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The smallest source region of an interplanetary magnetic cloud: A mini-sigmoid

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Abstract

We provide evidence for the smallest sigmoid eruption – CME – interplanetary magnetic cloud event ever observed by combining multi-wavelength remote sensing and in situ observations, as well as computing the coronal and interplanetary magnetic fields. The tiny bipole had 100 times less flux than an average active region (AR). It had a sigmoidal structure in the corona and we detected a very high level of twist in its magnetic field. On 11 May 1998, at about 8 UT, the sigmoid underwent eruption evidenced by expanding elongated EUV loops, dimmings and formation of a cusp. The Wind spacecraft, 4.5 days later, detected one of the smallest magnetic clouds (MC) ever identified (100 times less magnetic flux than an average MC). The link between the EUV bright point eruption and the interplanetary MC is supported by several pieces of evidence: timing, same coronal loop and MC orientation relative to the ecliptic, same magnetic field direction and magnetic helicity sign in the coronal loops and in the MC, comparable magnetic flux measured in the dimming regions and in the interplanetary MC and, most importantly, the pre- to post-event change of magnetic helicity in the solar corona is found to be comparable to the helicity content of the cloud.

Keywords: MHD and plasmas; Solar physics; Flares; Bursts and related phenomena; Interplanetary space

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1. Introduction

In general, coronal mass ejections (CMEs) are thought to be phenomena that involve a large-scale reconfiguration of the solar corona, accompanied by significant disturbances in the solar wind. CMEs appear in the interplanetary medium as interplanetary CMEs (ICMEs). A subset of these ICMEs, called magnetic clouds (MCs), has well defined characteristics: a coherent rotation of the magnetic field vector, an enhanced field strength, as well as a proton temperature lower than in the surrounding solar wind (Burlaga et al., 1981). This subset has been thoroughly studied and there is increasing evidence that the helicity sign of MCs matches that of their solar source region (Bothmer and Schwenn, 1994; Rust, 1994; Marubashi, 1997; Yurchyshyn et al., 2001). As in the case of CMEs, most of the MC studies have focused on large scale events which last as long as a few days (see e.g., Lepping et al., 1990;

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Zhao et al., 2001). However, both at the coronal level and in the interplanetary medium much smaller events are observed as well (e.g., narrow CMEs (Munro and Sime, 1985; Howard et al., 1985), and small interplanetary flux ropes (Shimazu and Marubashi, 2000)).

During a survey of X-ray bright points (Pohjolainen, 2000) with enhanced radio emission, we found an isolated radio bright point near the centre of the disc on 11 May, 1998 (see Fig. 1, left). This structure showed signs of an eruptive nature, such as elongated sigmoidal loops which later disappeared, EUV dimmings and cusp formation (in the largest event). We describe, in Section 2, the global evolution of the small bipolar AR at the photospheric level and in the corona. Then, the coronal eruptions are analyzed in Section 3, where we quantify the amount of magnetic flux and helicity involved. In Section 4, we analyze the interplanetary data plausibly associated with this coronal ejection, and we derive the same physical quantities as at the coronal level. In Section 5, we link the events observed in the corona and the interplanetary space and we conclude.

2. The small bipole at different atmospheric levels

We analyze the global evolution of the X-ray flux of this bipole using Yohkoh/Soft X-ray Telescope (SXT, Tsuneta et al., 1991) full-disc images (5 arcsec per pixel). The soft X-ray light curve presents several peaks (Fig. 1, right). The most intense events are observed during 11 May. The first one lasted for ≈26 min. Two X-ray bursts followed this one. 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 ≈3 h.

The photospheric magnetic evolution of this bipole can be followed in data obtained with the Michelson Doppler Imager (MDI, Scherrer et al., 1995) on board the Solar and Heliospheric Observatory (SOHO). We observe that the bipole orientation was changing with time (Fig. 2, top), the axis joining both polarities rotated clockwise, mostly because magnetic field elongations (that we call "tongues") are retracting. This implies a negative twist (see the Fig. 5 and corresponding discussion in López Fuentes et al., 2000). We measure the magnetic flux in the bipole, which at peak evolution was 3.2×10^{20} Mx (average between positive and absolute value of the negative fluxes); this value puts this bipole into the 'small active region' category (Schrijver and Zwaan, 2000).

The complete evolution of the EUV emission of this small AR is best covered by data from the SOHO/Extreme-Ultraviolet Imaging Telescope (EIT, 2.6 arcsec per pixel) (Delaboudiniere et al., 1995). Globally the EUV emission followed the evolution of the photospheric magnetic field; in particular, the emission extends and rotates in parallel to the photospheric "boundary conditions" (see Fig. 2, bottom). On top of this global behaviour, there is a specific evolution of the EUV emission that is linked to the magnetic stress accumulation in the corona, and later to the global magnetic instability (see Section 3.1).

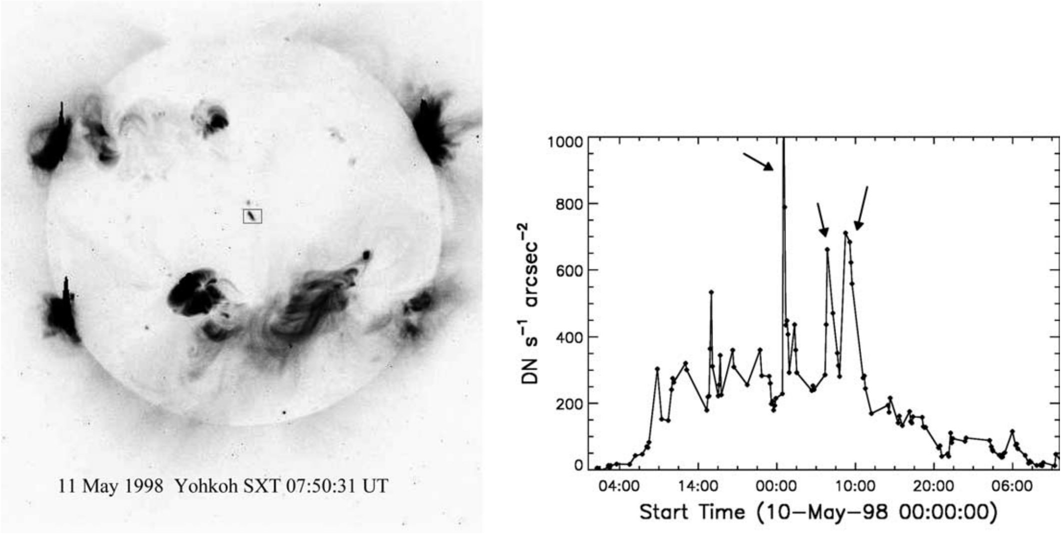

Fig. 1. SXT full disc image (left) and flux evolution (right) from the emergence to the disappearance of the small AR. The image corresponds to the time of maximum extension of the X-ray bright point (shown within the box), which is located very far from other ARs. The X-ray flux curve was obtained using the software SXT_FLUX with a fixed temperature of 2 MK, determined using the thin Aluminum (Al.1) and the Dagwood filters (Al–Mg). This program, from the Yohkoh software package, computes DN/s given the temperature and the filter, the DN/s values were calculated over the area covered by the small bright point and then divided by this area in arcsec^2. Three main bursts can be seen in X-rays (marked with arrows), all occurred on 11 May: the first at ~01:00 UT, the second at ~07:00 UT, and the third at ~08:30 UT.