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

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# Annual Report 2012

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

*Cover illustration: A close up, composite image of the Sun and comet Lovejoy (the striated line) taken with the SWAP EUV imager on PROBA 2 (ROB).*

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# Preface

*This report describes the highlights of scientific activities and public services at the Royal Observatory of Belgium in 2012.*

*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.*

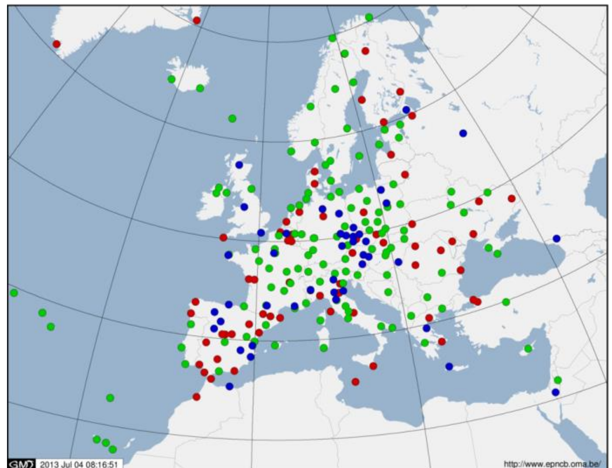
*If you need more or other information on the Royal Observatory of the Belgium and/or its activities please contact [rob_info@oma.be](mailto:rob_info@oma.be) or visit our website [http://www.astro.oma.be](http://www.astro.oma.be).*

*Kind regards*
*Ronald Van der Linden*
*Director General*

# Reference Systems and Planetology

# Global Navigation Satellite System (GNSS) for positioning, space weather, meteorology and for characterizing plate motions and deformations

ROB uses Global Navigation Satellite System (GNSS) data in order to first determine precise positions (at the mm level) and velocities (at the sub-mm/year level) of permanently tracking GNSS stations installed on the Earth's crust. This allows them to characterize regional and global ground deformations (geokinematics) and to integrate Belgium in international terrestrial coordinate reference systems. This is performed through the integration of several continuously observing GNSS reference stations and associated services in international GNSS observation networks. The 'GNSS' ROB team contributes actively to the European and global developments of GNSS observation networks, their products and applications since more than ten years. This has resulted in a number of responsibilities within the International GNSS Service (IGS) and the EUREF (European Reference Frame) Permanent GNSS Network (EPN). The EPN is a network of almost 250 permanently observing GNSS stations distributed all over Europe (see figure above) and which is managed by the ROB GNSS team (http://www.epncb.oma.be; it received about 2.5 million hits in 2012). The EPN is the foundation of the European Terrestrial Reference System (ETRS89) recommended by the EU for all geo-referencing in Europe.



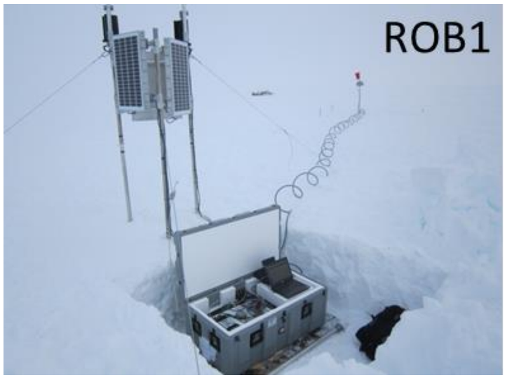

*EPN tracking network (status Dec. 2012). Red: stations tracking only GPS signals (31%); Blue: stations tracking GPS+GLONASS signals (51%);Green: stations tracking GPS+GLONASS signals and capable to track Galileo signals (18%).*

As the models correcting GNSS error sources have been improved with time, ROB scientists contributed to the first full reprocessing of the **EUREF Permanent GNSS Network** (EPN) and integrated its results in the EPN Central Bureau web site. From the results, more precise station positions, velocities and residual position time series, as well as troposphere parameters have been derived.

On Feb. 14, 2012, after more than 19 years of operation, ROB's primary permanent GNSS station which is integrated in the international observation networks of the EPN and IGS (International GNSS Service) was decommissioned. The replacement station (see right picture), located about 100 m from the old one, directly took over operations and was also integrated into the IGS and EPN networks. Compared to the old station, the new one has improved performance thanks to better visibility and equipment and enhanced multipath mitigation, as well as the ability to observe, next to GPS, also GLONASS and Galileo satellites.

*New permanent GPS+GLONASS+Galileo tracking station at ROB.*

Within the frame of a working group of the International Association Geodesy, chaired by ROB, we are creating a **dense velocity field** based on





*Installation of two new GNSS stations in Antarctica*

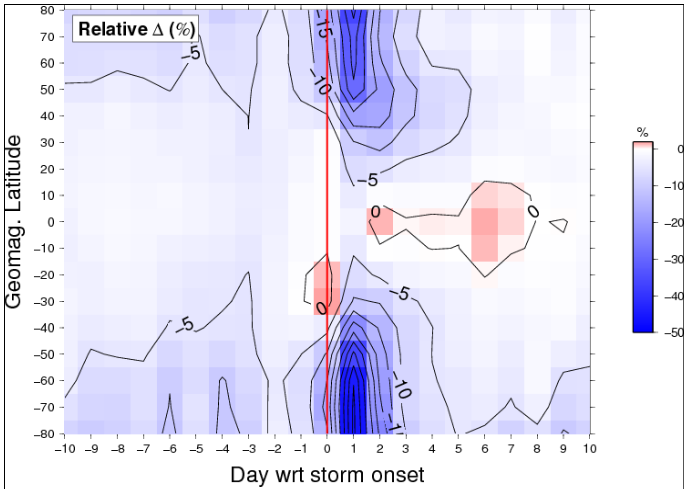
permanently observing GNSS stations installed throughout the globe. Up to now, this velocity field was estimated by combining the velocity solutions generated by different analysis centers, but we showed it was affected by geographically correlated biases. To get rid of these biases, we introduced in 2012 a new approach consisting of combining weekly positions prior to deriving the station velocities. We performed preliminary weekly combinations including 8 individual solutions and about 2000 stations over a period of 16 years. The agreement between the solutions leads to weekly RMS ranging from 2 to 8 mm.

Two new GNSS stations were installed around the Princess Elisabeth station in **Antarctica** in the frame of the IceCon project (see above figure). The IceCon project aims at a better understanding of the past and present ice volumes and extension of the Antarctic ice sheet in Dronning Maud Land through a new series of measurements and observations in conjunction with ice sheet system modelling. The new GNSS stations have been designed to run all year round and are equipped with solar panels and windturbines.

In addition, we recomputed improved daily positions for the ELIS permanent GPS station in Antarctica (installed by ROB in 2009 within the frame of the BELSPO GIANT project) by extending the network of GNSS reference stations included in the analysis in order to reduce the network effect. At present, not enough data are available for ELIS to determine reliable site velocities. A new analysis will be done in 2013 using additional data and enhanced modelling capabilities.

ROB scientists have also developed software to process and compare GNSS **antenna calibrations**. This work allowed detecting anomalies, even in the widely used igs08.atx standard calibration file containing the official antenna type mean phase calibrations. The IGS Antenna Working Group, responsible for maintenance of the igs08.atx file, as well as Geo++, the company responsible for the generation of the calibrations that contain the anomalies, were contacted. The igs08.atx will get an upgrade in 2013 to correct the erroneous values, according to ROB results. ROB scientists also investigated how different antenna calibration models can have an impact on the estimated station positions. A comparison of positions obtained on the one hand with type calibrations and on the other hand with individual calibrations resulted in position differences up to 1 cm in the up component. In the horizontal, position differences generally stay below 4 mm. The comparison of the positions obtained with individual calibrations provided by two different calibration facilities (Geo++ - robot calibration and UniBonn - anechoic chamber) demonstrated a difference of 2 mm in the horizontal components. In the up component, there is a significant bias of 5 mm. All these results confirm that although individual antenna calibrations are far from perfect and affected at the few mm level by near field multipath, they are more representative for the phase center variation of a specific antenna than an antenna-type mean calibration.

Additionally, the computation of local ties between our old and new permanent GNSS station in Uccle also demonstrate the limitation of GNSS to accurately, at the (sub)-mm level, determine local site eccentricities. This limitation is mainly caused by the imperfect calibration of the GNSS antennas.




Mean effect of 69 geomagnetic storms (1998-2005) on daily mean TEC w.r.t to the latitude for a period of 20 days around the events. This picture shows the mean relative differences (scaled by the observed) in percentage. The red line is day of the detected onset of the storms.

The GNSS team is involved in the Solar Terrestrial Center of Excellence (STCE) and uses GNSS observations to monitor the Earth's ionosphere and troposphere. The monitoring products are used by scientific as well as civil users.

In the frame of the ionosphere, a method to generate in near-real time 0.5°x0.5° grid VTEC (Vertical Total Electron Content) maps and VTEC variance over Europe each 15 minutes from the GNSS data from the EPN has been developed (see report of 2011). In 2012, we started to provide routinely, in near real-time the results of the **ionospheric monitoring**, obtained using this method, to the public. In addition, information on identified ionospheric disturbances are also communicated to the public via the web-site www.gnss.be (also integrated in the SIDC web portal) and an open access to the ionospheric data is now available via ftp://gnss.oma.be.

The ROB team also investigated the effect of geomagnetic storms on ionospheric daily mean TEC. We demonstrated that geomagnetic storms mainly affect the TEC in Polar regions with a maximum decrease of ionization one day after the onset (-3.2 ± 1.5 TECu in absolute and -19.6 ± 15.0% in relative differences). Pre-storm conditions can be retrieved again after 3-4 days.

The team also showed (in collaboration with the Solar Physics Department) that solar radio bursts can degrade GNSS signal reception. The GNSS carrier to noise ratio can even be used to deduce the solar flux. However, antenna and receiver technical details are the limiting factors of the study.

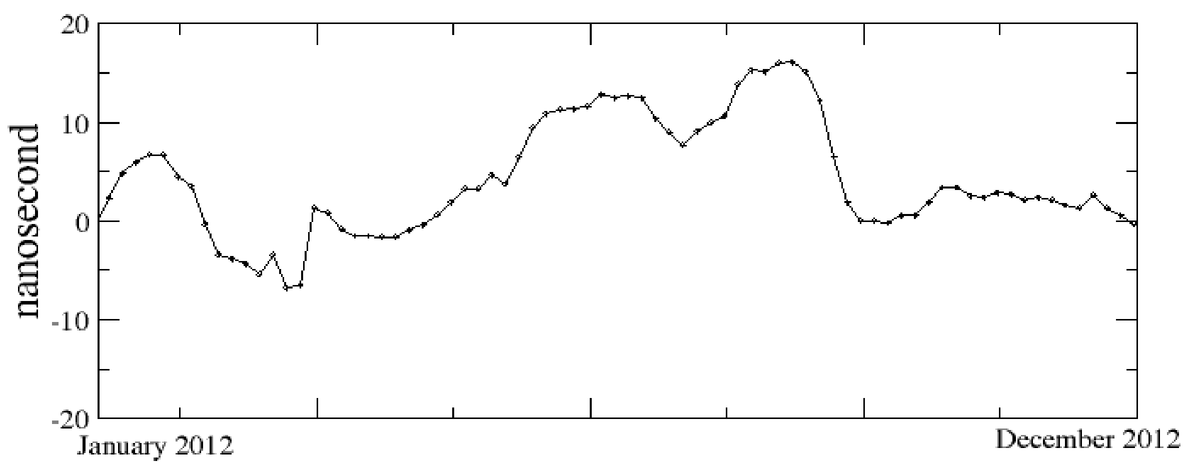
**Water vapour** plays a dominant role in the climate change debate, as it is the most important greenhouse gas and provides the strongest positive feedback mechanism for the surface warming. However, observing water vapour over a climatological time period in a consistent and homogeneous manner is challenging, because water vapour is highly variable both in space and time. In collaboration with RMI and BISA, ROB set up a world-wide techniques inter-comparison consisting of seven different devices observing water vapour: two ground-based (GPS and CIMEL sun photometer), one in-situ (radiosondes, attached to weather balloons) and four satellite-based (measuring in the visible wavelength range, GOME/SCIAMACHY/ GOME-2, and in the thermal infrared, AIRS). The main conclusion of this research is that CIMEL sun photometers and GPS are very valuable techniques to measure Integrated Water Vapour (IWV) and the most promising to build up long time series for climate applications, as long as the data homogeneity can be guaranteed. For the considered satellite data, the largest geographical variability of the IWV measurements relative to the co-located GPS observations is obtained, possibly due to the spatial coverage and the high variance of IWV.

ROB also improved its service which provides the European meteorological institutes with near real-time (NRT) GPS-based tropospheric Zenith Path Delay (ZPD) estimates used for assimilation in the Numerical Weather Prediction (NWP) models and for now casting applications. The goal of the improvement was to adhere to the next generation of user requirements and to new types of products and applications. After 6 months of validation (i.e. mid 2012), this new service became the official ROB solution within the E-GVAP project and the old service was discontinued.

# Time Transfer

The ROB scientists establish the Belgian time scale (UTC(ORB)) and participate in international timescales by incorporating Belgium in these timescales. We maintain presently six high-quality clocks for participation in two international timescales: the International Atomic Time (TAI) and the International GNSS Service Timescale (IGST). The present requirement for the clock precision and stability is at the level of the nanosecond over one day, which can only be achieved with high-quality clocks, when located in temperature-controlled environment. Our six clocks are located in such an environment and their performances are continuously monitored by inter-comparison between themselves and also with atomic clocks of other laboratories participating to TAI or IGST. In order to perform these comparisons, as well as to transfer time at the centres where the computations for the international timescales are performed, we need methods which insure a time-transfer precision matching the required precision of the timescales. These comparisons are usually performed using code measurements of GPS satellites in common view. The scientists involved in the project work on the improvement of the time transfer by using both code and phase measurements of geodetic receivers, in order to enhance its precision and accuracy. This requires the establishment of new analysis strategies, new error modeling, and new computer codes. It also requires the installation of new equipment and the adaptation of the procedures to these new equipment. The scientists of this project also take care of the legal issues related to the legal time. An additional important part of the work is related to the quality control and maintenance of the clocks, as our involvement in the definition of international timescale impose us a quasi-perfect reliability.

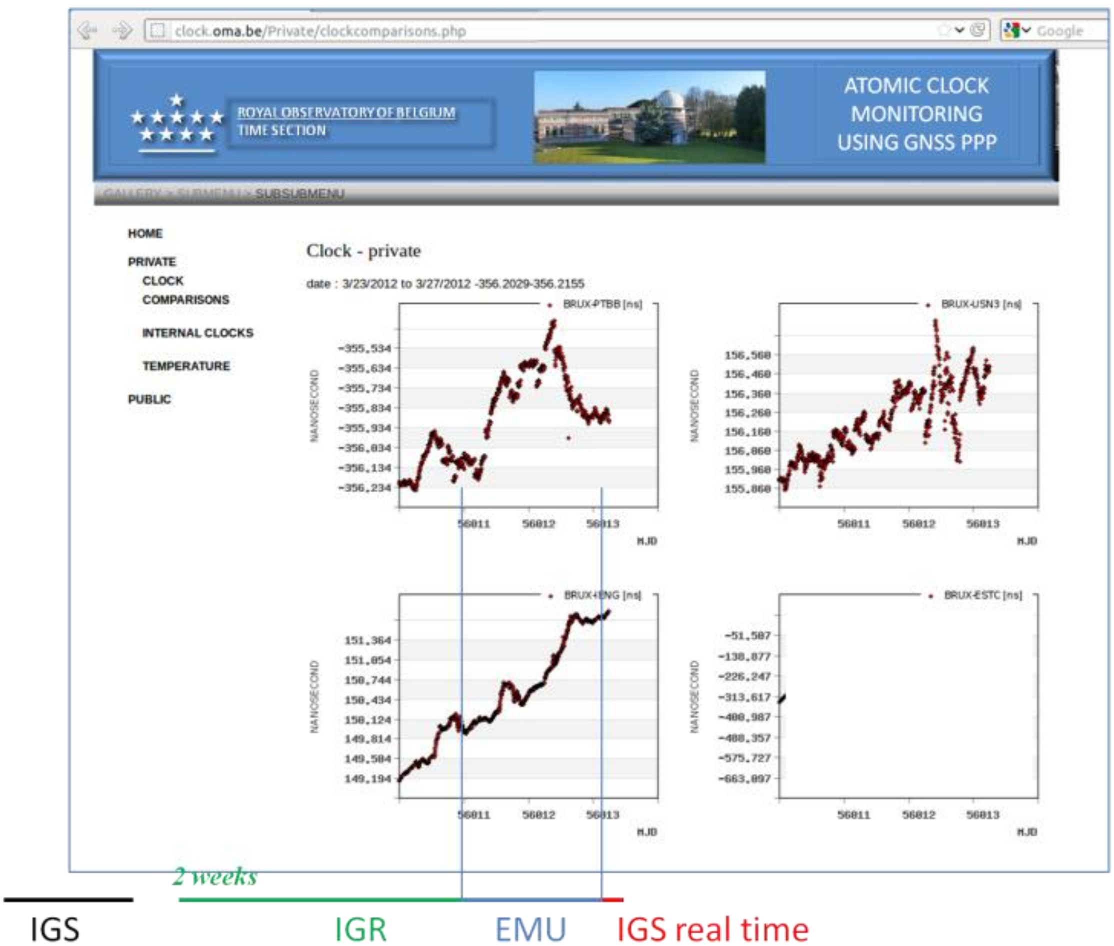
During 2012, thanks to the repair of the Maser in February 2012, to the complete renewal of the lab in 2011, and to the participation of the ORB clocks to the BIPM project Rapid UTC since February 2012, UTC(ORB) was realized with a quality never obtained in the past, the deviation from UTC did not exceed 16 nanoseconds. The top right figure provides the difference between the realization of UTC at ROB and UTC as a function of time for 2012.




*UTC (ORB) compared to the true UTC during the year 2012.*

On October 24, 2012, the law defining UTC and its realization at the Observatory as basis of Belgian Legal Time was signed by the ministers P. Magnette and J. Milquet.

The quasi real-time monitoring of atomic clocks using Precise Point Positioning (PPP, a method that performs precise position determination using a single GNSS receiver) was improved allowing now to detect a clock jump larger than 1.5 ns after some minutes using the IGS real-time products, or 0.8 ns after 90 minutes, using the Ultra Rapid orbit and clock products (EMU) delivered by the Canadian Analysis Center (NRCan), and a frequency change larger than $2x10^{-14}$ when looking at the last 24h data, or larger than $2x10^{-13}$ when looking at the last 2 hours, a world first. These results have led to an update of the Observatory clock website, http://clock.oma.be, where the near real-time monitoring of UTC(k) is available continuously for UTC(ORB) and several other laboratories (See figure below).




*Screenshot of website http://clock.oma.be*

# Geodesy and Geophysics of Terrestrial Planets

ROB scientists investigate the rotation and orientation variations and the tides of the terrestrial planets and large natural satellites in order to gain insight into their interior structure, composition, evolution, dynamics, and atmosphere. Geodesy data on the gravity field and rotation of a planet can be obtained from spacecraft flying by, in orbit around, or landed on the planets. In this project, radio science data from spacecraft in orbit around Mars and Venus, such as MarsExpress (MEX), Mars Global Surveyor (MGS), Mars Odyssey, Mars Reconnaissance Orbiter (MRO), and VenusExpress (VEX) are the principal source of information. Radio science data from the upcoming BepiColombo mission to Mercury and the ExoMars mission to Mars will be processed in the future. In addition, we use data from missions to the outer solar system like Voyager 1 and 2, Galileo, and Cassini.

The gravity field of planetary bodies is obtained by monitoring the trajectory of passing or orbiting spacecraft through performing Doppler and ranging measurements on radio links between the Earth and the spacecraft. For the analysis of these radio science data and for simulations of future experiments, a numerical code (GINS/DYNAMO) is used and further developed; this code is one of only a few codes in the world that can compute accurate orbits of spacecraft from radio science data. Because the gravity field of a planet is determined by the planet's mass distribution, spatial and temporal variations in the gravity field can be used to determine physical properties of the interior and atmosphere of the planet. Since the beginning of the space age, the large-scale structure of the gravity field of planets and moons has been successfully used to determine the moment of inertia, which is a measure of the radial density distribution and an important constraint on the interior structure. More recent efforts use tides, which can also be observed through their time-variable effect on the gravity field, to obtain more accurate information on the deep interior, in particular on global fluid layers such as a liquid iron core in terrestrial planets and an internal subsurface ocean in icy satellites.

Constraints on planetary interiors can also be obtained from rotation variations. Three broad classes of rotation variations are usually considered: rotation rate variations, orientation changes with respect to inertial space (precession and nutation), and orientation changes with respect to the rotation axis (polar motion and polar wander). They are due to both internal (angular momentum changes between solid and liquid layers) and external (gravitational torques) causes. By studying rotational variations of a terrestrial planet, more can be learnt about the excitation processes. Moreover, as the rotational response depends on the planet's structure and composition, also insight into the planetary interior can be obtained. This is particularly so for the rotational variations due to well-known external gravitational causes, such as for example for the nutations of Mars and the librations of Mercury and natural satellites.

*MarsExpress ESA spacecraft, presently around Mars (ESA)*

The team has a strong theoretical research component, which is oriented towards the investigation of the dependence of rotation variations, gravity field, and tidal variations on interior and atmosphere properties and orbital motion characteristics. These studies include the development of advanced models of rotation, the construction of detailed models for the structure and dynamics of solid and fluid layers of the planets, the investigation of the dynamical response of these models to both internal and external forcing, the modelling of the orbital motion of large bodies of our solar system, and the inclusion of general relativistic effects into the data analysis.

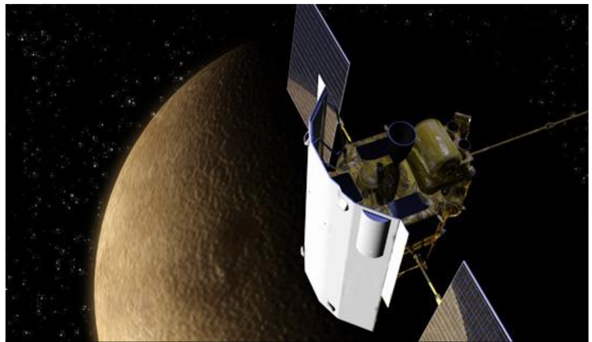
We are involved in several ESA solar system missions (Mars Express, Venus Express, BepiColombo, JUICE) and Cassini at Co-Investigator level, actively participate with ESA in preparations for new and upcoming missions, and lead the development of a coherent

X-band transponder and antenna for use in a future Mars lander mission. We also develop theories and strategies for the future exploitation of space data.

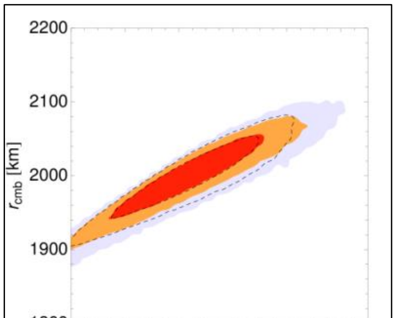
Highlights of results obtained in 2012 are listed below in order of increasing distance of the solar system body involved with respect to the Sun.

## Mercury

The MESSENGER spacecraft, in orbit around Mercury since March 2011, has accurately measured the gravity field of Mercury. Together with ground-based radar measurements of the rotation of Mercury, in particular the changes in the rotation rate (libration) and the angle between the rotation axis and the perpendicular to the orbital plane (obliquity), these data provide the best available information on the deep interior of Mercury. We have shown that the data strongly constrain the radius and average density of the core. The core radius is estimated to be about 2000 km, showing that Mercury's silicate shell consisting of crust and mantle is very thin compared to the other terrestrial planets of the Solar System. If sulfur is the only light element in the core, it contributes about 5% to the total mass of the core. In contrast to initial results published by MESSENGER scientists, we show that the data do not imply that the mantle must have a density significantly larger than the densities of plausible silicate minerals.

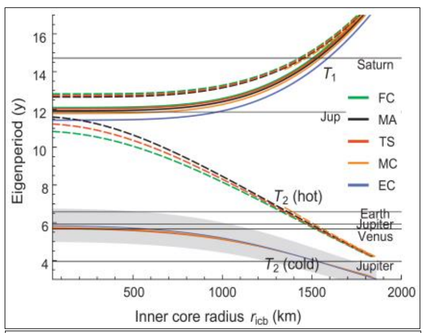


*MESSENGER mission to Mercury (credit NASA).*




*Core radius and core sulfur concentrations for interior models of Mercury that agree with the gravity and rotation data. The color shaded areas represent Bayesian confidence areas (0.68,0.95,0.997). The dashed contours delineate 0.68 and 0.95 Bayesian confidence regions if the effect on the inner core on the libration amplitude is neglected.*

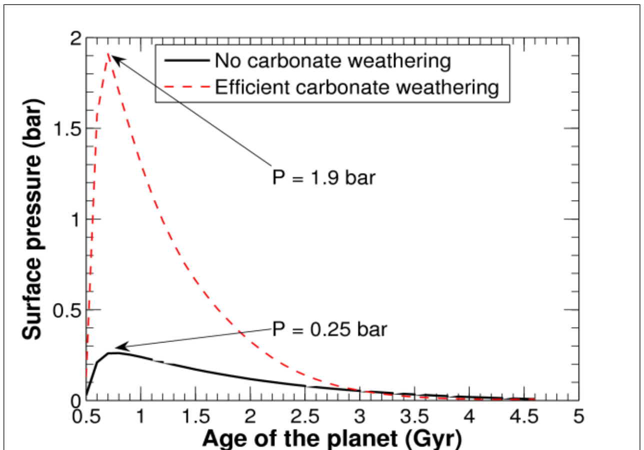
The planets of the Solar System perturb the orbital motion of Mercury with periods related to the orbital periods of the planets. As a result, the gravitational torque of the Sun on Mercury will also be variable at those periods and will induce long-period librations. We have shown that several long-period librations can attain large enough amplitudes to be detected by future spacecraft measurements if the period of the planetary forcing happens to be close to a free libration period. In a parallel effort, we have refined our methods to model the libration in terms of the interior structure and shown that the periods of the free modes of libration sensitively depend on the interior structure of Mercury. Future observations of the long period librations may thus be used to constrain the interior structure of Mercury, including the size of its inner core. The angular velocity of Mercury's mantle at planetary forcing periods is also amplified by the resonances, but remains much smaller than the current precision of Earth-based radar observations unless its period is very close to a free libration period. On the basis of the available radar observations of Mercury's rotation rate, we have concluded that it is currently not yet possible to determine the size of the inner core of Mercury.




*Periods of the two free libration eigenmodes (T1, T2) as a function of the inner core radius. Different curves represent the different interior models. The horizontal lines represent the period of the librations induced by planetary*

## Mars

The rotation of Mars, which can be described by precession, nutation, polar motion and length-of-day variations, is related to the interior of the planet as well as to the dynamics of its atmosphere. It can be estimated by measuring the Doppler shift on radio signals between a probe landed on Mars and tracking stations on Earth. Numerical simulations have been performed to assess the precision on the determination of the rotation parameters from Direct-To-Earth X-band Doppler measurements for a nearly equatorial lander. It was shown that such measurements for a lander mission with a nominal lifetime of one Martian year will allow better constraining the $CO_2$ mass budget of the Martian atmosphere and ice caps. Moreover, the polar moment of inertia will be improved and direct information on the core will be obtained. By combining tracking data from the Opportunity MER rover and the MER Spirit rover when it was stuck with historic tracking of the Viking and Pathfinder landers the most accurate Martian precession rate was estimated.




*Atmospheric mass evolution under two scenarii of atmospheric mass evolution. The first scenario (plain black line) assumes a reduced volatile supply due to impacts. The second scenario (dashed red line) assumes that sequestration of carbon dioxide into carbonate reservoir can remove up to 2 bars of $CO_2$ atmosphere from the end of the Noachian.*

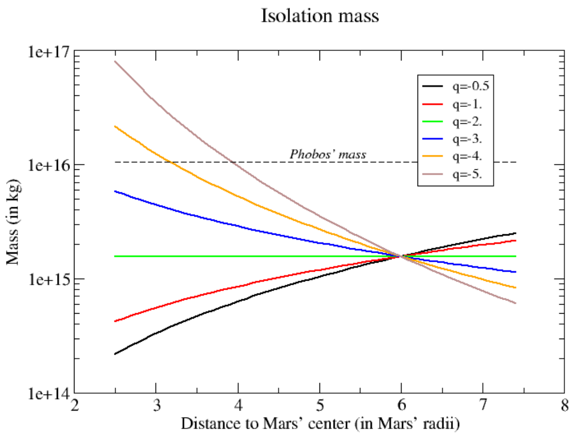
We have shown that impacts alone can hardly remove significant amounts of atmospheric mass of Mars between the end of the Noachian (3.9 Gyr ago) and the present. The atmospheric loss by other mechanisms is also small, except maybe by sequestration of carbon dioxide in carbonate reservoirs. Based on the estimated atmospheric pressures and assumed greenhouse warming, we have shown that saline solutions, possible for temperatures higher than 245 K, can only flow sporadically on Early Mars, at high latitudes and during high obliquity periods. Other sources of transient warming are then needed to allow the presence of liquid water.

## Phobos

The two Martian moons Phobos and Deimos might be asteroids captured by Mars' gravitational attraction or have formed in situ from accretion in a debris disk in Mars' orbit. We have reconsidered two specific scenarios for the case of in situ formation: the strong tide regime, for which accretion occurs close to the planet at the Roche limit, and the weak tide regime for which accretion occurs further away from the planet. The debris disk spreads inwards to and outward from the planet due to viscous effects. We have shown that when outward moving material crosses the Roche limit, small-sized moonlets are accreted from gravitational instabilities with a shape and density similar to Phobos and Deimos. Although they initially migrate outward due to interaction with the disk, the moonlets rapidly fall back onto Mars due to the tidal decay of their orbits once the disk is lost. In the weak tide regime, moonlets can accrete near the synchronous orbit with the mass of Deimos. A Phobos-mass embryo can also be formed in the same disk but closer to Mars (at 3-4 Mars radii) so that it rapidly falls back on Mars by tidal decay of its orbit.


*Image from MarsExpress of Phobos, the closer to Mars of the two Martian moons. (copyright ESA-DLR)*

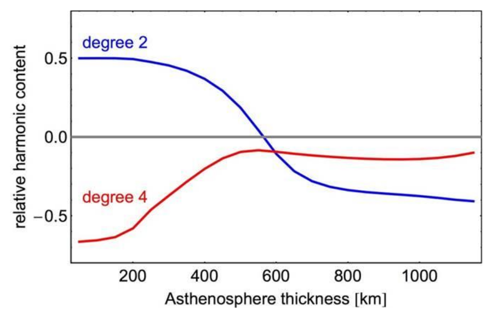
However, several embryos may accrete together in the disk (similarly to the final stage of terrestrial planet formation), and Phobos and Deimos may be the last two remnants of those bodies formed near the synchronous distance to Mars.




*Predicted mass of accreted objects (isolation mass) as a function of the distance to Mars for different density profiles of the debris disk (denoted by the coefficient q). All density profiles provide an accreted object with Deimos' mass at 6 Mars radii (near the current orbit of Deimos).*

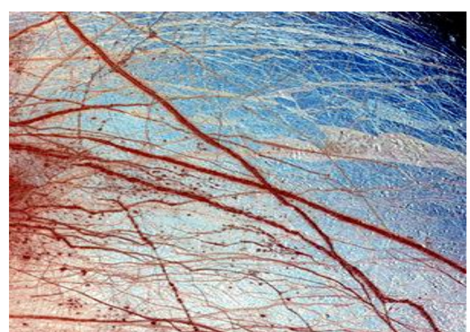
## Large natural satellites

Periodic tides raised by the central planet internally heat satellites by viscous friction. The heating is far from homogeneous and the distribution of dissipated power depends in a complicated way on the tidal potential and on the internal structure of the body. It was shown that essentially three spatial patterns of tidal heating exist associated with: (1) mantle dissipation (which is for example applicable to icy satellites with dissipation in the ice shell above an ocean), (2) dissipation in a thin soft layer (an asthenosphere or icy layer in contact with the mantle or core) and (3) dissipation in a thick soft layer (a deep asthenosphere or thick icy layer above a solid core). Tidal heating in a deep asthenosphere has been shown to best account for the distribution of Io's volcanism. In that case heating is maximum at the equator with less power in degrees higher than degree two (see top right figure).



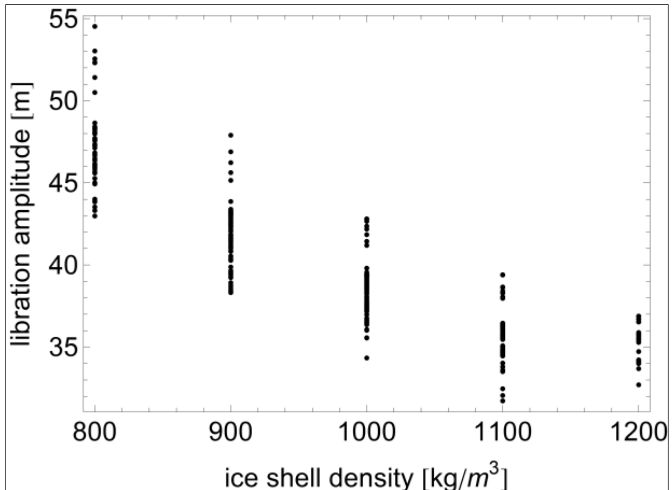

*Io's surface heat flux distribution.*

Theoretical studies predict that the equilibrium obliquities of the Galilean satellites are small and well below 1 degree. However, recent observations of cycloidal lineaments on the surface of Europa indicate that Europa's obliquity might be around 1 degree. A method has been developed to calculate the obliquity of an icy satellite that has a global subsurface ocean below its ice shell. The obliquity of Europa is shown to be smaller with an ocean than without and more than an order of magnitude smaller than the geological observations suggest. The obliquity of Europa, Ganymede and Callisto depends sensitively on the presence of an internal ocean and the interior structure and obliquity observations can put constraints on the interior of these satellites. In contrast, the obliquity of Io only weakly depends on the interior structure.

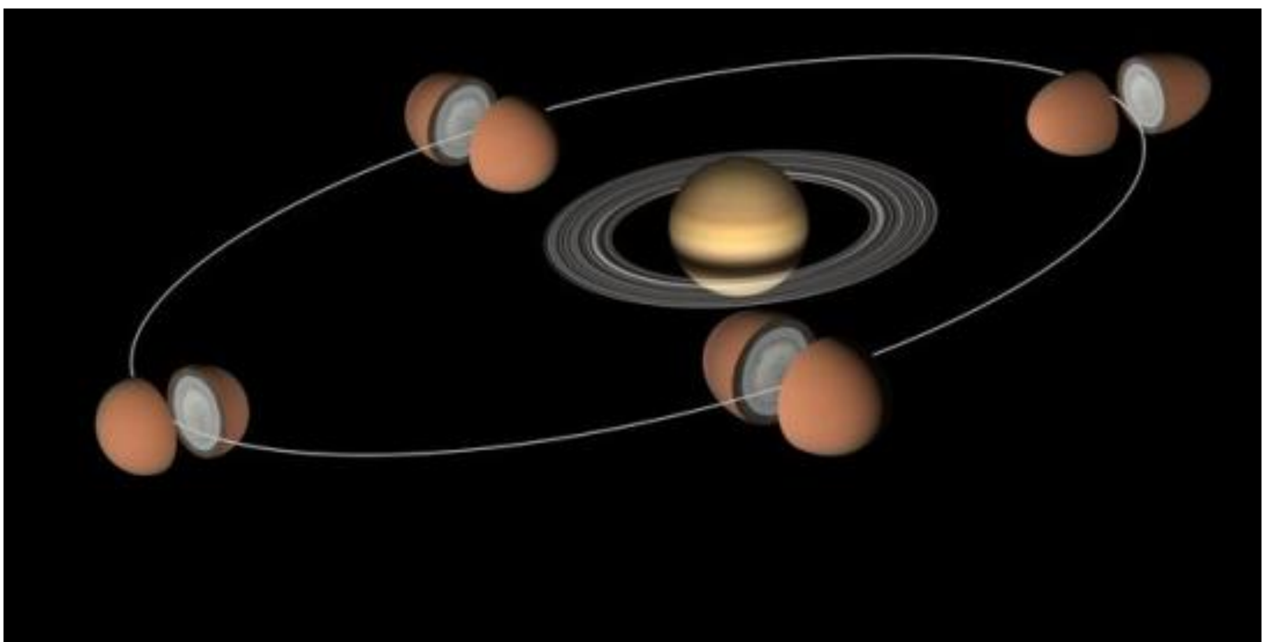


*Cassini image of the surface of Europa (NASA-ESA)*

As for Mercury, librations of synchronously rotating satellites can provide important insight into the interior structure of the rotating moons. Librations are modelled by calculating the dynamic rotational effect of the gravitational torque of the central planet on the static figure of the satellite. However, the satellites are also deformed by periodic tides and the central planet also exerts a torque on these tidal bulges. We have developed a method to study the librations for satellites with a subsurface ocean that are dynamically deformed by tides. The elastic tidal deformation strongly reduces the potential amplifying effect of an ocean and keeps the amplitude of libration close to that for an equivalent satellite without subsurface ocean.



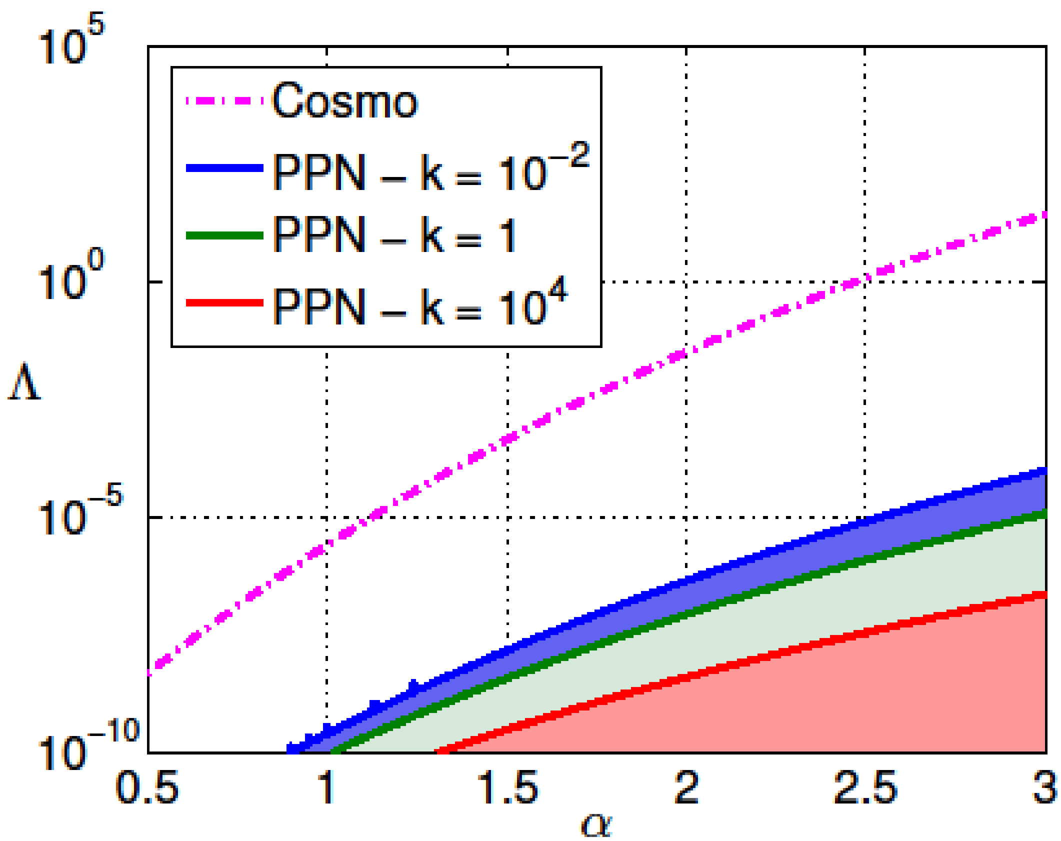

*Libration amplitude of the ice shell of Titan as a function of the density of the ice shell for a set of interior structure models of Titan with a subsurface ocean. For an entirely solid Titan, the libration amplitude is about 49 meter. The libration amplitude represents the amplitude of displacement of a given surface point on Titan's equator due to libration with respect to the reference position without libration*



Titan's tides raised by Saturn (NASA/JPL)

# Alternative theory of general relativity and radioscience

ROB scientists have also studied relativistic effects on the Range/Doppler signal of space probe in order to study the possibility to test General Relativity with different missions. In particular, the BepiColombo mission around Mercury has been studied in detail. For this mission, a very accurate knowledge of the orbit is expected (10cm in Range and 2µm/s in Doppler). In order to test General Relativity (GR), scientists will look for deviations from General Relativity in the Range/Doppler signals. ROB scientists have developed a method to simulate radioscience observables in any metric theory of gravity. A plethora of alternative theories of gravity exists in the literature. We have considered four different theories of gravity: Post-Einsteinian Gravity (PEG), MOND External Field Effect, Standard Model Extension and Chameleon theory . In particular, constraints on the parameters of the latter theory have been determined based on two different data sets. First, data about the luminosity as a function of redshift for Supernovae Ia were considered. Second, range and Doppler data from the Cassini mission have been analysed. We have shown that the constraints on the Chameleon theory based on the cosmological data are not compatible with Solar System constraints (See figure below). This means that the Chameleon theory cannot explain all the data with the same set of parameters.



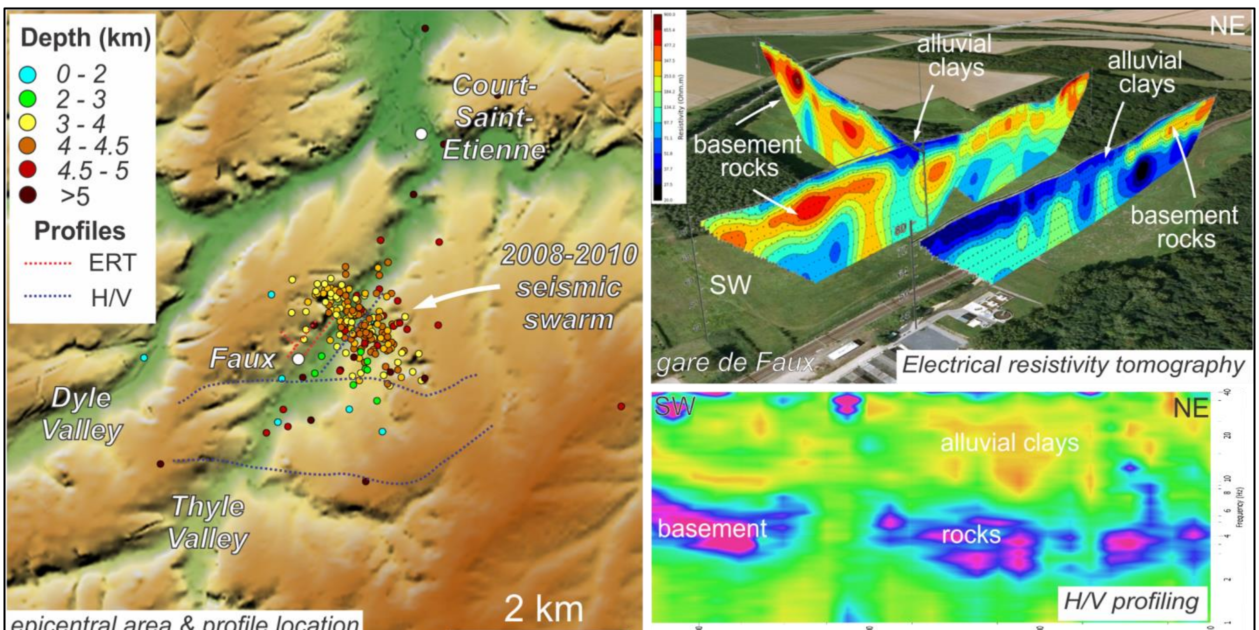

*Cosmological and Solar System confidence regions for the three parameters (k, Λ,α) characterizing a Chameleon theory*

# Seismology & Gravimetry

# Finding the source of the 2008-2010 low-magnitude seismic swarm at Court-Saint-Etienne

Between 2008 and 2010, nearly 300 seismic events have been recorded in the Thyle valley, 2 km SW of Court-Saint-Etienne (Walloon Brabant, Belgium). This low-magnitude seismic swarm was recorded by the permanent Belgian seismometer network and by some locally deployed temporary seismic network covering the epicentral area. An improvement of the hypocenter location by cross-correlation of different waveforms revealed that the majority of these small-magnitude earthquakes occurred along a narrow NW-SE oriented fault zone at several km's depth (3 to 6 km) in basement rocks of the Brabant Massif. Tectonic stress inversion of the focal mechanisms of the largest events of the 2008-2010 seismic swarms indicates a local WNW-ESE oriented maximum horizontal stress, which deviates from the regional present-day SE-NW-directed compression in NW Europe.

The derived NW-SE orientation of the seismic fault may be linked with an aeromagnetic gradient lineament representing a fault structure in the subsurface. In order to visualize a possible fault structure in the subsurface, we performed a geophysical investigation (Electrical Resistivity Tomography (ERT), H/V ambient noise analysis) at the hamlet of Faux. The absence of any clear fault structure in the conducted profiles, however, indicates that the fault structure does not reach up to the current erosion surface of the Brabant Massif and probably did not affect the surface in the Quaternary.



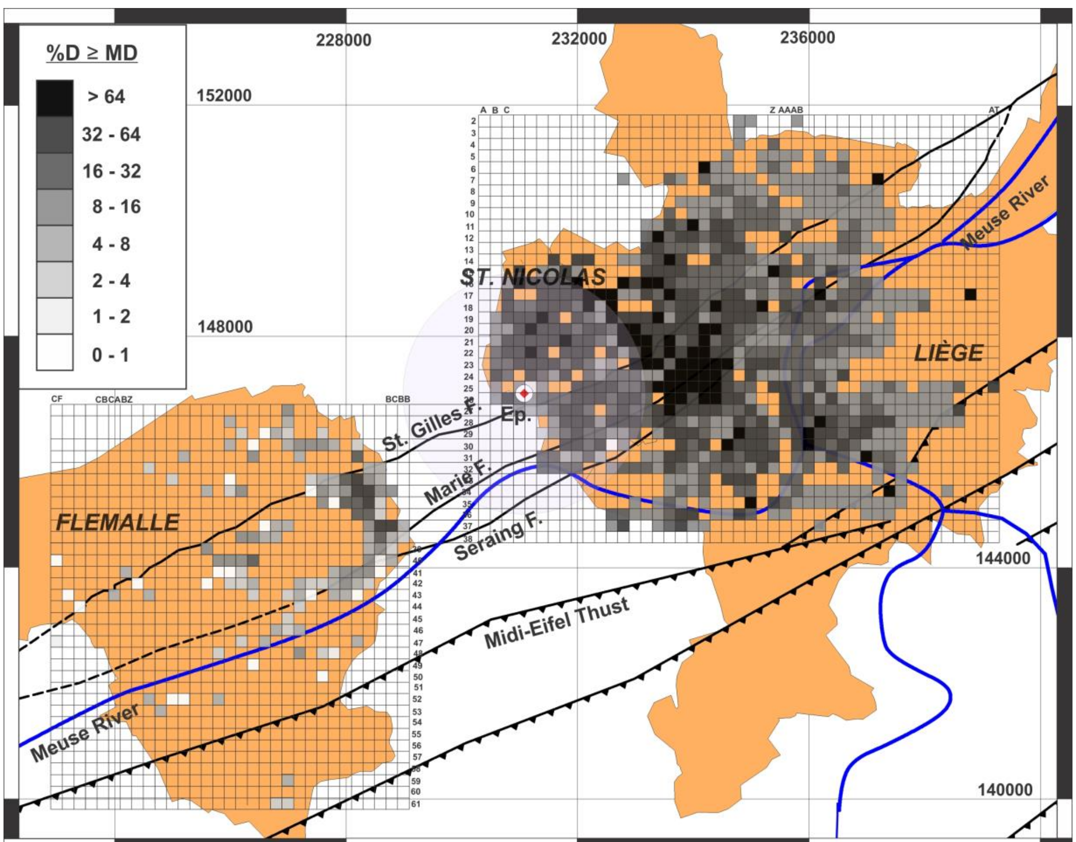

*The seismic swarm near Court-Saint-Etienne 2008-2010.*

# Comparison of ground motions estimated from prediction equations and from observed damage during the M=4.6 Liège earthquake

On 8th November 1983 an earthquake of magnitude 4.6 damaged more than 16,000 buildings in the region of Liège (Belgium). The extraordinary damage produced by this earthquake, considering its moderate magnitude, is extremely well documented, giving the opportunity to compare the consequences of a recent moderate earthquake in a typical old city of Western Europe with scenarios obtained by combining strong ground motions and vulnerability modelling.

The present study compares 0.3-second spectral accelerations estimated from ground motion prediction equations typically used in Western Europe with those obtained locally by applying the statistical distribution of damaged masonry buildings to two fragility curves, one derived from the HAZUS program of FEMA (FEMA, 1999) and another developed for high vulnerability buildings by Lang and Bachmann (2004), and to a method proposed by Faccioli et al. (1999) relating the seismic vulnerability of buildings with the damage and ground motions. The results of this comparison reveal a good agreement between maxima spectral accelerations calculated from these vulnerability and fragility curves and those predicted from attenuation law equations, suggesting peak ground accelerations for the epicentral area of the 1983 earthquake of 0.13 – 0.20 g.

*(Natural Hazards and Earth System Sciences, 13, 1983-1997, 2013)*



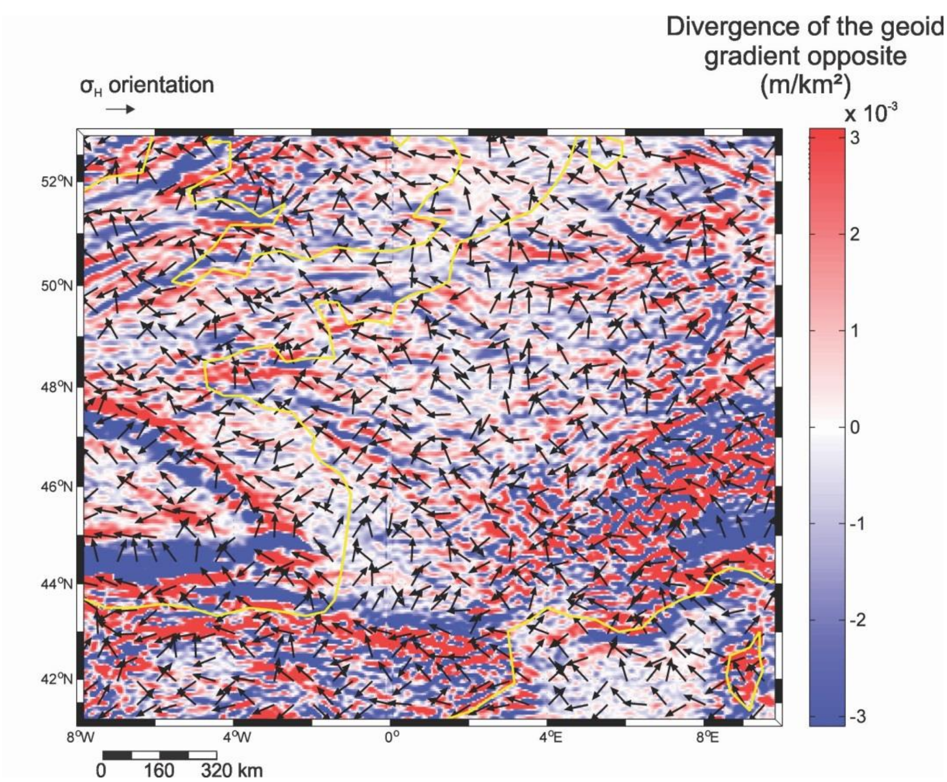

*Percentage of buildings presenting moderate or greater damages (%D ≥ MD) after the 1983 Liège earthquake calculated for square areas of 0.040 km² over the localities of Saint Nicolas, Liège and Flémalle. Projections: Belgian Lambert 72.*

# Local stress sources in Western Europe lithosphere

We propose a method to evaluate the stress generated at the local scale by the spatial variations of the Gravitational Potential Energy (GPE), which is related to inhomogeneous topography and mass distribution in the lithosphere. We show that it is possible to infer these local stress sources from the second spatial derivatives of a geoid height grid, used as a proxy of the GPE.

The coherence of the method is validated on a passive margin, the Bay of Biscay. The result is what is expected in such geological configuration, with respectively extensive local stress sources with the maximum horizontal principal stress parallel to the margin and compressive sources with the maximum horizontal principal stress perpendicular to the margin respectively in the continental and oceanic lithosphere.

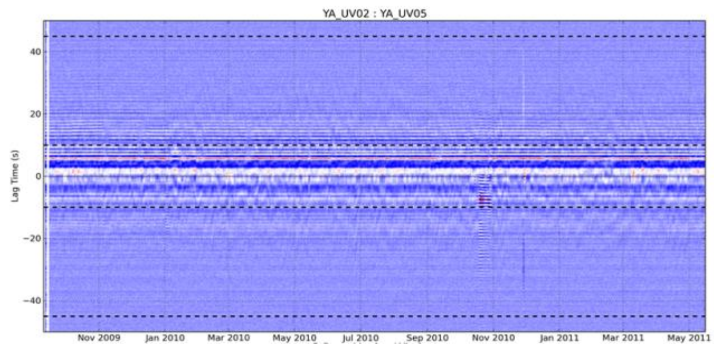
We apply the method to Western Europe providing a better understanding of the complex spatial variation of the present day tectonic activity. Our results indicate a stress pattern from the local sources dominated by short space wavelength - of the order of a few tens of km - variations in the tectonic style and in the direction of the maximal horizontal principal stress $\sigma_H$. The comparison of the $\sigma_H$ orientations and tectonic style from the local sources with the ones of the World Stress Map (WSM) data set indicates that the local stress sources can be representative of the deviatoric stress state in some regions. Our results explain 71% of the faulting styles for the earthquake fault-plane solutions in the WSM, which is better than the classical compressive NW-SE stress field model. In the central part of the Pyrenees, the agreement between earthquake fault slip directions and the direction of shear stress from the local sources acting on the associated fault planes is compatible with the extensive stress field evidenced by recent investigations. *(Lithosphere, vol 5; n°3; p 235-246, 2013)*



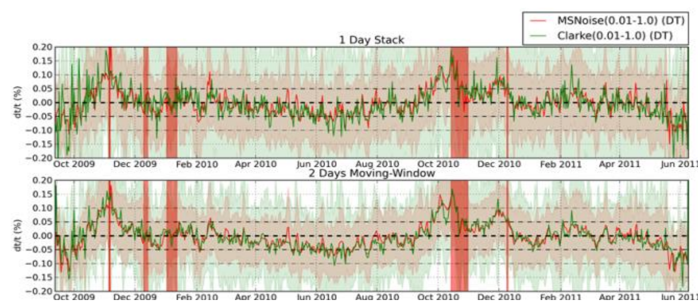

*Extensional (in red) or compressive (in blue) stress field and direction of the maximal principal horizontal stress $\sigma_H$ in Western Europe*

# Monitoring (changes in) physical properties of the Earth using ambient seismic noise – MSNoise package

Earthquakes occur every day all around the world and are recorded by thousands of seismic stations. In between earthquakes, stations are recording "noise". In the last 10 years, the understanding of this noise and its potential usage has been increasing rapidly. The method, called "seismic interferometry", uses the principle that seismic waves travel between two recorders and are multiple-scattered in the medium. By cross-correlating the two records, one gets information on the medium below/between the stations. Recent developments of the technique have shown those CCF can be used to image the earth at depth (3D seismic tomography) or study the medium changes with time.




*Piton de la Fournaise volcano dataset analysis : (a) Interferogram (each CCF is a pixel-wide column of the image) between one pair of seismic stations*




*Relative velocity changes as evidenced by analyzing the data using MSNoise and another method presented by Clarke in 2011, eruptions are shown as red vertical bars*

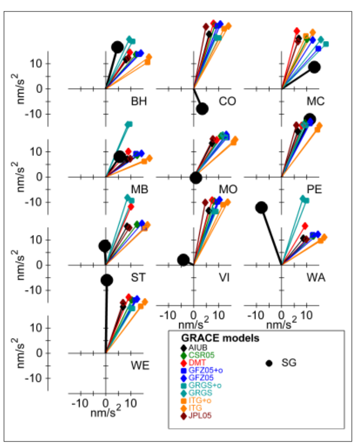
In 2010 we started to develop a software package “MSNoise” in order to detect in real time seismic wave velocity changes with large seismic datasets. MSNoise successfully identifies precursory relative velocity changes under the Piton de la Fournaise volcano (La Réunion Island, France), starting more than 30 days before the October 2010 eruption. For the last years, we have been applying MSNoise to the dataset acquired since 2010 on the Kawah Ijen volcano in Indonesia, allowing detecting velocity changes before and during unrests. This technique will be applied to geothermal field monitoring or to compute a new surface wave velocity tomography model for Belgium. MSNoise is available on http://www.msnoise.org and free for academic/research usage.

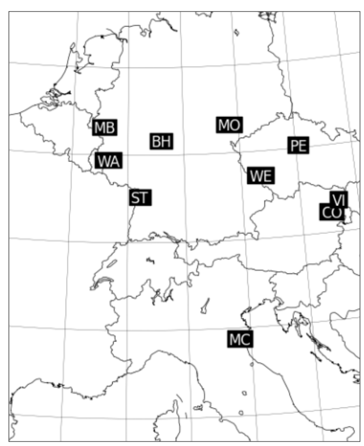
# The quest for a consistent signal in ground and GRACE gravity time series

Modelling continental hydrology is a key issue in the geosciences as the distribution of the water mass is the main source of uncertainty in many questions of geodesy and climatology, and because the water availability is a crucial problem with societal implication. Land-based gravity measurements are very sensitive to local water storage changes, of which the gravimetric signature depends on very local geologic and climatic conditions, e.g. rock porosity, vegetation, evaporation, and runoff rates; this signature can be more important than any tectonic effects and may induce large time correlated noise into the data. On a broader scale (wavelength larger than 400 km), observations of the Gravity Recovery and Climate Experiments (GRACE) satellite provide another way to estimate land water content. GRACE has now been orbiting the Earth for more than 10 years, monitoring the Earth gravity field time variations.

In the context of recent studies showing agreement between ground and space gravity in central Europe, the time series of the ground gravity, measured by superconducting gravimeters (SGs), computed from GRACE mission data, and from two global hydrological models are intercompared at 10 SG stations in Central Europe. Our study shows that there is only little agreement between the SG time series, even when they are separated by distance smaller than the GRACE space resolution. We also evidence that the time series obtained from GRACE, the hydrology models and the SGs do not show significant agreement, nor on the seasonal cycle nor on the interannual variability. Although the annual signal dominates the GRACE and hydrological model data sets and most of the SG time series, the annual component of the SGs, GRACE and hydrological models are not coherent (figure below). Those findings are consistent with the common sense that SG transfer function makes it only sensible to very local phenomena. This strongly disagrees with authors who claimed that it was possible to use superconducting gravimeters (SGs) to investigate regional or even continental water storage.

Terrestrial gravity measurements can be fruitfully used to perform comprehensive, local hydrogeological investigations; on the other hand GRACE has provided valuable information on large scale hydrological and geodynamic phenomena. But, our study shows that the feasibility of joined studies is still unclear.



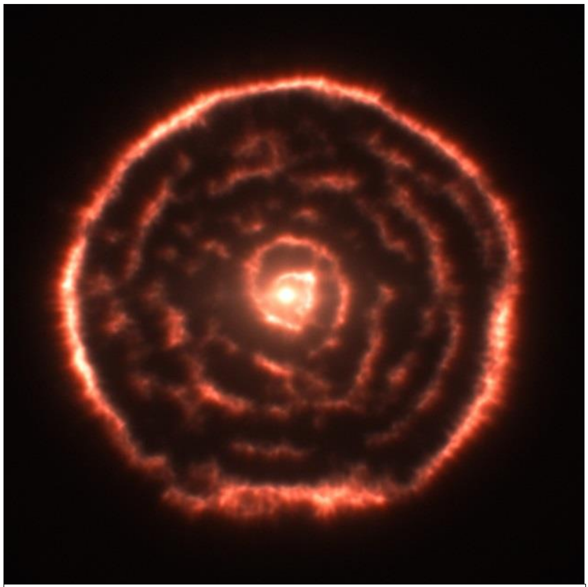

*Map of the SG stations (left) and phasor diagrams (right) of the annual components at the different SG stations for the SGs and 10 different GRACE solutions (angle in days, length in nm/s²). Those diagrams show that the amplitudes and phases do not indicate a common signal, but rather station maxima within a seasonal cycle, as expected. MB is the Membach station operated by the Royal Observatory of Belgium.*

# Astronomy and Astrophysics

# Circumstellar material

The mass loss in the final steps of evolution of intermediate mass stars is a complex process with repercussions on the internal evolution of the star itself. The complex interplay among various physical processes is not yet understood, but the structure of the circumstellar material must clearly reflect the history of the mass loss events. Therefore, astronomers of the ROB study in detail the circumstellar environment of evolved stars. This resulted in 2012 in the first Nature paper based on data of the Atacama Large Millimeter/ submillimeter Array (ALMA).

Observations revealed an unexpected spiral structure in the material around the old carbon star R Sculptoris. This feature has never been seen before and is probably caused by a hidden companion star orbiting the star. A slice through the new ALMA data reveals the shell around the star, which shows up as the outer circular ring, as well as a very clear spiral structure in the inner material. The paper, with a co-author of the ROB, was subject of an ESO press release.



*Visualisation of the unexpected spiral structure in the material around the star R Sculptoris. (Credit:ALMA, ESO/NAOJ/NRAO/*

*M. Maercker et al)*

*Antennas of the Atacama Large Millimeter/submillimeter Array (ALMA), on the Chajnantor Plateau in the Chilean Andes (Credit:ESO/C. Malin)*

# Stellar winds in hot stars

Hot, massive stars have radiatively driven stellar winds. When two of these stars form a binary system, their winds collide. At the ROB researchers try to elucidate the nature of this colliding-wind region. They do so by obtaining observational data (at various wavelengths) and comparing them to the theoretical models they developed.

*Artist's rendering of a colliding wind binary. (Credit: NASA/C. Reed)*

The massive colliding-wind binary Cyg OB2 #9 went through its periastron in 2011. Because of the high eccentricity of the orbit, this should lead to large changes in the emission at various wavelengths. The periastron passage was therefore monitored in X-rays, using the satellites XMM-Newton (ESA) and Swift (NASA), as well as at radio wavelengths, using the ground-based Expanded Very Large Array (EVLA). The results featured in 2012 in press releases by ESA, NASA and the journal Astronomy and Astrophysics and led to 2 refereed papers, with a co-author of the ROB.

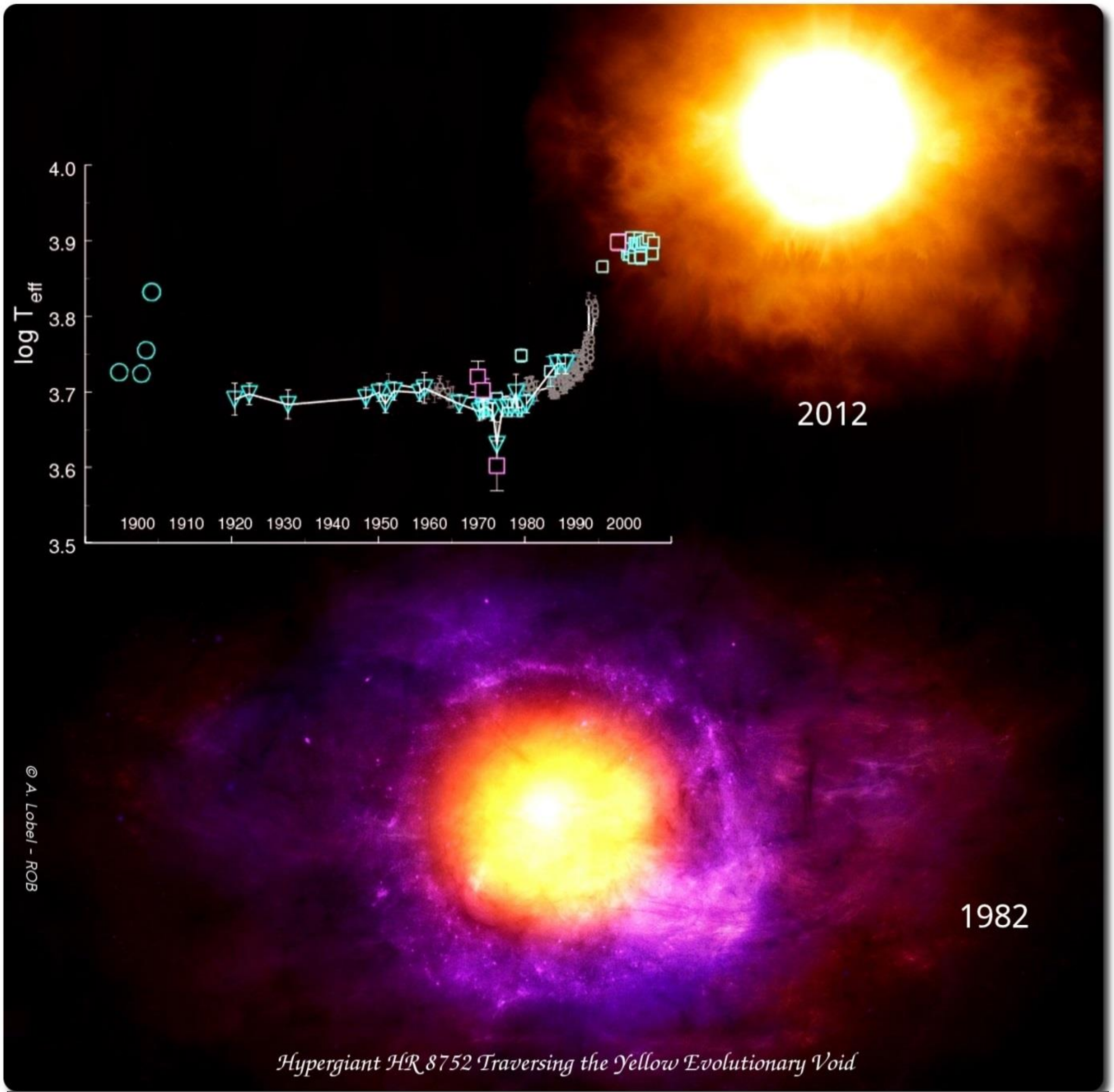
The observed radio light curve was analysed in detail at the ROB. It shows a steep drop in flux sometime before periastron. When the radio flux is at its lowest, the colliding-wind region is completely hidden. After periastron passage, the radio fluxes slowly increase as the colliding-wind region again becomes visible.

To understand these flux changes better, a simple model was developed that solves the radiative transfer in the stellar winds and the colliding-wind region. The model shows that the observed asymmetry of the radio light curve indicates that the primary has the stronger wind. The colliding-wind region also contributes to the free-free emission, which explains the high values of the spectral index seen after periastron passage. Combining the data with older Very Large Array (VLA) data results in an improved value for the orbital period of this system: P = 860.0 ± 3.7 days.

*VLA Panorama (Image courtesy of NRAO/AUI and NRAO)*

# Evolution of massive and luminous stars

In October 2012 a large long-term international research collaboration program was completed with the publication of a main journal paper on the white hypergiant HR 8752. The team, including an ROB astronomer, reported they finalized a thirty years long investigation of this remarkable hypergiant star. In that period the surface temperature of this gigantic and extremely bright star quickly rose from five to eight thousand degrees. With this discovery a crucial “missing link” in the evolution of hypergiant stars, the most luminous stars of our galaxy, has been found. These results received a lot attention in the press. The team also decided to publish all spectra and photometric observations on-line in the public domain.




*Artist’s rendition of the hypergiant HR8752 traversing the “Yellow Evolutionary Void”. The graph plots the temperature at the surface of the star observed over a century. It rose from 5000 to 8000 degrees between 1985 and 2005, while the radius of the hypergiant decreased from 750 to 400 times the radius of the Sun (ROB, A. Lobel)*

# The High Efficiency and Resolution Mercator Echelle Spectrograph HERMES

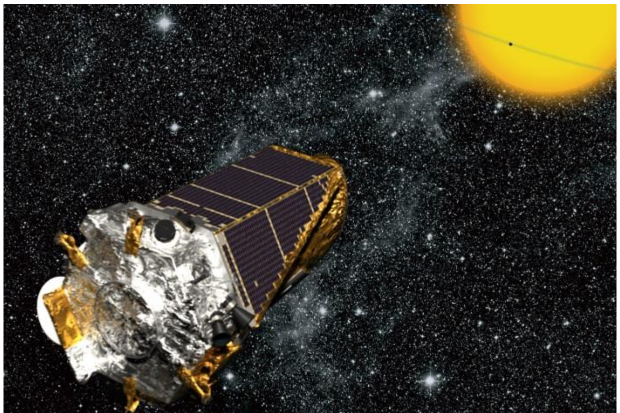
The HERMES spectrograph was designed, constructed, and integrated at the Mercator telescope in a collaboration between the ROB, the KULeuven, the ULB, the Thüringer Landessternwarte Tautenburg (Germany) and the Geneva Observatory (Switzerland).

The Hermes spectrograph is a unique tool to study binary evolution. One large program focuses on the wide variety of distinct (suspected or proven) classes of binary stars with evolved components. The binarity of the star HD137569 was confirmed, but no other binaries have been found yet. Another program aims to monitor the radial velocity of Kepler variable stars of intermediate spectral type with the goal to explain the physical origin of their observed light variations in terms of binarity, pulsation and/or stellar rotation (for more details on the Kepler mission, see further).

In 2012 various campaigns of spectroscopic observations were carried out by ROB staff members at the Observatory of Roque de los Muchachos, La Palma, Spain.

*The Mercator telescope, Roque de los Muchachos, La Palma, Spain*

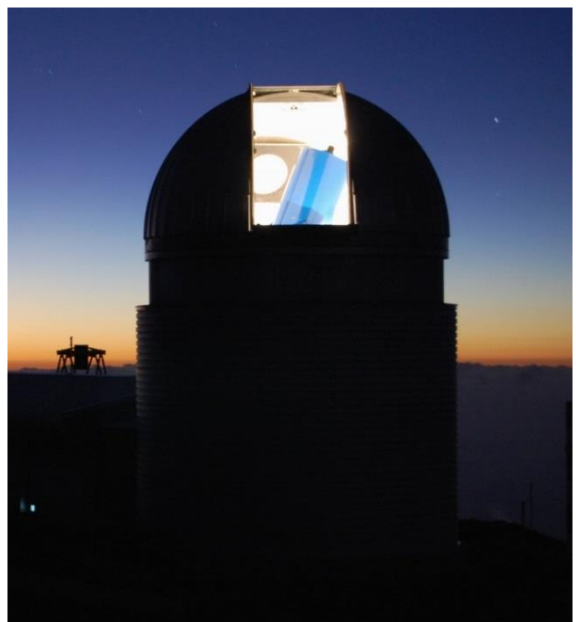
# The KEPLER mission



Credit: NASA/Kepler mission/Wendy Stenzel

NASA's Discovery mission Kepler is specifically designed to survey part of the Milky Way galaxy to discover hundreds of Earth-size and smaller planets in or near the habitable zone and to determine the fraction of the hundreds of billions of stars in our galaxy that might have such planets using the transit method. Kepler observed fixed fields located in the constellations Lyra-Cygnus during almost four years, and continuously monitored over 100.000 stars with a slow cadence and an additional 512 stars with a rapid cadence. This mission also provides extremely high-quality data for refined asteroseismic studies.

KIC 5988140 is a late A-type variable star discovered by Kepler. The analysis of the Kepler data revealed two dominant frequencies in the low frequency regime ($F_1$=2$F_2$=0.688 and $F_2$=0.344 $d^{-1}$), as well as nine more frequencies in the high frequency regime. Using time-series spectra acquired during several campaigns with the HERMES spectrograph attached to the Mercator-telescope on La Palma, we performed a full spectroscopic analysis, including an abundance study. Using spectrum synthesis, we derived improved atmospheric parameters. The star is of spectral type A7.5 IV-III with a metallicity slightly lower than that of the Sun. The radial velocity curve shows a double wave which corresponds well with the pattern in the light curve but with a phase delay of about 0.1 period between the moment of minimum velocity and that of maximum intensity. The high frequencies can be interpreted as due to pulsations of type δ Scuti (with frequencies in the range 5-25 d-1). With respect to the dominant lower frequencies, we explored three scenarios: a) binarity, b) rotational modulation with spots or inhomogeneity's over the stellar surface and c) pulsation of type γ Doradus. Binarity was discarded on the basis of the double wave shape of the radial velocity curve. Furthermore, for two quite different configurations of a spotted surface, the predicted light-to-velocity amplitude ratio is as much as 40 times larger than the observed value. In terms of pulsations of type γ Doradus, the expected amplitude ratio is a factor of 8 larger than observed. A follow-up study including a discussion on stable orbits in a triple system would be needed to truly unravel the origin of the low frequencies in the light and radial velocity variations of this intriguing object.



*Mercator telescope, Roque de los Muchachos, La Palma, Spain.*

In conclusion, we confirm the occurrence of various independent δ Scuti-type pressure modes in the Kepler light curve of KIC 5988140. However, with respect to the low-frequency content, we argue that the physical cause of the remaining light and radial velocity variations of this late A-type star cannot be simply explained in terms of the classical scenarios.

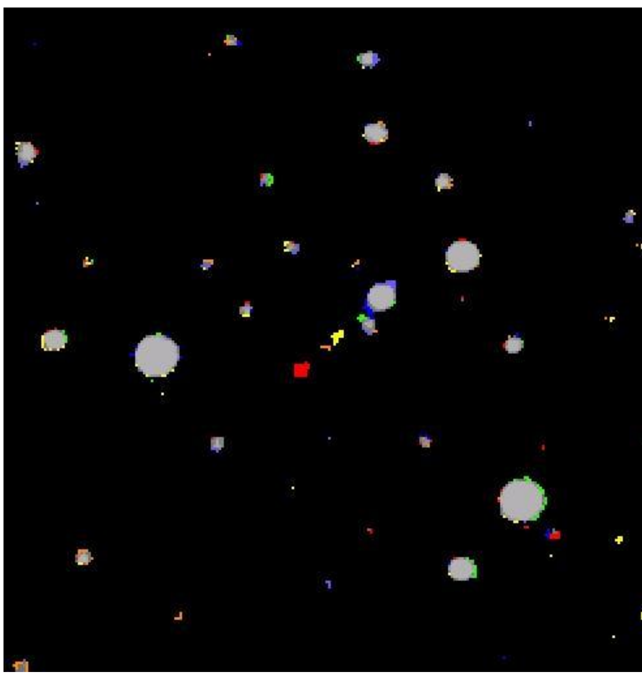
# Asteroid 2005 $CZ_{36}$

2005 $CZ_{36}$ is a PHA, i.e. a potentially hazardous asteroid. Asteroids or minor planets are rocky objects orbiting the Sun, in the same way as the well-known major planets. Most of the asteroids are in a safe orbit between Mars and Jupiter or beyond Neptune's orbit. But a few of them have deviating orbits, and some of them can dangerously approach the Earth. They can come so close to the Earth that a collision cannot be ruled out. If such an asteroid is larger than about 1 kilometre, a collision could cause a world-wide disaster, due to climatic effects. Such objects are called PHAs. Collisions between PHAs and the Earth are extremely rare, so that there is no reason for panic. Still is it wise to keep an eye on these PHAs, to be able to mitigate a collision, just in case one would be announced in a not-too-far future.

**2005 $CZ_{36}$ has been discovered with the Ukkel Schmidt Telescope at the Royal Observatory.**

2005 $CZ_{36}$ is such a PHA, and was discovered from Ukkel. 2005 $CZ_{36}$ is not the first PHA discovered from Ukkel. Adonis is an asteroid of about 1 kilometre and can make very close approaches to the Earth. It was discovered from Ukkel by Eugène Delporte in 1936. Asteroids have been searched for systematically in Ukkel since 1924. In the pre-CCD era this was done using photographic techniques, but when at the end of the 1980s it became clear that the photographic technique in Ukkel was no longer able to detect the faint objects that were still to be discovered, photographic observations were gradually abandoned in Ukkel. The situation changed when in 1996 a CCD camera was installed on the Schmidt Telescope. The observations of asteroids from Ukkel got a new impetus, thanks to the fact that suddenly asteroids 200 times fainter than those in the reach of the photographic techniques, could be observed from Ukkel. The rate of observations increased again and this led in 2005 to the discovery of a PHA from Ukkel.

The discovery of this object is a real thriller and would not have been possible without the cooperation between the different members of the observing team. The discovery observation was performed in the night of February 5 to 6, 2005 by Eric Elst and Henri Debehogne. The next night, before the observations of the previous night had been checked for possible new objects, Peter De Cat re-observed the same portion of the sky. This is important, because new asteroids have to be followed to get a first idea of their orbits. If a new asteroid is found and not tracked in the following nights, it gets lost after a few days, and one does not get recognition for the discovery.



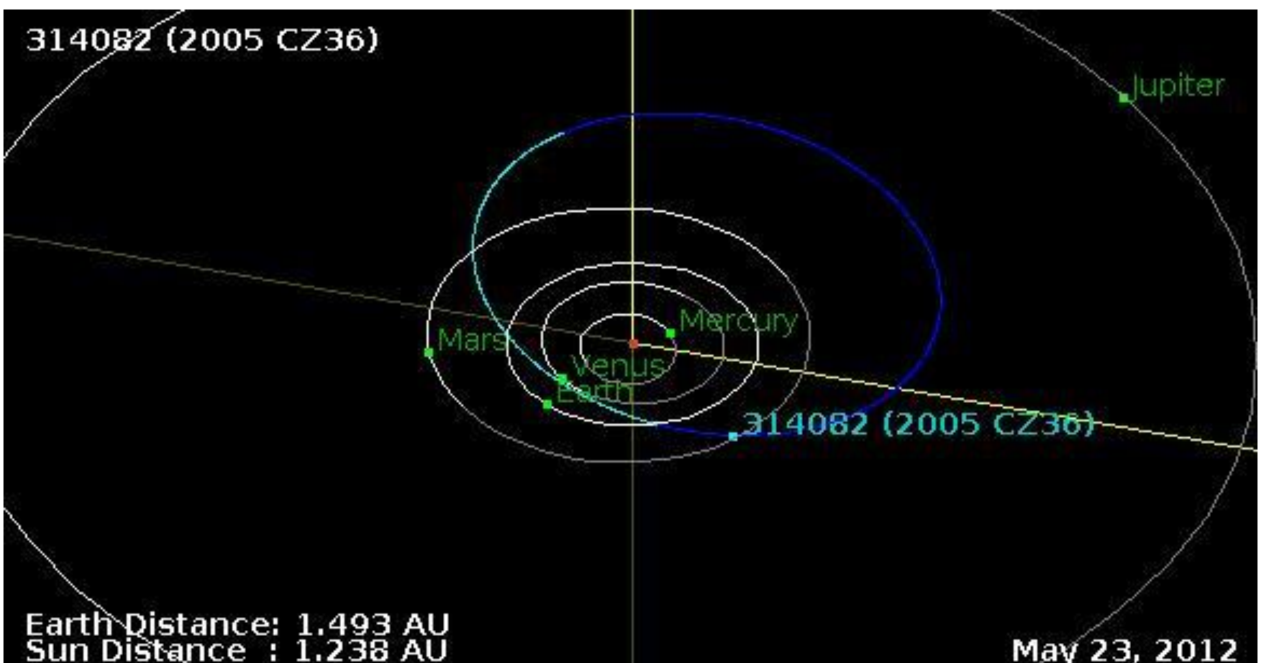
*Discovery image of 2005 $CZ_{36}$.*
*In order to easily detect asteroids among stars, the images have to be treated first. Different images with typical intervals of 10 minutes are superimposed. Pixels that have seen sky on all images are coloured in black, pixels that have seen an object on several images are coloured in grey, while pixels that have seen an object on only one image are coloured in a vivid colour, here using the colours of the rainbow in the sequence of the observations. Thus stars will appear as discrete grey dots, while asteroids, which have moved, will show up as small rainbows.*

On February 7 the observations were analysed. This means that moving objects have to be detected among fixed stars. Both stars and asteroids are point sources on the images, but stars have no measurable movement in the course of one night, while asteroids will already show a clear motion after 5 minutes, due to their orbital motion around the Sun. The technique used will therefore be one in which moving objects will prominently stand out among fixed objects.

The analysis of the observations of both nights, February 5/6 and 6/7, showed an unidentified object, but only on February 11, Thierry Pauwels realised that the object might be more interesting than the other new asteroids that are routinely found on the images. Its speed in the sky deviated clearly from the typical speed of main-belt asteroids, the bulk of the asteroids, which orbit the Sun between Mars and Jupiter. Therefore, the asteroid was put on the list of objects to be observed with the highest priority, but due to the weather and the full moon no more observations were possible until close to the end of February.

Thierry Pauwels observed in the night February 27/28. After three weeks the uncertainty on the position of the asteroid had become so large that several observations were necessary to recover the object. But it was with success, and the new position confirmed that it is an interesting object. Still, the number of positions was insufficient, and at that moment the international astronomical community was alerted, so that the object was re-observed in the night March 2/3 from Arizona and the UK. With all the observations, it was possible to publish a first preliminary orbit, and the asteroid received an official, but still preliminary designation: 2005 $CZ_{36}$. It was then clear that the object is a PHA.
The first but difficult operations had been done with success, but then it is still a long process to wait for additional observations to be able to compute a more precise orbit. From Ukkel there were additional observations in April and May 2005, but after that the asteroid had become too faint to be observable with our equipment. To be officially considered as discovered, an asteroid needs a very precise orbit, requiring years of observations. Additional observations were in December 2006, December 2007, January 2008 and eventually in January 2012. With the 2012 observations, sufficient positions were at hand to compute a precise orbit. At that moment the discovery was officially announced and attributed to Ukkel, and the asteroid received its final number: 314082.

Finally, once numbered, an asteroid can get a name. It is the privilege of the discoverer to propose a name, but it is the Working Group on Small Body Nomenclature of the International Astronomical Union that takes the final decision. There was a proposal to call it ``Haddock'', after one of the persons in the Belgian comic Tintin, and one of the discoverers wanted to call it ``Roadrunner'', after a common bird in California, but finally it became "Dryope", after the daughter of King Dryops and lover of Apollo in the Greek mythology. The name was published on December 28, 2012.




*The orbit of 2005 CZ_{36} in the Solar System. The perihelion distance, 0.944 astronomical units, is smaller than 1, meaning that the asteroid can come inside the orbit of the Earth. With its present orbit the object can approach the Earth as close as 2 million kilometers, which is rather close in astronomical terms. But due to perturbations by other planets, the minimal distance will change. Still, at the moment 2005 CZ_{36} poses no threat to the Earth, since in the coming 100 years no collisions with the Earth are possible.*
*Courtesy NASA/JPL-Caltech.*

# Constant as the Polar Star

“Constant as the Polar Star”

The Royal Observatory has again acquired a sculpture. A combination of coincidences led to this acquisition.

Marcus Vergette is a British artist with a passion for bells. He integrates bells in most of his sculptures. Since ROB scientist Thierry Pauwels has the same passion in his free time, he had contacted the artist. But it turned out that the artist had a few sculptures combining bells and astronomy. This is not so unexpected, since both bells and astronomy have a relation with "time". After the remark by Thierry Pauwels that some of his sculptures combined his job and his hobby, the artist came with a very surprising proposal: he was willing to donate one of his sculptures to the Royal Observatory. It took only little effort for us to accept the proposal. After all, it is a win-win situation, in which the artist gets the opportunity to get known on the continent, and the Royal Observatory to enrich its heritage.

The sculpture, called "Constant as the Polar Star", has the shape of a bell, with a sort of tunnel in the middle, which is exactly pointing to the Polar Star (in fact to the celestial Pole, since the Polar Star is very close to, but not exactly at the celestial Pole). The bell was installed on March 19, 2012, on the lawn just north of the dome of the Schmidt Telescope, by Marcus Vergette in collaboration with the technical staff of the Observatory, and the next day it was precisely adjusted to point to the Polar Star by Thierry Pauwels and Marcus Vergette. This was done in day time, when the Polar Star was invisible, using plumbs, levels, shadows and the position of the Sun.

*Marcus Vergette describes his sculpture as follows: "This sculpture in the shape of a bell was made of clay and fired in a hole in the ground, then broken into pieces, reassembled, and cast in bronze. By looking through the hole in the centre of the bell, the observer makes a sight line to the Polar Star. Bells have been made and used in almost all cultures; they are instruments of science, of music, and of thought. The title of this sculpture refers to our belief and search for the constant in an ever changing world."*

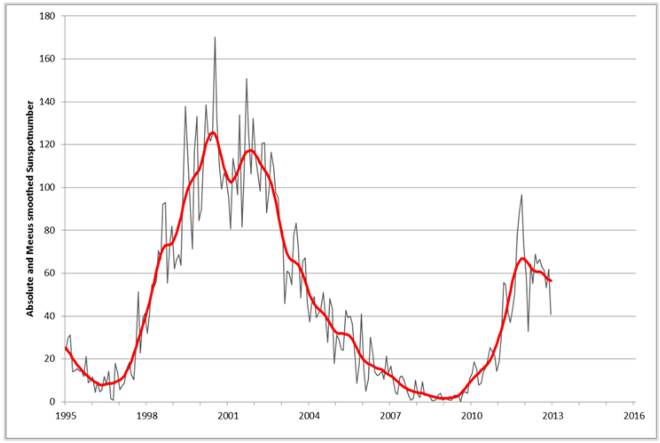
Thanks to the fact that the axis of symmetry of the bell is parallel to the rotation axis of the Earth, the bell produces remarkable shadow effects, although the artist himself had not realized this. The upper surface gets only sunlight in spring and summer, while the lower surface only gets sunlight in autumn and winter. The shadow of the bell turns around in the course of the day, but does not change its shape, except for a stretch. The shape only changes in the course of the year, where the clapper ball only projects a shadow on the grass around the equinoxes.

# Solar Physics and Space Weather

# Monitoring Space Weather: Solar-Terrestrial Highlights in 2012

In 2012, the official annual sunspot number (SSN) as determined by the SIDC (Solar Influences Data analysis Center), was 57.7. This is slightly higher than the average from the previous year, but lower than the activity recorded during the last months of 2011. As a result, the smoothed monthly SSN has gradually been decreasing.

Hemispheric activity evolved oppositely. The southern solar hemisphere reached a maximum during the summer months, while the activity in the northern hemisphere started again to rise during the second half of the year. From May till November, the Sun's outlook alternated between an active hemisphere with relatively many sunspots, and a hemispheric "face" that was pretty much void of these dark blemishes. These periodic ups-and-downs could clearly be seen not only in the daily sunspot numbers, but also in the radio flux, as well as in the extreme ultraviolet (EUV) and x-ray background flux (as measured by resp. PROBA2/LYRA and GOES).



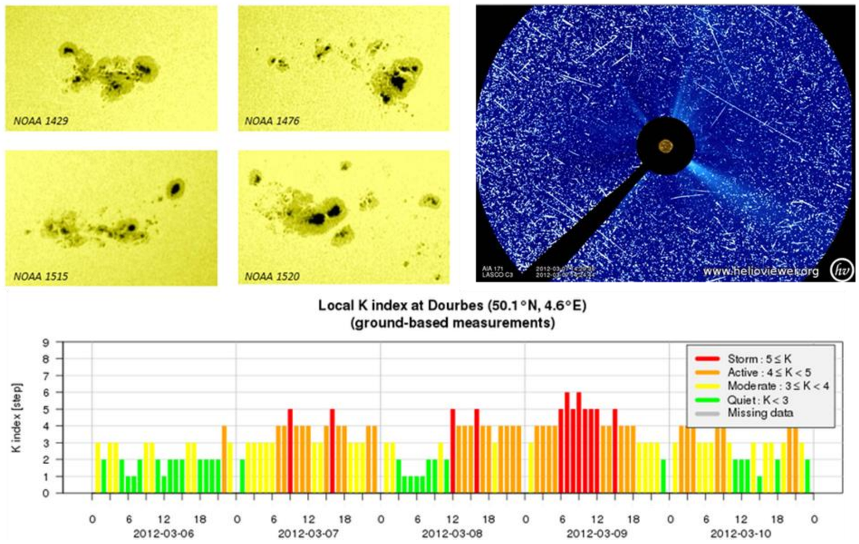

*The evolution of the monthly and monthly smoothed SSN since 1995. The low sunspot activity of the current solar cycle compared to the previous one is obvious.*

*Belgian and Dutch solar amateurs observing the Sun during their annual gathering late 2012, and wondering where the sunspots have gone. Talk of the day was whether SC24 maximum had already passed or not. The solar observations of amateur astronomers constitute a significant contribution to the compilation of the final sunspot number by the SIDC.*

Despite the declining SSN, the maximum of solar cycle 24 (SC24) is still expected to happen in the second half of 2013 or even in 2014. Indeed, if the 2011 high would be the real maximum, it would turn out to be an extraordinarily early maximum for such a weak cycle.

Moreover, weak solar cycles are also known to show several ups-and-downs during the period of maximum activity. Finally, the magnetic reversals at the solar poles are still not completed. In fact, for the southern hemisphere it still has to begin.

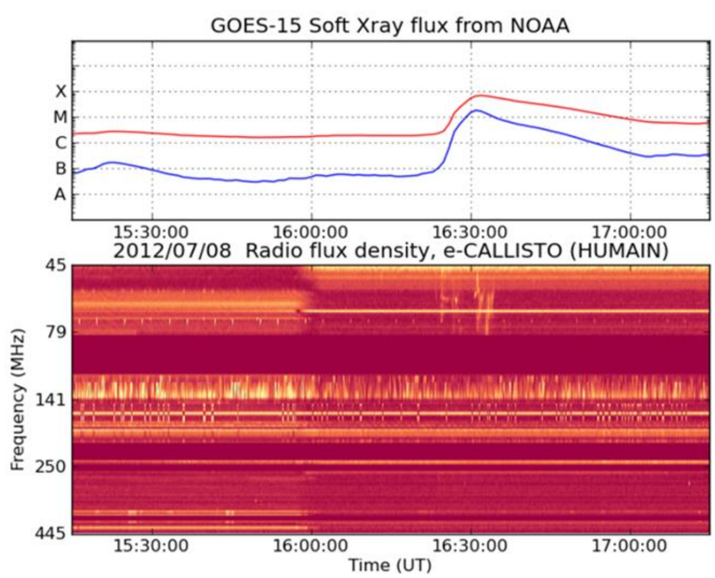
As these reversals occur during or near the true solar cycle maximum, it is yet another indication that the SC24 maximum still has to happen. For these reasons, the SC24 maximum is expected to occur a little bit later and to be a little bit lower than the original prediction by the international SC24 Prediction Panel, but still within the uncertainty margins.



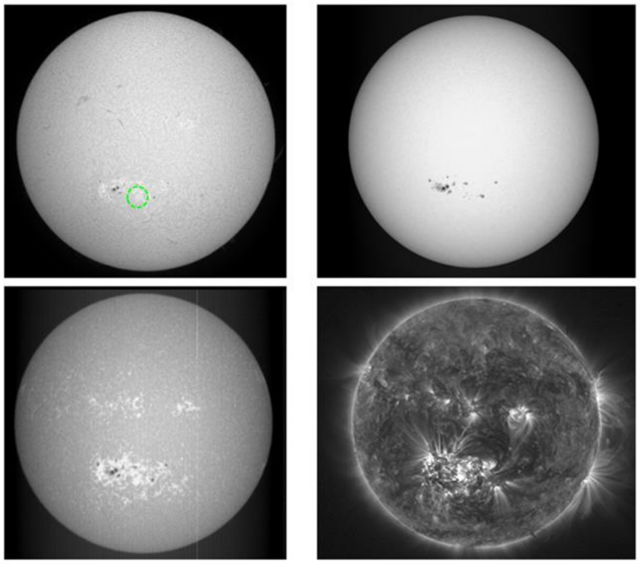

*Top left: The four largest sunspot groups in 2012, as imaged by the Solar Dynamics Observatory (SDO). Top right: The effects of the X5 proton flare from NOAA 1429 on the camera of SOHO's coronagraph are readily visible. Bottom: Dourbes recorded geomagnetic storming levels after strong X-class flares from NOAA 1429 on 5 and 7 March. The associated CMEs dumped a large amount of energy into the Earth's atmosphere and also increased substantially the number of electrons in the radiation belts, increasing the risk on malfunctions for Earth orbiting satellites.*

Though sunspot numbers were relatively low, 2012 saw several large groups transiting the solar disk. NOAA 1429 (March), 1476 (May), 1515 and 1520 (July) all attained areas about 6 to 8 times larger than Earth's surface, and they added to the number of strong flares. NOAA 1429 produced the 2nd largest flare so far (X5 on 7 March), which was accompanied by the strongest proton storm so far. It was only the second strong solar radiation storm for SC24, following a similar event early 2012 (23-24 January, NOAA 1402). In both cases, some airlines rerouted trans-polar flights because of communication problems, and some of the data received from spacecraft such as ACE were temporarily unusable. Also the Curiosity spacecraft, en route to Mars for a successful 6 August landing, recorded the proton events. As Curiosity keeps on making measurements of these energetic particles from the Martian surface, it continues to provide very valuable data for future (manned) Mars explorations.

NOAA 1515 was visible on the Sun from 27 June till 9 July 2012. It displayed significant sunspot dynamics, with sunspots continually whirling, splitting and crashing into each other. Hence, it is no surprise that during its transit, this active region produced 30 M-flares (medium class) and also 1 X-flare (eXtreme class; on 6 July). Such a high number of strong flares are a rare "tour-de-force", only performed by the most active sunspot regions.




*A weak type III radio burst followed by a type II burst recorded by the Humain Solar Observatory following an M6-flare from NOAA 1515. Type III bursts are caused by very fast electrons travelling through the hot solar corona and away from the Sun, while type II bursts usually are excited by magnetohydro-dynamic (MHD) shockwaves associated with a CME traveling through the corona.*



*NOAA 1520 as photographed by the telescopes of the Uccle Solar Equatorial Table (USET) and by the PROBA2/SWAP instrument on 11 July. The green circle on the pre-flare H-alpha image (08:15UT; top left) indicates the position of a small flare visible in USET's Ca II K and SWAP's EUV-image just 15 minutes later (resp. bottom left and right).*

NOAA 1520 was the largest sunspot group during 2012 and the second largest so far this solar cycle. This super group was magnetically not so complex and produced only a handful of strong flares. However, while it was rounding the west limb, it produced an M7-flare on 19 July which was accompanied by graceful round post-flare coronal loops. On 23 July, well on the Sun's backside, it produced another strong flare accompanied by a proton storm that was even registered on Earth. The speed of the related coronal mass ejection (CME) turned out to be one of the fastest ever recorded, arriving at STEREO-A only 19 hours after the eruption, a so-called "fast transit event".

The last 5 months of 2012 saw a decline in solar activity, with decreasing sunspot numbers and no medium flares at all in December. The last X-class flare was produced on 23 October by NOAA 1598. The period was mainly characterized by many filament and prominence eruptions, with the most spectacular one occurring on 31 August near the south-east solar limb.

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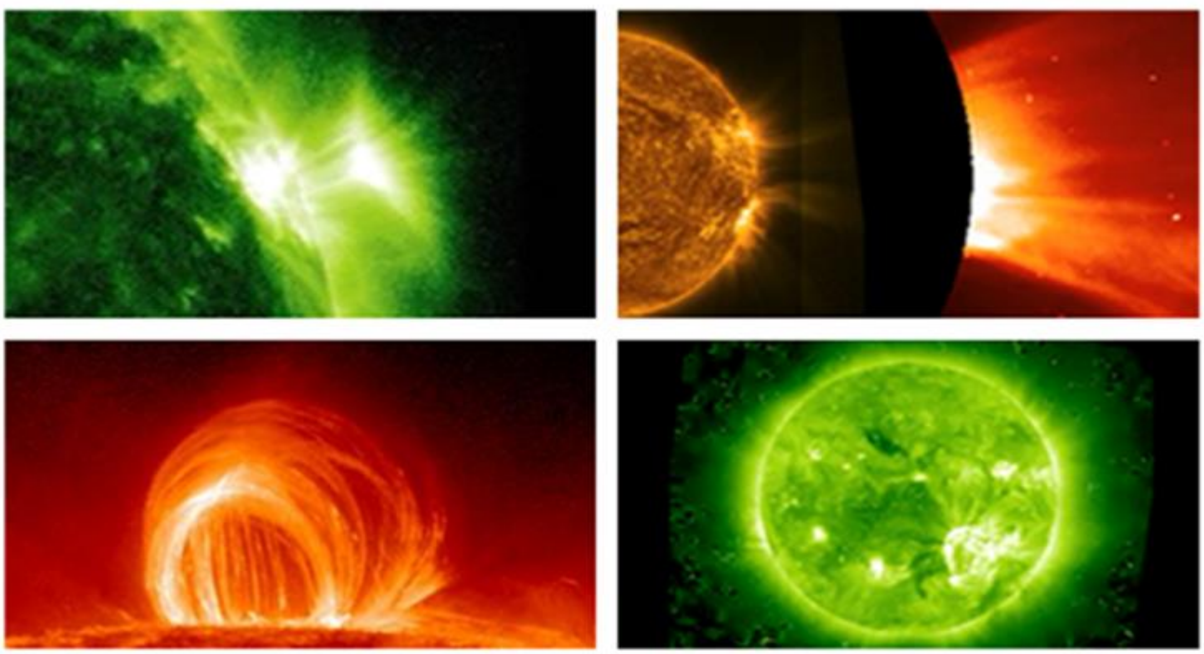
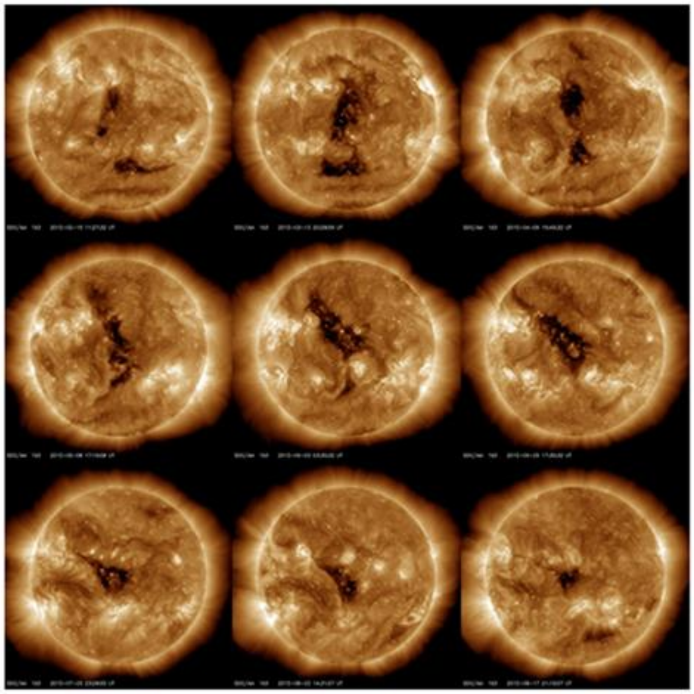
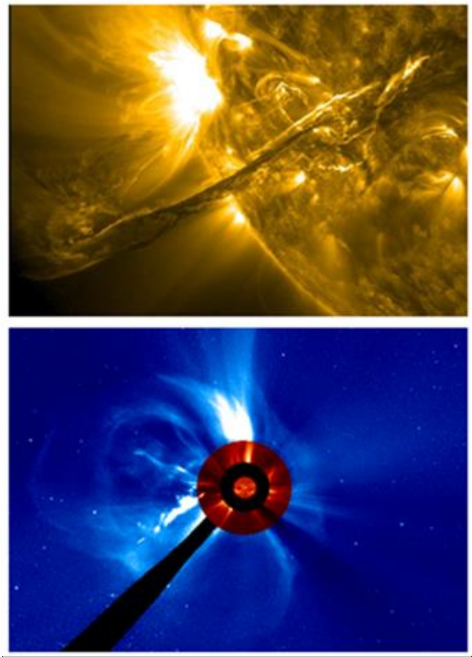


*Some fabulous solar flares and eruptions were produced during 2012. Supra-arcade down flows on 13 March (NOAA 1429, top left), a double trans-equatorial CME on 8 July (NOAA 1515, top right), gracious coronal loops on 19 July (bottom left), and a backside proton flare responsible for a transient coronal hole and one of the fastest CMEs ever recorded (23 July). The last two events were both courtesy of NOAA 1520.*



*A trans-equatorial coronal hole survived for 9 solar rotations during the February-September 2012 timeframe. Notice the gradual change in shape and size. Only during the first 3 transits (top row), geomagnetic storming was recorded.*



*View on the spectacular 31 August filament eruption by SDO (top) and SOHO's coronagraphs (bottom). Even though most of the ejected material was directed away from Earth, a glancing blow sparked a minor geomagnetic storm on 3 September.*

So far in this solar cycle, there has not been confined to the higher geomagnetic latitudes. Days with major to severe storming occurred on 9 March and 15 July 2012. The month of March was geomagnetically the most disturbed so far as a result from very active flaring periods. Interestingly, no geomagnetic storms occurred during the last 2 months of 2012. Coronal holes added occasionally to the geomagnetic unrest, especially during the first half of the year. In particular one coronal hole survived 9 (nine!) solar rotations, sparking geomagnetic storms during the first 3 transits.

In conclusion, despite the currently declining trend in solar activity, solar maximum is still expected for late 2013 or in 2014. Episodes of strong flaring activity can be anticipated, with severe geomagnetic impacts if the associated CMEs are Earth directed. This scenario remains valid even in the first few years of the declining phase of the solar cycle. Thus, Earth and its technology remain vulnerable to space weather effects for years to come.

# The 9th European Space Weather Week

Space weather describes the conditions in space that affect Earth and its technological systems. It has an impact on a large variety of domains and even on our daily life. Providing observers a view of the beautiful aurorae, it constitutes a threat for aircraft crew and passengers because of radiation. It hampers telecommunication and navigation. Space weather is also a concern for e.g. power companies, who fear a disastrous breakdown of their networks. The STCE understands the necessity of communication about space weather and recognizes at the same time the challenge to do so in thoughtful serenity.

Our knowledge is strengthened through national and international collaborations. The STCE puts a strong effort in building solid scientific foundations. One of the building stones of this scientific basis of space weather is the European Space Weather Week (ESWW), an annual international scientific conference. The worldwide science community benefits from this effort.


*The ninth edition of the European Space Weather Week focused on the space weather landscape in Europe, the innovations and challenges, solar variability and its effect on climate, modeling, spacecraft operations, space weather in the solar system and the final results of a European collaborative project about space weather services and products. This image shows PROBA2 orbiting Earth watching the Sun, the driver of space weather.*

With respect to content, the ESWW is interesting for scientists, policy makers, space weather end users, and developers of services. It offers a program for theoreticians and more practical oriented business. Since quite early in its existence, the STCE has been the local organizer of this event. The STCE makes the ESWW run smoothly and regularly introduces new concepts. It is no wonder that this varied and innovative program draws every year more participants: 319 in 2012!

One of the innovations in the 2012 edition of the ESWW was the educative program on the first day of the week. The Battle of the Solar Titans was introduced with a dynamic live quiz called “Higher Lower”. Here, participants had to indicate with their arms if they think the true answer is higher (left arm) or lower (right arm) than the proposed answer. An example: “PROBA2 is a micro-satellite launched on 2 November 2009, with onboard the EUV imager SWAP. Does it picture the Sun in a wavelength higher or lower than 170nm?” If you had been a participant and you had put your right arm in the air (the answer is indeed lower since SWAP captures the wavelength of 17.1nm), you would still be in the running for the title “Solar Titan of Monday”. The audience truly enjoyed this simple and amusing quiz with its immediate feedback. The actual “Battle of the Solar Titans” was played online and ran for the entire week. Most of the questions were provided by the participants.

Of course, the quiz was preceded by brain-filling sessions: “Meet and Greet” and “Scientists in the Sofa”. The “Meet and Greet”, also called “Space Weather Shopping”, introduced the participants to a broad variety of space weather topics. They hopped from one information point to another: Solar Orbiter satellite, Sailing on Sunshine, PROBA2, Comets, the public observatory MIRA, and Imaging the Sun and planets. In sessions lasting 5 to 10 minutes, specialists explained the basics in easy wording and with plenty of demo material.

*The European Space Weather Week started off with some educative space weather fun. The ninth edition offered "Space Weather Shopping" where participants could meet people involved in a specific area of space weather.*


*Dave Pitchford moderated "Scientists in the Sofa" with Marilena Mierla who studies coronal mass ejections, Dan Seaton who gives all his scientific attention to the EUV imager SWAP onboard PROBA2, and Shaun Bloomfield from Trinity College Dublin who also uses SWAP for his solar flare research.*

Since scientists are humans, we put 3 scientists in a sofa and asked them about their passion for space weather. Marilena Mierla's passion is about coronal mass ejections (CMEs). She turns data, provided by a fleet of satellites such as SDO and PROBA2, inside out. Marilena aims for a 3D vision of these massive plasma clouds and wants to know how they interact with the surrounding solar wind that fills the space in the heliosphere, the magnetic bubble that contains our solar system. She finds it especially interesting to see how practical measurements and theoretical science combine. In the end, the result is also useful for real space weather operations like forecasting. Dan Seaton, a PROBA2 scientist at the STCE, stated that "the open discussion format was a great opportunity for me as a scientist to learn about the space weather community's needs, interests, and concerns.  And I hope it was an equally good opportunity for data and forecast users to see what goes into the science that stands behind space weather forecasts."

This year's keynote speaker was none other than Professor Jocelyn Bell Burnell who discovered the first radio pulsars back in 1967. Pulsars are rapidly rotating remnants of exploded stars, emitting beams of electromagnetic radiation toward the Earth, very similar to a lighthouse. To have this top scientist at the ESWW was quite an honor! She gave a down to earth presentation on how radio astronomers worked in the sixties and seventies: screwdrivers and pliers, topped with brains.

*Professor Jocelyn Bell Burnell discovered the radio pulsars. She is seen here in action as our keynote lecturer*

We also introduced the participants of the ESWW9 to Twitter and Facebook. You could read instantaneously what the public thought of a presentation. We can assure you that nobody was offended or hurt: Twitter was used and perceived in a positive way.

# Public Outreach

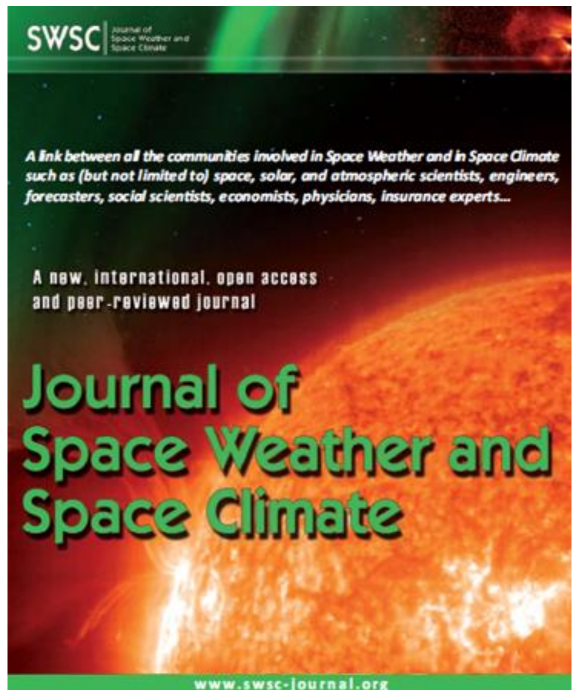
## COST: The European Space Weather Wave

In the sixties, scientist and engineers started to realize that the Sun and its daily activity had a non-negligible impact on humanity and in particular on the technological tools we use. “Space Weather” as a concept and a science was born. But it wasn’t until the nineties that Space Weather really took off as an important new branch of research.

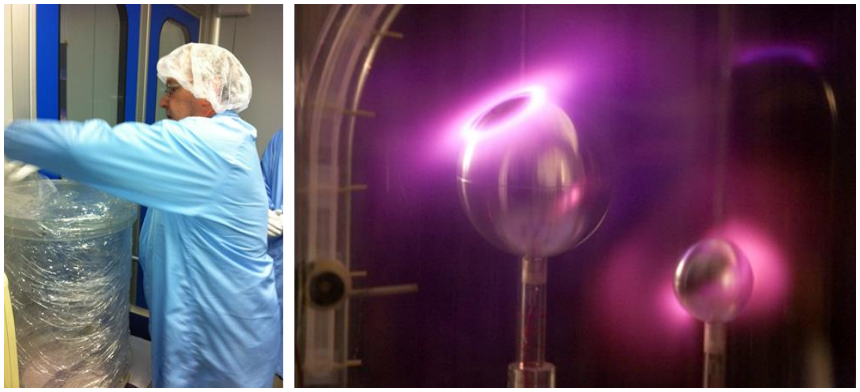
In 2000, the Regional Warning Centre (RWC) for Western Europe was installed in the offices of the Royal Observatory of Belgium. ROB solar physicists started to monitor the Sun and forecast its activity up to 3 days, 7/7. At about the same time, the space weather community in Europe started to organize itself. The Solar Influences Data analyses Centre (SIDC) and later the STCE (2007) established a strong position on the European and world map. In 2008, the STCE became a partner in a project “Developing Space Weather Products and Services in Europe” (ES0803) under the umbrella of the European Cooperation in Science and Technology (COST). This COST project acts as the glue between space researchers across Europe. It offers the communities in different European countries the basis and tools to organize themselves in an efficient way and to converge to a series of products and services. The STCE took the lead in the work group responsible for the specification of recommended products and services. Since its start in 2008, the members decided to include a focus on outreach and communication activities. This challenge was given in the hands of the communication cell of the STCE in 2010. A communication plan was developed, keeping in mind what the target audience is, identifying clear goals and discussing the tools and ways to communicate.

Within the COST-frame, starting already under a first action (COST-724), and continued under COST-ES0803, the European Space Weather Portal was developed. This website provides a centralized access point for the space weather community to share their knowledge and their research results and models.

Another big effort was the Journal of Space Weather and Space Climate (SWSC) that was launched in November 2010. This online open access journal collects scientific results in the field of space weather and space climate that used to be spread over a variety of journals and offers the possibility to publish valuable technical information, data and communication material. It offers a forum for the scientist organizing activities for the public. The STCE takes care of the editorial office and verifies if there are no hick-ups in the review process.




*The Journal of Space Weather and Space Climate was launched late 2010. It collects the science that used to be spread over a variety of journals and offers the possibility to publish valuable but more technical oriented papers, as well as papers describing outreach and communication activities.*



*The Norwegian experimental physicist Kristian Birkeland was one of the founding fathers of modern space science. A century ago, he demonstrated with his Terrella experiment the formation of the aurora. Recently, a modernized version of the Terrella has been designed, allowing the visualization of many other phenomena occurring in our space environment. The STCE is now building its own planeterrella. The image depicts the plexiglass case - a protective plastic covers it - in which a very low pressure is created. A cathode then fires electrons to a ball with a magnetic dipole inside.*

The STCE contributed also to a publication about the planeterrella, a planetary aurora simulator developed with CNRS support by Jean Lilensten at the Institut de Planétologie et d'Astro-physique de Grenoble (IPAG). We are actually building one ourselves! This is one of the strengths of such a collaborative project, i.e. a national activity can be lifted to an international level such that a broader community can benefit.

These are only a few of the many examples that were developed under the umbrella of this project. The COST project ended in 2012, culminating in a dedicated session during the European Space Weather Week where many of its results were presented.

## eHEROES go on a space trip

In 2011, a bunch of scientists spread over 15 institutes (in 14 countries) got the idea to work together around space exploration. The STCE was one of those 15. The proposal was approved and the project had its kick-off in March 2012 and got the sounding name eHEROES, short for Environment for Human Exploration and RObotic Experimentation in Space.


*Partners from all over Europe find each other in the project eHEROES. This project includes a study of solar and space events, their evolution and impact, and wants to set up a frame in which space exploration can be performed in the best possible way.*

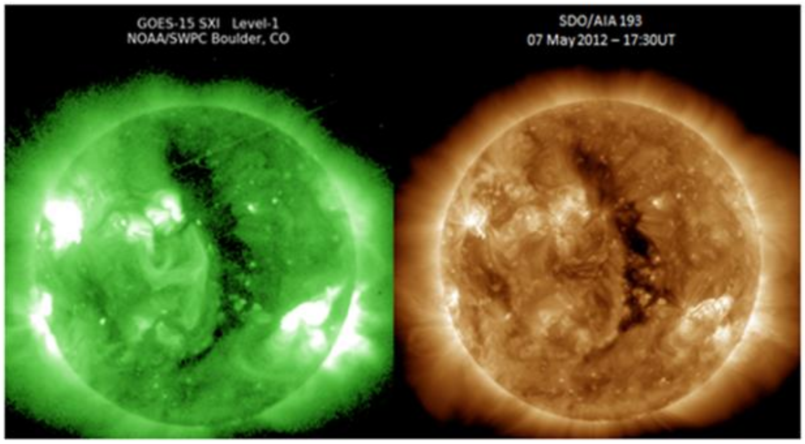
Not that we, the club of 15, wanted to go ourselves into space, but we wanted to exploit the existing data gathered on the numerous European and international space missions. We wanted to learn about the existing models and simulations and finally produce new value-added data products.

By collecting and studying this wealth of information, our knowledge of the space environment could increase dramatically. This definitely helps us to estimate and predict the threats that missions encounter when going outside the protective cocoon that provides the Earth's magnetic field.  So, we stay on Earth but do all the science and research necessary to make space exploration as safe as possible. However, these days, space exploration is not only limited to robotic missions but also involves humans. In Belgium for example, space trips are currently sold for the price of 77.777 Euro. This proves that space travels and space tourism are no longer science fiction, but are becoming a reality.

## Where's the coronal hole?

*posted: Dec 7, 2012*

Coronal holes are regions in the hot solar atmosphere ("corona") where the plasma density of that temperature is very low compared to its surroundings, and thus they look like dark shapes in the corona. They are also known to be the source of the high-speed solar wind, and as such can create geomagnetic disturbances when aimed at the Earth. As the larger coronal holes may hold their shape through several solar rotations, they are interesting for long term space weather predictions.




In general, both EUV (e.g. SDO ) and soft x-ray (SXR, e.g. GOES/SXI) images correspond very well in showing the coronal holes, though -of course- scientists have to keep an eye on some features that may be seen in SXR and not in EUV (or vice versa). However, images from late October were a bit more difficult to explain, as almost half a solar hemisphere was dark in SXR, while in EUV there was nothing peculiar to report. Where had the coronal hole gone?

*The online space weather stories show the violence and beauty of the ongoing solar activity and its impact on us and Earth. These broadcasts give 'Good to know' facts.*

As our society needs to be correctly informed about the dangers and threats that are linked to the Sun and space weather, a full-fledged work package “Dissemination” was included into the eHEROES project. Its main motives are “spread the word”, “make aware”, “instruct” and “educate”. We provide timely information with a daily update on the current space weather. These updates are more frequent in case of an extreme space weather event. The evolution of such events can then be followed in near real-time on the website through presto-messages and news items. The challenge we take now is to produce a space weather broadcast with an easy digestion and with a focused message. 99,99% of the population is not interested in the fact that the solar wind speed is 1062 km/s (which is by the way very high compared to a more normal value of 300 km/s), but many are interested in the chances to see polar light from, for example, Belgium. You can imagine that satellite operators have other interests. For them, it is e.g. crucial to know if the atmosphere will expand due to space weather events.

On the other hand, we also provide general information, things-to-know about space and space weather. One could consider it a guide to space. On the STCE website, we publish an online story of space interest every week. These stories provide background information on sunspots, flares, violent mass eruptions, satellite observations, and so on.

So, besides producing rocket science, eHEROES and in particular the STCE respond to all sorts of concrete needs, be it general or specific, informative or advisory, regular or near real-time.

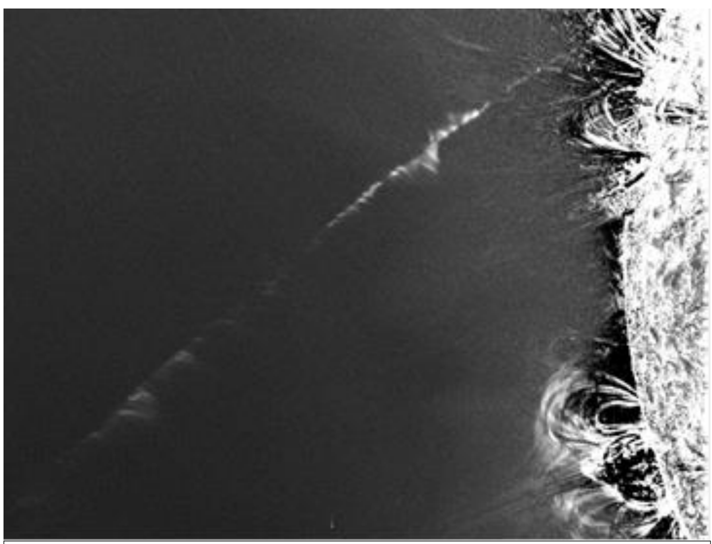
# PROBA2 - Not just observing the Sun!

PROBA2 is the second satellite in the ESA's PROBA series of small-scale satellites that are being used to validate new spacecraft technologies. PROBA2 contains five scientific instruments, two of which are designated to observe the Sun: "The Sun Watcher using Active Pixel Sensors and Image Processing" (SWAP, an EUV imager) which is designed to image the Sun in EUV at temperatures around 1 million degrees Kelvin, and the "Large Yield Radiometer" (LYRA) which measures the intensity of the whole Sun at 4 distinct wave lengths in the ultraviolet range. SWAP takes an image of the Sun every 2 minutes and LYRA makes 12,000 measurements in the same time!

PROBA2 is predominantly used to monitor "space weather". That is, to monitor the Sun for energetic events that may affect the Earth and orbiting satellites. Consequences of space weather are natural phenomena such as the aurora borealis and impacts on man's infrastructure, such as damaging satellites and causing large currents in power stations. We have reported in previous issues and other scientific journals the scientific benefits of PROBA2 for solar and space weather observations, however in this article we aim to look at some of the more unusual celestial observations.

## Comet Lovejoy – A Sun-grazing Comet

Comet C/2011 W3, more commonly known as comet Lovejoy, is a Sun- grazing comet which passed within 140,000 km (1.2 solar radii) of the visible solar surface in December 2011. Comet Lovejoy was observed in the SWAP field of view and can be seen in Figure 19, which is composed of several individual images superimposed on top of each other in order to map out the trail of the comet as it passed through the Sun's atmosphere. Images were taken between 23:41UT on 15 December 2011 and 09:23UT on 16 December 2011. The comet can be seen as a long streak moving from the left of the image to behind the Sun on the right. It appears as a series of striated lines due to its interaction with the Sun's magnetic field.



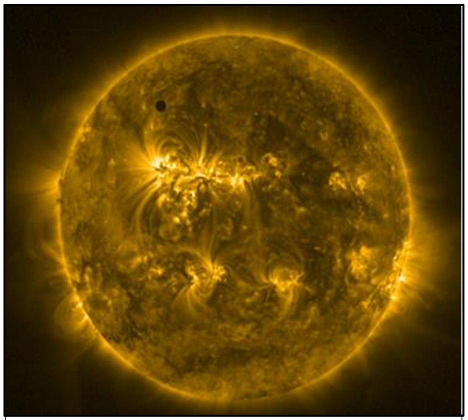
*A close up, composite image of the Sun and comet Lovejoy (the striated line) taken with the SWAP EUV imager on PROBA2. This single image is the superposition of several individual images taken with SWAP to show the progression of comet Lovejoy as it travels through the Sun's atmosphere*

The Sun is permeated with magnetic fields, which are highlighted by hot plasma trapped on them. These are seen emerging from the solar surface as a series of semi-circular (or loopy) structures (close to the Sun on the right of the figure above). Some magnetic fields cannot be seen as they have no hot material trapped on them, and are therefore invisible. However, when the comet passes through these regions, it interacts with the previously invisible fields and we see substantial changes in the direction and intensity of the comets tail, creating the striated windblown appearance of the comet tail.

## Venus Transit

Another important celestial event occurred on 5-6 June 2012, when Venus passed in front of the Sun with respect to the Earth. This event was also captured by SWAP and can be seen on the right, where Venus is the black circle obscuring the EUV light of the Sun. Due to the orbits of Earth and Venus, the alignment of these two planets with the Sun occurs rarely, but in pairs. The first alignment occurred in 2004. Preceding observations were made in 1874 and 1882, and we will have to wait until 2117 and 2125 for our next opportunity to observe a Venus transit in front of the Sun from the Earth.

The transit of Venus was visible from the Earth. However, due to the setting of the Sun and cloudy conditions, it was difficult to observe the transit from several locations on the Earth. PROBA2 was able to make uninterrupted images of the transit from its orbit around the Earth.

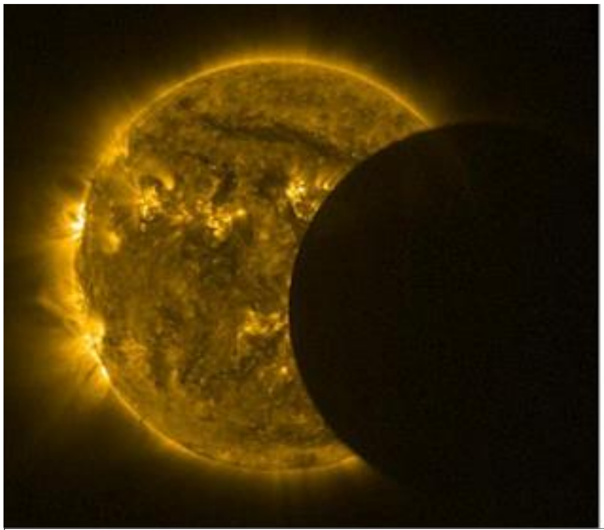


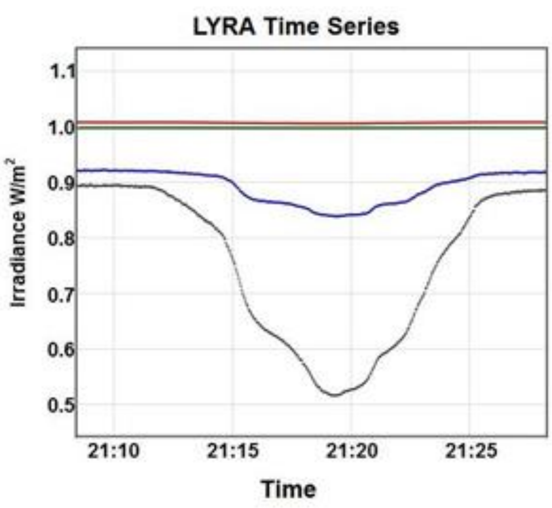
*An image of Venus passing in front of the Sun, taken by the PROBA2/SWAP instrument. Venus can be seen as a dark circle in the upper left quadrant of the image.*

## Solar Eclipse

On 20 May 2012, an annular solar eclipse could be observed from some parts of the Earth. An annular eclipse takes place when the Moon passes exactly between the Sun and the Earth, but is not big enough to cover the entire solar disk. PROBA2 orbits at 700 km above the Earth and passed repeatedly through the Moon's shadow taking 4 images of partial eclipses (where only part of the Sun is obscured).

The above figure shows an image of the eclipse taken by SWAP (left) and the associated solar output (light curves) recorded by LYRA (right). It can be clearly seen how the irradiance of the Sun is diminished by the eclipse. The solar eclipse is not only visually impressive, but gives researchers at the Royal Observatory of Belgium the chance to monitor the health of the SWAP instrument. The places where the Moon occults the Sun should show up as black, and variations from this can be calibrated and corrected in future images.





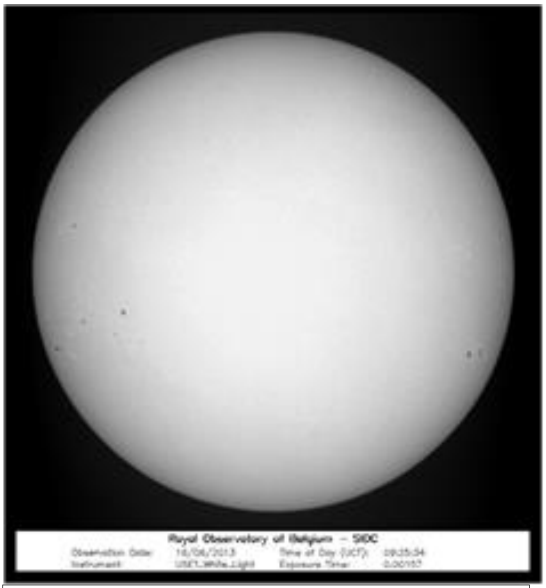

*An image of the total solar eclipse taken by SWAP (left) and its corresponding irradiance measured by LYRA (right). The differently colored light curves indicate the different pass bands the eclipse was seen in; Lyman alpha (Red), Herzberg (green); Aluminum (Blue) and Zirconium (Black).*

## Merging sunspot catalogues

While digging for clues as to the reason for changes in the relationship between different well-known solar indices, our team discovered that the Sun has changed its behaviour during recent years. To understand what is happening, we used a recently compiled catalogue, based on several other less detailed catalogues to assess the details. Here we explain how it all works.

## Sunspots

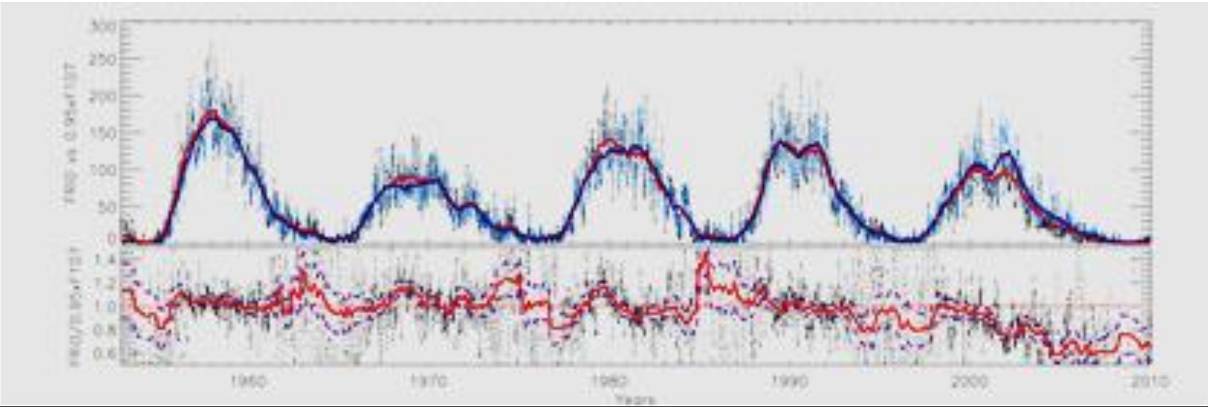
Sunspots are areas of the Sun that appear as dark spots compared to their surroundings. This is caused by their intense magnetic field that locally reduces the solar surface temperature. They appear and disappear in a matter of hours to weeks.



*Some small sunspots on the surface of the Sun. Image taken with USET's white light telescope.*

Sunspots and groups of sunspots come in different flavours. Over time, different schemes were used to classify them. The most used scheme is called the modified Zurich McIntosh classification. Basically, groups of sunspots are classified by size: A and B groups are the smallest and it goes on through C, D, E, F. The last letter, H, refers to decaying groups that are at the end of their lives.

## The sunspot number: one aspect of solar variability



*Upper panel: Sunspot Number (red) compared to radio flux (at 10.7 cm, in blue) from the 1950s up to now. Lower panel: Ratio between the two showing recent discrepancies.*

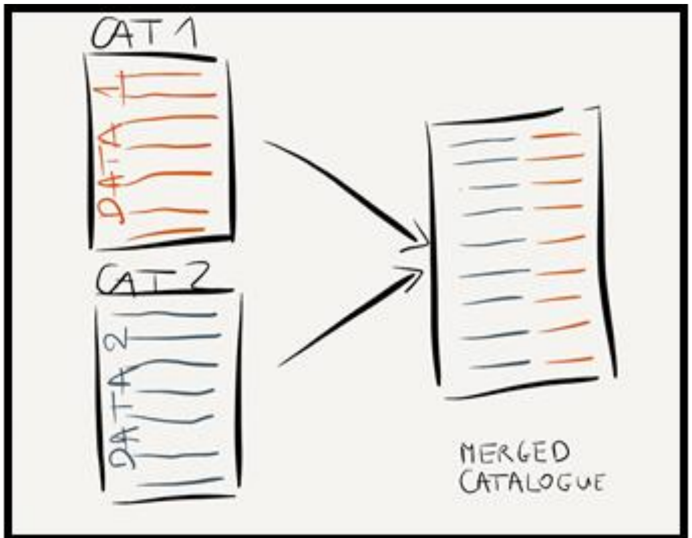
The International sunspot number, obtained with a formula combining the number of spots and groups of spots on the Sun's surface every day, has been computed each month by the SIDC since 1981 and exists since 1818. In parallel to this index, a number of other organizations around the world compute their own sunspot indices while various solar measurements are made from other sources (e.g. radio flux). They represent different aspects of the solar variability. For the last 50 years or so, all these quantities have agreed relatively well. However, around 1998-2000, they started to show persisting disagreements. While investigating possible technical or physical causes, the need for more detailed information about the sunspots and sunspot groups led us to look into the information available from sunspot catalogues.

### Sunspot catalogues

Various catalogues describing sunspot regions in more or less details are available from different sources over the internet. However, when looking for detailed information about the individual sunspots, information is much sparser. A recent catalogue from the Heliophysical Observatory in Debrecen, Hungary (http://fenyi.solarobs.unideb.hu/DPD/index.html ) stands out in terms of level of detail: It contains information on the individual sunspots and their relation to a group of spots. On the other hand, it lacks other, more basic information about the morphology of these groups (the different flavours mentioned above).

### Construction of merged catalogues

We use this very detailed catalogue from Debrecen, and complement it with the well-known, but less detailed USAF/NOAA catalogue (http://www.ngdc. noaa.gov/ ) that describes the different flavours of sunspot groups. The results have been published in a specialized scientific journal specialized at the end of 2012 (L. Lefèvre & F. Clette (2012), Survey and Merging of sunspot catalogues, Sol. Phys., DOI: 10.1007/s11207-012-0184-5). This merged catalogue enabled to successfully diagnose the recent disagreement between different aspects of solar activity. The discrepancies seem to be caused by a large difference in the number of small sunspots and stems from different sensitivities to the same phenomenon.



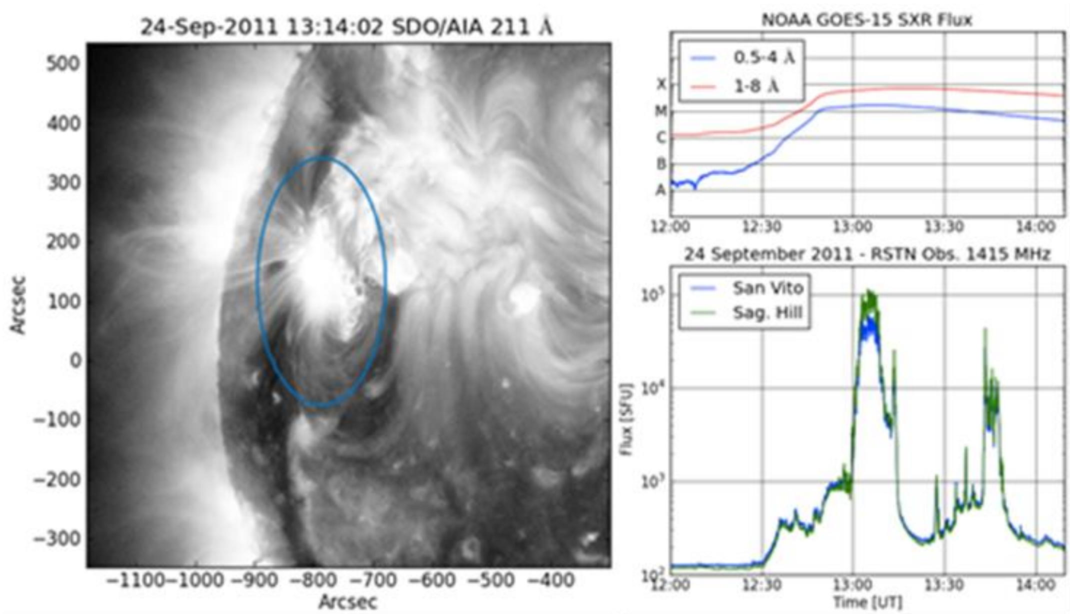

*Merging data from different catalogs into one "mother catalog".*

# Impact of a solar radio burst on the EPN GNSS network

The GNSS (Global Navigation Satellite System) research group of the ROB hosts the "Central Bureau" of the EUREF Permanent Network (EPN), a European-wide reference network of GNSS receivers that are used, amongst other things, for the monitoring of the ionospheric conditions. By design, the antennas plugged to the receivers have a wide field of view, in order to catch several satellites at once, and the Sun routinely falls in this field of view. During quiet conditions, the solar emission is too low to be detected by the receivers, but some flares produce intense radio emissions that act as wide band interferences and decrease the efficiency of the receivers.

On 24 September 2011, an M7.1 flare occurred in active region NOAA 1302, accompanied by the strongest radio burst in microwave range since December 2006. STCE solar and GNSS scientists studied this event in more details.

## The Solar event of 24 September 2011

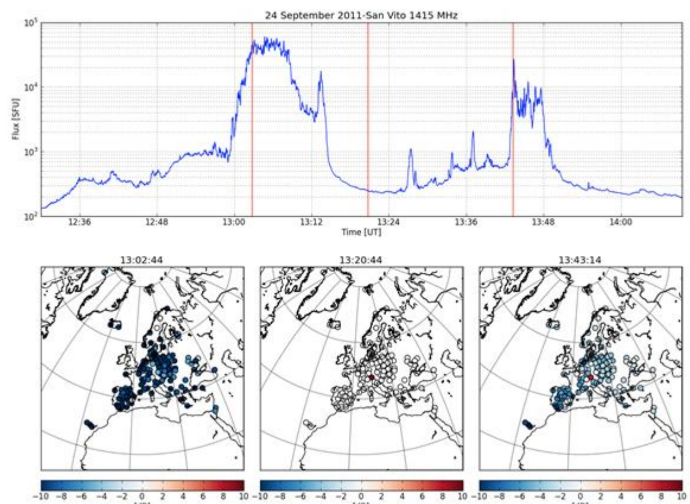



*Overview of the solar flare of 24 September 2011. Left: SDO/AIA picture showing the flaring region. Right: Light curves in soft x-ray (top) and at radio wavelengths (bottom).*

The figure above shows the evolution of the radio flux at 1415 MHz, a frequency which lies in between the two main frequencies used by GPS, i.e. L1 (1575 MHz) and L2 (1228 MHz), as observed by two observatories of the US Air Force Radio Solar Telescope Network. At the peak of the radio burst, the intensity is nearly 3 orders of magnitude above the quiet sun level and reaches nearly 100,000 Solar Flux Units (SFU). According to existing studies, such a flux level occurs less than once per solar cycle.

### Effects on the EPN network

The GPS data for each station archived at the observatory contain a "housekeeping" parameter, called the carrier-to-noise ratio ($C/N_0$), which is an indication of the quality of the received signal. For a given satellite and a given station, this parameter varies during the day depending on the satellite position in the sky. By subtracting two consecutive days, the relative $\Delta C/N_0$ reveals the unusual events such as solar flares. The figure below shows a series of maps of the EPN network, where color dots indicate the drop of $\Delta C/N_0$ as the radio burst progresses. Drops down to a factor 100 (20 dB) are observed for some stations, with a strong correlation with the local solar elevation.

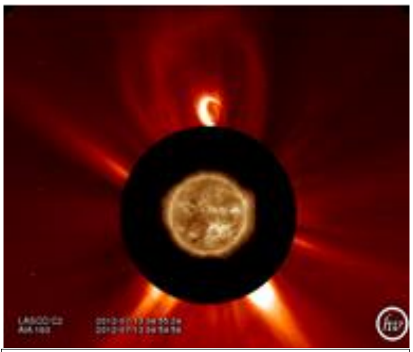



*Maps of the relative carrier-to-noise ratio $\Delta C/N_0$ at the L1-frequency during the radio burst, for the timings*

The network is made of different hardware (antenna and receivers), and the STCE scientists are looking at the technical parameters that can explain, besides the obvious effect of the solar elevation, the different behaviours observed during the event at different stations. On the other hand, it is possible, by estimating the noise level of the receivers, to determine the intensity of the solar radio burst at the GPS frequencies.

## Coronal Mass Ejections without distinct coronal signatures

Throughout the year 2012, there were several periods when the Sun was very active. This can be seen, for example, in the number of solar eruptions compared to previous years. We have different ways of observing these eruptions, as they can involve various phenomena like an impulsive increase in solar radiation, expulsion of solar plasma and the launch of energetic particles into space. All of these manifestations are observed in different ways with different instruments, but each of them tells us that an eruption has taken place on the Sun.



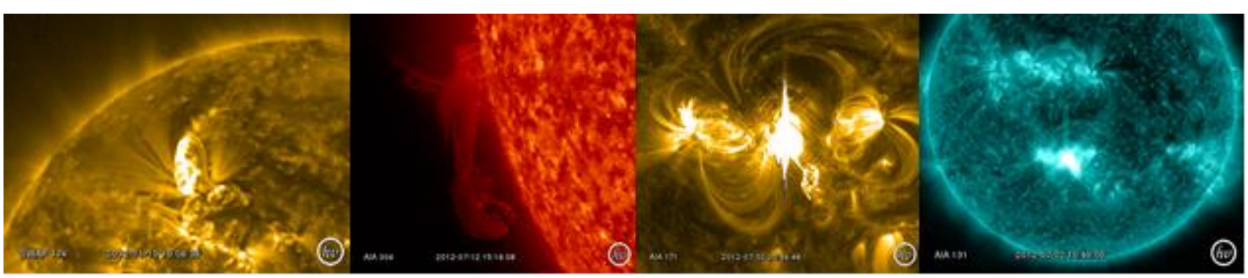
*A CME observed on 13 July 2012 with the LASCO coronagraph onboard the SOHO spacecraft.*

The clouds of plasma ejected from an eruption site travel outwards into space. We monitor them -in white light- with an instrument called a coronagraph. This instrument uses a disk to obscure the Sun and creates an artificial eclipse that allows us to observe the solar corona, the faint, tenuous atmosphere that surrounds the Sun. Whenever a plasma cloud is ejected from the Sun, it shows up as a bright feature in coronagraph images. We call these features Coronal Mass Ejections (CME, above image).

When a CME occurs, it is important for space weather forecasters to determine from which region on the solar disk this plasma cloud originates. If the eruption happened on the earth-facing side of the Sun, the plasma cloud and the shock that it produces are likely to travel towards Earth, and could spawn different space weather events like disruptions of satellites and communication systems, loss of electrical power, and polar lights.

From the coronagraph images alone, it is not possible to determine the source region of the eruption. Therefore, scientists combine information from different instruments in order to search for signatures in the corona that can indicate where the eruption happened (see figure below). These signatures include changes in the magnetic configuration of a certain region, solar flares (a sudden increase in the electromagnetic radiation we receive from the Sun), the formation of bright post-flare loop arcades, rising filaments (arched, bright, gaseous features extending outwards from the Sun's atmosphere), waves observed in EUV, dimmings (intensity depletions of the solar atmosphere in EUV wavelengths), and brightenings in the solar atmosphere.

However, some CMEs cannot be linked to any of these signatures. In that case, the most likely explanation is that the eruption happened on the far side of the Sun. Luckily, we have the two STEREO



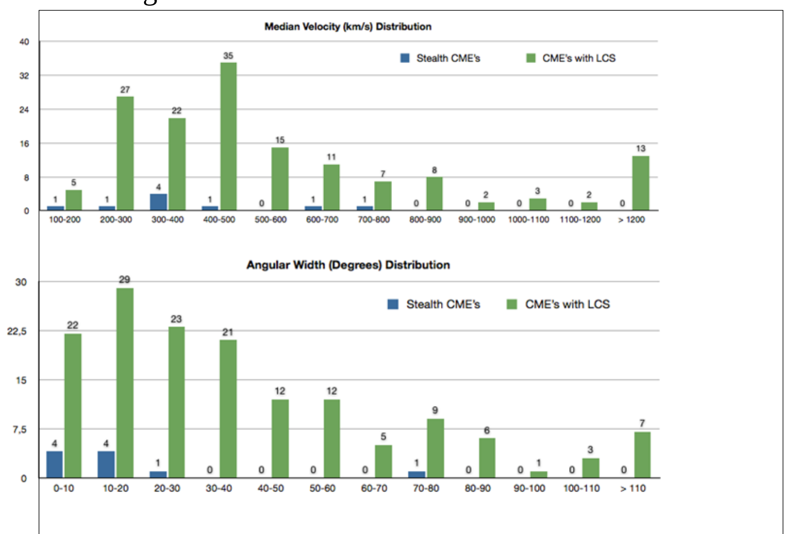
*Coronal signatures of solar eruptions: bright post-flare loops (left image), an erupting filament (second image from the left), and a flare observed in two different wavelengths (two images on the right).*

(Solar TErrestrial RElations Observatory) spacecraft, which provide us with a side-view of the Sun. They allow us also to identify the eruptions that occur on the backside of the Sun.

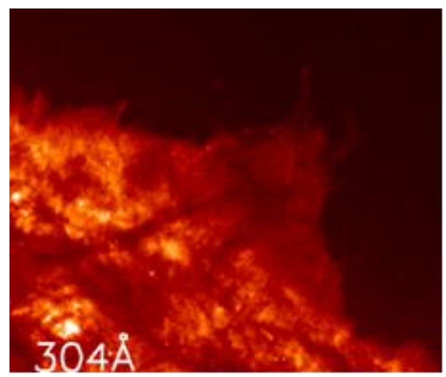
Surprisingly, it turns out that there are some CMEs that occur on the earth-facing side of the Sun (as confirmed by STEREO) that cannot be associated with any signatures on the solar disk. These CMEs are sometimes called “stealth CMEs” because they are undetected when they leave the Sun and can only be seen in coronagraph images. These stealth CMEs are problematic for space weather forecasters since their source location, and thus their possible effects, are difficult to identify. We ask the question why these CMEs lack clear signatures at their source regions and what observations of them can tell us about the physics involved.

To identify some stealth CMEs, we take the list of all CMEs detected in July 2012 by CACTus, a software tool that autonomously detects CMEs in the images from LASCO, the coronagraph on-board the SOHO spacecraft. We match this list to different catalogues of solar activity and remove CMEs that can be linked to flares, EUV brightenings or activity on the far side of the Sun. Inspection of solar images in various wavelengths allows us to further filter out the CMEs associated with filament eruptions, EUV waves or dimmings. We use the resulting list to characterize the general properties of stealth CMEs (see opposite page, top left figure). We find that these stealth CMEs are generally slow events, with a median velocity between 100 km/s and 500 km/s -although we do find a handful of faster stealth CMEs as well.

The angular width of most of the stealth CMEs is below 30 degrees, but again we find an outlier with a much larger width.




*Velocity (top) and angular width (bottom) distributions of stealth CMEs (blue) and CMEs with local coronal signatures (LCS; green).*

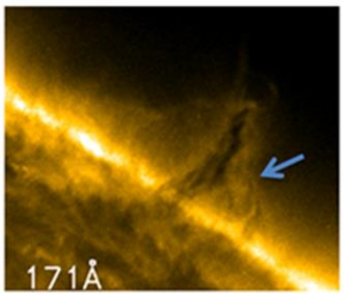


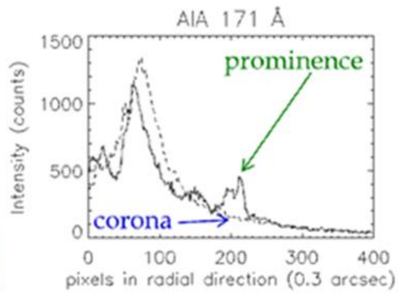

*A prominence observed by SDO/AIA which samples the plasma at about 80,000 degrees (304 band).*

The presence or absence of on-disk signatures can be linked to different theoretical models of eruptions to help establish the mechanisms by which the eruption is initiated and driven. We are compiling a list of stealth CMEs that occurred in the year 2012 and will select a few events to study in detail. Modelling these events using analytical and numerical models will give us an indication of which eruption mechanism is at work in triggering these events and help establish whether these CMEs in fact represent a class separate from more prototypical eruptions.

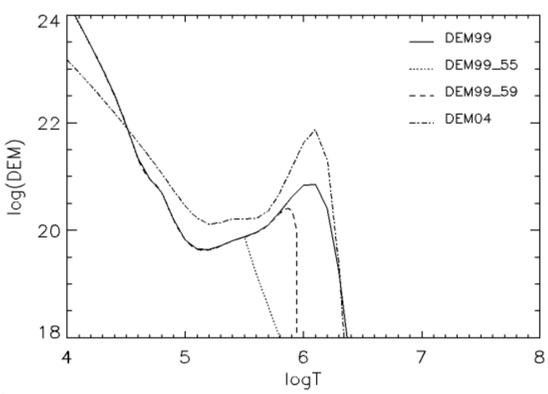
## On the nature of prominence emission observed by SDO/AIA

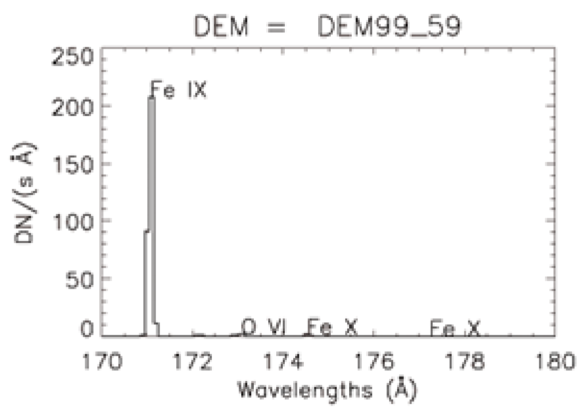
Prominences are bizarre structures in the chromosphere reaching all the way up into the solar corona. They are made of relatively cool (7000 degrees) and dense material suspended in the rarefied, million degrees hot corona (see top right figure). Despite this apparently unstable situation, prominences are common structures and can live for several weeks. Often, their life is ended by an eruption as part of a CME. The physics governing the stability of prominences is still not well understood. This is, amongst other things, because the cool plasma in the prominence core is optically thick. To deduce its properties from observations, a complex physical description is needed, including non-local thermodynamic equilibrium radiative transfer modelling.




*A prominence seen in the 171 band which samples the plasma at 600,000 degrees. For the first time, this band has shown a faint emission as indicated by the blue arrow. Right: Radial cuts across the prominence (solid line) and outside into the corona (dashed line) are shown. Stronger emission from the prominence above the coronal background is clearly visible.*




*Synthetic spectrum obtained using model DEM99_59 within the AIA 171 band. The Fe IX dominates the counts in the band*

*Amount of plasma (indicated as DEM) as a function of the logarithm of the temperature for the four PCTR models*

This core is interfaced to the corona through the prominence-corona transition region (PCTR), a relatively thin layer where the temperature gradient is very steep and the plasma becomes completely rare. This layer contributes to the insulation and pressure balance of the prominence against the corona. As the different properties of these two parts of the prominence require different techniques of investigations, a common picture of the whole core-PCTR is still missing. In particular the PCTR is often ignored or only partially integrated in the modelling. Instead, we concentrate on the understanding of the PCTR properties and aim at linking them to those of the massive and cooler core.

One of the partially known properties of the PCTR is the temperature structure, i.e. the amount of plasma along the temperature gradient. This is important as it allows deriving the total radiative losses of the layer, which feeds the energy balance equation. In the past, it was generally believed that not much emission of the prominence existed above 100,000 degrees. This was deduced from the fact that nothing was seen in prominence images from SOHO/EIT 171 band (sampling plasma at about 600,000 degrees). Other spectroscopic ultraviolet (UV) investigations were not able to disentangle the background-foreground coronal emission from that of prominences.

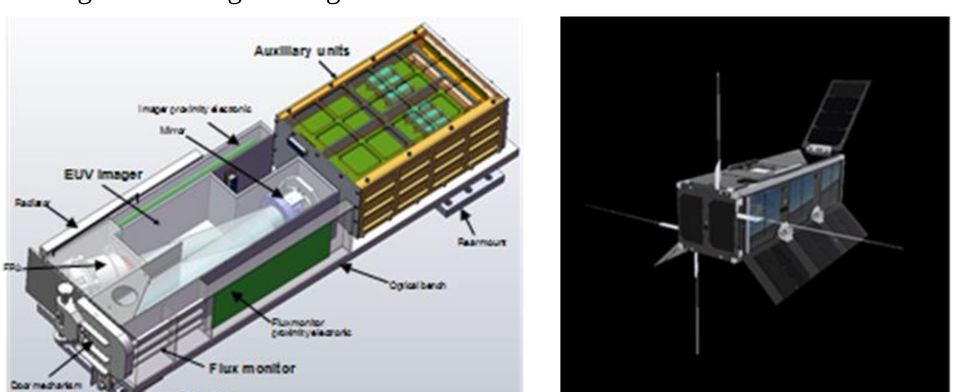
After the launch of NASA's SDO, things have changed. Its high signal-to-noise (S/N) EUV telescopes have revealed, for the first time, a faint prominence emission in the 171 band, as shown in the previous page's bottom figure. This has stimulated our curiosity, as the telescope's passband includes, in addition to Fe IX (8 times ionized iron), a smaller contribution from spectral lines emitted at lower temperatures (near 400,000 degrees). So, the question we asked was if this visible emission was coming from the cooler components falling into the band or from the dominant hotter line Fe IX at 700,000 degrees?

To answer this question, we simulated the emission of a prominence measured by AIA (Atmospheric Imaging Assembly), using different thermal models for the PCTR which are shown in top right figure. From spectroscopic observations, the models DEM99 and DEM04 were derived (DEM: Differential Emission Measure). In addition, we artificially removed the hotter contribution creating the DEM99_59 and DEM99_55 curves. An example of the PCTR emission measured by the AIA 171 band and produced using these models is shown in top left figure. Our tests show that when there are enough counts above the noise level, the 171 AIA band is always dominated by the emission from the hotter Fe IX ion. As a consequence, we conclude that the PCTR has much more emission above 400,000 degrees than what was previously thought. This very important result implies that, from now on, the core-PCTR model and energy balance equations should include this newly found hot component.

# Development of new solar instrumentation

Future missions for space astronomy and solar research require the development of critical optical components for improved UV solar observations. For the future space missions planned to study the Sun (e.g., ESIO, PICASSO; see figure below), new technologies capable of operating at high temperatures and in harsh environments are developed and investigated. Since industry progress in these fields is clearly insufficient, it has been a successful tradition in solar-terrestrial physics to trigger and perform specific technological developments. At ROB/STCE, we have identified and developed a specific expertise in the development of UV detectors based on wide band gap material (WBGM).

In 2012, the STCE/ROB team "Advanced technology for Solar Observations", together with our partners, meets the challenge of building a new generation of ultraviolet detectors.

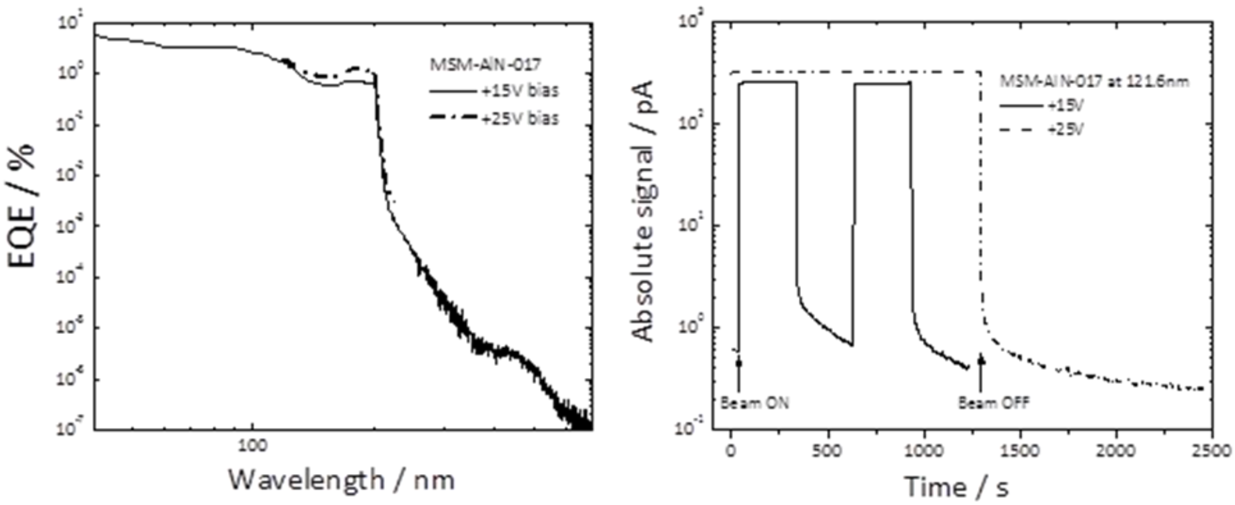



*Schematic representation of (left) the EUV Solar Imager for Observations (ESIO) prototype and (right) Pico-satellite for Atmospheric and Space Science Observations (PICASSO) onboard a CubeSat (QB-50) to be launched in 2015.*

## UV detectors developments (single pixel)

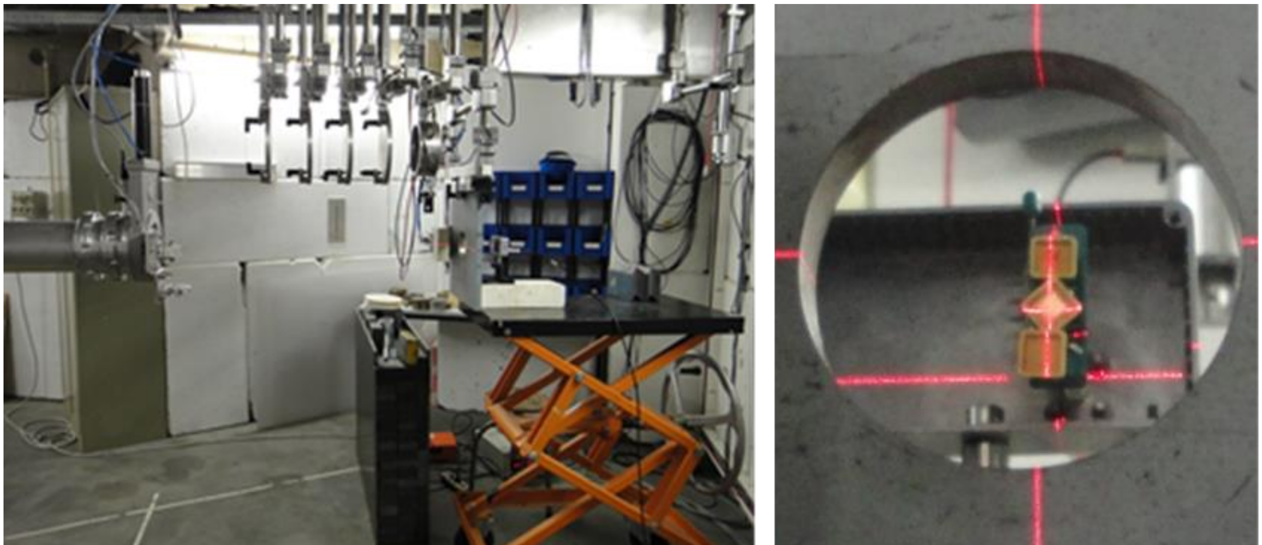
Knowing the harsh space environment, the radiation effect at the detector level is anticipated with the use of WBGM-based photo-detectors which are promising alternatives to the commonly used silicon photodetectors. By their nature, WBGM have very low sensitivity to visible light, a thermally-induced dark current much lower than other semiconductors, and a high level of radiation-hardness. For those reasons, WBGM-based photodetectors could significantly enhance the stability of the radiometric calibration of solar UV radiometers.

*Photographs of the AlN MSM photodiodes mounted on ceramic packaging. The MSM surface area (from left to right) are 4, 3, 2 and 1 mm diameter with 2 µm interdigitated finger width and 5 µm spacing between two electrodes.*




*Left: Absolute external quantum efficiency of the MSM-AlN-017 photodetector (3 mm diameter) in the range between 40–700 nm at +15 V and +25 V. Right: Signal stability test (at room temperature) under +15 V and +25 V bias at power level ~ 0.17 µW at 121.6 nm wavelength.*

After a first optimization step, innovative metal-semiconductor-metal (MSM) photodetectors based on aluminium nitride (AlN) were developed and characterized at DeMeLab (STCE/ROB) as shown in previous page's bottom figure. In the wavelength range of interest (here the 10-200 nm range), MSM-AlN is reasonably sensitive and stable under brief illumination with a negligible low dark current as shown in the above figure.Radiation hardness against protons is a primary concern for upcoming solar missions in space during long-period interplanetary orbits or when flying in low-Earth orbit and exposed to inner belt protons especially because of the South Atlantic Anomaly (SAA). Both ionization and atomic displacement damage effects are often the main cause of space-based instrument degradation. To assess their impact effects on our detectors, irradiation tests using a beam of 14.4 MeV protons were performed at LIF-CRC (Belgium) (see above figure). No significant degradation of the detector performance has been observed which demonstrates a good radiation tolerance for proton influence up to $1\times10^{11}$ /cm$^2$.



*Photograph of the proton test facility at LIF-CRC in Louvain-La-Neuve, Belgium (left) and the irradiated detectors (right).*

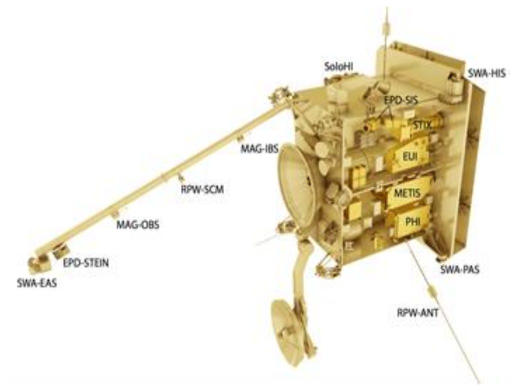
# Solar Orbiter Workshop

Solar Orbiter is the next ESA flagship for studying our closest star, the Sun. It is currently scheduled for launch in 2017. By approaching as close as 0.28 AU (astronomical unit; 1AU is nearly 150 million km), Solar Orbiter will view the Sun with high spatial resolution and combine this with in-situ measurements of the surrounding heliosphere. Thanks to its unique orbit, Solar Orbiter will deliver images and data of the unexplored Sun's polar regions and the side of the Sun not visible from Earth.

From 10 till 14 September, the scientific community behind Solar Orbiter assembled its "5$^{th}$ Solar Orbiter Workshop" (SO5) in the historical centre of Bruges. 180 scientists attended and discussed how science can best profit from the unique opportunities offered by Solar Orbiter, which is a partnership between ESA and NASA. The scientific synergy of Solar Orbiter with Solar Probe Plus and other missions was also highlighted.

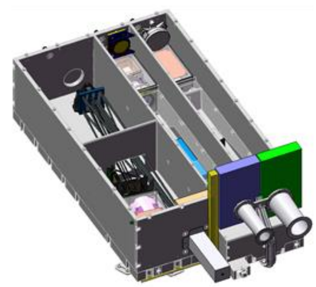
*Many young, new researchers at the STCE took the opportunity of the Solar Orbiter Workshop being*


*The poster of the conference was designed by Wim Vanderputten (Planetarium, Heizel). The poster includes the logos of the sponsors of the conference:*
*ESA, BELSPO, STCE and CSL.*




*Solar Orbiter and its suite of remote sensing and in-situ instruments. Note in particular the heat shield in the back, the deployable high gain antenna at the bottom and the in-situ boom on the left. Belgium is a leading partner in the international*

Solar physicists at STCE/ROB have a leading role in the EUI instrument on-board Solar Orbiter. The instrument concept was conceived at the Solar Physics group of ROB including the use of some of its key technologies (APS detectors, compression…). EUI is now being built by an international consortium under the leadership of Pierre Rochus from the Centre Spatial de Liège (CSL). A group of about 10 researchers at STCE/ROB is actively supporting this development. In the operational phase of the mission (>2017), the EUI instrument will be operated from the EUI Data Center at STCE/ROB.



*The EUI instrument will consist of 3 telescopes: 1 full sun imager (left) and two high resolution imagers (right). The latter two will image the solar corona in unprecedented resolution.*

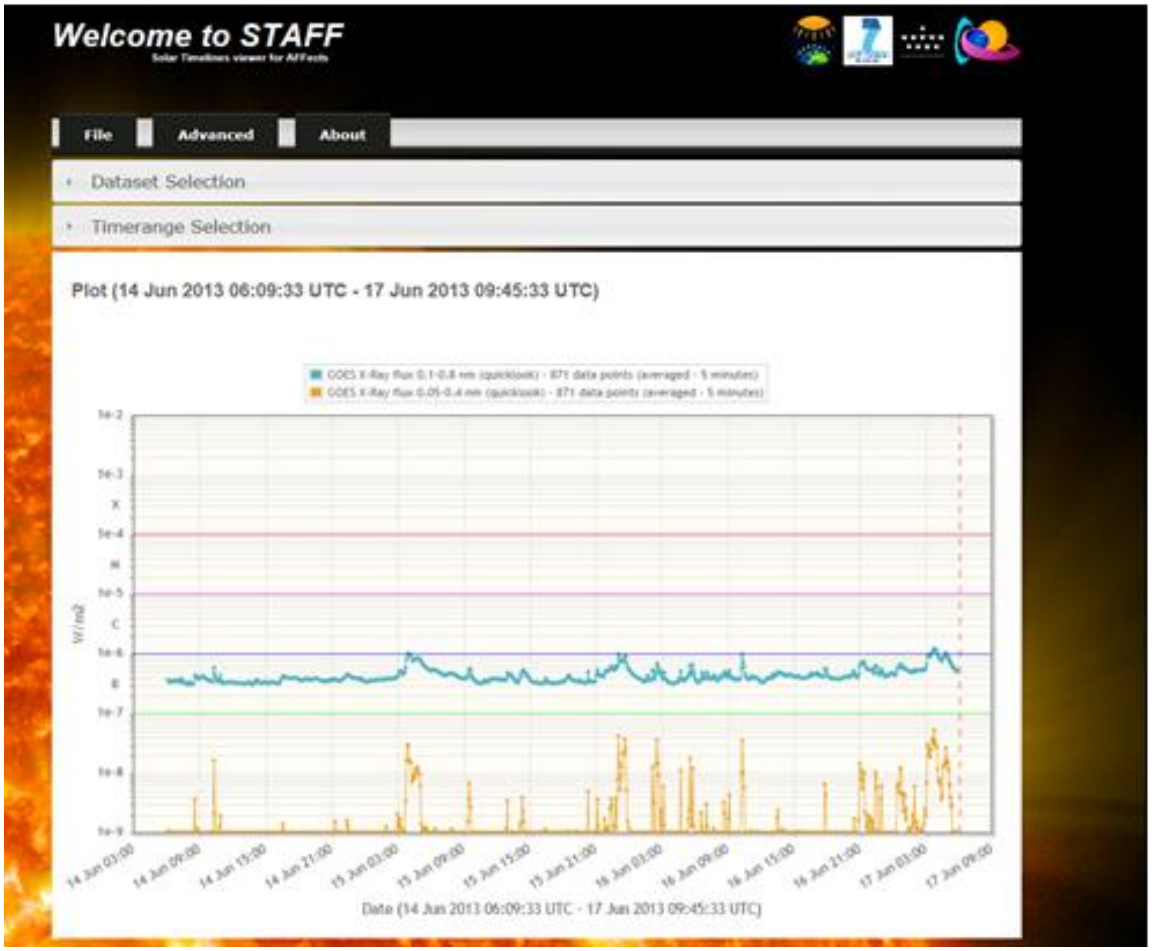
The Scientific Organizing Committee (SOC) of the Workshop, consisting of the principal investigators of all the instruments on-board Solar Orbiter, was co-chaired by Daniel Mueller (Project Scientist of Solar Orbiter, @ESA) and by Andrei Zhukov (Project Scientist of the EUI instrument onboard Solar Orbiter, @ROB). Local Organization was taken care of by the well-trained STCE team including Anne Vandersyppe, Olivier Boulvin, Sarah Willems, Petra Vanlommel, Jan Janssens and Bram Bourgoignie.

All details of the Solar Orbiter Workshop 5 can be found at [http://www.stce.be/solarorbiter5/](http://www.stce.be/solarorbiter5/)

*The Local Organizing Committee (LOC) at work: at the registration desk, the IT wizards, and keeping an eye on the pack during the conference dinner.*

# STAFF – Solar timeline viewer

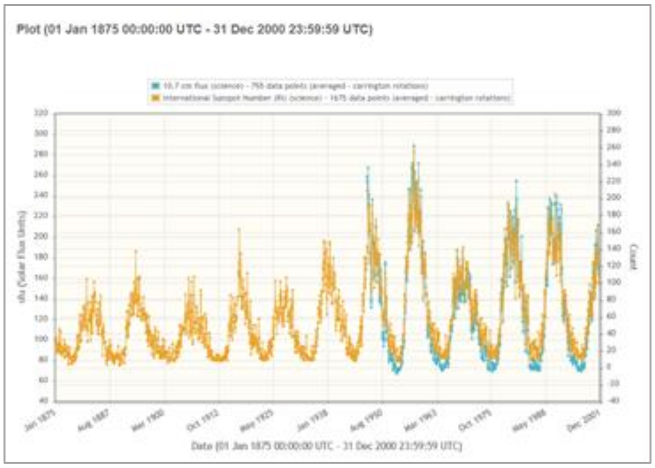
At ROB, a new tool called STAFF (Solar Timelines viewer for AFFECTS) was developed. It is a brand-new, easy-to-use web tool (http://www.staff.oma.be ) for viewing solar activity and space weather timeline data. It combines enormous datasets from different sources into one huge database and allows for comparing those on different time scales ranging from seconds to years.




*The STAFF web page, showing the x-ray flux from the GOES satellite for the last three days. Every peak in the curve corresponds to a solar eruption called "a solar flare".*

STAFF has the ability to:

- Combine any dataset over any timeframe;
- Show data in near-real time;
- Export data as txt, csv or xls file;
- Export data as image;
- View the same dataset over previous solar rotations;
- The StaffBox allows any user to insert the power of STAFF into their own website.




These features make STAFF an ideal tool for space weather forecasting and research as well as for generating timeline plots to be used in presentations or publications.

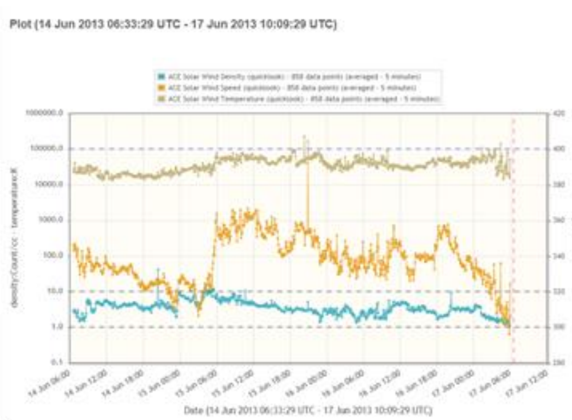
*The International Sunspot Number and 10.7 cm radio flux are shown. Both provide an estimate of solar activity on long timescales.*

STAFF was designed around the concept of combining timeline data, but with 4 constraints:

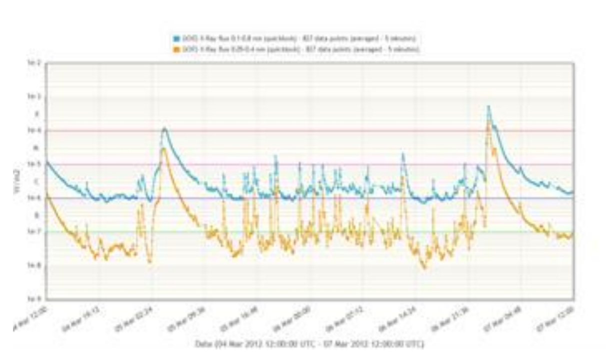
- Lots of data
- Speed
- Accessibility
- Usability

Taking on these 4 constraints proved quite a challenge, but after a thorough design phase, researchers found a workable solution.

*Today, STAFF has over 30 datasets (and still growing) which you can combine over a timespan ranging over 150 years in just a few mouse clicks, resulting in a plot in less than 1 second. In order to use STAFF, the user only needs to visit the STAFF web page and can start right away.*



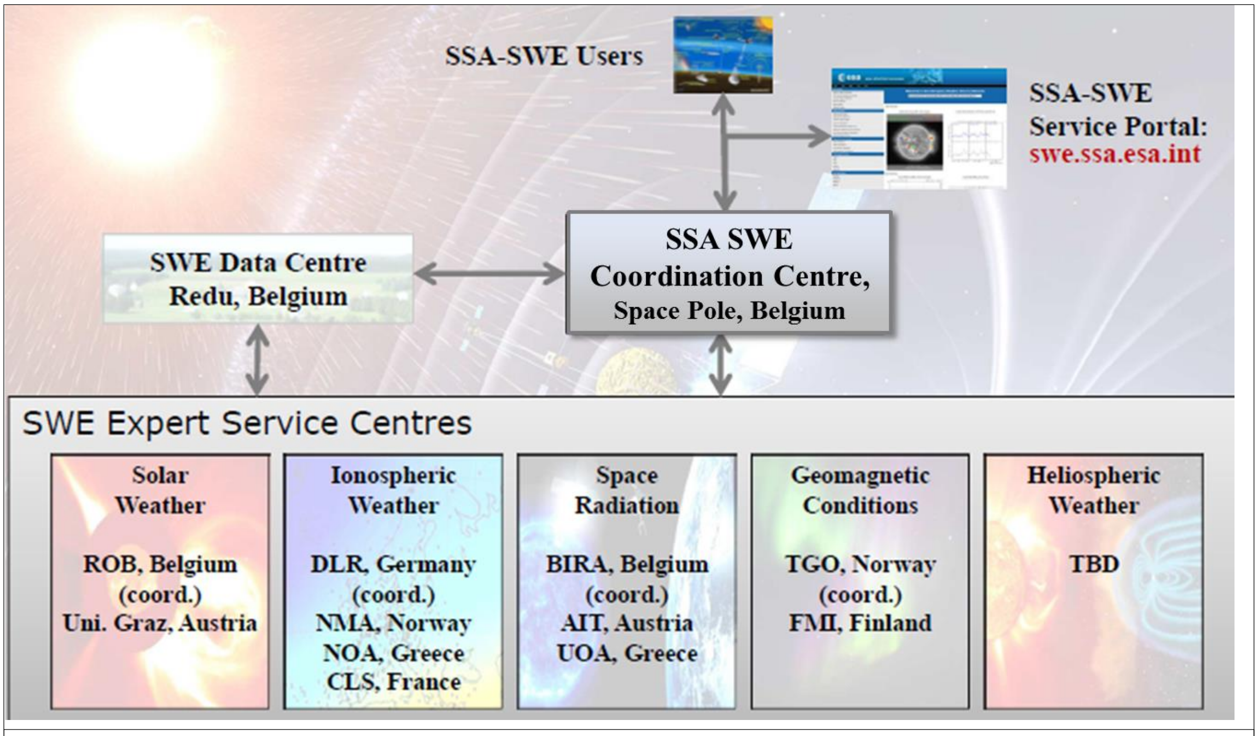

*Near real-time plot of solar wind data from the ACE satellite*



*GOES x-ray data featuring two X-class flares, which are giant eruptions on the Sun.*

# ESA's SSA Program: SN-I SWE Precursor Services project

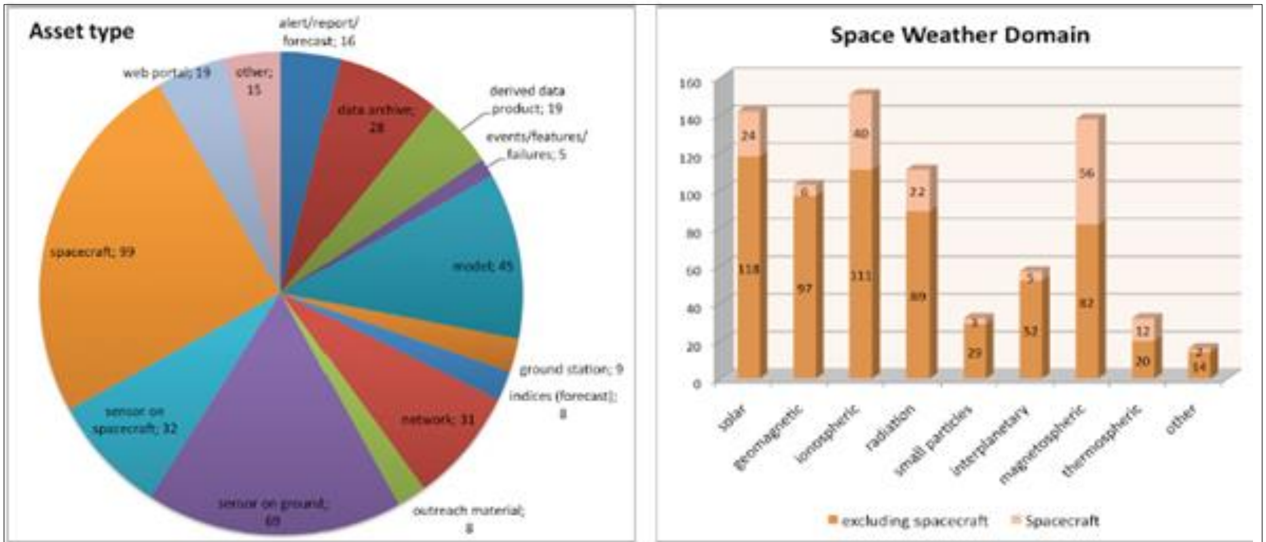
In order to protect Europe's space and ground-based infrastructure from space hazards and to inform the people about the condition of the space environment, ESA initiated the Space Situational Awareness (SSA) Program. It operates at two specific areas: the first one is the surveillance of objects orbiting the Earth in various orbits by detecting, tracking and imaging these objects; the second one concerns space weather that addresses primarily the effect of solar activity on manned space missions, satellites and ground infrastructure such as power grids and communication networks. As a first step in the development of a European SSA system, ESA launched the SSA Preparatory Program that focusses on the architecture of the future system, the specification of requirements and the provision of a set of precursor services covering the most urgent needs and based on existing assets.




*Space Weather Precursor Services Topology (© ESA)*

In this framework, BIRA and ROB participated in the study "Space Weather Segment Precursor Services - Part-1: Definition and Service Consolidation" as experts in resp. space radiation and solar weather. The figure above shows an overview of the architecture for SSA space weather element (SWE). The SWE service provision centers around the SWE Data Center at ESA's Redu station, and the SSA Space Weather Coordination Center (SSCC) located at the Space Pole in Belgium. The SSCC provides the first European Space Weather Helpdesk, with operators available to answer questions about the SWE service network or space weather conditions in general. BIRA initiated the SSCC. The provision of the user services is federated over a number of Expert Service Centers (ESCs) which are consortiums of expert groups with scientific and operating expertise in a particular service or a group of services. BIRA has been assigned as the coordinator of the ESC for Space Radiation and ROB for Solar Weather. The main goal of the SN-I project (Space weather and Near-Earth objects) was to define the SWE services and to consolidate them with potential users in the loop. As a first task led by ROB, a catalog was created with more than 500 SWE assets that have been identified in and outside Europe and includes high-quality scientific observations, results and models as well as a number of SWE products to local customers.

The figure below gives the asset distribution according to type and SWE domain. All assets were investigated for their suitability to provide SSA SWE services and gaps were identified.

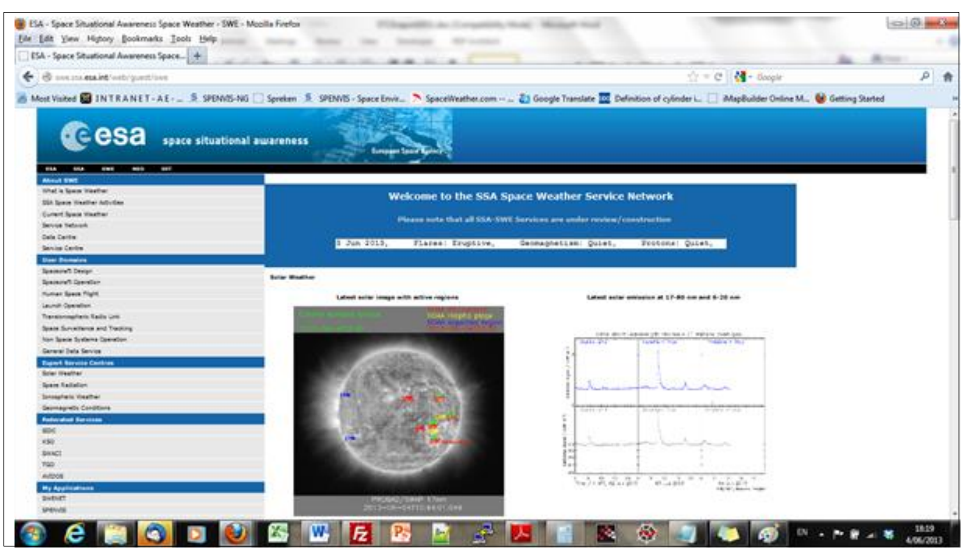



*The different types of SWE assets (left panel) and their distribution according to the SWE domain (right panel).*

Considering all these assets as possible building blocks, roadmaps have been written for the development and implementation of the following services: Spacecraft Design (SCD) - Spacecraft Operation (SCO) - Human Space Flight (HSF) - Launch Operations (LAU) - Transionospheric Link (TIO) - Space Surveillance and Tracking (SST) - Non Space Systems Operations (NSO) - General Data Service (GEN). ROB was in charge of GEN and BIRA was responsible for the SCD, HSF and NSO services.

In order to meet the customer requirements, these services and their goals were assessed with some test-users in the loop. To achieve this, a SN-I workshop was held at the ROB to collect all the feedback from potential end-users for the various services.

During the project, six ESA owned SWE applications or precursor services have been deployed at Redu. They are accessible via the SSA SWE portal (see figure below).




*Screenshot of SSA Space Weather Service Network at http://swe.ssa.esa.int/web/guest/swe*

# The Planetarium

## An influx still progressing

In 2012 the planetarium welcomed 48.923 visitors, an increase of 4.8% (+2243 visitors) compared to 2011 which was already an exceptional year for influx.


*Graphic of the number of visitors*

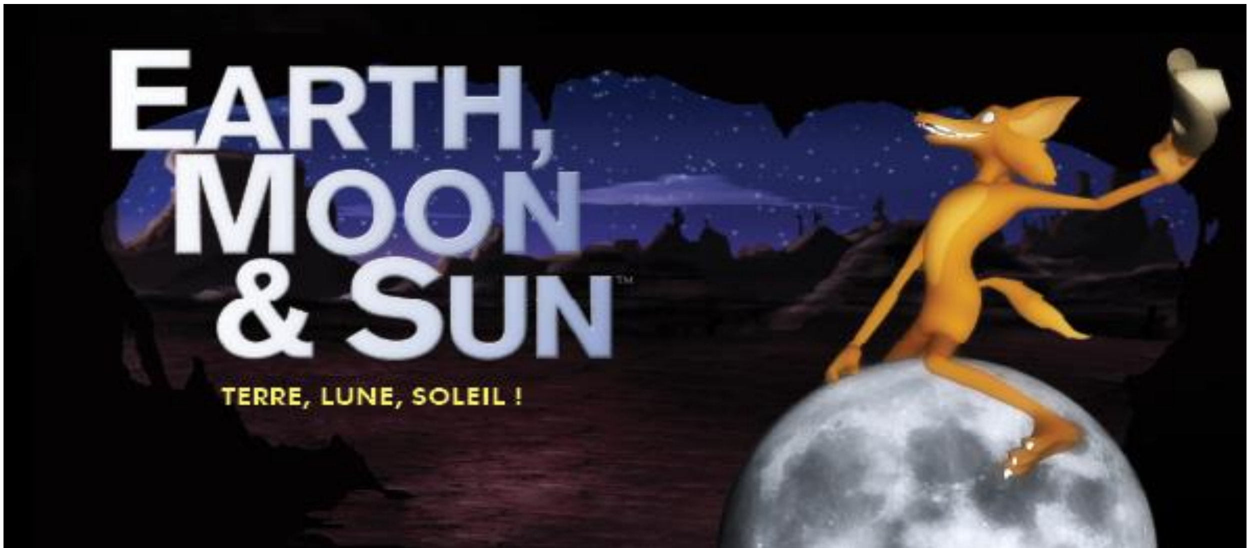
## Planetarium's new website

The Planetarium's website (www.planetarium.be) was entirely changed in November 2012. Simpler and more dynamic, it enables the users to discover the schedules and details of the sessions through an interactive process and shows' extracts can be watched. Monthly maps of the Belgian night sky are also available. The website was viewed 108.817 times (an increase of 32.2% compared to 2011) and 1.442.973 pages were visited in total.

## Workshop Planetarium / UNAWE

On the 25th April, for the first time, the Planetarium and its partner Universe Awareness (UNAWE) organized a special workshop for Dutch speaking preschool. The project called "Sterren in je klas" (« stars in your class ») enabled about thirty teachers to get used to astronomical concepts communicable to very young children from 3 to 6 years old.


*Left: Screenshot of the Planetarium's new website with show extracts.*
*Bottom: Workshop for preschool teachers*




*Poster of the show "Earth, Moon and Sun"*

### The new show: "Earth, Moon, Sun"

On the 27th Mars, the new show "Earth, Moon, Sun" was presented in preview and turned out to be a great success for the familial pubic. The film was especially aimed at a young audience (8-12 years) and was watched by 8033 visitors on a period of 9 months.

### Launching of the space-week:

The Planetarium finally hosted the official launching of the 2012 space week organized by the Vicomte Dirk Frimout, chair of the Euro Space Society. Industrials and scientists of the space industry gathered in the presence of the scientific policy minister Paul Magnette and the NASA's administrator Charles Bolden to participate to the celebration day of the 50th anniversary of Belgospace.


*Pictures of the official opening ceremony of the 2012 space-week*

## Researchers’ night

For the 2012 edition of the researcher night, the Planetarium offered special evening activities on the theme “Art and Science”: a full dome musical movie “Coral: rekindling Venus” about the wonders of the Great Barrier Reef as well as live show mixing dance, music, calligraphy, video, acrobatics. It was specially created by the Osa Mayor group for the occasion. A round table “women and sciences” including college representatives and the past NASA astronaut Kathy Sullivan was also proposed. More than 500 visitors were welcomed during this event.


*Posters of the researcher’s night*

## Darkness’ Night

The fourth edition of the Darkness’ Night took place on the 20th October at the Rouge-Cloître. Despite of the bad weather, several hundreds of visitors attended to a conference, an outdoor concert, or a guided walk. Some preferred to launch water rocket and the luckiest were able to observe the night sky through one of the many telescopes available.

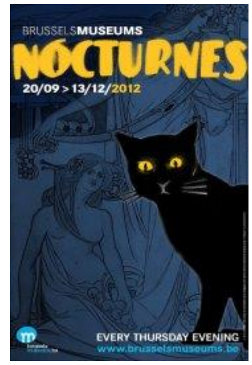

*Photos of the darkness’ night at the Cloître-Rouge*

## Visit of ESTEC

As part of the ESERO project, two buses were rented to bring about 80 heads of school and inspectors of the project “Espace & Enseignement” (Space & Education) to visit the ESTEC’s premises in the Netherlands. This well appreciated day was the final achievement of all ESERO’s work towards the education community.

Other projects of this kind were organized: the Inauguration of the exposition “Sciences at school” on the 9th Mars at the Planetarium, the formation days organized for the Dutch speaking teachers on May the 30th and November the 14th and the animation of the educative stand ESERO/Planetarium at the Iris fair on May the 6th.

### Night of the museums




The planetarium took part in the nights of the museums; during these two evenings: the 25th October and on the 29 November, 316 visitors and 368 visitors were welcomed respectively. The eight night shows were a real success and the room was full on several sessions.

### Science's Day

On the 25th November the Planetarium took part in the Science's Day ("Dag van de wetenschap") and offered several scientific activities commonly organized with the JCW association to 663 visitors.

*Photos of the Science's day*

### Photo Exposition

For the 50th anniversary of the European Southern Observatory (ESO), Photo exposition was installed in the Planetarium's hall: 50 of the most beautiful pictures taken by the ESO telescopes could be admired there.


*ESO's photos exposition*

### Means implemented

On the December 31st 2012, the Planetarium's personnel was composed of 17 members who take care of: animation and teaching, projection, reception, public relationships, maintenance, technical service, ICT and graphics service.

The Planetarium is a member of different touristic associations: Toeristische Attracties, Attractions & Tourisme, Brusselse Museumraad, Office de Promotion du Tourisme Wallonie-Bruxelles.

The planetarium is also member of several association of planetariums: « International Planetarium Society (IPS) », « Vereniging van Nederlandstalige Planetaria (PLANed) », « Association des Planétariums de langue Française (APLF) », « Arbeitsgemeinschaft deutschsprachiger Planetarien (ADP) » and is represented at all the annual meetings.

# Annex 1: Publications 2012

1. Arridge C. S. et al.. including Karatekin Ö.
*Uranus Pathfinder: exploring the origins and evolution of Ice Giant planets*
Experimental Astronomy 33, 753-791.

2. Baland R.-M., Yseboodt M., and Van Hoolst T.
*The obliquity of the Galilean satellites*
Icarus, 220, 435-448

3. A. Bemporad, F. P. Zuccarello , C. Jacobs, M. Mierla, S. Poedts
*Study of multiple coronal mass ejections at solar minimum conditions*
Solar Physics, 281, pp.223—236

4. Bernard-Salas J., Cami J., Peeters E., Jones A.P., Micelotta E.R., Groenewegen M.A.T
*On the Excitation and Formation of Circumstellar Fullerenes*
2012, ApJ 757, 41, 11pages

5. Beuthe M., Le Maistre S., Rosenblatt P., Pätzold M., and Dehant V.
*Density and lithospheric thickness of the Tharsis Province from MEX MaRS and MRO gravity data.*
J. Geophys. Res., 117, E04002, 32 pages, DOI: 10.1029/2011JE003976.

6. Bloemen, S., Marsh, T. R., Degroote, P., Ostensen, R. H., Papics, P. I., Aerts, C., Koester, D., Gänsicke, B. T., Breedt, E., Lombaert, R., Pyrzas, S., Copperwheat, C. M., Exter, K., Raskin, G., Van Winckel, H., Prins, S., Pessemier, W., Frémat, Y., Hensberge, H., Jorissen, A., Van Eck, S.
*Mass ratio from Doppler beaming and Romer delay versus ellipsoidal modulation in the Kepler data of KOI-74 2012 MNRAS,*
422, 2600-2608

7. K. Bonte, D. Berghmans, A. De Groof, K. Steed, S. Poedts
*SoFAST: Automated Flare Detection with the PROBA2/SWAP EUV Imager*
Sol. Phys., Online First, pp.

8. Borges Fernandes, M., Kraus, M., Nickeler, D. H., De Cat, P., Lampens, P., Pereira, C. B., Oksala, M. E.
*The Galactic unclassified B[e] star HD 50138. III. The short-term line profile variability of its photospheric lines*
2012, A&A 548, A13

9. Briquet M., Neiner C., Aerts C., Morel T., Mathis S., Reese D.R., Lehmann H., Costero R., Echevarria J., Handler G., Kambe E., Hirata R., Masuda S., Wright D., Yang S., Pintado O., Mkrtichian D., Lee B.-C., Han I., Bruch A., De Cat P., Uytterhoeven K., Lefever K., Vanautgaerden J., de Batz B., Frémat Y., Henrichs H., Geers V.C., Martayan C., Hubert A.M., Thizy O., Tijani A.
*Multisite spectroscopic seismic study of the beta Cep star V2052 Ophiuchi: inhibition of mixing by its magnetic field*
Monthly Notices of the Royal Astronomical Society 427, 483 (2012)

10. Bruneton J.-P., Rinaldi M., Kanfon A., Hees A., Schlögel S., and Füzfa A.
*Fab Four: When John and George Play Gravitation and Cosmology.*
Advances in Astronomy, 2012, id. 430694, DOI: 10.1155/2012/430694.

11. Brunsden E., Pollard K.R., Cottrell P.L., Wright D.J., De Cat P., Kilmartin P.M.
*Spectroscopic Pulsational Frequency Identification and Mode Determination of thegamma Doradus Star HD135825*
Monthly Notices of the Royal Astronomical Society 422, 3535 (2012)

12. Brunsden E., Pollard K.R., Cottrell P.L., Wright D.J., De Cat P.
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13. Bruyninx C., Altamimi Z., Becker M., Craymer M., Combrinck L., Combrink A., Dawson J., Dietrich R., Fernandes R., Govind R., Herring T., Kenyeres A., King R., Kreemer C., Lavallée D., Legrand J., Sánchez L., Santamaria-Gomez A., Sella G., Shen Z.
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Geodesy for Planet Earth, IAG Symposia Series, Vol 136, pp. 27-35, DOI 10.1007/978-3-642-20338-1_4

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Tectonophysics 581, 48-61 (2012).

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*Space- and ground-based measurements of sulphur dioxide emissions from Turrialba Volcano (Costa Rica)*
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*New observation strategies for the solar UV spectral irradiance*
J. Space Weather Space Clim., 2, pp.A16

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Journal of Space Weather and Space Climate, 2, pp.A06

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*Carbon dioxide dynamics in Kelud volcanic lake. Journal of Geophysical Research*
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Astronomy & Astrophysics, 543, A40, DOI: 10.1051/0004-6361/201218891.

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*9 positions of minor planets observed before 2012*
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*Time-resolved spectroscopy of BD+46°442: Gas streams and jet creation in a newly discovered evolved binary with a disk*
2012 A&A, 542, A27-

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2012, A&A 540, A32, 21pages
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# Annex 2:
# Human Resources
# 2012

## Personeel / Personnel

*Algemeen directeur:* Van der Linden Ronald

### *Vastbenoemd personeel / Personnel statutaire*

### Wetenschappelijk personeel / Personnel scientifique :

| Name/Nom | Functie/Fonction | Name/Nom | Functie/Fonction |
|---|---|---|---|
| Alexandre Pierre | Premier assistant 80 % | Groenewegen Martin | Eerstaanwezend assistent |
| Alvarez Rodrigo | Premier assistant | Hochedez Jean-François | Premier assistant |
| Berghmans David | Werkleider | Lampens Patricia | Onderzoeksleider |
| Blomme Ronny | Eerstaanwezend assistent | Lecocq Thomas | Assistant-stagiaire |
| Bruyninx Carine | Eerstaanwezend assistent | Legrand Juliette | Assistant |
| Camelbeeck Thierry | Chef de travaux | Pauwels Thierry | Werkleider |
| Clette Frédéric | Premier assistant | Robbrecht Eva | Assistant |
| Collin Fabienne | Premier assistant 50 % | Roosbeek Fabian | Premier Assistant |
| Cuypers Jan | Eerstaanwezend assistent | Van Camp Michel | Chef de travaux |
| De Cat Peter | Eerstaanwezend assistent | Van De Steene Griet | Eerstaanwezend assistent |
| Defraigne Pascale | Premier assistant 80 % | Van Hoolst Tim | Werkleider |
| Dehant Véronique | Chef de travaux | Vanneste Kris | Eerstaanwezend assistent |
| Frémat Yves | Assistant | Yseboodt Marie | Assistant |

### Technisch en administratief personeel / Personnel technique et administratif

| Name/Nom | Functie/Fonction | Name/Nom | Functie/Fonction |
|---|---|---|---|
| Milis Andre | Attaché A2 | Van Camp Lydia | Technisch deskundige 80% |
| Asselberghs Somnina | Technisch deskundige | Van Damme Daniel | Technisch deskundige (tot 30/04/2012) |
| Boulvin Olivier | Expert technique | Van De Putte William | Technisch deskundige |
| Bukasa Baudouin | Expert technique | Van Der Gucht Ignace | Technisch deskundige |
| Castelein Stefaan | Technisch deskundige | Vandekerckhove Joan | Technisch deskundige |
| Coene Yves | Expert technique | Vandercoilden Leslie | Expert technique |
| Driegelinck Eddy | Expert technique | Vanraes Stéphane | ICT deskundige |
| Dumortier Louis | Expert ICT | Vermeiren Katinka | ICT deskundige 80% |
| Duval David | Expert ICT | Van de Meersche Olivier | Expert Financier |
| Ergen Aydin | Expert technique | Wintmolders Sabrina | Administratief deskundige |
| Frederick Bert | Expert technique | Barthélémy Julie | Chef technicien de la recherche (tot 30/04/2012) 50% |
| Hendrickx Marc | Expert technique 80% | Bizerimana Philippe | Assistant technique |
| Herreman David | Expert ICT | Brebant Christian | Assistant administratif |
| Langenaken Hilde | Technisch deskundige | Bruyninckx Martine | Administratief assistent |
| Martin Henri | Expert technique | Danloy Jean-Marie | Assistant administratif |
| Mesmaker Dominique | Expert technique 80% | Depasse Béatrice | Assistant administratif |
| Moyaert Ann | ICT deskundige 80% | De Wachter Rudi | Technisch assistent |
| Renders Francis | Technisch deskundige | Feldberg Liesbeth | Administratief assistent |
| Somerhausen André | Expert ICT | Consiglio Sylvia | Administratief assistent |
| Strubbe Marc | Technisch deskundige | Jans Thimoty | Attaché A1 |
| Jacques Jean-Claude | Assistant technique | Kochuyt Anne-Lize | Attaché A1 |
| Janssens Paul | Assistant technique | Rezabek Oleg | Attaché A1 |
| Lemaitre Olivier | Assistant technique | Rogge Vincent | Attaché A1 |
| Trocmet Cécile | Assistant administratif | | Attaché A2 (vanaf 01/09/2012) |
| Van Den Brande Theophilis | Technisch assistent | De Knijf Marc | Attaché A2 |
| Vanden Elshout Ronny | Assistant technique | Dufond Jean-Luc | Attaché A2 |
| Verbeeren Anja | Administratief assistent | | |

## Personeel met externe beurzen / Personnel sur bourses externes

| Name/Nom | Functie/Fonction | Name/Nom | Functie/Fonction |
|---|---|---|---|
| Hees Aurélien | Boursier FRIA | Koot Laurence | Boursier FNRS |
| Kusters Dimitri | Boursier FRIA | | |

## *Contractueel personeel beheerd door de POD Wetenschapsbeleid*
## *Personnel contractuel géré par le SPP Politique Scientifique*

| Name/Nom | Functie/Fonction | Name/Nom | Functie/Fonction |
|---|---|---|---|
| De Vos Frédéric | Expert ICT | Rapagnani Giovanni | Attaché A1 |
| De Dobbeleer Rudy | Technisch assistant | Semeraro Vanessa | Administratief assistant |
| Motte Philippe | Collaborateur technique | Vandersyppe Anne | Administratief expert |
| Mouling Ilse | Administratief assistent 80% | Verbeeck Koen | Assistent SW1 50% |

## *Contractueel personeel / Personnel contractuel*

| *Naam/Nom* | *Functie/Fonction* | *Contract* |
|---|---|---|
| Aerts Wim | Assistent | STCE |
| Baire Quentin | Assistant | CHERCHEUR SUPPL. |
| Benmoussa Ali | Premier assistant | PRODEX |
| Bergeot Nicolas | Assistant | STCE |
| | Premier assistant (vanaf 01/08/2012) | PRODEX |
| Bettarini Lapo | Assistent (jusqu'au 31/03/2012) | PYSSOL |
| Beuthe Mikael | Assistant | PRODEX |
| | Premier assistant (vanaf 01/08/2012) | PRODEX |
| Bourgoignie Bram | Assistent-stagiaire | STCE |
| | Assistent (vanaf 01/08/2012) | STCE |
| Boyes John David | Assistent (vanaf 16/04/2012) | PRODEX |
| Callebaut Benoît | Assistant (jusqu'au 13/03/2012) | SOTERIA |
| Caudron Corentin | Assistant | ACTIE 2 |
| Chevalier Jean-Marie | Assistant | STCE |
| Dammasch Ingolf | Assistant | PRODEX |
| Champagne Georges | Assistant | SERVICE CONTRACT/ CHERCH. SUPPL. |
| De Cuyper Jean-Pierre | Eerstaanwezend assistent | DIGITALISATION |
| Delouille Véronique | Premier assistant | PRODEX |
| De Visscher Ruben | Assistent-stagiair (vanaf 01/08/2012) | PRODEX |
| Devos Andy | Assistent (vanaf 01/04/2012) | PRODEX |
| D'Huys Elke | Assistent | STCE |
| Dolla Laurent | Assistant | STCE |

| *Naam/Nom* | *Functie/Fonction* | *Contract* |
|---|---|---|
| Dominique Marie | Assistant | PRODEX |
| Garcia Moreno David | Assistant (tot 30/06/2013) | UE_SHARE |
| Gloesener Elodie | Assitant-stagiaire (depuis 01/10/2012) | 2PAI_PLANETTOP |
| Giordanengo Boris | Premier assistant | PRODEX |
| Gissot Samuel | Assistant | PRODEX |
| Janssens Jan | Assistent (vanaf 01/06/2012) | STCE |
| Joukov Andrei | Premier assistant | STCE |
| Karatekin Ozgur | Assistant | PRODEX |
| | Premier assistant (vanaf 01/08/2012) | PRODEX |
| Knuts Elisabeth | Assistant | HAZARDS. |
| Kraaikamp Emil | Assistent stagiair (vanaf 01/06/2012) | PRODEX |
| Kretzschmar Matthieu | Premier assistant (jusqu'au 30/06/2012) | VERVANGING |
| Kudryashova Maria | Assistant | 3UE_ESPACE |
| LeMaistre Sébastien | Assistant | PRODEX |
| Lefevre Laure | Assistant (jusqu'au 31/10/2012) | SOTERIA |
| Lobel Alex | Eerstaanwezend assistent | 3 GAIA |
| Lombardini Denis | Assistant | ANTARTIQUE |
| Magdalenic Jasmina | Assistant | ACTION 1 |
| Marqué Christophe | Assistant | STCE |
| Meeuws Fun | Assistent (tot 15/11/2012) | STCE |
| Mierla Marilena | Assistent (vanaf 01/08/2012) | ACTION 1 |
| Mitrovic Michel | Assistant | PRODEX |
| Nicula Bogdan | Assistant | STCE |
| Noack Léna | Assistant (vanaf 01/10/2012) | 2PAI_PLANETTOP |
| Parenti Suzanna | Premier assistant | PRODEX |
| Pham Lê Binh San | Assistant (à partir du 01/10/2012) | 2PAI_PLANETTOP |
| Podladchikova Olena | Premier assistant | STCE |
| Pottiaux Eric | Assistant | STCE |
| Pylyser Eric | Assistant | PRODEX |
| Rivoldini Attilio | Assistant | PRODEX |
| Robyns Sophie | Assistent-stagiaire (tot 15/02/2012) | MODERNISATION |
| Rodriguez Luciano | Assistant | PRODEX |
| Rosenblatt Pascal | Premier assistant | PRODEX |
| Seaton Daniel | Assistant | PRODEX |
| | Premier assistant (vanaf 01/08/2012) | PRODEX |
| Sodor Adam | Assistent (vanaf 01/07/2012) | ACTION 1 |
| Stegen Koen | Assistent (vanaf 01/10/2011) | PRODEX |
| Van de Camp Wendy | Assistent (tot 31/07/2012) | MODERNISATION |
| Van Hoof Peter | Assistent (tot 31/05/2012) | PRODEX |
| | Eerstaanwezend assistent (vanaf 1/06/2012) | PRODEX |
| Van Hove Bart | Assistent (vanaf 01/10/2011) | CHERSUPP |
| Vanlommel Petra (80%) | Eerstaanwezend assistent | STCE |
| Van Noten Koen | Assistent (vanaf 01/03/2012) | ACTIE 1 |

| *Naam/Nom* | *Functie/Fonction* | *Contract* |
|---|---|---|
| Verbeeck Francis | Assistent/ Eerstaanwezend assistent (vanaf 01/08/2012) | PRODEX<br>PRODEX |
| Verbeeck Koen (50%) | Assistant | HAZARDS |
| Verbruggen Wim | Assistent-stagiaire (tot 30/09/2012) | CHERSUPP |
| Verdini Andrea | Assistant | PRODEX |
| Verstringe Freek | Assistent (vanaf 01/04/2012) | STCE |
| Vleminckx Bart | Assistent (tot 30/09/2012) | CHERSUPP |
| Volpi Delia | Assistant (tot 31/03/2012) | ACTIE 1 |
| Wauters Laurence (60%) | Premier assistant | STCE |
| West Matthew | Assistant (tot 15/07/2013) | PRODEX |
| Zhu Ping | Assistant | ACTION 2 |

## Technisch en administratief personeel / personnel technique et administratif

| *Naam/Nom* | *Functie/Fonction* | *Contract* |
|---|---|---|
| Sojic Marko | Attaché A1 | Dotation |
| Van Elder Sophie (50%) | Attaché A1 | STCE |
| Wellens Véronique | Attaché A1 | Dotation |
| Geerts Ellen | Attaché A1 (tot 31/12/2012) | ESERO |
| Cornet Denis | Attaché A1 (jusqu'au 31/12/2012) | ESERO |
| De Decker Georges | Attaché A2 | Digitalisation |
| Hanjoul Michel | Attaché A2 | 1modernisation |
| Willems Sarah | Attaché A2 | STCE |
| Mampaey Benjamin | Attaché A2 | PRODEX |
| Van Hemelryck Eric | Attaché A2 | PRODEX |
| Malisse Vincent | ICT-deskundige (vanaf 15/05/2012) | PRODEX |
| Vander Putten Wim | ICT-deskundige | Dotatie |
| Bastin Véronique | Expert technique | Dotation |
| Coeckelberghs Hans | Technisch deskundige (tot 31/12/2012) | 1Planetarium |
| Noel Jean-Philippe | Expert technique (jusqu'au 30/04/2012) | STCE |
| Vandercoilden Myriam | Assistant administratif | Dotation Pole |
| Hernando Ana Maria | Assistant administratif | STCE |
| Smet Gert | Technisch assistent | Dotatie |
| Wijns Erik | Technisch medewerker | Dotatie |
| Vandeperre Arnold | Technisch assistent | Dotatie |
| Mertens Philippe | Administratief medewerker | 1Planetarium |
| El Amrani Malika | Collaborateur technique | Dotation |
| Herman Viviane | Collaborateur technique (20%) | Dotation |
| Ipuz Mendez Adriana | Collaborateur technique (50%) | Dotation |
| Reghif Harraz Mohammed | Collaboratuer technique (50%) | Dotation |
| Trindade Josefina | Collaborateur technique | Dotation |
| Vermeylen Jacqueline | Collaborateur technique | Dotation |
| Kurudere Hulya | Technisch medewerker | 1Planetarium |

## Gedetacheerd personeel / Personnel détaché

| *Naam/Nom* | *Functie/Fonction* | *Contract* |
|---|---|---|
| Vanhassel Luc | Adjunct technicus | BIPT (tot 31/01/2012) |
| De Rijcke Hendrick | Leraar | Onderwijs Vlaamse Gemeenschap |