Investigation of the halo (I)CME observed on August 25, 2001

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Abstract. In this work we investigate the characteristics of a halo CME that arrived at Earth and produced a geomagnetic storm. Using data from few satellites (SOHO, Ulysses, ACE, WIND) we have computed the CME characteristics and its impact to the Earth.

Key words: halo CME, geomagnetic storm

1. INTRODUCTION

Coronal mass ejections (CMEs) are huge bubbles of plasma ejected from the Sun into interplanetary space. A halo CME appears as a bubble surrounding the occulting disk. When directed towards the Earth, these phenomena are often responsible for geomagnetic storms. The halo observed by Large Angle and Spectrometric Coronagraph (LASCO) and Extreme Ultraviolet Imaging Telescope (EIT) instruments on 25.08.2001 was responsible for a geomagnetic storm. The halo CME had an outline asymmetry (OA) and was produced by a very powerful X5.3 flare observed few minutes before the CME onset. The event was first observed in LASCO-C2 at 16:50 UT as a bright front filling the SE quadrant, and was seen as a full halo CME in C2 by 17:27 UT.

2. THE INSTRUMENT AND OBSERVATIONS

We have used observational data from the satellite Solar and Heliospheric Observatory (SOHO). The satellite was launched on December 2, 1995. SOHO has on-board 12 instruments. For our study we used the data from two of these instruments. One of these is LASCO, which is equipped with two coronagraphs: C2 that records images of solar corona from 2 to 6 solar radii and C3 that records images from 3.7 to 32 solar radii. We computed the mass and the energy of the halo CME on 25 August 2001 using data from LASCO. We also computed the speed of the CME and, consequently, the arrival time at the Earth. From EIT data we have been able to identify the source of the CME.

In order to get a complete understanding of the studied event we have analyzed also the registrations of Advanced Composition Explorer (ACE) and Ulysses satellites. From Ulysses we could obtain information about the orientation of the magnetic field and its intensity, information that is important in the estimation of the CME impact on the Earth.

3. DATA ANALYSIS

The halo CME was first observed by LASCO-C2 at 16:50 UT, as a bright front filling the SE quadrant, becoming a full halo CME at 17:27 UT. This CME was associated with a powerful X5.3 flare which occurred in the active region (AR) 9591, situated at S17E34 on the solar disk. The CME and the flare are shown in a combined frame of EIT and LASCO-C2 images (Figure 1).

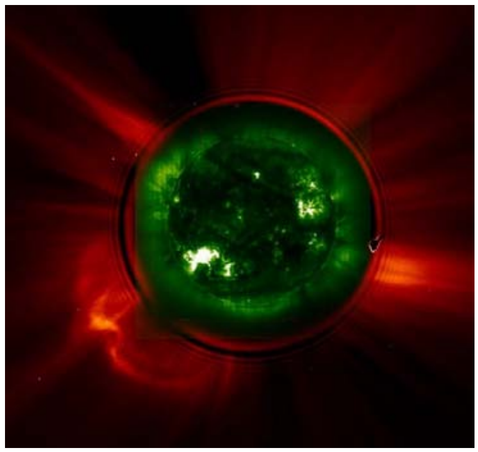

Figure 1 – Superimposed EIT and LASCO-C2 images

Using the instruments from SOHO we tried to determinate different characteristics of the CME. In order to obtain the approximate mass of the CME, we used a program available in Solar Soft library. The method is described by A. Vourlidas (2005) in the tutorial "On Deriving Mass & Energetics of Coronal Mass Ejections" and in A. Vourlidas et all (2000). We have estimated the CME mass and energy using data from LASCO-C2 and LASCO-C3 coronagraphs. We found a mass of around 5*1015g. Figure 2 displays the CME mass as function of time and height reached by the CME in the solar corona.

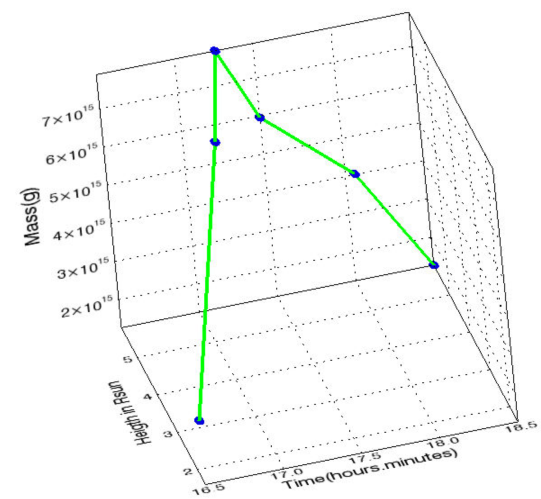

Figure 2 – 3D graphic illustrating the evolution of the CME mass in time and height (expressed in solar radii units).

Another point in our analysis was to identify the real speed of the CME in order to find the approximate time of the CME arrival at the Earth. The CME catalog generated and maintained at the CDAW Data Center, offers a projected value in the plane of the sky (POS) of the velocity for this event. In order to derive the radial speed of the halo CME and implicitly the arrival time near Earth, we used a technique developed by Dal Lago et al. (2003). They used the expansion speeds of the CMEs in order to infer their radial speeds. Radial propagation is related to the lateral expansion: $V_{rad} = 0.88\ V_{exp}$ (Schwenn et al. 2005). The arrival time of the CME (shock) at 1 AU is a function of the expansion speed $T_{tr} = 220.8-22.75*\ln(V_{exp})$

By applying this technique to our event (first observed by LASCO-C2 coronagraph at around 16:50 UT, August 25, 2001), we found that the CME had a radial speed of 1324 km/s and an expansion speed of 1505 Km/s. The measured plane of sky speed was 831 km/s. The estimated arrival time to the Earth was August 27, 2001 at 19:52 UT. Figure 3 displays the height-time (HT) diagram of the CME.

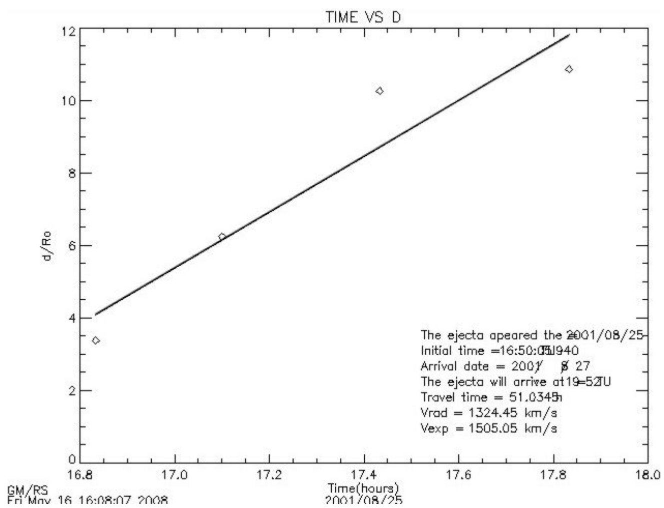

Figure 3 – Height (in solar radii) versus time (in hours) of the CME.

We also computed the energy of the CME. For this we used the programs available in the Solar Soft library. Knowing the mass of the CME and the velocity, the kinetic energy could be derived. We found out that the kinetic energy had a maximum point at around $6x10^{31}$ ergs. From the graphic shown in Fig. 4 we can observe the evolution of the kinetic energy.

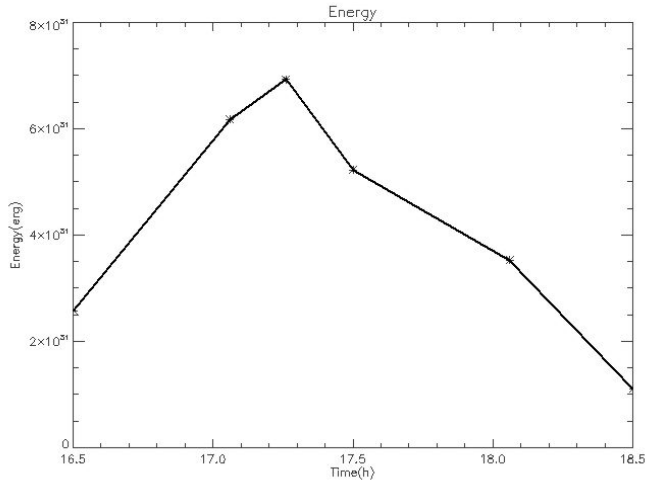

Figure 4 - The energy versus time of theAugust 25, 2001 CME.

Looking for terrestrial effects of such an event means looking for the three main perturbing agents and their arrival time:

- *Electromagnetic radiation* (after 8 minutes), mainly short wavelength, impacting the ionosphere balance and by that affecting the high frequency communications on the dayside of the Earth. This can be hazardous in case of radio blackout of air traffic operations. This halo CME had produced an hour long radio blackout over the Europe, Africa and Americas (http://www.spaceweather.com)

- *Energetic particles* (after few tens of minutes) have the potential to cause damages of electronic equipments and the biological risk is increased to humans in space. No major increase of energetic particles flux was detected (at least in the Earth direction) and no incident is known to be reported for this event.

- *The cloud of magnetized plasma* (after 51 hours in our case) interacting with the Earth's own magnetic field is particularly menacing. In our case the lack of important effects may be due to the IMF pointing north, enhancing the shield of the Earth own magnetic field. This manifested in a relatively low KP index (KP=4). Finally, only a few high latitude northern observers could witness some auroras show.

As we can see in the Figure 5, ACE mission recorded the ICME on August 27, 2001 at 19:25 UT with a strong magnetic field increasing to 18 nT. Until 20:30 UT the magnetic field increased at 23 nT. An indicator of a geomagnetic storm is the negative value of B_z. If the value of the B_z is around -10nT for a three hours period, it means it was an intense storm. For a moderate storm the value of Bz is -5nT for a two hours period and for a small one the B_z is -3nT for one-hour time (Gonzalez et al. 1994). The value registered by ACE, at the arrival time predicted by our computations, was B_z =-10nT, but which did not last for 3 hours.

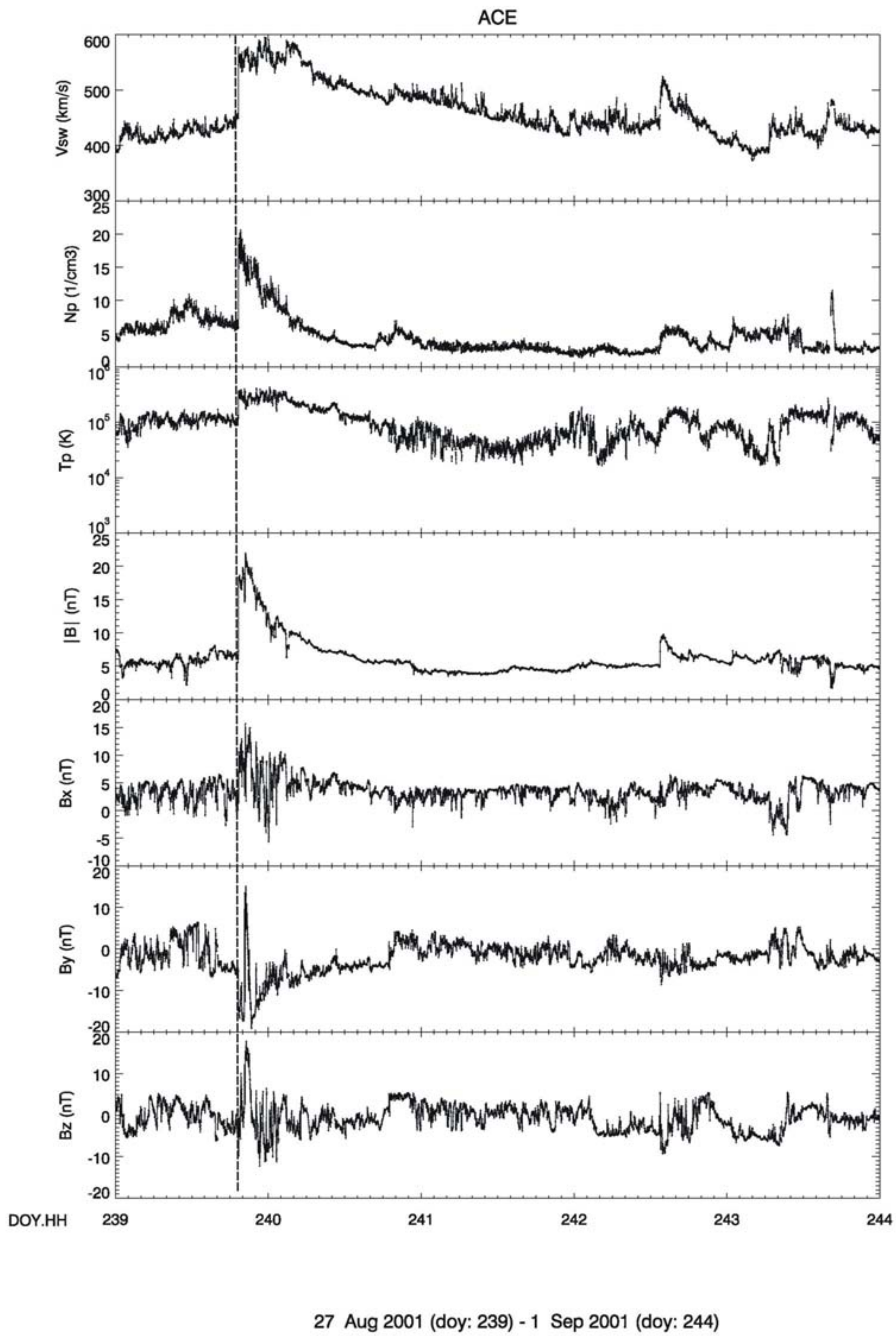

Figure 5 – Evolution of magnetic field, temperature and protons density recorded by ACE mission

WIND mission detected the incoming ICME at 19:50 UT. According to Gonzalez et al. (1999), we can identify if we have a magnetic cloud or not on the base of the values of three parameters: magnetic field, proton temperature and plasma beta. Citing the authors: “the magnetic cloud is a region of slowly varying and strong magnetic fields (10-25 nT or higher) with exceptionally low proton temperature and plasma beta, typically ~ 0.1”. From our data we can observe that at our interest time the magnetic field is between 10-20nT, the temperature starts to increase from $1x10^5$ K to $4x10^5$K and the plasma beta has a 0.9 value.

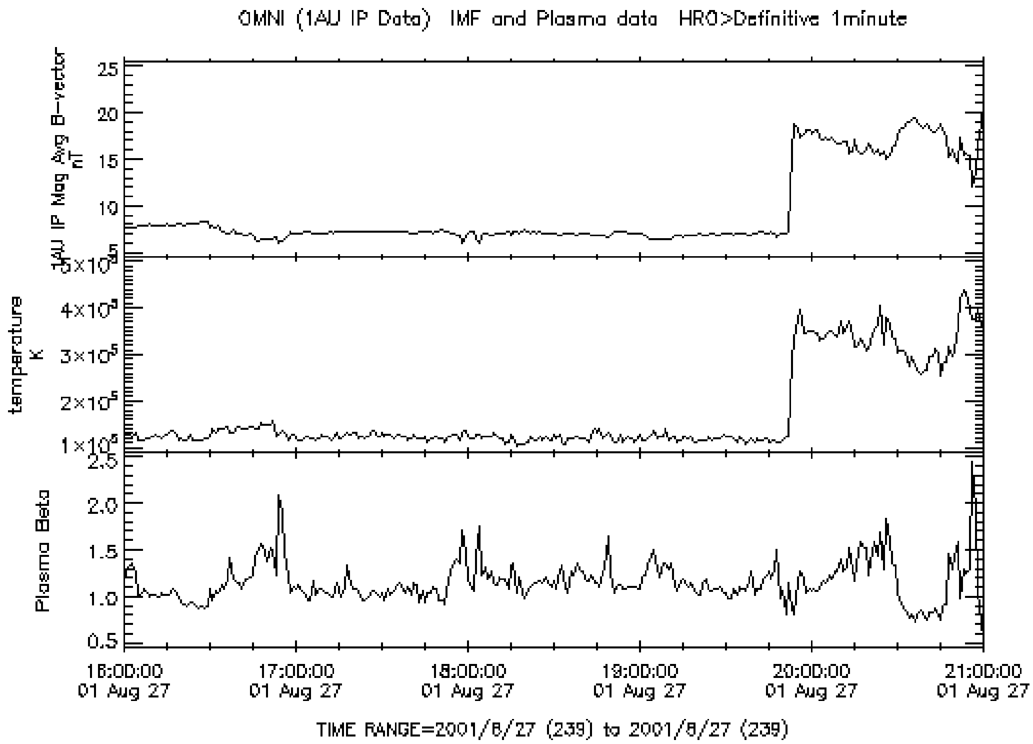

Figure 6 – Evolution of parameters recorded by WIND mission

On August 27, ACE satellite was positioned at a distance of 235 Earth-radii from the Earth on Earth – Sun direction and WIND satellite at a distance of 35 Earth radii from the Earth on Earth – Sun direction but much more northern than ACE, as we can see in the Figure 7. In this figure the x-axis represents the Sun-Earth direction. The time difference between the moment the shock hit the ACE and WIND is consistent with the calculated speed.

Near earth missions data and orbits were obtained from the GSFC/SPDF OMNIWeb interface at http://omniweb.gsfc.nasa.gov.

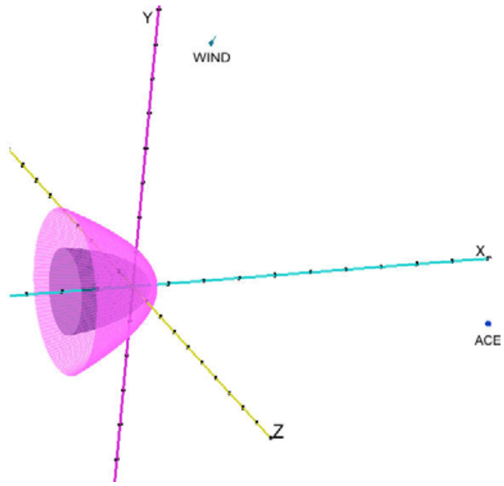

Figure 7 – The position of the ACE and WIND satellites on the August 27, 2001

4. CONCLUSION

We have analyzed a halo CME rising from a complex active region and we have computed its parameters of traveling into the interplanetary space. Using the method elaborated by Dal Lago et al. (2003), we have estimated quite accurate the real speed of the CME. The projected speed is around 830 km/s while the radial speed we inferred is around 1325 km/s. This gives us a very good estimation of the arrival time to the Earth, in agreement with the observations made by ACE and WIND.

Our study is an attempt to improve the space weather forecasting and it is very important for the life quality and security on the Earth.

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