NASA Heliophysics

The Heliophysics Division of the Science Mission Directorate investigates the nature of the Sun and how it affects the very nature of space, as well as the atmospheres of planets and the technology that exists there. We live in the extended atmosphere of an active star, not in the vacuum of space, as many people believe. Our Sun produces a constant stream of particles and energy known as solar wind, as well as a writhing magnetic system. This vast, dynamic solar atmosphere encompasses the Sun, Earth, and the planets, as well as extending far beyond the solar system.

This system's study not only aids our understanding of fundamental knowledge about the cosmos, but it also aids in the protection of our equipment and humans in space. NASA is interested in learning more about near-Earth space because extreme space weather can disrupt our communications, satellites, and power grids. The study of the Sun and space can also help us learn more about how stars affect the habitability of planets all around the universe.

The influence of the Sun on space, Earth, and other planets must be studied holistically in order to map out this interrelated system. NASA has a fleet of spacecraft strategically placed throughout our heliosphere, ranging from the Parker Solar Probe at the Sun, which is observing the very beginnings of the solar wind, to satellites orbiting Earth, and the farthest human-made object, Voyager, which is transmitting observations from interstellar space. Each mission is positioned at a strategic, well-planned vantage point to watch and analyze the flow of energy and particles throughout the solar system, all in the service of helping us understand the effects of the star we call home.

What We Study

We are positioned to provide a predictive picture of our role in the solar system, building on NASA's rich history of study of Earth's neighborhood and distant planetary systems. While sunlight is essential for life to exist, our star may also emit radiation and magnetic energy that can destroy planets' atmospheres, satellites, and even life itself. We research the

environment in space in order to safely launch spacecraft and astronauts through it. Closer to home, we're interested in learning more about near-Earth space because extreme space weather can disrupt our communications, satellites, and power grids.

The Sun's link to Earth and other planets must be studied holistically at both tiny and large scales in order to map out this interrelated system. Heliophysics involves a wide range of scientific topics to achieve this, including but not limited to:

- the sun's 11-year solar cycle
- giant solar explosions such as solar flares and coronal mass ejections
- the constant stream of solar particles called the solar wind
- the magnetic environment near Earth
- what drives change in the charged particles that surround Earth and inhabit the ionosphere
- boundaries of the solar system as it travels through our interstellar neighborhood.

Solar Science

The Sun is studied by NASA for a variety of reasons. The Sun's fluctuating radiation has an impact on Earth's habitability, which can be beneficial or harmful to life. The Sun's associated energy and plasma can cause changes in the space weather around us, as well as interfere with our space technology and communications systems. The Sun is the only star we can study closely, and it can help us learn more about other stars in the universe.

Space Weather

Space is filled with a thin and tenuous wash of particles, fields, and plasma due to the Sun's continual discharge of solar wind. This solar wind, along with other solar occurrences such as coronal mass ejections, affects the very nature of space and can interact with Earth's and other worlds' magnetic systems. As a result of these consequences, the radiation environment in which our spacecraft – and, one day, our people headed to the Moon and

Mars – travel changes. Satellite electronics, communications, and GPS signals, as well as – in severe cases – electricity grids on Earth, are also susceptible to space weather.

Magnetospheres

The magnetosphere is a sphere of magnetic fields that surrounds Earth and is formed by the planet's intrinsic magnetism. Although the magnetosphere shields humans on Earth from incoming solar radiation, it does change shape and size in reaction to such space weather, and these changes can damage communication signals and create power grid surges. The magnetosphere is being studied by NASA in order to better understand its role in our space environment. We can better comprehend the nature of space throughout the cosmos by examining this space environment close to home.

This type of research aids in the understanding of space physics, which is governed by complicated electromagnetic interactions unlike what we see on a daily basis on Earth.

Ionosphere, thermosphere, mesosphere

NASA investigates the layers of the atmosphere, such as the ionosphere, thermosphere, and mesosphere system, which is where aurora and other space weather occurrences occur. The ionosphere is a layer of Earth's atmosphere that stretches from 50 to 300 miles above the planet's surface. The layer is packed with electrically charged particles and overlaps the mesosphere and thermosphere's neutral particles. Because the ionosphere is sensitive to incoming solar material, it can react quickly to space weather.

Because the ionosphere houses low-Earth-orbiting spacecraft and is the region of space through which radio communications travel, alterations in the region can have a significant impact on human technology.

The ionosphere, which stretches from 50 to 400 miles above the surface, is an electrified layer of the upper atmosphere created by strong UV radiation from the Sun.

Heliosphere

The solar wind is a continuous stream of charged particles that flows past all of the planets, extending three times the distance to Pluto before being obstructed by the interstellar medium. The heliosphere is a huge bubble that forms around the Sun and its planets. NASA investigates the heliosphere to learn more about the underlying physics of the space around us, which tells us more about the nature of space throughout the cosmos, as well as how it drives planetary atmospheres that contribute to planet habitability.

Heliophysics Research

The heliophysics research program at NASA funds a wide range of studies into the interrelated system that connects the sun to Earth, the planets, and the particles and magnetic energy that travel across space.

The strategic goal of NASA's heliophysics program is to better understand the sun and its interactions with Earth and the rest of the solar system, including space weather.

The Heliophysics Research Program aims to meet the objectives set forth in NASA's 2014 Science Plan and the National Research Council's Decadal Strategy for Solar and Space Physics study, Solar and Space Physics: A Science for a Technological Society, published in 2013. Heliophysics research responds to these proposals by developing a program aimed at achieving three broad scientific objectives:

- From the sun to Earth and throughout the solar system, investigate the physical processes at work in the space environment.
- Improve our knowledge of the relationships between the sun, Earth, planetary space habitats, and our solar system's furthest reaches.
- To protect life and society, as well as to ensure exploration beyond Earth, develop the knowledge and aptitude to detect and predict extreme circumstances in space.

- NASA 2014 Science Plan

- 2013 National Research Council Decadal Strategy for Solar and Space Physics report, Solar and Space Physics: A Science for a Technological Society

The program encourages research in all subdisciplines of heliophysics, as well as research that crosses subdisciplines and takes a systems perspective. Understanding the fundamental processes and relationships across traditional science disciplines is emphasized throughout the program. The goal of the program is to characterize such phenomena on a wide range of spatial and temporal scales, to comprehend the fundamental processes that drive them, to comprehend how the processes interact to produce space weather events, and to develop a capability for predicting future space weather events.

The program shares responsibilities for learning about Earth, our solar system, the universe, and their interrelationships with other NASA research divisions (Planetary Science, Astrophysics, and Earth Science).

The program supports:

- Investigations of the sun

  Investigations of the sun, include phenomena occurring in the solar interior and atmosphere, as well as the sun's evolution and cyclic activity.

- Investigations of the origin and behavior of the solar wind, energetic particles, and magnetic fields in the heliosphere

  Investigations of the solar wind, energetic particles, and magnetic fields in the heliosphere, as well as their interactions with Earth and other planets and the interstellar medium.

- Investigations of the physics of magnetospheres

  Fundamental interactions of plasmas and particles with fields and waves, as well as coupling to the solar wind and ionospheres, are all investigated in the physics of magnetospheres.

- Investigations of the physics of the terrestrial mesosphere, thermosphere, ionosphere

  Studies into the physics of the terrestrial mesosphere, thermosphere, and ionosphere, as well as their interactions with the lower atmosphere and magnetosphere.

Program Elements

Heliophysics Supporting Research:

The Heliophysics Supporting Research program funds studies that use a variety of methodologies, including as theory, numerical simulation, modeling, data analysis, and interpretation. Investigations that combine data from current or previous NASA spacecraft with theory and/or numerical simulation to solve one of the four Heliophysics Decadal Survey goals will be given top priority.

Heliophysics Supporting Research includes studies of the solar interior, photosphere, chromosphere, transition region, and corona, as well as particle acceleration, transport, and modulation in the heliosphere, heliospheric plasma processes, turbulence, waves, composition, interplanetary coronal mass ejections/magnetic clouds, and the outer heliosphere and interstellar boundary.

Heliophysics Technology and Instrument Development for Science:

H-TIDeS, or Heliophysics Technology and Instrument Development for Science, is a NASA initiative that seeks proposals for technology and instrument development studies related to NASA's heliophysics missions.

The H-TIDeS program aims to answer key heliophysics questions by addressing the best science and/or technology investigations that can be carried out with instruments flown on suborbital sounding rockets, stratospheric balloons, the International Space Station,

CubeSats, or other flights of opportunity; state-of-the-art instrument technology development for instruments that may be flown on suborbital sounding rockets, stratospheric balloons, the International Space Station

The H-TIDeS program element has three components:

- Access to Information at Low Cost Space investigations could be science investigations in and of themselves, or proof-of-concept experiments for novel heliophysics techniques/detectors. Rides on research balloons, sounding rockets, the International Space Station, commercial reusable suborbital rockets, CubeSats, and other chance trips are all included. Such missions to space with the goal of returning scientific data are expected to make direct contributions to heliophysics science.

- Instrument and Technology Development investigations concentrate on the development of instrument technologies that show potential for application in scientific investigations on future heliophysics science missions, including laboratory instrument prototypes but not flight hardware. Instrument development proposals are not required to apply the outcomes of their work to scientific problems within the time frame specified in the proposal. They must, however, show that there are specific scientific issues for which the development is a prerequisite.

- Laboratory Nuclear, atomic, and plasma physics funds research into fundamental physical processes and the production of chemical, spectroscopic, and nuclear measurements that aid spacecraft measurements and model development.

Heliophysics Guest Investigators:

The 2013 Decadal Survey highly supported the Heliophysics Guest Investigators program. This program is available for projects that rely heavily on data sets from the Heliophysics System Observatory's missions. The sought research's focus changes over time to

guarantee that the most pressing concerns for recently launched heliophysics missions are addressed, and that high-value data products from currently operational heliophysics missions are generated to enable significant heliophysics science breakthroughs.

Heliophysics Grand Challenges Research:

The Heliophysics Grand Challenges Research program is another program that received great support in the 2013 Decadal Survey. The goals of this program, as indicated, are specifically designed to facilitate explorations of complex problems that come within the general field of heliophysics but have yet to be fully resolved. Independent research groups that use observational, theoretical, and modeling-based approaches have long worked on such issues. Major improvements in the discipline are increasingly being made as a result of tight collaboration between observers, theorists, and modelers.

To enable profound and transformational science, a cohesive attack on the most daunting broad problems necessitates the efforts of a synergistically interacting set of multidisciplinary teams led by a single Principal Investigator.

The Heliophysics Grand Challenges Research program has two components:

- One of the program's foundations is Theory, Modeling, and Simulations. Numerical simulations and modeling are becoming tools that can be utilized in conjunction with data analyses and rigorous theory building to answer the fundamental challenges of heliophysics as computing power becomes more affordable and available. They pave the path for new knowledge and science concepts that will be used in future strategic missions. The ultimate purpose of such investigations is to give a complete chain of reasoning spanning from basic natural laws to observational comparisons to the discovery of future quantitative tests of environmental behavior.

- The Heliophysics Grand Challenges Research program now has a second, new base in the shape of Science Centers. The 2013 Decadal Survey recommended this

section as well, and it is currently being developed into a program for implementation.

Heliophysics Living With a Star Science:

The Living With a Star Science initiative at NASA aims to create the scientific knowledge needed to successfully address those parts of heliophysics science that have an impact on life and society. To accomplish this, the H program seeks proposals for focus teams that will coordinate large-scale investigations that span disciplines and techniques, resulting in a better understanding of the entire system that connects the sun to the solar system, both directly and through the heliosphere, planetary magnetospheres, and ionospheres.

The creation of first-principles-based models for the coupled sun-Earth and sun-solar system, comparable to first-principles models for the lower terrestrial atmosphere, is a main goal of NASA's Living With a Star initiative. Models like these can be used as science tools, prototypes and test beds for prediction and specification capabilities, frameworks for linking diverse data sets at different points around the solar system, and strategic planning aids for exploring space and testing new mission concepts. The development and integration of such models for all of the system's many components are Strategic Capabilities.

Heliophysics Data Environment Enhancements:

The Heliophysics Data Environment Enhancements program's purpose is to enable breakthrough research in heliophysics by providing both a cutting-edge data environment and the required supporting infrastructure to enhance NASA missions' scientific returns. It is critical that observations be properly captured, processed, made public, documented, and quickly transformed into scientific findings. These investigations are being carried out in support of NASA's 2014 Strategic Plan's Heliophysics strategic goals and subgoals, as well

as Chapter 4.1 of the NASA 2014 Science Plan. The 2013 Decadal Survey also discusses the Heliophysics community's recommended priorities.

The program encompasses the data environment needs throughout heliophysics, including solar, heliospheric, and geospace sciences.

Space Weather

Space Weather Overview

The sun's steady outflow of solar wind fills space with a thin and tenuous wash of particles, fields, and plasma, despite the fact that space is nearly a thousand times emptier than even the greatest laboratory vacuums on Earth. This solar wind, along with other solar occurrences such as coronal mass ejections, affects the very nature of space and can interact with Earth's and other worlds' magnetic systems. As a result of these consequences, the radiation environment in which our spacecraft – and, one day, our astronauts heading to Mars – traverse changes.

The space environment around Earth can also change dramatically in reaction to upwelling atmospheric phenomena from below, as well as the Sun.

Satellite electronics, radio communications, GPS signals, spacecraft orbits, and even – in severe cases – power systems on Earth can all be affected by space weather. Space weather, like terrestrial weather, can be intense at times, yet it is always there. As a result, it's critical to comprehend space weather in order to forecast and prepare for it.

Heliophysics Space Weather Missions

All of NASA's current heliophysics projects help us learn more about the physical processes that shape the space environment surrounding Earth and throughout the solar system. The graphic below depicts the Heliophysics Fleet's current operational missions, as well as a general representation of their location in the solar system.

- Heliophysics missions

Space Weather Science Application (SWxSA)

The Heliophysics Division Space Weather Science Application (SWxSA) effort supports the multi-agency National Space Weather Strategy and Action Plan by expanding NASA's engagement in space weather science under a single budget element. It competes for ideas and products, builds on existing Agency capabilities, interacts with other national and international organizations like the National Science Foundation (NSF), and partners with user groups to make science knowledge more useful in operational settings.

O2R

As part of NASA's Research Opportunities in Space and Earth Science (ROSES) program, thirteen research proposals for the Heliophysics Space Weather Operations-to-Research (O2R) element were chosen in 2019. This brings the overall number of funded investigations within O2R to 39. These projects will aid in the improvement of predictions of energetic proton and/or heavy ion conditions in the heliosphere as a result of solar eruptions.

The major purpose of this financing is to help the grant recipient conduct research to develop numerical models and/or data usage approaches in order to increase forecasting capabilities and scientific knowledge.

SBIR

Engaging the commercial sector is a crucial part of the strategic plan. The Small Business Innovation Research program helps with this in part (SBIR). In 2019, four concepts for space weather technology were chosen for Phase I of the SBIR program, with six more in 2020. In 2018, two were chosen for Phase II. This takes the total number of SBIR Phase 1 proposals funded to ten, and the total number of SBIR Phase 2 proposals to two. Modeling

methodologies, tools to enable space weather extremes, and measurement technology to detect radiation levels aboard airplanes are all part of these initiatives.

NSF-NASA Space Weather Next Generation Software for Data-driven Models of Space Weather with Quantified Uncertainties (NSF-NASA SWQU)

Six further studies have been funded through the joint NSF-NASA SWQU solicitation. Through a pilot program, the National Space Weather Strategy and Action Plan (NSW-SAP) and the National Strategic Computing Initiative (NSCI) Update address overlapping objectives. The purpose of this pilot study is to revolutionize the development of predictive modeling of the magnetized solar atmosphere and solar wind, as well as their interactions with the Earth's magnetosphere and upper atmosphere.

Space Weather Council

The NASA Space Weather Council (SWC) was founded by the NASA Heliophysics Division in 2020 as a subgroup of the Heliophysics Advisory Committee (HPAC). In support of NASA's Heliophysics Division, the SWC was founded as a way to secure the advice of community specialists from a variety of fields on topics related to space weather (HPD).

The SWC is a community-based, interdisciplinary forum for gathering, coordinating, and delivering guidance on community analysis and feedback. It gives advise to the NASA Heliophysics Division's Heliophysics Advisory Committee (HPAC) (HPD). The Heliophysics Division's Space Weather Science Application (SWxSA) goals will be directly supported by the SWC.

Space Weather Instruments and Missions (SWIMS) Request for Information (RFI)

Under this Request for Information (RFI), NASA HPD wants to assess community interest, concepts, and rough order of magnitude (ROM) cost estimates for small complete missions, instrument suites, or single instruments that, if flown in space, would directly

address space weather science and/or observational needs. These instruments, suites, and missions could be carried as secondary payloads on rideshare flights or hosted on satellites or other platforms. The information gathered through this RFI will be used to inform programmatic choices about secondary or hosted payload options for future Science Mission Directorate (SMD) Heliophysics launches or missions.

National Space Weather Program

NASA heliophysics is the nation's space weather research arm, collaborating on the National Space Weather Strategy and Action Plan with other federal agencies such as the National Oceanic and Atmospheric Administration, the National Science Foundation, the United States Geological Survey, the United States Air Force Research Laboratory, and the United States Naval Research Laboratory. NASA supports advancements in space weather prediction models, such as those used by NOAA's Space Weather Prediction Center, the US government's official source for space weather forecasts, in addition to research missions.

Gateway and the Artemis Program

The Heliophysics section collaborates closely with the Artemis Program to assist human deep space exploration and to investigate potential methods for measuring the radiation environment on and around the Moon. These observations will help predict and validate the radiation environment that our astronauts will be exposed to.

The Heliophysics Division is helping to achieve this goal by providing radiation and space weather equipment for the Lunar Gateway, which is an early essential component of the Artemis Program. The Heliophysics Environmental and Radiation Measurement Experiment Suite (HERMES) was chosen in March 2020 and publicly publicized. A radiation instrument kit will be provided by the European Space Agency. The Gateway observations will kick off a heliophysics lunar constellation to undertake science research not feasible before, in cooperation with the Heliophysics two-spacecraft mission THEMIS/ARTEMIS already in lunar orbit.

- Heliophysics Environmental and Radiation Measurement Experiment Suite (HERMES)

This payload will allow for important science, will assist Artemis, and will look ahead to crewed trips to Mars.

Science Questions

Heliophysics is a branch of physics that aims to comprehend the nature of space, particularly how the Sun's magnetic fields and particles affect space across the solar system. Space weather, which can interfere with our communications and satellite technologies, is a term used to describe such occurrences near Earth. Knowledge of our space environment also aids us in comprehending the region through which spacecraft travel, as well as elucidating the forces that shaped planets and other stars.

Goals specified in the NASA 2014 Strategic Plan, NASA 2014 Science Plan, and the 2013 National Research Council Decadal Strategy for Solar and Space Physics study, Solar and Space Physics: A Science for a Technological Society, lead the NASA Heliophysics Division. We are currently attempting to answer three major issues about the Sun and its interactions with the Earth and the Solar System, including space weather, in order to increase our understanding of the Sun and its interactions with the Earth and the Solar System.

- What drives the constant change we observe on our sun?
- What drives the changes in near-Earth space, the planetary space environments, the heliosphere, and the interstellar medium?
- What are the impacts of this dynamic space system on humanity?

Heliophysics Data

The goal of heliophysics research is to figure out the nature and dynamics of the Sun, the heliosphere, planet plasma environments, and interstellar space. This study is based on data from a series of strategically located NASA satellites known as the Heliophysics System Observatory, as well as models based on those data. The Heliophysics Data Portal makes

the data from these missions available to the general public. The community can access data, relevant documentation, tools, and services in addition to the data. The Heliophysics Data Environment, or HPDE, is a collection of data and associated resources.

- Heliophysics Data Portal

The heliophysics community continues to obtain more data at an ever-faster pace as technology progresses. The Heliophysics Division devised a science data management strategy in 2007 to manage such huge amounts of data, which it continues to improve as needed. In 2016, the most recent version, 1.2, was released. This policy highlights NASA's open data policy as well as the need of archiving and curating data in standard forms. The Heliophysics Division is seeking to embrace an open source data analysis software architecture as NASA advances toward a more flexible environment.

- latest version, 1.2

Heliophysics data is currently handled and curated in two archives: the Solar Data Analysis Center (SDAC) and the Space Physics Data Facility (SPDF), both of which can be accessed through the data portal. SDAC primarily stores data related to solar science and remote sensing. All ionosphere, thermosphere, mesosphere (ITM), magnetosphere, and heliosphere mission science is archived in the SPDF (i.e. in-situ data).

- Solar Data Analysis Center
- Space Physics Data Facility
- data portal

These datasets can be used in conjunction with the Community Coordinated Modeling Center's (CCMC) physical models. Connecting the CCMC's modeling skills with data from the Heliophysics System Observatory lays the groundwork not just for new science, but also for developing the predictive capabilities needed for space weather forecasting.

Heliophysics Data Portal

The Heliophysics Data Portal, or HDP, is a sort of card catalog for a large number of data items. Users can use any combination of time, observatory, measurement type, general location, and other characteristics, as well as free-text (Google-like) keywords, to search for datasets. The data in question can frequently be plotted or accessed directly once located, and if not, data access services are available.

Space Physics Data Facility

The Space Physics Data Facility (SPDF) makes a huge collection of in-situ space physics datasets available for plotting, downloading, and direct application access. Data from various sets can be plotted together, and output datasets can be produced with only the variables or time ranges that are requested. Access to the prominent OMNI dataset of 1 AU solar wind data, as well as related solar and ground-based indices, are among the services offered.

Solar Data Analysis Center

The Solar Data Analysis Center, or SDAC, is a repository for a variety of datasets as well as a resource for locating others. It also includes connections to a number of useful resources, like the Solar Monitor and SolarSoft Latest Events. The Virtual Solar Observatory, or VSO, provides access to solar science and remote sensing data. The VSO offers simple interfaces for searching by time, data product, product nicknames (such as "H-alpha"), and other criteria. It then generates data files, which can be studied with SolarSoft or other software.

Community Coordinated Modeling Center (CCMC)

The Community Coordinated Modeling Center, or CCMC, is a multi-agency collaboration aimed at enabling, supporting, and conducting research and development for next-generation space scientific and space weather models. It provides automated model

runs, on-demand runs, visualization and analysis tools, as well as access to modern space research models.

Resources

Strategy & Guiding

- Heliophysics 2024 Decadal Survey
- A Decadal Strategy for Solar and Space Physics (2013)
    - Progress Toward Implementation of the 2013 Decadal Survey for Solar and Space Physics
    -  NASA Response to the Heliophysics Decadal Survey Midterm Report
- Heliophysics Advisory Committee
- Senior Reviews
- Science and Technology Definition Teams (STDTs)
- Heliophysics Science and Technology Roadmap for 2014-2033
- Science Mission Directorate Strategy
- NASA 2018 Strategic Plan
- Heliophysics Fleet Chart
- Heliophysics Organization Charts

Research

- Funding Opportunities

Education

- The Solar Cycle
- Space Weather FAQ
- Space Weather Storms
- Definitions of X, M and C class flares

- Impacts of Strong Solar Flares
- CMEs versus Solar Flares
- Sun Primer: Why NASA Scientists Observe the Sun in Different Wavelengths
- Tour of the Electromagnetic Spectrum: Video Series and Companion Book
- Mysteries of the Sun
- Heliophysics Vocabulary
- Mission Posters