THE EUV VARIABILITY EXPERIMENT (EVE) ON THE SOLAR DYNAMICS OBSERVATORY (SDO): SCIENCE PLAN AND INSTRUMENT OVERVIEW

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ABSTRACT

The highly variable solar extreme ultraviolet (EUV) radiation is the major energy input into the Earth's upper atmosphere and thus impacts the geospace environment that affects satellite operations, communications, and navigation. The Extreme ultraviolet Variability Experiment (EVE) aboard the NASA Solar Dynamics Observatory (SDO) will measure the solar EUV irradiance from 0.1 to 105 nm with unprecedented spectral resolution (0.1 nm), temporal cadence (10 sec), and accuracy (20%). The EVE program will provide solar EUV irradiance data for the NASA Living With the Star (LWS) program, including near real-time data products to be used in operational atmospheric models that specify the space environment and to assist in forecasting for space weather operations. The EVE program is expected to make significant progress towards real understanding of the physics of the solar EUV irradiance variations on time scales from flares to the solar cycle. Additional information about the EVE program can be found at http://lasp.colorado.edu/eve/.

1. INTRODUCTION

The Solar Dynamics Observatory (SDO) is the first spacecraft in NASA's Living With a Star (LWS) program, scheduled for a nominal five-year mission following launch in August 2008. The goal of the SDO mission is to understand solar variability and its societal and technological impacts. SDO will address how the Sun's magnetic field is generated and structured and how this stored energy is converted and released into the heliosphere and geospace environment through the solar wind, energetic particles, and photon output. An underlying theme of SDO is scientific research to enable improved space weather predictive capabilities, thus transitioning research to operations.

The EUV Variability Experiment (EVE) is one of three instruments onboard SDO. EVE will measure the solar extreme ultraviolet (EUV) and soft X-ray (XUV) spectral irradiance in order to better understand how solar magnetic activity is manifest in the ultraviolet wavelength ranges that drive the terrestrial upper atmosphere. The other two instruments are the Helioseismic and Magnetic Imager (HMI) and the Atmospheric Imaging Assembly (AIA). With this instrument combination the SDO will facilitate improved understanding of irradiance variations, flares and coronal mass ejections (CMEs), for use in ionosphere and thermosphere models for space weather operations, to better track satellites and manage communication and navigation systems. This paper describes the EVE science plan and instrumentation.

2. EVE SCIENCE PLAN

The EUV photons that EVE measures originate in the Sun's chromosphere and corona, and deposit their energy in the Earth's ionosphere and thermosphere, thus directly connecting the Sun and the Earth in just eight minutes. The solar output in the EUV and XUV spectrum (wavelengths shortward of 120 nm) varies

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with solar activity from a factor of 2 to several orders of magnitude depending on wavelength, and on timescales from seconds and minutes (flares) to days and months (solar rotation) to years and decades (solar sunspot or magnetic cycle) (Woods and Rottman, 2002). The EUV and XUV irradiance is the primary energy input to the Earth's upper atmosphere, heating the thermosphere, creating the ionosphere, and initiating many complex photochemical reactions and dynamical motions. Fluctuating EUV and XUV irradiance drives variability in the atmosphere, affecting satellite operations, navigation systems, and communications. While a small number of previous missions have measured the solar EUV irradiance and produced daily-averaged spectra, none has done so with the accuracy and high time cadence of EVE. In particular, EVE will undertake the first comprehensive study of the solar EUV irradiance variability on the time scale of flares.

2.1. EVE Science Objectives

EVE's measurements, modeling activities, and collaborations with the other SDO instruments support the following four scientific objectives:

(1) Specify the solar EUV irradiance and its variability on multiple times scales from seconds to years. EVE's highest priority is thus the acquisition of a suitable database to characterize the solar EUV irradiance spectrum and its variations during flares, active region evolution, and the solar cycle. EVE's spectrally resolved observations with a 10-sec time cadence will greatly advance the specification and understanding of the spectral variations during flare events throughout the XUV and EUV spectrum.

(2) Advance current understanding of how and why the solar EUV spectral irradiance varies. Extensive, multi-faceted investigations are planned to explore in detail the sources of EUV irradiance variations within a physical framework. This understanding is needed to develop a predictive capability for past and future space environment climatologies, and for verifying the direct EUV irradiance observations. Models will be generated to account for the observed EUV irradiances and their variations, with traceability to magnetic flux emergence and the solar dynamo. New understanding of the solar dynamo and its possible long-term evolution and intermittent behavior will then be directly applicable to studying the EUV irradiance variations on longer time scales, beyond those accessible to space-based observations (*e.g.*, Wang *et al*., 2005).

(3) Improve the capability to predict (both nowcast and forecast) the EUV spectral variability. The application of the physical understanding and specification of the solar EUV irradiance developed in EVE Objectives 1 and 2 will facilitate a unique capability for EUV irradiance predictions on multiple time scales associated with the solar cycle, rotation, and flares. These studies will contribute to more reliable short-term forecasts of EUV irradiance levels and hence of abrupt space weather phenomena.

(4) Understand the response of the geospace environment to variations in the solar EUV spectral irradiance and the impact on human endeavors. EVE will provide reliable knowledge of the solar EUV spectrum and its variability that the geophysics community has sought for decades, and without which LWS cannot fully succeed. Variations in EUV irradiance initiate space weather phenomena through both direct and indirect processes and are, consequently, crucial inputs for many geospace models. The EUV irradiances specified by EVE will enable progress in understanding, specifying, and forecasting for space weather operations that affect human endeavors, including spacecraft drag, communications, and navigation.

2.2. EVE Science Team

In addition to the EVE Principal Investigator, Dr. Tom Woods (University of Colorado's Laboratory for Atmospheric and Space Physics, LASP), EVE scientists include Frank Eparvier and Gary Rottman (LASP), Darrell Judge and Andrew Jones (University of Southern California, USC), Don McMullin (Praxis, Inc.), Greg Berthiaume (Massachusetts Institute of Technology, MIT), Scott Bailey (University of Alaska at Fairbanks, UAF), and Judith Lean, John Mariska, and Harry Warren (Naval Research Laboratory, NRL).

LASP provides overall EVE project management, instrument design, fabrication, calibration, instrument operations, and data processing software development. USC contributes a portion of the flight hardware and significant expertise in solar EUV irradiance measurements. MIT leads the development of CCD detectors. UAF provides calibration and geospace modelling expertise, and NRL undertakes solar spectral irradiance modelling, in particular improvements to the NRLEUV semi-empirical irradiance variability model (Warren, Mariska, and Lean, 2001; Lean, Warren, Mariska, and Bishop, 2003).

The EVE Science Team also includes several collaborators whose participation is vital to EVE's success. Drs. Tim Fuller-Rowell and Rodney Viereck (NOAA Space Environment Center), Dr. Jan Sojka (Utah State University), and Dr. Kent Tobiska (Space Environment Technologies) participate in various aspects of the space weather and operations effort through geospace and solar operational modelling. They will assist in transitioning EVE research to operations. In particular, EVE data will be used to improve, validate, or constrain such atmospheric models as CTIM (Fuller-Rowell *et al.*, 1996), GAIM (Schunk *et al.*, 2002) and NRLMSIS (Picone *et al.*, 2002), and the SOLAR2000 empirical solar irradiance model (Tobiska *et al.*, 2000). Furthermore, collaborations with SDO HMI and AIA science team members and with the broader community are important for linking the solar physics to the solar irradiance variations.

2.3. EVE Measurements and Data Products

To help meet the EVE objectives, the EVE instrument suite will measure the spectral irradiance from 0.1 to 5 nm at 1 nm resolution, from 5 to 105 nm with a resolution of 0.1 nm, and the hydrogen Lyman-α line at 121.5 nm with 1 nm resolution. The full spectral range will be measured every 10 seconds, continuously (except during satellite eclipse periods and planned calibration activities). The absolute accuracy goal of EVE's spectral irradiance measurements is better than 25% throughout the nominal five-year mission.

The primary EVE data products are solar EUV spectral irradiances at 0.1 nm and 1 nm resolution at a 10-sec time cadence and as daily averages. In addition, specific solar emission lines and broadband irradiances will be extracted and provided at both time cadences. These data products will be available within a day or so of receipt on the ground. Near real-time data products for space weather operations will also be generated within approximately fifteen minutes of ground receipt.

3. EVE INSTRUMENTATION

To meet the measurement and accuracy requirements, the EVE instrument is composed of several channels. The wavelength coverage of all channels is shown in Fig. 1, along with a sample solar spectrum. Eparvier *et al.* (2004) provides details of the optical designs for the EVE channels. The primary, high spectral resolution irradiance measurements are made by the Multiple EUV Grating Spectrographs (MEGS) (Crotser *et al.*, 2004), which have heritage from the TIMED SEE EUV Grating Spectrograph (EGS) (Woods *et al.*, 2005). The MEGS is composed of two spectrographs:

The MEGS-A channel is an 80° grazing incidence, off-Rowland circle spectrograph with a CCD detector to measure the solar spectrum between 5 to 37 nm at a resolution just less than 0.1 nm. The MEGS-B channel is a normal incidence, double-pass, cross-dispersing Rowland circle spectrograph with a CCD detector to measure the solar spectrum between 35 to 105 nm at a resolution just less than 0.1 nm.

Included as part of the MEGS-A package is a pinhole camera for use as the Solar Aspect Monitor (SAM) to provide a pointing reference for the EVE channels. MEGS-SAM will also make a spectral measurement of the solar irradiance in the 0.1 to 5 nm wavelength range at approximately 1 nm resolution by photon counting the energetic X-rays.

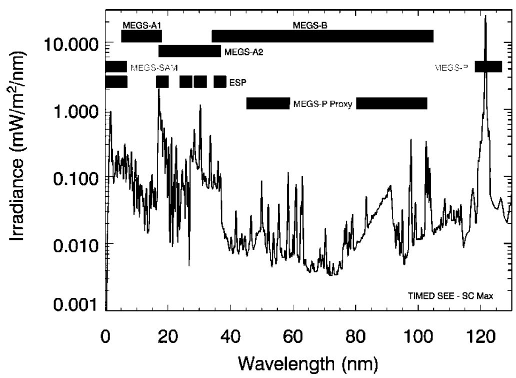

Fig. 1. The wavelength coverage of the various EVE channels plotted over a sample irradiance spectrum for solar maximum conditions (from the TIMED SEE instrument).

Onboard short-term calibration tracking is achieved by redundant, lower spectral resolution measurements at select bandpasses, made by the EUV Spectrophotometer (ESP). The ESP is a transmission grating and photodiode instrument similar to the SOHO SEM (Judge *et al.*, 1998). ESP has four channels centered on 18.2, 25.7, 30.4, and 36.6 nm that are each approximately 4 nm in spectral width. The ESP also has a central, zeroth-order diode with a filter to make the primary irradiance measurement in the 0.1 to 7 nm range. The ESP measurements are made at a high time-cadence (0.25 sec) and are therefore useful as indicators of rapid space weather events such as flares.

In addition, a photodiode with a filter to isolate Lyman-α at 121.5 nm (MEGS-P) is part of the MEGS-B. This measurement is used to track potential changes in the sensitivity of the MEGS on timescales of weeks and months. Annual sounding rocket underflights of similar instruments will track longer-term changes in the sensitivity of the EVE channels.

4. SUMMARY

SDO EVE plans to measure solar EUV spectral irradiance with unprecedented spectral and temporal resolution and accuracy. These measurements will contribute to space weather operations, and solar and atmospheric physics research, particularly the spectral and temporal nature of solar flares and their effects on the geospace environment. EVE research will help validate and improve empirical and first principle models of the solar irradiance variability and of the geospace environment. The EVE instrument has been carefully designed to meet or exceed all of its scientific objectives. It is being assembled in 2006, with spacecraft integration and test (I&T) scheduled in 2007. Managed by NASA's Goddard Space Flight Center (GSFC), SDO will be launched in August 2008 into geosynchronous orbit for a nominal five-year mission.

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