SOLI INVICTO

PROBA-3/ASPIICS and its potential synergies with Solar Orbiter/Metis

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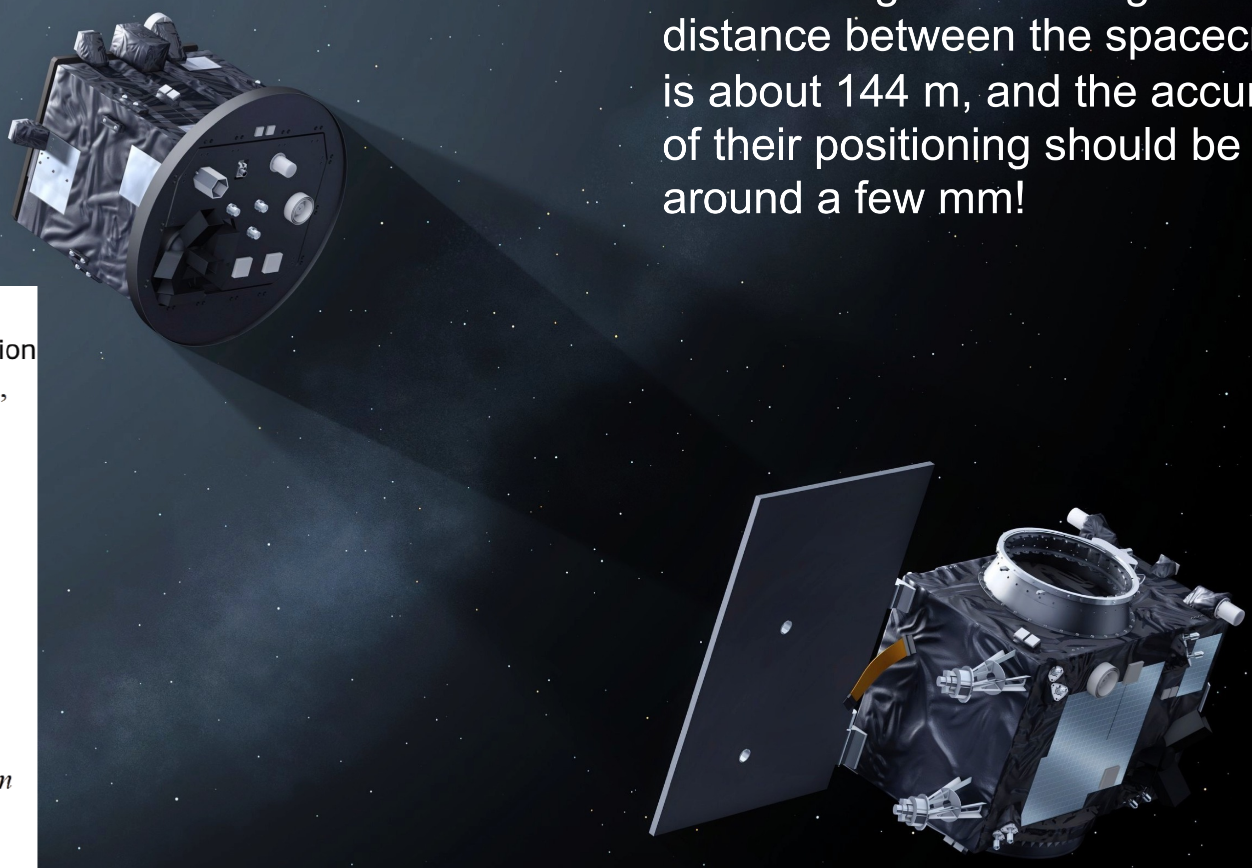
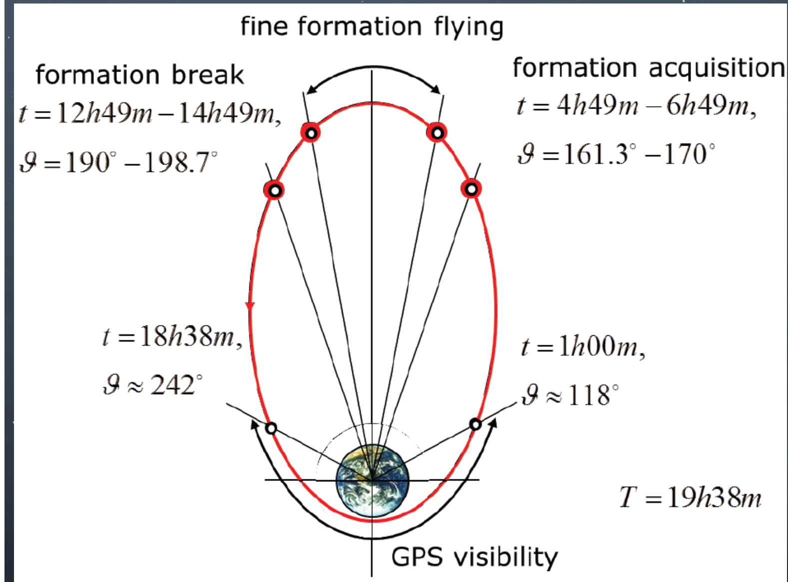
and the PROBA-3/ASPIICS science team

The PROBA-3 mission

- The ultimate coronagraph: artificial total eclipse created using two spacecraft in flight formation.
- A technological challenge: the distance between the spacecraft is about 144 m, and the accuracy of their positioning should be around a few mm!

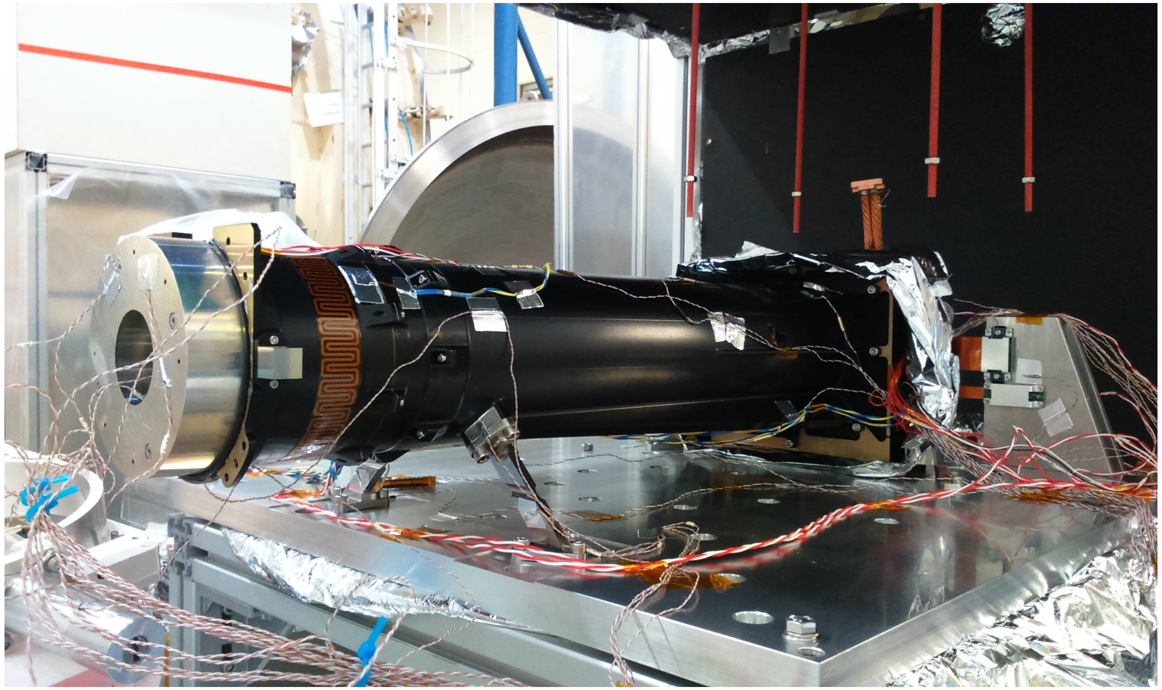




PROBA-3 orbit
duration: 19h 38min
fine formation flying: 6h

Launch: 2021 Q2

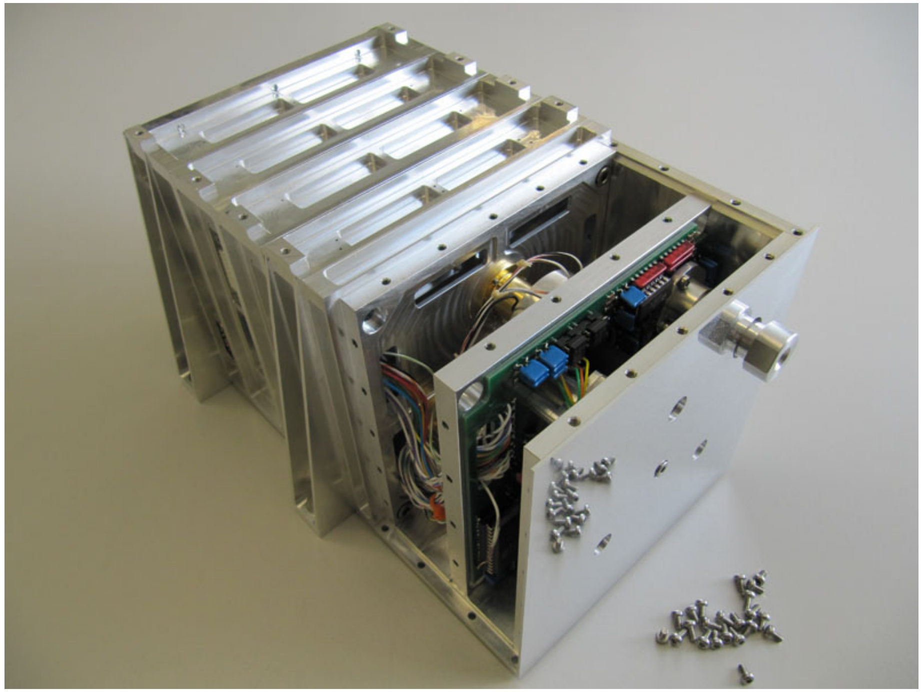
Scientific payload of PROBA-3



ASPIICS
(Association of Spacecraft for Polarimetric and Imaging Investigation of the Corona of the Sun)

PI: Andrei Zhukov (ROB, Belgium)

The telescope is placed on the main spacecraft, and the occulting disk is placed on the smaller spacecraft 144 m away. Together they form a giant coronagraph.



DARA
(Digital Absolute RAdiometer)

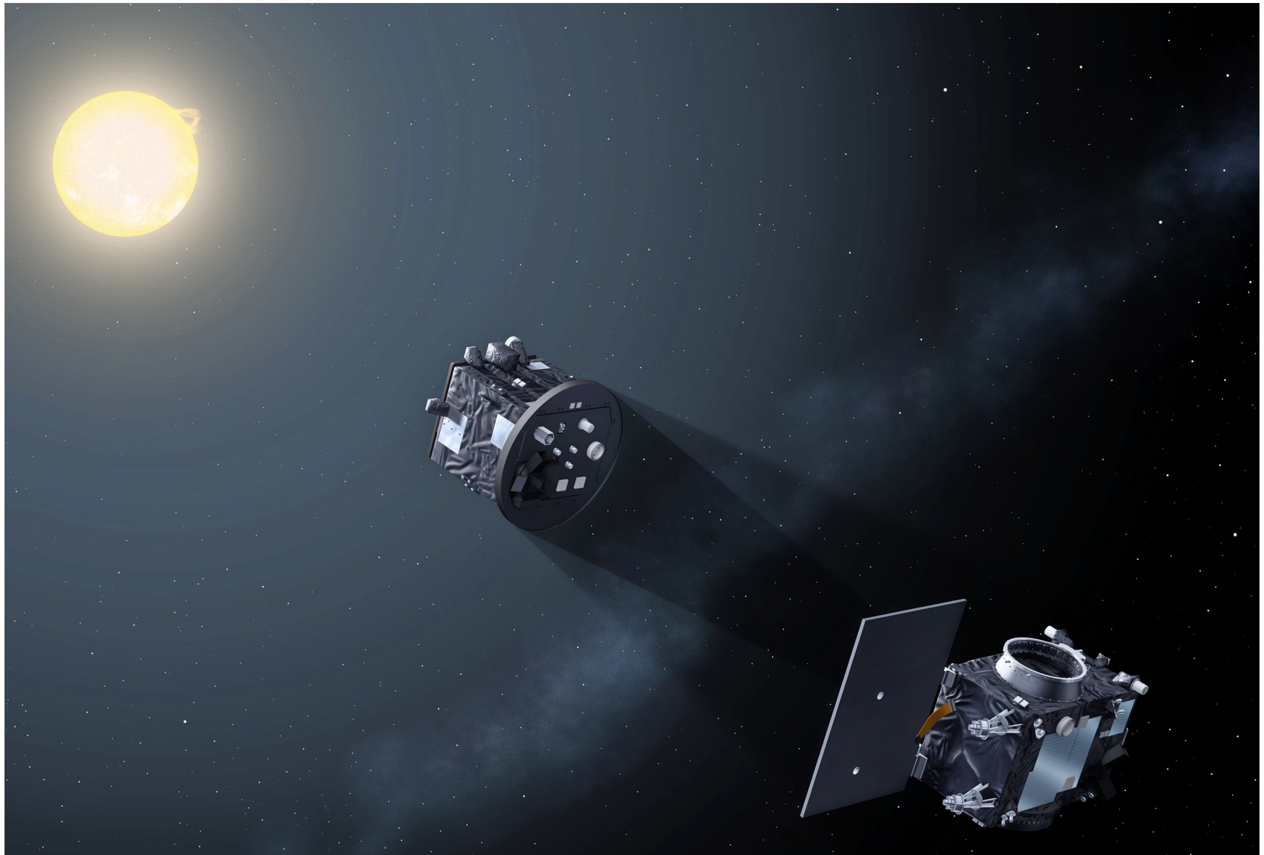
PI: Werner Schmutz (PMOD, Switzerland)

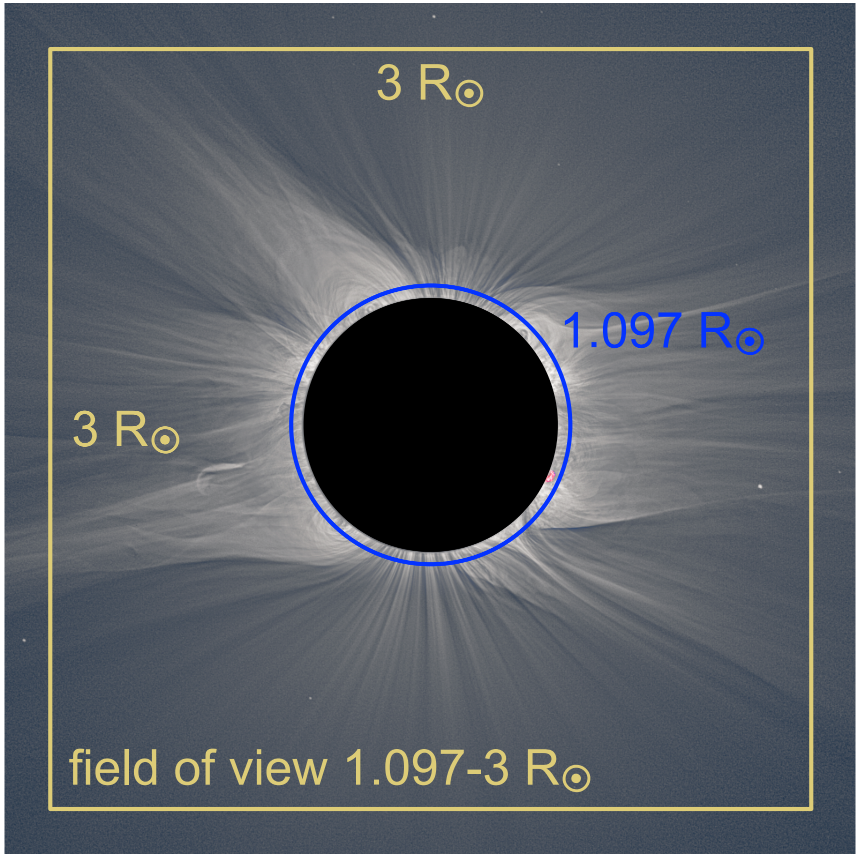
DARA is a total solar irradiance monitor placed on the occulter spacecraft.

PROBA-3/ASPIICS: the ultimate coronagraph!

- The formation flying will be maintained over 6 hours in every 20-hour orbit: *around a factor 100 improvement* in the duration of uninterrupted observations in comparison with a total eclipse.
- PROBA-3 will observe the corona two orbits per week on average: *around a factor 50 improvement* in the occurrence rate in comparison with a total eclipse.

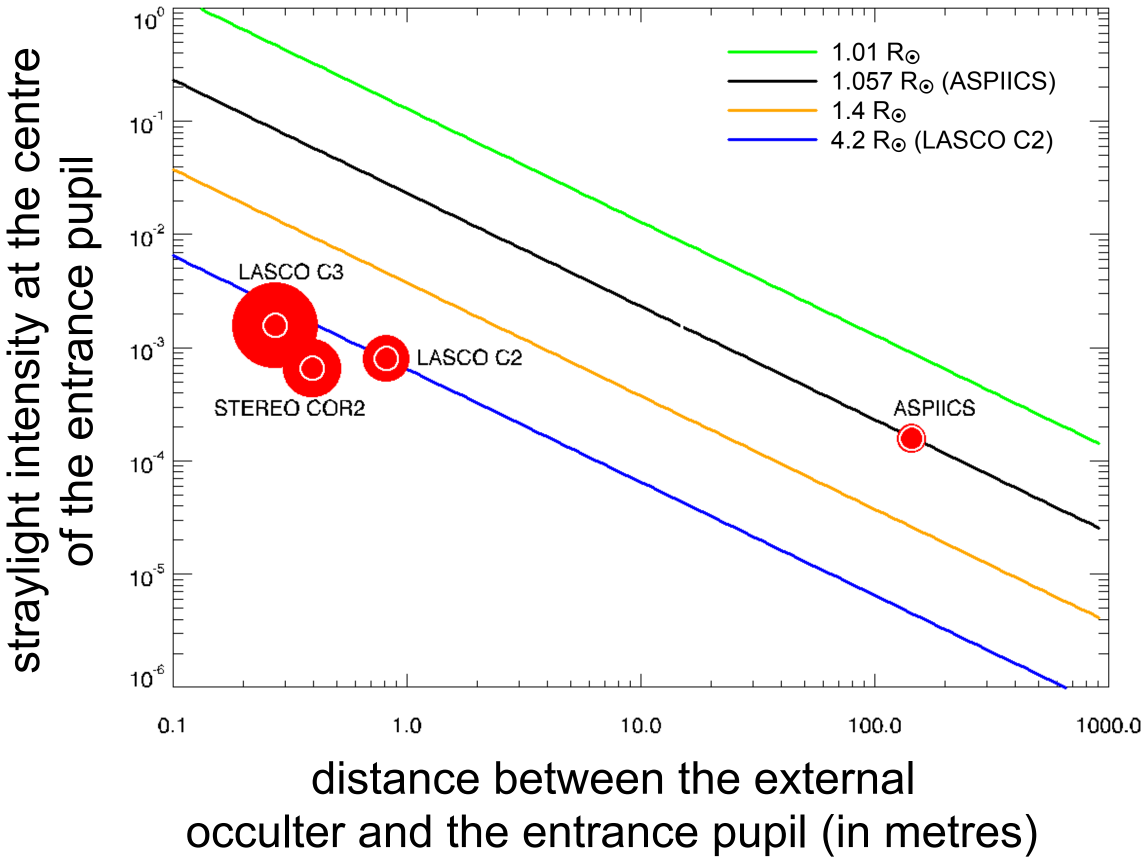
- 6 spectral channels:
  - white light (5350-5650 Å),
  - 3 polarized white light,
  - Fe XIV passband at 5304 Å.
  - He I D3 passband at 5877 Å.
- 2048x2048 pixels (2.8 arc sec per pixel)
- 60 s nominal synoptic cadence
  - 2 s using a quarter of the field of view.

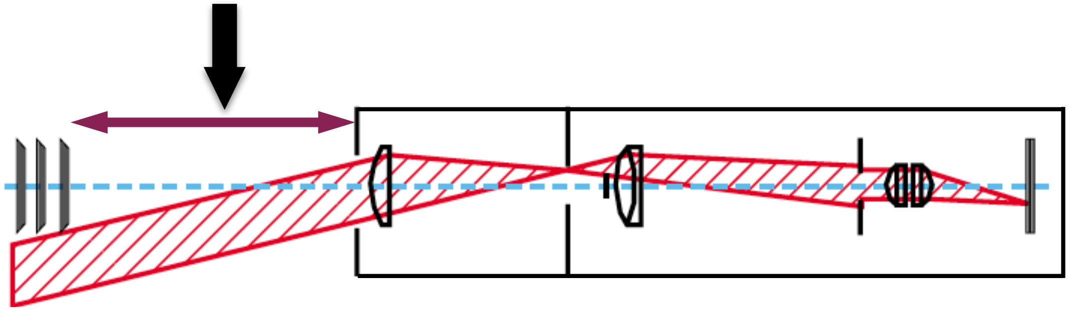




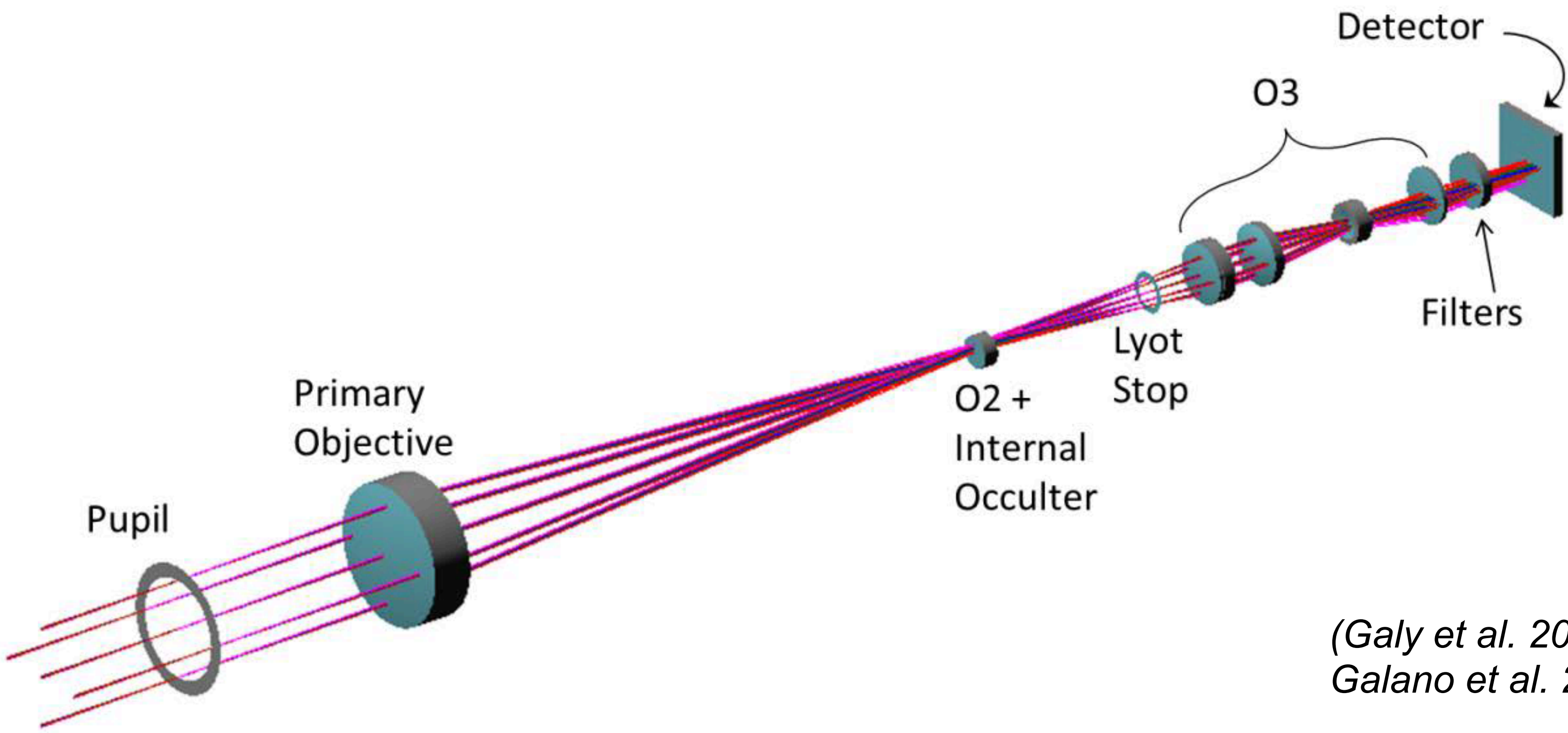
The main advantage of PROBA-3/ASPIICS

- The straylight critically depends on the distance between the external occulter and the entrance pupil.
- In ASPIICS, this distance is around two orders of magnitude larger than that in any other coronagraph built so far.
- This increase of distance allows in the same time:
  - to reduce the position of the inner edge of the field of view from 2.2 $R_\odot$ (LASCO C2) to 1.097 $R_\odot$ (ASPIICS),
  - to have the straylight around 5 times lower than that in other coronagraphs.





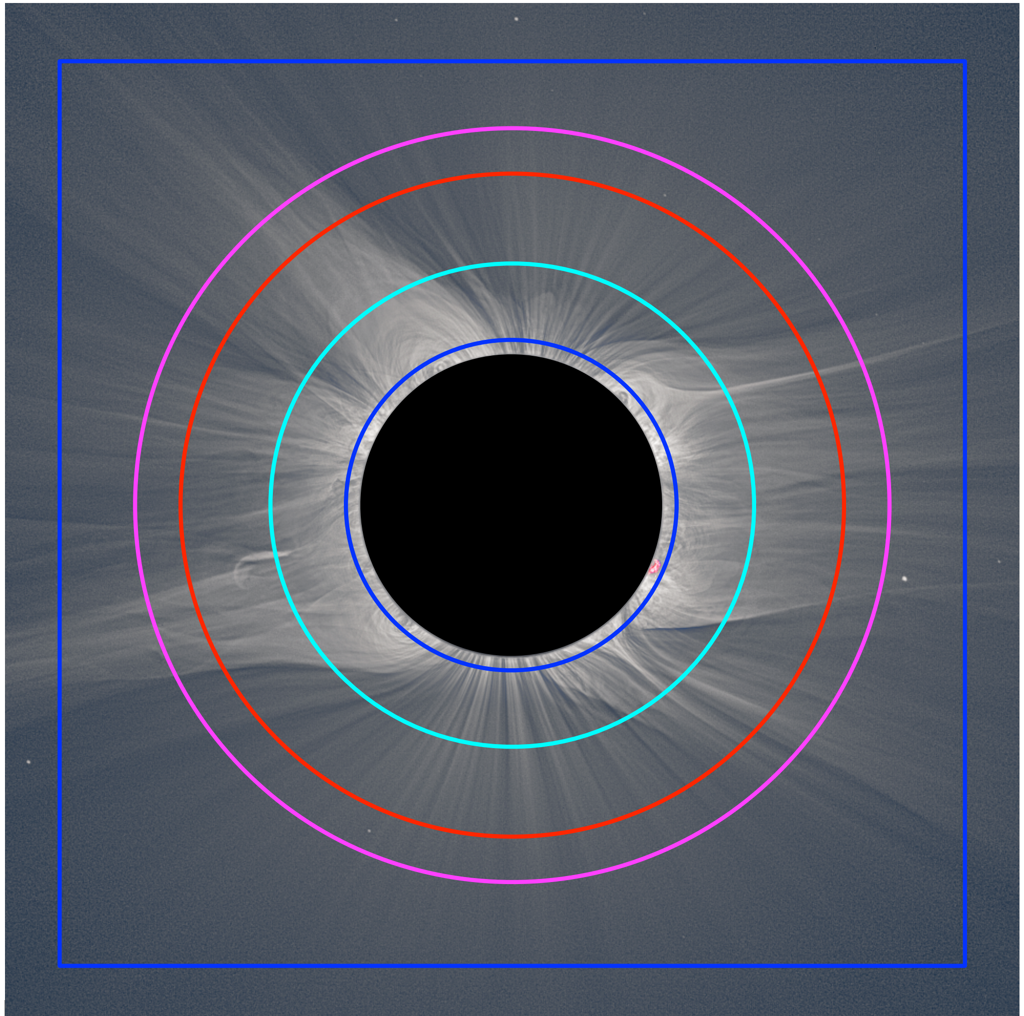
PROBA-3/ASPIICS optical design



(Galy et al. 2015, Galano et al. 2018)

- An externally occulted coronagraph with the occulter placed about 144 m in front of the entrance pupil.
- The optical design of ASPIICS follows the principles of the classic externally occulted Lyot coronagraph.

PROBA-3/ASPIICS in comparison with other coronagraphs



Inner edge of the field of view:

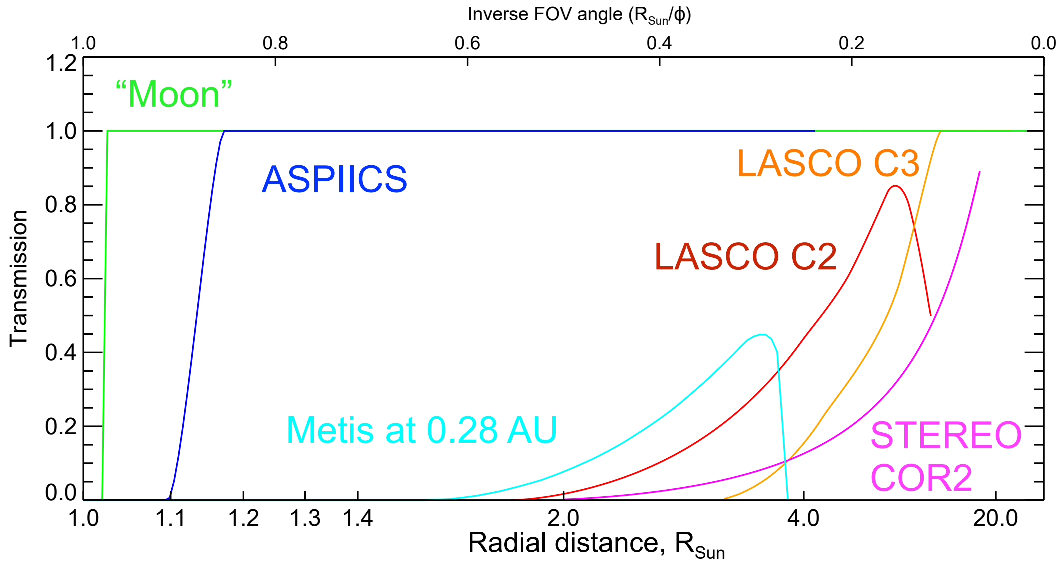
ASPIICS - 1.097 R☉

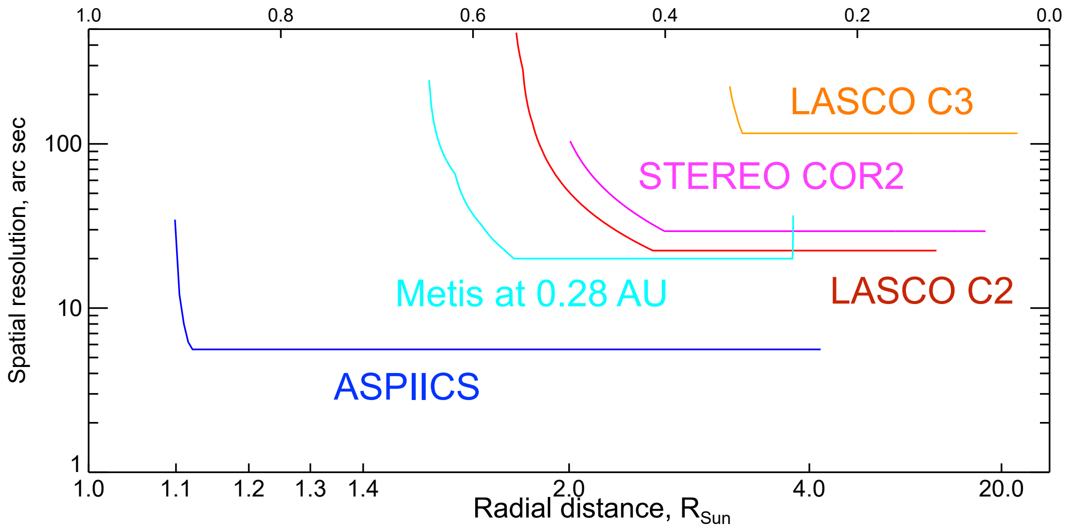
STEREO COR2 - 2.5 R☉

SOHO/LASCO C2 - 2.2 R☉

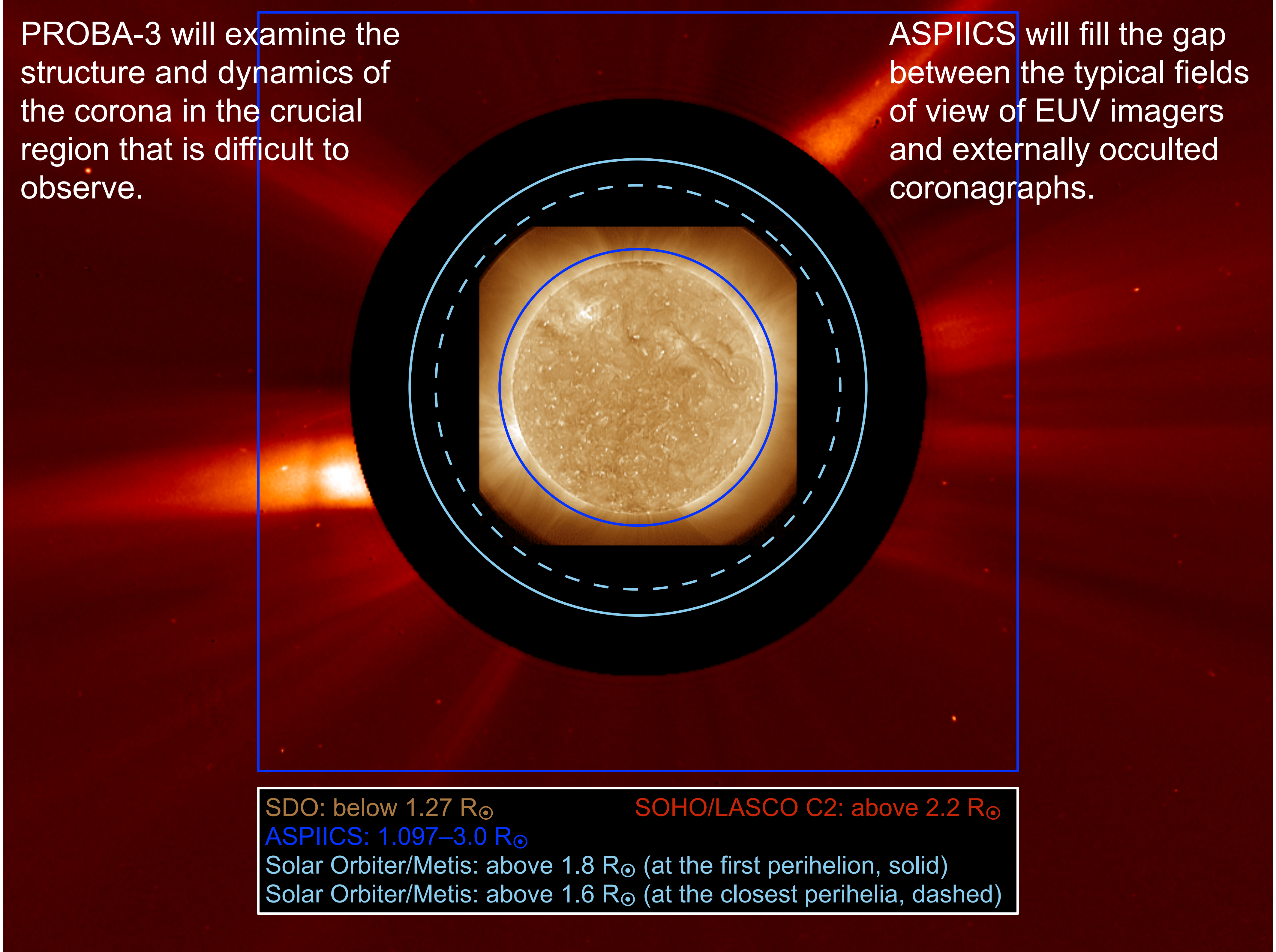
Solar Orbiter Metis at 0.28 AU - 1.6 R☉

vignetting function

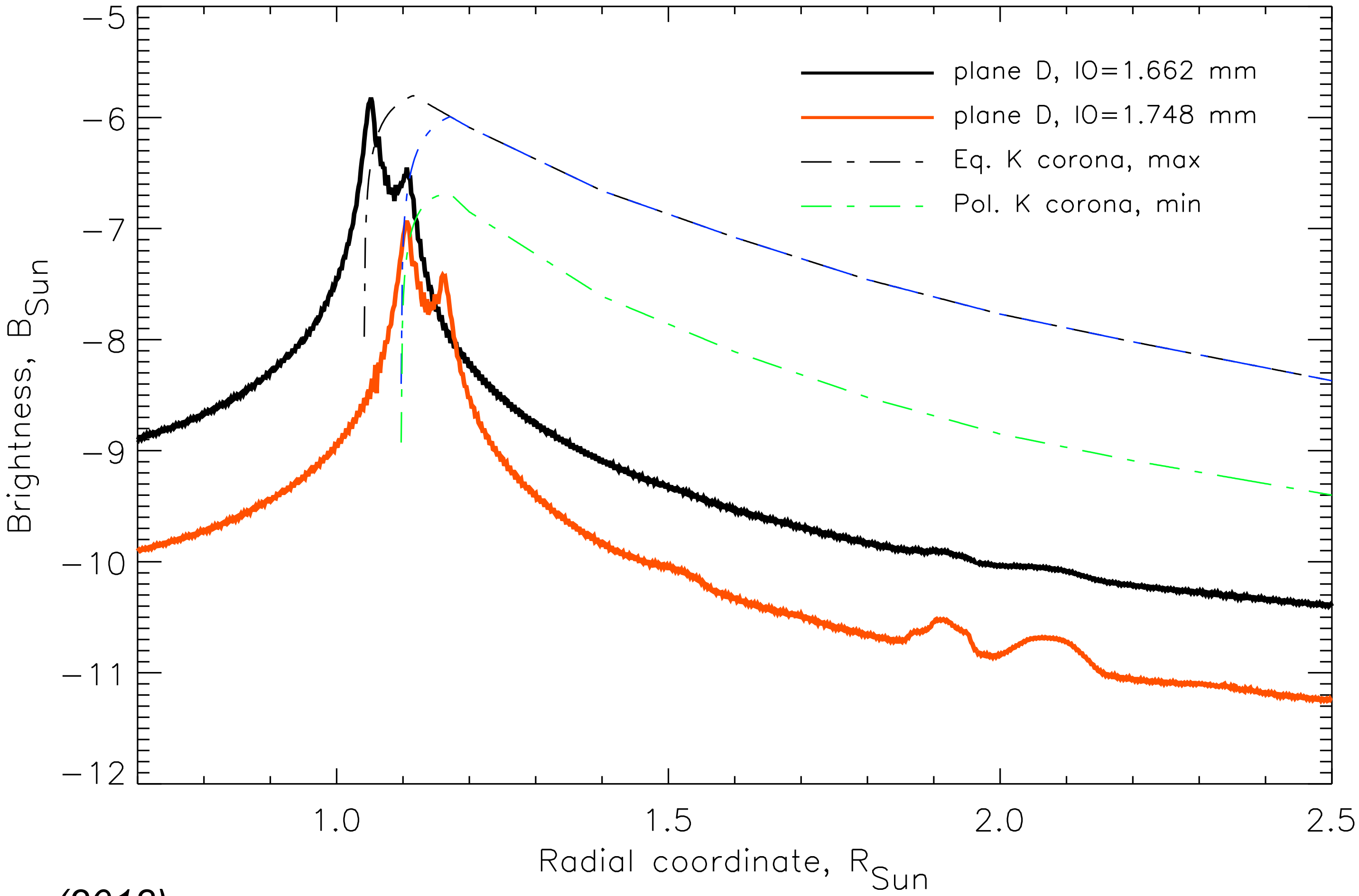




spatial resolution


PROBA-3 will examine the structure and dynamics of the corona in the crucial region that is difficult to observe.
ASPIICS will fill the gap between the typical fields of view of EUV imagers and externally occulted coronagraphs.
SDO: below 1.27 R⊙
SOHO/LASCO C2: above 2.2 R⊙
ASPIICS: 1.097–3.0 R⊙
Solar Orbiter/Metis: above 1.8 R⊙ (at the first perihelion, solid)
Solar Orbiter/Metis: above 1.6 R⊙ (at the closest perihelia, dashed)

Straylight in ASPIICS

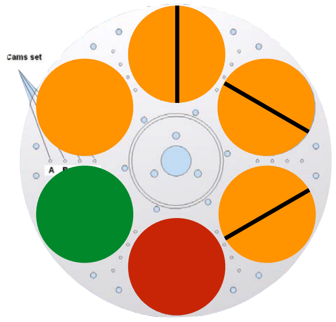


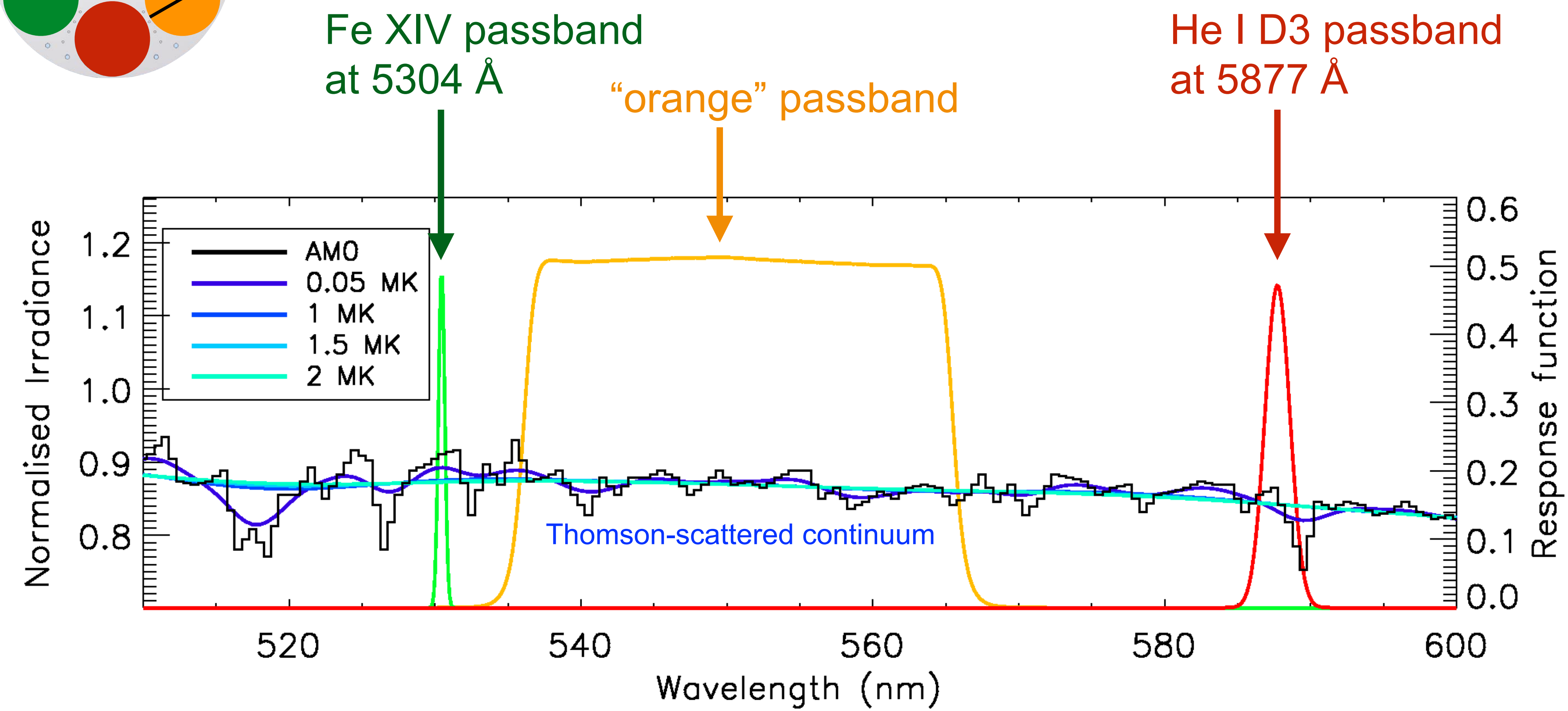
Shestov & Zhukov (2018)

- State-of-the-art diffraction calculations *(Aime 2013, Rougeot et al. 2017, Shestov & Zhukov 2018)* allow a reliable estimation of the straylight.

- In the inner part of the field of view, the straylight is dominated by the diffraction of the solar disk light on the external occulter.

Six filters of ASPIICS





- wide (5350-5650 Å) white-light ("orange") passband containing essentially the coronal continuum produced by the Thomson scattering,
- wide white-light passband combined with 3 polarizers oriented at angles of 0°, 60°, 120°.
- narrow (6 Å) passband centered at 5304 Å (coronal green line of Fe XIV + coronal continuum).
- narrow (20 Å) passband centered at 5877 Å (prominence line of He I D3 + coronal and prominence continuum).

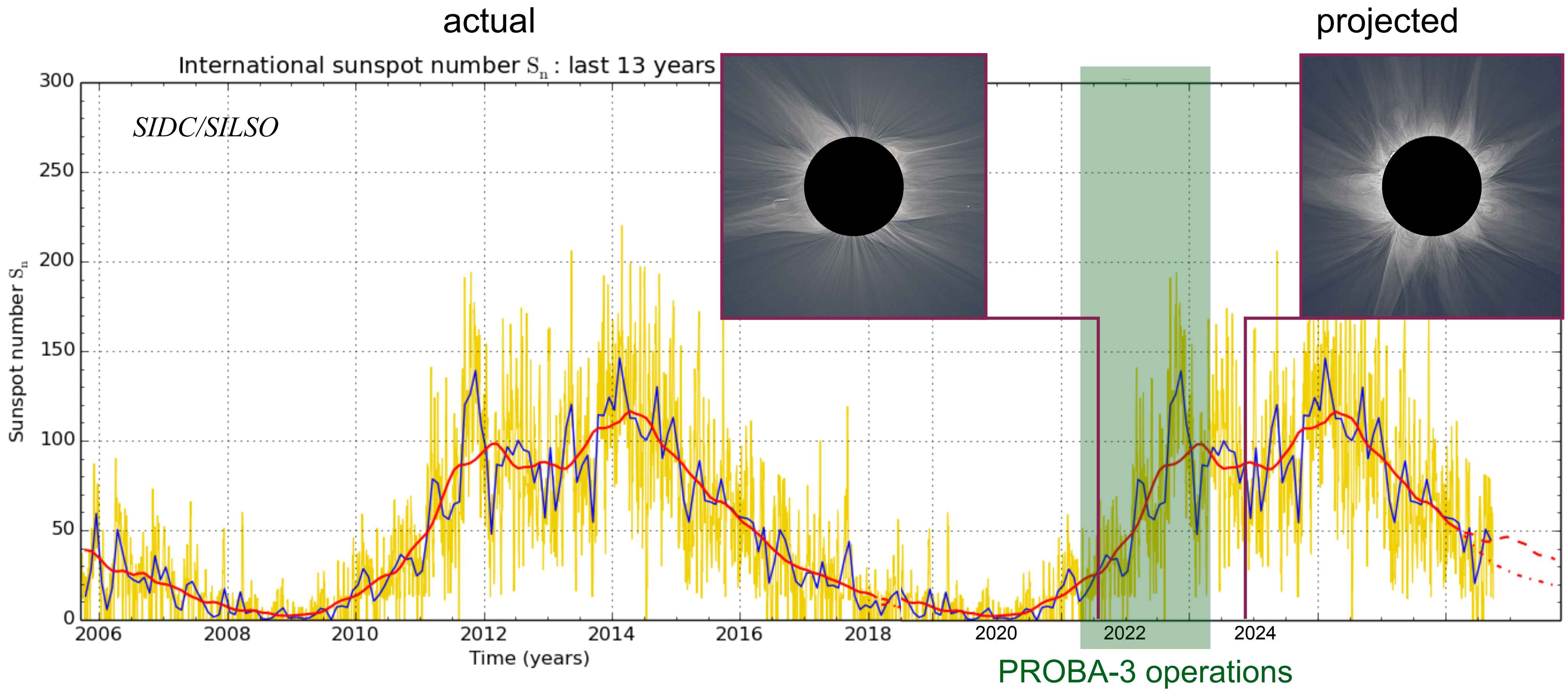
PROBA-3/ASPIICS scientific objectives

- The top-level scientific objectives of ASPIICS are:

  1. Understanding the physical processes that govern the quiescent solar corona by answering the following questions:
     - What is the nature of the solar corona on different scales?
     - What processes contribute to the heating of the corona?
     - What processes contribute to the solar wind acceleration?

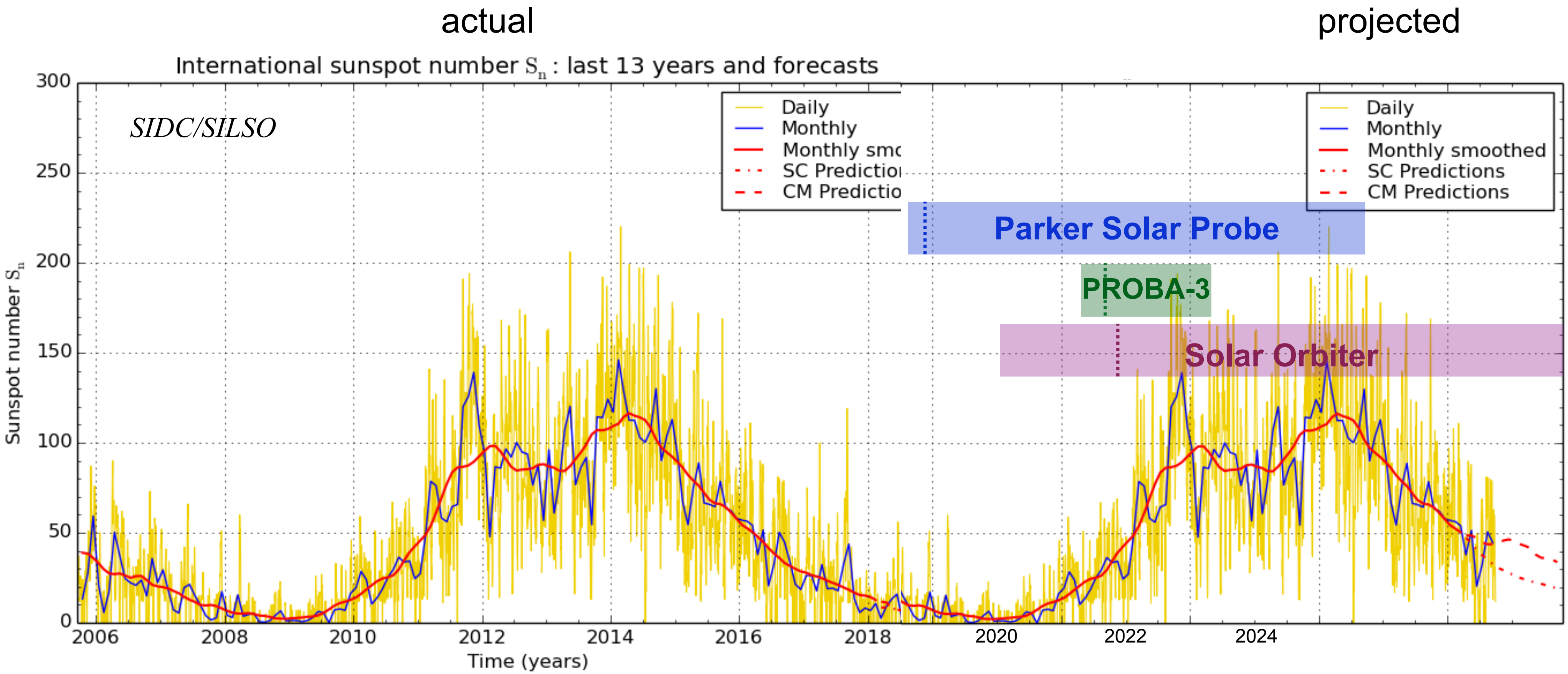
  2. Understanding the physical processes that lead to CMEs and determine space weather by answering the following questions:
     - What is the nature of the structures that form the CME?
     - How do CMEs erupt and accelerate in the low corona?
     - What is the connection between CMEs and active processes close to the solar surface?
     - Where and how can a CME drive a shock in the low corona?

What will the corona look like?



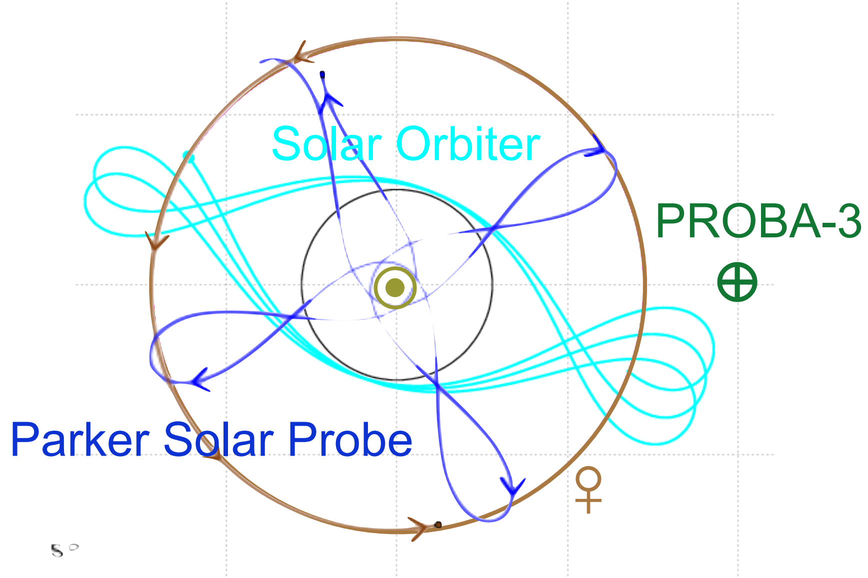
- Assuming the average solar cycle duration of 11 years, the solar activity during the operations of PROBA-3 (2021-2023) will be similar to that in 2010-2012 (rising phase to the solar cycle maximum).
- The first year of operations (2021-2022) will be dedicated to the quiet Sun observations.
- The second year of operations (2022-2023) will be dedicated to the CME observations.

PROBA-3 in synergy with other missions



- The PROBA-3 launch in 2021 would allow to make coordinated observations with other solar and heliospheric space missions, e.g., the Parker Solar Probe (NASA) and Solar Orbiter (ESA).
- The schedule of the launches and mission operations would allow around 20 months of coordinated operations of PROBA-3, Solar Orbiter, and Parker Solar Probe.

PROBA-3 in synergy with Solar Orbiter and Parker Solar Probe



- The complementariness of PROBA-3, Solar Orbiter, and Parker Solar Probe is both operational and scientific.

- The choice of periods of PROBA-3 coronagraphic observations needs to be optimized to collect the data on as many CMEs as possible. Far-side data from Solar Orbiter would be welcome!

- PROBA-3/ASPIICS will:

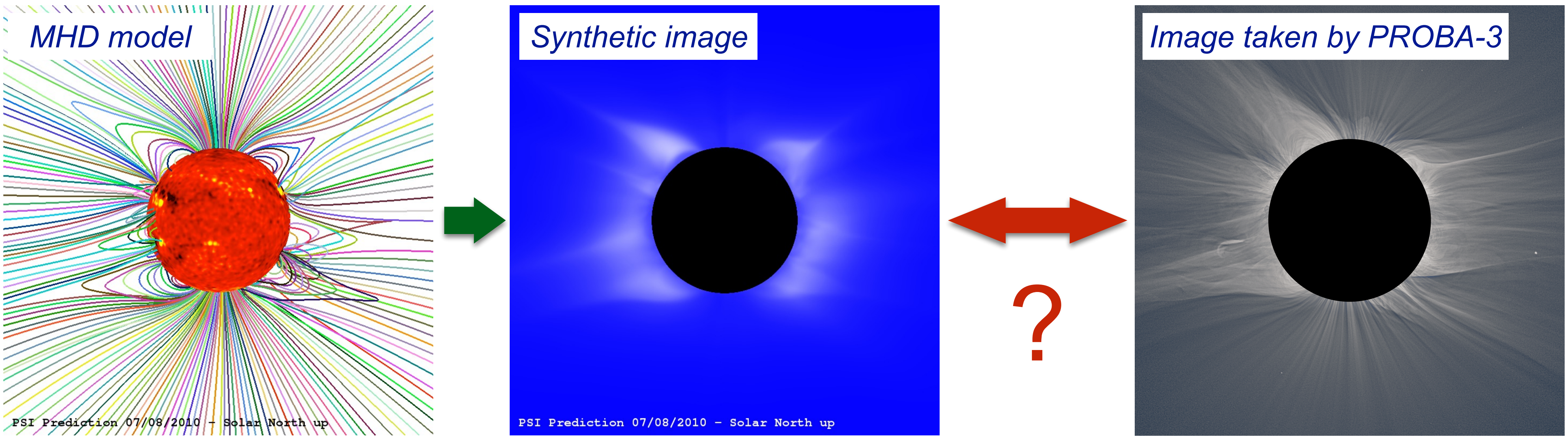
  - make above-the-limb observations of the coronal plasma that will be later sampled in situ by Solar Orbiter and Parker Solar Probe (in particular, near perihelia),

  - perform stereoscopic coronagraphy with Solar Orbiter/Metis (tomographic reconstructions, etc.),

  - help to determine the connectivity of field lines sampled by Solar Orbiter and Parker Solar Probe in situ.

PROBA-3 in synergy with Solar Orbiter and Parker Solar Probe

- Modern calculations of the coronal magnetic field are strongly model-dependent and cannot always reproduce accurately complex magnetic configuration of the solar corona.
- ASPIICS observations of the large-scale coronal structure (streamers, pseudo-streamers, coronal holes) will constrain the models of the coronal magnetic field and, therefore, the models of the interplanetary magnetic field.
- These models are important to determine the connectivity of field lines sampled by Solar Orbiter and Parker Solar Probe in situ (Sun-heliosphere connection).



Summary

- Due to the unique separation between the telescope and the occulter (around 144 m), PROBA-3/ASPIICS will be able to observe the inner corona as close to the solar centre as 1.097 $R_{\odot}$ in low straylight conditions.
- PROBA-3/ASPIICS will fill the gap between the low corona (typically observed by EUV imagers) and the high corona (typically observed by externally occulted coronagraphs).
- During around 20 months, the PROBA-3/ASPIICS science operations can be coordinated with operations of Solar Orbiter and Parker Solar Probe.
- PROBA-3/ASPIICS will allow tracking the connectivity of coronal structures to the solar surface and, in combination with state-of-the-art MHD models, allow us to determine reliably the large-scale coronal magnetic field configuration.
- PROBA-3 is on the way to be launched in the second quarter of 2021.