3.2 CLUSTER AND DEMETER SATELLITE DATA IN ESPAS

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Abstract. The web portal of the FP7 ESPAS (Near-Earth Space Data Infrastructure for e-Science) project allows to retrieve electron density data from two European missions. The Cluster mission consists of four identical satellites (C1, C2, C3, C4) launched in 2000 on elliptical polar orbits with an initial perigee at $\sim 4\,R_E$, an apogee at $\sim 19.6\,R_E$ and an orbital period of ~57 hours. The spacecraft continue to investigate the Earth's magnetic environment and its interaction with the solar wind in three dimensions. The DEMETER (Detection of Electro-Magnetic Emissions Transmitted from Earthquake Regions) mission has been launched in June 2004 into a quasi sun-synchronous circular orbit (inclination of 98.3°) at 710 km altitude. The satellite operated until December 2010 and was devoted to the study of ionospheric disturbances related to seismic activity and pre- and post-seismic signatures, and to human-induced ionospheric effects. Both missions carried several scientific instruments, with some of them in particular allowing to determine some plasma parameters at the position of the satellite. On Cluster, the WHISPER (Waves of HIgh frequency and Sounder for Probing Electron density by Relaxation) instrument determined the electron density. On DEMETER, ISL (Instrument Sonde de Langmuir) measured the electron density and temperature. The missions, instruments and datasets are described in this paper.

3.2.1 Introduction

The European Commission FP7 ESPAS (Near-Earth Space Data Infrastructure for e-Science) project has been developed from November 2011 during 4 years (`http://www.espas-fp7.eu/`). Its main goal was to facilitate the access to archived observations and model-derived data of the near-Earth space environment, from

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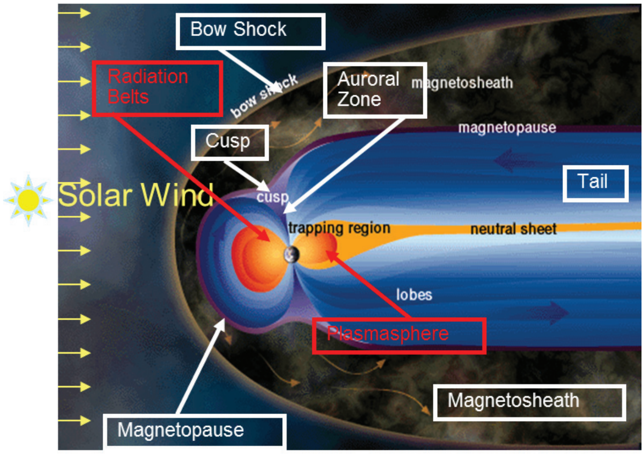

Fig. 3.2.1. Schematic representation of the magnetosphere of the Earth, its boundaries and sub-regions. (Courtesy of ESA)

the middle atmosphere up to the plasmasphere (Belehaki *et al.* 2014). The ESPAS web portal (`https://www.espas-fp7.eu/portal/`) offers an interoperable infrastructure to find, access and download data from various ground-based and space-borne instruments. This enables the exploitation of multi-instrument, multi-point science data for analysis, model building, data assimilation into models, model-observation comparison, space environment nowcast and forecast. This project ended in November 2015 and the ESPAS web portal is now fully operational.

The platform allows to access data from a variety of different sensors located on ground but also onboard satellites, and in particular Cluster and DEMETER (Detection of Electro-Magnetic Emissions Transmitted from Earthquake Regions). Cluster is a four-spacecraft mission still orbiting in the Earth's magnetosphere and solar wind, while DEMETER is an ionospheric mission that worked until end 2010.

This paper introduces the Earth's magnetosphere and one inner region, the plasmasphere in Sect. 3.2.2 and then the two missions and datasets in Sect. 3.2.3. The access to data through the ESPAS portal is described in the Chapter 5.1 and some conclusions are presented in Sect. 3.2.4.

3.2.2 Magnetosphere and plasmasphere

3.2.2.1 Magnetosphere

The magnetic field of the Earth (similar to a dipole) and the solar wind from the Sun create a magnetic cavity around the Earth called the terrestrial magnetosphere (Gold 1959). As shown on Fig. 3.2.1, it is compressed in the direction of the Sun (dayside, 12:00 LT [local time], $\sim 10\,R_E$) and elongated in the opposite direction (nightside, 00:00 LT, $\sim 100\,R_E$). As the solar wind escapes the Sun and is directed towards the Earth, it is deflected around the Earth by the magnetosphere. There is an external boundary called the magnetopause, two boundary regions, the magnetosheath above and the ionosphere below, and several sub-regions including the plasmasphere.

3.2.2.2 Plasmasphere

The plasmasphere is a region of the inner magnetosphere with a toroidal shape. It is globally in co-rotation with the Earth and populated by cold plasma coming mainly from the ionosphere (Lemaire and Gringauz 1998), (Kotova 2007), (Darrouzet *et al.* 2009a), (Singh *et al.* 2011), (Darrouzet and De Keyser 2013). It has been discovered in the late 50's, early 60's, with the first results obtained from ground-based instruments (whistlers detectors) (Carpenter 1963), but also from satellites (Lunik 2) (Gringauz 1963).

The plasmasphere is composed of electrons and positive ions, with an energy of a few eV, a density between 10 and 10^4 cm^{-3} and a temperature of about 10^4 K. Its outer boundary is called the plasmapause and is often characterized by a sharp decrease of the density. At the equator, it extends out to a radial distance of 2 to 8 R_E, depending on the geomagnetic activity (indicated by the index Kp). Figure 3.2.2 is a representation of the plasmasphere with its outer boundary and typical trajectories of the Cluster and DEMETER satellites.

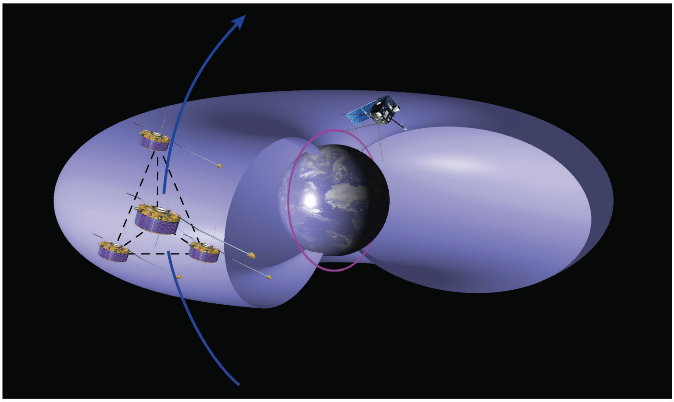

Fig. 3.2.2. Schematic representation of the plasmasphere around the Earth, with its outside boundary and typical trajectories of the 4 Cluster satellites and the DEMETER spacecraft. (Adapted from (Darrouzet *et al.* 2009a))

3.2.3 Missions and datasets

3.2.3.1 Cluster/WHISPER

The Cluster mission consists of 4 identical satellites: Rumba (C1), Salsa (C2), Samba (C3), Tango (C4) that have been launched in Summer 2000 (Escoubet *et al.* 1997). The satellites have a polar orbit (orbital time of 57 hours, initial perigee and apogee of about 4 and 19.6 R_E) and traverse the inner magnetosphere during every orbit around perigee. The 4 satellites are in a tetrahedral configuration that changes along the orbit. The spacecraft separation distances have been modified almost every year (from 10 to 10^4 km).

Onboard, there are 11 well-calibrated instruments, including the WHISPER (Waves of HIgh frequency and Sounder for Probing Electron density by Relaxation) instrument (Décréau *et al.* 1997). It is a wave instrument using for reception one of the two long double sphere antennas (wire booms with a sphere-to-sphere separation of 88 m) of the EFW (Electric Field and Wave) instrument (Gustafsson *et al.* 1997). Figure 3.2.3 shows one of the Cluster spacecraft with all the booms and antennas deployed. In particular the wire booms of the EFW instrument used by WHISPER are shown extending on both sides of the satellite.

The WHISPER instrument measures the electric field in the frequency range 2-80 kHz, with a frequency resolution of 0.163 kHz and a time resolution of 2 s in normal mode (Décréau *et al.* 2001). WHISPER has 2 modes: (i) an active mode, in which the sounder analyses the pattern of resonances triggered in the medium by a radio pulse; (ii) a passive mode, in which the receiver monitors the natural plasma emissions.

Several methods can be used to determine the electron plasma frequency F_{pe} from the data recorded by the WHISPER instrument: the identification of local wave cut-off properties (Canu *et al.* 2001), the observation of Bernstein modes

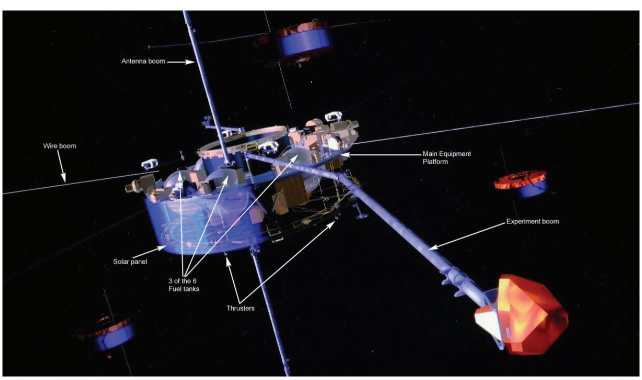

Fig. 3.2.3. Diagram of one of the Cluster spacecraft showing its main structural features. The wire booms of the EFW instrument used by WHISPER are shown extending on both sides of the satellite. (Courtesy of ESA)

(Trotignon *et al.* 2003) or the use of lower hybrid resonances (Kougblénou *et al.* 2011). This analysis carries out a direct or indirect determination of the electron density N_e related to F_{pe} by the simple relation:

$$N_e[cm^{-3}] = F_{pe}[kHz]^2/81.0 \tag{3.1}$$

Figure 3.2.4 presents four time-frequency electric field spectrograms recorded by the WHISPER instrument onboard each Cluster spacecraft during a plasmasphere crossing on 11 April 2002 (Darrouzet *et al.* 2004). This shows clearly the crossing of a plume during the inbound and outbound passes, as well as many small density structures inside the plasmasphere (Darrouzet *et al.* 2009b). From those spectrograms, it is possible to determine F_{pe} and then derive N_e in the plasmasphere and also at the plasmapause (Darrouzet *et al.* 2013).

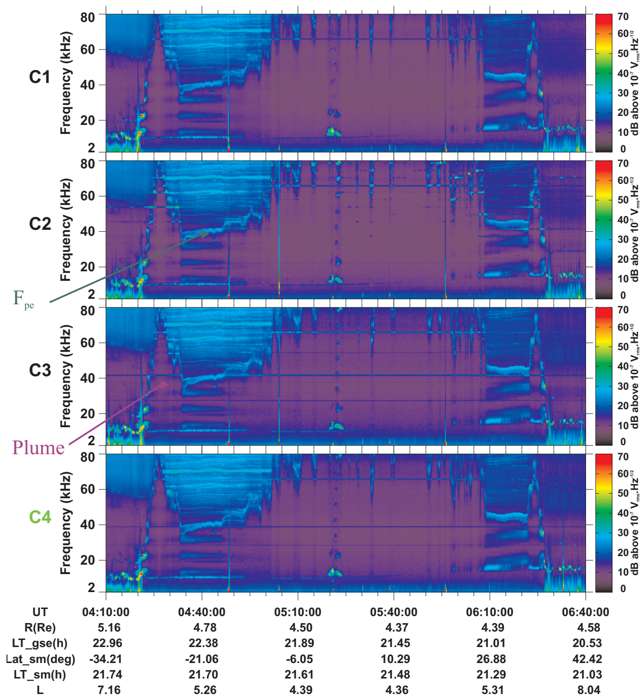

Fig. 3.2.4. Time-frequency electric field spectrograms measured by WHISPER onboard the four Cluster spacecraft on 11 April 2002 between 04:10 and 06:40 UT. The electron plasma frequency F_{pe} line is indicated by a green arrow. A plume crossing is shown by a purple arrow. The orbital parameters of C4 are indicated at the bottom of the figure. (Adapted from (Darrouzet *et al.* 2006))

3.2.3.2 DEMETER/ISL

DEMETER (Detection of Electro-Magnetic Emissions Transmitted from Earthquake Regions) was a micro-satellite (130 kg) devoted to the investigation of Earth ionosphere disturbances due to seismic and volcanic activities (Cussac *et al.* 2006). It was a sun-synchronous satellite orbiting at 710 km altitude, with a 98.3° inclination and was passing in almost the same local time everywhere during the day at 10:30 LT and during the night at 22:30 LT. It was launched in June 2004 and stopped working in December 2010.

DEMETER had two science modes of operation: (i) a survey mode collecting averaged data all around the Earth, with onboard processing to reduce the telemetry flow to 25 kb/s; (ii) a burst mode collecting data with a high bit rate of 1.7 Mb/s mainly activated above seismic regions.

Onboard, there were 6 instruments (see Fig. 3.2.5), including the ISL (Instrument Sonde de Langmuir) (Lebreton *et al.* 2006). ISL was a Langmuir probe comprised of two sensors: (i) a classical cylindrical sensor and (ii) a spherical sensor with its surface divided in seven segments. The two main observed properties measured by ISL were the electron density from 10^2 to $5.10^5\ \mathrm{cm}^{-3}$ and the electron temperature from 600 to 10000 K. They were obtained with a 1 s time resolution.

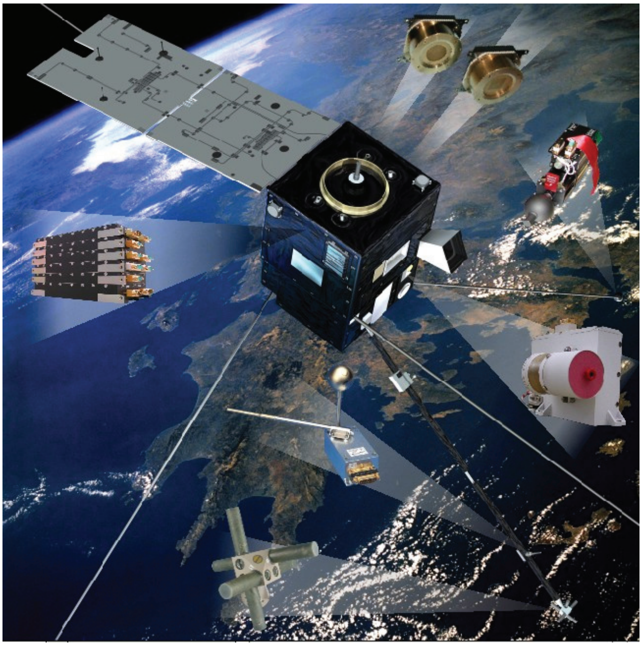

Fig. 3.2.5. Artistic representation of the DEMETER micro-satellite orbiting above the Earth, with the 6 instruments displayed around the satellite body. ISL is represented just below the satellite. (Courtesy of CNES)

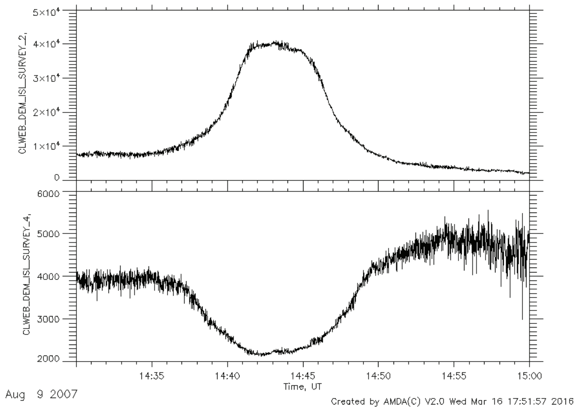

Fig. 3.2.6. Electron density in cm^{-3} (top) and electron temperature in K (bottom) measured by the ISL instrument on 9 August 2007 during 30 minutes. (Courtesy of AMDA/CDPP)

Figure 3.2.6 shows an example of the electron density and temperature measured by ISL on 9 August 2007 during 30 minutes, showing in particular an enhanced equatorial electron density between 14:38 and 14:48 UT, with a simultaneous electron temperature decrease.

The two datasets described in this section are available through the ESPAS web portal (`https://www.espas-fp7.eu/portal/`) and their access is described in the Chapter 5.1.

3.2.4 Conclusion

We describe in this paper two satellite datasets that can be downloaded through the ESPAS web portal. The first one is the electron density determined from the WHISPER instrument onboard the magnetospheric mission Cluster. The second one is the electron density and temperature measured by the ISL instrument onboard the ionospheric mission DEMETER. Both datasets are easy to use and interesting for combined ionospheric and magnetospheric research.

3.2.5 Acknowledgements

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