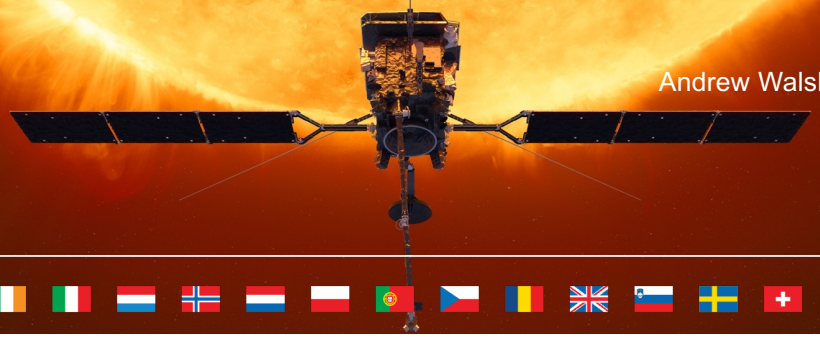
Solar Orbiter: Mission Status, Science Highlights and Look-Out for the High-Latitude Phase



Anik De Groof,
Daniel Müller, Yannis Zouganelis, Miho Janvier,
Andrew Walsh, David Williams, Pedro Osuna, Catherine Fischer

EGU General Assembly, Vienna, 29/04/2025

Solar Orbiter: Exploring the Sun and Heliosphere

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

Key mission characteristics:

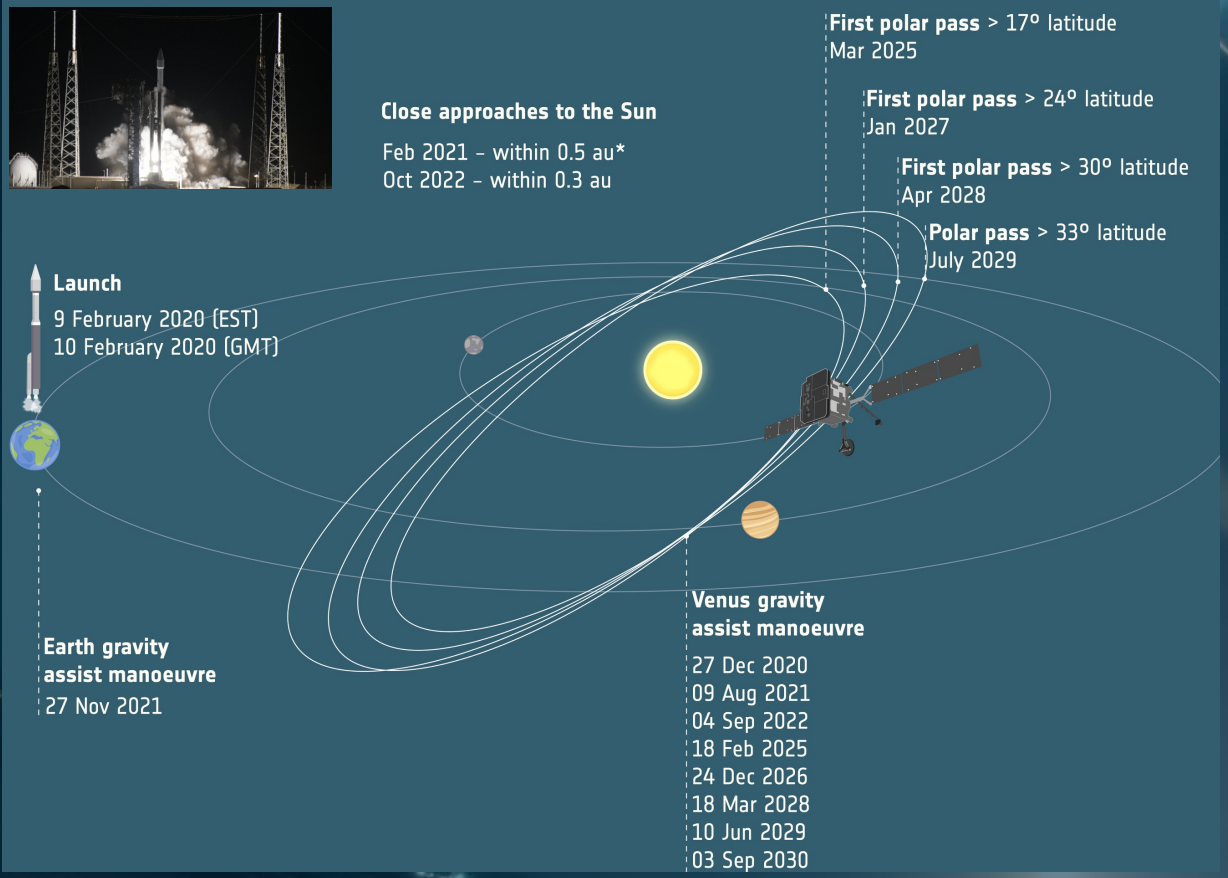
- Go closer to the Sun to disentangle space and time
- Incline orbit out of the ecliptic to observe the solar poles & measure high-latitude solar wind
- Coordinated high-resolution observations over solar cycle

Comprehensive payload:

- 10 remote-sensing and in-situ instruments
- Link the Sun's activity with solar wind variation

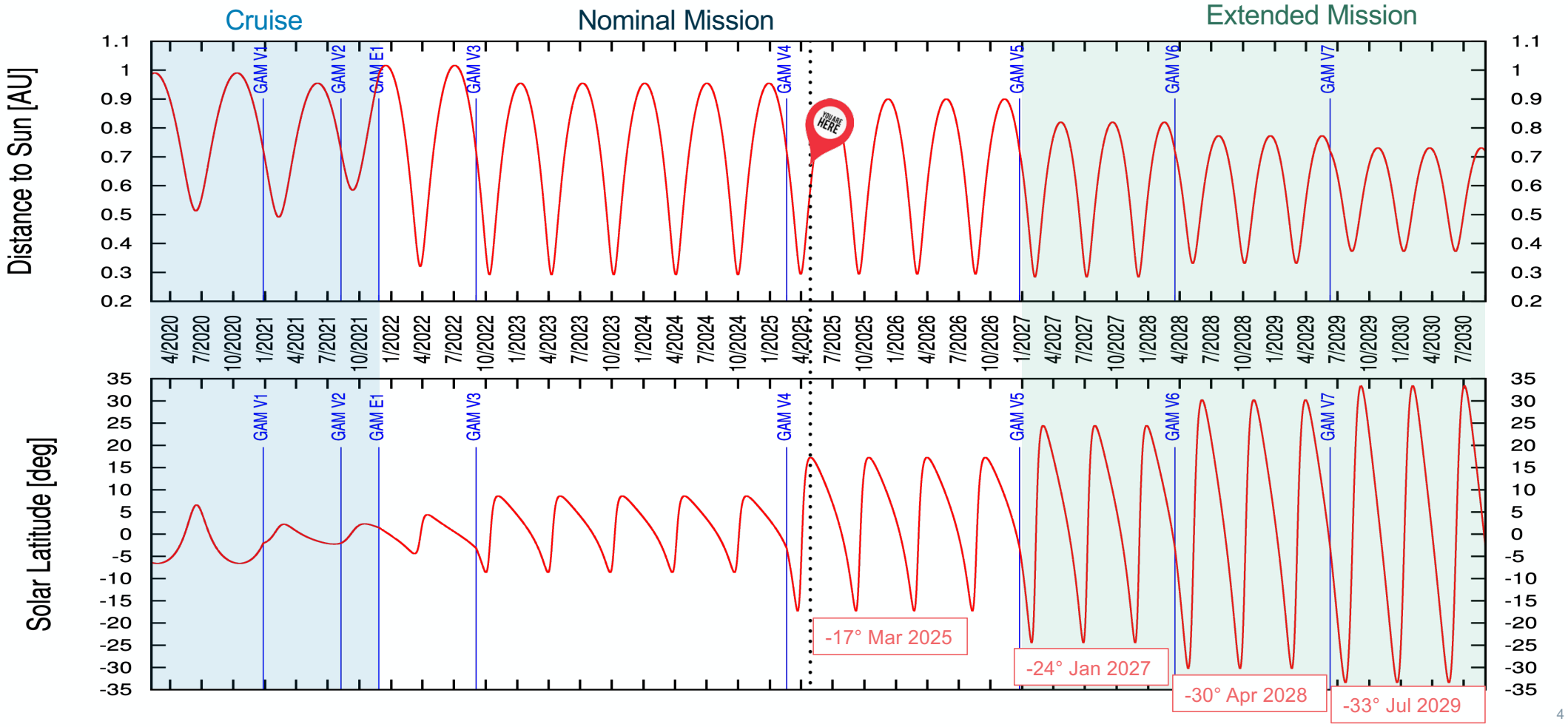
Mission overview:
Müller et al., A&A Special Issue, 2020

Where are we now?



- In February this year Solar Orbiter celebrated 5 years after launch.
- It has been 3.5 years in its Nominal Mission Phase:
  - Continuous InSitu + STIX observations
  - Remote Sensing Windows of intensive coordinated RS observations
  - Pointing coordinated with PSP, Hinode, IRIS, DKIST, …
  - RS synoptic observations along orbit
- As of February 2025 after Venus GAM #4 we entered ***High Latitude Mission Phase.***

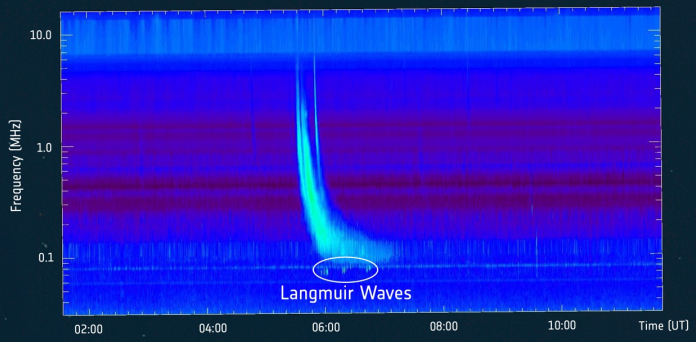
Mission Timeline



JOINING THE DOTS

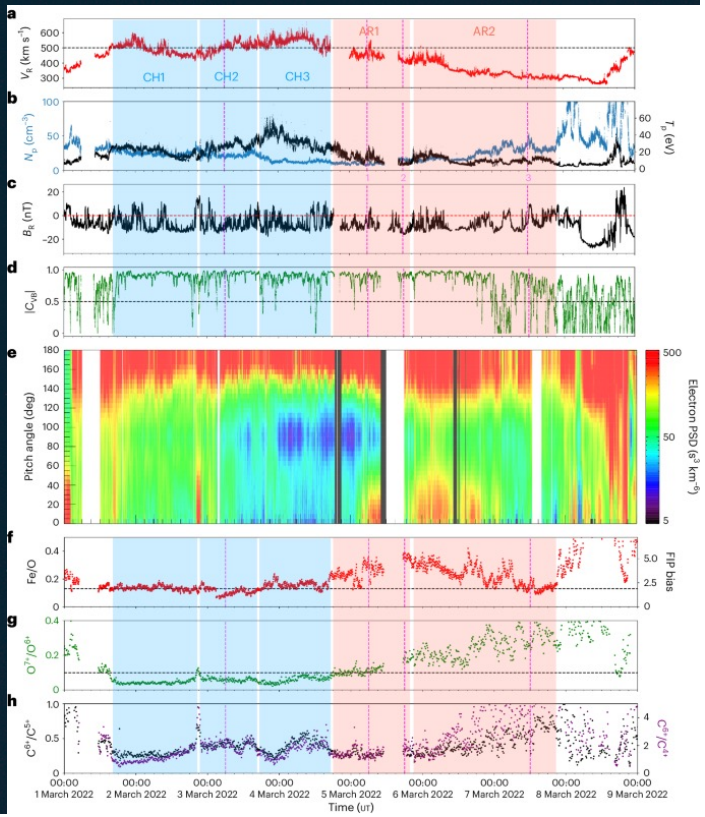
Solar Orbiter traced an energetic particle event on 21 March 2022 from the Sun through the solar wind

Also in March 2022, slow solar wind could be traced back to its source regions.

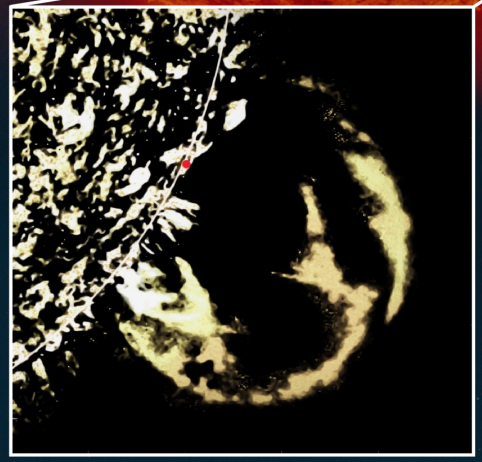


RPW detects radio signals of accelerated particles and plasma oscillations

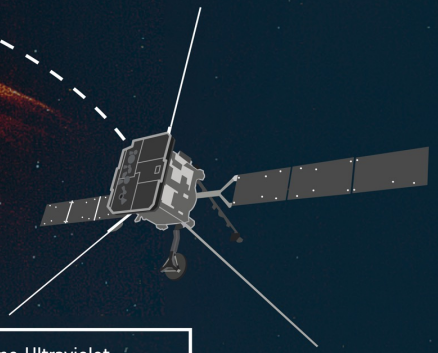
MAGnetic field In-Situ can be linked to source solar wind



Particles spiraling out on Sun's magnetic field lines reach Solar Orbiter



STIX observes source X-ray flare (red dot), **EUI** a shock wave (green)



EUI: Extreme Ultraviolet Imager

EPD: Energetic Particle Detector

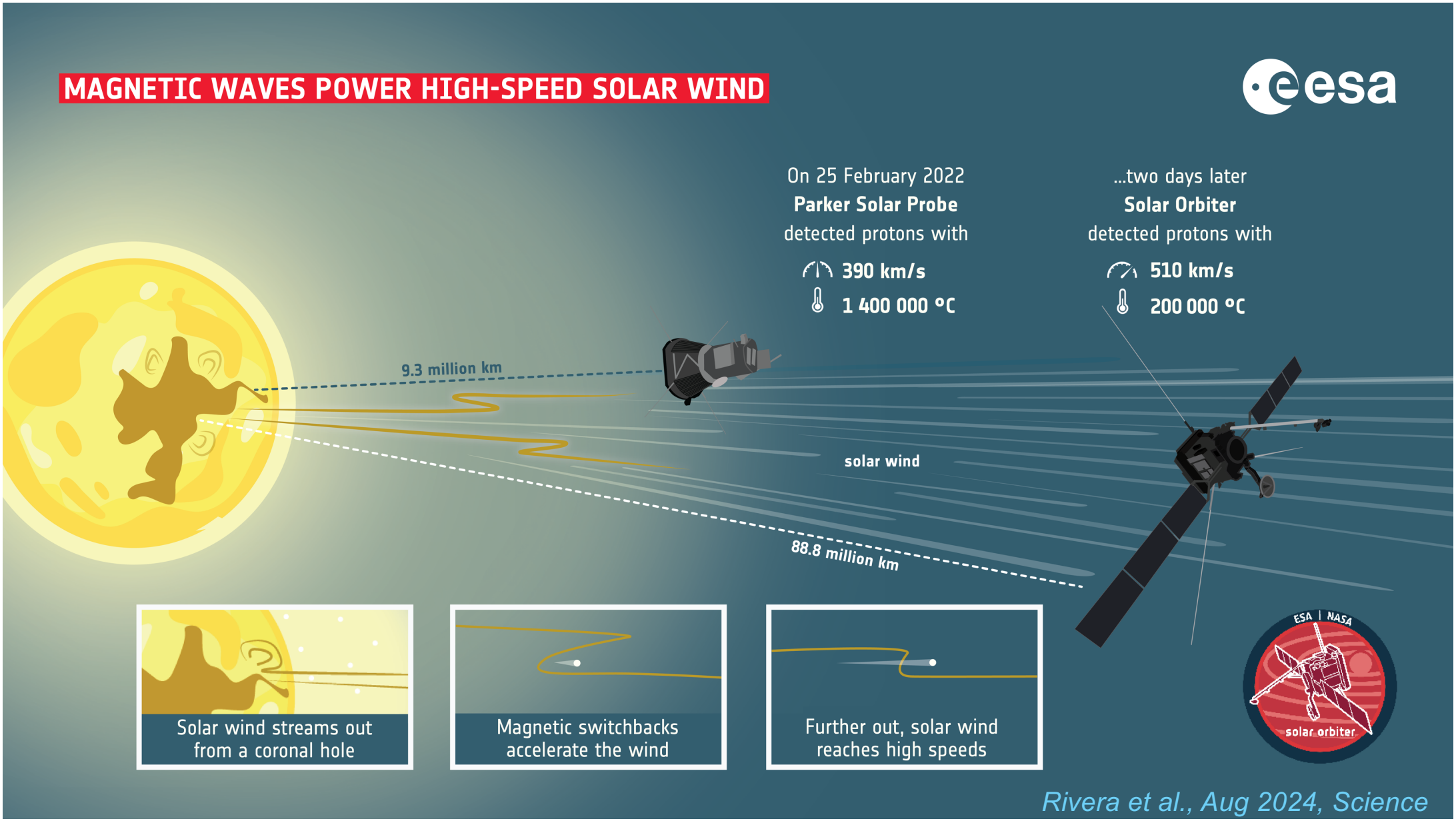
RPW: Radio and Plasma Waves

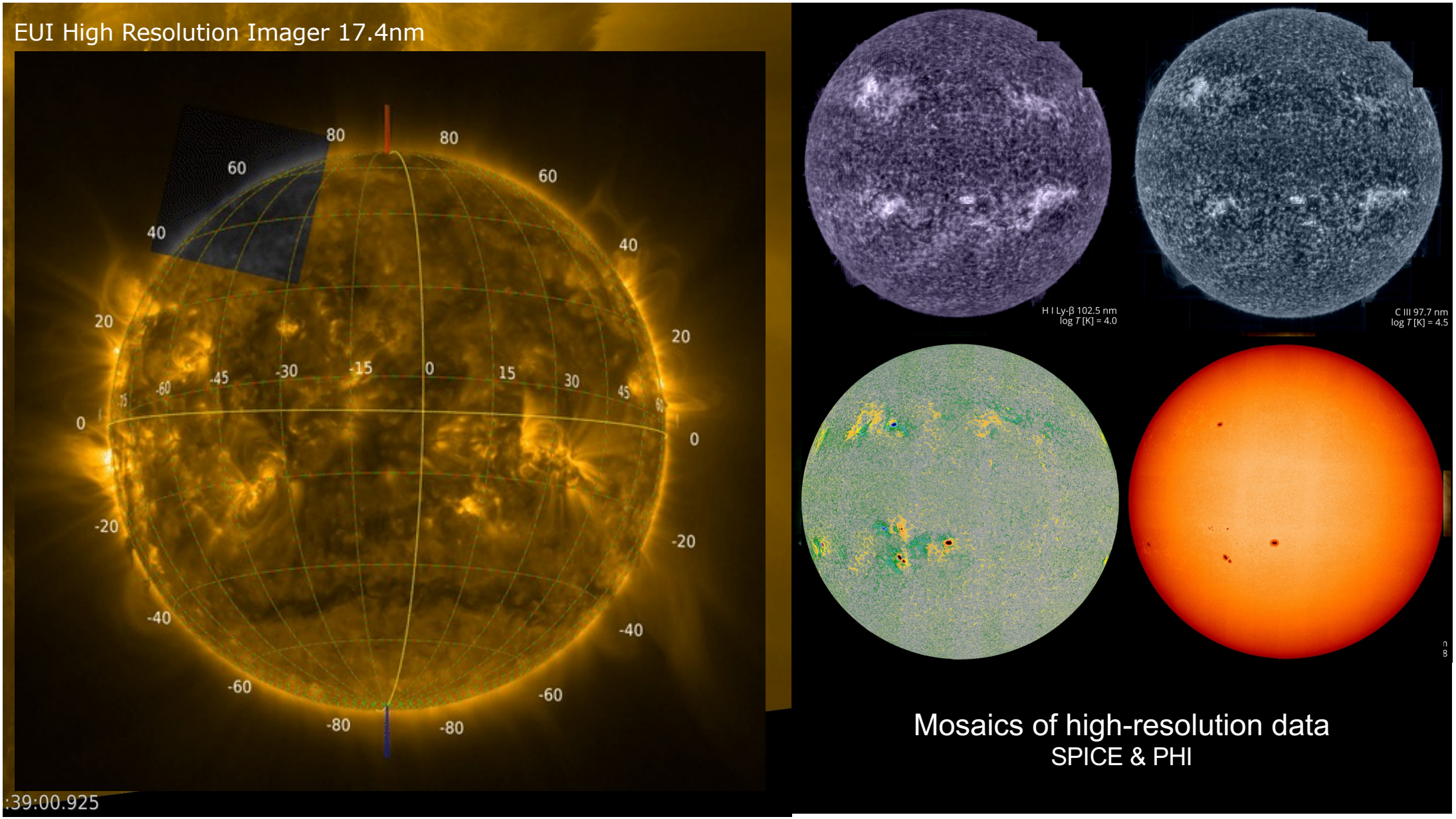
STIX: X-ray Spectrometer/ Telescope

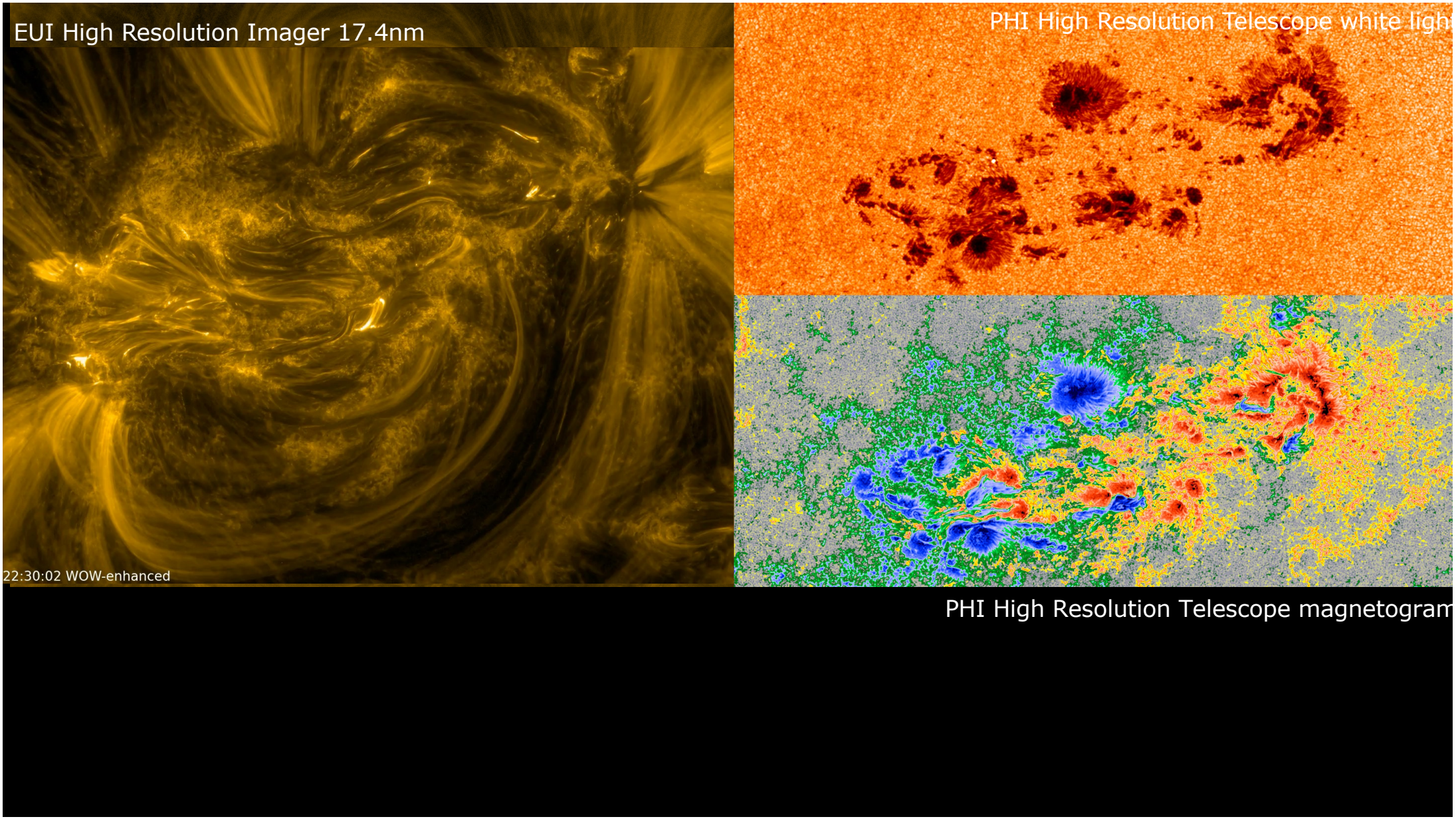
ESA & NASA/Solar Orbiter/EPD, EUI, RPW & STIX Teams

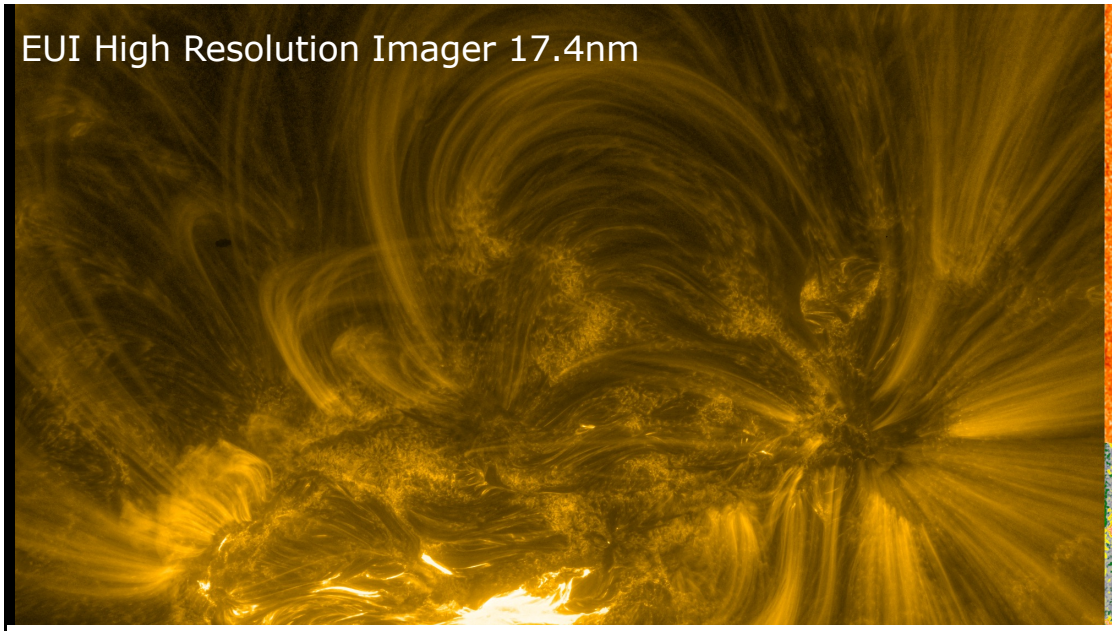
Yardley et al., ApJS 2023

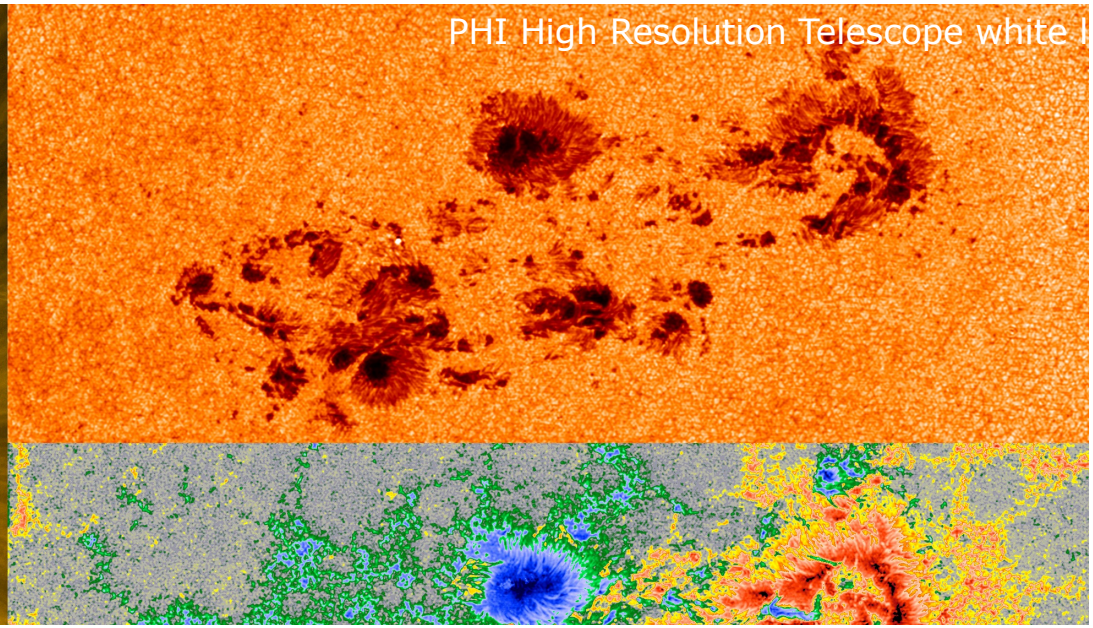
Yardley et al., Nature Astronomy 2024

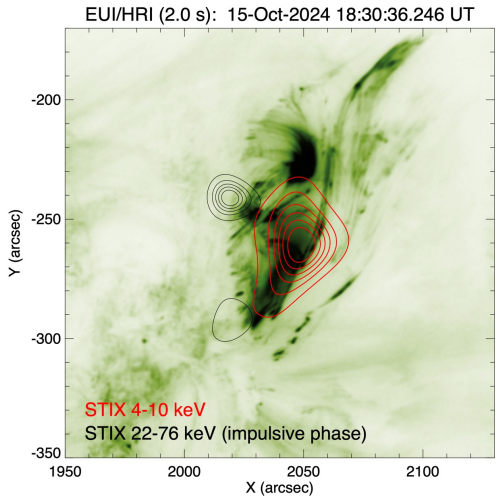

MAGNETIC WAVES POWER HIGH-SPEED SOLAR WIND
esa
On 25 February 2022
Parker Solar Probe
detected protons with
390 km/s
1 400 000 °C
...two days later
Solar Orbiter
detected protons with
510 km/s
200 000 °C
9.3 million km
solar wind
88.8 million km
Solar wind streams out from a coronal hole
Magnetic switchbacks accelerate the wind
Further out, solar wind reaches high speeds
ESA | NASA
solar orbiter
Rivera et al., Aug 2024, Science

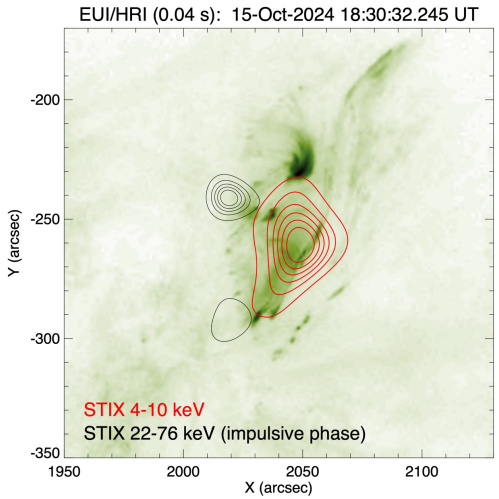

EUI High Resolution Imager 17.4nm
80
60
40
20
0
-20
-40
-60
-80
-30
-15
15
30
45
:39:00.925
H I Ly-β 102.5 nm
log T [K] = 4.0
C III 97.7 nm
log T [K] = 4.5
Mosaics of high-resolution data
SPICE & PHI

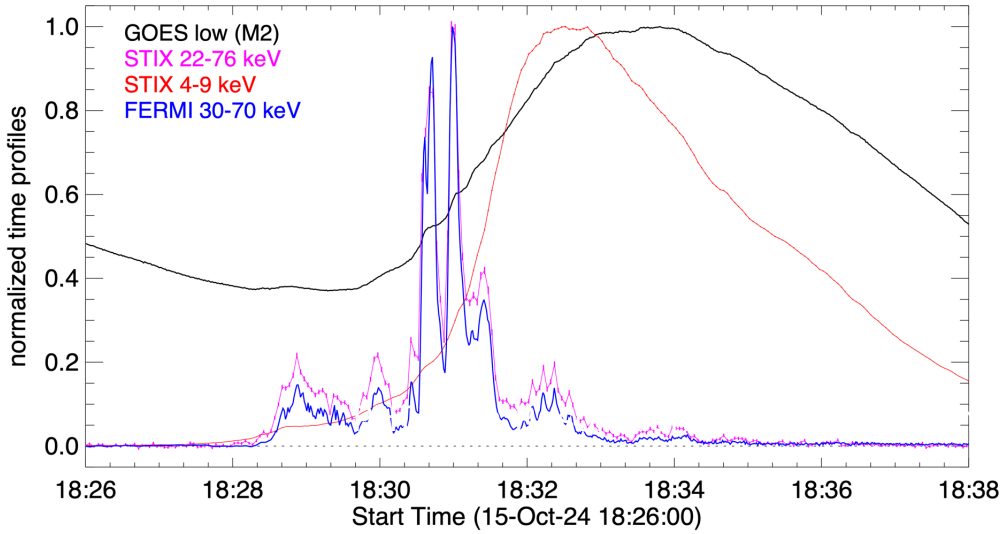

EUI High Resolution Imager 17.4nm
22:30:02 WOW-enhanced
PHI High Resolution Telescope white ligh
PHI High Resolution Telescope magnetogram



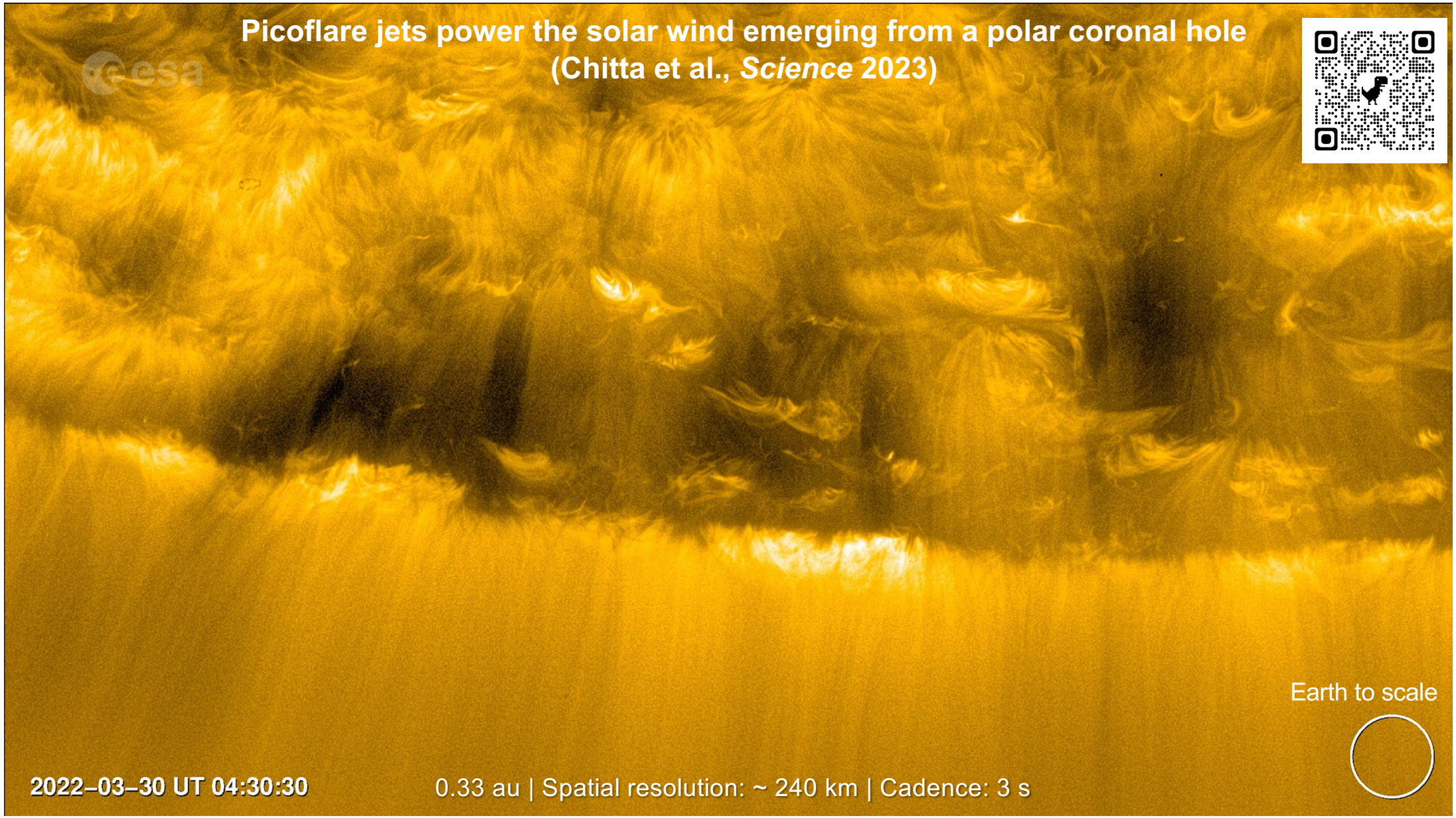








STIX X-ray telescope

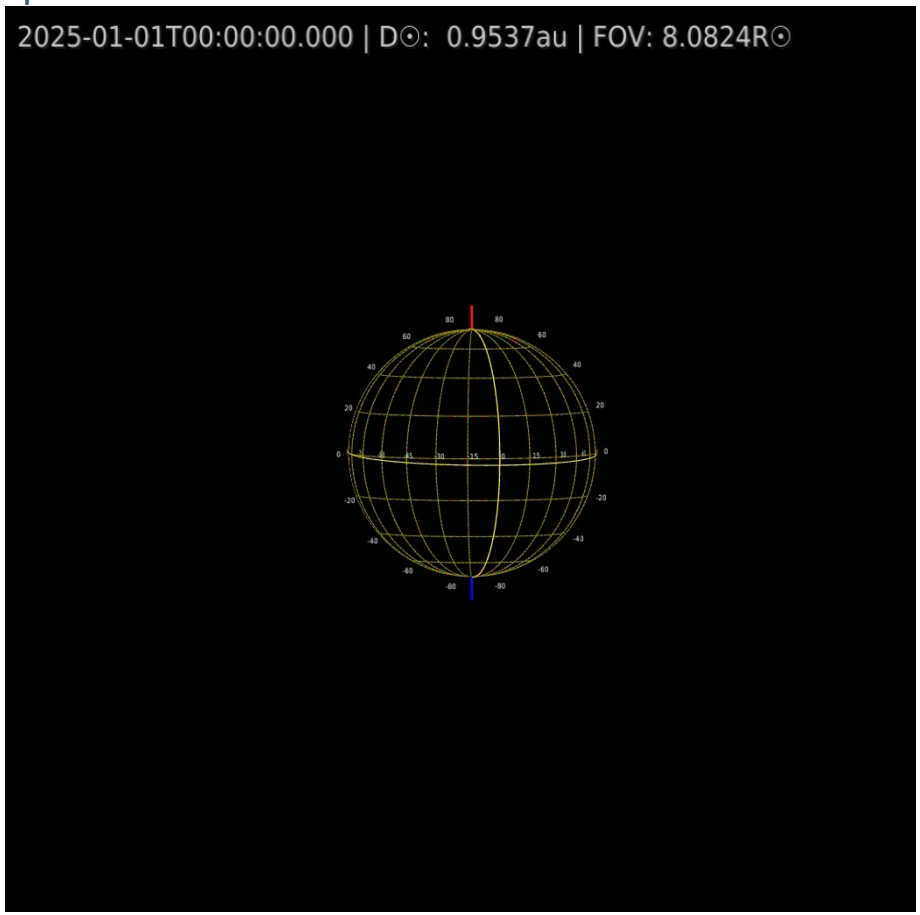

Picoflare jets power the solar wind emerging from a polar coronal hole
(Chitta et al., *Science* 2023)
esa
Earth to scale
2022–03–30 UT 04:30:30
0.33 au | Spatial resolution: ~ 240 km | Cadence: 3 s

Solar Orbiter High Latitude Phase

Solar Orbiter uses flyby's by Venus to tilt the orbit out of the ecliptic plane.

The last flyby, on 18 Feb 2025, allowed for the first time views of the Sun's higher latitudes not accessible by Earth (+- 17º heliographic latitude).

Last month: First views on South (22 Mar) & North pole (28 April)



Solar Orbiter High Latitude Phase

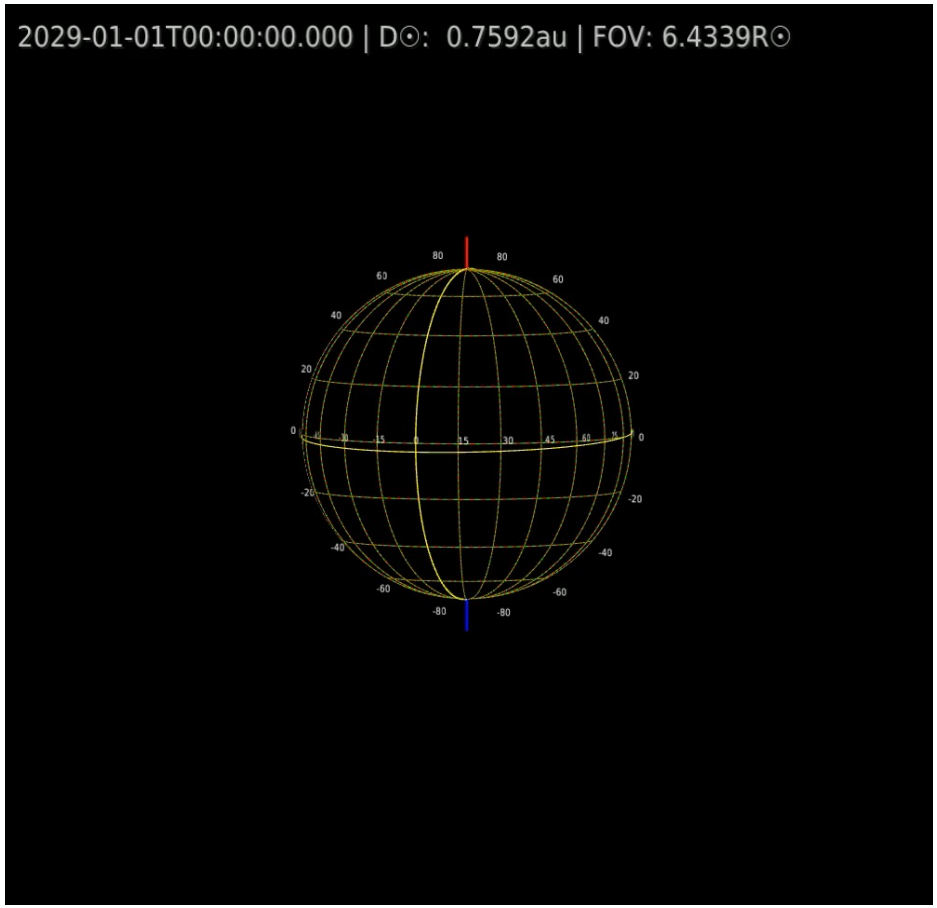
Solar Orbiter uses flyby's by Venus to tilt the orbit out of the ecliptic plane.

VGAM #4, on 18 Feb 2025, allowed for the first time views of the Sun's higher latitudes not accessible by Earth (+- 17º heliographic latitude).

In the coming years, the orbit will tilt further up to 33º in 2029.

This will provide

- Unprecedented views on the poles, in multiple wavelenghts
- In-Situ scans of the solar wind coming from latitudes ranging over 66 degrees
- Coronal imagery out of the ecliptic (Metis & SoloHI)



Solar Orbiter High Latitude Phase

New scientific opportunities!

However, it comes also with some challenges:

- Not getting as close to Earth as in previous orbits
- Orbits are shorter leading to an increase in RSW per year (9 in 2027!)
- Starting 2026 RS window locations start shifting within the calendar year

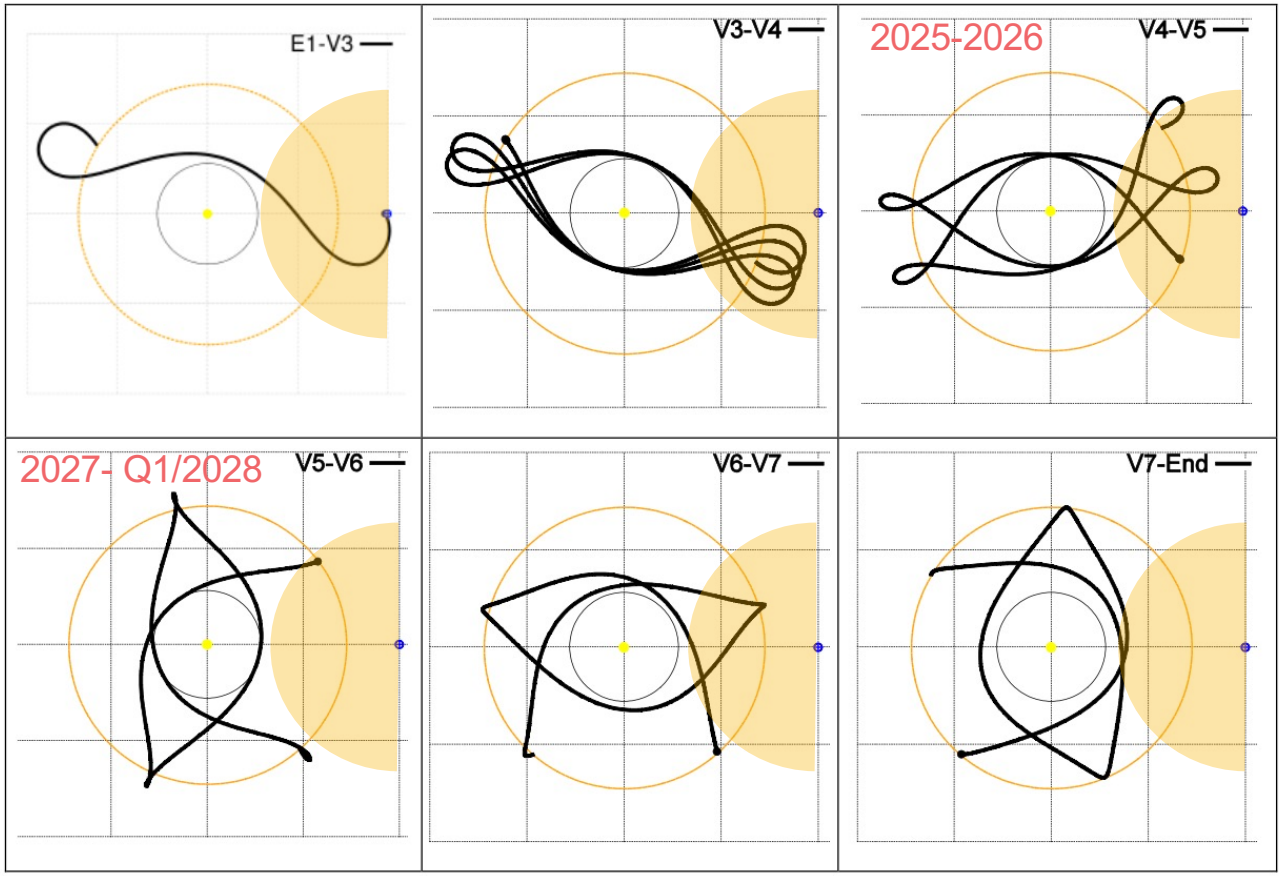
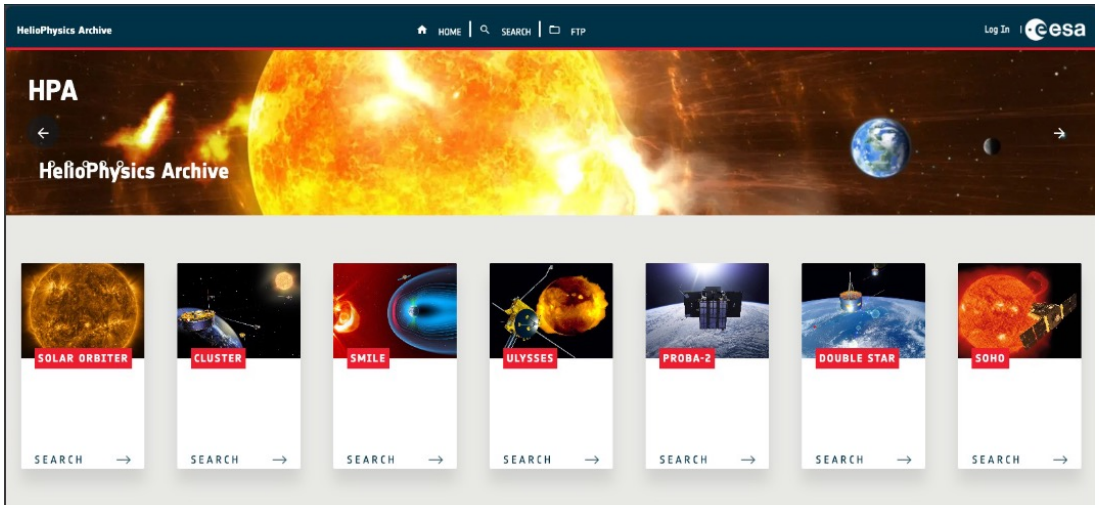
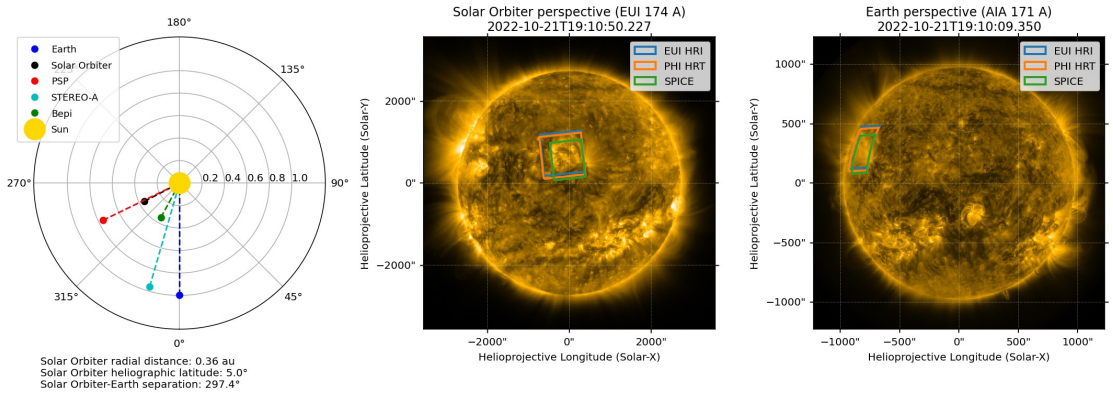


Figure 3-6 2020 February Launch: Science orbits projection in the Sun-Earth rotating frame

Useful links and references

- ESA News Stories & Video releases:
  www.esa.int/Science_Exploration/Space_Science/Solar_Orbiter
- Solar Orbiter science nuggets:
  www.cosmos.esa.int/web/solar-orbiter/science-nuggets
- Solar Orbiter Community Building Webinars:
  www.cosmos.esa.int/web/solar-orbiter/meetings
- Solar Orbiter and Heliophysics Archive:
  https://soar.esac.esa.int/soar/
  https://hpa.esa.int/hpa/
- Where is Solar Orbiter?
  https://solarorbiter.esac.esa.int/where/

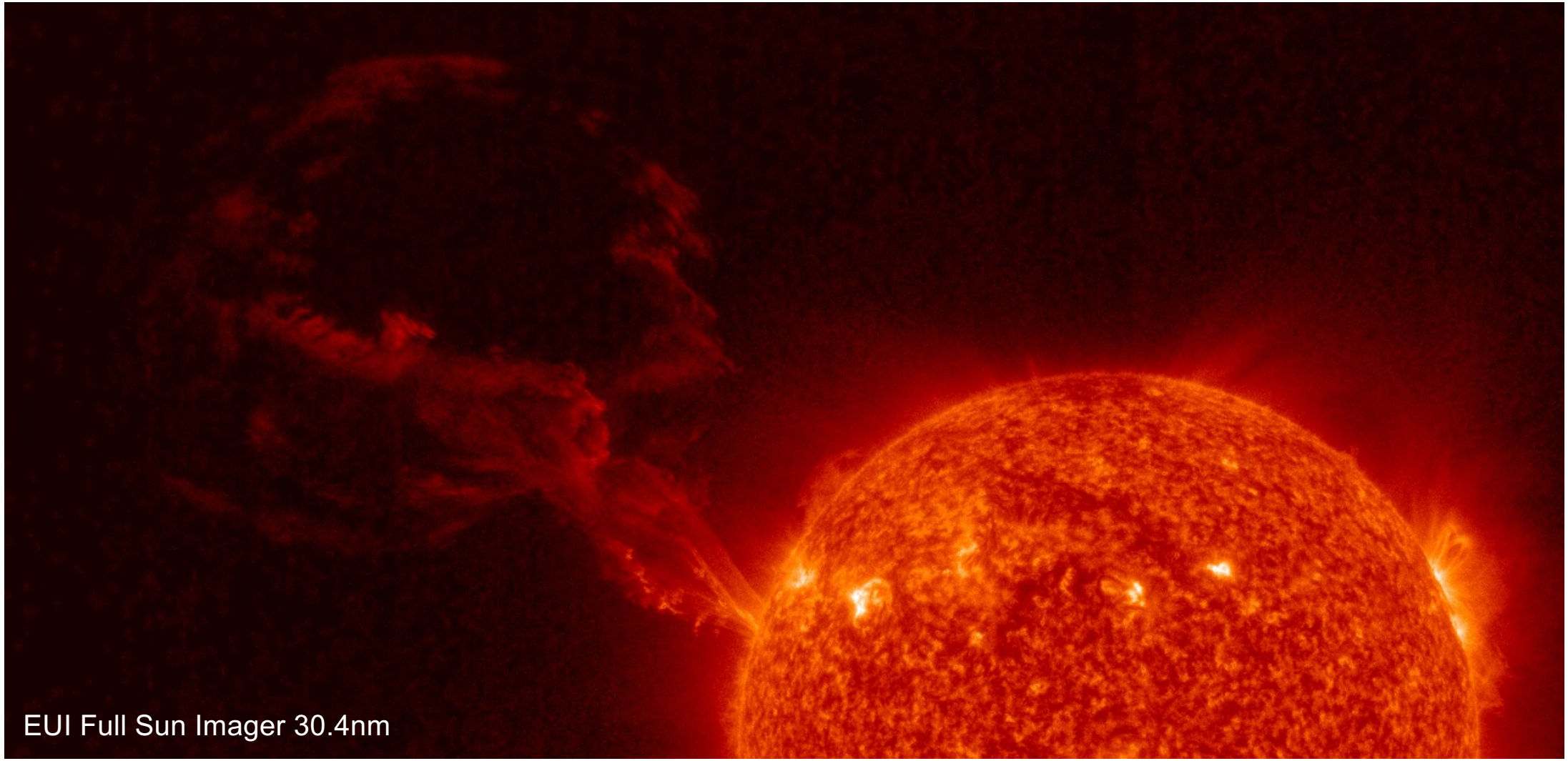




See also backup slides for more information

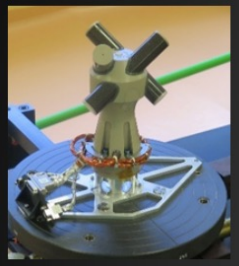
Experiment	Sensor	Time	SOOP name	X/Y location from Solar Orbiter	from Earth
EUI	HRI_EUV	2022-10-21 19:10:50.221-19:10:51.871	R_SMALL_MRES_MCAD_AR-Long-Term	-166"/728"	-796"/301"
PHI	HRT	2022-10-21 19:15:03.019-19:16:28.577	R_SMALL_MRES_MCAD_AR-Long-Term	-170"/668"	-802"/280"
SPICE	SW	2022-10-21 19:13:03.168-19:24:21.564	R_SMALL_MRES_MCAD_AR-Long-Term	-42"/566"	-805"/241"

Backup slides



Scientific instruments: in situ

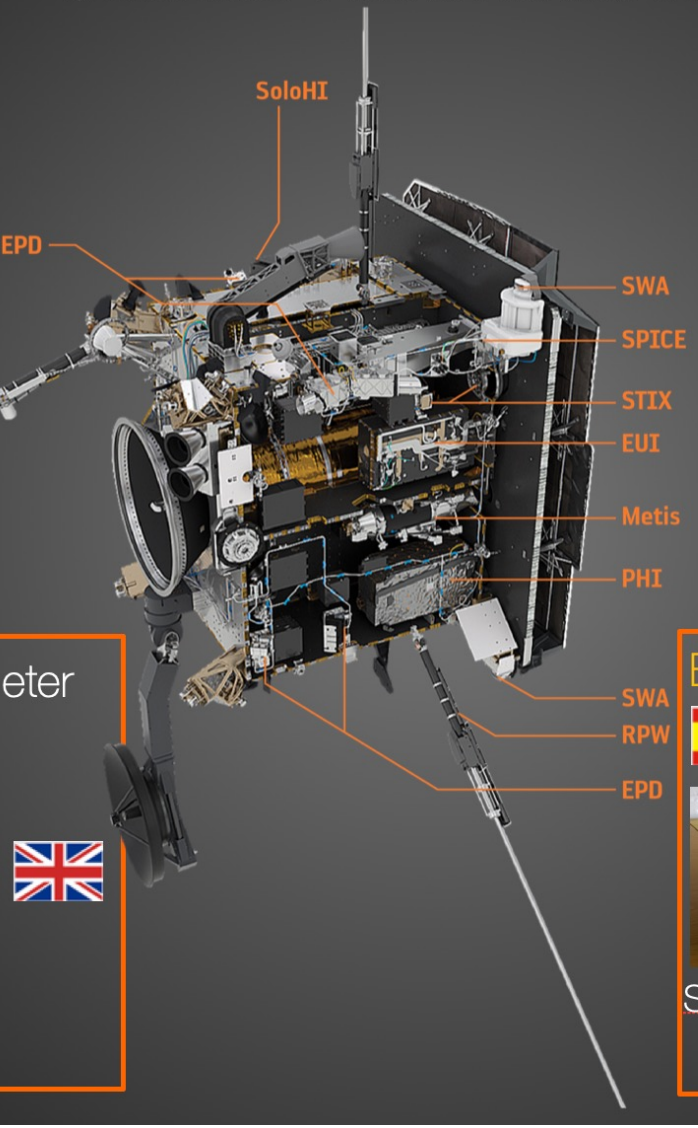
RPW: Radio & Plasma Waves



Search Coil Magnetometer

MAG: Magnetometer

Fluxgate Sensor (cover removed)



SWA: Solar Wind Analyser

Heavy Ion Sensor

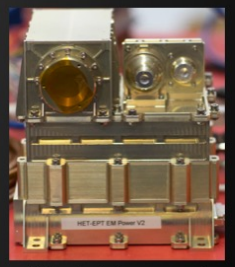
Electron Analyser System

Proton Alpha Sensor

EPD: Energetic Particle Detector

Suprathermal e^- and p^+

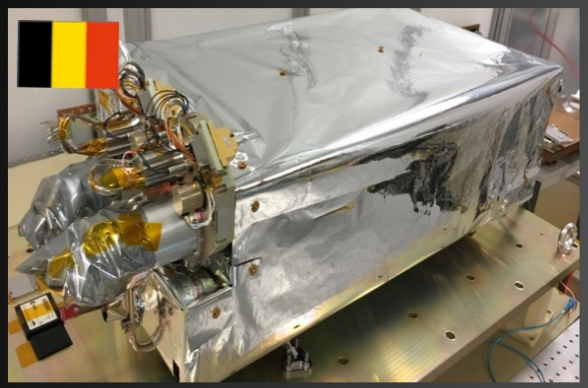
Suprathermal Ion Spectrograph



High Energy/ e^- p^+ Telescope

Scientific instruments: remote sensing

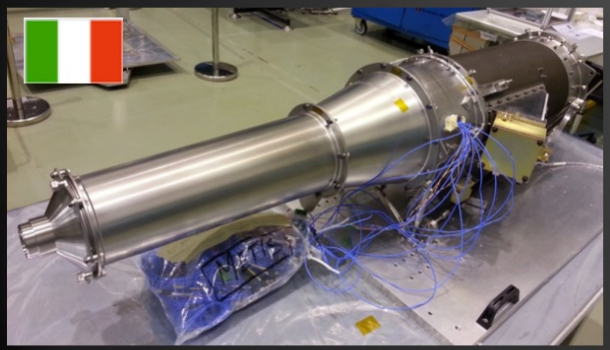
EUI: Full disk and high resolution images in EUV



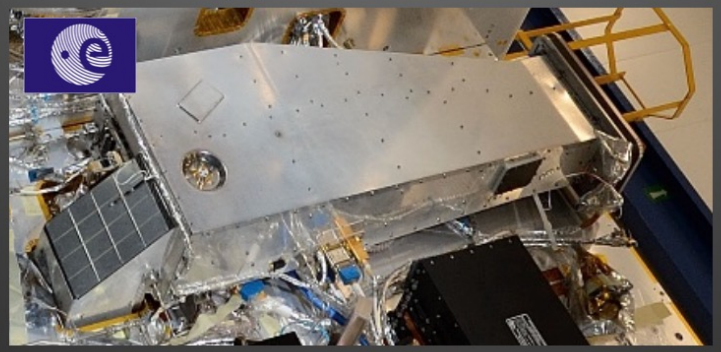
PHI: Full disk & high res vector magnetograms & velocity maps

STIX: Localise flares, record X-ray spectra

Metis: Coronagraphy in UV & visible



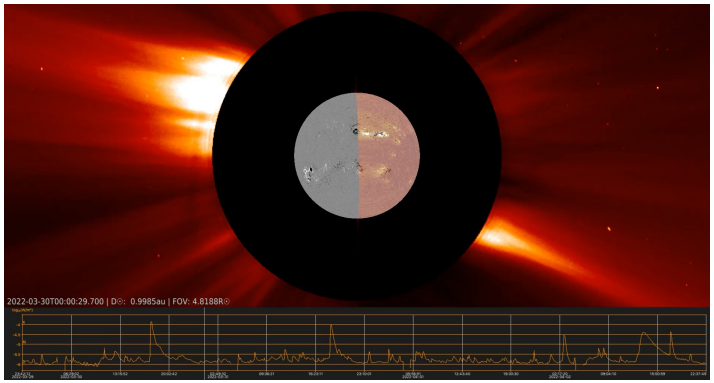
SPICE: EUV on-disk & off-limb spectroscopy



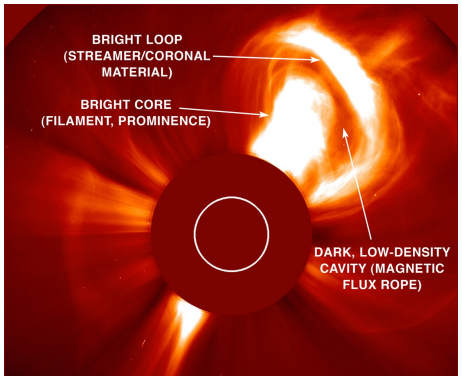
SoloHI: Heliospheric imager

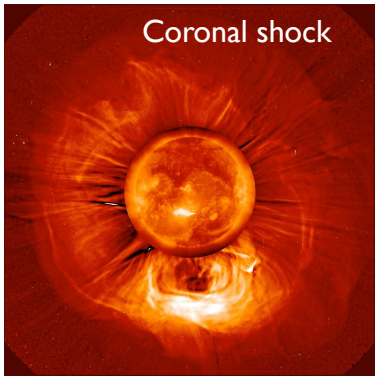
Answering the big questions in Solar Physics

#1: How and where do the solar wind plasma and magnetic field originate?

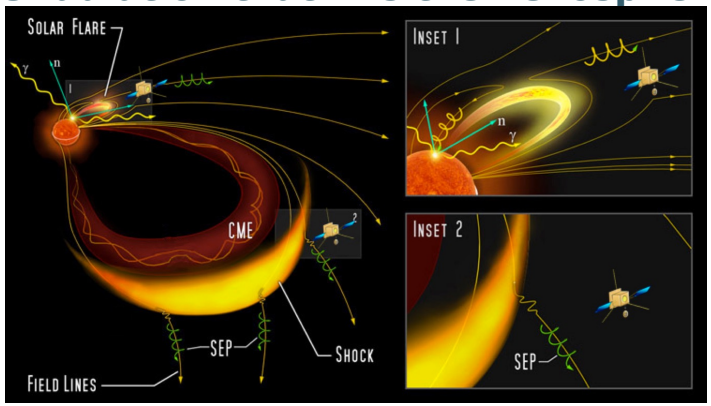


#2: How do solar transients drive heliospheric variability?

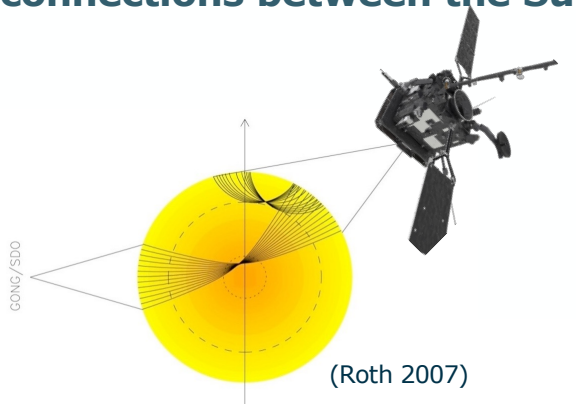




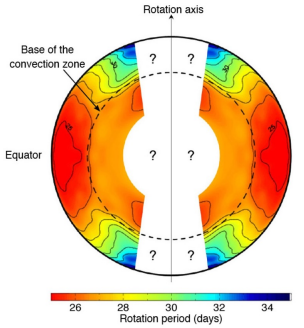
#3: How do solar eruptions produce energetic particle radiation that fills the heliosphere?



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



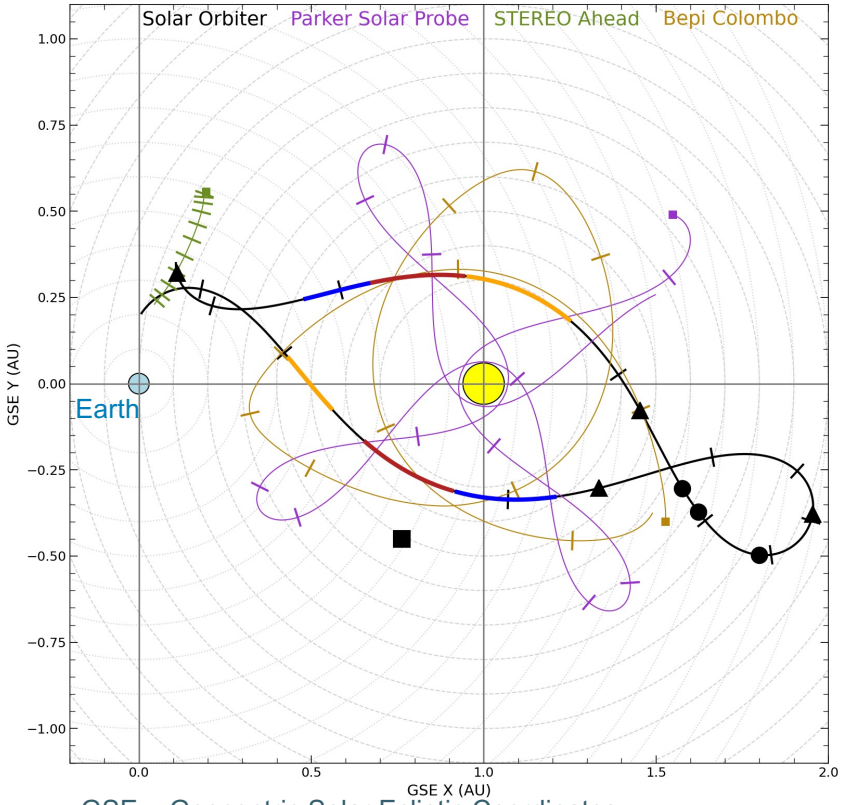
(Roth 2007)



Solar Orbiter's unique view on the Sun

Solar Orbiter's unique orbit around the Sun comes with some practical implications:

- **Changing viewpoint** with respect to Earth, changing **solar distance & latitude**
- Encounter mission -> limited resources
  - In-Situ payload & STIX observing continuously, rates vary along the orbit
  - Remote-sensing observations concentrated in **RS windows around perihelion & high-latitudes,**
  - RS synoptic observations along the orbit

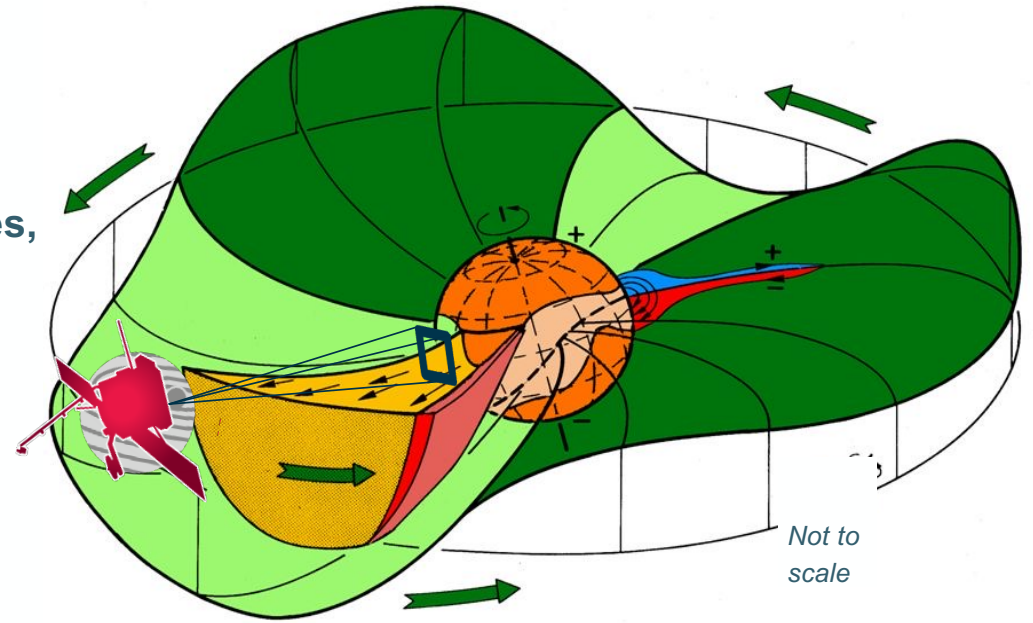


GSE = Geocentric Solar Ecliptic Coordinates

Solar Orbiter's unique view on the Sun

Solar Orbiter's unique orbit around the Sun comes with some practical implications:

- **Changing viewpoint** with respect to Earth, changing **solar distance & latitude**
- Encounter mission -> limited resources
  - In-Situ payload & STIX observing continuously, rates vary along the orbit
  - Remote-sensing observations concentrated in **RS windows around perihelion & high-latitudes,**
  - RS synoptic observations along the orbit



- RS window observations are coordinated in campaigns: **Solar Orbiter Observation Plans (SOOPs)**
- Solar Wind modelling for pointing decisions
- **Coordinated campaigns** with PSP, Hinode, IRIS, DKIST, Gregor, STEREO, ALMA, …

Solar Orbiter Science Operations Planning

Mission Level Plan (9-12 months ahead)

Decide on science priorities next year; place RS windows

Science Working Team
(+ requests for collaboration)

Long Term Plan (3-6 months ahead)

Coordinated observation plan for 3 months (SOOPs)
incl. optimal resource planning (data management)

Science Operations
Working Group
+ SOOP coordinators

Short Term Planning (1-2 weeks ahead)

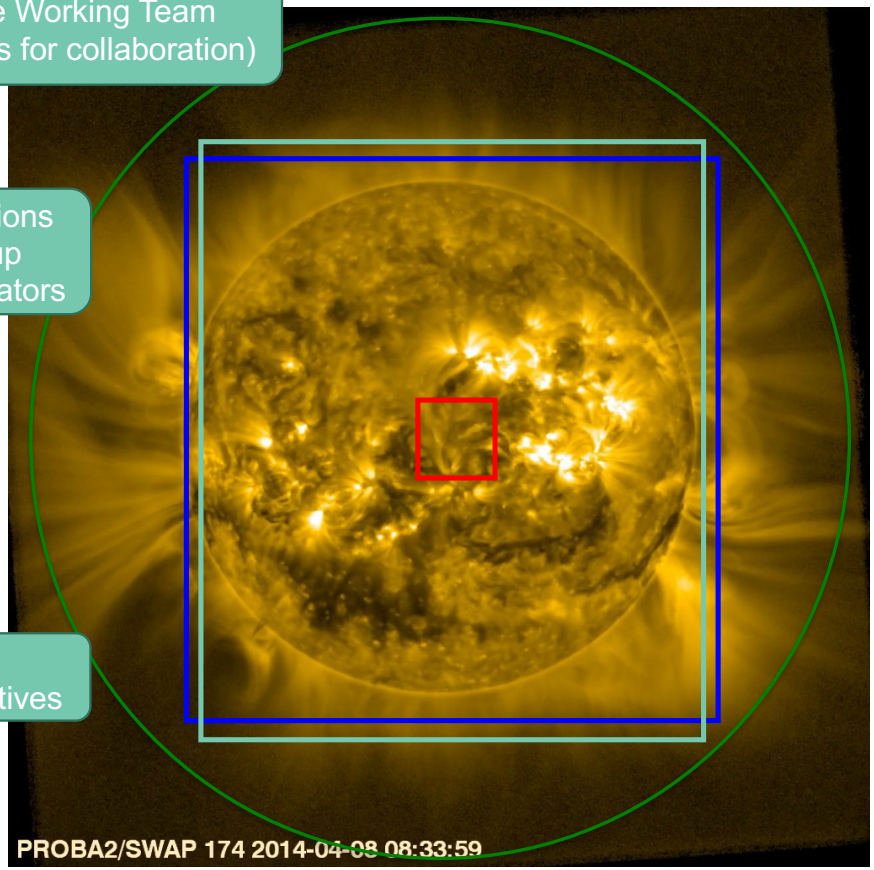
Individual instrument operations requests.
Uplink commands after constraint checking at ESAC and ESOC.

PI teams

Very-Short Term Planning (2-3 days ahead)

Spacecraft Pointing & instrument configuration
can be updated to few days in advance of actual operations

SOOP coordinators
+ instrument representatives



Be aware

- Solar Orbiter is **not a monitoring mission.** Instrument modes change, coordinated in SOOPs, to address varied science goals, according to varying opportunities.

- Unique orbit causes **changes in viewpoint, fields-of-view** and **RS resolution**
  1 arcsec as seen from Earth spans 4x wider area than from Solar Orbiter's perihelion

- **Delays in data download**: when Solar Orbiter is at far side, data may be stuck onboard for several months!
- **Low-Latency (LL) Data** = a kind of beacon data, low resolution but downlinked daily

- **Science data policy:** data publicly available 3 months after arrival on Earth
  After submission to ESA, all data is accessible from Solar Orbiter Archive

How to get involved in planning?

- Science planning is done well in advance, to exploit the scientific opportunities while respecting mission limitations

- **Mission Level Planning** (locate RS windows, define main science goals) is done by the Science Working Team and plans 6 months, at T-9months
  - Early Sep we plan for 2nd half 2026

For campaign coordination:
Contact project scientists at this point

- **Long Term Planning** (define the instrument modes in more detail, optimize resources) is done in Science Operations Working Group meetings, every 3 months
  - In July we are planning LTP21 = Q4-2025 (incl 3 RS windows)
  - In Oct we already plan LTP22 = Q1-2026 (incl 3 RS windows) ⚠

Planning roadmap : https://tinyurl.com/cby8f254