Publishable Summary for PIRG7-GA-2010-268288 SEP PROJECT

The SEP project aims to enhance our understanding of both the initial stages and the propagation to Earth of Solar Eruptive Phenomena such as the Coronal Mass Ejections (CMEs).
CMEs are a main driver of the variable Space Weather which impacts high-tech human (e.g. telecommunications) activities and infrastructures in both space and Earth. More specifically SEP addresses the following: (1) Understand the genesis of CMEs, (2) Determine the Flare-CME-Coronal Waves relationships, and (3) Determine accurate CME arrival times.

A major obstacle in the understanding of the Physics of Coronal Mass Ejections concerns their primordial magnetic structure, i.e. what is the magnetic structure when a CME is launched. While it is now widely accepted that most CMEs once in the outer corona and observed by coronagraphs, and when they impact the Earth and detected in-situ as magnetic clouds, posses a flux rope topology, i.e. coiled magnetic fields along the axis of a current channel, it is a matter of strong debate whether a flux-rope topology exists when a CME is born. There are CME models which require the presence of a flux-rope before the CME launch and others which form instead a flux rope during the eruption. The first analysis of the formation of a truly pre-existing flux-rope and its subsequent destabilization was performed in the frame of SEP. Using multi-spacecraft SDO and STEREO data the formation of a flux-rope during a confined solar flare was observed. The flux-rope was a hot (~10 MK) coiled structure as revealed by the analysis of its thermal properties. The structure then successively cooled down to emissions with decreasing characteristic temperature while the whole flux-rope and overlying-loops system was slowly rising for several hours. The flux-rope eventually became unstable and erupted after almost 7 hours after its formation. The delay between the onset of the associated flare and of the flux-rope acceleration from the study of its kinematic behaviour suggested an ideal (i.e., not requiring magnetic reconnection) triggering mechanism for the eruption. Thus, pre-existing flux-ropes are an ingredient of CMEs and long-term studies (i.e., not only around the onset time of the CME but also looking several hours prior to it for any signatures of pre-existing flux-ropes) of the evolutions during CME onsets should be conducted. This research was featured in a NASA news-item: http://www.nasa.gov/mission_pages/sdo/news/flux-ropes.html.

Moreover, the role of the background magnetic field in the initiation of CMEs was studied. It is well-known that the tension of the overlying magnetic field lines is the most important force opposing a CME. When the magnetic field above the rising magnetic flux drops off relatively fast with height, then a CME could take place; otherwise the eruption is confined. Extrapolations of the photospheric magnetic field in the corona using Hinode and SDO data were used to calculate the magnetic field distribution above an active region which gave rise to several CMEs during February 2011. The temporal evolution of the rate of the magnetic field decrease (decay-index) above the corresponding heights of initiation of each corresponding CME, as deduced from STEREO limb views of the event was calculated. It was found that the temporal evolution of the magnetic field decay-index was not the primary factor leading to the observed CMEs, but rather the magnetic helicity injection.

Frequently, in tandem with eruptive flares large-scale wave disturbances are observed. These so-called EUV waves, sometimes cover the entire solar surface. The nature of the EUV waves is matter of intense debate with both wave (fast-mode MHD) and non-wave interpretations (disk projection of expanding CME). The exact nature of EUV waves was addressed with a synthesis of the current observational and modeling information of this phenomenon. Understanding this phenomenon has significant implications for both understanding the early evolution of CMEs as well as for gauging coronal conditions. A hybrid picture invoking both wave and non-wave components was found to best reproduce the bulk of the observations recorded by modern instrumentation on-board various satellites (SOHO, TRACE, Hinode, STEREO, SDO). A period of strong lateral expansion that early CMEs undergo is the driver of EUV waves. The initially driven and then freely-propagating EUV wave drives several secondary phenomena in its path (e.g., loop and filament deflections and oscillations) while the erupting CME flux generates several non-wave phenomena like stationary dimmings. Estimates of the energetic content of EUV waves shows they rival the energy of small flares.

As far as the last objective of the SEP project for its first part is concerned a database of a dozen of Earth-directed CMEs for the interval 2010-2012 has been compiled; several of these CMEs had Space Weather effects since they caused geomagnetic storms. During this interval an Earth-directed CME appears as a limb event from the viewpoints of the twin STEREO spacecraft, which were ahead and behind the Earth's orbit by 70-130 degrees during that interval. This configuration would allow for accurate 3D determinations of the CME heights,sizes and directions during the scheduled activities during the ongoing second part of the SEP project. Moreover, a second database,
containing almost 100 limb observations of strong flares (M&X of the GOES classification) during the SDO-era
was compiled. This will be used in further analysis of flux ropes before and during CME onsets.

The expected impact of the SEP project would be to improve our understanding of both the genesis and the propagation of one of the most important drivers of Space Weather, namely the Coronal Mass Ejections.