Synergies between EUI and Metis

solar orbiter

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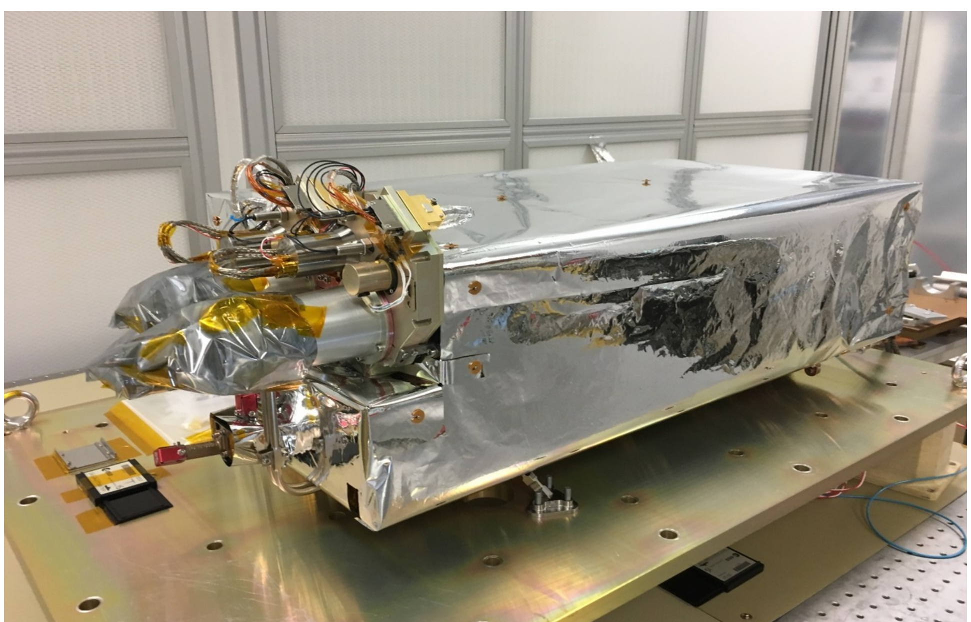
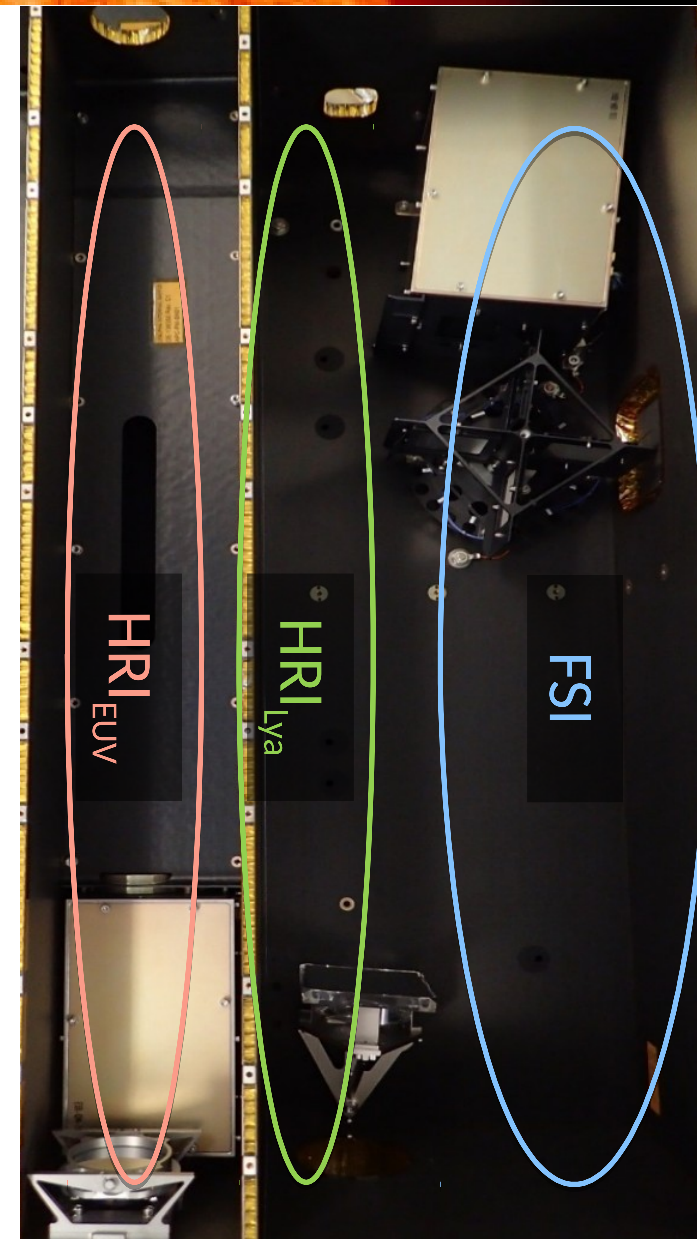
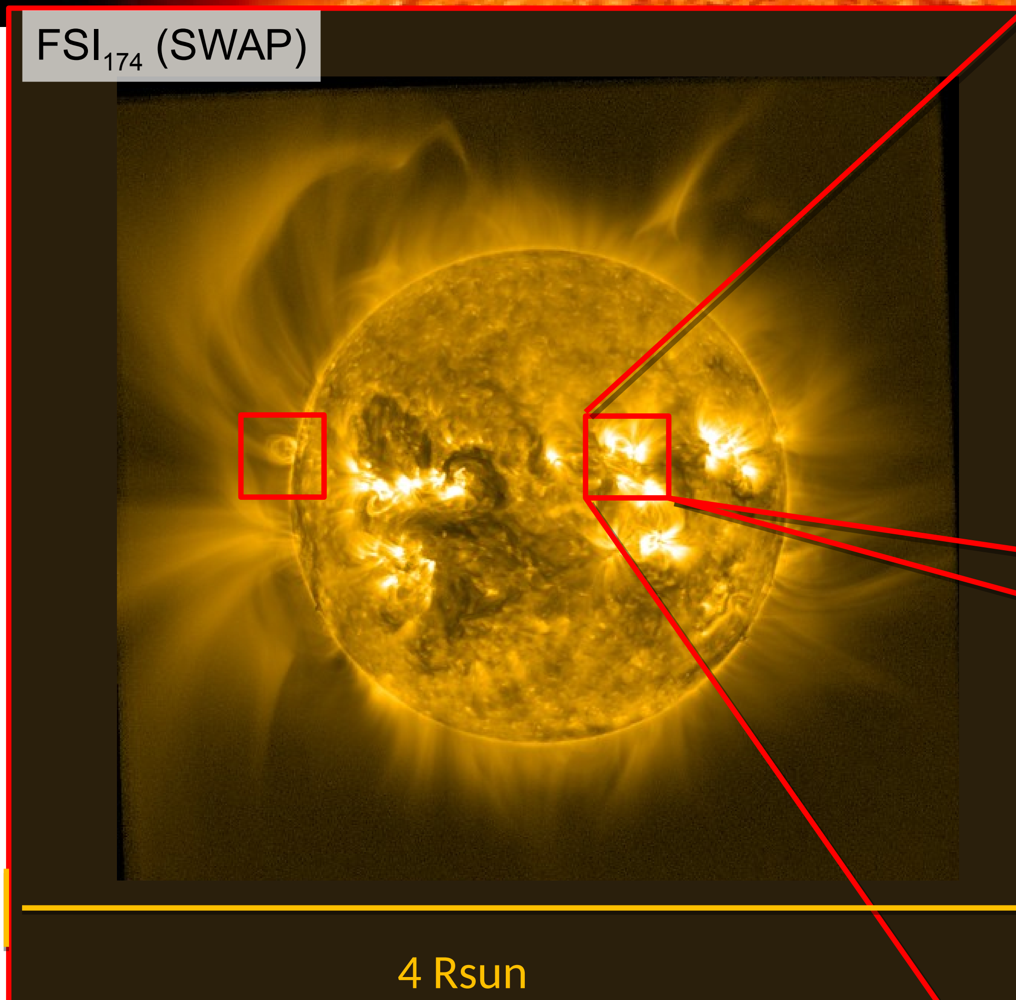
EUI: Extreme Ultraviolet Imager

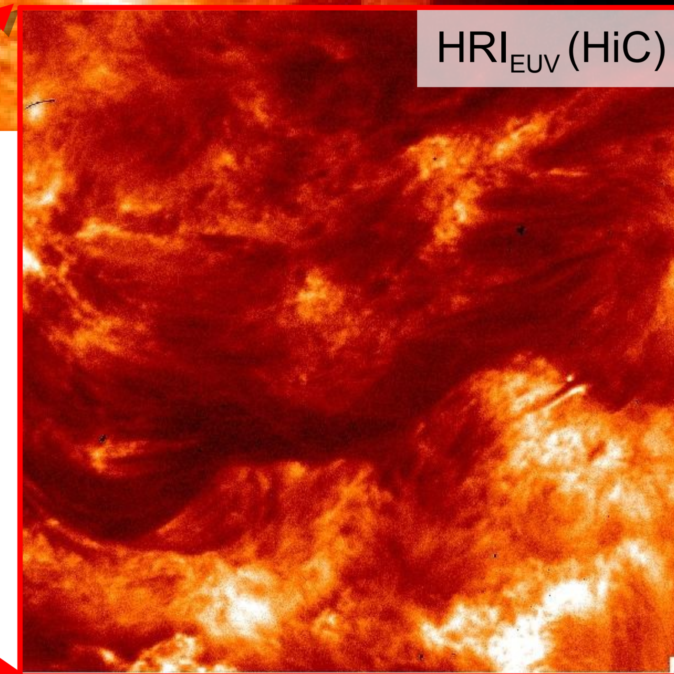
FSI dual EUV	Passband centre	174 Å and 304 Å alternatively
	Field of View	3.8 arcdeg × 3.8 arcdeg
	Resolution (2 px)	9 arcsec
	Typical cadence	600 s
HRI EUV	Passband centre	174 Å
	Field of View	1000 arc sec square
	Angular resolution (2 px)	1 arcsec
	Typical high cadence	2 s
HRI Lyman-α	Passband centre	1216 Å
	Field of View	1000 arcsec square
	Resolution (2 px)	1 arcsec
	Typical high cadence	Sub-second

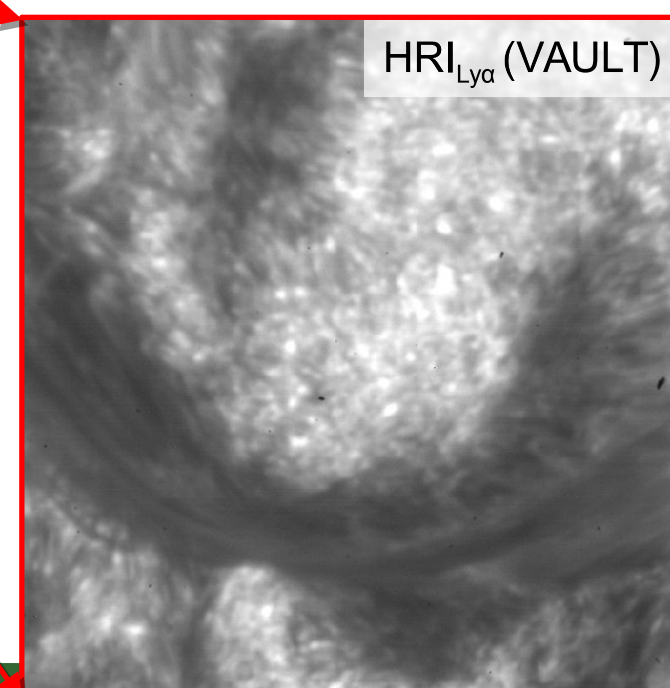




EUI @ perihelion







FSI: global morphology of the source regions

Active regions, coronal holes, CMEs, etc.

HRI: highest ever resolution UV images (200 km)

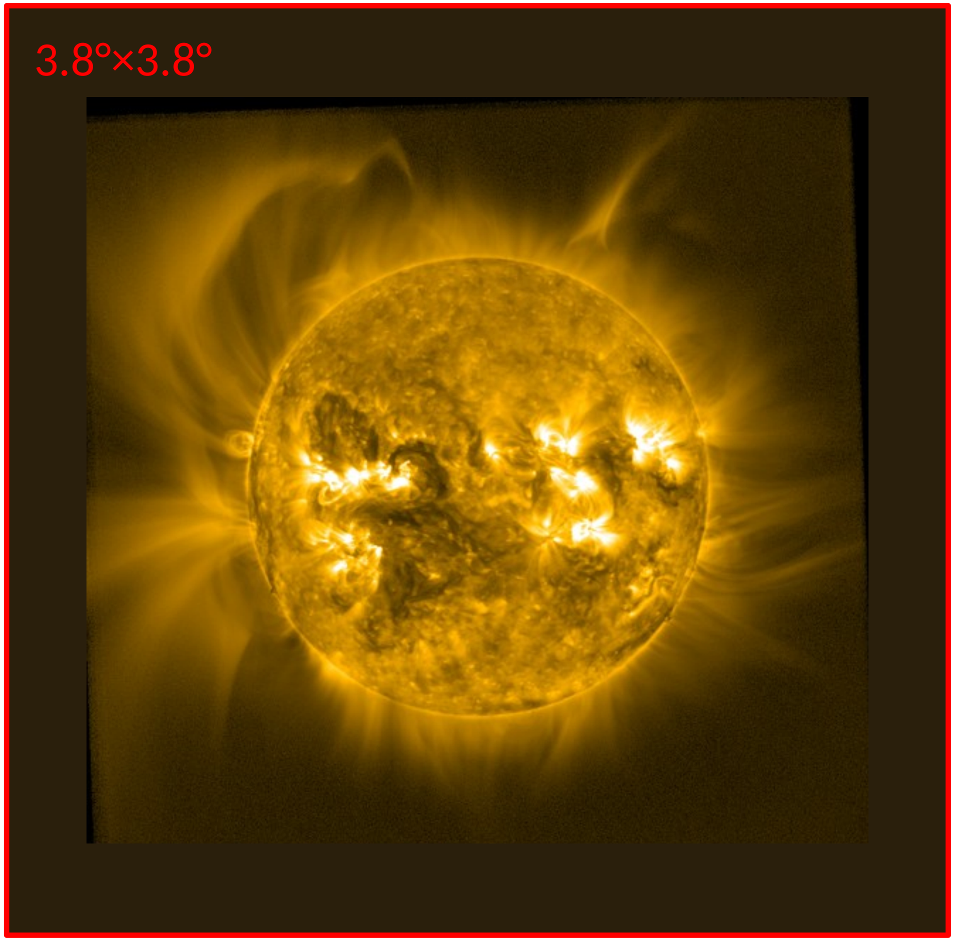
Fine scale structure, dynamics

EUV Observing Programs

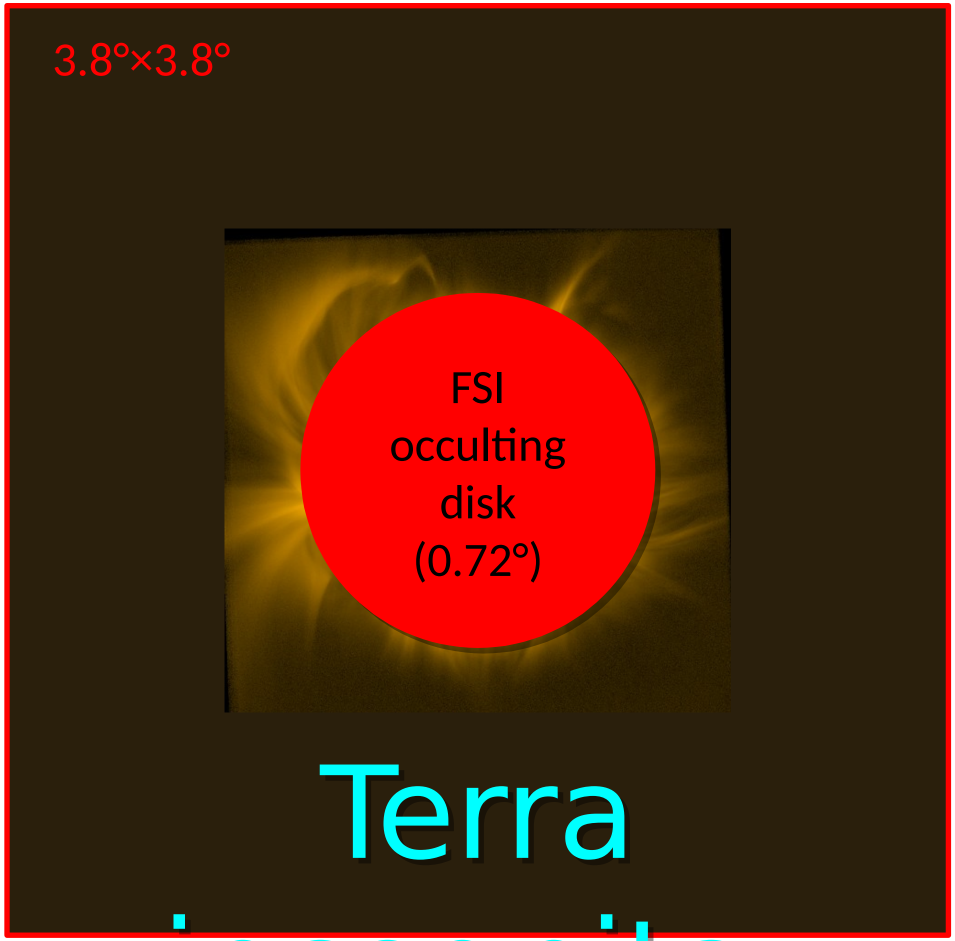
Science Program	Science Data Requirements	Ch.	Cad. (s)	Com pr.	TM (Gb /h)
Synoptic	4 x 4 Rsun window centered on disc center	FSI$_{174}$ FSI$_{304}$	600	50	**0.0075**
Find Event	4 x 4 Rsun window centered on disc center (4x4 binned)	FSI$_{174}$ FSI$_{304}$	60	4	**0.0025**
Faint High Corona	Full FOV centered on event.	FSI$_{174}$ FSI$_{304}$	1h		
Global eruptive event	Full FOV centered on event.	FSI$_{174}$ or FSI$_{304}$	10	10	**4.43**
Coronal Hole	Full FOV centered on CH with boundary and/or plumes. High lat., perihel., possibly near co-rot.	HRI$_{174}$ HRI$_{Ly\alpha}$	30 30	5 15	**1.75**
Quiet Sun	Full FOV centered on QS. Perihelion/encounter, near co-rotation	HRI$_{174}$ HRI$_{Ly\alpha}$	8 1	7 15	**16.6**
Active region	Full FOV centered on AR. Perihelion/encounter, near co-rotation	HRI$_{174}$ HRI$_{Ly\alpha}$	2 1	15 15	**19.7**
Eruptive event	Perihelion/encounter, near co-rotation Full FOV	HRI $_{174}$ HRI $_{Ly\alpha}$	1 1	15 15	**26.1**
Discovery	**High cadence dynamics Perihelion/encounter, near co-rotation, 645 x 645 FOV for Lyα**	**HRI $_{174}$** **HRI $_{Ly\alpha}$**	**1** **0.1**	**15** **15**	**26.1**

FSI: Large FOV + Occulting disk (>0.4 AU)

@ 0.28 A.U.



@ 0.43 A.U.



incognita

EUI/FSI and Metis

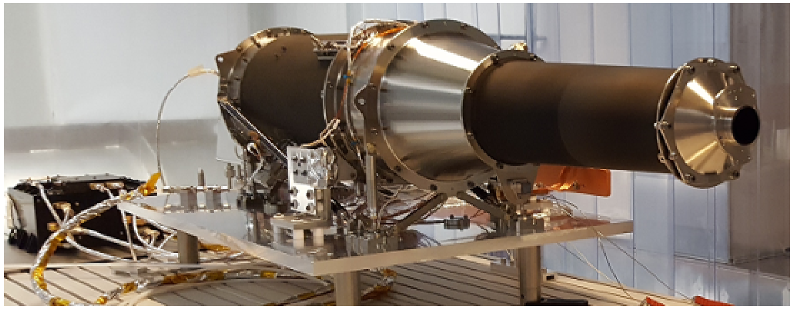
Metis (R > 1.6°)

- **121.6 nm** narrow-band imaging **(H I Ly-α)**

→ Maps of intensity and outflow velocity (via Doppler dimming)

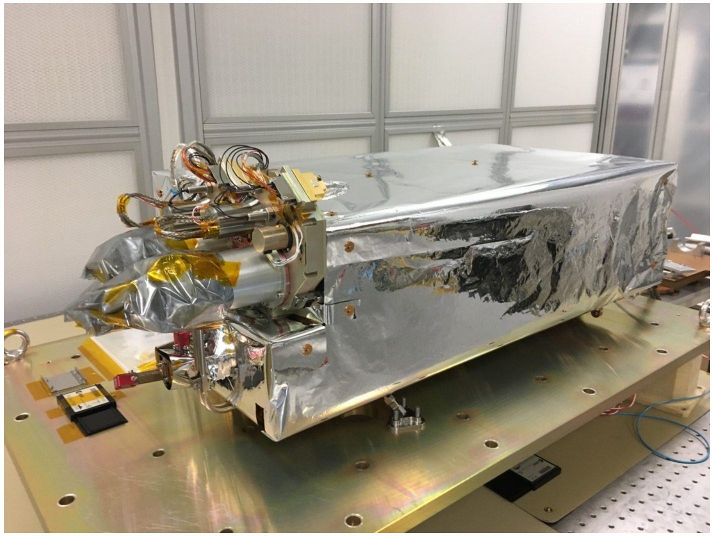
- **610 nm** visibile-light, broad-band polarized (**pB**) imaging

→ Maps of n_e

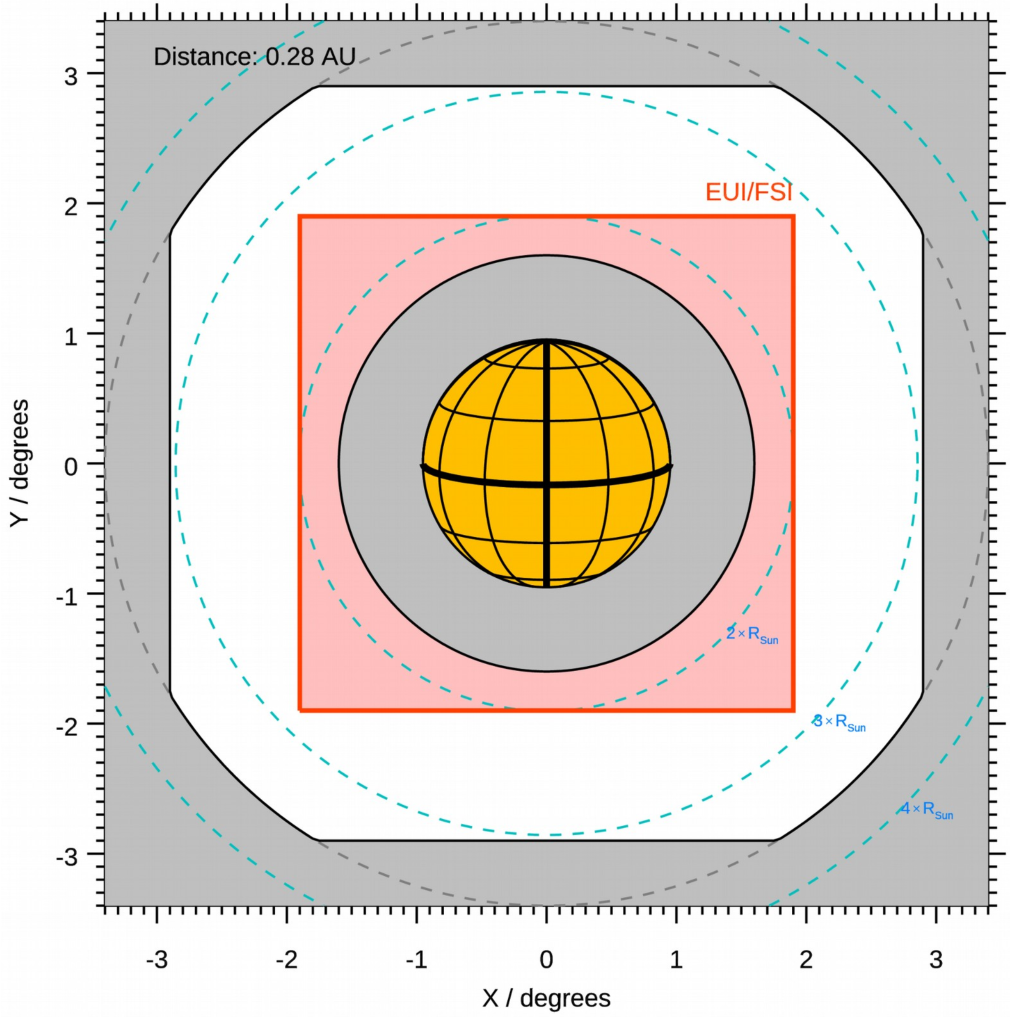


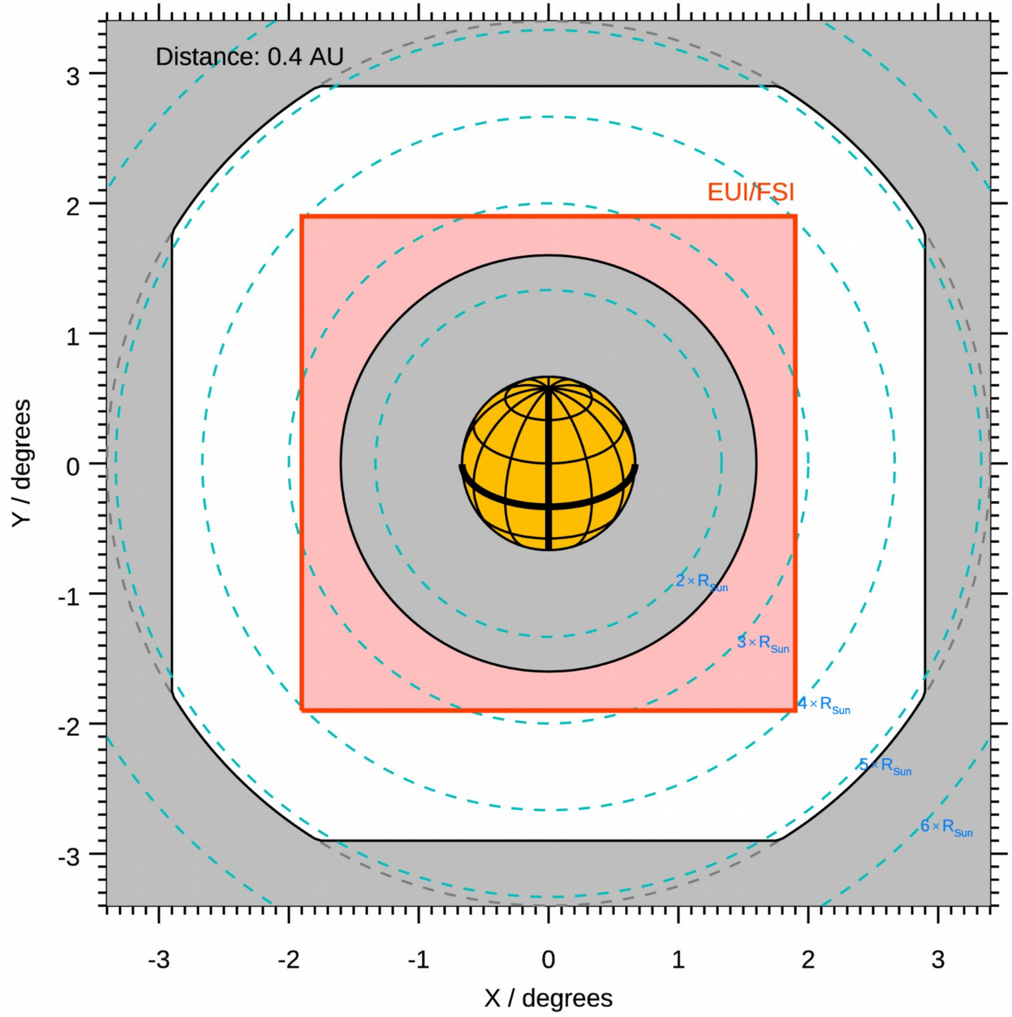
EUI/FSI (R < 3.8°)

- **30.4 nm** narrow-band imaging (He II, Si XI, and more)
- **17.4 nm** narrow-band imaging (Fe IX/X, and more)

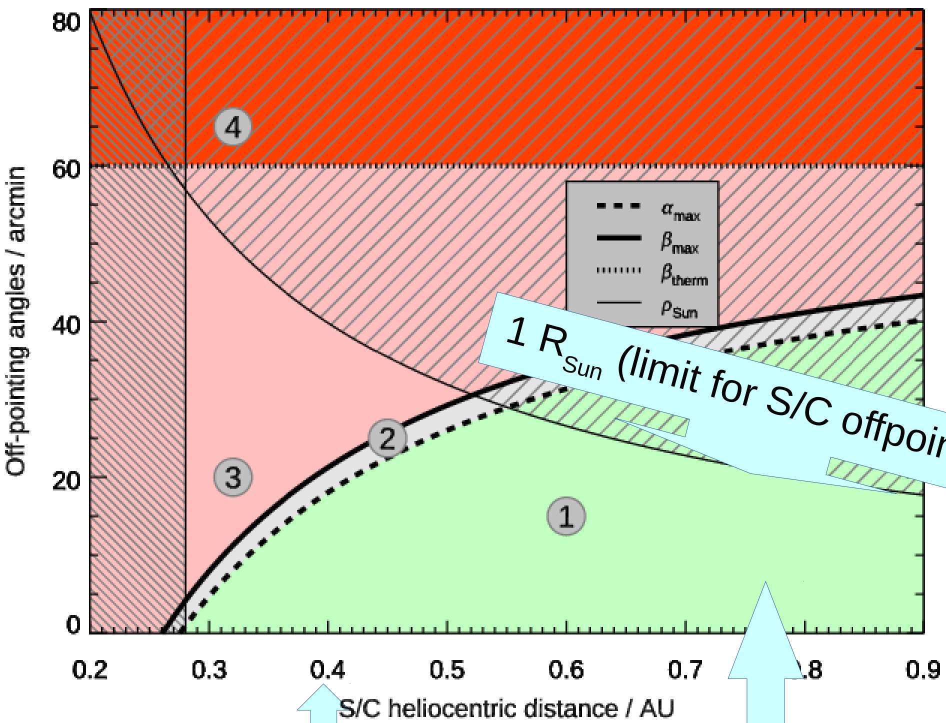


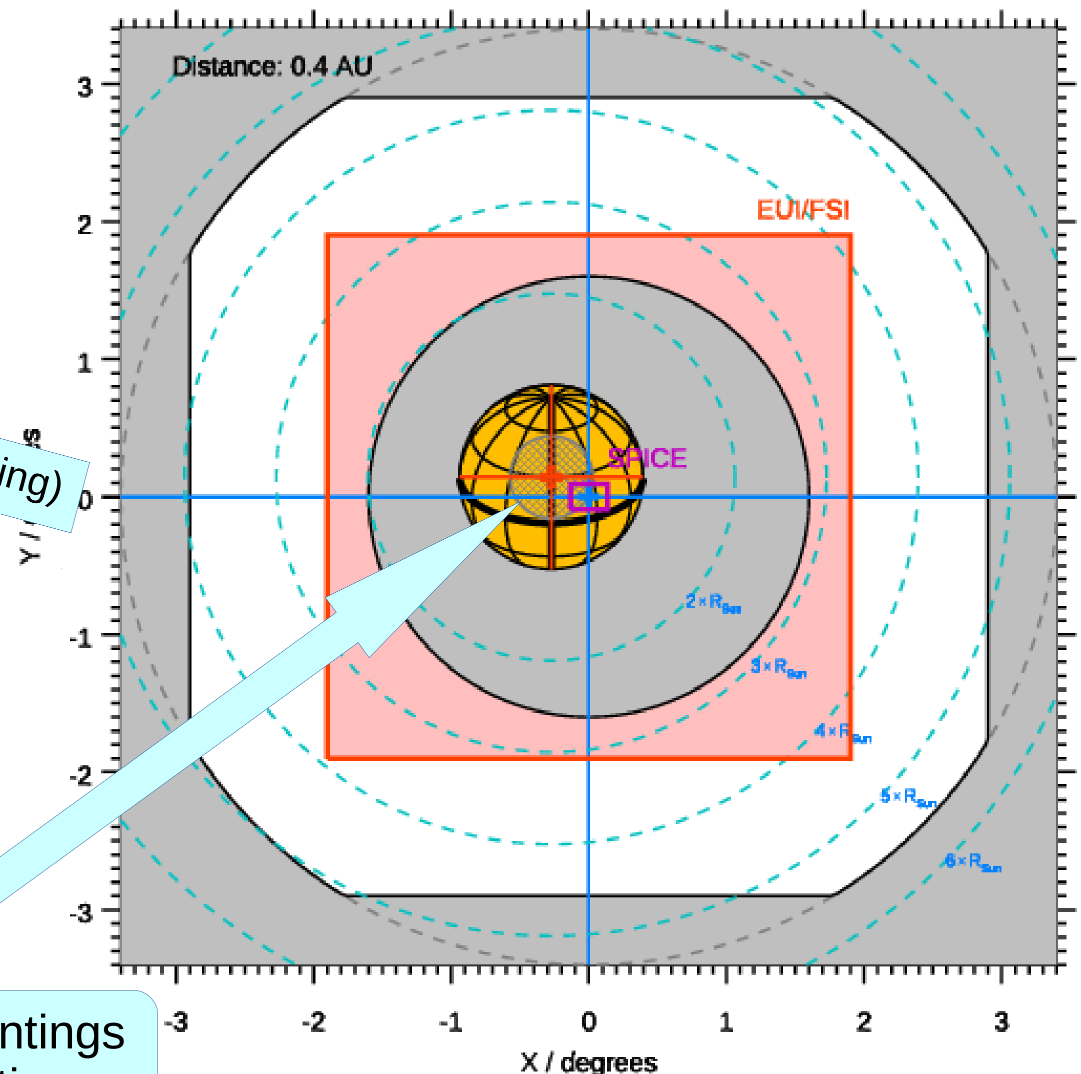
EUI/FSI and Metis





Constraints on Metis during off-pointings





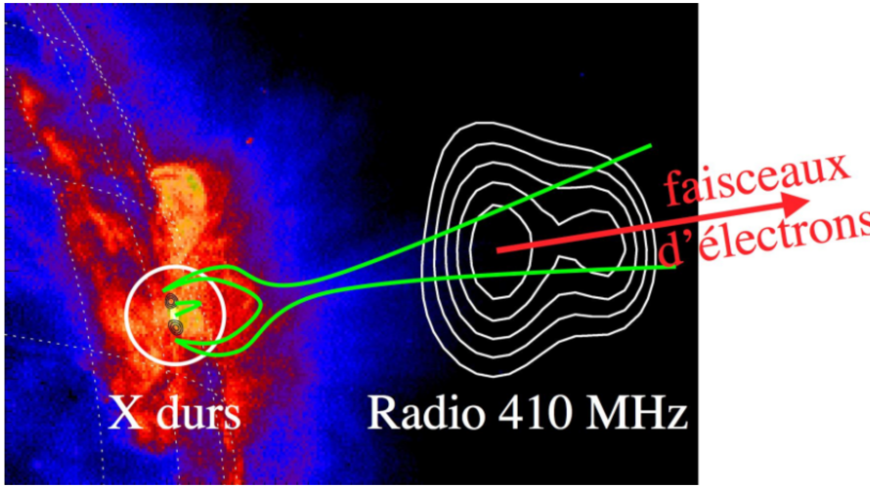
1 R_{Sun} (limit for S/C offpointing)

Limit for EUI/FSI occulted observations

Range of Solar Orbiter off-pointings compatible with Metis operations

Eruptions and particle acceleration

Solar Orbiter objective 3: *How do solar eruptions produce energetic particle radiation that fills the heliosphere?*



Method: identify the reconnection sites in flares and CMEs; identify the location and dynamics of CMEs and shocks.

Observations:

- **EUI/FSI**: 5 min cadence
  - global morphology evolution in chromosphere and corona
- **EUI/HRI**: 1 sec cadence (triggered)
  - dynamics/reconnections sites

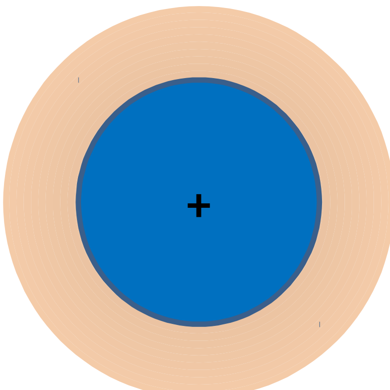
- **METIS**: 5 – 30 min / 1 – 5 min (triggered)
  - Maps of n_e, intensity and outflow velocity in H I Ly-α, for pre- and post-erupting corona / CME properties (triggered).

Note*: if off-pointing is Metis-compatible.*

→ SPICE, PHI, STIX, *in situ*

Sampling the temperature in prominences

Corona



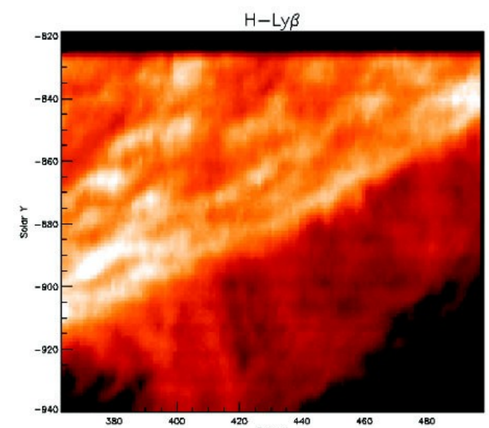
SPICE TR and coronal lines → 10^4 K – 1MK

H- Lyα → 2 10^4 K

SPICE H- Lyβ →

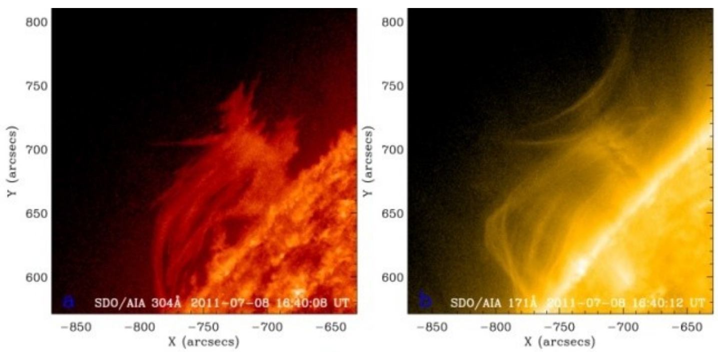
Fil. thread	SST Ha	Vault (Lya)	IRIS Mg II	Hi-C 193
Km	150-400	>300	350 – 580	600

EUI/FSI	EUI/HRI	SPICE	METIS (UV)
2000	220	870	9000



SOOP to be developed!

Coronal prominence-cavity systems (also with DKIST)



Wang et al 2016

- PCTR is hot (> 4 10^5 K), *Parenti et al. 2012*
- Dynamics & exchange of material, *Schmit & Gibson 2013*
- Temperature substructures,T>1.4 MK in the cavity e.g. *Kucera & Landi 2012, Habbal et al. 2010*
- Cavity height goes up to 1.6 Rsun

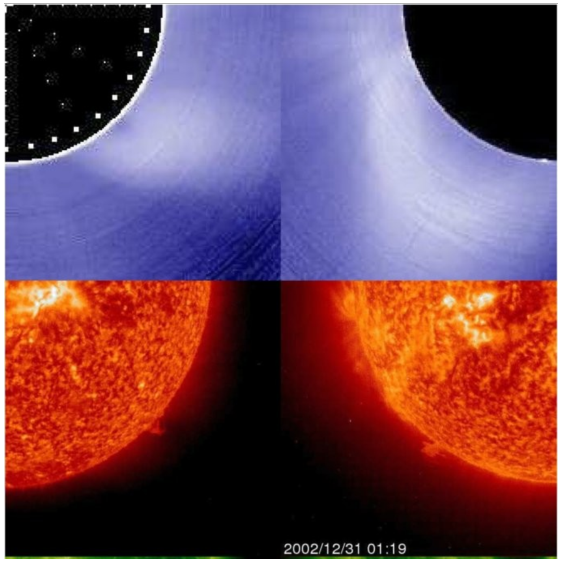
Solar Orbiter:

- Cavity-prominence morphology and dynamics EUI/FSI 171 and 304
- Prominence morphology and dynamics EUI/HRI Lya and 171 (x 3 in resolution) (pointing change)
- PCTR-corona with SPICE: link 171 – 304, N-T, Doppler-V (pointing change)
- Can Metis see the cavity above 1.6-1.7 Rsun? (pointing change) Density, dynamics

DKIST at the limb: Magnetic structure, Coronal density

- SOLO in quadrature
- SOLO in conjunction or opposition

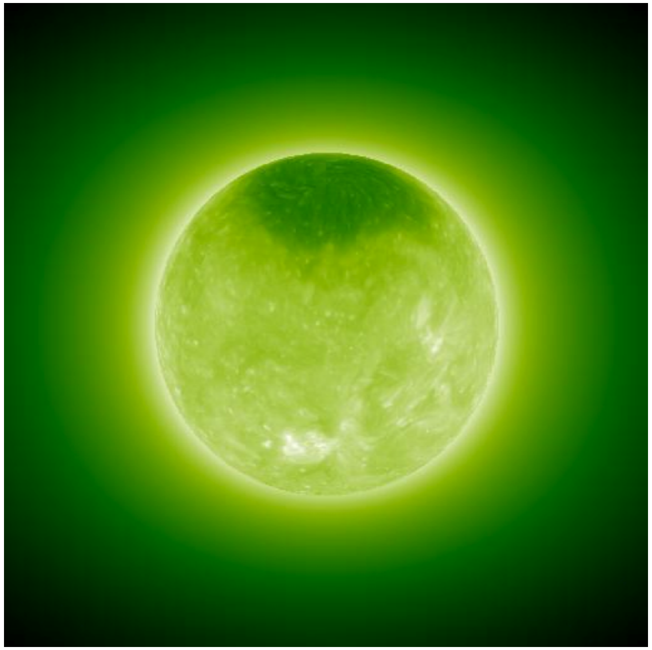
DKIST Use Case #155



Furler et al. 2009

Viewing the poles

Solar Orbiter Objective 1: *What drives the solar wind and where does the heliospheric magnetic field originate?*



PHI, SPICE & *in situ*

Method

- Monitor the flux tubes expansion and their influence on the Coulomb drag force (Aellig et al. 01, Antonucci 05)
- Detect waves in the plume-interplume regions (Gurman & Deforest 1998).

Observations:

- **EUI/FSI**: Plume tomography (10 min cadence)
- **METIS**: 1-60 min cadence
  - Plume tomography
  - Large scale polar morphology
  - He/H abundances (see previous slide) vs. outflow velocities
- **EUI/HRI**: Fine scales dynamic in plumes, CH boundaries.
  - HRI 17.4 at 30 sec cad.
  - HRI Ly-α at 15 sec cad.

Note*: If pointing is compatible with Metis. Or: alternating between disk-center and polar pointing.*

Coronal composition: Helium

Solar Orbiter Objective 1: *What drives the solar wind and where does the heliospheric magnetic field originate?*

Observations:

❑**METIS**: 20 min cadence

- ❑ Maps of n_e, intensity and outflow velocity in H I Ly-α.

Note*: Disk-centered pointing, preceded/followed by off-pointing to obtain limb SPICE composition maps*

Method:

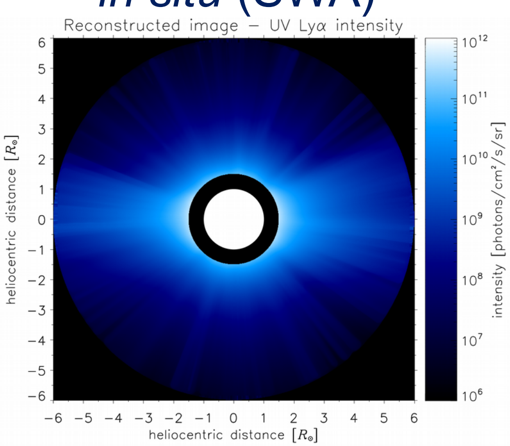
Take the ratio of resonantly scattered lines He I 30.4 nm (from EUI/FSI304) and H I 121.6 nm (from Metis/UV) to determine the abundance ratio He/H in the corona (Gabriel et al. 1995). Link this with in situ measurements.

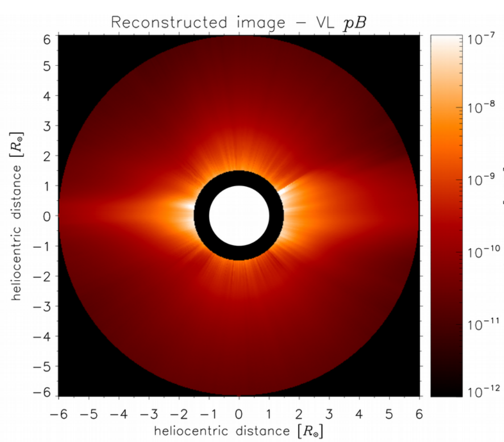
❑**EUI/FSI**: 20 min cadence, deep, coronagraphic exposures (> 0.4 AU)

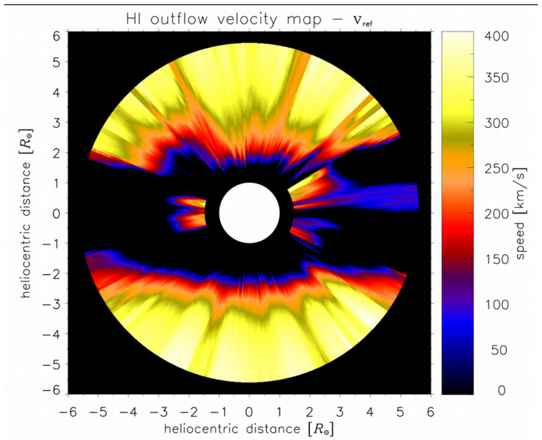
- ❑ Intensity of He II 30.4 Ly-α line (FSI_{304})

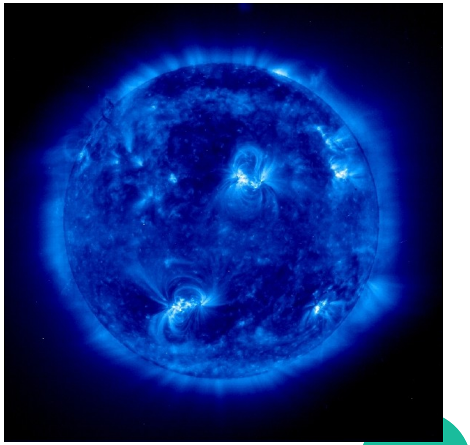
SPICE (composition maps)

in situ (SWA)



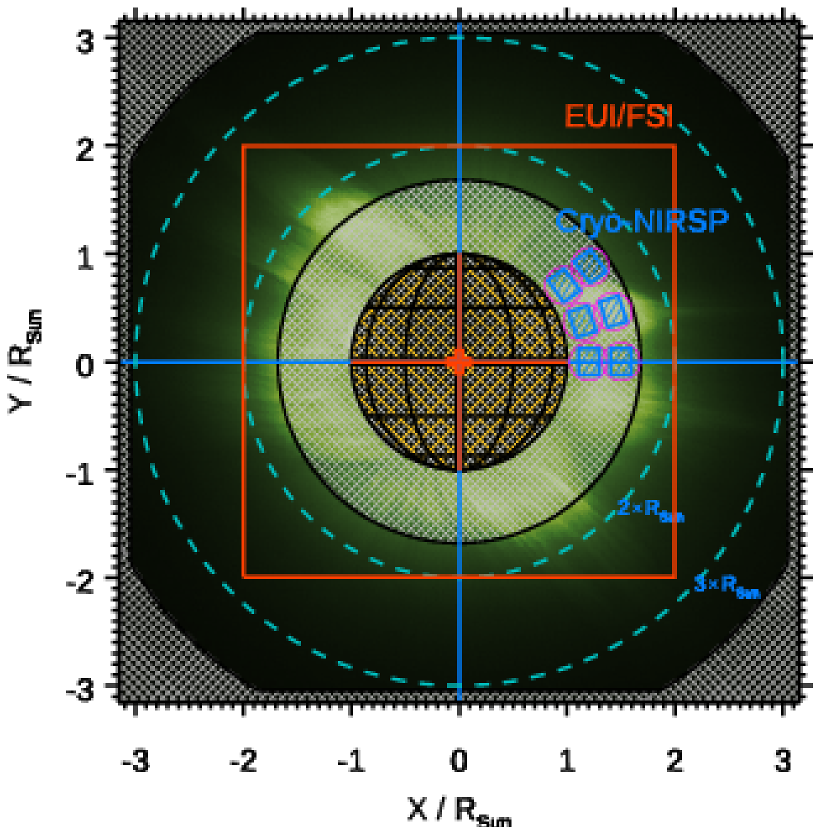


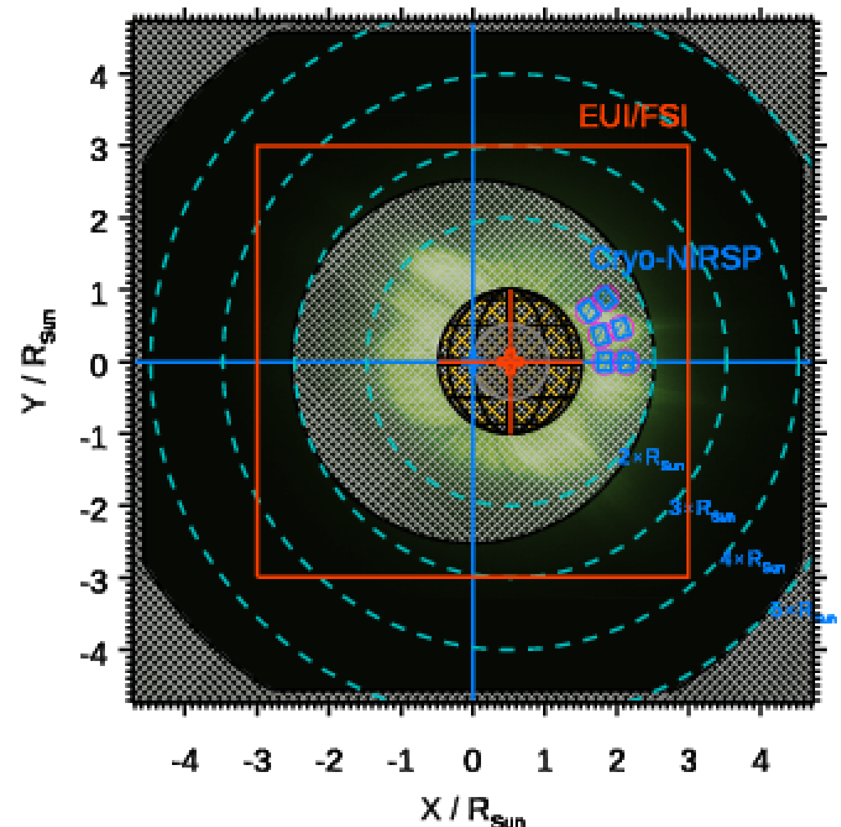




Coronal composition: Helium (also with DKIST)

Adding DKIST/CryoNIRSP mosaics to the Solar Orbiter observations (when in near-conjunction): it would provide measurements of intensity and polarization of He I 1083 nm and Fe XIII 1074.7 nm/Fe XIII 1079.7 nm, up to 1.5 R_{Sun}.



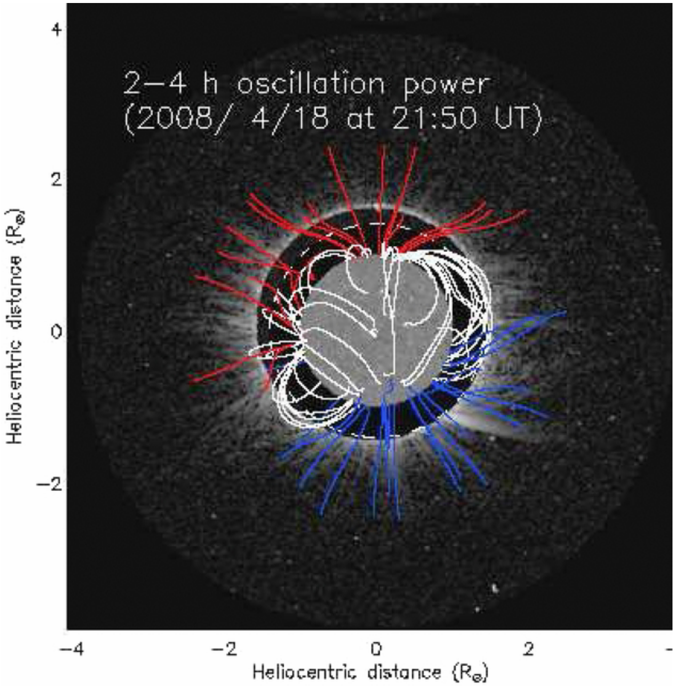


DKIST Use Case #60

(Safe) offset to reduce the gap between Metis and CryoNIRSP

Density oscillations

Solar Orbiter Objective 1: *What drives the solar wind and where does the heliospheric magnetic field originate?*



PHI, SPICE & *in situ*

Method

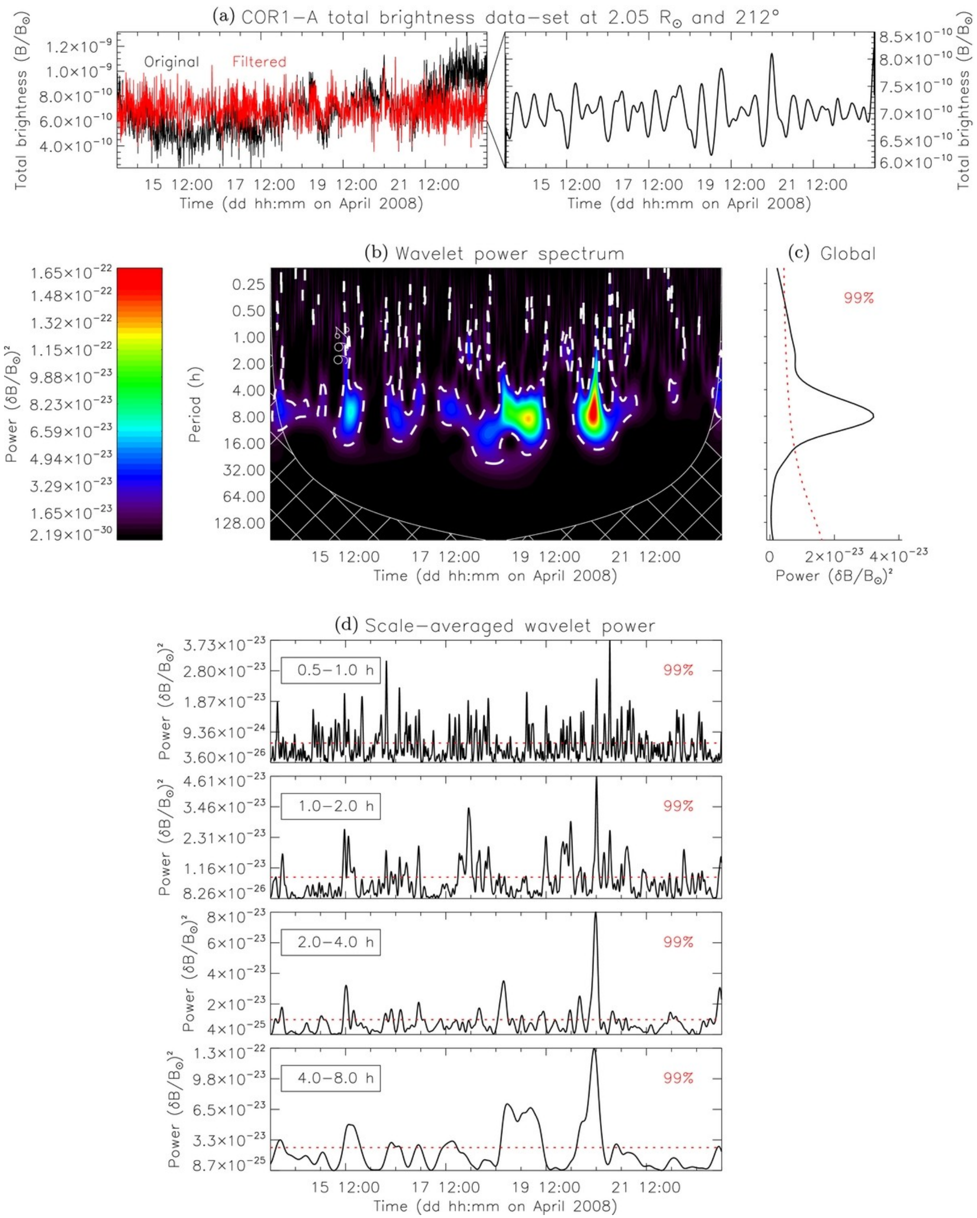
- Maps of fluctuations in the corona (e.g.: Telloni et al 2013, Telloni et al 2014)

Observations:

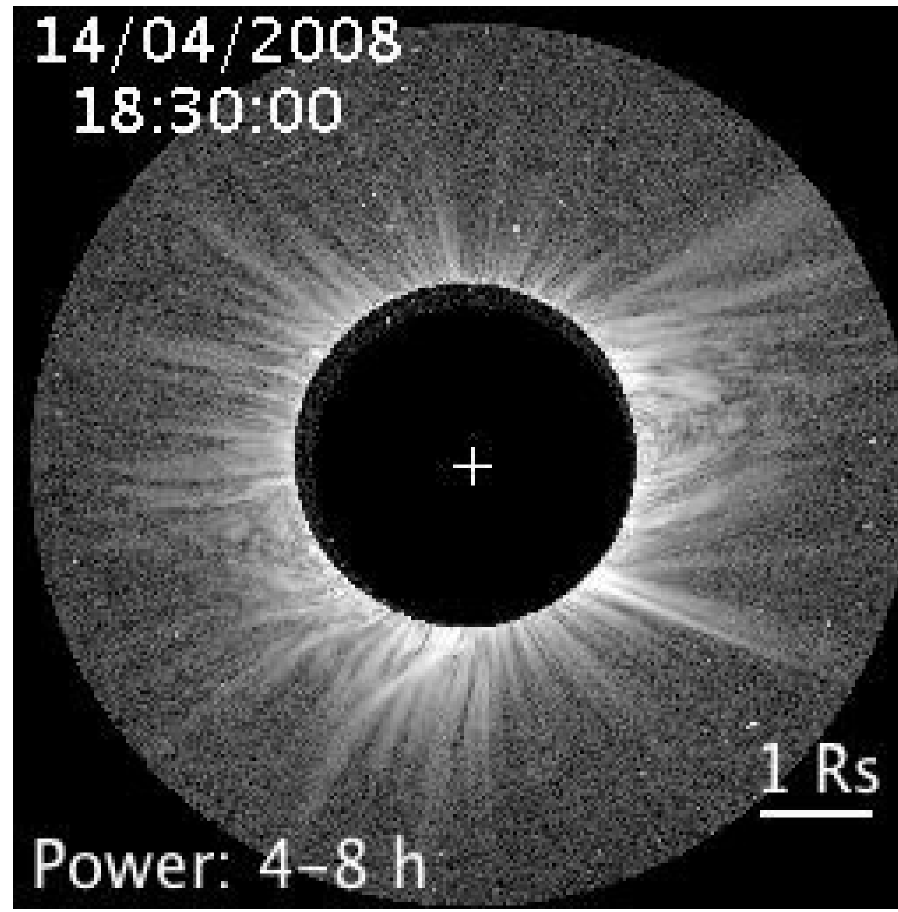
- **EUI/FSI**: Deep exposures (~20 min good SNR up 3 R_{Sun} in occulted mode)
- **METIS**: 1 s (@0.28 AU) and 5 - 20 min cadence

Notes*: Disk center pointing. Perihelion preferred (highest cadence): quasi co-rotation will allow disentangling intrinsic changes from rotation. However, EUI/FSI can operate in occulted mode only farther than 0.4 AU.*

Density oscillations



Telloni et al. ApJ 2013 (STEREO-A COR1 data)



How Solar Orbiter coordinated observations work

Solar Orbiter observations must fit within the Solar Orbiter Science Activity Plan (SAP).

SAP science objectives are addressed through Solar Orbiter Observing Programs (SOOPs).

These are coordinated campaigns of several, if not all, instruments adjusting their observation modes and parameters to serve one common science objective. Solar Orbiter's mission level and long-term planning will be performed at a SOOP level rather than on the level of individual instrument commands.

The latest version (v0.1, 10 July 2017) of the full SAP document as well as the list of all currently definitions SOOPs can be downloaded from the Solar Orbiter SOC (Science Operations Center) repository of public documentation:
https://issues.cosmos.esa.int/solarorbiterwiki/display/SOSP

More references:

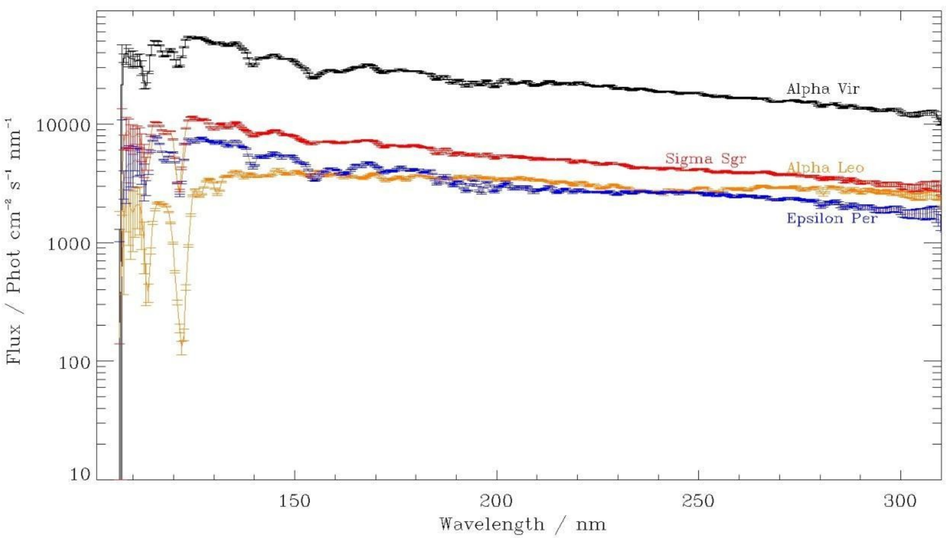
Zouganellis et al. 2019, Auchère et al. 2019 in the Solar Orbiter Mission Book (A&A)

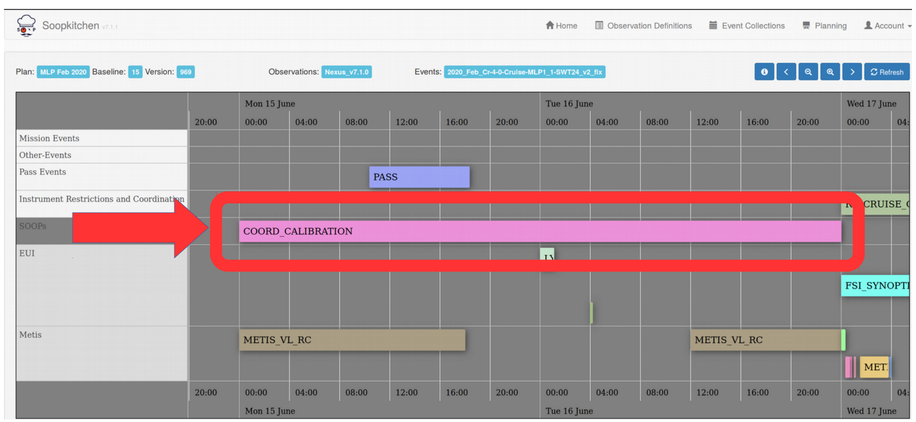
Some SOOPs requiring EUI and Metis

SOOP	Brief description
L_FULL_HRES_LCAD_MagnFieldConfig	High spatial resolution synoptic operations with full disk RS instruments, Metis and ins itu instruments. Low cadence (1/hour to 1/day).
L_FULL_HRES_MCAD_Coronal_He_Abundance	Simultaneous observations of the resonantly scattered component of He+ emission by EUI/FSI 30.4 nm, and neutral hydrogen by Metis Lyα (121.6 nm) to examine helium abundances in the corona.
L_SMALL_HRES_HCAD_Fast_Wind	Relating observed coronal holes and boundaries to the fast solar wind measured in situ.
L_SMALL_HRES_HCAD_SlowWindConnection	Observe with RS instruments the dynamics at a open-closed field boundary which will then be crossed in situ. High resolution RS observations required to catch dynamics.
R_FULL_HRES_HCAD_Density_Fluctuations	Study of density fluctuations in the extended corona as a function of the outflow velocity of the solar wind while evolving in the heliosphere. If SPICE participates, will need to have limb pointing for a period of time, then return to disc centre for the full-Sun instruments.
Triggered observations:	
L_FULL_HRES_HCAD_Eruption_Watch	Full-Disk, high resolution SOOP designed to catch eruptive events.
L_BOTH_MRES_MCAD_Flare_SEPs	This SOOP is aimed at understanding SEP properties and dynamics in relation to Flare events. EUI and STIX are leading this SOOP, while IS payload provides continuous observations. Synoptic support from other full disk RS instruments. Disk centre pointing preferred.

EUI and Metis intercalibration: UV standard stars

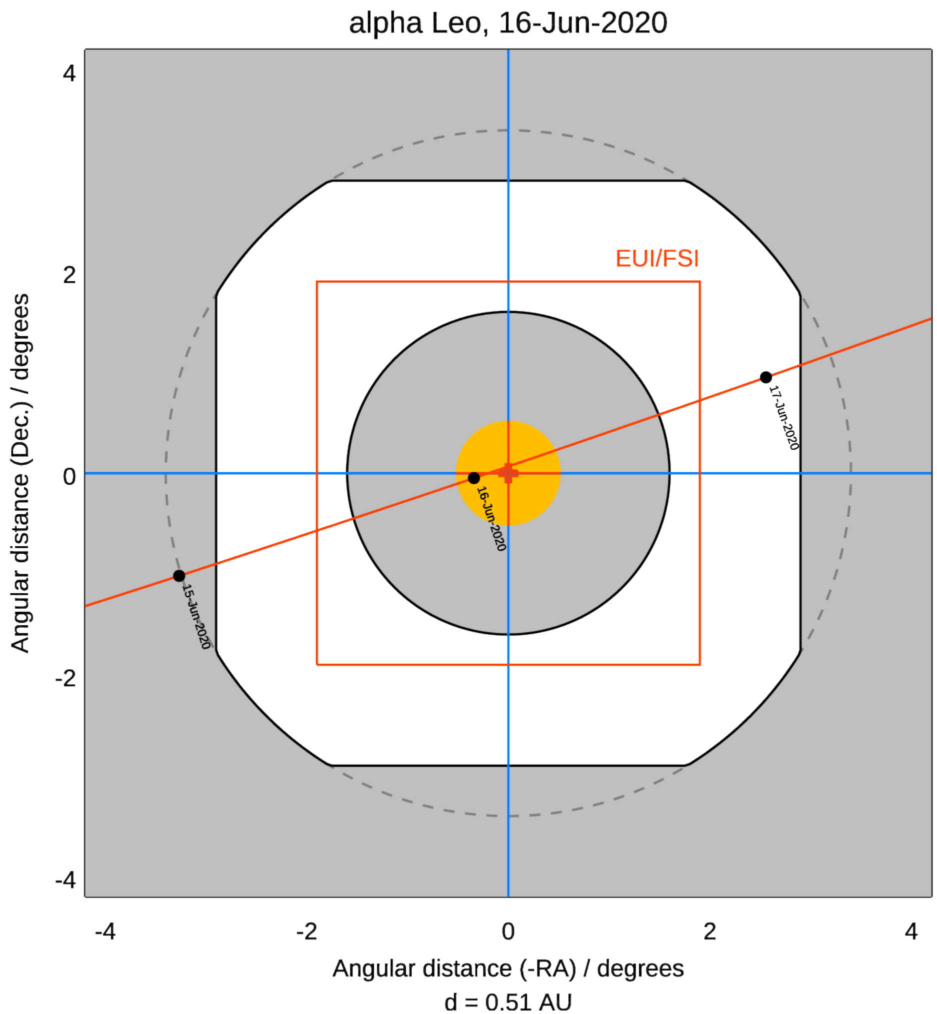
Some UV standard stars, observable by EUI/HRI and METIS/UV





Planning of coordinated observations

Transit of α Leo in June 2020



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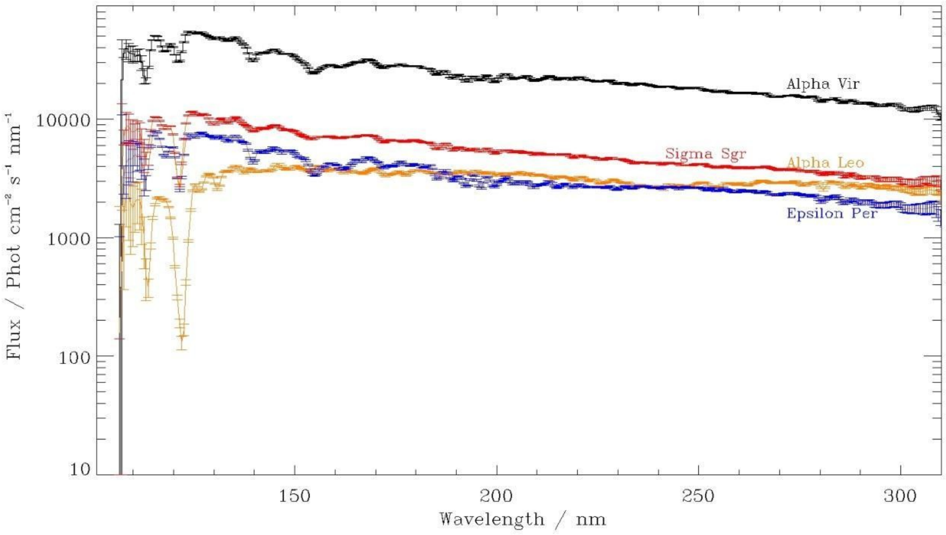

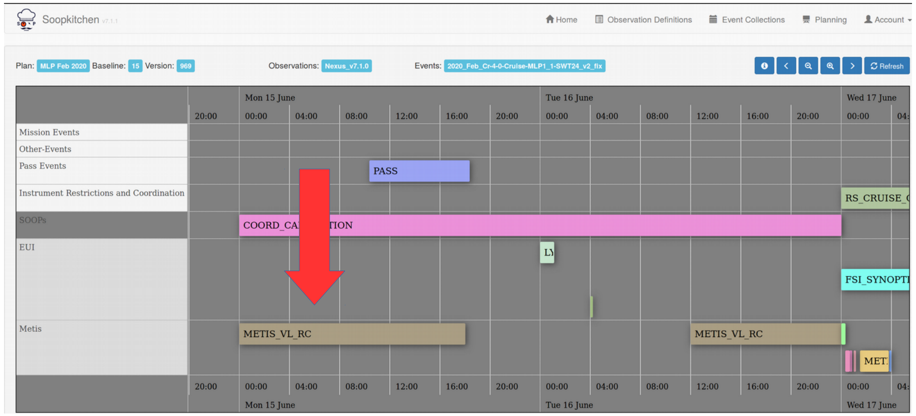

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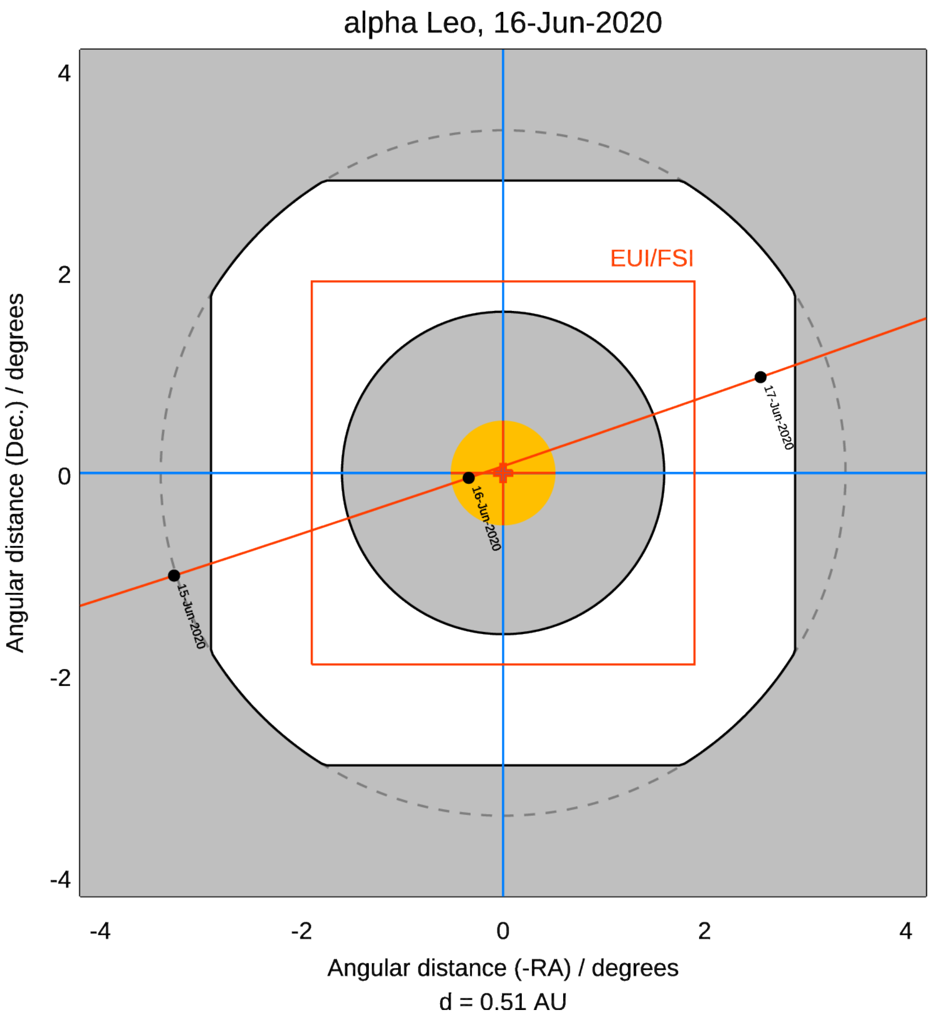

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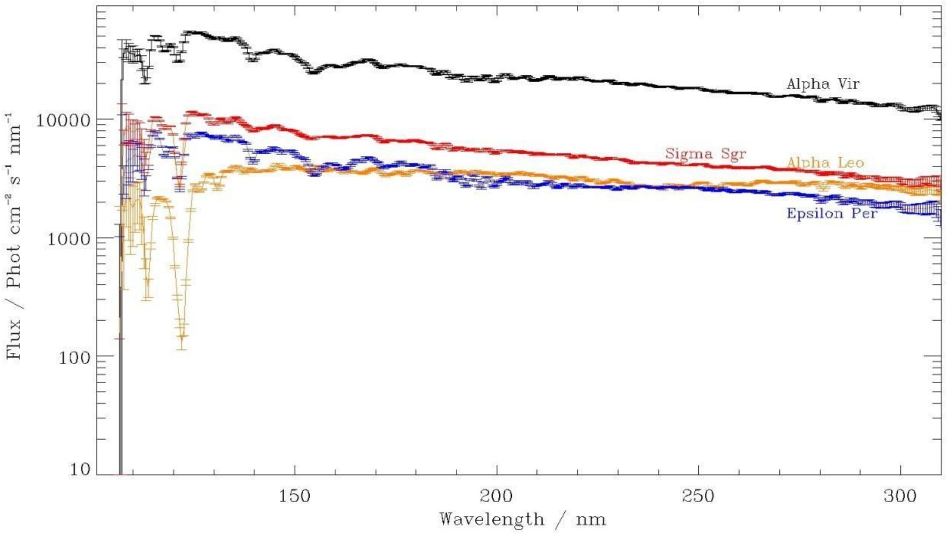

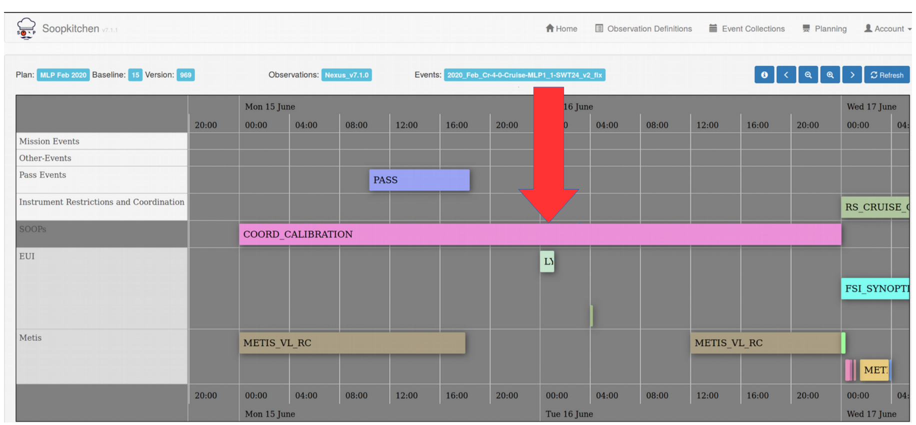

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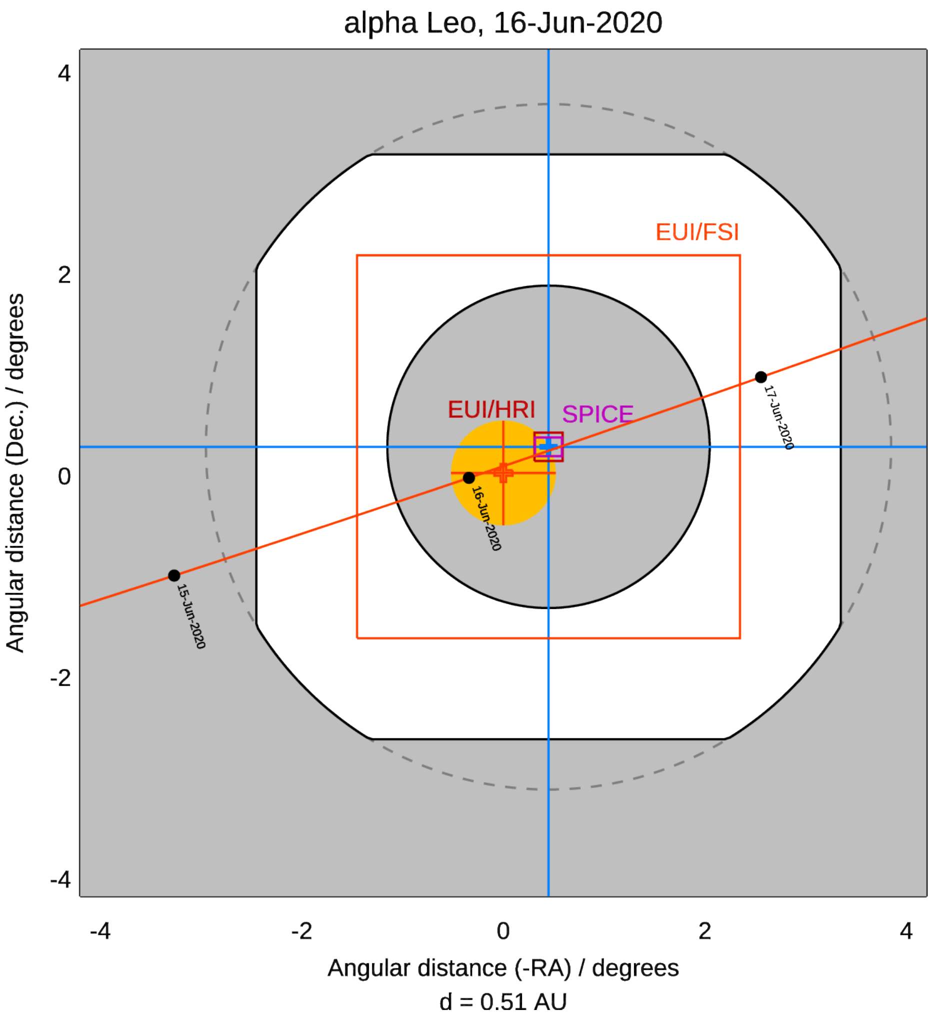
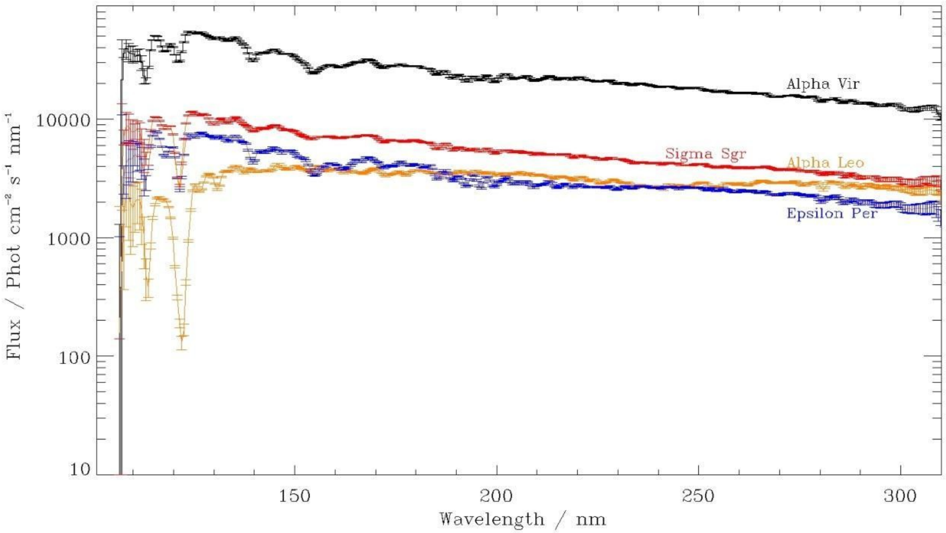
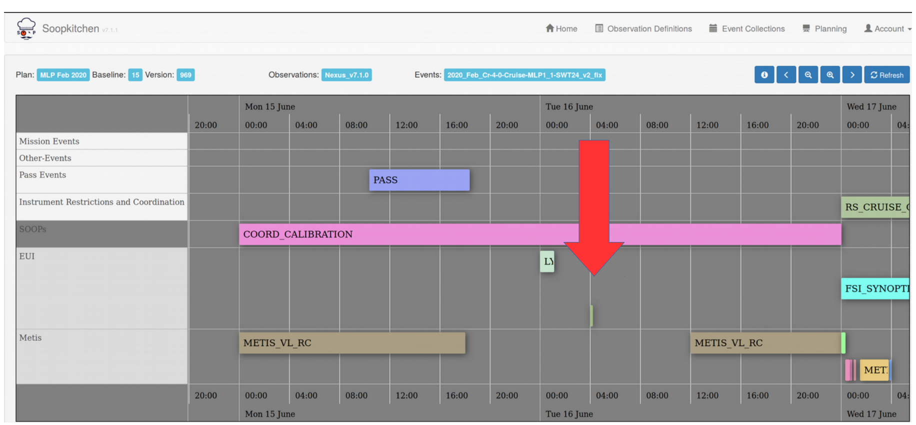


EUI and Metis intercalibration: UV standard stars

Some UV standard stars, observable by EUI/HRI and METIS/UV





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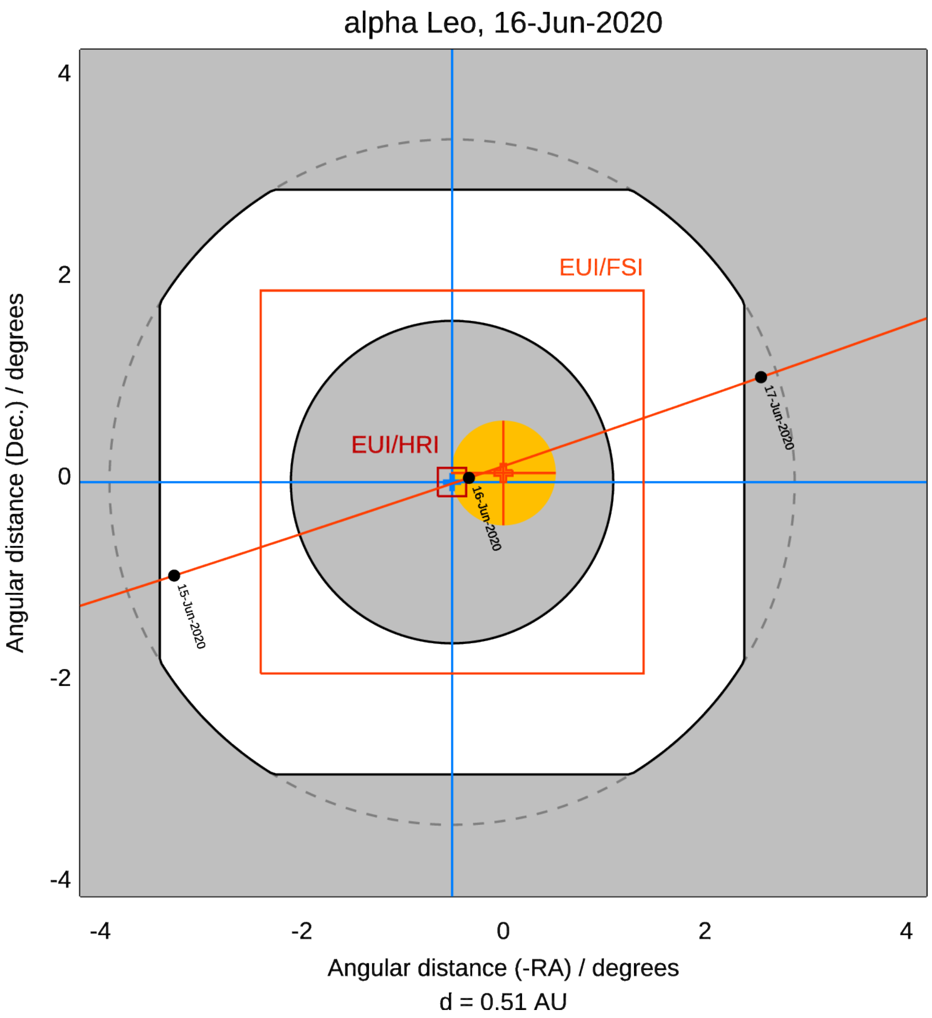
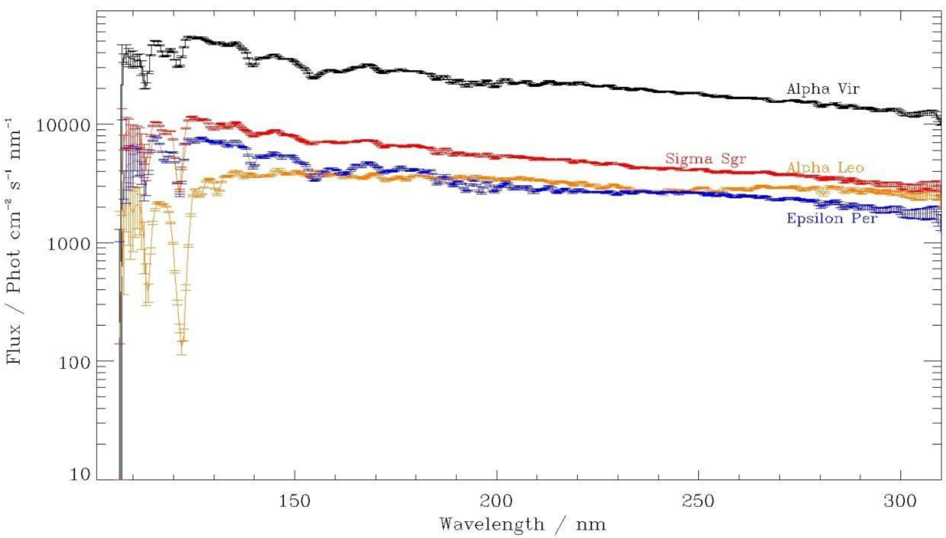
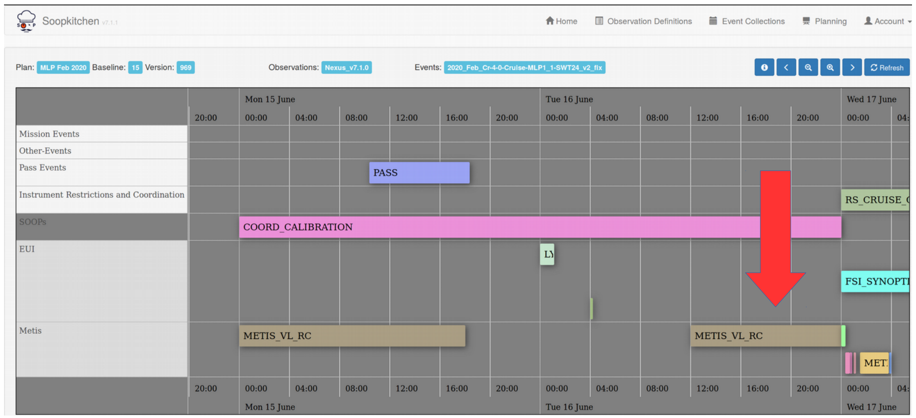


EUI and Metis intercalibration: UV standard stars

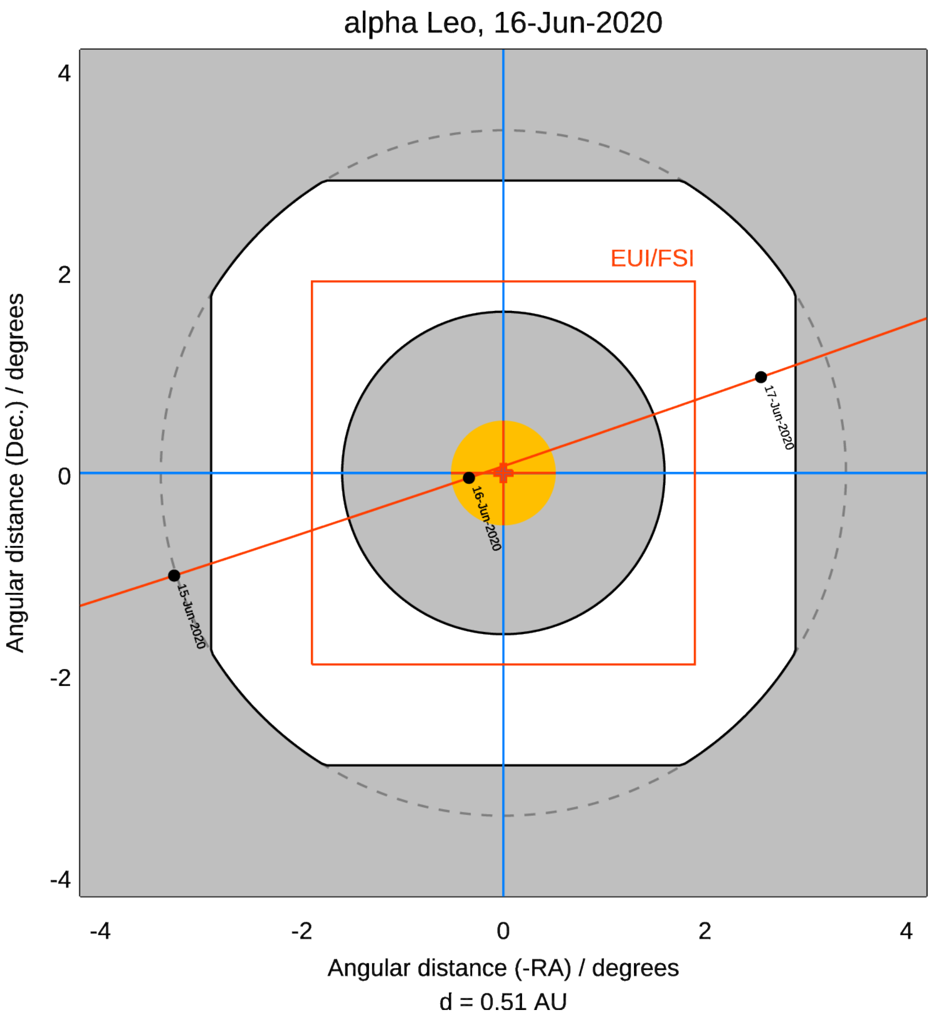
Some UV standard stars, observable by EUI/HRI and METIS/UV



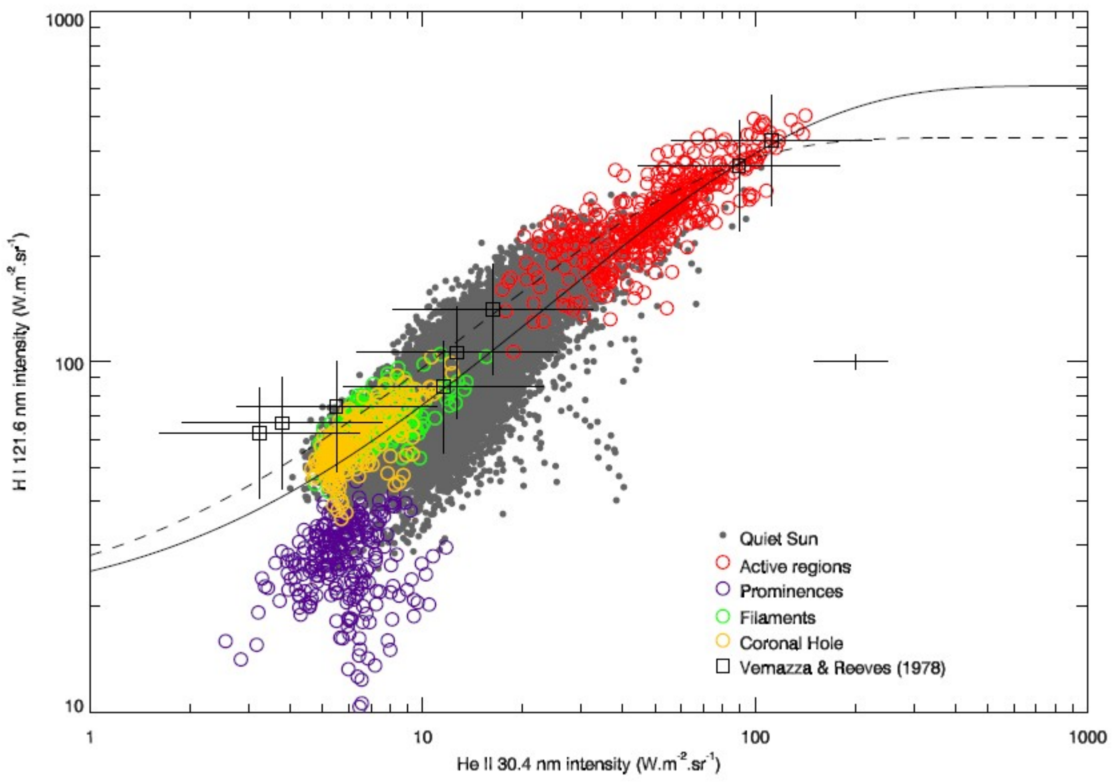


Planning of coordinated observations

Transit of α Leo in June 2020



Correlation H I / He II Ly-α (on-disk)



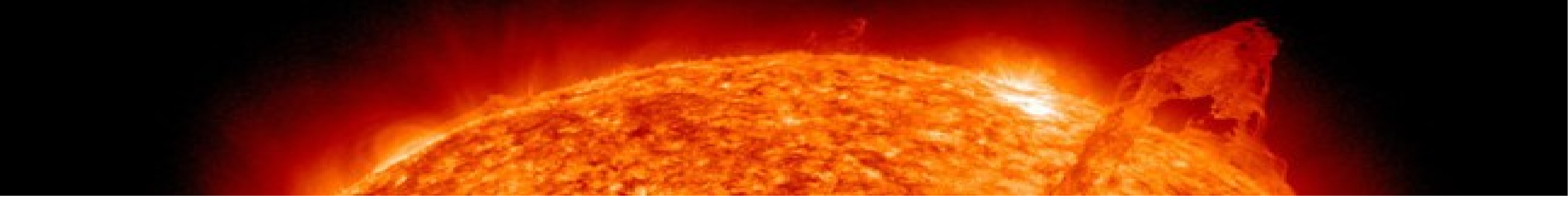
Gordino et al. in preparation:
H-Lyα from MXUVI rocket ; He II form SOHO/EIT

Solar Orbiter

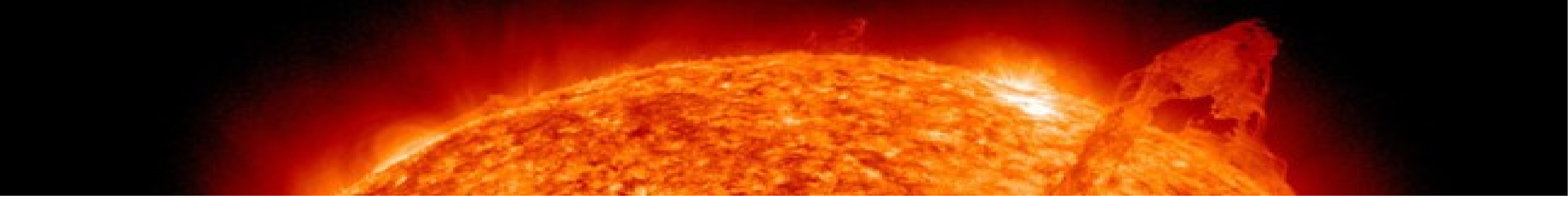
Corona:
EUI FSI He II 304
METIS H-Ly α

Disc (limited FOV):
EUI HRI H-Ly α
SPICE H- Lyb

EUI/FSI$_{304}$ disk images could become proxies for H I Ly-α disk radiance maps needed to compute Doppler Dimming of H I Ly-α from Metis/UV images (See also: Auchère 2005, Dolei et al. 2019)



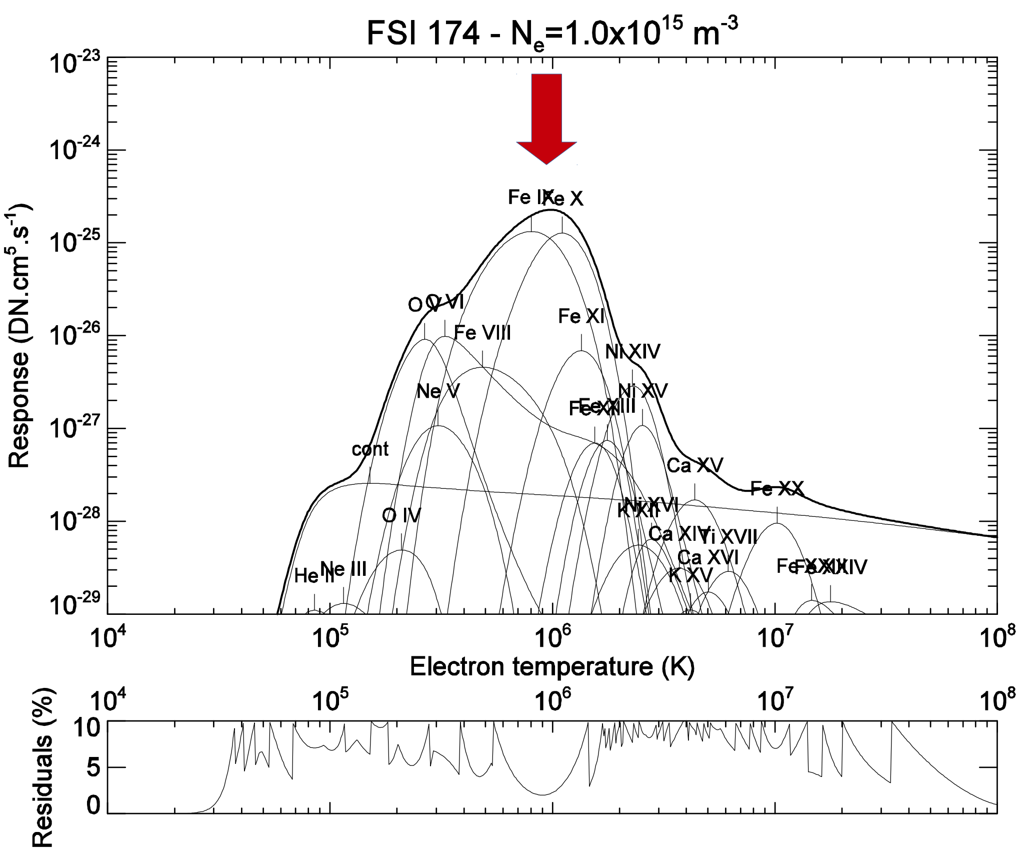
Thank you!

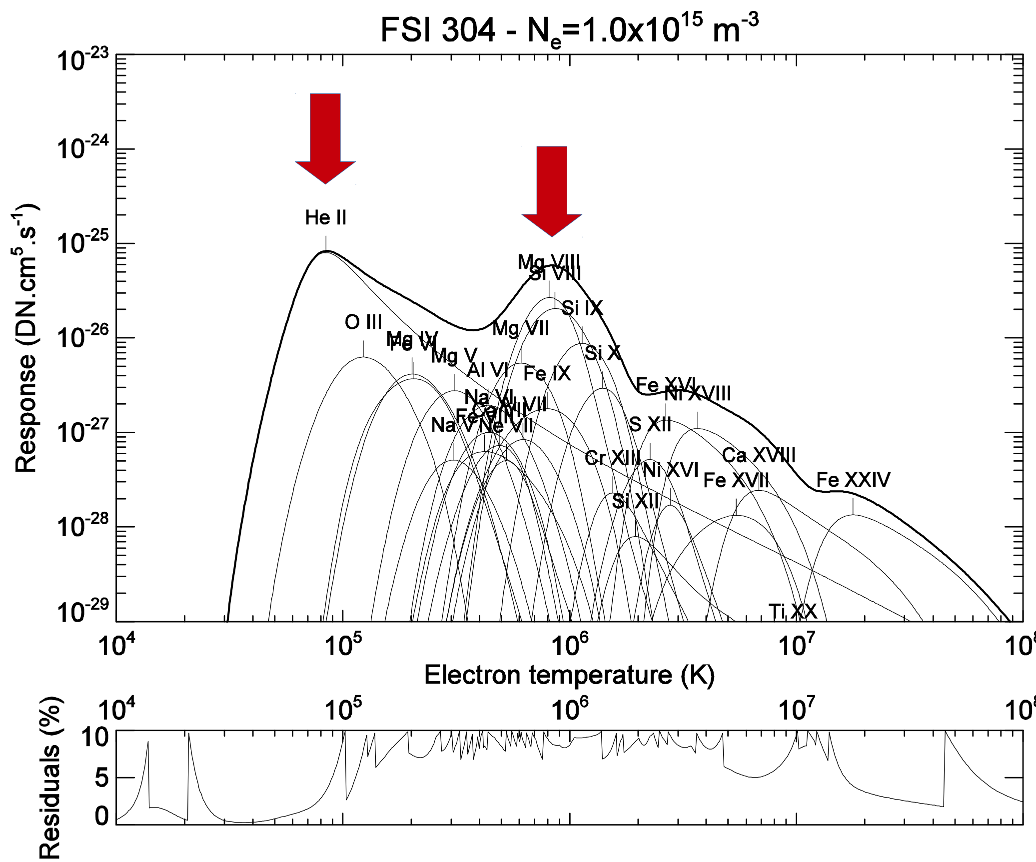


Extra slides

EUI/FSI Spectral response

Since EUI/FSI is a single bounce design, the spectral response is quite wide and several lines other than Si XI can contribute as much, especially Mg VIII and Si VIII lines. These are cool and may actually pick up at large distances in the corona.





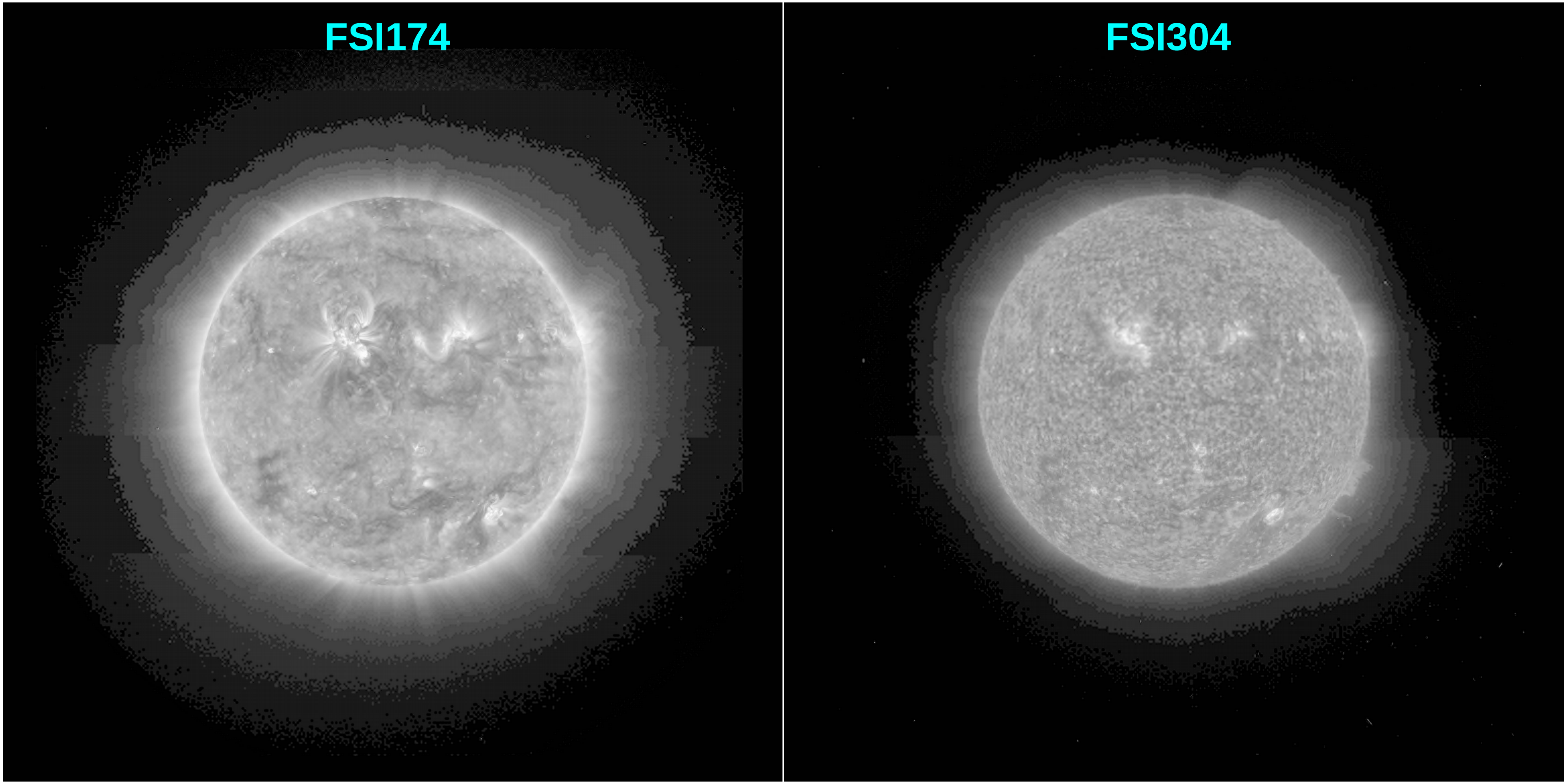
EUI Data products

- **L0**: raw decompressed data from telemetry pipeline
- **L1**: engineering data, uncalibrated, updated header (pointing and timing)
- **L2**: science data, corrected, calibrated to physical units
- **L3**: Visualization data.
  - JPEG2000 to feed JHelioviewer.
  - Histograms of data not owloaded (both science and calibration).

EUI Low-latency data

Beacon data	Low-resolution (high compression) FSI_{174} & FSI_{304} images	~15 minutes	Max. 1. MBytes / day
Synoptic data	Medium quality, But low cadence, FSI_{174} & FSI_{304} images	~15 minutes	
Sample HRI data	EUV & Lyα	1 set / day	

FSI beacon @ 0.0625 bpp (x192)



Some SOOPs requiring EUI and Metis

- **L_FULL_HRES_LCAD_MagnFieldConfig**
  - High spatial resolution synoptic operations with full disk RS instruments, Metis and in situ instruments. Low cadence (1/hour to 1/day).
    - How does the Sun's magnetic field change over time?
    - How is the heliospheric current sheet (HCS) related to coronal structure?
- **L_FULL_HRES_MCAD_Coronal_He_Abundance**
  - Simultaneous observations of the resonantly scattered component of He+ emission by EUI/FSI 30.4 nm, and neutral hydrogen by Metis Lyα (121.6 nm) to examine helium abundances in the corona / inner solar wind. These can be compared with SWA.
    - Source regions of the slow solar wind
    - Abundance of minor ions as a function of height in the corona as indicator of slow or fast wind

Some SOOPs requiring EUI and Metis

- **L_SMALL_HRES_HCAD_Fast_Wind**
  - Relating observed coronal holes and boundaries to the fast solar wind measured in situ.
    - Low FIP fast wind origins
    - Origin of the small-scale X-ray and UV jets in polar coronal holes
    - How does the heliospheric magnetic field disconnect from the Sun?
- **L_SMALL_HRES_HCAD_SlowWindConnection**
  - Try to catch with Remote Sensing instruments the dynamics at a open-closed field boundary which will then be crossed in situ. High resolution RS observations required to catch dynamics. This SOOP will in general need specific target pointing or target tracking unless the SC is far enough from the Sun to catch.
    - Does slow and intermediate solar wind originate from coronal loops outside of coronal holes?
    - Study fast plasma flows from the edges of solar active regions discovered with Hinode/EIS
    - Interchange reconnection between open and closed field lines and its role in slow wind generation
    - Magnetic reconnection in the chromosphere, the transition region and the corona
- **R_FULL_HRES_HCAD_Density_Fluctuations**
  - Study of density fluctuations in the extended corona as a function of the outflow velocity of the solar wind while evolving in the heliosphere. If SPICE participates, will need to have limb pointing for a period of time, then return to disc centre for the full-Sun instruments.
    - Study of density fluctuations in the extended corona as a function of the outflow velocity of the solar wind while evolving in the heliosphere

Some SOOPs requiring EUI and Metis

Triggered observations:

- **L_FULL_HRES_HCAD_Eruption_Watch**
  - Full-Disk, high resolution SOOP designed to catch eruptive events.
    - CME initiation
- **L_BOTH_MRES_MCAD_Flare_SEPs**
  - This SOOP is aimed at understanding SEP properties and dynamics in relation to Flare events. EUI and STIX are leading this SOOP, while IS payload provides continuous observations. Synoptic support from other full disk RS instruments. Disk centre pointing preferred.
  - For most of the science objectives SPICE is good to have, but as the SEP events are rather rare, it is not feasible to go hunting for these events and to point SPICE to any particular region. However, since all other instruments are involved, SPICE will probably be observing anyway
    - What causes SEPs' spectral breaks?
    - Explore the fact that only some of the hard X-ray peaks are related to escaping electrons, while others are not
    - X-ray prompt events
    - Delayed events (between X-ray peak and electron release time)
    - Explore the type III radio bursts delays
    - Double-power law spectra
    - Latitudinal and longitudinal transport of SEPs