Belgian Institute for Space Aeronomy (BIRA-IASB)

Institut d'Aéronomie Spatiale de Belgique (IASB)

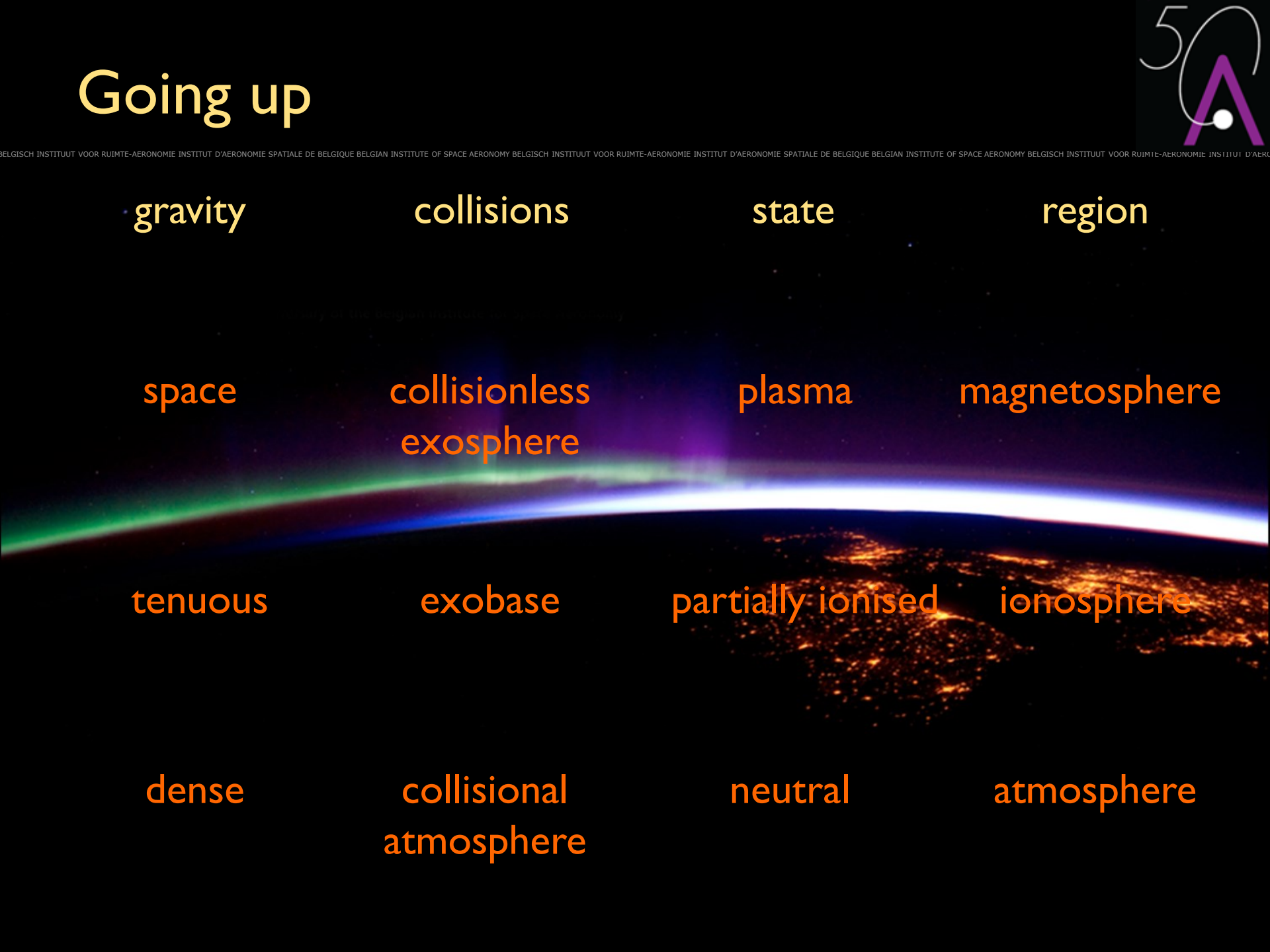
Belgisch Instituut voor Ruimte-Aeronomie (BIRA)

BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERONOMIE SPATIALE DE BELGIQUE BELGIAN INSTITUTE OF SPACE AERONOMY BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERONOMIE SPATIALE DE BELGIQUE BELGIAN INSTITUTE OF SPACE AERONOMY BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT D'AERO

Going up:
Out of the atmosphere and into space

Johan De Keyser
Head of the Space Physis Division

Going up



gravity

collisions

state

region

space

collisionless exosphere

plasma

magnetosphere

tenuous

exobase

partially ionised

ionosphere

dense

collisional atmosphere

neutral

atmosphere

Space Physics

Space physics is the fundamental science that studies the upper atmospheres of planetary objects (planets, moons, comets, …) and their interactions with interplanetary space

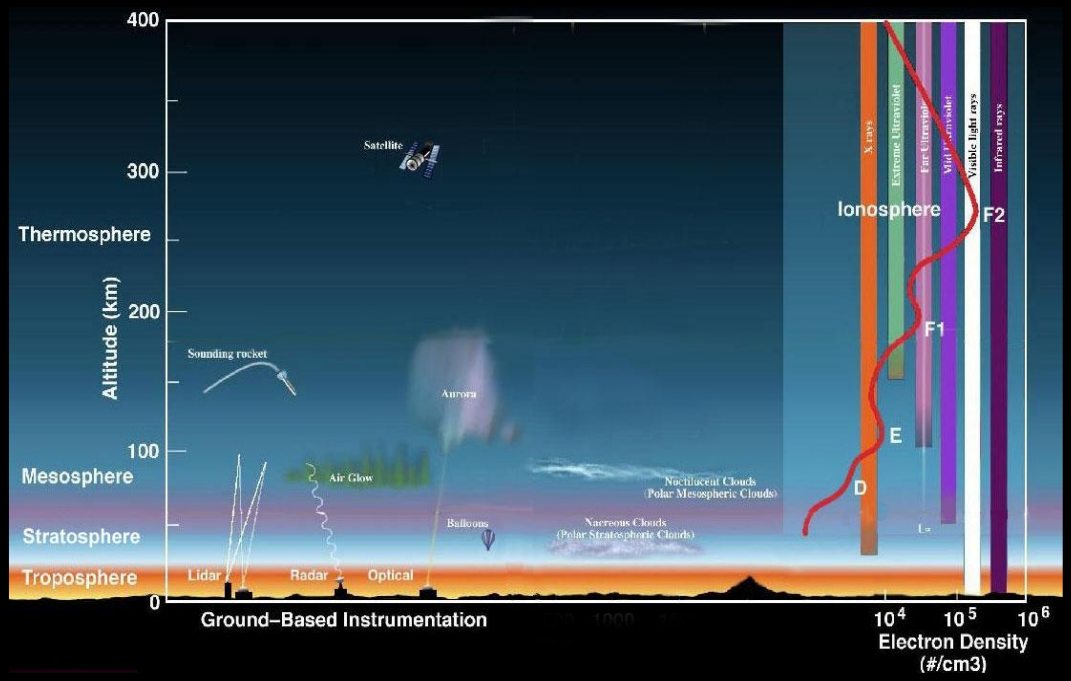
- ionosphere
- magnetosphere
- interplanetary space

The applied science that tries to assess or predict the impact of the conditions in space on natural or man-made systems, technologies, or living species is called *space weather*.

The ionosphere

The ionisation in the ionosphere comes from

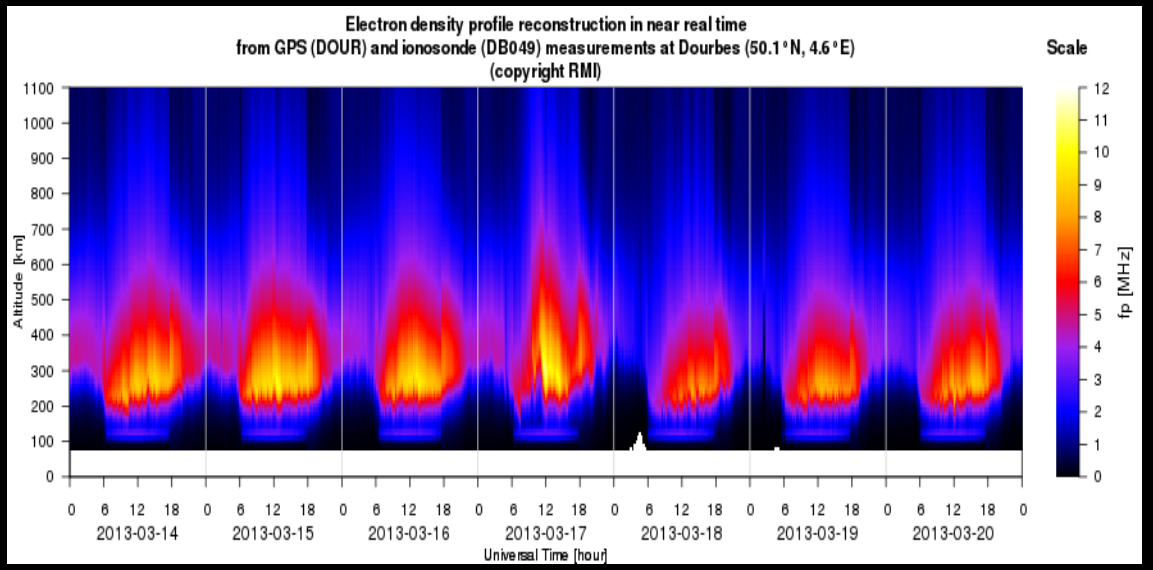
- Solar UV
- Particle precipitation
- Cosmic rays
- Meteors



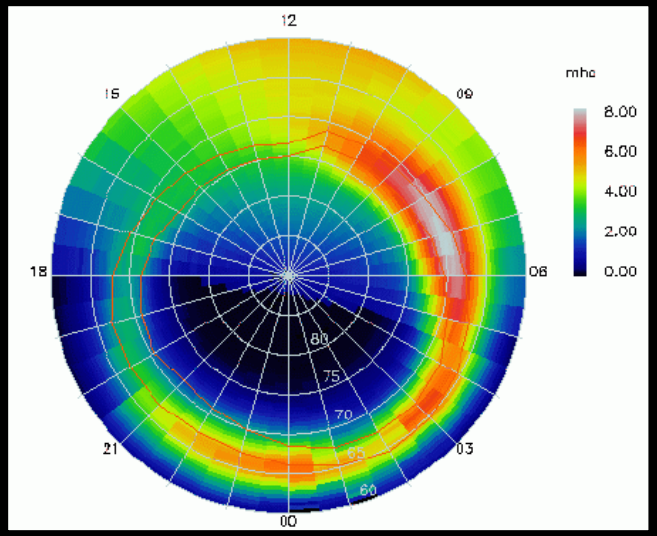
Result

- D, E, F layers
- Chemical reactions
- Ion-neutral drift
- Ion and electron outflow
- Airglow and auroral emission

There are strong diurnal and local variations in the ionisation content of the ionosphere. Only the F layer survives recombination during the night.



An important consequence of ionisation is the accompanying change in electric conductivity.



Marcel Nicolet started much of the work on ionospheric ionisation and its impact on atmospheric chemistry from the late 1930ies on. This work prompted the operation of an ionosonde in Dourbes.

Some ionospheric research has been done at BIRA-IASB by Kockarts and Wisemberg in the 1960ies.

Most of the Institute's work, however, focuses on the magnetosphere-ionosphere coupling.

Magnetosphere-ionosphere coupling

Ions and electrons move easily along geomagnetic field lines. Therefore, any electric potential structure in the magnetosphere can behave as a battery that powers an electric circuit closing through an ionospheric resistance. This creates a potential difference between the ionosphere and the magnetosphere:

- > 0 accelerating electrons ↓ and ions ↑ : diffuse aurora, arcs
- < 0 accelerates ions ↓ and electrons ↑ : black aurora, SAID

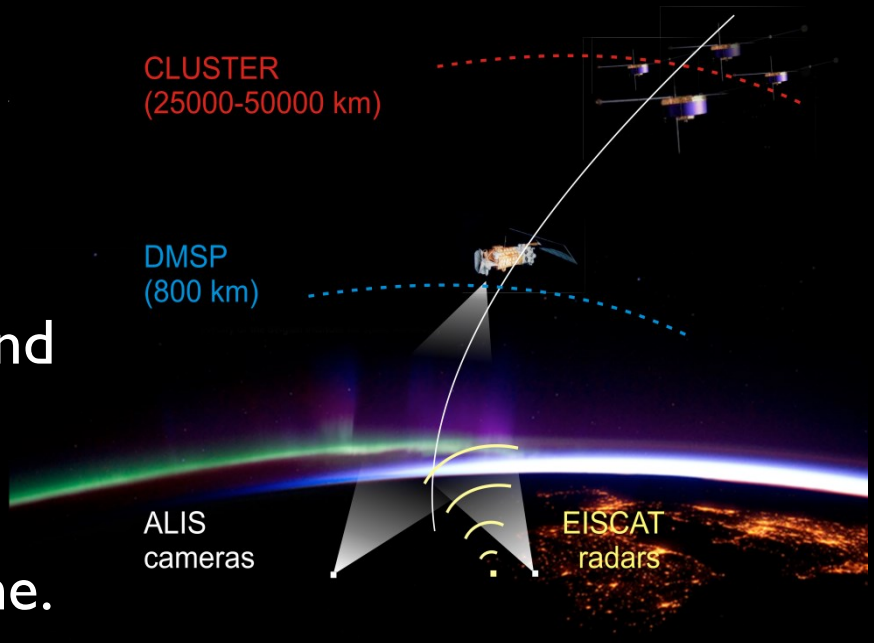
Y. Takasaka – Blue Moon

BIRA-IASB has contributed a lot of work on quasi-electrostatic magnetosphere-ionosphere coupling and aurora

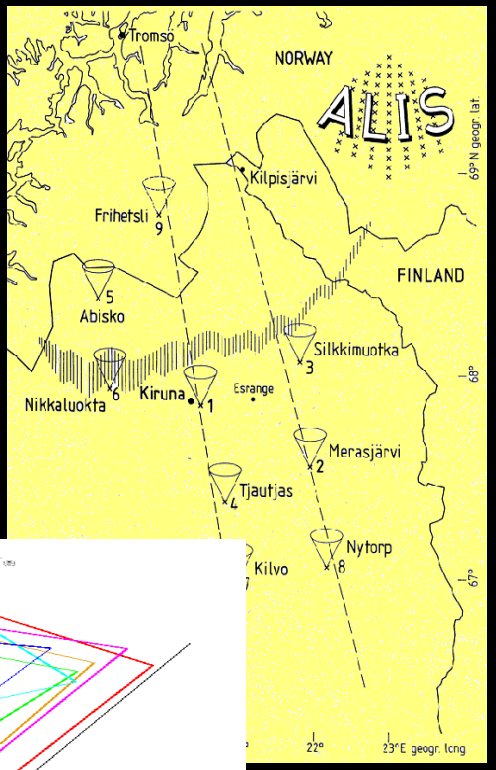
- current-voltage relation
- the coupled system
- Vlasov simulations of the particles on an auroral field line
- models of the generator
- interpretation of discrete auroral arc observations with Cluster, polar cap arcs, …
- subauroral ion drift
- auroral tomography with EISCAT, ALIS, …

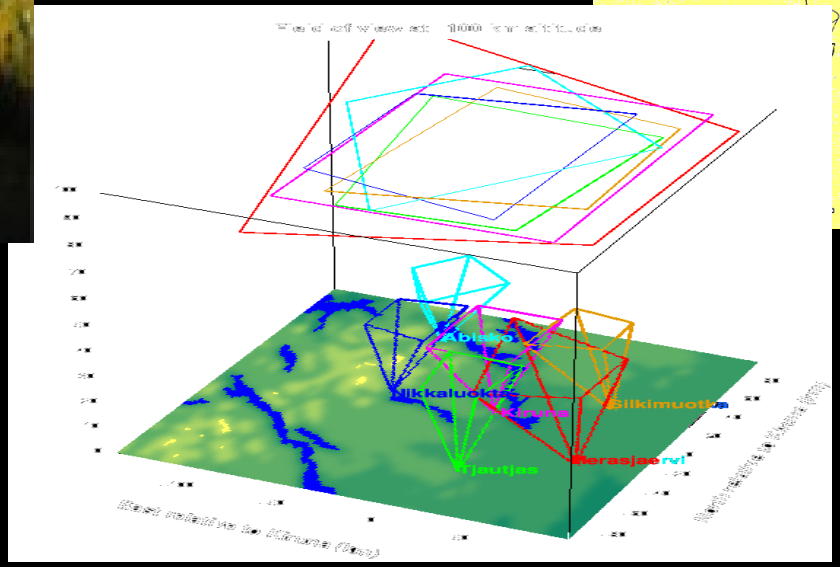
In these studies we try to link the observations by Cluster at high altitude, above the auroral acceleration region, to observations in low Earth orbit, below the acceleration region, and to ground based assets.

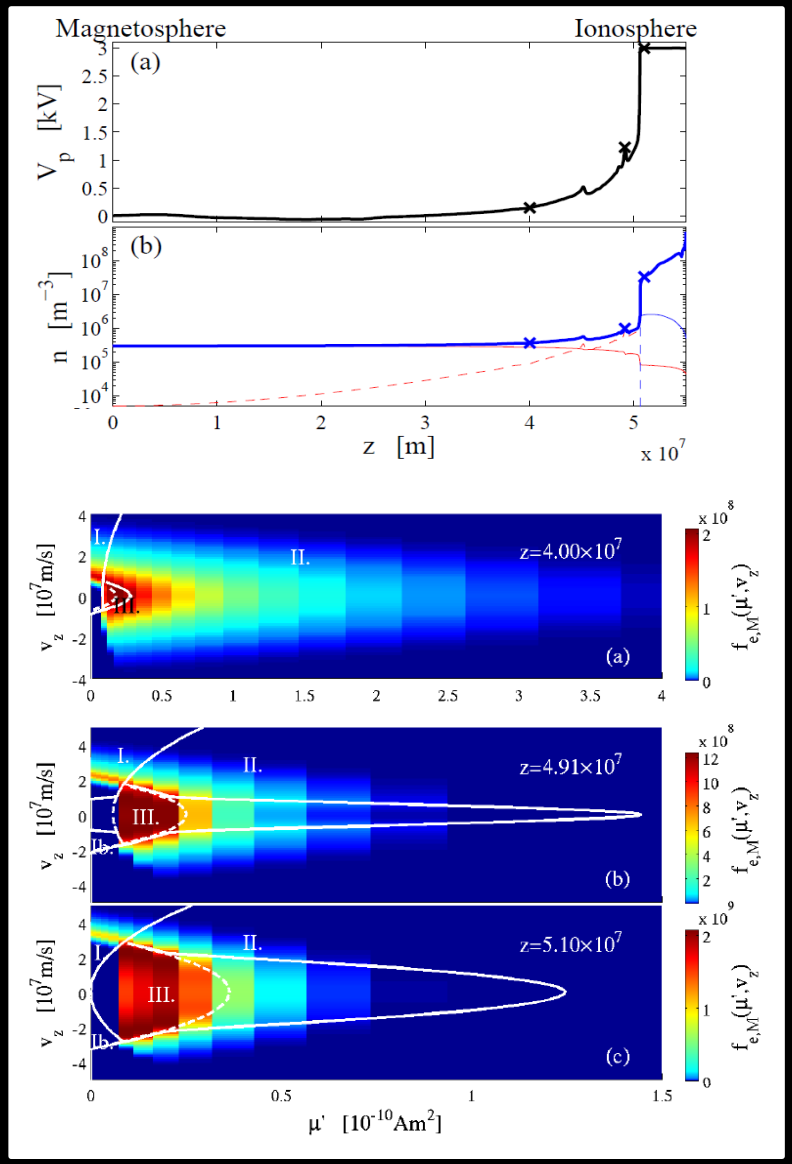
In the past years, we have been granted EISCAT observation time.



Simultaneous images of the same volume of sky have been used for ionospheric tomography, e.g. ALIS network in Scandinavia.







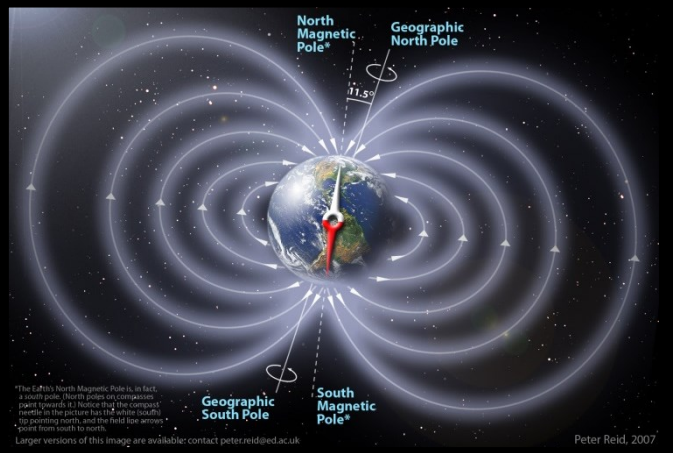
We performed Vlasov simulations of what happens along a field line :

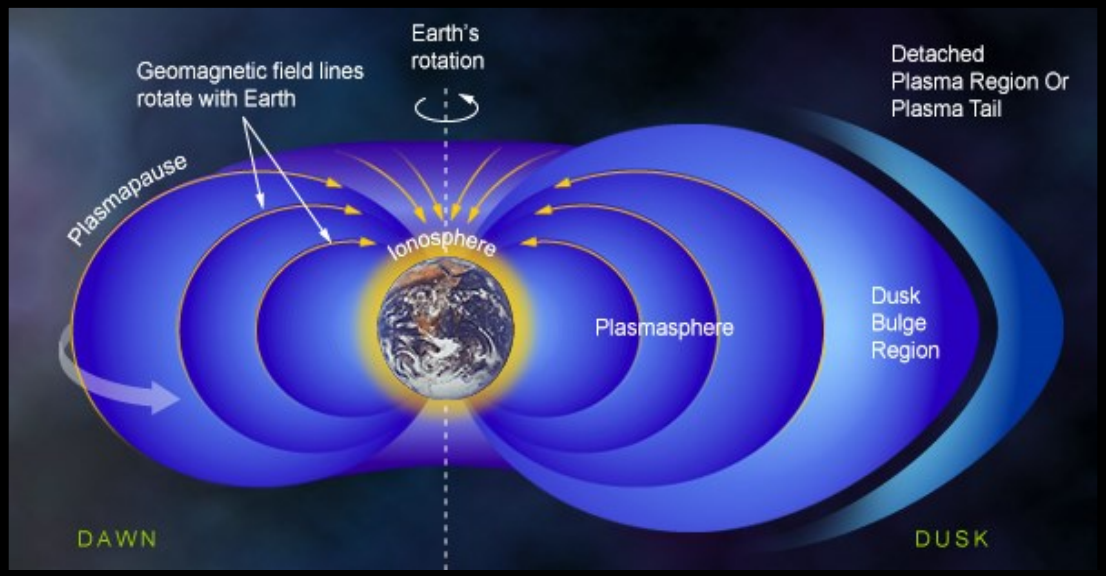
- How the electric potential is distributed with altitude.
- How the densities change.

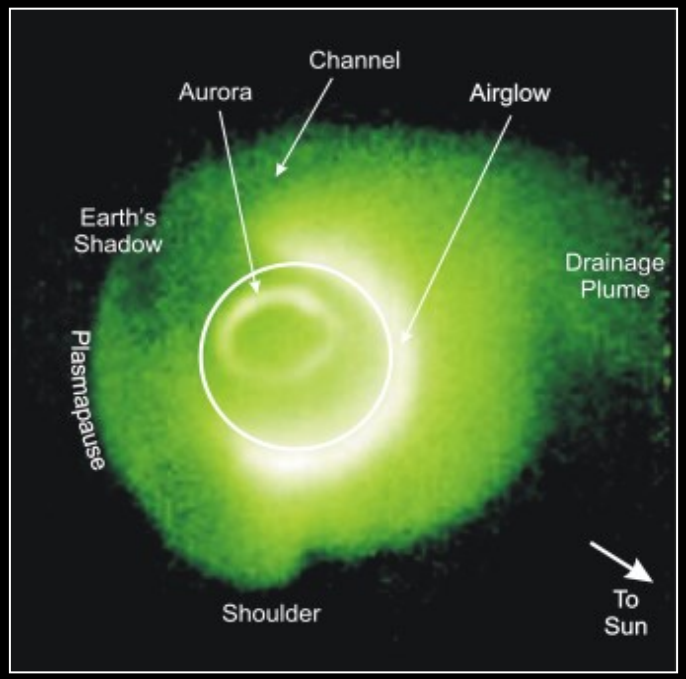
The velocity distributions for magnetospheric electrons distinguish the particles that (i) precipitate, (ii) are trapped in the electric potential well above their magnetic mirror point and (iii) those that can reach the equator.

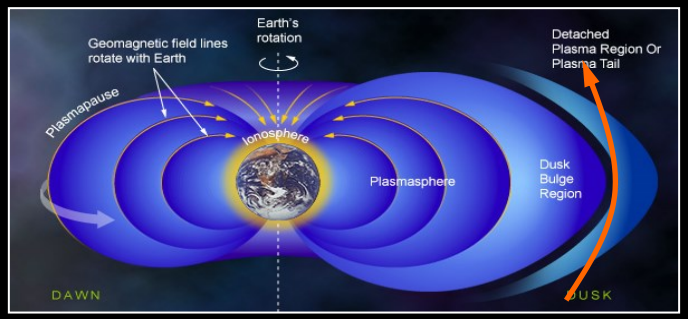
The inner magnetosphere

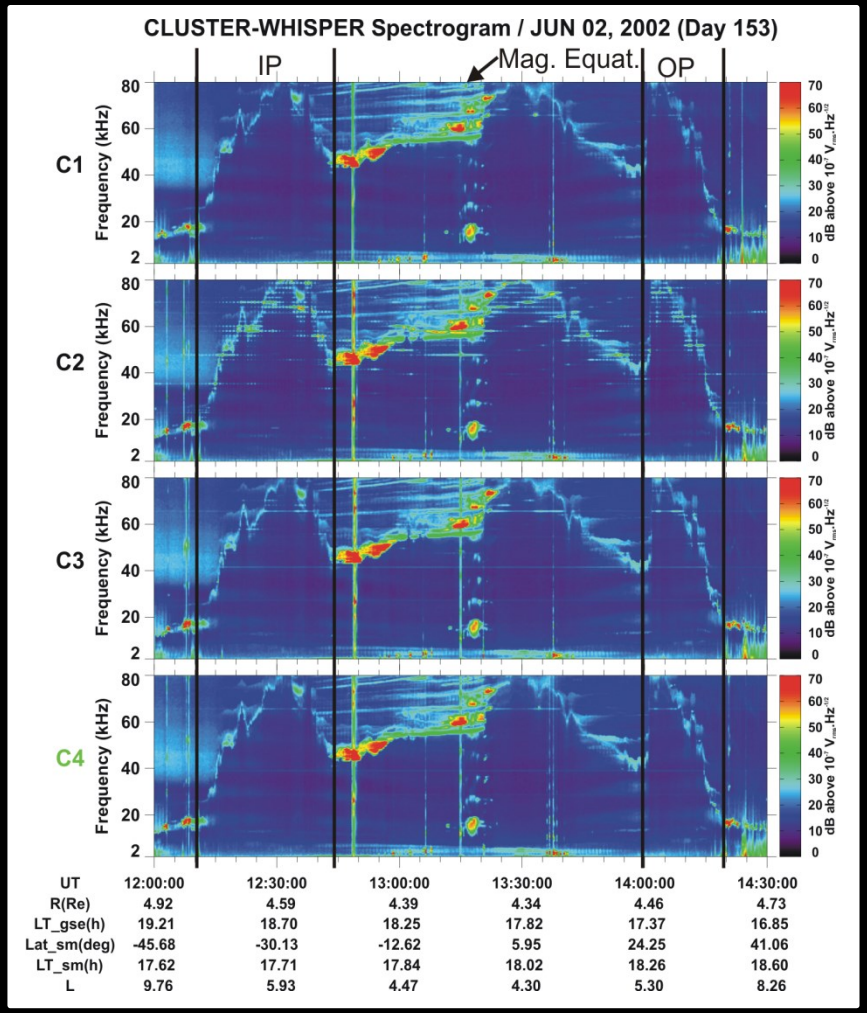
During the day, solar UV ionisation leads to ionospheric upflow. At low geomagnetic latitude, this plasma forms a reservoir on closed field lines, the plasmasphere, that replenishes the F-region at night.





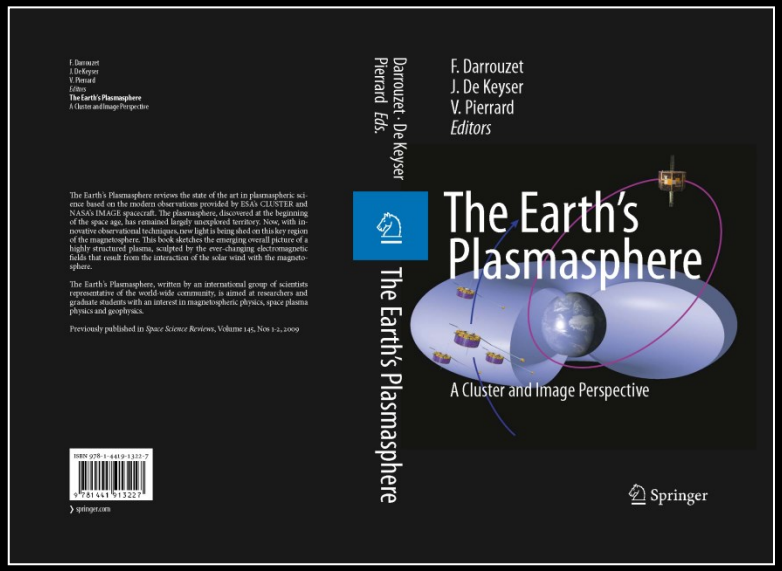

Channel
Aurora
Airglow
Earth's
Shadow
Drainage
Plume
Plasmapause
Shoulder
To
Sun


Earth's
rotation
Geomagnetic field lines
rotate with Earth
Detached
Plasma Region Or
Plasma Tail
Plasmapause
Ionosphere
Plasmasphere
Dusk
Bulge
Region
DAWN
DUSK


CLUSTER-WHISPER Spectrogram / JUN 02, 2002 (Day 153)
IP
Mag. Equat.
OP
C1
C2
C3
C4
Frequency (kHz)
dB above 10⁻⁷ V²/m²/Hz
UT 12:00:00 12:30:00 13:00:00 13:30:00 14:00:00 14:30:00
R(Re) 4.92 4.59 4.39 4.34 4.46 4.73
LT_gse(h) 19.21 18.70 18.25 17.82 17.37 16.85
Lat_sm(deg) -45.68 -30.13 -12.62 5.95 24.25 41.06
LT_sm(h) 17.62 17.71 17.84 18.02 18.26 18.60
L 9.76 5.93 4.47 4.30 5.30 8.26

There has been a flurry of research on plasmaspheric physics at BIRA-IASB, initiated long ago by J. Lemaire.

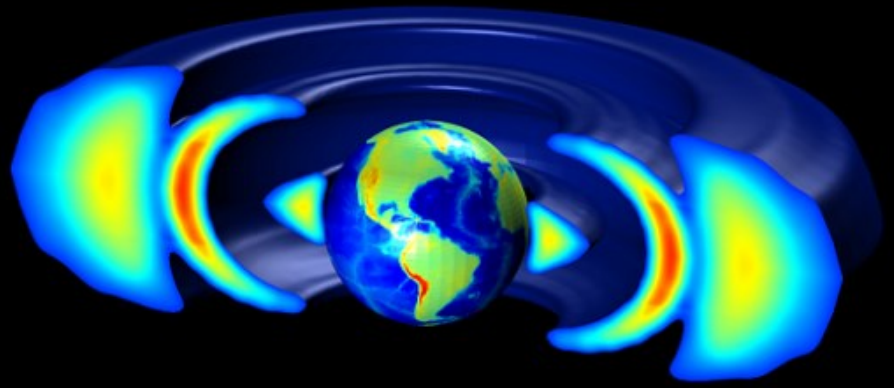
- Theoretical work predicting a plasmaspheric wind, recently confirmed by Cluster observations
- Observational analysis of plasma-sphere erosion and refilling, and of plumes, using the multi-spacecraft Cluster/WHISPER data
- Relating in situ data to remote sensing data with IMAGE using a dynamic plasmasphere model



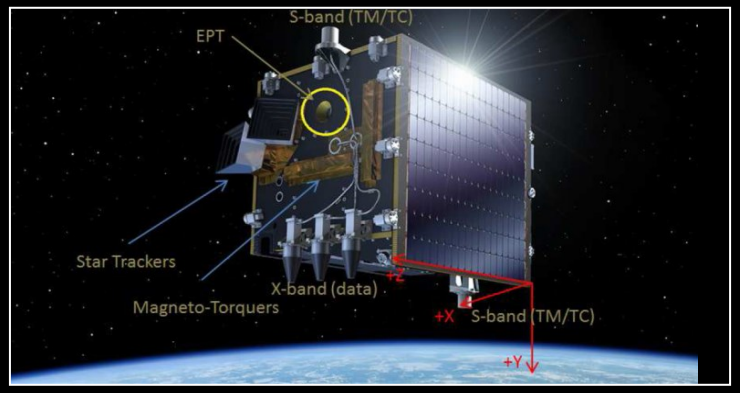
Radiation belts

Also in the inner magnetosphere, we find the radiation belts, containing energetic electrons and ions.

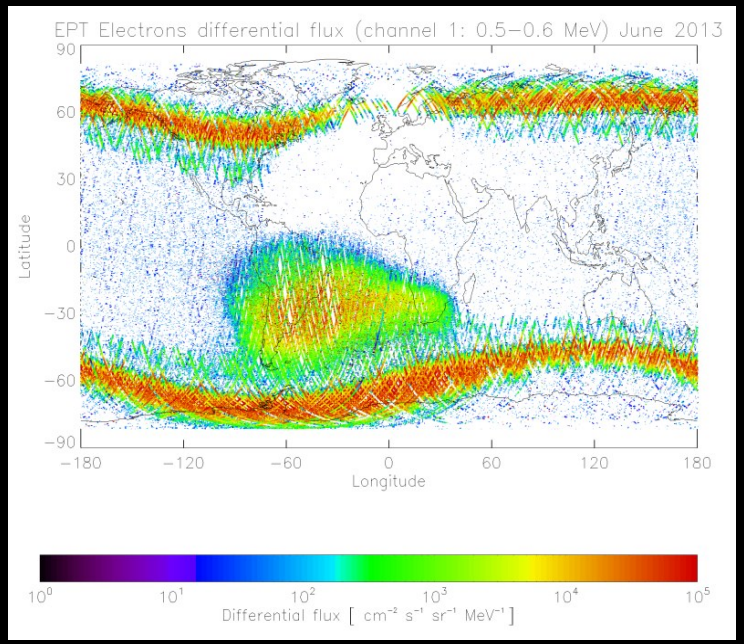
They are fed by magnetospheric storms (and other mechanisms) and gradually destroyed by radial diffusion, loss through the outer boundary of the magnetosphere, and pitch angle diffusion into the loss cone due to waves.

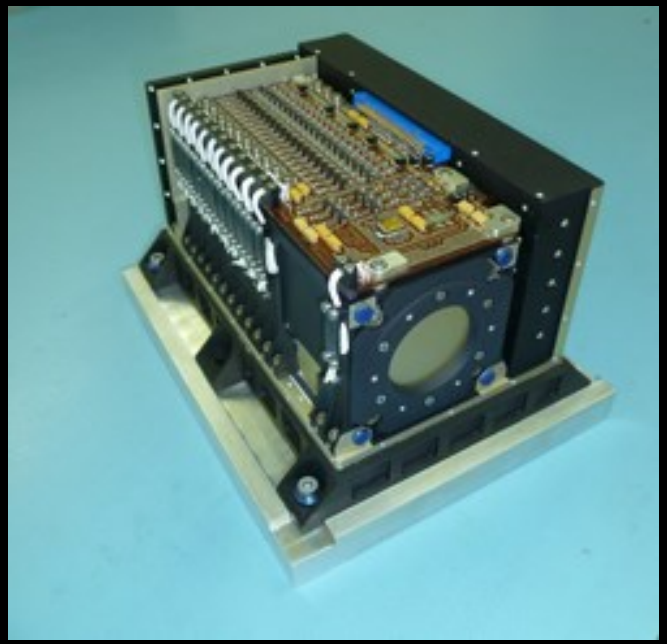


Radiation belt work at BIRA-IASB dates back to the 1980ies, in support of space weather activities.

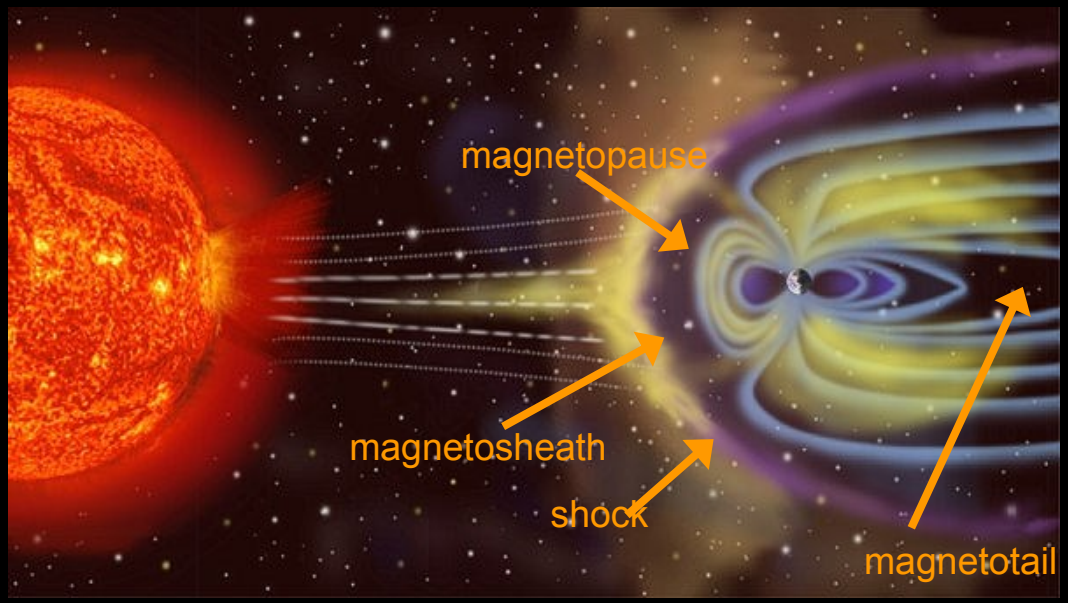


Together with UCL and Qinetiq Space, BIRA-IASB has built the Energetic Particle Telescope, carried on the Proba-V satellite in an 820 km high polar orbit, scanning the low-altitude footprint of the radiation belts.

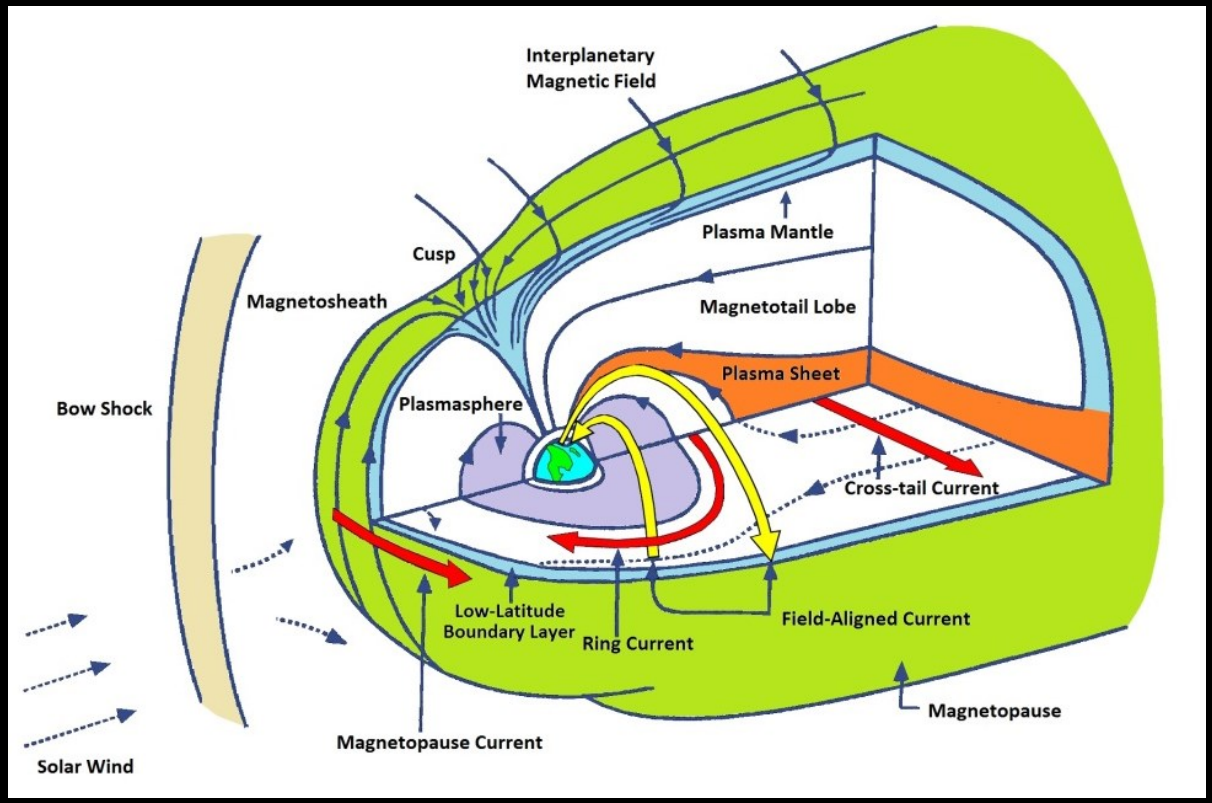




Outer magnetosphere



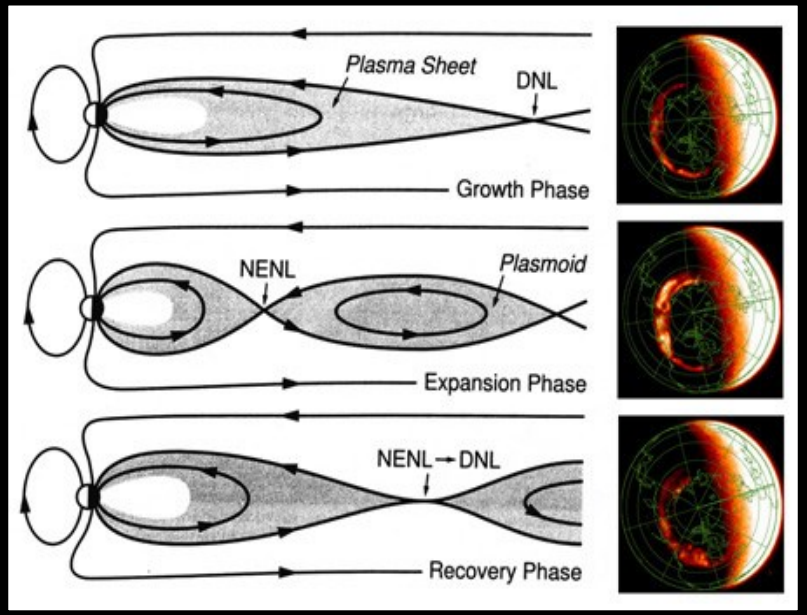
The Earth's magnetic field forms an obstacle in the flow of the magnetised solar wind plasma. The dayside is compressed. At the *bow shock* the supersonic flow becomes subsonic. The flow in the *magnetosheath* is deviated around the magnetosphere. The boundary between magnetosheath and magnetosphere is the *magnetopause*. On the night side, a long *magnetotail* is formed.



The magnetosphere is the region dominated by the geomagnetic field. It has a complex structure and is controlled by the interaction with the always varying solar wind. Different regions are separated by current-carrying plasma boundaries.

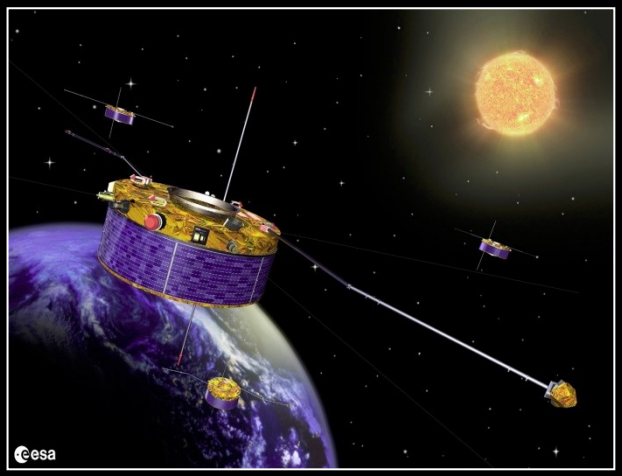
The solar wind-magnetosphere coupling leads to *substorms*.

- Magnetic flux is added by magnetic reconnection at the dayside, and removed at a distant neutral line (DNL) in the plasma sheet.
- Enhanced dayside reconnection triggers reconnection at a near-Earth neutral line (NENL), releasing a plasmoid tailward, but also earthward, leading to amagnetospheric reconfiguration.
- The plasma sheet boundary is a generator of strong aurora.



A vast body of research on structure and dynamics of the magnetosphere has been the hallmark of the Space Physics group, initiated by J. Lemaire and M. Roth.
The focus of this work has been on

- plasma interface structure
- dynamical plasma transfer processes
- surface waves on the magnetopause
- resonant wave mode conversion



Much of this work has been done in the context of ESA's 4-spacecraft Cluster mission since 2000. Several members of the group are CoI on Cluster instruments.

- New multi-spacecraft techniques (e.g. gradient computation)
- Magnetospheric boundary structure and motion
- Work on turbulence (FP7 STORM)

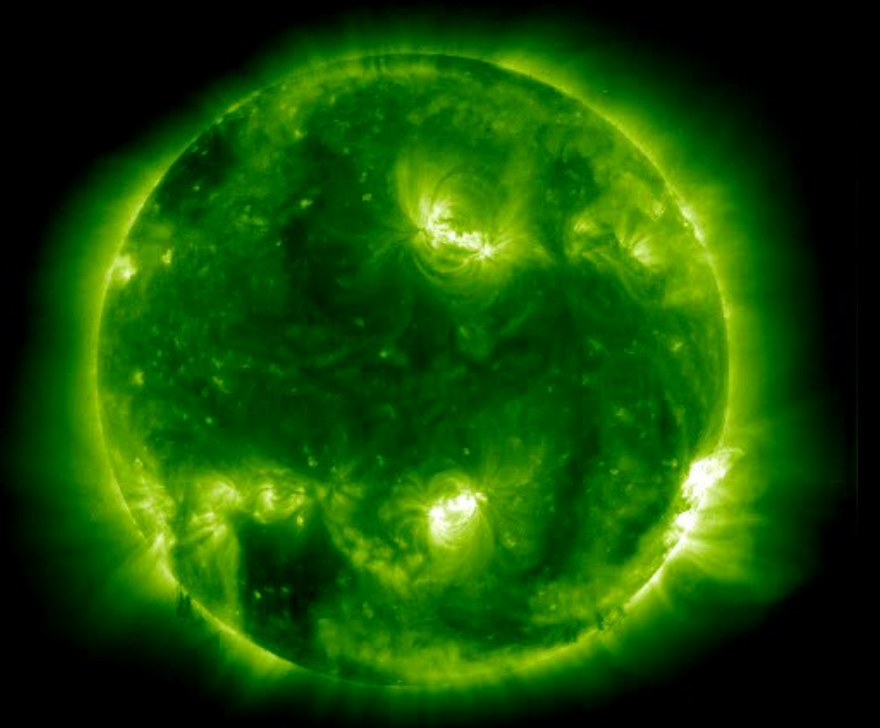
The interplanetary medium

The Sun produces a continuous outflow of magnetised plasma : the solar wind.

Perturbations on the Sun produce

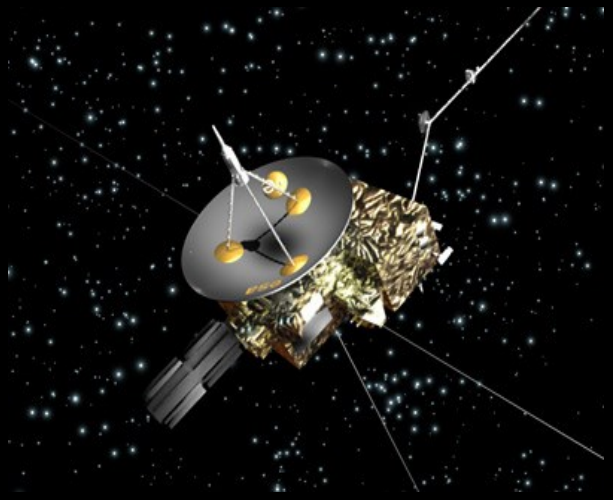
- enhanced UV emission (flares),
- enhanced thermal plasma outflo (coronal mass ejections),
- enhanced energetic particle flux (solar energetic particles).

Both plasma and field perturbation may have important dynamic consequences.



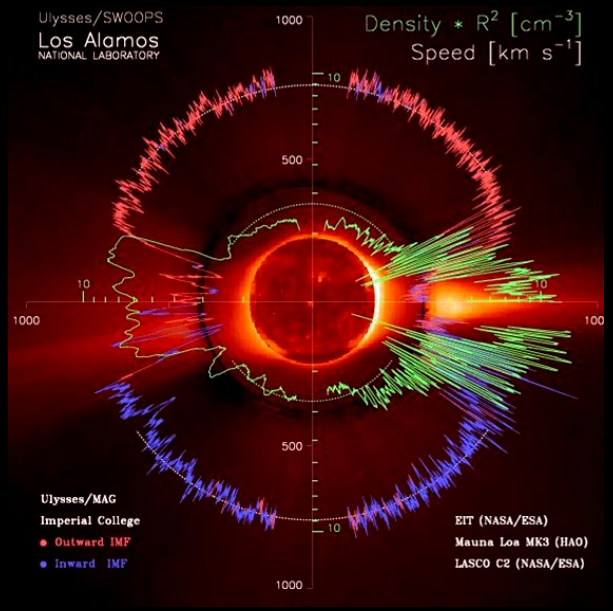
Work at the Institute has drawn on experience with ESA's Ulysses mission

- Large-scale structure: HCS, sector structure, origin of the solar wind
- Small-scale structure: plasma discontinuities, waves



Current work includes

- The problem of the high coronal temperature and solar wind speed
- Solar wind turbulence and its effect on the plasma distributions
- Acceleration and propagation of energetic particles



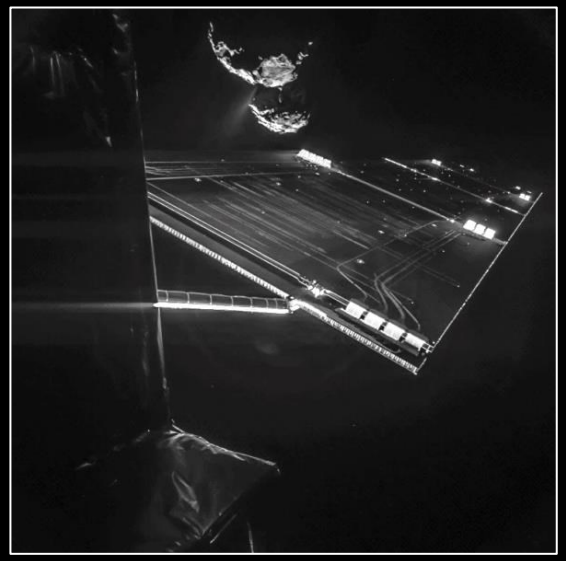
Other planetary bodies

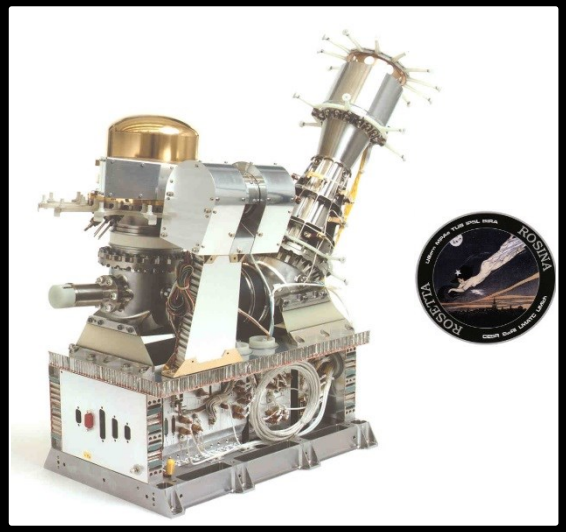
The focus of our work is on Earth, given the relative abundance of data. However, the same fundamental principles underly the environments of other planetary bodies.

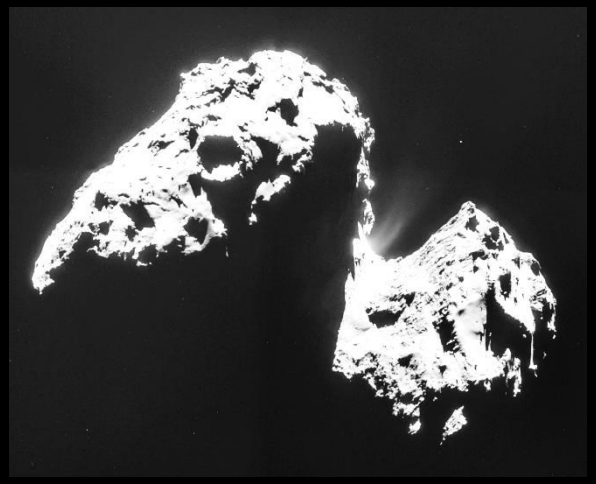
- Mercury has a magnetic field but not much atmosphere.
- Venus and Mars have atmospheres but do not have a (global) magnetic field.
- The gas giants have an intrinsic magnetic field, and thus have magnetospheres resembling that of Earth, but different from it because of the dipole field direction and the presence of inner sources of magnetospheric material.
- Comets have minimal gravity and no significant magnetic field; they cannot even retain their tenuous atmosphere.

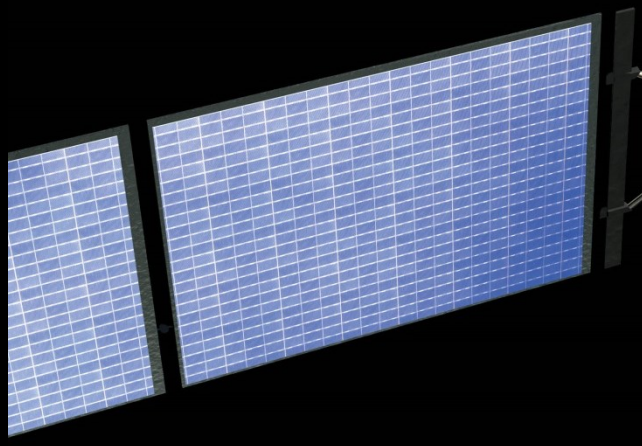
BIRA-IASB is involved in the DFMS mass spectrometer on Rosetta, a mission to examine a comet. The comet environment is driven by

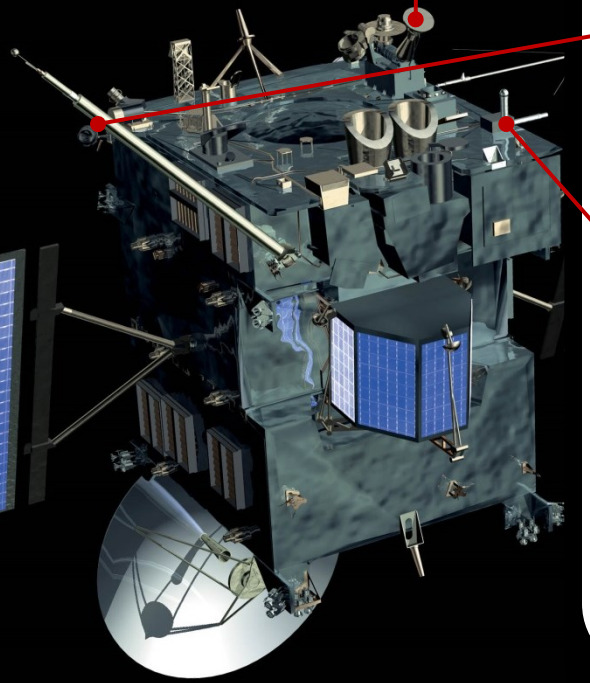
- Sunlight : CO_2 : H_2O depends on insolation, and is enhanced at R > 3 AU
- The solar EUV flux controls the photochemistry.
- Solar wind particle impact on gas / dust / surface leads to radiolysis.











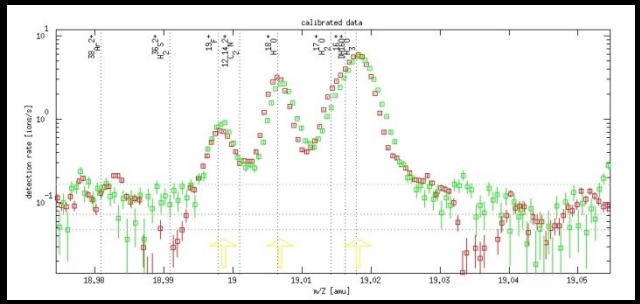
Mass spectrometer RTOF

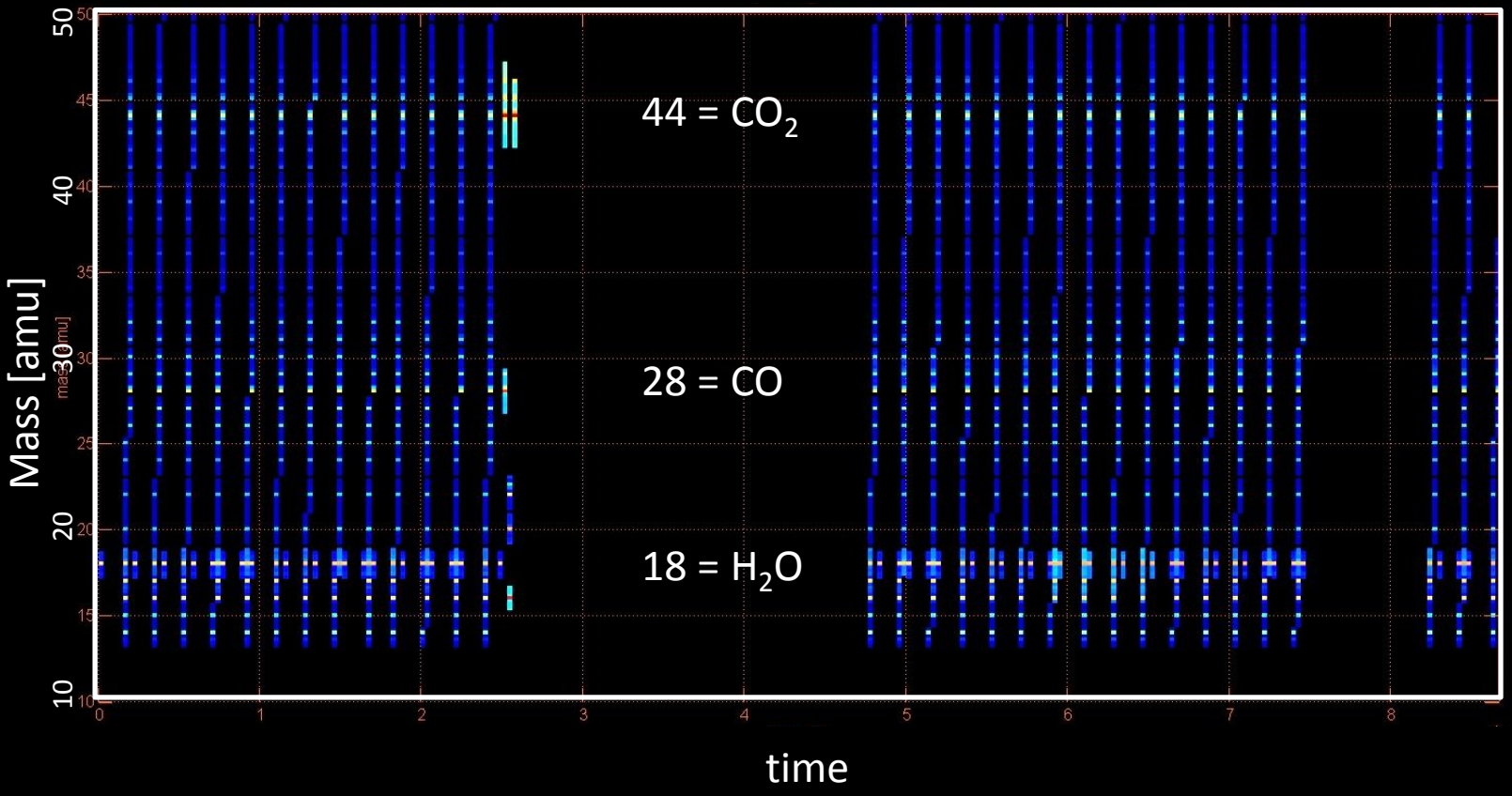
Mass spectrometer DFMS

Pressure sensor COPS

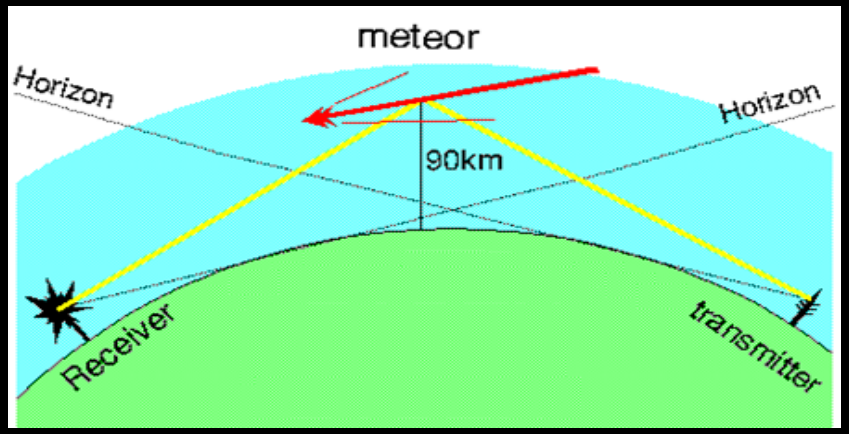
DFMS spectrograms

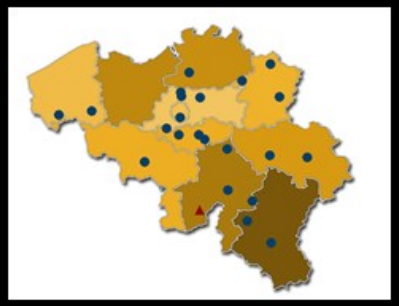
detection of ^{18}OH





Meteors

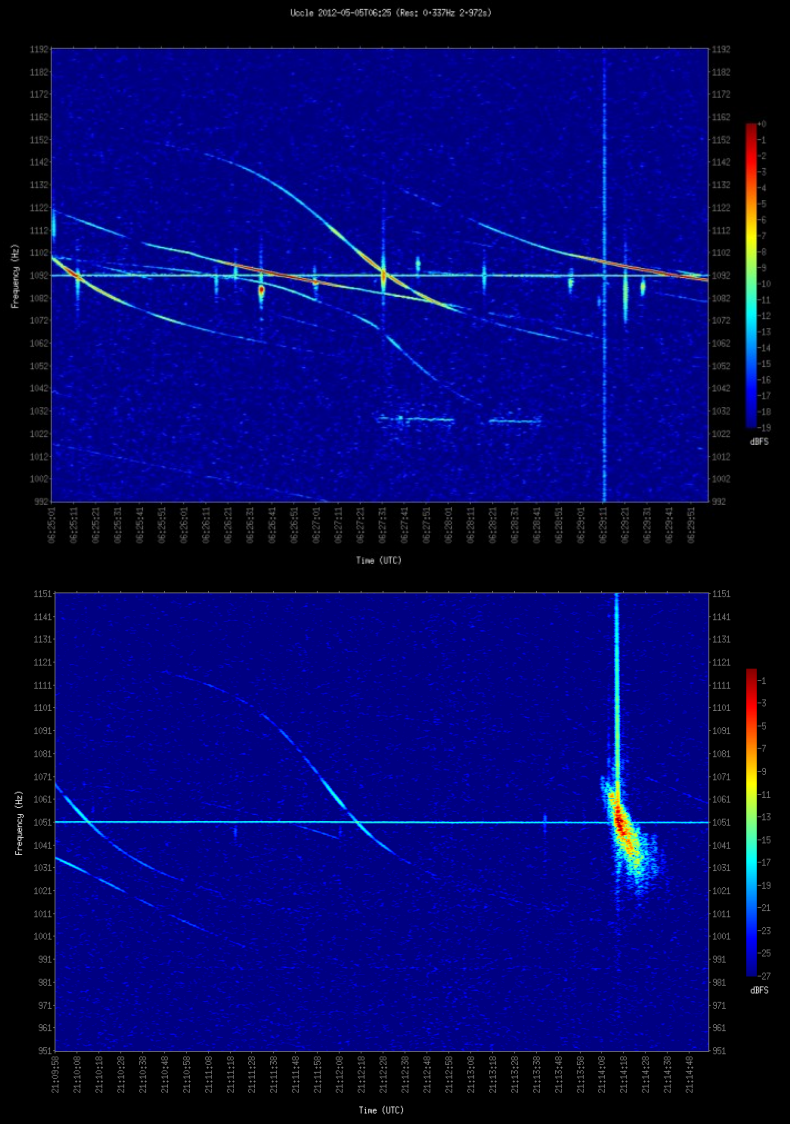




BISA operates BRAMS, a radio meteor network that monitors the sky above Belgium.

- The transmitter is located in Dourbes (RMI – STCE).
- There are ~25 receivers scattered over Belgium, with an interferometer in Humain (ROB – STCE), and many stations operated at public observatories or by amateur astronomers.

Receivers record reflections off meteor ionisation trails.



The spectrograms show the beacon (horizontal line), airplanes, meteors, … or the ionisation due to a Soyuz upper stage reentry.

Data storage & processing is provided by BIRA-IASB.

In a collaboration with VKI the meteor ablation profile is modeled, in order to "calibrate" BRAMS in terms of incoming mass.

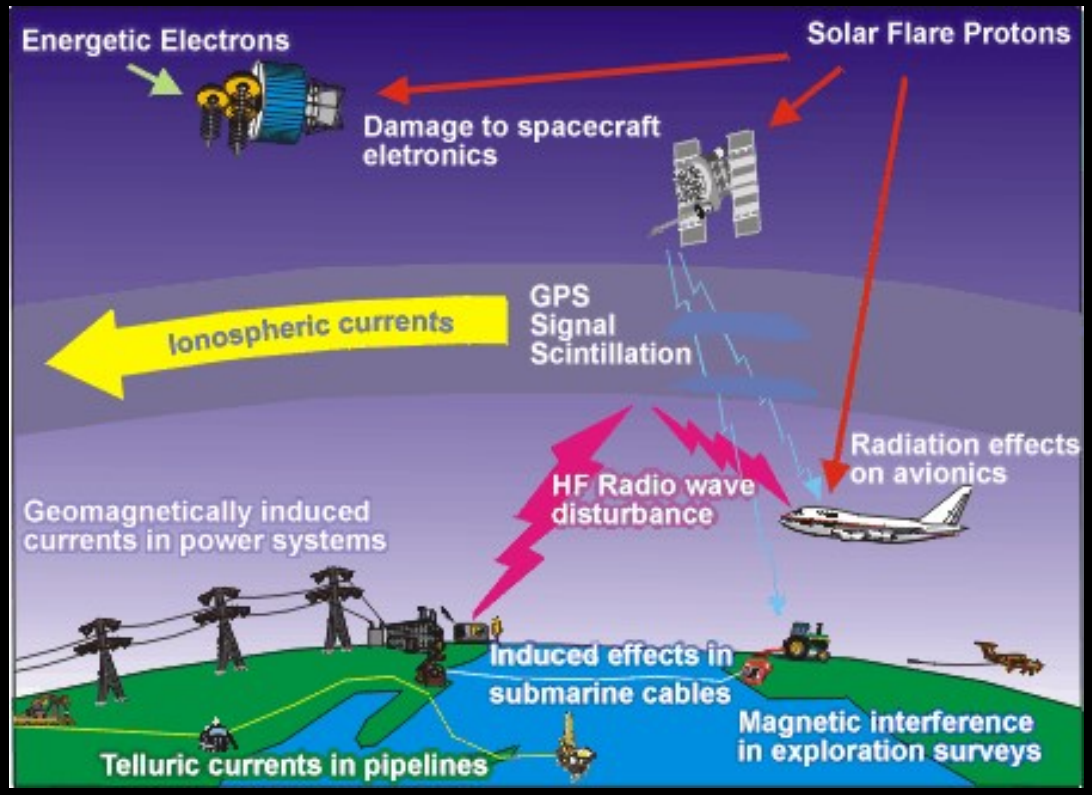
Space Weather

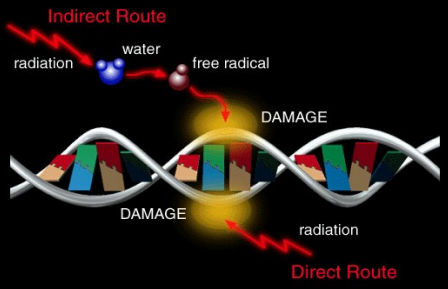
Changes on the Sun, in the solar wind, or in the magnetosphere, may have an impact on Earth or other planetary bodies, or on human activity in space and even on the ground.

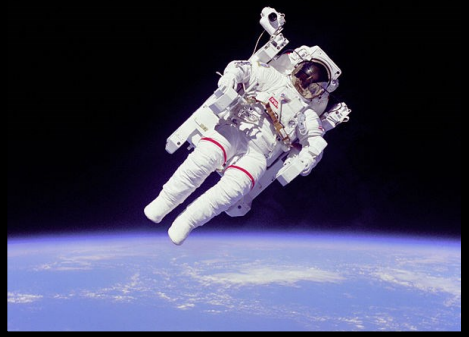
- *Space weather* refers to instantaneous conditions, often with the goal of nowcasting or forecasting those conditions in order to prevent risk during operations.

- *Space climate* refers to average conditions, e.g. averaged for a specific phase of the solar cycle, and is typically considered when designing instrument shielding to foresee safety margins.

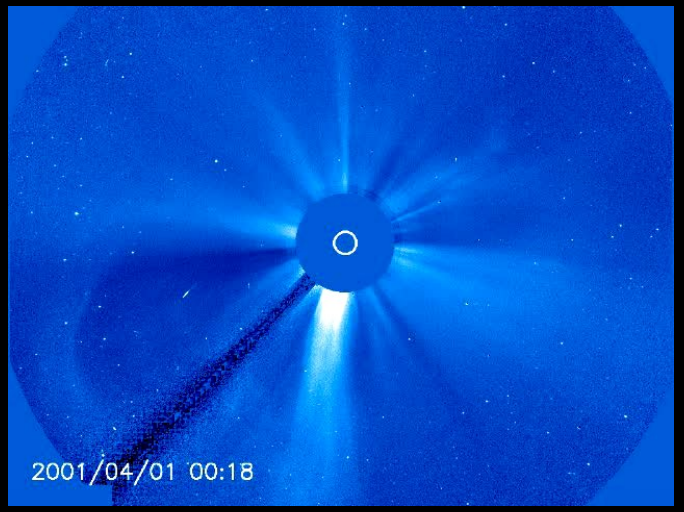
The range of space weather impacts on man and technological systems is vast …

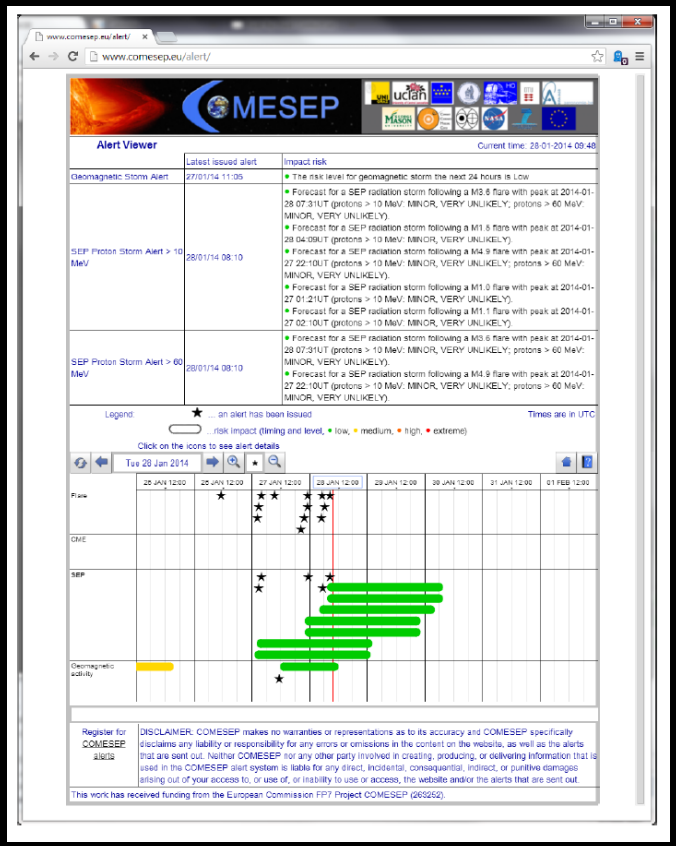






Solar energetic particles are the primary risk outside the magnetosphere.

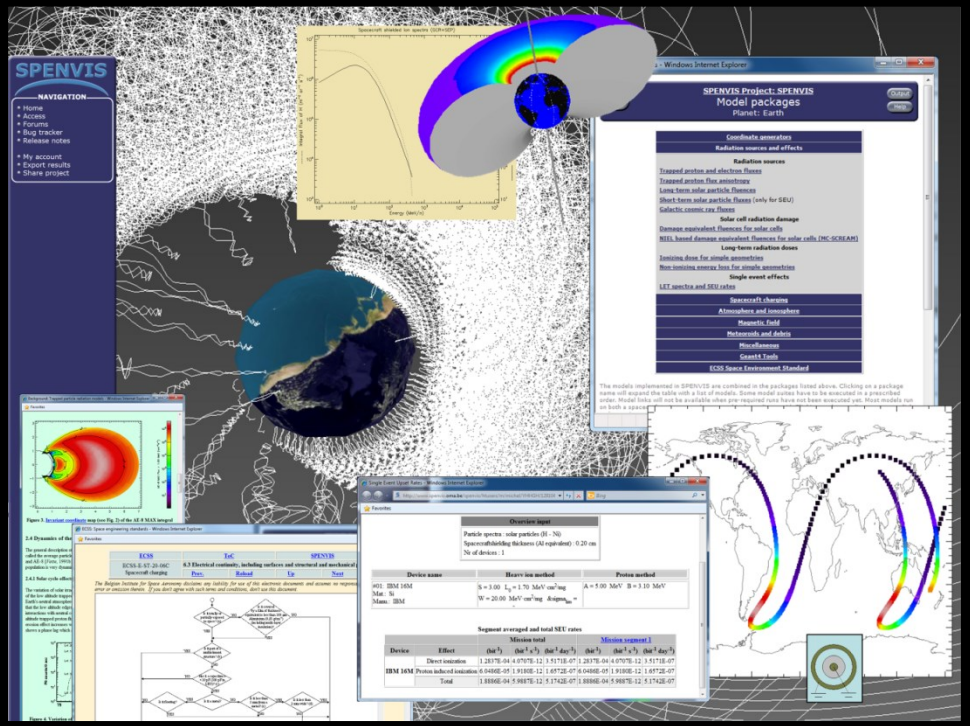




BIRA-IASB scientists have studied their generation and propagation, and try to incorporate that knowledge into space weather prediction tools, such as COMESEP.

This expertise is put to use in the context of ESA's SSA program.

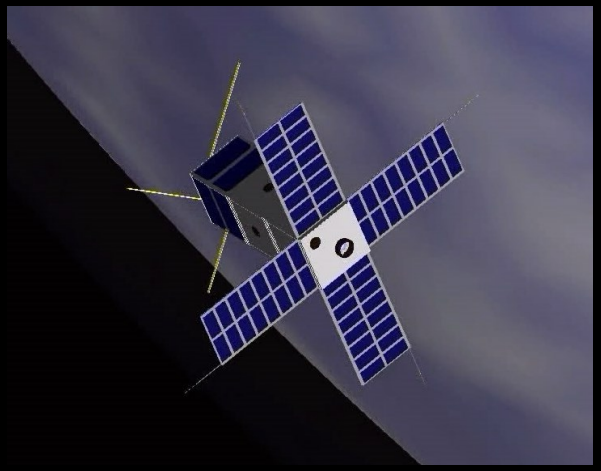
Since many years, and initiated by D. Heynderickx, BIRA-IASB has developed the SPENVIS system for ESA. This system provides an environment in which several engineering models can be run to assess the impact of space weather conditions (radiation, single event upsets, atmospheric drag, …)



The SSA Space Weather Coordination Centre (SSCC) is located at the Space Pole in Belgium. SSCC provides the first *European Space Weather Helpdesk*, with operators available to answer questions about space weather services or space weather conditions in general.

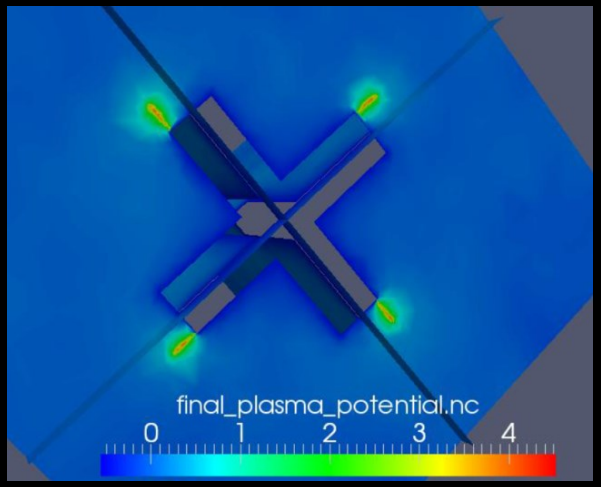
Experiments

The Division is progressively seeking to acquire scientific data by its own means.



Ground-based :

- BRAMS
- VLF antenna
- Spectrophotopolarimeter

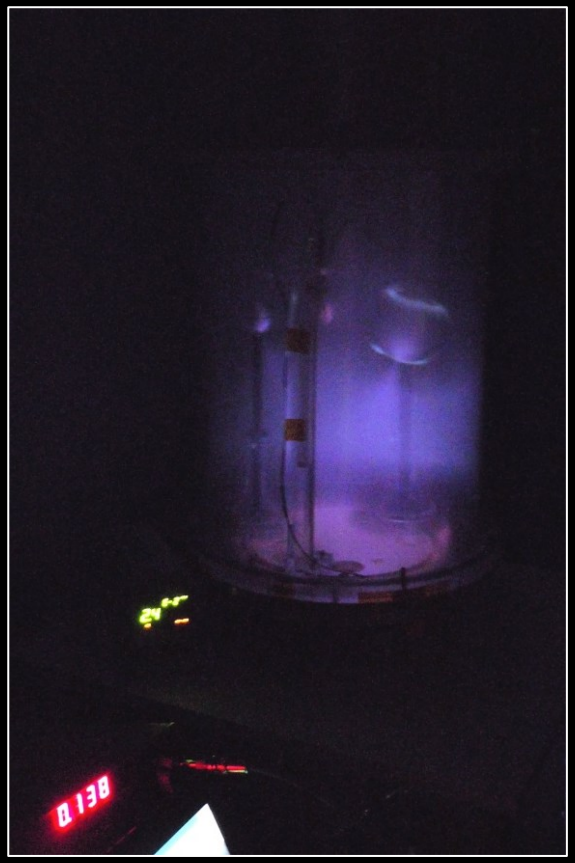


Space-based :

- EPT
- DFMS
- Langmuir probes on PICASSO

Education

- Teaching
  - KULeuven, UCLouvain, ULiège, ULB
  - Master in Space Studies
  - Internships, master thesis, PhD
- EPO activities
  - Open Doors
  - Via the ESERO Office
  - Expositions in the Planetarium, Redu, elsewhere
  - Demonstration material, e.g. the planeterella (STCE)



Funding

National

- Solar-Terrestrial Centre of Excellence
- Action 1 programs, supplementary researchers, IUAP : TOPERS, CHARM
- FNRS : EROSION
- Lotto : PICASSO

ESA

- Prodex : Ulysses, Cluster, Rosetta
- ESA GSTP : PICASSO
- ESA ITTs (SPENVIS, VSWMC, PIANOS, …)

European Commission

- FP7 COMESEP, ESPAS, …

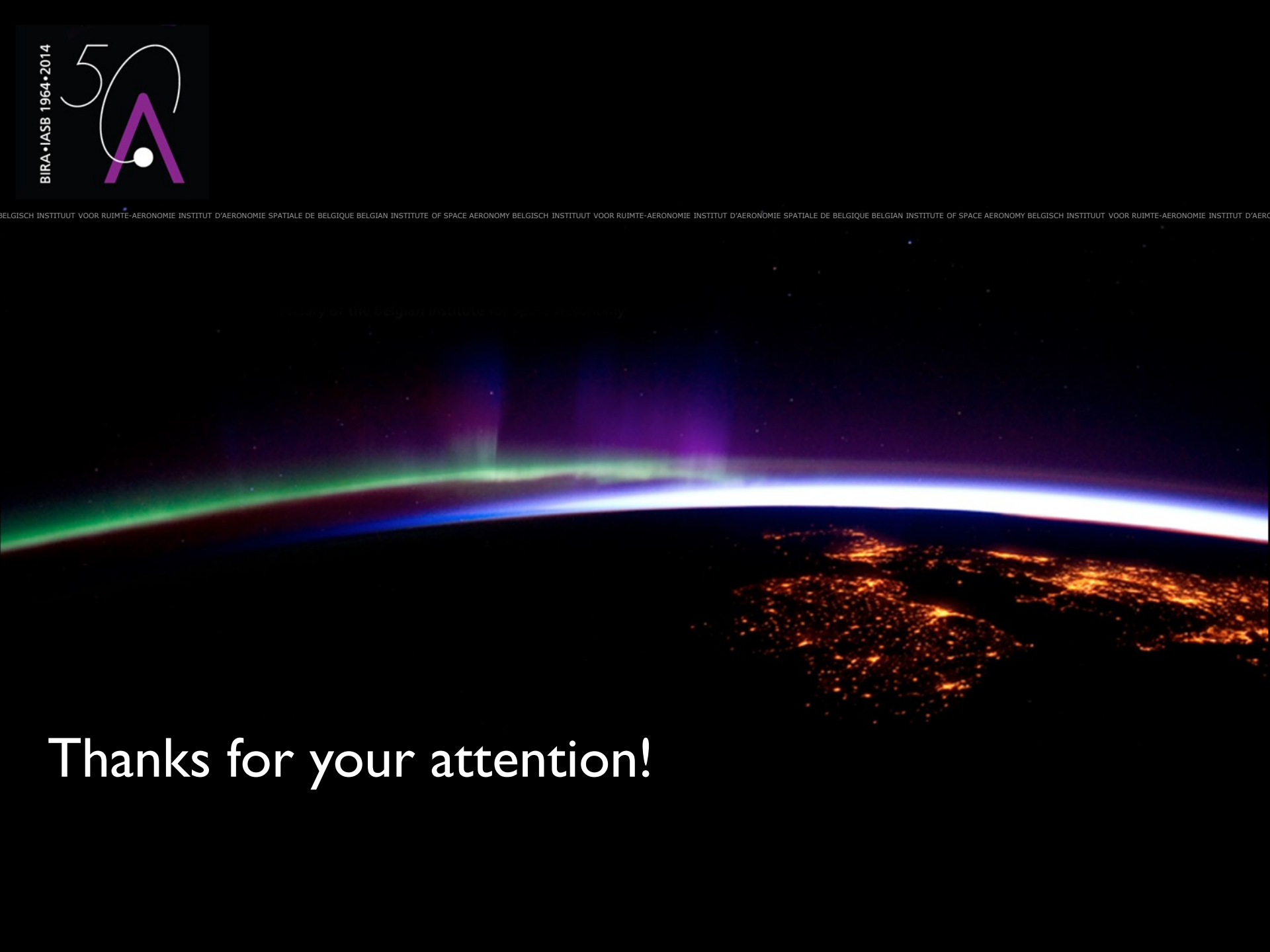
Other

- HPCN, EISCAT

People

Division members over the years …

Kris Borremans, Vladimir Cadez, Stijn Calders, Sophie Chabanski, Norma Crosby, Fabien Darrouzet, Bart Declercq, Erwin Dedonder, Johan De Keyser, Frederik Dhooghe, Mark Dierckxsens, Marius Echim, Leo Fedullo, Emmanuel Gamby, Andrew Gibbons, Herbert Gunell, Stefaan Hallet, Laszlo Hetey, Daniël Heynderickx, Michel Kruglanski, Hervé Lamy, Joseph Lemaire, Graciela Lopez, Lukas Maes, Romain Maggiolo, Ingrid Mann, Neophytos Messios, Peter Meuris, Sophia Moschou, Viviane Pierrard, Michaël Pieters, Bart Quaghebuer, Sylvain Ranvier, Michel Roth, Cyril Simon, Koen Stegen, Cem Tekin, Yuriy Voitenko, Jovo Vranjes, Jan Wera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Thanks for your attention!