Solar Orbiter

Exploring the Sun-Heliosphere Connection

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and the Solar Orbiter Science Working Team

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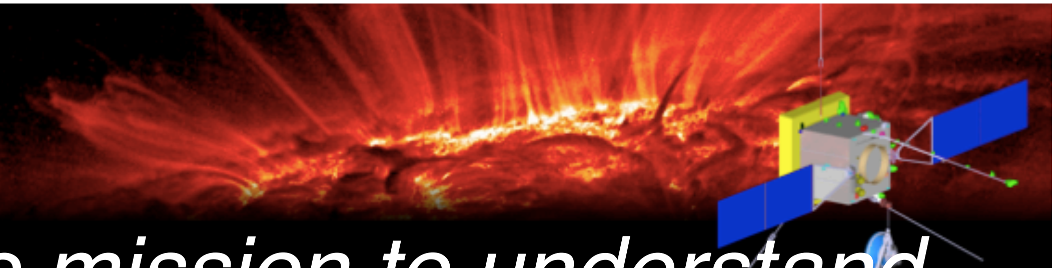
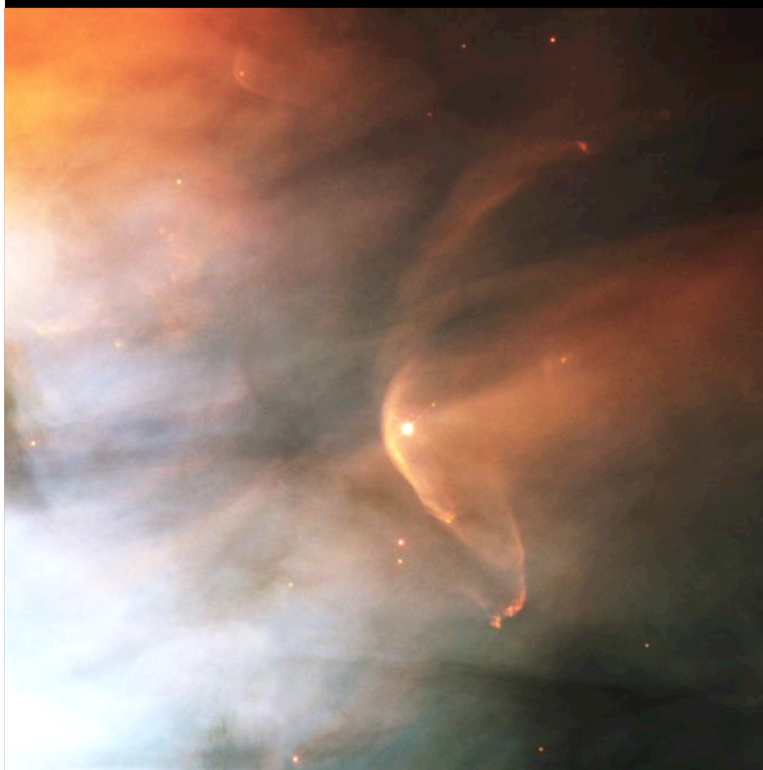
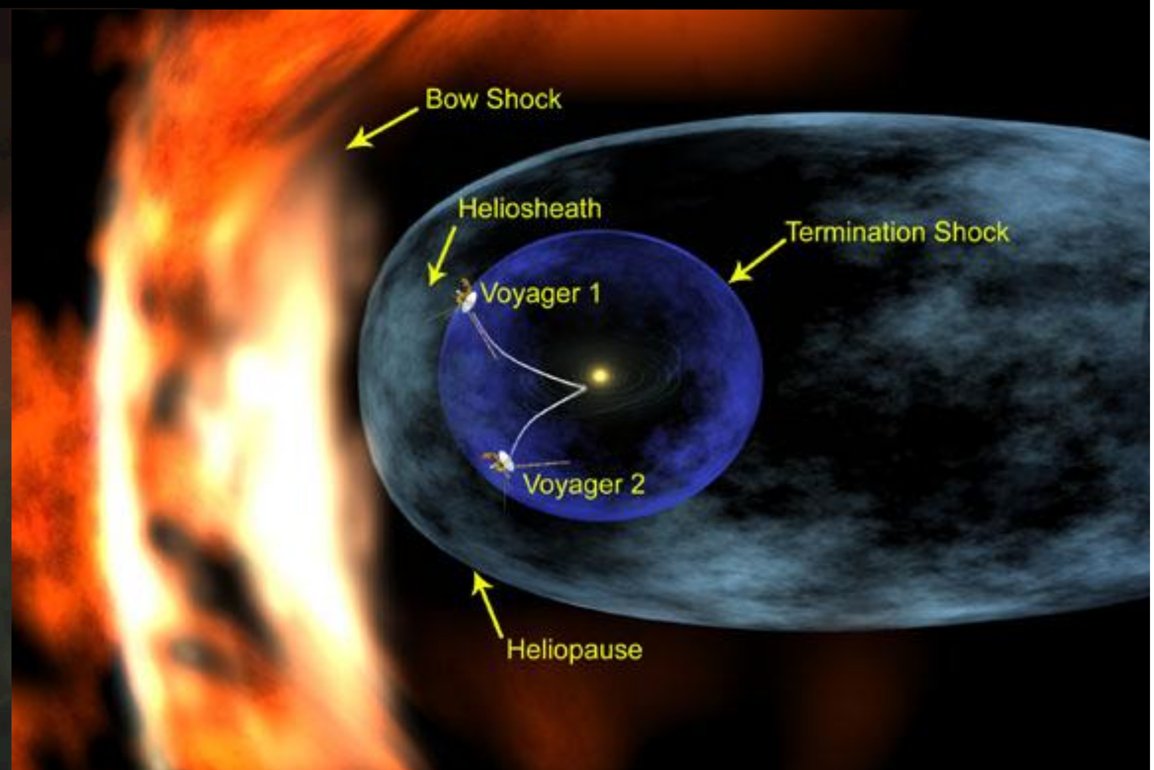


Solar Orbiter – The mission to understand how the Sun creates and controls the Heliosphere





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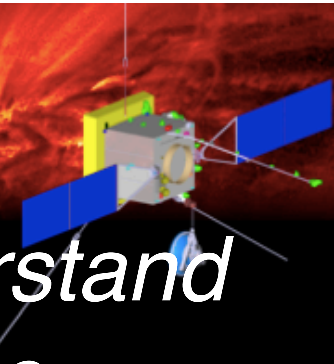

Solar Orbiter – The mission to understand how the Sun creates and controls the Heliosphere

- *Science Objectives*
- *Mission design and payload*
- *Supporting Observations*

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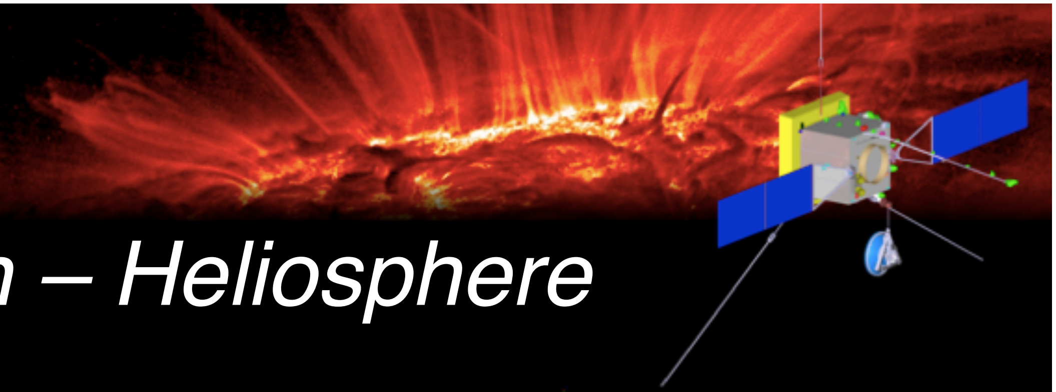

Why study the Sun – Heliosphere connection?

To answer ***How does the solar system work?*** ESA's Cosmic Vision Q2.

Sun's magnetized atmosphere and wind ***define planetary space environments*** (CV Q1)

It is the site of universal phenomena which can be studied and understood in detail (CV Q3): ***magnetic reconnection, collisionless shocks, turbulence and collective nonlinear effects and energetic particle acceleration***

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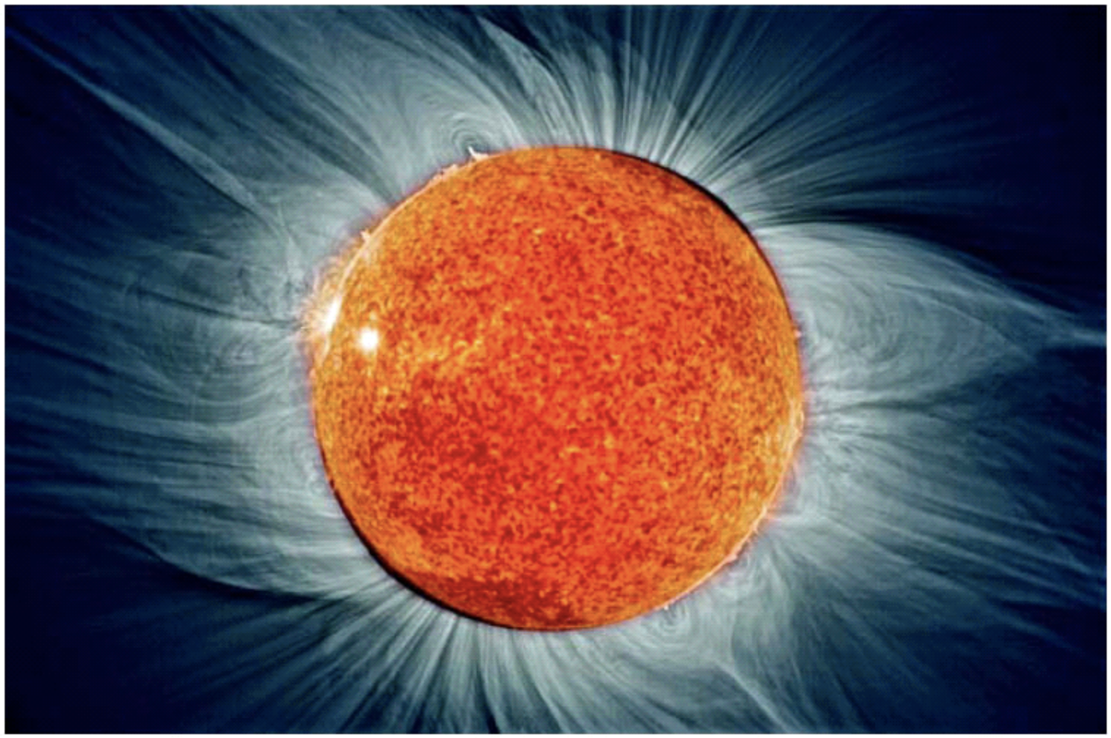
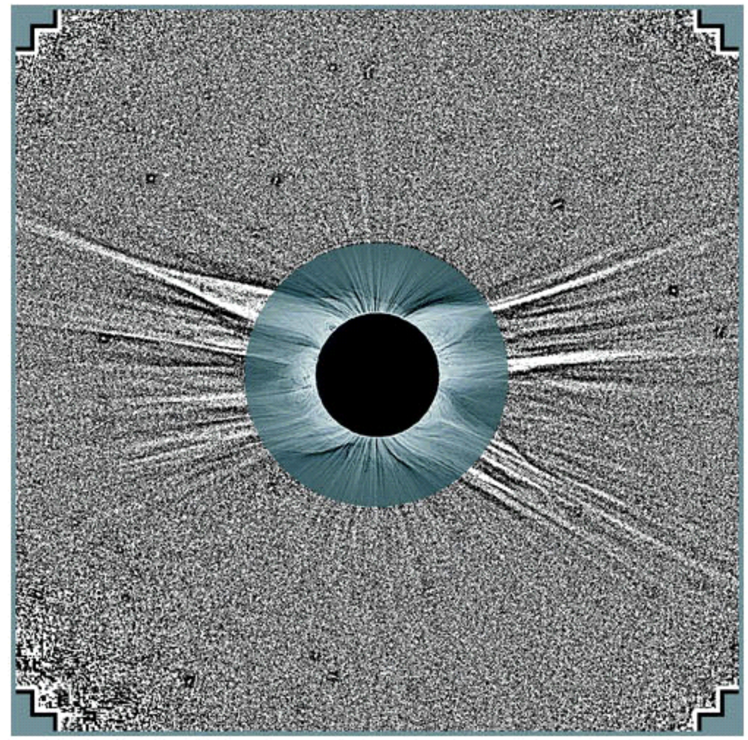
Solar corona, wind and magnetic activity





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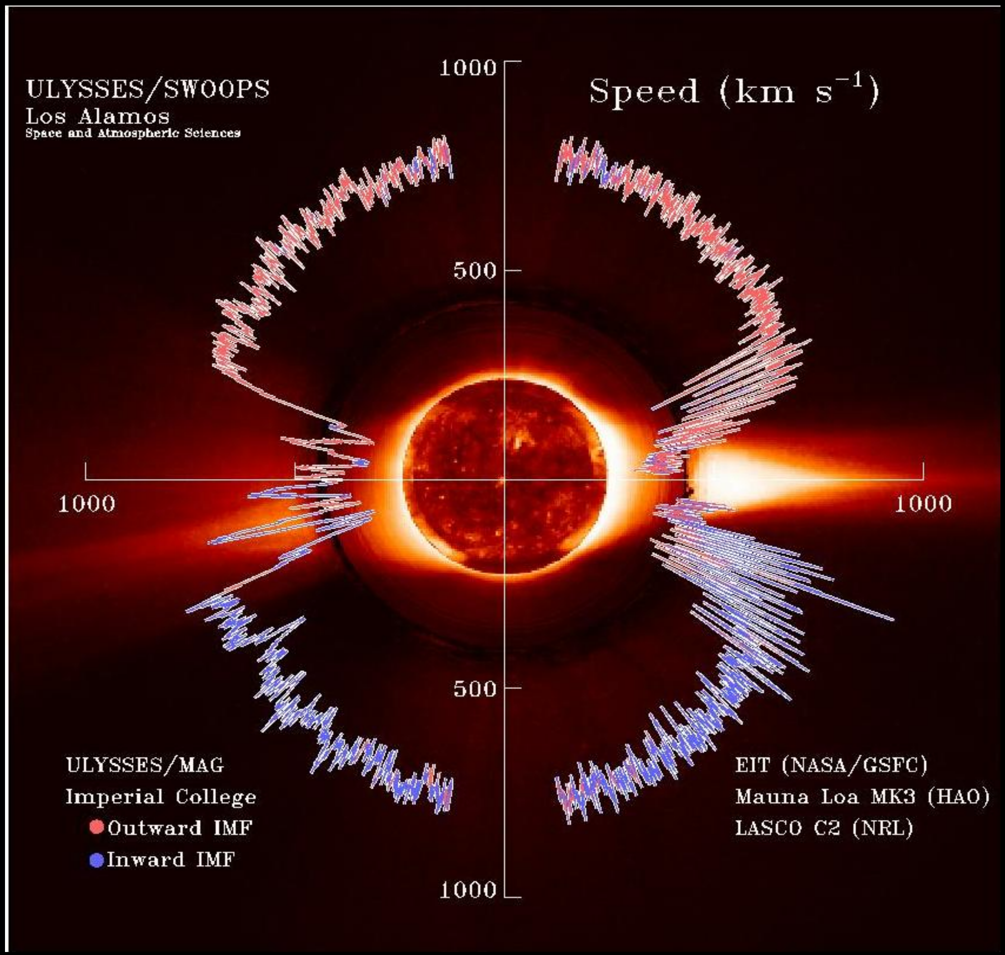
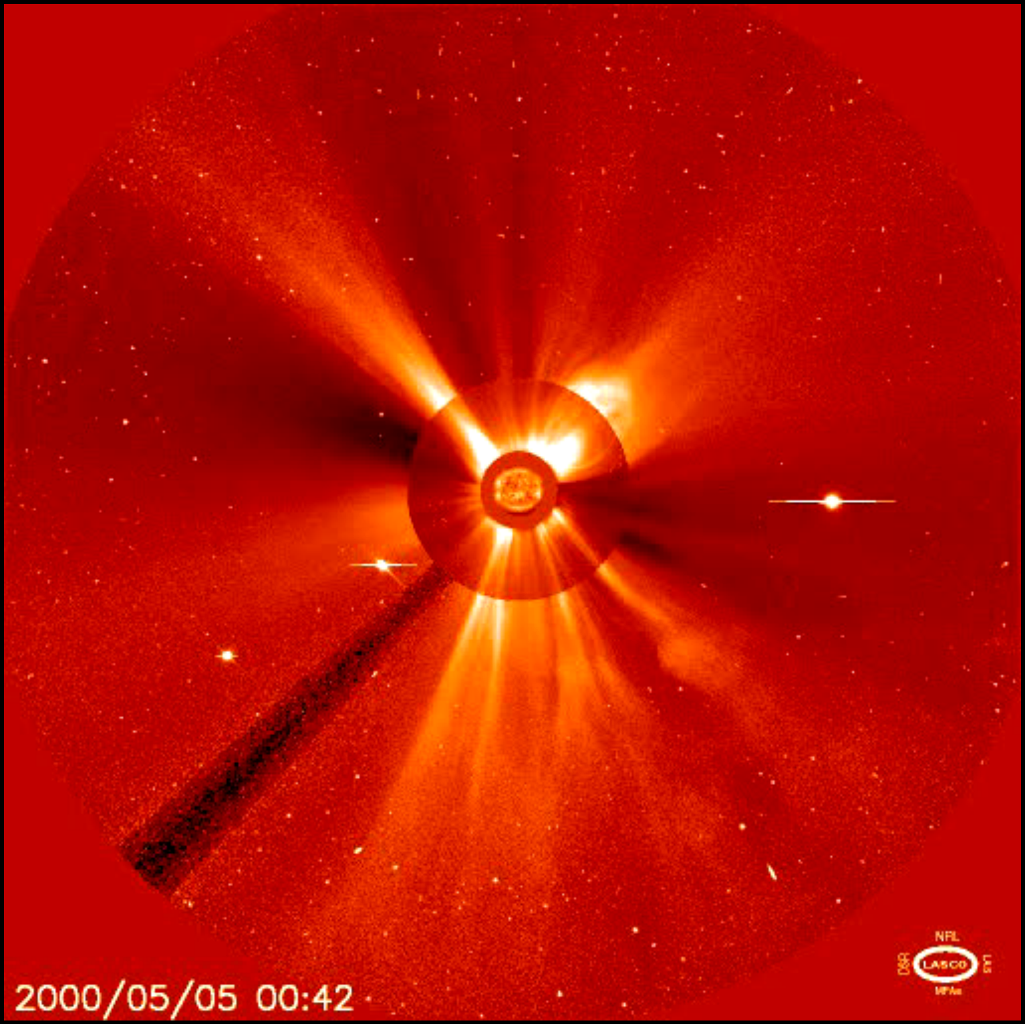


Solar corona, wind and magnetic activity



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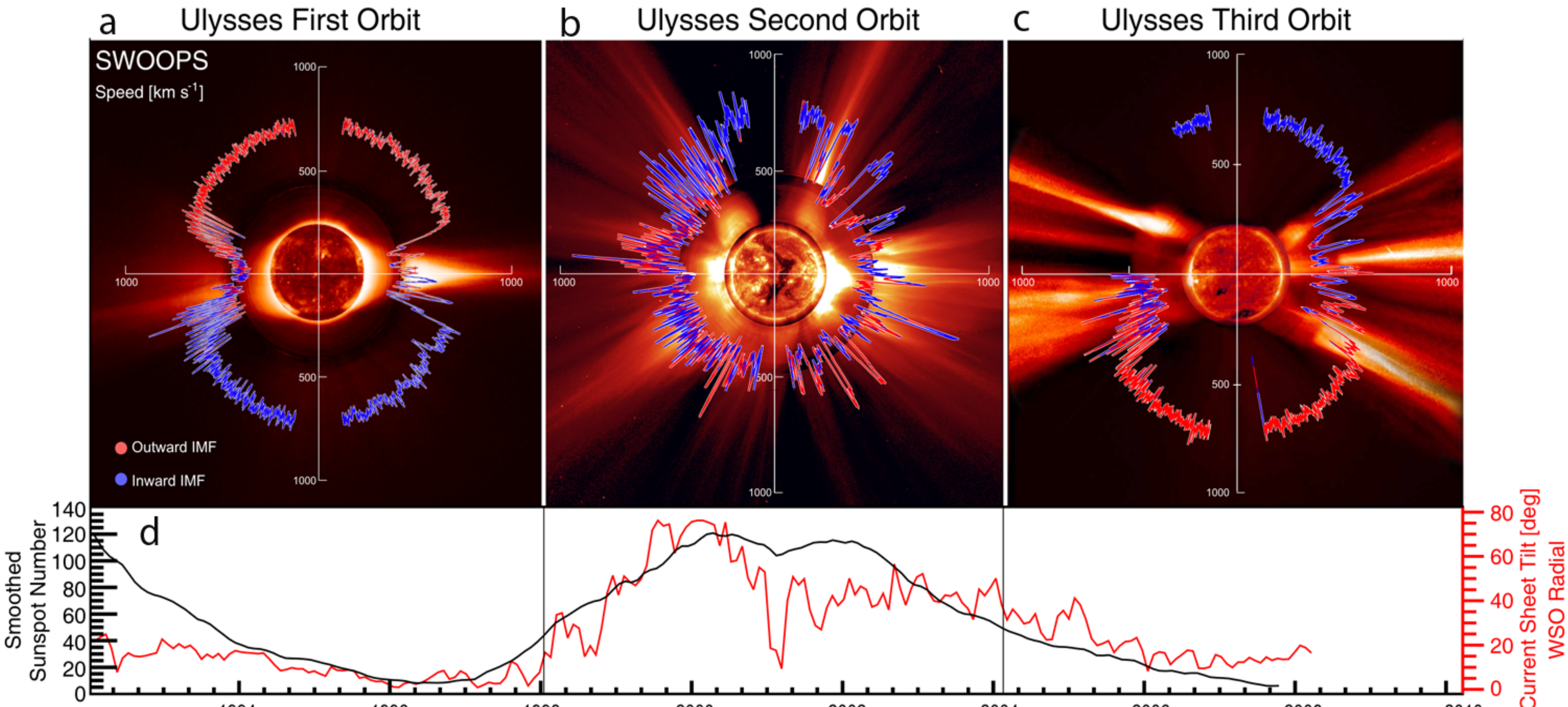
How does the Sun’s magnetic field control the heliosphere and why does magnetic activity change with time ?



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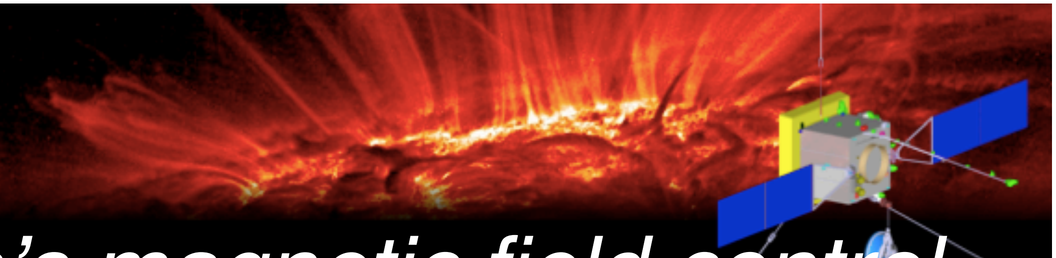

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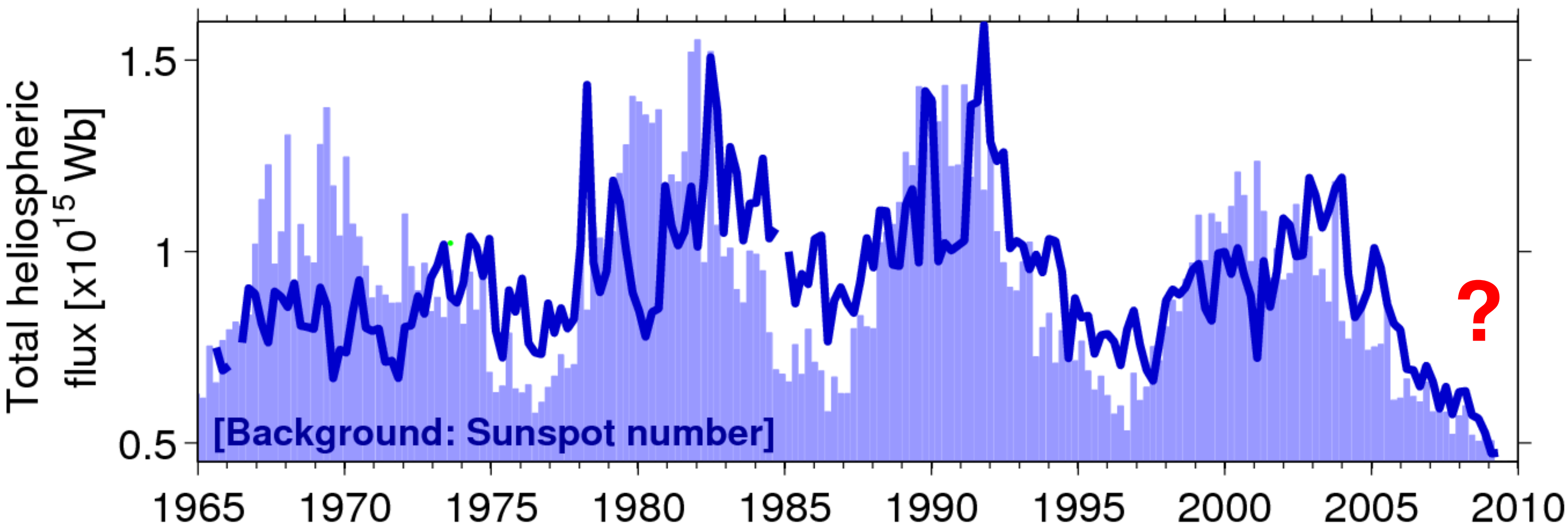

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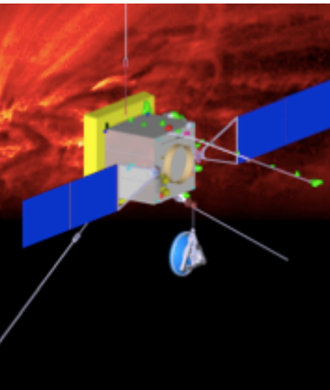

Solar Orbiter Mission

- Solar Orbiter is the logical and timely next step after Ulysses and SOHO, combining remote sensing and in-situ experiments.

- Solar Orbiter carries a dedicated payload of **10 selected remote-sensing and in-situ instruments** measuring from the photosphere into the solar wind.

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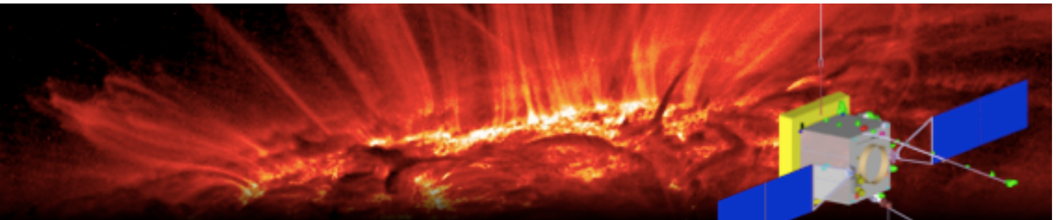

How does the Sun create and control the Heliosphere ?

Q1) How and where do the solar wind plasma and magnetic field originate in the corona?

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?

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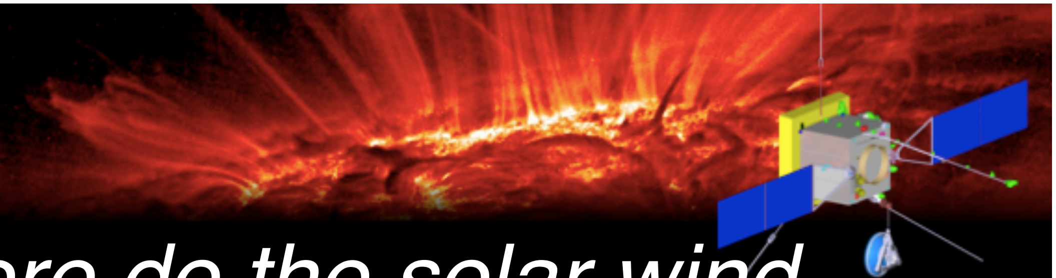


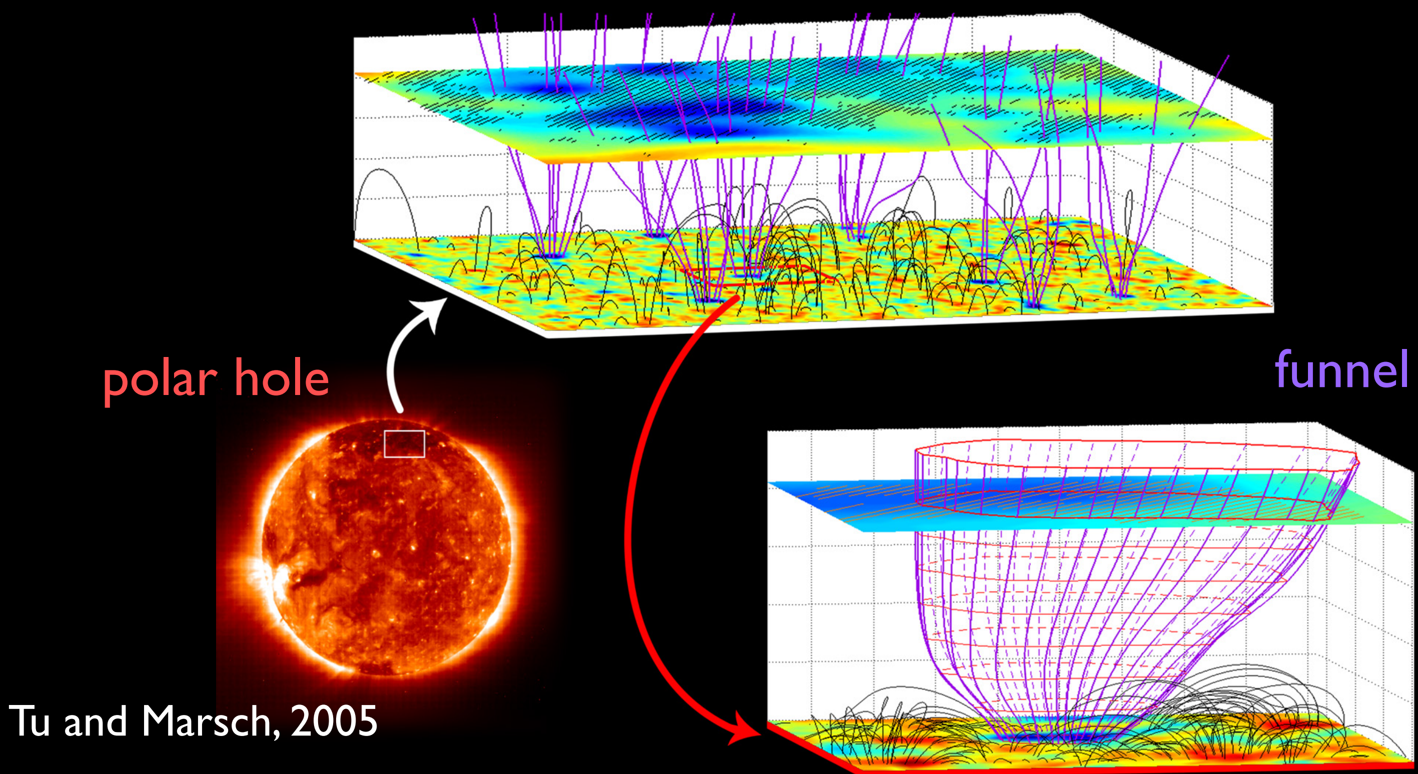
Q1) How and where do the solar wind plasma and magnetic field originate in the corona?

1.1) What are the source regions of the solar wind and the heliospheric magnetic field?

1.2) What mechanisms heat and accelerate the solar wind?

1.3) What are the sources of turbulence in the solar wind and how does it evolve?

1.1) What are the source regions of the solar wind and the heliospheric magnetic field?



Fast solar wind

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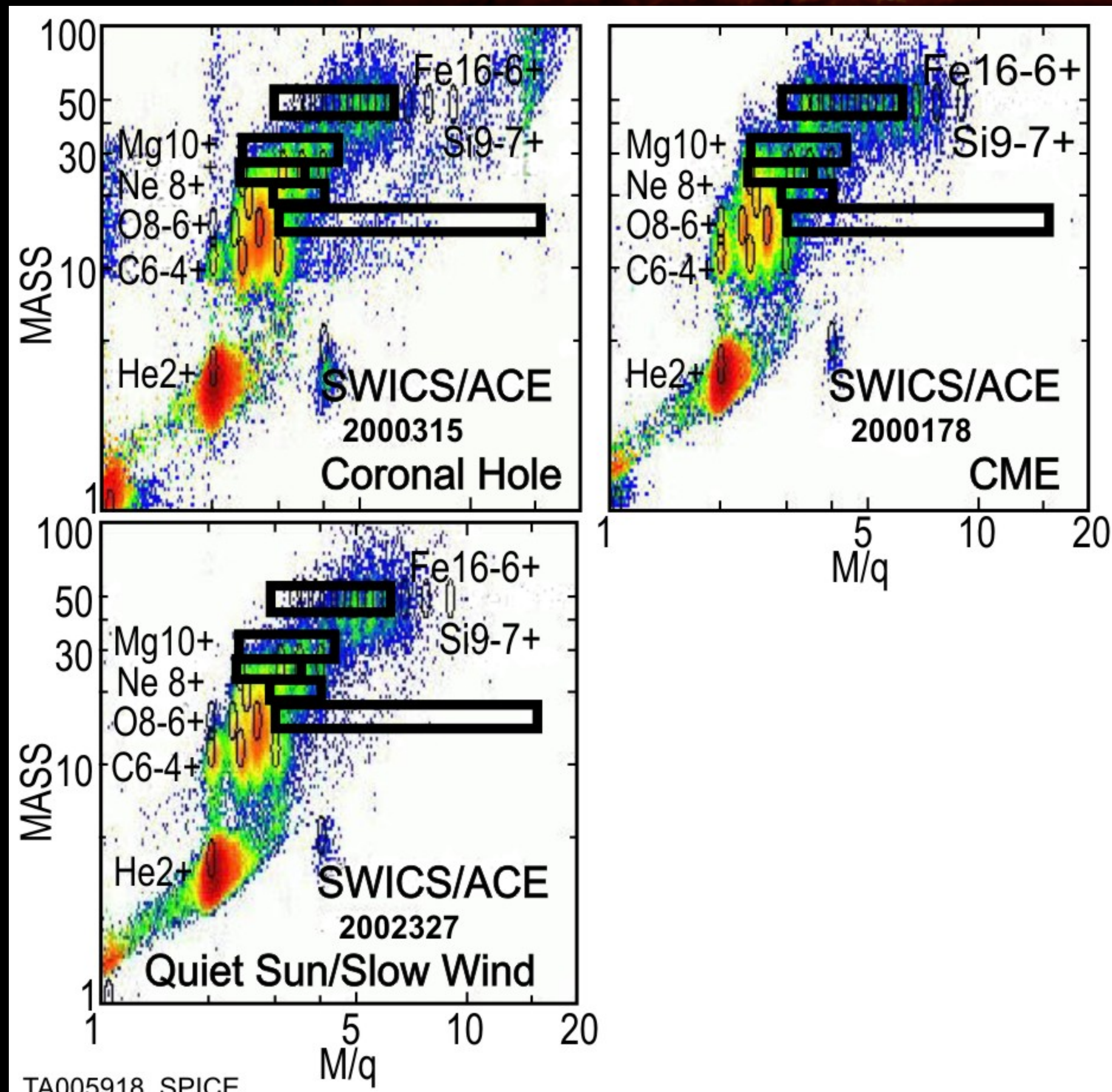

Remote sensing-in-situ composition correlation is fundamental

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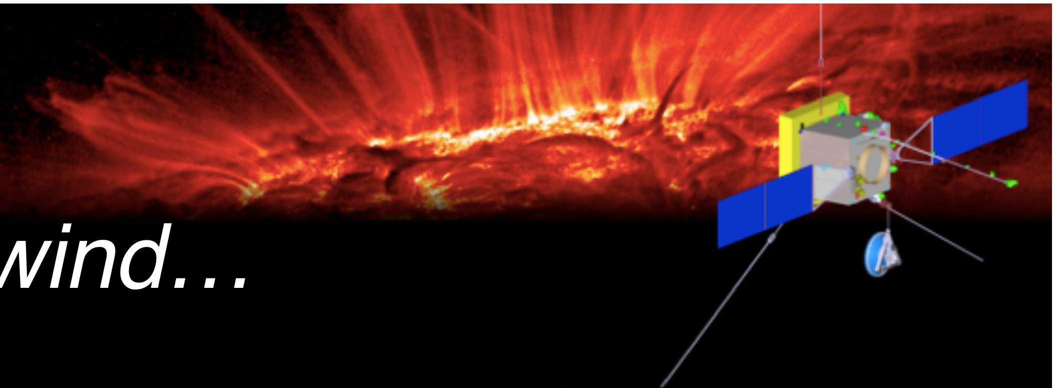
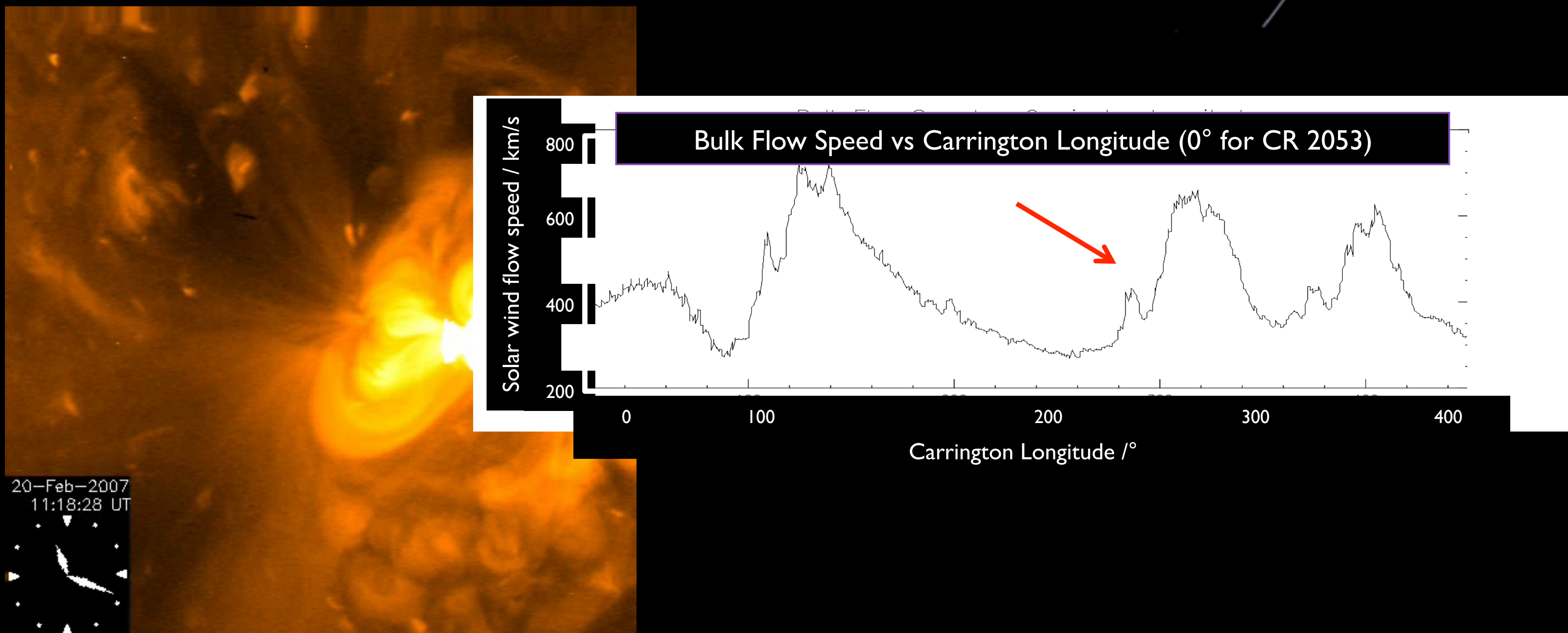


The slow solar wind…



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.

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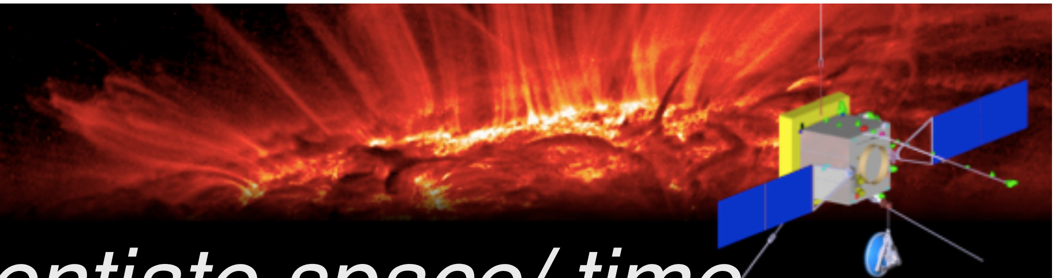
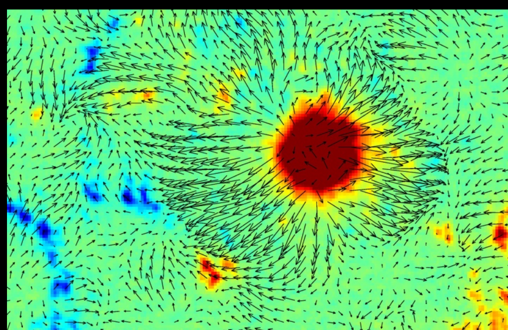
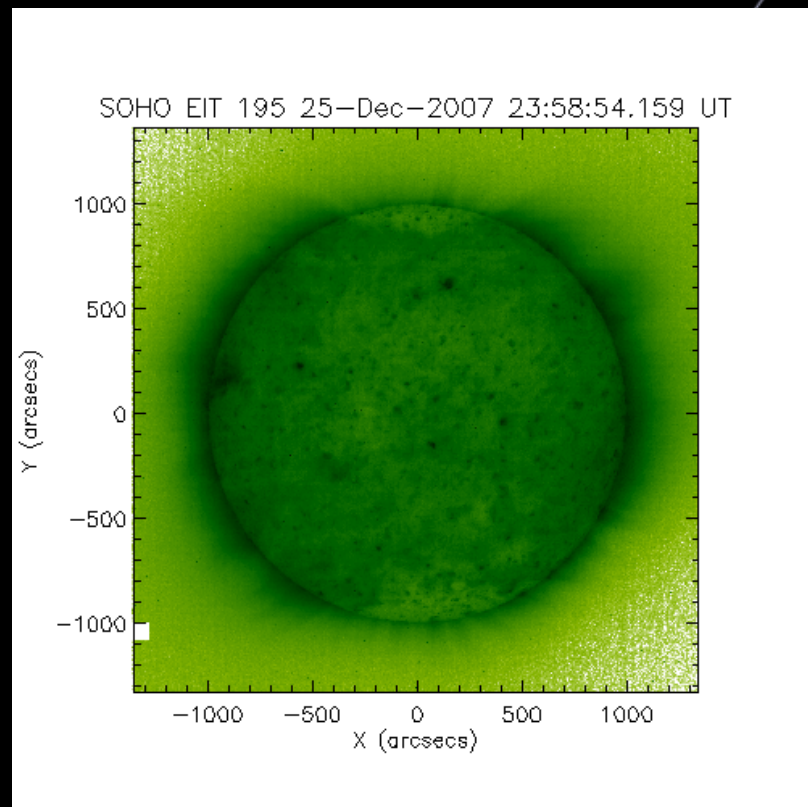


The need to differentiate space/ time structures…





…requires viewing a given solar region for more than an active region growth time (~ 10 days) ➔ implies going closer to the Sun.

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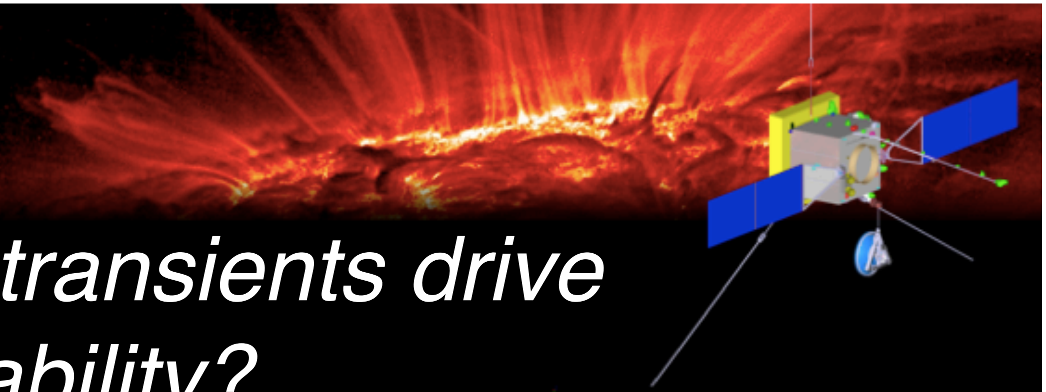

Q2) How do solar transients drive heliospheric variability?

2.1) How do Coronal Mass Ejections (CMEs) evolve through the corona and inner heliosphere?

2.2) How do CMEs contribute to the solar magnetic flux and helicity balance?

2.3) How and where do shocks form in the corona and inner heliosphere?

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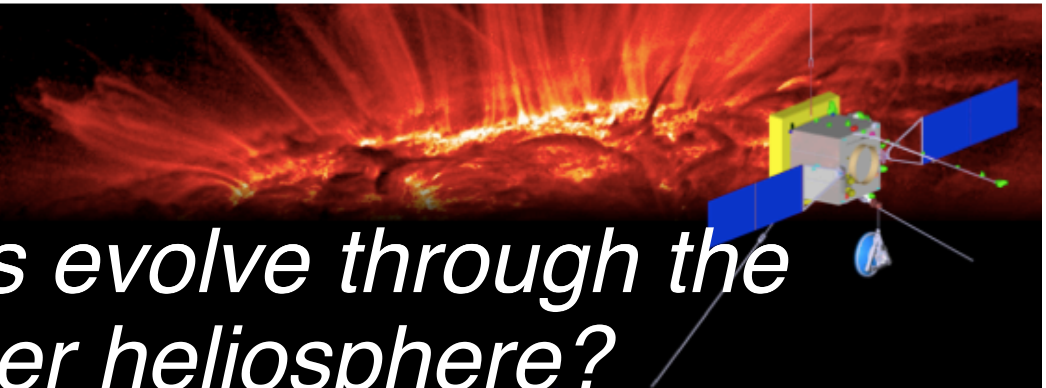
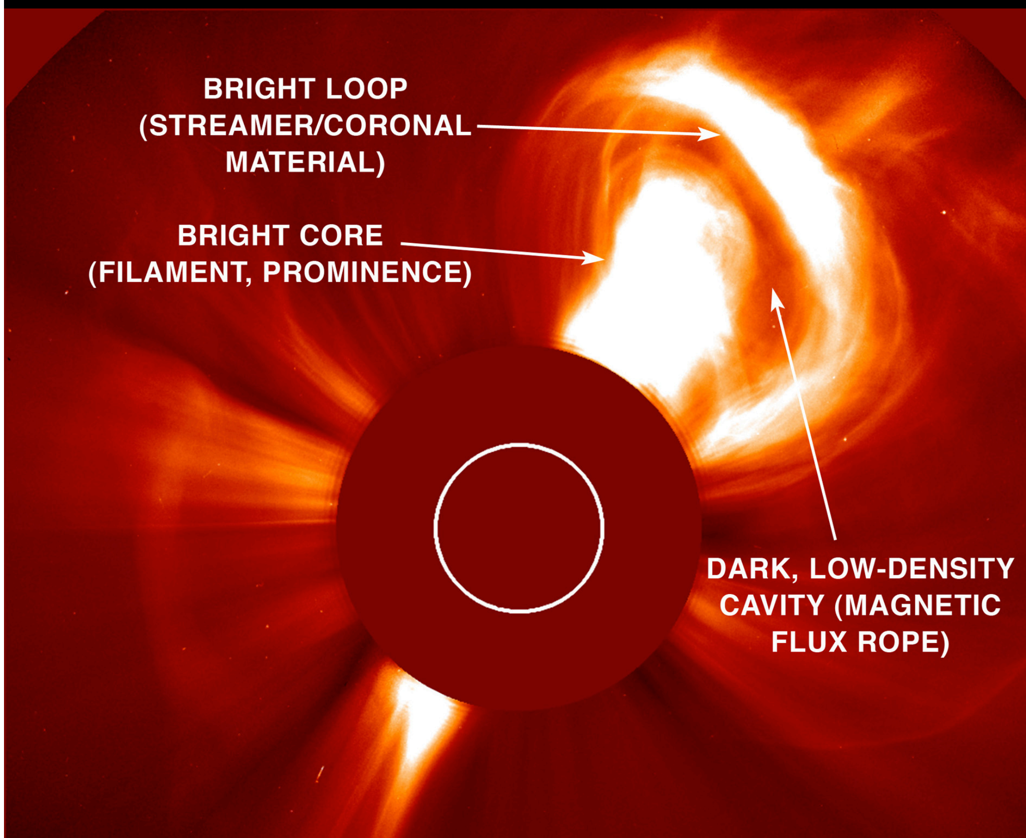
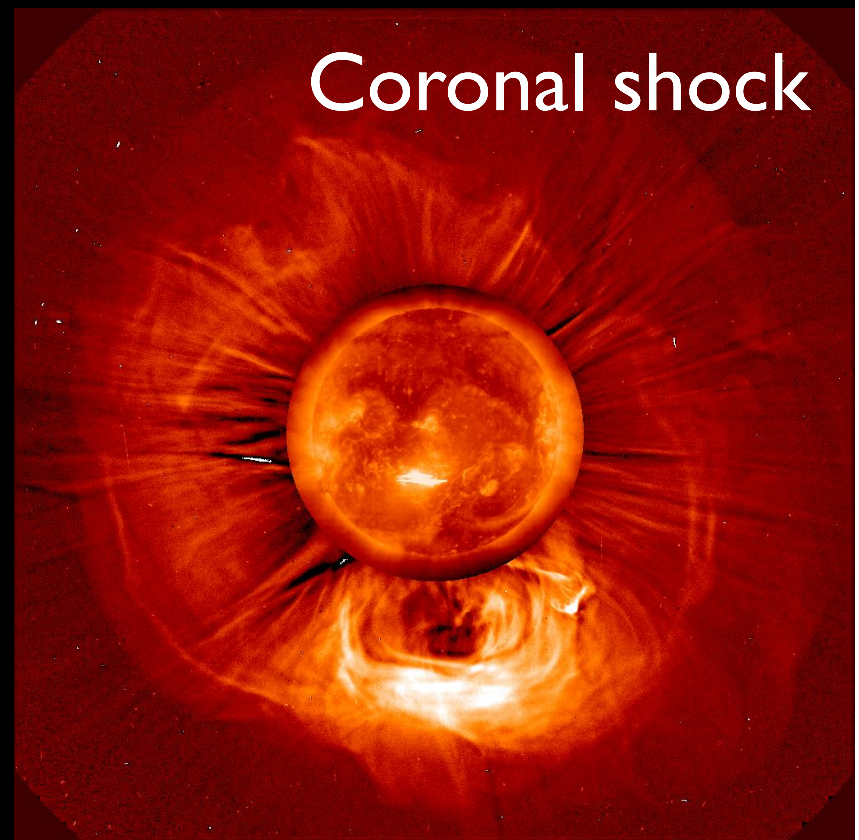


2.1) How do CMEs evolve through the corona and inner heliosphere?





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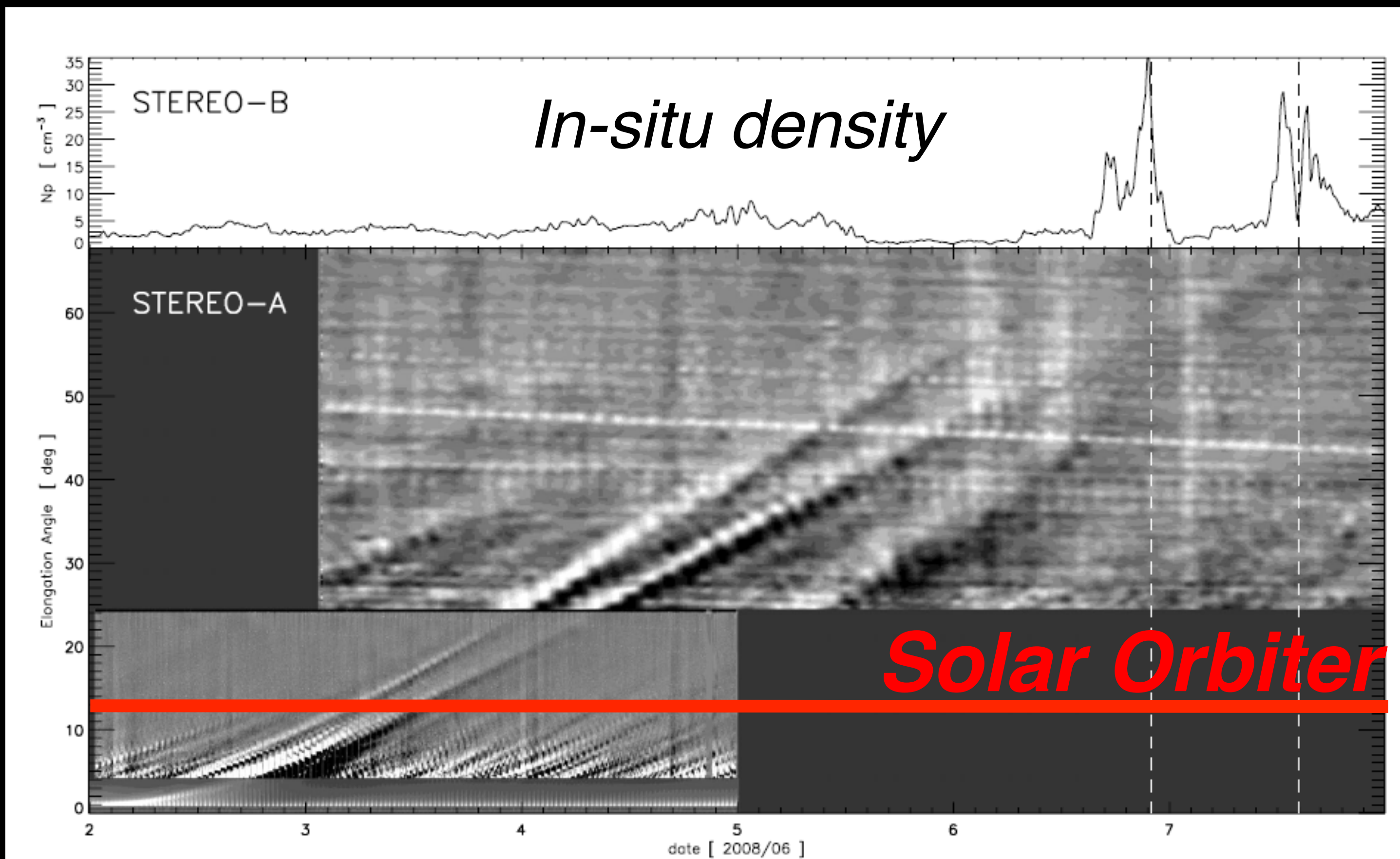
Requires combined in-situ and imaging observations close to the Sun



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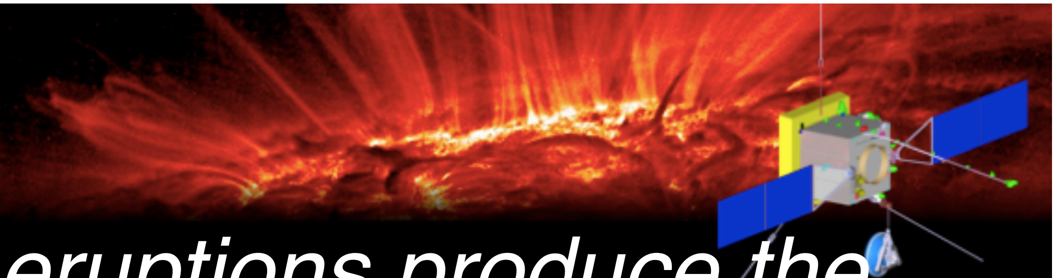

Q3) How do solar eruptions produce the energetic particle radiation that fills the heliosphere?

- 3.1) How and where are energetic particles accelerated at the Sun?
- 3.2) How are energetic particles released from their sources and distributed in space and time?
- 3.3) What are the seed populations for energetic particles?

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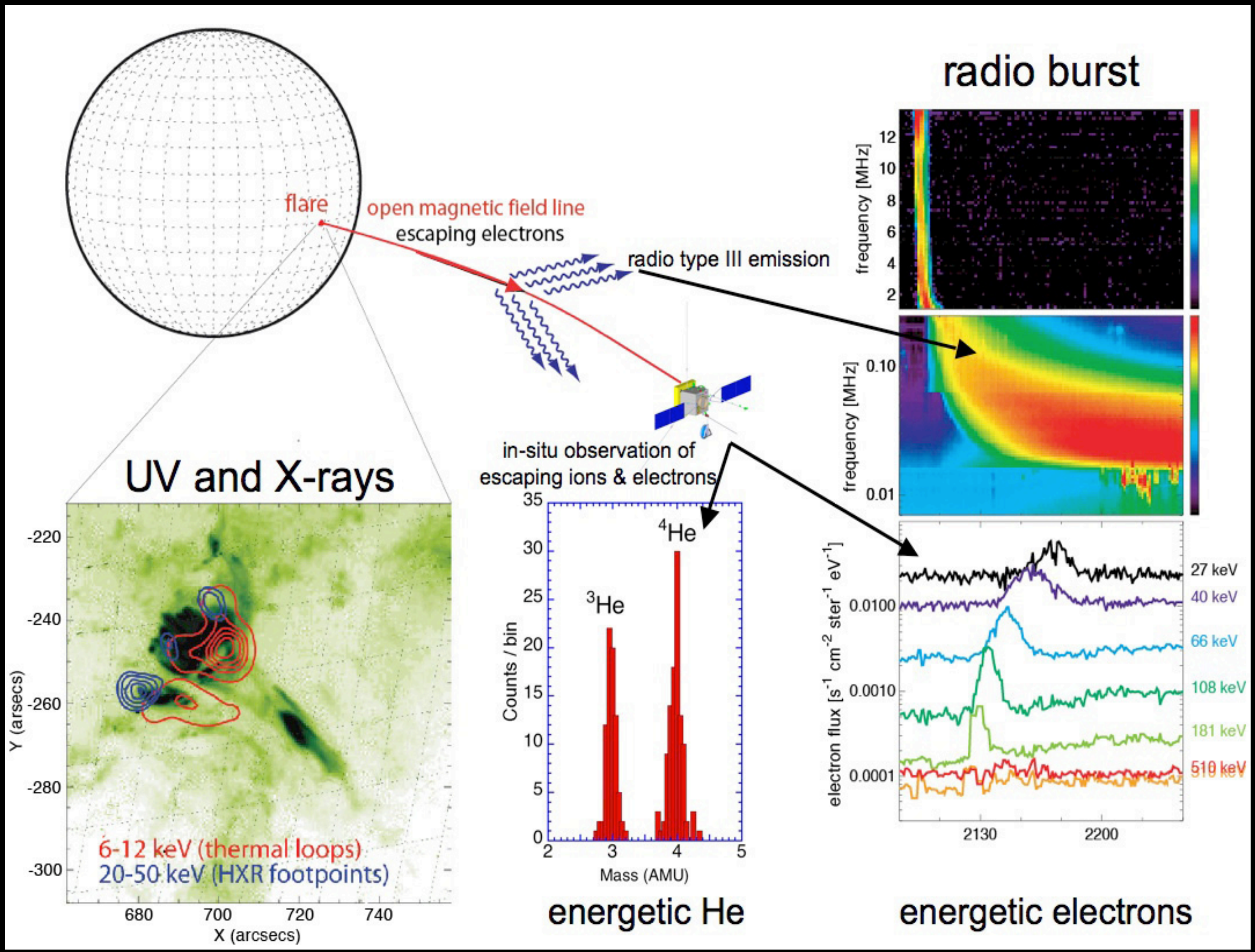
3.1) How and where are energetic particles accelerated at the Sun?



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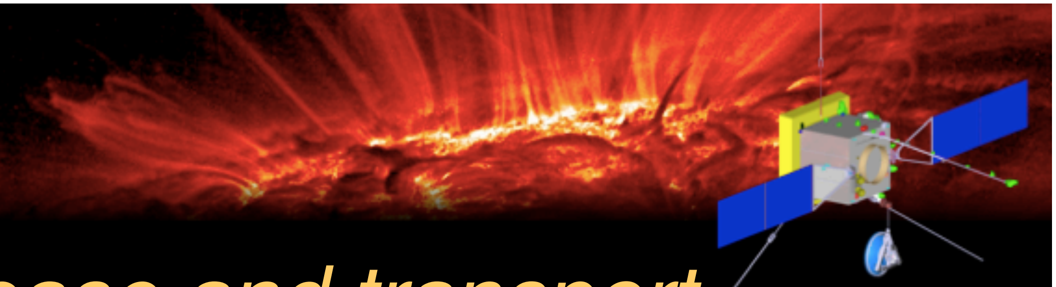
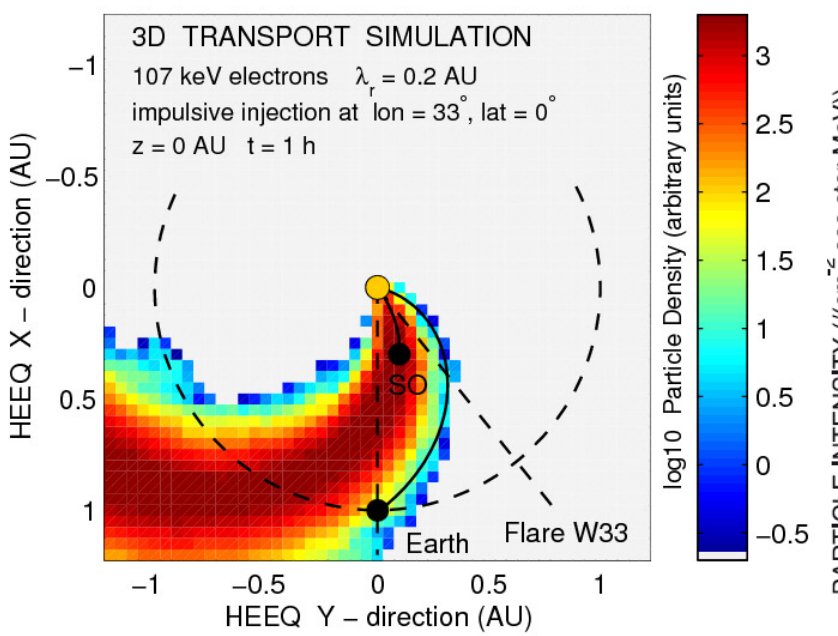
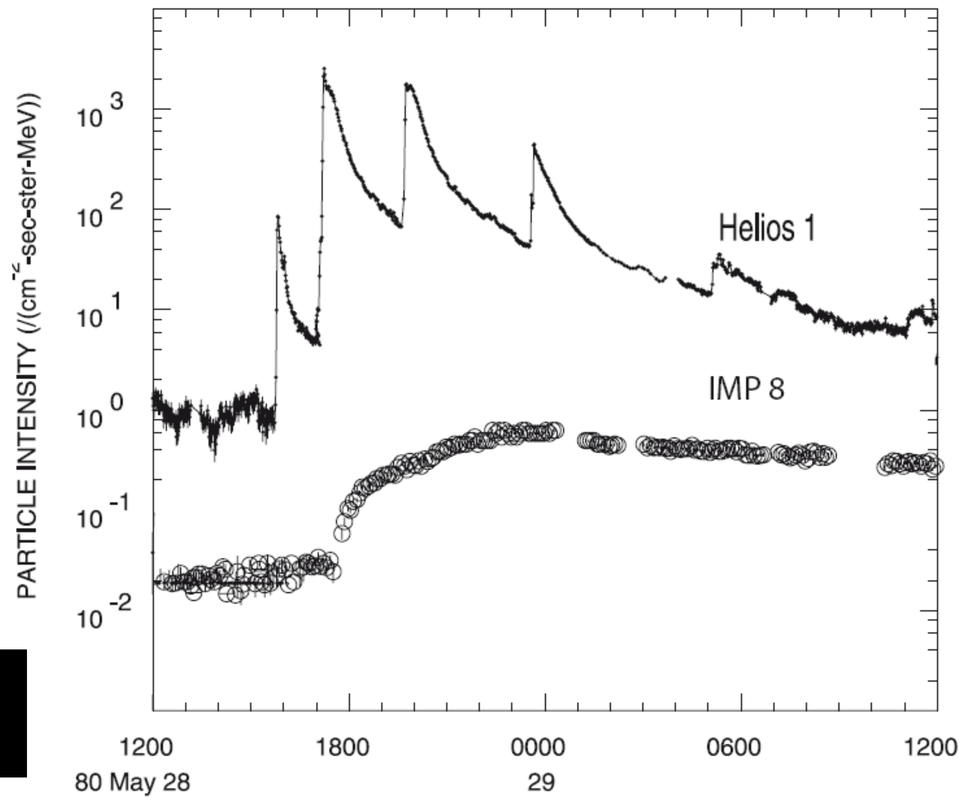


Understanding release and transport mechanisms requires going close to the Sun





Helios 1 / IMP 8. Scattering -> smoothing at 1 AU

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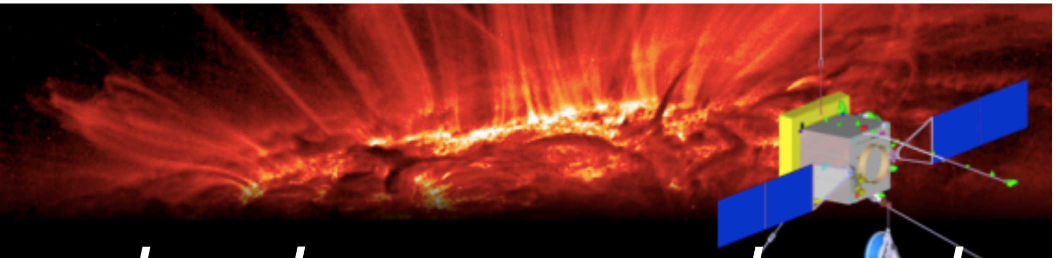
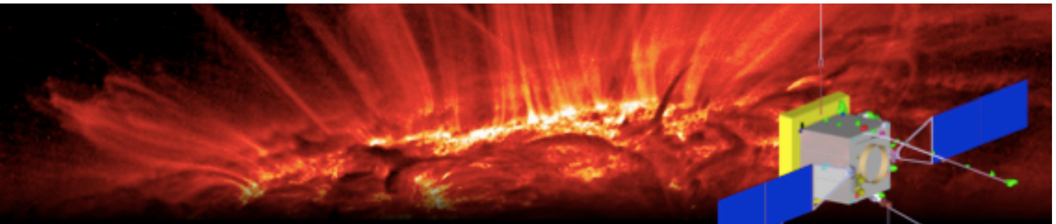


Q4) How does the solar dynamo work and drive the connections between the Sun and the heliosphere?

4.1) How is magnetic flux transported to and reprocessed at high solar latitude?

4.2) What are the properties of the magnetic field at high solar latitudes?

4.3) Are there separate dynamo processes acting on the Sun?



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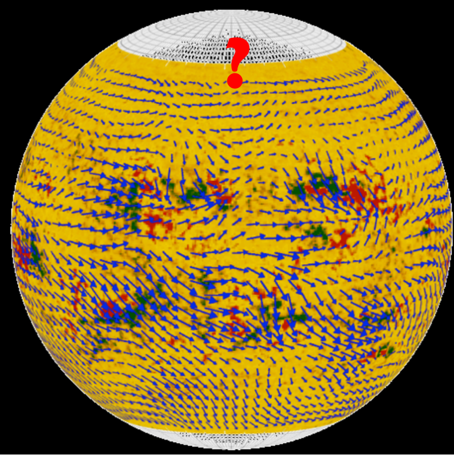
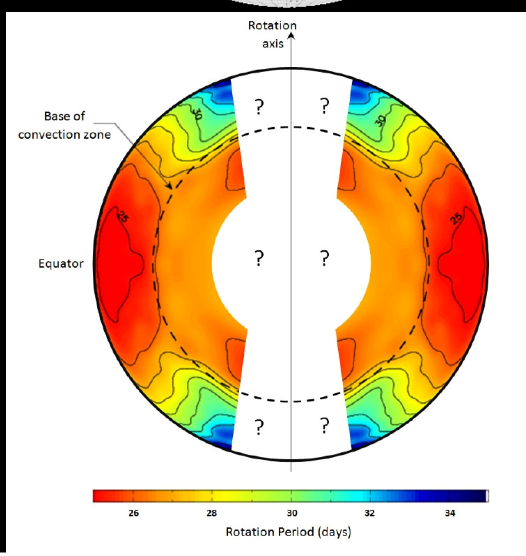
4.1) *How is magnetic flux transported to and reprocessed at high solar latitude?*





- Detect flows at and below the solar surface, in particular at high latitudes
- Most important flows are:
  - Differential rotation
  - Meridional circulation
  - Torsional oscillations

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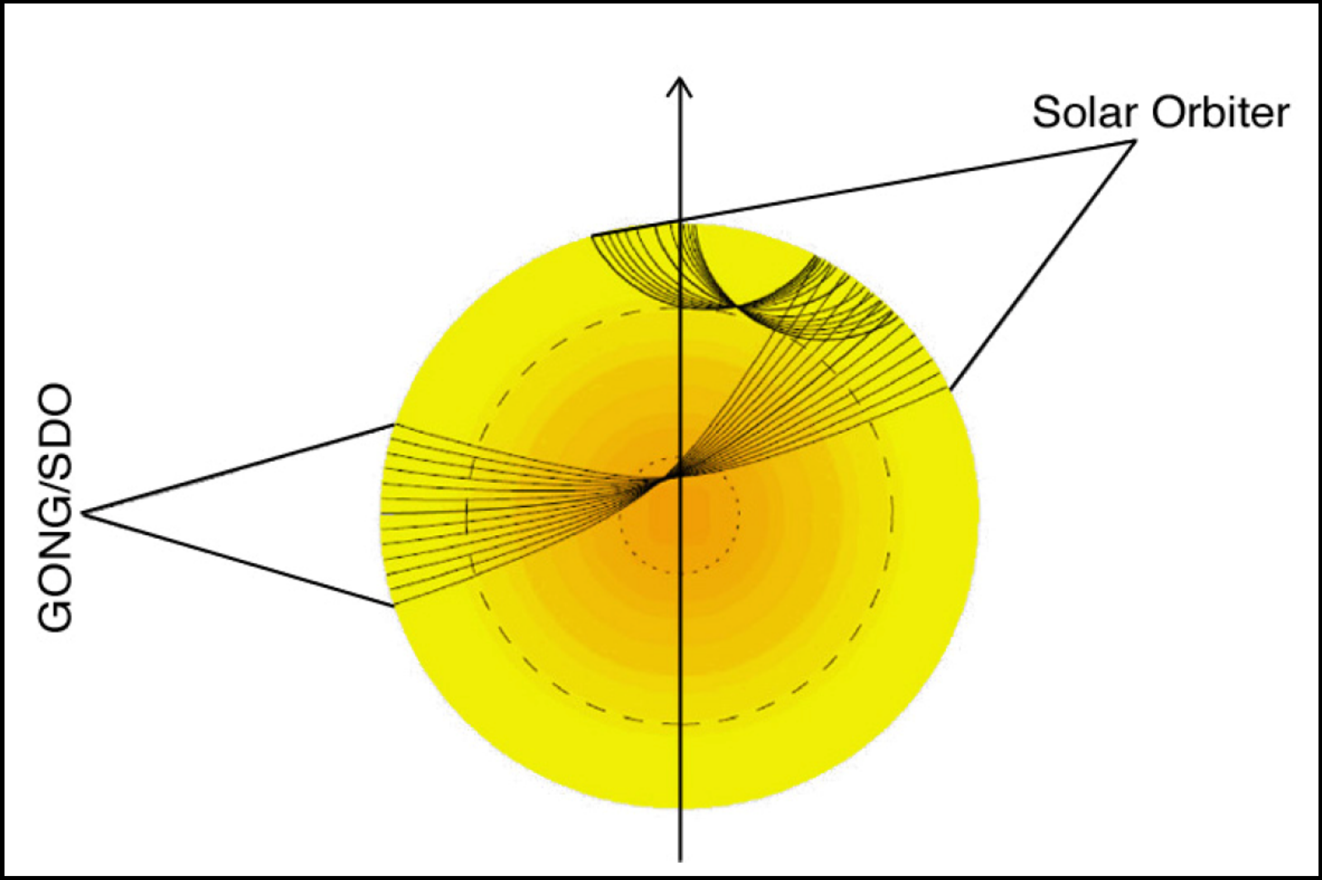
4.1) How is magnetic flux transported to and reprocessed at high solar latitude?



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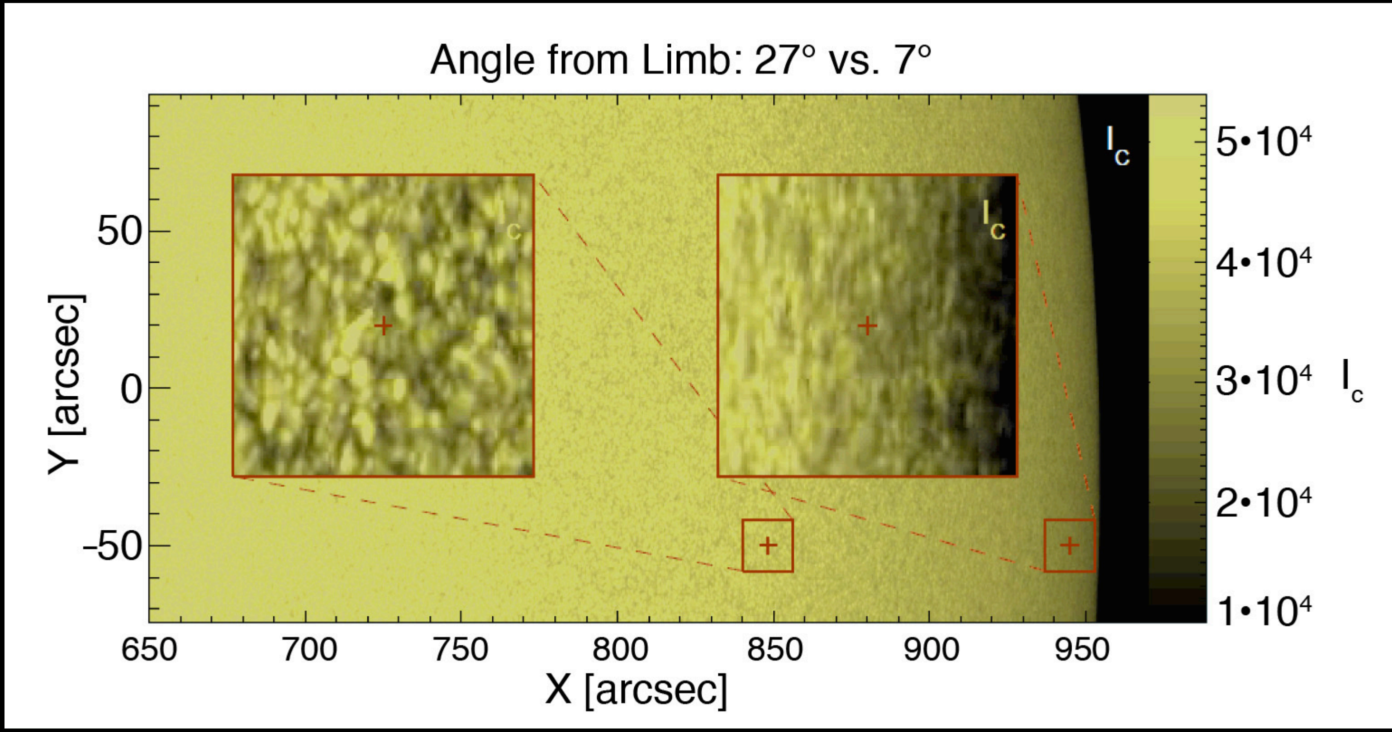
Requires going out of the ecliptic to observe polar flows and fields



At 27° magnetic measurement is far improved. Granulation tracking can now follow large-scale flows.

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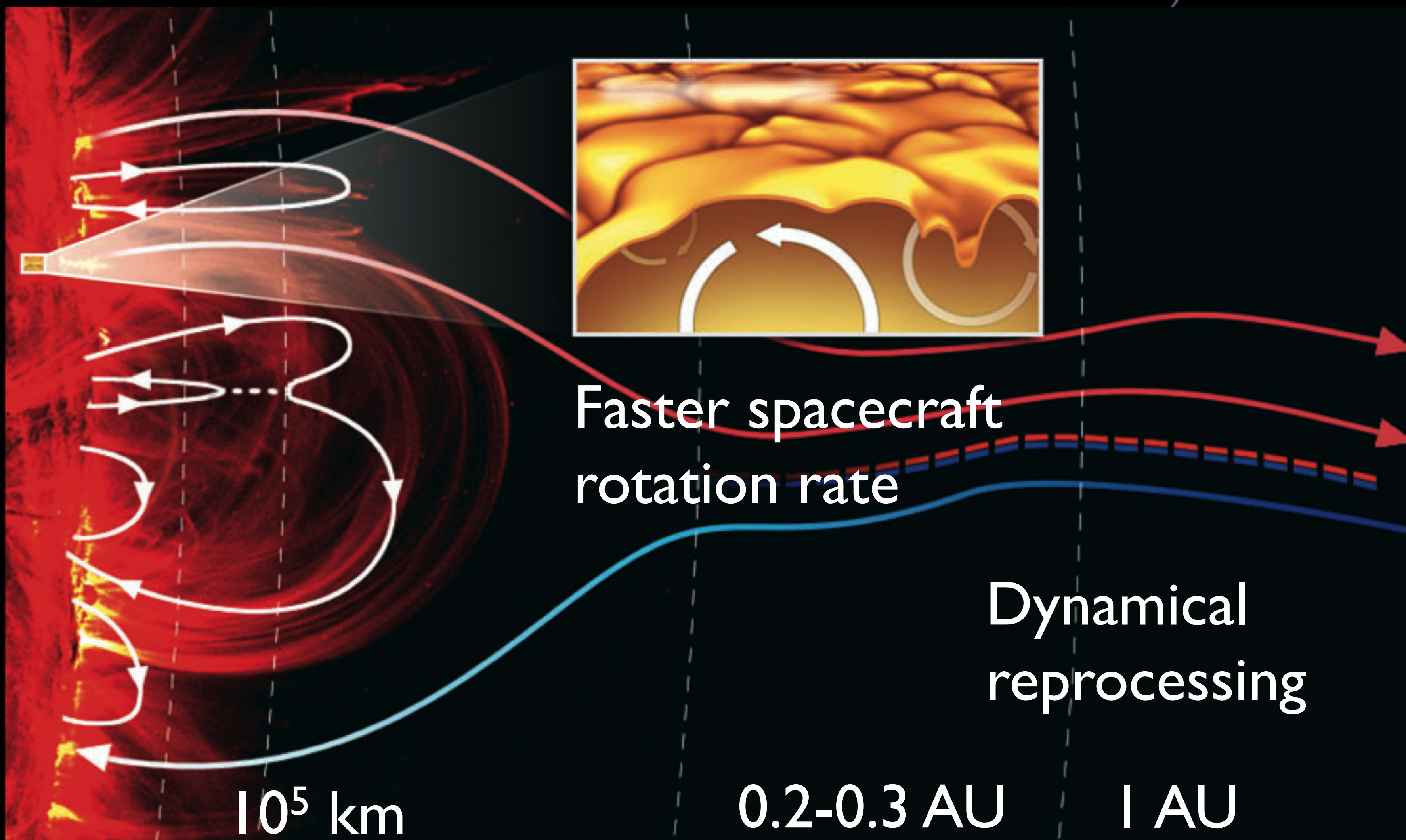
Summary



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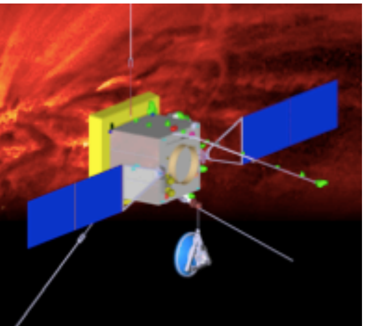
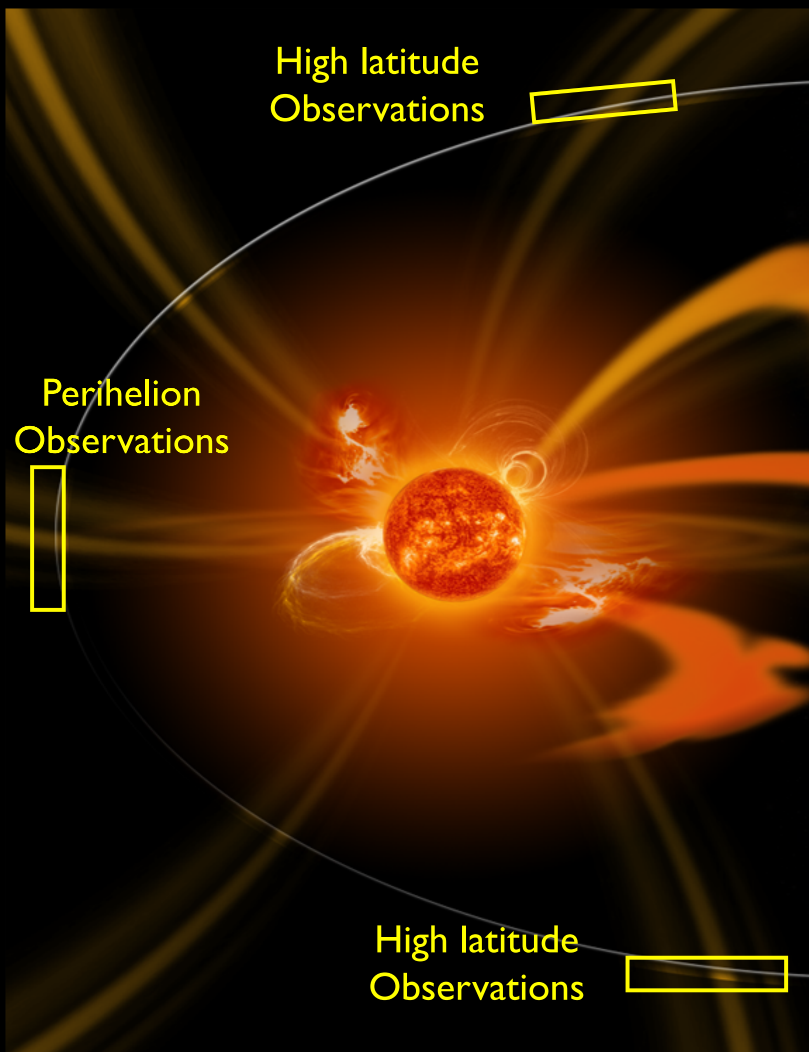
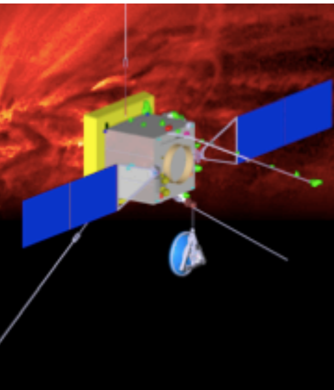


Solar Orbiter Mission Overview



Mission Summary

Launch date:	January 2017
Nominal Mission:	7.5 years
Extended Mission:	2.4 years
Orbit:	Elliptical orbit
	0.23 – 0.29 AU (perihelion)
	0.75 - 1.2 AU (aphelion)
Out of Ecliptic View:	Multiple gravity assists with Venus to increase inclination out of the ecliptic to >25 deg (nominal mission) >34 deg during the extended mission
Co-rotation:	Period of near-synchronization with the Sun's rotation per orbit, allowing observations of evolving structures on the solar surface & heliosphere for almost a complete solar rotation



All instruments have been selected through a joint ESA/NASA AO

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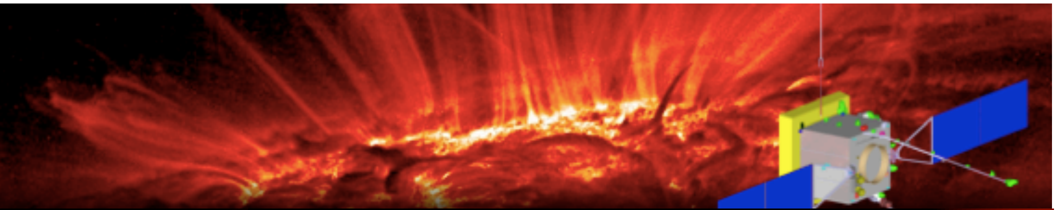

Investigation	*Collaboration*	*Measurement*
Solar Wind Analyzer (SWA) PI C. Owen, UK	UK, I, F, Japan, D, CH, USA	SW ion & electron bulk properties, ion composition (1eV- 5 keV electrons; 0.2 - 100 keV/q ions)
Energetic Particle Detector (EPD) J. Rodríguez-Pacheco, Spain	Spain, D, FI, GR, CH, F, Slovakia, USA	Composition, timing, distribution functions of suprathermal - energetic particles
Magnetometer (MAG) T. Horbury, UK	UK, A, I, H, D, F, E, DK, USA	DC vector magnetic fields (0 – 64 Hz)
Radio & Plasma Waves (RPW) M. Maksimovic, France	France, SE, CZ, NO, UK, A, D, GR, AU, I, H, FI, Russia	AC electric and magnetic fields (~DC – 20 MHz)
Polarimetric and Helioseismic Imager (PHI) S. Solanki, Germany	Germany, E, F, SE, NO, CH, AU, USA	Vector magnetic field and line-of-sight velocity in the photosphere
EUV Imager (EUI) P. Rochus, Belgium	Belgium, UK, F, D, USA	Full-disk EUV and high-resolution EUV and Lyman-α imaging of the solar atmosphere
Spectral Imaging of the Coronal Environment (SPICE) D. Hassler, USA	USA, UK, D, F, N	EUV spectroscopy of the solar disk and corona
X-ray Spectrometer Telescope (STIX) A. Benz, Switzerland	Switzerland, PL, D, CZ, IRE, A, UK, F, USA	Solar thermal and non-thermal x-ray emission (4 – 150 keV)
Coronagraph (METIS/COR) E. Antonucci, Italy	Italy, CK,F, D, GR, USA	Visible, UV and EUV imaging of the solar corona
Heliospheric Imager (SolOHI) R. Howard, USA	USA, Belgium, UK, Germany	White-light imaging of the extended corona

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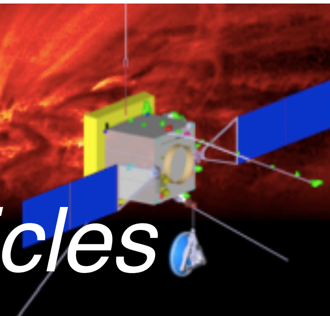
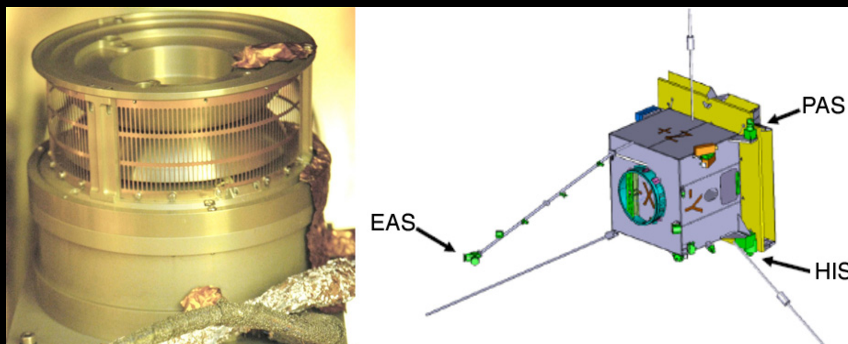
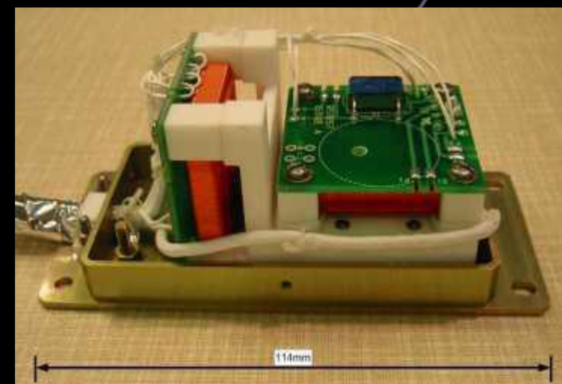


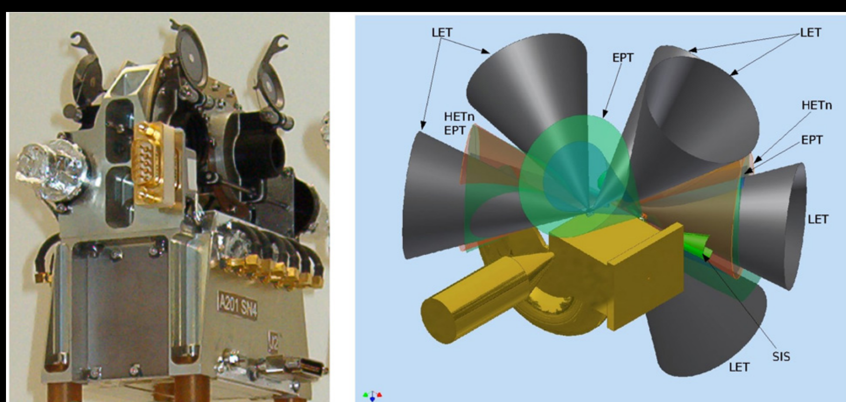
In-situ instruments: Fields and particles



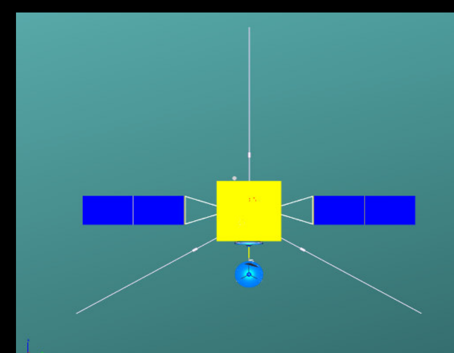
SWA Solar Wind Analyzer: Comprehensive *in-situ* measurements of solar wind ions, electron bulk properties and ion composition



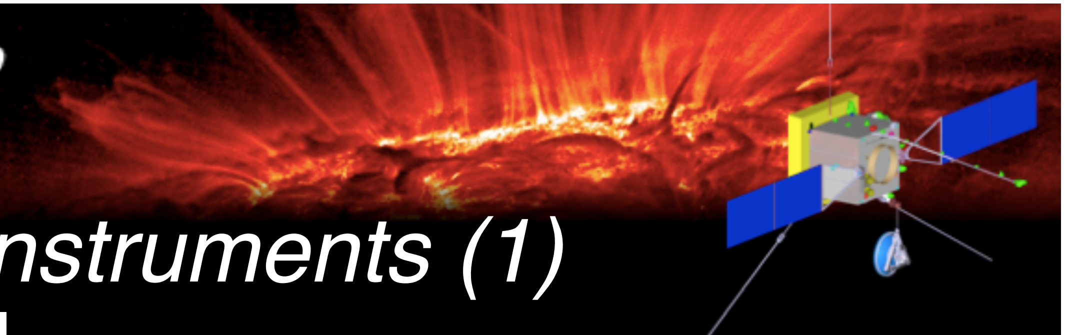
MAG Magnetometer: High Precision *in-situ* measurements of the heliospheric magnetic field



EPD Energetic Particle Detector: *In-situ* measurements of composition, timing and distribution functions of suprathermal and energetic particles



RPW Radio & Plasma Wave Experiment: High time resolution magnetic & electric field measurements of electromagnetic & electrostatic waves in the solar wind



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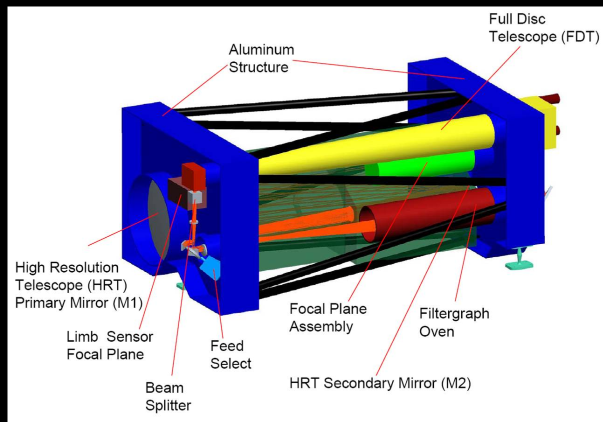
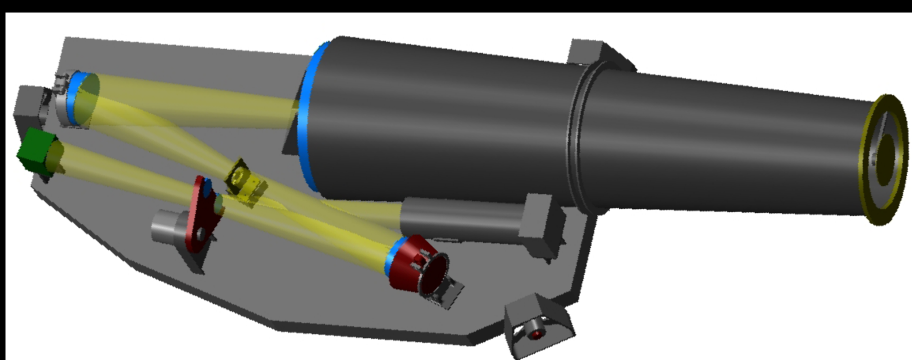
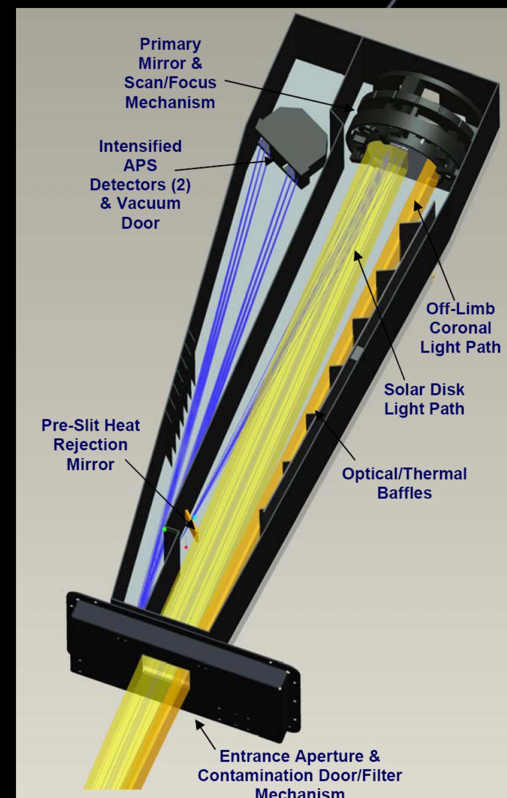
Remote-sensing instruments (1)



PHI vector magnetograph/polarimeter: high resolution & full disk measurements of the photospheric vector magnetic field & LOS velocity



METIS UV & WL Coronagraph: visible and UV (H I & He II) images of coronal structures out to 3 solar radii at 0.23 AU (5.3 solar radii at 0.3 AU)



SPICE UV Imaging Spectrograph: UV spectral images of the chromosphere and corona on the solar disk & in the corona out to >3.0 solar radii at 0.35 AU

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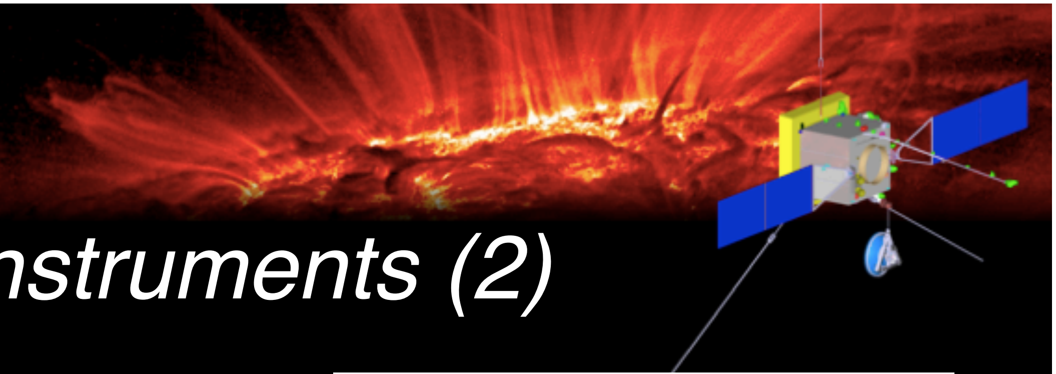
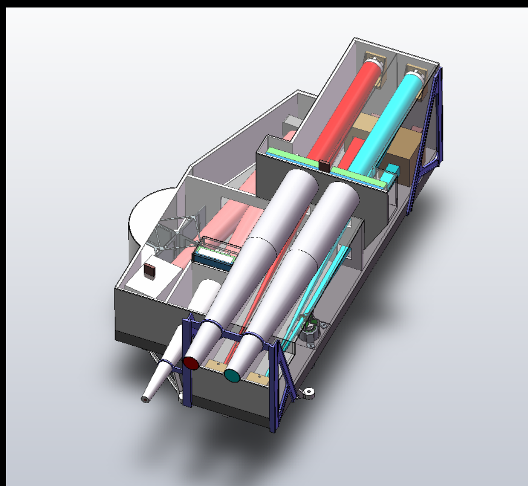
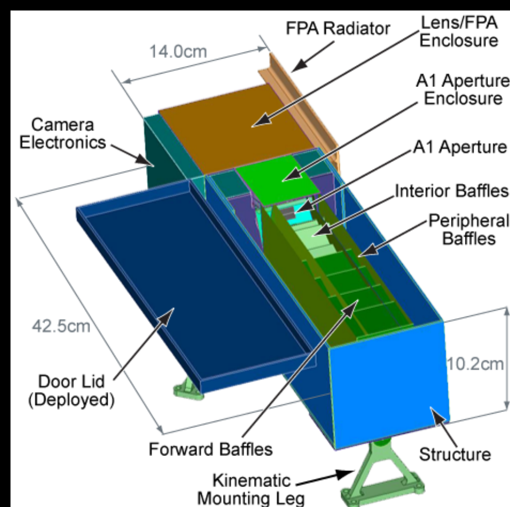


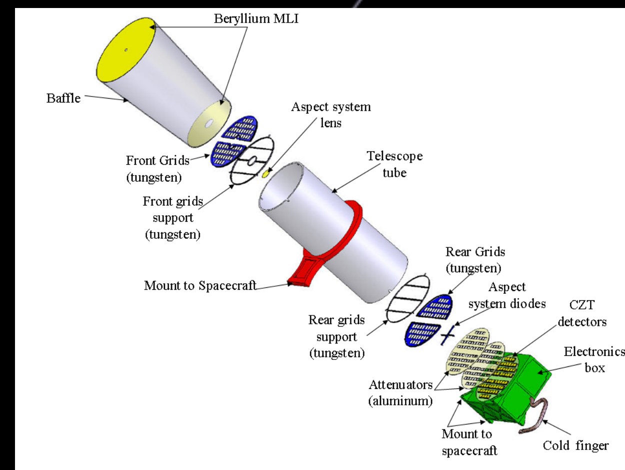
Remote-sensing instruments (2)



EUI UV & EUV Imager:
Full disk and high resolution images of the chromosphere and corona



SOLOHI Heliospheric Imager:
Wide angle white light images of the extended corona & heliosphere out to 40 deg elongation



STIX X-ray Imager: Imaging spectroscopy of solar thermal & non-thermal x-ray emission from flares & micro-flares

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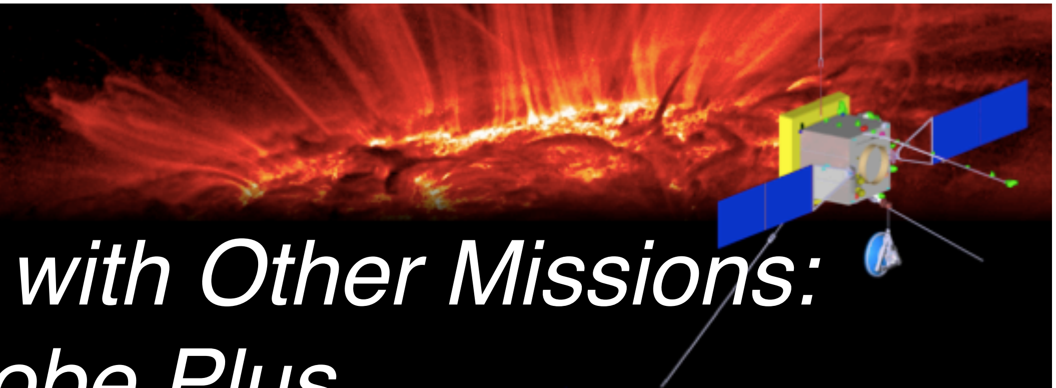
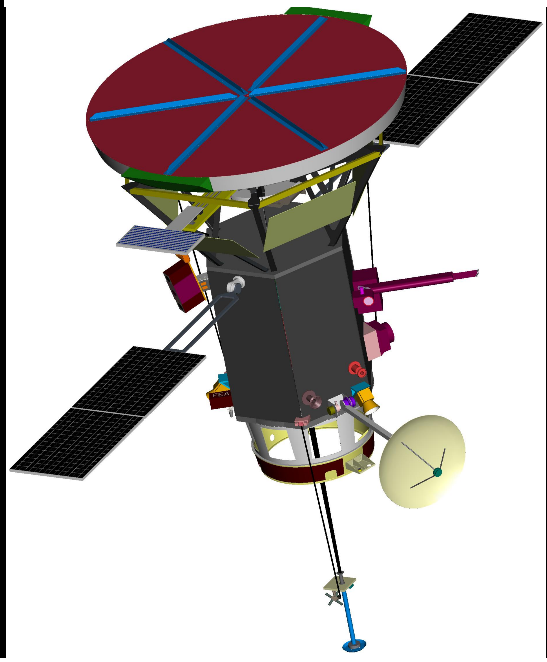
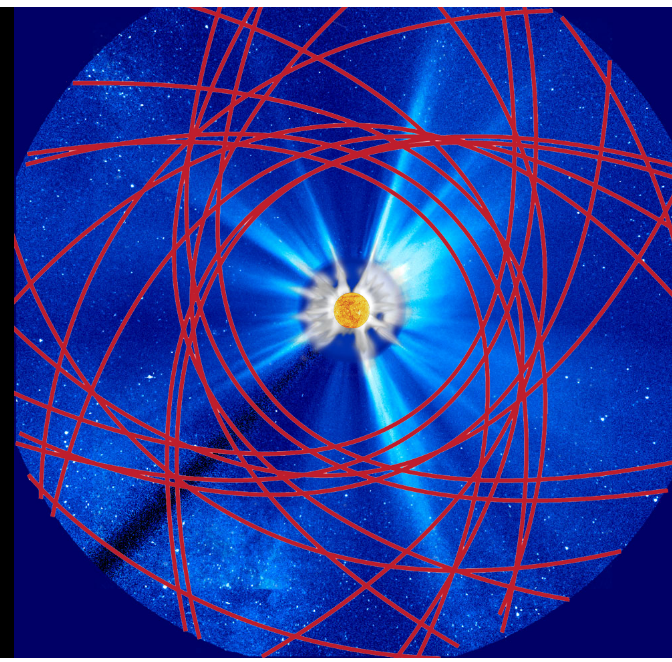


Potential Synergy with Other Missions: Solar Probe Plus

Joint NASA-ESA Solar Orbiter -
Solar Probe Assessment ‘09

Enhanced science from mutual context / alignments





Solar Orbiter

Spacecraft Presentation

P. Kletzkine

SRE-PS/01506

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Solar Orbiter Mission Requirements

- Orbit:
  - Reach Sun orbit with perihelion between 0.2 and 0.25 AU
  - Increase inclination with respect to Sun equator to:
    - 25° for nominal mission (goal)
    - 34° for extended mission (goal)
- Launcher:
  - 2017 with 2018 as back-up:
    - NASA-provided launch (Atlas 5 or Delta 4) as baseline
    - Soyuz-Fregat 2-1b from Kourou as back-up
- Science Payload (Instruments and dedicated support elements):
  - Mass: 180 kg **max. incl. maturity margins**
  - Power: 180 W **incl. maturity margin**

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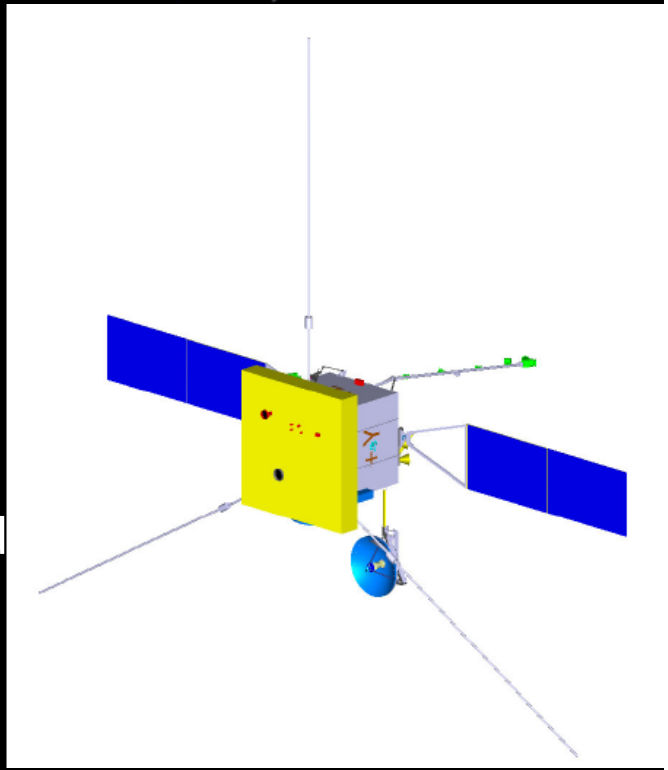
Spacecraft Basic Facts

- Three-axis stabilised spacecraft, Sun pointing
- Closest Sun encounter 0.234 AU (2017 launch)
- Heatshield to protect spacecraft and payload
- Overall mass ~ 1320 kg, Maximum power demand ~ 1100W, Bipropellant thrusters
- Several swing-bys (Earth and Venus) required to arrive to nominal orbit and to crank up solar latitude; launch opportunity every 19 months.
- Re-use BepiColombo unit designs or technology
- Ground Station X/Ka band - New Norcia



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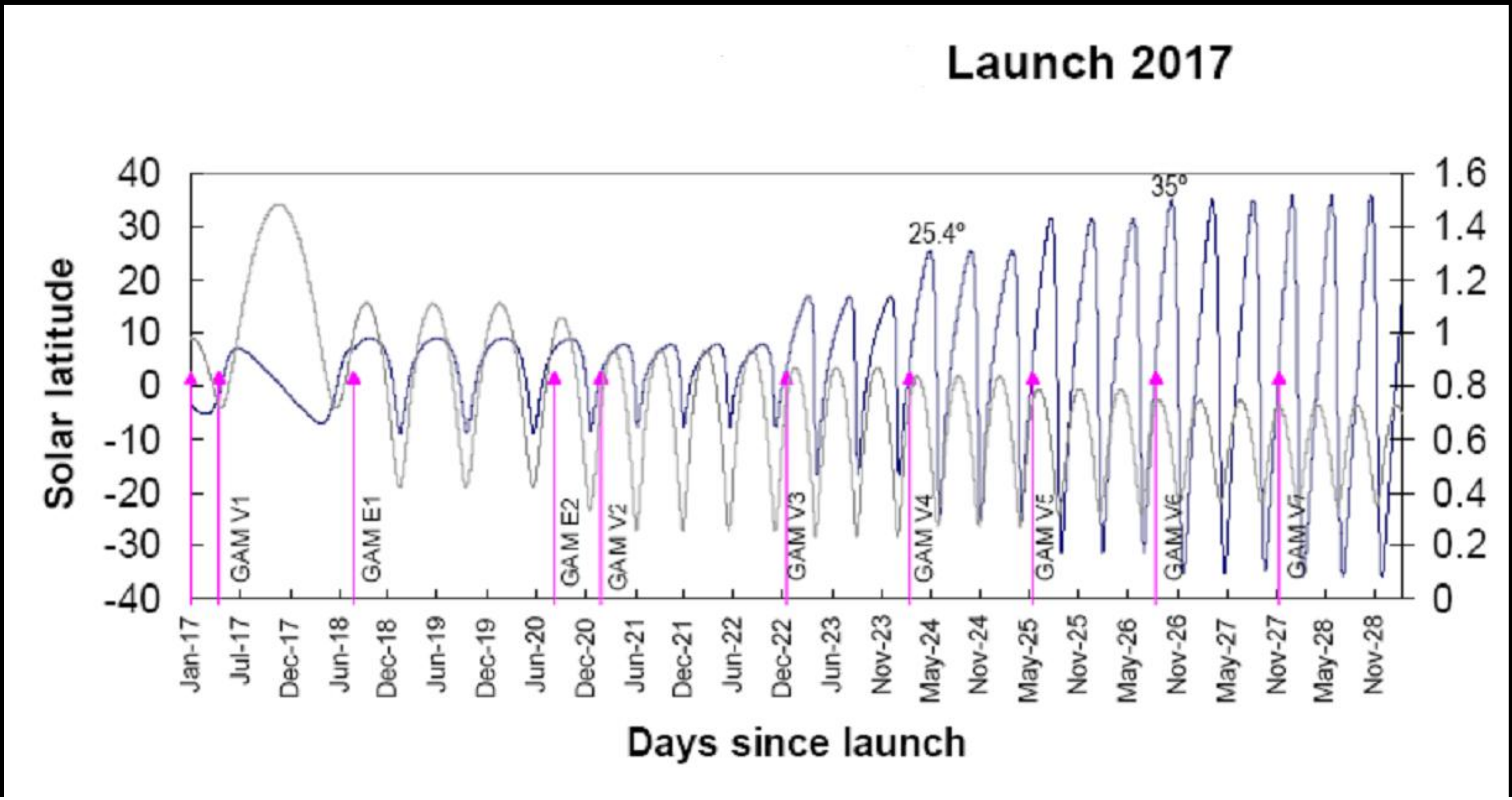
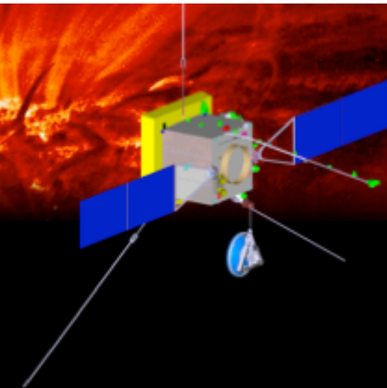
Solar Latitude and Spacecraft-Sun Distance





Mission Timeline

Launch	4 January 2017	30 July 2018
Begin NMP	10 February 2021	18 December 2021
End NMP	5 July 2024	26 August 2024
Duration (days)	2738	2219
Final inclination	25.4°	27.8°
End EMP	10 December 2026	3 March 2027
Final inclination	35°	33.5°
Duration (days)	3627	3138

- For the 2017 launch, the cruise duration is longer than in the 2018 case.

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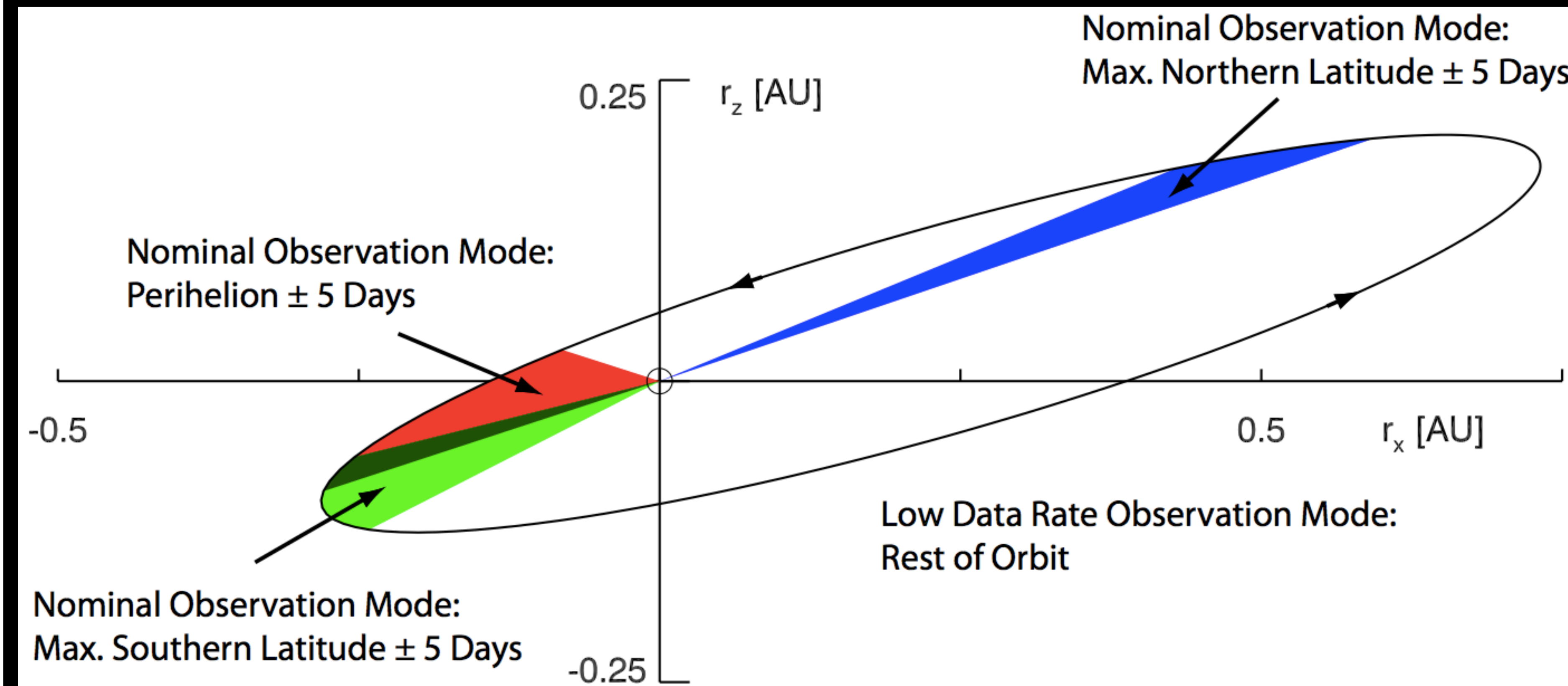
Observation Modes



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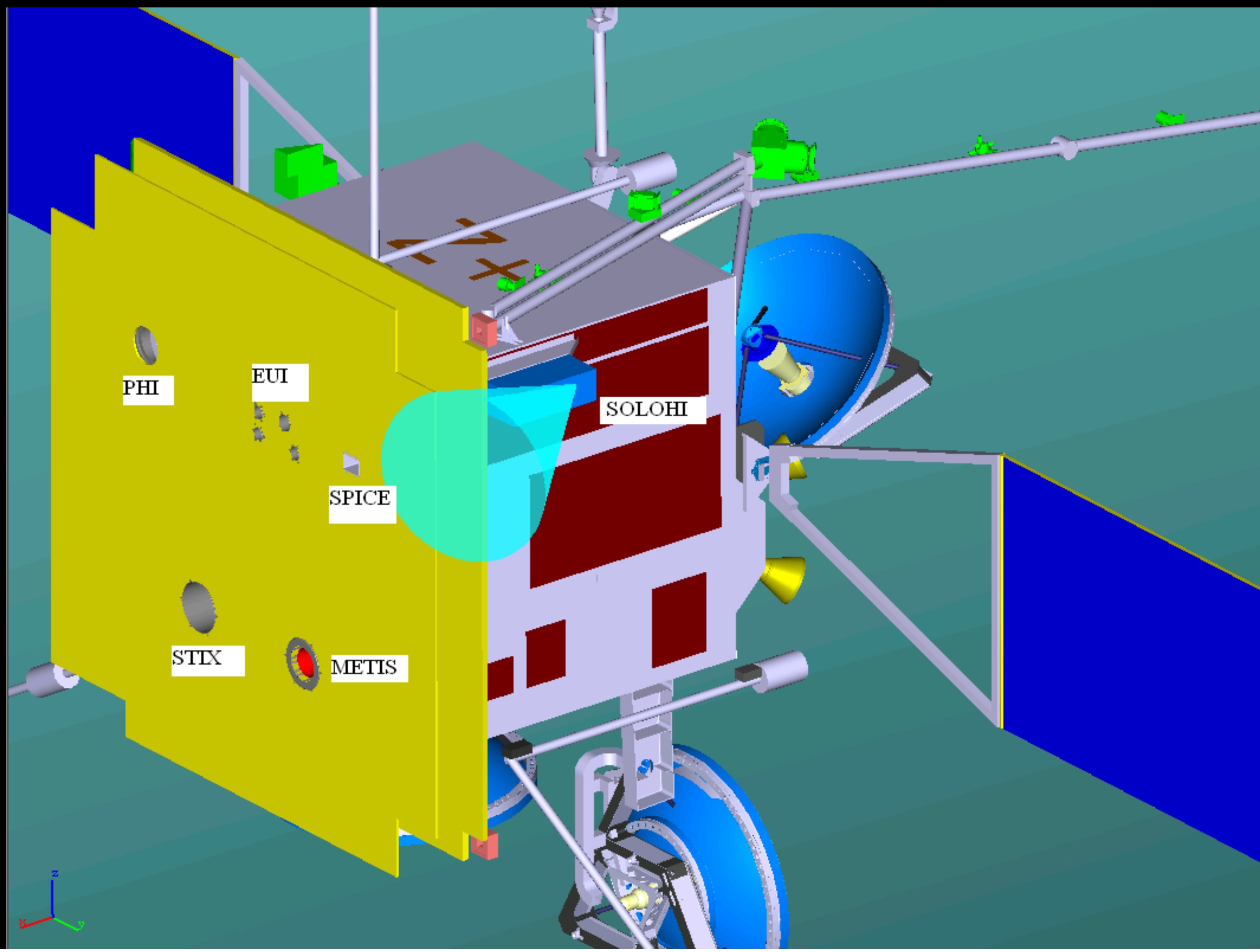
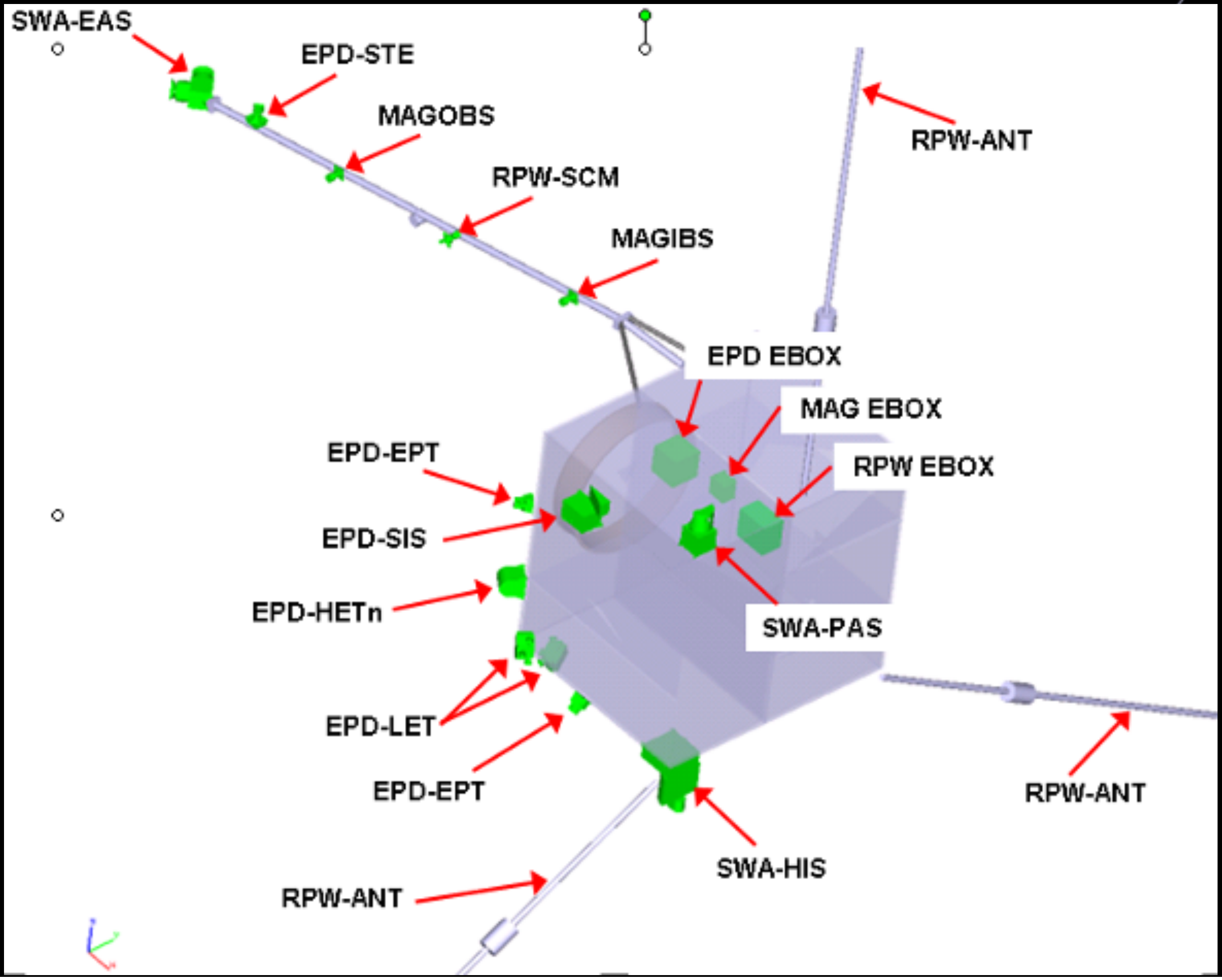
Payload Accommodation - Remote Sensing



Payload Accommodation – In-Situ



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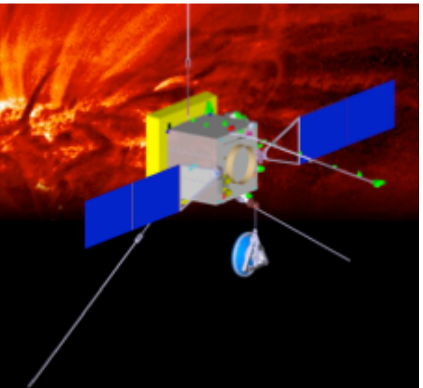

Technology Development (1/2)

- **Ahead of the implementation (B2/C/D) phase**
- **Completed or on-going: Detector Characterization, Heat Rejecting Entrance Window, Liquid Crystal Variable Retarders, Sun Sensor**
- **Initiation in 2009:**
  - Heat-rejecting entrance window (*continuation*)
  - Materials selection and testing (*UV, high temperature*)
  - Methodology for high solar flux testing acceleration (*study*)
  - Solar concentrator test facility upgrade (*feasibility study*)
  - Small high flux test facilities *(~60cm Ø beam at ~ 20 Solar Constants at ESTEC*)
  - High intensity high temperature solar generator (*study, building on BepiColombo results*)

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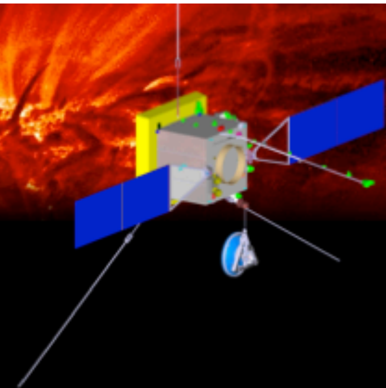

Technology Development (2/2)

- **Planned to start ahead of the implementation (B2/C/D) phase:**
- **kick-off in 2010:**
  - Feedthroughs, door and mechanisms
  - Heatshield breadboard, manufacturing and testing
  - Antenna adaptation study
  - High intensity high temperature solar cell assemblies
  - Antenna adaptation validation
  - Star tracker
  - Solar generator screening tests
- **kick-off in 2011:**
  - High flux generator prototype manufacturing and validation testing
  - Spacewire-based Solar Orbiter spacecraft simulator

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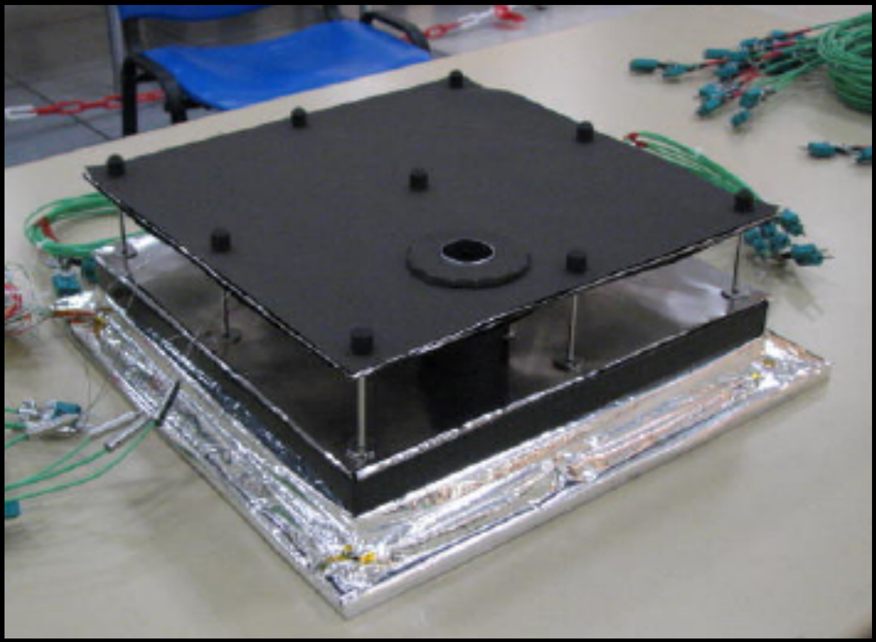
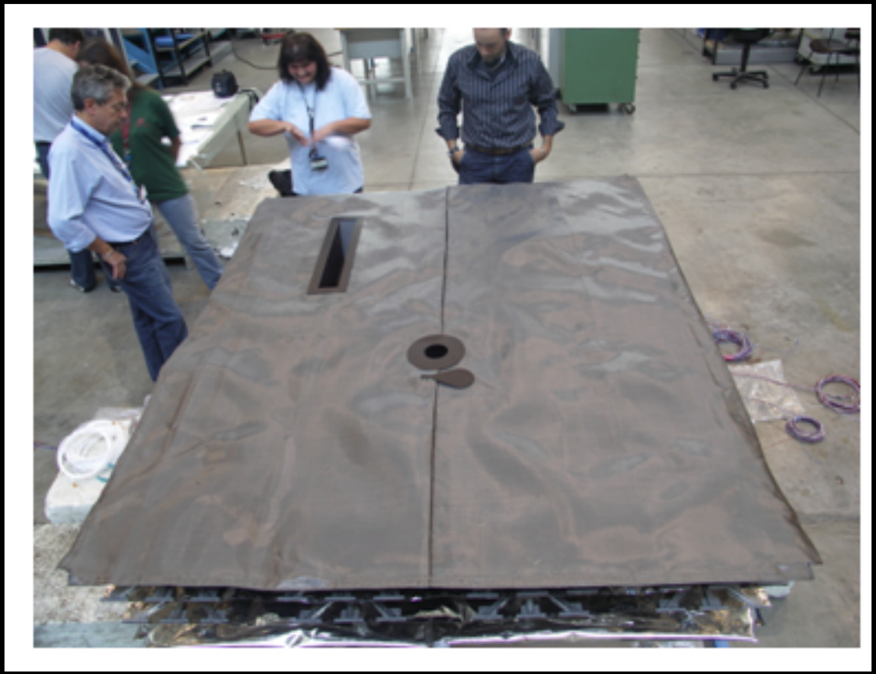
Heatshield

- Manufactured and successfully tested prototypes:
  - scaled model (40 cm) (left)
  - and full size (2m x 2m) (right)
- More breadboarding planned, with more design fidelity





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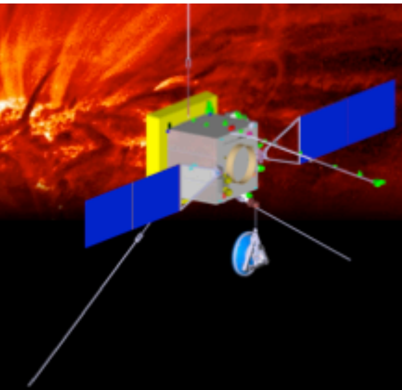
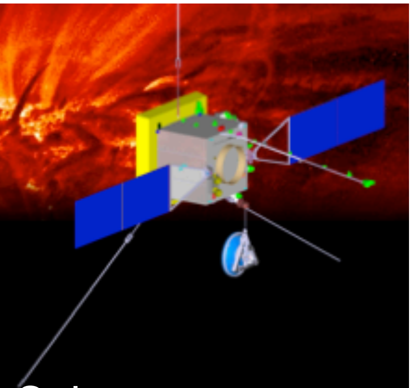


Schedule

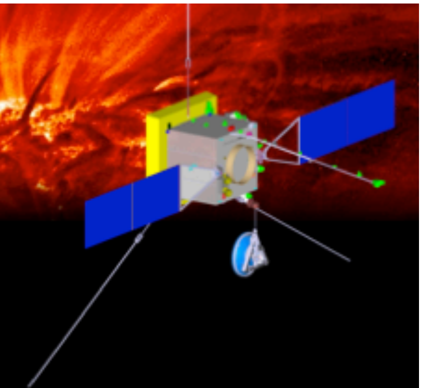
- Launch opportunity in January 2017
  - Risky (mandated ESA 6-month margin not achieved)
  - Next phase will study schedule recovery possibilities
  - Confirmed and flagged by Technical & Programmatic Review as high risk

- Launch opportunity in July 2018
  - Compatible with Cosmic Vision boundary conditions
  - Achieves good schedule margin (12 months versus 6 months required)
  - Back up launch opportunity in February 2020 to be studied in detail



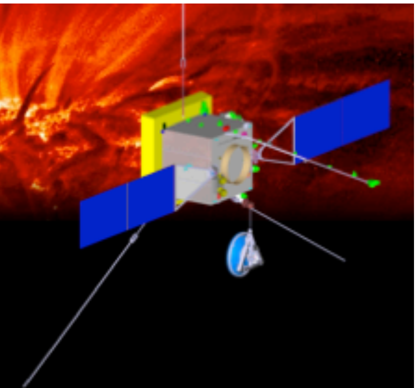
Solar Generator (1/2)

- Solar Generator technology of BepiColombo not compatible with Solar Orbiter environment at 0.234 AU
  - Different cell technology – to be qualified
  - Risk for cost, mass, power, stray light…
  - Confirmed and flagged by Technical & Programmatic Review as highest risk
- Mitigation: What we have done already
  - Include additional contingency in mass and cost – already included
  - Initiate Technology Development Activities at Generator, Solar Cells, and Test Facility levels
  - Consider at least 2 solar cell technologies



Solar Generator (2/2)

- Mitigations: what else could we still do about it?
  - Reduce environment (= regain BepiColombo heritage)
    - increase closest perihelion from 0.234 AU to around 0.28
    - development (double-sided array) significantly lower risk
    - Scientific impact to be fully evaluated
    - preliminary Mission Analysis indications: can be done, and high solar latitudes can probably still be reached, but periods of quasi Sun-synchronicity would be shorter



Technical Conclusions

- The Solar Orbiter mission is feasible.
- Schedule decisions (2017 / 2018) have to be taken.
- The critical technical areas have been identified, a range of Technology Development Activities are either on-going or planned.
- The Solar Generator technologies require particular attention.
- The Heat Shield development has already been largely addressed.
- Instrument teams selected for phase A, at work on design and interface definition (undergoing first ESA review).

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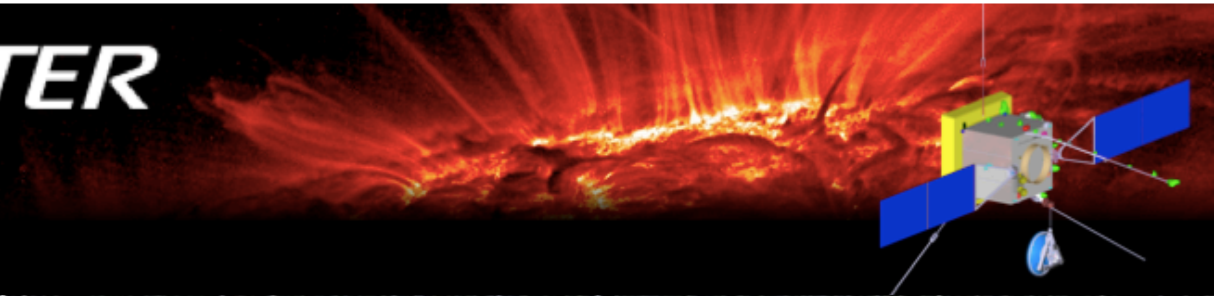

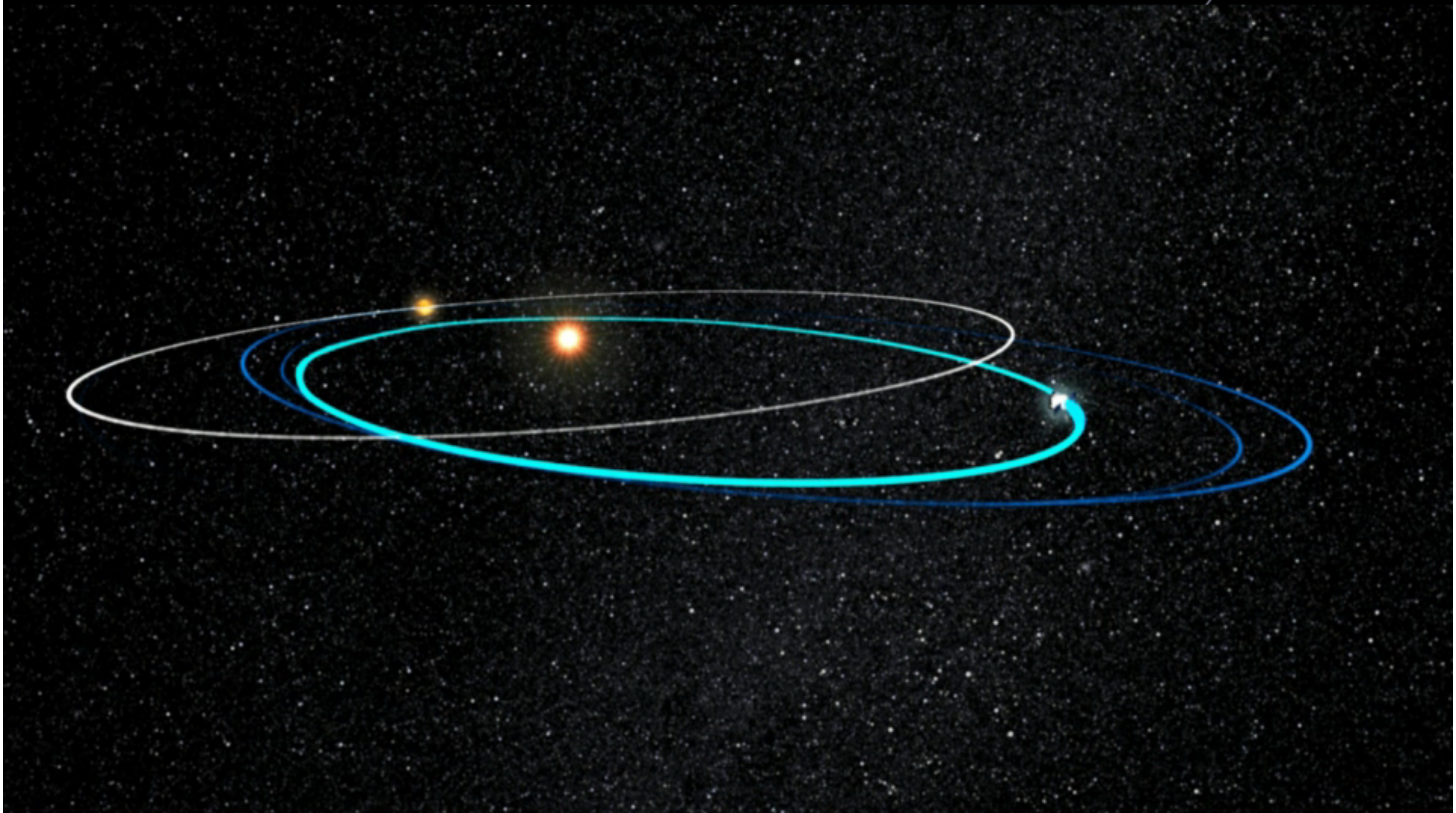

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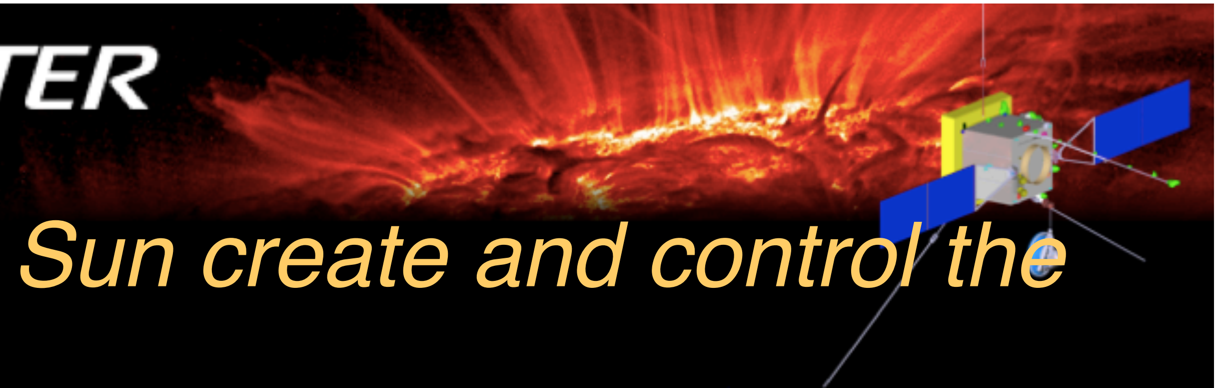


How does the Sun create and control the Heliosphere ?

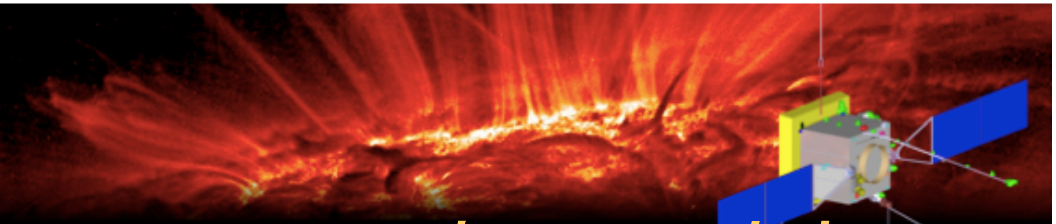
Q1) How and where do the solar wind plasma and magnetic field originate in the corona?

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?

SOLAR ORBITER



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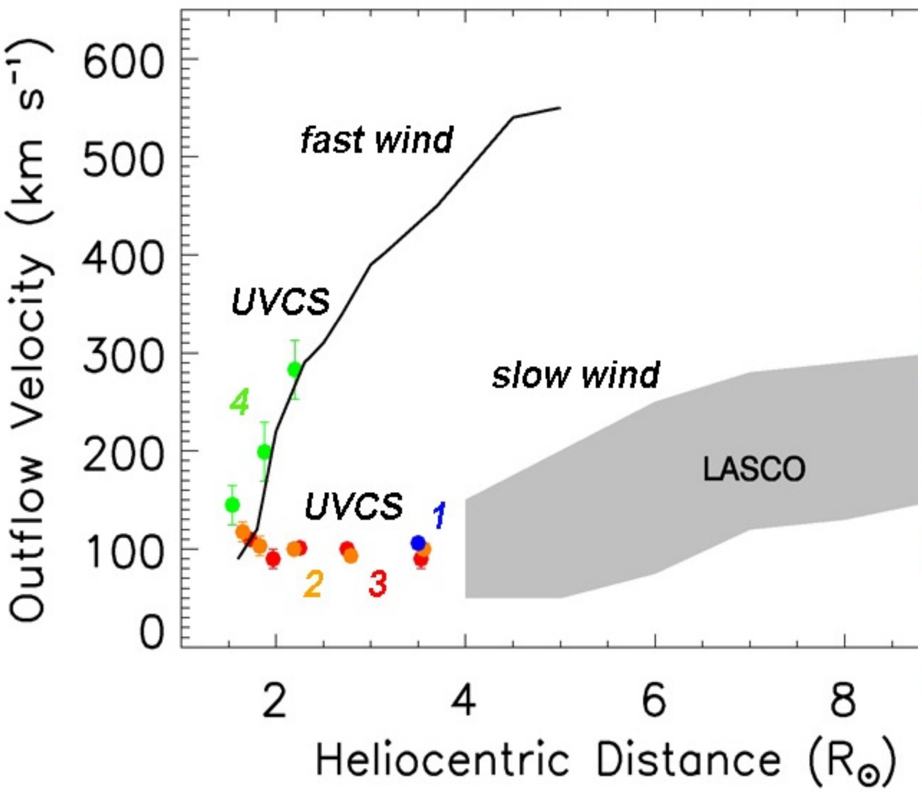
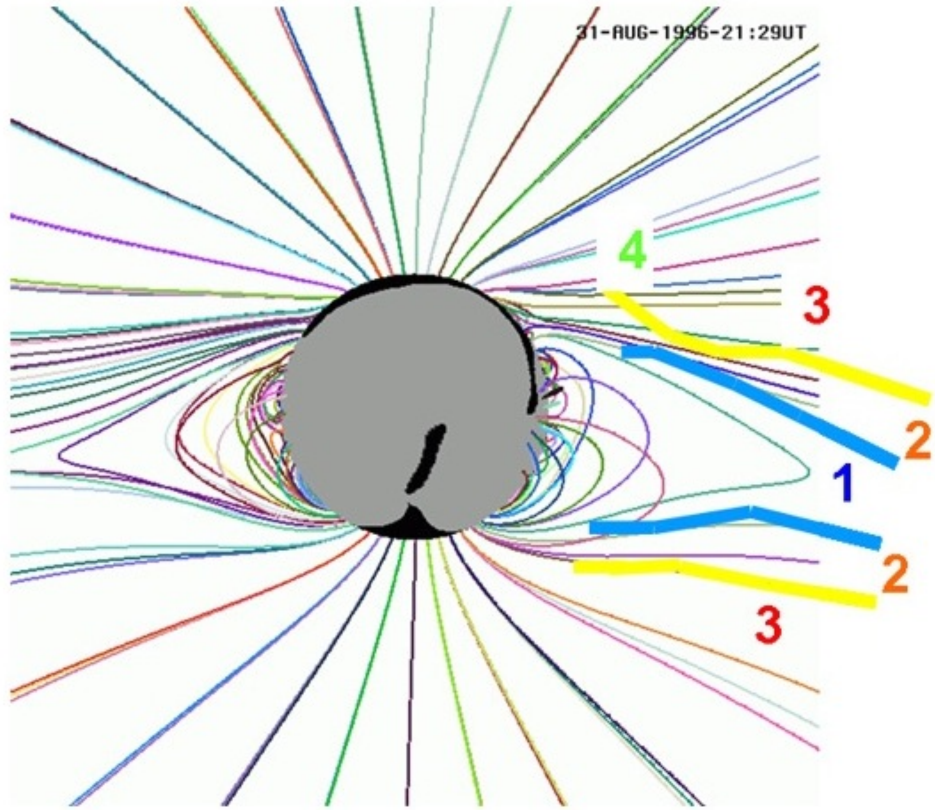
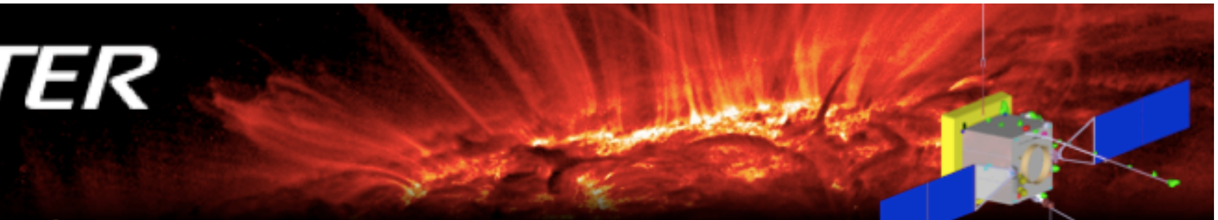

Outflow Velocity (km s-1)
Heliocentric Distance (R☉)
fast wind
slow wind
UVCS
UVCS
LASCO
1
2
3
4
0
100
200
300
400
500
600
2
4
6
8


31-AUG-1996-21:29UT
4
3
2
1
2
3

SOLAR ORBITER



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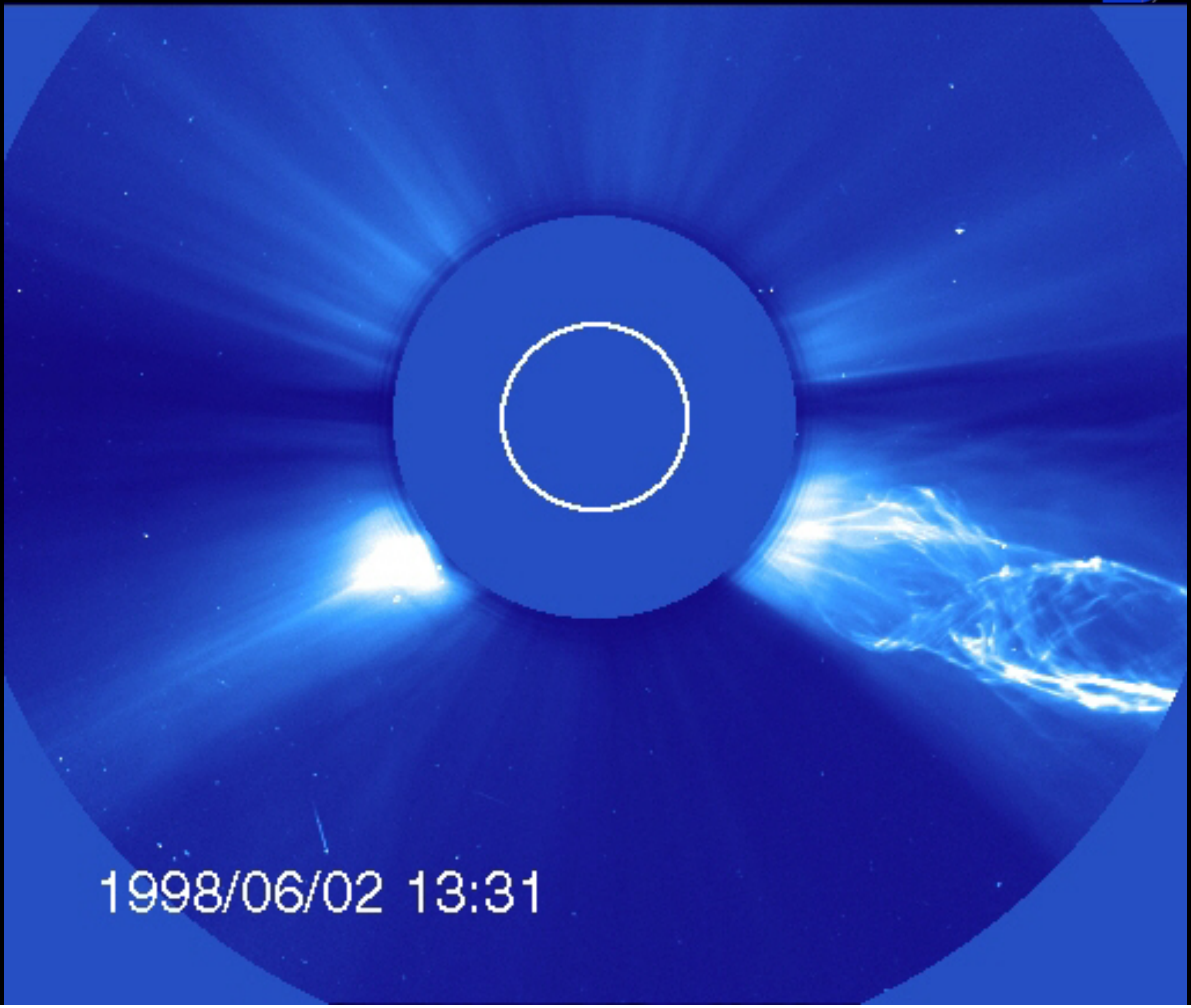

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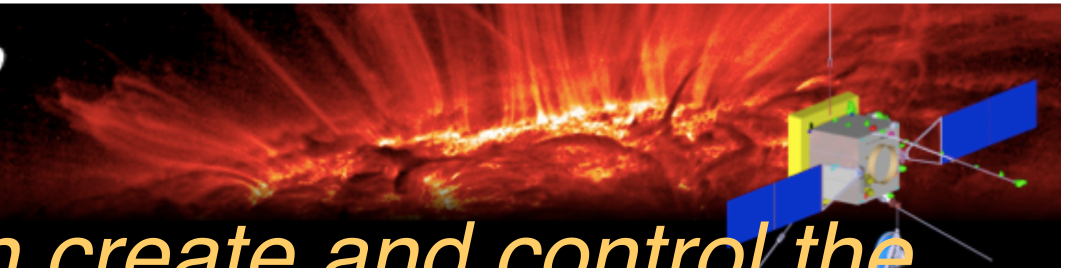

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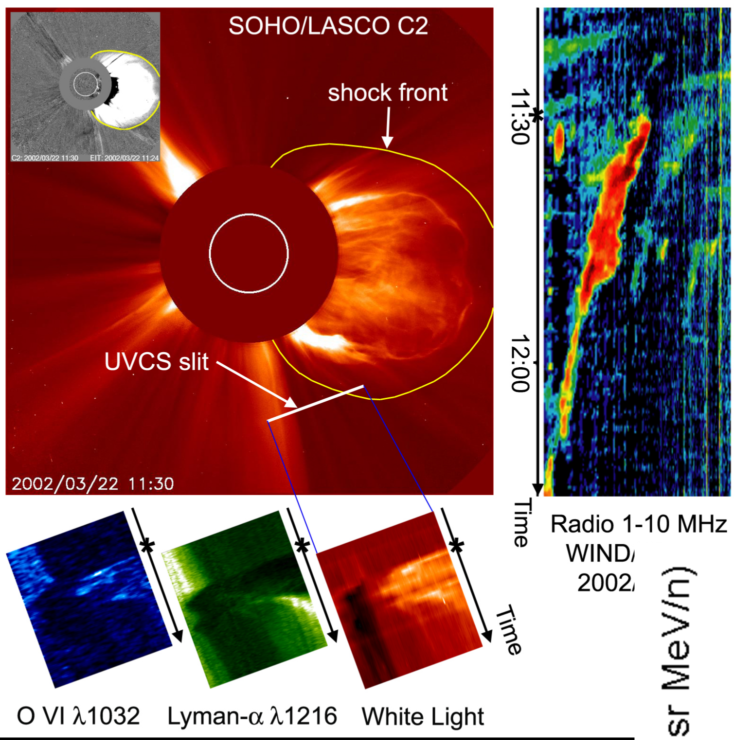

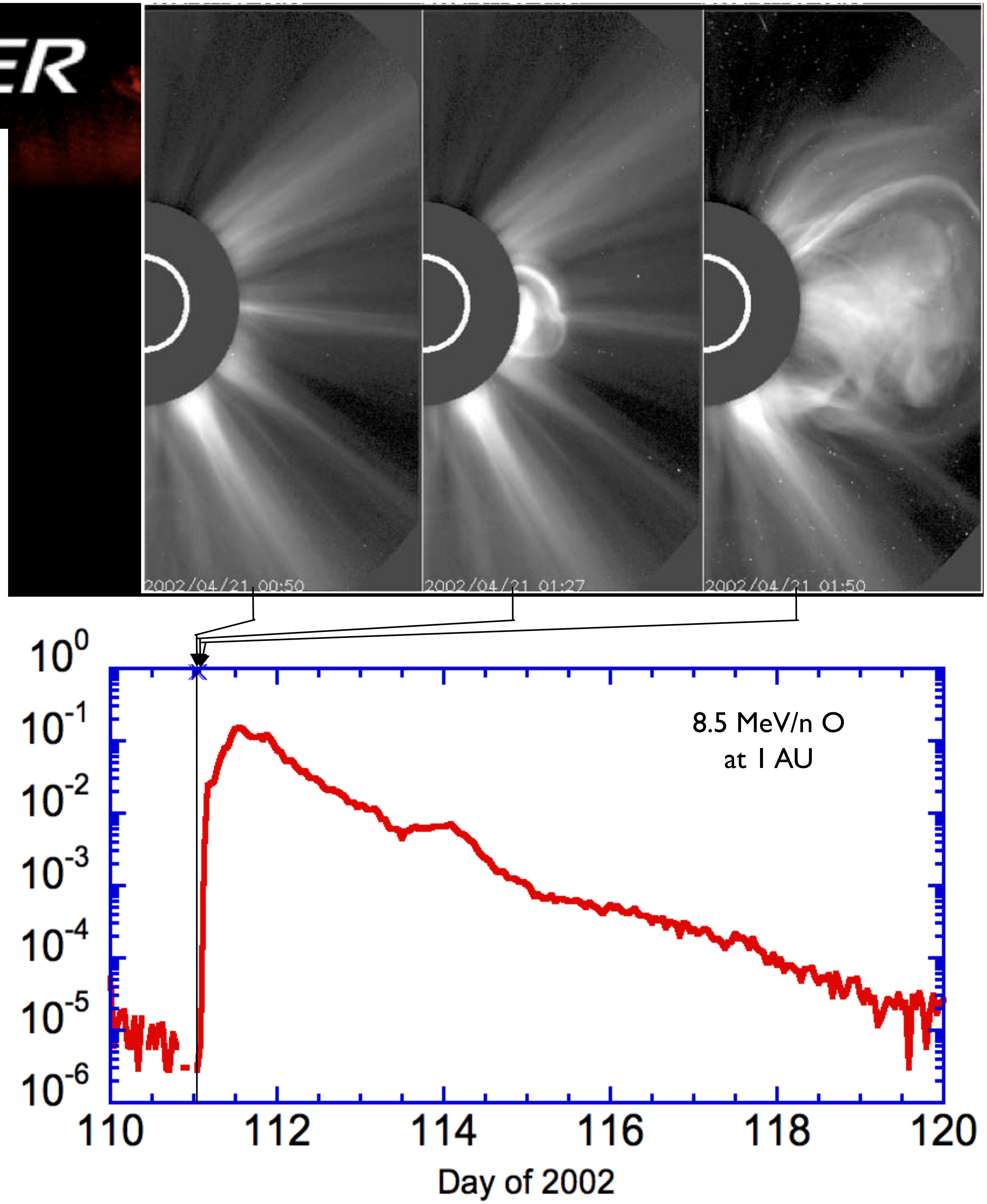

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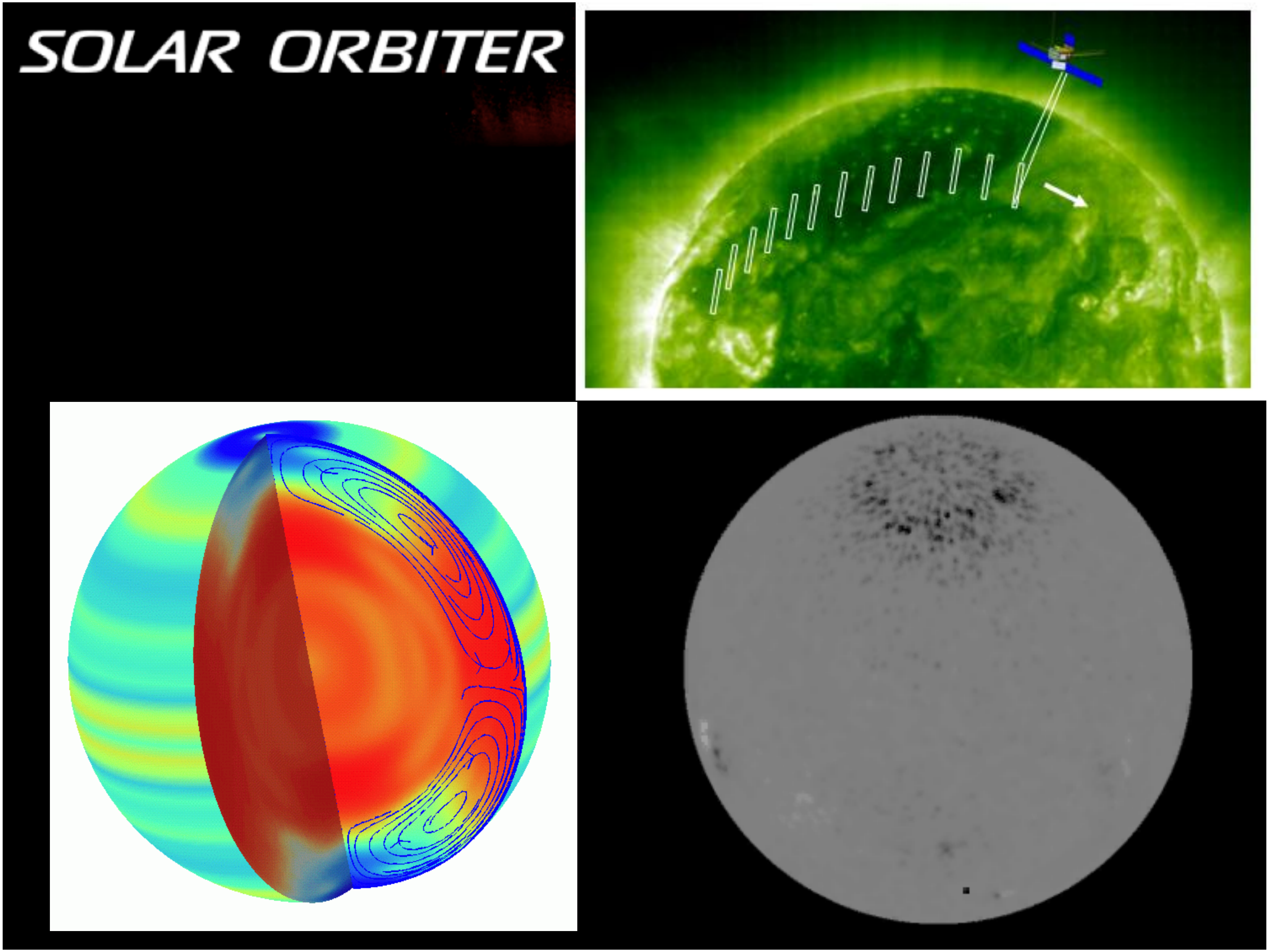
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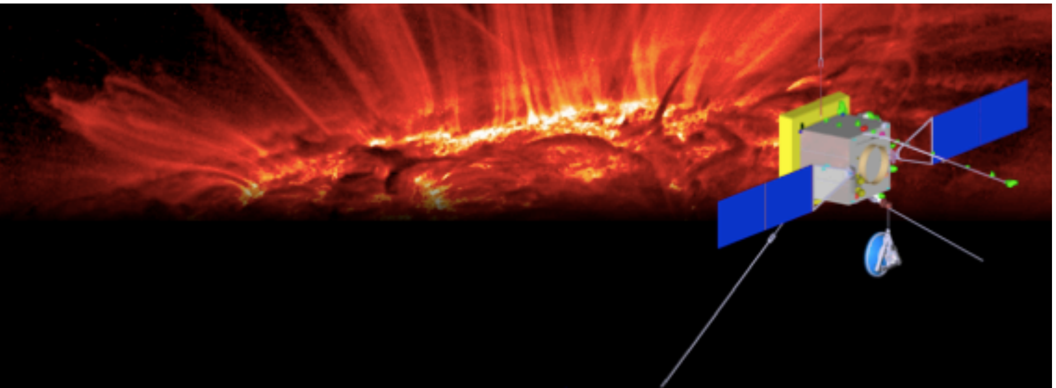

Conclusions

Solar Orbiter answers the Cosmic Vision question „How does the solar system work?“ :

- Exemplified by the theme of Sun-Heliosphere Connection: Solar Orbiter will reveal how the Sun creates and drives the heliosphere.
- The selected payload is optimized to answer the most fundamental science questions of solar and heliospheric physics
- It is an exciting, well studied and mature mission, with focused and timely scientific objectives.
  Now is the time for Solar Orbiter.