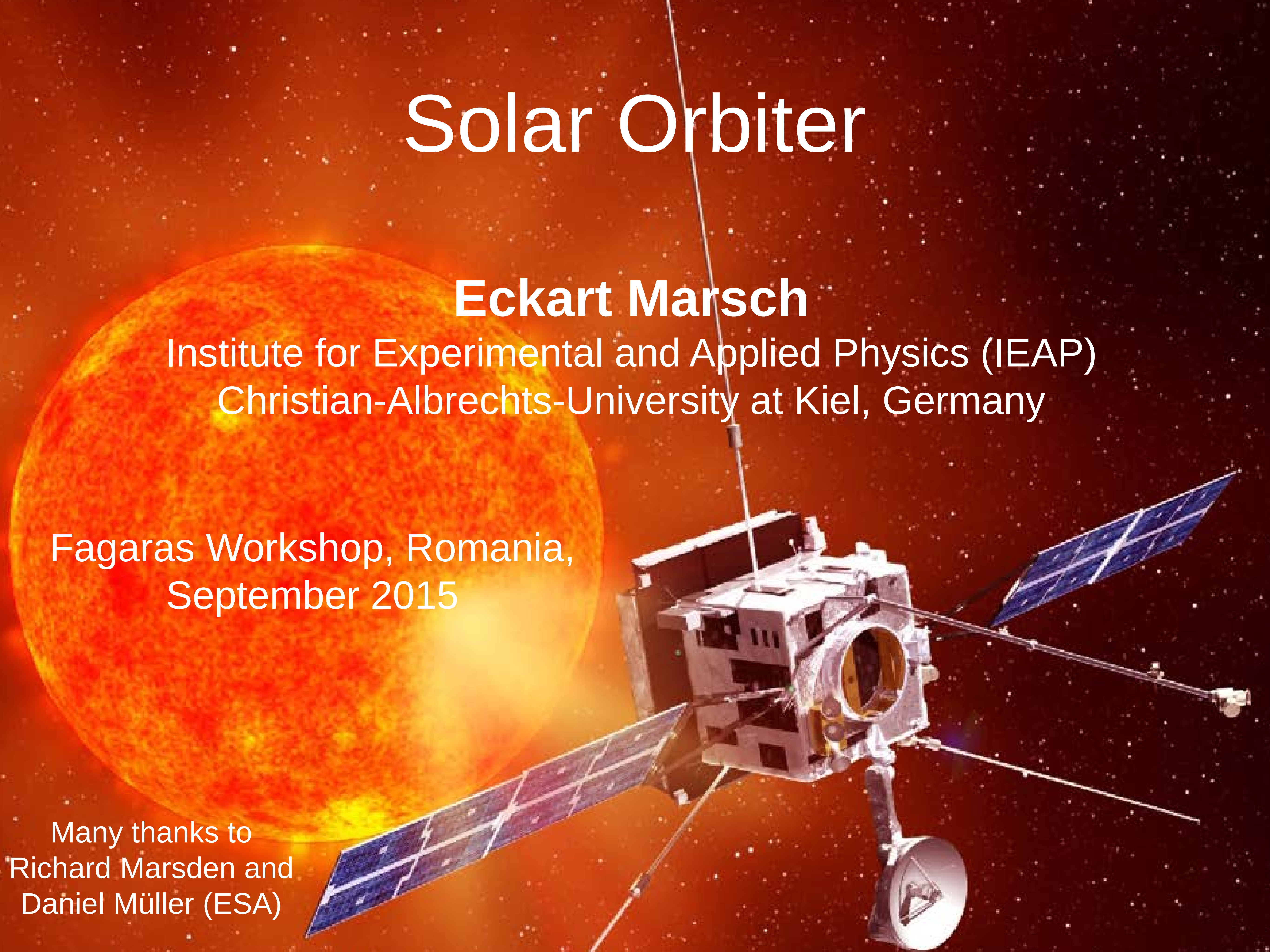


Solar Orbiter

Eckart Marsch

Institute for Experimental and Applied Physics (IEAP)

Christian-Albrechts-University at Kiel, Germany

Fagaras Workshop, Romania,

September 2015

Many thanks to

Richard Marsden and

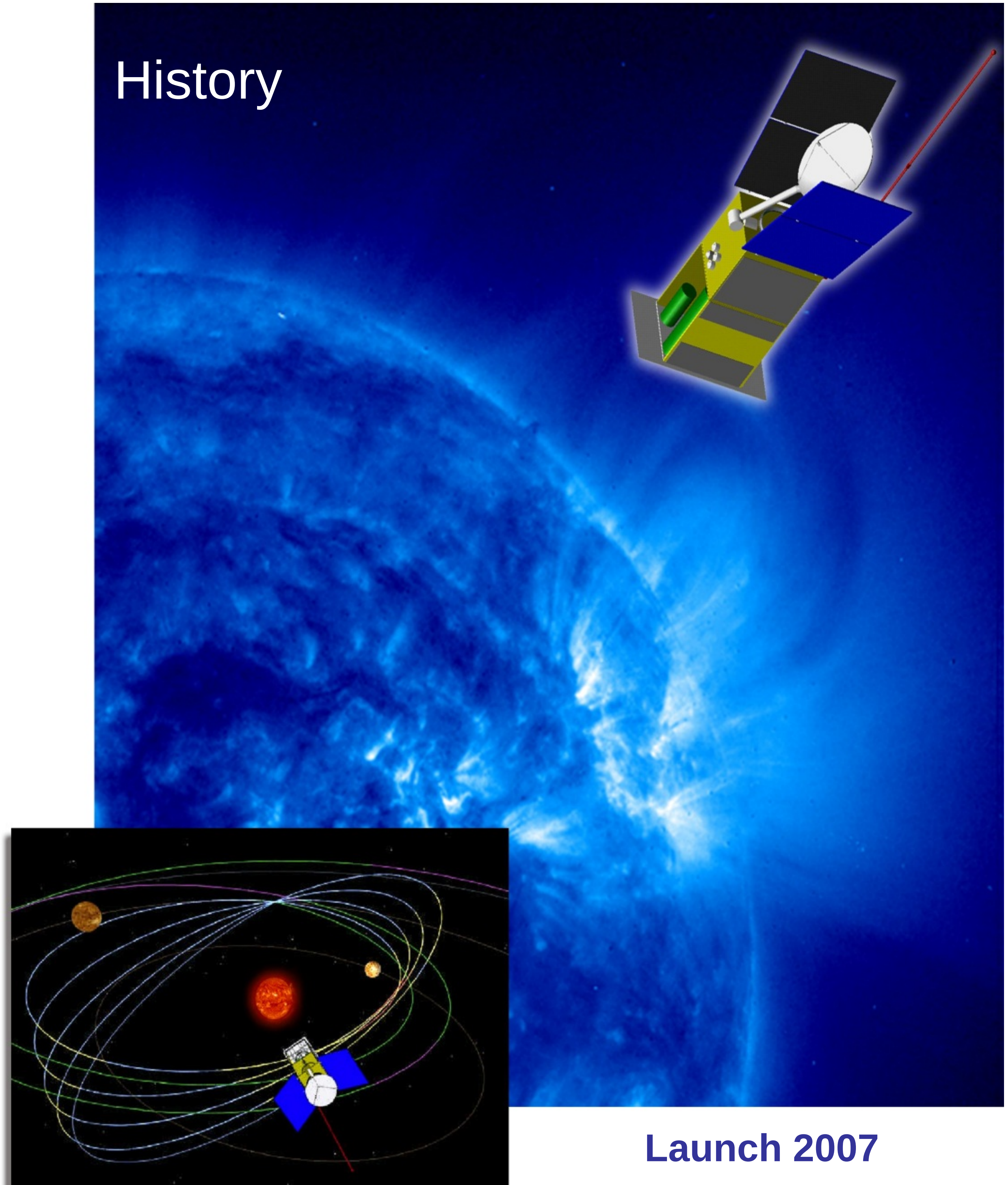
Daniel Müller (ESA)

Solar Orbiter:
Exploring the Sun-Heliosphere Connection

- First medium-class mission of ESA’s Cosmic Vision 2015-2025 programme, implemented jointly with NASA.
- Dedicated payload of 10 *remote-sensing* and *in-situ* instruments measuring from the photosphere into the solar wind.

Talk Outline:

- History
- Scientific objectives
- Mission overview
- Spacecraft and payload
- Mission synergies



Launch 2007

Mission Proposal in Response to the ESA Call for
Mission Proposals for Two Flexi-Missions (F2 and F3)
Submitted January 27, 2000

Solar Orbiter
High-Resolution Mission to the Sun and Inner Heliosphere

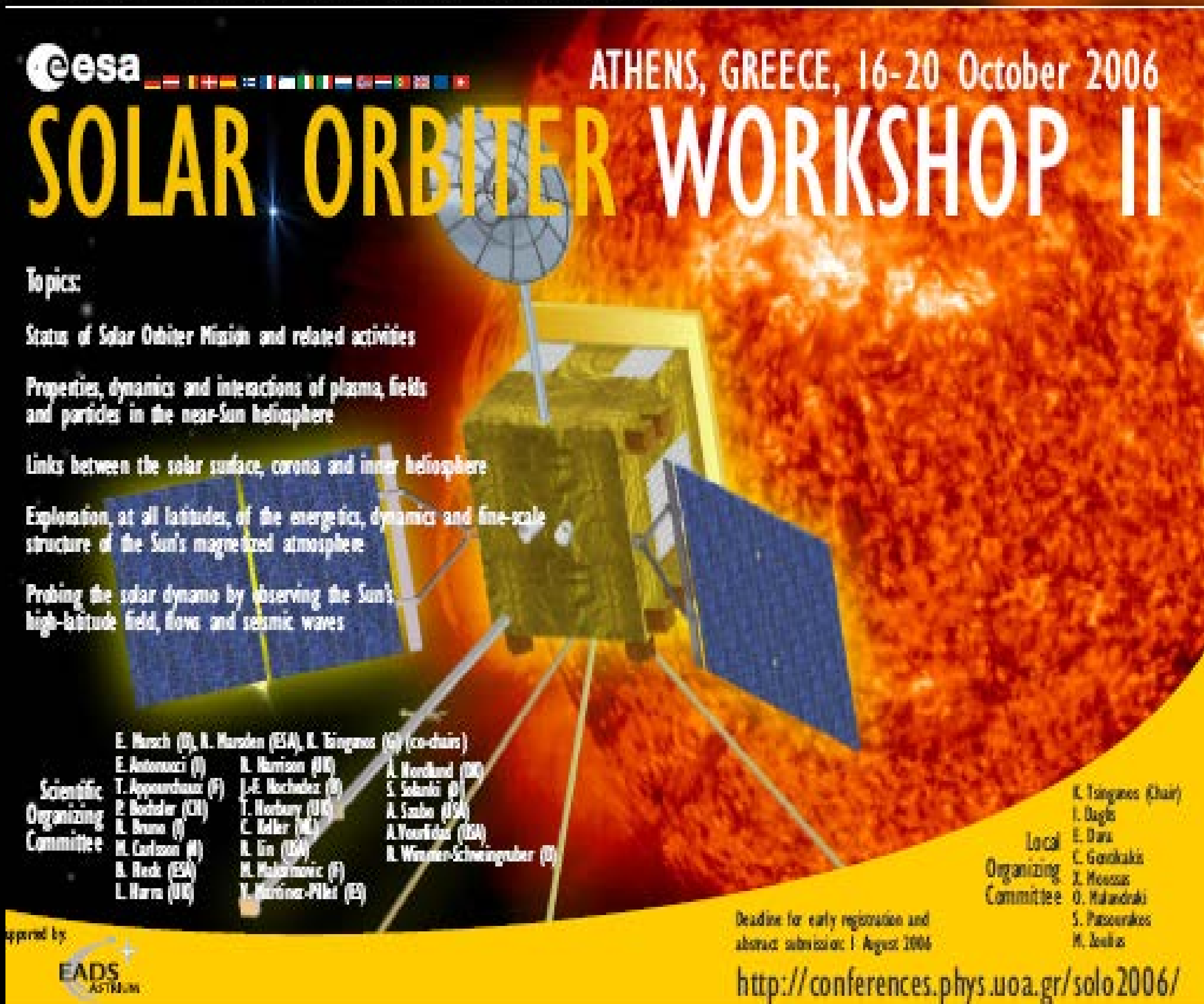
Assessment Study Report
July 2000 SCI(2000)6

Study team members:
E. Marsch, Max-Planck-Institut für Aeronomie, Katlenburg-Lindau, D
E. Antonucci, Osservatorio Astronomico di Torino, Pino Torinese, I
P. Bochsler, University of Bern, Switzerland, CH
J.-L. Bougeret, Observatoire de Paris, Meudon, F
R. Harrison, Rutherford Appleton Laboratory, Chilton, UK
R. Schwenn, Max-Planck-Institut für Aeronomie, Katlenburg-Lindau, D
J.-C. Vial, Institut d'Astrophysique Spatiale, Université de Paris-Sud, F

ESA study scientists:
B. Fleck, ESA/GSFC, Greenbelt, Maryland, USA
R. Marsden, ESA/ESTEC, Noordwijk, The Netherlands, NL

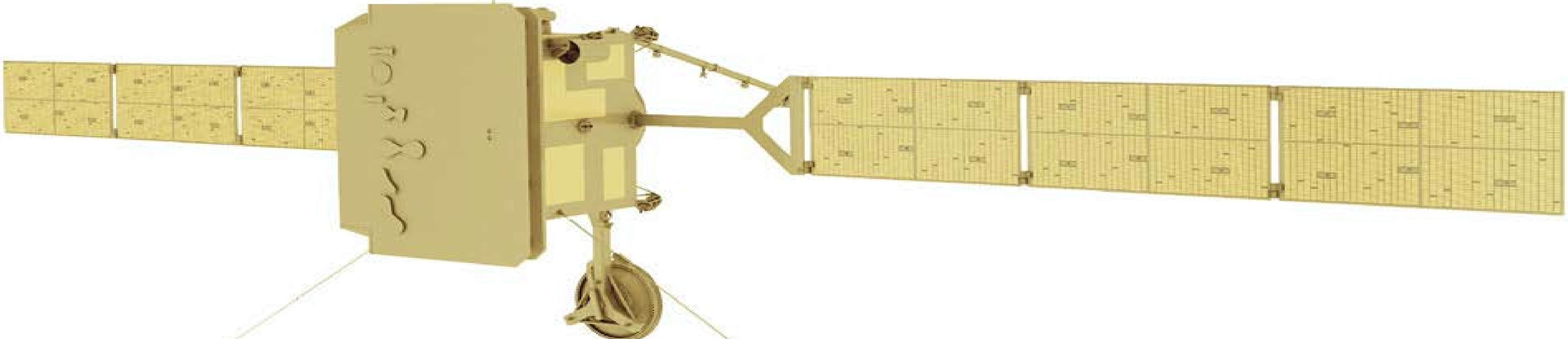
5 Workshops

2011 Telluride, USA
2012 Brugge, Belgium



Solar Orbiter status

- Solar Orbiter was approved on 4 October 2011 and assigned a budget within ESA's Cosmic Vision 2015-2025 science programme.
- It is now in Phase C that started end of 2012.
- Solar Orbiter is an ESA-led mission with strong NASA participation for provision of launcher and payload elements.



- The system-level Principle Design Review (PDR) was completed successfully in March 2012, and instrument PDRs are all completed.
- Work progress is compatible with schedule for October 2018 launch.

How does the Sun create and control the heliosphere? Four key science questions:

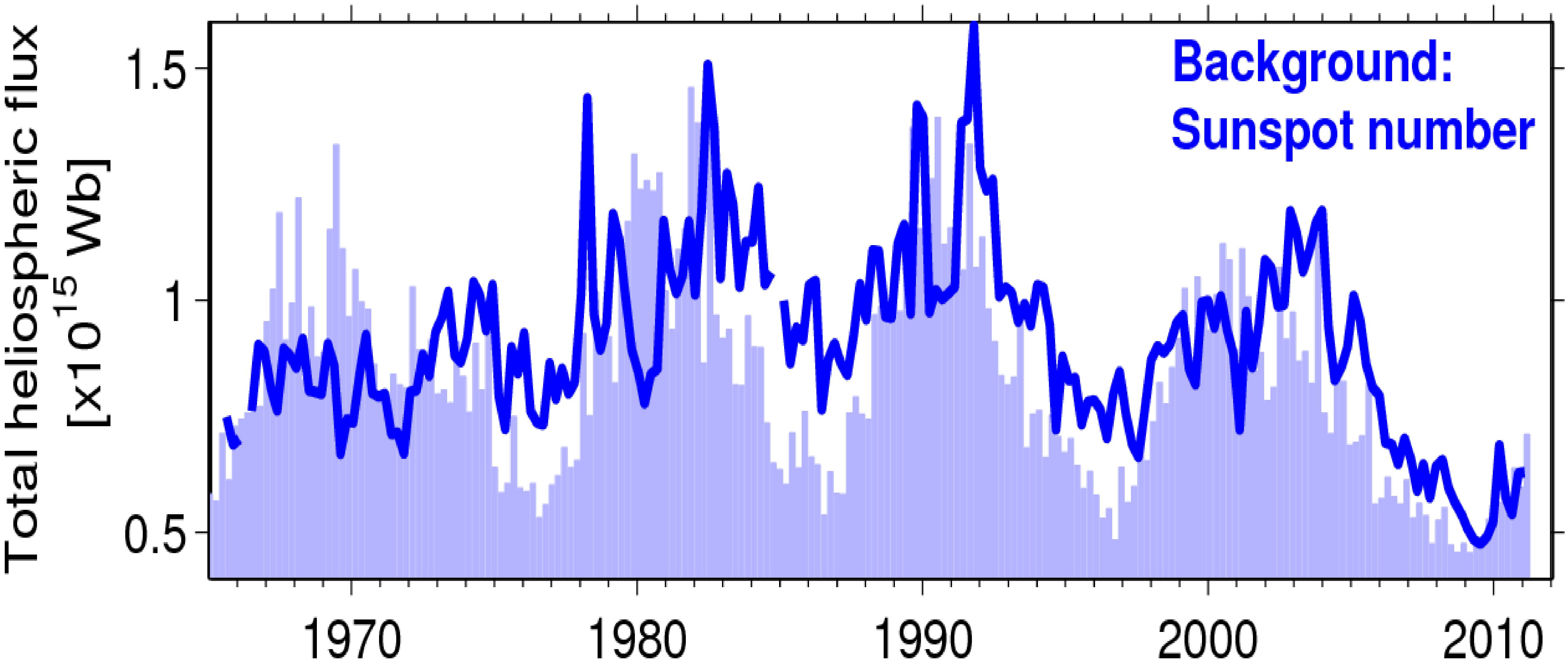
Q1) What drives the solar wind, and where does the coronal magnetic field originate from?

Q2) How do solar transients drive heliospheric variability?

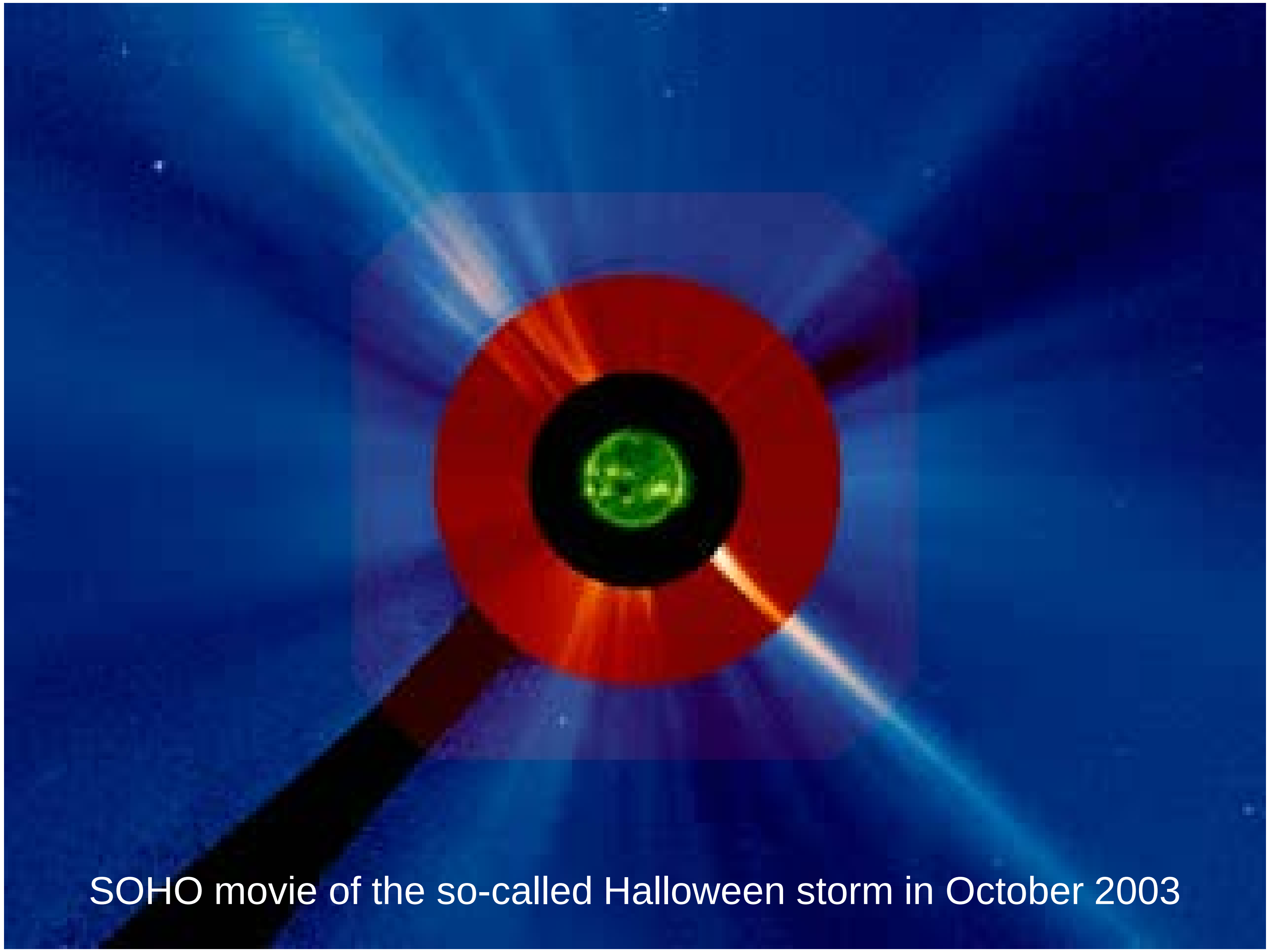
Q3) How do solar eruptions produce energetic particle radiation that fills the heliosphere?

Q4) How does the solar dynamo work and drive connections between the Sun and the heliosphere?

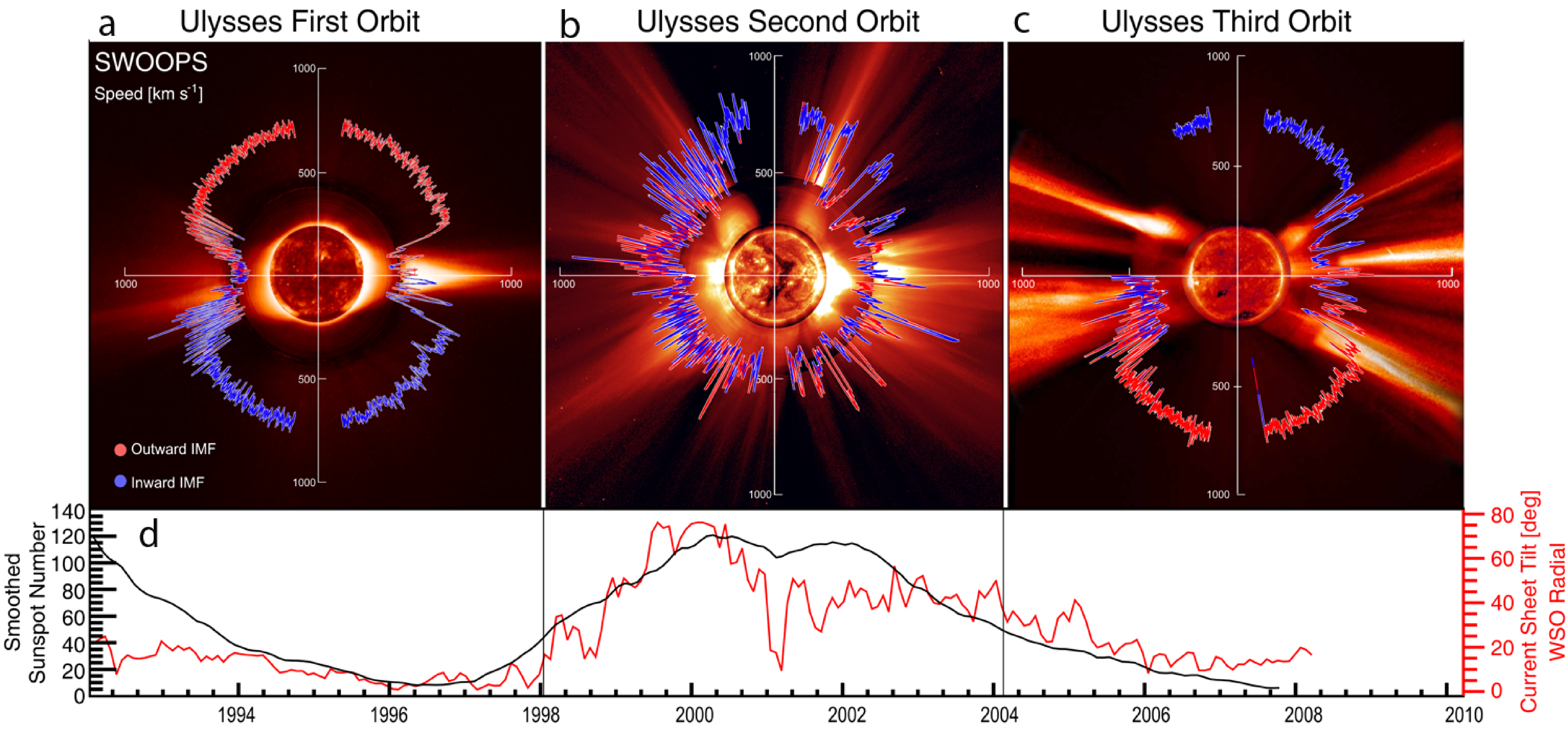
Why and how does the solar magnetic field change with time?



Why does the solar corona emit solar wind, drive transient ejections, and show magnetic activity?

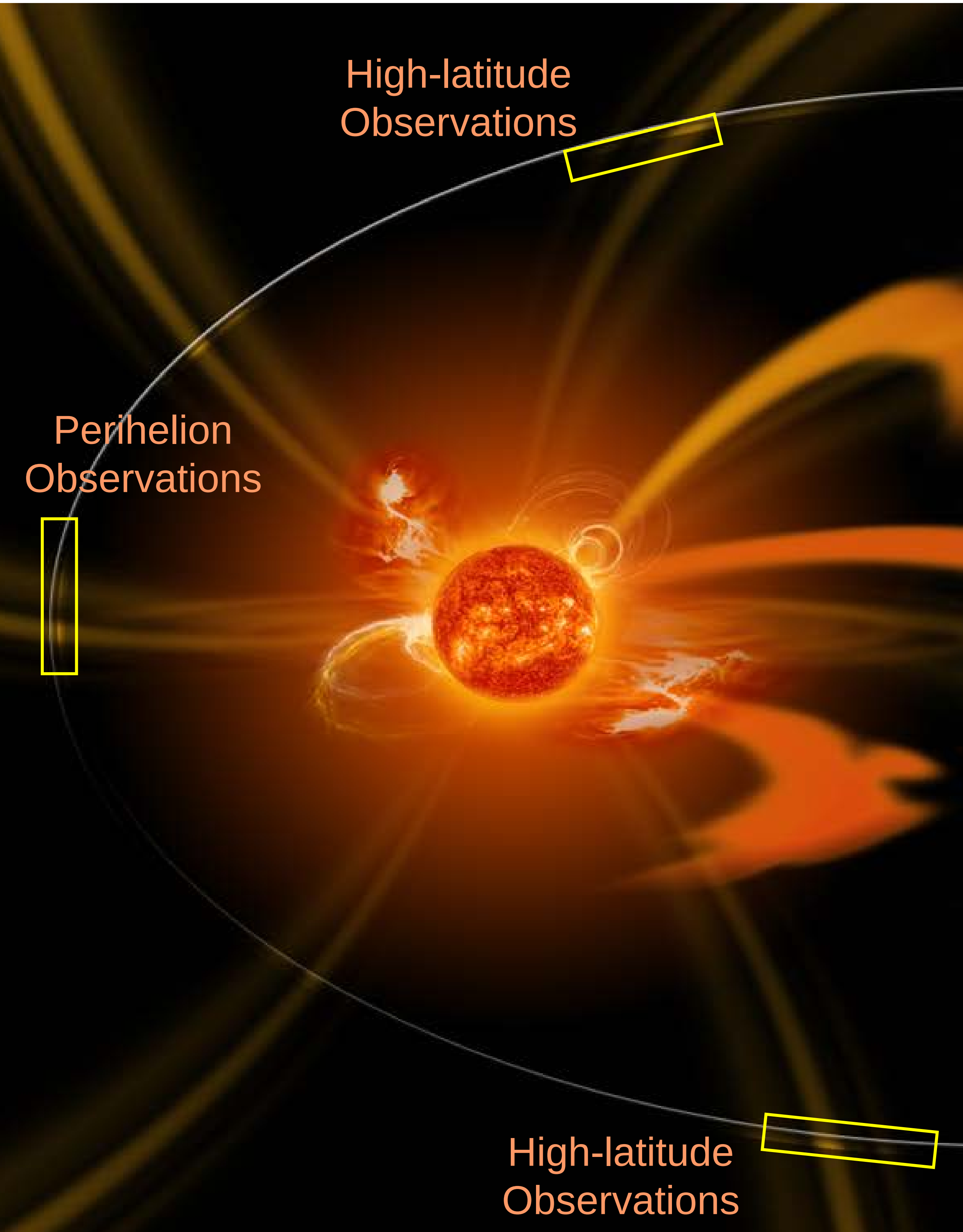

SOHO movie of the so-called Halloween storm in October 2003

How does the Sun sustain and shape the Heliosphere?



McComas et al., GRL 2008

Mission Overview



Launch date: October 2018

Cruise phase: 2.5 years

Nominal mission: 7 years

Extended mission: 3 years

Orbit: 0.28 – 0.32 AU (perihelion)
0.74 -- 0.91 AU (aphelion)

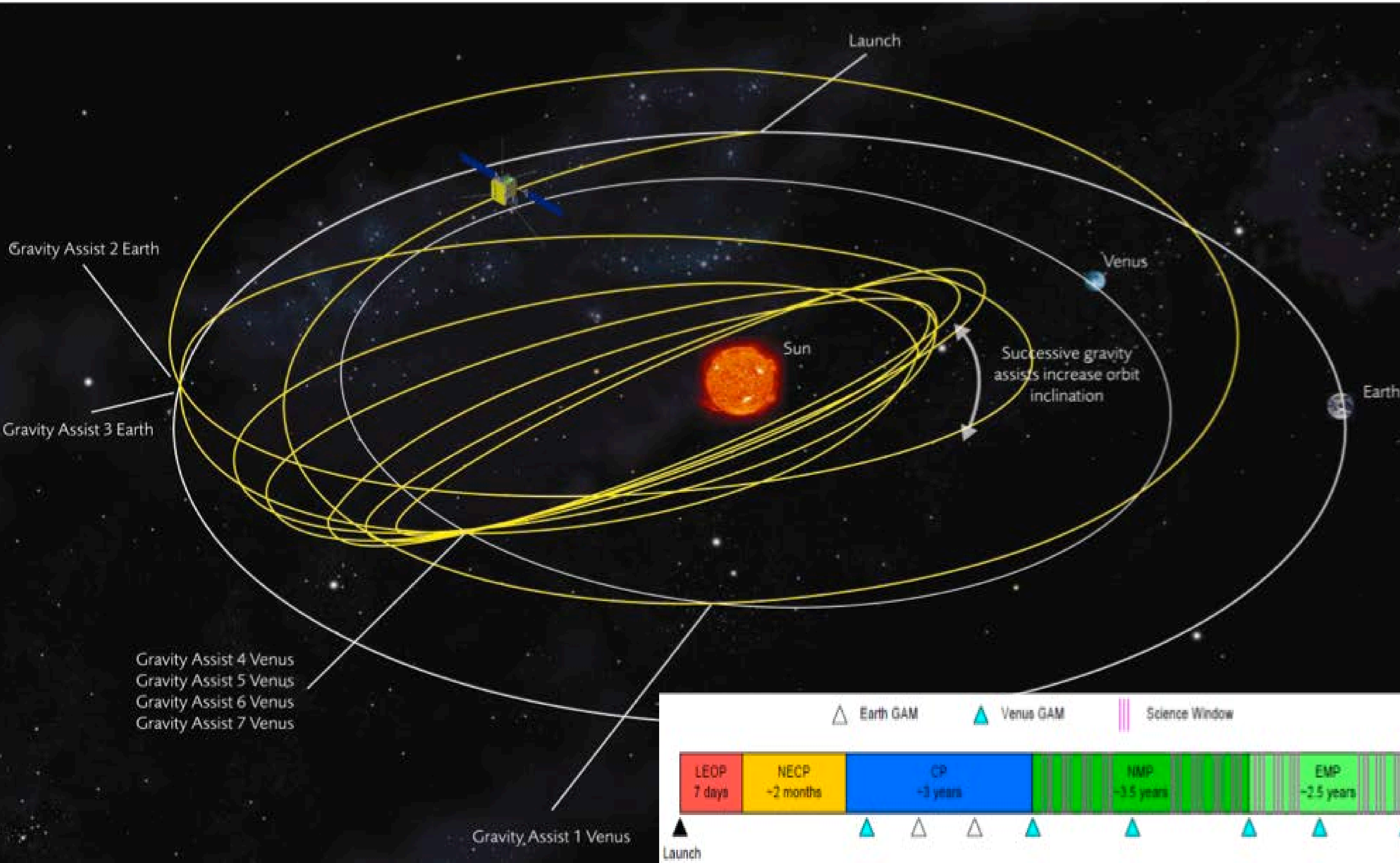
Telemetry: Dual X-band, rate 150 kbps at 1AU

Spacecraft: 3-axis stabilized, Sun-pointing

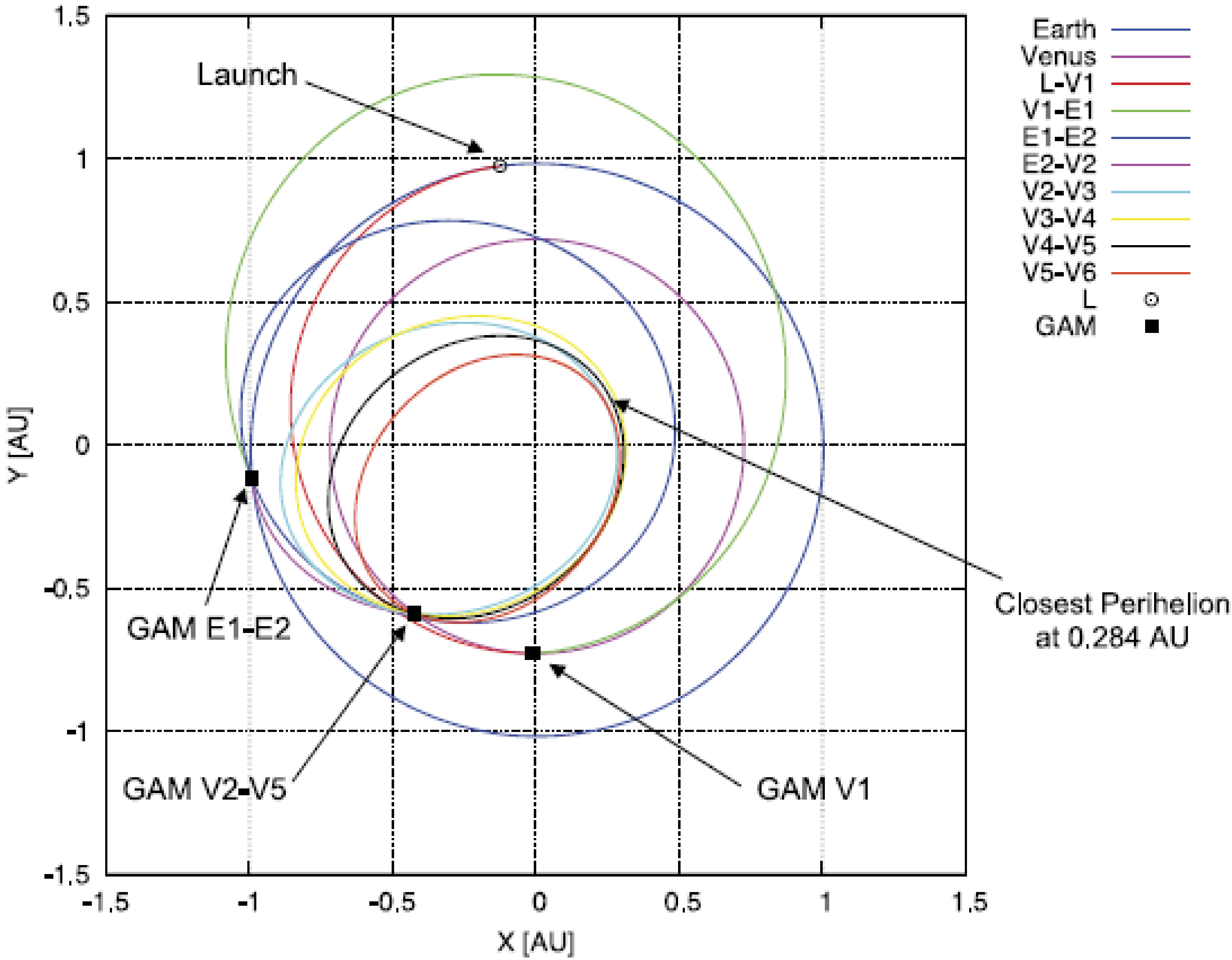
Out-of-ecliptic view:
Multiple gravity assists with Venus to increase inclination out of the ecliptic to 25° (nominal mission), 34° (extended mission)

Reduced relative rotation:
Continuous observation of evolving structures on the solar surface and heliosphere for almost a complete solar rotation

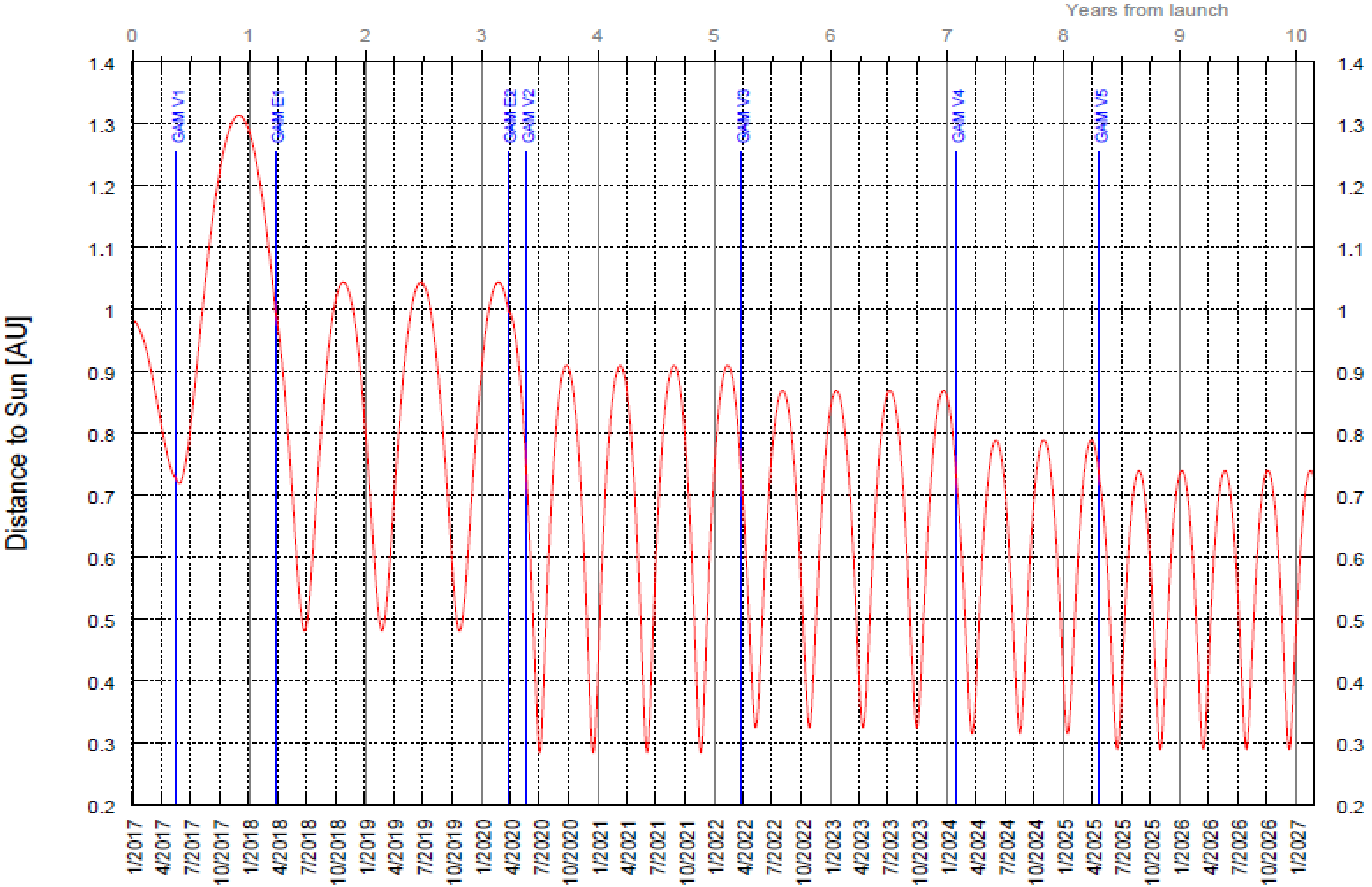
Mission Profile



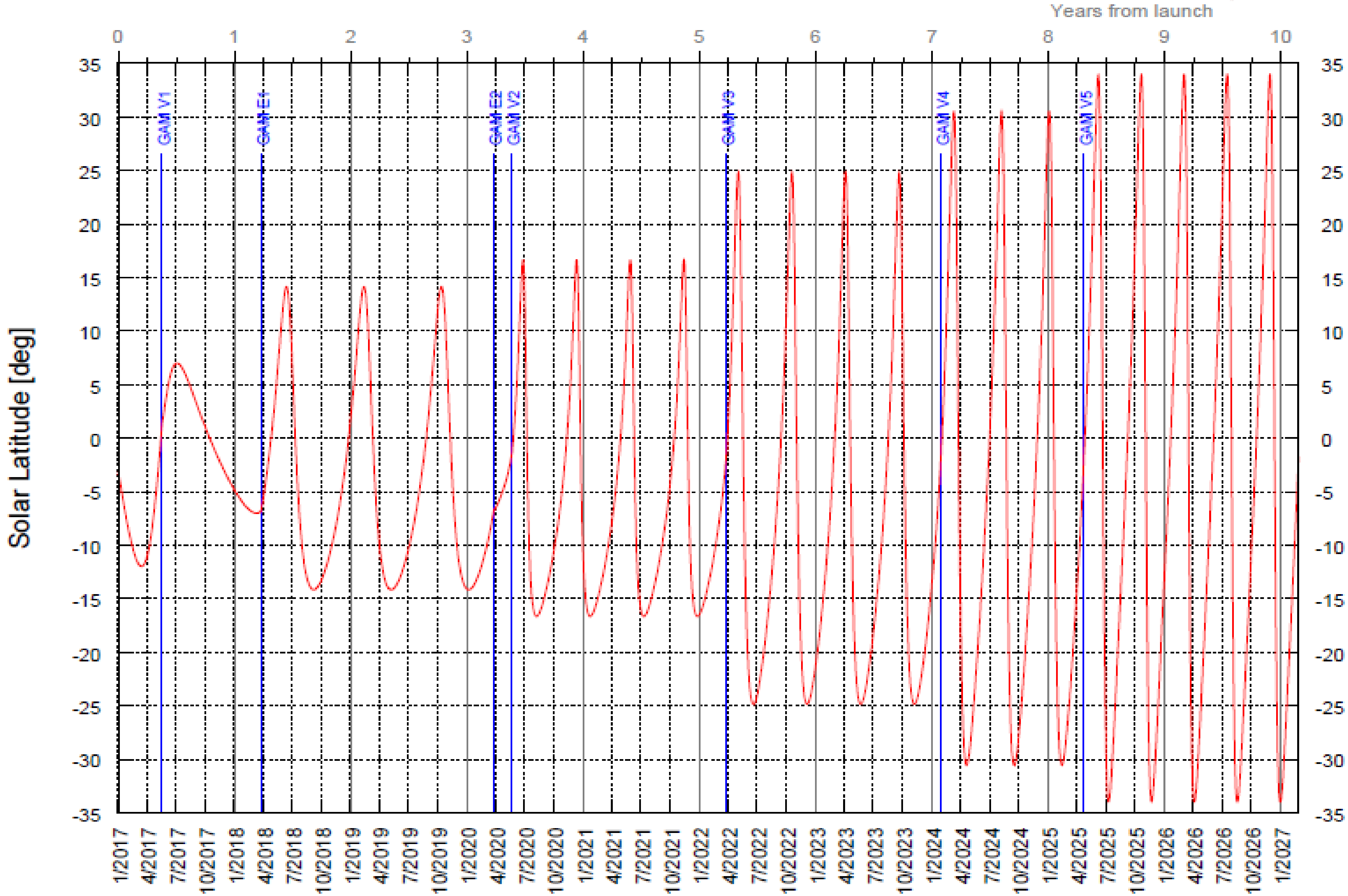
Orbital characteristics



2017 Launch: Solar distance vs. time



2017 Launch: Solar latitude vs. time



How does the Sun create and control the Heliosphere?

Q1) What drives the solar wind, and where does the coronal magnetic field originate from?

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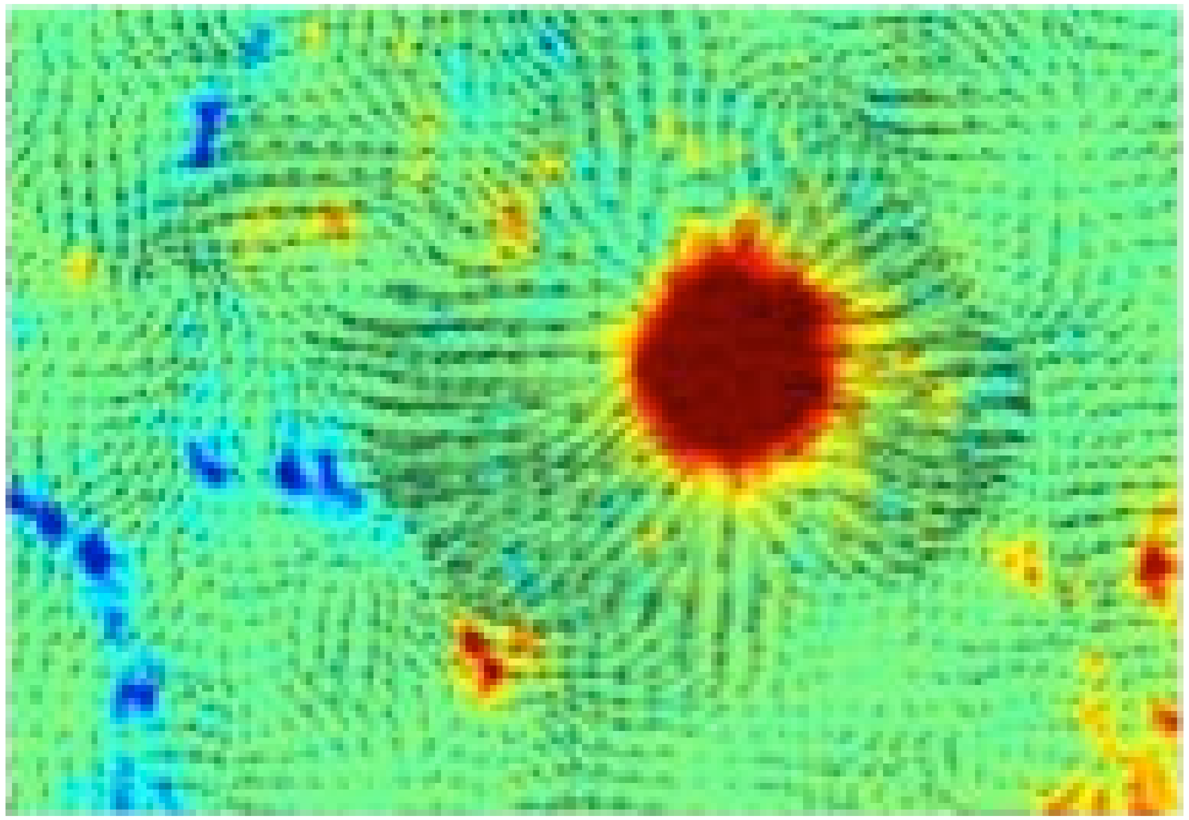
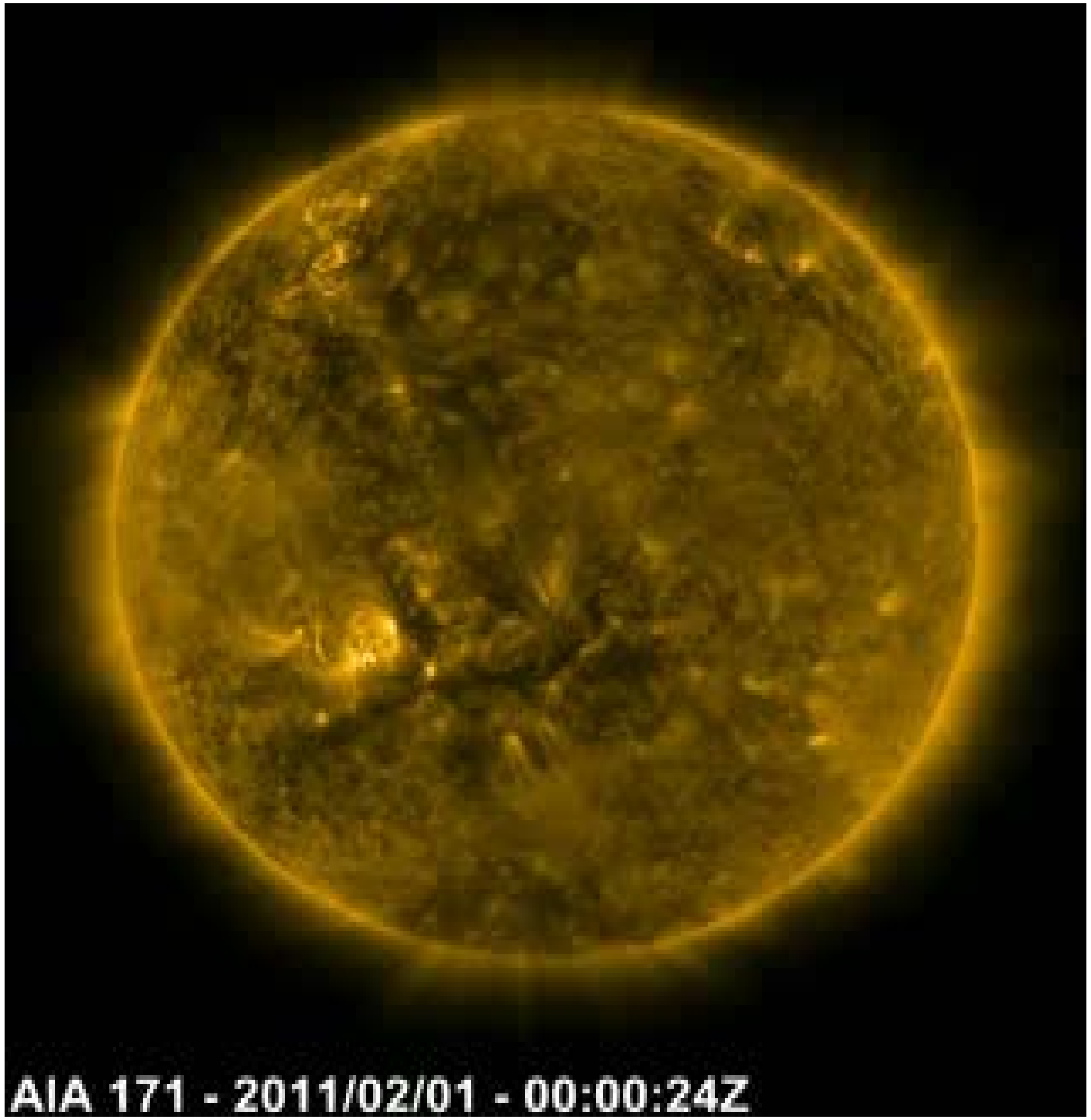
Identifying the sources of the solar wind and of the heliospheric magnetic field

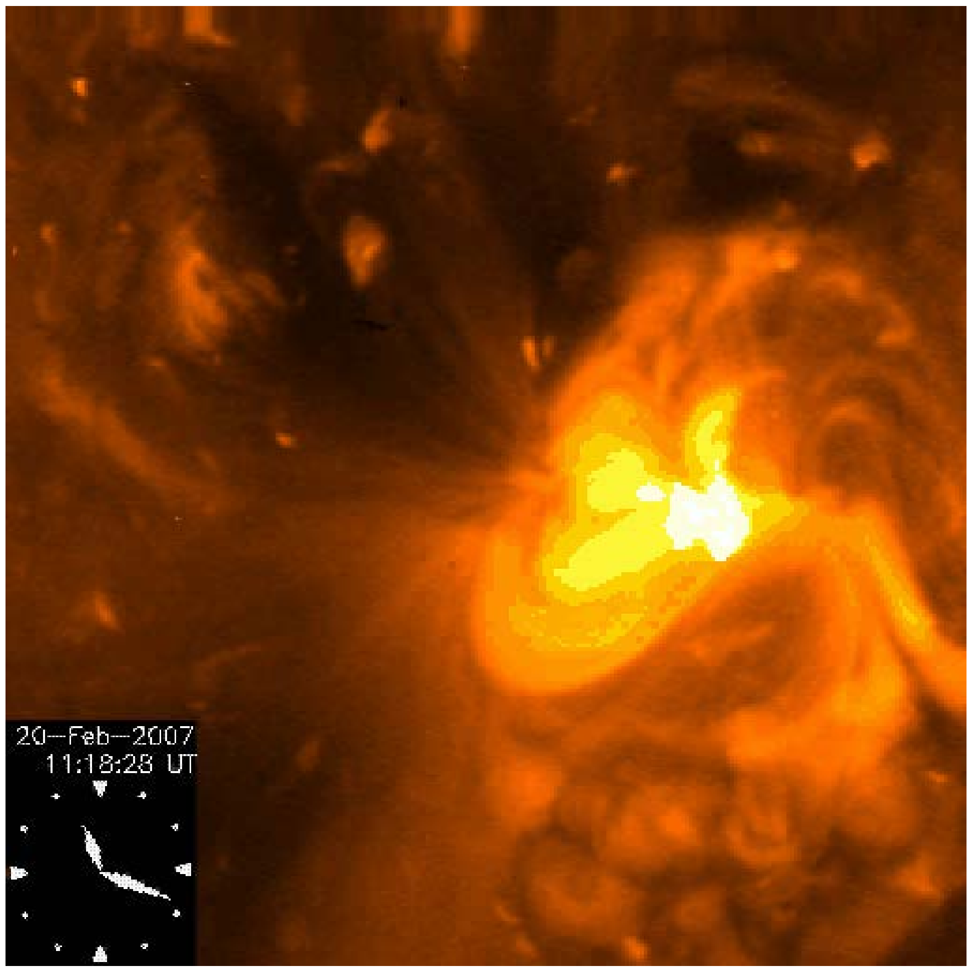
Disentangling space-time structures:

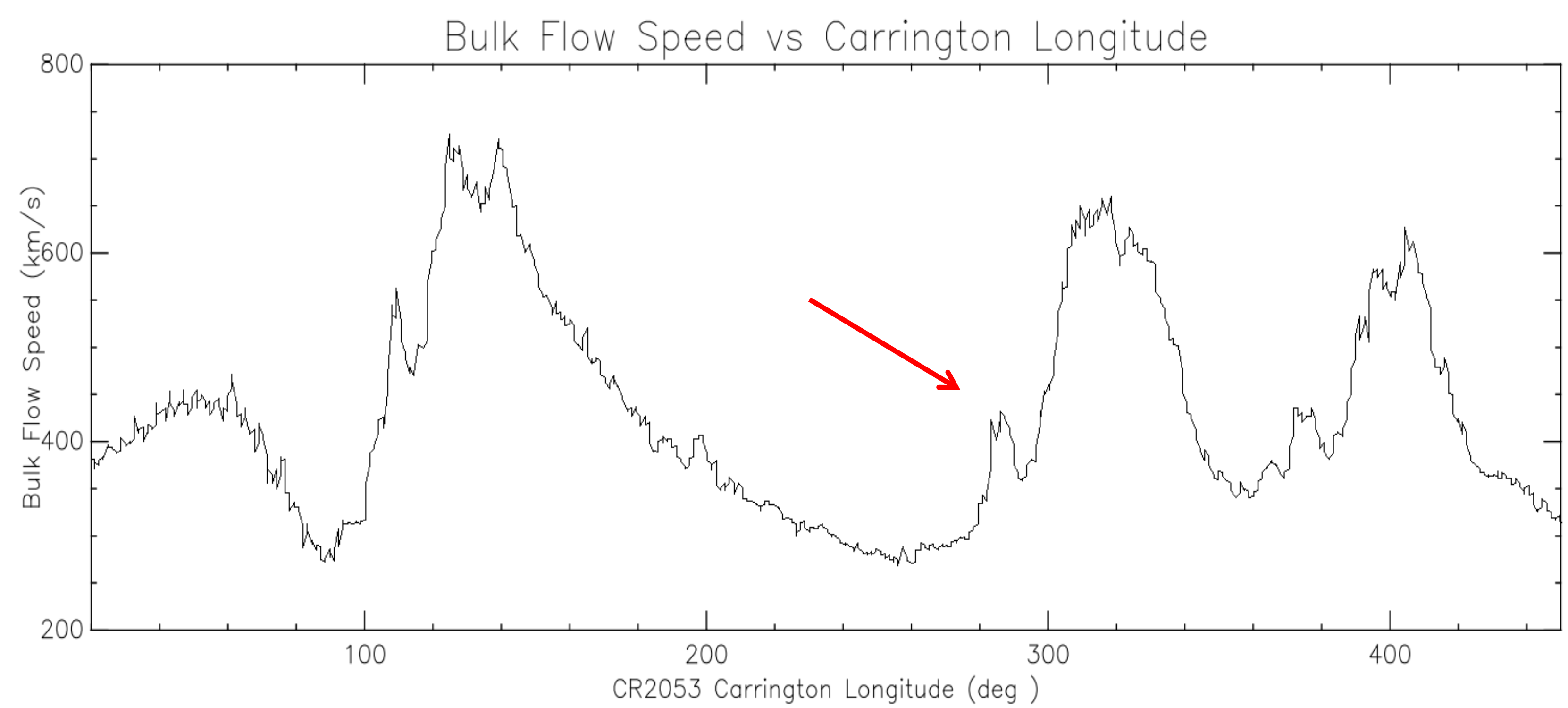
- requires viewing a given active region for more than its growth time (~ 10 days)
- implies going closer to the Sun





Where does the slow solar wind come from?

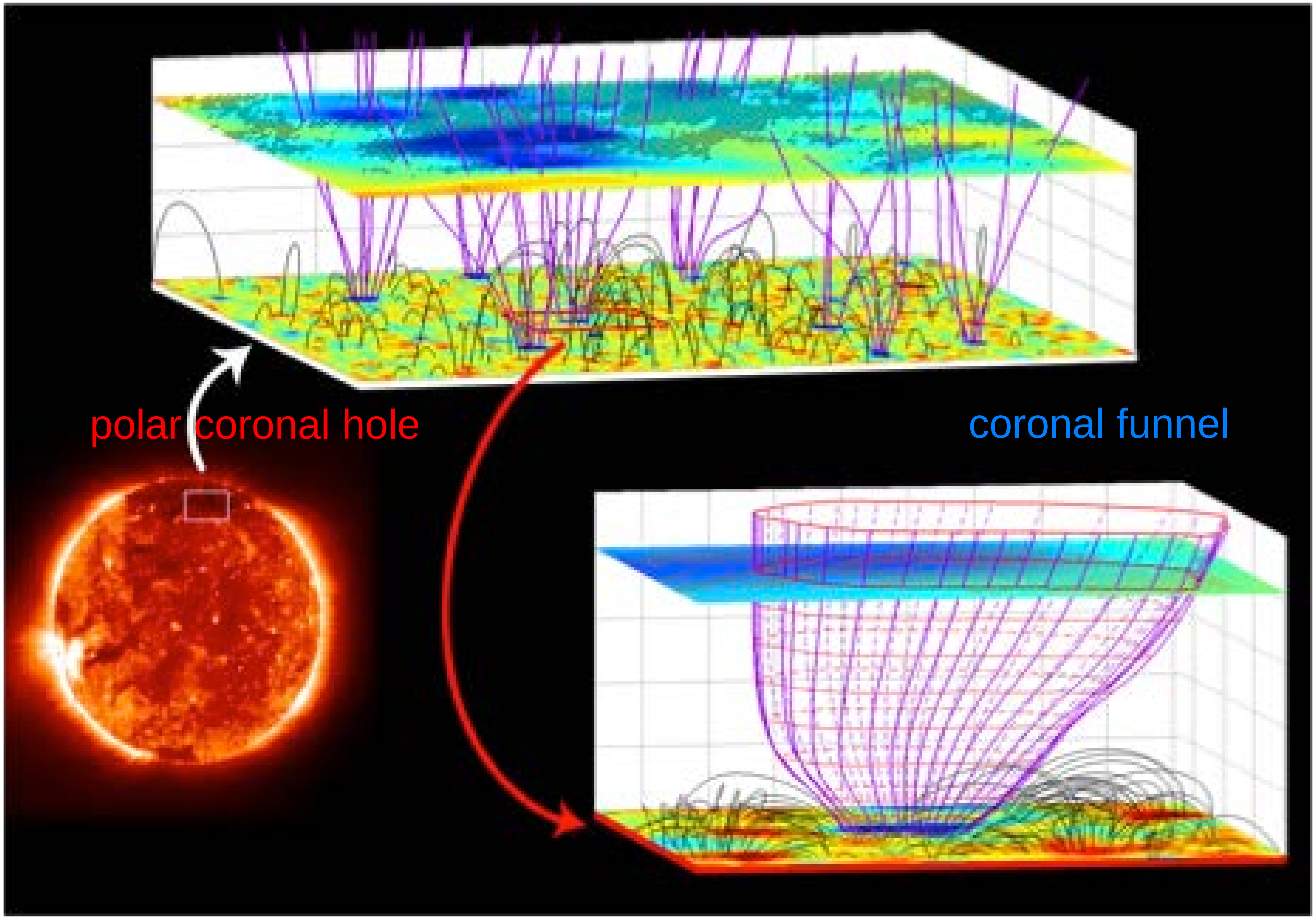




There are multiple sources of slow solar wind – active regions are one source.

Identifying reliably the source traits in the solar wind by the time it gets to 1 AU is extremely challenging, and can only be carried out on a statistical basis. Understanding the detailed origin can only be achieved by getting closer.

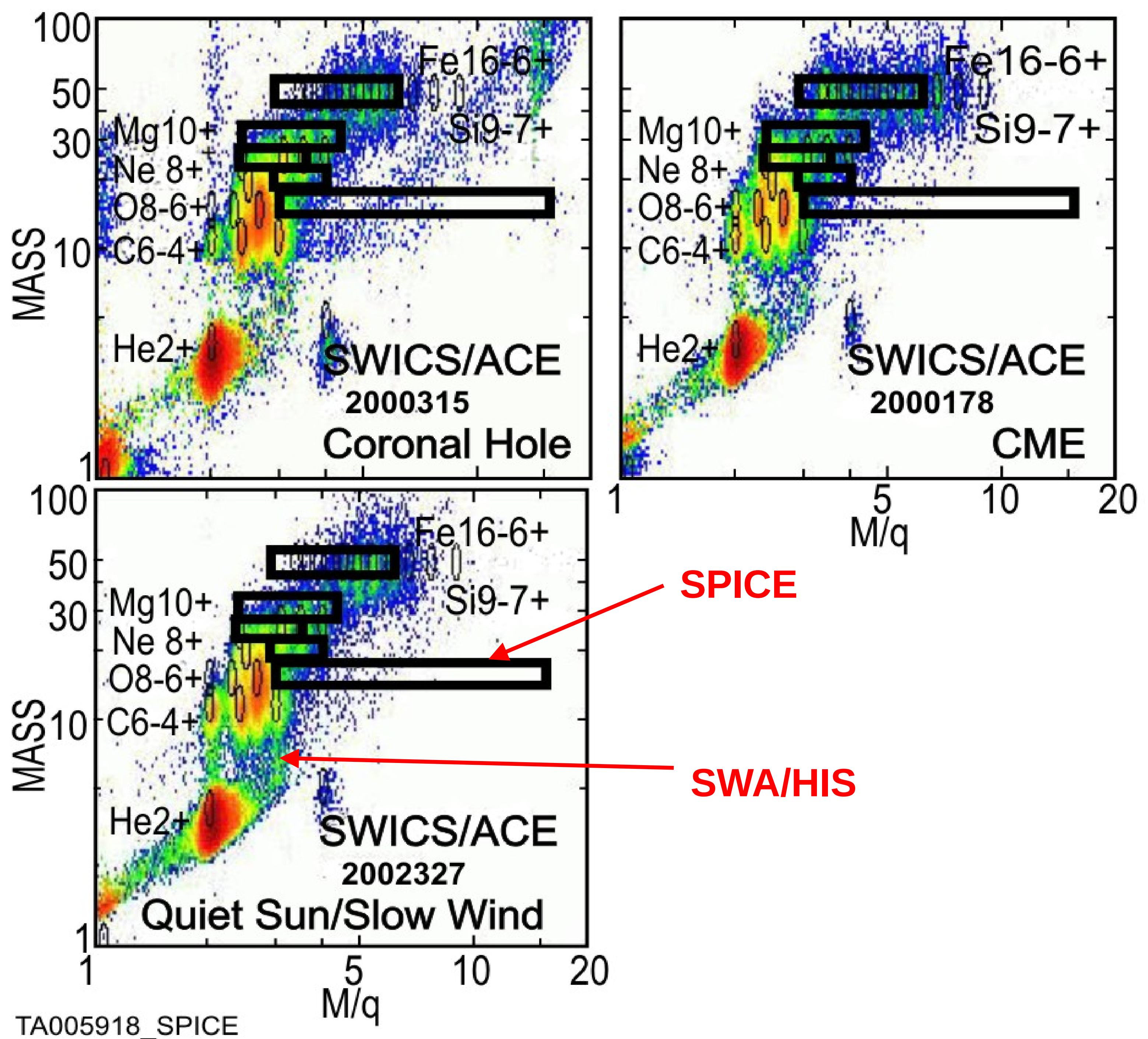
How do fast solar wind streams originate in coronal magnetic field structures?



Tu, Zhou, Marsch et al., Science 2005

Linking in-situ and remote-sensing observations

Correlating the remote-sensing spectroscopic with the in-situ composition measurements of the same ions is fundamental for establishing the sun-heliosphere connections.



How does the Sun create and control the Heliosphere?

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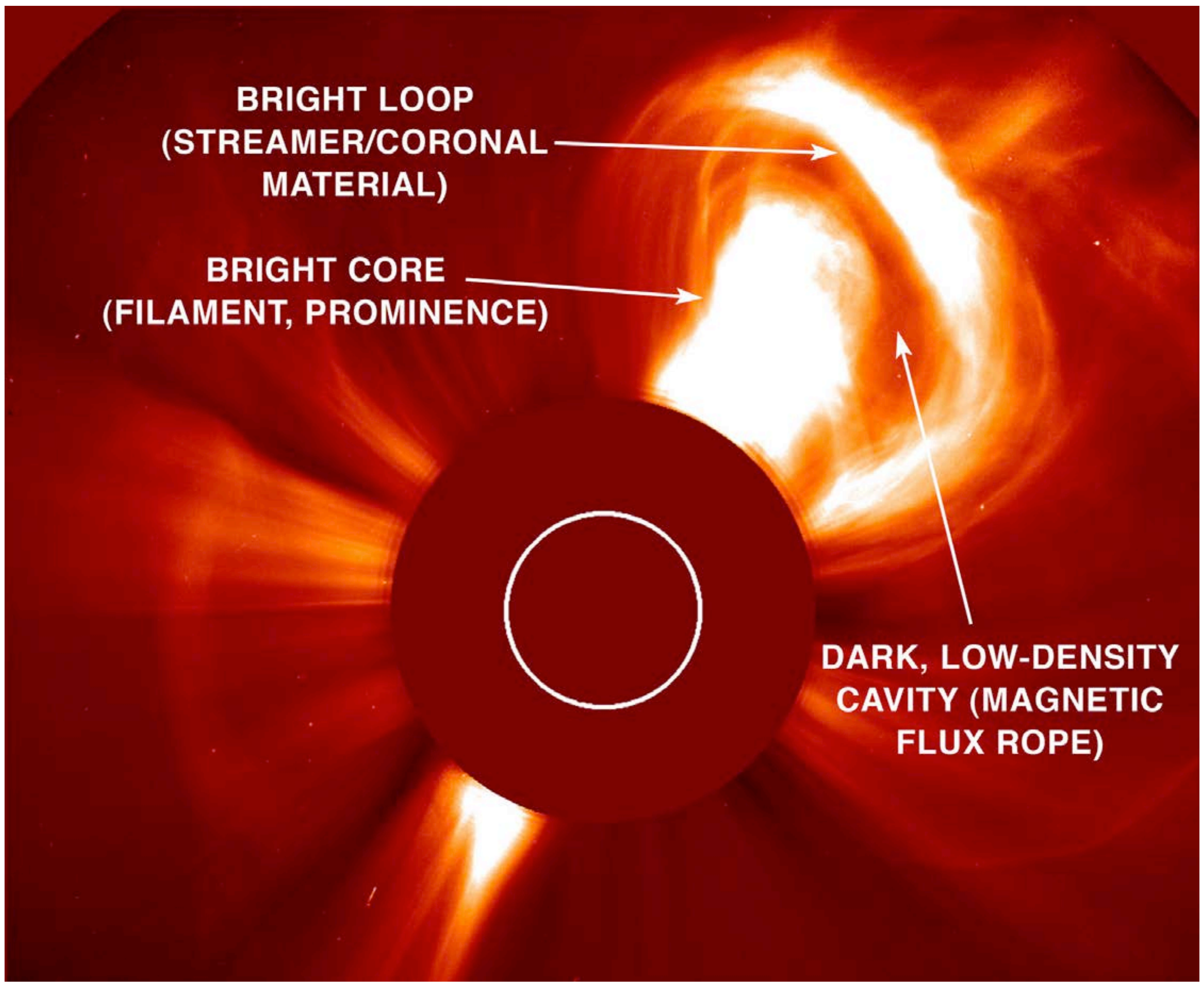
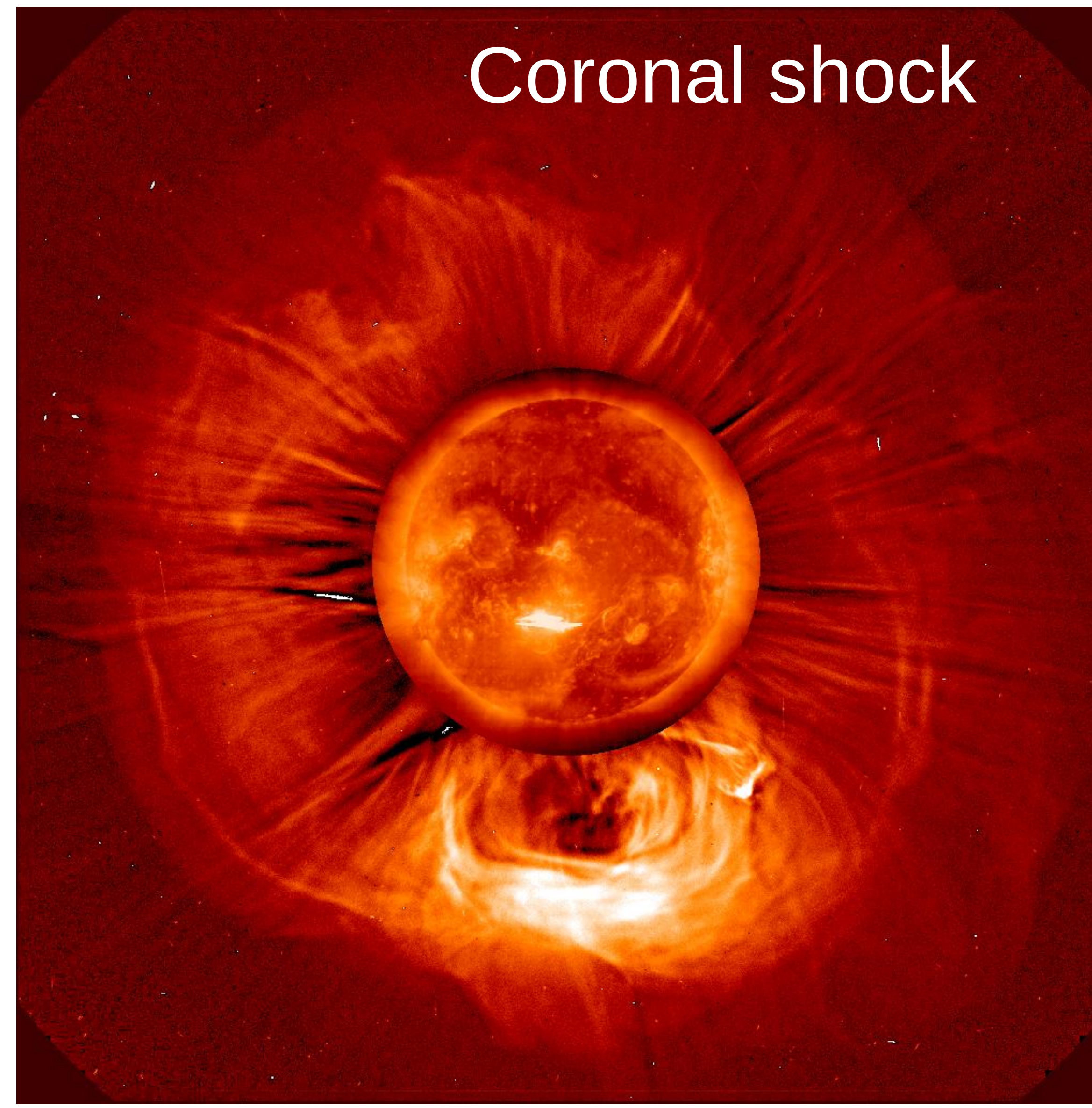
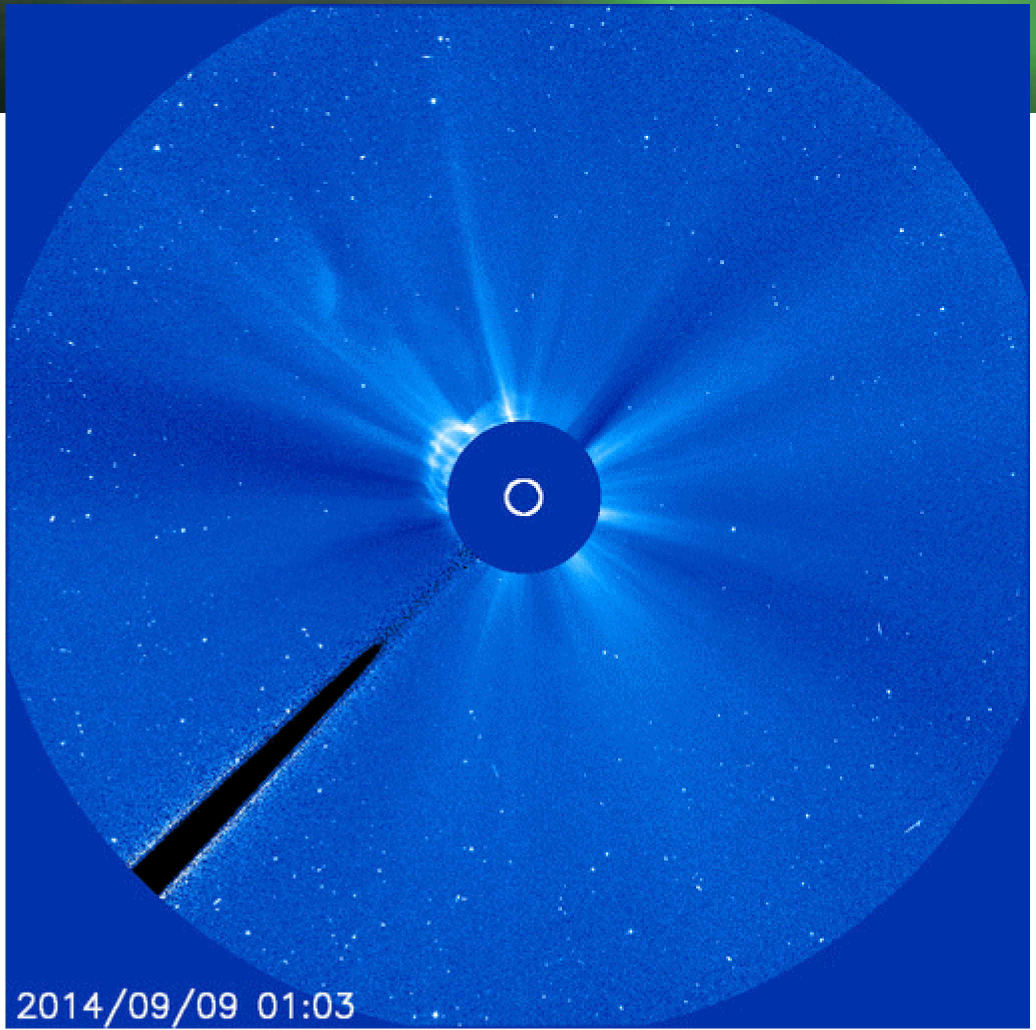
How do solar transients drive heliospheric variability?

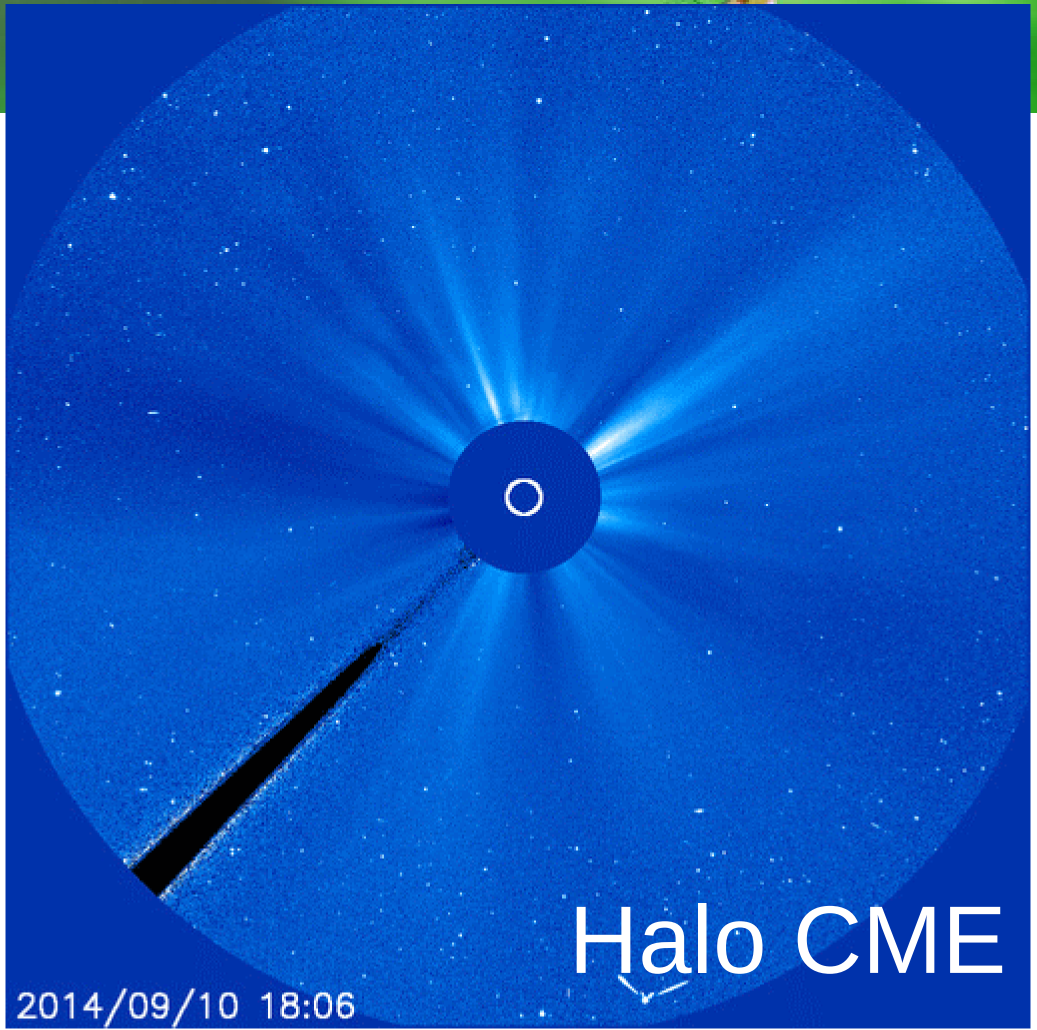




How do CMEs evolve through the corona and inner heliosphere?


Space weather
Sun Earth connection
ISS


2014/09/09 01:03


Halo CME
2014/09/10 18:06

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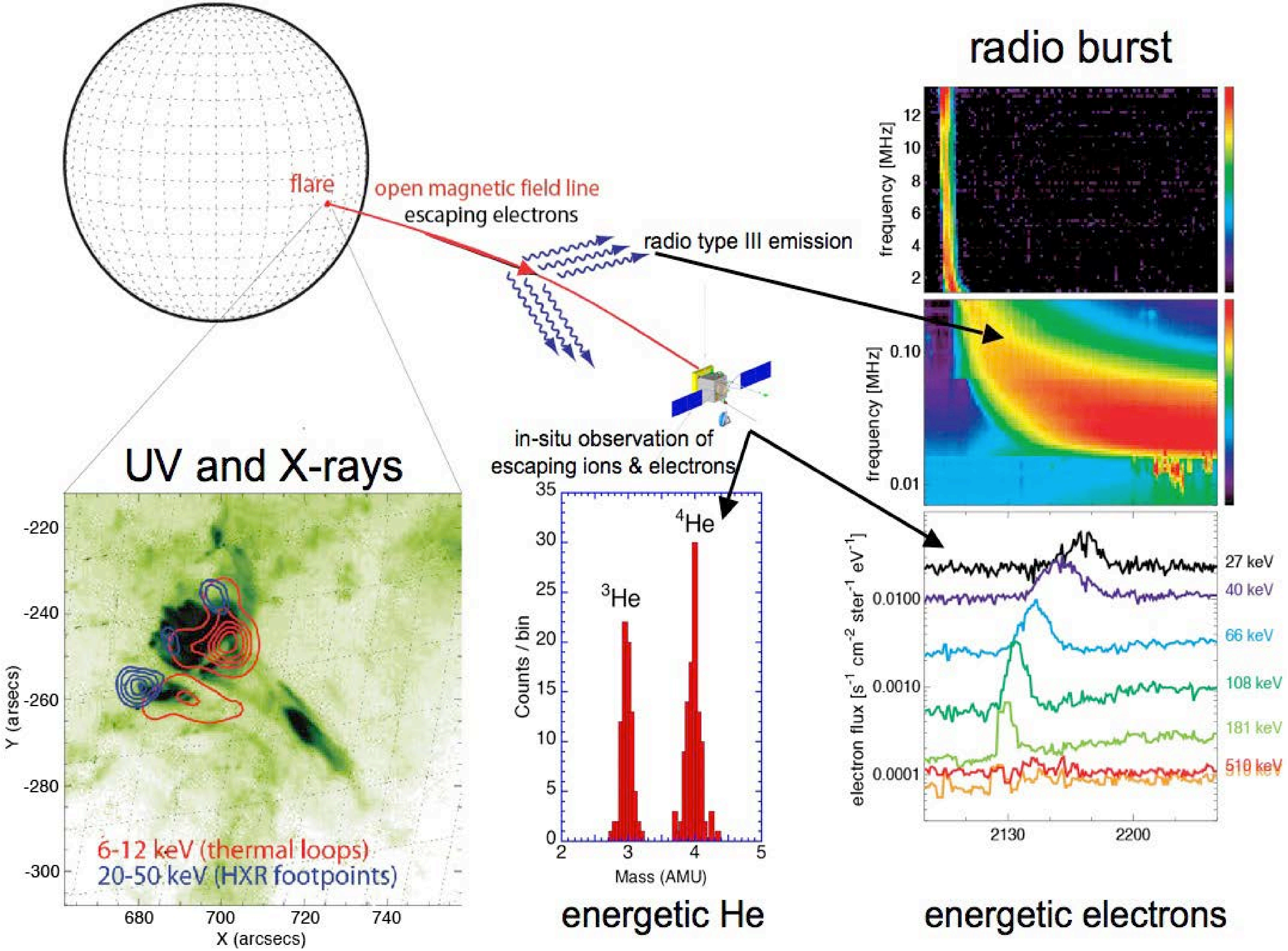
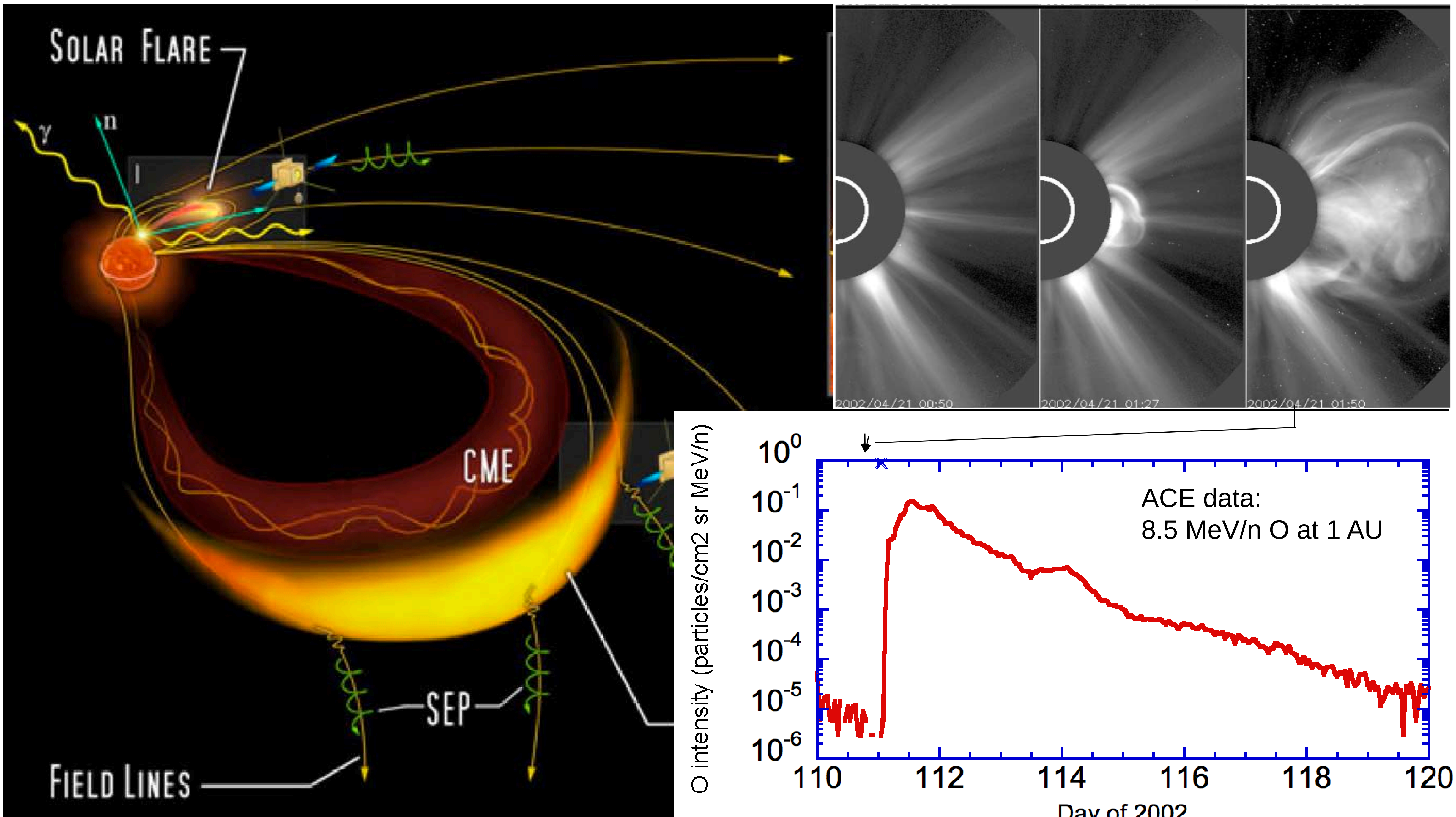
Q4) How does the solar dynamo work and drive connections between the Sun and the heliosphere?

How and where are energetic particles accelerated?



How do solar eruptions (flares and CMEs) produce energetic particles and radiation?



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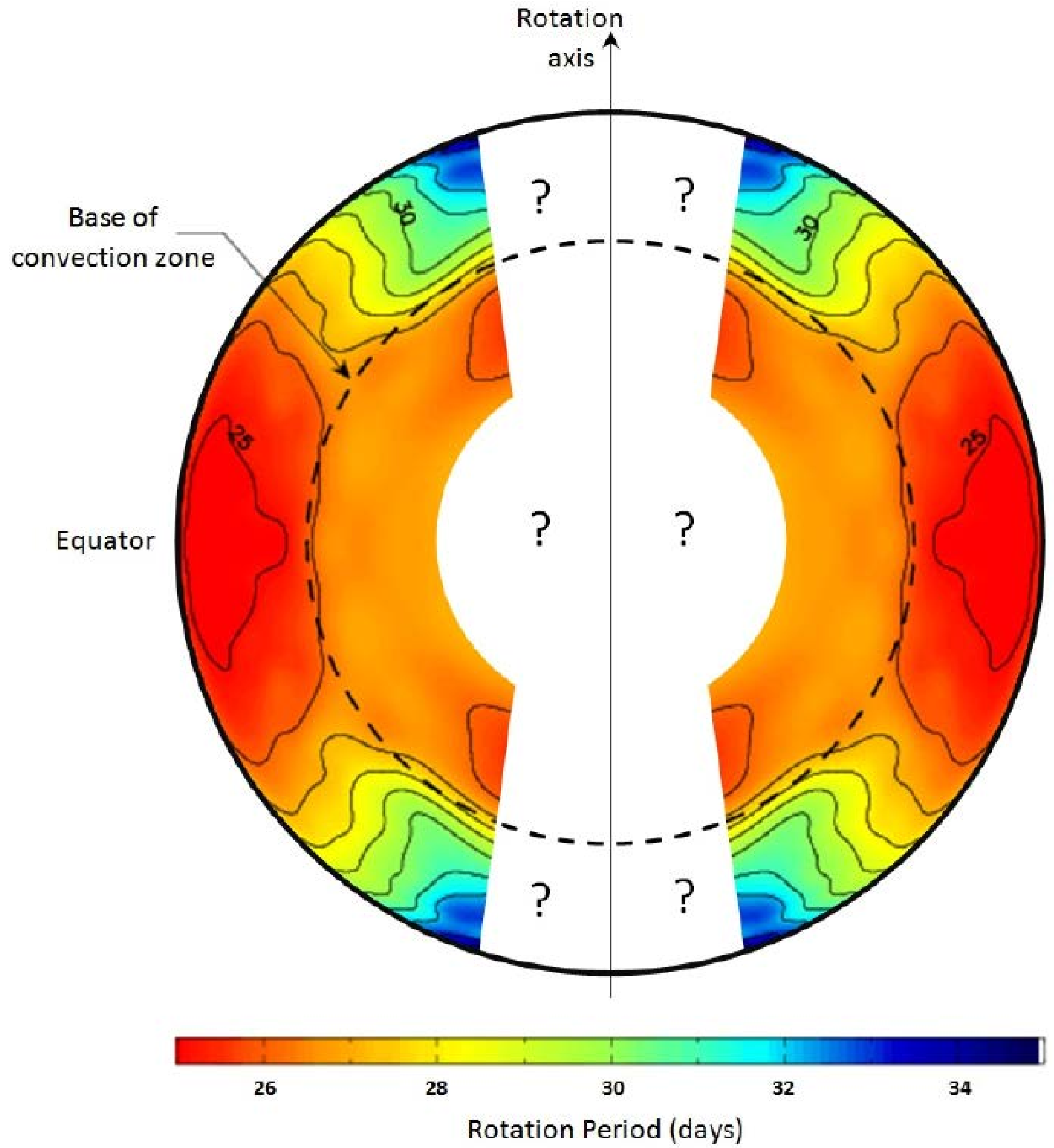
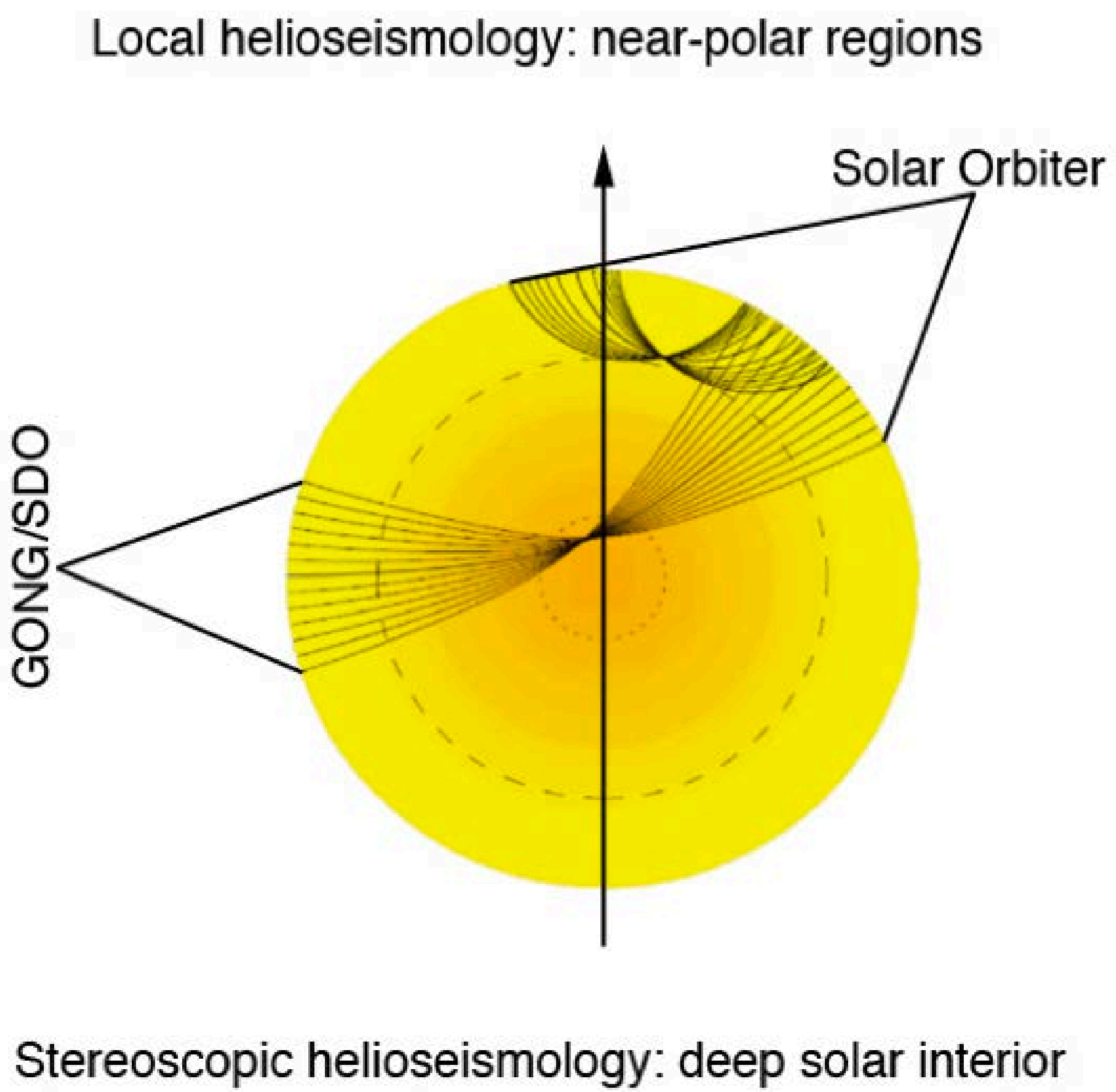
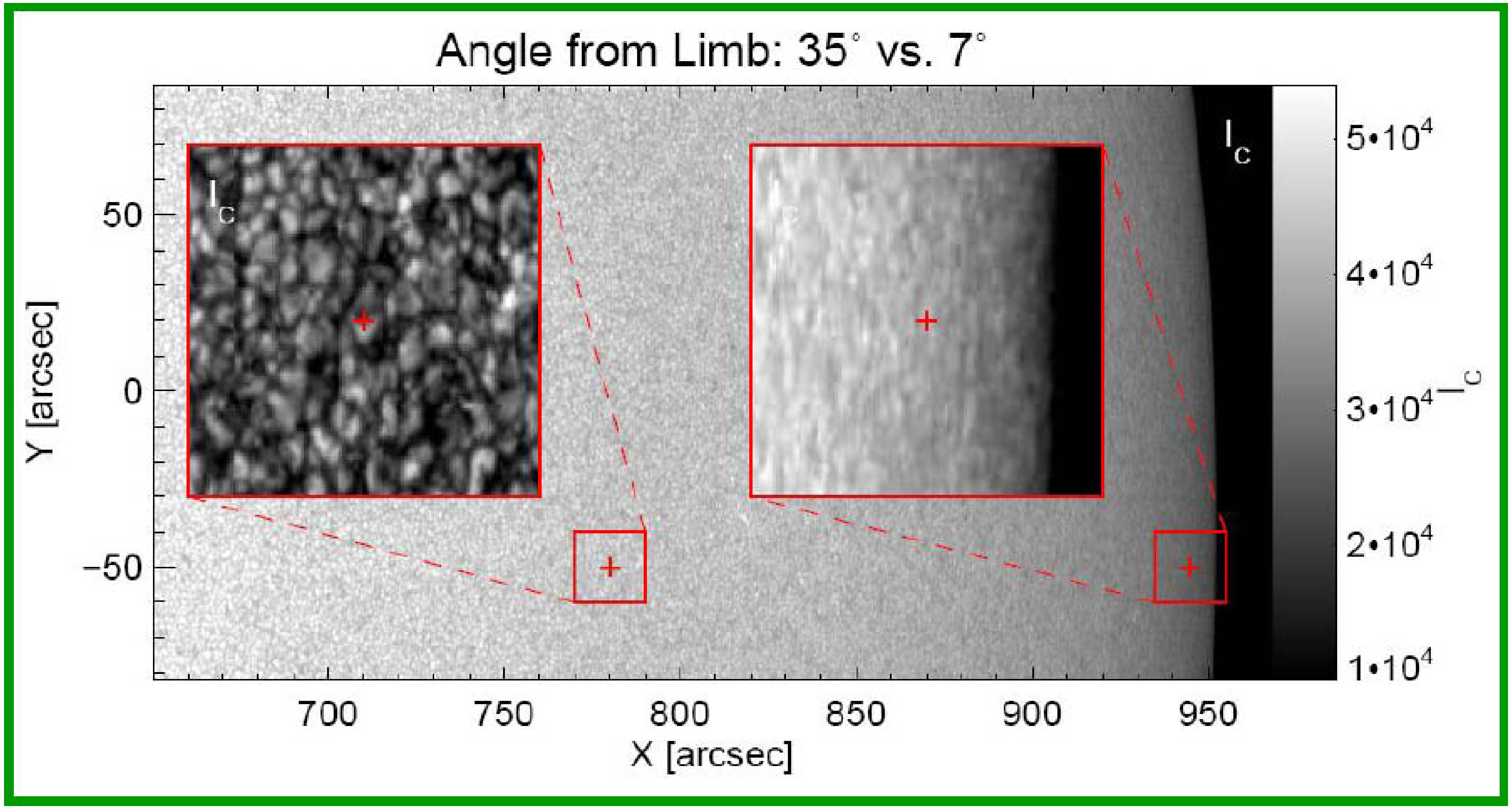
Probing the solar dynamo at the solar poles





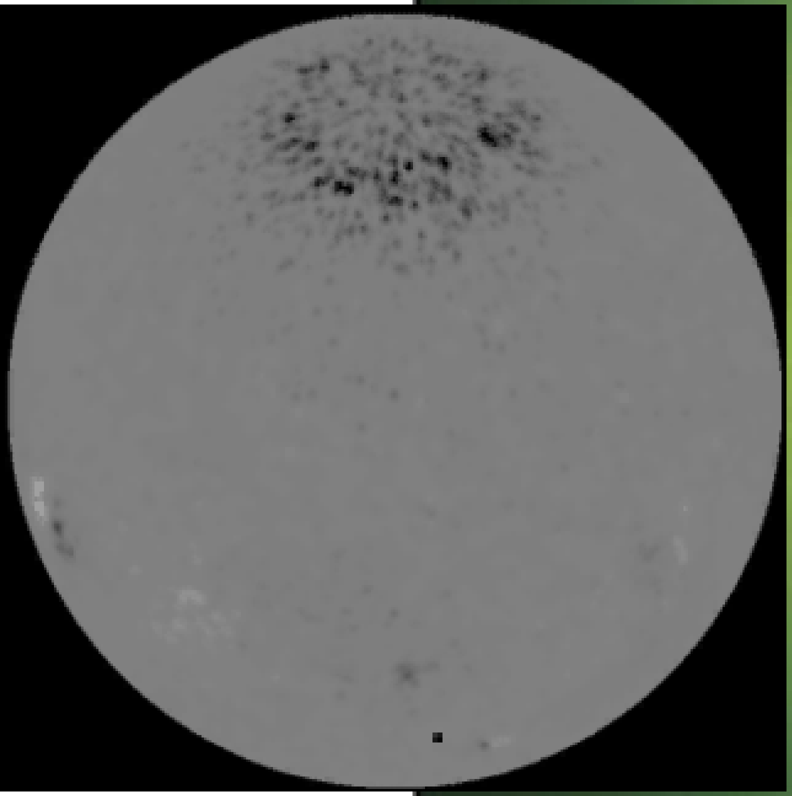
Solar Orbiter will use local helioseismology to determine the unknown properties (flows and fields) of the solar interior below the poles.

Resolving magnetoconvection at the poles



Solar Orbiter will provide low-noise, high-spatial-resolution and full-vector measurements of the solar magnetic field near the poles. The Hinode 7º aspect angle only allows qualitative results to be obtained, but at 35º the Solar Orbiter measurements will be far improved. Also granulation tracking will then be possible and following large-scale flows.

Imaging of the Sun’s pole



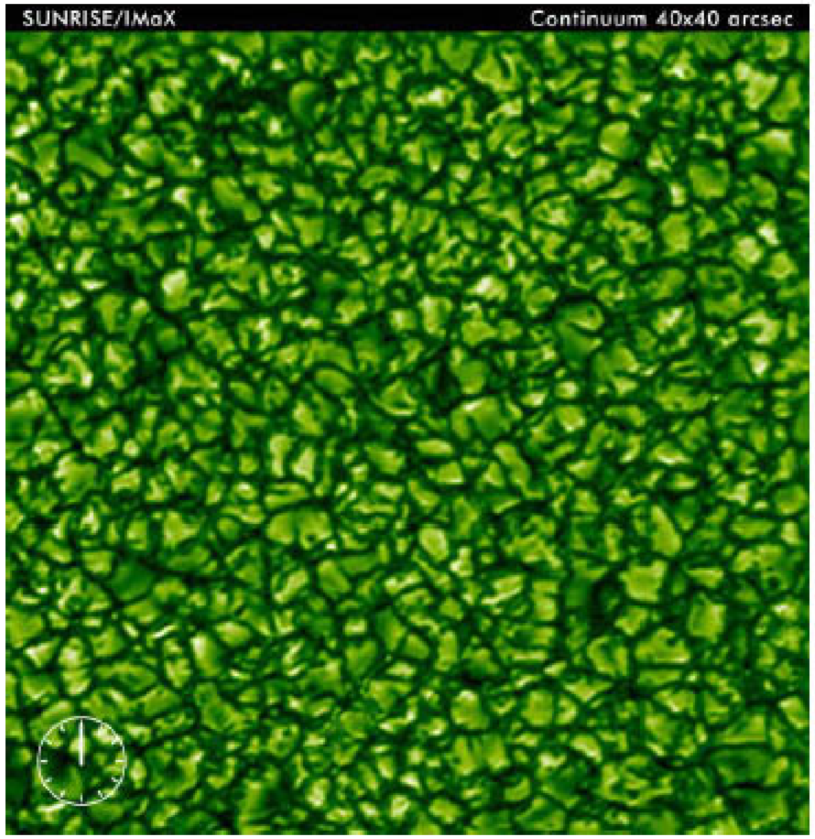
Simulated view of the ultraviolet corona from 35° heliolatitude. *Solar Orbiter’s* remote-sensing instruments and out-of-ecliptic vantage point will enable the first simultaneous measurements of the polar magnetic field and the associated structures in a polar coronal hole. (Courtesy EUI consortium.)

SO/PHI

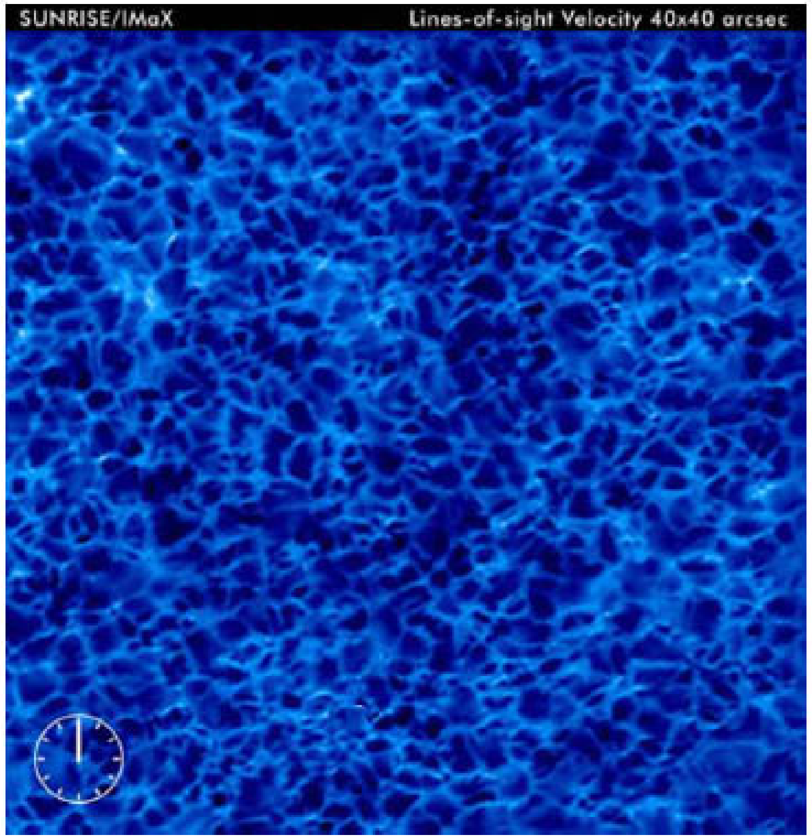
delivers in a 2-D field of view on the visible solar surface information on

– temperature => photometry (intensity imaging)
– gas flows/motions => spectroscopy (differential imaging)
– magnetic fields => polarimetry (differential imaging)

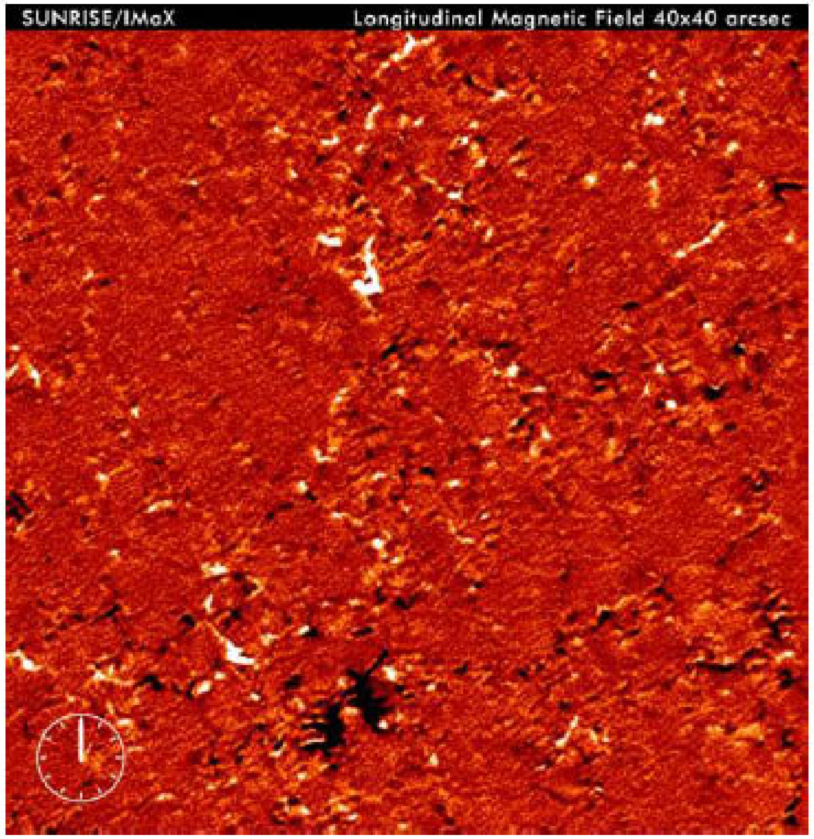
Sunrise field of view: 40 arcsec x 40 arcsec



Granulation in continuum

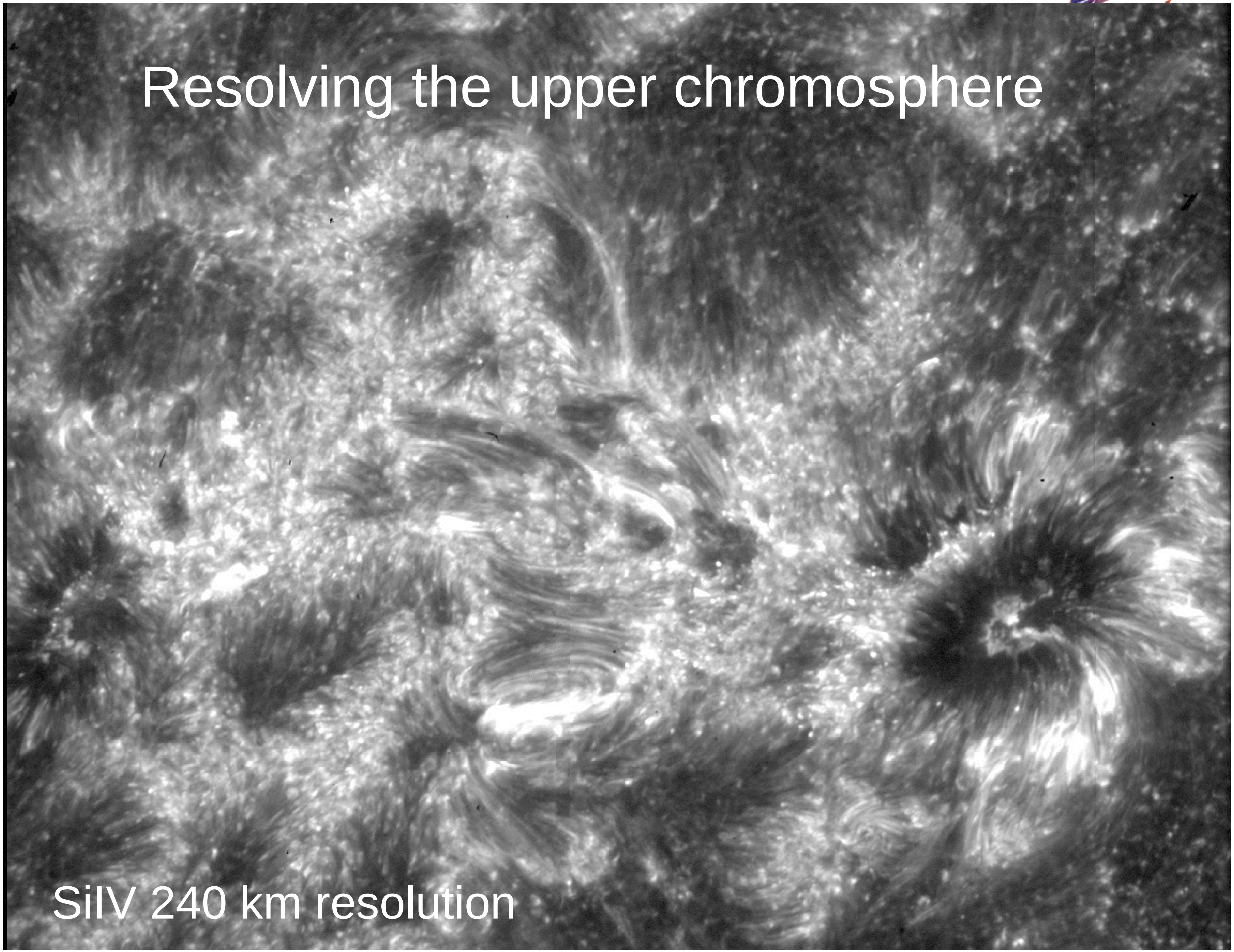


Line-of-sight velocity



Longitudinal magnetic field

IRIS



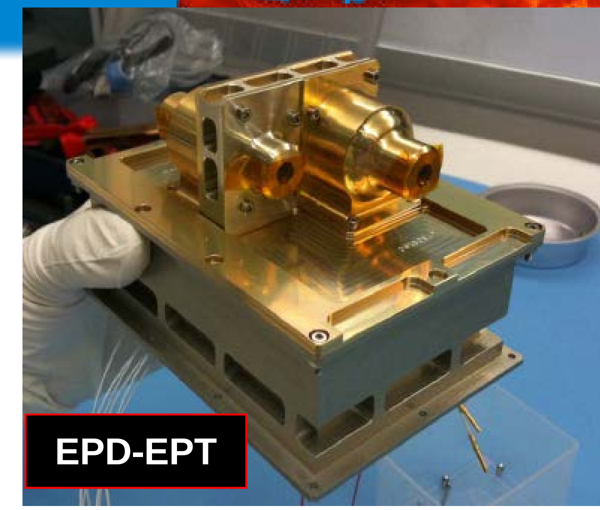
Payload: In-Situ Instruments

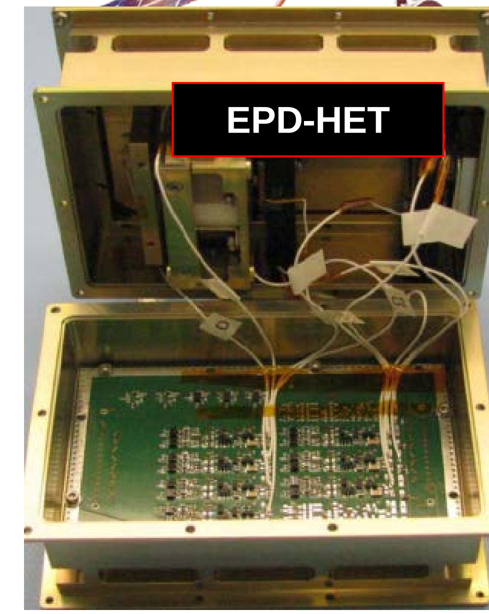
EPD	Energetic Particle Detector	J. Rodríguez-Pacheco(E)	Composition, timing and distribution functions of energetic particles
MAG	Magnetometer	T. Horbury (UK)	High-precision measurements of the heliospheric magnetic field
RPW	Radio & Plasma Waves	M. Maksimovic (F)	Electromagnetic and electrostatic waves, magnetic and electric fields at high time resolution
SWA	Solar Wind Analyser	C. Owen (UK)	Sampling protons, electrons and heavy ions in the solar wind

Payload: Remote-Sensing Instruments

EUI	Extreme Ultraviolet Imager	P. Rochus (B)	High-resolution and full-disk EUV imaging of the on-disk solar corona
METIS	Coronagraph	E. Antonucci (I)	Visible and (E)UV imaging of the off-disk corona
PHI	Polarimetric & Helioseismic Imager	S. Solanki (D)	High-resolution vector magnetic field, line-of-sight velocity in photosphere, visible imaging
SoloHI	Heliospheric Imager	R. Howard (USA)	Wide-field visible imaging of the solar corona and wind
SPICE	Spectral Imaging of the Coronal Environment	European-led	EUV spectroscopy of the solar disk and near-Sun solar corona
STIX	Spectrometer/Telecope for Imaging X-rays	S. Krucker (CH)	Imaging spectroscopy of solar X-ray emission

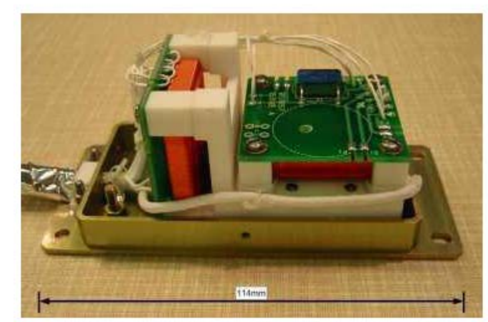
4 in-situ instruments

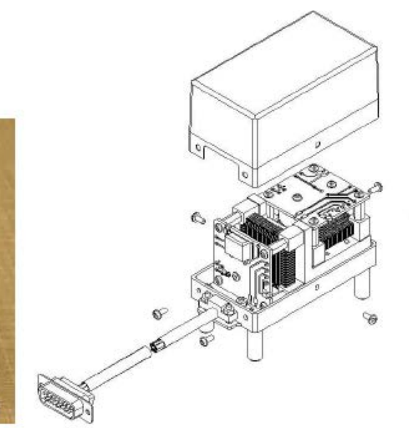




-- Detectors for energetic and solar wind particles: electrons (1eV - 20 MeV), protons (0.2 keV - 100 MeV), heavy ions (SWA, EPD)

MAG Flux Gate





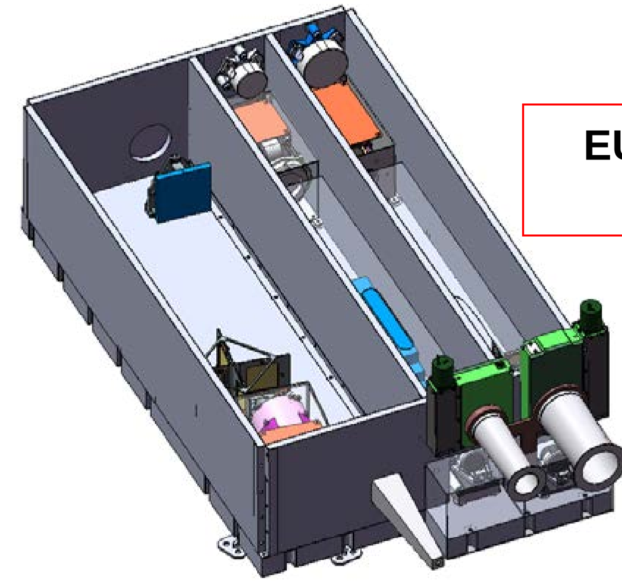
-- Magnetometers (DC – 64 Hz) : DC magnetic field (MAG)

-- Radio & plasma wave detectors: AC electric and magnetic fields (DC to 20 MHz / 0.1 Hz to 500 kHz) (RPW)

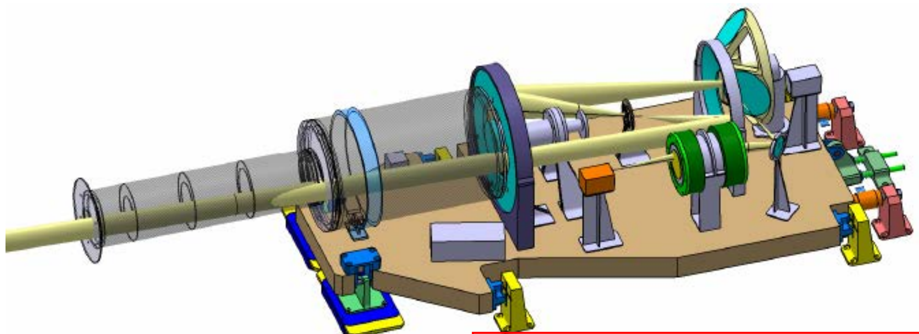
6 Remote-sensing instruments

Imagers / polarimeter / coronograph
(EUI, SOLOHI, PHI, METIS)
Bandwidths: Visible, UV, EUV

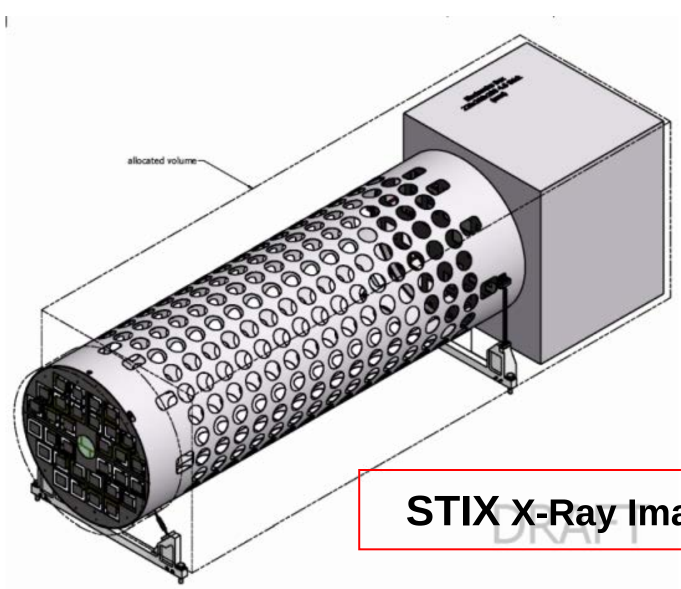
Spectral Imagers / Spectrometers
(SPICE, STIX)
Bandwidths: EUV and x-ray



EUI 3-telescope Imager

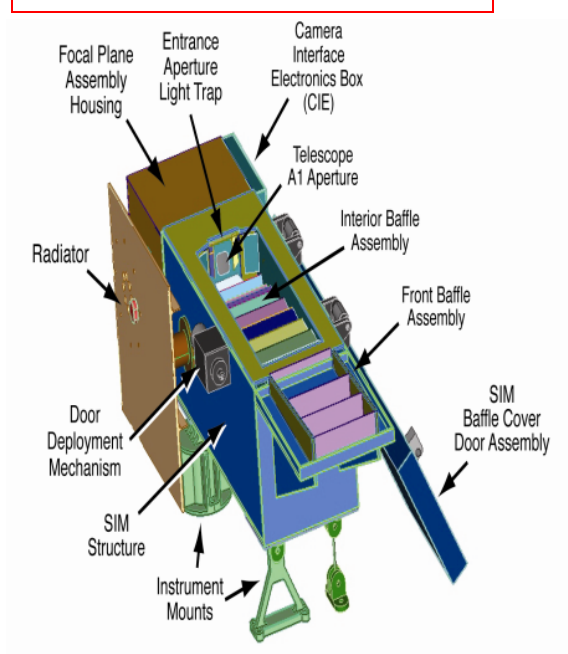


METIS 2-channel Coronograph

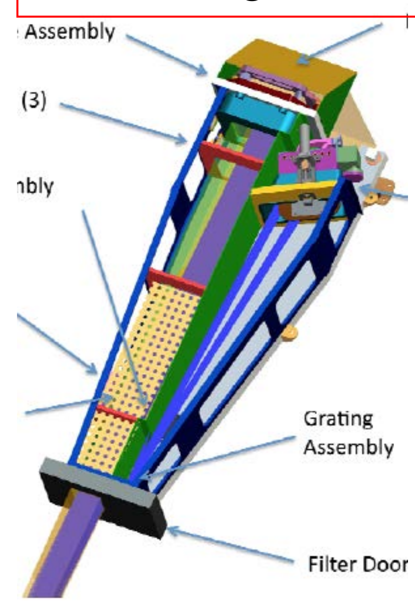


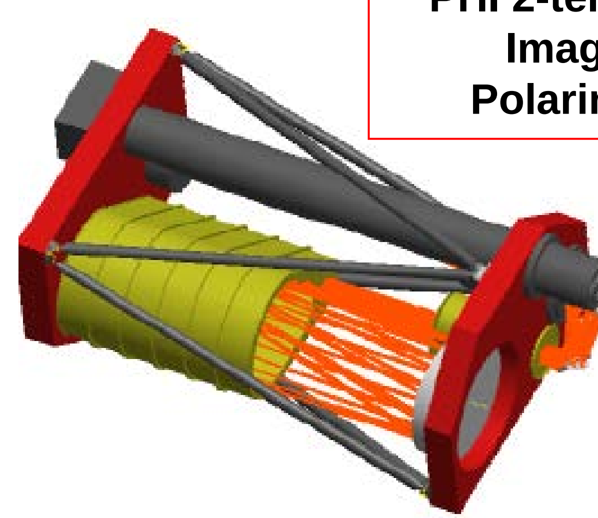
STIX X-Ray Imager

SOLOHi 1-telescope Imager



SPICE Spectral Imager

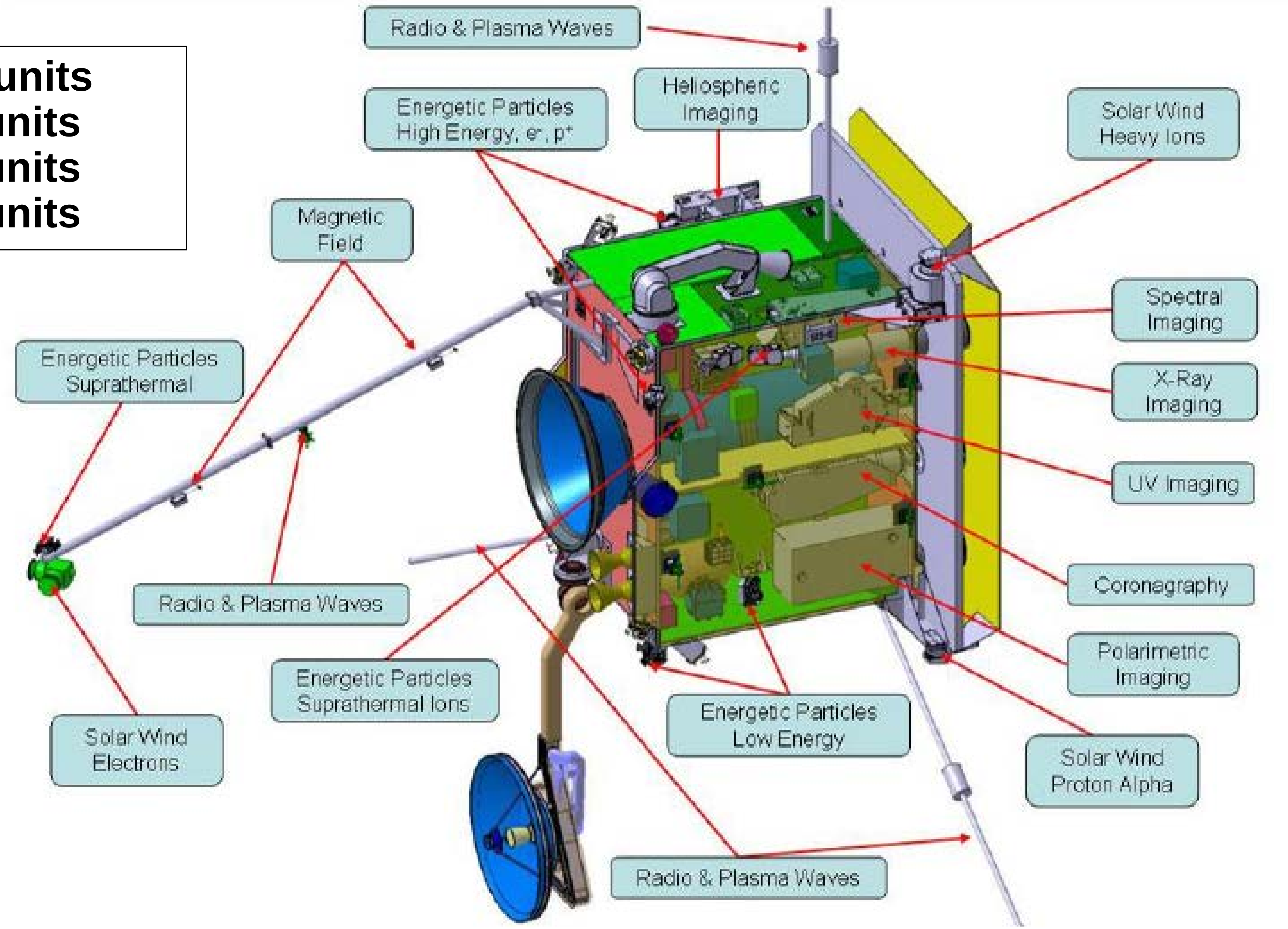




PHI 2-telescope Imager / Polarimeter

Instrument locations on spacecraft

EPD : 10 units
SWA: 4 units
MAG: 3 units
RPW: 5 units



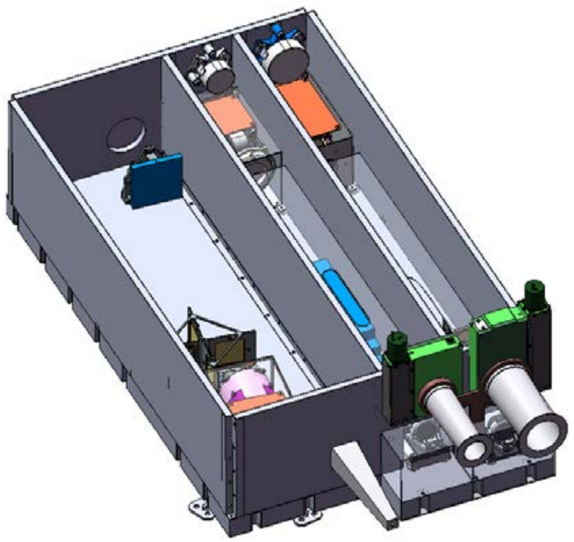
EUI

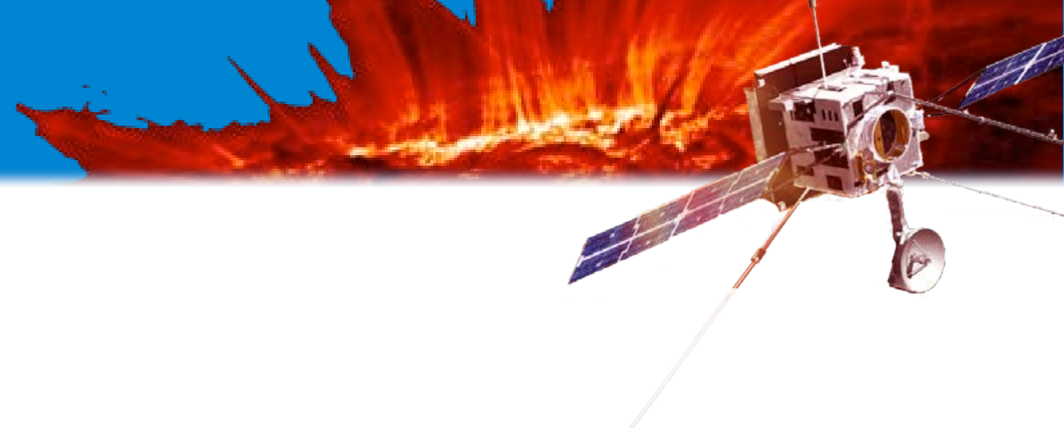
has three channels:

- EUV full-sun (FSI) and high-resolution (HRI_{EUV}) imagers
- Ly-α high-resolution ($HRI_{Ly\alpha}$) imager

Dual FSI	**FSI 304 Å: He II 0.08 MK** **FSI 174 Å: Fe IX-X 1MK**	**FSI-304** **FSI-174**
EUV HRI	**HRI 174 Å: Fe IX-X 1MK**	**HRI-174**
Ly α HRI	**HRI 1216 Å: H Ly α, 10-80 kK** upper chromosphere	**HRI-Ly α**

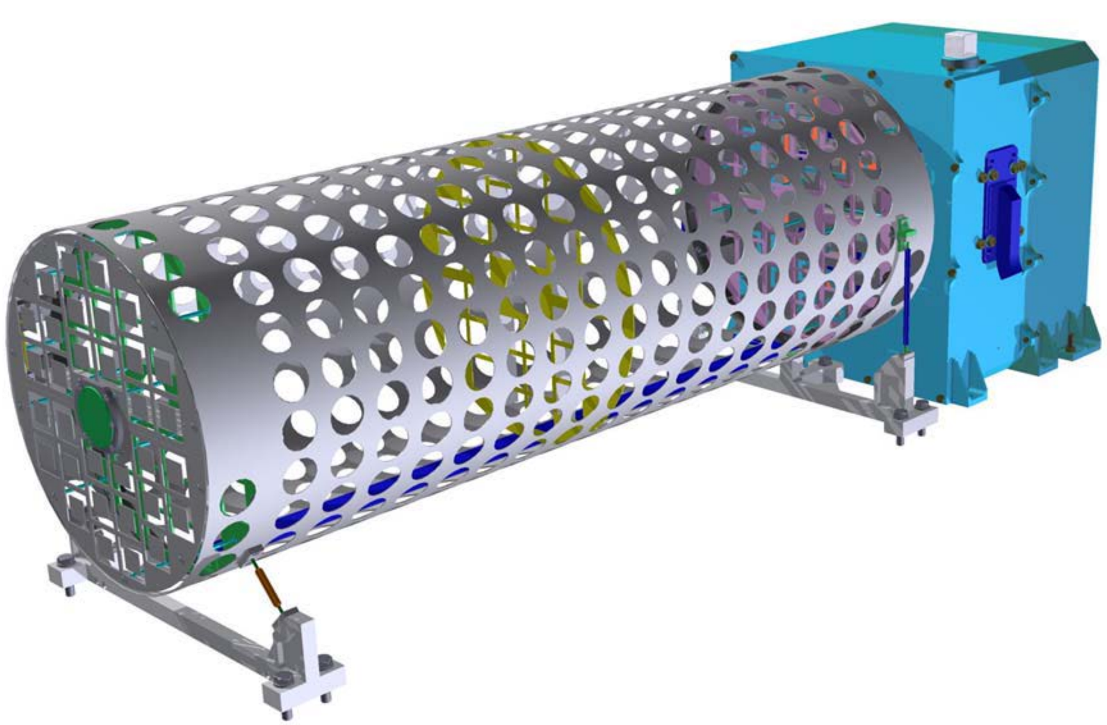
Channel	Parameter	Values
FSI	Passbands FOV Resolution (2 px) Cadence	17.4 nm & 30.4 nm 3.8 arcdeg (⬄ 2 Sun ∅) 9 arcsec (⬄ 1800 km, 3k² px) 600 s
HRI_{EUV}	Passbands FOV Resolution (2 px) Cadence	17.4 nm 0.28 arcdeg (⬄ 15% Sun ∅) 1 arcsec (⬄ 200 km, 2k² px) ≥ 1 s
HRI_{Lya}	Passband FOV Resolution (2 px) Cadence	121.6 nm 0.28 arcdeg (⬄ 15% Sun ∅) 1 arcsec (⬄ 200 km, 2k² px) ≤ 1 s





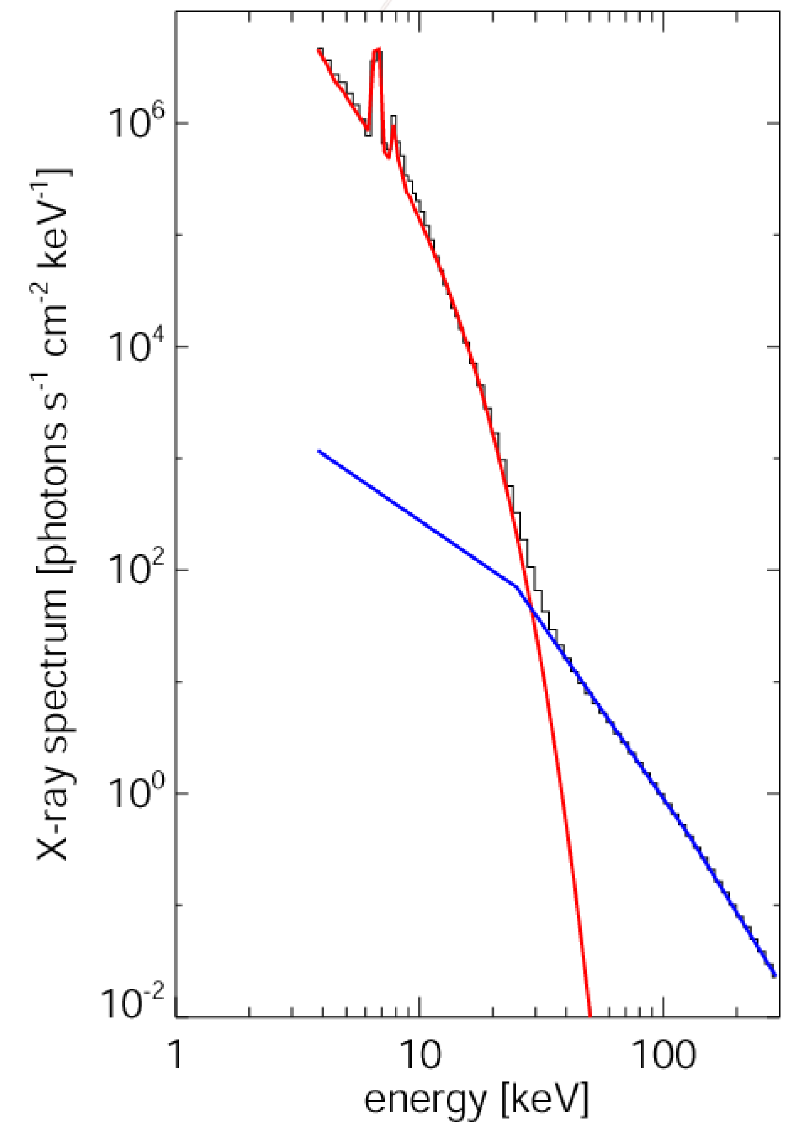
STIX

Parameter	
Energy range	4 – 150 keV
Energy resolution	1 keV at 5 keV 15 keV at 150 keV
Effective area	6 cm^2
Finest angular resolution	7 arcsec
Field of View	2°
Time resolution	≥ 0.1 s



Flare diagnostics:

- Timing
- Linkage

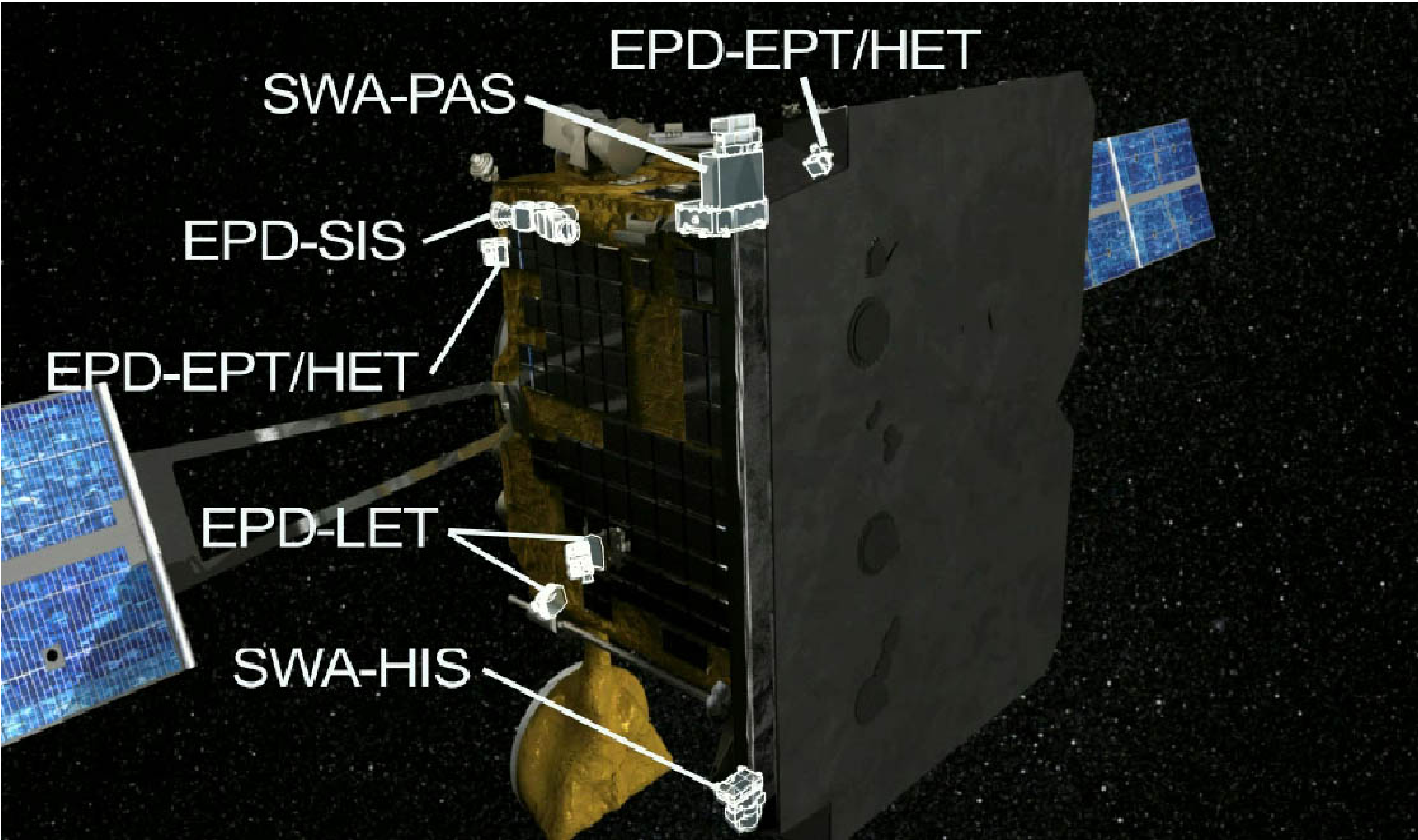


Electron acceleration in flares:

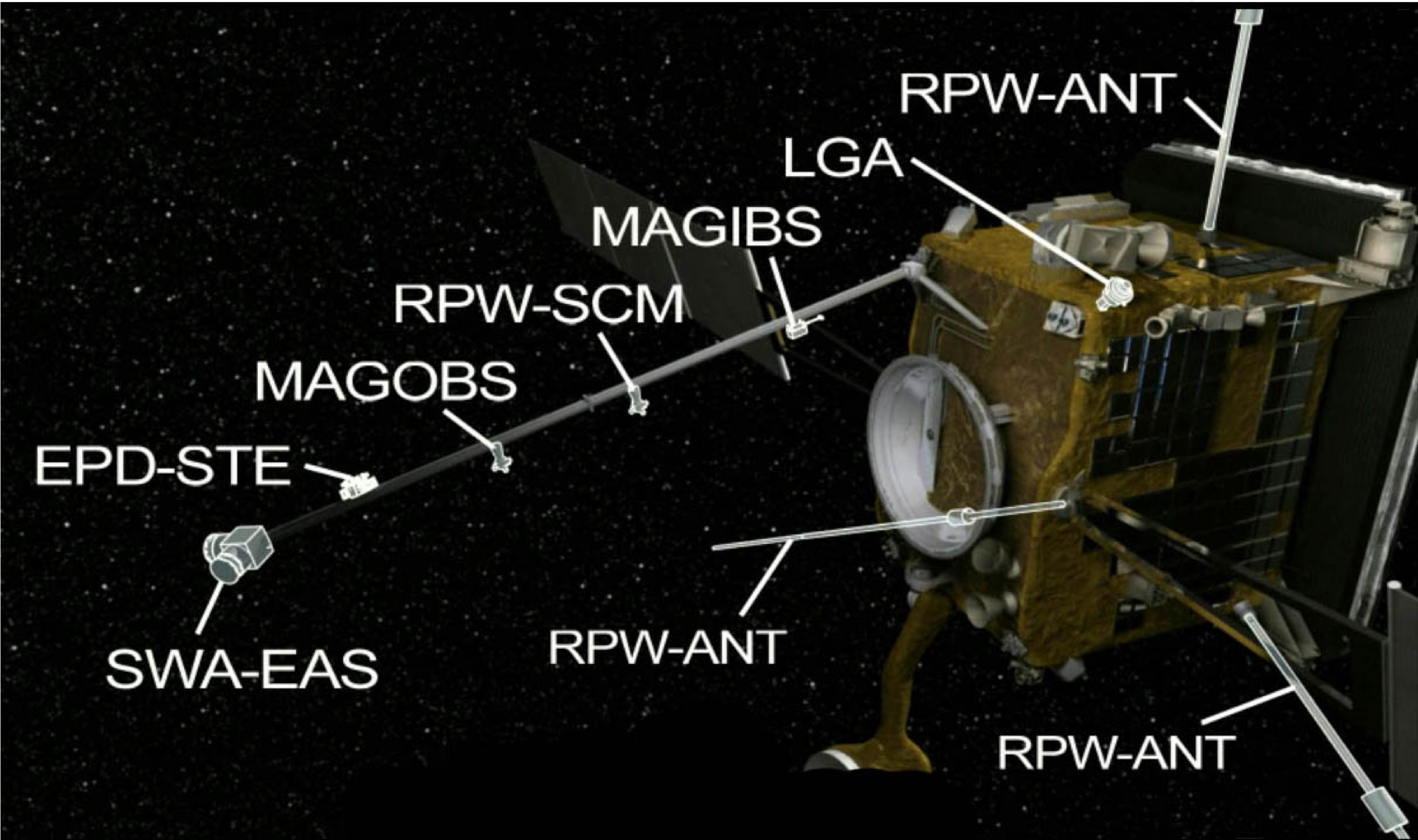
Non-thermal bremsstrahlung with energies > 5 keV

Thermal bremsstrahlung T ~ 10 - 40 MK

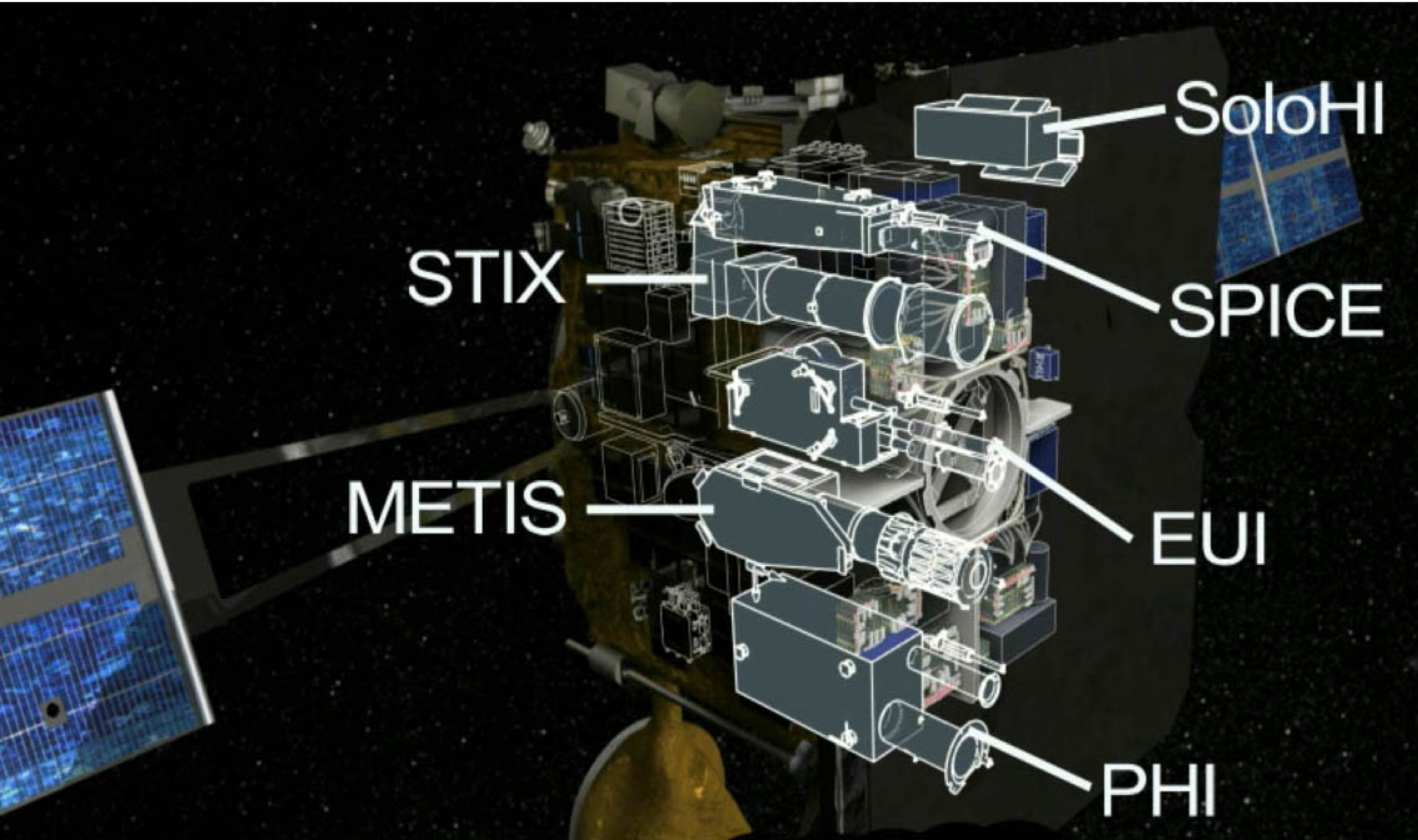
In-situ instruments



In-situ boom-mounted instruments



Remote-sensing instruments



Innovations and new technologies in space

The space environment and mission profile drive new

- **Spacecraft design:**

–Maximal solar flux at 0.28 AU is 17,5 kWm^{-2}

–Heat shield required (13 solar constants)

–Thermoelastic distorsions of S/C and instruments

–Poynting stability and coalignement of optical instruments

–Solid state mass memory; payload data generation rate 120kbps

–On board data processing units

- **Instrument design:**

–Optical entrance windows and filters: Heat rejection windows for PHI, X-ray entrance window for STIX, and heat rejecting mirror for SPICE

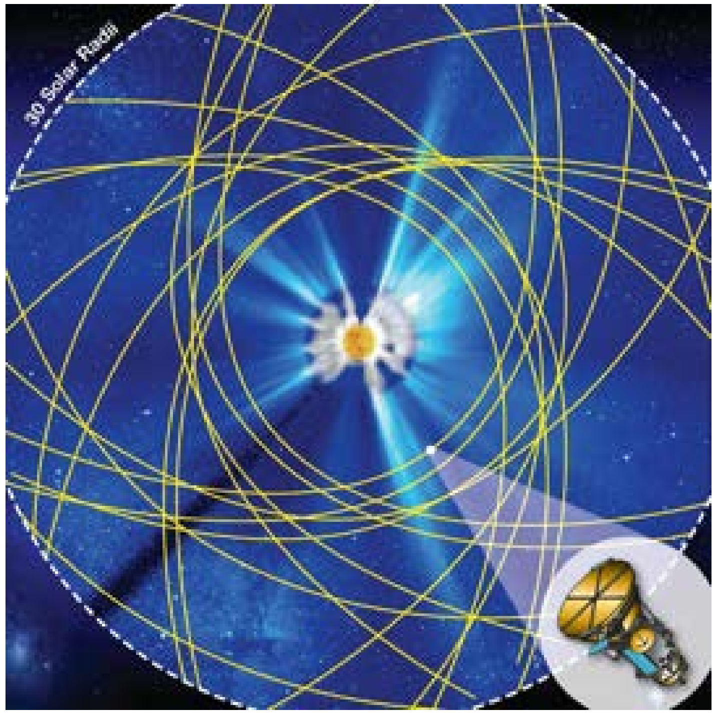
–Liquid crystal variable retarders for PHI polarization, and solid crystal etalon for PHI filtergraph

–New photon detectors (APS, back-illuminated CMOS)

–New wave antenna deployment mechanism

ESA technology image (May 2014): Solar Orbiter's essential sunshield is lowered into Europe's largest vacuum chamber for its trial by sunlight.

Synergies between Solar Orbiter and other observatories



Solar Orbiter:

+ unique orbit (solar distance, inclination, longitude)
+ comprehensive payload suite
- limited telemetry due to orbital characteristics

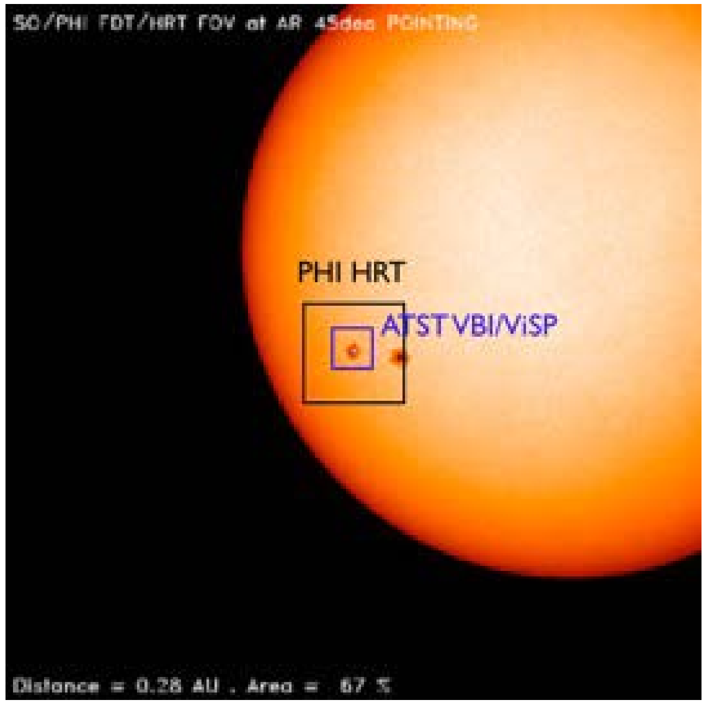
Solar Probe Plus:

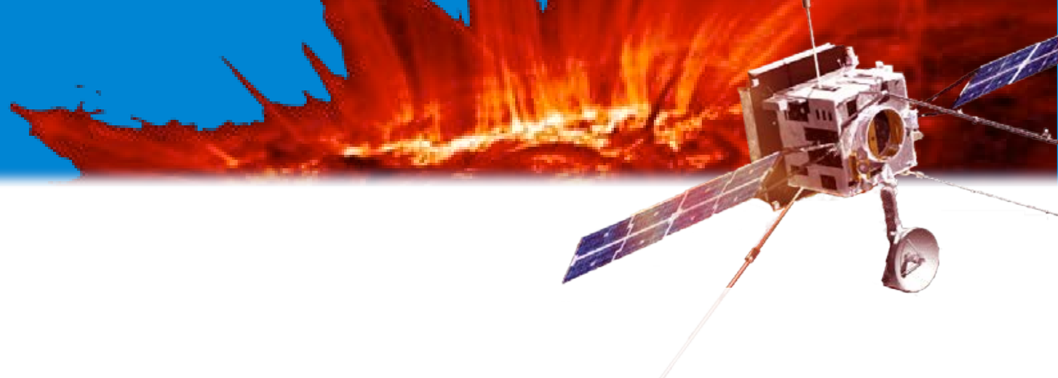
+ unique orbit (minimal perihelion < 10 Rs)
- payload mass constrained by orbital characteristics, mostly in-situ instrumentation

Near-Earth assets:

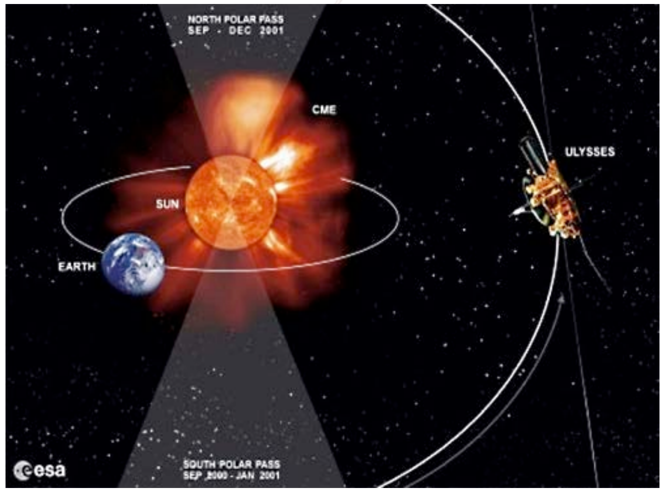
+ much higher data return (SDO, ATST)
- limited to Sun-Earth line

→ Depending on orbit, Solar Orbiter remote-sensing data can be complemented either by high-res/high-cadence **co-spatial** data from other observatories or data with **additional spatial coverage**, e.g. for helioseismology

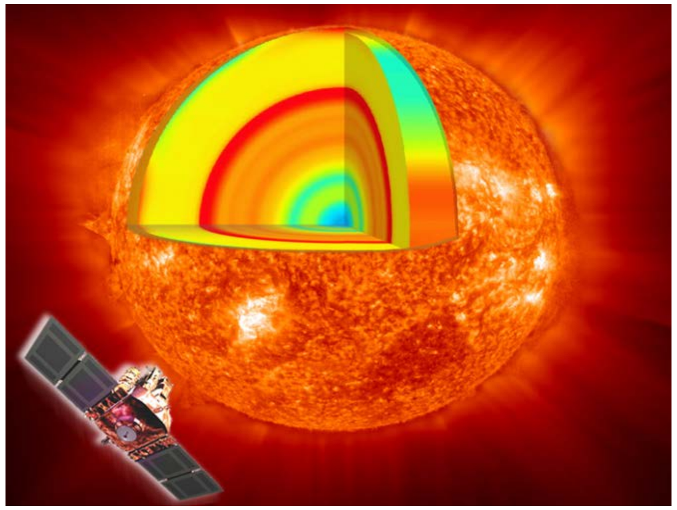




Conclusions



Solar Orbiter will answer the question:
How does the Sun create and control the Heliosphere?



- It is the first medium-class mission of ESA's Cosmic Vision 2015-2025 science programme.
- As a joint ESA/NASA project, it is the logical next step in heliophysics after Helios, Ulysses, and SOHO.
- It will reveal, with its 10 dedicated remote-sensing and in-situ instruments measuring from the photosphere into the solar wind, the detailed temporal and spatial connections between sun and heliosphere.