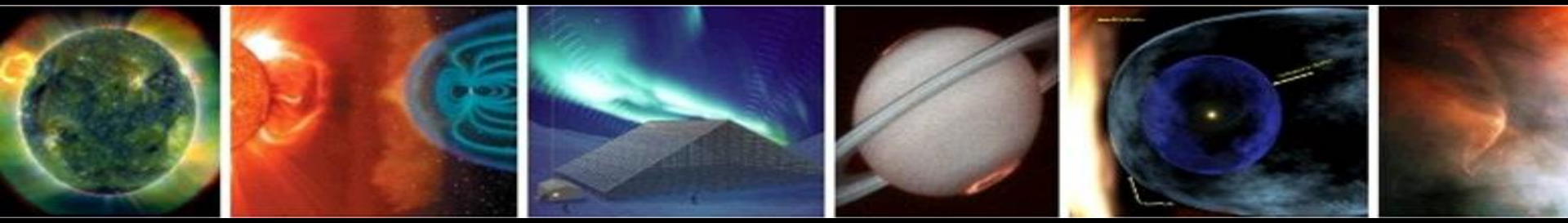
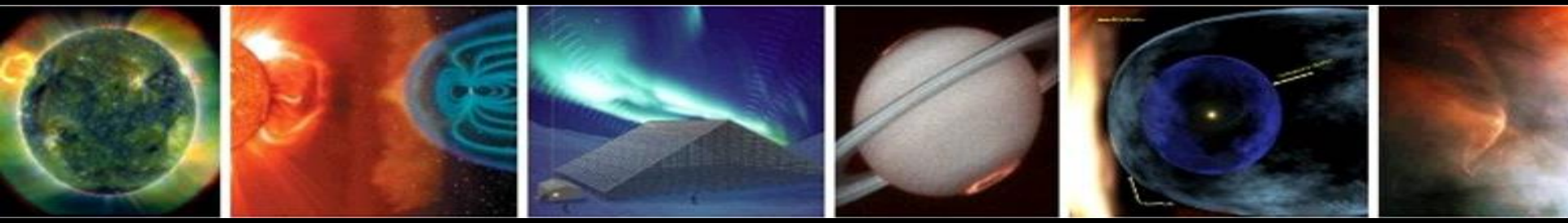


Particles and Fields in the Solar System

The Space Mission Part of LASP

Daniel N. Baker

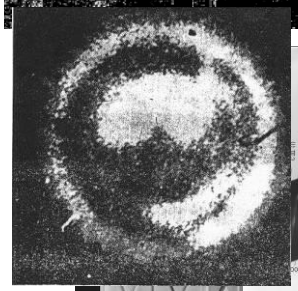
Laboratory for Atmospheric and Space Physics
University of Colorado

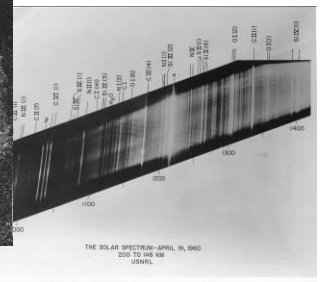


"I like the dreams of the future better than the history of the past"

Thomas Jefferson

LASP...*The Early Years*





1947 The University of Colorado Physics Department begins research collaboration with NRL and the Air Force to develop rocket payloads to perform Solar EUV measurements; in 1948 the University forms the Upper Air Laboratory (UAL)

1951 UAL develops Solar UV/EUV instruments and leads the development of rocket pointing control systems for NRL and AFGL flown on V-2s and Aerobee-Hi's

1954 UAL personnel Stacey, Jackson, Nidey, et al. form Ball Brothers Research Corporation

1958 NASA is formed under President Eisenhower

1959 UAL and NRL have measured Solar UV and EUV spectrum down to 50 nm and obtained the first solar X-ray image, UAL begins Solar, Terrestrial, and Planetary research with NASA funding

Early 1960's UAL changes its name to the Laboratory for Atmospheric and Space Physics (LASP)

LASP
LABORATORY FOR ATMOSPHERIC AND SPACE PHYSICS
UNIVERSITY OF COLORADO AT BOULDER

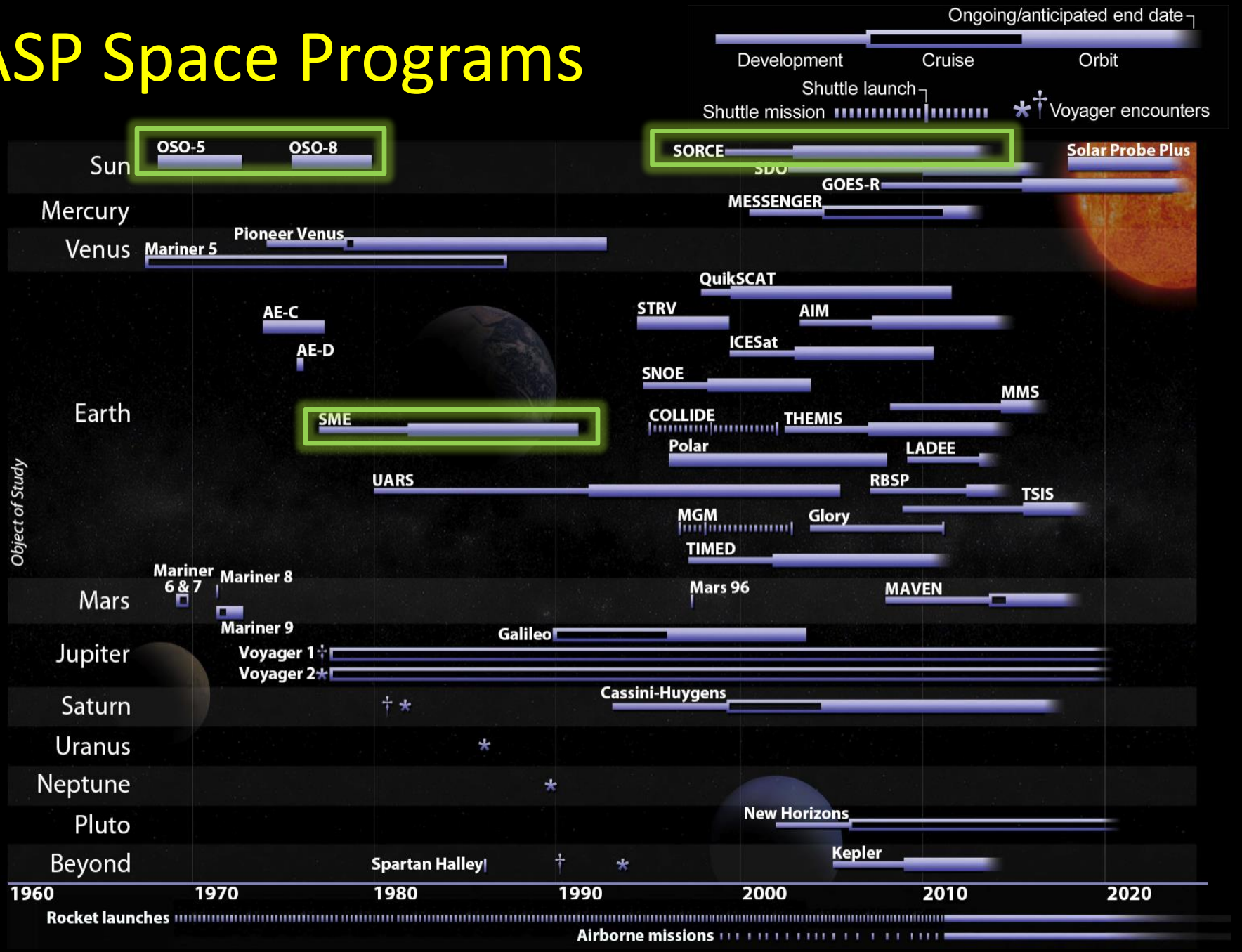
1960's LASP enters Earth orbiting and interplanetary era of research with OSO and Mariner instrumentation.

Pushing the Frontiers of Space Research

- LASP conducts theoretical and experimental research in….
  - Planetary Studies
  - Solar Influences
  - Atmospheric Sciences
  - Space Physics

- LASP has successfully developed scientific instrumentation for….
  - 14 Deep Space Missions
  - 20 Earth-Orbiting Missions
  - 240 Sub-Orbital Rocket Experiments

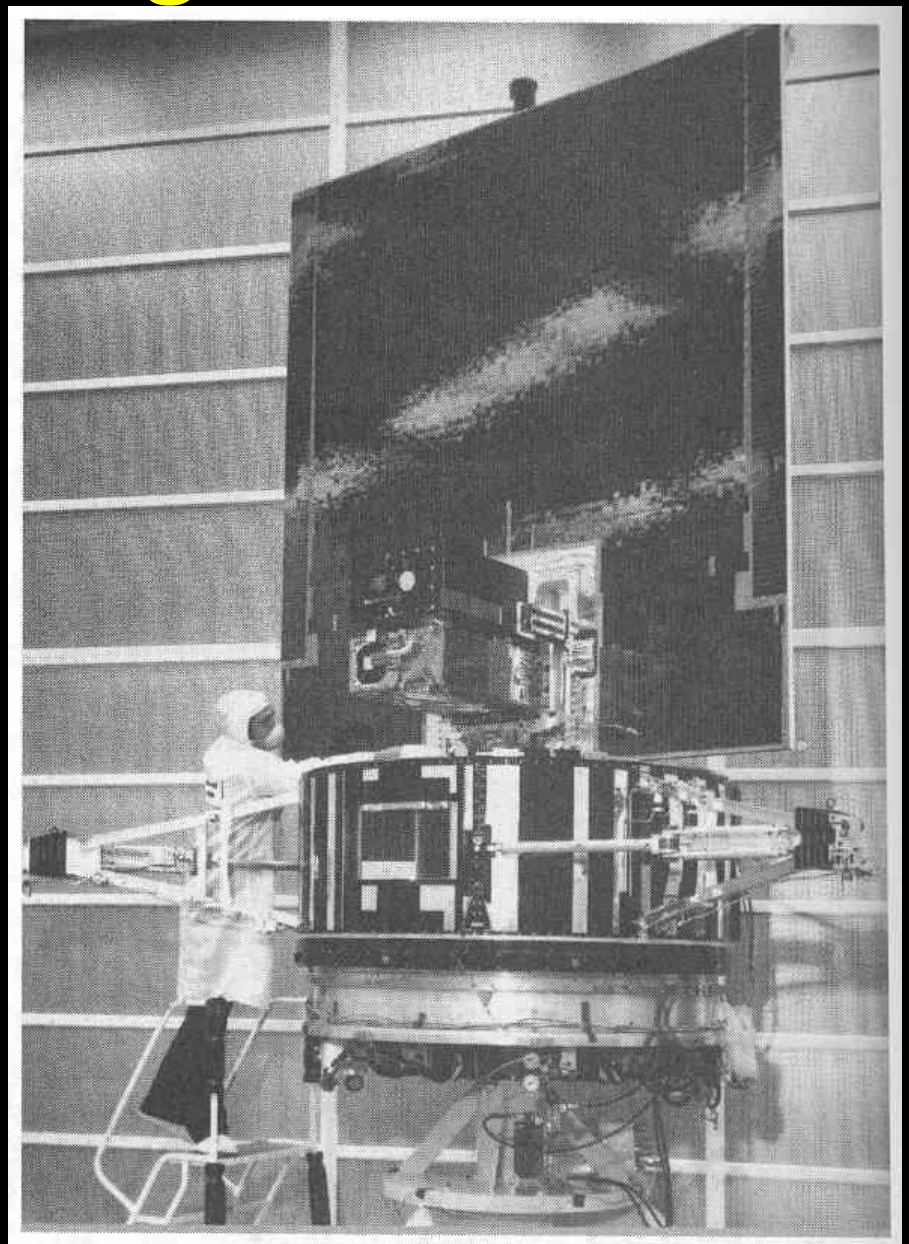
LASP Space Programs



Our Active Sun

Understanding Solar Variability

Orbiting Solar Observatory

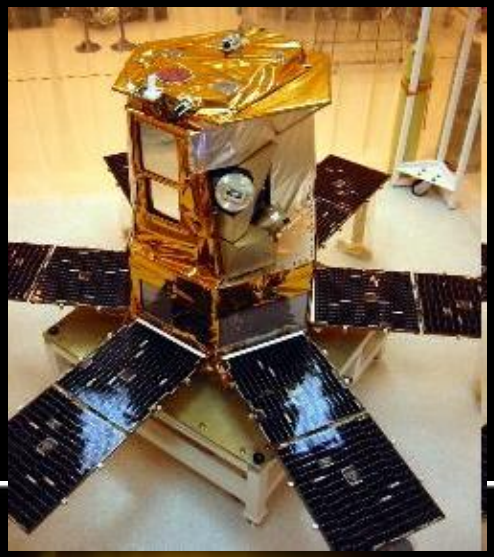


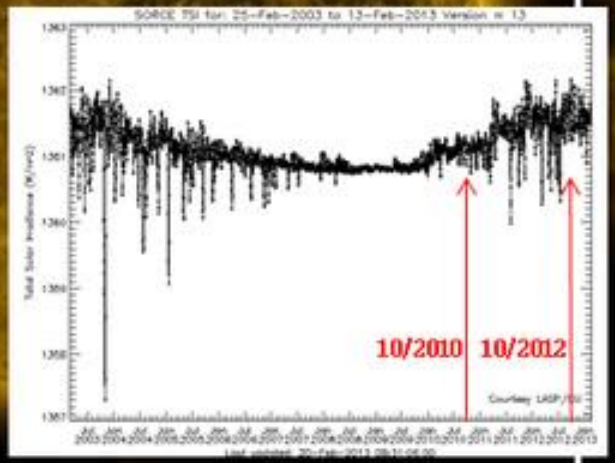
OSO An engineer checks two spectrometers on OSO 8.
Hughes Aircraft

Solar Mesosphere Explorer - SME

LASP Missions: SORCE

1998 – present (launched Jan ’03)



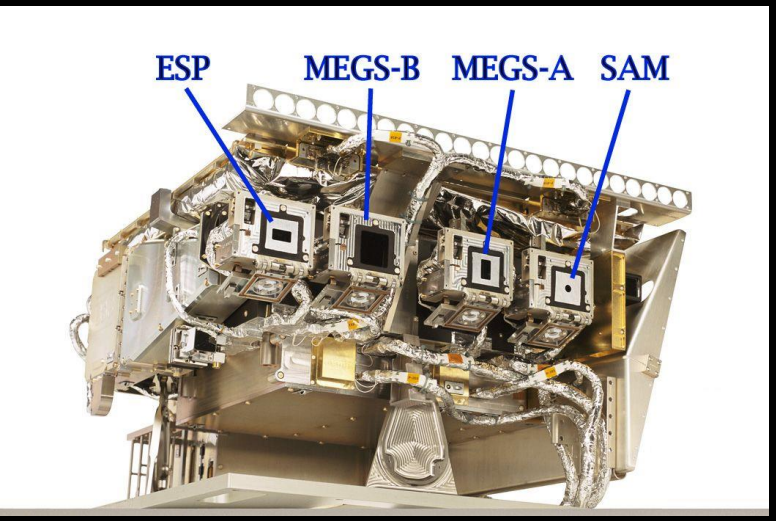


October 2010

October 2012

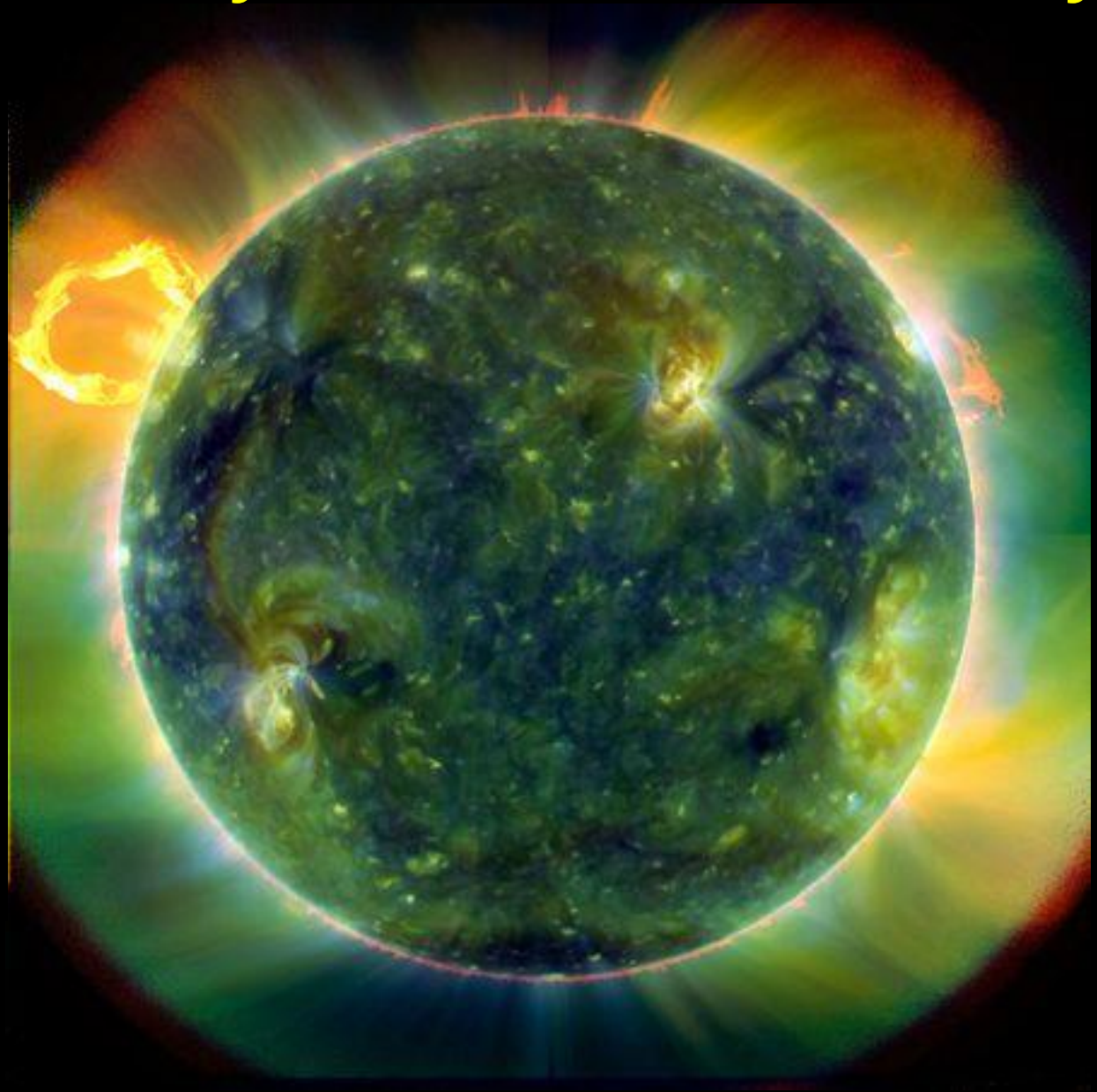
Solar Dynamics Observatory (SDO)

- SDO launched Feb. 11, 2010
- Completed commissioning on 4/30/10
- Continues in normal operations (24/7 data)

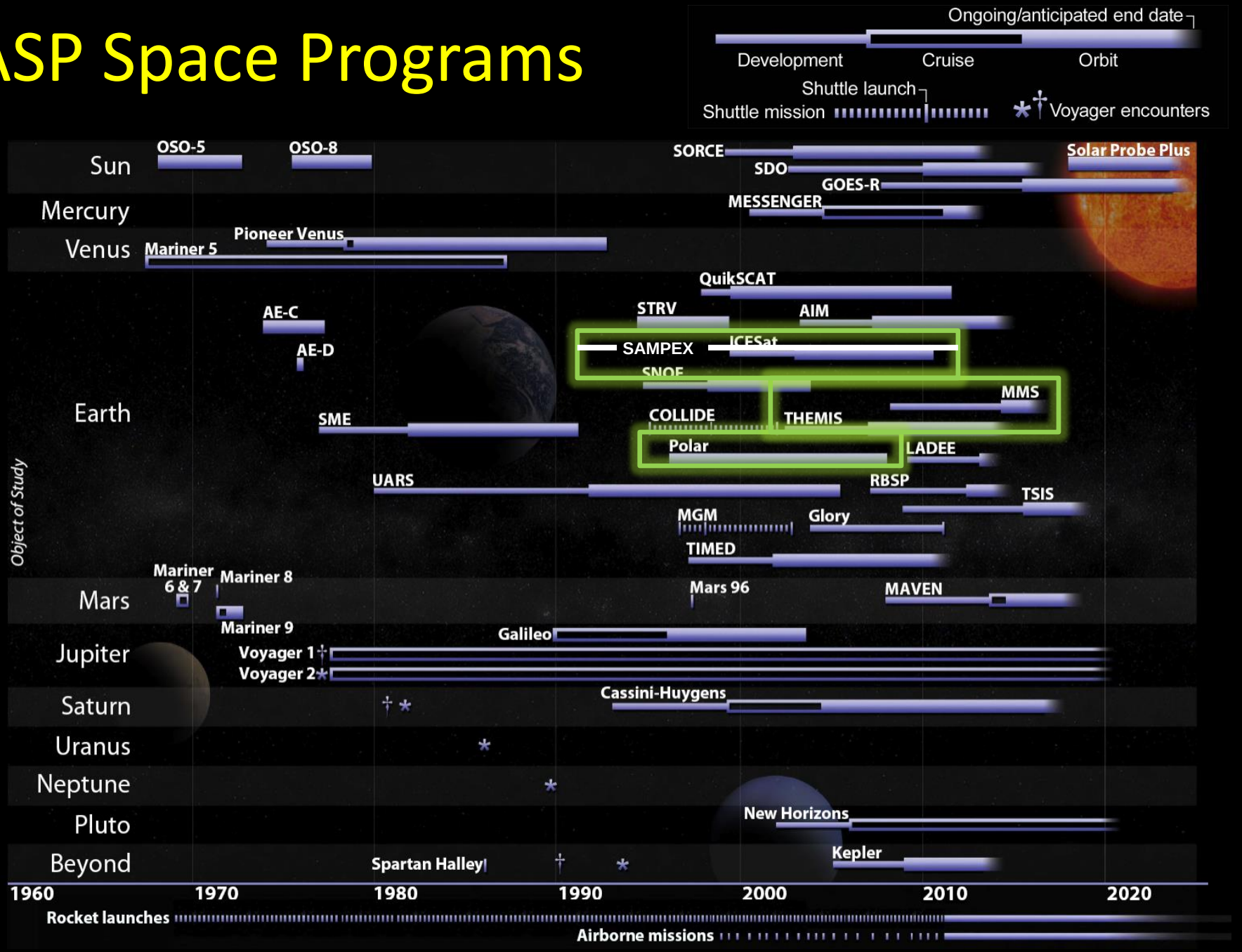


- SDO EVE provides:
  - Full EUV coverage: 0.1-122 nm
  - Good spectral resolution: 0.1 nm
  - High cadence: 10 sec
  - Low latency: Space Weather data in <15 min
- SDO AIA provides EUV images
- SDO HMI provides magnetic field images

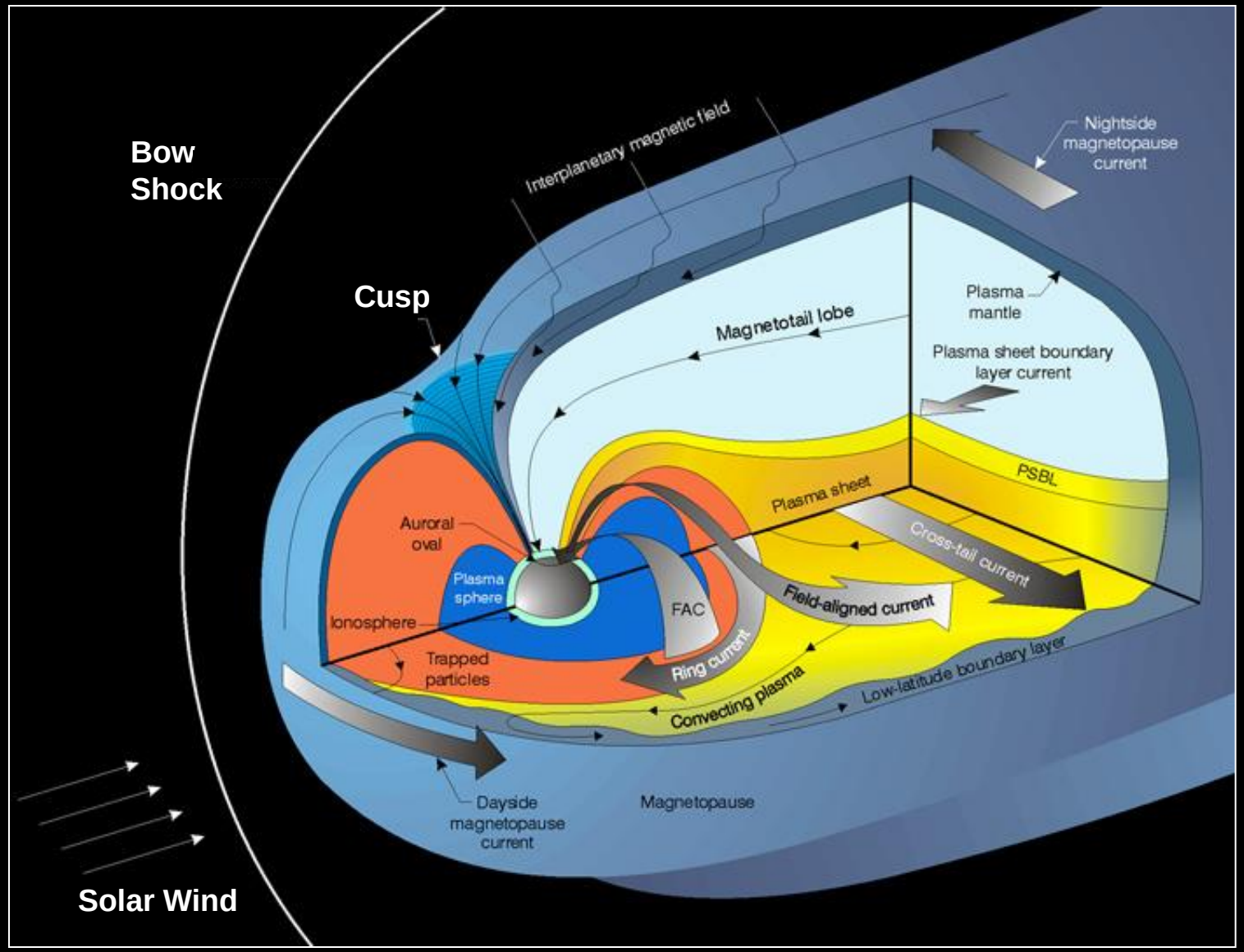
Solar Dynamics Observatory



LASP Space Programs

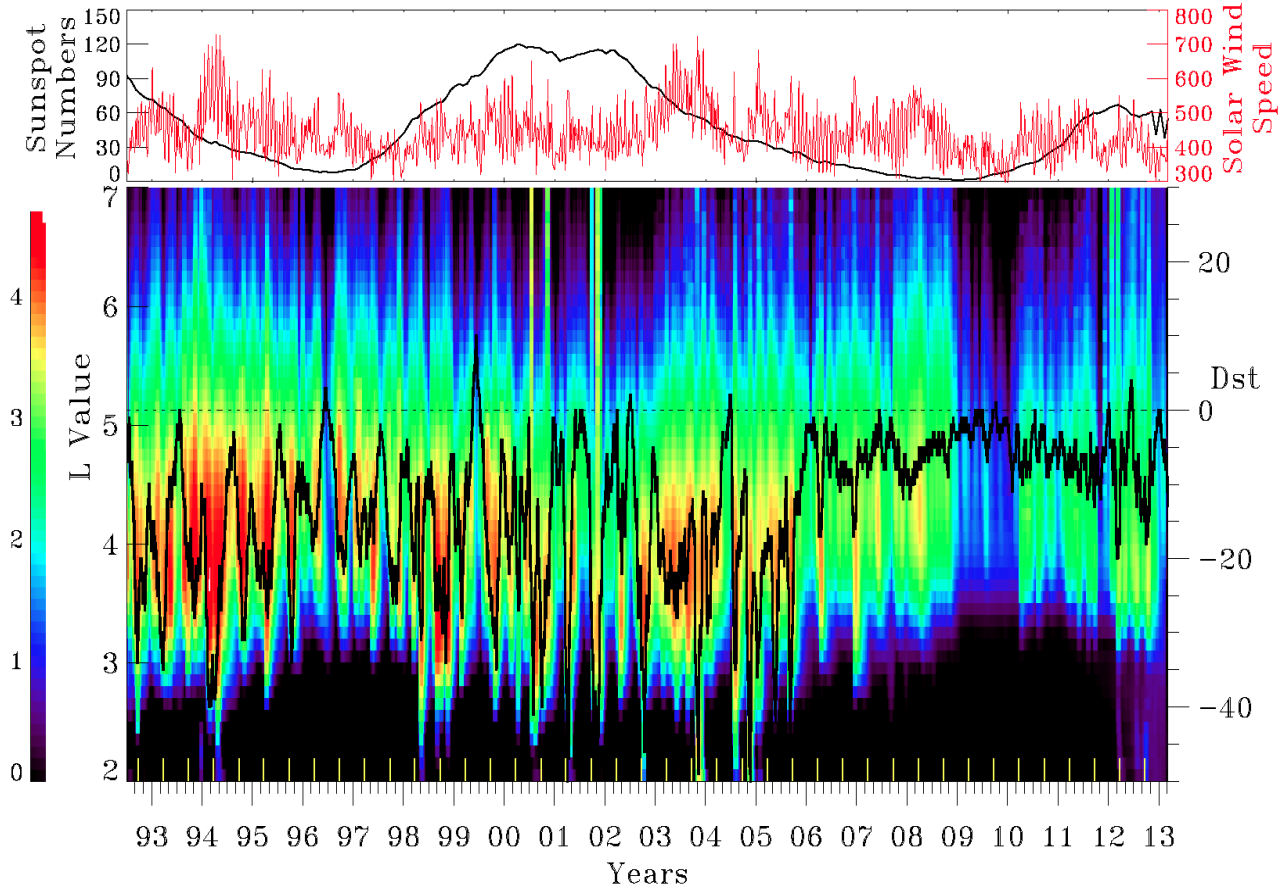


Magnetospheric Regions and Currents

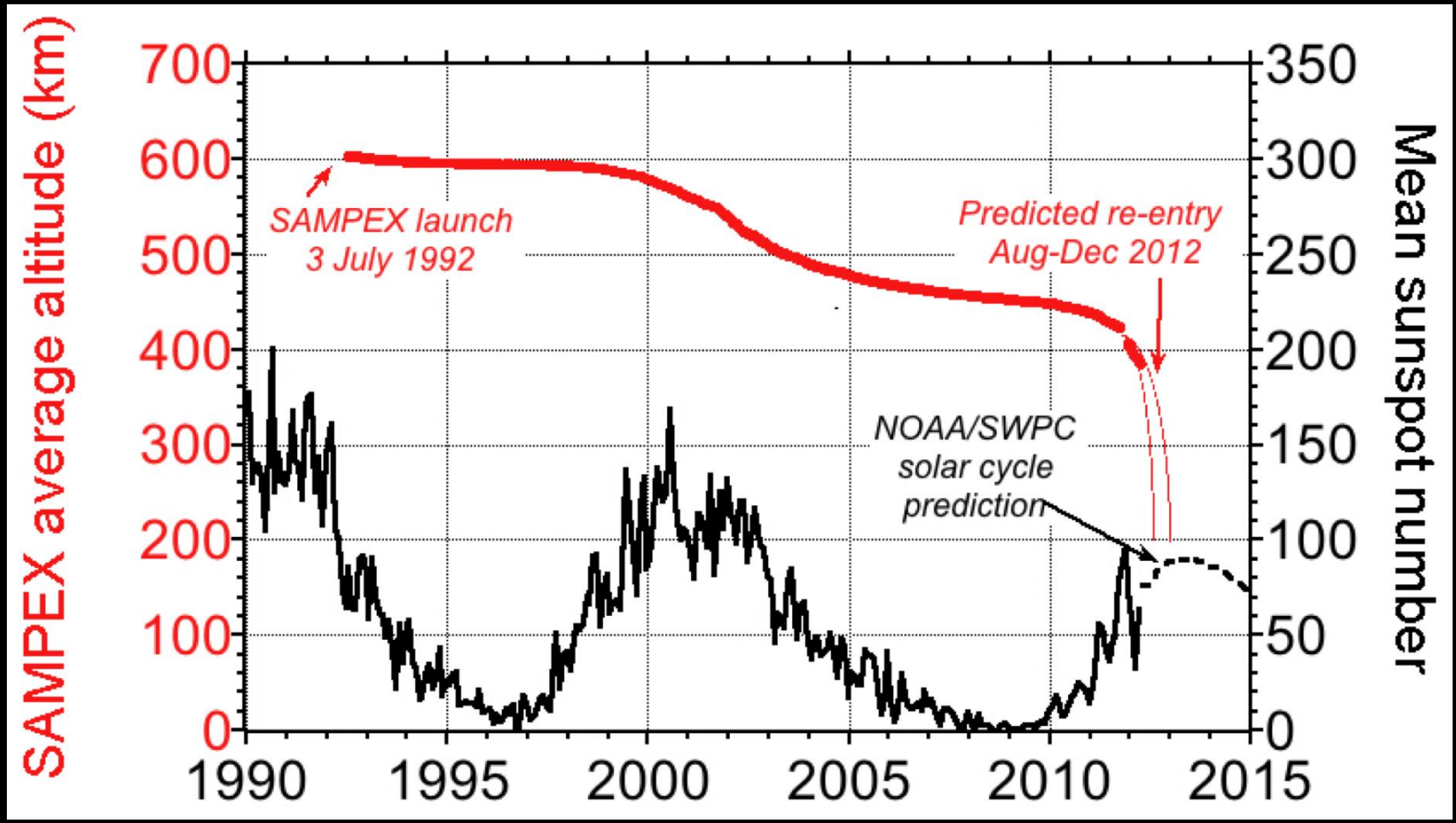


Earth’s Magnetosphere-Ionosphere System

20-Year SAMPEX History

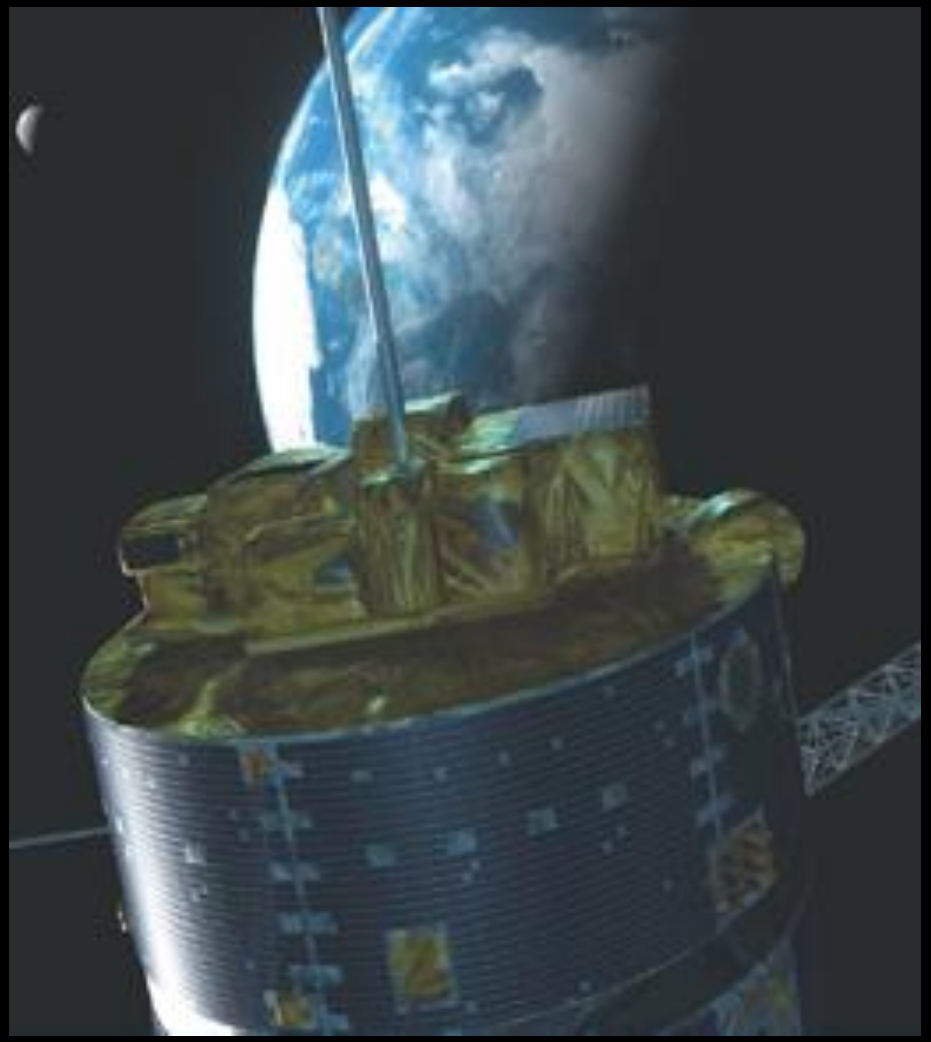


Demise of SAMPEX



Re-entry on 13 November 2012

NASA Polar Mission



LASP Missions: SNOE

Feb 1995 – Dec 2003 (launched Feb ’98)

SNOE: Global Observations of Nitric Oxide

Polar Orbit – constant local time near 11AM/PM

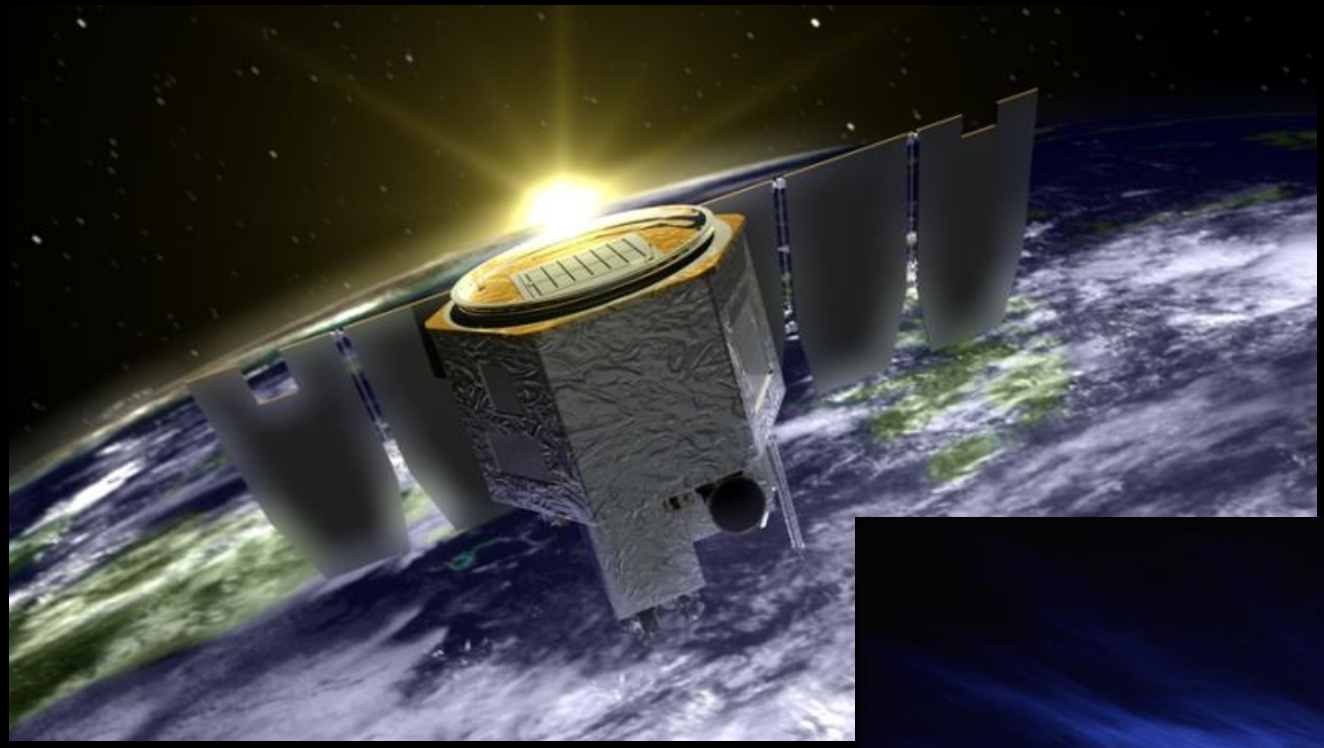
Operated from 1998 to late-2003; Built by students with professional oversight for $3.5M

Spinning satellite – nitric oxide densities were obtained from 95 to 150 km

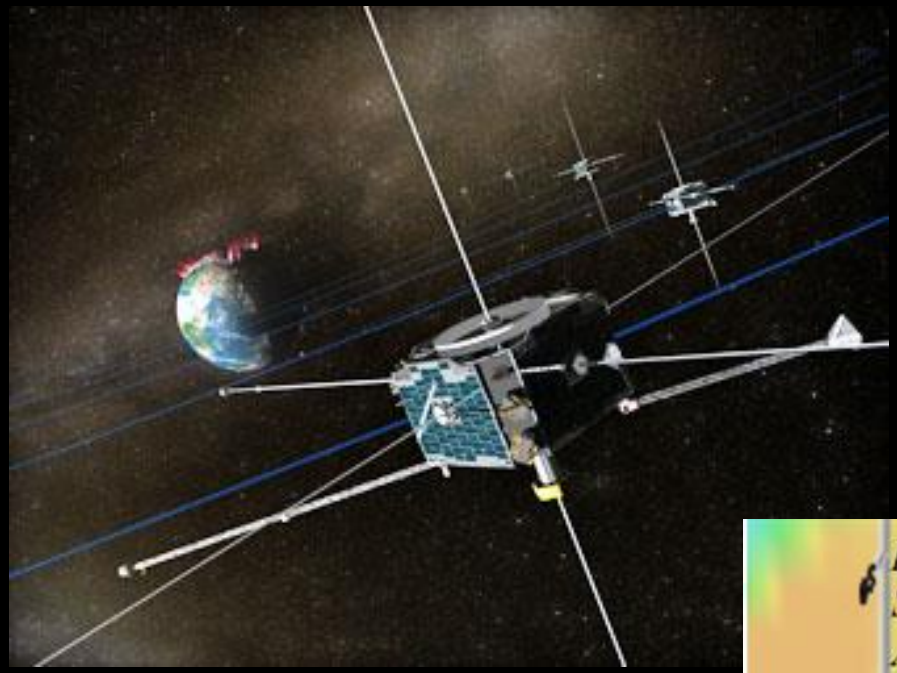
SNOE UVS observed 237 nm fluorescently-scattered solar radiance – NO was only measured at locations that were illuminated by the Sun.

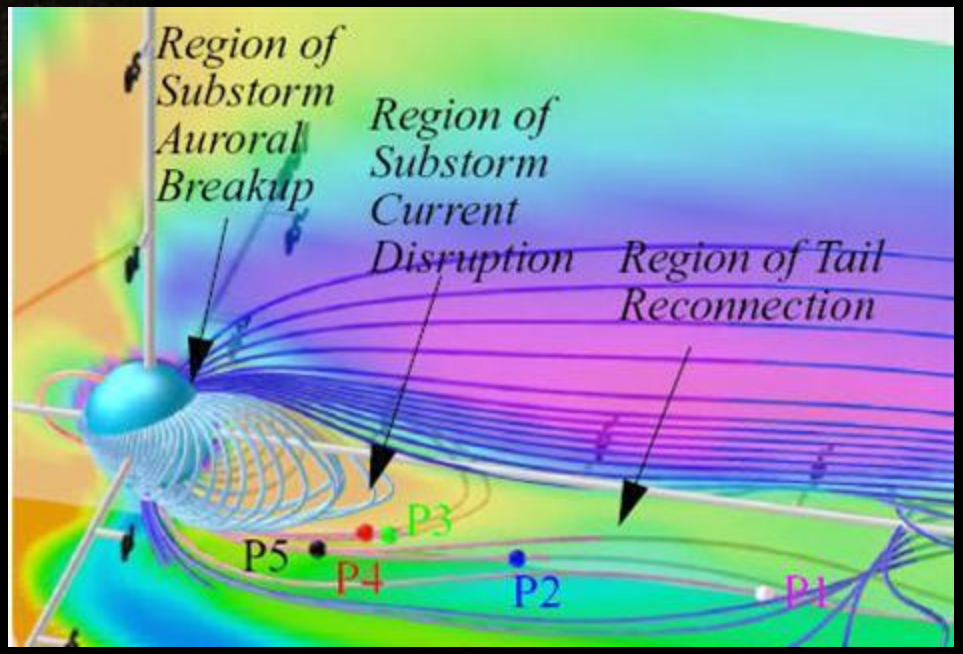
LASP Missions: AIM

2003 – present (launched Apr ’07)



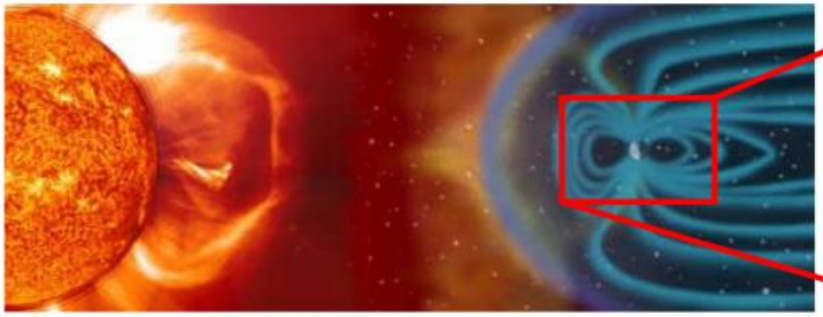
THEMIS: 5-Spacecraft Mission



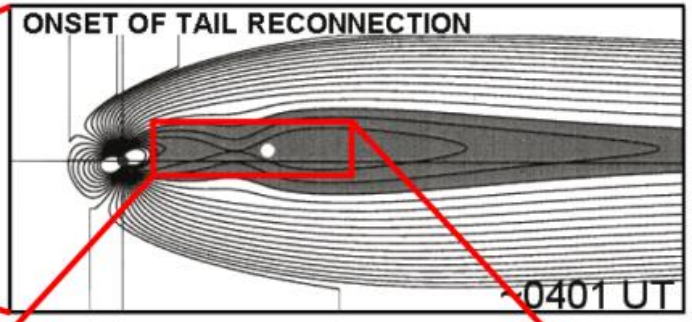


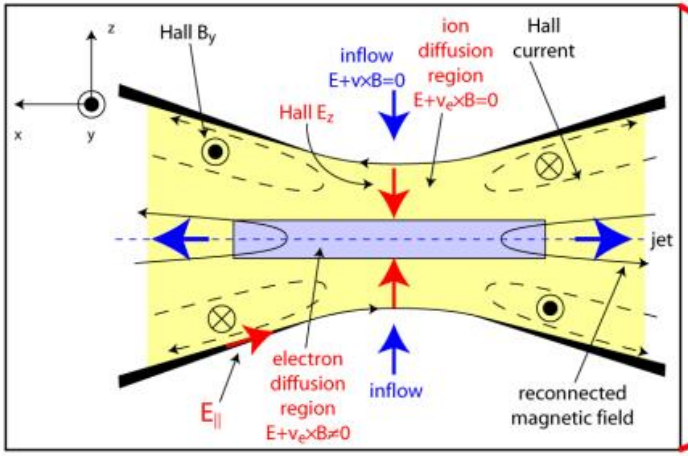
Multiscale Effects in Solar-Terrestrial Plasmas

Sun-Earth Coupling

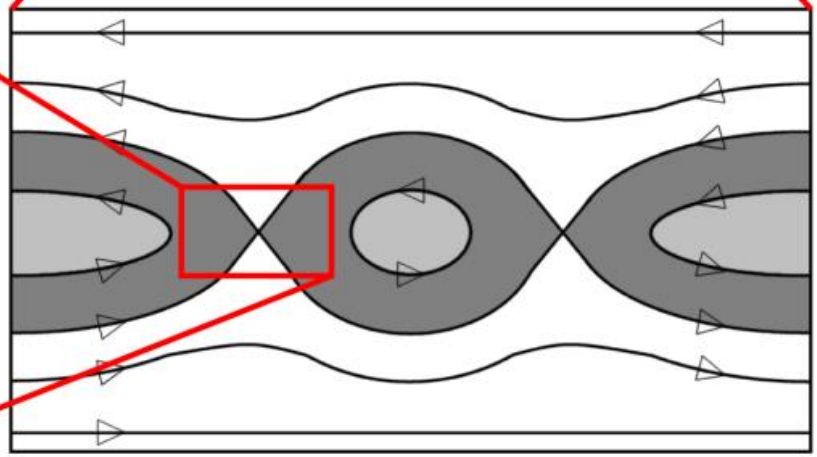


Magnetospheric Energy Loading





Diffusion Region Physics



Reconnection and Reconfiguration

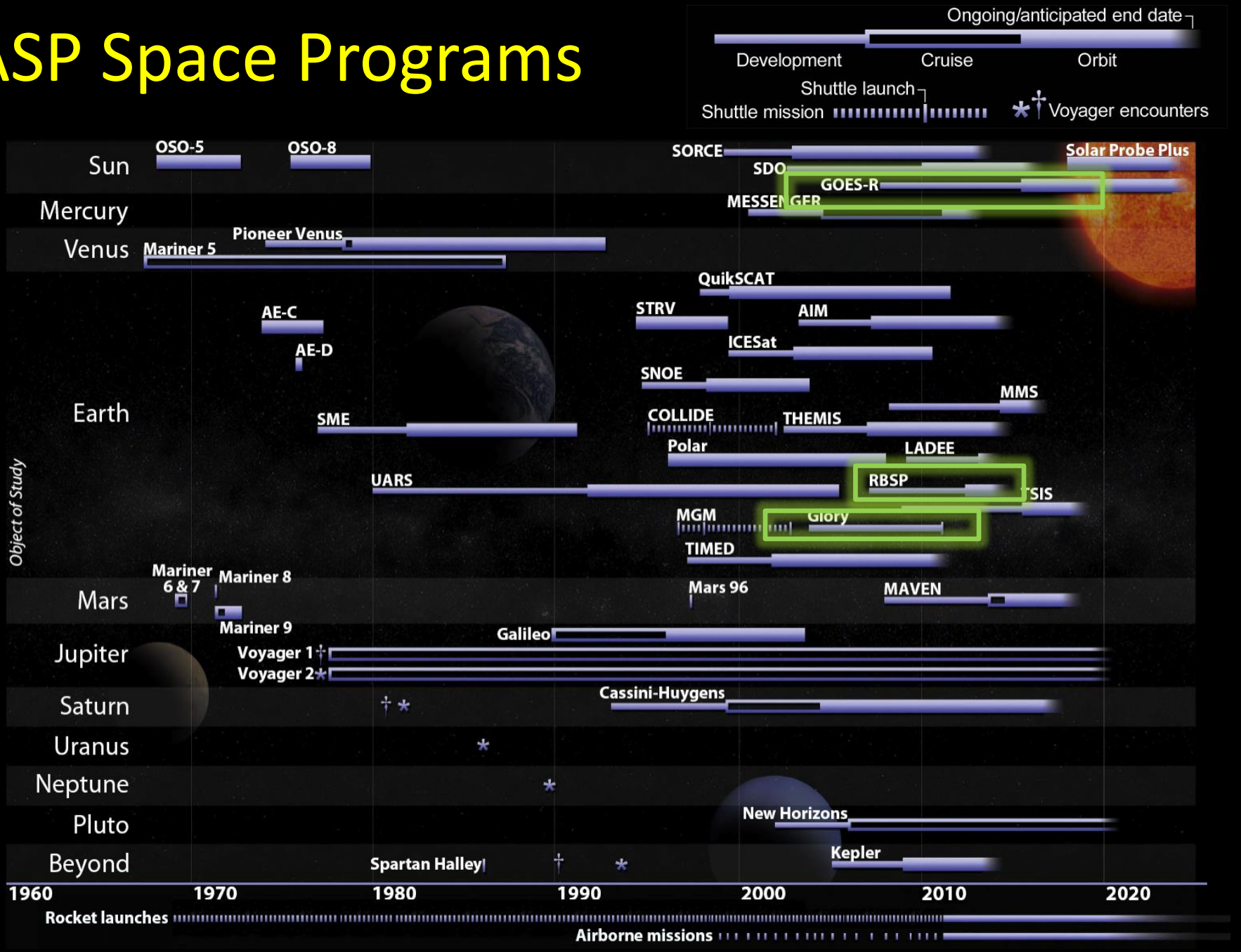
Understanding Magnetic Reconnection: MMS

We need to learn:

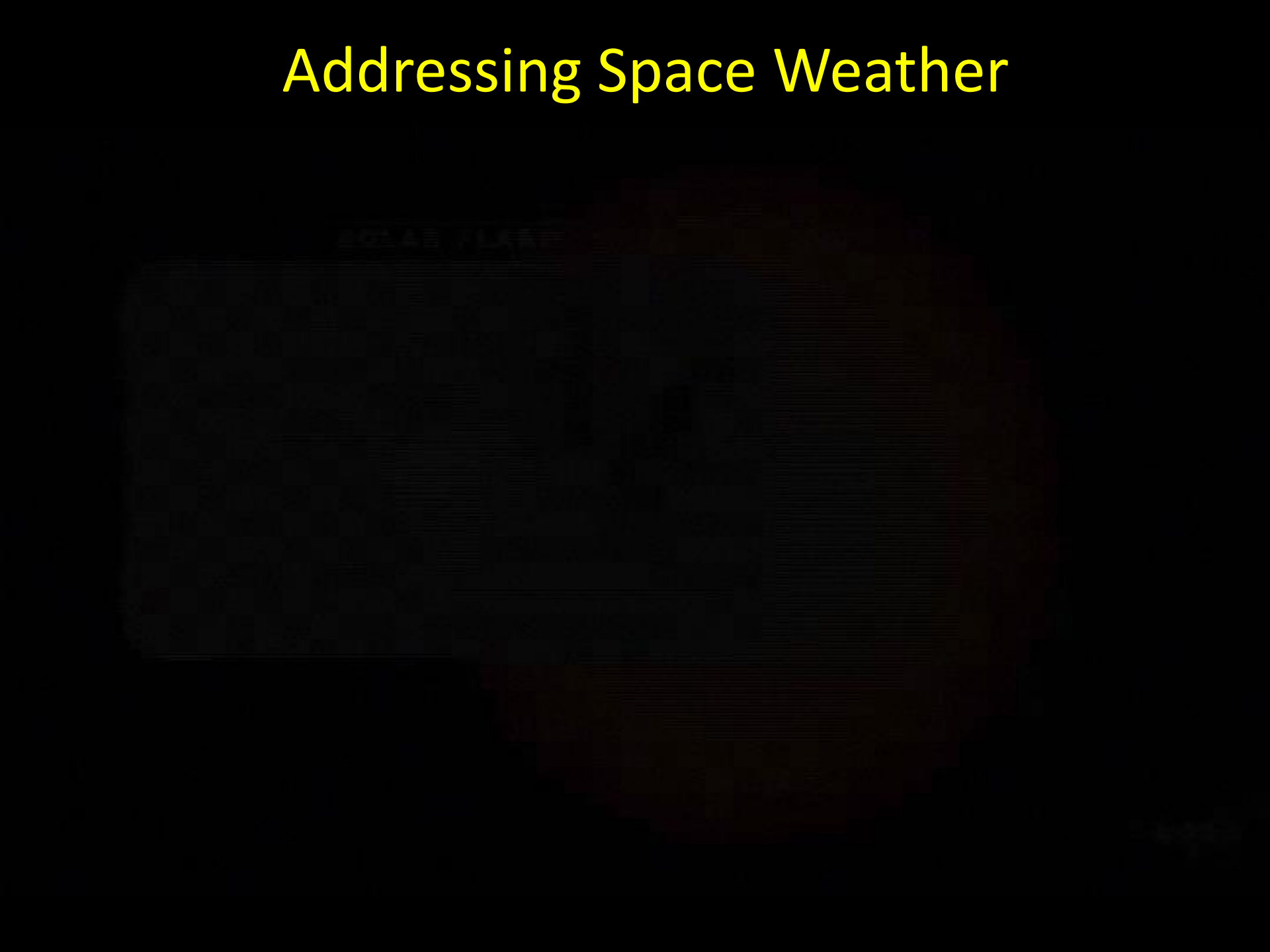
- How complex systems catastrophically reconfigure themselves
- How local (multiscale) turbulence relates to global-scale system instability: MMS
- How the progression of geomagnetic disturbances relate to one another (and ultimately lead to global dynamical changes)

MMS Launched on 12 March 2015

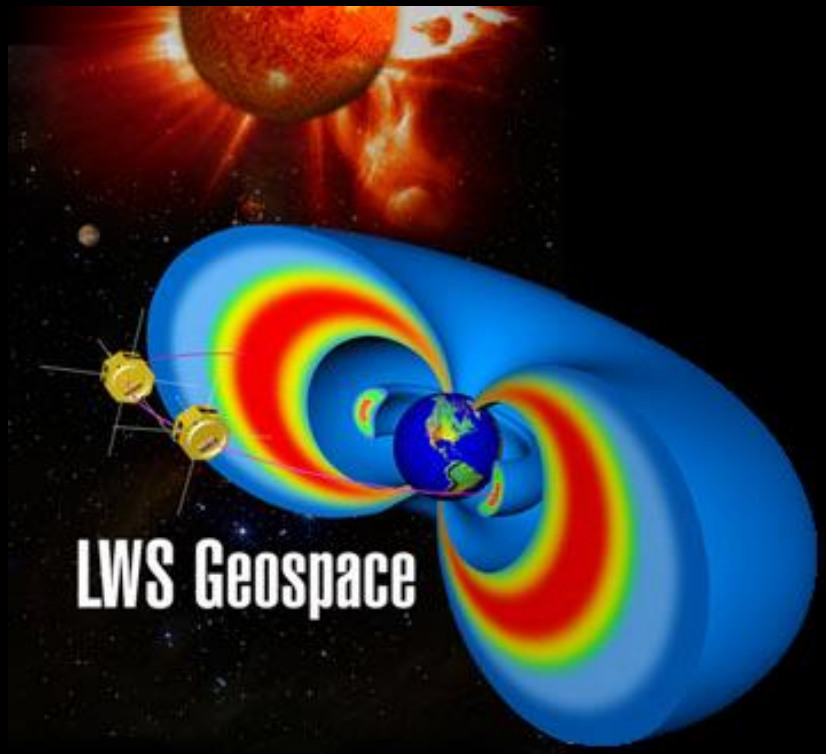
LASP Space Programs



Addressing Space Weather



RBSP Science Definition Report



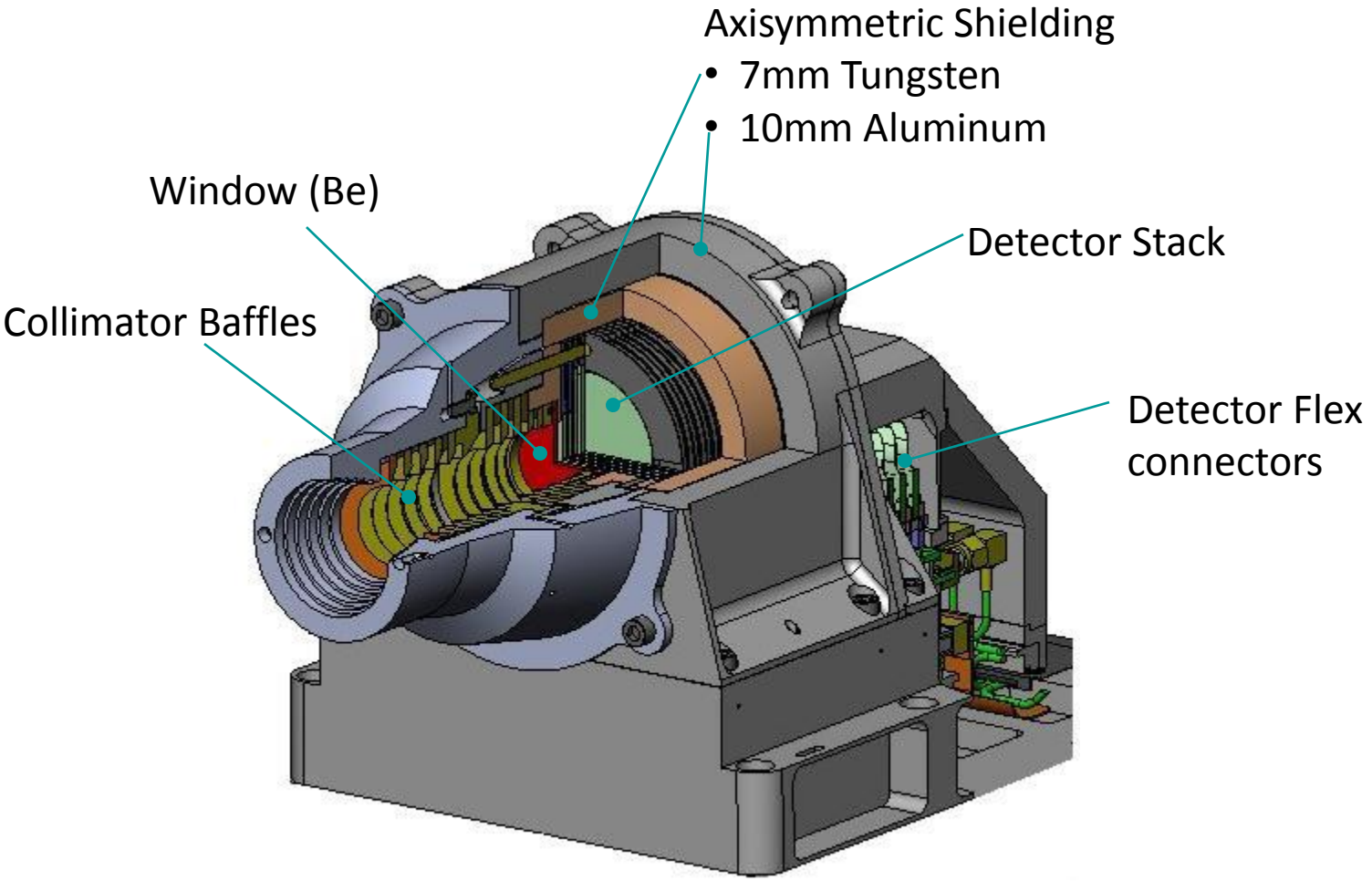
Mission Objectives:

1. Differentiate among competing processes affecting the acceleration and loss of radiation belt electrons;
2. Understand the creation and decay of new radiation belts;
3. Quantify the relative contribution of adiabatic and nonadiabatic processes;
4. Understand the role of “seed” or source populations; and
5. Develop and validate specification models of the radiation belts.

Radiation Belt Storm Probes (RBSP) constellation

RBSP addresses the scientific and programmatic goals of the NASA Living With a Star program.

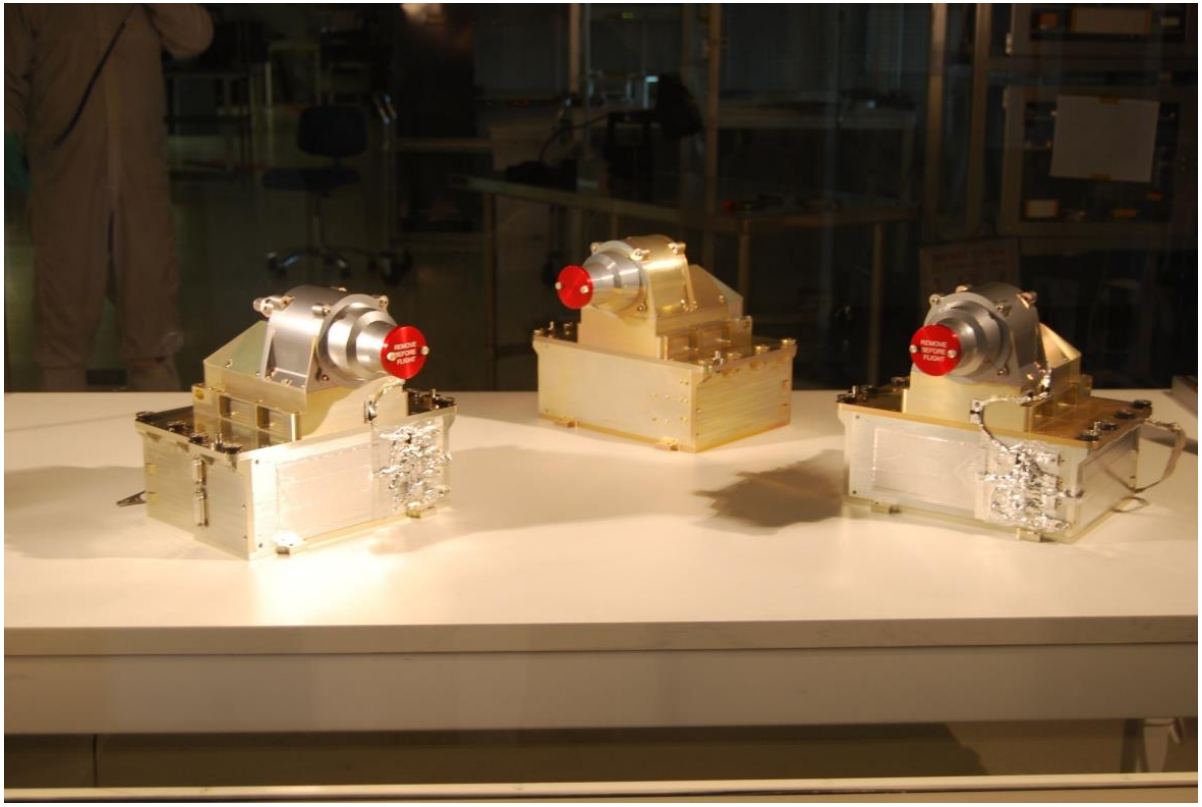
Relativistic Electron-Proton Telescope (REPT) Instrument



LASP-Built Instrument!

The Radiation Belt Storm Probes (RBSP) program

REPT Flight Units (Right/Left) and EM (Center)

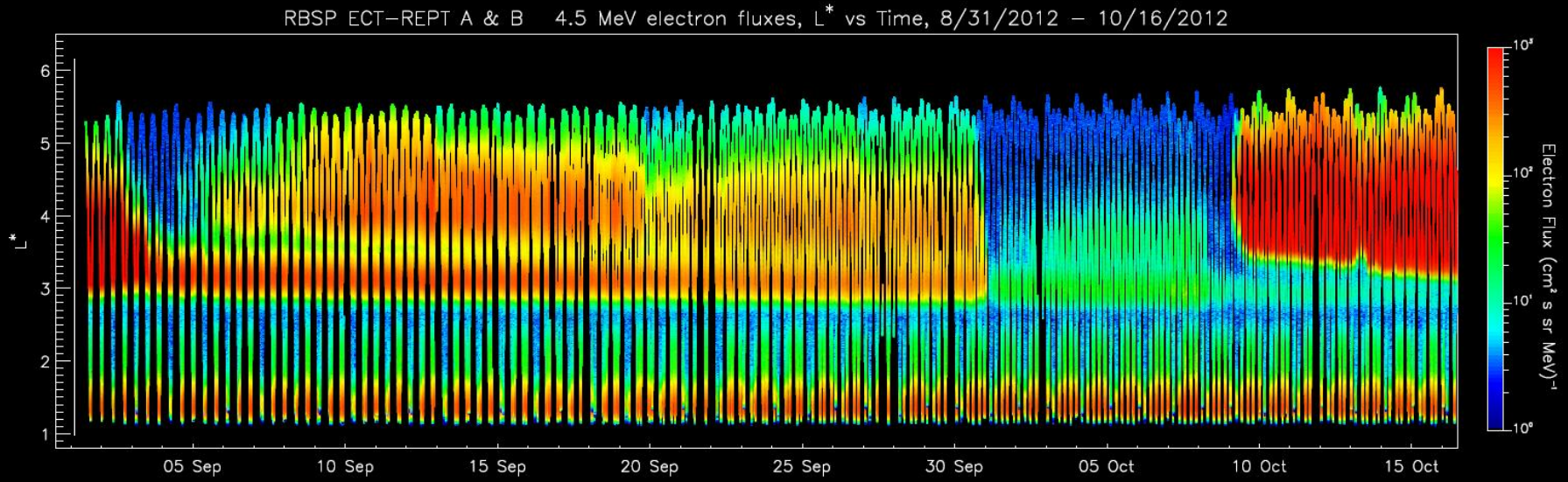


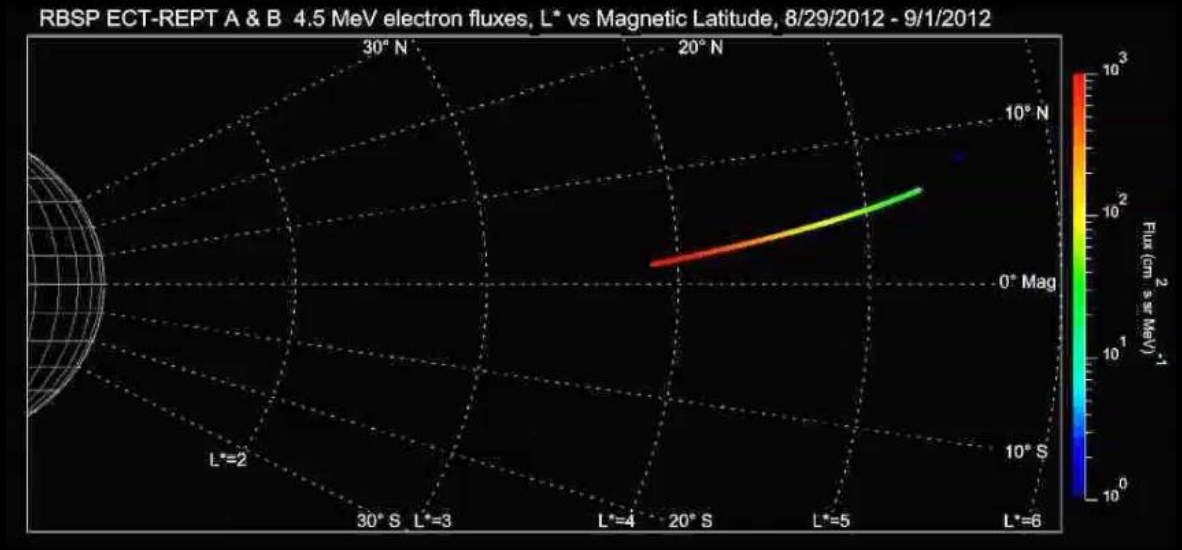
Relativistic Electron-Proton Telescope (REPT): $1 < E_e < 20$ MeV ; $15 < E_p < 200$ MeV

REPT addresses key scientific and programmatic goals of the NASA RBSP (LWS) program.

RBSP Launch—30 August 2012

Radiation Belt Evolution





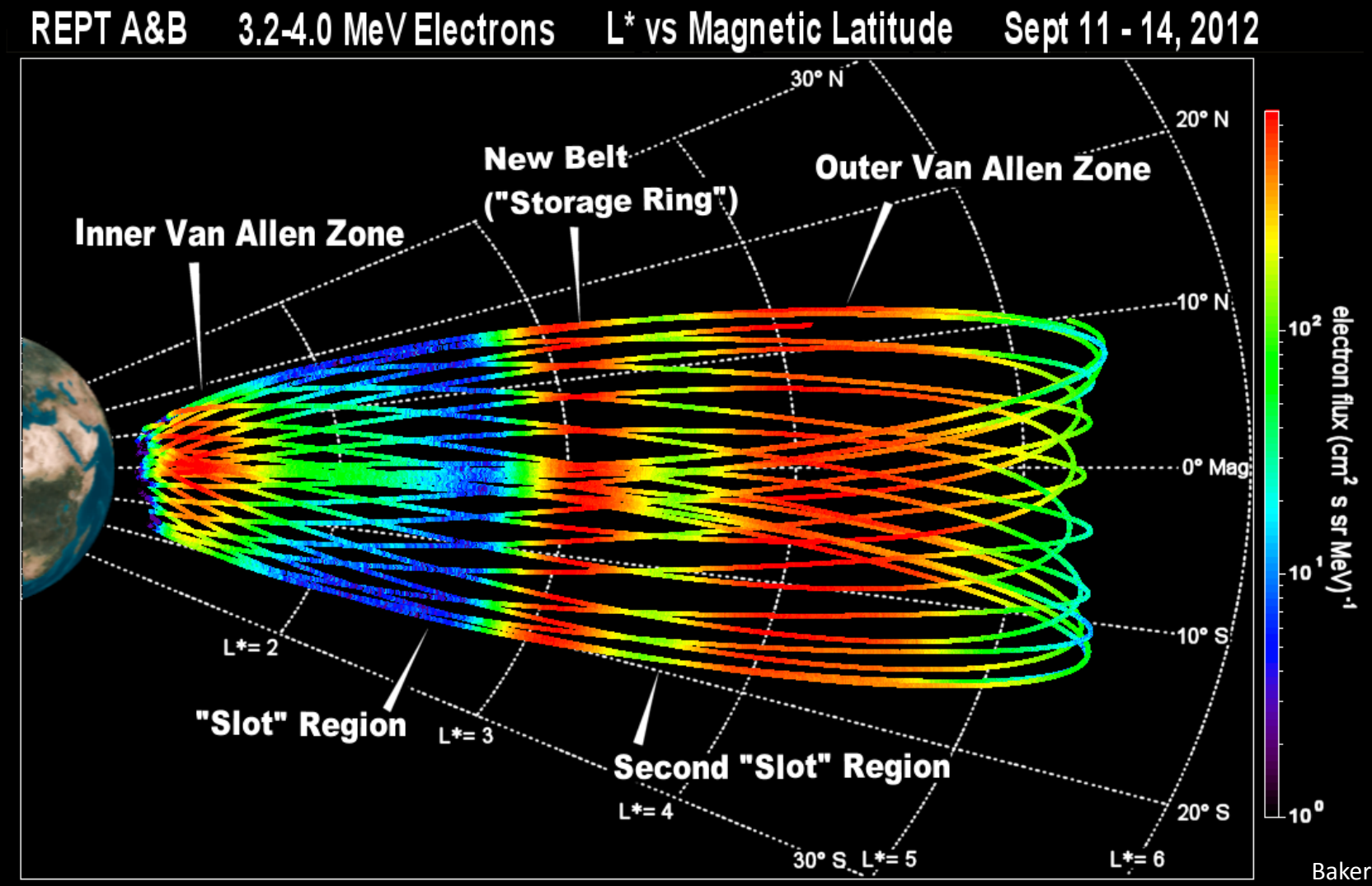
REPT L-shell sorted electron flux:

-Linear time plot (above)

-Meridional magnetic latitude plot (left), 3 days at a time.

Baker et al., Science, 2013

Rewriting Science Textbooks



Baker et al.,Eos

Remarkable Radiation Belt Results

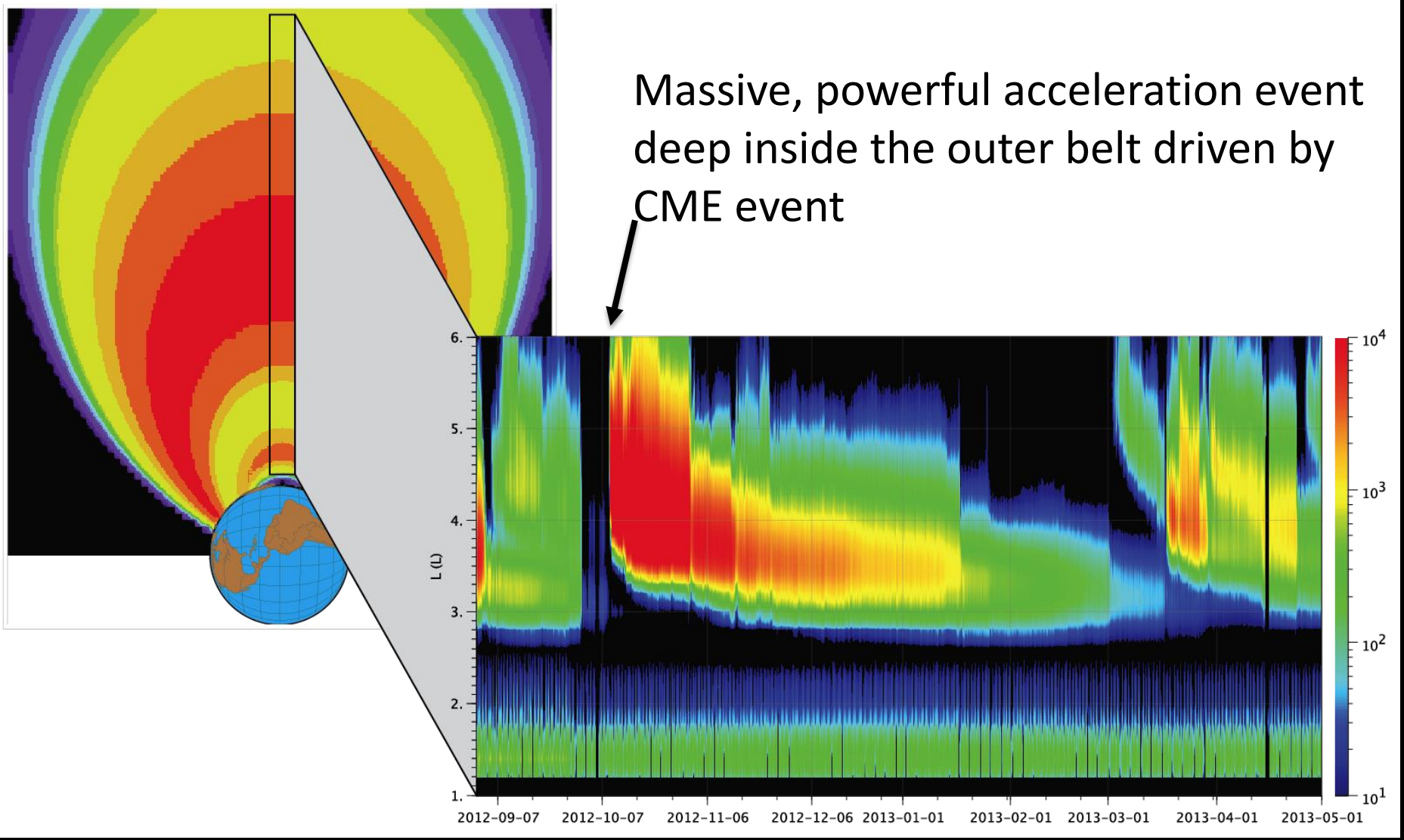
[Courtesy Andy Kale]

Science Express Online
28 February 2013

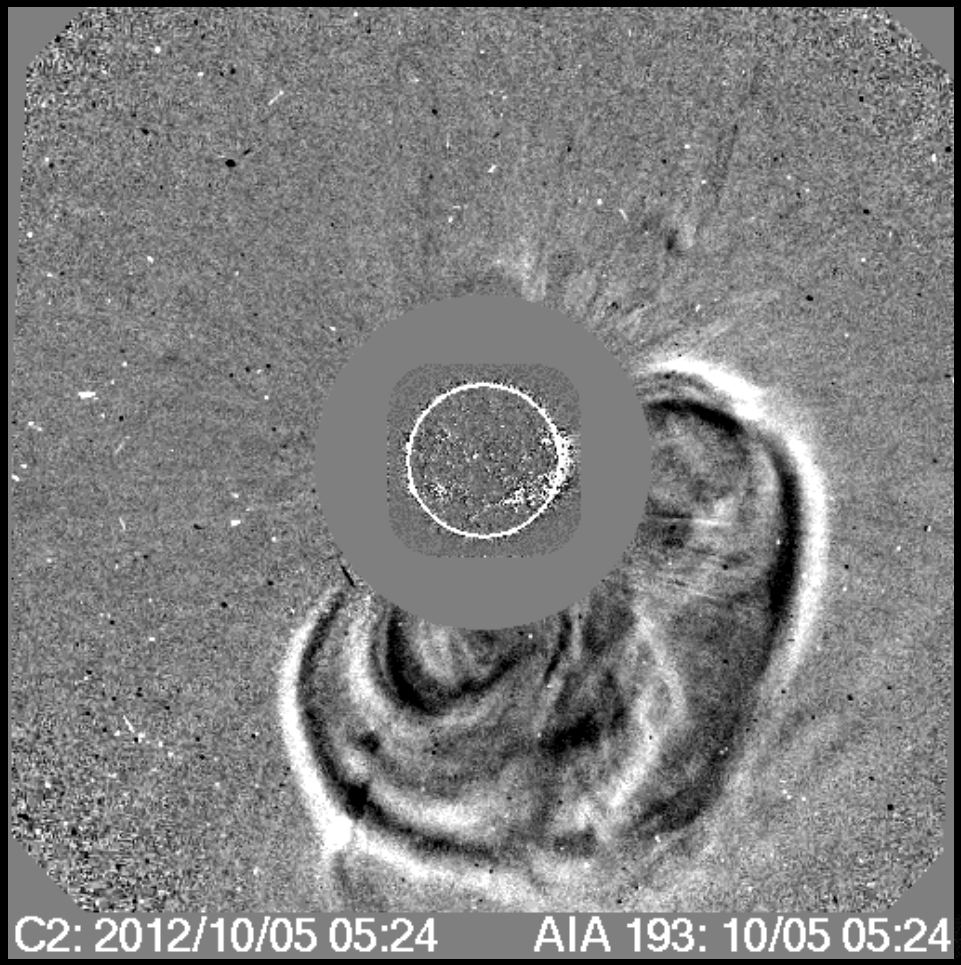
Science *Issue*
12 April 2013

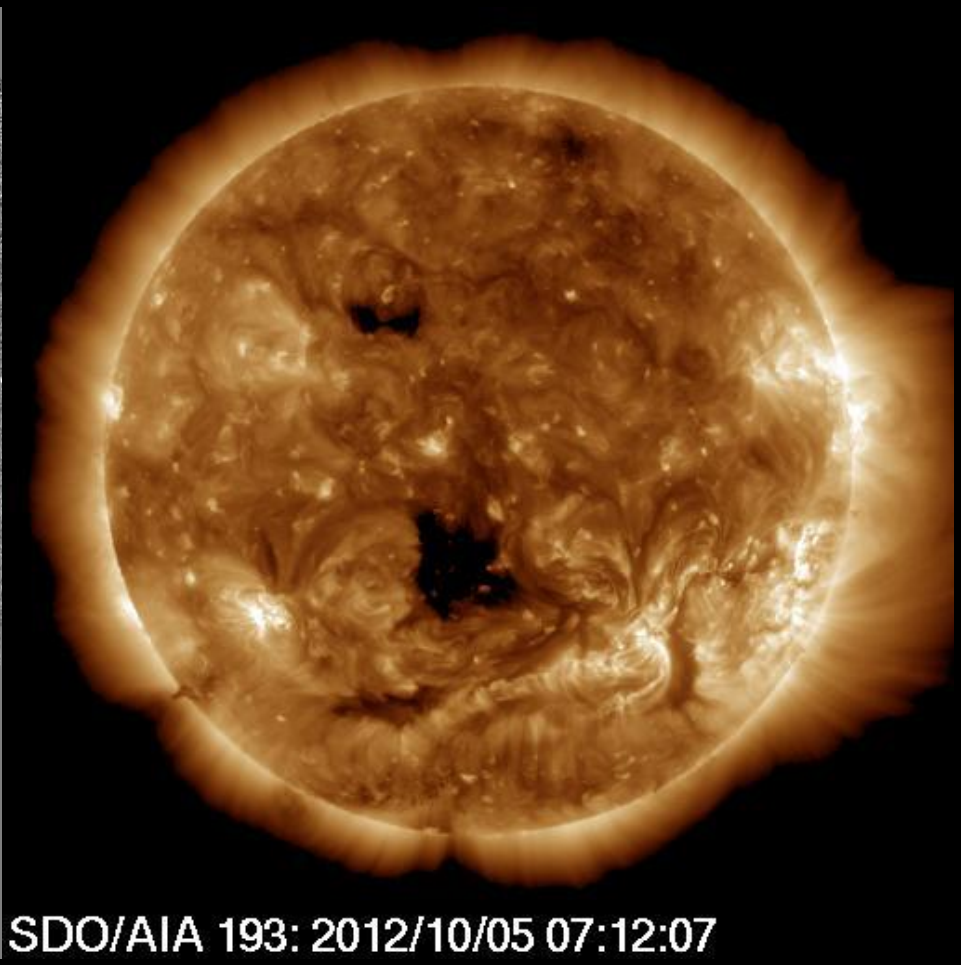
Baker et al., 2013

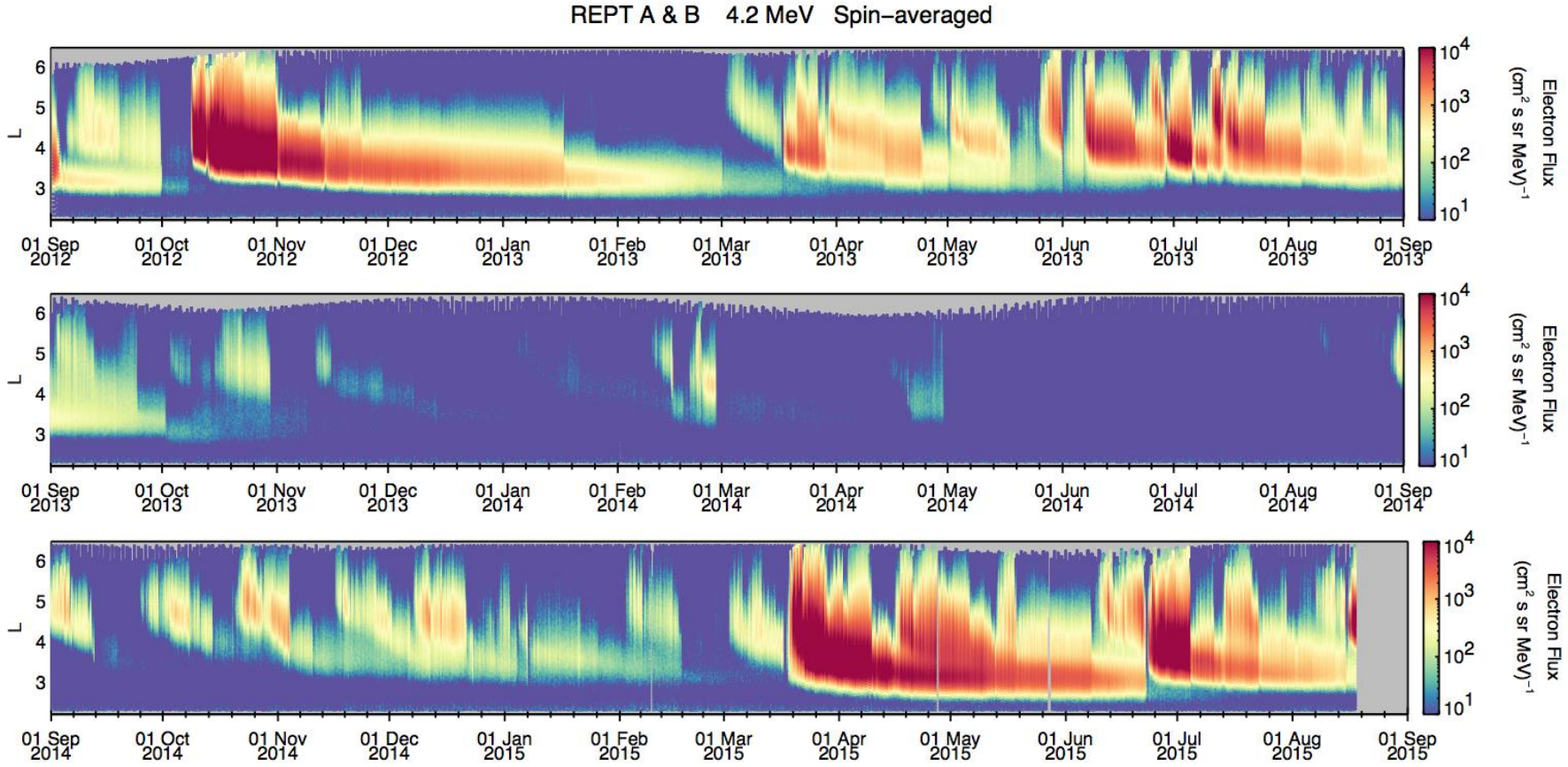
Complete Loss and Rapid Acceleration:
REPT on the Van Allen Probes



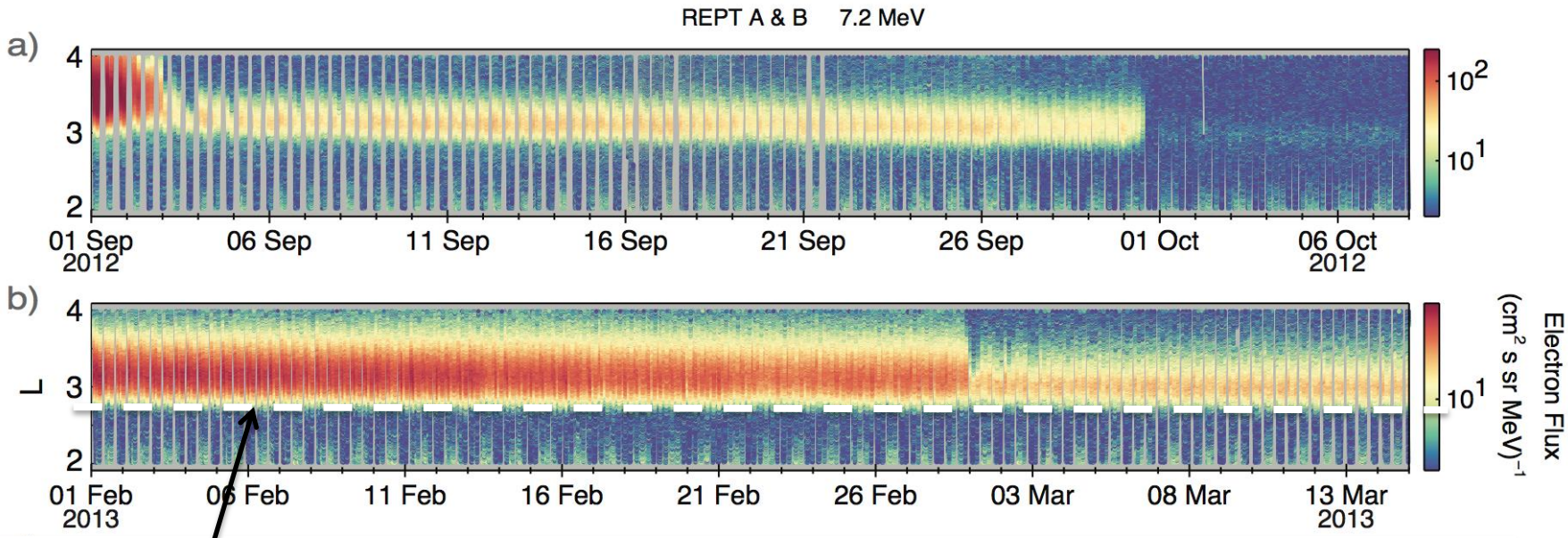
SDO: Solar Drivers of Earth Changes





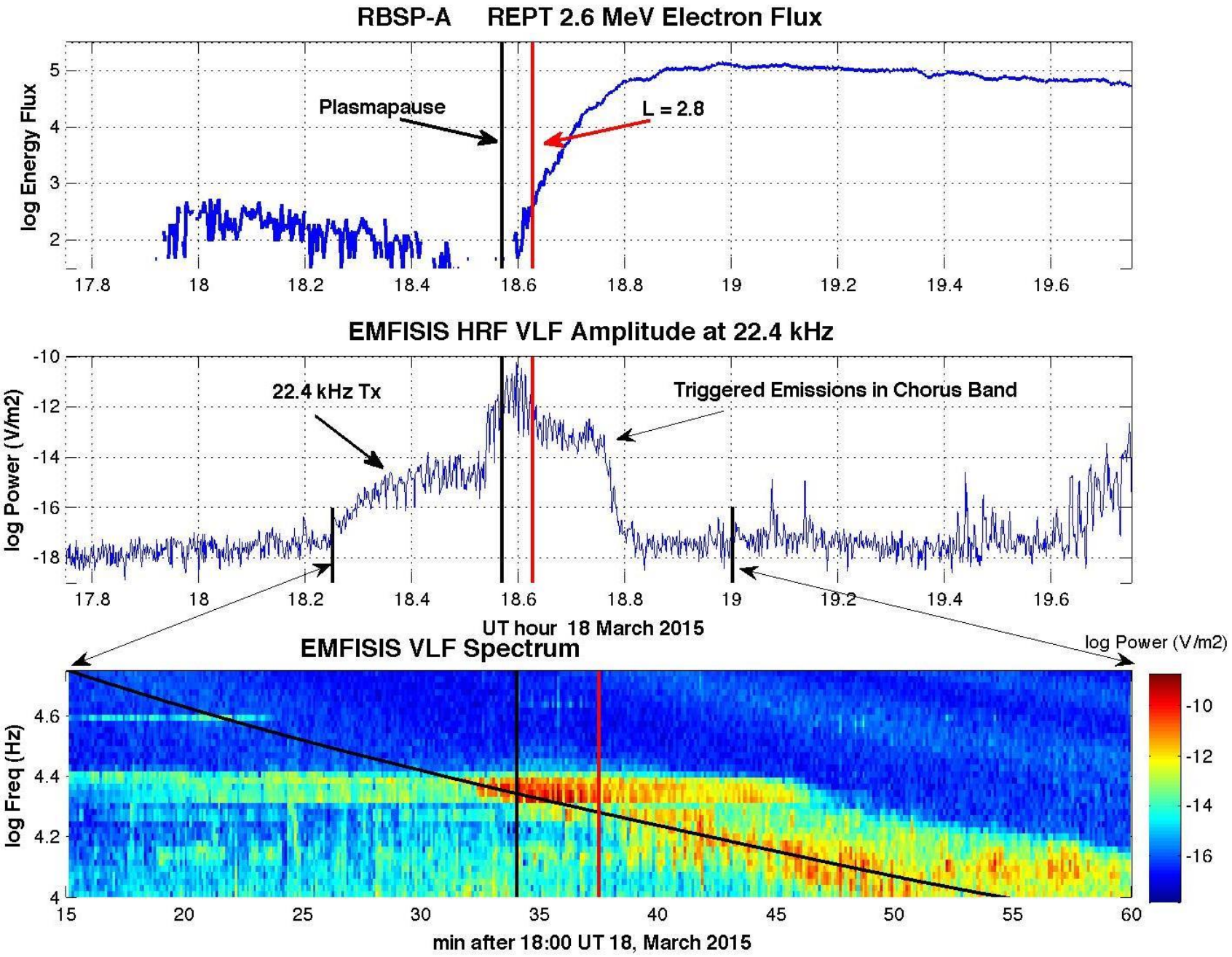

REPT A & B 4.2 MeV Spin−averaged
L
6
5
4
3
01 Sep 2012
01 Oct 2012
01 Nov 2012
01 Dec 2012
01 Jan 2013
01 Feb 2013
01 Mar 2013
01 Apr 2013
01 May 2013
01 Jun 2013
01 Jul 2013
01 Aug 2013
01 Sep 2013
01 Sep 2013
01 Oct 2013
01 Nov 2013
01 Dec 2013
01 Jan 2014
01 Feb 2014
01 Mar 2014
01 Apr 2014
01 May 2014
01 Jun 2014
01 Jul 2014
01 Aug 2014
01 Sep 2014
01 Sep 2014
01 Oct 2014
01 Nov 2014
01 Dec 2014
01 Jan 2015
01 Feb 2015
01 Mar 2015
01 Apr 2015
01 May 2015
01 Jun 2015
01 Jul 2015
01 Aug 2015
01 Sep 2015
10^4
10^3
10^2
10^1
Electron Flux
(cm^2 s sr MeV)$^{-1}$

An Impenetrable Barrier?



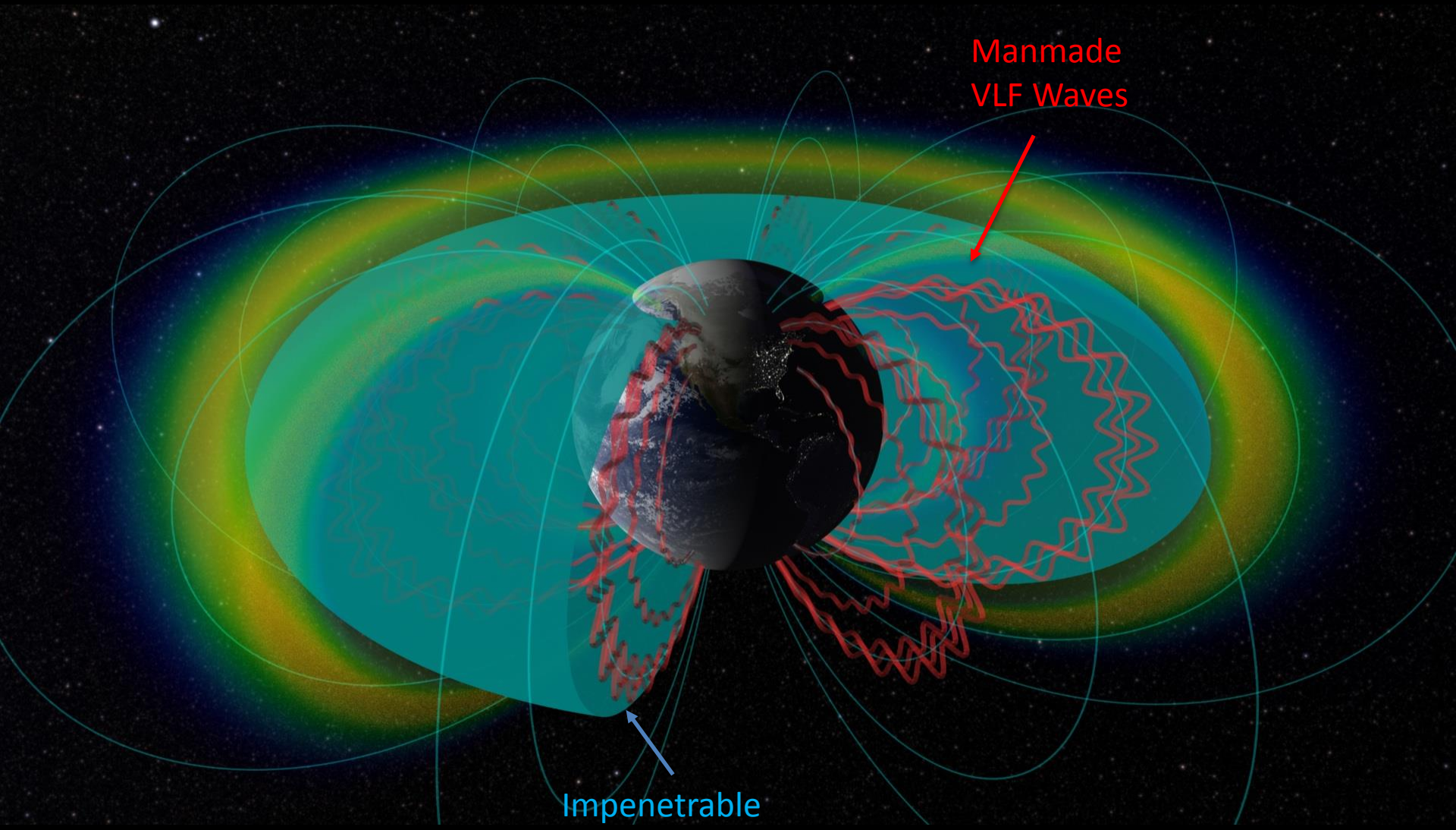
Ultrarelativistic electrons seem never to penetrate inward of L~2.8

Baker et al., Nature, 2014



Foster, Baker, Erickson,…(2015)

Electron Barrier and VLF Bubble



LASP Colorado Student Space Weather Experiment

CSSWE studies violent solar flares and their effects on Earth's radiation belt electrons.

- NSF-funded CubeSat mission
- Designed, built, and tested by CU-Boulder students

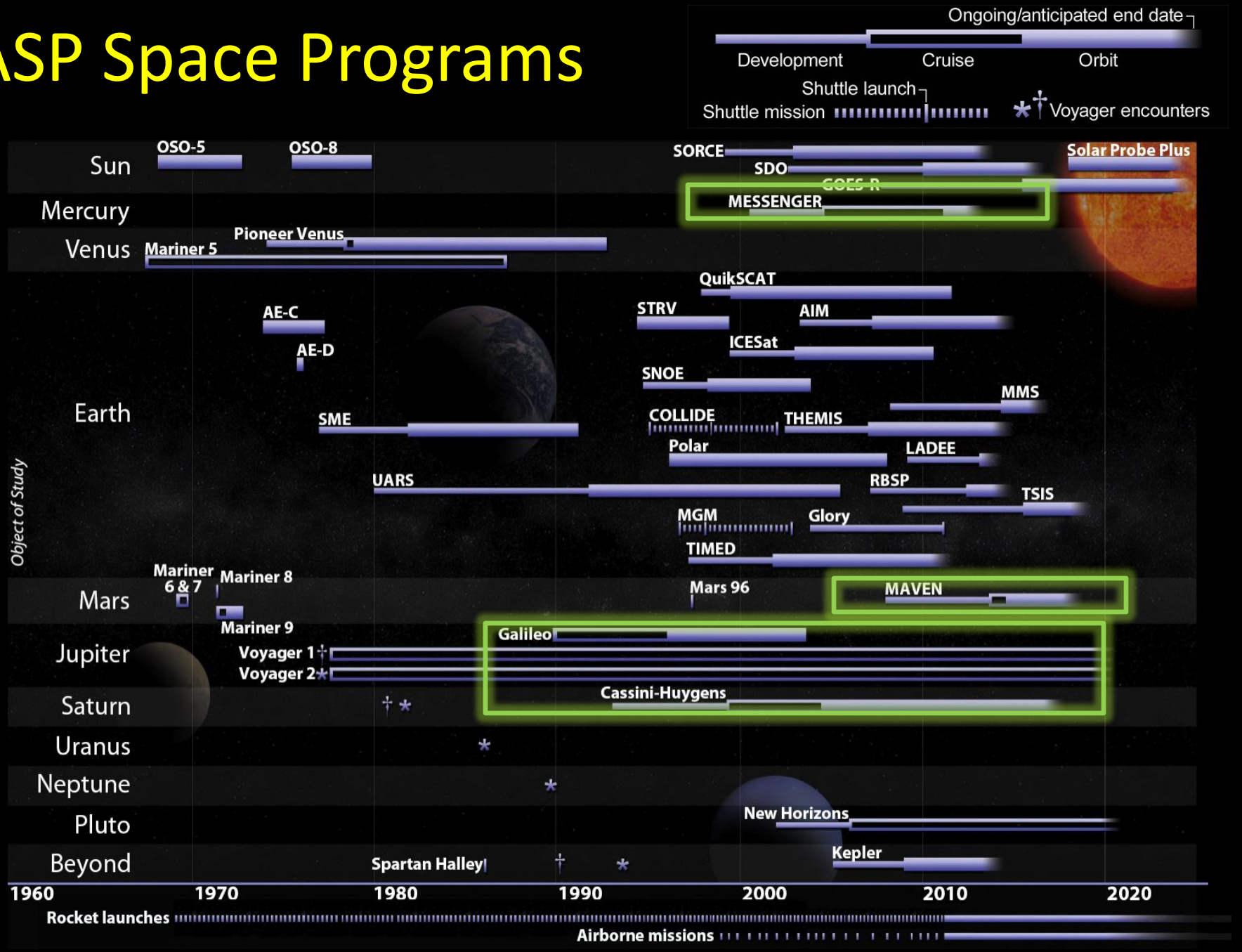
The LASP/CSSWE team poses near a LASP Mission Operations room in 2011. CSSWE houses the Relativistic Electron and Proton Telescope integrated little experiment (REPTile). (Courtesy LASP)

The LASP/CSSWE launched onboard the Atlas 5 rocket on September 13, 2012, from the Vandenberg Air Force Base in California. (Courtesy United Launch Alliance)

Current update:

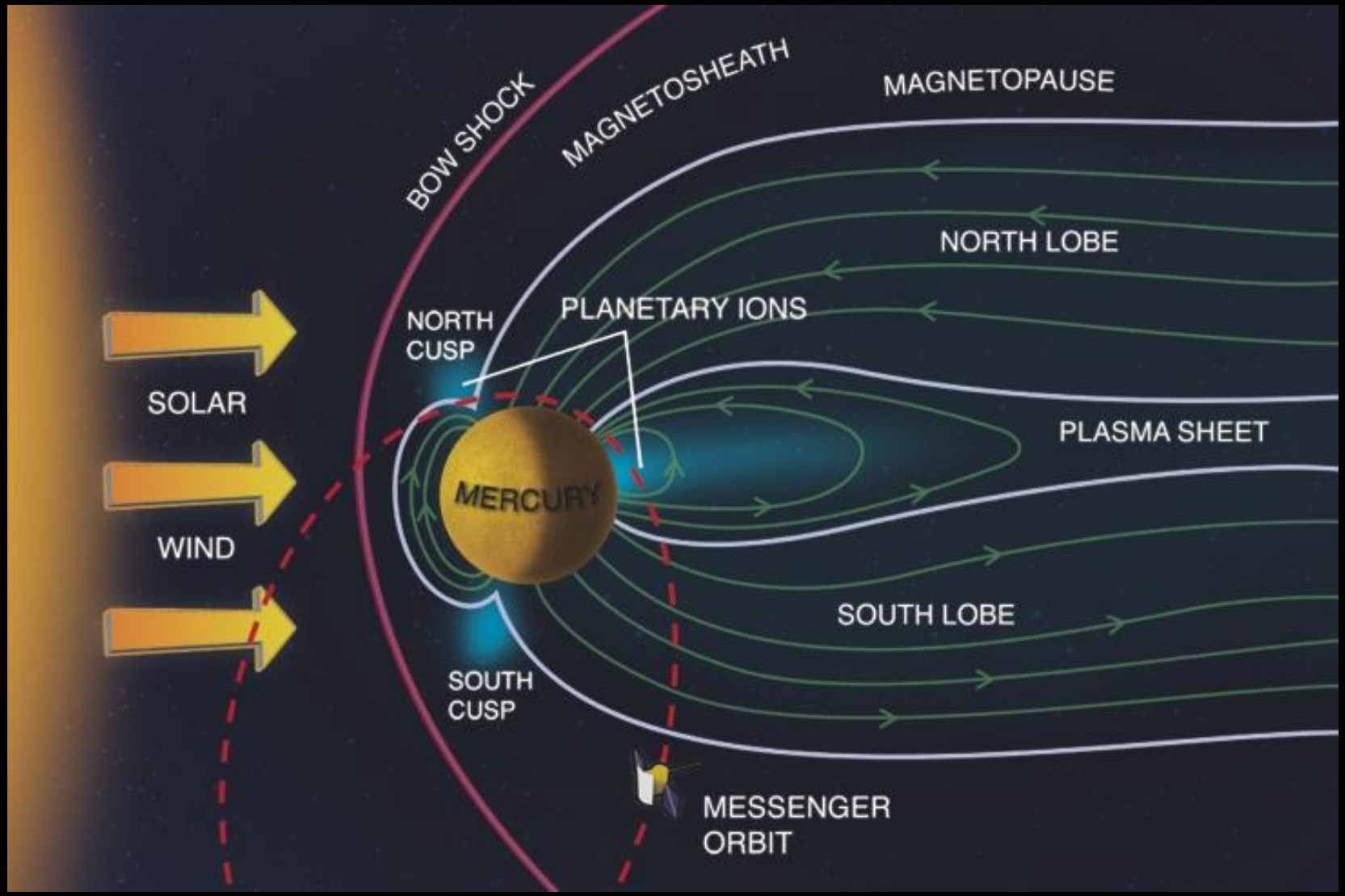
- Launched and deployed September 13, 2012
- First beacons received September 14, 2012
- Systems operated successfully: Telemetry, voltages, and temperatures nominal
- Science operations Oct. 2012 – Present

LASP Space Programs



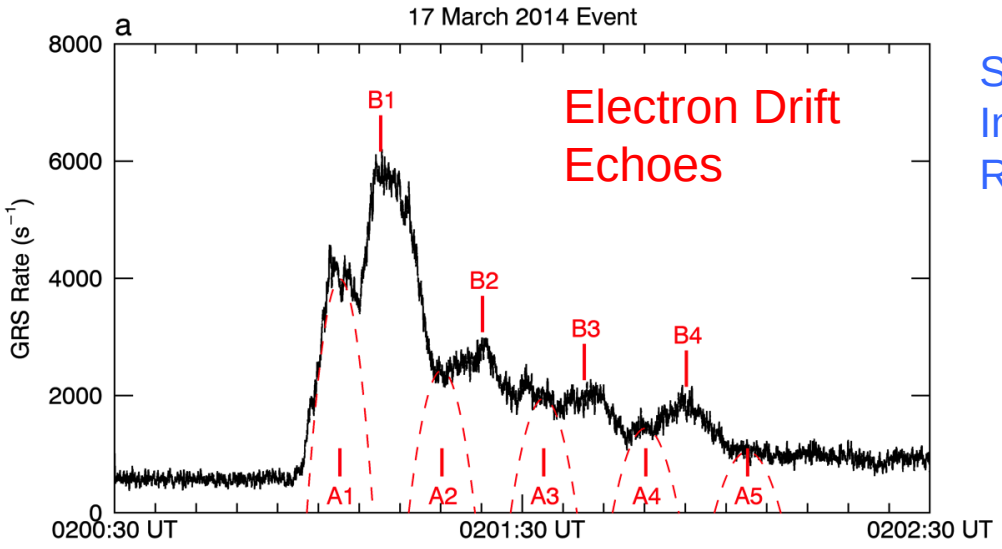
Mercury MESSENGER

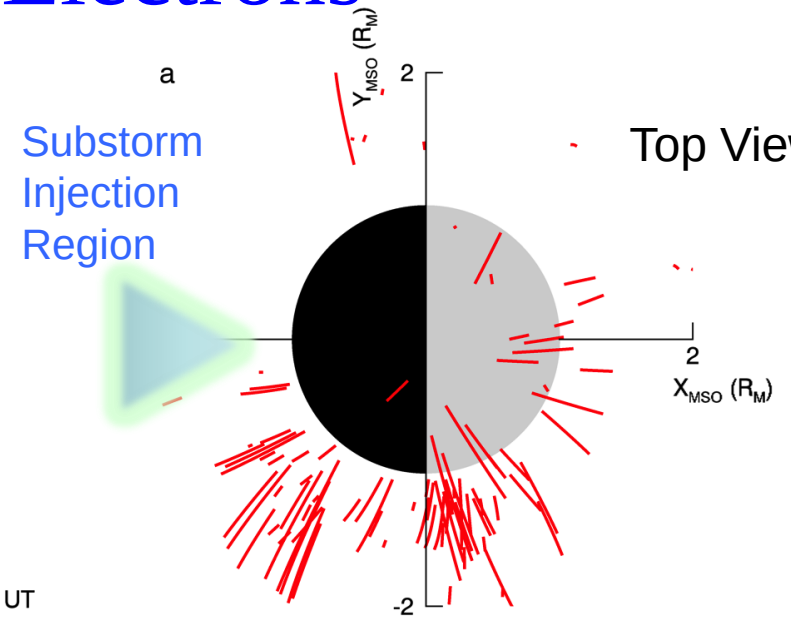
MESSENGER: The Mercury System

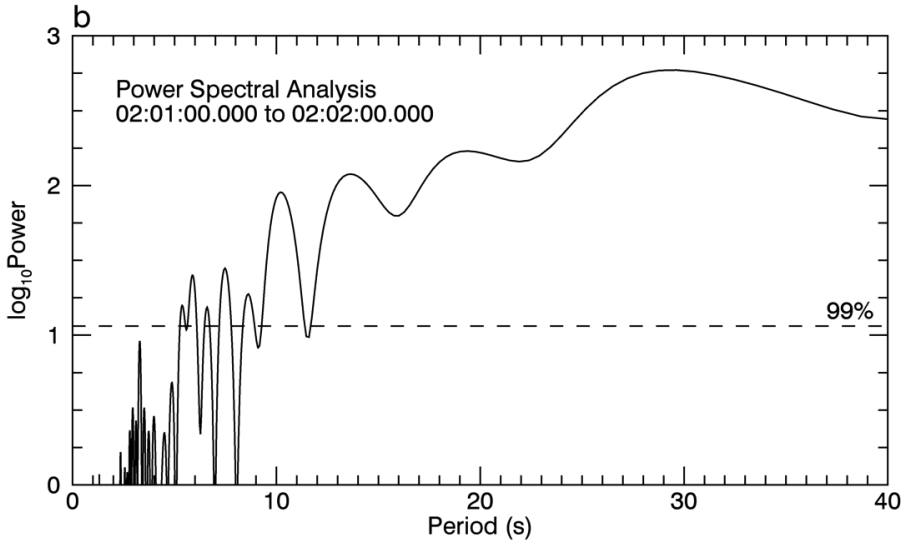


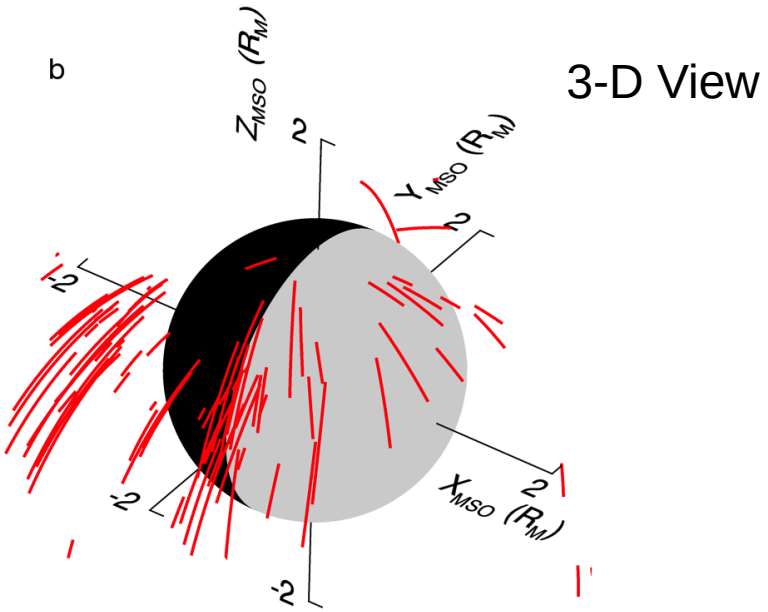
Zurbuchen et al., ***Science***, 2011

MESSENGER Energetic Electrons









[Baker et al., JGR, 2015]

MAVEN

Mars Atmosphere and Volatile EvolutioN (MAVEN) Mission

Mars Scout Mission
Launched: 2013

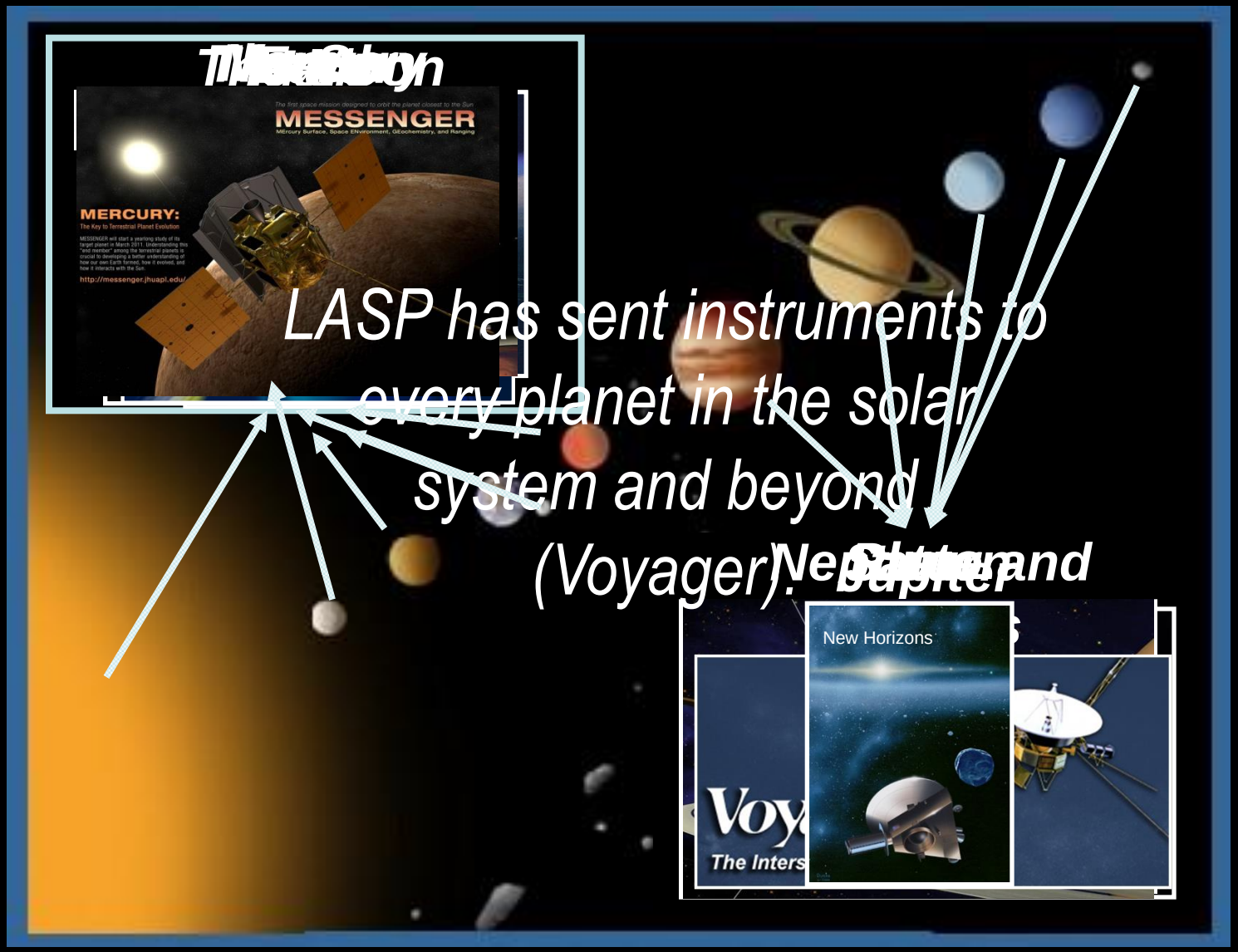
Key Understanding of Mars

Solar wind-planetary interactions
— Evolution and loss of atmosphere

Inference of historical changes
— Interpreting water loss from planet

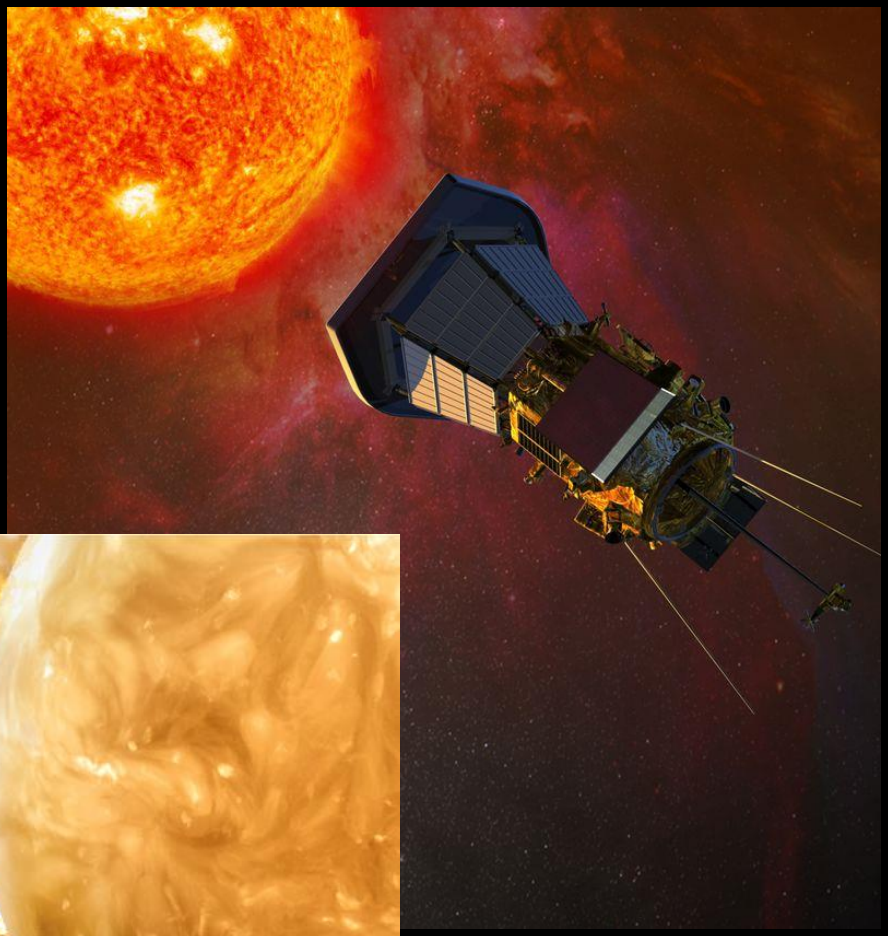
Program carried out as Scout mission
— PI-led project (LASP/UCB/GSFC)

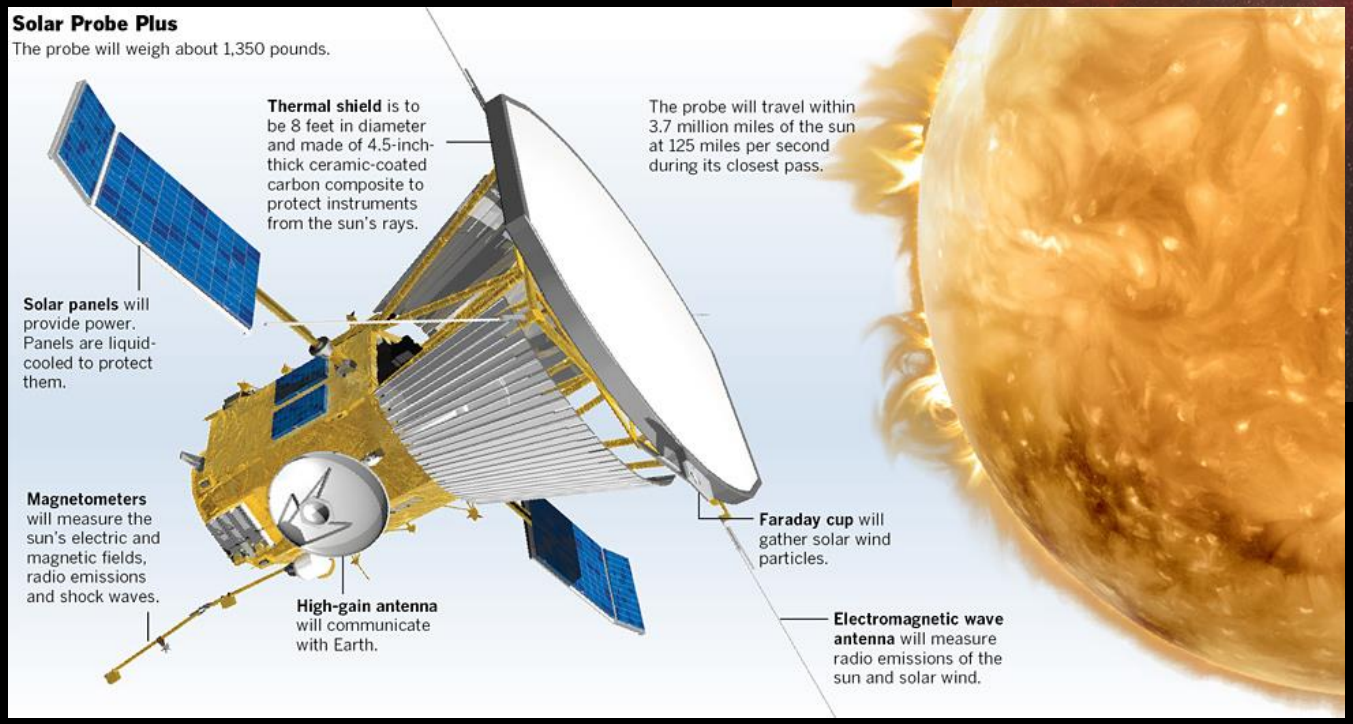
LASP Space Investigations



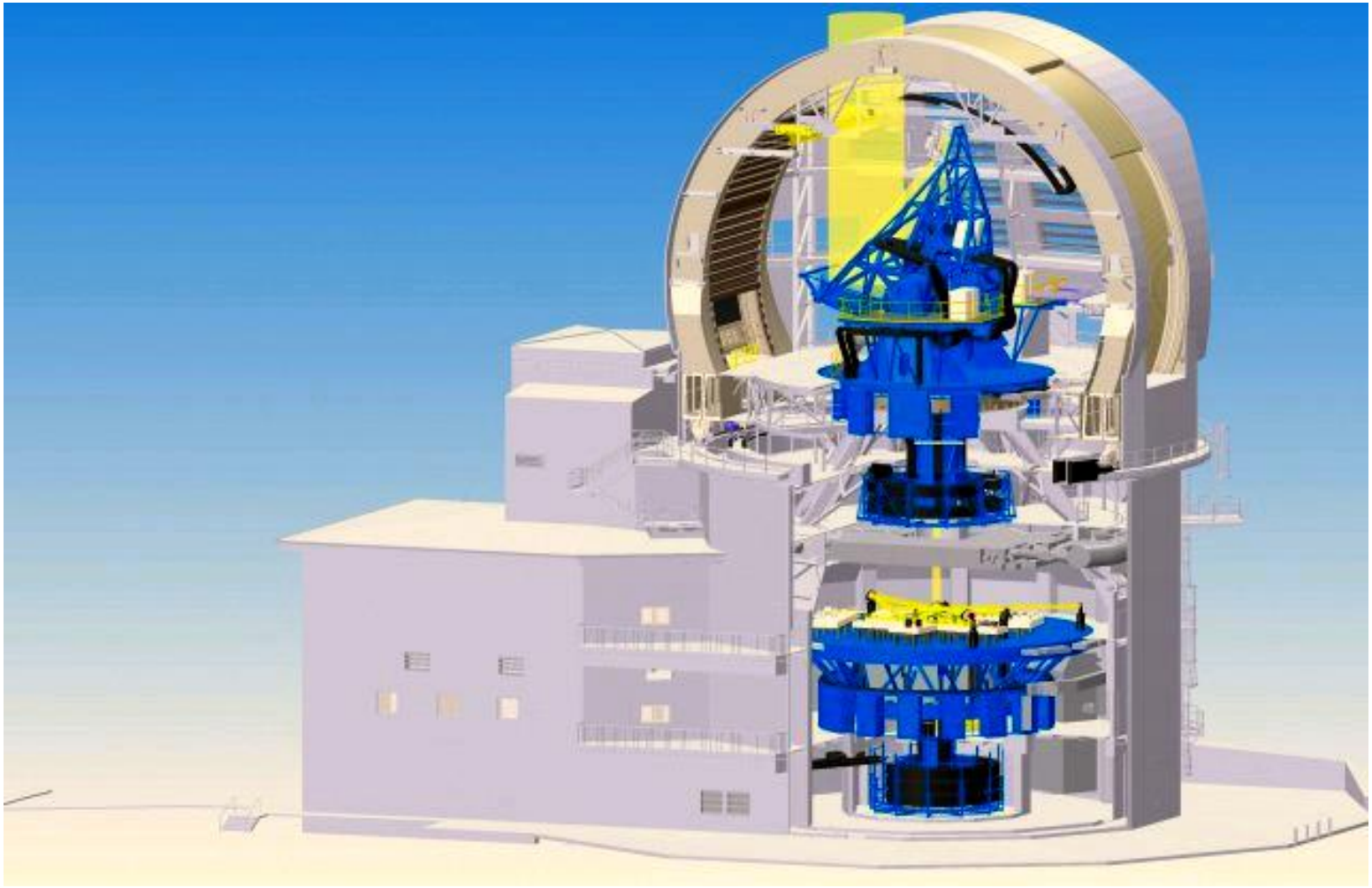
Solar Probe Plus - 2018

Multiple deep passes into solar corona

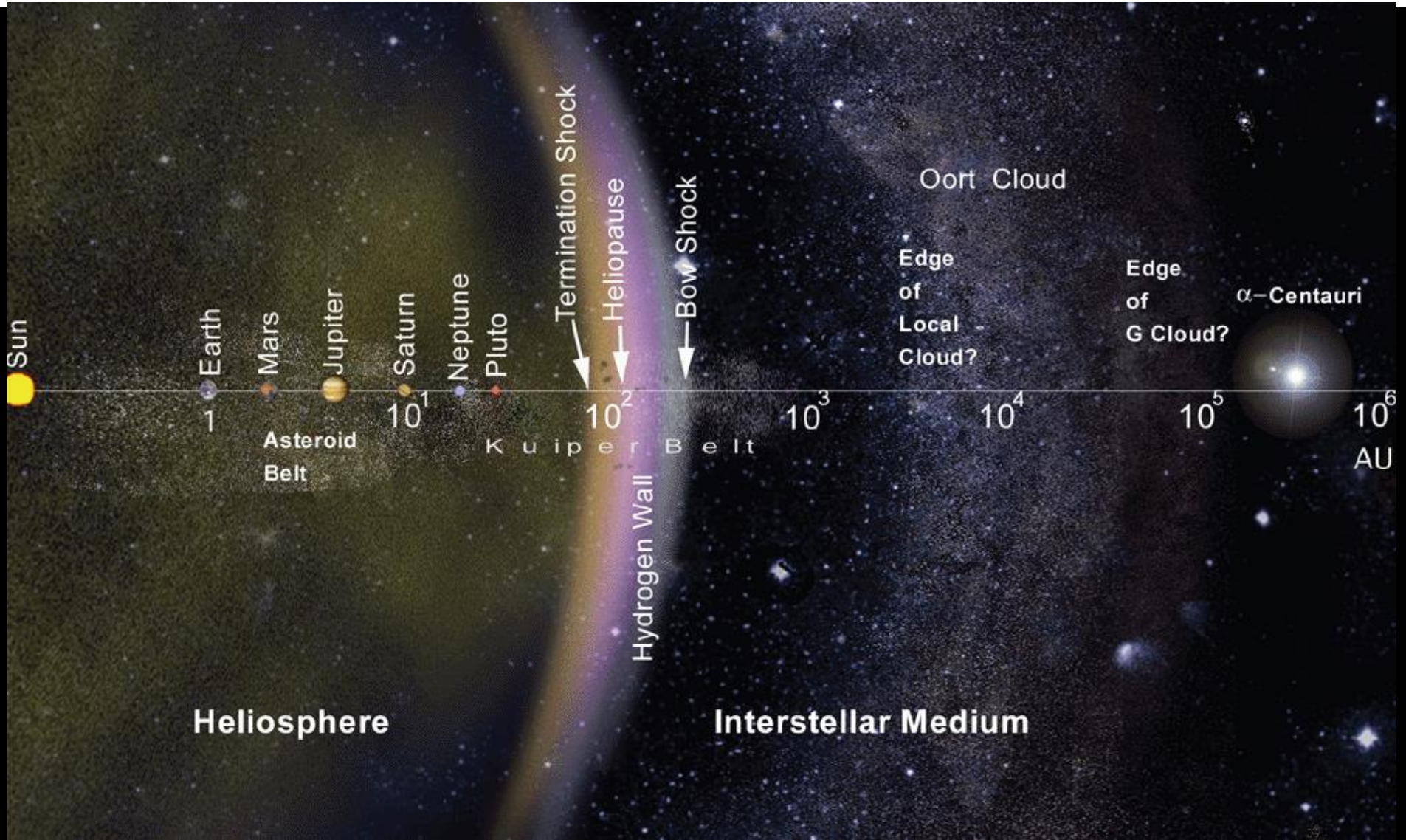




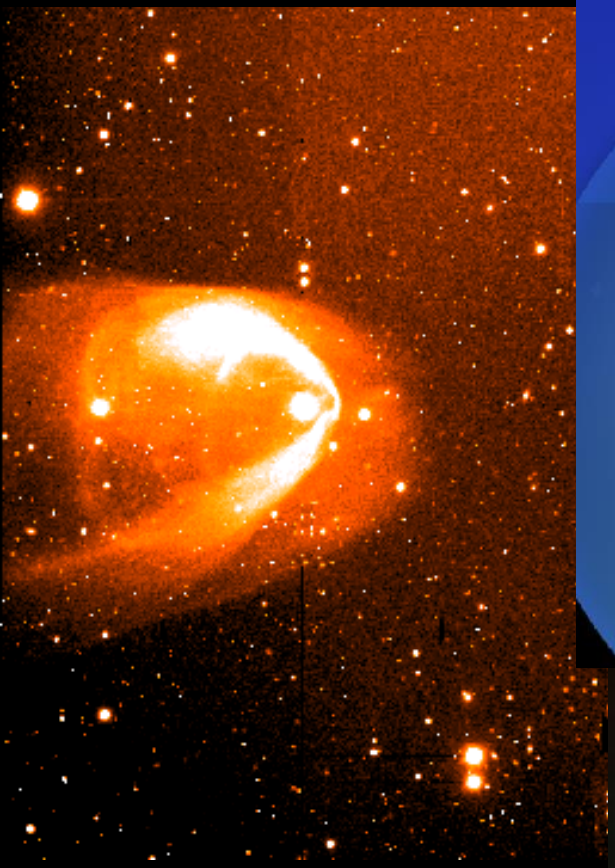
NSF's Daniel K. Inouye Solar Telescope ~ 2018

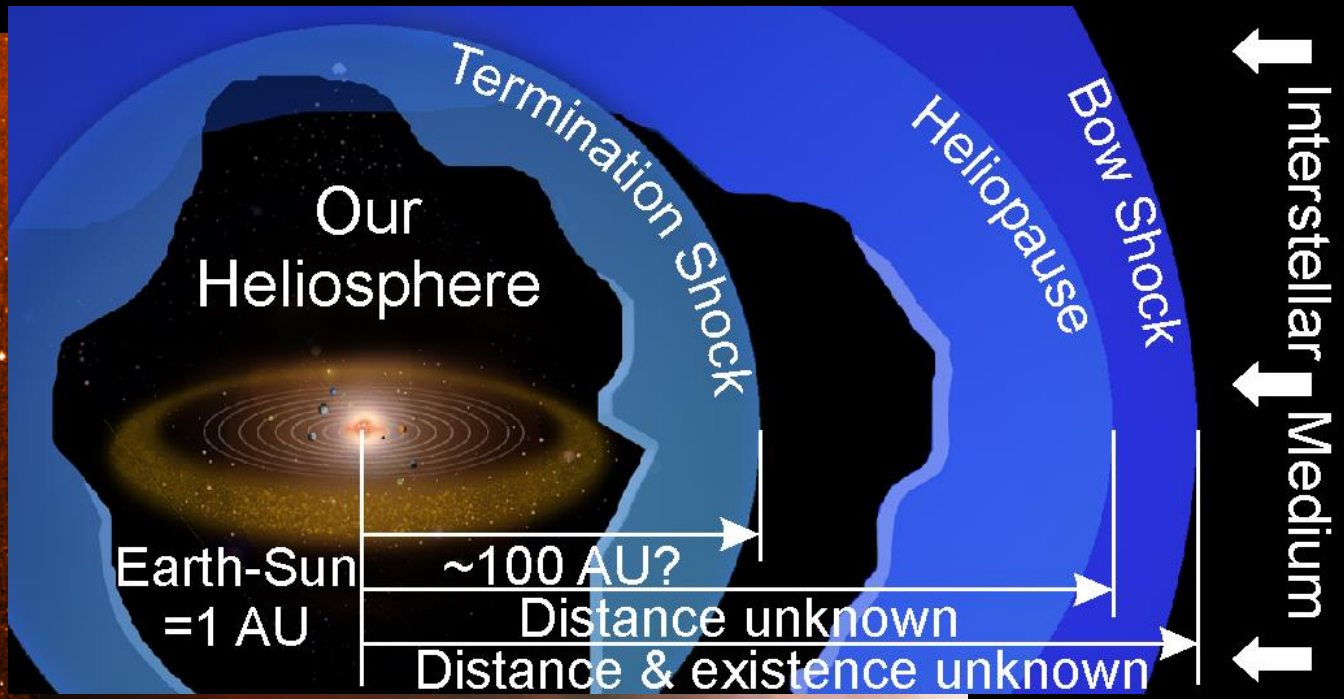


Our Place in the Universe



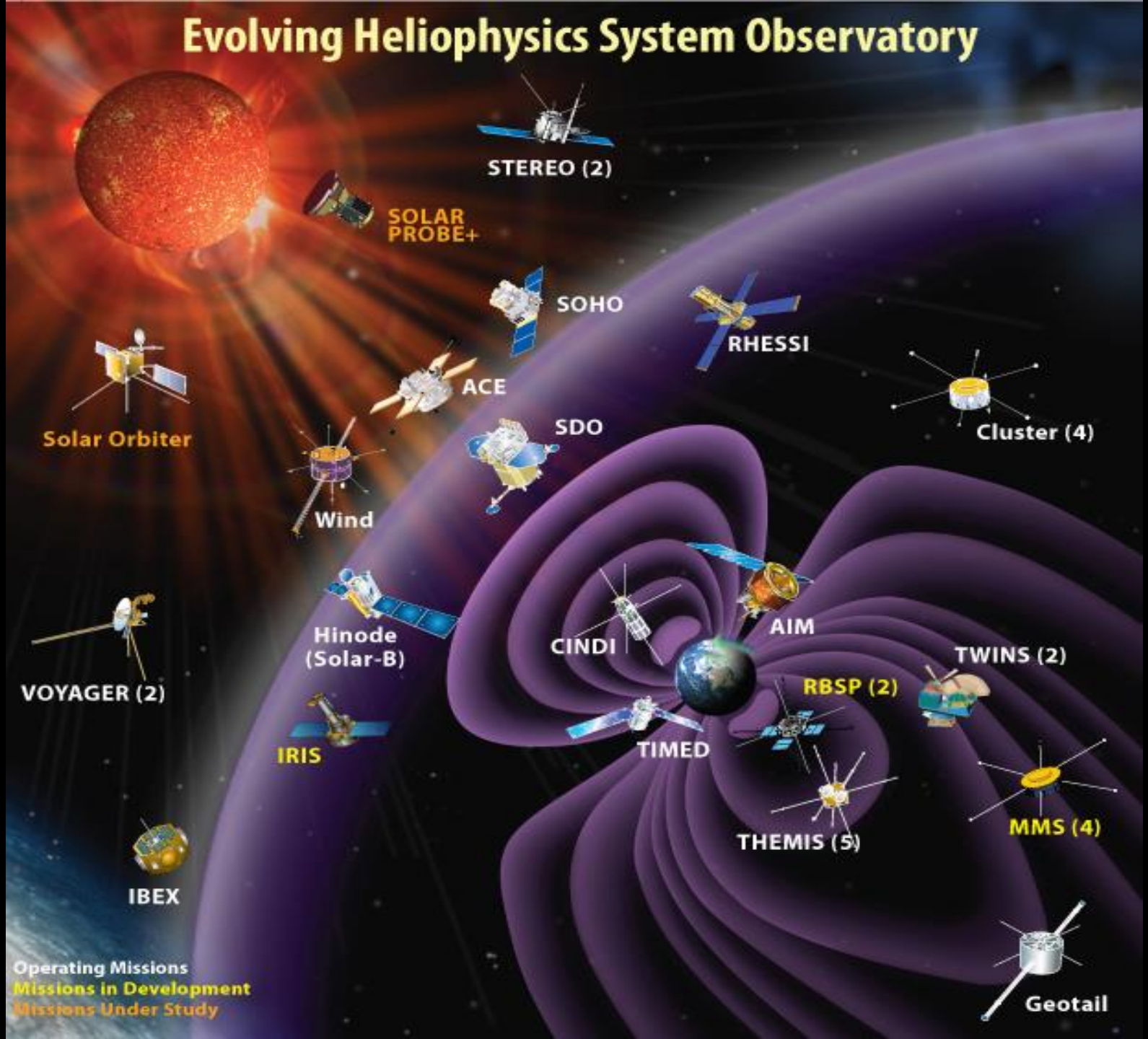
Astrospheres and Our Heliosphere





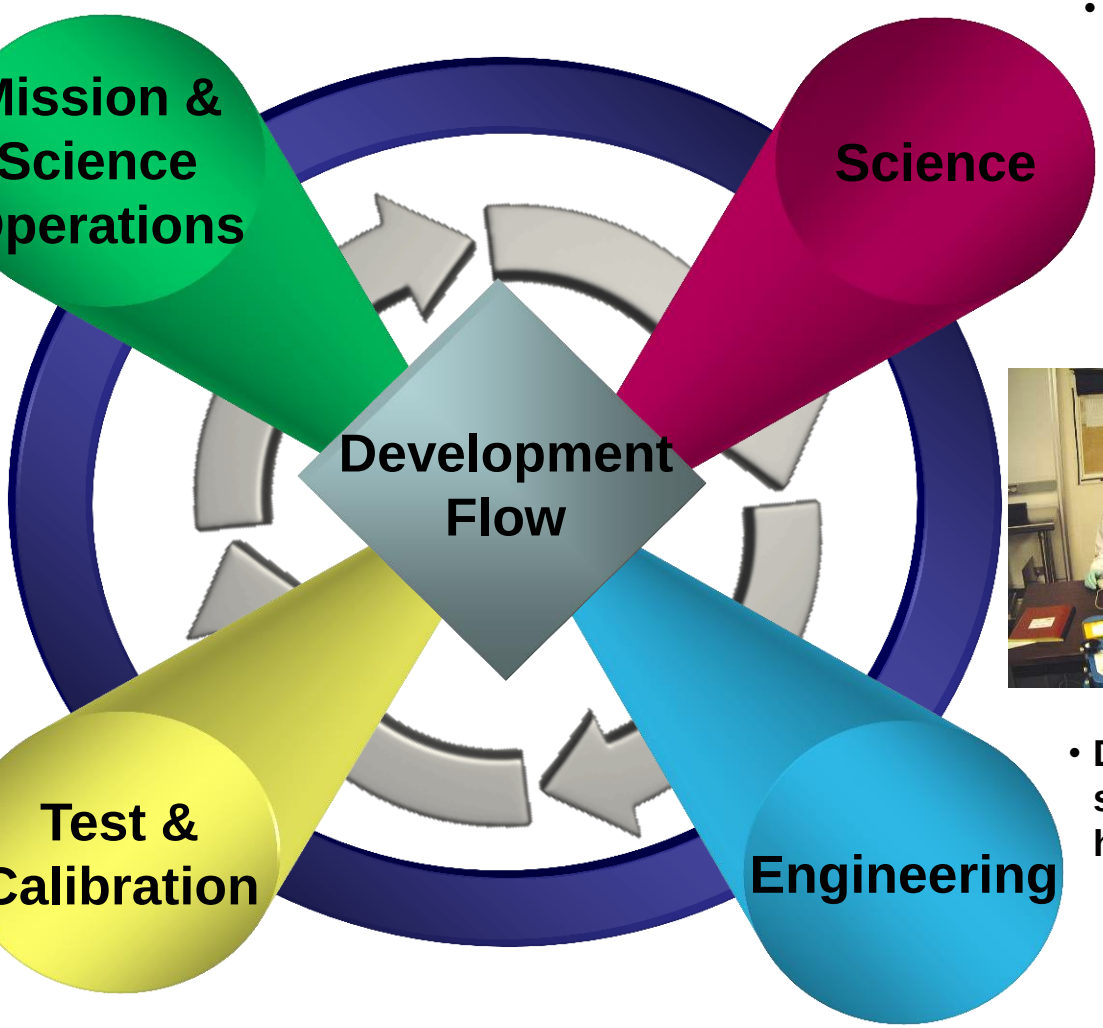
Left image courtesy of R. Casalegno, C. Conselice et al., WIYN, NOAO

Other images from HubbleSite.org


Evolving Heliophysics System Observatory
STEREO (2)
SOLAR PROBE+
SOHO
RHESSI
ACE
Solar Orbiter
SDO
Cluster (4)
Wind
Hinode (Solar-B)
AIM
CINDI
TWINS (2)
VOYAGER (2)
RBSP (2)
TIMED
IRIS
MMS (4)
THEMIS (5)
IBEX
Geotail
Operating Missions
Missions in Development
Missions Under Study

Unique Synergism within LASP

Student Involvement Throughout



- Spacecraft Operations
- Payload Operations
- Science Data Analysis
- Mission Scheduling

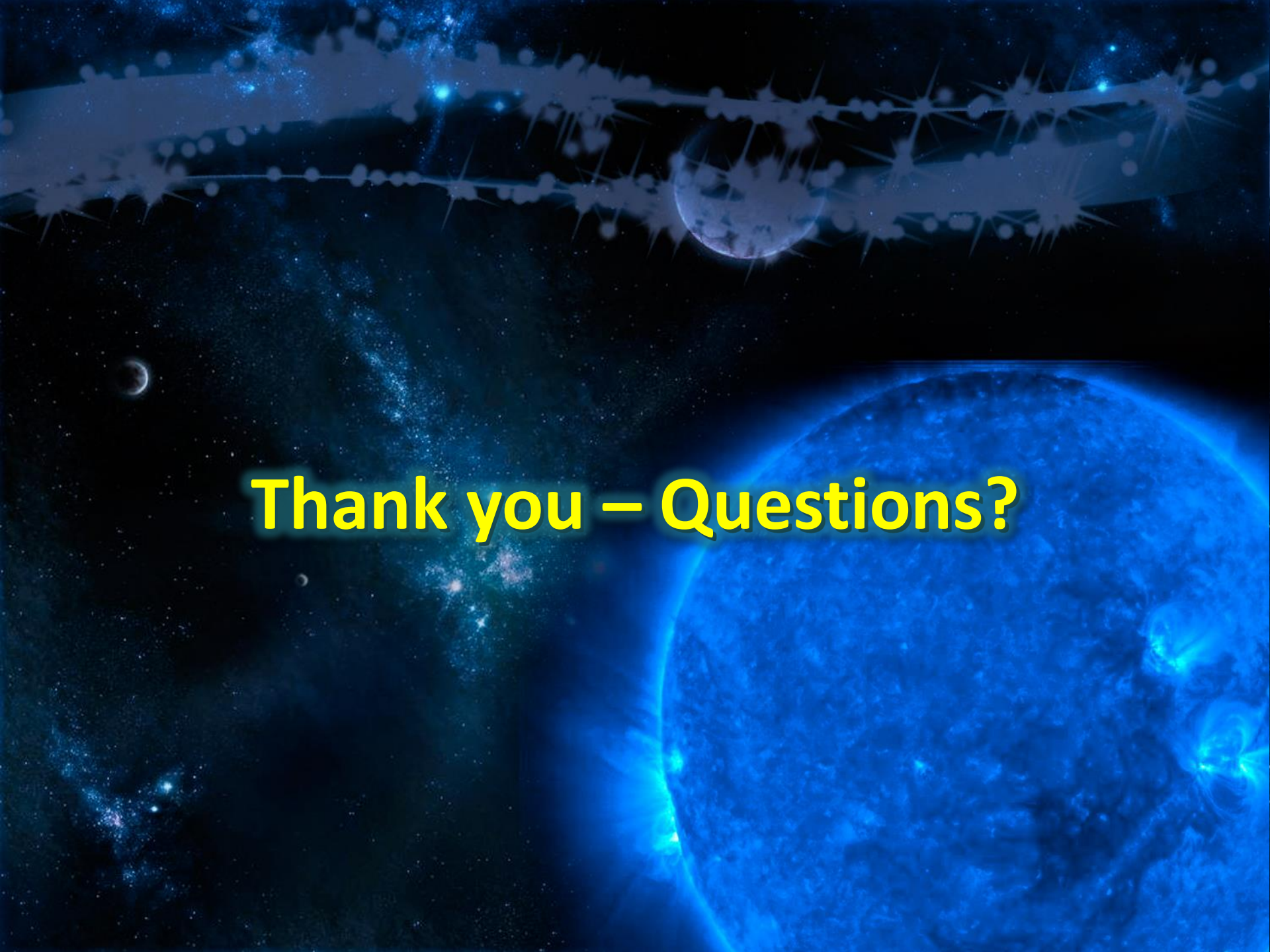
- In-House Facilities

- Identify/Address Space Science Questions
  - Planetary
  - Atmospheric
  - Solar
  - Space Physics

- Design, build, test space system hardware

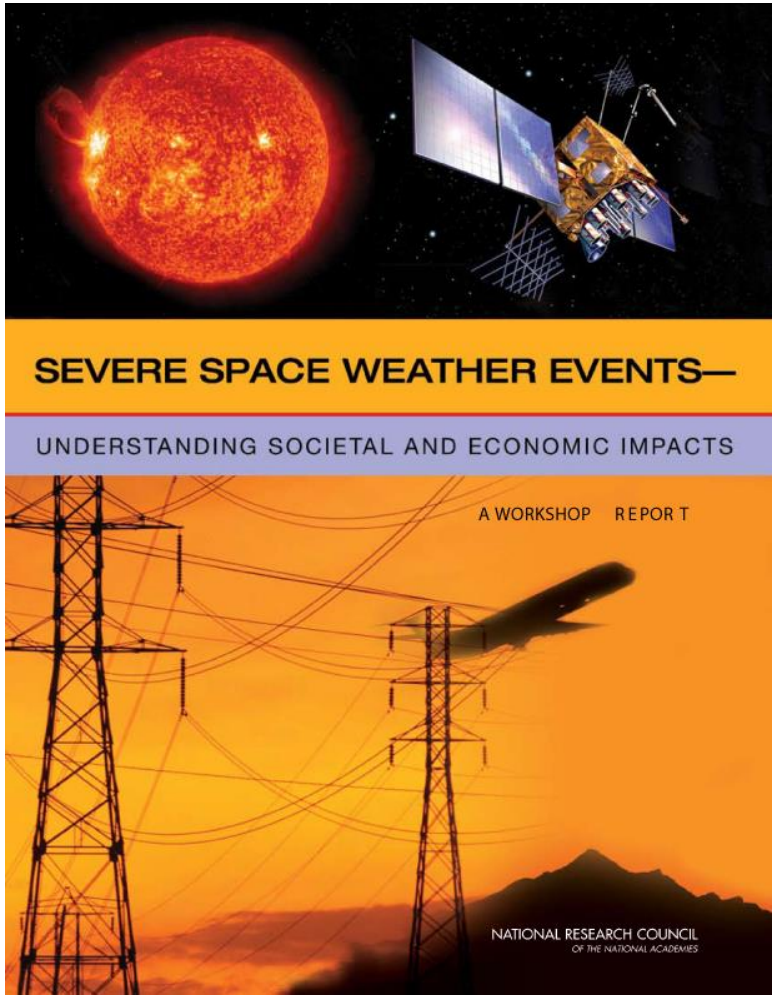
Summary

- LASP traces its origins back over 65 years to the Upper Air Laboratory of CU-Boulder.
- Space physics observations of the Sun and Earth's space environment have been central to the LASP mission from the very beginning.
- Wide-ranging modern measurements of plasmas, energetic particles, and fields in space place LASP at the forefront of international space physics research.
- The application of LASP scientific knowledge and technical prowess to space weather issues also places the Lab in an important position of societal relevance in our modern technological society.


Thank you – Questions?

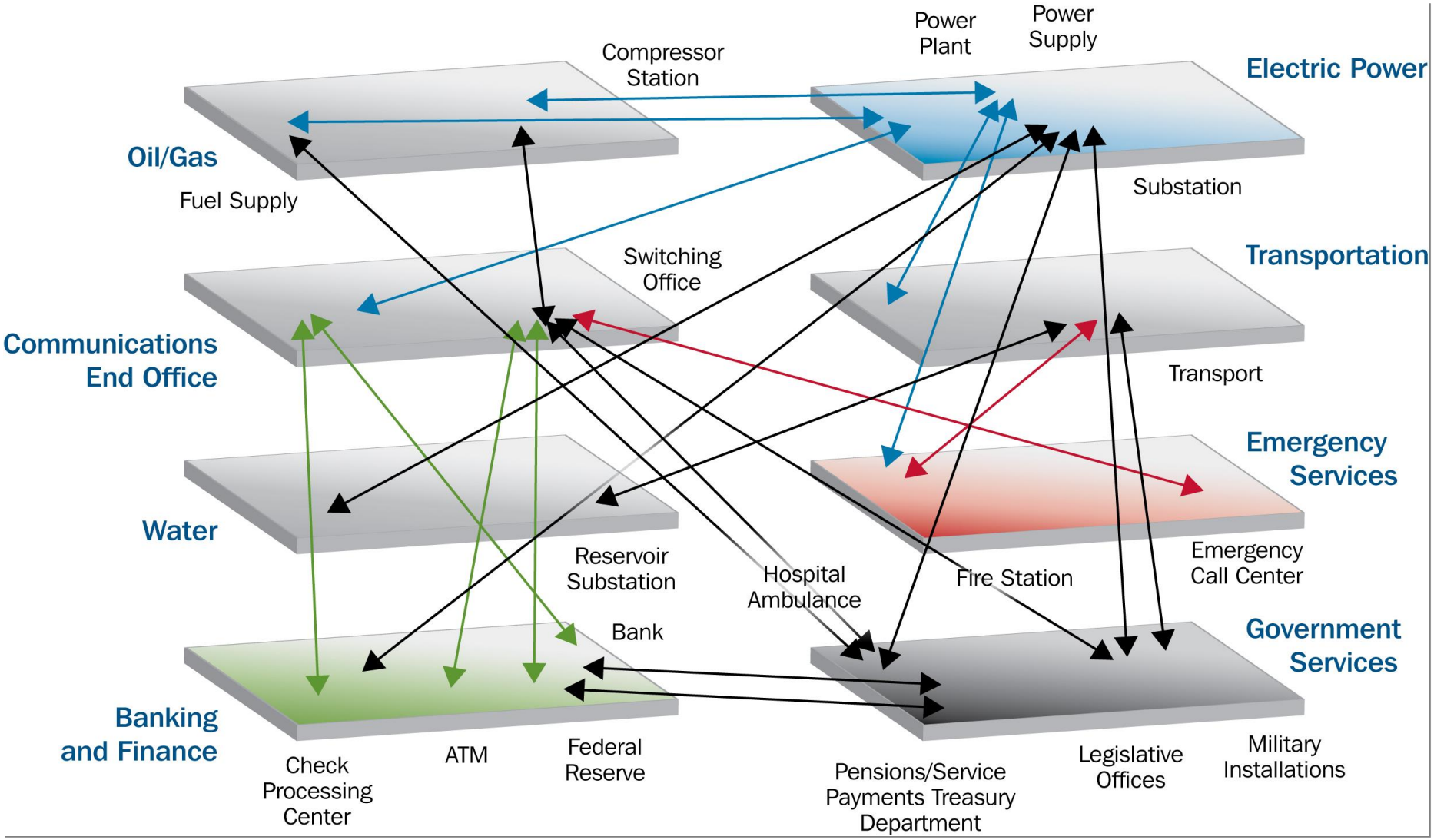
The Societal and Economic Impacts of Severe Space Weather Events

- *May 22-23, 2008 in DC*
- *Approximately 80 attendees from academia, industry, government, and industry associations*
  - **Association reps aggregated data and helped avoid concerns about proprietary or competition-sensitive data**
- *Analyses in specific areas; e.g., GPS, power industry, aviation, military systems, human and robotic exploration beyond low-Earth orbit*
- *Econometric analysis of value of improved SpaceWx forecasts*

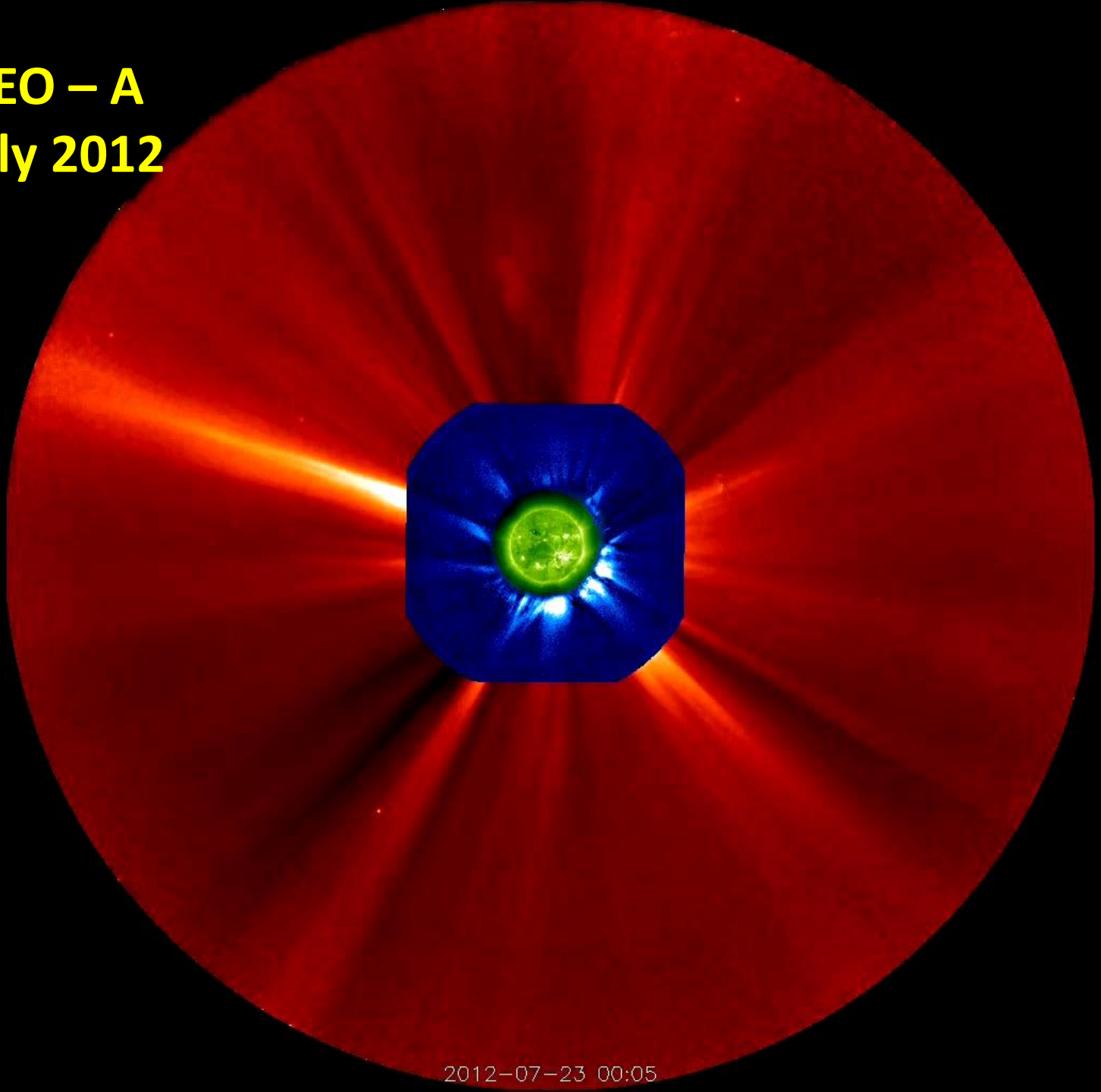


[http://www.nap.edu/catalog.php?record_id=12507]

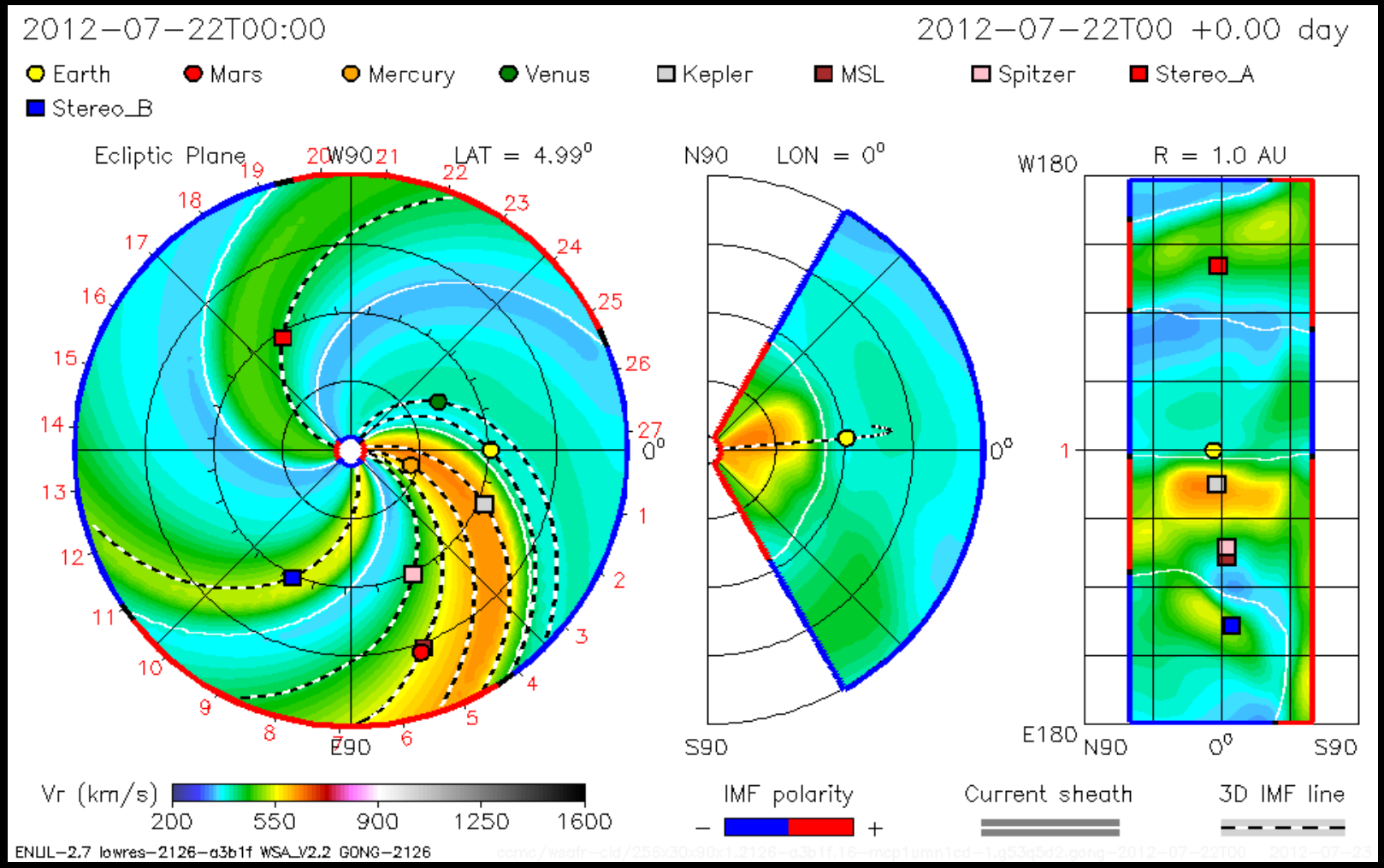
The Interdependencies of Society



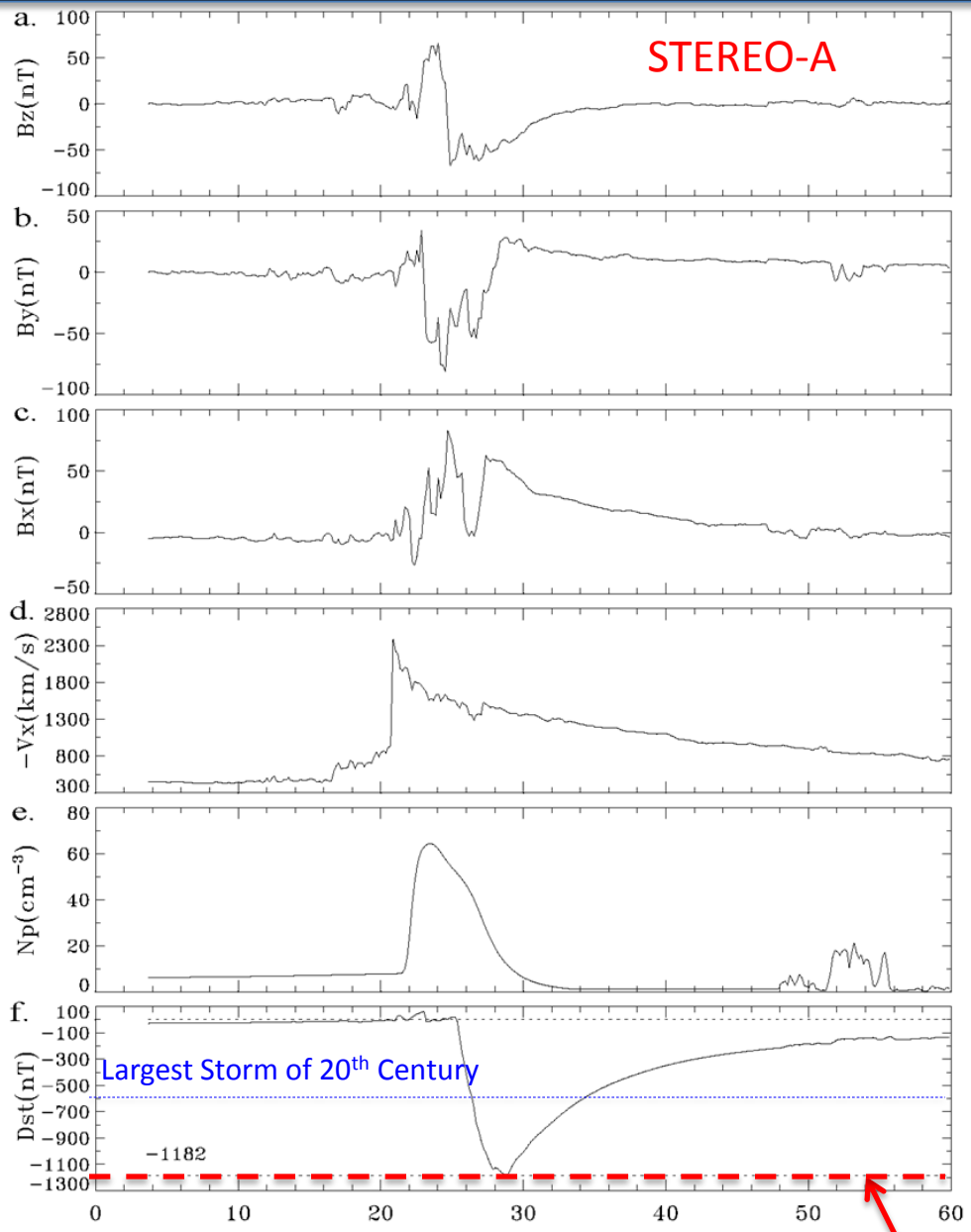
STEREO – A
23 July 2012



WSA-ENLIL Model: Solar Wind Speed



Space Weather Disaster Scenario



IMF Bz

IMF By

IMF Bx

Solar Wind Speed

Solar Wind Density

Storm Time (Ring Current) Index, Dst

Worst case: 24 July 2012