NASA Space Exploration and the Heliophysics Space Weather Science and Applications Program

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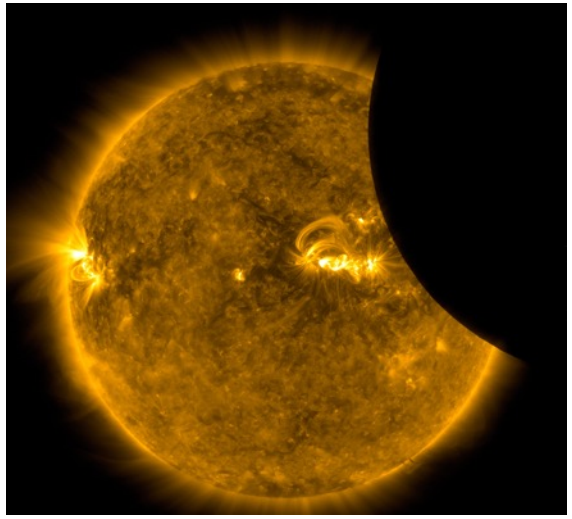
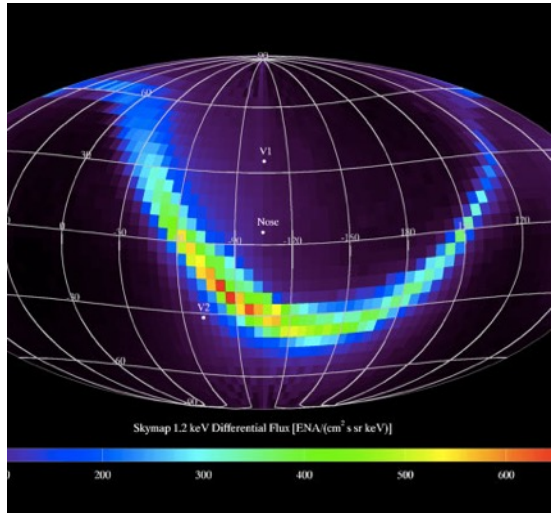
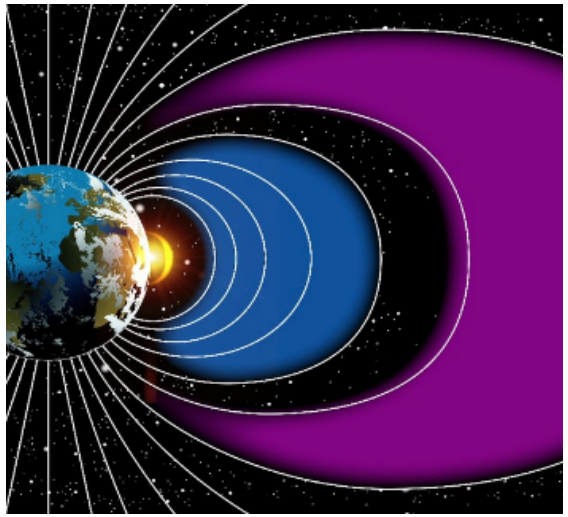
NASA Heliophysics Division

11th NASA Space Exploration & Space Weather Workshop
October 17, 2019







The Dawn of a New Era for Heliophysics

Heliophysics Division (HPD), in collaboration with its ***partners***, is poised like never before to:

Strategically advance understanding of solar and space physics, make ***amazing discoveries***

Augment the Helio fleet with ***new missions*** and a robust ***suborbital*** program

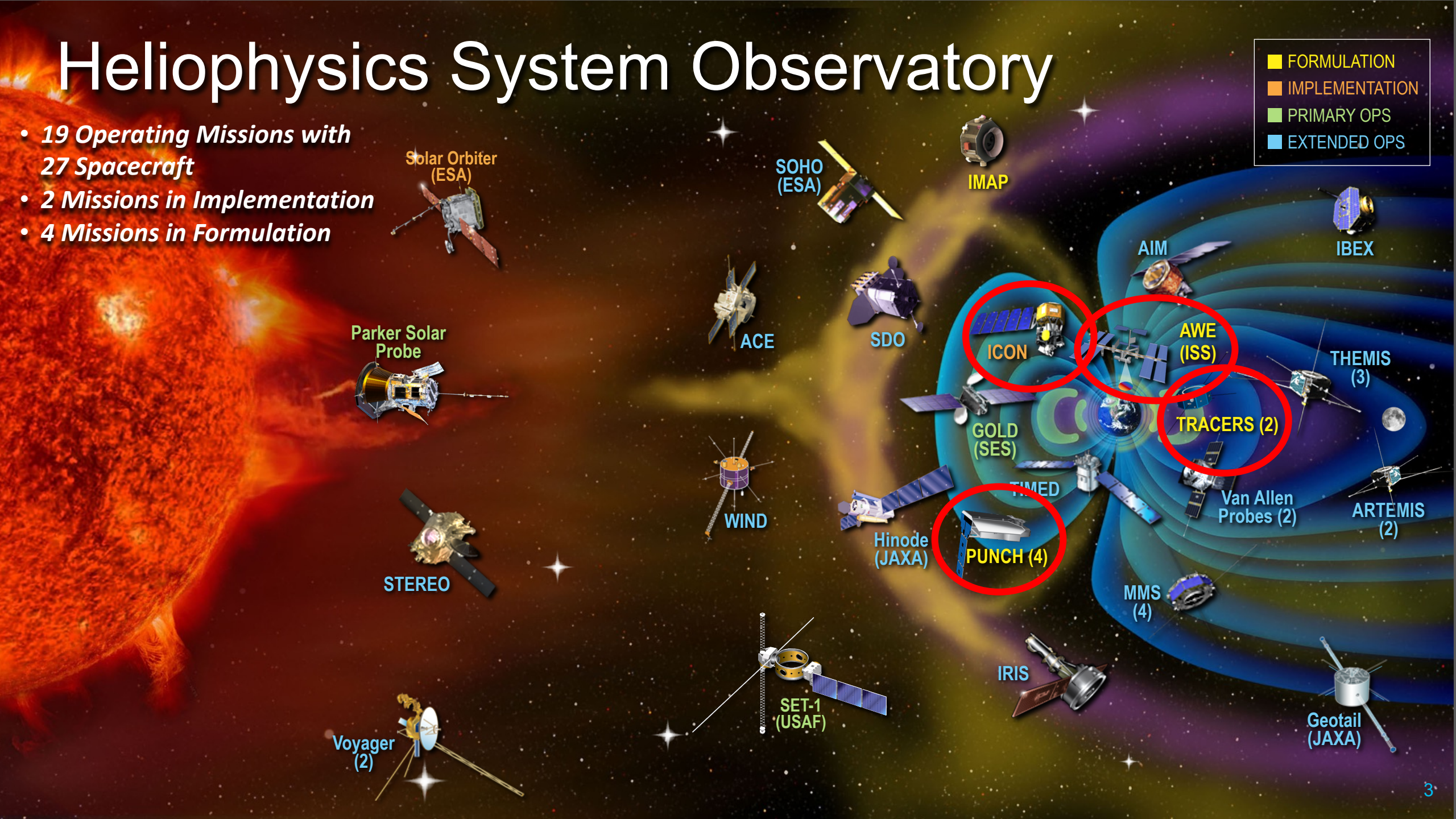
Fulfill its role for the Nation enabling advances in ***space weather***

Engage the public with science knowledge and citizen science

Develop the ***next generation*** of heliophysicists

Heliophysics System Observatory

- *19 Operating Missions with 27 Spacecraft*
- *2 Missions in Implementation*
- *4 Missions in Formulation*



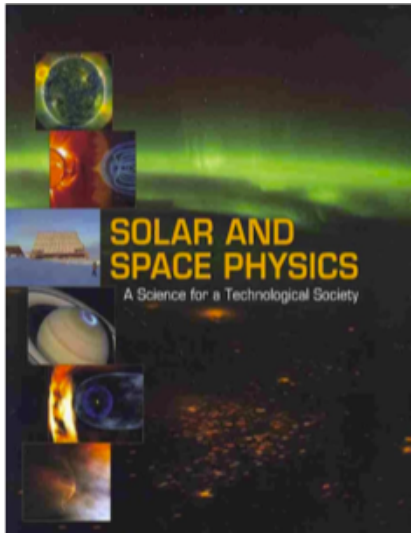
Heliophysics Space Weather Science and Applications Program

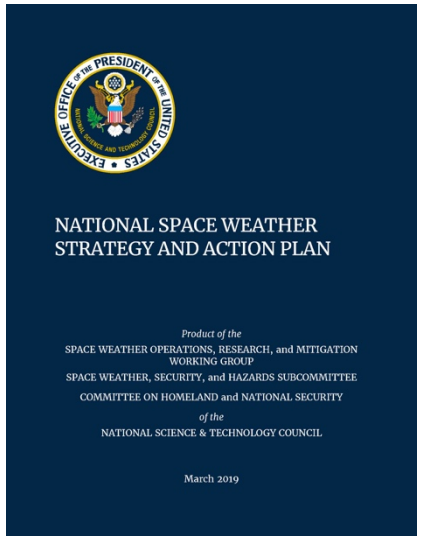
Space Weather Science and Applications (SWxSA)

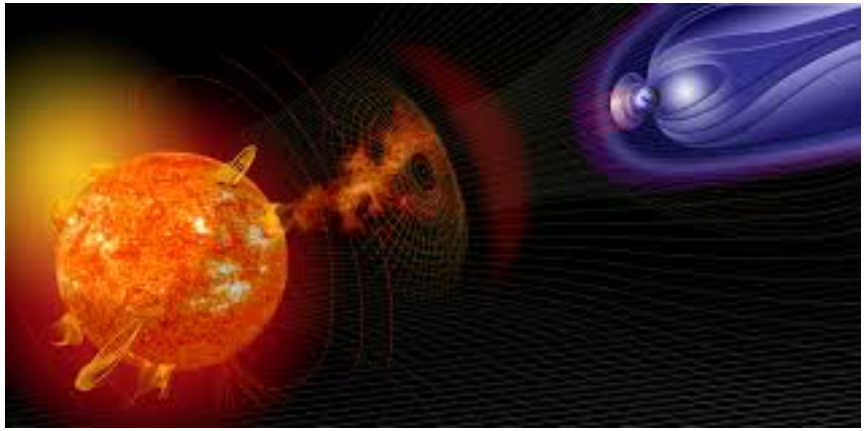
- A new program in the NASA Heliophysics Portfolio
- Totally integrated into and consistent with the goals, research investigations, missions, and technology of the NASA Heliophysics Division
- Does not impact the Heliophysics Division research and mission resources

Space Weather Science and Application (SWxSA)

- **Establishes** an expanded role for NASA in space weather science under single budget element
  - **Consistent** with the recommendation of the NRC Decadal Survey and the OSTP/SWORM 2019 National Space Weather Strategy and Action Plan
- ***Competes*** ideas and products, ***leverages*** existing agency capabilities, ***collaborates*** with other agencies, and ***partners*** with user communities
- **Distinguishable** from other heliophysics research elements in that it is specifically focused on investigations that significantly advance understanding of space weather. This progress is then applied to enable more accurate characterization and predictions with longer lead time
- **Transition** technology/techniques, tools, models, data, and knowledge from research to operational environments
- **Focused** on Artemis and National Space Weather Capability







SWxSA R2O Strategy Elements

- **Inherently involves multiple Government agencies and collaborations between the private and public sectors,** and an understanding of the general R2O process is needed by all to clarify roles and responsibilities
- Acknowledgement of the differences between SWxSA and typical NASA research and analysis (R&A) efforts
- The need for a well-defined but flexible process to facilitate the transition of NASA technology into operations and the feeding of ideas and questions back to basic research activities
- The requirement for sustained support for product developers through all stages of the process – research, transition, operations
- Emphasis on active operational entity and/or end-user participation, including resource commitment, throughout the R2O process
- **The desire for research and operational space weather experts to serve as a bridge between the end users and the broader research community**

Space Weather Science and Application ROSES & SBIRs

3 calls were made between ROSES 2017 and ROSES 2018 in Space Weather Operations-to-Research (SWO2R)

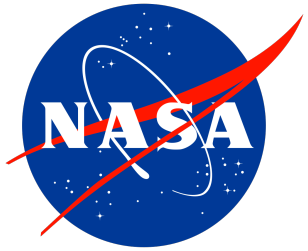
- 8 selections made for ROSES 2017 SWO2R
  - Focus: Improve predictions of background solar wind, solar wind structures, and CMEs
- 9 selections made for ROSES 2018 (1) SWO2R
  - Focus: Improve specifications and forecasts of the energetic particle and plasma encountered by spacecraft
- ROSES 2018 (2) SWO2R selections upcoming:
  - Focus: Improve forecasts of solar energetic particles and heavy ions
  - 4-6 selections anticipated in October 2019

ROSES 2019 call released – no focus topic

Small Business Innovation Research (SBIR) Program for Space Weather

- 2018 – Selected 2 Phase II
- 2019 – Selected 4 Phase I
- 2020 – Language for Call has been approved

Interagency Partners



NASA-NOAA (MOU):

- Collaboration between GSFC/CCMC and NOAA/SWPC on space weather modeling capability
- Collaboration between JSC/SRAG and NOAA/SWPC
- Co-funding O2R proposals
- Accommodation for SWFO mission on IMAP launch

NASA-NSF (MOU):

- Coordinating ICON & GOLD opportunities (joint NASA mission GI and NSF CEDAR solicitations)
- Consulted on solicitation design for Science Centers
- Co-funding CCMC
- New opportunity focused on Computational Aspects of Space Weather

NASA-NSF-NOAA (MOU):

- Pilot O2R research activity, MOU

NASA-USGS:

- NASA collaborating with USGS to enable Magneto-Telluric Survey in southwest

NASA-NSF-NOAA-DoD (in work):

- Preparing Quad-Agency MOU focused on Space Weather

Space Weather Science and Application
Ongoing Steps

- Develop NASA Heliophysics Space Weather Science and Applications Implementation Plan
- Define transition framework and implement pilot test-bed with NOAA SWPC
  - Define process
  - Transition one or two test cases
  - Implement a mirror test-bed capability to enhance transitioning
- Develop with Human Exploration & Operations Mission Directorate (HEOMD) a lunar space environment capability to safeguard human and robotic explorers beyond low-earth-orbit
  - Participating in Lunar Gateway Payload Working Group
    - Responded to 'Call for Information' for Heliophysics and space weather payloads
    - Energetic particles and solar wind sensor package rated high to launch with the Power and Propulsion Element of Gateway Phase 1
- Define
  - Strategic instrument development for ESA L5 mission
  - Robust multipurpose space weather package for additional rideshare opportunities
- Secure counsel of community expertise
- Work in concert with the OSTP Space Weather Operations, Research, and Mitigation (SWORM) Working Group and in accordance to the 2019 National Space Weather Strategy and Action Plan (NSW-SAP)

Heliophysics and the Lunar Gateway

- The Gateway presents new opportunities to conduct high priority heliophysics investigations
  - Observing geospace from lunar distances, enables advancement of knowledge and understanding for the coupling of the magnetosphere/ITM/upper atmosphere regions and interactions of the high/mid/equatorial regions can be obtained
  - The platform provides the opportunity to develop sensor technologies and observational capabilities for solar and space physics research
- The Gateway will leverage the application of heliophysics science to mitigate space weather impacts on human exploration at the Moon and beyond.
  - Development of Earth-Independent capability for space weather monitoring and prediction for exploration missions at the Moon and beyond is made possible by the Heliophysics Division Space Weather Science and Application program.
  - In discussions with HEOMD to establish space weather capability requirements for the Gateway and for human exploration beyond geospace

NASA Selects 12 New Lunar Science, Technology Investigations

The selected investigations will go to the Moon on future flights through NASA's **Commercial Lunar Payload Services (CLPS)** project and the NASA Exploration Campaign.

The following four missions support heliophysics science objectives:

1. **The Lunar Surface Electromagnetics Experiment (LuSEE):** PI: Stuart Bale, University of California, Berkeley
   - LuSEE will integrate flight-spare and repurposed hardware from the **Parker Solar Probe** FIELDS experiment, the **STEREO**/Waves instrument, and the MAVEN mission to make comprehensive measurements of electromagnetic phenomena on the surface of the Moon.

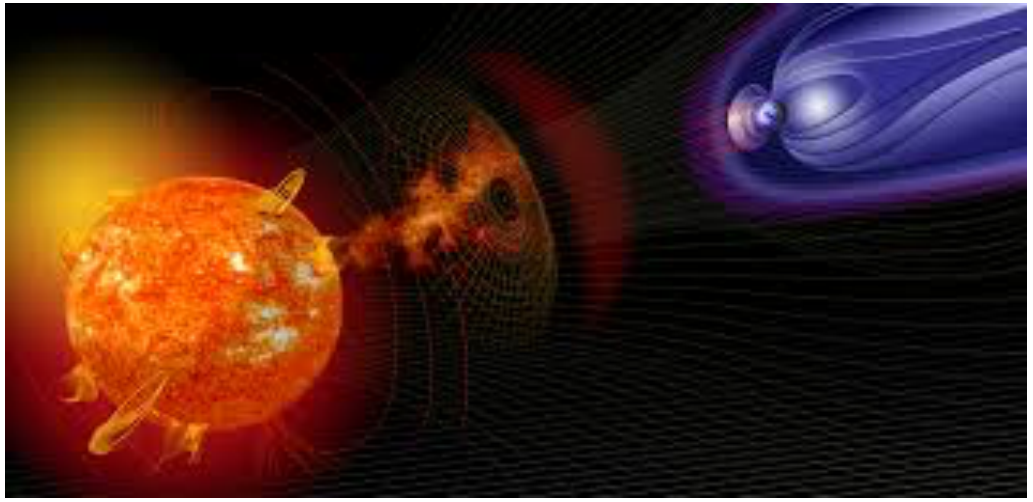
2. **The Lunar Environment heliospheric X-ray Imager (LEXI):** PI: Brian Walsh, Boston University
   - LEXI will capture images of the interaction of Earth's magnetosphere with the flow of charged particles from the Sun, called the solar wind.

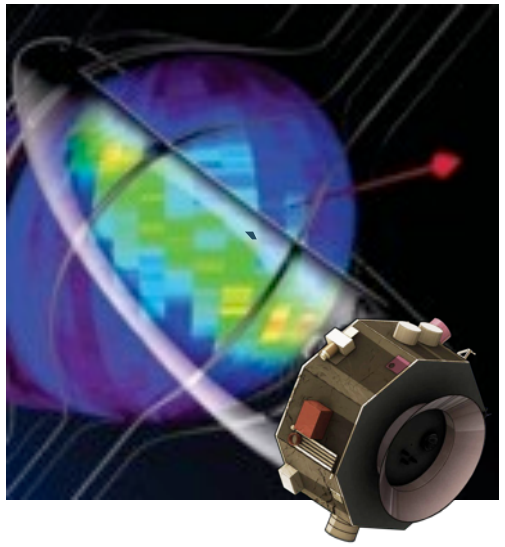
3. **Lunar Demonstration of a Reconfigurable, Radiation Tolerant Computer System:** PI: Brock LaMeres, Montana State University, Bozeman
   - Lunar Demonstration of a Reconfigurable, Radiation Tolerant Computer System aims to demonstrate a radiation-tolerant computing technology. Due to the Moon's lack of atmosphere and magnetic field, radiation from the Sun will be a challenge for electronics. This investigation also will characterize the radiation effects on the lunar surface.

4. **The Lunar Magnetotelluric Sounder:** PI: Robert Grimm, Southwest Research Institute, San Antonio.
   - The Lunar Magnetotelluric Sounder is designed to characterize the structure and composition of the Moon's mantle by studying electric and magnetic fields. The investigation will make use of a flight-spare magnetometer, a device that measures magnetic fields, originally made for the MAVEN spacecraft, which is currently orbiting Mars.

Summary

It is a Great Time to be a Heliophysicist!





The Heliophysics Division is poised like never before to:

- Capitalize on our unique opportunity to study the Sun and its effects throughout the Heliosphere
- Augment the Heliophysics fleet with new, innovative missions, a robust suborbital program, and an enhanced ride share program
- Make research and technology investments to enable science, e.g. interstellar probe, solar sails
- Develop the next generation of Heliophysicists and engage the public with science knowledge
- Fulfill our responsibility for the Nation enabling advances in space weather
- Play a critical role in Exploration supporting the Artemis mission
- Lean forward for success in the next decade

Backup

Missions

Ionospheric Connection Explorer (ICON)

Mission Line: Explorers

Launch Vehicle: Pegasus XL rocket

Launch Site: Cape Canaveral

Launched: **October 10, 2019**

ICON Principal Investigator: Tom Immel (UC Berkeley)

Description:

- ICON will study the frontier of space: the dynamic zone high in our atmosphere where terrestrial weather from below meets space weather above.
- In this region, the tenuous gases are anything but quiet, as a mix of neutral and charged particles travel through in giant winds.
- These winds can change on a wide variety of time scales -- due to Earth's seasons, the day's heating and cooling, and incoming bursts of radiation from the sun.

Next Step*: Awaiting launch*

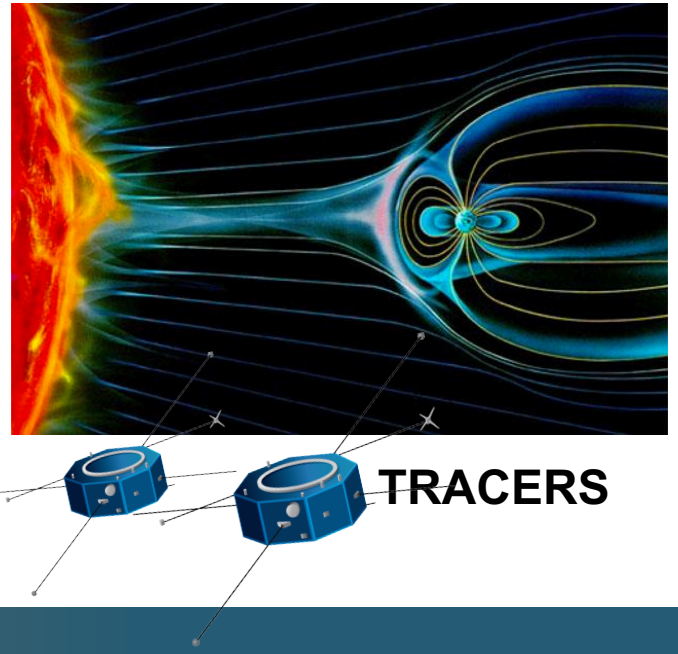
Explorers AO 2016 SMEX Selections

Polarimeter to Unify the Corona and Heliosphere (PUNCH)

- Focuses directly on the Sun's corona, and how it generates the solar wind
- Image and track the solar wind as it leaves the Sun.
- Track coronal mass ejections to better understand their evolution and develop new techniques for predicting such eruptions
- Composed of four suitcase-sized satellites
- **Principal Investigator:** Dr. Craig Deforest at Southwest Research Institute

Tandem Reconnection and Cusp Electrodynamics Reconnaissance Satellites (TRACERS)

- Observe particles and fields at the Earth's northern magnetic cusp region and study how magnetic fields around Earth interact with those from the Sun.
- First space mission to explore this process in the cusp with two spacecraft, providing observations of how processes change over both space and time.
- **Principal Investigator:** Craig Kletzing at University of Iowa



LRD NLT Aug 2022

"We carefully selected these two missions not only because of the high-class science they can do in their own right, but because they will work well together with the other heliophysics spacecraft advancing NASA's mission to protect astronauts, space technology and life down here on Earth" – Thomas Zurbuchen

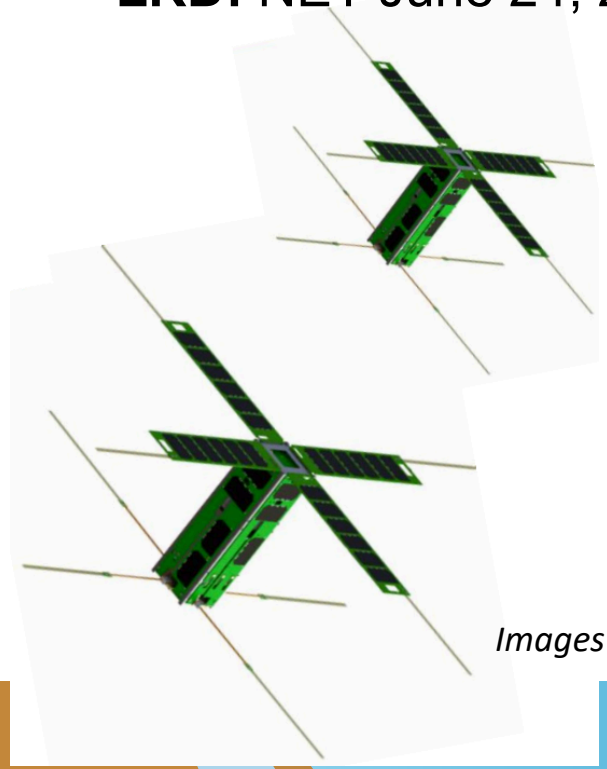
Enhanced and Tandem Beacon Experiment (E-TBEx)

Launch Vehicle: Falcon Heavy

Rideshare: w/Space Test Program-2 multi-manifest launch – total of 23 satellites

Launch Site: Cape Canaveral

LRD: NET June 24, 2019



Images from CubeSat Workshop Apr 2018

Principal Investigator: Ronald Tsunoda (SRI/University of Michigan)

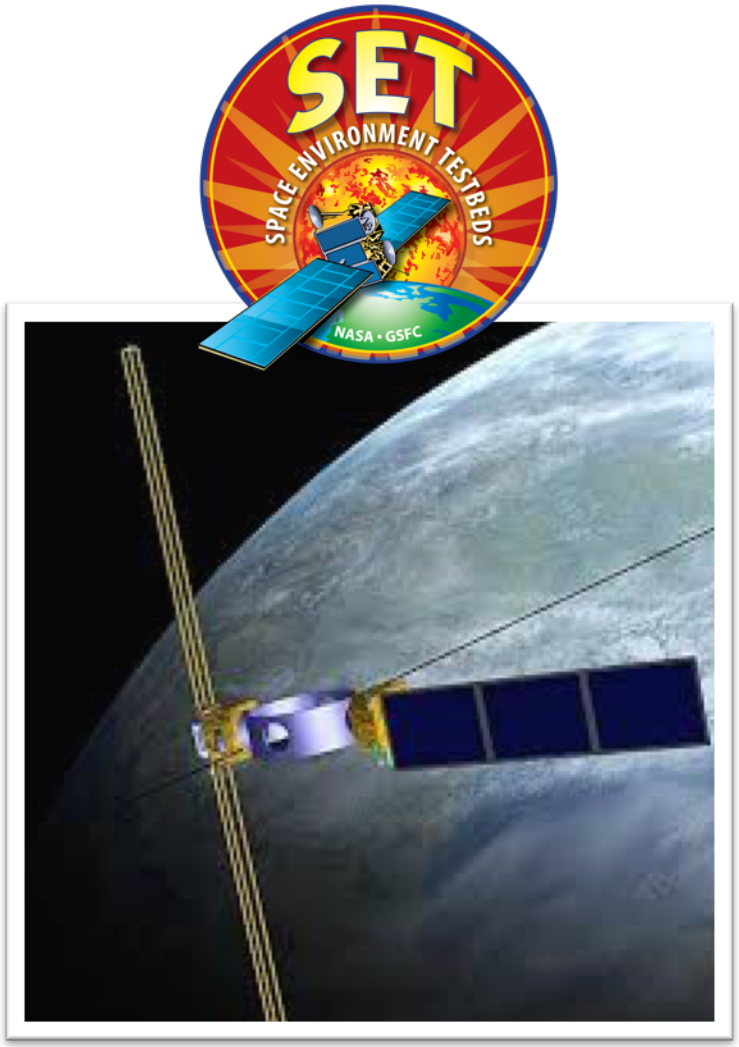
Description:

- Pair of 3U CubeSats each carrying tri-frequency radio beacons
- Measures how radio signals can be distorted by large bubbles that form naturally in the Earth's charged upper atmosphere
- Tracks how the ionosphere disrupts signals by monitoring, from the ground, beacon tones transmitted from eight orbital locations: the six COSMIC-2 spacecraft (NOAA) and the twin E-TBEx CubeSats (NASA)

Impact:

- These bubbles interfere with communications and GPS in large regions near Earth's magnetic equator

Space Environment Testbed (SET-1) Mission



Mission Line: Living With a Star

Launch Vehicle: Falcon Heavy

Launch Site: KSC

LRD: June 24, 2019

Observatory: SET-1 hosted payload on Air Force Research Laboratory (AFRL) Demonstration and Science Experiments (DSX) spacecraft

Description:

- Define the mechanisms for induced space environment and effects
- Reduce uncertainties in the definitions of the induced environment and effects on spacecraft and their payloads
- Improve design and operations guidelines and test protocols so that spacecraft anomalies and failures due to environmental effects during operations are reduced

Upcoming CubeSat Missions

E-TBEx – The Enhanced Tandem Beacon Experiment is a pair of 3U CubeSats each carrying tri-frequency radio beacons. It measures how radio signals can be distorted by large bubbles that form naturally in the Earth's charged upper atmosphere. It tracks how the ionosphere disrupts signals by monitoring, from the ground, beacon tones transmitted from eight orbital locations: the six COSMIC-2 spacecraft (NOAA) and the twin E-TBEx CubeSats (NASA). June 2019

SORTIE: The Scintillation Observations and Response of The Ionosphere to Electrodynamics is a scientific investigation mission on a 6U CubeSat to advance understanding of ionospheric irregularities and the roles of various drivers in their formation in order to improve predictive capabilities. October 2019

OPAL – The Oxygen Photometry of the Atmospheric Limb is a 3U CubeSat experiment designed to study temperature fluctuations in the lower thermosphere by focusing on remote optical observations of atmospheric temperatures. October 2019

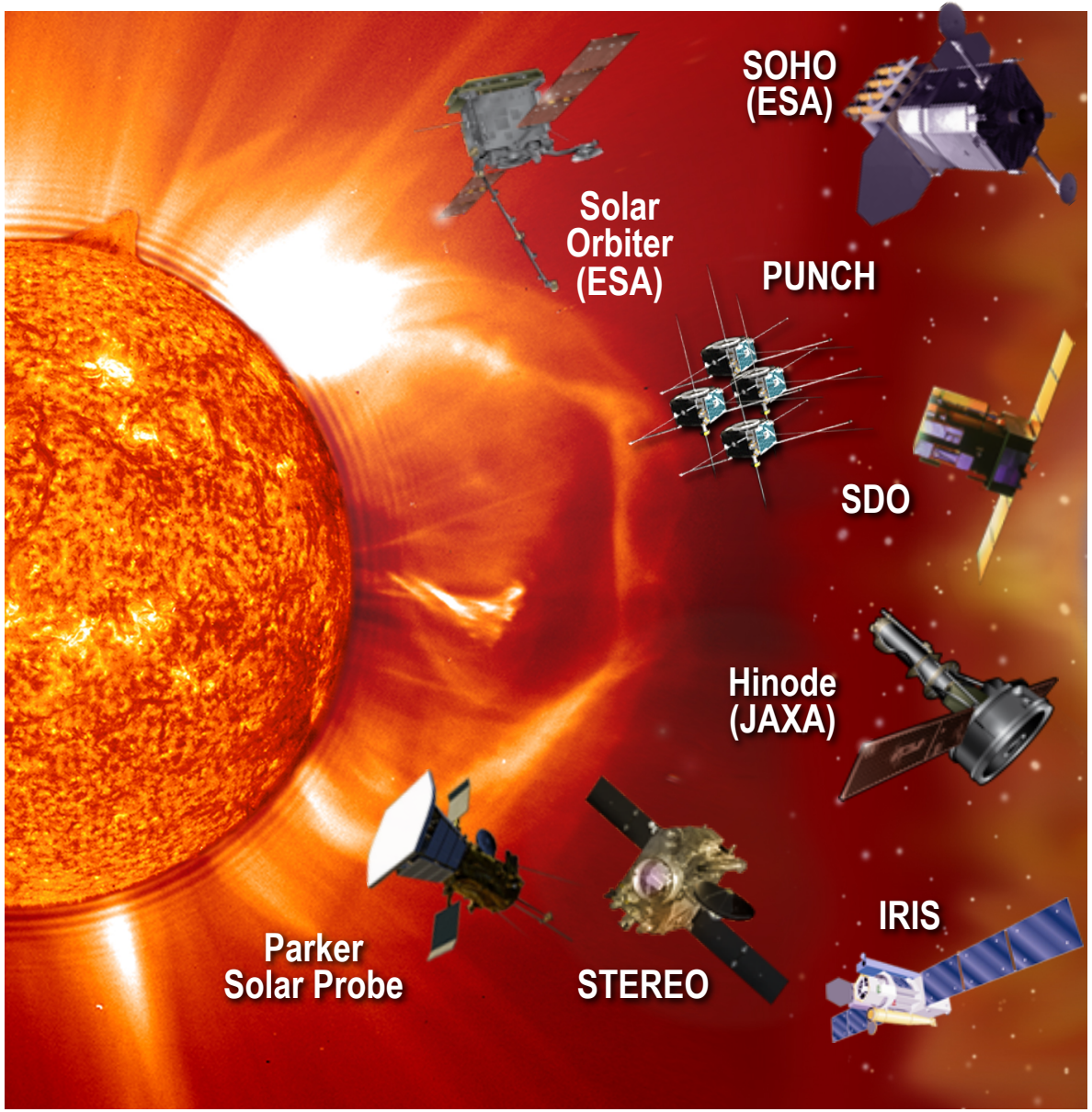
LLITED: The Low-Latitude Ionosphere/Thermosphere Enhancements in Density Mission consists of two 1.5U CubeSats that will make simultaneous thermosphere/ionosphere measurements of the Equatorial Temperature and Wind Anomaly (ETWA) and the Equatorial Ionization Anomaly (EIA) to investigate the coupling between the two features. 2020

Upcoming CubeSat Missions

petitSat: The Plasma Enhancement in The Ionosphere-Thermosphere Satellite is a scientific investigation 6U CubeSat mission designed to provide in-situ measurements of plasma density, 3D ion drift, as well as ion and neutral composition. It will determine the conditions under which Medium-Scale Traveling Ionosphere Disturbances (MSTIDs) generate large plasma enhancements, which can interfere with radio waves used for communication and navigation. 2020

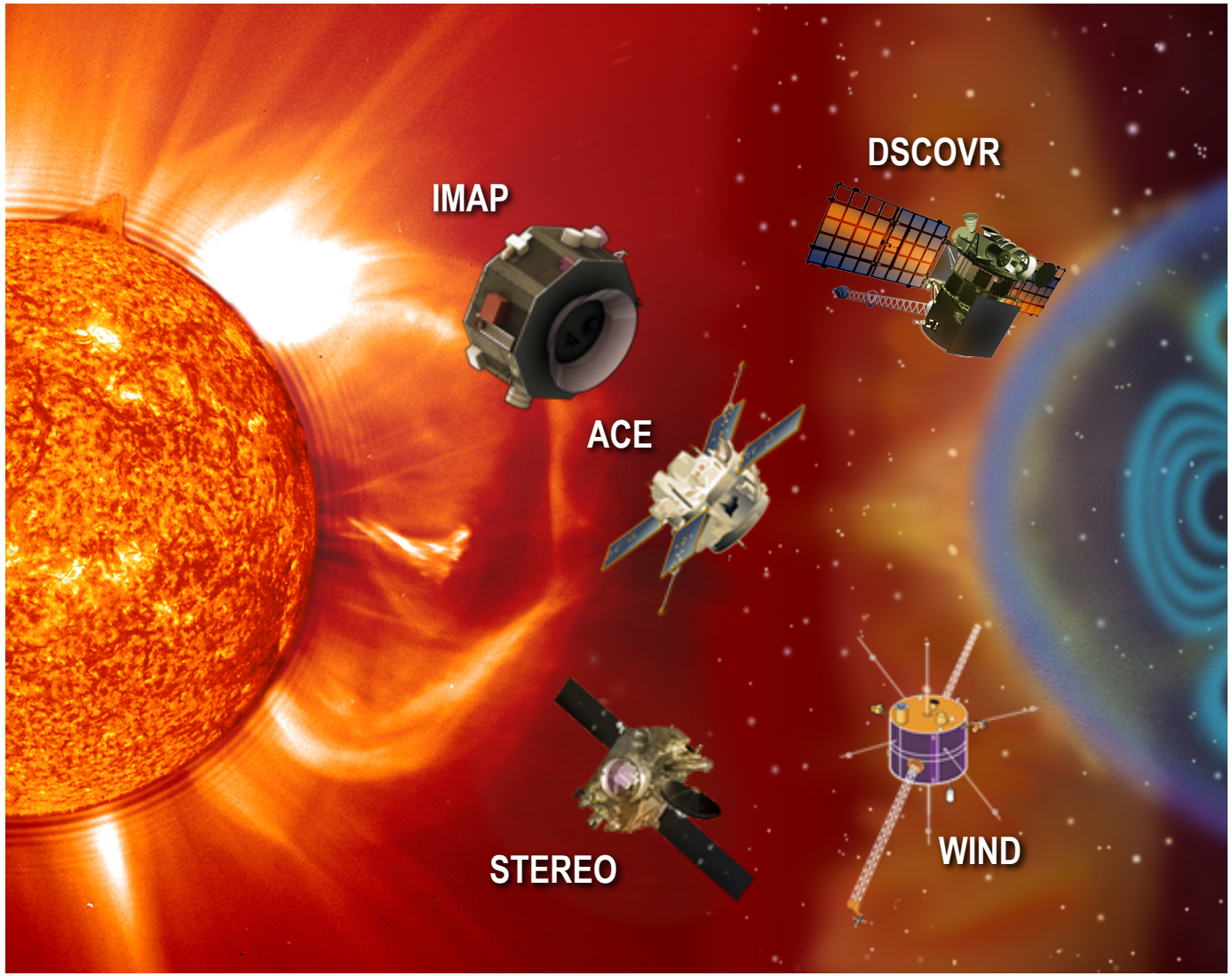
SPORT: The Scintillation Prediction Observations Research Task is a US-Brazil mission using a 6U CubeSat with six remote and in situ instruments, that seeks to understand the pre-conditions under which ionospheric variability develops that leads to scintillation of RF signals. 2020

LAICE: The Lower Atmosphere/Ionosphere Coupling Experiment is a 6U CubeSat with four sensors to remotely observe gravity wave signatures in the mesosphere, while simultaneously observing in-situ plasma and neutral gravity wave-induced fluctuations at LEO altitudes. The observations will be correlated with tropospheric storm data from weather satellites in an attempt to trace the probably origins of the waves, and to better determine their global distribution. 2020 – NSF/NASA



Eyes on the Sun

- Parker Solar Probe (8/12/2018)
- Solar Orbiter (ESA/NASA) (LRD Feb 2020)
- Polarimeter to Unify the Corona and Heliosphere (PUNCH) (LRD Aug 2022)
- Solar Dynamics Observatory (SDO) (2/11/2010)
- Solar TErrestrial RElations Observatory (STEREO) (10/25/2006)
- Hinode (JAXA/NASA) (9/23/2006)
- Interface Region Imaging Spectrograph (IRIS) (6/27/2013)
- Solar and Heliospheric Observatory (SOHO) (ESA/NASA) (12/2/1995)

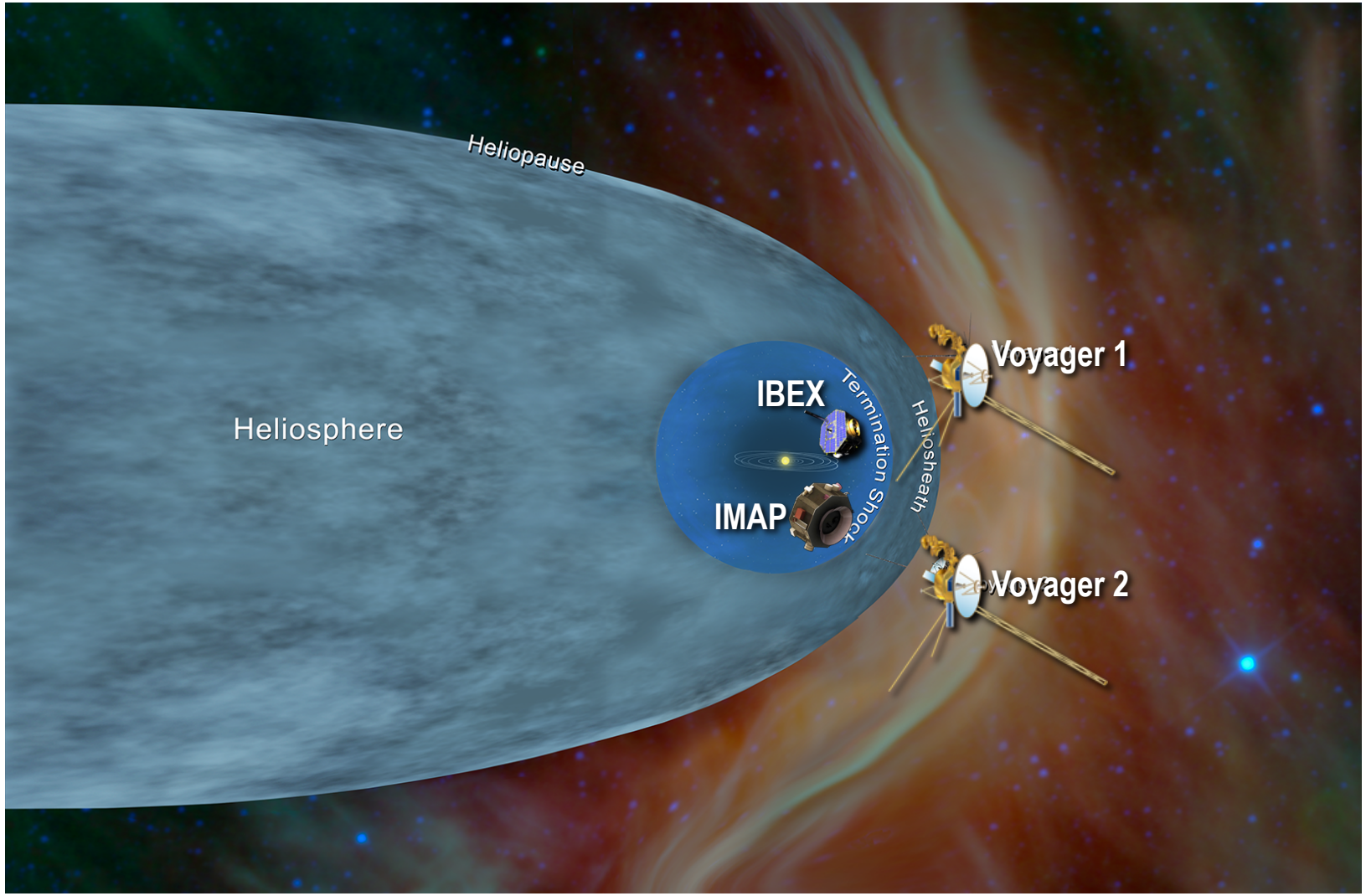


Sailing in the Solar Wind

- Interstellar Mapping & Acceleration Probe (IMAP) LRD 10/2024
- Deep Space Climate Observatory (DSCOVR) (2/11/2015)
- Advanced Composition Explorer (ACE) (8/27/1997)
- Solar TErrestrial RElations Observatory (STEREO) (10/25/2006)
- Wind (11/1/1994)

Guardians of the Magnetosphere & Ionosphere

- Global-scale Observations of the Limb and Disk (GOLD) (1/25/2018)
- Magnetospheric Multiscale Mission (MMS) (3/14/2015)
- Van Allen Probes (8/30/2012)
- Aeronomy of the Ice in the Mesosphere (AIM) (4/25/2007)
- Time History of Events and Macroscale Interactions in Substorms (THEMIS) (2/17/2007)
- Thermosphere Ionosphere Mesosphere and Dynamics (TIMED) (12/7/2001)
- Geotail (JAXA-lead) (7/24/1992)
- Solar Environment Testbeds-1 (SET-1) LRD 6/22/2019
- Ionospheric Connection Explorer (ICON) LRD 2019
- Atmospheric Wave Experiment (AWE) LRD 8/2022
- Tandem Reconnection & Cusp Electrodynamics Reconnaissance Satellites (TRACERS) (LRD Aug 2022)



To infinity & beyond!

- Voyager 1 & 2 (9/5/1977 & 8/20/1977)
- Interstellar Mapping & Acceleration Probe (IMAP) LRD 8/2024
- Interstellar Boundary Explorer (IBEX) (10/19/2008)

Future Missions & Opportunities

Solar Orbiter Collaboration (with ESA)

Mission Line: Living With Star

Launch Vehicle: U.S. provided Atlas-V 411

Launch Site: Cape Canaveral

LRD: Feb. 2020

Solar Orbiter Collaboration Project Scientist: Chris St. Cyr

U.S. Provided Instruments:

- HIS (Heavy Ion Sensor), part of SWA, and SoloHI (Heliospheric Imager)

Description:

- Solar Orbiter aims to make significant breakthroughs in our understanding both of how the inner heliosphere works, and of the effects of solar activity on it.
- The spacecraft will take a unique combination of measurements: in situ measurements will be used alongside remote sensing close to the Sun to relate these measurements back to their source regions and structures on the Sun's surface.

Interstellar Mapping and Acceleration Probe (IMAP)

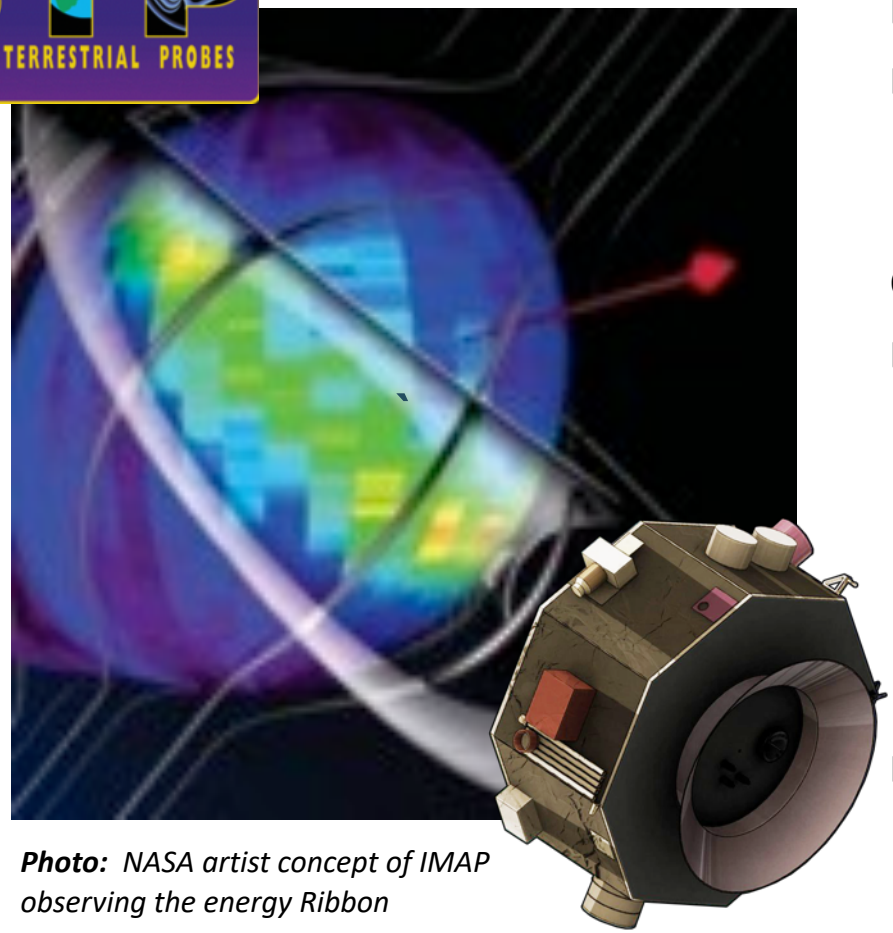


Photo: *NASA artist concept of IMAP observing the energy Ribbon*

Mission Line: Solar Terrestrial Probes; selected June 1, 2018

LRD: October 2024

Project Scientist: David McComas of Princeton University

- Project Management and Mission Operations Center at Johns Hopkins University's Applied Physics Laboratory in Laurel, Maryland

Orbit: L1 Lagrangian point

Description:

- Sample, analyze, and map particles streaming to Earth from the edge of interstellar space.
- Investigate the generation of cosmic rays in the heliosphere and beyond.
- 10 scientific instruments
- Investigating possible accommodation of a Tech Demo ins

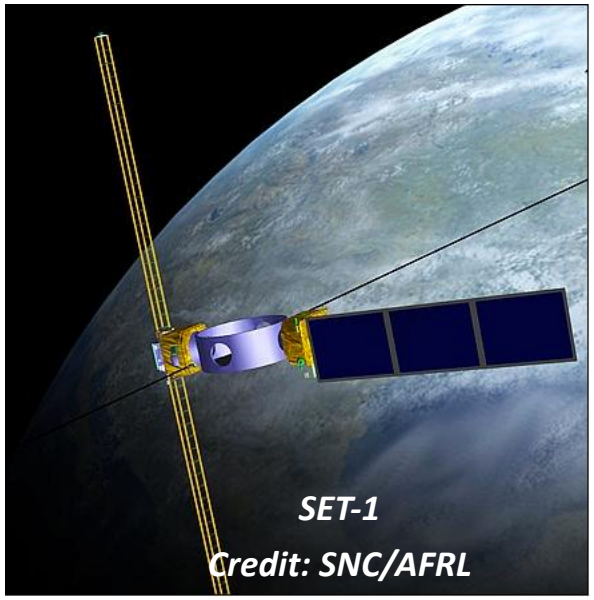
Rideshare opportunities on the ESPA Grande:

- Competitive Missions of Opportunity including Tech Demo and Science
- NOAA Space Weather Follow-On L-1

Geospace Dynamics Constellation

- Decadal Survey identified GDC as next LWS large strategic mission:
  - "…provide the first simultaneous, multipoint observations of how the ionosphere-thermosphere system responds to, and regulates, magnetospheric forcing over local and global scales…"
- Science and Technology Definition Team convened in May 2018
  - Discussions are limited to the science objectives and measurement requirements; no instrument-specific or mission implementation details
  - Study report expected to be delivered July 2019
- LRD anticipated NET 2029

Future Rideshare Opportunities

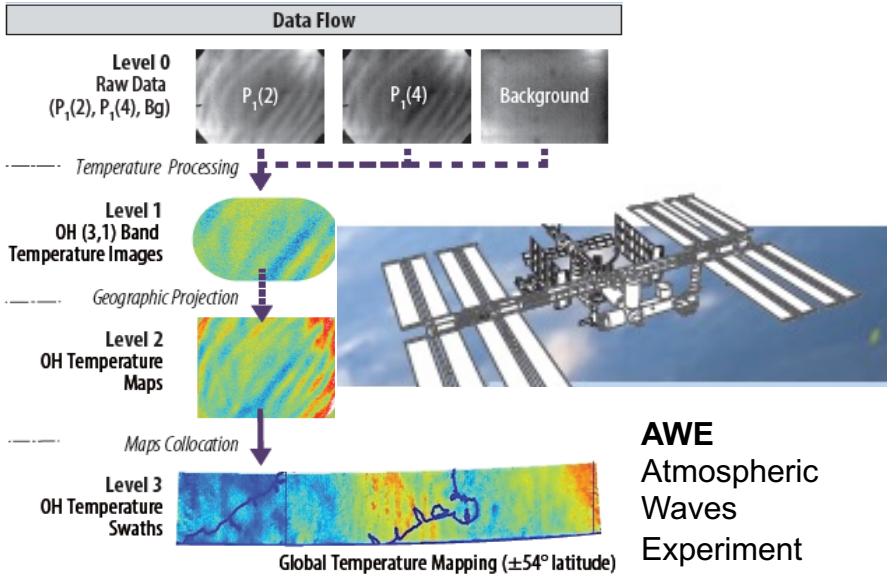


- SMD has embraced Rideshare opportunities as a standard practice to maximize mass to orbit
  - Enabling additional opportunities for science community
- SMD has finalized a Rideshare policy
- Rideshare opportunities on IMAP ESPA Grande
  - Science MO SCM & Technology Demonstration MO SCM
  - NOAA Space Weather Forward Observatory
  - If there are open ESPA ports after the above missions are accommodated, they will be offered to other SMD investigations under new Rideshare Policy.
- In support of rideshare, HPD is developing a mission-unique ESPA Systems Interface Specification

2016 Explorers Mission of Opportunity Selections

Atmospheric Waves Experiment (AWE)

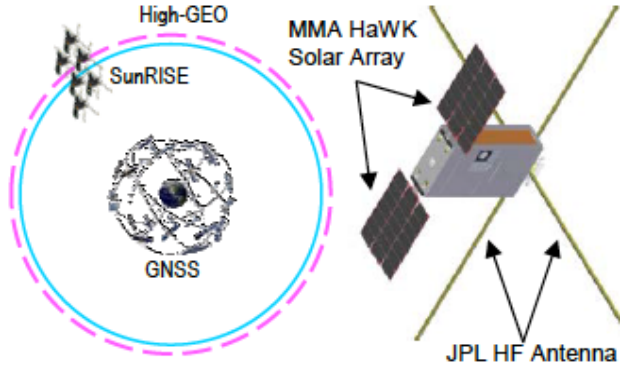
- Attached to the exterior of the ISS, AWE will focus on airglow to determine what combination of forces drive space weather in the upper atmosphere.
- LRD NET Aug. 2022



AWE
Atmospheric Waves Experiment

Sun Radio Interferometer Space Experiment (SunRISE)

- Selected for a seven-month, $100,000 extended formulation study.
- SunRISE would be an array of six CubeSats operating like one large radio telescope to investigate how giant space weather storms from the Sun are accelerated and released into planetary space.



SunRise
Sun Radio Interferometer Space Experiment