

On the Solar Sources of Polar-crown Coronal Mass Ejections

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Introduction

Coronal mass ejections (CMEs) from the polar crown filament region originate above 60-degree latitude during solar activity maxima. Cessation of these high-latitude CMEs marks the end of the maximum phase when the solar poles reverse their polarity (Gopalswamy et al. 2003). The eruption mechanism of the polar CMEs is not well understood: they originate from bipolar magnetic regions in contrast to the low-latitude ones, which may occur from both bipolar and multipolar regions. One of the key questions is whether the polar CMEs are associated with flare-like brightening and if so what the nature of the CME-flare relationship is (Gopalswamy 2013). Flare-like brightening is not expected if the polar CMEs are simple expansions of magnetic loops suggested by Gosling (1990) to explain non-rope ICMEs or mass expansions (Antiochos et al. 1999) similar to Sheeley blobs (Sheeley et al. 1997). Uchida et al. (1992) also talked about active region expansion without any reconnection. If polar CMEs are not similar to the low-latitude ones, then they are expected have the following properties: (i) they occur without any reconnection and hence without post eruption arcades (PEAs), (ii) they start at a height of a few solar radii, and (iii) they should be slow (~10 km/s), and (iv) they should accelerate slowly (~4 m/s²) like the solar wind.

Polar CMEs become prolific during the maximum phase of solar cycles (Gopalswamy et al. 2012). For cycle 24, we have a number of instruments observing the polar CMEs: SOHO, STEREO, and SDO. We use these data to show that none of the three properties (i)-(iii) listed above apply to the polar CME studied. We conclude that the polar CMEs may not be different from the low-latitude CMEs. By inference, we think that the same eruption mechanism should apply to both high and low-latitude CMEs.

Gopalswamy, N. et al., ApJ 598, L63, 2003
Gopalswamy, N., Solar Wind 13, AIP Conf Proc 1539, 5, 2013

A Polar CME with 3-part Structure

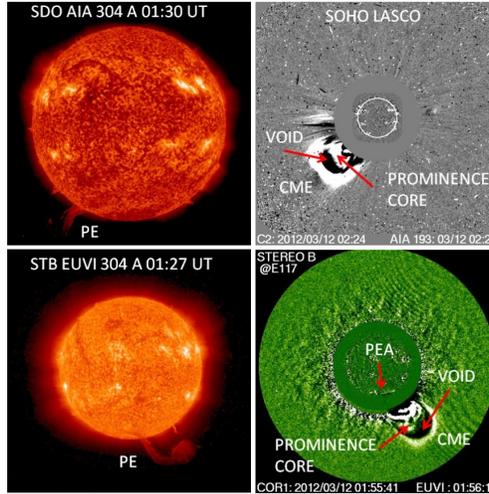


Figure 1 A 3-part CME observed by SOHO/LASCO (top right). The prominence core (PE) was observed by SDO/AIA (top left) and STEREO-B/EUVI (bottom left). The CME was also observed by STEREO-B/CORI1 (bottom right) with the same 3-part structure viewed from a different vantage point. Thus, morphologically, the high-latitude (HL) CME is similar to any other CME from lower latitudes.

CME Kinematics and PEA

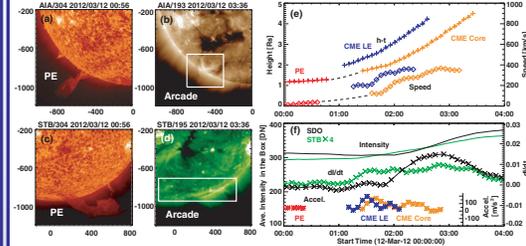


Figure 2. (a, c) The prominence eruption (PE) from the polar crown and (b, d) the post-eruption arcade of the event in Fig. 1 as imaged by SDO and STEREO. PE is best observed in the 304 Å images, while the arcade is well observed in the 195 Å images. (e) The PEA intensity I in EUV and its derivative dI/dt are compared with the acceleration profiles of the CME leading edge (LE) and the prominence core. There is a flare-like brightening; the intensity (I) of the arcade resembles a gradual X-ray event; dI/dt resembles Neupert effect, and peaks with CME acceleration.

- The CME speed increased from 400 km/s (COR1) to 746 km/s (LASCO).
- The initial acceleration was 150 km/s², typical of PE CMEs
- The acceleration typically peaks around 2.5 Rs, as in regular CMEs
- The CME mass from LASCO images is 1.7x10¹⁵ g
- The CME kinetic energy is 3.4x10³⁰ erg
- The speed and acceleration are more than an order of magnitude greater than the mass expansion rates.
- The mass and kinetic energy are slightly above those of the general population

Source Region Free Energy

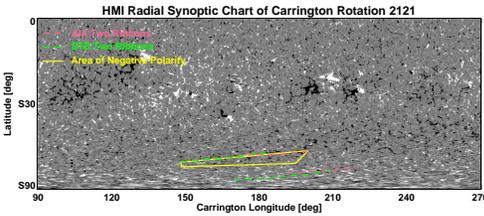


Figure 3. HMI synoptic chart for the 2012 March 12 event showing the PEA extending over a length of 2.8x10⁵ km (E113 to E41). The arcade width is ~2.2x10⁵ km. Assuming PEA width ~ height, the PEA volume V ~ 6.6x10³⁰ cm³. The average field strength B under the northern footprint of the PEA ~ 5.5 G. The magnetic potential energy (VB²/8π) ~ 7.8x10³⁰ erg.

The free energy in the source region can be estimated as the magnetic potential energy of the source region. Since the PEA was very extended in the STEREO/EUVI image, we overlaid the PEA on the HMI synoptic magnetic field chart to get the average field strength under the arcade.

The negative polarity was clear in the synoptic chart, so we used the triangular region as in Fig. 3 to get the average field strength. The positive polarity was on the poleward side. Since we know the length and width of the arcade, we can estimate the PEA volume assuming the height to be similar to the width. The estimated free energy ~7.8x10³⁰ erg is more than a factor of 2 higher than the CME kinetic energy and hence adequate to power the CME.

Gosling, J. T., AGU Monograph 58, 343, 1990
Antiochos, S. K. et al., ApJ, 510, 485, 1999
Sheeley, N. R. et al., ApJ 484, 472, 1997
Uchida, Y. et al., PASJ 44, L155

Thermal Energy Content of the PEA

- Aschwanden et al. (2013) showed that the temperature and emission measure can be obtained in various coronal structures from the coronal holes to active regions, so long as the temperatures are in the range 0.5 – 10 MK.
- The differential emission measure (DEM) distribution is modeled by a Gaussian function in logarithmic temperature. By fitting Gaussian functions to the observations, one can obtain the peak DEM and temperature in coronal structures
- Fig. 4 shows that the PEA is hotter than the surroundings. The formation of polar PEA is similar to that in regular flares

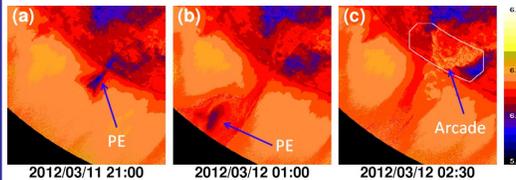


Figure 4. Temperature maps for the 2012 March 12 polar crown prominence eruption (PE) at three instances: (a) pre-eruption, (b) early phase, and (c) late phase. The heated arcade is shown enclosed by a polygon in (c). Each temperature map was made from 6 SDO/AIA EUV images at 94, 131, 171, 193, 211, 335 Å. The color bar to the right indicates the logarithmic temperature: 5.7, 6.0, 6.3, and 6.7 correspond to 0.5 MK, 1.0 MK, 2.0 MK, and 5.0 MK, respectively. The arcade is at a temperature of ~2 MK, hotter than the surrounding corona (~1 MK).

From the computed temperature and emission measure, we estimated the thermal energy content of the arcade as 7.3x10²⁸ erg. The PEA thermal energy is 2.2% of the CME kinetic energy, not too different from the values 0.5% to 10% (mean 3.2%) for major flares (Emslie et al. 2012)

Aschwanden, M. J., et al. Solar Phys. 283, 5, 2013
Emslie, A. G., et al., ApJ, 759, 71, 2012

Future Work

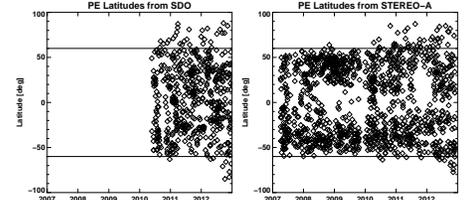


Figure 5. Locations of prominence eruptions detected by automatically in SDO and STEREO 304 Å images. The HL activity ended in the northern hemisphere and the polarity reversed. More HL activity is expected from the southern hemisphere. We plan to perform statistical analysis of the polar CMEs and the associated PEAs using these data

Summary

We reported on a polar CMEs, which has a post-eruption arcade (PEA) observed in soft X-ray and EUV wavelengths. We find

- the polar CME has the usual 3-part structure of low-latitude (LL) CMEs
- the PEA intensity variation is similar to that of the CME speed
- the time derivative of the PEA intensity is similar to CME acceleration
- the initial CME acceleration is ~150 m/s², typical of PE-related CMEs
- the acceleration is much bigger than the slow-wind acceleration
- the mass (1.7x10¹⁵ g) and kinetic energy (3.4x10³⁰ erg) are also typical of LL CMEs
- the free energy in the source is more than enough to power the CME
- the ratio of the thermal energy content of PEA to the CME kinetic energy is very similar to that from low-latitude CMEs.

Thus, we conclude that the polar-crown CME is fundamentally similar to the low-latitude CMEs and hence may have similar eruption mechanism.