Imaging the Solar corona

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Royal Observatory of Belgium

Credit: Andrew Struder, 2017 Aug 21
NASA Astronomy Picture of the day

"Basic SIDC seminar"
ROB 2018 Jan 10

Abstract

As the solar corona is one of the prime research topics of the SIDC, we will further explore where Matt West left the subject in his basic seminar of 2017 Nov 22. Except at times of solar eclipses, the solar corona is not (or hardly) visible without specialised telescopes on space platforms. We will focus on instrumental aspects of two types of telescopes in which "Belgium" is playing a pioneering role: EUV imagers and coronagraphs. Both type of instruments show the same solar corona, yet the images look different in many ways. Why is that?

Despite decades of analysis and modelling, crucial insight is missing in the gap between the capabilities of both instruments. At a few million km from the solar surface, the magnetic structuring of the corona looses its dominance over the gas pressure, and the typical corona topology fades into the solar wind. Exactly this crucial region is where both EUV imagers and coronagraphs up till now have delivered poor data and where some of the remaining big solar questions are waiting to be addressed: How does the structuring and dynamics of the corona drive the solar wind? From which part on the Sun is the solar wind at Earth originating?

The talk will close with an outlook on the two main developments of SIDC currently in the space-shipyards: the ASPIICS coronagraph on PROBA-3 and the EUI telescopes onboard Solar Orbiter. Thanks to unprecedented mission concepts, both instruments are expected to bring us 'closer' to understanding the solar corona than ever before.

Overview

1. The solar corona: what is it and why do we care?
2. Coronagraphs
3. EUV imagers
4. The gap. What are we missing?
5. Closer to the sun than ever before:
   - ASPIICS on PROBA-3
   - EUI on Solar Orbiter
6. Conclusions

The solar corona what is it and why do we care?


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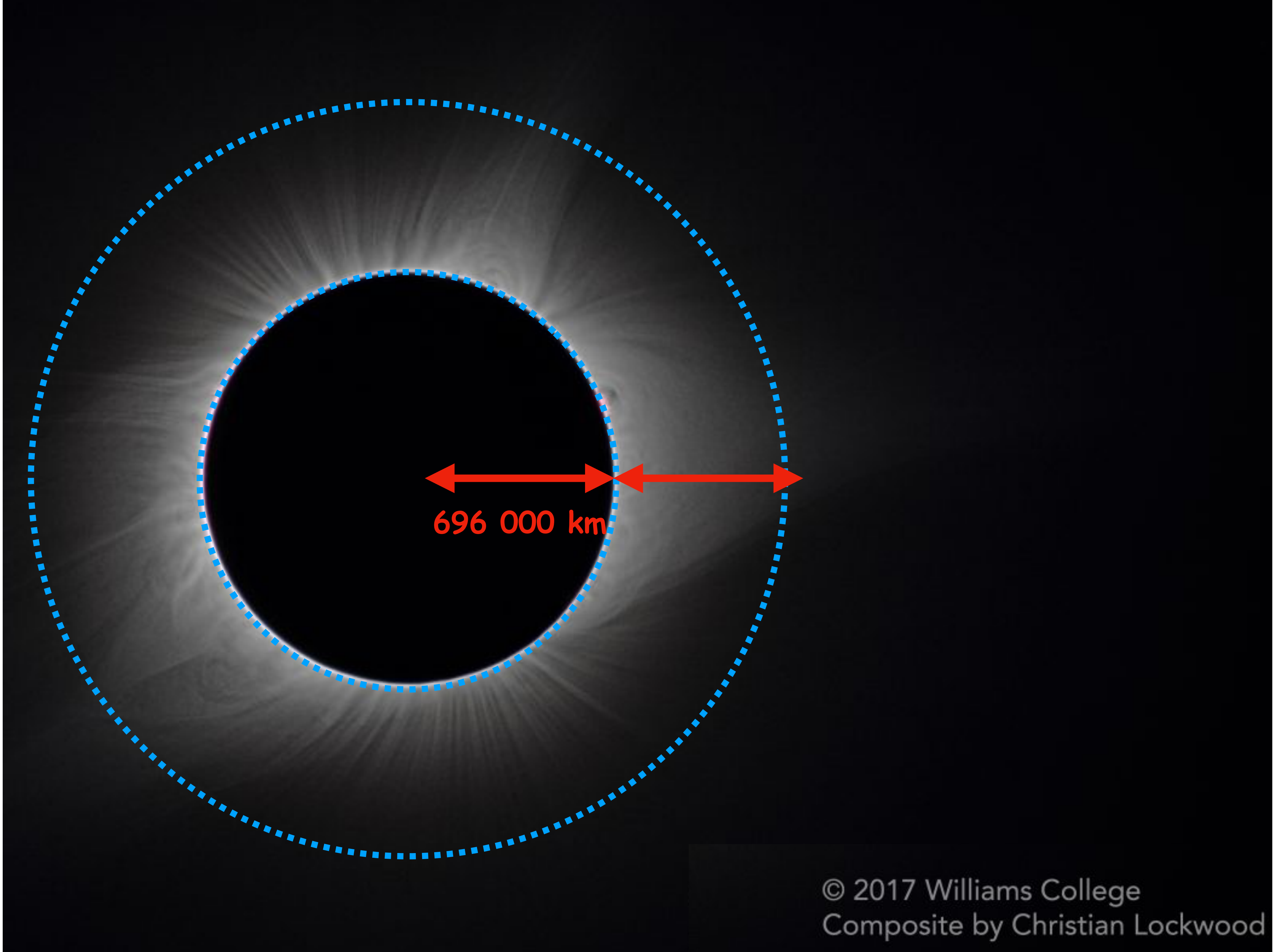
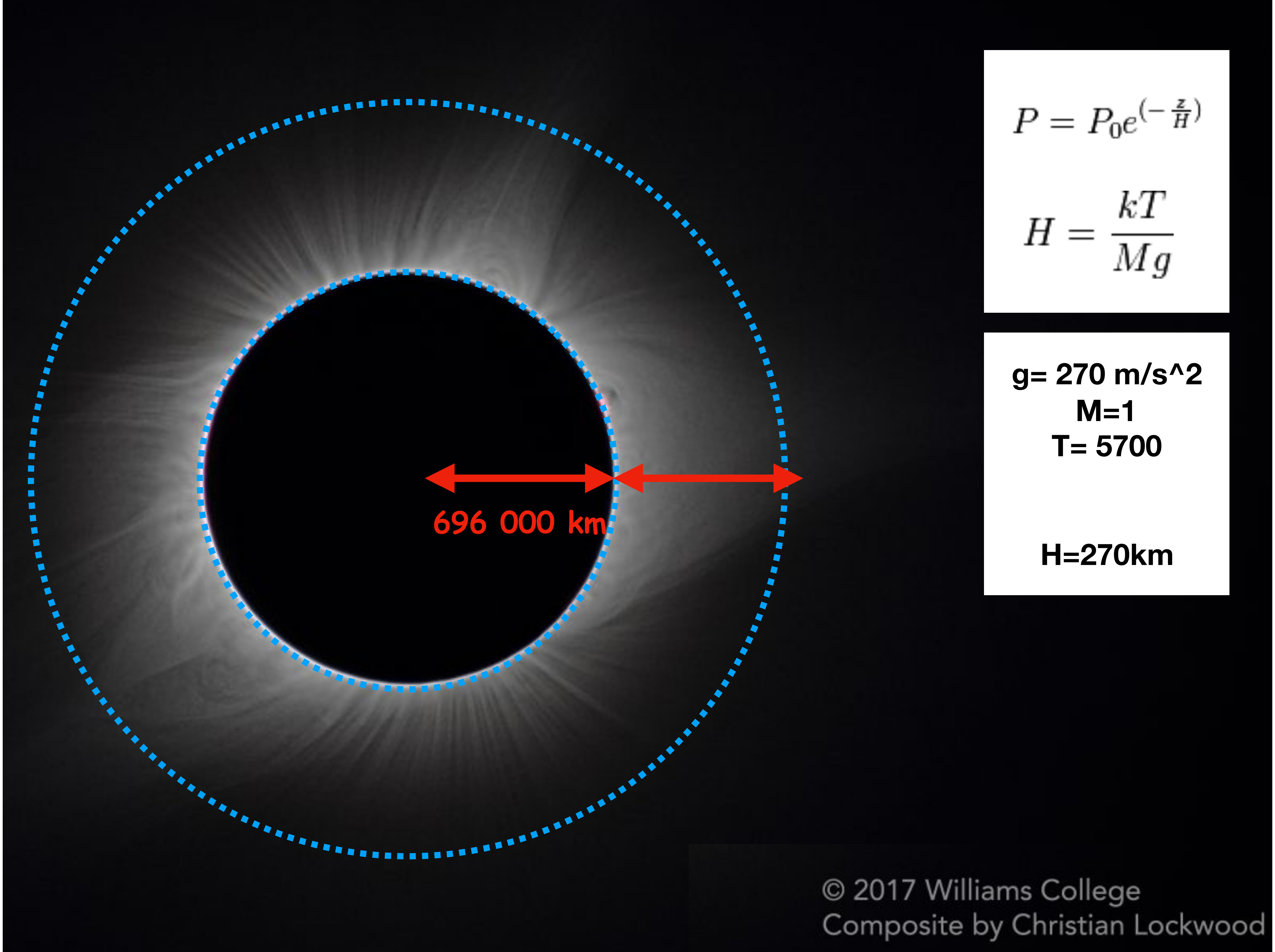
Composite by Christian Lockwood


696 000 km



$$P = P_0 e^{\left(-\frac{z}{H}\right)}$$

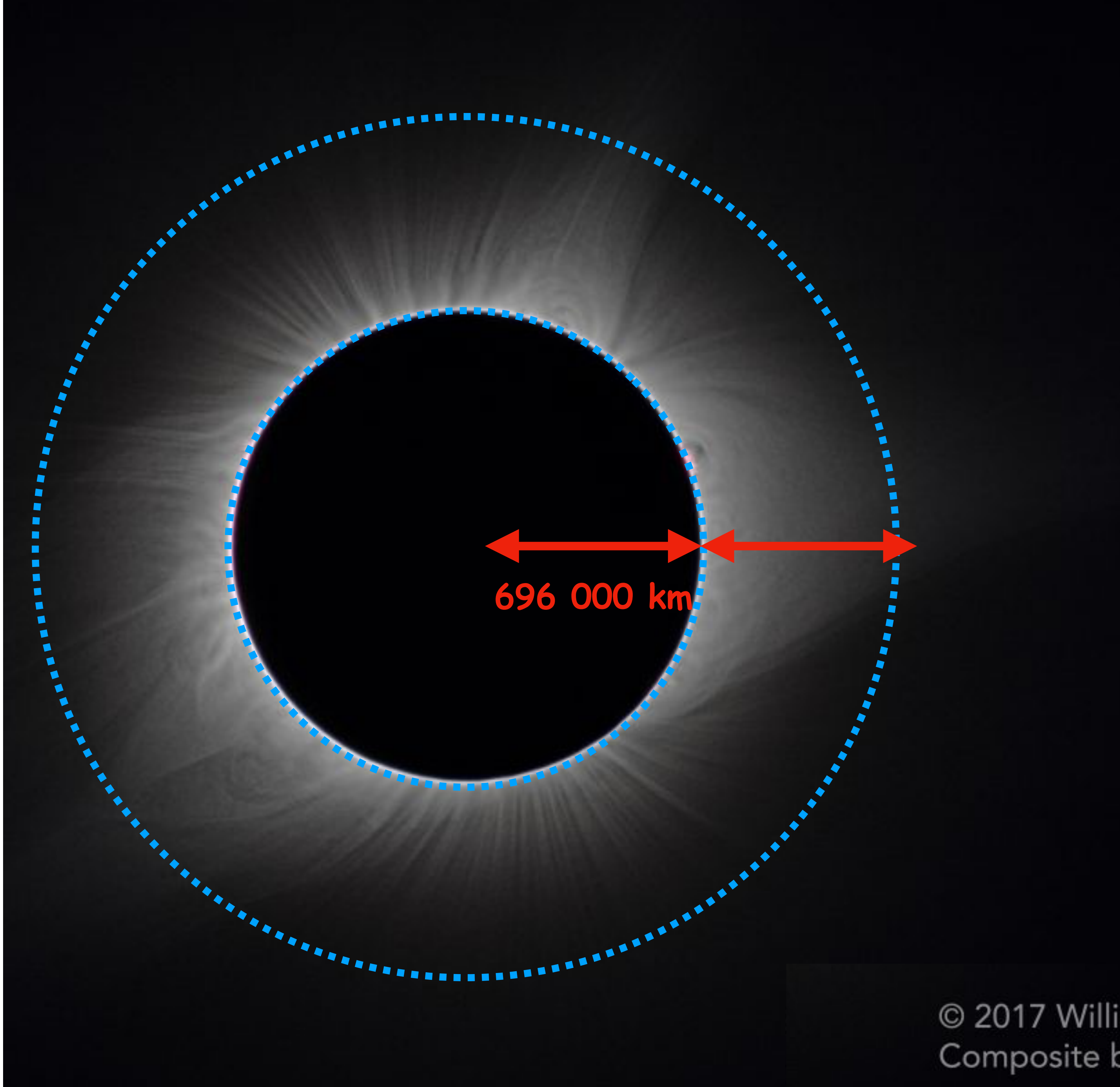
$$H = \frac{kT}{Mg}$$

g= 270 m/s^2

M=1

T= 5700

H=270km



$$P = P_0 e^{(-\frac{z}{H})}$$

$$H = \frac{kT}{Mg}$$

g= 270 m/s^2

M=1

~~T= 5700~~

>1 million C

H=270km

Eclipse 1999, Hungary

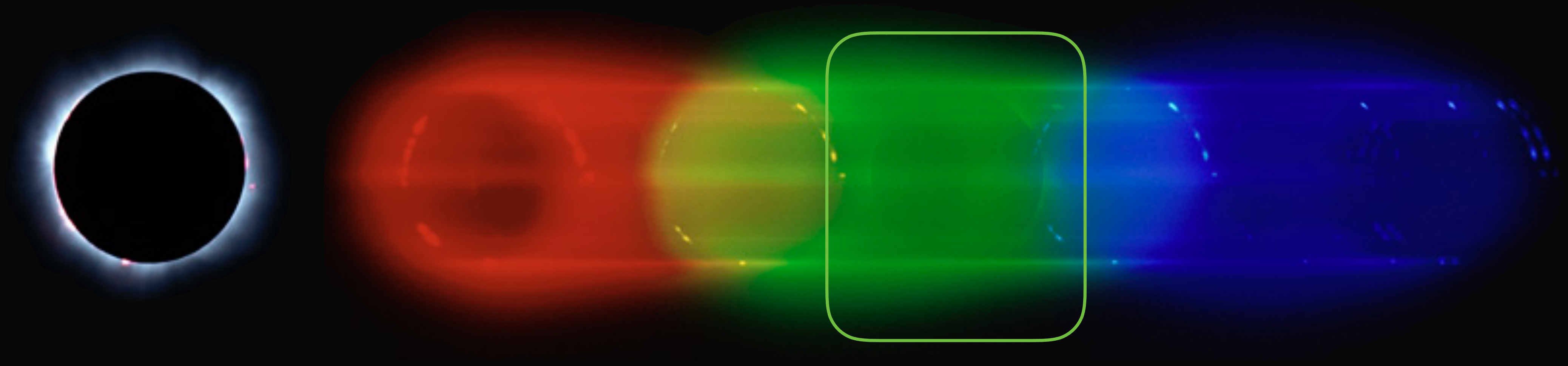
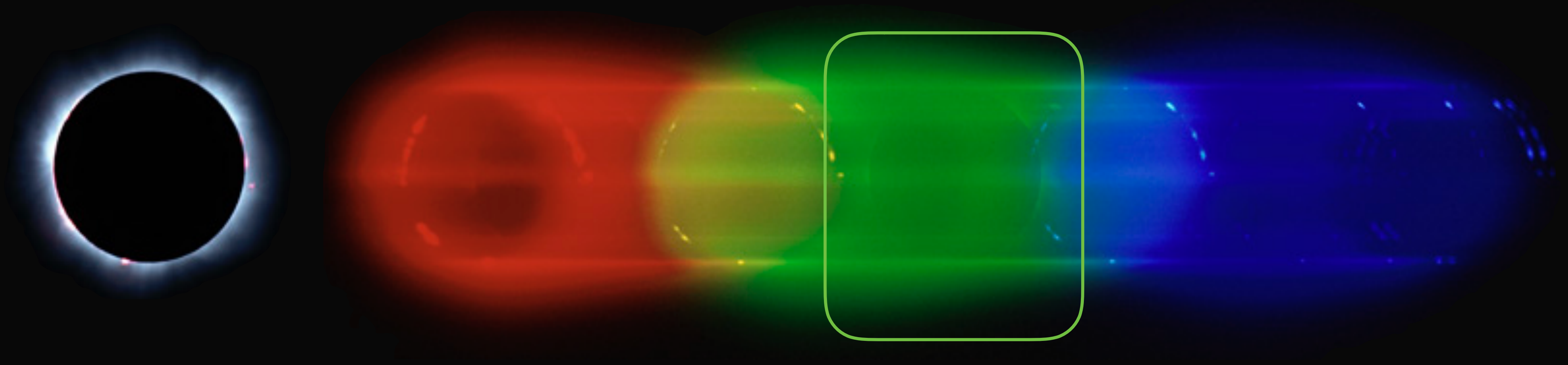


Image Courtesy www.eurastro.de/webpages/MRSPECT.HTM

Eclipse 1999, Hungary



530.3nm

~~Coronium~~

Bengt Edlen: Fe XIV

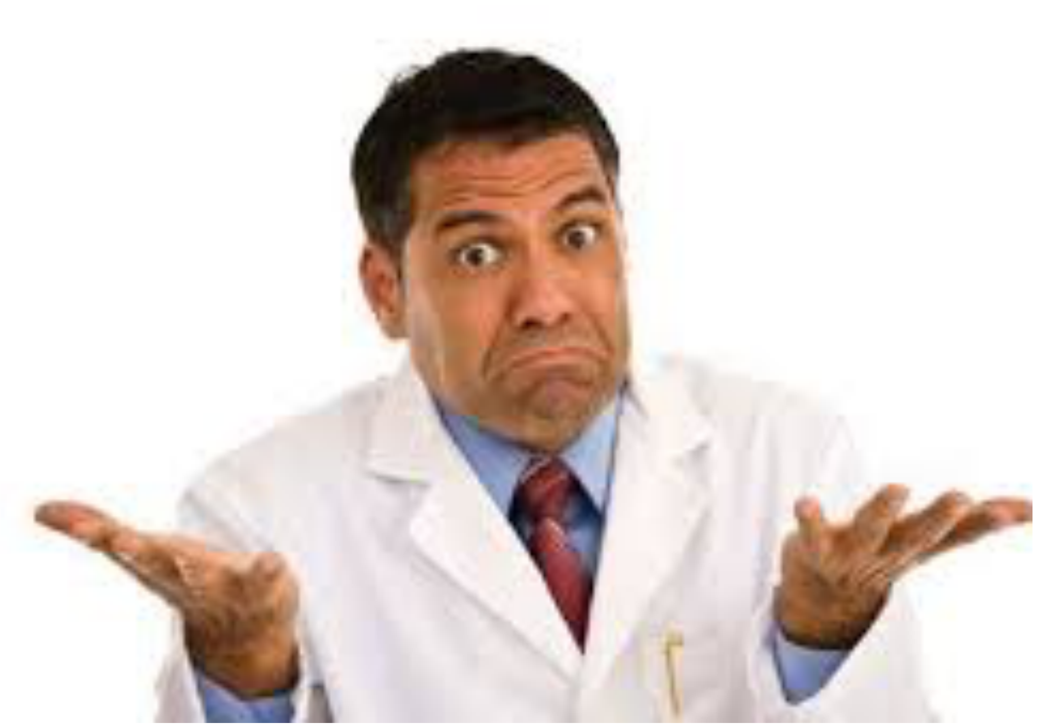
Image Courtesy www.eurastro.de/webpages/MRSPECT.HTM

The corona is big & hot

So what?

The corona is big & hot

So what?

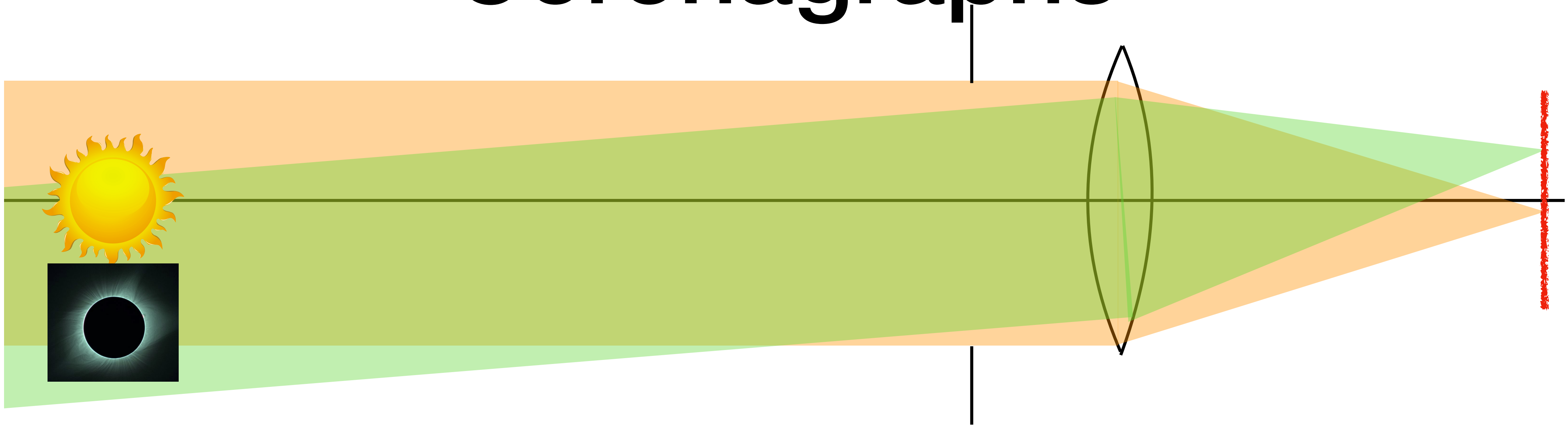


Studying the hot solar corona helps to understand

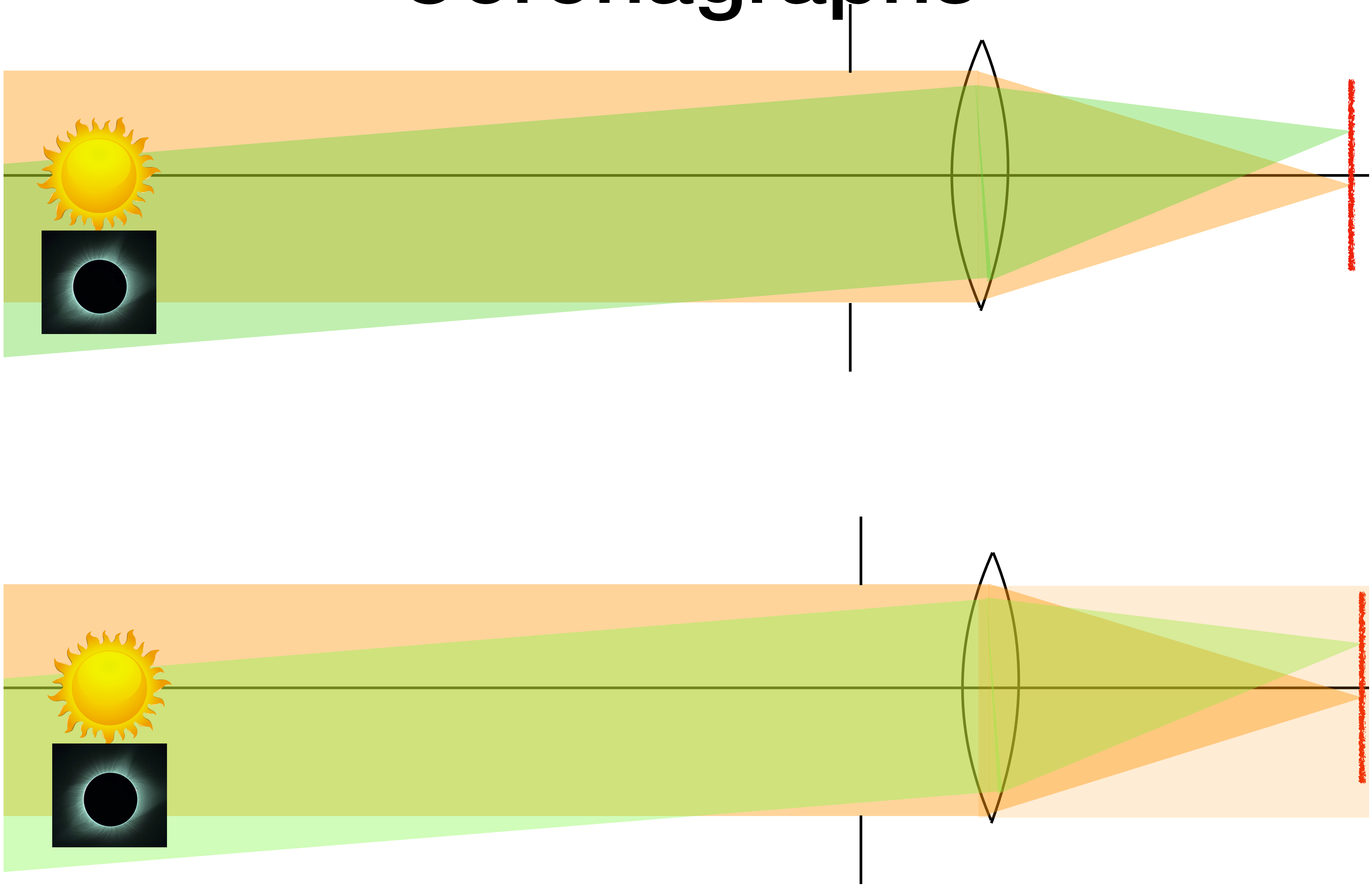
- other star's atmosphere
- atomic physics, plasma physics and perhaps nuclear fusion
- the influence of solar activity on the Earth

Coronagraphs.
Why is imaging the corona hard?

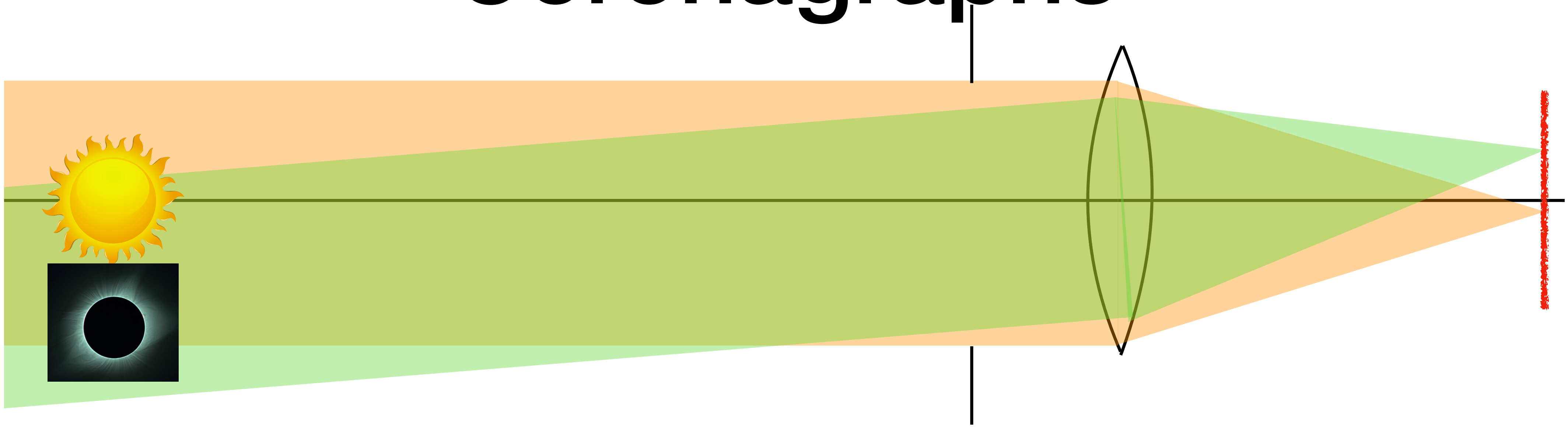
Coronagraphs

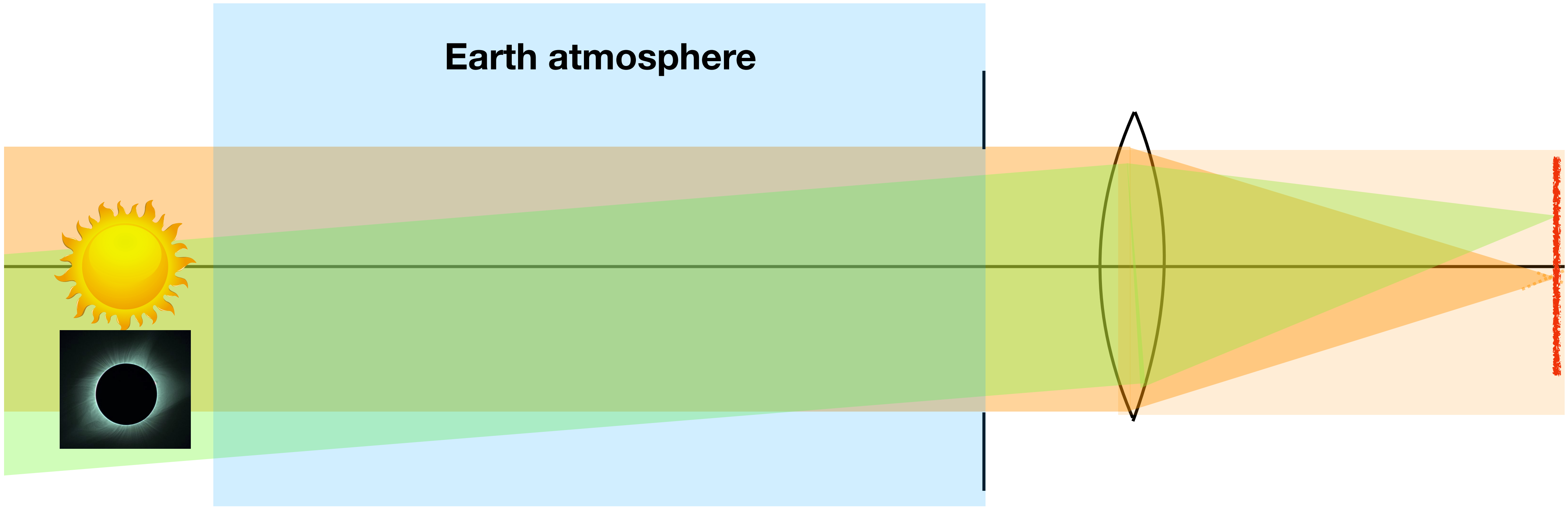


Coronagraphs

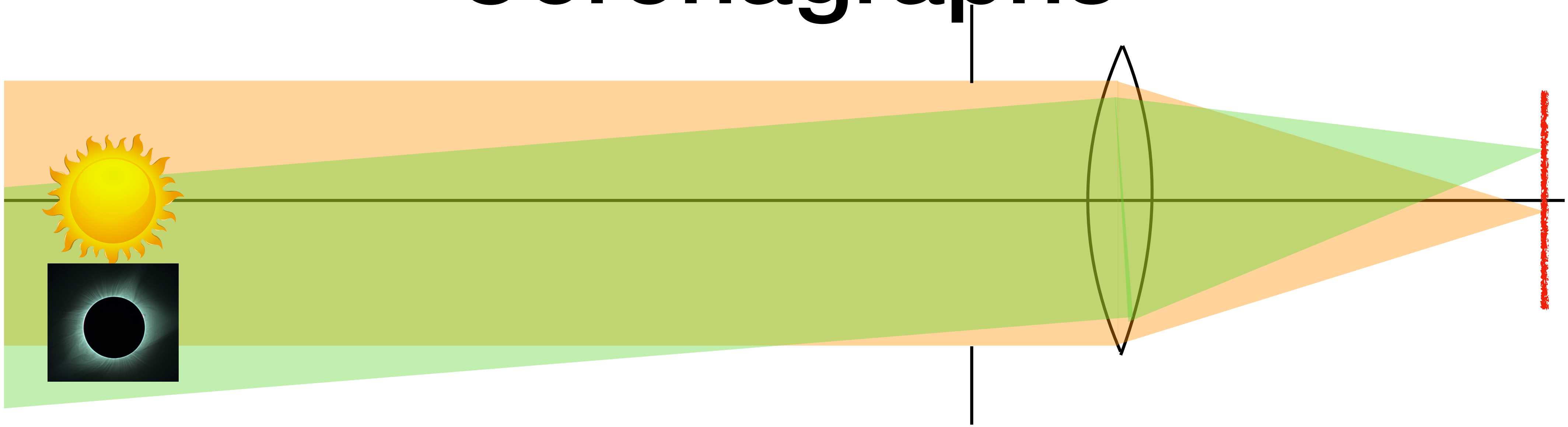


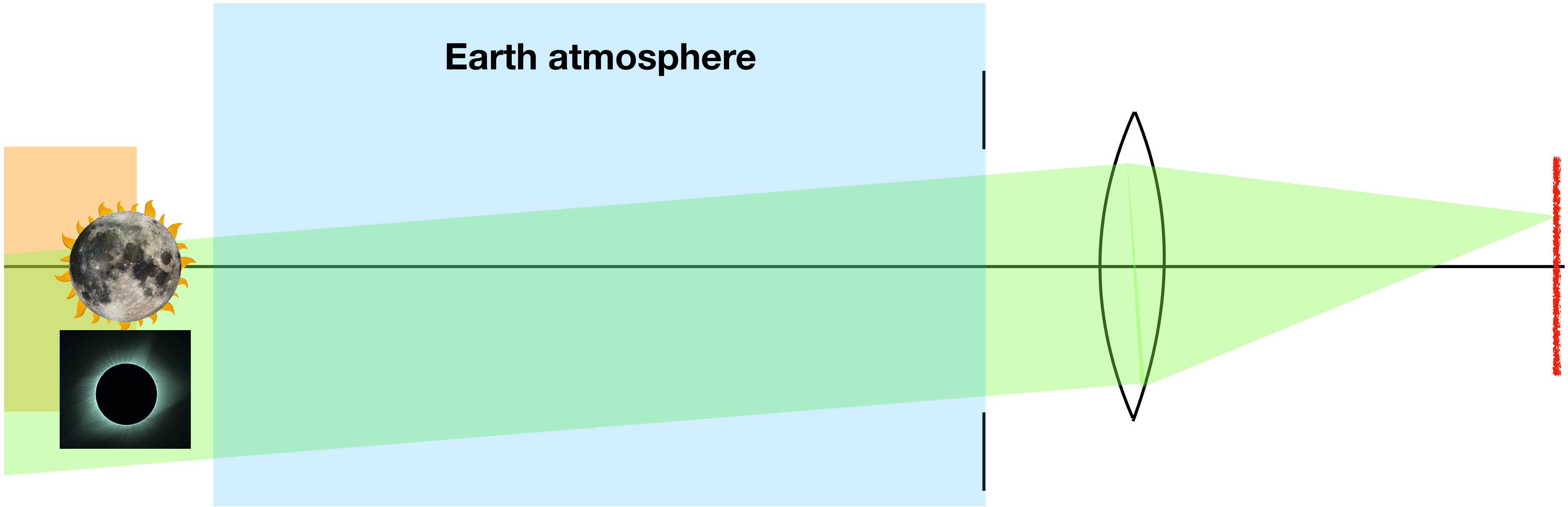
Coronagraphs



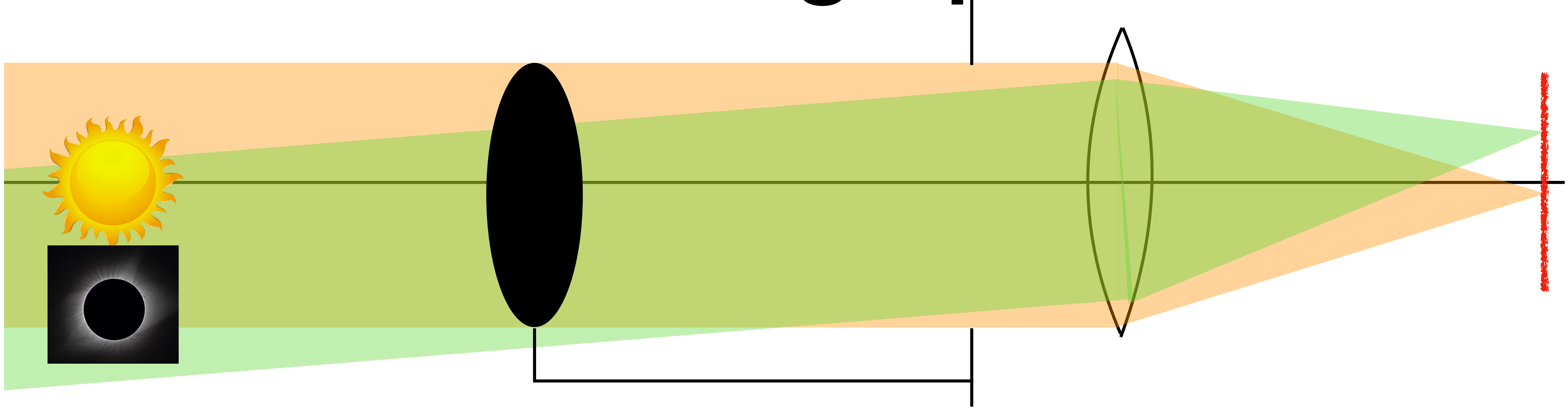


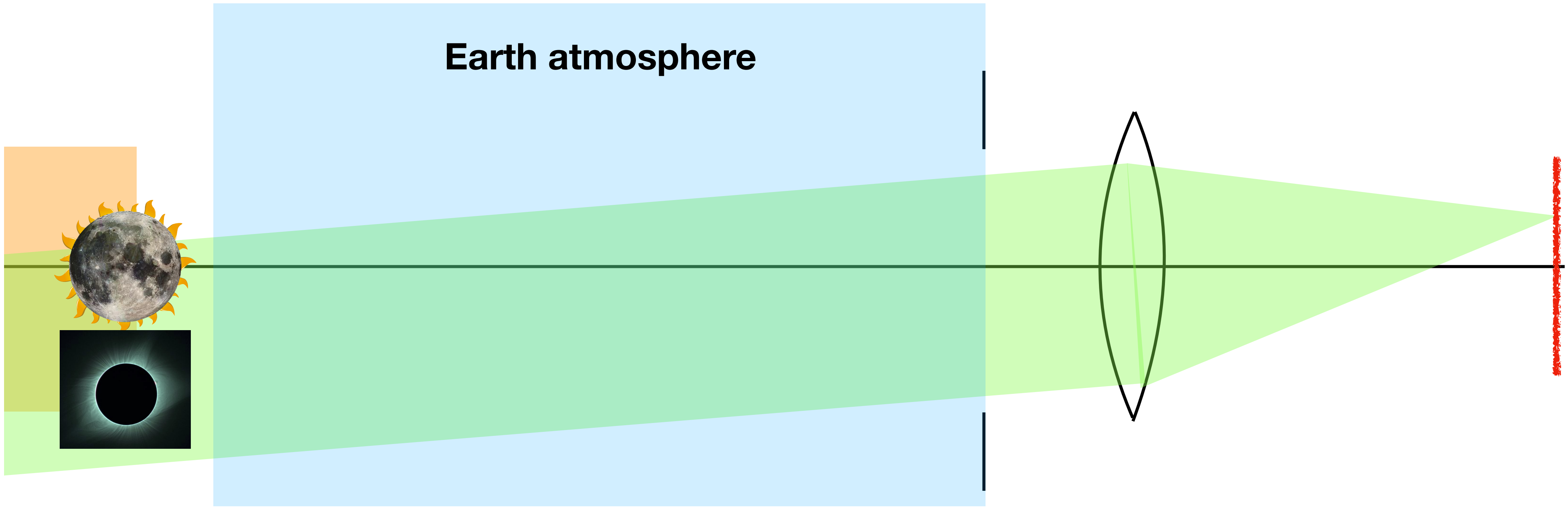
Coronagraphs



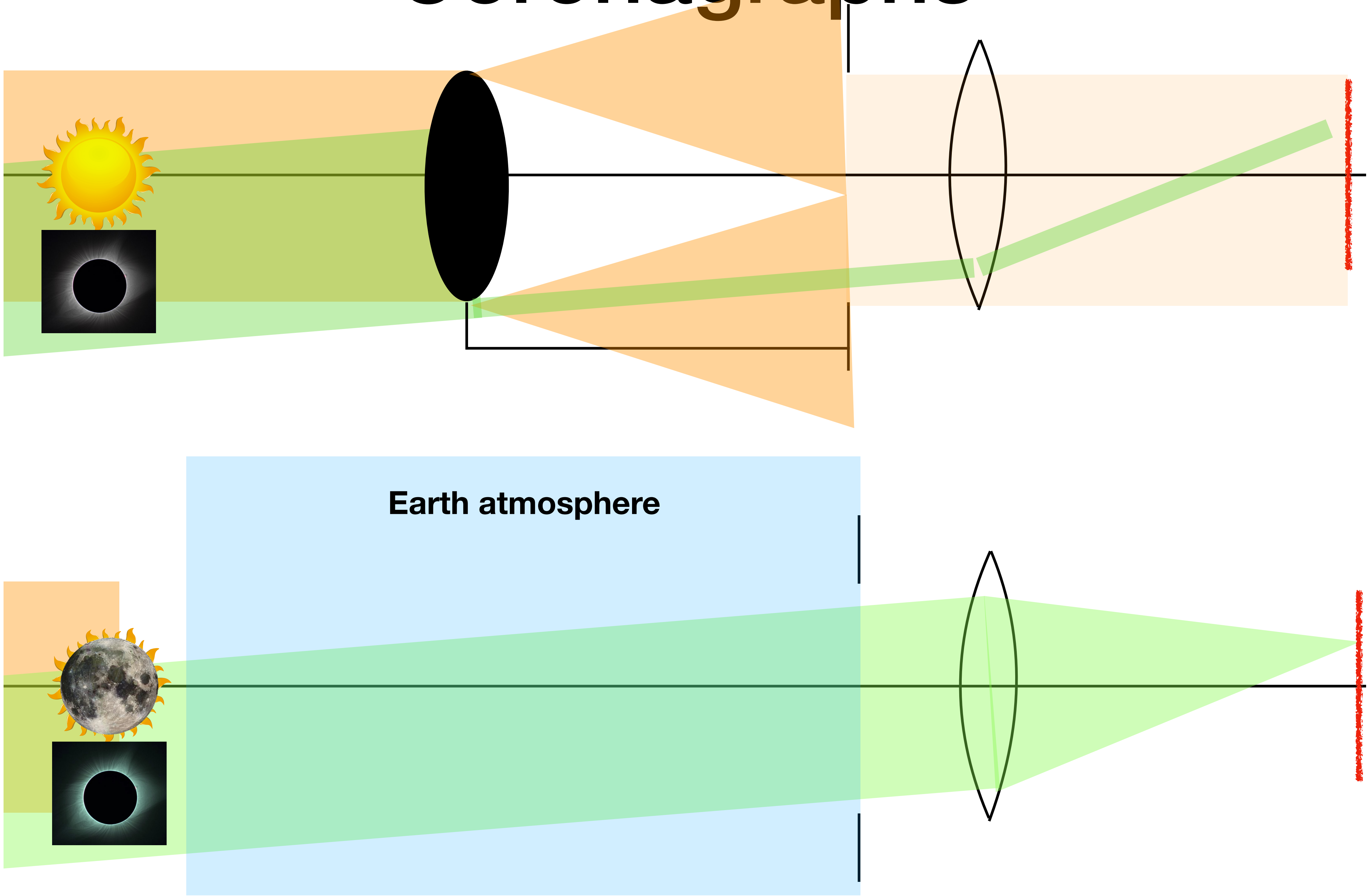


Coronagraphs

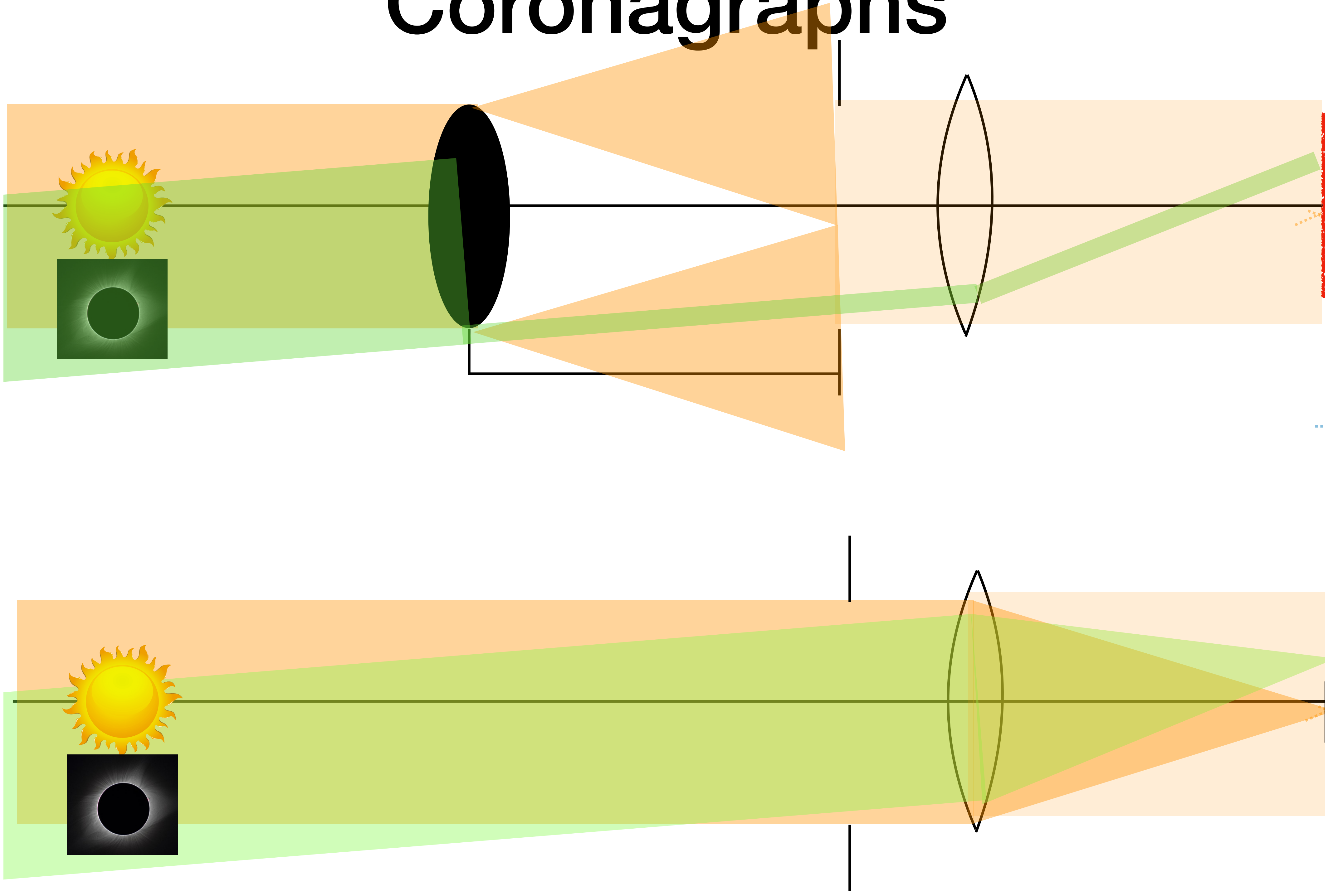


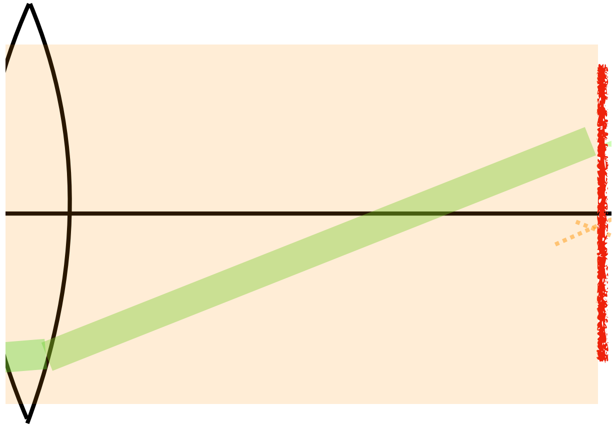


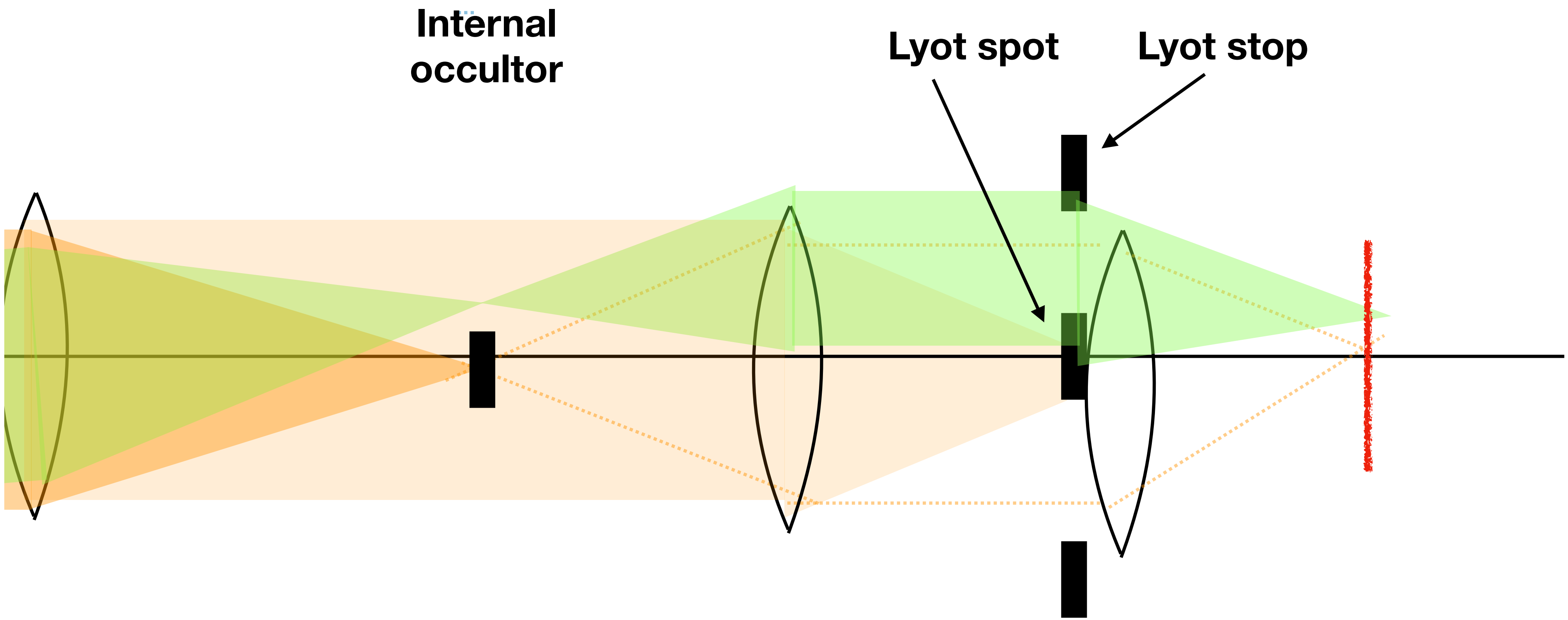
Coronagraphs

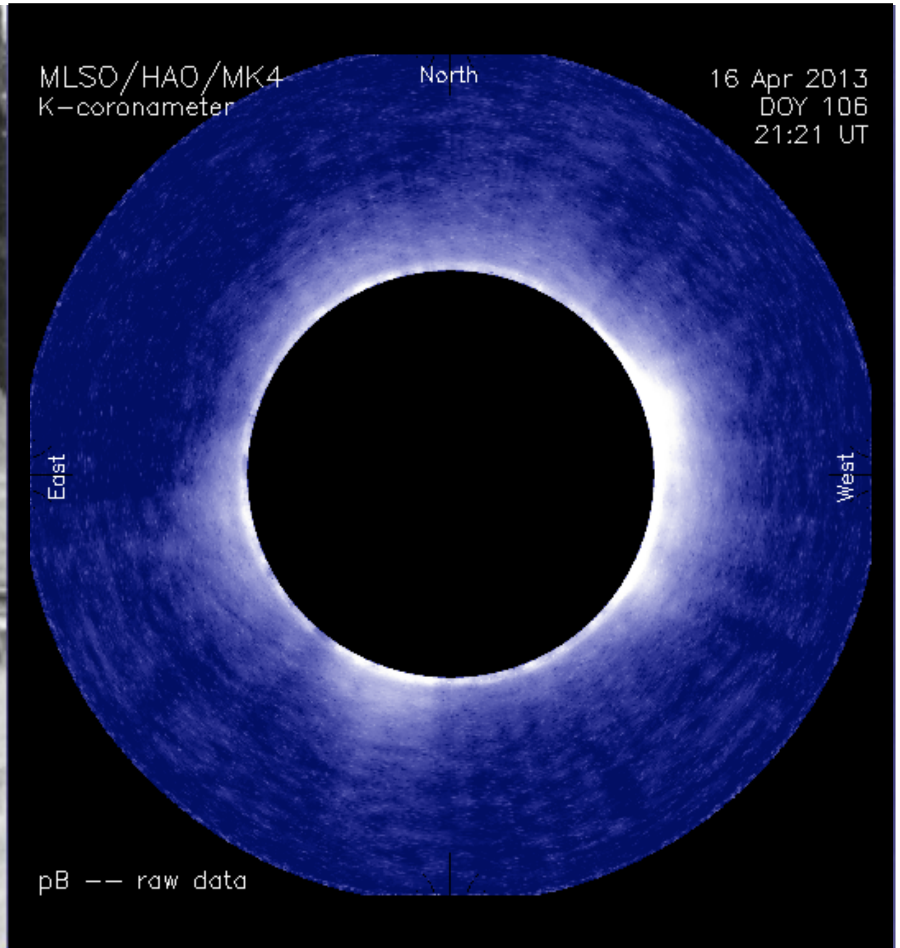


Coronagraphs



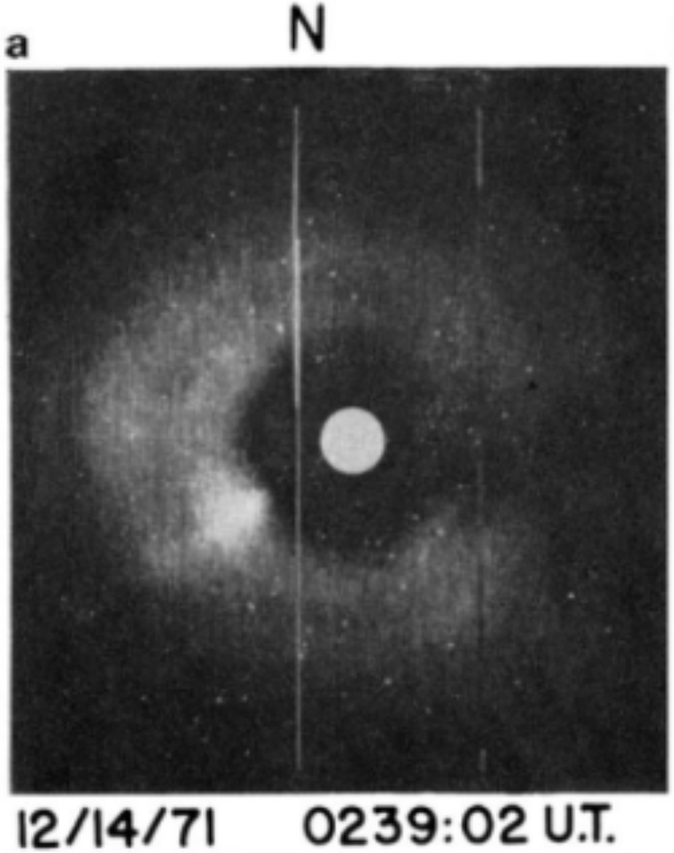



Internal occultor
Lyot spot
Lyot stop

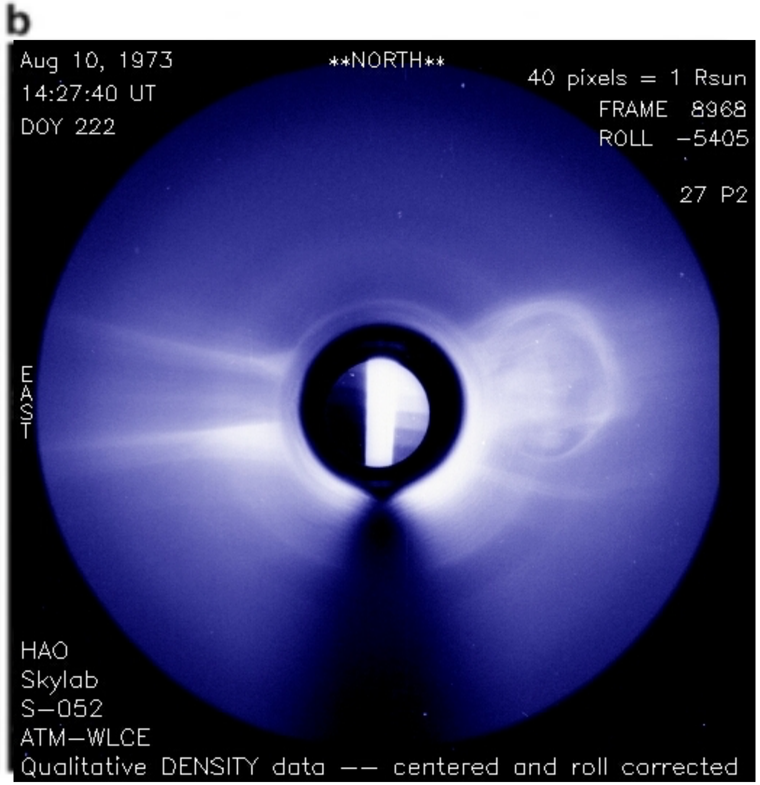


Bernard Lyot, 1939, at Pic du Midi
French Astronomer
Inventor of the Coronagraph

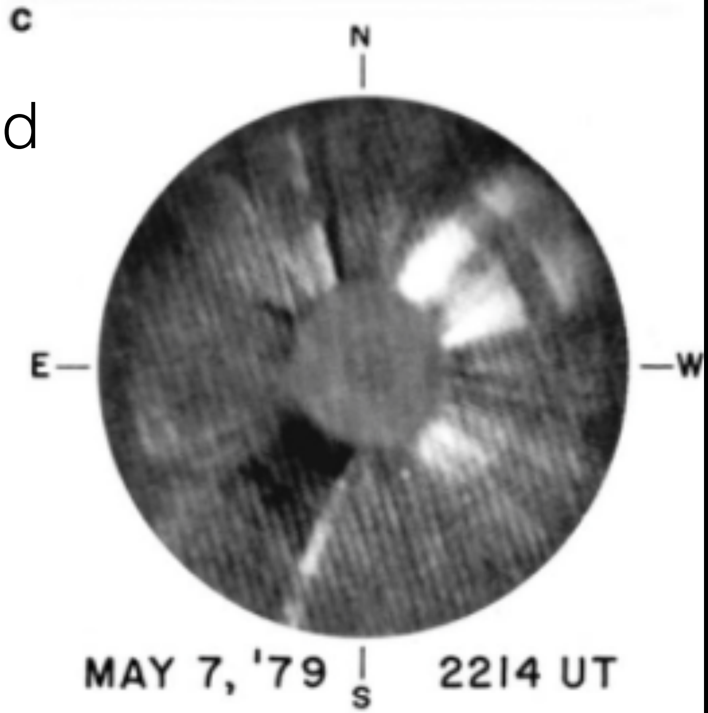
OSO-7
Dec 1971



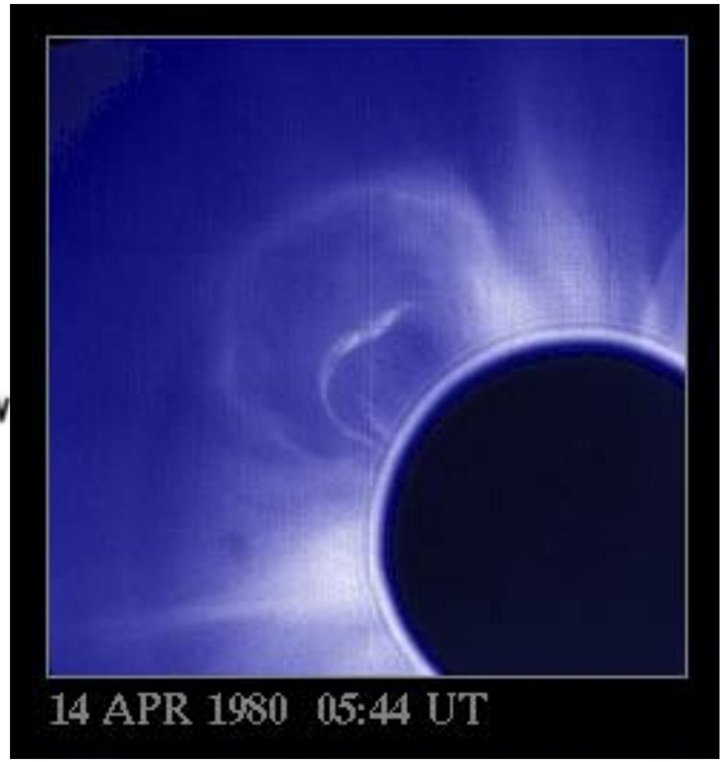
Skylab
Aug 1973



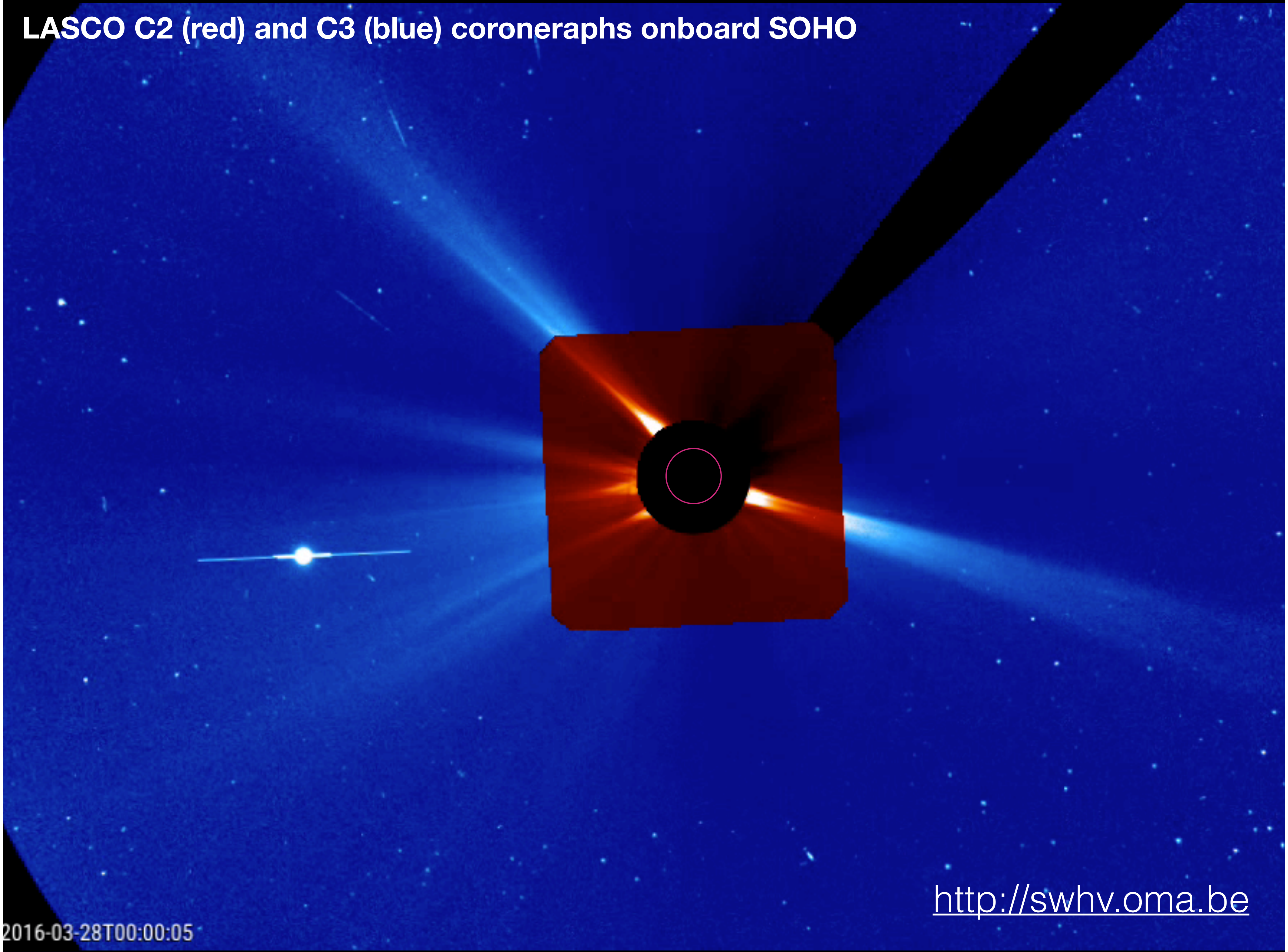
P78/Solwind
May 1979



SMM/C/P
April 1980



LASCO C2 (red) and C3 (blue) coroneraphs onboard SOHO

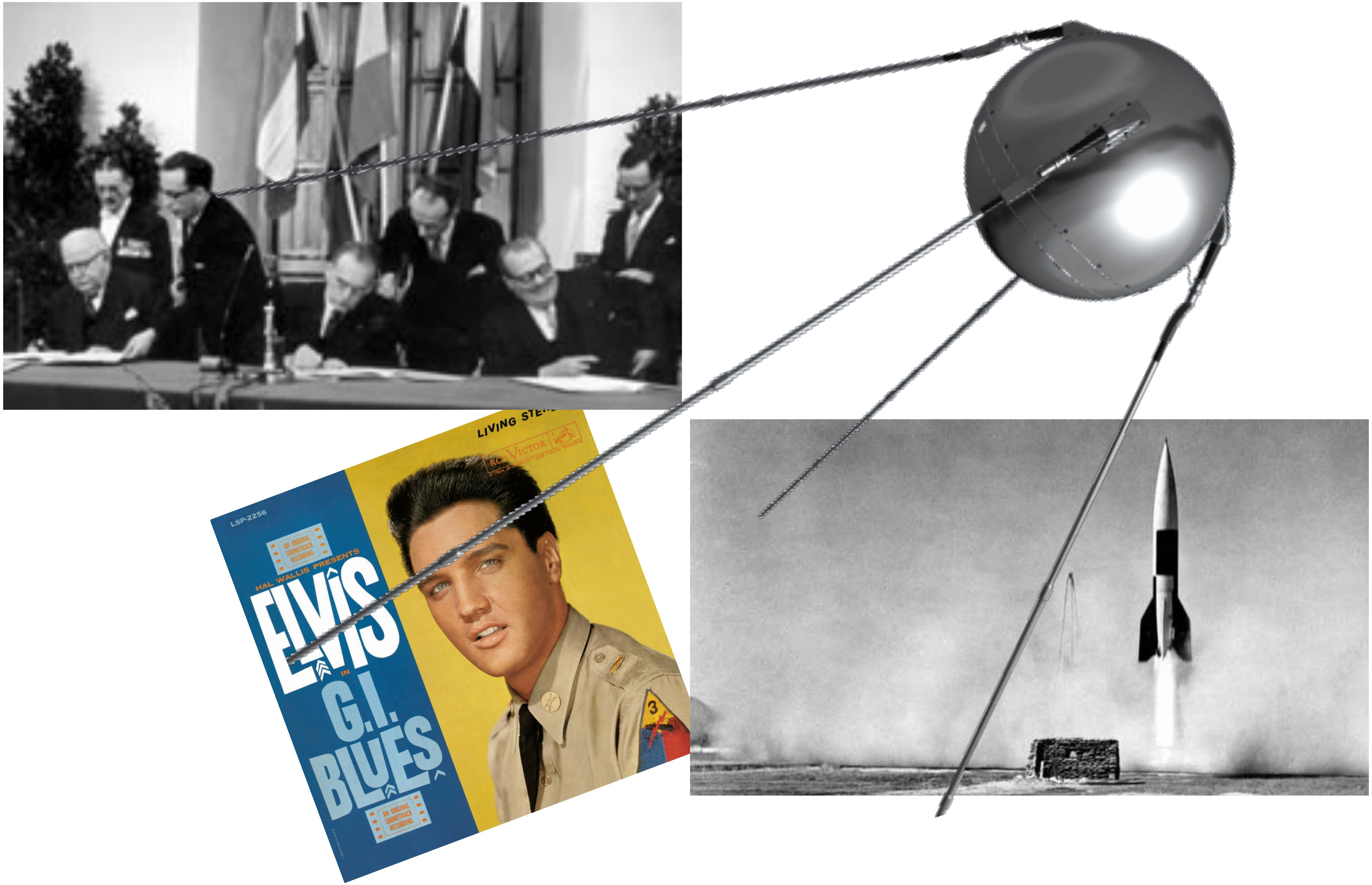


http://swhv.oma.be

EUV imagers

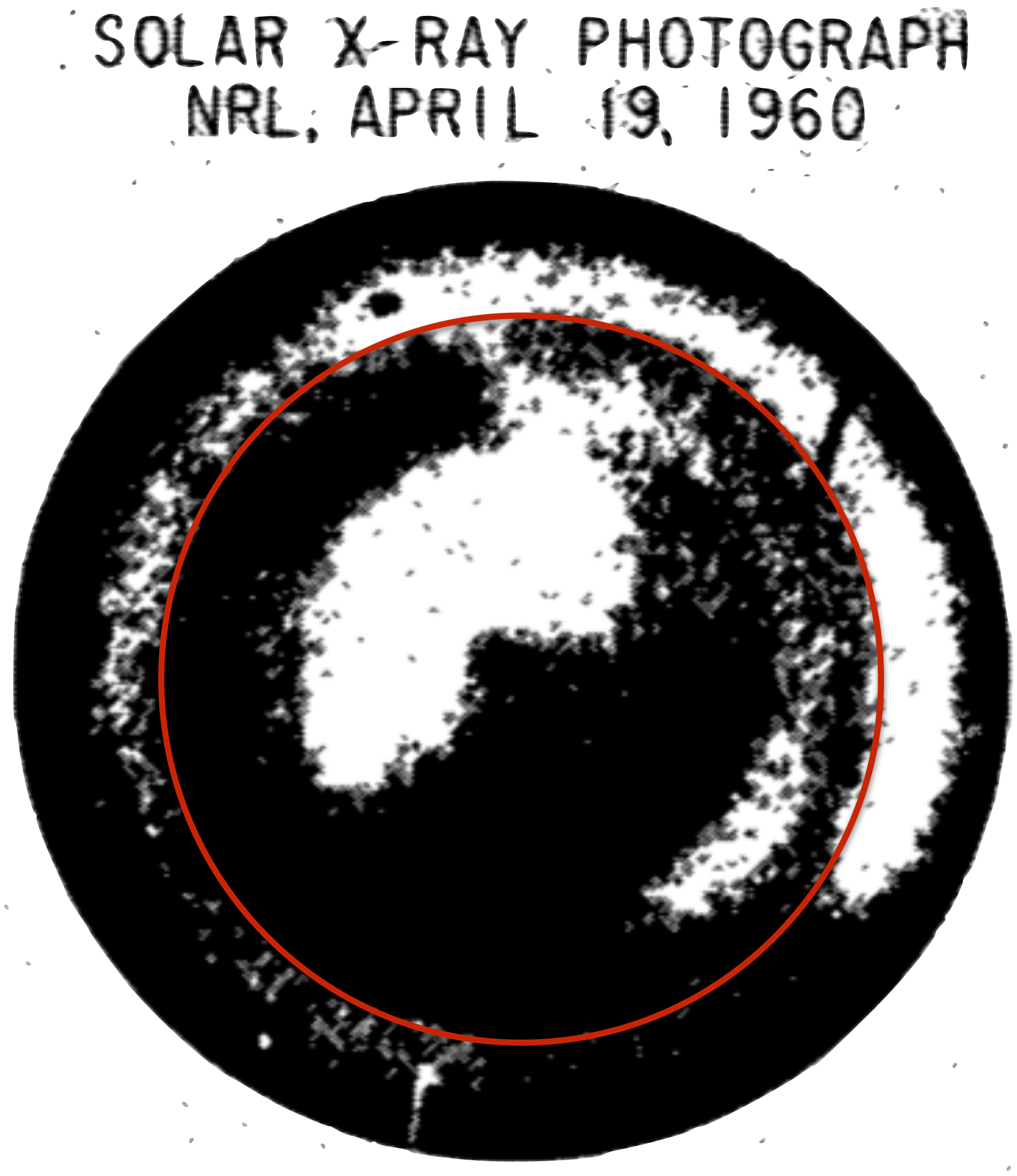
What does the corona look like under the occultor?

The beginning of the space age



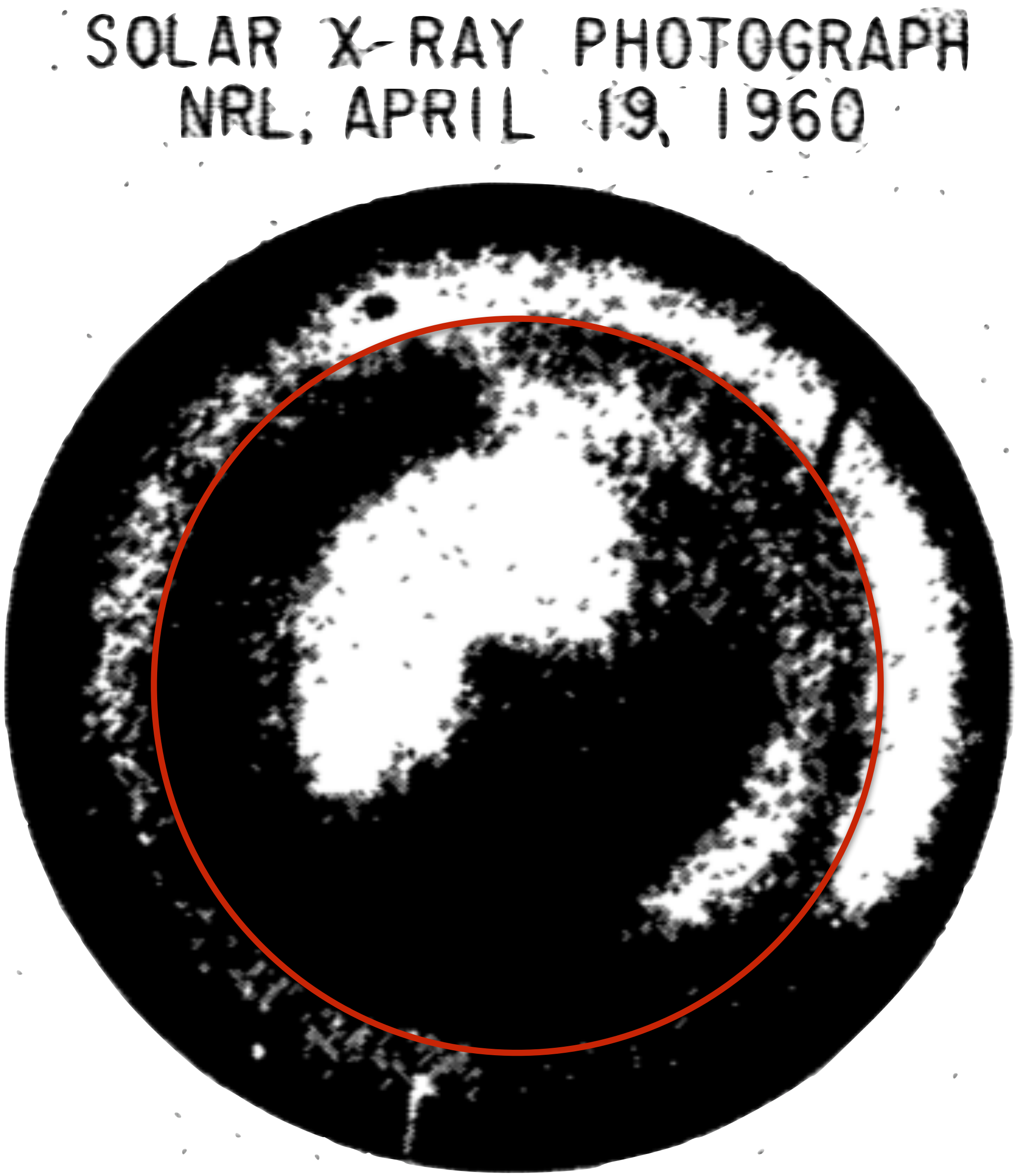
Pinhole camera

Friedman (1963) IAUS, 16, 45

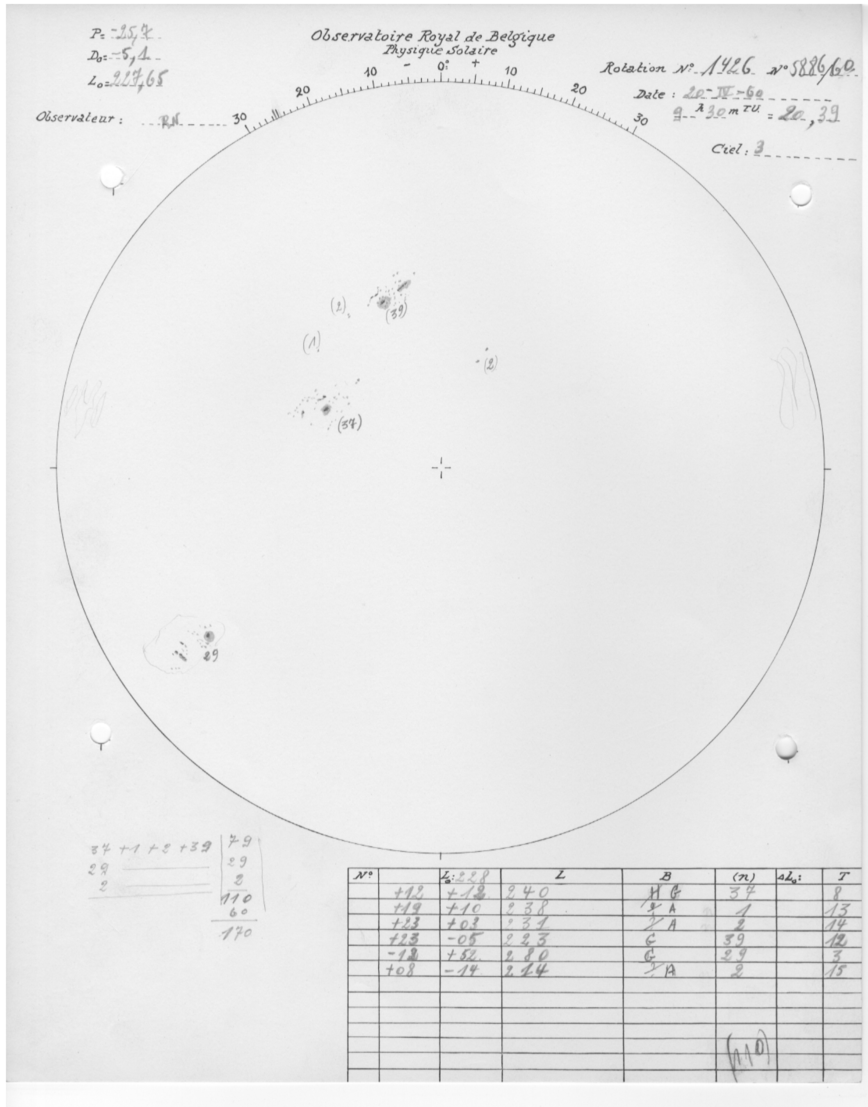


Pinhole camera

Friedman (1963) IAUS, 16, 45



Pinhole camera

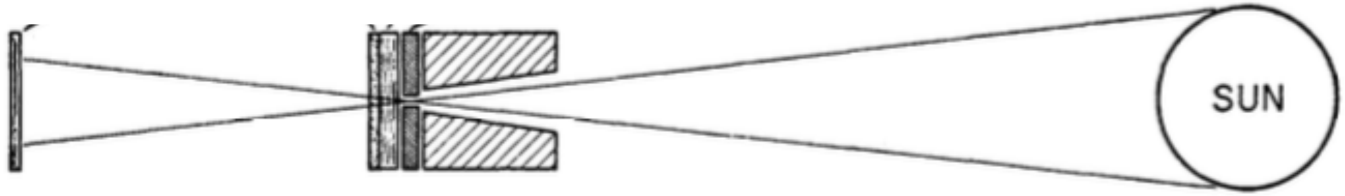


April 20 1960 Sunspot drawing
from Royal observatory of Belgium

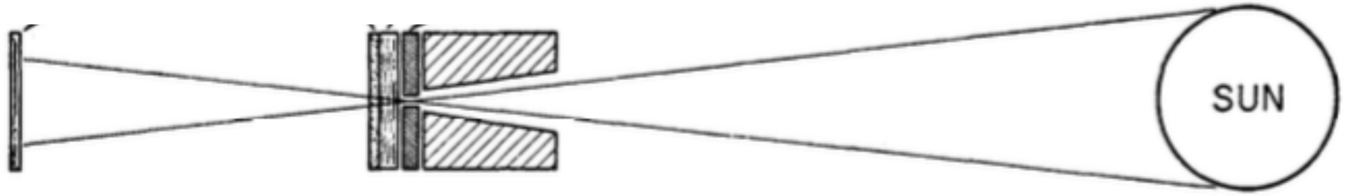
[Friedman (1963) IAUS](), 16, 45

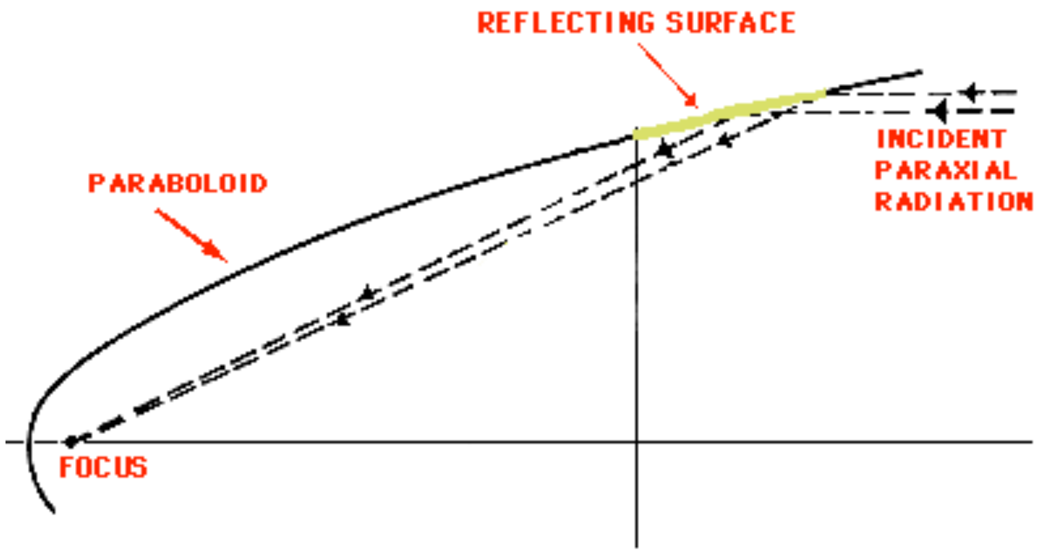
April 20 1960 Sunspot drawing
from Royal observatory of Belgium
Richard Nuttinck, André Koeckelenbergh

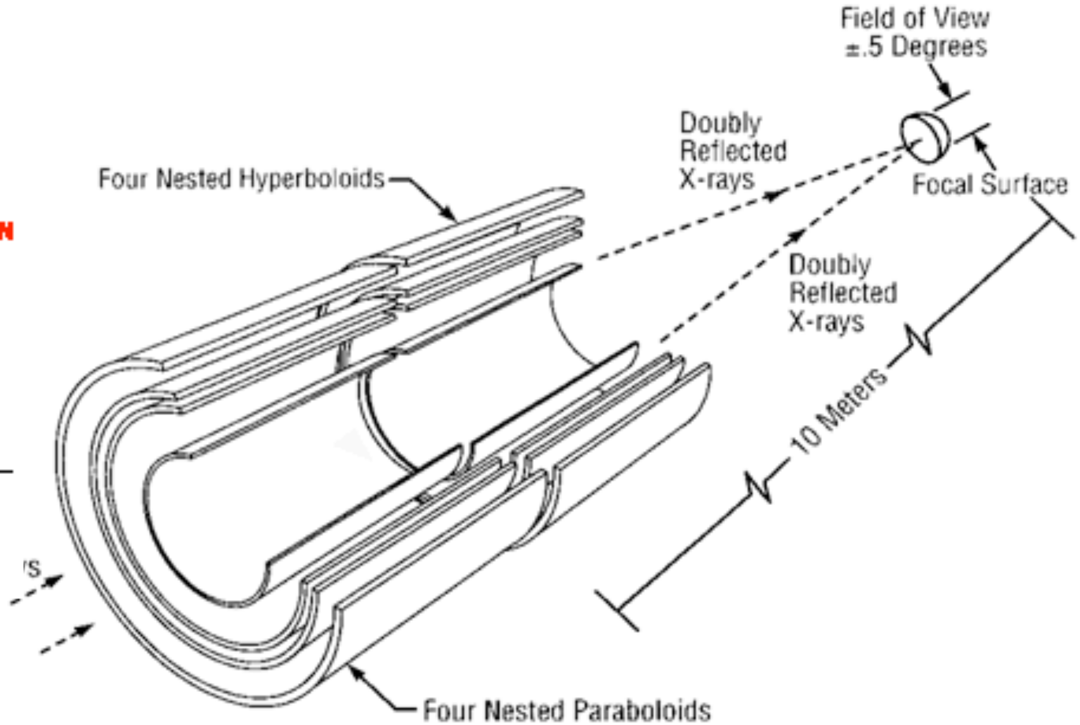
Focussing X-rays is hard



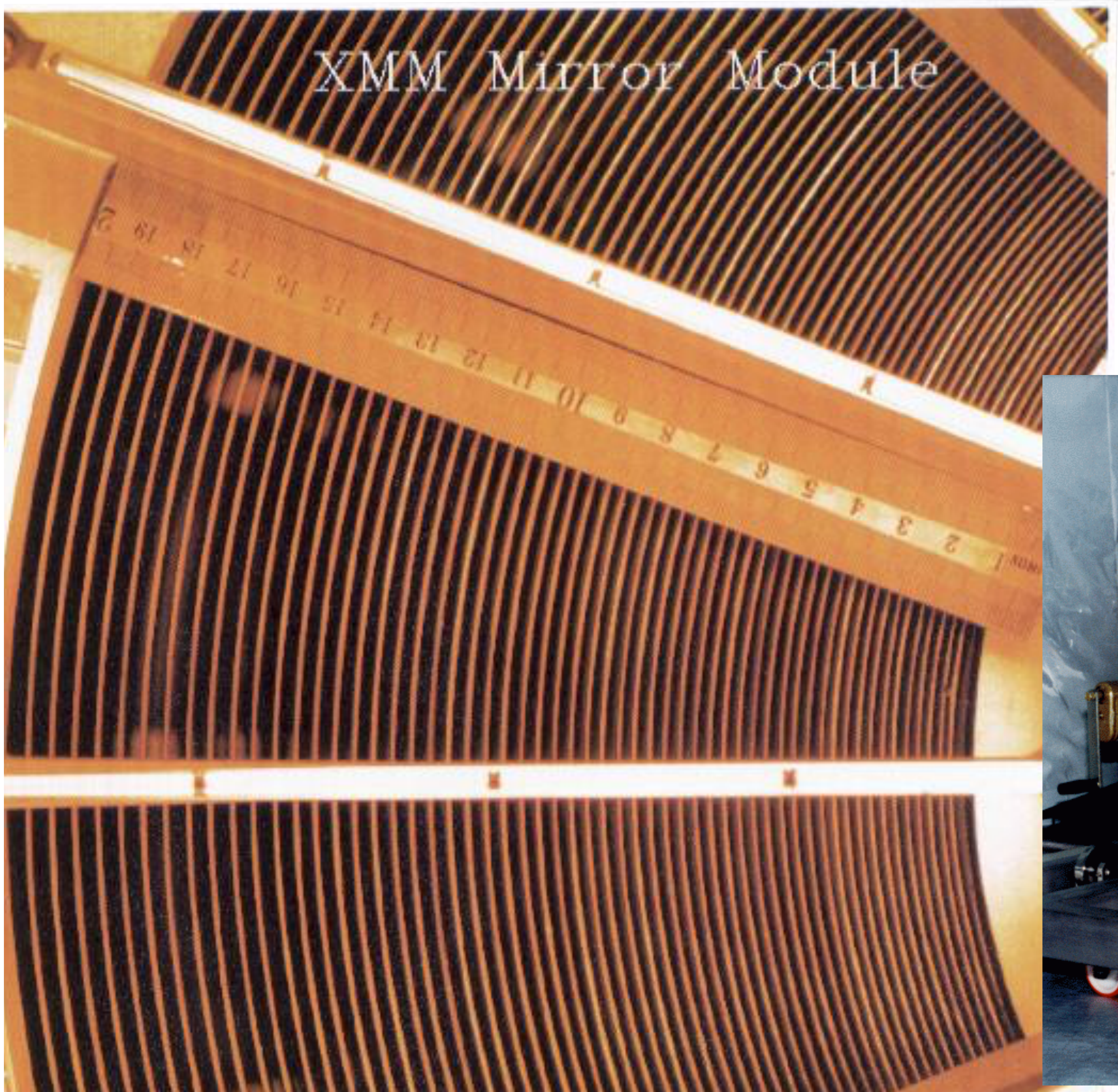
Focussing X-rays is hard

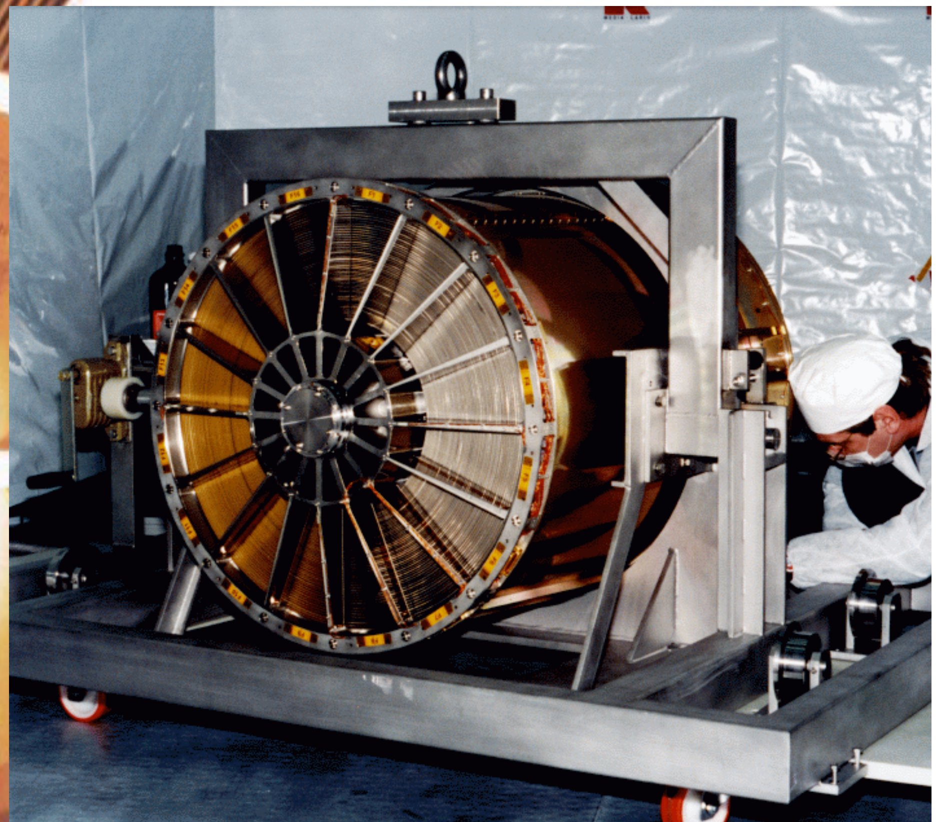




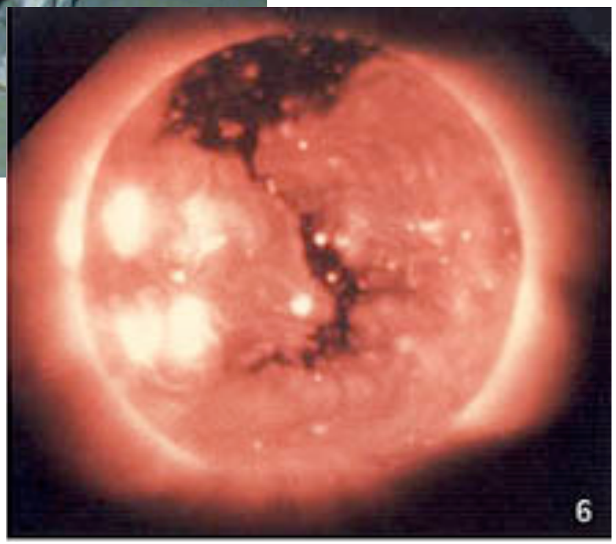


XMM mirrors during tests at Centre Spatial de Liege



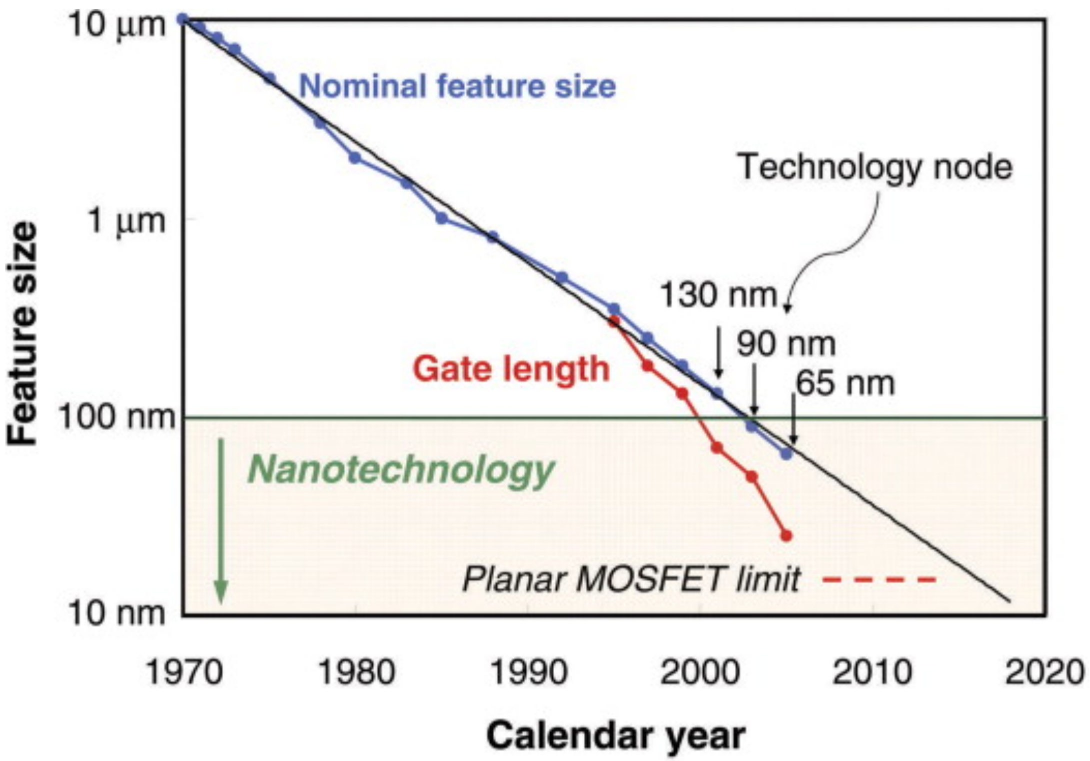


Skylab (1973-74)

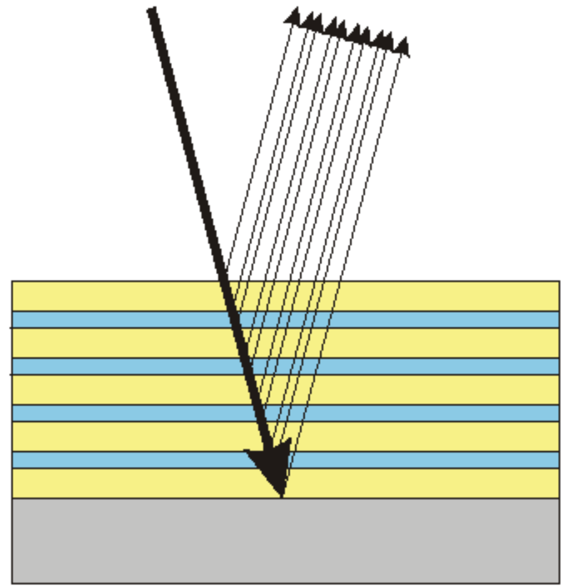


http://history.nasa.gov/SP-402/ch1.htm

1990s: EUV lithography develops normal incidence EUV optics



"EUV light at 13.5 nanometers can etch features as small as 100 nanometers across,"

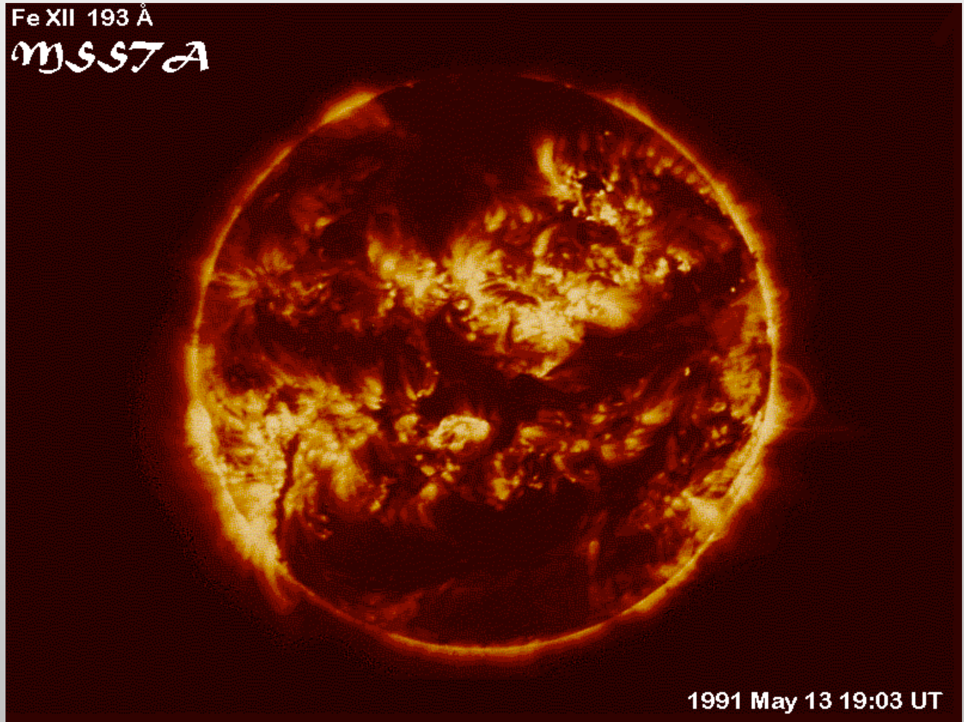


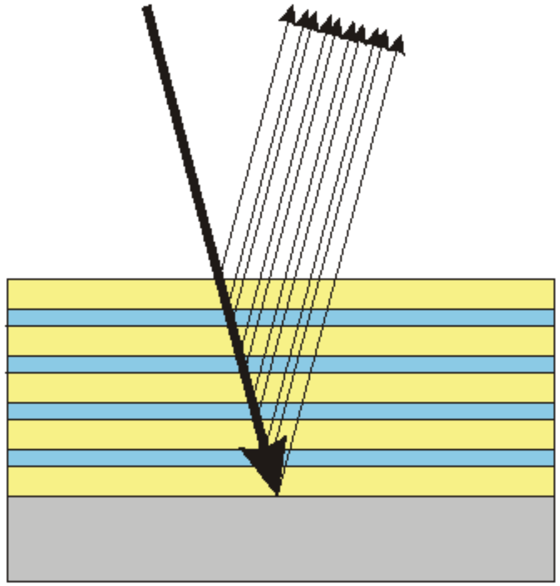
Molybdenum:
heavy scatter element that absorbs EUV strongly

Silicon:
light element that absorbs EUV only weakly

1990s: EUV lithography develops normal incidence EUV optics

1990's: prototypes on sounding rockets



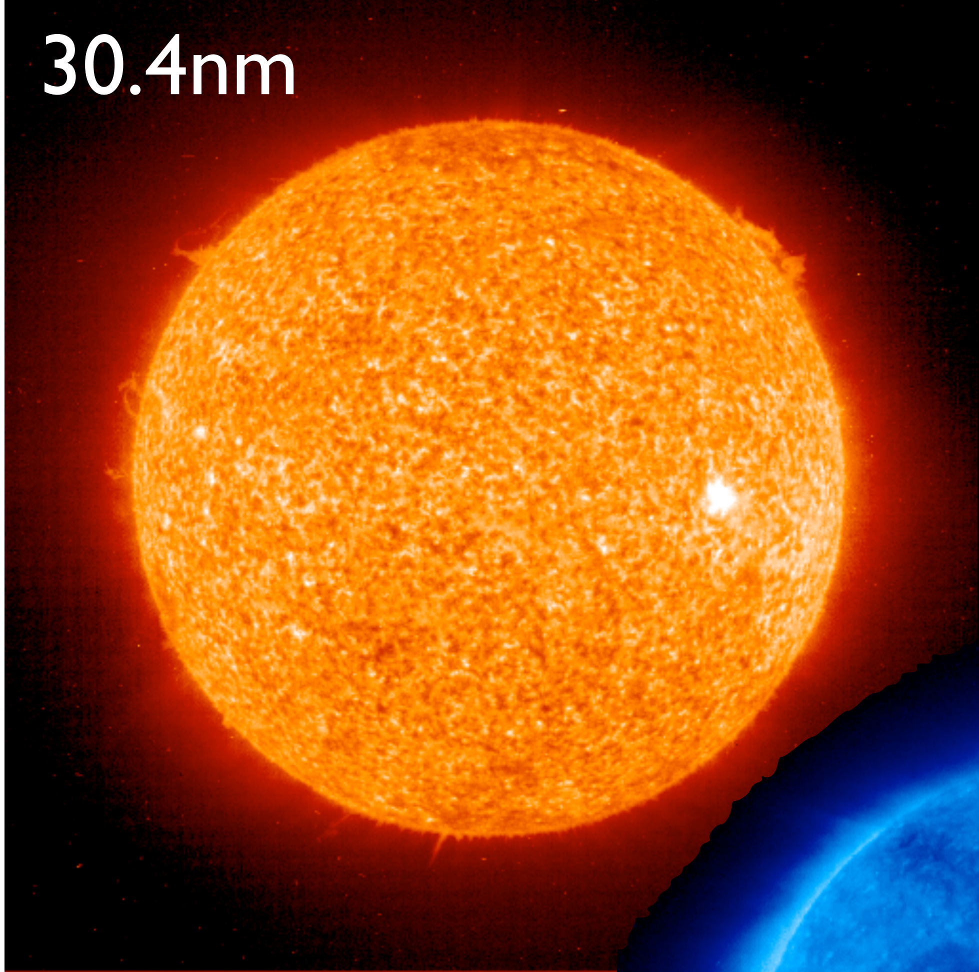


Molybdenum:
heavy scatter element that absorbs EUV strongly

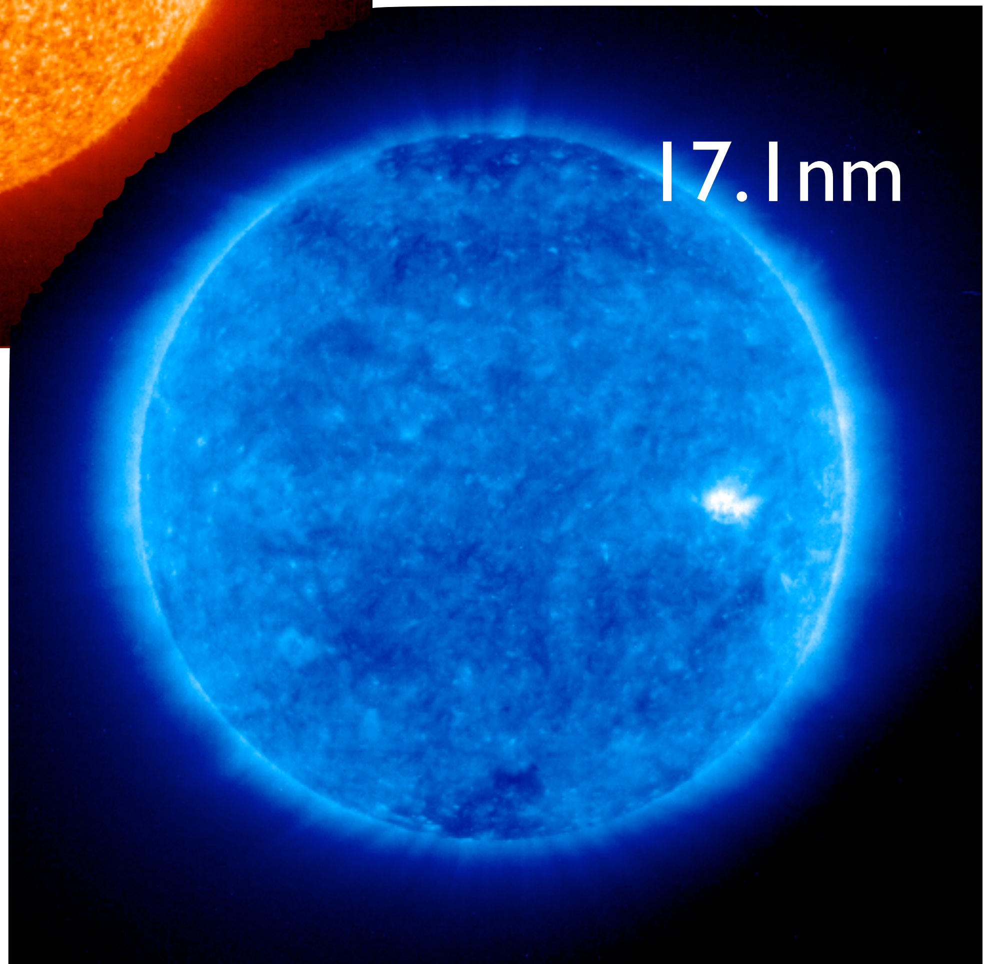
Silicon:
light element that absorbs EUV only weakly

EIT

Extreme ultraviolet
Imaging Telescope

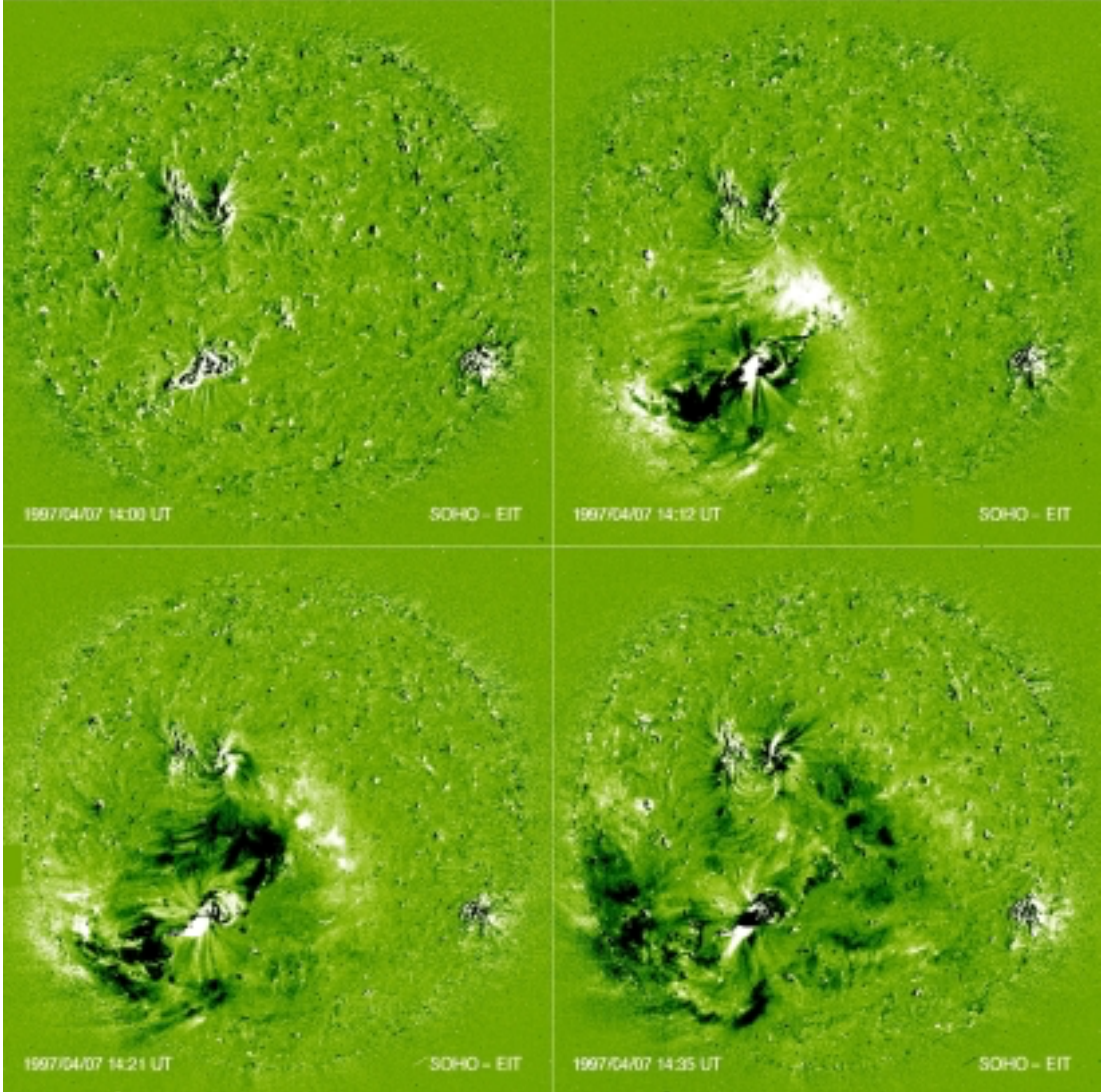


23 layers
Mo: 26.2 Å
Si: 137.8 Å



11 layers
Mo: 36.2 Å
Si: 54.3 Å

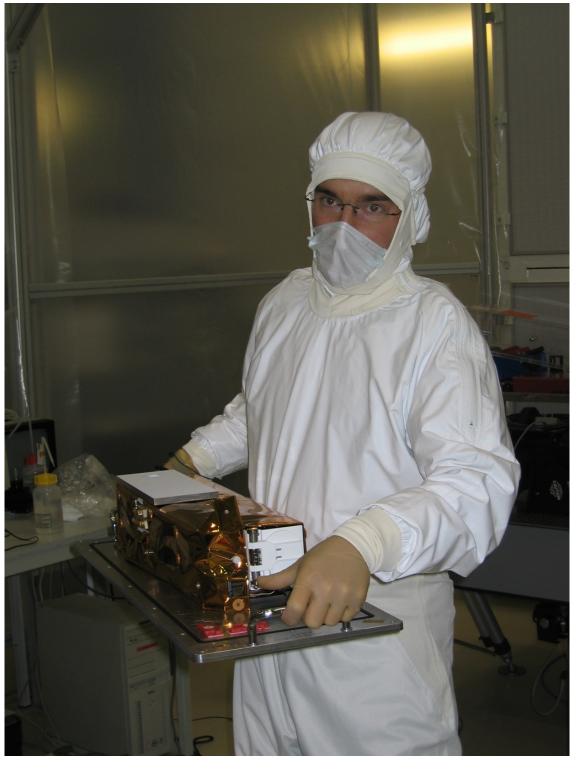
PI: JP Delaboudinière
†2016 June

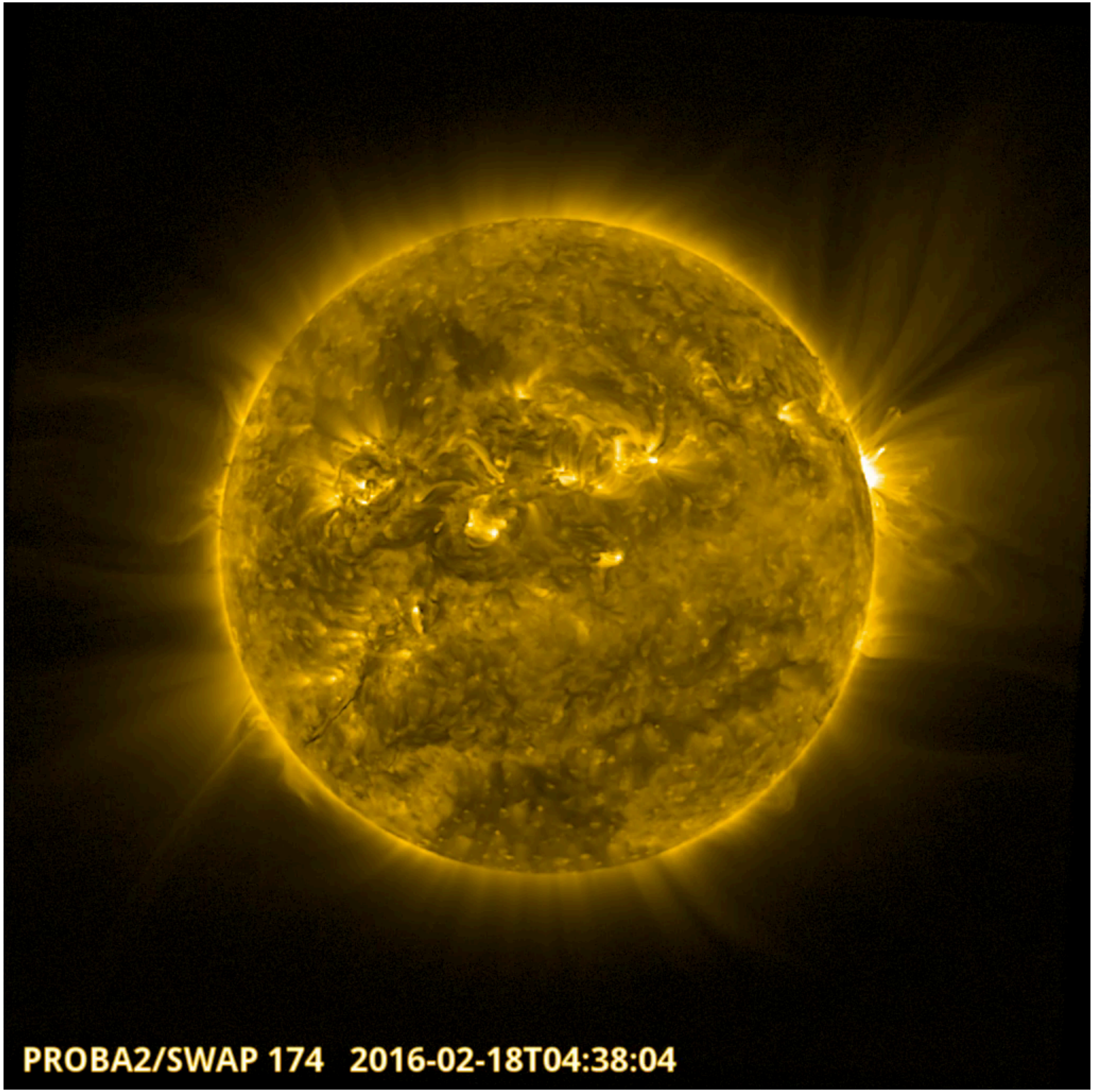

1997/04/07 14:00 UT
SOHO - EIT
1997/04/07 14:12 UT
SOHO - EIT
1997/04/07 14:21 UT
SOHO - EIT
1997/04/07 14:35 UT
SOHO - EIT

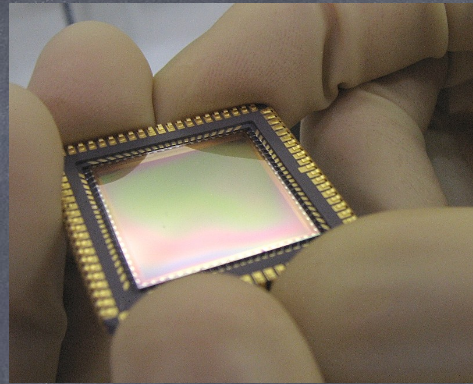
"EIT waves"

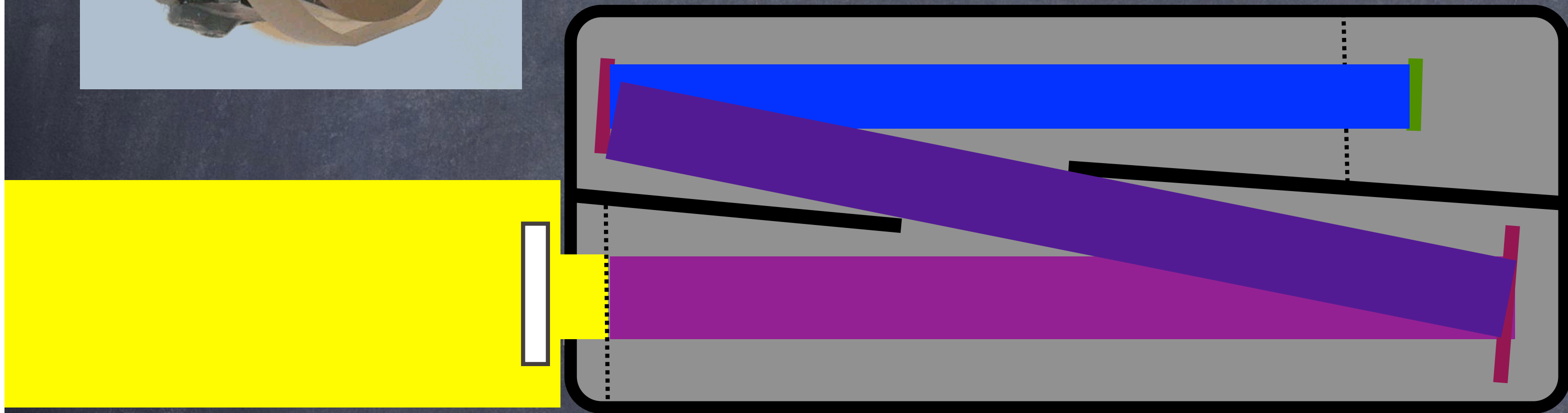
http://proba2.sidc.be

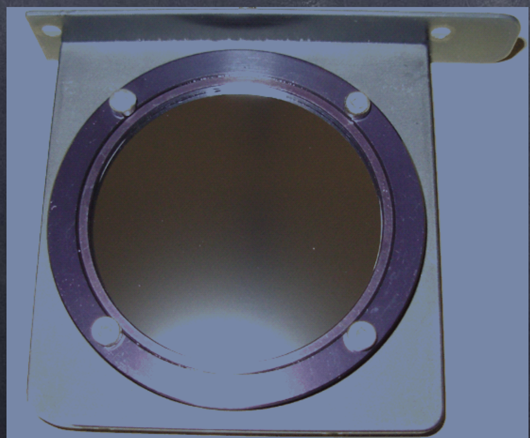
SWAP onboard PROBA2

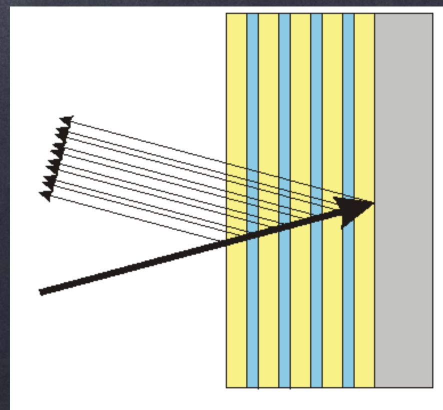




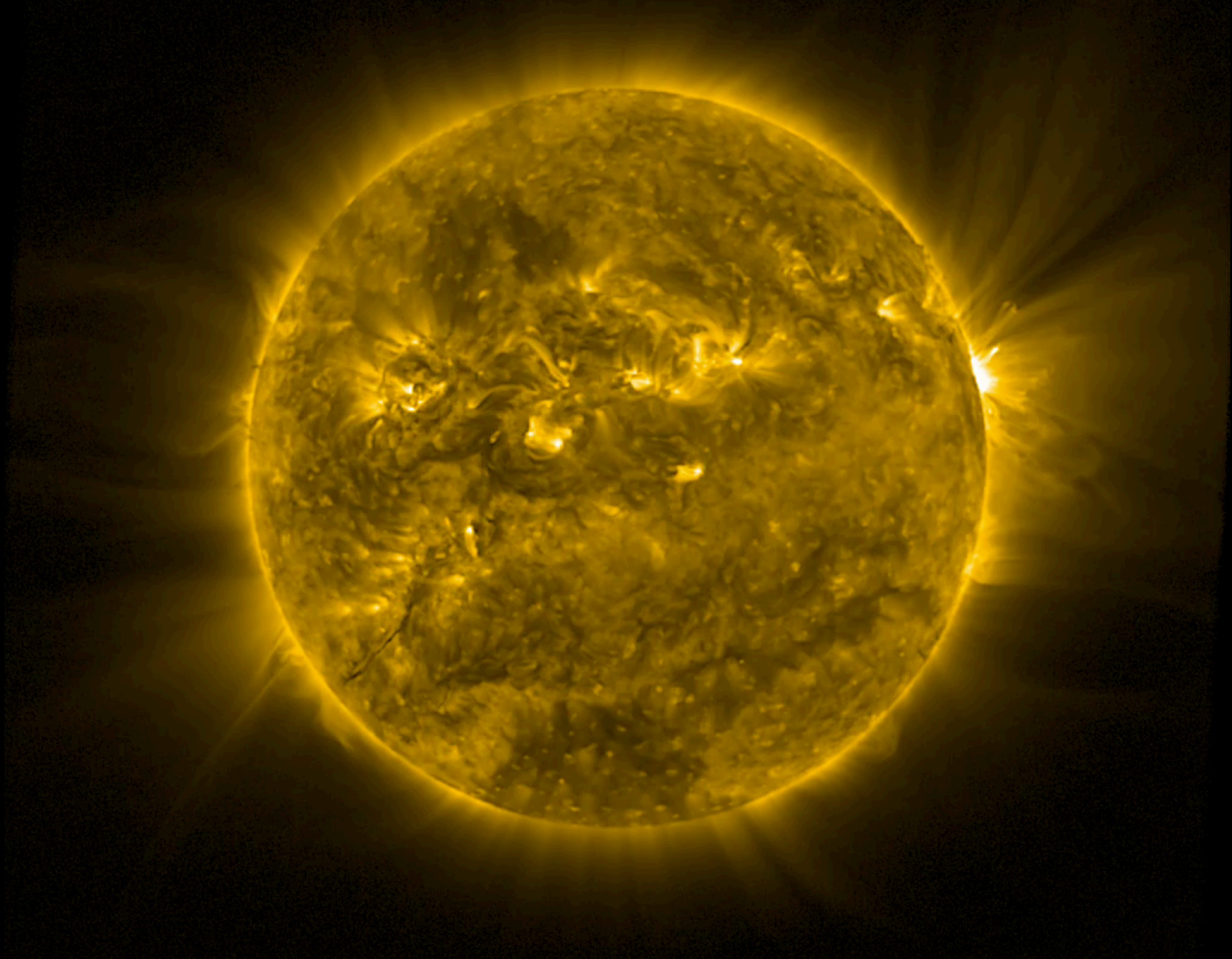


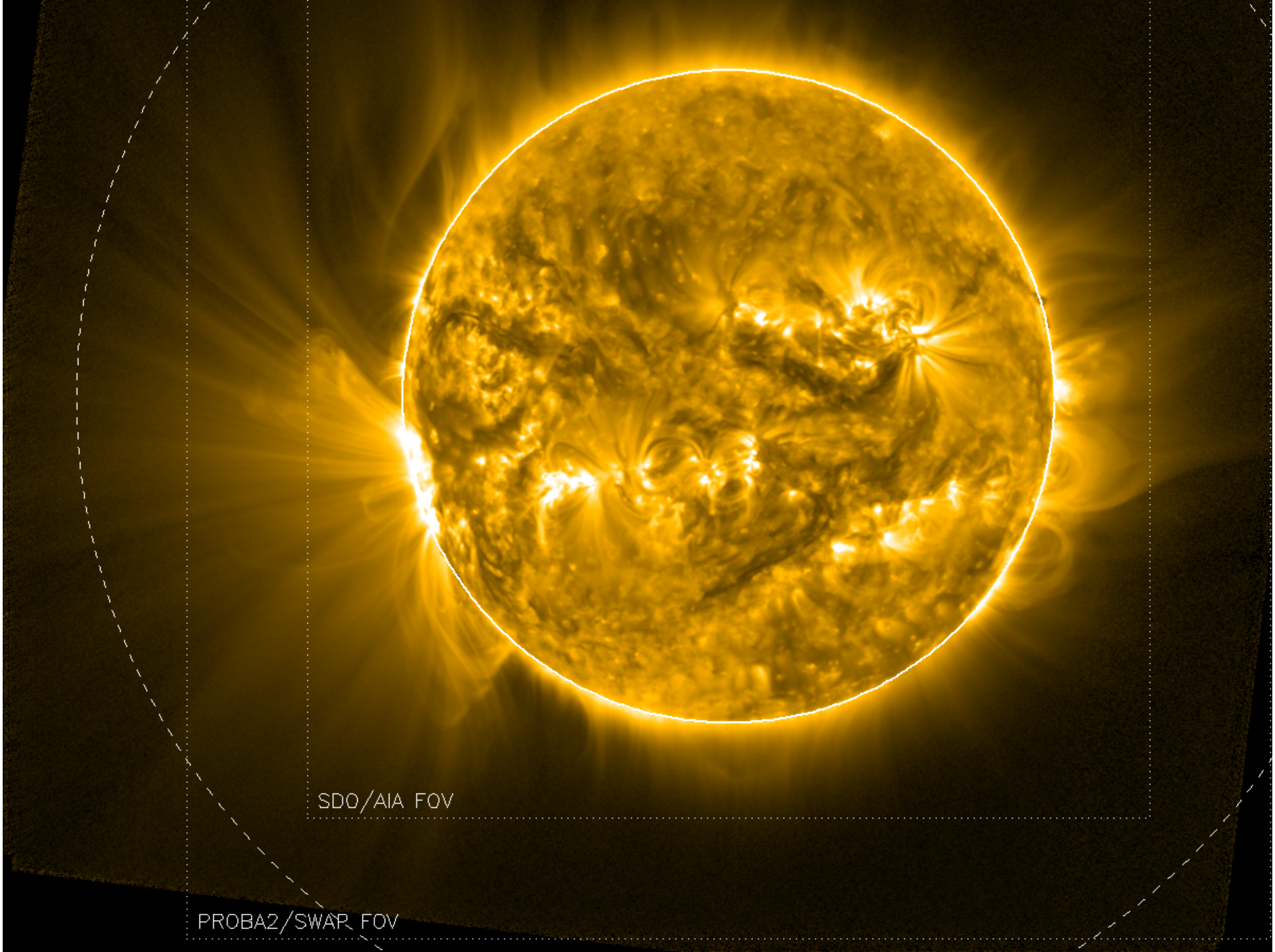


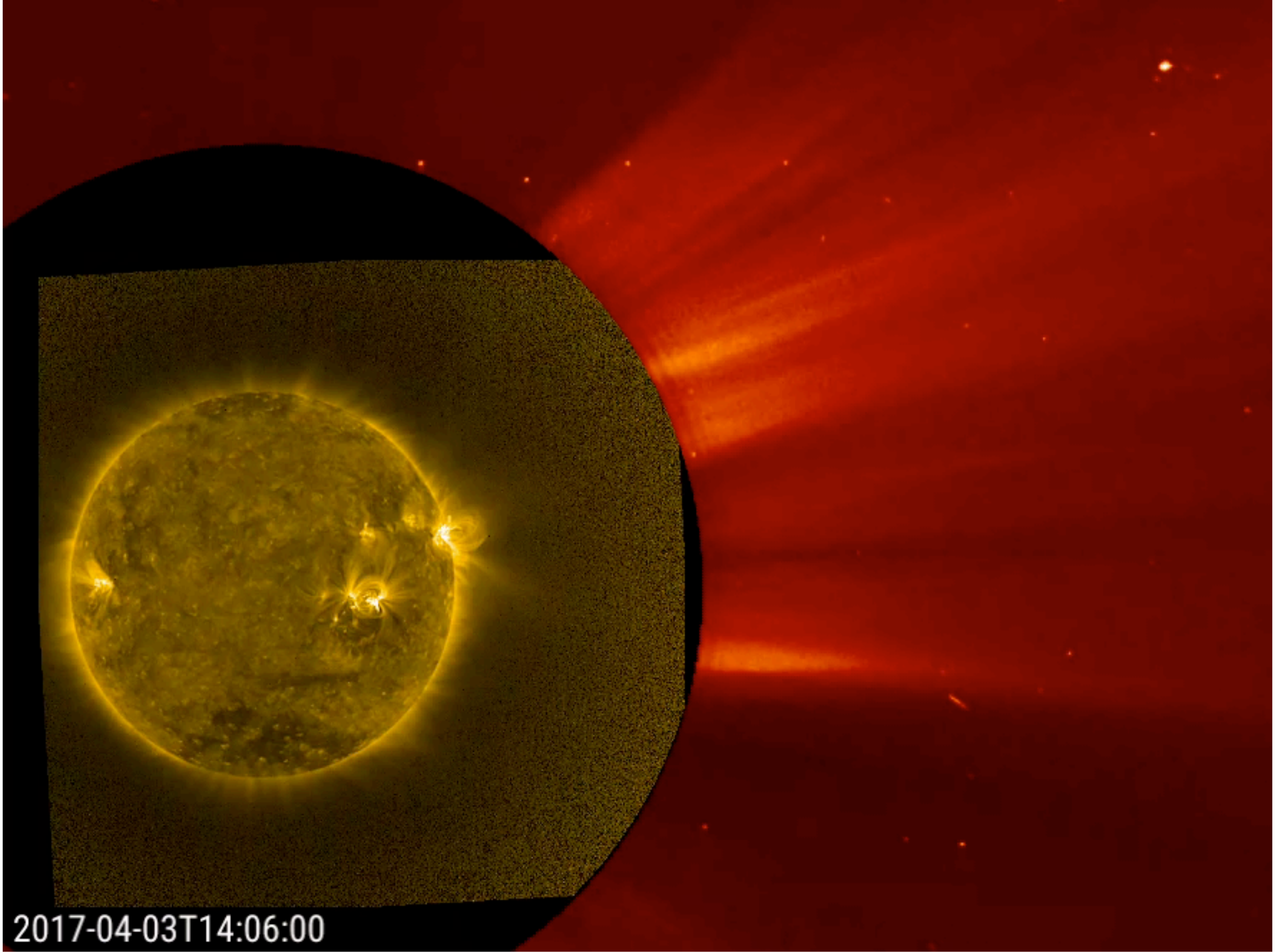




“Sun Watcher using APS and Image Processing” (SWAP) onboard PROBA2




SDO/AIA FOV
PROBA2/SWAP FOV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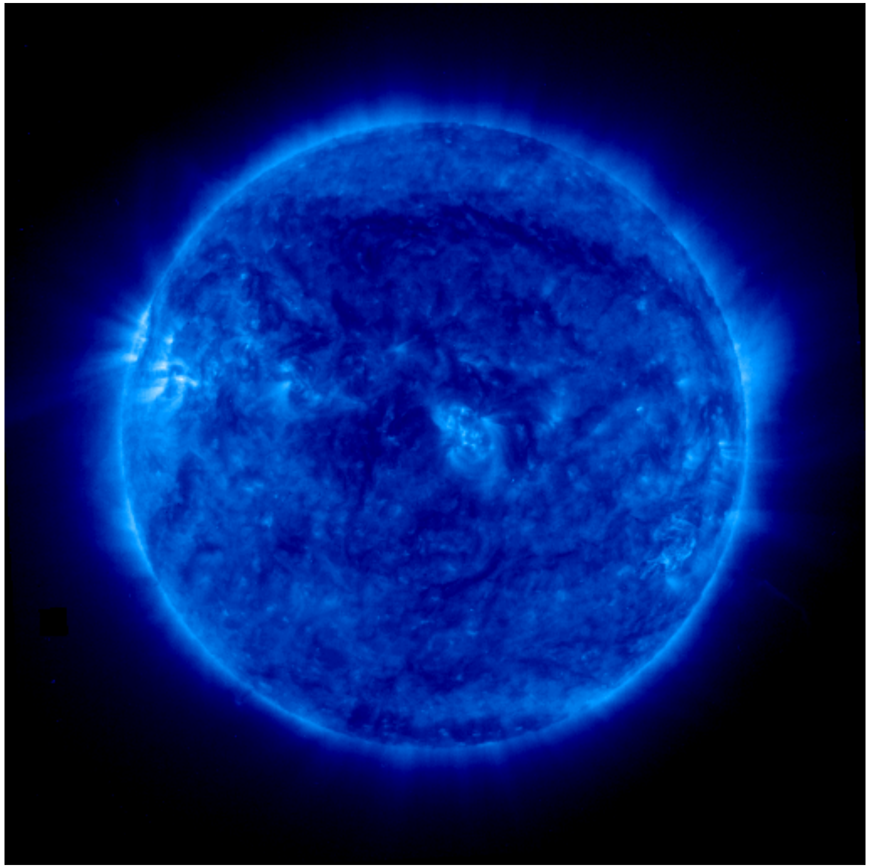
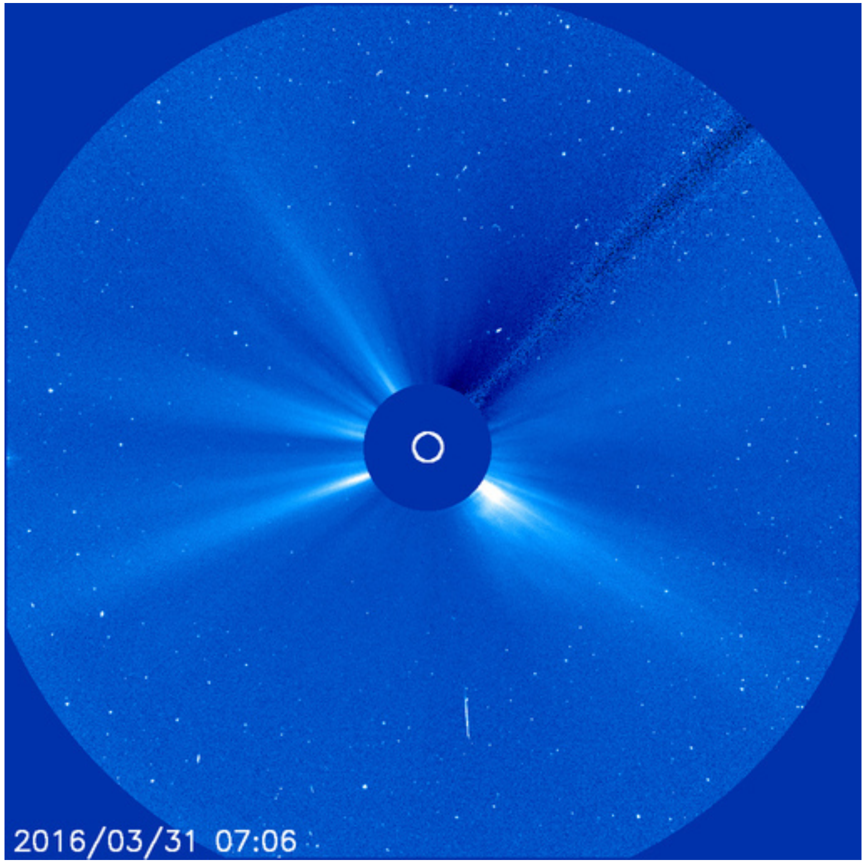
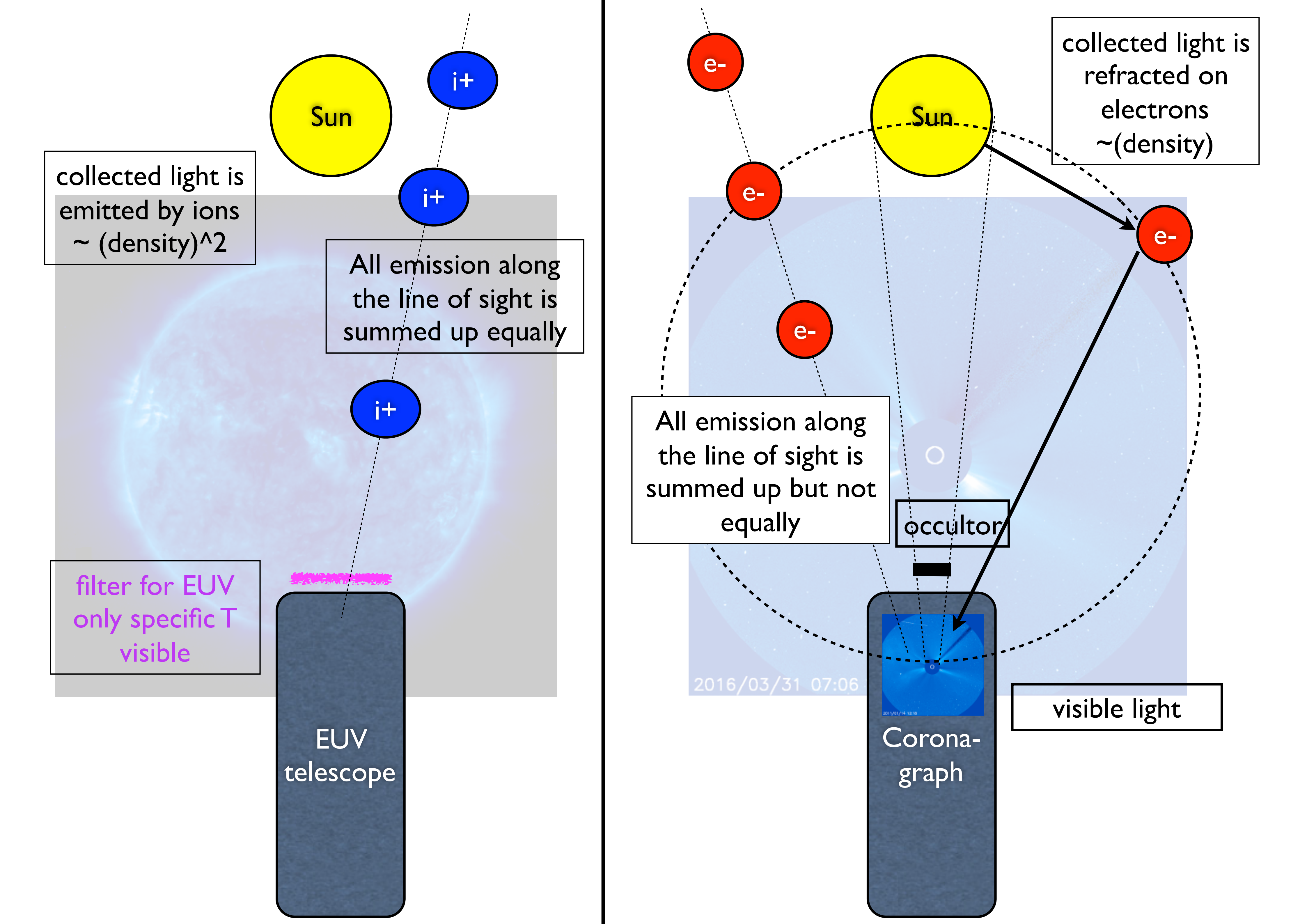
What are we missing?

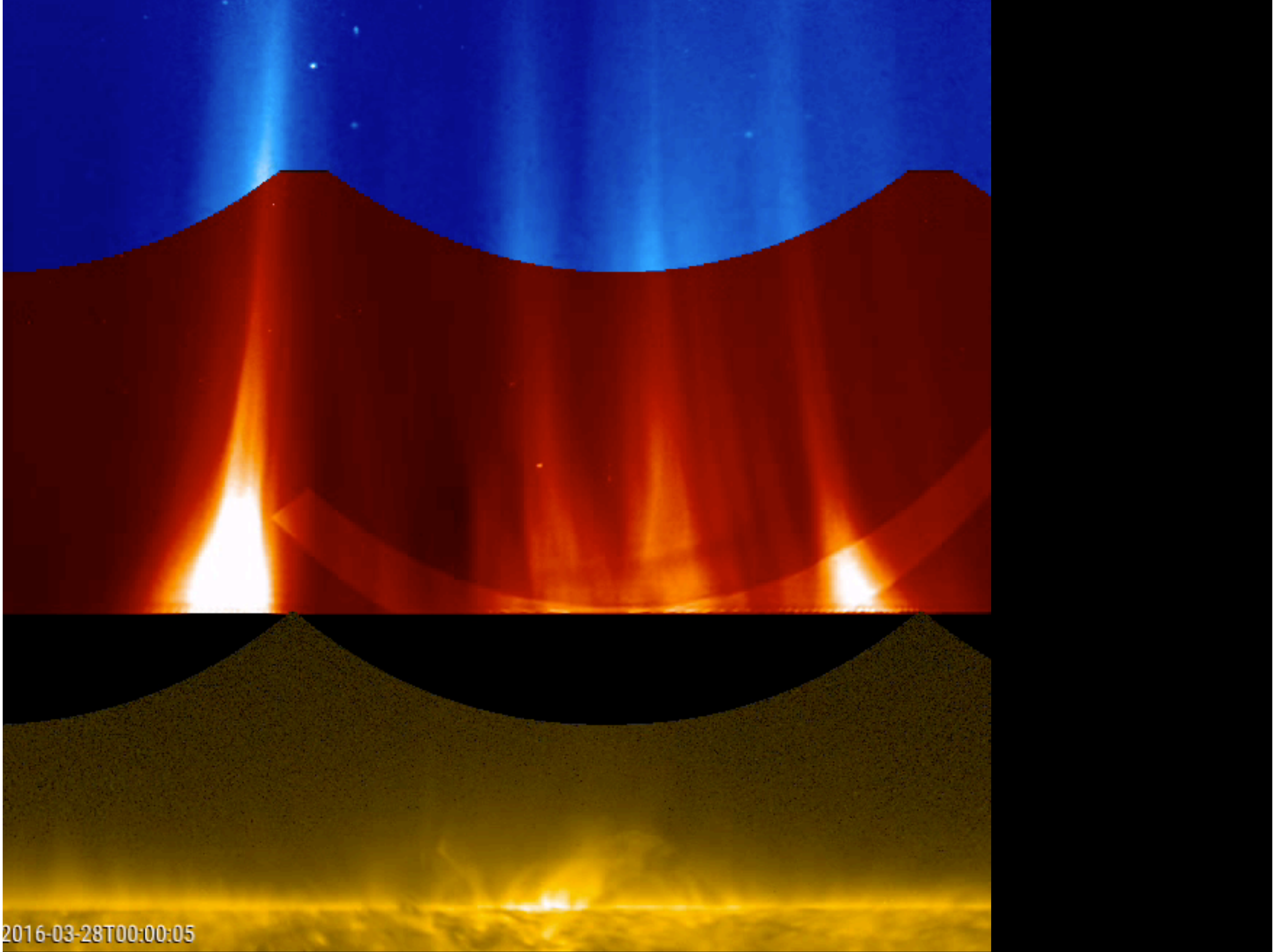


EUV imagers



coronagraphs


Sun
i+
i+
i+
collected light is emitted by ions ~ (density)^2
All emission along the line of sight is summed up equally
filter for EUV only specific T visible
EUV telescope
e-
e-
e-
e-
Sun
collected light is refracted on electrons ~(density)
All emission along the line of sight is summed up but not equally
occultor
2016/03/31 07:06
visible light
Corona-graph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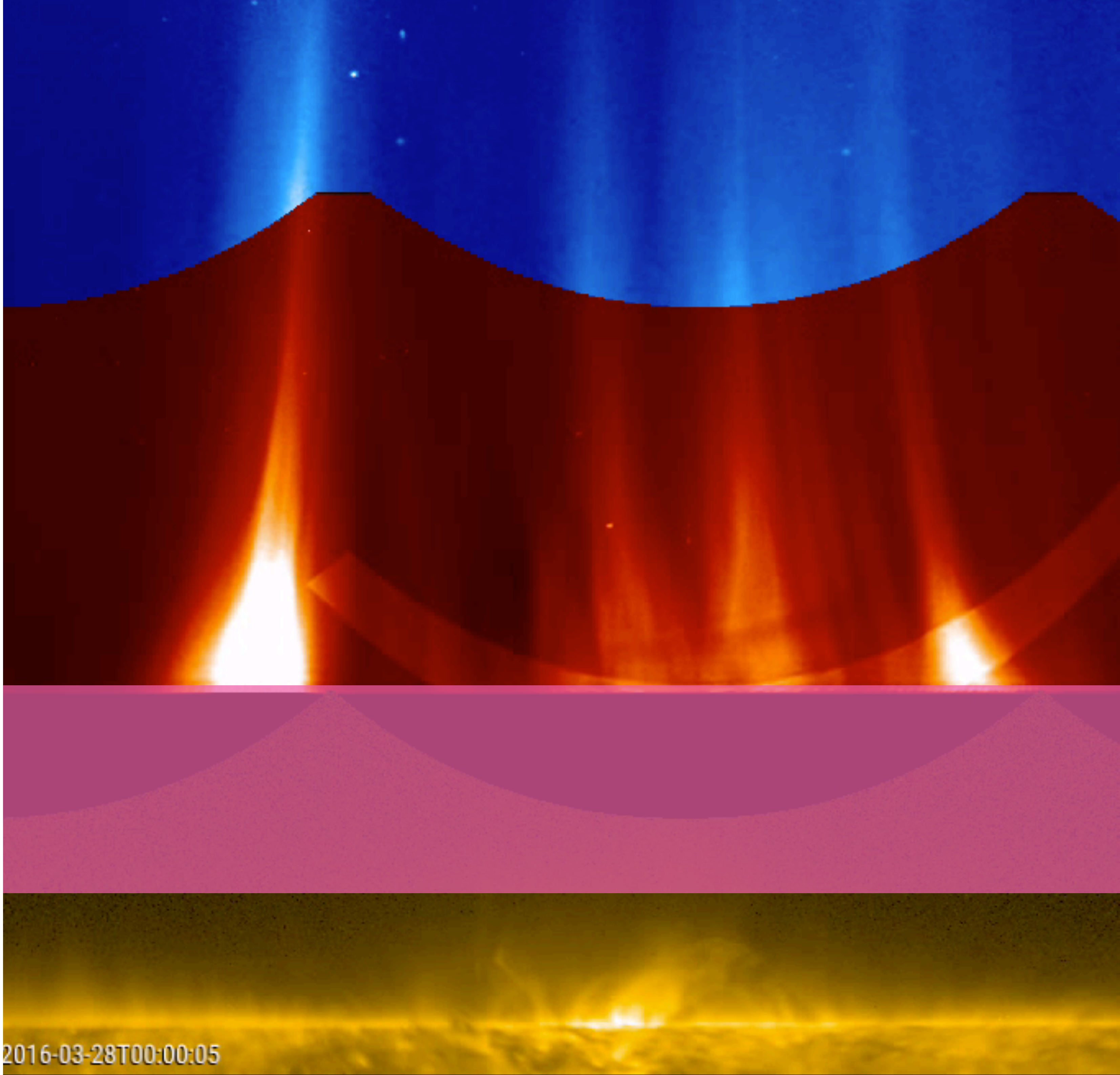
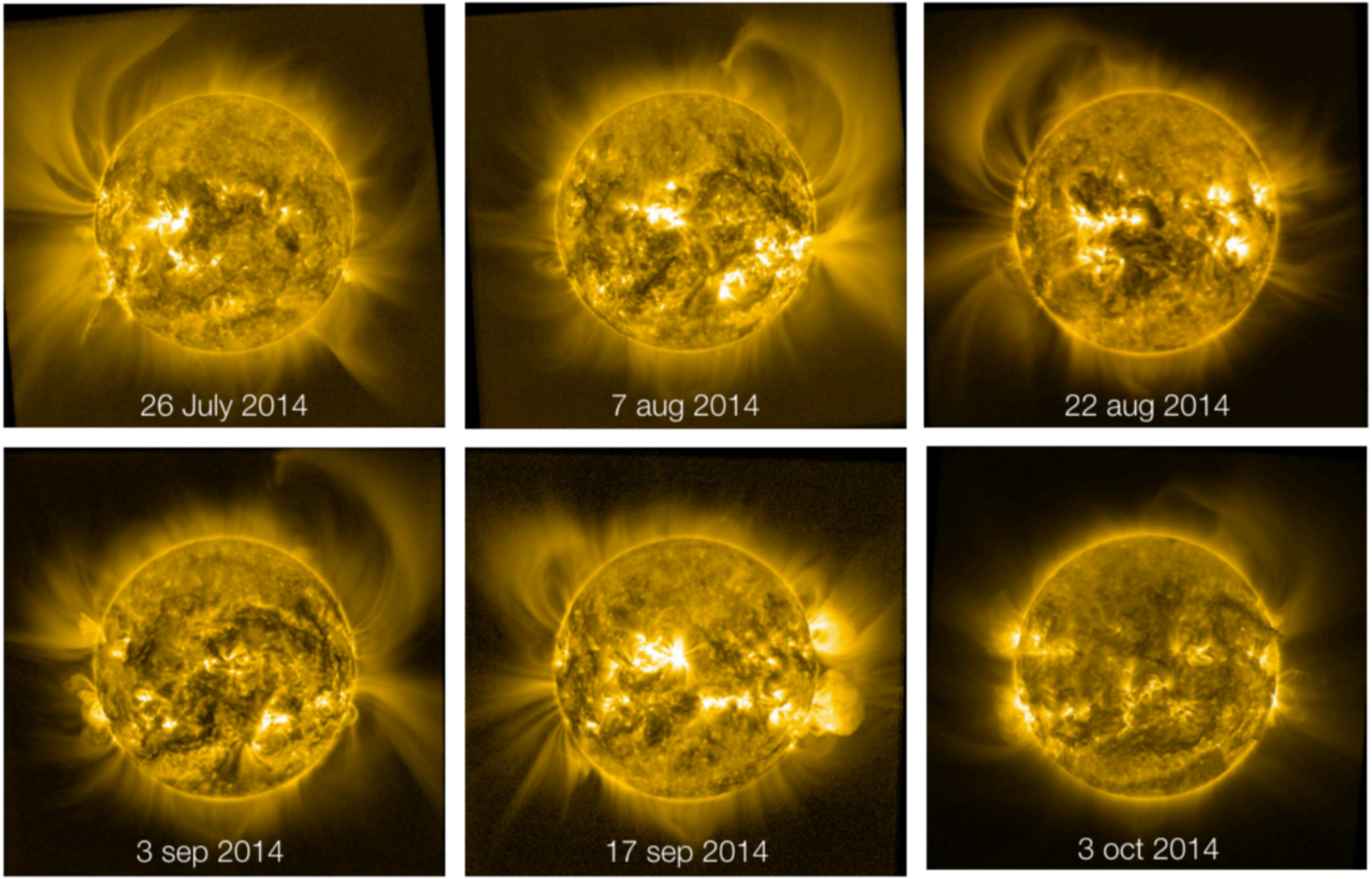
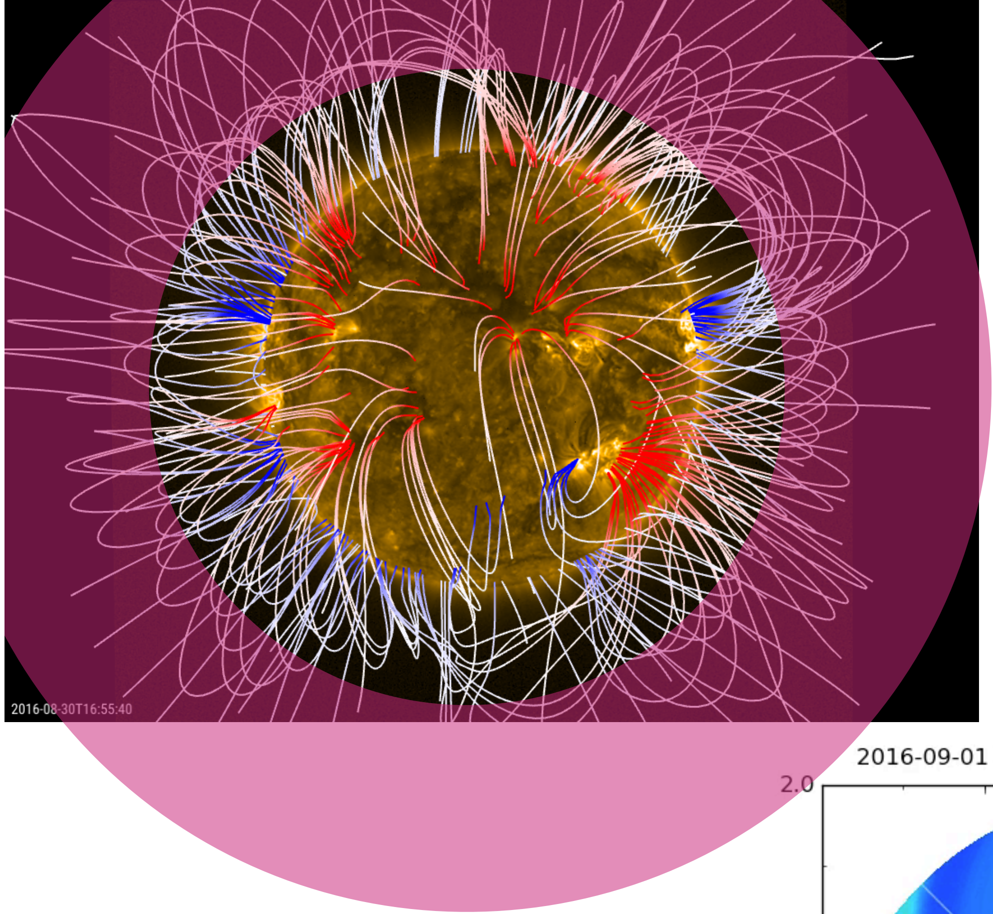


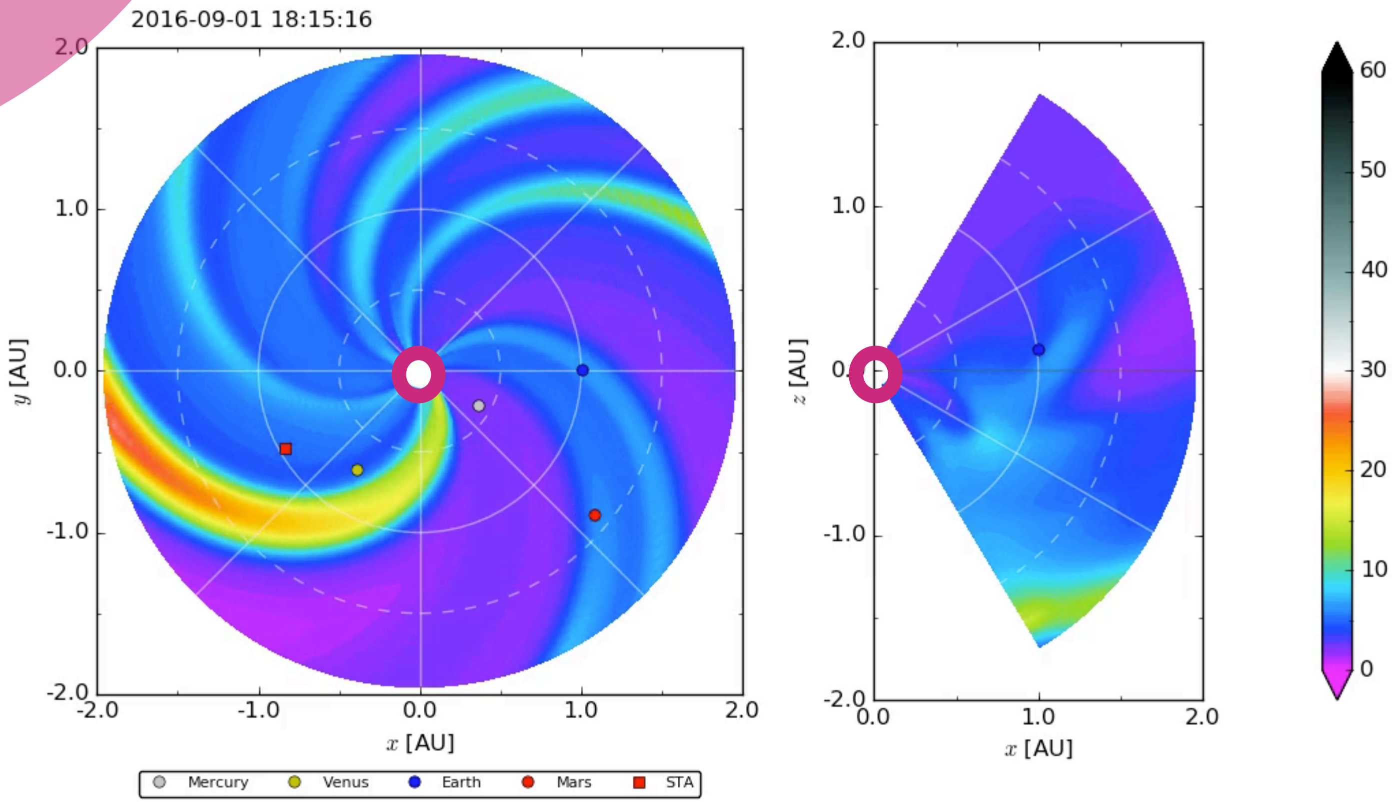
The gap

Surprisingly long lived structures in the gap

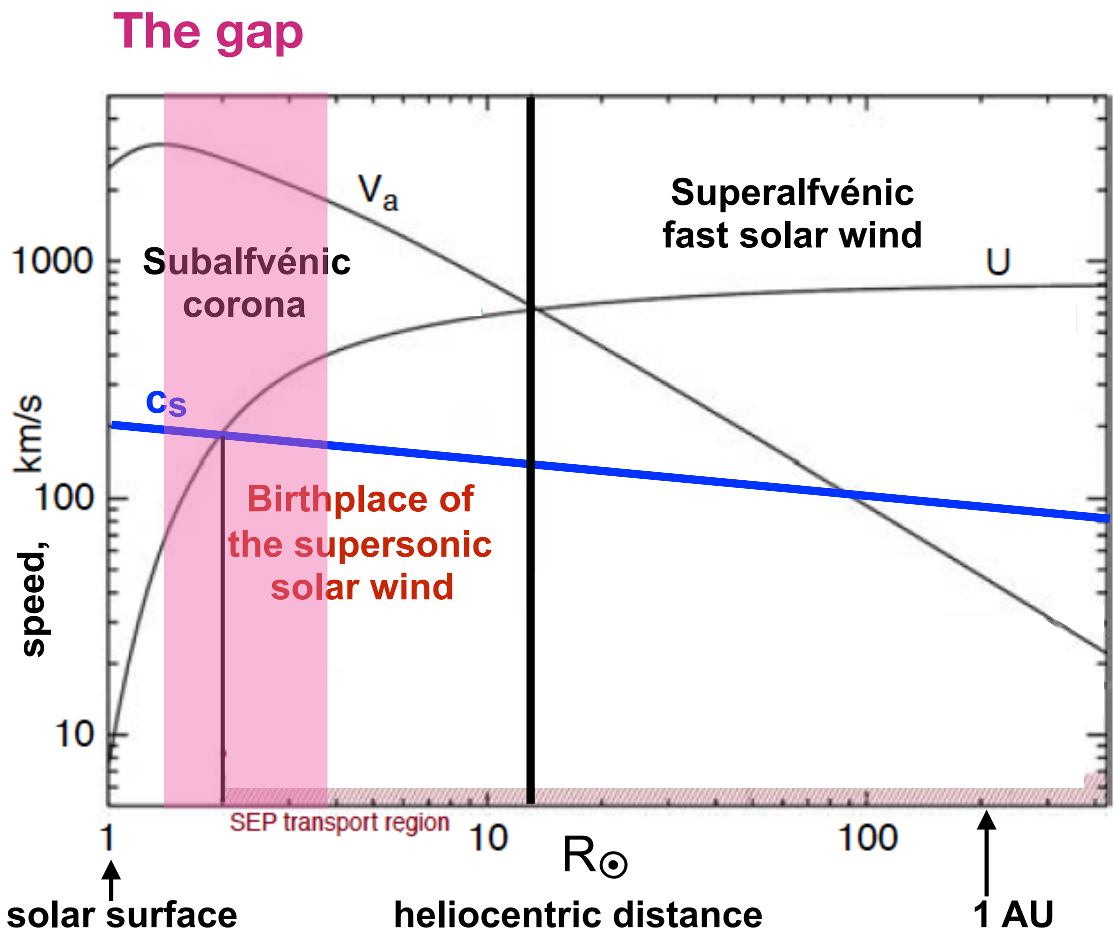




EUHFORIA (U Helsinki, KULeuven)



The gap is where physics happens

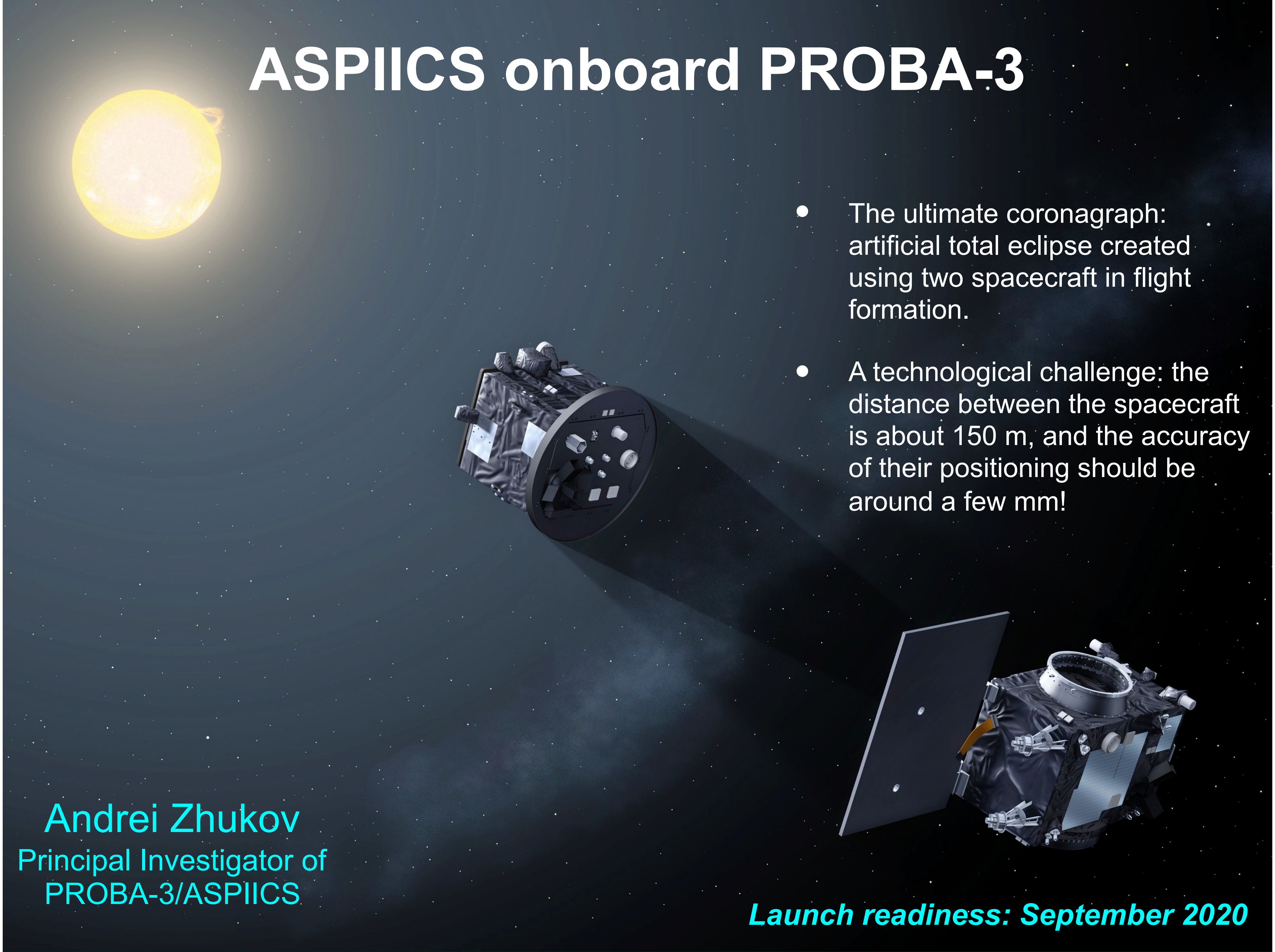


(after Fox et al. 2016)

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.


I am looking for my quarter I dropped!
Did you drop it here?
No I dropped it two blocks down the street!
Then why are you looking for it here?
Because the light is better here!
?

Filling the gap:
ASPIICS on PROBA-3


ASPIICS onboard PROBA-3
• 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!
Andrei Zhukov
Principal Investigator of PROBA-3/ASPIICS
Launch readiness: September 2020

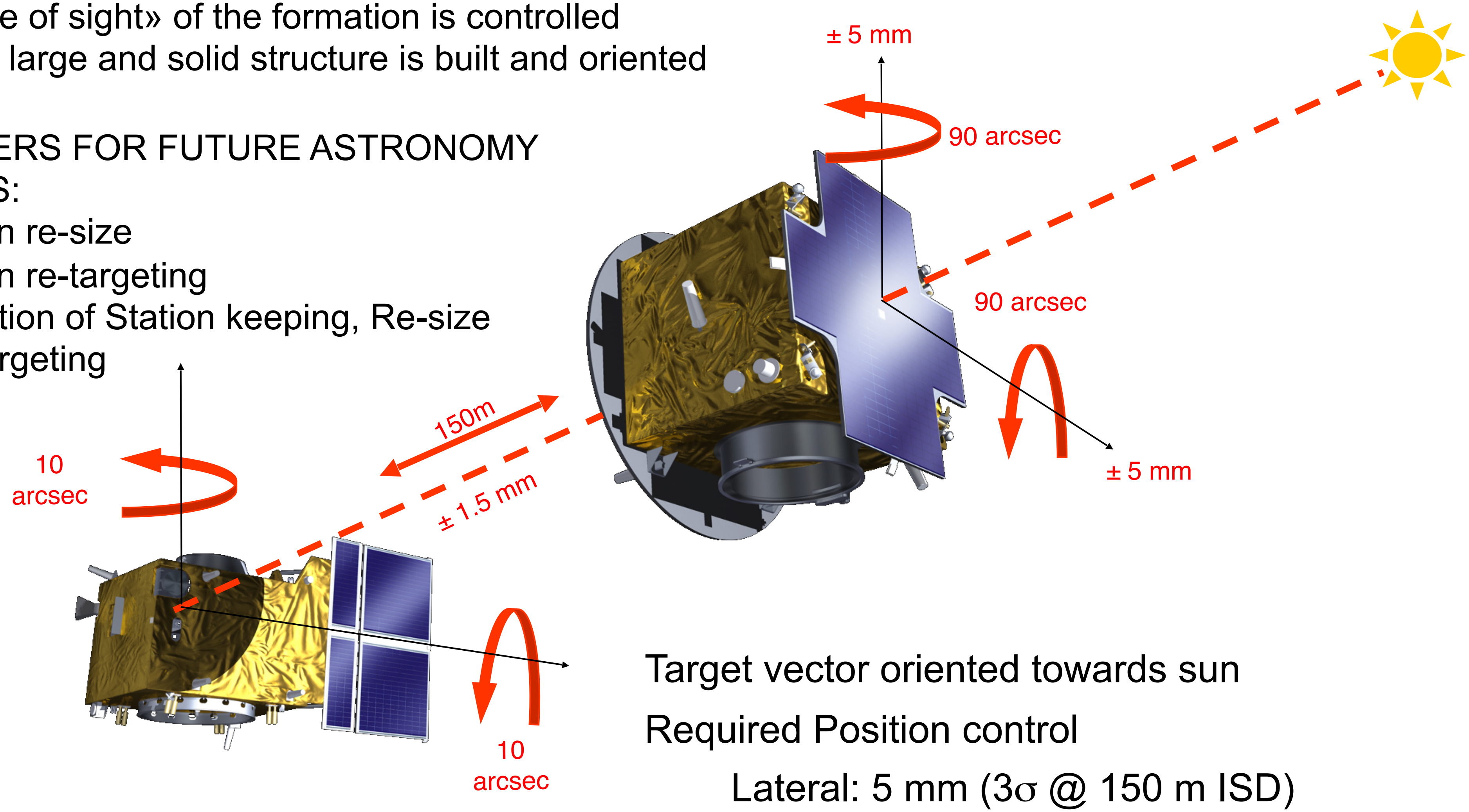
Precise formation flying

PRECISE FORMATION FLYING

- The relative lateral and longitudinal positions are controlled
- The absolute attitude is controlled
- The «line of sight» of the formation is controlled
- A virtual large and solid structure is built and oriented

MANEUVERS FOR FUTURE ASTRONOMY MISSIONS:

- Formation re-size
- Formation re-targeting
- Combination of Station keeping, Re-size and re-targeting



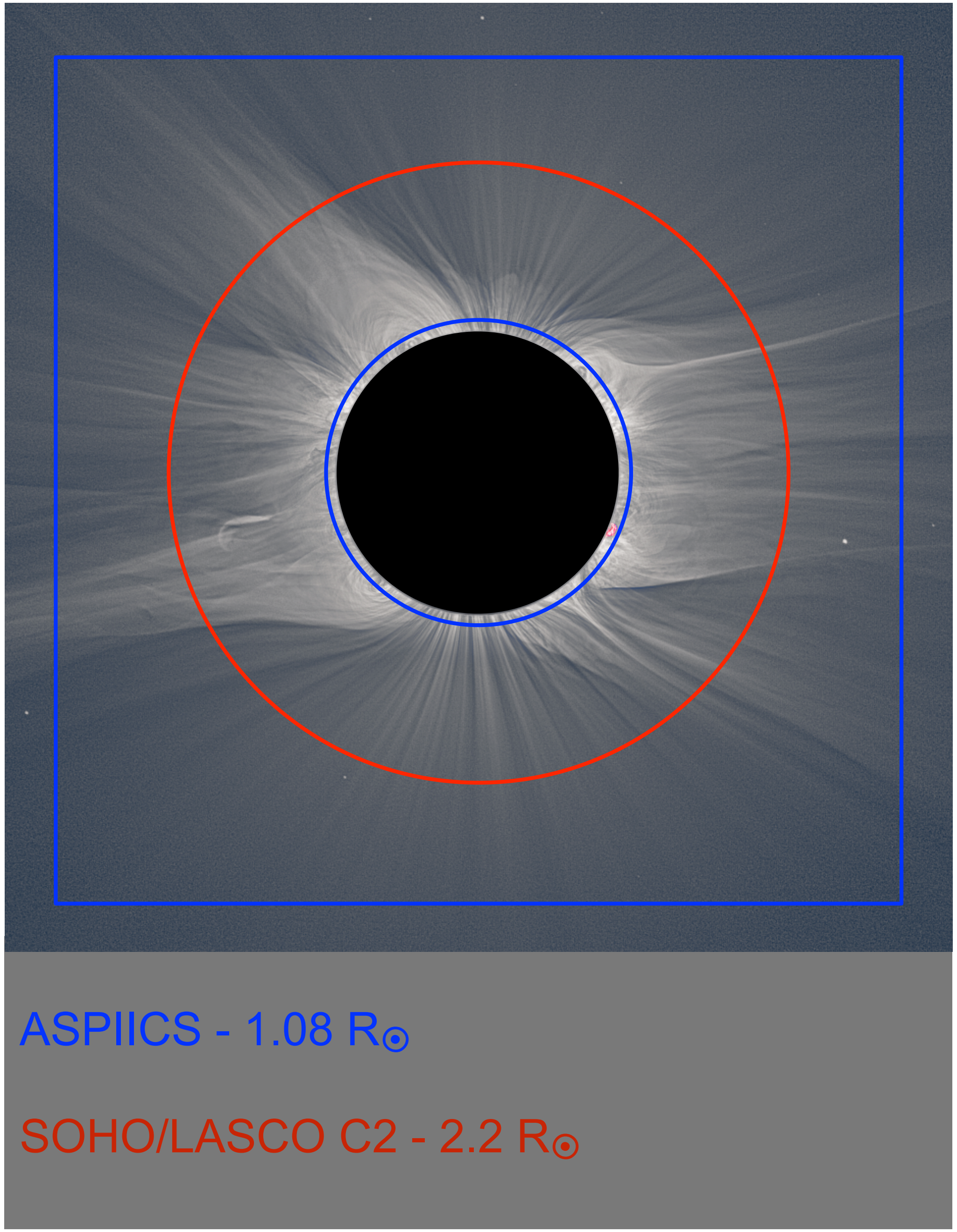
Target vector oriented towards sun

Required Position control

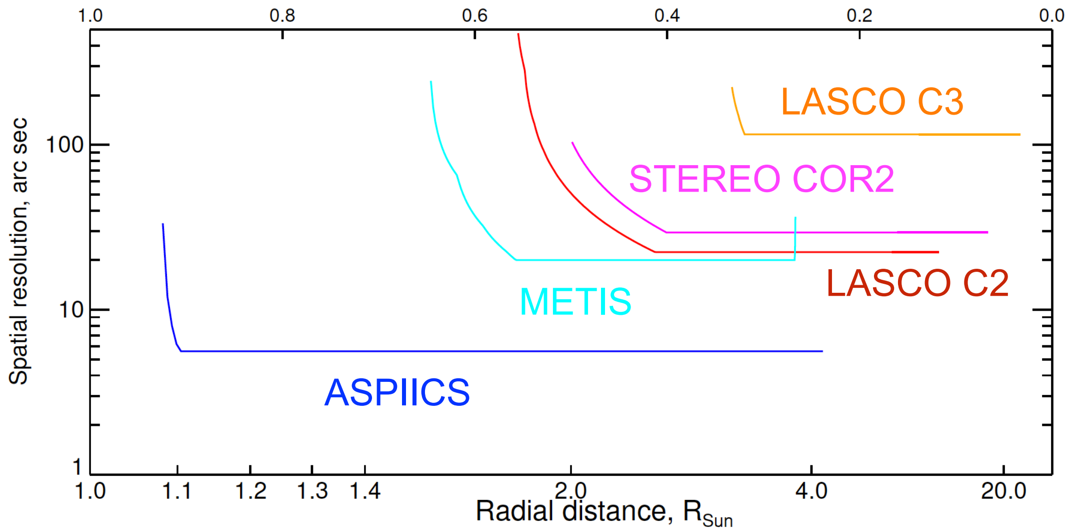
Lateral: 5 mm (3σ @ 150 m ISD)

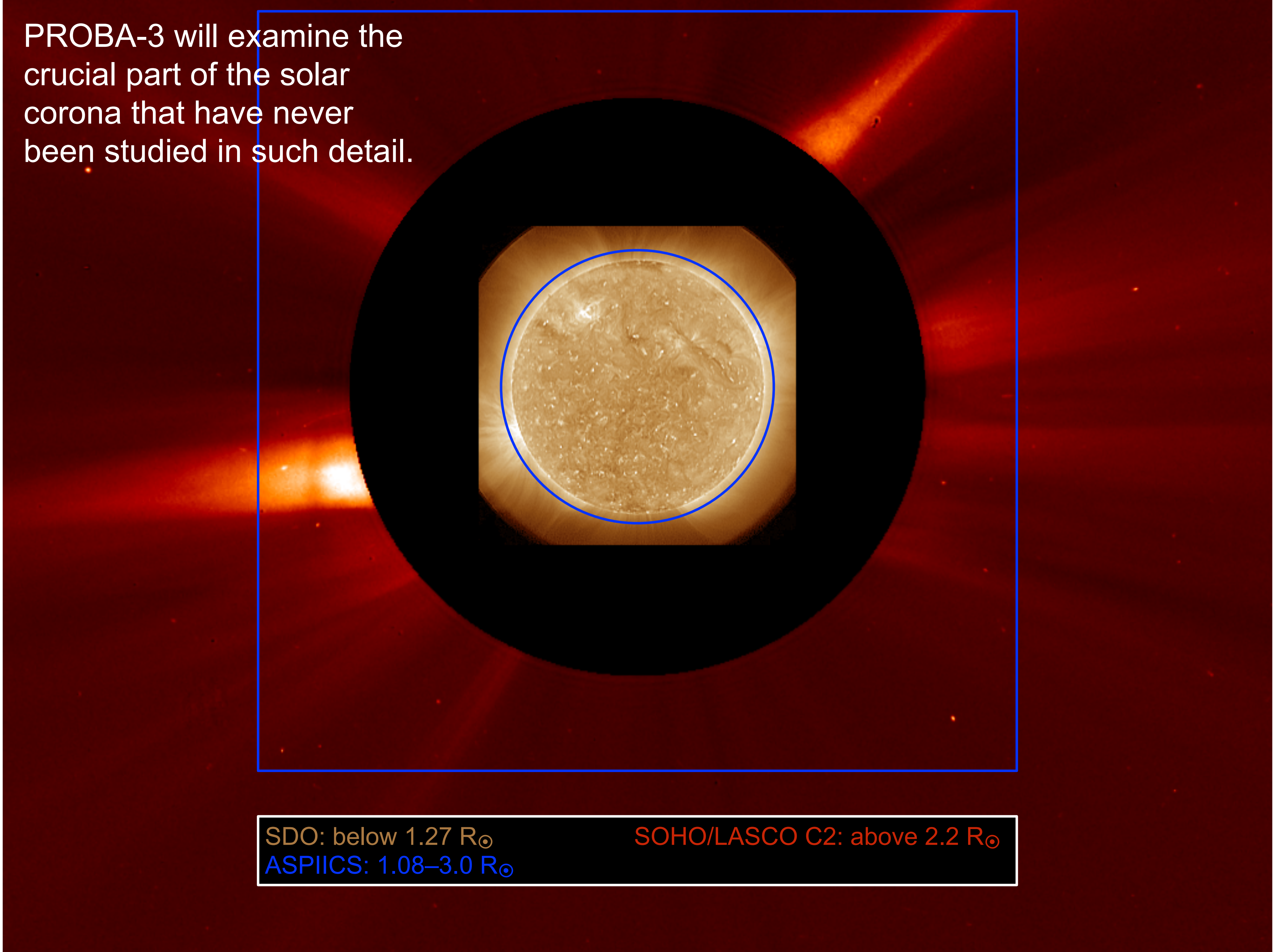
Longitudinal: 1.5 mm (3σ @ 150 m ISD)

PROBA-3/ASPIICS in comparison with other coronagraphs



- The inner edge of the ASPIICS field of view (1.08 R☉) will be lower than that of any other existing or planned space coronagraph.
- ASPIICS will therefore fill The Gap between the typical fields of view of EUV imagers and externally occulted coronagraphs!
- The spatial resolution of ASPIICS will be at least 3.5 times better than the resolution of other coronagraphs.

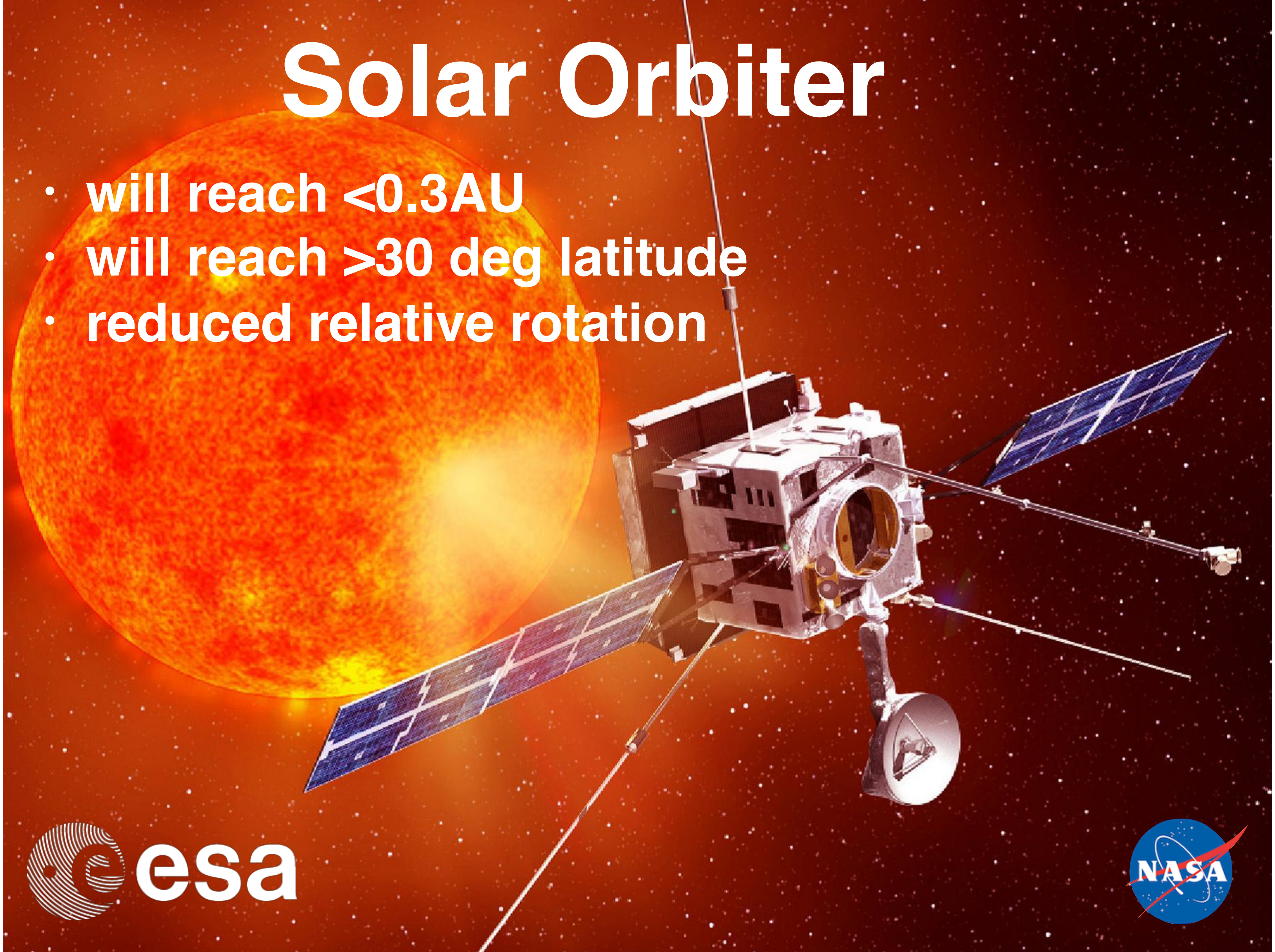



PROBA-3 will examine the crucial part of the solar corona that have never been studied in such detail.
SDO: below 1.27 R⊙
ASPIICS: 1.08–3.0 R⊙
SOHO/LASCO C2: above 2.2 R⊙

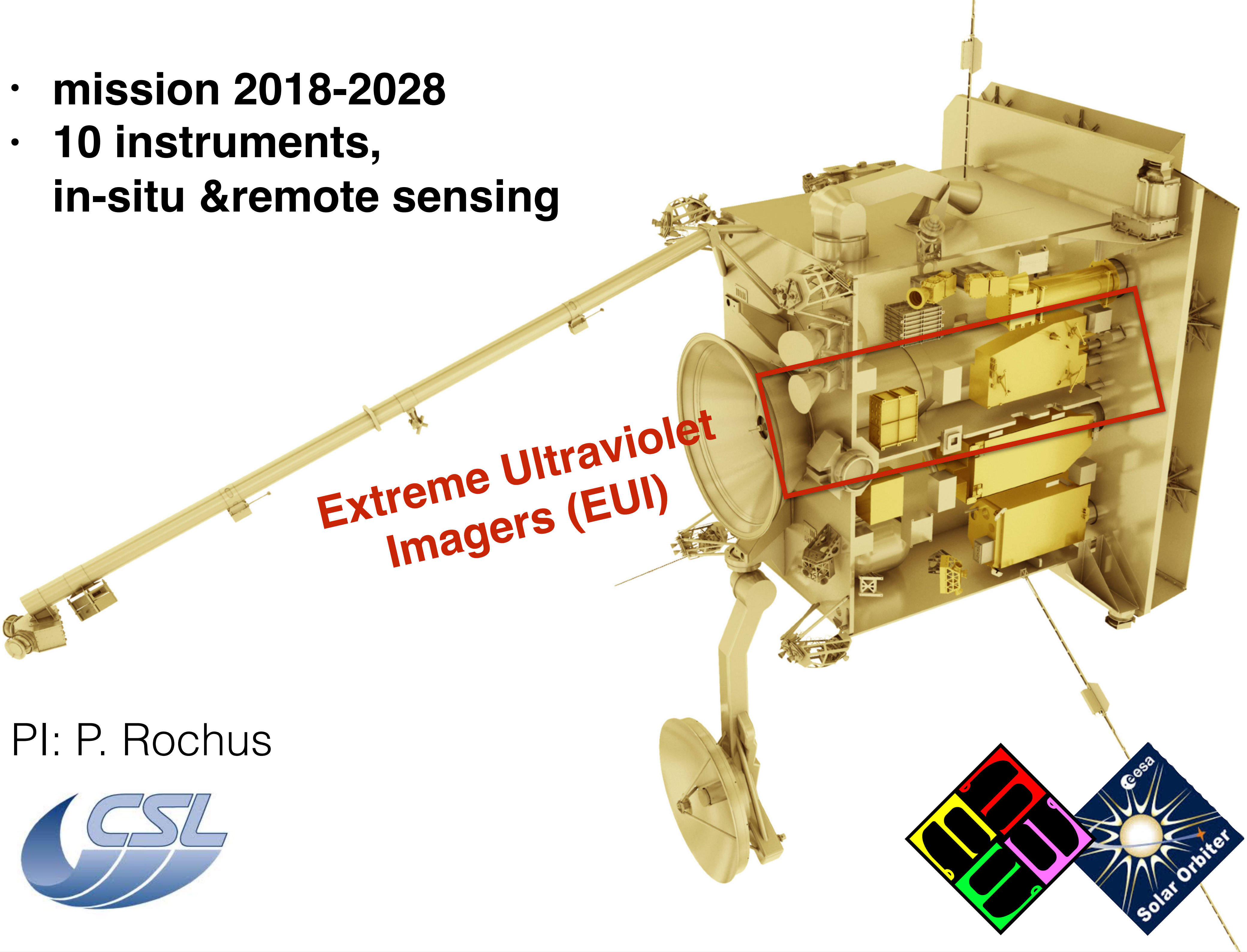
Filling the gap
EUI on Solar Orbiter

Solar Orbiter

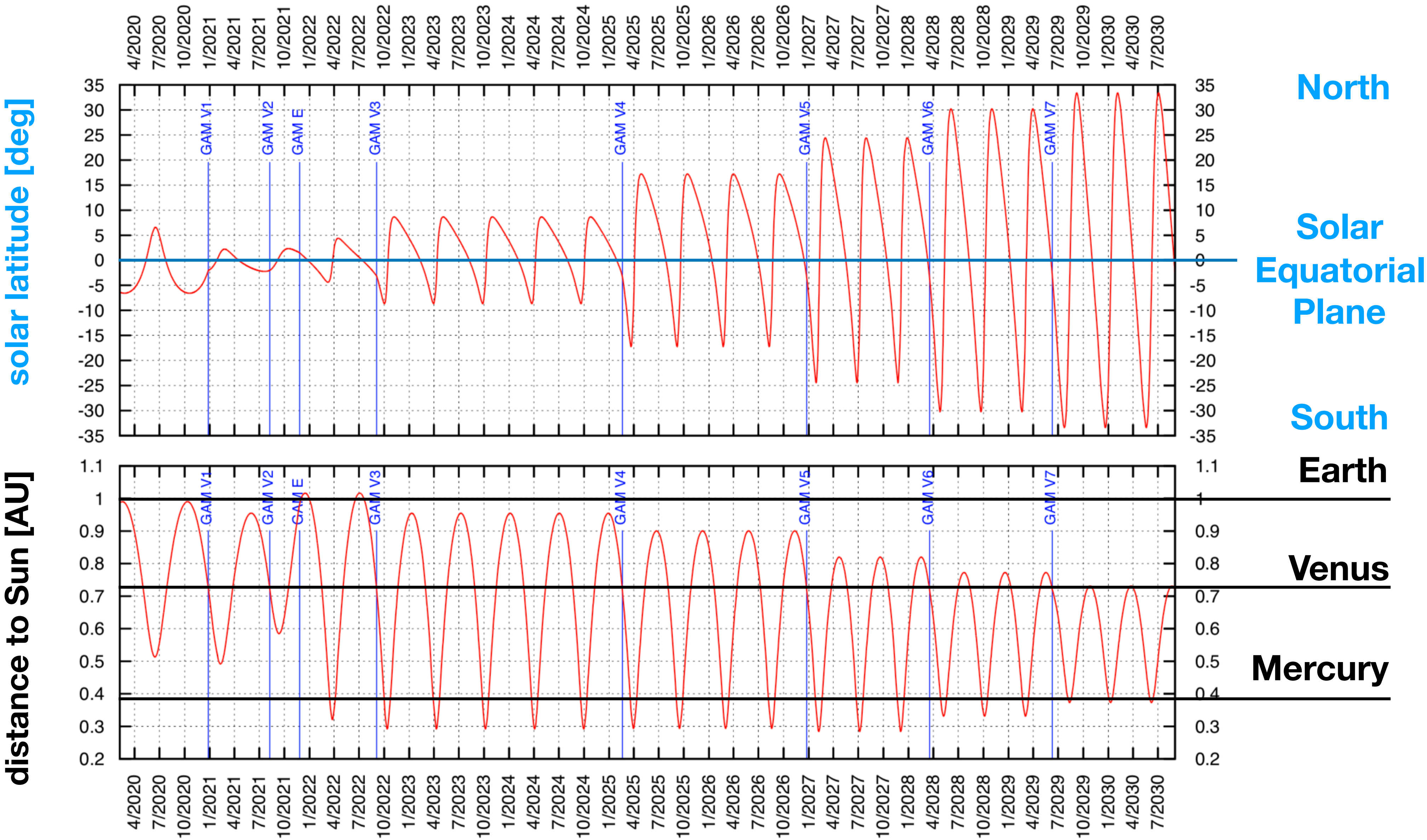
- will reach <0.3AU
- will reach >30 deg latitude
- reduced relative rotation



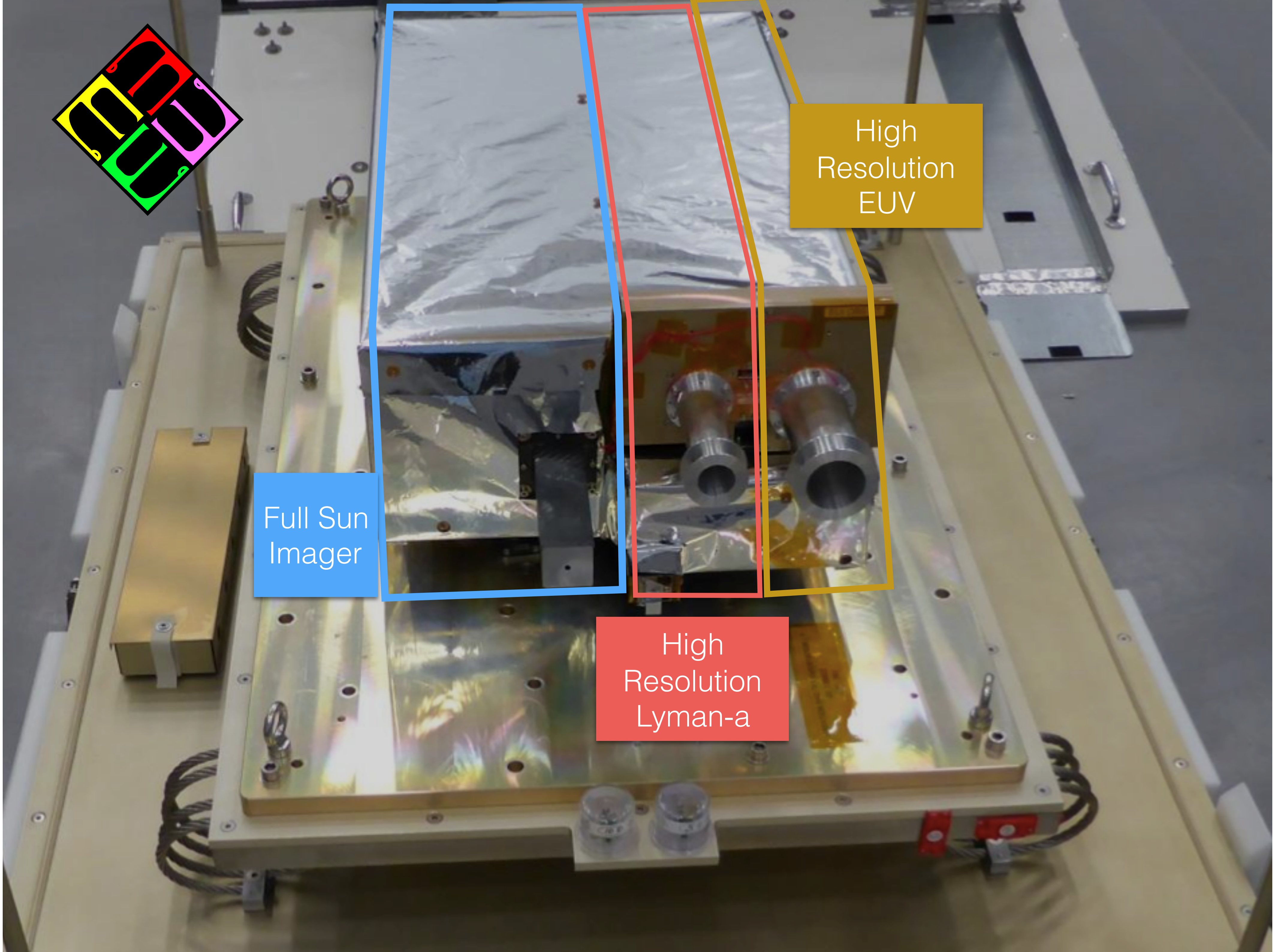
- **mission 2018-2028**
- **10 instruments, in-situ &remote sensing**



PI: P. Rochus



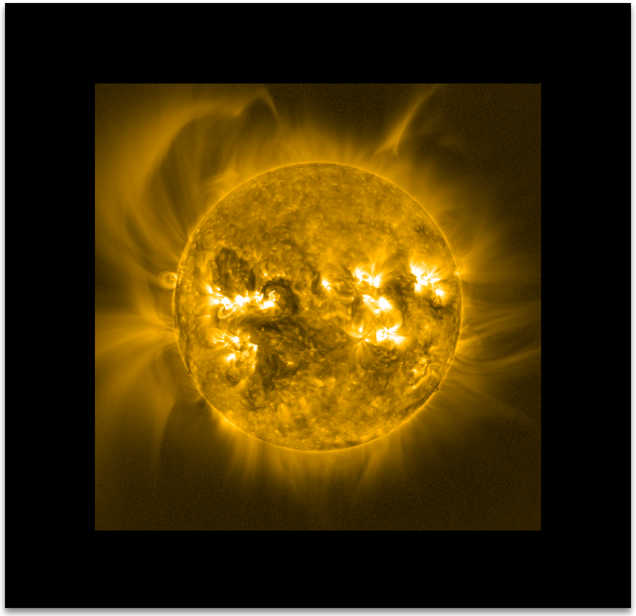
solar latitude [deg]
distance to Sun [AU]
North
Solar
Equatorial
Plane
South
Earth
Venus
Mercury
GAM V1
GAM V2
GAM E
GAM V3
GAM V4
GAM V5
GAM V6
GAM V7

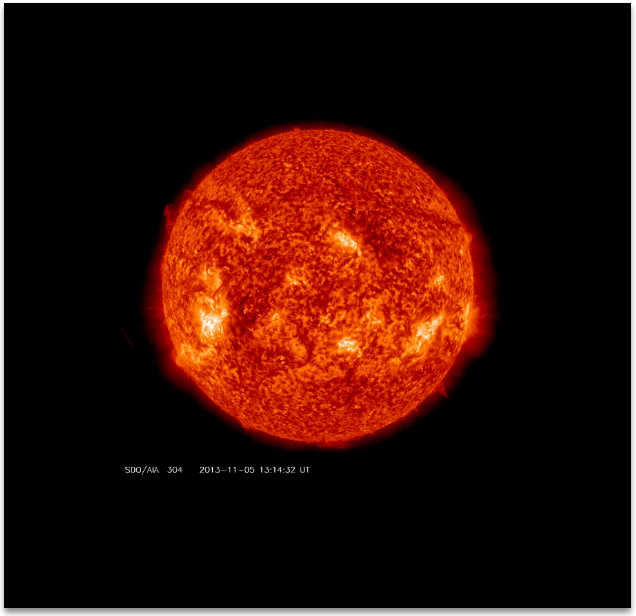

High Resolution EUV
Full Sun Imager
High Resolution Lyman-a

FSI: Full Sun Imager

FOV: 3.8°x3.8°, @ 0.28 AU: 4 Rsun x 4 Rsun

17nm





30.4nm

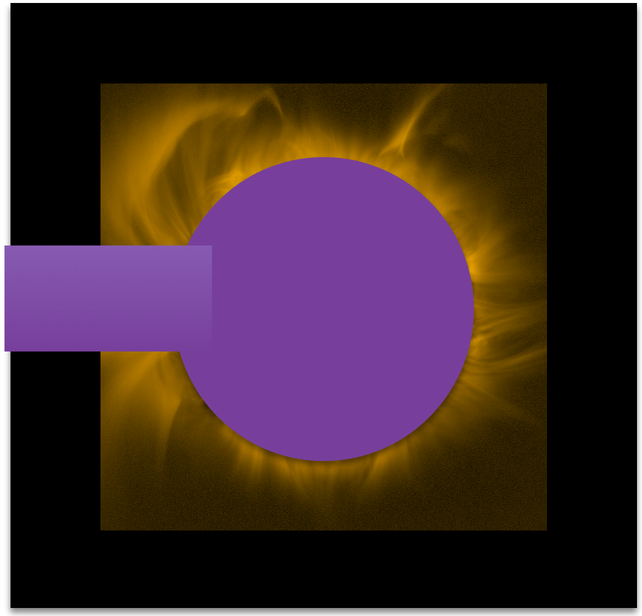
resolution: 9 arcsec on 2 pixels

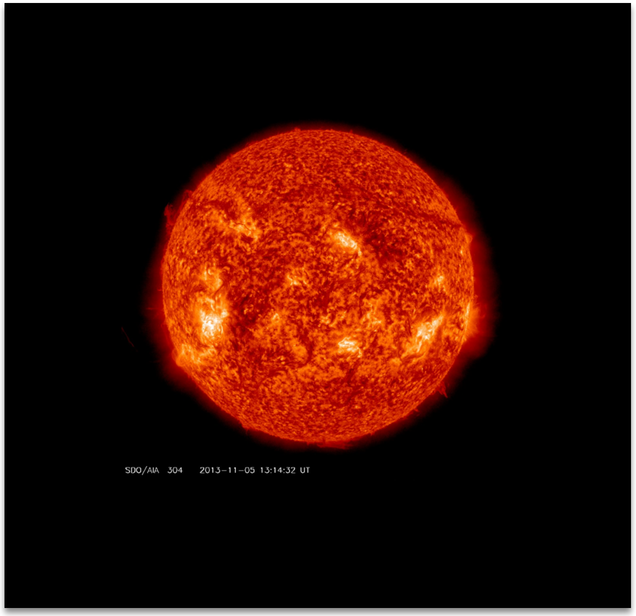
@ 0.28 AU =1830 km on 2 pixels

FSI: Full Sun Imager

FOV: 3.8°x3.8°, @ 0.28 AU: 4 Rsun x 4 Rsun

17nm



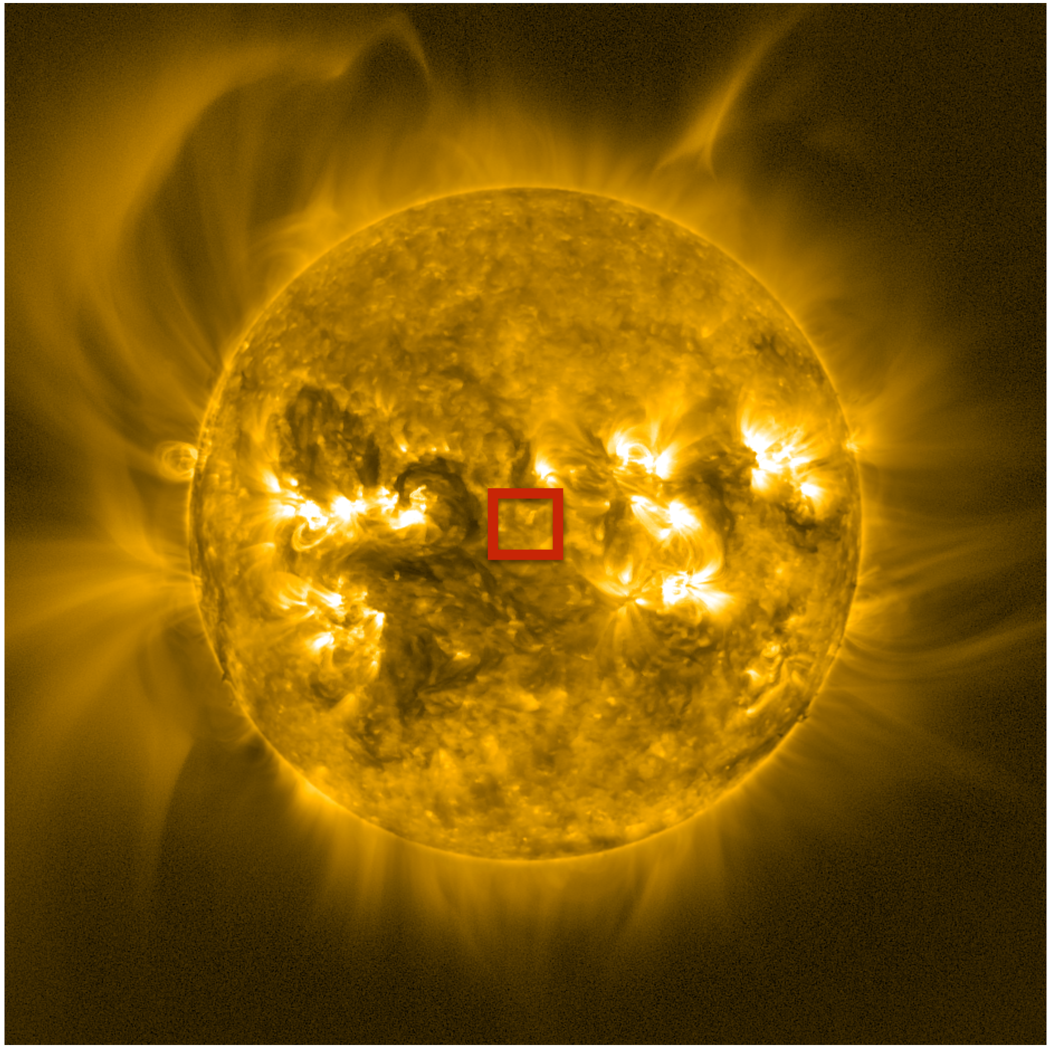


30.4nm

resolution: 9 arcsec on 2 pixels

@ 0.28 AU =1830 km on 2 pixels

HRI:High Resolution Imagers



field of view:

17’x17’

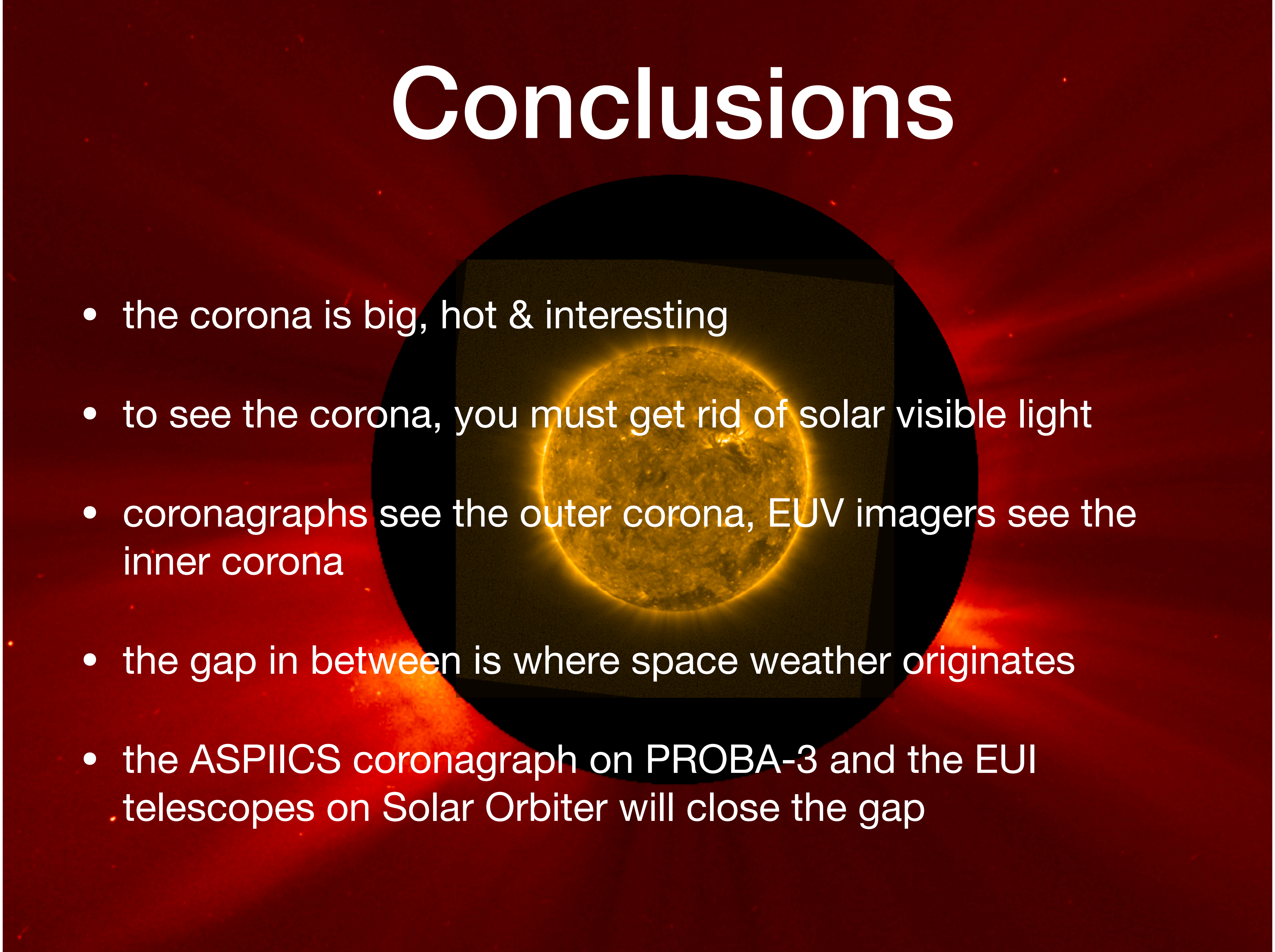
@ 0.28 AU = (0.16 R)^2

resolution:

1 arcsec on 2 pixels

@ 0.28 AU = 200km

Airbus UK



Conclusions

- the corona is big, hot & interesting
- to see the corona, you must get rid of solar visible light
- coronagraphs see the outer corona, EUV imagers see the inner corona
- the gap in between is where space weather originates
- the ASPIICS coronagraph on PROBA-3 and the EUI telescopes on Solar Orbiter will close the gap

Thanks: BELSPO/PRODEX for financing our instruments, CSL & partners for building them, colleagues at ROB for getting all the work done, A. Zhukov for providing ASPIICS slides.