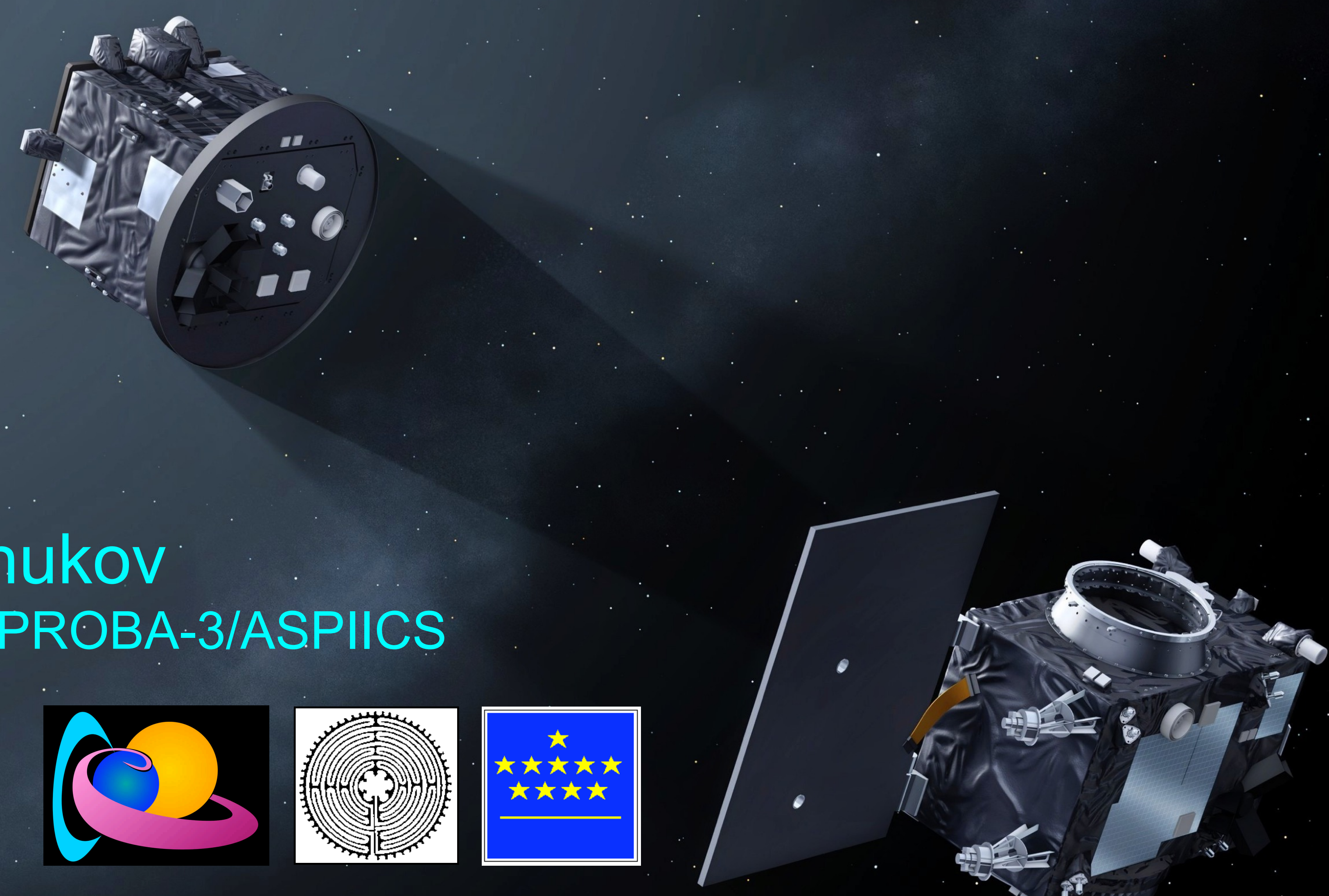
SOLI INVICTO

ASPIICS: a Giant Solar Coronagraph onboard the PROBA-3 Mission



Andrei Zhukov

Principal Investigator of PROBA-3/ASPIICS

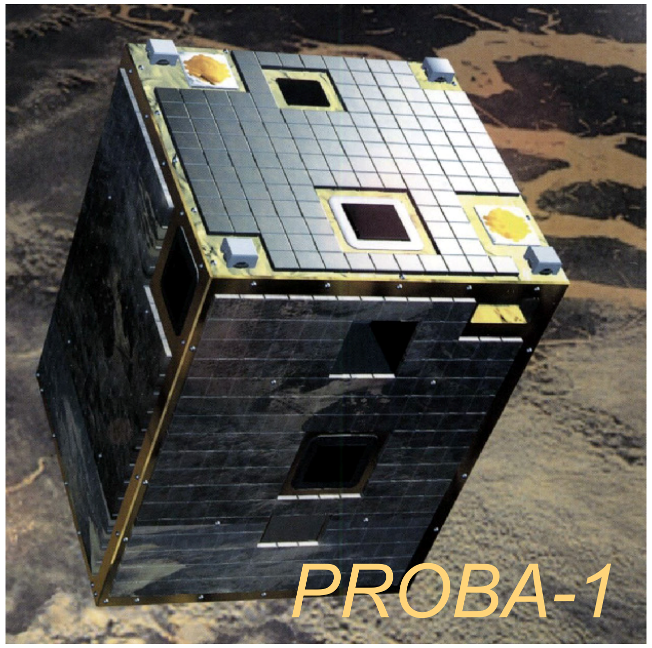
Solar-Terrestrial Centre of Excellence
SIDC, Royal Observatory of Belgium

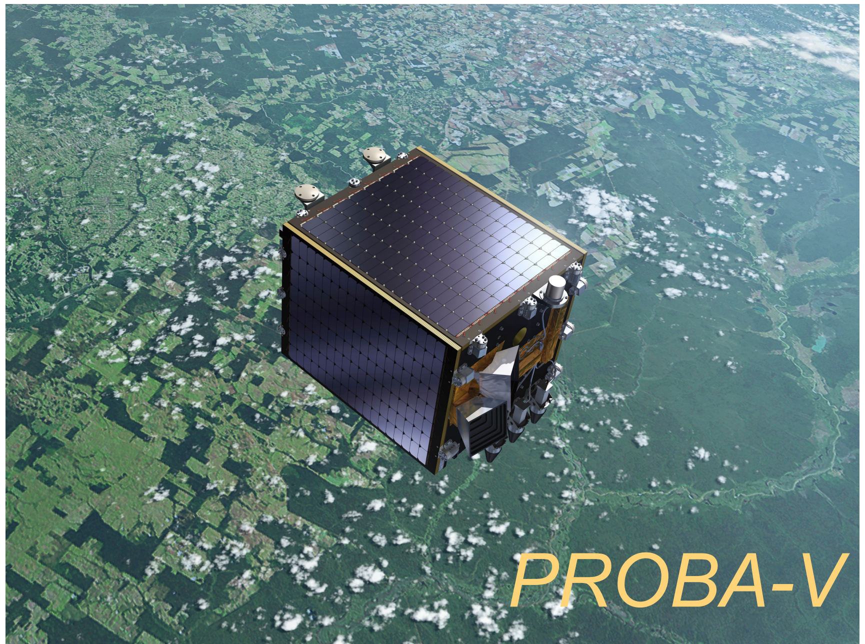
Skobeltsyn Institute of Nuclear Physics
Moscow State University, Russia

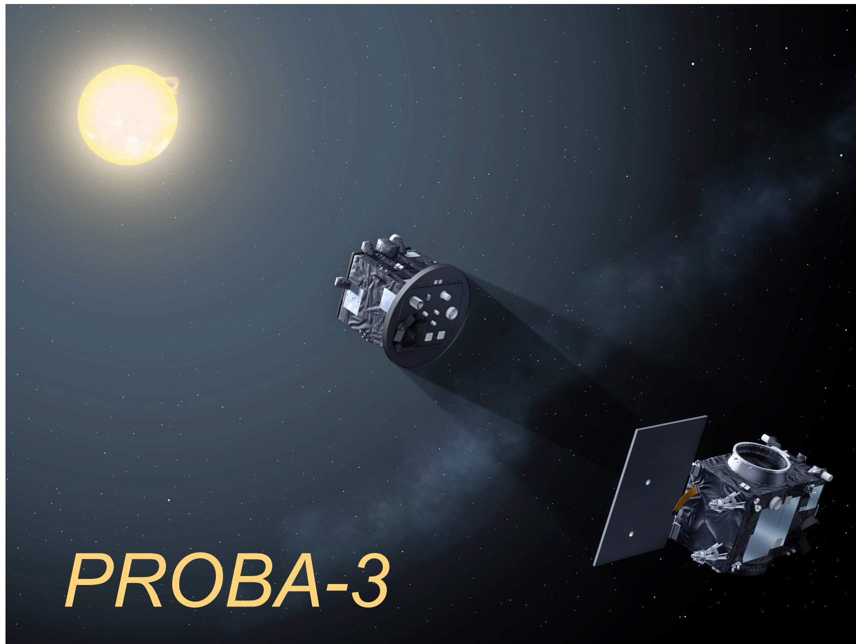
PROBA-3: the next in line

Spacecraft in the PROBA (PRoject for On-Board Autonomy) series of the ESA Directorate of Technical and Quality Management are small technology demonstration missions that also have scientific goals.

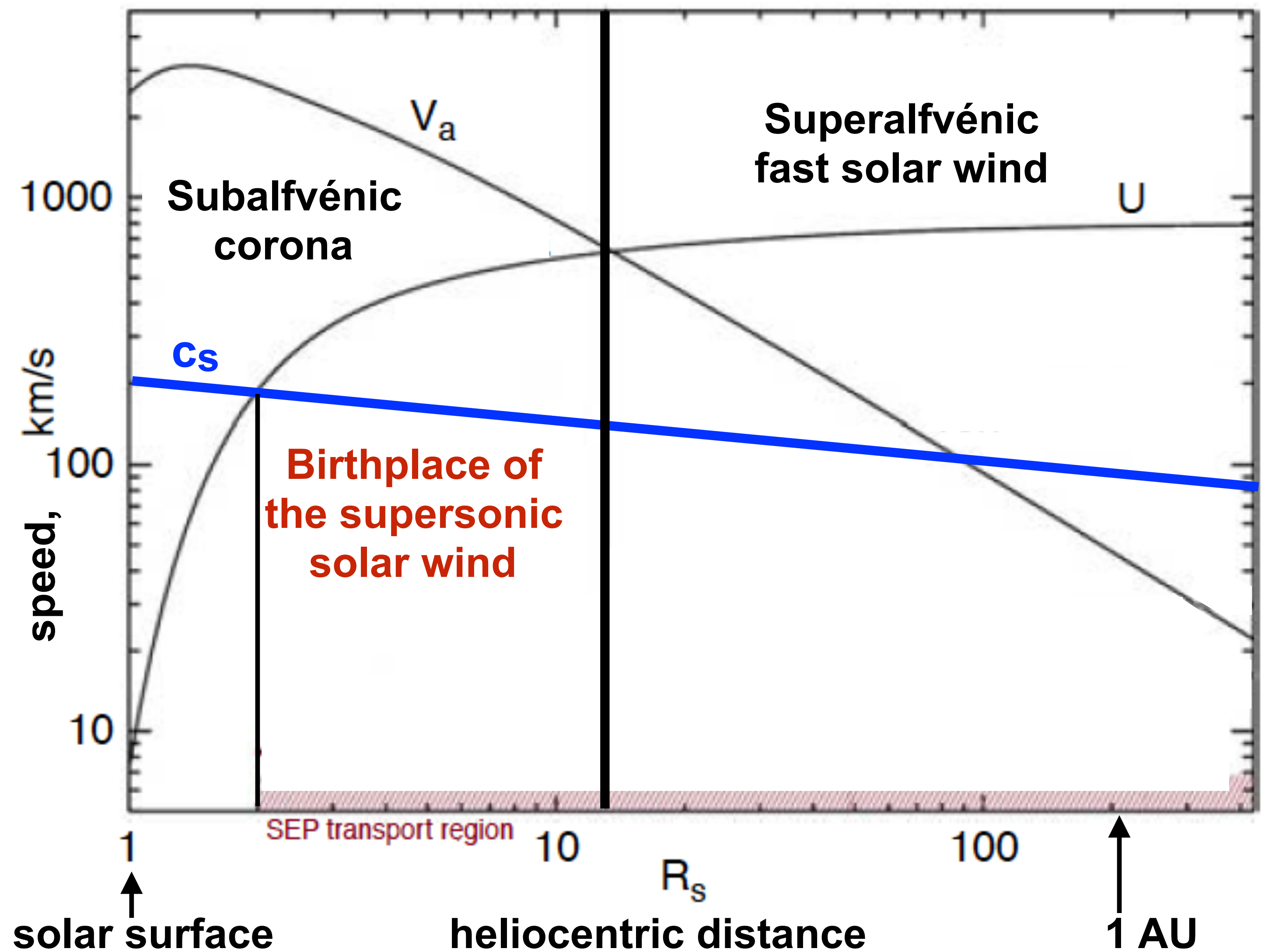
- PROBA-1 (2001 - to date): Earth observations
- PROBA2 (2009 - to date): solar corona observations and space weather
- PROBA-V (2013 - to date): monitoring of the worldwide vegetation
- PROBA-3 (to be launched in 2019): a giant solar coronagraph to study the inner corona.







Why do we need observations of the inner solar corona?

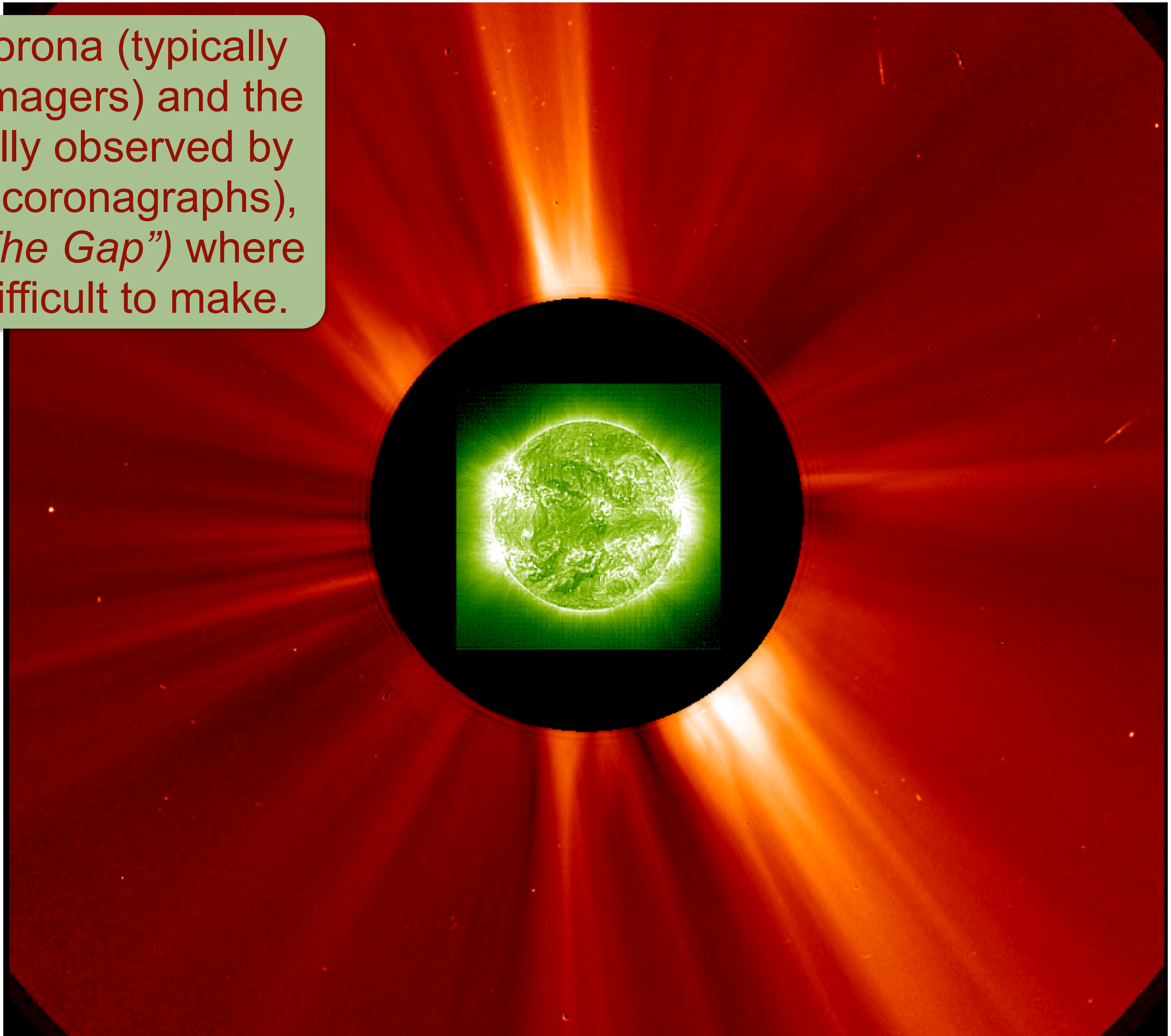


(After Fox et al. 2016)

- 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 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.



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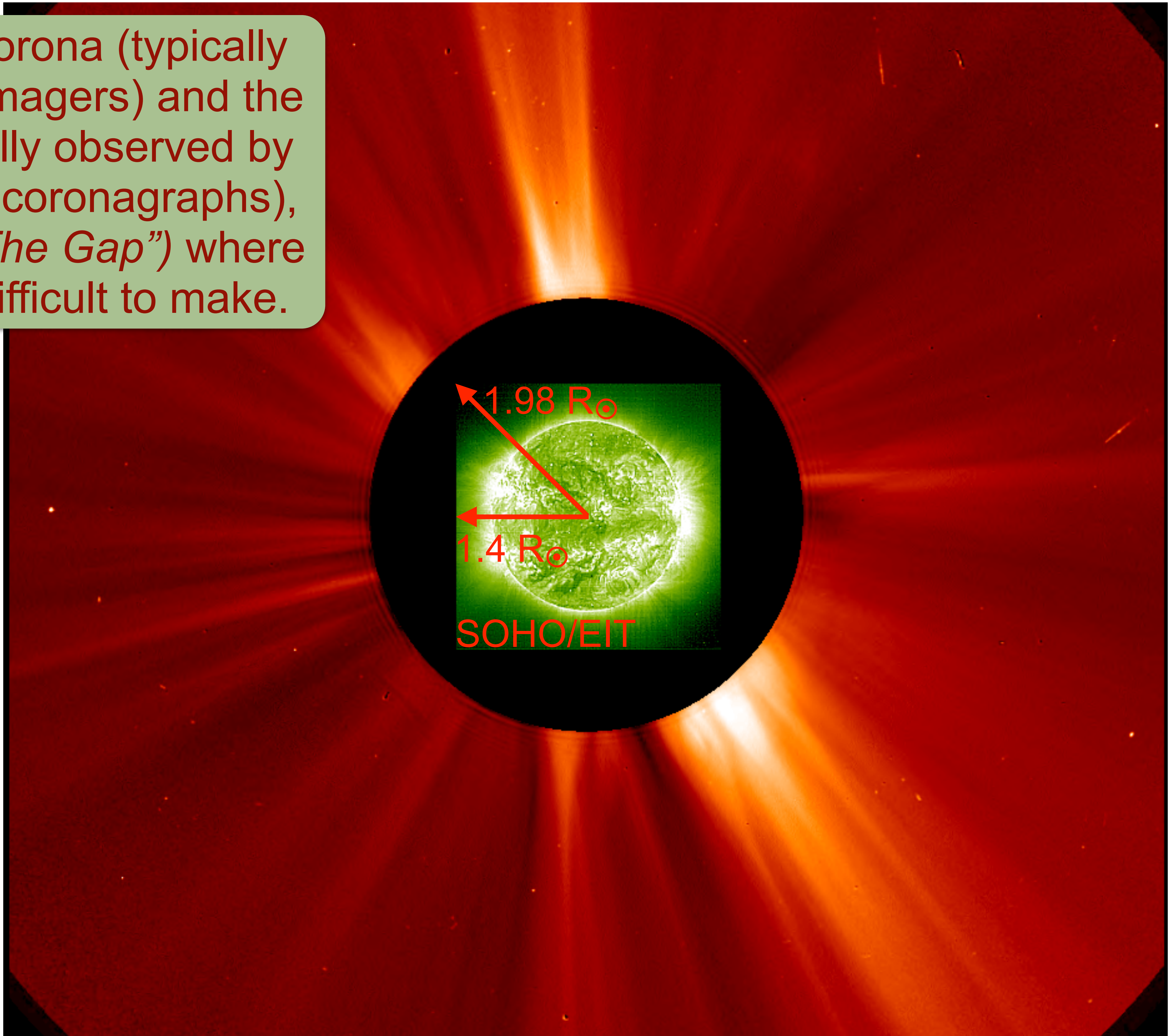

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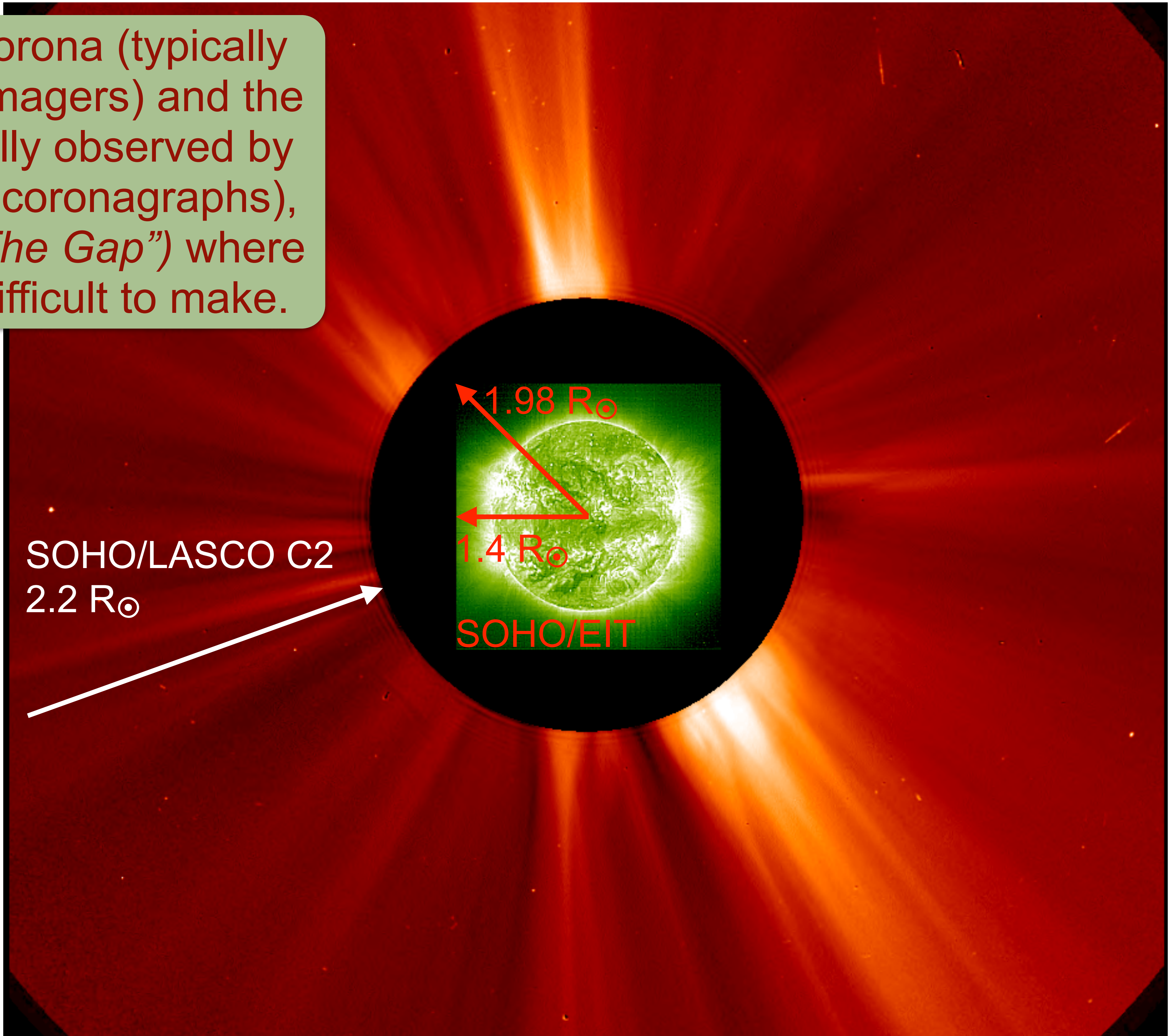

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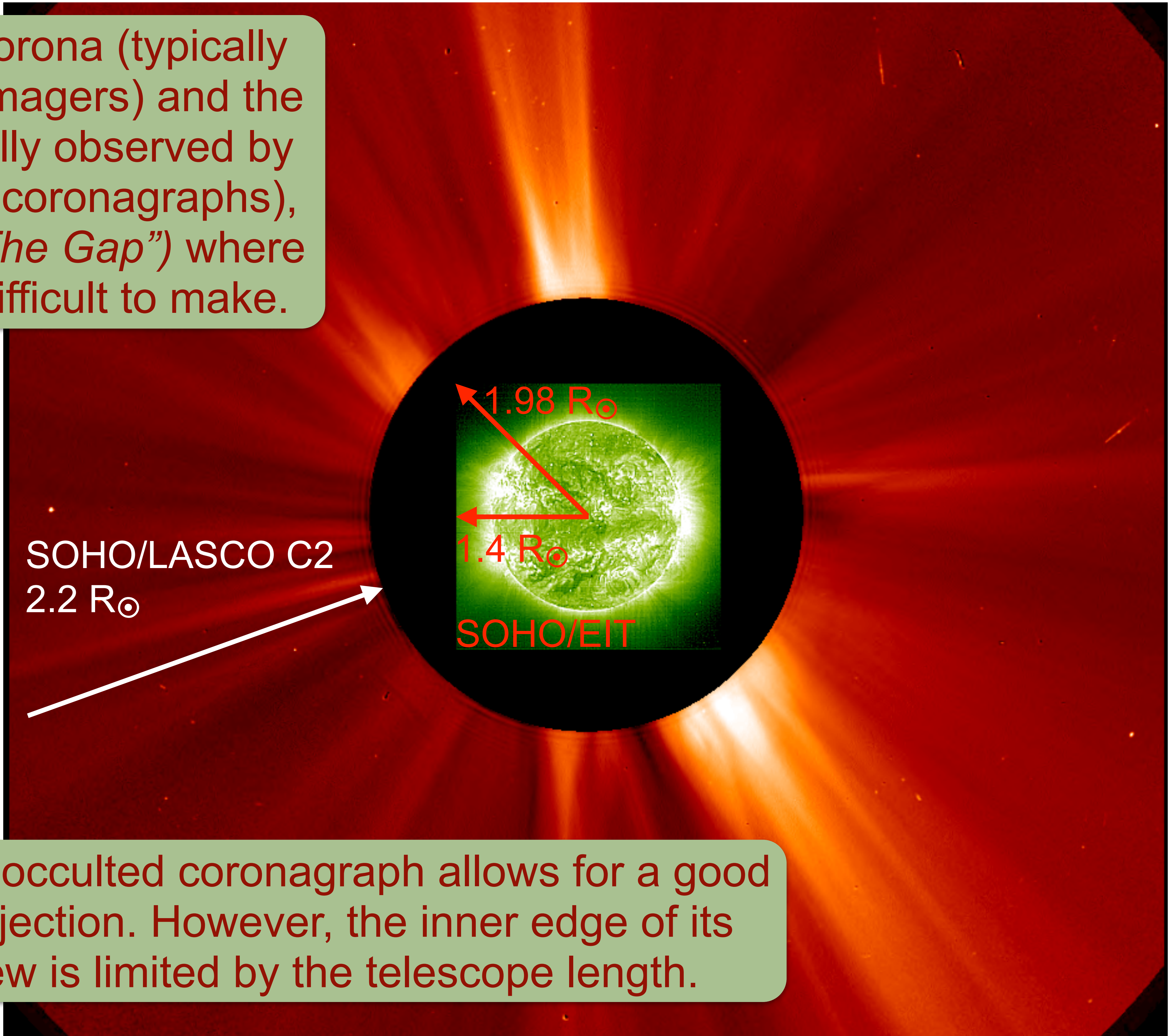
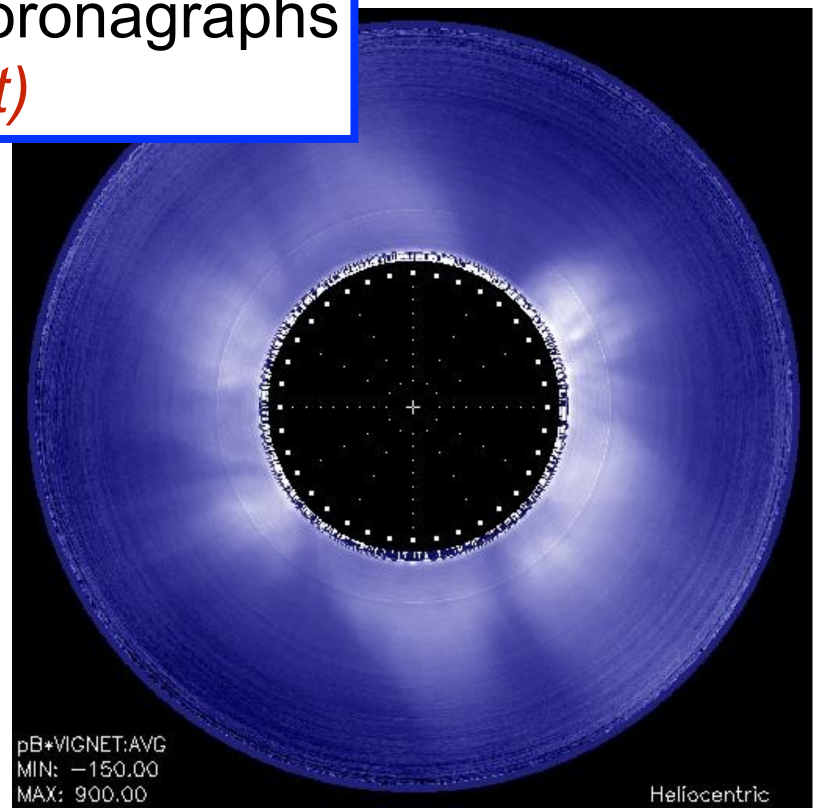


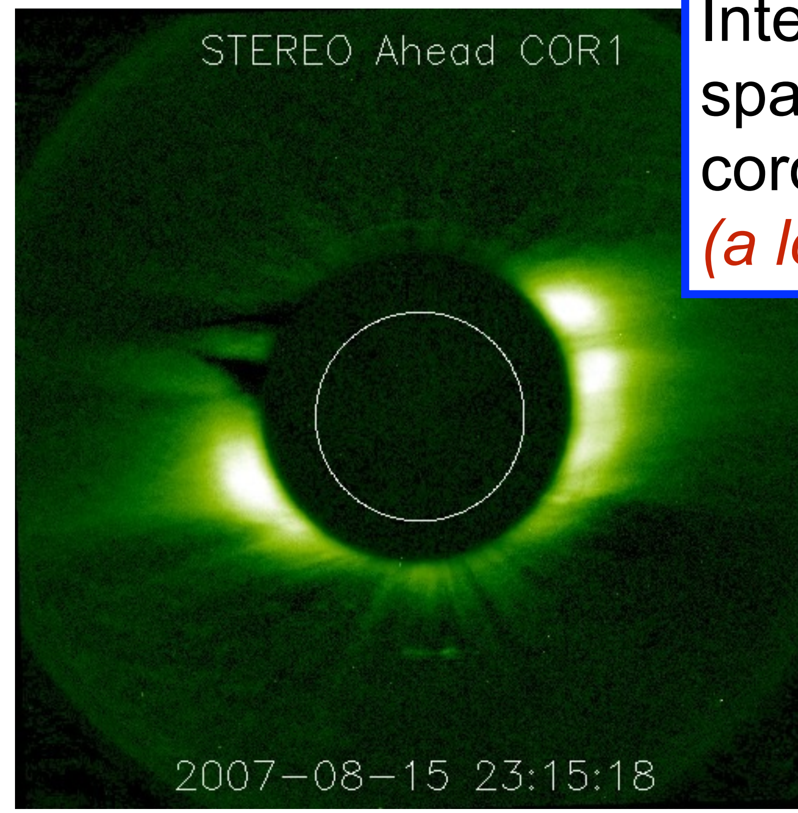
An externally occulted coronagraph allows for a good straylight rejection. However, the inner edge of its field of view is limited by the telescope length.

How to close *The Gap*?

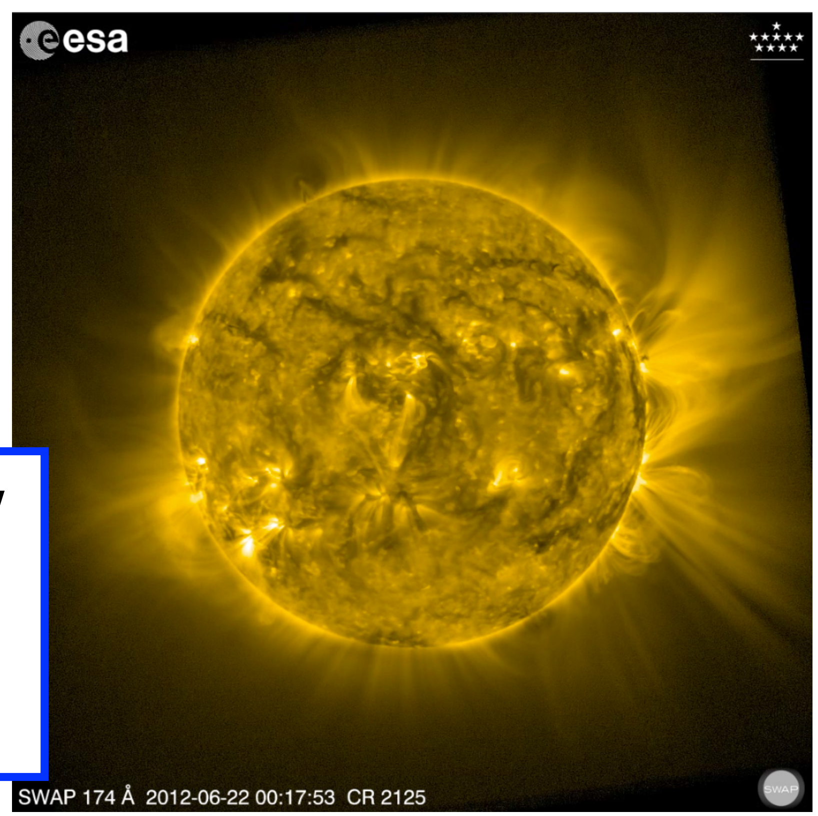
Ground-based coronagraphs
(a lot of straylight)



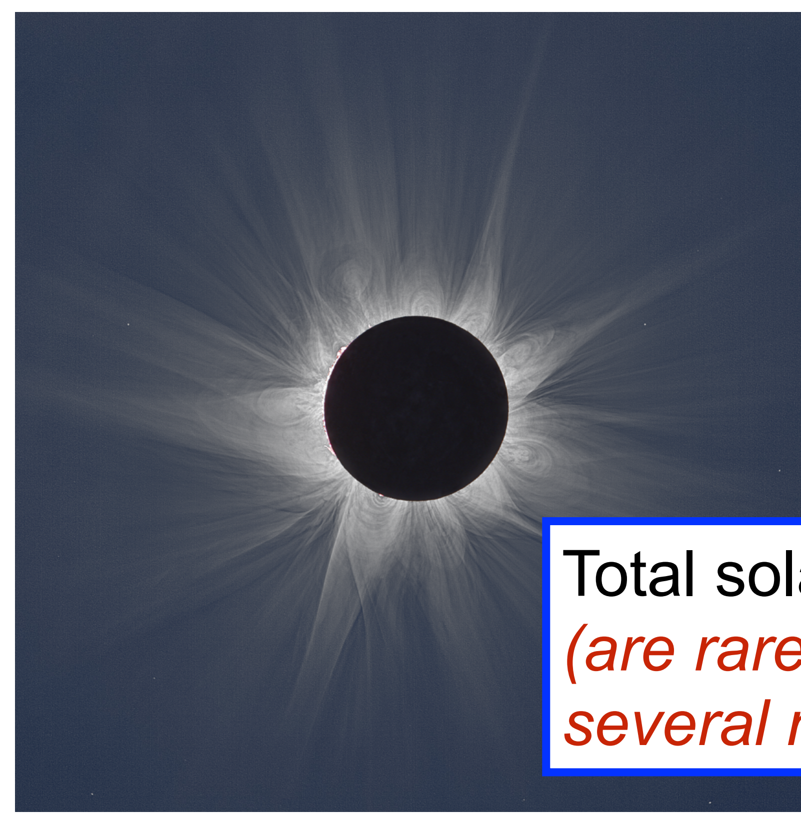
Internally occulted space-borne coronagraphs
(a lot of straylight)



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

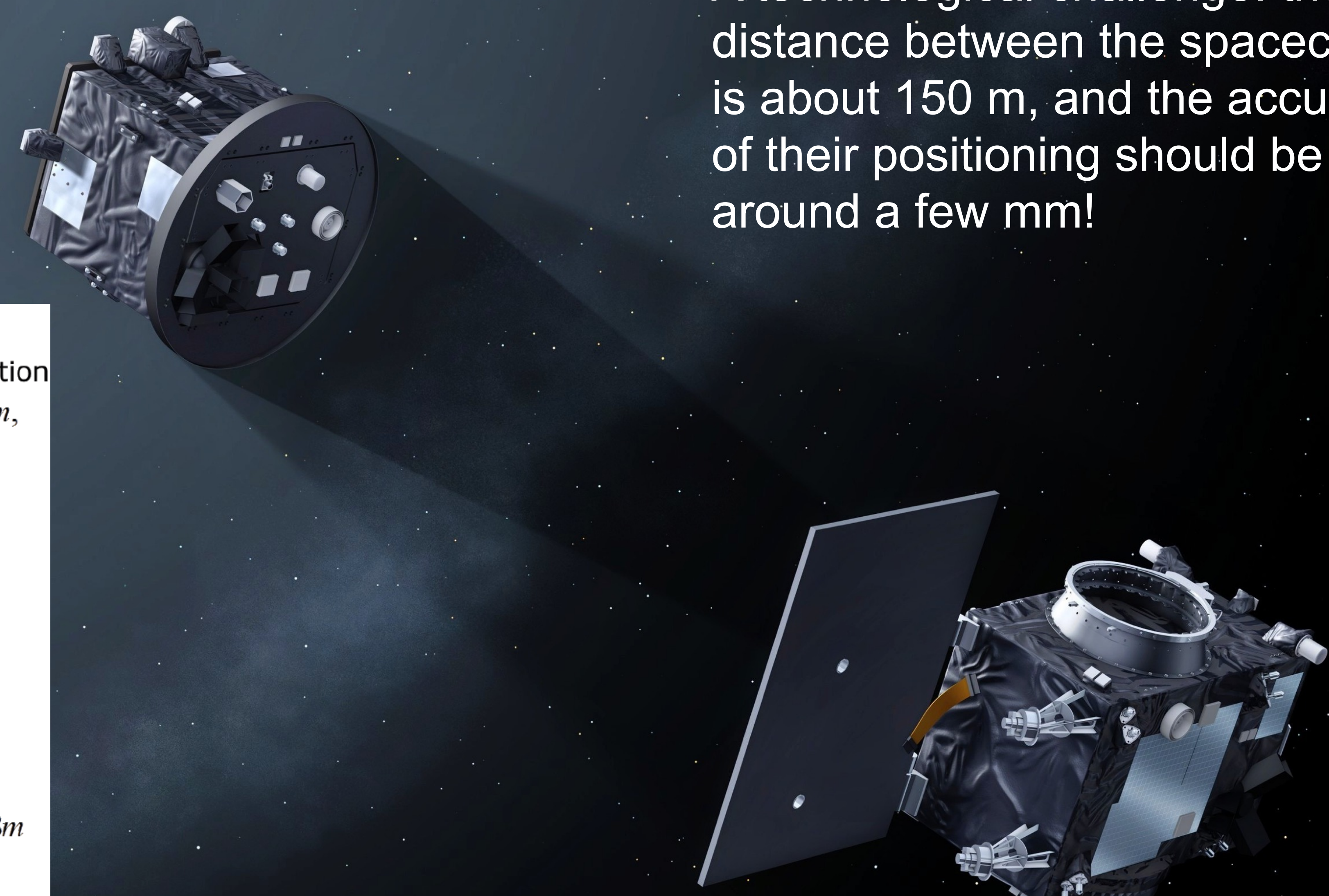


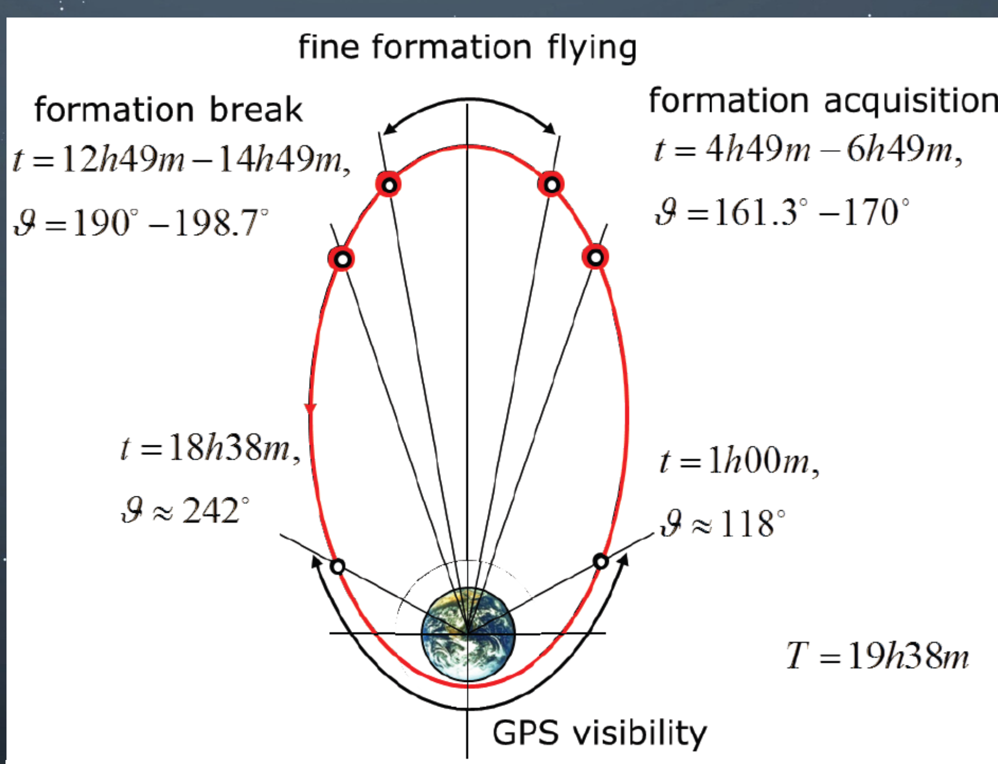
Total solar eclipses
(are rare and last only several minutes)



The PROBA-3 mission

- The ultimate coronagraph: artificial total eclipse created using two spacecraft in flight formation.
- A technological challenge: the distance between the spacecraft is about 150 m, and the accuracy of their positioning should be around a few mm!

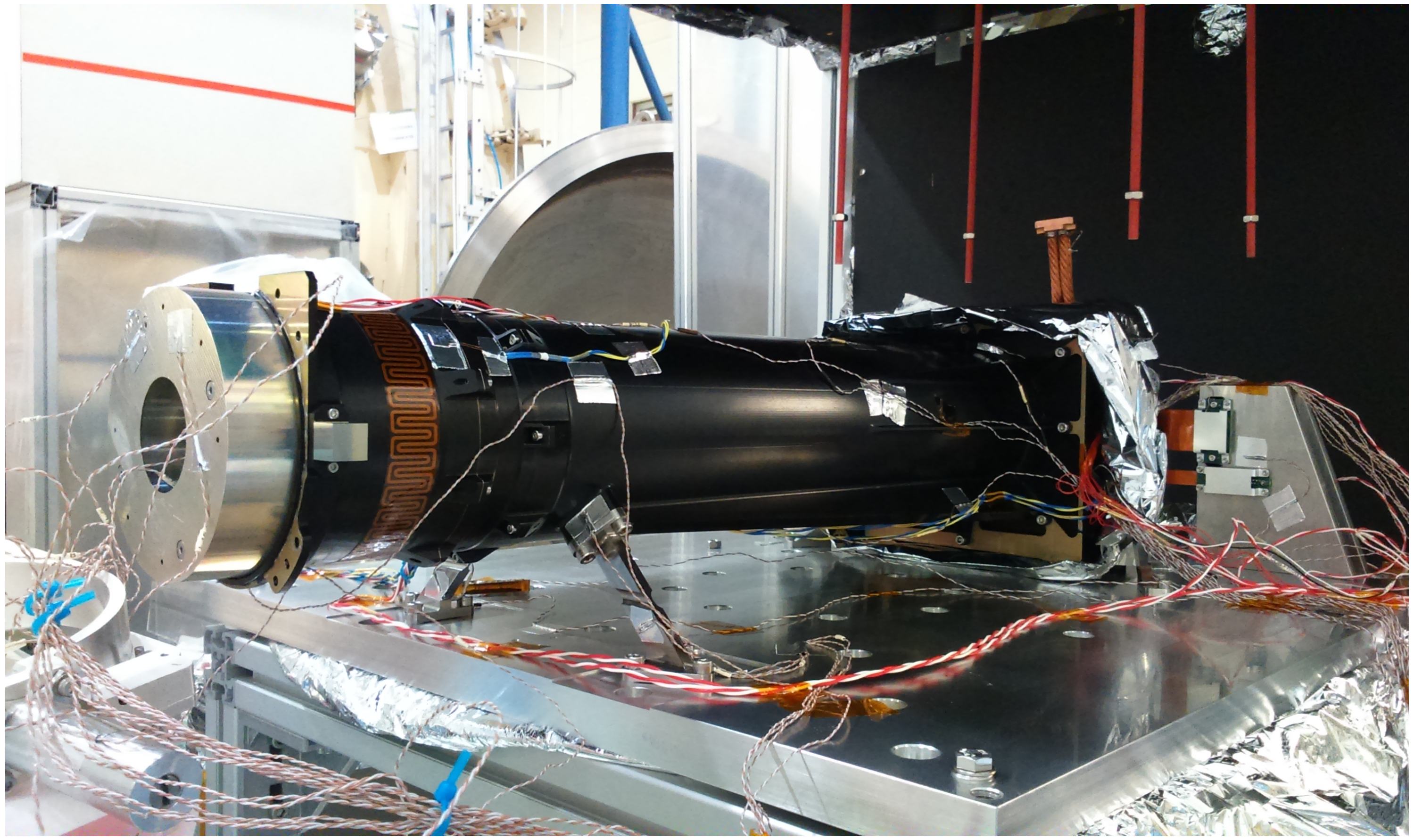


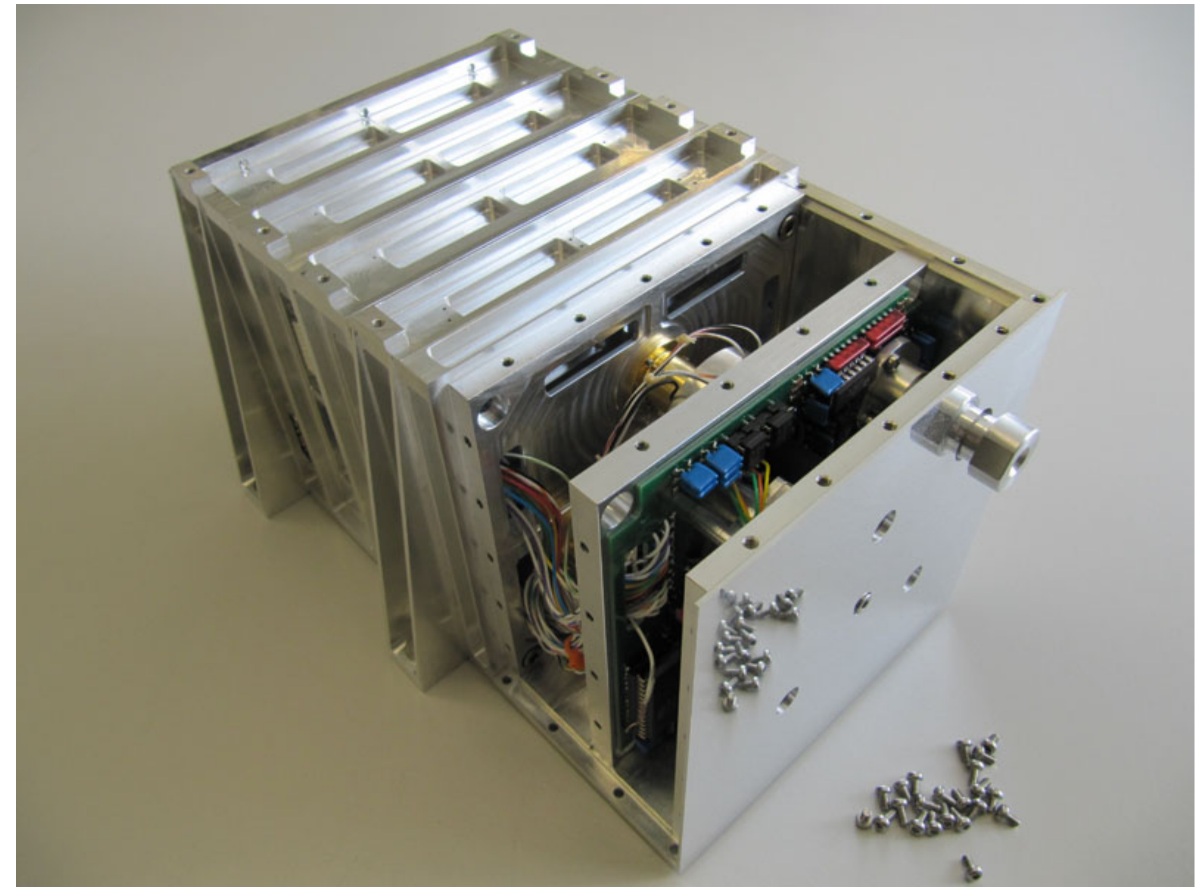


PROBA-3 orbit
duration: 19h 38min
fine formation flying: 6h

Tentative launch date: end 2019

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)

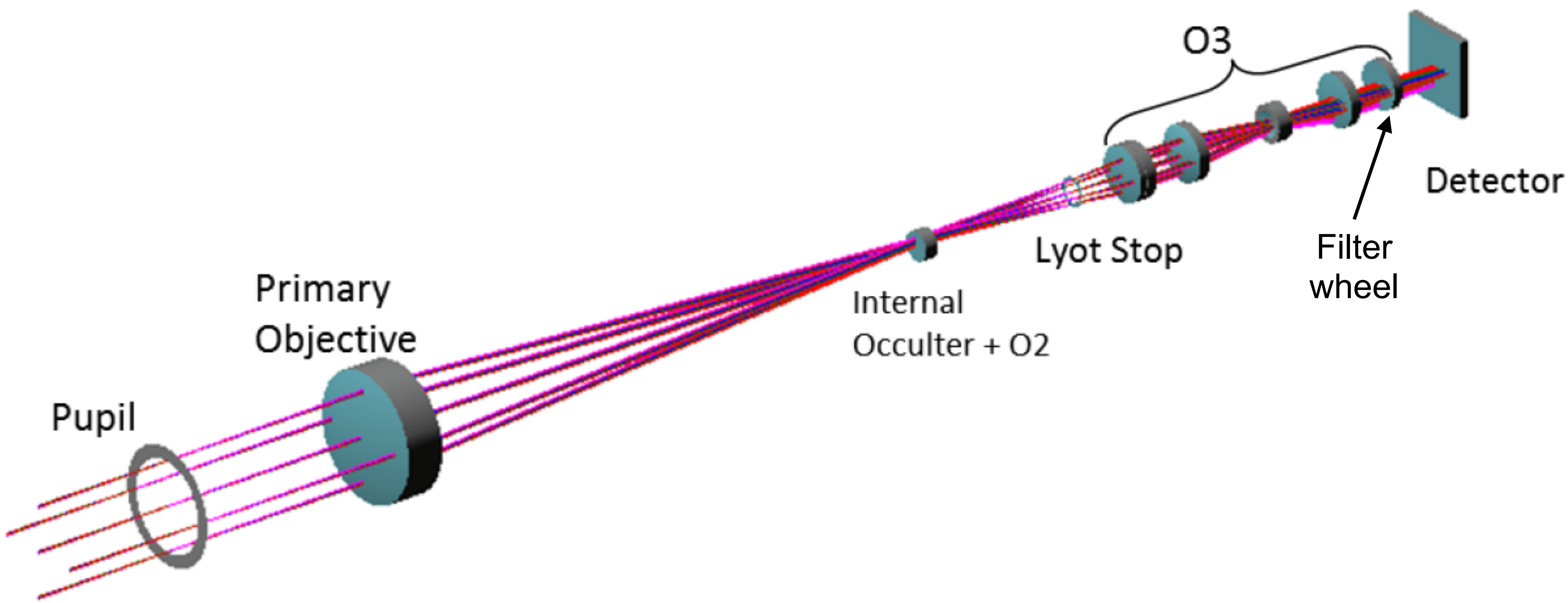
The telescope is placed on the main spacecraft, and the occulting disk is placed on the smaller spacecraft 150 m away. Together they form a giant coronagraph.

DARA
(Digital Absolute RAdiometer)

PI: Werner Schmutz (PMOD, Switzerland)

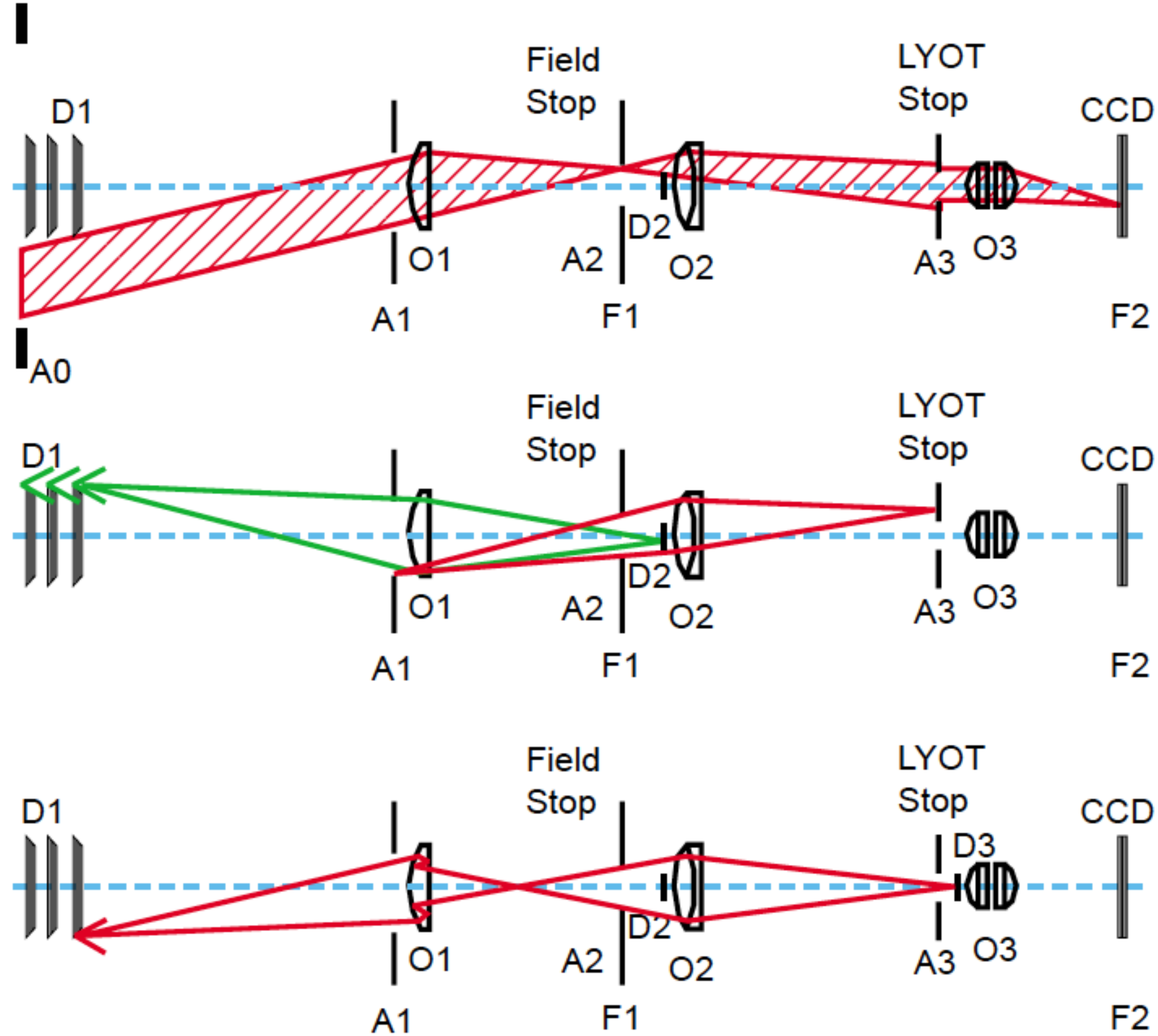
DARA is a total solar irradiance monitor placed on the occulter spacecraft.

PROBA-3/ASPIICS optical design



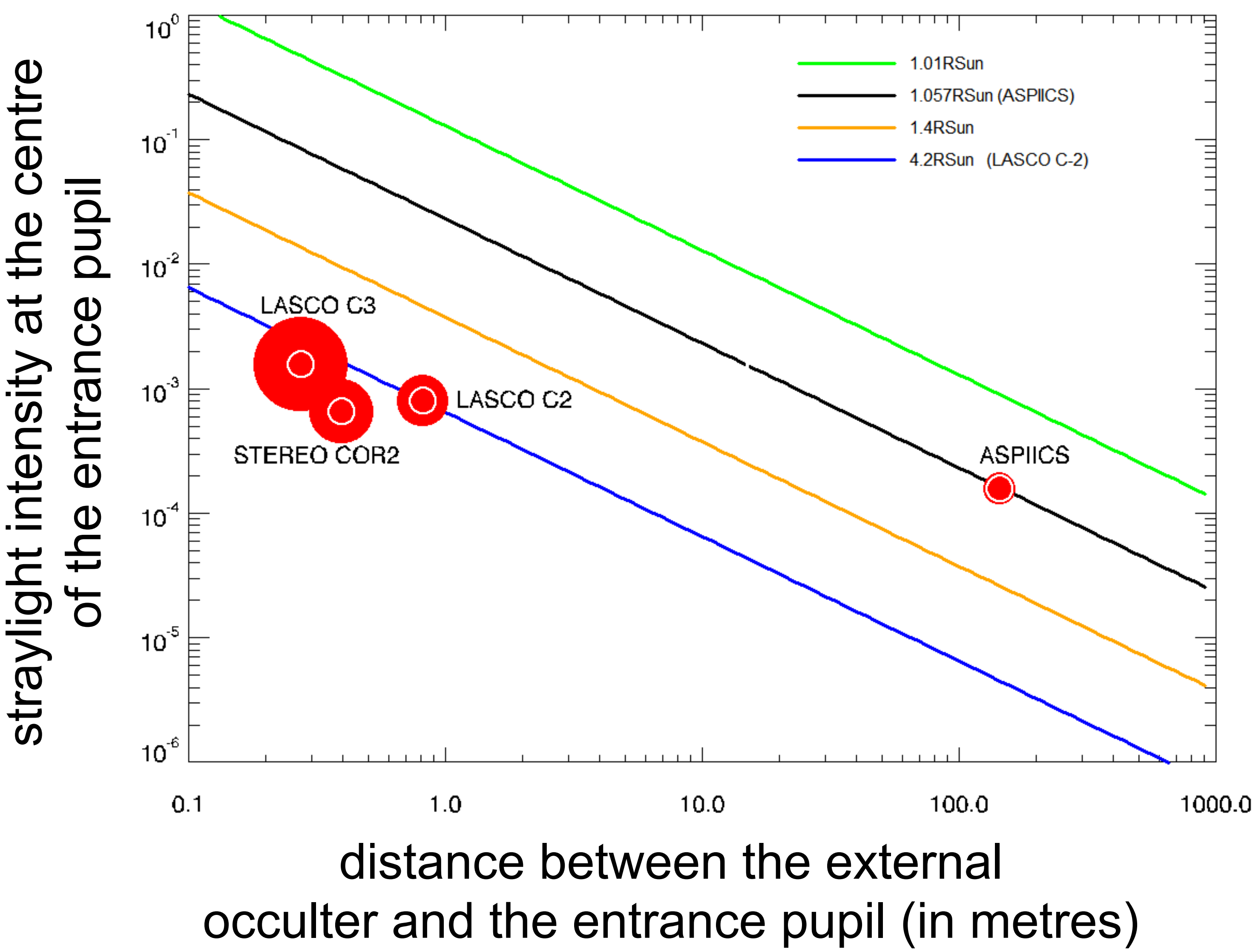
- An externally occulted coronagraph with the occulter placed about 150 m in front of the entrance pupil.
- The optical design of ASPIICS follows the principles of the classic Lyot coronagraph.

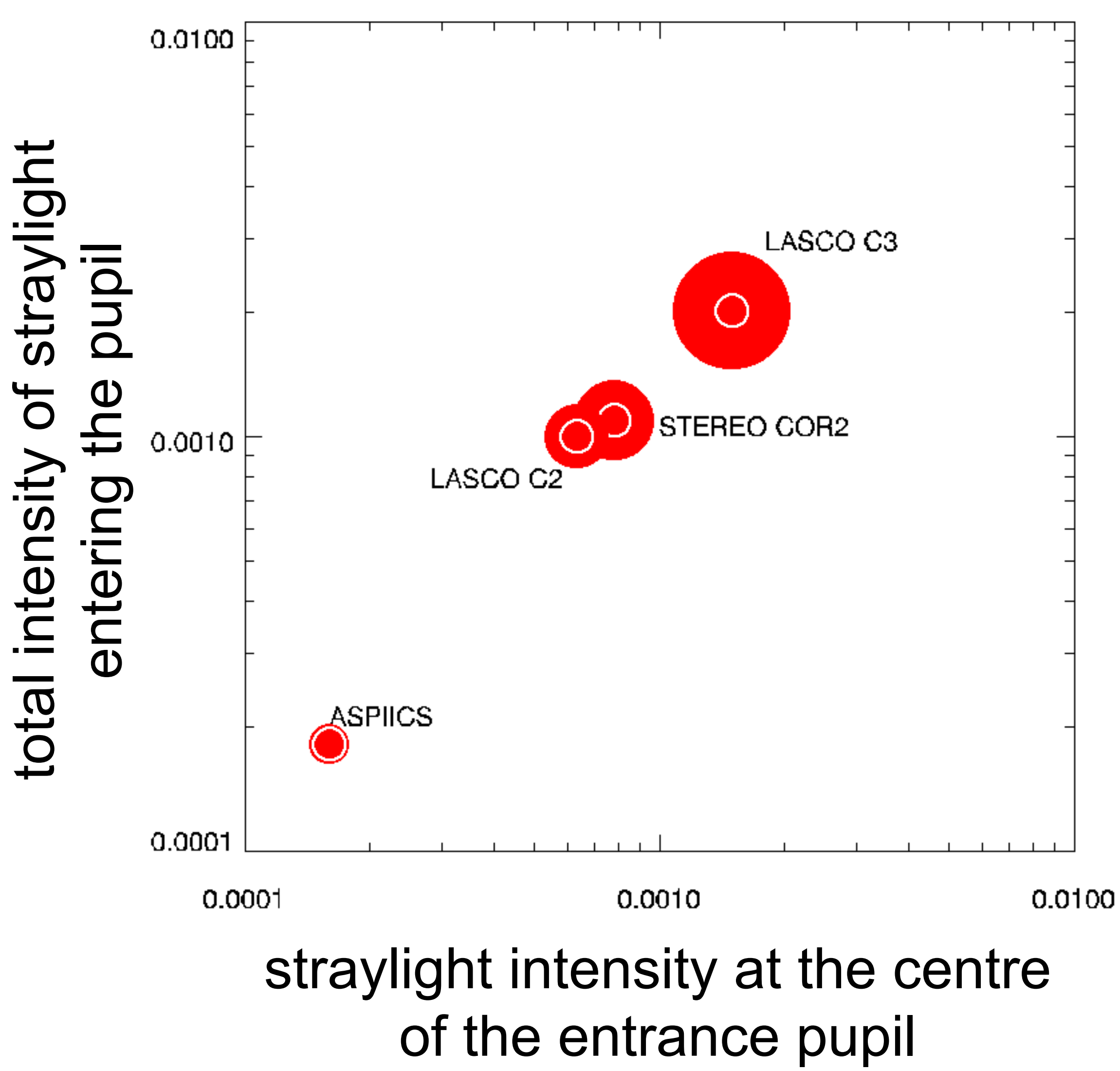
Straylight blocking in externally occulted coronagraphs *(Howard et al. 2000).*



A0, front aperture
A1, entrance aperture
A2, field stop
A3, Lyot stop
D1, external occulter
D2, internal occulter
D3, Lyot spot
F1, primary focal plane
F2, secondary focal plane
O1, objective lens
O2, field lens
O3, relay lens

Why do we need PROBA-3/ASPIICS?
Better straylight rejection



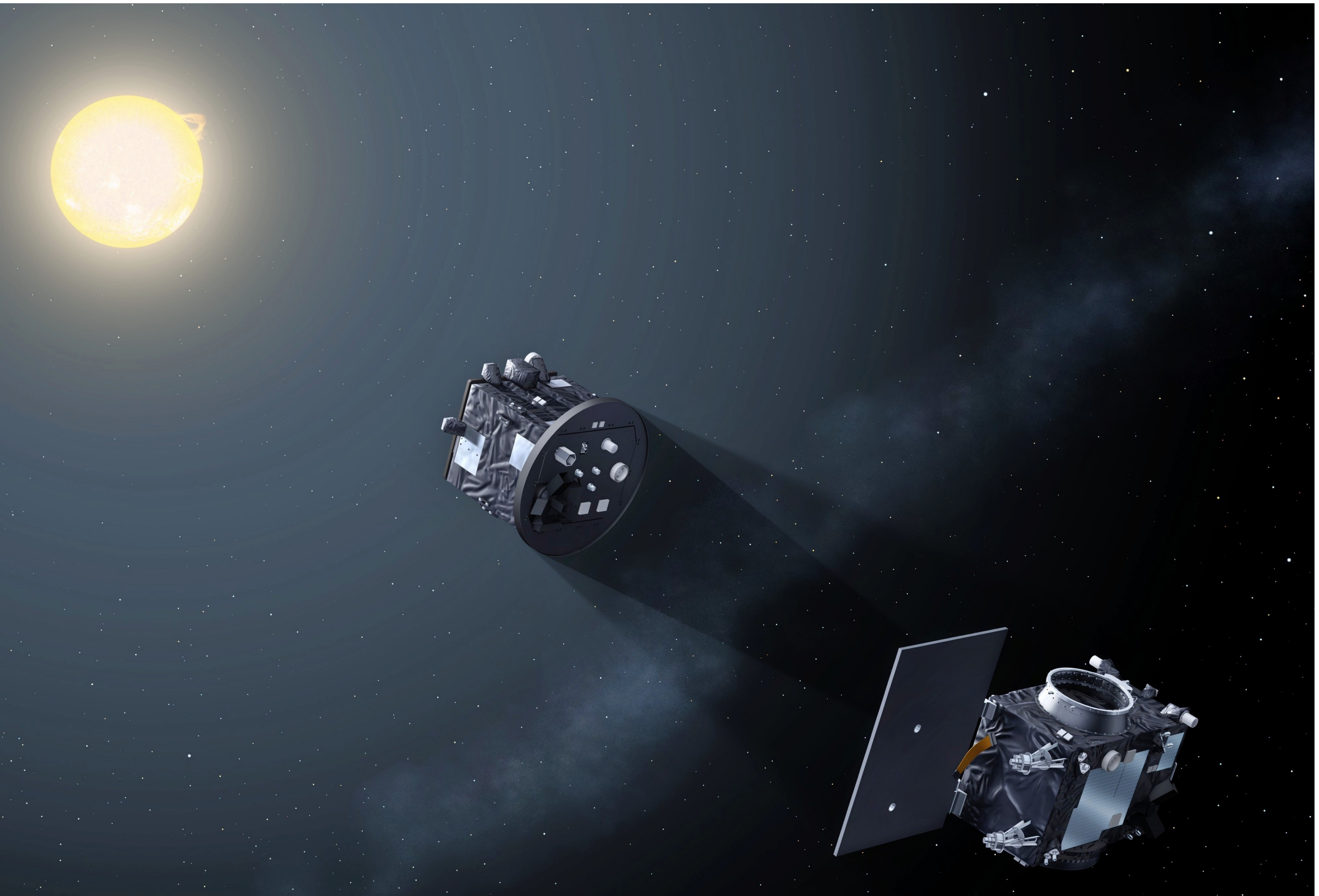


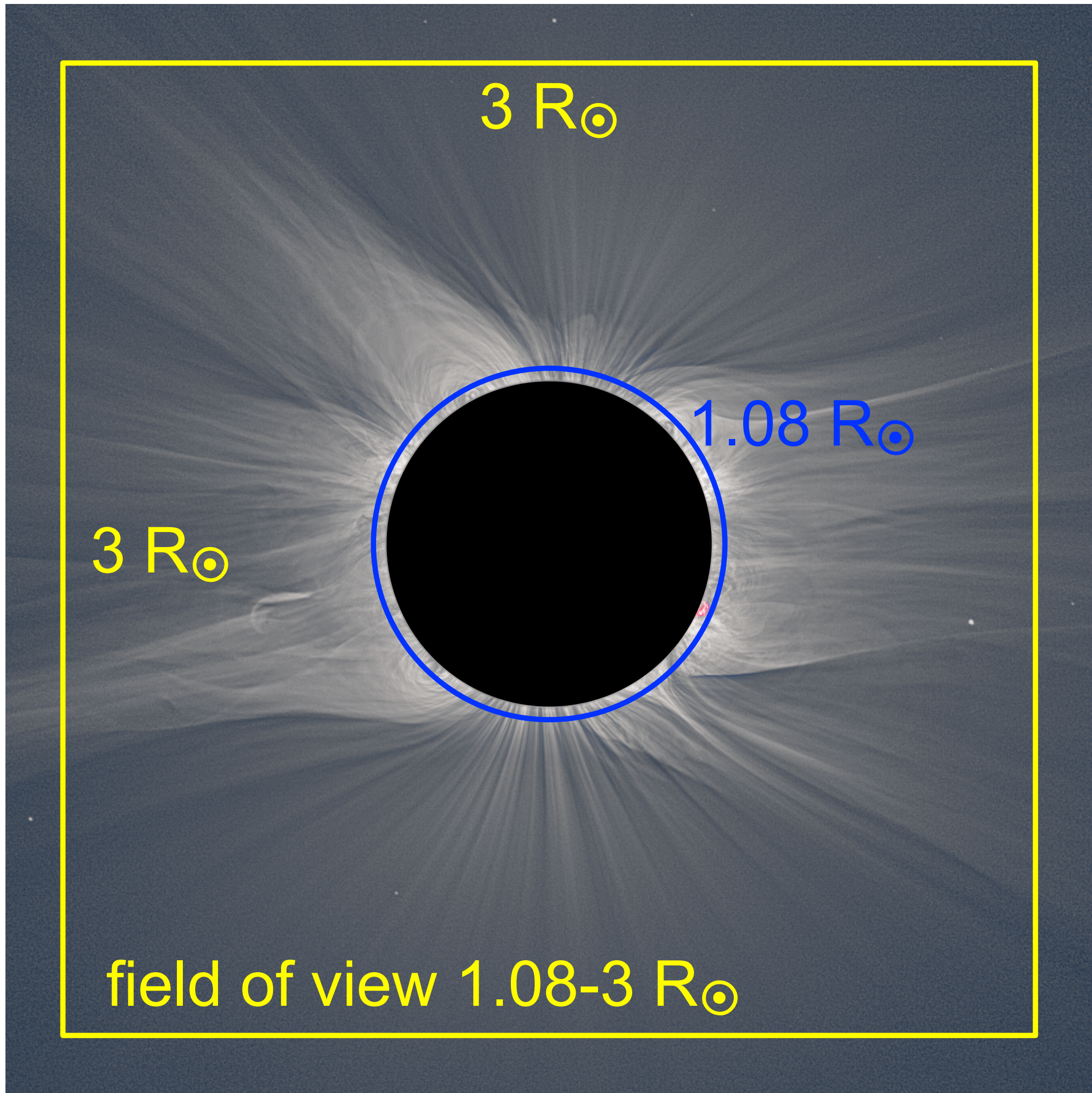
- Using theoretical calculations (Fort et al. 1978, Lenskii 1981), one can show that ASPIICS will achieve a factor 5 better straylight rejection than other coronagraphs, while occulting to smaller radial distances.

PROBA-3/ASPIICS: the ultimate coronagraph!

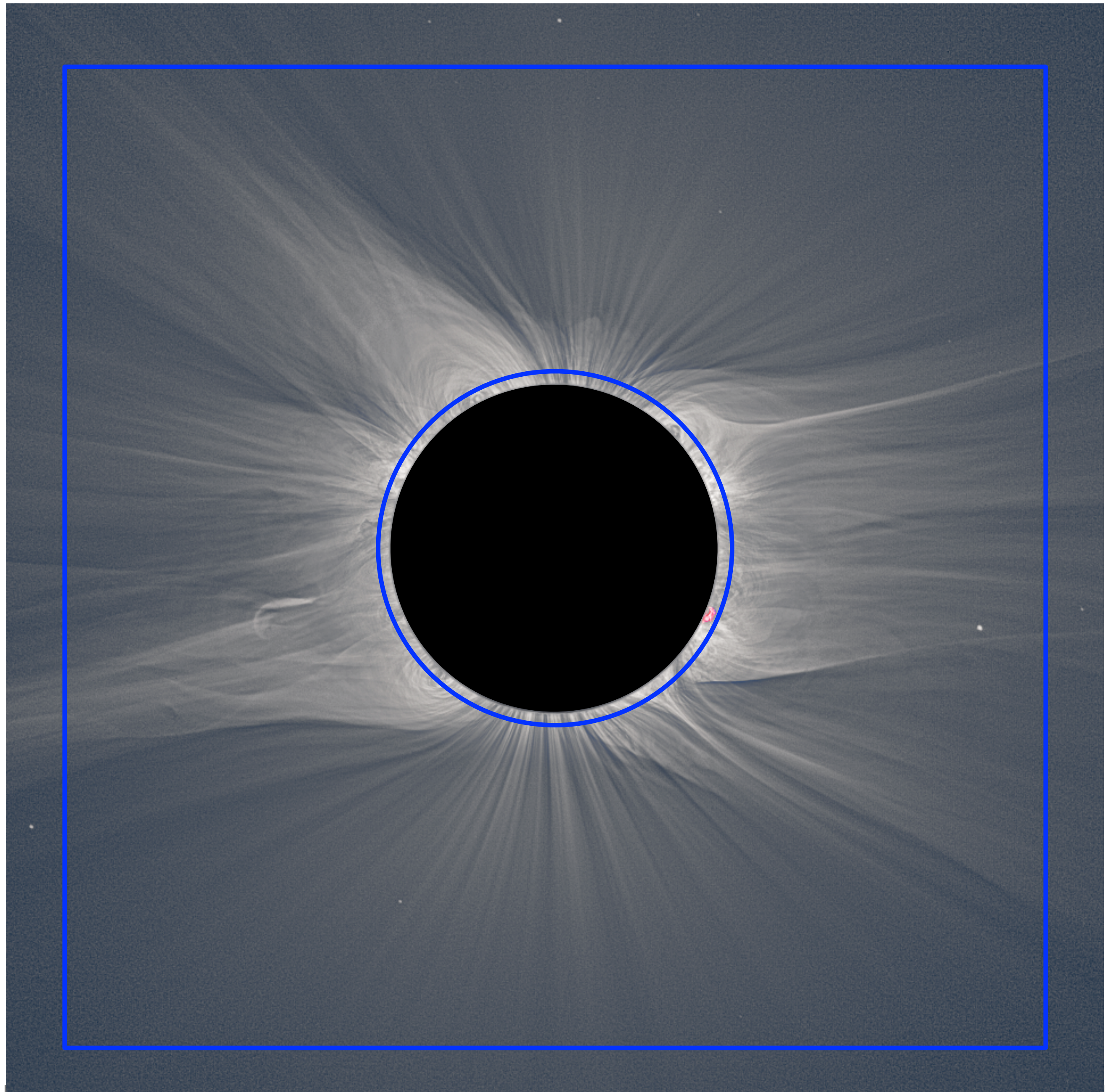
- The formation flying will be maintained over 6 hours in every 20-hour orbit: *around a factor 100 improvement* in the duration of uninterrupted observations in comparison with a total eclipse.
- PROBA-3 will observe the corona two orbits per week on average: *around a factor 50 improvement* in the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

- 6 spectral channels:
  - white light (5400-5700 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.





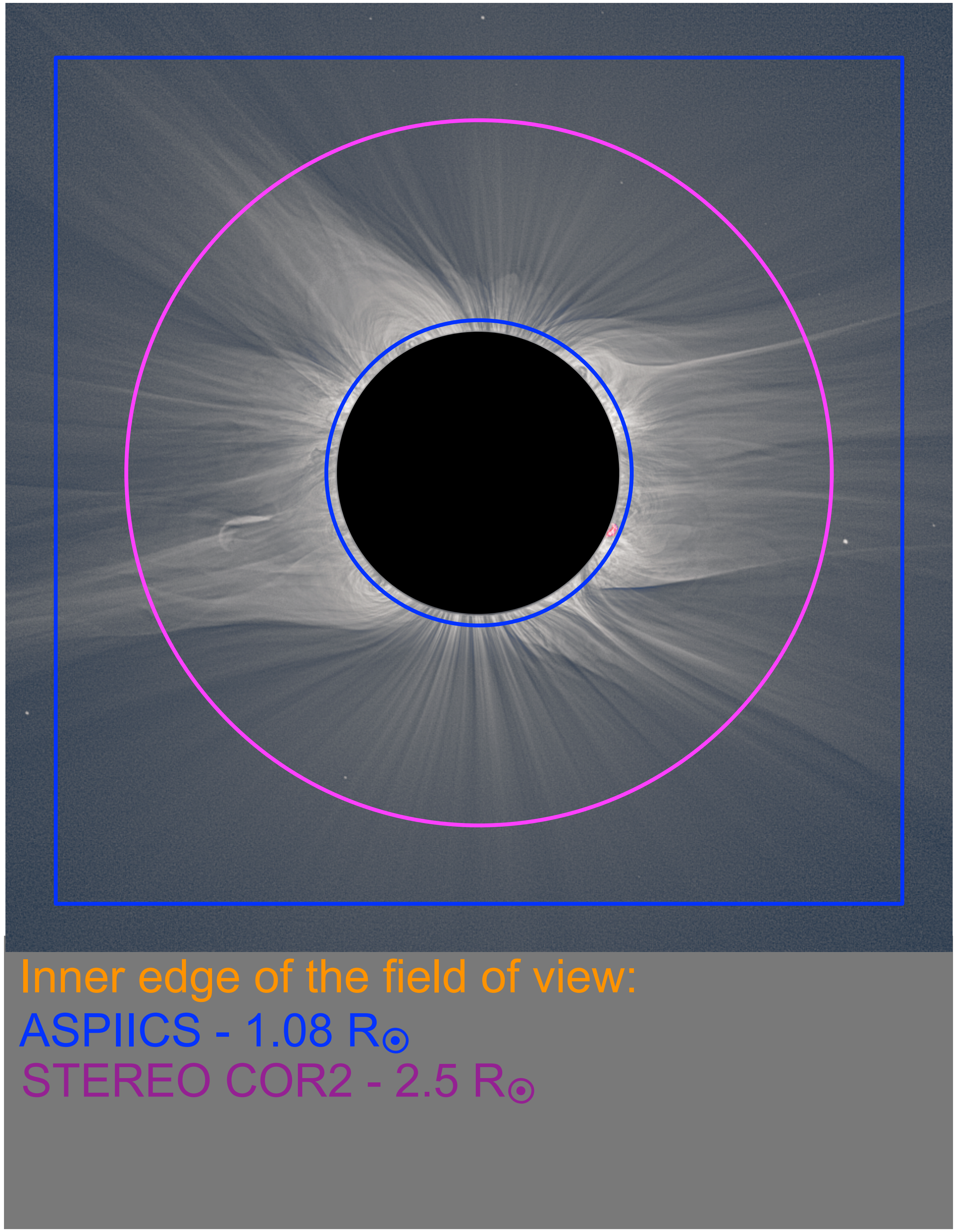
PROBA-3/ASPIICS in comparison with other coronagraphs



Inner edge of the field of view:
ASPIICS - 1.08 $R_\odot$

- The inner edge of the ASPIICS field of view (1.08 $R_\odot$) will be lower than that of any other existing or planned space coronagraph.
- ASPIICS will therefore cover The Gap between the typical fields of view of EUV imagers and externally occulted coronagraphs!
- ASPIICS straylight rejection will be at least a factor 5 better than that of other space coronagraphs, even if ASPIICS occults down to lower heights.
- The spatial resolution of ASPIICS will be at least 3.5 times better than the resolution of other coronagraphs.

PROBA-3/ASPIICS in comparison with other coronagraphs



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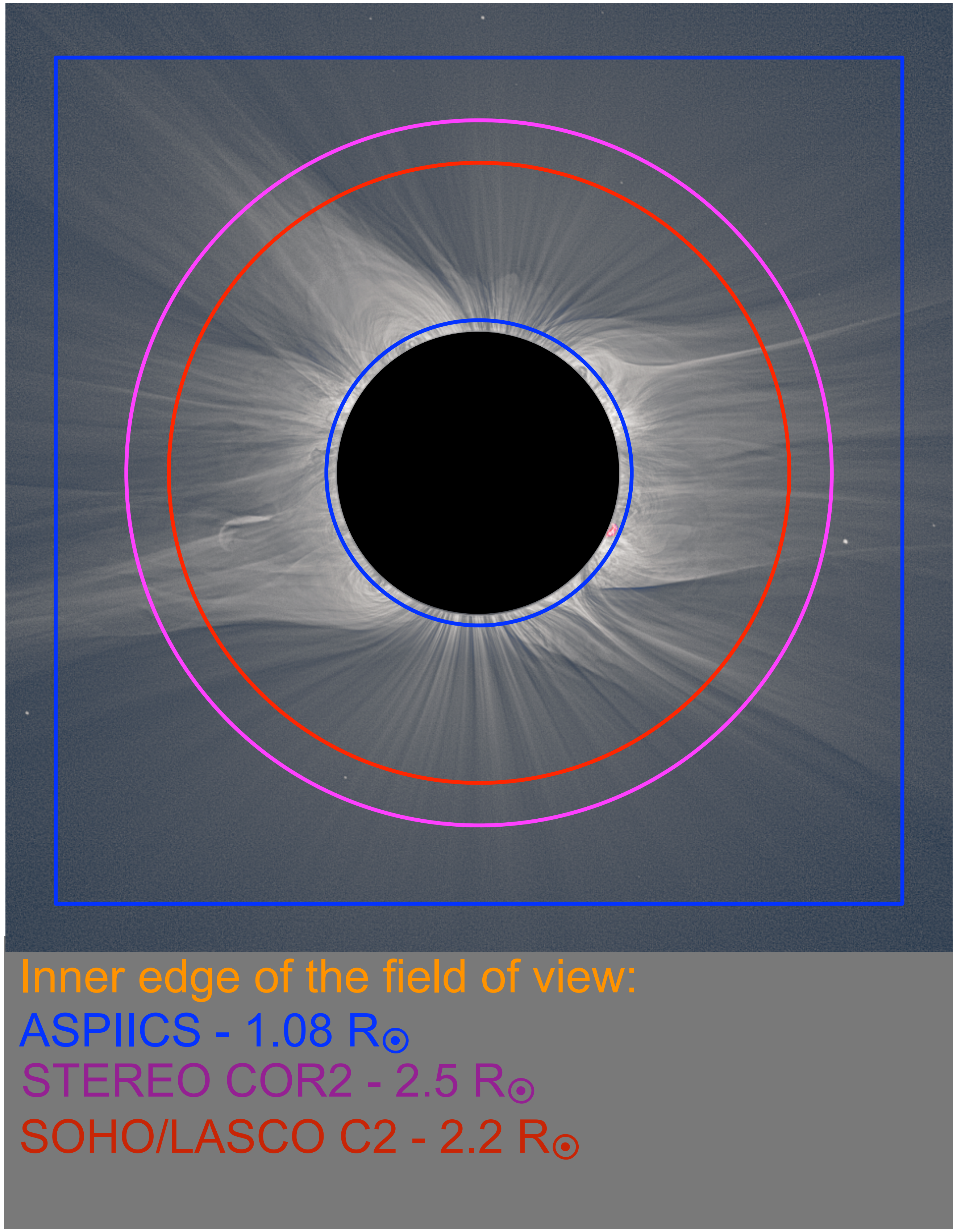

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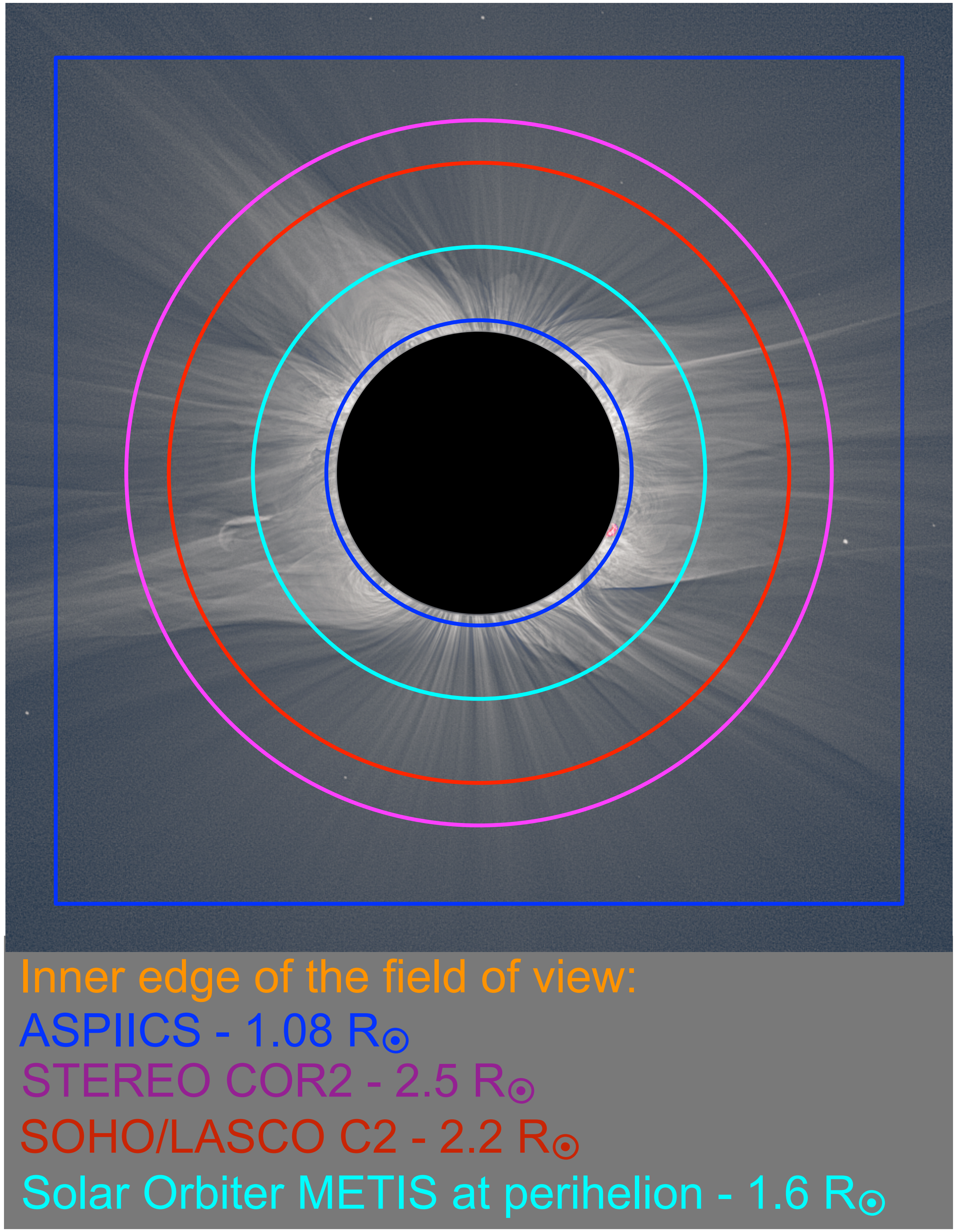

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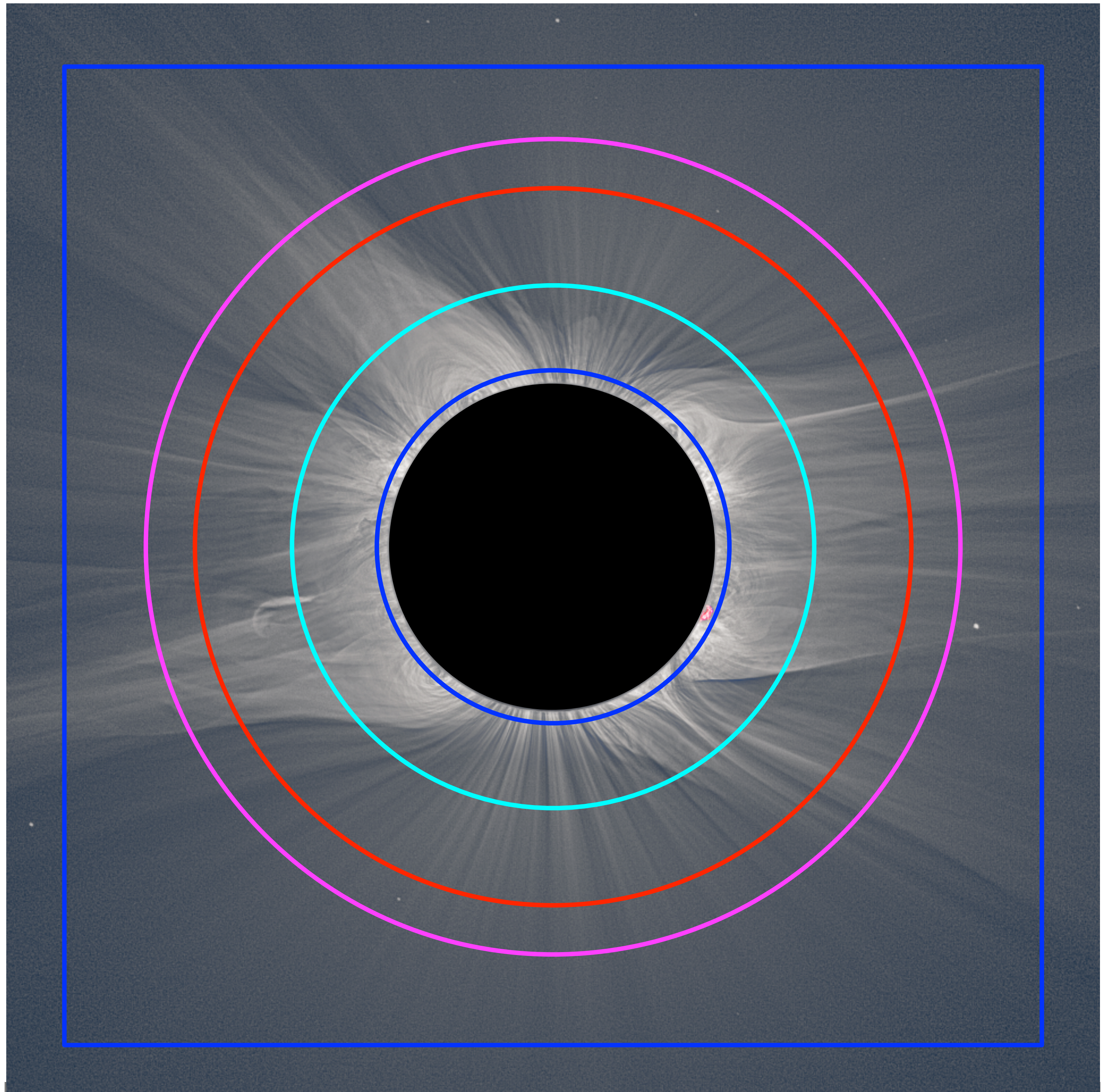

Inner edge of the field of view:
ASPIICS - 1.08 R⊙
STEREO COR2 - 2.5 R⊙
SOHO/LASCO C2 - 2.2 R⊙
Solar Orbiter METIS at perihelion - 1.6 R⊙

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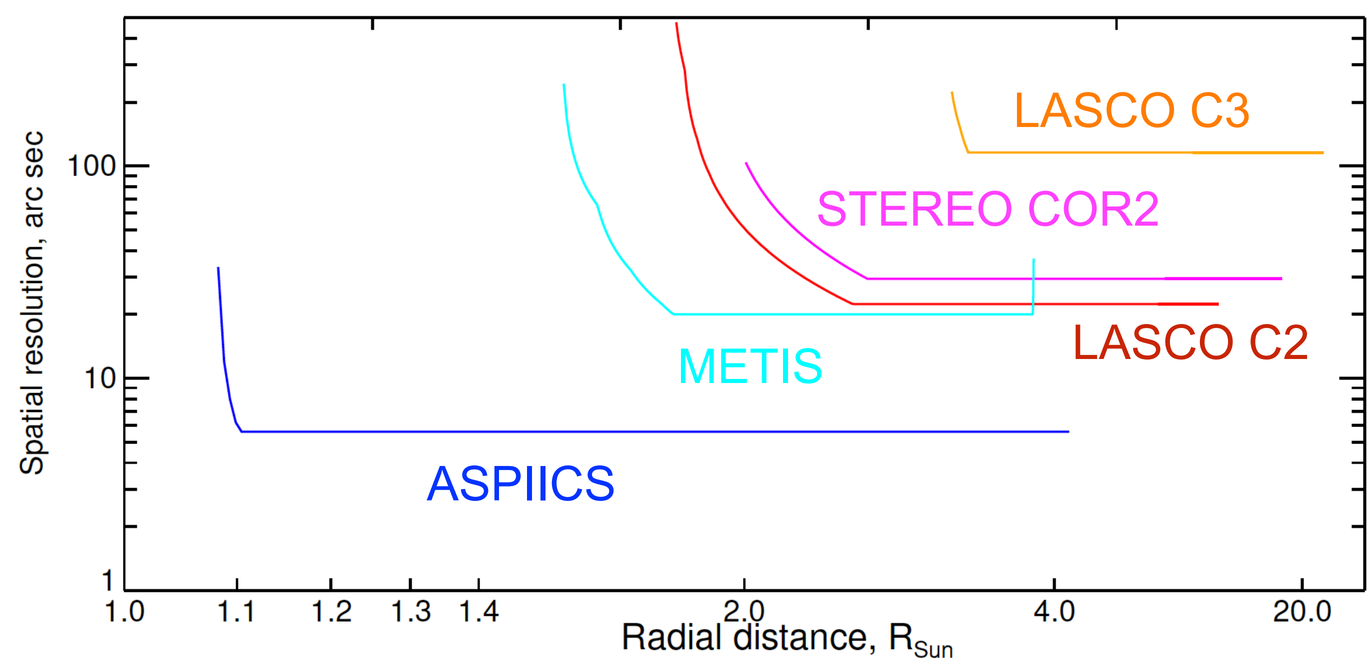


PROBA-3/ASPIICS scientific objectives

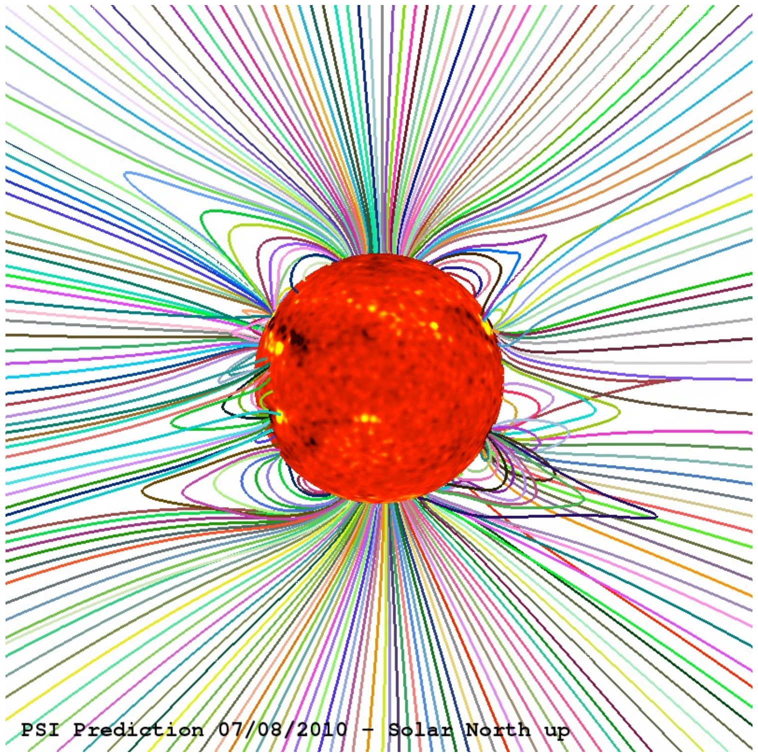
- The top-level scientific objectives of ASPIICS are:

  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?

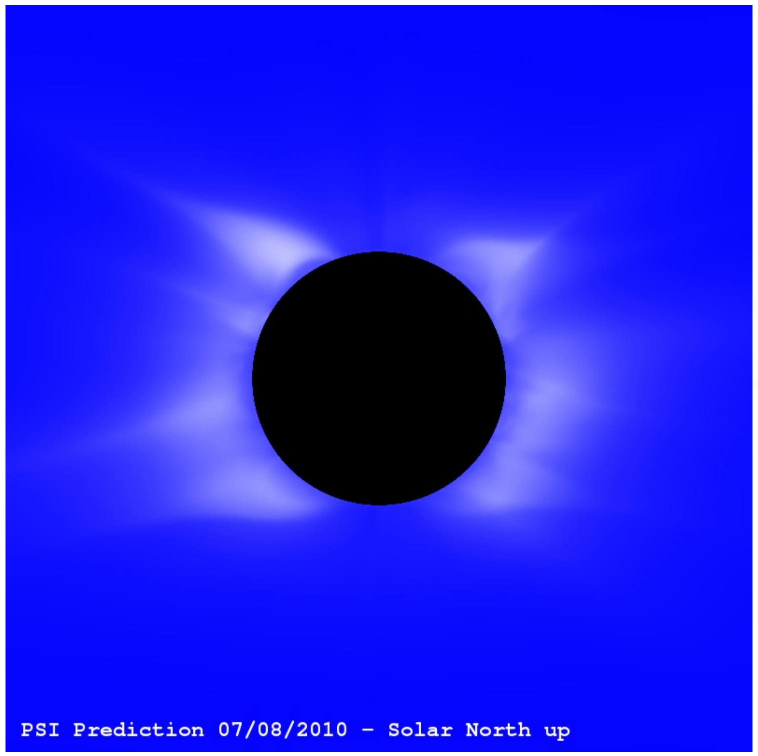
  2. Understanding the physical processes that lead to CMEs and determine space weather by answering the following questions:
     - What is the nature of the structures that form the CME?
     - How do CMEs erupt and accelerate in the low corona?
     - What is the connection between CMEs and active processes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

Coronal structuring and dynamics

MHD model of the coronal magnetic field



Calculated coronal brightness



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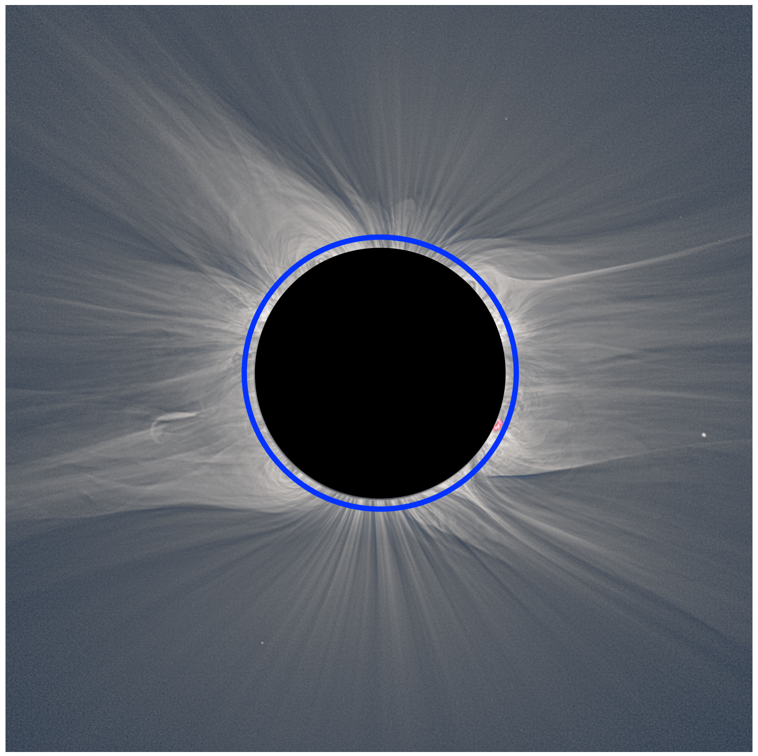
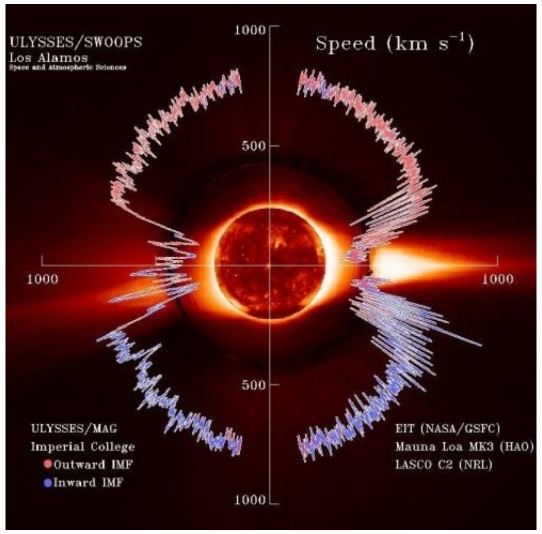
Corona observed by PROBA-3/ASPIICS



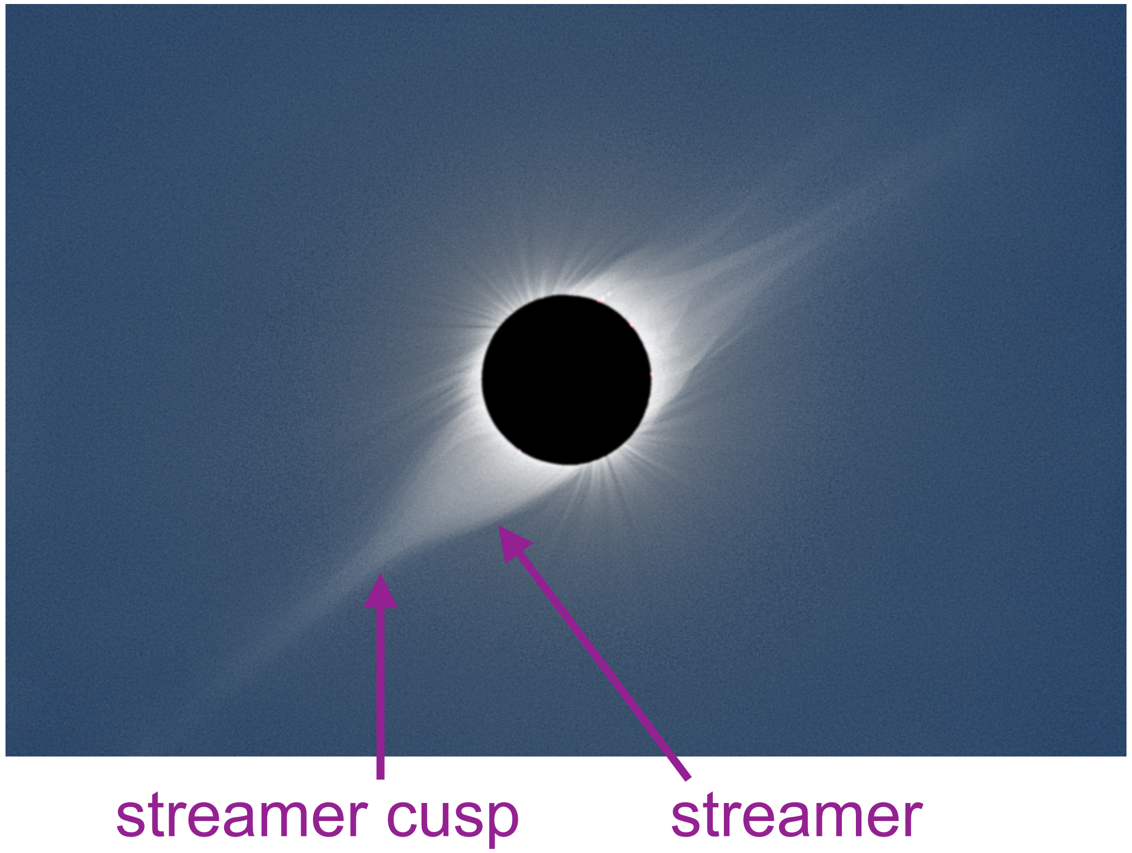
- The magnetic field plays a dominant role in the structuring and dynamics of coronal plasma. However, the coronal magnetic field is not routinely measured but is extrapolated from photospheric magnetograms (often not very successfully).
- The crucial transition between closed-field regions (magnetic field dominated) and open-field regions (solar wind dominated) occurs in *the Gap* between the low and high corona.
- PROBA-3/ASPIICS will measure the structuring and dynamics of the solar corona and constrain models of the coronal magnetic field.

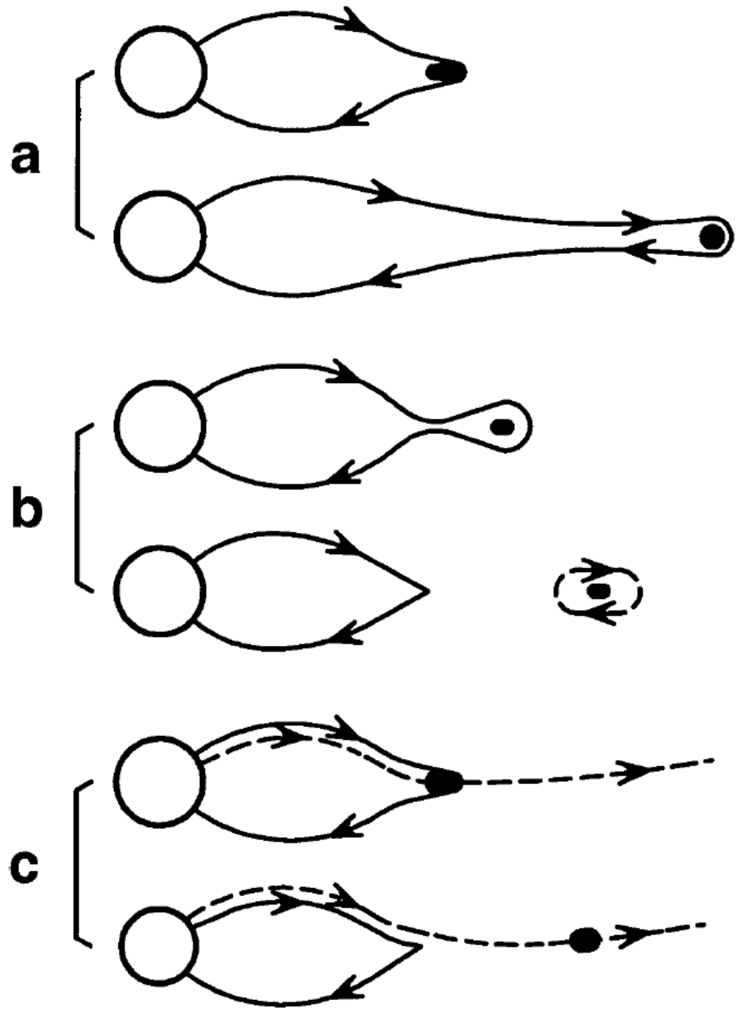
Origin of the slow solar wind

- 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.



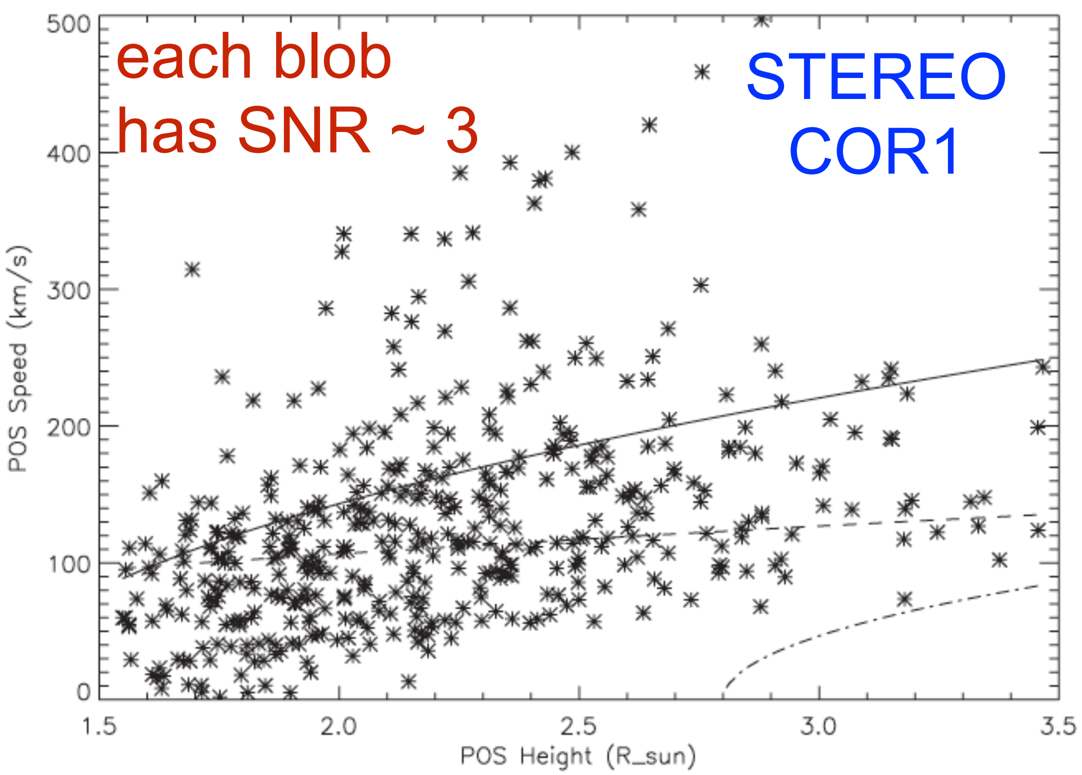
(McComas et al. 1998)



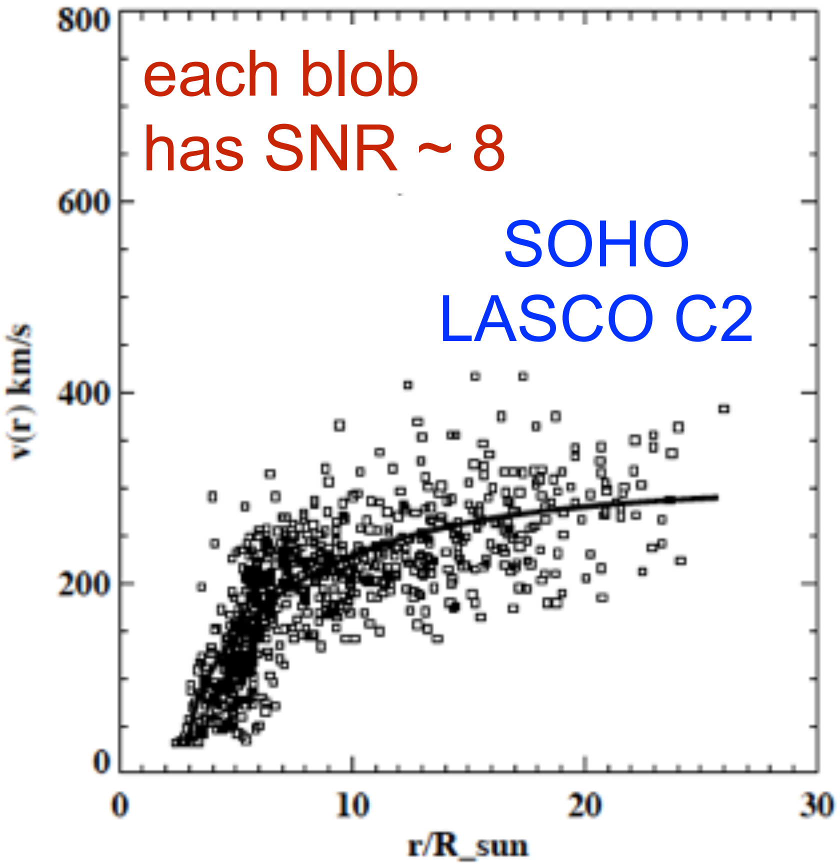


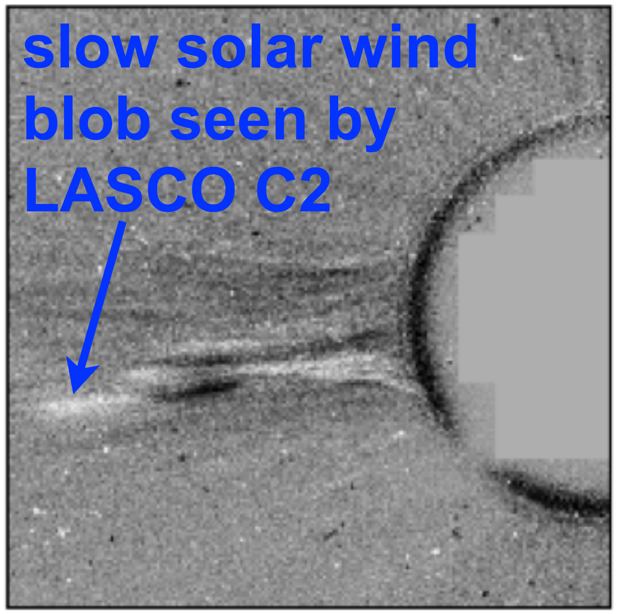
(Y.-M. Wang et al. 2000)

Origin of the slow solar wind



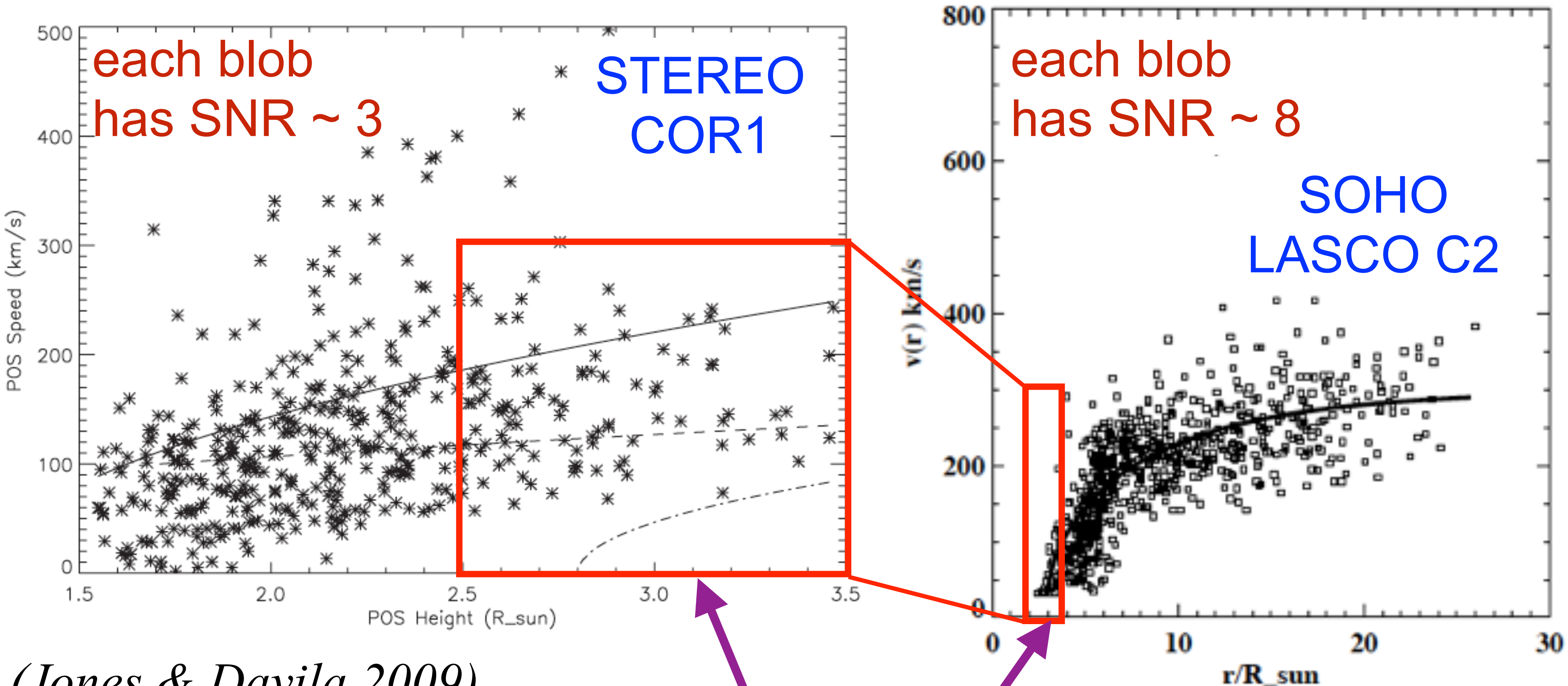
(Jones & Davila 2009)





(Sheeley et al. 1997)

Origin of the slow solar wind



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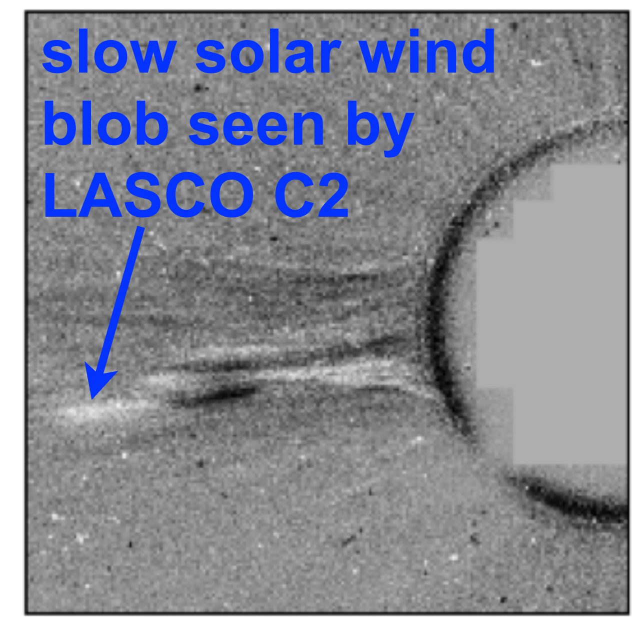
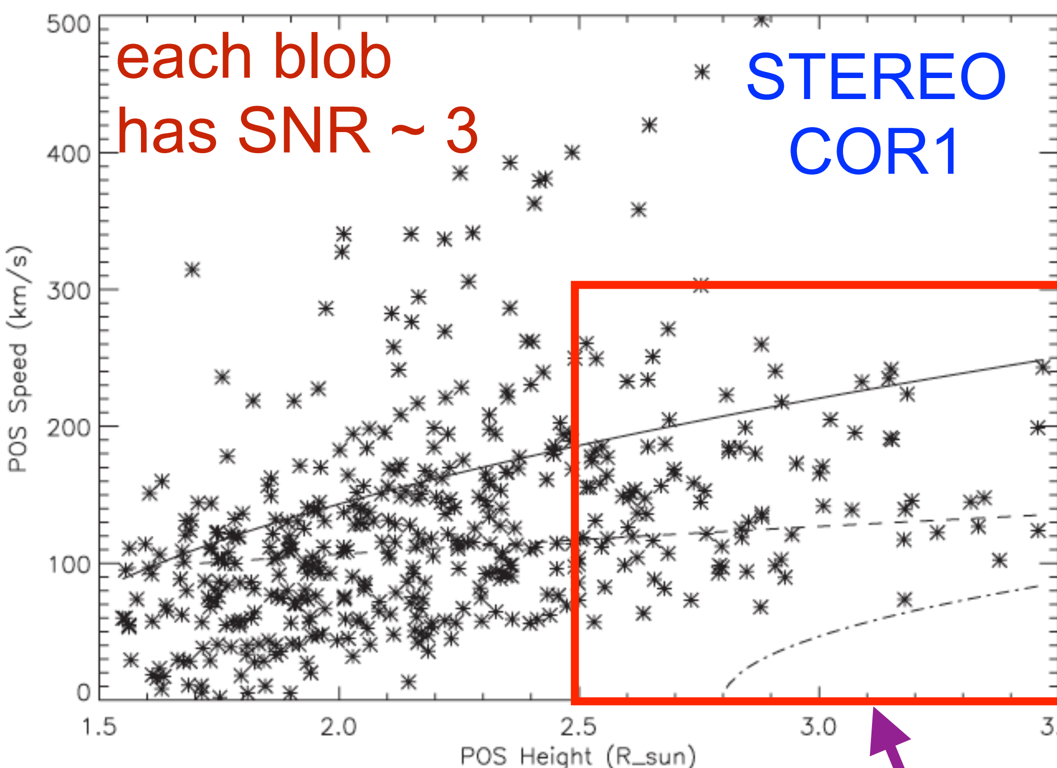


(Sheeley et al. 1997)

A discrepancy between measurements
made by different coronagraphs!

Origin of the slow solar wind



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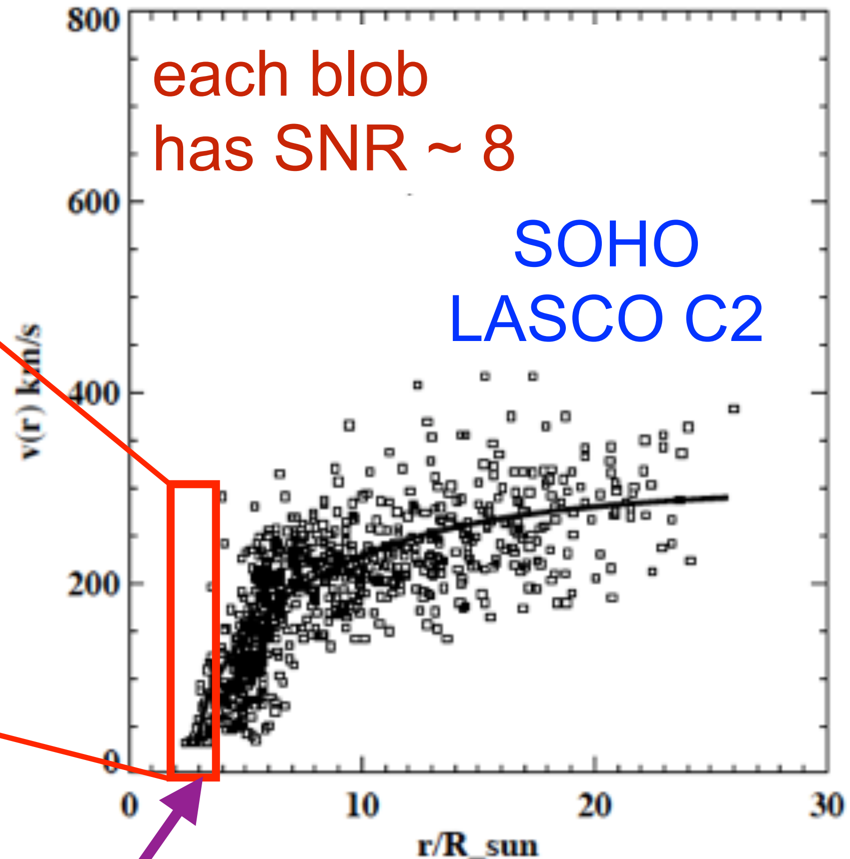
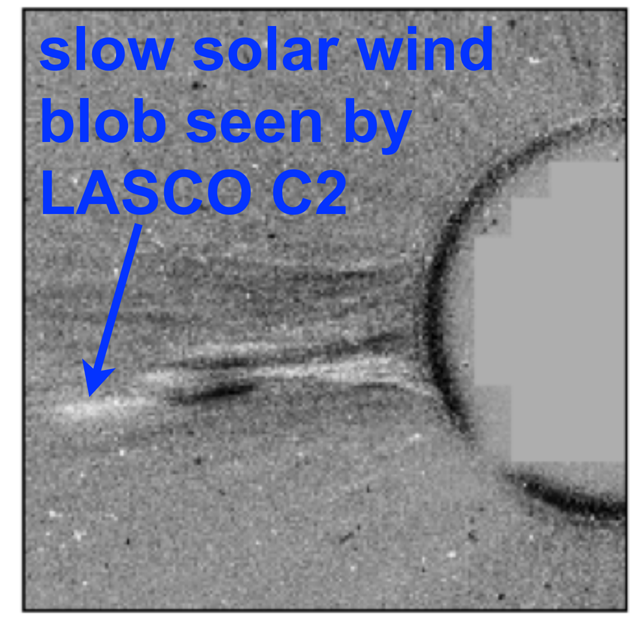




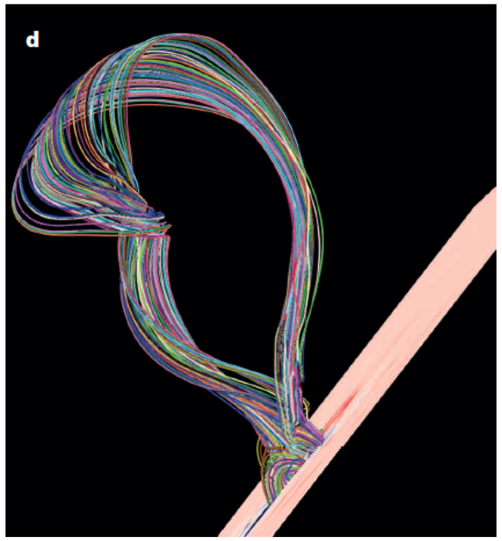
(Sheeley et al. 1997)

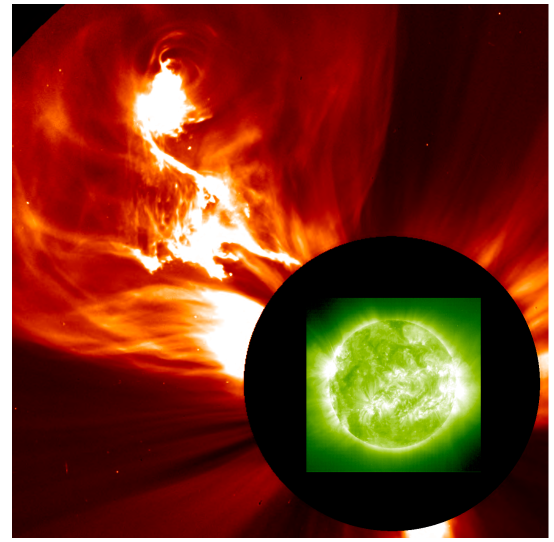
A discrepancy between measurements
made by different coronagraphs!

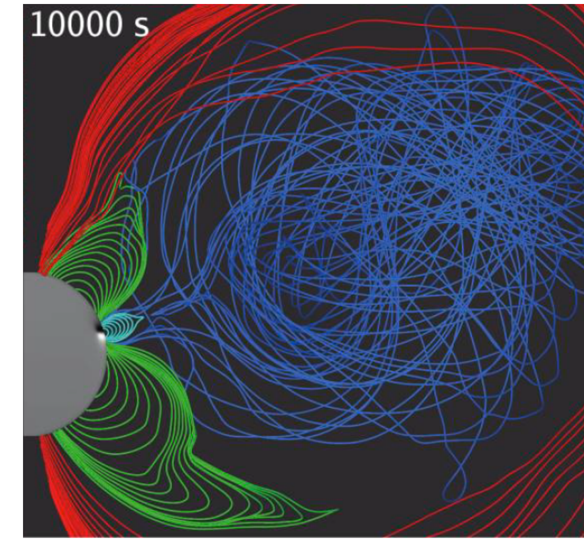
- PROBA-3/ASPIICS, with its high signal-to-noise ratio (SNR ~ 20), will allow us to investigate small-scale dynamic phenomena at the streamer cusps and provide precise measurements of the early phase of the slow solar wind acceleration.

CME onset and acceleration

(Amari et al. 2014)

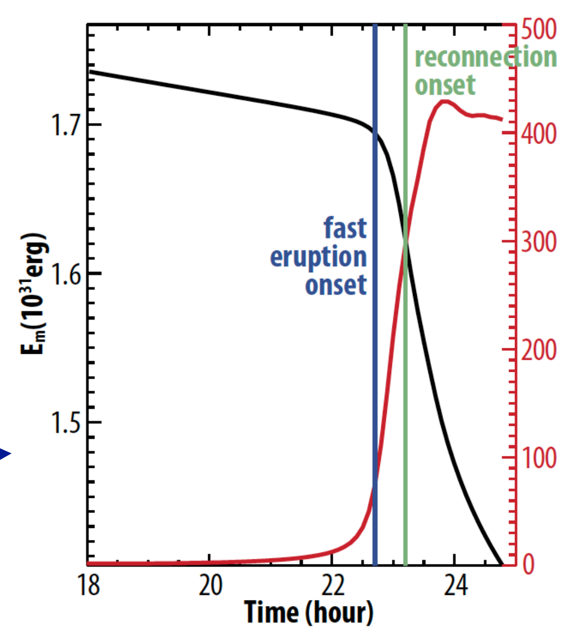


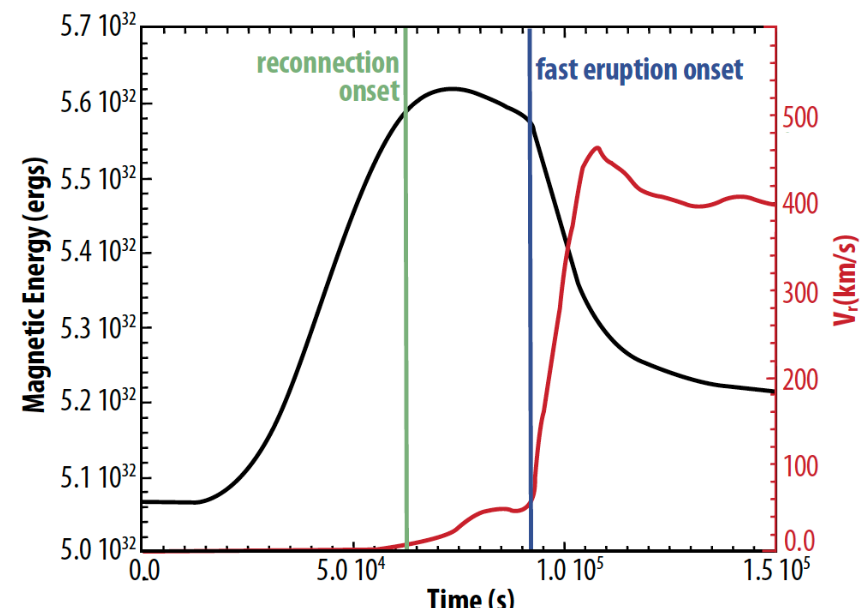




(Lynch et al. 2008)

torus instability





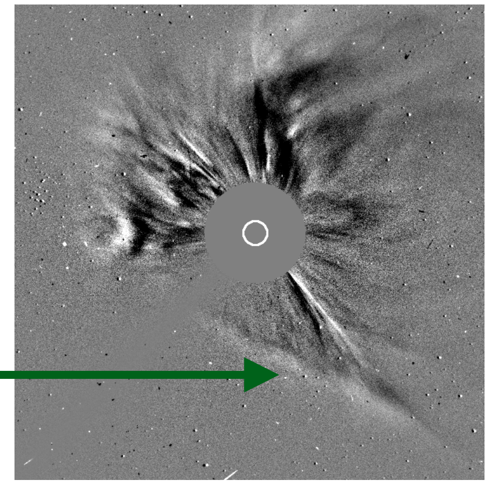
magnetic breakout

(Karpen et al. 2012)

- The CME initiation mechanism is still not clear.
- Distinguishing between different proposed mechanisms requires observations of the CME initiation process in the inner corona.
- PROBA-3/ASPIICS will measure the CME kinematics in the inner corona and observe in detail the coronal restructuring during CMEs.

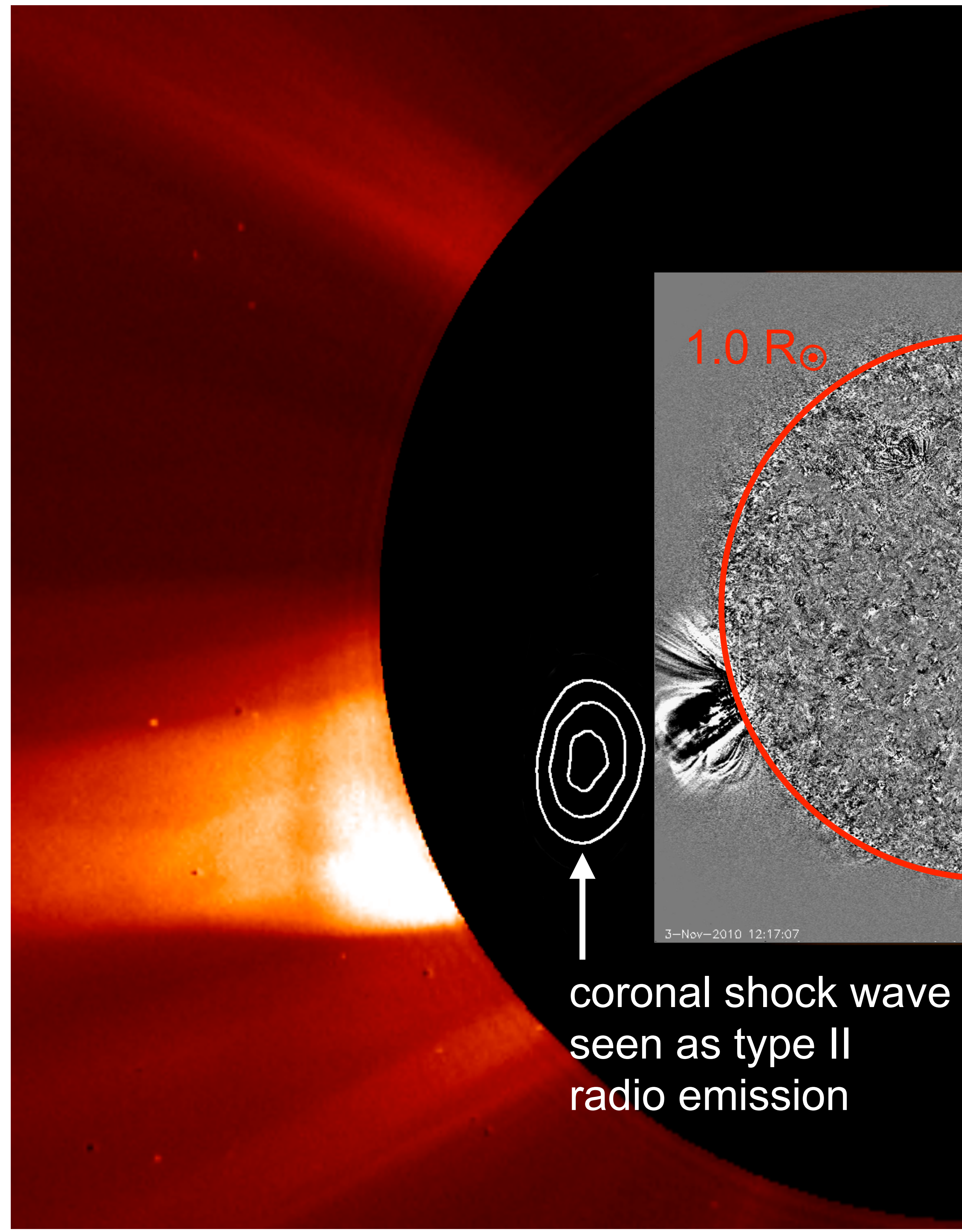
Origin of shock waves in the inner corona

Coronal shock waves can be observed by coronagraphs in white light.



(Sheeley et al. 2000)

- The origin of coronal shock waves is still debated, with flare-related (blast wave) and CME-related (piston-driven wave) mechanisms proposed.
- Ground-based radio observations of type II bursts show that shocks often form in the inner corona, namely in the Gap.
- PROBA-3/ASPIICS will observe the CME and shock dynamics in The Gap providing us with conclusive evidence for the origin of coronal shock waves observed concurrently by ground-based radio instrumentation.



Summary

- PROBA-3 will test formation flying technologies that can be used by future ESA missions.
- PROBA-3/ASPIICS will be a significant advance from previous, current, and planned solar coronagraphs.
- Due to the unique telescope to occulter separation (around 150 m), ASPIICS will be able to observe the inner corona as close to the solar centre as 1.08 $R_\odot$ 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).
- PROBA-3/ASPIICS observations will be crucial for solving several outstanding problems in solar and heliospheric physics:
    - structure and dynamics of the magnetized solar corona,
    - sources of the slow solar wind,
    - onset and early acceleration of CMEs,
    - origin of coronal shocks waves.