Spatial coherence of interplanetary coronal mass ejection sheaths at 1 AU

M. Ala-Lahti[1], J. Ruohotie, S. Good[1], E. Kilpua[1], and N. Lugaz[2]

[1]Department of Physics, University of Helsinki, Helsinki, Finland

[2]Space Science Center and Department of Physics, University of New Hampshire, Durham, NH, USA

ICMEs and their sheath regions

Interplanetary coronal mass ejections (ICMEs) are large-scale transients in the heliosphere that originate from huge eruptions of plasma and magnetic flux from the Sun. The speed of an ICME often exceeds the speed of the ambient solar wind and a shock wave and sheath form in front of the ICME (Fig. 1). Spatial coherence of ICMEs has previously been investigated by Lugaz et al. (2018).

ICME-driven sheath regions are characterized by turbulent magnetic fields and compressed and heated plasma. These plasma environments have a strong capability to cause space weather disturbances.

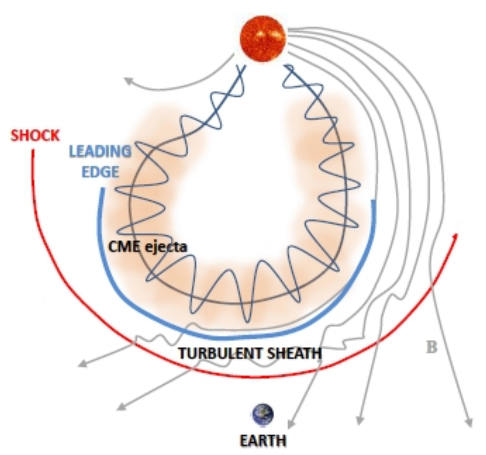

Fig. 1: Sketch of an ICME-driven sheath and shock.

Data and methods

- List of studied events constructed from the list of ICMEs of Lugaz et al. (2018) and includes 29 ICME-driven sheath regions in total.
- 5 min averages of magnetic field measurements of ACE and Wind are investigated. The correlation is also separately examined for low- and high-pass filtered data.
- Spatial coherency is estimated by computing the Pearson correlation coefficients that are compared to the non-radial spacecraft separation.
- The non-radial spacecraft separation varied from 0.001 to 0.012 AU.
- Overall correlation (σ_{tot}) of magnetic field magnitude and components is also estimated (Olkin and Pratt 1958).
- Wind data is shifted to maximize cross-correlation of σ_{tot} for an individual event and in addition, to align the sheath beginning, defined by a fast forward shock, that is referred as *shock alignment (SA).*

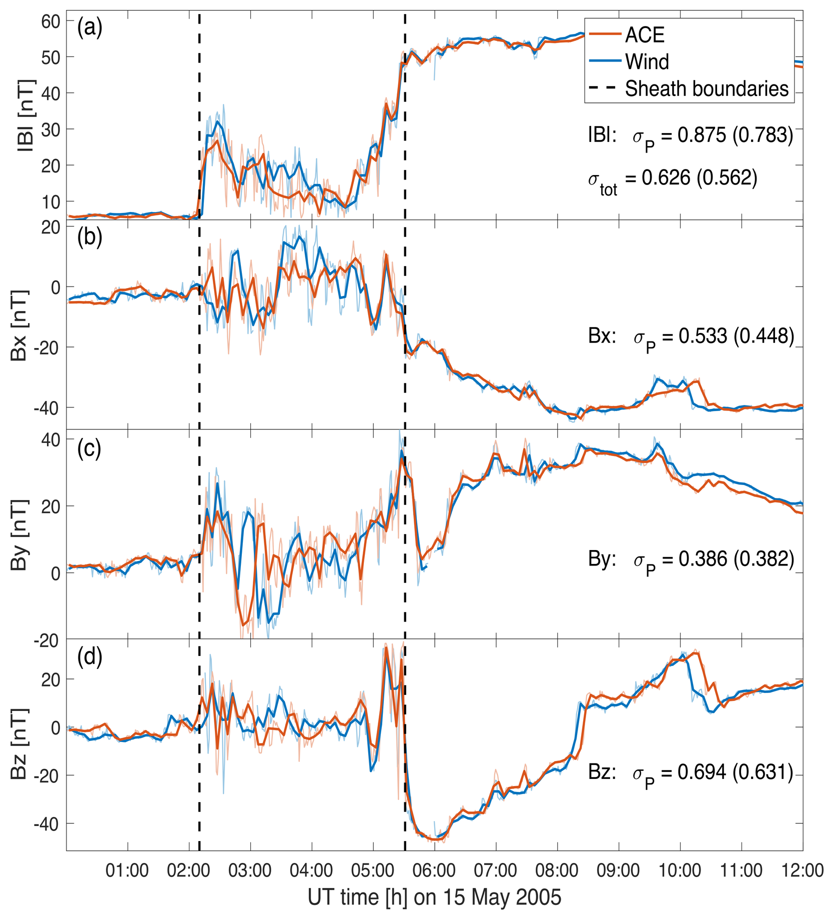

Fig 2. Magnetic field (a) magnitude, and (b-d) components in GSE coordinates measured by ACE (orange) and Wind (blue; time-shifted) spacecraft for the ICME-driven sheath region observed on 15 May 2005 (bounded by dashed lines). The non-radial spacecraft separation during the event was 0.0036 AU. Data is averaged using 5 min window length, and, for comparison, also 1 min averaging (shaded) is shown.

Results

- The extent of spatial coherence estimated by extrapolating least-squares linear fittings for the data shown in Fig. 3 until zero correlation is achieved.
- Results of the extrapolation, scale lengths, are given in Table 1.
- The largest sheath coherence is reported in the GSE y-direction.
- The same magnitude ordering of scale lengths also apply for the low-pass filtered magnetic field data (Fig. 4).
- Correlations of high-pass filtered magnetic field together with B_{RMS} decrease quickly with a function of frequency (Fig. 4).

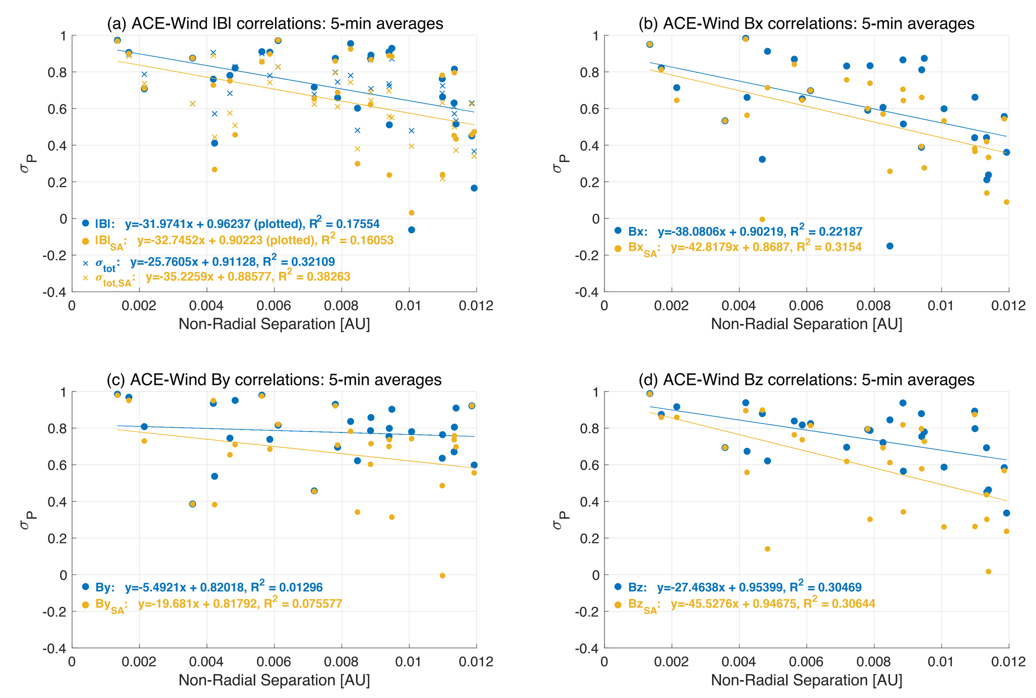

Fig 3. Pearson correlation coefficients of magnetic field (a) magnitude, and (b-d) components in GSE coordinates measured by ACE and Wind as a function of non-radial separation of the spacecraft.

Magnetic Field Parameter	Scale Length [AU] Maximized σ_{tot}	SA	ICMEs
$\lvert B\rvert$	0.030±0.001	0.028±0.001	0.260
B_x	0.024±0.001	0.020±0.001	0.065
B_y	0.149±0.035	0.042±0.002	0.094
B_z	0.035±0.003	0.021±0.001	0.061
σ_{tot}	0.035±0.002	0.025±0.001	

Table 1. Scale lengths and their standard deviations of magnetic field magnitude and its components in ICME sheaths. The standard deviations are computed by using 1, 5, and 10 min data averaging windows.

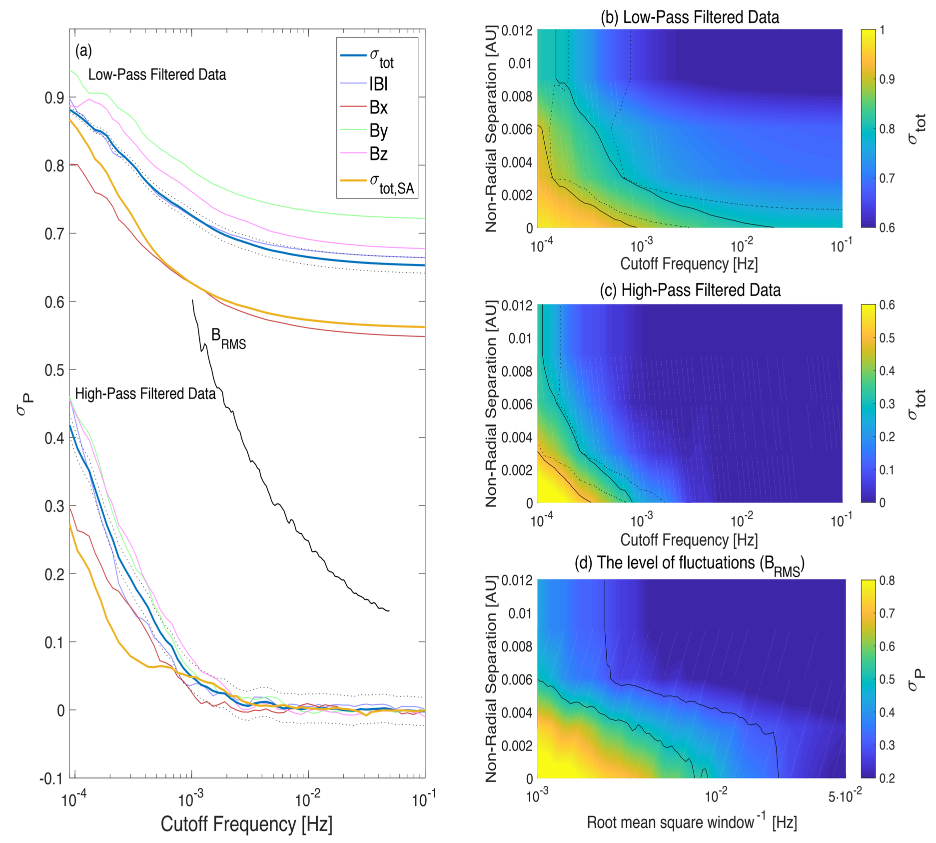

Fig 4. Correlation as a function of frequency filtered magnetic field data. (a) Average correlation of all studied events for both low- and high-pass filtered data, and for the level of fluctuations (B_{RMS}) as a function of cutoff frequency. (b) Total correlation as a function of cutoff frequency and non-radial separation for low-pass filtered data. Solid contours mark σ_{tot} = 0.8 and σ_{tot} = 0.9. For comparison, dotted contours give the corresponding interfaces for B_y. (c) Total correlation as a function of cutoff frequency and non-radial separation for high-pass filtered data. Solid contours mark σ_{tot} = 0.3 and σ_{tot} = 0.5. (d) Correlation as a function of inverse of root-mean-square window and non-radial separation for the level of fluctuations. Solid contours mark σ_{tot} = 0.3 and σ_{tot} = 0.5.

Conclusions

- Our results imply that magnetic fields in the sheath are more coherently structured and well correlated compared to the solar wind:

  We discover magnetic fields have larger scale lengths in ICME sheaths than those reported for the solar wind but, in general, smaller than for the ICME ejecta (see Fig. 5).

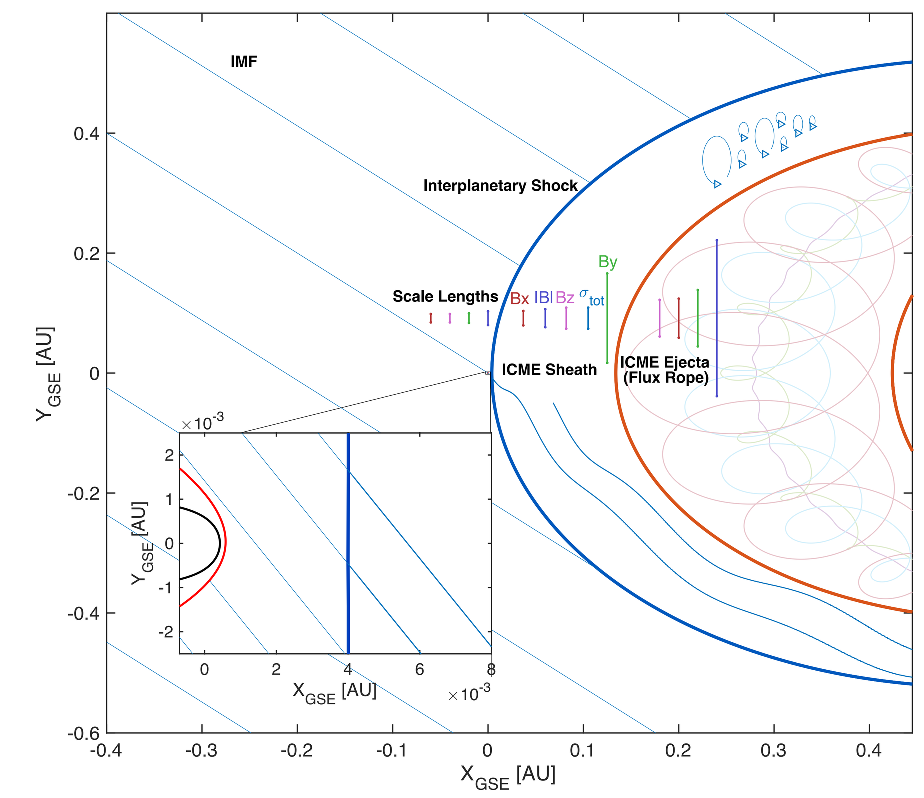

Fig 5. Sketch of an ICME complex in Earth-centered interplanetary space in the ecliptic plane. The sheath is occupied by magnetic fluctuations and the field lines drape around the ICME ejecta. Also, turbulent progress of the fluctuations is exemplified by the eddies within the sheath. Scale lengths of the solar wind (Richardson & Paularena, 2001), ICME sheath (Table 1), and ICME ejecta (Lugaz et al., 2018) are illustrated in the y-direction.

- Field line draping (e.g., Gosling & McComas, 1987) and alignment of pre-existing IMF discontinuities at the shock passage (e.g., Neugebauer et al., 1993) can increase (decrease) the magnetic field in y-direction (x-direction) causing observed large (small) scale length.
- Our results together with the high fluctuation levels in the sheath (e.g., Kilpua et al., 2019) raise a question of the occurrence of periods of geoeffective magnetic fields in ICME sheaths that have limited non-radial extent. From this perspective, the nature of the interactions with the magnetosphere would depend on the fine structure of the ICME sheath and not just on the aforementioned more global east-west asymmetry between the sheath flanks. The comparatively higher coherence of B_z (Fig. 4) for the high-pass filtered magnetic field also implies that these local out-of-ecliptic field periods would be embedded in the interplanetary magnetic field in the sheath.

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I am more than happy to hear possible questions and comments.
Please contact me: matti.ala-lahti@helsinki.fi