Proceedings Title IAU Symposium
Proceedings IAU Symposium No. 226, 2004
A.C. Editor, B.D. Editor & C.E. Editor, eds.

DOI: 00.0000/X000000000000000X

Solar sources of geoeffective CMEs: a SOHO/EIT view

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Abstract. Observations of the low solar corona, in particular in the EUV, are an effective means of identifying the solar sources of coronal mass ejections (CMEs). SOHO/EIT, with its continuous 24 hours per day coverage, is well suited to perform this task. Source regions and start times of frontside full and partial halo CMEs (that may be geoeffective) can thus be determined. The most frequent EUV signatures of CMEs are coronal dimmings. EIT waves, eruptive filaments and post-eruption arcades are also reliable signatures. Frontside halo CMEs with source regions close to the solar disc center have the strongest chance to hit the Earth. The inspection of the EIT data together with photospheric magnetograms may give an idea about the ejected interplanetary flux rope magnetic field and, in particular, about the presence or absence of southward (geoeffective) field. If a source region is situated close to the solar limb, the corresponding CME also may be geoeffective, as the CME-driven shocks have large angular extent. In this case the storm can be produced by the sheath plasma behind the shock, provided it contains strong enough southward interplanetary magnetic field. Some implications for the operational space weather forecast are discussed. EIT and LASCO are capable to identify the solar sources of the most of geomagnetic storms. In some cases, however, the identification is uncertain, so the observations by the future STEREO mission will be needed for the investigation of similar events.

Keywords. Sun: coronal mass ejections (CMEs), Sun: solar-terrestrial relations

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1. Introduction

The study of coronal mass ejection (CME) phenomenon is very important for solar-terrestrial relations. It is now known that CMEs play a key role in producing geomagnetic storms (e.g. Gosling, Bame, McComas, *et al.* 1990; Kahler 1992). To be geoeffective, a CME or CME-associated disturbance (e.g. a post-shock sheath) should arrive to the Earth and contain suitable magnetic field orientation: the north – south interplanetary magnetic field (IMF) component B_z should be negative (southward), strong enough and long-lasting (Burton, McPherron & Russel 1975; Gonzalez & Tsurutani 1987).

Halo CMEs attract particular attention in the study of geoeffective solar eruptions. A full halo CME has a shape of a bright irregular ring completely surrounding the coronagraph occulter (Howard, Michels, Sheeley, *et al.* 1982), i.e. it is a CME with the angular width of 360°. Full halo CMEs are currently interpreted as an end-on view of CMEs propagating approximately along the Sun – Earth line (see e.g. discussion in Plunkett, Thompson, Howard, *et al.* 1998). A partial halo is a wide CME (angular width larger than e.g. 120°) which also can be directed towards the Earth.

CMEs are now routinely observed by the Large-Angle Spectroscopic Coronagraph (LASCO, see Brueckner, Howard, Koomen, *et al.* 1995) onboard the Solar and Heliospheric Observatory (SOHO). Coronagraph observations, however, cannot distinguish between frontside and backside halo CMEs, as the occulting disc obscures a direct view of the initiation site. This is why observations of the low corona are necessary. The Extreme-ultraviolet Imaging Telescope (EIT, see Delaboudinière, Artzner, Brunaud, *et al.* 1995) onboard SOHO observes the full disc of the Sun 24 hours per day in four extreme-ultraviolet (EUV) bandpasses, and its "CME Watch" data series (one image in the Fe XII (195 Å) bandpass every 12 minutes) is well suited for the detection of CME signatures in the low corona. The observations of the CME source region are crucial for the problem of CME initiation, and its solution may ultimately lead to the prediction of CME occurrences. Additionally, the observations of the low corona, combined with the photospheric magnetic field measurements may provide us with an important information on the magnetic field orientation in the resulting interplanetary CME (ICME).

2. Tracking ICMEs back to the Sun

The procedure of identification of the solar source of an ICME is now well established (Fox, Peredo & Thompson 1998; Webb, Cliver, Gopalswamy, *et al.* 1998; Brueckner, Delaboudiniere, Howard, *et al.* 1998; Bothmer & Schwenn 1998; Berdichevsky, Bougeret, Delaboudinière, *et al.* 1998; Webb, Cliver, Crooker, *et al.* 2000; Webb, Lepping, Burlaga, *et al.* 2000; Cane, Richardson & St. Cyr 2000; Gopalswamy, Lara, Yashiro, *et al.* 2001; Wang, Ye, Wang, *et al.* 2002; Zhang, Dere, Howard, *et al.* 2003; Cane & Richardson 2003; Zhao & Webb 2003; Zhukov, Veselovsky, Clette, *et al.* 2003). It can be summarized as follows. First, the ICME is identified using in situ plasma and magnetic field measurements. The average speed of the ICME is determined and the approximate start time from the Sun is calculated assuming the constant speed en route from the Sun to the Earth. All the full and partial halo CMEs that occurred close to the estimated start time are identified, using CME catalogues (e.g. Yashiro, Gopalswamy, Michalek, *et al.* 2004) or through the direct inspection of LASCO data. Their travel times to the Earth are estimated using the measured plane-of-the-sky velocities, and probable candidates are selected. The variation of the travel time depending on the CME speed in the plane of the sky has been investigated e.g. by Gopalswamy *et al.* (2001) and Cane & Richardson (2003).

The next step is to look at the low corona activity to determine the origin of the candidate halo CMEs. CME signatures observed by EIT (primarily in the Fe XII bandpass at 195 Å) are: coronal dimmings (including transient coronal holes, TCHs) – sudden local decreases in brightness; EIT waves – bright fronts often propagating from eruption sites; post-eruption arcades; erupting filaments (seen as prominences when observed above the limb); different limb signatures like loop opening, plasmoid rising, etc. Any of these features implies that a CME has occurred. Dimmings represent the most frequent CME signature in the low corona and are due to the evacuation of mass during CMEs. TCHs have been interpreted by Webb *et al.* (2000b) as footpoints of the ejected interplanetary flux rope (see, however, Kahler & Hudson 2001). Zhukov & Auchère (2004) showed that only a half of the CME mass observed by EIT during the event of May 12, 1997 is erupted from TCHs, the rest was ejected from weaker and larger dimming regions. EIT waves seem to be produced by compression during the opening of the field lines during the CME lifting. Arcades, prominences and loop opening are present in the "standard model" of a CME, see e.g. discussion by Hudson & Cliver (2001).

Often (especially during the years of low solar activity) there is only one halo CME with distinct signatures in EIT close to the estimated start time. In such cases the identification is relatively straightforward. Sometimes, however, it may happen that no halo CME is reported around the estimated start time (e.g. Cane & Richardson 2003). In principle, this may be due to the insufficient LASCO sensitivity. The Thomson scattering is most

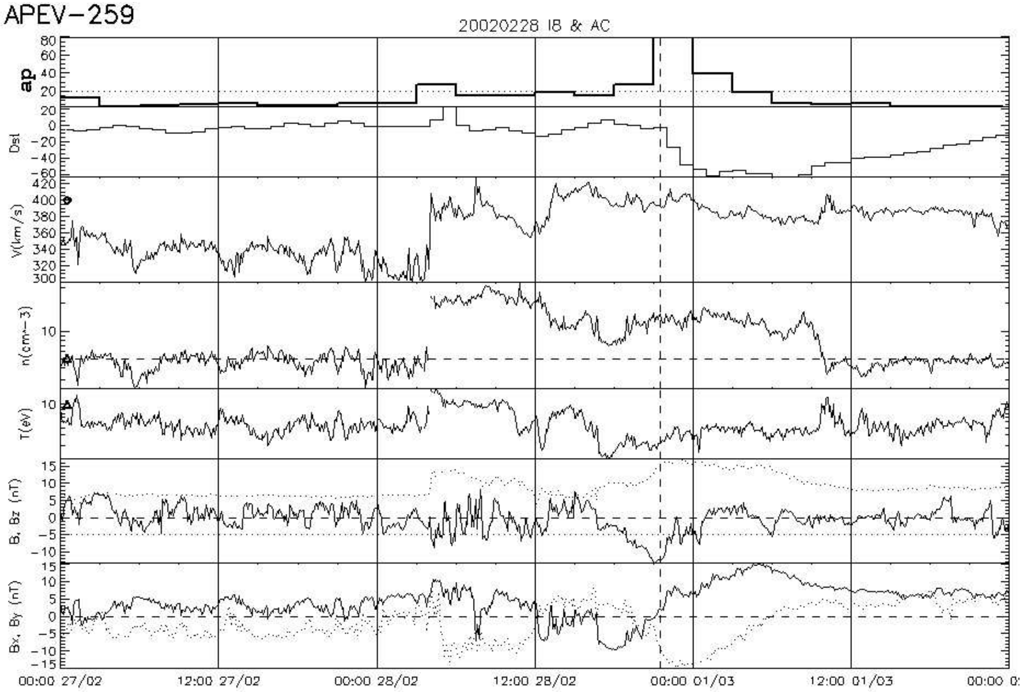

Figure 1. Solar wind (ACE) and geomagnetic data for the storm on February 28 – March 1, 2002. From top to bottom: 3-hour a_{p} index; 1-hour D_{st} index; solar wind speed; proton number density; proton temperature; IMF magnitude (dotted line) and its B_z component (solid line); IMF B_x (solid line) and B_y (dotted line) components. The plot is taken from the APEV database (http://alpha.sinp.msu.ru/apev). All times are UT.

efficient close to the plane of the sky, so some Earth-directed events – which naturally have a lot of material out of the plane of the sky – may be missed by LASCO. Let us take a look at one of these events.

The geomagnetic storm occurred on February 28 – March 1, 2002 (peak $A_{\mathrm{p}} = 80$, peak $D_{\mathrm{st}} \sim -60$ nT). Figure 1 shows the Advanced Composition Explorer (ACE) observations of the solar wind structure that produced the storm. The shock arrived around 04:00 UT, followed by the ESW magnetic cloud (for the classification see e.g. Bothmer & Schwenn 1998; Mulligan, Russel & Luhmann 1998) starting approximately at 16:30 UT and ending about 9:30 UT on March 1. The ICME speed is around 400 km/s, so the disturbance has left the Sun around February 24 (assuming the constant propagation speed). LASCO CME catalogue (Yashiro *et al.* 2004) and the LASCO operations scientist (http://lasco-www.nrl.navy.mil/cmelist.html) did not report any full or partial halos around this time (see also Cane & Richardson 2003); the last halo before the estimated start time occurred on February 20. CACTus software (Robbrecht & Berghmans 2004) did not detect any halos neither. All the reported CMEs were narrow and originated from the vicinity of the solar limb (so it is unlikely that they were directed towards the Earth, see below).

EIT data must now be inspected to identify all the CME signatures occurred during several days around the estimated start time. The eruptions associated with reported CMEs are rejected. Thus a coronal dimming not associated with any of the reported CMEs has been revealed (figure 2). It occurred next to the filament channel close to the disc center, with filament starting to rise slowly around 16:45 UT on February 24. Around

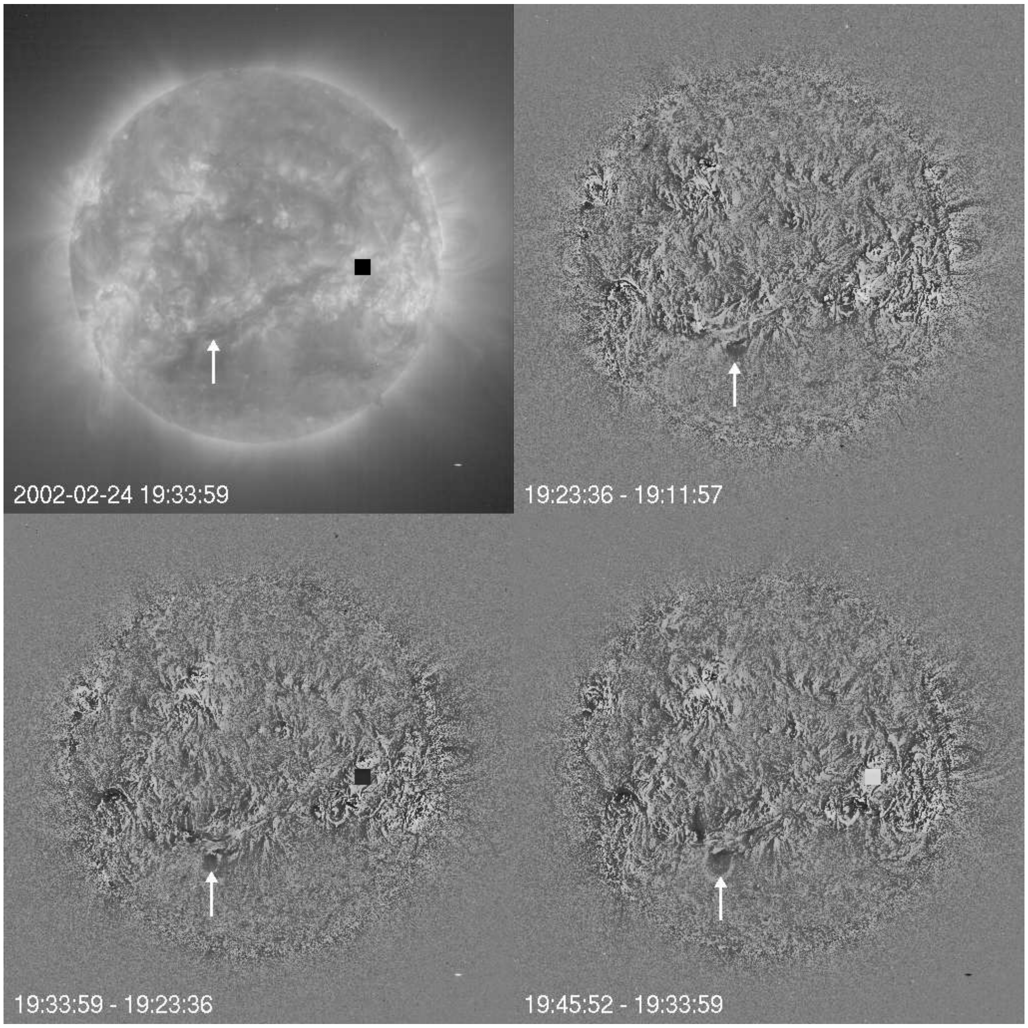

Figure 2. The eruption on February 24, 2002 observed by SOHO/EIT in the Fe XII (195 Å) bandpass. The top left panel is a plain image, other panels are running difference images. The arrows mark the place of the eruption in a filament channel (see top left panel) manifested as a dimming in running difference images. All times are UT.

19:23 UT a small, but clear dimming is visible to the south of the channel, indicating that an eruption indeed happened. Although no CMEs were reported, attentive inspection of the running difference LASCO C2 movie for the end of February 24 reveals an extremely weak partial halo CME starting around 18:30 UT. It spanned around 150° from NE to SW limb (figure 3). It has to be stressed that the identification of this CME is very difficult without a priori knowledge of its start time obtained using the EIT data. It seems that in this case it is easier to detect the dimming observed by EIT than the LASCO CME.

Therefore, presumable cases of ICMEs without any LASCO counterpart have to be double-checked. The described event shows that LASCO sensitivity allows us to detect even very weak CMEs, although sometimes EUV signatures are easier to find. A statistical study is needed to verify if ICMEs without corresponding LASCO CMEs indeed occurred.

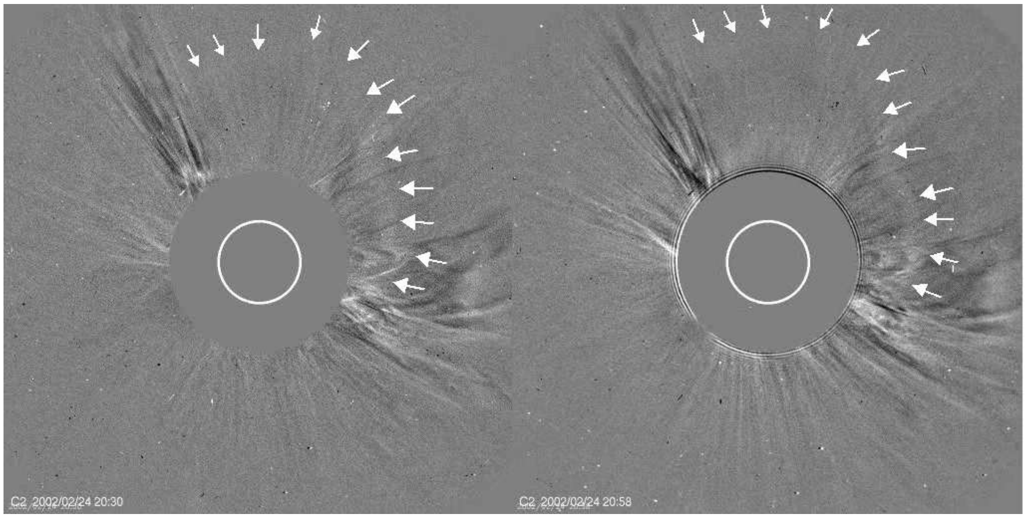

Figure 3. SOHO/LASCO C2 running difference images (20:30−19:54 UT, left, and 20:58−20:30 UT, right) showing a very weak partial halo CME marked by arrows.

3. Positions of source regions on the solar surface

Several studies addressed the distribution of the source regions of geoeffective CMEs on the solar surface (Lyons, Stalkton-Chalk & Lewis 1999; Cane *et al.* 2000; Wang *et al.* 2002; Zhang *et al.* 2003; Manoharan, Gopalswamy, Yashiro, *et al.* 2004; Srivastava & Venkatakrishnan 2004). There is a concentration of source regions near the solar disc center, approximately inside the circle with the radius of about 40°. In some studies (Wang *et al.* 2002; Zhang *et al.* 2003) it has been noted, however, that there is an east – west asymmetry in this distribution: geoeffective CMEs have a slight preference to originate from the western hemisphere. This finding is still controversial as e.g. Cane *et al.* (2000) and Srivastava & Venkatakrishnan (2004) did not find such an asymmetry. An explanation of this asymmetry has been proposed (Wang, Shen, Wang, *et al.* 2004): CMEs which are faster than the ambient solar wind are deflected to the east by the magnetic force of the ambient spiral IMF. The explanation seems to be plausible as the asymmetry seems to be more pronounced for fast events. A dynamic model of this interaction is still to be developed, and a statistical study including weaker events is needed to verify if the longitudinal asymmetry indeed exists.

Another interesting finding by Zhang *et al.* (2003) is that four major storms (with $D_{\mathrm{st}} < -100$ nT) have been produced by the east-limb partial halo CMEs without any signatures on the solar disc. All these CMEs are very slow (around 200 km/s), and it seems possible that EUV dimmings in slow cases are continuously replenished with plasma and thus are not pronounced.

However, alternative sources for these storms can be proposed. For example, Zhang *et al.* (2003) identify the source of the storm on April 22, 1997 as a partial halo CME first seen in the LASCO C2 field of view on April 16, 07:35 UT. Indeed, EIT shows no signatures of this event, and this may indicate that it is a backside CME. On the other hand, an eruption close to the disc center was observed by EIT at 14:36 UT on April 16 (figure 4). A dimming is clearly seen, with a bright front ahead of it resembling the front of an EIT wave. Unfortunately, the eruptive signatures are seen only in one image as the data gap of 83 minutes followed. So, strictly speaking, we cannot state for sure if an EIT wave or a dimming indeed occurred. No CME has been observed by LASCO in

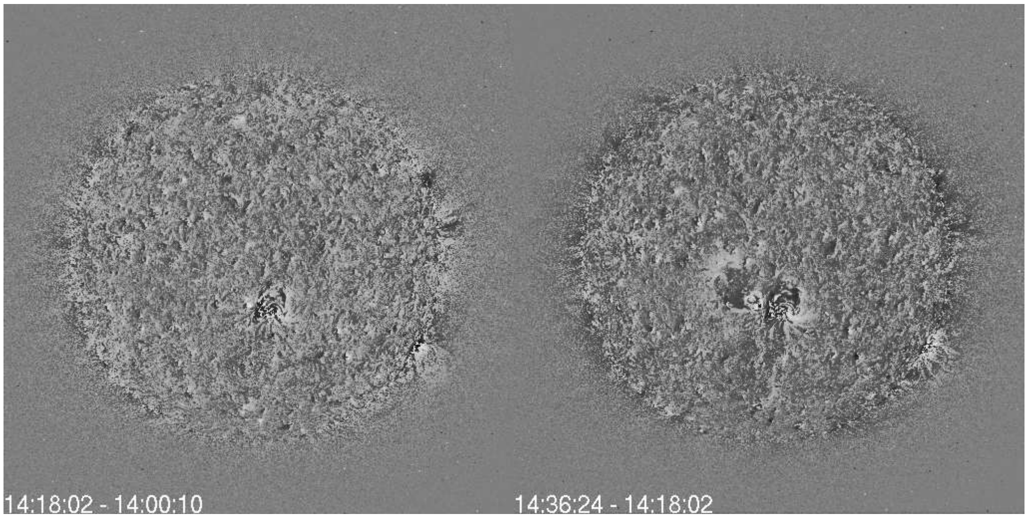

Figure 4. SOHO/EIT running difference images in the Fe XII (195 Å) bandpass showing the eruption on April 16, 1997 at 14:36 UT.

association with this event. It is unlikely that this eruption is the source of the CME identified by Zhang *et al.* (2003) as the CME started around 7 hours before the dimming.

So, in this case one has a choice between two alternative interpretations. On the one hand, the partial halo CME can be identified as the source of the storm, assuming that EIT did not observe the dimming because of a very slow CME speed. On the other hand, this CME can be classified as a backside one because of the absence of on-disc signatures, and a weak EIT event can represent a signature of a CME undetected by LASCO because of its insufficient sensitivity. Such a situation takes place in three out of four east-limb events identified by Zhang *et al.* (2003). In the fourth case it seems that EIT did not observe any alternative source. Thus, sources of slow CMEs seem to be the most difficult to identify.

Although there is a strong concentration of geoeffective CMEs' source regions close to the disc center, even CMEs originating at the limb can arrive to the Earth (provided they are wide enough) and produce geomagnetic storms. In most of such cases, however, only an interplanetary shock is observed (e.g. Manoharan *et al.* 2004) as the angular extent of the shock is larger than that of a corresponding CME. The CME thus misses the Earth and only the shock arrives.

An example of such an event is presented in figures 5–6. An EIT wave (figure 5) was observed above the east limb on October 21, 2003. It was propagating from the active region behind the limb (future NOAA AR 0486) as indicated by the rising post-eruption loops. However, the eruption was so powerful and wide that the corresponding CME was a full halo (figure 6): the south-western streamer was deflected by the CME-associated disturbance (probably the CME-driven shock). The geomagnetic storm ensued on October 24 as the interplanetary shock arrived around 15:00 UT. A short interval of cold plasma (22:00 UT, October 24 – 01:00 UT, October 25) may represent the CME matter following the hot post-shock sheath. This event illustrates that it can be misleading to consider CMEs as originating from a small source region – in this case such a region would be located on the back side of the Sun, right behind the east limb. Nevertheless, the corresponding disturbance arrived to the Earth due to the non-local nature of CME-associated structures.

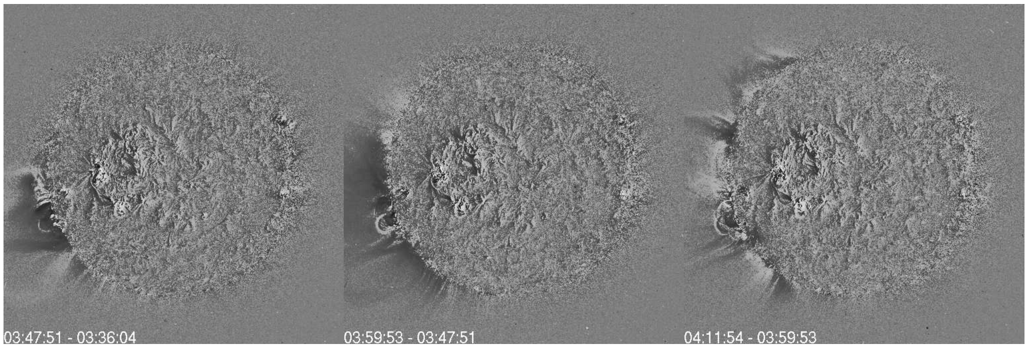

Figure 5. Running difference images illustrating the EIT wave observed by SOHO/EIT in the Fe XII (195 Å) bandpass above the eastern limb. All times are UT.

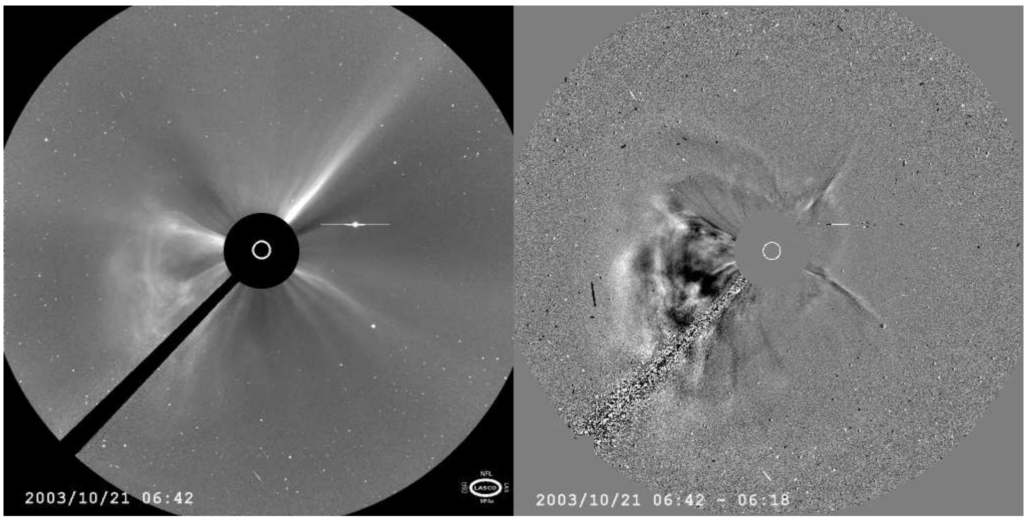

Figure 6. SOHO/LASCO C3 plain (left) and running difference (right) images showing the full halo CME on October 21, 2003. All times are UT.

4. Predicting the CME onset and the IMF direction?

Once the CME is observed, its arrival time to the Earth can be estimated on the base of the measured plane-of-the-sky speed (Brueckner *et al.* 1998; Gopalswamy *et al.* 2001; Cane & Richardson 2003). However, to assess the strength of a possible storm, not only the CME arrival, but also the IMF B_z component has to be predicted. Moreover, a big challenge is to predict the CME before it actually happened, so precursors of eruptions have to be identified.

Sigmoidal active regions (i.e. the ones displaying S-shaped structure in the soft X-rays) have been reported to have a higher probability to erupt than non-sigmoidal active regions (e.g. Canfield, Hudson & McKenzie 1999). Sigmoids can also be observed by EIT, especially in the Fe XV (284 Å) bandpass (compare the sigmoids observed by SXT and EIT in figure 4 of the paper by Sterling, Hudson, Thompson, *et al.* 2000). EIT has a narrower temperature response and thus is better suited for the investigation of the active regions fine structure. EIT observations demonstrate convincingly that a sigmoid is a collective feature (Glover, Ranns, Harra, *et al.* 2000; Zhukov *et al.* 2003) – a continuous S-shaped structure can almost never be traced. Pevtsov, Canfield & Zirin

(1996) and Glover, Ranns, Brown, *et al.* (2002) suggested that a single twisted unstable flux tube is formed of two sheared J-shaped loops right before the eruption. However, in such cases either the detector saturation effect is apparent in the middle of the sigmoid (Glover *et al.* 2002), or the S-shaped structure is inhomogeneous (Pevtsov *et al.* 1996), indicating that multiple flux systems are involved. EIT observations suggest that the sigmoid is better described by the separatrix surface model (Titov & Démoulin 1999) than by the kink-unstable twisted flux tube model (Rust & Kumar 1996).

This uncertainty of the observational definition of a sigmoid does not allow us to use sigmoids efficiently in the operational space weather forecast as different works give different statistics on the probability of eruption (Canfield *et al.* 1999; Glover *et al.* 2000). Moreover, the sigmoids can also appear right after the eruption (Glover, Harra, Matthews, *et al.* 2001; Zhukov *et al.* 2003) – a fact that does not seem to agree with the kink-unstable twisted flux tube eruption scenario. Finally, nothing indicates when the eruption will occur. An active region may have a sigmoidal shape during its whole passage from the east to the west limb, but produce only a couple of CMEs during this time (Gibson, Fletcher, Del Zanna, *et al.* 2002).

Although the eruption time cannot be predicted reliably now, one can obtain an indication on the resulting IMF orientation (in particular, on its B_z component which is crucial for the assessment of the strength of a possible geomagnetic disturbance). If the photospheric magnetic field of the CME source region has a bipolar configuration (it is often the case), one can determine the orientation of a neutral line and thus get an idea about the inclination of the axis of the ejected interplanetary flux rope (Marubashi 1997; Yurchyshyn, Wang, Goode, *et al.* 2001; McAllister, Martin, Crooker, *et al.* 2001; Bothmer 2003). If the shear of the magnetic field can be determined (looking e.g. at the post-eruption arcade in the EIT data), the direction of the magnetic field in the flux rope can be reasonably estimated.

Yurchyshyn *et al.* (2001) showed that for the full halo CME on February 17, 2000 the source region neutral line was oriented along the north – south direction, similarly to the resulting interplanetary flux rope orientation. As the axial field in the flux rope was northward, the magnetic cloud produced only a very weak geomagnetic disturbance. On the contrary, the halo CME on July 14, 2000 ("Bastille day") originated from an active region with the neutral line oriented along the east – west direction. This orientation will produce a negative B_z either in the leading or in the trailing part of the flux rope.

The inclinations of the flux rope axes close to the Sun and in the heliosphere do not always correspond to each other. The neutral line in the event of May 12, 1997 had the north – south orientation (Webb *et al.* 2000b), and, if its inclination is conserved, the flux rope had to have the ENW orientation, i.e. to be not geoeffective. However, the interplanetary flux rope was of the SEN type and produced a major geomagnetic storm. The reason for such a change of orientation seems to be that during the low activity years the CMEs are deflected by the fast flows from polar coronal holes (Cremades & Bothmer 2004) and thus have the tendency to have a small inclination with respect to the ecliptic plane. The CME on February 17, 2000 propagated without such an influence because of the absence of polar coronal holes during the activity maximum. Another explanation (Webb 2002) suggests that the interplanetary flux rope results rather from the large-scale dipole field than from the local bipolar field of the source region.

5. Conclusions

EIT and LASCO are capable to identify reliably the source regions of the most of geoeffective ICMEs. The identification works especially well if a CME is isolated and is not very slow. In some cases, however, the identification of the source region is not clear. These cases include very slow CMEs, when a partial halo CME observed by LASCO has no EIT source (Zhang *et al.* 2003), but an eruption seen by EIT close to the disc center has no LASCO counterpart or there are no EIT events at all. The identification can also be difficult in complicated cases of multiple (interacting) CMEs – a problem not discussed in this paper.

We have to note that these doubtful cases can correspond to major geomagnetic storms. To determine the sources of ICMEs more precisely, the propagation of CMEs has to be tracked from a vantage point out of the Sun – Earth line as well. STEREO mission (Solar – Terrestrial Relations Observatory) will for the first time provide such observations. So, although the combination of EIT and LASCO is sufficient in the most of the cases, the STEREO data will be necessary to identify unambiguously the solar sources of geomagnetic storms.

Acknowledgements

The author thanks the organizers of the Symposium for the invitation to give this talk and for financial support. EIT data have been used courtesy of SOHO/EIT consortium. The LASCO data used here are produced by a consortium of the Naval Research Laboratory (USA), Max-Planck-Institut für Aeronomie (Germany), Laboratoire d'Astronomie (France), and the University of Birmingham (UK). SOHO is a project of international cooperation between ESA and NASA. ACE SWEPAM and MAG instrument teams and the ACE Science Center are acknowledged for providing the ACE data, as well as the World Data Center for Geomagnetism, Kyoto, Japan, for the A_{p} and D_{st} indices. The author is grateful to V. Bothmer, A. V. Dmitriev, G. Lawrence, D. Berghmans, E. Robbrecht, R. Van der Linden, I. S. Veselovsky and N. Nitta for useful discussions. This work is partially supported by the INTAS Project 03-51-6206.

References

Berdichevsky, D., Bougeret, J.-L., Delaboudinière, J.-P., Fox, N., Kaiser, M., Lepping, R., Michels, D., Plunkett, S., Reames, D., Reiner, M., Richardson, I., Rostoker, G., Steinberg, J., Thompson, B., von Rosenvinge, T. 1998, *Geophys. Res. Lett.* 25, 2473

Bothmer, V. & Schwenn, R. 1998, *Ann. Geophys.* 16, 1

Bothmer, V. 2003, in: A. Wilson (ed.), *Proc. ISCS 2003 Symposium, 'Solar Variability as an Input to the Earth's Environment'*, ESA SP-535, p. 419

Brueckner, G.E., Howard, R.A., Koomen, M.J., Korendyke, C.M., Michels, D.J., Moses, J.D., Socker, D.G., Dere, K.P., Lamy, P.L., Llebaria, A., Bout, M.V., Schwenn, R., Simnett, G.M., Bedford, D.K., Eyles, C.J. 1995, *Sol. Phys.* 162, 357

Brueckner, G.E., Delaboudiniere, J.-P., Howard, R.A., Paswaters, S.E., St. Cyr, O.C., Schwenn, R., Lamy, P., Simnett, G.M., Thompson, B., Wang, D. 1998, *Geophys. Res. Lett.* 25, 3019

Burton, R.K., McPherron, R.L. & Russell, C.T. 1975, *J. Geophys. Res.* 80, 4204

Cane, H.V., Richardson, I.G. & St. Cyr, O.C. 2000, *Geophys. Res. Lett.* 27, 3591

Cane, H.V. & Richardson, I.G. 2003, *J. Geophys. Res.* 108(A4), SSH 6-1

Canfield, R.C., Hudson, H.S. & McKenzie, D.E. 1999, *Geophys. Res. Lett.* 26, 627

Cremades, H. & Bothmer, V. 2004, *A&A* 422, 307

Delaboudinière, J.-P., Artzner, G.E., Brunaud, J., Gabriel, A.H., Hochedez, J.F., Millier, F., Song, X.Y., Au, B., Dere, K.P., Howard, R.A., Kreplin, R., Michels, D.J., Moses, J.D., Defise, J.M., Jamar, C., Rochus, P., Chauvineau, J.P., Marioge, J.P., Catura, R.C., Lemen, J.R., Shing, L., Stern, R.A., Gurman, J.B., Neupert, W.M., Maucherat, A., Clette, F., Cugnon, P., van Dessel, E.L. 1995, *Sol. Phys.* 162, 291

Fox, N.J., Peredo, M. & Thompson, B.J. 1998, *Geophys. Res. Lett.* 25, 2461

Gibson, S.E., Fletcher, L., Del Zanna, G., Pike, C.D., Mason, H.E., Mandrini, C.H., Démoulin,

P., Gilbert, H., Burkepile, J., Holzer, T., Alexander, D., Liu, Y., Nitta, N., Qiu, J., Schmieder, B., Thompson, B.J. 2002, *ApJ* 574, 1021
Glover, A., Ranns, N.D.R., Harra, L.K., Culhane, J.L. 2000, *Geophys. Res. Lett.* 27, 2161
Glover, A., Harra, L.K., Matthews, S.A., Hori, K., Culhane, J.L. 2001, *A&A* 378, 239
Glover, A., Ranns, N.D.R., Brown, D.S., Harra, L.K., Matthews, S.A., Culhane, J.L. 2002, *J. Atm. Sol.-Terr. Phys.* 64, 497
Gonzalez, W.D. & Tsurutani, B.T. 1987, *Planet. Space Sci.* 35, 1101
Gopalswamy, N., Lara, A., Yashiro, S., Kaiser, M.L., Howard, R.A. 2001, *J. Geophys. Res.* 106, 29207
Gosling, J.T., Bame, S.J., McComas, D.J., Phillips, J.L. 1990, *Geophys. Res. Lett.* 17, 901
Howard, R.A., Michels, D.J., Sheeley, N.R., Jr., Koomen, M.J. 1982, *ApJ* 263, L101
Hudson, H.S. & Cliver E.W. 2001, *J. Geophys. Res.* 106, 25199
Kahler, S.W. 1992, *Ann. Rev. Astron. Astrophys.* 30, 113
Kahler, S.W. & Hudson, H.S. 2001, *J. Geophys. Res.* 106, 29239
Lyons, M., Stockton-Chalk, A.B. & Lewis, D.J. 1999, in: A. Wilson (ed.) *Proc. 9th European Meeting on Solar Physics, 'Magnetic Fields and Solar Processes'*, ESA SP-448, p. 943
Manoharan, P.K., Gopalswamy, N., Yashiro, S., Lara, A., Michalek, G., Howard, R.A. 2004, *J. Geophys. Res.* 109, A06109
Marubashi, K. 1997, in: N. Crooker, J.A. Joselyn & J. Feynman (eds.), *Coronal Mass Ejections*, AGU Geophys. Monogr. Ser., vol. 99, p. 147
McAllister, A.H., Martin, S.F., Crooker, N.U., Lepping, R.P., Fitzenreiter, R.J. 2001, *J. Geophys. Res.* 106, 29185
Mulligan, T., Russell, C.T. & Luhmann, J.G. 1998, *Geophys. Res. Lett.* 25, 2959
Pevtsov, A.A., Canfield, R.C. & Zirin, H. 1996, *ApJ* 473, 533
Plunkett, S.P., Thompson, B.J., Howard, R.A., Michels, D.J., St. Cyr, O.C., Tappin, S.J., Schwenn, R., Lamy, P.L. 1998, *Geophys. Res. Lett.* 25, 2477
Robbrecht, E. & Berghmans, D. 2004, *A&A* 425, 1097
Rust, D.M. & Kumar, A. 1996, *ApJ* 464, L199
Srivastava, N. & Venkatakrishnan, P. 2004, *J. Geophys. Res.* 109, A10103
Sterling, A.C., Hudson, H.S., Thompson, B.J., Zarro, D.M. 2000, *ApJ* 532, 628
Titov, V.S. & Démoulin, P. 1999 *A&A* 351, 707
Wang, Y.M., Ye, P.Z., Wang, S., Zhou, G.P., Wang, J.X. 2002, *J. Geophys. Res.* 107(A11), SSH 2 - 1
Wang, Y., Shen, C., Wang, S., Ye, P. 2004, *Sol. Phys.* 222, 329
Webb, D.F. 2002, in: A. Wilson (ed.), *Proc. SOHO 11 Symposium, 'From Solar Min to Max: Half a Solar Cycle with SOHO'*, ESA SP-508, p. 409
Webb, D.F., Cliver, E.W., Gopalswamy, N., Hudson, H.S., St. Cyr, O.C. 1998, *Geophys. Res. Lett.* 25, 2469
Webb, D.F., Cliver, E.W., Crooker, N.U., St. Cyr, O.C., Thompson, B.J. 2000, *J. Geophys. Res.* 105, 7491
Webb, D.F., Lepping, R.P., Burlaga, L.F., DeForest, C.E., Larson, D.E., Martin, S.F., Plunkett, S.P., Rust, D.M. 2000, *J. Geophys. Res.* 105, 27251
Yashiro, S., Gopalswamy, N., Michalek, G., St. Cyr, O.C., Plunkett, S.P., Rich, N.B., Howard, R.A. 2004, *J. Geophys. Res.* 109, A07105
Yurchyshyn, V.B., Wang, H., Goode, P.R., Deng, Y. 2001, *ApJ* 563, 381
Zhao, X.P. & Webb, D.F. 2003, *J. Geophys. Res.* 108(A6), SSH 4 - 1
Zhang, J., Dere, K.P., Howard, R.A., Bothmer, V. 2003, *ApJ* 582, 520
Zhukov, A.N., Veselovsky, I.S., Clette, F., Hochedez, J.-F., Dmitriev, A.V., Romashets, E.P., Bothmer, V., Cargill, P. 2003, in: M. Velli, R. Bruno & F. Malara (eds.), *Proceedings of the Tenth International Solar Wind Conference*, AIP Conference Proceedings, vol. 679, p. 711
Zhukov, A. & Auchère, F. 2004, *A&A* (in press)

Discussion