Plasmashperic products for space weather service

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Outline

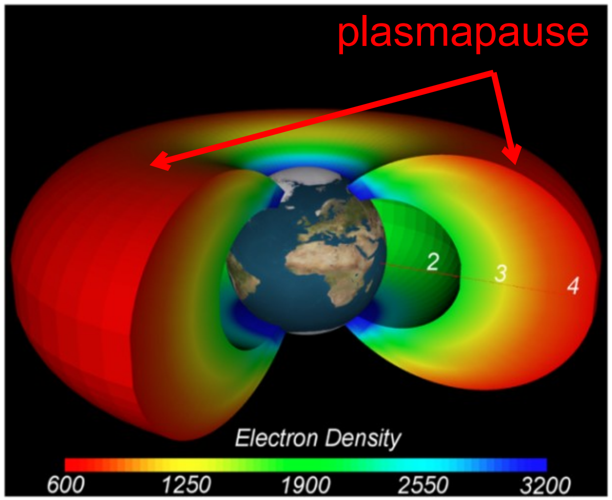
I. Plasmasphere – plasmapause – plasmatrough specifications

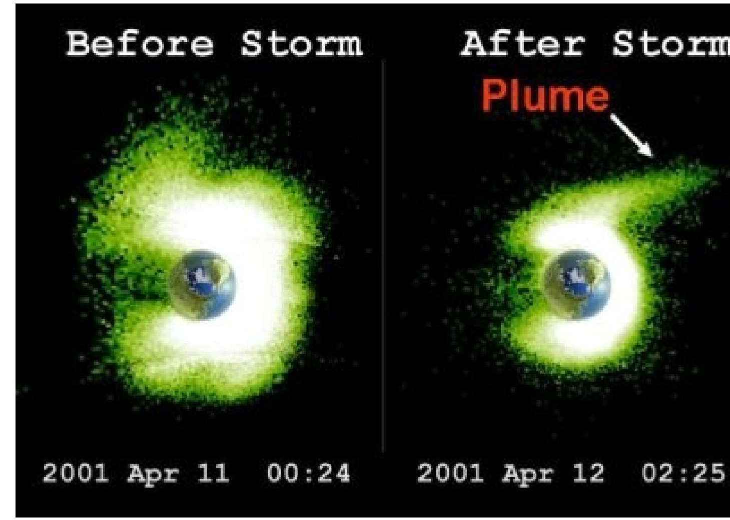
1. In-situ measurements
2. Ground based measurements

II. ESA P3-SWE-LII Plasmaspheric Products for Space Weather Services

1. Products characterizing the plasmasphere and plasmapause
2. Use cases – for SWE/SPINE community

Plasmasphere – plasmapause





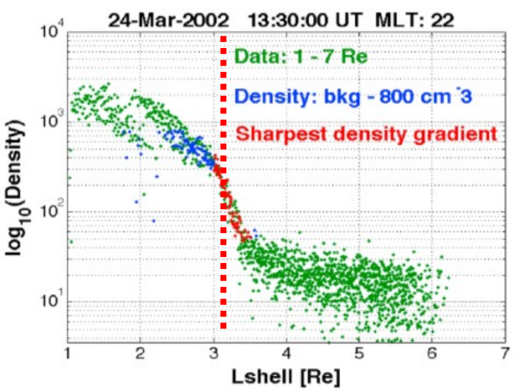


Figure 2. An ideal example of the $\log_{10}$ density versus L shell (R_E) for a 0.5 h bin centered at 22 MLT at 13:30 UT on 24 March 2002.

Plasmasphere:
Cold plasma corotating with the Earth

Plasmapause:
sharp density drop

IMAGE view of the erosion of the plasmasphere as a response to a geomagnetic storm (Jerry Goldstein/SwRI)

Dynamically linked to magnetospheric, ionospheric processes

I.1 In-situ measurements of **cold** plasma density/electron density

A. Electron density: upper hybrid resonance frequency measured by (mostly) high frequency electric field:

- Many satellites since ‘90s: Akebono, CRRES, Polar, IMAGE, THEMIS, RBSP, Arase...

B. Plasma mass density: lower hybrid resonance frequency measured either by passive and active method:

- Few examples only: Cluster WHISPERs

No real-time data available at the moment

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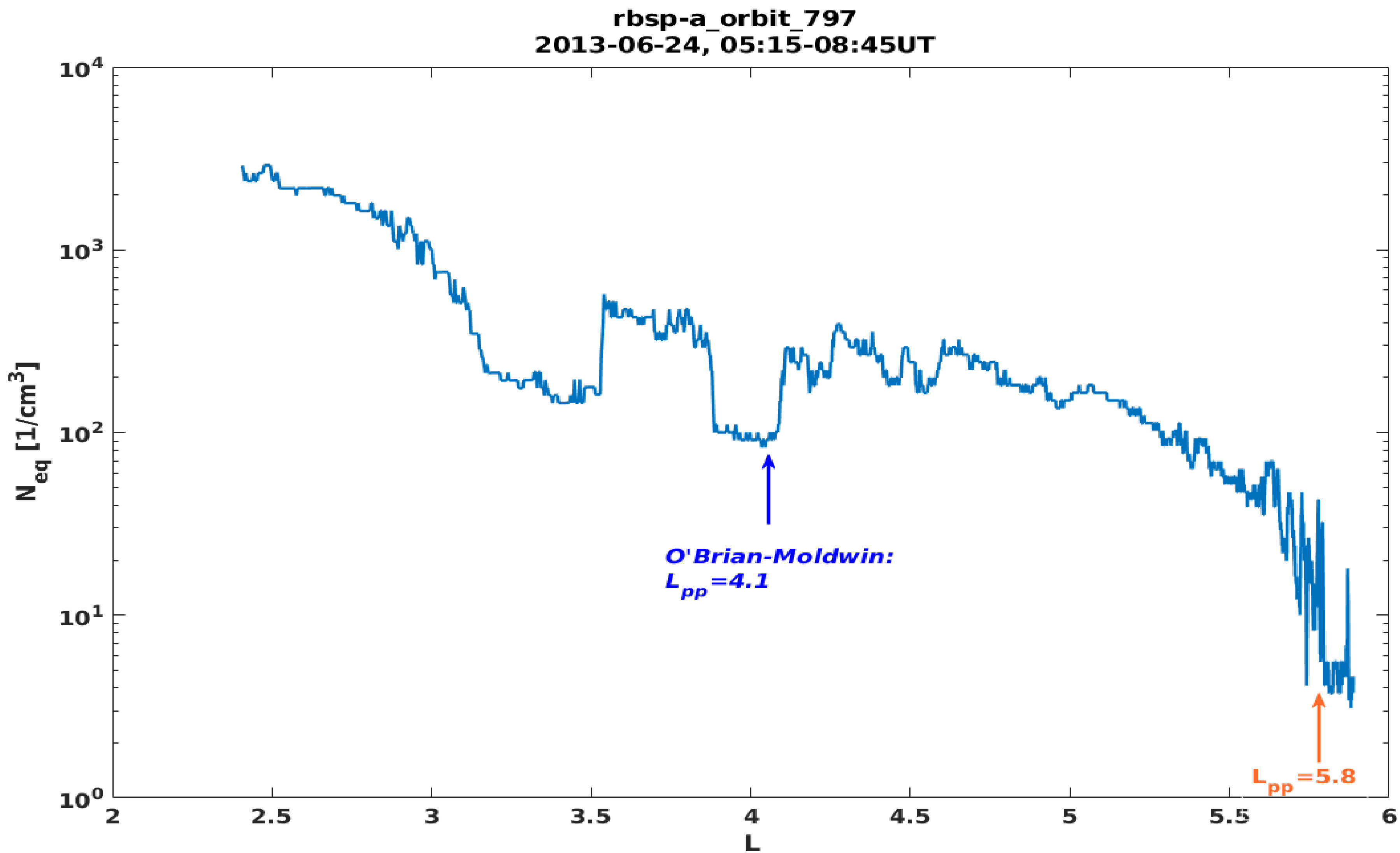
We need sustainable data!

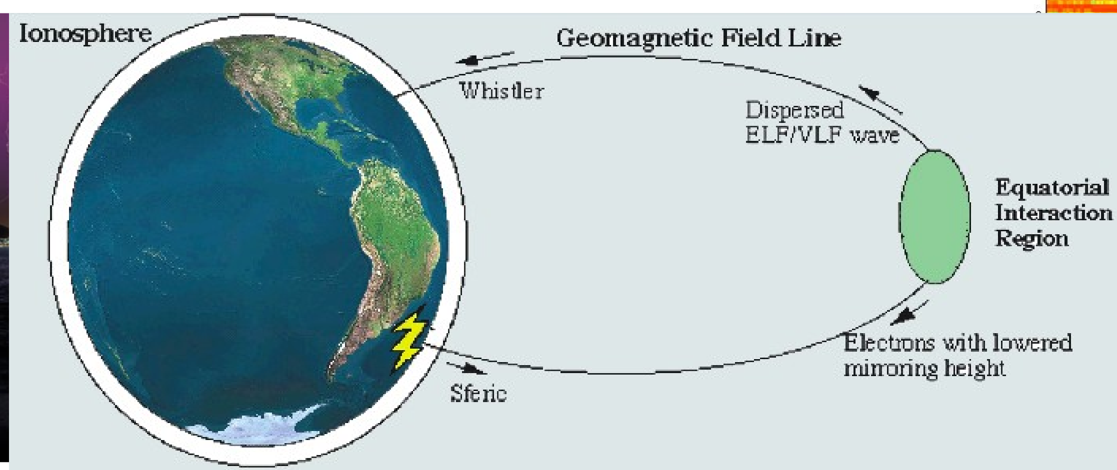
Equatorial electron density measured by RBSP-A, 14 June 2013

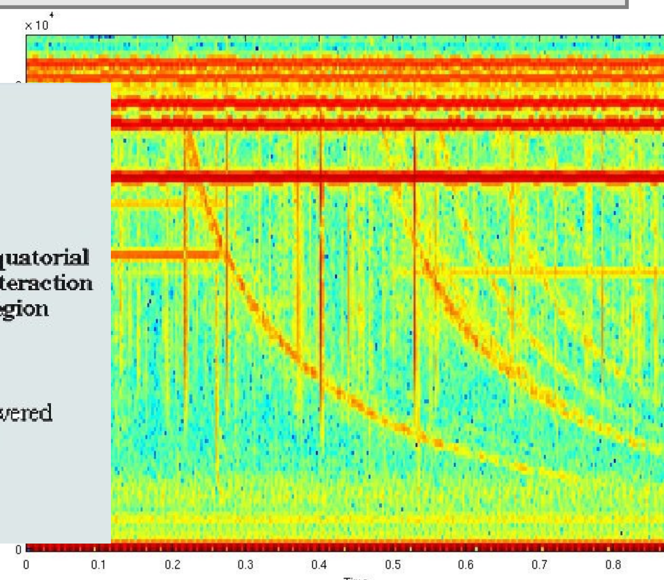


VLF whistler: frequency dependent propagation speed:

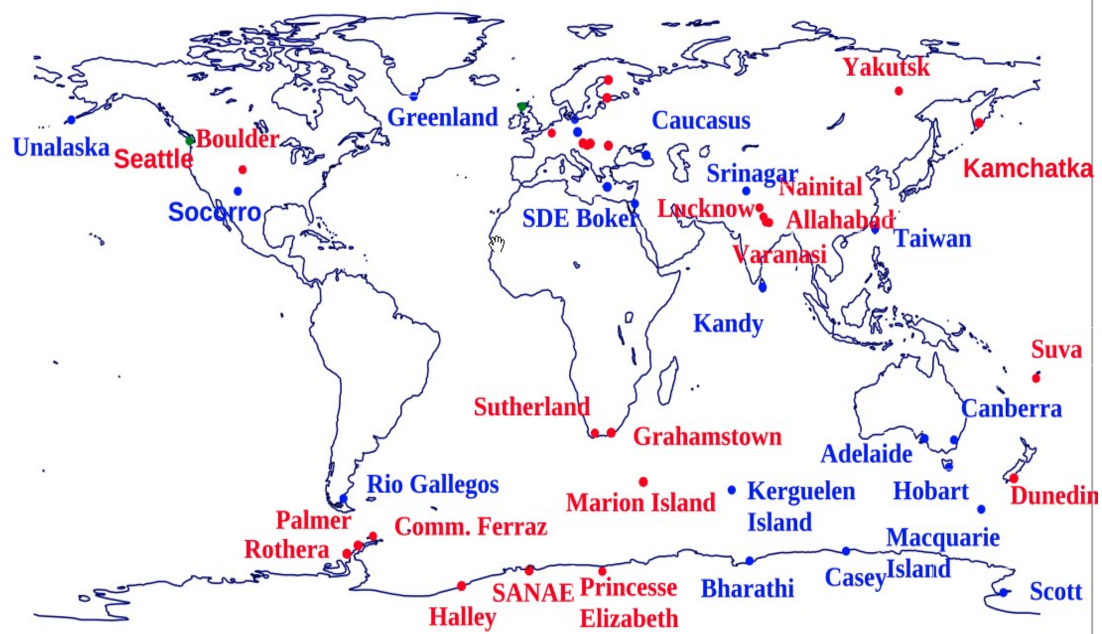
$$T_m(f) = \frac{1}{2c}\int_s \frac{f_p f_H}{f^{1/2}(f_H - f)^{3/2}}\,ds$$

equatorial electron density from f_p





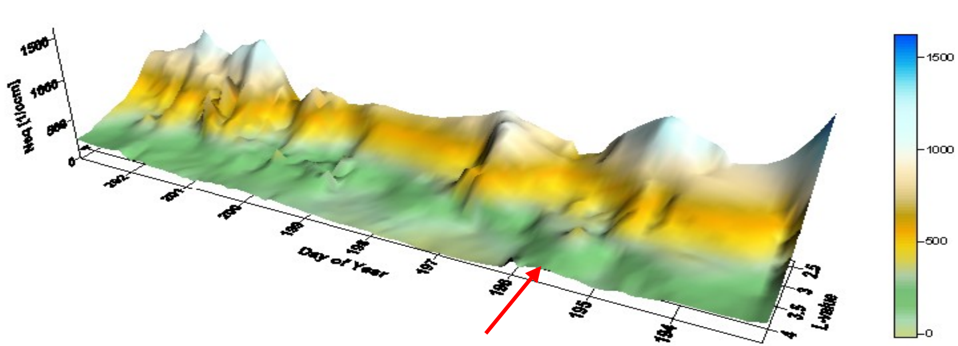
Automatic Whistler Detector and Analyzer Network (AWDANet)
a worldwide network of automated whistler receivers



Improvement under the PLASMON (EU FP7 project)

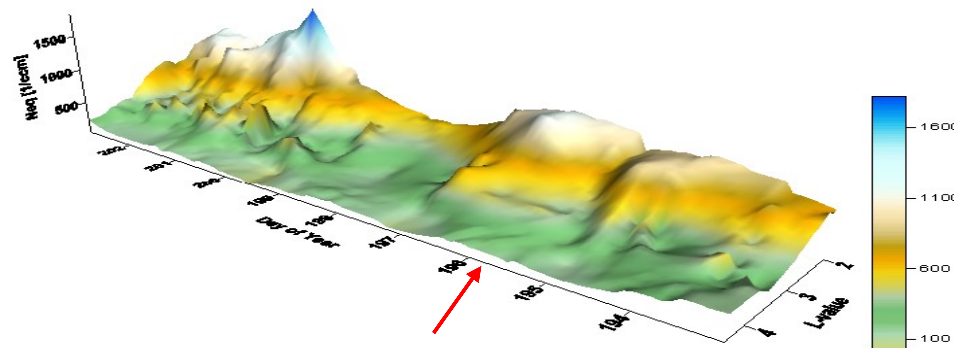
I.2 Ground based measurements of cold plasma density/electron density

Automatic **retrieval of equatorial electron densities and density profiles by *AWDANet***



SC

Rothera



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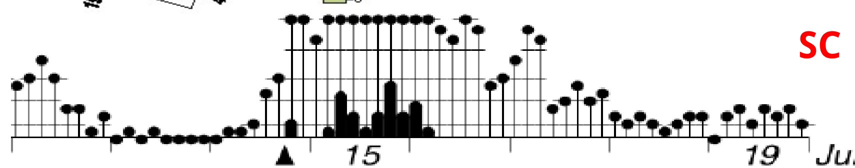
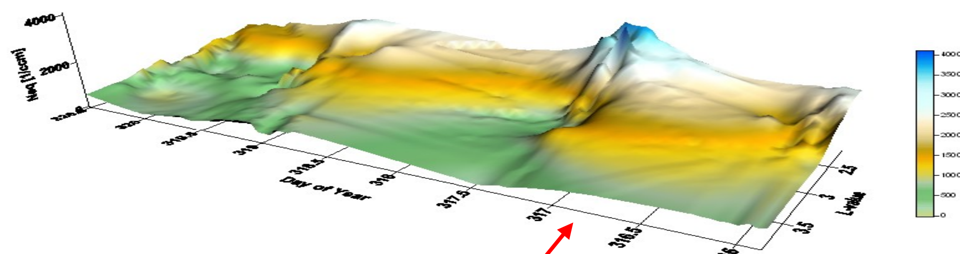


Halley

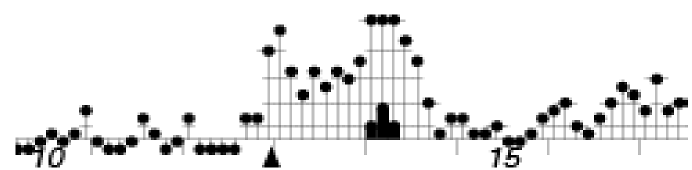
Storm on 15 July 2015



SC

Storm on 14 November 2012

Karymshina

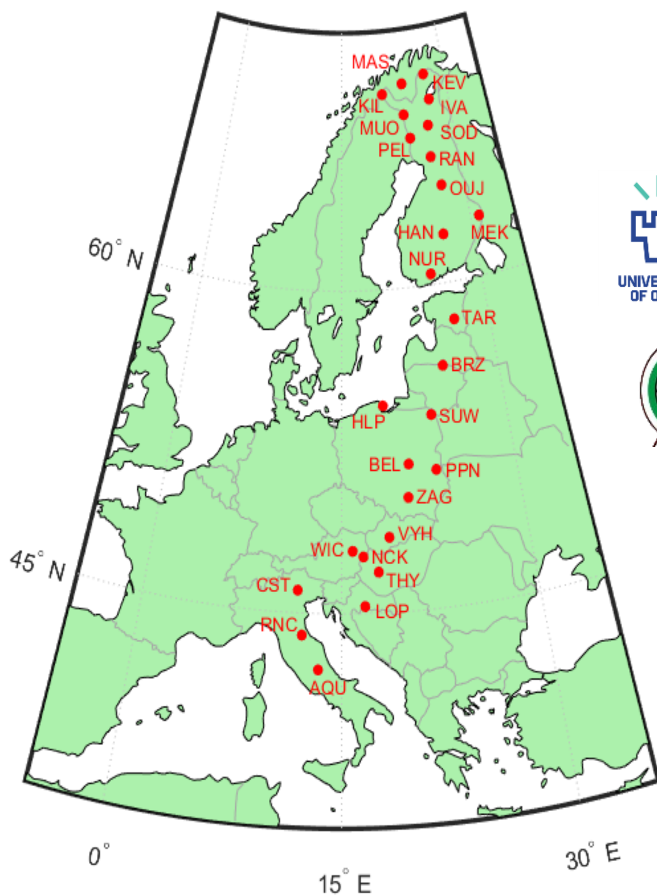


→ plasmaspheric electron densities

I.2 Ground based measurements of cold plasma density/electron density

EMMA

A European quasi-Meridional Magnetometer Array

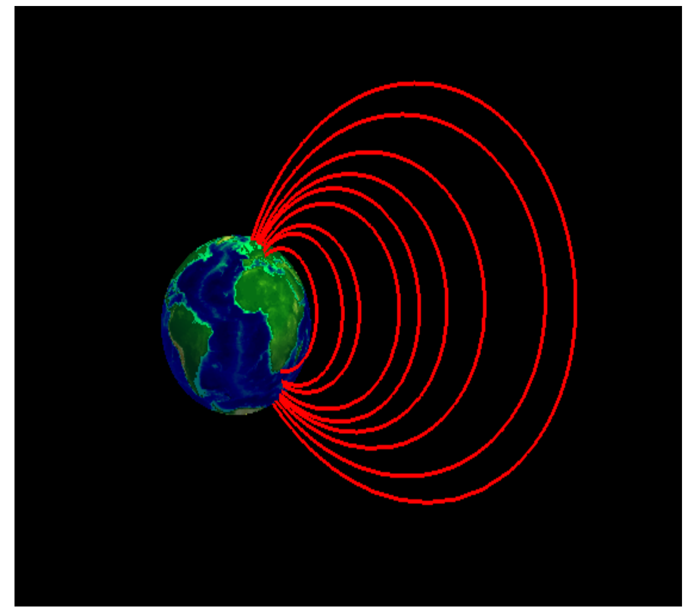


FMI

UNIVERSITY OF OULU

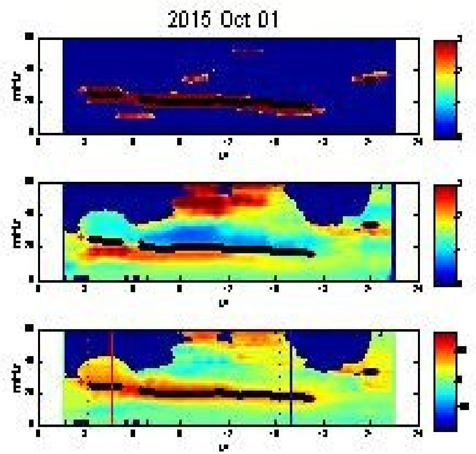
Institute of Geophysics Polish Academy of Sciences

MBFSZ MINING AND GEOLOGICAL SURVEY OF HUNGARY



EMMA covers the L-range 1.5-6.0

PLASMON heritage
near real-time plasmasphere monitoring



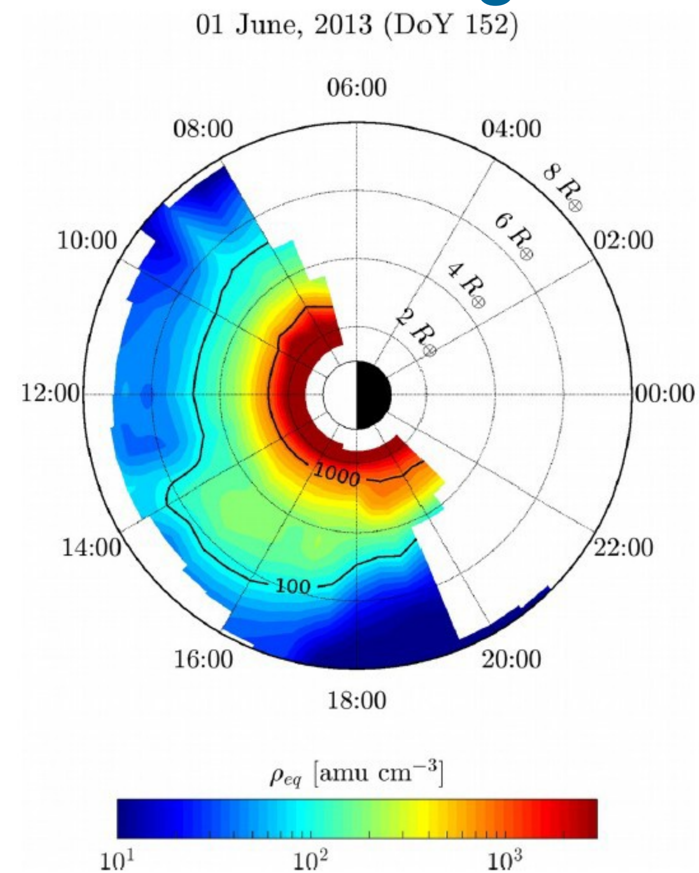
FLR (black line) detected in the cross-spectrum of BRZ-SUW at L=2.61

FLRID (at MBFSZ)

- Field Line Resonances (FLRs) **detected automatically** in NRT
- FLR detection is based on the **gradient** technique

FLRINV (at Univ. of L'Aquila)

- FLR inversion
- based on Singer et al (1981) solution (MHD wave eq. In arbitrary magnetic field)



$$v_A = B/\sqrt{\mu_0 \rho}$$ → **plasmaspheric and trough mass densities**

A proxy for the midnight PP position from Swarm data

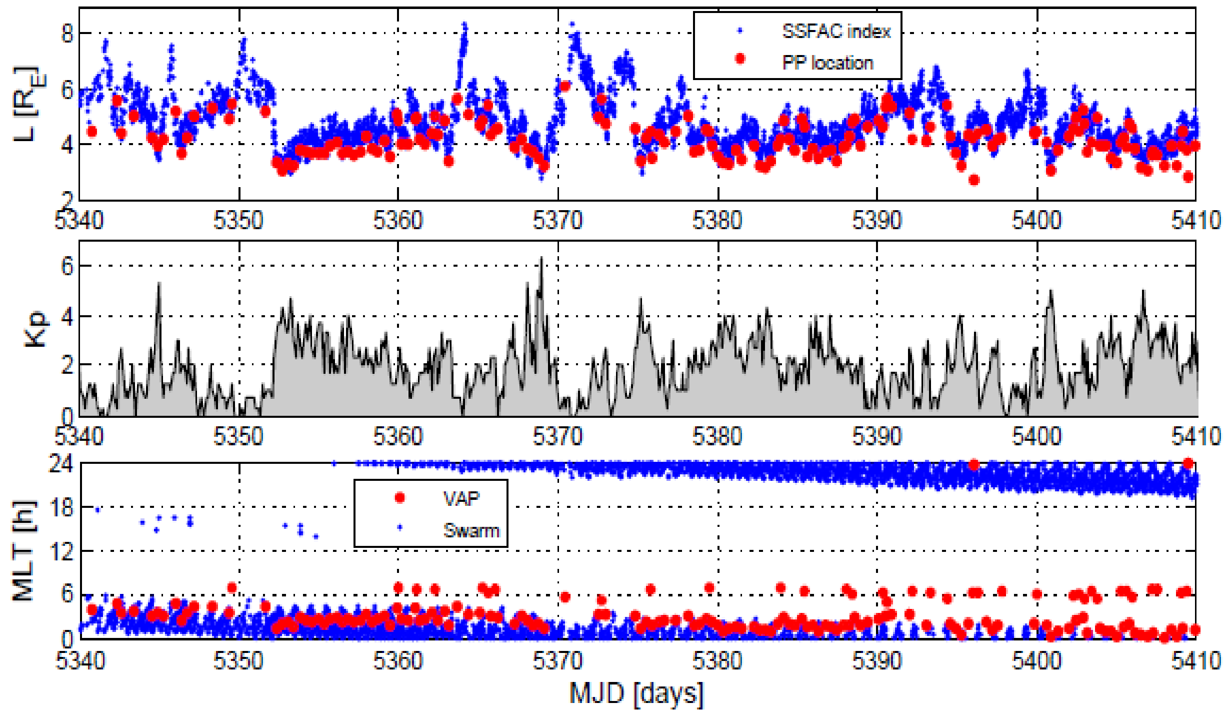
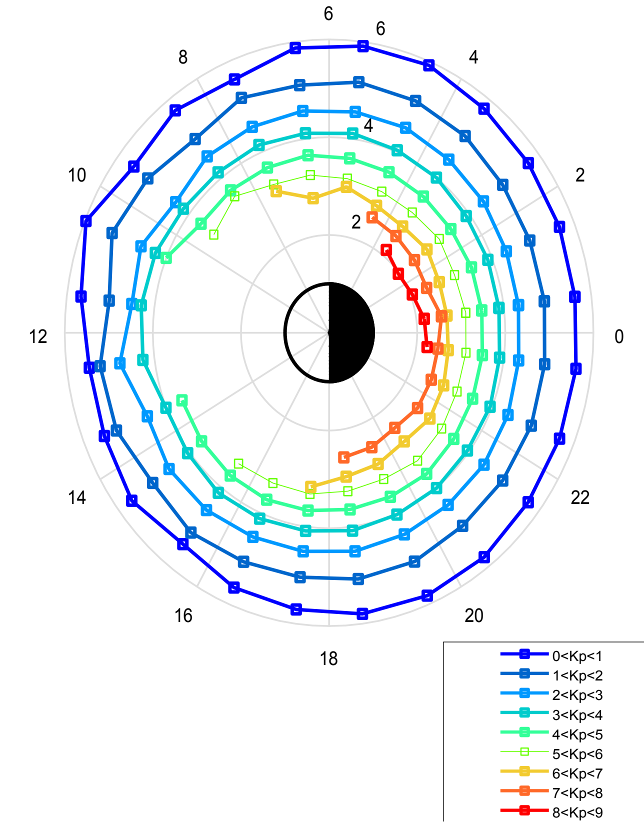


Figure 11. **(a)** Swarm SSFAC index (blue) and VAP PP_N_e (red) locations, **(b)** variation of the Kp index, and **(c)** MLT of the Swarm (blue) and VAP (red) observations.

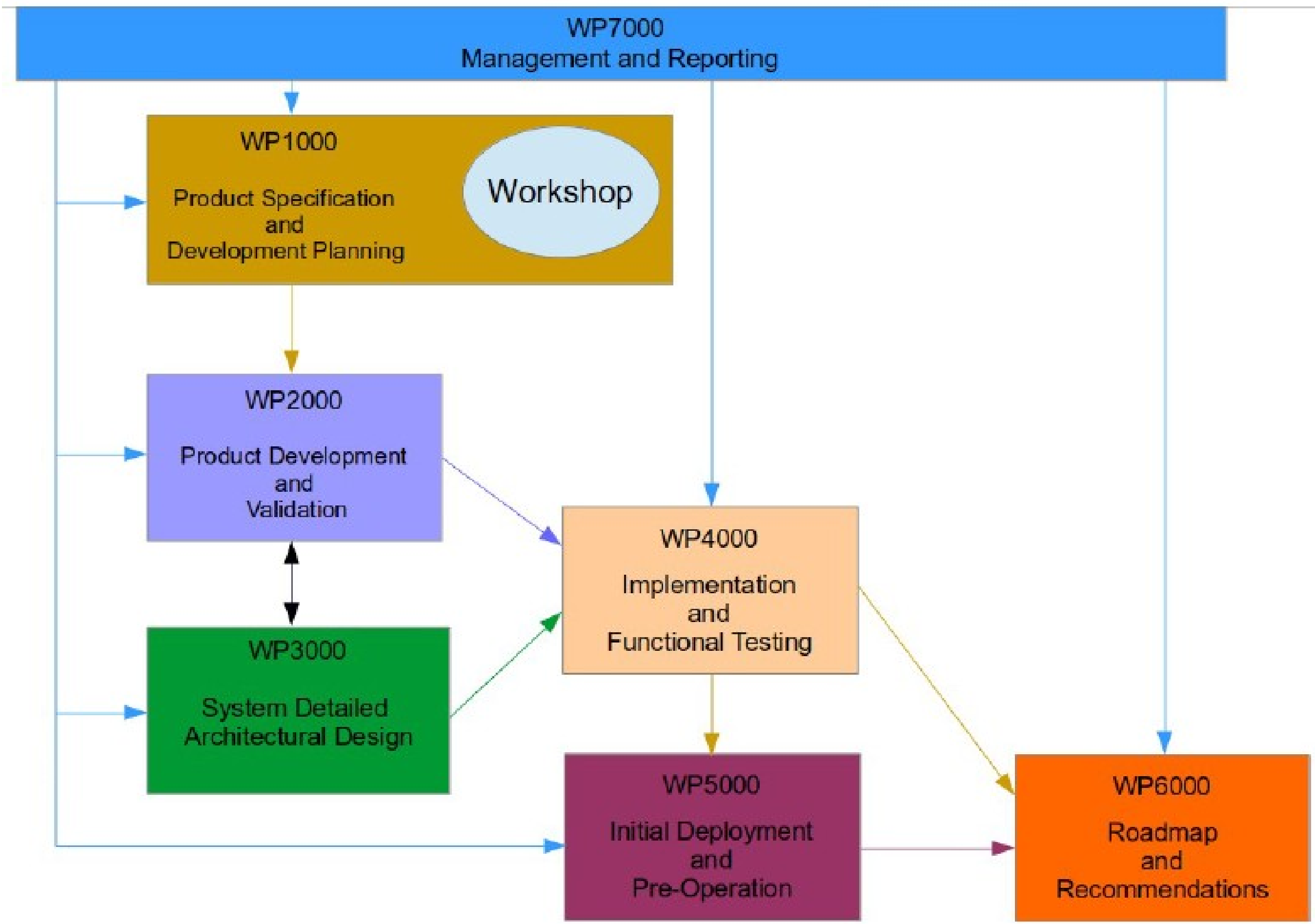
Heilig and Lühr, 2018



SSFAC boundary statistics (> 160 000 observations of CHAMP and Swarm)

ESA P3-SWE-LII Plasmaspheric Products for Space Weather Services

PLASMA is a ESA-funded project to develop and validate procucts to characterize plasmasphere and plasmapause.



ESA P3-SWE-LII Plasmaspheric Products for Space Weather Services

Development of products characterizing the plasmasphere / plasmapause and related ionospheric phenomena

The products to be developed will be based on the following key concepts:

- the plasmaspheric products need to be based on **sustainable inputs**.
- the plasmaspheric products will incorporate all available **major data sources and methods**
- for the development and validation of the products, we will use **historical/archive data as well as available models** within and outside ESA SSA SWE.

We will develop products

- based exclusively on **ground based** measurements
- based exclusively on **in-situ** measurements
- plasmasphere models based on **historical/archive** ground and space-based data
- plasmasphere models based on **real-time** ground and space-based data

Products characterizing the plasmasphere and plasmapause (nowcast, forecast and archive)

1. **Plasma density – (PD-M) with parameters:**
   - **1.1 Plasma electron density (PED)**
   - **1.2 Plasma mass density (PMD)**
   - **1.3 Field-aligned electron density (FAED)**
   - **1.4 Field aligned Mass density (FAMD)**

2. **2D electron density map (PEDM)**

3. **2D plasma mass density map (PMDM)**

4. **Plasmasphere index (PSI)**

5. **Plasmapause location limits (LPP-M)**
   - **5.1 ULpp+ and ULpp-**
   - **5.2 VLpp-**

6. **Midnight Plasmapause Proxy (MPP)**

7. **Empirical Plasmapause Model (PPM)**

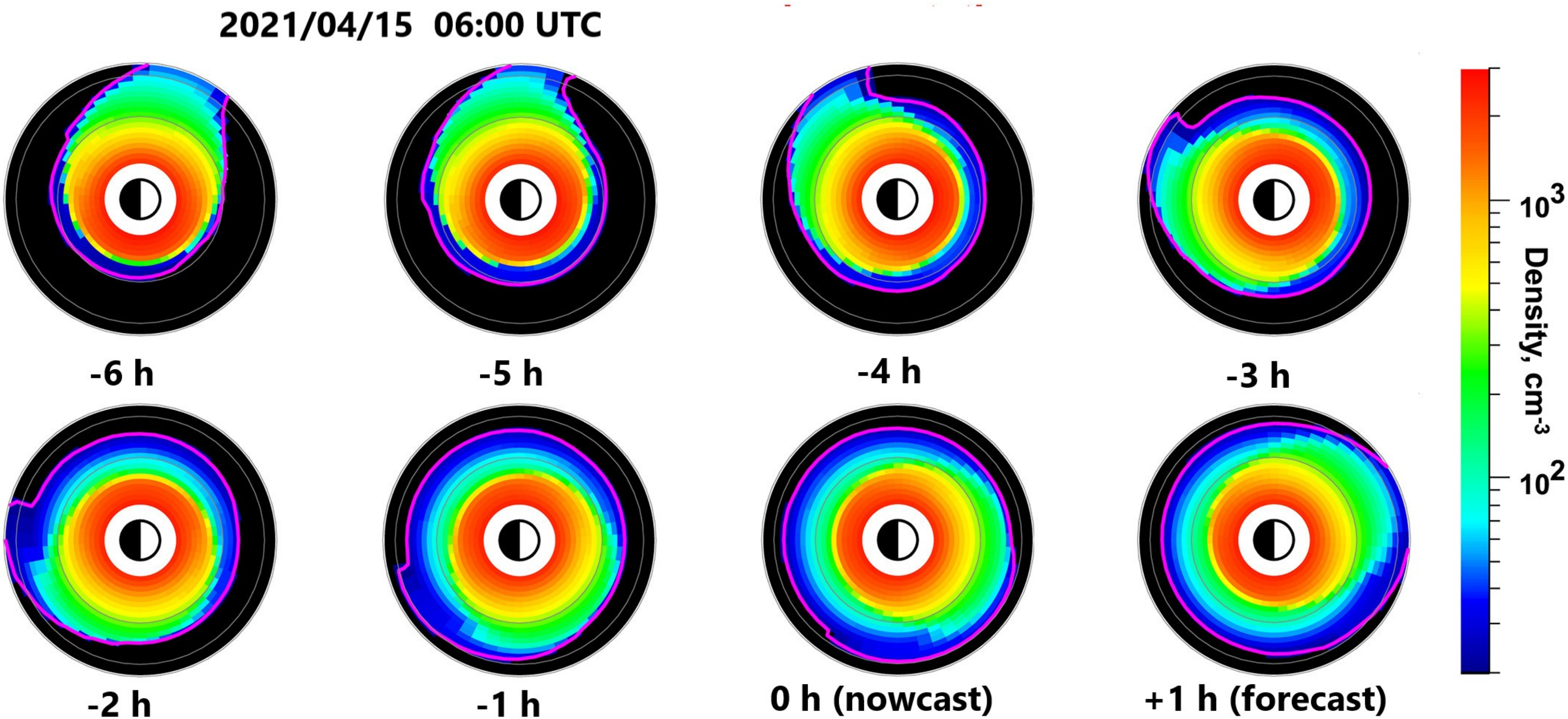
Mother products (products serve as background models but not provided directly to the users)

8. **3D Empirical Plasma Density Model (EPDM)**

9. **3D Data-assimilative Plasma Density Model (DPDM)**

Products characterizing the plasmasphere and plasmapause

2D electron density map (PEDM) (0.1L and 1h MLT resolution)



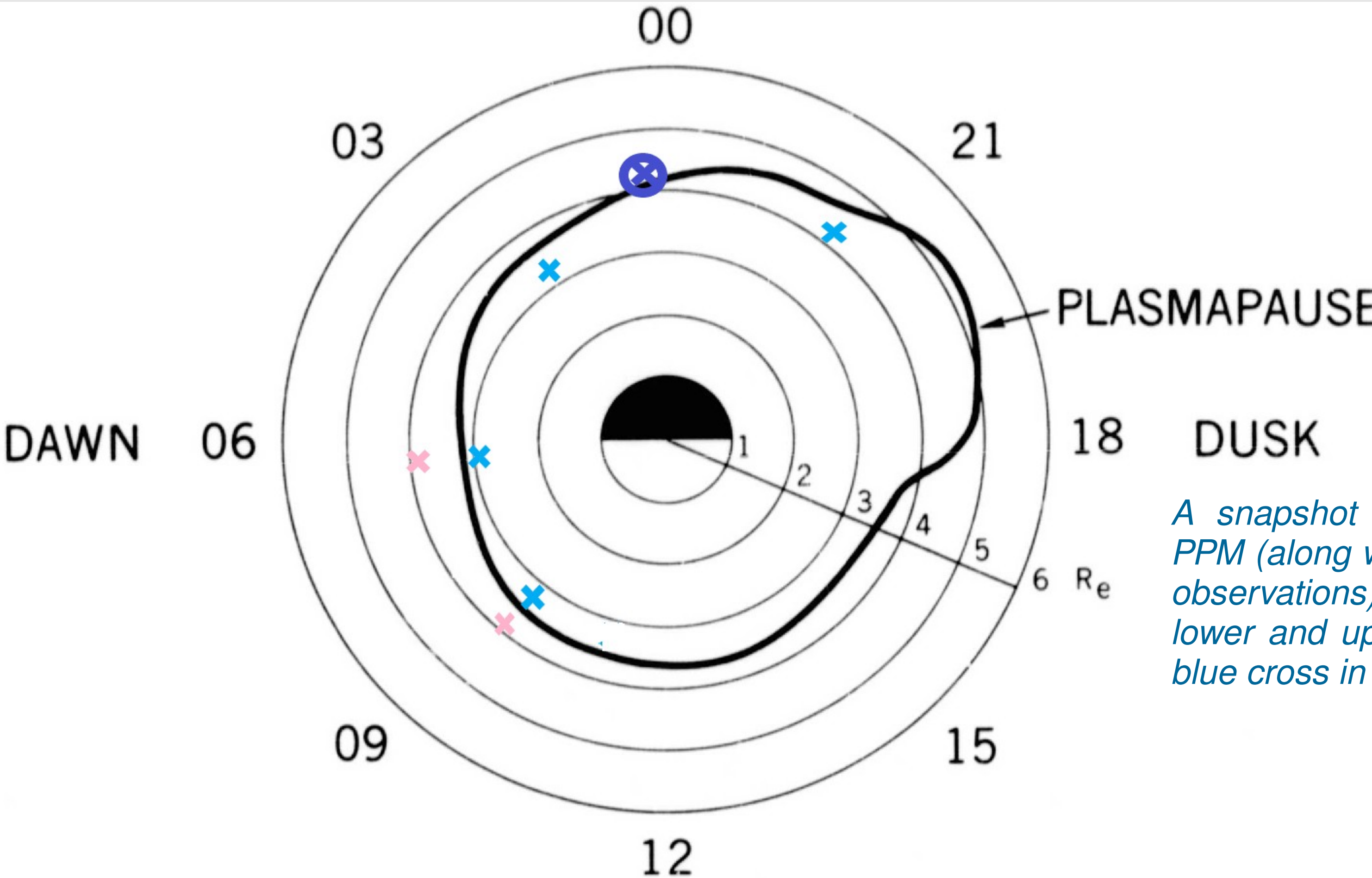
Products characterizing the plasmasphere and plasmapause

Plasmaspheric index (PSI)

Category index	State/trend	Colour
-1	eroding plasmasphere	red
0	no clear trend	yellow
1	refilling	green
2	saturated	light blue

Products characterizing the plasmasphere and plasmapause

Plasmapause location limits (LPP), midnight plasmapause proxy (MPP) and plasmapause model (PPM)

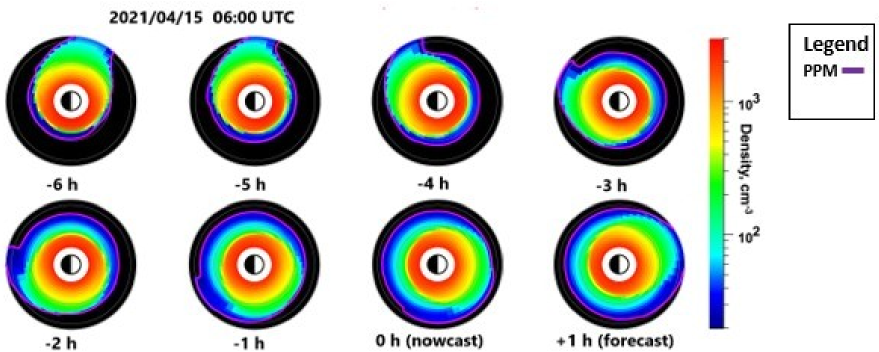


A snapshot of the plasmapause based on PPM (along with corresponding MPP and LPP observations). Light blue and pink crosses are lower and upper PP limits, accordingly, while blue cross in a circle indicates the MPP

Products characterizing the plasmasphere and plasmapause

Planned content of the federated webpage for *the pre-operation phase (~second half of 2022)*

Plasmaspheric (equatorial) electron density



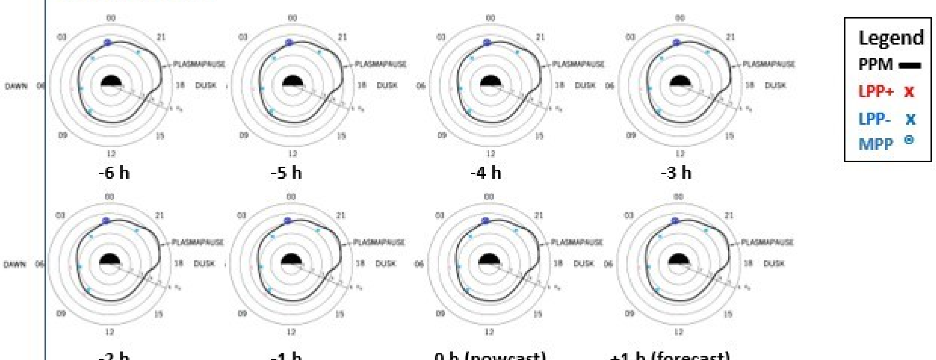
2D electron density maps (forecast, nowcast, archive)
2D plasma mass density maps (forecast, nowcast, archive)

Plasmaspheric index

Current state (09:15 UT)	1: refilling
Predicted state (+1 h)	-1: eroding
Predicted min (next 24 h)	-1: eroding
Predicted max (next 24 h)	0: no clear trend

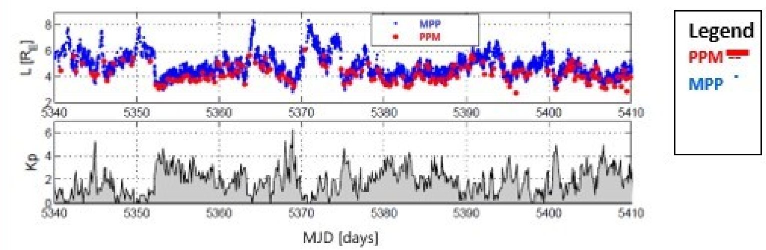
Category index	State/trend	Colour
-1	eroding	red
0	no clear trend	yellow
1	refilling	green
2	saturated	light blue

Plasmapause



Plasmapause maps (forecast, nowcast, archive)

Time history of the plasmapause



Midnight Plasmapause proxy (measurement, archive)
Plasmapause limits (measurement, archive)

Use cases

A. Direct use of plasmaspheric products

1. Radiation Belt and Ring Current models:

- plasma/electron density point measurements, hourly 2D equatorial density maps
- plasmapause size and shape (L, MLT), PP location proxies → important for energetic particle dynamics (provides a realistic input for radiation flux modelling)

2. Spacecraft operators:

- plasmapause size and shape, PP location proxies, plasma densities outside of the plasmapause → surface charging
- plasmasphere index

3. Ionosphere models:

- plasma/electron densities, density maps and density models → Plasmasphere Total Electron Content (PTEC)

B. Indirect use of plasmaspheric products

1. Spacecraft operators:

- through A.1. → inner belt proton flux >50MeV → Single Event Upset/Latchup
- plasmapause size and shape (L, MLT), PP location proxies → important for energetic particle dynamics (provides a realistic input for radiation flux modelling)

2. Spacecraft launchers + MEO/HEO satellite operators:

- through A.1. → slow lifting of GEO satellites from LEO e.g., by electric propulsion; orbiting in plasmasphere/radiation belts

3. Spacecraft designers:

- through A.1. → Deep Dielectric Charging/Discharging

4. Telecommunication and navigation (MEO/HEO) satellite operators/users:

- through A.1. →ionospheric disturbances

5. Insurance companies:

- through A.1-3. → post-event analysis

Tools using plasmaspheric products

1. Spacecraft operators (charging risk assessment):

- spatial density profiles along any or a predefined trajectory (orbit)
- temporal density variation at a location e.g., for GEO satellites

2. Ionosphere modellers (for removal of PTEC contribution from TEC to clean ionospheric TEC):

- Plasmaspheric TEC (PTEC, from the lowest altitude available from the models out to the plasmapause)
    a. various PTECs: vertical, slant, point-to-point

    b. global vertical PTEC map: