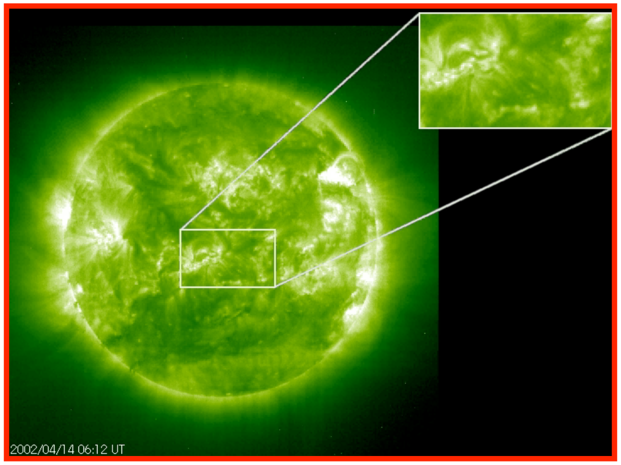
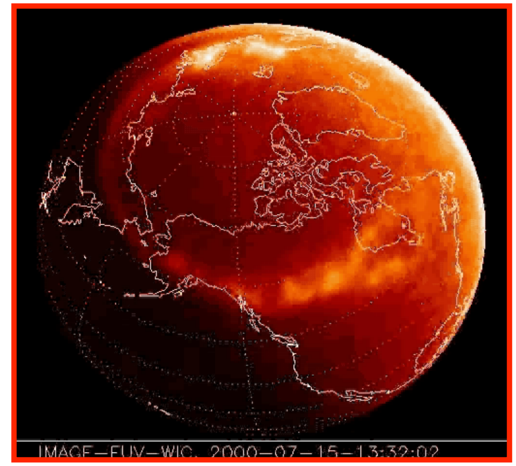




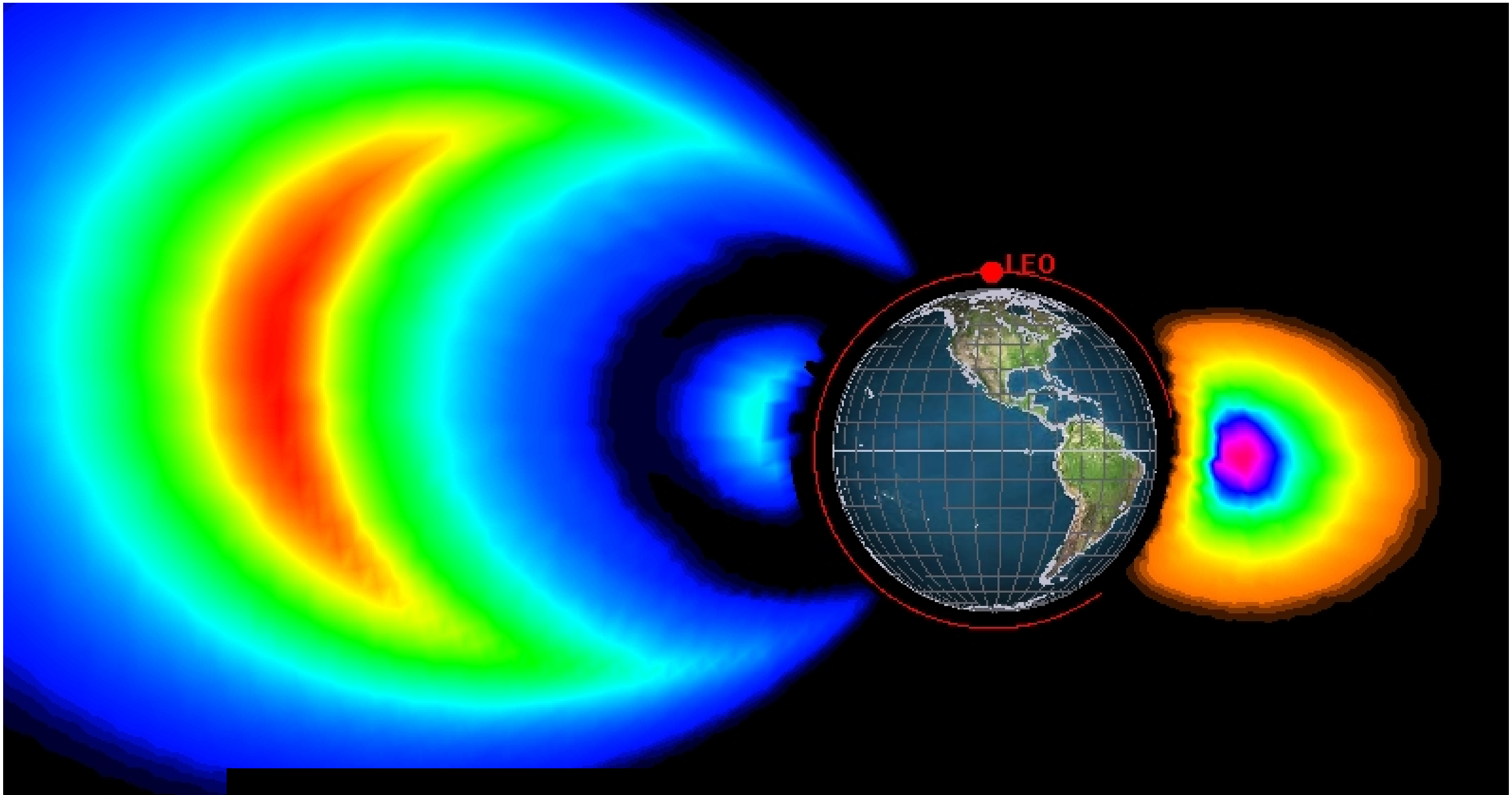
An Overview of Heliophysics Exploration

Daniel N. Baker, Director
Laboratory for Atmospheric and Space Physics
Astrophysical and Planetary Sciences Department
Department of Physics
University of Colorado - Boulder


TWENTY-FIVE CENTS
MAY 4, 1959
SPACE and the RADIATION BELT
TIME
E WEEKLY NEWSMAGAZINE
PHYSICIST
JAMES VAN ALLEN
$7.00 A YEAR
VOL. LXXIII NO. 18

Outline of Presentation

- Disciplinary Roots
- Decades of Discovery: 1960s-1970s
- Decades of Cooperation: 1980s-1990s
- Building the Great Observatory
- Comparative Planetology
- Toward the Future

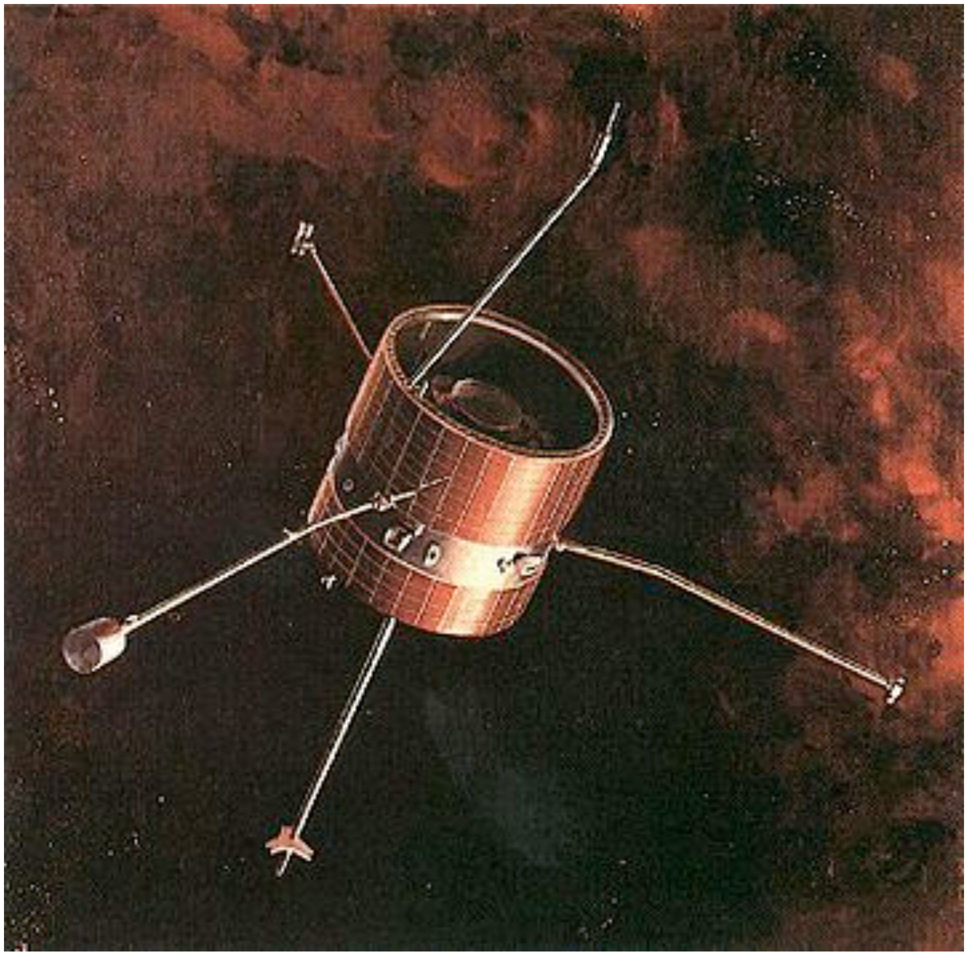


Electron (left) and Proton (right) Radiation Belt Models

Excellent Personal History

- The origins of Explorer 1 and the US space program in cosmic ray studies
- The important role of university research in the Cold War setting

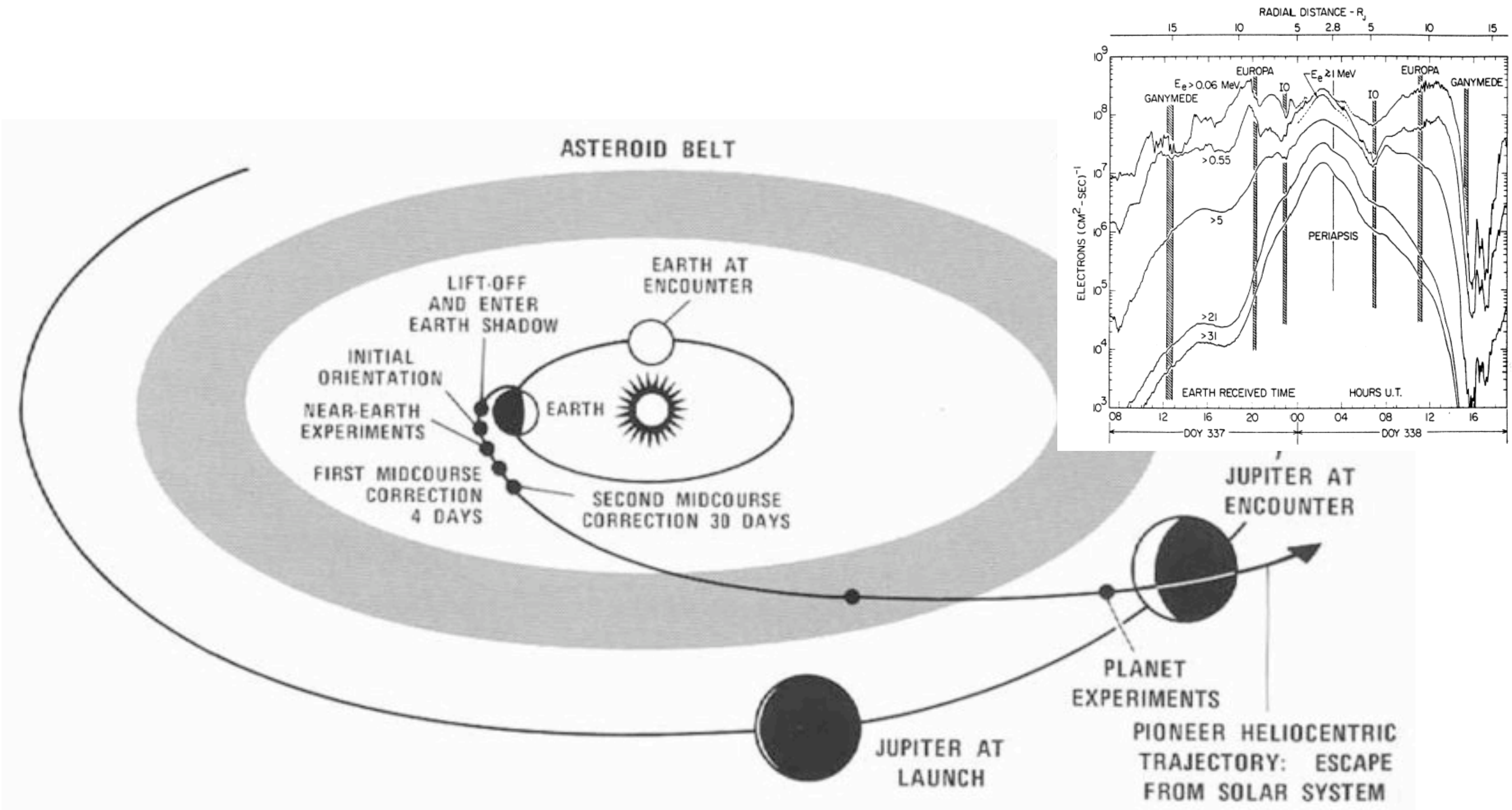
Heliophysical Exploration of the 1960s



Pioneer 6 Spacecraft

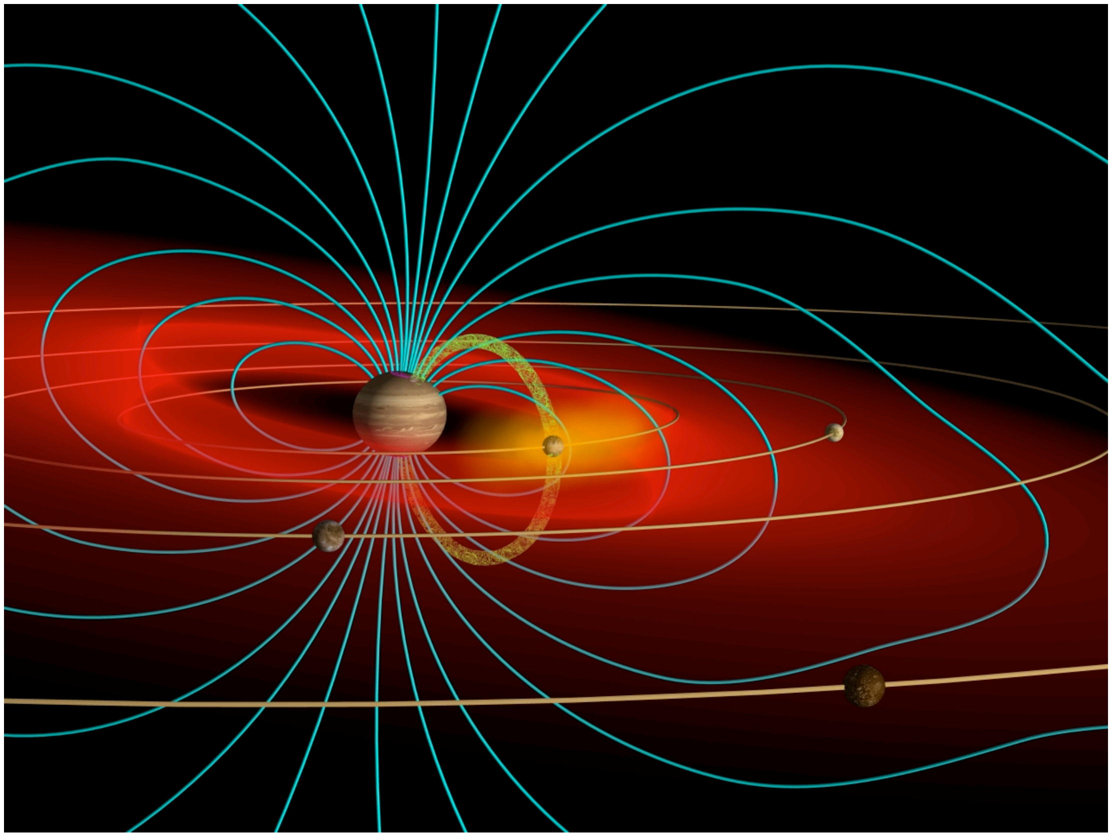
- Pioneer 6, 7, 8, 9
- Solar wind and magnetic field mapping in interplanetary space
- Cosmic ray measurements and solar particle studies

Exploration of the 1970s: Amazing Era



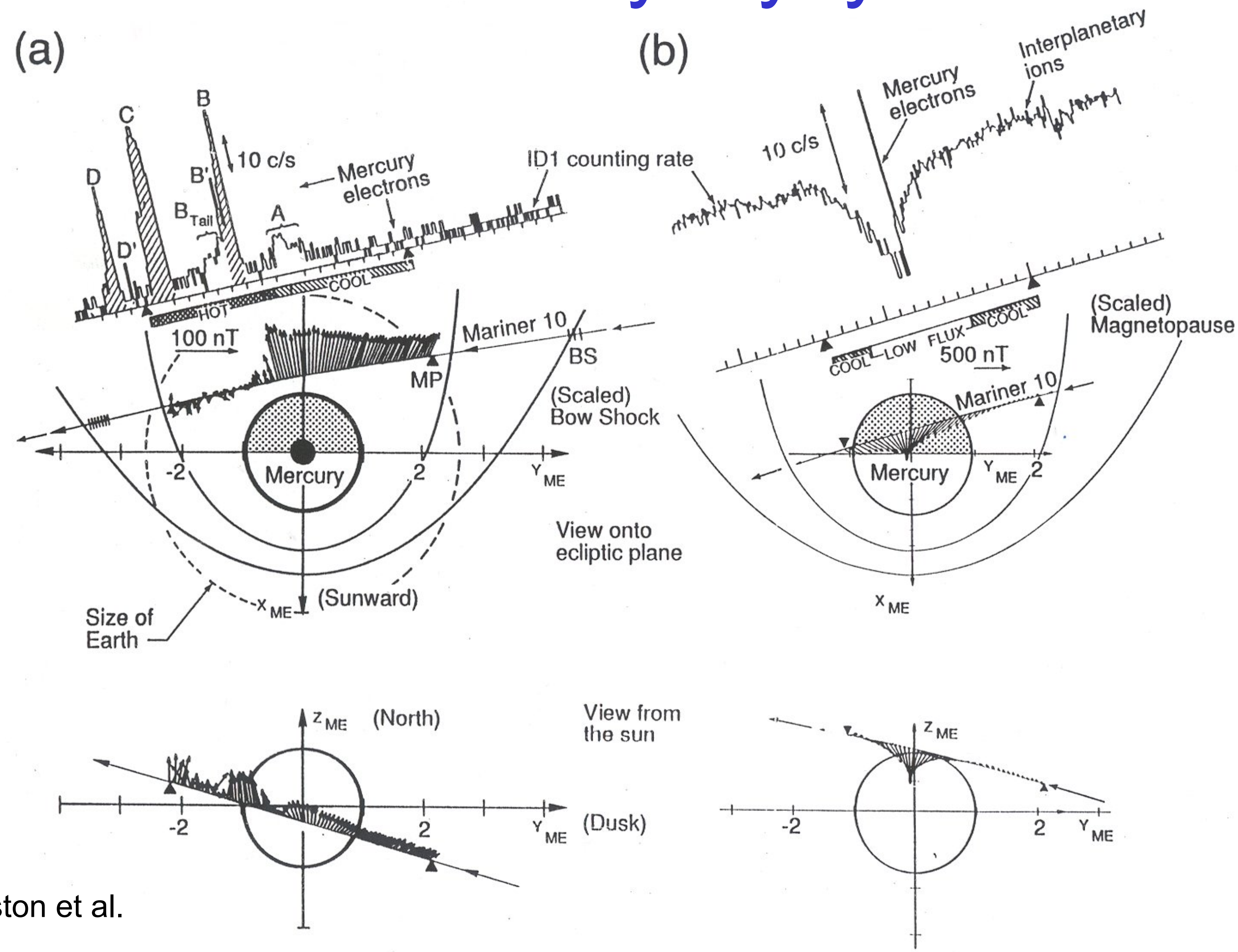
Pioneer 10 (and 11) to Jupiter, Saturn and Beyond

Observations of Jovian Magnetosphere



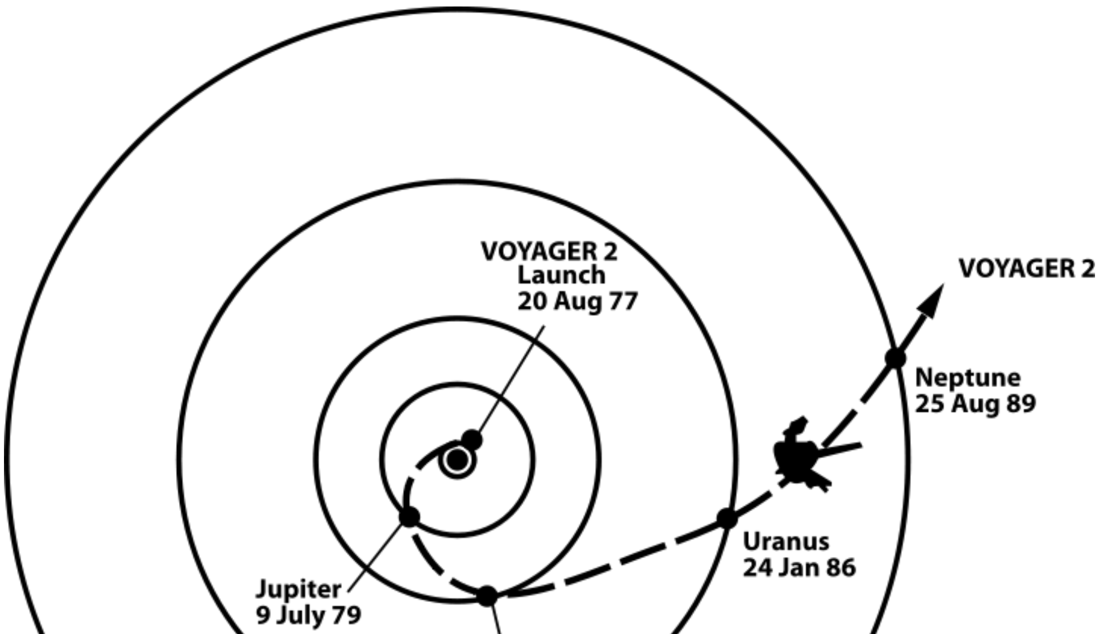
- Discovery of huge magnetospheric volume around Jupiter
- In situ observations of powerful Jovian Van Allen belts
- Dominant role of Galilean moons in magnetospheric processes

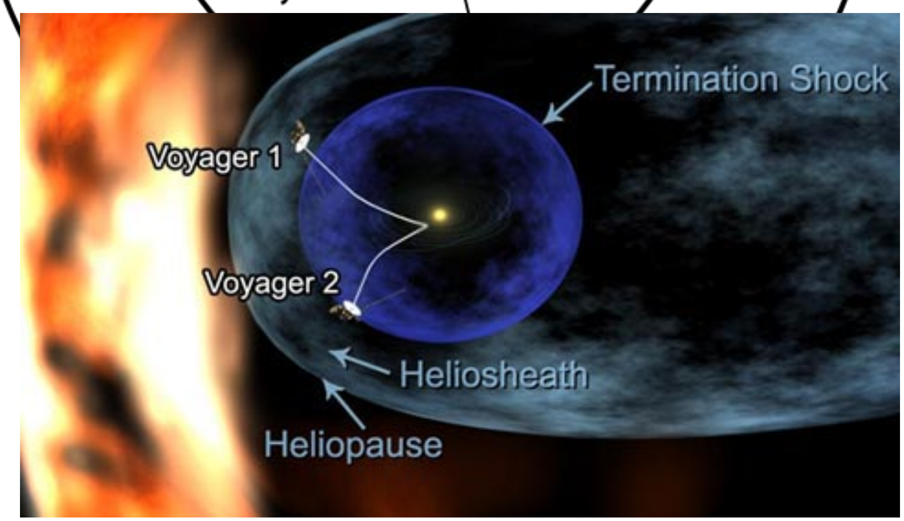
Mariner 10 Mercury Flybys: 1974-75



S. Christon et al.

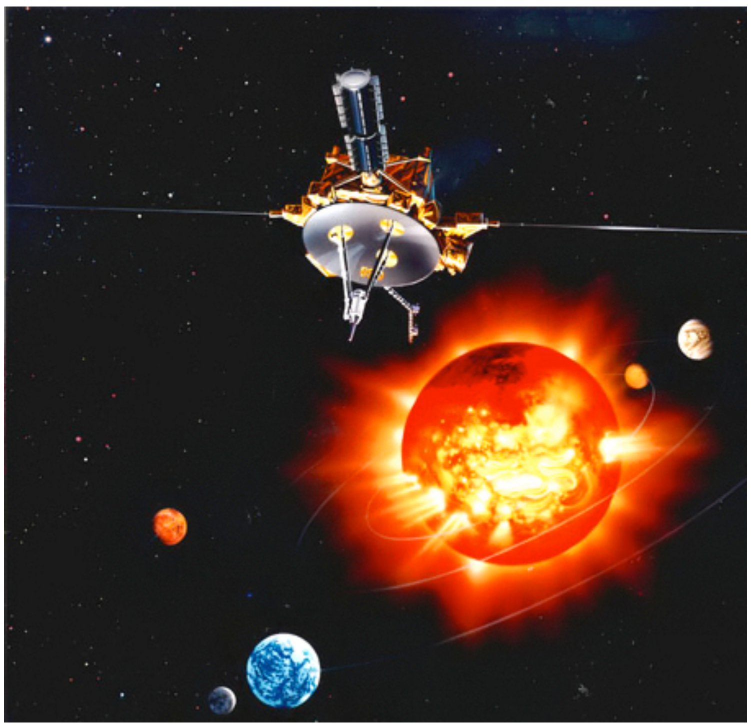
Voyager Exploration of Outer Planets

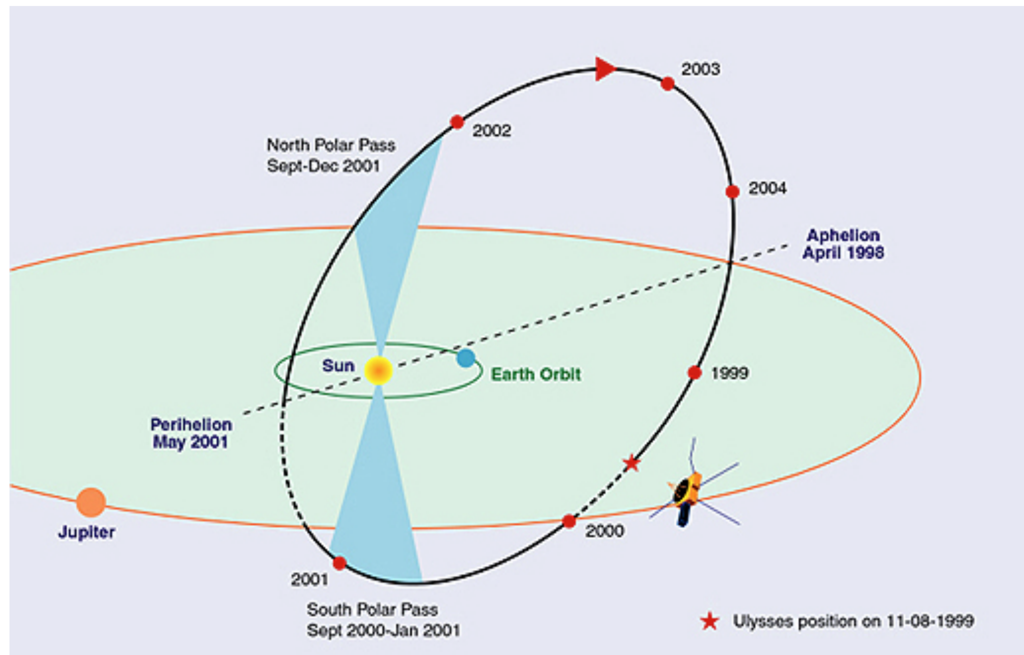




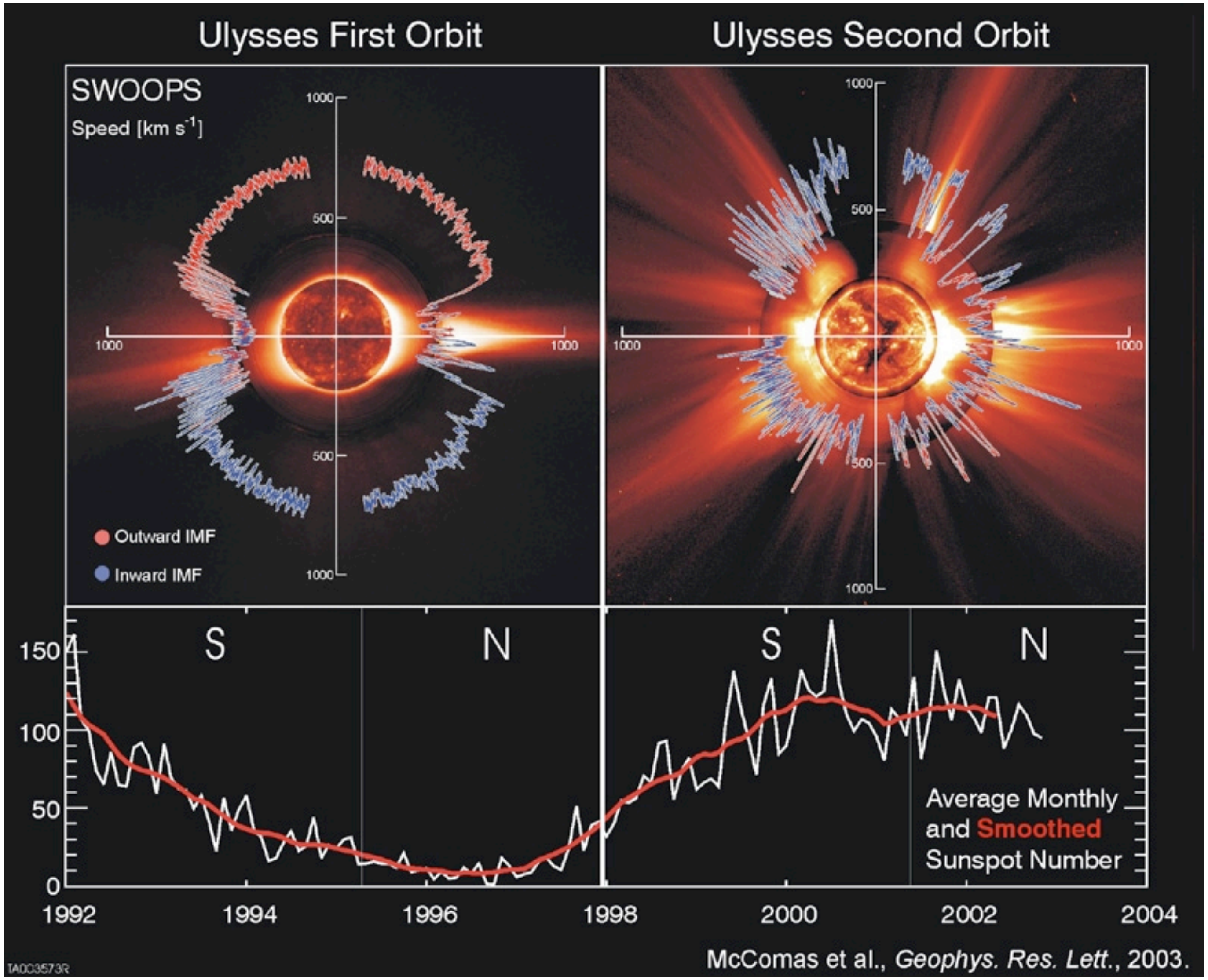
- Voyager 1 & 2 flybys of Jupiter and Saturn
- Voyager 2 surveys of magnetospheres of Uranus and Neptune
- Today, Voyager exploration of the outer boundaries of the heliosphere

Ulysses Solar Polar Mission 1990-2008

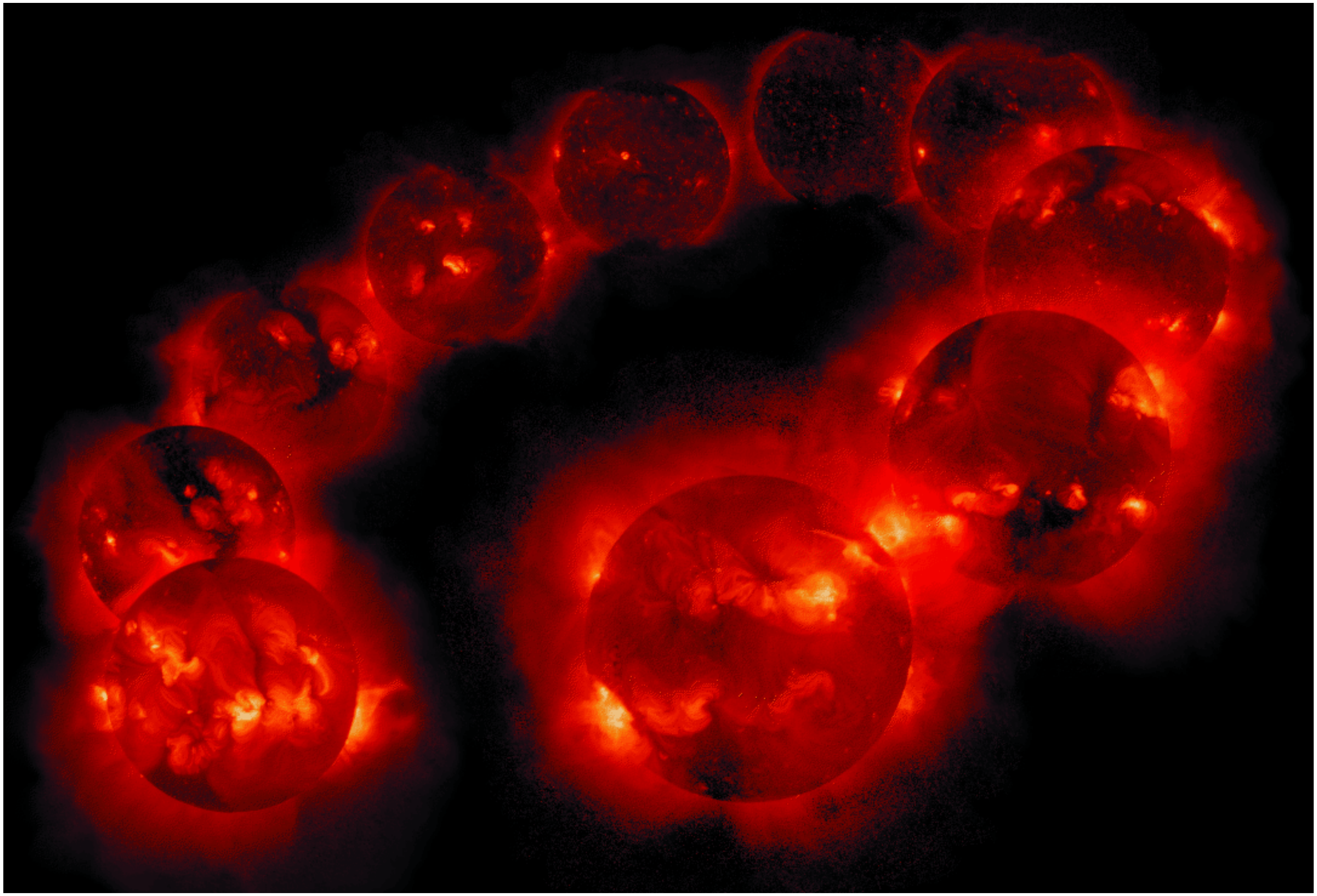




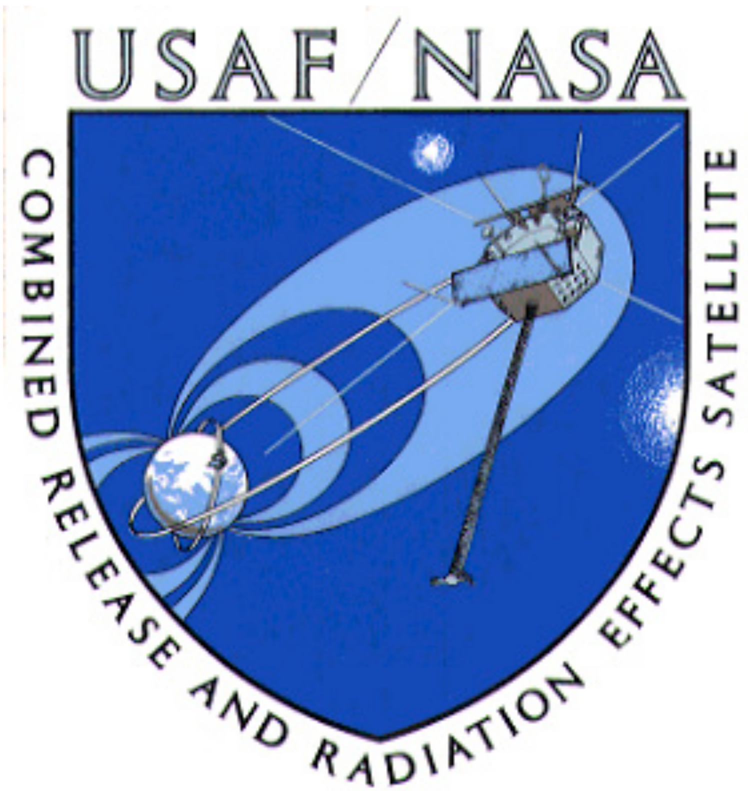
The 3-D Heliosphere



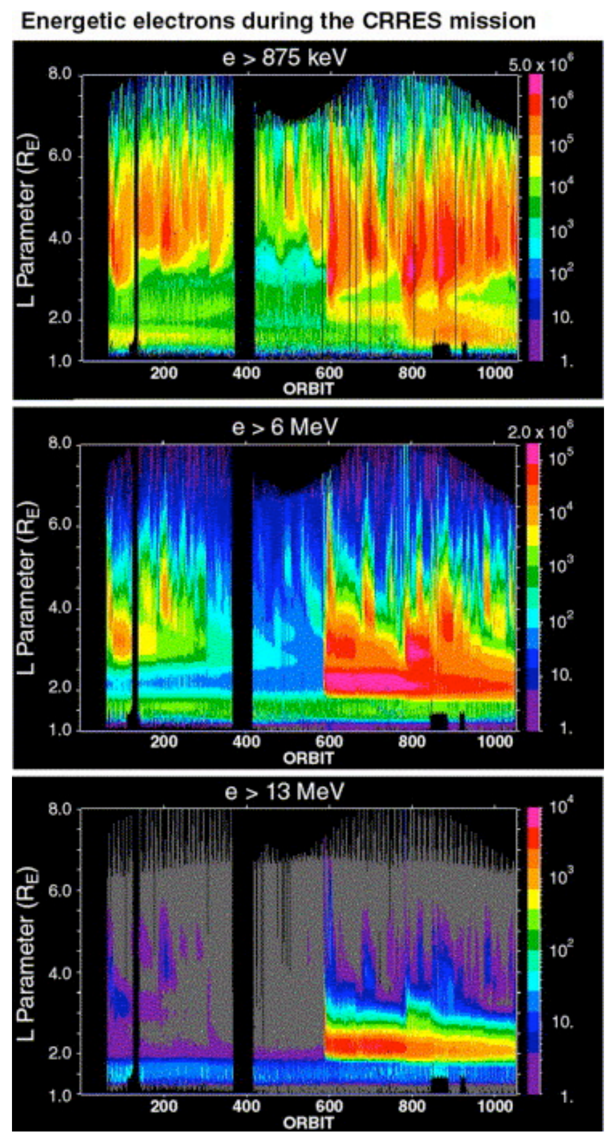
Yohkoh Soft X-rays: The 11-Year Solar Activity Cycle



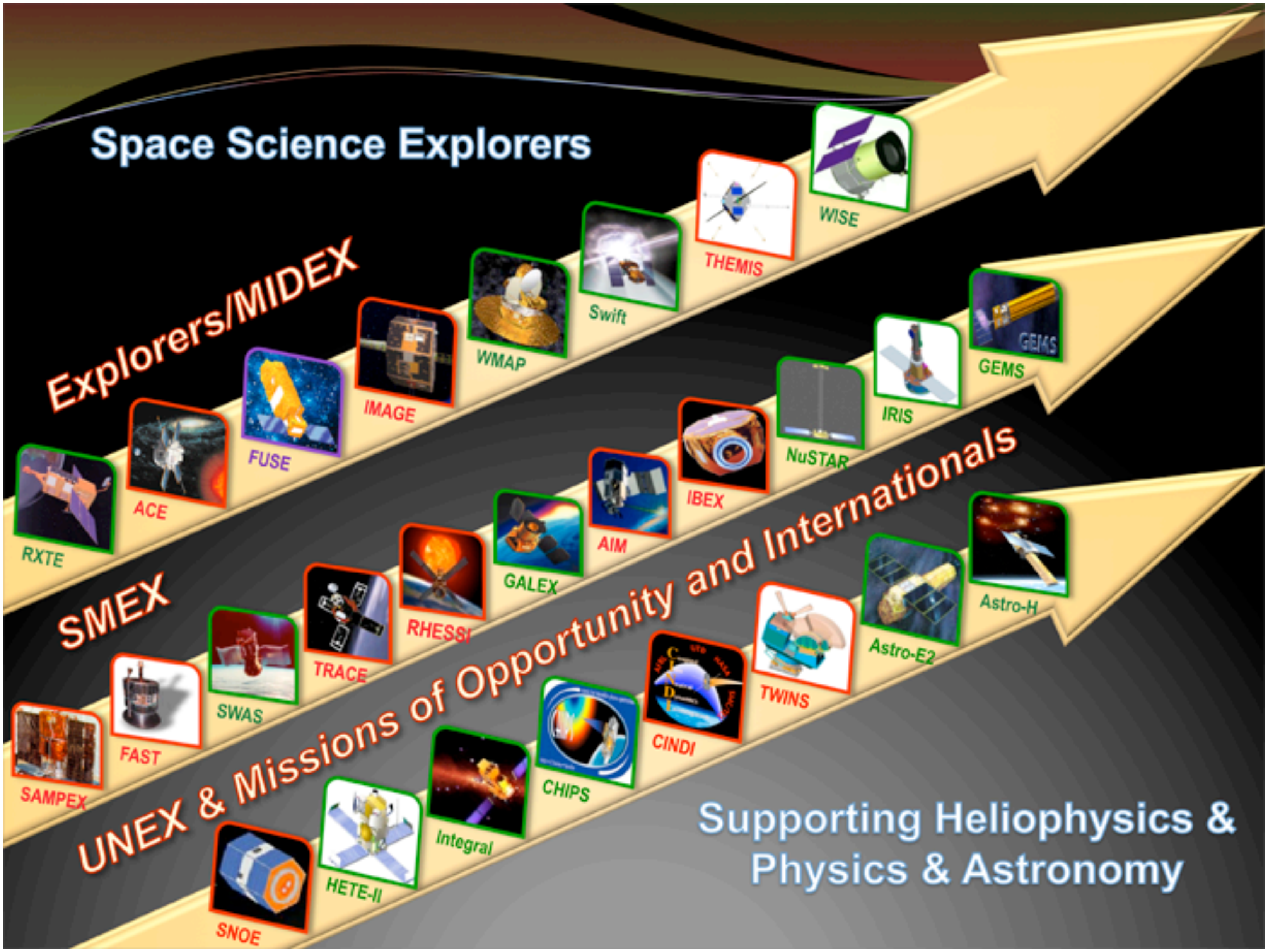
CRRES: Van Allen Belts Revisited



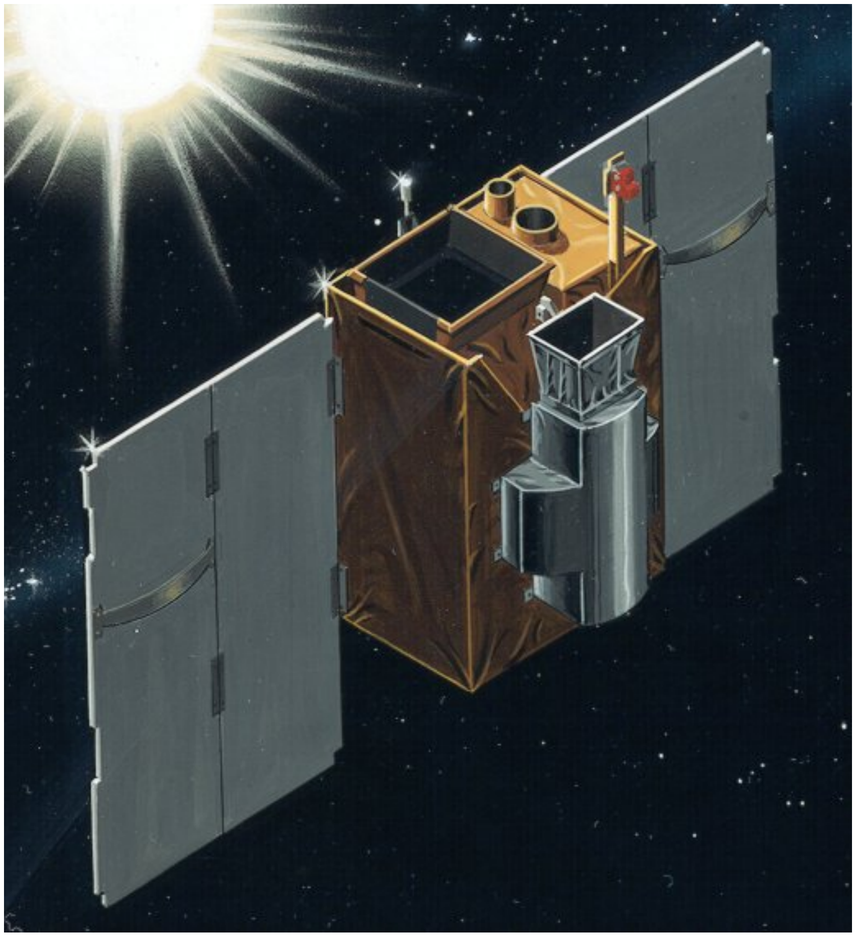
Mission Phase: 1990-1991

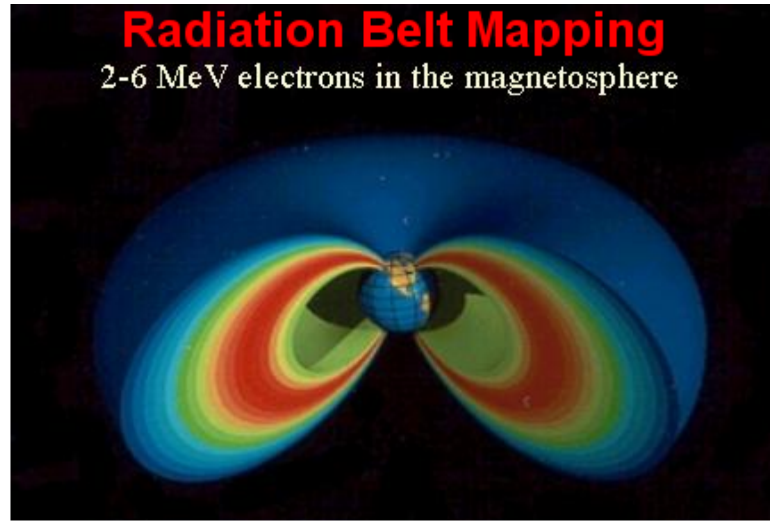


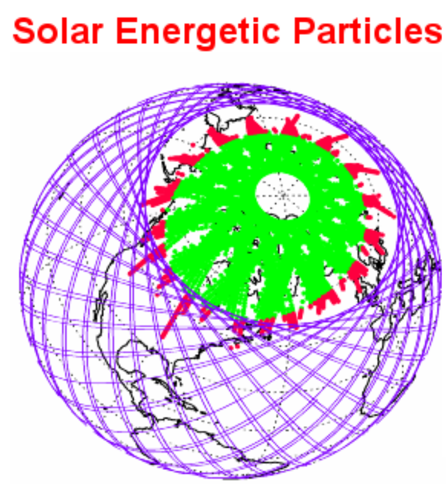
Explorers: Remarkable Small Missions

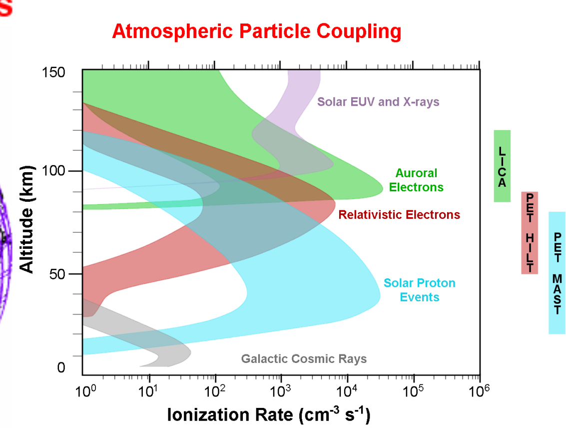


The Solar, Anomalous, and Magnetospheric Particle Explorer: SAMPEX

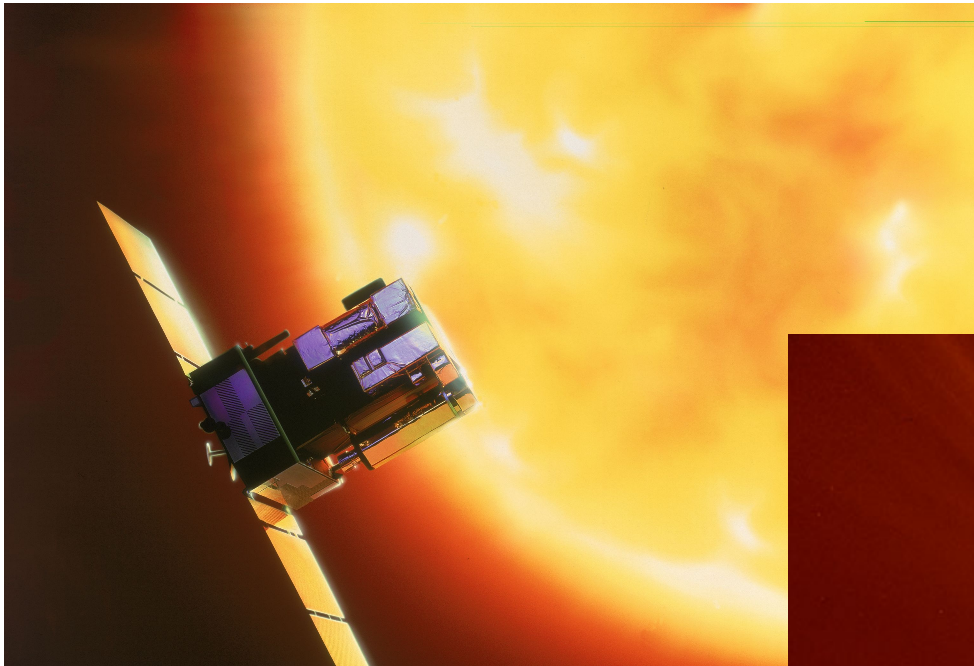




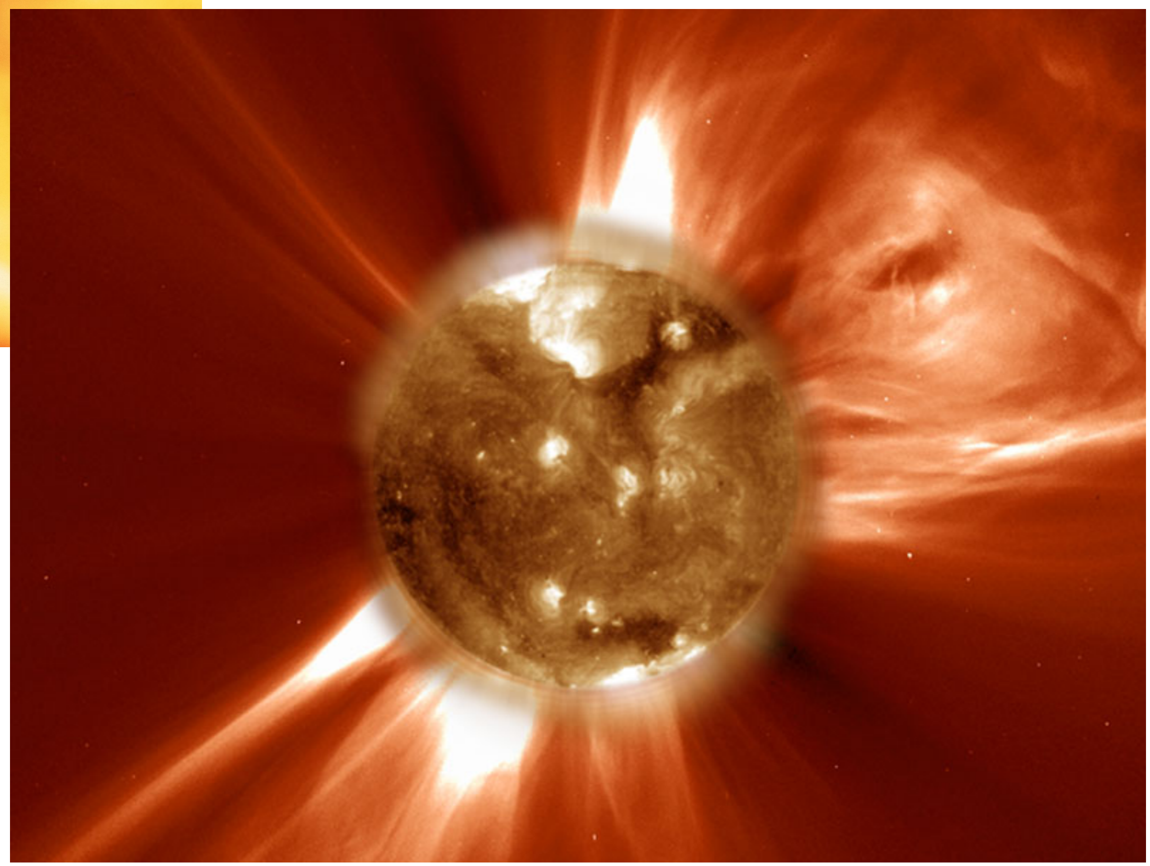




Solar Heliospheric Observatory: SOHO

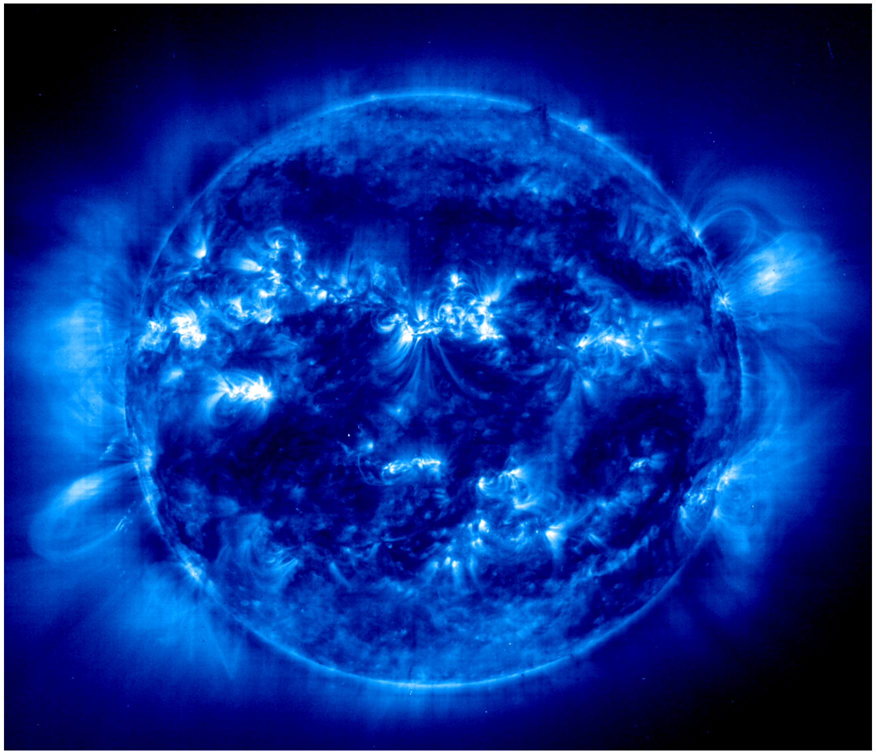


Transformative solar sentinel



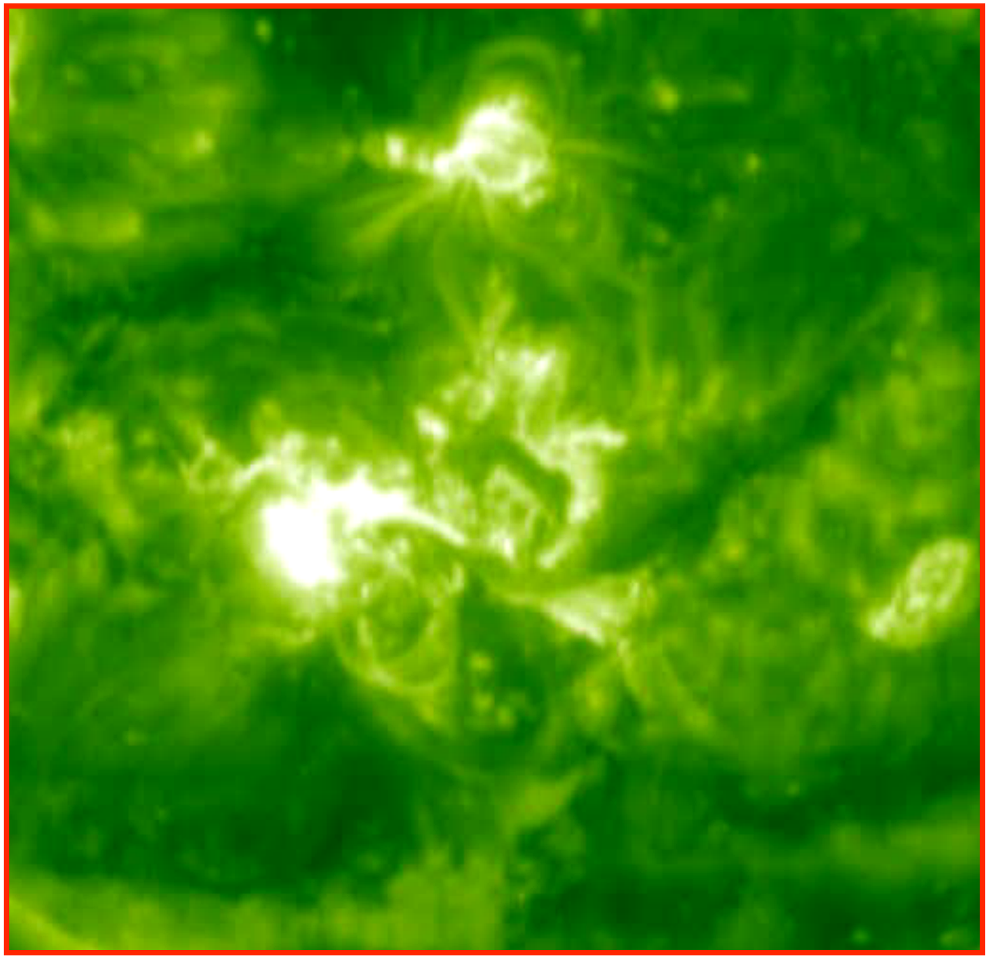
Mission period:
1995 - present

SOHO: The Active Sun



Solar Maximum:
15 July 2000

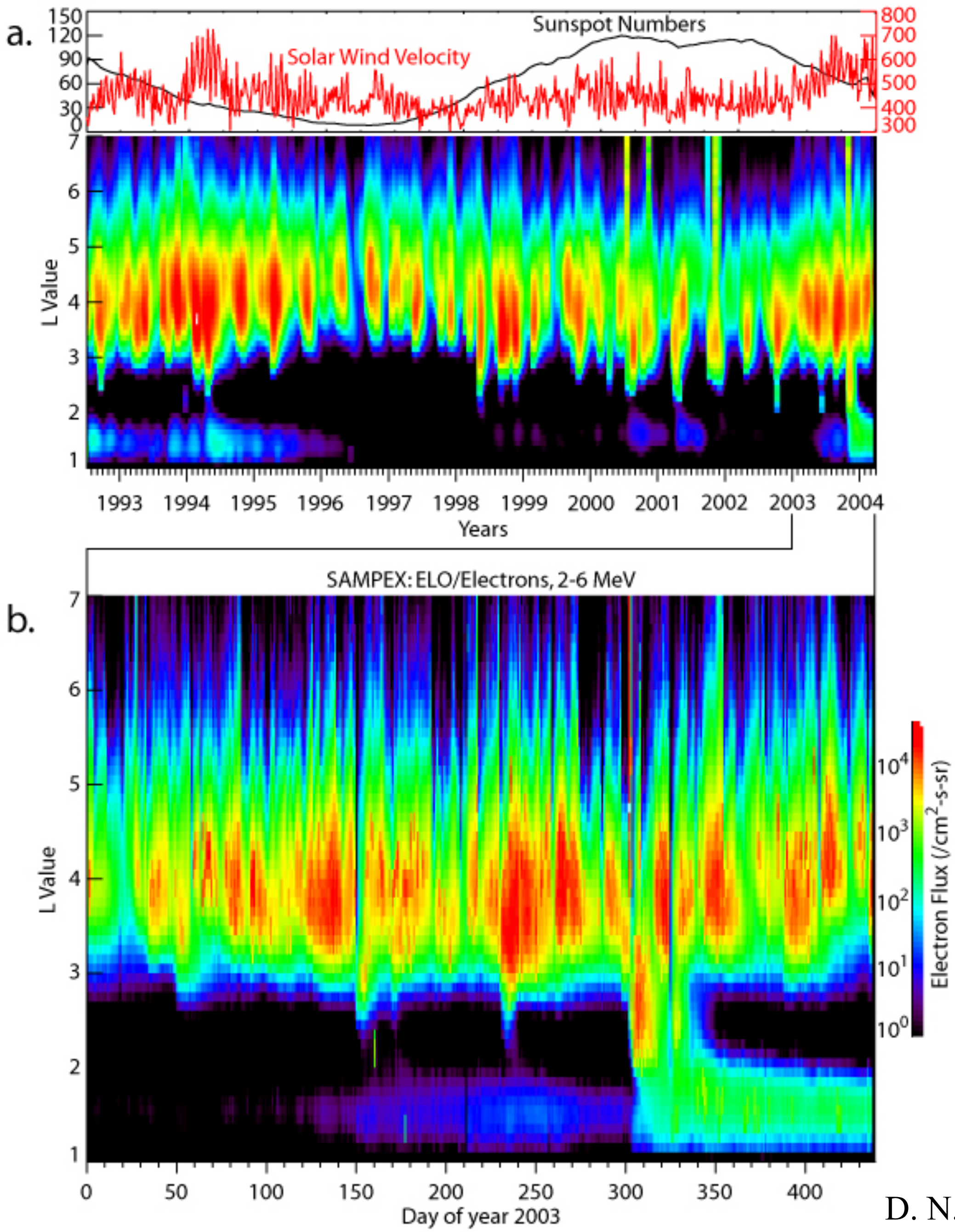
Halloween Storms
October 2003



Coronal Mass Ejection - Earth Impact

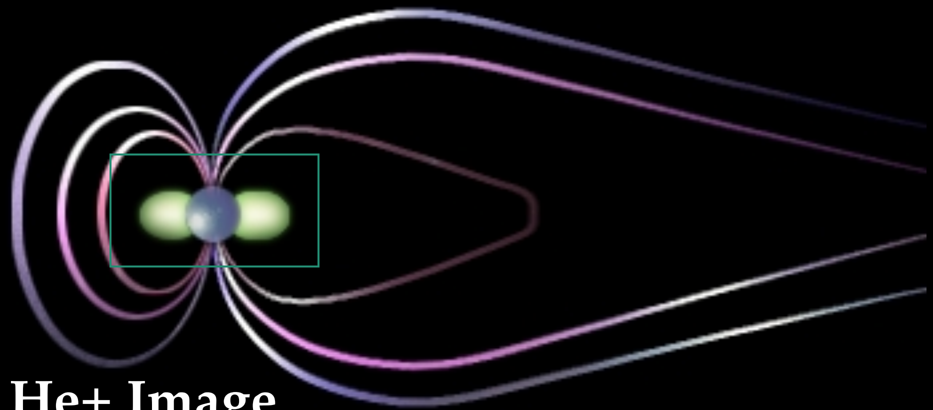
Courtesy of NASA

SAMPEX Observations Of Halloween Storm Effects

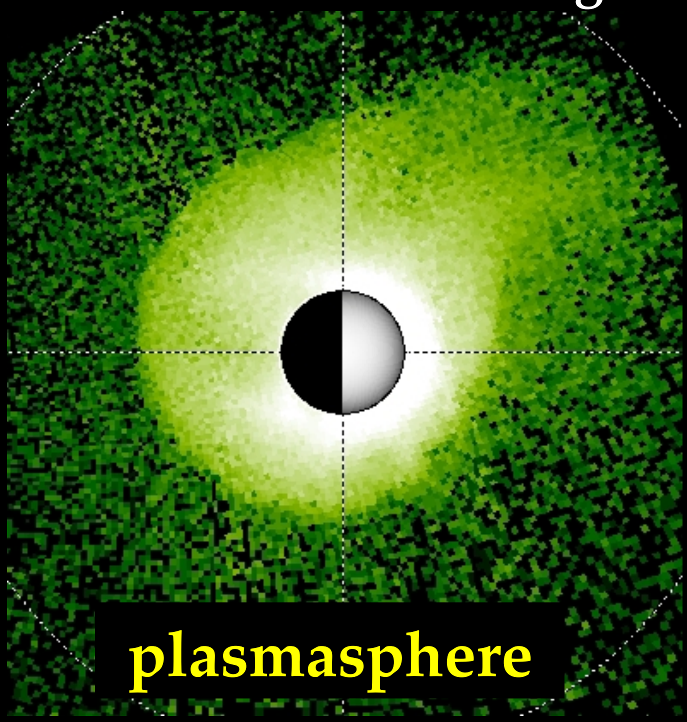


D. N. Baker et al., Nature, 2004

IMAGE Mission: Plasmasphere Made Visible

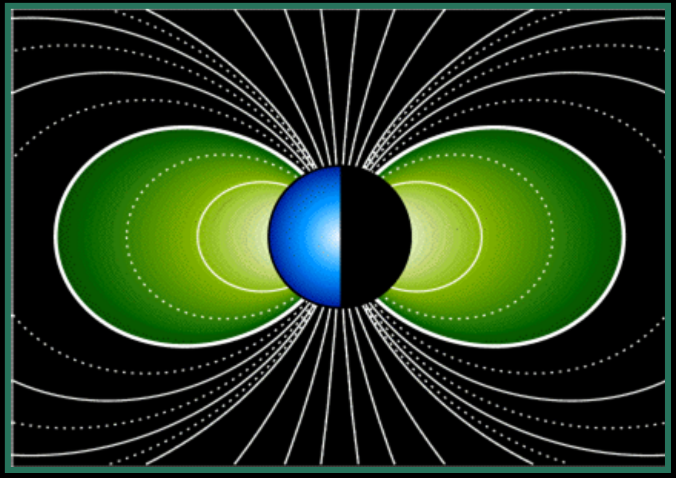


Global EUV He+ Image



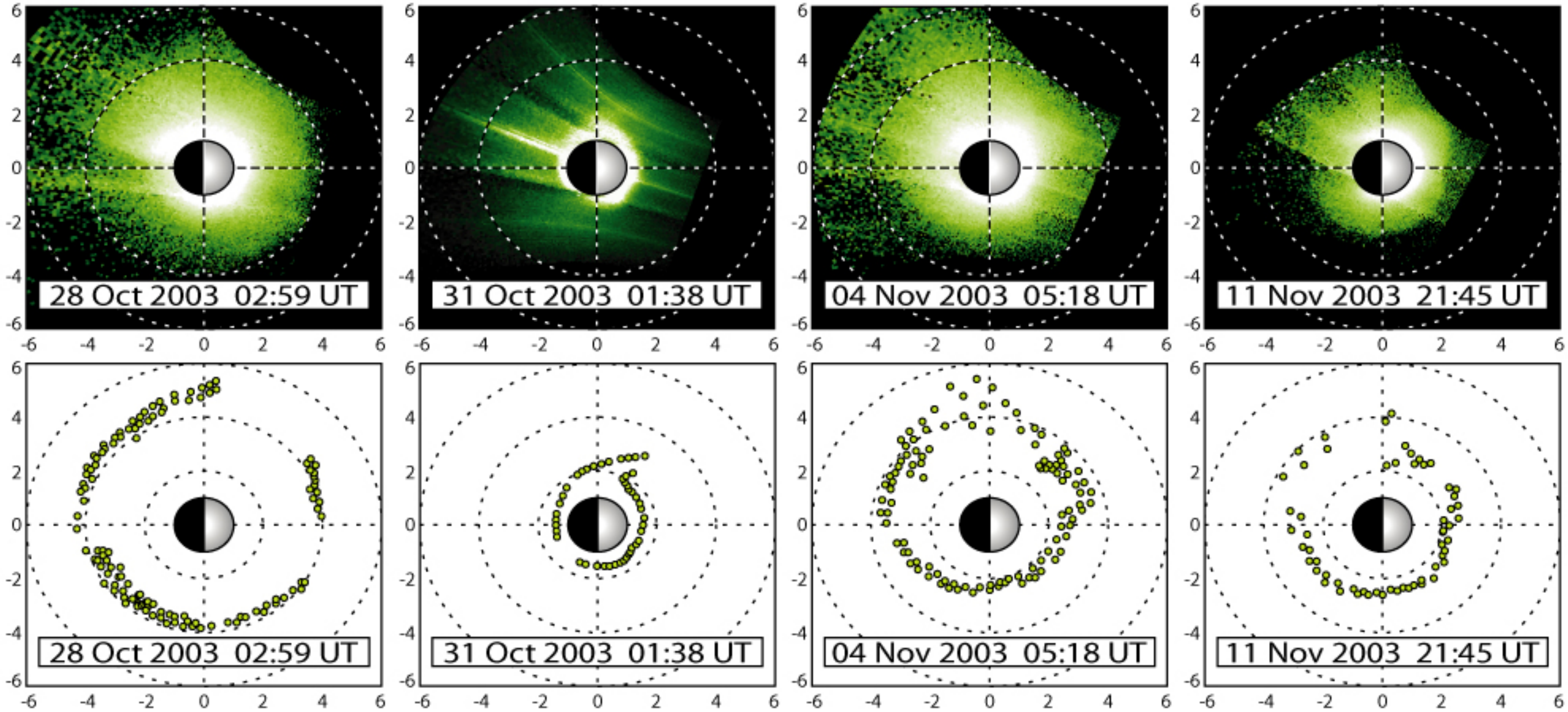
He$^+$ 15%

Plasmasphere

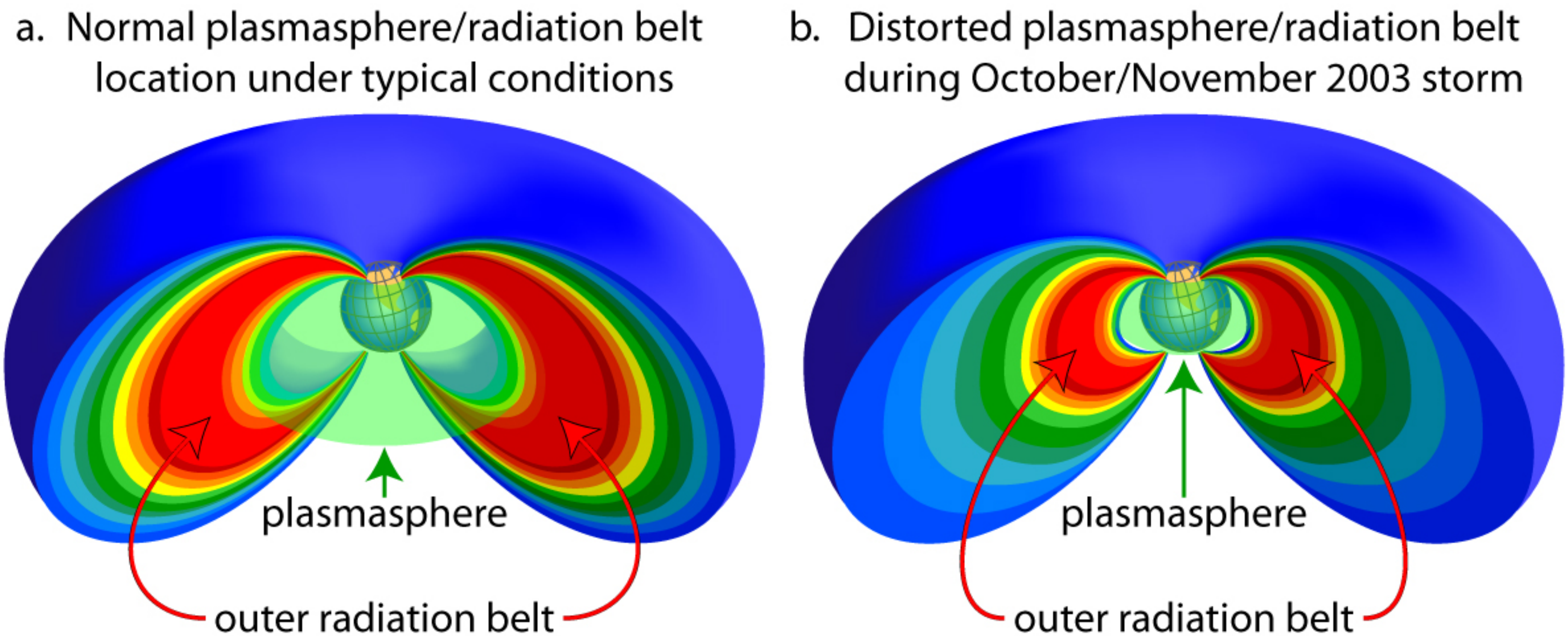


(Courtesy of J. Goldstein)

Dramatic Changes in Plasmasphere

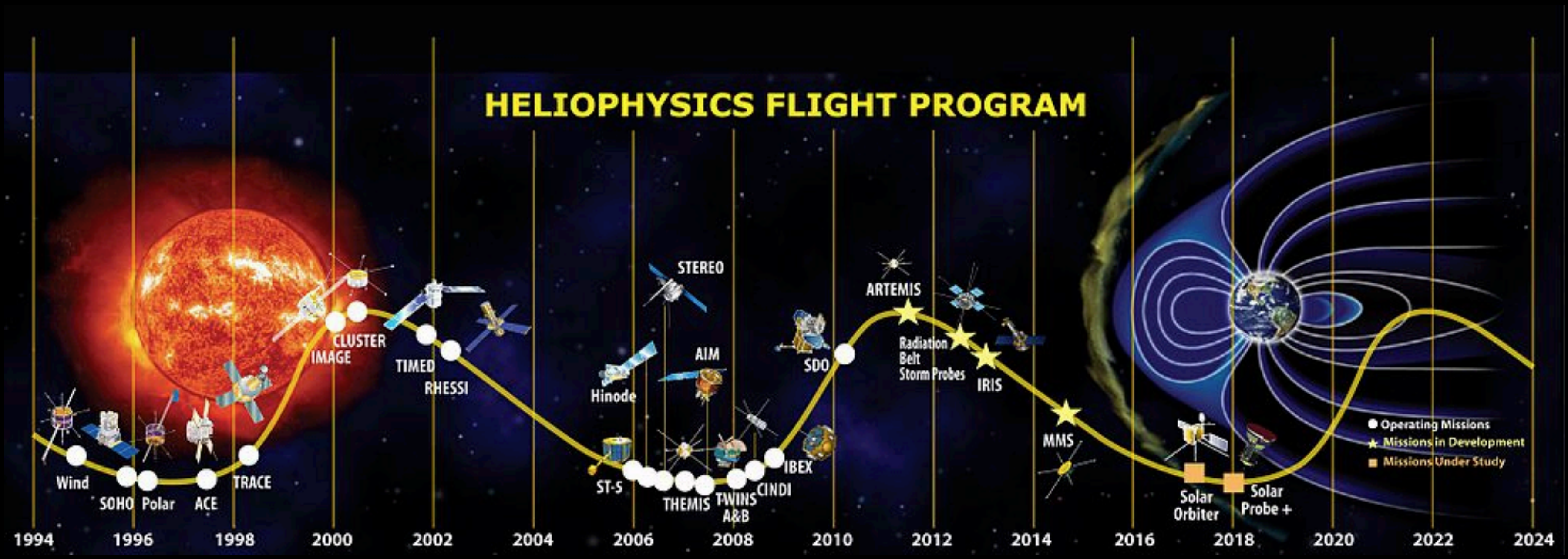


Complete Change of Radiation Belts During Halloween 2003 Solar Storm

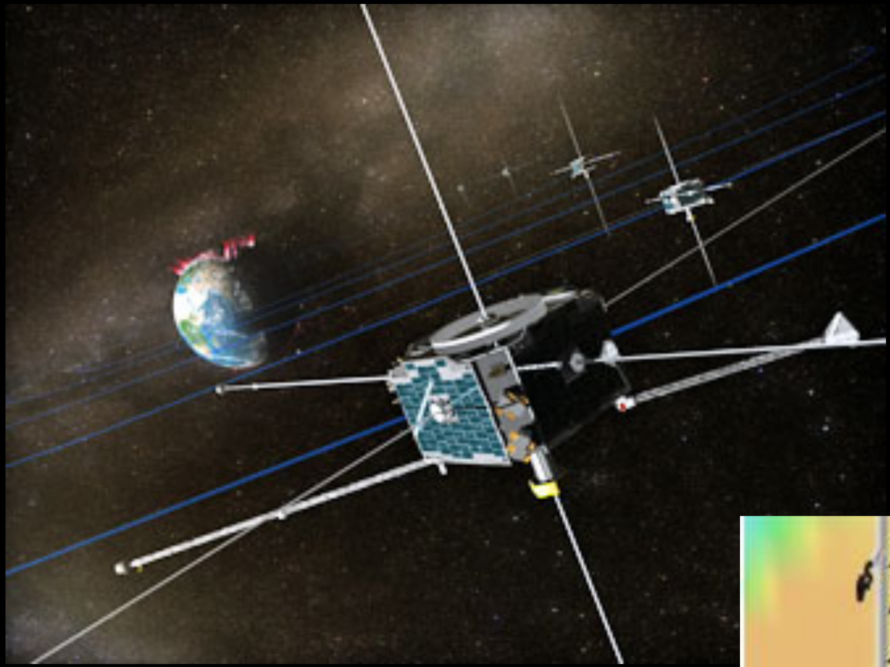


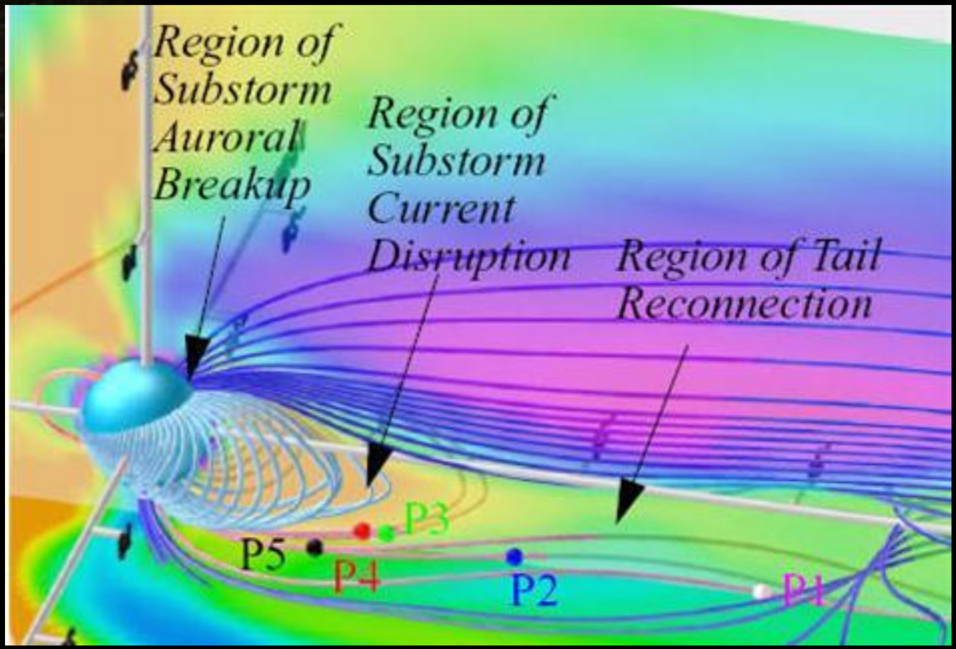
D. N. Baker et al., Nature, 2004

Heliophysics Flight Program: 1994→

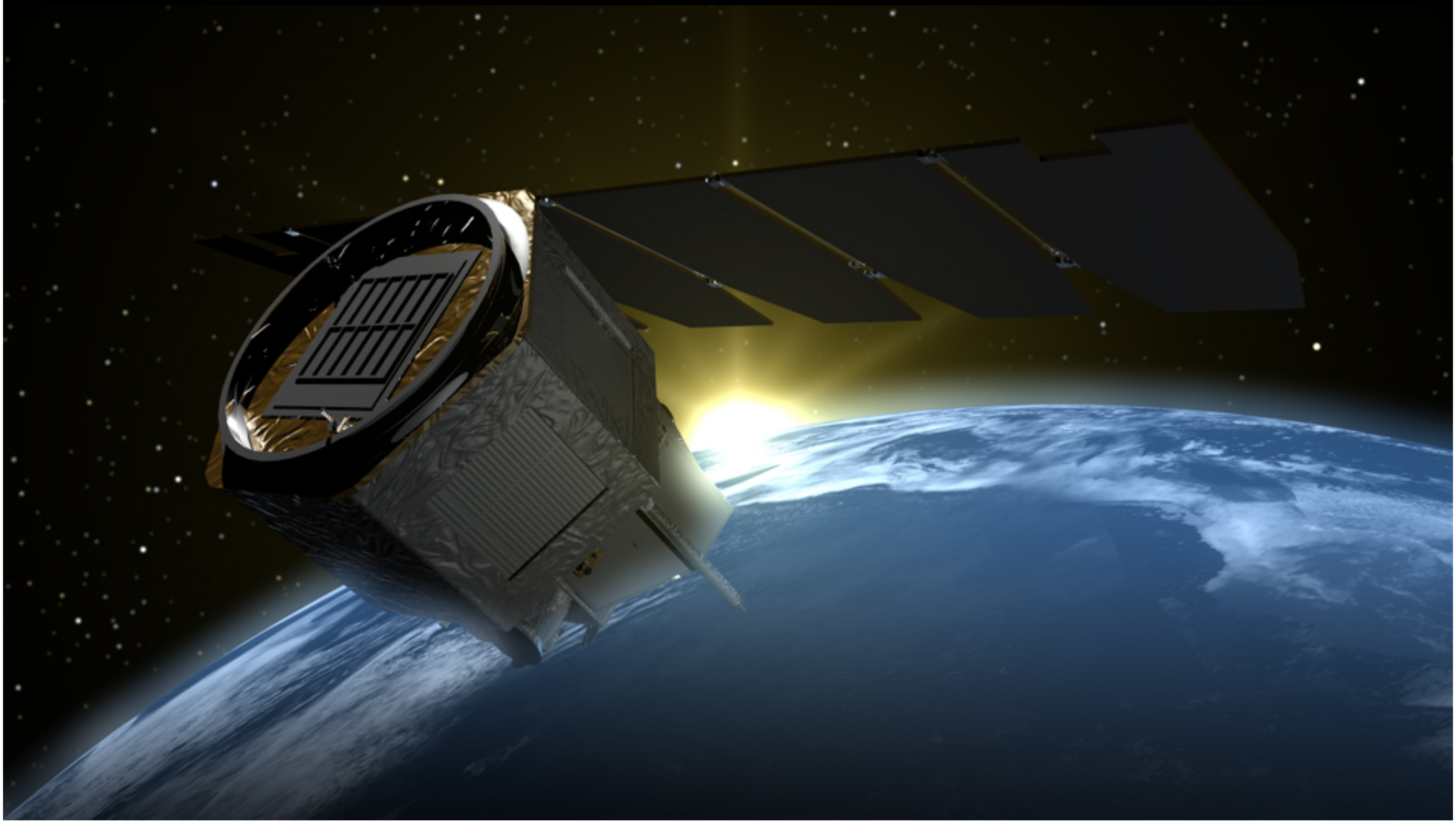


THEMIS: 5-Spacecraft Mission

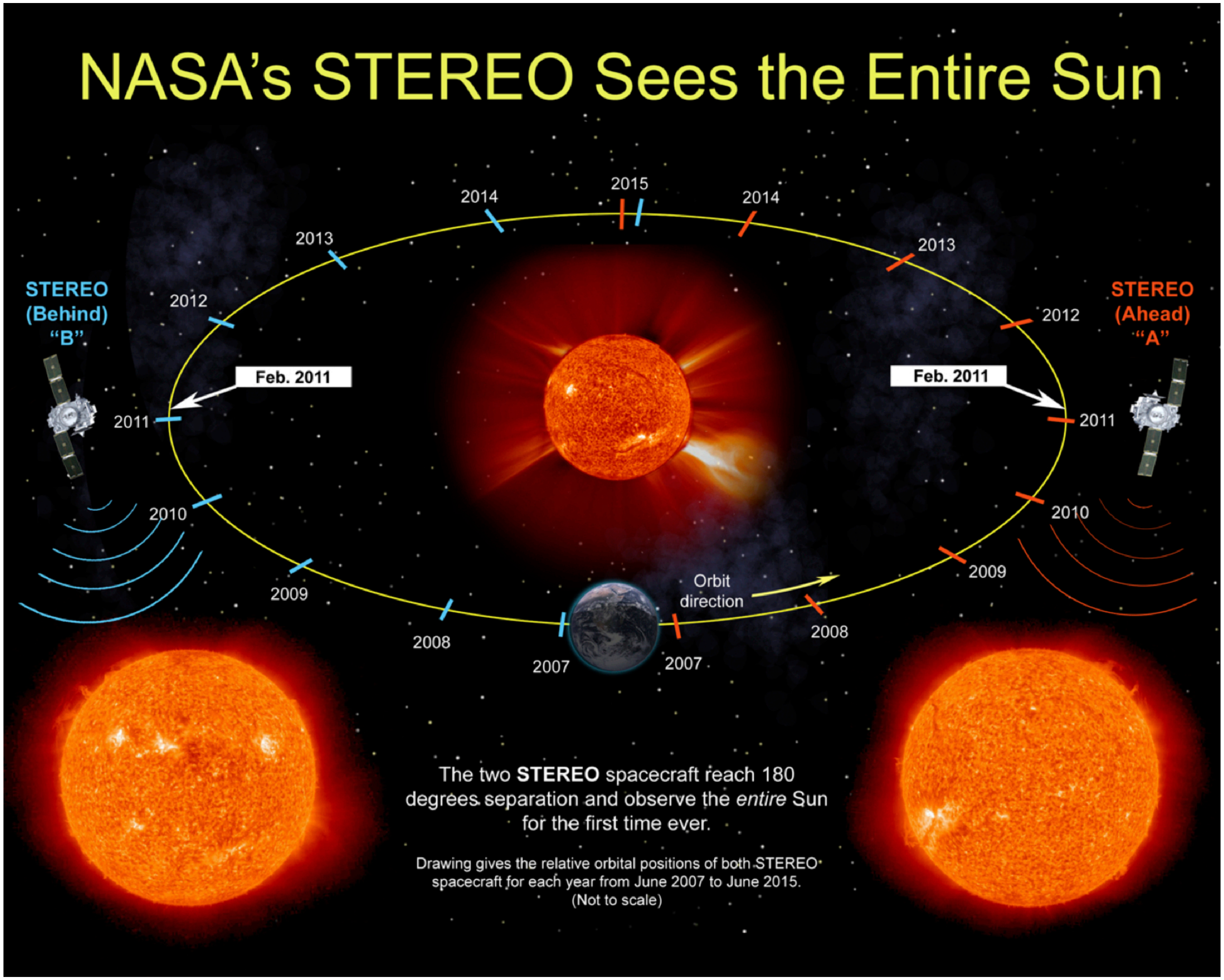




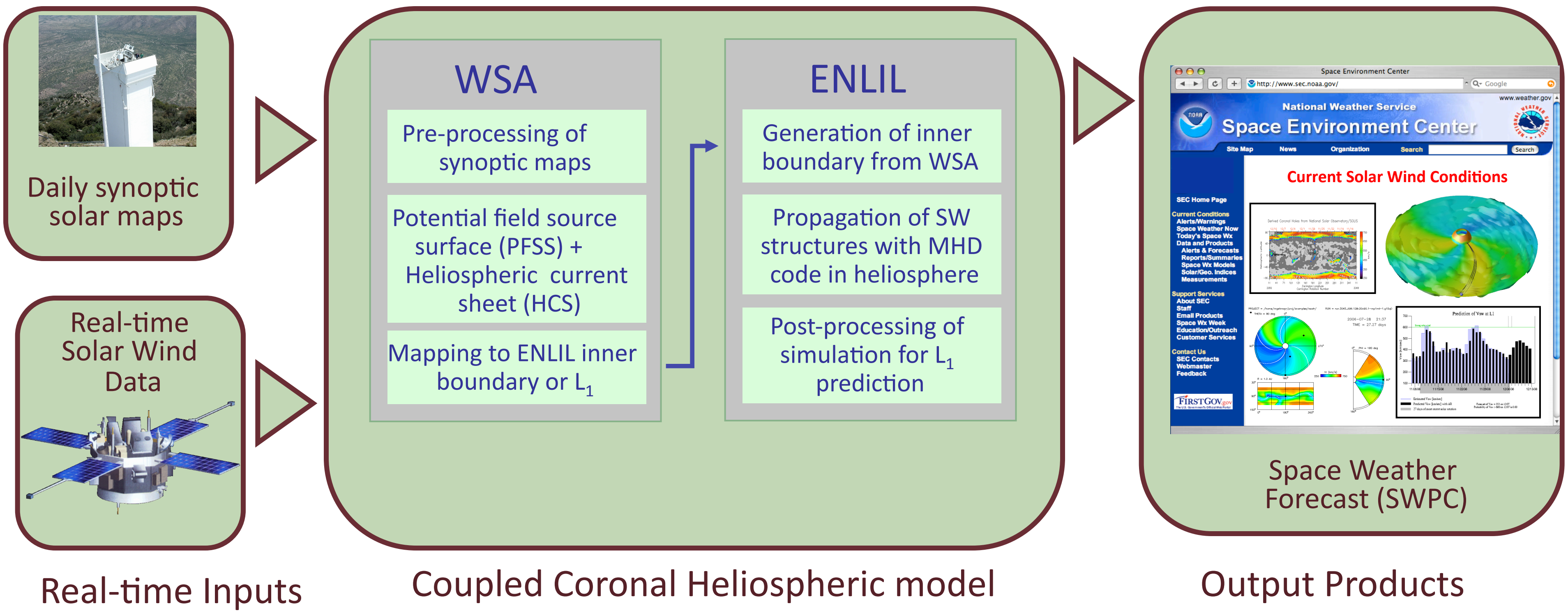
Aeronomy of Ice in the Mesosphere (AIM)



STEREO Dual Spacecraft Mission

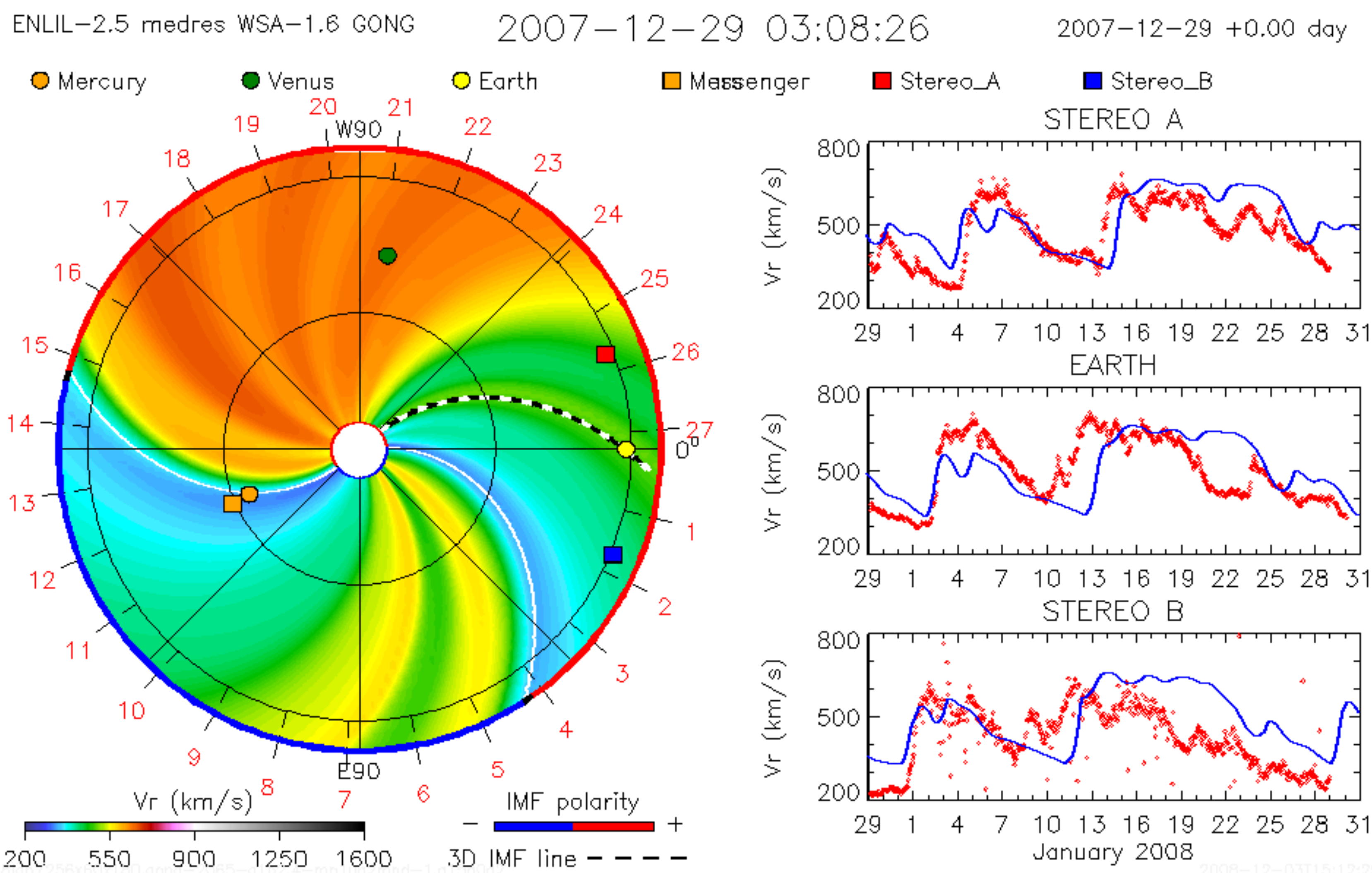


Real-Time Solar Wind Forecast Model



[Odstrcil et al., 2010]

Model Comparison: STEREO and ACE

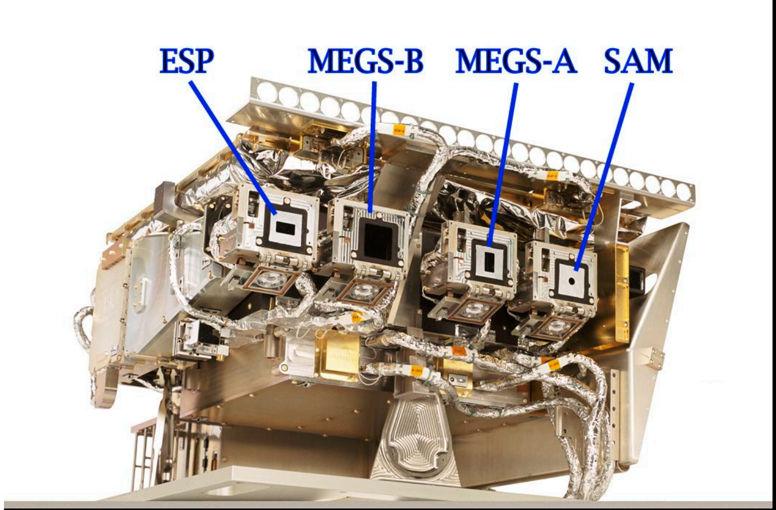


[Baker et al., 2009]

Solar Dynamics Observatory (SDO)

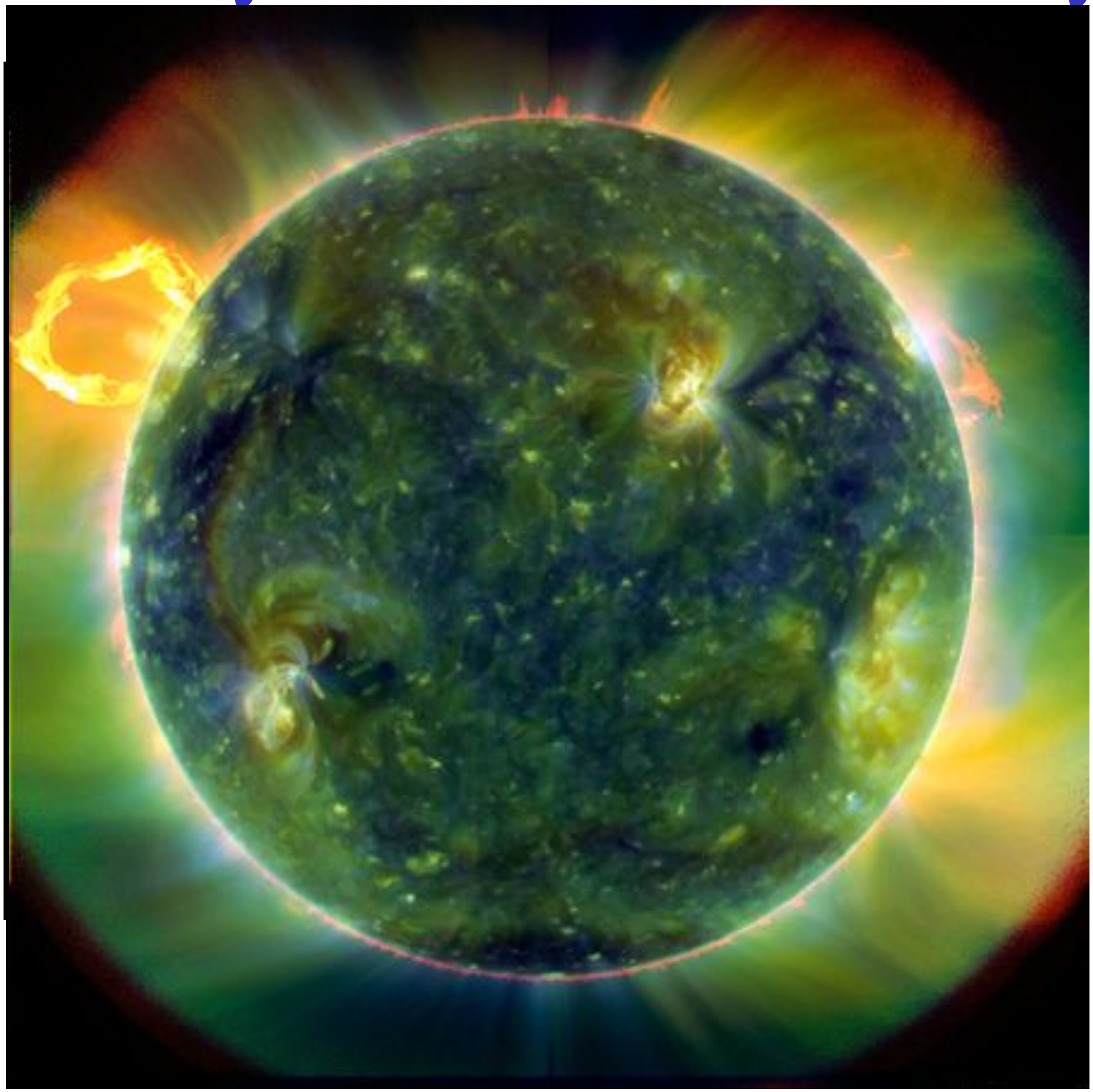
- SDO launched Feb. 11, 2010
- Completed commissioning on 4/30/10
- Now in normal operations (24/7 data)

Photo from Andrew Jones



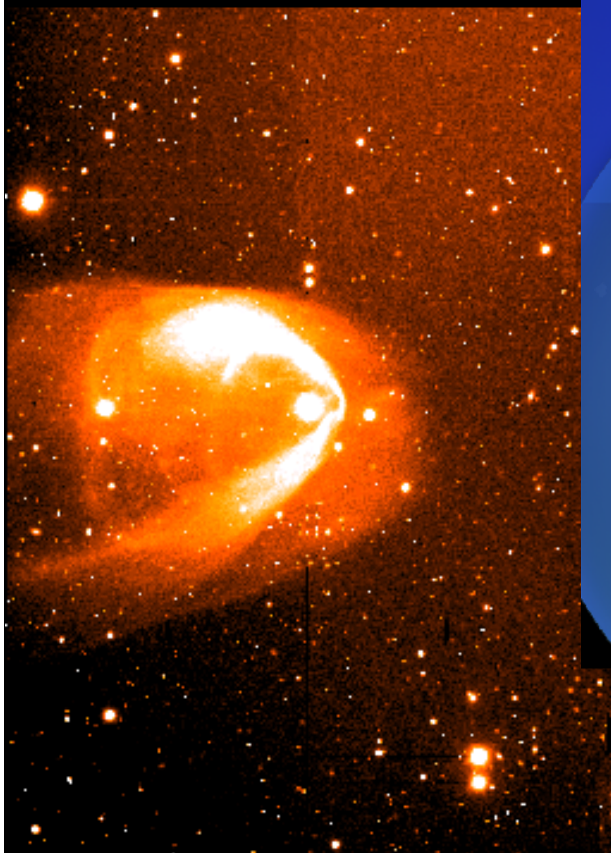
- SDO EVE provides:
  - Full EUV coverage: 0.1-122 nm
  - Good spectral resolution: 0.1 nm
  - High cadence: 10 sec
  - Low latency: Space Weather data in <15 min
- SDO AIA provides EUV images
- SDO HMI provides magnetic field images

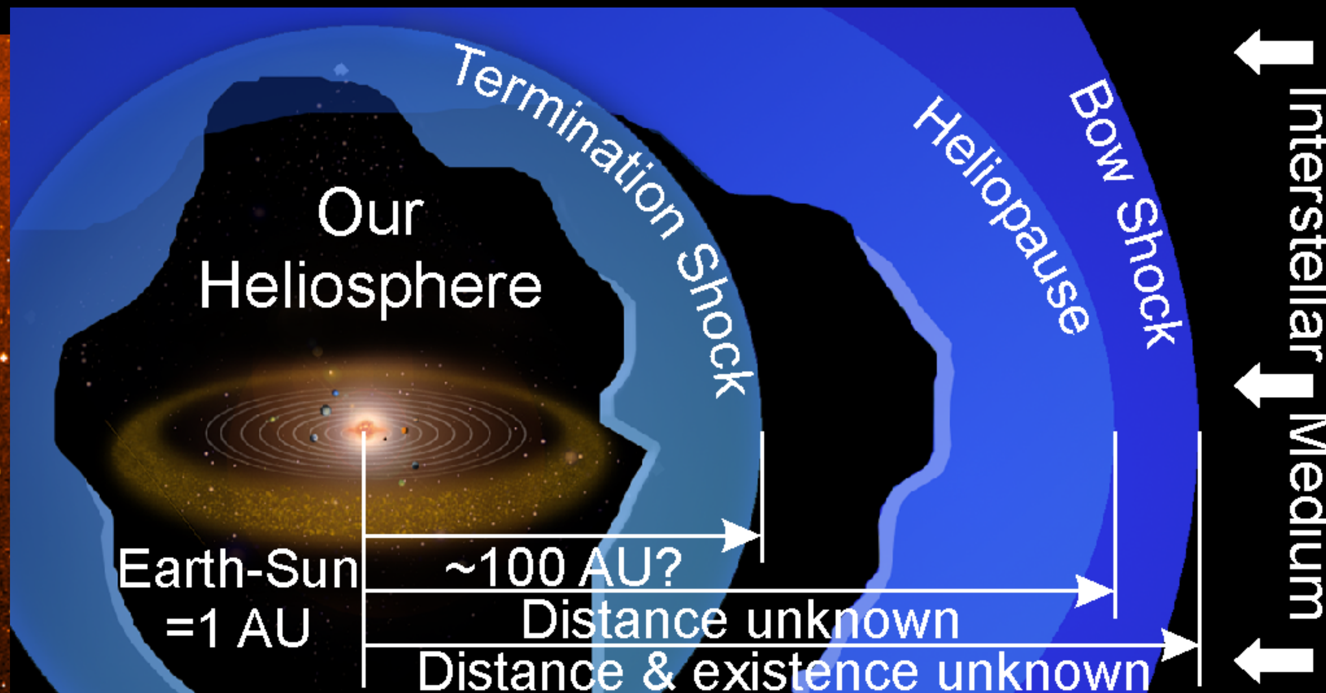
Solar Dynamics Observatory



We Live in the Outer Atmosphere of a Highly Variable Magnetic Star…

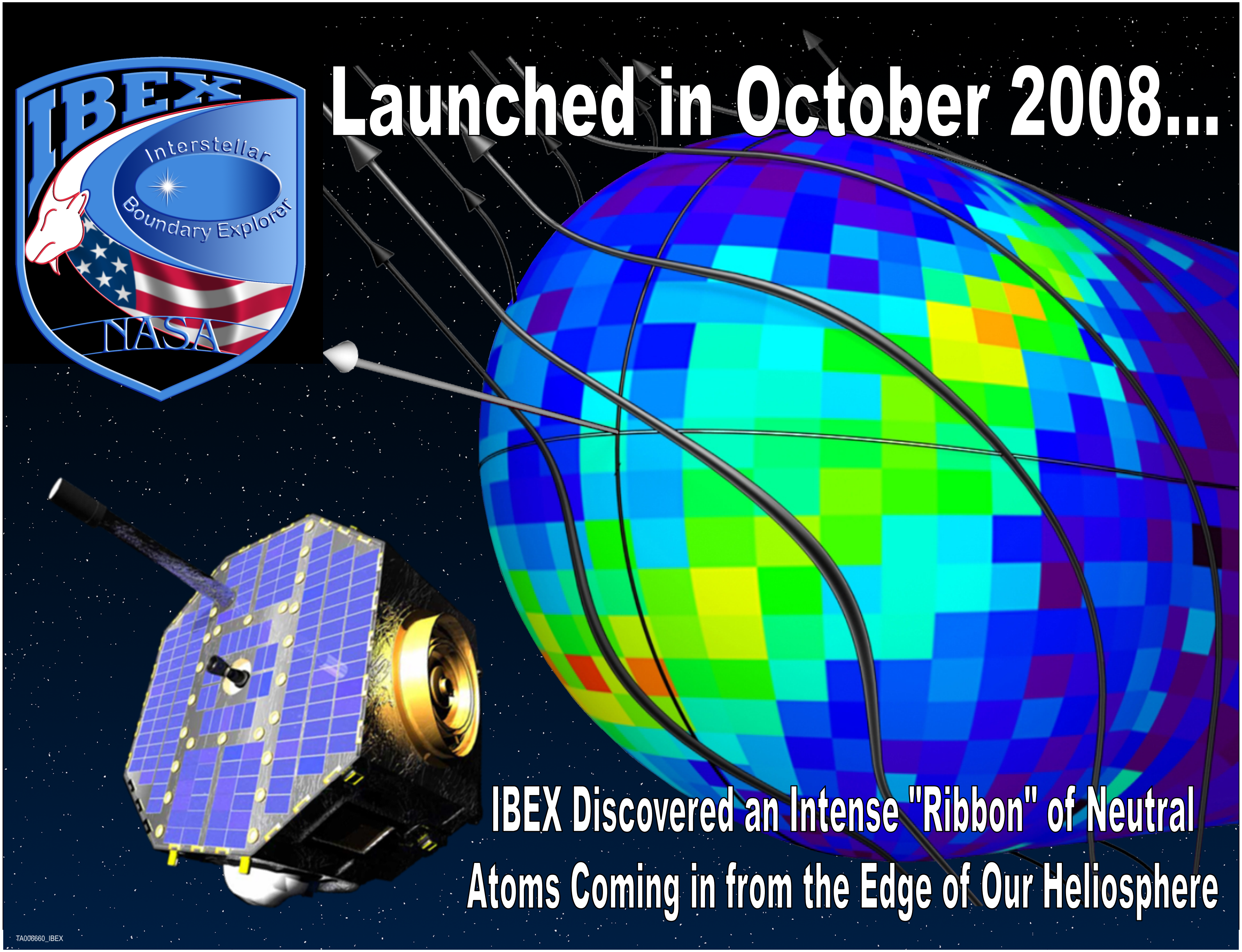
Astrospheres and Our Heliosphere





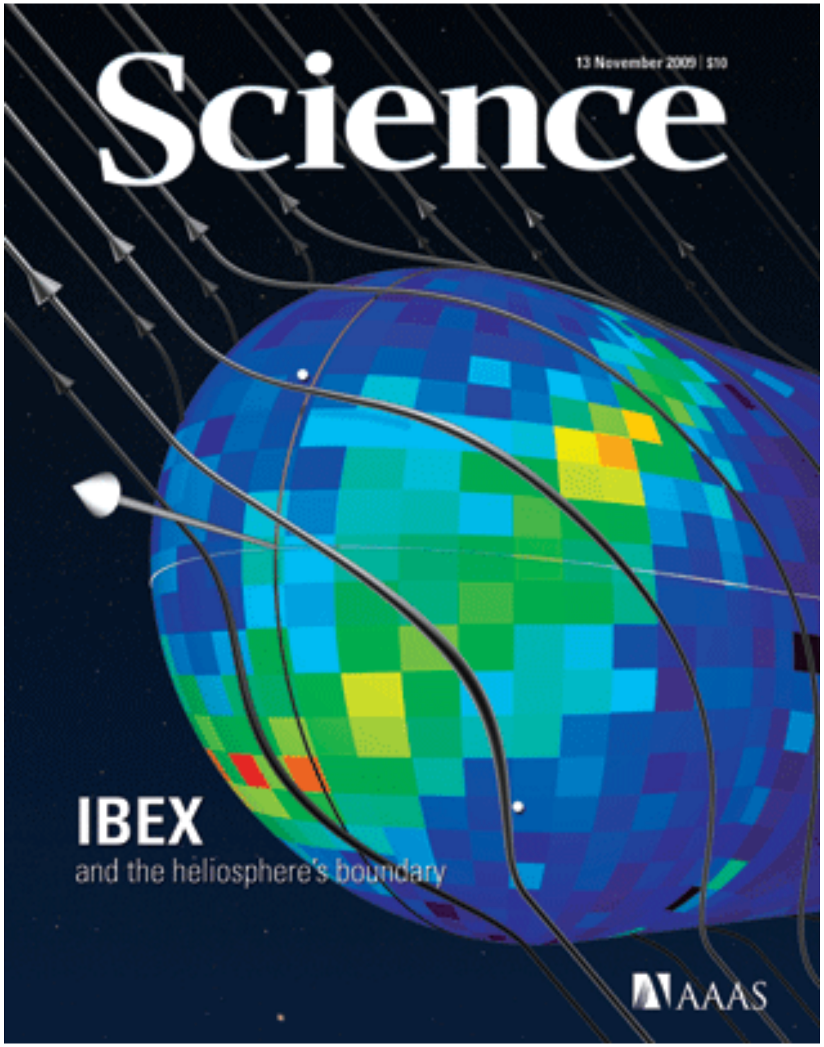
Left image courtesy of R. Casalegno, C. Conselice et al., WIYN, NOAO

Other images from HubbleSite.org

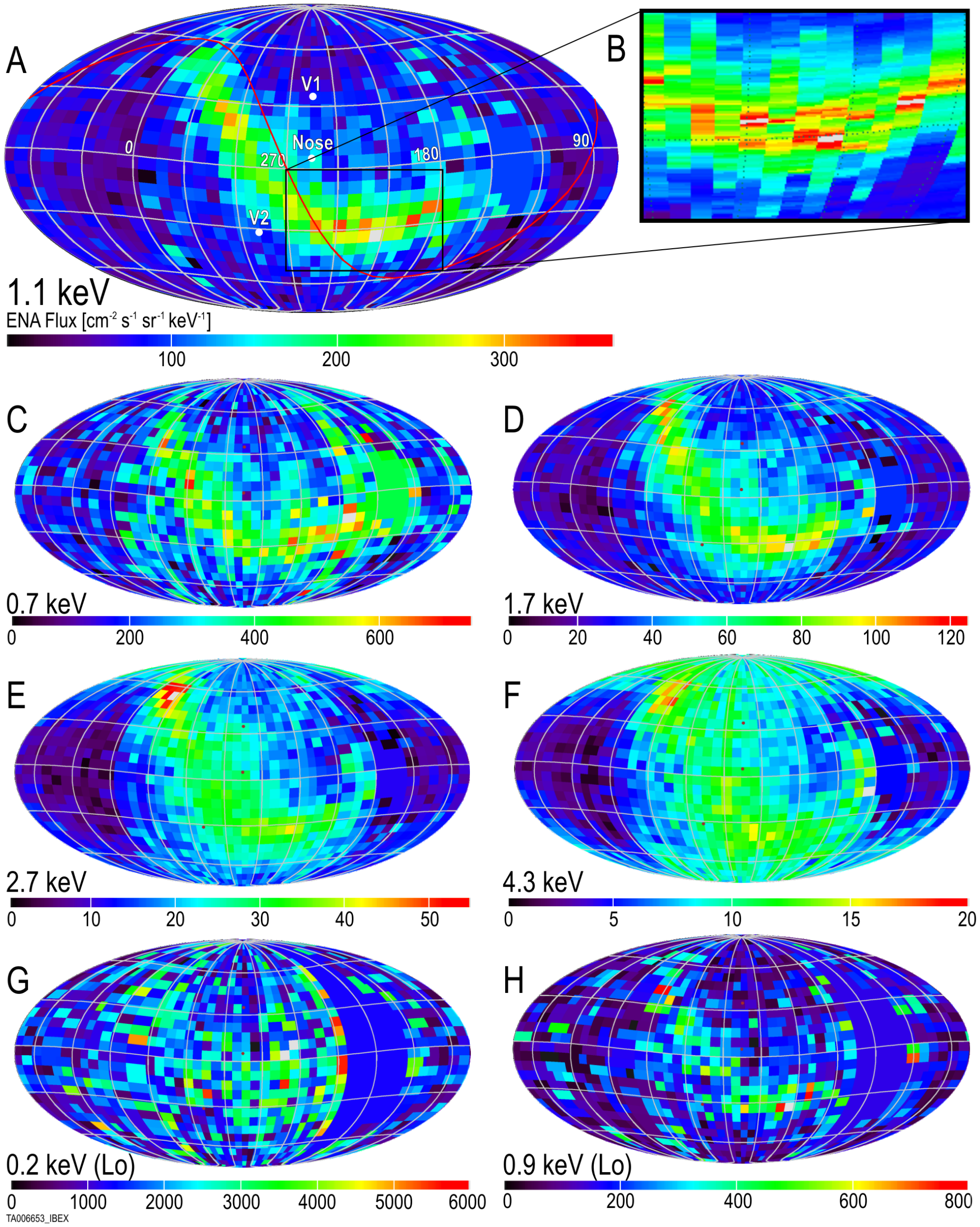


IBEX
Interstellar
Boundary Explorer
NASA
Launched in October 2008...
IBEX Discovered an Intense "Ribbon" of Neutral
Atoms Coming in from the Edge of Our Heliosphere
TA006660_IBEX

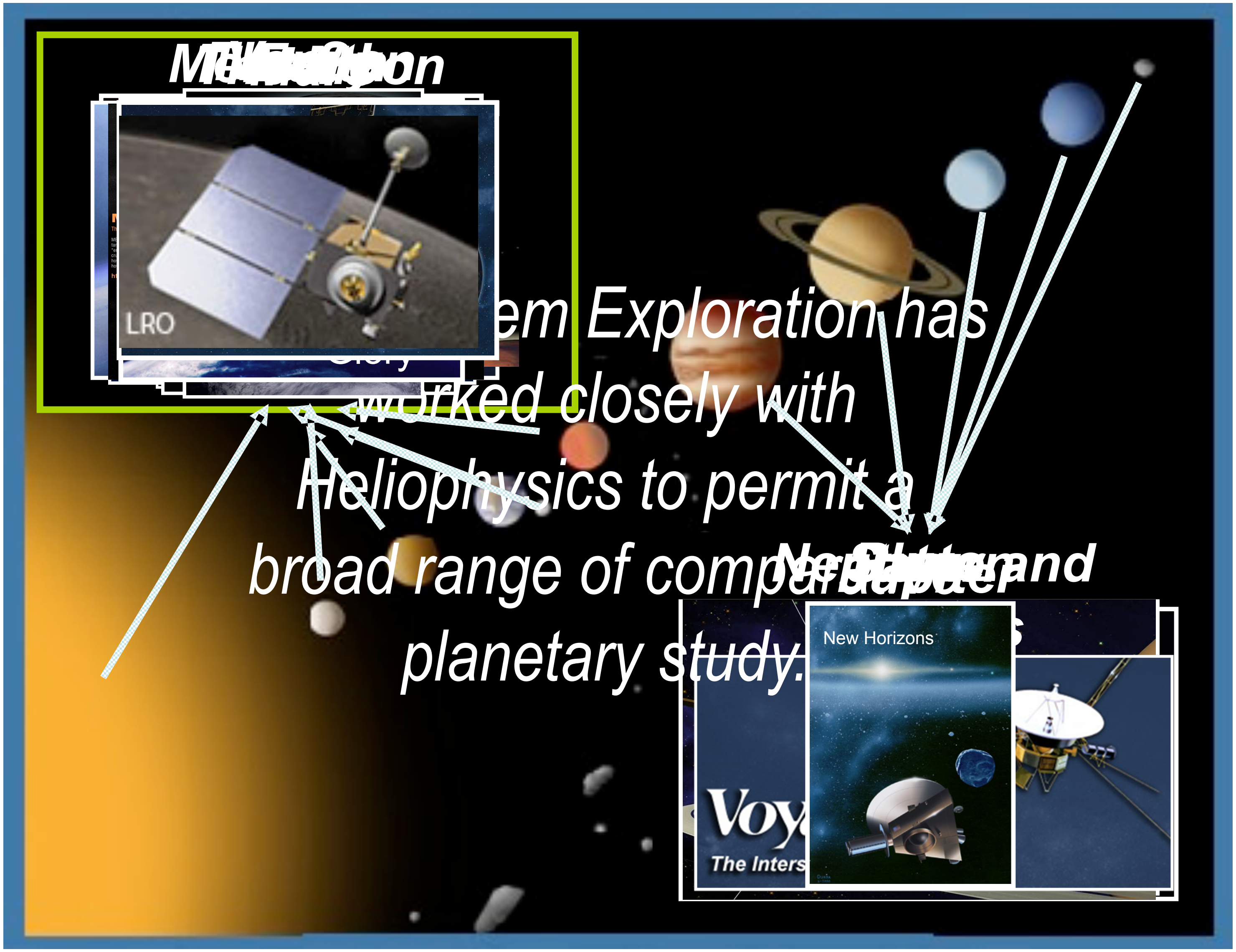
First Images of Solar System Edge



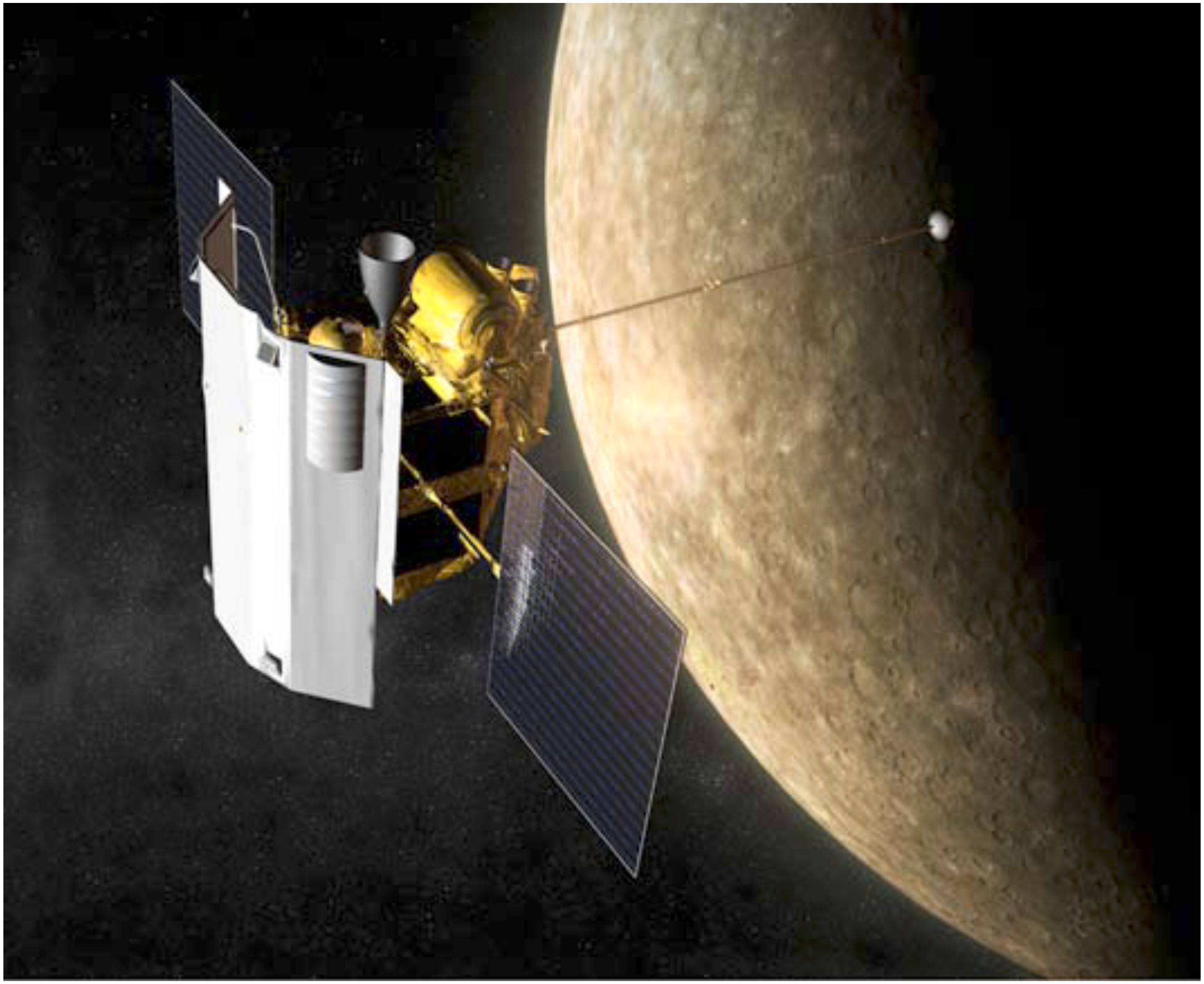
13 November 2009



Space Physics in Solar System Context

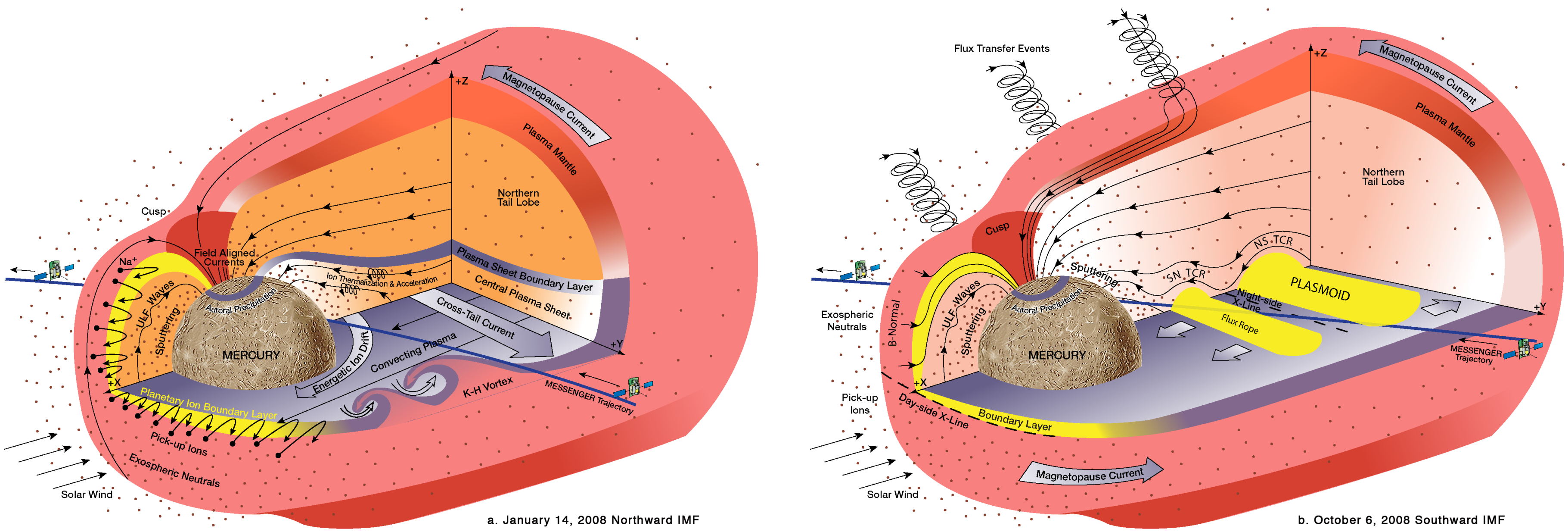


Mercury MESSENGER



M1: Plasma and Fields

Mercury's Magnetosphere Post-Flyby View



Northward IMF

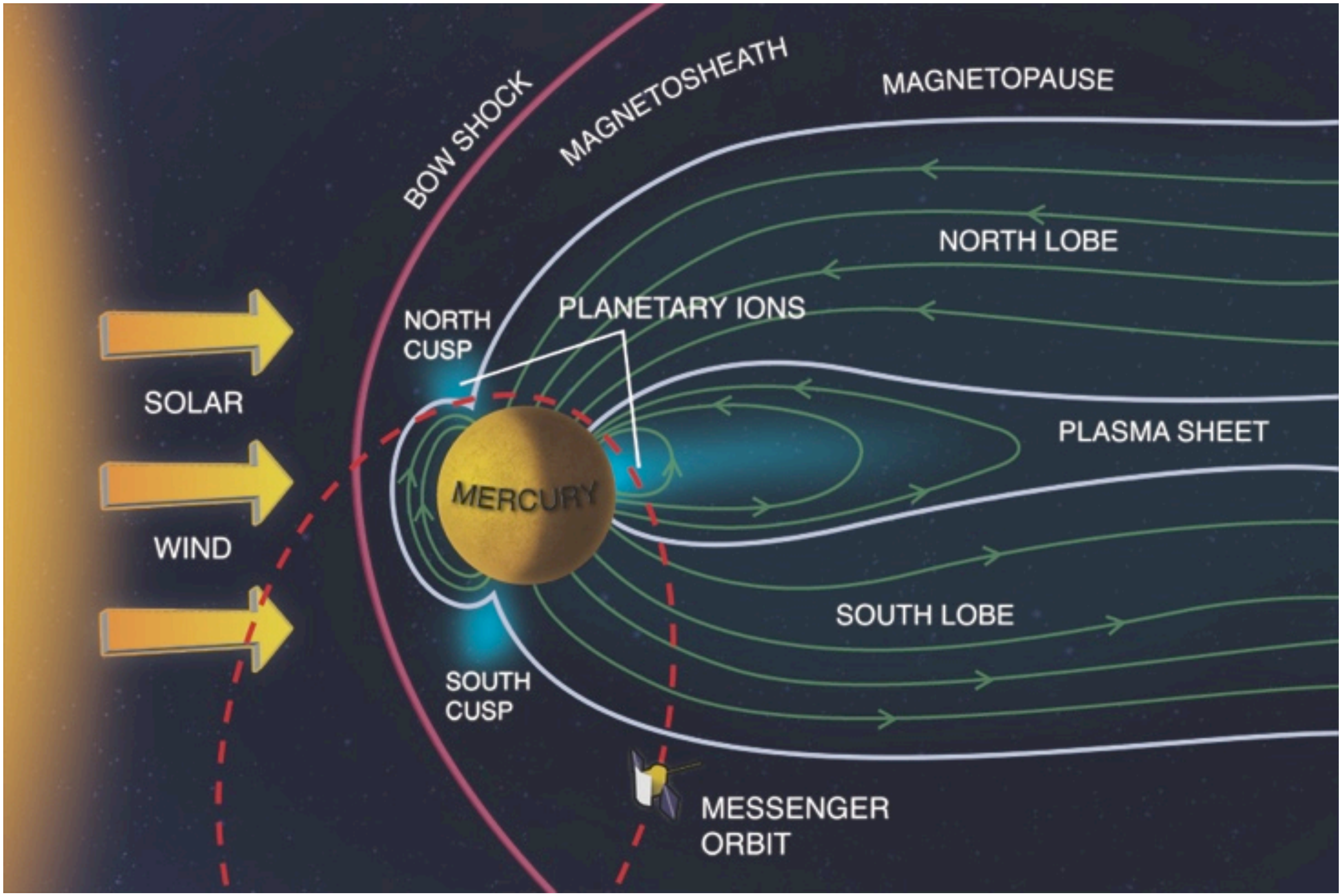
- Magnetopause Boundary Layer
- Kelvin-Helmholtz Waves on Flanks

[Slavin et al., 2009, 2010]

Southward IMF

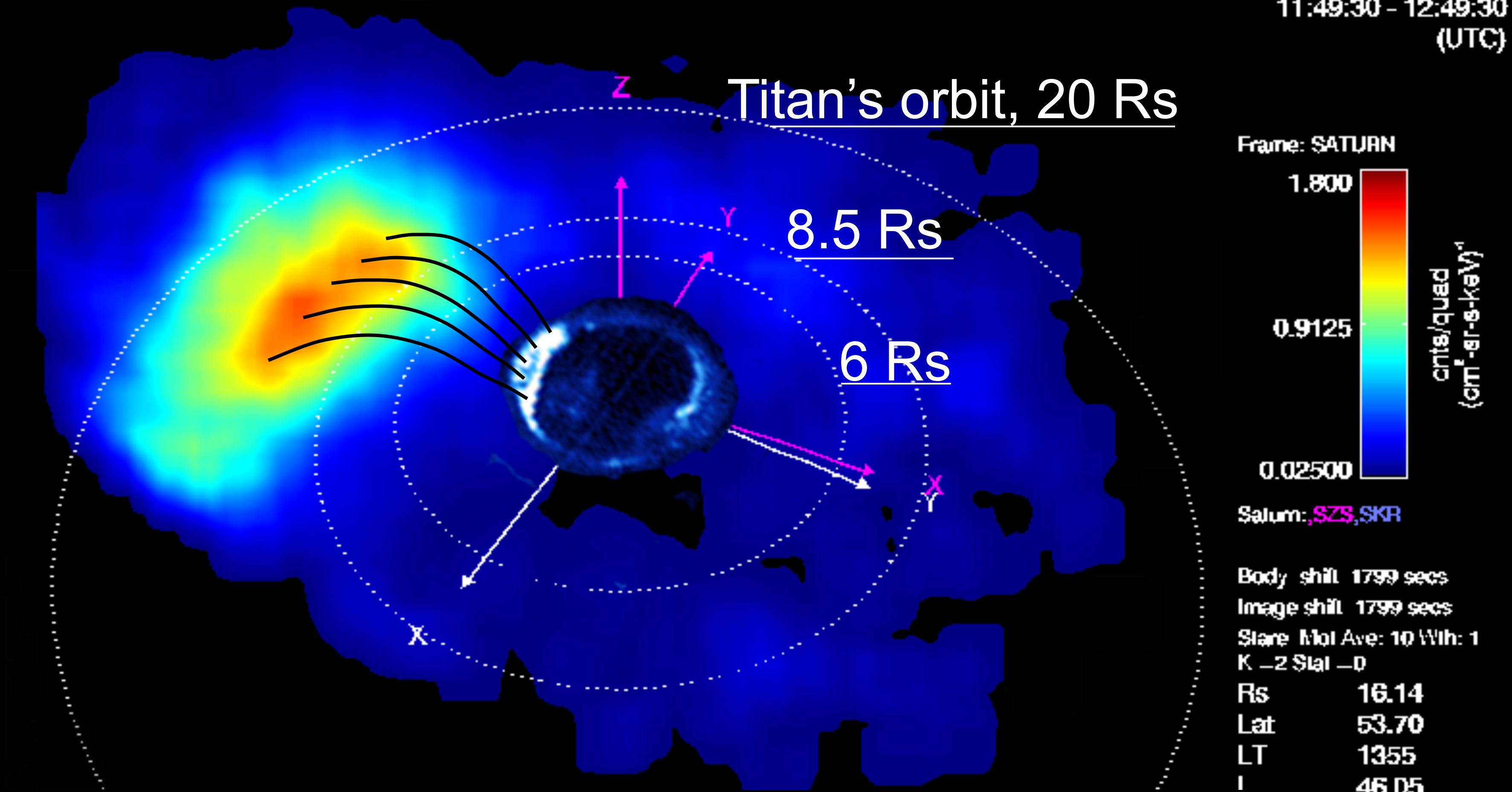
- Magnetopause B-normal is ~ 10 times Earth values; Dungey Cycle Time is ~ 2 min;
- Large Flux Transfer Event when IMF $B_z < 0$
- Plasmoid and TCRs imply NMNL X ~ -2.6 R_M

MESSENGER: The Mercury System



Zurbuchen et al., 2011

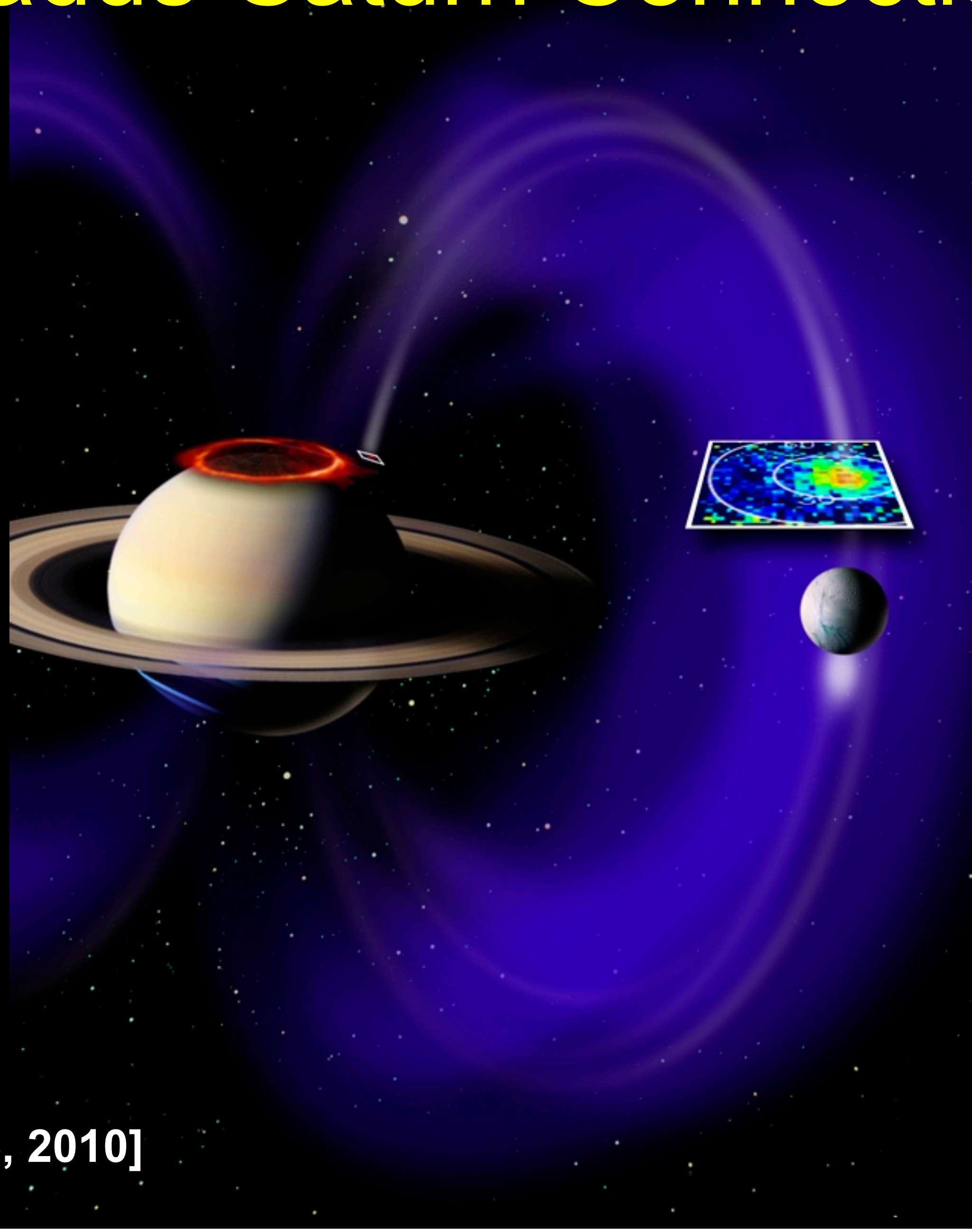
The emission of Energetic Neutral Atoms from the Ring Current reveals the presence of an acceleration region in the equatorial plane that rotates in lock-step with the bright auroral ultraviolet emission.



An electric current mapping along Saturn's magnetic field connects the ring current enhancement with the ionosphere. The current generates electric fields parallel to the magnetic field, accelerates electrons into the atmosphere, and stimulates the UV emission.

[D. Mitchell et al.]

Enceladus-Saturn Connection



[Pryor et al., Nature, 2010]

MAVEN

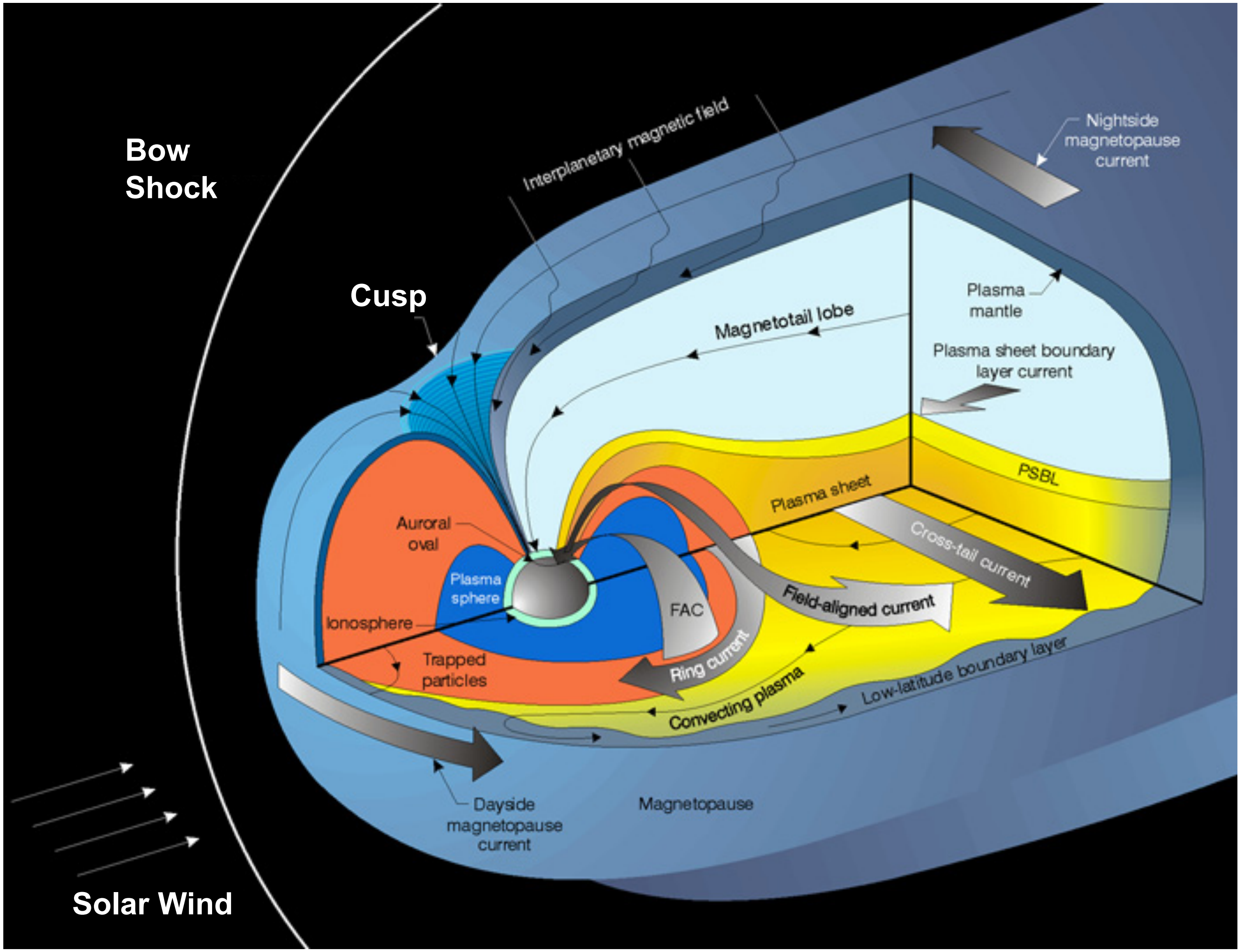
Mars Atmosphere and Volatile EvolutioN (MAVEN) Mission

Mars Scout Mission
Launch date: 2013

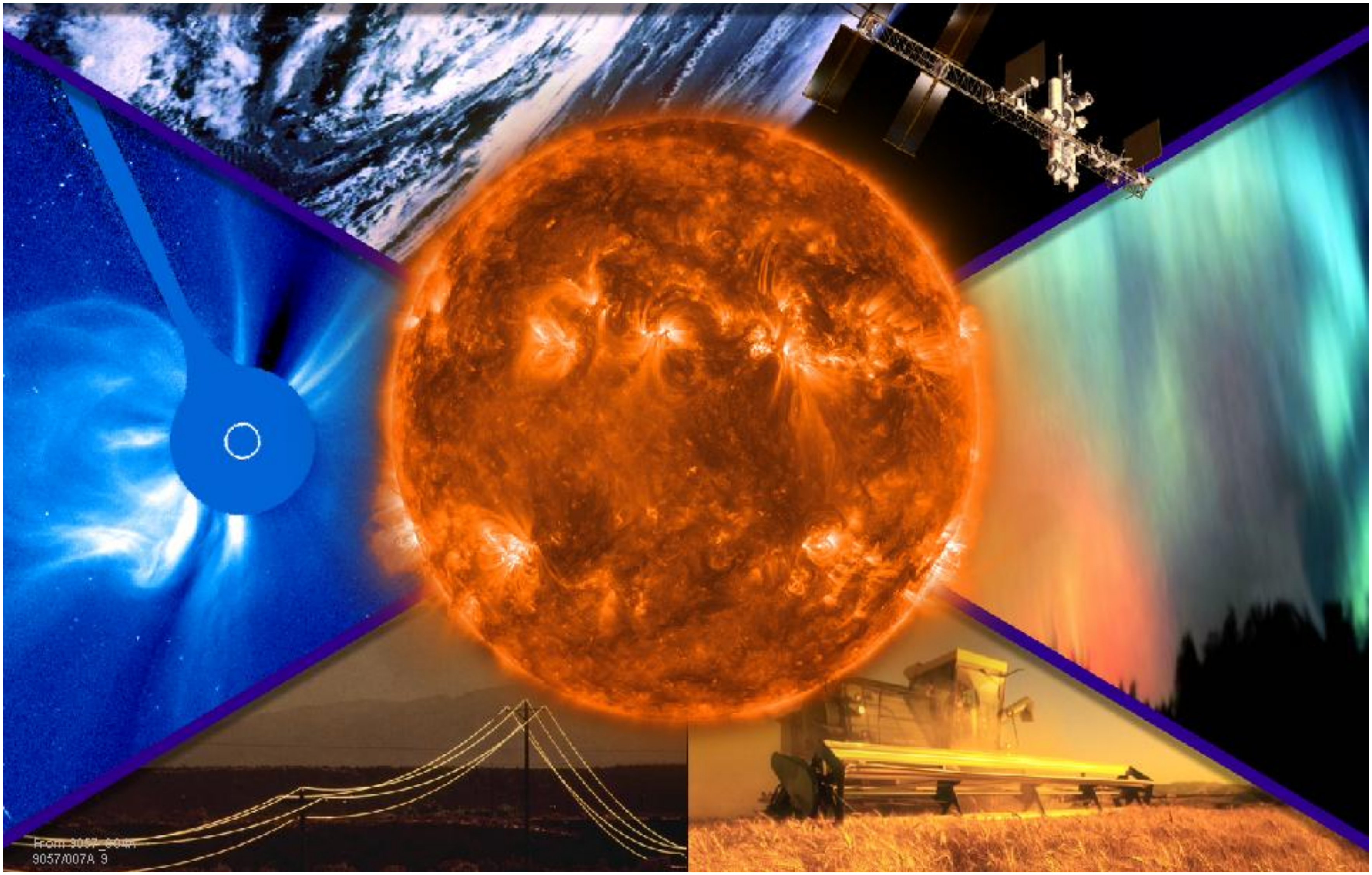
Key Understanding of Mars

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)

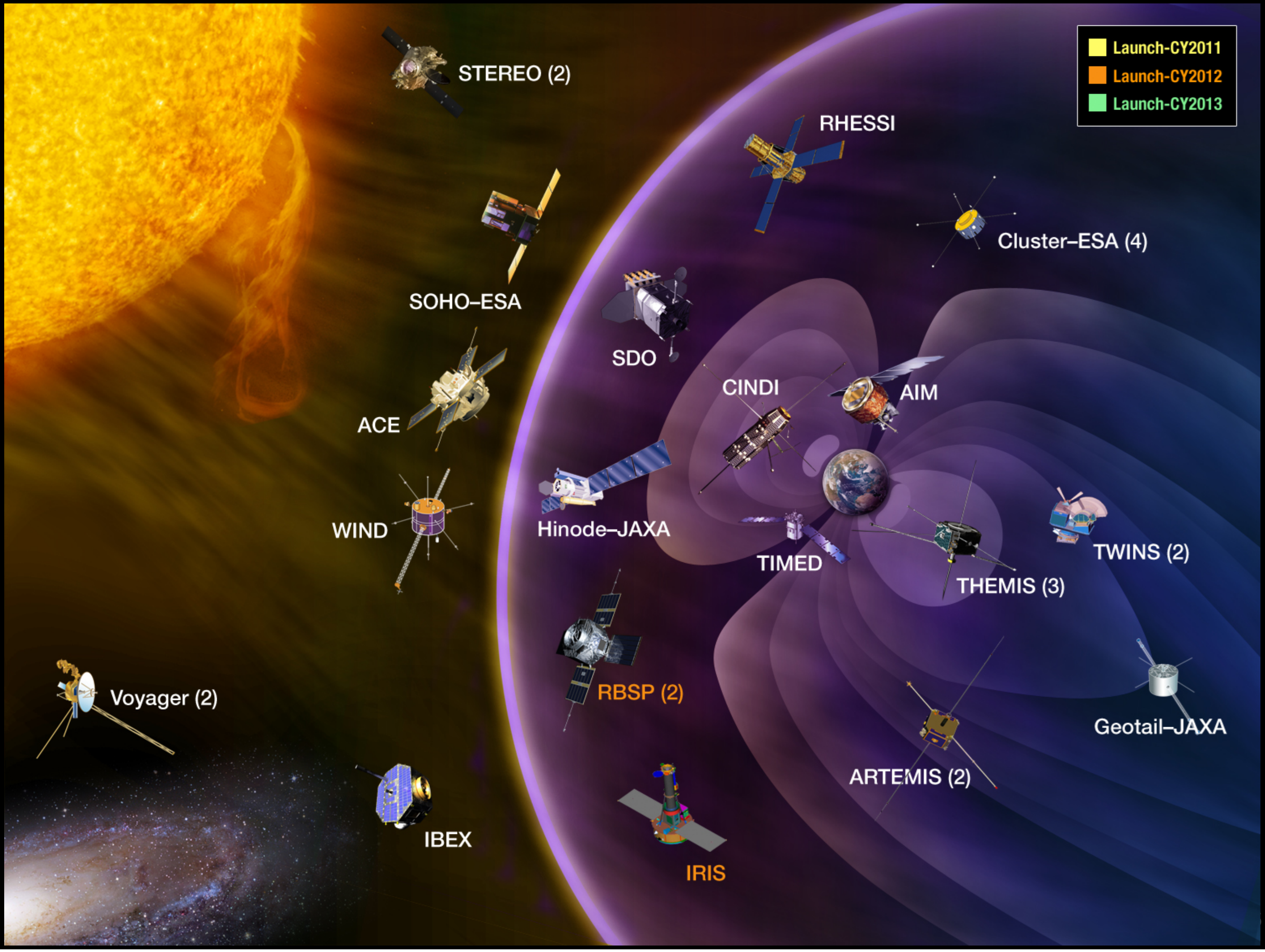
Magnetospheric Regions and Currents



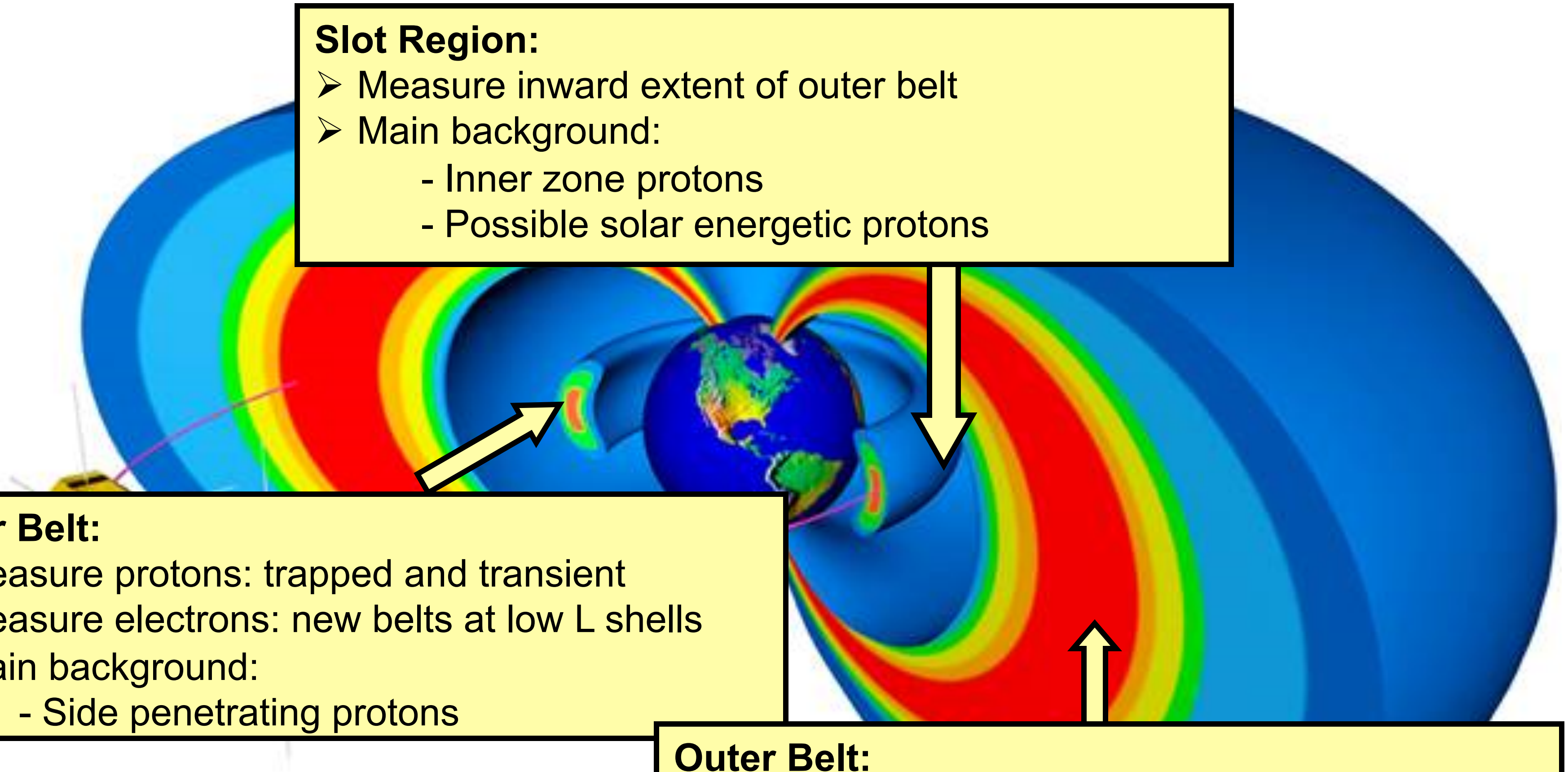
Sun-Earth Relationships



The Heliophysics System Observatory



Key Radiation Belt Regions: RBSP



Slot Region:
- Measure inward extent of outer belt
- Main background:
  - Inner zone protons
  - Possible solar energetic protons

Inner Belt:
- Measure protons: trapped and transient
- Measure electrons: new belts at low L shells
- Main background:
  - Side penetrating protons

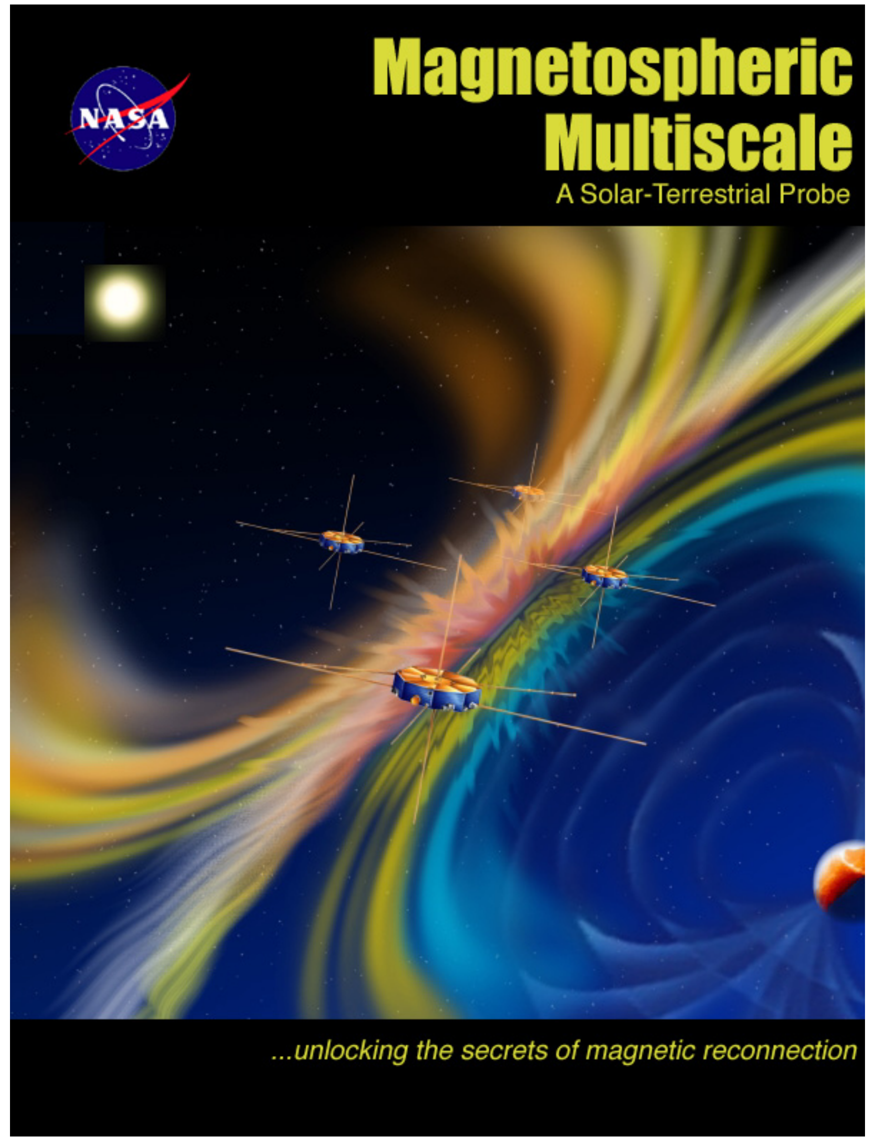
Outer Belt:
- Measure electrons: intense & “normal” events
- Main backgrounds:
  - Side penetrating electrons
  - Possible solar energetic protons

International Living With a Star (ILWS)

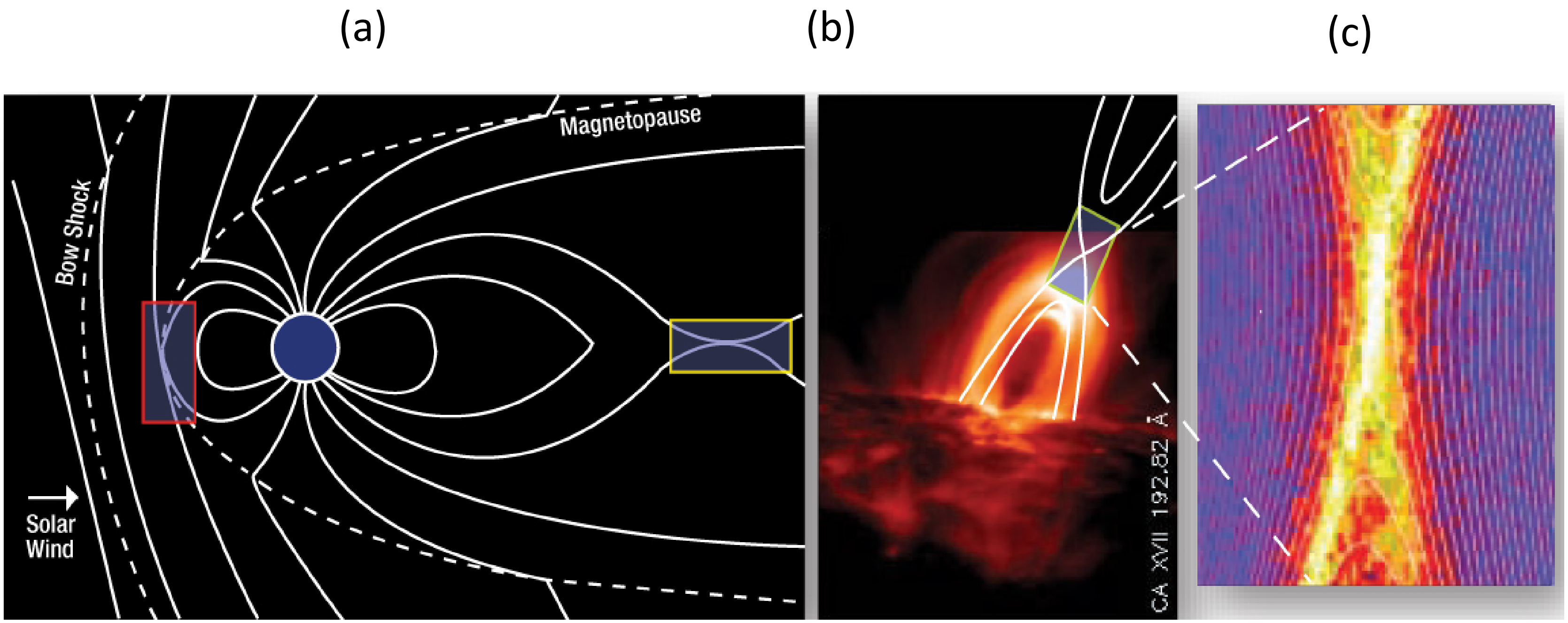
What Must We Study Next?

We need to learn:

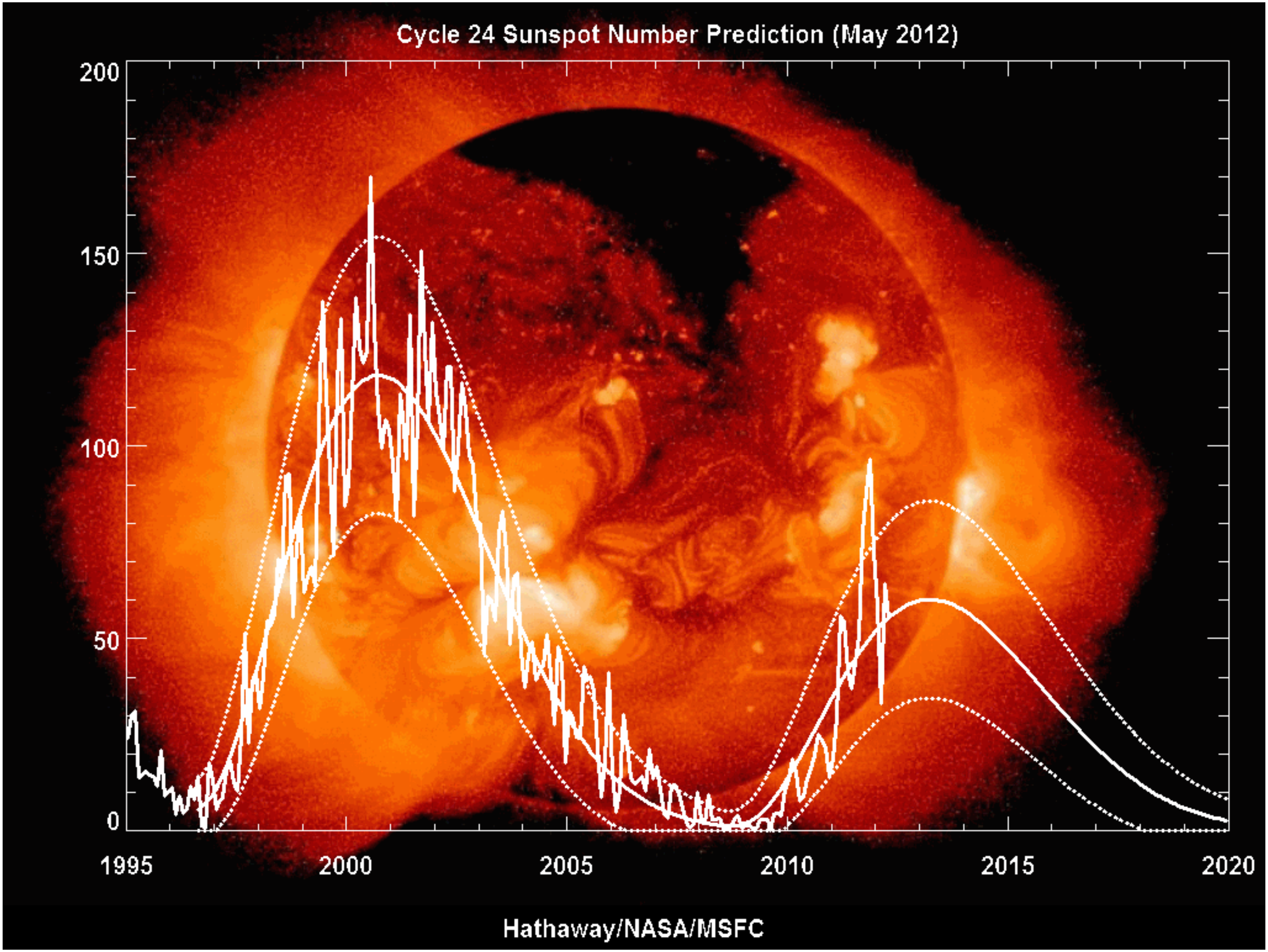
- How complex systems catastrophically reconfigure themselves
- How local (multiscale) turbulence relates to global-scale system instability: MMS
- How the progression of geomagnetic disturbances relate to one another (and ultimately lead to global dynamical changes)



A Fundamental Universal Process

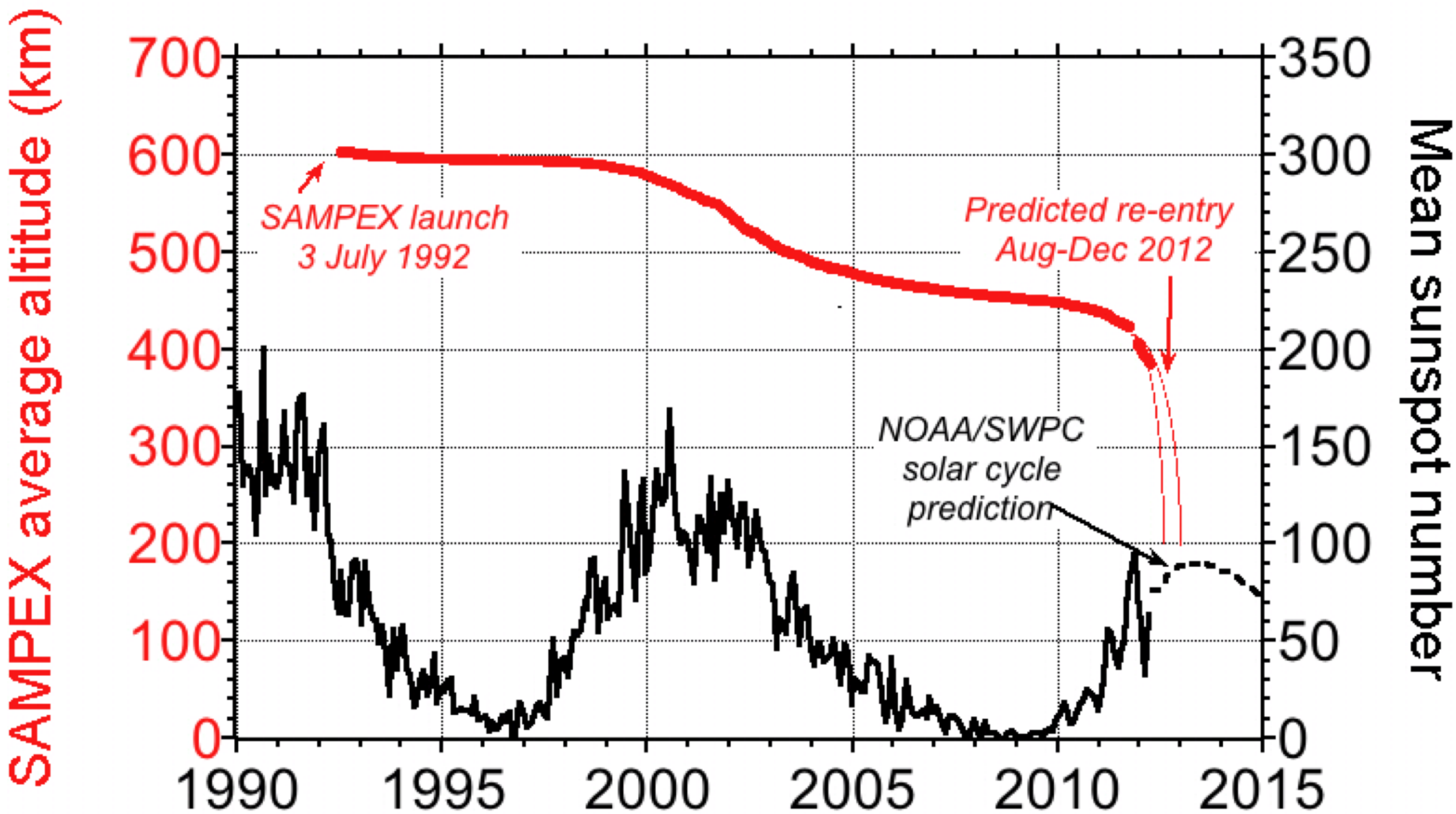


Magnetic reconnection is important in the (a) Earth's magnetosphere, (b) in the solar corona (solar flares and CMEs) and throughout the universe (high energy particle acceleration). Simulations (c) are used to guide experiments.



Cycle 24 Sunspot Number Prediction (May 2012)
200
150
100
50
0
1995
2000
2005
2010
2015
2020
Hathaway/NASA/MSFC

The End of SAMPEX Era



[Baker, Mazur, Mason, SWJ,2012]

Summary

- A fascinating discipline, rich in history
- The Sun, the Earth, the planets, and the interplanetary medium out to the fringes of the solar system form a highly coupled system
- The missions and programs touched on here barely scratch the scientific surface of what has been learned in the last five decades
- Heliophysics uniquely combines basic science with crucially important applied aspects
- I urge you to use this Summer School to begin deeply examining the many facets of the discipline!