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Automatic identification of the bow shock, radiation belt edge and the neutral sheet in Cluster measurements

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Abstract *Three boundary layers, the bow shock, the neutral sheet and the outer rim of the outer radiation belt were detected automatically by our algorithm developed as a part of the Boundary Layer Identification Code (BLIC) Cluster Active Archive (CAA) project. The neutral sheet and the radiation belt positions are determined from magnetic field and energized electron measurements, respectively, working properly onboard all Cluster spacecraft. For bow shock identification we use magnetometer data and, when available, ion plasma instrument data. In addition, WHISPER electron density, EFW spacecraft potential measurements and wake indicator auxiliary data are also used so the events can be identified by all Cluster probes in highly redundant way, as the magnetometer and these instruments are still operational in all spacecraft. The software tool could later be modified to analyze the measurements of other satellites.*

Here we focus on the algorithms however these results could be used for further scientific analysis as well as development of bow shock, radiation belt and neutral sheet models; or statistical studies.

Radiation belt edge

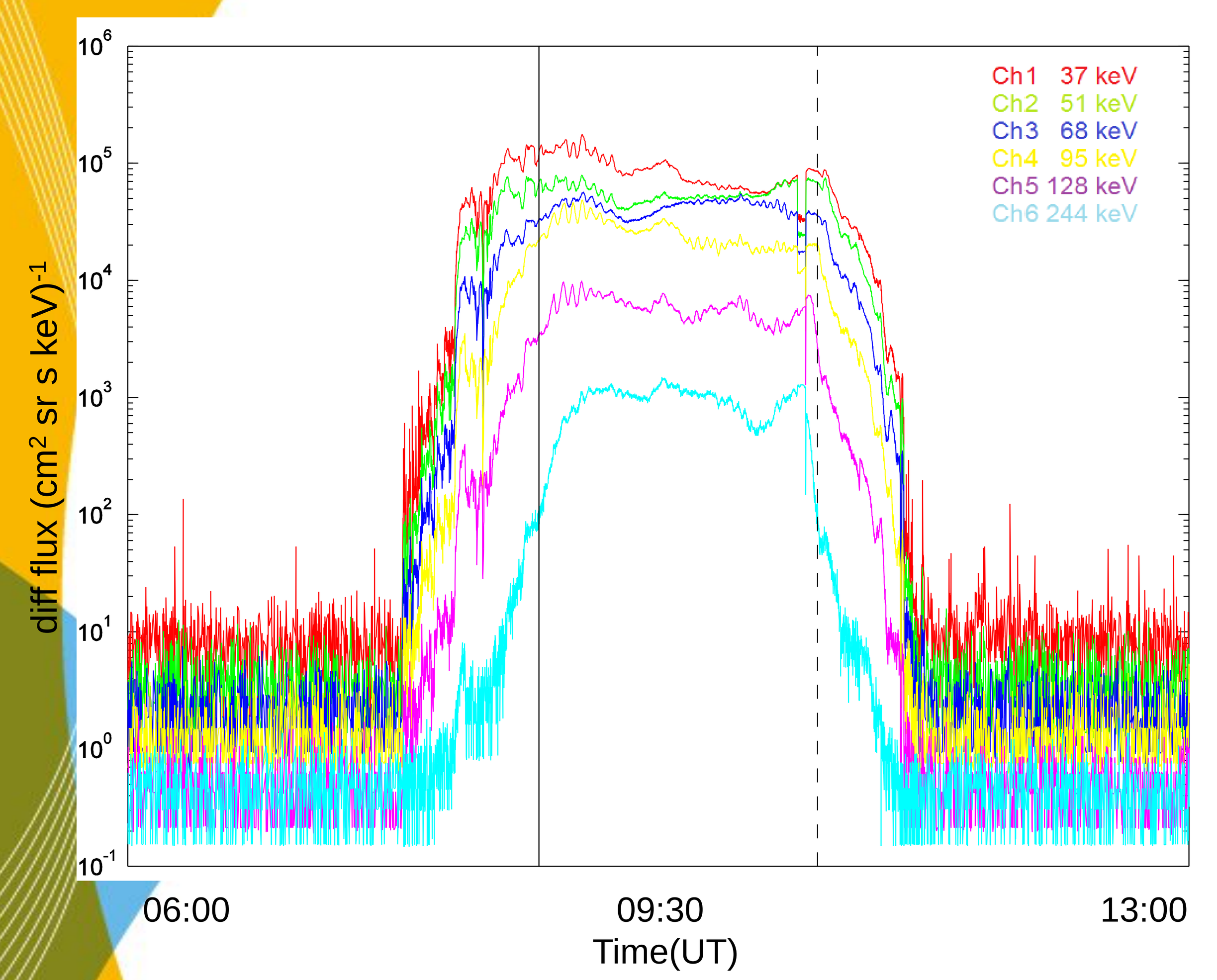
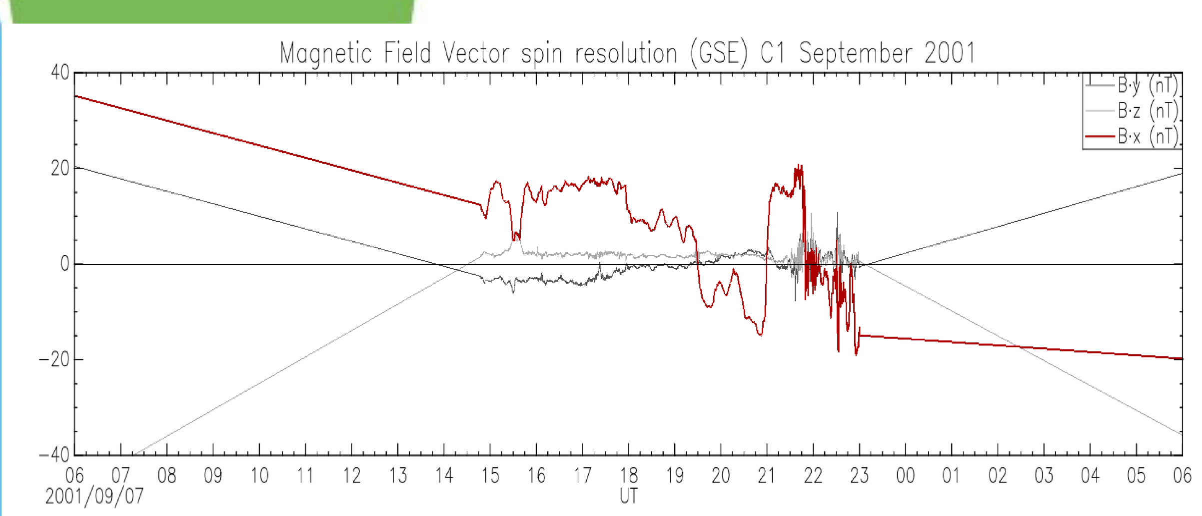


Figure 1.: *Radiation belt crossing event from 06:00 to 13:00 on September 23, 2001 on board Cluster SC4. The vertical solid and dashed lines are the determined edges of the radiation belt based on the measured differential fluxes of the Channel 6.*

After long debate a very simple definition was given for radiation belt crossings by the instrumental team of Cluster Ionspectrometry (PI: Iannis Dandouras). The spacecraft is in the radiation belt if the differential flux of the omnidirectional suprathermal electron measurements of in the highest (>244 keV) chanel of the RAPID (Research with Adaptive Particle Imaging Detectors; Wilken et al, 2001) instrument. Is greater than 100 (cm^2 sr s keV)$^{-1}$ (Figure 1). The data of the Chanel 6 was one minute median filtered to avoid false identification of fluctuations.

Neutral sheet



time_first	time_last	normal	only 1/min	1 min smooth	time_first (smoothed)	time_last (smoothed)
07-Sep-2001 19:29:44	07-Sep-2001 22:48:32	33	10	13	07-Sep-2001 19:29:36	07-Sep-2001 22:07:14

Figure 2.: *Cluster SC3 neutral sheet crossing event from September 7, 2001 19:44 (UT) to September 7 22:48 (UT). Bx, By, Bz magnetic field components (FGM) were plotted. The number of crossing was counted three different ways: all of them were considered, only 1/min and the number of crossings in 1 min smoothed data.*

The neutral sheet crossing is identified by the sign change of X component of the magnetic field, B_x, in the GSE or GSM coordinate system (e.g. Wang and Xu, 1994). B_x is a good indicator of the tail-like component of the field far in the tail and in the midnight sector. In the dawn and dusk sectors of the near-Earth tail the Y component of the geomagnetic field becomes large and even dominant. Also, as pointed out by Lopez (1990), in the dipolar field region the use of GSE/GSM coordinates overestimates the magnetic latitude of the neutral sheet. The automated search is performed for those orbits that have their apogee on the night side (X < 0). The perigee region is excluded by demanding that |B| < 50 nT. From the remaining part of the B_x data the sign changes are identified (Figure 2).

Bow shock identification

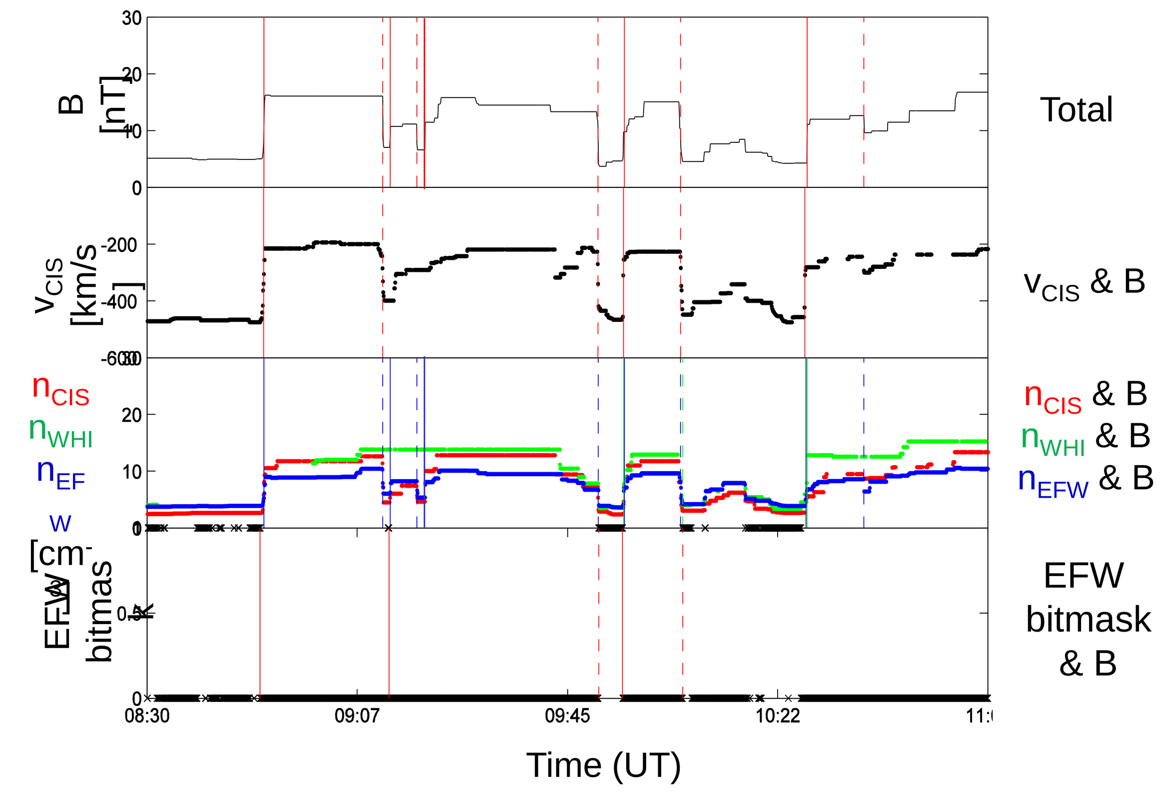


Figure 3.: *Multiple bow shock crossing identification on March 9, 2001 between 08:30 and 11:00 onboard spacecraft 1. The fields are from top to bottom: the magnetic field magnitude, solar wind ion plasma speed; CIS ion, WHISPER electron and EFW density calculated from spacecraft potential by empirical density form and EFW wake indicator bit. The inward crossings were indicated with red vertical lines, the outward crossings are green. All physical quantity were one minute median filtered before searching.*

Crossing the bow shock makes a sharp gradient in the magnetic field, the solar wind ion velocity, ion and electron density measured by the FGM (Fluxgate Magnetometer, Balogh et al., 2001), CIS HIA (Cluster Ion Spectrometer Hot Ion Analyser, Reme et al., 2001), WHISPER (Whisper of HIgh frequency and Sounder for Probing Electron density by Relaxation, Decreau et al, 2001) and EFW (Electric Field and Wave, Gustafsson et al., 2001). This jump is detected by the software in the magnetic field magnitude, CIS HIA ion density and WHISPER electron density. The CIS ion speed drops but technically it can also be considered as a jump. Using the empirical density formula

$$n_{EFW}=200(V_{sc})^{-1.85}$$

where n_{EFW} is the calculated density and V_{sc} is the EFW spacecraft potential (Gustafsson et al., 2001) the jumps of EFW potential can be detected. The jump of the condition is identified by the rate and the difference of smoothed (averaged or median) quantity. All measurements are one-minute median filtered to decrease the noise and eliminate the false identification of fluctuations. A transition is considered only if the last intersection is at least one minute far. Maximum and minimum value of the quantity can be given.

The wake identification bit EFW can be used for identifying whether the spacecraft is in the solar wind (See CAA EFW User Guide). By the way this bit can provide false identification so the detected crossing can be accepted only if the crossing can be seen in the magnetic measurements too.

In optimal case we get different time series of magnetic field magnitude, CIS HIA plasma ion velocity and density, WHISPER density, EFW empirical formula and EFW wake indicator bit. The magnetic field is compared individually against each of the four other quantities, and from each pair, the common results are kept. Finally the four different time series are unified (Figure 3).

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Results

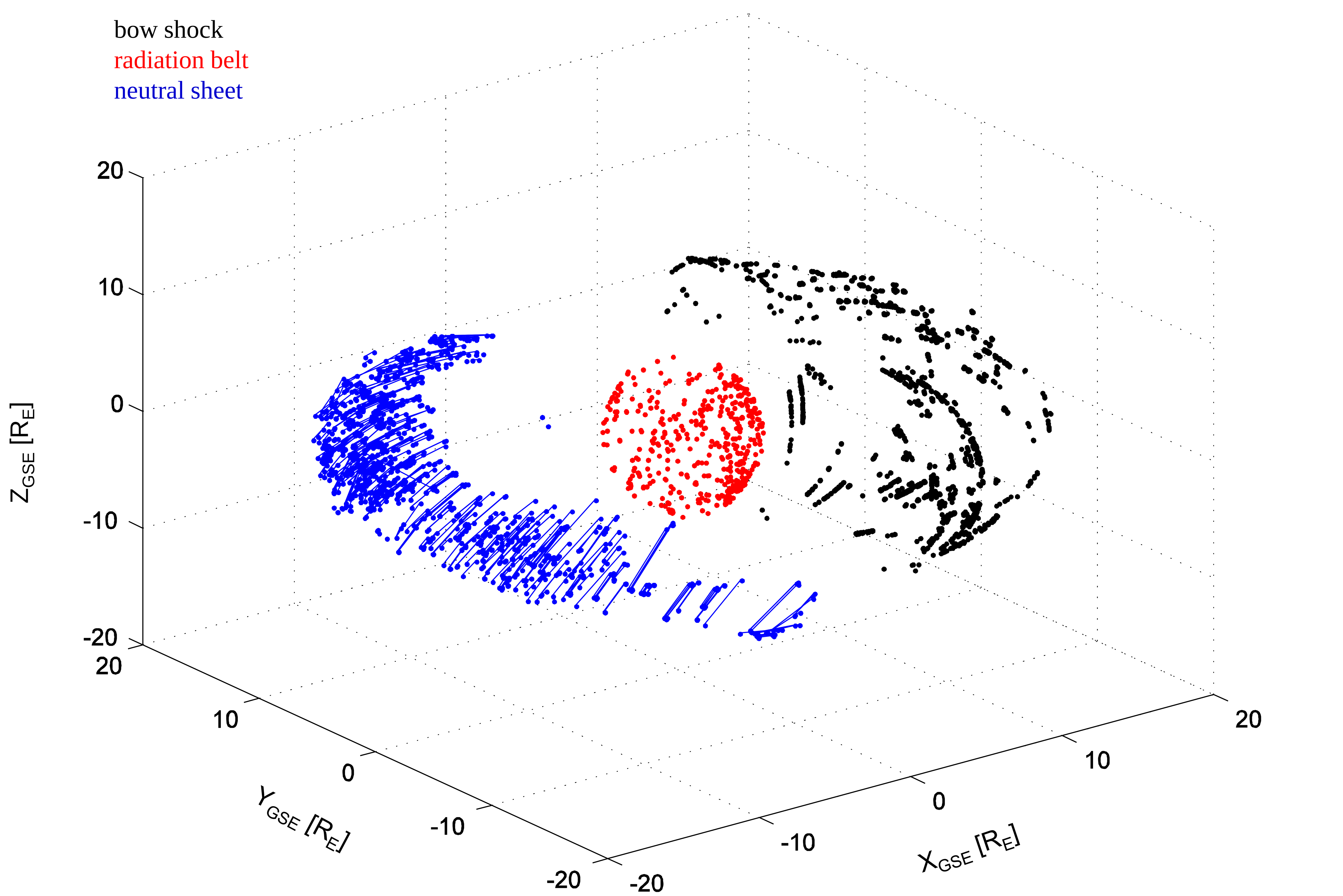

Figure 4.: *The result of the BLIC project in 3D GSE system: the identified bow shock (black) and radiation belt edge (red) crossings based on Cluster FGM, CIS HIA, EFW, WHISPER and RAPID measurements from March, 2001 to February, 2002. The bow shock and radiation belt are raw data provided by the automatic search algorithms and manual validation is necessary for accepting these results. The neutral sheet crossings (blue) had already been validated manually, so only the first and last crossings were plotted. Their identification were based on FGM measurements and Cluster position data from 2001 to 2006.*