FINAL REPORT ISSI TEAM 180

1. Title of your Team project: Directional Discontinuities of the Interplanetary Magnetic Field

2. Objectives:

Directional discontinuities (DDs) are surfaces across which the magnetic field abruptly changes direction. They can be categorized into rotational and tangential DDs (RDs and TDs for short), depending on whether the magnetic field lines cross the discontinuity surface, or not. In the first case the plasma particles on the two sides of the discontinuity can freely cross the DD by moving along the magnetic field lines, in the latter the plasma particles on the two sides of the surface are kept strictly apart. The interplanetary magnetic field, which is the field of solar origin carried outward by the solar wind, is filled with discontinuities. Whether those are RDs or TDs has important consequences for the fate of the plasma particles, explaining why much effort is being spent on identifying the true nature of the discontinuities from spacecraft data.

The proposal listed four objectives, two of which are so closely related that they are combined below:
- Objective 1: to check published results claiming the absence of rotational discontinuities in the solar wind, by establishing tighter limits on the magnitude of the magnetic field components transverse to the DD surface, which requires precise knowledge of the orientation of the DD surface. For this purpose the team was to develop a new method to quantify the uncertainties in the orientation of the DD surface, obtained from timing the sequential passage of the DD across the four Cluster spacecraft.
- Objective 2: to apply a more rugged test to distinguish RDs from TDs, which is based on a property of RDs that they share with Alfven waves (namely that they obey the so-called Walen relation, and to identify the nature of the fluctuations in which the DDs often are embedded, and to evaluate whether these fluctuations could play a role in the formation of RDs.
- Objective 3: to investigate the internal structure and/or temporal evolution of the DDs that must be involved to explain the differences in the profiles of the magnetic field across the DDs as recorded by the four Cluster spacecraft.

3. Dates of meetings:

- First Meeting: 19 - 23 October 2009, attended by Stein Haaland, Tim Horbury, Goetz Paschmann, Bengt Sonnerup, Joachim Vogt, Robert Wicks (as Young Scientist); Wai-Leong Teh could not attend because of visa problems, but participated in telecons.
- Second Meeting: 01 - 06 July 2010, attended by Stein Haaland, Goetz Paschmann, Bengt Sonnerup, Wai-Leong Teh, and Joachim Vogt (with guest appearance of Andre Balogh)
- An additional editorial meeting was held on 14 - 18 June 2011, attended by Stein Haaland, Goetz Paschmann, Bengt Sonnerup, and Joachim Vogt.
- To finish the team's work, Bengt Sonnerup, Stein Haaland and Goetz Paschmann were given the opportunity to spend two weeks at ISSI as Guests, from 15 to 26 October 2012.

4. Participants:

The participants are listed under Item 3. Note that Tim Horbury had only committed himself for the 1st meeting, where he played a key role in reviewing the work plan. Robert Wicks, who attended the 1st meeting under the Young Scientist Program, contributed significantly to Objective 3, but could not participate in later meetings. Wai-Leong Teh could not attend the 1st meeting due to visa problems, but attended the 2nd meeting and subsequently led the main effort under Objective 3.

5. Assessment of the Team activities; highlights:

The work was highly successful in that it produced not only significant advances in analysis methodology, but also important results regarding the nature of the solar wind discontinuities. Highlights were:
- the construction of the magnetic field map of a few selected DDs, which demonstrates their internal structure (see attached Figure).
- the development of a method to quantify the uncertainty in the boundary parameters based on four-spacecraft timing, which is the fundamentally new capability of the Cluster and other four-spacecraft missions.
- the optimization of the minimum-variance analysis technique of the magnetic field, and its application to show that the subset of DDs of the arc-polarized type have significant normal magnetic fields.
- the finding, based on tests of the Walen relation, that a large fraction of the DDs are RDs and that these RDs are intimately related to the fluctuations surrounding the DDs.

6. Outcome in relation to the objectives:

Objective 1: As a first step, a method was developed to quantify the accuracy of the four-point timing approach to boundary parameter estimation, and published by Vogt et al. (2011), as shown below. However, it turned out that the component of the magnetic field normal to the DD surfaces is so small that it could not be reliably determined with the timing method. We then focused on the Minimum Variance Analysis (MVA) method, originally invented by one of the team members (Bengt Sonnerup) in 1967, and discovered that it could be optimized to yield, for DDs of the arc-polarized type, small but significant normal magnetic fields. The new method and the results, including a theory for the arc-polarized structures, were published in the papers by Sonnerup et al. (2010) and Haaland et al. (2012).

Objevtive 2: This involved the careful analysis of a total of 190 DDs, which was completed only at the October 2012 meeting. The main results are that a large fraction of the DDs met the requirements for rotational discontinuities (RDs), and that those RDs are intimately related to the fluctuations they are embedded in (Paper by Paschmann et al, to be submitted, 2012)

Objective 3: Applying the MHD reconstruction technique, developed by Sonnerup and co-workers, to selected solar wind DDs, their internal structure could be determined in terms of maps of the magnetic field lines (see paper by the et al. 2011). An example is shown in the attached Figure.

7. Publications resulting from the team work including acknowledgment to ISSI:

Sonnerup, B. U. Ö., Haaland, S. E., and Paschmann, G., On arc-polarized structures in the solar wind, Annales Geophysicae, 28, 1229-1248, 2010

Teh, W.-L., Sonnerup, B. U. Ö, Paschmann, G., and Haaland, S. E., Local structure of directional discontinuities in the solar wind, J. Geophys. Res.,116, A04105, 2011

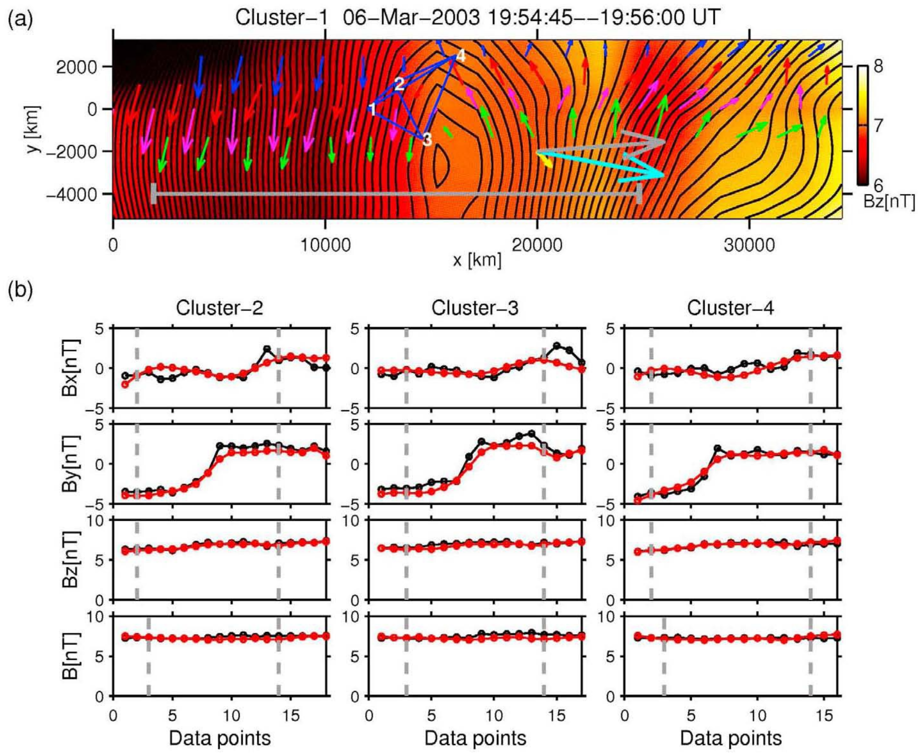
Vogt, J., Haaland, S., and Paschmann, G., Accuracy of multi-point boundary crossing time analysis, Annales Geophysicae, 29, 2239, 2011

Haaland, S., Sonnerup, B.U.Ö, and Paschmann, G., More about arc-polarized structures in the solar wind, Annales Geophysicae, 30, 867-883, 2012

Paschmann, G., Haaland, S., and Sonnerup, B.U.Ö, Discontinuities and Alfvenic fluctuations in the solar wind, to be submitted to Annales Geophysicae, 2012

ATTACHMENTS:

Figure to go with Objective 3 (taken from Teh et al., 2011).



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- (a) Map of the magnetic field lines (shown in black) within a directional discontinuity in the solar wind, obtained from the magnetic field measurements, indicated by the colored arrows, taken at fixed intervals during the passage of a directional discontinuity (DD) across the four Cluster spacecraft. The spacecraft configuration at one specific instance is shown by the blue tetrahedron. The background color indicates the strength of the magnetic field along the axis perpendicular to the page, as calibrated by the color bar on the right. The fact that some of the field lines are closed indicates the presence of magnetic islands embedded in the DD. Without such internal structure, the field lines would be straight and essentially parallel. The numbers along the map axes give distances in km.
- (b) Comparison of the three magnetic field components and its magnitude (in black) measured by the Cluster spacecraft 2, 3, and 4, with the predictions (in red) from the field map based on the Spacecraft 1 measurements. The good agreement indicates that the map is a good approximation to reality.