DEFLECTION OF CORONAL MASS EJECTION IN THE INTERPLANETARY MEDIUM

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Abstract. A solar coronal mass ejection (CME) is a large-scale eruption of plasma and magnetic fields from the Sun. It is believed to be the main source of strong interplanetary disturbances that may cause intense geomagnetic storms. However, not all front-side halo CMEs can encounter the Earth and produce geomagnetic storms. The longitude distribution of the Earth-encountered front-side halo CMEs (EFHCMEs) has not only an east–west (E–W) asymmetry (Wang *et al.*, 2002), but also depends on the EFHCMEs' transit speeds from the Sun to 1 AU. The faster the EFHCMEs are, the more westward does their distribution shift, and as a whole, the distribution shifts to the west. Combining the observational results and a simple kinetic analysis, we believe that such E–W asymmetry appearing in the source longitude distribution is due to the deflection of CMEs' propagation in the interplanetary medium. Under the effect of the Parker spiral magnetic field, a fast CME will be blocked by the background solar wind ahead and deflected to the east, whereas a slow CME will be pushed by the following background solar wind and deflected to the west. The deflection angle may be estimated according to the CMEs' transit speed by using a kinetic model. It is shown that slow CMEs can be deflected more easily than fast ones. This is consistent with the observational results obtained by Zhang *et al.* (2003), that all four Earth-encountered limb CMEs originated from the east. On the other hand, since the most of the EFHCMEs are fast events, the range of the longitude distribution given by the theoretical model is E40°,W70°, which is well consistent with the observational results ($E40°$, $W75°$).

1. Introduction

A solar coronal mass ejection (CME) is a large-scale eruption of the plasma and magnetic fields from the Sun (e.g., Howard *et al.*, 1982, 1985; Hundhausen, 1988, 1993; Gosling, 1990, 1996; Webb *et al.*, 2000; St. Cyr *et al.*, 2000; Gopalswamy *et al.*, 2000). Generally, a typical CME injects roughly 10^{23}maxwells of magnetic flux and 10^{13}kg of plasma into interplanetary space (Gosling, 1990; Webb *et al.*, 1994). CMEs are believed to be the main sources of the strong interplanetary disturbances that cause many moderate to intense geomagnetic storms (e.g., Sheeley *et al.*, 1985; Gosling *et al.*, 1991; Webb *et al.*, 2000; Wang *et al.*, 2003).

Since CMEs may be approximated as axial directed symmetrical structures, the front-side halo CMEs are thought to be directed towards the Earth and most likely causing geomagnetic storms (Howard *et al.*, 1982). However, not all front-side halo CMEs have geoeffectiveness. Webb *et al.* (2000) analyzed the relationship between

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halo CMEs, magnetic clouds (MCs), and geomagnetic storms, and suggested that the halo CMEs associated with solar activity within 0.5 $R_\odot$ of Sun center appear to be excellent indicators of increased geoactivity 3–5 days later. By analysis of 36 Earth-directed halo CMEs, Cane *et al.* (2000) suggested that the locations of typical geoeffective solar events are in longitude $\lesssim 40°$ east and west. Gopalswamy *et al.* (2000) also found that CMEs originating near the central meridian with average longitude about 17° will not miss the Earth. All the studies above show that the Earth-encountered CMEs' sources concentrate near the central meridian and their distribution seems to be approximately symmetric in longitude.

To the contrary, recent results suggested that the solar source distribution of the geoeffective halo CMEs has east–west (E–W) asymmetry by statistically examining the LASCO (Large-Angle Spectroscopic Coronagraph on board the Solar and Heliospheric Observatory)-observed halo CMEs from March 1997 to 2000 (Wang *et al.*, 2002). The number of geoeffective halo CMEs originating from the west hemisphere is larger than that from the east by 57%, and such CMEs may be expected at $\sim$ W70° but cannot be beyond E40°. A similar asymmetry in the source longitude distribution was presented by Cane *et al.* (1988) for helium abundance enhancements, though the E–W asymmetry was not proposed definitely. Recently, Cane and Richardson (2003) further confirmed the results by analysis of a more complete sample of front-side halo CMEs. Moreover, in the identification of the solar sources of major geomagnetic storms between 1996 and 2000, Zhang *et al.* (2003) also obtained the same conclusion about such an E–W asymmetry.

E–W asymmetrical distribution has always been found in sunspots, solar flares, solar magnetic structures, etc. (e.g., Maunder, 1907; Bartsch, 1973; Heras *et al.*, 1990; Joshi, 1995; Meunier, 2003). However, these asymmetries are different from our results because our results are obtained by investigating only the halo CMEs reaching the Earth. For all front-side halo CMEs, the distribution does not appear E–W asymmetric (Wang *et al.*, 2002).

The E–W asymmetry in previous studies implies that the west halo CMEs more likely encounter the Earth and therefore cause geomagnetic storms. Wang *et al.* (2002) and Zhang *et al.* (2003) suggested that the Parker spiral interplanetary magnetic fields (Parker, 1963) deflect CMEs when they propagate in the interplanetary medium. CMEs will move outward along a curved line but not a straight line, and form an asymmetric distribution source. Cane and Richardson (2003) raised another possible explanation that some CMEs preferentially occur to the east of the active region in terms of differential rotation. To reveal the nature of this asymmetry and further find whether it has other new characteristics, we investigate the definite Earth-encountered front-side halo CMEs (EFHCMEs) during 1996 – 2002 again by using the Cane and Richardson (2003) sample, and give an approximate theoretical analysis. The observations are described in the next section. The results are presented in Section 3. In Section 4, a possible theoretical explanation is given. Finally, we conclude and summarize the paper in Section 5.