In heliospace physics, the Space Science Division (SSD) performs RDT&E in solar and heliophysics space-based sensors, notably in-house coronagraphs, heliospheric imagers, and solar spectrometers. Analysis and modeling of the data from the instruments have led to a stream of insights and discoveries that, in turn, support further scientific exploration as well as operational use in providing real-time threat warnings. As an example, the SSD-led Large Angle and Spectrometric Coronagraph Experiment (LASCO), which has been flying on the European Space Agency (ESA)/NASA Solar and Heliospheric Observatory (SOHO) at Lagrangian point L1 since 1995, continues to return excellent data to NASA for science as well as civilian and military operational applications via a beacon to the Space Weather Prediction Center in Boulder, Colorado. To ensure continued detection of extreme space-weather events before they impact Earth, the Office of Science and Technology Policy 2015 National Space Weather Action Plan calls for development of a solar coronagraph LASCO replacement. Accordingly, SSD is designing an advanced coronagraph prototype, the Compact Coronagraph (CCOR), with an SSD-designed solar occulter that significantly reduces both size and fragility of the instrument for operational deployment; CCOR is intended for a Space Weather Follow-On mission in 2021. In addition to applications, SSD is leading a broad range of heliospheric research hardware and software projects, including the Wide-Field Imager for Solar Probe (WISPR). WISPR is a visible light heliospheric imager slated for launch on NASA’s 2018 Parker Solar Probe (PSP) mission. SSD delivered the WISPR flight instrument to the spacecraft in May 2017. WISPR images will observe the large-scale structure of the solar corona and take in situ measurements of the solar wind as the PSP approaches within 10 solar radii of the Sun’s center. In this never-before explored region, WISPR will discover the fundamental nature of dynamic coronal structures as the PSP spacecraft flies through them.
Extreme-Ultraviolet Imaging Spectrometer (EIS) on Hinode
Imaging the Extreme-Ultraviolet Atmosphere of the Sun

**Objectives**

- The primary objective of the Extreme-Ultraviolet Imaging Spectrometer (EIS) program is to observe and understand the fundamental physical properties that form the solar upper atmosphere. The observed properties include coronal heating, the initiation of solar flares and coronal mass ejections, and the formation of the solar wind.

- EIS measurements include the electron temperature, density, and dynamical properties of solar magnetic flux tubes in flares, active regions, coronal holes, and the quiet Sun. EIS determines the morphology of active regions and flares over temperatures ranging from about 100,000 K to 10,000,000 K.

**Space Science Division Approach**

- The EIS articulated mirror images the EUV Sun between about 170 Å and 290 Å onto a slit. Light passing through the slit is diffracted by a grating, and spectra are imaged onto two CCDs. The instrument can remotely and passively sense the solar atmosphere at any location on the solar disk or slightly above the solar limb.

- Solar images are made by moving the mirror in small steps in the east-west direction. Combining all the spectra produces a EUV image that covers a field of view determined by the scientific program being implemented.

**Payoffs**

- EIS measures the precise state of the solar atmosphere and explosive phenomena within it with high spatial resolution, thereby observationally enabling precision determination of potential threat-warnings. This precision enables benchmarking and validation of solar atmospheric modeling capabilities, which ensures their accuracy. Accurate models determine which potential threat warnings will evolve into real space weather storms at Earth and threaten space-based DoD/Navy systems. The EIS data have ushered in the beginning of a quantitative era of solar atmosphere physics that removes ambiguity from threat-warning predictions. Shown to the right is a solar flare imaged in spectral lines of different temperatures. Blue is Fe X (1,000,000 K), yellow is Fe XV (2,000,000 K), and orange is Ca XVII (5,000,000 K).

**For more information**


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Objective

- To develop models for the specification and forecasting of the solar irradiance at extreme-ultraviolet wavelengths (EUV, 5–120 nm) and integrate these capabilities into operational models of thermospheric and ionospheric conditions.

Space Science Division Approach

- Proxies for solar activity are currently used to represent solar inputs to models of thermospheric and ionospheric conditions. These proxies are only indirectly related to solar activity and are difficult to forecast.
- Our approach is to develop both empirical relationships and physical models that relate variations in solar magnetic fields to the EUV radiation emitted from the solar photosphere, chromosphere, transition region, and corona.
- To develop such relationships and models, we study the physical conditions in the solar atmosphere using the most recent space-based solar observatories, such as Hinode, STEREO, and the Solar Dynamics Observatory.
- We also study the structure of magnetic flux on the solar surface and develop models of how this flux evolves.
- In the years ahead, we will integrate into new models of the solar EUV irradiance our understanding of solar magnetic fields and the conditions in the solar atmosphere.
- We are also participating in interdisciplinary research to study the role of EUV irradiance variability in determining the state of Earth's thermosphere and ionosphere.

Payoffs

- Variations in thermospheric density play an important role in predicting conjunctions between operating satellites and orbital debris. These conjunctions cannot be predicted without accurate forecasts of solar activity.
- The solar EUV irradiance is responsible for the formation of Earth's ionosphere, which is a critical component of many systems, such as over-the-horizon radar.
AT A GLANCE

What is it?
The Large Angle and Spectrometric Coronagraph (LASCO) is a three-telescope instrument onboard the ESA/NASA Solar and Heliospheric Observatory (SOHO) satellite, which images the atmosphere around the Sun known as the solar corona.

How does it work?
LASCO images the solar corona over three nested fields of view from a half million miles to 14 million miles above the solar surface. The imaged light in the visible range is scattered off fast moving electrons that, with other charged particles, comprise the space environment. The Sun’s dynamic corona is the source of space weather at Earth.

What will it accomplish?
LASCO real-time images are used by multiple research and operational groups to study the Sun’s corona and provide forecasts of the near-Earth space environment. These forecasts provide warnings and arrival times for solar storms, which have the potential to disrupt satellite communications and other essential space-enabled technologies.

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Objectives
- Advance the understanding of the structure of the Sun’s corona, the origin of coronal mass ejections (CMEs), and the dynamic coupling between CMEs and Earth.
- CMEs, the most energetic phenomena in the solar system, are major drivers of geomagnetic space weather storms that adversely affect intelligence, surveillance, and reconnaissance; precision engagement, missile detection and intercept; communications on the move; spacecraft anomaly assessment; orbital tracking; polar flight; and the power grid.

Space Science Division Approach
- The Large Angle and Spectrometric Coronagraph (LASCO) images the solar corona on a continuous duty cycle from the Solar and Heliospheric Observatory (SOHO) satellite.
- Near real-time images are made available on a U.S. Naval Research Laboratory website to other U.S. Government agencies and the general public for space weather forecasting and basic research of coronal processes and the solar plasma environment.

Payoffs
- The 20 years of LASCO observations form the cornerstone of understanding the solar corona and its link with the near-Earth space environment.
- LASCO real-time images have introduced the capability and demonstrated the need for space weather forecasting and solar storm warnings and arrival times.
- LASCO imaging has been used to validate the fundamental physical structures of the solar corona, contributing to physics-based modeling of this environment toward the goal of longer-term space weather forecasting.
The Magnetic Storm Program

*Magnetic Disruptions to Earth’s Space Environment*

**Objective**
- Develop understanding of magnetic storms as they travel from the Sun to Earth and capabilities for predicting their effects on Earth’s space weather environment.

**Space Science Division Approach**
- To provide the pre-storm coronal magnetic field via photospheric magnetogram data driving, and then to closely couple the corona, heliosphere, and magnetosphere in both models and observations.
  - Model the pre-storm magnetic state of the solar corona by driving simulations with the observed photospheric magnetic field evolution from NASA’s Helioseismic and Magnetic Imager (HMI).
  - Develop a magnetospheric modeling program which can take input from the heliospheric code. Fully couple the Sun-to-Earth model system, from the HMI data-driven coronal model to the heliospheric model and the magnetospheric model.
  - Develop a magnetospheric imaging satellite to image geomagnetic storms, in a similar fashion to the coronal and heliospheric imaging currently conducted by the U.S. Naval Research Laboratory. The new imaging satellite will add a critical global perspective to the current, local view of the magnetosphere provided by in situ measurements.

**Payoffs**
- A fully integrated, observation- and simulation-based forecast of the coupled Sun-heliosphere-magnetosphere system, to address the need by the Navy and the Marine Corps for predicting damaging effects of magnetic storms on communications, GPS, and magnetic anomaly detection.

**AT A GLANCE**

**What is it?**
Solar and geomagnetic storms can disrupt Earth’s magnetosphere which then can allow energetic solar wind particles to stream down Earth’s field lines. These phenomena can disrupt satellite, radio, and global positioning system communications in Earth’s space environment. Developing a better understanding of these storms, via observation and modeling, is critical to providing accurate storm threat warnings and effective mitigation of the hazards.

**How does it work?**
Magnetic storms are studied via a coupled program of white light Thomson scattering observations of the corona and heliosphere, and of numerical models of the Sun-to-Earth space environment.

**What will it accomplish?**
Developing a full-system predictive understanding of magnetic storms will enable forecasts of disruptive near-Earth space weather phenomena, such as geomagnetic storms, magnetic anomalies, and magnetospheric ring current evolution.

**For more information**


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**AT A GLANCE**

**What is it?**
SECCHI is the five-instrument imaging package onboard the twin STEREO spacecraft launched by NASA in 2006. Designed to observe eruptions from the Sun from two different perspectives, it enables reconstructions of three-dimensional morphology and kinematics of coronal mass ejections (CMEs) as they propagate from the Sun and through the heliosphere.

**How does it work?**
The SECCHI package contains extreme-ultraviolet (EUV) imagers (EUVIs) that observe the Sun in several EUV wavelengths, imaging solar activity in the low solar corona. Two coronagraphs (COR1 and COR2) and two heliospheric imagers (HI1 and HI2) track CMEs continuously from the Sun to Earth.

**What will it accomplish?**
STEREO images have provided valuable new information about three-dimensional CME structure and kinematics, which is improving space weather forecasting capabilities.

**For more information**


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**Objectives**
- Image solar eruptive events simultaneously from the two different perspectives of the twin STEREO-A and STEREO-B spacecraft to infer three-dimensional structure.
- Track the morphology and kinematic evolution of coronal mass ejections (CMEs) continuously from the Sun to Earth.

**Space Science Division Approach**
- SECCHI includes EUVIs that continuously monitor the solar corona and provide stereoscopic imaging of solar flares and prominence eruptions.
- SECCHI includes two coronagraphs, COR1 and COR2, designed to detect CMEs erupting from the Sun, whereby external occulters blocking the solar photosphere enable the imaging of the faint white light coronal emissions. The two coronagraphs collectively cover plane-of-sky distances of 1.4 solar radii to 15.6 solar radii from the Sun.
- SECCHI includes two heliospheric imagers, HI1 and HI2, designed to monitor the Sun-Earth line and track CMEs through the interplanetary medium all the way to Earth, covering angular distances from the Sun from 3.9° to 89°.

**Payoffs**
- The stereoscopic imaging capabilities of the STEREO mission and its NRL-designed SECCHI imaging package have provided crucial new information about the three-dimensional morphology of solar eruptive phenomena.
- The heliospheric imagers in SECCHI have provided the first images of CME fronts hitting Earth.
- The continuous Sun-to-Earth kinematic tracking of CMEs provided by SECCHI ultimately will improve operational space weather forecasting capabilities.
The Solar Energetic Particles Program
Investigating the Major Space Radiation Hazard

**Objectives**

- Establish the necessity of a suprathermal “seed particle” distribution as a precursor to an intense SEP event (to be observed by the U.S. Naval Research Laboratory’s Ultraviolet Spectro-Coronograph (UVSC) Pathfinder experiment).
- Devise alternative diagnostics of the solar “accelerator” to allow SEP event warning/prediction from routine ground and space-based solar observations.

**Space Science Division Approach**

- Experimental (UVSC Pathfinder) effort to detect seed particles directly through their effect on the hydrogen Lyman $\alpha$ line profile, following charge exchange between a suprathermal proton and neutral hydrogen.
- Modeling and observation of the solar upper atmosphere to identify likely sites of flare energy release, suprathermal particle production, and shockwave initiation.
  - The key ingredients appear to be magnetic nulls and significant levels of magnetohydrodynamic (MHD) waves.
  - Waves can be detected or inferred through a variety of means: Doppler shifts and/or spectral line broadening, and element abundance anomalies due to fractionation by the ponderomotive force.
  - Magnetic nulls can be inferred from extrapolations of the photospheric field, and from radio observations.
- Theoretical studies of reconnection in such environments to characterize the dynamics. A magnetic null allows high plasma compression, and the resulting hard spectrum of suprathermal particles can be suitable for the initiation of shock acceleration.

**Payoffs**

- Prediction of the SEP event hazard from the presence or absence of coronal seed particles, MHD waves, and magnetic nulls. No such forecasting currently exists.
- Potential for specification of a suite of ground and space-based monitoring instruments dedicated to accurate SEP event forecasts.

**For more information**


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The SoloHI Experiment
Solar Orbiter Heliospheric Imager

AT A GLANCE

What is it?
The Solar Orbiter Heliospheric Imager (SoloHI) images the variable and gusty solar wind to identify the plasma emissions, including coronal mass ejections, leaving the Sun. It is one of 10 experiments carried on the Solar Orbiter mission, which is designed to study the relationship between the Sun and the solar wind.

How does it work?
The electrons in the solar wind plasma scatter sunlight, and can be imaged by blocking the solar disk light. The intensity of the scattered light is up to 12 orders of magnitude dimmer than the solar disk. SoloHI will track features as they leave the lower corona and are transported to the spacecraft, which will be in an elliptic orbit about the Sun with closest approach being 0.28 AU.

What will it accomplish?
SoloHI, with the other experiments on Solar Orbiter, will reveal (1) how the solar environment is extended into the solar wind, (2) what controls its density, velocity, composition, and (3) how to acquire this information before the local processes have changed the solar wind in its transport to Earth.

For more information

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Left-hand panel: The SoloHI instrument is a simple telescope located in the shadow of the spacecraft heat shield with additional baffles to reduce the sunlight by 10^{12}. The gray baffles in the middle are designed to trap reflections from the solar array from reaching the optical system. The detector is an Advanced Pixel Sensor; it is cooled to -55°C by radiating away the heat to deep space. Right-hand panel: An image of the solar wind from the SECCHI/HI instrument on board the STEREO mission. The Sun is located outside the image on the right. The bright linear features at the right are streamers projecting from the Sun. The Milky Way is shown at the left.

Objectives
- How and where do the solar wind plasma and magnetic field originate in the corona?
- How do solar transients drive heliospheric variability?
- How do solar explosions produce energetic particle radiation that fills the heliosphere?
- How does the solar dynamo work and drive connections between the Sun and the heliosphere?

Space Science Division Approach
The Solar Orbiter Heliospheric Imager (SoloHI) was delivered by the Space Science Division to NASA in April 2017, and will be launched on the European Space Agency’s Solar Orbiter satellite in 2019. In orbit, SoloHI will conduct a varied observing program that includes the following items:
- Regular full-field images at a constant cadence to observe the steady state outflow, and the gusty outflow of coronal mass ejections (CMEs), co-rotating interaction regions (CIRs), and the sun-grazing comets.
- Small-field images at a high cadence to capture CME shocks traveling radially outward.
- Small-field images to measure the power spectral density in order to determine where wave energy is being deposited.

Payoffs
- The 40° field-of-view of SoloHI will follow the outflowing plasma from the Sun toward the spacecraft and connect the remote sensing observations of the Sun to the in situ observations at the spacecraft. The spacecraft will have perihelia as close as 0.28 to the Sun, much closer than the usual distance of 1 AU. At 0.28 AU, the solar wind will have a simpler structure, in which the wind has not been distorted by processes such as turbulence that is present to 1 AU. The absence of distortion will enable the connection of solar features to solar wind structures. Additionally, SoloHI observations will enable prediction of the transport of CMEs (an example is shown in the image on the right) and CIRs from the Sun to Earth.
**Objectives**

- To determine the existence of suprathermal seed particles in the solar corona near the Sun. This determination will confirm the necessary role of seed particles in the production of hazardous solar energetic particles (SEPs).
- To determine temperatures, densities, and outflow velocities of coronal plasmas to constrain models of coronal shock acceleration.

**Space Science Division Approach**

- To continuously monitor coronal regions for seed particles at distances of 1.8 solar radii and 3 solar radii distance from Sun-center by measuring the enhancements in the wings of the hydrogen Lyman-alpha spectral line at 121.6 nm.
- To correlate the properties of the preexisting seed particle with those of the SEPs produced by the passage of a CME shock through the corona.

**Payoffs**

- UVSC Pathfinder will demonstrate new technology for a high-throughput, compact coronagraph design.
- UVSC Pathfinder will validate the concept of an advanced warning system for SEP storms which will safeguard and improve DoD operations.

**For more information**


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Objectives

- Understand the morphology, velocity, acceleration, and density of solar wind structures close to the Sun.
- Derive the three-dimensional structure of the solar corona to determine the sources of the solar wind.
- Determine the roles of turbulence, waves, and pressure-balanced structures in the solar wind.
- Measure the physical properties of coronal mass ejections (CMEs) and their associated shocks as they evolve in the solar corona and inner heliosphere.

Space Science Division Approach

- The Wide-Field Imager for Parker Solar Probe (WISPR) comprises two wide-field telescopes with custom large format active pixel sensor (APS) detectors that will provide unprecedented capabilities to image the solar corona from the unique vantage point afforded by the Parker Solar Probe (PSP) orbit. PSP will complete 24 orbits about the Sun over 7 years, coming within 3.8 million miles (8.9 Rs) above the solar photosphere.
- The U.S. Naval Research Laboratory (NRL) is the WISPR principal investigator institution for NASA, and leads a consortium of national and international science partners.
- The Space Science Division developed the WISPR instrument, and, in May 2017, delivered it to NASA.
- WISPR mission operations and data analysis will be provided from on-site at NRL-DC.
- WISPR builds on the successful NRL STEREO/SECCHI heliospheric imagers.

Payoffs

- Development of an innovative compact, lightweight, low power, and radiation-hard APS camera suitable for a variety of space applications.
- Answers to fundamental questions about the physical processes responsible for generation and evolution of the solar wind and CMEs, thus enabling improved specification and modeling of the space environment and the impacts of solar variability on Earth.
- WISPR serves as a pathfinder for future operational sensors (such as a potential mission to the L5 Lagrange point) that would provide heliospheric imager observations for timely and accurate space weather forecasts to meet DoD needs.

For more information


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