tramper, F. ; Sana, H. ; Bernini-Peron, M. ; Bestenlehner, J. M. ; Crowther, P. A. ; Hawcroft, C. ; Ignace, R. ; Kuiper, R. ; van Loon, J. Th. ; Mahy, L. ; Marcolino, W. ; Najarro, F. ; Oskinova, L. M. ; Pauli, D. ; Ramachandran, V. ; Sander, A. A. C. ; Verhamme, O.
X-Shooting ULLYSES: Massive stars at low metallicity: VI. Atmosphere and mass-loss properties of O-type giants in the Small Magellanic Cloud
Astronomy & Astrophysics, 692 issue A88, pp. 24 (2024). <http://dx.doi.org/10.1051/0004-6361/202451893>
- [5] Baland, Rose-Marie
The obliquity of Mercury: Models and interpretation
IAU Symposium, 382, pp. 1-11 (2024). <http://dx.doi.org/10.1017/S1743921323004398>
- [6] Bamahry, Fikri ; Legrand, Juliette ; Bruyninx, Carine ; Fabian , Andras
EPOS-GNSS Data Quality Monitoring Web Portal
International Association of Geodesy Symposia, pp. 1–9 (2024). http://dx.doi.org/10.1007/1345_2024_264
- [7] Banu, S.A. ; Winslow, R.M. ; Scolini, Camilla ; Davies, E.E. ; Farrugia, C.J. ; Murphy, A.K. ; Lugaz, N. ; Al-Haddad, N.
Characterization of Small Flux Ropes Using Juno Spacecraft Cruise-phase Data
The Astrophysical Journal, 976 issue 1, pp. 79 (2024). <https://doi.org/10.3847/1538-4357/ad833>
- [8] Basili, R. ; Danciu, L. ; Beauval, C. ; Sesetyan, K. ; Vilanova, S. ; Adamia, S. ; Arroucau, P. ; Atanackov, J. ; Baize, S. ; Canora, C. ; Caputo, R. ; Carafa, M. ; Cushing, E. ; Custódio, S. ; Demircioglu Tumsa, M. ; Duarte, J. ; Ganas, A. ; García-Mayordomo, J. ; Gómez de la Peña, L. ; Gràcia, E. ; Jamsek Rupnik, P. ; Jomard, H. ; Kastelic, V. ; Maesano, F. ; Martin-Banda, R. ; Martinez-Loriente, S. ; Neres, M. ; Perea, H. ; Sket-Motnikar, B. ; Tiberti, M. ; Tsereteli, N. ; Tsironi, V. ; Vallone, R. ; Vanneste, Kris ; Zupancic, P.
The European Fault-Source Model 2020 (EFSM20): geologic input data for the European Seismic Hazard Model 2020
NHES, 24 issue 11, pp. 3945–3976 (2024). <http://dx.doi.org/10.5194/nhess-24-3945-2024>
- [9] Bernini-Peron, M. ; Sander, A. A. C. ; Ramachandran, V. ; Oskinova, L. M. ; Vink, J. S. ; Verhamme, O. ; Najarro, F. ; Josiek, J. ; Brands, S. A. ; Crowther, P. A. ; Gómez-González, V. M. A. ; Gormaz-Matamala, A. C. ; Hawcroft, C. ; Kuiper, R. ; Mahy, L. ; Marcolino, W. L. F. ; Martins, L. P. ; Mehner, A. ; Parsons, T. N. ; Pauli, D. ; Shenar, T. ; Schootemeijer, A. ; Todt, H. ; van Loon, J. Th.
X-Shooting ULLYSES: Massive stars at low metallicity: VII. Stellar and wind properties of B supergiants in the Small Magellanic Cloud
Astronomy & Astrophysics, 692 issue A89, pp. 31 (2024). <http://dx.doi.org/10.1051/0004-6361/202450475>
- [10] Bertrand, Bruno ; Defraigne, Pascale ; Hees, Aurélien ; Sheremet, Alexandra ; Courde, Clément ; Chabé, Julien ; Ventura-Traveset, Javier ; Dilssner, Florian ; Schoenemann, Erik ; Mendes, Luis ; Delva, Pacôme
Searching for large dark matter clumps using the Galileo Constellation clock variations
Advances in Space Research, 74 issue 6, pp. 2551-2563 (2024). <http://dx.doi.org/10.1016/j.asr.2024.03.080>
- [11] Bhattacharya, S. ; Lefèvre, L. ; Chatzistergos, T. ; Hayakawa, H. ; Jansen, M.

Rudolf Wolf to Alfred Wolfer: The Transfer of the Reference Observer in the International Sunspot Number Series (1876–1893)

Solar Physics, 299 issue 4, pp. 45 (2024). <http://dx.doi.org/10.1007/s11207-024-02261-7>

- [12] Björklund, R. ; Vigouroux, C. ; Effertz, P. ; García, O.E. ; Geddes, A. ; Hannigan, J. ; Miyagawa, K. ; Kotkamp, M. ; Langerock, B. ; Nedoluha, G. ; Ortega, I. ; Poyraz, Deniz
Intercomparison of long-term ground-based measurements of total, tropospheric, and stratospheric ozone at Lauder, New Zealand
Atmospheric Measurement Techniques, 17 issue 23, pp. 6819-6849 (2024). <https://doi.org/10.5194/amt-17-6819-2024>
- [13] Blomme, R. ; Rauw, G. ; Volpi, D. ; Nazé, Y. ; Abdul-Masih, M.
The colliding-wind binary HD 168112
Astronomy & Astrophysics, 687, pp. A106, 13 pp. (2024). <http://dx.doi.org/10.1051/0004-6361/202450227>
- [14] Blomme, R. ; Rauw, G. ; Volpi, D. ; Nazé, Y. ; Abdul-Masih, M.
The colliding-wind binary HD 168112
Bulletin de la Société Royale des Sciences de Liège, 93 issue 3, pp. 262-267 (2024).
<http://dx.doi.org/10.25518/0037-9565.12342>
- [15] Borzi, A.M. ; Minio, V. ; De Plaen, R. ; Lecocq, T. ; Alparone, S. ; Aronica, S. ; Cannavò, F. ; Capodici, F. ; Ciraolo, G. ; D'Amico, S. ; Contrafatto, D. ; Di Grazia, G. ; Fontana, I. ; Giacalone, G. ; Larocca, G. ; Lo Re, C. ; Manno, G. ; Nardone, G. ; Orasi, A. ; Picone, M. ; Scicchitano, G. ; Cannata, A.
Integration of microseism, wavemeter buoy, HF radar and hindcast data to analyze the Mediterranean cyclone Helios
Ocean Science, 20, pp. 1-20 (2024). <http://dx.doi.org/10.5194/os-20-1-2024>
- [16] Borzi, A.M. ; Minio, V. ; De Plaen, R. ; Lecocq, T. ; Cannavò, F. ; Ciraolo, G. ; D'Amico, S. ; Lo Re, C. ; Monaco, C. ; Picone, M. ; Scardino, G. ; Scicchitano, G. ; Cannata, A.
Long-term analysis of microseism during extreme weather events: Medicanes and common storms in the Mediterranean Sea
Science of The Total Environment, 915 issue 169989 (2024).
<http://dx.doi.org/10.1016/j.scitotenv.2024.169989>
- [17] Britavskiy, Nikolay ; Mathieu, Renzo ; Naze, Yael ; Rauw, Gregor ; Vynatheya, Pavan
Tracing the evolution of short-period binaries with super-synchronous fast rotators
Astronomy and Astrophysics, 684 issue A35, pp. 21 (2024). <http://dx.doi.org/10.1051/0004-6361/202348484>
- [18] Calcines Rosario, Ariadna ; Auchère, Frédéric ; Corso, Alin ; Del Zanna, Giulio ; Dudík, Jaroslav ; Gissot, Samuel ; Hayes, Laura A. ; Kerr, Graham S. ; Kintziger, Christian ; Matthews, Sarah A. ; Musset, Sophie ; Orozco Suárez, David ; Polito, Vanessa ; Reid, Hamish A. S. ; Ryan, Daniel F.
Spectral Imager of the Solar Atmosphere: The First Extreme-Ultraviolet Solar Integral Field Spectrograph Using Slicers
Aerospace, 11 issue 3 (2024). <http://dx.doi.org/10.3390/aerospace1103020>
- [19] Caldiero, Alfonso ; Le Maistre, Sebastien
Small bodies global gravity inversion via the level-set method
Icarus, 411 (2024). <http://dx.doi.org/10.1016/j.icarus.2023.115940>
- [20] Chabot, N. L. ; Rivkin, A. S. ; Cheng, A. F. ; Barnouin, O. S. ; Fahnestock, E. G. ; Richardson, D. C. ; Stickle, A. M. ; Karatekin, O. ... ; Senel, C. B. ... ; Wünnemann, K. ; Zannoni, M. ; Zhang, Y.
Achievement of the Planetary Defense Investigations of the Double Asteroid Redirection Test (DART) Mission
The Planetary Science Journal, 5 issue 2, pp. 49 (2024). <http://dx.doi.org/10.3847/PSJ/ad16e6>
- [21] Clette, Frédéric ; Jain, Shantanu ; Podladchikova, Tatiana
The McNish and Lincoln Solar-Activity Predictions: The Method and Its Performance
Solar Physics, 299 issue 2, pp. 22 (2024). <http://dx.doi.org/10.1007/s11207-024-02266-2>
- [22] Coburn, J. T. ; Verscharen, D. ; Owen, C. J. ; Maksimovic, M. ; Horbury, T. S. ; Chen, C. H. ; Micera, Alfredo ; Jagarlamudi, V. K.
The Regulation of the Solar Wind Electron Heat Flux by Wave-Particle Interactions
The Astrophysical Journal, 964 issue 1, pp. 100 (2024). <https://doi.org/10.3847/1538-4357/ad1329>

- [23] Collier, Hannah ; Hayes, Laura A. ; Purkhart, Stefan ; Krucker, Säm ; Ryan, Daniel F. ; Polito, Vanessa ; Veronig, Astrid M. ; Harra, Louise K. ; Berghmans, David ; Kraaikamp, Emil ; Dominique, Marie ; Dolla, Laurent R. ; Verbeeck, Cis
Solar flares in the Solar Orbiter era: Short-exposure EUV/FSI observations of STIX flares
Astronomy & Astrophysics, 692 issue id.A176 (2024). <http://dx.doi.org/10.1051/0004-6361/202451838>
- [24] Couto, Victor Hugo ; Gonçalves, Pedro ; Sermeus, Jan
A narrative review of Brazilian and Portuguese students' perceptions and conceptions about climate change
Terrae Didactica, 20 (2024). <http://dx.doi.org/10.20396/td.v20i00.8674120c>
- [25] Coyette, Alexis ; Baland, Rose-Marie ; Van Hoolst, Tim
Revisiting the Cassini States of synchronous satellites with an angular momentum approach
Proceedings of the International Astronomical Union. 2022;18(S382):73-79.
<https://doi.org/10.1017/S1743921323004118>
- [26] Cuadrat-Grzybowski, Michal ; Clesse, Sébastien ; Defraigne, Pascale ; Van Camp, Michel ; Bertrand, Bruno
Probing primordial black holes and dark matter clumps in the Solar System with gravimeter and Global Navigation Satellite Systems networks
Physical Review D, 110 issue 6, pp. 063029 (2024). <http://dx.doi.org/10.1103/PhysRevD.110.063029>
- [27] Çubuk-Sabuncu, Y. ; Jónsdóttir, K. ; Árnadóttir, T. ; Mordret, A. ; Caudron, C. ; Lecocq, T. ; De Plaen, R.
Temporal Seismic Velocity Changes Associated With the Mw 6.1, May 2008 Ölfus Doublet, South Iceland: A Joint Interpretation From dv/v and GPS
Journal of Geophysical Research: Solid Earth, 129 issue e2023JB027064 (2024).
<http://dx.doi.org/10.1029/2023JB027064>
- [28] Dabrowski, B. ; Wolowska, A. ; Vocks, C. ; Magdalenic, Jasmina ; Zhang, P. ; Flisek, P. ; Marqué, Christophe ; Rothkaehl, H.
Fine structures of a solar type III radio bursts observed with LOFAR
Acta Geophysica, pp. 1-7 (2024). <https://doi.org/10.1007/s11600-024-01421-4>
- [29] Dannehl, M. ; Delouille, V. ; Barra, V.
An experimental study on EUV-to-magnetogram image translation using conditional Generative Adversarial Networks
Earth and Space Science, 11 issue 4, pp. e2023EA002974 (2024). <https://doi.org/10.1029/2023EA002974>
- [30] De Cat, Peter ; De Becker, Michaël ; Kumar, Brajesh
The prospects of pulsating stars studies with the International Liquid Mirror Telescope
Bulletin de la Société Royale des Sciences de Liège, 93 issue 2, pp. 855-862 (2024).
<http://dx.doi.org/10.25518/0037-9565.11902>
- [31] de Wit, S. ; Bonanos, A. Z. ; Antoniadis, K. ; Zapartas, E. ; Ruiz, A. ; Britavskiy, N. ; Christodoulou, E. ; De, K. ; Mavelias, G. ; Munoz-Sanchez, G. ; Tsopela, A.
Investigating episodic mass loss in evolved massive stars: II. Physical properties of red supergiants at subsolar metallicity
Astronomy & Astrophysics, 689 issue A46, pp. 22 (2024). <http://dx.doi.org/https://doi.org/10.1051/0004-6361/202449607>
- [32] Debnath, D. ; Sundqvist, J.O. ; Moens, N. ; Van der Sijpt, C. ; Verhamme, O. ; Poniatowski, Luka
2D unified atmosphere and wind simulations of O-type stars
Astronomy & Astrophysics, 684, pp. A177 (2024). <https://doi.org/10.1051/0004-6361/202348206>
- [33] Deshmukh, K. ; Sana, H. ; Mérand, A. ; Bordier, E. ; Langer, N. ; Bodensteiner, J. ; Dsilva, K. ; Frost, A. J. ; Gosset, E. ; Le Bouquin, J. -B. ; Lefever, R. R. ; Mahy, L. ; Patrick, L. R. ; Reggiani, M. ; Sander, A. A. C. ; Shenar, T. ; Tramper, F. ; Villaseñor, J. I. ; Waisberg, I.
Investigating 39 Galactic Wolf-Rayet stars with VLTI/GRAVITY: Uncovering a long-period binary desert
Astronomy & Astrophysics, 692 issue A109, pp. 21 (2024). <http://dx.doi.org/10.1051/0004-6361/202452352>
- [34] Dewitte, Steven ; Mauritsen, Thorsten ; Meyssignac, Benoit ; August, Thomas ; Schifano, Luca ; Smeesters, Lien ; Roca, Rémy ; Brindley, Helen ; Russell, Jacqueline ; Clerbaux, Nicolas ; Hollmann, Rainer ; Megner, Linda ; Haberreiter, Margit ; Gumbel, Joerg ; Marotzke, Jochem ; Riedi, Jérôme ; Riihelä, Aku ; Trent, Tim ; Wendisch, Manfred

The Earth Climate Observatory space mission concept for the monitoring of the Earth Energy Imbalance
IOP conference series, Proceedings International Radiation Symposium 2024 (2024).

- [35] Dimarcq, Noël ; Gertsvolf, Marina ; Mileti, Gaetano ; Bize, Sébastien ; Oates, Chris ; Peik, Ekkehard ; Calonico, Davide ; Ido, Tetsuya ; Tavella, Patrizia ; Meynadier, Frédéric ; Petit, Gérard ; Panfilo, Gianna ; Bartholomew, John ; Defraigne, Pascale ; et, al
Roadmap towards the redefinition of the second
Metrologia, 61, pp. 01001 (2024). <http://dx.doi.org/10.1088/1681-7575/ad17d2>
- [36] Drilleau, Mélanie ; Samuel, Henri ; Garcia, Raphaël F. ; Rivoldini, Attilio ; Perrin, Clément ; Wiczorek, Mark ; Lognonné, Philippe ; Banerdt, William B.
Constraints on Lateral Variations of Martian Crustal Thickness From Seismological and Gravity Field Measurements
Geophysical Research Letters, 51 issue 4 (2024). <http://dx.doi.org/10.1029/2023GL105701>
- [37] Filice, V ; Le Maistre, S ; Dehant, V ; Van Hoolst, T ; Bernauer, F ; Garcia, RF
PIONEERS: a 6DoF motion sensor to measure rotation and tides in the Solar System
Earth, Planets and Space, 76 (2024). <http://dx.doi.org/10.1186/s40623-023-01951-z>
- [38] Frost, A. J. ; Sana, H. ; Mahy, L. ; Wade, G. ; Barron, J. ; Le Bouquin, J. -B. ; Mérand, A. ; Schneider, F. R. N. ; Shenar, T. ; Barbá, R. H. ; Bowman, D. M. ; Fabry, M. ; Farhang, A. ; Marchant, P. ; Morrell, N. I. ; Smoker, J. V.
A magnetic massive star has experienced a stellar merger
Science, 384 issue 6692, pp. 214-217 (2024). <http://dx.doi.org/10.1126/science.adg7700>
- [39] Frost, A. J. ; Sana, H. ; Mahy, L. ; Wade, G. ; Barron, J. ; Le Bouquin, J. -B. ; Mérand, A. ; Schneider, F. R. N. ; Shenar, T. ; Barbá, R. H. ; Bowman, D. M. ; Fabry, M. ; Farhang, A. ; Marchant, P. ; Morrell, N. I. ; Smoker, J. V.
An interaction and merger in a massive multiple system create a magnetic field in a massive star
Bulletin de la Société Royale des Sciences de Liège, Proceedings of the 41st Liège International Astrophysical Colloquium "The eventful Life of massive multiples", held in Liège 15-19 July 2024, eds Y. Nazé & E. Bozzo, 93 issue 3, pp. 85-102 (2024). <http://dx.doi.org/10.25518/0037-9565.12274>
- [40] Furst, T. ; Mahy, L. ; Nazé, Y.
The Star Formation History of the Young Open Cluster NGC 2244: Study of the Binary Fraction
Bulletin de la Société Royale des Sciences de Liège, 93 issue 2, pp. 589-600 (2024).
<http://dx.doi.org/10.25518/0037-9565.11808>
- [41] Gaia Collaboration ; many authors including Blomme, R., Frémat, Y., Mahy, L., Lobel, A. and Pauwels, T.
Gaia Focused Product Release: A catalogue of sources around quasars to search for strongly lensed quasars
Astronomy and Astrophysics, 685, pp. A130, 40 pp. (2024). <https://doi.org/10.1051/0004-6361/202347273>
- [42] Gaia Collaboration ; many authors including Blomme, R., Frémat, Y., Mahy, L., Lobel, A. and Pauwels, T.
Discovery of a dormant 33 solar-mass black hole in pre-release Gaia astrometry
Astronomy & Astrophysics, 686, pp. L2, 23 pp. (2024). <http://dx.doi.org/10.1051/0004-6361/202449763>
- [43] Georgoulis, M. K. ; Yardley, S. L. ; Guerra, J. A. ; Murray, S. A. ; Ahmadzadeh, A. ; Anastasiadis, A. ; Zhukov, Andrei
Prediction of solar energetic events impacting space weather condition
Advances in Space Research (2024). <https://doi.org/10.1016/j.asr.2024.02.030>
- [44] Gerekos, C. ; Steinbrügge, G. ; Jebaraj, I. C. ; Casillas, A. ; Donini, E. ; Sánchez-Cano, B. ; Magdalenic, Jasmina ; Blankenship, D. D.
Observation of solar radio burst events from Mars orbit with the Shallow Radar instrument
Astronomy & Astrophysics, 683, pp. A56 (2024). <https://doi.org/10.1051/0004-6361/202347900>
- [45] Gillmann, Cedric ; Hakim, Kaustubh ; Lourenco, Diogo L. ; Quanz, Sascha P. ; Sossi, Paolo A.
Interior Controls on the Habitability of Rocky Planets
Space: Science & Technology, 4, pp. 0075 (2024). <http://dx.doi.org/10.34133/space.0075>
- [46] Goli, Marta ; Le Maistre, Sébastien ; Yseboodt, Marie
About the improvement in Mars Polar Motion determination from radio tracking of two landers

Planetary and Space Science, 251 (2024). <http://dx.doi.org/https://doi.org/10.1016/j.pss.2024.105958>

- [47] Gopalswamy, N. ; Christe, S. ; Fung, S. F. ; Gong, Q. ; Gruesbeck, J. R. ; Jian, L. K. ; Kanekal, S. G. ; Kay, C. ; Kucera, T. A. ; Leake, J. E. ; Li, L. ; Mäkelä, P. ; Nikulla, P. ; Reginald, N. L. ; Shih, A. ; Tadikonda, S. K. ; Viall, N. ; Wilson, L. B. ; Yashiro, S. ; Golub, L. ; DeLuca, E. ; Reeves, K. ; Sterling, A. C. ; Winebarger, A. R. ; DeForest, C. ; Hassler, D. M. ; Seaton, D. B. ; Desai, M. I. ; Mokashi, P. S. ; Lazio, J. ; Jensen, E. A. ; Manchester, W. B. ; Sachdeva, N. ; Wood, B. ; Kooi, J. ; Hess, P. ; Wexler, D. B. ; Bale, S. D. ; Krucker, S. ; Hurlburt, N. ; DeRosa, M. ; Gosain, S. ; Jain, K. ; Kholikov, S. ; Petrie, G. J. D. ; Pevtsov, A. ; Tripathy, S. C. ; Zhao, J. ; Scherrer, P. H. ; Rajaguru, S. P. ; Woods, T. ; Kenney, M. ; Zhang, J. ; Scolini, C. ; Cho, K. -S. ; Park, Y. -D. ; Jackson, B. V.
The multiview observatory for solar terrestrial science (MOST)
Journal of Atmospheric and Solar-Terrestrial Physics, 254 , 106165 (2024).
<https://doi.org/10.1016/j.jastp.2023.106165>
- [48] Gramigna, E. ; Lasagni Manghi, R. ; Zannoni, M. ; Tortora, M. ; Park, R. ; Tommei, G. ; Le Maistre, S. ; Michel, P. ; Castellini, F. ; Keepers, M.
The Hera Radio Science Experiment at Didymos
Planetary and Space Science, 246, 105906 (2024). <https://doi.org/10.1016/j.pss.2024.105906>
- [49] Greatorex, Harry J. ; Milligan, Ryan O. ; Dammasch, Ingolf E.
On the Instrumental Discrepancies in Lyman-Alpha Observations of Solar Flares
Solar Physics, 299 issue 162 (2024). <http://dx.doi.org/10.1007/s11207-024-02407-7>
- [50] Grimani, C. ; Fabi, M. ; Persici, A. ; Sabbatini, F. ; Villani, M. ; Frassati, F. ; Antonucci, E. ; Pancrazzi, M. ; Telloni, D. ; Kühl, P. ; Rodríguez-Pacheco, J. ; Wimmer-Schweingruber, R. F. ; Andretta, V. ; Chioetto, P. ; Da Deppo, V. ; Gissot, S. ; Jerse, G. ; Messerotti, M. ; Naletto, G. ; Plainaki, C. ; Romoli, M. ; Spadaro, D. ; Stangalini, M. ; Teriaca, L. ; Uslenghi, M. ; Abbo, L. ; Burtovoi, A. ; Landini, F. ; Nicolini, G. ; Russano, G. ; Sasso, C. ; Susino, R.
Observation of solar energetic particles with Metis on board Solar Orbiter on February 25, 2023
Astronomy & Astrophysics, 686 (2024). <http://dx.doi.org/10.1051/0004-6361/202449386>
- [51] Groenewegen, M.A.T.
Primary Period–Luminosity-Relation Calibrators in the Milky Way: Cepheids and RR Lyrae: Physical basis, Calibration, and Applications
Proceedings IAU Symposium No. 376, pp. 128-149 (2024). <https://doi.org/10.1017/S1743921323002995>
- [52] Hajduk, M. ; van Hoof, P. A. M. ; Zijlstra, A. A. ; Van de Steene, G. ; Kimeswenger, S. ; Barría, D. ; Tafuya, D. ; Toalá, J. A.
Non-thermal radio emission in Sakurai’s Object
Astronomy & Astrophysics, Volume 688, id.L21, 6 pp., 688 issue L, pp. 21-26 (2024).
<http://dx.doi.org/%20%2010.1051/0004-6361/202450496>
- [53] Hawcroft, C. ; Sana, H. ; Mahy, L. ; Sundqvist, J. O. ; de Koter, A. ; Crowther, P. A. ; Bestenlehner, J. M. ; Brands, S. A. ; David-Uraz, A. ; Decin, L. ; Erba, C. ; Garcia, M. ; Hamann, W. -R. ; Herrero, A. ; Ignace, R. ; Kee, N. D. ; Kubátová, B. ; Lefever, R. ; Moffat, A. ; Najarro, F. ; Oskinova, L. ; Pauli, D. ; Prinja, R. ; Puls, J. ; Sander, A. A. C. ; Shenar, T. ; St-Louis, N. ; ud-Doula, A. ; Vink, J. S.
X-Shooting ULLYSES: Massive stars at low metallicity. III. Terminal wind speeds of ULLYSES massive stars
Astronomy & Astrophysics, 688 issue A105, pp. 19 (2024). <http://dx.doi.org/10.1051/0004-6361/202245588>
- [54] Hawcroft, C. ; Mahy, L. ; Sana, H. ; Sundqvist, J. O. ; Abdul-Masih, M. ; Brands, S. A. ; Decin, L. ; de Koter, A. ; Puls, J.
Empirical mass-loss rates and clumping properties of O-type stars in the Large Magellanic Cloud
Astronomy & Astrophysics, 690 issue A126, pp. 18 (2024). <http://dx.doi.org/10.1051/0004-6361/202348478>
- [55] Hayakawa, H. ; Suyama, T. ; Clette, Frédérique ; Bhattacharya, Shreya ; Lefèvre, Laure ; Ohnishi, K.
Katsue Misawa’s sunspot observations in 1921–1934: a primary reference for the Wolf–Brunner transition
Monthly Notices of the Royal Astronomical Society, 532 issue 4, pp. 4289-4303 (2024).
<https://doi.org/10.1093/mnras/stad2791>
- [56] Hayakawa, Hisashi ; Murata, Koji ; Teague, E. Thomas H. ; Bechet, Sabrina ; Sôma, Mitsuru

Analyses of Johannes Kepler's Sunspot Drawings in 1607: A Revised Scenario for the Solar Cycles in the Early 17th Century

The Astrophysical Journal Letters (2024). <http://dx.doi.org/10.3847/2041-8213/ad57c9>

- [57] Heinemann, S.G. ; Owens, M.J. ; Temmer, M. ; Turtle, J.A. ; Arge, C.N. ; Henney, C.J. ; Pomoell, J. ; Asvestari, E. ; Linker, J.A. ; Downs, C. ; Caplan, R.M. ; Scolini, Camilla
On the Origin of the Sudden Heliospheric Open Magnetic Flux Enhancement During the 2014 Pole Reversal
The Astrophysical Journal, 965 issue 2, pp. 151 (2024). <https://doi.org/10.3847/1538-4357/ad2b69>
- [58] Holdsworth, D. L. ; Cunha, M. S. ; Lares-Martiz, M. ; Kurtz, D. W. ; Antoci, V. ; Barceló Forteza, S. ; De Cat, P. ; Derekas, A. ; Kayhan, C. ; Ozuyar, D. ; Skarka, M. ; Hey, D. R. ; Shi, F. ; Bowman, D. M. ; Kobzar, O. ; Ayala Gómez, A. ; Bognár, Zs ; Buzasi, D. L. ; Ebadi, M. ; Fox-Machado, L. ; García Hernández, A. ; Ghasemi, H. ; Guzik, J. A. ; Handberg, R. ; Handler, G. ; Hasanzadeh, A. ; Jayaraman, R. ; Khalack, V. ; Kochukhov, O. ; Lovekin, C. C. ; Mikołajczyk, P. ; Mkrtichian, D. ; Murphy, S. J. ; Niemczura, E. ; Olafsson, B. G. ; Pascual-Granado, J. ; Paunzen, E. ; Posiłek, N. ; Ramón-Ballesta, A. ; Safari, H. ; Samadi-Ghadim, A. ; Smalley, B. ; Sódor, Á. ; Stateva, I. ; Suárez, J. C. ; Szabó, R. ; Wu, T. ; Ziaali, E. ; Zong, W. ; Seager, S.
TESS Cycle 2 observations of roAp stars with 2-min cadence data
Monthly Notices of the Royal Astronomical Society, 527 issue 4, pp. 9548-9580 (2024).
<http://dx.doi.org/10.1093/mnras/stad3800>
- [59] Ishii, M. ; Costa, J. E. R. ; Kuznetsova, M. M. ; Andries, Jesse ; Gopalswamy, N. ; Belehaki, A. ; Spann, J. F.
Pathways to global coordination in space weather: International organizations, initiatives, and space agencies
Advances in Space Research (2024). <https://doi.org/10.1016/j.asr.2024.06.017>
- [60] Jiang, Guo ; Jianghui, Geng ; Jing, Zeng ; Xiangyu, Song ; Pascale, Defraigne
GPS/Galileo/BDS phase bias stream from Wuhan IGS analysis center for real-time PPP ambiguity resolution
GPS Solutions, 28, 67 (2024). <https://doi.org/10.1007/s10291-023-01610-6>
- [61] Joshi, Santosh ; De Cat, Peter ; De Becker, Michaël ; Kolenberg, Katrien ; Mondal, Soumen ; Ganesh, Shashikiran ; Mahy, Laurent ; Karinkuzhi, Drisya ; Yadav, Abhay Pratap ; Baug, Tapas ; Pandey, Jeewan Chandra ; Misra, Kuntal ; Stalin, C. S. ; Veerabathina, Nilakshi ; Joshi, Bhuwan ; Bergman, David ; Van Doorselaere, Tom
Proceedings of the 3rd BINA Workshop: Scientific Potential of Indo-Belgian Co-operation
Bulletin de la Société Royale des Sciences de Liège, 93 issue 2, pp. 1-31 (2024).
<http://dx.doi.org/10.25518/0037-9565.11581>
- [62] Kahraman Aliçavuş, F. ; Aliçavuş, F. ; Çoban, Ç. G. ; Handler, G. ; De Cat, P.
Single-lined eclipsing binaries with δ Scuti components: GQ Dra, RR Lep, and TYC 683-640-1
Monthly Notices of the Royal Astronomical Society, 527 issue 2, pp. 4076--4086 (2024).
<http://dx.doi.org/10.1093/mnras/stad3467>
- [63] Kahraman Aliçavuş, Filiz ; Handler, Gerald ; Chowdhury, Sowgata ; Niemczura, Ewa ; Jayaraman, Rahul ; De Cat, Peter ; Ozuyar, Dogus ; Aliçavuş, Fahri
On the existence of 'Maia variables'
Publications of the Astronomical Society of Australia, 41, pp. e082 (2024).
<http://dx.doi.org/10.1017/pasa.2024.76> c
- [64] Kuchar, T.A. ; Sloan, G.C. ; Mizuno, D.R. ; Kraemer, K.E. ; Boyer, M.L. ; Groenewegen, M.A.T. ; Jones, O.C. ; Kemper, F. ; McDonald, I. ; Oliveira, J.M., ; Sewilo, M. ; Srinivasan, S. ; van Loon, J. Th. ; Zijlstra, A.
SMC-Last Extracted Photometry
Astronomical Journal, 167, pp. 149 (2024). <https://doi.org/10.3847/1538-3881/ad2601>
- [65] Kumar Shrivastav, Arpit ; Pant, Vaibhav ; Berghmans, David ; Zhukov, Andrei N. ; Van Doorselaere, Tom ; Petrova, Elena ; Banerjee, Dipankar ; Lim, Daye ; Verbeeck, Cis
Statistical investigation of decayless oscillations in small-scale coronal loops observed by Solar Orbiter/EUI
Astronomy & Astrophysics, 685, pp. A36 (2024). <http://dx.doi.org/10.1051/0004-6361/202346670>
- [66] Lario, D. ; Balmaceda, L. A. ; Gomez-Herrero, R. ; Mason, G. M. ; Krupar, V. ; Mac-Cormack, C. ; Kouloumvakos, A. ; Cernuda, I. ; Collier, H. ; Krucker, S. ; Carcaboso, F. ; Richardson, I. G. ; Kumar, P. ; Wijzen, N. ; Strauss, R. D. ; Dresing, N. ; Warmuth, A. ; Rodriguez-Pacheco, J. ; Rodriguez-Garciaa, L. ;

- Jebaraj, I. C. ; Ho, G. C. ; Bucik, R. ; Pacheco, D. ; Hutchinson, A. ; Horbury, T. S. ; Rodriguez, L. ; Zhukov, A. N. ; Aran, A. ; Nitta, N. V.
A rapid sequence of SEP events associated with a series of EUV jets: Solar Orbiter, STEREO-A and near-Earth spacecraft observations
 The Astrophysical Journal, 975, pp. 84 (2024). <http://dx.doi.org/10.3847/1538-4357/ad6c47>
- [67] Laurent-Varin, Julien ; James, Theo ; Marty, Jean-Charles ; Jorda, Laurent ; Le Maistre, Sebastien ; Gaskell, Robert
New gravity field of comet 67P/C-G based on Rosetta's Doppler and optical data
 Icarus, 424, 116284 (2024). <https://doi.org/10.1016/j.icarus.2024.116284>
- [68] Li, X. ; Senthamizh Pawai, V. ; Shukhobodskaia, D. ; Butala, M. D. ; Rodriguez, L. ; Magdalenic, J. ; Delouille, V.
A transfer learning method to generate synthetic synoptic magnetograms
 Space Weather, 22 issue 1, pp. e2023SW003499 (2024). <http://dx.doi.org/%2010.1029/2023SW003499>
- [69] Lim, Daye ; Van Doorselaere, Tom ; Nakariakov, Valery M. ; Kolotkov, Dmitrii Y. ; Gao, Yuhang ; Berghmans, David
Undersampling effects on observed periods of coronal oscillations
 Astronomy & Astrophysics, 690 issue id.L8 (2024). <http://dx.doi.org/10.1051/0004-6361/202451684>
- [70] Lugaz, N. ; Lee, C.O. ; Al-Haddad, N. ; Lillis, R.J. ; Jian, L.K. ; Curtis, D.W. ; Galvin, A.B. ; Whittlesey, P.L. ; Rahmati, A. ; Zesta, E. ; Scolini, Camilla ; Moldwin, M.
The Need for Near-Earth Multi-Spacecraft Heliospheric Measurements and an Explorer Mission to Investigate Interplanetary Structures and Transients in the Near-Earth Heliosphere
 Space Science Reviews, 220 issue 7, pp. 73 (2024). <https://doi.org/10.1007/s11214-024-01108-8>
- [71] Lugaz, N. ; Zhuang, B. ; Scolini, Camilla ; Al-Haddad, N. ; Farrugia, C.J. ; Winslow, R.M. ; Regnault, F. ; Möstl, C. ; Davies, E.E. ; Galvin, A.B.
The Width of Magnetic Ejecta Measured near 1 au: Lessons from STEREO-A Measurements in 2021–2022
 The Astrophysical Journal, 962 issue 2, pp. 193 (2024). <https://doi.org/10.3847/1538-4357/ad17b9>
- [72] Magnus, E. ; Groenewegen, M.A.T. ; Girardi, L. ; Pastorelli, G. ; Marigo, P. ; Boyer, M.
Calibration of the JAGB method for the Magellanic Clouds and Milky Way from Gaia DR3, considering the role of oxygen-rich AGB stars
 Astronomy and Astrophysics, 691, pp. A350 (2024). <https://doi.org/10.1051/0004-6361/202450677>
- [73] Maharana, A. ; Cramer, W.D. ; Samara, E. ; Scolini, C. ; Raeder, J. ; Poedts, S.
Employing the coupled EUHFORIA-OpenGGCM model to predict CME geoeffectiveness
 Space Weather, 22 issue 5, pp. p.e2023SW003715 (2024). <https://doi.org/10.1029/2023SW003715>
- [74] Maharana, A. ; Isavnin, A. ; Scolini, C. ; Wijssen, N. ; Rodriguez, L. ; Mierla, M. ; Magdalenic, J. ; Poedts, S.
Implementation and validation of the FRi3D flux rope model in EUHFORIA (Corrigendum)
 Advances in Space Research (2024). <https://doi.org/10.1016/j.asr.2024.03.044>
- [75] Maharana, A ; Linan, L ; Poedts, S ; Magdalenic, J.
Toroidal modified Miller-Turner CME model in EUHFORIA: Validation and comparison with flux rope and spheromak
 Astronomy & Astrophysics, 691, pp. 27 (2024). <http://dx.doi.org/10.1051/0004-6361/202450459>
- [76] Maharana, Anwasha ; Isavnin, Alexey ; Scolini, Camilla ; Wijssen, Nicolas ; Rodriguez, Luciano ; Mierla, Marilena ; Magdalenic, Jasmina ; Poedts, Stefaan
Corrigendum to "Implementation and validation of the FRi3D flux rope model in EUHFORIA" [Adv. Space Res. 70(6) (2022) 1641–1662]
 Advances in Space Research, 73 issue 12, pp. 6310-6310 (2024). <http://dx.doi.org/10.1016/j.asr.2024.03.044>
- [77] Mahy, L
Identifying Quiescent Compact Objects in Massive Galactic Single-lined Spectroscopic Binaries
 Bulletin de la Société Royale des Sciences de Liège, 93 issue 2, pp. 437-444 (2024).
<http://dx.doi.org/10.25518/0037-9565.11741>

- [78] Majumdar, Satabdwa ; D'Huys, Elke ; Mierla, Marilena ; Vashishtha, Nitin ; Talpeanu, Dana-Camelia ; Banerjee, Dipankar ; Reiss, Martin A.
Probing Velocity Dispersion Inside Coronal Mass Ejections: New Insights on Their Initiation
The Astrophysical Journal Letters, 970 issue 1 (2024). <http://dx.doi.org/%2010.3847/2041-8213/ad5da5>
- [79] Mandal, Sudip ; Peter, Hardi ; Klimchuk, James ; Solanki, Sami K. ; Chitta, Lakshmi Pradeep ; Aznar Cuadrado, Regina ; Schühle, Udo ; Teriaca, Luca ; Berghmans, David ; Verbeeck, Cis ; Auchère, Frederic ; Stegen, Koen
Investigating coronal loop morphology and dynamics from two vantage points
Astronomy & Astrophysics, 682, pp. id.L9 (2024). <http://dx.doi.org/10.1051/0004-6361/202348776>
- [80] Merle, T.
Dancing with the stars: a review on stellar multiplicity
Bulletin de la Société Royale des Sciences de Liège, 93 issue No 2, pp. 170--214 (2024).
<http://dx.doi.org/10.25518/0037-9565.11641>
- [81] Merle, Thibault ; Pourbaix, Dimitri ; Jorissen, Alain ; Siopis, Christos ; Van Eck, Sophie ; Van Winckel, Hans
An update of SB9 orbits using HERMES/Mercator radial velocities
Astronomy & Astrophysics, 684 issue id.A74 (2024). <http://dx.doi.org/10.1051/0004-6361/202345918>
- [82] Nazé, Yaël ; Britavskiy, Nikolay ; Labadie-Bartz, Jonathan
TESS observations of non-Be fast rotators
Astronomy & Astrophysics, 689 issue A320, pp. 17 (2024). <http://dx.doi.org/https://doi.org/10.1051/0004-6361/202450966>
- [83] Neefs, Ben ; Van Noten, Koen ; Vanneste, Kris ; Camelbeeck, Thierry
The Belgian traditional macroseismic (BTM) database of the twentieth century
Journal of Seismology (2024). <https://doi.org/10.1007/s10950-024-10266-9>
- [84] Nelson, C. J. ; Calchetti, D. ; Gandorfer, A. ; Hirzberger, J. ; Sinjan, J. ; Solanki, S. K. ; Berghmans, D. ; Strecker, H. ; Blanco, J.
A multi-instrument study of ultraviolet bursts and associated surges in AR 12957
Astronomy and Astrophysics, 691, A247 (2024). <https://doi.org/10.1051/0004-6361/202451925>
- [85] Nelson, C. J. ; Hayes, L. A. ; Müller, D. ; Musset, S. ; Freij, N. ; Auchère, F. ; Aznar Cuadrado, R. ; Barczynski, K. ; Buchlin, E. ; Harra, L. ; Long, D. M. ; Parenti, S. ; Peter, H. ; Schühle, U. ; Smith, P. ; Teriaca, L. ; Verbeeck, C. ; Zhukov, A. N. ; Berghmans, D.
Spatial distributions of EUV brightenings in the quiet-Sun
Astronomy & Astrophysics, 692 issue id. A236 (2024). <http://dx.doi.org/%2010.1051/0004-6361/202346886>
- [86] Niemela, A. ; Wijsen, N. ; Aran, A. ; Rodriguez, L. ; Magdalenic, J. ; Poedts, S.
Cannibals in PARADISE: The effect of merging interplanetary shocks on solar energetic particle events
Astrophysical Journal Letters (2024). <http://dx.doi.org/10.3847/2041-8213/ad4c70>
- [87] Nilsen, K. ; Kivi, R. ; Laine, M. ; Poyraz, Deniz ; Van Malderen, R. ; von der Gathen, P. ; Jepsen, N.
Time-varying trends from Arctic ozonesonde time series in the years 1994–2022
Nature Scientific Reports, 14 issue 1, pp. 27683 (2024). <https://doi.org/10.1038/s41598-024-75364-7>
- [88] Niyonzima, Laetitia ; Vryghem, Pauline ; Bodehou, Modeste ; Craeye, Christophe ; Le Maistre, Sébastien
Wideband Low-Profile Circularly Polarized All-Metal Antenna for Triton Exploration
18th European Conference on Antennas and Propagation (EuCAP) (2024).
<https://doi.org/10.23919/EuCAP60739.2024.10500916>
- [89] Palmerio, Erika ; Carcaboso, Fernando ; Khoo, Leng Ying ; Salman, Tarik M. ; Sánchez-Cano, Beatriz ; Lynch, Benjamin J. ; Rivera, Yeimy J. ; Pal, Sanchita ; Nieves-Chinchilla, Teresa ; Weiss, Andreas J. ; Lario, David ; Mieth, Johannes Z. D. ; Heyner, Daniel ; Stevens, Michael L. ; Romeo, Orlando M. ; Zhukov, Andrei N. ; Rodriguez, Luciano ; Lee, Christina O. ; Cohen, Christina M. S. ; Rodríguez-García, Laura ; Whittlesey, Phyllis L. ; Dresing, Nina ; Oleynik, Philipp ; Jebaraj, Immanuel C. ; Fischer, David ; Schmid, Daniel ; Richter, Ingo ; Auster, Hans-Ulrich ; Frascetti, Federico ; Mierla, Marilena
On the Mesoscale Structure of CMEs at Mercury's Orbit: BepiColombo and Parker Solar Probe Observations
The Astrophysical Journal, 963 issue 2, pp. 108 (2024). <http://dx.doi.org/10.3847/1538-4357/ad1ab4>

- [90] Pauwels, Tinne ; Reggiani, Maddalena ; Sana, Hugues ; Mahy, Laurent
Low-mass Stellar and Substellar Candidate Companions around Massive Stars in Sco OB1 and M17
The Astronomical Journal, 168 issue 5, pp. 13 (2024). <http://dx.doi.org/10.3847/1538-3881/ad6f06>
- [91] Petrova, E. ; Van Doorselaere, T. ; Berghmans, D. ; Parenti, S. ; Valori, G. ; Plowman, J.
Observations of Fan-Spine Topology by Solar Orbiter/EUI: Rotational Motions and Indications of Alfvén Waves
Astronomy and Astrophysics, 687, A13, 13 pp. (2024). <https://doi.org/10.1051/0004-6361/202348799>
- [92] Pezzini, Luca ; Zhukov1, Andrei ; Bacchini, Fabio ; Arrò, Giuseppe ; López, Rodrigo ; Micera, Alfredo ; Innocenti, Maria Elena ; Lapenta, Giovanni
Fully Kinetic Simulations of Proton-beam-driven Instabilities from Parker Solar Probe Observations
The Astrophysical Journal, 975, 37 (2024). <http://dx.doi.org/10.3847/1538-4357/ad7465>
- [93] Pham, L.B.S. ; Bingen, C. ; Piccialli, A. ; Lamort, L. ; Lefever, C. ; Yseboodt, M. ; Jonas, C.
Soapbox Science Brussels: an Outreach Platform for the Promotion of Women in Science in Belgium
Memorie della Società Astronomica Italiana (MemSAIt), 95 issue 2, pp. 46-51 (2024).
http://dx.doi.org/10.36116/MEMSAIT_95N2.2024.46
- [94] Planquart, L. ; Paladini, C. ; Jorissen, A. ; Escorza, A. ; Pantin, E. ; Drevon, J. ; Aringer, B. ; Baron, F. ; Chiavassa, A. ; Cruzalebes, P. ; Danchi, W. ; De Beck, E. ; Groenewegen, M.A.T. ; Hron, J. ; Khouri, T. ; Lopez, B. ; Lykou, F. ; Montarges, M. ; Nardetto, N. ; Ohnaka, K. ; Olofsson, H. ; Rau, G. ; Rosales, A.J. ; Sanchez-Bermudez, J. ; Scicluna, P. ; Siess, L. ; Thevenin, F. ; Van Eck, S. ; Vlemmings, W.H.T. ; Weigelt, G. ; Wittkowskiski, M.
An impressionist view of V Hydrae: When MATISSE paints Asymmetric Giant Blobs
Astronomy and Astrophysics, 687, pp. A306 (2024). <https://doi.org/10.1051/0004-6361/202348226>
- [95] Poulet, F. ; Piccioni, G. ; Langevin, Y. ; Dumesnil, C. ; Tommasi, L. ; Carlier, V. ; Filacchione, G. ; Amoroso, M. ; Arondel, A. ; D'Aversa, E. ; Barbis, A. ; Bini, A. ; Bolsée, D. ; Bousquet, P. ; Caprini, C. ; Carter, J. ; Dubois, J. -P. ; Condamine, M. ; Couturier, S. ; Dassas, K. ; Dexet, M. ; Fletcher, L. ; Grassi, D. ; Guerri, I. ; Haffoud, P. ; Larigauderie, C. ; Le Du, M. ; Mugnuolo, R. ; Pilato, G. ; Rossi, M. ; Stefani, S. ; Tosi, F. ; Vincendon, M. ; Zambelli, M. ; Arnold, G. ; Bibring, J. -P. ; Biondi, D. ; Boccaccini, A. ; Brunetto, R. ; Carapelle, A. ; Cisneros González, M. ; Hannou, C. ; Karatekin, O. ; Le Cle'ch, J. -C. ; Leyrat, C. ; Migliorini, A. ; Nathues, A. ; Rodriguez, S. ; Saggin, B. ; Sanchez-Lavega, A. ; Schmitt, B. ; Seignovert, B. ; Sordini, R. ; Stephan, K. ; Tobie, G. ; Zambon, F. ; Adriani, A. ; Altieri, F. ; Bockelée, D. ; Capaccioni, F. ; De Angelis, S. ; De Sanctis, M. -C. ; Drossart, P. ; Fouchet, T. ; Gérard, J. -C. ; Grodent, D. ; Ignatiev, N. ; Irwin, P. ; Ligier, N. ; Manaud, N. ; Mangold, N. ; Mura, A. ; Pilorget, C. ; Quirico, E. ; Renotte, E. ; Strazzulla, G. ; Turrini, D. ; Vandaele, A. -C. ; Carli, C. ; Ciarniello, M. ; Guerlet, S. ; Lellouch, E. ; Mancarella, F. ; Morbidelli, A. ; Le Mouélic, S. ; Raponi, A. ; Sindoni, G. ; Snels, M.
Moons and Jupiter Imaging Spectrometer (MAJIS) on Jupiter Icy Moons Explorer (JUICE)
Space Science Reviews , 220 issue 3 (2024). <http://dx.doi.org/10.1007/s11214-024-01057-2>
- [96] Rauw, G. ; Blomme, R. ; Nazé, Y. ; Volpi, D.
X-raying the wind-wind collisions in HD 168112 and HD 167971
Bulletin de la Société Royale des Sciences de Liège, 93 issue 3, pp. 256-261 (2024).
<http://dx.doi.org/10.25518/0037-9565.12337>
- [97] Rauw, G. ; Blomme, R. ; Nazé, Y. ; Volpi, D. ; Fernandez-Vera, S.
Ups and downs in the X-ray emission of the colliding wind binaries HD 168112 and HD 167971
Astronomy & Astrophysics, 687, pp. A197, 10 pp. (2024). <http://dx.doi.org/10.1051/0004-6361/202450158>
- [98] Reiss, Martin A. ; Muglach, Karin ; Mason, Emily ; Davies, Emma E. ; Chakraborty, Shibaji ; Delouille, Veronique ; Downs, Cooper ; Garton, Tadhg M. ; Grajeda, Jeremy A. ; Hamada, Amr ; Heinemann, Stephan G. ; Hofmeister, Stefan ; Illarionov, Egor ; Jarolim, Robert ; Krista, Larisza ; Lowder, Chris ; Verwichte, Erwin ; Arge, Charles N. ; Boucheron, Laura E. ; Foullon, Claire ; Kirk, Michael S. ; Kosovichev, Alexander ; Leisner, Andrew ; M{}{o}stl, Christian ; Turtle, James ; Veronig, Astrid
A Community Data Set for Comparing Automated Coronal Hole Detection Schemes
The Astrophysical Journal Supplement Series, 271 issue 1 (2024). <http://dx.doi.org/10.3847/1538-4365/ad1408>

- [99] Rodriguez, L. ; Shukhobodskaiia, S. ; Niemela, A. ; Maharana, A. ; Samara, E. ; Verbeke, C. ; Magdalenic, J. ; Vansintjan, R. ; Mierla, M. ; Scolini, C. ; Sarkar, R. ; Kilpua, E. ; Asvestari, E. ; Herbst, K. ; Lapenta, G. ; Chaduteau, A.D. ; Pomoell, J. ; Poedts, S.
Validation of EUHFORIA cone and spheromak coronal mass ejection models
Astronomy & Astrophysics, 689, A187, 16 pp. (2024). <https://doi.org/10.1051/0004-6361/202449530>
- [100] Royer, P. ; Merle, T. ; Dsilva, K. ; Sekaran, S. ; Van Winckel, H. ; Frémat, Y. ; Van der Swaelmen, M. ; Gebruers, S. ; Tkachenko, A. ; Laverick, M. ; Dirickx, M. ; Raskin, G. ; Hensberge, H. ; Abdul-Masih, M. ; Acke, B. ; Alonso, M. L. ; Bandhu Mahato, S. ; Beck, P. G. ; Behara, N. ; Bloemen, S. ; Buysschaert, B. ; Cox, N. ; Debosscher, J. ; De Cat, P. ; Degroote, P. ; De Nutte, R. ; De Smedt, K. ; de Vries, B. ; Dumortier, L. ; Escorza, A. ; Exter, K. ; Goriely, S. ; Gorlova, N. ; Hillen, M. ; Homan, W. ; Jorissen, A. ; Kamath, D. ; Karjalainen, M. ; Karjalainen, R. ; Lampens, P. ; Lobel, A. ; Lombaert, R. ; Marcos-Arenal, P. ; Menu, J. ; Merges, F. ; Moravveji, E. ; Nemeth, P. ; Neyskens, P. ; Ostensen, R. ; Pápics, P. I. ; Perez, J. ; Royer, S. ; Prins, S. ; Samadi-Ghadim, A. ; Sana, H. ; Sans Fuentes, A. ; Scaringi, S. ; Schmid, V. ; Siess, L. ; Siopis, C. ; Smolders, K. ; Sodor, S. ; Thoul, A. ; Triana, S. ; Vandenbussche, B. ; Van de Sande, M. ; Van De Steene, G. ; Van Eck, S. ; van Hoof, P. A. M. ; Van Marle, A. J. ; Van Reeth, T. ; Vermeylen, L. ; Volpi, D. ; Vos, J. ; Waelkens, C.
MELCHIORs: The Mercator Library of High Resolution Stellar Spectroscopy
Astronomy & Astrophysics, 681 issue A107, pp. 1-17 (2024). <http://dx.doi.org/10.1051/0004-6361/202346847>
- [101] Ruiz Lozano, Luca ; Oliva, Fabrizio ; Karatekin, Özgür ; Bellucci, Giancarlo ; Dehant, Véronique ; D'Aversa, Emiliano ; Carrozzo, F. Giacomo ; Schmidt, Frédéric ; Cruz Mermy, Guillaume ; Thomas, Ian R. ; Vandaele, Ann Carinne ; Daerden, Frank ; Ristic, Bojan ; Patel, Manish R., ; López-Moreno, J.J.
Observation of the Southern Polar cap during MY34-36 with ExoMars-TGO NOMAD LNO
Icarus, Volume 410 issue Ices in the Solar System; origin, evolution and distribution (2024).
<https://doi.org/10.1016/j.icarus.2023.115698>
- [102] Ryan, D. F. ; Laube, S. ; Nicula, B. ; Krucker, S. ; Maloney, S. A. ; Battaglia, A. F. ; Warmuth, A. ; Csillaghy, A. ; Müller, D.
3D evolution of a solar flare thermal X-ray loop-top source
Astronomy & Astrophysics, 681 issue A61 (2024). <https://doi.org/10.1051/0004-6361/202347212>
- [103] Samara, E. ; Arge, C. N. ; Pinto, R. F. ; Magdalenic, J. ´ ; Wijzen, N. ; Stevens, M. L. ; Rodriguez, L. ; Poedts, S.
Calibrating the WSA Model in EUHFORIA Based on Parker Solar Probe Observations
The Astrophysical Journal, Volume 971, Number 1, pp. 17 (2024). <https://doi.org/10.3847/1538-4357/ad53c6>
- [104] Sana, H. ; Tramper, F. ; Abdul-Masih, M. ; Blomme, R. ; Dsilva, K. ; Maravelias, G. ; Martins, L. ; Mehner, A. ; Wofford, A. ; Banyard, G. ; Barbosa, C. L. ; Bestenlehner, J. ; Hawcroft, C. ; John Hillier, D. ; Todt, H. ; Larkin, C. J. K. ; Mahy, L. ; Najarro, F. ; Ramachandran, V. ; Ramírez-Tannus, M. C. ; Rubio-Díez, M. M. ; Sander, A. A. C. ; Shenar, T. ; Vink, J. S. ; Backs, F. ; Brands, S. A. ; Crowther, P. ; Decin, L. ; de Koter, A. ; Hamann, W. -R. ; Kehrig, C. ; Kuiper, R. ; Oskinova, L. ; Pauli, D. ; Sundqvist, J. ; Verhamme, O. ; Xshoot-U Collaboration
X-Shooting ULLYSES: Massive stars at low metallicity. II. DRI: Advanced optical data products for the Magellanic Clouds
Astronomy & Astrophysics, 688, pp. A104, 22 pp. (2024). <http://dx.doi.org/10.1051/0004-6361/202347479>
- [105] Santos, A. ; Achilleos, N. ; Millas, Dimitrios ; Dunn, W. ; Guio, P. ; Arridge, C.
Characterizing the magnetic and plasma environment upstream of Ganymede
Journal of Geophysical Research: Space Physics, 129 issue 10, pp. e2024JA032689 (2024).
<https://doi.org/10.1029/2024JA032689>
- [106] Sarkar, Mrinmoy ; Joshi, Santosh ; De Cat, Peter
Amplitude Modulation in a δ Scuti star HD 118660
Bulletin de la Société Royale des Sciences de Liège, 93 issue 2, pp. 285--293 (2024).
<http://dx.doi.org/10.25518/0037-9565.11678>
- [107] Sarkar, Mrinmoy ; Joshi, Santosh ; Dupret, Marc-Antoine ; Trust, Otto ; De Cat, Peter ; Semenko, Eugene ; Lampens, Patricia ; Goswami, Aruna ; Mkrkichian, David ; Karinkuzhi, Drisya ; Yakunin, Ilya ; Gupta, Archana

The pulsating variable HD 118660 through the magnifying glass of asteroseismology. TESS photometry
Monthly Notices of the Royal Astronomical Society, 534 issue 4, pp. 3211--3220 (2024).
<http://dx.doi.org/10.1093/mnras/stae2258>

- [108] Scolini, Camilla ; Lugaz, Noé ; Winslow, Réka M. ; Farrugia, Charles J. ; Magyar, Norbert ; Bacchini, Fabio
On the Role of Alfvénic Fluctuations as Mediators of Coherence within Interplanetary Coronal Mass Ejections: Investigation of Multi-spacecraft Measurements at 1 au
The Astrophysical Journal, 961 issue 1 (2024). <https://doi.org/10.3847/1538-4357/ad0ed1>
- [109] Scolini, Camilla ; Palmerio, E.
The spheroid CME model in EUHFORIA
Journal of Space Weather and Space Climate, 14, pp. 13 (2024). <https://doi.org/10.1051/swsc/2024011>
- [110] Shenar, T. ; Bodensteiner, J. ; Sana, H. ; Crowther, P. A. ; Lennon, D. J. ; Abdul-Masih, M. ; Almeida, L. A. ; Backs, F. ; Berlanas, S. R. ; Bernini-Peron, M. ; Bestenlehner, J. M. ; Bowman, D. M. ; Bronner, V. A. ; Britavskiy, N. ; de Koter, A. ; de Mink, S. E. ; Deshmukh, K. ; Evans, C. J. ; Fabry, M. ; Gieles, M. ; Gilkis, A. ; González-Torà, G. ; Gräfener, G. ; Göteborg, Y. ; Hawcroft, C. ; Hénault-Brunet, V. ; Herrero, A. ; Holgado, G. ; Janssens, S. ; Johnston, C. ; Josiek, J. ; Justham, S. ; Kalari, V. M. ; Katabi, Z. Z. ; Keszthelyi, Z. ; Klencki, J. ; Kubát, J. ; Kubátová, B. ; Langer, N. ; Lefever, R. R. ; Ludwig, B. ; Mackey, J. ; Mahy, L. ; Maíz Apellániz, J. ; Mandel, I. ; Maravelias, G. ; Marchant, P. ; Menon, A. ; Najarro, F. ; Oskinova, L. M. ; O'Grady, A. J. G. ; Ovadia, R. ; Patrick, L. R. ; Pauli, D. ; Pawlak, M. ; Ramachandran, V. ; Renzo, M. ; Rocha, D. F. ; Sander, A. A. C. ; Sayada, T. ; Schneider, F. R. N. ; Schootemeijer, A. ; Schösser, E. C. ; Schürmann, C. ; Sen, K. ; Shahaf, S. ; Simón-Díaz, S. ; Stoop, M. ; Toonen, S. ; Tramper, F. ; van Loon, J. Th. ; Valli, R. ; van Son, L. A. C. ; Vigna-Gómez, A. ; Villaseñor, J. I. ; Vink, J. S. ; Wang, C. ; Willcox, R.
Binarity at LOw Metallicity (BLOeM): A spectroscopic VLT monitoring survey of massive stars in the SMC
Astronomy & Astrophysics, 690 issue A289, pp. 22 (2024). <http://dx.doi.org/10.1051/0004-6361/202451586>
- [111] Shevchuk, M. ; Melnik, V. ; Brazhenko, A. ; Dorovskyy, V. ; Frantsuzenko, A. ; Poedts, S. ; Magdalenic, Jasmina
Polarization properties of the decameter spikes
Frontiers in Astronomy and Space Sciences, 11, pp. 1396326 (2024).
<https://doi.org/10.3389/fspas.2024.1396326>
- [112] Sicignano, T. ; Ripepi, V. ; Marconi, M. ; Molinaro, R. ; Bhardwaj, A. ; Cioni, M.-R.L. ; de Grijs, R. ; Storm, J. ; Groenewegen, M.A.T. ; Ivanov, V.D. ; De Somma, G.
The VMC Survey – L. Type II Cepheids in the Magellanic Clouds: Period-Luminosity relations in the near-infrared bands
Astronomy and Astrophysics, 685, pp. A41 (2024). <https://doi.org/10.1051/0004-6361/202348650>
- [113] Smit, H.G. ; Poyraz, Deniz ; Van Malderen, R. ; Thompson, A.M. ; Tarasick, D.W. ; Stauffer, R.M. ; Johnson, B.J. ; Kollonige, D.E.
New insights from the Jülich Ozone Sonde Intercomparison Experiment: calibration functions traceable to one ozone reference instrument
Atmospheric Measurement Techniques, 17 issue 1, pp. 73-112 (2024). <https://doi.org/10.5194/amt-17-73-2024>
- [114] Sorokina, Daria ; Van Doorselaere, Tom ; Talpeanu, Dana-Camelia ; Poedts, Stefaan
MHD modelling of coronal streamers and their oscillations
Astronomy & Astrophysics, 682 issue id.A168, pp. 8 (2024). <http://dx.doi.org/10.1051/0004-6361/202347623>
- [115] Stepanovic, Jabuk ; Sermeus, Jan ; Claes, Sandy
Revealing Incomplete Data through Scientific Visualizations in an Immersive Dome Experience
IMX '24: Proceedings of the 2024 ACM International Conference on Interactive Media Experiences (2024).
<http://dx.doi.org/10.1145/3639701.3656305>
- [116] Stoop, Mitchel ; de Koter, Alex ; Kaper, Lex ; Brands, Sarah ; Portegies Zwart, Simon ; Sana, Hugues ; Stoppa, Fiorenzo ; Gieles, Mark ; Mahy, Laurent ; Shenar, Tomer ; Guo, Difeng ; Nelemans, Gijs ; Rieder, Steven
Two waves of massive stars running away from the young cluster R136
Nature, 634 issue 8035, pp. 809-812 (2024). <http://dx.doi.org/10.1038/s41586-024-08013-8>

- [117] Svennevig, K. ; Hicks, S.P. ; Forbriger, T. ; Lecocq, T. ; Widmer-Schmidrig, R. ; Mangeney, A. ; Hibert, C. ; Korsgaard, N.J. ; Lucas, A. ; Satriano, C. ; Anthony, R.E. ; Mordret, A. ; Schippkus, S. ; Rysgaard, S. ; Boone, W. ; Gibbons, S.J. ; Cook, K.L. ; Glimsdal, S. ; Løvholt, F. ; Van Noten, Koen ; Assink, J.D. ; Marboeuf, A. ; Lomax, A. ; Vanneste, K. ; Taira, T. ; Spagnolo, M. ; De Plaen, R. ; Koelemeijer, P. ; Ebeling, C. ; Cannata, A. ; Harcourt, W.D. ; Cornwell, D.G. ; Caudron, C. ; Poli, P. ; Bernard, P. ; Larose, E. ; Stutzmann, E. ; Voss, P.H. ; Lund, B. ; Cannavo, F. ; Castro-Díaz, M.J. ; Chaves, E. ; Dahl-Jensen, T. ; Pinho Dias, N.D. ; Déprez, A. ; Develter, R. ; Dreger, D. ; Evers, L.G. ; Fernández-Nieto, E.D. ; Ferreira, A.M.G. ; Funning, G. ; Gabriel, A.-A. ; Hendrickx, M. ; Kafka, A.L. ; Keiding, M. ; Kerby, J. ; Khan, S.A. ; Dideriksen, A.K. ; Lamb, O.D. ; Larsen, T.B. ; Lipovsky, B. ; Magdalena, I. ; Malet, J.-P. ; Myrup, M. ; Rivera, L. ; Ruiz-Castillo, E. ; Wetter, S. ; Wirtz, B.
A rockslide-generated tsunami in a Greenland fjord rang Earth for 9 days
Science, 385, pp. 1196–1205 (2024). <http://dx.doi.org/10.1126/science.adm9247>
- [118] Torres-Orozco, Rafael ; Capra, Lucia ; Márquez-Ramírez, Víctor H. ; Sosa-Ceballos, Giovanni ; De Plaen, Raphael ; Cid, Héctor E. ; Sulpizio, Roberto ; Arámbula-Mendoza, Raúl
Andesite magma genesis, conduit dynamics and variable decompression from shallow reservoirs drive contrasting PDC events at Volcán de Colima, Mexico
Journal of Volcanology and Geothermal Research, 453 (2024).
<http://dx.doi.org/10.1016/j.jvolgeores.2024.108143>
- [119] Valantinas, A ; Thomas, N. ; Pommerol, A. ; Karatekin, O. ; Ruiz Lozano, L. ; Senel, C. B. ; Temel, O. ; Hauber, E. ; Tirsch, D. ; Bickel, V. T. ; Munaretto, G. ; Pajola, M. ; Oliva, F. ; Schmidt, F. ; Thomas, I. ; McEwen, A. S ; Almeida, M. ; Read, M. ; Rangarajan, V. G. ; El-Maarry, M. R. ; Re, C. ; Carrozzo, F. G. ; D'Aversa, E. ; Daerden, F. ; Ristic, B. ; Patel, M. R. ; Bellucci, G. ; Lopez-Moreno, J. J. ; Vandaele, A. C. ; Cremonese, G.
Evidence for transient morning water frost deposits on the Tharsis volcanoes of Mars
Nature Geoscience, 17 issue 7, pp. 608-616 (2024). <http://dx.doi.org/10.1038/s41561-024-01457-7>
- [120] Valentino, A. ; Magdalenic, Jasmina
Modelling non-radially propagating coronal mass ejections and forecasting the time of their arrival at Earth
Astronomy & Astrophysics, 690 issue A137 (2024). <https://doi.org/10.1051/0004-6361/202449521>
- [121] Van Hoolst, Tim ; et, al
Geophysical characterization of the interiors of Ganymede, Callisto and Europa by ESA's JUPITER ICy moons Explore
Space Science Reviews, 220 issue 53, pp. 1-73 (2024). <http://dx.doi.org/10.1007/s11214-024-01085-y>
- [122] Vanden Broeck, Grégory ; Bechet, Sabrina ; Clette, Frédéric ; Rauw, Gregor ; Schröder, Klaus-Peter ; Mittag, Marco
Relationship between TIGRE solar S-index and USET Ca II K full disk images
Astronomy & Astrophysics, 689, pp. A95 (2024). <http://dx.doi.org/10.1051/0004-6361/202450125>
- [123] Vanneste, Kris ; Neefs, Ben ; Camelbeeck, Thierry
Testing the applicability of GMPEs for the Hainaut region (Belgium) using intensity data
Bulletin of Earthquake Engineering, 22, pp. 5321-5345 (2024). <http://dx.doi.org/10.1007/s10518-024-01958-1>
- [124] Vervoort, Morgan ; Wils, Katleen ; Vanneste, Kris ; Urrutia, R. ; Pino, M. ; Kissel, C. ; De Batist, Marc ; Van Daele, Maarten
Co- and postseismic subaquatic evidence for prehistoric fault activity near Coyhaique, Aysén Region, Chile
NHSS, 24 issue 10, pp. 3401–3421 (2024). <http://dx.doi.org/10.5194/nhess-24-3401-2024>
- [125] Vrancken, Jasmine ; Abdul-Masih, Michael ; Escorza, Ana ; Menon, Athira ; Mahy, Laurent ; Marchant, Pablo
Constraining the overcontact phase in massive binary evolution: III. Period stability of known B+B and O+B overcontact systems
Astronomy & Astrophysics, 691 issue A150, pp. 11 (2024). <http://dx.doi.org/10.1051/0004-6361/202450849>
- [126] Wesson, R. ; Matsuura, Mikako ; Zijlstra, Albert A. ; Volk, Kevin ; Kavanagh, Patrick J. ; García-Segura, Guillermo ; McDonald, I. ; Sahai, Raghvendra ; Barlow, M. J. ; Cox, Nick L. J. ; Bernard-Salas, Jeronimo ; Aleman, Isabel ; Cami, Jan ; Clark, Nicholas ; Dinerstein, Harriet L. ; Justanont, K. ; Kaplan, Kyle F. ; Manchado, A. ; Peeters, Els ; Van de Steene, Griet C. ; van Hoof, Peter A. M.

JWST observations of the Ring Nebula (NGC 6720): I. Imaging of the rings, globules, and arcs
Monthly Notices of the Royal Astronomical Society, 528 issue 2, pp. 3392-3416 (2024).
<http://dx.doi.org/10.1093/mnras/stad3670>

- [127] White, Stephen M. ; Shimojo, Masumi ; Iwai, Kazumasa ; Bastian, Timothy S. ; Fleishman, Gregory D. ; Gary, Dale E. ; Magdalenic, Jasmina ; Vourlidas, Angelos
Electron Cyclotron Maser Emission and the Brightest Solar Radio Bursts
The Astrophysical Journal, 969 issue 1, pp. 11 (2024). <http://dx.doi.org/10.3847/1538-4357/ad4640>
- [128] Worley, C. C. ; Smiljanic, R. ; Magrini, L. ; Frasca, A. ; Franciosini, E. ; Montes, D. ; Feuillet, D. K. ; Taberner, H. M. ; Hernández, J. I. González ; Villanova, S. ; Mikolaitis, Š. ; Lind, K. ; Tautvaišienė, G. ; Casey, A. R. ; Korn, A. J. ; Bonifacio, P. ; Soubiran, C. ; Caffau, E. ; Guiglion, G. ; Merle, T. ; Hourihane, A. ; Gonneau, A. ; François, P. ; Randich, S. ; Gilmore, G. ; Lewis, J. R. ; Murphy, D. N. A. ; Jeffries, R. D. ; Kopusov, S. E. ; Blomme, R. ; Lanzafame, A. C. ; Bensby, T. ; Bragaglia, A. ; Alfaro, E. J. ; Walton, N. A. ; Vallenari, A. ; Prusti, T. ; Biazzo, K. ; Jofré, P. ; Zaggia, S. ; Heiter, U. ; Marfil, E. ; Jiménez-Esteban, F. ; Albarrán, M. L. Gutiérrez ; Morbidelli, L.
The Gaia-ESO Survey: The DR5 analysis of the medium-resolution GIRAFFE and high-resolution UVES spectra of FGK-type stars
Astronomy & Astrophysics, 684 issue id.A148 (2024). <http://dx.doi.org/10.1051/0004-6361/202347558>
- [129] Yates, A.S. ; Caudron, C. ; Mordret, A. ; Lesage, P. ; Pinel, V. ; Lecocq, T. ; Miller, C.A. ; Lamb, O.D. ; Fournier, N.
Seasonal Snow Cycles and Their Possible Influence on Seismic Velocity Changes and Eruptive Activity at Ruapehu Volcano, New Zealand
Journal of Geophysical Research: Solid Earth, 129 issue e2024JB029568 (2024).
<http://dx.doi.org/10.1029/2024JB029568>
- [130] Yerlès, Matéo ; Schifano, Luca ; Dewitte, Steven ; Thienpont, Hugo ; Smeesters, Lien
Cubesat multispectral space-based imaging spectrometer enhancing climate change monitoring
SPIE, 13019, pp. 206-211 (2024). <http://dx.doi.org/10.1117/12.3017992>
- [131] Yordanova, E. ; Temmer, M. ; Dumbović, M. ; Scolini, C. ; Paouris, E. ; Werner, A. L. E. ; Dimmock, A. P. ; Sorriso-Valvo, L.
Refined Modeling of Geoeffective Fast Halo CMEs During Solar Cycle 24
Space Weather, 22 issue 1 (2024). <https://doi.org/10.1029/2023SW003497>
- [132] Yseboodt, Marie ; Baland, Rose-Marie ; Le Maistre, Sébastien
Comparison of Mars rotation angle models
IAU Symposium, 382, pp. 198-204 (2024). <http://dx.doi.org/10.1017/S174392132300409X>
- [133] Zeng, G. ; Querel, R. ; Shiona, H. ; Poyraz, D. ; Van Malderen, R. ; Geddes, A. ; Smale, P. ; Smale, D. ; Robinson, J. ; Morgenstern, O.
Analysis of a newly homogenised ozonesonde dataset from Lauder, New Zealand
Atmospheric Chemistry and Physics, 24 issue 10, pp. 6413-6432 (2024). <https://doi.org/10.5194/acp-24-6413-2024>

Non-Refereed Publications

- [134] Blomme, R. ; Daflon, S. ; Gebran, M. ; Herrero, A. ; Lobel, A. ; Mahy, L. ; Martins, F. ; Morel, T. ; Berlanas, S. R. ; Gosset, E. ; Maíz Apellániz, J. ; GES Working Group 13
Hot stars in the Gaia-ESO Survey
Massive Stars Near and Far. Proceedings of the International Astronomical Union, 361, pp. 95-96 (2024).
<https://doi.org/10.1017/S1743921322002253>
- [135] Bodensteiner, J. ; Sana, H. ; Mahy, L. ; Shenar, T. ; Banyard, G. ; Wang, C.
Near and far: a hunt for binary-interaction products
Massive Stars Near and Far, Edited by J. Mackey, J.S. Vink and N. St-Louis. Proceedings of the International Astronomical Union, held 8-13 May 2022 in Ballyconnell, Ireland. Cambridge University Press, 2024, 361, pp. 299-301 (2024). <http://dx.doi.org/10.1017/S1743921322002204>
- [136] Bruyninx, Carine ; Brockmann, Elmar ; Kenyeres, Ambrus ; Legrand, Juliette ; Liwosz, Tomasz ; Pacione, Rosa ; Söhne, Wolfgang ; Völksen, Christof
EUREF Permanent Network Regional Network Associate Analysis Centre Technical Report 2023
International GNSS Service - Technical Report 2023, pp. 139-146 (2024). <http://dx.doi.org/10.48350/191991>
- [137] Bruyninx, Carine ; Pedersen, Helle
Geo-INQUIRE Horizon Europe project. D2.4 WP2 Research infrastructures coordination progress report with access and KPI monitoring
Deliverable of Geo-INQUIRE project (2024). <http://dx.doi.org/https://doi.org/10.48440/exwk-n055>
- [138] Defraigne, Pascale ; Meynadier, Frédéric ; Tavella, Patrizia
Looking for a lunar reference timescale
Proceedings of the Journées Systèmes de Référence, Nice, 2023 (2024).
<https://journées2023.sciencesconf.org/488586/document>
- [139] Fabry, M. ; Hawcroft, C. ; Frost, A. J. ; Mahy, L. ; Marchant, P. ; Le Bouquin, J.-B. ; Sana, H.
Constraining the dynamical mass of the massive binary 9 Sagittarii
Massive Stars Near and Far, Edited by J. Mackey, J.S. Vink and N. St-Louis. Proceedings of the International Astronomical Union, held 8-13 May 2022 in Ballyconnell, Ireland. Cambridge University Press, 2024, 361, pp. 305-306 (2024). <http://dx.doi.org/10.1017/S174392132200206X>
- [140] Frémat, Y.
Astrophysical Parameters associated to Hot stars in Gaia DR3
EES2023: Proceedings of the Evry Schatzman School, eds. Babusiaux, C. and Reylé, C., pp. 59-69 (2024).
<http://dx.doi.org/10.48550/arXiv.2411.04887>
- [141] Frost, A. J. ; Bodensteiner, J. ; Rivinius, T. ; Baade, D. ; Merand, A. ; Selman, F. ; Abdul-Masih, M. ; Banyard, G. ; Bordier, E. ; Dsilva, K. ; Hawcroft, C. ; Mahy, L. ; Reggiani, M. ; Shenar, T. ; Cabezas, M. ; Hadrava, P. ; Heida, M. ; Klement, R. ; Sana, H.
HR 6819 - a post-interaction binary system originally thought to be a triple system containing a black hole
Massive Stars Near and Far, Edited by J. Mackey, J.S. Vink and N. St-Louis. Proceedings of the International Astronomical Union, held 8-13 May 2022 in Ballyconnell, Ireland. Cambridge University Press, 2024, 361, pp. 307-310 (2024). <http://dx.doi.org/10.1017/S1743921322002216>
- [142] Hakim, Kaustubh
Positive Weathering Feedback Compensates Carbonates at Shallow Ocean Depths
Proceedings of the International Astronomical Union, 382 issue Complex Planetary Systems II: Latest Methods for an Interdisciplinary Approach, pp. 123-125 (2024).
<http://dx.doi.org/10.1017/S1743921323004957>
- [143] Hawcroft, C. ; Sana, H. ; Mahy, L. ; Sundqvist, J. O. ; Abdul-Masih, M. ; Bouret, J. C. ; Brands, S. A. ; de Koter, A. ; Driessen, F. A. ; Puls, J.
New empirical mass-loss rates and clumping properties of massive stars
Massive Stars Near and Far, Edited by J. Mackey, J.S. Vink and N. St-Louis. Proceedings of the International Astronomical Union, held 8-13 May 2022 in Ballyconnell, Ireland. Cambridge University Press, 2024, 361, pp. 168-173 (2024). <http://dx.doi.org/10.1017/S1743921322003234>

- [144] Lanthermann, C. ; Le Bouquin, J.-B. ; Sana, H. ; Mérand, A. ; Monnier, J. ; Perraut, K. ; Frost, A. J. ; Mahy, L. ; Gossett, E. ; De Becker, M. ; Kraus, S. ; Anugu, N ; Davies, C. L. ; Ennis, J. ; Gardner, T. ; Labdon, A. ; Setterholm, B. ; Ten Brummelaar, T. ; Schaefer, G.
Multiplicity of northern bright O-type stars with optical long baseline interferometry. Results of the pilot study
American Astronomical Society, AAS Meeting #243, id. 447.05. Bulletin of the American Astronomical Society, 56 (2024).
- [145] Lecocq, T. ; Debeir, O. ; De Plaen, R. ; Lemenkova, P.
SeismoStorm Final Report
BELSPO (2024). https://www.belspo.be/belspo/brain2-be/projects/FinalReports/SEISMOSTORM_FinRep.pdf
- [146] Mahy, L. ; Lanthermann, C. ; Gosset, E. ; Hutsemékers, D. ; Kluska, J. ; Lobel, A. ; Reggiani, M. ; Sana, H.
Multiplicity of Galactic Luminous Blue Variable stars
Massive Stars Near and Far, Edited by J. Mackey, J.S. Vink and N. St-Louis. Proceedings of the International Astronomical Union, held 8-13 May 2022 in Ballyconnell, Ireland. Cambridge University Press, 2024, 361, pp. 273-278 (2024). <http://dx.doi.org/10.1017/S1743921322002848>
- [147] Manuel Mascarenhas, Adrien ; Maurice, Lucas ; Martínez Picar, Antonio ; Marqué, Christophe
First Meteor Observations with SPADE
WGN, 52 issue 4-5, pp. 97-99 (2024). <https://www.imo.net/publications/wgn/>
- [148] Maurice, Lucas ; Manuel Mascarenhas, Adrien ; Martínez Picar, Antonio ; Marqué, Christophe
Pulse radar transmitter for the Humain BRAMS array?
WGN, 52 issue 4-5, pp. 100-102 (2024). <https://www.imo.net/publications/wgn/>
- [149] Mouhaou, Déborah ; Martínez Picar, Antonio ; Marqué, Christophe ; Gunessee, Akhil
Radio meteor echoes observation with SPADE
Proceedings of the International Meteor Conference, Redu, 31 September – 3rd August, pp. 31—33
- [150] Petitclercq, E. ; Van Noten, Koen ; Van Lysebetten, G. ; Van der Veken, J. ; Van Breusegem, M. ; Beyene, A.Y. ; Duren, Thierry ; Orban, P.
GeoCamb – Geothermal Energy Potential in Cambrian rocks focusing on public buildings. Final Report
Brussels: Belgian Science Policy Office 2024. BRAIN-be 2.0 - (Belgian Research Action through Interdisciplinary Networks), pp. 108 (2024).
- [151] Phurailatpam, Hemantakumar ; More, Anupreeta ; Narola, Harsh ; Ng, Leo ; Janquart, Justin ; Van Den Broeck, Chris ; Hannuksela, Otto Akseli ; Singh, Neha ; Keitel, David
ler : LVK (LIGO-Virgo-KAGRA collaboration) event (compact-binary mergers) rate calculator and simulator
arXiv:2407.07526 [astro-ph.IM]. <https://doi.org/10.48550/arXiv.2407.07526>
- [152] Rauer et al., many authors including Mahy L. and Merle T.
The PLATO Mission
eprint arXiv:2406.05447 (2024). <http://dx.doi.org/10.48550/arXiv.2406.05447>
- [153] Sana, H. ; Abdul-Masih, M. ; Banyard, G. ; Bodensteiner, J. ; Bowman, D. M. ; Dsilva, K. ; Eldridge, C. ; Fabry, M. ; Frost, A. J. ; Hawcroft, C. ; Janssens, S. ; Mahy, L. ; Marchant, P. ; Langer, N. ; Van Reeth, T. ; Sen, K. ; Shenar, T.
The Nature of Unseen Companions in Massive Single-Line Spectroscopic Binaries
Massive Stars Near and Far, Edited by J. Mackey, J.S. Vink and N. St-Louis. Proceedings of the International Astronomical Union, held 8-13 May 2022 in Ballyconnell, Ireland. Cambridge University Press, 2024, 361, pp. 267-272 (2024). <http://dx.doi.org/10.1017/S1743921322003180>
- [154] Trust, O. ; Jurua, E. ; De Cat, P. ; Joshi, S.
High-resolution spectroscopy of “hump and spike” stars
Proceedings of the 6th East African Astronomical Society Workshop (2024).
- [155] Van der Swaelmen, M. ; Merle, T. ; Van Eck, S. ; Jorissen, A.
New spectroscopic binaries with Gaia and the Gaia-ESO survey
Proceedings of the Annual meeting of the French Society of Astronomy and Astrophysics, pp. 339-342 (2024). <http://dx.doi.org/2024sf2a.conf..339V>

- [156] Van Noten, Koen ; De Plaen, Raphael
Bepaling van de sokkeldiepte van het Brabant Massief met behulp van seismische ruismetingen ter hoogte van de Bospoortbrug te Halle
Expertiserapport ROB-DVW 2024-01. Koninklijke Sterrenwacht van België, Ukkel., pp. 34 (2024).
- [157] Vanneste, Kris ; Onvani, Mahsa
Waveform processing in BELSHAKE, the Belgian ground-motion database
Proceedings of the 18th World Conference on Earthquake Engineering (WCEE24), Milan, Italy, pp. 12 (2024).

Datasets

- [158] Bamahry, Fikri ; Legrand, Juliette ; Bruyninx, Carine
EPOS-GNSS data quality check (update for 2024)
<https://gnssquality-epos.oma.be/DOI/ROB-EPOS-EGDM.php>
- [159] Bechet, Sabrina ; Clette, Frédéric
USET whole-disk images - L1 centered
<http://dx.doi.org/10.24414/nc7j-b391>
- [160] Clette, Frédéric ; Lefèvre, Laure
Real-time Estimated International Sunspot Number
<https://sidc.be/SILSO/datafiles>
- [161] Clette, Frédéric ; Lefèvre, Laure
12-month Sunspot Number forecasts
<https://sidc.be/SILSO/forecasts>
- [162] Clette, Frédéric ; Bechet, Sabrina ; Lemaître, Olivier ; Boulvin, Olivier ; Vanden Broeck, Grégory ; Lefèvre, Laure ; Vandekerckhove, Joan ; Bhattacharya, Shreya
USET whole-disk images - L0
https://www.sidc.be/uset/data/cameras/output_img/FTS/L0/
- [163] Clette, Frédéric ; Bechet, Sabrina ; Lemaître, Olivier ; Boulvin, Olivier ; Vanden Broeck, Grégory ; Lefèvre, Laure ; Vandekerckhove, Joan ; Bhattacharya, Shreya
USET daily sunspot drawings (photosphere)
<https://www.sidc.be/uset/searchFormDrawing.php>
- [164] Gaia Collaboration ; many authors including Blomme, R., Frémat, Y., Mahy, L., Lobel, A. and Pauwels, T.
VizieR Online Data Catalog: Gaia FPR. Analysis of QSO environment
VizieR Online Data Catalog (2024). <https://www.cosmos.esa.int/web/gaia/fpr>
- [165] Lefèvre, Laure ; Delouille, Véronique ; Berhgmans, David ; Clette, Frédéric
International Sunspot Number
<https://sidc.be/SILSO/datafiles>
- [166] Marqué, Christophe ; Martinez Picar, Antonio ; Magdalenic, Jasmina ; ROB, Technical team
SAFIRE light curve
<https://www.sidc.be/humain>
- [167] Marqué, Christophe ; Martinez Picar, Antonio ; Magdalenic, Jasmina ; ROB, Technical team
SPADE spectra
<https://www.sidc.be/humain>
- [168] Marqué, Christophe ; Martinez Picar, Antonio ; Magdalenic, Jasmina ; ROB, Technical team
HSRS light curves
<http://swe.ssa.esa.int/web/guest/solar-weather>
- [169] Marqué, Christophe ; Martinez Picar, Antonio ; Magdalenic, Jasmina ; ROB, Technical team
ARCAS spectra
<https://www.sidc.be/humain>
- [170] Marqué, Christophe ; Martinez Picar, Antonio ; Magdalenic, Jasmina ; ROB, Technical team
HSRS spectra
<https://www.sidc.be/humain>
- [171] Marqué, Christophe ; Martinez Picar, Antonio ; Magdalenic, Jasmina ; ROB, Technical Team
Callisto spectra
<https://www.sidc.be/humain>
- [172] Neefs, Ben ; Van Noten, Koen ; Vanneste, Kris ; Camelbeeck, Thierry
The Belgian Traditional Macroseismic (BTM) Database of the 20th Century

<http://dx.doi.org/https://doi.org/10.24414/2b5w-j029>

- [173] Pottiaux, Eric
ROB's operational quasi-real-time GNSS-based tropospheric delay estimates submitted to E-GVAP (From 1 Jan 2024 until 31 Dec 2024)
<http://dx.doi.org/10.24414/g0a5-w340>
- [174] Pottiaux, Eric
ROB's Operational World-Wide Near Real-Time (NRT) GNSS-based tropospheric delay estimates submitted to E-GVAP (From 1 Jan 2024 until 31 Dec 2024)
<http://dx.doi.org/10.24414/wyt6-xr18>
- [175] Pottiaux, Eric
Dataset ROB's Operational European Near Real-Time (NRT) GNSS-based tropospheric delay estimates submitted to E-GVAP (from 1 Jan 2024 until 31 Dec 2024)
<http://dx.doi.org/10.24414/v6a7-n161>
- [176] Pottiaux, Eric
ROB's operational final GNSS position and tropospheric delay estimates computed in the context of its E-GVAP participation (From 1 Jan 2024 until 31 Dec 2024)
<http://dx.doi.org/10.24414/sa82-av08>
- [177] Pottiaux, Eric
ROB's operational final GNSS-based tropospheric delay models, grids, and maps (from 1 Jan 2024 until 31 Dec 2024)
<http://dx.doi.org/10.24414/4wz9-2q58>
- [178] Pottiaux, Eric
ROB's operational quasi-real-time GNSS-based tropospheric delay models, grids, and maps (from 1 Jan 2024 until 31 Dec 2024)
<http://dx.doi.org/10.24414/rbcj-gn57>
- [179] Pottiaux, Eric
ROB's operational European near real-time GNSS-based tropospheric delay models, grids, and maps (from 1 Jan 2024 until 31 Dec 2024)
<http://dx.doi.org/10.24414/j0db-n505>
- [180] Vanneste, Kris ; Onvani, Mahsa
Belgian ground-motion database (BELSHAKE) flatfile
<http://dx.doi.org/10.5281/zenodo.10669582>

Other Publications

- [181] Alexandre, Pierre ; Alexandre-Lamotte, Dominique
Les tremblements de terre en Europe au Moyen Âge et à la Renaissance. Étude critique des sources et catalogue des tremblements de terre en Europe de 284 à 1550
Uccle, Belgium, Royal Observatory of Belgium (2074 pages), 2024. <http://dx.doi.org/10.24414/srvz-2k77>
- [182] de Clercq, Ewoud
Ontwikkeling van een geofysische databank van de KSB ERT-profielen
Internship thesis supervised by Vanneste, Kris; Van Noten, Koen (UGent).
- [183] Janssens, Jan
Ruimteweer in België
Nederlands Tijdschrift voor Natuurkunde, 90 issue 07, pp. 58-62 (2024).
<https://www.ntvn.nl/archief/ntvn/2024/>
- [184] Maharana, A.
Advanced CME models for improved geo-effectiveness predictions
PHD thesis supervised by Poedts, S.; Magdalenic, J.; Rodriguez, L. (KULeuven).
<https://research.kuleuven.be/portal/en/project/3E200739>
- [185] Mahy, L.
Basic stellar observables
in Encyclopedia of Astrophysics (Sc. Ed. Ilya Mandel, section editor F.R.N. Schneider).
<http://dx.doi.org/10.48550/arXiv.2412.05671>
- [186] Martin, A.
Study of intact fragile stalagmites in the Han-sur-Lesse caves to evaluate the smallest earthquake ground motions likely to break them
PhD thesis supervised by Lecocq, T.; Camelbeeck, T.; Fagel, N. (Université de Liège, Belgique).
<https://hdl.handle.net/2268/320566>
- [187] Niemela, A. E.
EUHFORIA and PARADISE: A story about CMEs shocks and particles
PHD thesis supervised by Poedts, S.; Magdalenic, J.; Rodriguez, L. (KULeuven).
<https://research.kuleuven.be/portal/en/project/3E200881>
- [188] Nowé, Sylvain
Characterization of cryo-, hydro- and volcano-seismic sources in the Vatnajökull icecap region (Iceland), from the analysis of ambient seismic noise correlograms
PhD thesis supervised by Lecocq, T.; Caudron, T. (Université libre de Bruxelles).
<http://hdl.handle.net/2013/ULB-DIPOT:oai:dipot.ulb.ac.be:2013/377392>
- [189] Pauwels, T., Bruyninx, C.
Annuaire de l'Observatoire royal de Belgique – Jaarboek van de Koninklijke Sterrenwacht van België 2025
EPO, ISBN: 0373-4900 (2025). https://www.astro.oma.be/common/pdf/ybook/yearbook_2025.pdf
- [190] Pham, L. B. S. ; Piccialli, A. ; Bingen, C. ; Yseboodt, M. ; Jonas, C.
Soapbox Science Brussels - Vrouwelijke wetenschappers in de straten van Brussel
Science Connection, 71, pp. 12-14 (2024).
https://www.belspo.be/belspo/organisation/publ/pub_ostc/sciencecon/71sci_nl.pdf
- [191] Pham, L. B. S. ; Piccialli, A. ; Bingen, C. ; Yseboodt, M. ; Jonas, C.
Soapbox Science Brussels - Des femmes scientifiques dans les rues de Bruxelles
Science Connection, 71, pp. 12-14 (2024).
https://www.belspo.be/belspo/organisation/publ/pub_ostc/sciencecon/71sci_fr.pdf
- [192] Piccialli, Arianna ; Sermeus, Jan ; Lejoly, Simon ; Claes, Sandy ; Stepanovic, Jakub ; Mahieux, Arnaud ; Lefever, Karolien ; Fratta, Stéphanie ; Vandaele, Ann Carine
Het VAMOS project

Science Connection, 71, pp. 24-27 (2024).

https://www.belspo.be/belspo/organisation/publ/pub_ostc/sciencecon/71sci_nl.pdf

- [193] Piccialli, Arianna ; Sermeus, Jan ; Lejoly, Simon ; Claes, Sandy ; Stepanovic, Jakub ; Mahieux, Arnaud ; Lefever, Karolien ; Fratta, Stéphanie ; Vandaele, Ann Carine

Le projet VAMOS

Science Connection, 71, pp. 24-27 (2024).

https://www.belspo.be/belspo/organisation/publ/pub_ostc/sciencecon/71sci_fr.pdf

- [194] Siljeström, Sandra ; Baatout, Sarah ; de Vera, Jean-Pierre ; Dehant, Veronique ; Freissinet, Caroline ; Gross, Christoph ; Lee, Natuschka M. ; Mangold, Nicolas ; Noack, Lena ; Plesa, Ana-Catalina ; Rivoldini, Attilio ; ten Kate, Inge Loes

Mars in Short: Past and Present Geology and Climate

in Mars and the Earthlings: A Realistic View on Mars Exploration and Settlement (Sc. Ed. Verseux, Cyprien and Gargaud, Muriel and Lehto, Kirsi and Viso, Michel). http://dx.doi.org/10.1007/978-3-031-66881-4_2

- [195] Van Hoolst, Tim

Verkenning van oceanen in Jupiters ijsmanen met de JUICE-sonde

In Lessen voor de XXIe eeuw: Wetenschap voor een nieuwe wereld (267-290 pages - Sc. Ed. P. d'Hoine and B. Pattyn,)

Annexe 2: Workforce

Staff Statistics

On 31 December 2024, 193 collaborators worked at the ORB-KSB, including 21 people at the Planetarium and 4 at the Royal Academy of Overseas Sciences. This number confirms the trend in increasing numbers of personnel over the last years at the ORB-KSB, but it also confirms the decrease in the number of statutory employees. Compared to last year, there was an increase of 5 contractual employees (136 compared to 131 in 2023) and a decrease of 3 statutory employees (57 compared to 60 in 2023). The mean age of the staff is 43 years, with 89% of the workers between 26 and 59 years.

Staff number by status on December 31

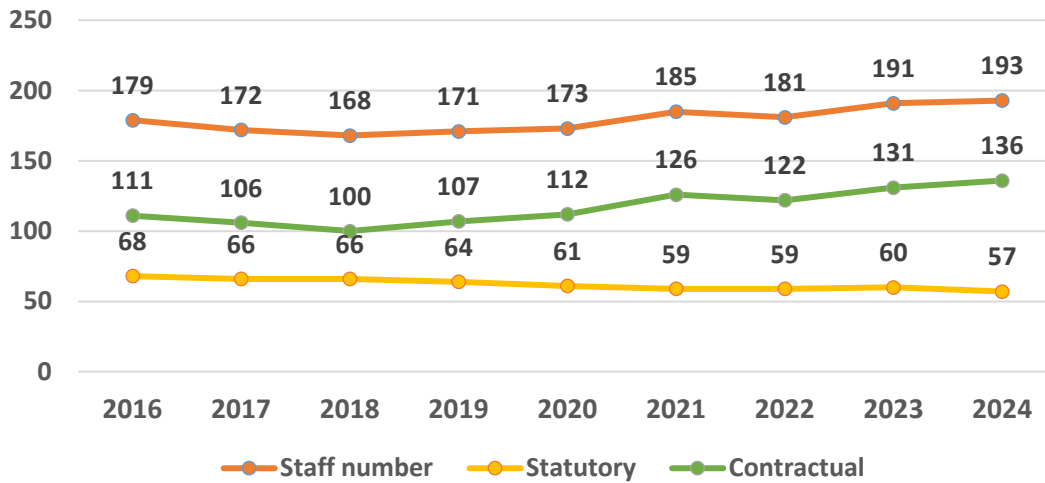


Figure 66: Credit: ORB-KSB.

Age of the staff on 31 December 2024

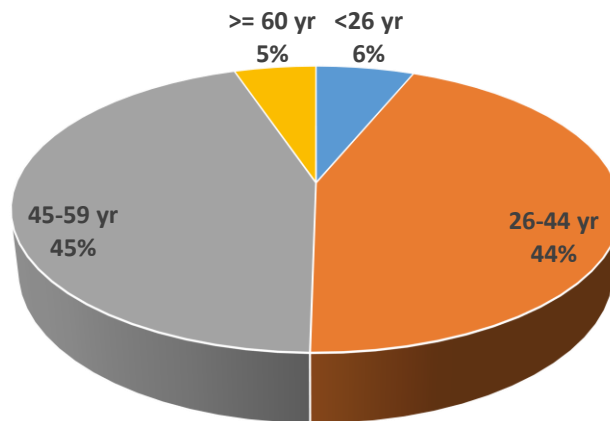


Figure 67: Credit: ORB-KSB.

The majority of the staff (70%) are contractual collaborators. This is particularly true for scientists, 82% of whom are contractuals, and for employees of level D, of whom all staff are contractual collaborators.

Staff figures by level and status on 31 December 2024

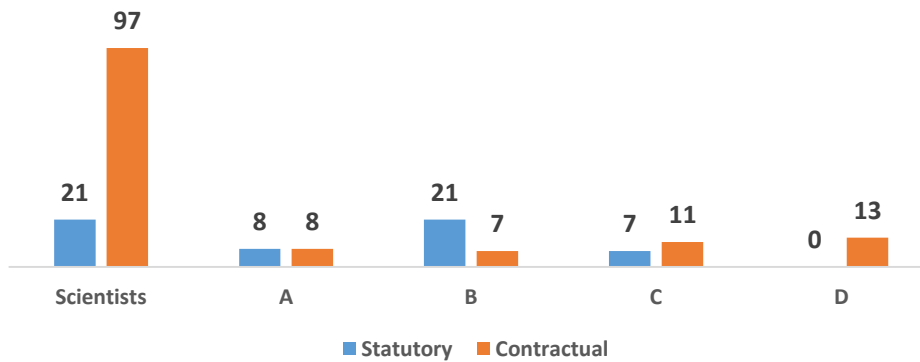


Figure 68: Credit: ORB-KSB.

The fact that more and more scientists are contractual is because scientific research is increasingly funded by external projects. Moreover, scientists make up the majority of the staff (61% in 2023), highlighting the fact that the ORB-KSB is a research institute.

Scientists and non scientists share in 2024

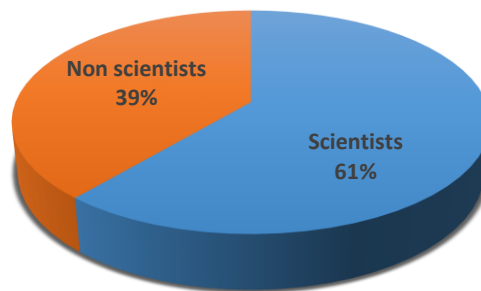


Figure 69: Credit: ORB-KSB.

Non scientific staff by level in 2024

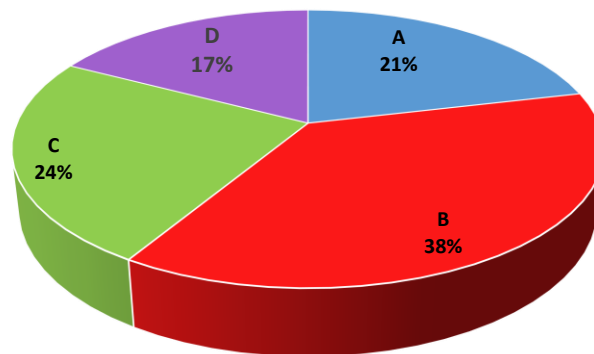
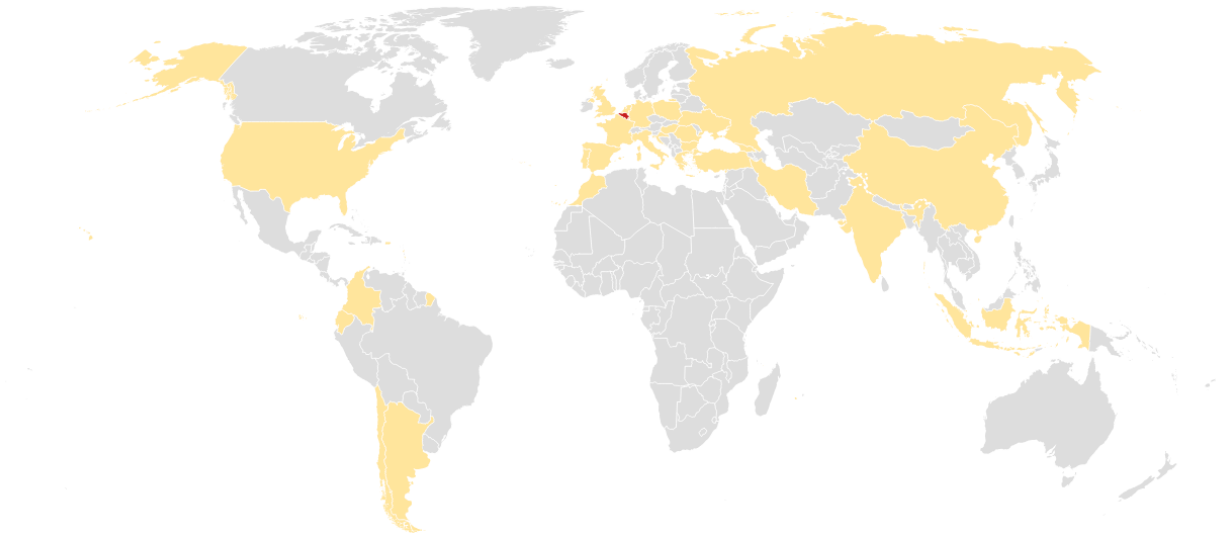


Figure 70: Credit: ORB-KSB.

A wide range of nationalities is represented within the ORB-KSB staff, with the majority (128) holding a Belgian nationality and the rest as citizens from 28 other countries. Among the scientific staff, 25 nationalities are present, compared with only 7 nationalities among the non-scientific staff. This highlights the international character of scientific research.

Nationalities of the ORB-KSB staff in 2024

- Argentina
- Belgium
- Bulgaria
- Chile
- China
- Colombia
- Croatia
- Ecuador
- France
- Georgia
- Germany
- Greece
- Hungary
- India
- Indonesia
- Iran
- Italy
- Luxembourg
- Morocco
- Netherlands
- Poland
- Portugal
- Romania
- Russia
- Spain
- Turkey
- Ukraine
- United Kingdom
- United States of America



Source: The Royal Observatory of Belgium • Created with Datawrapper

Figure 71: Credit: ORB-KSB.

Analysis by Gender

Staff's gender share on December 31

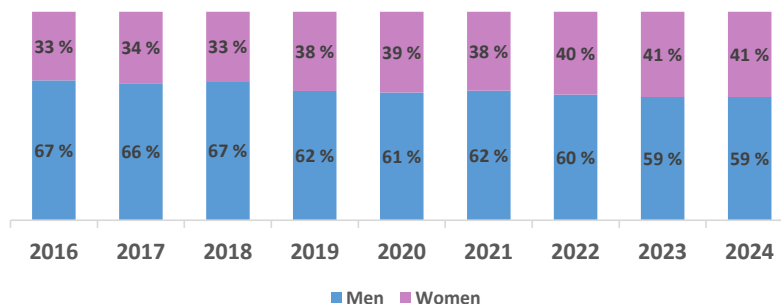


Figure 72: Credit: ORB-KSB.

On 31 December 2024, female staff constituted 41% of the employees at the ORB-KSB, which is the same proportion as in 2023. Since 2016, when only 33% of the staff was female, there is an increase of women in the workforce. This concerns mainly contractual staff where, between 2016 and 2024, female contractual staff increased by 66% (from 38 on 31 December 2016 to 63 on 31 December 2024) while male contractual staff

remained stable (73 on 31 December 2016 and 73 on 31 December 2024 with very few variations between

those dates). In contrast, the gender balance of the statutory staff has a slight decreasing trend (from 31% on 31 December 2016 to 28% on 31 December 2024).

Gender share on December 31 according to status

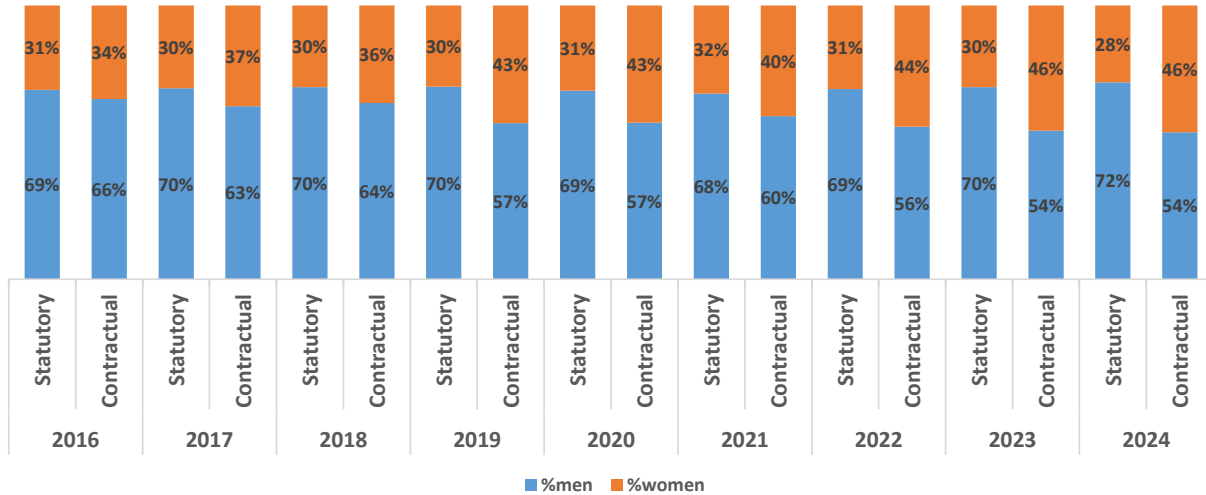


Figure 73: Credit: ORB-KSB.

When considering the staff hierarchy, we can see an inversion of women to men ratio between:

- C- and D-level workers, where women are in the majority (56% for C-level workers and 77% for D-level workers) and
- Scientists (SW), A- and B-level workers, where women only make up about one third (31% for A-level workers and 32% for B-level workers), with a slightly larger proportion for scientists (38% of scientists being women).

Gender share in 2024 according to level

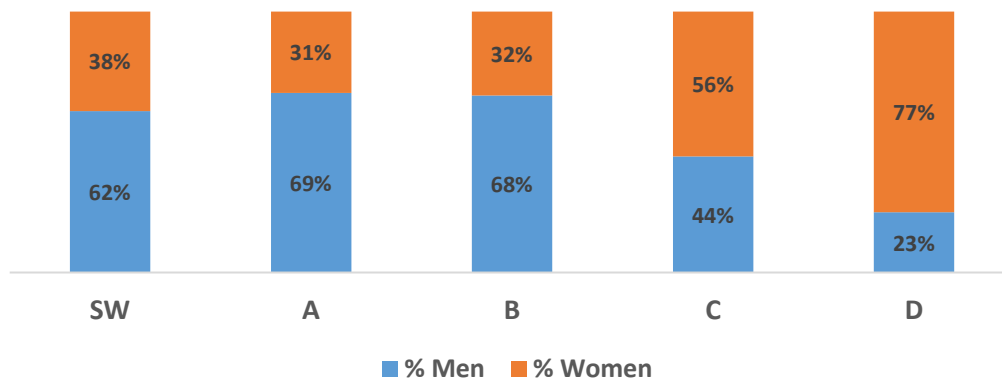


Figure 74: Credit: ORB-KSB.

When looking at the highest diploma level of the employees from a gender perspective, we see that the majority of female and male employees have a master level diploma, in accordance with the required

level for scientific research activity (62% of the female staff and 70% of the male staff). However, there is a higher proportion of the female staff with no diploma or a high-school-level diploma as their highest education level when compared to their male counterparts.

% of men and % of women with their highest diploma at a given level on 31 December 2024

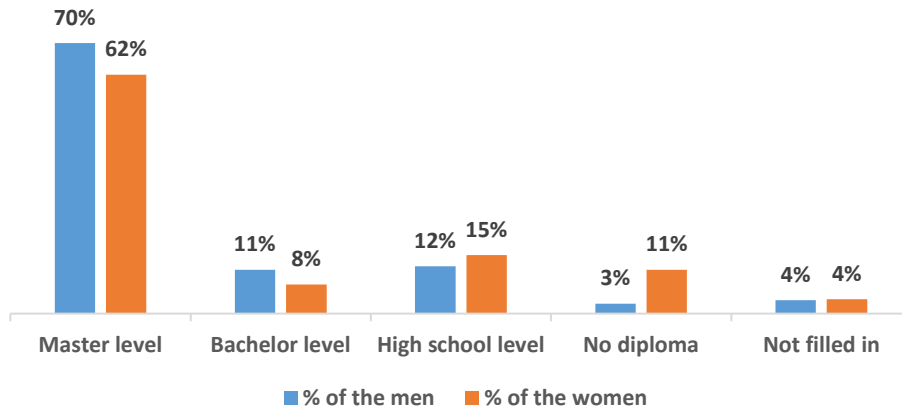


Figure 75: Credit: ORB-KSB.

The gender balance among scientists is slightly lower when compared to that of the administrative staff; on 31 December 2024, only 38% of scientists were female, while this proportion amounts to 45% for the administrative staff.

Gender share on December 31 for scientists and non scientists

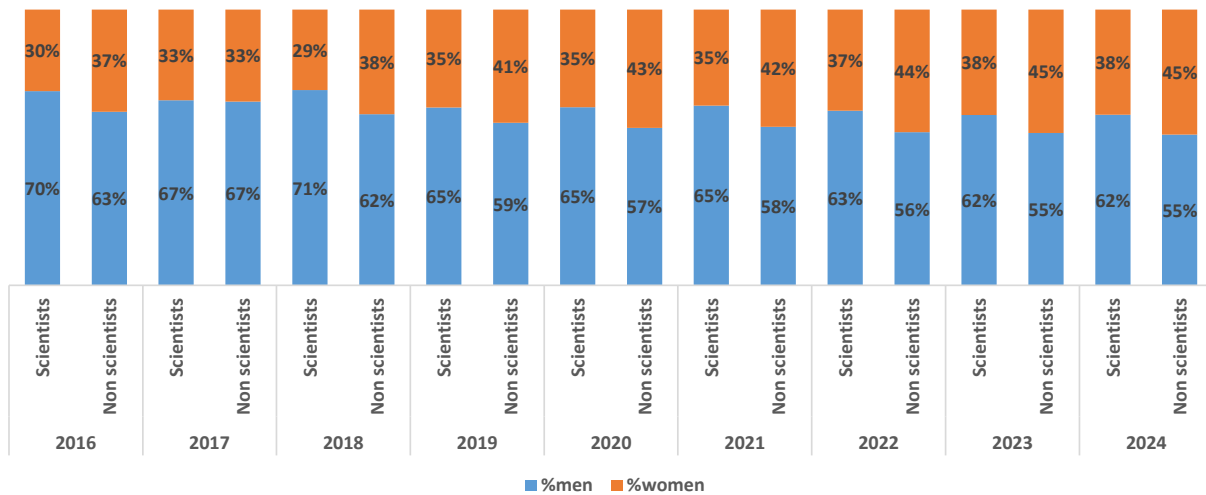


Figure 76: Credit: ORB-KSB.

A slight decrease of the female proportion of the workforce is present among the scientific statutory staff (from 33% on 31 December 2016 to 29% on 31 December 2024), while there is an increase for the scientific contractual staff in the same period (from 21% on 31 December 2016 to 40% on 31 December 2024, an increase of 86%).

Scientist's gender share on December 31 according to status

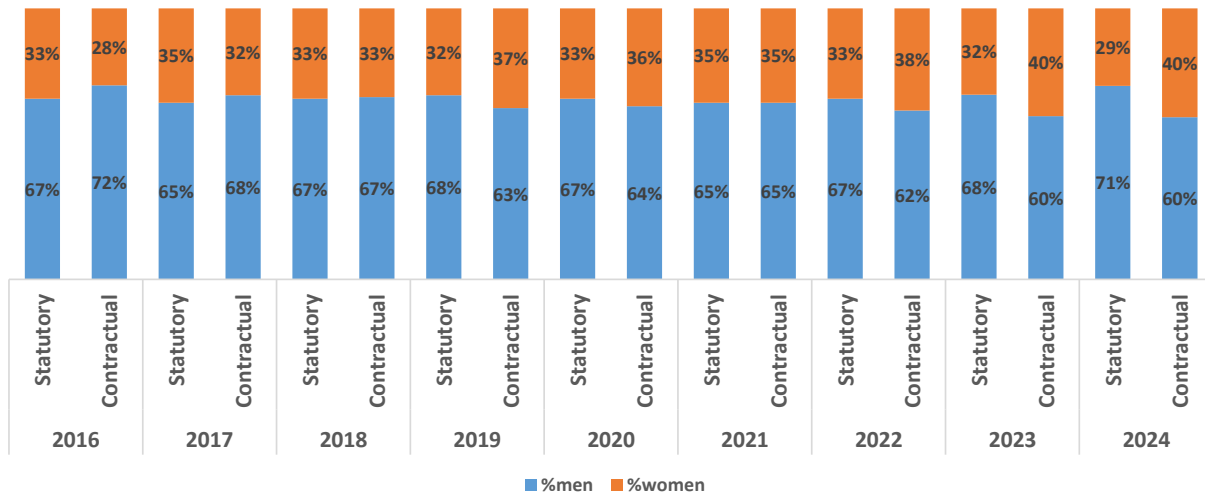


Figure 77: Credit: ORB-KSB.

Gender share on 31 December 2024 according to age

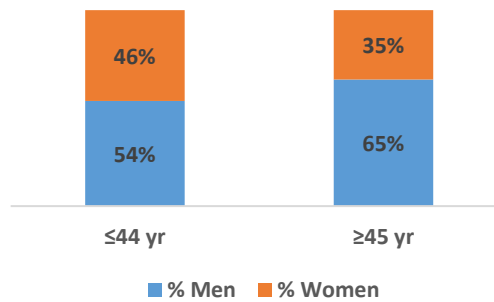


Figure 78: Credit: ORB-KSB.

The ratio of the number of male and female staff is more balanced for younger employees, with 46% of the staff younger than 44 years old being female on 31 December 2023, while only 35% of the staff older than 45 years being male.

However, for staff younger than 44 years old, the share of female staff is higher among non-scientists (65%) than among young scientists (39%). This is particularly the case for female staff at B- (60%), C- (73%) and D- (83%) levels compared to female staff in management level (A and SW, with 41% of the staff being female). For employees older than 45 years, the difference between levels and between scientists (34%) and non-scientists (35%) is much less significant, except for D-level employees (71% being female).

Gender share on 31 December 2024 for scientists and non scientists according to age

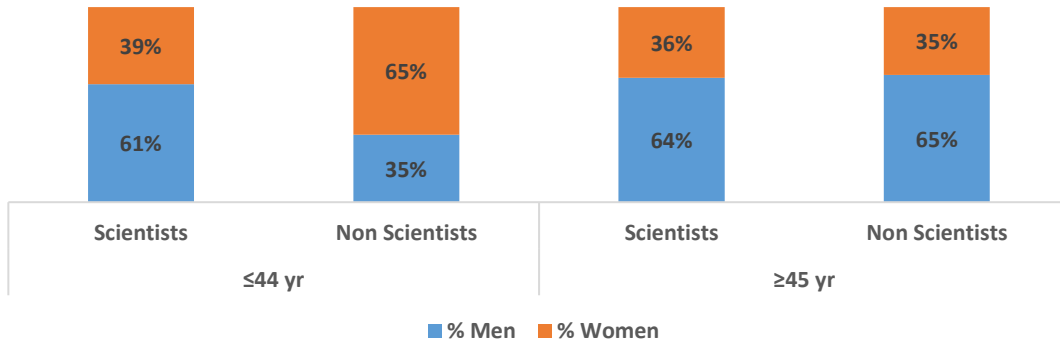


Figure 79: Credit: ORB-KSB.

Gender share on 31 December 2024 according to age and level

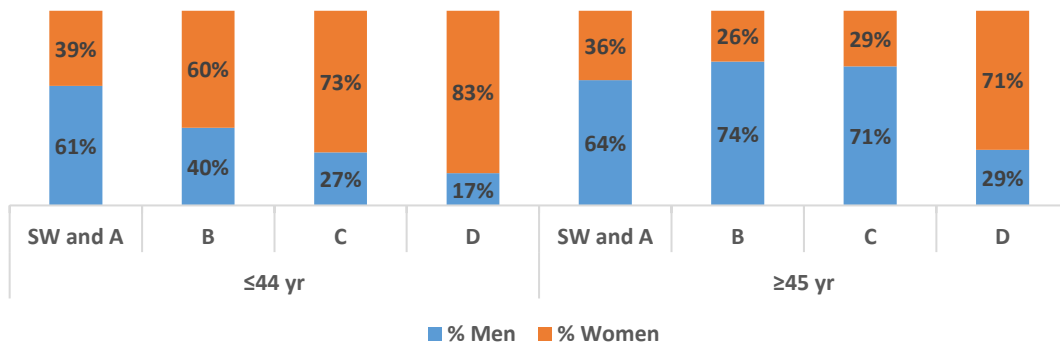


Figure 80: Credit: ORB-KSB.

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