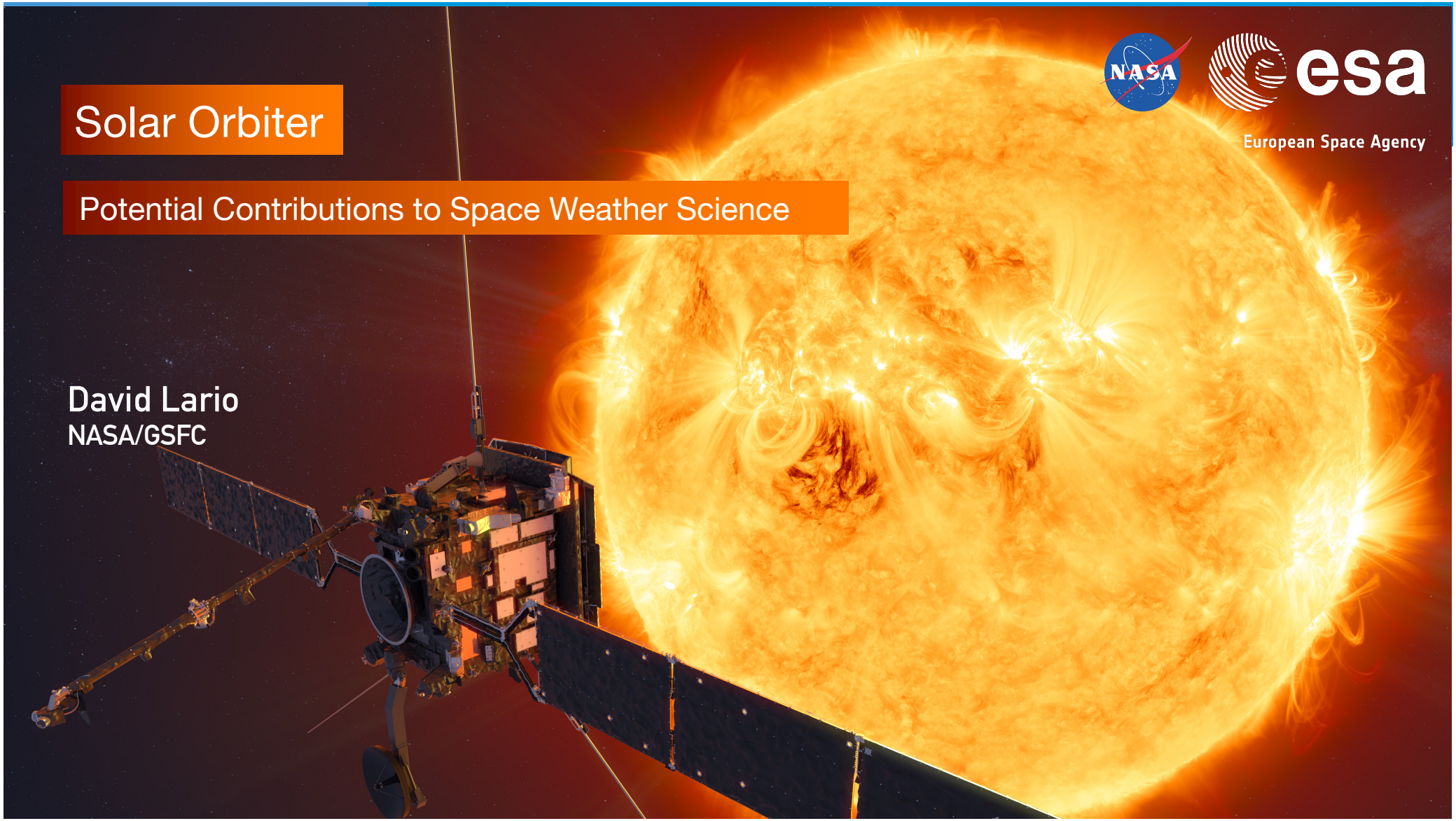
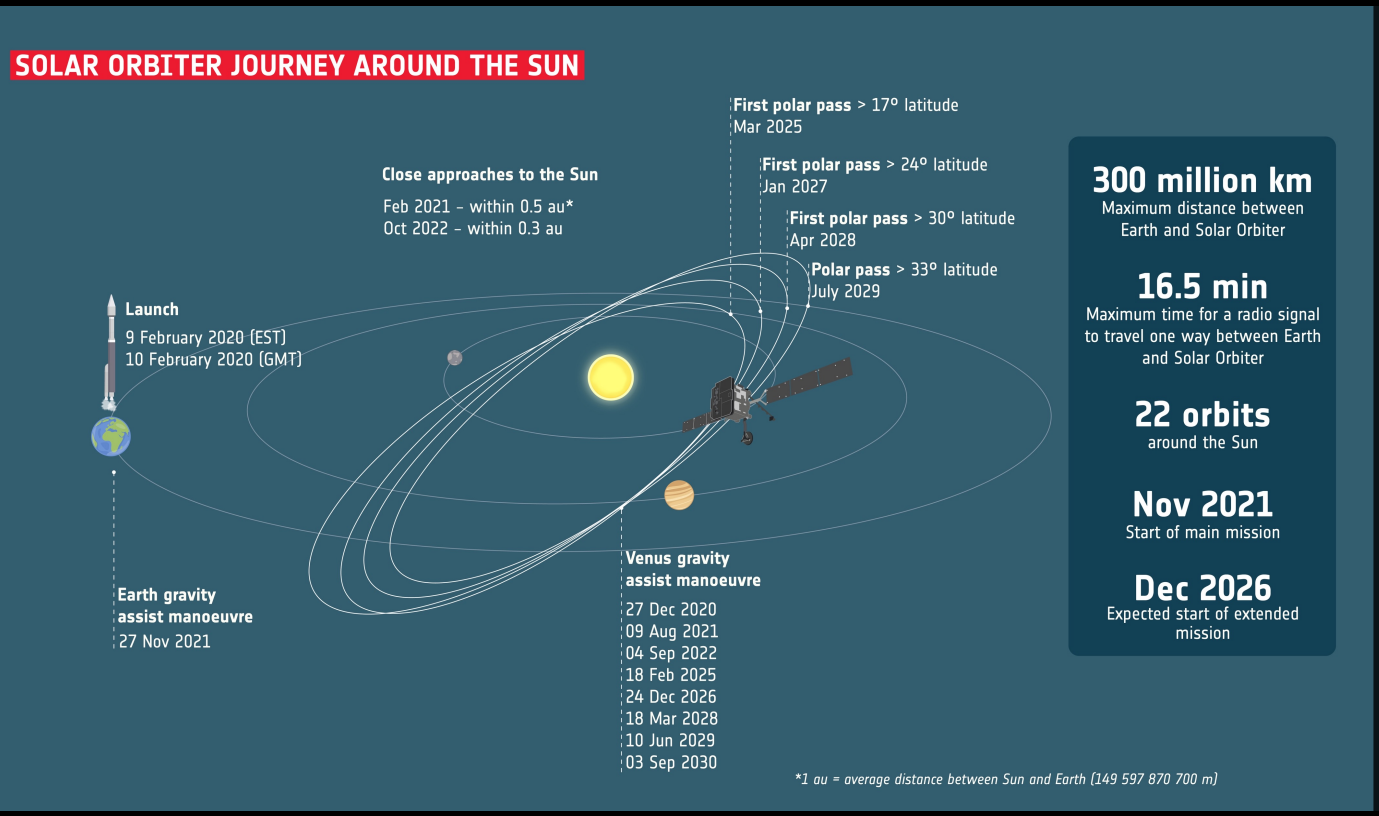
# Solar Orbiter

## Potential Contributions to Space Weather Science

David Lario
NASA/GSFC



# Solar Orbiter
# Exploring the Sun and Heliosphere




## Mission Summary

**Launch: 10 February 2020, 04:03 UTC**

**Cruise phase:** 1.8 years

**Nominal mission:** 5 years (started on 27 Nov 2021, first close perihelion @0.32 au in March 2022)

**Extended mission:** 3.5 years

**Orbit:** 0.28–0.91 au (period: 150–180 days)

**First images of the Sun's poles:**
Multiple gravity assists at Venus will increase inclination out of the ecliptic (Max. solar latitude ~33° during extended mission)

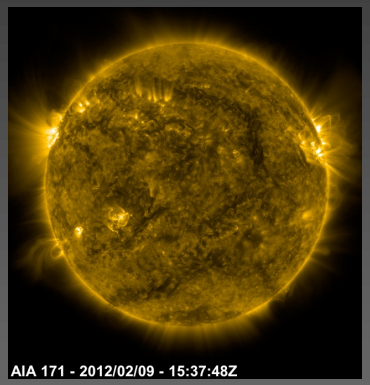
**Reduced relative rotation:**
Observations of evolving structures on solar surface & in heliosphere for almost a complete solar rotation (~1 month)

*Mission overview:*
*Müller et al., A&A Special Issue, 642, A1, 2020*

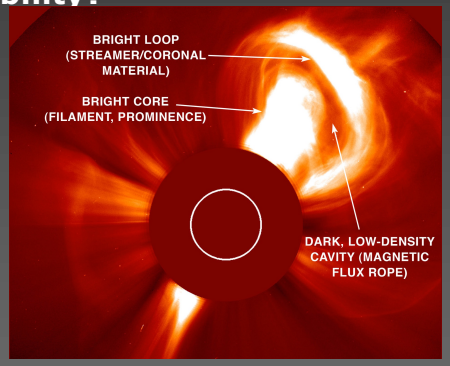
# How Does the Sun Create and Control the Heliosphere and Why Does Solar Activity Change with Time?

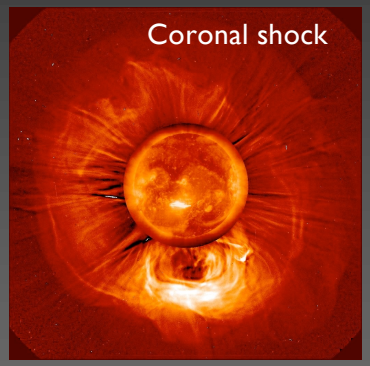
## #1: How and where do the solar wind plasma and magnetic field originate?

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

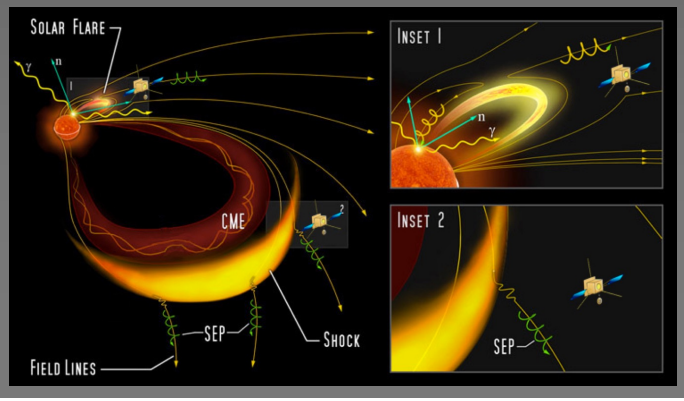



## #2: How do solar transients drive heliospheric variability?

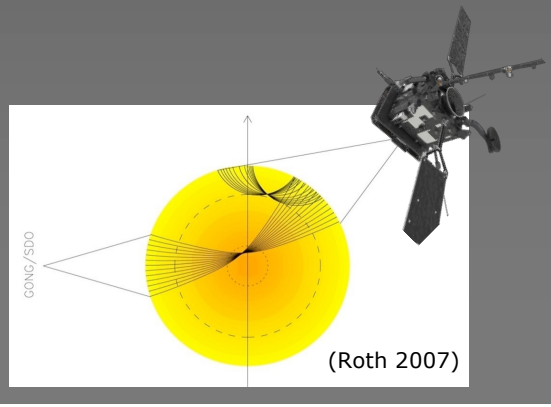


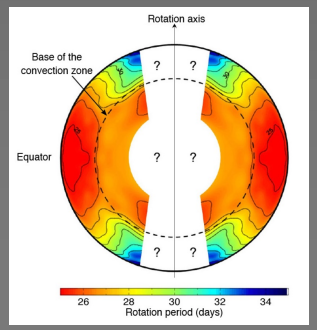




## #3: How do solar eruptions produce energetic particle radiation that fills the heliosphere?

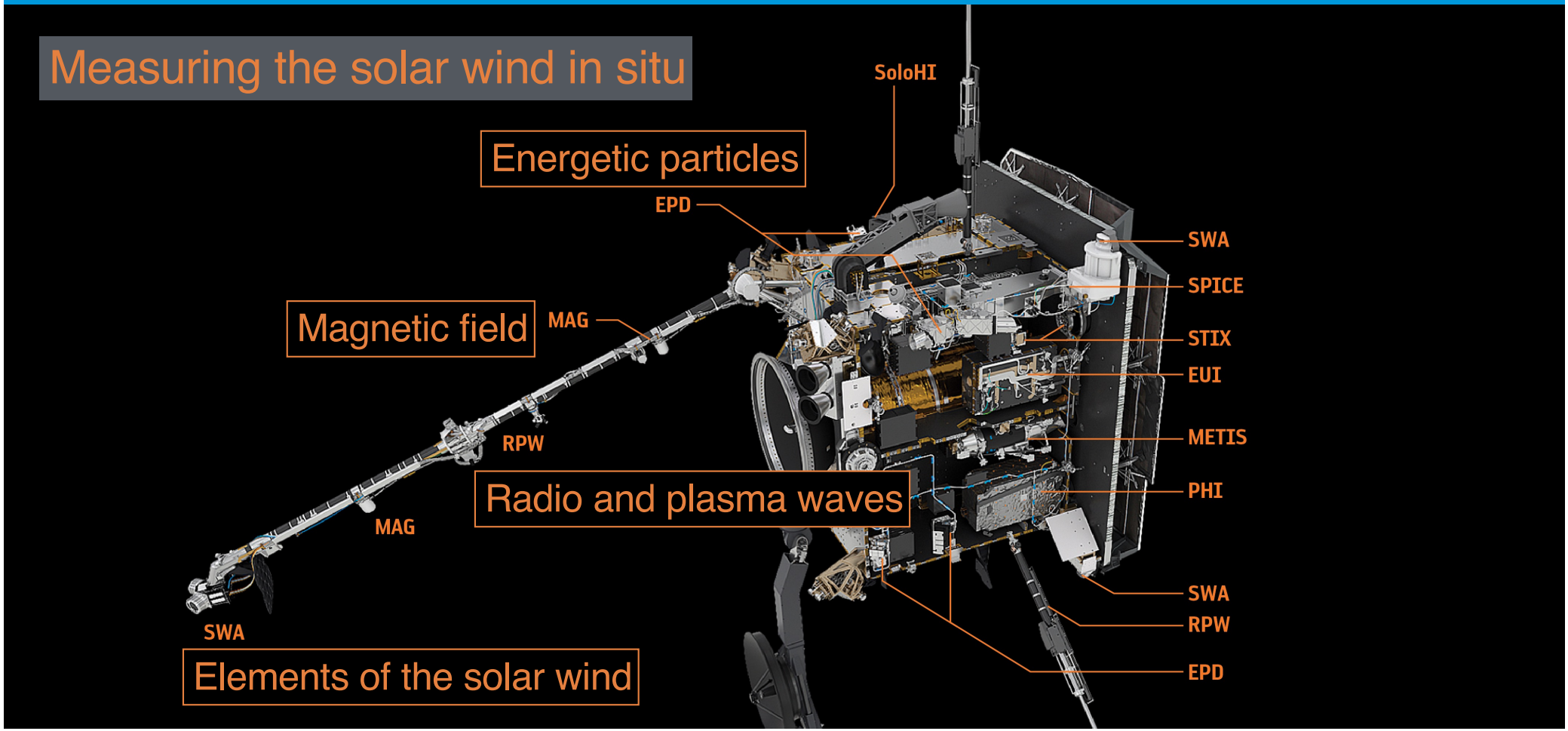



## #4: How does the solar dynamo work and drive connections between the Sun and the heliosphere?



# Solar Orbiter Payload



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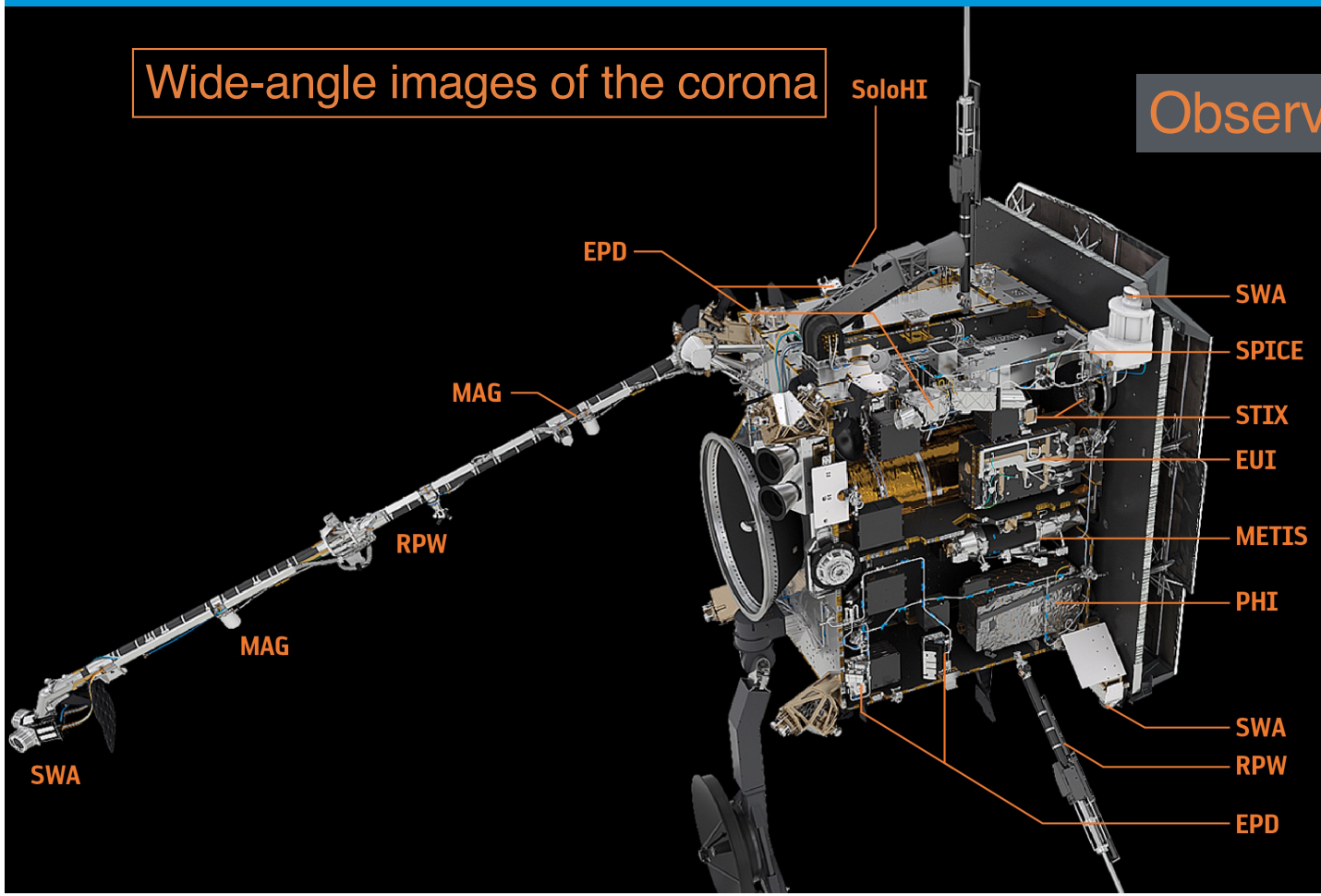
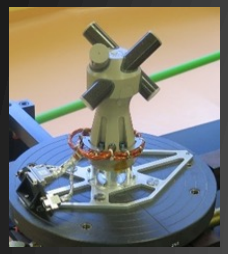



## Observing the Sun remotely

- UV spectral images
- X-ray emission
- UV high-res images
- Images of the corona
- Visible-light polarimetry

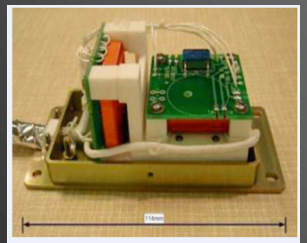
# Scientific instruments: in situ

## RPW: Radio & Plasma Waves



Search Coil Magnetometer

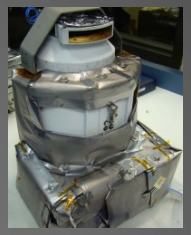
## MAG: Magnetometer



Fluxgate Sensor (cover removed)




## SWA: Solar Wind Analyser

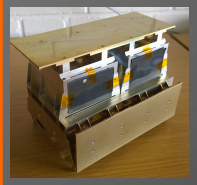


Heavy Ion Sensor

Electron Analyser System

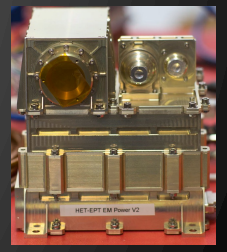
Proton Alpha Sensor

## EPD: Energetic Particle Detector



Suprathermal $e^-$ and $p^+$

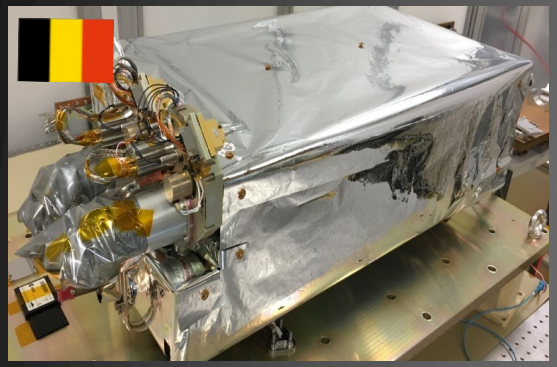
Suprathermal Ion Spectrograph



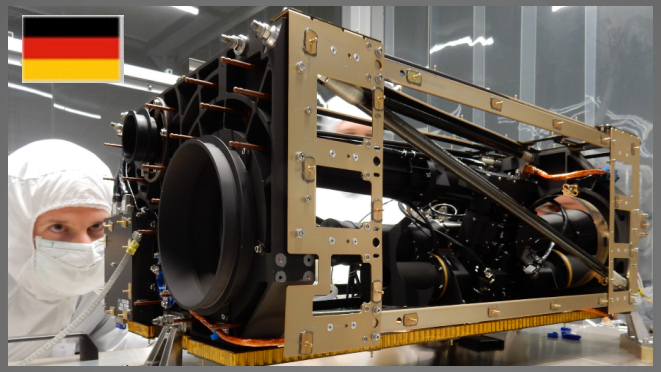
High Energy/ $e^-$ $p^+$ Telescope

# Scientific instruments: remote sensing

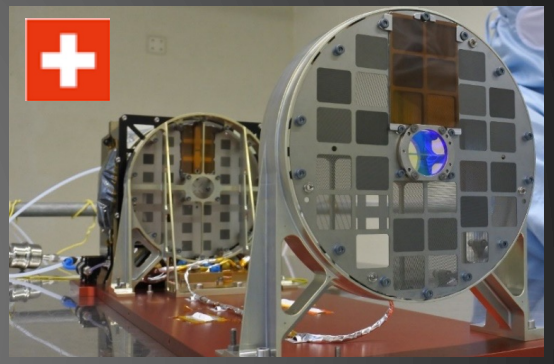
**EUI:** Full disk and high resolution Images in EUV



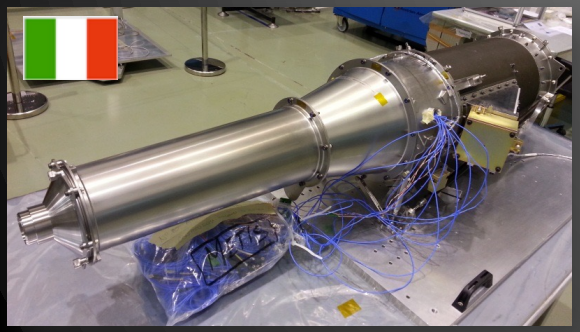
**PHI:** Full disk & high res vector magnetograms & velocity maps



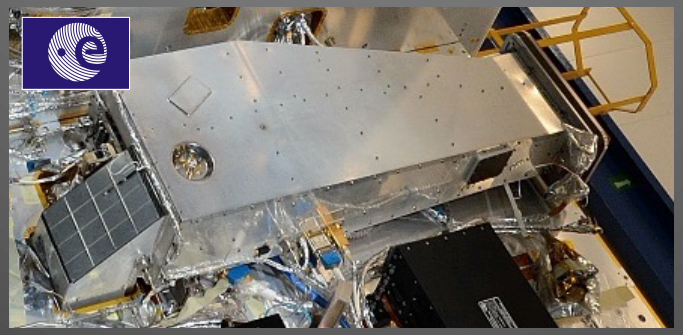
**STIX:** Localize flares, record X-ray spectra



**Metis:** Coronagraphy in UV & visible



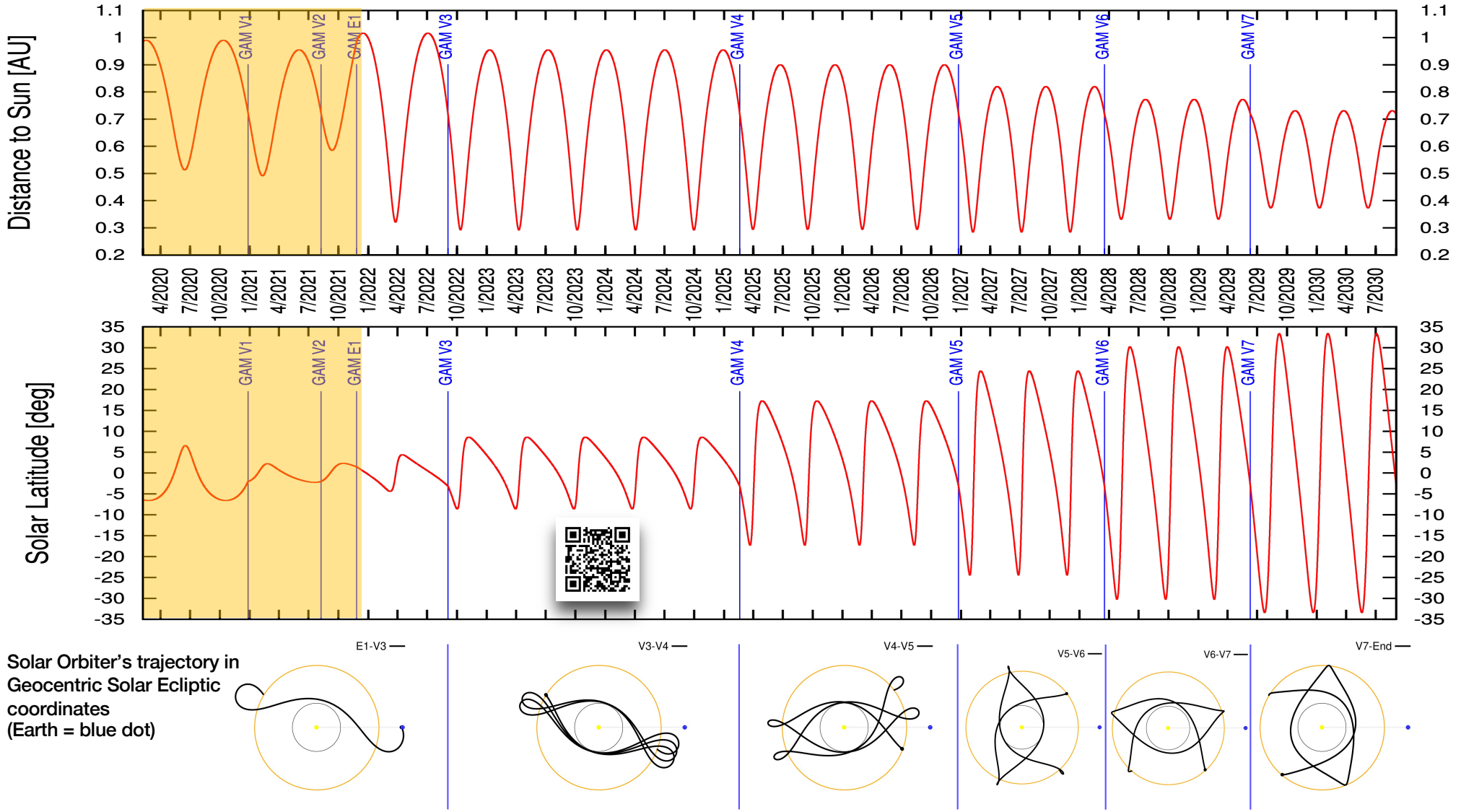
**SPICE:** EUV on-disk & off-limb spectroscopy



**SoloHI:** Heliospheric imager

# Solar Orbiter: Exciting science

- Solar Orbiter:
  - connects features & events in solar atmosphere with their inner heliospheric consequences
  - will follow features on the Sun for longer due to partial co-rotation
  - will deliver first images of the solar disk and the corona from out of the ecliptic → first observations of solar poles
  - provides the first magnetograms, helioseismic time series, X-ray images & EUV spectra from outside the Sun-Earth line
  - allows first stereoscopy of velocity & magnetic field vectors, also from outside ecliptic

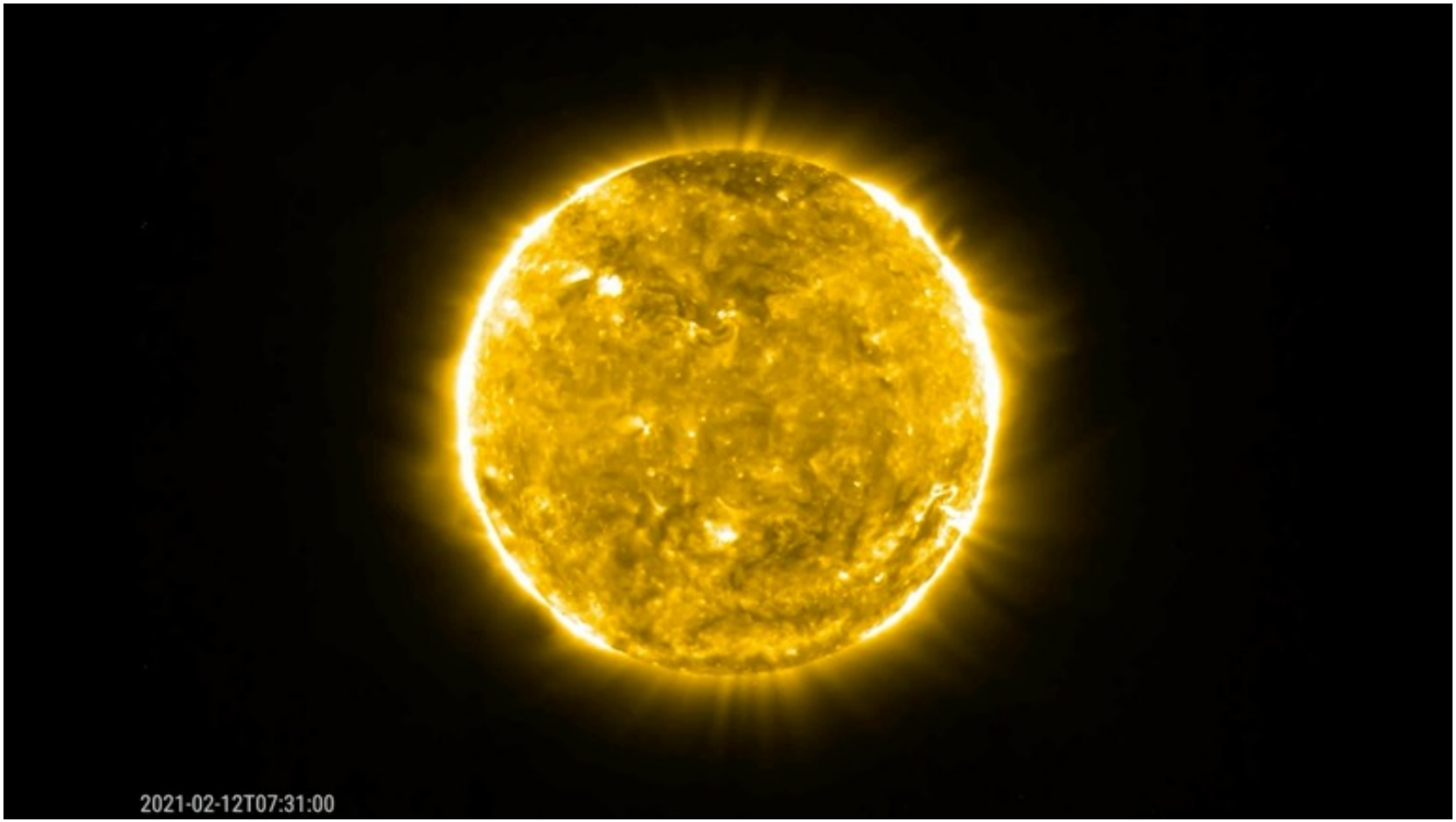



Solar Orbiter's trajectory in Geocentric Solar Ecliptic coordinates (Earth = blue dot)

# Nota bene

- Solar Orbiter is **not a real-time monitoring mission.**
- Instrument modes are coordinated in Solar Orbiter Observing Plans (SOOPs). These plans address different science goals, according to varying opportunities.
- Unique orbit causes **changes in viewpoint, fields-of-view** and **observing resolution**
- **Delays in data download**: when Solar Orbiter is at far side, data may be stored onboard for several months!
- **Low-Latency (LL) Data** = a kind of ‘beacon’ data, low resolution, not optimal for science, but downlinked daily
- **Science data policy:** published in data archive 3 months after arrival on Earth

# Combination of Remote-Sensing Observations to track CMEs




**SolO**
**0.51 AU**
**174°W**

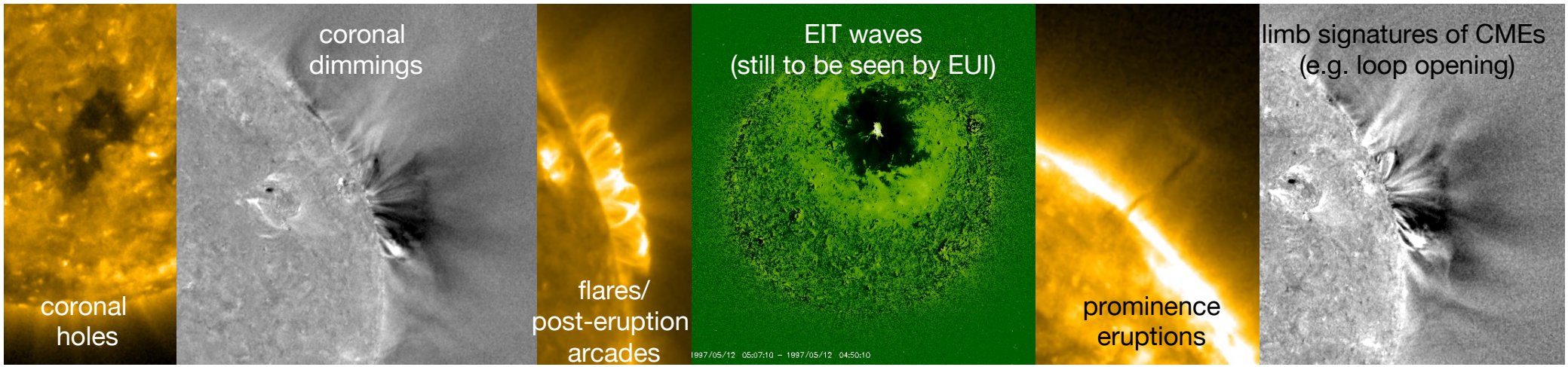
**EUI**
**METIS**
**SOLOHi**

www.esa.int/ESA_Multimedia/Missions/Solar_Orbiter/

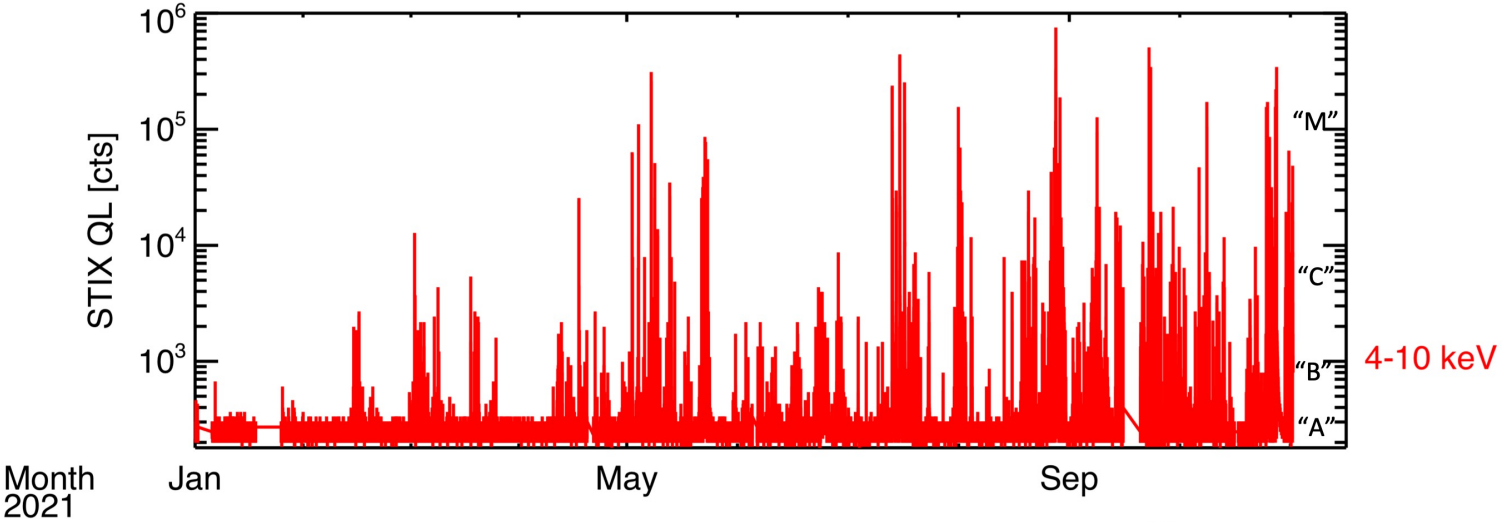
**CME also seen by SOHO moving out of the west limb**

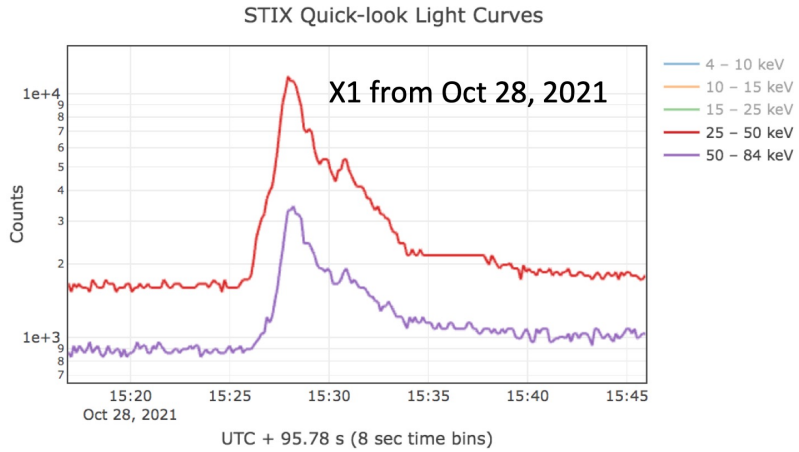
# EUI detailed observations of solar eruptions

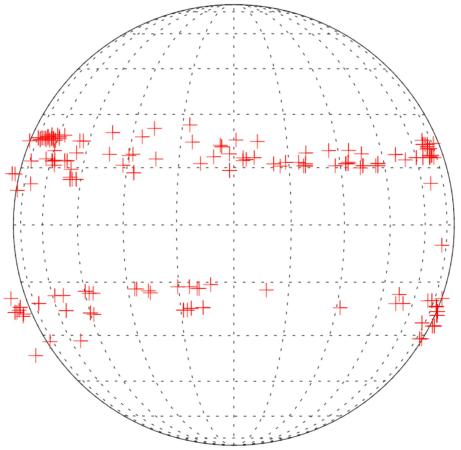
- Two synoptic programs will provide monitoring of solar sources of disturbed space weather in the heliosphere (coronal holes, flares, CME signatures).
- EUI will be useful as an EUV monitor of the solar far side as seen from Earth (STEREO A will be within only 35° from the Sun-Earth line until the end of 2024).



# Continuous observations of X-ray flares



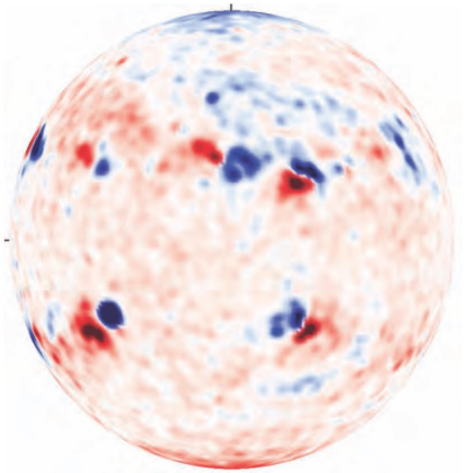
https://pub023.cs.technik.fhnw.ch//view/plot/lightcurves#

# High-Latitude and Far-Side Vector Magnetograms

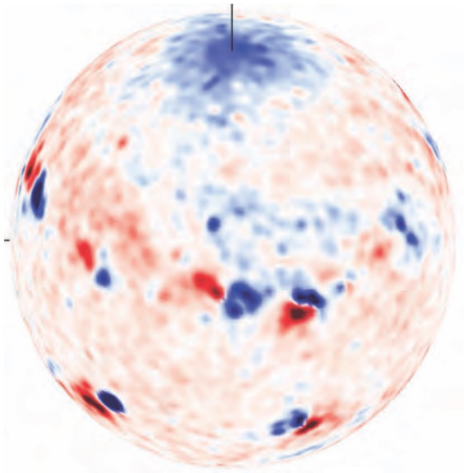
Polar magnetic field observations are essential to improve long- and short- term predictions models:

Long-term: understanding and predicting solar cycles, and thus improve solar dynamo models.

Short-term: Inaccurate knowledge of polar field impacts the models used to locate the source regions of the solar wind.

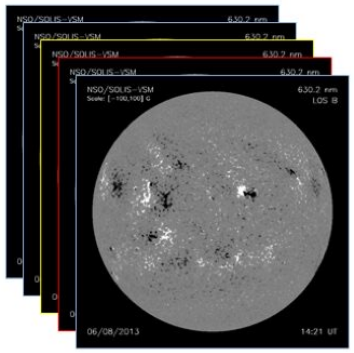


***Ecliptic***

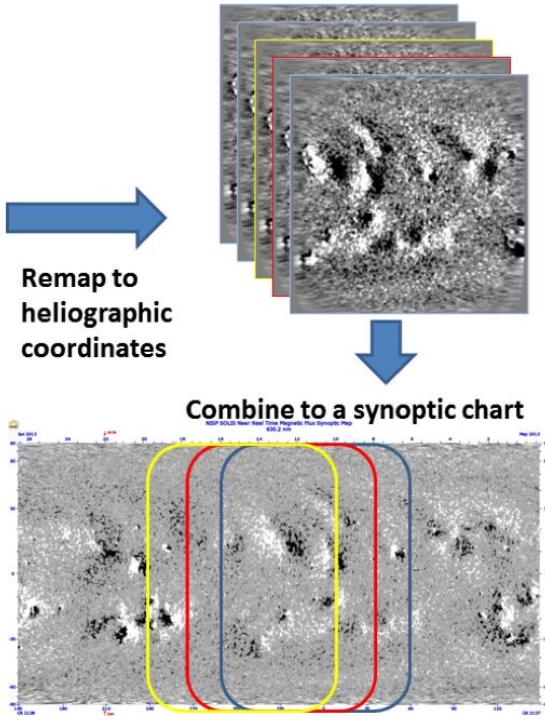


***Solar Orbiter @ 33 deg.***

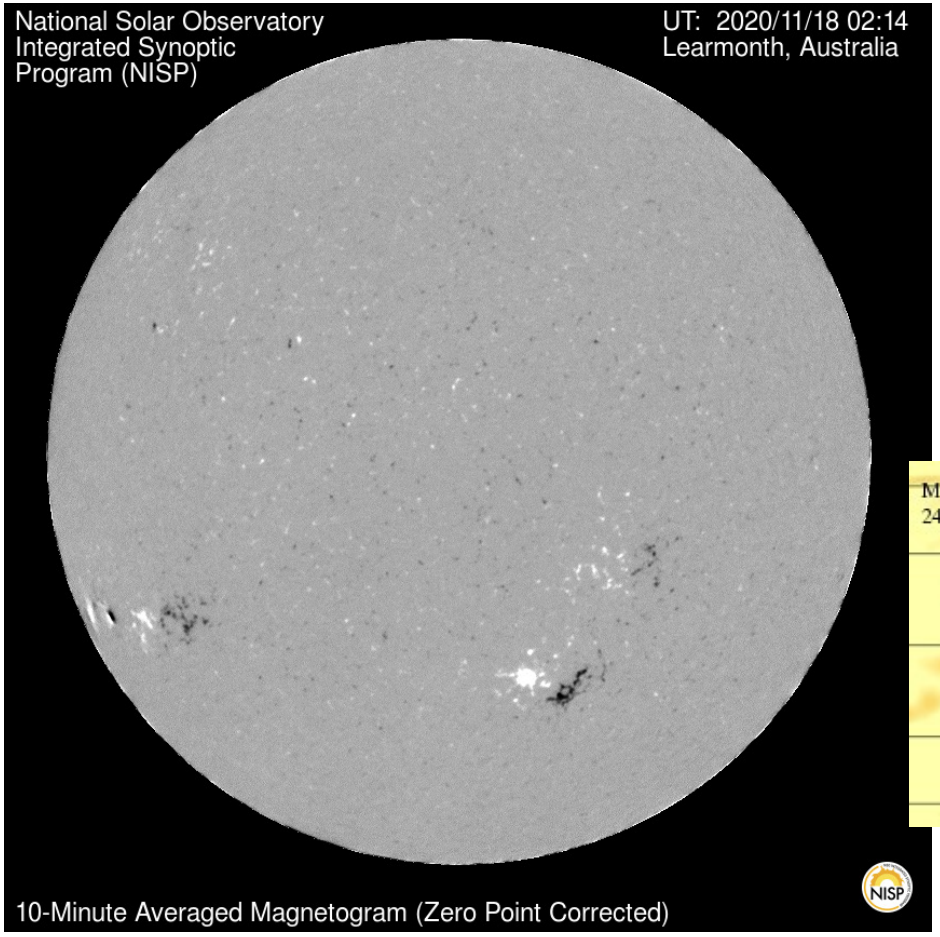
Far-side magnetic field observations will improve the synoptic magnetograms currently built from a single observer point.



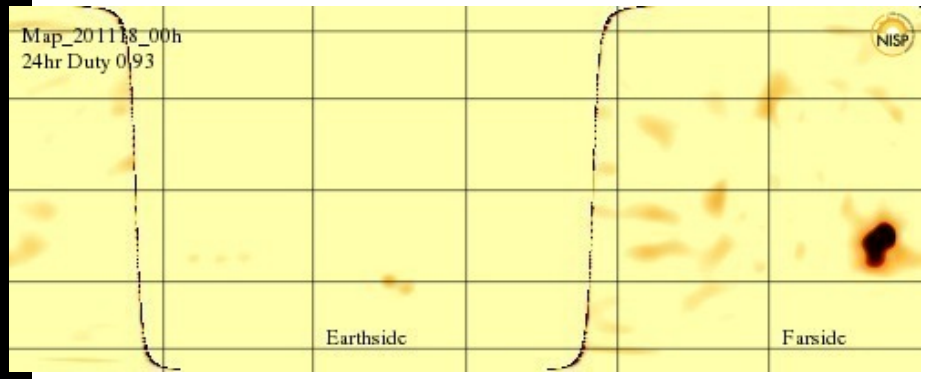
**Full disk daily observations in sky-coordinates.**



# Magnetograms from the far side of the Sun

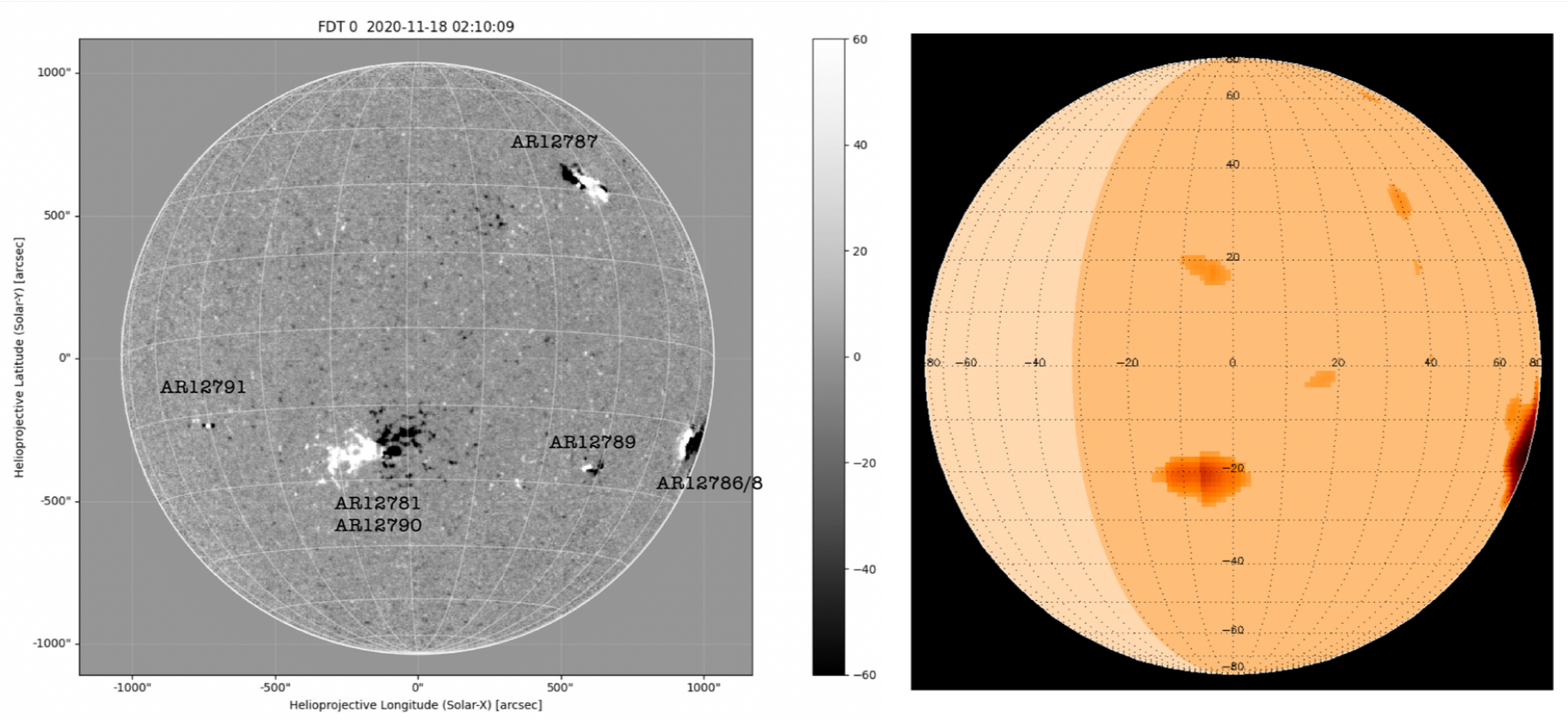



**Earth**
**18 Nov**
**2020**




**GONG FarSide AR prediction**
nso.edu/research/tech-development/gong-far-side/
gong2.nso.edu/archive/patch.pl?menutype=i

# Magnetograms from the far side of the Sun




**SolO**
**0.92 AU**
**122°W**

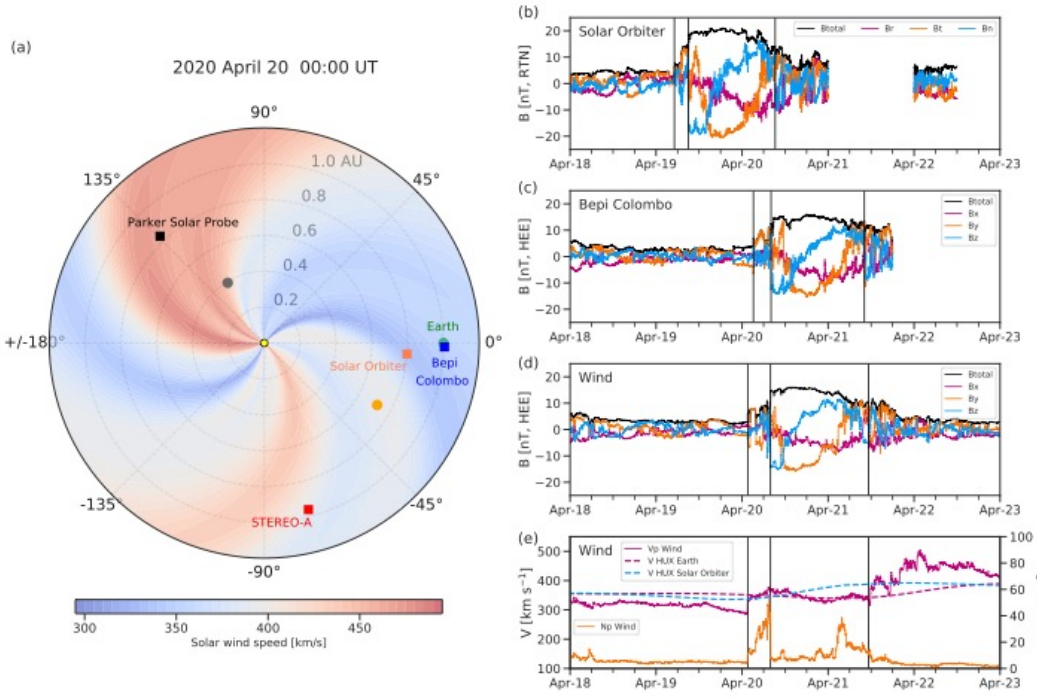
**PHI**

**GONG FarSide AR prediction**

Courtesy of Strecker, Jain et al. (in preparation)

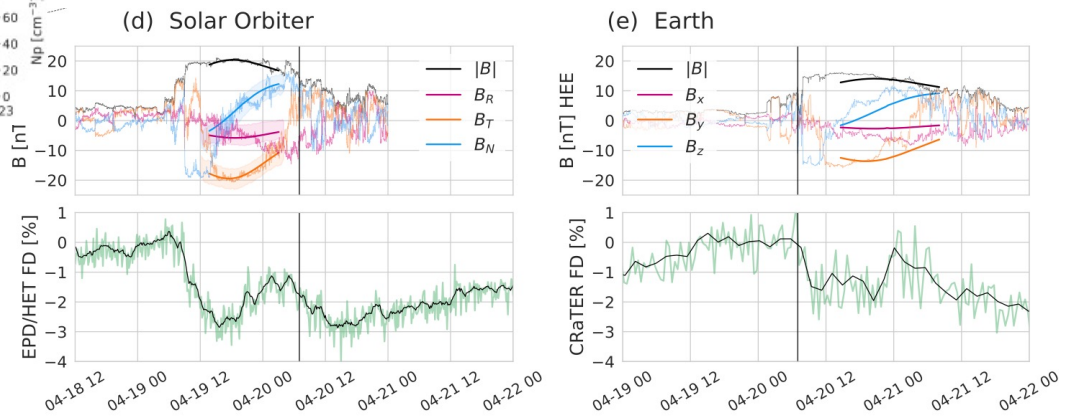
# Solar Orbiter as Circumstantial Upstream Monitor

**April 2020**



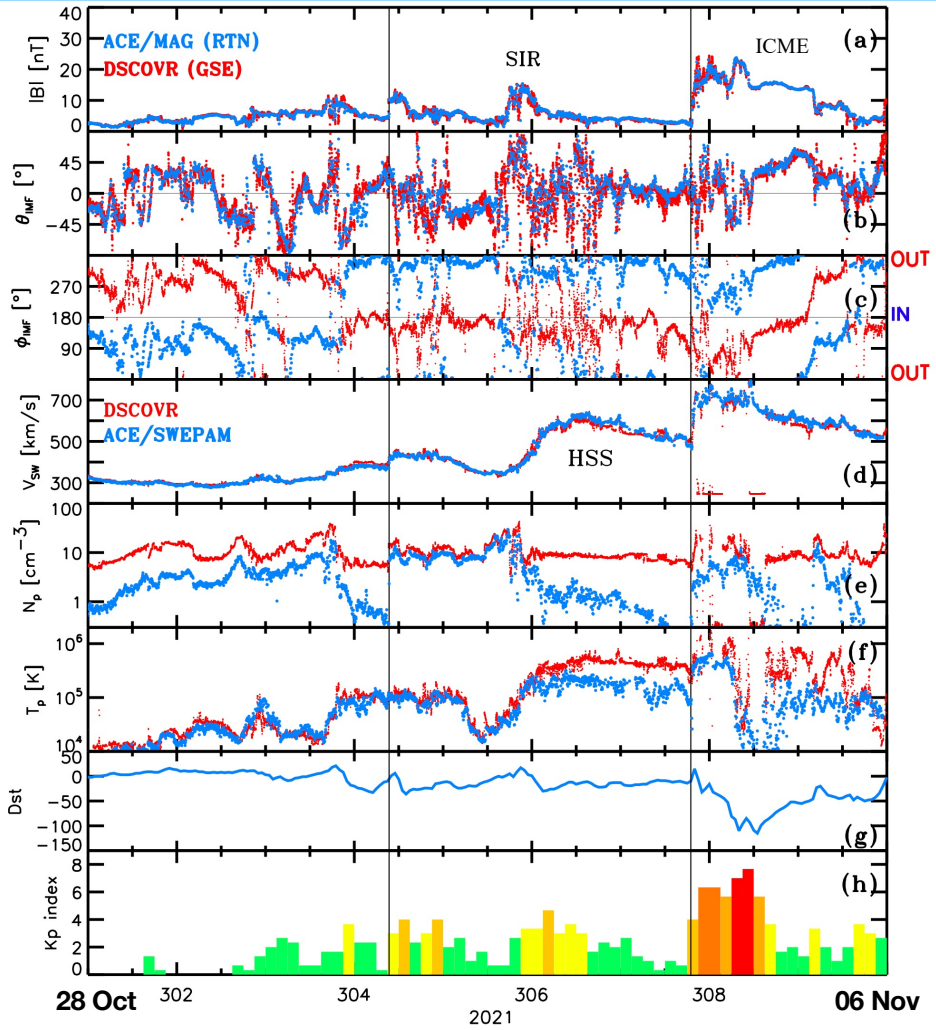

Davies et al. [2021, A&A]

**SolO**
**0.80 AU**
**3°E**




Freiherr von Fostner et al. [2021, A&A]

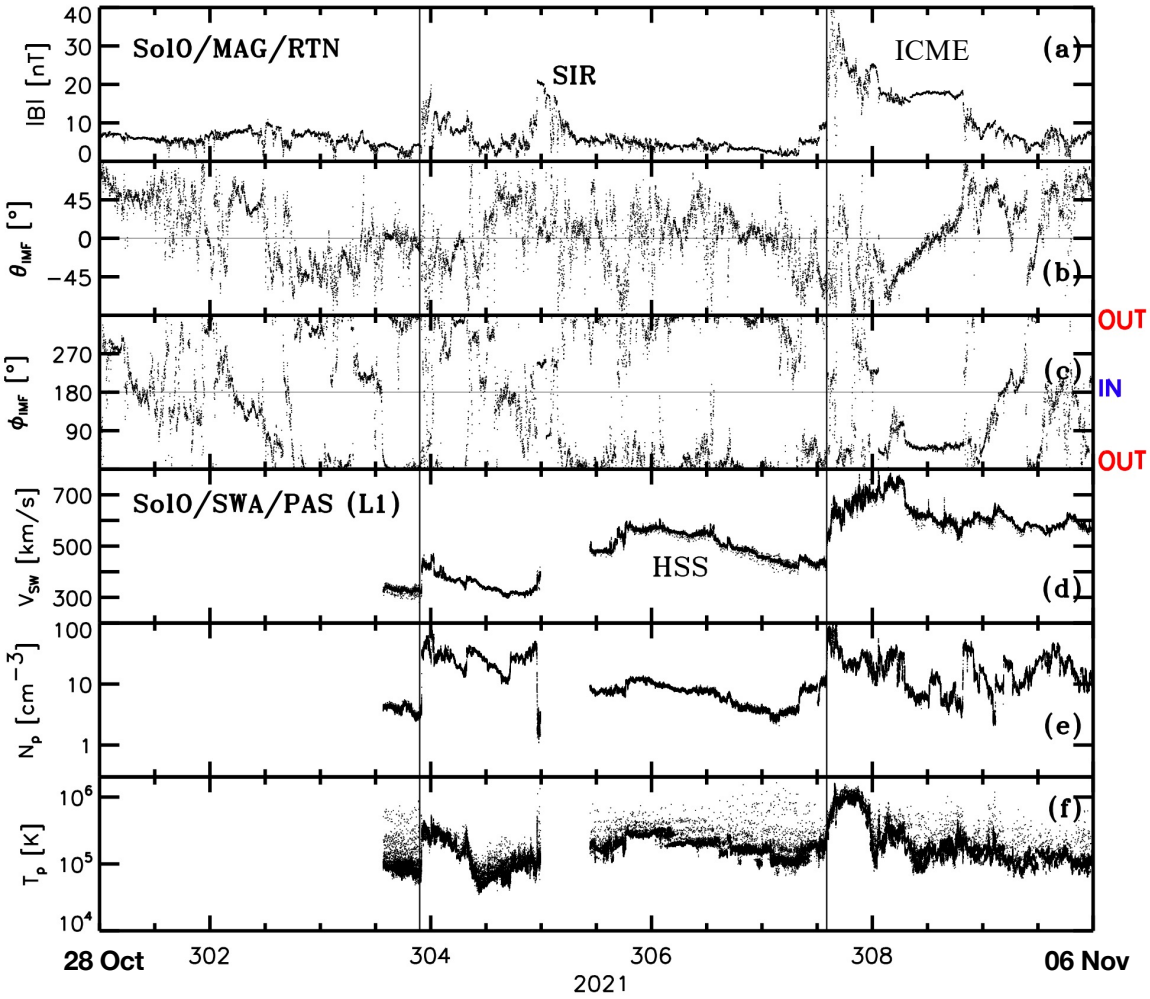
# Solar Orbiter as Circumstantial Upstream Monitor




**Halloween 2021 events**

**SolO**
**0.80-0.86 AU**
**3°E-1°E**

# Solar Orbiter as Circumstantial Upstream Monitor




**Halloween 2021 events**

**SolO**
**0.80-0.86 AU**
**3°E-1°E**

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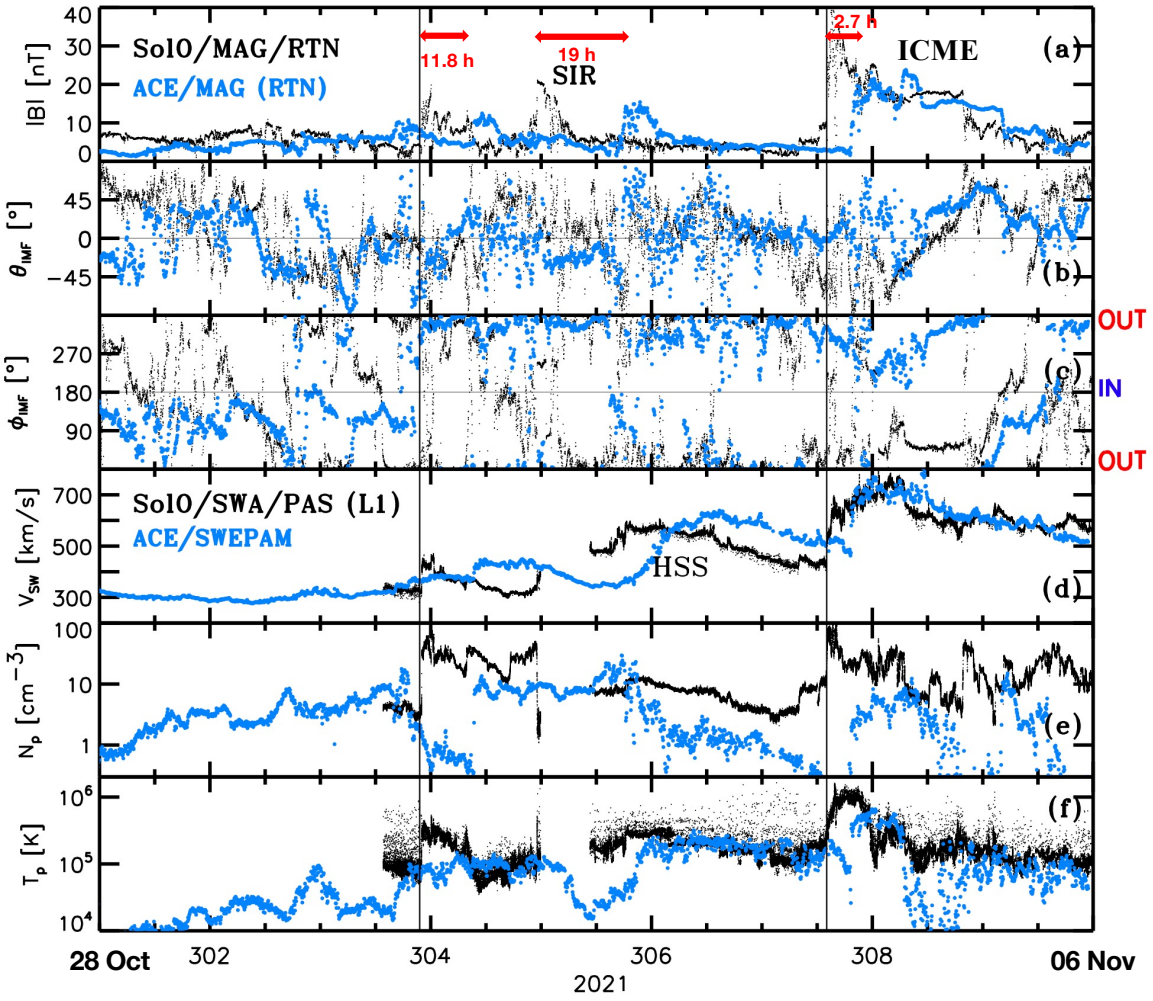
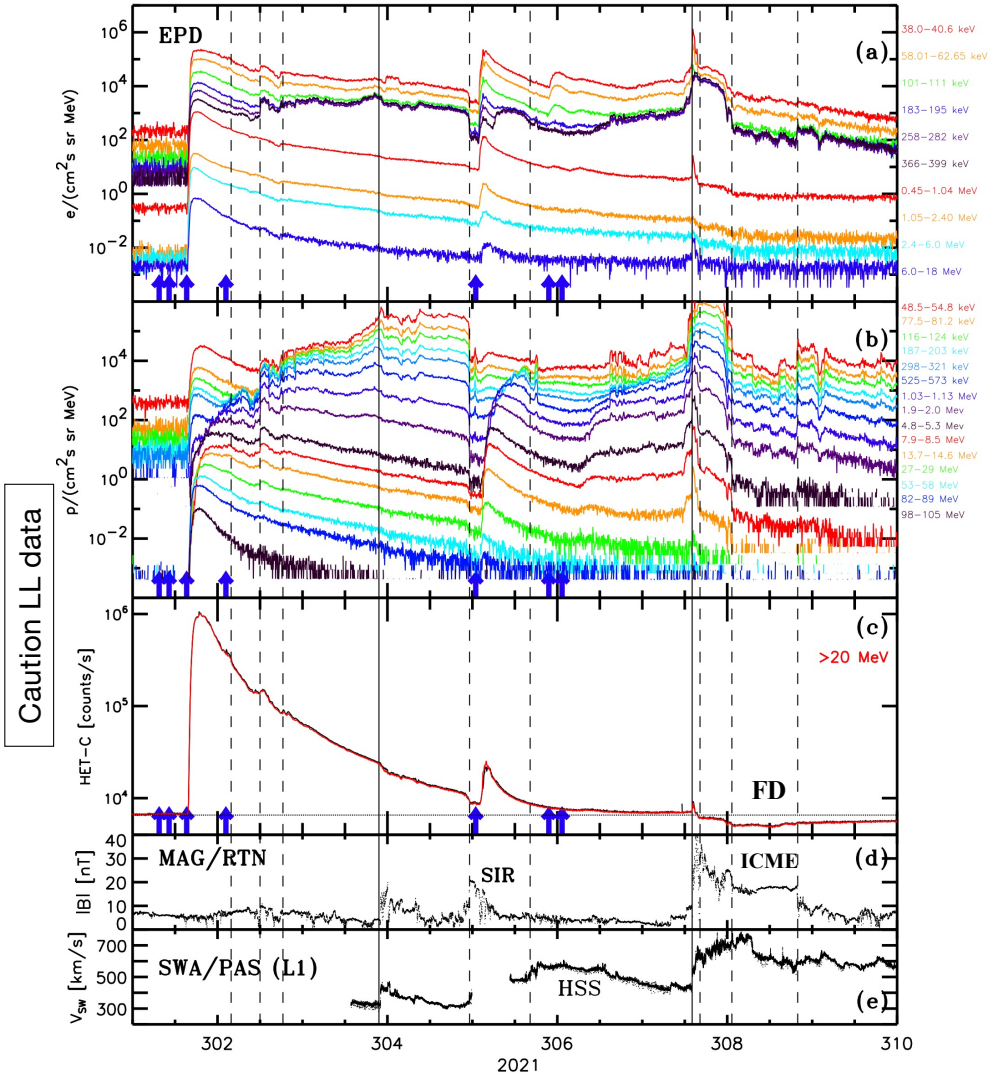
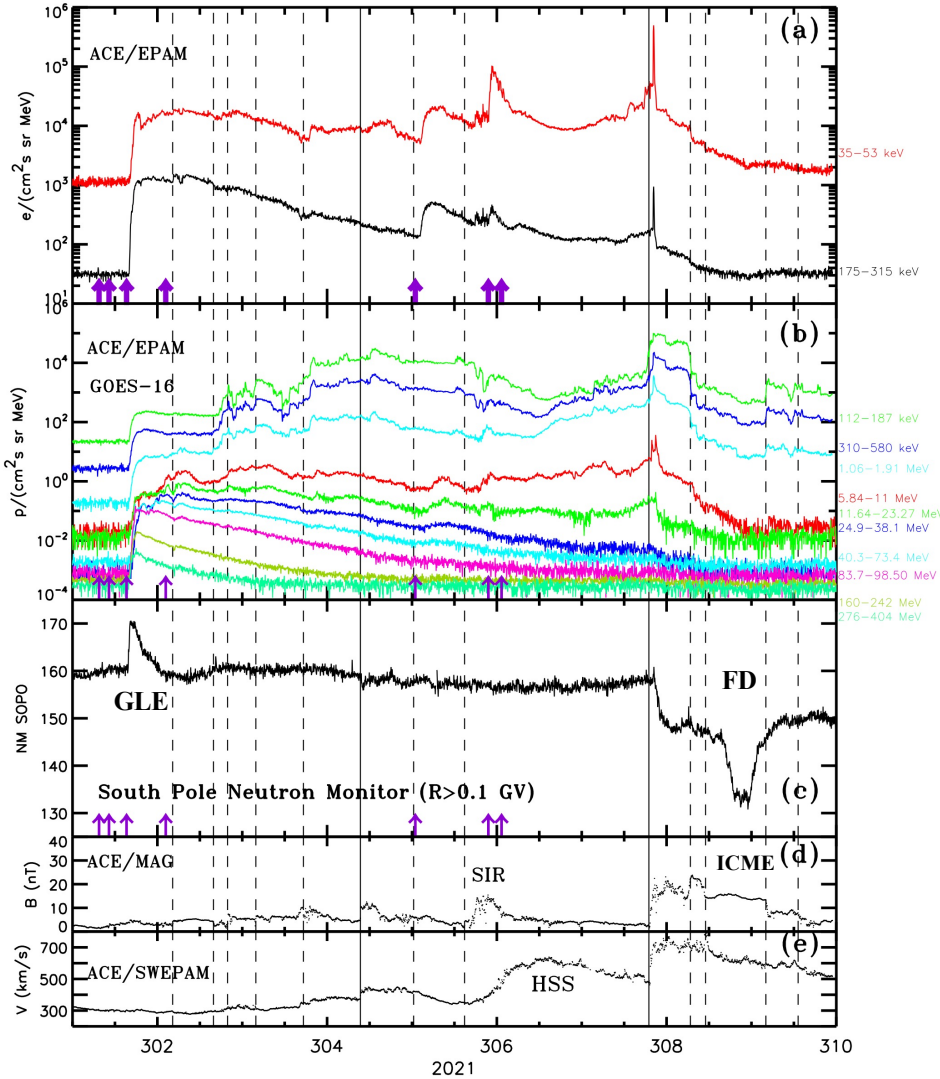



**Halloween 2021 events**

**SolO**
**0.80-0.86 AU**
**3°E-1°E**

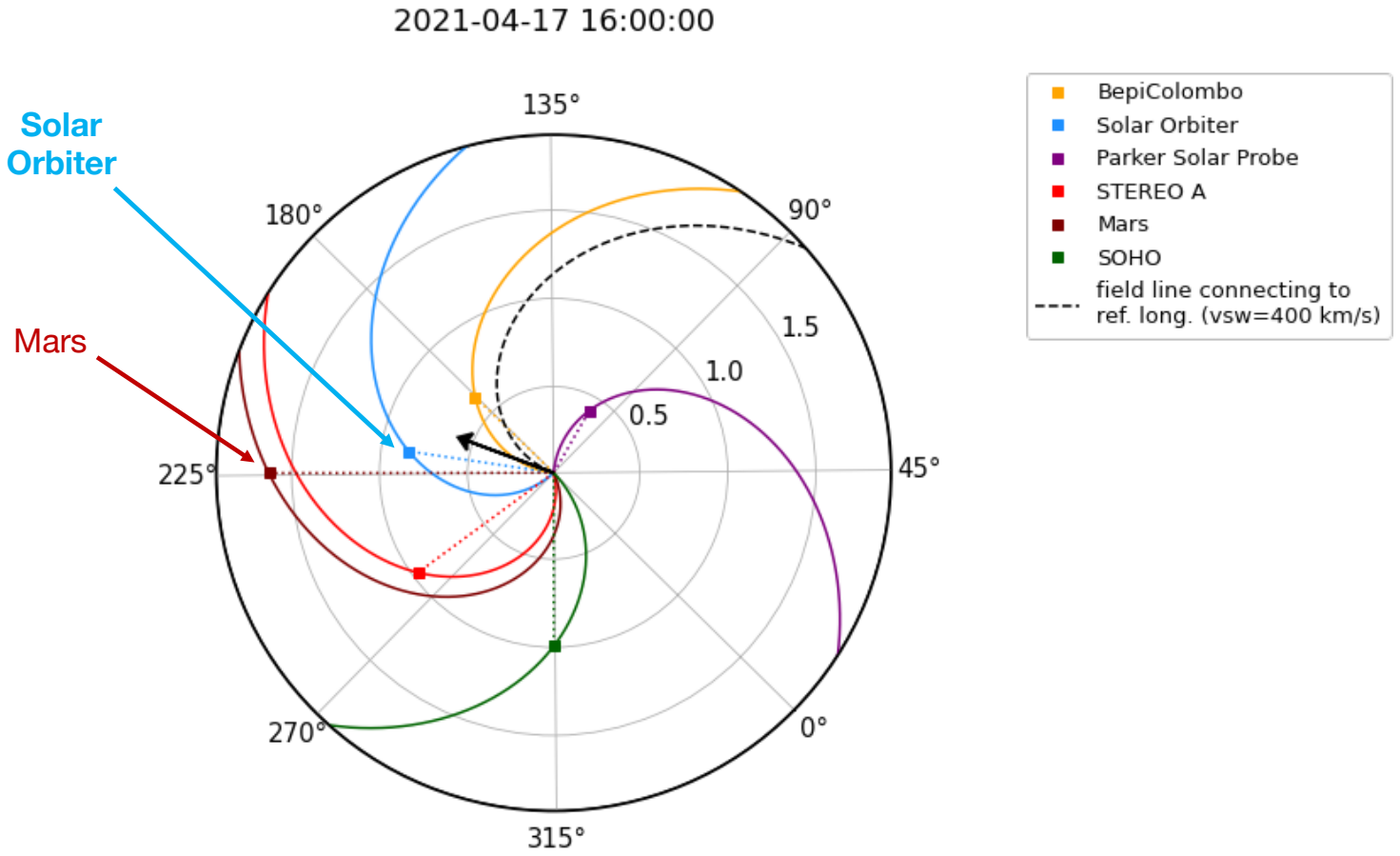



Caution LL data



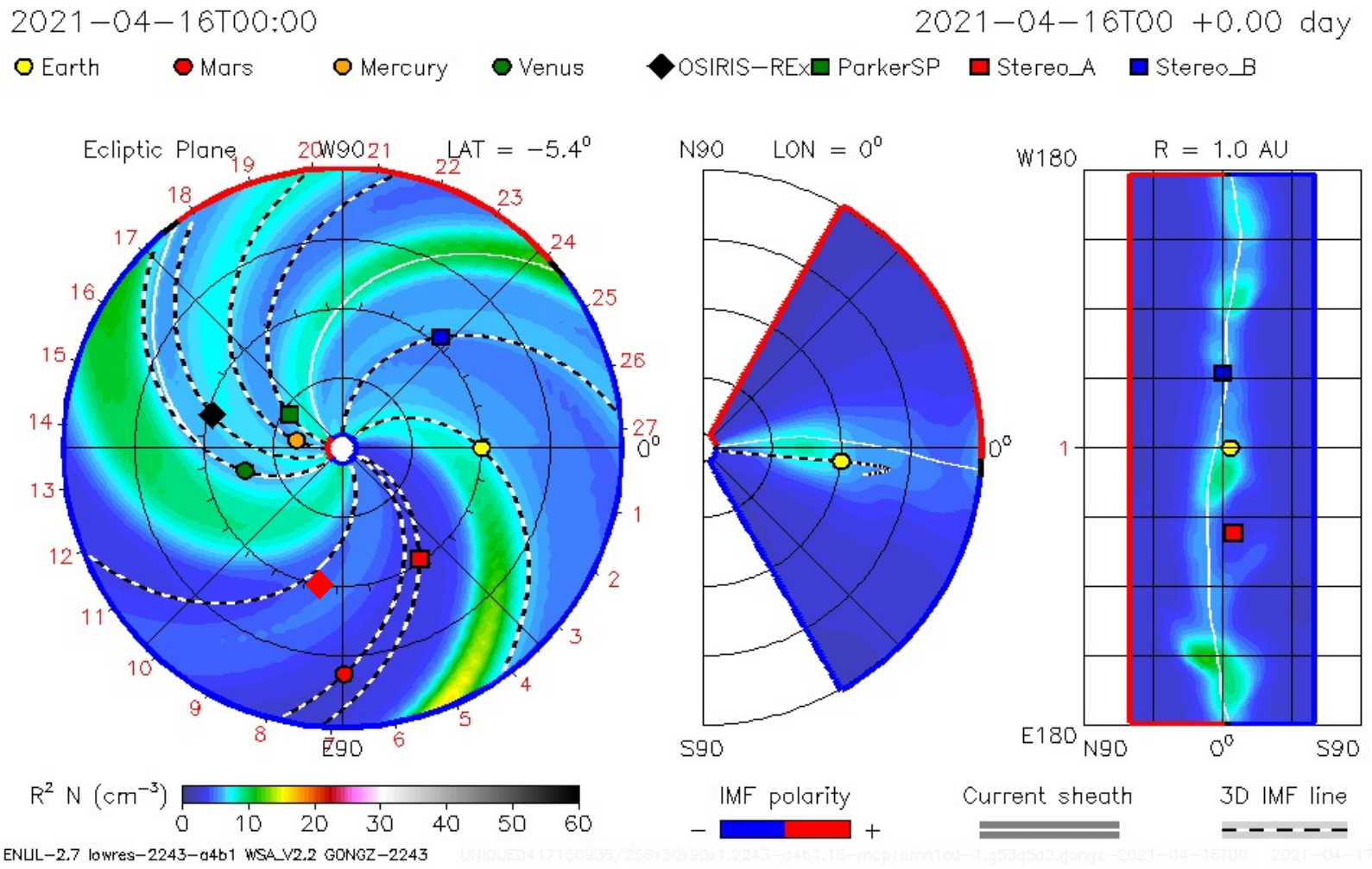
# Solar Orbiter as Circumstantial Upstream Monitor for other Planets

## The case of the CME event on 2021 Apr 17




**SolO**
**0.85 AU**
**98°E**

**Mars**
**1.6 AU**
**90°E**



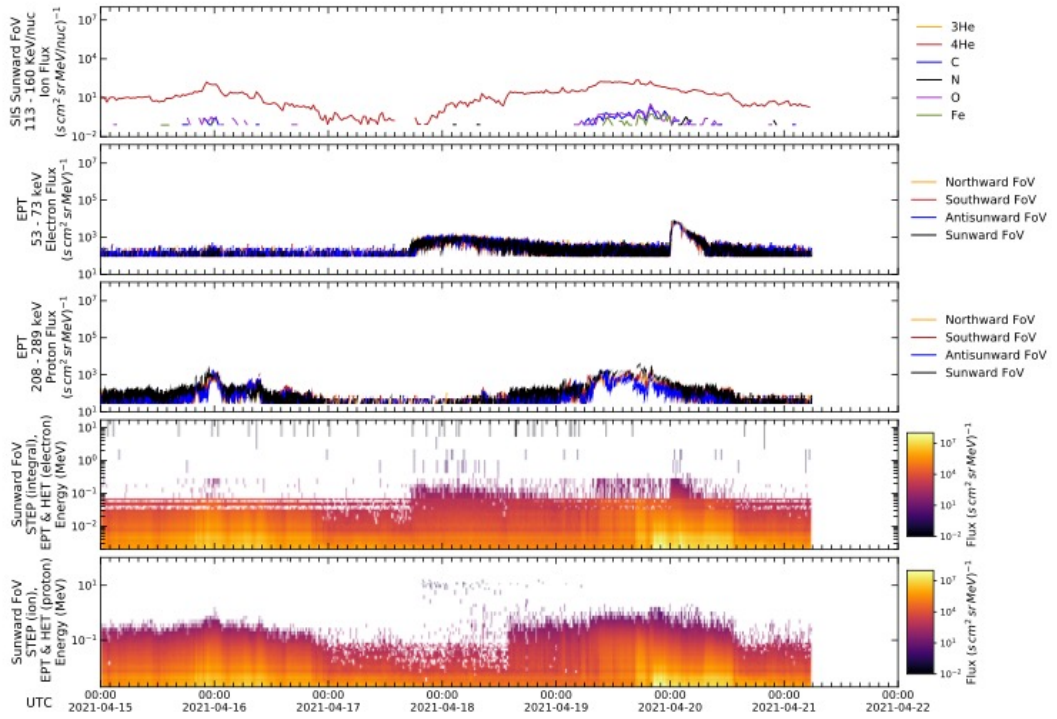

**◆SolO**
**0.85 AU**
**98°E**

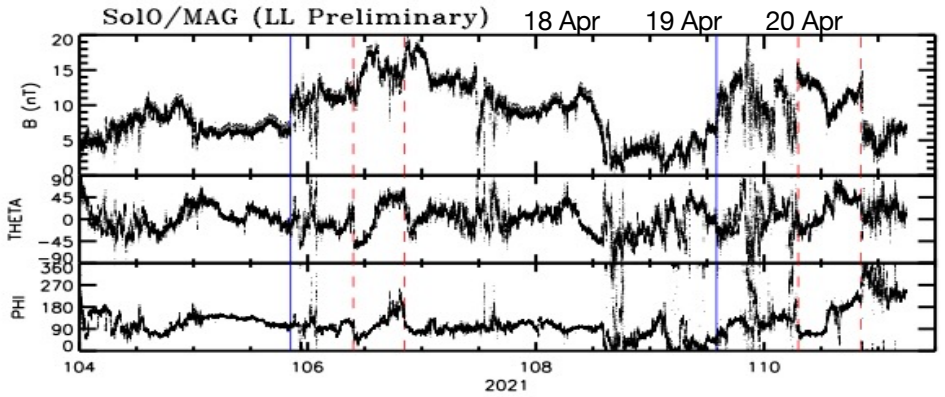
**●Mars**
**1.6 AU**
**90°E**

**https://iswa.gsfc.nasa.gov/downloads/20210417_210200_2.0_anim.tim-den.gif**

# Low-Latency Data Display

(at that time)



NEWS | April 22, 2021

# NASA's Ingenuity Mars Helicopter Logs Second Successful Flight

**Ingenuity's Second Flight As Seen by Perseverance:** NASA's Mars Perseverance rover acquired this image using its left Mastcam-Z camera. Mastcam-Z is a pair of cameras located high on the rover's mast. This is one still frame from a sequence captured by the camera while taking video. This image was acquired on Apr. 22, 2021. Credits: NASA/JPL-Caltech/ASU/MSSS. Download image ›

## Related images and videos

Second Color Image Taken by Ingenuity

The Third Color Image Taken by Ingenuity

Perseverance's Left Navcam Views Ingenuity During its Third Flight

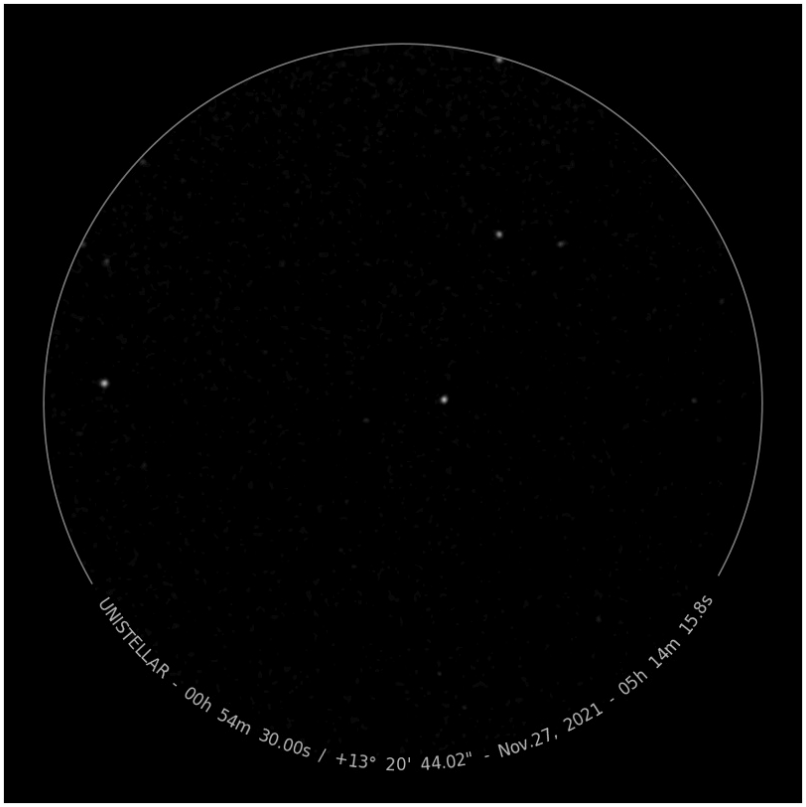
› more images
› more videos

# Summary

- Solar Orbiter allows us to connect features & events in solar atmosphere with their inner heliospheric consequences

- Solar Orbiter provides data to support and improve space weather studies, but

- Solar Orbiter is **not a real-time monitoring mission.**




DATA
Archive https://soar.esac.esa.int/soar/ ( https://issues.cosmos.esa.int/solarorbiterwiki/display/SOSP/Archive+Support+Data )
SPDF https://cdaweb.gsfc.nasa.gov SDAC https://umbra.nascom.nasa.gov/ https://sdac.virtualsolar.org/

Mission Pages: https://sci.esa.int/web/solar-orbiter https://www.nasa.gov/solar-orbiter
https://www.cosmos.esa.int/web/solar-orbiter

Key mission Facts Sheet: http://www.esa.int/Science_Exploration/Space_Science/Solar_Orbiter

Twitter @ESASolarOrbiter

News Multimedia https://www.esa.int/ESA_Multimedia/Missions/Solar_Orbiter/

A&A special issue on mission+payload: https://www.aanda.org/component/toc/?task=topic&id=1082

Where is Solar Orbiter? https://solarorbiter.esac.esa.int/where/
SPICE Kernels https://www.cosmos.esa.int/web/spice/solar-orbiter
Orbit Plots: https://issues.cosmos.esa.int/solarorbiterwiki/display/SOSP/Orbit+Plots

Public Science Operations pages (incl. long term plans and SOOP (Solar Orbiter Observing Plan) definitions):
https://issues.cosmos.esa.int/solarorbiterwiki/display/SOSP/Solar+Orbiter+SOC+Public

Science planning is done well in advance, to exploit the scientific opportunities while respecting mission constraints
Planning roadmap: https://tinyurl.com/cby8f254

Science Activity Plan https://issues.cosmos.esa.int/solarorbiterwiki/pages/viewpage.action?pageId=16941385

DATA
Archive https://soar.esac.esa.int/soar/ ( https://issues.cosmos.esa.int/solarorbiterwiki/display/SOSP/Archive+Support+Data )
SPDF https://cdaweb.gsfc.nasa.gov SDAC https://umbra.nascom.nasa.gov/ https://sdac.virtualsolar.org/

Data availability http://www.davidstansby.com/soda/

Instruments Sites
EPD http://espada.uah.es/epd/data/archive
EUI https://wwwbis.sidc.be/EUI/data/
MAG https://www.imperial.ac.uk/space-and-atmospheric-physics/research/missions-and-projects/space-missions/solar-orbiter/
METIS http://metis.oato.inaf.it
PHI https://www2.mps.mpg.de/en/projekte/solar-orbiter/phi/
RPW https://rpw.lesia.obspm.fr/rpw-data/daily-summary-plots/
SPICE https://spice.ias.u-psud.fr/data/archives
STIX https://pub023.cs.technik.fhnw.ch/view/plot/lightcurves
SWA https://www.ucl.ac.uk/mssl/research/solar-system/space-plasma-physics/missions/solar-orbiter/

Working Groups https://sites.google.com/view/solo-wg/

Modelling and Data Analysis Working Group (MADAWG) https://sites.google.com/site/solarorbiterdawg/home
Connectivity tool http://connect-tool.irap.omp.eu/

First Results A&A issue: https://www.aanda.org/component/toc/?task=topic&id=1340