DISCONNECTION OF CORONAL FIELD LINES DUE TO THE EMERGENCE OF NEW PHOTOSPHERIC FLUX AS THE CAUSE OF CMES AND INTERPLANETARY SHOCKS

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Abstract. A scenario is presented whereby CMEs and interplanetary shocks are consequences of a large scale rearrangement of the coronal magnetic field induced by the disconnection of field lines from the solar surface due to the emergence of flux with opposite polarity. In this scenario the CME is the mass released from the previously closed structure and the interplanetary shock is formed by the injection of faster solar wind from an extended or newly created coronal hole which results from the opening of the field lines. Here CMEs and interplanetary shocks are associated events, but not cause-effect related. Observational and computational evidence supporting this view is provided.

Key words: Solar activity – CMEs – Interplanetary shocks

1. Introduction

By combining the Solwind coronagraph/polarimeter observations with the Helios 1 interplanetary observations, Sheeley et al. (1985) found that virtually every interplanetary shock was associated with the previous occurrence of a coronal mass ejection (CME). However, a detailed analysis of this association has shown that it is difficult to consider it as a cause-effect relation with CMEs being the pistons driving the shocks (see for instance Bravo and Pérez-Enríquez, 1994; Bravo and Nikiforova, 1994; Bravo and Rivera, 1994). We have suggested that interplanetary shocks are actually driven by the sudden injection of faster solar wind from a coronal hole due to a sudden increase in the hole's area produced by the emergence of new photospheric flux with opposite magnetic polarity (Bravo, 1993, 1994). Here we describe in detail a scenario in which the CME, the interplanetary shock, and the possible occurrence of a prominence eruption or a flare are all consequences of the emergence of new flux with opposite magnetic polarity and none of them is directly the cause of any other.

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2. The Emergence of New Photospheric Material and the Production of a CME

The photospheric magnetic field is observed to change from one solar rotation to the next and even from one day to another, showing the continuous emergence of subphotospheric material carrying fresh magnetic field whose polarity may be different from the previous one. These changes of the photospheric magnetic field make the chromospheric and coronal fields rearrange, producing changes in the topology of their magnetic structures that may include the opening of previously closed field lines as well as the closing of the previously open ones. A consequence of this would be the change in size and shape of the coronal holes and the evolution of coronal helmets, among others.

A particularly interesting case would be the emergence of new material with opposite magnetic polarity at one side of a coronal helmet which is besides a coronal hole, as helmets commonly are. Such an event could lead to the disconnection of some or all of the closed field lines of the helmet, as shown in Figure 1.

The disconnection of lines will brake the stability of the region by reducing the confining effect of the magnetic tension on the helmet's plasma. So, an upward force will appear which will accelerate the plasma to the interplanetary space and a curved-front type CME is produced. The acceleration of CMEs in the corona was noticed since the very early coronagraph observations (see for instance Hildner et al., 1975) and it is importantant to point out that this behaviour is contrary to what we would expect if CMEs had an explosive origin. The curved-front type of the CMEs associated with interplanetary shocks has also been observed (see Bravo and Nikiforova, 1994). Once the helmet field lines are open and the confined plasma is released, it will incorporate to the solar wind flow and probably will be indistinguishable of it in interplanetary space.

3. Prominence Eruptions and Flares Associated with CMEs

If a prominence is inside the helmet (a common situation), it may be driven to erupt also by the destabilization of the region or directly by the emergence of the new flux. In this case, the prominence material will rise too, accompanying the helmet plasma as the "bright core" sometimes observed below the CME arch. Due to its nearness to the newly open field lines, it can be possible for the material of the prominence to go out into the interplanetary space transporting its own field and plasma characteristics. This material could possibly be identified in the solar wind and probably it is what has been called a "cloud", a "CME", an "ejecta", etc. It is also possible that the

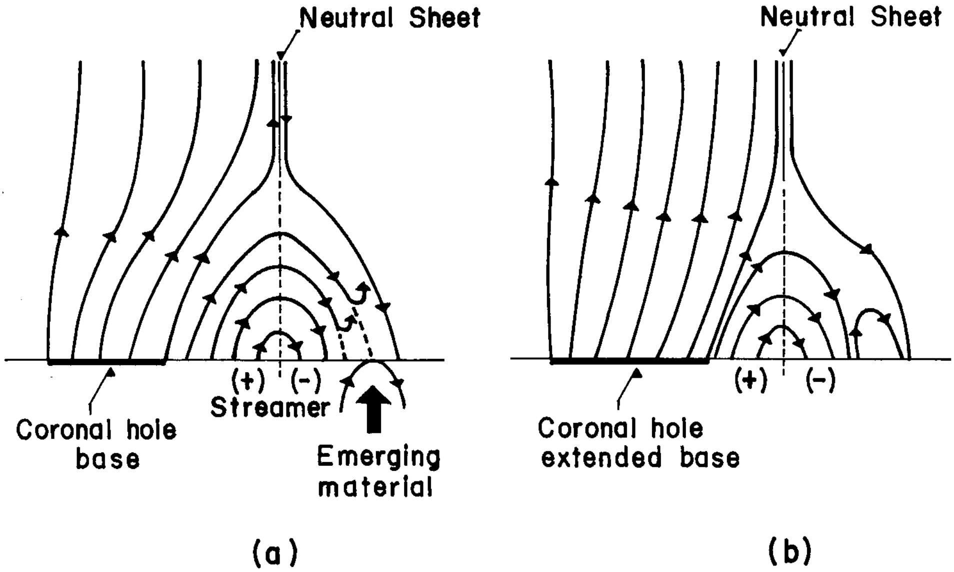

Fig. 1. Disconnection of field lines due to the emergence of opposite polarity flux.

global perturbation generated by the emergence of the flux affects a nearby active region driving a flare. In this case the material ejected from the flare might also be incorporated to the solar wind flow carrying its own characteristics as in the prominence case. The possibility of the injection into the solar wind of the material ejected from the eruption of a prominence or a flare has been discussed in earlier papers (see Bravo and Rivera, 1994; Bravo and Lanzagorta, 1994)

4. The Asymmetric Character of CMEs

As the disconnection occurs only at one side of the coronal helmet, the CME will be asymmetric, with one leg of the structure remaining at the Sun. In this case the final appearance of the CME will be only a bright ray. This type of asymmetric evolution has been frequently observed in curved-front CMEs although their asymmetrical nature has not received much attention.

A well known example is the 18 August 1980 CME, analysed by Illing and Hundhausen (1986). Zhang and Wang (1993) studied this particular CME by simulating numerically the evolution of the corona to reproduce the CME structure. They tried different kinds of initial perturbations at one side of a coronal helmet surrounded by open field lines: a thermal pressure impulse, a speed increment, a magnetic flux emergence with the same polarity, and a magnetic flux emergence with opposite polarity. They concluded that the asymmetrical crescent high density structure of this CME can only be reproduced by the emergence of magnetic flux of different polarity.

5. The Formation of the Interplanetary Shock

Concerning the coronal hole beside the helmet in Figure 1, we see that the disconnected lines will add to its flux tube, producing the field (and flux) lines to become more straight and reducing the divergence of the hole. It has been proved, by combining observations and computations, that the velocity of the solar wind increases as the divergence of the flux tube decreases (see for instance Levine et al., 1977; Wang and Sheeley, 1990). Then, the velocity of the plasma from the hole will increase after the disconnection of the helmet field lines. Such a sudden increase of the velocity of the solar wind from the hole will form an interplanetary shock. The shock will show behind the high speed wind from the extended hole which is driving it.

So, in this scenario, the mass ejected by the opening of the field lines of the helmet (the CME) is not the piston driving the shock. That is, CMEs and interplanetary shocks, although associated events, are not cause-effect related.

6. Observations of Sudden Changes in Coronal Holes

After all the mass contained in the previously closed coronal structures has been drained, a dark extension of the coronal hole will appear, showing a larger coronal hole. The same will happen with the creation of a new hole when it was not previously beside the helmet and that will become apparent after the CME process. This extension or creation of coronal holes in relation to coronal transients has been frequently observed in the soft X-ray images from YOHKOH (see for instance Watanabe et al., 1994).

7. Conclusions and Discussion

The scenario proposed here could explain the solar observations related to the formation of interplanetary shocks invoking as a common cause the emergence of new photospheric material with opposite magnetic polarity which disconnects previously closed field lines. In it, the physical mechanism driving the interplanetary shock is the sudden increase in the velocity of the solar wind from a suddenly extended or newly created coronal hole, and all the other solar events are only peripheral. In terms of the old controversy between Gold (1955) and Parker (1961) of whether interplanetary shocks are ejecta-driven shocks (with closed field lines behind them) or blast or fast-wind-driven shocks (with open magnetic field lines behind), the scenario outlined here supports Parker's view.

Finally, it is important to point out that we are not proposing that the mechanism described here is the way in which all CMEs are originated. There are different types of CMEs and they surely have different origins; we only refer here to those CMEs which are associated with the formation of an interplanetary shock. We are not trying to prove, either, that the mechanism presented here is the only way to produce an interplanetary shock. It may be also possible that the material ejected by the prominence eruption or by the flare into interplanetary space can be fast enough to produce a shock. In such cases, the presence of the coronal hole, which seems to be always in the source region of a large-scale interplanetary disturbance (Hewish and Bravo, 1986), serves only to make possible the incorporation of this material into the solar wind flow.

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