Solar Orbiter

Science Highlights and Mission Status

9th Metis Workshop
January 2024

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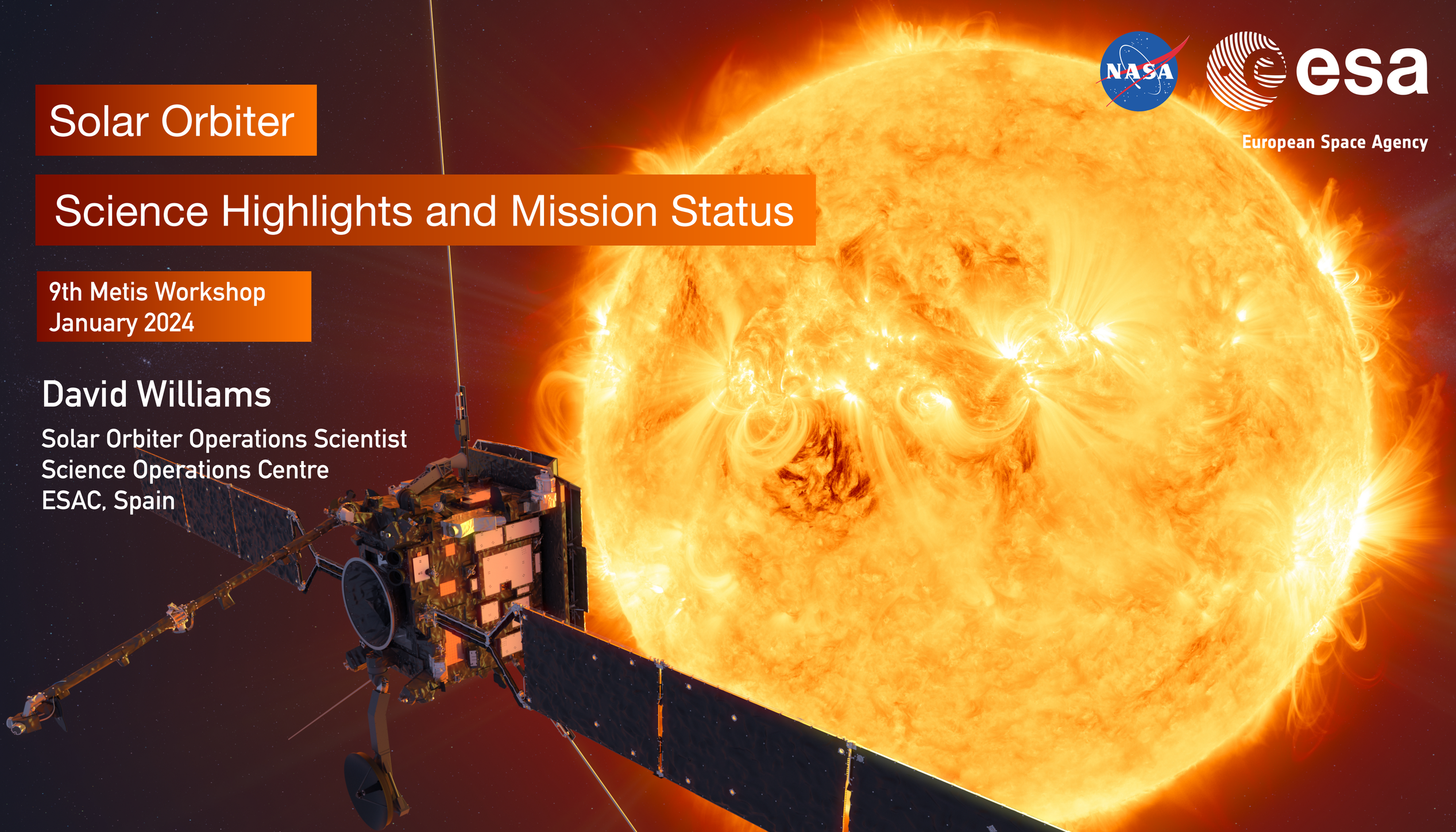
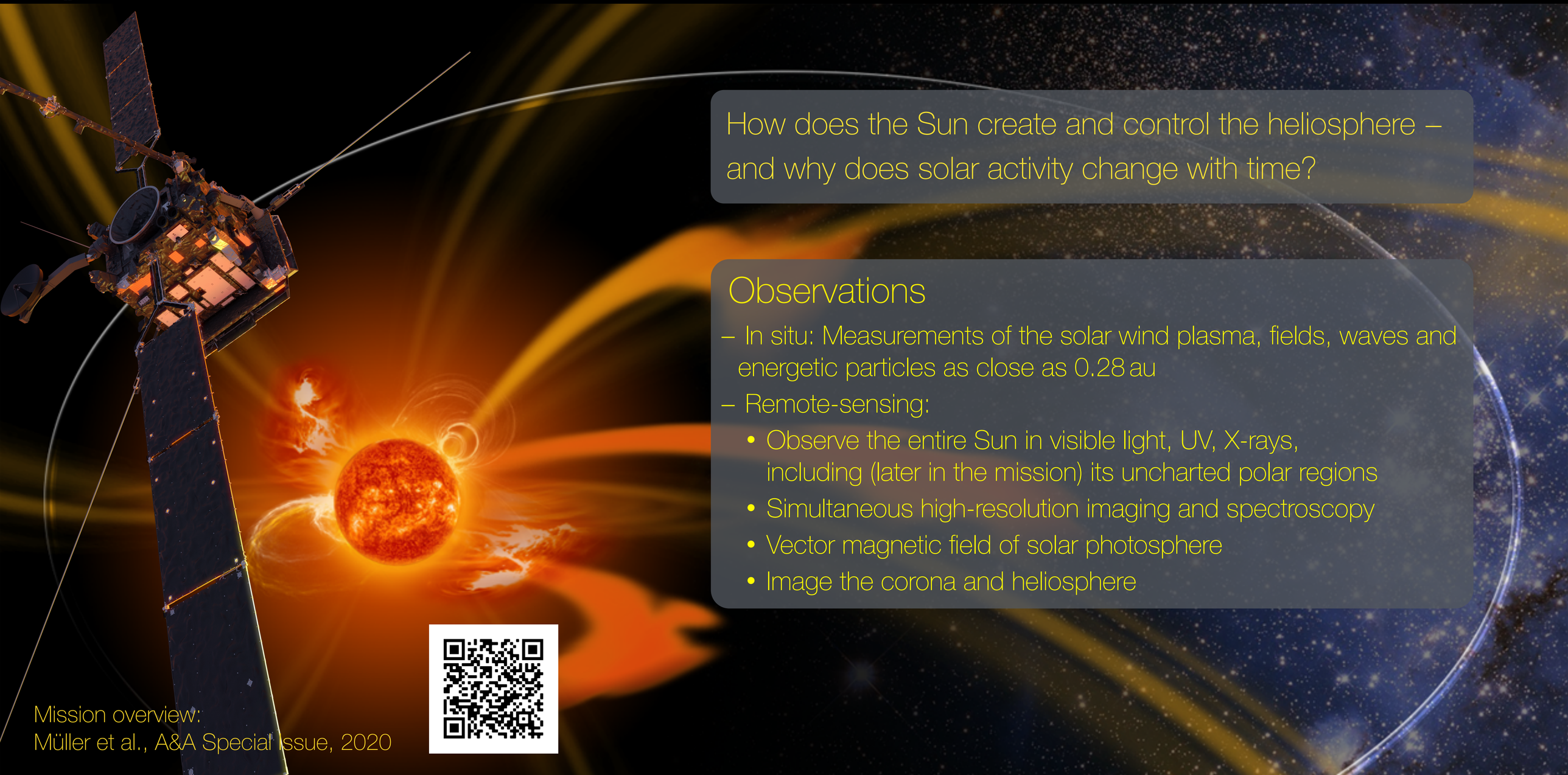
ESAC, Spain



NASA

esa
European Space Agency

Solar Orbiter: Exploring the Sun and heliosphere



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

Observations

- In situ: Measurements of the solar wind plasma, fields, waves and energetic particles as close as 0.28 au
- Remote-sensing:
  - Observe the entire Sun in visible light, UV, X-rays, including (later in the mission) its uncharted polar regions
  - Simultaneous high-resolution imaging and spectroscopy
  - Vector magnetic field of solar photosphere
  - Image the corona and heliosphere

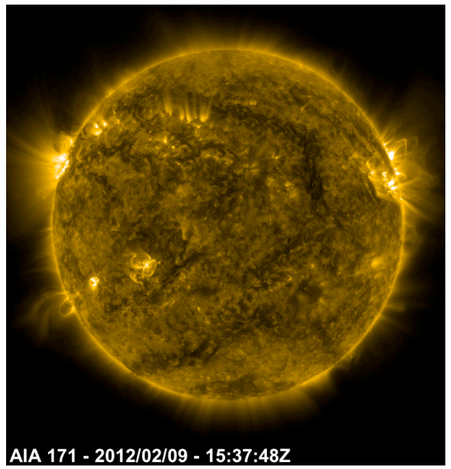
Mission overview:
Müller et al., A&A Special Issue, 2020

Answering the Big Question™ by breaking it down

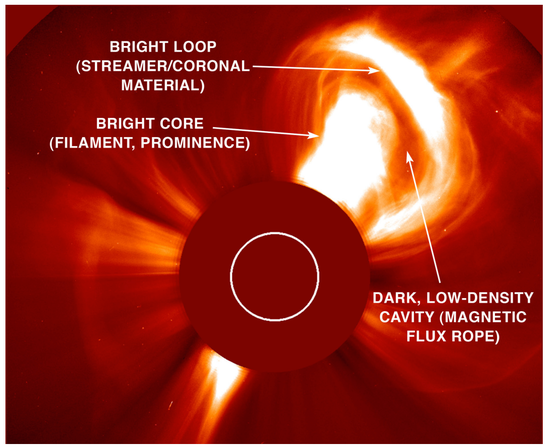
#1: How and where do the solar wind plasma and magnetic field originate?

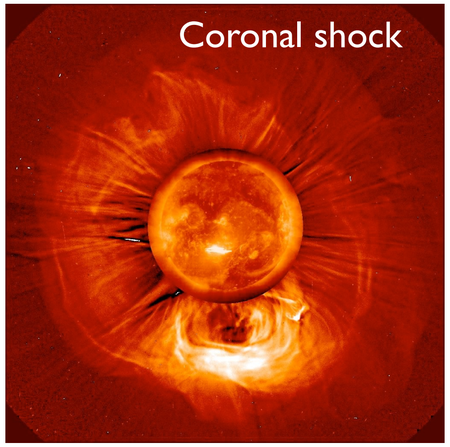
Disentangling spatial structures and time evolution requires viewing a given region for more than an active region growth time (~ 10 days)

→ So we need to go closer to the Sun

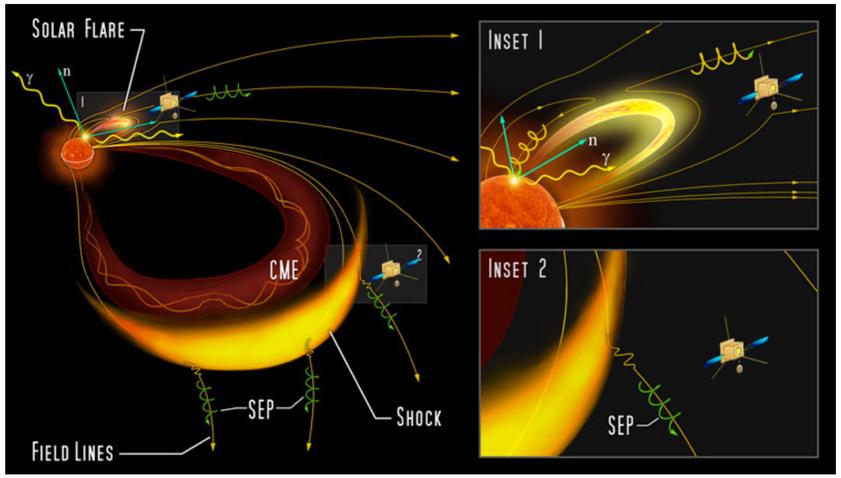


#2: How do solar transients drive heliospheric variability?

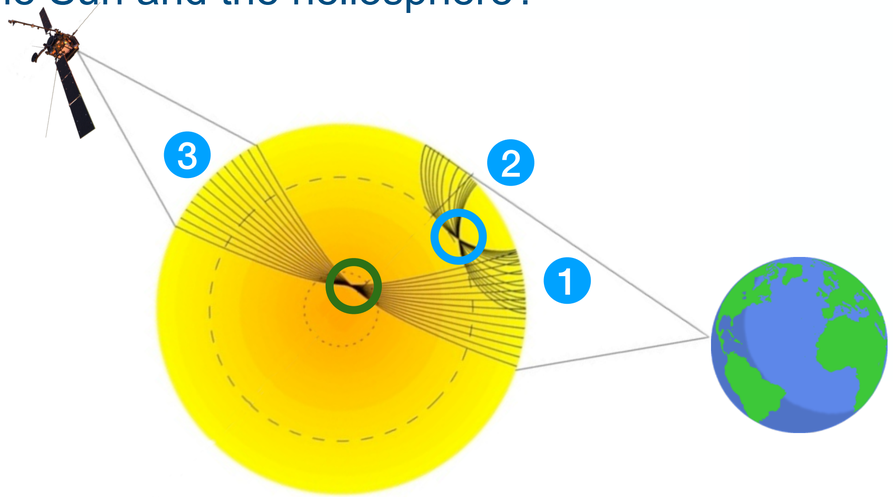




#3: How do solar eruptions produce energetic particle radiation that fills the heliosphere?

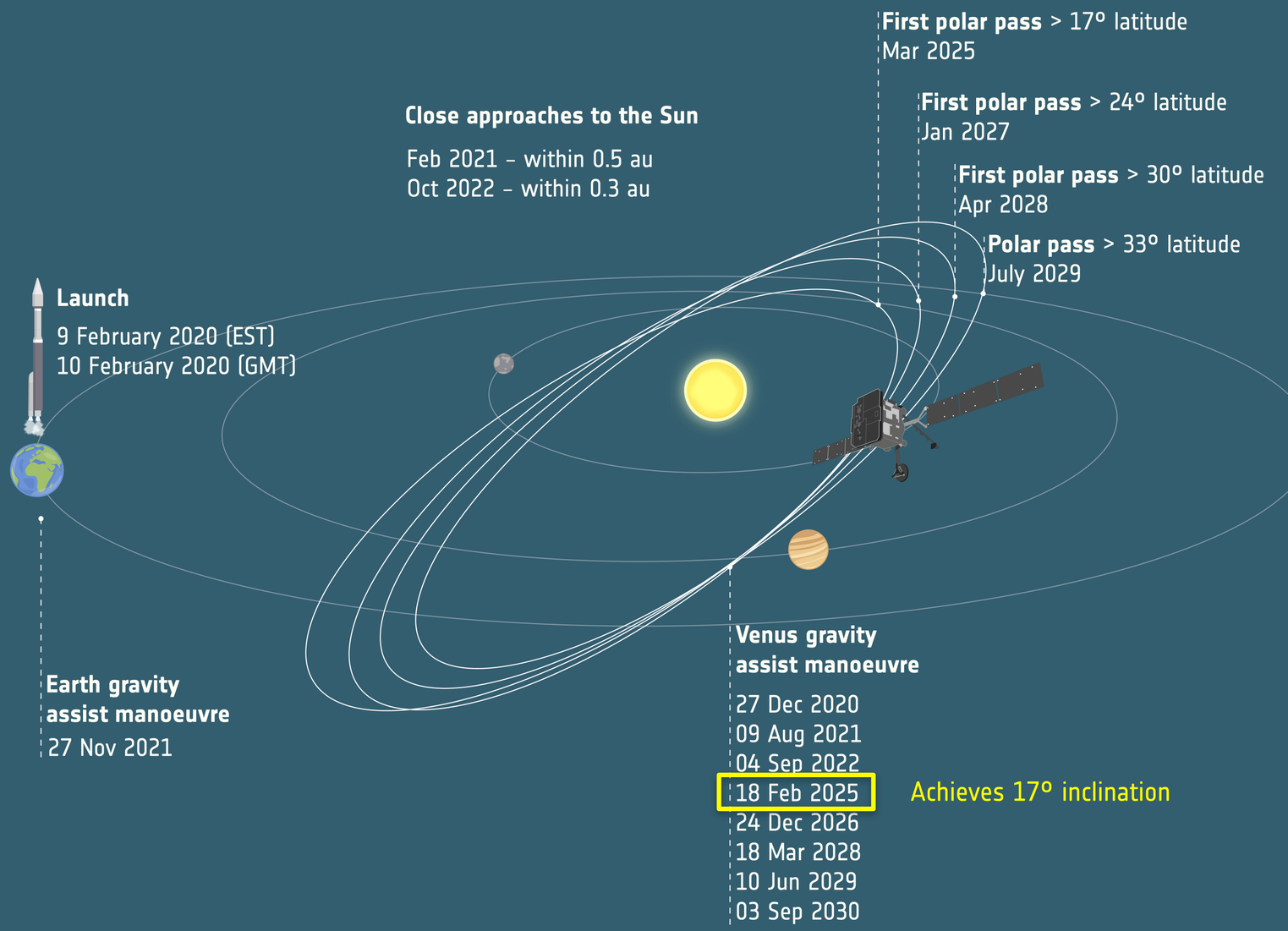


#4: How does the solar dynamo work and drive connections between the Sun and the heliosphere?

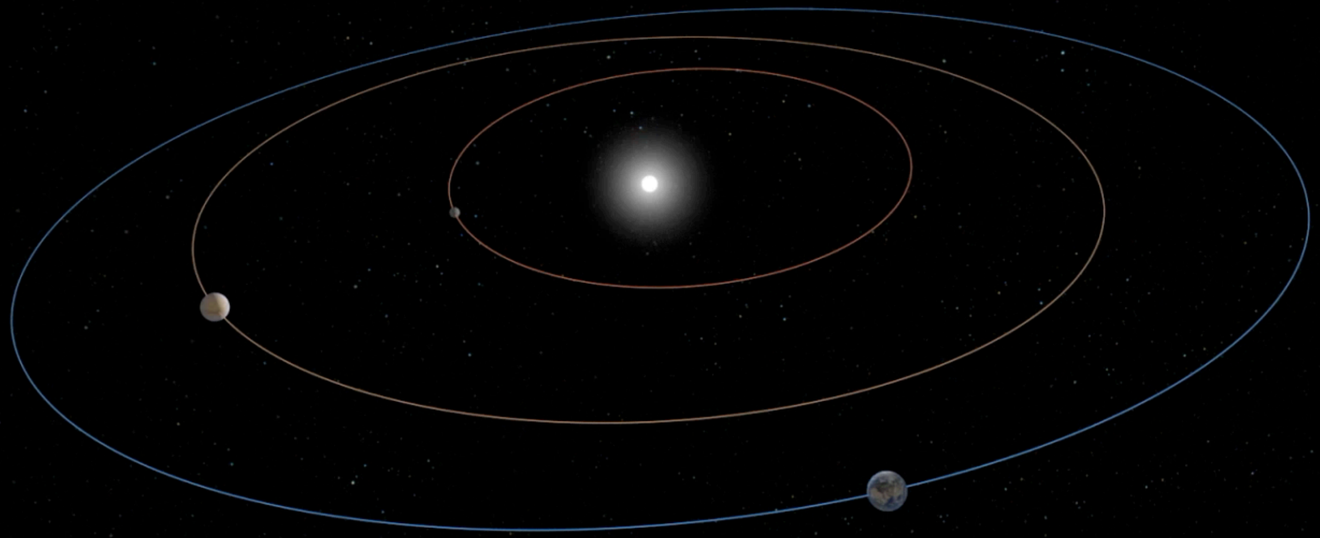


Mission Summary

- Launch: Feb 2020
- Nominal Mission Phase: Dec 2021-Dec 2026
- Orbit: 0.28-1.00 au (period: 170-200 days)
- Four close perihelia so far, latest one on 7 October 2023 @0.29 au
  - Next is 4 April 2024 at same distance
- Polar views: Venus GAMs will increase inclination vs. solar equator:
  - 24° in Jan 2027 (start of extended mission),
  - 33° in July 2029



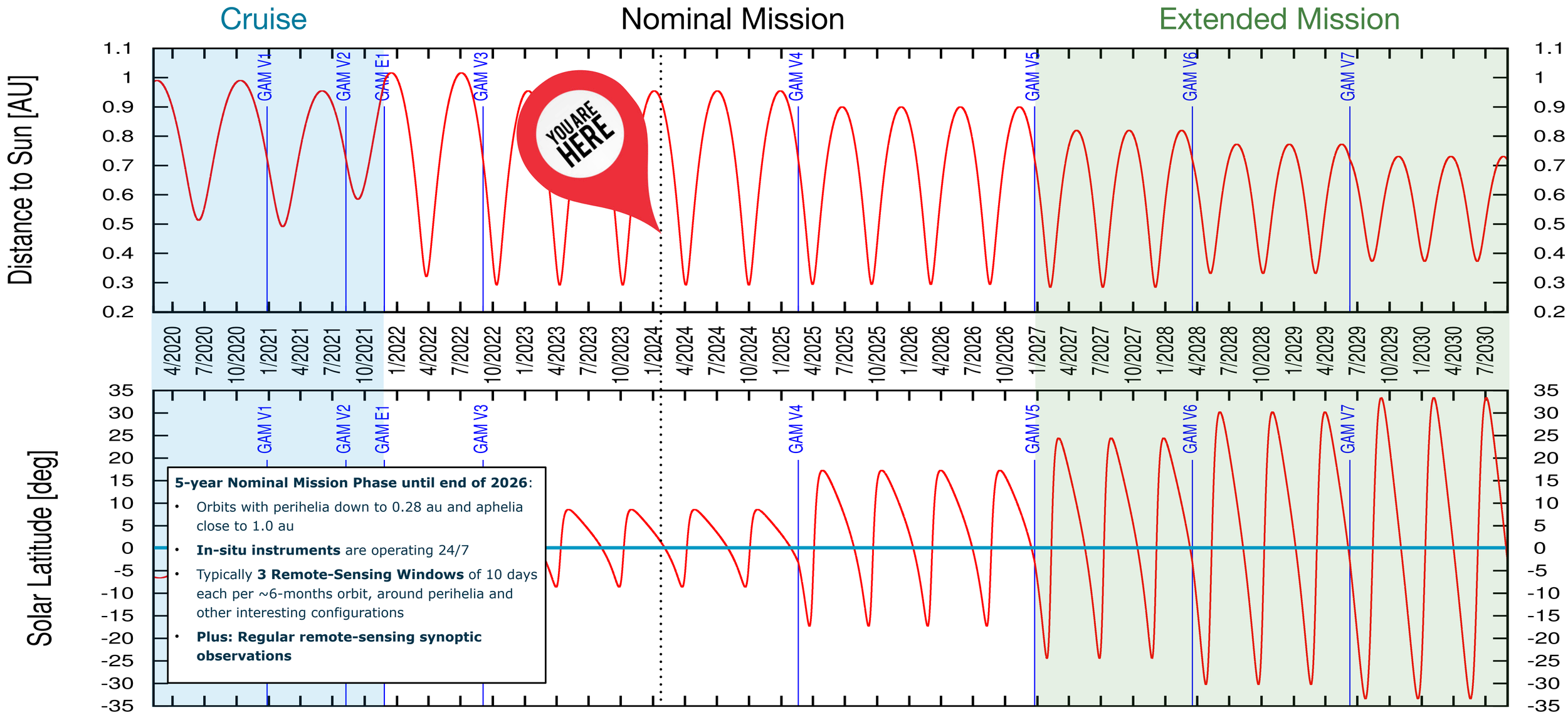
Solar Orbiter’s 10-year Journey in 35 Seconds



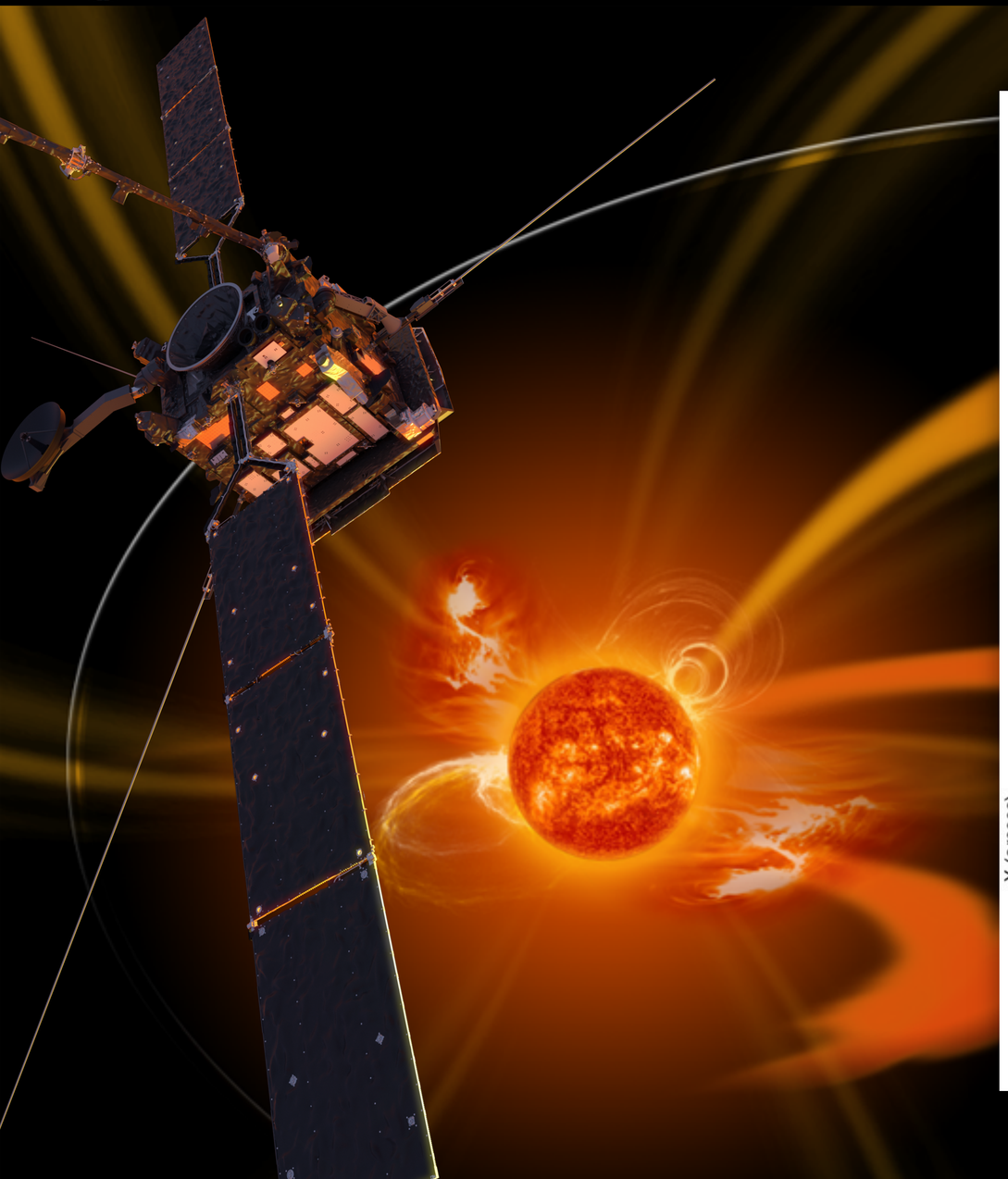
6 Feb 2020

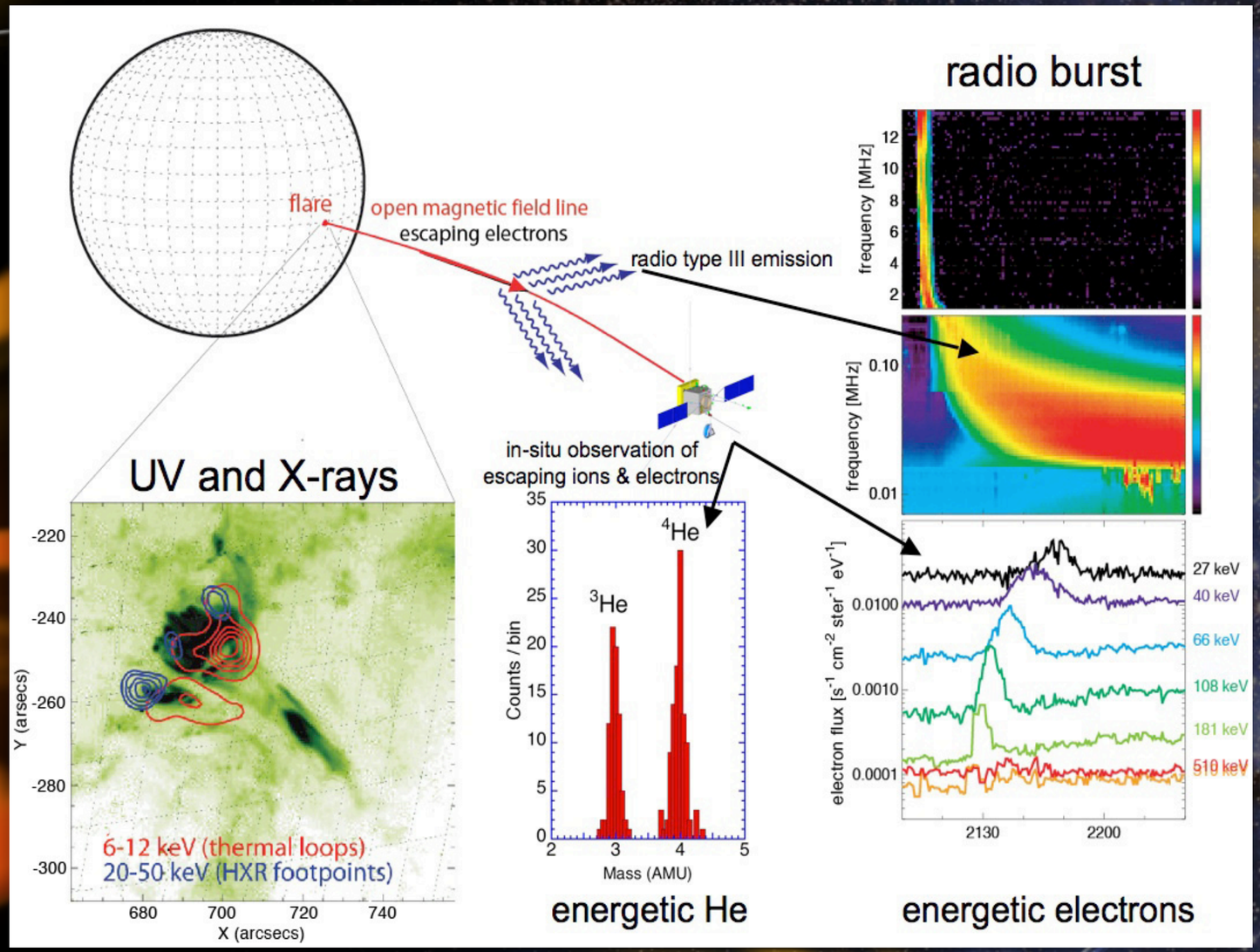
Feb 2020 – Launch

Mission Timeline



Goal: Linking the Sun to the heliosphere



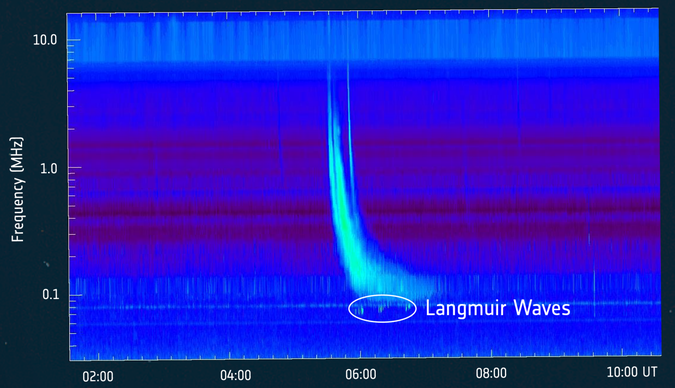


Solar Orbiter Assessment Study Report (2009)

Goal: Linking the Sun to the heliosphere ✔

JOINING THE DOTS

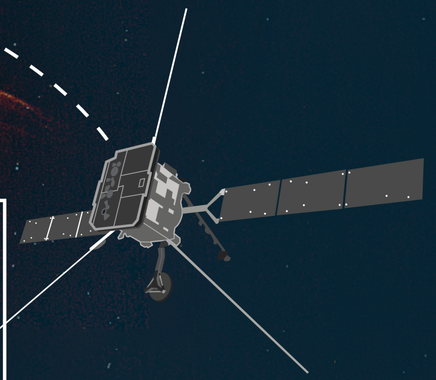
Solar Orbiter traced an energetic particle event on 21 March 2022 from the Sun through the solar wind



RPW detects radio signals of accelerated particles and plasma oscillations

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

EUI & STIX observes eruption rising over solar limb in extreme ultraviolet and X-rays

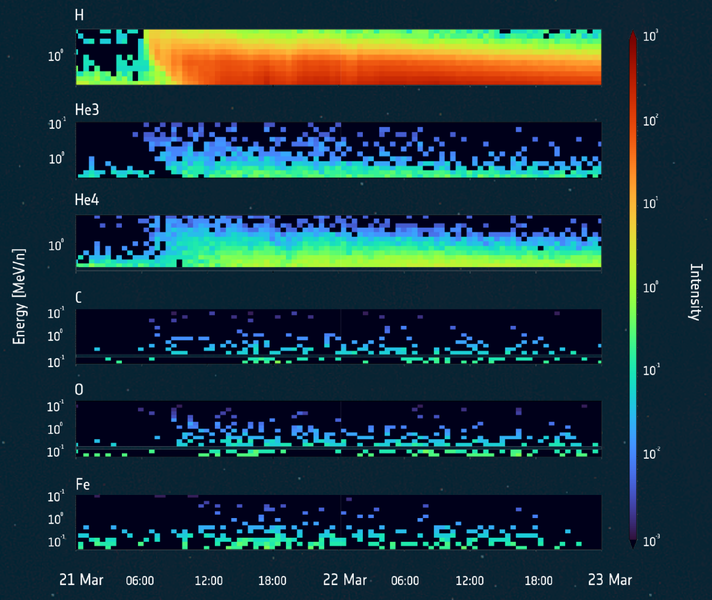


EUI: Extreme Ultraviolet Imager

EPD: Energetic Particle Detector

RPW: Radio and Plasma Waves

STIX: X-ray Spectrometer/Telescope



EPD detects particles with various composition and energy

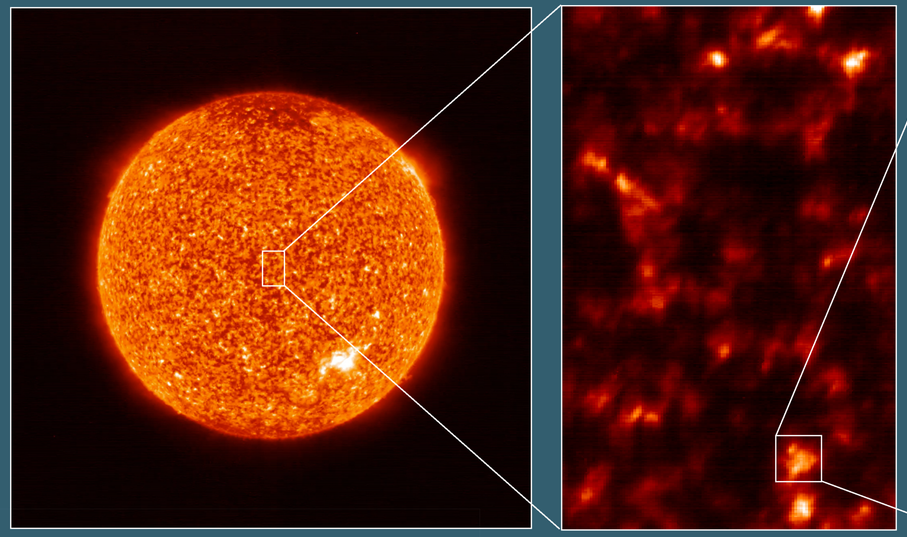
ESA & NASA/Solar Orbiter/EPD, EUI, RPW & STIX Teams

COMBINING REMOTE OBSERVATIONS AND IN SITU MEASUREMENTS

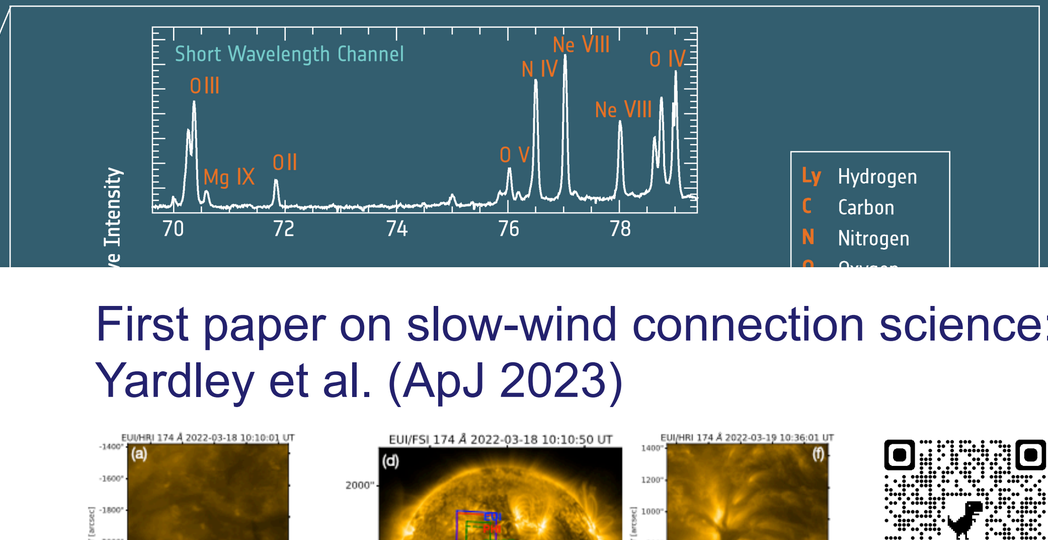
JULY 2020

Both sets of data are used to piece together a more complete picture of what is happening on the Sun and in the solar wind, the flow of electrically charged particles that is continuously released by our star.

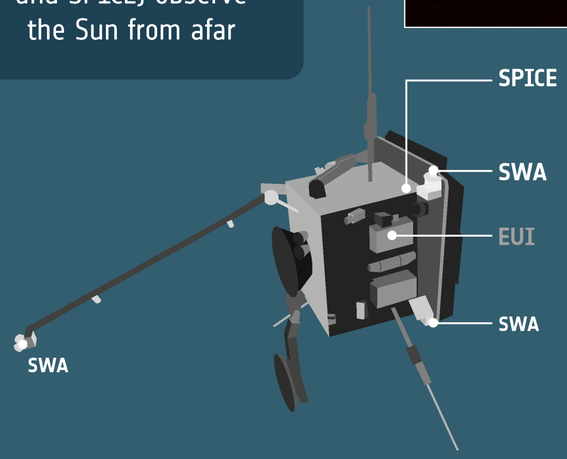
Extreme Ultraviolet Imager **(EUI)**



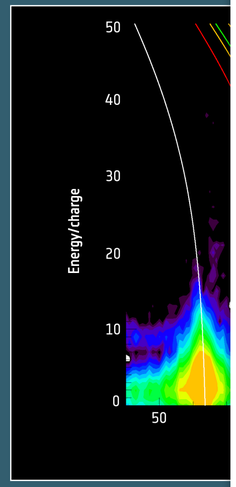
Spectral Imaging of the Coronal Environment **(SPICE)**



The **remote-sensing instruments** (such as EUI and SPICE) observe the Sun from afar



The ***in situ*** **instruments** (such as SWA) measure the electric and magnetic fields, and the particles near the spacecraft



First paper on slow-wind connection science: Yardley et al. (ApJ 2023)

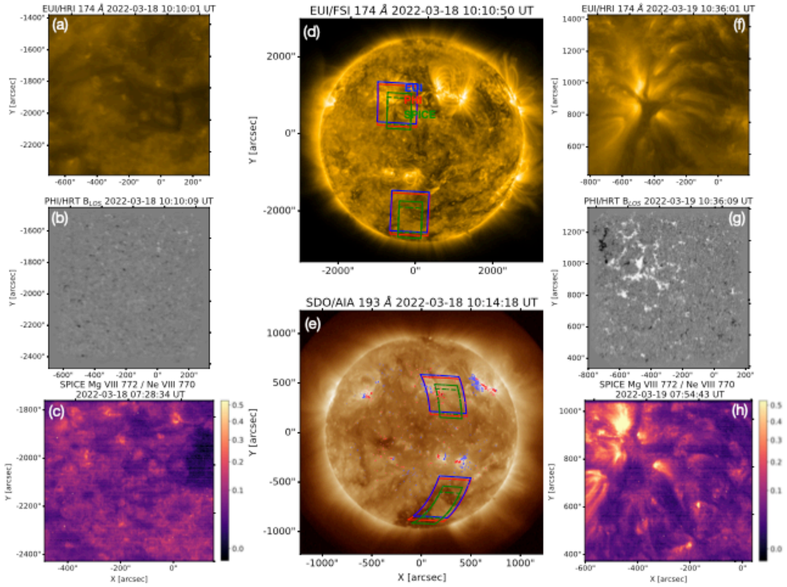
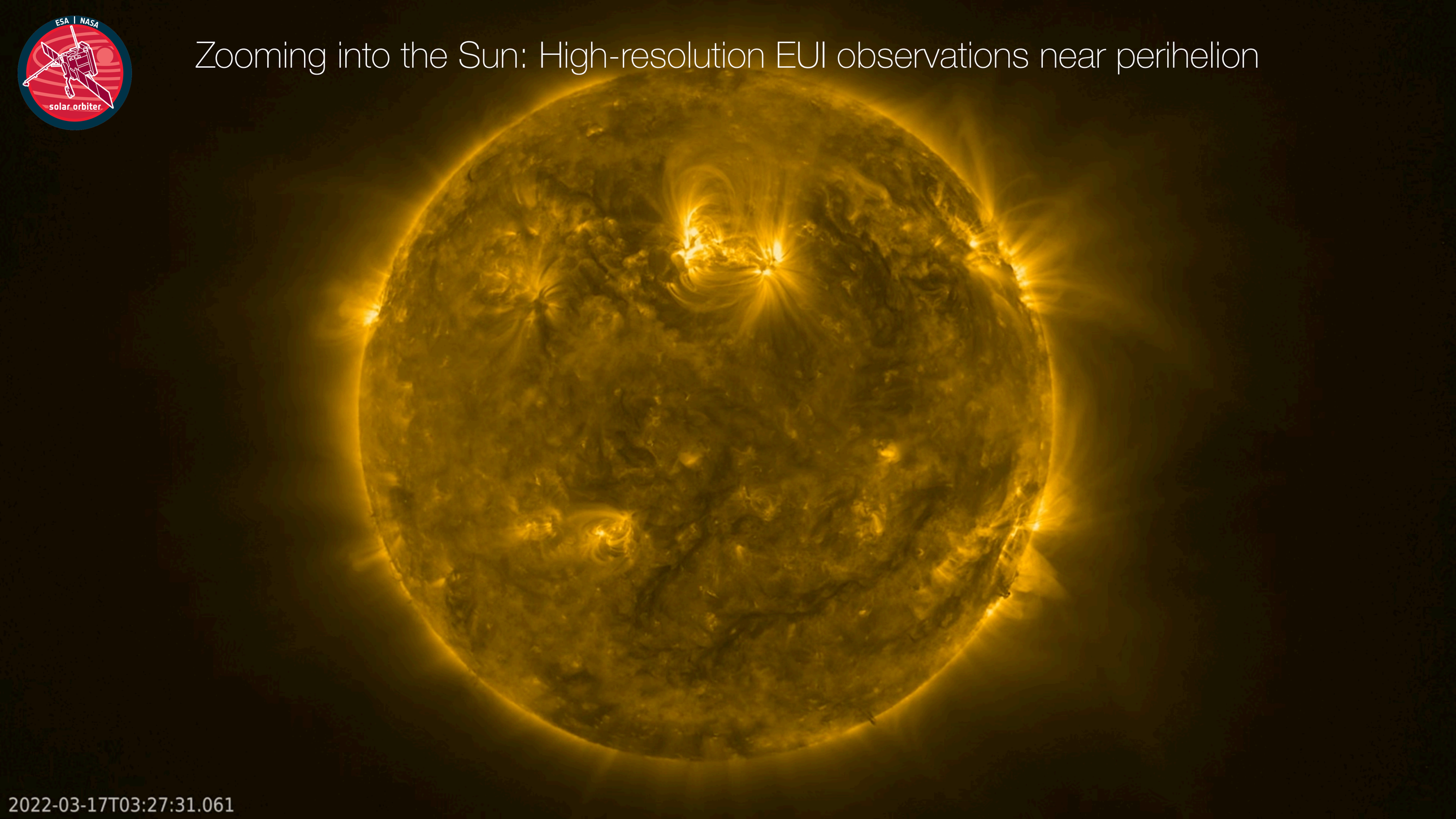


Figure 6. High-resolution data taken during RSW2 of the Slow Wind SOOP on 2022 March 18 (panels a–c) and 2022 March 19 (panels f–h). The FOVs of EUI/HRI, PHI/HRT and SPICE are shown in blue, green, and red on EUI/FSI 174 Å and SDO/AIA 193 Å data, similar to Figure 5.

#TheSunUpClose

Zooming into the Sun: High-resolution EUI observations near perihelion



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Picoflare jets power the solar wind emerging from a coronal hole on the Sun

Recent results by Chitta et al. (*Science* 2023)

Earth to scale

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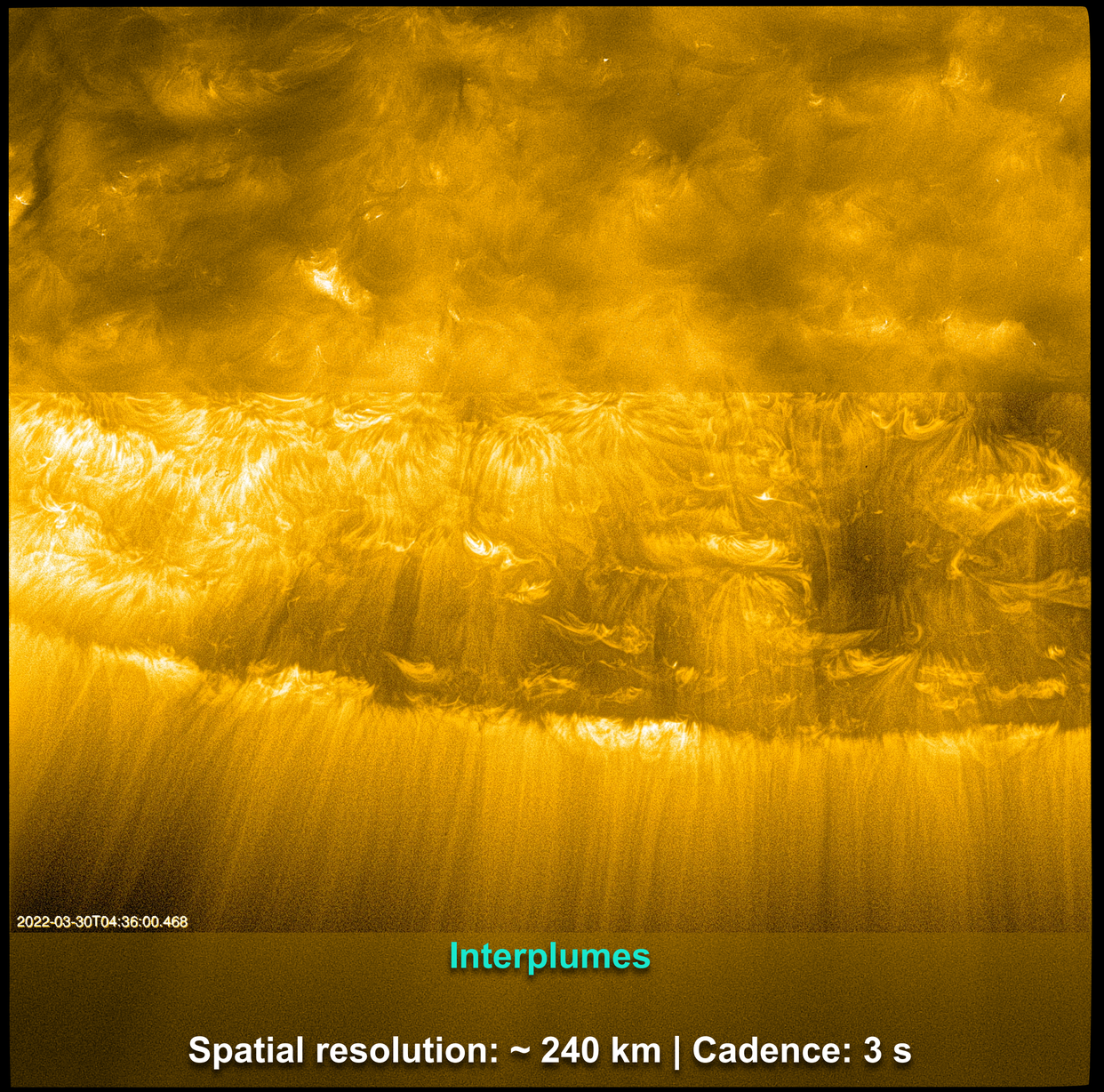
Coronal hole structures observed with EUI – a closer look



Chitta et al., *Science* 2023

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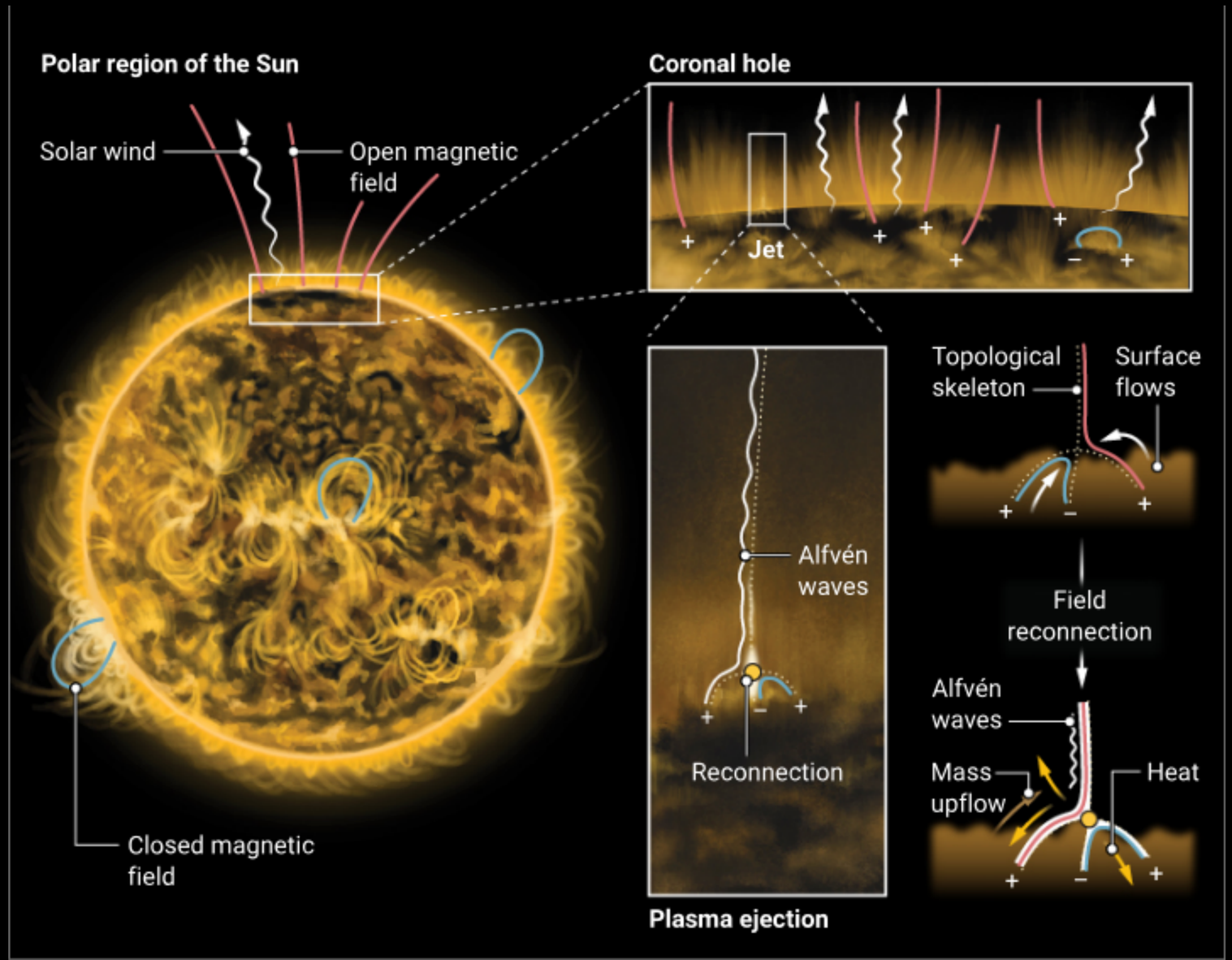
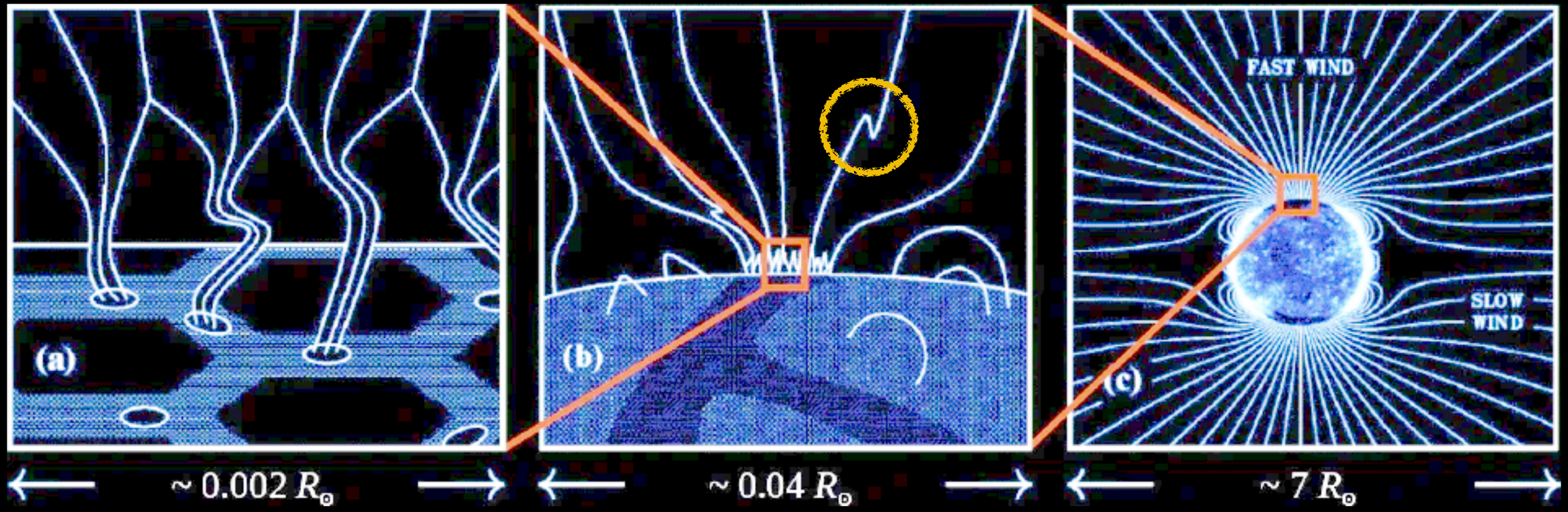


Thin jets underlie the solar wind
(Ugarte-Urra & Wang, *Science*, Sep 2023)

Science | AAAS

“Coronal holes are the darkest and least active regions of the Sun,
as observed both on the solar disk and above the solar limb”

Cranmer, S. R. Coronal Holes. Living Rev. Sol. Phys. 6, 3 (2009)



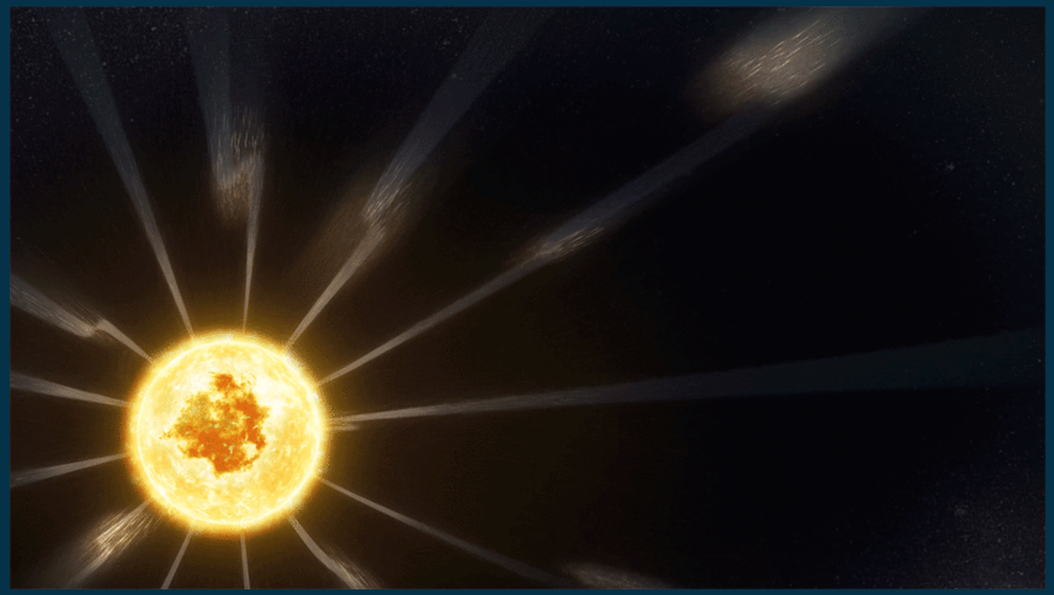
Cranmer, S. R. & van Ballegooijen, A. A. ApJS, 156, 265 (2005)

“The extended corona and solar wind connected with coronal holes
tends to exist in an ambient time-steady state,
at least in comparison with other regions.”

Formation of magnetic switchbacks in the solar corona

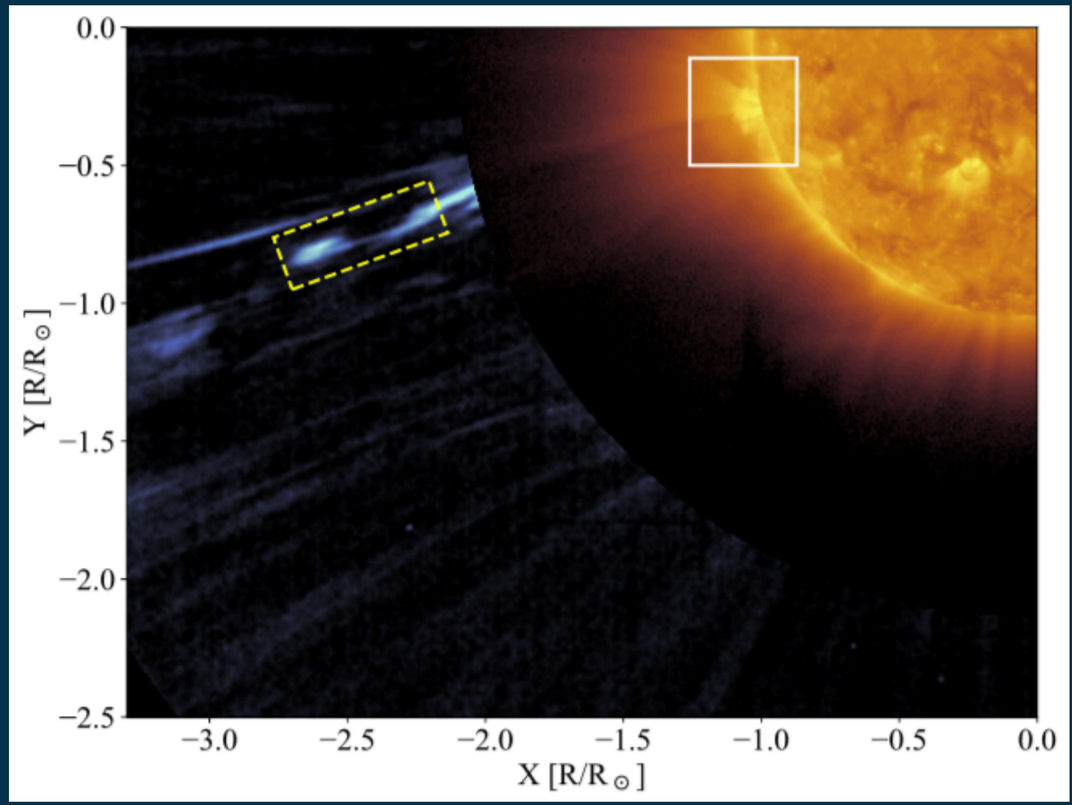
- Parker Solar Probe observations have revived the interest in magnetic switchbacks, first seen in Helios data from 1970s

- Do switchbacks have a solar origin, or do they form locally in the solar wind?

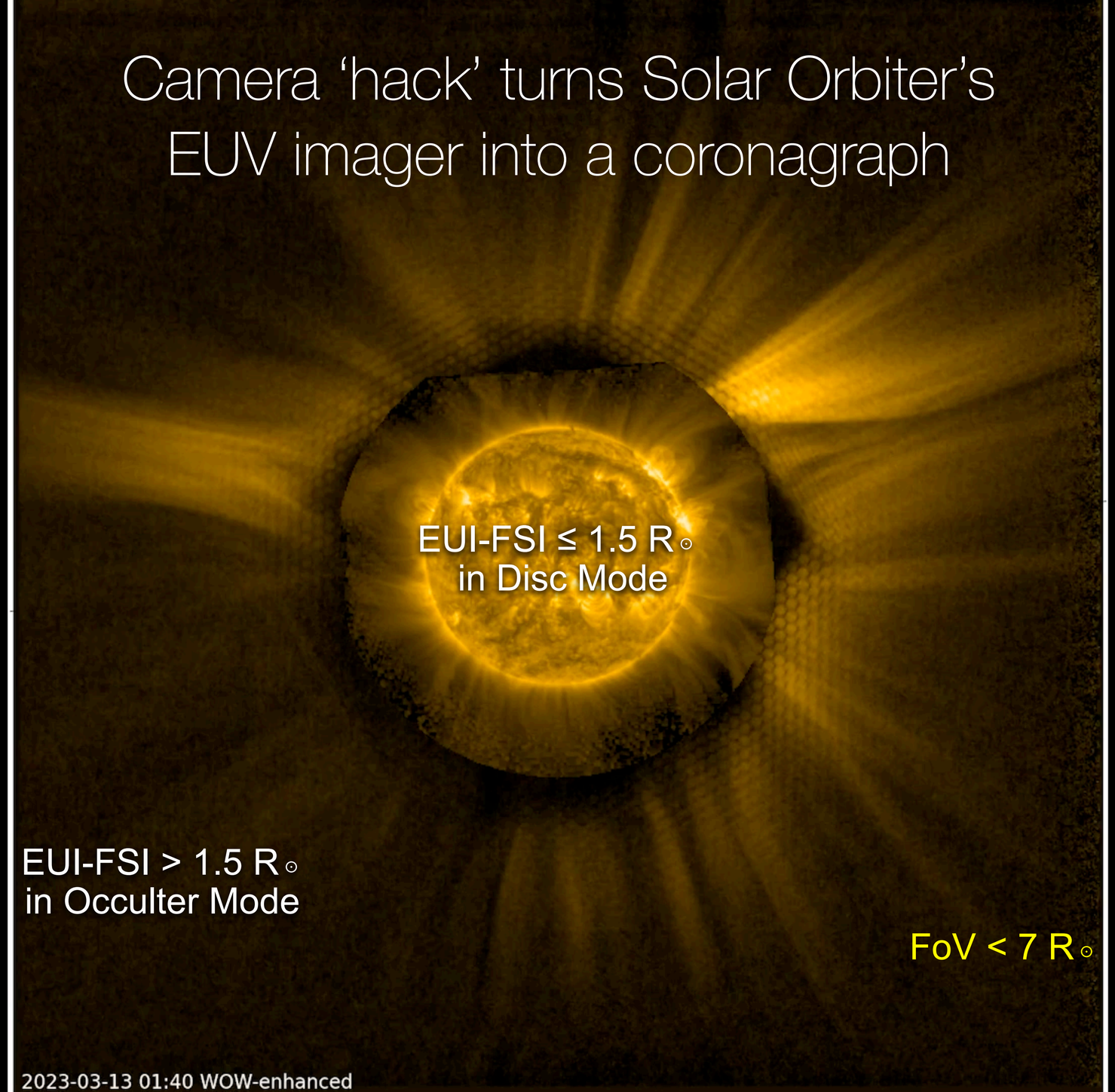


Credits: NASA GSFC/Conceptual Image Lab/Adriana M. Gutierrez

During the March 2022 perihelion passage, Metis imaged a magnetic switchback for the first time in the solar corona (Telloni et al. 2022, ApJL)



Camera ‘hack’ turns Solar Orbiter’s EUV imager into a coronagraph



Auchère et al. (A&A 2023)

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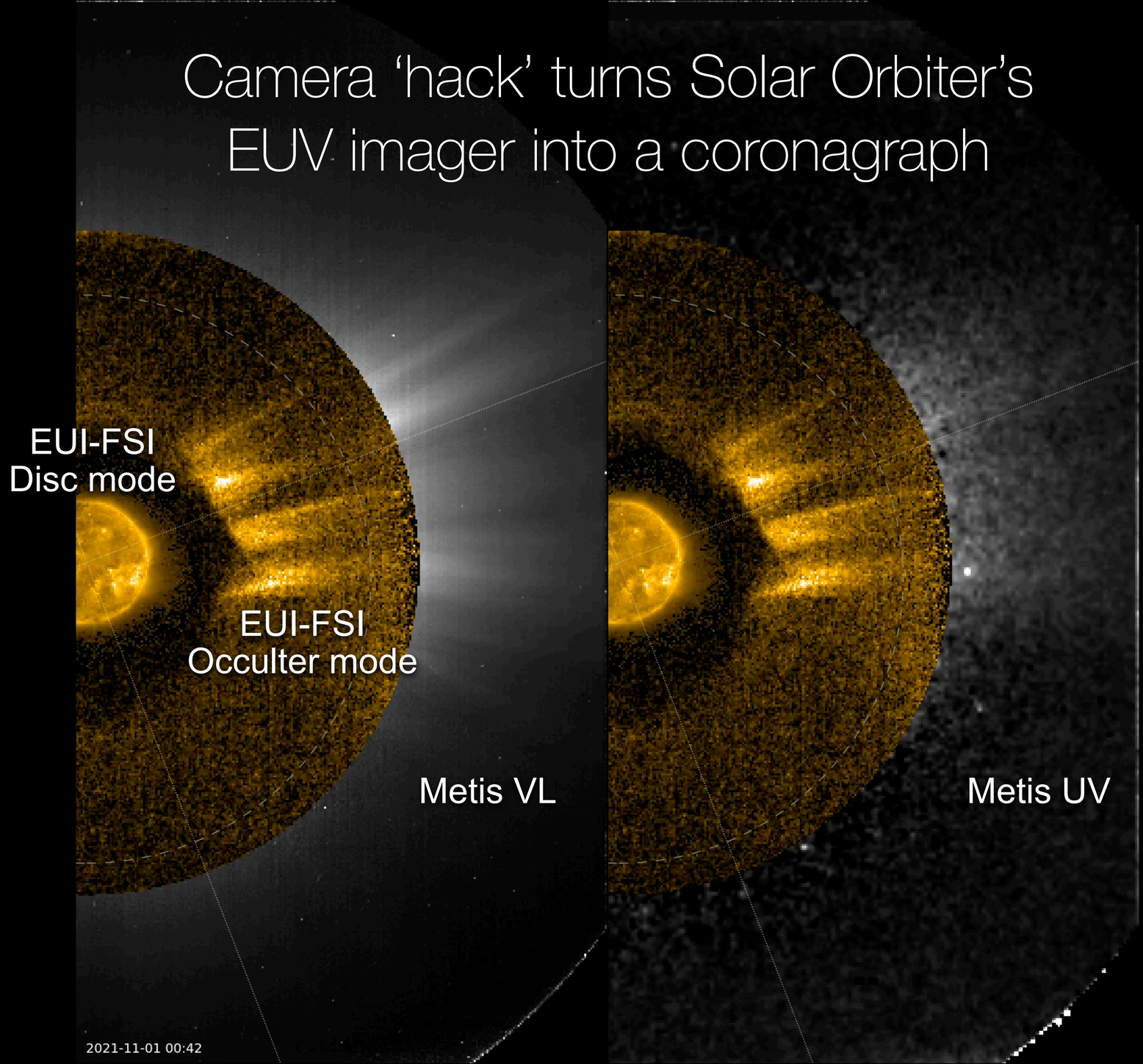
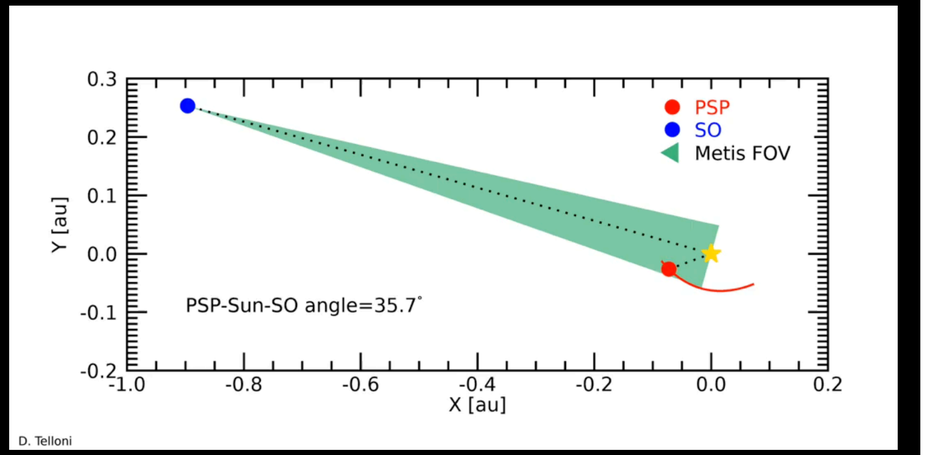
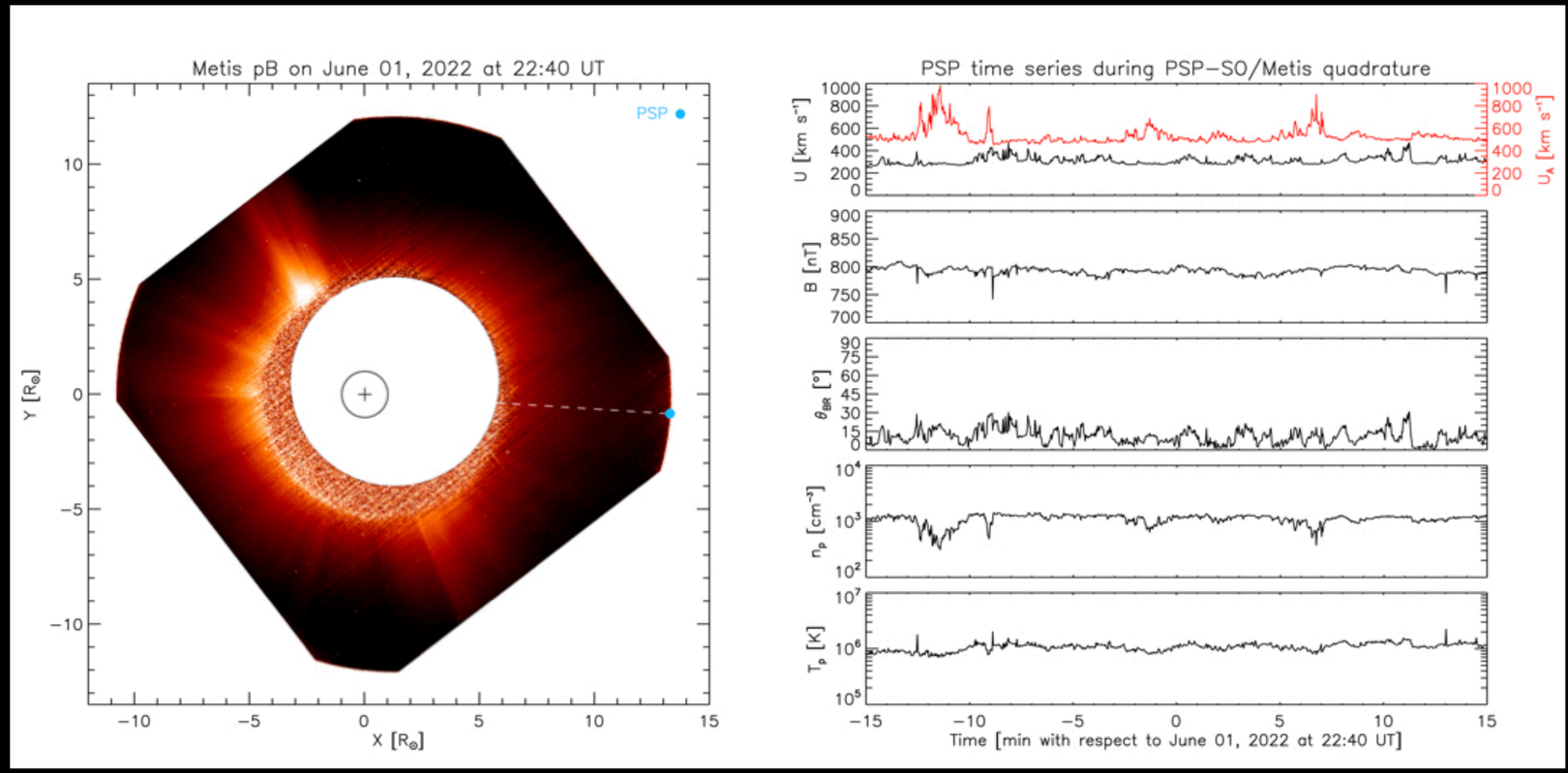


Auchère et al. (A&A 2023)

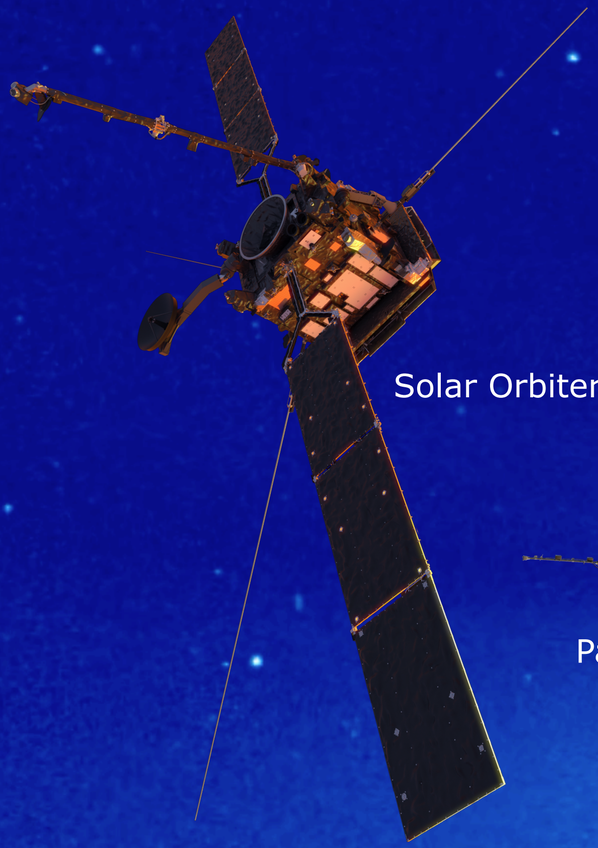
Teamwork in the heliosphere: Parker Solar Probe and Solar Orbiter join forces to measure coronal heating rate



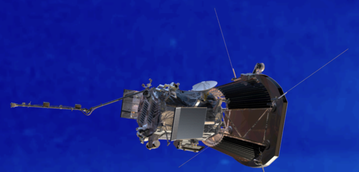


[Telloni et al. (A&A 2023)]

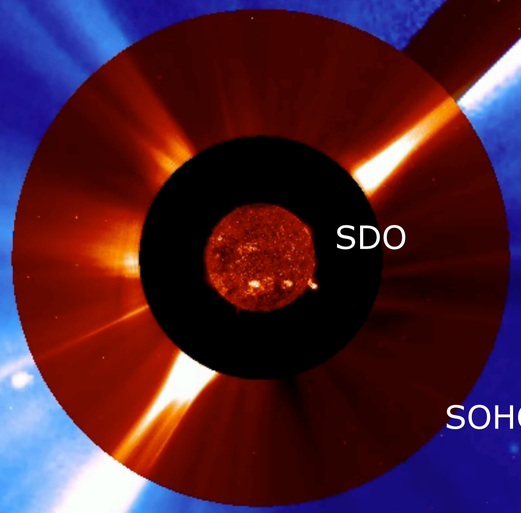
Teamwork in the heliosphere

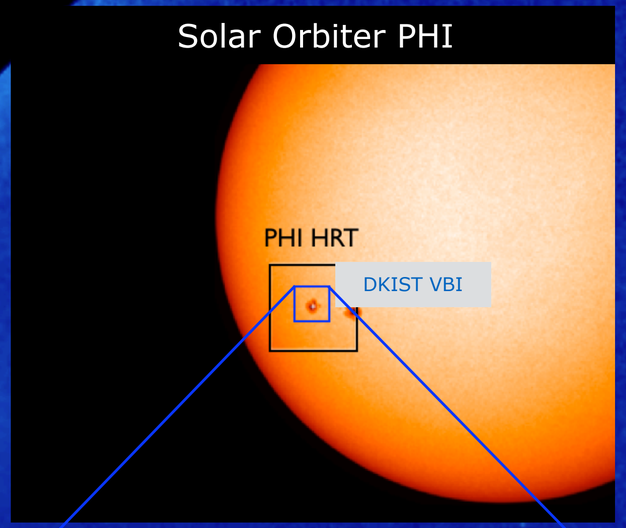


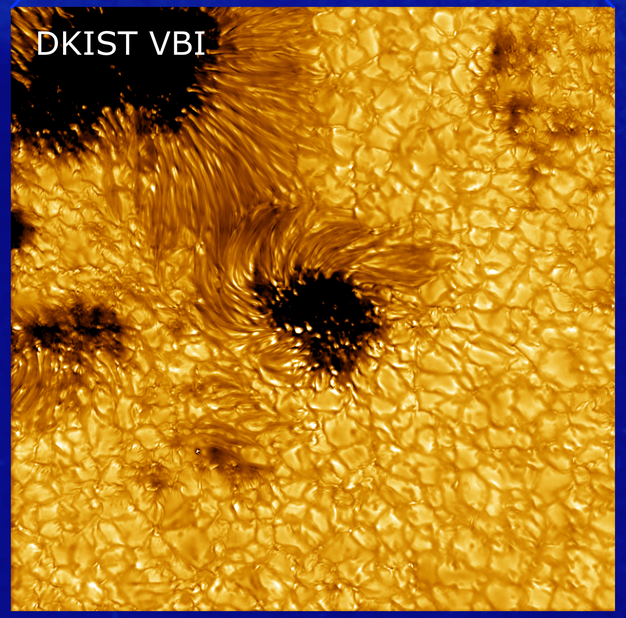
Solar Orbiter



Parker Solar Probe







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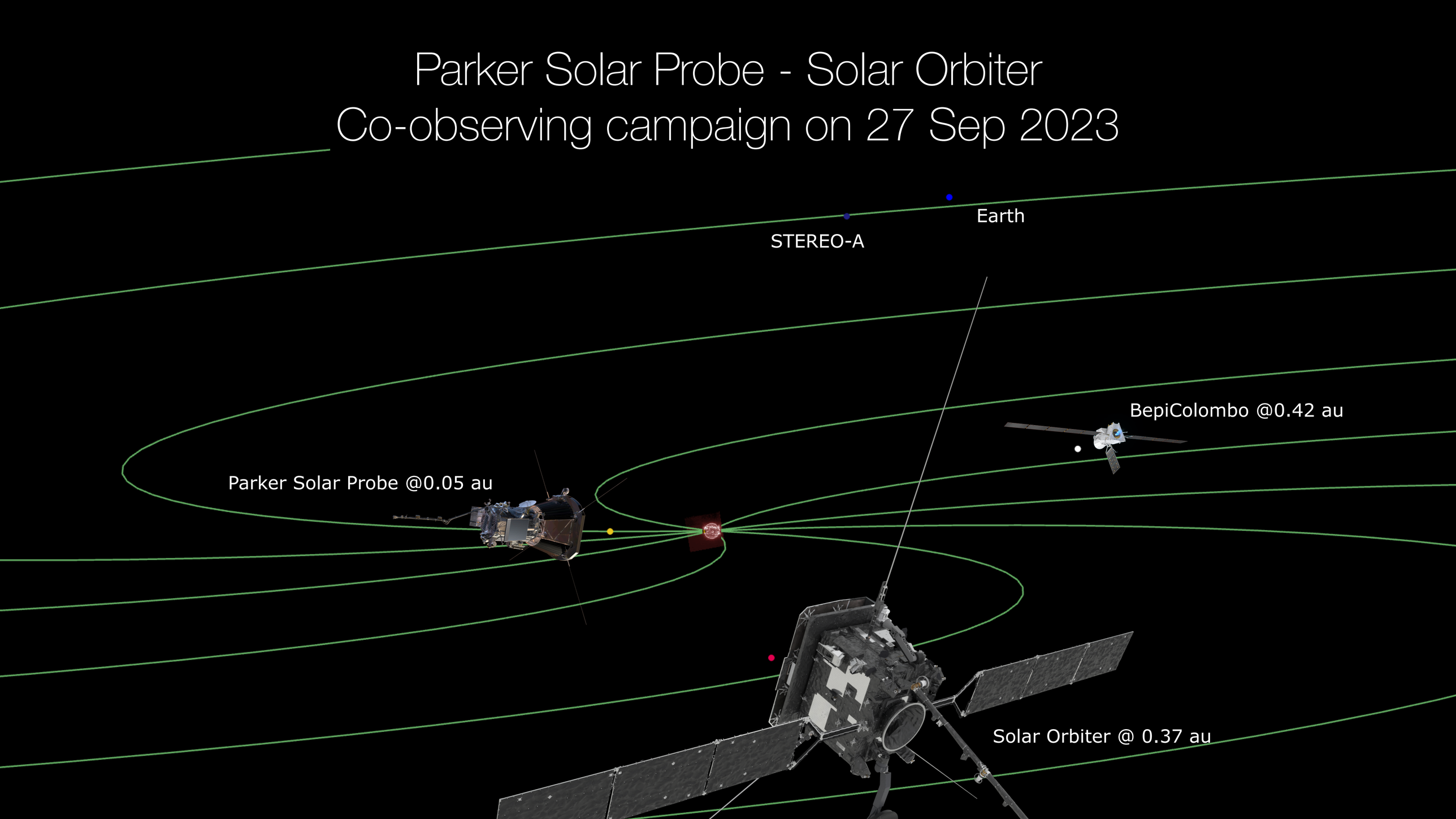
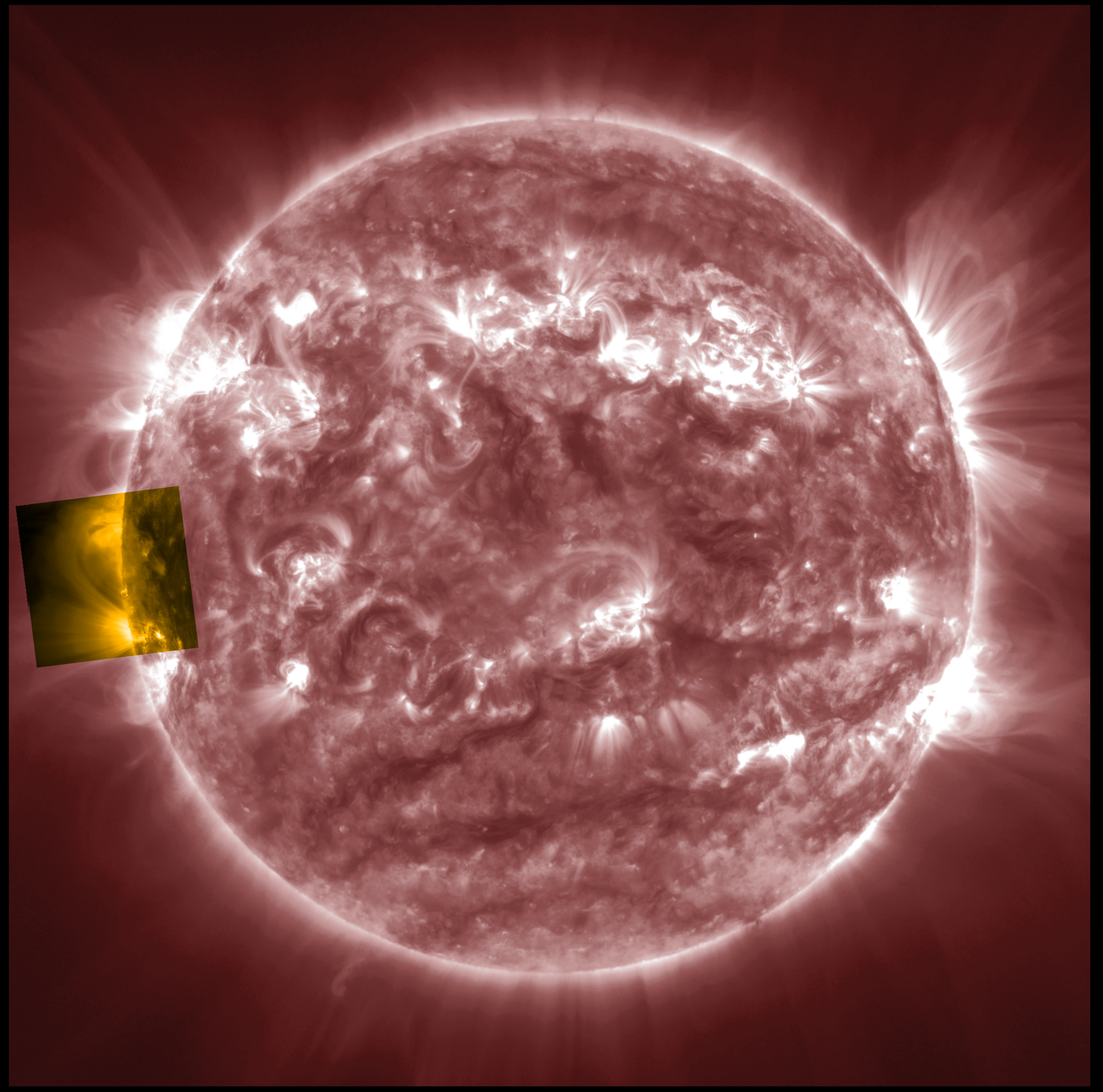
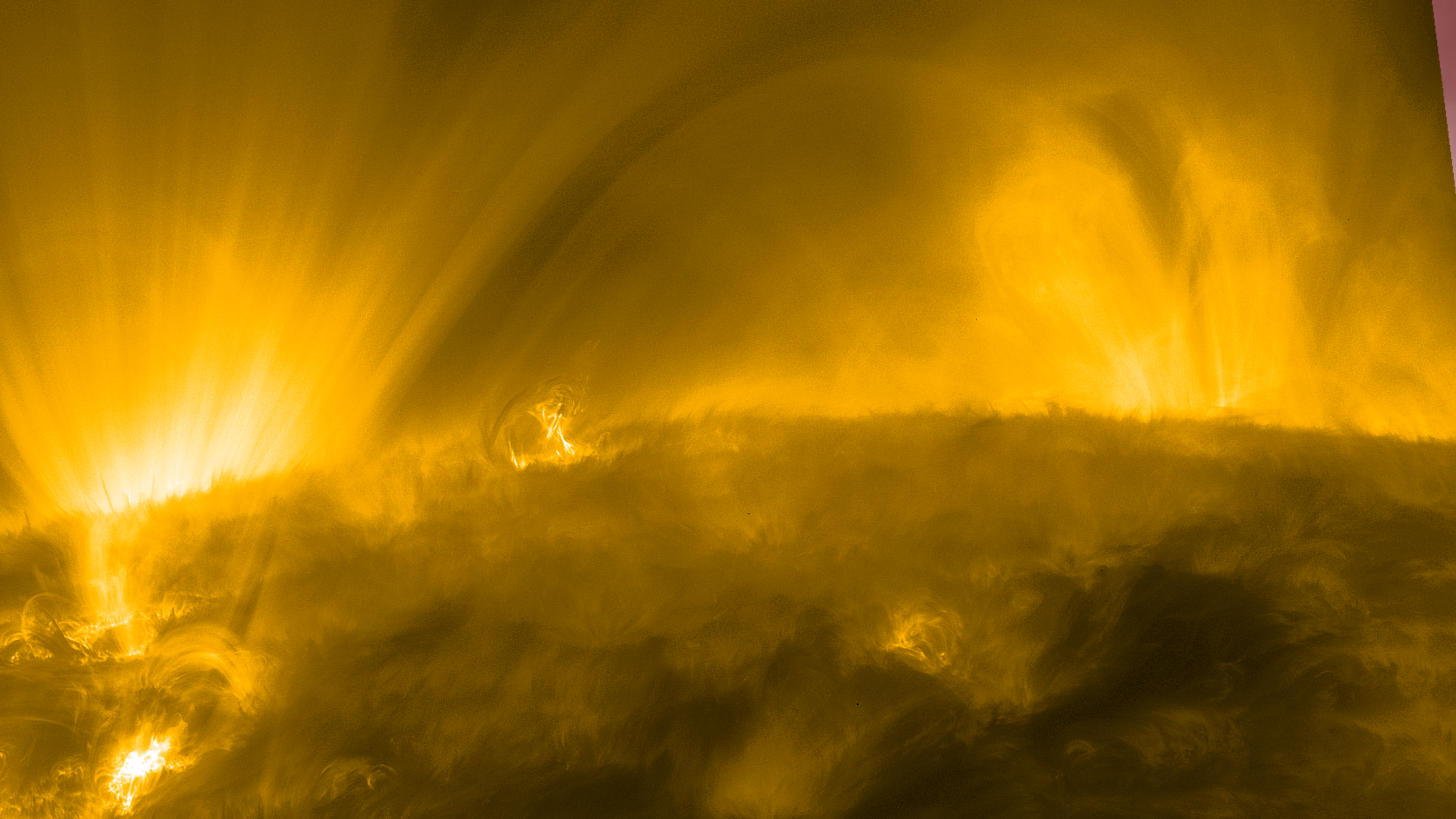
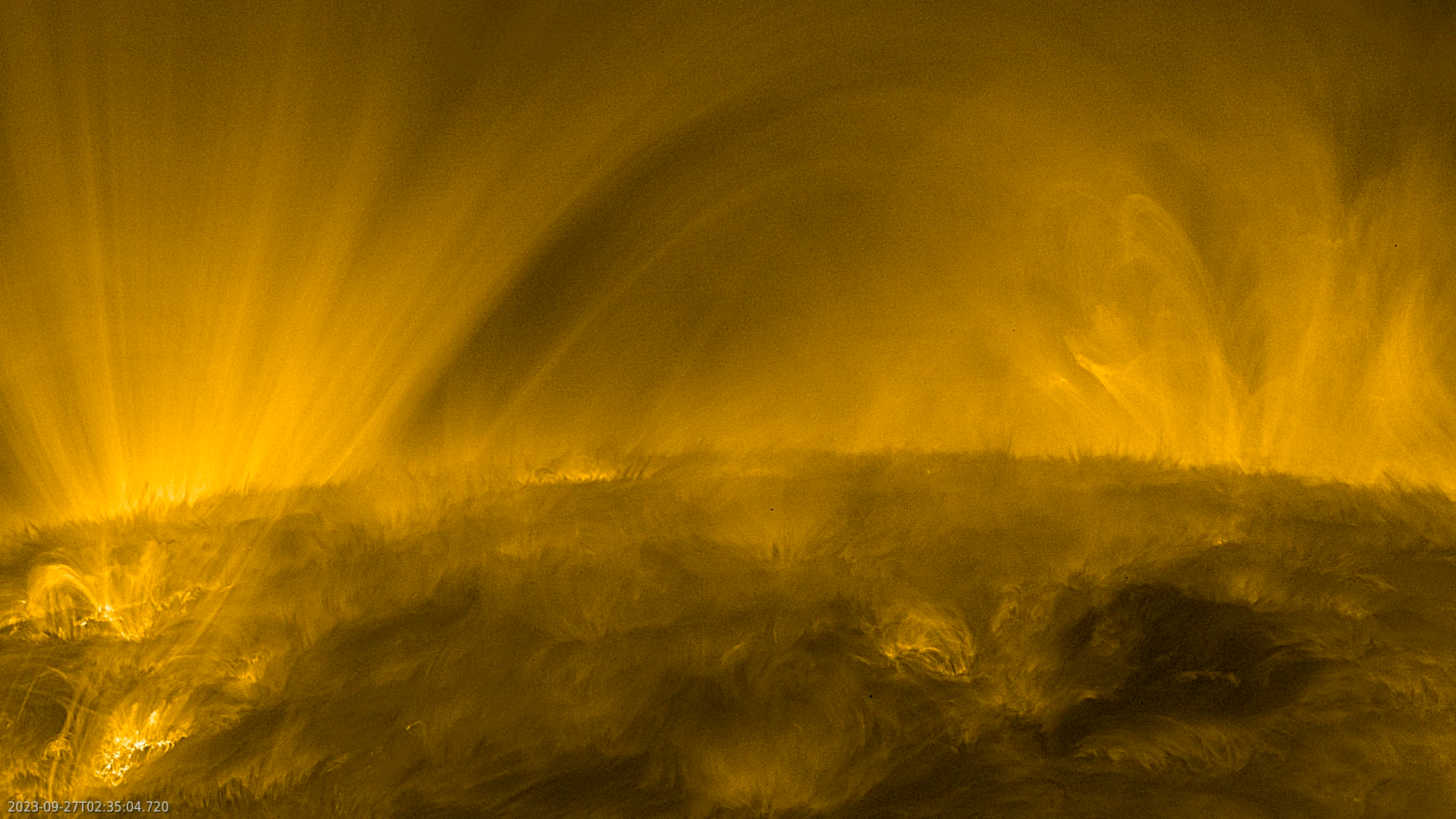
Parker Solar Probe - Solar Orbiter
Co-observing campaign on 27 Sep 2023





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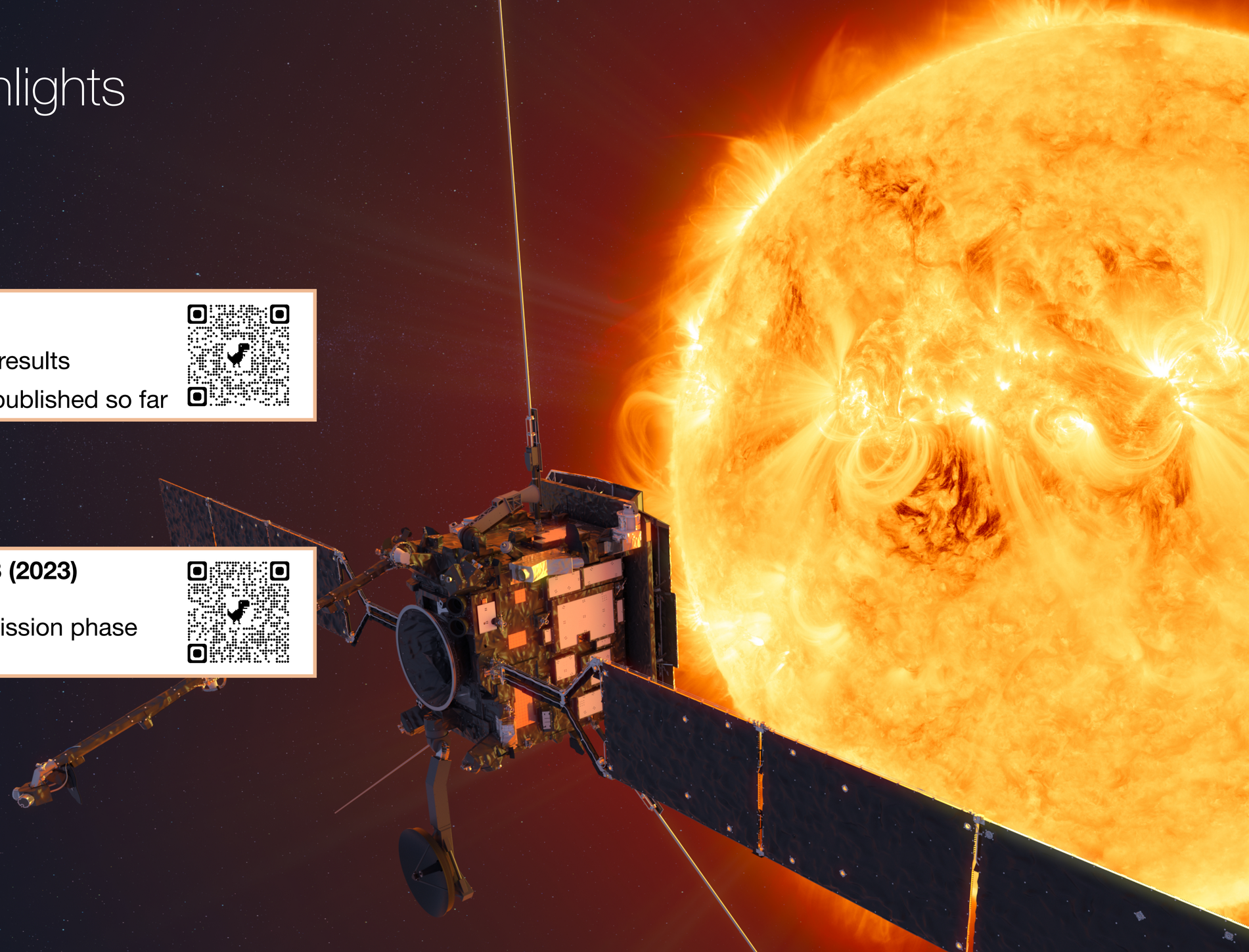
More science highlights

Solar Orbiter Science Nuggets

- Short articles showcasing recent results
- Started in March 2023; 22 items published so far

Solar Orbiter A&A Special Issue #3 (2023)

- First science results of nominal mission phase



Solar Orbiter: Here comes the Sun

Summary

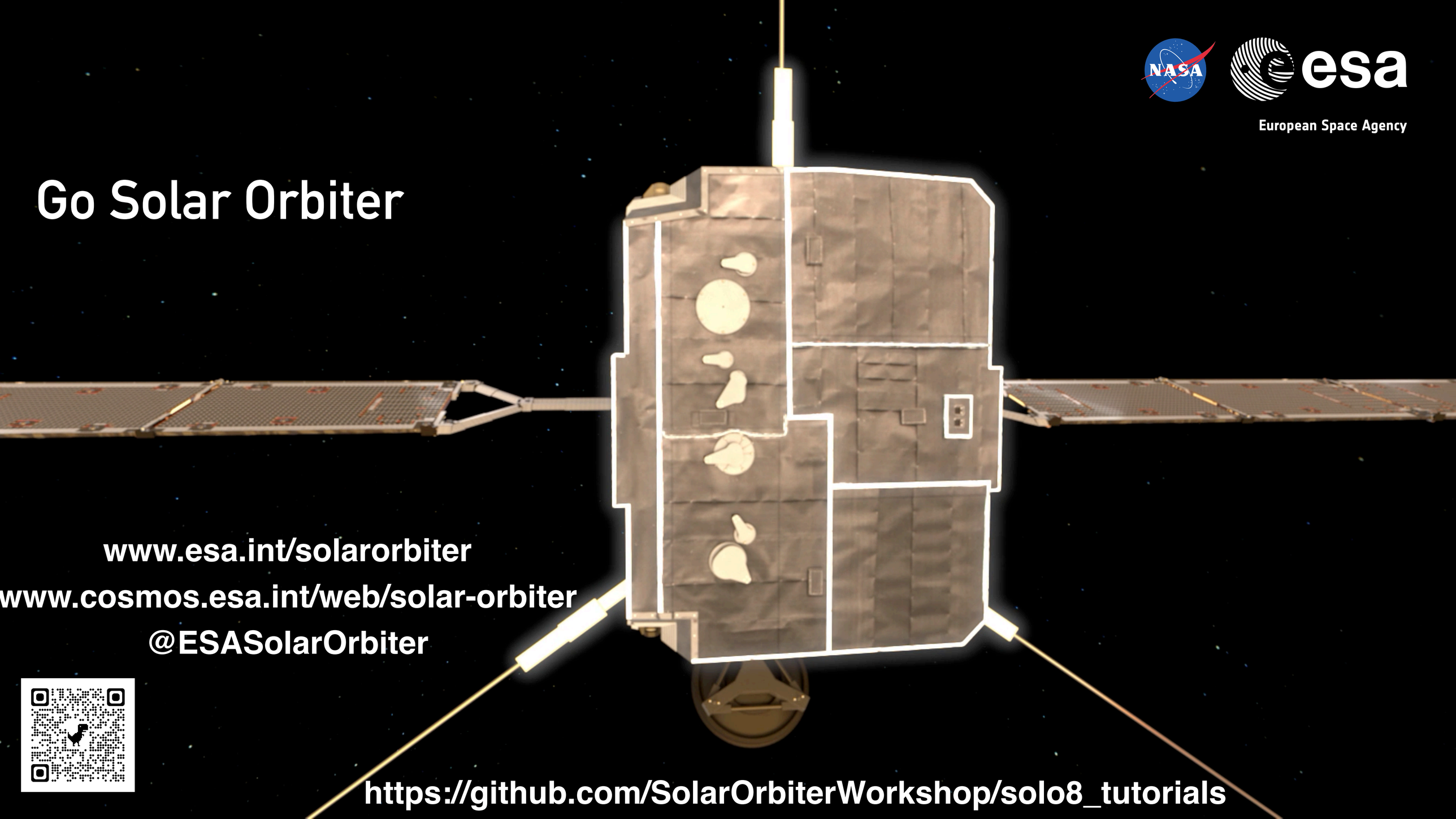
- First four ‘hot’ perihelia successfully completed
- Exciting science results!
- Successful multi-mission coordination

A vibrant science community:

- Solar Orbiter’s topical science WGs: Open to everyone

Open data policy:

- Instrument teams have 3 months for data calibration & validation
- After submission to ESA, all data is publicly accessible from the Solar Orbiter Archive


NASA
esa
European Space Agency
Go Solar Orbiter
www.esa.int/solarorbiter
www.cosmos.esa.int/web/solar-orbiter
@ESASolarOrbiter
https://github.com/SolarOrbiterWorkshop/solo8_tutorials

Coordination: Support from Solar Orbiter

- Most importantly: **Talk to us early.** We have a long lead time on planning
- We may need to **allocate the telemetry** for your campaign up to **18 months in advance.**
- Targets**:**
  - If your campaign requires **complex pointings**, it may need to be run in a **remote sensing window**. Rought dates are chosen by the Science Working Team up to **18 months in advance.**
  - For **simple geometric pointings** (e.g. point to the pole) outside of remote sensing windows we need to fix the pointing up to **7 months in advance.**
- Detailed **science planning** is done up to **6 months in advance.**
- If you want to track a **specific target** remember the latest we can change our pointing is **3 days in advance.**

SOOP pointings

SOOPs run

Solar Orbiter documentation

Archive access

Where is Solar Orbiter?