Instruments for Deep Space Weather Prediction and Science.
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Introduction: We discuss remote space weather monitoring system concepts that could mount on the Deep Space Gateway and provide predictive capability for space weather events including SEP events and CME crossings, and advance heliophysics of the solar wind. Accurate predictions of space weather are of critical importance for deep-space missions, because particle storms and related events can induce harmful or even lethal ionizing doses in unprotected astronauts, and feasible mitigation strategies all involve at least partial suspension of mission operations while astronauts retreat to a small, massy radiation shelter within the spacecraft. Storm predictions with high false-positive rates waste valuable astronaut time, and storm predictions with significant false-negative rates could harm astronauts through excessive radiation exposure.

The monitoring/prediction system comprises a polarizing coronagraph and a wide-field heliospheric imager, mounted on the Gateway to provide "nowcast" images to the Gateway and/or the ground. The system could be mounted on a Sun-pointed portion of the Platform, such as a solar array mount; or could be body-mounted with an included gimbal to achieve Sun pointing from a variety of Gateway attitudes. Polarization enables 3-D measurement of the position and trajectory of solar wind features (including CMEs) en-route from the Sun, to predict event arrival at the Gateway or at Earth. Mass, power, and telemetry requirements vary greatly depending on desired additional benefits. A compact dual-channel platform (DAMASC form) could operate with under 10kg of mass, a few watts of required power, and a few kbps of telemetry, but with applicability limited to basic space weather prediction; while a larger platform (DELPHI form) might require 40-50kg, 30W of power, and up to 1Mbps ot telemetry, but would yield discovery science of the poorly mapped large-scale structure of the solar wind far from the Sun.

Space Weather Prediction

The most important space weather events are caused by passage of coronal mass ejections (CMEs) and, more commonly but less vigorously, solar wind stream interaction regions (SIRs, also corotating interaction regions or CIRs). These events involve propagating density fronts or shocks that are caused by fast-moving, dense bodies of solar wind material ejected from the Sun at high speed. Shocks, in particular, can produce delayed solar energetic particles (SEPs) and other sources of ionizing radiation, cause spacecraft charging events, and/or cause geomagnetic storms at Earth. CMEs are impulsive ejection events caused by magnetic instabilities at the Sun, and are difficult to predict based on direct solar observation alone – but can be identified in image sequences from coronagraphs. The very largest CMEs are associated with large geomagnetic storms and with near-lethal ionizing radiation pulses in deep space. SIRs are caused by interaction of quasi-stationary wind streams leaving the Sun at different rates, and can give rise to stationary shocks with similar symptoms to mid-sized CMEs. Tracking CMEs and SIRs improves strength and arrival time predictions by factors of 2-3 with current technology, and coronagraph measurements are considered critical assets by NOAA's Space Weather Prediction Center.

CMEs and SIRs can be detected and tracked using ordinary visible sunlight, scattered from free electrons in interplanetary space. The degree of polarization of the scattered light is an indicator of 3-D location of the feature. The scattered light is faint and, more than about a solar radius above the Sun, cannot normally be detected from within Earth's atmosphere. However, probes in Earth orbit or deep space (e.g. *Skylab, SMM, SOHO, STEREO*) can image features quite far from the Sun in the sky. *SOHO*, in particular, has been operated for over two decades because its coronagraph (*SOHO*/LASCO) has become important for identification and early tracking of CMEs departing the Sun, to predict terrestrial space weather.

Currently, *SOHO* is the only operating coronagraph in deep space. Deploying additional space-weather-capable imaging instruments is a critical part of any viable long-term manned exploration strategy.

Instrument concepts

We will describe three principal concepts, in increasing order of instrument quality and resource requirements. A basic space weather prediction capability would be satisfied by the DAMASC concept, a dual-acquisition, minimal-resource instrument that affords tracking of space weather events from Sun through the inner heliosphere. Improved tracking and imaging are afforded by the DELPHI concept, a steerable high quality imaging system that can be scanned around the inner heliosphere to track events of import, or in a regular pattern to capture space weather fronts as they propagate. To capture both space weather prediction and advance understanding of the currently not-well-explored cross-scale physics of the inner heliosphere, SP4CE, a quad-camera system with fully annular wide-field imaging, would provide high resolution imagery of the entire inner heliosphere on a 1-2 minute cadence.