The JUICE Spacecraft and its Instrumentation, Overviews ans Challenges

Fabrice Cipriani, Thibaut Prod’homme

With contributions from : Petteri Nieminen, Marco Vuolo, Giovanni Santin, Mika Holmberg, Grégoire Déprez, Olivier Witasse

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Outline

I. Space Environment engineering : Challenges to spacecraft, impact on the design

II. Overview of the Jupiter radiation and plasma environments and of the JUICE mission

III. JUICE design for radiation and plasma related effects mitigation (platform and instruments)

IV. Conclusion and Some Take aways

Space Environment and Effects

- Defines what ***Space Environments*** will the System be exposed to ?

→ Gravity

→ Electro-Magnetic radiation

→ Atmospheres : Mesosphere, Thermosphere, Exosphere

→ Plasmas : Ionosphere, Magnetospheres, interplanetary space, CMEs… etc..

→ Radiation : Radiation Belts (Earth, Jupiter), SEPs, GCRs ..

→ Micrometeorites and Debris

→ Planetary surfaces : regolith, dust

- Defines which detrimental ***Effects*** such environments might produce on Systems and Sub-systems

→ Orbit control / trajectories / operations

→ Thermal, Power budgets

→ Surface materials erosion

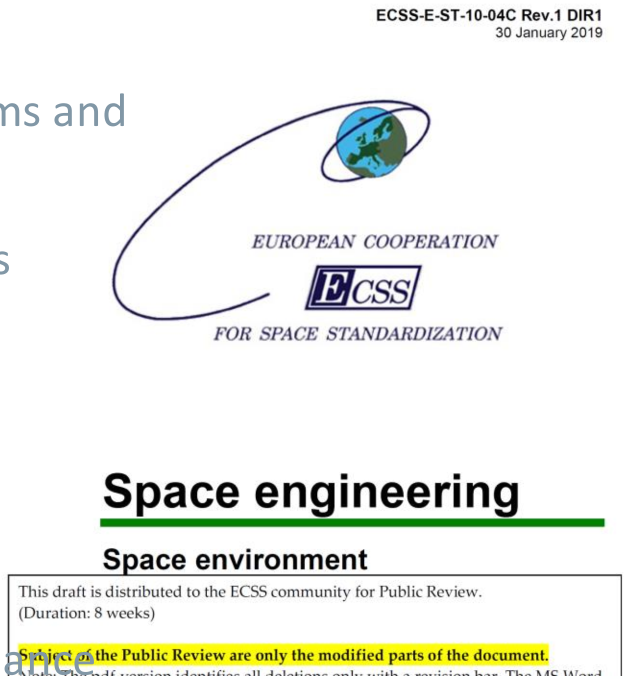
→ Surface Charging, ESDs

→ Deep charging, SEE, SEU, DD

→ Impacts (materials structural / performance degradation..)

→ Landings, contamination

→ …


ECSS-E-ST-10-04C Rev.1 DIR1
30 January 2019

EUROPEAN COOPERATION
ECSS
FOR SPACE STANDARDIZATION

Space engineering

Space environment

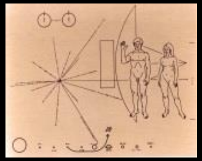
This draft is distributed to the ECSS community for Public Review.
(Duration: 8 weeks)

Subject of the Public Review are only the modified parts of the document.

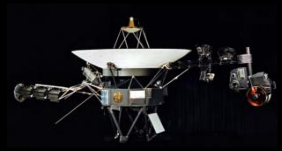
Jupiter System

Archetype for gas giants and potential habitats

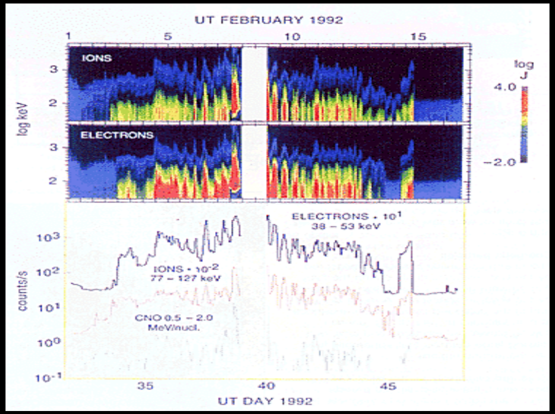
Past and future missions to Jupiter



Pioneer 10 & 11 flybys
(1973, 1974)



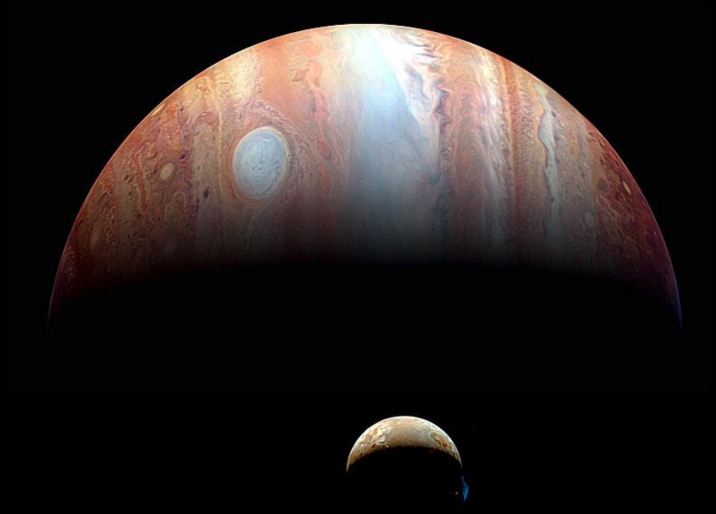
Voyager 1 & 2 fly-bys
(1979)



Ulysses high-inclination manoeuvre (1992)

Europa Clipper

Launch 2024

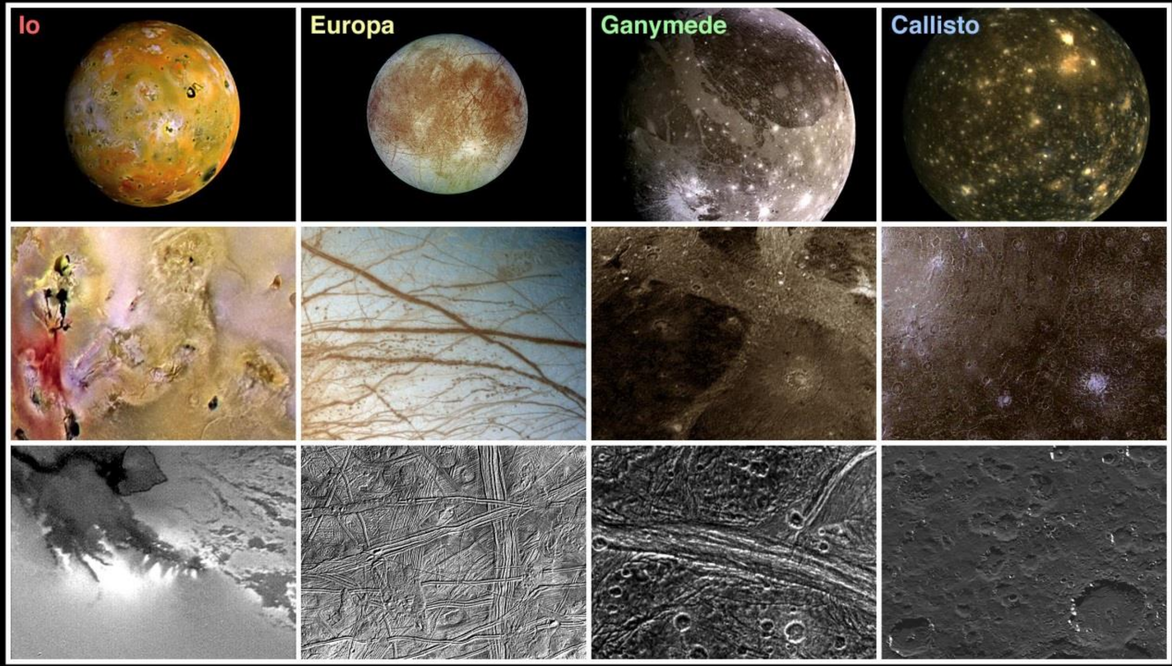


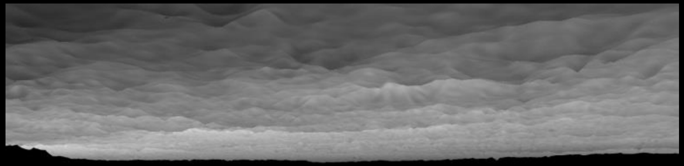
New Horizons fly-by
(2007)

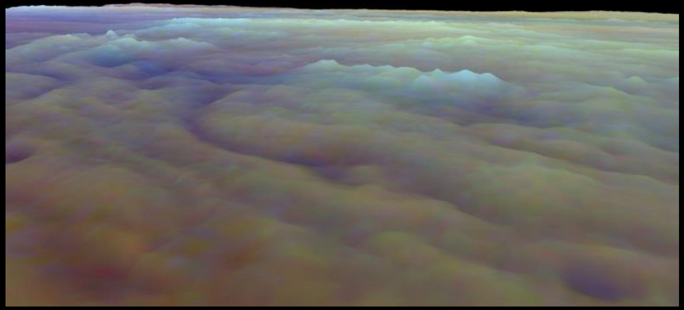
JUNO
(2016)

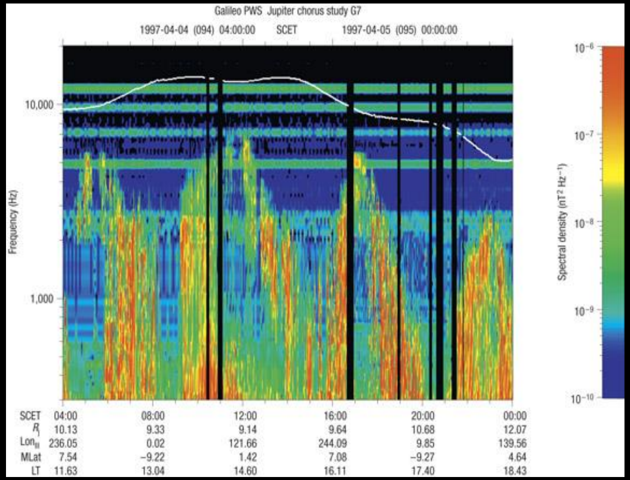
Cassini fly-by (2000)

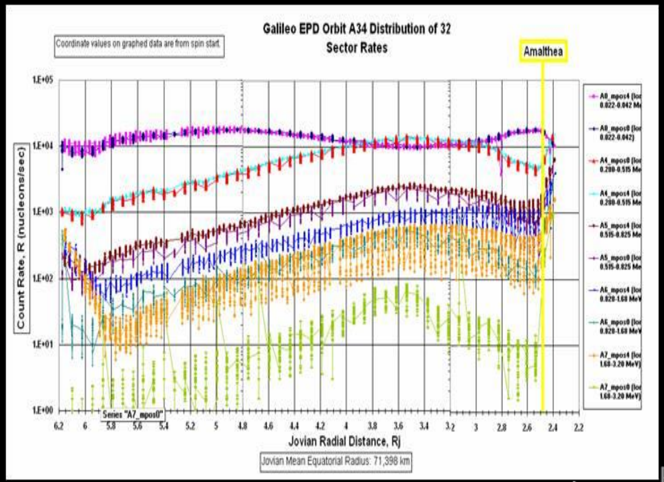
NASA Galileo Orbiter 1995-2003

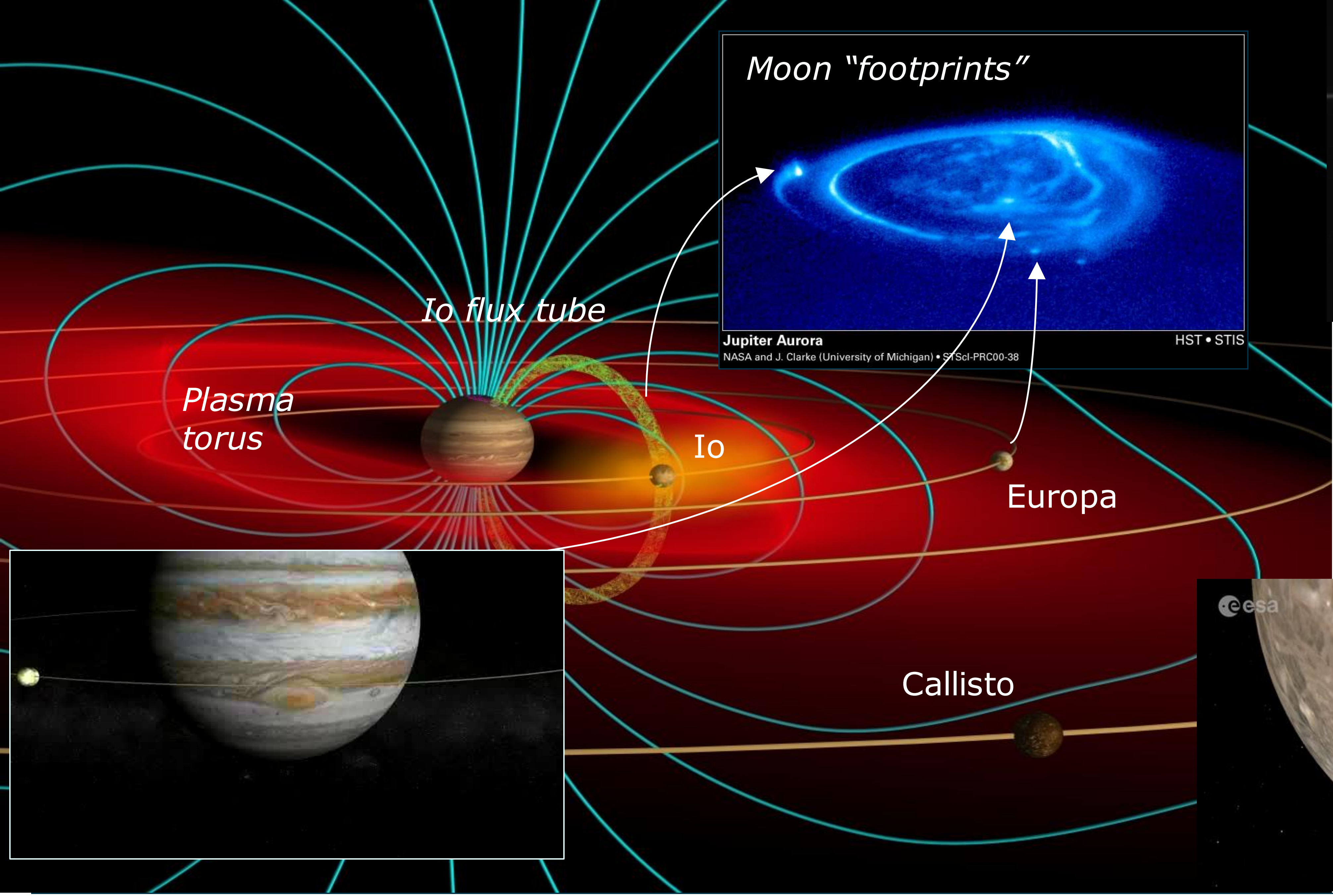


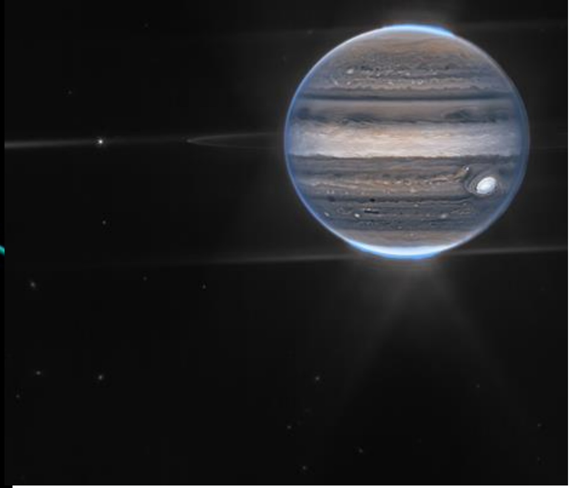




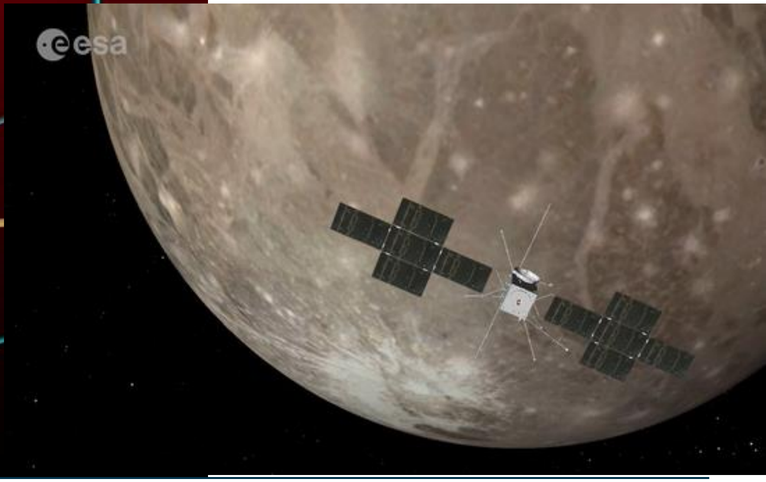




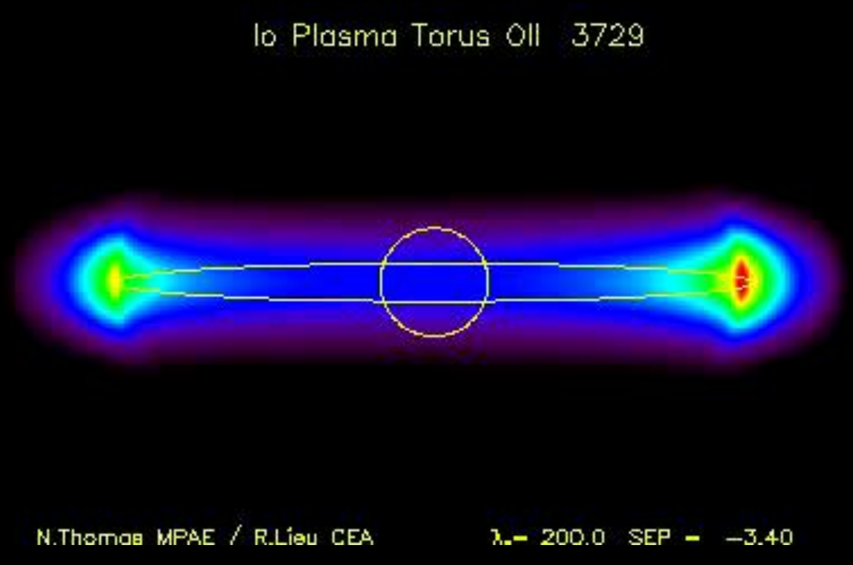


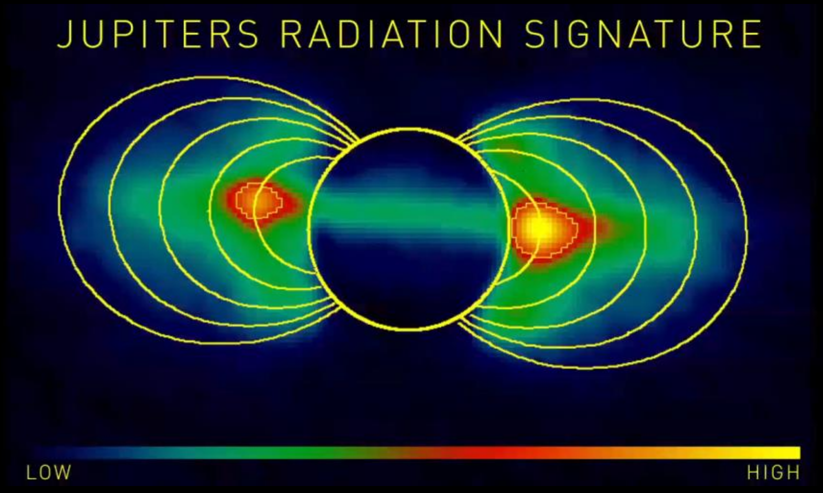


Jupiter's plasma environment



Plasma torus and the radiation belts



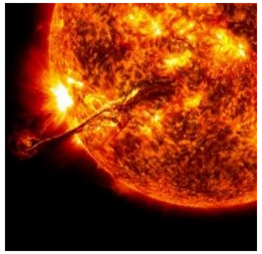


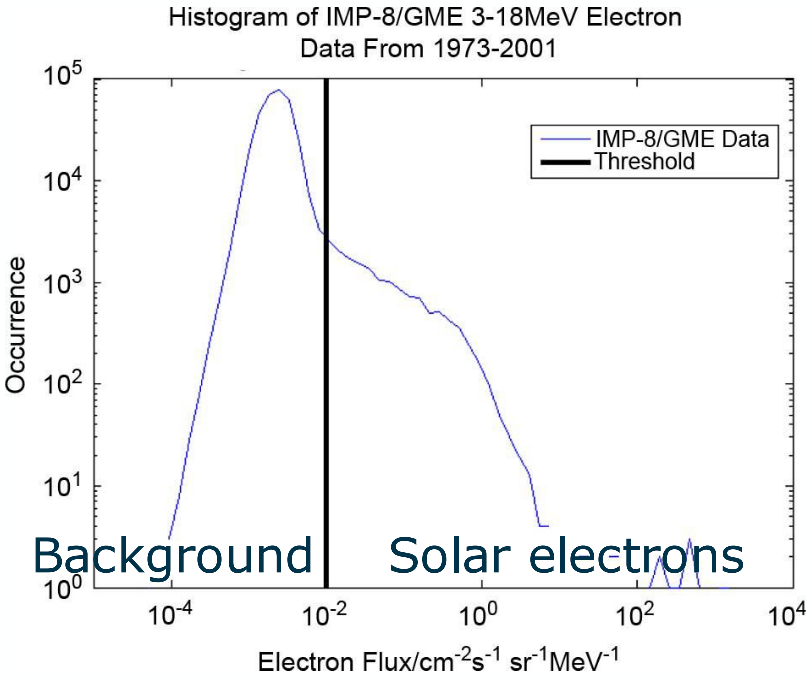
1400 MHz

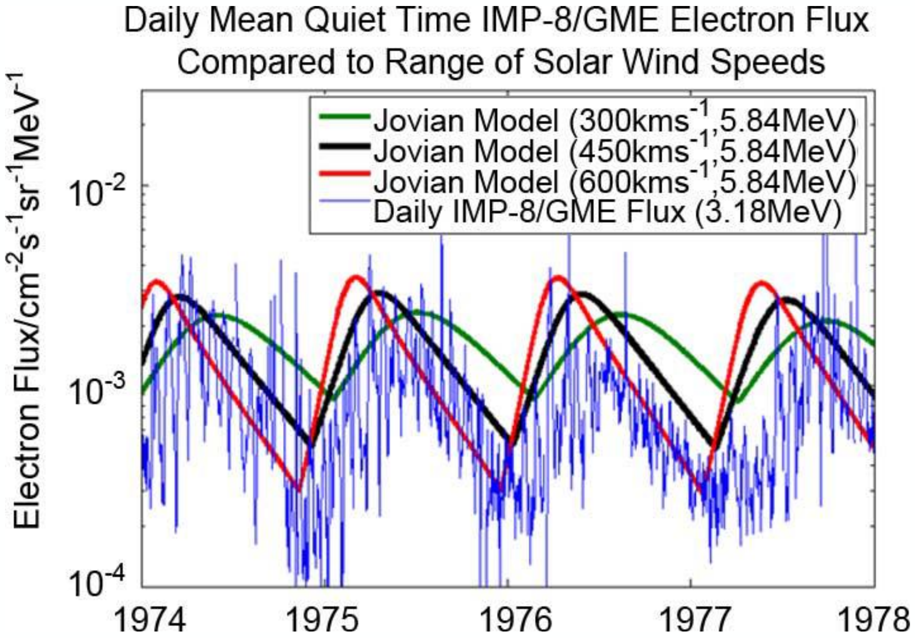
JAXA Sprint-A, launched 14.9 2013

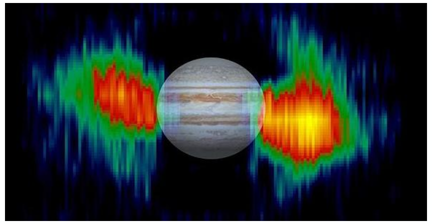
Plasma torus and radiation belts wobble due to 7°tilt between Jupiter rotational and magnetic axes. Jupiter rotational period 9 h 56 min

Interplanetary environment
Solar and Jovian electrons









Taylor, 2011

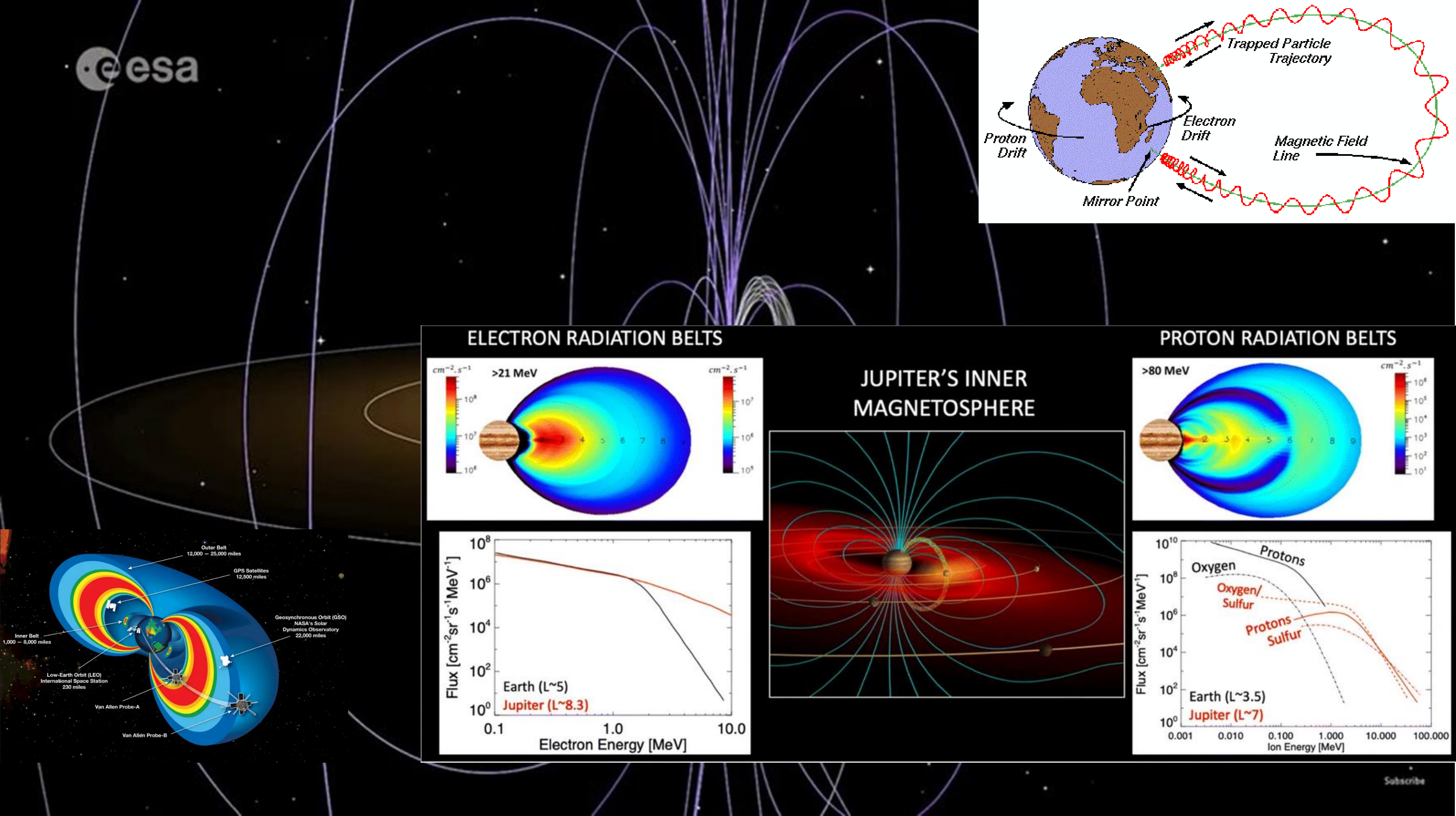
Intermediate energies 0.2-10 MeV

Less damage than protons / ions

Effects: TID after thin shielding, charging, signal noise / contamination

Jupiter radiation belt: primary source of energetic electrons in Heliosphere at solar quiet time

- Accelerated to 10s or 100s MeV
- Leak out of Jovian magnetosphere
- Diffuse in the Heliosphere along magnetic field


esa
Trapped Particle Trajectory
Electron Drift
Proton Drift
Magnetic Field Line
Mirror Point
Outer Belt
12,000 – 25,000 miles
GPS Satellites
12,500 miles
Inner Belt
1,000 – 8,000 miles
Geosynchronous Orbit (GSO)
NASA's Solar
Dynamics Observatory
22,000 miles
Low-Earth Orbit (LEO)
International Space Station
230 miles
Van Allen Probe-A
Van Allen Probe-B
ELECTRON RADIATION BELTS
>21 MeV
JUPITER'S INNER MAGNETOSPHERE
PROTON RADIATION BELTS
>80 MeV
Flux [cm^{-2}sr^{-1}s^{-1}MeV^{-1}]
Earth (L~5)
Jupiter (L~8.3)
Electron Energy [MeV]
Protons
Oxygen
Oxygen/Sulfur
Protons
Sulfur
Earth (L~3.5)
Jupiter (L~7)
Ion Energy [MeV]
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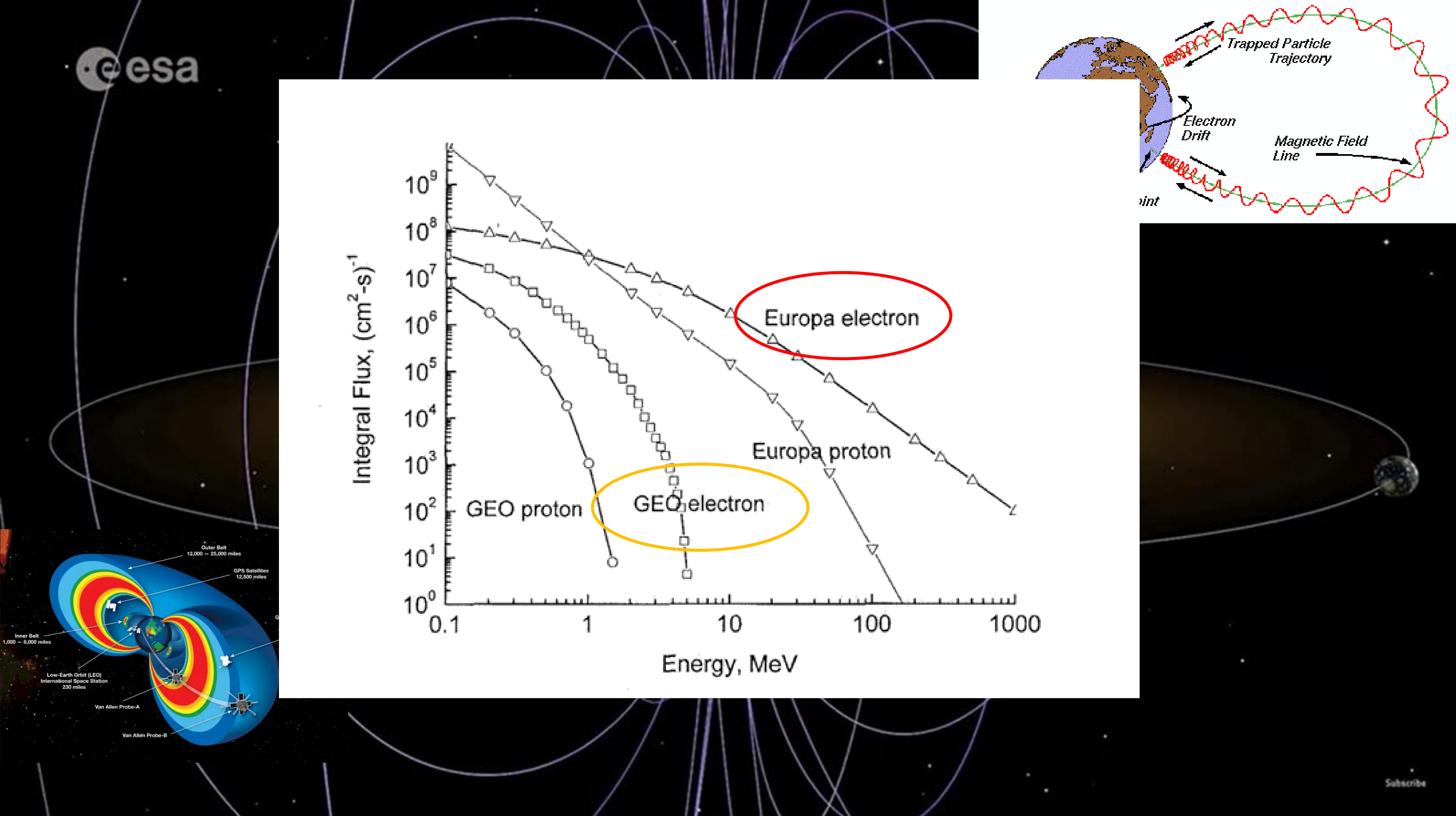

Integral Flux, (cm²-s)⁻¹
10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹
0.1
1
10
100
1000
Energy, MeV
Europa electron
Europa proton
GEO proton
GEO electron
Trapped Particle Trajectory
Electron Drift
Magnetic Field Line
Outer Belt 12,000 – 25,000 miles
GPS Satellites 12,500 miles
Inner Belt 1,000 – 8,000 miles
Low-Earth Orbit (LEO) International Space Station 230 miles
Van Allen Probe-A
Van Allen Probe-B
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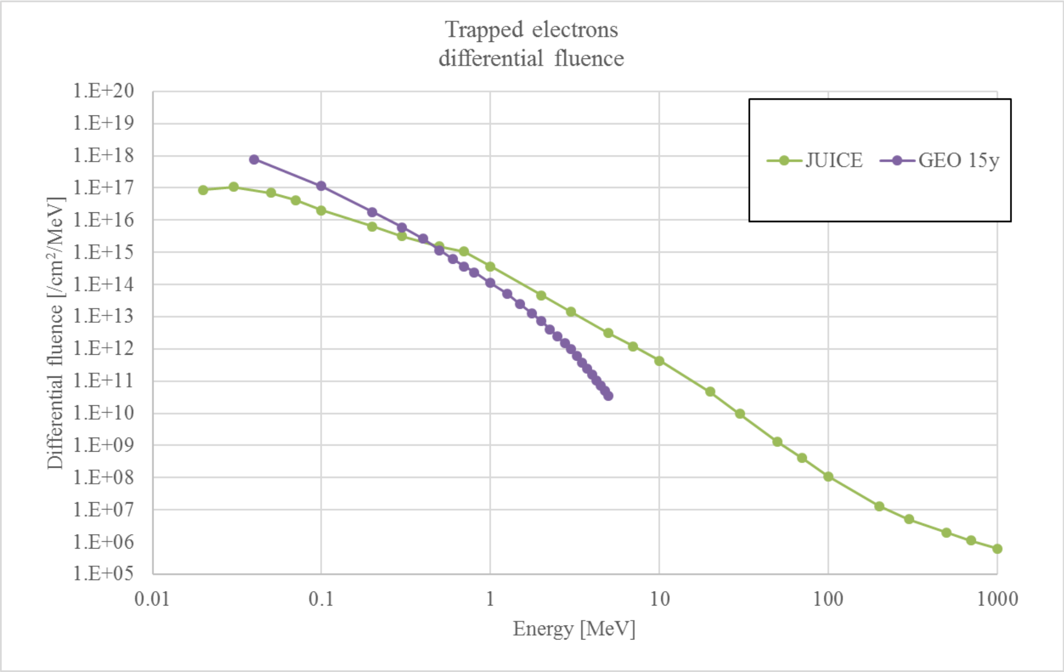
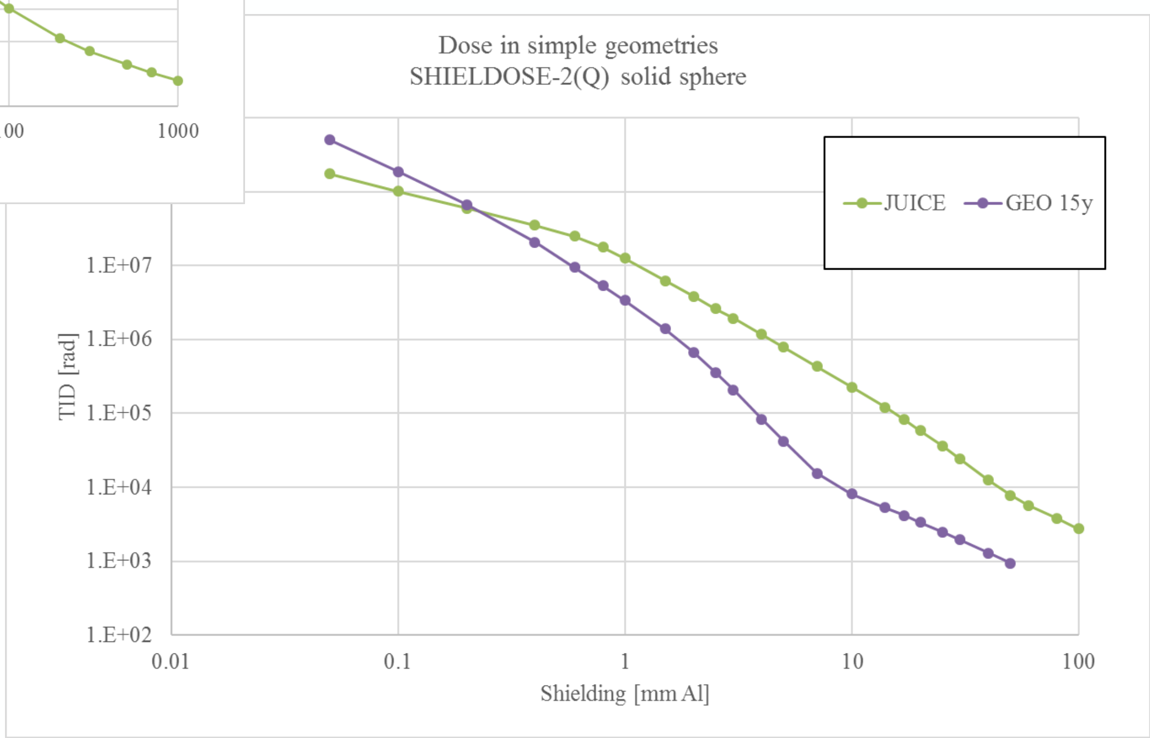
GEO e- fluence from IGE-2006 (UPPER) model

JUICE diff fluence from JUICE specs i5.5

TID for JUICE is the Total SHD-2Q (including protons) also from i5.5

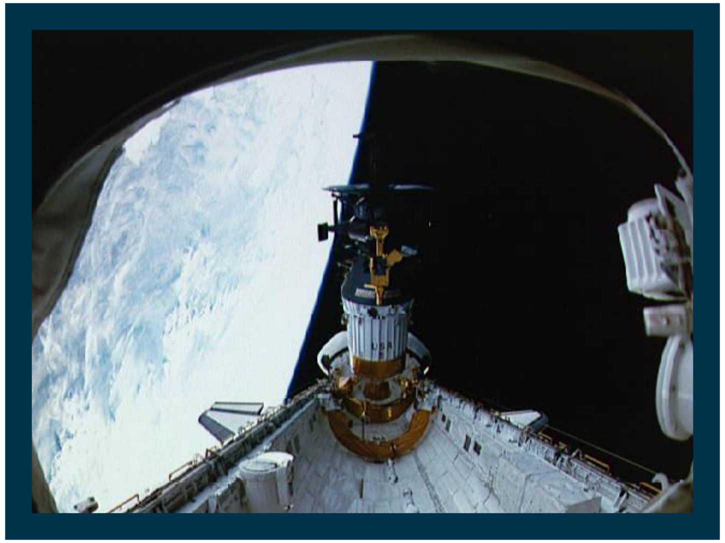


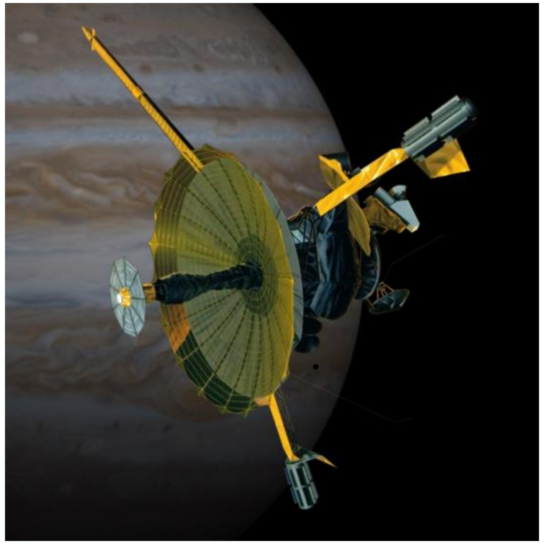


G. Santin, P. Truscott, R. Gaillard, R. Garcia Alia, "Radiation environments: space, avionics, ground and below", RADECS 2017 Short Course Notes

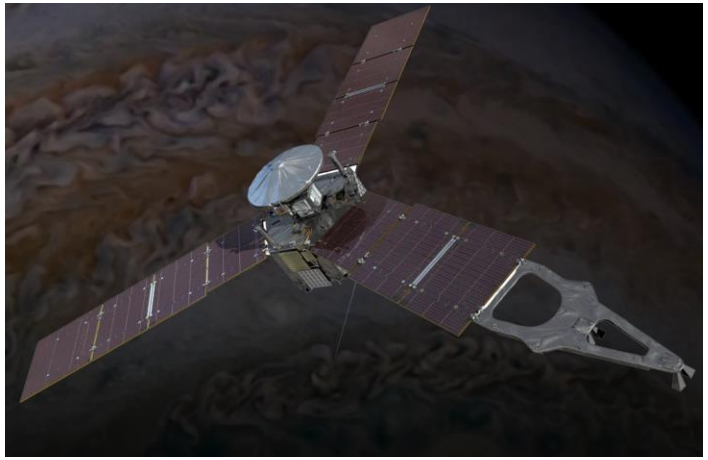
Touring Jupiter isn’t a cakewalk

NASA Galileo explored Jupiter between 1995 and 2003

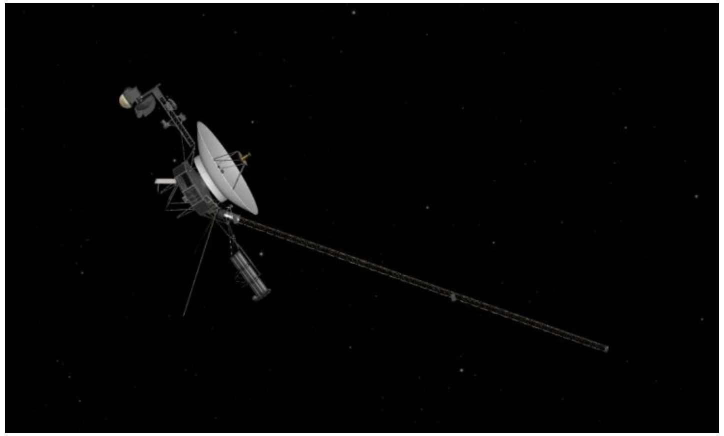




NASA JUNO



Voyager 2

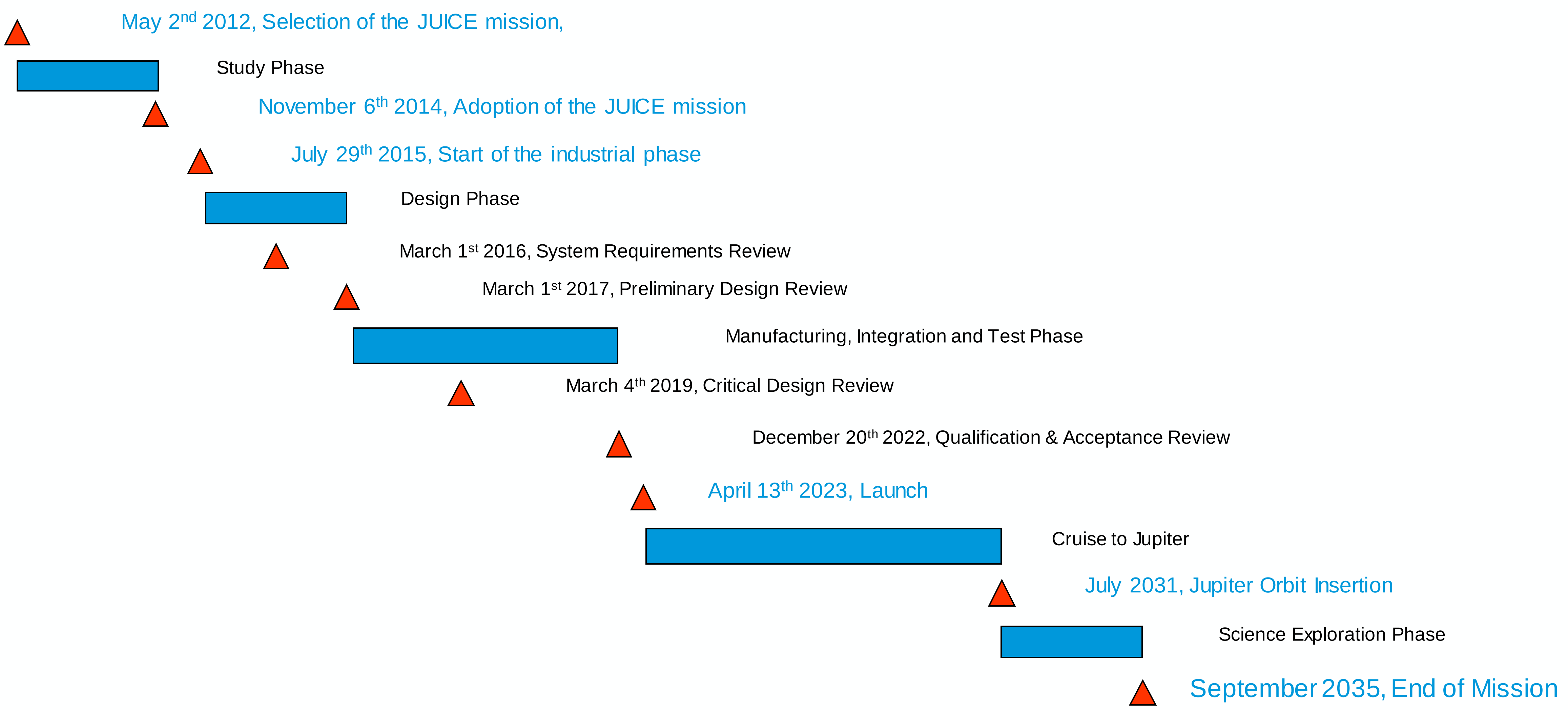


The spacecraft was designed to survive 150krad : it endured 600krad behind 2.2g/cm2

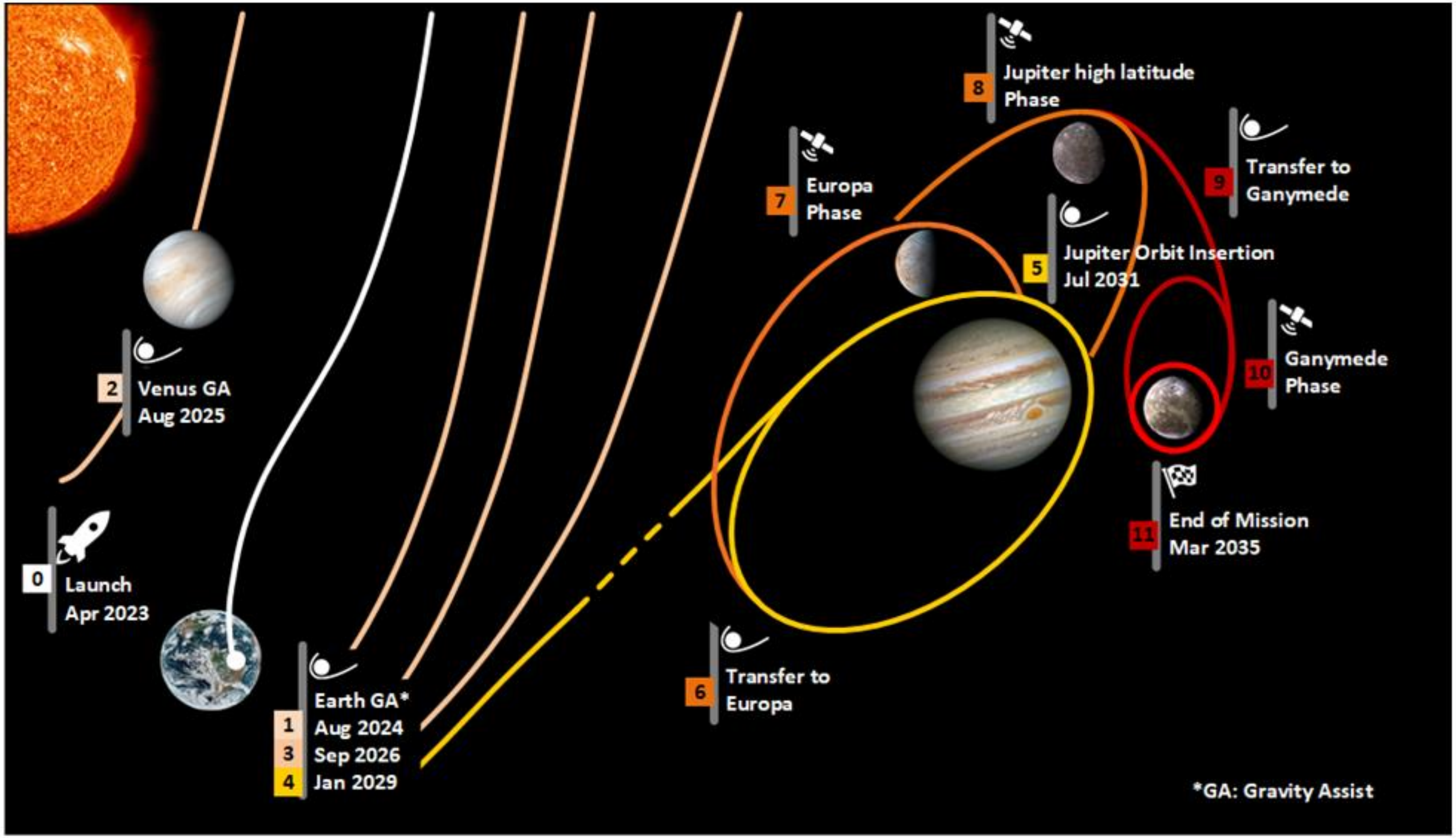
- Detector noise
- Power glitches
- Leakage currents
- Internal ESD noise
- Cerenkov Florescence radiation on optical elements
- Oscillators frequency shifts

In mid 1979, Voyager 2 visits the Jovian magnetosphere and its trajectory approached Ganymede, experienced many sporadic events (strong electrostatic charging).

JUICE development timeline

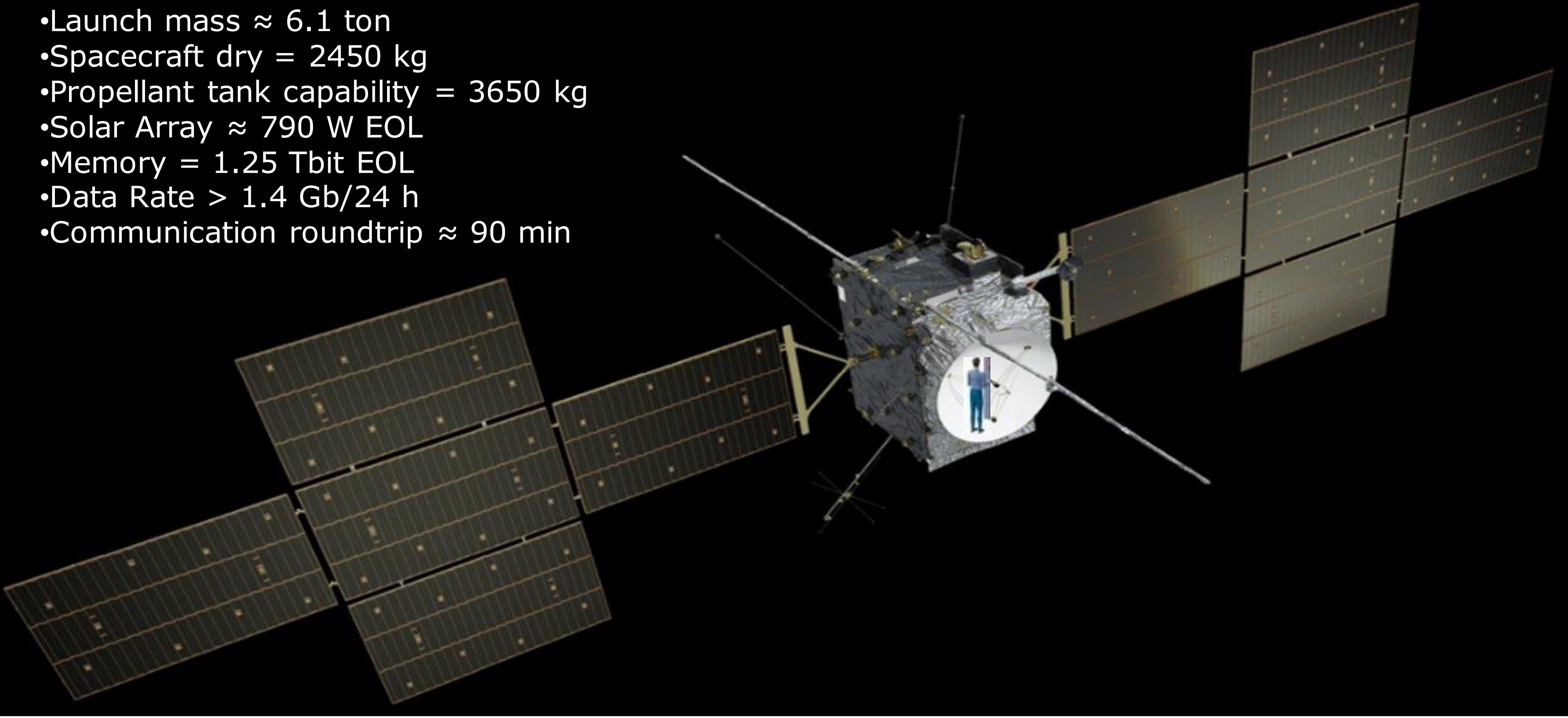


Mission timeline

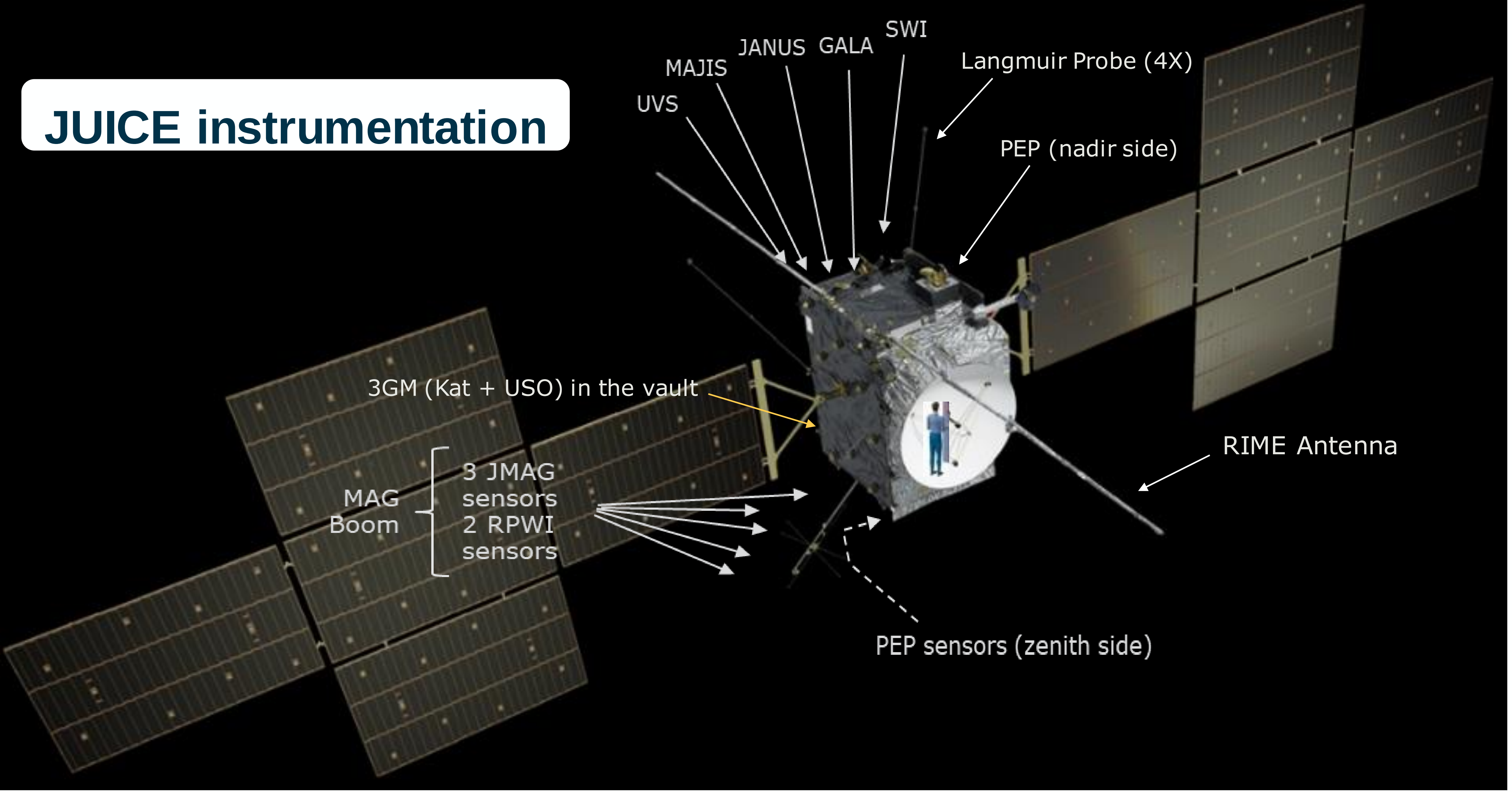


Juice – the spacecraft

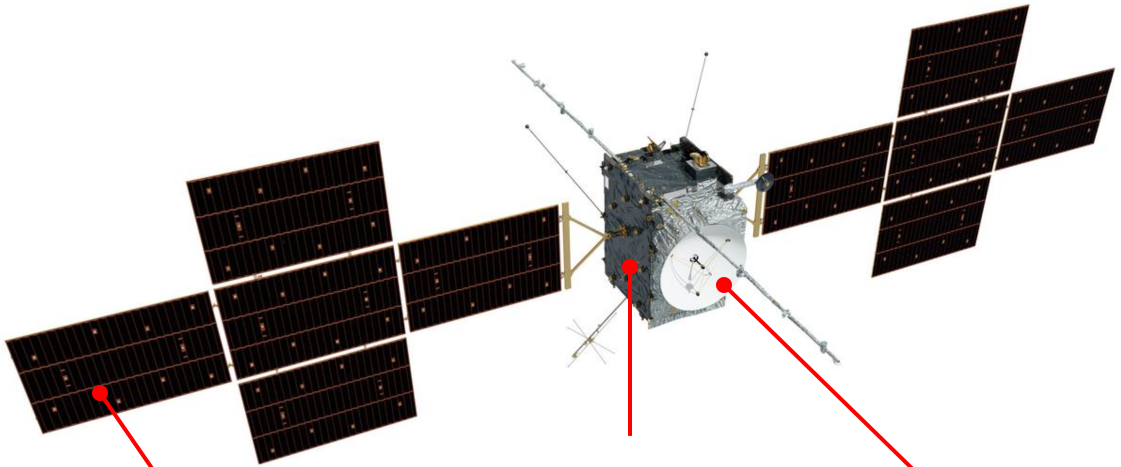
- Launch mass ≈ 6.1 ton
- Spacecraft dry = 2450 kg
- Propellant tank capability = 3650 kg
- Solar Array ≈ 790 W EOL
- Memory = 1.25 Tbit EOL
- Data Rate > 1.4 Gb/24 h
- Communication roundtrip ≈ 90 min



JUICE instrumentation



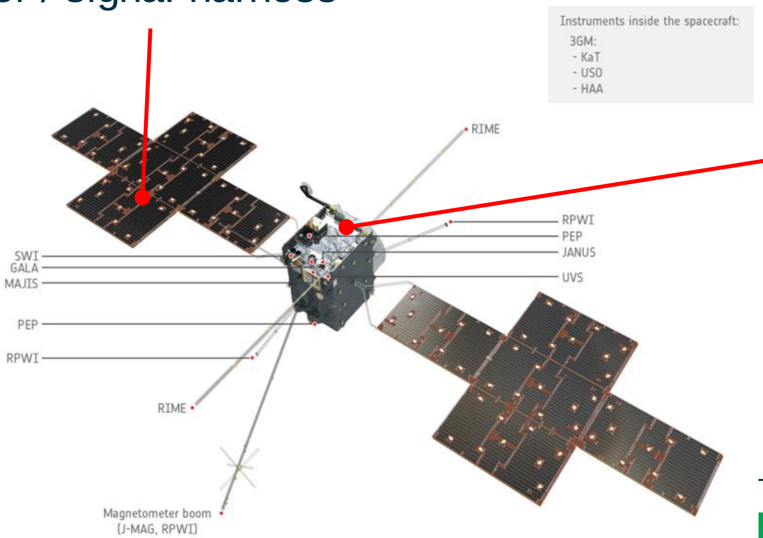
Radiation Effects



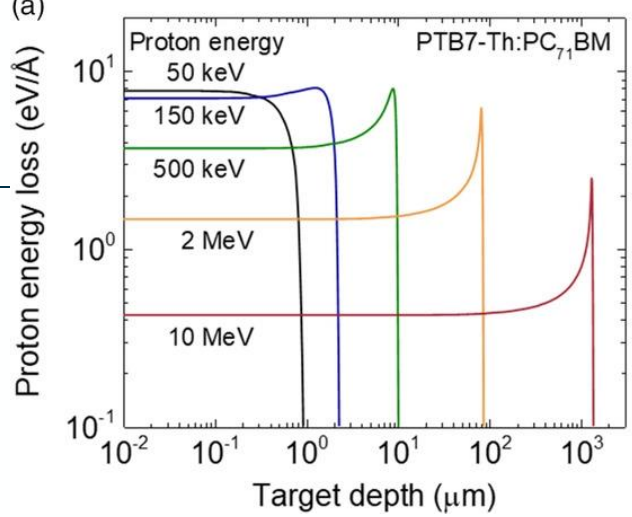
Multi-Layer Insulation

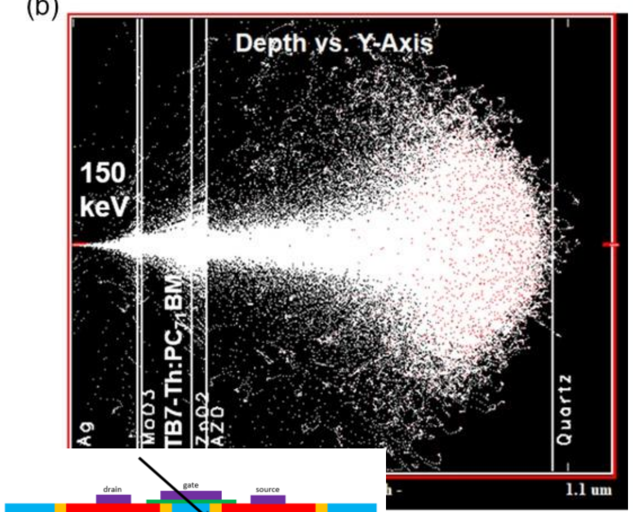
High Gain Antenna

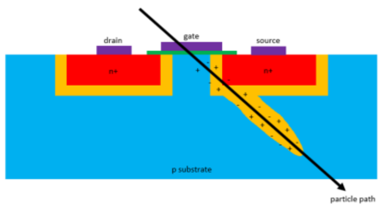
2356 Solar cells, 85m^2
Power / signal harness

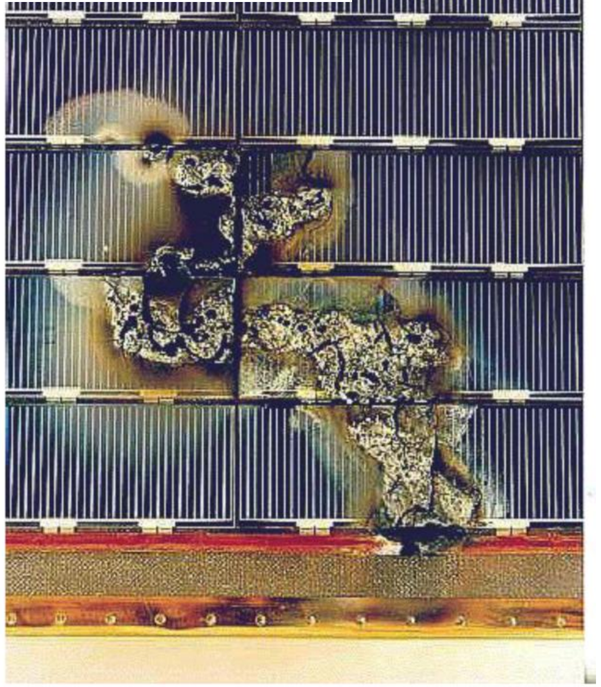


Payloads radiators

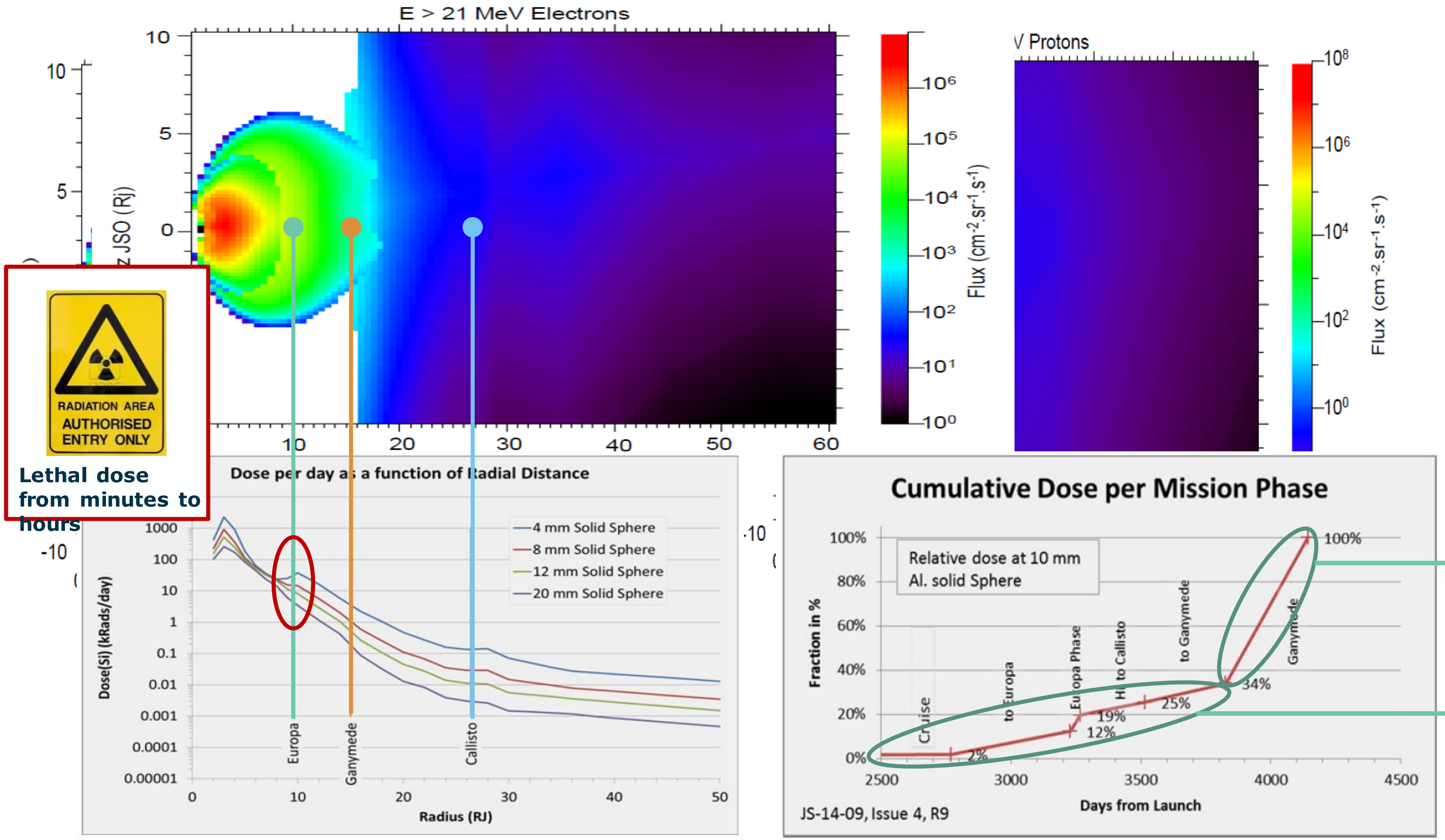








Radiation environment predictions



JOSE, JOREM models have been revisited and used to predict radiation impact on JUICE

Ganymede phase ~ 70% of the total dose

Cruise + Europa + Callisto ~ 30%

Electrons at Jupiter

Trapped radiation at Jupiter: intense, energetic (>100 MeV) and highly penetrating electron component

Cherng et al (1996) identified **high-Z** materials as optimal shielding for TID against electrons (MCNPX, NOVICE)

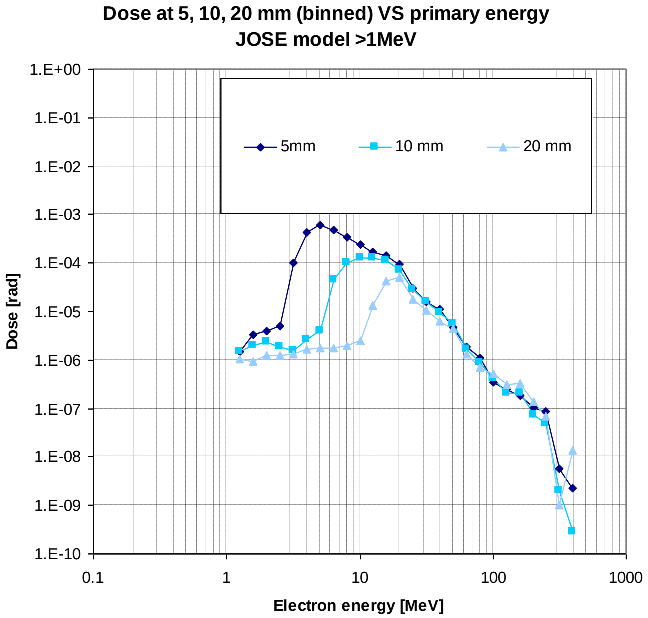
Ansart et al (2012): (Geant4) max **dose** reduction factor ~2

Mission design: for given TID, **mass saving factor ~1.5**

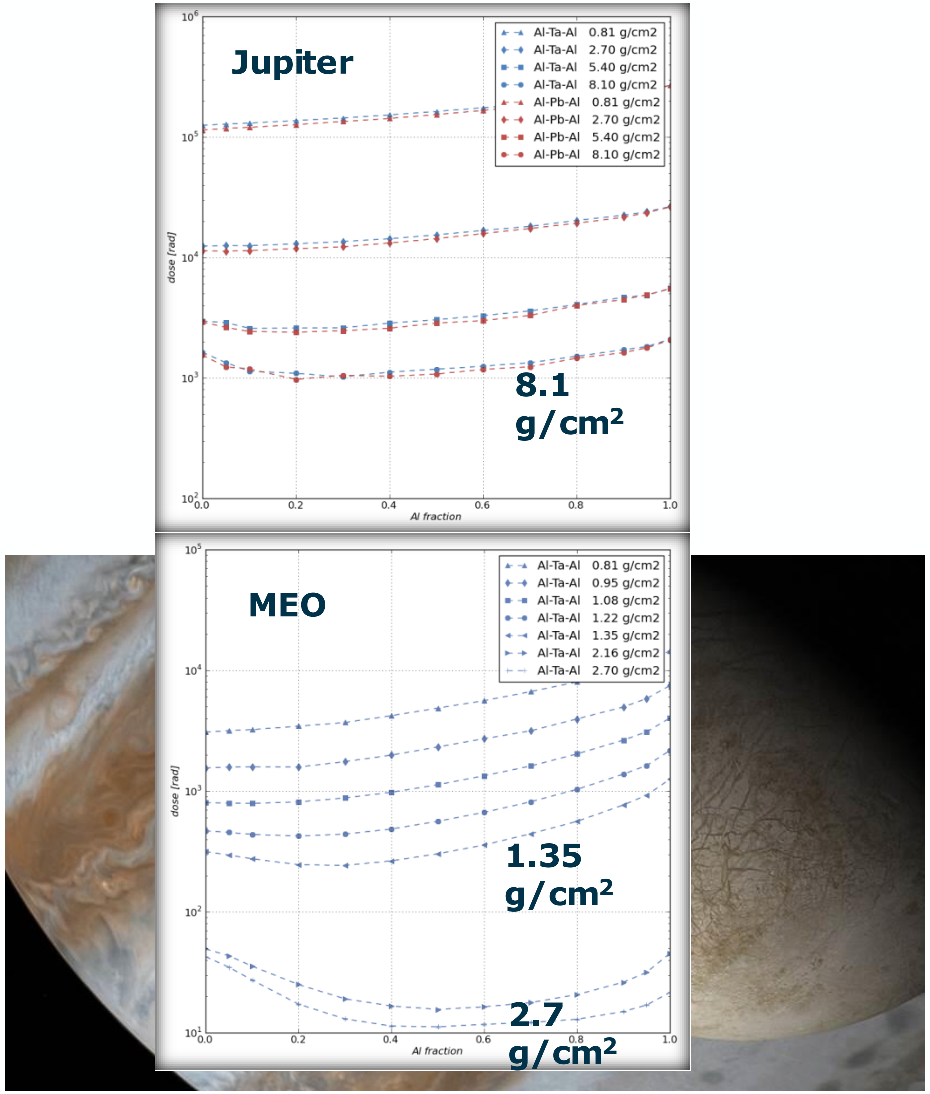
E.g. 3.24 g/cm2 (Al) ~ 2.16 g/cm2 (Ta),

or 1.22 g/cm2 (Al) ~ 0.81 g/cm2 (Ta)

Note: **layered** shielding may be better against **transients**



M.Cherng, I.Jun, and T.M.Jordan, IEEE TNS Vol 43, No 6, 1996
M. Ansart et al., RADECS 2012 Conference Proceedings, 2012

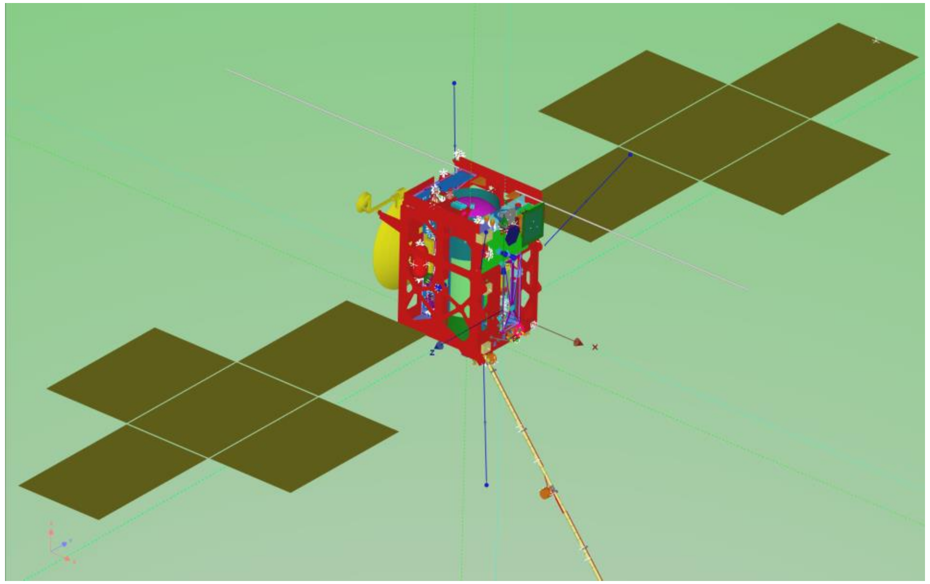


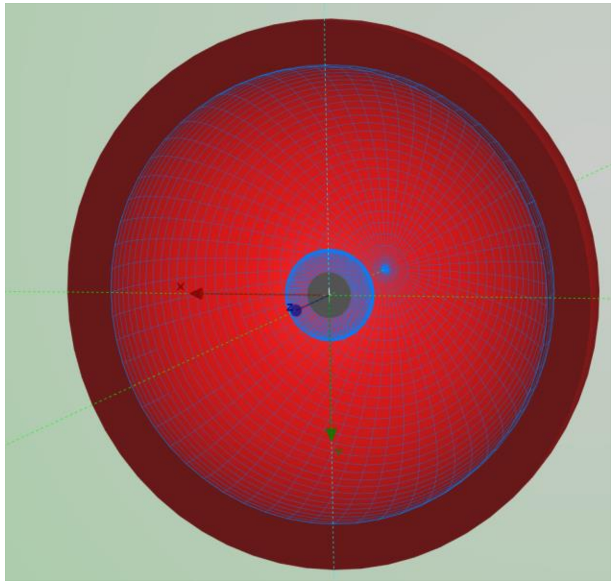
Geometry models

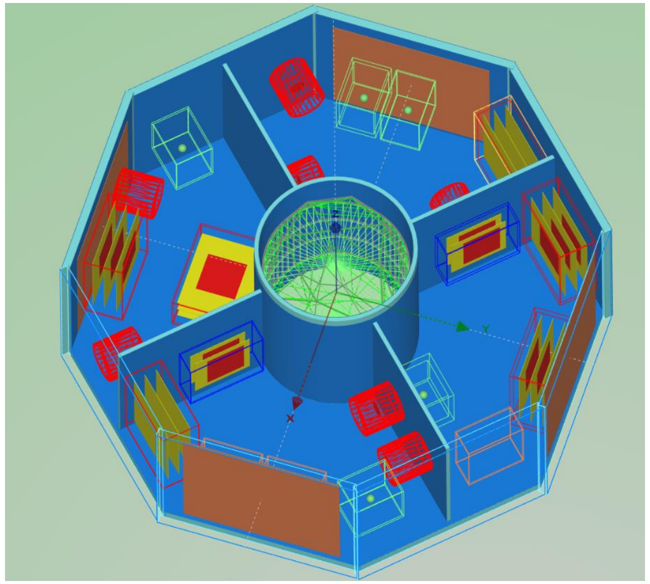
JUICE - IMU Geometry

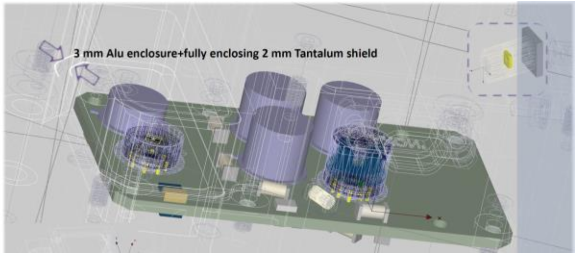
Sphere: 1mm Pb+4mm Al + Si det (0.5 mm r)

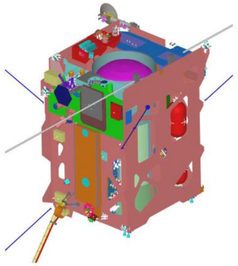
TEST Spacecraft for sharing info



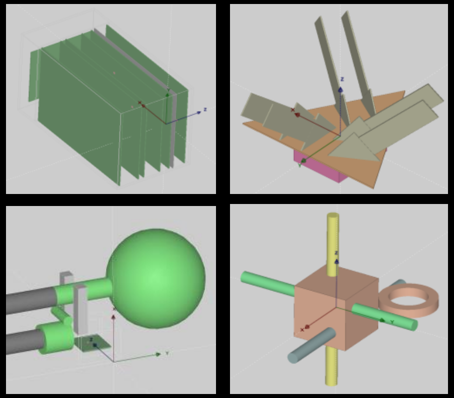




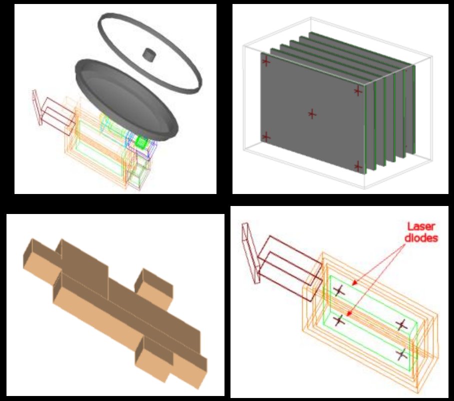




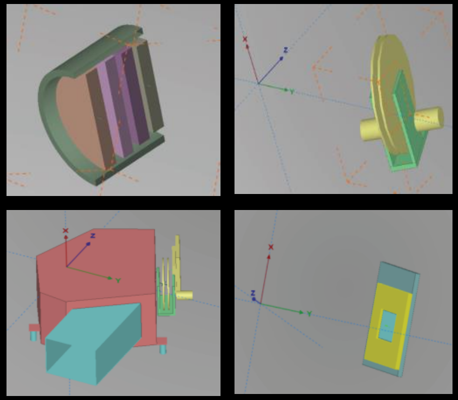
JUICE Instrument radiation models (GDML – GEANT4 - FASTRAD)



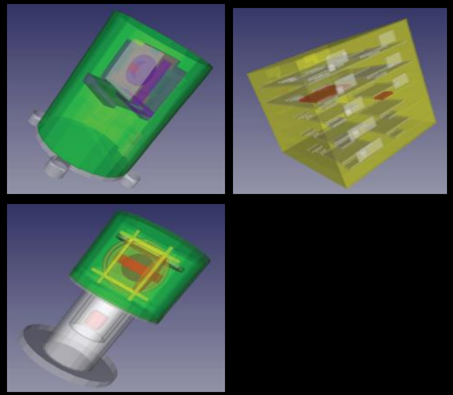
RPWI (IRF; OHB Sweden)



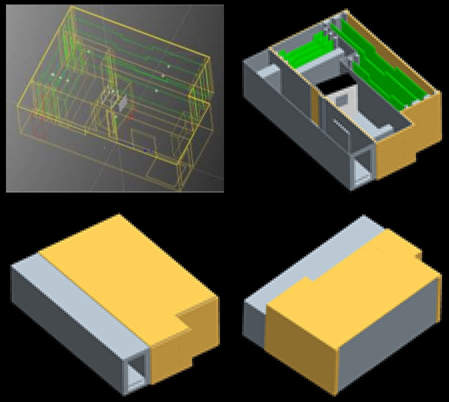
GALA (DLR)



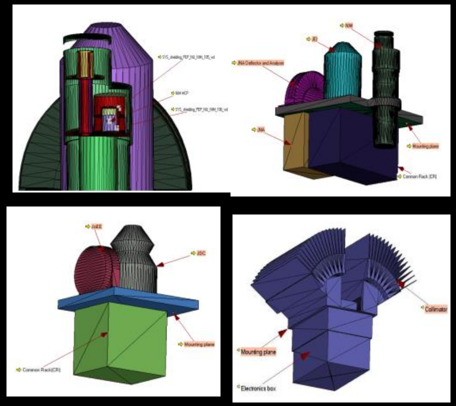
JANUS (Univ. Napoli; ASI)



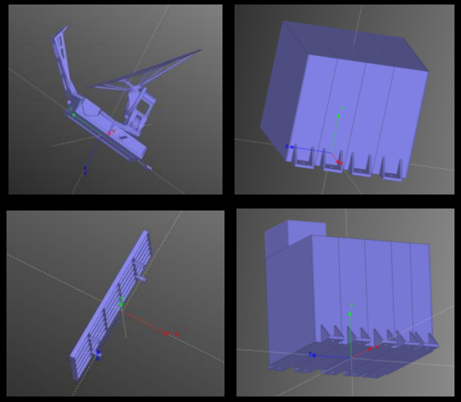
JMAG (IC; Univ. Leicester)



UVS (SRI, US)



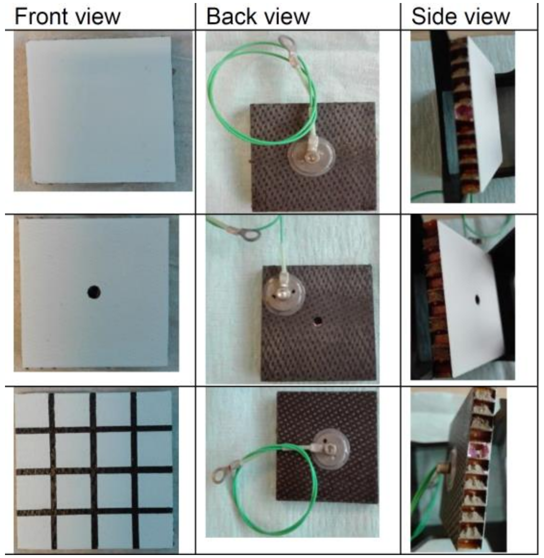
PEP (IRF)

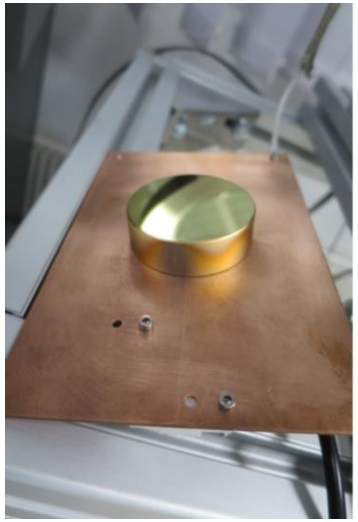


SWI (MPS; DLR)

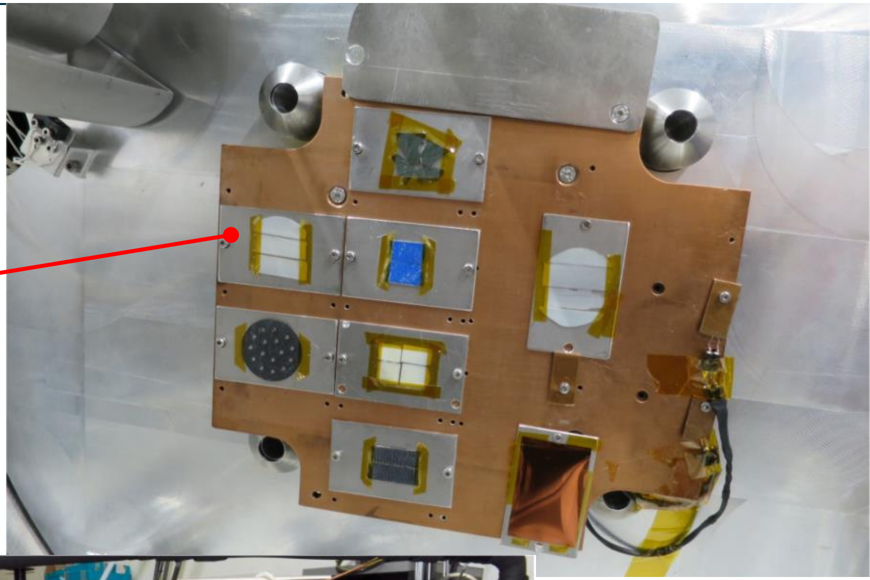
- Variety of radiation tools by instrument teams & industry
- GDML chosen as interface format
- Models used for accommodation studies and optimisation

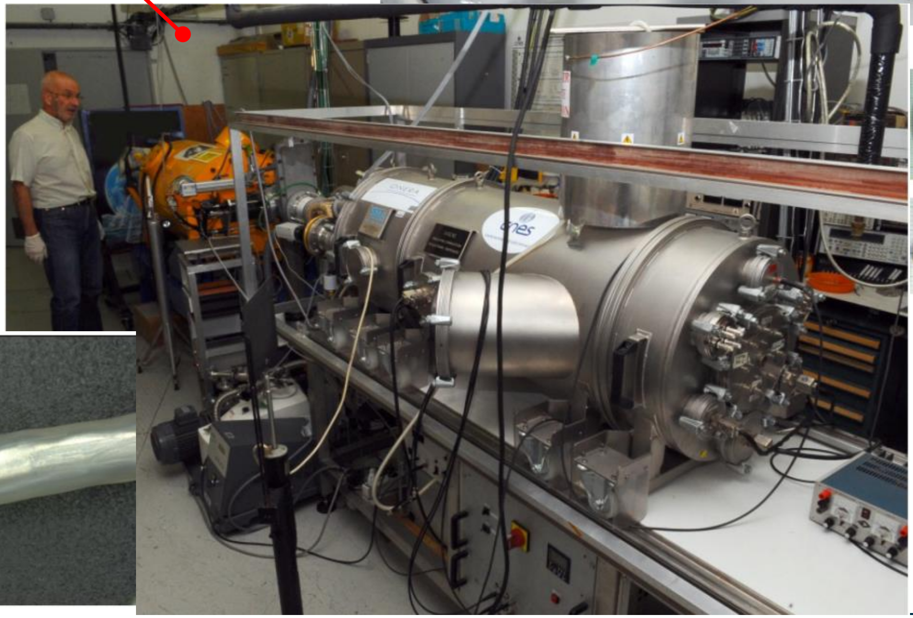
Testing campaigns – e.g. materials, deep charging



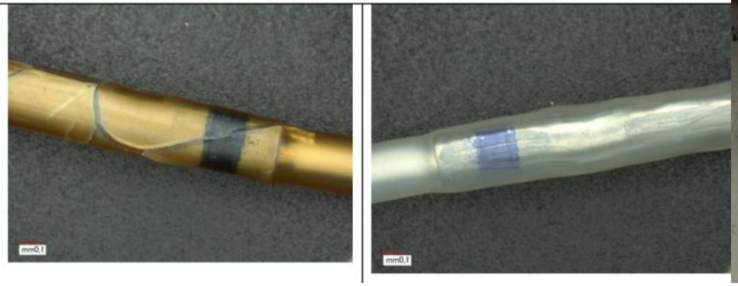


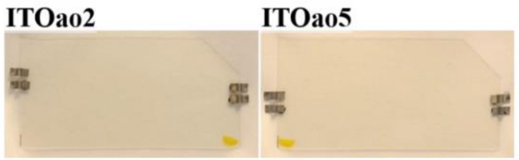
Irradiation of electrical connector materials at low temperatures





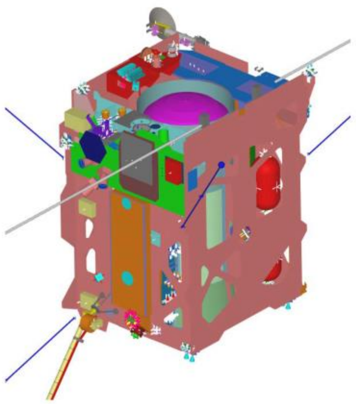
Materials Testing campaigns (charging at low temperature under electron irradiation)

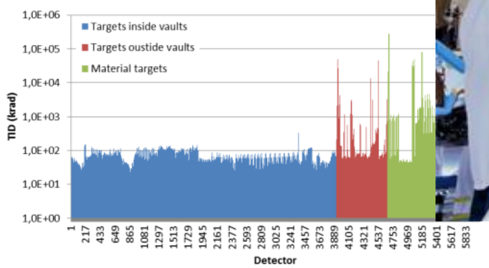


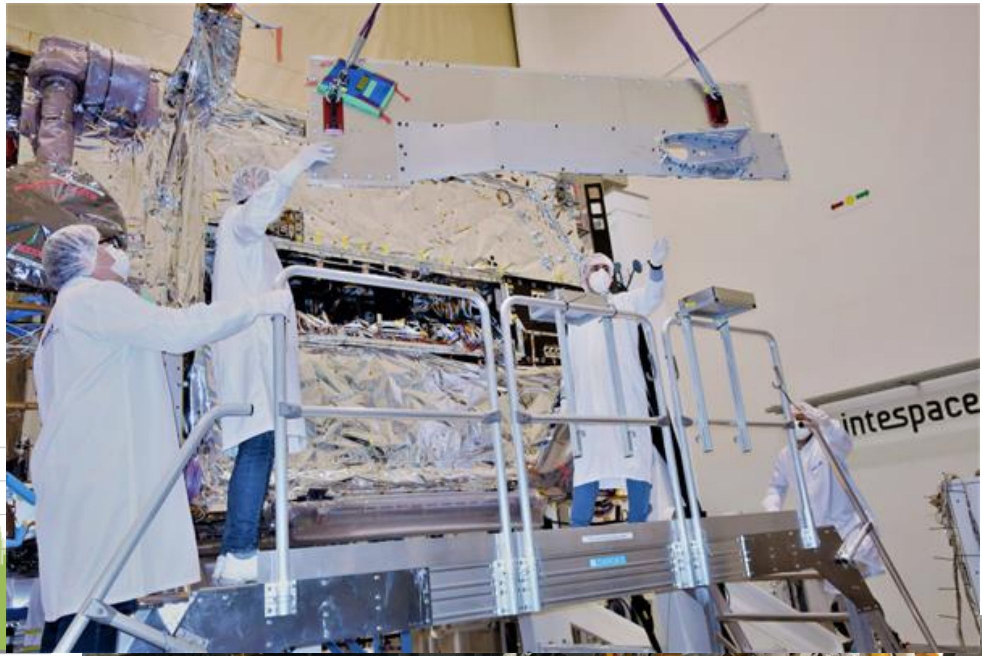


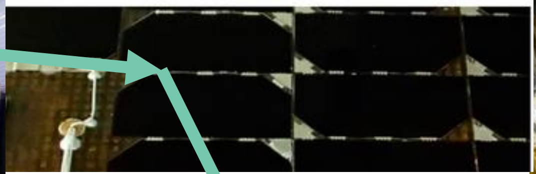
Protection measures against radiation …

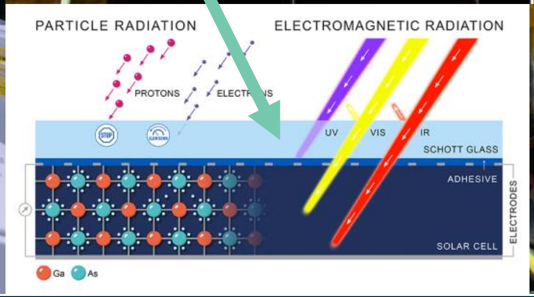
- Extensive radiation analysis campaigns on platform and payloads
- Two radiation shielding vaults which are built along the central cylinder, to protect sensitive electronics → around **150kg**
- 2300kg, **250kg** payload including shielding
- Extra thick Solar Arrays protective glass ~ + **30kg**

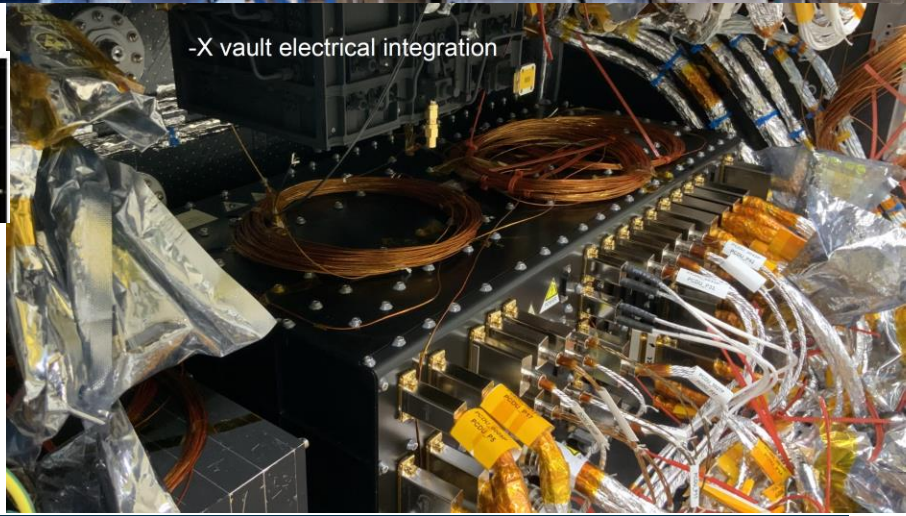








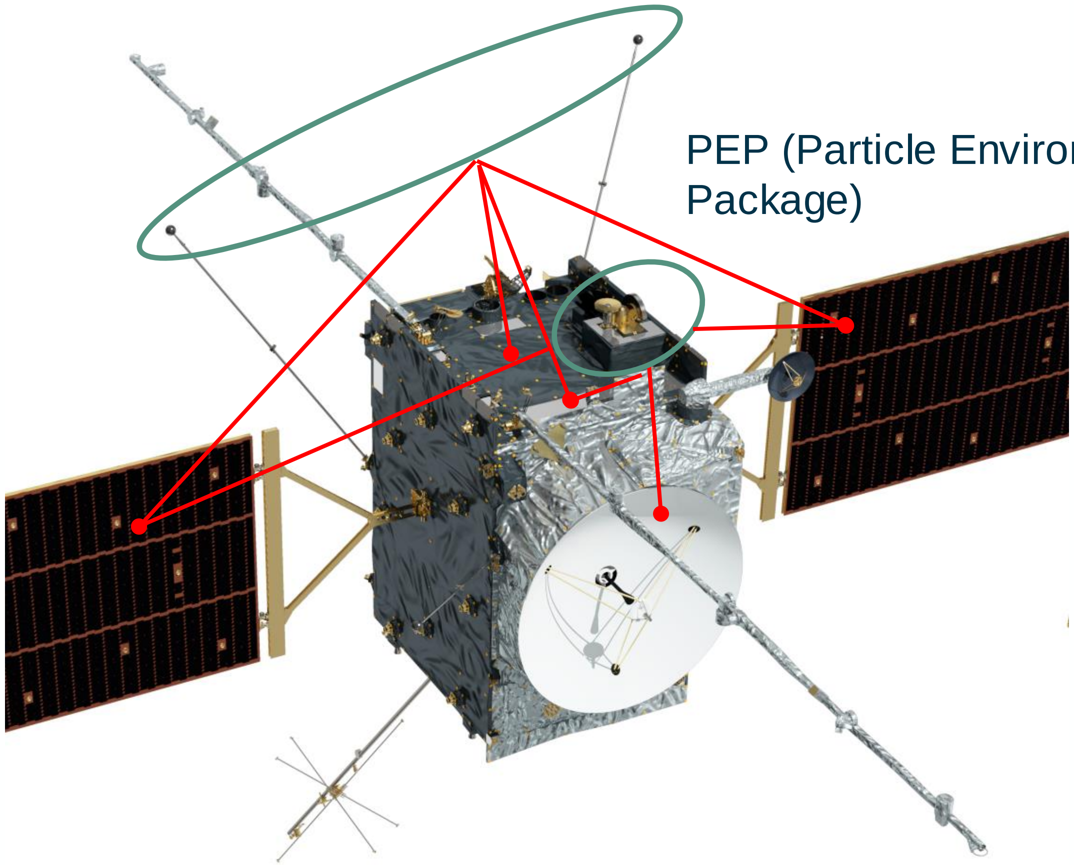




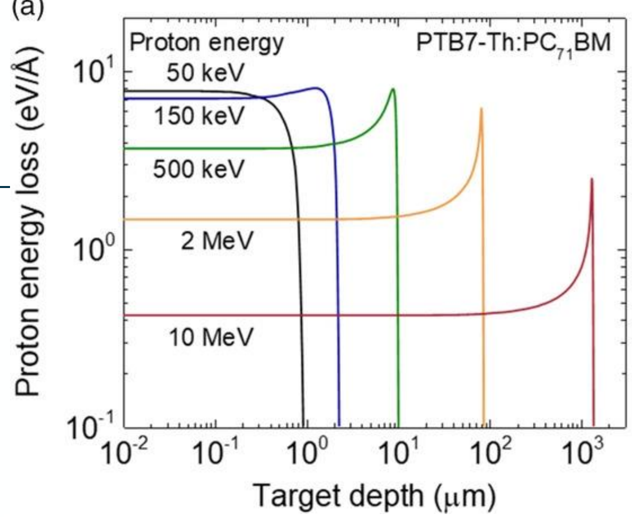
Plasma Effects

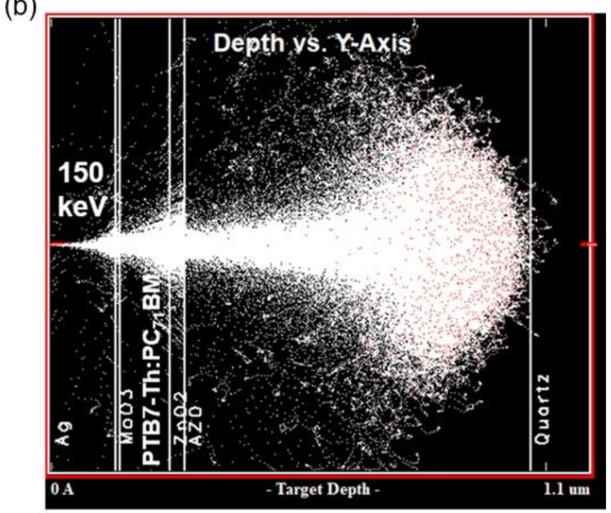
RPWI (Radio Plasma Wave Instrument)

PEP (Particle Environment Package)

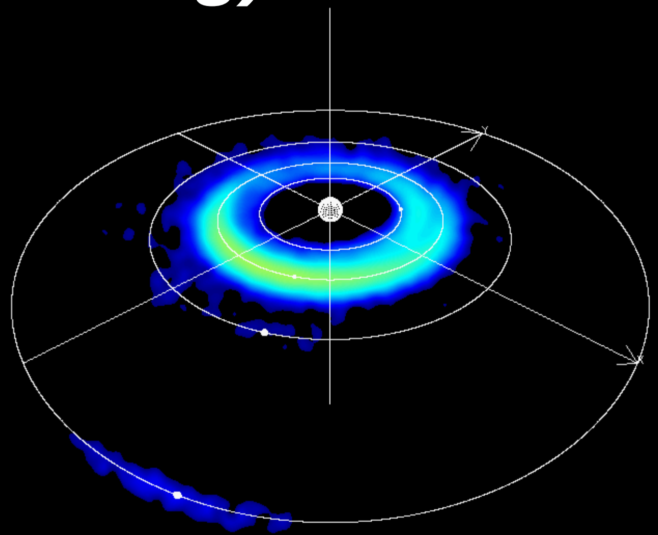


MAG and RWI

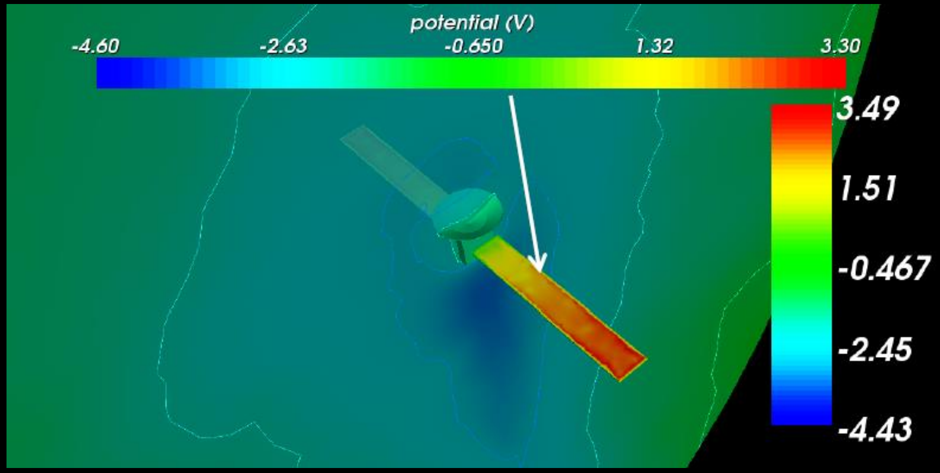


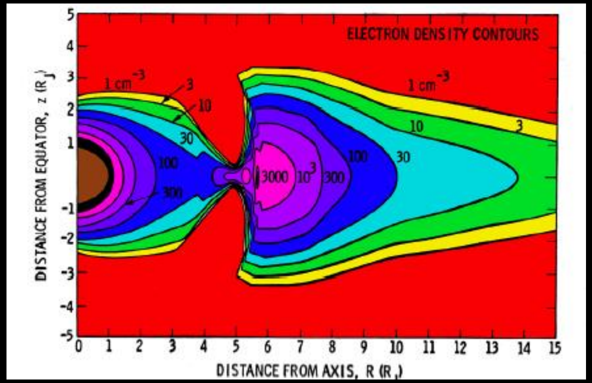


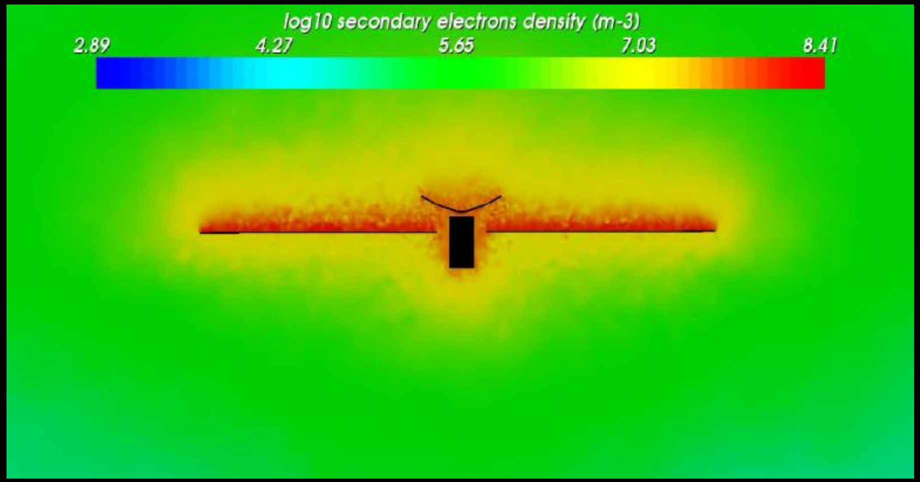
Plasma environment and charging (SPIS modelling)



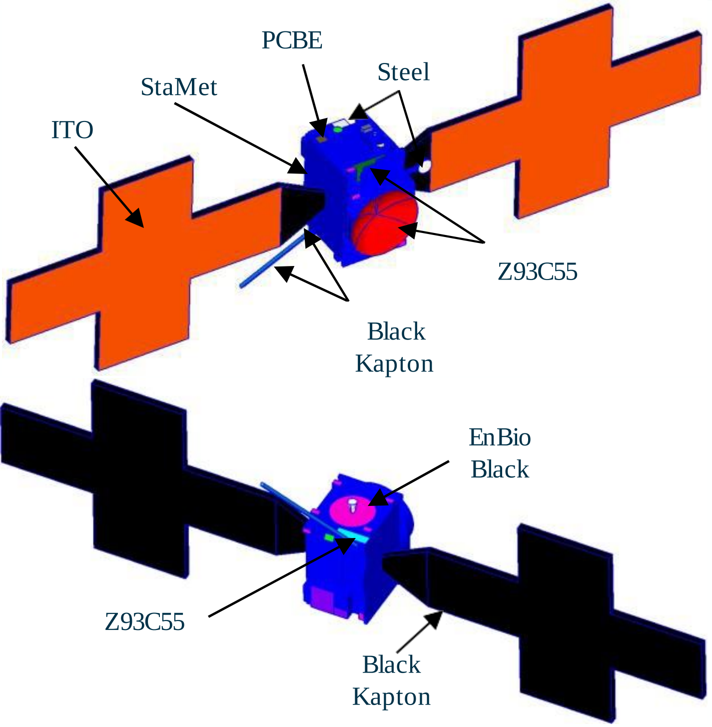
PEP JENI Energetic Neutral Atoms (ENA) simulation

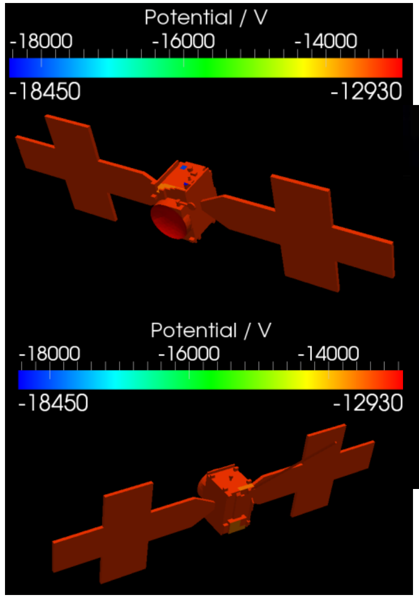


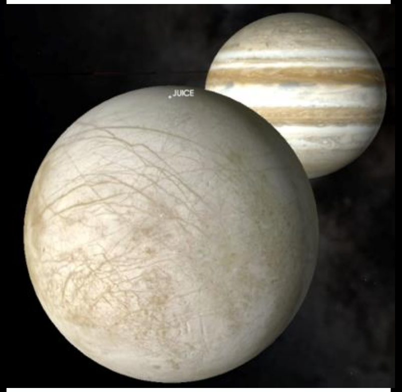


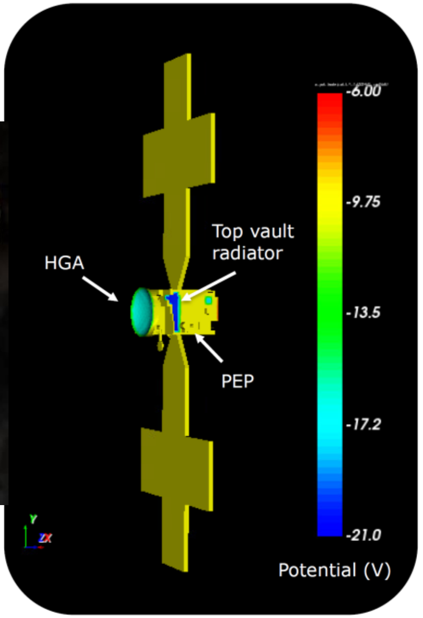


Extensive Simulations campaigns

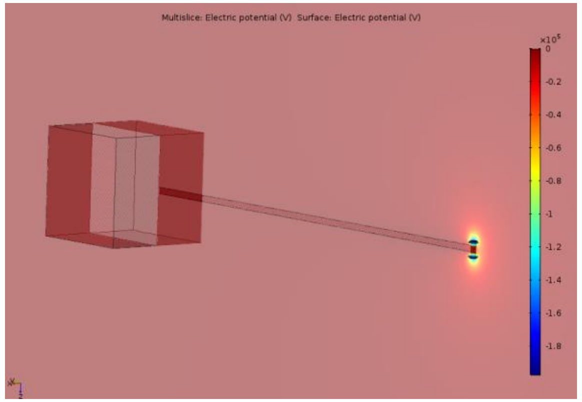


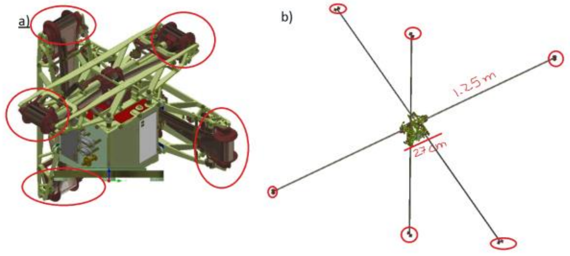


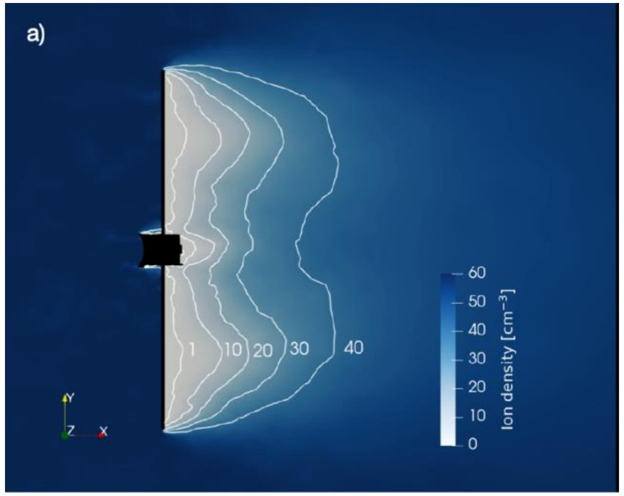




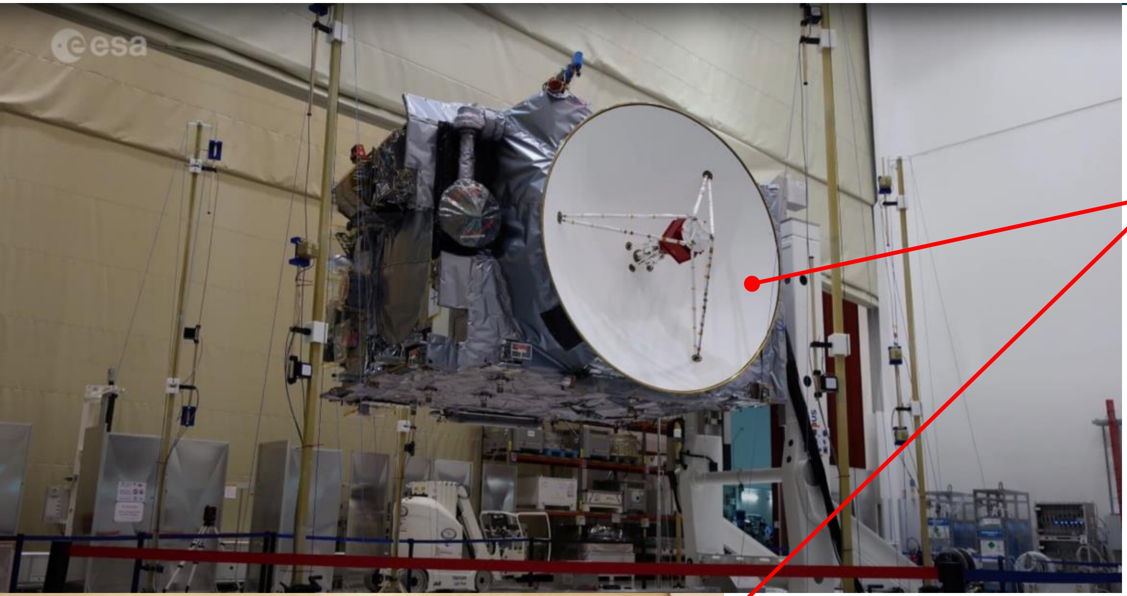
Charging predictions by auroral electrons (HGA, RWI parts) and during the moons flybys



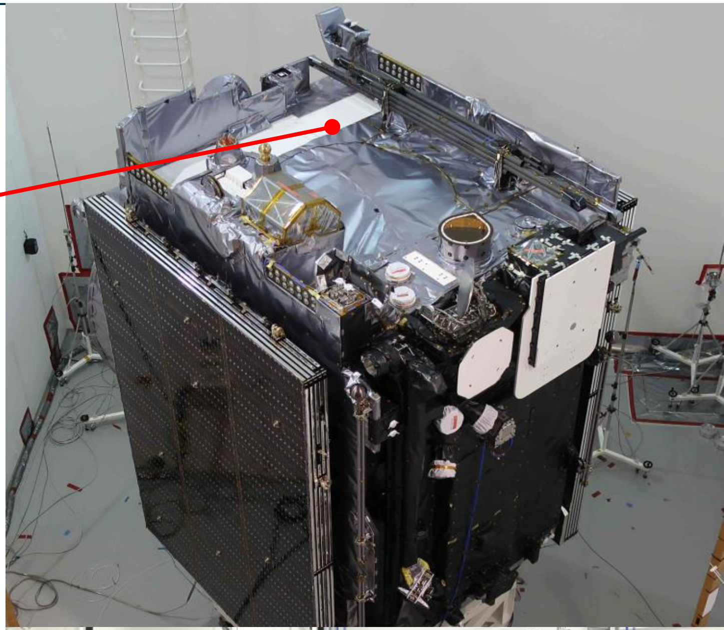


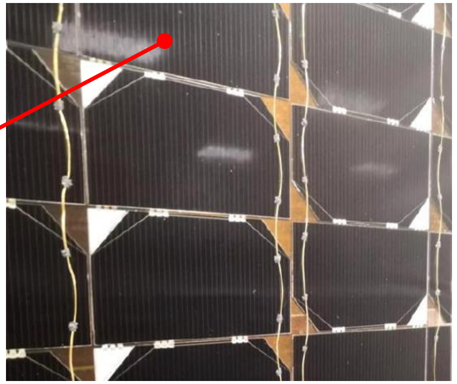


JUICE protection measures against plasma and charging

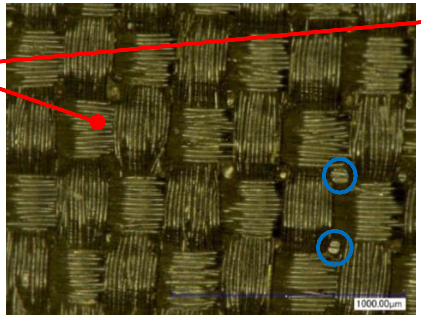


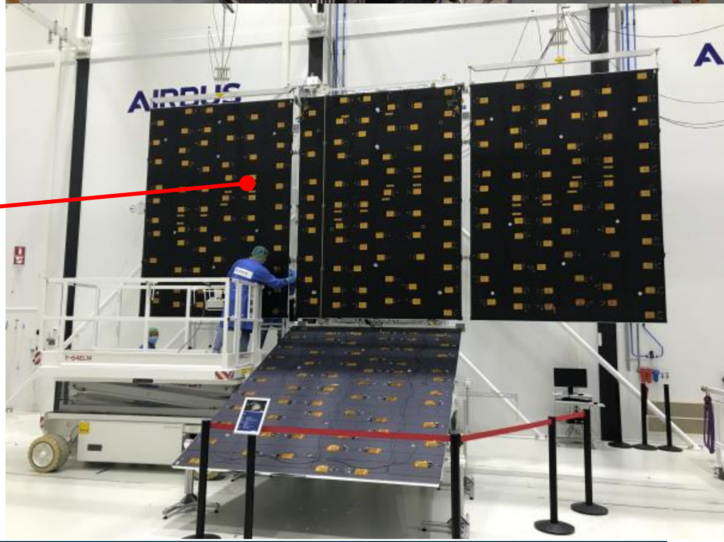
Conductive MLI, HGA and radiator white paints





Solar arrays optimization with ITO coating on solar cells (85m^2), strings organization and carbon fiber structure (backside)





Summary

→ JUICE development timeline has been quite short, about 7 years from SRR to launch. This was however preceded by ***quite extensive preliminary studies*** (incl. radiation and plasma during the study phase).

→ The current status is very satisfactory, en route to Jupiter, science data incoming mostly nominally

→ Radiation and Plasma protections (together with EMC) have been the main drivers

→ Significant modelling assessments already during early phases (Phase 0/A)

→ Shielding Mass optimization started before PDR (choice of materials) and was finalised before CDR

→ 10 Instruments, all designs were assessed against radiation already at PDR, radiation testing campaigns were performed until I-CDR

→ ***Environment modelling and testing have been crucial …***

→ RADEM is returning nice data !

Solar System Tour

Date	Event or phase
April 2023	Launch from Kourou with Ariane 5
August 2024	Earth flyby #1
August 2025	Venus flyby
September 2026	Earth flyby #2
January 2029	Earth flyby #3
July 2031	Jupiter orbit insertion
July 2031- June 2032	Energy reduction phase
July 2032	2 Europa flybys
August 2032-August 2033	Jupiter inclined phase - Callisto flybys
November 2033-November 2034	Phase "transfer to Ganymede"
December 2034	Ganymede orbit insertion
September 2035	End of mission