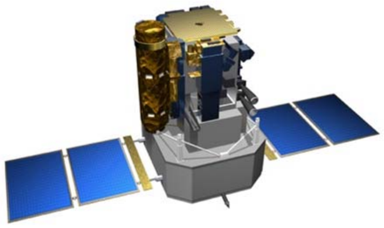
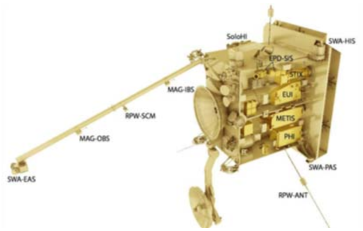




Italian participation to space-borne heliophysics missions

Alessandro Gabrielli – ASI

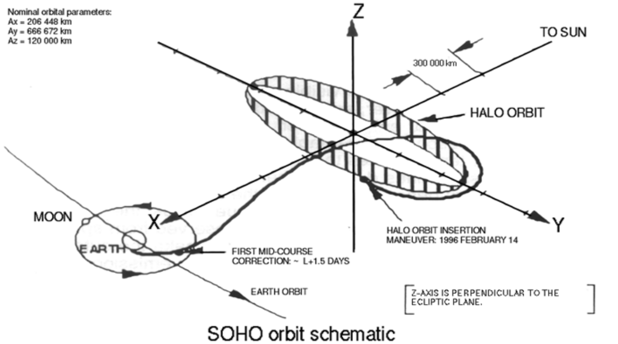
Heliospheric physical processes for understanding Solar-Terrestrial Relations -International School of Space Science

Italian participation to heliophysics missions

1. UltraViolet Coronagraph Spectrometer (UVCS) @ Solar & Heliospheric Observatory (SOHO) mission
2. SECCHI coronagraphs @ Solar TErrestrial RElations Observatory STEREO mission
3. Sounding-rocket Coronal Experiment (SCORE) @ HERSCHEL mission
4. Multi Element Telescope for Imaging of the Sun (METIS) @ Solar Orbiter mission
5. Solar Wind Analyzer (SWA) @ Solar Orbiter mission

Solar & Heliospheric Observatory mission

1. Dimensions: 4.3 x 2.7 x 3.7 m
2. Width with solar array deployed: 9.5 m
3. Total mass at launch: 1850 kg
4. Payload (12 instruments): 610 kg
5. SOHO was launched in december 1995 by an Atlas Centaur rocket
6. Halo orbit in SEL-1 in march 1996
7. Telemetry during real-time operation: 200 Kbits/s (through DSN)
8. Overall mission cost: 1Billion €
9. Design Operational lifetime: 2 years
10. Extended Lifetime: 11 year solar cycle



SOHO orbit schematic

SOHO cooperation

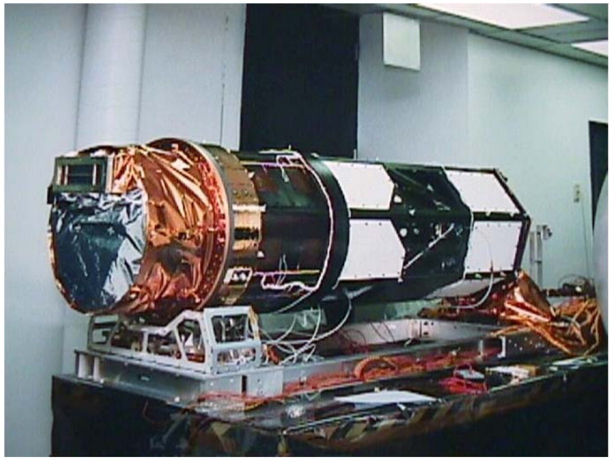
1. International cooperation between ESA and NASA to study the Sun from its deep core to the outer corona and the solar wind.

2. S/C service module: industrial consortium from 14 European countries led by the Prime contractor ADS: solar panels, thrusters, attitude control systems, communications integrated and tested in Toulouse.

3. Payload module: carrying the 12 scientific instruments assembled in Portsmouth, UK, and mated with the service module in Toulouse. During the building and assembly of the spacecraft, several hundred engineers were employed by the project.

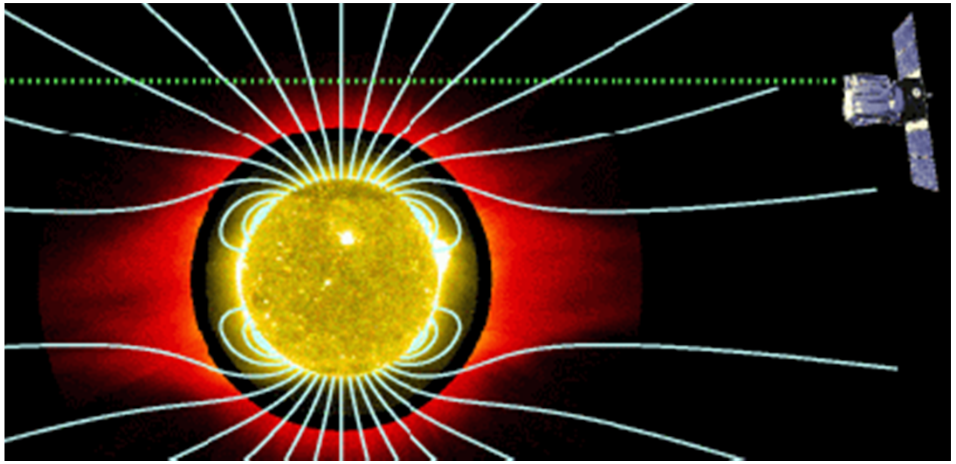
UltraViolet Coronagraphic Spectrometer

1. UVCS continuously observed the ultraviolet and visible light emission of the extended corona of the Sun since SOHO insertion in SEL-1 orbit
2. UVCS is NASA-ASI joint program, Italy was responsible of the development of the UVCS spectrometer
3. Dr. J. Kohl is the Principal Investigator and Prof. G. Noci is the Co-Principal Investigator of the UVCS.
4. Italian industries: Alenia Spazio and Officine Galileo



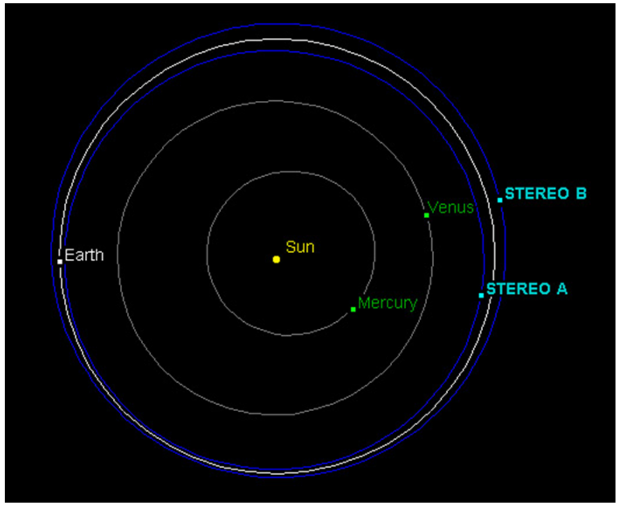
UVCS observation objectives

1. The scientific objective of the UVCS is the investigation of the solar wind in the region where it undergoes acceleration and of the processes that accelerate the wind.
2. It addressed a broad range of scientific questiond regarding the heating of the corona
3. UVCS makes measurements (along LoS) of the solar corona between 1.5 - 10 $R_\odot$



Solar TErrestrial RElations Observatory

1. It employs two nearly identical space-based observatories - one ahead of Earth in its orbit (STEREO A), the other trailing behind (STEREO B)- to provide imaging and stereoscopy in polarized visible light from 1.5 solar radii in the corona to the inner heliosphere.
2. They were conceived to provide the first-ever stereoscopic measurements to study the Sun and the nature of its coronal mass ejections (CMEs).
3. SECCHI coronagraphs to observe the 3D structure of coronal mass ejections.

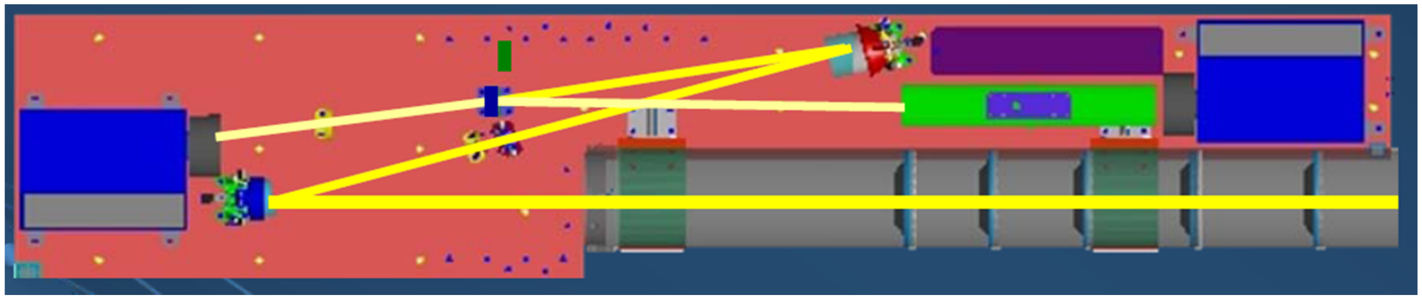


STEREO mission objectives

1. It was launched in 2006 with the following goals:
   - Understand the causes and mechanisms of coronal mass ejection (CME) initiation.
   - Characterize the propagation of CMEs through the heliosphere.
   - Discover the mechanisms and sites of energetic particle acceleration in the low corona and the interplanetary medium.
   - Improve the determination of the structure of the ambient solar wind.
2. Communications with the STEREO Behind spacecraft were interrupted on October 1, 2014 due to the star tracker failure and the IMU laser gyro failure causing a bad pointing of HGA towards Earth

SCORE / HERSCHEL mission

1. The HERSCHEL ("HElium Resonant Scattering in the Corona and HEliosphere") sounding-rocket mission was launched in 2007.
2. The Principal Investigator of the program is J.D. Moses of the Naval Research Laboratory, US. The Deputy Principal Investigator is E. Antonucci of the INAF-OATo.
3. HERSCHEL consists of an international effort to design, build, test, launch on a sounding rocket and analyze data from two complementary instruments: the Sounding-rocket Coronagraphic Experiment (SCORE), and the HERSCHEL Extreme Ultraviolet Imaging Telescope (HEIT).
4. Mission duration: 5 min.



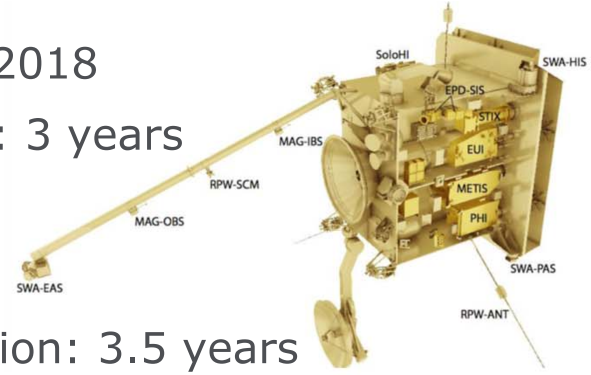
SCORE mission objectives

1. First measurement of the outflow velocity and abundance of helium in the solar corona (1.5 – 3.5 $R_\odot$) and the the coronal electron density distribution.
2. The instrument consists of an externally occulted telescope based on mirrors coated with multi-layers with good reflectivity in EUV (30.4 nm) waivelength band and in UV (121,6 nm) and polarized VL

Solar Orbiter mission

Launch: Oct 2018

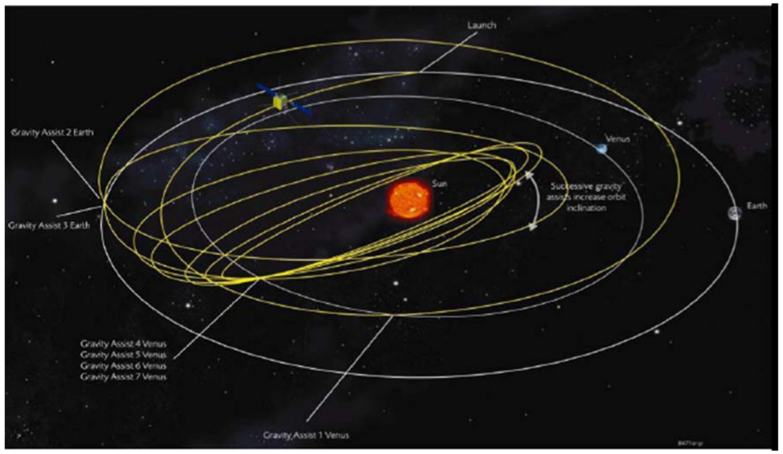
Cruise Phase: 3 years

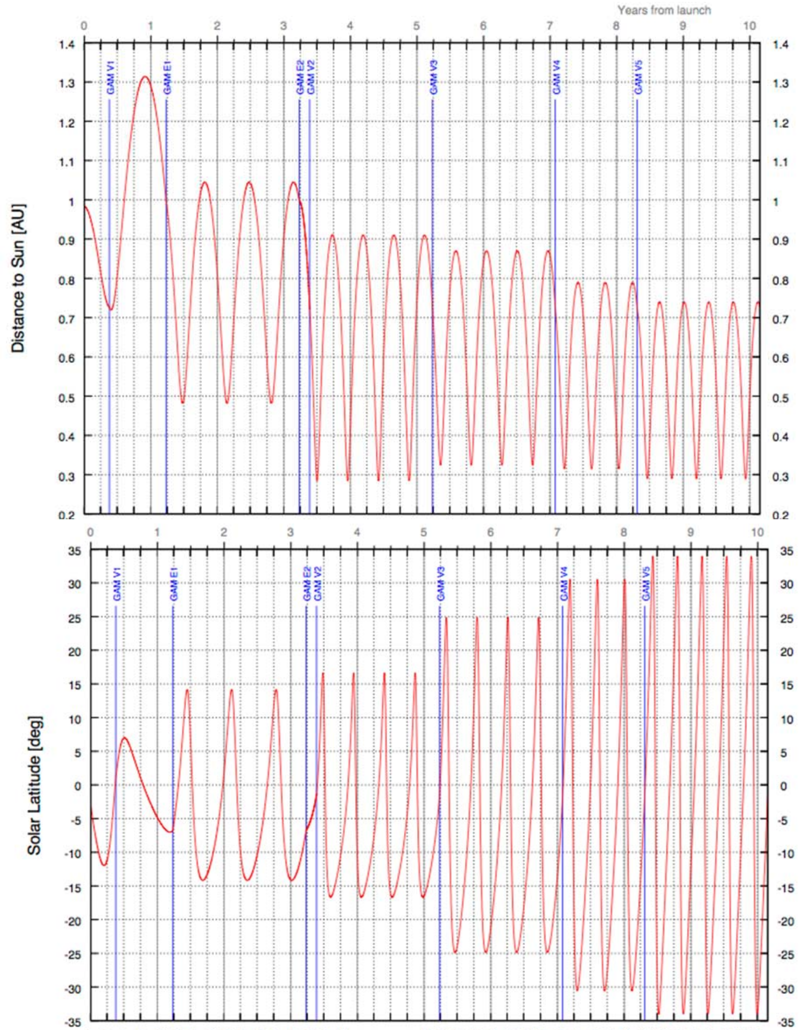


Nominal Mission: 3.5 years

Extended Mission: 2.5 years

Operational Orbit: 0.28–0.91 AU





METIS Science: Unique observations

Principal Investigator: Prof. Ester Antonocci, Osservatorio Astrofisico di Torino

1. Origins and acceleration of the solar wind streams
    - Region where the solar wind is accelerated from 100 km/s
2. Sources of the solar energetic particles (SEP),
    - Region where the most dramatic phases of the propagation of the coronal mass ejections occurs
3. Origin and early propagation of coronal mass ejections (CME)
    - Path of the shock front accelerating particles in the solar corona
4. Regions of the magnetic field of the corona

Scientific Observation requirements (1/2)

1. **Observation bands.** Gregorian telescope providing simultaneous imaging of the full corona in:
   - polarized visible light (580-640 nm) and
   - narrow-band ultraviolet H I Lyα (121.6 ±10 nm)

2. **Observation regions.** Unprecedented scientific observations of the corona, including the Sun's polar regions, at distance from 0.28 AU to 0.5 AU.

3. **Field of View** (FOV) and Ensquared Energy (EE)

VL channel

1.5° < FOV < 1.8°   EE ≥ 60% inside 60×60 μm

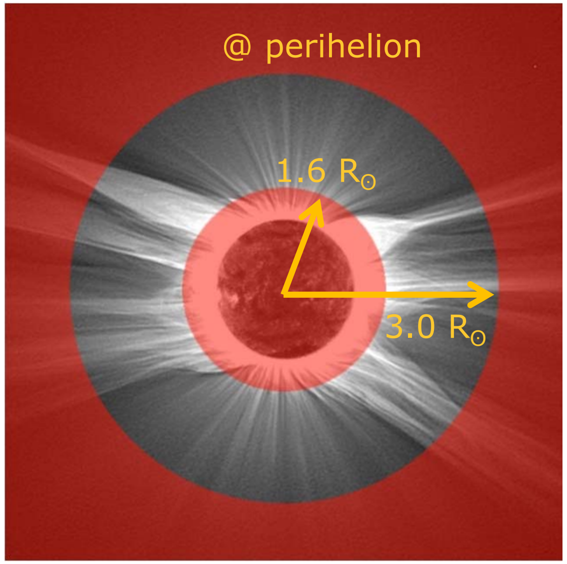
1.8° < FOV < 2.1°   EE ≥ 80% inside 40×40 μm

FOV > 2.1°   EE ≥ 80% inside 25×25 μm

UV channel

1.5° < FOV < 2.4°   EE ≥ 80% inside 30×30 μm

2.4° < FOV < 2.9°   EE ≥80% inside 60×60 μm

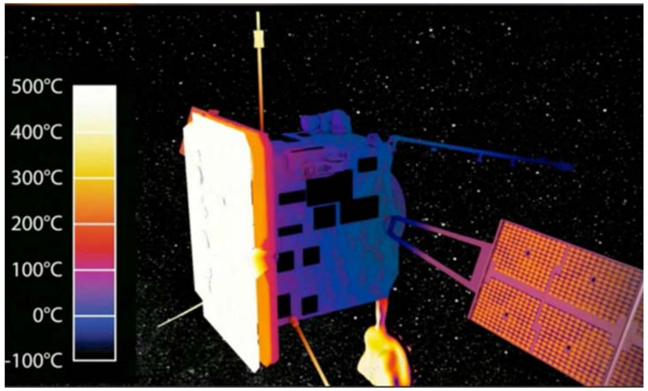


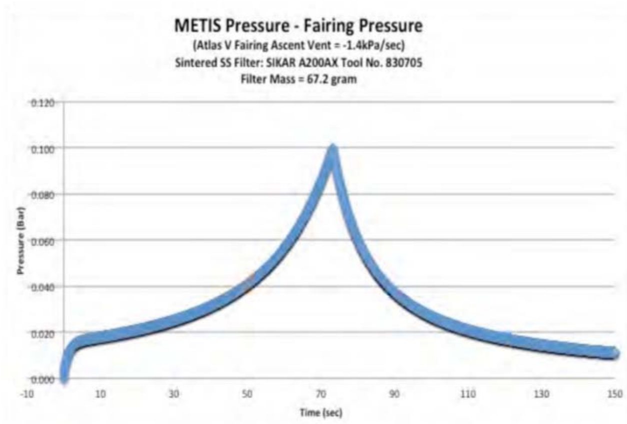
Scientific Observation requirements (2/2)

4. **Stray Light** suppression requirement expressed in ratio of the Corona radiance B_{cor} $(R_{\odot})$ over Sun-disk radiance B_{sd}:
   - B_{cor} $(R_{\odot})$ / B_{sd} < $\mathbf{10^{-9}}$ visible light
   - B_{cor} $(R_{\odot})$ / B_{sd} < $\mathbf{10^{-7}}$ in HI Ly-α
5. **Pointing stability**. Instrument pointing of the line of sight towards the centre of the Sun shall not exceed 1 arcmin with 95% confidence level during the scientific observations.
6. **Contamination**. The maximum allowed level of contaminants on the mirrors surfaces is 3.3 ppm for particulate and 100 ng/cm^2 for molecular, when METIS will be integrated on the Solar Orbiter
5. **Detector temperatures.** During scientific observation, Detector sensors shall be cooled down in the temperature range of:
   - [−40 ; −15] °C for the Visibile light detector
   - [−35 ; −5] °C for the Ultra Violet detector

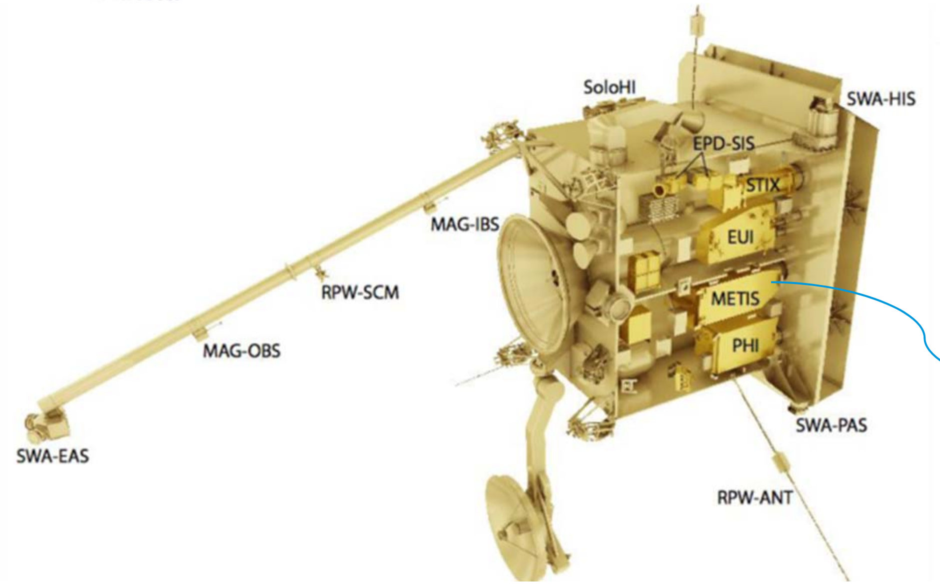
Technical requirements and challenges

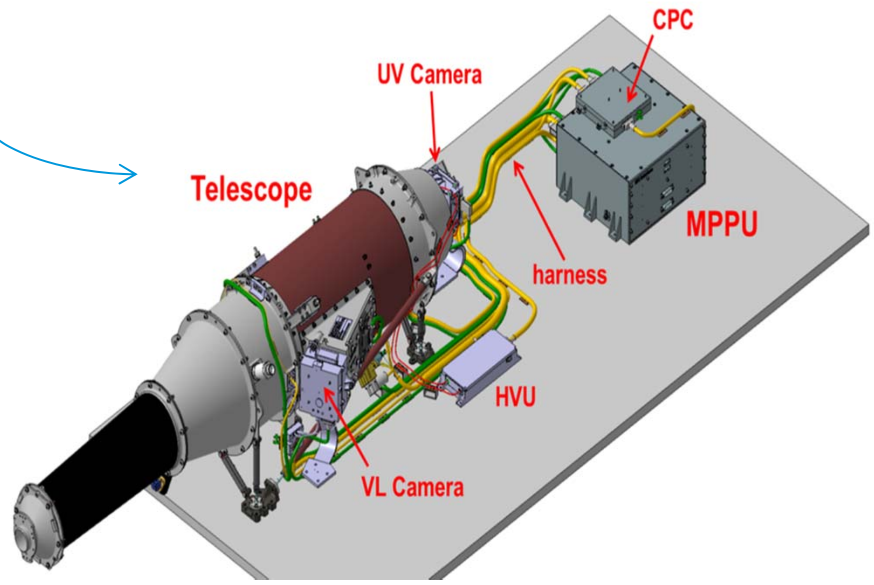
1. Extreme **temperature** environement at 0.28 UA
2. Instrument allocated **mass**: ≤ 29.7 kg
3. Average **power** consumption: ≤ 28 W
4. **Cleanliness** and **contamination** control:
   - ≤ 3.3 ppm of particulates on mirrors
   - ≤ 100 ng/cm^2 of molecular on mirrors
5. **Outgassing:** TML < 0.1% and CVCM < 0.01% for materials that are close to optics
6. **Purging**: dry N_2 from S/C integration to launch @ [80-160] l/hr
7. **Venting**: for outgasses exit and prevention of contaminants deposition on optics. Ascent vent and purge vente rates accomodated so as to have Δp< 0.1 bar guaranteed during ascent phase.
8. Contamination protection **cap**. At the entrance telescope to prevent external particulates from S/C. Pure mechanical devices are allowed to eject the cap once in orbit

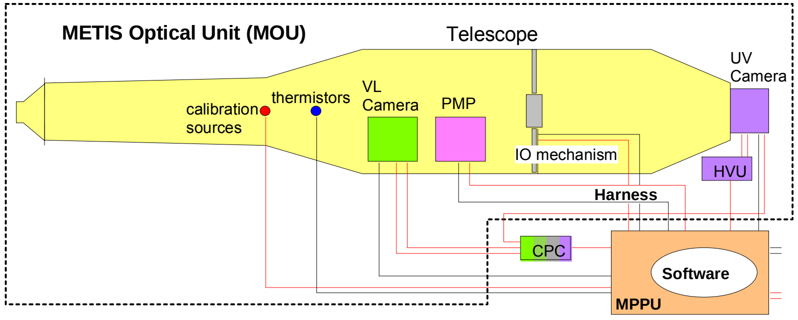




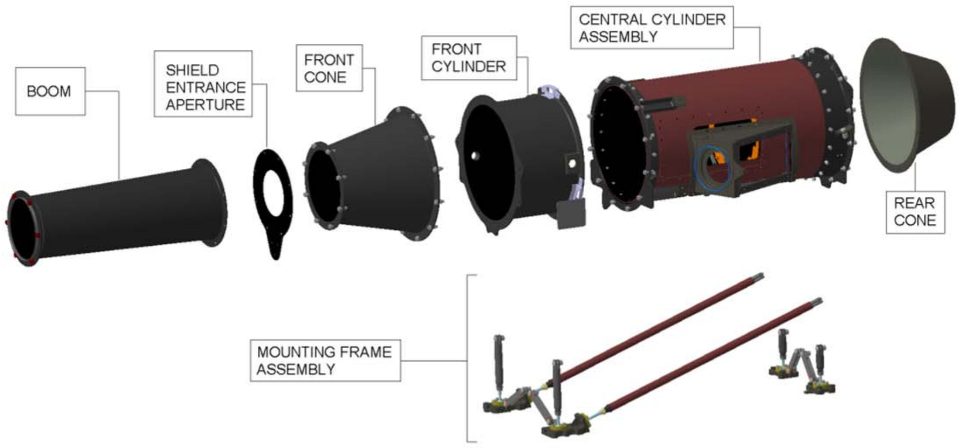
METIS Layout

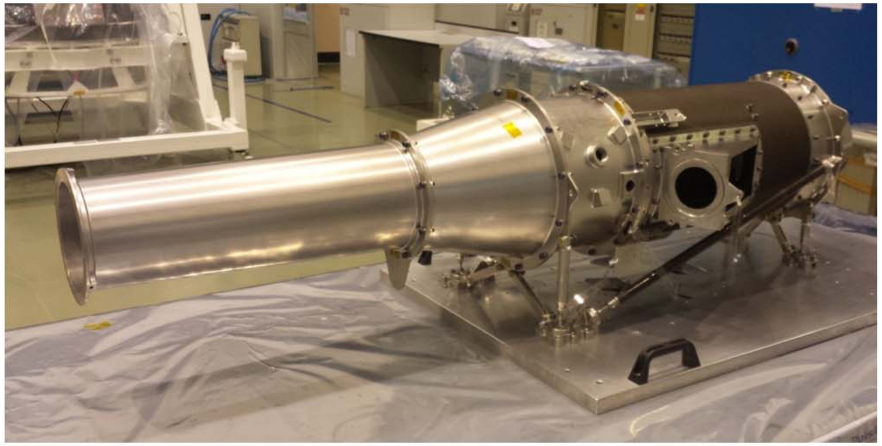


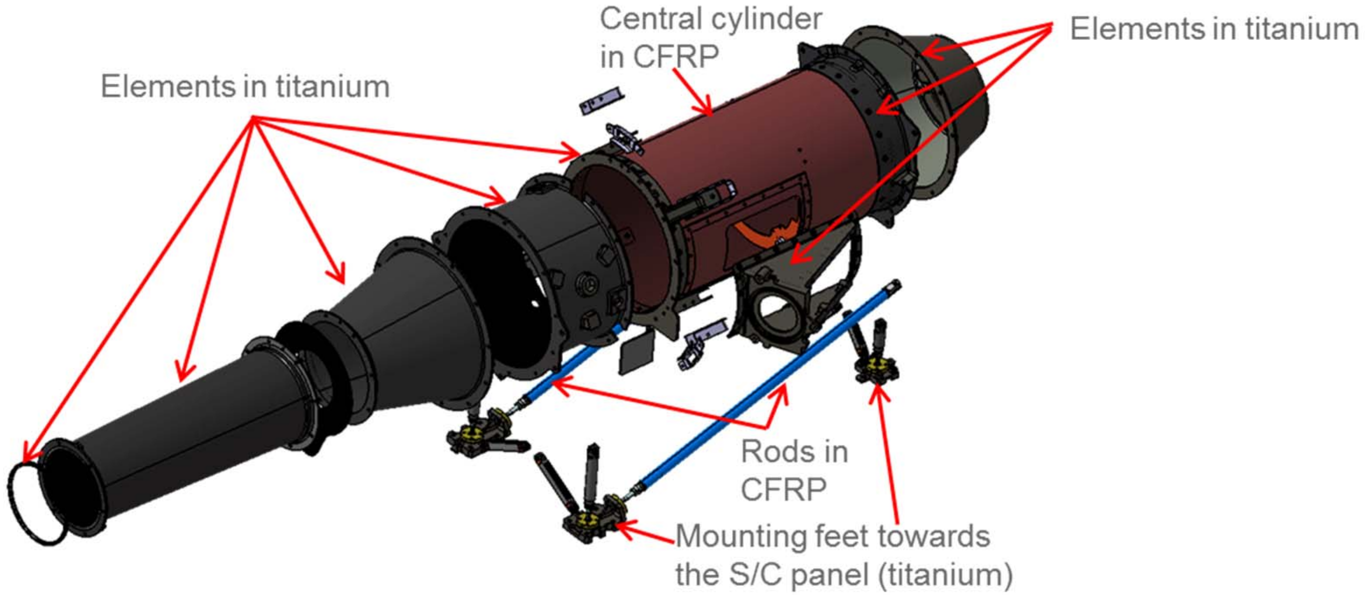




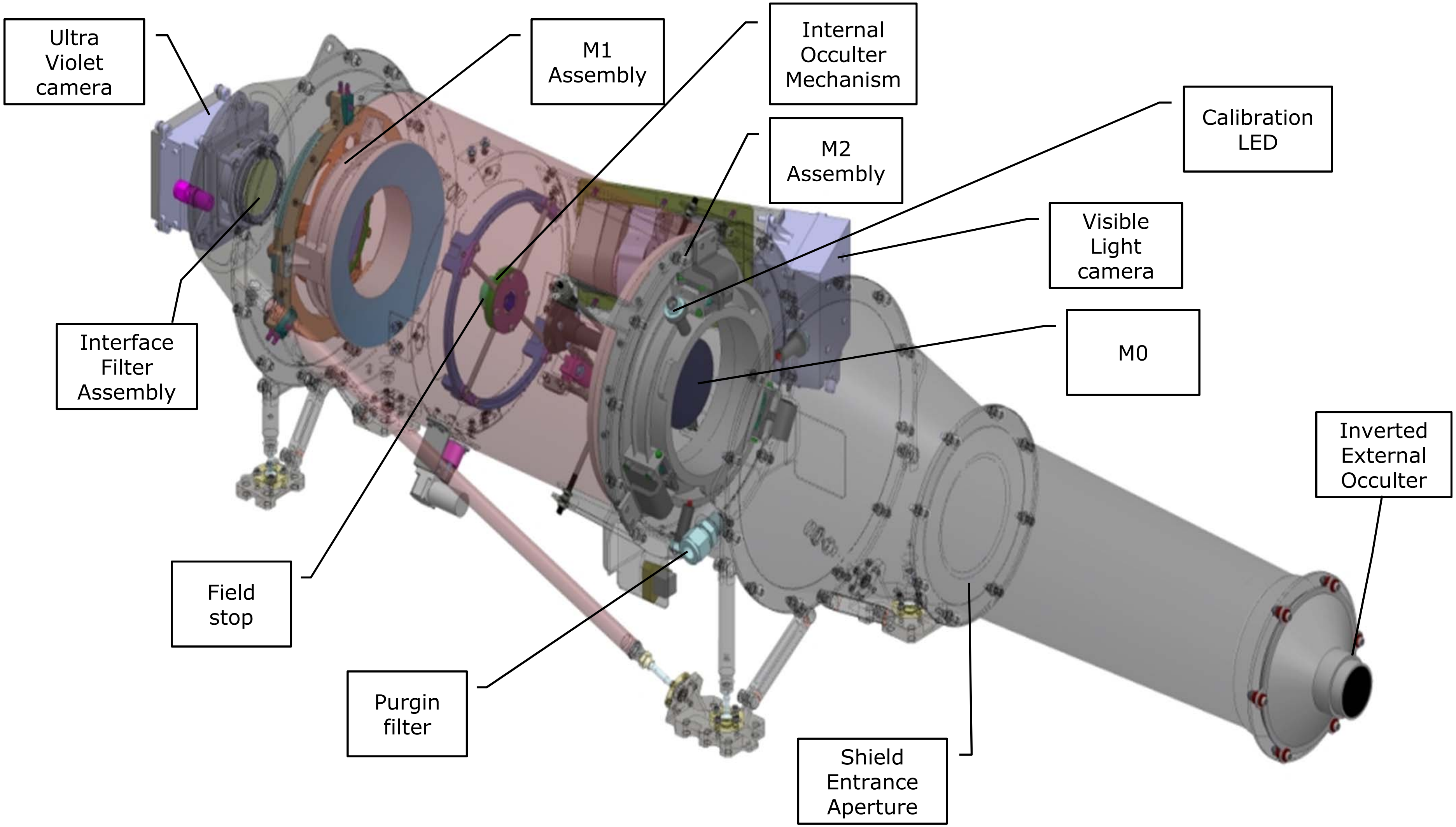
Telescope structure





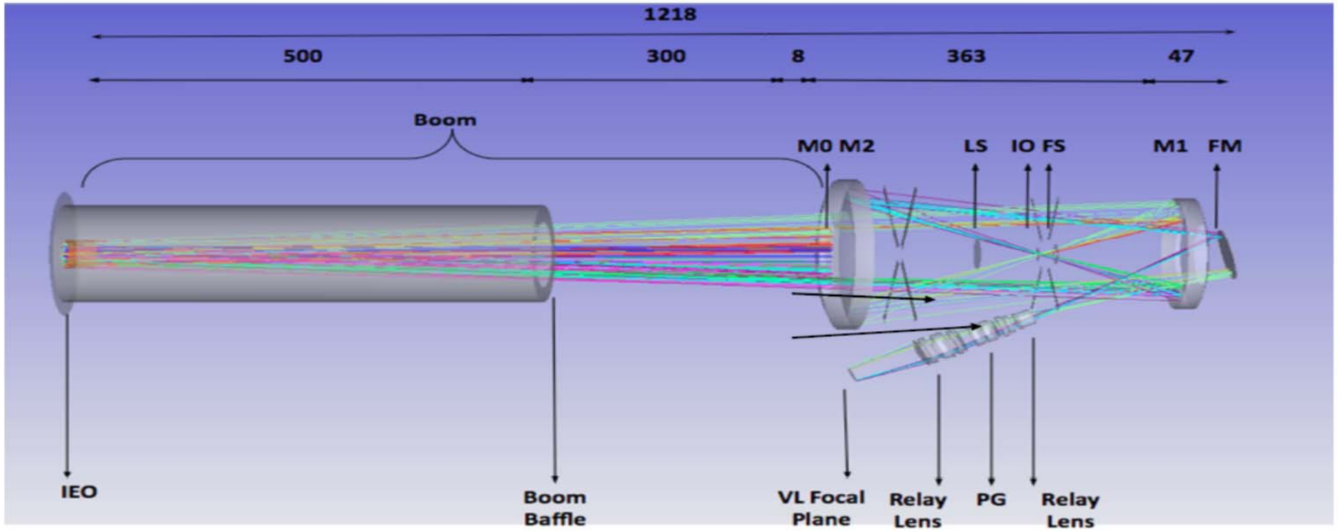


Coronagraph Configuration

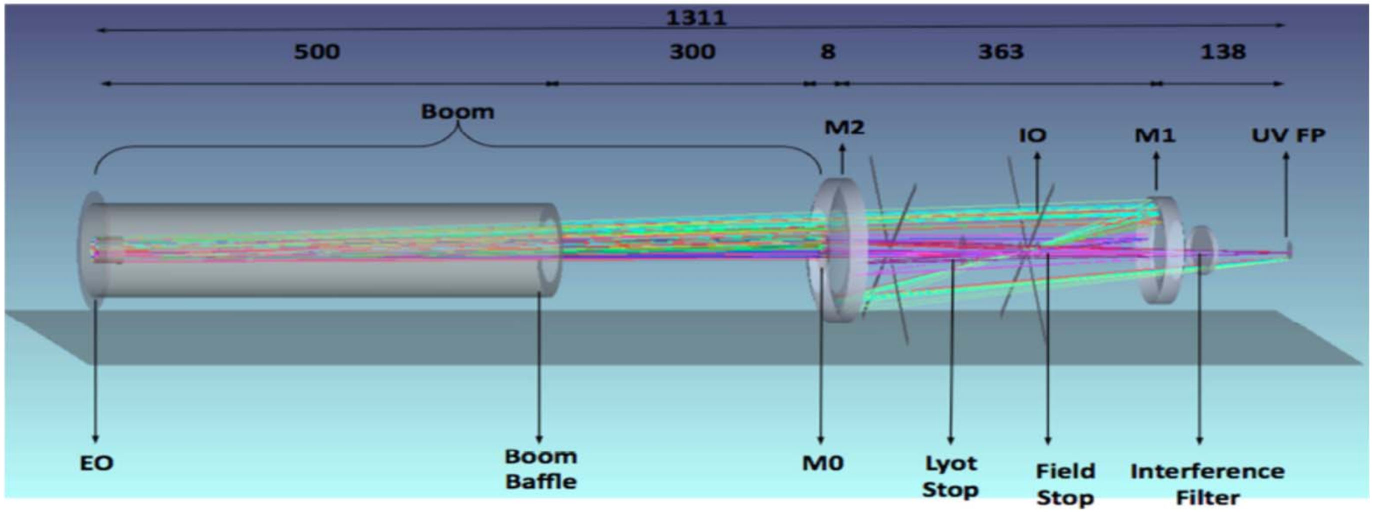


Optical design

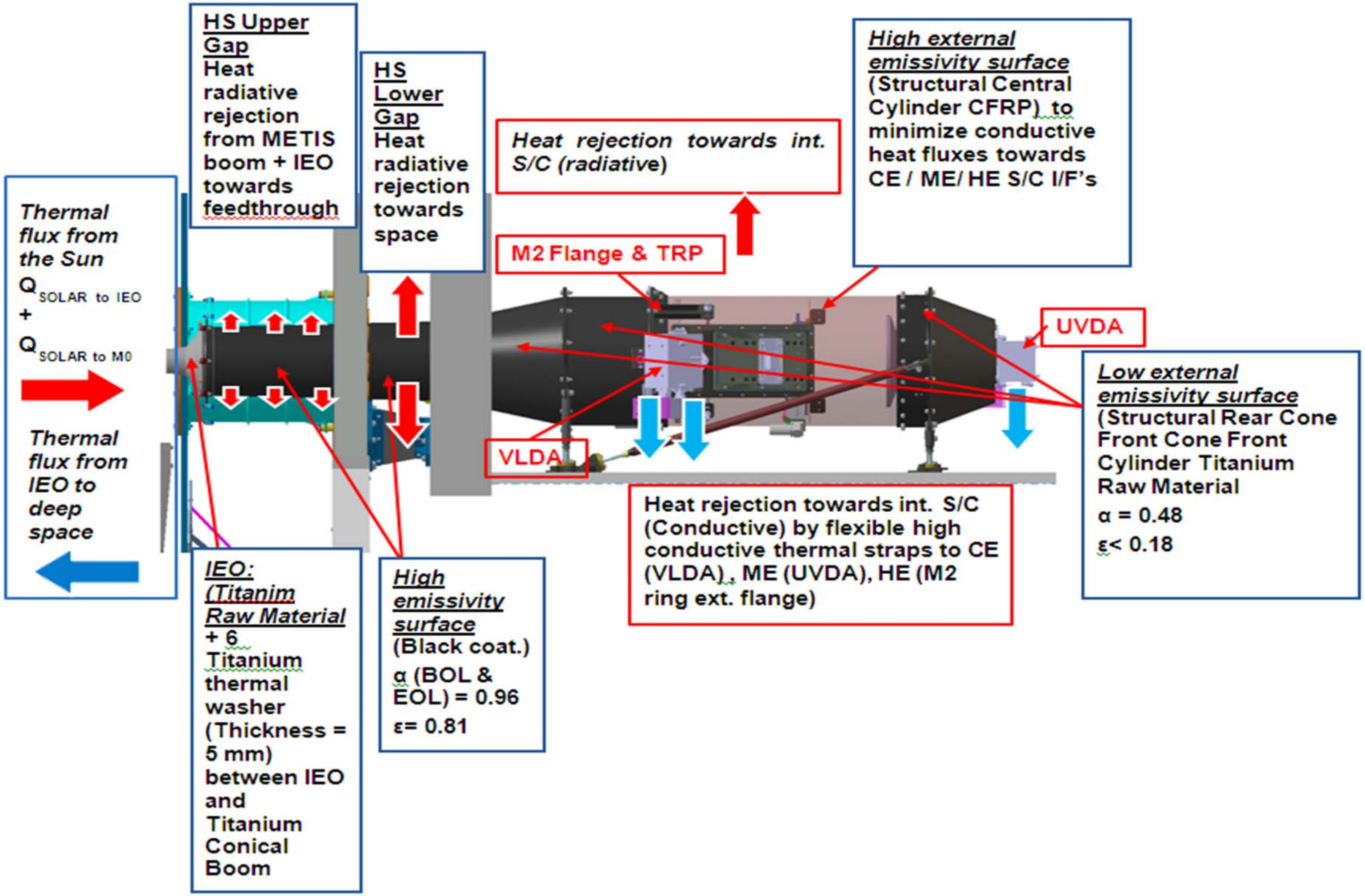
Visible Light path



Ultra violet path

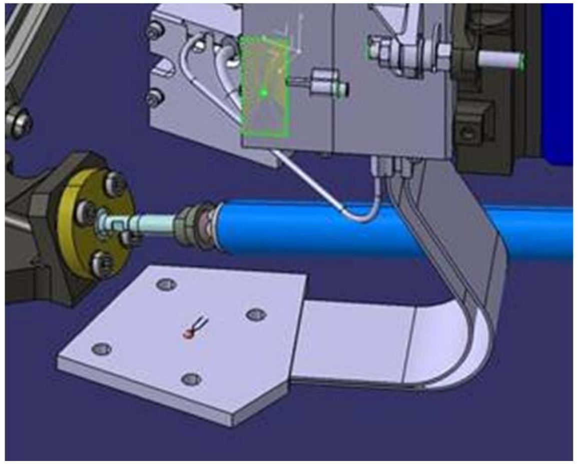


Solar thermal flux management

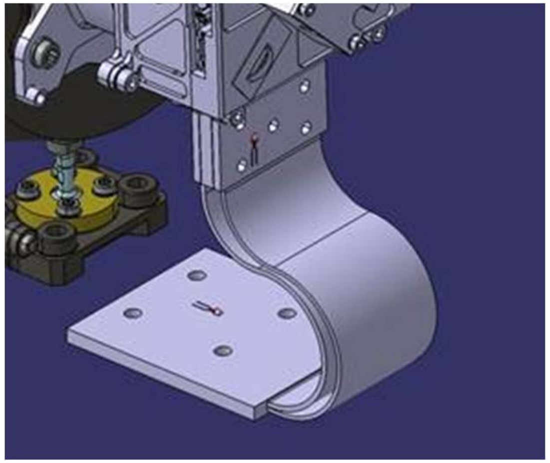


Telescope links with S/C radiators

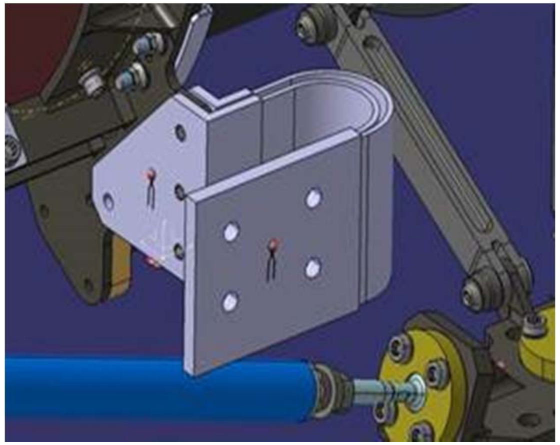
I/F	Max Heat Flux to S/C [W]	Min. Op. [C°]	Max. Op. [C°]	Min. Non-op. [C°]	Max. Non-op. [C°]	Min. Switch-on [C°]	Max. Switch-on [C°]
CE	4.2	-65	-35	-35	60	-45	-35
ME	3.9	-45	-20	-30	60	-30	0
HE	6	-20	50	-30	60	-30	60



Thermal strap connected to the "CE" radiator of the S/C, for cooling the VL sensor



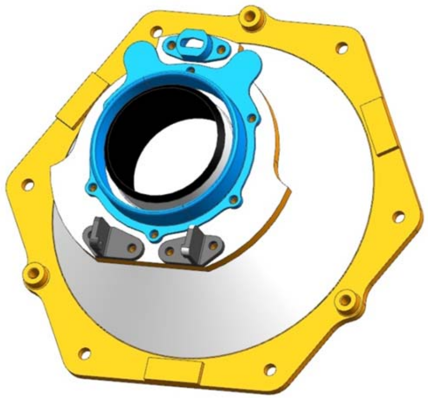
Thermal strap connected to the "ME" radiator of the S/C, for cooling the UV sensor

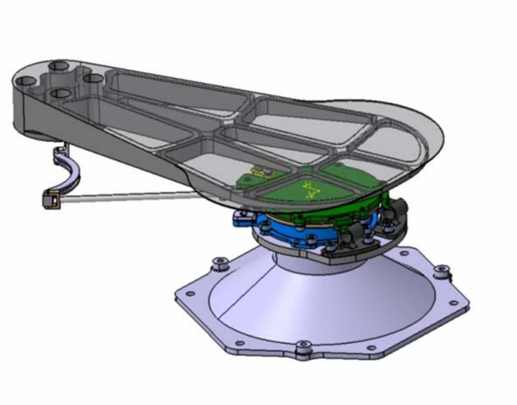


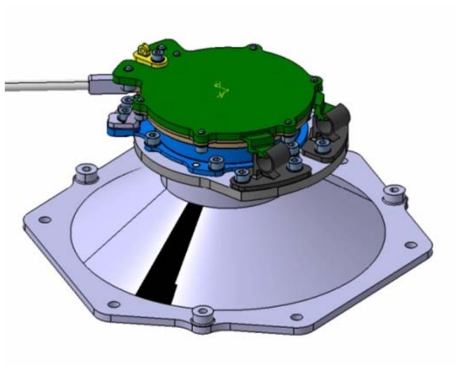
Thermal strap connected to the "HE" radiator of the S/C, for cooling the Telescope structure

Inverted external occulter IEO

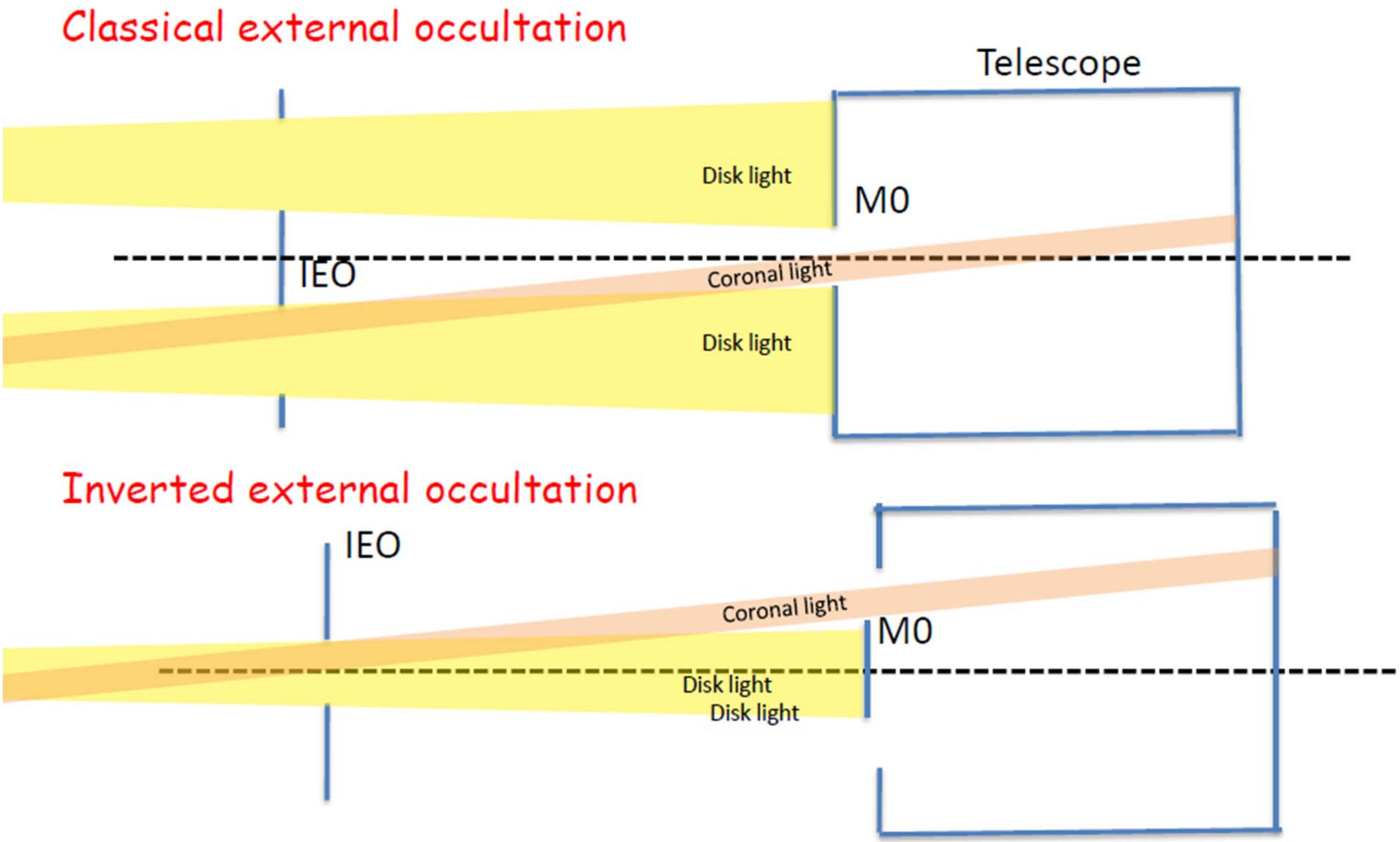
1. Designed by METIS Science Team to optimise stray light suppression requirement and optical performance
2. Made up of Titanium, due to the very stringent mechanical tolerances requested and in order to avoid thermo-mechanical impact at the I/F with the Titanium Boom.
3. On the internal surface a coating of Aktar Magic Black will be applied.
4. Interface with Contamination Protection Cap, that prevents contaminants and light into IEO during pre-launch and LEOP







Inverted occultation principle



Solar disk rejection mirror & Lyot stop

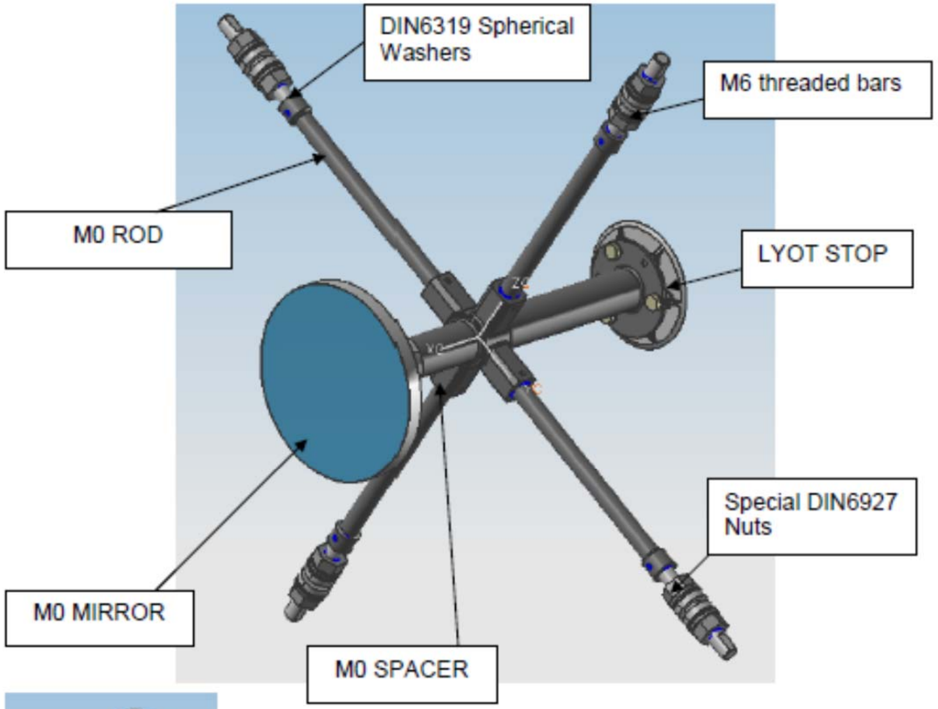
1. The mirror M0 reject back to IEO the solar disk light.
2. LYOT Stop suppresses the M0 edge diffraction to M1

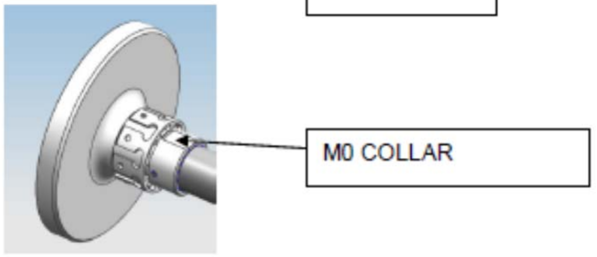
Zerodur: Mirror

Invar: Collar, Lyot Stop

Ti6Al4V: structure and screws

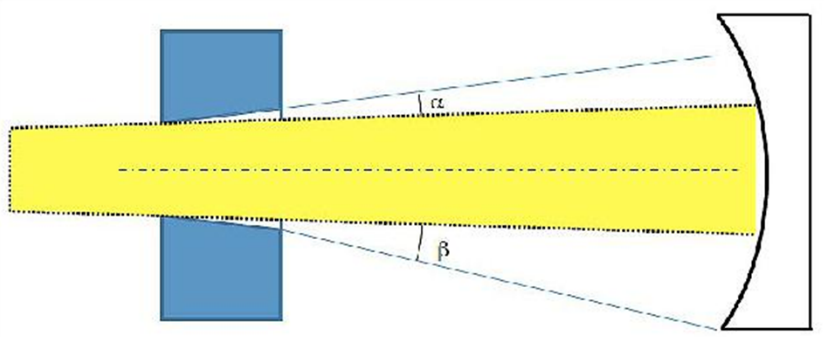
Nominal Mass: 0,303 kg





METIS in-flight off-pointing

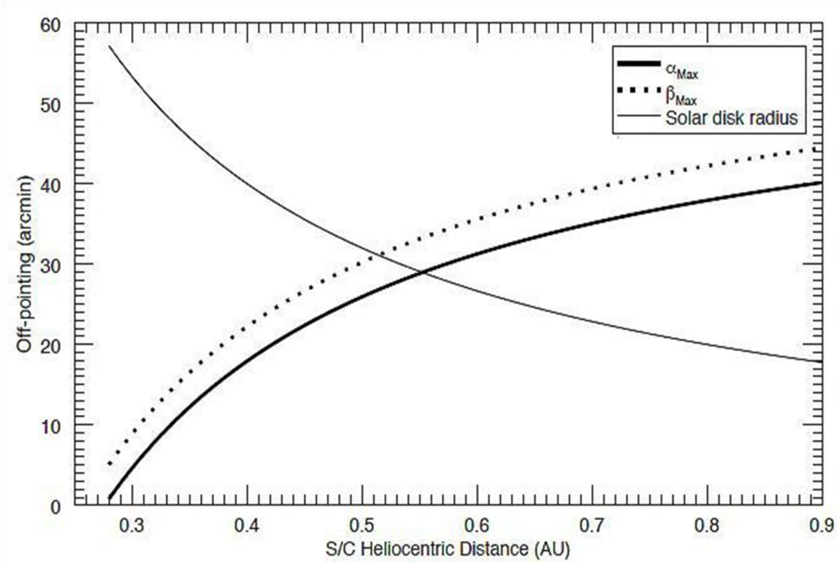
1. α_{max} : solar disk light onto internal IEO -> limit of acceptable performance
2. β_{max}: solar disk light unblocked ->0.5 AU is the limit of observation
3. If LoS out of Max offset pointing error -> Heatshield door closes



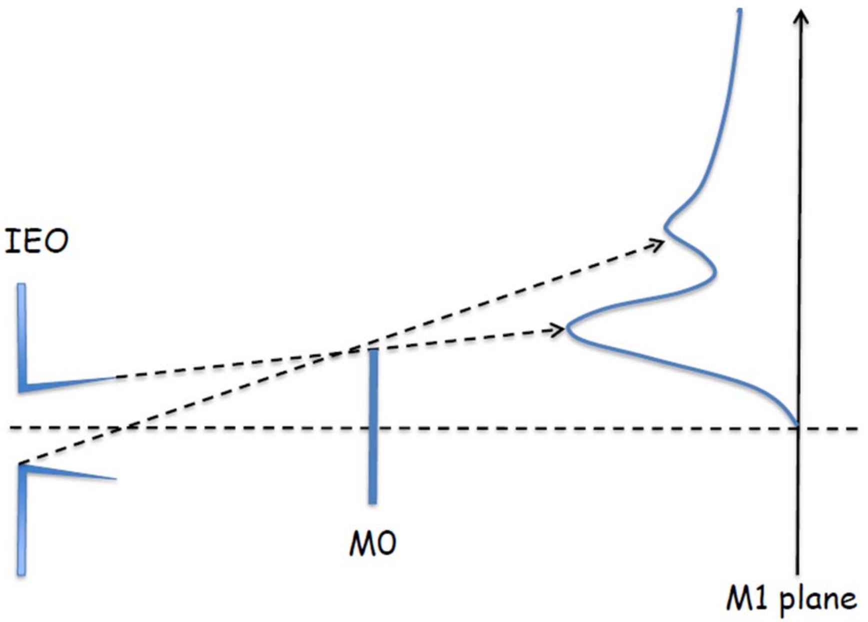
$\alpha_{max} = \alpha - \Lambda\alpha = \alpha - [APE_{SC} + (APE_{METIS} + \Lambda\alpha_{cone})] = \alpha - [3.5' + (1' + 1.8')] =$
$(64.2' - 16'/d(AU)) - 6.3'$

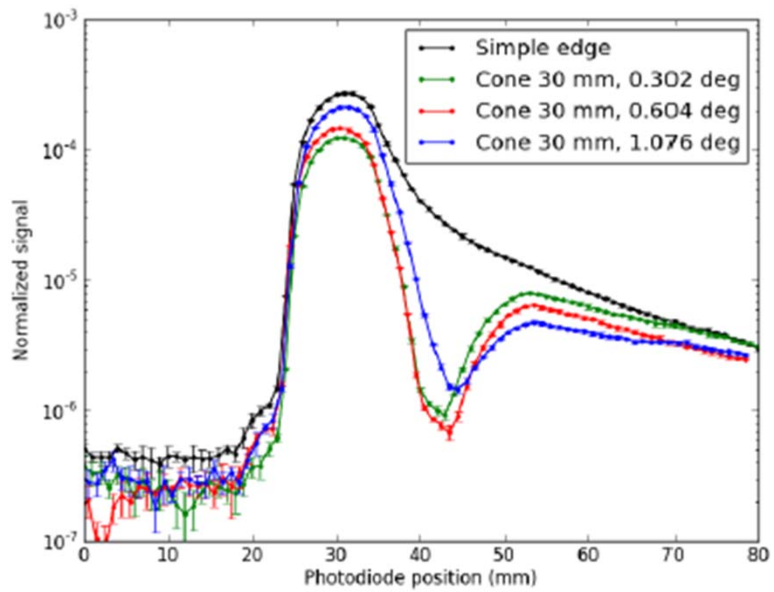
$\beta_{max} = \beta - \Delta\beta = \beta - [APE_{SC} + APE_{METIS}] = \beta - [3.5' + 1')] = (66.6' - 16'/d(AU)) - 4.5'$

At closest approach (0.28 AU): $\alpha = 7.1'$ $\beta = 9.6'$ $\alpha_{max} = 0.8'$ $\beta_{max} = 5.0'$

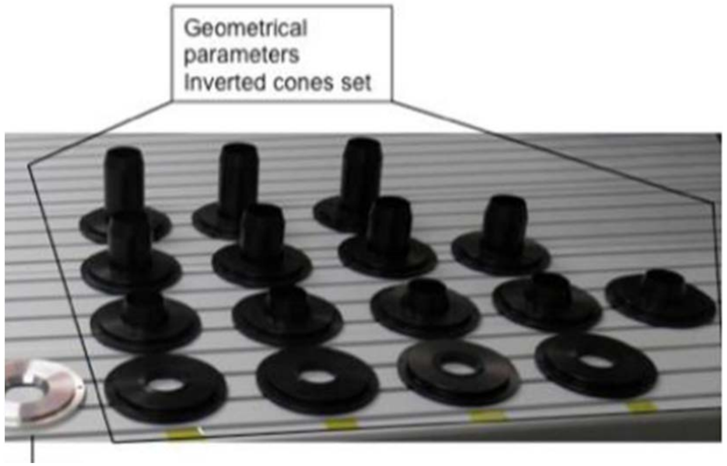


IEO - Optimization Design





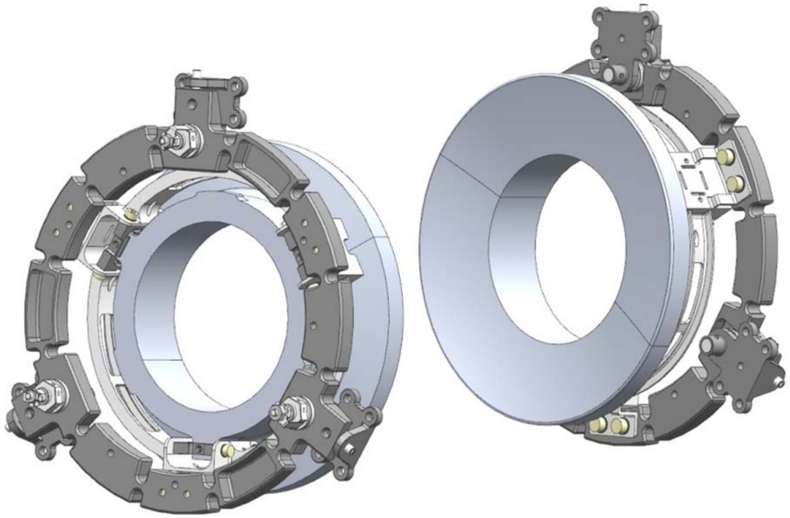
1. IEO contribution to stray-light



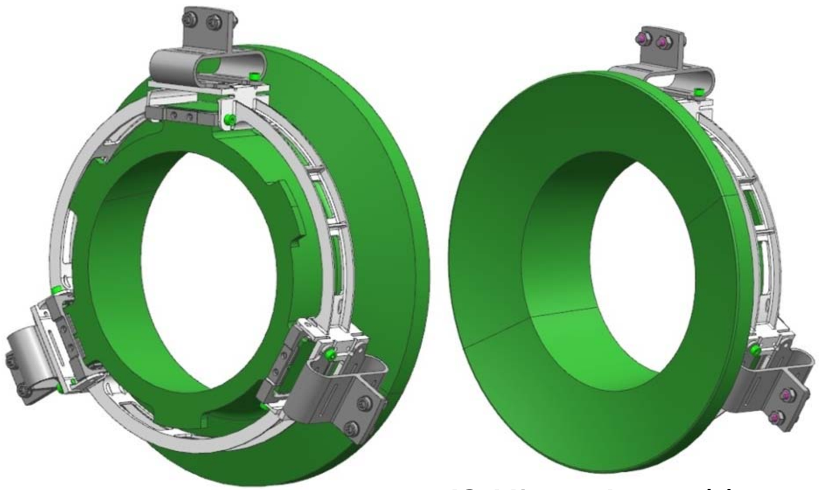
Primary and Secondary Mirrors

1. M1 and M2 mirror assemblies

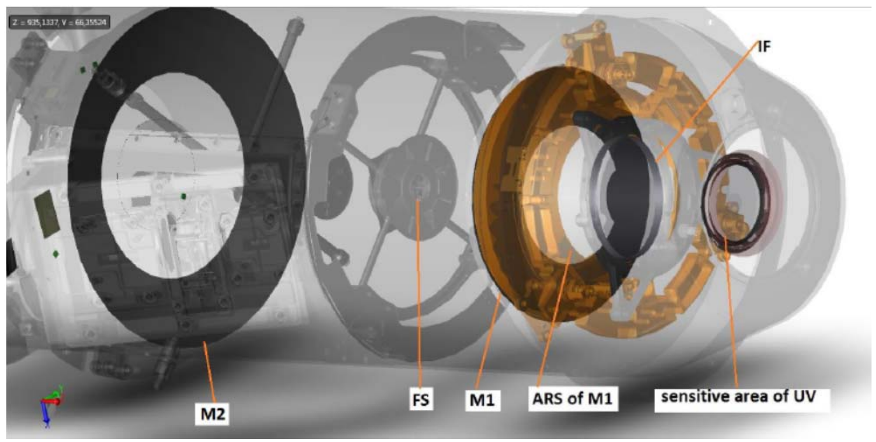
Zerodur: Mirror
Invar: Ring, Frame
Ti6Al4V: structure, brackets and screws
Nominal mass: 1,281(M1)/1,51(M2) kg



M1 Mirror Assembly

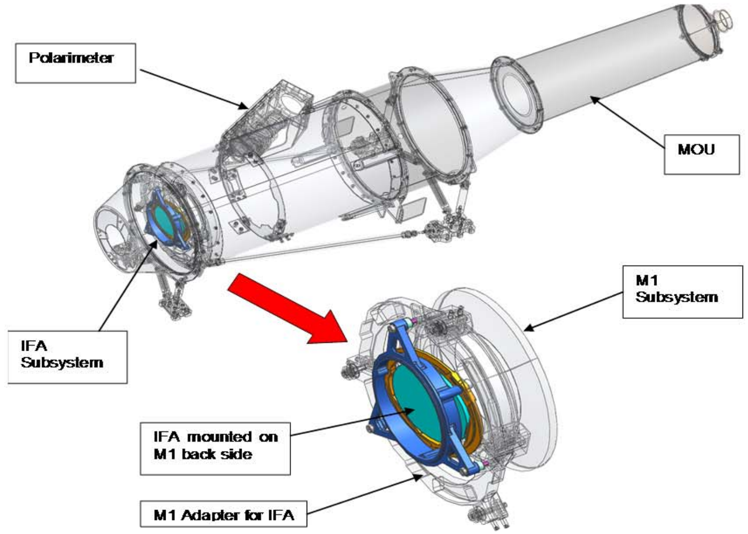


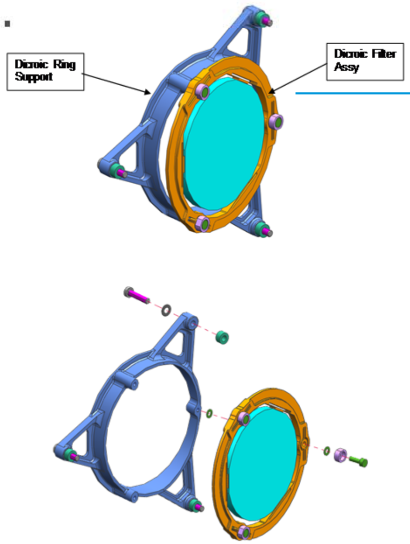
M2 Mirror Assembly



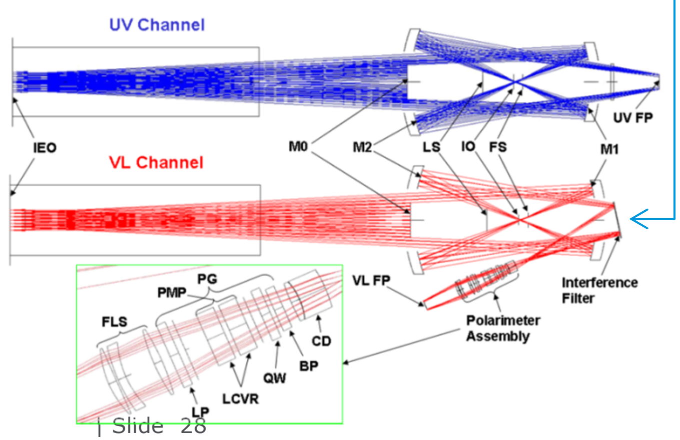
Interface Filter Assembly (IFA)

Designed to support a Dicroic Filter on the M1 back side, transparent to UV light and centered on the optical axis and rotated 12° in order to reflect light in the visible channel to the polarimeter.





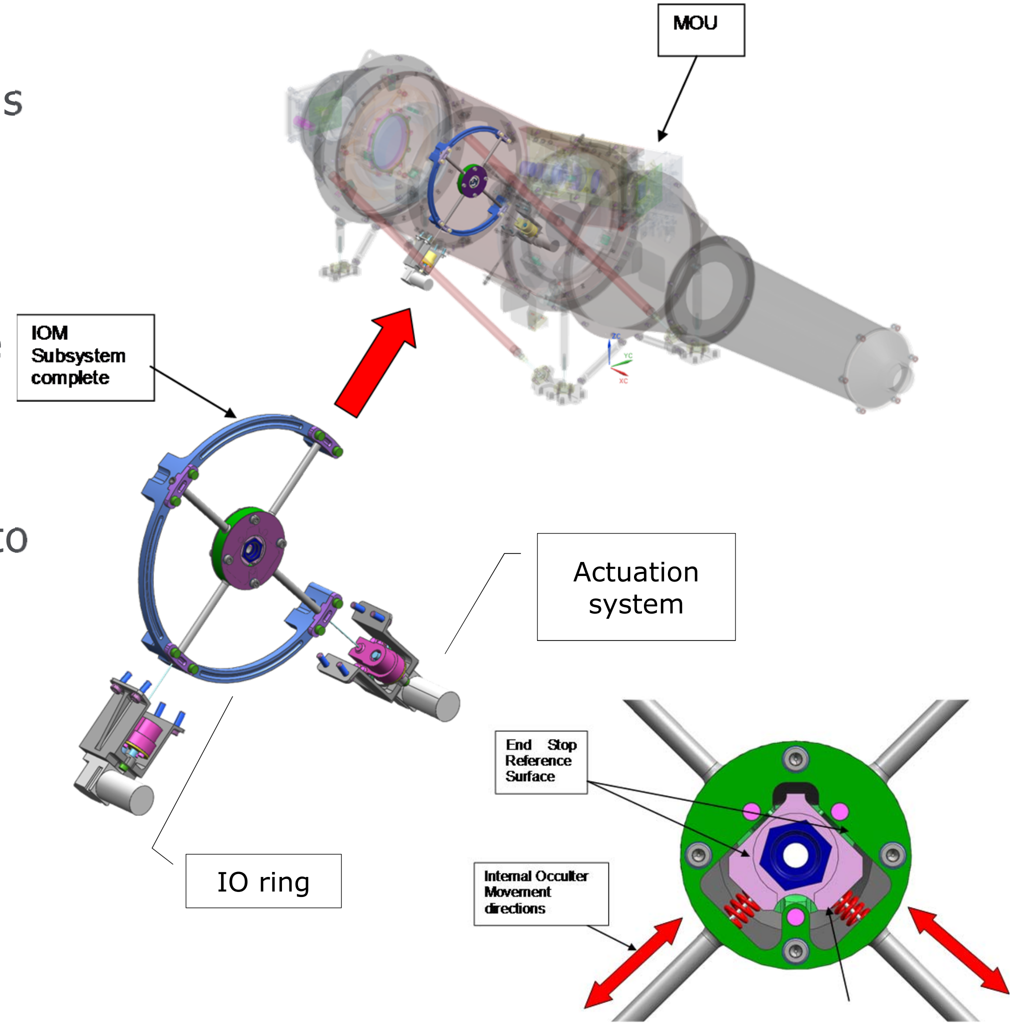
IFA SM

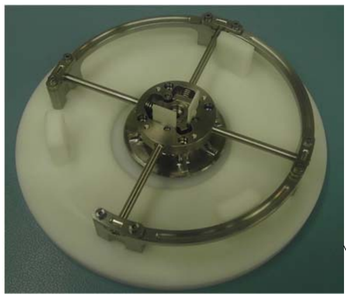


Alessandro Gabrielli

Internal Occulter Mechanism (IOM)

1. Accommodated inside the Metis Optical unit (MOU) along the optical axis, and placed at a location corresponding to the intermediate focal plane of the telescope.
2. The IOM function is to adjust the Internal Occulter position to compensate for any External Occulter misalignment or Spacecraft off-pointing.





IOM STM

Polarimeter

Focusing barrel: Aluminium Alloy RSA 463 AH

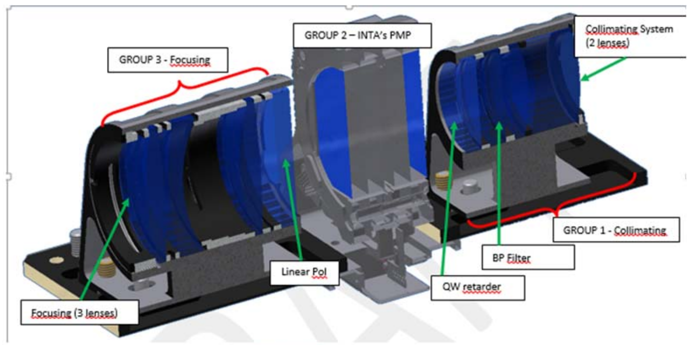
- Linear Polariser: Glass SK1300
- Focusing lenses: Glass SK1300
- Inner Spacers: Aluminium Alloy RSA 463 AH

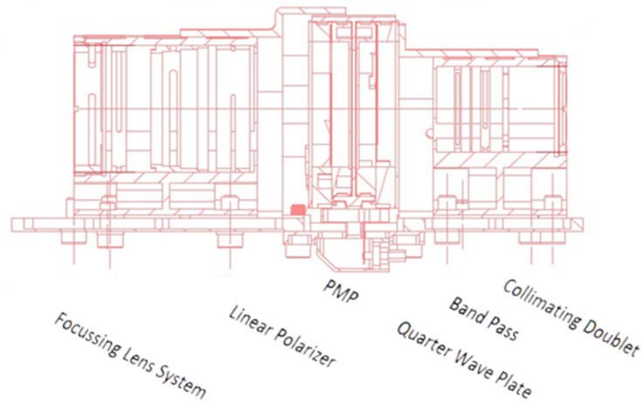
PMP Unit

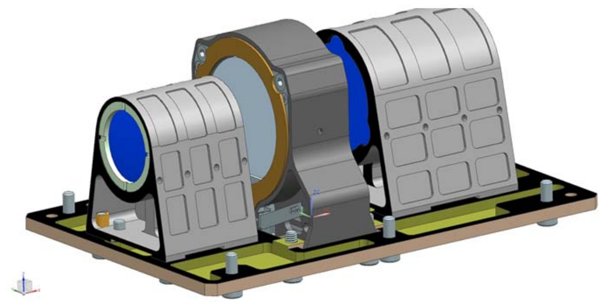
- Structure : Ti 6Al-4V (gr.5)
- Polarizer Mount: AL 6082-T651
- Polarizer: K5G20+colorPol

Collimating barrel: Aluminium Alloy RSA 463 A

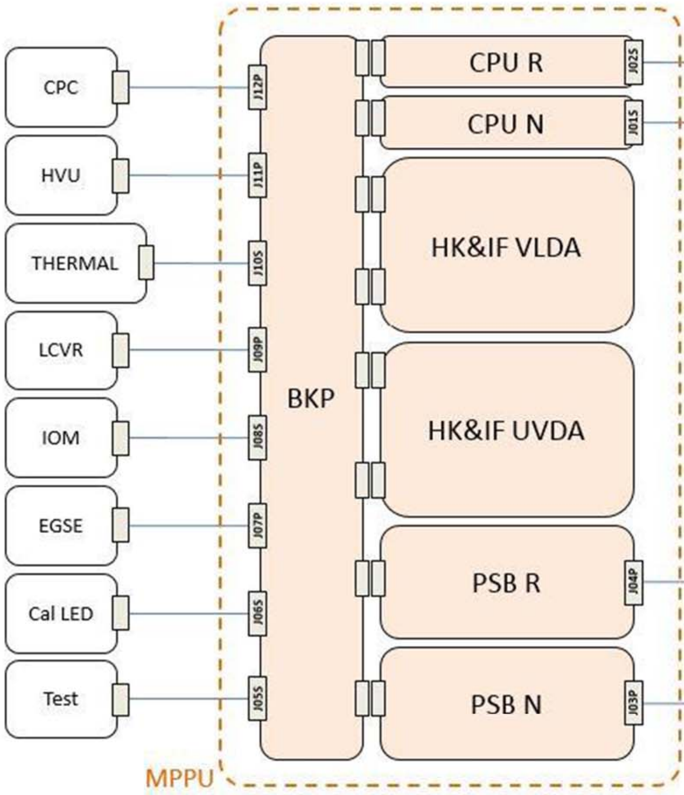
- Collimating Doublet: Glass SK1300
- Band Pass: Glass SK1300
- Quarter Wave Plate: Glass SK1300
- Inner Spacers: Aluminium Alloy RSA 463 AH

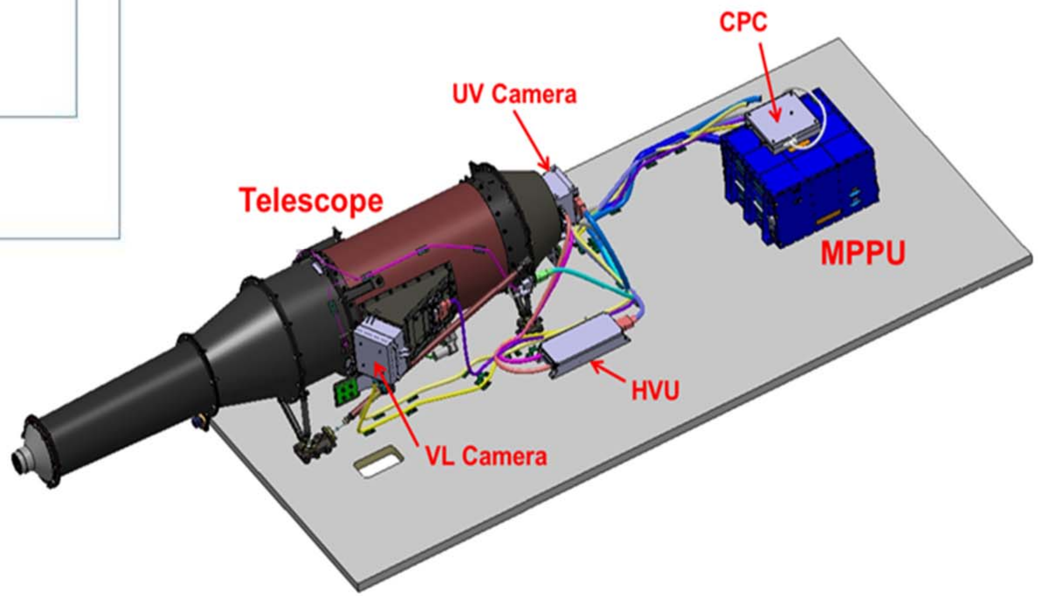






Electrical architecture

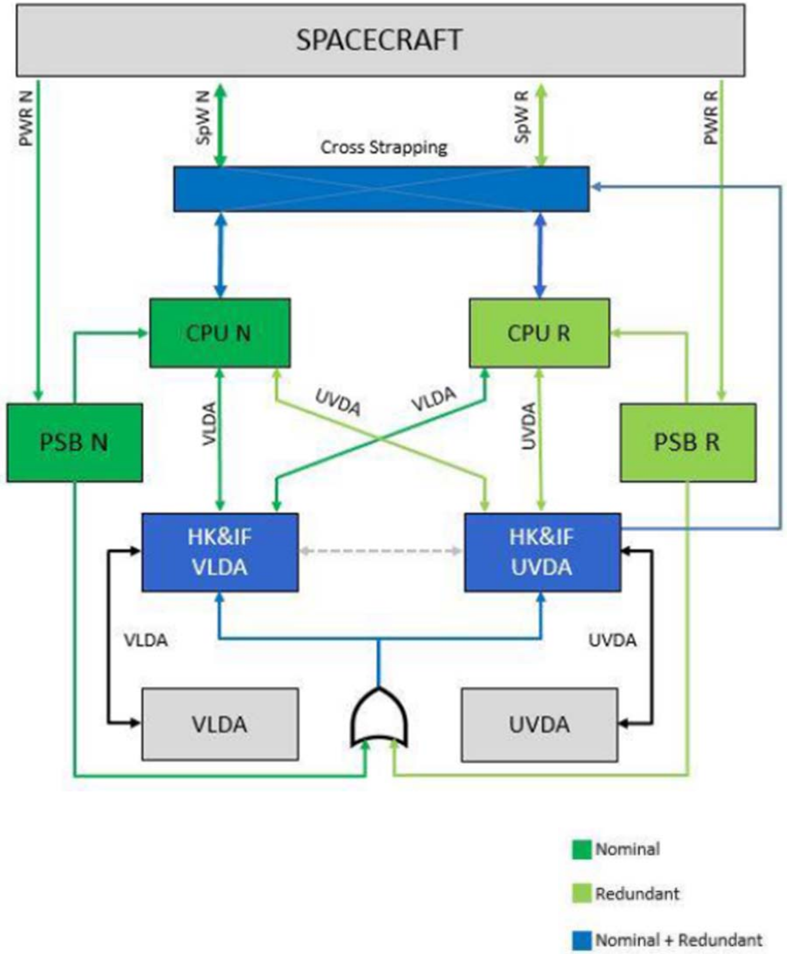




METIS Power & Processing Unit (MPPU)

MPPU

- 2 x CPU boards (Main & Redundant)
- 2 x Power Supply Boards (Main & Redundant)
- 1 x HK & IF Board (partially redundant)
- 1 x Backplane

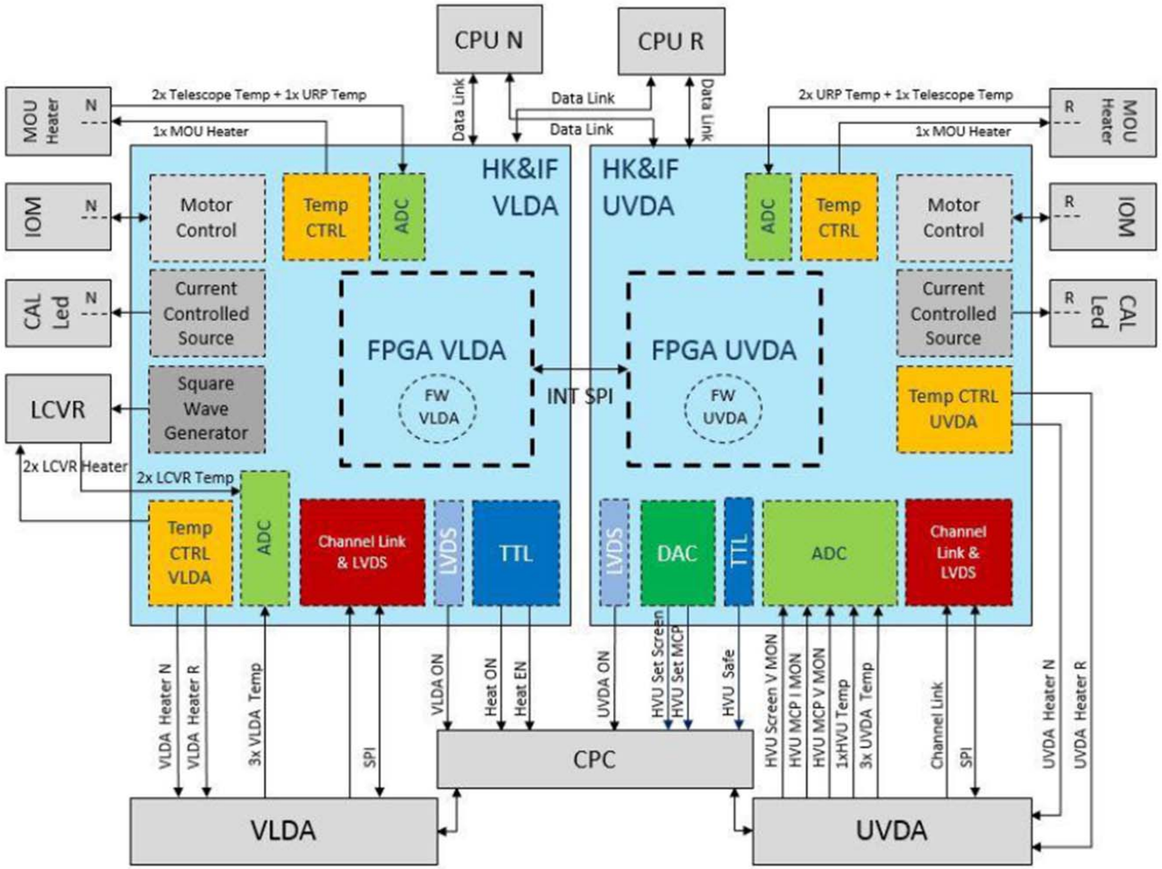


The redundant functions are:

- Processing and memory buffering
- SpW I/Fs (cross-strapped)
- Power
- Subsystems: Thermal control, IOM, Calibration LEDs.

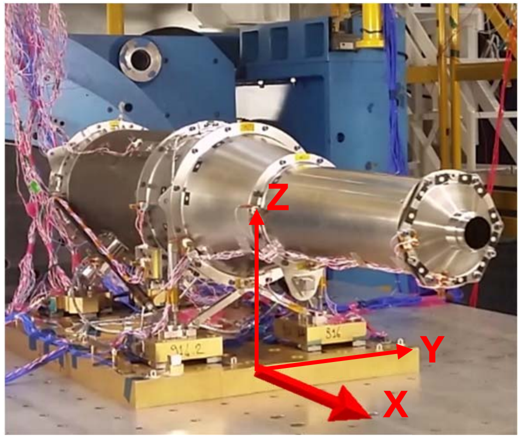
Housekeeping (HK) & Interfaces Board

- Separated electronics channels for UVDA and VLDA (if a channel fails, the other works)
- Redundant driving for IOM, LCVR, LEDs, Heaters & Thermistors
- HK acquisition
- UVDA & VLDA data acquisition
- UVDA & VLDA TC/TC management
- Multi-protections on power supply rails

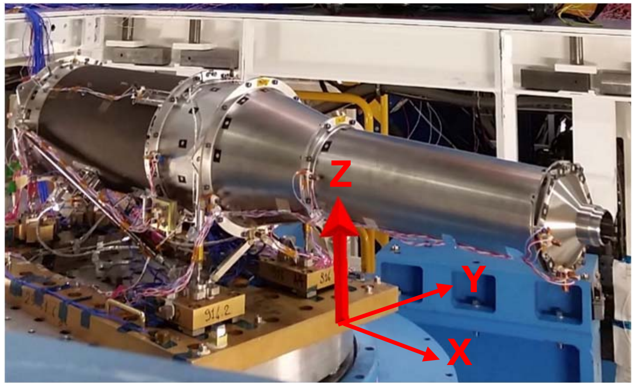


METIS Structural test

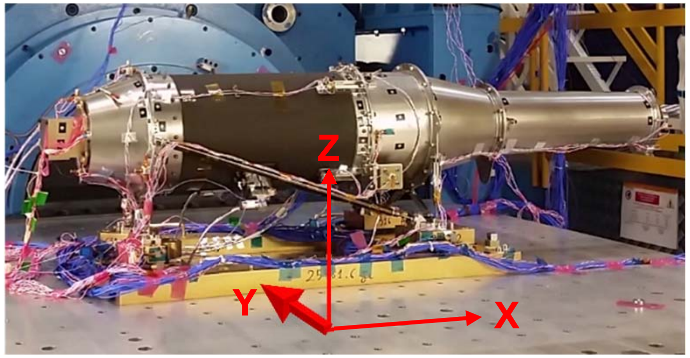
- Vibration test campaign performed from 24/04 to 4/06/2015 at TAS-I Rome on a structural model of the METIS Telescope consisting of the flight representative structure equipped with mechanically representative models of the optical elements and of the detectors.
- First resonant frequency: 156.6 Hz (X axis), in good agreement with the predictions.
- No damage of the structure and no significant change of the dynamics characteristics and of the position of the interface planes with the optical elements and the detectors produced by the tests.



Test set-up for vibrations along X-axis



Test set-up for vibrations along Z-axis

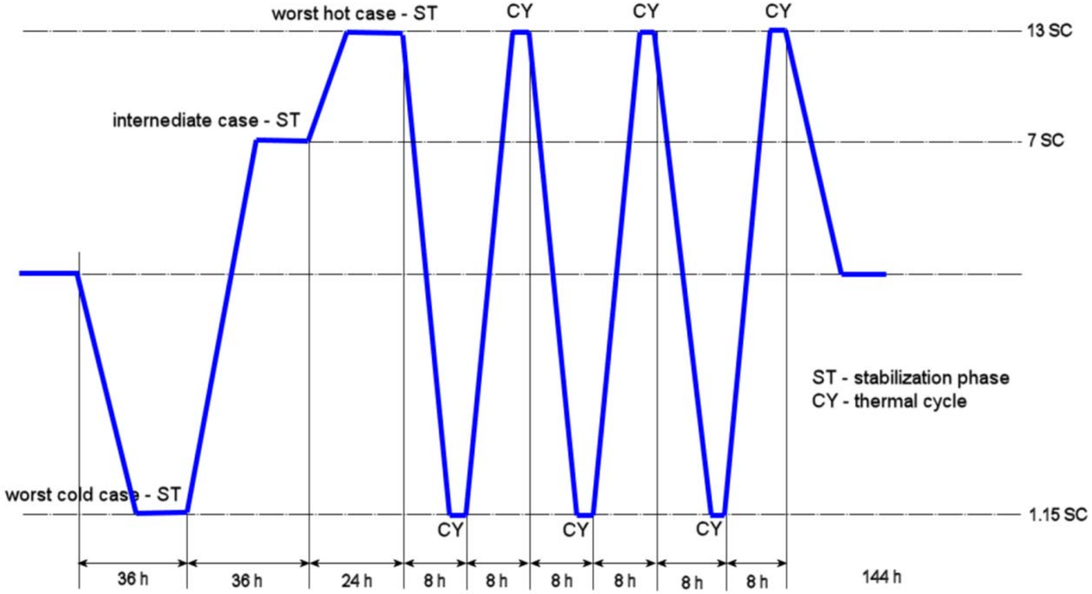


Test set-up for vibrations along Y-axis

Thermal-vacuum test

- The thermal-vacuum test of the METIS Telescope to be performed at the ESTEC Test Center, equipped with a solar simulator.
- Simulator performance: up to 13 solar constant (≈17 kW/m^2), corresponding to the minimum solar distance of 0.28 AU.
- Simulating to the flight condition, the telescope will be protected by an “heat shield” which leaves only the aperture directly exposed to the Sun.

Thermal-vacuum chamber equipped with the solar simulator



Planned thermal test phases

Cleanliness & Contamination Control (1/2)

Cleanliness & Contamination Control along the design and PFM AIT phases

C&CC actions in the design phase

1. Selection of low outgassing materials, according to standard ECSS-Q-ST-70-01C

C&CC actions during production phases:

1. Cleaning of the structural parts to 100 ppm and of the optical elements 3.3 ppm.
2. Bake-out of the structural parts with TQCM monitoring (the treatment guarantees a molecular cleanliness level of 50 ng/cm^2).
3. Application of contamination barrier (black coated Al foil) on the internal side of the CFRP cylinder of the Telescope.
4. Packaging in suitable containers with contamination witnesses.

Cleanliness & Contamination Control (2/2)

C&CC actions during AIT in OPSys:

1. Cleanliness verification at acceptance (inspection/certificates).
2. Cleaning of delivered structural parts to achieve 3.3 ppm.
3. Monitoring of the deposition in the ISO 5 integration cleanroom.
4. Particulate cleaning during integration as necessary.

C&CC actions during transportation:

1. METIS kept under purging with grade ≥4.6 GN2 inside the transport container.
2. During airline transportation GN2 overpressure will be guaranteed.

Contamination control during environmental tests

1. Purging will be provided continuously except for:
   - Vacuum thermal cycling where a temporary protection cap on the aperture will be used.
   - EMC and random vibration tests where a temporary protection cap on the aperture will be used and GN2 atmosphere inside the Telescope will be provided.

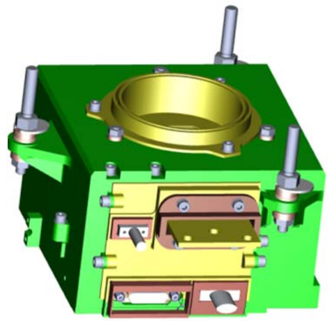
Scientific Collaboration with MPS

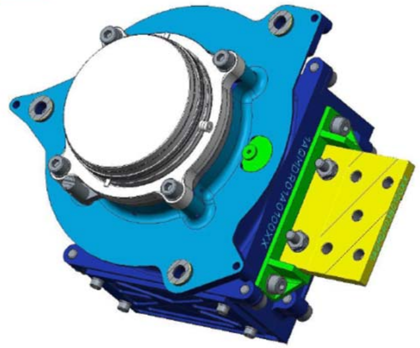
Max-Planck-Institut für Sonnensystemforschung

ASI-MPS scientific collaboration contract signed in October 9th, 2013

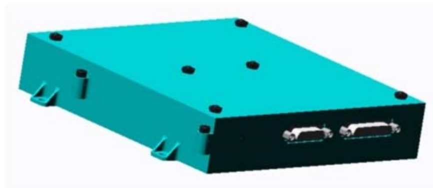
All intellectual rights of the METIS Detection Subsystem belong to the Max Plank Institute for Solar System Research.

- Visible light detector assembly (VLDA) operating in visible polarized and unpolarized light
- Ultraviolet Detector Assembly (UVDA) operating in the Lyman alpha line of H I,
- A Camera Power Converter (CPC) fed by the METIS MPPU and powering both cameras,
- A High Voltage Unit (HVU), providing the high voltages required by the intensification system of the UVDA.


VLDA


UVDA

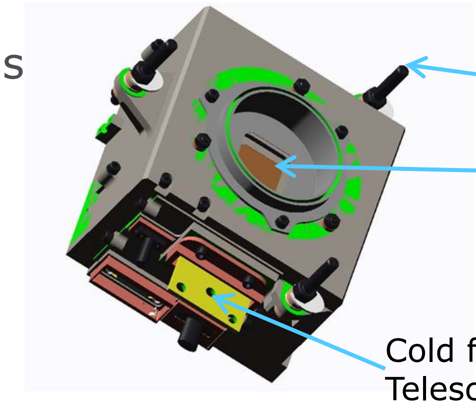

HVU


CPC

Visible Light Detector Assembly (VLDA)

Camera features

- CMOS APS with 2k x 2k, 10 μm pixels
- APS passive cooling via cold finger
- Internal temperature sensor
- Internal annealing heater
- Front-end digital electronics
- Power interface towards the CPC
- Data interface towards the MPPU

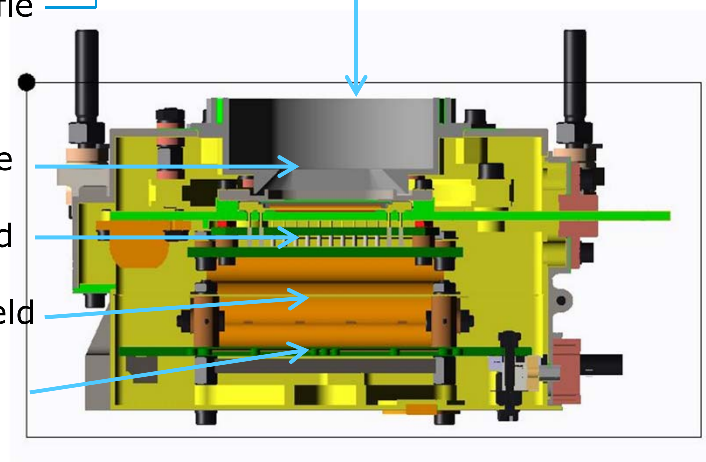


Budgets

- Mass = 0.7 kg (with margins)
- Power = 2.4 W (with margins)

Required sensor temperatures

- Science range: [-40, -15] °C
- Switch-on range: [-50, +50] °C



Ultra-Violet Detector Assembly (UVDA)

Camera features

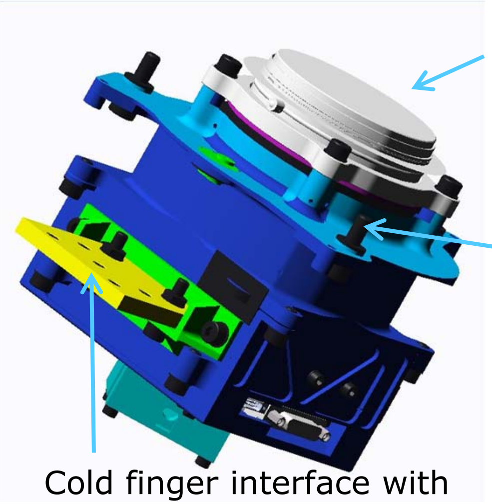
- CMOS APS with 1k x 1k, 15 μm pixels
- APS passive cooling via cold finger
- Intensifier with sealed KBr photocathode (MgF2 entrance window).
- Fiber optic coupler (2:1 de-magnification)
- Internal temperature sensor
- Front-end digital electronics
- Power interface towards the CPC
- Data interface towards the MPPU

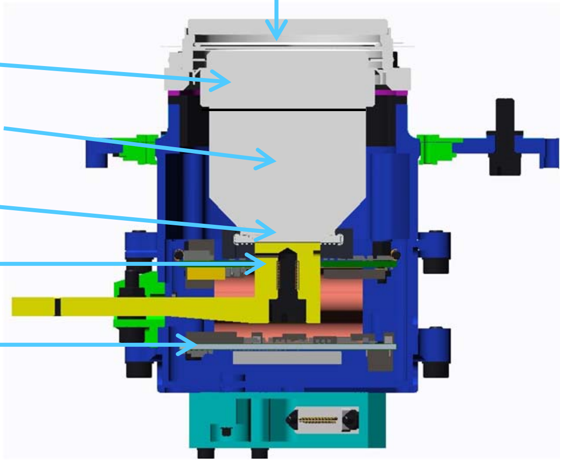
Budgets

- Mass = 1.2 kg (with margins)
- Power = 1.53 W (with margins)

Required sensor temperatures

- Science range: [-35, -5] °C
- Switch-on range: [-45, +50] °C

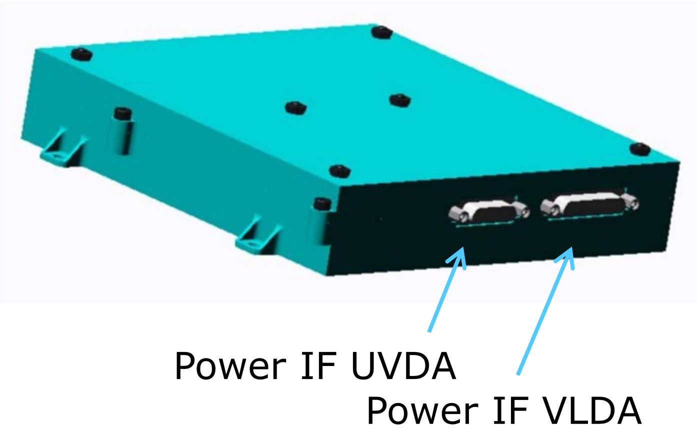




METIS Detection subsystems

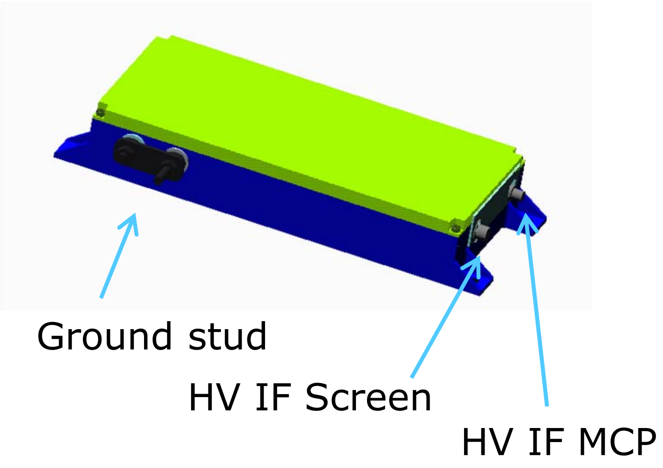
Camera Power Converter (CPC)

- Converts (switched ±7V, unregulated ±0.5V) power received from the METIS MPPU and distributes it to the VLDA and to the UVDA
- +7V supply directly routed to the VLDA annealing heater
- Power consumption: 1.4 W (both cameras on)
- Mass: 0.37 Kg



High Voltage Unit (HVU)

- Receive power from the METIS MPPU
- Provides to the UVDA intensifier the supply voltages of +0 V to +1 kV to the MCP back side and up to +6 kV to the Phosphor Screen
- Mass = 0.38 kg (with margins)
- Power = 1.3 W (with margins)

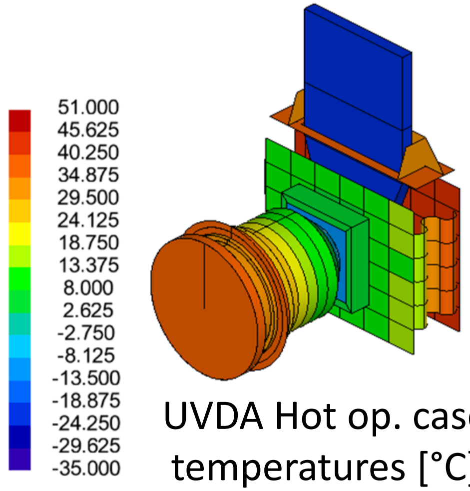


METIS Detectors - *A Thermal Challenge*

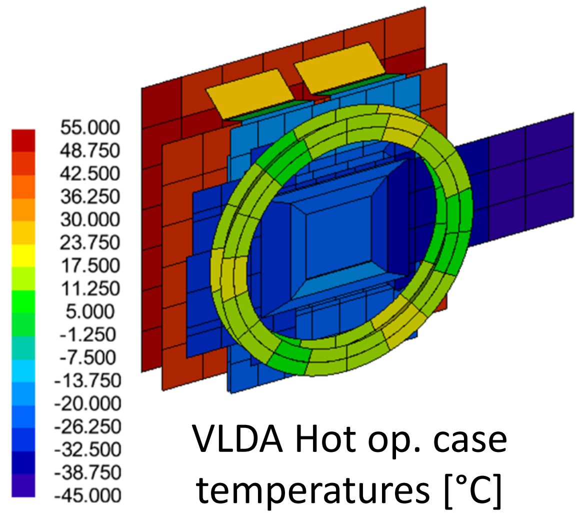
Hot environment
- Up to 13 solar constants in pinging on the instrument aperture at 0.28 AU
- Despite the extreme care in reducing the heat flux conducted along the instrument, temperatures about 60 °C to 70 °C characterize the detectors mounting interface.
- Despite the extremely effective heat shield, a cavity temperature of about 50 °C must still be accounted for.

Cold sensors
- Ideal science performance requires sensor temperatures between -40 °C and -15 °C for the VLDA and -35 °C and -5 °C (UVDA).

Goal achieved by using:
- highly conductive cold fingers directly glued to the sensor packages,
- thermal washers, and insulators to isolate the sensor from the housing and from the electronics,
- thermal baffles,
- appropriate external and internal coatings.



UVDA Hot op. case temperatures [°C]



VLDA Hot op. case temperatures [°C]

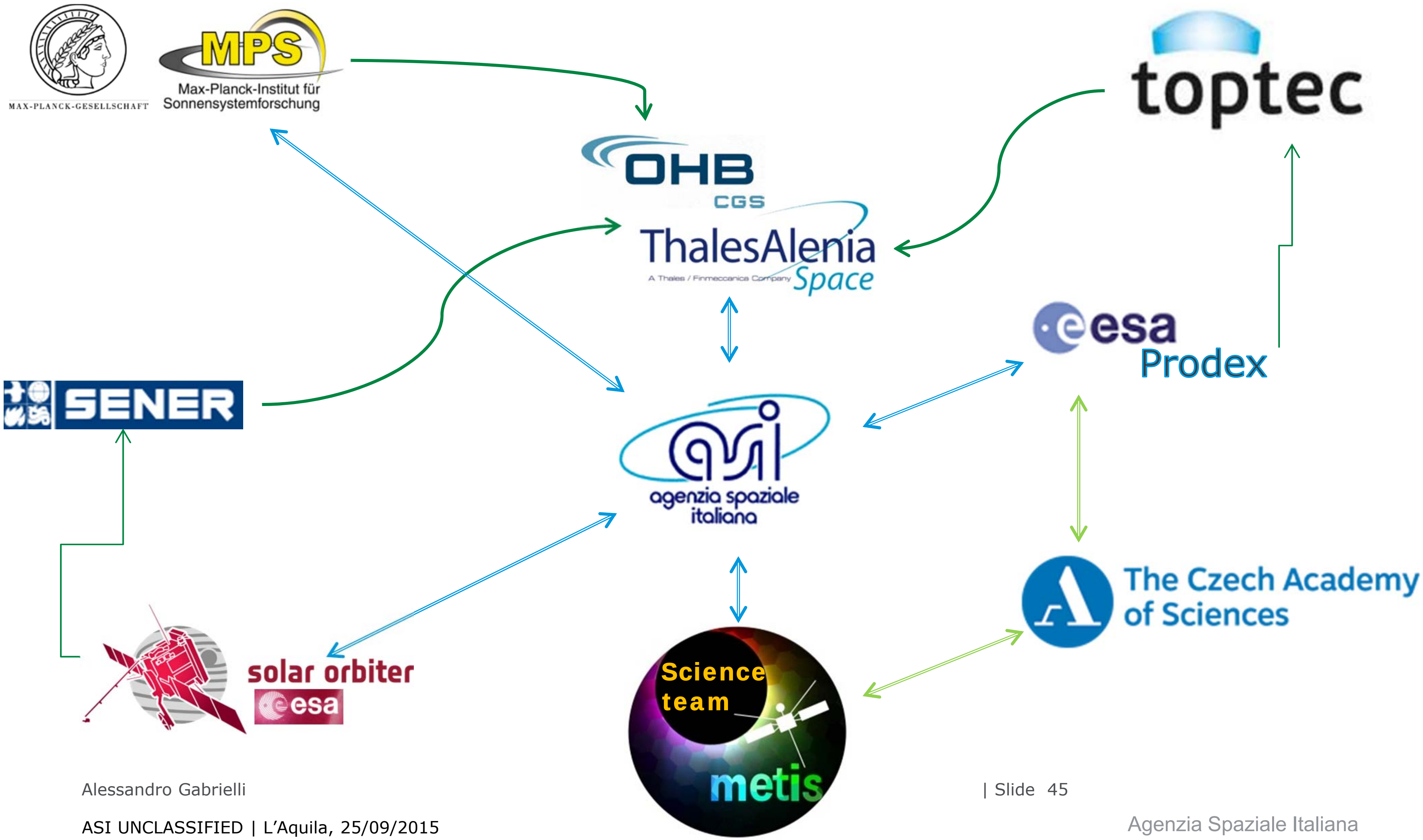
METIS – an industrial programme

- June 2011 ASI selected TAS-I, Turin, to lead the Phase B study of METIS. Concluded at the end of 2012 with partially successful PDR
- Deep reshuffle of the instrument with descoping of instrument secondary features
- In 2013 ASI issued a call for tender for the Phase C-D.
- The 36-month contract for the Phase C/D, awarded to an industrial consortium led by CGS and TAS-I, kicked-off in Oct. 2013

METIS – milestones

- METIS Electrical Model delivery: November 2015
- Instrument CDR with ESA: Oct-Dec 2015
- METIS Flight model delivery: January 2017
- Solar Orbiter launch: October 2018

METIS – Partnership



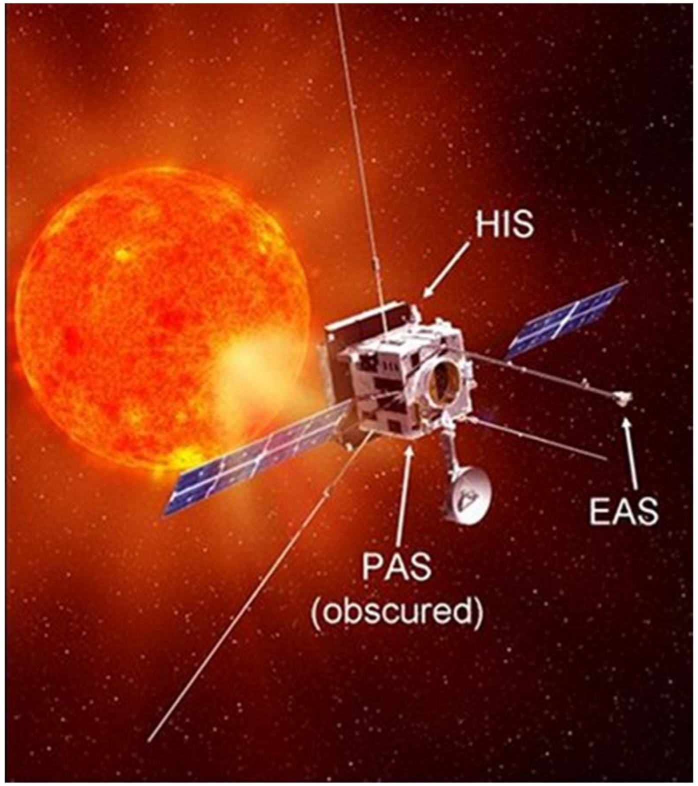
METIS Scientific Team

1. Giampiero Naletto- Experiment Manager
2. Marco Romoli- Instrument Scientist
3. Silvano Fineschi- Experiment Scientist
4. Gianalfredo Nicolini- Project Control
5. Daniele Spadaro - Scientific Team Coordinator
6. Vincenzo Andretta - Scientific Operations.

http://metis.oato.inaf.it

SWA: Solar Wind Plasma Analyser

1. The Solar Wind Plasma Analyser, SWA, consists of a suite of sensors: Electron Analyser System (EAS), Proton-Alpha Sensor (PAS), Heavy Ion Sensor (HIS).
2. SWA will measure the ion and electron bulk properties (including, density, velocity, and temperature) of the solar wind, between 0.28 and 1.4 AU from the Sun. In addition SWA will measure solar wind ion composition for key elements (e.g. the C, N, O group and Fe, Si or Mg).



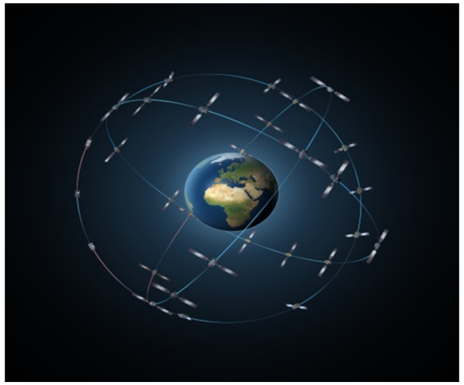
The future: SPACEWEATHER

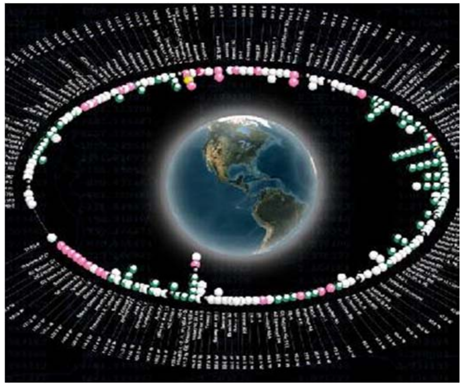
1. Solar storm from the Sun travels through space and impacts the Earth's magnetosphere
2. Spaceweather for preserving our national economy since energy and radiation from solar flares and coronal mass ejections can:

- Cause colorful auroras, often seen in the higher latitudes
- Harm astronauts in space
- Damage sensitive electronics on orbiting spacecraft
- Create blackouts on Earth when they cause surges in power grids.

1. Transition from «in-situ science» to «monitoring» of the Sun
2. At present only Large Angle and Spectrometric Coronagraph Experiment, LASCO C2 and C3 are the only instruments to be still operative for monitoring activities!

Spaceweather for preserving our national economy





H2020 Space Weather

1. H2000 is the European Framework Programme for research and innovation, and is the successor of the EU Senveth Framework Programme (FP7)
2. H2020 Protection of European assets in and from Space 2014 selected three projects:
   - FLARECAST- Flare Likelihood And Region Eruption foreCASTing [Start Date: 2015-01-01, End Date: 2017-12-31]
   - HESPERIA- High Energy Solar Particle Events foRecastIng and Analysis [Start Date: 2015-05-01, End Date: 2017-05-01]
   - PROGRESS - Prediction of Geospace Radiation Environment and solar wind parameters [Start Date: 2015-01-01, End Date: 2018-01-01]
3. https://ec.europa.eu/programmes/horizon2020/en/draft-work-programmes-2016-17