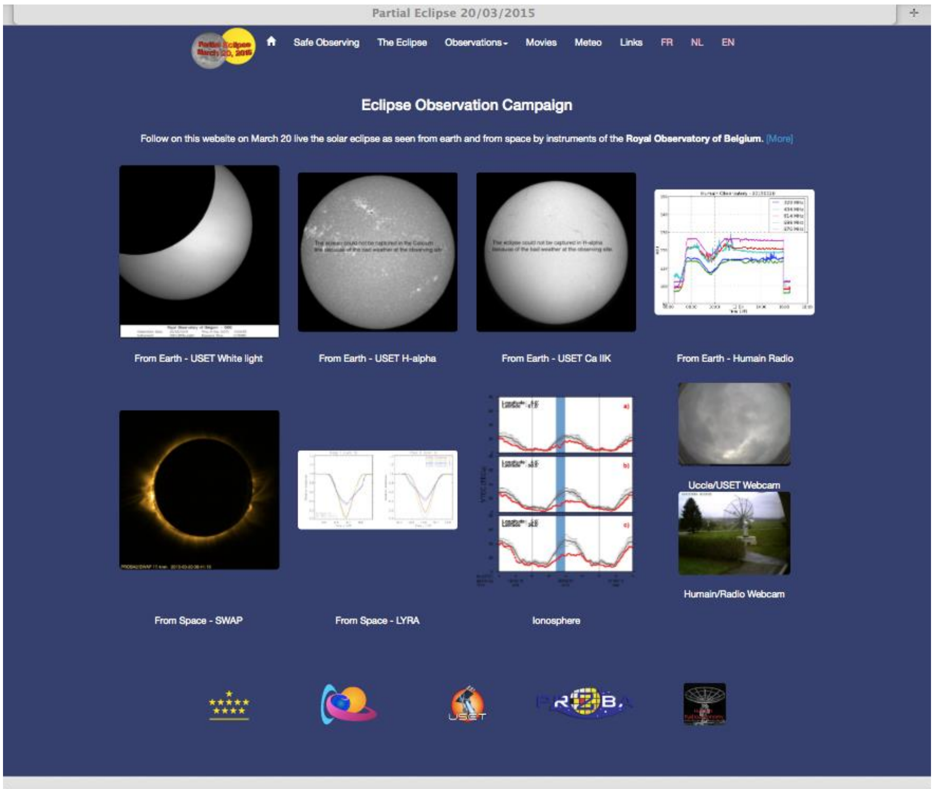
Koninklijke Sterrenwacht van België
Observatoire royal de Belgique
Royal Observatory of Belgium



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Cover illustration: ***Screen shot of the website created for the partial solar eclipseof March 20, 2015 (updated with results by Petra Vanlommel, STCE, ROB)***

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Table of contents

Preface

This report describes the highlights of scientific activities and public services at the Royal Observatory of Belgium in 2015.

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.*

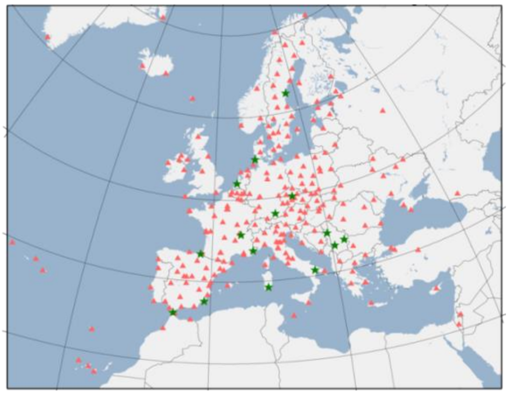
Space geodesy with GNSS (Global Navigation Satellite System)

Global Geodetic Reference Frame for Sustainable Development

In February 2015, the UN General Assembly adopted (with the support of Belgium and ROB) the resolution "A Global Geodetic Reference Frame for Sustainable Development", the first resolution recognizing that geodesy is fundamental for monitoring changes to the Earth. The resolution outlines the value of ground-based observations (such as GNSS) and remote satellite sensing when tracking changes in populations, ice caps, oceans and the atmosphere over time. It calls for greater multilateral cooperation in geodesy, including the open sharing of geospatial data, to maintain the Global Geodetic Reference Frame (such as the International Terrestrial Reference Frame – ITRF). This resolution is important for ROB because it outlines the societal importance of ROB's GNSS observations in Uccle, which contributes to the ITRF as well as ROB's role in the EUREF regional GNSS network, which is the European densification of the ITRF primary network, and allows an easy access and alignment of national reference frames to the ITRF.

GNSS station at ROB that is ensuring the contribution of Belgium to the ITRF

EUREF Permanent GNSS Network (EPN)



EPN GNSS tracking stations, status Dec. 2015. Green stars (*) indicate new stations included in 2015

The European Terrestrial Reference System (ETRS89), which is the European component of the ITRF, is maintained and distributed through the EUREF Permanent GNSS Network (EPN). ROB is responsible for the EPN Central Bureau (CB) that performs the daily monitoring and management of the EPN. In 2015, ROB integrated 16 new stations in the EPN network: 4 in Spain, 1 in Sweden, 2 in Italy, 2 in France, 3 in Serbia, 1 in Czech Republic, 1 in the Netherlands, and 2 in Germany.

The EPN CB web site (http://www.epncb.oma.be) received in 2015 a monthly mean of 8700 visits from 3800 unique visitors. The EPN CB ftp site received a monthly mean of 4350 visits (mean of 1 300 000 hits/month) from 360 unique visitors.

Measuring ground deformations using GNSS

GNSS–based deformation monitoring is performed at ROB by computing each day the position of the continuous observing GNSS sites. These positions are obtained with a reliability of 2-3 mm in the horizontal and 5-6 mm in the vertical components. Using these daily site positions over a period of more than 3 years, we can obtain very precisely the movement of the site.

Construction of the European Plate Observing System – EPOS - started

As one of the partners in the EPOS-IP H2020 project (kick-off Oct. 2015), ROB participates now to the construction of the European Plate Observing System (EPOS), one of the large European research infrastructures that focuses on the understanding of the Solid Earth through the integration of multi-disciplinary observations. In this new H2020 project, ROB is responsible for the preparation of the consortium agreement for the GNSS component of EPOS and the development of GNSS metadata management software.

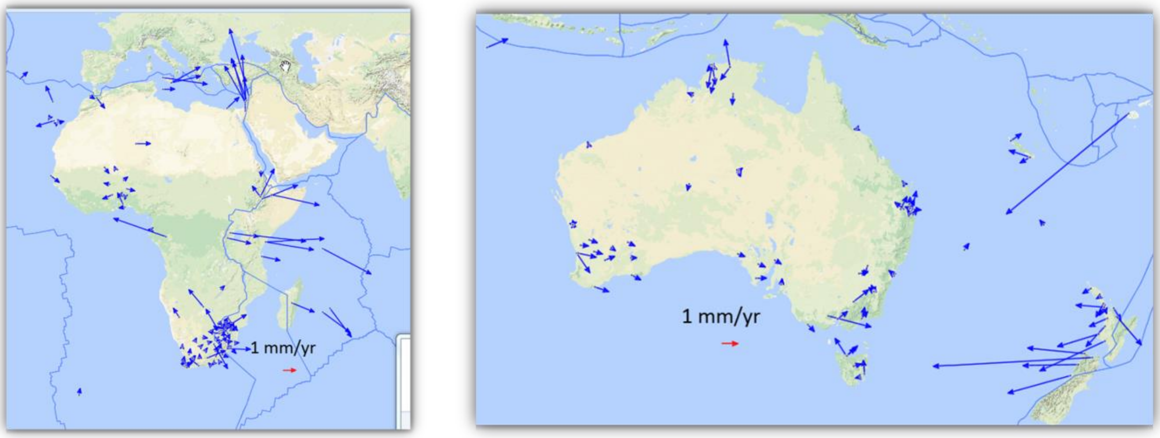
A member of ROB was also elected chair of the EPOS Implementation Phase Council (IPC) and was also invited to join the EPOS Project Development Board (PDB). According to the EPOS-IP Grant Agreement, the IPC deals with all issues concerning the consortium and the grant agreement; the PDB drives the consortium and interacts with the Board of Governmental Representatives for decisions concerning the EPOS construction.

Belgium

ROB has validated in 2015 the accuracy of the positions and velocities of the Belgian dense GNSS network that were computed in 2014 by analyzing the noise processes of position time series. It was demonstrated that the formal errors outcome of the GNSS least-squares adjustment need to be multiplied by a mean factor of 2.6 for the vertical and 4.3 for horizontal velocity field. First comparisons of the GNSS vertical velocity field w.r.t. gravity measurements and INSAR measurements show promising results. Using the data from the GNSS receivers of all our permanent stations, as well as using the data from GNSS stations operated by the regions, we evaluated the ground deformations in Belgium and found no significant deformations in the horizontal while in the vertical there seems to be a small subsidence (about 1 mm/year level) in the region of the Belgian coast.

At the global scale

ROB has densified, improved and analyzed the global combination of a dense velocity field containing about 2800 GNSS stations. Based on the updated velocity field (June 2015), intraplate deformations for the major tectonic plates were derived. We have also highlighted the very good agreement with ITRF2008 plate motion model and the quality of the estimated combined velocity field that shows very small residual velocities in non-deforming zones.



Residual velocity field for African and Nubian plates (left) and Australian plate (right)

Improving the knowledge of the Earth's atmosphere

As GNSS signals travel through the Earth's atmosphere, they contain information on the state of the ionosphere and the troposphere. To extract this information from GNSS signals, networks of continuously observing GNSS stations, with well-known station positions, are used. For that purpose, members of the ROB "GNSS project" maintain a network of continuously observing GNSS stations and contribute actively to the elaboration and extension of the European GNSS network, known as the EUREF Permanent Network (EPN). In a second step, the GNSS data from these networks are used to compute information on the state of the Earth's ionosphere and troposphere.

Troposphere

ROB uses the observations from permanently tracking GNSS stations for the monitoring of short-term tropospheric variations (linked to meteorological applications and short-term forecasting) and for assessing long-term tropospheric trends (linked to re-analysis and climate applications).

The BRAIN-BE project "COmbining Regional Downscaling EXpertise in Belgium: CORDEX and Beyond" (CORDEX.be) was kicked-off in Brussels on March 31, 2015. This project includes the major actors (4 FSI: ROB, RMI, BISA, RBINS – VITO – 3 universities: UCL, KUL, ULg) involved in climate research in Belgium. In 2015, ROB developed the methodology to produce climate-quality GNSS tropospheric delay time series. This method will be used in 2016 to analyze GNSS observations for the period 2000-2010 and deliver a climate-quality dataset which will be utilized by the project partners to validate their high-resolution climate model runs over Belgium.

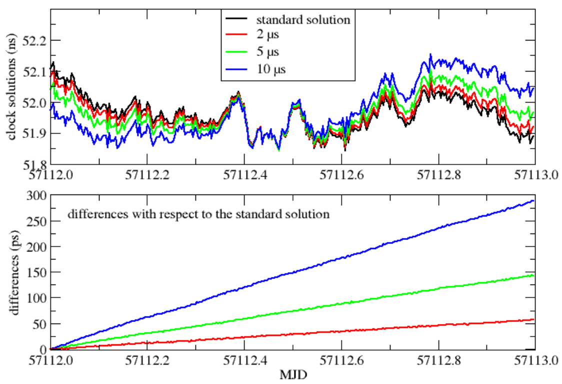
ROB also installed a new world-wide hourly troposphere monitoring service, contributing to the EUMETNET E-GVAP program in support of data assimilation in global Numerical Weather Prediction (NWP) models (such as those at Météo France and the U.K. Met Office).

World-wide Network of GNSS stations analyzed every hour by the new global troposphere monitoring in support of global NWP models (Status: January 2016)

Two benchmark datasets were provided to Royal Meteorological Institute (RMI) to validate the ingestion of GNSS-based tropospheric zenith path delays in the data assimilation system of their high-resolution NWP model ALARO. First results showed neutral to positive impact of the GNSS data products on the statistic score on the short-range forecast, showing the capability of ALARO to better capture the humidity field when assimilating GNSS results. To improve these results even further, ROB started estimating slant tropospheric delays. First results show that our slant tropospheric delays are of similar quality as the datasets provided by other COST partners with strong expertise in estimating slant delays (e.g. GFZ, Germany).

Time transfer and scale

Precise time transfer for timescales

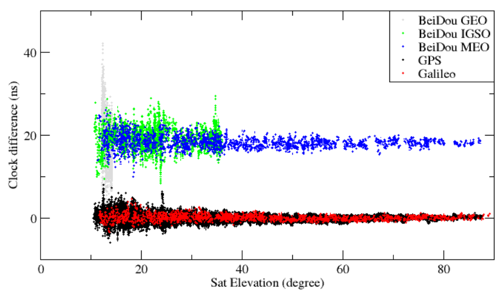


Impact of a given delay between the code and carrier phase latching simulated with the Doppler frequency determined from the carrier phase data

ROB Service 1 works on time-transfer, an essential part of the realization of timescales. ROB has developed tools available for the scientific community and based on GNSS. The principle consists in connecting the atomic clocks that we want to monitor in different remote laboratory to GNSS receivers. By analyzing the GNSS observations, it is possible to determine the synchronization error between the clock connected to the GNSS receiver and the satellite clocks. As the GNSS provides in the navigation message the synchronization errors between the satellite clocks and a reference time scale, one deduces the synchronization error between the clock connected to the GNSS receiver and the reference time scale of the GNSS. The classical "common-view" approach of time transfer has been replaced by a more complex method using GNSS signals in an optimal way in order to improve both the precision and accuracy of the clock comparisons. ROB has found recently the origin and solved a longstanding issue in time transfer, making an apparent frequency difference between the code and phase solutions, two methods used for positioning and time-transfer. It was due to the existence of some delay between the code and phase measurement made by the receiver. The effect was then quantified with simulations. ROB demonstrated that the effect can efficiently be modelled using the estimated Doppler frequency determined from the phase data and that the frequency difference in the clock solution is directly proportional to the delay between the code and phase measurements: for a delay of 1 µs, a daily drift in the PPP (Precise Point Positioning) solution will appear with a magnitude of 30 ps for a mid-latitude station. This very important result gave rise to a recommendation at the last CCTF (Consultative Committee for Time and Frequency) in September 2015. It was published with peer-review in IEEE and furthermore was published in December in "Inside GNSS", a printed magazine that reaches an international audience of 35,000 people, also available freely online.

Time transfer for users

ROB Service 1 has upgraded the R2CGGTTS software developed at ROB for standard GNSS time transfer, to include the satellites from the Chinese GNSS constellation BeiDou. This constellation comprises Geostationary (GEO) satellites, Medium Earth Orbit (MEO) satellites and Inclined Geo-Synchronic Orbit (IGSO) satellites. It was shown that only the signals from the MEO satellites could provide Time Transfer results with the same quality level as GPS satellites do. However, some satellite elevation-dependent variations were pointed out, revealing some multipath of the signal at the satellite level.



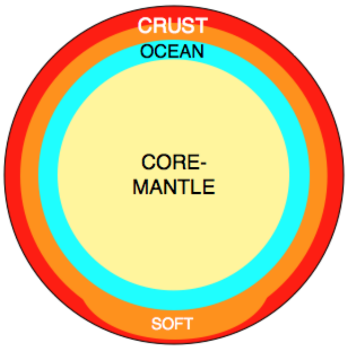
Time Transfer noise using different GPS, Galileo and BeiDou satellites, as a function of the satellite elevation

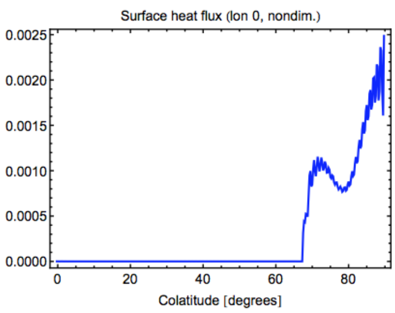
Planetary Science

A global subsurface ocean for Enceladus

In 2015, small variations in the rotation rate of the mid-sized icy moon Enceladus have been observed by an American team. These librations are due to the gravitational torque of Saturn on the non-spherically symmetric mass distribution of the satellite. ROB Service 1 demonstrated that the observed libration amplitude of Enceladus indicates that Enceladus has a global subsurface ocean and that the ice shell is on average between 14 km and 26 km thick. In an independent study, it was also shown that the obliquity of Enceladus is too small to explain the observed heat flow by obliquity tides, even when the effect of an internal ocean and of elasticity is taken into account.

ROB Service 1 showed that the observed libration amplitude is at least 4 times larger than that expected for an entirely solid satellite or a satellite having local liquid regions. Therefore, a partially decoupling layer must exist. Given the composition of Enceladus, this demonstrates that the small satellite Enceladus, like the largest icy satellites of the solar system, must have a global subsurface ocean. Such a hypothesis is not unexpected since Enceladus has active geysers at its south polar region, but nevertheless is not easily explainable in terms of the thermal evolution of the satellite. ROB Service 1 showed that, in contrast to the large icy satellites, the existence of a global subsurface ocean can strongly increase the libration amplitude. This difference in behavior is essentially due to the much smaller tides on Enceladus. ROB Service 1 showed that the libration mainly depends on the thickness of the ice shell for realistic values of the ice rigidity and viscosity. Enceladus deviates from hydrostatic equilibrium of Enceladus, as indicated by the observed gravity field and topography, and affects the libration by changing the principal moments of inertia of the ice shell and therefore also the torques exerted on the shell. The non-hydrostatic structure was modelled in two ways: ROB Service 1 assumed that the bottom of the ice shell is not an equipotential surface or that the interface between the core and the ocean does not correspond to an equipotential surface. The other surface is assumed to be an equipotential surface of the self-gravitational potential, the centrifugal potential and the static tidal potential. The final results showed that even without precise information on the rigidity and viscosity of the ice and on the non-hydrostatic structure, the ice shell can be shown to on average between 14 km and 26 km thick. The thickness of the ice shell at the South Pole can be as thin as 3 km.





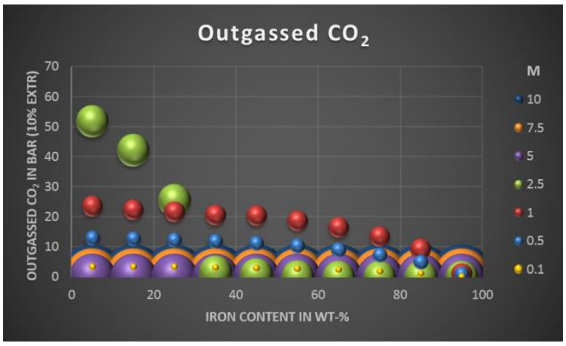
Localized dissipation within Enceladus' crust due to softer rheology at the south pole

We also applied the membrane theory to Enceladus with the aim of finding an explanation for the anomalous heating at the south pole of this moon. We developed a new `3D' thin shell theory describing the viscoelastic deformation of an icy crust with variable thickness and depth-dependent rheology and showed that tidal dissipation at the South Polar Region can be largely increased assuming a softer rheology there.

Interior structure of super-Earths

ROB Service 1 studied the interior structure, dynamics and evolution of super-Earths and water-rich exoplanets. The stability of putative mantle mineral phases and their equations of state as well as ultra-high pressure thermoelastic properties of the stable iron phases were investigated with several external scientists. Solid iron properties at high to very high pressure (even extending the ultra-high pressures expected in super-Earths) were determined on the basis of first-principles quantum mechanical calculations. Suitable equations of state to the ab initio data were studied and significant differences with equations of state used in the exoplanet literature were discovered. We also examined the extrapolation of different equation of state formulations for mantle minerals to ultra-high pressures since thermoelastic properties for pressures larger that 100GPa are generally not available for most mantle mineral phases. Mantle mineral phases for exoplanets were calculated with a new code for the equations of state. The results show that for pressures below 500GPa, the deviations in density between the different equation of state formulations is below 2% and that it can be as large as 10% if the pressure is larger than 1TPa. We are currently investigating the implication of those findings on the mass-radius relation of different classes of solid super-Earths.

We also studied the influence of the interior structure and mass of exoplanets on the occurrence of melting. The built-up of an atmosphere through outgassing from the planetary interior was studied for terrestrial exoplanets with masses ranging from Mars-size to Super-Earth-size with up to 10 Earth masses. Is was shown that one-plate planets may suffer strong volcanic limitations if their mass and/or iron content exceeds a critical value, leading to insufficient greenhouse effect needed for the outer boundary of the habitable zone, thus reducing their possible surface habitability.



Melt depletion for terrestrial planets of different mass and composition after 4.5 Gyr for Earth-like initial conditions and heat sources

The thermal evolution of exoplanets with a thick outer water layer was investigated and the habitability of the deep water layers was characterized. H_2O layers thicker than about 150 kilometers will consist of solid ice below a surface water layer, although the heat from the silicate mantle can melt the ice above the mantle from below, depending amongst others on the thickness of the ocean-ice shell and the mass of the planet. Deep water-ice layers may hinder the existence of volcanism at the water-mantle boundary due to the high pressure for both stagnant lid and plate tectonics silicate shells. A large planet mass, a high average density and a low surface temperature all result in a reduced habitability of water-rich planets with a deep ocean compared to a planet with an Earth-like ocean.

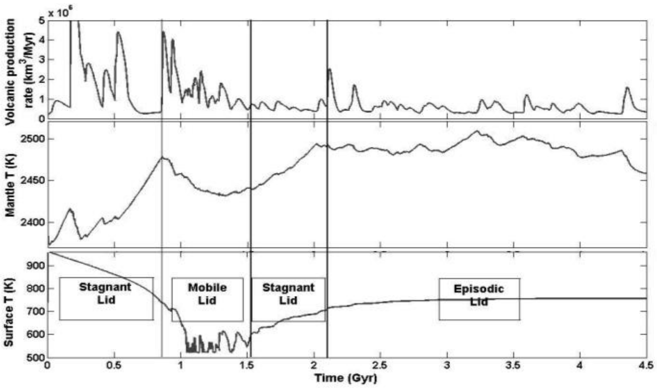
Evolution of atmospheres including impact effects

Evolution of the atmosphere of Venus

ROB developed a coupled model of mantle convection and atmospheric evolution, which includes feedback of the atmosphere on the mantle via the surface temperature. This model takes into account two mechanisms that deplete or replenish the atmosphere: atmospheric escape to space and volcanic degassing of the mantle.

During early atmospheric evolution the hydrodynamic escape is dominant, while for later evolution non-thermal escape is important, as observed by the ASPERA instrument on the Venus Express Mission. The atmosphere is replenished by volcanic degassing from the mantle, using mantle convection simulations based on those of Armann and Tackley (2012), and include episodic lithospheric overturns.

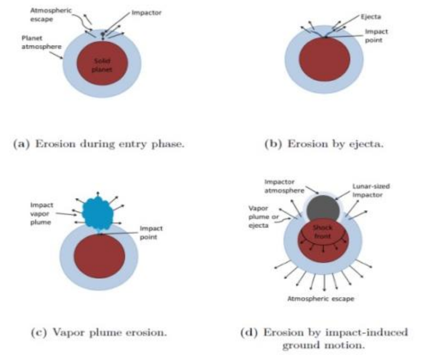
The evolving surface temperature is calculated from the amount of CO2 and water in the atmosphere using a grey radiative-convective atmosphere model. This surface temperature in turn acts as a boundary condition for the mantle convection model. We have obtained a Venus-like behavior (episodic lid) for the solid planet and an atmospheric evolution leading to the present.



Comparative evolution of volcanic production rate, surface temperature and volume averaged mantle temperature with time for the reference case. Also indicated are the different convective regimes. The transition from mobile lid to stagnant lid is progressive. Early evolution (before 700Myr) follows an episodic, but mostly stagnant, lid pattern

CO2 pressure is unlikely to vary much over the history of the planet; with only a 0.25-20% post-magma-ocean build-up. In contrast, water pressure is strongly sensitive to volcanic activity, leading to variations in surface temperatures of up to 200 K, which has an effect on volcanic activity and mantle convection. Low surface temperatures trigger a mobile lid regime that stops once surface temperatures rise again, making way to stagnant lid convection that insulates the mantle.

We have also incorporated a model for erosion from meteorite impacts into the existing framework of the long term evolution model we previously developed. Our study indicates that the contribution of silicate vapor to the atmosphere could help to suppress hydrodynamic loss as the mean molecular weight of the atmosphere is increased.



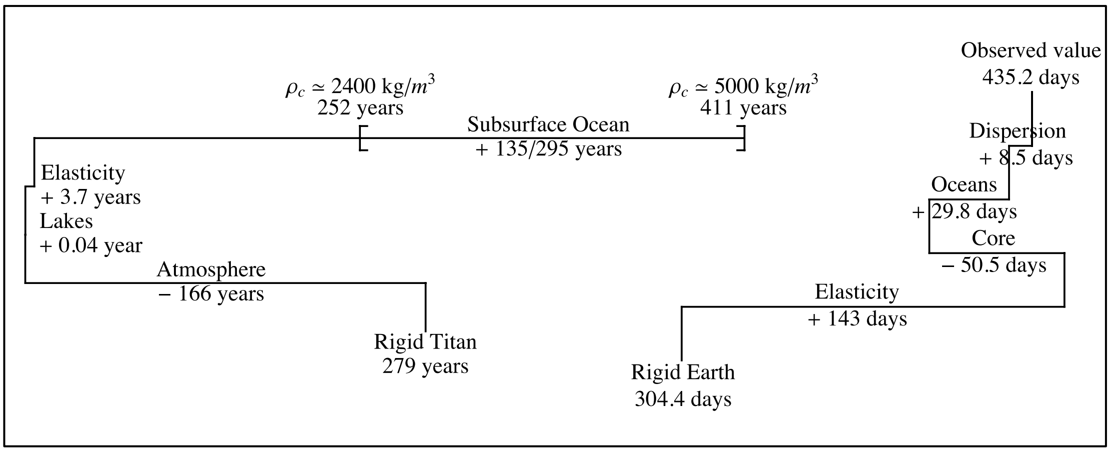
Mechanisms for the impact erosion of the atmosphere illustrated

A snowing core inside Mercury forming a solid inner core for Mercury

An important constraint on the interior structure of Mercury is obtained from the measured obliquity of Mercury. Within the usual assumption that the liquid core is fully coupled to the mantle and solid inner core on the timescales of the precession of Mercury, the moment of inertia of Mercury can be obtained from the obliquity. ROB Service 1 has developed a new extended model of Mercury's obliquity. The obliquity model initially developed for icy satellites was modified to apply to the 3:2 spin-orbit resonance of Mercury. In addition, viscous torques at the fluid core boundaries were added to the model and a Poincaré flow model of the fluid core was used to better model the pressure torques. ROB Service 1 has shown that libration together with obliquity strongly constrains the core size and density. The Love number too can provide accurate information on the core of Mercury, but the current observational precision on the Love number does not allow inferring better constraints on the core size than from rotation only. The tides indicate that the inner core is smaller than about 1200 km. ROB Service 1 also used an estimate of Mercury's radial contraction since the Late Heavy Bombardment to independently estimate the size of the inner core. It was shown that Mercury's inner core is likely not much larger than 1000 km if the crust thickness is below 30 km but could be larger for thicker crusts. The results show that Mercury cooled probably less than 200 K since the late heavy bombardment, a value corresponding rather well to estimates of the cooling of Mars. A further constraint on the core can be obtained from the fact that Mercury currently has a global magnetic field and very recent observations show it also had a magnetic field in the very early stages of Mercury's history. In our approach we have assumed that the dynamo is principally driven by secular cooling, heat generated by solid iron crystallization, and gravitational energy released by sinking of iron-rich snow and upwelling of iron depleted fluid. This shows that, given the estimates of the present day core-mantle boundary heat flow, a significant part of the liquid core is not convecting and as a consequence our approach cannot explain the present day internally generated magnetic field. Likewise, early in Mercury's history, prior to the advent of solid iron crystallization, secular cooling alone cannot explain the measured almost 3.5-billion-year-old remnant crustal magnetization. Further investigations about other plausible driving mechanism are required in order to explain Mercury's past and present magnetic field.

Titan polar motion

We studied the polar motion of Titan forced by its atmosphere and lakes, using the atmospheric forcing derived from new wind and pressure data from a General Circulation Model developed by T. Tokano (2010) and the Ocean Circulation Model for Titan's polar lakes developed by T. Tokano (2014). Because we explicitly take a subsurface ocean into account, both the rotation variations of the ice shell and of the interior below the ocean have to be studied. This model includes the effects of pressure and gravitational torques between the internal layers, tidal deformation, and angular momentum exchanges between the atmosphere, lakes and the surface. We showed that, in contrast to the Earth, the period of the Chandler wobble, a free mode of polar motion, is substantially influenced by the atmosphere and by the global subsurface ocean. The forced polar motion is mainly forced by the atmosphere of Titan whereas the hydrocarbon lakes induce a polar offset. The polar motion follows an elliptical path with amplitude of about 50 m for a solid and rigid Titan and a main

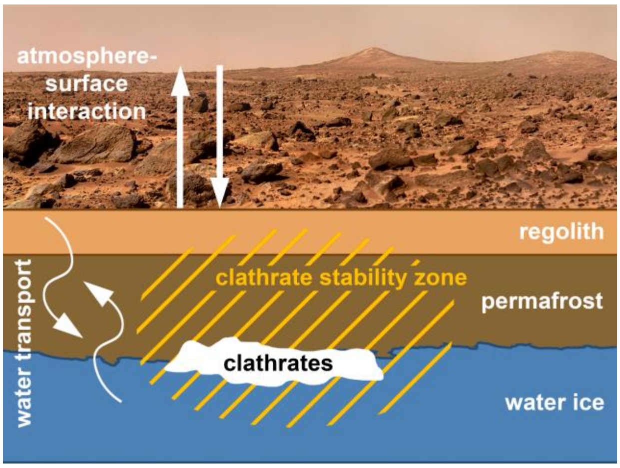


Contributions of different parameters to the Chandler wobble periods of Titan (left) and of the Earth (right, from Smith and Dahlen (1981)). The effect of the lakes is too small to be distinguished.

period equal to the orbital period of Saturn. The subsurface ocean can largely increase the polar motion amplitude due to resonant amplification with a wobble free mode of Titan. For thin ice shells, the polar motion amplitude can reach several tens of km and shorter periods become dominant.

Methane from the interior of Mars

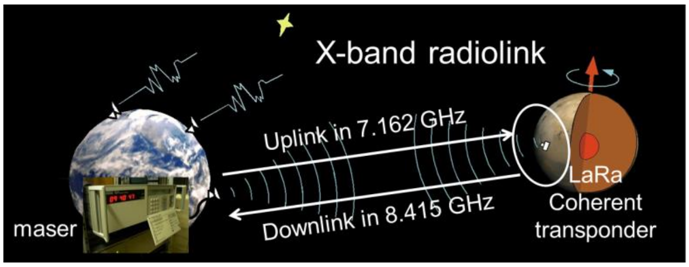
ROB Service 1 has modeled gas transport through the porous Martian regolith focusing on water vapor and methane. The thermal model used includes several layers of varying thickness with depth and properties that can be changed to correspond to those of Martian rocks at locations studied. It also includes the transport of water vapor through the subsurface and the different phases considered are vapor, ice and adsorbed H_2O. We have shown that the methane release due to destabilization of clathrate hydrates could provide a sudden flux of CH4 into the atmosphere that could feasibly create a plume as observed by Mumma et al. (2009).



Clathrate inside Mars

Radioscience experiments for obtaining the nutation of Mars

ROB is a lead partner of the radio science experiment RISE (Rotation and Interior Structure Experiment) of the forthcoming NASA InSight mission to Mars. It also leads the LaRa (Lander Radioscience) experiment of the 2018 ESA ExoMars mission. As part of the preparation for the data analysis of these instruments, ROB Service 1 theoretically computed the nutations of the reference interior structure models of Mars that have been selected by the SEIS experiment for computing the propagation of synthetic seismic events. The set of models have all a liquid core and are in agreement with Mars' moment of inertia and the tidal Love number k2. Several large amplitude nutations are expected to be resonantly amplified. Their determination by the radioscience experiments will allow constraining the moment of inertia of the core. That will in turn lead to information about the radius and composition of the core.



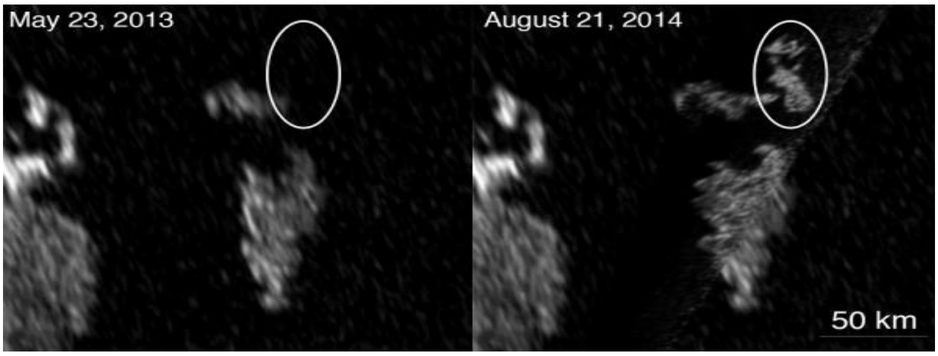
Radioscience experiment for obtaining information on the interior of Mars

Mars Ionospheric Model

We developed an empirical model called MoMo (Mars Ionospheric Model) in collaboration with an ESA scientist who has full access to the data, in order to predict the vertical Total Electron Content (vTEC) from only F10.7P solar flux index (measure of the noise level generated by the Sun at a wavelength of 10.7 cm) at Mars. The vTEC is the integration of the electron density on a perpendicular to the surface of Mars. Knowledge of the vTEC is important for being able to correct the radioscience data for the ionospheric perturbations. We compared our results with data from the MARSIS instrument on the Mars Express satellite for the period 2005-2014. We showed that there were no mean differences with the MARSIS observations, with possible errors at the level of ~0.1 TECu depending on the solar zenith angle (SZA), season and hemisphere of interest. This confirms the validity of our computations and of the model.

Titan lakes

The Cassini spacecraft, exploring the Saturnian system, has discovered surface lakes/seas that appear in various shapes and sizes on Titan. These lakes and seas are filled with liquid hydrocarbons, primarily methane and ethane.



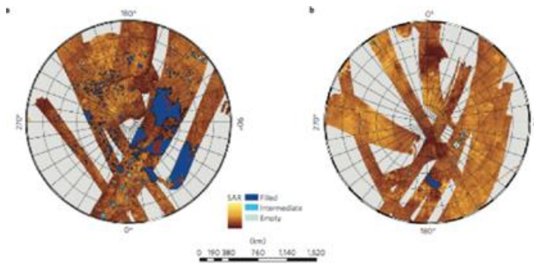
Saturn's moon Titan "Magic Island" of the Kraken Mare sea: photos taken during two different flybys. (Photo: NASA/JPL-Caltech/ASI/Cornell)

The northern high-latitudes exhibit a much higher abundance of lakes of all types than the southern ones. This observed asymmetric distribution of lakes with respect to the equator may reflect the seasonal changes. Lately, Cassini Radar and VIMS (Visible and Infrared Mapping Spectrometer) provided observations suggesting for the first time temporal variations in lake surfaces. Active shoreline processes have been observed on Ontario Lacus. The variation in the shorelines could be explained by different speculations including evaporation, tides or the low spatial resolution of the ISS images. Moreover, other phenomena have also been observed on Ligeia Mare and Kraken Mare; some specific areas, referred to as “Magic Islands”, are very dark which correspond to a liquid filled area for much of Cassini flybys but there are a few flybys for which the same areas are brighter. In Ligeia Mare, these ephemeral phenomena have been interpreted as surface waves, rising bubbles or suspended or floating solids while, for Kraken Mare's “Magic Islands”, VIMS data indicate specular reflections interpreted as waves or wet ground. As seen on Earth, tides may also generate such “Magic Islands” in shallow areas, which we are verifying.

Titan's obliquity and its eccentric orbit around Saturn with an orbital period of one Titan day (15.9454 Earth days) cause time-dependent tidal forces, which leads to periodic surface displacements of seas/lakes. Some theoretical estimates of tidal amplitude yield smaller depth changes than those observed from shoreline positions and, therefore, the tide is not considered as a dominant contributor to the predicted change on Ontario Lacus. Other numerical results yield in a tidal amplitude twice smaller. Preliminary results obtained by a model (developped in collaboration with UCL) on Ontario Lacus predict a tidal range that is larger by a factor of 3 than the one obtained in this previous numerical study for a fully rigid Titan. Titan being deformable because of its global subsurface ocean, these results would be an upper bound of the lakes/seas surface displacements which would tend to confirm that the tides are not the main cause of hypothetical Ontario Lacus shoreline changes.

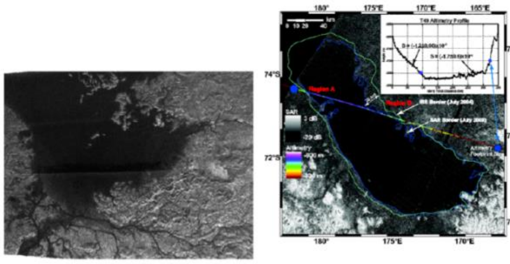
As a matter of fact, several parameters (which are not well known) such as bathymetry, evaporation and infiltration, winds and the vertical deformations of lakes/seas bottom following solid body tides could significantly modify the results, not only the tidal range but also the current speed and orientation. New SAR data analysis indicates that the depth of some sea(s)/lake(s) would have been underestimated. For example, the maximal depth of Ontario Lacus could be about 90 m instead of 30 m. This change is due to a better knowledge of lake's liquid properties, which modifies the radar attenuation to be considered and which in turn results in a more accurate interpretation of the measurements and thus in a different bathymetry. The presence of islands in lakes or seas must be reconsidered in this new context.

In order to study the time dependent response of icy satellite surface seas and lakes to tidal forces we use an existing numerical ocean model developed for terrestrial applications in collaboration with UCL. The Second-generation Louvain-la-Neuve Ice-Ocean Model, SLIM (www.climate.be/slim), is a hydrodynamical model based on the discontinuous Galerkin finite element method developed at UCL. The main advantage of a finite element method formulation is that it allows one to use unstructured grids without the need of nested grids. Hence we can model precisely the complex shorelines of Titan's seas and make use of high resolution where needed (for example, in the throat of Kraken Mare or where the bathymetry gradient is high).



Geographic distribution of lakes in the (a) northern and (b) southern hemispheres.

The lakes are color coded according to their morphologic type (filled, intermediate, empty)



Images of Cassini Radar showing (a) lakes and seas with irregular margins, islands and estuaries, suggestive of flooding of the landscape (Image credit: NASA/JPL) (b) Variations of shorelines suggestive of evaporation and tides

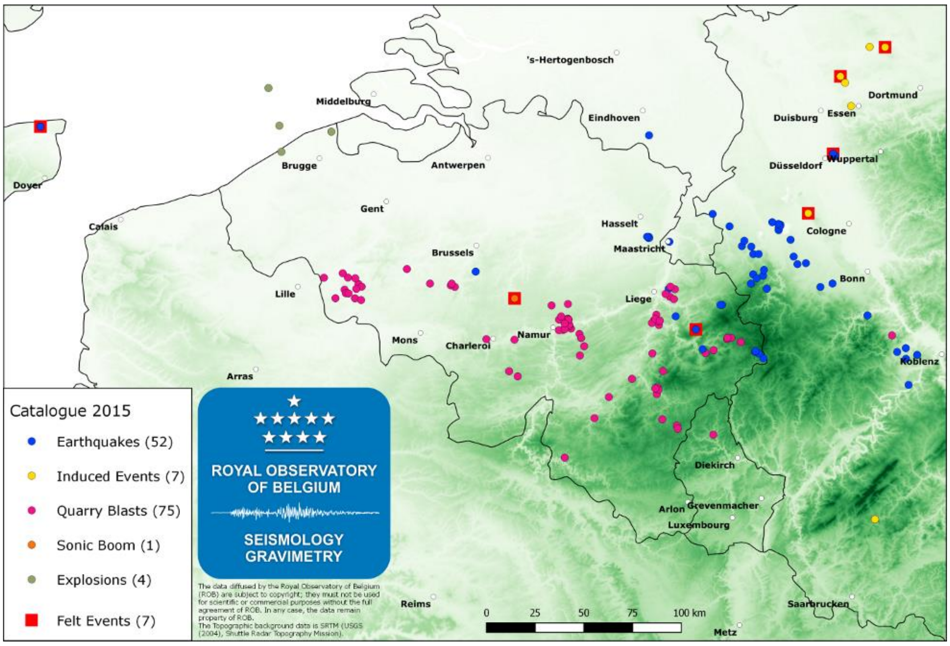
The 2D depth averaged shallow water equations are discretized on curved surface using triangular or quadrangular meshes. The effect of gravitational tide is taken into account by considering the spatial derivatives of the time-dependent tidal potential provided in the literature. The numerical code allows us to study the impact of a large number of parameters and processes such as the bathymetry, wind stress, evaporation, precipitation and wetting-drying through a novel, very efficient algorithm that was primarily designed to simulate tides in rivers and estuaries on Earth. Over the last 6 years, SLIM has been extensively used to model the Scheldt (Belgium) and Mahakam (Indonesia) river-sea continua, as well the Great Barrier Reef (Australia).

Seismology and Gravimetry

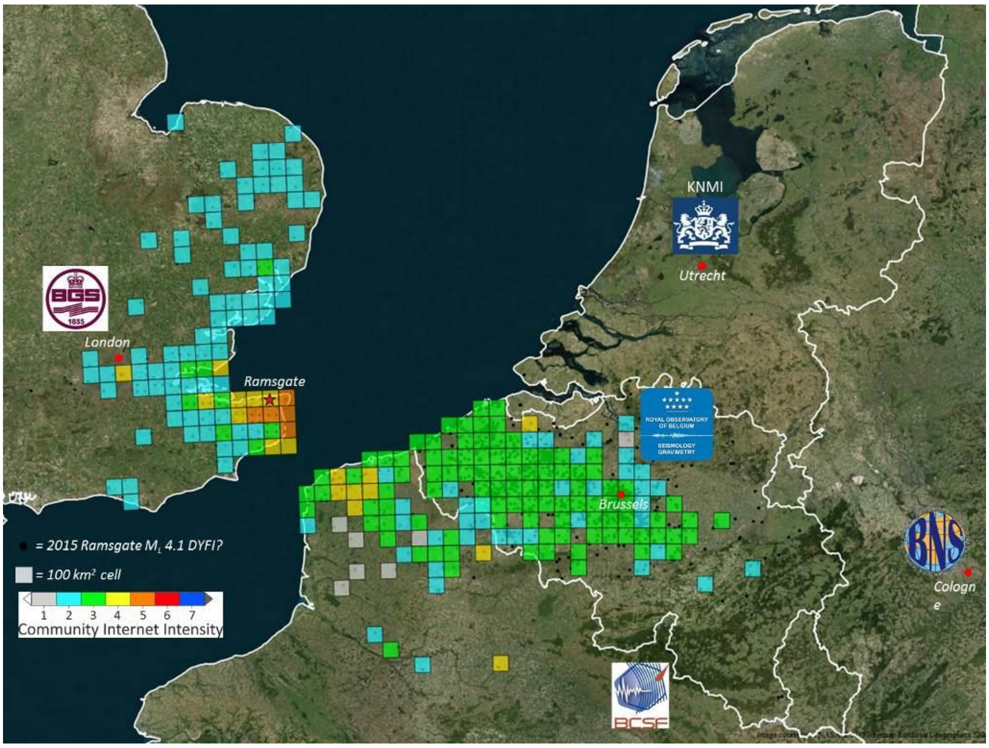
The main mission of the Operational Directorate Seismology and Gravimetry is studying seismic activity, its causes and its consequences in Western Europe. In support of this scientific research and to provide the authorities, the media and the public with relevant information about the seismic activity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

Seismic activity

A total of 52 natural earthquakes were located in or near Belgium in 2015. 2 earthquakes, one F16 sonic boom and 4 induced events were felt in or around Belgium. The largest earthquake in 2015 was the 22 May 2015 Ramsgate (UK), with a magnitude ML=4.1. In 2015, no damage was reported in Belgium. Concurrently, the observatory measured 7 induced events and 75 quarry blasts. There were at least 4 measurable explosions at sea or close to the Belgian shore. Explosions are performed by the Belgian Army to destroy WW1 and WW2 bombs. One F16 broke the sound barrier above southern Walloon-Brabant. This sonic boom, 3 seismic events and 3 induced events were felt by the Belgian population in 2015. The 3 felt earthquakes occurred in Düsseldorf on 14 January 2015 (ML=1.5), in Spa on 13 May 2015 (ML=2.9) and in Ramsgate on 22 May 2015 (UK, ML=4.1). The Spa event was felt only very locally (10 km radius).
The Ramsgate earthquake was particularly well felt in Belgium along an E-W axis, from Ostend to Liège at a distance more than 300 km from the epicentre. For this earthquake, 1986 testimonies were submitted on our web site, together with testimonies submitted to the BCSF (France) and BGS (UK). Figure 2 shows the impact of this earthquake.
The felt induced events occurred in Germany: in Haltern on 28 April 2015 (ML=2.0), Gladbeck on 1 September 2015 (ML=2.5) and Bergheim on 22 December 2015 (ML=2.4). Our transfrontier collaboration with the Cologne University (BNS) dates back to 2010 and provides real-time macroseismic maps of felt events on the ROB and BNS common macroseismic inquiry website.
For comparison, in 2014, 79 earthquakes occurred in and around Belgium. The largest was located in Tiel (Netherlands, ML=2.7) and only one event was felt in Belgium (Court-Saint-Etienne, 10 January 2014, magnitude ML=1.0).



Events recorded in 2015 by the Belgian Seismic Network of the Royal Observatory of Belgium



Macroseismic map showing the observed effect of the ML 4.1 Ramsgate earthquake as reported by citizens in Belgium, France and United Kingdom. The map shows the institutes collaborating in the exchange of data.

Membach 20-40

Membach station: the superconducting gravimeter GWR-C021 was installed in August 1995 in Membach. In 2015, this instrument will have been continuously measuring gravity changes for 20 years. Concurrently, seismometers will have been measuring Earth vibrations for 40 years. The ROB celebrated this event in October 2015, together with the Walloon Public service. Three days were planned:

- One commemorative day: 14 October: official celebration, presentation to the press.
- Two scientific days:
    - 15 October: Scientific workshop in seismology « Earthquake activity and hazard in north western Europe », Dam of La Gileppe. 67 participants, of which 1 from the USA, 2 from France, 8 from Germany, 2 from the Netherlands, 1 from Luxembourg, 24 from U. Liège, 4 from U. Mons, 2 from ULB, 2 from KUL and 1 from UCL. Moreover, there were 3 participants from private companies, 2 from Flemish administration and 1 from Walloon administration. Remaining attendees came from the ROB and the engineers from the SPW Wallonie.
    - 23 October: « Hydrology, Geophysics and Geodesy – HG², a new way to manage water resources », Royal Observatory of Belgium, Brussels. This was organized together with the Belgian National Committee of the International Hydrological Programme, U. Gent, UCL, U. Liège, VUB, ISSeP and SPW Wallonie.

BAELEN Membach

Les 40 ans de la station sismique

On célébrait ce mercredi les quarante ans de la station sismique de Membach, entrée en service en 1975. Elle représente un important maillon du réseau sismologique belge, et sa gestion dépend de l'Observatoire Royal de Belgique. Elle dispose aussi depuis 1995 d'un gravimètre à supraconductivité qui en fait un outil parmi les plus performants. Pour l'occasion, après l'intervention d'Yvon Loyaerts, directeur général des voies hydrauliques au SPW, on entendait les explications de Ronald van der Linden, directeur général de l'Observatoire Royal de Belgique, soulignant au barrage de la Gileppe l'importance opérationnelle de cet outil. Il a permis de s'assurer de la stabilité du sol lors de la construction du viaduc de l'Eau Rouge, et de mesurer aussi la fiabilité de l'érection de la tour de la Gileppe, qui culmine à 78 mètres. Cette station de Membach ausculte en permanence le sous-sol de notre région et transmet des données sur le plan international. ■ **Y.H.**

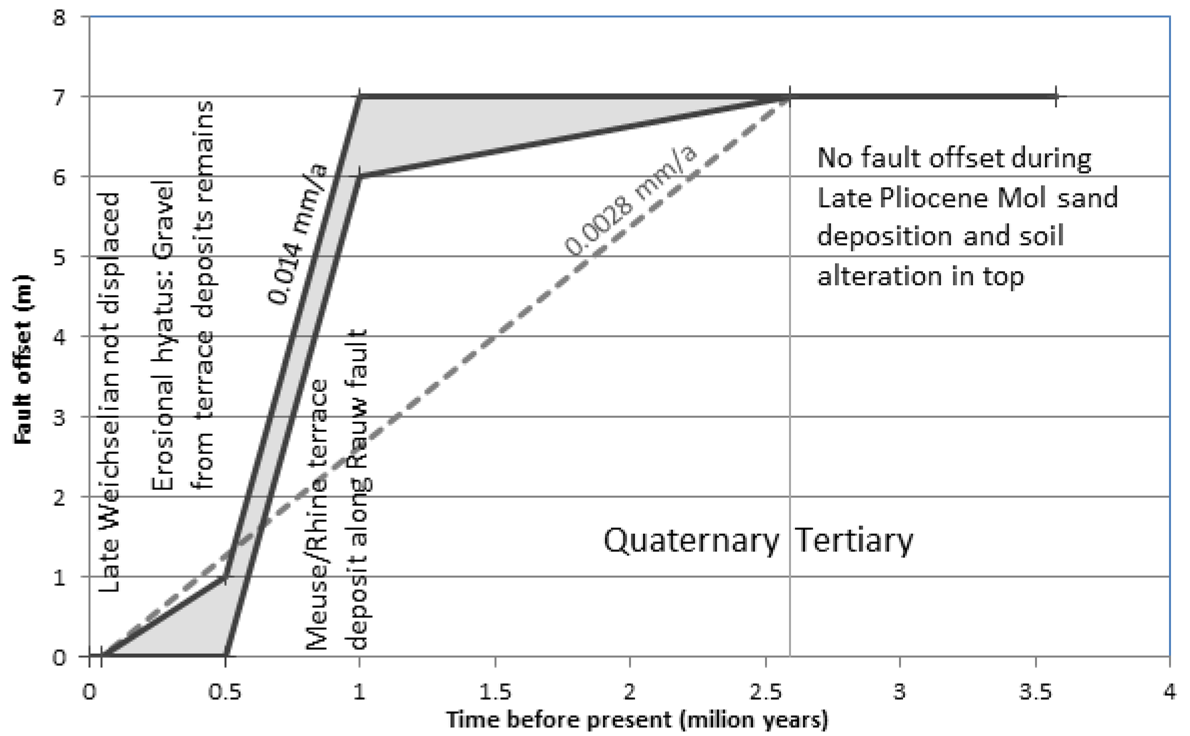
ÉdA Yves Hurard

L'allocution de Ronald van der Linden, directeur de l'O.R.B. à La Gileppe.

Celebrating the Membach 20-40 anniversary: visit of the station, official reception at La Gileppe (© L'Avenir-Le Jour Verviers, 2015-10-16), workshop in La Gileppe, logo (© Wim Vander Putten, Planetarium), the GWR company proudly exhibiting about the Membach 20-40 anniversary on its booth during the AGU 2015 Fall meeting

Excavating across the Rauw fault

The Rauw Fault is the closest fault to the nuclear zone of Mol-Dessel with some indirect evidence for Late Pleistocene movement. In the framework of a seismic hazard study, as part of the ONDRAF/NIRAS R&D programme for the region in cooperation with the ROB, we wanted to assess the amount and the timing of this fault movement. The trench investigation in 2014 continued in 2015 with interpretation and sample analyses. Samples from the trench are sent for dating via optical stimulated luminescence (OSL), electron spin resonance (ESR), cosmic ray nucleide (CRN), radiocarbon (14C), pollen and charcoal wood type analysis.
Dating and stratigraphy investigations shows that most of the 7 m observed offset of the Rauw fault occurred between 1 Ma and 0.5 Ma, associated with Rhine/Meuse terrace deposition in the sunken block along the Rauw fault. A long period of erosion (0.5 Ma – 31 ka) caused relief inversion because the gravel of the terrace deposits protected that area from erosion. In other words, differential erosion transformed the former depression into the present Campine Plateau and removed any evidence for individual faulting events.
However, the timing of the terrace deposition and recognition of its reworked gravel in the trench is important to infer conclusions on the episodic movement of the fault. The 7 m-displacement occurred in a relatively short time-window compared to a long period before without any movement during the entire 30 m of Mol Sand deposition and soil formation in its top (3.58 -2.59 Ma). Older deposits show again increasing offset. The Rauw fault is therefore considered as episodically active. There has been no fault offset during the last 45 ka and probably not during the last 0.5 Ma.
Together with the absence of historical or instrumental seismic activity, this suggests that the Rauw fault is presently inactive but might be reactivated in the future.

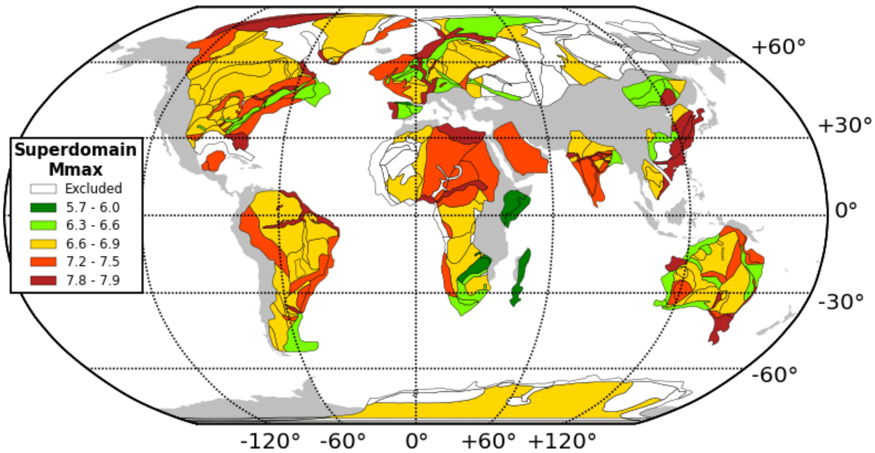


Rauw fault average displacement history and average slip rates derived from the trench. The two hypotheses on the timing are depicted in full and dashed lines. The two full lines allow for the possibility of 1 m of movement either before the fault displacement event that influenced the course of the Rhine/Meuse rivers, or after this terrace deposition

What is the largest magnitude possible?

Mmax, the largest earthquake magnitude assumed to be possible in a given region, is an important parameter in seismic hazard assessment (SHA). However, due to the short length of our earthquake catalogs, it is very difficult to determine Mmax, particularly in stable continental regions (SCR). A method that is commonly used to estimate Mmax in SCR is based on tectonic analogy, and assumes that Mmax should be similar in tectonically similar regions around the world. In this approach, the SCR have been divided in 255 domains, and tectonically similar domains were combined in "superdomains". Taking the largest magnitude observed in each superdomain, a superdomain Mmax distribution has been derived that is often applied as a global prior in SHA. The apparent Mmax differences between SCR domains that are implied by the concept of superdomains are shown in the map below.

The question we wanted to address is whether these differences are real or just reflect a short time sample. Could they also be explained by a uniform global Mmax value? We explored this possibility and showed that the hypothesis of a global uniform Mmax cannot presently be rejected. Simulations with larger Mmax and longer catalogs confirm that catalog length is the limiting factor in our knowledge of Mmax. These results have been presented at 3 international meetings and a manuscript is accepted by Seismological Research Letters.



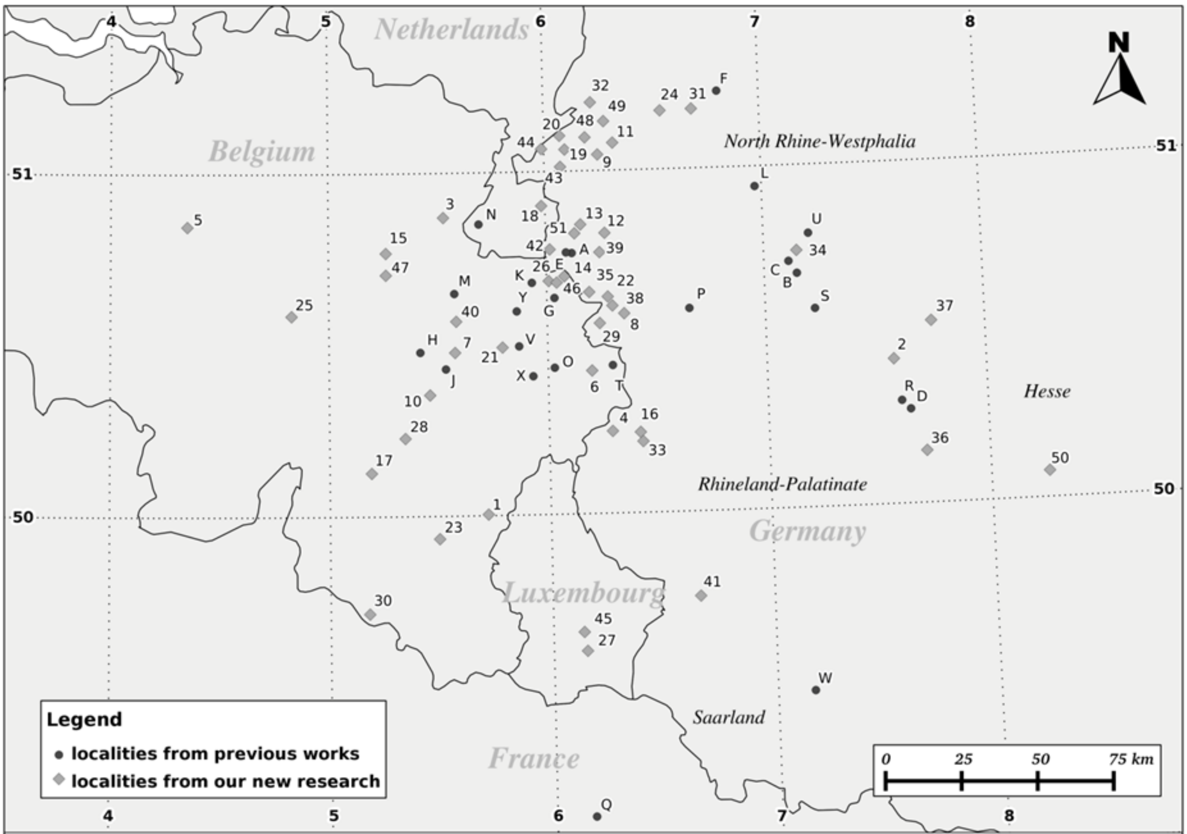
Map showing apparent Mmax differences between SCR superdomains. We showed that these differences are probably due to limited catalog lengths

Looking back in history for earthquakes: the earthquake of December 3, 1828 and the first official inquiry

Through historical research in record offices and libraries, new data have provided information about 75 localities, to be compared to the most complete dataset for this earthquake, SisFrance (2014 version) which only listed 36 localities. Most of the catalogues indicated a location of the earthquake near Aachen, suggesting that it occurred in the Roer Graben. Unlike previous studies, where the epicentre is simply supposed to be located where the macroseismic effects are the strongest, we took into account the global macroseismic field to evaluate the epicentre and its uncertainty.

We confirm an epicentre in the Hautes-Fagnes, with an estimated uncertainty of around 30 km. Hence, we proved that this earthquake is not related to the active faults of Roer Graben. With an estimated magnitude of MW 4.2 (-0.2/+0.4), this event is the largest known one in this region since the M = 6 ¼ event that occurred on 18 September 1692, more to the north-west, in the region of Verviers, which is the strongest known earthquake in the stable part of Europe to the north of the Alps. Even if the intensity of earthquakes is moderate, historical criticism allowed us not only to better estimate their location and magnitude, but also to correct previous misinterpretation. Hence, we could sort out information about this 3 December 1828 and the 23 February 1828 earthquakes. This previous confusion complicated the evaluation of their respective felt areas.

We also showed that the Prussian government made the first official inquiry on earthquake effects ever done in this part of Europe. The questionnaire sent by the Prussian government prefigures the seismic inquiries conducted today after the occurrence of earthquakes.



List of localities from previous works

A Aachen (4)	F Düsseldorf (2)	L Köln (2)	Q Metz (2)	V Spa (9)
B Bad Godesberg (1)	G Eupen (4)	M Liège (7)	R Oberlahnstein (1)	W Sankt Wendel (1)
C Bonn (3)	H Fraiture (2)	N Maastricht (5)	S Remagen (3)	X Stavelot (5)
D Braubach (1)	J Hamoir (2)	O Malmedy (3)	T Rocherath (1)	Y Verviers (5)
E Burtscheid (3)	K Henri-Chapelle (3)	P Mechernich (1)	U Siegburg (2)	

List of localities from our new research

1 Bastogne (1)	12 Eschweiler (1)	23 Laneuville (1)	34 Pützchen* (1)	45 Walferdange* (1)
2 Bendorf (1)	13 Euchen (2)	24 Liedberg (1)	35 Roetgen (1)	46 Walhorn (1)
3 Bilzen (1)	14 Eynatten (1)	25 Liernu (1)	36 SanktGoar* (1)	47 Waremme (1)
4 Bleialf (1)	15 Gelinden* (1)	26 Lontzen (1)	37 Selters (2)	48 Wassenberg (1)
5 Bruxelles* (2)	16 Gondenbrett (1)	27 Luxembourg* (1)	38 Simmerath (1)	49 Wegberg (1)
6 Bütgenbach (1)	17 Han-sur-Lesse (2)	28 Marche (1)	39 Stolberg (1)	50 Wiesbaden* (2)
7 Comblain-au-Pont (1)	18 Heerlen* (1)	29 Monschau* (3)	40 Tillf (1)	51 Würselen (1)
8 Dedenborn (1)	19 Heinsberg* (1)	30 Muno* (1)	41 Trier* (1)	
9 Doveren (1)	20 Karken (1)	31 Neuss (1)	42 Vaals (1)	
10 Durbuy (1)	21 LaReid (1)	32 Niederkrüchten (1)	43 Waldenrath (1)	
11 Erkelenz (2)	22 Lammersdorf (1)	33 Prüm (1)	44 Waldfeucht (1)	

* mentioned in Sis France
(n) number of sources by locality discovered thanks to our research

Localities where information is reported for the 3 December 1828 earthquake (published in J. Seismology)

Astronomy and Astrophysics

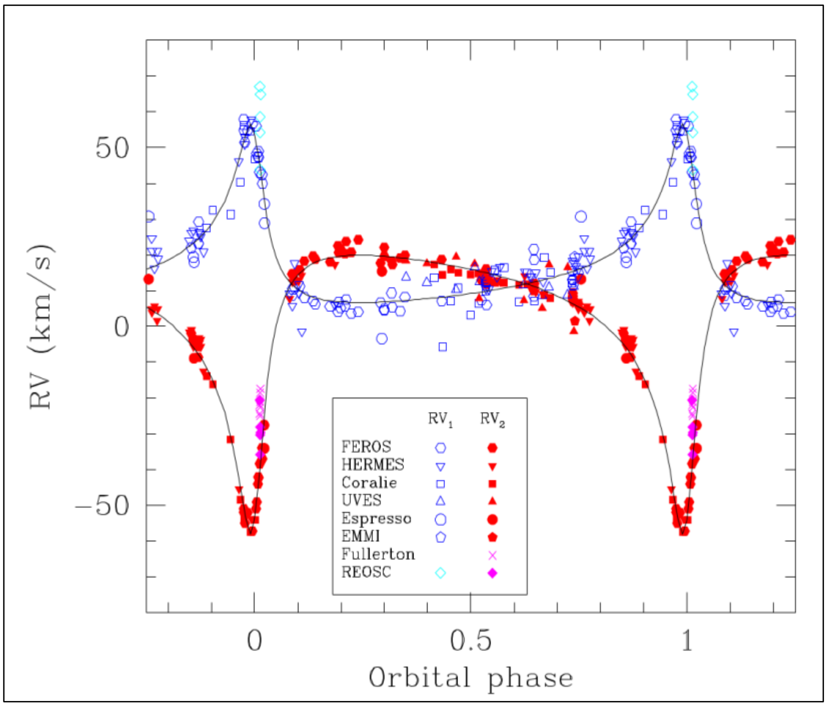
The astronomers of the Operational Directorate Astronomy and Astrophysics do research in astronomy and they also observe solar system objects. Stellar evolution, mass loss of stars, variable and multiple stars as well as rapidly rotating stars are studied. Astrometry of minor planets is carried out and 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.

Workshop "Massive Stars and the Gaia-ESO Survey"

Ronny Blomme (ROB) and Jorick Vink (Armagh Observatory, UK) co-organized the workshop on "Massive Stars and the Gaia-ESO Survey", held at the ROB, 5-7 May 2015. Funding was obtained from the European Science Foundation, via the GREAT (Gaia Research for European Astronomy Training) collaboration. Additional funding was made available by the Fonds de la Recherche Scientifique (FNRS) via G. Rauw (Université de Liège). The ROB provided in-kind contributions. 50 participants attended the meeting: this includes 6 SOC members, 11 invited speakers and 28 participants who gave a contributed talk.

HERMES spectra of the non-thermal radio emitter 9 Sgr were used to refine the orbital parameters of this binary

The 2013-2014 periastron passage of the non-thermal radio emitter, 9 Sgr, was observed in a multiwavelength monitoring campaign. As part of that campaign, the JVLA (Jansky Very Large Array) radio telescope was used to obtain fluxes at 3.6, 6 and 20 cm approximately every month from beginning of February 2013 till mid-May 2014. The data revealed a substantial amount of radio frequency interference and plots of the observed visibility amplitudes as a function of time and frequency were made. These were used for the final calibration of the 9 Sgr radio during 2015. Optical spectra of 9 Sgr and two other non-thermal emitters (HD 168112 and HD 167971) were obtained as part of the observing proposal on the HERMES instrument on the Mercator telescope. Some data on HD 167971 were also collected by C. Nitschelm (Universidad Católica del Norte, Chile) with the FEROS instrument at ESO, Chile. The radial velocities from the reduced HERMES spectra of 9 Sgr were determined and the spectra of 9 Sgr have been used as part of a publication (see figure). The publication also presents X-ray data of this star, obtained by the collaborators from the Liège group.



Radial velocity curve of 9 Sgr, folded in orbital phase. Open symbols indicate the primary star, filled symbols the secondary. The different symbols indicate different instruments. Figure from Rauw et al. (2016, A&A, submitted).

A weak magnetic field in the normal main-sequence δ Scuti star HD 188774 = KIC 5988140

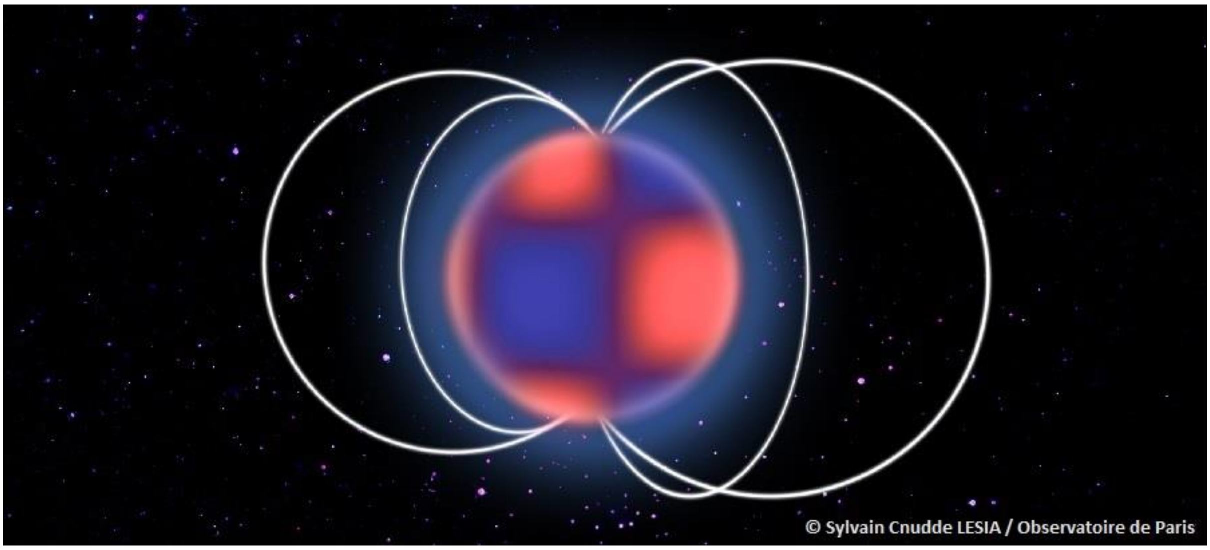
A weak magnetic field has been detected in the normal main-sequence δ Scuti star HD 188774 = KIC 5988140. This discovery is an unexpected result which shows that the low frequencies detected in some of the candidate hybrid stars observed by the Kepler satellite may have a different origin than (gravity mode) pulsations or binarity. Following this discovery, press releases have been issued by the Observatoire de Paris, the Canada-France-Hawaii Telescope and the Royal Observatory of Belgium to announce this surprising result.

Two types of pulsating stars exist among stars with a mass between 1.5 and 2.5 solar masses: the δ Scuti stars and the γ Dor stars. Theory tells us that, when such stars have a surface temperature between 6900 and 7400 kelvins, they can have both types of pulsations, i.e. they are called "hybrid stars". The NASA space mission Kepler provided a wealth of new candidate "hybrid stars", even outside the theoretically predicted physical parameter range.

Coralie Neiner (LESIA, CNRS / Observatoire de Paris / UPMC / Université Paris Diderot) and Patricia Lampens (ROB) have therefore sought which physical phenomena could mimic the hybrid character in delta Scuti stars. One possibility could be the presence of a magnetic field which would produce spots on the rotating stellar surface and mimic the γ Dor pulsations. However, no magnetic field had ever been observed in a δ Scuti star until now…

They proposed to observe HD 188774, a Kepler hybrid candidate star, in order to look for the presence of a magnetic field. Based on spectropolarimetric measurements obtained at the Canada-France-HawaiiTelescope (CFHT), they showed that the star exhibits a clear magnetic signature. This represents the very first detection of a magnetic δ Scuti star. It further shows that the signature of a magnetic field can be confused with that of γ Dor type pulsations.

The discovery that HD 188774 is a magnetic δ Scuti star and not a true hybrid star opens the perspective of a new interpretation for the Kepler observations of other hybrid stars, and of pulsating stars in that mass range. This has important implications for understanding the (deep) interior structure of such stars.



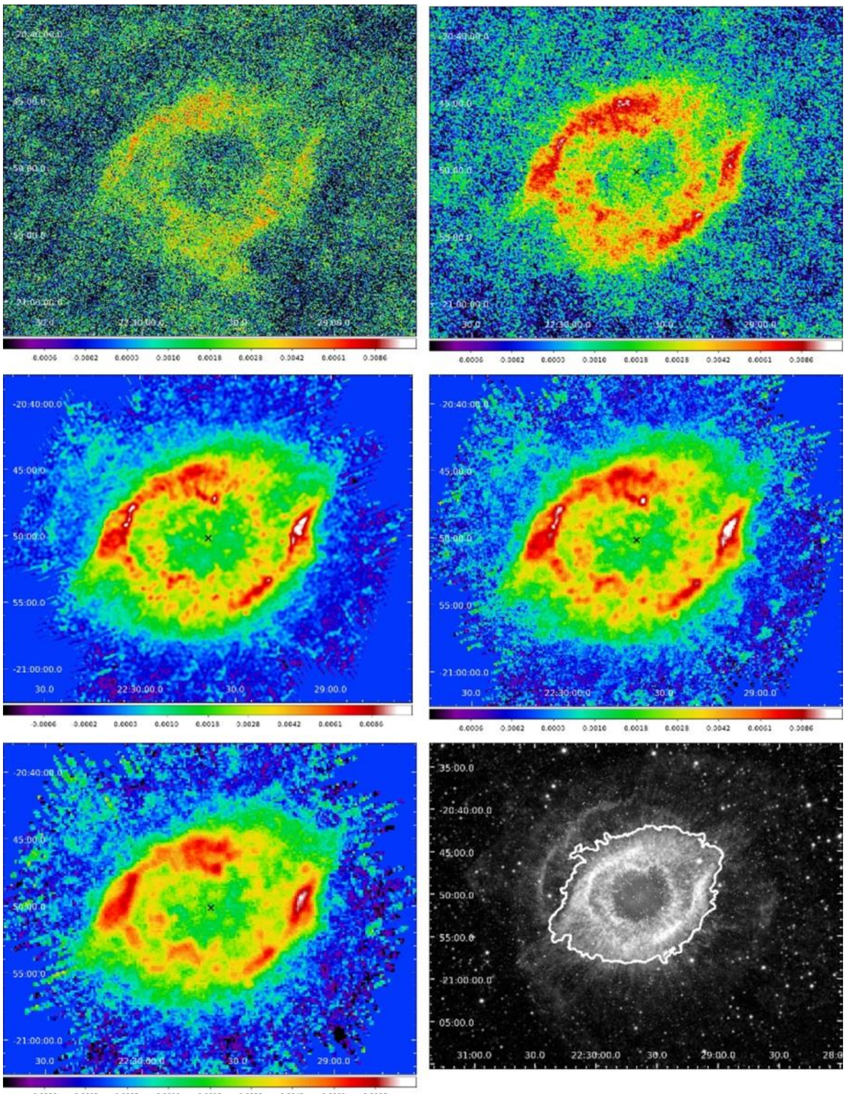
The origin of mysterious blue light near the Yellow Hypergiant HR 5171A

An international team of astronomers, including Alex Lobel, astrophysicist of the Royal Observatory of Belgium, has discovered the origin of mysterious blue light near the Yellow Hypergiant HR 5171A. The light was accidentally observed in the early 1970s by a team member, but without providing a good explanation for it. More than 40 years later the team's research reveals the light was caused by Polycyclic Aromatic Hydrocarbon molecules or PAHs. PAHs are ring-shaped molecules. They are observed in large gas clouds in specific conditions between and near stars. On Earth the molecules form by incomplete combustion of fossil fuels. In the Milky Way they are observed in dusty nebulae.

The bright central star is the yellow hypergiant HR 5171A observed with Spitzer/NASA in infrared light. The Gum48d nebula around it is an active star formation region.

Herschel imaging of the dust in the Helix nebula (NGC 7293)

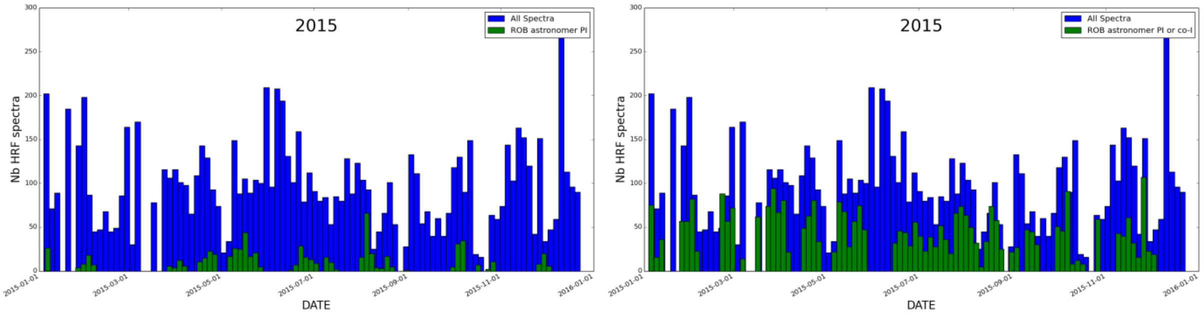
G. Van de Steene, P.A.M. van Hoof and M. Groenewegen collaborated with Mireya Etxaluze (Departamento de Astrofísica, CSIC-INTA, Madrid, Spain) and others on the analysis of the Herschel SPIRE spectrum of NGC 7293 (the Helix nebula) which showed the very first detection of the OH+ molecular ion in a planetary nebula. This was already highlighted in an ESA press release in 2014, but the paper "Herschel imaging of the dust in the Helix nebula (NGC 7293)" appeared in 2015 and the Herschel images of the Helix nebula were used as front page illustration of a volume of Astronomy and Astrophysics.



***Herschel* images of NGC 7293. *Top row left to right*: PACS 70 and PACS 160 μm images, *second row*: SPIRE 250 and SPIRE 350 μm images, and *bottom row*: SPIRE 500 μm and a NASA/JPL-Caltech composite image. The colour bar under the *Herschel* images shows the flux density in Jansky/pixel. The grayscale image is the NASA/JPL-Caltech composite image (pia15817.html) including infrared data from *Spitzer* wavelengths 3.6 to 4.5 μm and 8 to 24 μm, WISE data at 3.4 to 4.5 and 12 to 22 μm, and ultraviolet data from GALEX at 0.15 to 2.3 μm. The region observed by *Herschel* and considered in this paper is indicated by the white contour in this last image**

The HERMES echelle spectrograph

HERMES is the acronym for High Efficiency and Resolution Mercator Echelle Spectrograph. The whole project was to design, construct, and integrate the spectrograph at the Mercator telescope in collaboration between the ROB, the KU Leuven, the ULB, the Thüringer Landessternwarte Tautenburg (Germany) and the Geneva Observatory (Switzerland). ROB took a leading and very active part to the development of the data reduction software. The spectrograph and its pipeline have now entered their exploitation phase and have already produced about 27000 spectra.



Time distribution of the number of HRF spectra (blue bars). In 2015, 8% of the HERMES spectra were obtained for ROB PIs (left panel, green bars), while 37% were obtained for ROB PIs and/or co-Is (right panel, green bars)

One of the ROB commitments towards the HERMES consortium consists in performing 3 to 4 2-weeks observing runs and to financially support these (i.e. the costs cover the man power, the trip to La Palma, the accommodation, as well as all technical and administrative costs for the telescope time). In 2015, 2 observing runs were under the ROB's responsibility. Another commitment is to contribute to the maintenance of the reduction pipeline. During 2015 as in previous years, of the Hermes web-services were maintained: server disk space monitoring, mailing/alert system aimed to warn ROB colleagues when predefined observations were carried-on and reduced. A daily mirroring is still performed in order to always have a copy at ROB of the raw and reduced data at the telescope and KU Leuven.
In 2015 26 papers that make use of the HERMES spectrograph data were published, among which 6 had at least one ROB member in the authors list. The total refereed papers using HERMES data is now over 100.

Short-period spectroscopic binary and triple systems

A number of short-period spectroscopic binary and triple systems has been detected among the sample of 48 candidate hybrid A/F-type stars of the Kepler mission whose radial velocities are being monitored with the HERMES spectrograph. These results which are based on a collection of 250 high-resolution spectra indicate a spectroscopic multiplicity fraction of about 25%. For various systems, the derived radial velocities have led to the determination of a first orbital solution (in collaboration with the Konkoly Observatory, Budapest, Hungary; based on HERMES Consortium prog. nr 52).

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).

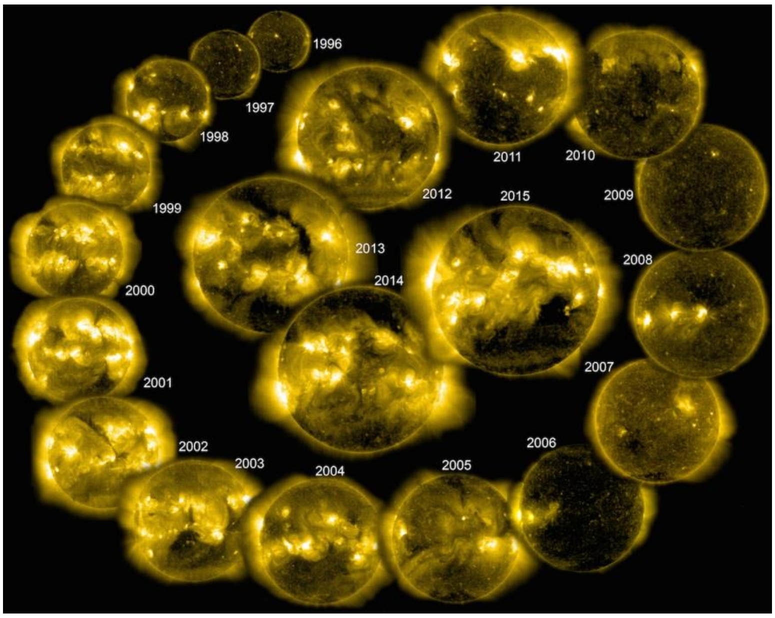
SOHO 20 years!

On December 2, 2015 we celebrated the 20th anniversary of the launch of the ESA/NASA solar observatory "Solar and Heliospheric Observatory" (SOHO). The discoveries made by the instruments on SOHO have revolutionized solar physics and space weather worldwide (see ESA press release)[1].

The SOHO observatory was launched on Dec 2 1995 as a joint ESA/NASA mission. Belgium (ROB & CSL) participated in the very succesfull EIT telescope thanks to BELSPO/ financing.

At the Royal Observatory of Belgium, the birthday of SOHO was celebrated with particular nostalgia. Indeed, the start and subsequent successes of SOHO has been the most important driver in the past 20 years behind the space activities at the "Solar Influences Data analysis Center" (SIDC), a research group of around 40 people at ROB. Together with the Centre Spatial de Liège (CSL), ROB/SIDC participated in the Extreme Ultraviolet Imaging Telescope (EIT) on SOHO.

EIT was originally regarded as the "context imager" for the spectrographs onboard SOHO producing only 4 sets of (static) images per day, during a lifetime of 2 years. Soon however it became clear that movies of EIT images showed unexpected dynamics such as enormous 'tsunamis' on the Sun (which we now call EIT waves) that are related to coronal mass ejections. The SOHO mission was extended several times and is, 20 years later, still operating a subset of the instruments, including EIT.



A snapshot per year showing the evolution of the solar corona over 2 solar cycles in the 28.4nm bandpass of EIT

The very first generation of the post-docs at ROB/SIDC has contributed significantly in the calibration of the instrument, the science planning and the exploitation of the EIT data set. A special way of operating the telescope, the "EIT shutterless mode" was designed and pioneered at ROB. This experience brought us to the later SWAP telescope on PROBA2 and the upcoming EUI telescopes on Solar Orbiter.

EIT, together with the LASCO coronagraphs onboard SOHO, have been essential elements in the effort to monitor solar activity and forecast the impacts at the Earth. Also in this field, called space weather, the successes of SOHO ignited a parallel success at ROB/SIDC with the development of automated processing software and space weather activities. In this context, the

[1] http://www.esa.int/Our_Activities/Space_Science/SOHO_celebrates_20_years_of_discoveries

SIDC research group received at the 12th European Space Weather Week the "International Marcel Nicolet medal 2015" for structuring the international space weather community.

Over the years, EIT images made it to popular science and eventually appeared as an illustration in the worldwide press whenever the sun was mentioned.

EIT images as an icon of the Sun in popular press

The Sunspot number

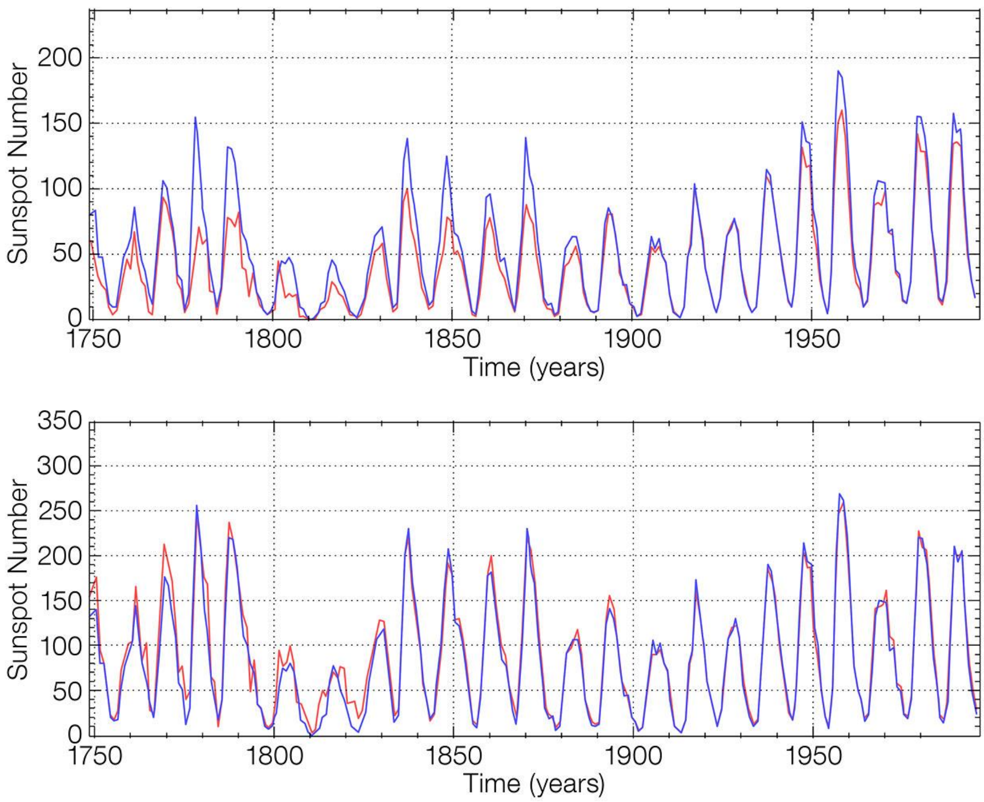
The Sunspot Number, the longest scientific experiment still ongoing, is a crucial tool used to study the solar dynamo, as well as space weather and climate change. In 2011, the WDC-SILSO, together with a community of about 50 scientists, initiated the first end-to-end recalibration of this reference data set. In July 2015, a first updated version of the series was officially released. Several major improvements were brought to the series over the “modern” part, from 1850 to the present.

Sunspot Number research could be compared to a marathon in the sense that thanks to curious scientists such as Galileo, we have observational sunspot data dating back to 400 years ago. But, while the amount of data is impressive, the accuracy of the observations was not regulated in the same way 400 years ago as it is today. For example, what was sometimes seen as only one group of spots at the time (Figure below) would in fact be counted as several groups today. This difference can drastically impact the Sunspot Number (composed of both the number of groups and the number of spots on the Sun) extracted from this particular data.

Sunspot drawings from J.C. Staudacher for February 13th and 15th of 1760

Sunspots are an important scientific tool for the study of the Sun all the way to the climate on Earth. However, these accuracy problems caused by a lack of knowledge at the time or documentation afterwards have to be taken into acount.

This is why a team of scientists, including Drs. Clette and Lefèvre from the WDC-SILSO, took it upon themselves to correct and improve the data. To identify possible issues, two official sunspot series were taken into account: the International Sunspot Number (the blue line in the graph below) and the Group Sunspot Number (red). The results of the two lists are largely similar, but occasionally there are noticeable inconsistencies in the numbers (upper panel of Figure).



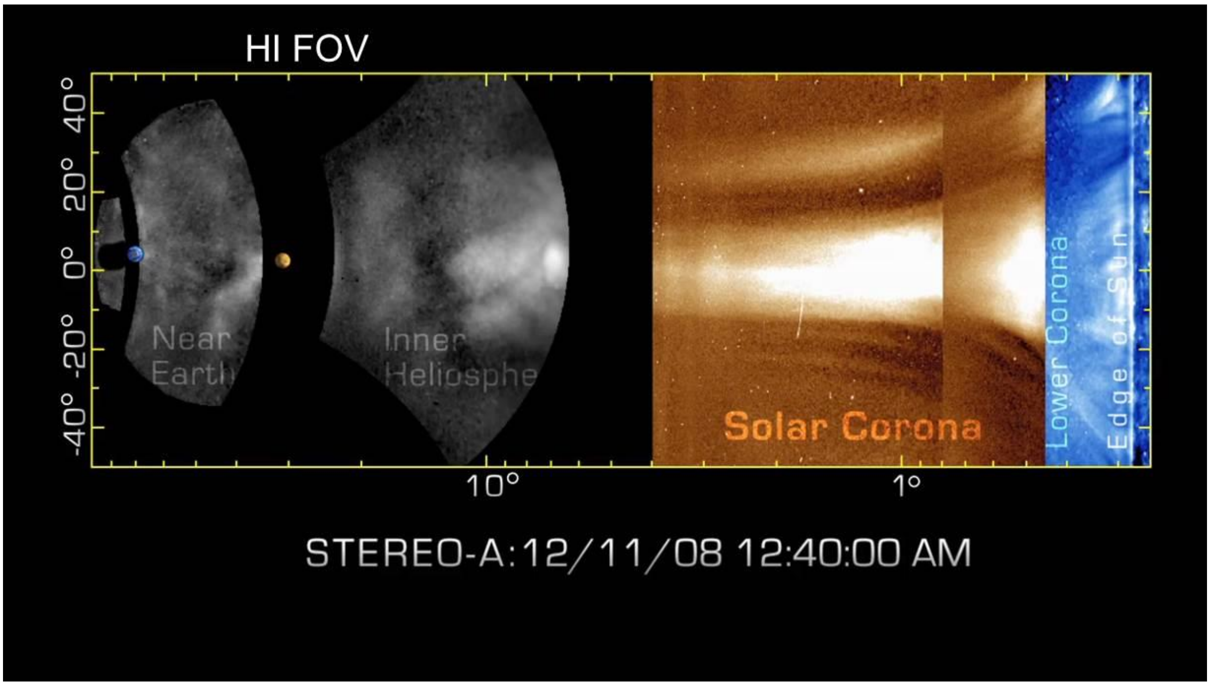
Wolf number (blue) and Group Number (red) before the corrections (upper panel) and after corrections (lower panel). Agreement between these two well-known series is improved after corrections

The corrections that were found change the long-term history of solar activity: what we call the Modern Maximum (a very active period that starts around the 1950s) is not so different from the rest of the sunspot series anymore (lower panel of Figure). This tendency for Solar Cycles to be higher and higher as we progress toward the present indeed almost vanishes after correction. This fact is important for the analysis of evolution of the Earth's climate.

The results of this important Solar Physics community effort were announced in August 2015 at the International Astronomical Union General Assembly.

Automatic detection of Coronal Mass Ejections (CMEs) in Heliospheric Imager (HI) data

The advent of wide-angle imaging of the inner heliosphere has revolutionised the study of the solar wind and, in particular, solar wind structures such as Coronal Mass Ejections (CMEs). CMEs comprise enormous plasma and magnetic field structures that are ejected from the Sun and propagate at what can be immense speeds through interplanetary space. With Heliospheric Imaging (HI) came the unique ability to track the evolution of these features as they propagate through the inner heliosphere. Prior to the development of wide-angle imaging of the inner heliosphere, signatures of such solar wind transients could only be observed within a few solar radii of the Sun, and in the vicinity of a few near-Earth and interplanetary in-situ probes. HI has, for the first time, filled that vast and crucial observational gap, as can be seen below.



Combined view of coronagraphs (blue and yellow) and heliospheric imagers (grey) showing the solar wind and CMEs between the Sun and the Earth. The Sun is at the right of the image, the Earth is at the left. From Deforest et al., 2011

The European FP7 HELCATS project (www.helcats-fp7.eu) provides access to advanced catalogues - validated and augmented through the use of techniques and models - for the analysis of solar wind structures, based on observations from European-led space instrumentation, providing a strong foundation for enhanced exploitation and advancement of European heliospheric research.

ROB task consisted in the implementation of a technique in order to automatically detect CMEs in HI data. For doing so, we have adapted CACTus (http://sidc.oma.be/cactus/), to work with HI images, as it was only working with coronagraph data before (SOHO-LASCO and STEREO-COR2). This is a big challenge due to several factors. The geometry of the observations is completely different, CMEs are fainter in HI data, the images include planets and stars that have to be removed, and the cadence is much lower than that in a regular coronagraph. In spite of all the complications, we have succeeded to modify CACTus to work with HI. It is the first time that this task is performed successfully. The result of this work is the production of a catalogue of automatically detected CMEs in HI data for the full duration of the STEREO mission (from 2007 until present). This catalogue contains about 1000 CMEs, and it is available at www.sidc.be/cactus/hi. A snapshot of the catalogue is shown below. A real time output will be available in the near future.

CACTus for STEREO/HI-1

A software package for 'Computer Aided CME Tracking' (adapted from CACTus)

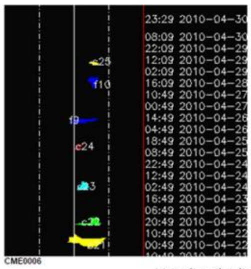
CMEs detected by CACTus - /A/2010/04/

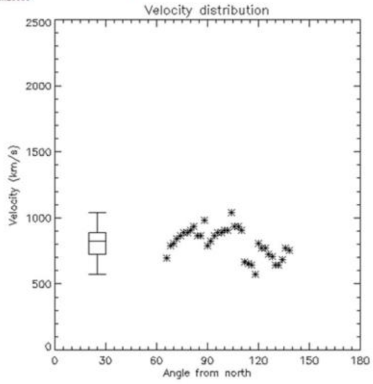
Show comparison with the Manual catalog and other level images

```
:Issued: Fri Mar 20 00:19:07 2015
:Product: CACTus catalogue for HI
#-----------------------------------------------------------------------
# Instrument: SECCHI-A | Detector: hi_1
# Minimal CME width: 0010
#
  first hi_1: 2010-03-31T00:09:01.008   20100331_000901_24h1A_br01.fts
  last  hi_1: 2010-04-30T23:29:01.005   20100430_232901_24h1A_br01.fts
#
#-----------------------------------------------------------------------
# Output: Detected cmemap with the following characteristics:
#
#    CME: CME number
#   Flow: Flow number. Flows are suspicious detections,
#          their color in the detectionmap is dark blue
#     t0: first apparition in field of view
#     pa: principal angle, counterclockwise from North (degrees)
#     da: angular width (degrees),
#    NPA: Northernmost propagation angle (degrees),
#    SPA: Southernmost propagation angle (degrees),
#      v: median (projected) velocity (km/s)
#     dv: variation (1 sigma) of velocity over the width of the CME
#   minv: lowest velocity detected within the CME
#   maxv: highest velocity detected within the CME
#
```

# CME	t0	pa	da	NoPA	SuPA	v	dv	minv	maxv
0025	2010/04/29 13:29	0115	010	0110	0120	0283	0017	0266	0313
0024	2010/04/25 16:49	0095	010	0090	0100	0272	0016	0252	0300
0023	2010/04/24 05:29	0101	014	0094	0108	0213	0037	0205	0295
0022	2010/04/22 23:29	0108	032	0092	0124	0350	0029	0300	0397
0021	2010/04/22 05:29	0106	048	0082	0130	0397	0080	0343	0621
0020	2010/04/20 09:29	0053	010	0048	0058	0389	0017	0361	0416
0019	2010/04/20 02:09	0076	076	0038	0114	0416	0037	0334	0491
0018	2010/04/19 06:49	0096	084	0054	0138	0448	0075	0340	0571
0017	2010/04/15 22:49	0070	016	0062	0078	0330	0047	0239	0368
0016	2010/04/15 08:49	0080	012	0074	0086	0437	0031	0368	0454
0015	2010/04/13 10:49	0081	094	0034	0128	0345	0255	0219	0983
0014	2010/04/12 00:09	0101	022	0090	0112	0361	0043	0310	0454
0013	2010/04/10 00:49	0099	038	0080	0118	0312	0034	0239	0354
0012	2010/04/08 18:09	0084	040	0064	0104	0249	0060	0196	0402
0011	2010/04/08 06:49	0093	058	0064	0122	0544	0053	0454	0668
0010	2010/04/06 20:49	0094	012	0088	0100	0283	0119	0268	0520
0009	2010/04/06 04:09	0097	046	0074	0120	0582	0278	0416	1264
0008	2010/04/05 12:09	0080	020	0070	0090	0268	0009	0256	0285
0007	2010/04/04 04:09	0124	024	0112	0136	0397	0084	0357	0562
0006	2010/04/03 12:09	0102	072	0066	0138	0823	0110	0571	1041
0005	2010/04/02 18:09	0104	016	0096	0112	0276	0075	0195	0397
0004	2010/04/02 14:09	0083	010	0078	0088	0407	0033	0361	0454
0003	2010/04/02 11:29	0121	010	0116	0126	0409	0101	0327	0621
0002	2010/04/02 05:29	0116	012	0110	0122	0459	0073	0316	0505
0001	2010/04/01 14:49	0115	010	0110	0120	0427	0058	0372	0544

# Flow	t0	pa	da	NoPA	SuPA	v	dv	minv	maxv
0010	2010/04/28 22:09	0114	012	0108	0120	0327	0000	0327	0327
0009	2010/04/26 12:49	0102	036	0084	0120	0345	0050	0237	0426
0008	2010/04/14 04:09	0103	018	0094	0112	0376	0037	0319	0437
0007	2010/04/13 18:49	0083	014	0076	0090	0265	0045	0242	0365
0006	2010/04/09 08:49	0071	014	0064	0078	0188	0083	0178	0357
0005	2010/04/06 08:09	0067	014	0060	0074	0301	0011	0287	0319
0004	2010/04/04 23:29	0129	010	0124	0134	0319	0023	0285	0357
0003	2010/03/31 17:29	0110	012	0104	0116	0340	0090	0260	0498
0002	2010/03/31 14:49	0121	014	0114	0128	0405	0064	0357	0505
0001	2010/03/31 12:49	0084	024	0072	0096	1770	0000	1770	1770



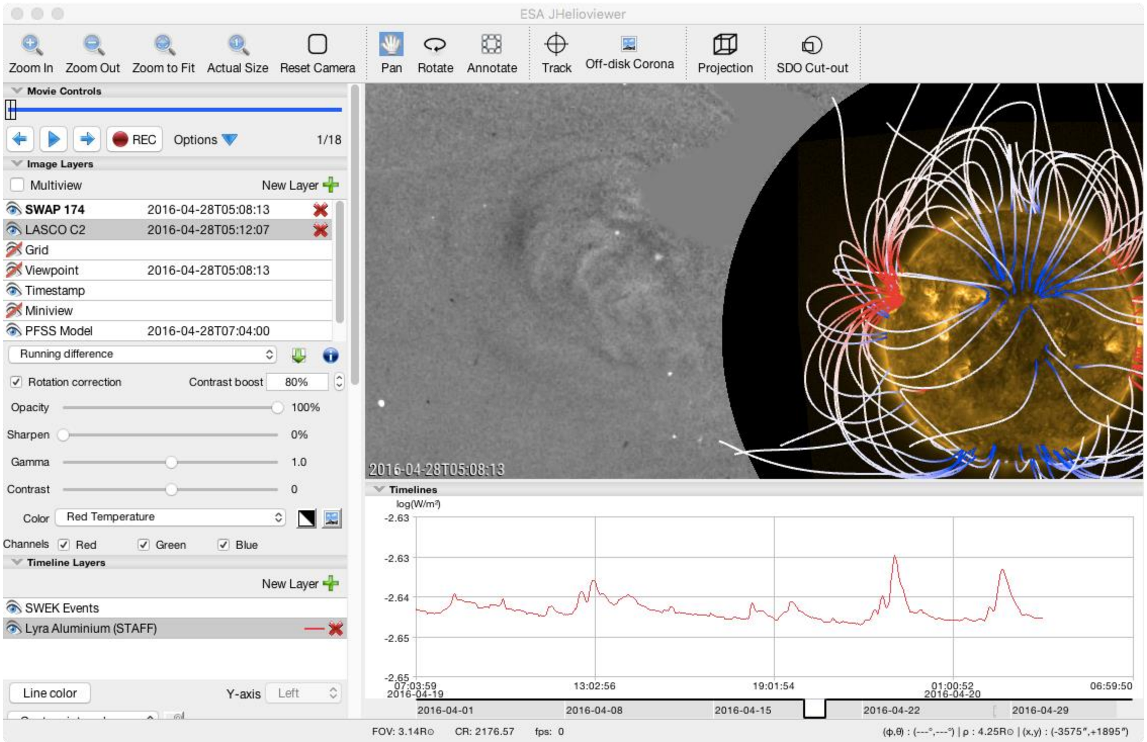


The HELCATs automatic CME catalogue. The events are listed in the middle, when clicking on them information on the CME is obtained (a video on the left and information on the CME speed on the right)

A comparison of our automatic CME catalogue with a pre-existing manually-made CME catalogue is underway. This exercise, apart from providing validation to our method, is allowing us to obtain important insights on the automatic algorithm itself, and providing important constraints and information that can be applied to enhance our knowledge on CMEs.

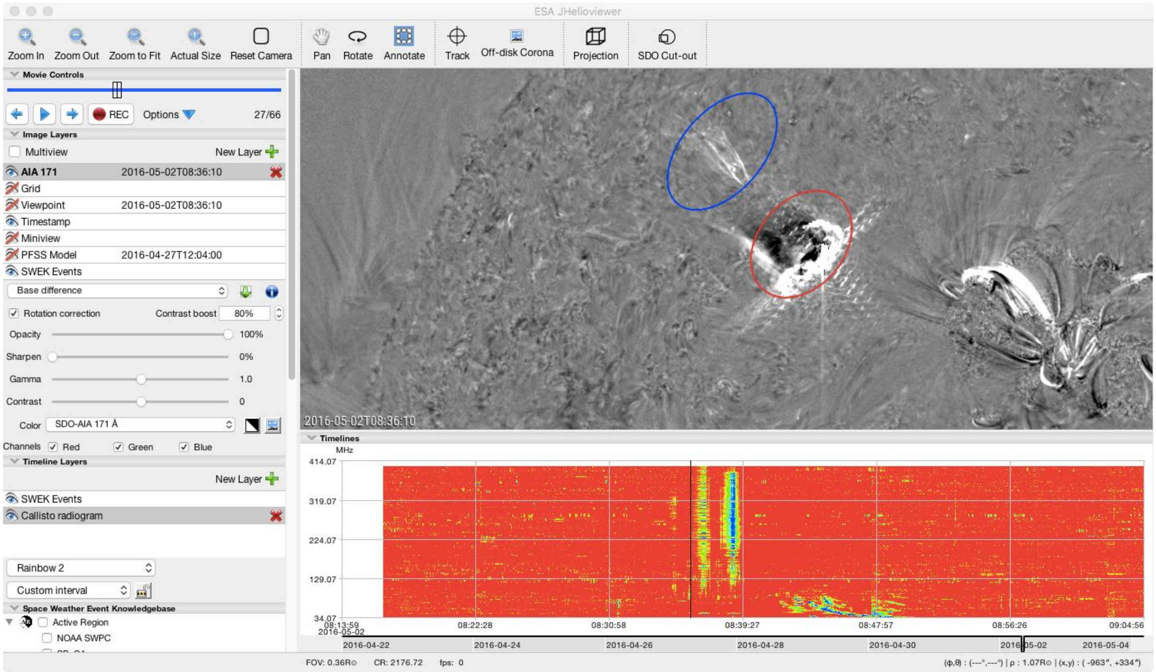
Sunny views with jHelioviewer

The activity on the Sun is monitored by many different solar telescopes both on the ground as well as in space. Satellites such as the NASA STEREO mission even image the back-side of the Sun. In many cases, the data is available in near-real-time from various websites. For a solar physicists or a space weather operator, it can become quiet labor intensive to crawl through all the available data and make a synthesis of what is going on at the Sun.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.



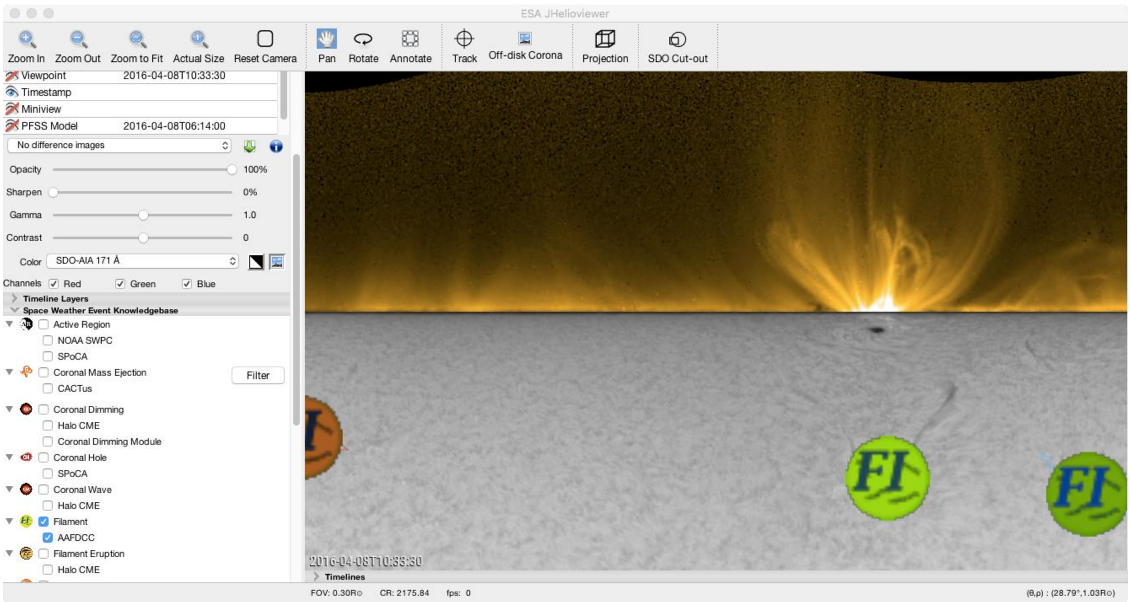
Screenshot of a jHelioviewer session showing a PROBA2/SWAP image (yellow) with a magnetic field extrapolation (PFSS, red-white-blue) and in the background a SOHO/LASCO C2 difference image showing a CME. The bottom panel shows A PROBA2/LYRA timeline with flares

For these reasons, a team of software developers at ROB have overhauled the existing jHelioviewer application and boosted its functionalities. Once installed on the user computer, jHelioviewer allows you to access a variety of solar data from different servers and, by just clicking a few buttons, display movies of combined data sets, with chosen zoom and perspective and even with your favorite projection. The new version also incorporates access to a space weather event (e.g. flares) and displays their timelines synchronized with the running movie.



Screenshot of a jHelioviewer session showing an SDO/AIA difference image with an ongoing flare spray (blue circle) and flare (red circle). The bottom panel displays a Humain/eCallisto radiospectrograph showing a co-occuring type II radioburst

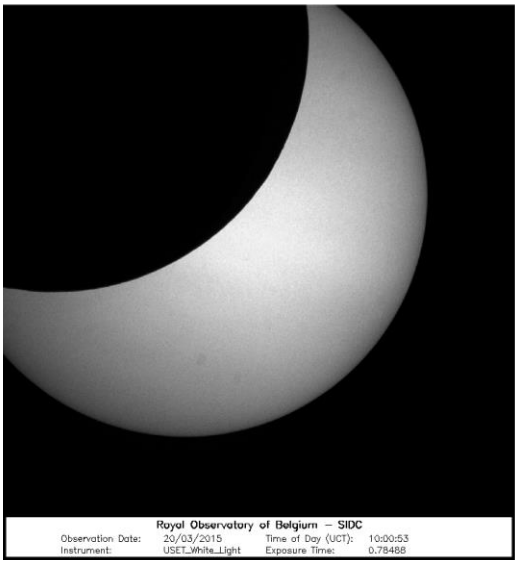
This new version 2.10 has been improved under the contract “High Performance Distributed Solar Imaging and Processing System” of the European Space Agency (ESA), awarded to the SIDC @ Royal Observatory of Belgium (ROB). The application is freely available for all platforms from http://sidc.be/jhelioviewer where also a user manual is available. At the time of this writing (May 2016), hunderds of users worldwide have downloaded the application.



Screenshot of a jHelioviewer session showing a log/polar projection of a ROB/USET Halpha image (grey, note the sunspot) and the off-limb counterpart by PROBA2/SWAP. The “FI” labels show the location of filaments as extracted live from the Heliosphysics Event Knowledgebase

Partial Solar Eclipse, March 20, 2015: A science party for everyone!

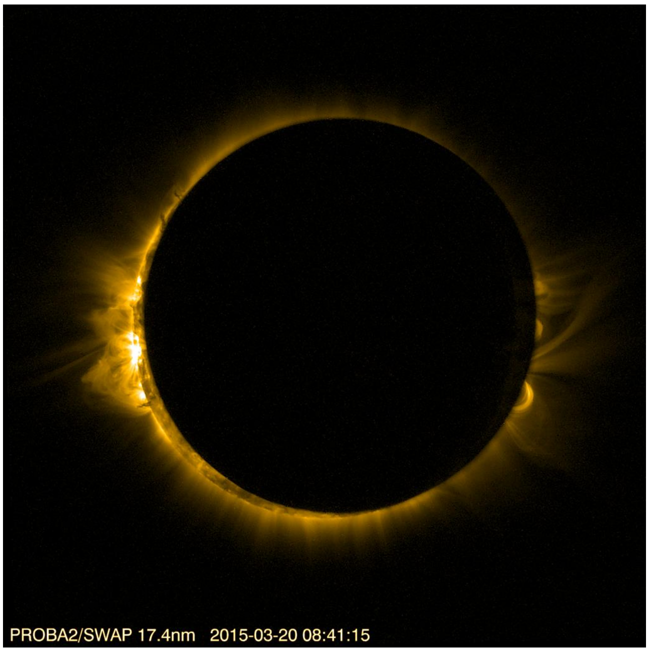
On Friday March 20, an impressive partial solar eclipse was visible from Belgium between 9:26 UT and 11:47 UT. This eclipse could be seen in its totality only from the Faroe Islands and Svalbard (Norway), and was partial in Europe.



The clouds obstructed our view at the observation site Uccle. We could capture only one, very nice, White Light image of the eclipse with the USET telescope.

Witnessing a solar eclipse is a rare experience. In the past, a total eclipse was the only way to observe the immediate environment around the Sun and to get an idea of the structure and composition of the solar atmosphere. It made scientists realise how complex and extended the solar atmosphere actually is. Nowadays, we have instruments that can create an artificial eclipse on a permanent base, but they suffer from technical limitations. Observing a solar eclipse in the normal way remains valuable for us scientists as it allows us to calibrate our solar instruments.
But above all, a solar eclipse offers us the opportunity to put our favourite object of study, the Sun, in the picture and to share our enthusiasm.

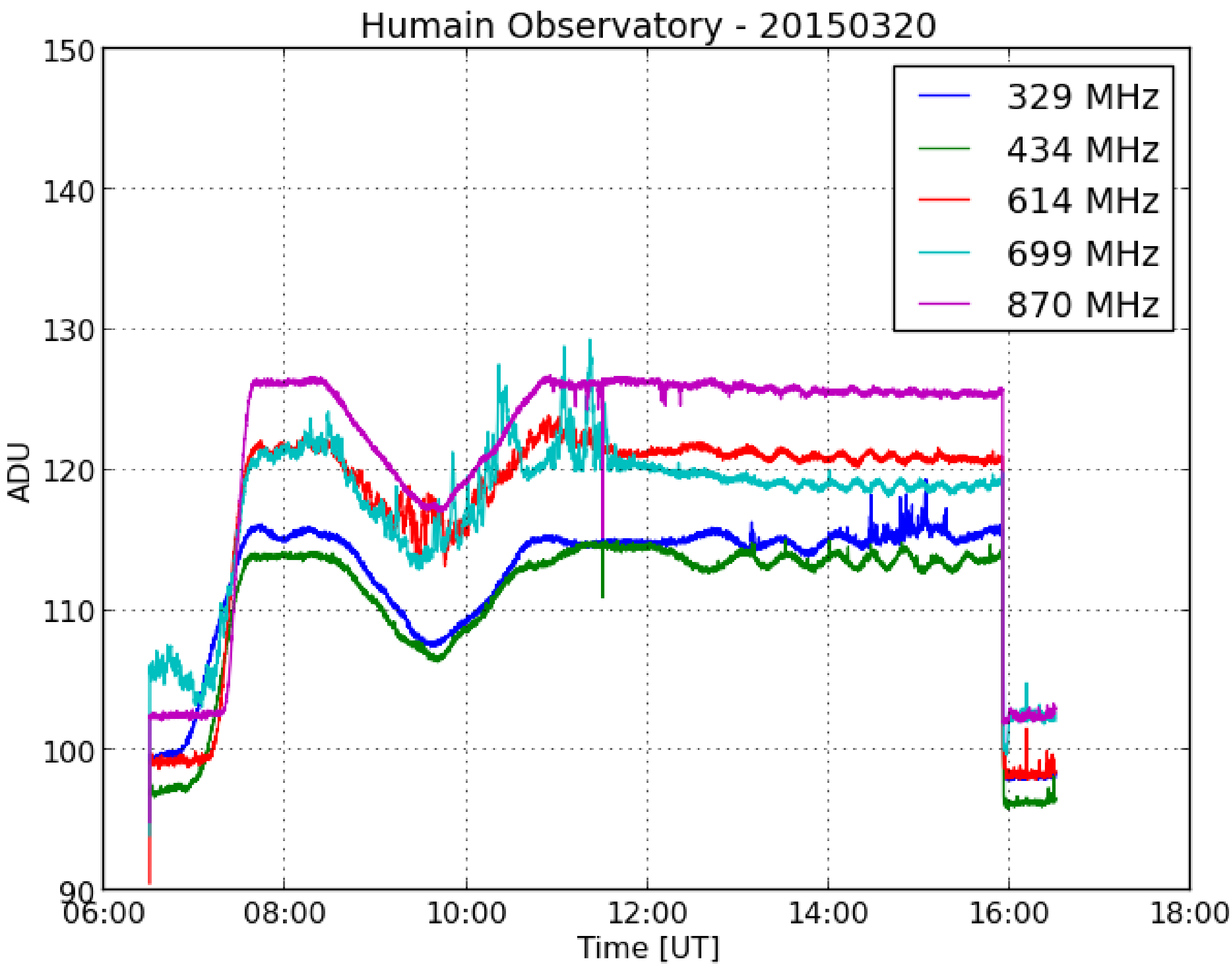
We coordinated an observation campaign so that all our instruments were ready to observe the eclipse from all possible sides. Those that didn't have the chance to observe the eclipse themselves, could follow the spectacle on the eclipse website, http://sidc.be/eclipse2015/, where data, images and movies were put as soon as they were available.
While the optical observations from ground were unfortunately plagued by the cloud cover, the radio telescopes in Humain could observe this event continuously. The PROBA2 satellite was the first to send around images from space, while other satellites were used to track changes in the ionosphere.
At the planetarium, more than 300 children and adults came together to watch the eclipse with their own eyes, through telescopes set up outside, or by looking at images streamed live from our instruments located in Uccle, Humain and space. Our experts were happy to show and explain what an eclipse looks like when observed



The solar eclipse seen from space by the satellite PROBA2. The SWAP telescope pictures the Sun in extreme ultraviolet light.

with radio-antennas from Earth and why our satellite could observe the eclipse up to 4 times that day! The State Secretary for Science Policy, Mrs. Elke Sleurs was definitely impressed. The planetarium was the place to be where radio and television crews found our visitors enthusiastic to tell how they experienced this one-in-a-life-time event and our experts glad to clarify the science behind it.

If you want to look at the March 2015 solar eclipse pictures and movies once more, check http://sidc.be/eclipse2015/index.php.



At the radioastronomy station Humain, we could measure the eclipse with a 6 meter dish, unhampered by the clouds. The radio light flux curves show the rise of the Sun around 07:30UT. During the eclipse, the flux decreases as the Moon passes in front of the Sun.

Information services

The activities related to the information services consist of several tasks: answering questions and inquiries from public and press, assisting in all kind of outreach activities, giving general information on ROB and on astronomy and astronomy related subjects, advising the planetarium, organize the visits to the ROB, including the organization and coordination of open doors days and related activities, all kind of assistance for exhibitions and public relations activities (press communications, press conferences etc.) and preparing of texts for printing or for the web site. (*http://www.astro.oma.be/en/news/*)

Information to public, media and authorities

In 2015 the scientific information service of the ROB had to answer to about 965 questions from the public sent to the ROB by email (about 510, not included the ones related to visits or visit requests), telephone (more then 350) or by letter or fax (105). As usual most were about sunset and sunrise, twilights, equinoxes and solstitia, horizontal coordinates of sun and moon, the amount of shadow, sun dials, moon rise and set, moon phases, eclipses in 2015 and other years, all sort of calendar topics (Easter dates, beginning and end of Ramadan, time keeping, time zones, …) tides, star maps and visibility of constellations over the world, comets now and in history, Mars, Venus and other planets in the sky, fireballs, meteors, UFOs, satellite re-entries, candidate meteorites, information about historical scientific instruments, the profession of astronomer, external influences (sun, planets, universe,…) on climate change, structure of the universe, on satellites and space missions, photographs and images of the Observatory, history of the observatory, amateur astronomy associations and public observatories, planets and the moon, atmospheric halos, goniometry and positional astronomy, names of asteroids, giving and/or registering of stars names, adopting or buying stars, black holes, etc..

In 2015 there was a lot of interest from the public and the media, but also from within the Observatory, for the partial eclipse of sun on March 20. Information about this was given to the press (see A.3.2) but also to personnel and visitors. The topic on the web site was consulted about 5000 times. SIDC and the Planetarium have dedicated activities on this occasion.

Questions about the sun and its influence on earth (space weather etc.); about seismology, gra-vimetry and GPS, about asteroids and impact of asteroids on earth were forwarded to other sections of the observatory. Questions about weather and climate were sent to the Meteorological Institute and those about space travel and aeronomy to the Belgian Institute for Aeronomy.

Information to the media (TV, radio and written press) was given by the service on numerous occasions. 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 2015 26 groups visiting and more than 580 emails (in/out) related to visits or inquiries. We welcomed, amongst other groups, the Brussels Expat Club, personnel of the EU Satellite Navigation Programme

Unit, members and invitees of CD&V Brussels, the president of MR and collaborators, participants of the colloquium “Hydrology, Geophysics and Geodesy – HG², a new way to manage water resources?”, Applied Physics students of the University of Twente, and a group of Belgian pupils and officials of the German speaking community.

Website

There is no consistent information on the number of visitors to our webpages directly available. Probably the statistics of the previous years are still valid, but there is no guarantee: many of the web pages of the information services had about 1000 visitors per months (depending on the season). Pages on sun rise and sun set, moon phases, daylight saving time, or date of Easter … had before a large number of hits per month, but this seems not the case anymore. In March there was an increase in web visitors because of the solar eclipse.
The content of web pages with the answers to frequently asked questions was regularly updated. For 2015, the pages on daylight saving time and on the Islamic calendar (Ramadan) had at least one update or revision. New data about the position of the sun during the year were added.
The Dutch versions of the pages on the celestial phenomena of the month (information given by R. Dejaiffe, put on the web by H. Langenaken) were revised on a regular basis.
J. Cuypers initiated or assisted in putting new items, as e.g. press releases or announcements on the news pages of the ROB. In 2015 there were 15 topics published.

Mons superstar

The exhibition “Mons Superstar”, one of the events of Mons 2015, European Captial of Culture, highlighted several famous inhabitants of this City. Since Jean-Charles Houzeau, the second director of the ROB is one of them, the Observatory provided documentation on Houzeau and put the heliometer at the disposal of the exhibition. An old picture of the heliometer figured also on the publicity for this exhibition.

Archive digitization

Information on archives, archiving and the archives of the ROB were distributed. The website was updated (http://archief-as.oma.be/). A lot of documents and photographs were digitized: 200000 scans of 19th century administration and the oldest annals, already scanned in 2014 were finalised and put in the database. The scan of 90000 other documents (old, annuaries, annals and other publications from the beginning of the 20th century started. 8000 photoslides and 3000 photographs were scanned at ROB b y M. Schulmann (funded by Art. 60 till August 2015), but most of the work related to this topic was done by H. Langenaken and she followed the appropriate courses and information sessions.
Funding was by different large and small digitisation projects, details still to be added.

The Planetarium

PLANETARIUM.be

New attendance record for the Internet site of the Planetarium

The Planetarium's website (www.planetarium.be) brook its 2014 record by being visited 168,112 times (106,046 unique visitors, 2,198,901 hits). It was most viewed during school holidays, which shows that it is used to prepare a family visit, setting the Planetarium as a recognized family outing destination.

Presentation of Belgian scientific results of Rosetta

On February 27, Belgian scientist’s progress and findings thanks to Rosetta spacecraft and Philae lander data were presented to the general public. This was the opportunity to discover the Belgian contribution to this adventure. The session ended with the 360° film screening « Ice Worlds ».

Night of the shooting stars

In the evening and night of August 12, 2015 the public was welcome at the Observatory to observe the sky and the shooting ('falling') stars. The Planetarium was the main organiser of this event, with ROB and BISA assisting. Amateur astronomers, individuals and organisations, put telescopes at the disposal of the visitors to observe the sky. BISA showed how to detect meteors with radio signals. The Schmidt telescope could be visited by the public.

The number of visitors was limited to 500 by pre-registration but because of the bad weather not all showed up.

Selection CANSat

The Planetarium hosted the presentation and selection day of the Cansat project. Tens teams of secondary school students presented and defended their project of scientific measurements of the atmosphere, which has to be boarded in a soda can. Laureates can afterwards launch from the Netherlands their experiment in a mini-spacecraft.

ASGARD Project

The ESERO office and its partners organised the 2015 session of the ASGARD project. This allows secondary school students to prepare science experiments mounted in a stratospheric balloon. The launch took place on April 23 from the IRM site.

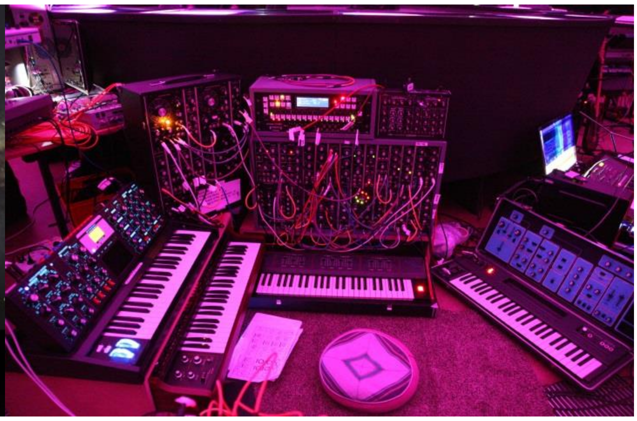
Darkness' Night

As every year since 2009, the Planetarium assembled its partners at Rouge-Cloître to welcome the general public for the Darkness' Night. The evening program consists of observing sessions, conferences, tales in the woods and music under the open sky.

Poetry under the stars, Choir Stemmer and Cosmic Nights

In 2015, the Planetarium organized several special evenings which mix arts and sciences. These events are:

- Cosmic Nights on May 29 ;
- Choir Stemmer on June 6 ;
- Poetry under the star on Septembre 10, with the collaboration of the non profit association be.poetic



Annex 1: Publications

Publications with peer review

[1] Aerts W., Bruyninx C., Defraigne P., Vandenbosch G., Zeimetz P.
Influence of RF absorbing material on the calculated GNSS station position
GPS Solutions, GPS Solutions, 20(1), 1-7, doi : 10.1007/s10291-014-0428-y, Jan. 2016

[2] Aragon-Angel A., Hernandez-Pajares M., Defraigne P., Bergeot N. and Prieto-Cerdeira R.
Modelling and Assessing Ionospheric Higher Order Terms for GNSS Signals
Proceedings of ION GNSS+ 2015, pp. 3511-3524, 2015

[3] Aschwanden, M. J.; Boerner, P.; Caspi, A.; McTiernan, J. M.; Ryan, D. F.; Warren, H. P.
Benchmark Test of Differential Emission Measure Codes and Multi-thermal Energies in Solar Active Regions
Solar Physics vol. 290 pp. 2733-2763 (2015)

[4] Aschwanden, M. J.; Boerner, P.; Ryan, D. F.; Caspi, A.; McTiernan, J. M.; Warren, H. P.
Global energetics of solar flares: II. Thermal Energies
Astrophysical Journal vol. 802:53 (2015)

[5] Ben Moussa, A.; Giordanengo, B.; Gissot, S.; Dammasch, I.E.; Dominique, M.; Hochedez, J.-F.; Soltani, A.; Bourzgui, N.; Saito, T.; Schühle, U.; Gottwald, A.; Kroth, U.; Jones, A.R.
Degradation assessment of LYRA after 5 years on orbit - Technology Demonstration
Experimental Astronomy vol. 39 pp. 29-43 (2015)

[6] Balona L.A., Baran A.S., Daszyńska-Daszkiewicz J., De Cat P.
Analysis of Kepler B stars: rotational modulation and Maia variables
2015, Monthly Notices of the Royal Astronomical Society 451, 1445

[7] Beuthe M.,
Tides on Europa: The membrane paradigm,
2015, Icarus, 248pp. 109-134, DOI: 10.1016/j.icarus.2014.10.027

[8] Beuthe M.,
Tidal Love numbers of membrane worlds: Europa, Titan, and Co.,
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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	Premier assistant
Alvarez Rodrigo	Premier assistant
Berghmans David	Eerstaanwezend werkleider
Blomme Ronny	Werkleider
Bruyninx Carine	Eerstaanwezend werkleider
Camelbeeck Thierry	Chef de travaux principal
Clette Frédéric	Premier assistant
Collin Fabienne	Premier assistant
Cuypers Jan	Eerstaanwezend werkleider
De Cat Peter	Werkleider
Defraigne Pascale	Chef de travaux principal
Dehant Véronique	Maître de recherches
Frémat Yves	Premier assistant
Groenewegen Martin	Werkleider
Hochedez Jean-François	Chef de travaux
Lampens Patricia	Onderzoeksleider
Lecocq Thomas	Assistant
Legrand Juliette	Premier assistant
Pauwels Thierry	Eerstaanwezend werkleider
Robbrecht Eva	Assistant
Roosbeek Fabian	Premier assistant
Van Camp Michel	Chef de travaux principal
Van De Steene Griet	Werkleider
Van Hoolst Tim	Eerstaanwezend werkleider
Vanneste Kris	Werkleider
Yseboodt Marie	Premier assistant

Technisch en administratief personeel / Personnel technique et administratif

	Name/Nom	Functie/Fonction
A :	Milis Andre	Adviseur A3
	De Knijf Marc	Attaché A3
	Dufond Jean-Luc	Attaché A2
	Rogge Vincent	Attaché A2
	Jans Thimoty	Attaché A1
	Kochuyt Anne-Lize	Attaché A1
	Rapagnani Giovanni	Attaché A1
	Rezabek Oleg	Attaché A1
	Wellens Véronique	Attaché A1
B :	Boulvin Olivier	Expert technique
	Bukasa Baudouin	Expert technique
	Castelein Stefaan	Technisch deskundige
	Claerhout Alexandre	Expert ICT
	Dumortier Louis	Expert ICT
	Duval David	Expert ICT
	Ergen Aydin	Expert technique
	Frederick Bert	Expert technique

	Hendrickx Marc	Expert technique
	Herreman David	Expert ICT
	Langenaken Hilde	Technisch deskundige
	Lemaitre Olivier	Expert technique
	Martin Henri	Expert technique
	Mesmaker Dominique	Expert technique
	Moyaert Ann	ICT deskundige
	Somerhausen André	Expert ICT
	Strubbe Marc	Technisch deskundige
	Van Camp Lydia	Technisch deskundige
	Van De Putte William	Technisch deskundige
	Van Der Gucht Ignace	Technisch deskundige
	Vandekerckhove Joan	Technisch deskundige
	Vandercoilden Leslie	Expert technique
	Van de Meersche Olivier	Expert financier
	Vermeiren Katinka	ICT deskundige
	Vermeylen Lore	Technisch deskundige
	Wintmolders Sabrina	Administratief deskundige
C :	Bizerimana Philippe	Assistant technique
	Brebant Christian	Assistant administratif
	Bruyninckx Martine	Administratief assistent
	Consiglio Sylvia	Administratief assistent
	Depasse Béatrice	Assistant administratif
	De Wachter Rudi	Technisch assistent
	Feldberg Liesbeth	Administratief assistent
	Segers Cindy	Adminstratief assistent
	Trocmet Cécile	Assistant administratif
	Vanden Elshout Ronny	Assistant technique
D :	Vanparijs Thomas	Technisch medewerker

A.2. Personeel met externe beurzen / Personnel sur bourses externes

Name/Nom	Functie/Fonction
Gloesener Elodie	Boursier FRIA

A.3. Contractueel personeel beheerd door de POD Wetenschapsbeleid / Personnel contractuel géré par le SPP Politique Scientifique

	Name/Nom	Functie/Fonction
SW11	Katsiyannis Athanassios	Assistant
B :	Malisse Vincent	ICT-deskundige
	Vandersyppe Anne	Administratief expert
C :	De Dobbeleer Rudy	Technisch assistant
	Mouling Ilse	Administratief assistent
	Semeraro Vanessa	Administratief assistant
	Sinchiri Kevin	Administratief assistant
D :	Inkeleer Jérémy	Collaborateur technique
	Motte Philippe	Collaborateur technique
	Rodriguez Carolina	Collaborateur technique

A.4. Contractueel personeel / Personnel contractuel

Wetenschappelijk personeel / Personnel scientifique

Naam/Nom	Functie/Fonction
Andries Jesse	Werkleider
Attié Raphaël	Assistant
Baire Quentin	Assistant
Benmoussa Ali	Chef de travaux
Bergeot Nicolas	Chef de travaux
Beuthe Mikael	Chef de travaux
Bonte Katrien	Assistent
Bourgoignie Bram	Assistent
Champagne Georges	Assistant
Chevalier Jean-Marie	Assistant
Dammasch Ingolf	Assistant
Cuyper Jean-Pierre	werkleider
Delouille Véronique	Chef de travaux
Deproost Marie-Hélène	Assistant-stagiaire
Devos Andy	Assistent
D'Huys Elke	Assistent
Dolla Laurent	Assistant
Dominique Marie	Assistant
Gerbal Nicolas	Assistent-stagiaire
Gillmann Cédric	Assistant
Giordanengo Boris	Chef de travaux
Gissot Samuel	Chef de travaux
Janssens Jan	Assistent
Joukov Andrei	Chef de travaux
Huang Wei	Assistant-stagiaire
Karatekin Ozgur	Chef de travux
Knuts Elisabeth	Assistant
Kraaikamp Emil	Assistent
Laguerre Raphael	Assistant
Lefevre Laure	Chef de travaux
Lobel Alex	Werkleider
Lombardini Denis	Assistant
Magdalenic Jasmina	Chef de travaux
Martinez Picar Antonio	Assistent
Marqué Christophe	Chef de travaux
Mierla Marilena	Assistant
Mitrovic Michel	Assistant
Nicolaes Dries	Assistant-stagiaire
Nicula Bogdan	Chef de travaux
Noack Léna	Assistant
Özdemir Nilüfer Aslihan	Assistant
Parenti Suzanna	Chef de travaux
Péters Marie-Julie	Assistant-stagiaire
Podladchikova Olena	Chef de travaux
Pottiaux Eric	Chef de travaux
Pylyser Eric	Assistant
Rekier Jeremy	Assitant
Ryan Daniel	Assistant

Rivoldini Attilio	Assistant
Rodriguez Luciano	Chef de travaux
Rosenblatt Pascal	Chef de travaux
Stegen Koen	Assistent
Triana Santiago	Assistant
Trinh Anthony	Assistent
Van Hoof Peter	Werkleider
Van Hove Bart	Assistent
Vanlommel Petra	Eerstaanwezend assistent
Van Noten Koen	Assistent
Vansintjan Robbe	Assistent
Verbeeck Francis	Eerstaanwezend assistent
Verbeeck Koen	Assistent
Verdini Andrea	Assistant
Verstringe Freek	Assistent
Vleminckx Bart	Assistent
Wauters Laurence	Chef de travaux
West Matthew	Assistant
Zhu Ping	Assistant

Technisch en administratief personeel / personnel technique et administratif

	Naam/Nom	Functie/Fonction
A :	Van Elder Sophie	Attaché A1
	Cornet Denis	Attaché A1
	Mestdagh Pieter	Attaché A1
	De Decker Georges	Attaché A2
	Hanjoul Michel	Attaché A2
	Willems Sarah	Attaché A2
	Mampaey Benjamin	Attaché A2
	Van Hemelryck Eric	Attaché A2
B :	Bastin Véronique	Expert technique
	Coeckelberghs Hans	Technisch deskundige
	Delmeule Nicolas	Expert ICT
	Rigo Ghislain	Expert technique
	Vander Putten Wim	ICT-deskundige
C :	Hernando Ana Maria	Assistant administratif
	Michaux Kevin	Administratief assistant
	Smet Gert	Technisch assistent
	Smetryns Daan	Technisch assistent
	Stokart Luc	Assistant techniquet
	Vandeperre Arnold	Technisch assistent
	Wijns Erik	Technisch medewerker
D :	El Amrani Malika	Collaborateur technique
	Gonzales Andres	Administratief medewerker
	Herman Viviane	Collaborateur technique
	Ipuz Mendez Adriana	Collaborateur technique
	Kurudere Hulya	Technisch medewerker
	Reghif Harraz Mohammed	Collaborateur technique
	Vermeylen Jacqueline	Collaborateur technique
	Verbraeken Ulrike	Technische medewerker

A.5.Gedetacheerd personeel / Personnel détaché

Naam/Nom	Functie/Fonction
Duynslaeger Thierry	Leraar