CME SHOCK WARPS CORONAL STREAMER - OBSERVATION AND MHD SIMULATION

B. van der Holst1, L. van Driel-Gesztelyi1,2,3,4, and S. Poedts1

1Centre for Plasma Astrophysics, K.U. Leuven, Celestijnenlaan 200B, B-3001 Leuven, Belgium
2Observatoire de Paris, LESIA, 92195 Meudon Cedex, France
3MSSL, University College London, Holmbury St. Mary, Dorking, Surrey, RH5 6NT, UK
4Konkoly Observatory, 1525 Budapest, Pf. 67, Hungary

ABSTRACT

A fast (v \geq 1000 \text{ km s}^{-1}) CME was observed on 14 January 2002, which was linked to an M4.4 long-duration flare event and a post-eruption loop system visible on, but partially occulted by, the SW limb. The fast expanding CME collided with a North-hemispheric helmet streamer, which was located above NOAA AR 9773 and was in 60° distance from the CME source region. An interaction with the CME (i) pushed the streamer aside and (ii) created a deflection, setting off an outward propagating wavelike deformation along it.

At the same time, a decametric-hectometric type-II radio burst was observed with the WAVES RAD2 instrument onboard the WIND spacecraft. Type-II burst are indicative of shock waves. At about the time of the CME-streamer interaction a splitting was seen in the type-II emission, which indicated a shock continuing to propagate away from the Sun (thus getting into lower and lower density domains) and another branch, which indicated a shock propagating into denser plasma domain. We interpret this fine-structure of the type-II burst as a result of the CME-streamer interaction. We suggest that the shock wave, which was associated with this fast CME, penetrated into the helmet streamer and then died away in the denser plasma (the splitting lasted for about 30 minutes). With our 2-D MHD code we simulate this CME-streamer interaction, using the observed configuration and magnetic topology. The simulation results confirm our hypothesis.

Keywords: coronal mass ejection, shock interaction, numerical simulation.

1. INTRODUCTION

It is still a question whether streamer deflections, which frequently occur in interaction with CMEs, are caused by shocks or by compressive magnetoacoustic waves (Hundhausen, 1987). Hundhausen, concluded that streamer deflections are more frequent than high-speed CMEs, thus most of the streamer warps are caused by compressive magnetoacoustic waves, which move from the sides of the CMEs approximately transverse to the nearly radial magnetic field. Sheeley, Hakala & Wang (2000) showed examples of fast, super-Alfvénic, CMEs associated with the deflection of streamers and solar rays. In those cases there was little doubt that the deflections were caused by shock waves.

The shocks generated by CMEs can be observed in the interplanetary (IP) medium since they accelerate particles and these particles emit radio waves. The frequency drift of the resulting type-II radio emissions are related to the dynamics of the shock (and the related CME) from the high corona into the interplanetary medium. Changes in the shock and CME dynamics can be caused by interaction with structures in the interplanetary space, e.g. collision with another CME, which can lead to shock–dense matter (dense core of an ejected filament) or shock–shock interaction (Gopalswamy et al., 2001).

Recent advances in numerical methods and computer systems have made it possible to address complicated dynamic phenomena occurring in the heliosphere. The simulation of large-scale interplanetary interactions requires consideration of the preexisting structured ambient solar wind, realistic treatment of the launch phase of transient disturbances, and accurate tracking of interactions among multiple ambient and transient structures. We aim to study the distortion of shocks and CMEs propagating in the outer corona, their possible appearance in observations, and phenomena generated by collisions of magnetic structures (e.g. streamers with radial magnetic field, flux ropes ejected during CMEs) and interplanetary shocks. Substantial local warps or kinks in the streamer deformations and related phenomena should figure prominently in the interplanetary medium and may have observable consequences in various wavelengths. In this paper we make an at-

tempt to relate simulations to multi-wavelength observations of a common interaction type analyzing a CME-related shock and its interaction with a helmet streamer.

![GOES 10 X-rays](image)

**Figure 1.** Soft-X-ray flux between 1-8 Å indicates that a long-duration flare event (LDE) of M4.4 GOES-class started at 5:29 UT on 14 January 2002. LDEs are strongly correlated with filament eruptions and CMEs.

2. OPTICAL OBSERVATIONS

A fast ($v \geq 1000$ km s$^{-1}$) CME was observed on 14 January 2002 (Fig. 2). The CME appeared in the SOHO/LASCO C2 field of view at 5:35 UT at the SW quadrant, and by 6:55 UT it became a full halo event according to the CME catalog at http://lasco-www.nrl.navy.mil/cmeplist.html. The classification of the CME as a halo event was especially surprising, since the source region of the CME was not on the disc, but behind the limb. Though there was no lower coronal observation available to identify the CME source region (Yohkoh was not operational, there was no EIT data for this day and TRACE was observing another part of the Sun), from Catania Hα data (Fig. 3) we can say that the CME came from AR 9767 and the eruption of the filament linked to this AR, which was a few degrees behind the SW limb at the time of the event. First of all, the CME was related to an M4.4 long-duration flare event (LDE, Fig. 1), for which no AR identification was given in the GOES flare list. LDEs are normally associated with filament eruption. Hα observations show no change in filaments seen on the disk, but reveal a growing post-eruption loop system partially occulted by the SW limb (Fig. 3). The fast expanding CME collided with a North-hemispheric helmet streamer, which was located above NOAA AR 9773 and was in 60° distance from the CME source region. We observed two different features in the way this fast CME affected the streamer: (a) a gradual change in position as the streamer was pushed aside, presumably, by the expanding magnetic structure of the CME or, possibly, by compressive (fast) magneto-acoustic waves and (b) a fast formation of a deflection at about 7.8 R$_{\odot}$ distance (Fig. 4).

There was a second CME, which occurred along the investigated NW streamer with its foot-point over AR 9773. The latter CME was a slower event with a speed of about 450 km s$^{-1}$, and appeared in the C2 field of view at 8:35 UT.

![Evolution of the CME](image)

**Figure 2.** Evolution of the CME in the LASCO/C3 FOV using the difference image subtraction technique. Note the change in the position and shape of the streamer on the NW hemisphere as the CME expands.

3. RADIO EVENTS

Radio bursts were observed during the CME event in the decametric-hectometric domain onboard the WAVES experiment with the RAD2 and RAD1 receivers (Bougeret et al., 1995). The event generated type-III and type-II radio emissions as the CME propagated through the solar corona and interplanetary medium (Fig. 5). The radio event started with type-III bursts about half an hour after the beginning of the long-duration flare event. Type-III bursts are generated by quasi-continuous beams of suprathermal electrons injected into the interplanetary medium (Lin, 1985). The tracking of type-III radio sources at different frequencies permits to determine the radial dependence of the coronal and interplanetary density (Leblanc et al., 1999). At about 6:20 UT a type-II burst, with a stronger fundamental and a weaker harmonic component, became visi-
4. MHD SIMULATION RESULTS

This CME-streamer event is simulated using our 2-D MHD code. We took the density in the streamer 5 times that of the ambient medium. The initial pressure $p$ is constant throughout the domain and the magnetic field is uniform, such that $\beta = 2p/B^2 = 0.04$. The direction of the field lines in the simulation corresponds to the observed large-scale magnetic configuration at the interaction face. The ratio of the Alfvén speed outside to inside the streamer is 2.24. Outside the streamer the initial upward flow speed (away from the Sun) is $v_b = 0.7c_s$, where $c_s$ is the acoustic sound speed, and $v_b = 0.13v_A$, where $v_A$ is the Alfvén speed. Inside the streamer the ratios are $v_b/c_s = 0.61$ and $v_b/v_A = 0.11$. At time $t = 0$, a CME is generated as a pulse with a ratio of the pressure of the CME-pulse to ambient medium equal to 1000, the ratio of the densities is 70, and the ratio of the velocities is 11.5. In Fig. 6, four snapshots of the simulation are shown. The upward propagating deflection of the streamer due to the CME leading shock front (actually the left wing of the shock) is clearly visible as well as the shock propagation inside the streamer. In future calculations, we will include improved geometry and an initial streamer that is closer to the observations.

5. SUMMARY AND CONCLUSIONS

Using data of the SOHO/LASCO coronagraphs we observed a fast CME on 14 January 2002, which collided with a North-hemispheric helmet streamer at about 60° heliographic distance from the CME source region. The interaction with the CME (i) pushed the streamer aside and (ii) created a deflection, setting off an outward propagating wavelike deformation along it.

The CME was accompanied by a decametric-hemispheric type-II radio burst observed with the WAVES RAD2 and RAD1 instruments onboard the WIND spacecraft. It is now well established that type-II bursts result from shocks driven by CMEs. At about the time of the CME-streamer interaction a splitting was seen in the type-II emission, indicating the shock continuing to propagate away from the Sun (thus getting into lower and lower density
domains) but another, short-lived branch appeared to propagate into some denser plasma domain. We interpret this fine-structure of the type-II burst as a result of the CME-streamer interaction. We suggest that the shock wave, which was associated with this fast CME, partially penetrated into the helmet streamer and then died away in the denser plasma.

For the origin of the two types of CME-streamer interaction observed during this event, we propose that the sudden streamer deflection was caused by a shock, while the change in the streamer position, which showed up almost immediately after the appearance of the CME, was caused by fast magneto-acoustic waves propagating from the side of the CME. Using our 2-D MHD code we simulate this CME-streamer interaction, using the observed configuration and magnetic topology. The simulation results confirm our hypothesis.

ACKNOWLEDGMENTS

These results were obtained in the framework of the projects OT/98/14 (K.U.Leuven), G.0344.98 (FWO-Vlaanderen), and 14815/00/NL/SFe(IC) (ESA Prodex 6). L.v.D.G. was supported by the Research Fellowship F/02/035 of the K.U. Leuven and by the Hungarian Government grants OTKA T-038013, T-032846. The SOHO/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 joint project by ESA and NASA. The WAVES instrument is a joint effort of the Paris-Meudon Observatory, the University of Minnesota, and the Goddard Space Flight Center. The Hα data were obtained at the Catania Astrophysical Observatory (Italy) and at Big Bear Solar Observatory (USA).

REFERENCES


