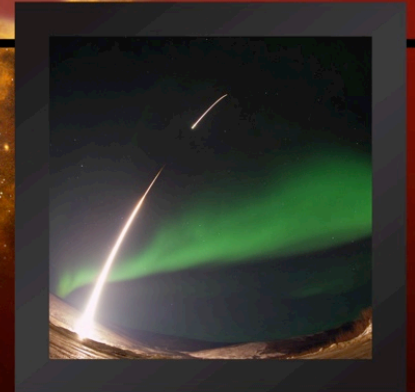
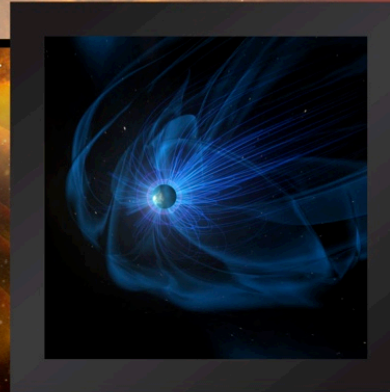


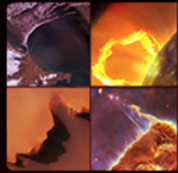
# HELIOPHYSICS DIVISION



# LIVING WITH A STAR



Elsayed Talaat  
Heliophysics  
NASA Headquarters



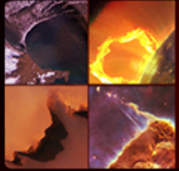
# Why do Science?

		<i>For Utility</i>	
		<b>No</b>	<b>Yes</b>
<i>For Understanding</i>	<b>Yes</b>	<b>Bohr</b>	<b>Pasteur</b>
	<b>No</b>		<b>Edison</b>

From Donald Stokes (Woodrow Wilson School for Public and International Affairs, Princeton University)

## ***The Sun-Earth Connection -- Science in the Pasteur Mode***

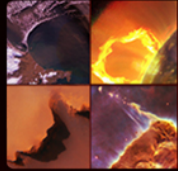
- ***How a star works***
- ***How it affects humanity's home***
- ***How to live with a star***



# Living With A Star

- The Living With a Star (LWS) program emphasizes the science necessary to understand those aspects of the Sun and the Earth's space environment that affect life and society.
- The ultimate goal is to provide a predictive understanding of the system, and specifically of the space weather conditions at Earth and in the interplanetary medium.
- LWS missions have been formulated to answer specific science questions needed to understand the linkages among the interconnected systems that impact us.
- LWS products impact technology associated with space systems, communications and navigation, and ground systems such as power grids.
- The coordinated LWS program includes *strategic missions, targeted research and technology development*, a space environment test bed flight opportunity, and partnerships with other agencies and nations.





# NASA's Van Allen Probes Revolutionize View of Radiation Belts

**A new study based on data from NASA's Van Allen Probes** shows that all 3 regions—inner belt, slot region, outer belt—can appear different depending on the energy of electrons considered and general conditions in the magnetosphere.

A recent study of data from the Van Allen Probes published on Dec. 28, 2015 in the *Journal of Geophysical Research* has given us new understandings on the shape of the Van Allen Belts, or radiation belts, and how electrons behave at different energy levels within the belts themselves. This new analysis reveals that the observed shape can vary from a single, continuous belt with no slot region, to a larger inner belt with a smaller outer belt, to no inner belt at all. While the shapes of the belts do change, we now know that most of the observed differences are accounted for by considering electrons at different energy levels separately.

The twin Van Allen Probes satellites expand the range of energetic electron data we can capture. In addition to studying the extremely high-energy electrons—carrying millions of electron volts, the Van Allen Probes can capture information on lower-energy electrons that contain only a few thousand electron volts. Additionally, the spacecraft measure radiation belt electrons at a greater number of distinct energies than was previously possible.

Precise observations like this, from hundreds of energy levels, rather than just a few, will allow scientists to create a more precise and rigorous model of what, exactly, is going on in the radiation belts, both during geomagnetic storms and during periods of relative calm. This information will help us better predict and prepare for dangerous space weather events that have the potential to impact Earth's environs.

Traditionally, the radiation belts have been thought to include a larger, more dynamic outer belt and a smaller, more stable inner belt with an empty slot region separating the two. Now we know the shape appears different depending on what energy electrons one observes.

When looking at the **lowest electron energy levels** – about 0.1 MeV, the inner belt expands into the empty slot region, diminishing the outer belt

At the **highest electron energies** measured—above 1 MeV—we only see electrons in the outer belt.

**During geomagnetic storms**, the empty slot region can fill in completely with lower-energy electrons.

*The Johns Hopkins Applied Physics Laboratory in Laurel, Md., built and operates the Van Allen Probes for NASA's Science Mission Directorate. The mission is the second mission in NASA's Living With a Star program, managed by NASA's Goddard Space Flight Center in Greenbelt, Md.*



# Connecting the Dots: Furthering our Understanding of 'Sympathetic Solar Events' with NASA SDO and STEREO data

Jin, M., Schrijver, C., Cheung, M., DeRosa, M., Nitta, N., & Title, A. (2016).

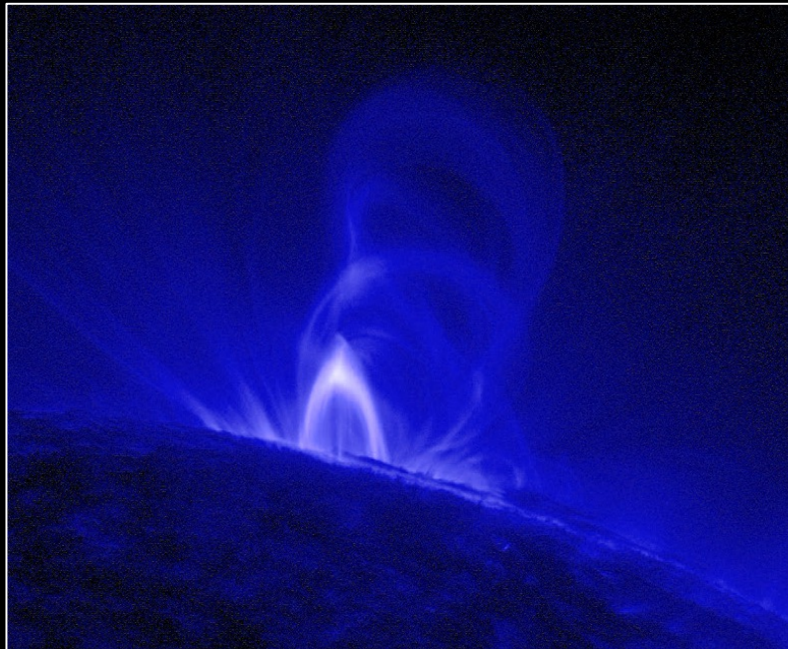
A NUMERICAL STUDY OF LONG-RANGE MAGNETIC IMPACTS DURING CORONAL MASS EJECTIONS. *The Astrophysical Journal*, 820(1)

**The term “sympathetic solar events,” or SSEs, refers to sequences of eruptions from the solar corona that have causal relations, even though they are far apart.**

With the simultaneous operation of the NASA Heliophysics Solar TERrestrial RELations Observatory (STEREO) from behind the sun and the Solar Dynamics Observatory (SDO) near Earth, we have reached, for the first time, nearly complete coverage of the sun from multiple perspectives. This gives us an unprecedented opportunity to investigate sympathetic solar events on a global scale. SSEs may also present important implications in understanding space weather.

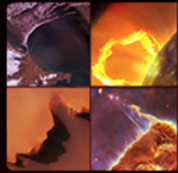
The physical mechanisms of how CMEs spread from one region of the sun to another, and how they interact with the large-scale magnetic field around them to cause SSEs, remain largely unknown.

New research by Jin, et. al published in the *Astrophysical Journal* this week used data on solar activity from February 15, 2011 as inputs into the Space Weather Modeling Framework model to investigate what mechanisms contribute to the creation and existence of this solar phenomenon. They show that a CME's impact on surrounding solar structures, particularly in causing SSEs, depends not only on the intrinsic magnetic strength of those surrounding structures and the distance to the CME source region, but also on the interaction of the CME with the large-scale solar magnetic field. The orientation of the connecting flux ropes also plays a large role in whether or not magnetic coupling will occur to trigger an SSE. With continued research and analysis, it may be possible to establish an empirical relationship to predict regions that are likely to be more active due to SSEs. Understanding what causes active regions to erupt would greatly aid space weather forecasting.



The “flux ropes” of a CME, which refer to erupting structures of magnetized plasma that form loops of different orientations and strengths, seem to play a role in how and why CME's spread and SSEs are triggered. It is thought that flux ropes of a CME connect through magnetic coupling to other CME flux ropes, either directly or through connecting to the large-scale magnetic field around it, causing SSEs.

Image from SDO instruments, July 2012  
<http://svs.gsfc.nasa.gov/cgi-bin/details.cgi?aid=11180>



# Solar Probe Plus

**Description** Spacecraft in a highly eccentric elliptical orbit with a minimum perihelion of 9.9 Solar Radii (~4.3 million miles). Employs a combination of in-situ measurements and imaging to achieve the mission's primary scientific goal: to understand how the Sun's corona is heated and how the solar wind is accelerated.

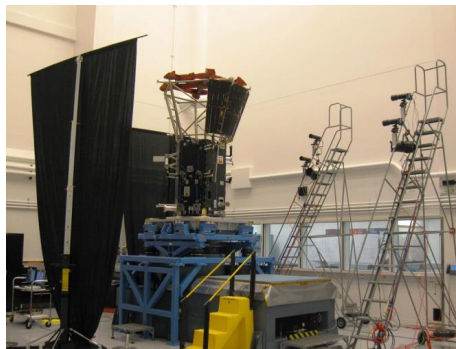
## Upcoming Milestones

SIR – May 2016

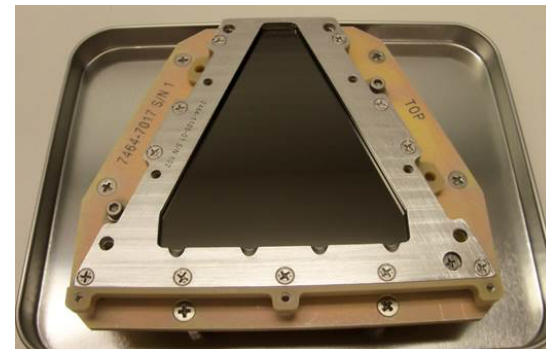
PER – October 2017

PSR – March 2018

LRD – July 2018



High-Speed Camera Setup for Flight Spacecraft Modal Test



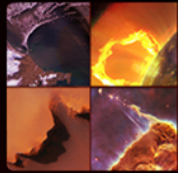
ISOIS EPI-Lo FM MCP Assembly

## Recent Accomplishments

- MOR – Nov 2015
- FIELDS whip antenna: Testing and analysis of EM antenna and clam shell successfully completed, retiring this risk.
- Launch Vehicle: Successfully completed the Mission Specific Requirements Review
- Cooling System: Completed top and bottom manifold assembly (welding) and inspection
- Mag Boom: Successfully completed EM boom thermal vacuum pop-n-catch test
- Structure: Flight structure shipped to Aerojet for installation of propulsion subsystem

## Watch Items/Concerns

- Late delivery of first Solar Array platen could impact schedule reserve.
- Truss Structure Assembly (TSA) developed a weld crack during vibe test; FRB initiated.



# Solar Orbiter Collaboration

**Description** Will use a unique combination of measurements: In situ measurements will be used alongside remote sensing, close to the sun ( $\sim 0.3$  AU), to relate these measurements back to their source regions and structures on the sun's surface. Operates both in and out of the ecliptic plane. Measures solar wind plasma, fields, waves and energetic particles close enough to the Sun to ensure that they are still relatively pristine.

## Upcoming Milestones

Mission Delta-CDR

Kick-Off – April 2016

Close-Out – June 2016

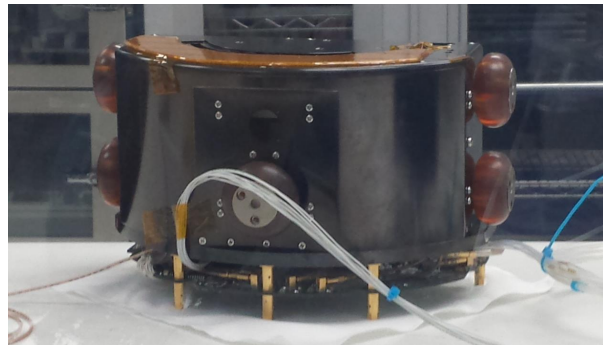
SoloHI PER – April 2016

HIS PER – June 2016

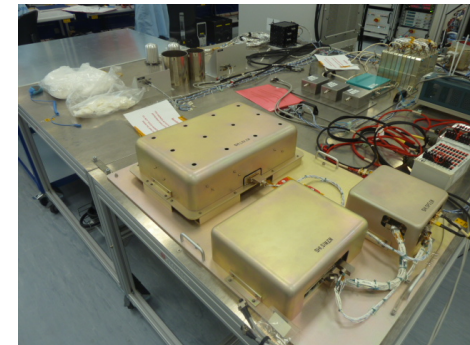
SoloHI PSR – June 2016

HIS PSR – September 2016

LRD – October 2018



HIS Flight Model Detector Section-Time Of Flight



SoloHI Electrical Model

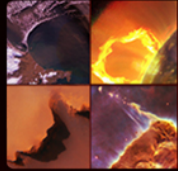
## Recent Accomplishments

- Heavy Ion Sensor (HIS) instrument Post Acceleration (PAC) isolator completed peer review, fabrication and testing beginning.
- Solar Orbiter Heliospheric Imager (SoloHI):
  - Thermal correlation successfully completed; no requirement for additional heaters or heater resizing.
  - Stray light testing complete; results indicate science requirements should be met.

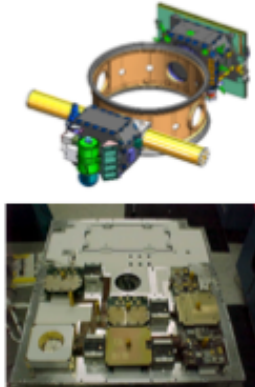
## Watch Items/Concerns

- Schedule risk (spacecraft) to LRD
- Completion of IRAP High Voltage Power Supply delayed at IRAP, impacting the HIS delivery. .





# Space Environment Testbeds



## Launch Information:

- **Spacecraft:** AFRL Deployable Structures Experiment (DSX)
- **Launch Vehicle:** SpaceX Falcon Heavy
- **Date:** March 2017
- **Site:** Cape Canaveral
- **Orbit:** 6,000 x 12,000 km, 45 degree inclination MEO

**Description** Space Environment Testbeds (SET) improves the engineering approach to accommodate and/or mitigate the effects of solar variability on spacecraft design and operations by: 1) collecting data in space to develop a physics-based understanding of response of spacecraft materials, components, & sensors/detectors to space environments; 2) collecting data in space to validate new & existing ground test protocols for the effects of solar variability on emerging technologies; and 3) developing & validating engineering environment models, tools, & databases for spacecraft design & operations.

## Upcoming Milestones

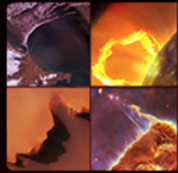
- TVAC tests planned for March-April 2016. Activities scheduled for FY16 include work with the separation system, mission readiness review (MRR), and 4 mission rehearsals.

## Recent Accomplishments

- All flight hardware has been delivered, including the separation system for the DSX secondary payload.
- EMI / EMC tests are complete and showed no problems.
- Vibe tests completed for payload module.

## Watch Items/Concerns

- None



# Next LWS mission recommended by NRC: Geospace Dynamics Constellation (GDC)

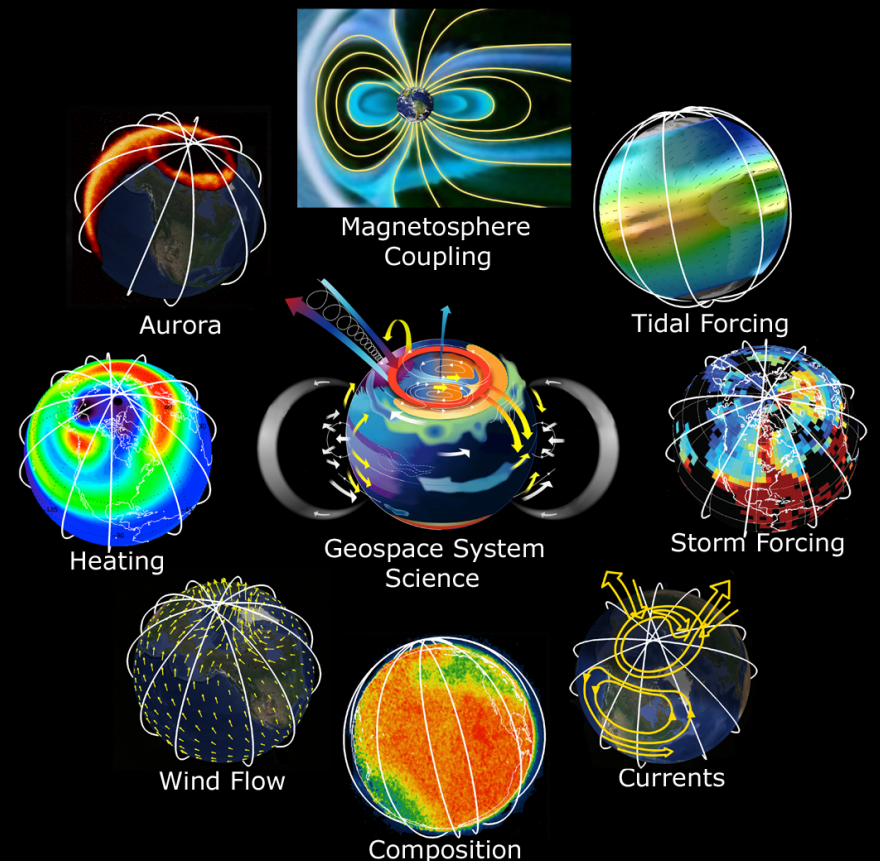
Geospace Dynamics Constellation  
will provide:

**Breakthroughs in our understanding**, providing simultaneous, self-consistent global patterns at 320-450 km of key parameters and interconnections that produce the dynamical global interaction between the atmosphere-ionosphere and the magnetosphere/solar wind.

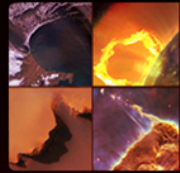
**Unprecedented knowledge**, for example of how global upper atmospheric winds, neutral density and E-fields (ion drifts) and currents respond to variations in solar EUV irradiance, tropospheric forcing, and solar wind/magnetospheric driving.

Global, simultaneous measurements as **input for data-starved models** that will be of great benefit for both ionospheric/thermospheric and magnetospheric research as well as a large variety of space weather applications.

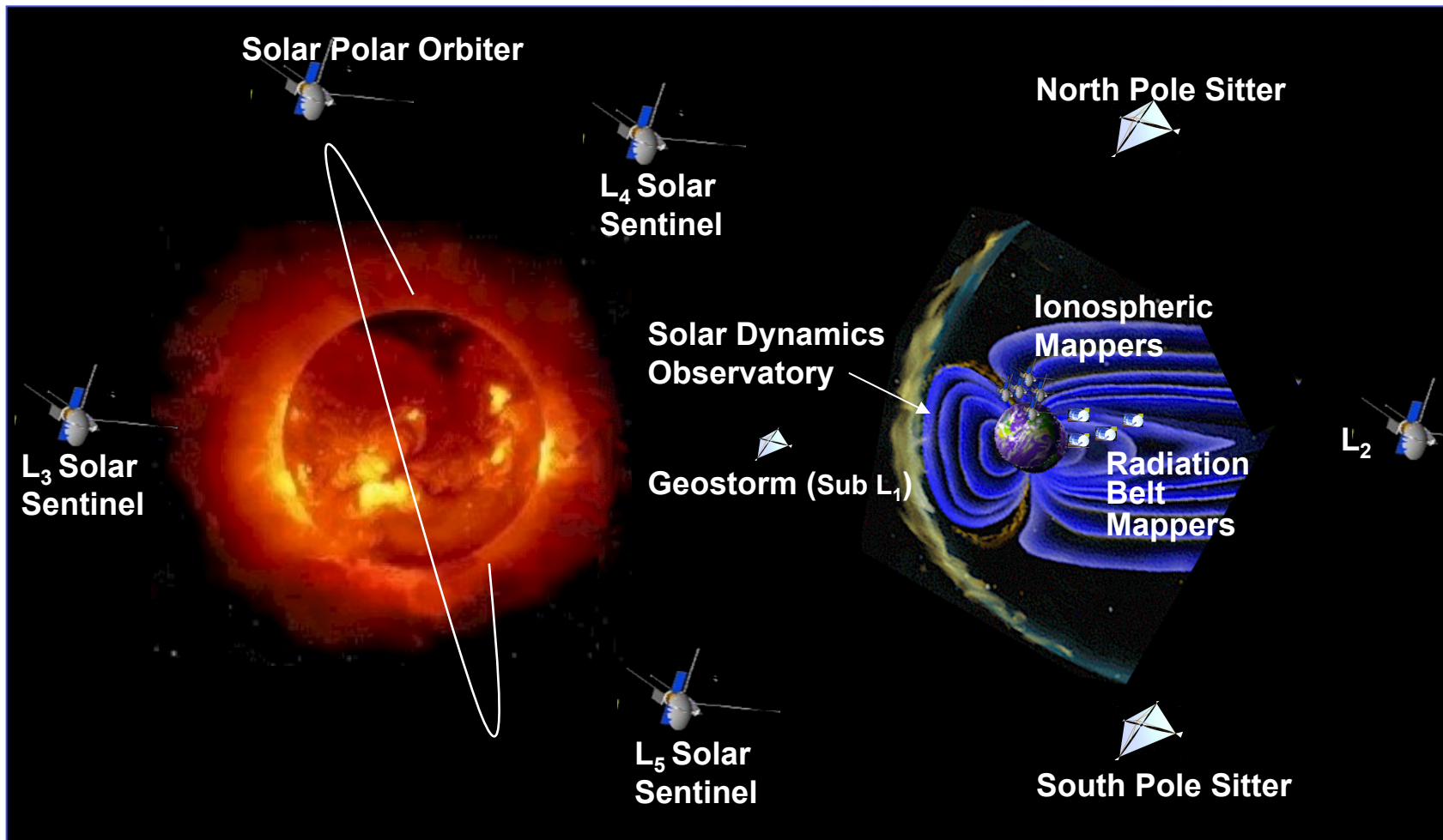
## Geospace Dynamics Constellation



**Expected Outcome → Major impact to our knowledge of I/T/Mag System and its coupling to the Sun, Space Weather effects**



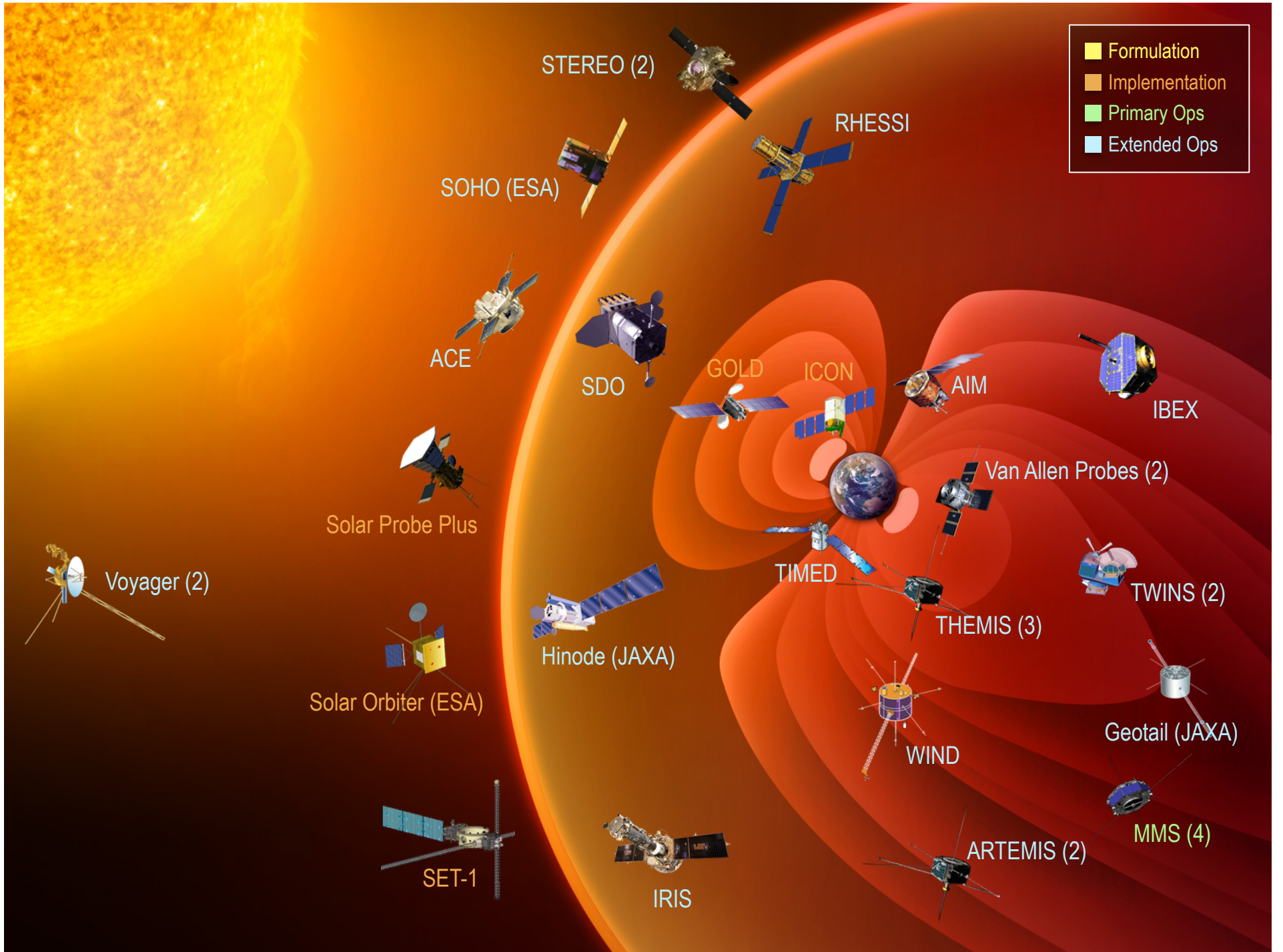
# Original LWS Architecture Concept: Establish Space Weather Research Network

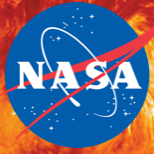


Distributed network of spacecraft providing continuous observations of Sun-Earth system.

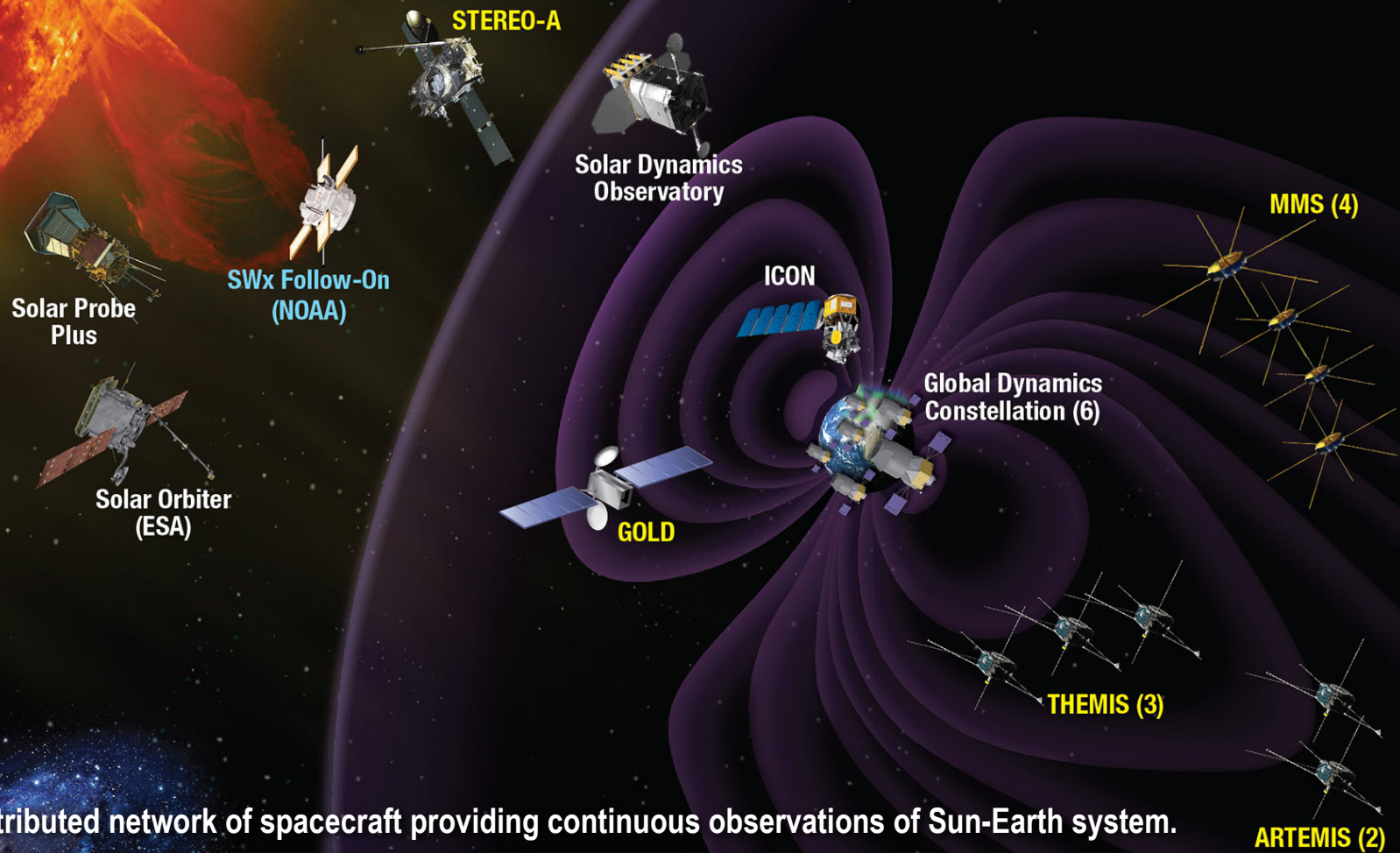
- **Solar Dynamics Network** observing Sun & tracking disturbances from Sun to Earth.
- **Geospace Dynamics Network** with constellations of smallsats in key regions of geospace.







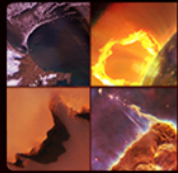
# Possible Near-Future LWS+ Architecture: Active Space Weather Research Network



Distributed network of spacecraft providing continuous observations of Sun-Earth system.

- **Solar Dynamics Network** observing Sun & tracking disturbances from Sun to Earth.
- **Geospace Dynamics Network** with constellations of smallsats in key regions of geospace.

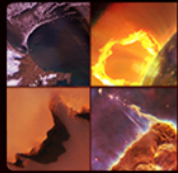




# LWS Strategic Goals – 2006

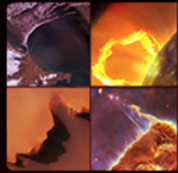
<b>Strategic Goal 1</b>	Deliver the understanding and modeling required for useful prediction of the variable solar particulate and radiative environment at the Earth, Moon, Mars, and throughout the solar system.
<b>Strategic Goal 2</b>	Deliver the understanding of how and to what degree variations in the solar radiative and particulate output contribute to changes in global and regional climate over a wide range of time scales.
<b>Strategic Goal 3</b>	Deliver the understanding and modeling required for effective forecasting/specification of magnetospheric radiation and plasma environments.
<b>Strategic Goal 4</b>	Deliver understanding and predictive models of upper atmospheric and ionospheric responses to changes in solar electromagnetic radiation, and to coupling above and below.





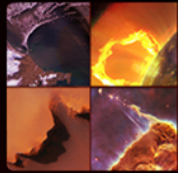
# LWS 10-Year Vision Beyond 2015: Strategic Science Areas (SSA)

- **SSA-0, Physics-based forecasting of solar electromagnetic, energetic particle and plasma outputs**
- **SSA-1, Physics-based Geomagnetic Forecasting Capability**
- **SSA-2, Physics-based Satellite Drag Forecasting Capability**
- **SSA-3, Physics-based Solar Energetic Particle Forecasting Capability**
- **SSA-4, Physics-based TEC Forecasting Capability**
- **SSA-5, Physics-based Scintillation Forecasting Capability**
- **SSA-6, Physics-based Radiation Environment Forecasting Capability**



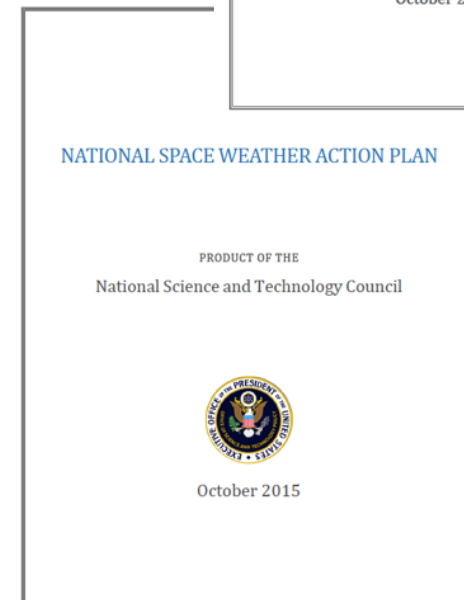
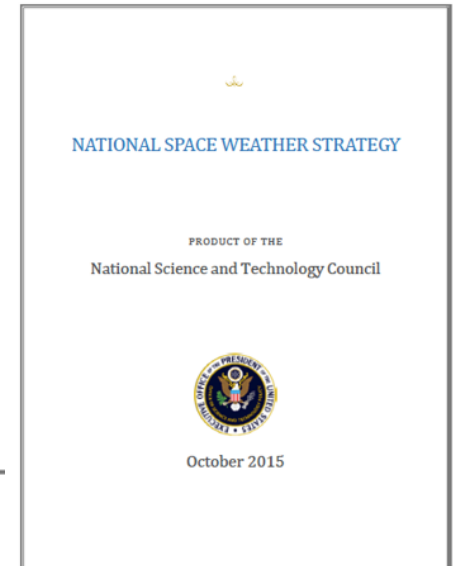
# National Space Weather Strategy

- Office of Science Technology Policy (OSTP), Executive Office of the President, lead the multi-agency effort that developed a National Space Weather Strategy (NSWS).
- NSWS articulates strategic goals for improving forecasting, impact evaluation, and enhancing National Preparedness (protection, mitigation, response and recovery) to a severe space weather event.
- Space Weather Action Plan (SWAP) was developed to establish cross-Agency actions, timelines and milestones for the implementation of the NSWS.
  - Enhances the transition of research to operations for space weather observations, modeling tools, advance warning capabilities and mitigation approaches
  - Incorporates severe space weather events in Federal emergency preparedness, planning, scenarios, training, and exercises
  - Establishes Federal and non-Federal stakeholder collaborations to enhance observing systems and networks and data management activities

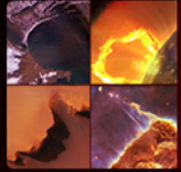


# Integrated Approach to Forecasting and Mitigation

- Action 5.6 - Improve Effectiveness and Timeliness of the Process that Transitions Research to Operations
  - 5.6.1 – Develop a formal process to enhance coordination between research modeling centers and operational forecast centers (R2O)
  - 5.6.2 – Develop a plan that will ensure the improvement, testing, and maintenance of operational forecasting models leveraging existing capabilities in academia and the private sector and enable feedback from operations to research to improve operational space-weather forecasting (O2R)
- NASA, NSF, NOAA, DOD developed a coordinated briefing on R2O and O2R concepts and presented it to OMB and OSTP.







## Goal 1: Establish Benchmarks for Space-Weather Events (5 topic areas)

Benchmarking will happen for:

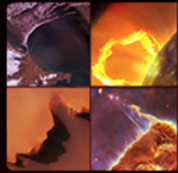
1. Induced geo-electric fields
2. Ionizing radiation
3. Ionospheric disturbances
4. Solar radio bursts
5. Upper atmospheric expansion

### **Timeline:**

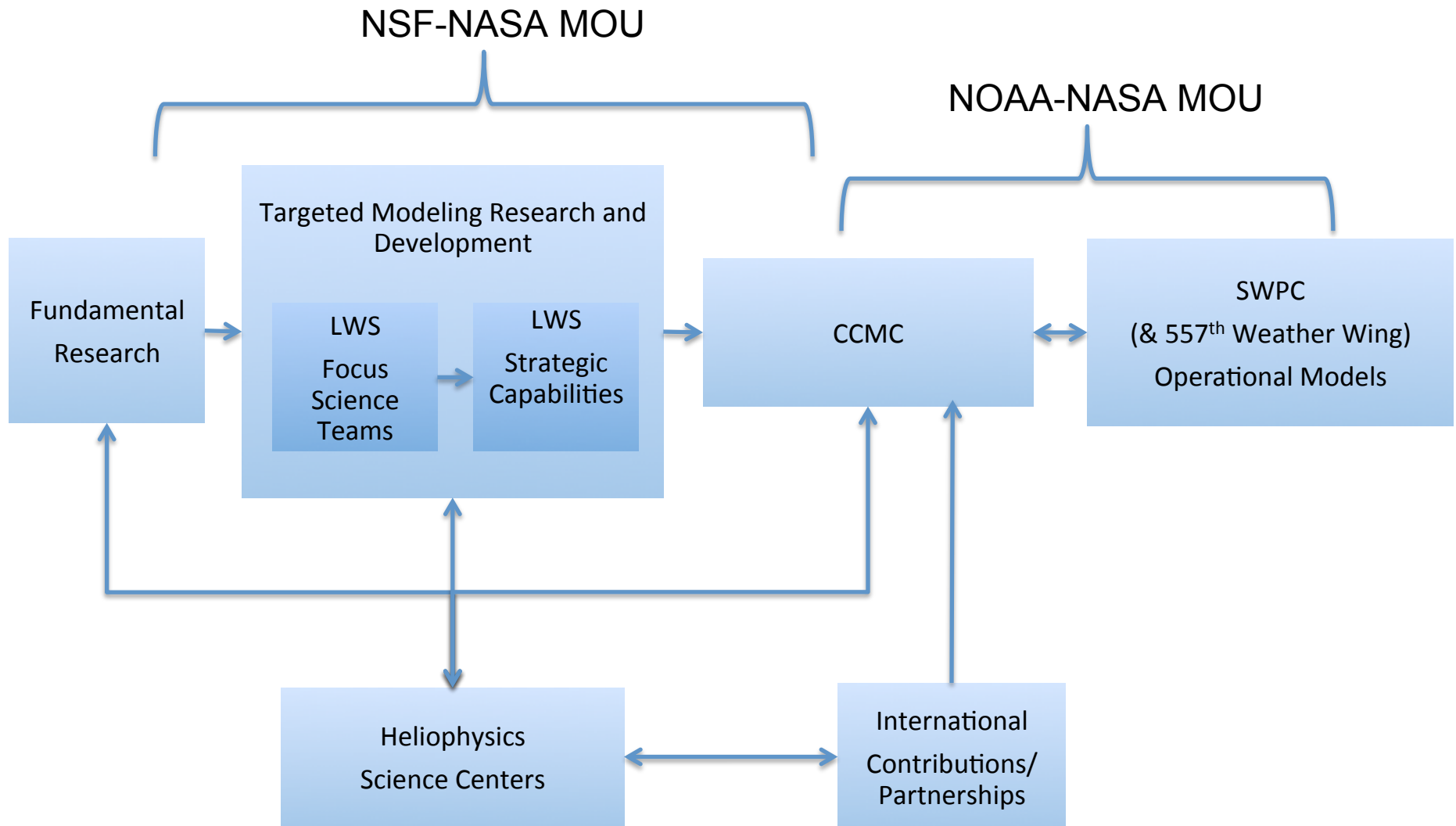
Phase 1 benchmarks: 180 days (April 2016)

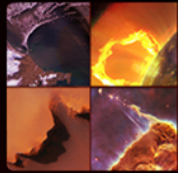
Complete Assessment report of gaps: 1 yr (November 2016)

Phase 2 updated benchmarks: 2 yr (November 2017)



# Future Modeling R2O Concept of Operations





# LWS Steering Committee Finding 1: Procedure for Development of Annual TR&T Science Topics 1/2

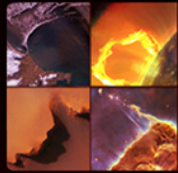
It is vital for the success of the Living with a Star Targeted Research and Technology (LWS TR&T) program that there be active community engagement in the development of annual TR&T science topics. The LWS TR&T Steering Committee (TSC) finds that the following procedure should be followed to solicit and obtain community input for and to then develop these science topics:

## Encourage active community input to TR&T science topics:

- Announce call for community input to science topics through SPA news, Solar News, and other newsletters and e-mail lists every 2 weeks for a 6 week input period.
- Produce a short summary and explanation of this call for presentation at conferences, in newsletters, and at individual institutions.
- Hold an Online town hall where the call for topics is explained and community questions and input are solicited.
- Release the suggested science topics online as they are submitted, without submitter identifying information. Include a comment box for each topic to provide a place for comments and discussion. This page should be archived.

## Draft science topics at second TSC meeting:

- At its second meeting, following the 6 week input period, the TSC develops draft science topics based on the community input received and based on the established LWS TR&T goals.



# LWS Steering Committee Finding 1: Procedure for Development of Annual TR&T Science Topics 2/2

## Solicit community comment on draft TR&T science topics:

- Release (online) these draft science topics to the community for a comment period of at least 6 weeks.
- During this comment period, present these draft science topics at / via:
  - conferences
  - online town halls
  - Newsletters and e-mail lists

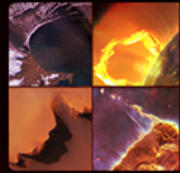
## Finalize science topics at third TSC meeting:

- At its third meeting, following this comment period, the TSC finalizes the TR&T science topics and compiles the TSC annual report, incorporating community feedback on the previously released draft science topics.

## Findings for Future year TSCs

- Seek science topic input via:
  - Final write-up of LWS institutes.
  - Town hall and science discussion sessions at conferences.
  - Final write-up of LWS science teams.

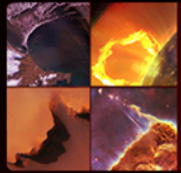




## LWS Steering Committee Finding 2: Short-term SWORM tasks

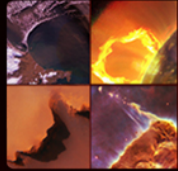
The TSC suggests the following short-term task to assist NASA in carrying out its SWORM benchmarking activities:

- NASA should establish LWS SWORM “Tiger Teams” to support the five SWORM benchmarking activities. These teams would be distinct from, but complementary to current LWS teams, such as the Focused Science Topic teams and the Strategic Capability teams.
- The charter of each Tiger Team would be to
  - Assist and support the government study board by providing findings as directed and by reviewing the gap assessment performed by the governmental study board. Specifically, the teams would identify gaps in science, perform evaluation of uncertainties, and identify collections of available data, as well as critical missing data.
  - Identify and implement any short-term science actions that need to be taken to feed into the Phase-2 improved benchmarking process. Science actions could include synthesizing models and data, and providing tools relevant to benchmarking.
- A fast-track selection process should be implemented so that the Tiger Teams have sufficient time to complete their tasks within the deadlines identified in the SWAP. Based on these deadlines, the announcement-to-selection process should be no more than a few months.
- For this fast-track process, no restrictions should be put on proposal teaming structures in order to maintain flexibility to best serve the SWORM activities. For example, both team proposals and individual proposals should be allowed for each benchmarking topic, thus allowing the LWS Program Office the flexibility to form the tiger teams from these proposals and / or to select individual investigations.



## LWS Steering Committee Finding 3: Long-term traceability and alignment

- With regards to the longer-term activities identified in the SWAP report, the TSC finds that it should trace out the correspondence between all the SWORM actions to which NASA is contributing and the LWS TR&T Strategic Science Areas (SSA's).
- Based on this correspondence, the TSC should develop findings at its next meeting detailing how the TR&T's SSA-targeted activities can feed into and / or address NASA SWORM actions.
- In future years, the TSC should include Tiger Team feedback to the program in order to more closely align TR&T activities to the SWORM goals.



# LWS Science looking forward

## ROSES 2016:

- FSTs will be developed incorporating inputs from previous Steering Committee reports and will be informed by SWAP science priorities

## ROSES 2017:

- New procedure initiated for development of FSTs
- Mandatory funding in President's FY17 budget request

*“Living with a Star is supported in part with mandatory funding. The mandatory investment includes \$10 million for Living With a Star (LWS) Science, to accelerate efforts in support of the Administration’s multi-agency Space Weather Action Plan. Work will include benchmark maturation, implementation of FY2016 plans, and continuation of planning efforts between the agencies. The investment will also augment Living with a Star Research and Analysis elements that address space weather”*