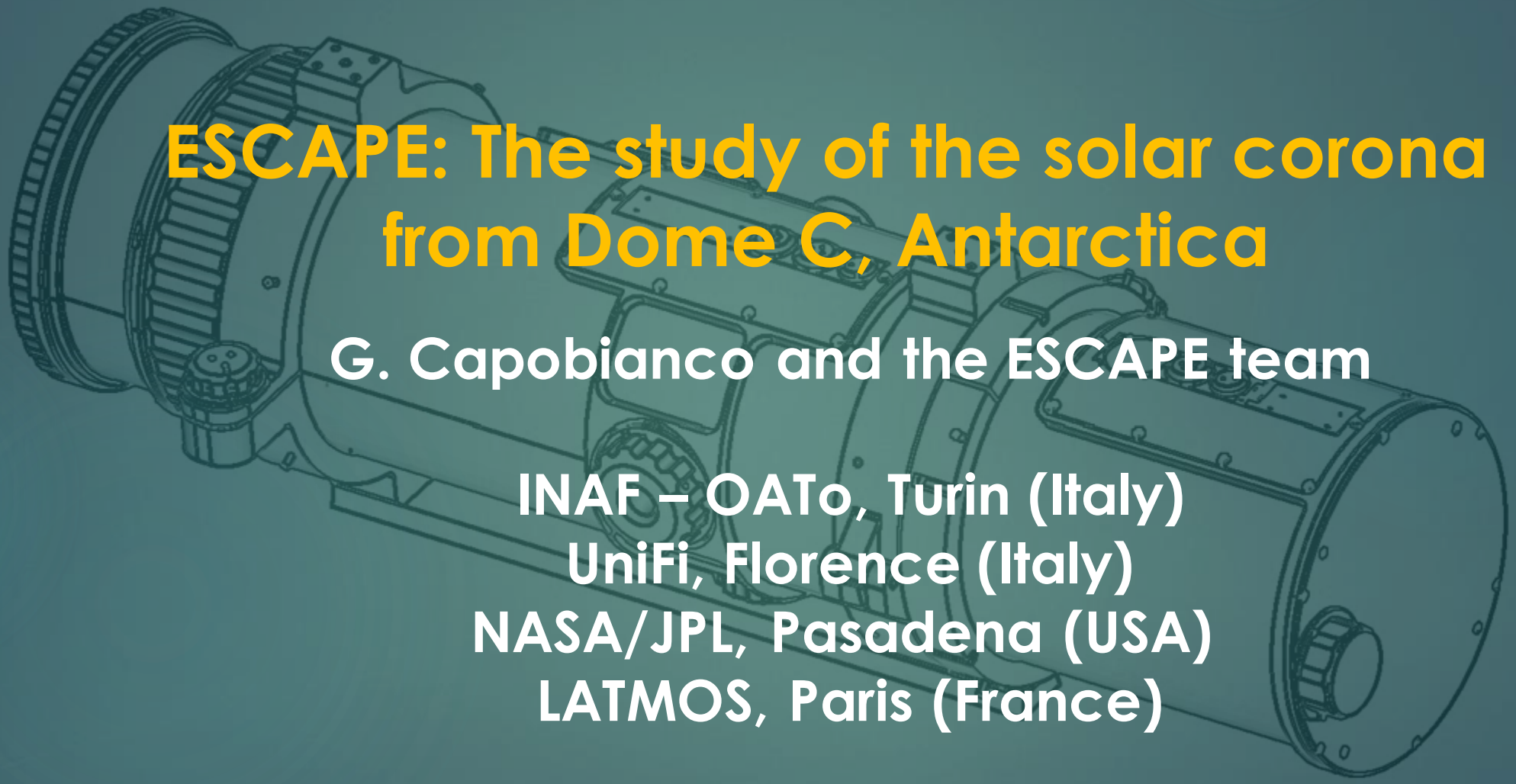


ESCAPE: The study of the solar corona from Dome C, Antarctica

G. Capobianco and the ESCAPE team

INAF – OATo, Turin (Italy)
UniFi, Florence (Italy)
NASA/JPL, Pasadena (USA)
LATMOS, Paris (France)

gerardo.capobianco@inaf.it

ESCAPE: The study of the solar corona from Dome C, Antarctica

OUTLINE

- The ESCAPE Project
- Observations of the solar corona
- Description of AntarctiCor
- ESCAPE results (Dome C sky brightness)
- ESCAPE results (solar corona data)
- Conclusions

ESCAPE: The study of the solar corona from Dome C, Antarctica

THE ESCAPE PROJECT

ESCAPE: Extreme Solar Coronagraphy Antarctic Program Experiment

Ground-based observation from Antarctica of the linearly polarized solar corona in white-light (591 nm ± 5nm)

AntarctiCor is the name of the coronagraph designed and optimized for the purpose

ESCAPE: The study of the solar corona from Dome C, Antarctica

ESCAPE TIMELINE

2014 → Call PNRA for long term experiments

2015 → ESCAPE Proposal selected

2016 → Instrument design and development

2017 → Instrument manufacturing and test

2018 → 1st Antarctica campaign

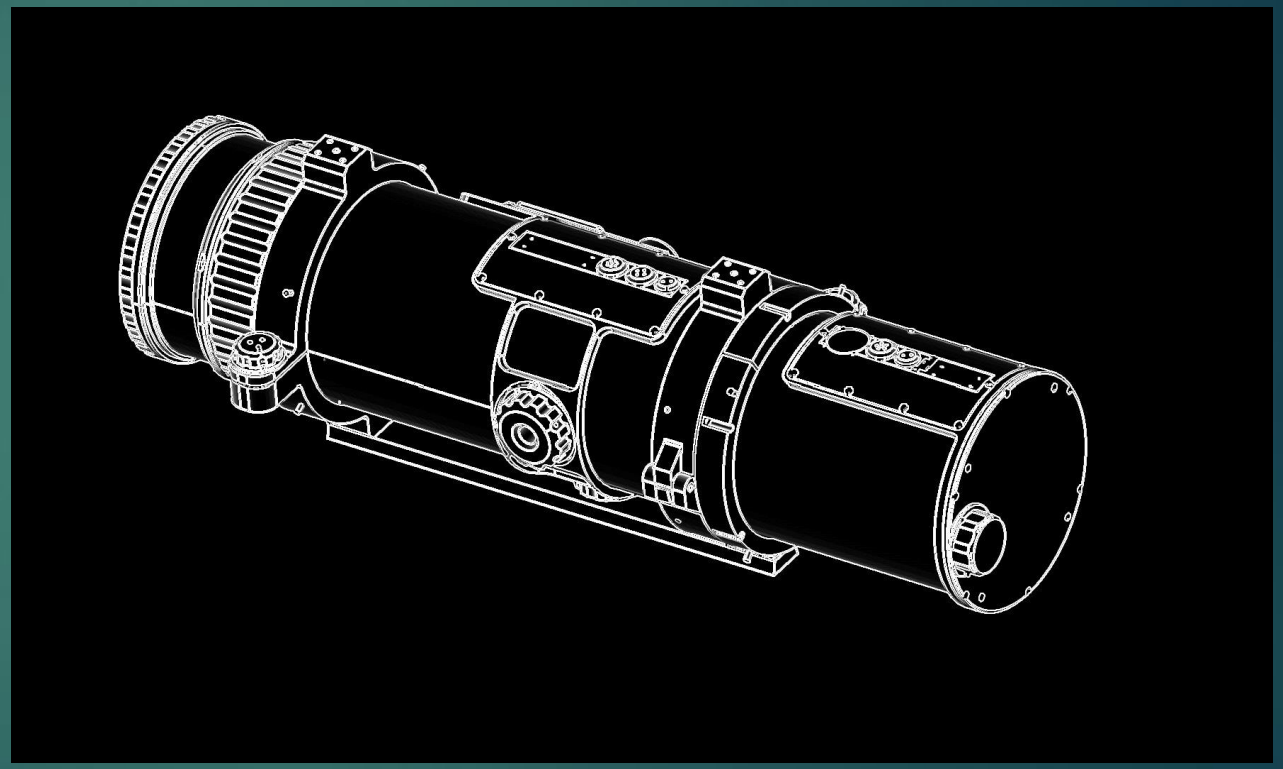
2019 → 2nd Antarctica campaign

2020 →

2021 → 3th Antarctica campaign

2022 → 4th Antarctica campaign

2023 → End of the project



ESCAPE: The study of the solar corona from Dome C, Antarctica

ESCAPE TIMELINE

BEFORE

ESA mission PROBA-3 ASPIICS instrument design

2014 → Call PNRA for long term experiments

2015 → ESCAPE Prososal selected

2016 → Instrument design and development

2017 → Instrument manufacturing and test

2018 → 1st Antarctica campaign

2019 → 2nd Antarctica campaign

2020 →

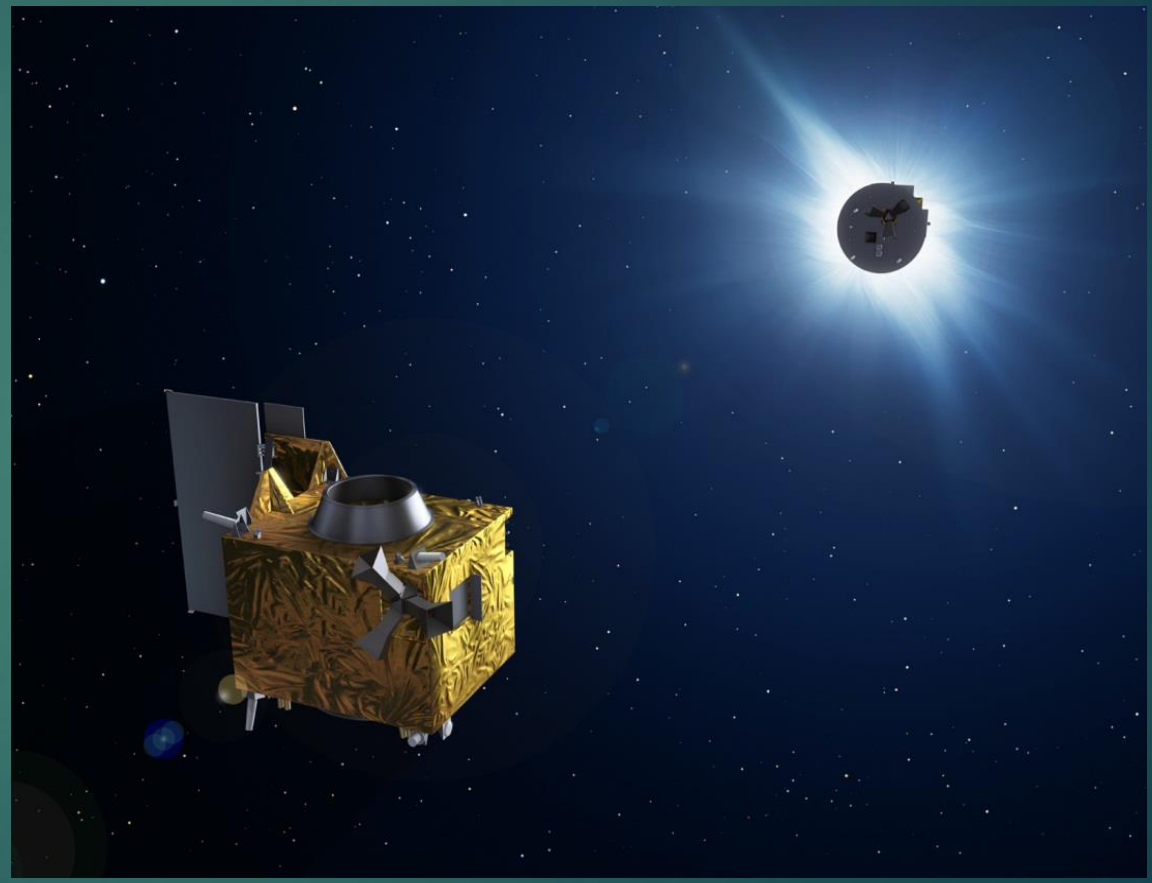
2021 → 3th Antarctica campaign

2022 → 4th Antarctica campaign

2023 → End of the project

AFTER

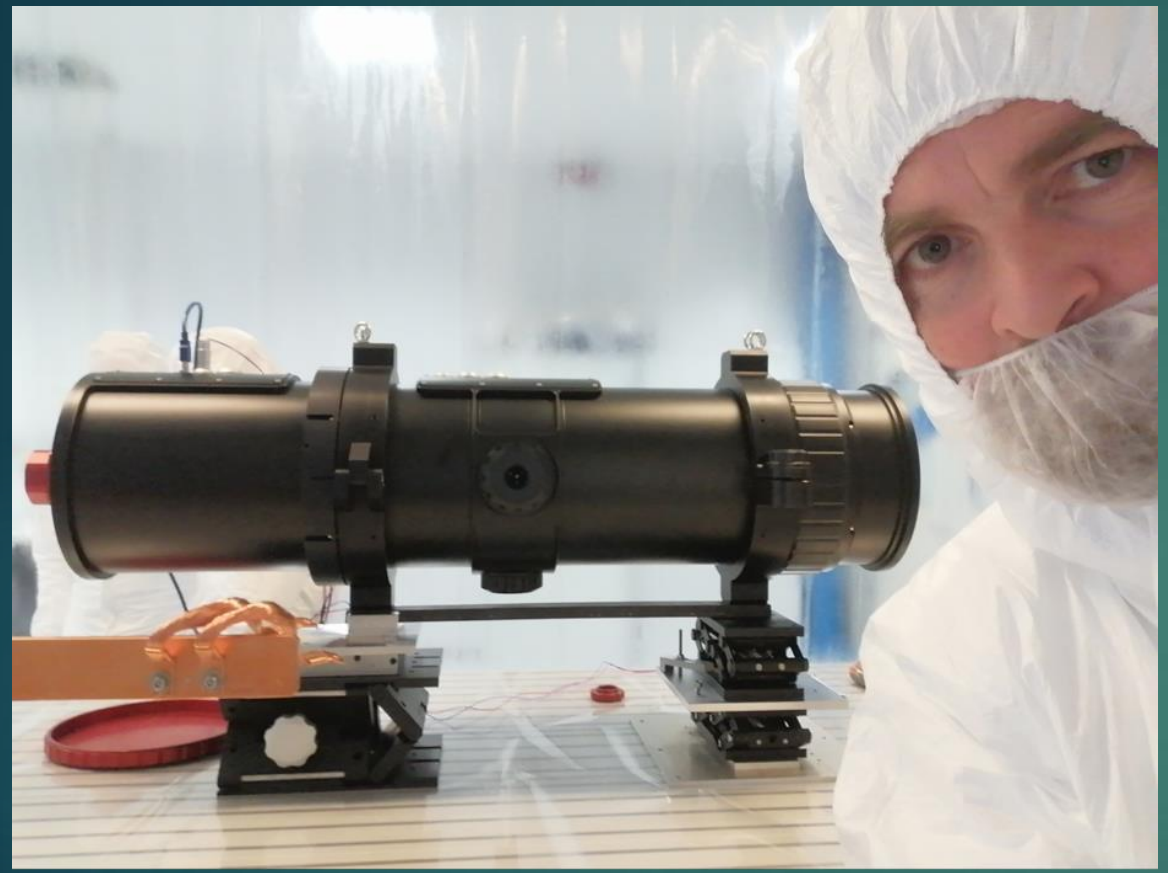
CorMag, ESCAPE 2(?)...



ESA-PROBA3 Mission Concept – Courtesy of ESA

ESCAPE: The study of the solar corona from Dome C, Antarctica

ESCAPE TIMELINE in SNAPSHOT



September 2018 – AntarctiCor tests with the sun simulator in Turin, Italy

ESCAPE: The study of the solar corona from Dome C, Antarctica

ESCAPE TIMELINE in SNAPSHOT

January 2019 – First installation of ESCAPE in Antarctica on the ASTEP mount

ESCAPE: The study of the solar corona from Dome C, Antarctica

ESCAPE TIMELINE in SNAPSHOT

October 2019 – Test of the mount in the OATo workshop

ESCAPE: The study of the solar corona from Dome C, Antarctica

ESCAPE TIMELINE in SNAPSHOT

December 2019 – Installation of ESCAPE in the Baader Planetarium @ Concordia

ESCAPE: The study of the solar corona from Dome C, Antarctica

ESCAPE TIMELINE in SNAPSHOT

November 2022 – The ESCAPE installation for the 2022/2023 campaign

ESCAPE: The study of the solar corona from Dome C, Antarctica

ESCAPE TIMELINE in SNAPSHOT

January 2023 – Coronagraphic observations in progress...

ESCAPE: The study of the solar corona from Dome C, Antarctica

SCIENTIFIC OBJECTIVES

1.Polarimetric observations of the solar corona in the spectral broad-band K-corona emission (586 – 596 nm). Retrieve the electron density required by mostly of the coronal diagnostics

2.Demonstrate that Concordia is one of the few existing sites for coronal observations by exploiting Dome C **unique low sky brightness**

3.Field-test of a space coronagraph (ASPIICS) for a solar mission of the European Space Agency (PROBA-3) to be launched in June 2024 and for the **stratospheric balloon** platform HEMERA launched summer 2022 and summer 2023.

Measurements of interest for Space Weather projects

ESCAPE: The study of the solar corona from Dome C, Antarctica

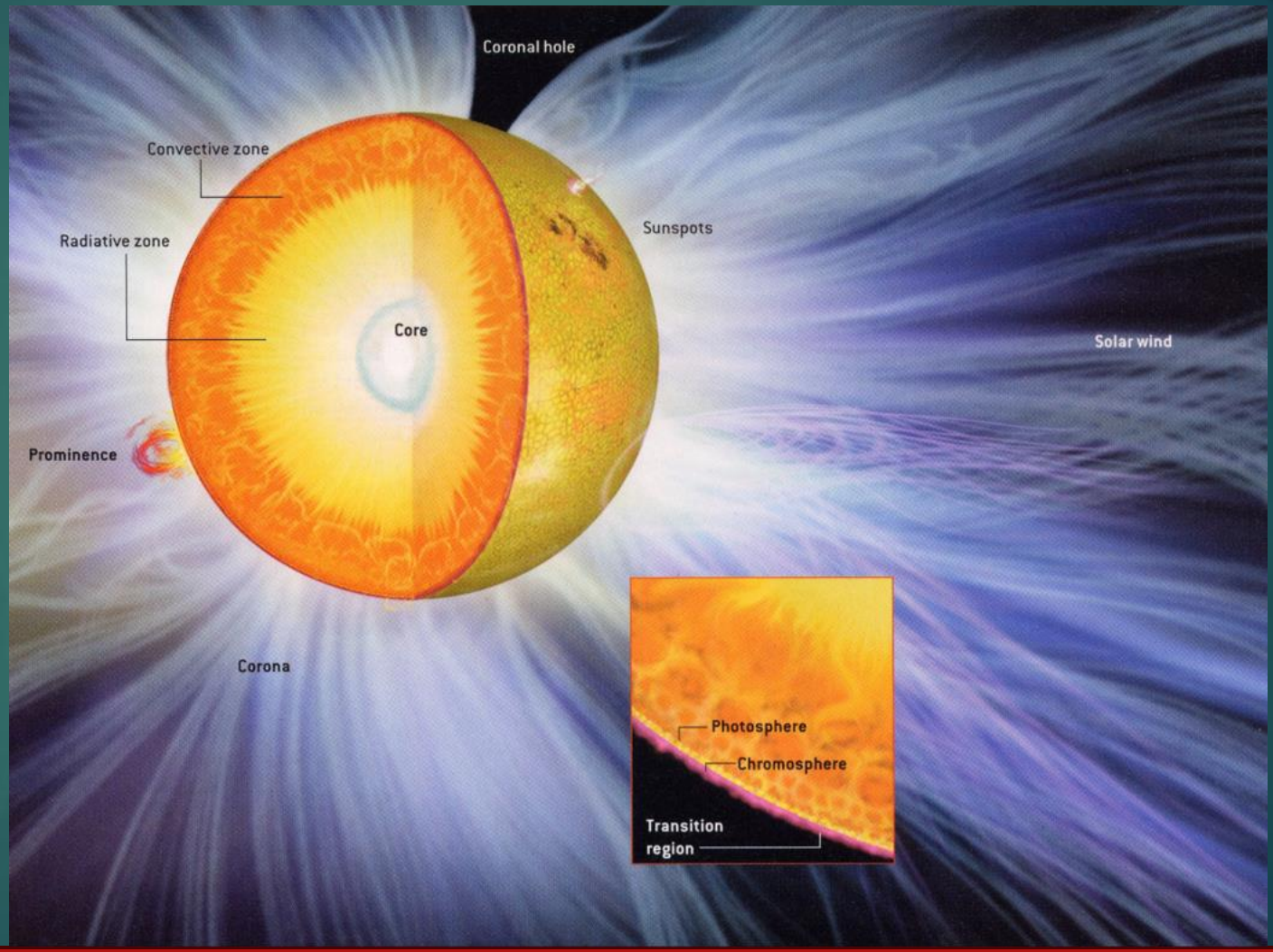
SOLAR CORONA

The solar corona is the outermost part of the Sun atmosphere.

T_{corona} (1.E6 K) ~ 200 T_{sun}
WHY??

ρ_{corona} ~ 1.E-7 ρ_{sun} →
→ B_{corona} ~ 1.E-6 B_{sun}
(difficult to observe)

The particles expelled by the Sun (95% p^+ and e^-)are accelerated in the corona (from 300 to 800 km/s) and propagates through the solar system (solar wind).
How this mechanism works?



ESCAPE: The study of the solar corona from Dome C, Antarctica

SOLAR CORONA

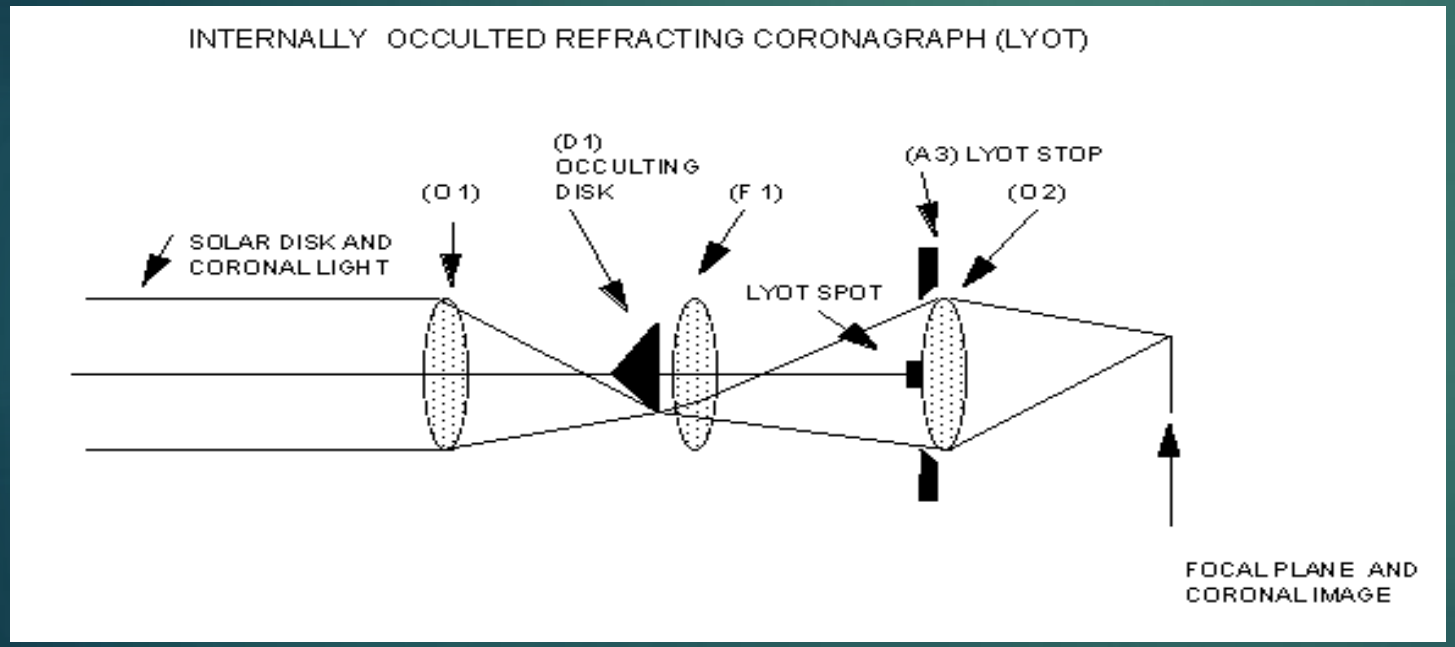
The auroras are generated by the interaction of the solar wind with the geomagnetic field

ESCAPE: The study of the solar corona from Dome C, Antarctica

INSTRUMENTATION

In 1930's the french astronomer **Bernard Lyot** invent the coronagraph

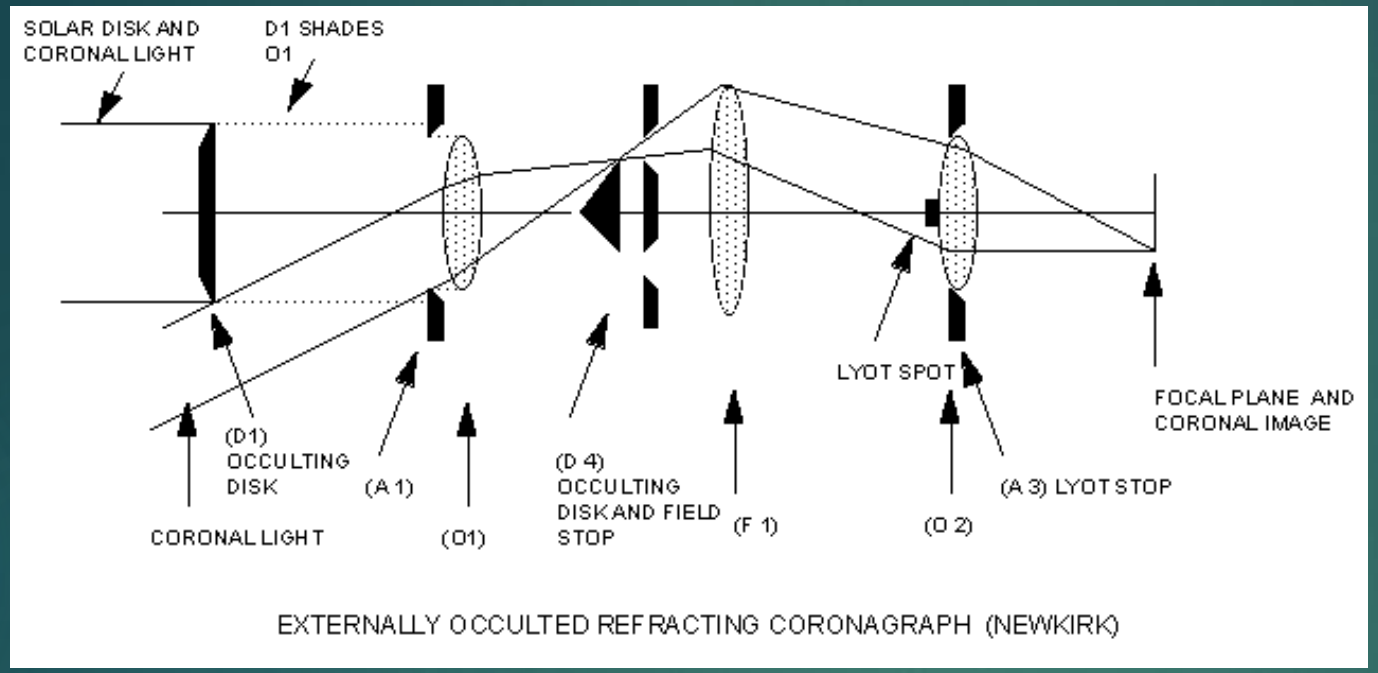
Since the coronal light is very faint a coronagraph MUST:
- Block the solar disk light
- Block the light diffracted by the edges of the optical elements



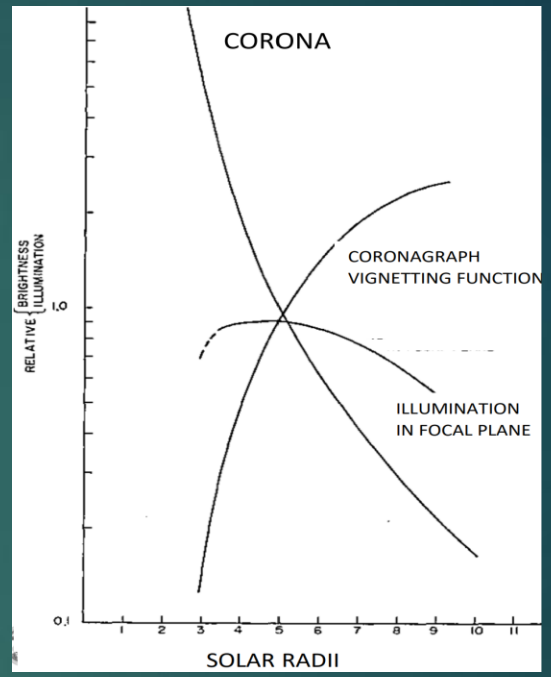
ESCAPE: The study of the solar corona from Dome C, Antarctica

INSTRUMENTATION

All the (in operation) space-based solar coronagraphs are externally occulted



EXTERNALLY OCCULTED REFRACTING CORONAGRAPH (NEWKIRK)



PRO

- Very steep vignetting function mitigates the large dynamic range of the coronal brightness
- Only way to achieve low stray light in the outer corona

CONS

- Lower end of FOV not lower than 1.5 Rs
- Low throughput at the lower end of the field of view

ESCAPE: The study of the solar corona from Dome C, Antarctica

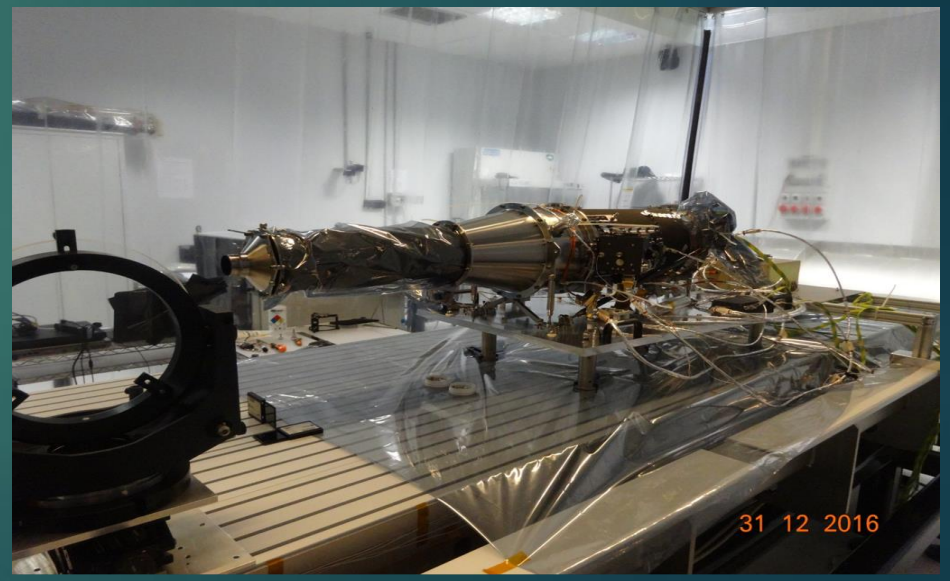
INSTRUMENTATION

Ground-based solar coronagraphs:

- K-Cor @Mauna Loa (Hawaii) performing a few hours/day observations – closed from November 2022 after the Mauna Loa volcano eruption
- ESCAPE @ Dome C (Antarctica) performing seasonals observation for 12h/day

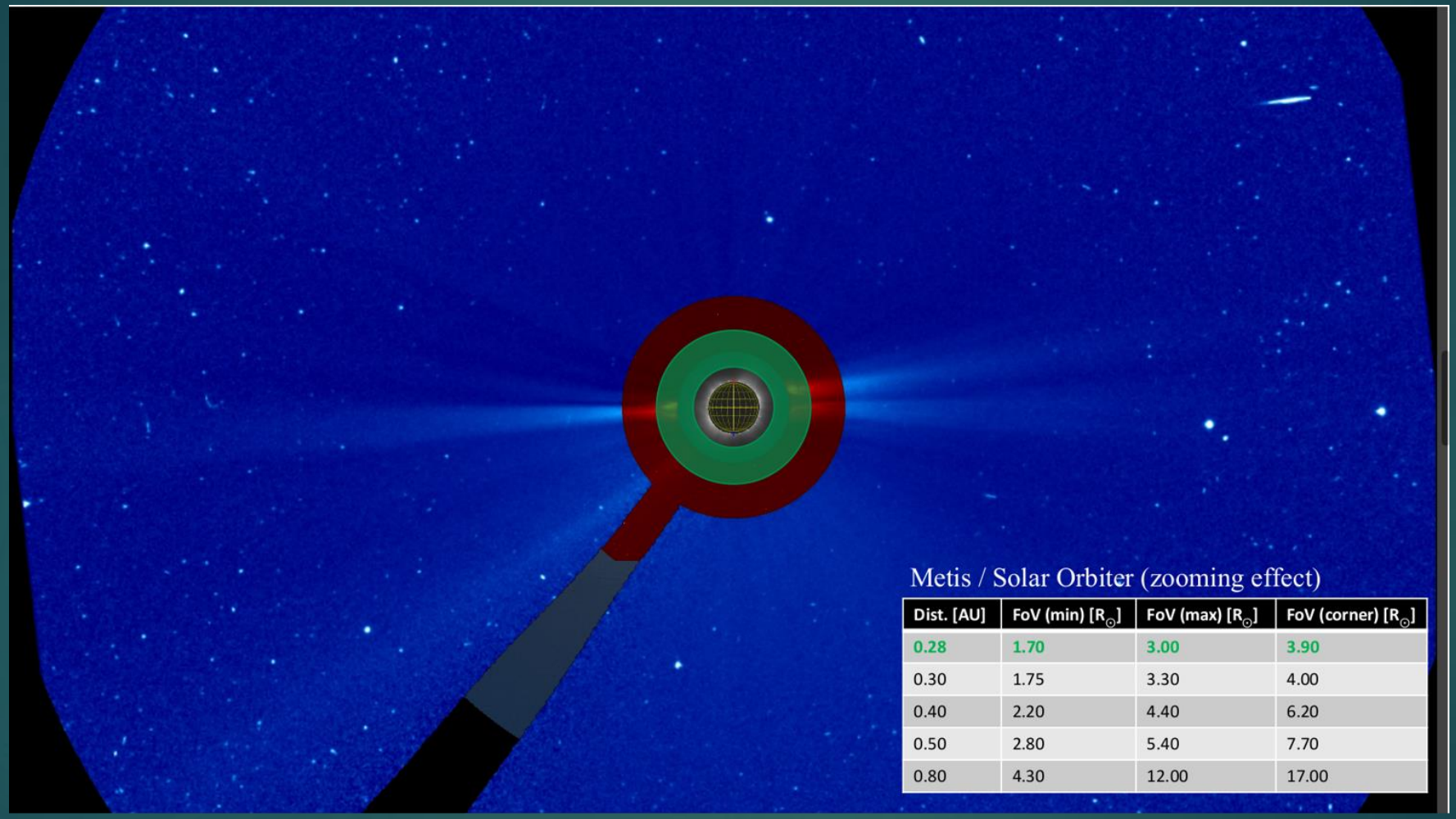
Space-based solar coronagraph:

- LASCO C2/C3 on-board SOHO mission from 1995
- Metis on-board Solar Orbiter launched Feb. 2020
- A few days ago launched Aditya with Visible Emission Line Coronagraph (VELC)



ESCAPE: The study of the solar corona from Dome C, Antarctica

IMPORTANCE of GROUND OBSERVATIONS

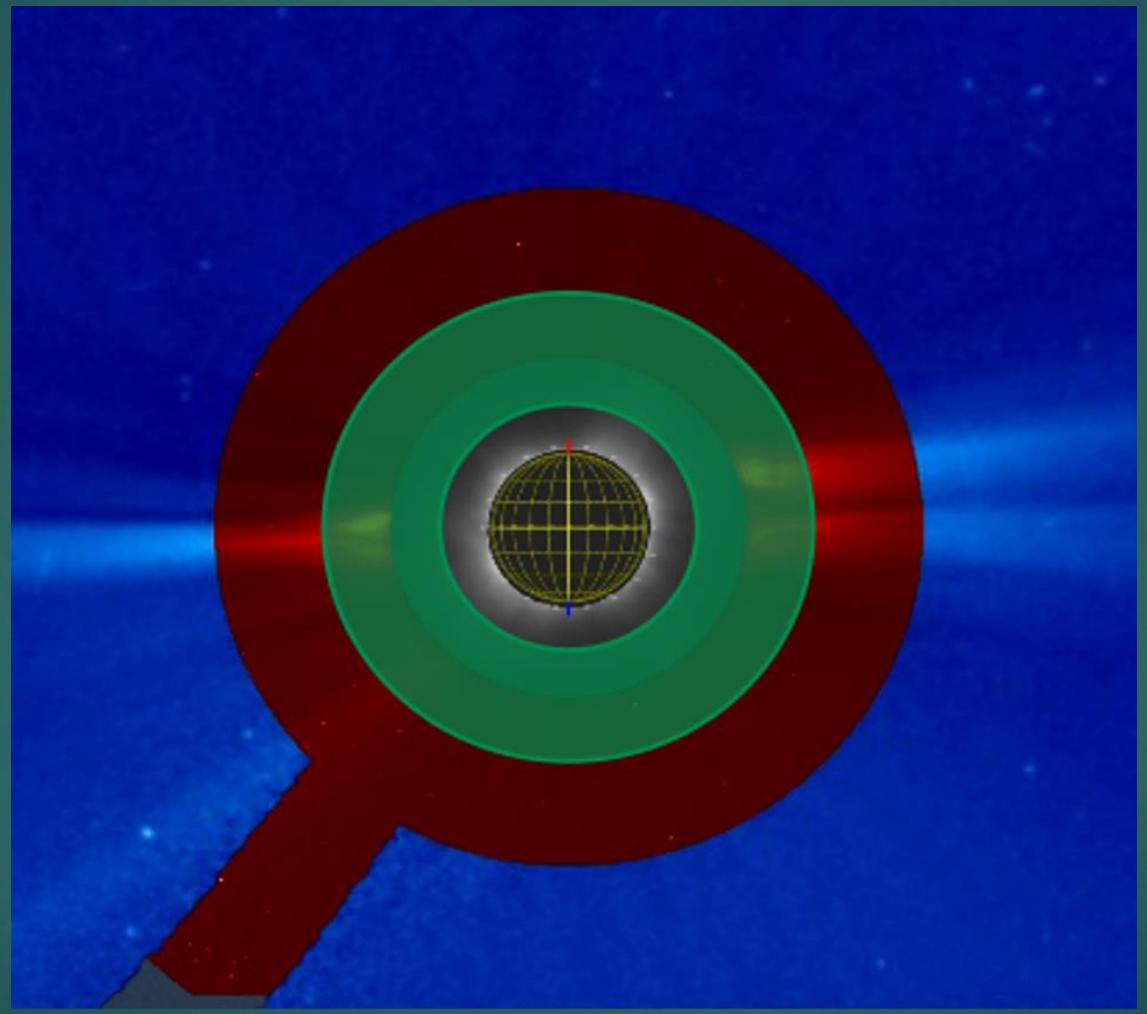


Metis / Solar Orbiter (zooming effect)

Dist. [AU]	FoV (min) [$R_\odot$]	FoV (max) [$R_\odot$]	FoV (corner) [$R_\odot$]
0.28	1.70	3.00	3.90
0.30	1.75	3.30	4.00
0.40	2.20	4.40	6.20
0.50	2.80	5.40	7.70
0.80	4.30	12.00	17.00

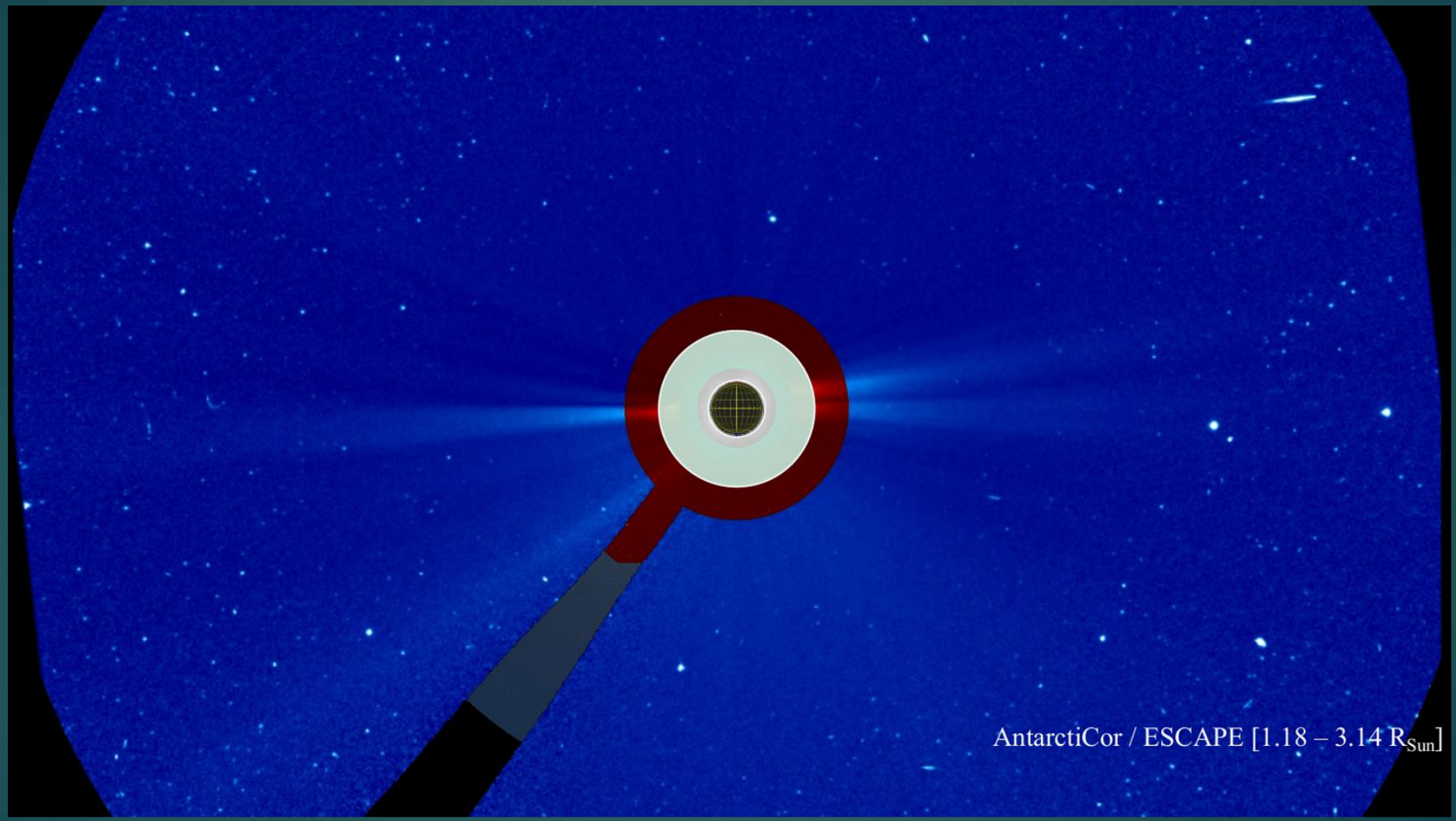
ESCAPE: The study of the solar corona from Dome C, Antarctica

IMPORTANCE of GROUND OBSERVATIONS



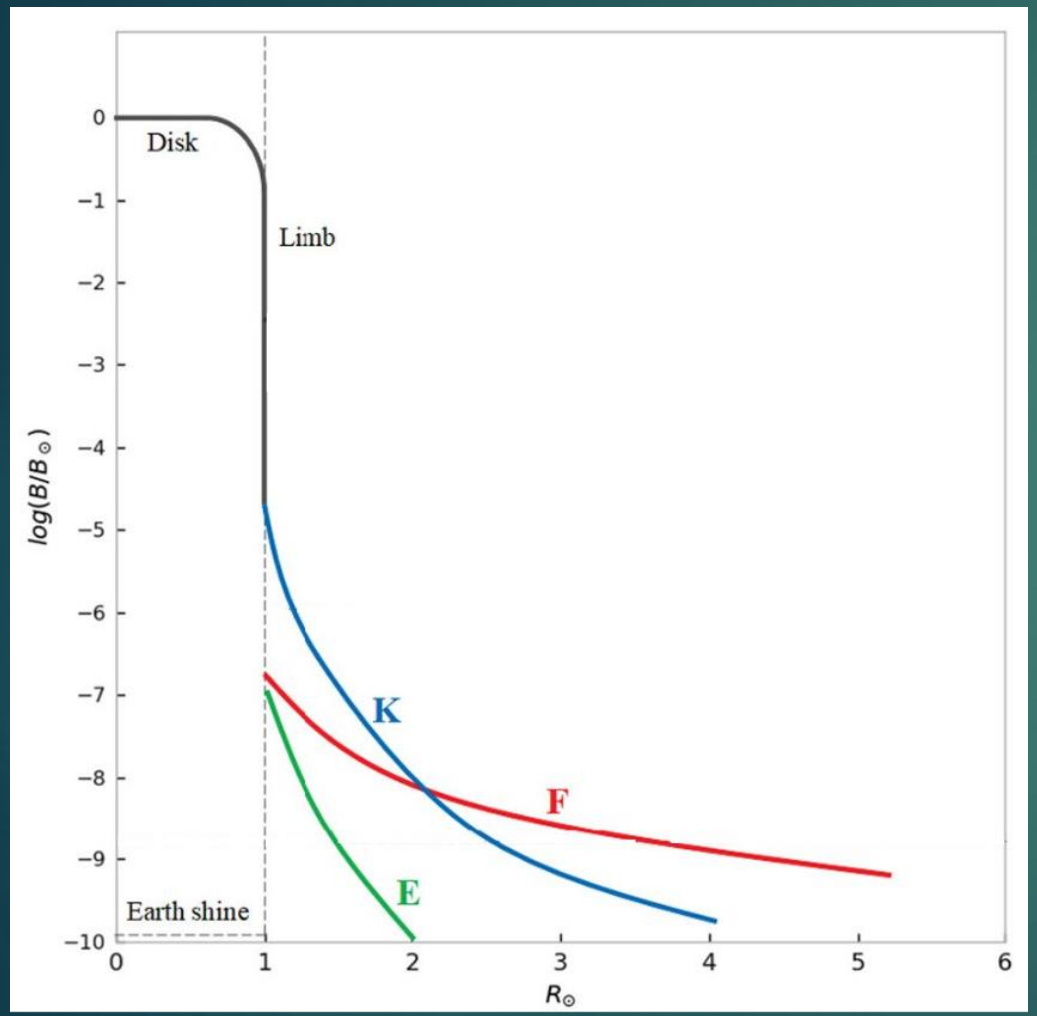
ESCAPE: The study of the solar corona from Dome C, Antarctica

IMPORTANCE of GROUND OBSERVATIONS



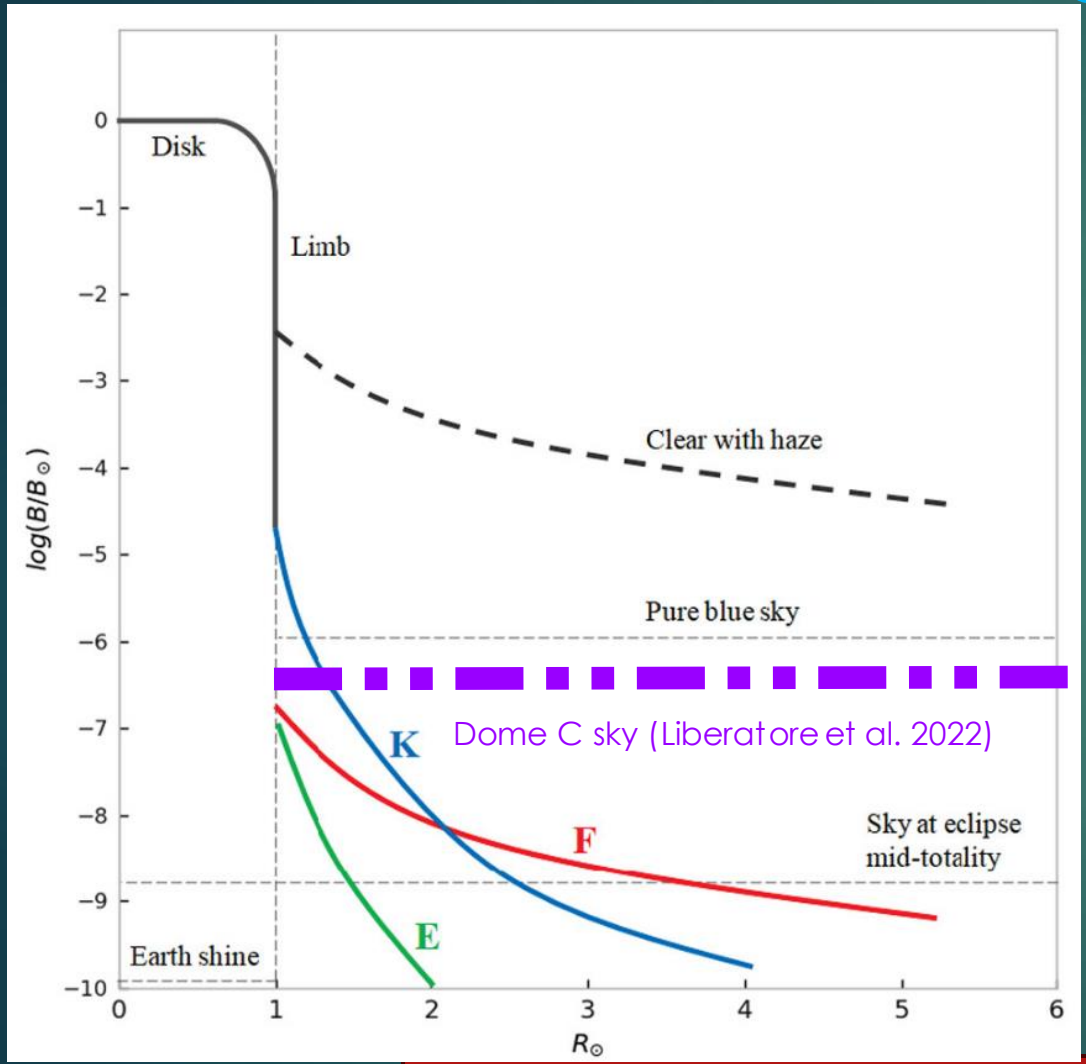
ESCAPE: The study of the solar corona from Dome C, Antarctica

CORONOGRAPHIC SITE SELECTION



ESCAPE: The study of the solar corona from Dome C, Antarctica

CORONOGRAPHIC SITE SELECTION



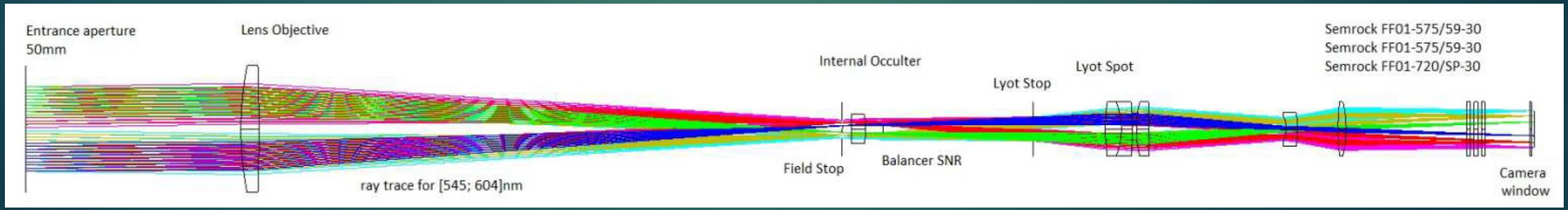
By definition of coronagraphic sky

$B_{sky} \leq 1.E\text{-}6\ B_{sun}$

AntarctiCor Optical Design

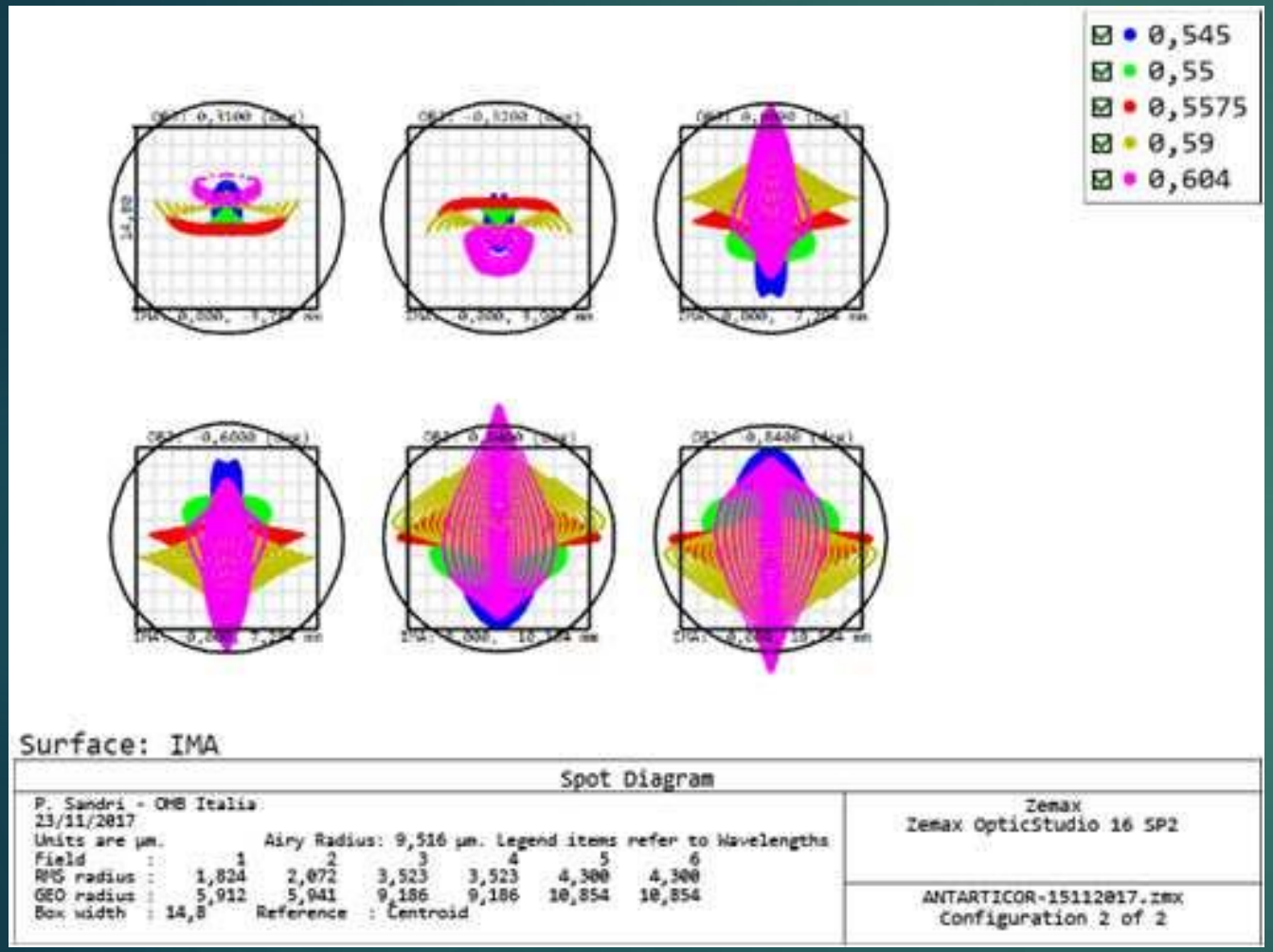
AntarctiCor Instrument Parameters	
Telescope design	Classic internally-occulted Lyot coronagraph [8]
Aperture	50 mm
Eff. Focal Length	700 mm
Spectral Ranges	591 nm ± 5 nm K-corona; 530.3 nm ± 0.25 nm FeXIV "green line"
Camera type	Interline transfer CCD by PolarCam®, mod. U4 [10]
Camera format	1950 × 1950
Pixel size	$(7.4\ \mu m)^2$
Plate scale	4.3 arcsec/pixel (8.6 arcsec/polarization super-pixel)
Field-of-View	$\pm 0.6^\circ = \pm 2.24 R_\odot$ ($\pm 0.84^\circ = \pm 3.14 R_\odot$ along CCD diagonals)
Polarization analysis	spatial modulation by linear micropolarizer array on CCD sensor

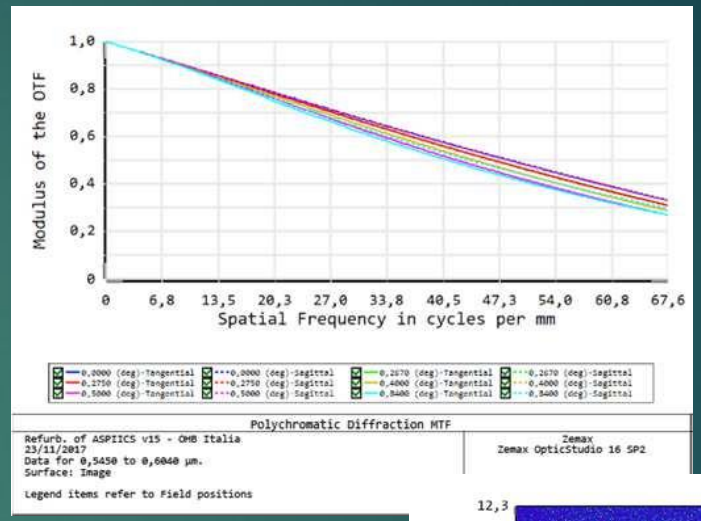
Fineschi et al., 2019

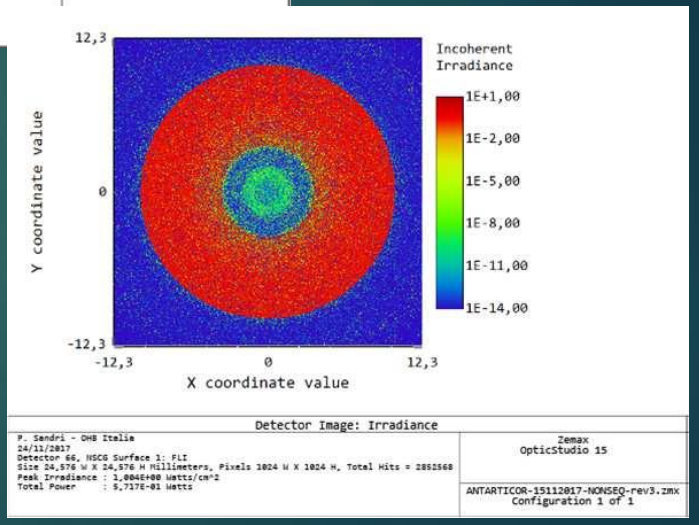


ESCAPE: The study of the solar corona from Dome C, Antarctica

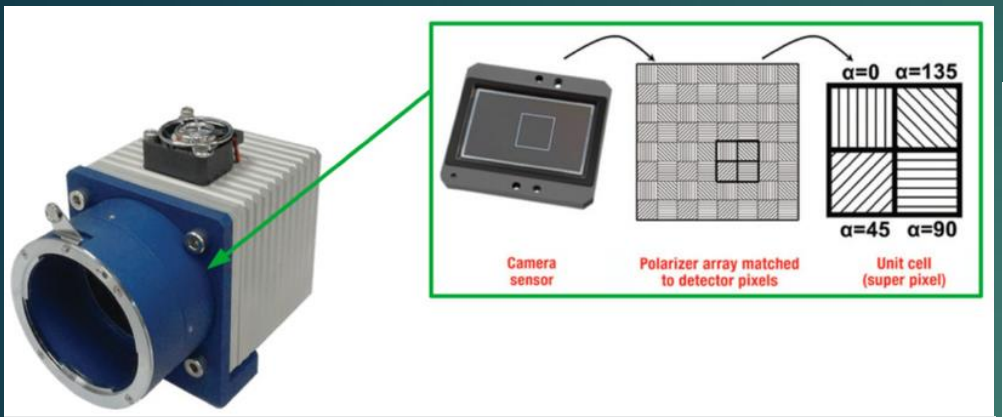
AntarctiCor Optical Design





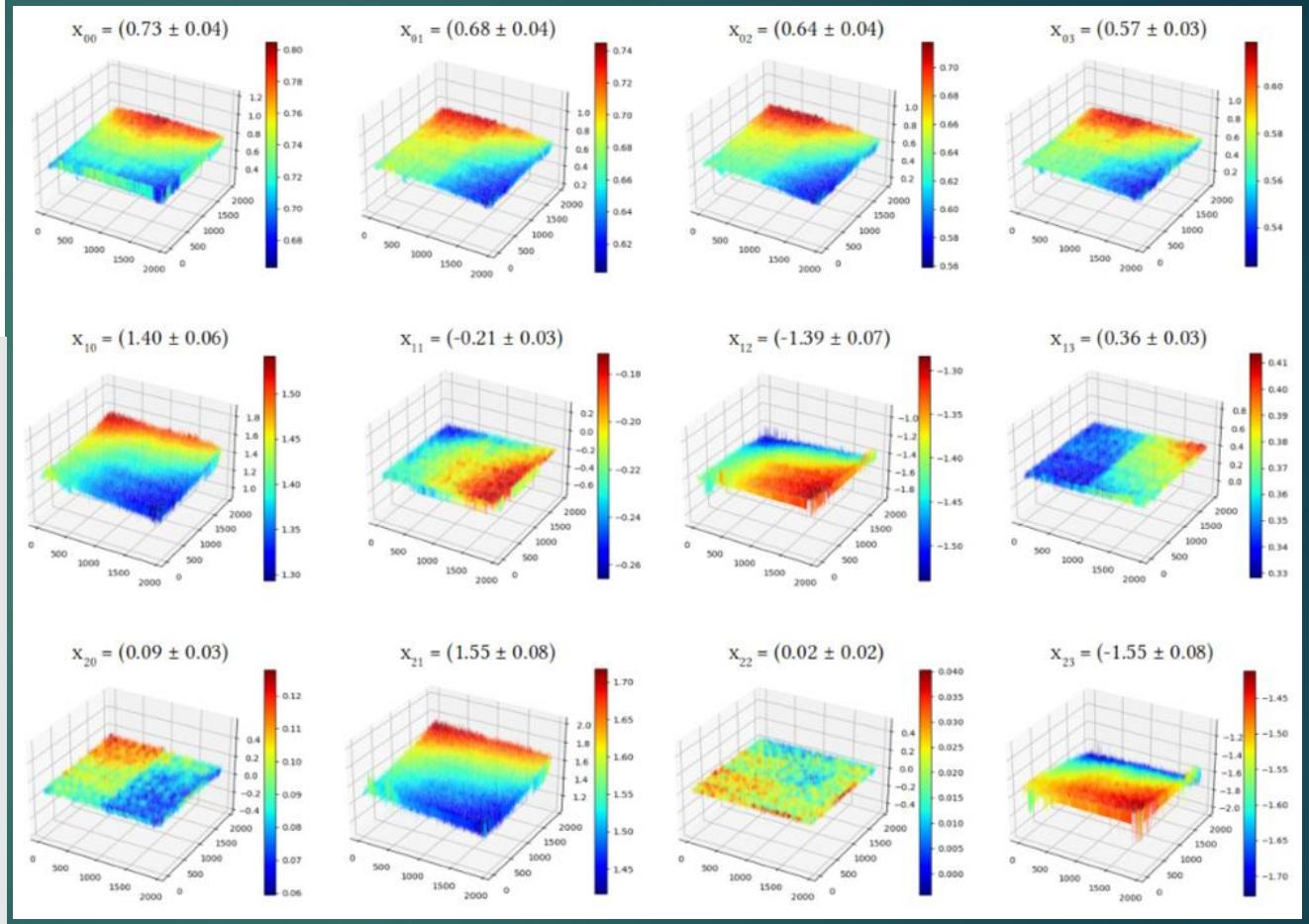


ESCAPE: The study of the solar corona from Dome C, Antarctica



Sensor Type	Interline transfer CCD ON Semiconductor KAI04070
Micropolarizers orientation	0°, 45°, 90°, 135°
Pixel Size	7.4 µm × 7.4 µm
Usable Pixels	1950 × 1950, 3.8 MP
Frame Rate	14 fps
Saturation Capacity	44 ke−
Dark Noise	3 e−/s
Quantum Efficiency	76% @ 470 nm
Physical Envelope	60 × 60 × 95 mm
Weight	210g
Power Requirement	8 W, 12VDC
Interface	USB 3.0
Lens Mounting Type	F-Mount

AntarctiCor Detector



Liberatore et al., 2021

ESCAPE Pointing System

Customized COTS german equatorial mount for extended temperature range (-40°C to +40°C)

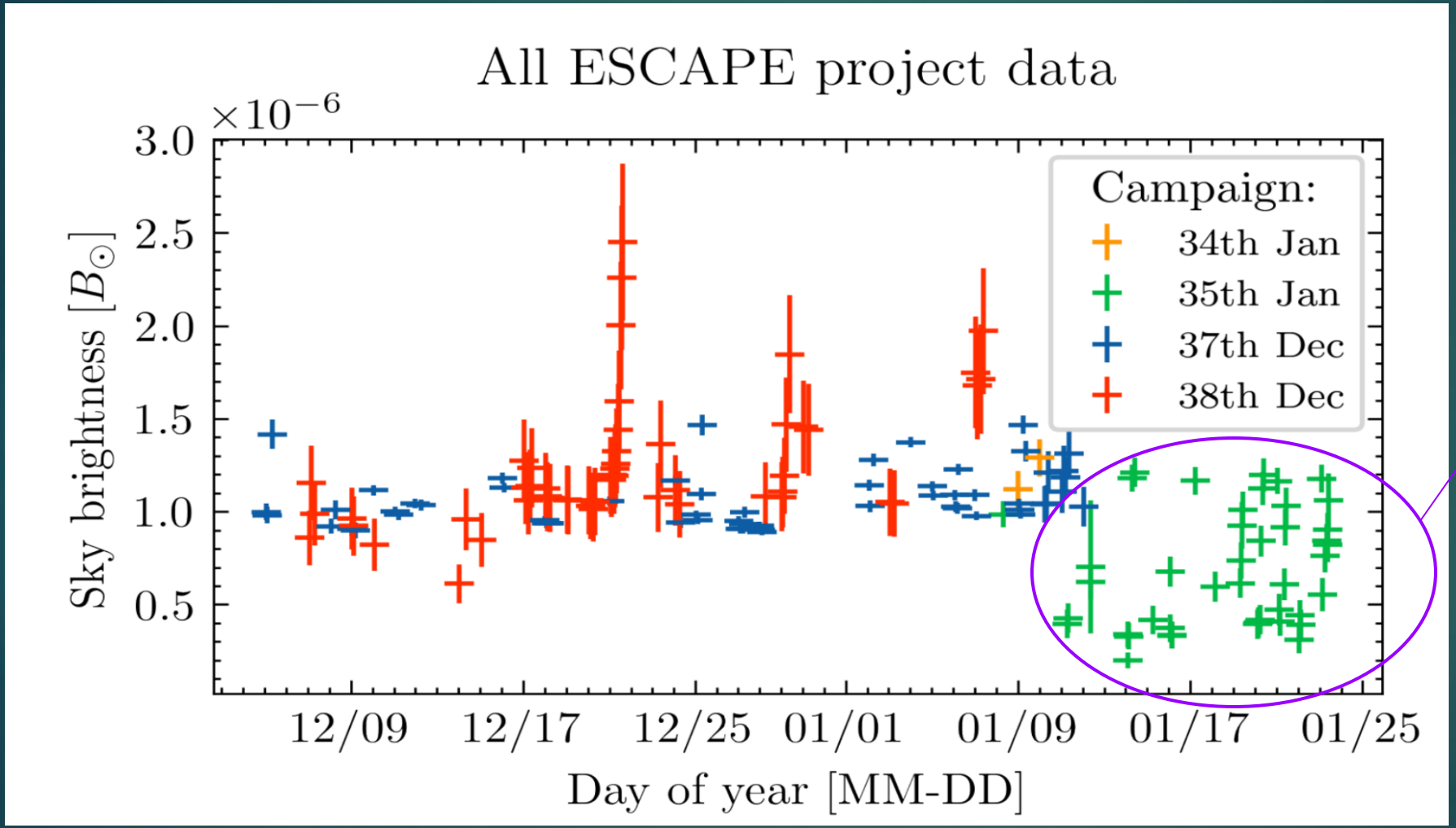
Requirements

Pointing accuracy: better than 1 arcmin

Tracking accuracy: better than 15 arcsec/min

ESCAPE: The study of the solar corona from Dome C, Antarctica

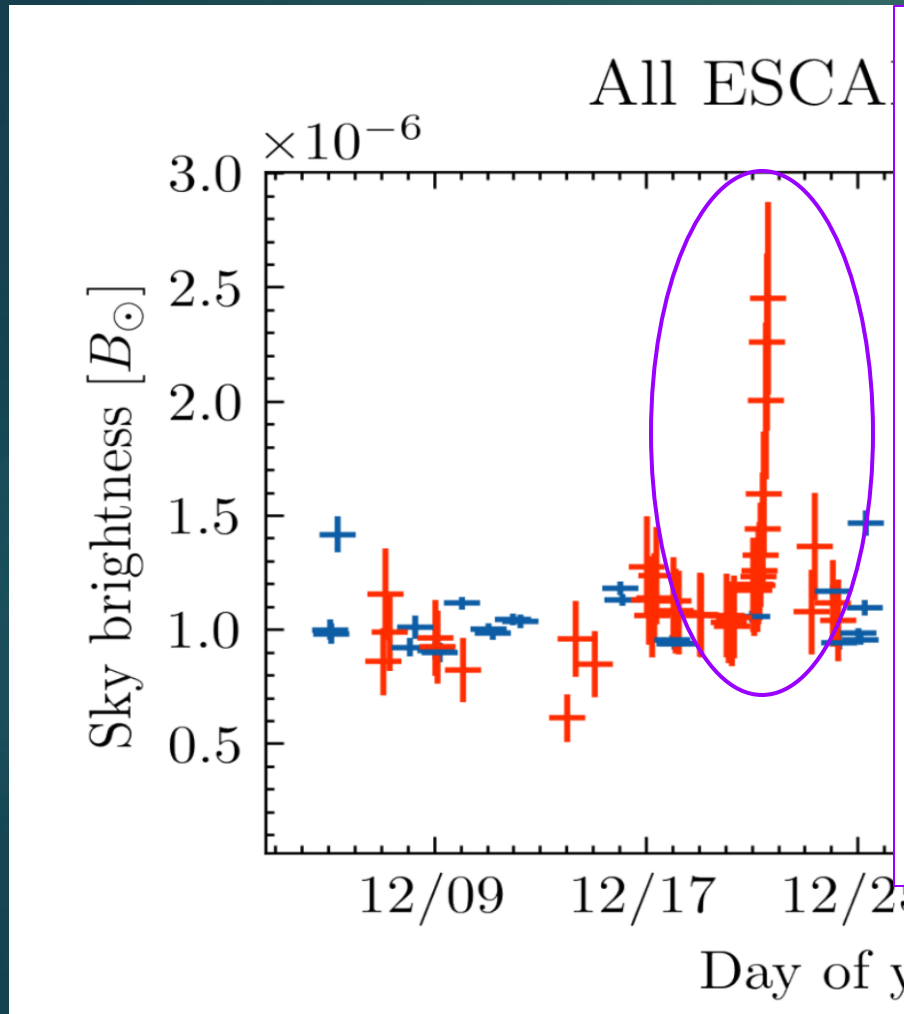
Results – Dome C Sky brightness

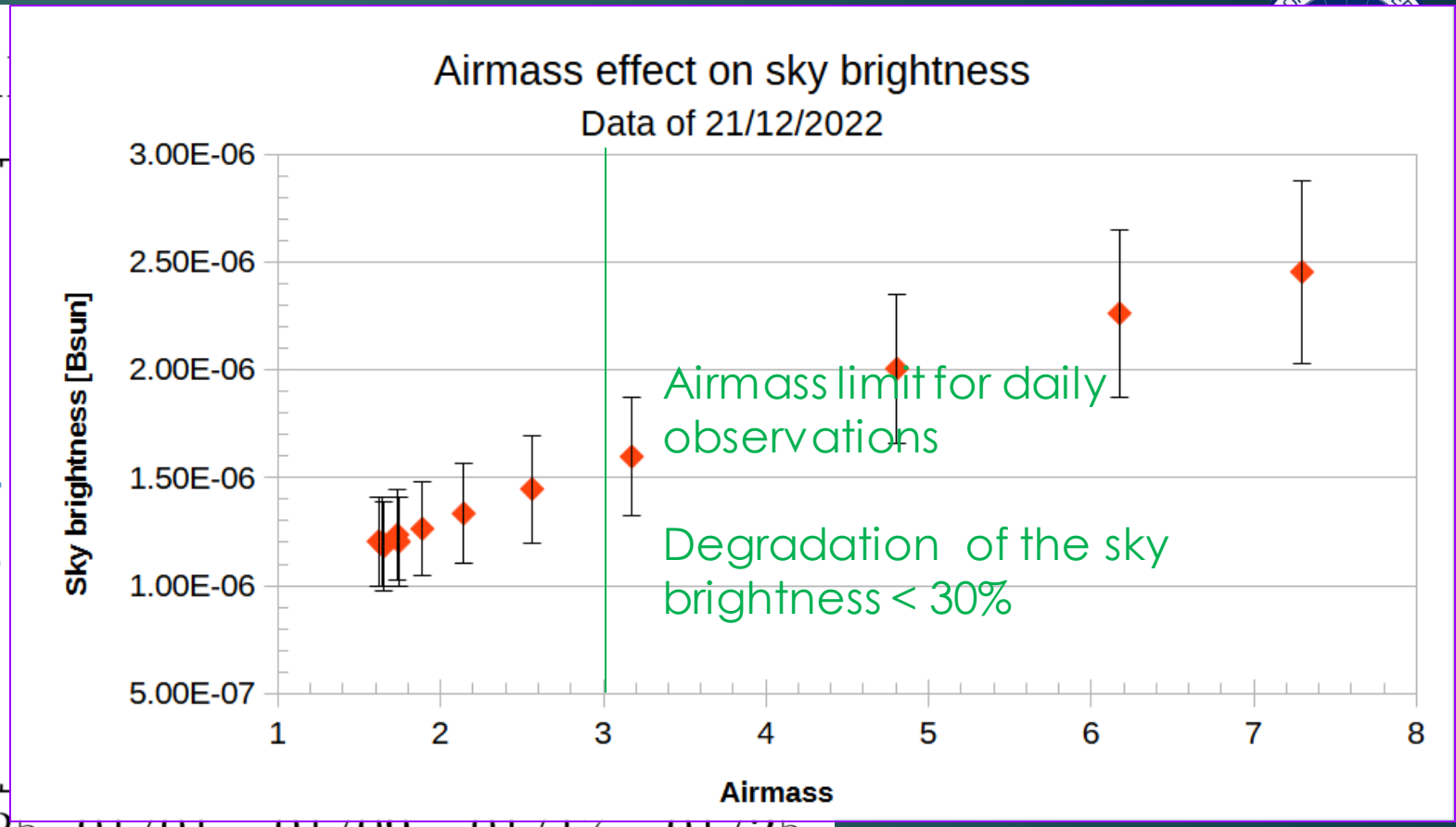


January seems to be the best period for coronal observations

ESCAPE: The study of the solar corona from Dome C, Antarctica

Results – Dome C Sky brightness

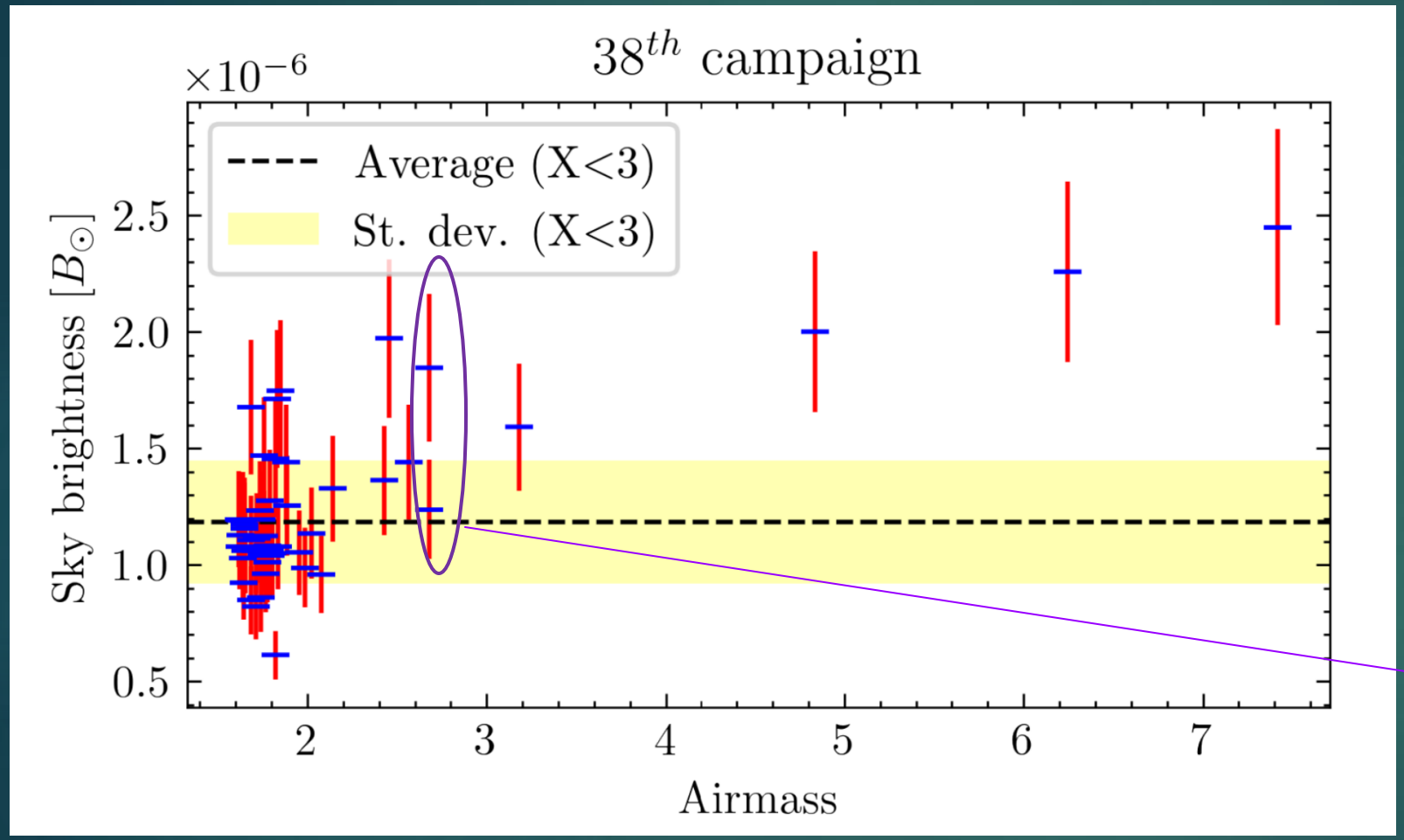


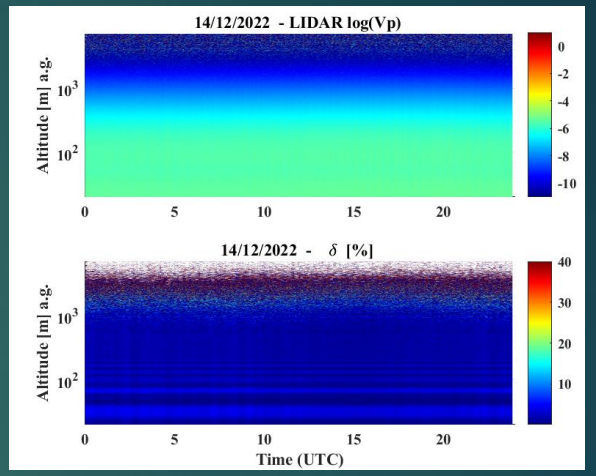


Haudemand et al., in preparation

ESCAPE: The study of the solar corona from Dome C, Antarctica

Results – Dome C Sky brightness



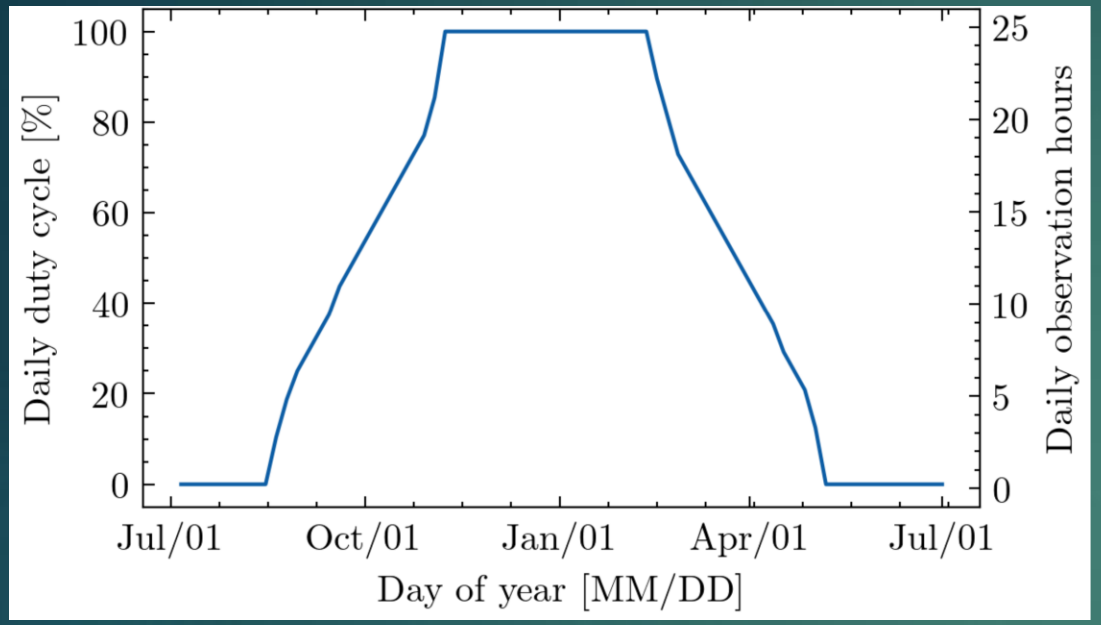


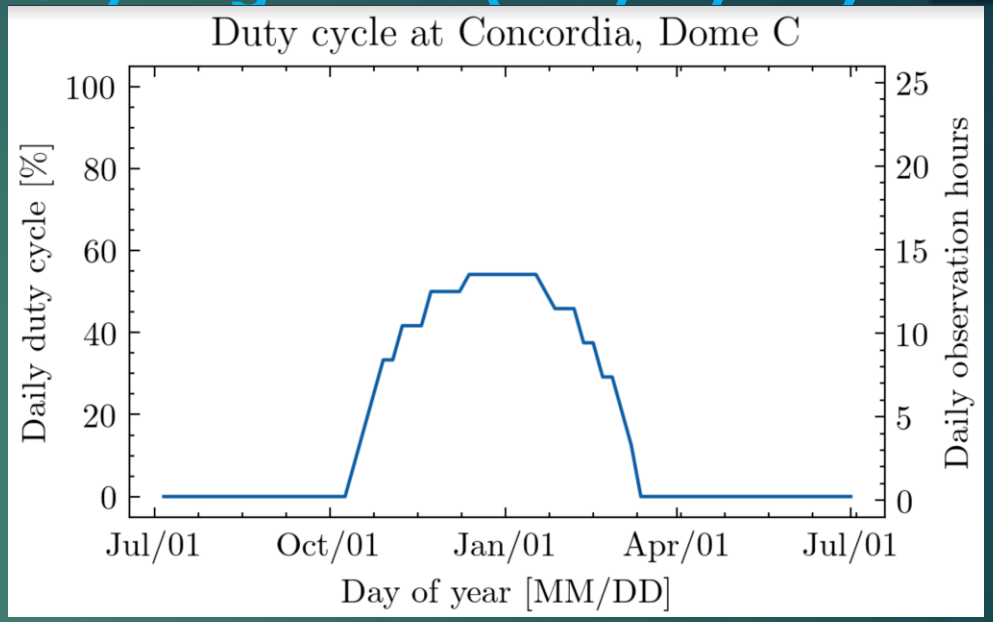
Check of the atmospheric condition with ICE-OPT data (courtesy of M. Del Guasta)

Diamond Dust

ESCAPE: The study of the solar corona from Dome C, Antarctica

Results – Dome C Sky brightness (duty cycle)

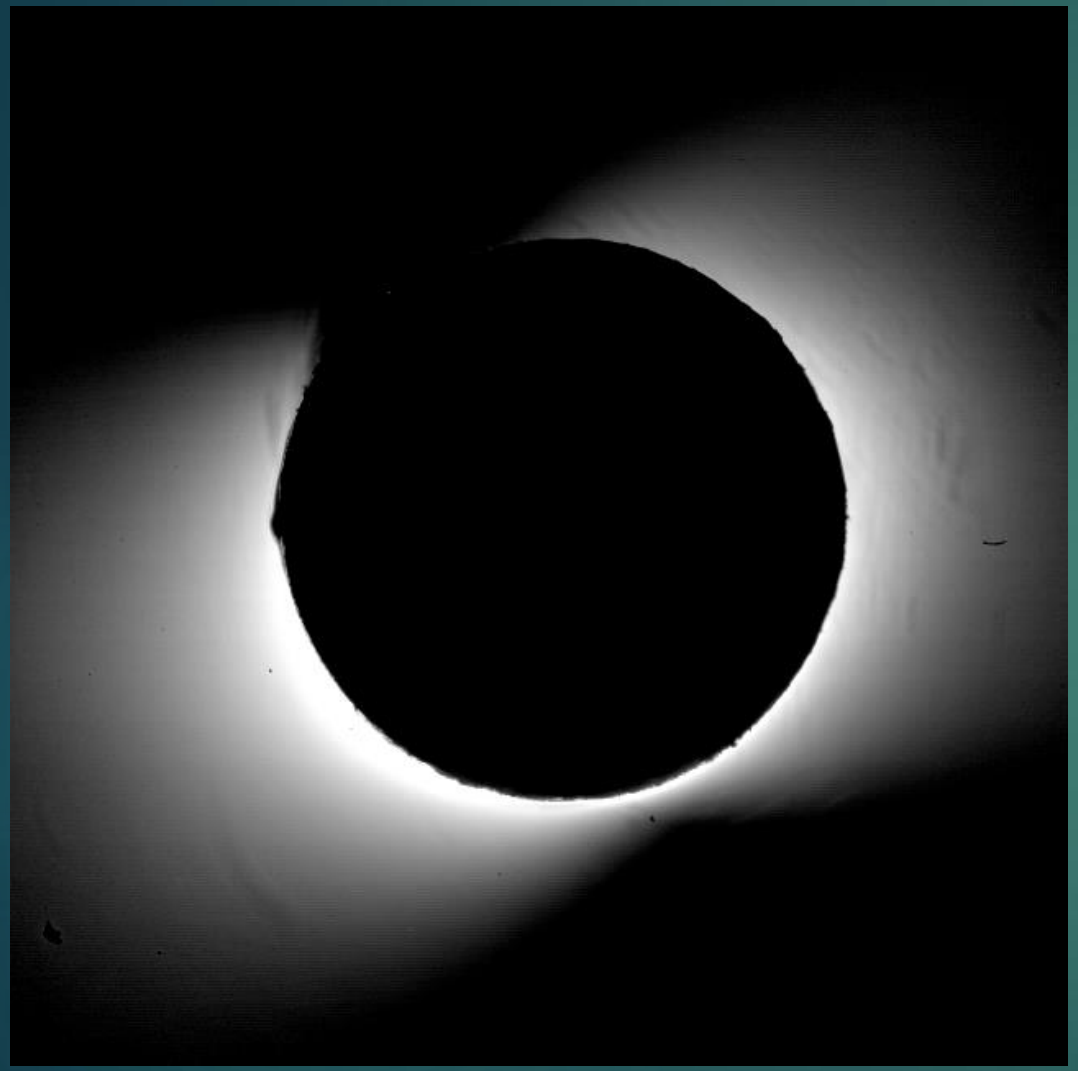




Taking into account the limits in the airmass and the typical conditions we estimate for Dome C a duty cycle of the 10% I.e., approx 850 obs. hours/yrs

ESCAPE: The study of the solar corona from Dome C, Antarctica

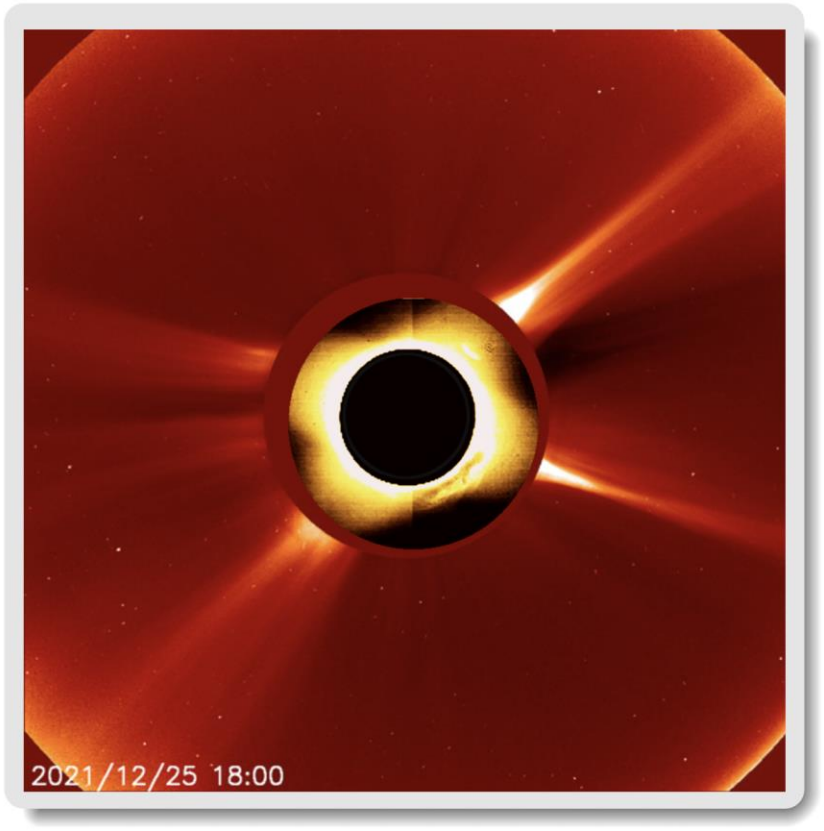
Results – Solar Corona

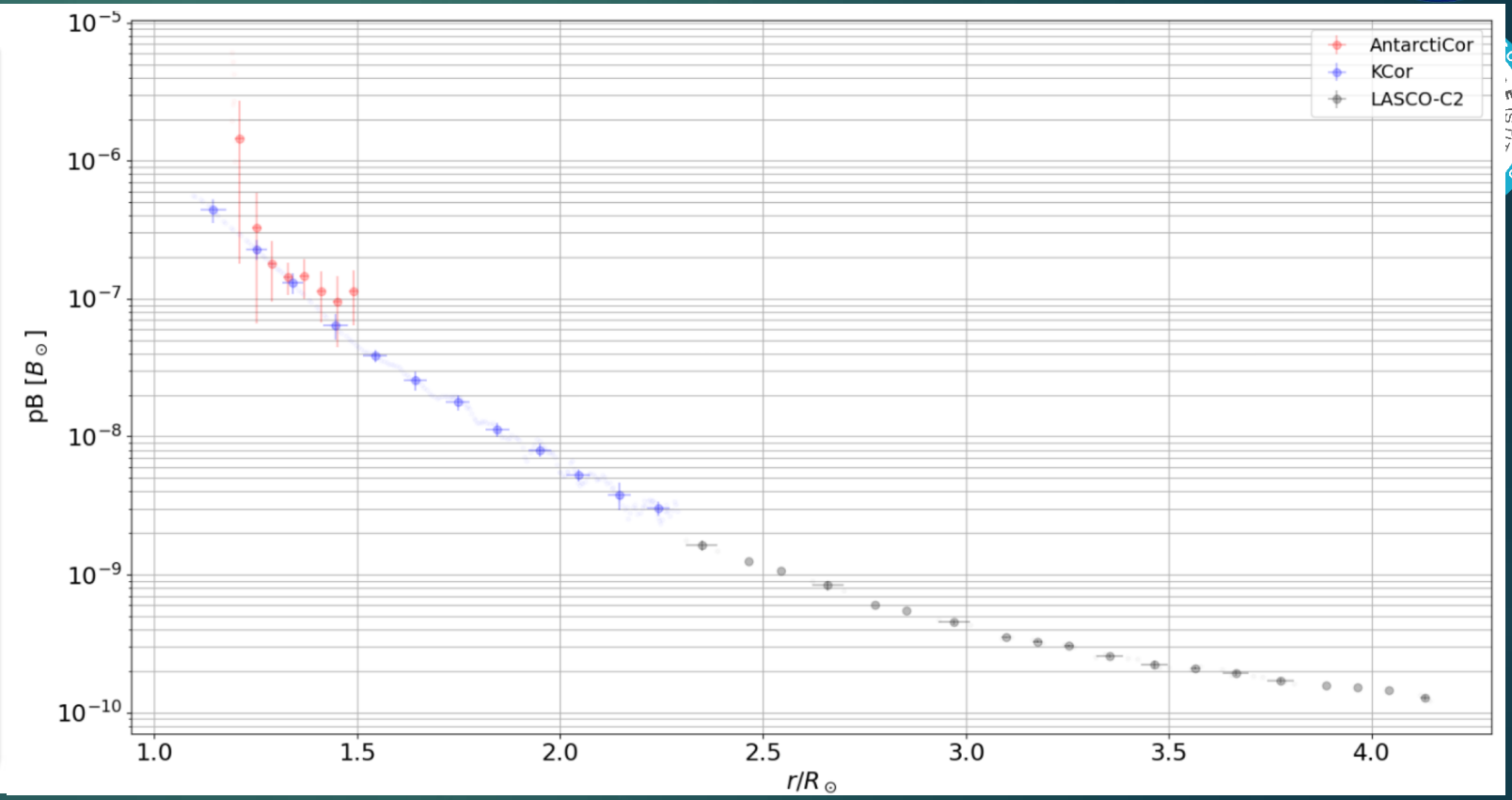


Solar Corona @ minimum solar activity (23/01/2020)

Results – Solar Corona

25/12/2021 The new solar cycle (25) is effective!





ESCAPE: The study of the solar corona from Dome C, Antarctica

CONCLUSIONS

- The solar corona is still a puzzle to be composed

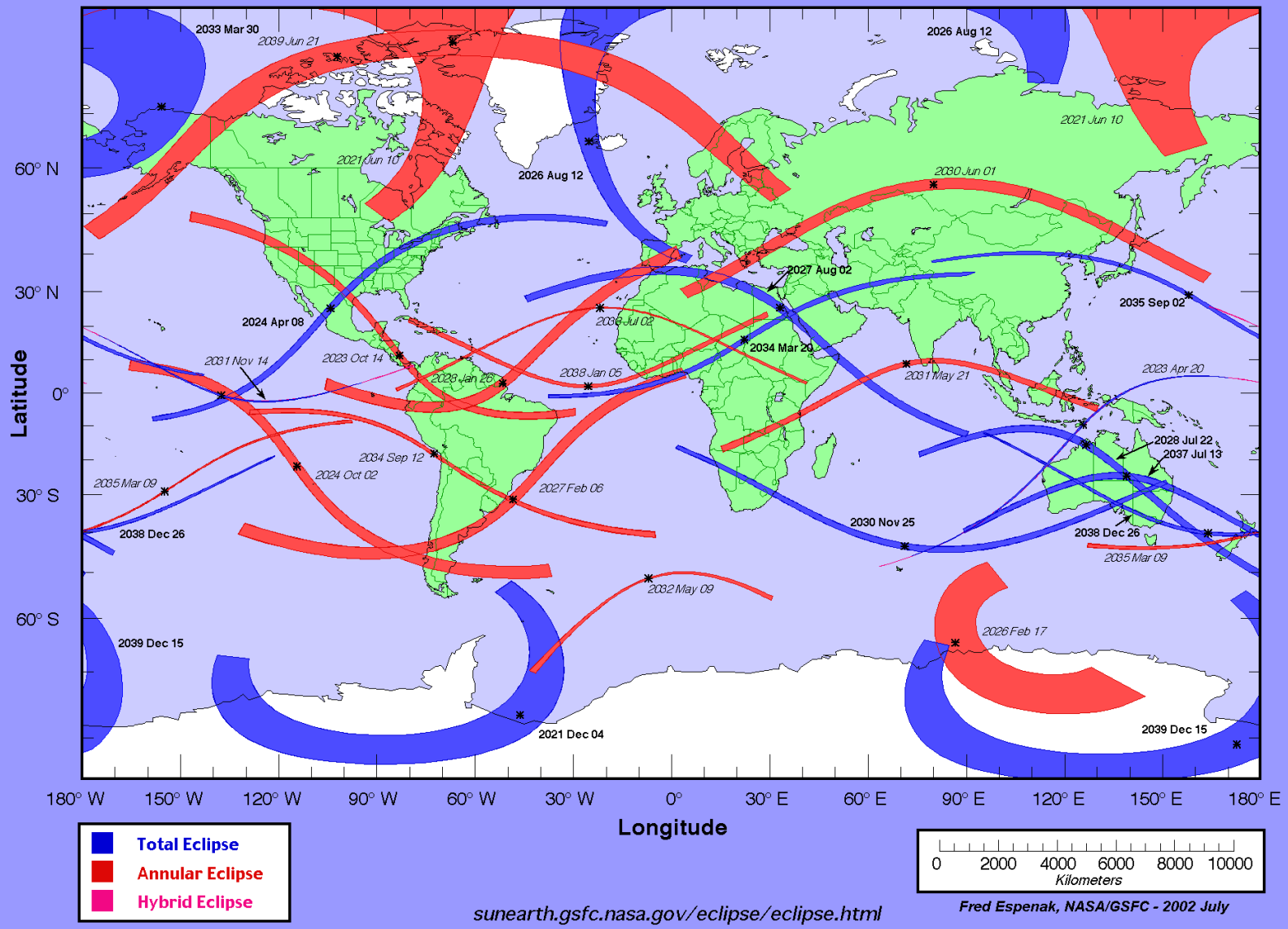
- At the moment the ground-based observations are extremely usefull for near limb observations (where the solar magnetic fields recombines and close loops) and are complementary to space-based observations

- The ESCAPE experiment demonstrate that Dome C is one of the few site in the world with a “coronagraphic” sky. The duty cycle for coronal observation at Dome C is of 10%. A tower should increase the duty cycle up to the 15%.

- Ready for the next solar maximum observations (2025-2026) !!! :)

ESCAPE: The study of the solar corona from Dome C, Antarctica

What's next...



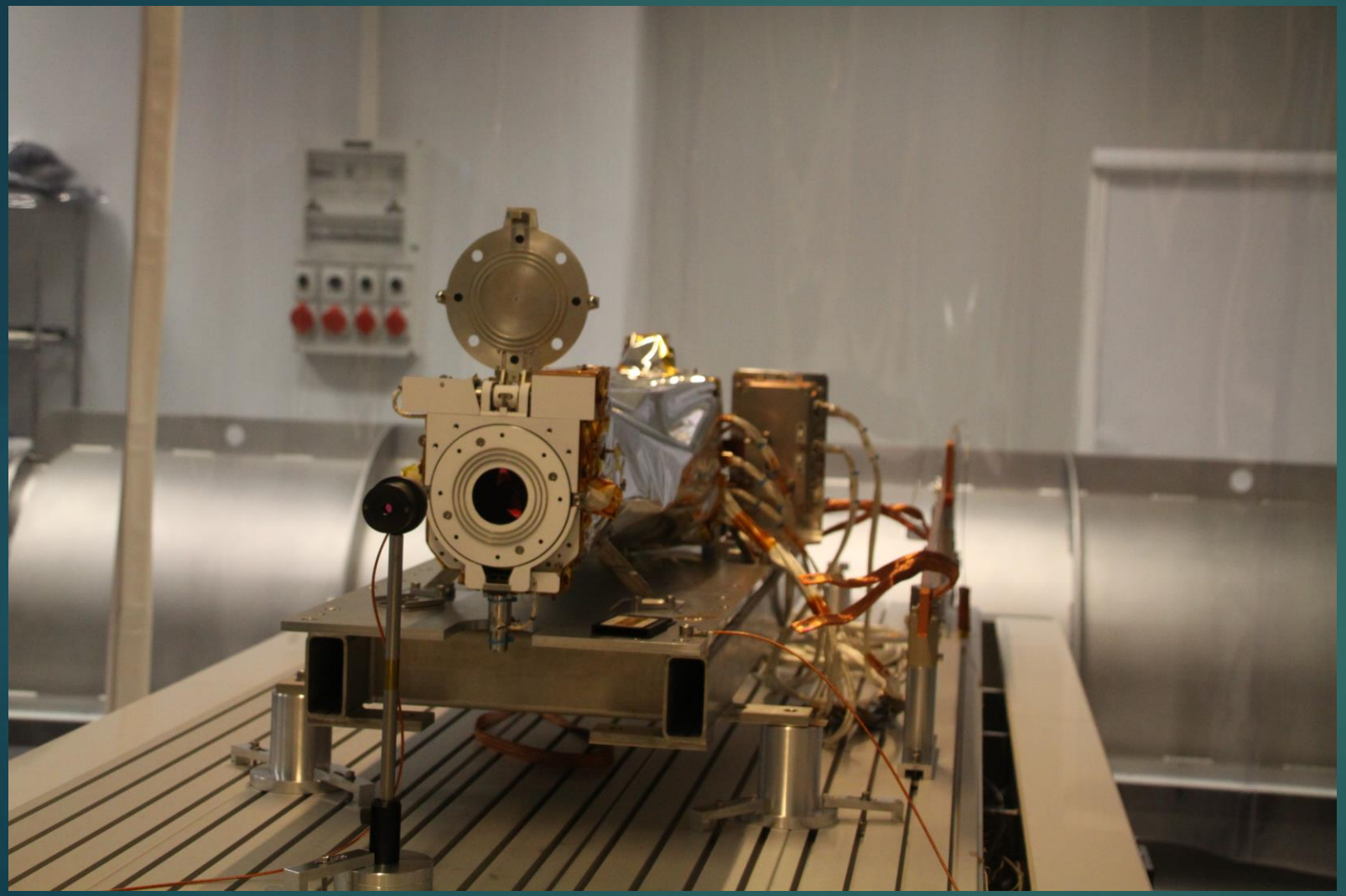
2024 April 08: Total Solar Eclipse

ESCAPE: The study of the solar corona from Dome C, Antarctica

What's next...

June 2024 : NASA CODEX installed on the ISS

ESCAPE: The study of the solar corona from Dome C, Antarctica



What's next...

June 2024: PROBA-3 in orbit

ESCAPE: The study of the solar corona from Dome C, Antarctica

What's next...

Summer 2025: 3th flight of CorMag

ESCAPE: The study of the solar corona from Dome C, Antarctica

THANKS!!!