SOLI INVICTO

ASPIICS

an Externally-Occulted Coronagraph for the PROBA-3 Mission

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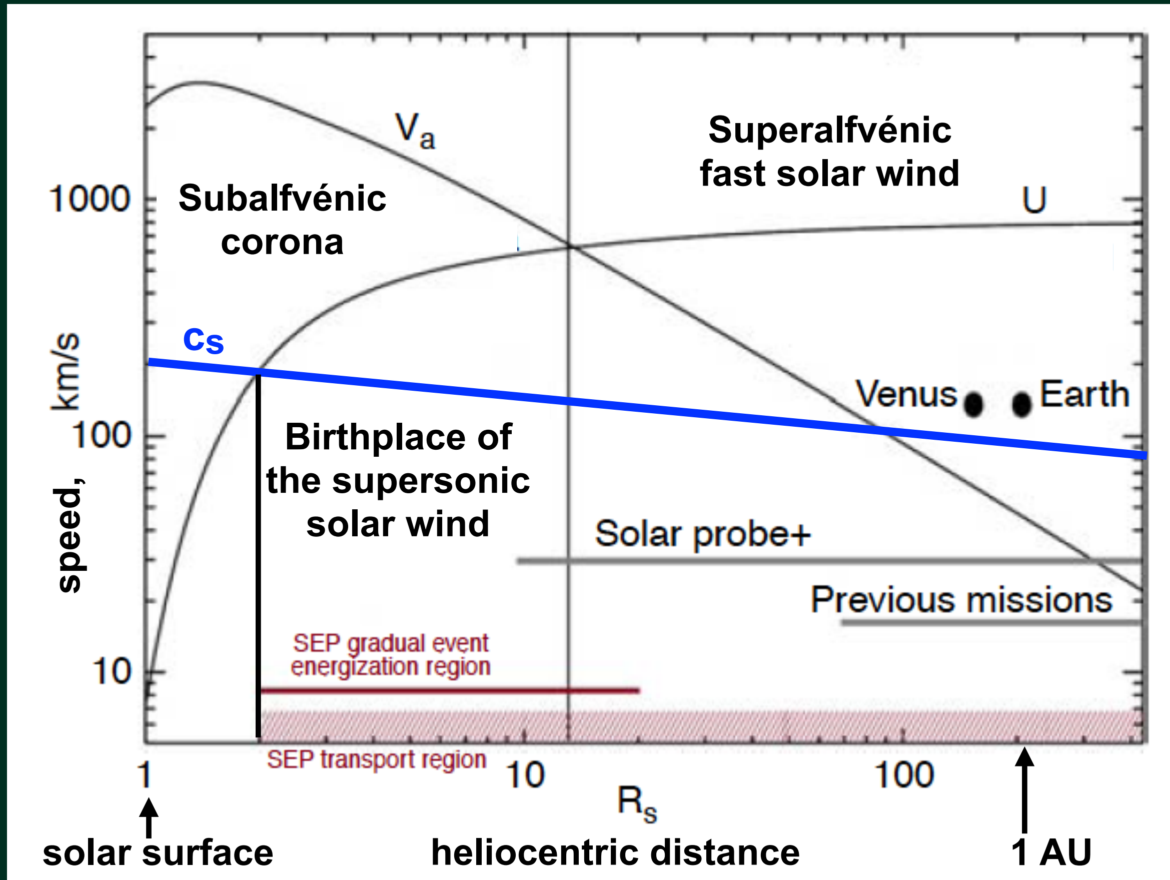
Future solar space missions with the involvement of the Centre Spatial de Liège (CSL)

- Extreme-ultraviolet Solar Imager for Operations (ESIO)
  - *CSL: Project Management; ROB: definition of requirements*
  - *the subject of the presentation by Tanguy Thibert (CSL)*
- Extreme Ultraviolet Imager (EUI) onboard Solar Orbiter
  - *CSL: Principal Investigator (Pierre Rochus) and project management; ROB: Co-Principal Investigator (David Berghmans)*
- Solar Orbiter Heliospheric Imager (SoloHI)
  - *CSL: optical design, mock-up straylight tests, bidirectional reflectance distribution function measurements on black samples*
- Wide-field Imager for Solar Probe plus (WISPR)
  - *CSL: optical design and a straylight test*
- ASPIICS coronagraph onboard PROBA-3
  - *CSL: management of the industrial consortium; ROB: Principal Investigator (Andrei Zhukov)*
  - *the subject of this presentation*

Why do we need observations of the inner solar corona?

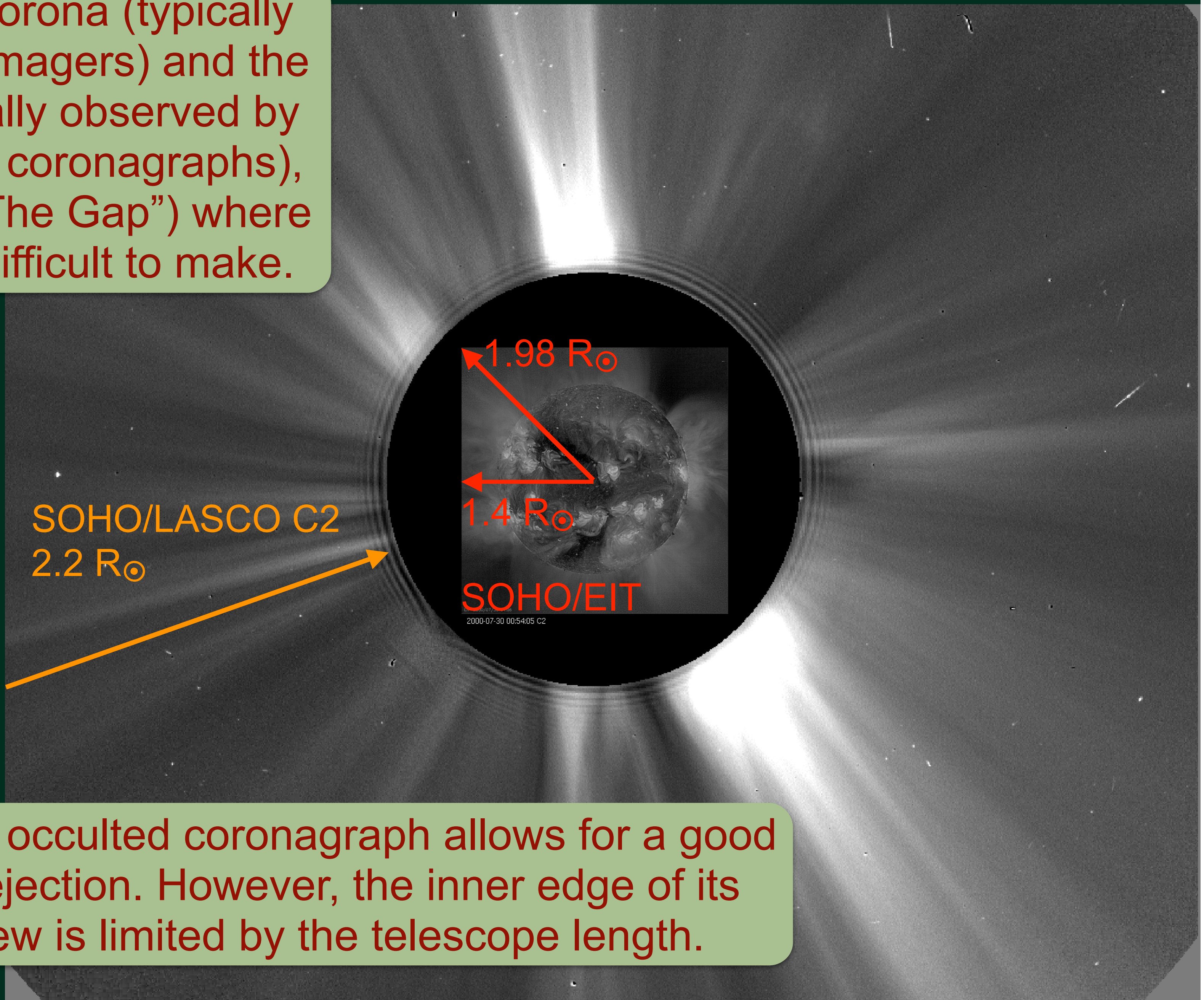


(After the report of the Science and Technology Definition Team of Solar Probe Plus)

- A typical simulated solar wind acceleration profile shows that the solar wind becomes supersonic around 2-3 $R_\odot$ from the center of the Sun.
- Coronal mass ejections (CMEs) are also accelerated in this region.

Imaging observations of the solar corona

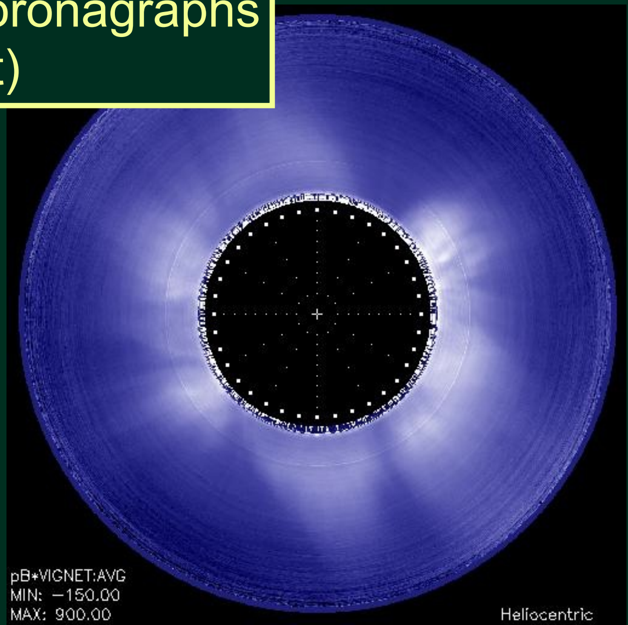
Between the low corona (typically observed by EUV imagers) and the high corona (typically observed by externally occulted coronagraphs), there is a region ("The Gap") where observations are difficult to make.



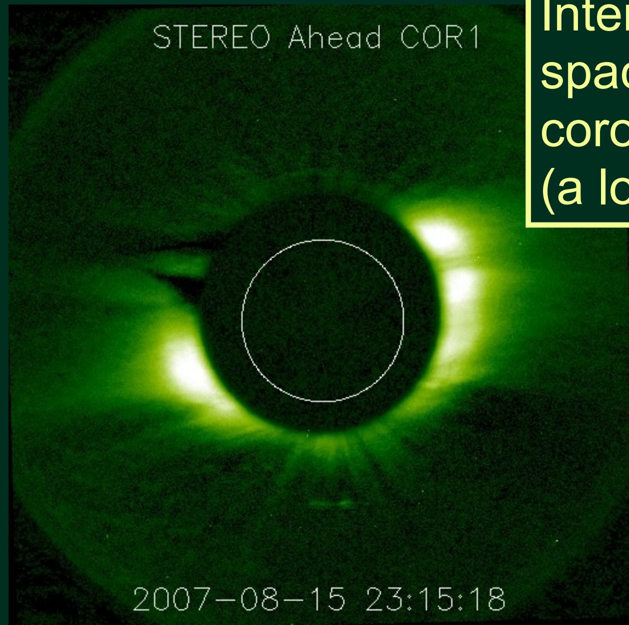
An externally occulted coronagraph allows for a good straylight rejection. However, the inner edge of its field of view is limited by the telescope length.

How to close *The Gap*?

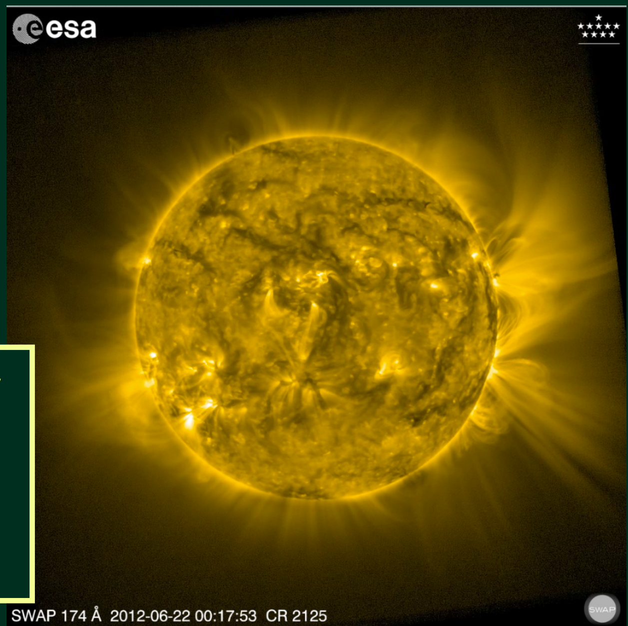
Ground-based coronagraphs
(a lot of straylight)



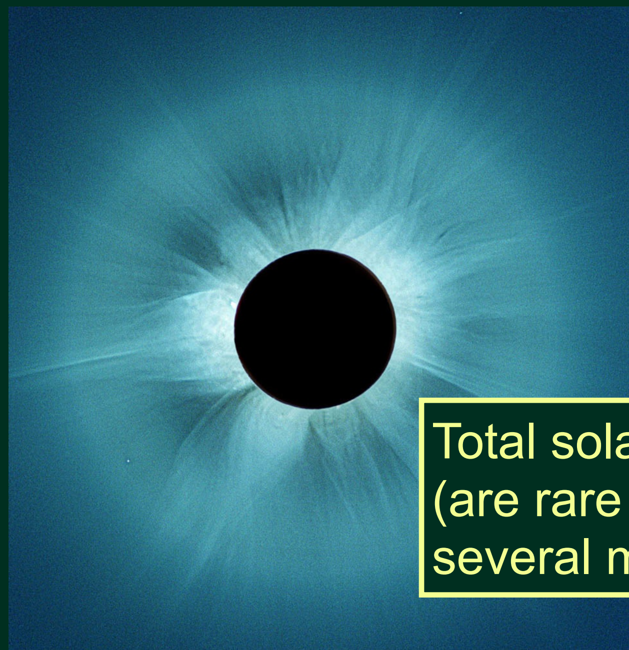
Internally occulted
space-borne
coronagraphs
(a lot of straylight)



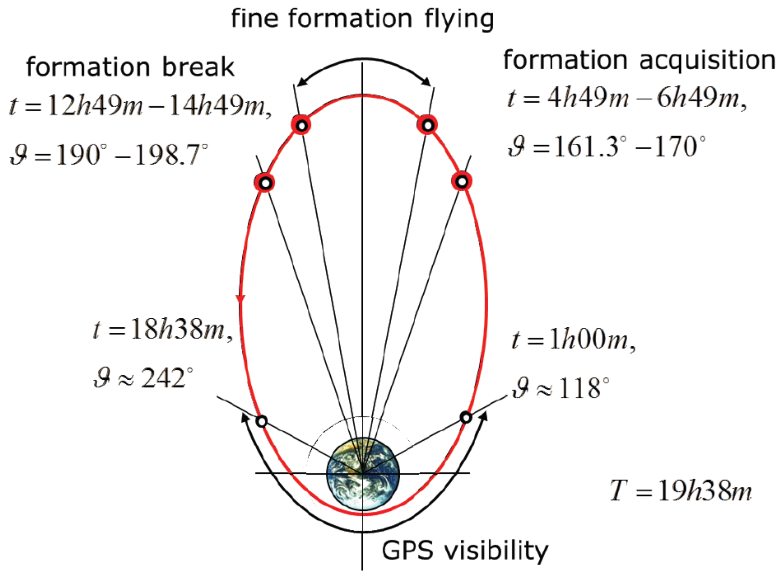
Wide field-of-view
EUV imagers
(very long
exposure times)



Total solar eclipses
(are rare and last only
several minutes)



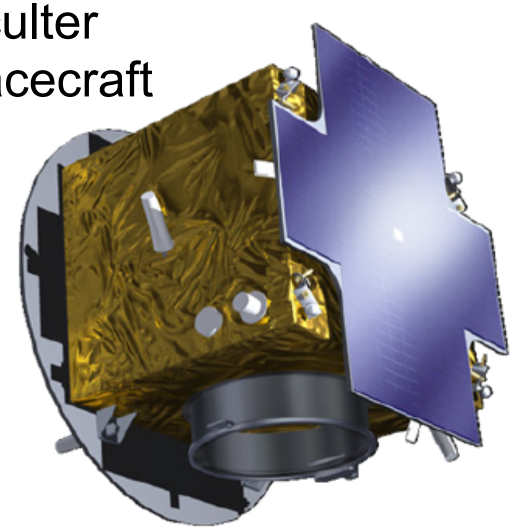
The PROBA-3 mission



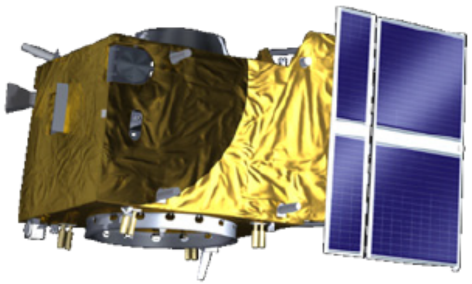
PROBA-3 orbit

The ultimate coronagraph: artificial total eclipse created using two spacecraft in flight formation.

occulter spacecraft



towards the Sun



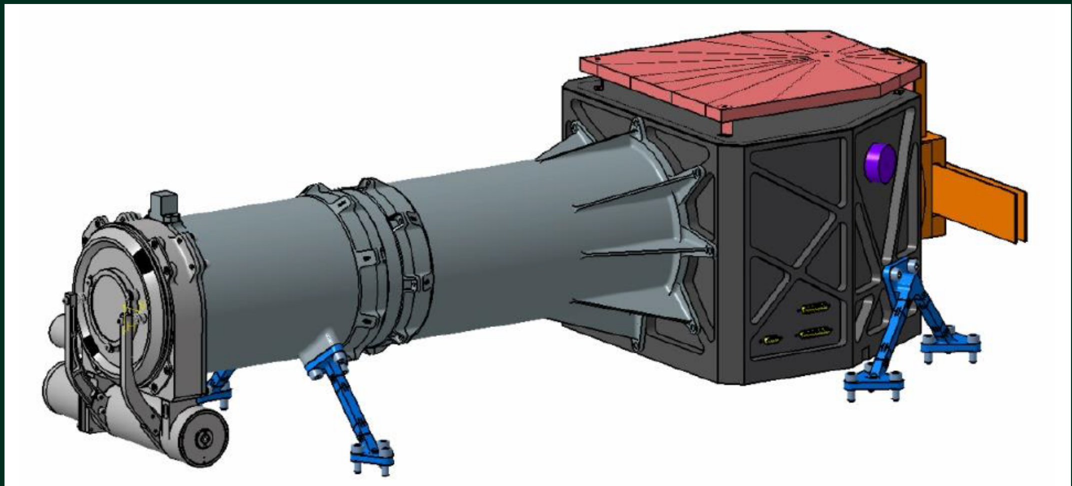
main spacecraft

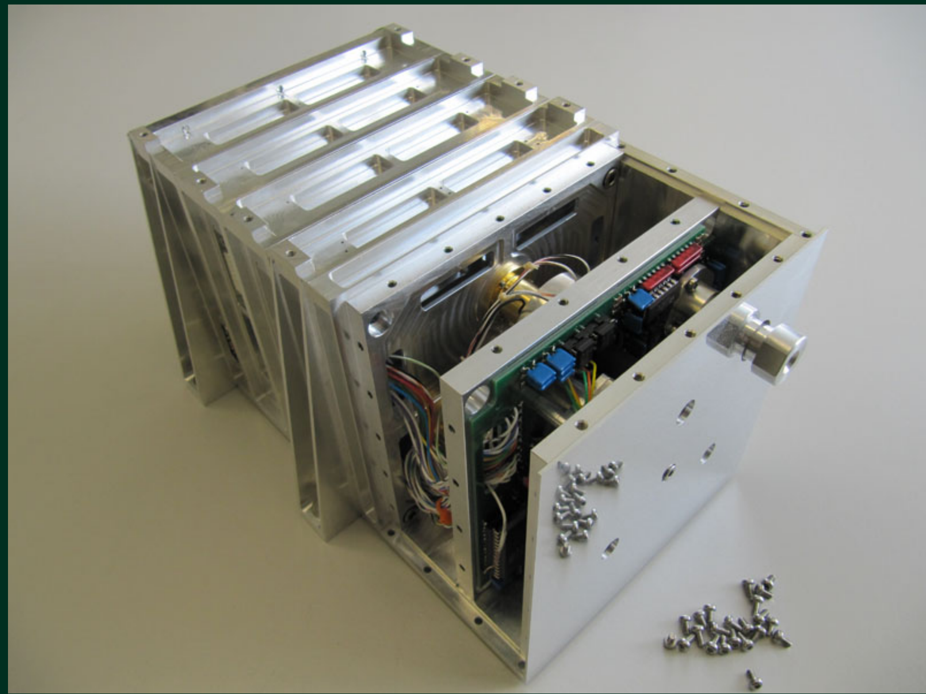
- The formation flying is maintained over 6 hours in every 20-hour orbit: *around a factor 100 improvement* in the duration of uninterrupted observations in comparison with a total eclipse.

- A technological challenge: the distance between the spacecraft is 150 m, and the accuracy of their positioning should be around a few millimeters!

Tentative launch date: 2018

Scientific payload of PROBA-3





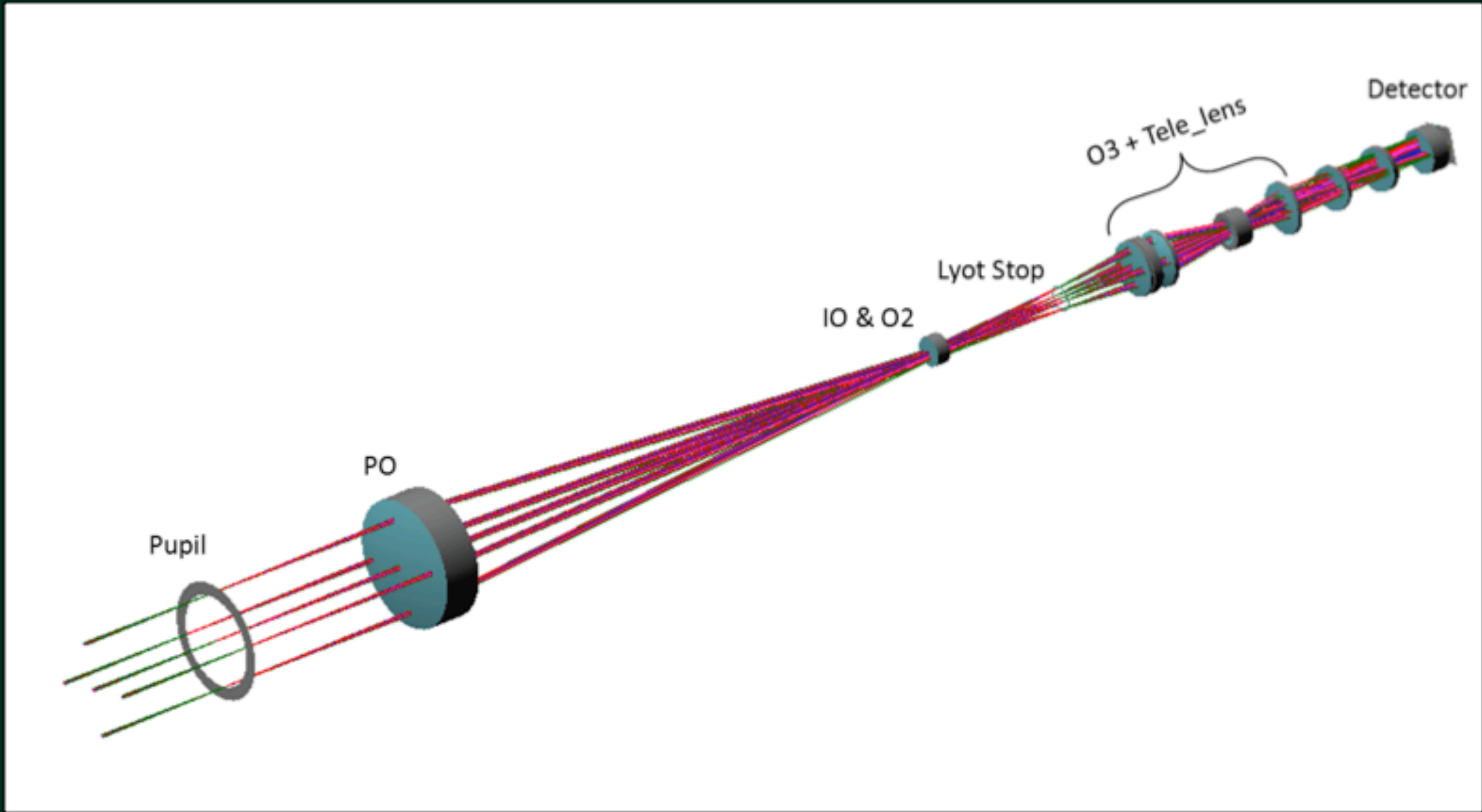
ASPIICS
(Association of Spacecraft for Polarimetric and Imaging Investigation of the Corona of the Sun)

The telescope is placed on the main spacecraft, and the occulting disk is placed on the occulter spacecraft.
Together they form a giant coronagraph.

DARA
(Digital Absolute RAdiometer)

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

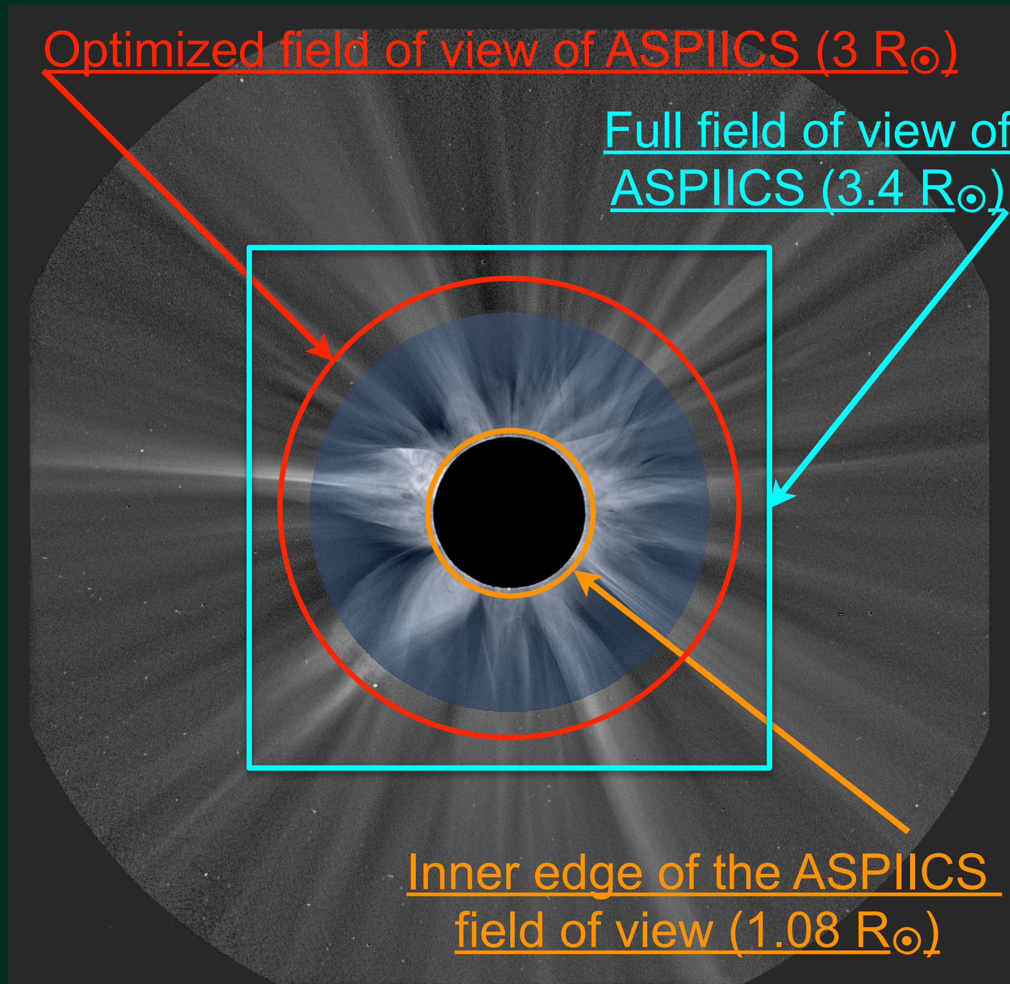
ASPIICS characteristics



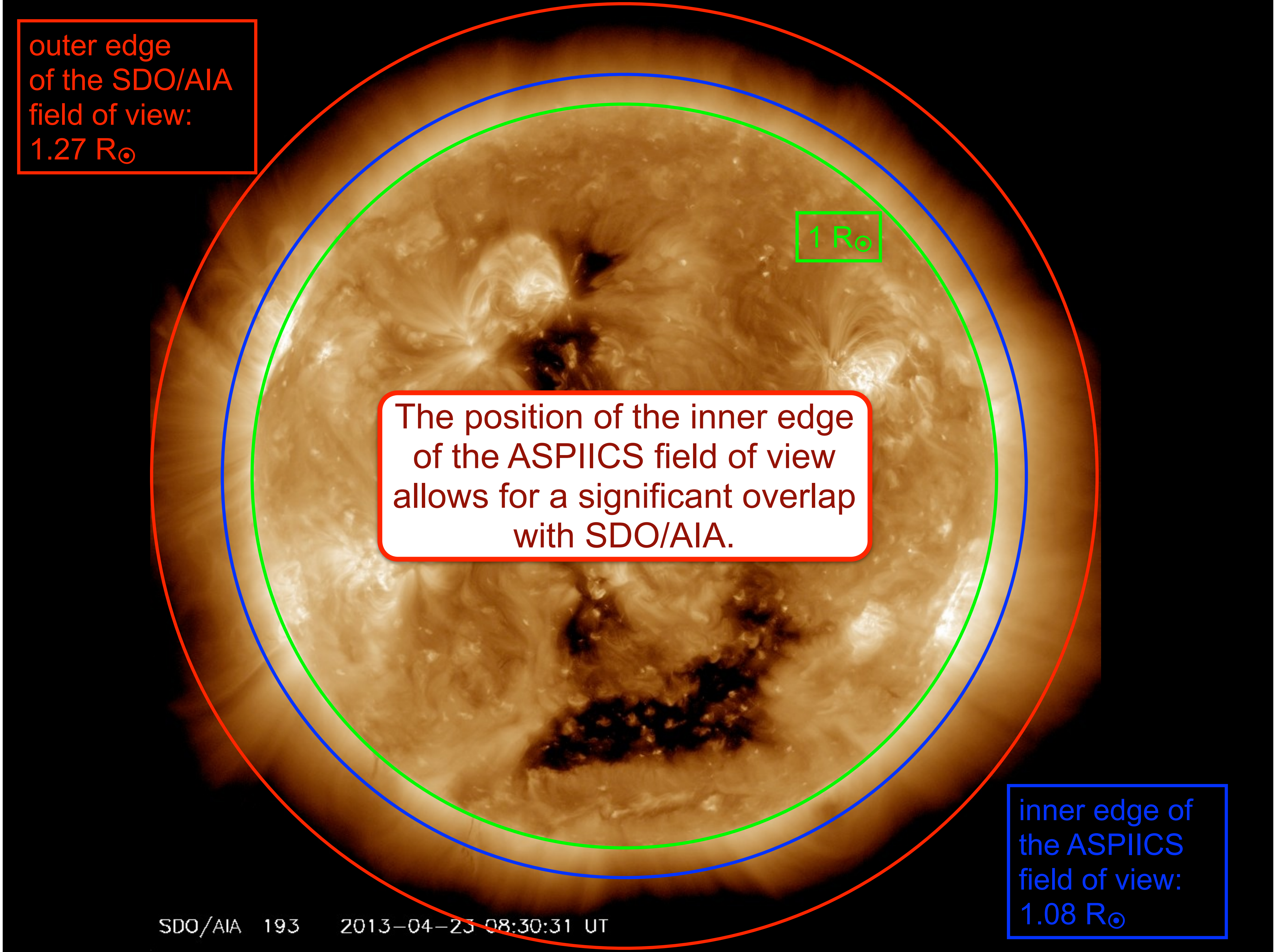
- An externally occulted coronagraph with the occulter placed 150 m in front of the pupil.
- The optical design of ASPIICS follows the principles of the classic Lyot coronagraph.

ASPIICS characteristics

- 6 channels:
  - 1 white light,
  - 3 polarized light,
  - 1 narrow-band filter centered at the Fe XIV line at 5305 Å.
  - 1 narrow-band filter centered at the He I D3 line at 5876 Å.
- 2048x2048 pixels
  - 3.2 arc sec per pixel
- Outer edge of the field of view: 3 $R_\odot$ (optimized)
  - 3.4 $R_\odot$ (full field of view)
- 60 s nominal cadence
  - 2 s using a quarter of the field of view



ASPIICS will cover *The Gap* between the typical fields of view of EUV imagers and externally occulted coronagraphs!



outer edge of the SDO/AIA field of view: 1.27 R⊙
1 R⊙
The position of the inner edge of the ASPIICS field of view allows for a significant overlap with SDO/AIA.
inner edge of the ASPIICS field of view: 1.08 R⊙
SDO/AIA 193 2013-04-23 08:30:31 UT

ASPIICS scientific objectives

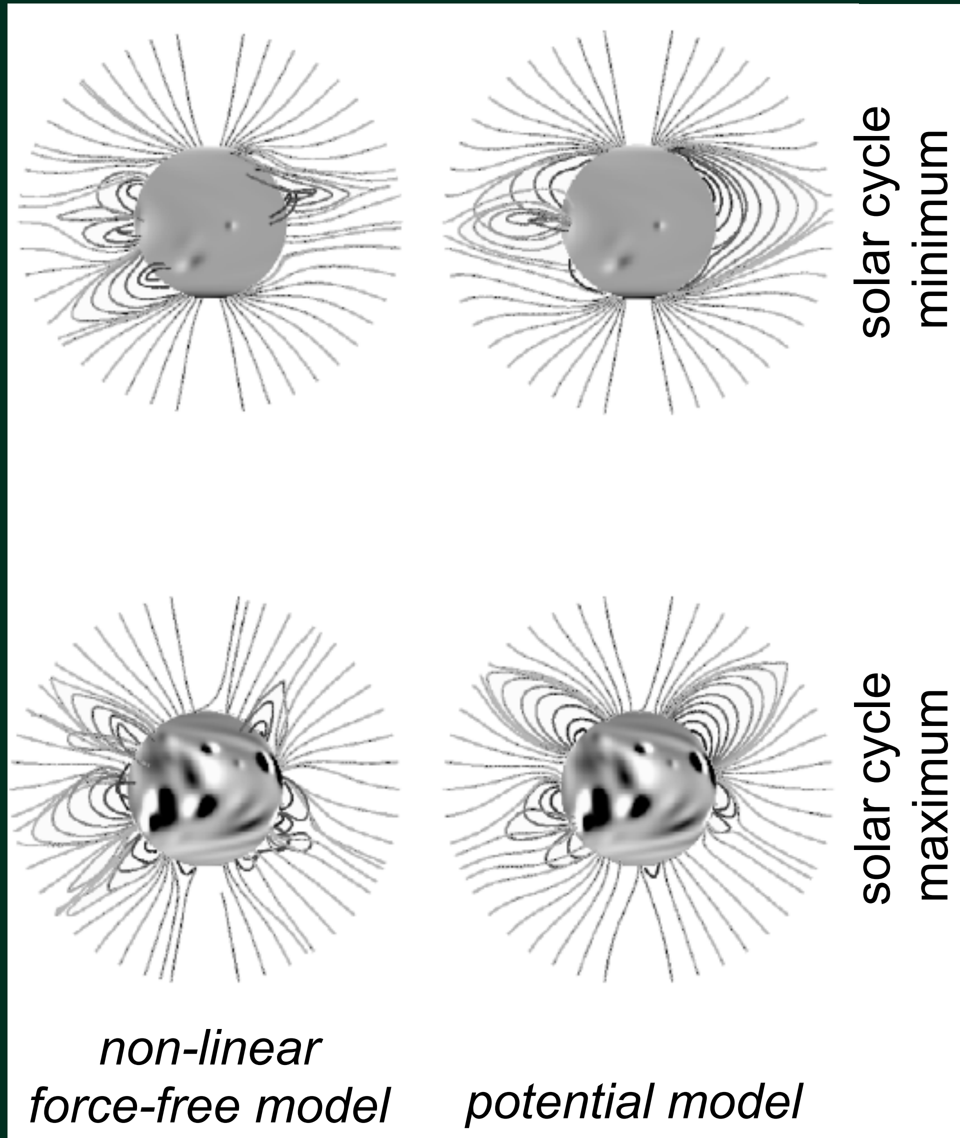
- The top-level scientific objectives of ASPIICS are:

  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 and what is the role of waves?
     - 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 coronal 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?

Coronal magnetic field

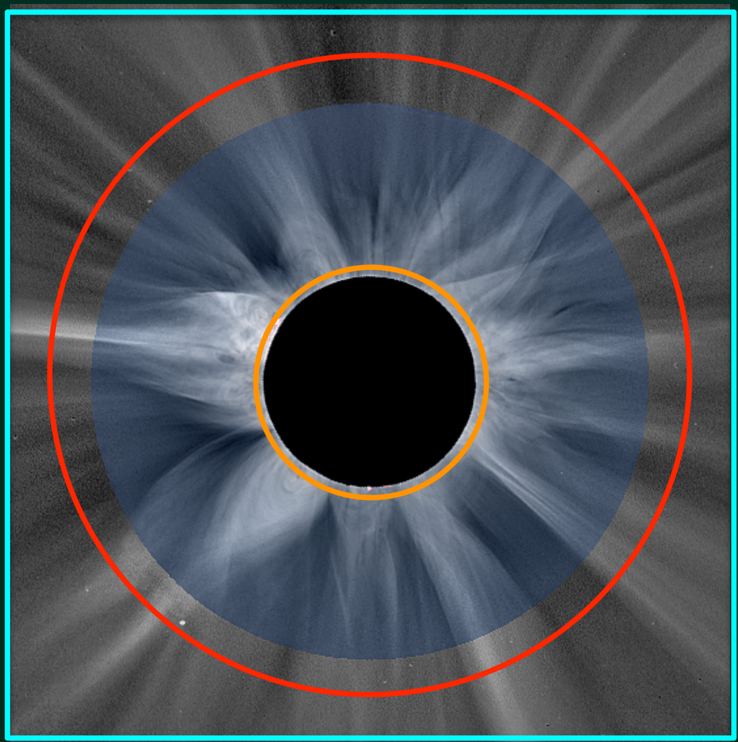
- The magnetic field often plays a dominant role in the structuring and dynamics of plasma in the solar corona (low plasma beta regime: $\beta = 8\pi p/B^2 < 1$).
- However, the coronal magnetic field cannot be routinely measured at the moment. Instead, it is extrapolated from photospheric magnetograms.
- The extrapolated field is strongly model-dependent.
- The extrapolated field cannot always reproduce the complex magnetic configuration of the solar corona.



(Yeates et al. 2010)

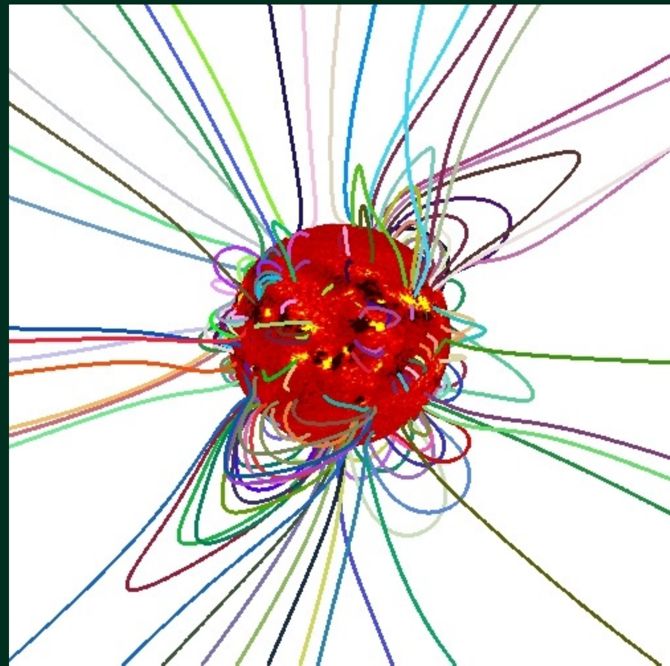
ASPIICS Formation Flying Coronagraph

What is the nature of the solar corona on different scales?



ASPIICS field of view

?

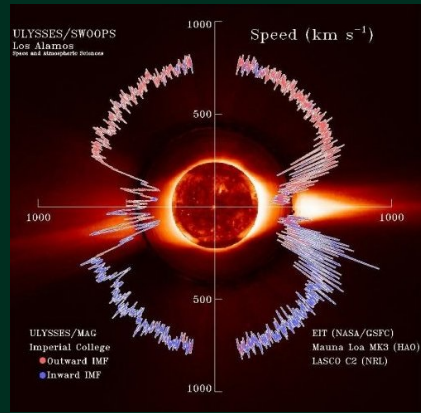


MHD model
of the coronal magnetic field

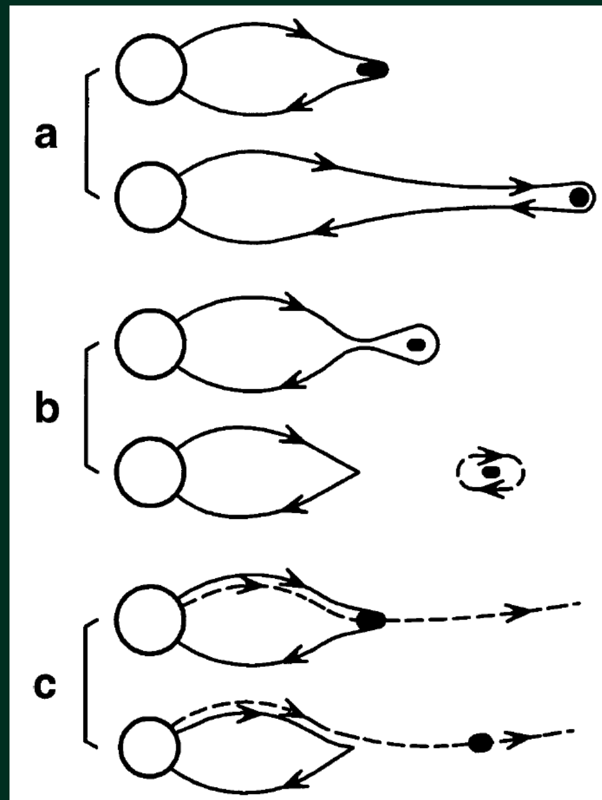
ASPIICS will answer questions about the structuring and dynamics of the solar corona on different scales, as well as constrain coronal magnetic field models.

What processes contribute to the solar wind acceleration?

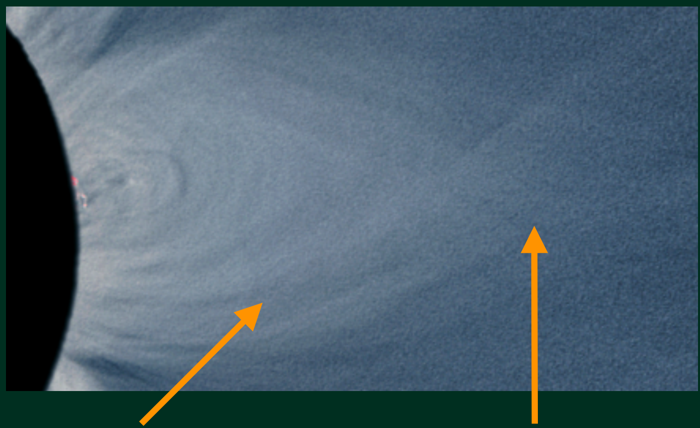
- The origin of the slow solar wind is still debated, mainly due to its non-stationary, inhomogeneous character.
- Dynamic processes at the streamer cusps are considered to be a viable mechanism to produce the slow solar wind.
- However, the cusp region is very difficult to observe as it is situated in *The Gap* between the low and high corona.



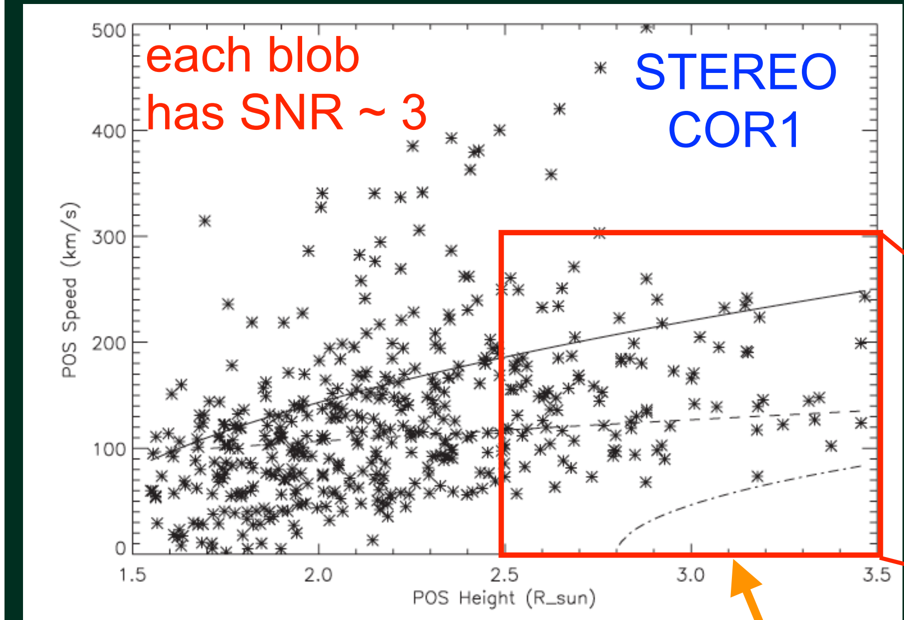
(McComas et al. 1998)



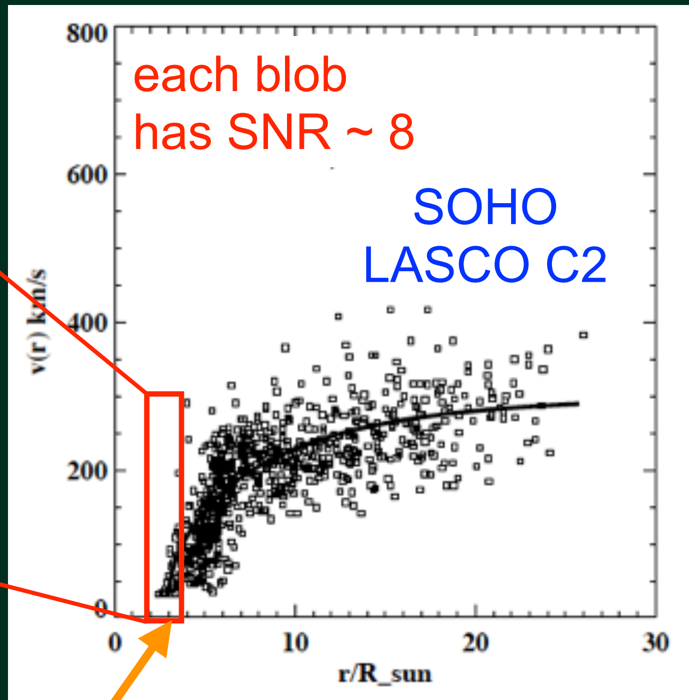
(Y.-M. Wang et al. 2000)

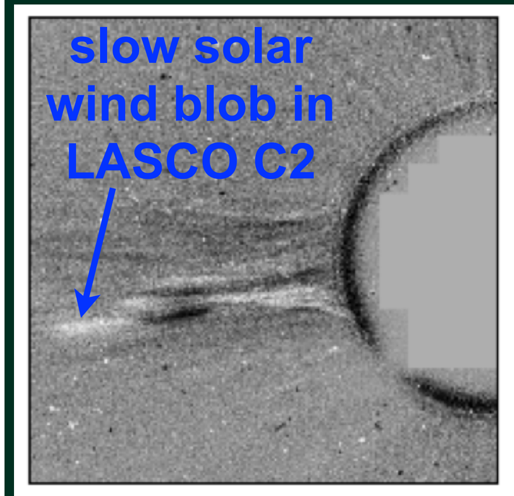


What processes contribute to the solar wind acceleration?



(Jones & Davila 2009)





(Sheeley et al. 1997)

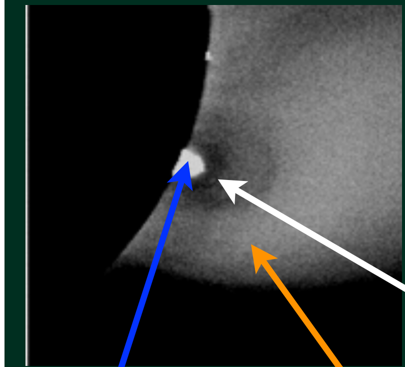
A discrepancy between measurements made by different coronagraphs!

ASPIICS, with its high signal-to-noise ratio (SNR ~ 20), will allow us to make detailed investigations of small-scale dynamic phenomena in the solar wind source region, in particular at the interface between fast and slow streams.

ASPIICS Formation Flying Coronagraph

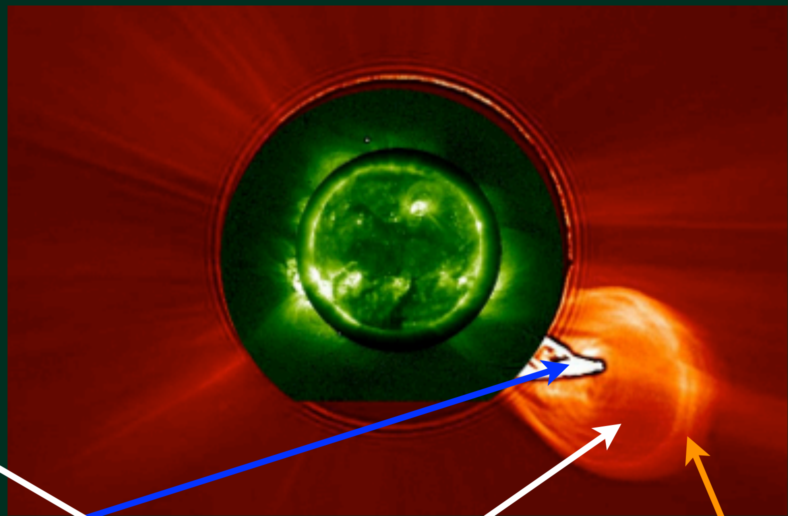
How do CMEs erupt and accelerate in the low corona?

quiescent state

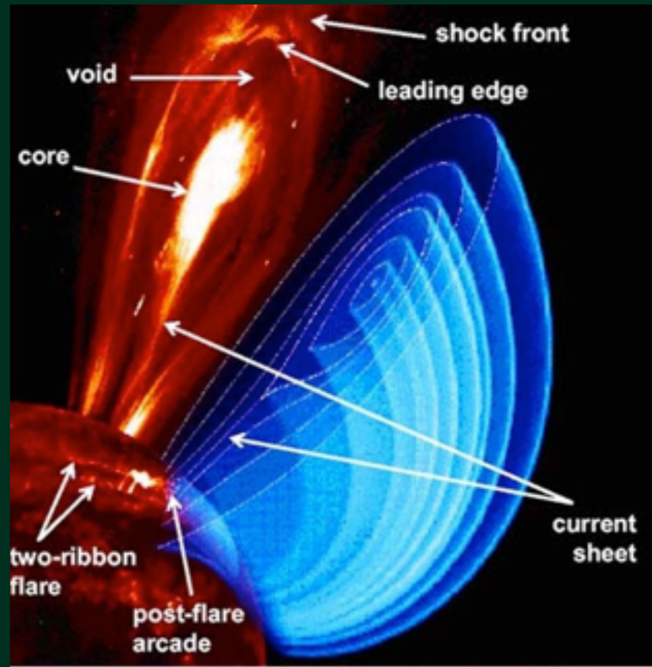


?

erupting state



interpretation



(Adapted from the Solar Sentinels STDT Report)

cavity (void)

prominence

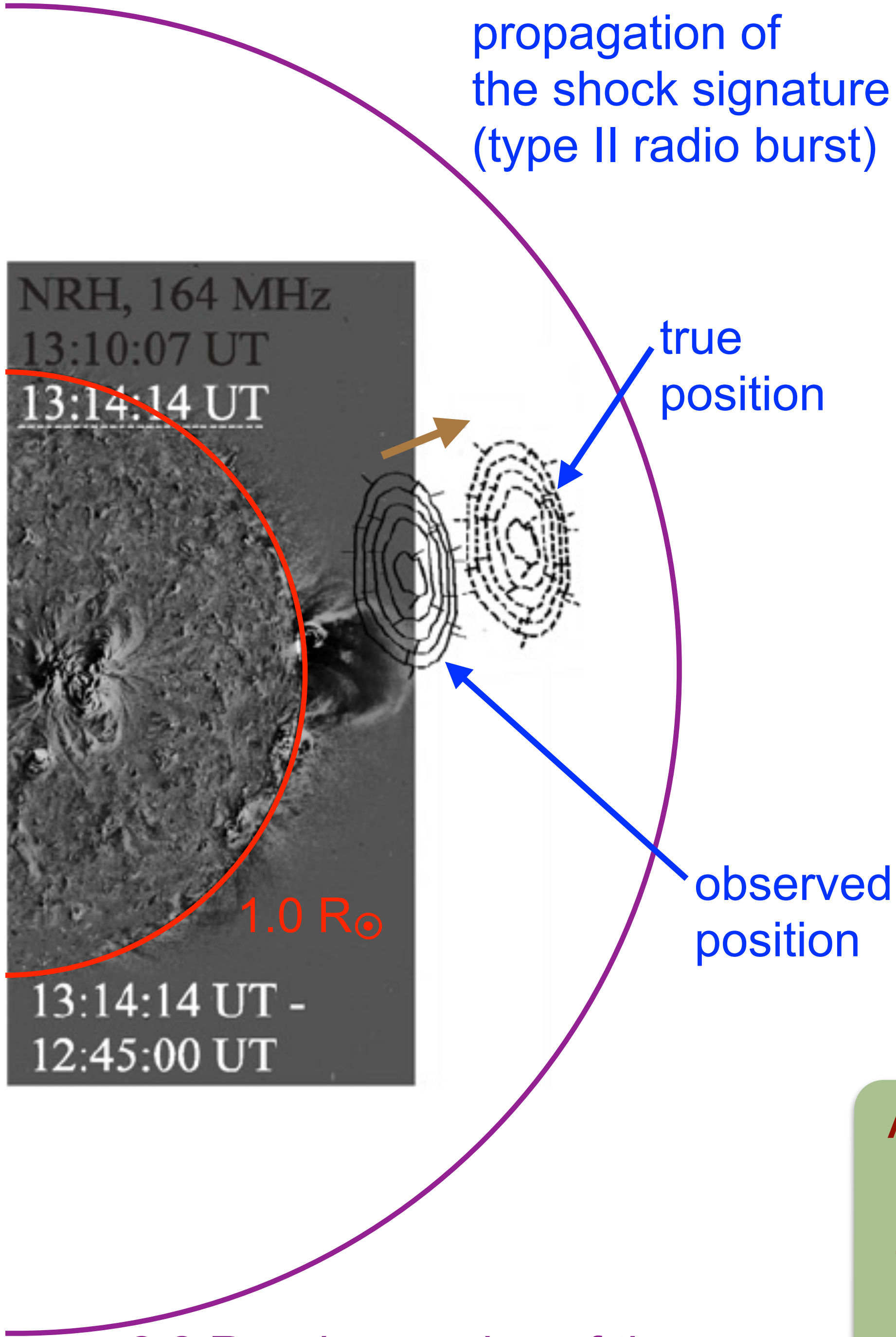
bulk of the streamer

?

CME frontal structure

ASPIICS will be an ideal instrument to investigate the onset, acceleration, and early evolution of CMEs inside *The Gap*.

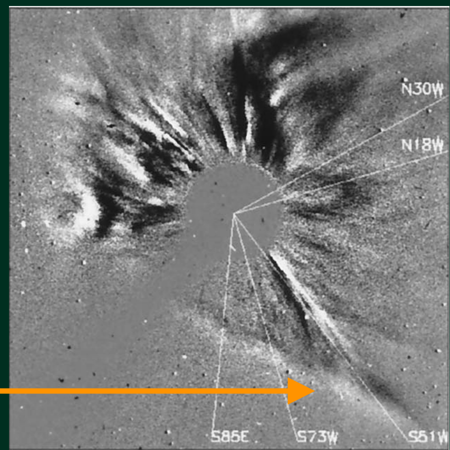
(after Magdalenić et al. 2010)



2.2 R⊙ - inner edge of the LASCO C2 field of view

Where and how can a CME drive a shock in the low corona?

Coronal shocks can be observed by coronagraphs in white light observations.



(Sheeley et al. 2000)

ASPIICS will observe the CME dynamics in *The Gap* providing us with conclusive evidence for the origin of coronal shocks observed concurrently by ground-based radio instrumentation.

Outlook

- PROBA-3 is a perfect example of a mission driven by both science and technology.
- ASPIICS is a unique solar coronagraph project.
- It will cover *The Gap* between the low corona (typically observed by EUV imagers) and the high corona (typically observed by externally occulted coronagraphs).
- ASPIICS observations will be crucial for solving several outstanding problems in solar physics:
  - structure of the magnetized solar corona,
  - sources of the slow solar wind,
  - onset and early acceleration of CMEs,
  - origin of coronal shocks waves.
- PROBA-3 will test formation flying technologies that can be used by future ESA missions. Several formation flying missions were proposed to ESA in the past:
  - DynaMICCS (a comprehensive solar observatory),
  - XEUS (X-ray observations of galaxies and their supermassive black holes),
  - SolmeX (measurements of the magnetic field in the solar corona),
  - FLIP3 (high-energy solar physics).

ASPIICS
Formation Flying Coronagraph