Solar Orbiter

Exploring the Sun-Heliosphere Connection

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European Space Agency

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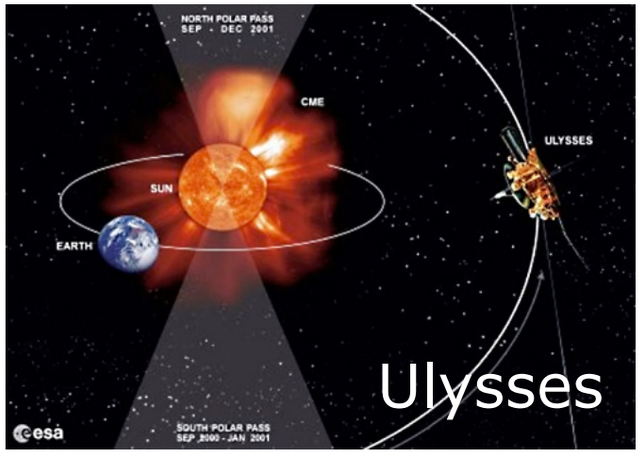
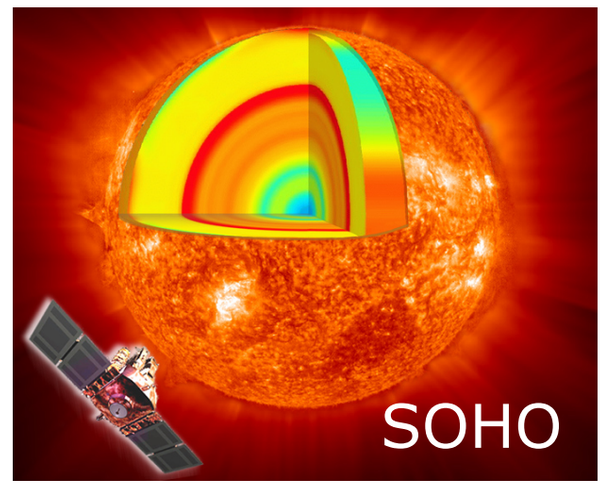
Solar Orbiter

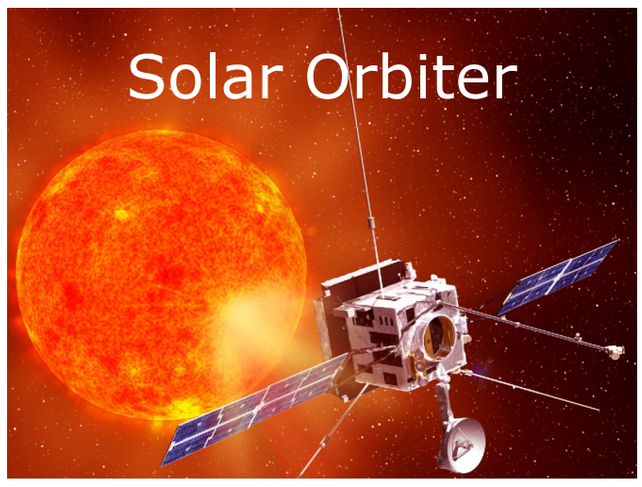
- First medium-class mission of ESA's Cosmic Vision 2015-2025 programme, implemented jointly with NASA
- Dedicated payload of 10 remote-sensing and in-situ instruments measuring from the photosphere into the solar wind

Talk Outline

- Mission Overview
- Spacecraft & Payload
- Science Objectives
- Science Operations & Synergies







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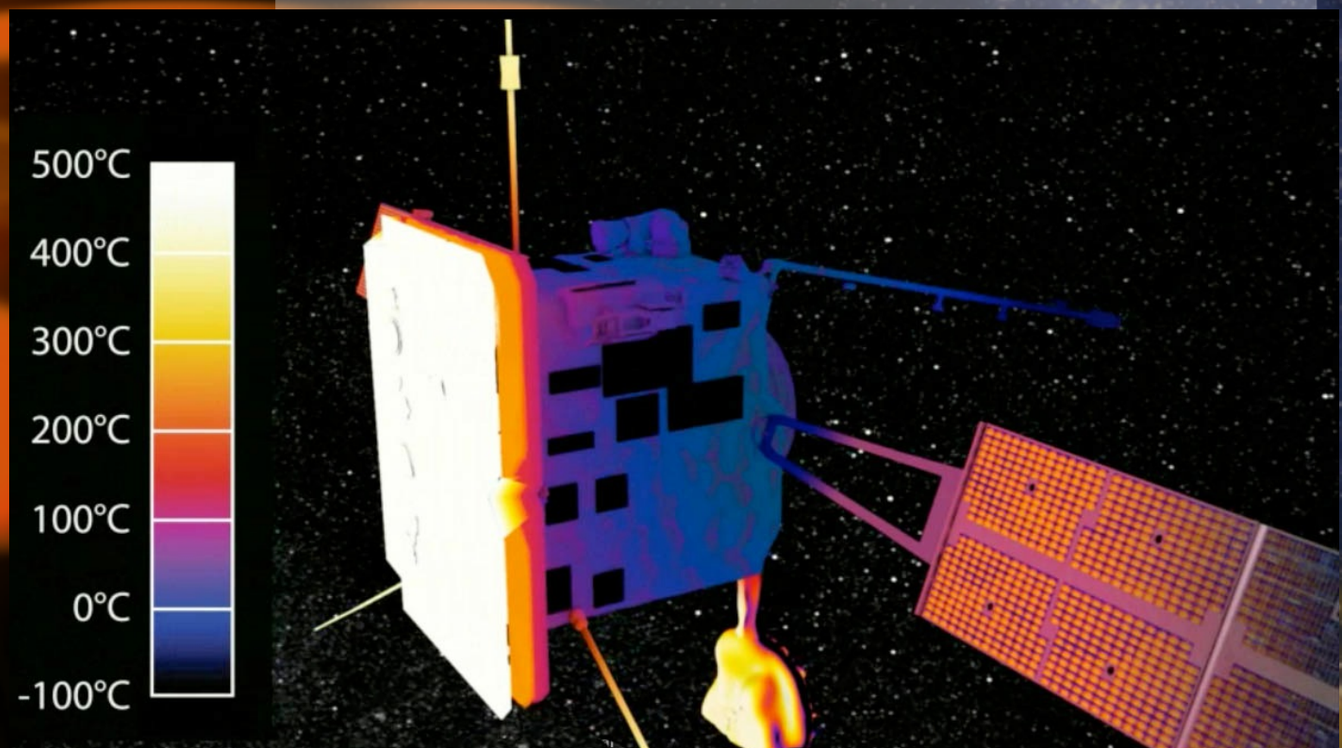
The Spacecraft

Three-axis stabilized spacecraft, Sun pointing

- Closest Sun encounter: 0.28 AU
- Heat shield to protect spacecraft and payload



Solar Orbiter
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The Spacecraft

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- Closest Sun encounter: 0.28 AU
- Heat shield to protect spacecraft and payload
- Overall mass: ~ 1800 kg
  Maximum power demand: ~ 1100W
- Re-use of BepiColombo unit designs and technology
- NASA-provided launch vehicle

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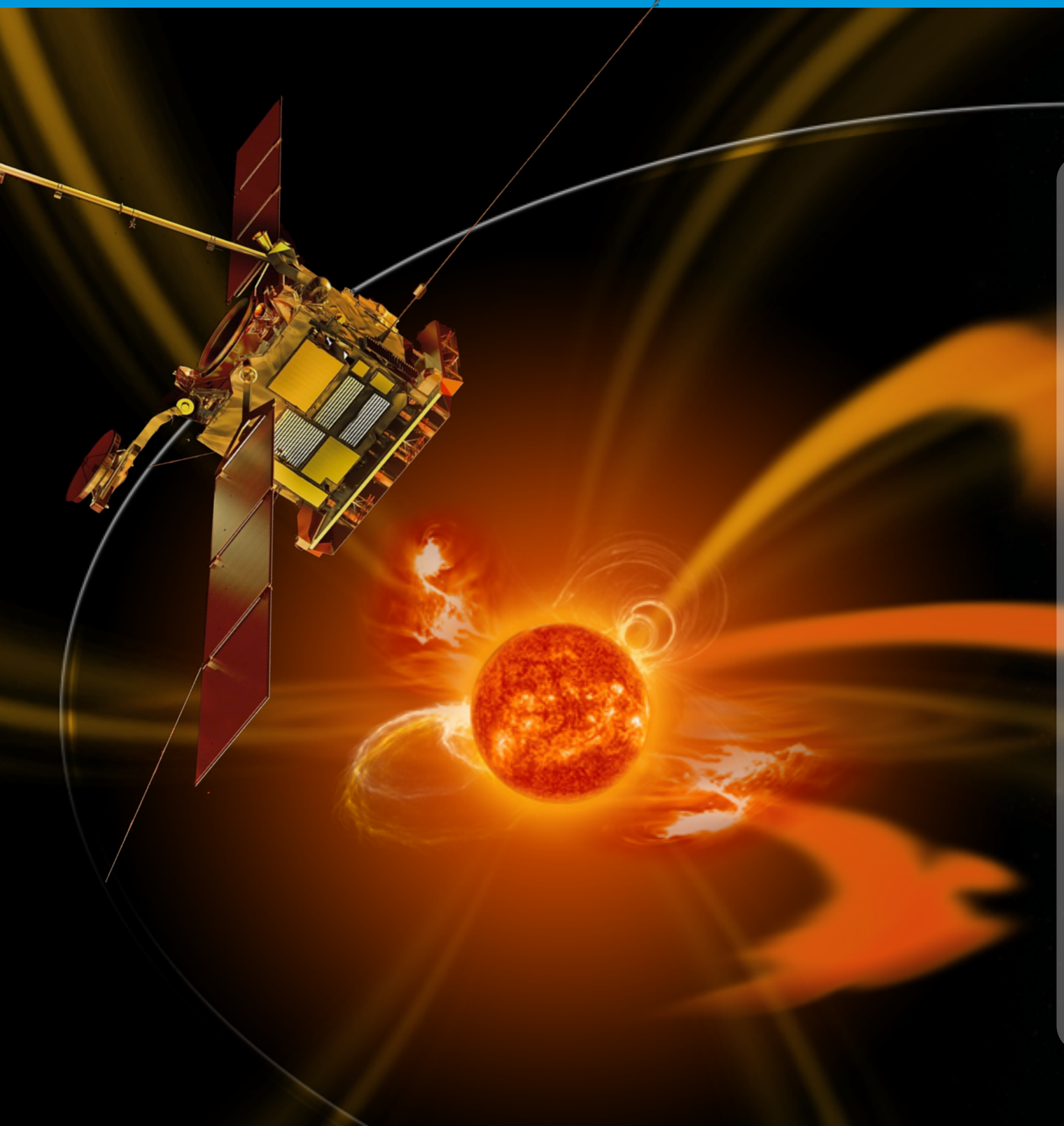

Mission Summary

Launch: July 2017 (Backup: Oct 2018)

Cruise Phase: 3 years

Nominal Mission: 3.5 years

Extended Mission: 2.5 years

Orbit: 0.28–0.91 AU (P=150-180 days)

Out-of-Ecliptic View:
Multiple gravity assists with Venus to increase inclination out of the ecliptic to >24° (nominal mission),
>34° (extended mission)

Reduced relative rotation:
Observations of evolving structures on solar surface & in heliosphere for almost a complete solar rotation

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Remote-sensing windows
(10 days each)

High-latitude
Observations

Perihelion
Observations

High-latitude
Observations

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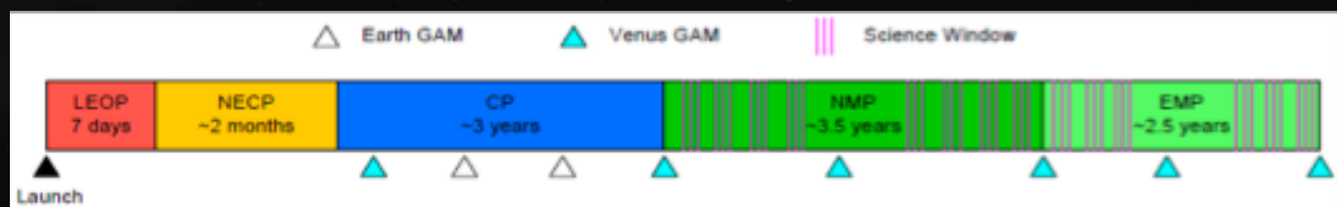
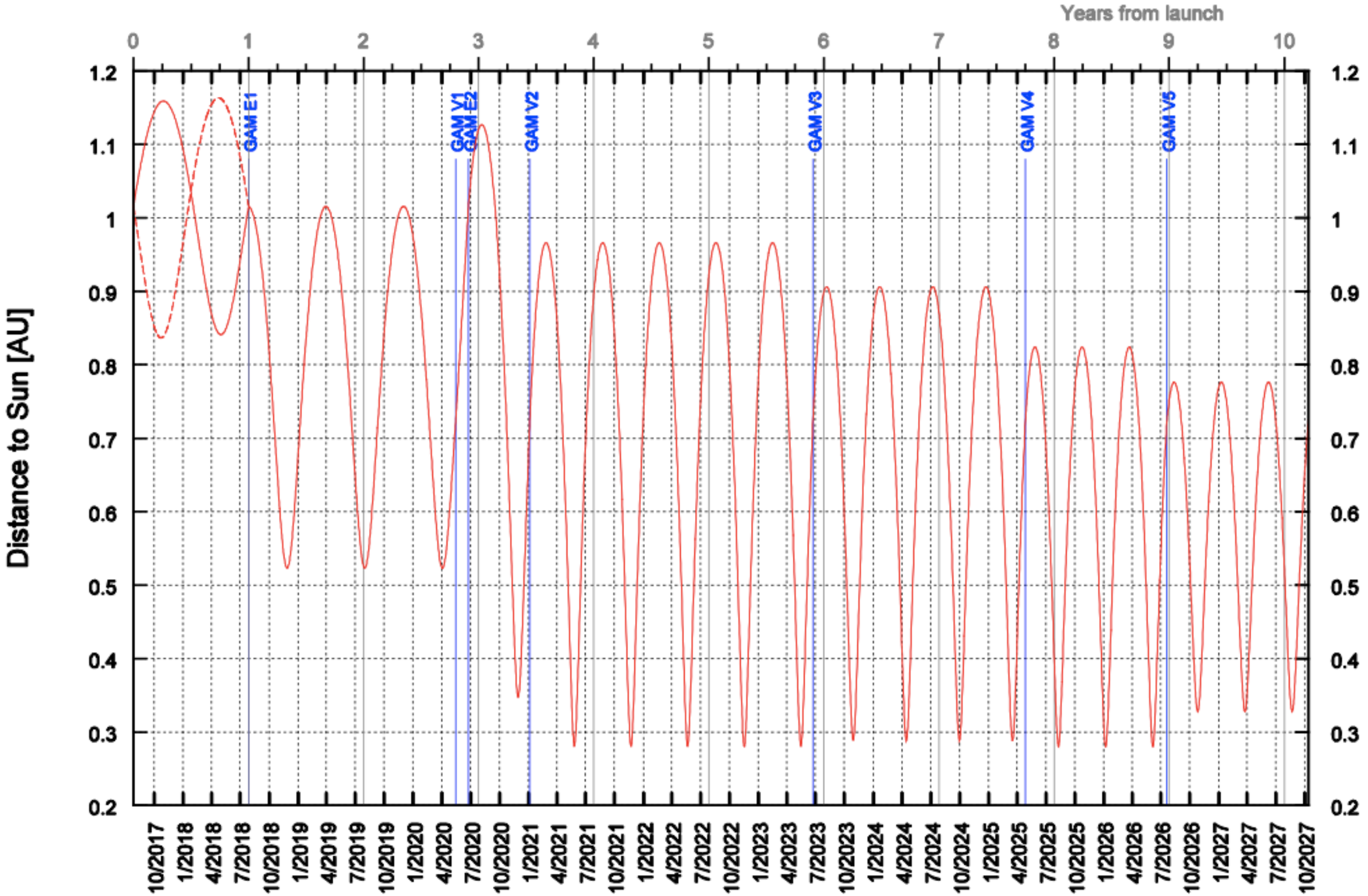
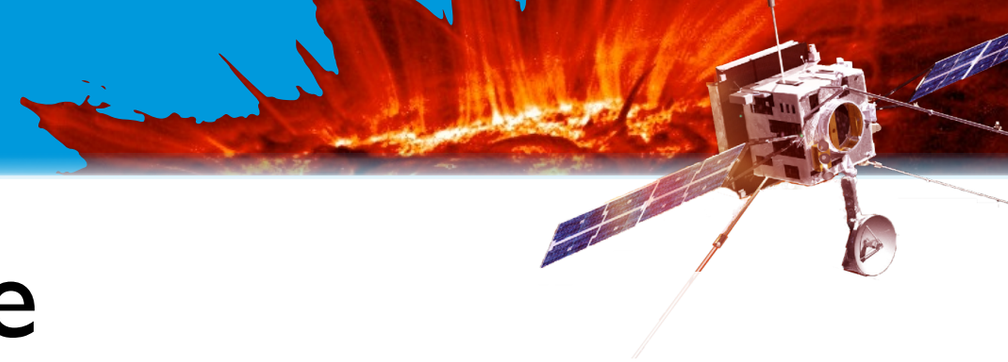
Mission Profile

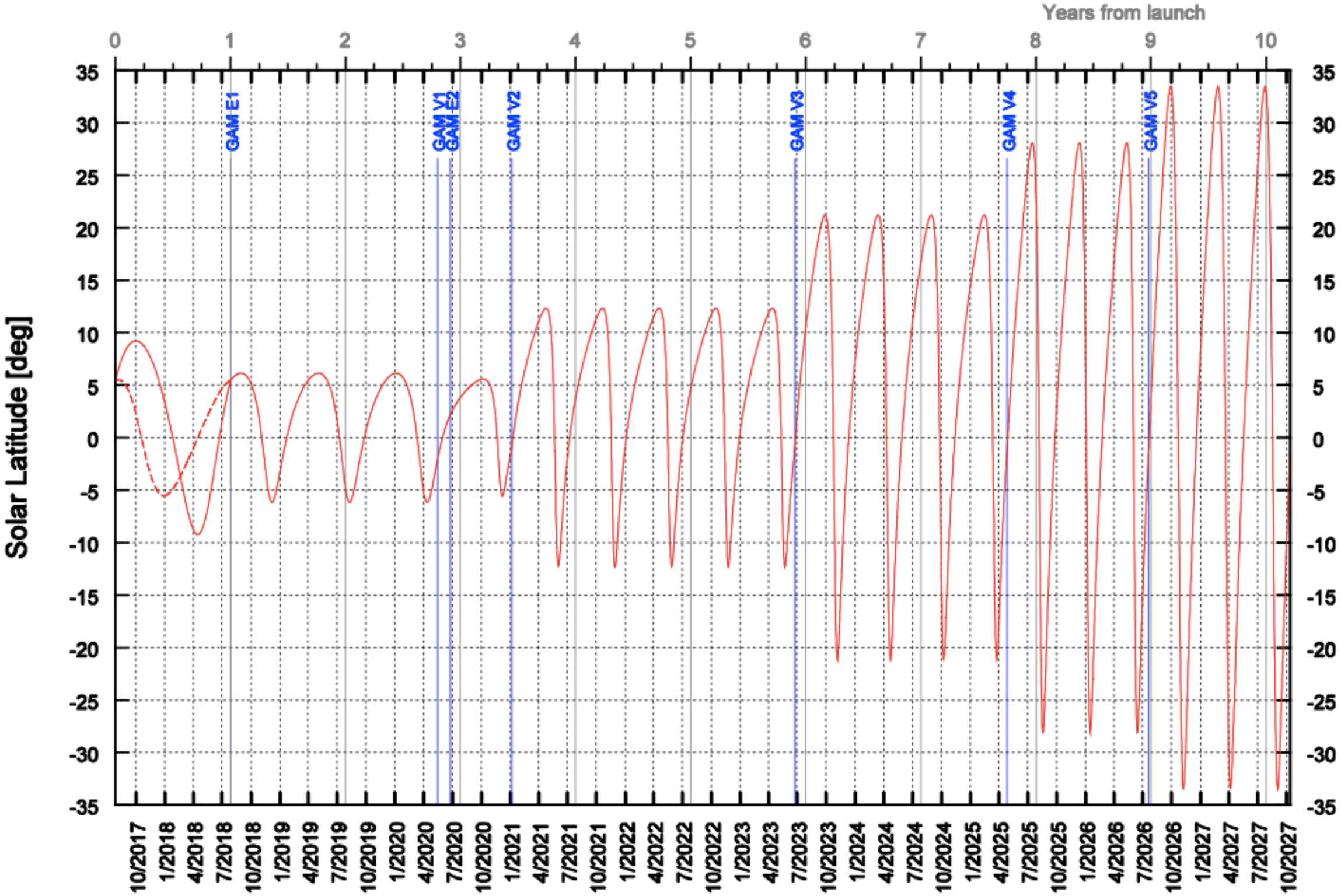


July 2017 Launch: Solar Distance



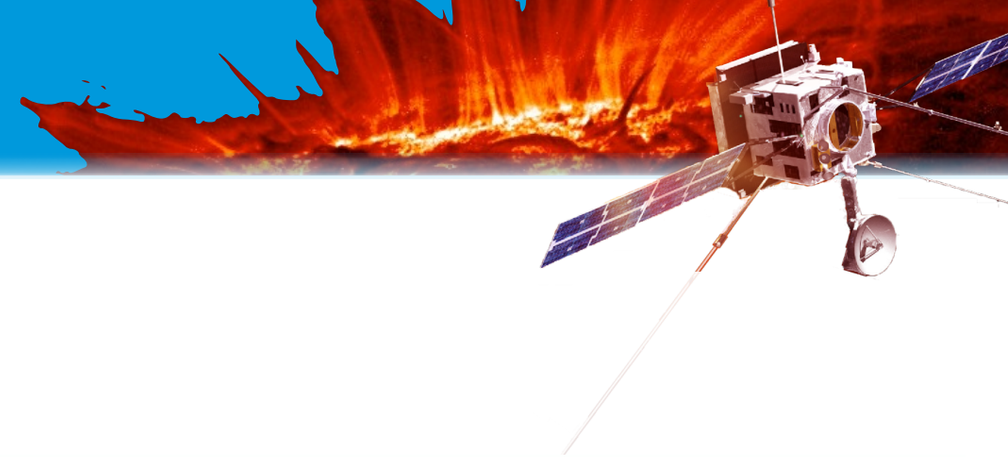


July 2017 Launch: Solar Latitude

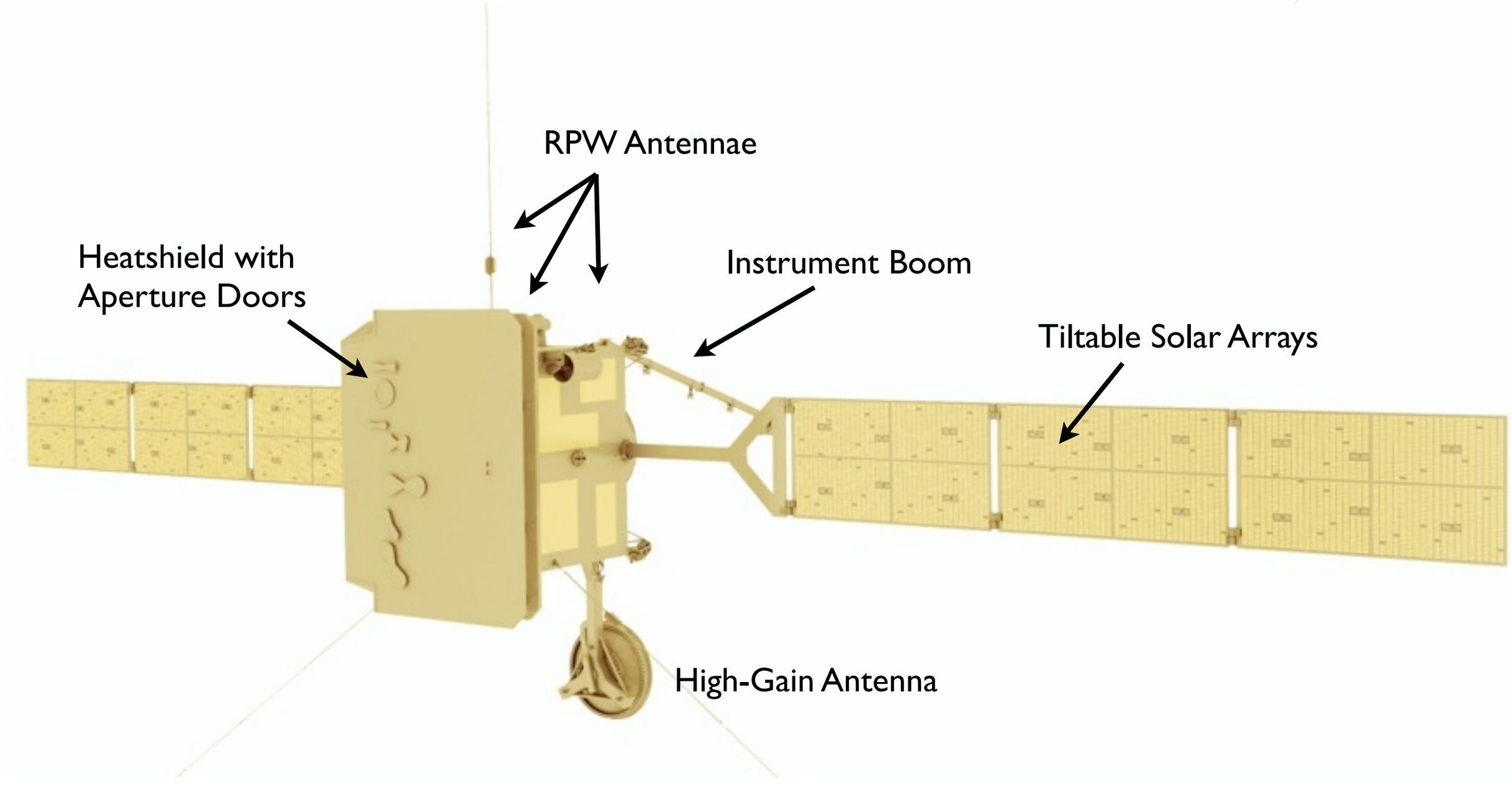


Payload

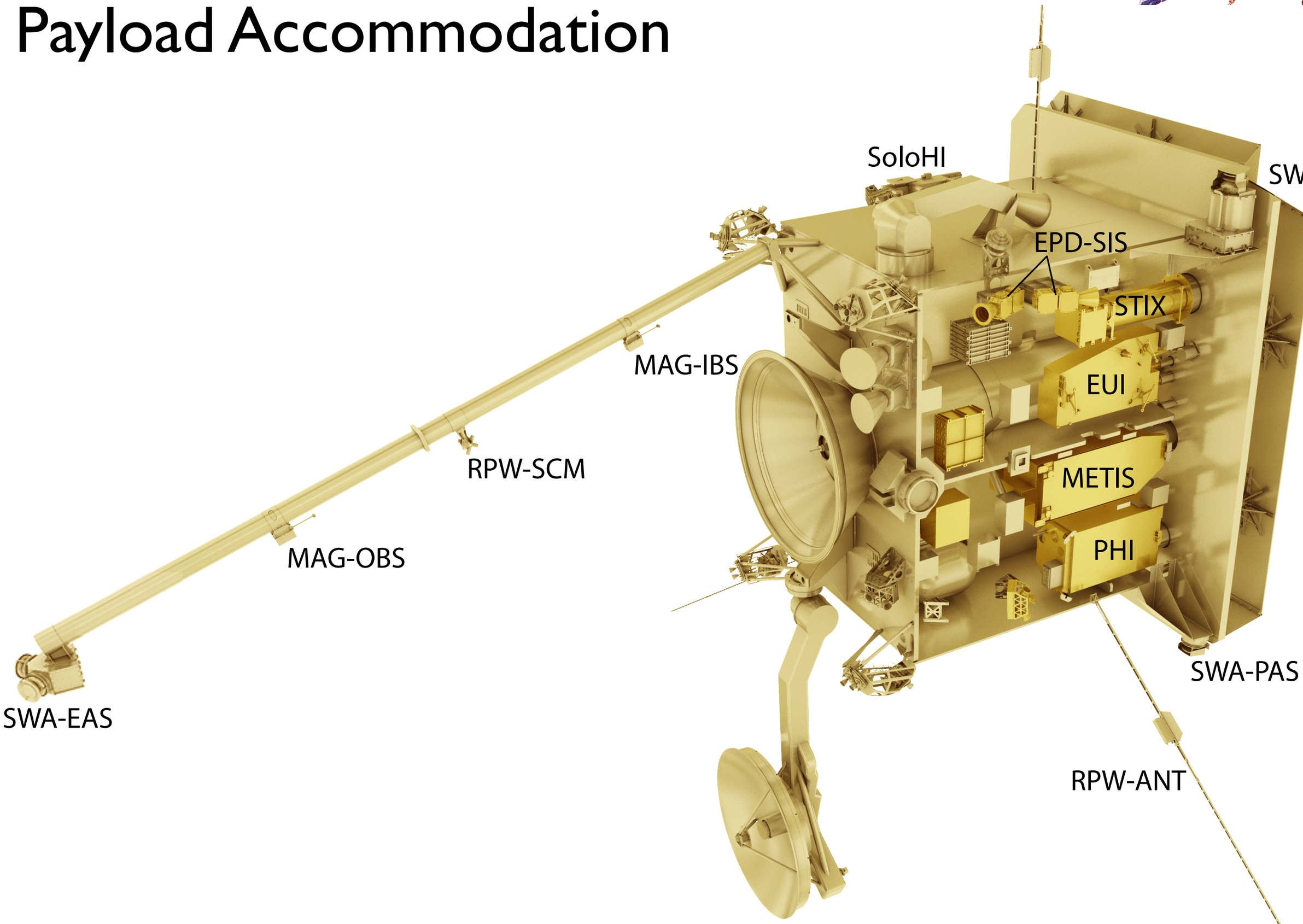
In-Situ Instruments			
EPD	Energetic Particle Detector	J. Rodríguez-Pacheco	Composition, timing and distribution functions of energetic particles
MAG	Magnetometer	T. Horbury	High-precision measurements of the heliospheric magnetic field
RPW	Radio & Plasma Waves	M. Maksimovic	Electromagnetic and electrostatic waves, magnetic and electric fields at high time resolution
SWA	Solar Wind Analyser	C. Owen	Sampling protons, electrons and heavy ions in the solar wind
Remote-Sensing Instruments			
EUI	Extreme Ultraviolet Imager	P. Rochus	High-resolution and full-disk EUV imaging of the on-disk corona
METIS	Multi-Element Telescope for Imaging and Spectroscopy	E. Antonucci	Imaging and spectroscopy of the off-disk corona
PHI	Polarimetric & Helioseismic Imager	S. Solanki	High-resolution vector magnetic field, line-of-sight velocity in photosphere, visible imaging
SoloHI	Heliospheric Imager	R. Howard	Wide-field visible imaging of the solar off-disk corona
SPICE	Spectral Imaging of the Coronal Environment	European-led facility instrument	EUV spectroscopy of the solar disk and near-Sun corona
STIX	Spectrometer/Telescope for Imaging X-rays	S. Krucker	Imaging spectroscopy of solar X-ray emission

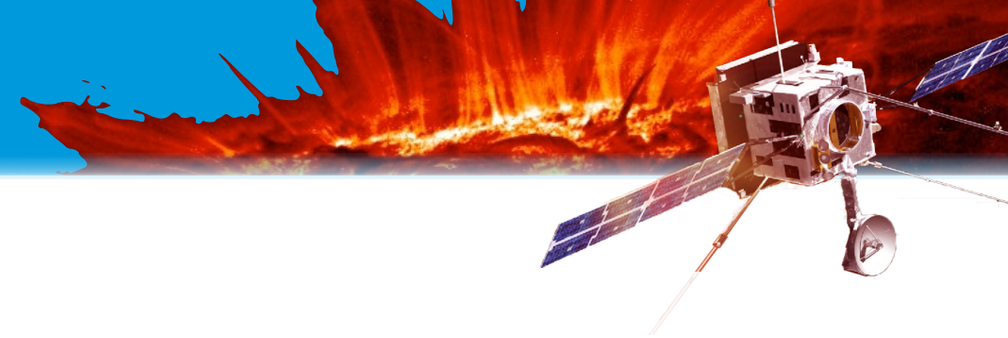


The Spacecraft

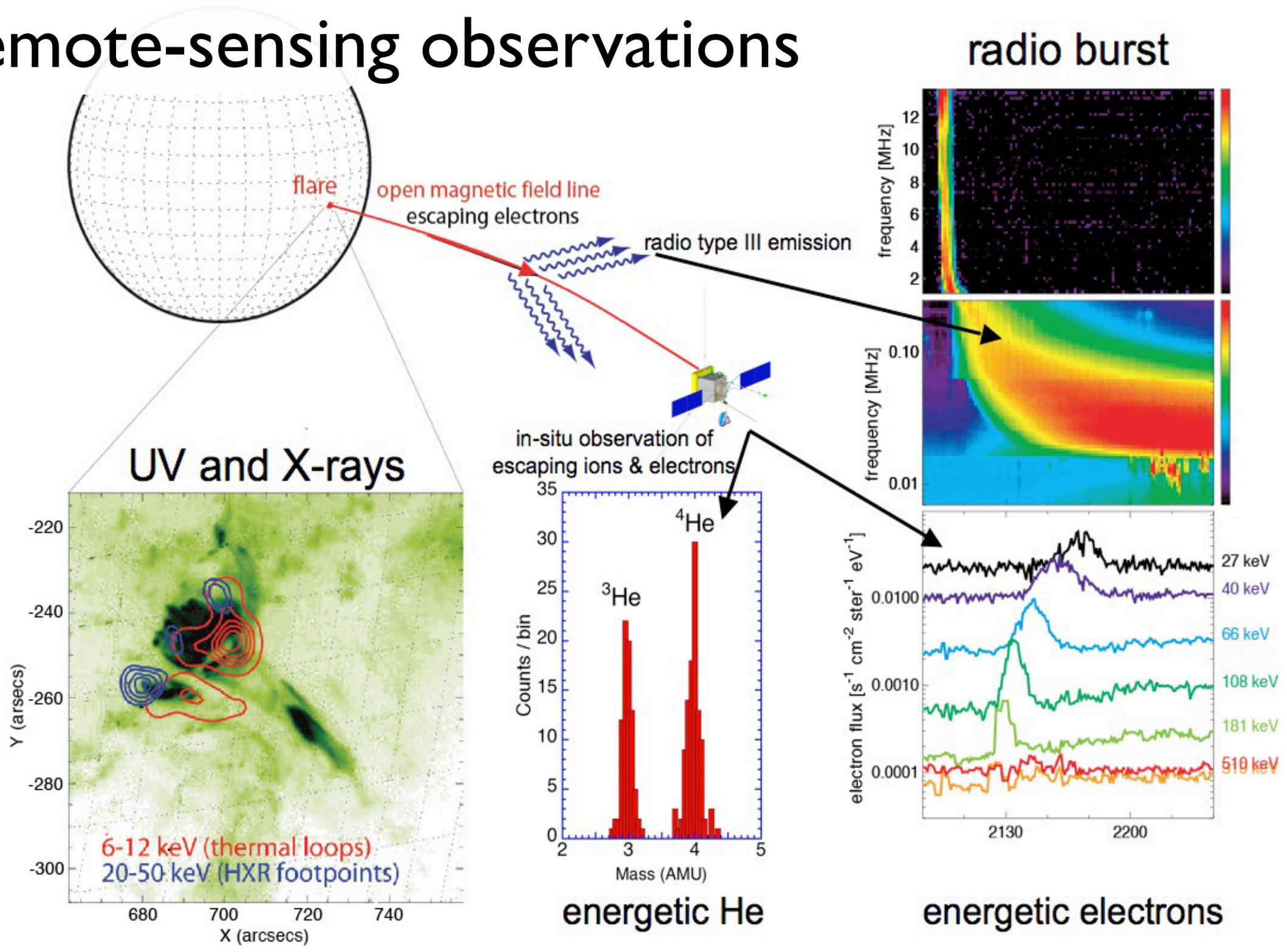


Payload Accommodation



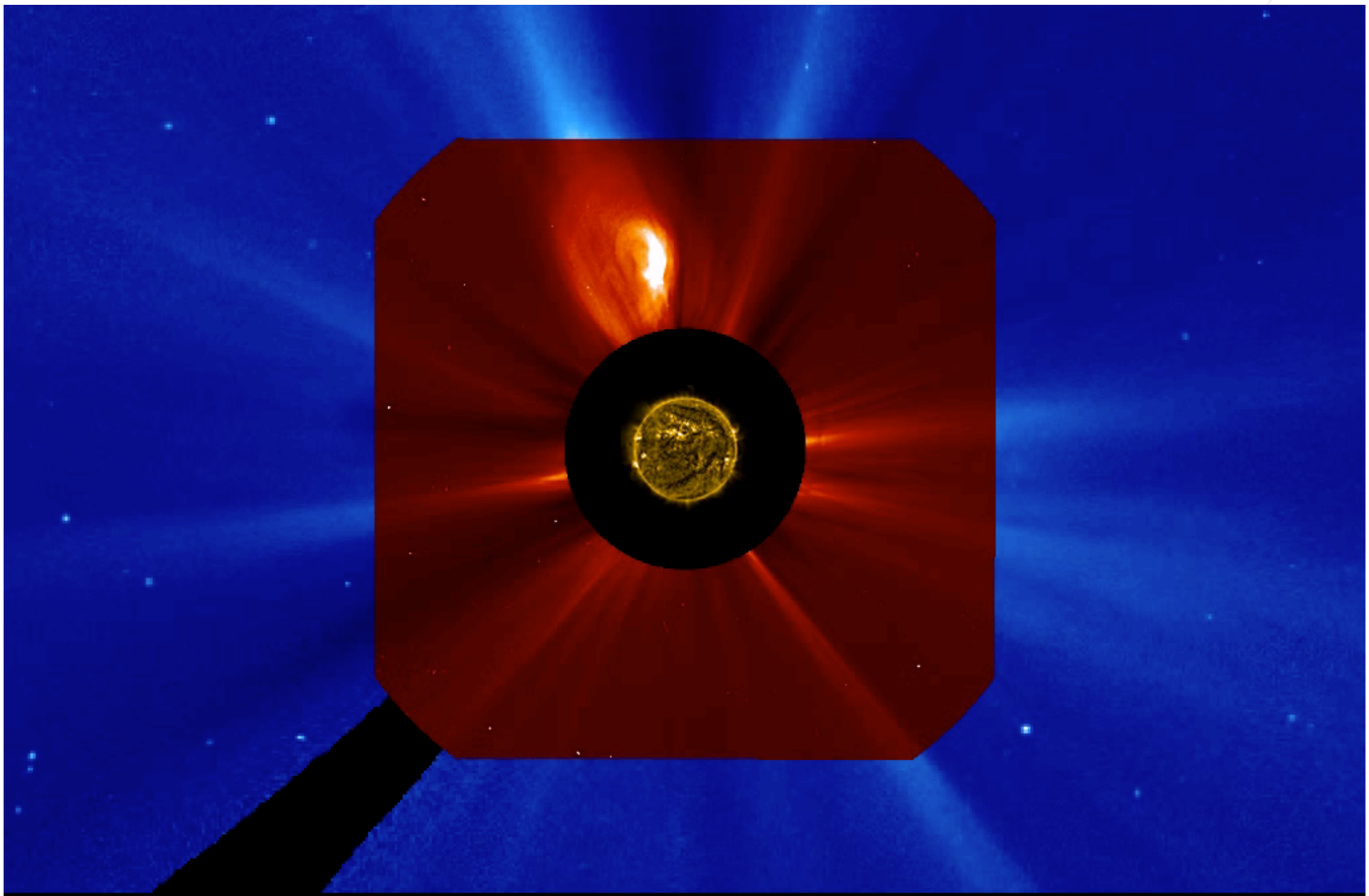


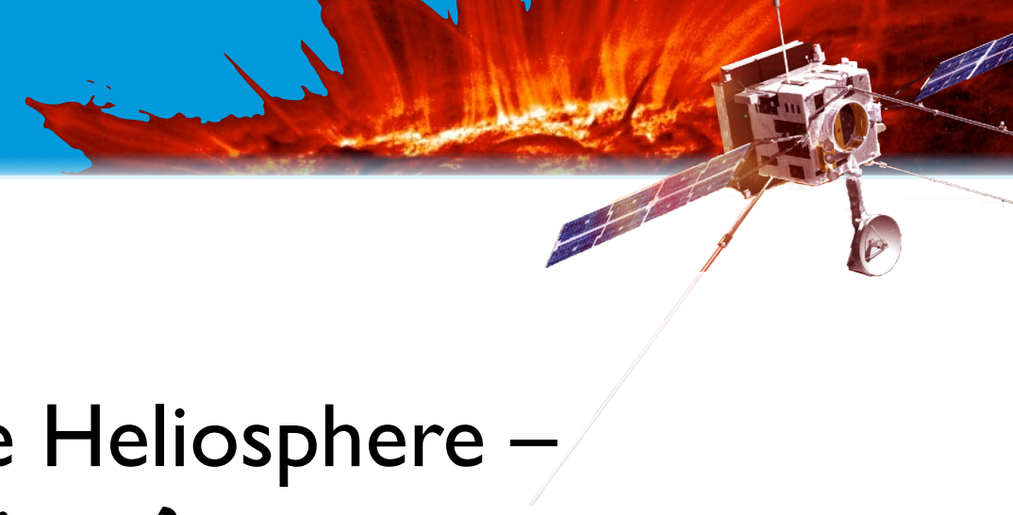
Solar Orbiter = Linking in-situ and remote-sensing observations



Solar corona, wind and magnetic activity

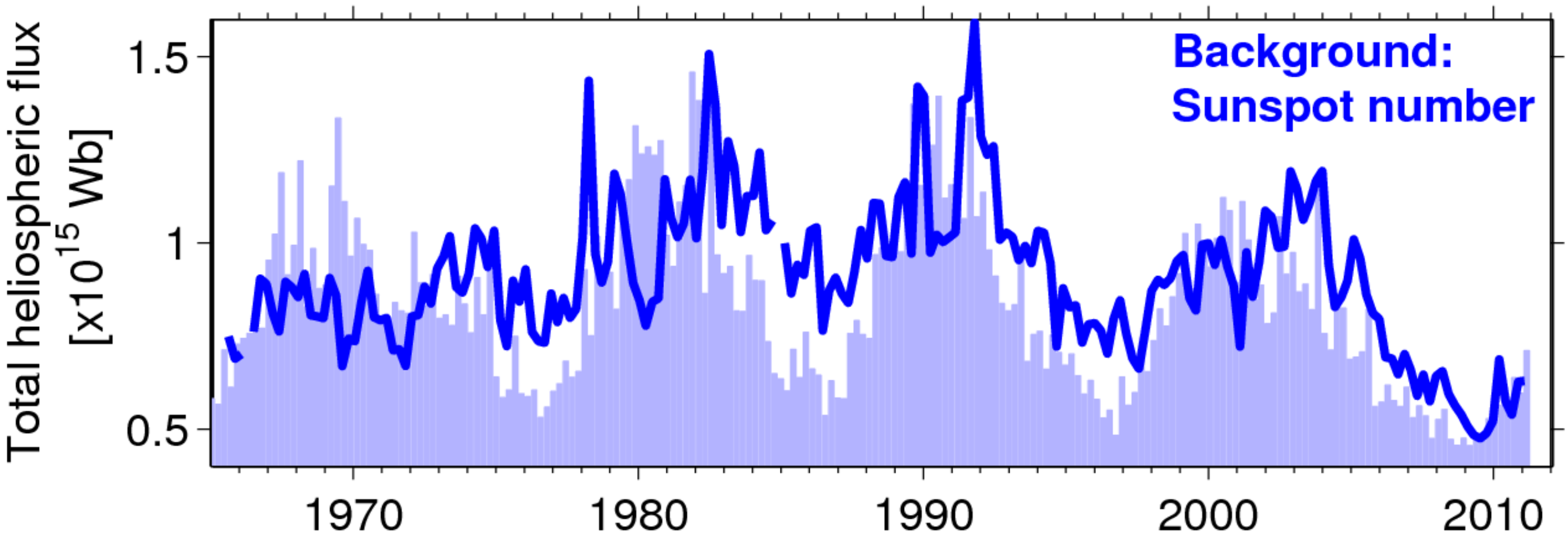
→ dynamic heliosphere

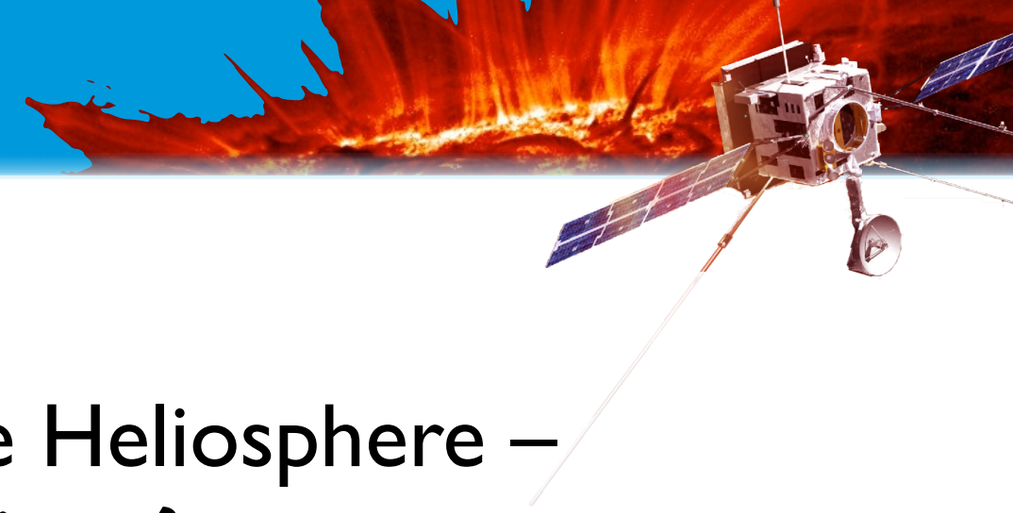




Solar Orbiter Science Focus:

How does the Sun create and control the Heliosphere – and why does solar activity change with time ?





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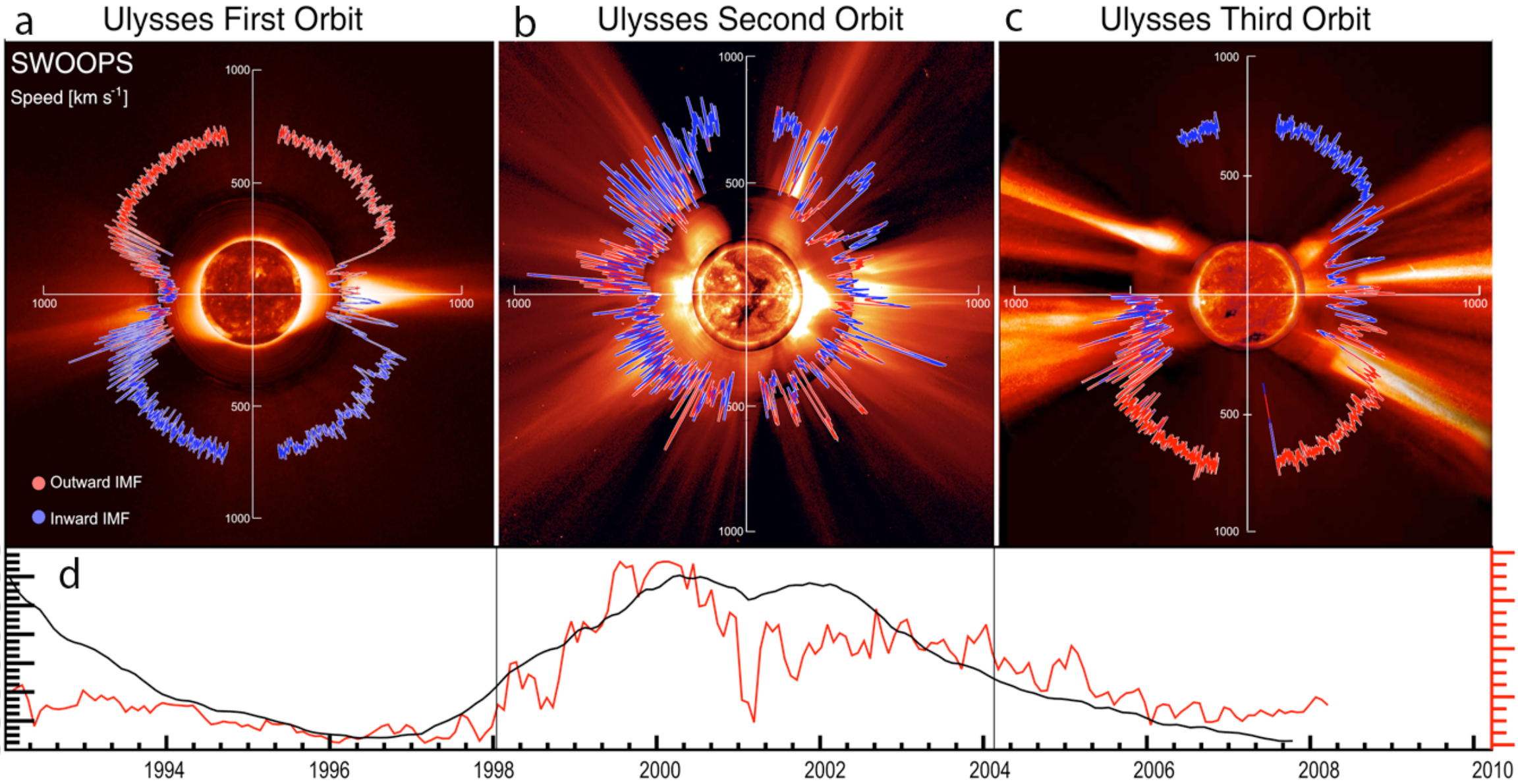
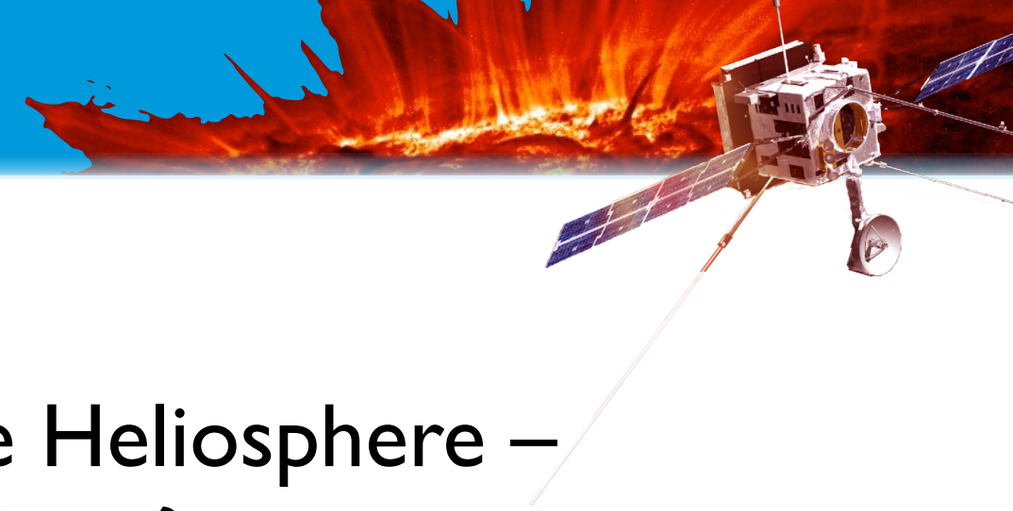


McComas et al., GRL 2008



Solar Orbiter Science Focus:

How does the Sun create and control the Heliosphere – and why does solar activity change with time ?

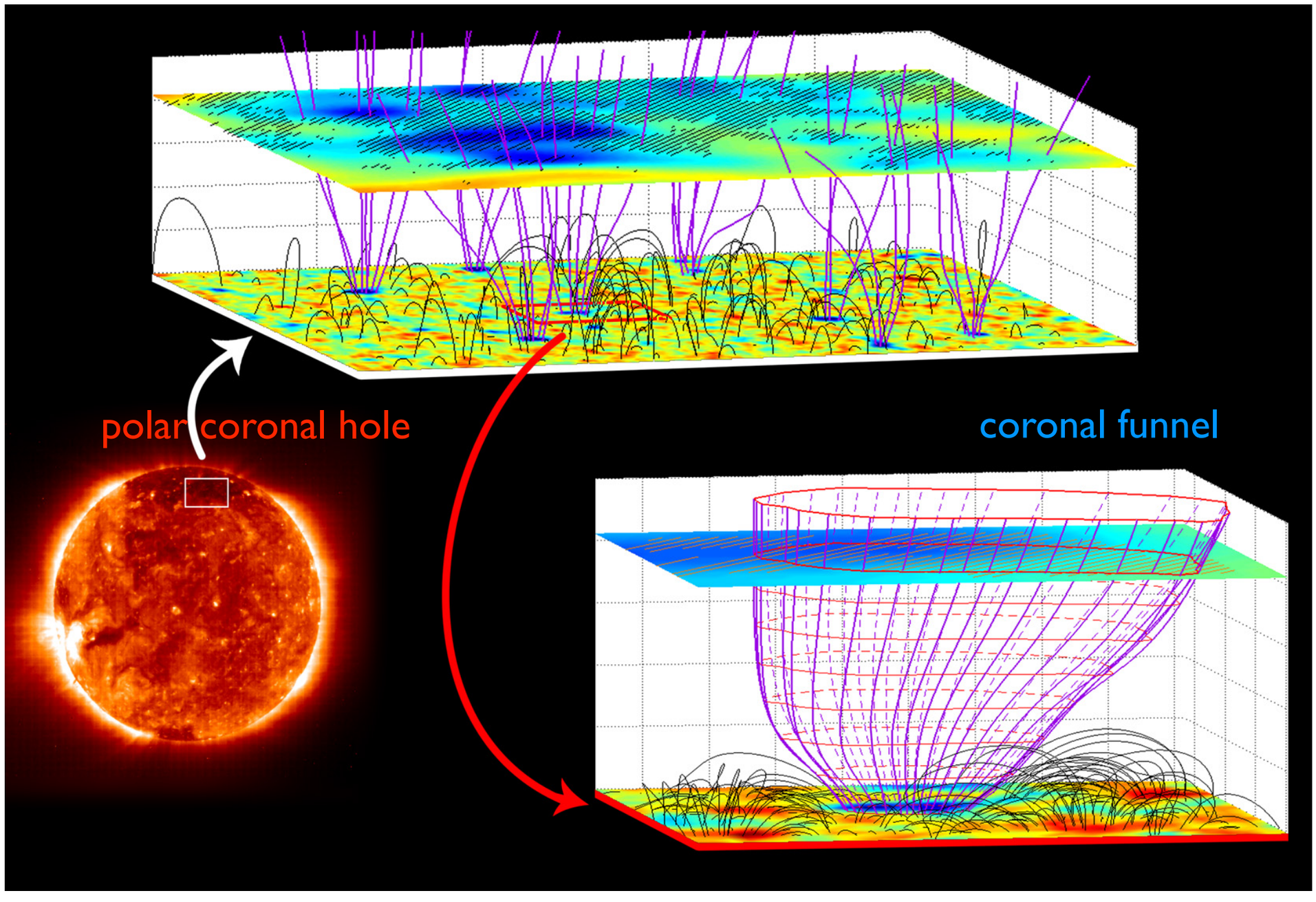
➡ What drives the solar wind and where does the coronal magnetic field originate from?

➡ How do solar transients drive heliospheric variability?

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

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

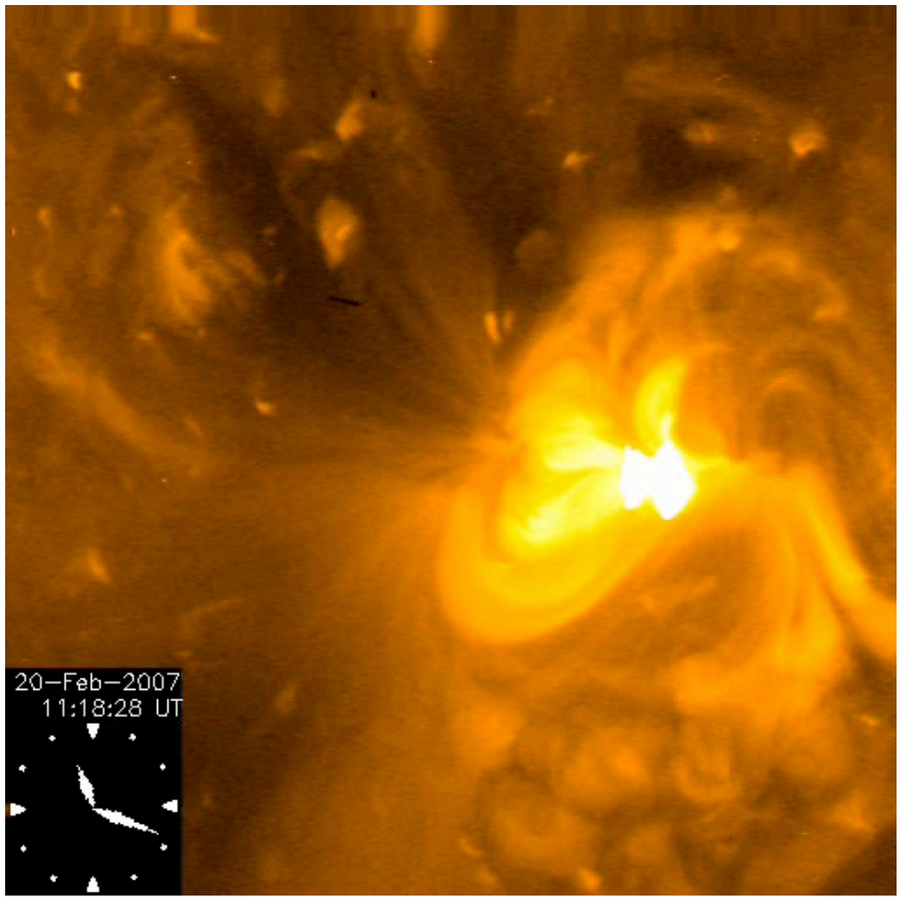
How and where do the solar wind plasma and magnetic field originate in the corona?

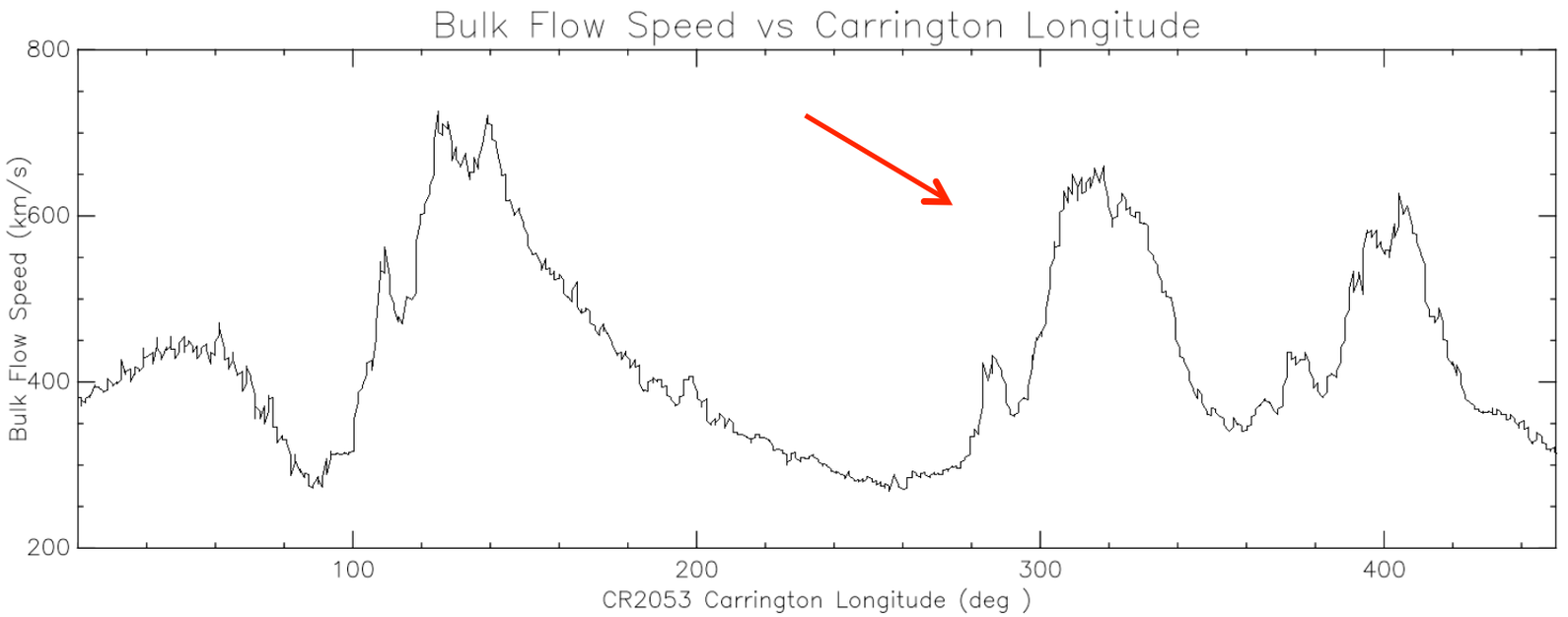


Tu, Zhou, Marsch et al., Science 2005

How and where do the solar wind plasma and magnetic field originate in the corona?

The Slow Solar Wind





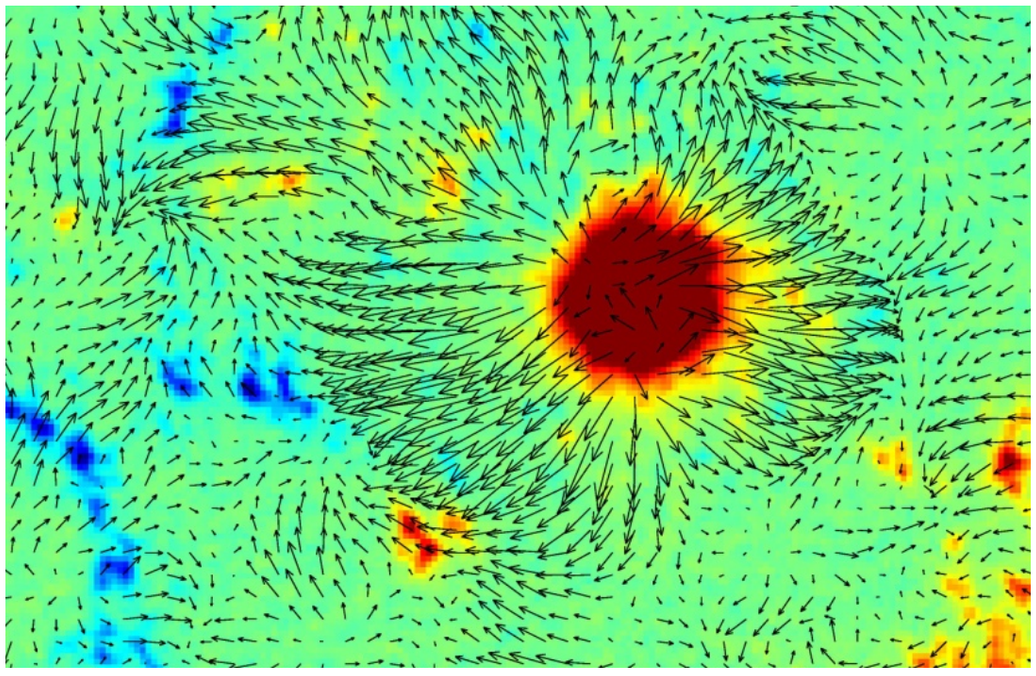
Harra et al., ApJL 2008

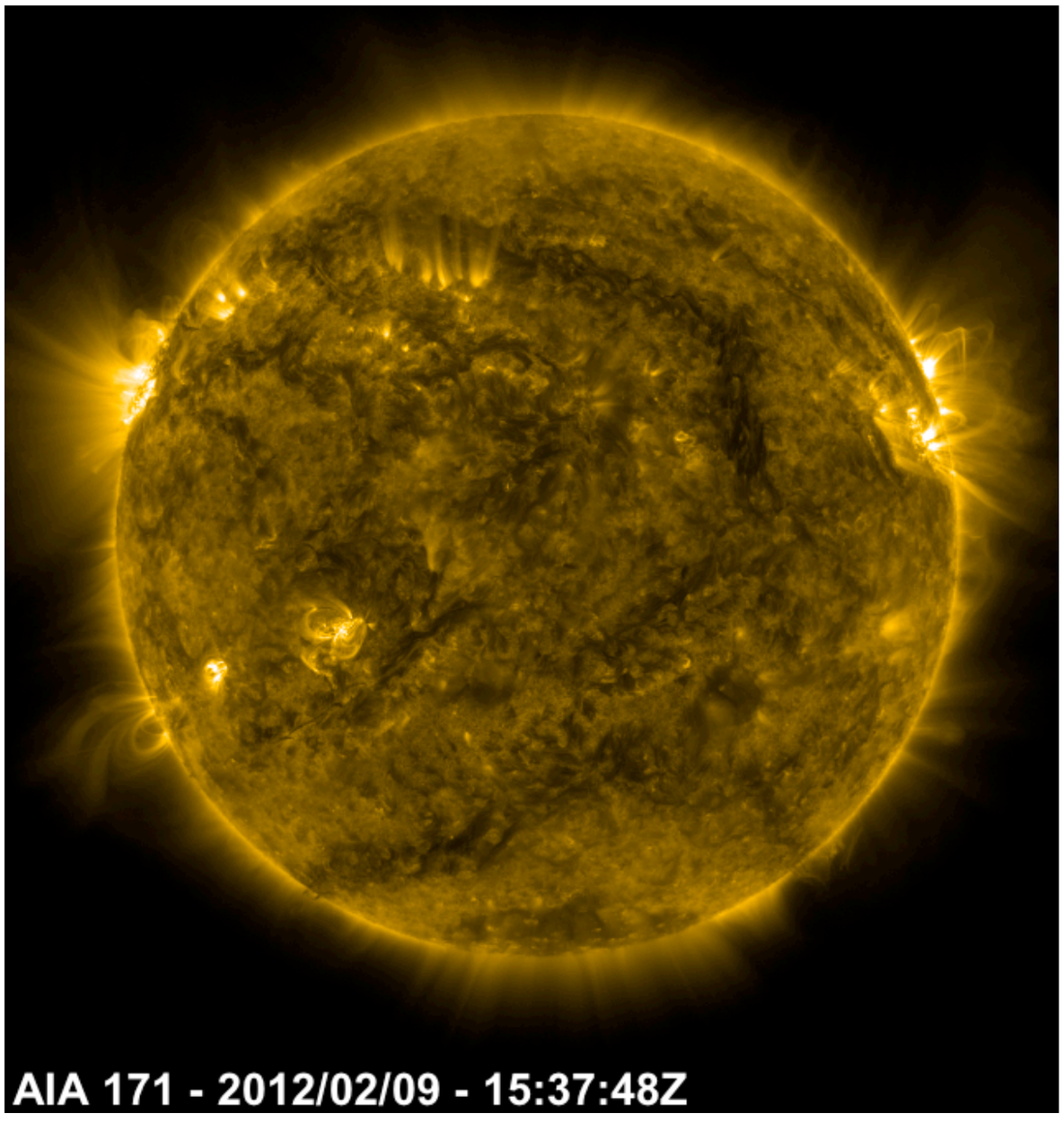
There are multiple sources of slow solar wind – active regions are one source. Identifying the source directly in the wind by the time it gets to 1 AU is extremely challenging and can only be carried out on a statistical basis.

Understanding the detailed physical processes can only be achieved by getting closer.

How and where do the solar wind plasma and magnetic field originate in the corona?

- Disentangling space/time structures requires viewing a given region for more than an active region growth time (~ 10 days)
  → implies going closer to the Sun

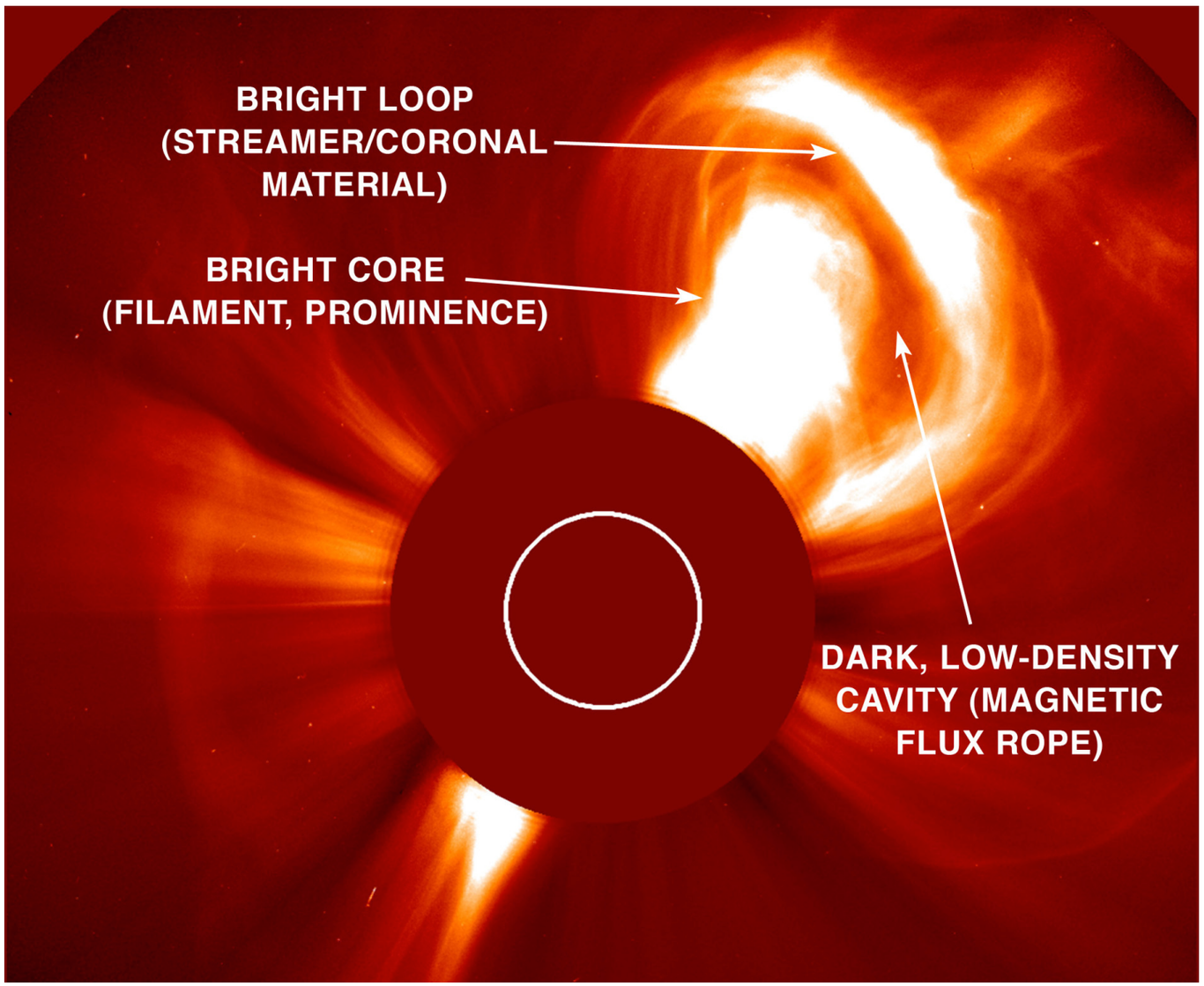


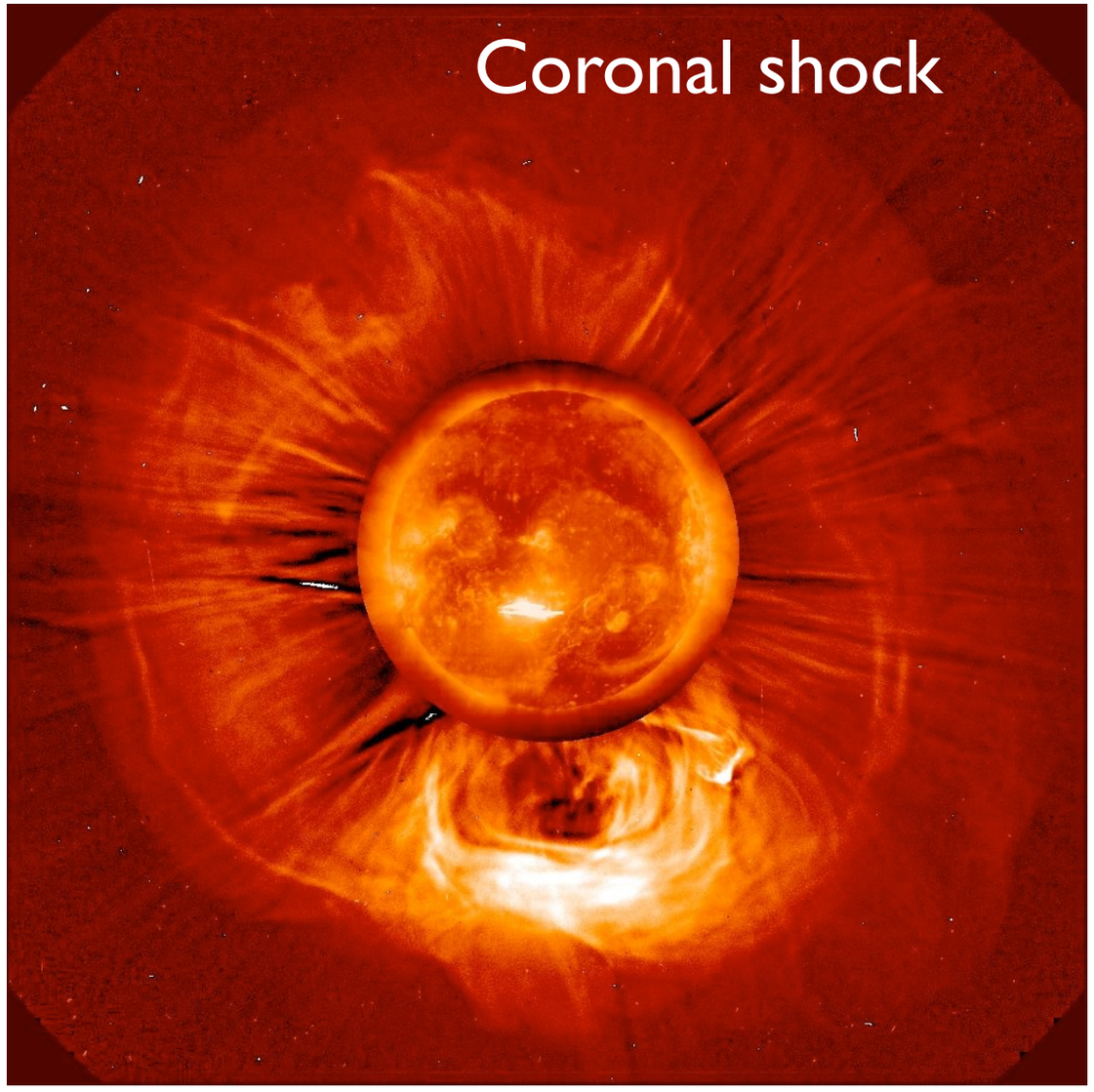


How and where do the solar wind plasma and magnetic field originate in the corona?

- What are the source regions of the solar wind and heliospheric magnetic field?
- What mechanisms heat the corona and heat and accelerate the solar wind?
- What are the sources of solar wind turbulence and how does it evolve?

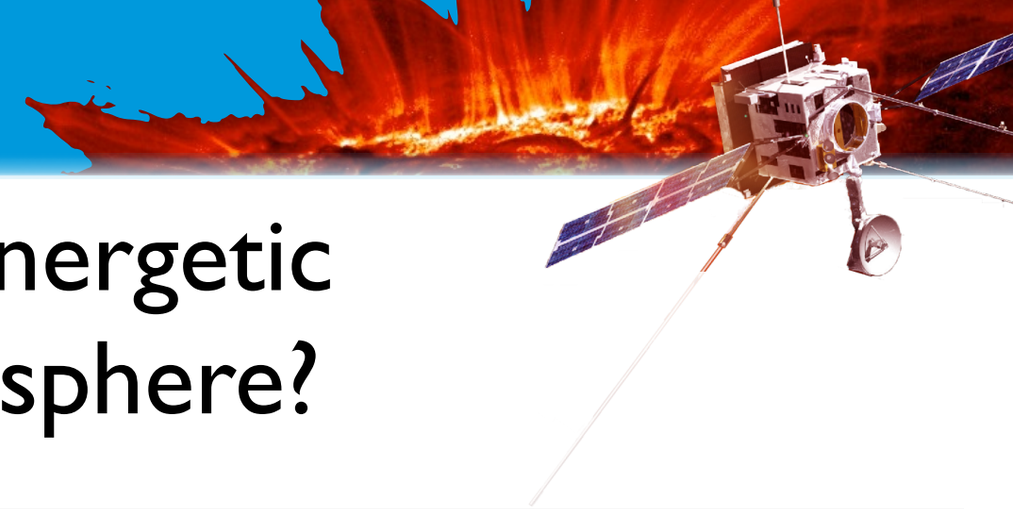
How do solar transients drive heliospheric variability?



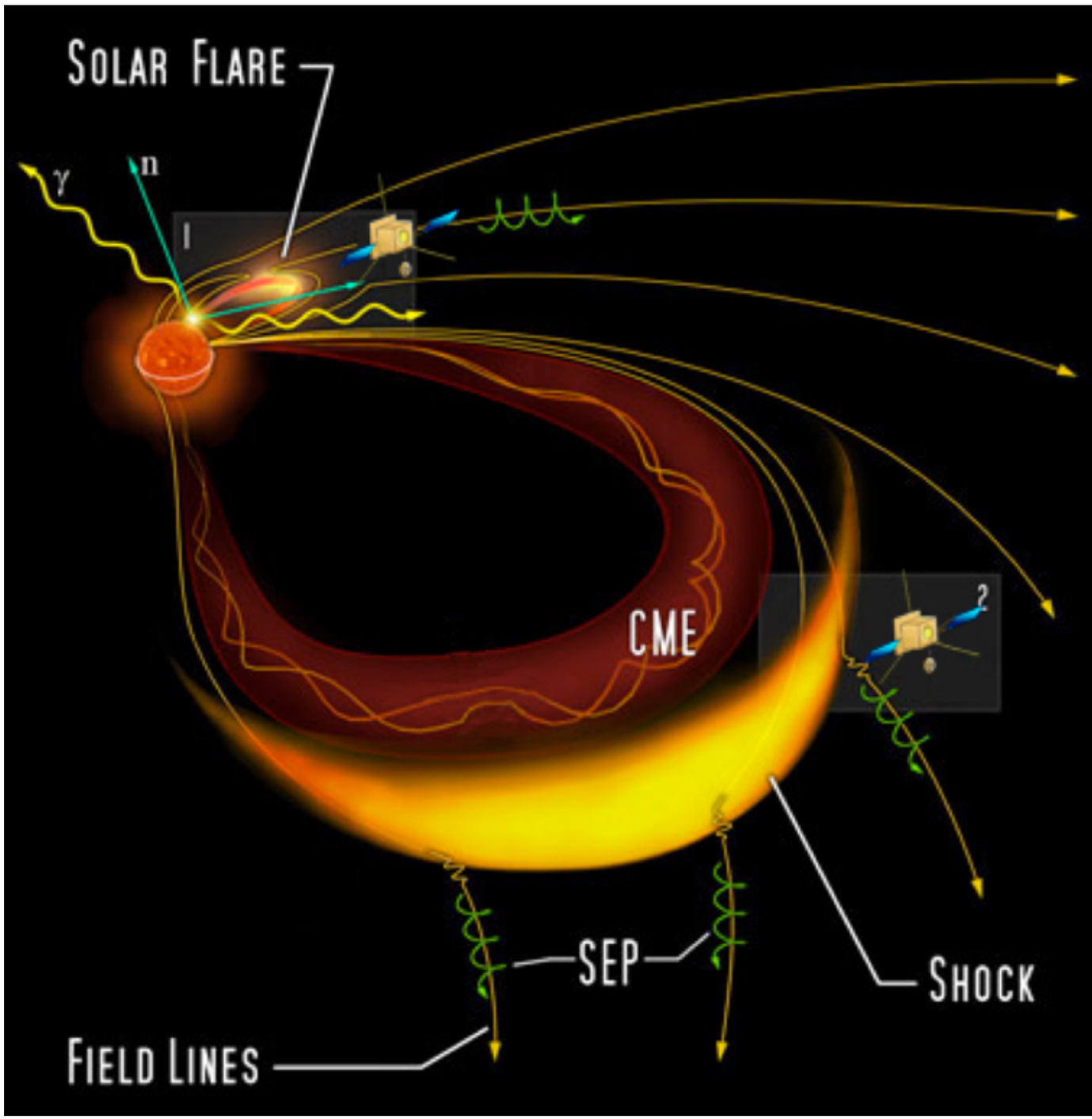


How do solar transients drive heliospheric variability?

- How do CMEs evolve through the corona and inner heliosphere?
- How do CMEs contribute to solar magnetic flux and helicity balance?
- How and where do shocks form in the corona?

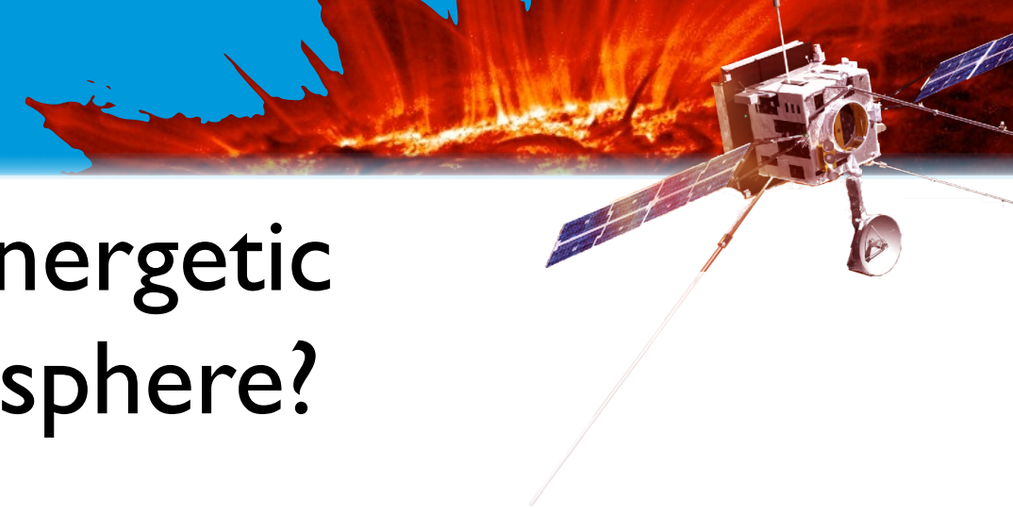


How do solar eruptions produce energetic particle radiation that fills the heliosphere?



- Relative importance of SEP acceleration due to flares and CME driven shocks cannot be determined at 1 AU due to particles mixing

- Solar Orbiter will allow tests of the relative importance of these two acceleration mechanisms



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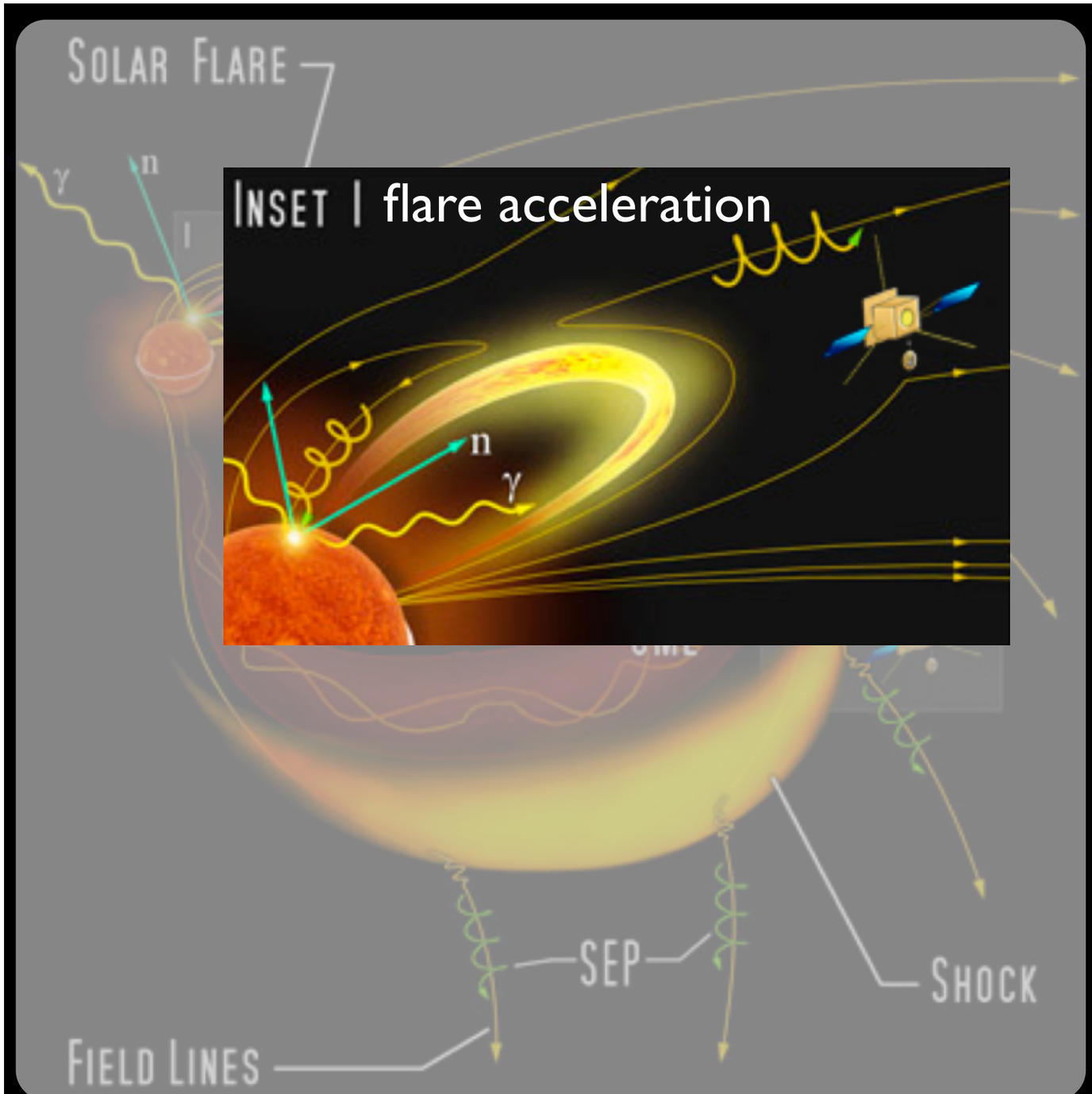

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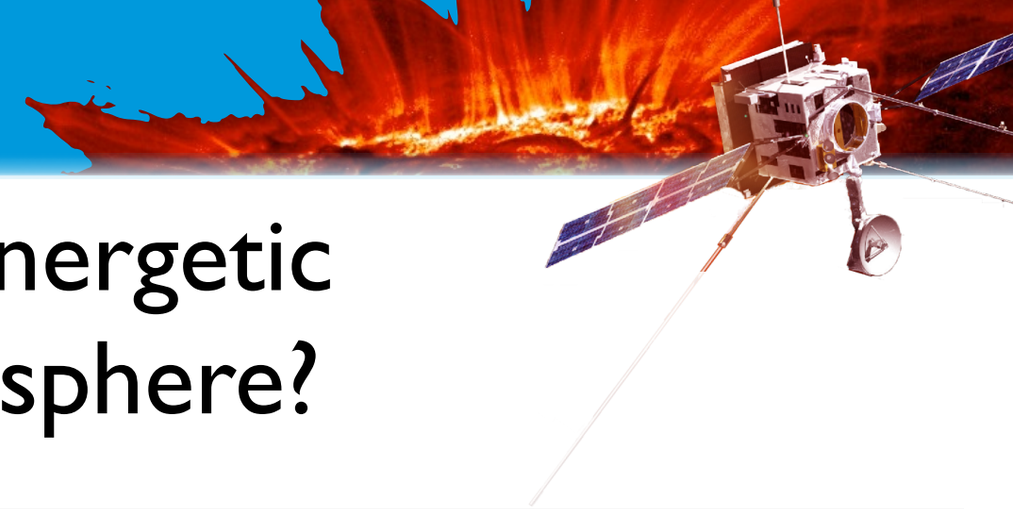

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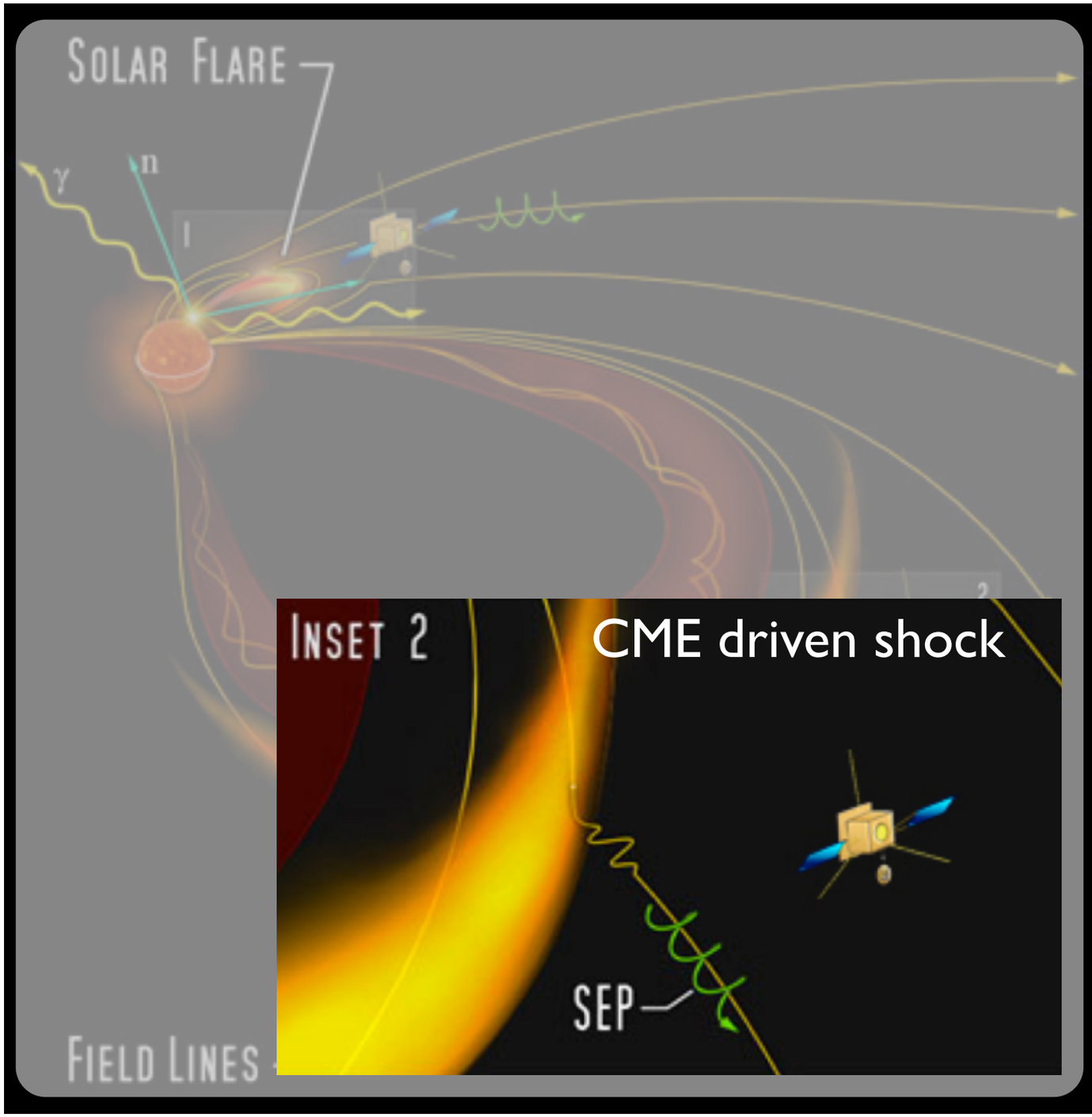

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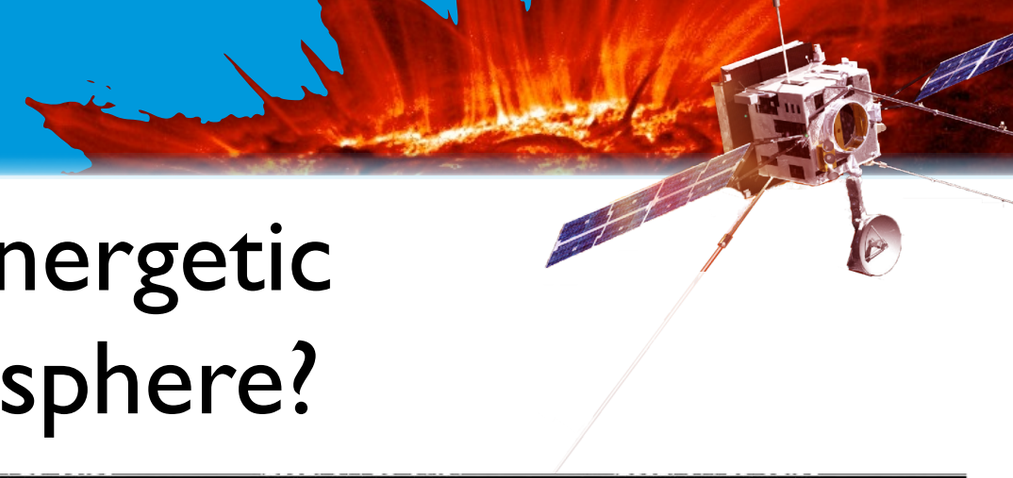

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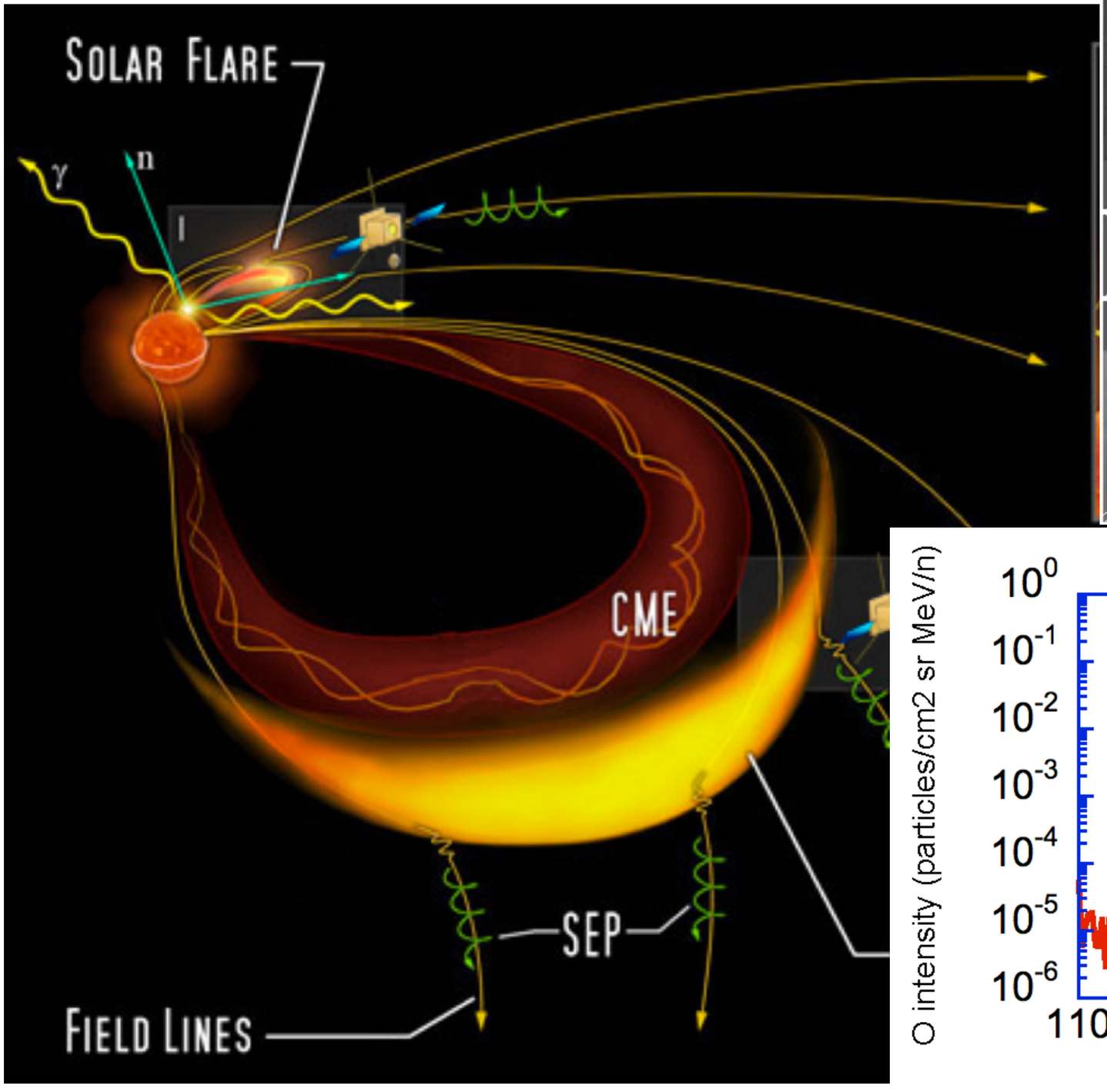
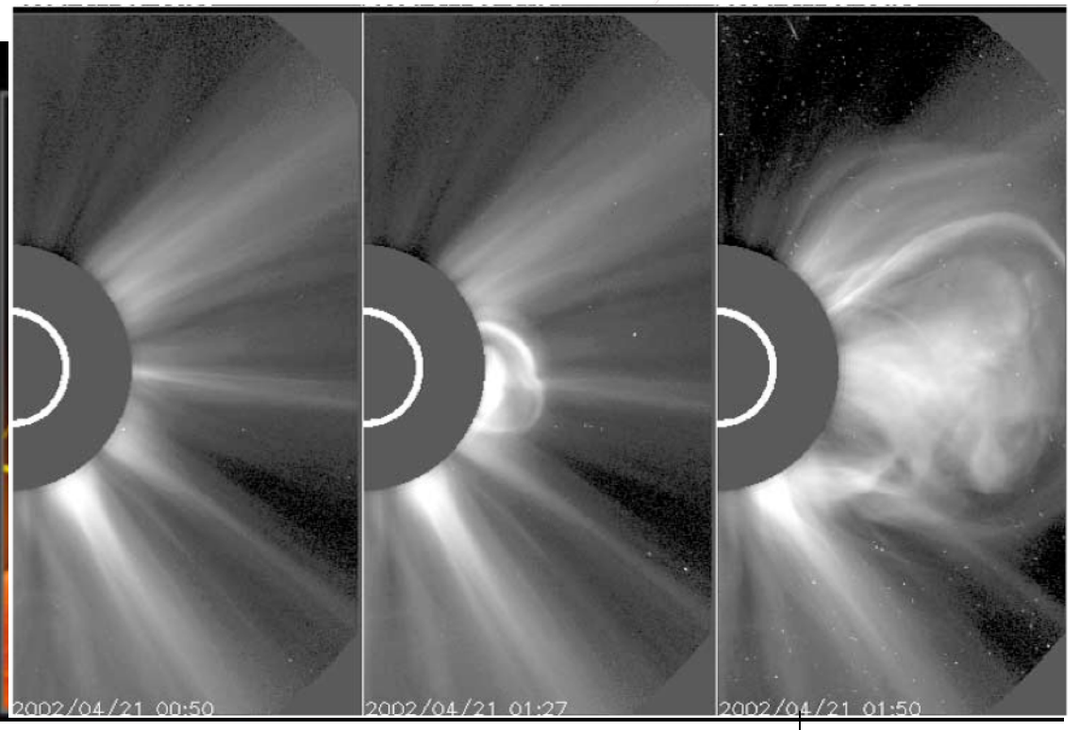
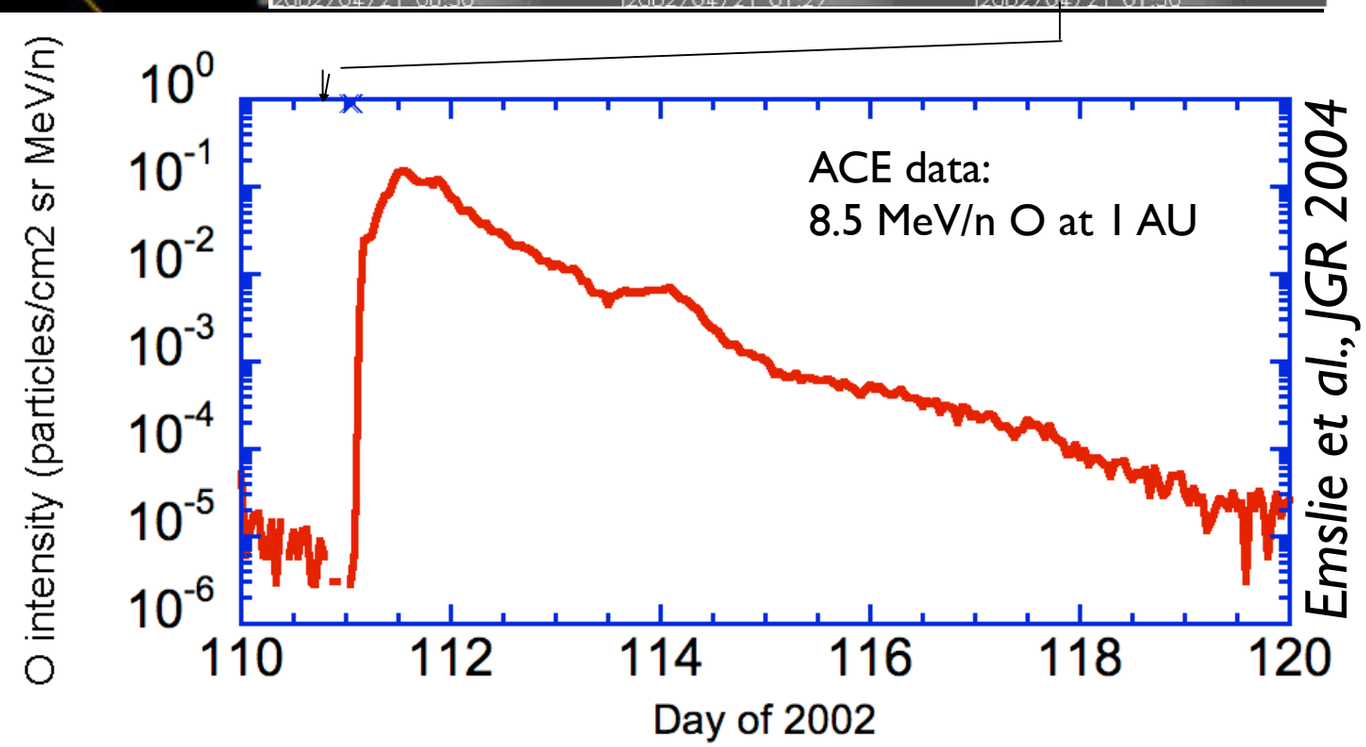
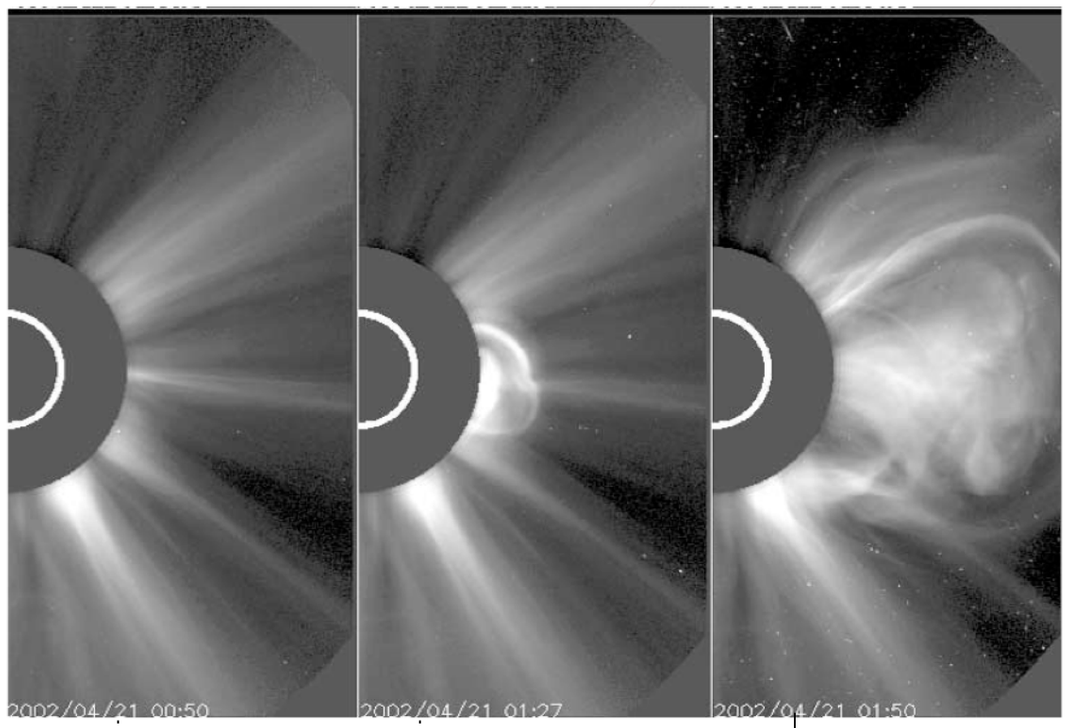




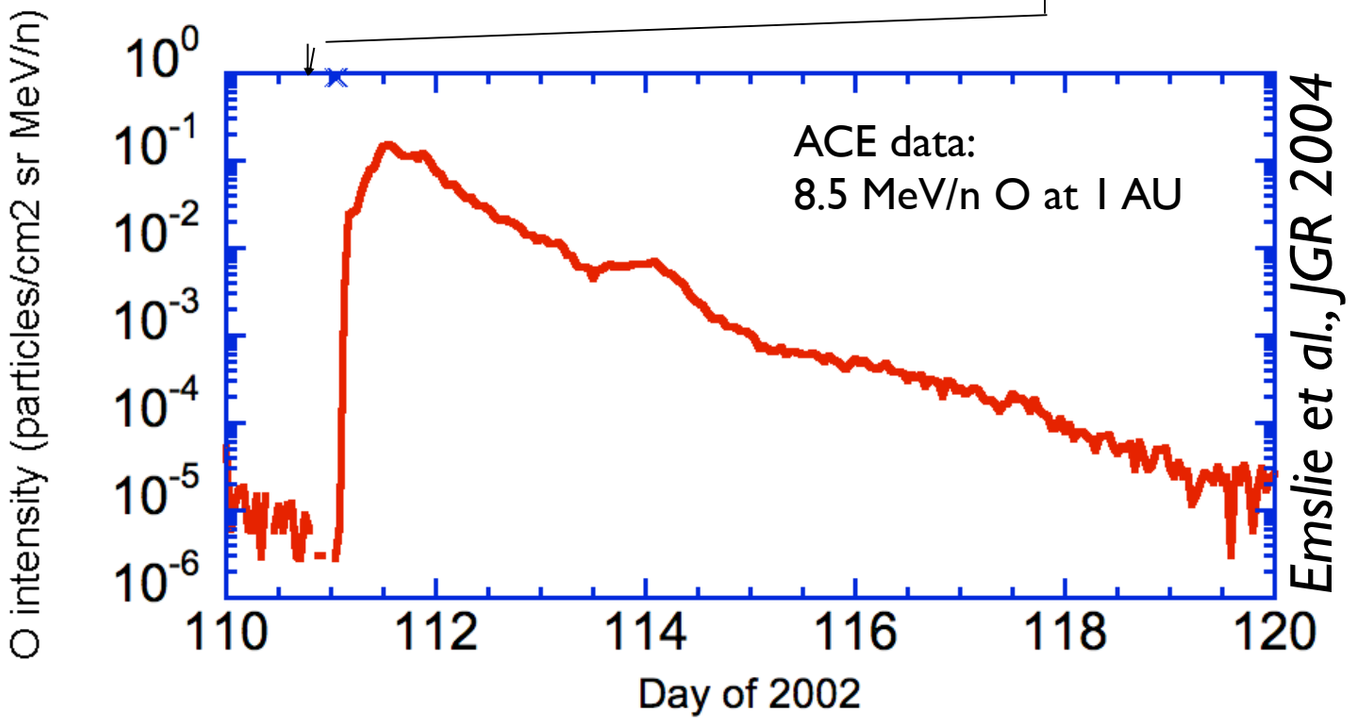


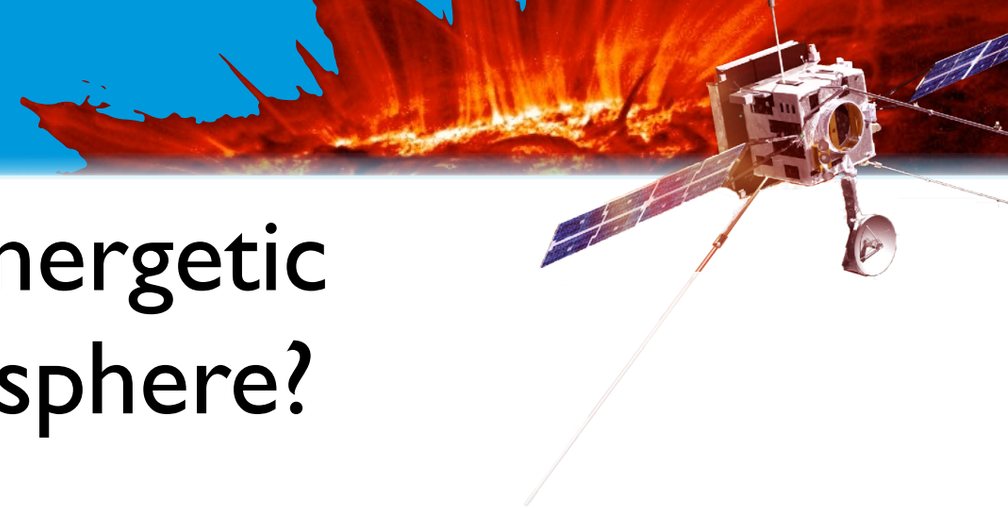
How do solar eruptions produce energetic particle radiation that fills the heliosphere?

- SOHO/LASCO observations of CME:
  - v = 2700 km/s at 18 R_{Sun}
  - CME-driven shock passes Earth 51h after CME lift-off



- ACE observations of SEPs (O nuclei):
  - Intensity increase of 5 orders of magnitude
  - Intensities remain elevated for days, long after the shock has passed Earth



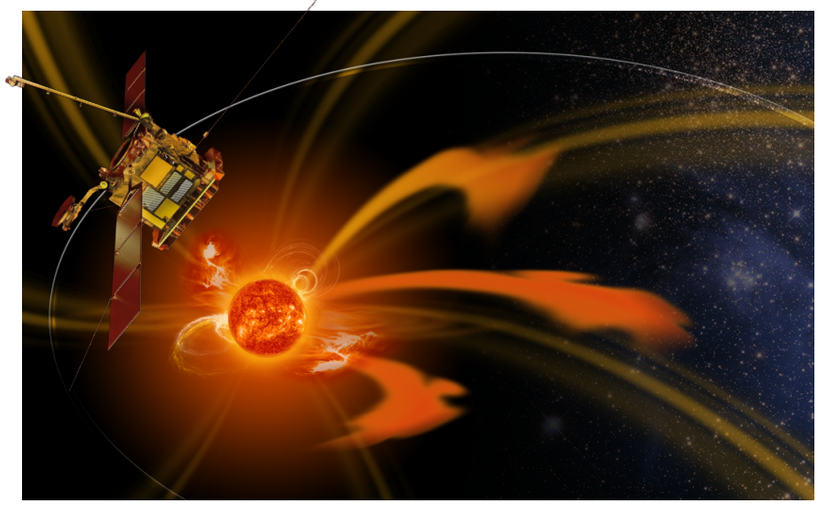


How do solar eruptions produce energetic particle radiation that fills the heliosphere?

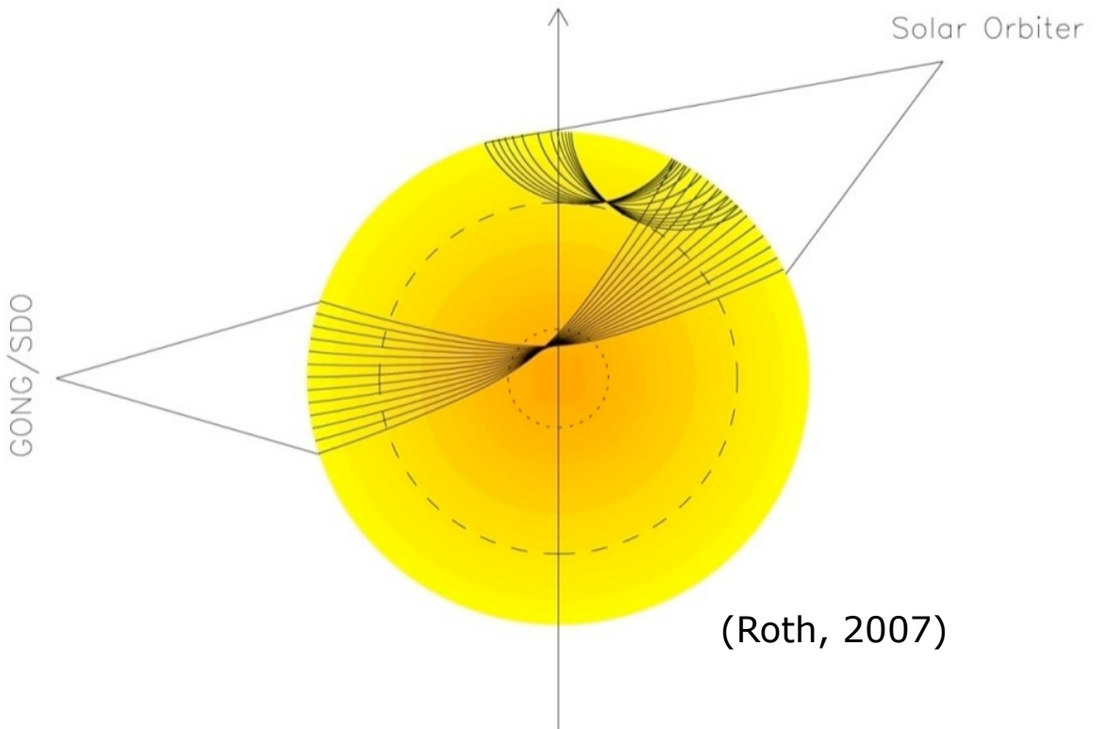
- How and where are energetic particles accelerated at the Sun?
- How are energetic particles released from their sources and distribute in space and time?
- What are the seed populations for energetic particles?

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

- **Solar Orbiter will see the Sun's far side and higher latitudes**
  - Improved combined helioseismic data (near + far sides)
    - Global helioseismology: reduced leakage effect
    - Local helioseismology: probing deeper layers
  - Large- and small-scale flow patterns at poles



- **Probing of the deep solar interior**
  - Seismic estimates for the deep meridional return flow



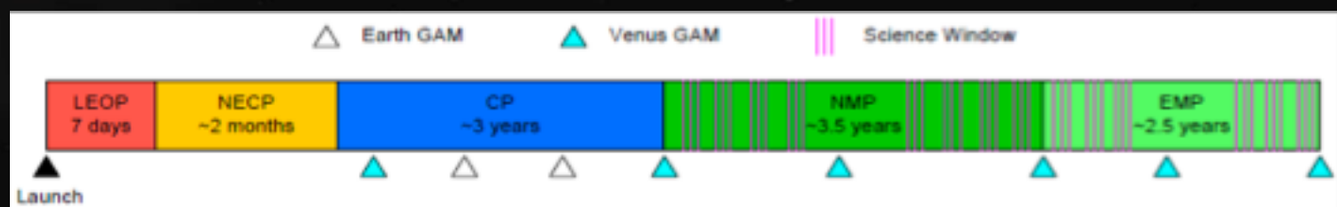
(Roth, 2007)

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

- How is magnetic flux transported and re-processed at high solar latitudes?
- What are the properties of the magnetic field at high solar latitudes?
- Are there separate dynamo processes acting in the Sun?

Science Operations & Synergies

Launch
Gravity Assist 2 Earth
Venus
Sun
Successive gravity assists increase orbit inclination
Earth
Gravity Assist 3 Earth
Gravity Assist 4 Venus
Gravity Assist 5 Venus
Gravity Assist 6 Venus
Gravity Assist 7 Venus
Gravity Assist 1 Venus



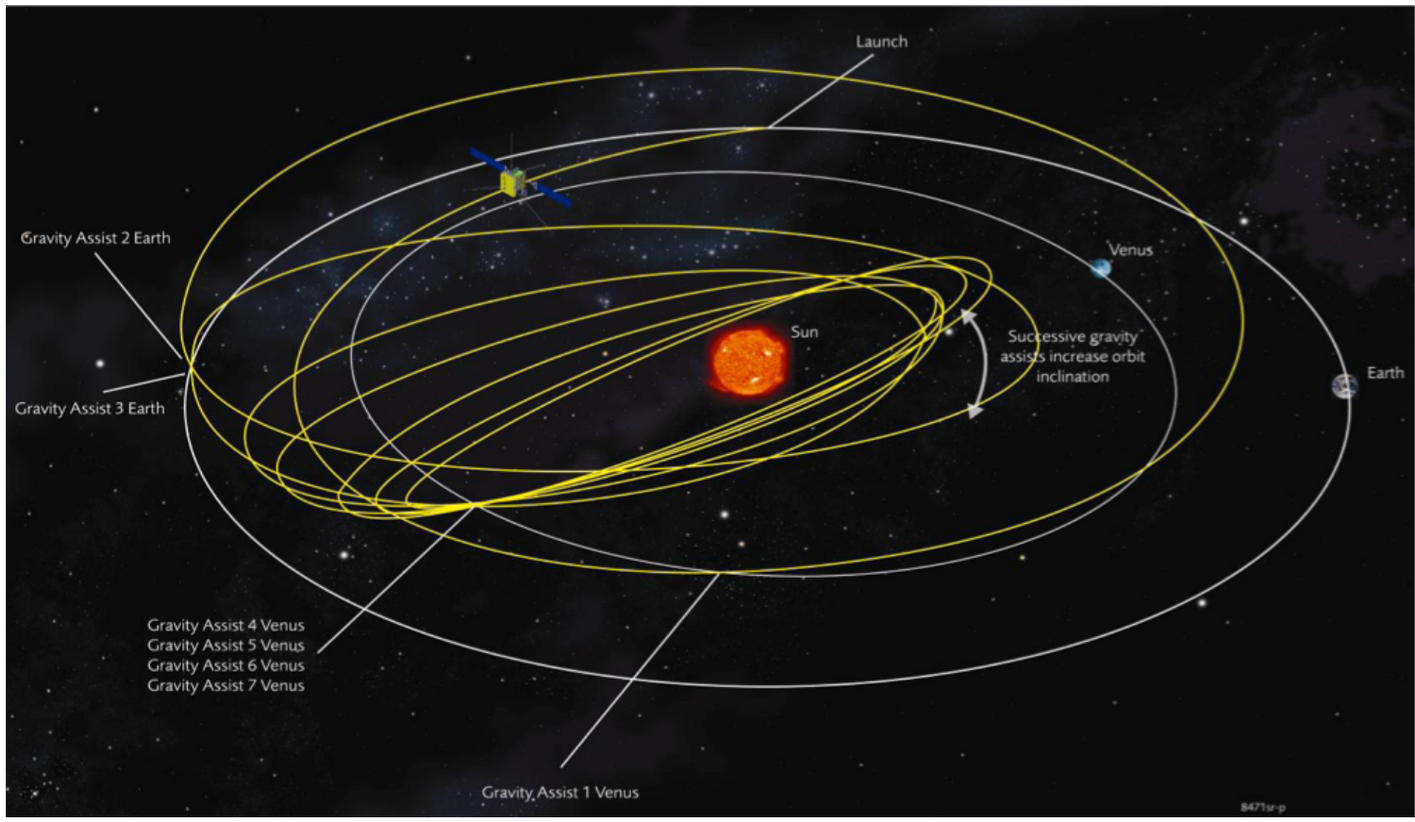
Science Operations

Science data acquisition:

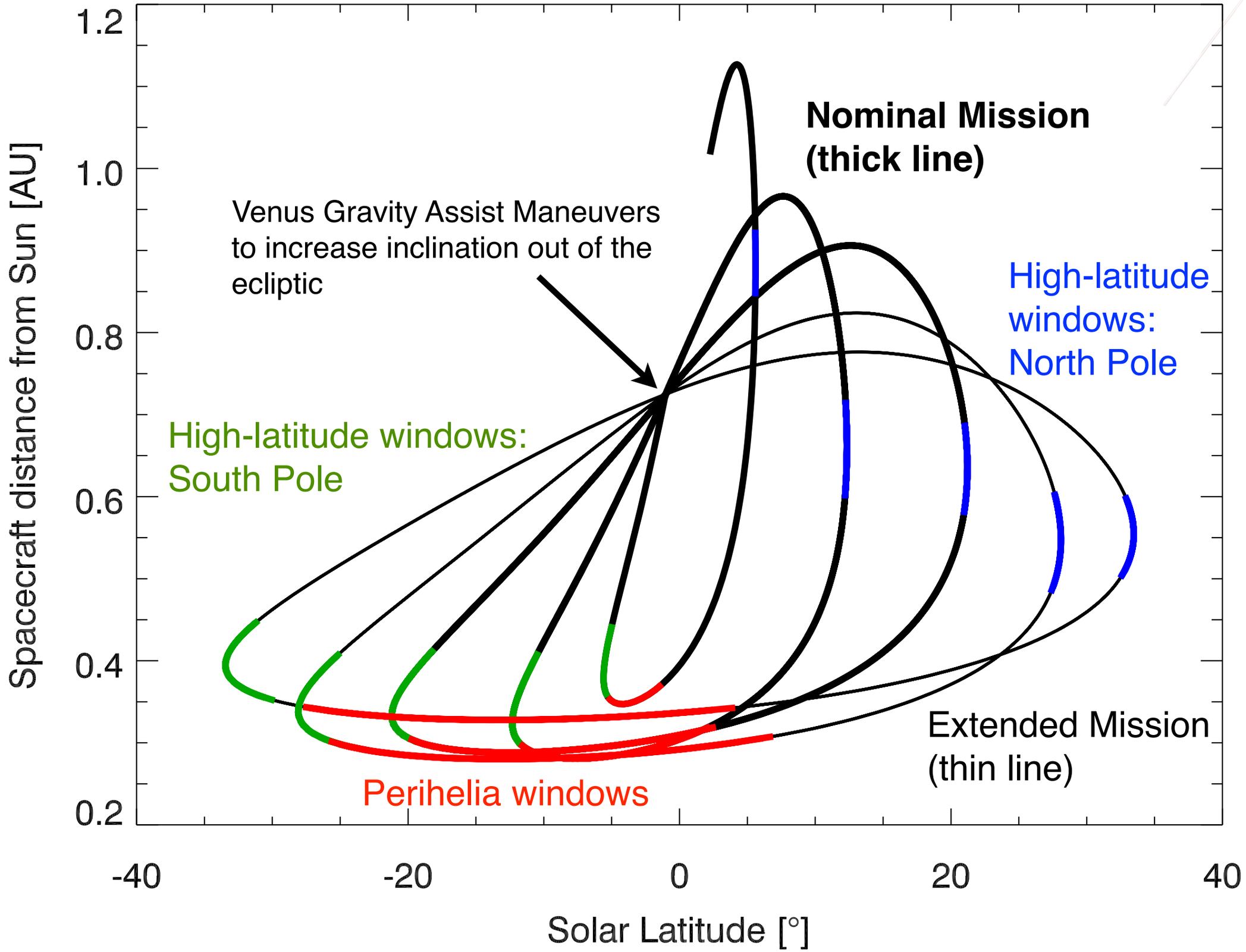
- Complete payload suite will observe during three 10-day windows per orbit, typically centered around perihelia and min./max. heliolatitude
- In-situ instruments will operate continuously, starting in cruise phase

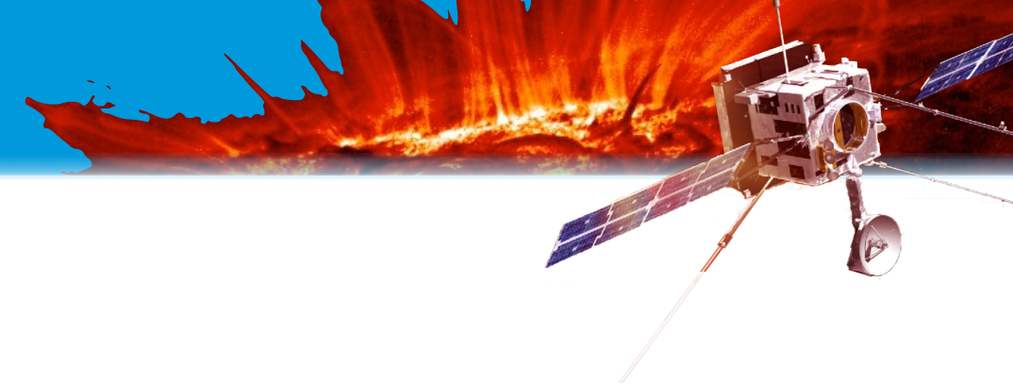
Operational Constraints:

- Limited telemetry due to orbital characteristics (baseline: 595 Gbit/ 168-day orbit)
- Variable data latency (up to 150 days) due to large variations in S/C-Earth distance
  → Need for long-term planning of top-level science operations
- Payload will be operated as a suite (all instruments co-pointed)

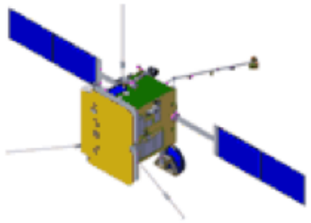


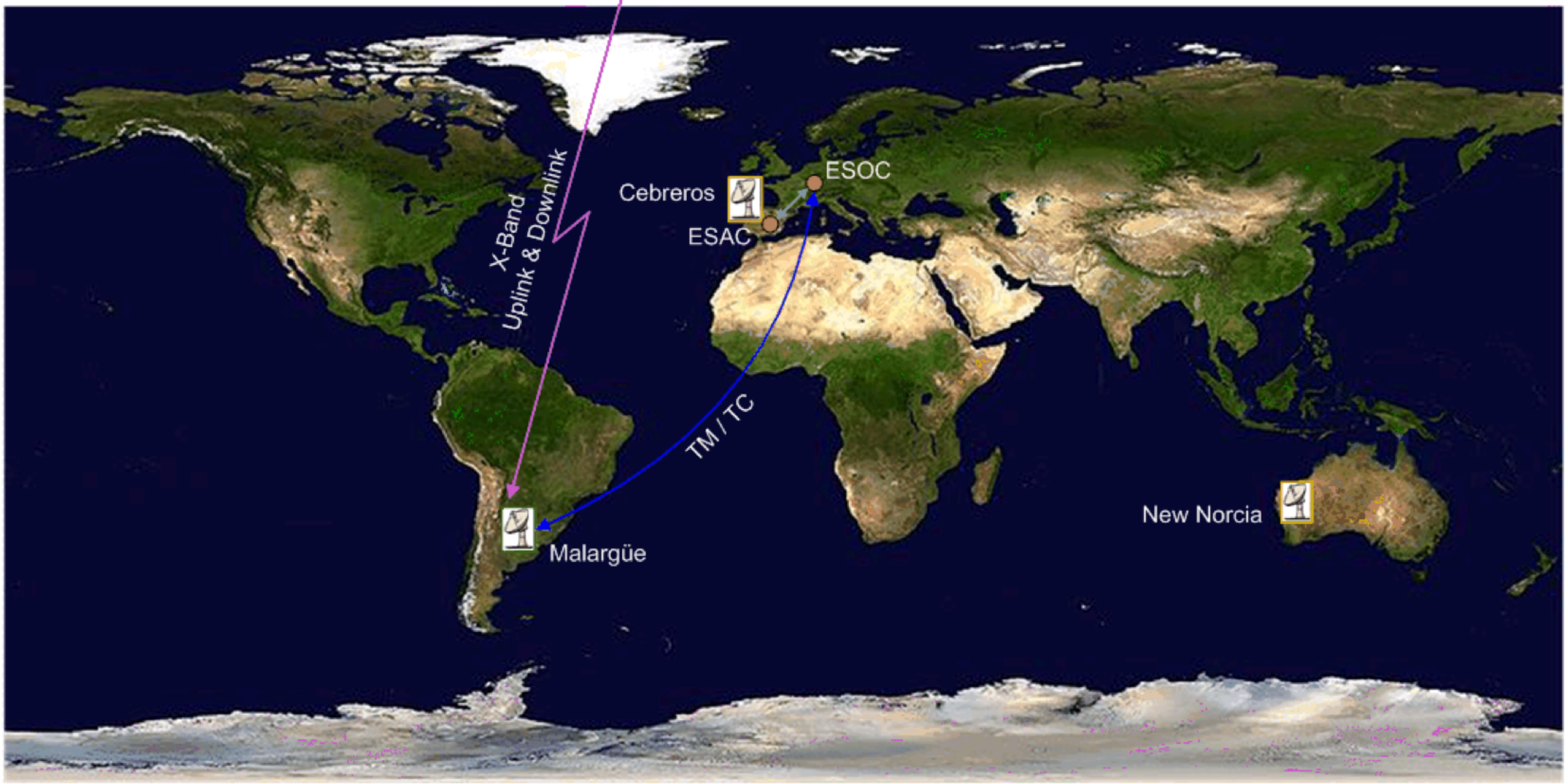
High Data Rate Observing Windows



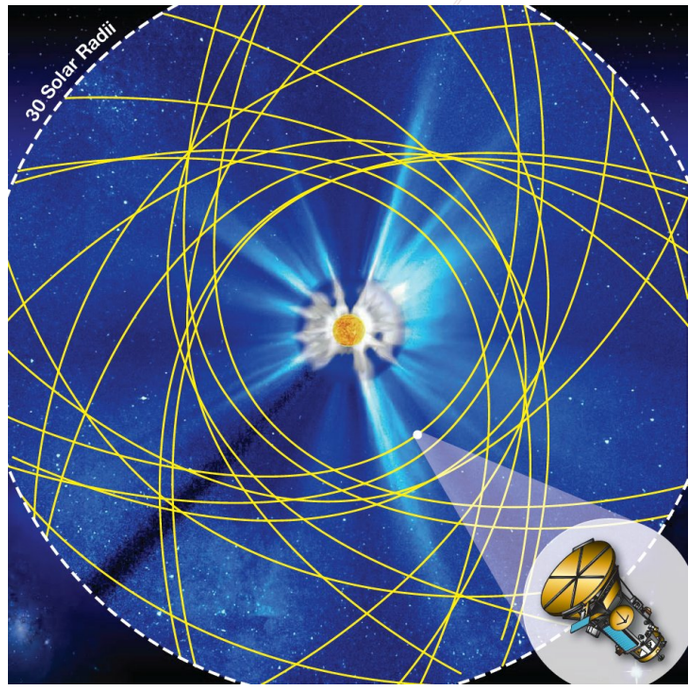


Mission Ground Segment





Synergy between Solar Orbiter and other Observatories

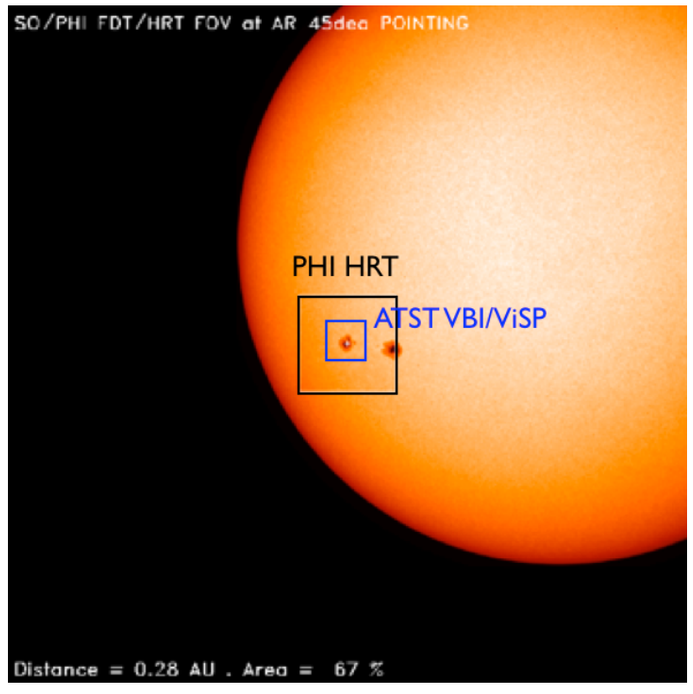


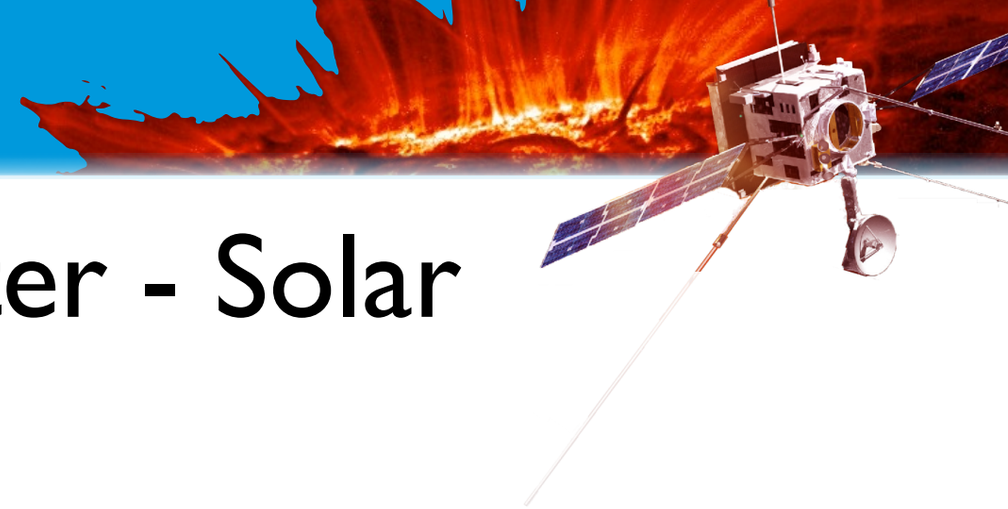
<u>Solar Orbiter:</u>
+ unique orbit (solar distance, inclination, longitude)
+ comprehensive payload suite
- limited telemetry due to orbital characteristics

<u>Solar Probe Plus:</u>
+ unique orbit (min. perihelion ≲10 R_{Sun})
- payload mass constrained by orbital characteristics, mostly in-situ instrumentation

<u>Near-Earth assets:</u>
+ much higher data return (SDO, DKIST)
- limited to Sun-Earth line

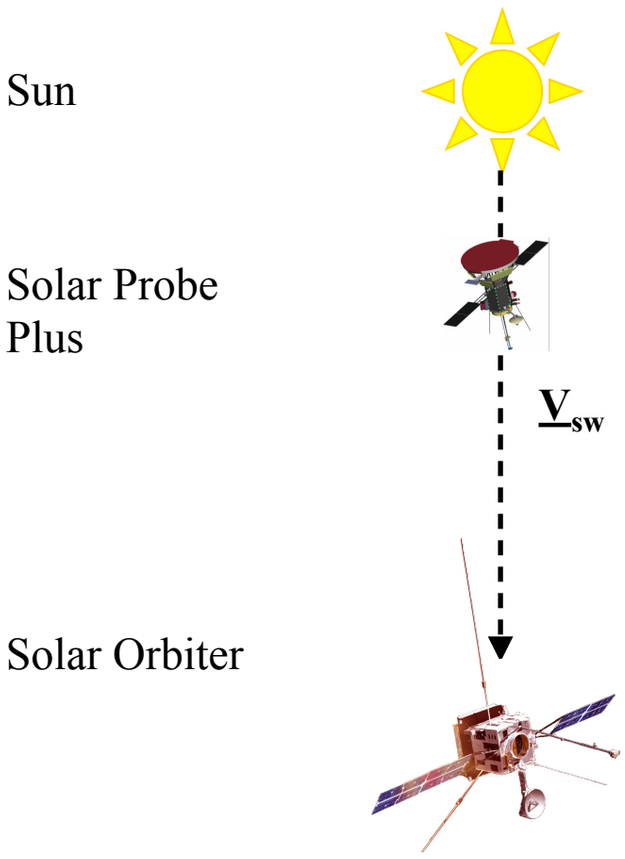
→ Depending on orbit, Solar Orbiter remote-sensing data can be complemented either by high-res/high-cadence **co-spatial** data from other observatories or data with **additional spatial coverage**, e.g. for helioseismology





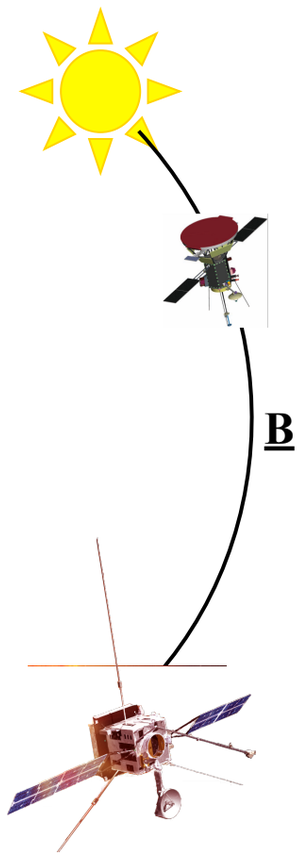
Joint Observations Solar Orbiter - Solar Probe Plus

Example of alignments/quadratures:



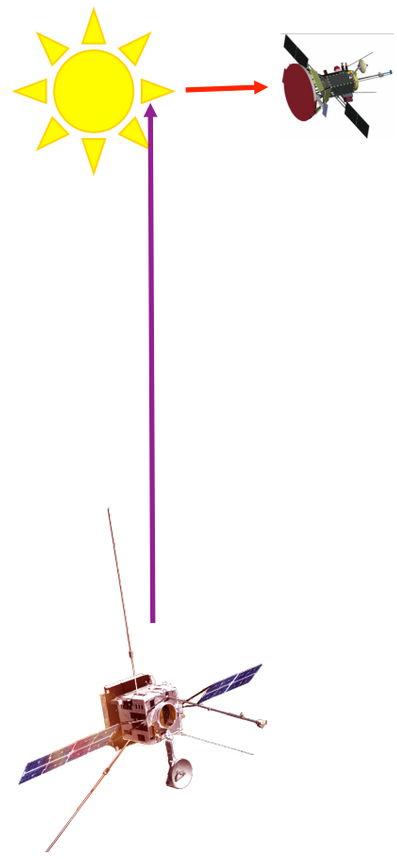
Radial alignments:

SO and SPP observe the same SW plasma



IMF alignments:

SO and SPP connect to the same IMF footpoint



Quadratures:

SO remote-sensing and SPP in-situ @ ≥9.5 Rs

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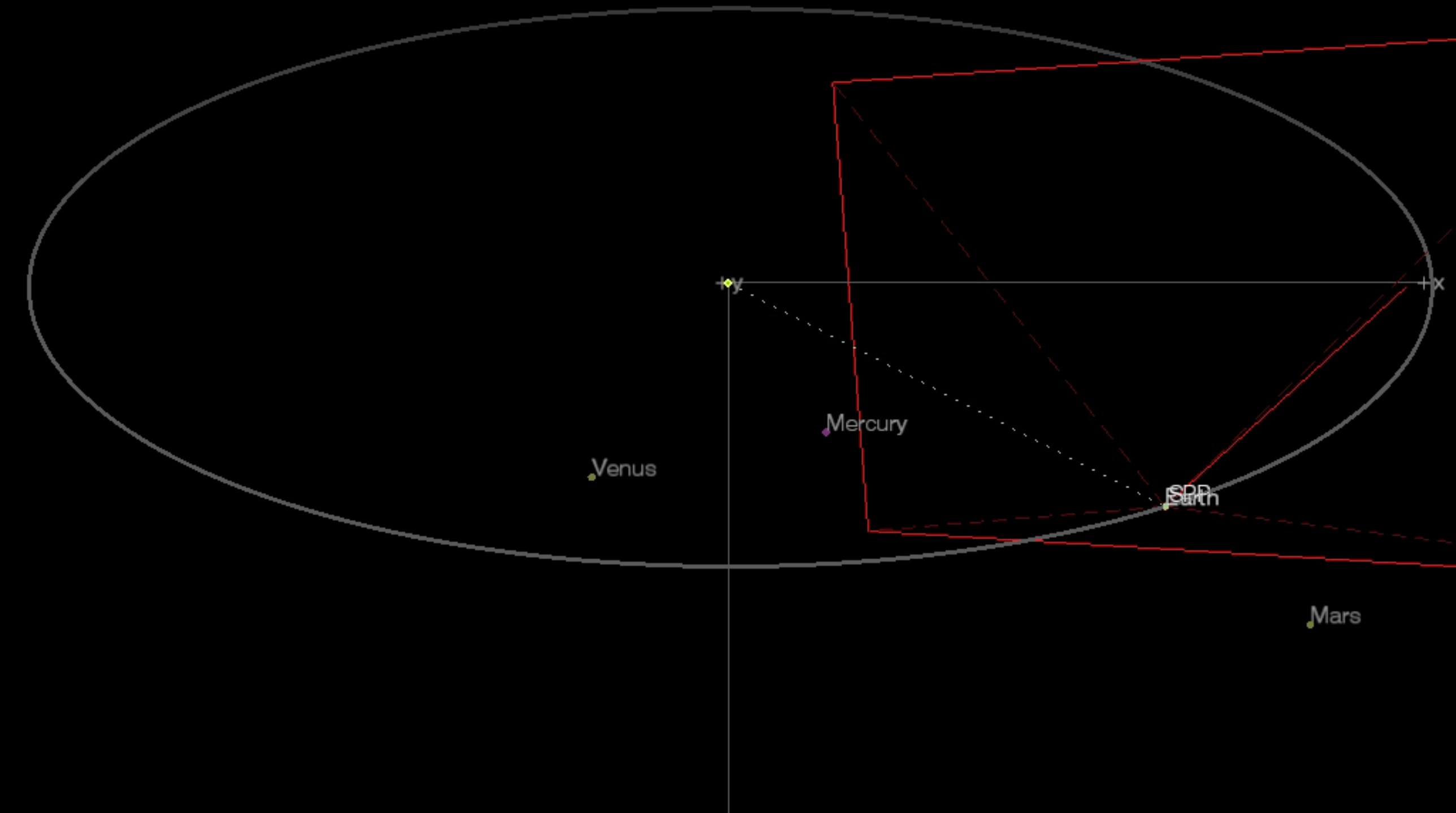


Development Status

- Payload:
  - Critical Design Reviews (CDRs) of 7 out of 10 instruments completed.

- Spacecraft:
  - Subsystem CDRs on-going
  - System-level CDR scheduled to start in Dec 2014
  - Solar Generator: dedicated review conducted for CDR input, actual solar generator CDR will take place after system-level CDR
  - Spacecraft Structural Thermal Model (STM) assembly on-going: Primary Structure STM equipped with models of propulsion and being populated with STMs of various spacecraft units.
  - Heat Shield STM successfully passed 10 solar constants flux test in ESTEC's Large Space Simulator

- Ground Segment:
  - Requirements Reviews successfully completed.
  - Design Review of Science Ground Segment in Sep/Oct 2014.

- NASA awarded launch vehicle contract (Atlas V 411) in Mar 2014

Solar Orbiter
Exploring the Sun-Heliosphere Connection

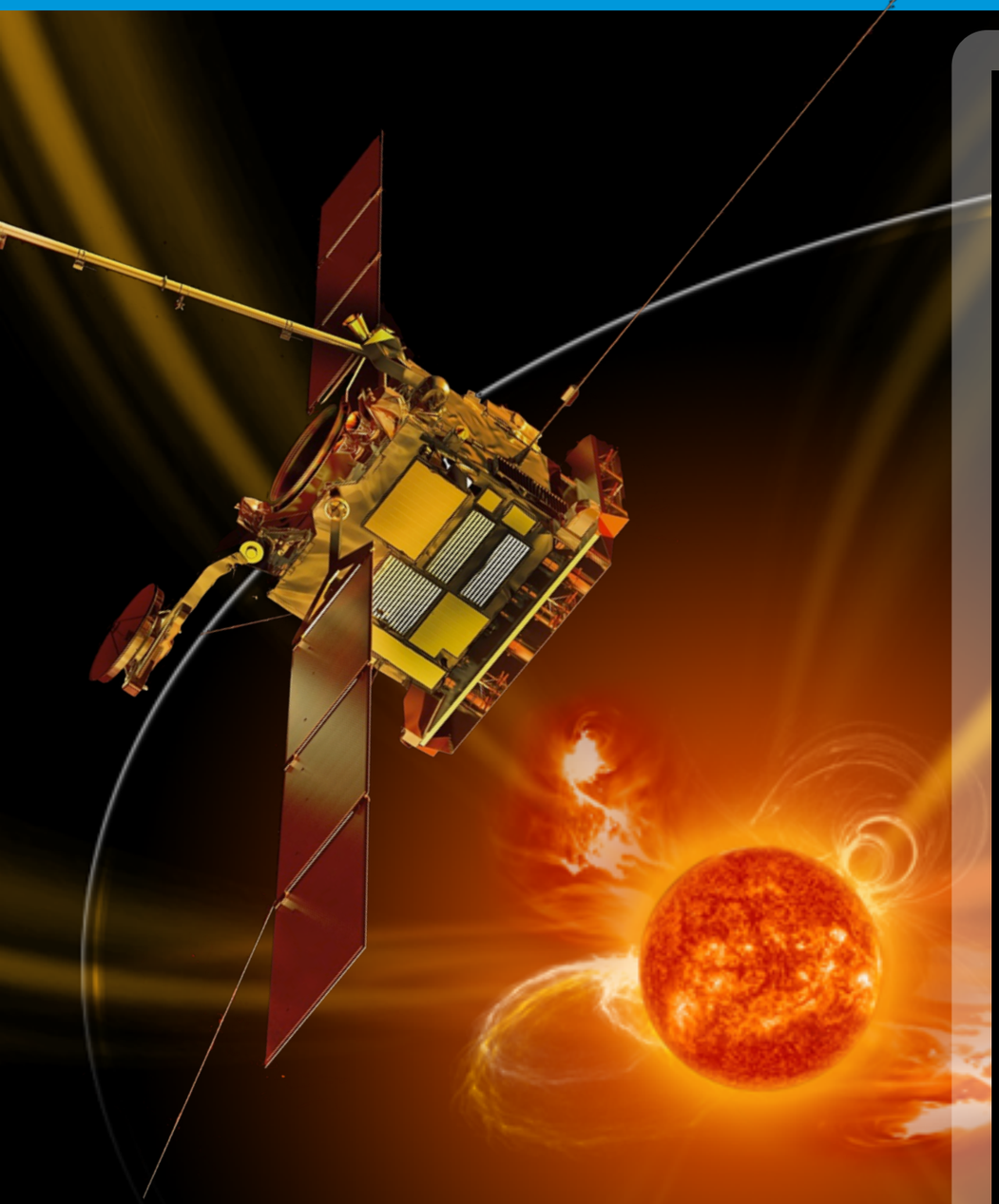
Summary

- Solar Orbiter will address the central question of heliophysics: How does the Sun create and control the heliosphere?

- Solar Orbiter will make
  - In-situ measurements of the solar wind plasma, fields, waves and energetic particles as close as 0.28 AU from the Sun
  - Simultaneously high-resolution imaging and spectroscopic observations of the Sun in and out of the ecliptic plane (up to 34°).
- The combination of in-situ and remote-sensing instruments, together with the new, inner-heliospheric perspective, distinguishes Solar Orbiter from all previous and current missions, enabling new science which can be achieved in no other way.
- Solar Orbiter has unique synergies with SPP, DKIST and other new observatories

Solar Orbiter STM at Airbus D&S facilities, Stevenage, UK

Solar Orbiter
Exploring the Sun-Heliosphere Connection



www.solarorbiter.org