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A study of the Earth's upstream region using Cluster measurements

Thesis contents

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Introduction

The cosmic environment of the Earth is determined by the interaction between our planet's magnetic field and the solar wind. The state of solar wind plasma has an influence on the Earth's cosmic environment i.e, the magnetosphere, magnetosheath, geotail and the position of the bow-shock. In addition the variation of solar wind discharges accounts for the different particle population and deviating energy distributions. It is impossible to separate the temporal variation of measured date to spartial variations if the environment changes dynamically. This makes necessary to perform measurements utilising multiple spacecrafts. The four Cluster spacecraft were designed and launched for this particular purpose (Escoubet et al., 1997a,b). Their main objective was to observe the Earth's magnetic field and it's plasma environment. To facilitate this all four spacecraft were equipped with particle detectors and plasma instruments to observe the electromagnetic waves in the magnetosphere. I have analyzed the measurements of FGM[1] fluxgate magnetometer (Balogh et al., 1997), CIS[2] plazma instrument (Rème et al., 1997, 2001) and RAPID[3] energetic particle detector (Wilken et al., 1997). It is with these measurements that I calculated the pitch-angle distribution of supratermal particles, in addition, I have developed a unique method for the transformation of measurements to the plasma frame from spacecraft frame to negate the Compton-Getting effect. In the summation of all this data I also compensated for the mistake of RAPID detector heads.

The *hot flow anomalies* are temporary disturbances of our planet's bow-shock and the upstream region. The events were initally discovered by AMPTE[4] and ISEE[5] missions in 1985 (Schwartz et al., 1985; Thomsen et al., 1986). The main features of this diamagnetic cavity is a compressed magnetic field on the rim and is filled by hot, tenuous plasma. It is worth noting that the direction of this plasma differs significantly to the direction of solar wind flow. The HFAs can disturb the solar wind significantly and shoot energized particles into the foreshock region. This feature was discovered near to the bow-shock and only later was it recognized that it can disturb the magnetopause. This, in turn, has an influence on the surface of our planet. Their origin and forming mechanism of this anomoly has not been clarified. It now seems that tangential discontinuities interact with the bow-shock. The discontinuity itself, travels across the bow-shock and at the

[1] Fluxgate Magnetometer
[2] Cluster Ion Spectrometry experiment
[3] Research with Adaptive Particle Imaging Detectors
[4] Active Magnetospheric Particle Tracer Explorer
[5] International Sun-Earth Explorer

discontinuity the magnetic field's magnitude and direction change, this is what creates the electric field. This electric field accelerates the passing particles and makes them bounce back so particles can be accelerated to having higher energies (approximately 300 kev for protons). The energy source of the acceleration might be the ion-beam instability. This scenario does not only occur with the Earth as a similar feature was observed at Mars (Øieroset et al., 2001) and this suggests the existence of HFAs at another planets (e.g Venus and gas giants).

The aims of the thesis

I have determined the exact conditions of HFAs and identificated them by usingCluster FGM, CIS and RAPID measurements and calculations. I analyzed the 2003 spring period when the orbit of the fleet intersects the bow-shock. This is close to the apogee and I found fifty suspicious events. My search was supported and made be easier by the large separation of Cluster satellites in 2003. I proceeded in two different ways: firstly I chose more events and studied particularly global features of HFAs. In the first case I calculated the transformation of the pitch angle distribution, the parameters of the solar wind and the analysis of charged particle events. Secondly, I determined that the geometrical parameters of the tangential discontinuities create hot flow anomalies through the analysis of other discontinuities. It is from this point that I used the measurements from ACE[6] satellite, with its orbit of 1.5 millin km from the Earth, far beyond the bowshock. Using Lin's hybrid HFA simulation (Lin, 2002, 2003)and result based on my HFA catalog I discovered two new conditions of HFA formation. In addition to these two new conditions I also performed a size estimation and my results confirm this theory.

The last chapter of my thesis concerns searching the sheet-like structure with Cluster magnetic measurements. These structures can explain the magnetic fields turbulent features but they can play role in forming more complex magnetic structures. The plasma mixing creates a complex magnetic field structures in the frozen plasma. It has been found that Spacecraft having intersected these regions observe the sheet-like structures. I have performed detailed analysis and have plotted their paths, this code has been developed by myself and I have performed statistical analysis on the features of fitted sheets.

[6]Advanced Composition Explorer

Applied methods

I used Cluster FGM 22 Hz sample rated, 1 s and 4 s averaged magnetic, RAPID 4 s averaged particle flux and 128 s temporal with good spatial resolution, furthermore I have used CIS HIA[7] 4 s resolution plasma measurements. I also had to use AVE MAG and SWEPAM 16 s and 1 hour averaged data. I havedetermined the tangential discontinuitys geometrical parameters by minimum variance and crossproduct methods. I developed and my own method for size estimation. My task was made easier by plot and analyzer program named HEDGEHOD developed by *Dr. Géza Erdős, CSc.* in FORTRAN. I mainly used my own codes that were developed in IDL[8], C/C++ and JAVA languages. One of theses codes is RAPIDView which was developed to plot, process and correct Cluster RAPID data. I also used the LinCheker program developed to study HFAs in IDL. I have implemented my own special methods to transform to the solar wind frame from spacecraft frame. Another code I developed is called PlanarMS and is designed to seek planar sheet-like structures in IDL. The description of all methods used can be found in the "Introduction“ chapter of my thesis.

Thesises

1. I solved the problem of transforming to solar wind frame from spacecraft frame and to consider the Compton-Getting effect (Compton and Getting, 1935; Keppler, 1978). Originally, I needed this method to process RAPID measurements. I continued to corrected the RAPID data. It was the case that one detector head malfunctioned so the base levels were shifted. The instrument collected data in periods of 32 s or 128 s which is quite long comparing with the variation of the magnetic field. It is for this reason that I used special methods to calculate a better pitch angle distribution. I used these methods at analyzing HFAs (Facskó, 2004; Kecskeméty et al., 2006).

2. I studied single HFA events. I used the Cluster multispacecraft measurements from February 15 to April 20, 2003 when the fleet separation was high between 5000 and 10000 km. I observed the events in series. All plazma parameters fulfilled our formation conditions among them the 10 million K degree temperature in the core. Almost all events were coupled by proton events with a smooth profile and these particle events started before and finished after the magnetic filed signatures. The

[7] Hot Ion Analyses
[8] Interactive Data Language

flux starts to increase in the quasi-parallel region before the tangential discontinuity (Kecskeméty et al., 2006).

(a) I found 50 events in the Spring term in 2003. This is a valuable new result because:

   i. So many events were not known before or if they were know of, they were not published.

   ii. HFAs were considered rare events. My opinion is that this is not true, a HFA always forms if its conditions are fulfilled. It is the case that only a few satellites could observe and detect them before Cluster (Kecskeméty et al., 2006).

(b) I chose two events (February 16, 2003, 10:45-51 (UT) and March 7, 2003, 10:14-16 (UT)) and studied them particularly. These events were chosen because RAPID observed a high energized particle flux and I could use my pitch angle calculation method with the transformed measurements on February 16, 2003 (Kecskeméty et al., 2006).

   i. The two particular events analyzed on February 16, 2003 (high proton flux) and March 7 (low proton flux) show that the location of the tangential discontinuity and the bow-shock was similar in both cases (Kecskeméty et al., 2006).

   ii. In both cases the upstream magnetic field became quasi-perpendicular at the tangential discontinuity (Kecskeméty et al., 2006).

   iii. On February 16 the final bow-shock crossing followed between 70 and 180 minutes of the HFA observation. On March 7 the Cluster-1 remained in the magnetosheath however the other spacecrafts were close to the inward bow-shock crossing. The bow-shock was compressed better in February and its inward-outward motion may have been high. This might be responsible for the ten times higher 40 keV proton flux in February and the longer increasing phase (Kecskeméty et al., 2006).

3. Using the previous events I searched and found some global features. I performed this global study because I wanted to check Lin (2002, 2003) hybrid simulations. There was predicted several size-angle and size-speed dependencies. I confirmed and explained them (Facskó et al., 2006a,b,c).

   (a) I determined the geometrical features of HFA events above: their angle between the Sun-Earth direction γ and the magnetic field vector direction change

$\Delta\Phi$ inside the discontinuity. I discovered an about 45^o there is a wide empty cone around the Sun direction where no normal vector points and also I found the directional change to be increasedg. Both results confirm the theory (Facskó et al., 2006a,b).

(b) I estimated the typical size of HFAs ($2.3 \pm 0.9\, R_{Earth}$) based on cross time and separation of spacecrafts and the propagation time of the event. This size estimation confirms the theory (Facskó et al., 2006a,b).

(c) I determined the size-angle and size-speed plots and I found their shape agrees with the simulation results: the size-γ function has maxima and the others increase monotonically (Facskó et al., 2006a,b,c).

(d) I discovered that the solar wind speed is higher about 200 km/s at formation of HFAs, with long time average. I used ACE SWEPAM measurements to calculate the average. The frequency of fast solar wind depends on solar spot cycle so the frequency of HFAs also depends of solar spot cycle (Facskó et al., 2006a,c).

(e) Not only the solar wind speed but also its fast magnetosonic Mach numbers are high. This means that the HFA events might appear more frequently in the outer Solar System (Facskó et al., 2006a).

4. In the high resolution measurements of Cluster FGM I seeked and found sheet-like structures. I proved that plazma mixing has dominant role in formation of small scale magnetic fluctuations of the solar wind (Németh et al., 2006).

   (a) We have shown that the mixing of field lines by a laminar flow can generate highly varying intermittent fluctuations in the data measured by a space probe crossing the mixed magnetic field. Mixing can generate structures of much smaller scales than the scale of the velocity variations of the driving flow. In this case the generated small-scale structures are sheet-like (approximately planar) (Németh et al., 2006).

   (b) The effect of the mixing and the 2D fluctuations can not be distinguished, because of the deep relationship of the two phenomena. On the contrary, mixing is a good candidate for the role of the generator process of the observed mostly-2D fluctuations. Fluctuations of the interplanetary magnetic field were studied using Cluster four-point measurements. We have found the sheet-like structures in the measured data. More than half of the fluctuations are located in sheet-like structures (Németh et al., 2006).

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