Metis
The coronagraph for Solar Orbiter

INAF ISTITUTO NAZIONALE DI ASTROFISICA

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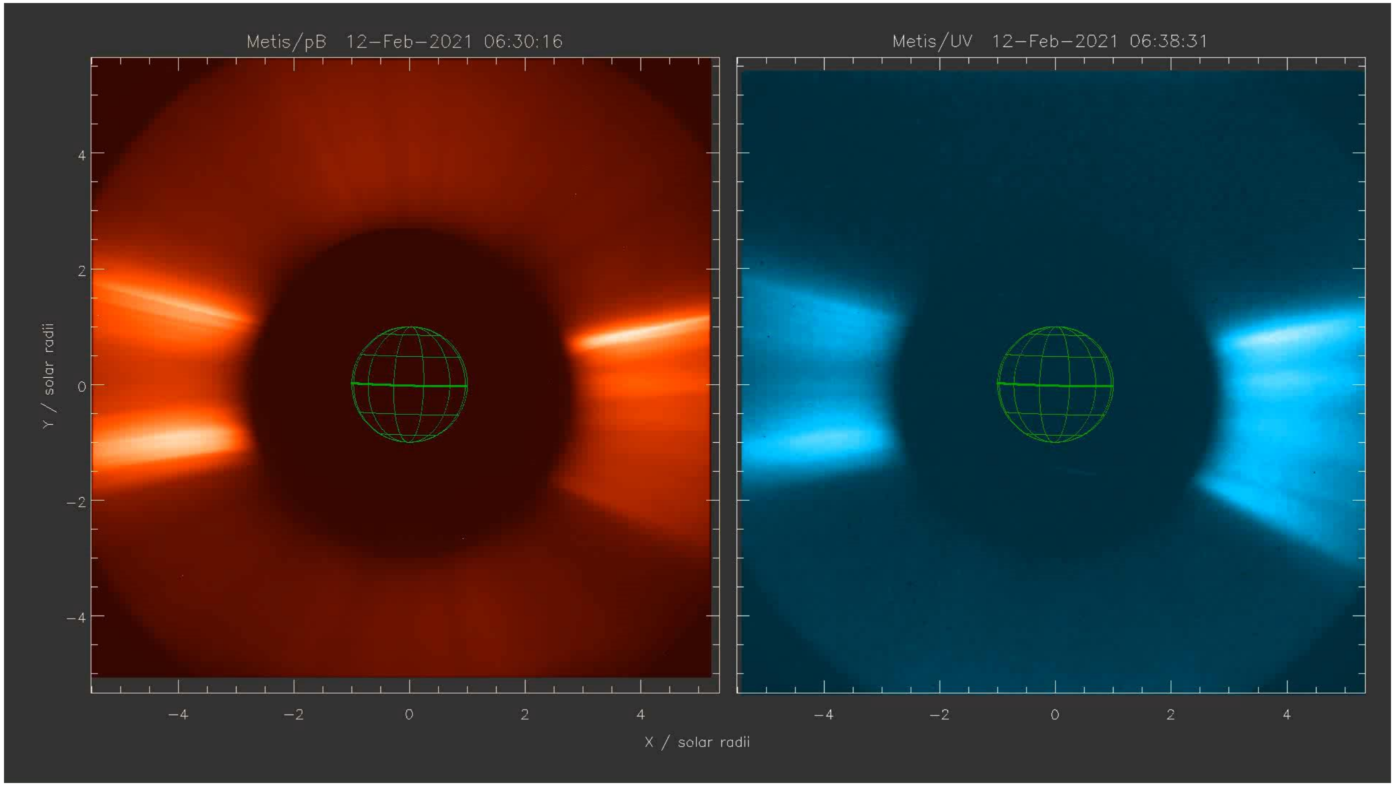
Audizione RSN-3 Sessione 8

28 May, 2021

Results



Feb 12, 2021 - 1-st ever observation of **Coronal Mass Ejection** in HI-Lyman-α (blue) and simultaneously in linearly-polarized, visible-light (red).

https://www.media.inaf.it/2021/05/17/solar-orbiter-osserva-le-sue-prime-cme/

Outline

- Solar Orbiter Mission
- Team,
- Risultati e/o Prospettive,
- Aspetti scientifici/tecnologici,
- Programmazione,
- Fondi,
- Leadership e Criticità.

Solar Orbiter Mission overview

Now (Cruise Phase):

3x telemetry rate

Synoptic program throughout the orbit

Nominal mission starts 27 Nov 2021 after Earth GAM

M1 of Cosmic Vision 2015-2025

Launch date: 10 February 2020

Commissioning +Cruise phase: ~1.9 years

Nominal mission: 5 years

Extended mission: 3 years

Orbit:

0.28 – 0.32 AU (perihelion)

0.74 -- 0.91 AU (aphelion)

Out-of-ecliptic view:
Multiple gravity assists with Venus to increase inclination out of the ecliptic to >24° (nominal mission), >34° (extended mission)

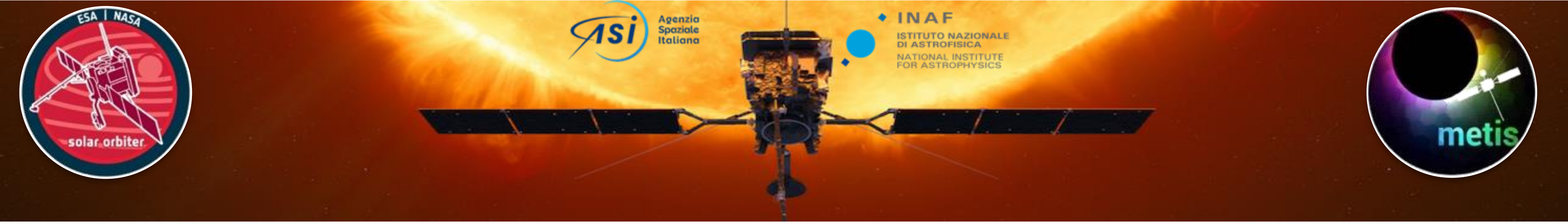
Reduced relative rotation:
Continuous observation of evolving structures on the solar surface and heliosphere for almost a complete solar rotation

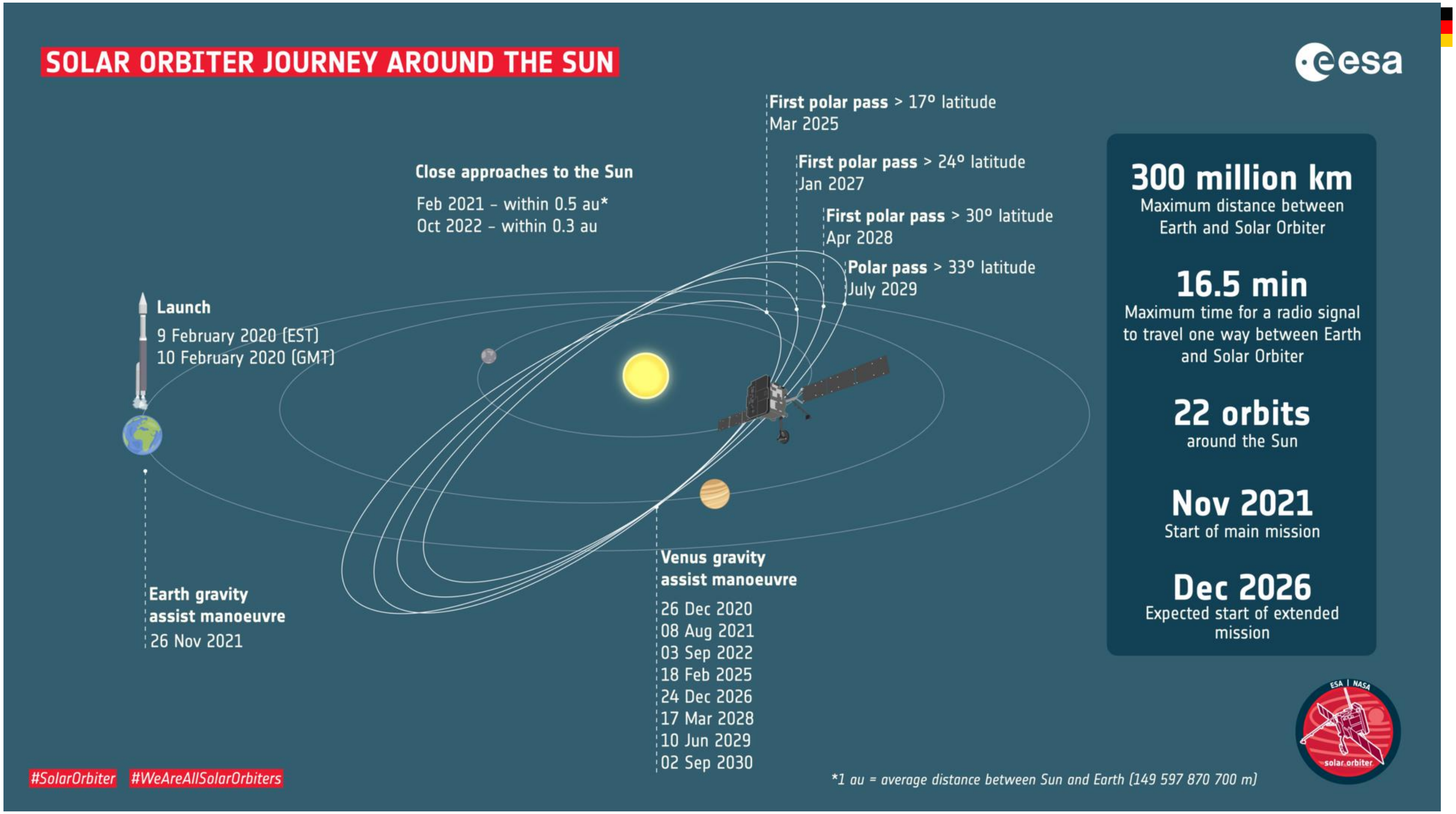
Solar Orbiter Proposal History

1998	Recommendation to fly an observatory in orbit around the Sun, expressed by the solar and heliophysics community at the meeting “Crossroads for European Solar and Heliospheric physics” in Tenerife.
1999	The concept of an ESA Solar Orbiter was formulated in an ESA pre-assessment study.
2000	Solar Orbiter was proposed in the frame of the Horizon 2000+ ESA Scientific Program. Solar Orbiter proposers: E. Marsch, **E. Antonucci**, P. Boscheler, J.-L. Bougeret, R. Harrison, R. Schwenn, J.-C. Vial.
	Selection of Solar Orbiter by the ESA Science Program Committee.
	Delta Assessment Study: Solar Orbiter — a high-resolution mission to the Sun and inner heliosphere. Solar Orbiter Assessment Study Report, ESA-SCI(2000)6.
2004	ESA Science Program Committee confirms the selection of Solar Orbiter within the Horizon 2000+ Program.
2007-2008	Proposal of the scientific instruments of the Solar Orbiter payload.
2008	Solar Orbiter is integrated in the new Cosmic Vision 2015-2025 ESA Program and has to re-compete.
2009	Announcement of the scientific instruments selection.
	Issue of the Second Assessment Study Report: Solar Orbiter — Exploring the Sun-heliosphere connection. Solar Orbiter Assessment Study Report, ESA/SRE(2009)5.
2010	Selection of Solar Orbiter as a candidate for the first medium class mission, M1, of the Cosmic Vision Program.
2011	Selection of Solar Orbiter as the first element of Cosmic Vision 2015-2025.

Why Solar Orbiter?

- First large space solar observatory after SOHO
- Payload: RS and in-situ instrumentation
- Close up view of the Sun (0.28 AU)
- First time of Sun's poles imaging (34° tilt)
- Reduced rotation speed (7.7°/day)
- Synergies with several space missions: SOHO, STEREO, SDO, *PSP, Proba3, ASO-S, Aditya, UVSC, PUNCH, CODEX, Solar C,* and Ground based telescopes
- Space weather-related events





SOLAR ORBITER JOURNEY AROUND THE SUN
esa
First polar pass > 17° latitude
Mar 2025
First polar pass > 24° latitude
Jan 2027
First polar pass > 30° latitude
Apr 2028
Polar pass > 33° latitude
July 2029
Close approaches to the Sun
Feb 2021 – within 0.5 au*
Oct 2022 – within 0.3 au
Launch
9 February 2020 (EST)
10 February 2020 (GMT)
Earth gravity
assist manoeuvre
26 Nov 2021
Venus gravity
assist manoeuvre
26 Dec 2020
08 Aug 2021
03 Sep 2022
18 Feb 2025
24 Dec 2026
17 Mar 2028
10 Jun 2029
02 Sep 2030
300 million km
Maximum distance between Earth and Solar Orbiter
16.5 min
Maximum time for a radio signal to travel one way between Earth and Solar Orbiter
22 orbits
around the Sun
Nov 2021
Start of main mission
Dec 2026
Expected start of extended mission
#SolarOrbiter
#WeAreAllSolarOrbiters
*1 au = average distance between Sun and Earth (149 597 870 700 m)

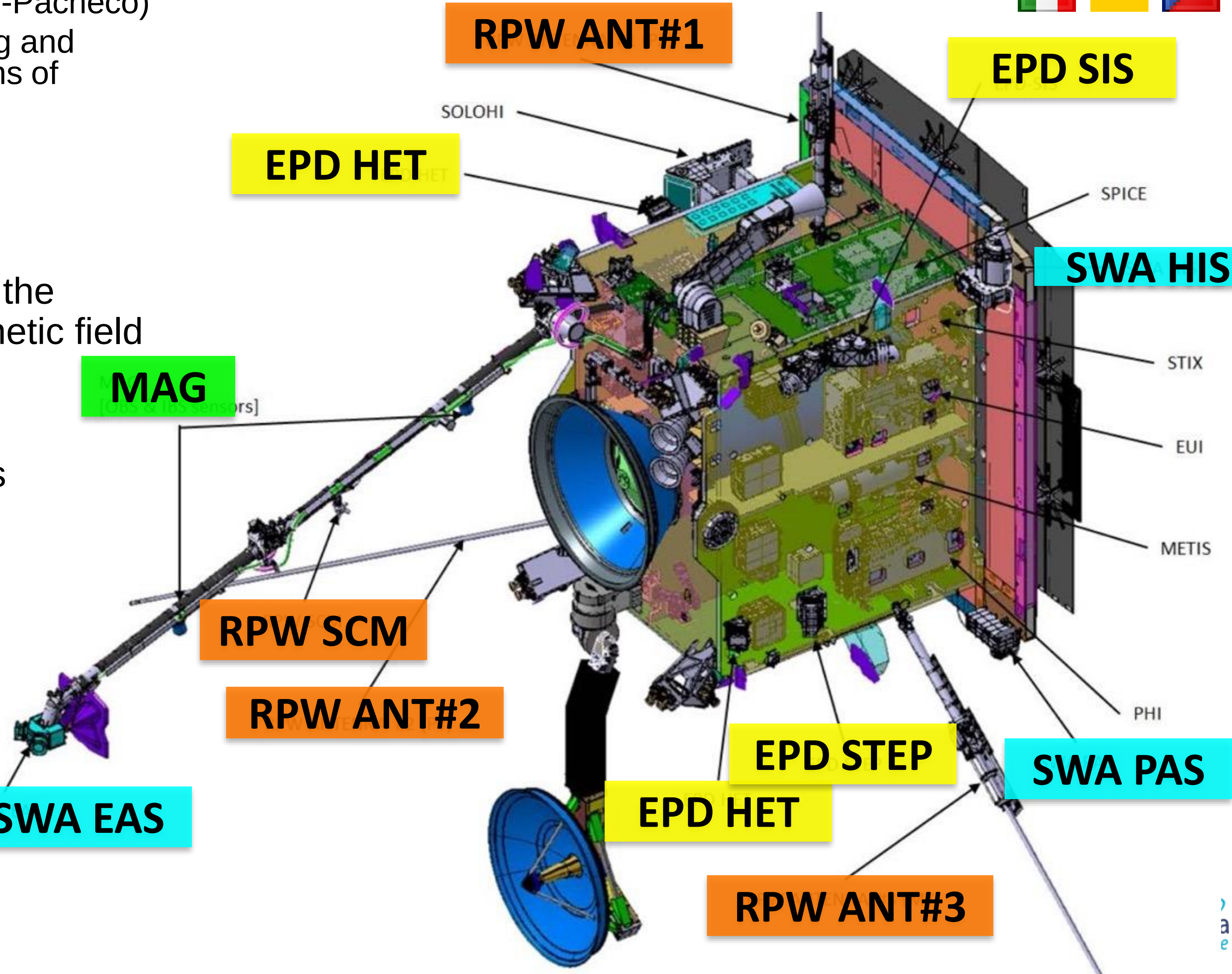
In situ Instruments

EPD (J. Rodriguez-Pacheco)
Composition, timing and distribution functions of energetic particles

MAG (T. Horbury)
High-precision measurements of the heliospheric magnetic field

SWA (C. Owen)
Sampling protons, electrons and heavy ions in the solar wind.

RPW (M. Maksimovic)
Electromagnetic and electrostatic waves, magnetic and electric fields at high time resolution



Remote Sensing Instruments

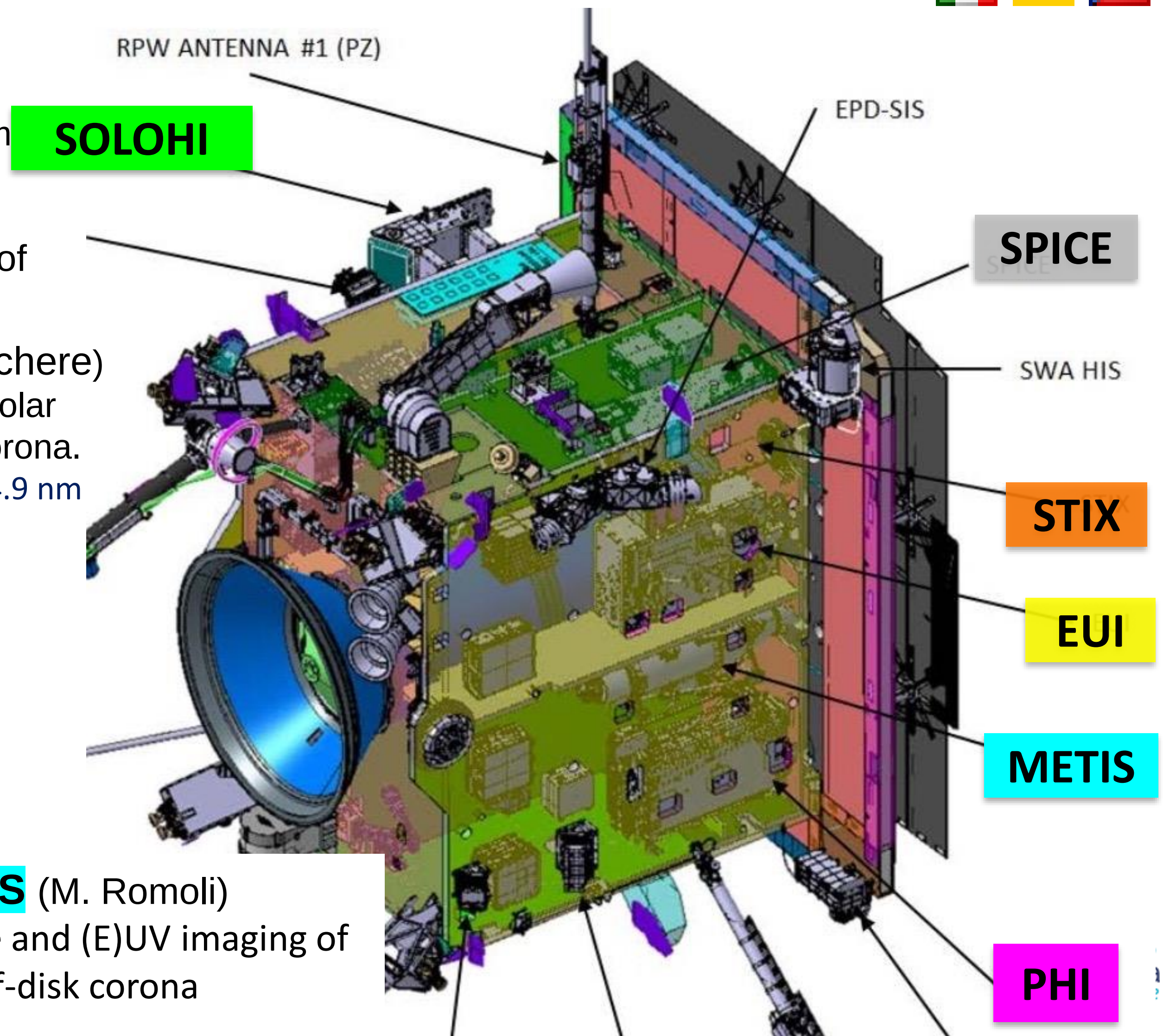
EUI (P. Rochus)
High-resolution and full-disk EUV imaging of the on-disk solar corona. HRI 17.4 and 121.6nm FSI 17.4 and 30.4nm

SOLOHI (R. Howard)
Wide-field visible imaging of the solar corona and wind

SPICE (A. Fludra/F. Auchere)
EUV spectroscopy of the solar disk and near-Sun solar corona.
70.4 - 79.0 nm and 97.3 - 104.9 nm

STIX (S. Krucker)
Imaging spectroscopy of solar X-ray emission

PHI (S. Solanki)
High-resolution vector magnetic field, line-of-sight velocity in photosphere, visible imaging



METIS (M. Romoli)
Visible and (E)UV imaging of the off-disk corona

Metis Team & INAF Leadership in Solar Orbiter

- Metis Team coordinated and funded by the Italian Space Agency (ASI)
- Scientific Team
  - University of Florence (**PI: Marco Romoli**)
  - INAF – Turin Astrophysical Obs. (**Resp. Scientifico INAF Silvano Fineschi**)
  - INAF – Capodimonte Astronomical Observatory, Naples
  - INAF – Catania Astrophysical Observatory
  - INAF –IASF, Milan
  - INAF –IASP, Rome
  - INAF – Monteporzio Astronomical Observatory, Rome
  - INAF – Trieste Astronomical Observatory
  - University of Padua
  - University of Urbino
  - CNR-IFN Padua
- Institute of Astronomy, Czech Academy of Science and Toptec
- Max Planck Institut für Sonnensystemforschung (MPS)
- Naval Research Laboratory, Washington DC, USA
- Industrial Team:
  - OHB Italia, Milan
  - Thales Alenia Space – Turin

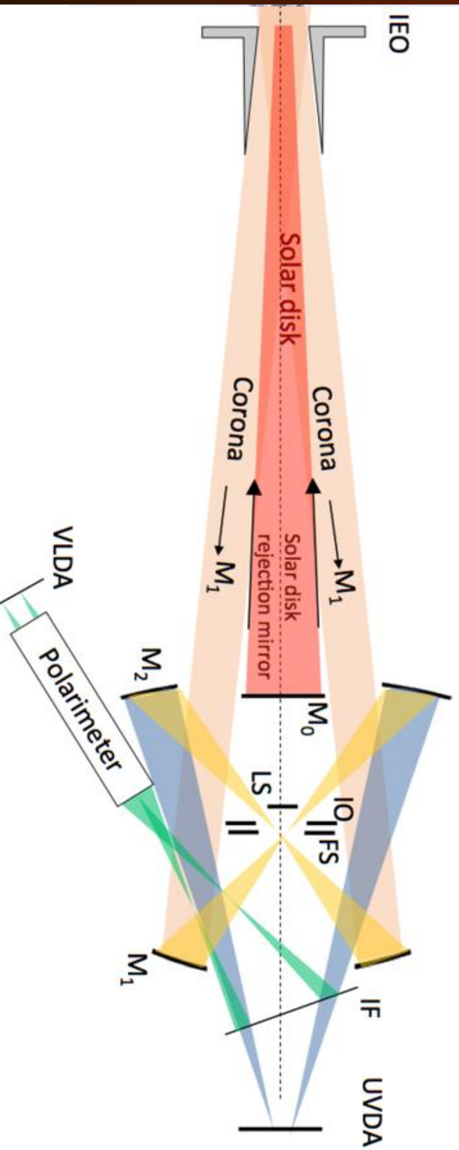
Metis Timeline

Nov 2016	Metis integration
Dec 2016	First calibration campaign
Apr 2017	Second calibration campaign
26 Apr 2017	Metis delivery to ESA
Jul 2017	Metis integration on the S/C
Dec 2018	Environmental test campaign
1 Aug 2019	Cap ejection test
31 Oct 2019	Transportation to launch site
10 Feb 2020	Launch
Feb 2020	Commissioning
13 Mar 2020	Metis first light
Jun 2020	Start of Cruise Phase
Nov 2021	Start of Nominal Phase
Jan 2026	Start of Extendend Phase
Sep 2030	Mission end

Solar Orbiter + Metis scientific objectives

Solar Orbiter Top-level Science Questions	Unique Metis contribution The only SolO instrument observing the:
How and wehere do the **solar wind plasma** and **magnetic field** originate in the corona	region where the solar wind is **accelerated** from ~100km/s to near the asymptotic value
How do **solar transients** drive heliospheric variability	Region where the first phase of the propagation of **CMEs** occur
How do solar eruptions produce **energetic particle radiation** that fills the heliosphere	Path of the **shock front** accelerating particles in the solar corona
How does the solar **dynamo** work and drive connections between the Sun and the heliosphere	Overall **magnetic field configuration** in the corona

Metis: Solar Orbiter Coronagraph



Metis is an imaging externally occulted all-reflecting coronagraph designed to provide:

- Full Imaging of the extended corona (1.7 - ~9 $R_\odot$) in UV (121.6±10 nm), and visible light (580-640nm) in total and polarized brightness (level 2 data), with different spatial resolution and detector exposure time, depending on the science goal and the instantaneous field of view (FoV)
- Density distribution in corona of H^0, and e^- (Level 3 data)
- Global Maps of solar wind outflow (H^0) (Level 3 data)
- Large scale dynamics of H^0, and e^- in CMEs (Level 3 data)

Italian instrument with Germany (detectors) and Czech Rep. (mirrors) contribution

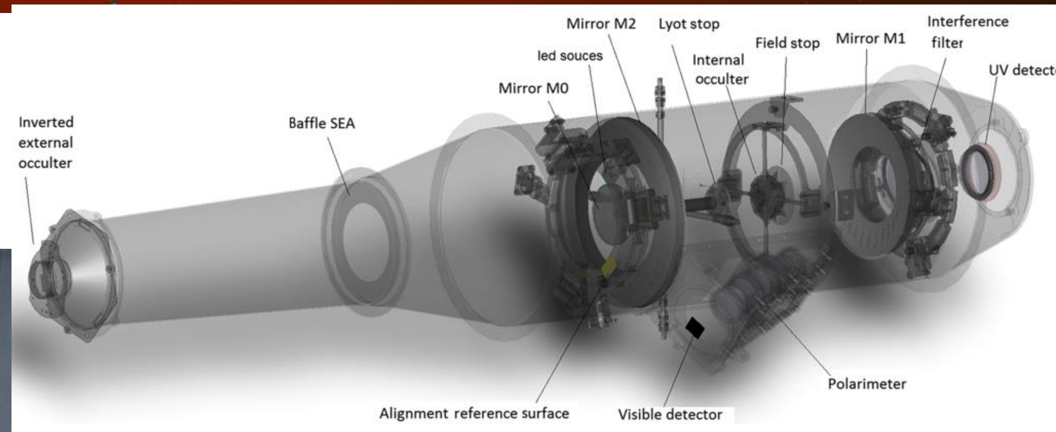
METIS Design Overview

Externally occulted coronagraph

Detectors:

VL: APS

UV: Intensified APS



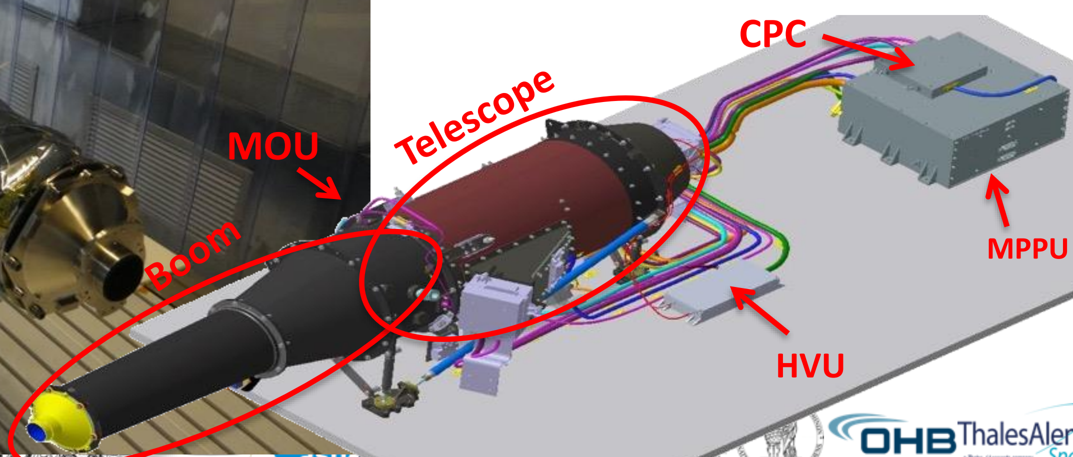
Four Units:

MOU METIS Optical Unit

MPPU METIS Power Processing Unit

HVU   High Voltage Unit

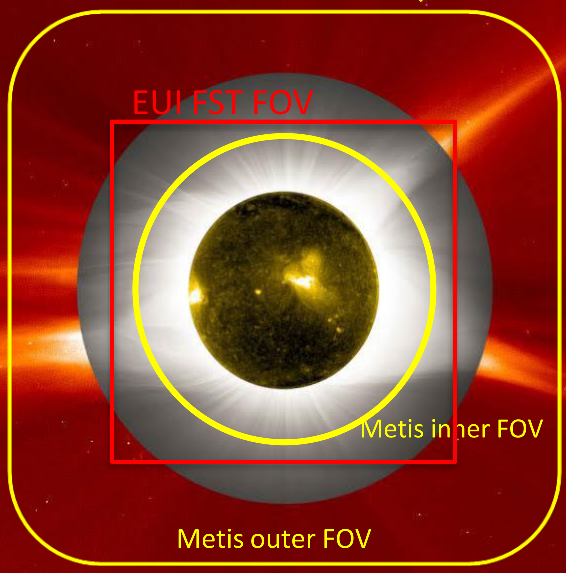
CPC   Camera Power Converter



FoV and Zoom effect

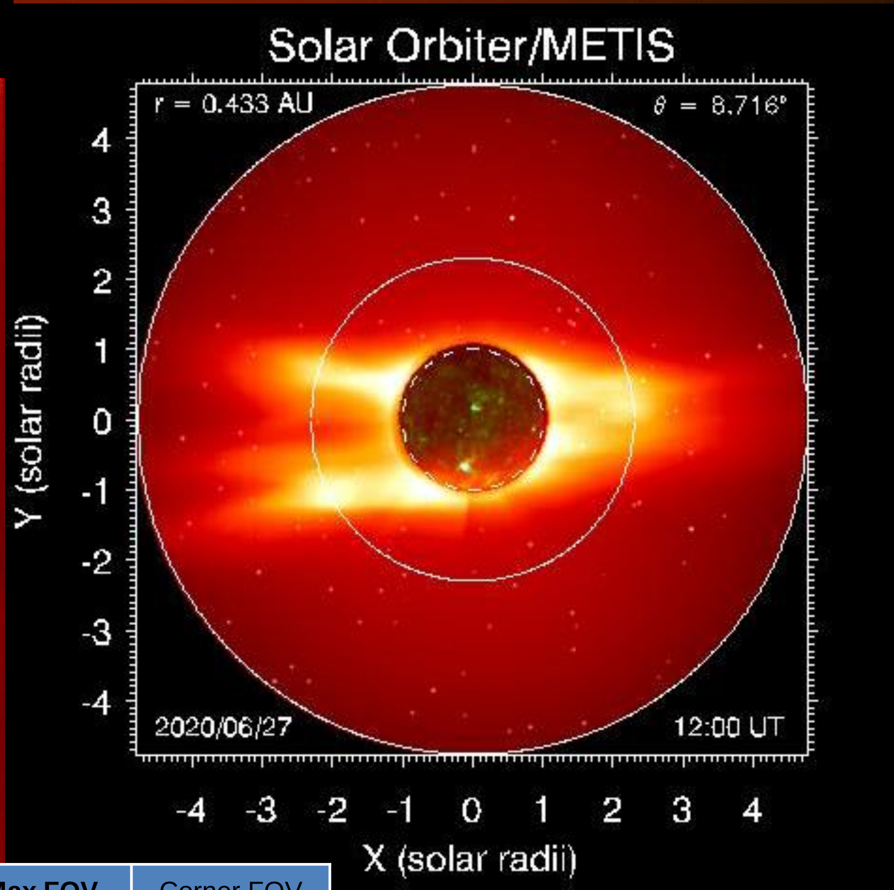
Metis: near-Sun coronagraphy

Polarized VL imaging @ 580 - 640 nm
UV HI Ly α imaging @ 121.6 ± 10 nm
FoV (1.6° · 2.9° annular, 1.7 – 3.0 $R_\odot$ @ 0.28 AU)



SOLOHI FOV

Spatial resolution ≤ 4000 km (20”) @ 0.28 AU
Time resolution ≥ 1 sec
Simultaneous VL and UV imaging



Zooming effect in the FOV due to the orbit's eccentricity offers the chance of observing interplanetary H around the Sun

Dist. (AU)	Min FOV	Max FOV	Corner FOV
0.28	1.7 $R_\odot$	3.0 $R_\odot$	3.6 $R_\odot$
0.3	1.8 $R_\odot$	3.3 $R_\odot$	3.8 $R_\odot$
0.4	2.4 $R_\odot$	4.4 $R_\odot$	5.1 $R_\odot$
0.5	3 $R_\odot$	5.4 $R_\odot$	6.4 $R_\odot$
0.8	4.8 $R_\odot$	8.7 $R_\odot$	10.2 $R_\odot$

Mission Profile & Metis Coronagraphic Observations

Metis - first coronagraph pointing to the Sun close-up & out-of-ecliptic

Close to the Sun 0.28 AU (min perihelion) fine structure of wind plasma in corona in extended latitude & longitude ranges

Out of the ecliptic ~ 34°
access to longitudinal structure of corona, solar wind and magnetic flux tubes channeling outflows

Reduced rotation relative to the Sun 7.7°/d
intrinsic evolution of solar wind and of coronal density inhomogeneities due to reduced rotation effect at the limb

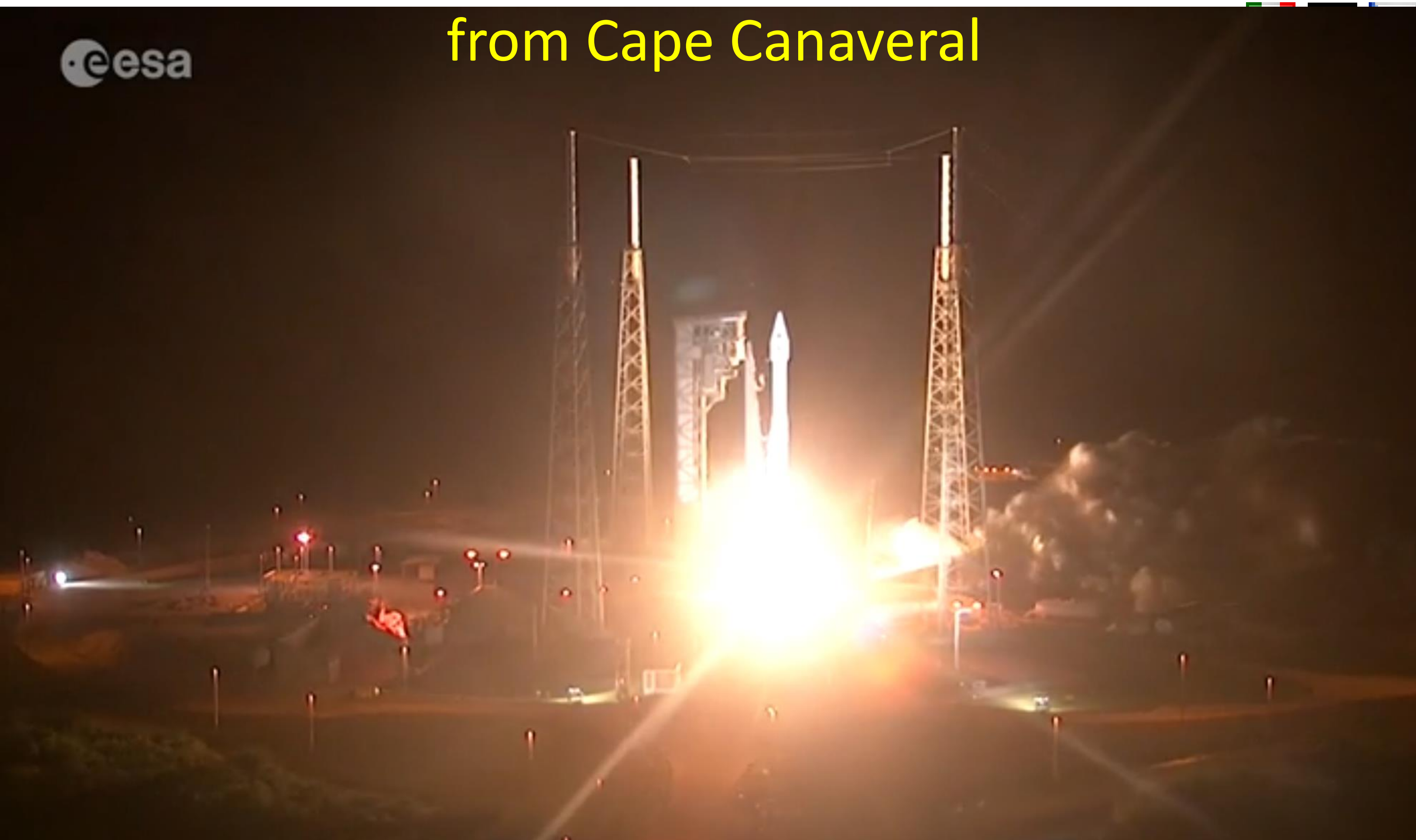
Out of the geocorona
best UV coronal seeing conditions

UVCS SOHO UV corona

Courtesy of A. Panasyuk

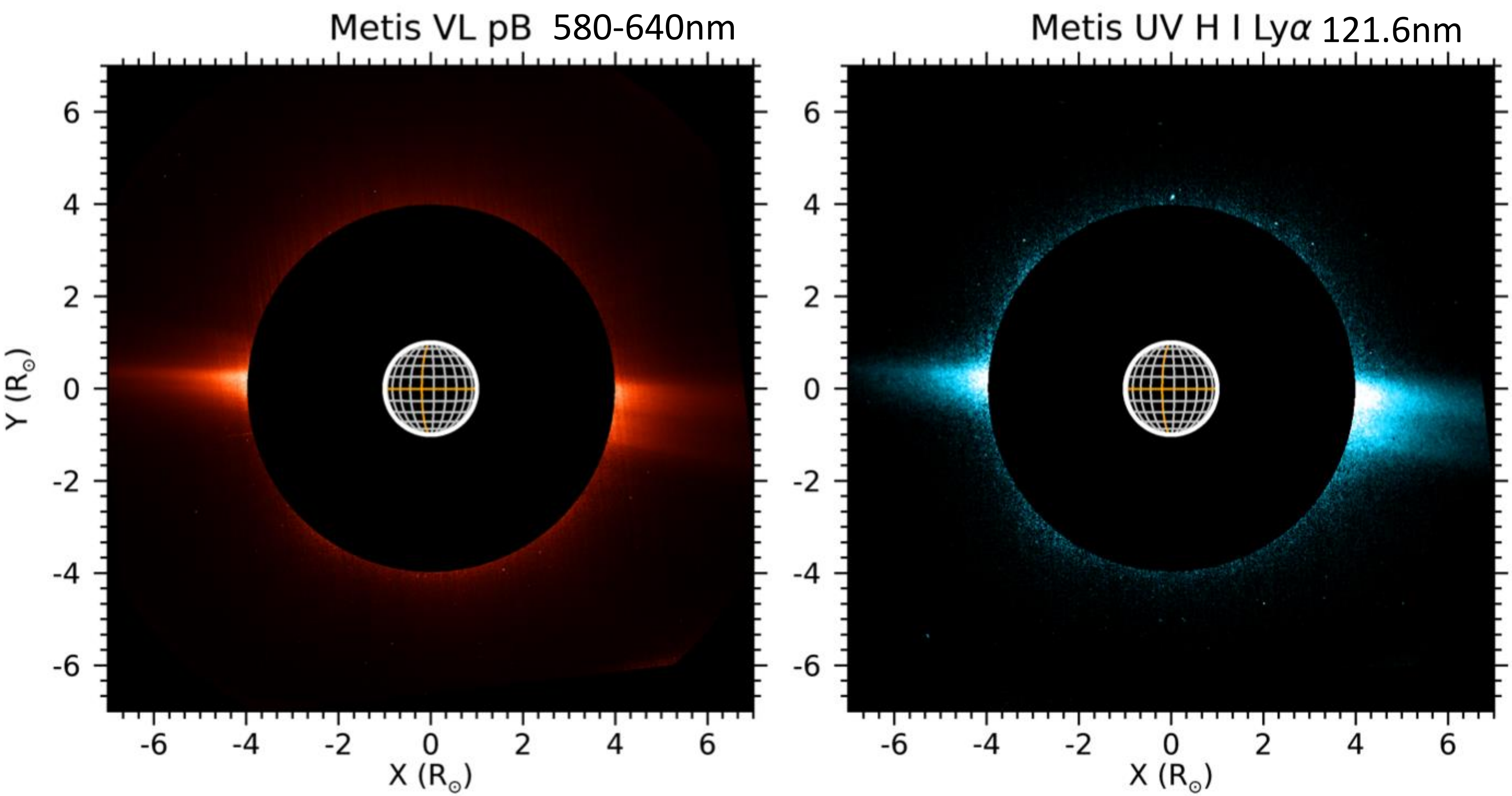
Launch, February 10th 2020

from Cape Canaveral

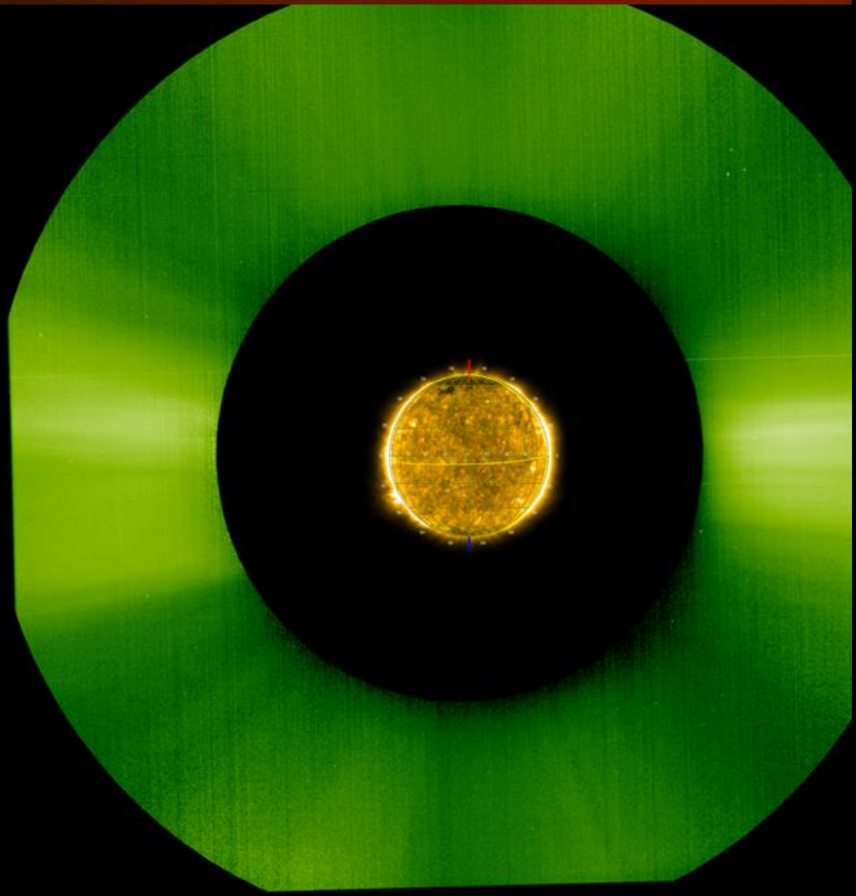


First images

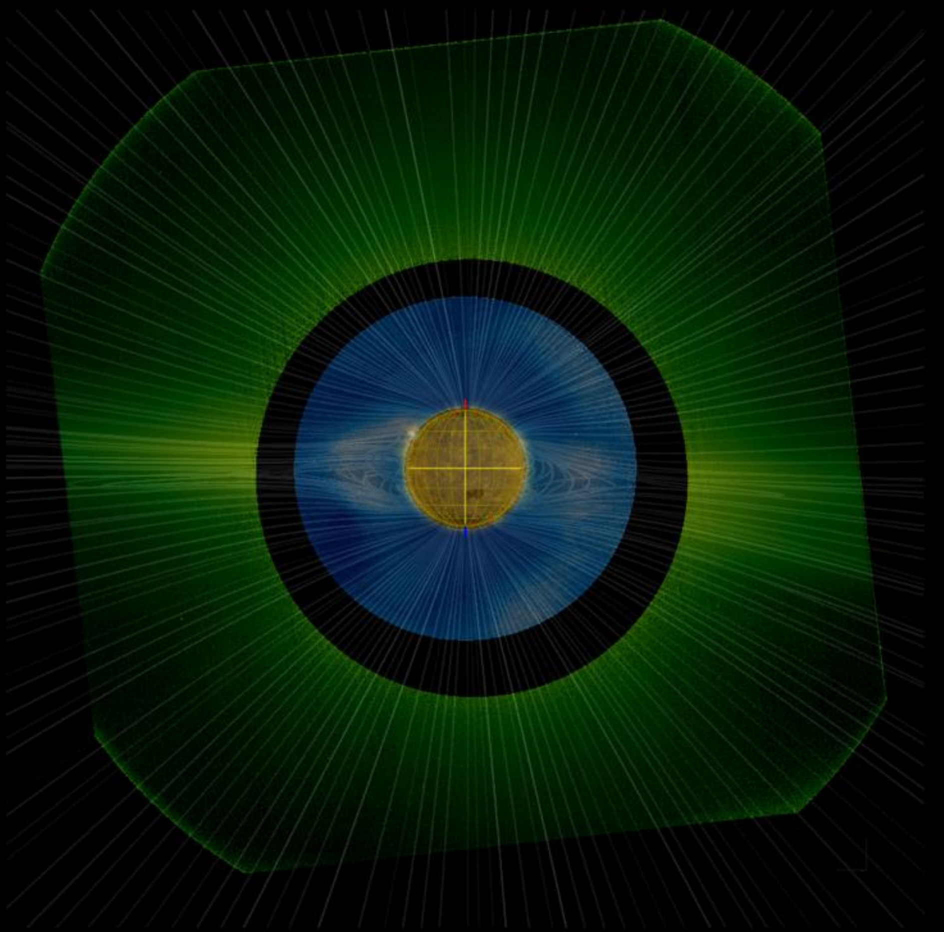
2020/05/15 11:39 UT - 11:41 UT
Distance: 0.6 AU -> FOV 3.8 – 7.0 Rs



First images



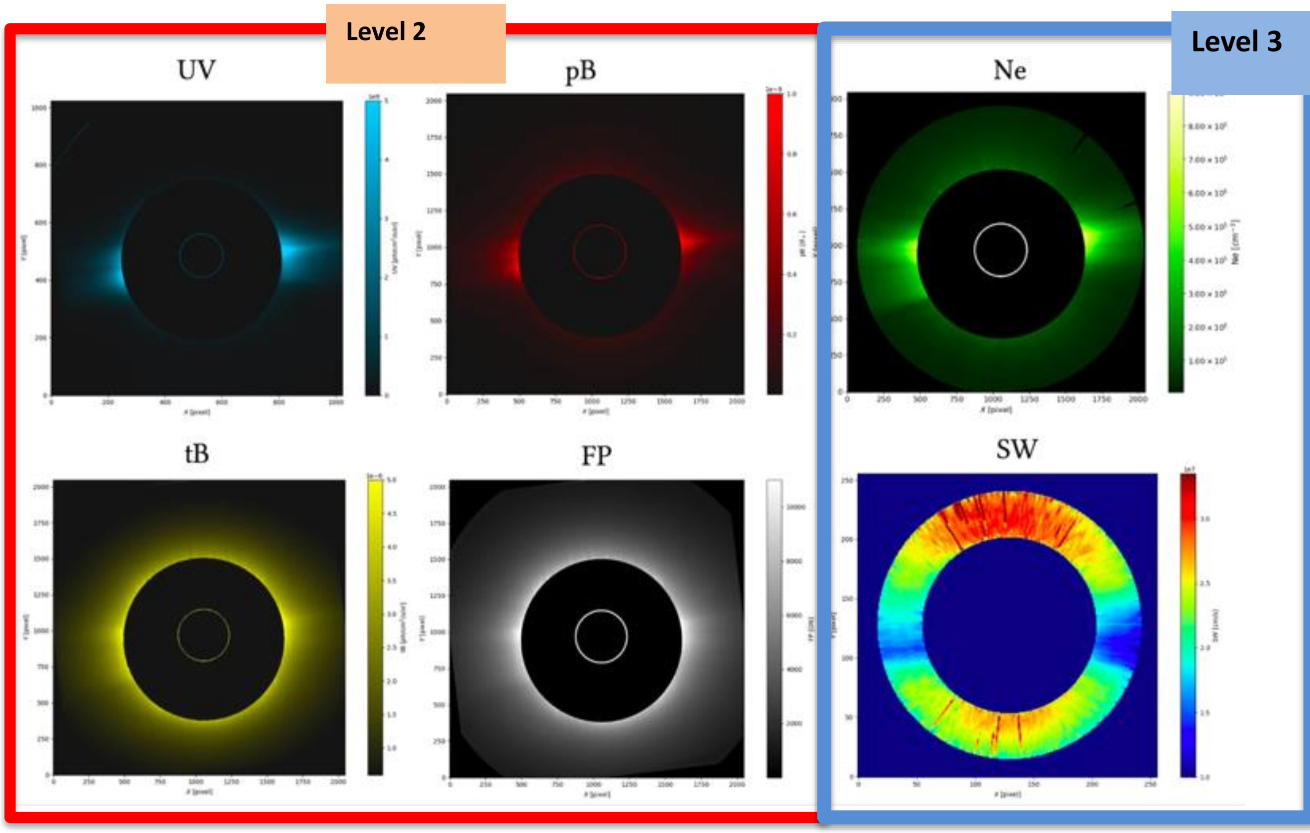
Metis VL pB + EUI/FSI @ 17.4nm.



Credits: Mauna Loa Solar Observatory, Predictive Science, NASA/SDO

Metis data

Metis will make available the following Level 2 calibrated data products, within 3 months from ground download.



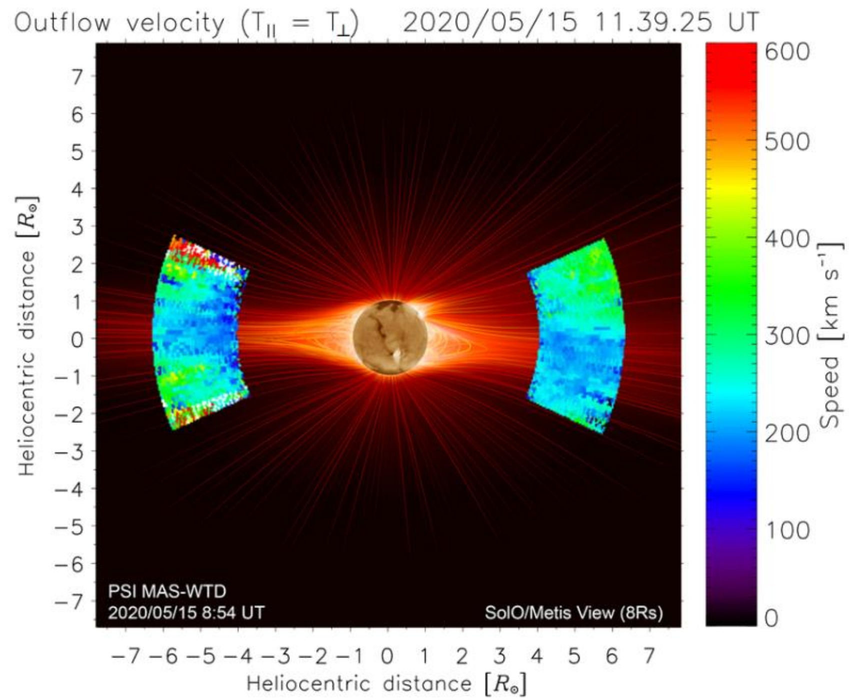
For details:
E. Antonucci et al. (2019)
A&A SO mission book
Webpage:
http://metis.oato.inaf.it

Level 2 data release will start with the Nominal Mission (> Dec 2021)

Solar Wind

How and where do the solar wind and magnetic field originate in the corona

Metis maps regions where the solar wind is accelerated from ~100 km/s to near its asymptotic value.



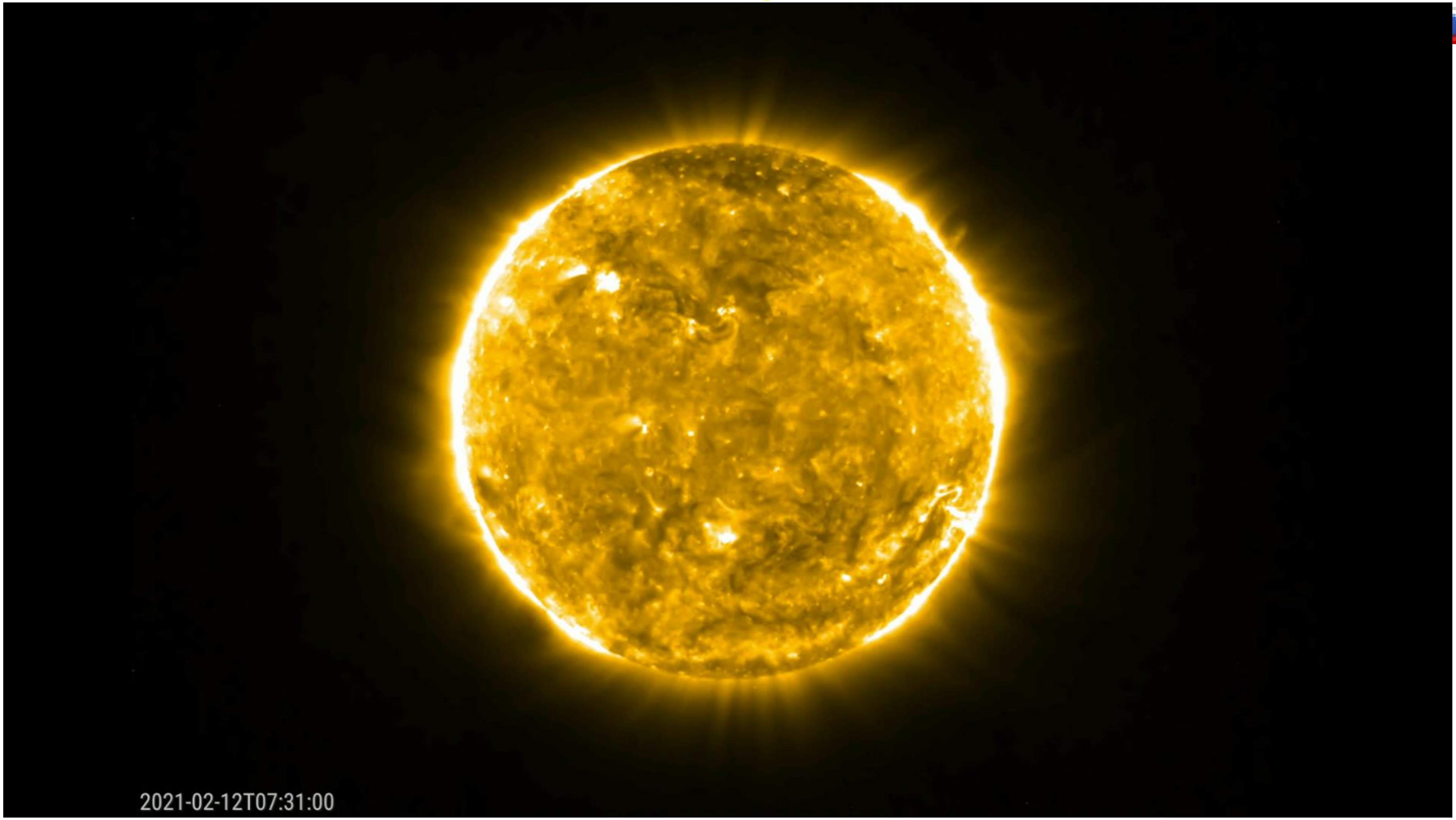
Doppler dimming technique

From the comparison *of* **coronal UV HI Lyα** emission
dimmed due to **coronal expansion**
with UV HI Lyα emission for **a static corona** (no dimming) synthesized on the basis of electron density from VL pB **2D maps** of the coronal plasma **wind speed** are generated.
(Dolei et al., 2018; Dolei et al., 2019)

A&A (in press) Solar Orbiter first result special issue:

M. Romoli et al. (2021): *First light observations of the solar wind in the outer corona with the Metis coronagraph .*

Coronal Mass Ejection (12/02/2021)



Personale INAF Coinvolto

Team Summary

15. Personale INAF coinvolto

Numero di partecipanti INAF al progetto: 27

Struttura	Nfte	N0	TI 21	TI 22	TI 23	TD 21	TD 22	TD 23	Nex	Extra
O.A. TORINO	13	1	5.40	3.75	3.75	0.70	0.70	1.00	0	0.00
O.A. TRIESTE	1	0	0.10	0.00	0.00	0	0	0	0	0.00
IASF MILANO	1	0	0.25	0.20	0.20	0	0	0	0	0.00
IAPS ROMA	1	2	0.20	0.00	0.00	0	0	0	0	0.00
O.A. CAPODIMONTE	3	0	1.35	0.85	0.85	0	0	0	0	0.00
O.A. CATANIA	4	0	1.45	1.45	1.45	0	0	0	0	0.00
O.A. ROMA	0	1	0.00	0.00	0.00	0	0	0	0	0.00
Totali	23	4	**8.75**	**6.25**	**6.25**	**0.70**	**0.70**	**1.00**	0	**0.00**

Fondi

Finanziamento ASI - 2010-2021

INAF Supporto scientifico alla realizzazione:

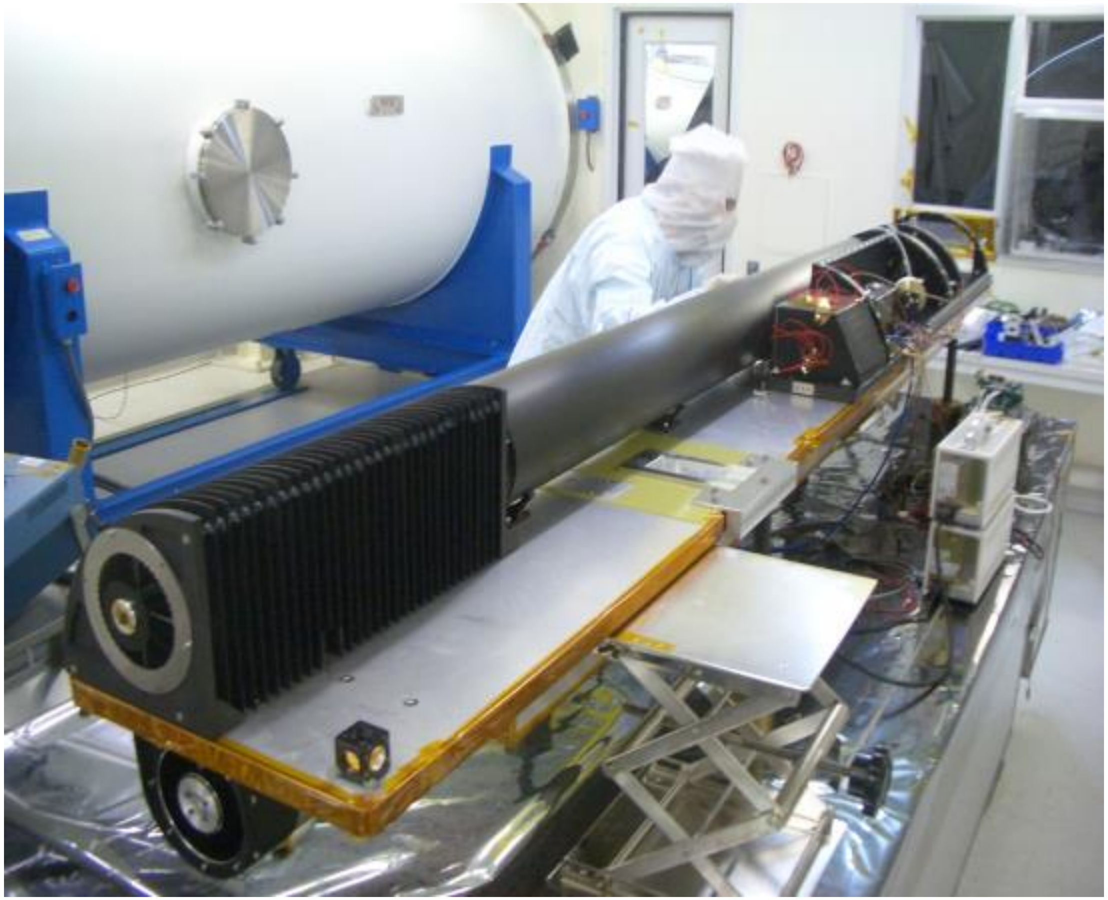
- 2010: 450k€ (Fase A)
- 2012: 2,400 k€ (Fase B2-C1)
- 2015: 2,200 k€ (Fase B2-C1
- 2018: 2,400 k€ (Fase D/E)
- 2021: Contract to be renewed

Fondi a sostegno

21. Totale fondi a disposizione (dato aggregato, k€)

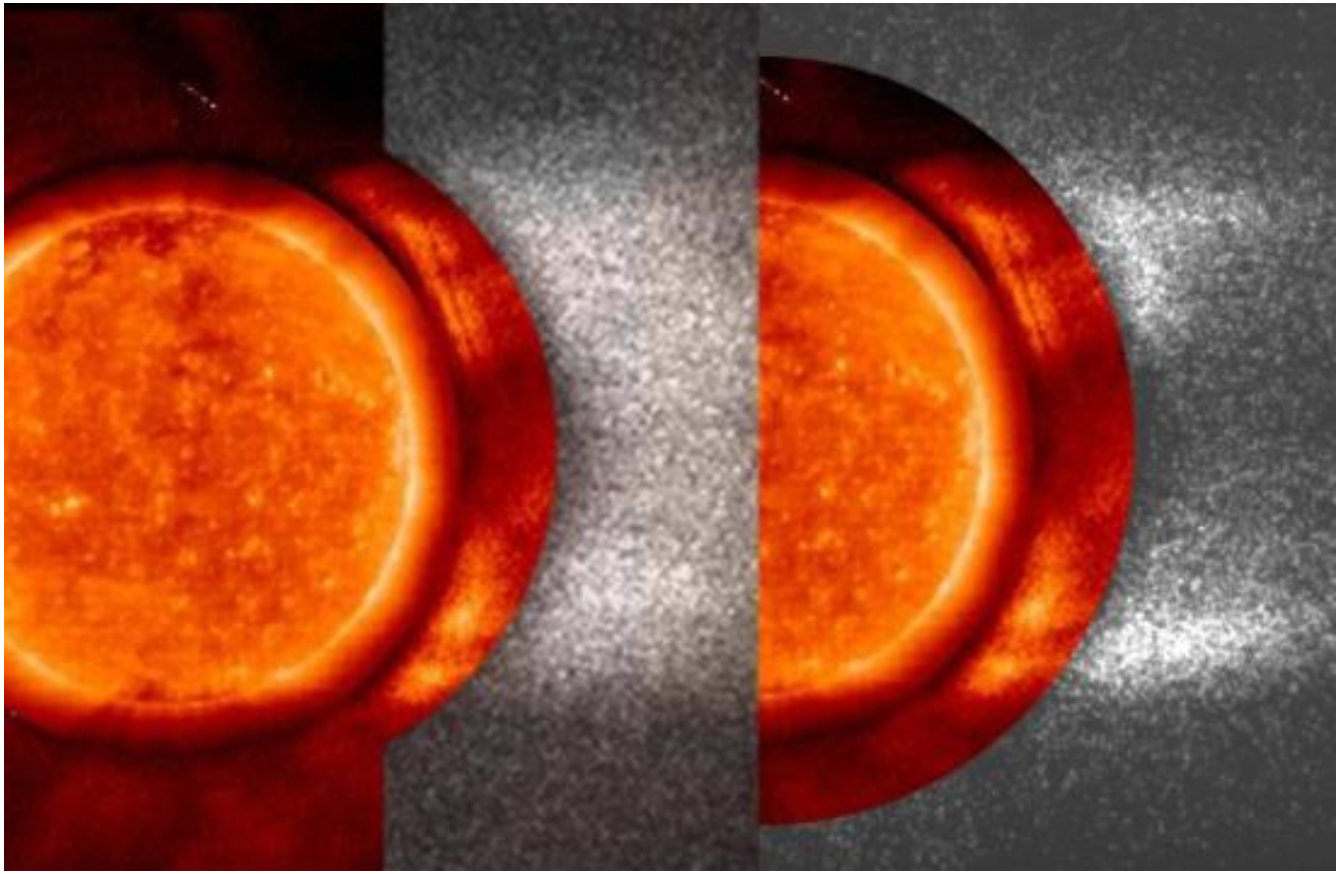
Certi 2021	Certi 2022	Certi 2023	Presunti 21	Presunti 22	Presunti 23
400.0	0.0	0.0	0.0	500.0	500.0

Sub-orbital SCORE: Metis Prototype



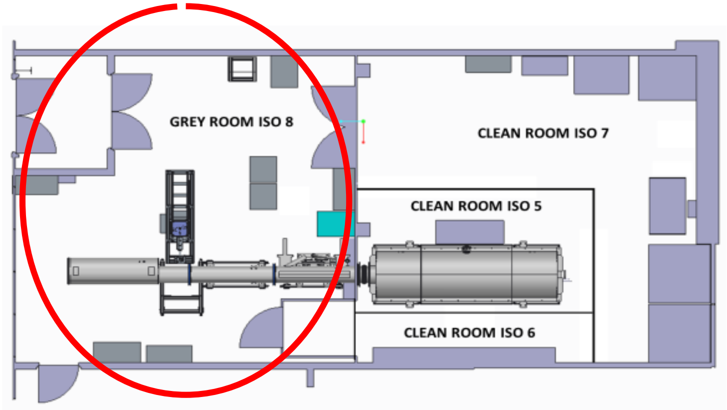
- First launch 2009
- Second launch 2022 – Metis coordinated observations

Sub-orbital SCORE: Metis Prototype

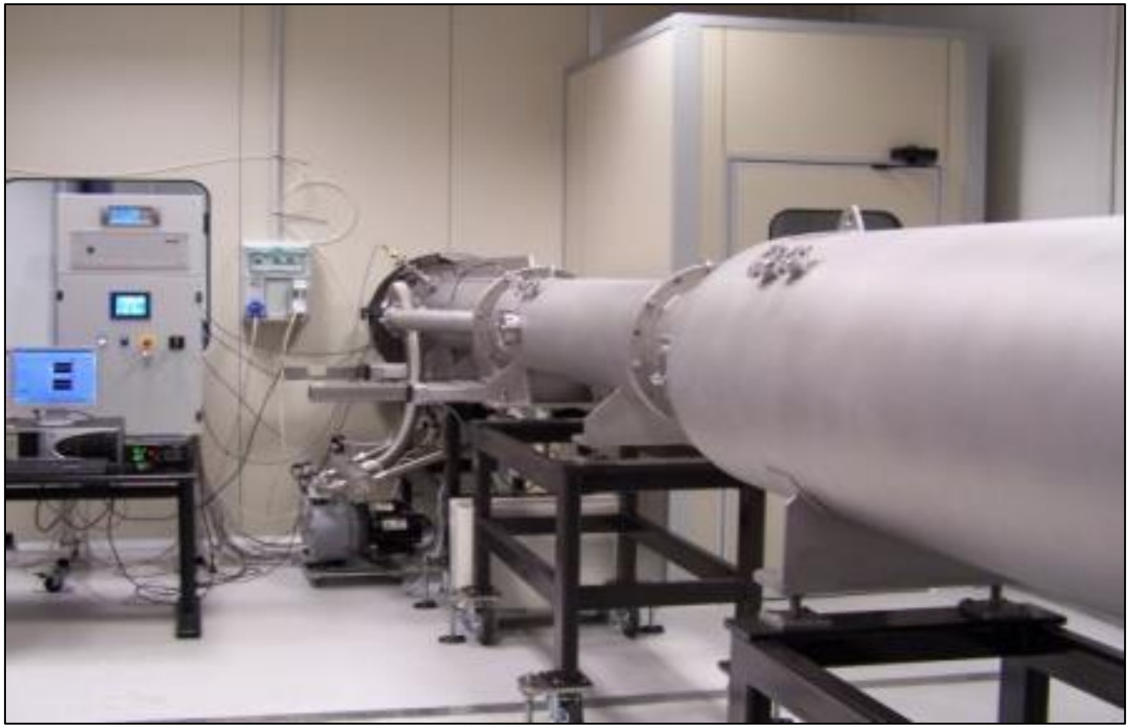


Moses, Antonucci, Newmark,Fineschi et al. 2020,
"Global helium abundance measurements in the solar corona", Nature Astronomy.

INAF Optical Payload System (OPSys) Facility

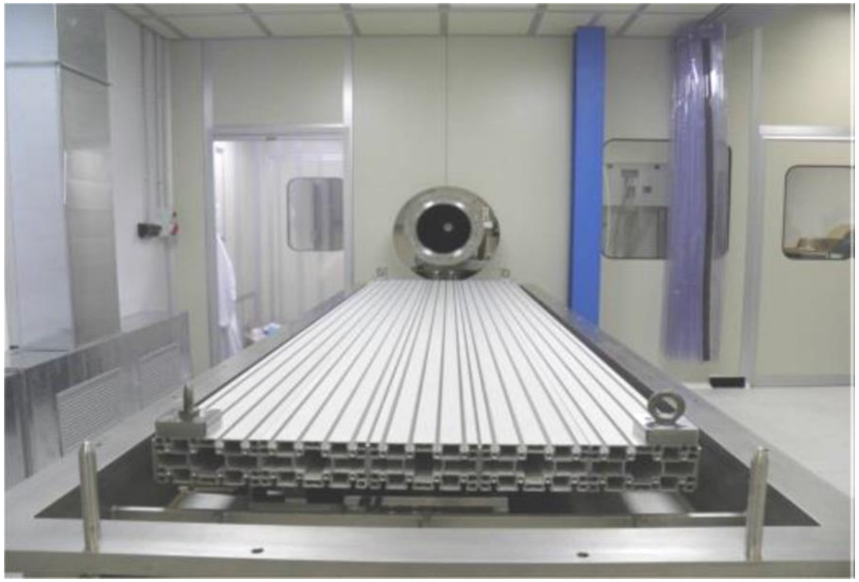


- ISO 8 Grey Room
- ISO 7 Clean Room
- ISO 5 Clean Area



2006 Regione Piemonte co-finanziamento

INAF Optical Payload System (OPSys) Facility



- The SPace Optics Calibration Chamber (SPOCC) Vacuum-chambere with Motorized Optical Bench

Criticalità

- Formazione giovani ricercatori: PhD, AdR $\Rightarrow$ Analisi dati
- Necessità di "Piccoli" programmi tecnologici (e.g., sub-orbitali, stratosferici) per
  - prototipizzazione nuova strumentazione
  - Mantenimento team INAF con le competenze sperimentali acquisite con le precedent missioni e disponibili per proposte di nuove