Instruments development and testing for the Solar Orbiter mission

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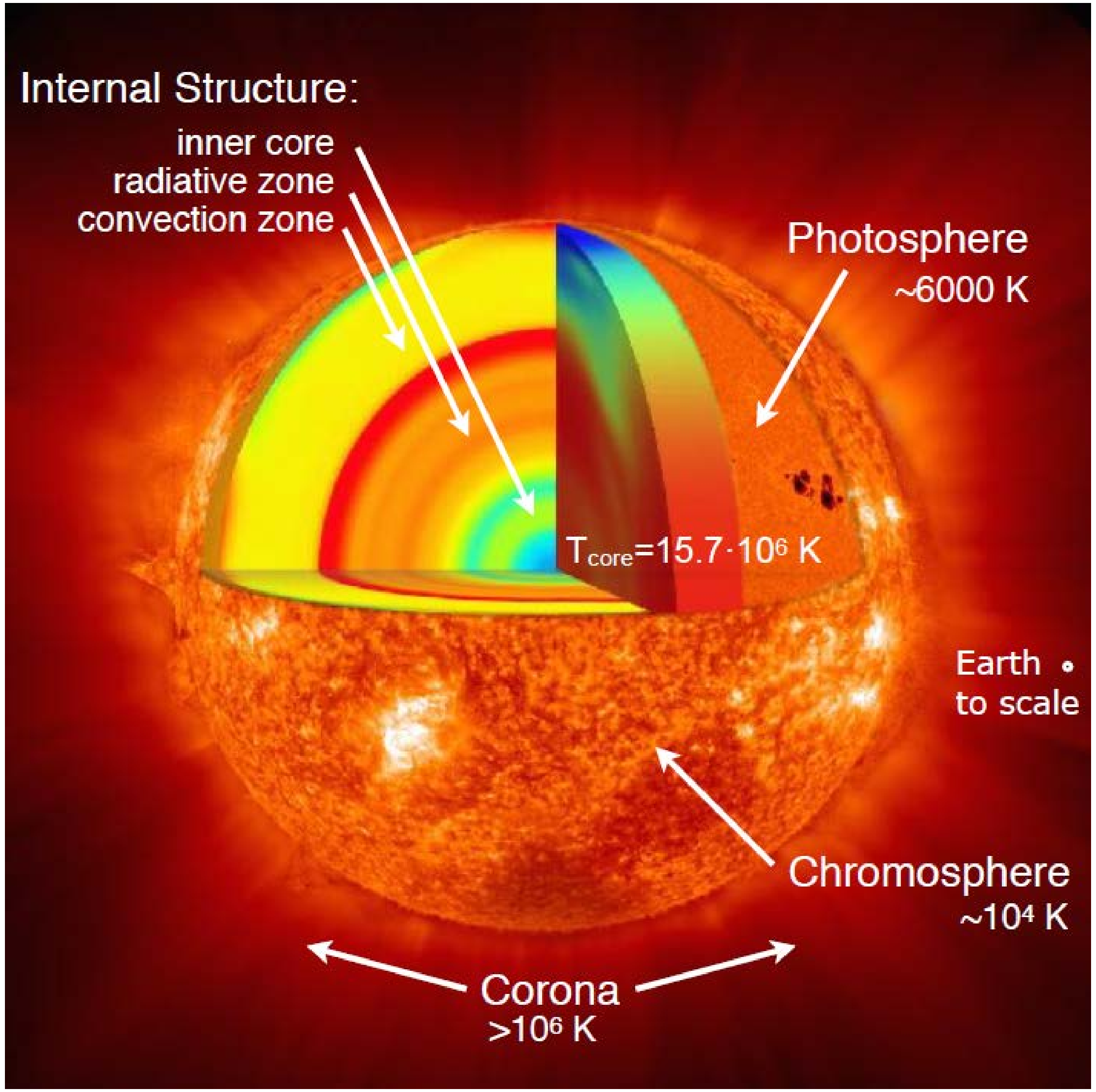
Outline

- The Solar Orbiter mission
- The payload complement
- Development constraints
- Environmental testing

Solar Orbiter science objectives

- Exploring the Sun-Heliosphere Connection
- First medium-class mission of ESA's Cosmic Vision 2015-2025 programme, implemented jointly with NASA
- Dedicated payload of 10 remote-sensing and in-situ instruments measuring from the photosphere into the solar wind



<u>**Overarching Science Question:**</u>

How does the Sun create and control the Heliosphere – and why does solar activity change with time?

Science objectives

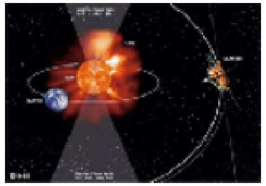
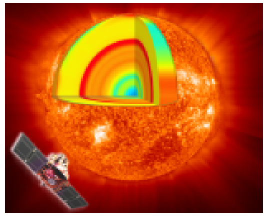
- Solar Orbiter addresses central questions concerning our Sun:
  - How does the Sun create and control the heliosphere?
  - What drives the solar wind?
  - Why does solar activity change over time?

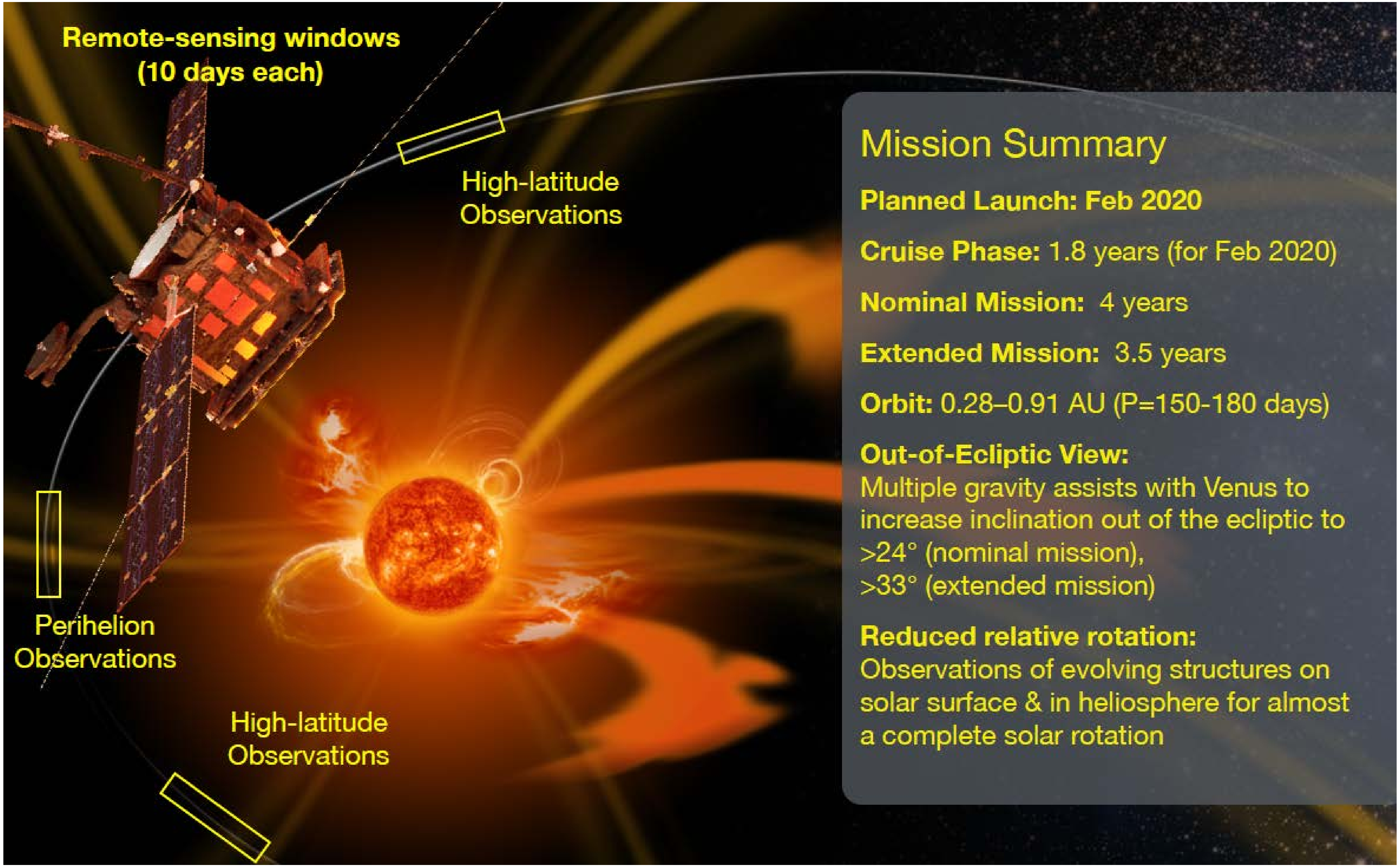
- Closest approach 0.28 AU (42 million km – within the orbit of Mercury) – **closest-ever images and following features at the surface**

- Later in the mission, orbit change to a highly inclined orbit (up to 32° of solar latitude) – **first images of the poles**

- Unique combination of in-situ and remote-sensing instruments – **correlate what we see and what we measure**

Past solar and heliospheric missions

	ESA-NASA	NASA	JAXA	ISRO
	Ulysses (1990 – 2009)		Yohkoh (1991 – 2001)	
	SOHO (1995 – today)			
		TRACE (1998 – 2010)		
		RHESSI (2002 – today)		
		STEREO (2006 – today)	Hinode (2006 – today)	
		SDO (2010 – today)		
	Solar Orbiter (2020)	Parker Solar Probe (2018)		Aditya-L1 (2020?)



Mission Summary

Planned Launch: Feb 2020

Cruise Phase: 1.8 years (for Feb 2020)

Nominal Mission: 4 years

Extended Mission: 3.5 years

Orbit: 0.28–0.91 AU (P=150-180 days)

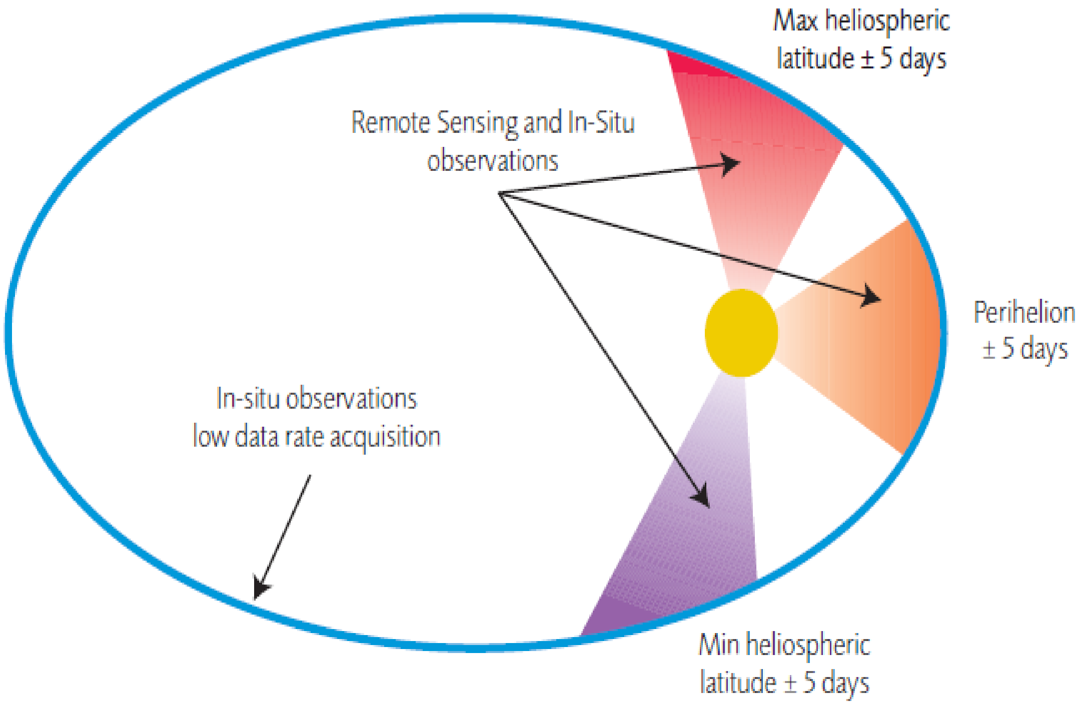
Out-of-Ecliptic View:
Multiple gravity assists with Venus to increase inclination out of the ecliptic to
>24° (nominal mission),
>33° (extended mission)

Reduced relative rotation:
Observations of evolving structures on solar surface & in heliosphere for almost a complete solar rotation

Concept of operations

- Nominally sun pointing, with possibility to point at the limb for off-limb observations

- Telemetry-constrained
  - In-situ data continuously acquired
  - Remote-sensing operations planned in three 10-day Remote Sensing Windows per orbit
  - Planning cycles (long-term to very-short-term)
  - Inter-instrument communication capability on board

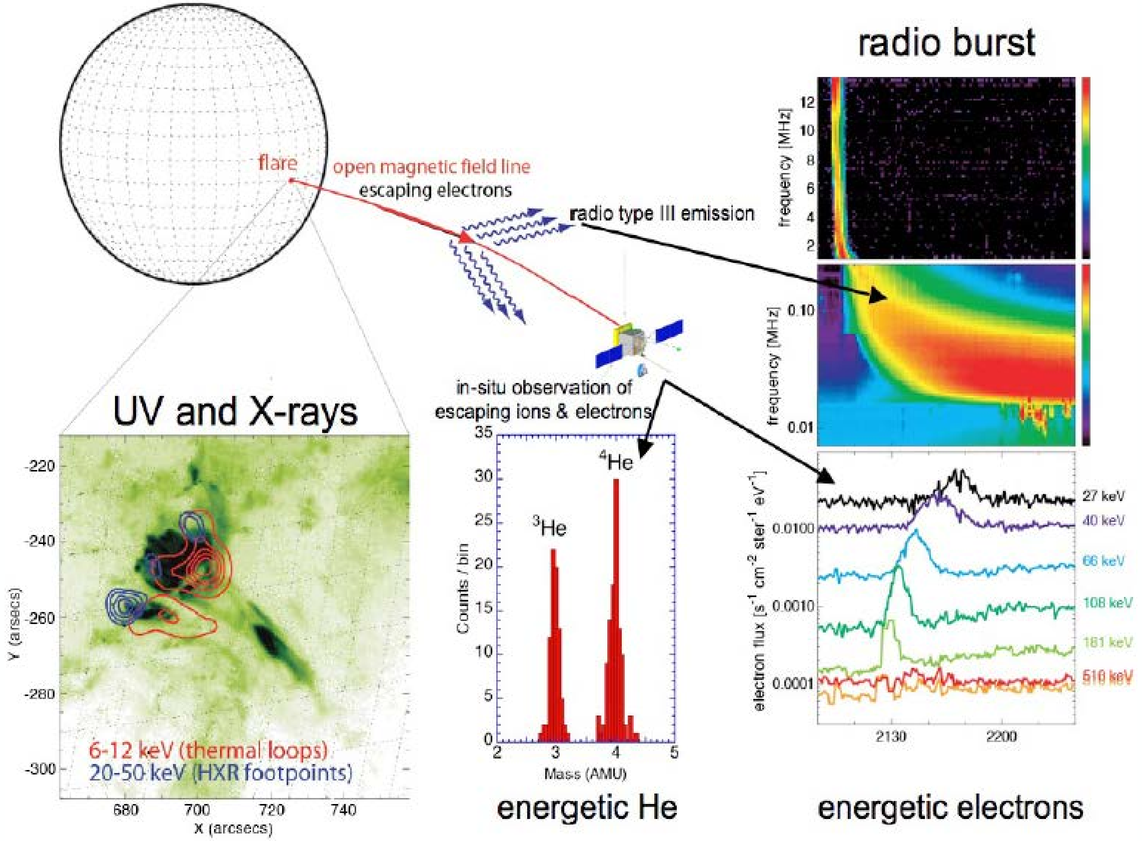


Definition of the payload complement

Solar Orbiter is a mission designed to observe the Sun and the heliosphere, and link heliospheric phenomena back to their sources on the Sun.

- In-situ measurements of the solar wind plasma, fields, waves (SWA, MAG, RPW) and energetic particles (EPD)

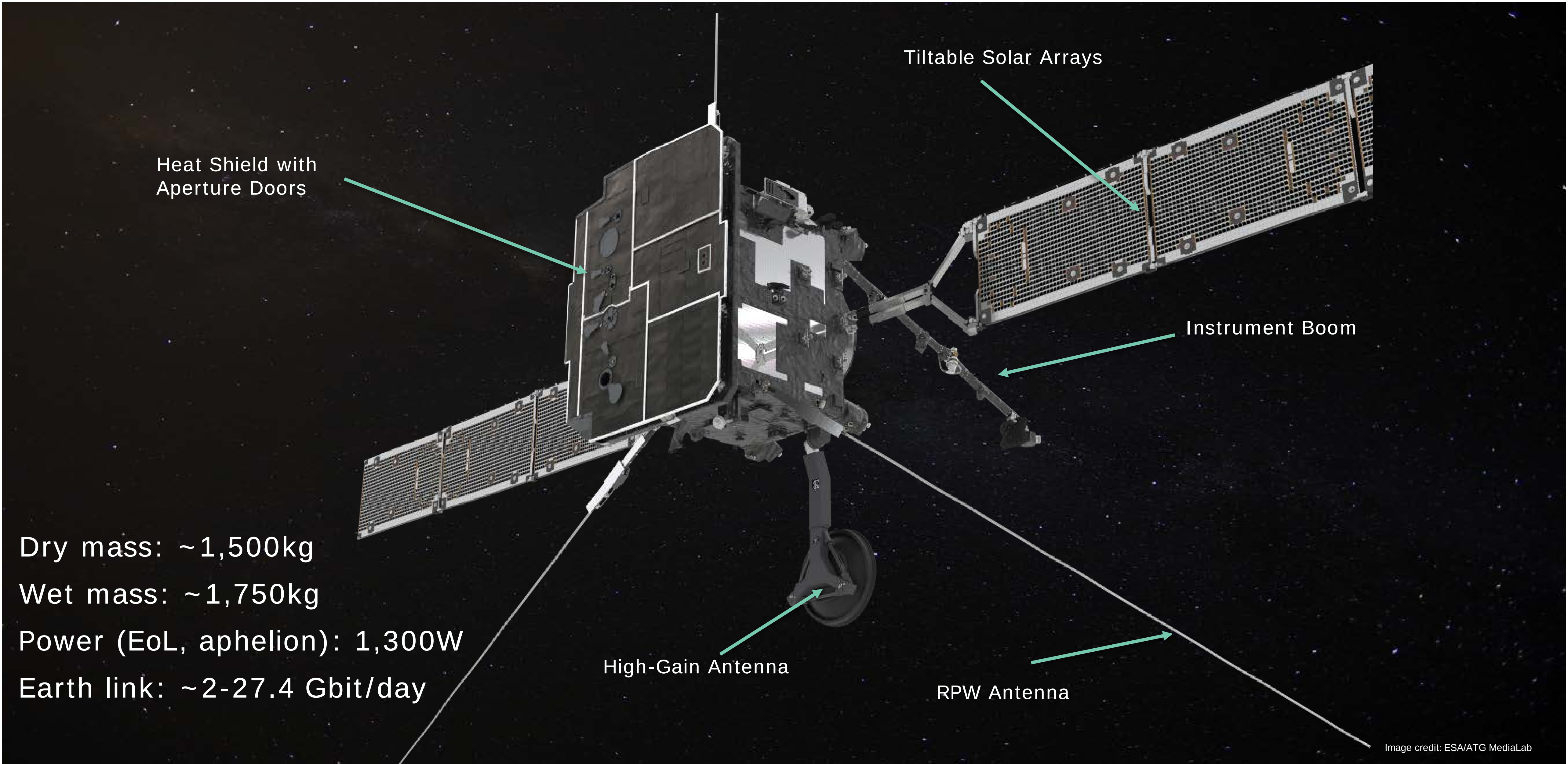
- Remote-sensing measurements
  - Simultaneous high-resolution images and spectra (EUI, SPICE, PHI)
  - Vector magnetic field of solar photosphere (PHI)
  - Full-disk imaging in visible, UV, X-rays (PHI, EUI, STIX)
  - Coronal imaging (METIS, SoloHI)



The Solar Orbiter Instruments

In-Situ Instruments			
EPD	Energetic Particle Detector	J. Rodríguez-Pacheco	Composition, timing and distribution functions of energetic particles
MAG	Magnetometer	T. Horbury	High-precision measurements of the heliospheric magnetic field
RPW	Radio & Plasma Waves	M. Maksimovic	Electromagnetic and electrostatic waves, magnetic and electric fields at high time resolution
SWA	Solar Wind Analyser	C. Owen	Sampling protons, electrons and heavy ions in the solar wind
Remote-Sensing Instruments			
EUI	Extreme Ultraviolet Imager	P. Rochus	High-resolution and full-disk (E)UV imaging of the on-disk corona
METIS	Coronagraph	M. Romoli	Visible and UV Imaging of the off-disk corona
PHI	Polarimetric & Helioseismic Imager	S. Solanki	High-resolution vector magnetic field, line-of-sight velocity in photosphere, visible imaging
SoloHI	Heliospheric Imager	R. Howard	Wide-field visible imaging of the solar off-disk corona
SPICE	Spectral Imaging of the Coronal Environment	ESA facility instrument	EUV imaging spectroscopy of the solar disk and near-Sun corona
STIX	Spectrometer/Telescope for Imaging X-rays	S. Krucker	Imaging spectroscopy of solar X-ray emission

Spacecraft overview



Dry mass: ~1,500kg

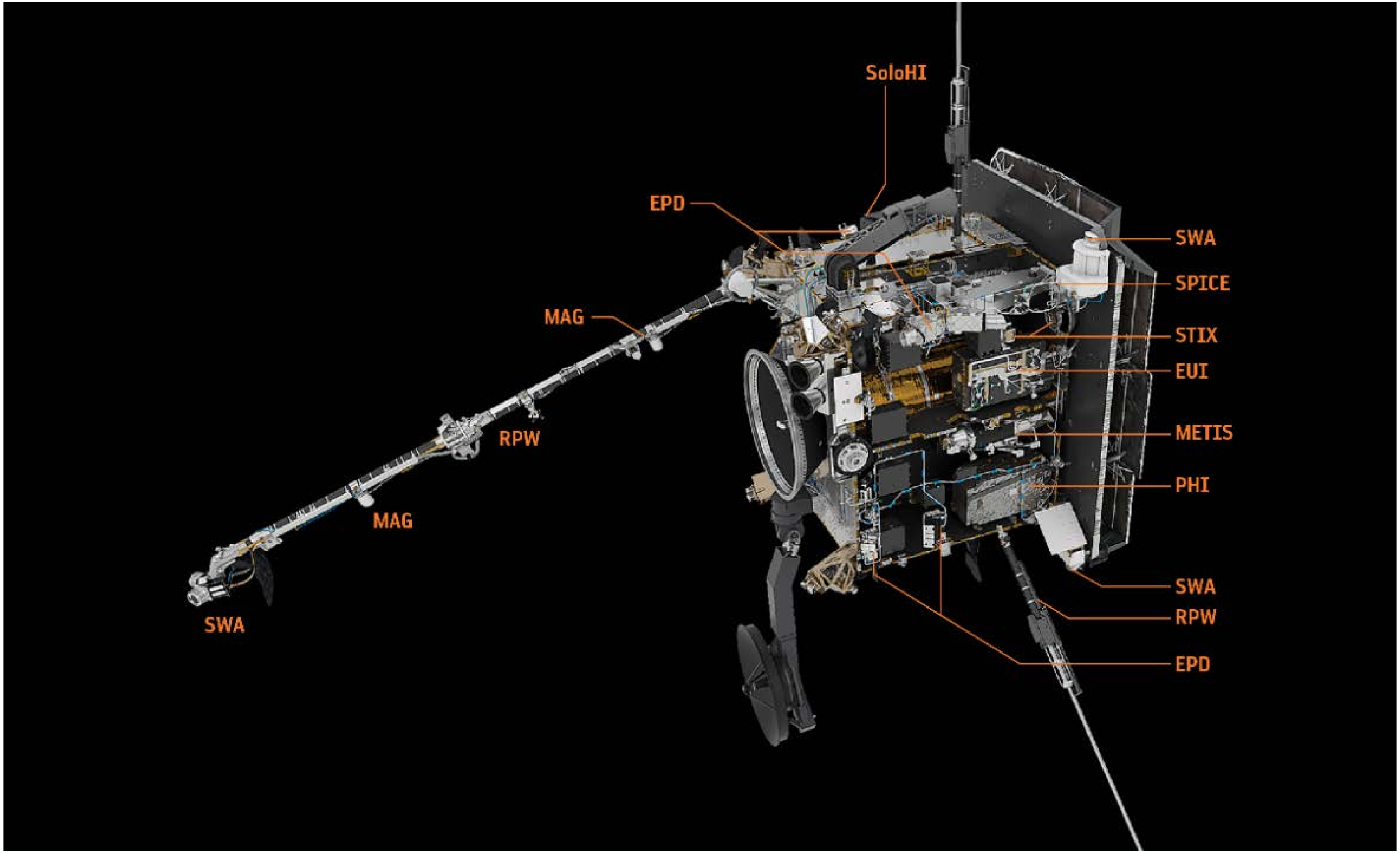
Wet mass: ~1,750kg

Power (EoL, aphelion): 1,300W

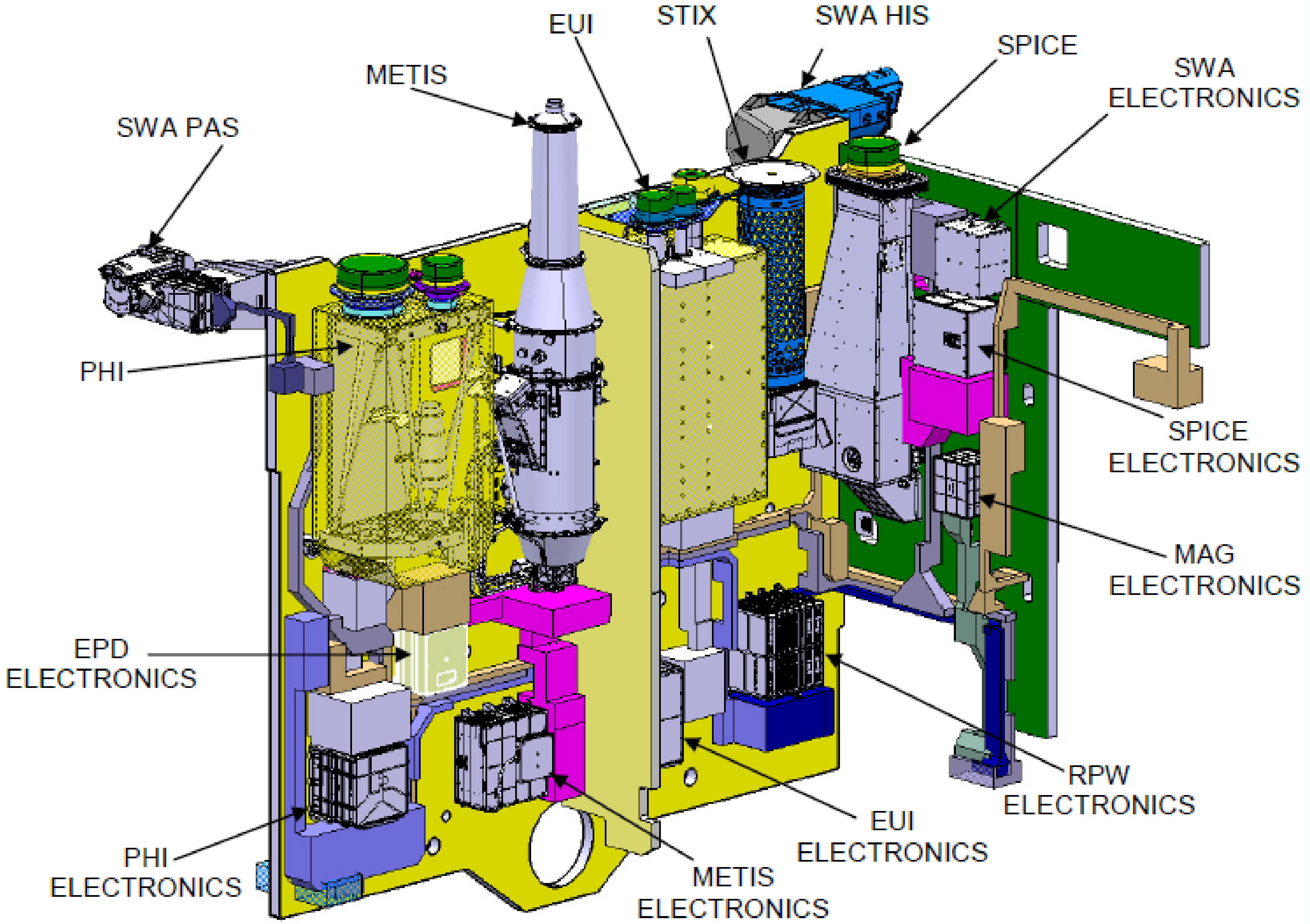
Earth link: ~2-27.4 Gbit/day

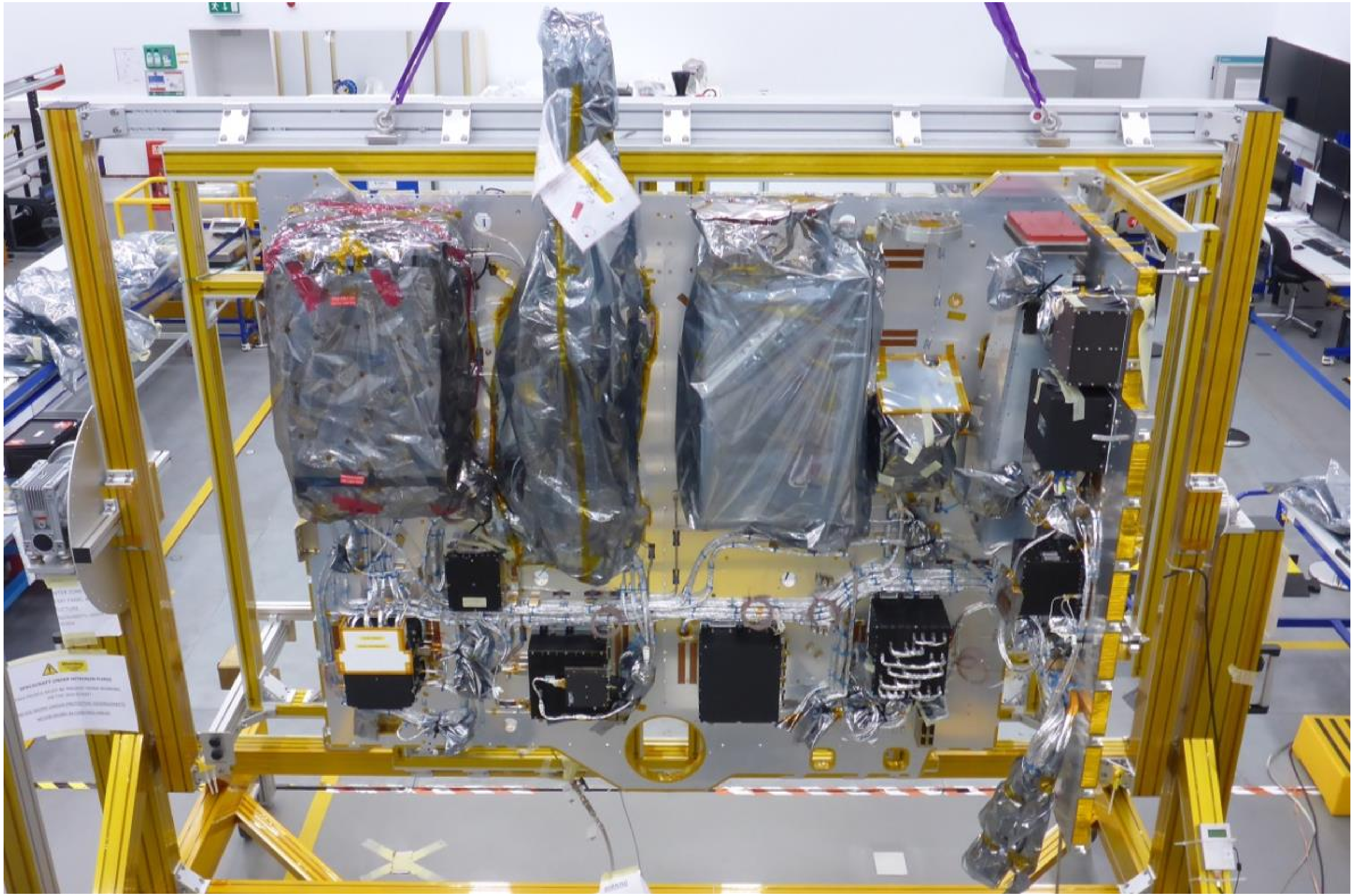
Image credit: ESA/ATG MediaLab


AIRBUS


SoloHI
EPD
SWA
SPICE
STIX
EUI
METIS
PHI
SWA
RPW
EPD
MAG
RPW
MAG
SWA

Instruments accommodation

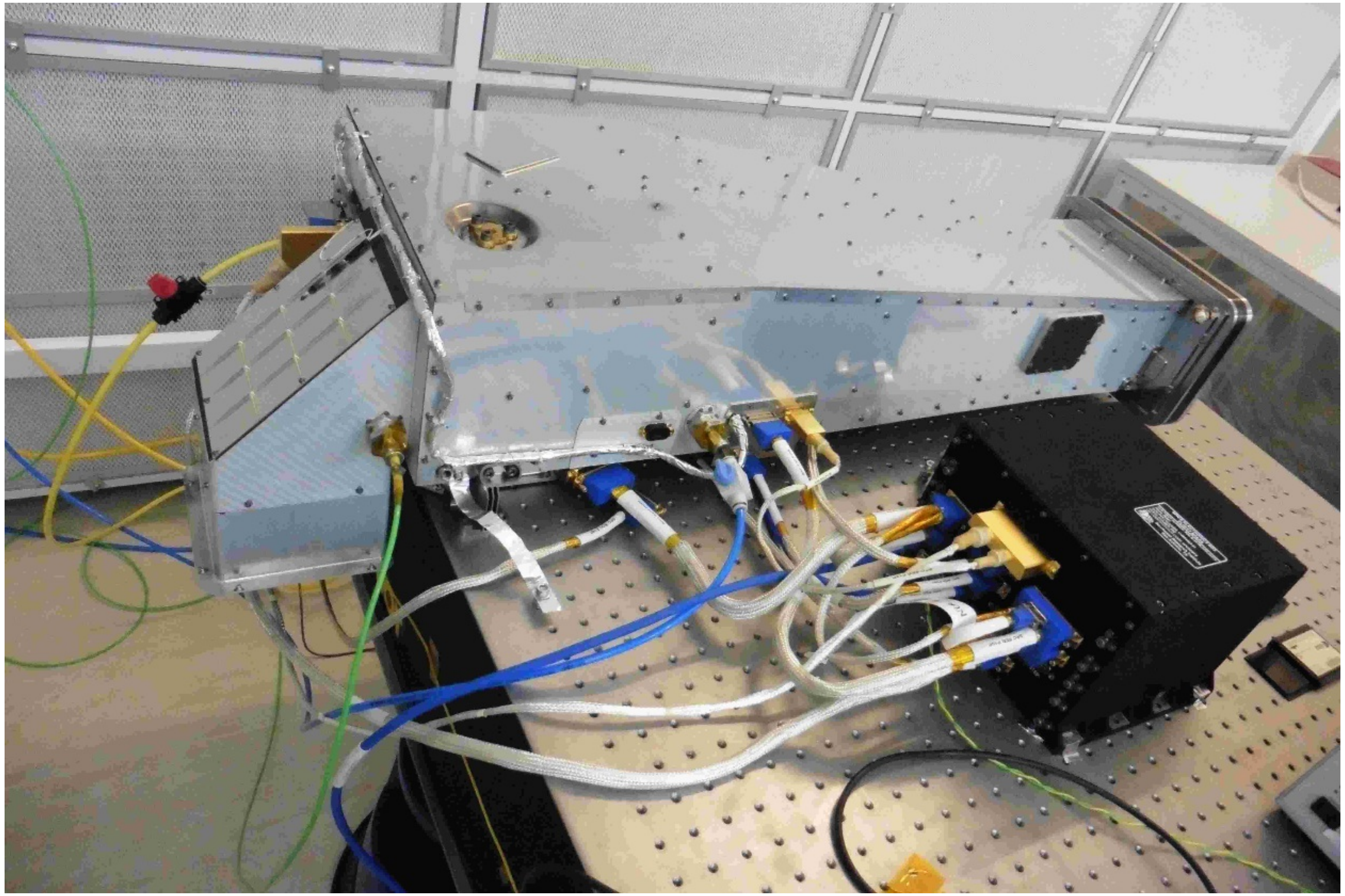


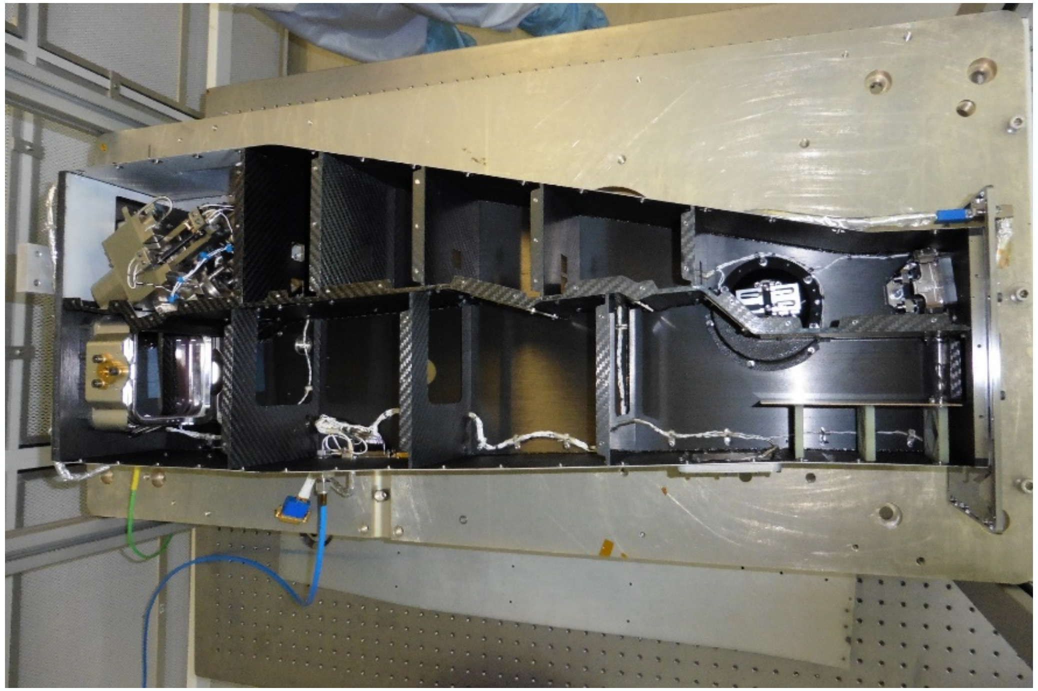


Development constraints (1/2)

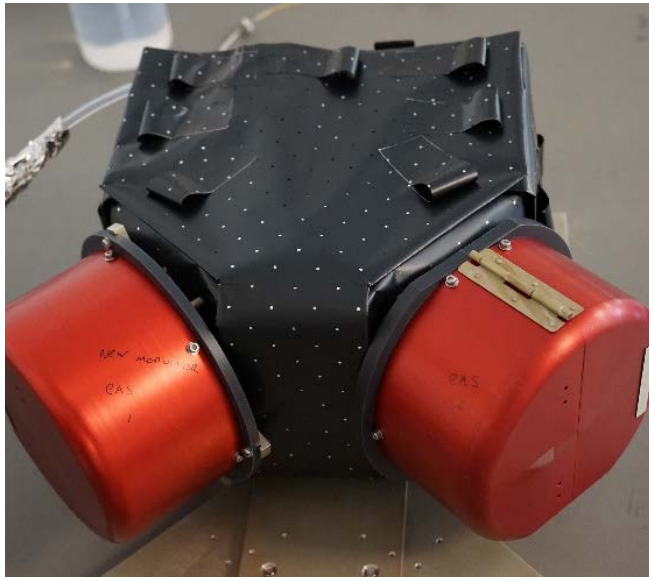
Accommodation constraints:

- ❑ Mass: 210kg for the whole payload complement
- ❑ Power: 245W for the whole payload complement
- ❑ Data: constraints on data rate, on data storage and on data downlink
- ❑ EMC: constraints on emission (conducted and radiated) and charging
- ❑ Cleanliness (molecular and particulate): constraints on materials selection



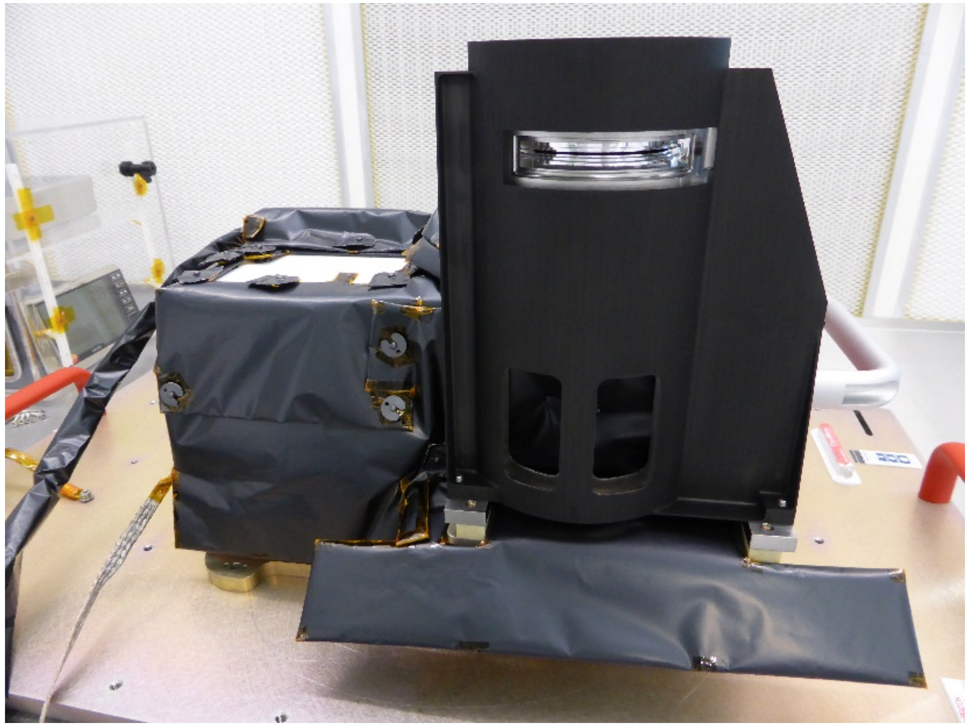


SPICE high-resolution imaging spectrometer at extreme ultraviolet (EUV) wavelengths: 25 kg, 30 W

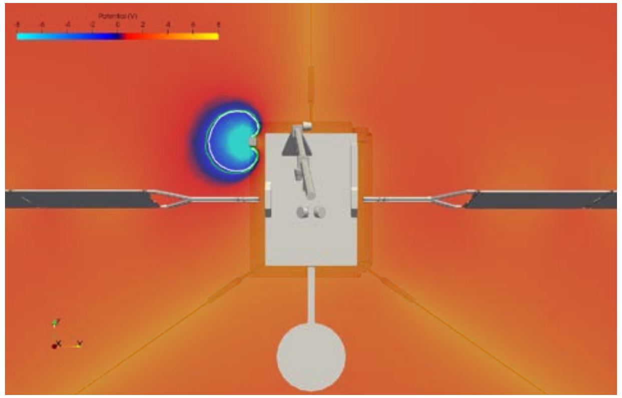


SWA-EAS: Electron analyser
<6 kg
11W (+heating power)

SWA-PAS: Proton-Alpha sensor
<5kg
5 W (+heating power)



Development constraints (2/2)



Examples of conflicting requirements:

- ❑ In-Situ versus Remote-Sensing instruments
    - ➢ In-situ instruments needs magnetic cleanliness and stringent requirements on surface charging;
    - ➢ Remote-Sensing instruments generally use mechanisms and need fine pointing (→ reaction wheels); they have non-conductive optical elements and coatings…
    - ➢ Possible Solutions: careful choice of motors, magnetic shielding, special coatings development

- ❑ Verification of single point failure elements by test, versus cleanliness (e.g. SoloHI and METIS instruments on Solar Orbiter)
    - ➢ Protective doors used to protect sensitive surfaces from molecular and particulate contamination
    - ➢ Possible Solution: plan for tests in “clean tents”

Environmental testing

❑The goal of the environmental tests is to submit the units to the mechanical and thermal loads that will be experienced during launch and in orbit:

➢Sine vibration

➢Acoustic

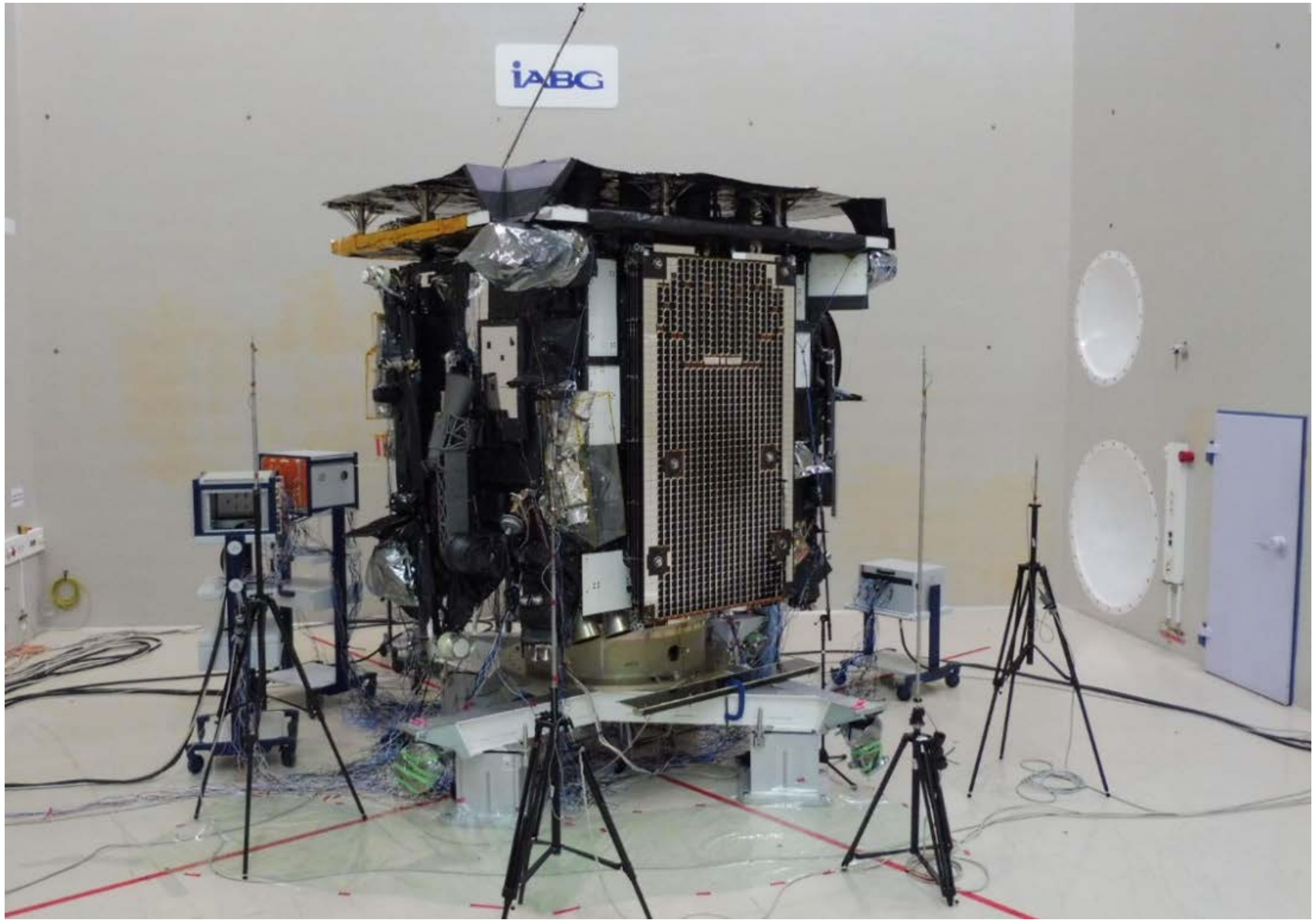
➢Shock

➢Thermal vacuum

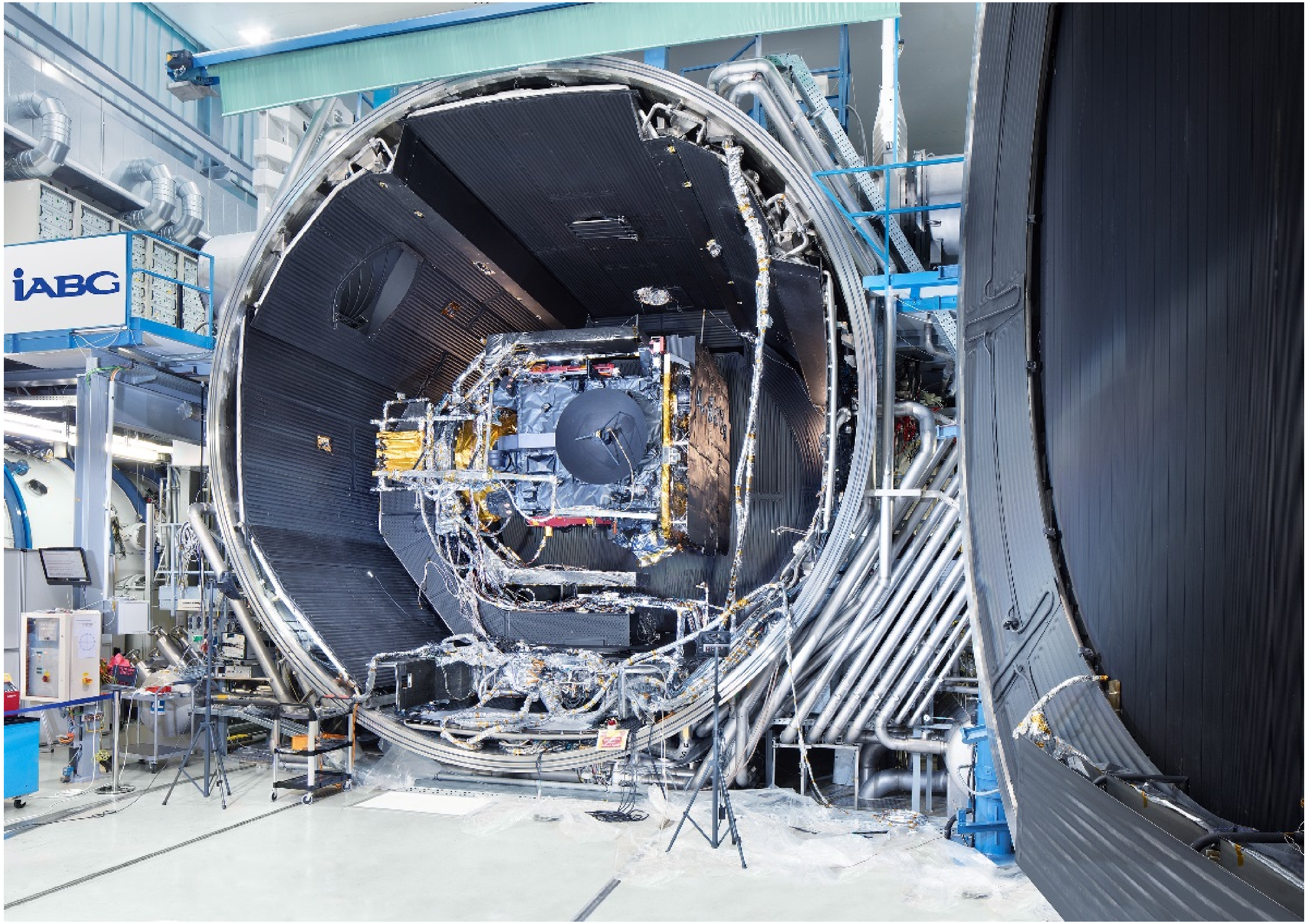
❑The tests are done at unit (instrument) level, then at system (spacecraft) level.

❑There are qualification tests (e.g. on Structural and Thermal model) and acceptance tests (on the Flight model)

©ESA-Corvaja, (credit Airbus/IABG), at IABG space test centre



© IABG, ready for vibro-acoustic test (credit ESA/Airbus/IABG)



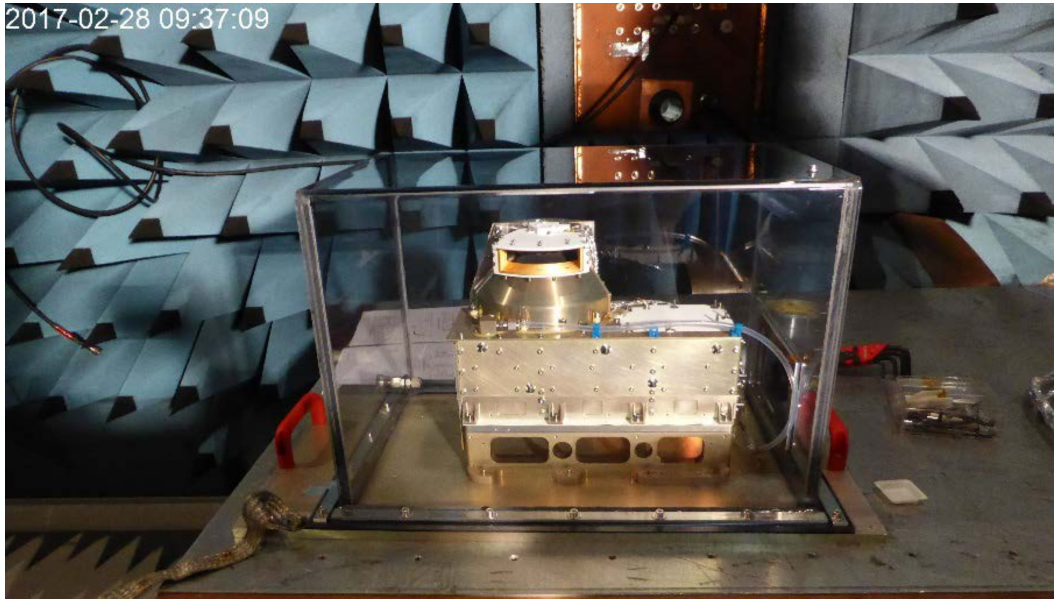
Thermal tests in high vacuum:

- ❑ Sun simulation
- ❑ Temperature changes (cycles)

© IABG, SolO in TVTB chamber (credit ESA/Airbus/IABG)

Other testing

- ❑Deployment tests
- ❑Electromagnetic Compatibility (EMC)
- ❑Magnetics (depending on the mission)
- ❑Functional verification

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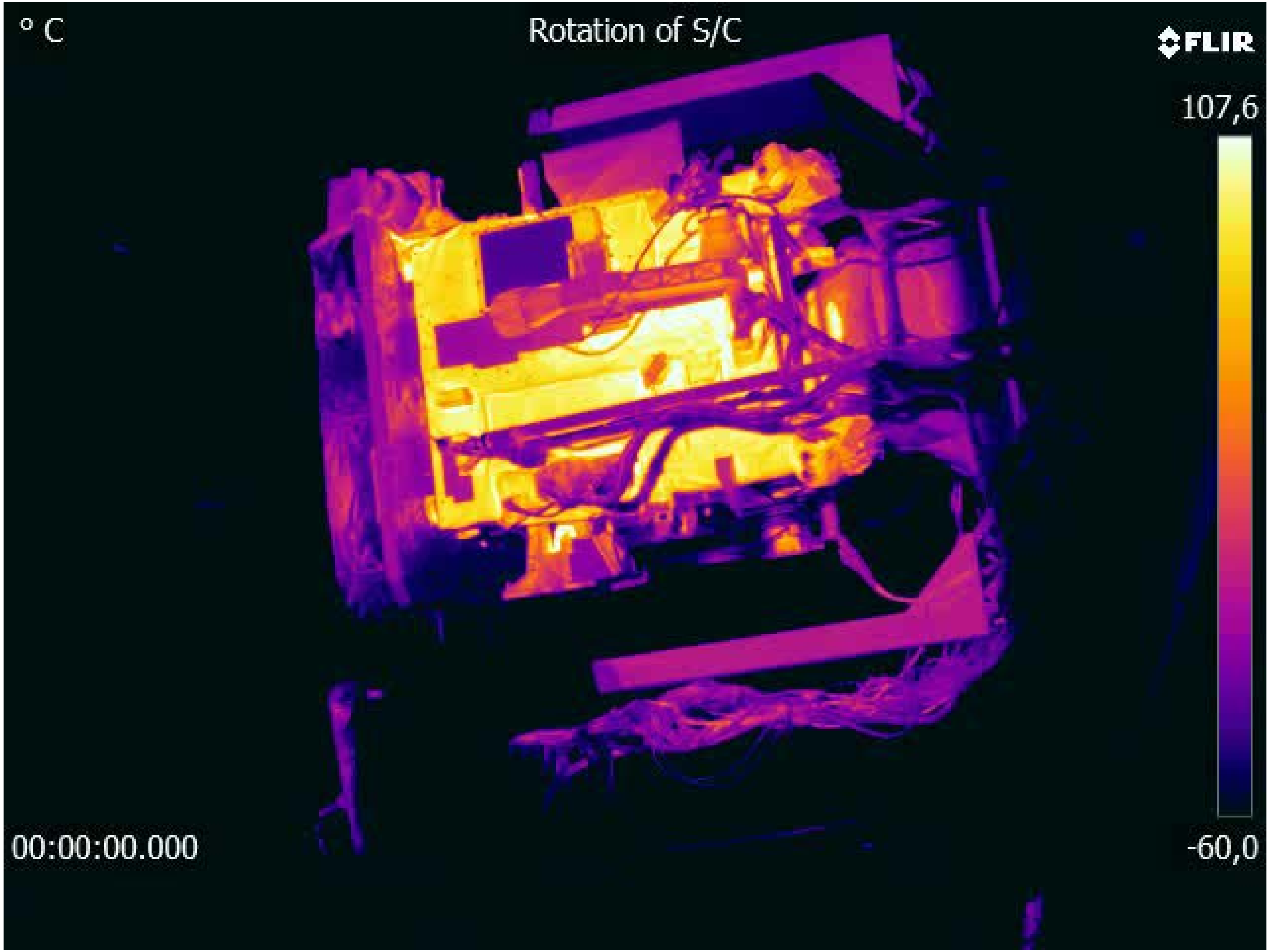
° C
Rotation of S/C
FLIR
107,6
00:00:00.000
-60,0

Our rocket: Atlas 5 , version “411”

- 2 stages
- 1 booster

- Fairing of 4 meters diameter
- 58 m high in total
- Approximately 400 ton *at the beginning! (while Solar Orbiter is just 1.8 ton)*


ASTROTECH
SPACE OPERATIONS
W
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NASA
esa


NASA
esa
solar orbiter
OVERSIZE LOAD


WIDE LOAD

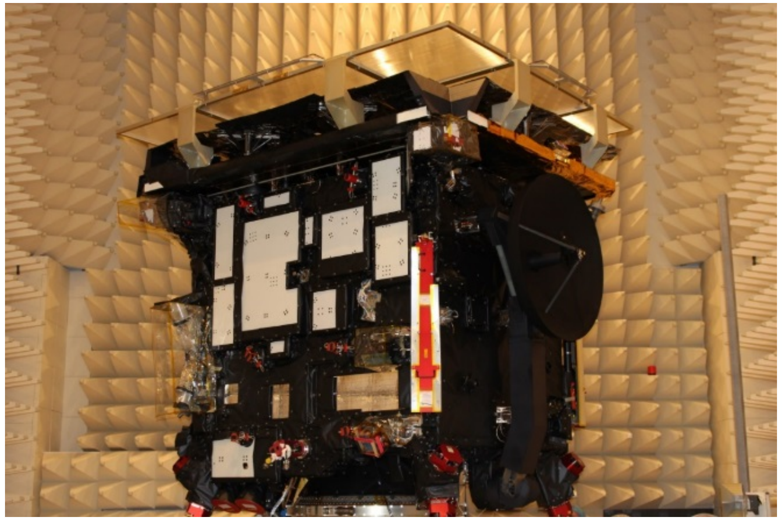

esa

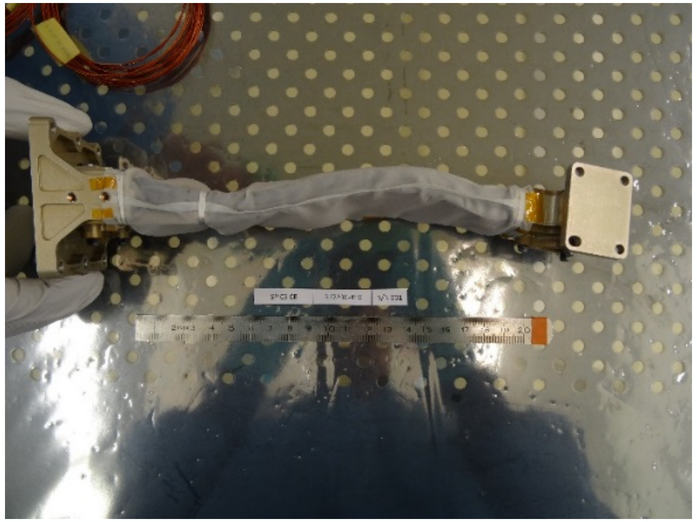
NASA
ULA
-00:00:30
HOUR MINUTE SECOND

Backup slides

Engineering challenges: thermal

- ❑ Heat shield:
  - ➢ SolarBlack coating
  - ➢ 40 cm thick (high-T MLI, star brackets, low-T MLI)
  - ➢ Surface temperature between -200° C and +520° C
- ❑ SORA radiators and thermal straps
  - ➢ Stand-off from main structure to limit TED
  - ➢ Pyrolitic graphite: very high conductivity (1 W/K) for very low structural stiffness



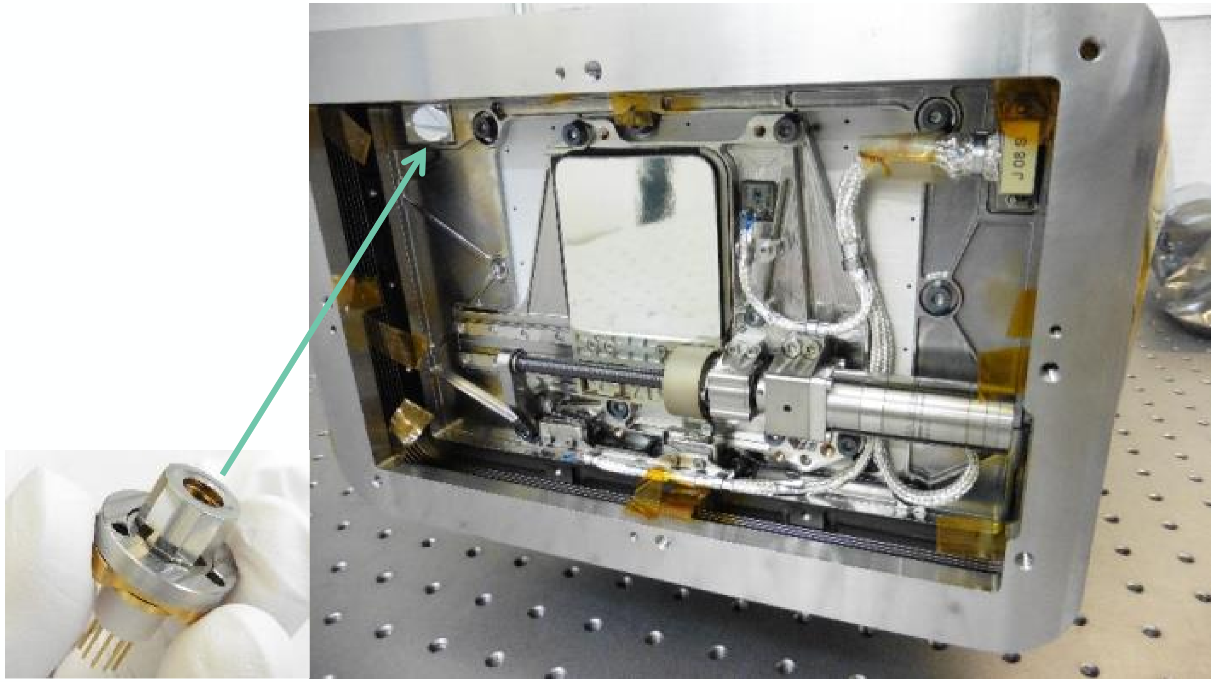


Engineering challenges: EMC, magnetic cleanliness and charging

- ❑ Specific design of electronic boards to minimize EMC emissions (and definition of EMC-quiet operations)
- ❑ Selection of non-magnetic materials
- ❑ Shielding of magnetic components
- ❑ Harness layout to avoid creating current loops
- ❑ Ensuring conductivity of all external surfaces

Engineering challenges: contamination control

- ❑Stringent requirements on molecular contamination (UV instruments) and particulate contamination (coronograph and high-voltage instruments)
- ❑Mitigations:
  - ➢ Selection of low-outgassing materials and systematic bake-out
  - ➢ Purge system with high purity nitrogen
  - ➢ Monitoring during Spacecraft TVAC
  - ➢ Heat shield doors (+Metis cap), instrument doors
  - ➢ Regular inspections and cleaning
- ❑ Extensive modelling of in-flight molecular contamination
- ❑ In-flight measurements by the Contamination Monitoring System (CMS)



CMS-1 on front panel of SPICE

For more information and latest news

ESA general portal:

https://www.esa.int/Science_Exploration/Space_Science/Solar_Orbiter

ESA science portal:

https://sci.esa.int/web/solar-orbiter

Solar orbiter’s journey around the Sun: animation showing the orbital manoeuvres:

http://www.esa.int/spaceinvideos/Videos/2019/10/Solar_Orbiter_s_journey_around_the_Sun

Twitter: @ESASolarOrbiter