Outflow velocity and composition maps with SPICE:

synergy with the other instruments on Solar Orbiter

A. Giunta, A. Fludra, M. Caldwell, T. Grundy, S. Guest, S. Sidher
and the SPICE team

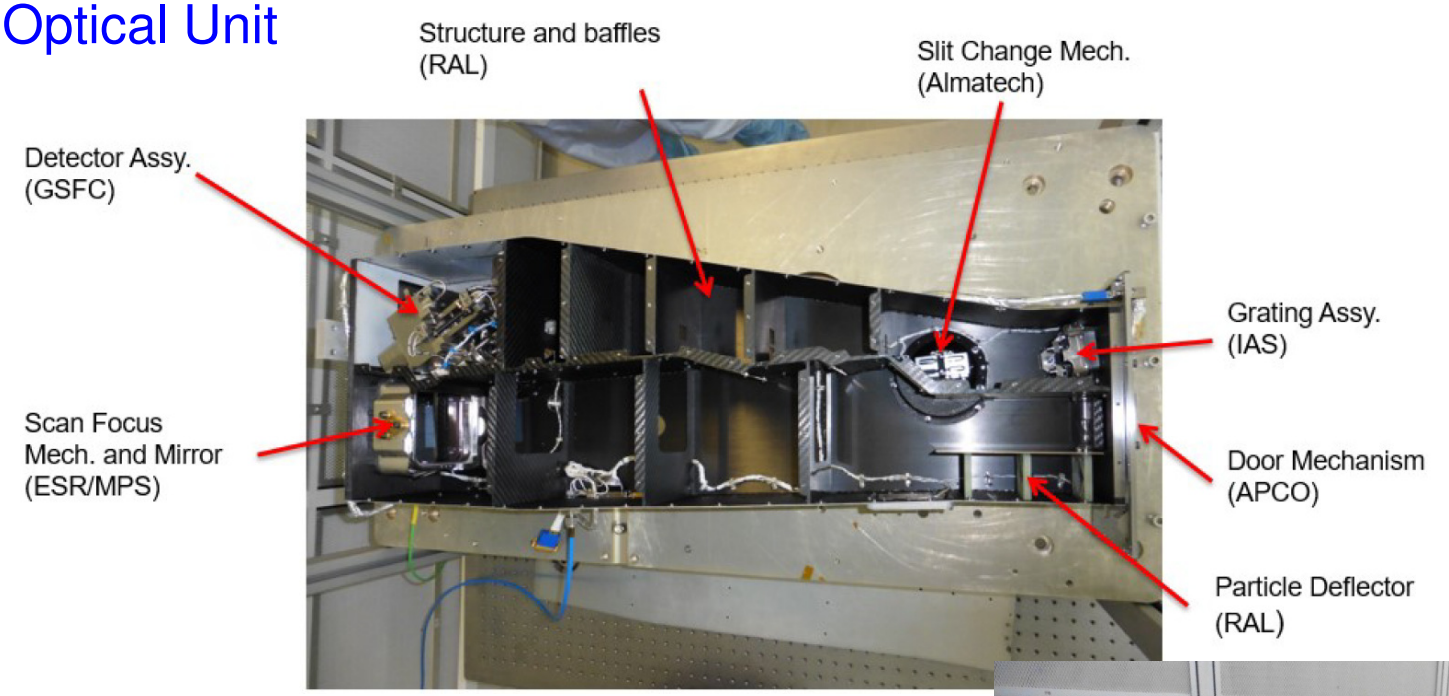
RAL Space, STFC, Harwell Oxford, UK

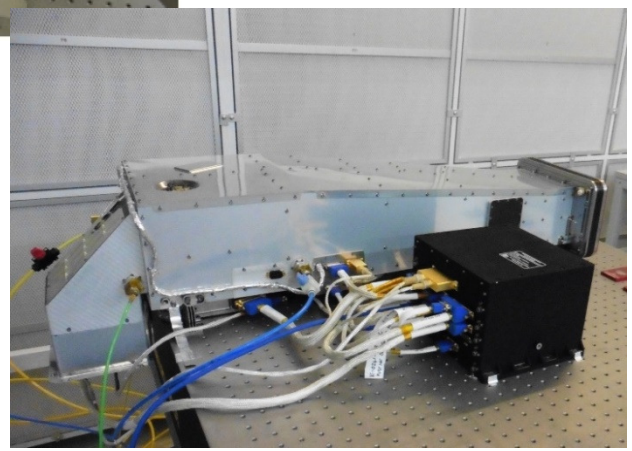
Outline

- The SPICE spectrometer:
  - Main features (optical unit, spectral range and resolution, field-of-view)
  - Observables and derived quantities (intensity, velocity, density, composition maps)
- Solar Orbiter key scientific questions:
  - SPICE and METIS contributions: Synergy and Challenge
- Synergy with the other instruments on Solar Orbiter:
  - How to support the linking between SPICE and METIS observations

The SPICE spectrometer: *Main features*

Optical Unit





Single-mirror *telescope* with f=622 mm (off axis paraboloid operating at near normal incidence).

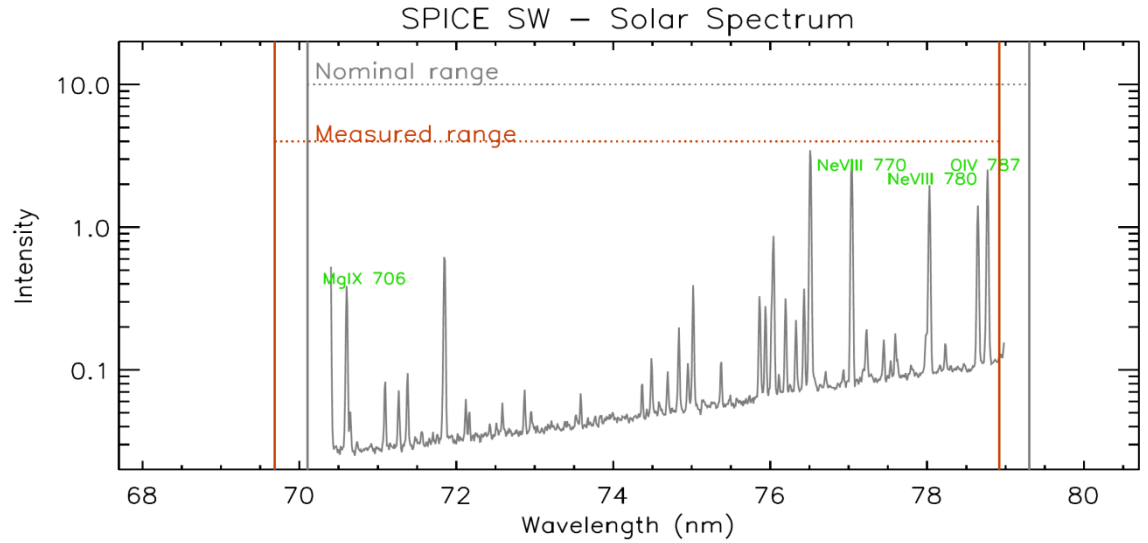
A Toroidal Variable Line Space *grating* images a choice of 4 spectrometer slits.

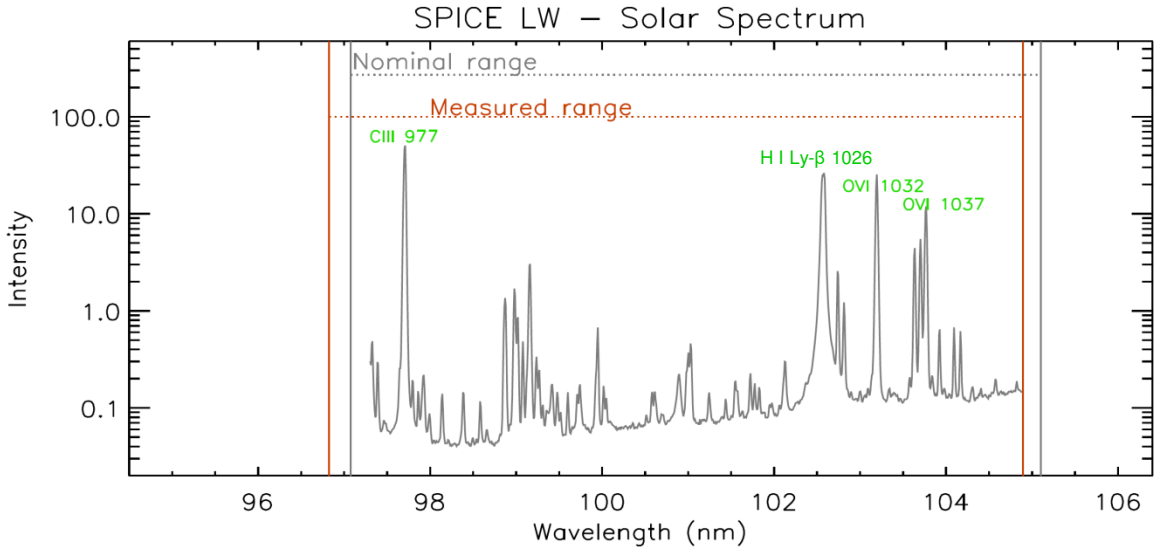
Slit imaged onto two 1024 x 1024 intensified Active Pixel Sensor *detectors*.

Two *spectral bands* are recorded simultaneously.

The SPICE spectrometer: *Main features*

Spectral range and resolution





Short Wavelength (SW)

Measured range:

69.826-78.920 nm

698.26-789.20 Å

Dispersion:

0.0095 nm/pixel

Long Wavelength (LW)

Measured range:

96.825-104.89 nm

968.25-1048.9 Å

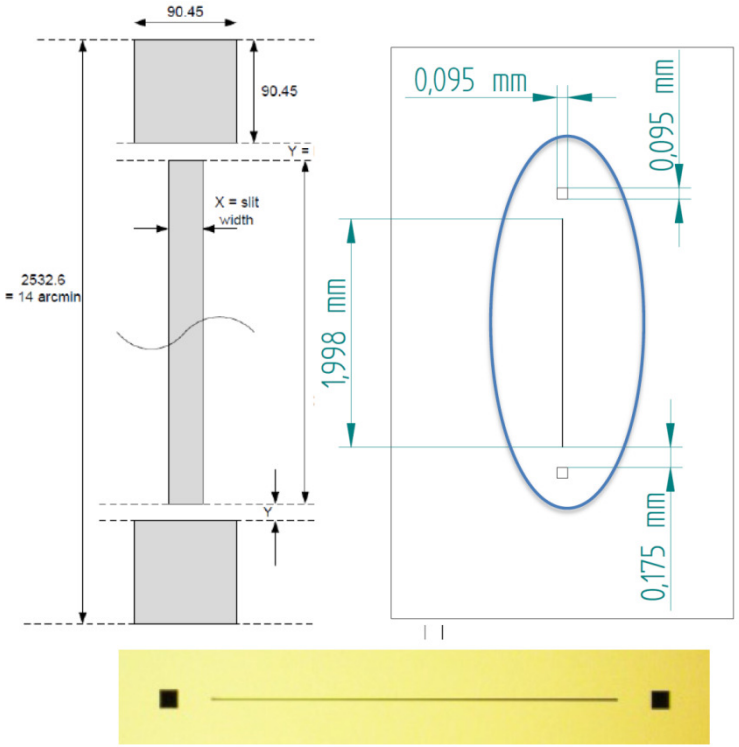
Dispersion:

0.0083 nm/pixel

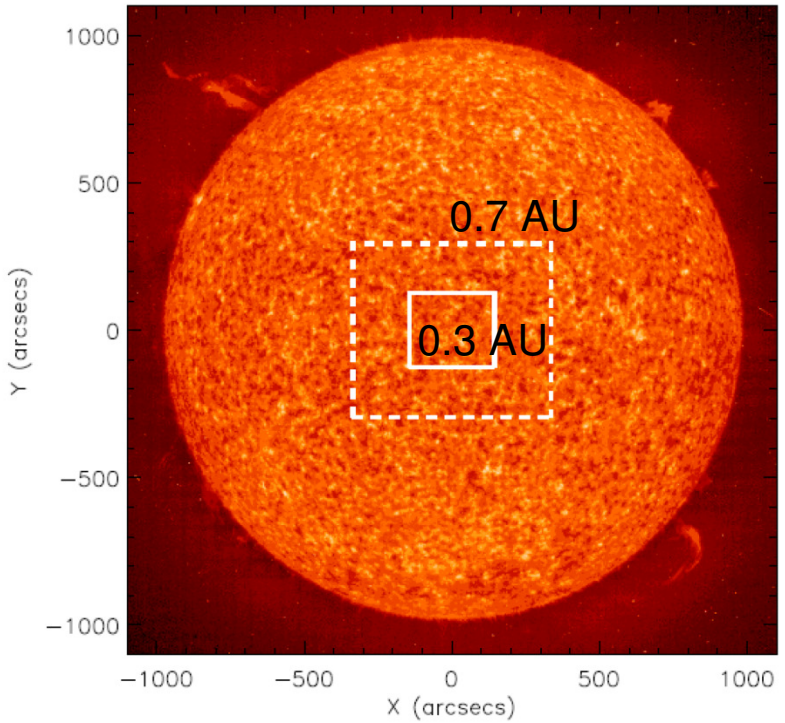
The SPICE spectrometer: *Main features*

Slits and Field-of-View (FOV)

- Four *slits* (2″, 4″, 6″, 30″), 2″= 6 μm, 500 km resolution at perihelion
- Narrow slits are 11 arcmin long, plus 30x30 arcsec window at each end. Total length 14′.



- *FOV* at 0.3 AU (solid line) and at 0.7 AU (dashed line)
- 16′x14′ area
- 14′=slit length including windows
- 11′=narrow slit length



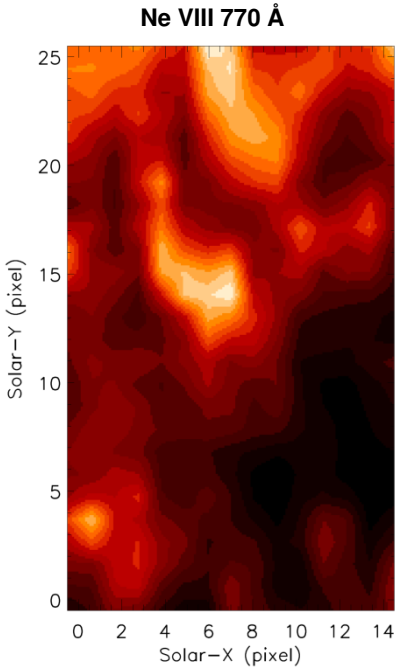
The SPICE spectrometer: *Observables*

Intensity, velocity and density maps

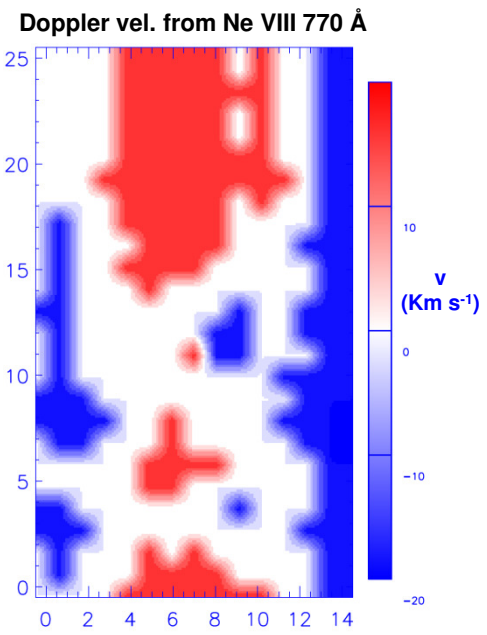
Quantitative knowledge of the physical and chemical state of the plasmas in the solar atmosphere (sources of outflows and ejection processes)

Observations of emission lines from a wide range of ionized atoms of H, C, O, N, Ne, S, Mg, Si, and Fe, covering temperatures from 10,000 to 10 million K

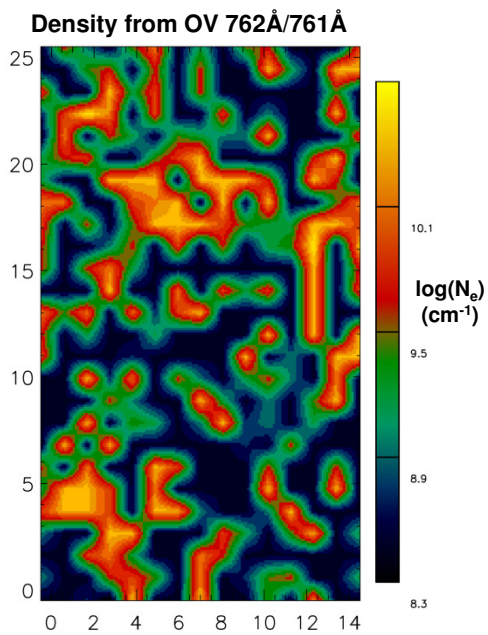
Intensity maps



Velocity maps



Density maps



Observations of 17th April 2009 12:00-16:00 UT made by SOHO/SUMER, JOP220/HOP109

The SPICE spectrometer: *Observables*

Composition (or FIP bias) maps

SPICE is the only instrument on Solar Orbiter that can investigate elemental abundances on the Sun surface and specifically the *separation of the elements according to the First Ionisation Potential* (FIP).

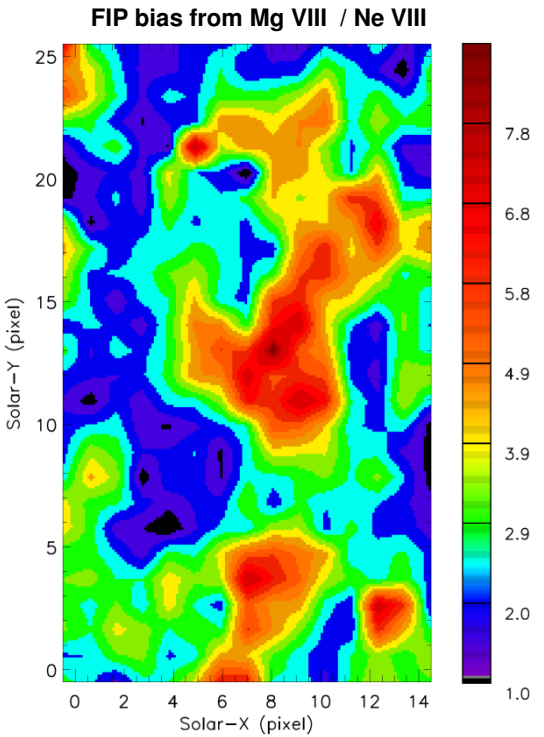
Through the FIP effect there is a preferential enhancement of elements with low FIP (e.g. Si, Mg, Fe) compared to those with high FIP (e.g. H, C,O, Ne).

The FIP bias depends on the source region on the Sun.

↓

Connection to solar wind structures observed by in-situ instruments

Observations of emission lines from low FIP (Fe III, Mg VIII, IX) and high FIP (C II, III, O II, III, IV, V, VI, Ne VIII, Ar IV, V) elements to derive the FIP maps using a range of models (e.g. line ratios, emission measure).



Solar Orbiter key scientific questions

SPICE and METIS contributions

Solar Orbiter top-level questions	SPICE contribution (SPICE manual – SPICE-RAL-RP-0002)	METIS contribution (METIS instrument paper – Antonucci et al. 2019)
1. What drives the solar wind and where does the magnetic field originate?	Identify features that give rise to solar wind and follow the evolution of source regions.	Investigate the region where solar wind is accelerated to near its asymptotic values.
2. How do solar transients drive heliospheric variability?	Identify jets, areas of coronal dimming; characterise shocks in low corona and investigate plasmas in proto-CME on disk.	Investigate the region where the first, most dramatic phase of the propagation of CMEs sources occurs.
3. How do solar eruptions produce the energetic particle radiation that fills the heliosphere?	Identify jets and reconnection sites that give rise to SEPs and provide thermodynamic characteristics of plasmas is SEPs sources.	Identify the path of shock fronts accelerating particles in the solar corona.
4. How does the solar dynamo work and drive connections between the Sun and the heliosphere?	Determine evolution of magnetised regions via the study of EUV emission and provide constraints on meridional circulation at high latitude.	Study of the overall magnetic configuration by identifying the closed and open magnetic field regions in the corona.

Solar Orbiter key scientific questions

Synergy between SPICE and METIS: top-level questions 1 and 2

Question 1: source of solar wind and coronal magnetic field

SPICE
Identify features that give rise to solar wind and follow the evolution of source regions.

METIS
Investigate the region where solar wind is accelerated to near its asymptotic values.

Complement each other: small SPICE FOV (outflow velocity and composition at the source regions) into a wider METIS context (measurements of Doppler dimming effect and outflow velocity of neutral H/proton component).

Question 2: how solar transients drive heliospheric variability

SPICE
Identify jets, areas of coronal dimming; characterise shocks in low corona and investigate plasmas in proto-CME on disk.

METIS
Investigate the region where the first, most dramatic phase of the propagation of CMEs sources occurs.

Identify where the CMEs come from (SPICE) and follow the very first phase of its evolution (METIS).

Solar Orbiter key scientific questions

Synergy between SPICE and METIS: top-level questions 3 and 4

Question 3: solar eruptions and SEPs

SPICE	*METIS*
Identify jets and reconnection sites that give rise to SEPs and provide plasma thermodynamic characteristics.	Identify the path of shock fronts accelerating particles in the solar corona.

Identify jets and reconnection sites from where SEPs originate (SPICE) and identify the path of shock fronts of SEPs (METIS).

Question 4: solar dynamo and connections between Sun and heliosphere

SPICE	*METIS*
Determine evolution of magnetised regions via the study of EUV emission and provide constraints on meridional circulation at high latitude.	Study of the overall magnetic configuration by identifying the closed and open magnetic field regions in the corona.

Follow evolution of magnetised regions , closed and open magnetic field lines at the Sun surface (SPICE) and study of the overall magnetic configuration (METIS).

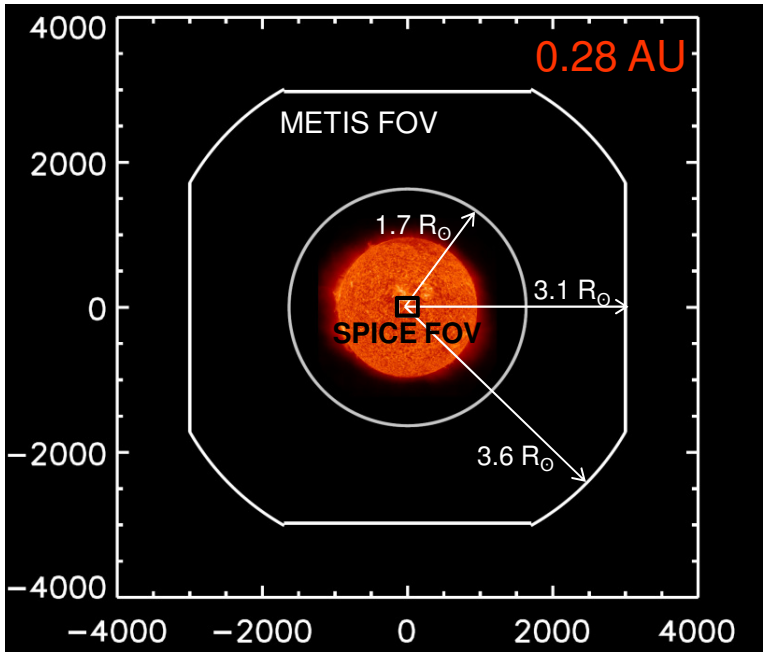
Solar Orbiter key scientific questions

Challenge of SPICE and METIS observations

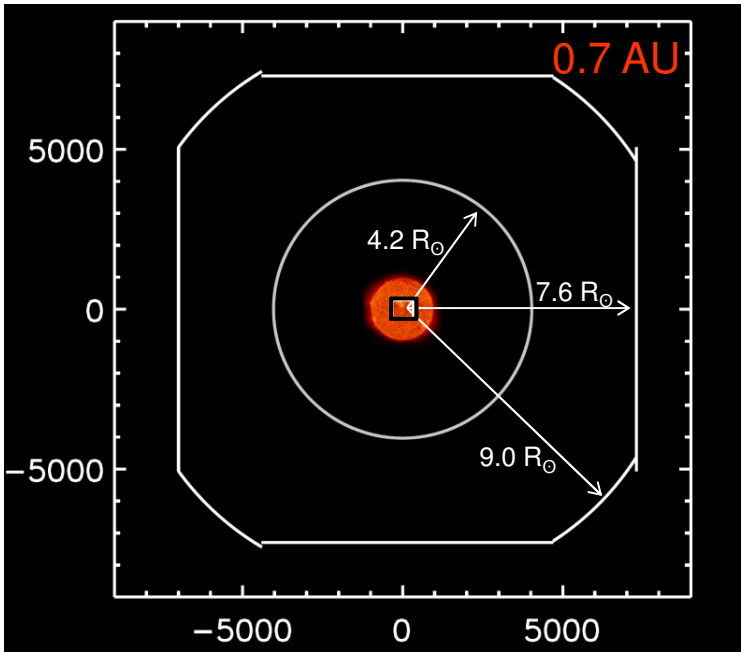
The main challenge is to the *pointing* and the *solar distance*.

Sun centre

SPICE will observe only in the middle of the Sun and will miss any possible feature that could be an important source.
METIS will prevent direct sunlight reaching the focal plane even for a distance <0.51 AU.



SPICE FOV = 0.14 R$_O$



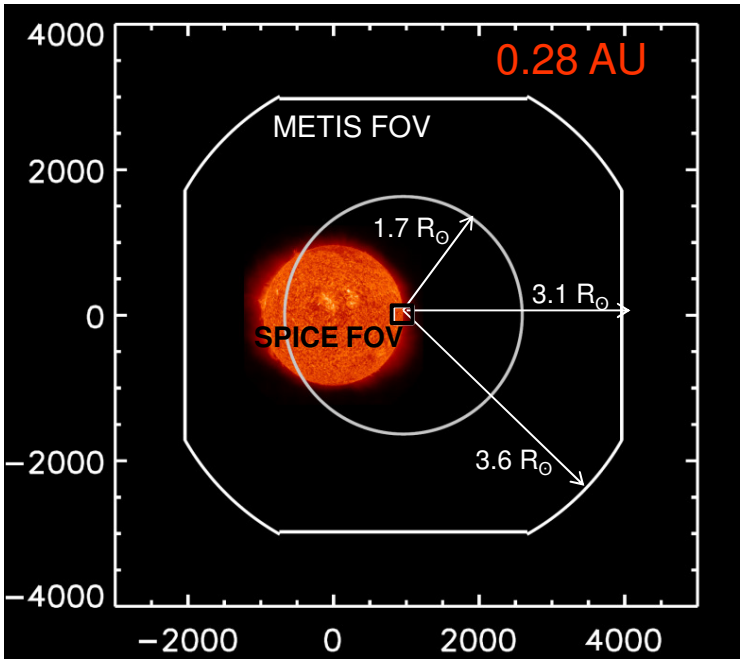
SPICE FOV = 0.35 R$_O$

Solar Orbiter key scientific questions

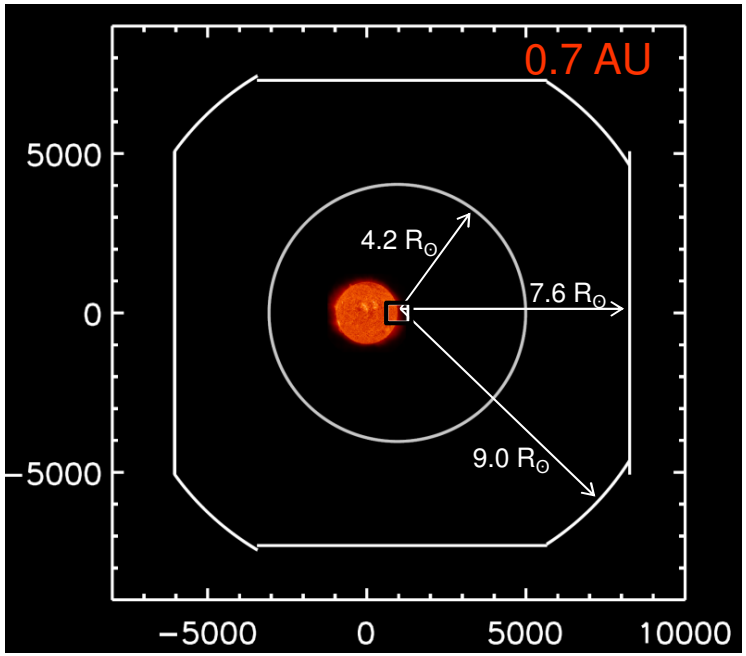
Challenge of SPICE and METIS observations

Off-pointing (including solar limb pointing)

SPICE will be able to observe and track any solar feature.
METIS can observe only if the solar distance is >0.51 AU otherwise the door will have to be closed to prevent stray light problems.



SPICE FOV = 0.14 R$_O$



SPICE FOV = 0.35 R$_O$

Synergy with other Solar Orbiter instruments

Support of SPICE and METIS synergy

As part of the Solar Orbiter payload, the link between SPICE and METIS observations will be supported by the other Remote Sensing (RS) and In-Situ (IS) instruments.

In particular the connection and analysis of the information acquired by SPICE and METIS can be strongly supported by the following instruments:

- **RS instruments:**
  - EUI
  - PHI

  Full disk observations for global view and context (EUI/FSI and PHI/FDT) but also high resolution measurements to be compared directly with SPICE FOV (EUI/HRI and PHI/HRT).

- **IS instruments:**
  - SWA
  - EPD

  To connect composition from the source on the Sun up to the spacecraft position (SWA/HIS) and detect the evolution of energetic particles.

Conclusions

- SPICE and METIS complement each other allowing to *track solar features from the Sun surface up to the outer corona* before reaching the spacecraft.

- The *challenge* due to the pointing and instrument constraints at different solar distances during off-pointing can be *reduced by a careful planning*.

- The other instruments on Solar Orbiter, both RS (in particular *EUI and PHI*) and IS (in particular *SWA and EPD*) can *fulfil the gaps* in the measurements taken by SPICE and METIS and support their synergy.