Summary Report

Plasmasphere Monitoring for Space Weather Impact Prediction (PM4SWIP)

Fraunhofer IPM

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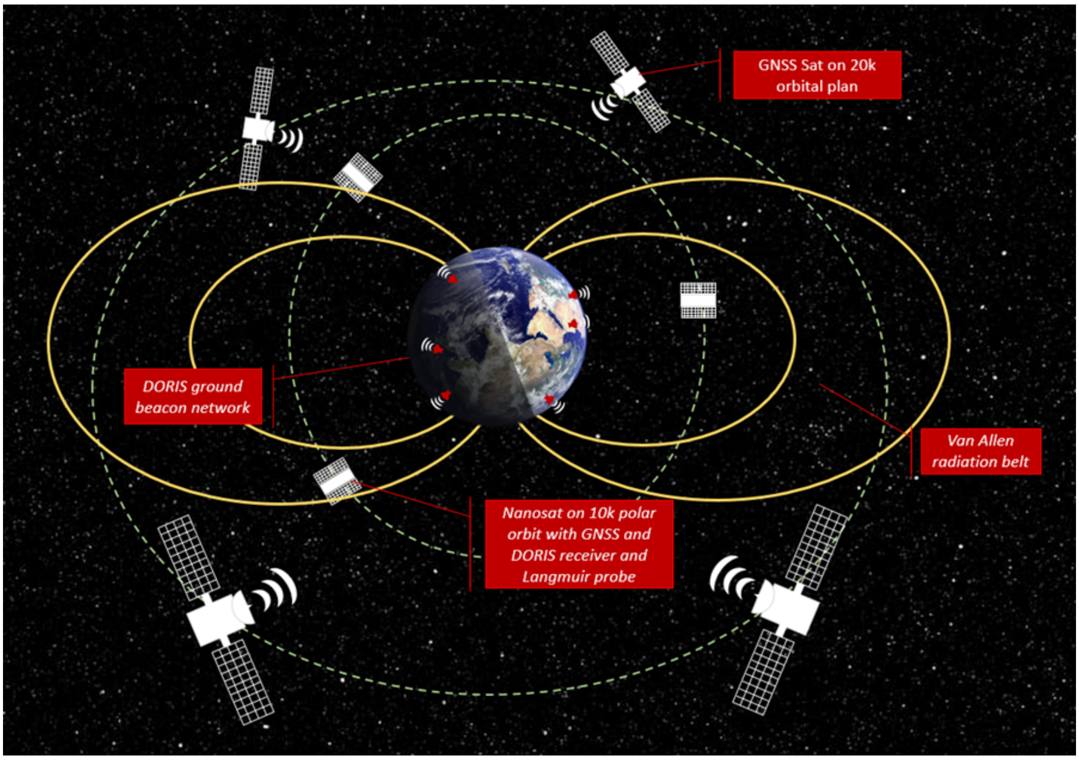
Summary

Space weather observations and prediction of expected disturbances on ground and space-based infrastructures are critical for the safety and evolution of our modern society. Space weather events, like solar storms, can have crucial impact on navigation, communication, power grids and other electrical conducting infrastructures. Therefore, space weather predictions are of high importance, but recently lack a reliable estimation of the Geo-effectivity as well as detailed information on regions and systems potentially affected. In the sun to earth interaction chain, the plasmasphere is a central source of information with respect to the Geo-effectivity of solar storms and not well investigated until now. This is surprising since the compression and change of the plasmapause is a direct information source for the strength of the solar wind and solar storm impact. The radial location of the plasmapause is controlled by a combination of the co-rotational and solar wind-driven convectional electric fields. The size as well as shape of the plasmasphere is depending on the level of geomagnetic activity. Therefore, it is an indicator of space weather events. Early warning can be given to terrestrial and orbital users based on the plasmasphere measurements. Although thousands of ground GNSS receivers provide a continuous, but regional, monitoring of the ionosphere and plasmasphere (without distinction between both layers). The plasmasphere monitoring from a satellite on a MEO (medium earth orbit) altitude has never been done before and the data will be a unique source for ionosphere/plasmasphere model calibration [1] at the MEO altitude (proposed 6,000 km) and above.

The ESA OSIP Project PM4SWIP has accomplished a concept study for a satellite mission on Plasmasphere monitoring for Space Weather impact prediction. The mission is based on a satellite constellation of 3 CubeSats (see Figure 1) orbiting at high inclination Polar orbits of about 6,000 km altitude for monitoring the plasma density variation and detecting the plasmapause location. Each CubeSat may host a DORIS Beacon receiver (400 MHz and 2 GHz) and a multi-frequency / multi-constellation GNSS receiver (e.g. the Galileo -enabled ENSPACE receiver). Additionally, each CubeSat will host a Langmuir probe (the Spherical EUV and Plasma Spectrometer – SEPS) for in-situ electron density measurements, which can in addition provide valuable EUV measurements. With this configuration we are able to determine the total electron content (TEC) towards nadir, zenith and the in-situ plasma density. Finally, all satellites will be equipped with a suitable radiation monitor.
Solar storms have their major space weather impact, when they reach the ionosphere by magnetosphere/plasmasphere coupling. From the applications perspective, one important response of the ionosphere/plasmasphere coupling in this context is the change in the electron density distribution, because of their direct effects on radio signals. Observation of changes in the ionosphere/plasmasphere, in particular in the electron density, is important to recognize the solar-terrestrial impact on communication and navigation systems.

The adequacy of the proposed measurement concept for plasmasphere monitoring and plasmapause detection has been extensively investigated by simulation studies using predicted high inclination near polar orbits for CubeSats together with a realistic three-dimensional electron density

ionosphere/plasmasphere model [2]. We found that onboard multi-GNSS total electron content (TEC) measurements and in-situ electron density data from Langmuir probe can successfully detect the plasmapause location by identifying sharp changes in the TEC and electron density derivatives when the CubeSats fly over mid-latitude regions. Although one CubeSat can independently detect the plasmapause location, a constellation of 3 satellites helps to map the plasmapause location simultaneous during day and night. The simulation study shows that the proposed mission fulfils the observation requirements for several science cases like the reconstruction of the topside plasmasphere and monitoring global dynamic distribution of plasmapause, reconstruction of plasmaspheric total electron content, developing a fully operational model of plasma density including plasmasphere and plasmapause [2] monitoring, Ionosphere/plasmasphere model calibration, monitoring ionospheric and plasmaspheric irregularities, modeling the vertical total electron content, EUV measurements to improve models of the upper atmosphere, radiation monitoring.



A satellite constellation of 3 CubeSats orbiting at high inclination Polar orbits of about 10,000 km.

The concept and feasibility study of the satellite mission shows its capability to continuously monitor the movement/shift in the plasmapause boundary, using GNSS signals as well as an onboard Langmuir probe. The study includes all information for the constellation of two orbits about 6.000 and 10.000 km with its Pro and Con's. The possibility of a radiation monitor, as suggested by the ESA project team, is also discussed in the document.

The technical requirements for GNSS and DORIS receivers, and SEPS instrument are investigated and defined. The orbit design and launch feasibility as well as mission operations concept including ground segment, data reception and data distribution are investigated for near real-time operations. Considering 23 ground stations from KSAT service for data downloading it is found that one CubeSat is visible about 460 times a day for a duration of about 30-60 minutes. Over 90% cases data download latency is found below 15 minutes. The mission fact sheet in Table 1 provides more detailed information on constellation, orbit parameters and suggested payloads with their parameters (Weight, Power, Volume).

Table: Mission Fact Sheet

Constellation:				
Shall consist of three CubeSats placed into the MEO Orbit at 6000 km height.				
Orbitparameter:				
SMA [km]	12 000			
T [s]	13082 s (3h:38m:2s)			
ECC [-]	0			
INC [deg]	110			
Payloads:	Weight [g]	Power [W]	Volume [U]	Provider & Comments
DORIS-GNSS	500 (+shielding & housing)	13 consum.	1 U (100x100x70)	In development by CNES
DORIS antenna	500	passive	4 U (210x210x50)	
GNSS antenna	425	passive	1 U 28 mm height 92 mm edge diameter	Antcom
SEPS	600	7.5 consum.	3 U 220 mm (total height), 80 mm sphere diameter	IPM Frauenhofer (optional E-Box as socket for preamplifier and electrometer + 50 x 180 x 120 mm)
Floating Gate Dosimeter	100 (+shielding & housing)	< 0.5 consum.	1 U	iC-Málaga [1]
Fail-safe bus	> 500	> 31 provision	2 U	Including [2]: On-board computer UHF transceiver S-band transmitter Z-magnetorquer Electric Power System
Total	> 3000	31 consum.	12 U	
Ground reception:				
One CubeSat will be visible about 460 times a day for a duration of about 30-60 minutes considering 23 ground stations from KSAT service. The maximum latency for data downloading is found about 1 hour. However, over 90% cases the latency is below 15 minutes.				
S-Band				

Investigation of the mission potential to improve space weather services with focus on the ESA-S2P Space Weather network has been done. Determination of potential real-time dissemination channels via Galileo also has been addressed. The dissemination of any gathered data on Earth's plasmasphere and space weather events needs to be differentiated regarding its use: Scientific and/or commercial services as well as emergency services. The PM4SWIP Mission has strong potential to make significant contributions to all three kind of services. Scientific and/or commercial services can benefit from plasmasphere data to understand, predict and mitigate space weather related impact on their services, such as GNSS or satellite communication. While this mission provides limited plasmasphere data on a global scale, its outputs can be used to populate ionospheric models. These models can help predict satellite communication disturbances as well as lowering satellite orbit determination and prediction uncertainties. For emergency services, any space weather warnings need to be provided to governmental agencies for Civil Protection and Disaster Management. It is then up to these agencies to decide the dissemination method for such warnings. PM4SWIP can improve Early Warnings with detailed spatio-temporal solar storm impact information. Especially the combination of PM4SWIP mission data with information from existing and recently discussed ESA Space Weather missions at Lagrange points L1 and L5, as well as, LEO observations can close the observation chain from Sun to Earth. The mission data are important for existing national and international Space Weather Services and could therefore be a valuable addition to ESA's distributed space weather monitoring system (D3S).

An important challenge of the anticipated mission is the deployment of measurements with small satellites on a MEO covering remote sensing tasks (with GNSS and DORIS signal) and in-situ observations with (Langmuir probes and dosimeters). This deployment will be a unique source of data for scientific investigations of the plasmasphere, on the one hand, and an excellent opportunity, on the other hand, to advance space technology (satellite bus systems and scientific payloads) for small satellite missions on MEO altitudes. Other missions prove the possible integration of GNSS remote sensing technology (reflectometer) and space weather sensors (dosimeter) on a cubesat, see the PRETTY satellite [4]. The described PM4SWIP mission will progress in altitude with benefit for other future concepts for medium-earth and lunar-transfer orbits. The challenges, that have to be tackled, include the adaptation of the GNSS receiver to visibility and signal strength conditions in the MEO altitude, the development of an integrated DORIS receiver for small satellite use that is also capable for long signal range observation at MEO altitudes and the adaptation of hardware, in general, to the increased radiation (MEO compared to LEO). Apart from small satellite concepts, progress in these challenges will also be beneficial for larger MEO satellite concepts: the next generation Galileo system and an anticipated co-location of geodetic methods in space, see studies in [5] and [6]. The specifications of the PM4SWIP mission concept are challenging but can be be achieved based on the existing technology according to the recent investigations. More detailed investigations on the designated satellite setup need to be done in further studies together with industry.

List of literature

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