National Aeronautics and Space Administration

Heliophysics Overview
Ionospheric Effects Symposium

Doug Rowland for
Elsayed R. Talaat
Chief Scientist, Heliophysics Division
Science Mission Directorate

9 May 2017

HPD Objectives and Programs

Solar Terrestrial Probes

Strategic Mission Flight Programs

Living With a Star

Strategic Mission Flight Programs

Solve the <u>fundamental physics</u> mysteries of heliophysics: Explore and examine the physical processes in the space environment from the sun to the Earth and throughout the solar system.

Build the knowledge to forecast space weather throughout the heliosphere: Develop the knowledge and capability to detect and predict extreme conditions in space to protect life and society and to safeguard human and robotic explorers beyond Earth.

Understand the nature of our home in space: Advance our understanding of the connections that link the sun, the Earth, planetary space environments, and the outer reaches of our solar system.

Explorers

Smaller flight programs, competed science topics, often PI-led

Research

Scientific research projects utilizing existing data plus theory and modeling

Helio Program Highlights

- **ICON Observatory testing continues with the start of Comprehensive Performance Tests (CPTs)**
- **Pre-Ship Review scheduled for July 19, 2017**

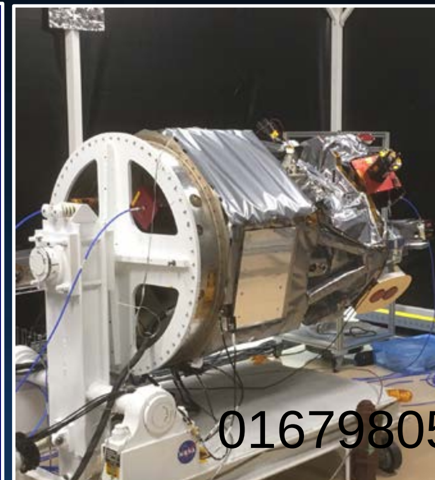
- **GOLD instrument onboard SES-14 spacecraft at Airbus facility in Toulouse, France**
  - ➢ Mechanical integration completed April 12, 2017
  - ➢ Instrument alignment to spacecraft was flawless

- **ISOIS flight EPI-Lo first instrument to be successfully integrated onto the spacecraft**
- **Solar Array Cooling System mechanically and electrically integrated to primary structure**
- **SWEAP SPAN A/B and SWEM successful PSR April 25**
- **Flight Solar Array Wing-1 successfully completed Medium Irradiance High Temperature Testing at SolAero, exposing the wing to 5.3 Suns for 15 hours**

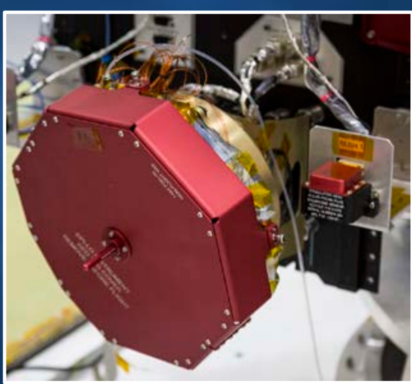
- **SoloHI shipped to Airbus facility in Stevenage, UK**
- **SoloHI mechanical integration to spacecraft was completed April 25**
- **SOC Science Workshop was held April 3-7 in Granada, Spain**

Mission Development Snapshots

ICON
Observatory in clean tent configured for Comprehensive Performance Testing in Gilbert, AZ, April 2017



GOLD
Mechanical integration at Airbus in Toulouse, France, April 12, 2017



SPP
EPI-Lo instrument integrated with spacecraft covered with red safety cap, at JHU/APL, April 17, 2017

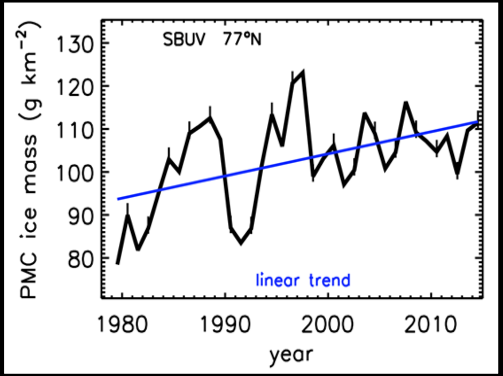
SOC
SoloHI final configuration at NRL prior to shipment to Airbus in Stevenage, U.K. March 2017

NASA and NOAA satellite data shows that air on the edge of space is getting colder and more humid

Image taken from the Earth Observatory in July, 2010

Every summer, something strange and wonderful happens high above the north pole. Ice crystals form and cling to the smoky remains of meteors, forming electric-blue clouds with tendrils that ripple hypnotically against the sunset sky called Noctilucent clouds (NLCs), also referred to as Polar Mesospheric Clouds (PMCs). PMC's form at very high altitudes, between 50-53 miles, in the midst of the region called the mesosphere. Because these clouds reflect light after the sun sets, they've been dubbed "night clouds."

Recently, researchers used observations from instruments aboard NASA's Aeronomy of Ice in the Mesosphere (AIM) mission and NOAA's Solar Backscatter Ultraviolet Radiometer (SBUV) to reveal new information about these clouds. The SBUV series of satellites have observed PMCs since 1979, showing that the ice mass in PMCs has been increasing over the past 36 years. A rigorous interpretation of the SBUV results was recently developed using observations from AIM, which has measured PMCs, temperature, and water vapor since 2007. Analysis of AIM observations allow the SBUV PMC results to be expressed in terms of the underlying changes which have occurred in the mesosphere.



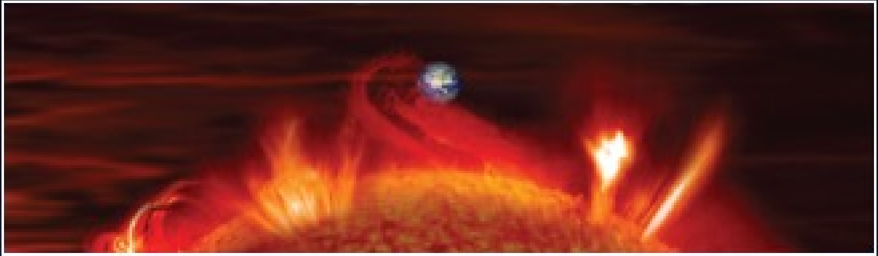
July averages of SBUV PMC ice water content for 72–82°N latitude.

In looking at these changes over time, the scientists found that ice mass and water density are increasing in the mesosphere, while temperatures are decreasing. These atmospheric changes are consistent with global climate model predictions. It has been suggested that these changes in PMCs are related to increased concentrations of greenhouse gases. While the release of carbon dioxide warms the surface of the earth, it cools the upper atmosphere; and, at the same time, increases in atmospheric methane lead to increases in water vapor at high altitudes. These facts point to a growing belief that greenhouse gases and global change have increased the number and brightness of PMCs.

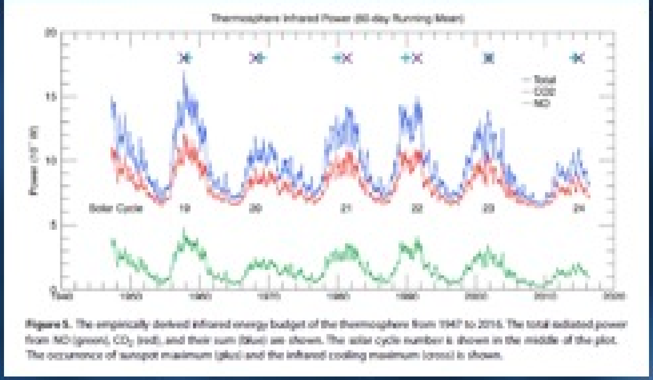
Hervig, Mark E., Uwe Berger and David E. Siskind, Decadal variability in PMC and implications for changing temperature and water vapor in the upper mesosphere, J. Geophys. Res. Atmos.,121, doi:10.1002/2015JD024439

TIMED SABER Data Enables Scientists to Derive a 70-year Time Series of the Thermosphere's Infrared Energy Budget

With its long, comprehensive dataset, the Heliophysics TIMED mission provides scientists the data they need on Earth's thermosphere to help us see a clearer picture.



Outlined in a paper published in December by the *Geophysical Research Letters,* a team of scientists developed a 70-year long time series of infrared energy emitted by the nitric oxide and carbon dioxide molecules in Earth's thermosphere (>100 km). This infrared energy regulates the temperature of the thermosphere in response to energy input from the sun. The 15-year-long dataset of infrared emissions measured by the SABER instrument on NASA's TIMED satellite is a critical contributor to the time series.



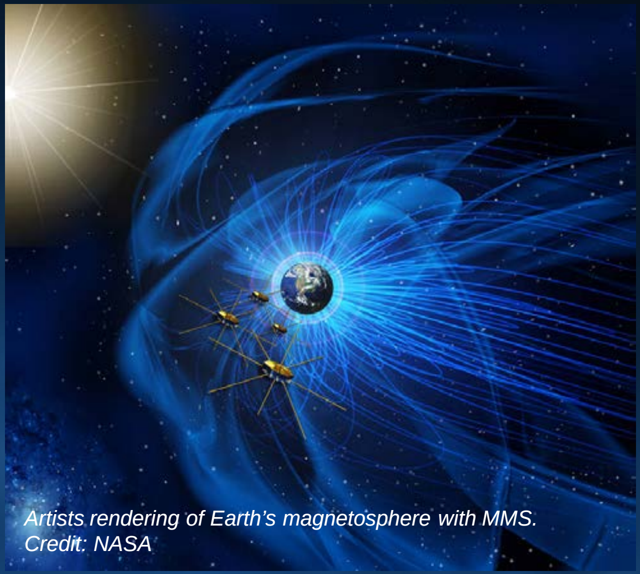
This figure shows the 70-year time series of infrared cooling and the occurrence of the infrared radiative cooling maximum (cross) and the occurrence of the sunspot maximum (plus).

From the long TIMED database, scientists were able for the first time to establish a statistical relationship between the energy output of the upper atmosphere and solar and geomagnetic indices that proxy energy input into the upper atmosphere. They then used this relationship to extend the energy output series back in time to cover five solar cycles, providing new, direct terrestrial context (thermal structure of the upper atmosphere) to these indices.

When the authors integrated the solar index over the time span of each individual solar cycle, they found that the total energy is nearly constant from solar cycle to solar cycle. They also found a similar small variation in the total infrared energy emitted by the Earth's upper atmosphere when integrated by solar cycle. This result was totally unexpected – typically we think of 11-year cycles as being "strong" or "weak," and that the overall cycles have been getting "weaker" over the past several decades. This new research disputes these views.

Mlynczak, M. et al., (2016), *The global infrared energy budget of the thermosphere from 1947 to 2016 and implications for solar variability*, Geophys. Res. Lett., 43, 11,934–11,940, doi:10.1002/2016GL070965

MMS Makes the Invisible, Visible: Energy Transfer in the Magnetosphere



Artists rendering of Earth's magnetosphere with MMS.
Credit: NASA

A new finding using MMS data dives deeper into the structure of the magnetosphere as the data allow scientists to explore energy transfer in kinetic Alfvén waves for the first time.

The four MMS spacecraft fly in a compact 3-D pyramid formation, with just four miles between them – closer than ever achieved before and *near enough to fit between two Alfvén wave peaks.*

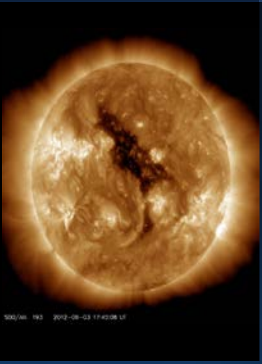
MMS Uses Earth's Magnetosphere as a Laboratory to Study Fundamental Space Physics Processes and Phenomena

Having multiple spacecraft take observations at such small scales allow scientists to analyze high-resolution details of the Alfvén wave and to examine the mechanisms for energy exchange between Alfvén wave fields and charged particles.

Alfvén waves are not only found in our magnetosphere but are found in other places like the sun's corona and may explain how the solar wind is heated to such extreme temperatures. They are even thought to be in the extra-galactic jets of quasars.

Gershman, et al. WAVE-PARTICLE ENERGY EXCHANGE DIRECTLY OBSERVED IN A KINETIC ALFVÉN-BRANCH WAVE. *Nature Communications.* Soon to be published.

Earth's Radiation Belts: Not-So-Calm After the Storm



High Speed Solar streams (HSSs) originate in the sun's corona, from coronal "holes." HSSs stream out into space faster than that of the solar wind surrounding the hole.

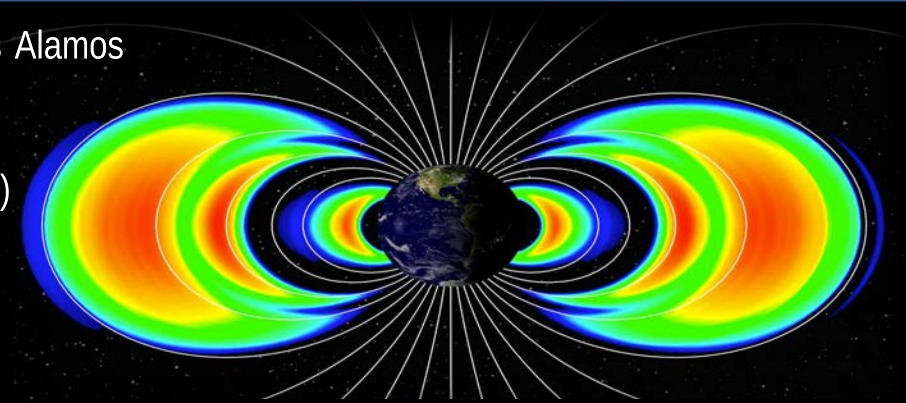
If the hole persists on the corona for some time, HSSs can impact Earth over multiple solar orbits, battering Earth's magnetosphere each time the coronal hole aligns with Earth. *Image (left): Coronal holes are regions where the sun's corona is dark. Credit: NASA SDO/AIA*

Scientists analyzed 43 HSSs events using NASA, NOAA and Los Alamos National Laboratory Data. Here is what they found:

First ~ six days: solar wind speed > 550 kilometers per second (kps)

2-3 days after that: solar wind speed ~ 300-400 kps (called the trailing edge)

During the trailing edge Earth's magnetic field relaxed and went quiet



Van Allen Probes data used in an animation of the Van Allen Radiation Belts Credit: NASA GSFC/JHU-APL

Surprisingly, the Earth's radiation belts didn't go quiet. As the solar and magnetic field activity decreased, the number of high-energy electrons in the outer radiation belts increased, peaking as the trailing edge passed over.

Until now, radiation belts were almost always considered to be their most dangerous during storms, not in the calm period afterward.

Denton, M. H., and J. E. Borovsky (2017), The response of the inner magnetosphere to the trailing edges of high-speed solar-wind streams, JGR, doi:10.1002/2016JA023592.

Heliophysics: Research

ROSES16

Completed Panels:

- 7/9 Elements awarded
- 18.5% preliminary success rate up from ROSES15 at 17.6%

Panels in progress:

- LWS panels completed
- USPI panel complete
- Decision meetings to be scheduled

Upcoming Panels:

- MMS GI panel anticipated soon

ROSES17

Panels in progress:

- 165 GI Step 1 proposals received
  - Step 2 proposals due in May

Upcoming Panels:

- Proposals due for additional elements between July 2017 and February 2018

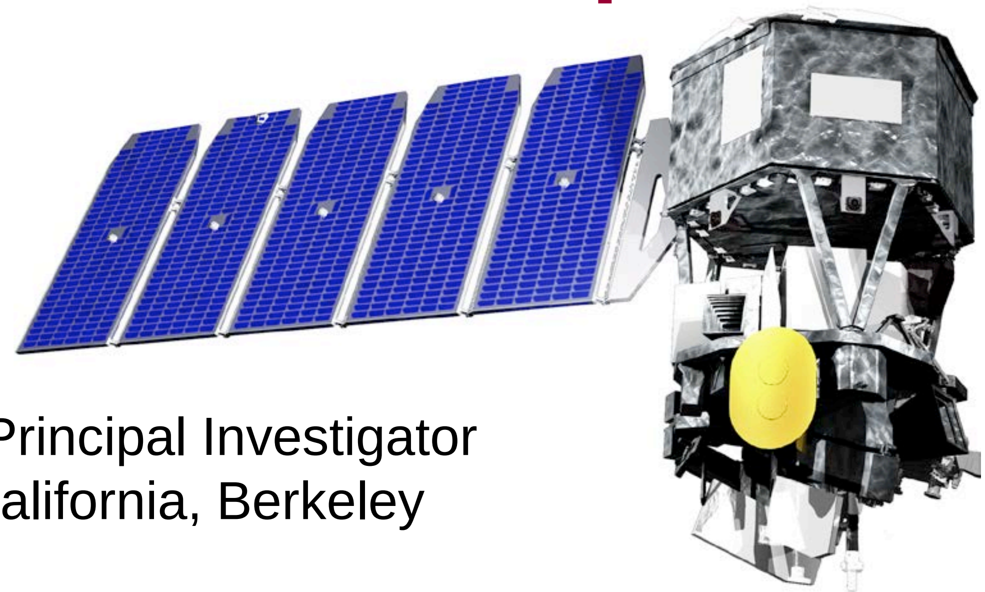
Heliophysics: ROSES16 Status

ELEMENT	STEP 1 PROPOSALS (Due Date)	STEP 2 PROPOSALS (Due Date)	AWARDS (Expected)	YEAR 1 ($M)
B.2 H-SR	**235**	**212**	**31**	**$6.3M**
B.3 H-TIDeS	**87**	**71**	**13**	**$5.3M**
B.4 H-GI Open	**197**	**181**	**33**	**$3.0M**
B.5 H-GCR TMS	**44**	**40**	**10**	**$4.4M**
B.6 H-LWS	**74**	**63**	(15-20)	($3.75M)
B.7 H-DEE	**28**	**24**	**7**	**0.5M**
B.8 H-GI MMS	**57**	**40**	(8-10)	(1.3M)
B.9 H-GCR SC	*PPD ROSES17*	*PPD ROSES17*	-	-
B.10 H-USPI	**7**	**5**	(2)	($0.4M)
E.5 ISE	**41**	**39**	**11**	**$0.95M**

Heliophysics: ROSES17 Status

ELEMENT	STEP 1 PROPOSALS (Due Date)	STEP 2 PROPOSALS (Due Date)	AWARDS (Expected)	YEAR 1 ($M)
B.2 H-SR	(7/6)	(9/7)	(25-30)	($6.0M)
B.3 H-TIDeS	(5/17)	(7/20)	(12)	($4.0M-$6.0M)
B.4 H-GI Open	**165**	(5/18)	(25-30)	($4.7M)
B.5 H-GCR TMS	N/A	N/A		
B.6 H-LWS	(6/7)	(8/9)	(15-20)	($3.75M)
B.7 H-DEE	(5/17)	(7/20)	(10-12)	(0.5M)
B.8 H-GI MMS	(11/9)	(1/11/18)	(8-10)	(1.3M)
B.9 H-GCR SC	*TBD*	*TBD*	*TBD*	*TBD*

The Ionospheric Connection Explorer



Thomas Immel, Principal Investigator
University of California, Berkeley

The Ionospheric Connection Explorer – Understanding the connection between our atmosphere and space

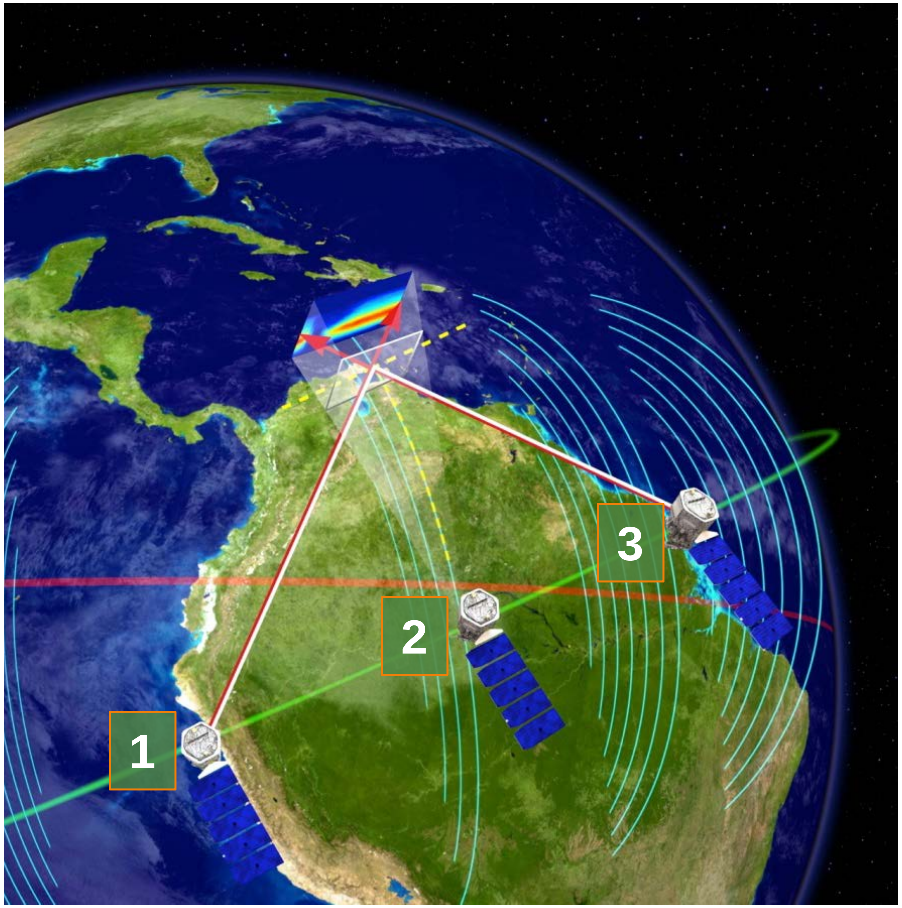
ICON will help us to understand the unpredicted variability in the space plasma observed at low and middle latitudes by measuring:

1. Each of the potential drivers of high plasma densities (neutral wind, composition, and temperature, and ionospheric conductivity)
2. The key responses of the system (the motion and density of the plasma)

The densest plasma between the Earth and Sun is in the equatorial ionosphere.

This environment is ICON's primary science target

ICON coordinates key science measurements in a new way



- ICON measures the **drivers**:

  Neutral winds, temperatures and **composition** in the thermosphere

- ICON measures the **responses**:

  Electric field, **plasma motion** and **plasma density**

ICON makes measurements remotely in the critical boundary region between the atmosphere and ionosphere (90-160 km)

– un-reachable by in-situ spacecraft,

– measuring all of the key quantities,

– at the same place and the same time.

Pos. 1 and 3 MIGHTI wind, temperature

Pos. 2 EUV/FUV ion,neutral density and composition. IVM – ion drift on field line

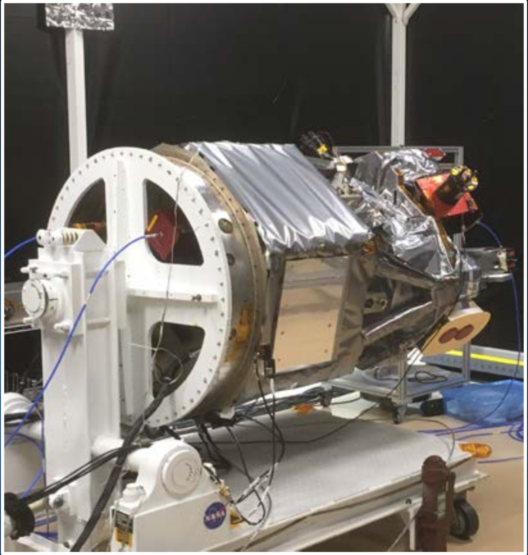
Mission implementation

Mission Summary	
Launch vehicle	Pegasus XL RTS - Kwajalein
Spacecraft	LEOStar-2, 3-axis stabilized, no consumables
Orbit	575 km circular, 27° inclination
Ground segment	Berkeley Ground Station, WGS, Santiago
Mission & Science Ops	24 months Phase E Operated from UCB
Status	Observatory in EMI/EMC @ OATK in AZ LV motor inspections

Ionospheric Connection

Recent Accomplishments:

- Stage 3 motor reassembly completed
- Stage 2 motor cleared for flight
    - Reassembly in process
- Observatory testing continues with the start of Comprehensive Performance Tests (CPTs).



Observatory in clean tent configured for Comprehensive Performance Testing Gilbert, AZ, April 2017

Upcoming Milestones/Events:

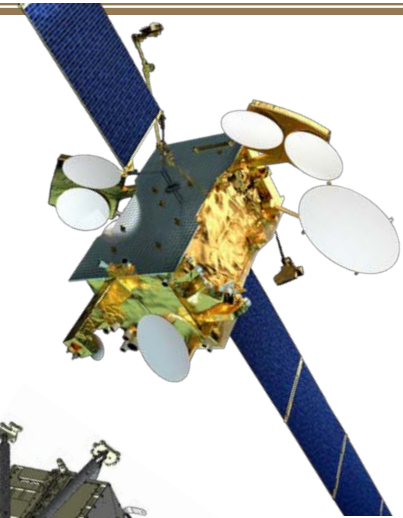
- Observatory Pre-Ship Review: July 2017
- LRD: October 2017

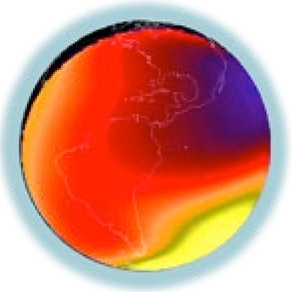
GOLD

Richard Eastes, Principal Investigator
University of Central Florida

GOLD Mission Overview

- **Host Mission**
  - SES-14 is host mission
    - Geostationary orbit at 47.5°W
    - Launch scheduled for late 2017
    - Electric propulsion
- **GOLD Instrument**
  - Two identical, independent imaging spectrographs
  - Each observes limb and disk at 132-160 nm
- **Science Data Center at UCF**
  - Produces O/N_2, Tdisk, etc.
  - Using proven techniques
  - Data on website, also at NASA Space Physics Data Facility (SPDF)





GOLD Spectrographic Imaging

Disk Image **Detector Image**

- **Entrance slit of one (of two) channel is shown as white rectangle**
- **Slit step rate and position are commandable, can dwell on selected longitude range**

Recent Accomplishments:

- GOLD instrument onboard SES-14 spacecraft at Airbus facility in Toulouse, France
  - Mechanical integration completed April 12, 2017
  - Instrument alignment to spacecraft was flawless
- All ground system tests successful
- Science algorithms in place for operational phase

Ongoing:

- Science team is testing the Level 3/4 data product algorithms.

Upcoming Milestones/Events:

- Launch Readiness Date: April 2018

GOLD mechanical integration at Airbus

Heliophysics Program 2016-2025

HELIOPHYSICS

Solar Terrestrial Probes

Magnetospheric Multiscale (MMS)
March 2015

Interstellar Mapping and Acceleration Probe (IMAP)
2024*

Heliophysics MO
2023*

Living With a Star

Space Environment Testbeds (SET)
NET January 2018

Solar Probe Plus
July 2018

Solar Orbiter Collaboration (with ESA)
February 2019

Geospace Dynamics Constellation (GDC)
2024*

Explorers

Ionospheric Connection Explorer (ICON)
October 2017

Global-scale Observations of the Limb and Disk (GOLD)
April 2018

Heliophysics MO
2020*

Heliophysics SMEX
2022*

Heliophysics MO
2022*

Heliophysics MIDEX
2024*

Heliophysics MO
2024*

Research Program

Hesh – May 2017
Hassler – May 2017
Hall – May 2017
Chrisley – June 2017
Koehler – June 2017
France – June 2017

Ongoing

Heliophysics Missions
Astrophysics Missions
Planetary Missions
External to SMD

2016 2017 2018 2019 2020 2021 2022 2023 2024 2025

*Notional

BACK-UP

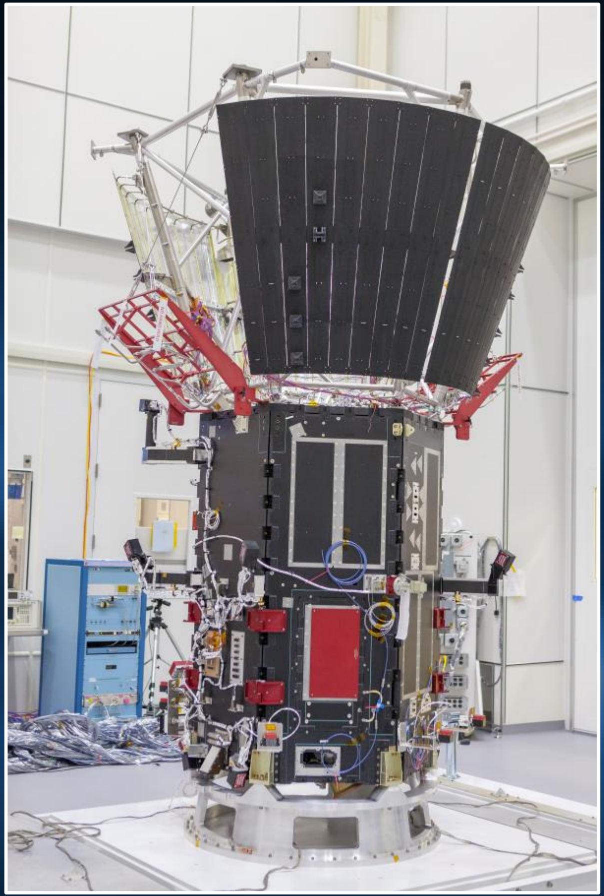
Solar Probe Plus

Recent Accomplishments:

- ISOIS flight EPI-Lo instrument was successfully integrated onto the spacecraft
  - First instrument integrated onto the spacecraft!
- Solar Array Cooling System mechanically and electrically integrated with primary structure
- Flight Solar Array Wing-1 successfully completed Medium Irradiance High Temperature Testing at SolAero, exposing the wing to 5.3 Suns for 15 hours
- FIELDS Flight Main Electronics Package successfully integrated mechanically to the spacecraft

Upcoming Milestones/Events

- Pre-Environmental Review: September 26, 2017
- Pre-Ship Review: March 8, 2018
- Launch Readiness Date: July 31, 2018

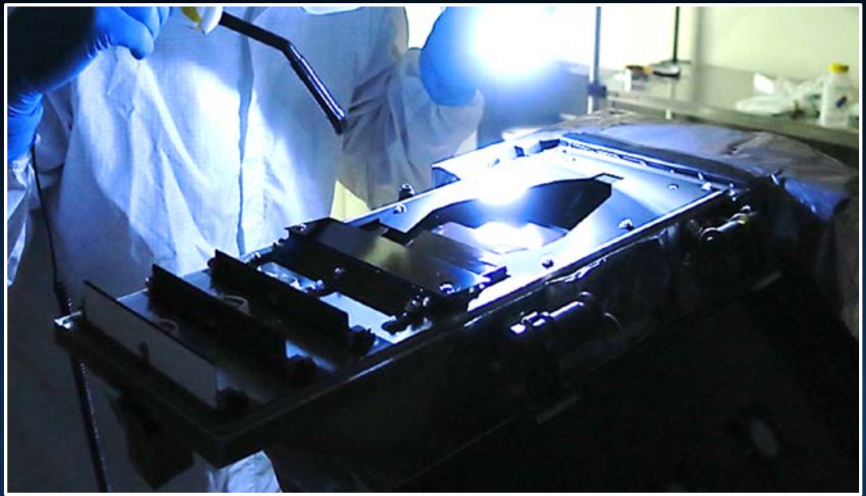


Solar Array Cooling System Integration – Spacecraft Closed for Alignment Measurements

Solar Orbiter Collaboration

Recent Accomplishments:

- SoloHI completed Pre-Ship Review
- SoloHI shipped to Airbus, Stevenage UK on April 14 and received on April 17
- Placed in Cleancube (Class 10,000 cleanroom)
- Successfully passed incoming inspections, full functional test, and instrument alignment verification



SoloHI undergoing final black light cleanliness inspection prior to shipment

Upcoming Milestones/Events:

- SoloHI mechanical integration to spacecraft: April 25, 2017