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Observatoire royal de Belgique
Royal Observatory of Belgium

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Mensen voor Aarde en Ruimte, Aarde en Ruimte voor Mensen
Des hommes et des femmes pour la Terre et l'Espace, La Terre et l'Espace pour l'Homme

Cover illustration: *Open Doors(ROB)*

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Preface

This report describes the highlights of scientific activities and public services at the Royal Observatory of Belgium in 2014.

A list of publications and the list of personnel is included at the end.

Due to lack of means and personnel the report is only in English. A description of the most striking highlights is available in Dutch and French.

If you need more or other information on the Royal Observatory of the Belgium and/or its activities please contact rob_info@oma.be or visit our website http://www.astro.oma.be.

Ronald Van der Linden
Director General

Reference Systems and Planetology

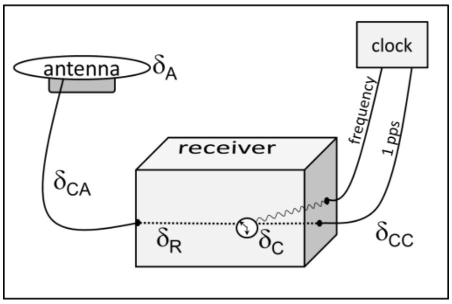
This Operational Directorate Reference Systems and Planetology contributes to the elaboration of reference systems and timescales, integrates Belgium in the international reference frames, and studies the interior, rotation, dynamics, and crustal deformation of the Earth and other terrestrial planets and moons of our solar system

The principal activities are grouped into two general themes:

1. *Space geodesy and timescales with GNSS (Global Navigation Satellite System), and*
2. *Rotation and interior structure of the Earth and other terrestrial planets and satellites.*

Space geodesy with GNSS (Global Navigation Satellite System)

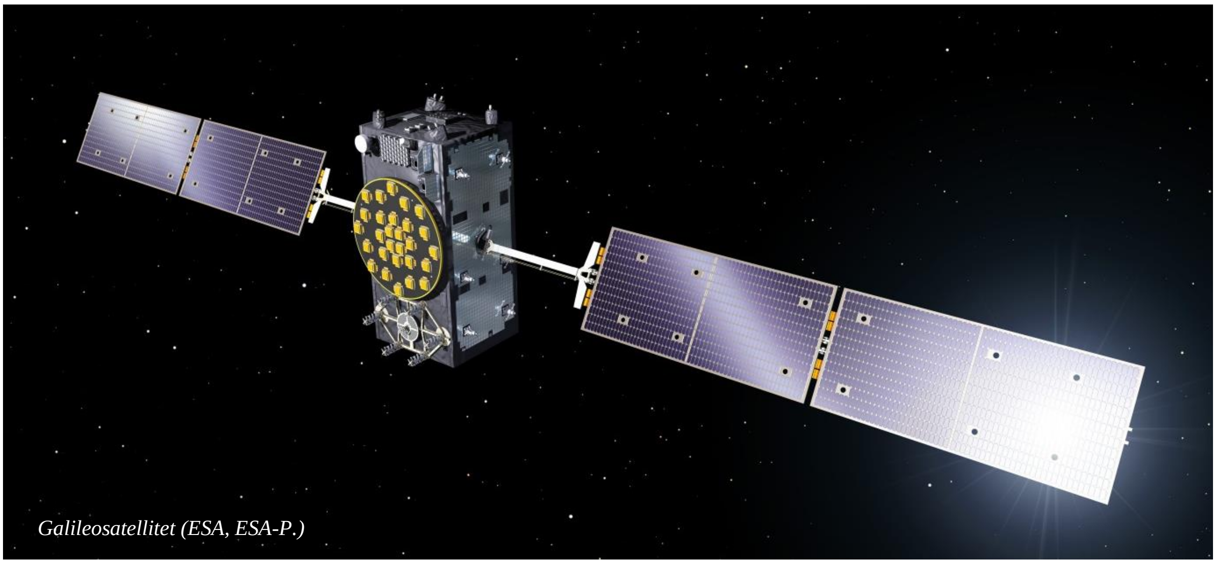
Measure of the hardware delays of Galileo signals inside the receiver and antenna



GNSS station hardware delays

Using global navigation satellite system (GNSS) signals for accurate timing and time transfer requires the knowledge of all electric delays of the signals inside the receiving system (see figure). GNSS stations dedicated to timing or time transfer are classically calibrated only for Global Positioning System (GPS) signals. Due to the ESA need for calibrated stations to determine accurate satellite clock data, the ROB developed a procedure to compute the hardware delays of a GNSS receiving station for Galileo signals, once the delays of the GPS signals are known. The approach consists in measuring the apparent differences between the ionospheric delays measured on GPS and Galileo signals for satellites in simultaneous view in the same direction, hence suffering the same ionospheric delay. While they should be equal to zero, these apparent differences contain an offset due to the different hardware delays present in the GPS and Galileo measurements made by the receiver. The uncertainty on the so-determined hardware delays for Galileo signals is estimated to be 3.7 ns for each isolated code in the L5 frequency band, and 4.2 ns for the ionosphere-free combination of E1 and one code of the L5 frequency band. This procedure is now used by the ESA for calibration of the receivers involved in the Time Validation Facility. (See also Defraigne *et al.*, 2014, IEEE transactions on ultrasonics, ferroelectrics, and frequency control, 61(12), pp. 1967-1975.)

Belgian GNSS permanent stations show no significant horizontal ground motions



Galileosatellitet (ESA, ESA-P.)

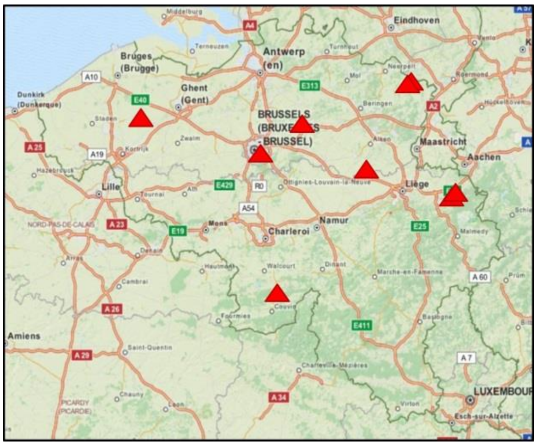
The GNSS receivers of all our permanent stations were upgraded to observe, in addition to GPS, GLONASS and Galileo satellites.

Using these data, as well as the data from GNSS stations operated by the regions, we evaluated the ground deformations in Belgium and found no significant deformations in the horizontal (see figure) while in the vertical there seems to be a small (about the mm-level/year) subsidence in the region of the Belgian coast.

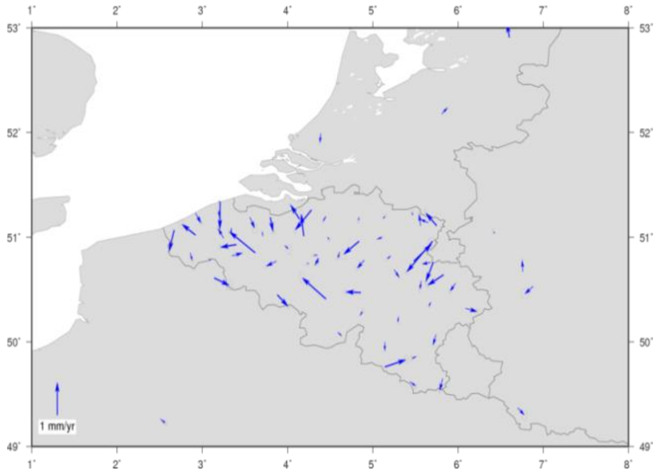
A future GNSS service within EPOS (European Plate Observing System)

At the European scale, we actively contributed to the elaboration of the GNSS Thematic Core services which will be implemented in the EPOS (European Plate Observing System) ESFRI (European Strategy Forum on Research Infrastructures) project.

The ROB will be involved in the EPOS Implementation Phase (as a partner in an H2020 proposal) and will be in charge of setting up the governance of the GNSS component of EPOS and will be transposing some of the tools developed for our EPN Central Bureau to EPOS.



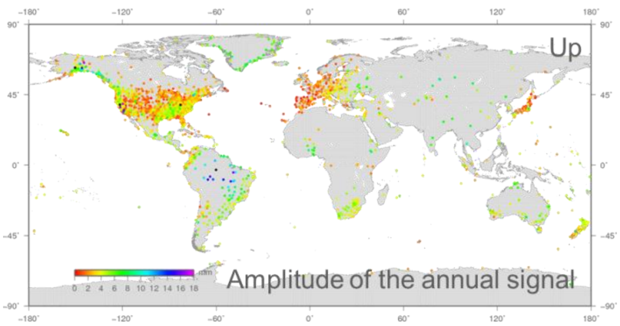
GNSS permanent stations of ROB



Horizontal ground deformation monitored by the Belgian stations

Combination of regional GNSS solutions to monitor tectonic and loading-induced surface deformations

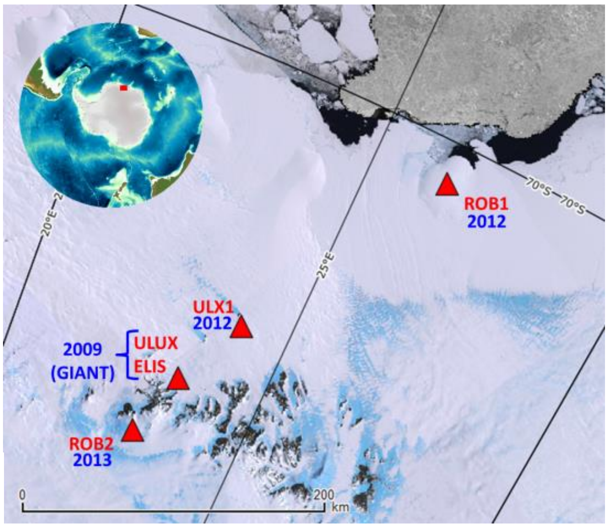
In the frame of the IAG Working Group on “Integration of dense velocity fields into the ITRF, 2011-2015", the procedure to perform the global combination of a dense velocity field has been upgraded in 2014 leading to a more precise velocity field (reduction by 10% to 50% of the RMS of some individual residual position time series). In addition, the amplitudes and the phases of the annual signals of the GNSS stations show the signature of loading effects, especially in the up component (see Figure).



Amplitude of the annual signal in the up component (mm) showing a clear spatial correlation

Antarctica

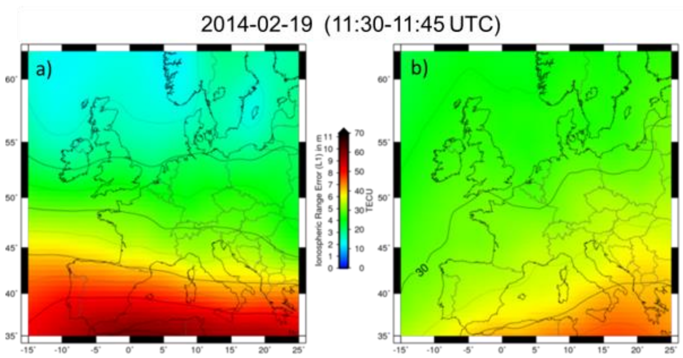
In the frame of the IceCon project (BELSPO), the GNSS stations installed since 2009 around the Princess Elisabeth station (see Figure) have been revisited. A first estimate of the ground motions of the GNSS stations shows that station installed on the Derwael ice rise (ROB1) has a subsidence of about 1.4 m/year compared to the station at the Princess Elisabeth base ELIS). This large subsidence is due to ice and snow compaction, surface thinning and vertical motion of the ice (Raymond effect).



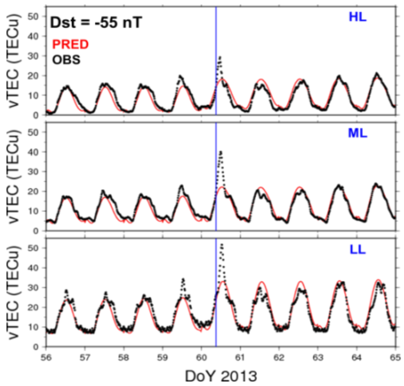
GNSS stations installed in the frame of the IceCon and GIANT projects

Large ionosphere perturbations and Solar radio bursts detected in near real time by GNSS

The capability of the ROB-IONO software to detect in near real-time abnormal ionospheric behaviour over Europe was demonstrated. The results have been published in the Space Weather and Space Climate journal. An empirical model to predict the vertical Total Electron Content (vTEC) every 15 minutes from the F10.7 index in entrance was developed. First results show differences lower or equal than 5 TECu for 89.9 % of the time for the period 1998-2014 between the modelled and observed values above Brussels.

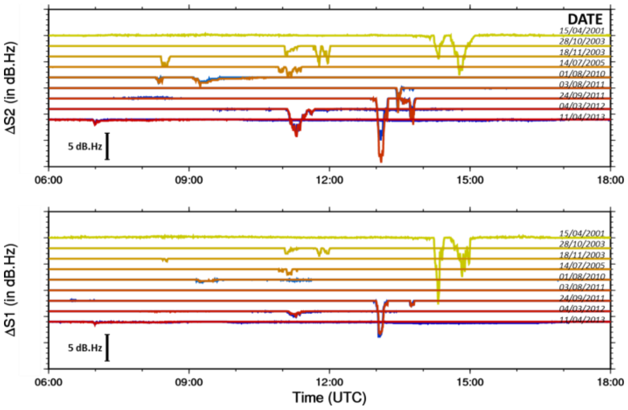


Total Electron Content (TEC) over Europe showing (a) abnormal values during the 2014-02-19 event and compared to (b) normal expected values.



TEC prediction (red) compared to observation (black) for three different latitudes over Europe for 9 days in 2013. HL: high latitude; ML: mid-latitude; LL: low-latitude. The blue line corresponds to a storm onset on 1st March, 2013.

The impact of solar radio bursts on GNSS carrier to noise density from 2001 until 2013 was investigated using GPS and GLONASS data of the EPN. A method was developed to detect such GNSS signal degradations in a near real-time approach.



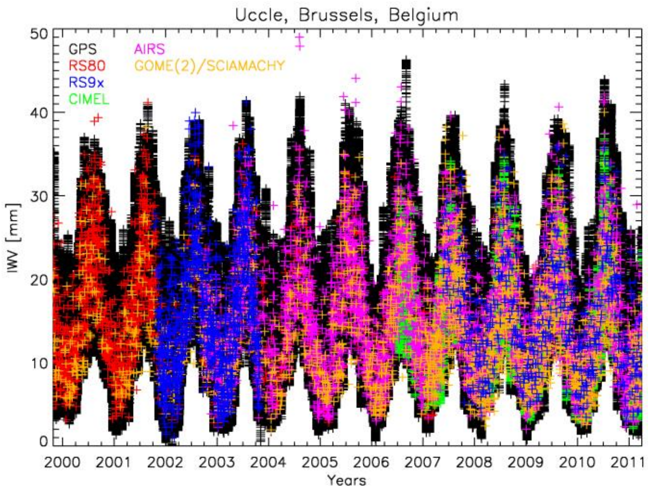
Near real-time detection of solar radio bursts on GNSS degrading the signal for nine events from 2001 on.
Each color corresponds to an event.

Top: degradation of the GNSS signals on L2 GNSS frequency.

Bottom: same for the L1 GNSS frequency.

Troposphere water vapour determined by GNSS can be used for climate applications

The water vapour data observed/estimated from various ground-based, in-situ and satellite techniques at 28 world-wide sites were compared (see figure) and it was demonstrated that GPS is a good candidate instrument to produce water vapour time series for climate applications (published in AMT, Atmospheric Measurement Techniques).
Two demonstration prototypes were presented: (1) of GNSS-based methods and products for non-numerical nowcasting (water vapour time series and maps, horizontal gradients, water vapour content change rate…); (2) of real-time PPP (Precise Point Positioning) capable of delivering tropospheric estimates every 10 sec with a latency of 100 sec. This last prototype demonstrated in general a 4-10 mm agreement with the estimated tropospheric zenith path delays obtained with post-processing products generated with the Bernese software 5.2 using also PPP.



Water vapour time series observed from GPS, radiosonde (RS80/9x), CIMEL and satellites instruments at Uccle (2000-2011).

The validity and behaviour of GPS-based tropospheric gradients in Corsica based on two different GNSS software was studied and a general (long-term) good agreement (both in direction and amplitude), a correlation with the temporal water vapour distribution along the year, and an anti-correlation with the downslope of the relief (published in Advances in Space Research) was found.

Rotation and interior structure of the Earth and other terrestrial planets and satellites

The interior and rotation of Mimas

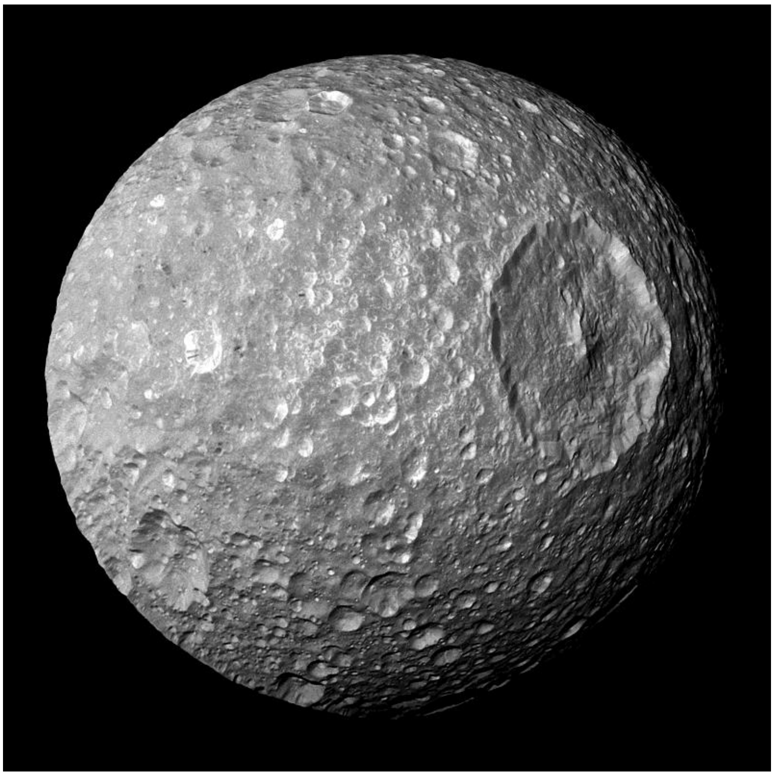
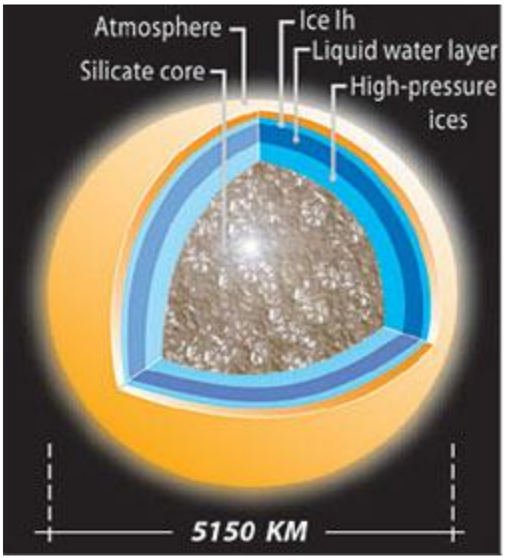


Image taken by the Cassini spacecraft on 13 February 2010 of Mimas, moon of Satur (NASA).

The majority of the large and medium-sized satellites of the solar system are locked in a 1:1 spin-orbit resonance and therefore, such as our Moon, always approximately show the same face to their central planet. The rotation of Mimas, a moon of Saturn, has been measured by using images taken by the Image Science Subsystem of the Cassini spacecraft operating in the Saturnian system since 2004. The data confirm that Mimas is in a synchronous rotation around Saturn. In other words, Mimas is spinning with an angular speed on average equal to that of its orbital motion around Saturn. In addition, small periodic variations in the rotation, called librations, have been measured. The amplitude of the libration depends on the interior structure and shape of the satellite. Among the measured librations the libration with period equal to the orbital period is particularly sensitive to the interior structure. Its measured amplitude is about twice as large as the value predicted for a solid Mimas in hydrostatic equilibrium. Two competing hypothesizes have been brought forward to explain the result: either Mimas somehow formed with a strongly elongated core that has not yet relaxed towards a shape in hydrostatic equilibrium, or Mimas harbors a global subsurface ocean deep below its outer icy shell. In either case, the interior structure of Mimas is significantly more complicated and interesting than one would expect from its old heavy-cratered surface. The results were published in Science on 17 October 2014.

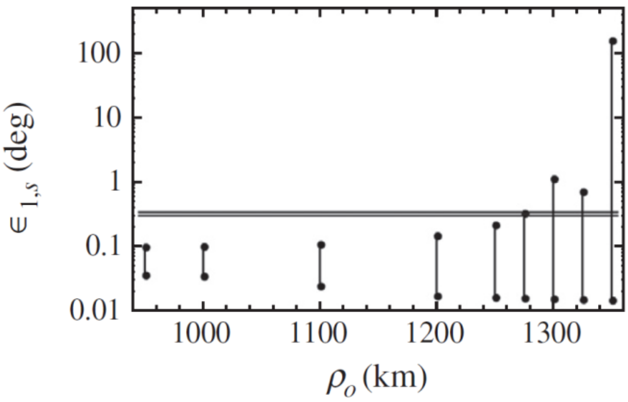
The long-period librations of large icy satellites



Interior of Titan.(http://www.universe-galaxies-stars.com/Titan_28moon29.html)

Titan and the Galilean satellites (Europa, Ganymede and Callisto) have librations (periodic variations in the rotation with respect to the uniform rotation) at a period equal to the orbital period as a result of the gravitational torque exerted by their central planet during the eccentric Keplerian orbit. Over the last few years, we have developed models to study the libration of visco-elastic moons with a global subsurface ocean. Deviations of a Keplerian orbit due to perturbations by the Sun, other planets and moons induce additional periodicities in the orbital motion. Based on an orbital theory, we have calculated the orbital perturbations and have numerically evaluated the amplitude and phase of the librations for many possible interior structure models of the icy moons constrained by the mass, radius and gravity field. We have shown that the tidal deformation increases the amplitude of the long-period librations, whereas it decreases the libration at the shorter orbital period. For Titan, the long period librations have much smaller amplitudes (below 20 m at the equator) than the libration induced by the atmosphere. Five different librations of Ganymede with periods of about one year may be much larger (above 100 m) due to a possible resonant amplification with an internal rotational normal mode. Their amplitude largely depends on the interior model showing that future libration observations (such as with JUICE) will shed light on the satellite's interior. Large resonant amplifications are not possible for Europa and Callisto. The largest non-Keplerian libration of Europa has a period of 1.32 year and a maximal amplitude of 22 m. For Callisto, the largest libration has a period equal to the orbital period of Jupiter (11.86 year) and a maximal amplitude of 95m.

Geodesy constraints on Titan's interior structure

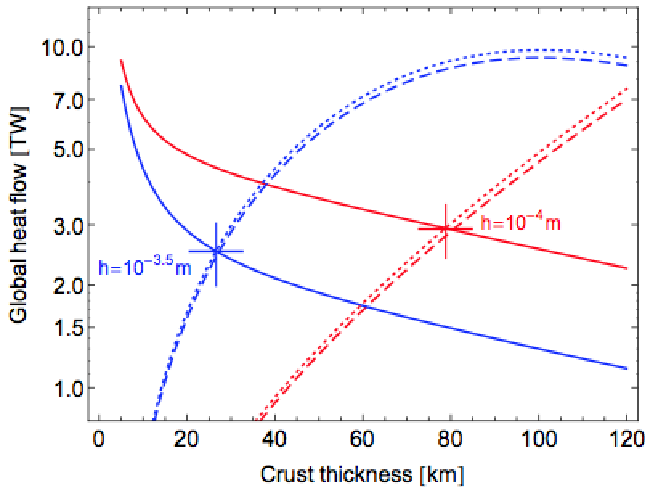


The measured obliquity, represented by the horizontal line, can be reproduced only for a dense ocean.

Recent observations by the Cassini space-craft have shown that both the tides and the obliquity, the angle between the rotation axis and the normal to the orbital plane, of Titan are larger than expected. Both observations provide evidence for the existence of a global ocean beneath the surface of Titan. The largest satellite of Saturn therefore joins the large icy Galilean moons of Jupiter in having a subsurface ocean. We have studied the constraints that tides together with obliquity impose on Titan's interior and also took into account the departure of hydrostatic equilibrium as demonstrated by the large-scale topography and gravity field. It has been shown that the measured obliquity can be reproduced only for a dense ocean (between 1275 and 1350 kg/m3) above a differentiated interior with a full separation of rock and ice. The thickness of the outer ice shell is at least 40 km and the ocean thickness is less than 100 km. The elevated density (>3400 kg m-3) found for the rocky core further suggests that it might possess a significant fraction of iron.

The membrane paradigm for tides of large icy satellites

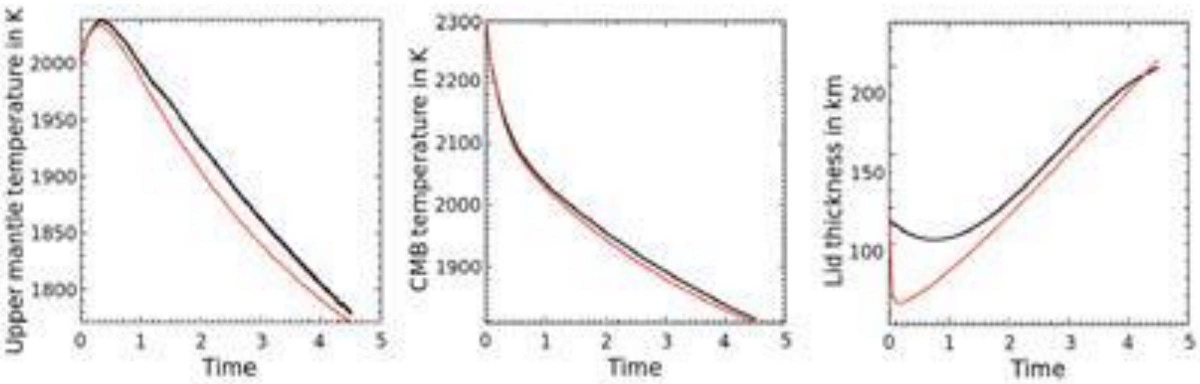
Large icy satellites, like Jupiter's moon Europa, have a thin icy crust, which is decoupled from the mantle by a subsurface ocean. The crust responds to tidal forcing as a deformed membrane, cold at the top and near the melting point at the bottom. We have developed a membrane theory of viscoelastic shells with depth-dependent rheology with the dual goal of predicting tidal tectonics and computing tidal dissipation. Two parameters characterize the tidal response of the membrane: the effective Poisson's ratio and the membrane spring constant, which is proportional to the crust thickness and the effective shear modulus. In this approach, approximate analytical expressions have been determined for the tidal Love numbers characterizing the tidal response of the satellite to tidal forcing. Membrane formulas predict the tidal displacement and tidal potential variations with an accuracy of a few tenths of percent if the crust thickness is less than one hundred kilometers.



Example of the accuracy of membrane predictions: global heat flow in Europa's crust if the crust is convecting in the stagnant lid regime. The heat transferred by convection (solid curves) is at equilibrium with the heat due to tidal dissipation (dashed curves, computed with the membrane approach) at specific values of the crust thickness. Solutions are given for two grain sizes h. For comparison, dotted curves show the heat due to tidal dissipation computed with the matrix propagation method. The difference in crust thickness predictions is negligible.

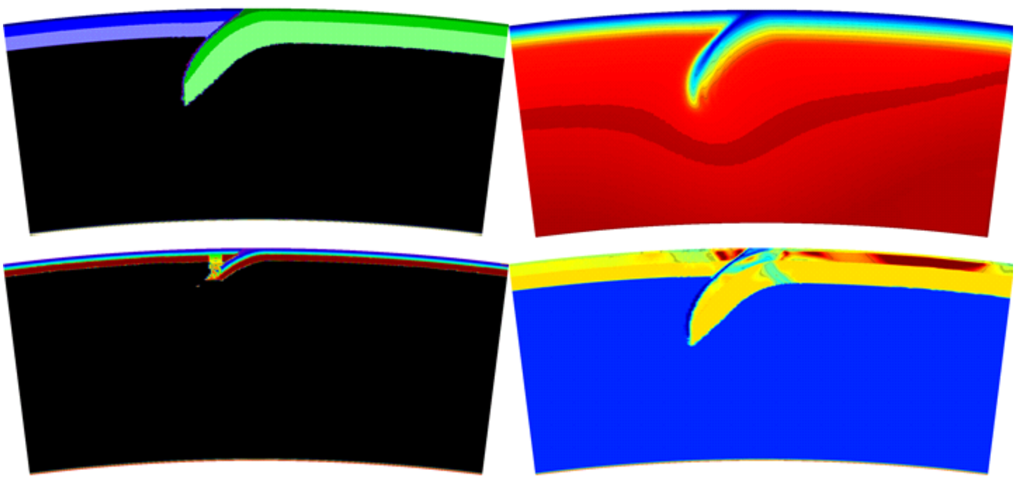
Mantle convection in terrestrial planets and plate tectonics

A new numerical code (CHIC) for the simulation of the thermal evolution of terrestrial planets has been developed at the ROB over the last few years. The thermal evolution of the mantle is calculated either by solving the energy conservation equation supplemented by boundary-layer theory (1D parameterized thermal evolution model) or by solving the energy, mass, and momentum conservation equations (2D/3D convective thermal evolution). The code provides information on the temperature field, convective velocities and convective stresses in the mantle. Simulations can also be run in steady-state regime. CHIC has been benchmarked with different convection codes, and compared to published interior-structure models and 1D parameterized models. The CHIC code handles surface volcanism, crustal development, and different regimes of surface mobilization like plate tectonics. It is therefore well suited for studying scenarios related to the habitability of terrestrial planets, including local processes as for example crust formation in subduction zones.



Upper mantle temperature, CMB temperature and lid thickness for a thermal evolution of Mars for a 2D spherical annulus (black curve) and the 1D parameterized model (red).

We have used CHIC to study the formation of continents on early Earth. The simulations suggest that the formation of continents may start very early in Earth's evolution, fitting the geological observations concerning early Earth. The first continental crust may have formed at diverging ocean plates. The driving force for the initiation of ridge formation comes from uprising mantle plumes that lead to plastic deformation of the ocean crust.



Simulation of the subduction process of an oceanic plate including dehydration of the subducted slab and related melting processes.

Awards

Carine Bruyninx received the Ivan I. Mueller Award of the American Geophysical Union (AGU)

Dr. Carine Bruyninx, responsible for the GNSS (Global Navigation Satellite System) research group of the Royal Observatory of Belgium, has received on Dec. 16, 2014 in San Francisco, the Ivan I. Mueller Award of the Geodesy Section of the American Geophysical Union (AGU), see http://honors.agu.org/sfg-awardees/bruyninx-receives2014-ivan-i-mueller-award-for-service-and-leadership.

This high-level recognition has been awarded to Carine Bruyninx for her leadership in space geodesy and devotion to the scientific GNSS community and its related services, in particular for her role as head of the Central Bureau of the EUREF (European Reference Frame) Permanent GNSS Network (EPN) since 1996.

The EPN is the backbone of the European Terrestrial Reference Frame used for georeferencing in Europe. In 2014, 18 new stations were included in the EPN, reaching now a total of 264 stations.

Véronique Dehant, Doctor Honoris Causa of the Paris Observatory

(© Veronique Pipers 1point2)

Véronique Dehant, scientific researcher of the Royal Observatory of Belgium has been nominated Doctor Honoris Causa of the Paris Observatory on November 13, 2014.

She is responsible for the Operational Directorate "Reference Systems and Planetary Science" at ROB. She is also Extraordinary Professor at the Université Catholique de Louvain.

She was or is involved as Principal Investigator (PI) or Co-Principal Investigator (Co-PI) or Co-Investigator (Co-I) of several radioscience space experiments aiming at planetary geodesy and at physics of the interior of terrestrial planets.

She is Academician (Royal Academy of Belgium, Science class) since 2010 and was awarded with several prizes, including the Descartes Prize of the European Union in 2003. She has taken several international responsibilities at President level such as President of the Geodesy Section of the American Geophysical Union.

She is author of more than 415 publications including 150 refereed publications, and of more than 900 oral or poster presentations.

Three review chapters in the 'Encyclopedia of the Solar System'

The expertise developed in the research group *Rotation and interior structure of the Earth and other terrestrial planets and satellites* has been used to write three review chapters in the prestigious 'Encyclopedia of the Solar System' synthesizing our knowledge on the 'interior structure and evolution of Mars', on the 'rotation of planets' and on 'Probing the Interiors of Planets with Geophysical Tools'.

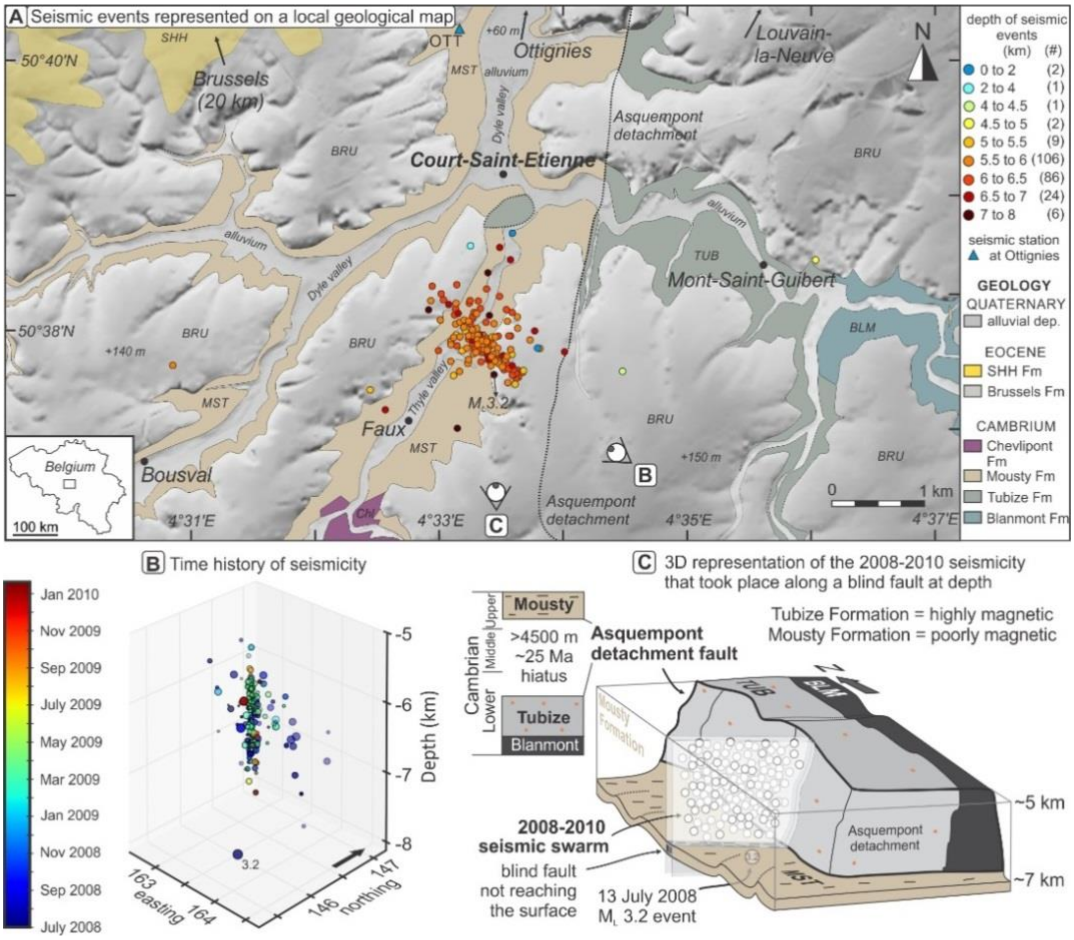
Seismology and Gravimetry

The main mission of the Operational Directorate Seismology and Gravimetry is studying seismic activity, its causes and its consequences in Western Europe. In support of this scientific research and to provide the authorities, the media and the public with relevant information about the seismic activity in real time in our region, this operational direction develops and maintains a network of seismic monitoring in Belgium.

Source of the 2008-2010 Walloon Brabant seismic swarm in the Brabant Massif revealed!

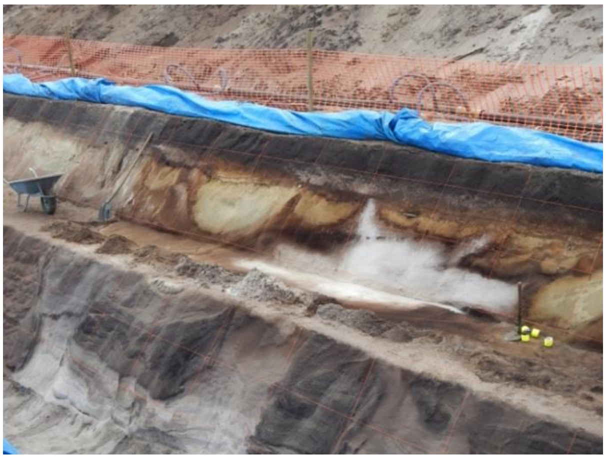
The small town of Court-Saint-Etienne in Walloon Brabant was struck by a low-magnitude (M_L -0.7 to M_L 3.2) earthquake sequence from 12 July 2008 until 18 January 2010. 239 events were recorded by the Belgian permanent seismic network that was improved by a local seismic network installed around Court-Saint-Etienne and Ottignies. The seismic sequence was reported regularly in the Belgian media during these 1.5 years as 60 of the 239 events were felt by the local population. In collaboration with Anjana K. Shah (USGS), Dr. Koen Van Noten, Dr. Thomas Lecocq and Dr. Thierry Camelbeeck (ROB) found the causative source of these earthquakes using a multidisciplinary geological, seismological and geophysical approach.

By locating all individual earthquakes, Van Noten and colleagues demonstrated that the seismic activity of these earthquakes occurred along a single, vertical blind fault structure at a depth between 5 km and 7 km below the hamlet of Faux (see Figure 1). The fault developed in the ~500 million year old, clayey Mousty rock formation of the Brabant Massif. By analysing the variation of magnetic properties of the surrounding rock formations at depth, the authors moreover discovered that this fault is only present at depth and does not continue towards surface to have a surface expression. The results of this BELSPO MO-33-028 project are accepted for publication in *Tectonophysics* and the authors were congratulated by the journal editor because of the excellence and clear representation of their work.



A: Epicentral distribution of the 2008-2010 seismic swarm at Court-Saint-Etienne. Individual earth-quakes (dots coloured by depth) are aligned in a NW-SE direction.
B: 3D hypocentral distribution of seismicity at depth. Note the verticality of the seismicity.
C: A NW-SE oriented causative fault was detected by analysing the magnetic properties of rock formations in the Brabant Massif. Matched filtering of aeromagnetic data showed that the fault is present in the low magnetic, clay-dominated Mousty rock formation

Rauw Trenching



In the framework of a seismic safety study for the nuclear zone of Mol-Dessel commissioned by NIRAS/ODRAF, we studied the Rauw Faults, the closest one with some indirect indications of Quaternary activity. The indications are:

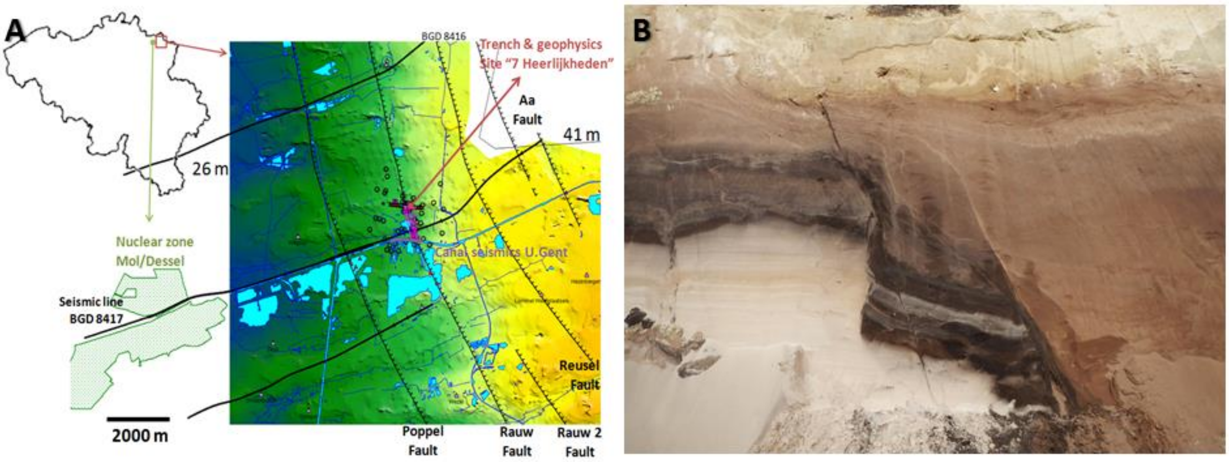
1) A two to three million years old lignite layer in the Mol sands is displaced vertically 15 m, down to the east, by this fault.

2) The fault probably caused a temporary westward shift of the Rhine/Meuse River course one million years ago. Gravel and Lommel sand were deposited on the eastern side of the fault by the rivers. Later differential erosion between gravelly Lommel sand (east) versus pure Mol sand (west) caused relief inversion and formed the Campine Plateau on the east. Geomorphological and geophysical surveys allowed locating the fault with 7 m vertical offset of all the internal layers within the Mol sands. In 2014 we opened a new trench on this fault.

The trench revealed intensely cryoturbated (deformed by ice) sediments, younger than twenty thousand years old, overlying Mol sand (see figures). The narrow main fault juxtaposes two blocks.

On the left, upward moving side of the fault: white Mol sands overlain by a black lignite-rich sand layer followed by brown-coloured Mol sand. On the right, downward moving side: the upper part of the brown-coloured Mol sand.

The brown colour is due to soil formation around two million years ago, after retreat of the sea but still before the ice age cooling. The average base of the cryoturbated glacial sediments is not displaced and the fault itself is deformed by freezing/thawing. The fault movement is therefore certainly older than twenty thousand years. The complete 7 m of fault movement is younger than the soil formation in the top of Mol Sand, around two million years. Most probably there was an episode of activity with large earthquakes around 1 million years ago. In the trench, the Lommel sand deposit is eroded, apart from the remaining gravel, so there is no possibility for more precise dating of the fault movement. Future efforts should therefore concentrate further northward where the sediments that are contemporary with the fault movement may be preserved.



A. Elevation model of the investigated area with indication of trench, faults and seismic lines.

B. Picture of the Rauw fault on the inclined northern wall of the excavation.

Antarctica Seismological

Starting in 204 and funded for 2 years by BELSPO, the BRAIN-be pioneer project “Seismic Monitoring of the East-Antarctic Ice Sheet” lead by Denis Lombardi is dedicated to the investigation of the dynamics of the East-Antarctic ice sheet, the interaction of draining ice stream with the ocean and connection of ice strain induced seismicity, basal seismicity and ice stream flow focusing on one of the major ice stream in East-Antarctica, the Sør Rondane ice stream. To achieve these goals, during the 2013-2014 Belgian Antarctic Expedition, a first experiment using 4 seismometer coupled to 4 GPS devices that were developed in collaboration with IGN-France was done near the coast (Figure 3), 180 km north of the Princess Elisabeth Station, at the transition zone between an ice rise promontory (where the ice is grounded) and the Roi Baudouin Ice Shelf (where the ice is floating over the ocean).

The seismic records and GPS positions show a strong correlation of daily seismicity peaks with daily downward vertical displacements as large 130 cm in 5 hours. These observations indicate that oceanic low tides generate daily flexure of the ice-shelf creating opening surface crevasses at the transition between the grounded ice and the floating ice. These remarkable findings will be complemented in 2015 during the 2014-2015 Belgian Antarctic Expedition with the deployment of a dense network coupling 15 seismometers and GPS instruments at the contact between the Sør Rondane ice stream and the Roi Baudouin Ice Shelf, 160 km north-east of the Princess Elisabeth Station where the ice flows as fast as 300 m per year. This experiment is expected to provide very promising results concerning the ice-sheet dynamics.

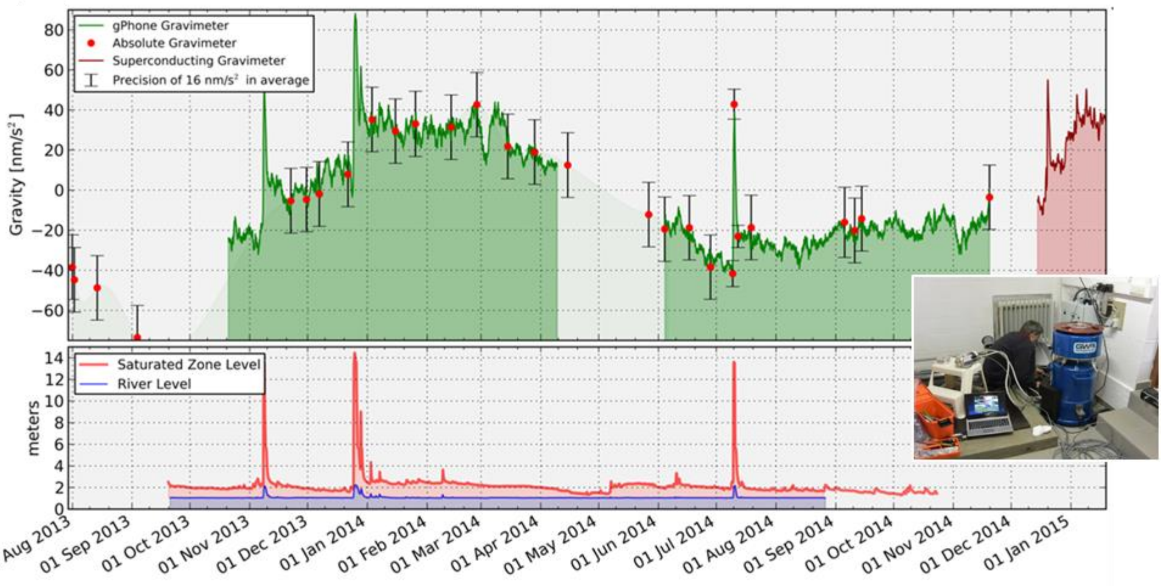
On the Roi Baudouin Ice Shelf, East Antarctica, seismologist Denis Lombardi from the Royal Observatory of Belgium is installing a seismometer (here hidden below the ice) and a GPS device (here visible, mounted on the aluminium pole).

Karst Aquifer Research by Geophysics

Karst aquifers supply drinking water to 25% of the world population. Their heterogeneous sizes and hydrogeological characteristics are difficult to evaluate and present challenges for modelling storage capacities. Our FNR-FNRS project aims at leveraging our previous experience in karst, hydrogeology, gravimetry and geophysics to understand the water dynamics and storage in the unsaturated and saturated zones of the Rochefort karst system. This project benefits from the Rochefort Cave Laboratory facility.

The recorded gravimetric data from November 2013 to January 2015 (see figure) shows 6 bumps (4 high and 2 low) in response to rapid water level changes of the saturated zone. Concurrently, a slower increase in gravity of 50 nm/s² should be related to the slow recharge of the vadose zone through the winter as it does not correspond to any trend of the saturated zone. This increase in gravity through the winter is counterbalanced by a decrease through the summer when evapotranspiration is predominant.

End November, an iGrav superconducting gravimeter was successfully installed in the surface laboratory, replacing the gPhone spring gravimeter installed in 2013 by U. Luxembourg. The gPhone gravimeter will be installed in the cave in early 2015, about 40 m just under the surface laboratory. Combining the continuous gravity measurements in the cave and at the surface is paramount to separate the water storage changes in the epikarst and infiltration zone above the cave from changes in the phreatic zone below the cave.



November 2013 – January 2015. gravity measurements (red dots for the absolute gravimeter, green line for gPhone and red line for the superconducting gravimeter). Tidal, atmospheric, and polar motion effects were removed. The average value of 981,011,438 nm/s² was removed. Rapid increases in gravity can be observed when the cave was flooded. Slower increases in gravity are related to the recharge of the vadose zone while slower decrease is related to the discharge of the vadose zone; (down) level of the Lomme River in Rochefort (blue) and piezometric surfaces in the caves (red). Insert: Connecting the cryogenic system to liquefy helium on 2014-11-27

First complete historical review of the Kawa Ijen volcano since 1786

The Royal Observatory of Belgium has a long experience of applying the historical criticism methods on earthquake reports. In an international collaboration, scientists of the ROB critically reviewed the history of the Kawah Ijen volcano (Java, Indonesia) by exploiting an enormous amount of historical sources. The sources were obtained from the archives of the Center for Geological and Volcanological Hazard Mitigation in Bandung, from the archives of the Dutch Colonies in Utrecht and directly from documents kept at the Observatory of the Kawah Ijen.

Although proofs of sulphur mining activities linked to a gunpowder manufacture has been identified since 1786, the first detailed report about the volcano dates back to 1789 when a local Dutch commander visited the volcano. A good estimation of the unrests and shape changes of the volcano were obtained from the sometimes detailed reports from the settlers. The first seismic records have been obtained in May 1987 and telemetered to the Observatory of the Kawah Ijen where they were recorded on circular drum paper. Digital scanning by the ROB of all the historical reports and the drum papers resulted in the first integrated historical database for the Kawah Ijen volcano. In a last step, the historical unrests were reinterpreted using the current knowledge of seismic event types, lake temperature and water level. Everything has been integrated in the WOVODAT (http://www.wovodat.org/) database

This historical review is essential in the objective of forecasting volcanic unrests at Kawah Ijen using the digital seismic network deployed by the Royal Observatory of Belgium and the USGS since 2010.

The "explosion" of 1993 when half of the lake (1 km in diameter) was affected by a strong upwell of bubbles. Photo: P. Blonde.

Astronomy and Astrophysics

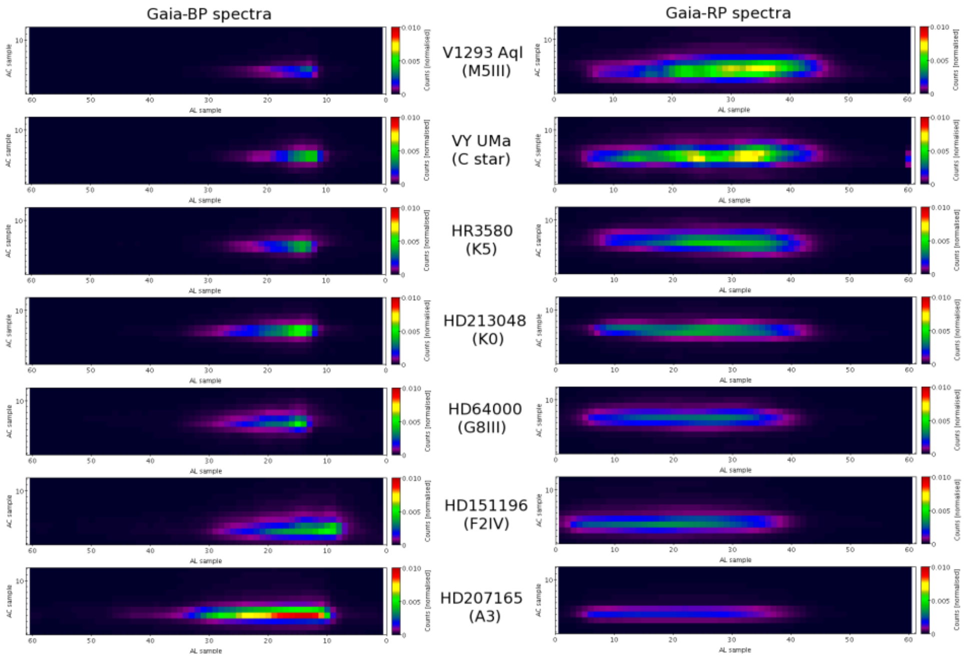
The astronomers of the Operational Directorate Astronomy and Astrophysics do research in astronomy and they also observe solar system objects. Stellar evolution, mass loss of stars, variable and multiple stars as well as rapidly rotating stars are studied. Astrometry of minor planets is carried out and planetary satellites are observed. The researchers are active in the preparation and/or reduction and interpretation of data coming from dedicated observational campaigns, large scale surveys and space telescopes.

The service maintains databases and provides software for scientists. General information on astronomical and related phenomena are distributed to public and press. Digitisation and archiving of photographic plates is also a task of this group.

Go! for Gaia

After a long commissioning phase the Gaia satellite received a go! for the nominal mission. The software developed in previous years started processing in 2014 the commissioning phase data when the ecliptic pole region was intensively observed. The Gaia website reported regularly on highlights and new findings. In a few topics astronomers from the ROB where directly or indirectly involved: asteroid observations, light curves of variable stars and the first spectra.

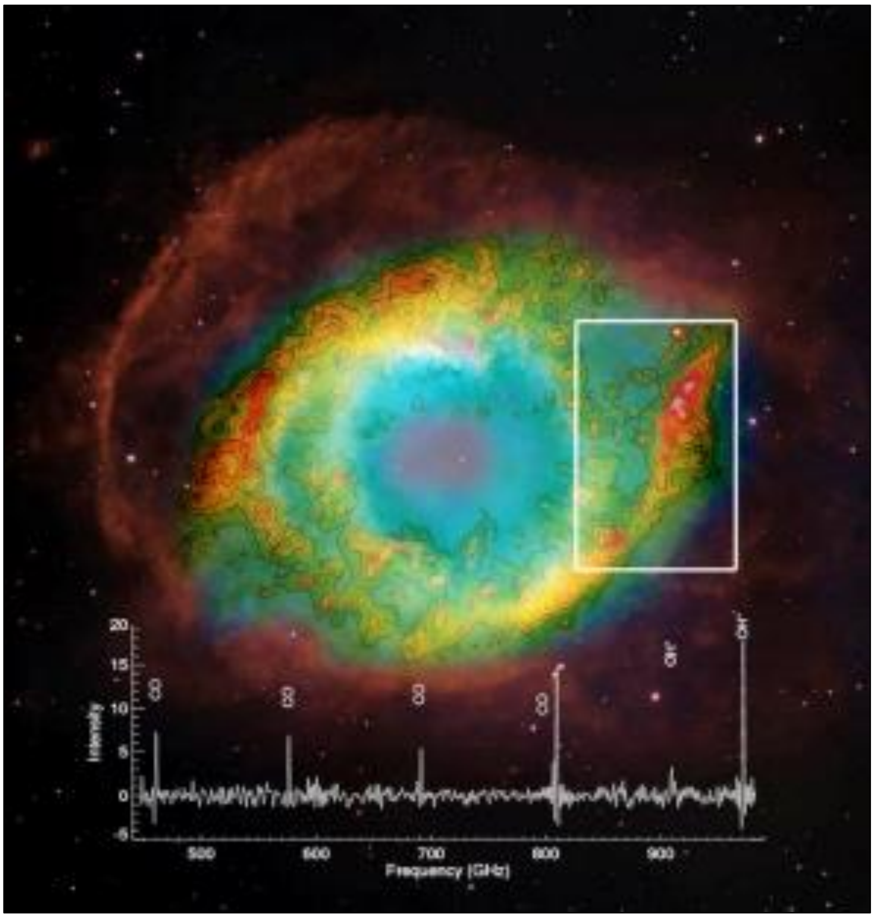
Meanwhile funding has been obtained to organize the workshop “Massive Stars and the Gaia-ESO Survey” at the ROB in May 2015. A large part of the analysis of the massive-star data in this Gaia-ESO Survey is done at the ROB



From Gaia observations temperature information for stars can be deduced. The blue photometer (BP, left) of Gaia receives light with shorter wavelengths, and the red photometer (RP, right) receives light with longer wavelengths. The plot is arranged with cool stars at the top, to hotter stars (around 8000ºC) at the bottom. Hotter stars will have more light in the blue than in the red. (*credits: ESA/Gaia/DPAC/Airbus DS*).

Water-building molecule in planetary nebulae

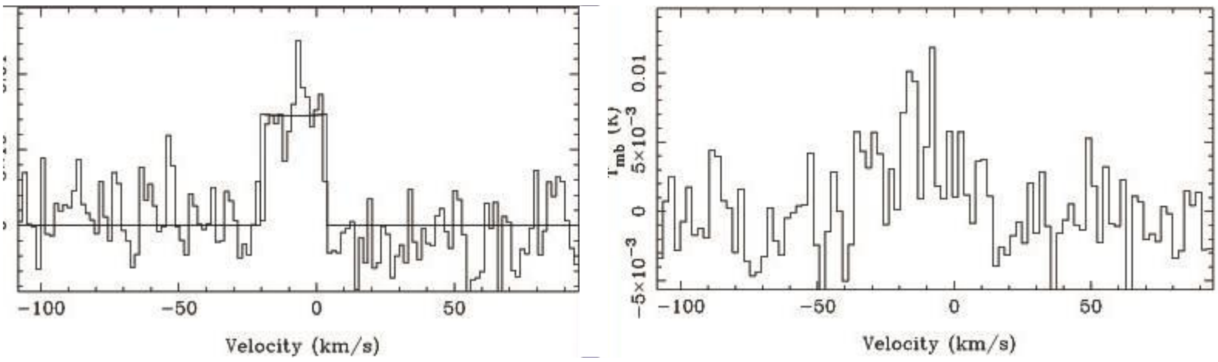
Astronomers of the ROB have discovered that the molecule OH+, vital for creating water exists in planetary nebulae, the burning embers of dying Sun-like stars.
Stars like the Sun burn hydrogen for billions of years. Once the fuel begins to run out, the central star becomes a red giant, and when it becomes unstable it expels its outer layers to form a planetary nebula. The remaining core of the star becomes a hot white dwarf. The intense radiation of the white dwarf was thought to destroy the molecules in the rings of material around the planetary nebulae. The harsh radiation was also assumed to restrict the formation of new molecules in those regions.
But a molecule, known as OH+, a positively charged combination of single oxygen and hydrogen atoms and vital to the formation of water, seems to rather like this harsh environment, and perhaps even depends upon it to form. This was an unexpected result and highlighted in an ESA press release.



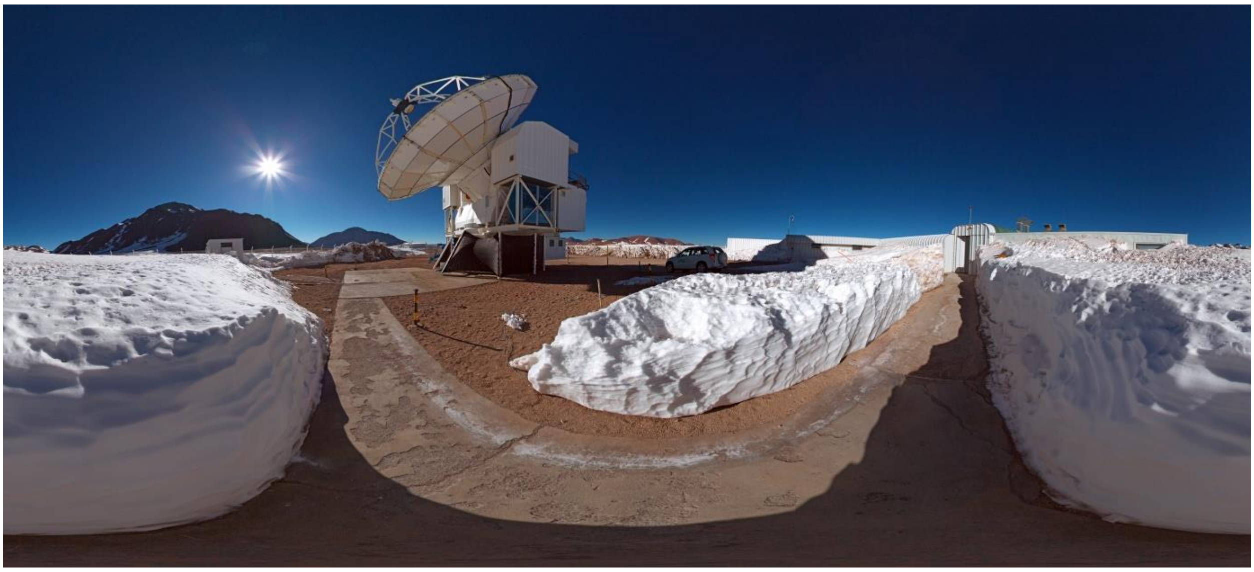
The image presents the Helix Nebula at optical wavelengths, as seen by the Hubble Space Telescope and by Herschel's SPIRE instrument at wavelengths around 250 micrometres. A spectrum is shown for the region identified on the image, showing the clear signature of CO and OH+ emission in the clumpy outer regions of the planetary nebula.
Credit: NASA, NOAO, ESA, the Hubble Helix Nebula Team, M. Meixner (STScI), and T.A. Rector (NRAO).

Detection of carbon oxide (CO) around a Red Giant star

A highlight of the research at ROB reported in 2014 was the detection of carbon oxide (CO) around an Red Giant Branch (RGB) star.
Based on several considerations, RGB stars *must* loose mass, about 0.2 solar mass for a star like the Sun, but by which mechanism(s) is unclear. The mass loss could be related to radiation pressure on dust grains, like for their cooler and more luminous evolutionary descendants, the Asymptotic Giant Branch stars, or related to chromospheric activity, like in hotter stars. Previous studies had indicated that a model with dust could fit the spectral energy distributions of the RGBs better than a model without dust. Finding CO in an RGB star would be a confirmation of the presence of dust. In one star a CO line was detected (see Figure). This is so far unique, and opens up the way to investigate the mass-loss mechanism on the RGB with more powerful telescopes like the Atacama Large Millimeter/submillimeter Array (ALMA) of ESO.



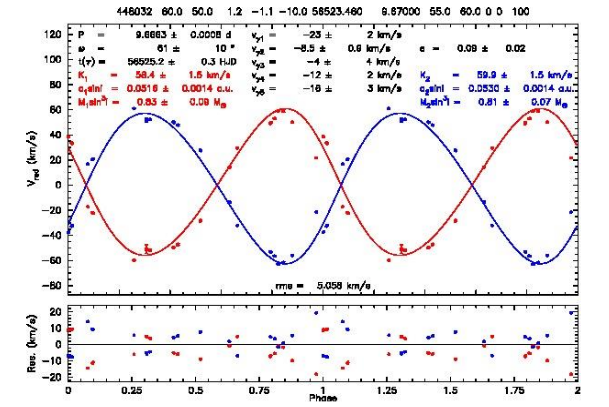
In the left-hand panel of the above picture the CO J=2-1 line is shown observed with the 30m IRAM telescope, in the right-hand panel the CO J=3-2 line which was observed with the 12m APEX telescope.



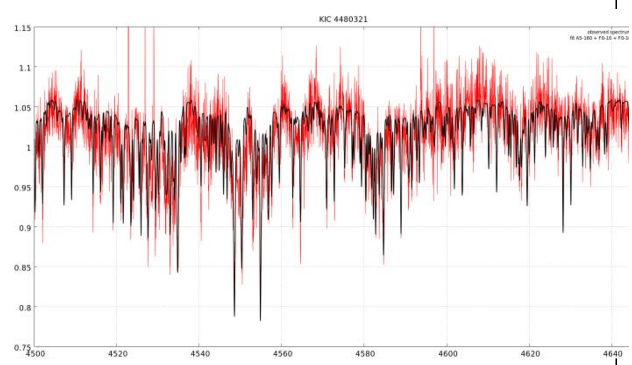
One of the radio telescopes used for the detection of the CO line in a red giant: The 12m ESO-APEX telescope (Atacama Pathfinder Experiment) on the Chajnantor plateau in Chile's Atacama region (Credit: ESO)

New binary systems detected through radial velocity monitoring with the HERMES spectrograph

A large number of spectroscopic binary and triple systems are detected among the sample of 40 candidate hybrid stars of the Kepler mission whose radial velocities are being monitored with the HERMES spectrograph of the Mercator telescope at La Palma. First results indicate a possible multiplicity fraction of almost 20% (7/38 targets). For various other binary systems, the derived radial velocities have led to the determination of a first orbital solution.

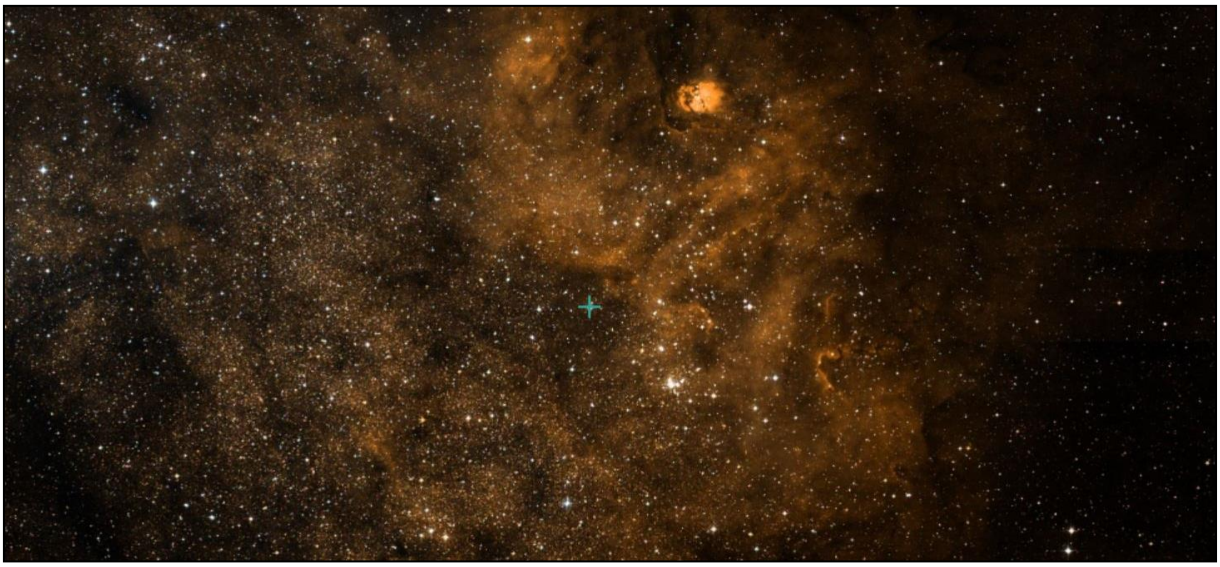


Preliminary spectroscopic orbital solution for the new triple system KIC 4480321



A part of the spectrum of triple system KIC 4480321: observed (red) vs reconstructed (black)

Spectra taken by the HERMES instrument showed also that the non-thermal radio emitter HD 168112 has radial velocity variations consistent with binarity. This is the first optical evidence of binarity for this object.



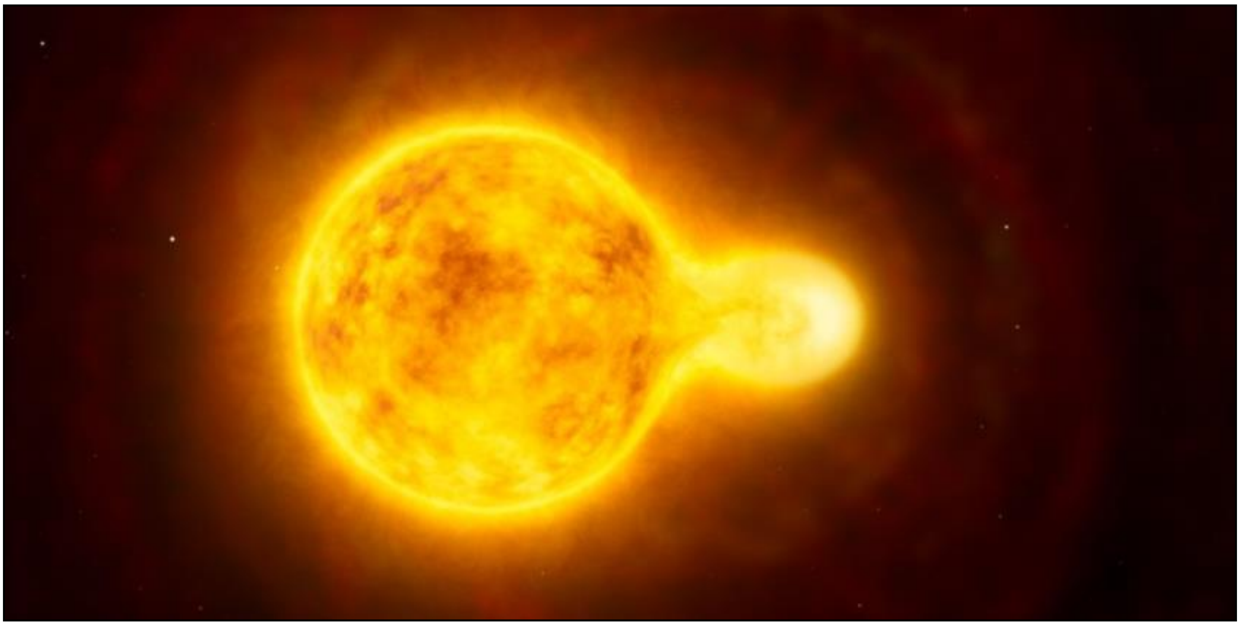
HD168112 and its surroundings (Credit: Digitized Sky Survey)

The yellow hypergiant HR5171

HR5171 in Centaurus (Credit ESO/Digitized Sky Survey 2)

HR 5171 (also known as V776 Cen) is a yellow hypergiant star in the constellation Centaurus. It is a very rare type of star with only a dozen known in our galaxy. It is one of the largest ten stars found so far. Its size is over 1300 times that of our Sun. Observations with ESO's Very Large Telescope Interferometer (VLTI) have shown that it is actually a double star, with the companion in contact with the main star, in a so called common enveloppe evolu-tionary phase.

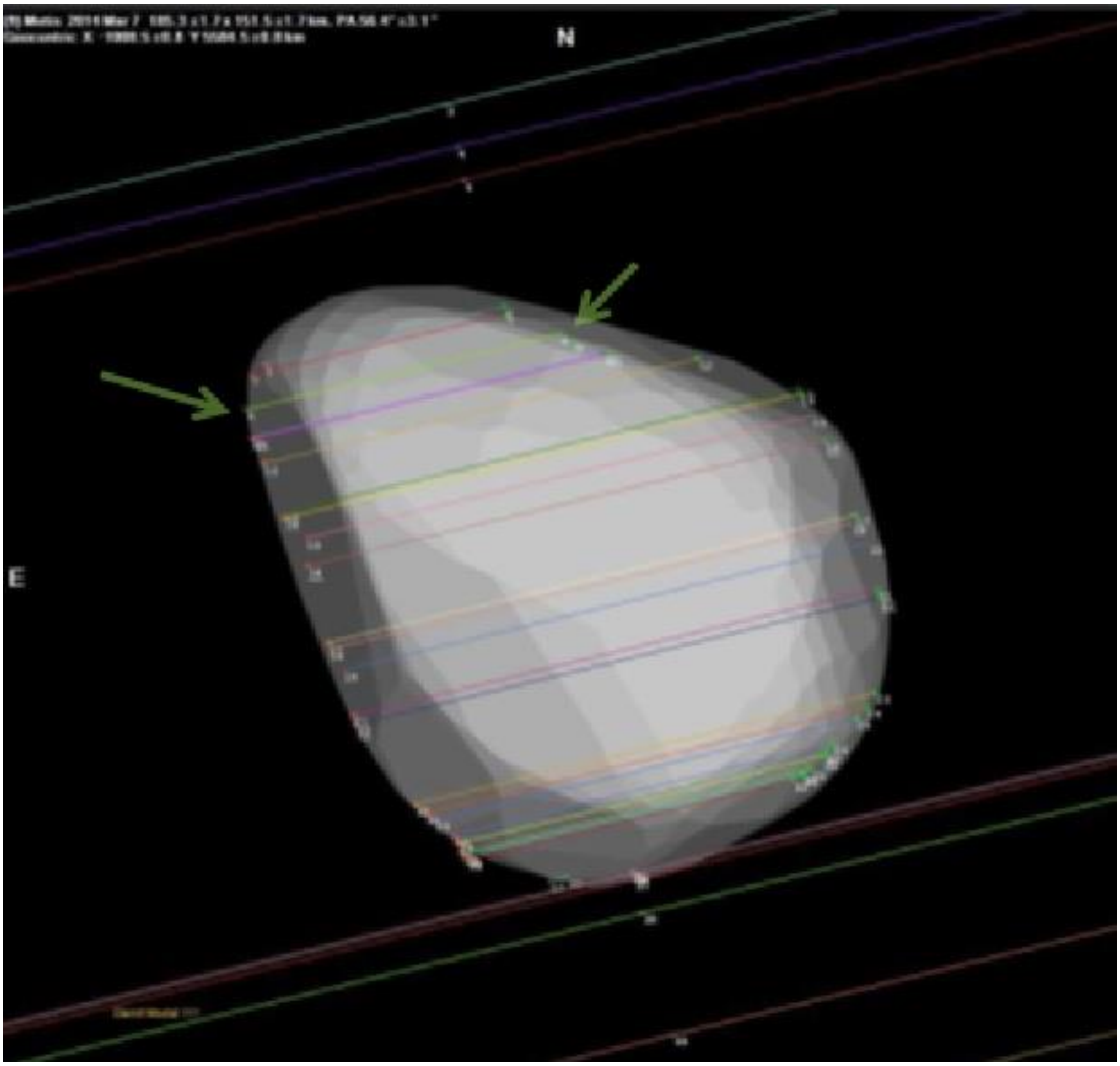
Observations spanning over sixty years, some from amateur observers, also indicate that this rare and remarkable object is changing very rapidly and has been caught during a very brief phase of its life. The ROB is involved in the analysis of this star and the VLTI results were subject of an ESO Press Release.



Artist impression of the yellow hypergiant star HR5171 (Credit: ESO)

Observing occultations of stars by minor planets

Observers at the ROB attempted to observe so called PLANOCCULT phenomena, possible occultations of stars by minor planets (3 events were attempted, 20 frames and films were recorded, giving 3 light curves). 2014 has been successful in giving the sixth positive occultation since the start of observations of these events in 2003: the occultation by (9) Metis on the night of March 6/7. This occultation turns out to be one of the best, if not the best worldwide observed occultation ever. Results are used to define the shape of the asteroid.



Reconstruction of the shape of asteroid (9) Metis using occultation observations of March 6, 2014. Line 8 represents the Ukkel observation. The bizarre shape of the asteroids explains why the occultation occurred 20 seconds earlier in Ukkel than predicted.
Figure by Eric Frappa (Occult/Damit/Euraster)

Solar Physics and Space Weather

The Operational Directorate Solar Physics and Space Weather studies the outer layers and the atmosphere of the Sun, with a particular focus on solar activity and the influence it exerts on the Earth and its space environment (space weather).

5 years PROBA2 science

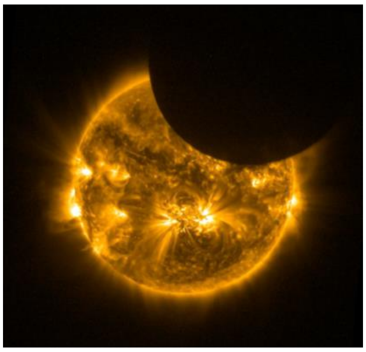
PROBA2, the second satellite in the European Space Agency's series of PRoject for OnBoard Autonomy, was launched on 2 November 2009. Consequently, on Sunday 2 November 2014, PROBA2 was 5 years in orbit! Congratulations, PROBA2!

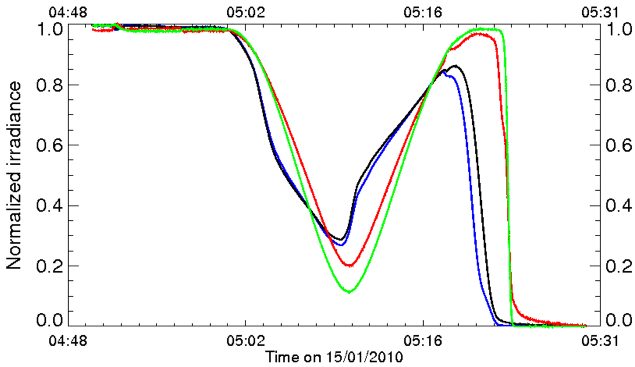
The PROBA2 spacecraft hosts 17 technical developments and four scientific instruments. The latter four concern two particle detectors to monitor the plasma environment of the spacecraft (DSLP and TMPU) and two complementary instruments to observe the Sun (SWAP and LYRA).

The solar instruments SWAP (Sun Watcher using Active Pixel System detector and Image Processing) and LYRA (Large Yield RAdiometer) are being operated from the PROBA2 Science Center at the Royal Observatory of Belgium, part of the Solar Terrestrial Center of Excellence (STCE) in Ukkel, in collaboration with the Mission Operations Center in Redu.

In the five years since its launch, the spacecraft has orbited the Earth more than 25000 times, covering more than a billion kilometres in space. The solar instruments onboard took over 1 million images of the Sun, and recorded over 6000 solar flares!

After all these years in the harsh environment of space, PROBA2's solar images and data are still of such high quality that they are regularly used for scientific research both by the space weather community as in solar physics. The PROBA2 team gratefully took this occasion to express their appreciation to all PROBA2 collaborators who made this possible. On Friday 7 November 2014, a small celebration 5 years of PROBA2 science was organised at the STCE. The celebration commenced with a small toast on PROBA2, where the EUV data proofed not only to be scientifically useful but also tasty. The team made use of the opportunity to look back on some of the highlights of PROBA2's scientific achievements: the SWAP and LYRA observation campaigns resulted not only in a continuous stream of solar data, but provided several high quality data sets of specific events like for example solar eclipses (see figure) and the passage of comet Lovejoy. More details on some highlights are provided on the following webpage: http://proba2.oma.be/birthday





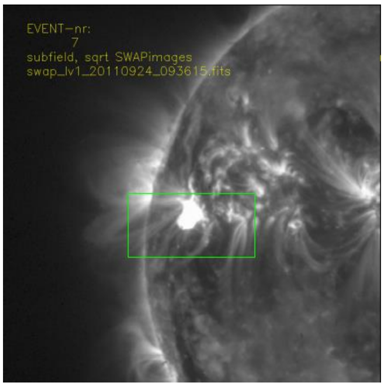
SWAP image and LYRA irradiance plot of the annular solar eclipse on 23 October 2014

The images from SWAP for monitoring the Sun in the 17.4 nm EUV bandwidth, were exploited with the aim to consider and further develop the capabilities of automated image processing methods for detecting solar flares and CMEs. Flares and CMEs are both believed to be different manifestations of magnetic field restructuring, through reconnection (flares) and the expulsion of mass (CMEs). Both of these explosive events are important drivers of space weather. This work was done in a collaboration between the University of Leuven and the Royal Observatory of Belgium (STCE/ROB).

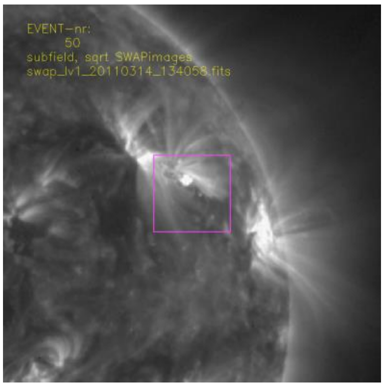
As part of thesi the Solar Feature Automated Search Tool (SoFAST), a software package that automatically processes the SWAP EUV images and localises and identifies dynamic events in near real-time was developed. The SoFAST online event list is available on http://www.sidc.be/sofast.

On one hand, the output of this software tool is intended as a potential service to the Space Weather Segment of ESA's Space Situational Awareness (SSA) program. On the other hand, the PROBA2/SWAP images were considered as a model for the data from the Extreme Ultraviolet Imager (EUI) prepared for the future *Solar Orbiter* mission, where onboard intelligence is required for prioritising data to fit in the extremely limited telemetry quota. Also the first SoFAST EUV event catalogue was compiled by running the tool over more than three years of SWAP data, acquired during the period from April 2010 to June 2013. Not only solar flares have been revealed in the SWAP images in an automated way, the resulting catalogue lists 2171 events covering a variety of typical EUV dynamics, ranging from the smallest EUV brightenings and post-flare loops to jets and large eruptions. Below we provide some example images showing the appearance of the different event types detected by SoFAST in SWAP EUV images.

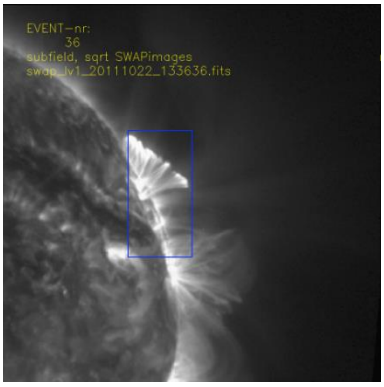
EUV FLARE



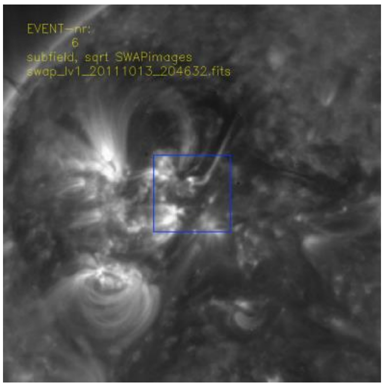
AR TRANSIENT BRIGHTENING



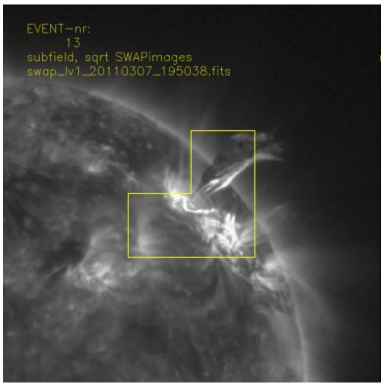
POST-ERUPTIVE LOOPS



CORONAL EUV JET



ERUPTION



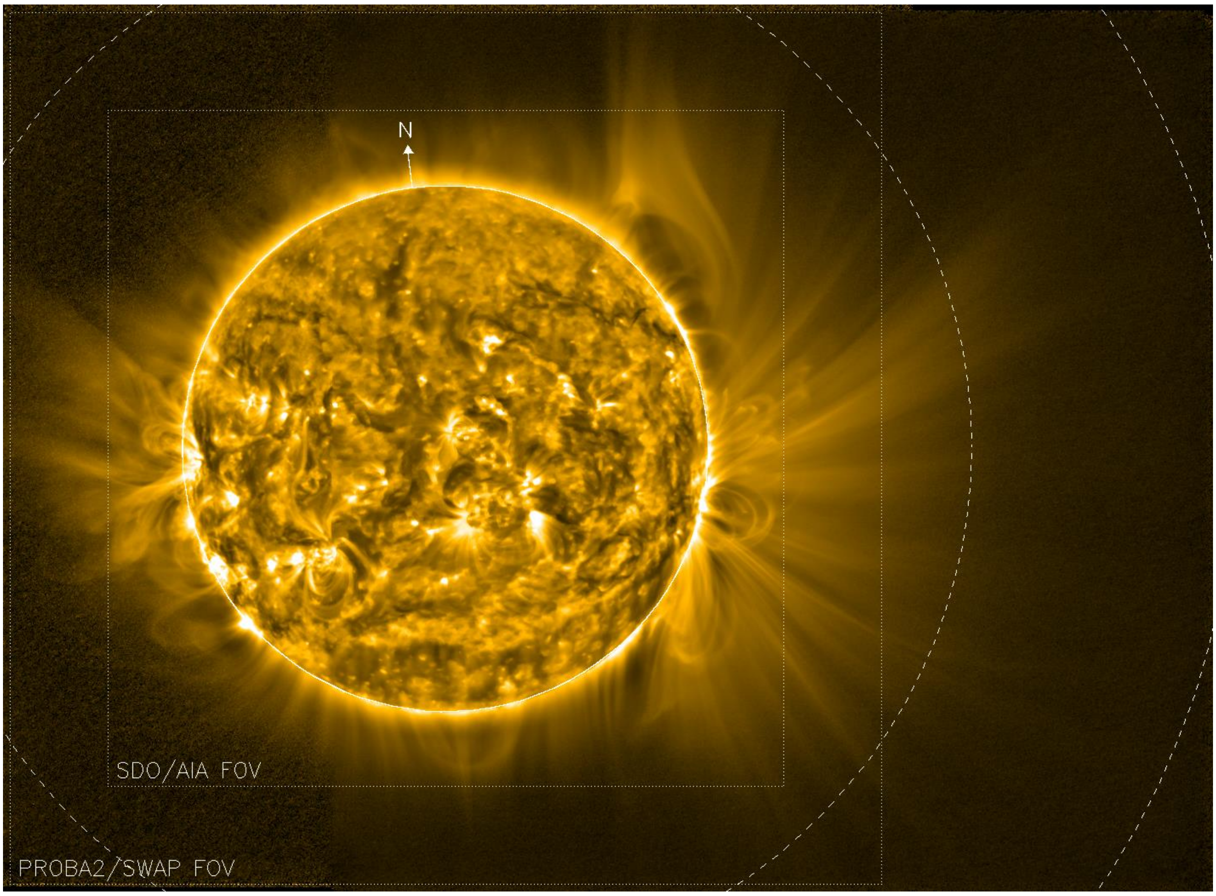
Thank you PROBA2 for bringing these observations to us!

Example images showing the appearance of the different events types detected by SoFAST in SWAP EUV images

The SWAP instrument (Sun Watcher Using APS Detectors and Image Processing)

ROB runs the Science Center (P2SC) for the Sun-observing instruments on PROBA2. PROBA2 is the second satellite in the European Space Agency's series of PRoject for OnBoard Autonomy (PROBA) missions. The SWAP instrument (Sun Watcher Using APS Detectors and Image Processing) is an EUV imager that detects light at a wavelength of 17.4 nm which is emitted by solar coronal plasma at a temperature of about one million degrees Kelvin. PROBA2 was launched in 2009 and since then SWAP has been taking high quality data of the solar corona out to a nominal field-of-view of 1.7 solar radii.

The strength of SWAP compared to other solar EUV imagers relies on its large FOV and it's ability to off-point to view the corona at even higher heights. The extent of the brightness in the corona above the solar disk is dependent on the solar cycle. More features are present at large heights near solar maximum (Seaton et al., 2013). By processing the data to bring out the brightness in the upper corona, the SWAP team at ROB is able to analyze the long-lived features in that region in a more comprehensive way. To facilitate this analysis, we make movies of each Carrington Rotation (one full rotation of the Sun, about 27 days). Using the Carrington movies it is easy to identify large structures, and the 3D nature of the corona is clearly visible as these structures rotate with the Sun.



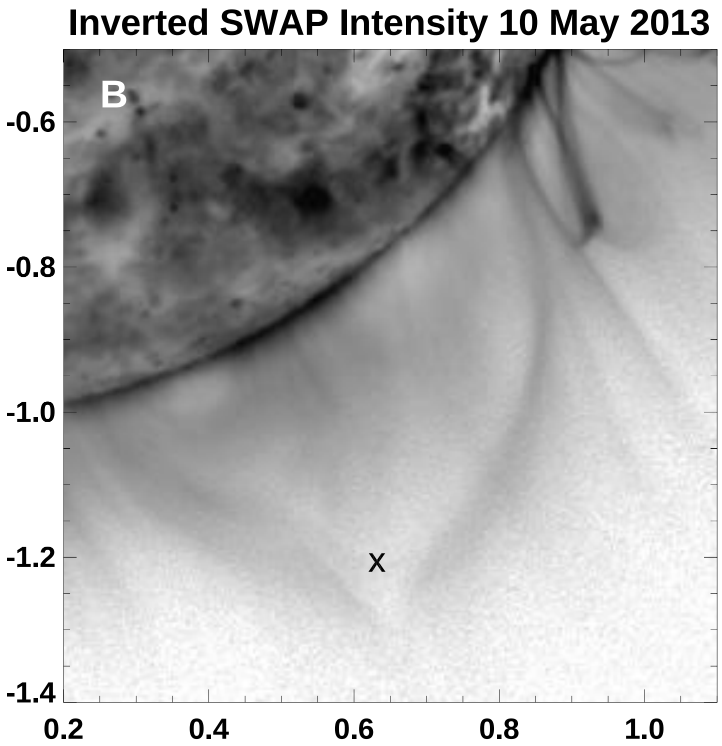
SWAP's large field of view and off-point capabilities capture solar coronal signal out to nearly three solar radii. Data for this mosaic image, which is made from several SWAP images, was taken on 26 November 2014. Dotted lines indicate the field of view (FOV) of SWAP and NASA's AIA EUV imagers. The dashed lines are drawn at intervals of one solar radii.

One long-lived structure that we identified using this type of movie was a pseudostreamer, which is a magnetic structure consisting of two side-by-side closed loop tunnels surrounded by open magnetic field, where all of the open field is of the same polarity. The figure below shows a SWAP image of this SWAP image of a pseudostreamer. The colortable has been inverted so that bright coronal features appear dark. The boundary of the closed and open field forms a cusp-shape. The 'x' marks the uppermost extent of the closed magnetic fieldpseudostreamer, where the cusp-shaped boundary between the open field and the closed loop-tunnels is
clearly seen in the corona. Pseudostreamers are not uncommon in the corona. However, this one is interesting because it was part of a larger stable structure.

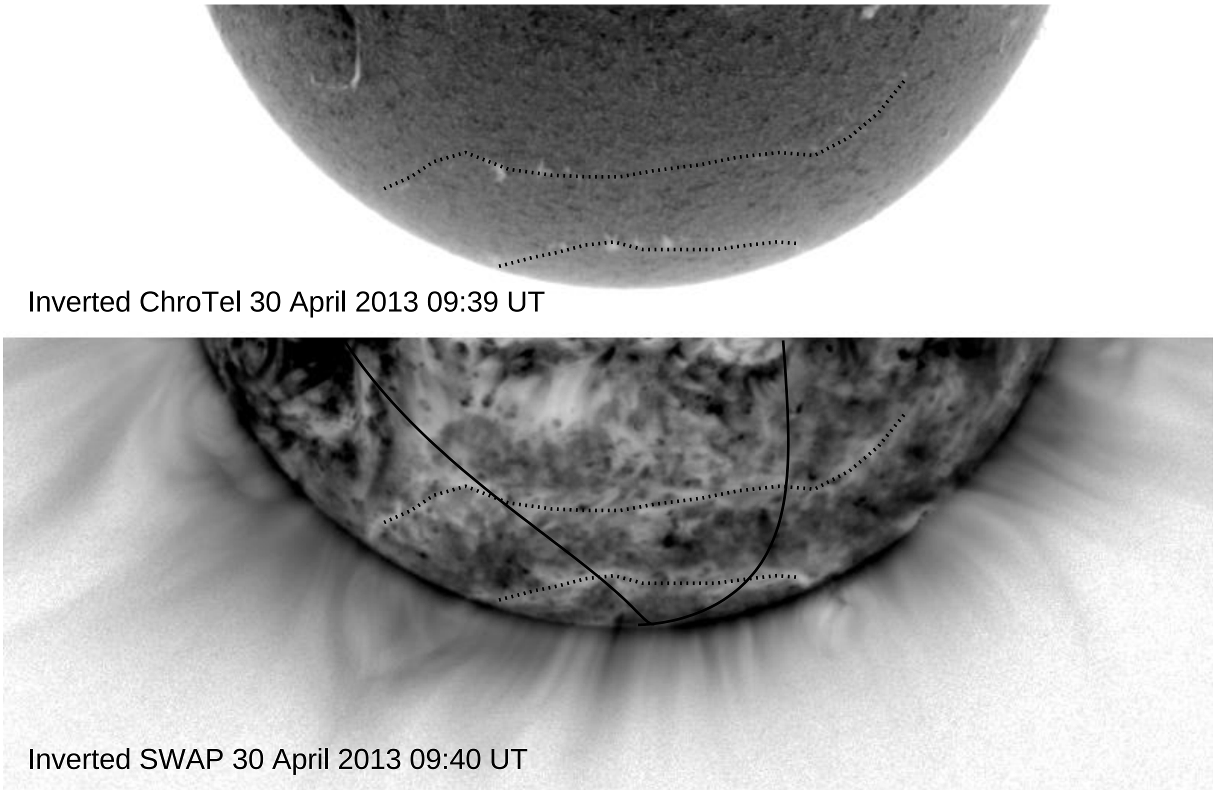
This pseudostreamer had, as usual, two photospheric neutral lines (one in the center at the bottom of each loop-tunnel), which separate different polarities of magnetic field. However, these two neutral lines diverge along the length of the structure. As they diverge, eventually a volume of open field forms between the loops, field that is in the opposite direction of the original pseudostreamer open field. Thus, the single pseudostreamer splits into two streamers, with two current sheets in the upper corona where the various domains of open field meet. The split occurs in space as opposed to in time, so both the pseudostreamer and the streamers are present concurrently.

This elongated structure was visible on the Sun for several rotations, and was seen to reform after eruptions occurred along its length. Rachmeler et al. (2014) presented analysis of SWAP and CoMP (Coronal Multichannel Polarimeter) data to support its magnetic structure identification. This was also the first use of CoMP data for pseudostreamer identification. Unlike EUV imagers, CoMP measures emission line polarization, which is directly sensitive to the magnetic field in the corona.

Following this work, investigations are ongoing for other structures identified in the Carrington movies that have heretofore not been discussed in the scientific literature including coronal fans, and a pseudostreamer at the south pole, both of which are visible in the figure.



SWAP image of a pseudostreamer. The grey scale has been inverted so that bright coronal features appear dark. The boundary of the closed and open field forms a cusp-shape. The 'x' marks the uppermost extent of the closed magnetic field



(top) An inverted Hydrogen-alpha image of the solar disk.

(bottom) An inverted SWAP image of the solar disk. On both images, the dotted lines trace diverging filament channels and closed-loop tunnels, which lie above photospheric neutral lines.

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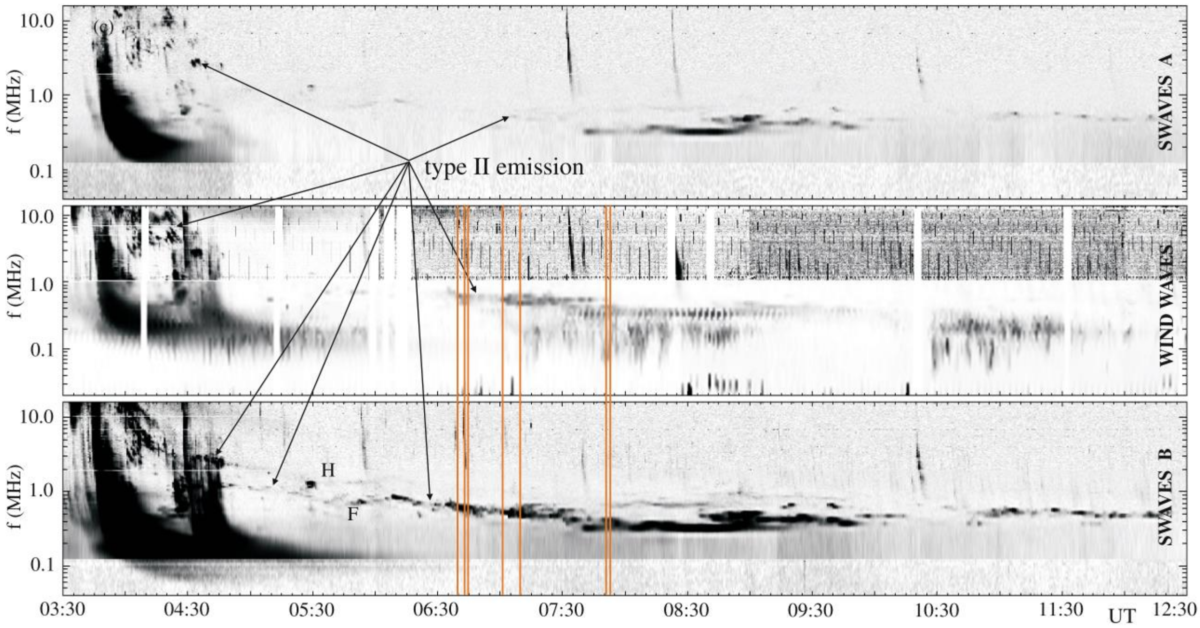
Radio triangulation brings new insights into the CME and CME-driven shock waves physics

The largest eruptive processes in the solar corona are solar flares and coronal mass ejections (CMEs). Solar flare is a process of rapid energy release which causes extensive plasma heating and non-thermal particle acceleration and CME is ejection of plasma confined in erupting magnetic flux ropes, propagating from the inner solar corona into the interplanetary space.

The major energy release during the CME/flare process is followed by the formation of the large scale disturbances and shock waves that travel through the corona and the interplanetary space. Electrons, accelerated at the propagating shock waves can induce radio emission, so called type II radio bursts (Figure 1). Radio observations cover a broad frequency domain, and since different wavelengths correspond to different heights in the solar atmosphere, radio events can be traced from the low corona up to large distances in the interplanetary medium.

The understanding of the physics of the propagation of the CMEs and the CME-driven shock waves is of outmost importance for the Space Weather Forecasting and consequently a lot of effort is being put in the related studies. However, the relative position of the CME, the associated shock wave and its radio signatures (type II bursts) stays a subject of the open debate.

One of the important missing information is radio imaging observations (allows positioning of the radio emission) in the interplanetary range. In order to compensate for this lack of spatial information the specific radio observations, so called radio triangulation measurements (also referred to as direction-finding measurements) from two or more widely separated spacecraft are being studied. With the help of different direction-finding methods the radio triangulation observations allow obtaining the position of the radio emission.



A dynamic spectrum or radio spectrogram is a graphical presentation of the radio emission intensity, recorded at a number of closely spaced single frequencies. In the spectrograms the horizontal x-axis represents time increasing from left to the right and the vertical y-axis represents frequency.

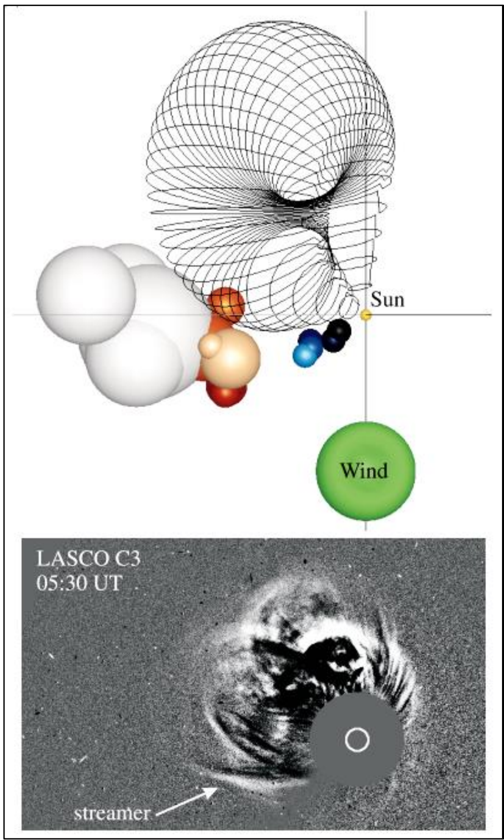
The dynamic spectrum shows radio emission (dark structures) in decameter to kilometer wavelength range. The two top panels show the observations by STEREO/Waves, and the bottom panel is observations by WIND/Waves.

The orange lines indicate times for which radio triangulation analysis was performed.

In the multiwavelength study of the 2012 March 5 solar eruptive event (Magdalenić et al., 2014), radio triangulation observations from STEREO/Waves B and WIND/Waves spacecraft were employed in order to obtain the position of the radio signatures of the shock wave (type II burst) in the interplanetary space. Because of the different types of antenna on these spacecraft, different direction-finding methods were applied for observations from different spacecraft.

An extensive radio triangulation analysis was for the first time applied to different types of radio bursts in the same event. The results of radio triangulation were compared with the CME propagation path reconstructed in three dimensions using SOHO/LASCO coronagraph observations and STEREO COR and HI instruments.It was found that the interaction of the shock wave and a nearby coronal streamer resulted in the intensification of the interplanetary type II radio emission. The source of the type II radio burst was determined to be situated on the southern flank of the CME, and not close to the leading edge of the CME as it is most often assumed. Such a relative position of the radio signatures of the shock wave and the CME explain why, in this and probably also in majority of other CME/flare events, a strong discrepancy can be found between the CME speeds (usually speeds measured at the nose of the CME) and the shock wave speeds inferred from the radio observations (type II bursts).

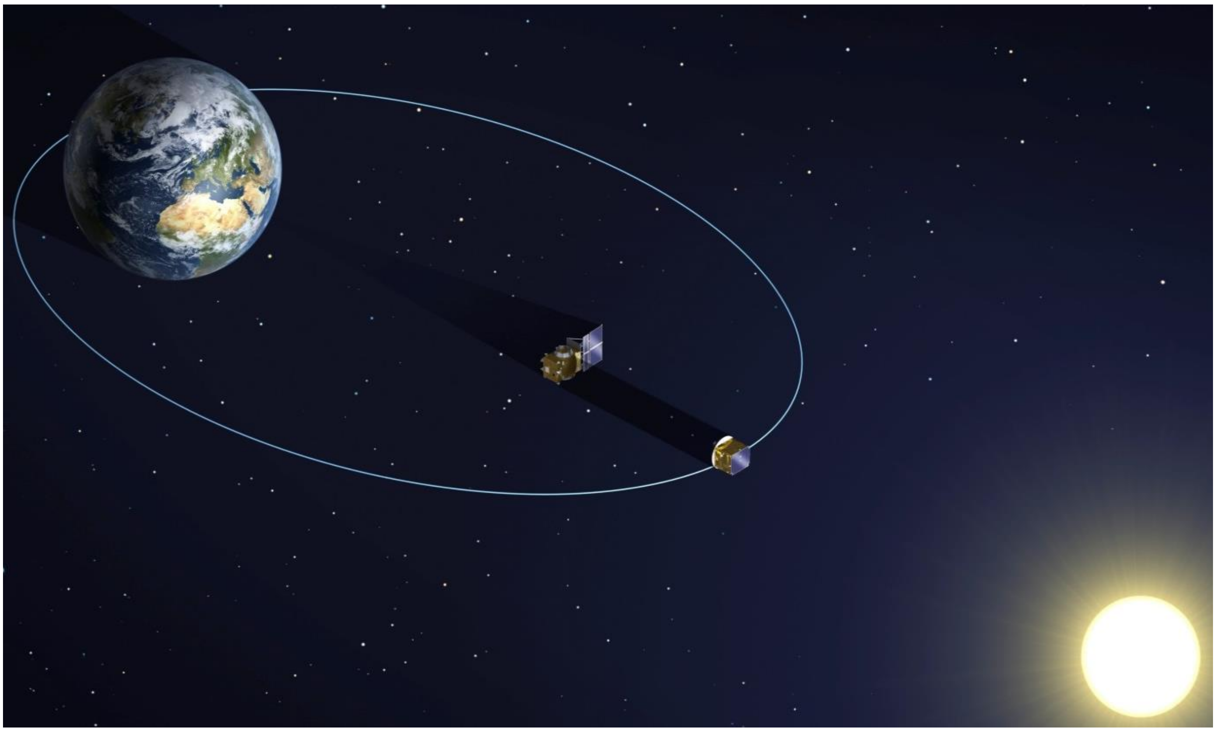
This type of the study is currently possible only for the CME/flare events observed by STEREO/Waves A and WIND/Waves spacecraft due to the, hopefully only temporary, loss of STEREO B observations.



The reconstructed propagation path of the type II radio burst.
The view of the reconstructed type II burst sources (orange to gray spheres) together with the reconstructed CME flux rope, as seen from Earth (upper panel).
The green sphere is the positions of the WIND/Waves spacecraft.
The CME flux rope, obtained from the 3D reconstruction with self-similar expansion, is presented as a black grid croissant. The 3D reconstruction of the streamer situated close to the southern flank of the CME is plotted in dark and light blue spheres. The yellow sphere represents the Sun.

For comparison, the SOHO/LASCO C3 coronagraph image shows the CME as seen from Earth.
The radio source sizes are relative as well as the size of Earth and the Sun.

The project of a new solar coronagraph goes on



An artist's representation (not to scale) of PROBA-3 in a high elliptical orbit observing the solar corona (courtesy: ESA).

After the success of PROBA-1, PROBA2, and PROBA-V missions, the European Space Agency (ESA) is aiming to launch the next spacecraft of the PROBA series (PRoject for On-Borad Autonomy), and the ROB/STCE will take a leading role in its scientific endeavors. The new PROBA, PROBA-3 to be launched in 2019, will be again a technology demonstration mission led by the Department of Technical and Quality Management of ESA. PROBA-3 will feature a unique telescope to observe the corona of the Sun: a giant coronagraph.

A coronagraph is a telescope that allows us to observe the corona in a way very similar to that used during solar eclipses. During a natural total eclipse, the solar disk is occulted by the Moon and one can see the faint corona around it. Instead of the Moon, a ground-based or space coronagraph uses an occulting disk placed inside the telescope. For the PROBA-3 mission, the telescope will be installed on a spacecraft, and the Moon will be replaced by an occulter that will be placed on another spacecraft. This will form a giant coronagraph that will be as close as ever to reproducing the conditions of a natural total solar eclipse. The coronagraph is called ASPIICS, which stands for Association of Spacecraft for Polarimetric and Imaging Investigation of the Corona of the Sun.

To ensure the quality of images taken by ASPIICS, the two spacecraft of the PROBA–3 mission will be moving together as a nearly rigid system along a part of the orbit, thanks to novel technologies of the satellite formation flying. Formation flying means that the two spacecraft will move in coordination and maintain relative distances and orientations with a high precision. The distance between the two spacecraft will be around 150 m, and the position control accuracy for the alignment will be around a few millimeters.

The resulting length of the coronagraph (around 150 m) is unprecedented for solar observations. This will lead to a dramatic reduction of the coronagraph straylight and allow us to see the corona very close to the solar limb, similarly to what is done during a total eclipse. The duration of a total solar eclipse is less than seven and a half minutes, and they occur at most twice per year. ASPIICS will observe the solar corona for two years during six-hour intervals out of the orbit duration of 19.5 hours. The increase in observing time in comparison with eclipses is enormous and will allow us to track the detailed evolution of the large-scale solar corona. ASPIICS will occasionally reach a very high cadence of observations (up to 1 image per 2 seconds), which will allow us to track the physical

processes at fine coronal scales, including coronal waves and magnetic reconfiguration processes that may be responsible for the slow solar wind acceleration. The eclipse-like field of view of ASPIICS will allow us to track the onset and early evolution of coronal mass elections (CMEs), which are the primary drivers of disturbed space weather in the Solar System in general and on Earth in particular.
The work on the PROBA-3 mission started in 2007, but after several years the progress was stalled due to programmatic reasons. Only in 2014 the implementation phase (phase C) was kicked-off both for the spacecraft and for the coronagraph. The spacecraft development is led by SENER, Spain, with QinetiQ Space Belgium responsible for the onboard computer and avionics. The industrial consortium building the coronagraph consists of seven countries and is led by the Centre Spatiale de Liège, Belgium. Solar-Terrestrial Center of Excellence at the Royal Observatory of Belgium hosts the ASPIICS Principal Investigator, Dr. Andrei Zhukov. The ROB/STCE team will guide the industrial team developing the instrument hardware, provide the PROBA-3 Science Operations Center, and lead the science exploitation of the ASPIICS data.

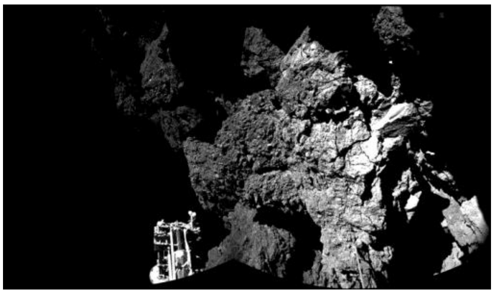
Space Weather Centre provides nowcast and forecast bulletins to support ESA spacecraft operations

Reported by the SSCC operators, the Space Weather forecasters at SIDC and BIRA

The European Space Agency (ESA) has a Space Situational Awareness (SSA) network in place of European space weather products available for end users through a web portal http://swe.ssa.esa.int. The products include ESA owned applications, as well as, European space weather products developed by different European expert groups. The SSCC (SSA Space Weather Coordination Centre) serves as the first point of contact, interlaying between the expert centres and the users of European Space Weather products available through the SSA network.
One of the purposes of the SSCC is to provide support to end-users on aspects related to Space Weather. An excellent example is the regular delivery of space weather bulletins to the operations teams of both the Rosetta and Venus Express spacecrafts.

Space Weather information for Rosetta

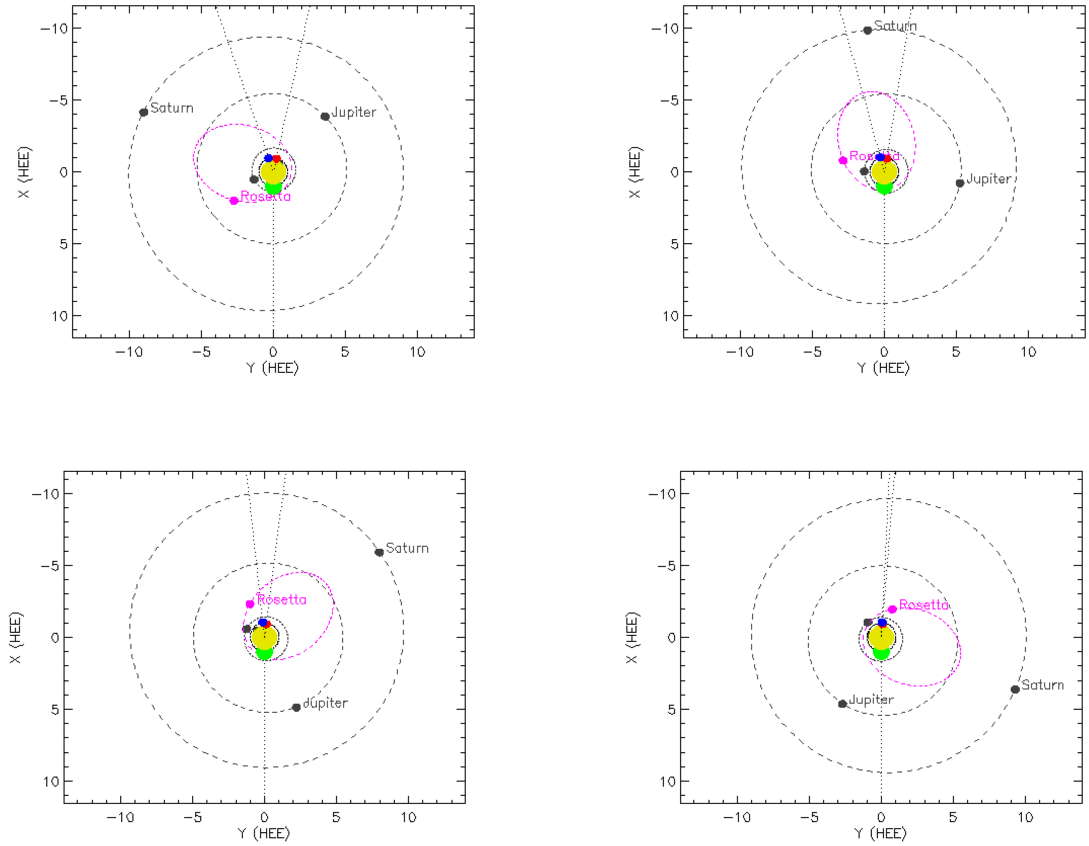
The Rosetta mission is an interplanetary mission whose main objective was to rendezvous with and make in-situ measurements of comet 67P/Churyumov-Gerasimenko. The spacecraft was launched on 2 March 2004 and achieved its rendezvous from 6 August 2014 on. The lander Philae landed successfully at the comet's surface on 12th November 2014. The Rosetta mission accompanies the comet along its orbit around the Sun through its perihelion (August 2015) until the nominal mission ends in December 2015. The spacecraft includes eleven scientific instruments on board as well as a lander (Philae) including ten additional instruments. The Rosetta orbiter and lander spacecraft are controlled by the Rosetta Mission Operations Centre (RMOC) located at ESOC using the ground station New Norcia (Australia).



The lander Philae approaching Rosetta.

The SSCC provided 20 bulletins in 2014 from 13 October on to support the Rosetta mission operations team. Each week one bulletin was sent, while during the month of November one bulletin was sent every two working days. One special bulletin was sent on November 1 at the occurrence of a significant rise of the amount of protons.

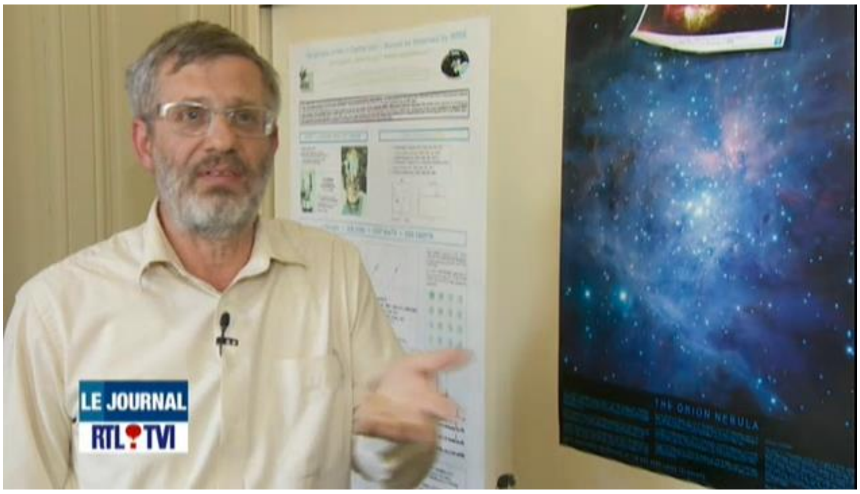
The bulletins (see figure 3) included a description of the past space weather activity and a forecast for the next 2 days, focussing on the activity that could occur near the Rosetta spacecraft. Due to the comet orbit and the Earth orbit around the Sun, the relative position of the spacecraft with respect to the Earth is changing. A solar wind model (top left figure of the example bulletin) was implemented to determine the magnetic connectivity of the Rosetta spacecraft with the active regions on the Sun. This enabled to assess which active regions potentially could create a radiation storm at Rosetta. An instrument was on board of the Rosetta spacecraft to measure any increase of the amount of protons in its environment, due to space weather activity. On disk observations from the viewpoint of Earth taken by PROBA2/SWAP and SDO/AIA and from the backside of the Sun taken by STEREO/EUVI were combined to identify solar activity in regions that were magnetically connected to Rosetta and that could potentially cause space weather events near Rosetta.



Evolution of the relative position of Earth (green), Rosetta, STEREO A (red) and B (blue) spacecraft from 11 September 2014 (top left) to 11 March 2015 (bottom right). (source: NASA SSC)

Information services

Information to public, media and authorities



In 2014 the scientific information service of the ROB had to answer more than 500 questions from the public sent to the ROB by email (about 250, not included the ones related to visits or visit requests), telephone (more then 250) or by letter or fax (50). As usual most were about sunset and sunrise, about astronomical phenomena (including all kind of sky objects) or calendar (e.g. Ramadan) and time related matters. About 90 questions could not be answered on short terms and required more research. Information to the media (TV, radio and written press) was given by the service on numerous occasions. The fireball visible in Belgium on 18/01/2014 was amongst the highlights.

Other members of the ROB appeared in news items on other topics (Solar activity, space weather, seismic activity, Mars, comets and mission Rosetta, exoplanets …).

As each year groups and individual visitors had to be guided in the Observatory this year. The individual visitors were mainly journalists and other media related persons or amateur astronomers with a specific demand and/or students. Groups were, in general, received on the first Tuesday of the month. In order to give some idea on the work load: there were in 2014 29 groups visiting and more than 130 emails (in/out) and 60 telephone calls related to visits or inquiries (excluding open doors). We welcomed, amongst other groups, the Friends of the Museum of Natural Sciences, a group of collaborators of the Human Resources service of the European Commission, participants of a Climate Workshop at the RMI, members of the Belgian Nuclear Society (a summary of ROB activities was given by J. Cuypers during their meeting at the RMI) and a group of Greek students and teachers invited by the European Parliament. Individual visitors included Capt. Brian Connon (head of USNO), Matie Hoffman (Boyden Observatory) and Dr. Tiia Illemaa (Tartu, Estonia).

Open doors

During the weekend October, 11-12 the three institutes in Uccle (ROB, RMI, BISA) welcomed about 7000 visitors for their open doors days. Because of the 50th anniversary of the BISA, this institute made a larger than usual effort for this event. At the Observatory the book “Ukkel 1883-1913 Uccle, l’Observatoire royal, Historique des bâtiments/de Koninklijke Sterrenwacht bouwhistorisch bekeken“ was presented.

The Planetarium

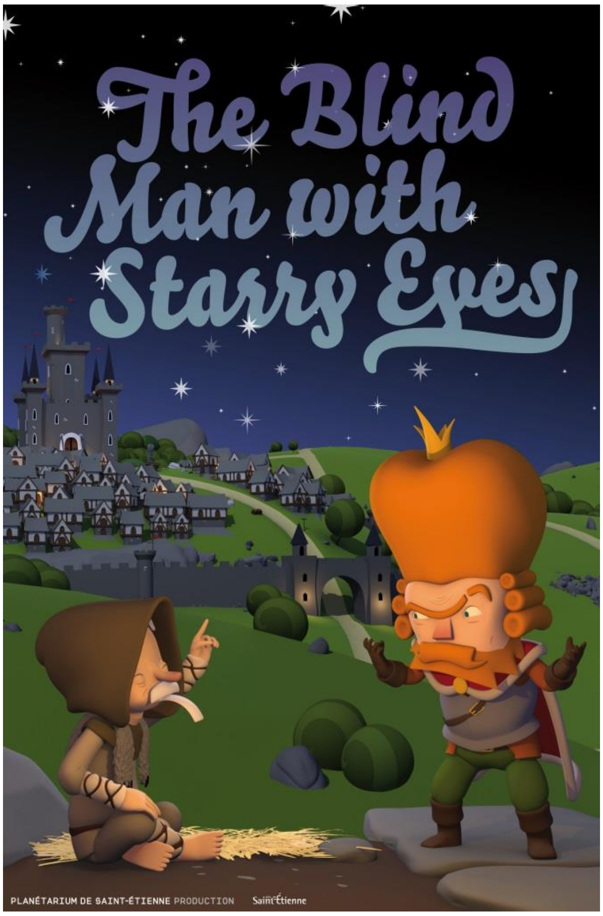
PLANETARIUM.be

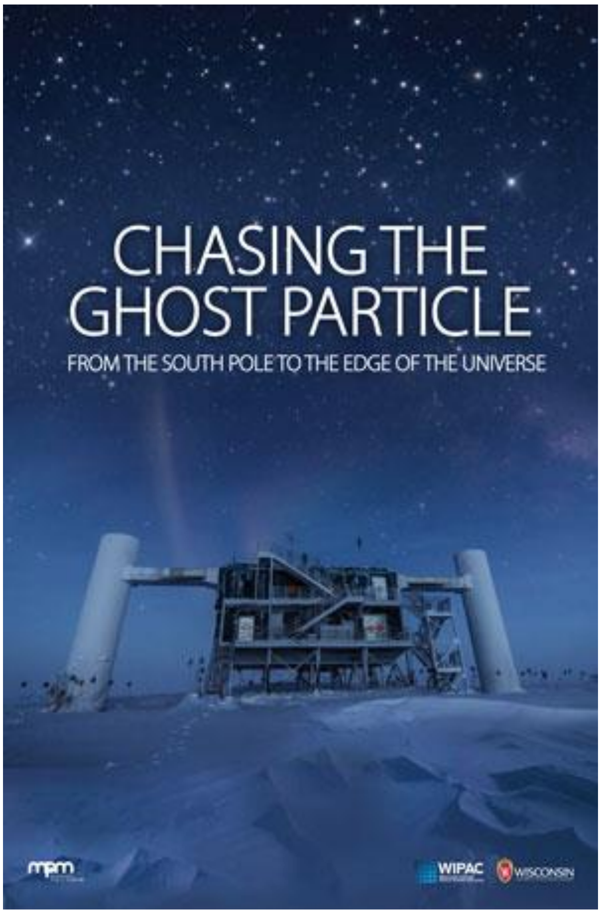
Attendance record for the Internet site of the Planetarium

The Planetarium's website (www.planetarium.be) was visited 131,636 times (91 177 unique visitors, 1,554,744 hits) in 2014, setting the highest total since its inception. It was the most viewed during the months of July and August and during school holidays, which shows that it is used to prepare a family visit, setting the Planetarium as a recognized family outing destination.

New spectacle : « The Blind man with starry eyes »

The new Planetarium show "The Blind man with starry eyes / The blind eyes to the stars." was presented in preview on December 19. It is especially dedicated to children since in the form of graphic storytelling and visual narrative basics of astronomy are explained. This film was produced by the Planetarium of Saint-Etienne and is generally highly appreciated by the public it addresses.





Neutrinos in the spotlight

The planetarium film "Chasing the ghost particle" (production of the University of Wisconsin-Madison) was shown on several occasions in 2014: on October 17 for the Night on Mars (Music, Art, Research, Science) and 6 November and 4 December for the Museums Nocturnes. It is a full-dome movie highlighting the Ice-Cube neutrino detection experiment in Antarctica, and thus allowing the public to learn more about an issue of contemporary but highly specialised research.

Launch of the ATV-5 Georges Lemaître

On August 30, the Planetarium organised a major event to mark the launch of the ATV-5 Georges Lemaître towards the International Space Station. The live broadcast of the launch was accompanied by oral presentations by ESA and scientists of the Space Pole and people from industry and the academic, world under the guidance of Frank De Winne. Despite the inauspicious time (between midnight and 4 am), about 80 participants attended the event.

De heer Philippe Courard
Staatssecretaris voor het Wetenschapsbeleid

De heer Jean-Jacques Dordain
Directeur Generaal ESA

De heer Eric Béka
Hoge Vertegenwoordiger van België voor het ruimtevaartbeleid

De heer Philippe Mettens
Voorzitter van de POD Wetenschapsbeleid

De heer Ronald Van der Linden
Algemeen directeur van de Koninklijke Sterrenwacht van België

hebben de eer U uit te nodigen in het Planetarium van Brussel
op vrijdag 25 juli 2014 vanaf 02u00 in de ochtend

voor het **live volgen van de lancering van ATV-5 Georges Lemaître.**

Dit evenement zal gepresenteerd en van commentaar voorzien worden
door M. Frank De Winne, Hoofd van het European Astronaut Centre.

Antwoord a.u.b. voor 12 juli via: planetarium@planetarium.be (verplichte registratie)

Monsieur Philippe Courard
Secrétaire d'Etat à la Politique scientifique

Monsieur Jean-Jacques Dordain
Directeur général de l'ESA

Monsieur Eric Béka
Haut Représentant de la Belgique pour la politique spatiale

Monsieur Philippe Mettens
Président du SPP Politique scientifique

Monsieur Ronald Van der Linden
Directeur général de l'Observatoire royal de Belgique

ont l'honneur de vous inviter au Planétarium de Bruxelles
le vendredi 25 juillet 2014 à partir de 02h00 du matin

à la **retransmission du lancement de l'ATV-5 Georges Lemaître.**

L'événement sera animé et commenté par M. Frank De Winne, Responsable du Centre des astronautes européens.

First Belgian edition of FameLab

The ESERO bureau located at the Planetarium has participated in the first Belgian edition of FameLab. The selection contest was organised at the Planetarium on April 7. This science competition is an initiative of the British Council and invites young researchers between 21 and 40 to explain a scientific concept in just three minutes. The local laureates participated in the regional Benelux final.

Annex 1: Publications

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Annex 2:
Human Resources

Algemeen directeur: Van der Linden Ronald

A.1. Vastbenoemd personeel / Personnel statutaire

Wetenschappelijk personeel / Personnel scientifique

Name/Nom	Functie/Fonction
Alexandre Pierre	Chef de travaux
Alvarez Rodrigo	Chef de travaux
Berghmans David	Eerstaanwezend werkleider
Blomme Ronny	Werkleider
Bruyninx Carine	Werkleider
Camelbeeck Thierry	Premier chef de travaux
Clette Frédéric	Chef de travaux
Collin Fabienne	Chef de travaux
Cuypers Jan	Werkleider
De Cat Peter	Werkleider
Defraigne Pascale	Chef de travaux
Dehant Véronique	Premier chef de travaux
Frémat Yves	Chef de travux
Groenewegen Martin	Werkleider
Hochedez Jean-François	Chef de travaux
Lampens Patricia	Onderzoeksleider
Lecocq Thomas	Assistant
Legrand Juliette	Chef de travaux
Pauwels Thierry	Eerstaanwezend werkleider
Robbrecht Eva	Assistant
Roosbeek Fabian	Chef de travaux
Van Camp Michel	Premier chef de travaux
Van De Steene Griet	Werkleider
Van Hoolst Tim	Eerstaanwezend werkleider
Vanneste Kris	Werkleider
Yseboodt Marie	Chef de travaux

Technisch en administratief personeel / Personnel technique et administratif

Name/Nom	Functie/Fonction
Asselberghs Somnina	Technisch deskundige
Bizerimana Philippe	Assistant technique
Boulvin Olivier	Expert technique
Brebant Christian	Assistant administratif
Bruyninckx Martine	Administratief assistent
Bukasa Baudouin	Expert technique
Castelein Stefaan	Technisch deskundige
Claerhout Alexandre	Expert ICT
Coene Yves	Expert technique (overleden op 16/10/2014)
Consiglio Sylvia	Administratief assistent
Danloy Jean-Marie	Assistant administratif
De Knijf Marc	Attaché A2
De Wachter Rudi	Technisch assistent
Depasse Béatrice	Assistant administratif
Dufond Jean-Luc	Attaché A2
Dumortier Louis	Expert ICT
Duval David	Expert ICT
Ergen Aydin	Expert technique
Feldberg Liesbeth	Administratief assistent

Frederick Bert	Expert technique
Hendrickx Marc	Expert technique
Herreman David	Expert ICT
Jacques Jean-Claude	Expert technique
Jans Thimoty	Attaché A1
Janssens Paul	Assistant technique
Kochuyt Anne-Lize	Attaché A1
Langenaken Hilde	Technisch deskundige
Lemaitre Olivier	Expert technique
Martin Henri	Expert technique
Mesmaker Dominique	Expert technique
Milis Andre	Adviseur A3
Moyaert Ann	ICT deskundige
Rapagnani Giovanni	Attaché A1
Rezabek Oleg	Attaché A1
Rogge Vincent	Attaché A2
Somerhausen André	Expert ICT
Strubbe Marc	Technisch deskundige
Trocmet Cécile	Assistant administratif
Van Camp Lydia	Technisch deskundige
Van de Meersche Olivier	Expert financier
Van De Putte William	Technisch deskundige
Van Den Brande Theophilis	Technisch assistent
Van Der Gucht Ignace	Technisch deskundige
Vandekerckhove Joan	Technisch deskundige
Vanden Elshout Ronny	Assistant technique
Vandercoilden Leslie	Expert technique
Vanraes Stéphane	ICT deskundige
Verbeeren Anja	Administratief deskundige
Vermeiren Katinka	ICT deskundige
Vermeylen Lore	Technisch deskundige
Wellens Véronique	Attaché A1
Wintmolders Sabrina	Administratief deskundige

A.1. *Personeel met externe beurzen / Personnel sur bourses externes*

Name/Nom	Functie/Fonction
Gloesener Elodie	Boursier FRIA
Kusters Dimitri	Boursier FRIA
Koot Laurence	Boursier FNRS

A.2. Contractueel personeel beheerd door de POD Wetenschapsbeleid / Personnel contractual géré par le SPP Politique Scientifique

Name/Nom	Functie/Fonction
De Dobbeleer Rudy	Technisch assistant
Malisse Vincent	ICT-deskundige (vanaf 01/01/2014)
Motte Philippe	Collaborateur technique
Mouling Ilse	Administratief assistent
Semeraro Vanessa	Administratief assistant
Vandersyppe Anne	Administratief expert
Vanparijs Thomas	Technisch medewerker (vanaf 01/08/2014)

A.3. Contractueel personeel / Personnel contractuel

Wetenschappelijk personeel / Personnel scientifique

Naam/Nom	Functie/Fonction
Aerts Wim	Assistent
Andries Jesse	Werkleider (tot 31/01/15)
Baire Quentin	Assistant
Benmoussa Ali	Chef de travaux
Berckmans Julie	Assistent-stagiaire (tot 31/03/14)
Bergeot Nicolas	Chef de travaux
Beuthe Mikael	Chef de travaux
Bonte Katrien	Assistent (vanaf 01/09/14)
Bourgoignie Bram	Assistent
Caudron Corentin	Assistant
Champagne Georges	Assistant
Chevalier Jean-Marie	Assistant
Dammasch Ingolf	Assistant
De Cuyper Jean-Pierre	werkleider
Delouille Véronique	Chef de travaux
De Visscher Ruben	Assistent-stagiair (tot 31/07/14) Assistent (vanaf 01/08/14)
Devos Andy	Assistent
D’Huys Elke	Assistent
Dolla Laurent	Assistant
Dominique Marie	Assistant
Garcia Moreno David	Assistant (tot 31/07/14)
Gillmann Cédric	Assistant (jusqu’au 15/11/14)
Giordanengo Boris	Chef de travaux
Gissot Samuel	Chef de travaux
Janssens Jan	Assistent
Joukov Andrei	Chef de travaux
Huang Wei	Assistent-stagiaire (vanaf 16/02/14)
Karatekin Ozgur	Chef de travaux
Knuts Elisabeth	Assistant
Kraaikamp Emil	Assistent stagiair (tot 28/02/15)
Kudryashova Maria	Assistant (tot 31/08/14)
Lefevre Laure	Assistant
Lobel Alex	werkleider
Lombardini Denis	Assistant
Magdalenic Jasmina	Chef de travaux
Martinez Picar Antonio	Assistent
Marqué Christophe	Chef de travaux
Mierla Marilena	Assistent (tot 31/07/2016)

Mitrovic Michel	Assistant
Nicula Bogdan	Chef de travaux
Noack Léna	Assistant (tot 01/10/2014)
Parenti Suzanna	Chef de travaux
Podladchikova Olena	Chef de travaux
Pottiaux Eric	Chef de travaux
Pylyser Eric	Assistant
Rachmeler Laurel	Assistent (tot 01/04/2015)
Ryan Daniel	Assistant (tot 15/01/2015)
Rivoldini Attilio	Assistant
Rodriguez Luciano	Chef de travaux
Rosenblatt Pascal	Chef de travaux
Seaton Daniel	Chef de travaux
Sodor Adam	Assistent (tot 01/07/2014)
Stegen Koen	Assistent
Trinh Anthony	Assistent (tot 28/02/2014)
Van Hoof Peter	Werkleider
Van Hove Bart	Assistent (tot 30/09/2015)
Vanlommel Petra	Eerstaanwezend assistent
Van Noten Koen	Assistent (tot 30/06/2016)
Vansintjan Robbe	Assistent (tot 31/03/2015)
Verbeeck Francis	Eerstaanwezend assistent
Verbeeck Koen	Assistant
Verbruggen Wim	Assistent-stagiaire (tot 30/09/2014)
Verdini Andrea	Assistant
Verstringe Freek	Assistent
Vleminckx Bart	Assistent-stagiaire Assistent (vanaf 01/03/2014)
Wauters Laurence	Premier assistant
West Matthew	Assistant
Zhu Ping	Assistant (tot 31/12/2014)

Technisch en administratief personeel / personnel technique et administratif

Naam/Nom	Functie/Fonction
Bastin Véronique	Expert technique
Coeckelberghs Hans	Technisch deskundige
Cornet Denis	Attaché A1
De Decker Georges	Attaché A2
Delmeule Nicolas	Expert ICT
El Amrani Malika	Collaborateur technique
Gonzales Andres	Administratief medewerker
Hanjoul Michel	Attaché A2
Herman Viviane	Collaborateur technique
Hernando Ana Maria	Assistant administratif
Ipuz Mendez Adriana	Collaborateur technique
Kurudere Hulya	Technisch medewerker
Mampaey Benjamin	Attaché A2
Mestdagh Pieter	Attaché A1
Reghif Harraz Mohammed	Collaboratuer technique
Rigo Ghislain	Expert technique (tot 31/01/15)
Smet Gert	Technisch assistent
Stokart Luc	Technisch assistent (vanaf 14/10/14)
Trindade Josefina	Collaborateur technique (tot 30/06/14)

Van Elder Sophie	Attaché A1
Van Hemelryck Eric	Attaché A2
Vandeperre Arnold	Technisch assistent
Vander Putten Wim	ICT-deskundige
Verbraeken Ulrike	Technisch medewerker (vanaf 01/10/14)
Vermeylen Jacqueline	Collaborateur technique
Wijns Erik	Technisch medewerker
Willems Sarah	Attaché A2

A.4. Gedetacheerd personeel / Personnel détaché

Naam/Nom	Functie/Fonction
Duynslaeger Thierry	Leraar (Onderwijs Vlaamse Gemeenschap)