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Radio and X-ray studies of Coronal Mass Ejections and their relevance for Space Weather

Résumé

The solar corona is a highly dynamical medium : instabilities of the magnetic field, which structures the plasma, lead to the acceleration and heating of charged particles and to the ejection of large structures into the heliosphere, the Coronal Mass Ejections (CMEs). These ejected magnetic structures can interact with the Earth's magnetic field and thereby affect the plasma environment and the high atmosphere of the Earth. It also leads to the induction of electric currents in the ground at high geometric latitudes. Studying the origin and propagation of CMEs is of interest for both astrophysics in general and space weather applications. The understanding of the basic processes is indeed a pre-requisite for developing prediction methods of potentially geo-effective disturbances based on observations of the solar corona.

The CMEs are observed and studied through coronographic images. The basic limitation of the coronagraph is that it shows the corona only in the plane of the sky, and blocks by necessity the view on the solar disk. But the geoeffectiveness of a CME depends crucially on the proximity to the Sun-Earth line and the onset and early evolution of CMEs in the low corona are not accessible to coronographic observations. One of the problems is the difficulty to estimate of the arrival time of a CME at Earth, because direct coronographic measurements of the propagation speed of Earth-directed CMEs are not possible from the Sun-Earth line.

This thesis presents the study of CMEs in three different stages : (1) a case study of the CME evolution in the low corona and of its role in particle acceleration, (2) the relationship between the polarisation of the type IV radio emission associated with Earth-directed CMEs in the corona and the orientation of the magnetic field observed as the CMEs arrive at the Earth, and (3) the estimation of the travel times of CMEs to the Earth.

Radio imaging of the low-coronal manifestations of CMEs is able to show the signatures on the solar disk. Previous studies with the Nançay Radioheliograph (NRH) suggest indeed that radio images at metric wavelengths track the early evolution of CMEs well before they become visible in the corona. The examination of the CME evolution in the low corona developed in this work was illustrated through the study of the eruptive event on 26 April 2008, which offered a unique opportunity to investigate the physical link between a single well-identified CME, electron acceleration as traced by radio emission, and the production of solar energetic particles (SEPs) observed in the space. We conduct a detailed analysis combining radio observations (NRH and Decameter Array, Wind/WAVES spectrograph) with remote-sensing observations of the corona in extreme ultraviolet (EUV) and white light as well as in-situ measurements of energetic particles near 1AU (SoHO and STEREO spacecraft). By combining images taken from multiple vantage points we were able to derive the time-dependent evolution of the 3-D pressure front developing around the erupting CME. Finally, we identified, from the radio and SEP observations, three different particle acceleration regions associated to the evolution of the same CME, separated in longitude by about 140o. The observations for this event showed that it is misleading to interpret multi-spacecraft SEP measurements in terms of one acceleration region in the corona. An article

(Salas-Matamoros, Klein and Rouillard) has been submitted to Astronomy & Astrophysics journal.

Besides, we want to explore if there is a relationship between the orientation of the polarity of type IV radio bursts and the orientation of the magnetic field observed at the Earth based on the study of Earth-directed CMEs in the low corona. The basic idea is that the sense of polarization of the radio emission reflects the orientation of the magnetic field in the erupting solar structure. This is work in progress that will be included in the manuscript of the thesis but it is not totally developed yet.

Another issue Space Weather faces is the determination of CME arrival time at Earth based on their propagation speed. It is known that the fundamental tool to measure CME speeds in the corona is coronography, but the Earth-directed speed of a CME cannot be measured by a coronagraph located on the Sun-Earth line. Various proxies have been devised, based on the coronographic measurement. As an alternative, we explore radiative proxies. Both observation and theory reveal that the dynamics of a CME in the low corona are closely related to the evolution of the energy release in the associated flare as traced by the soft X-ray and microwave emission. We present a reassessment of the statistical relationships between limb-CME velocities and radiative parameters, using the SOHO/LASCO catalog, GOES and microwave (from NoRP and RSTN) observations. Then we use the radiative fluences as proxies of CME speed of Earth-directed CMEs, together with the empirical interplanetary acceleration model devised by Gopalswamy et al. (2001), to predict the CME arrival time at Earth. These predictions are compared with observed arrival times and with the predictions based on coronographic measurements. A first article has been published (Salas-Matamoros and Klein, 2015. Solar Physics, Volume 290, Issue 5, pp.1337-1353, in press arXiv:1503.08613). The second one has been submitted in Space Weather and Space Climate.