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Earth-Affecting Solar Causes Observatory (EASCO): A potential International Living with a Star Mission from Sun–Earth L5 ☆

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ABSTRACT

This paper describes the scientific rationale for an L5 mission and a partial list of key scientific instruments the mission should carry. The L5 vantage point provides an unprecedented view of the solar disturbances and their solar sources that can greatly advance the science behind space weather. A coronagraph and a heliospheric imager at L5 will be able to view CMEs broadsided, so space speed of the Earth-directed CMEs can be measured accurately and their radial structure discerned. In addition, an inner coronal imager and a magnetograph from L5 can give advance information on active regions and coronal holes that will soon rotate on to the solar disk. Radio remote sensing at low frequencies can provide information on shock-driving CMEs, the most dangerous of all CMEs. Coordinated helioseismic measurements from the Sun–Earth line and L5 provide information on the physical conditions at the base of the convection zone, where solar magnetism originates. Finally, in situ measurements at L5 can provide information on the large-scale solar wind structures (corotating interaction regions (CIRs)) heading towards Earth that potentially result in adverse space weather.

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1. Background and motivation

The solar plasma impact on Earth's magnetosphere resulting in geomagnetic storms originates from two sources on the Sun: the coronal mass ejections (CMEs) from closed magnetic field regions and high-speed solar wind streams (HSS) from coronal holes, which are open magnetic field regions. A corotating interaction region (CIR) forms when HSS overtakes the slow solar wind ahead. CIRs arrive at Earth with physical properties somewhat similar to those of the interplanetary CMEs (ICMEs). Both ICMEs and CIRs have magnetic fields enhanced above the quiet solar wind value by a factor of 3–4. Enhanced magnetic field from the Sun with a component anti-parallel to Earth's magnetic field causes magnetic reconnection, thus initiating a geomagnetic storm (see, e.g., Gonzalez et al., 2002). The sole cause of severe magnetic storms ($Dst < -150$ nT) is ICMEs, while moderate storms can be due to both CIRs and ICMEs (see e.g., Gosling et al., 1990; Zhang et al., 2007). However, there are major differences in the geospace consequences of storms caused by CIRs and ICMEs (Borovsky and Denton, 2006). CMEs can start driving shocks very close to the Sun (~0.5 solar radii above the surface) as inferred from type II radio burst observations (Gopalswamy et al., 2009a). CIR shocks, on the other hand, commonly form at a few AU from the Sun. CME-driven shocks accelerate energetic particles from near the Sun to large distances into the heliosphere. The CIR shocks also accelerate particles, but generally, beyond Earth orbit and the particle intensity is relatively small. Understanding the origin of CMEs and CIRs, their propagation in the interplanetary medium and their interaction with geospace are some of the major goals of space weather research.

The wealth of knowledge on CMEs accumulated over the last three decades has been from coronagraphs located along the Sun–Earth line (ground-based or space-borne). The occulting disk of a coronagraph located along the Sun–Earth line blocks that part of the Earth-directed CMEs that arrives at Earth. The CME plasma remote-sensed by a coronagraph located along the Sun–Earth line and the one arriving at Earth correspond to different parts of the CME. It is likely that the occulting disk also blocks the nose of the CME-driven shock, where the shock is strongest and hence likely to accelerate particles. The case of CIRs is worse because we can observe them only when they are about to hit Earth (except for the white light observations using Heliospheric

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Imager on board the Solar Terrestrial Relations Observatory (STEREO) mission and the Solar Mass Ejection Imager (SMEI)—see Harrison et al., 2009). Therefore, one needs to observe from a different vantage point that provides a full view of CMEs still close to the Sun and of CIRs well before they arrive at Earth. The fifth Sun–Earth Lagrange point (L5) is ideally suited for such an observing location. From an L5 view, one can observe the Earth-arriving parts of CMEs that eventually would to be sampled by spacecraft at L1 (this is not possible when the coronagraph is located along the un-Earth line). For shock-driving CMEs directed toward Earth, one can observe the radial structure of the entire disturbance consisting of the shock, sheath, flux rope, and prominence core. A low-frequency radio telescope can provide information on the properties of the shock in the coronagraphic field of view. An inner coronal imager at EUV wavelengths and a magnetograph can provide the necessary information on the solar sources of CMEs (active regions, filament regions) and CIRs (coronal holes). STEREO mission observes the Sun at large angles from the Sun–Earth line, but the angle is constantly changing so it is difficult to get uniform data as being provided by SOHO.

In this paper, we provide the scientific rationale for an L5 mission, which we call the Earth Affecting Solar Causes Observatory (EASCO) and describe the baseline instrumentation that can achieve the scientific objectives of such a mission. An L5 mission is ideally suited to fulfill the goals of the International Living with a Star (ILWS) program in characterizing the solar variability that affects Earth. Section 2 describes the L5 vantage point with respect to other Lagrange points. Section 3 describes the science issues related to CMEs and CIRs and the required measurements. Section 4 describes the baseline EASCO mission. Section 5 contains discussion and conclusions.

2. The L5 vantage point

A restricted three-body problem (one of the masses is much smaller than the other two) yields five equilibrium points, known as Lagrangian points L1–L5 named after the French-Italian mathematician Joseph Lagrange (see Cornish, 1999 for a detailed analysis of the Lagrange points). For the Sun–Earth gravitational system (see Fig. 1), the L1 point is most familiar because it is a stable location used by spacecraft such as SOHO, Wind, and the Advanced Composition Explorer (ACE) that continuously observe the Sun by remote sensing and in-situ techniques. The L2 point is located on Earth's night side, which is well suited for deploying astrophysical observatories. L1 and L2 are at 1.5×10^6 km away from Earth. The L3 point is behind the Sun at Earth's orbit, roughly 2 AU from Earth. The L4 and L5 points lead and trail Earth and are located at 60° away from the Sun–Earth line. The Sun, Earth and L4 or L5 make an equilateral triangle, so L4 and L5 are $\sim$1 AU away from Earth. In this paper, we are concerned with the L5 point. L4 is equally suitable for observing Earth-directed CMEs, but not for observing CIRs before they hit Earth (CIRs first arrive at Earth and then at L4).

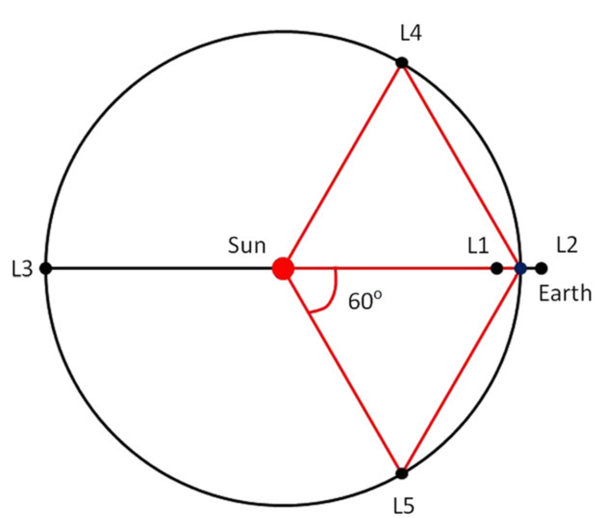

Fig. 1. A sketch of the Sun–Earth system showing the five Lagrange points, L1–L5 with respect to Earth's orbit around the Sun. All the Lagrange points view the Sun continuously save L2, which is located on the night side of Earth. L5 is located at 60° away from the Sun–Earth line, trailing Earth.

The Ahead and Behind spacecraft of the STEREO mission have recently crossed the L4 and L5 points, respectively, providing valuable information for a future L5 mission (Webb et al., 2010), including on the dust accumulation around L4 and L5 thought to be hazardous to spacecraft. STEREO observations indicate that there is no unusual level of dust or other objects at these Lagrange points, reducing one of the major risk factors of an L5 mission (St. Cyr et al., 2009; St. Cyr, 2010, private communication). The STEREO-B (SB) spacecraft also provides a benchmark orbit to get to L5, except that the spacecraft needs to be stopped and stationed at L5.

3. Scientific measurements from L5

The key science drivers for making measurements from L5 can be recognized from the following science questions: 1. What is the origin of solar magnetism and how does it relate to the solar sources of CMEs and CIRs? 2. What is the source of energy for CMEs? 3. How do CMEs accelerate particles, alone and in combination with flare reconnection? 4. Where and when do shocks form in the corona and how do they evolve? 5. What is the internal magnetic structure of CMEs and CIRs that cause magnetic storms? Answering these questions require making accurate measurements from the solar interior to the atmosphere and into the heliosphere. The measurements include the magnetic and plasma properties of active regions, filament regions, and coronal holes as the solar sources of Earth-affecting disturbances. These measurements are also made at the photospheric and coronal levels and inference is made about the solar interior. Measurements of the solar disturbances are made as they propagate into the heliosphere. Finally, in situ measurements of the solar wind plasma and magnetic field are made when the disturbances reach L5.

3.1. Geoeffective and SEP-producing CMEs

The solar source locations of CMEs that caused major space weather events (large gradual solar energetic particle (SEP) events and/or major geomagnetic storms) during solar cycle 23 are shown in Fig. 2. The CME sources were identified as either the H-alpha flare location listed in the Solar Geophysical Data (SGD) or the location of the EUV eruption identified in the Extreme-ultraviolet Imaging Telescope (EIT) images. The source locations of storm-producing CMEs tend to cluster near the central meridian because only these CMEs head directly to Earth and interact with the magnetosphere (Gopalswamy et al., 2007). There is a slight western bias to these source locations (average around W15) because of the eastward deflection of CMEs due to the solar rotation (Gosling et al., 1987). W15 in Earth view corresponds to W75 from L5. From Earth view, energetic CMEs from W15 generally appear as halo CMEs, so it is difficult to measure their speeds accurately from a coronagraph viewing along the Sun–Earth line (Gopalswamy et al., 2010). On the other hand, these CMEs are limb CMEs for L5 view and hence the sky-plane speed from L5 view is close to the space speed. The average direction of geoeffective CMEs is marked as "GEO" in Fig. 3. One other difficulty with the halo CMEs from an Earth view has been