Linking coronal observations of a ‘mini’ active region with its interplanetary manifestation.

S. Dasso,1,2 C.H. Mandrini,1 S. Pohjolainen,3 L.M. Green,4 P. Démoulin,5 L. van Driel-Gesztelyi6,7 C. Foley,7 and C. Copperwheat7
1IAFE, CONICET-UBA, Buenos Aires, Argentina, sdasso@iafe.uba.ar.
2Departamento de Física, FCEN-UBA, Buenos Aires, Argentina.
3Tuorla Observatory/VISPA, University of Turku, Finland.
4The Faulkes Telescope Project, Cardiff University, UK.
5Observatoire de Paris, LESIA, Meudon, France.
6Konkoly Observatory, Budapest, Hungary.
7Mullard Space Science Laboratory, University College London, UK.

Abstract. We analyze the smallest ‘sigmoidal eruption - CME - interplanetary magnetic cloud’ event even observed. We find: (a) the same magnetic helicity sign and (b) similar magnetic flux values in the coronal source region and associated cloud, and (c) that pre- to post-ejection magnetic helicity change is approximately the same amount as the helicity content in the interplanetary cloud. These results stress the importance of complementary solar and interplanetary studies, to achieve a better understanding of the origin of eruptive phenomena.

Resumen. Analizamos el vínculo entre el evento ‘erupción sigmoidal - CME - nube magnética interplanetaria’ más pequeño observado hasta ahora. Encontramos: (a) el mismo signo de la helicidad magnética (HM) y (b) valores comparables de HM y flujo magnético en la región coronal y en la nube interplanetaria, y (c) que el valor del cambio en la helicidad magnética en la corona solar antes y después de la erupción resulta aproximadamente igual al contenido de helicidad en la nube magnética interplanetaria. Estos resultados acentúan aún más la importancia de realizar estudios solares e interplanetarios complementarios para comprender mejor el origen de los fenómenos eruptivos.

1. Introduction
Coronal Mass Ejections (CMEs) are huge expulsions of magnetized mass, generally involving a large scale reconfiguration of the solar corona. Their interplanetary manifestation, the so-called ICMEs, produce significant disturbances in the solar wind when they travel from the Sun through the heliosphere. Magnetic clouds (MCs) are a subset of ICMEs, presenting (a) a coherent rotation of the magnetic field vector, (b) an enhanced field strength, and (c) a proton temperature lower than in the surrounding solar wind (Burlaga et al., 1981). Most of MCs studies have focused on larger events observed in situ lasting from ~ 10 hours up to a few days. However, both at the coronal level and in the interplanetary medium much smaller events are observed as well. In this paper we report observations of a small active region (AR) situated near the solar disc centre on May 11, 1998 (see left top panel of Fig. 1). This structure showed
signs of an eruptive nature, such as elongated sigmoidal loops, dimmings, and cusp formation. In the next section we describe and analyze the solar and interplanetary data, quantifying the magnetic flux and helicity in both environments. Finally, in Section 3, our conclusions are given.

2. Coronal and Interplanetary Data Analysis

Soft X-rays observations (Yohkoh/Soft X-ray Telescope) indicate the presence of several emission peaks on May 11; in particular, three events were identified. The first one (at \( \sim 00:42 \) UT) lasted for \( \approx 26 \) minutes. The second event occurred between 06:00 UT and 08:00 UT; while the third, which started at about 8:30 UT, had a duration of \( \approx 3 \) hours. The later event was followed by the formation of coronal dimmings and a cusp. The photospheric magnetic field of this bipole was observed with the Michelson Doppler Imager (MDI/SOHO). We computed the magnetic flux in the dimmings after the third event finding \( F_{\text{dimming}} = 13 \pm 2 \times 10^{19} \) Mx.

An important physical quantity to link coronal observations to interplanetary ones is the magnetic helicity (MH), because it is nearly conserved both in the corona and the heliosphere. To compute this quantity we need first to model the coronal magnetic field. Using MDI magnetograms, we extrapolated the observed photospheric line of sight component of the field to the corona under the linear (constant \( \alpha \)) force-free field assumption: \( \vec{\nabla} \times \vec{B} = \alpha \vec{B} \). The value of \( \alpha \) is chosen so as to best fit the observed coronal loops observed with the Transition Region and Coronal Explorer, TRACE (see Figure 1). Unluckily, TRACE images are only available before the first X-ray burst and it is difficult to distinguish the shape of individual coronal loops and to use their images to determine the value of \( \alpha \). Thus, we use the previously determined values for \( \alpha \) to compute \( H_{\text{cor}} \). Having the model, we compute the relative coronal magnetic helicity, \( H_{\text{cor}} \), using a linearized expression of the one given by Berger (1985), Eq. (A23).

When a flux tube is ejected from the solar corona into the interplanetary medium, it carries part of the MH contained in the coronal field. Therefore, we need to compute the variation of the coronal MH from before to after the event to compare this variation to the helicity content of the associated interplanetary event. Our results are shown in Table 1.

We analyze the interplanetary data from the Wind spacecraft from 2-5 days after the coronal event with the hope to identify the interplanetary manifestation of the eruption (http://cdaweb.gsfc.nasa.gov/cdaweb/istp – public/). By scanning the \textit{in situ} observations of plasma and magnetic field we are able to isolate a small MC, from 22:00 UT on 15 May to 01:50 UT on 16 May, around 110 hours after the sigmoidal eruption. Considering the observed average speed of the solar wind (\( \sim 350 \pm 50 \) km/s) we expect a travel time of \( \sim 119 \pm 17 \) hours from the corona to \( \sim 1 \)AU; then, this event is a good candidate to be associated to the coronal eruption.

We obtain the components of the field in the local cartesian system of coordinates using the minimum variance (MV) method (as done by Dasso et al. (2003)),
Figure 1. SXT full disc image (Top) and magnetic isocontours of the photospheric field, MDI (Middle) at 00:03 UT (positive: continuous, negative: dashed) overlaid to the TRACE (195 Å) image taken at 00:38 UT. Computed field lines are superimposed (green + blue and magenta correspond to $\alpha = -0.08$ Mm$^{-1}$ and $\alpha = -0.11$ Mm$^{-1}$, respectively). Bottom: Observed (blue thick lines) and fitted (red thin lines) cloud magnetic field.

Table 1. Left block of columns shows time, range of $\alpha$, and range of $H_{\text{cor}}$. The right block shows the fluxes $F_z$ and $F_\phi/L$, and $H_{MC}/L$, using Lundquist’s model.

<table>
<thead>
<tr>
<th>Time UT</th>
<th>$\alpha$ Mm$^{-1}$</th>
<th>$H_{\text{cor}}$ $10^{39}$Mx$^2$</th>
<th>$F_z$ $10^{19}$Mx</th>
<th>$F_\phi/L$ $10^{10}$Mx/AU</th>
<th>$H_{MC}/L$ $10^{39}$Mx$^2$/AU</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:03</td>
<td>-0.08/-0.11</td>
<td>-5.2/-7.5</td>
<td>1.3</td>
<td>20.</td>
<td>-3.0</td>
</tr>
<tr>
<td>11:11</td>
<td>-0.08/-0.11</td>
<td>-2.9/-4.2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
such that $B_{z,\text{cloud}}$ is the axial component (positive at the cloud centre), $B_{y,\text{cloud}}$ is the azimuthal component after the spacecraft reaches the minimum distance to the MC axis, and $B_{x,\text{cloud}}$ is the radial component, also after leaving the MC centre.

We model the small cloud field considering a linear force-free field configuration (Lundquist, 1950). The physical parameters that fit best the observations are computed following the method described in Dasso et al. (2003). The radius of the cloud ($R = 1.6 \times 10^{-2}$ AU) is estimated from the duration of the MC and the observed solar wind speed. The observations and the fitted curves are shown in right panels of Figure 1 for $B_{z,\text{cloud}}$ and $B_{y,\text{cloud}}$ ($|B_{x,\text{cloud}}| << |B_{y,\text{cloud}}|, |B_{z,\text{cloud}}|$).

We next compute some global quantities that are comparable to the corresponding coronal ones. An expression for the gauge-invariant relative magnetic helicity per unit length ($H_{MC}/L$) has been deduced by Dasso et al. (2003) for the model used here. We compute $H_{MC}/L$, the magnetic flux ($F_{z,\text{cloud}}$) of $B_{z,\text{cloud}}$ (i.e., along the flux tube) and the magnetic flux ($F_{\phi,\text{cloud}}L = \int_0^R dr B_\phi(r)$) of $B_{\phi,\text{cloud}}$ (i.e. across a section of the cloud containing its axis). Our results are shown in Table 1.

3. Conclusions

There are several observational evidences that support the link between the third X-ray event and the small MC: a) the location, i.e. the eruption occurred very close to disc centre and, since the ejecta travel dominantly in the radial direction, this implies that the resulting magnetic cloud has a chance to be observed by Wind; b) the timing, i.e. 4.5 days travel time is expected for a slow MC ($\sim 350$ km/s) to reach Wind, c) the signs of the the axial magnetic field of the MC and of the AR, and d) of the helicities, all agree.

We also quantified this link through the measured magnetic fluxes and calculated helicities. We know that the photospheric magnetic bipole disappeared about one day after the eruption, so the erupting flux rope was detached from its original solar source when it was observed by Wind. Using a simple proportionality we find a length of $\approx 0.5$ AU for the flux tube. However, because detached field lines must reconnect with interplanetary field lines leading to a propagation of twist along the new connections with the Alfvén speed ($\approx 100$Km/s), the most probably length of the flux rope is $\sim 1$AU. Therefore, the estimated cloud helicity is $|H_{MC}| \approx 1.5 \times 10^{39}$Mx$^2$, being in good agreement with the decrease of the magnetic helicity in the corona, $2.3 \times 10^{39}$ Mx$^2 \leq |\Delta H_{\text{cor}}| \leq 3.3 \times 10^{39}$ Mx$^2$ (Table 1).

The values of magnetic flux in the dimmings are similar to the flux associated with the azimuthal component of the cloud (Table 1), so the ejection could be the result of the expulsion of a twisted flux tube formed during the eruption by successive reconnections in a sheared magnetic arcade.

Based on the evidences discussed above, we conclude that the observed coronal eruption (third X-ray burst) indeed resulted in the small MC.

More studies linking solar and interplanetary observations, as the analysis presented here, will help to get a better understanding of the origin of eruptive phenomena and will improve the forecast of space weather conditions.
Acknowledgments. We thank: the NASA’s Space Physics Data Facility (SPDF), the SOHO/EIT and SOHO/MDI and TRACE consortia, and the SURF UK facility for SXT data. CHM and SD acknowledge support from: UBACyT X329, PIPs 2693 and 2388 (CONICET), and PICTs 12187 and 14163 (ANPCyT). S.D. and C.H.M. are members of the Carrera del Investigador Científico, CONICET. C.H.M. and Lv.D.G. thank TET (Hungary) and SECyT for financial support through their cooperation program (AR03/02 and HU/A01/UIII/01). Lv.D.G. was supported by the Hungarian Government grant OTKA T-038013.

References