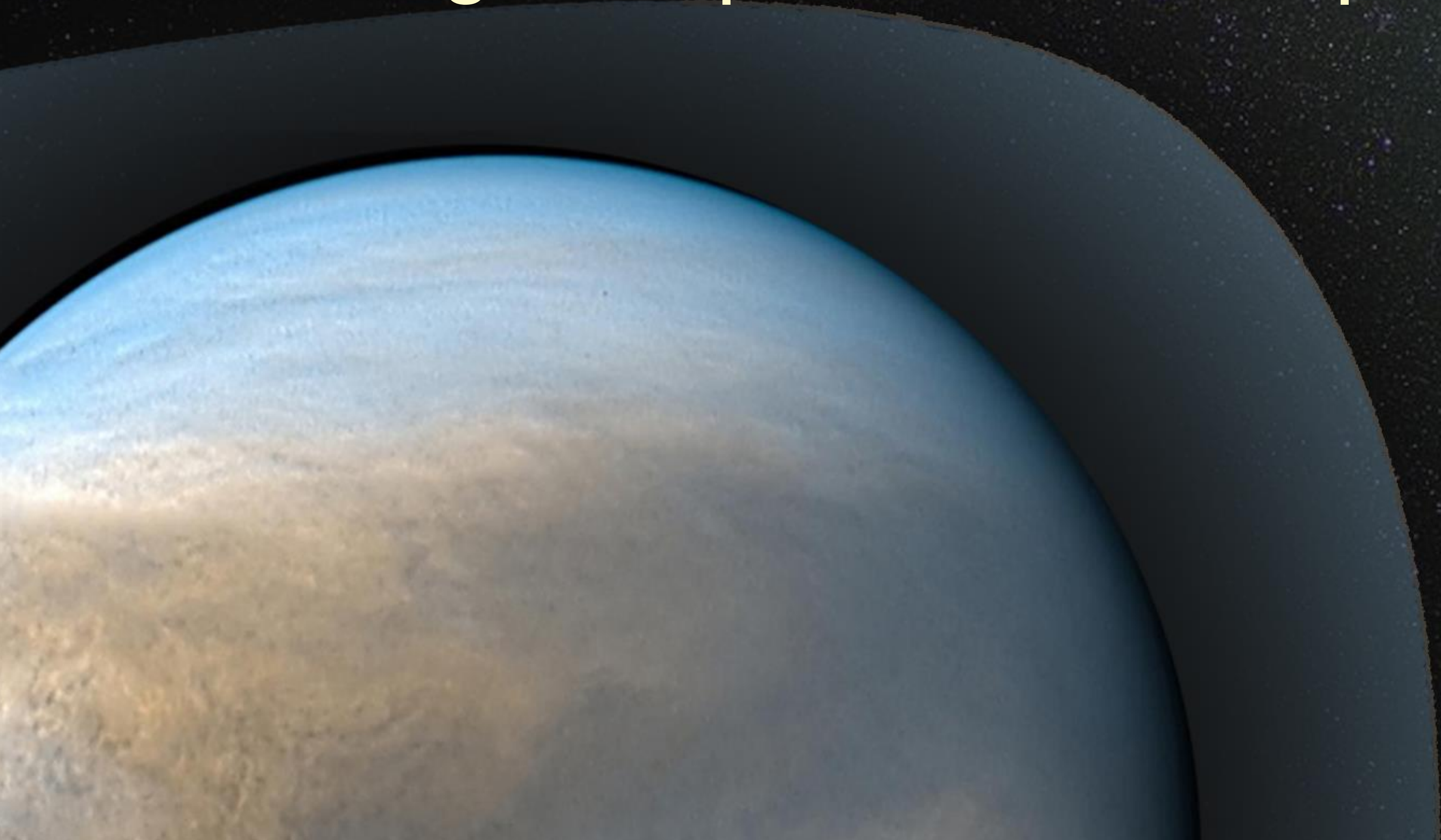
MVSE

Magnetospheric Venus Space Explorers



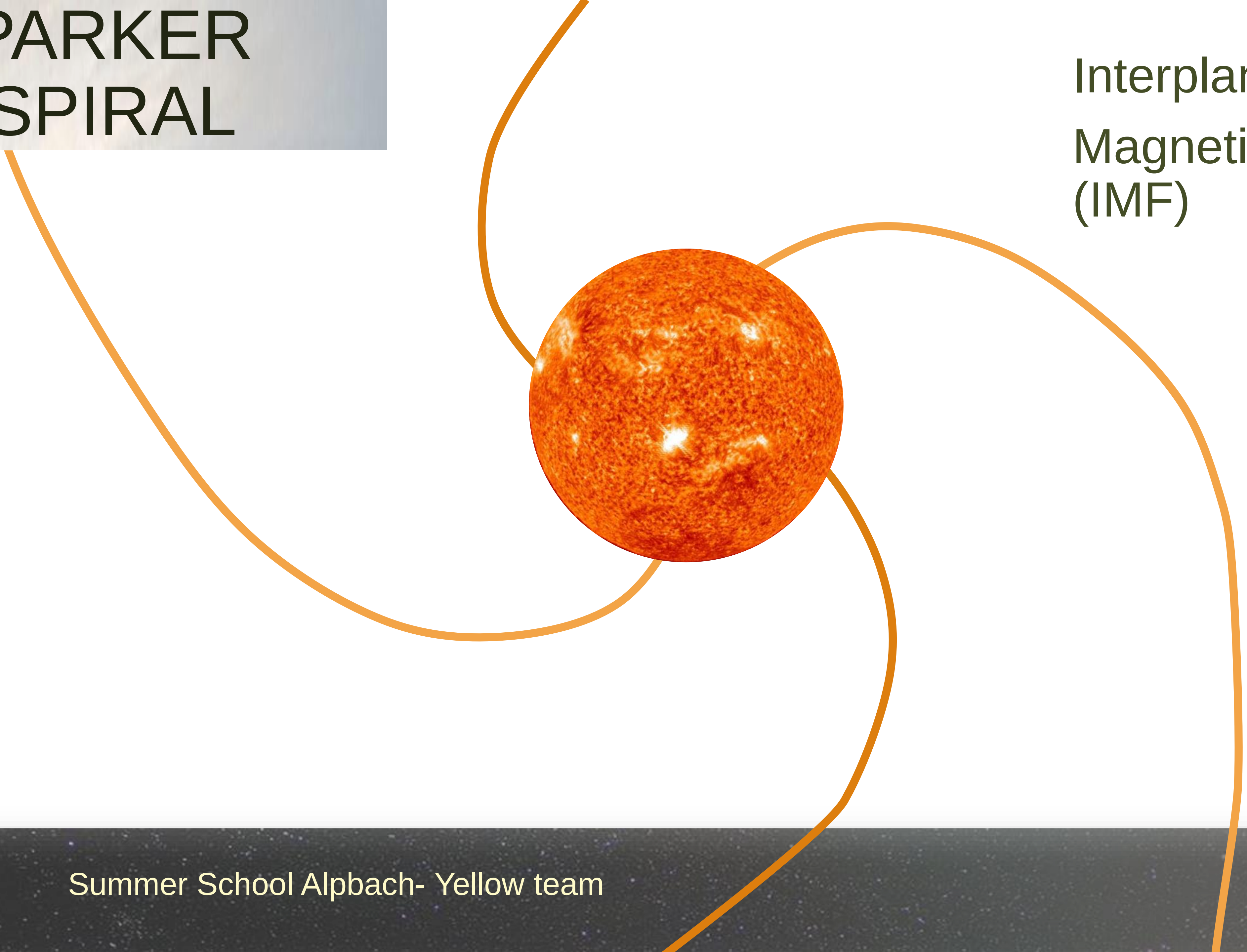
SUMMER SCHOOL
ALPBACH 2022

YELLOW TEAM

MISSION STATEMENT

Understanding the plasma environment of induced magnetospheres

PARKER SPIRAL



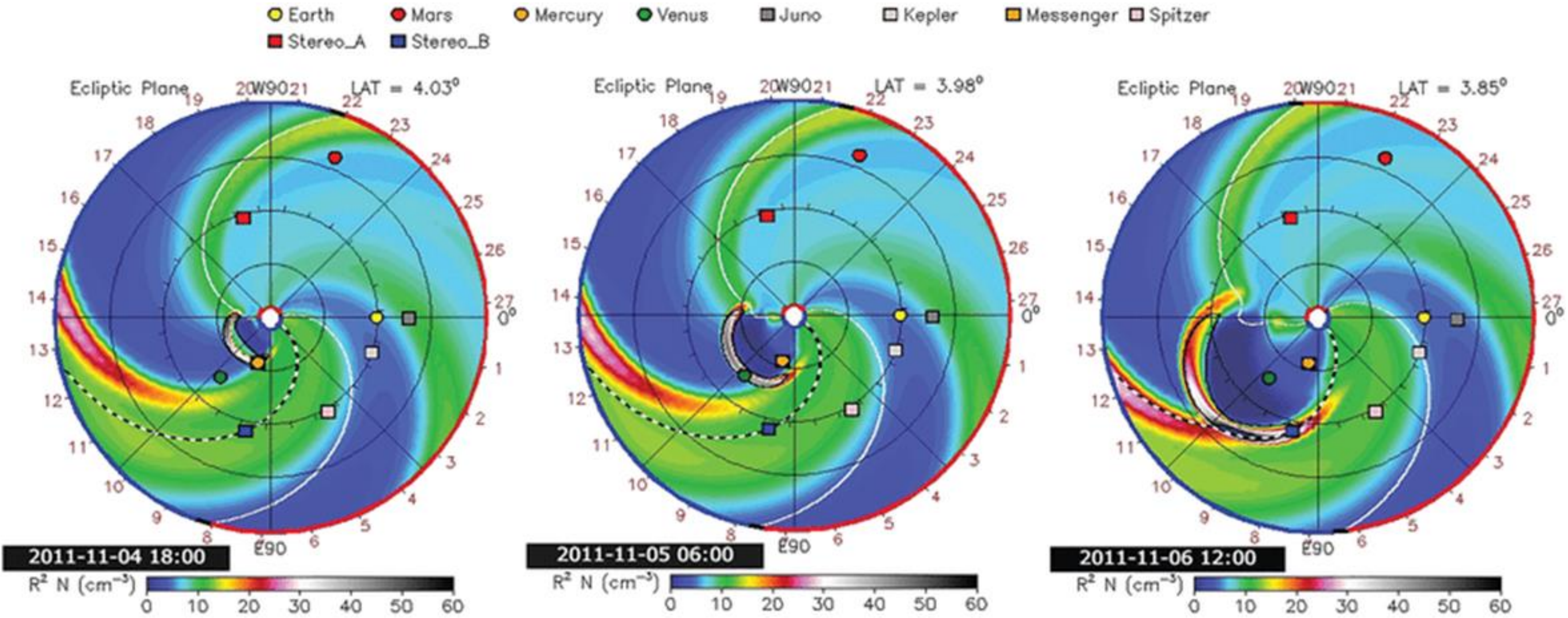
Interplanetary

Magnetic Field (IMF)

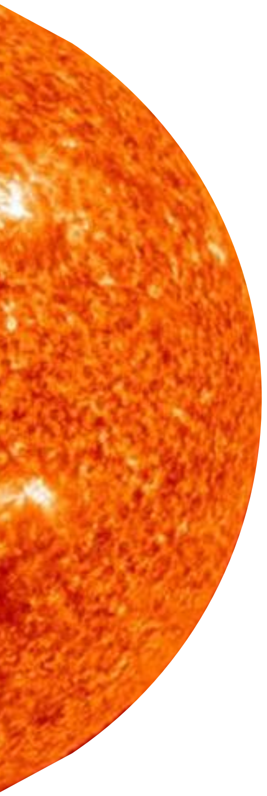
SOLAR ERUPTIVE EVENTS

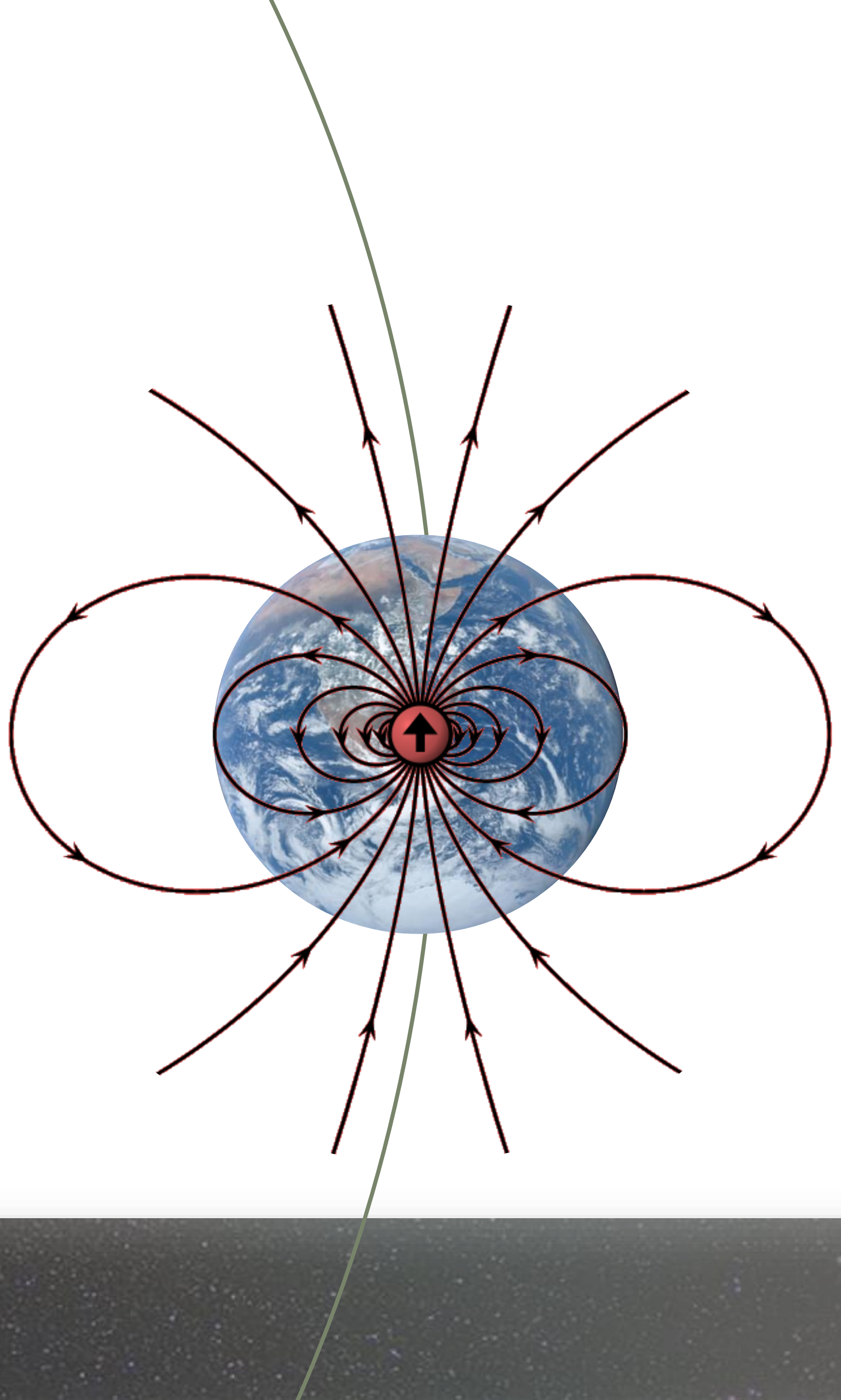
CMEs on 22 july 2012, NASA

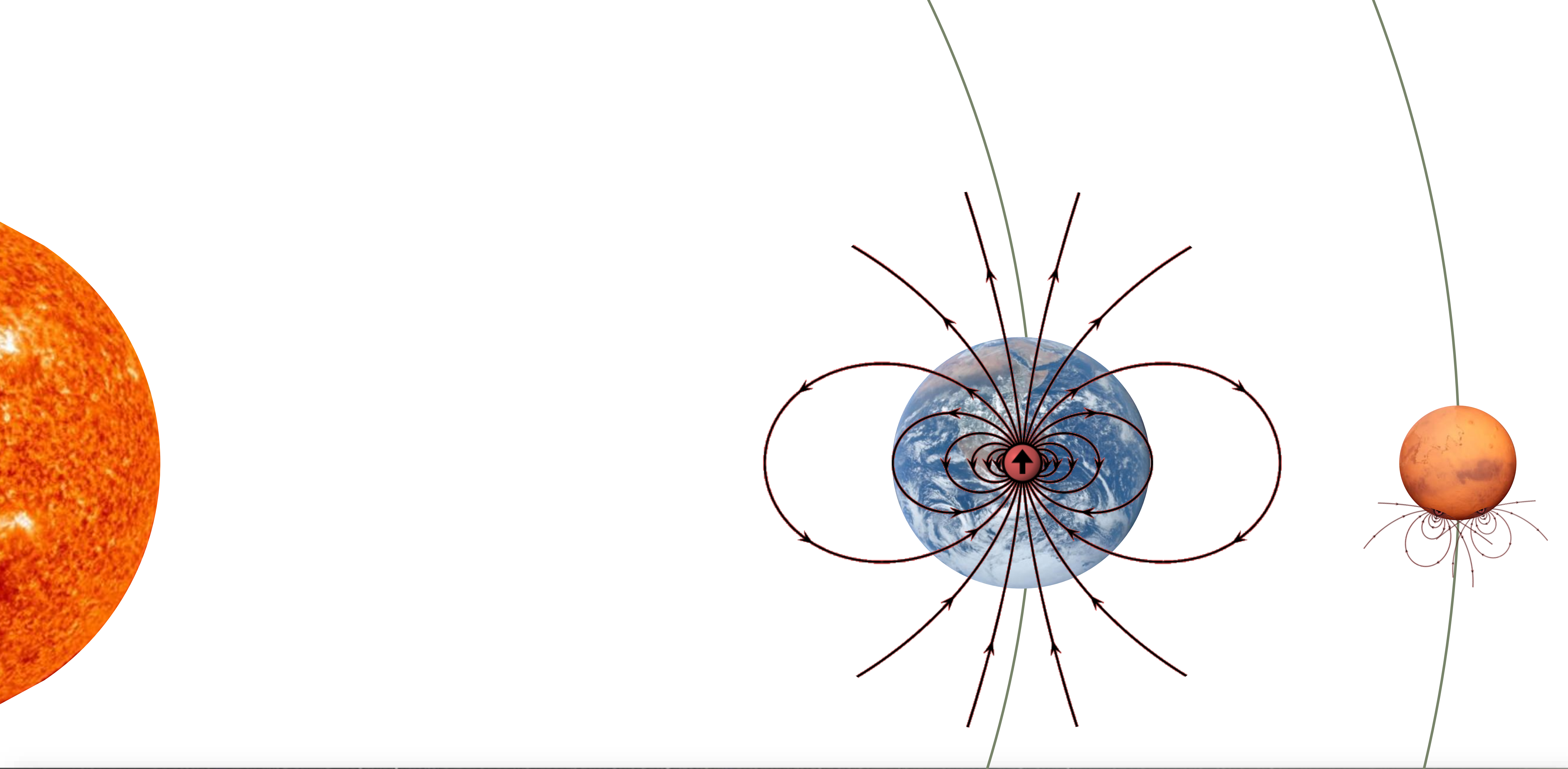
- Interplanetary Coronal Mass Ejections (ICMEs)
- Co-rotating Interaction Region (CIR)
- Solar Flare

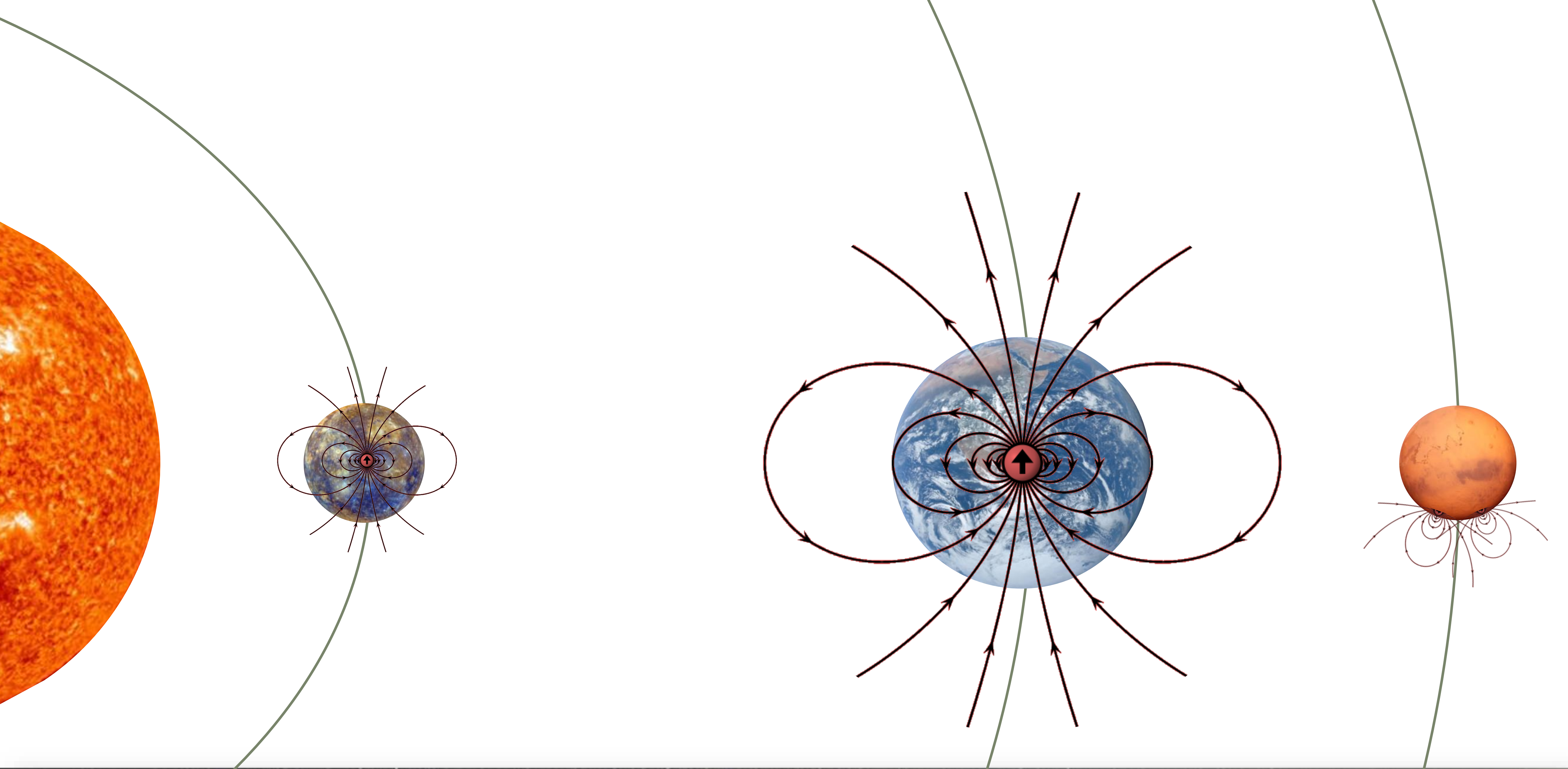


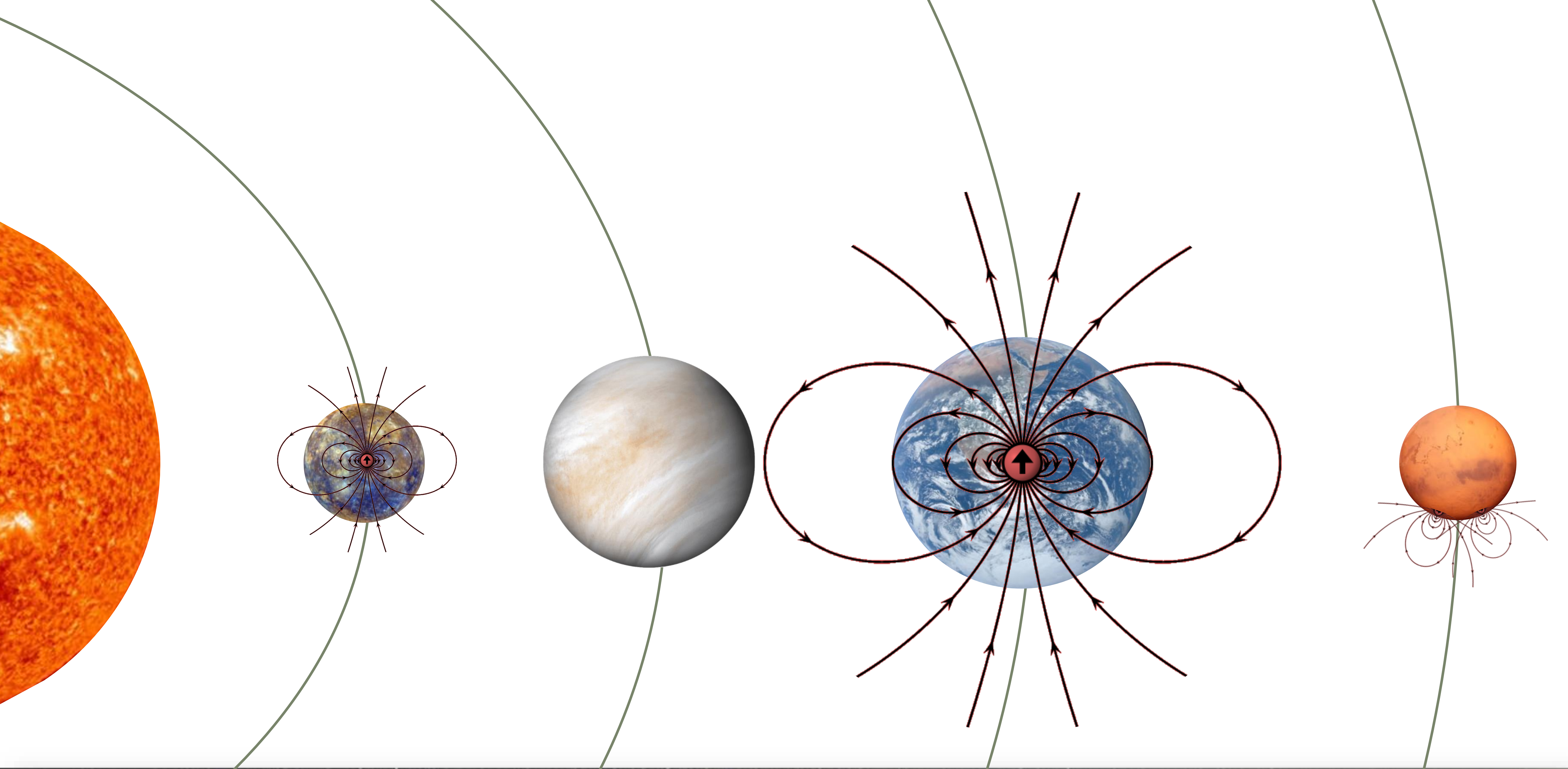
WSA-ENLIL model simulation with CME cone extension of the 3 November 2011 CME: when it reached Mercury (left), Venus (middle) and STEREO-B (right). Salman et al. 2020







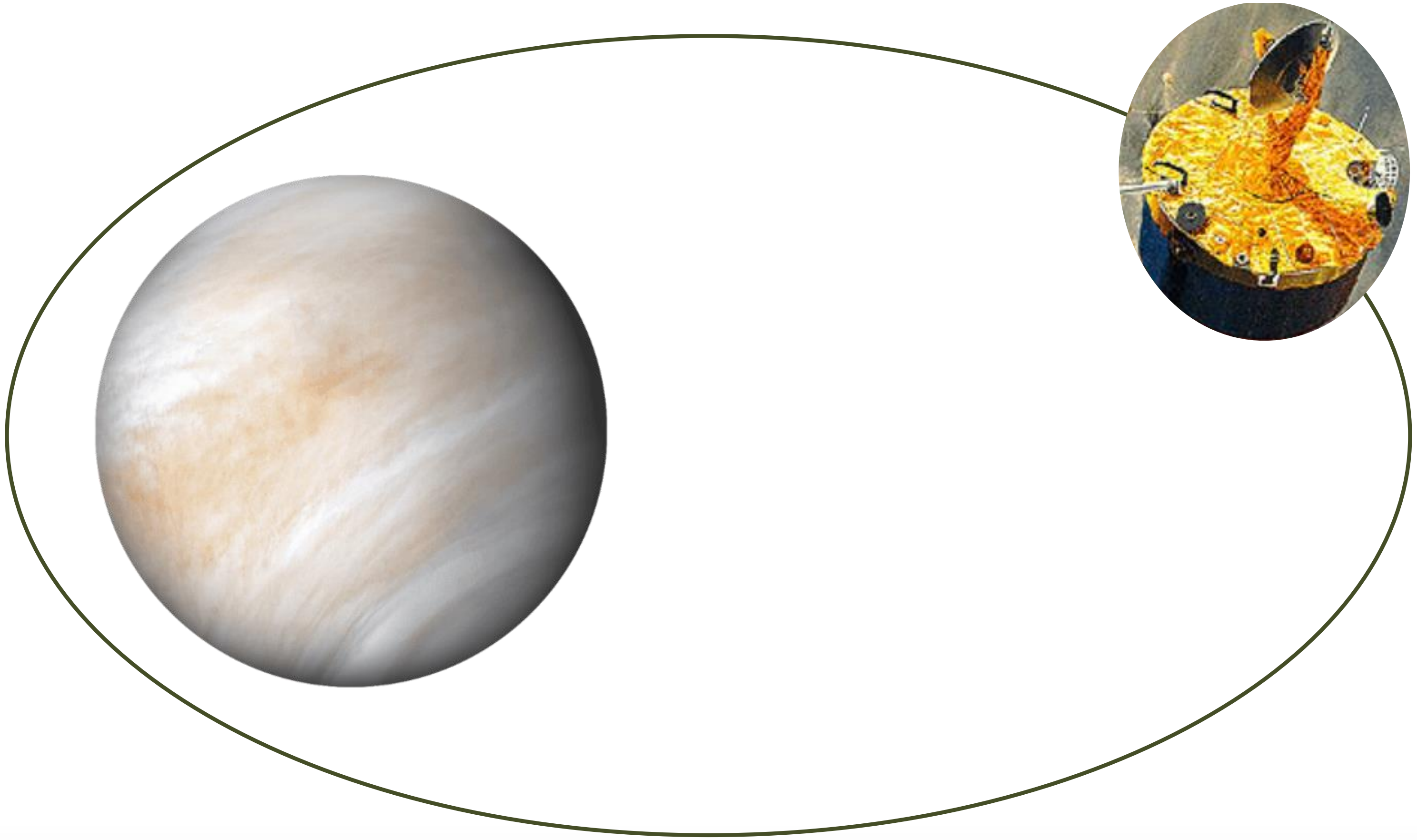




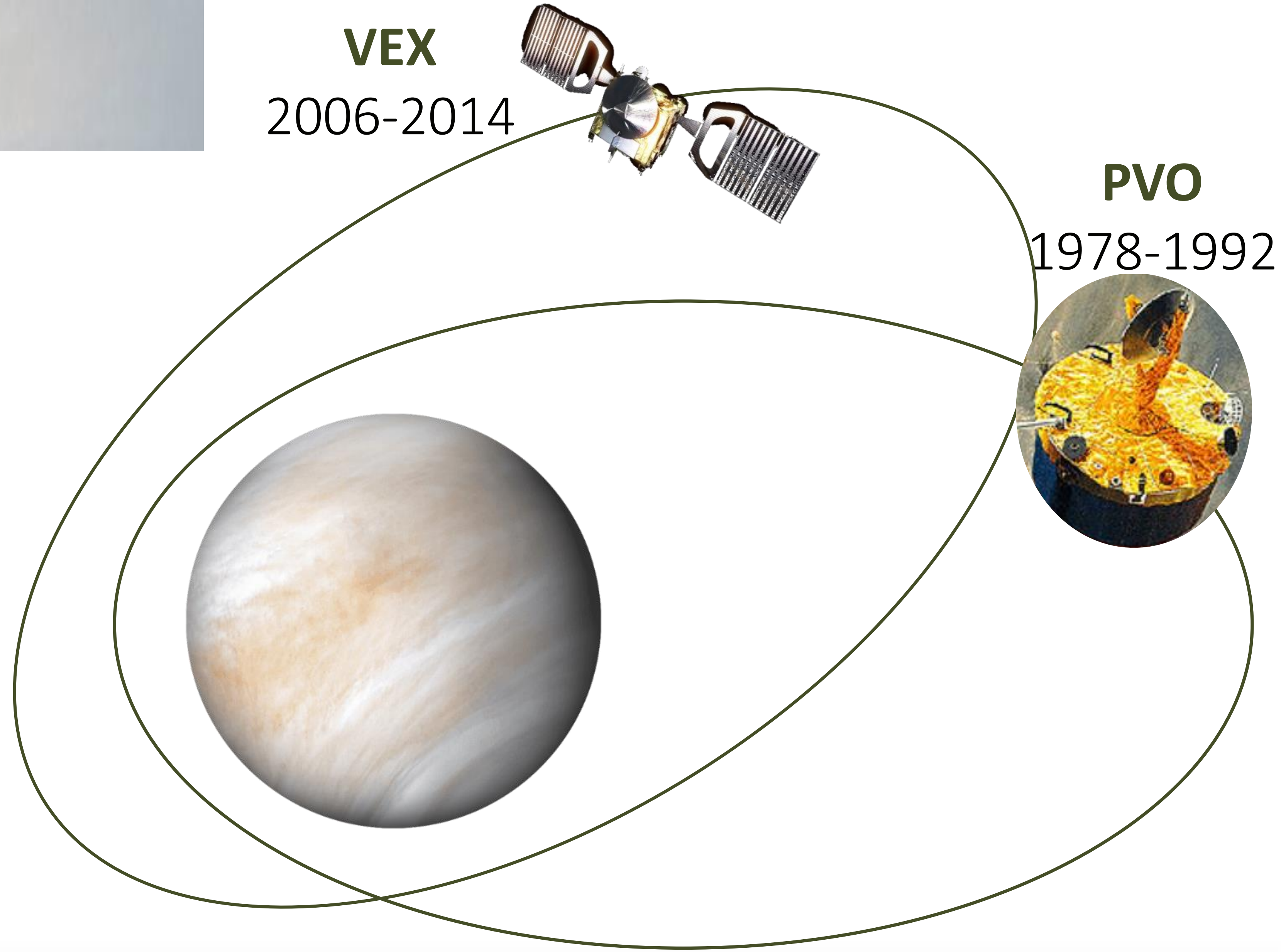
HERITAGE

PVO

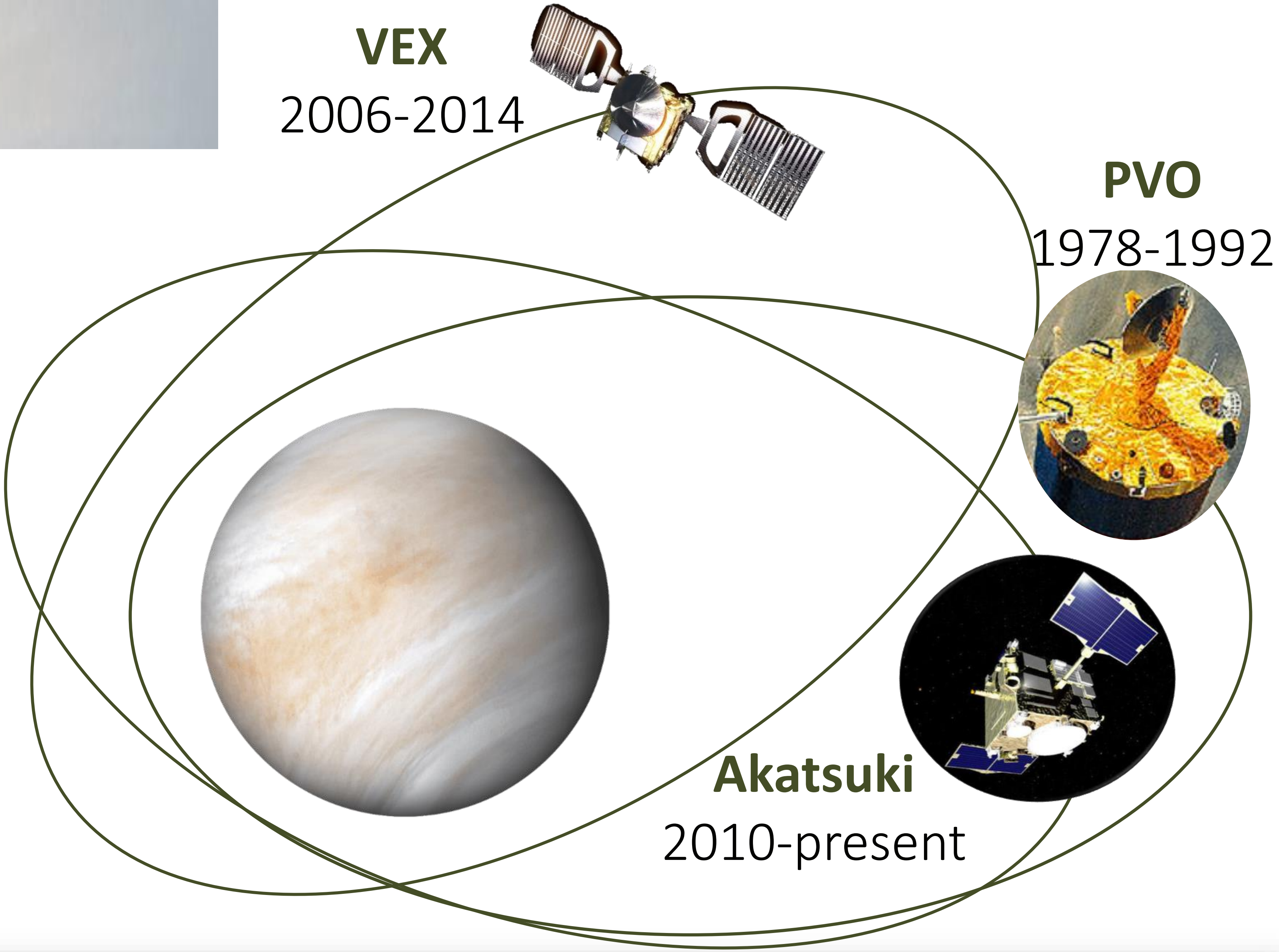
1978-1992



HERITAGE



HERITAGE

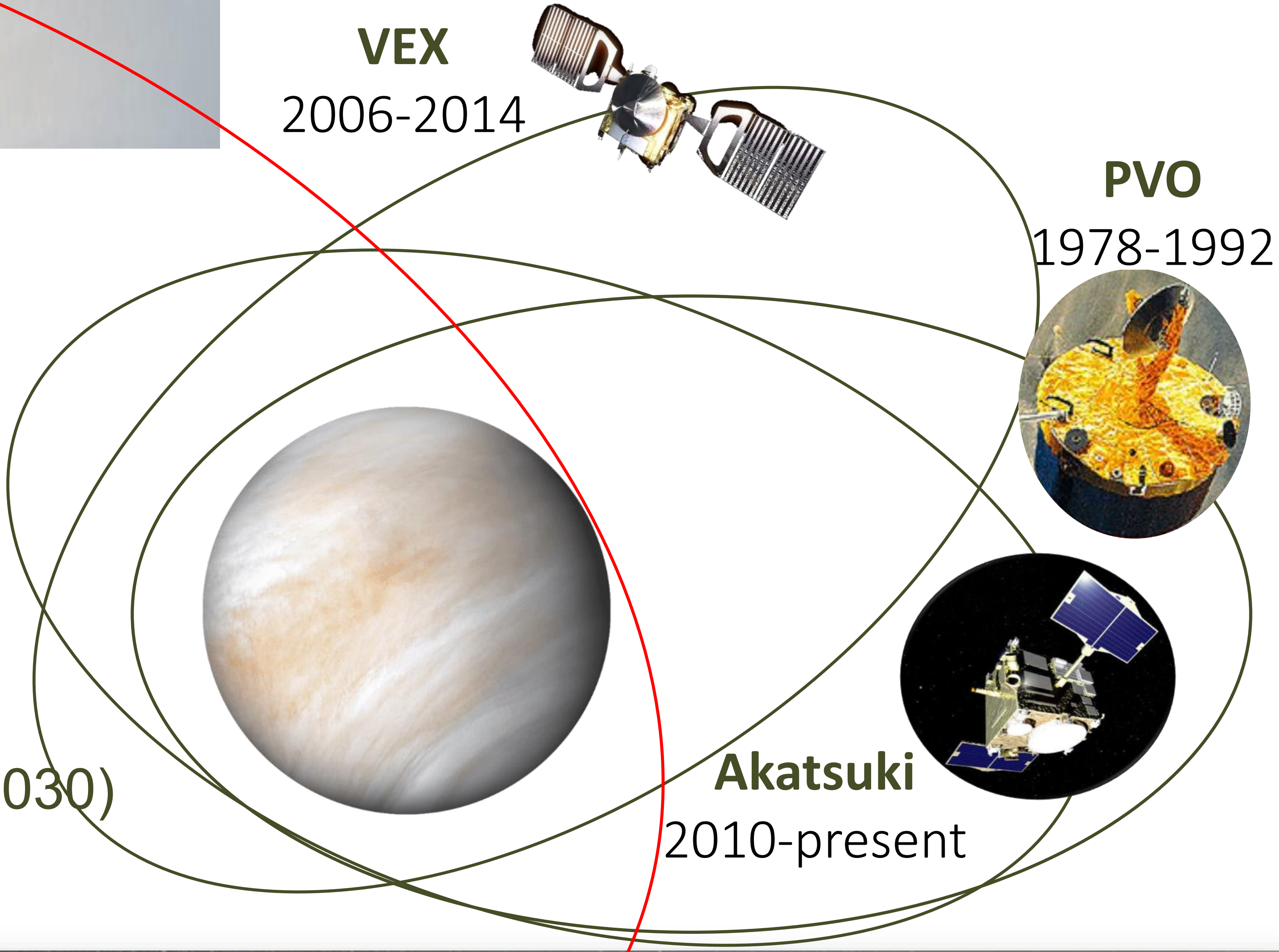


HERITAGE

BepiColombo
- 2 flybys of Venus
- CA : **552 km**

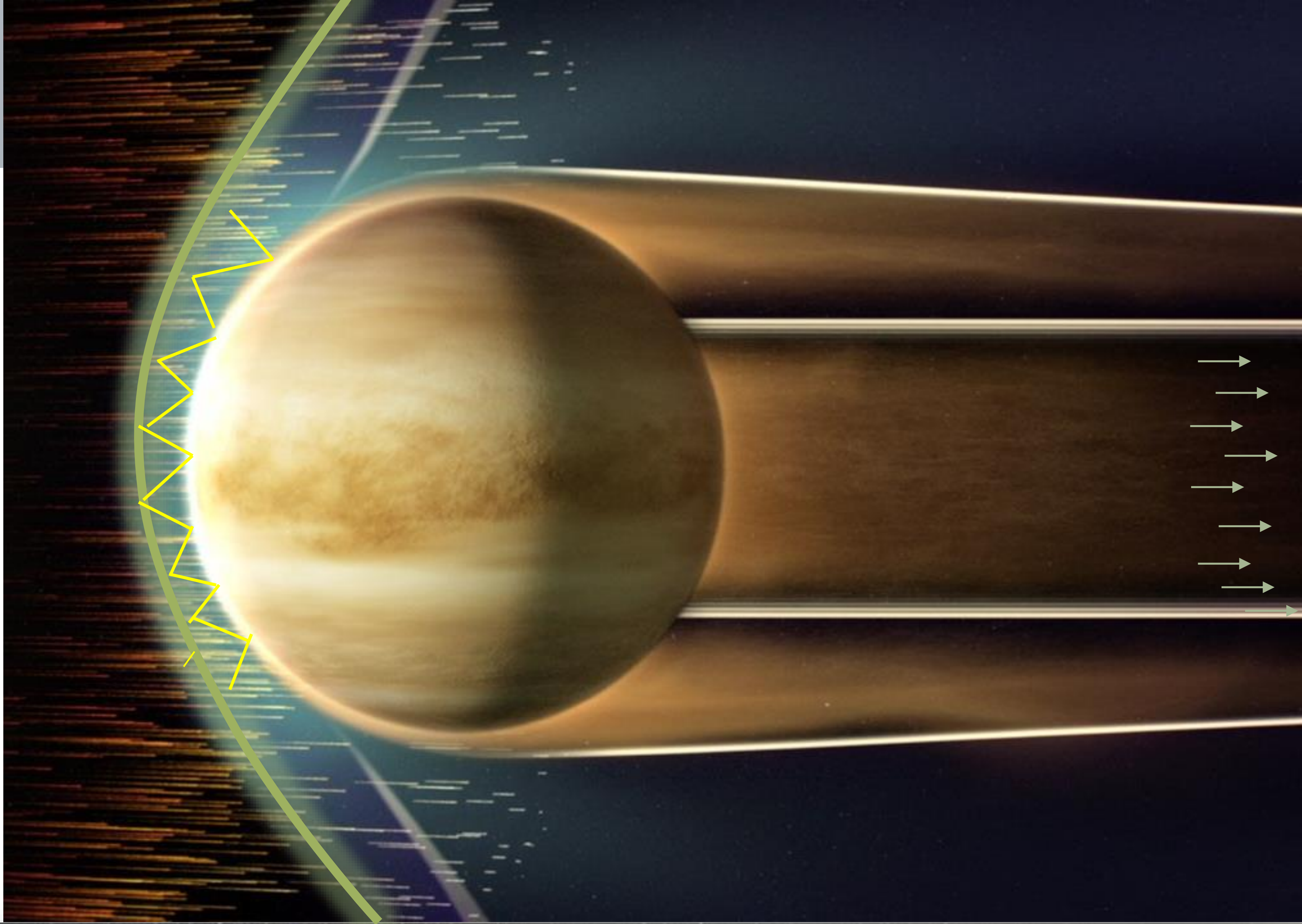
Parker Solar Probe
- 5 flybys (2 to come)

Solar Orbiter
- 2 flybys (6 more 2022-2030)
- CA : ~**8000 km**



CURRENT KNOWLEDGE

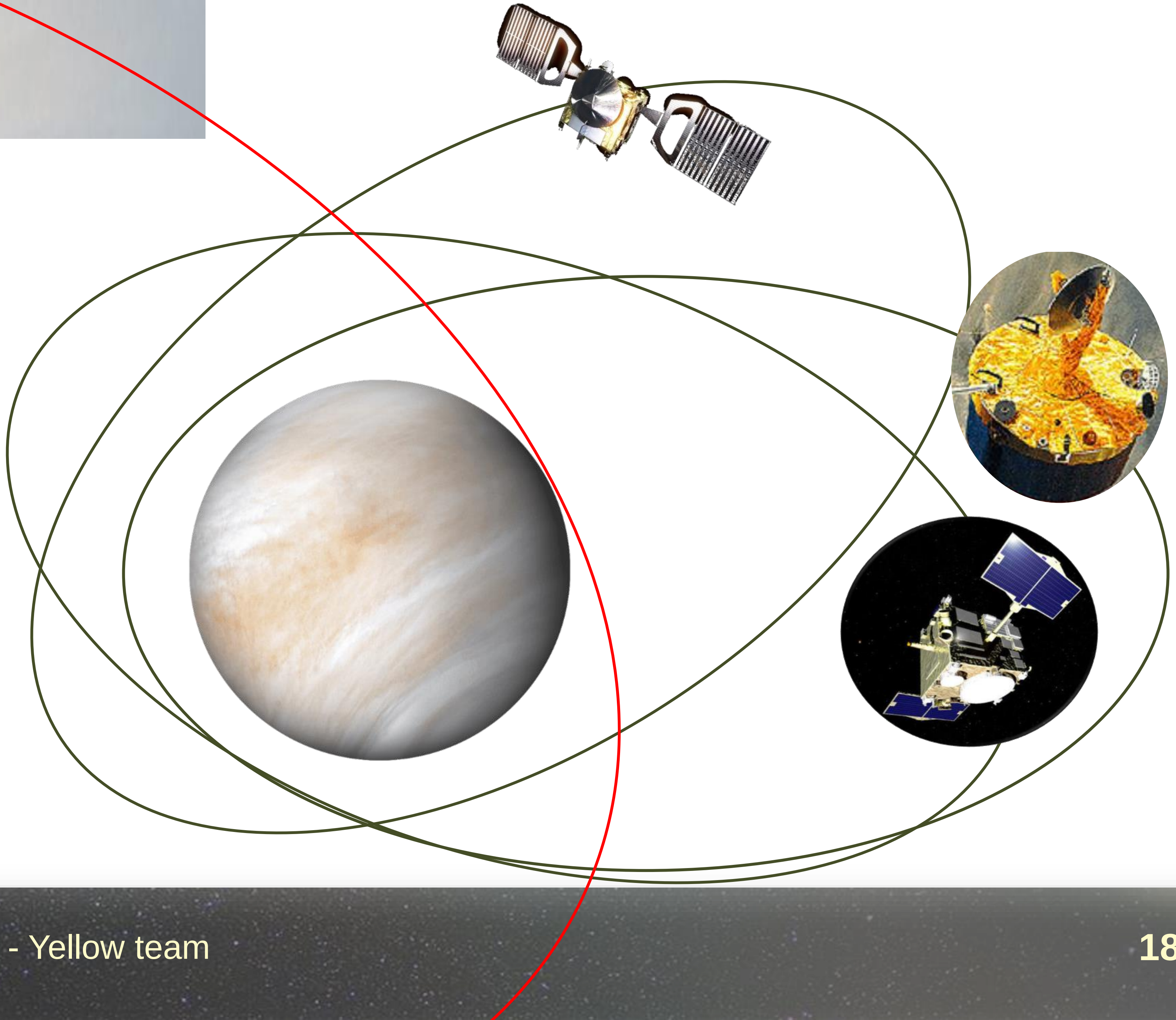
- Bow shock
- Magnetotail
  - Energetic particles at long distances
- Strong ionospheric variations



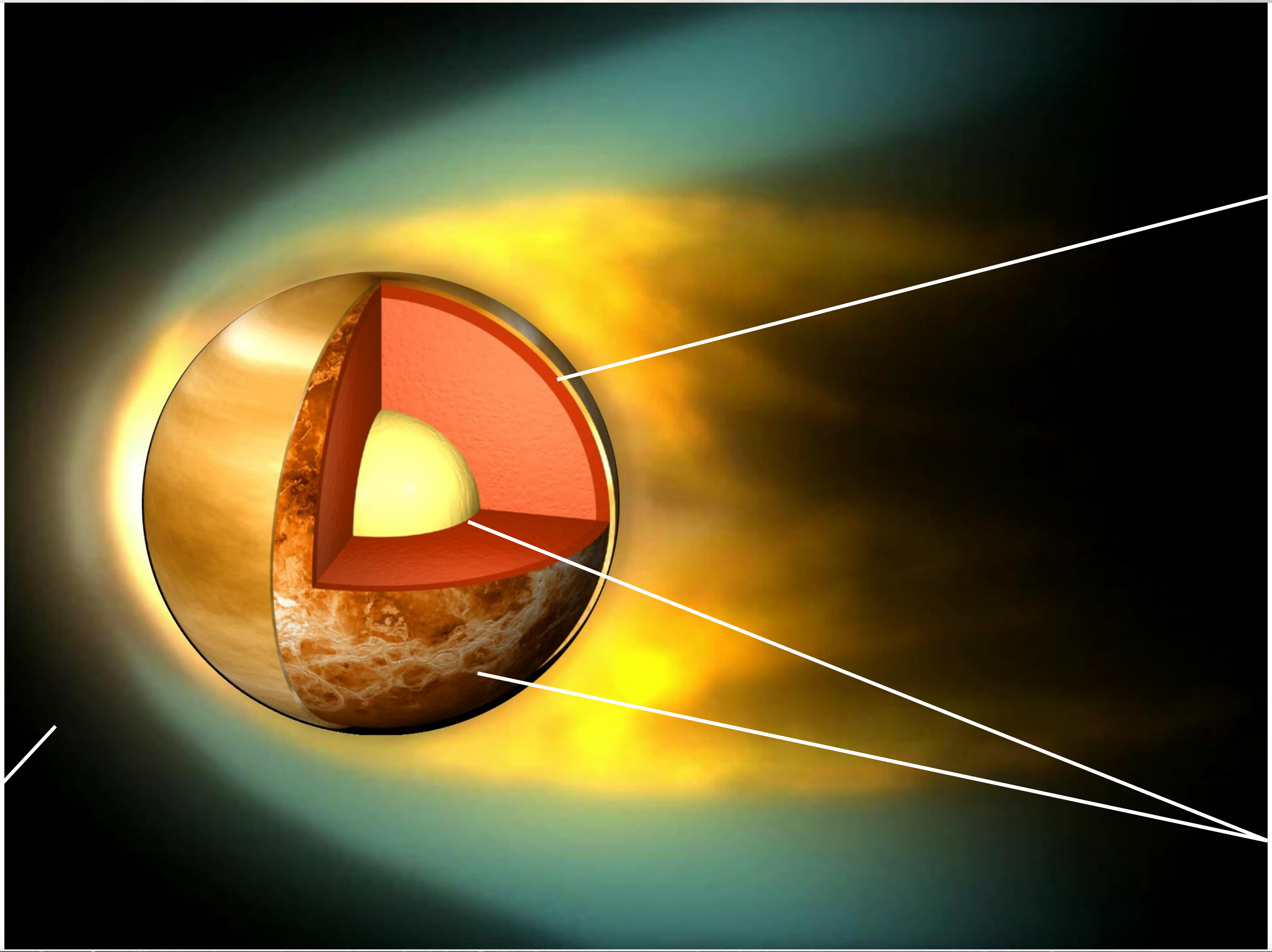
HERITAGE

- **One-point** measurements
  - Space
  - Time

- Not optimized for **plasma**
  - Temporal resolution



FUTURE MISSIONS TO VENUS

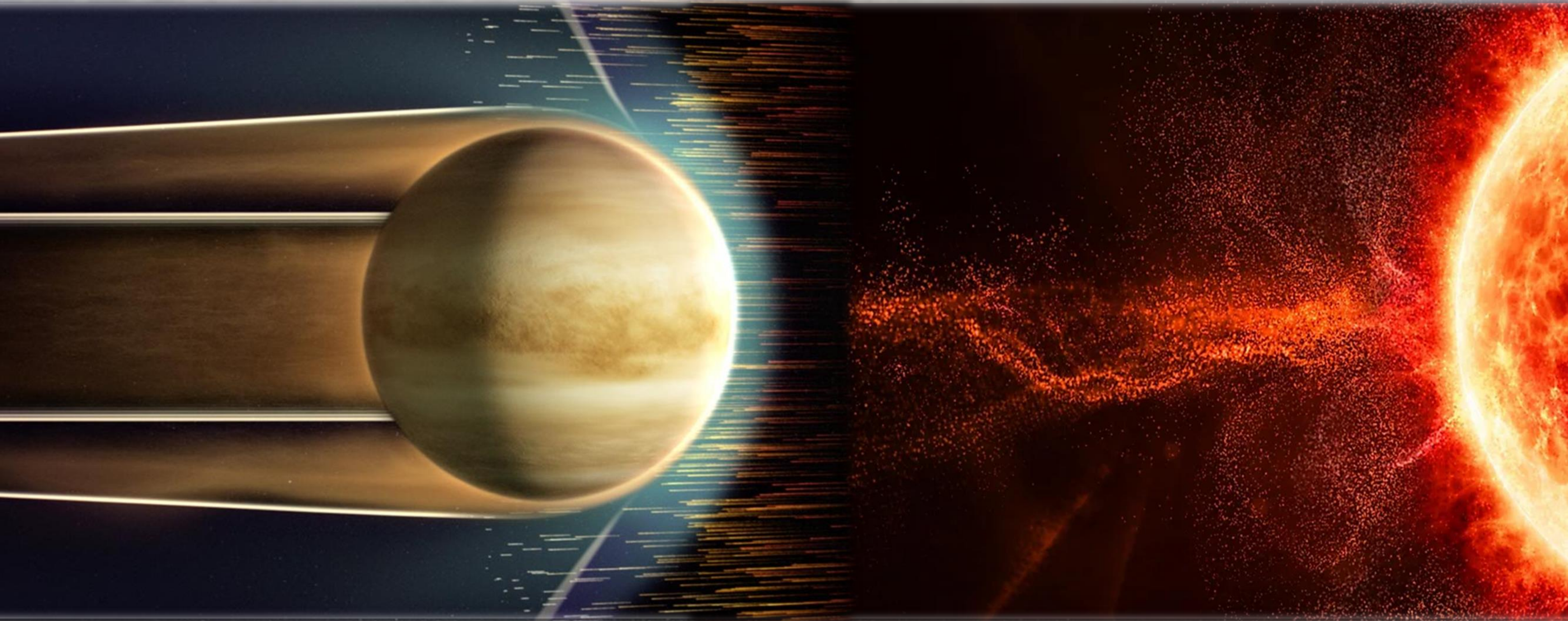


DAVINCI (NASA)
Investigate deep atmosphere, chemistry and imaging

EnVison (ESA)
High resolution radar mapping and atmospheric studies

Veritas (NASA)
Geological features and core composition

HOW DOES THE SUN DRIVE THE DYNAMICS OF AN INDUCED MAGNETOSPHERE ?



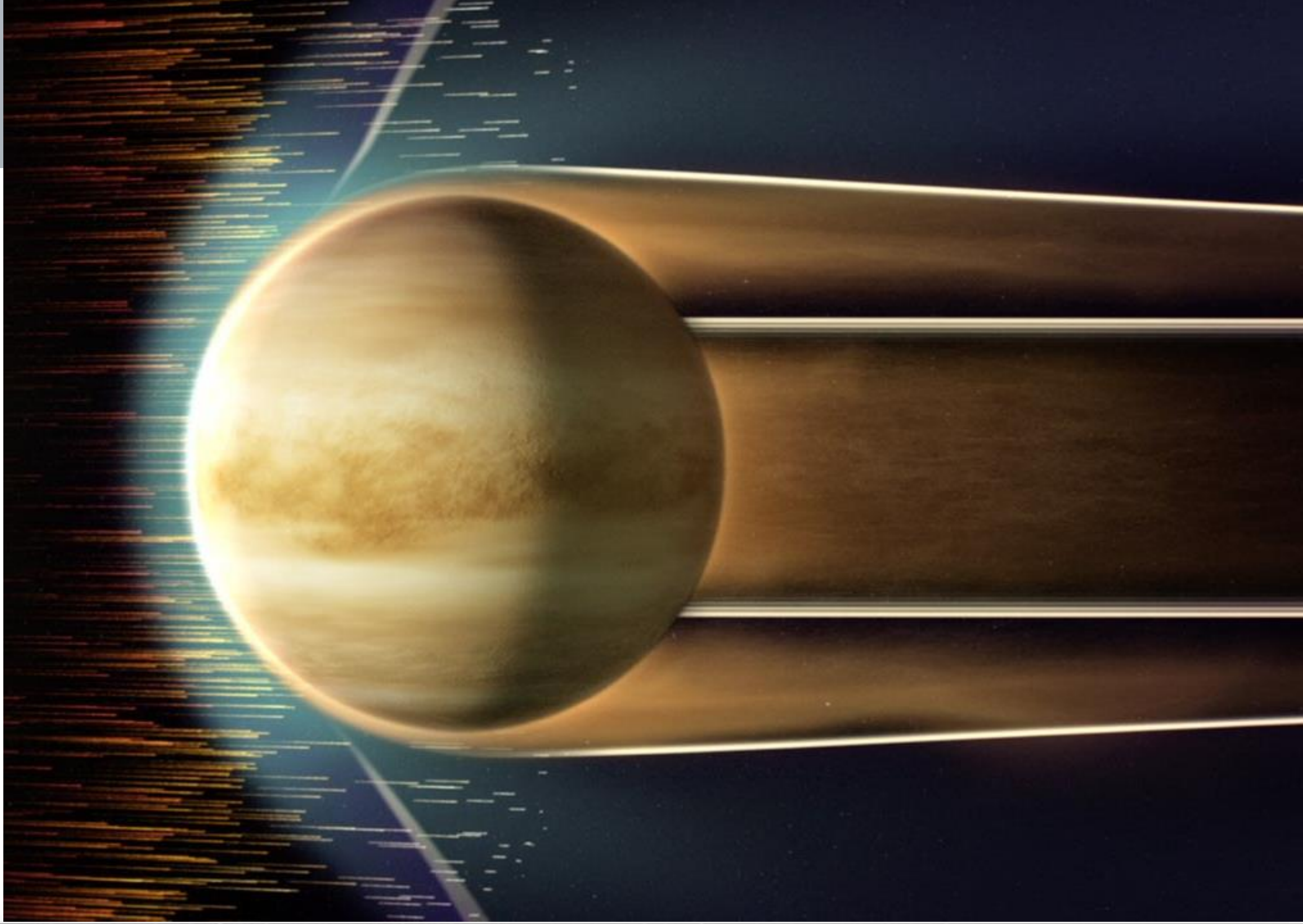
SCIENCE OBJECTIVES

SO 1 - Observe the ***reactions*** of an induced magnetosphere to the variations of the solar wind conditions

- SO 1.1 - Change of magnetosphere structure
- SO 1.2 - Variation of heating process

RATIONALE

- Variations in average range
- Typical structure
- Energy input



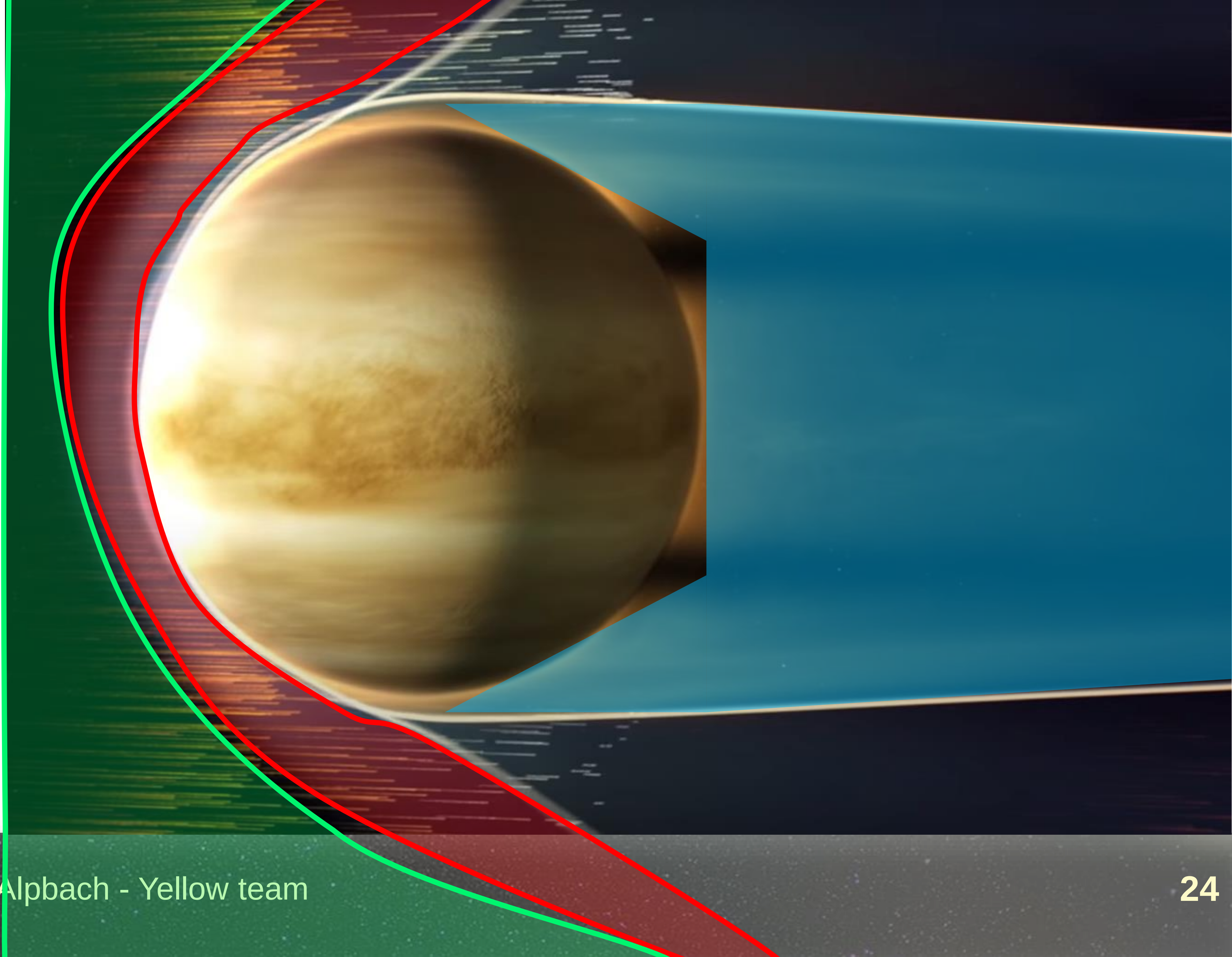
SCIENCE OBJECTIVES

SO 2 - Observe the reactions of an induced magnetosphere to ***solar eruptive events***

- Interplanetary Coronal Mass Ejections (ICMEs)
- Co-rotating Interaction Region (CIR)
- Solar Flares

Rationale: Solar eruptive events impose **extreme** boundary conditions

- Upstream of bow shock: **P1**
- Downstream of bow shock day side: **P2**
- Magnetotail: **P3**



ALPBACH SUMMER SCHOOL 2022

MVSE

MAGNETOSPHERIC VENUS SPACE EXPLORERS

TEAM YELLOW

SCIENCE AND INSTRUMENT REQUIREMENTS – FIELD MEASUREMENTS

Scientific Measurement Requirement	Instrument Performance Requirement
SR1 B-field (SO1/SO2): Measure the **3D magnetic field** with a frequency to resolve electromagnetic plasma waves	**IR1:** Measure magnetic field from DC to 2 kHz in a range ±600 nT with a resolution of ±0.1 nT for each component
SR2 E-field (SO1/SO2): Measure at least **two components of Electric field** with a high enough frequency to resolve plasma oscillations	**IR2:** Measure electric field from DC to ±100 $mV\ m^{-1}$ with a resolution of 0.1 $mV\ m^{-1}$

SCIENCE AND INSTRUMENT REQUIREMENTS – PLASMA PARTICLES

Scientific Measurement Requirement	Instrument Performance Requirement
SR3 Particle distribution (SO1/SO2): **Ion and electron distribution** with a frequency to resolve plasma waves affecting the plasma moments	**IR3:** 4π field of view and a resolution of 11.25°× 22.5°× 0.2 (res. azimuth × res. polar × ΔE/E) and a sampling rate of 4 s
SR4 Ion composition (SO1/SO2): Measurements of the **ion composition** to resolve the most common pickup ions from Venus' atmosphere	**IR4:** Mass spectrometer resolving H, He, O and C ions

SCIENCE AND INSTRUMENT REQUIREMENTS – LOCATION

Scientific Measurement Requirement	Instrument Performance Requirement
SR5 Location (SO1/SO2): Measurements of the **undisturbed solar wind**, measurements **downstream** of the **bow shock** on **dayside** and measurements in the **magnetotail**	**IR5:** One S/C in the dayside with distance **>1.7 Rv (P1)** One S/C in the dayside with distance **<1.3 Rv (P2)** One S/C in the nightside with distance **>3 Rv and <5 Rv (P3)**

SCIENCE AND INSTRUMENT REQUIREMENTS – TIME

Scientific Measurement Requirement	Instrument Performance Requirement
SR6 Orbit timing (SO1/SO2): SR5 shall be satisfied **simultaneously long enough** to measure reactions to solar wind	**IR6:** Ideal constellation for at least one hour continuously and at least once every

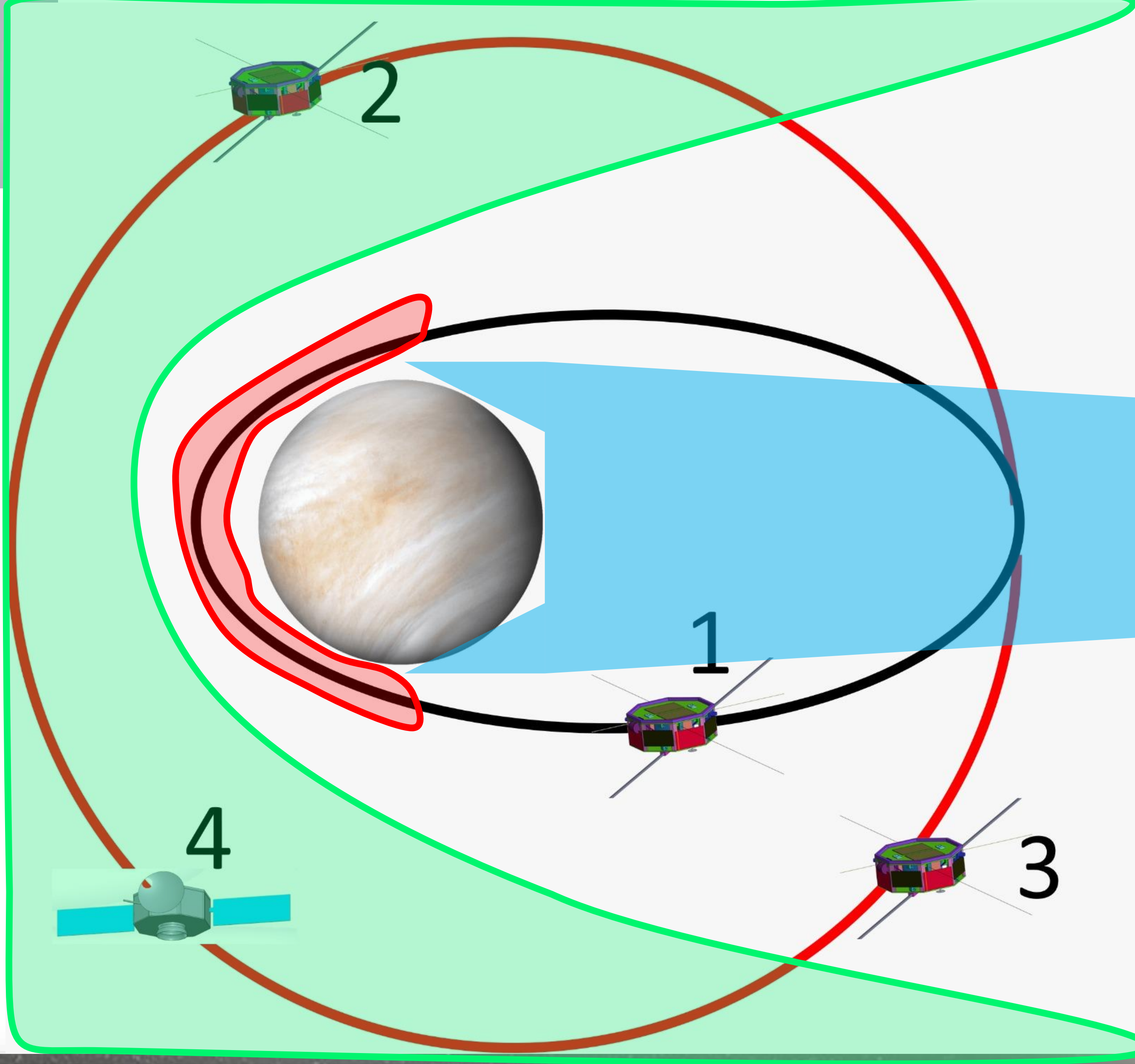
Mission Requirement
Mission duration (SO2): The mission shall measure **more than 10** solar eruptive events

SCIENCE AND INSTRUMENT REQUIREMENTS – KEY DRIVERS

Requirement	Driving
SR5 and SR6 Location and Time	**Mission architecture** Number of s/c and constellation
SR2, SR3 and SR4 Electric field and plasma properties	**Mission architecture** Spinning s/c

WHAT THE MISSION WILL DO?

- Multi-point measurements
- Measurements of dynamic plasma processes on short timescales
- State-of-the-art instrumentation



PAYLOAD

ALPBACH SUMMER SCHOOL 2022

MVSE

MAGNETOSPHERIC VENUS SPACE EXPLORERS

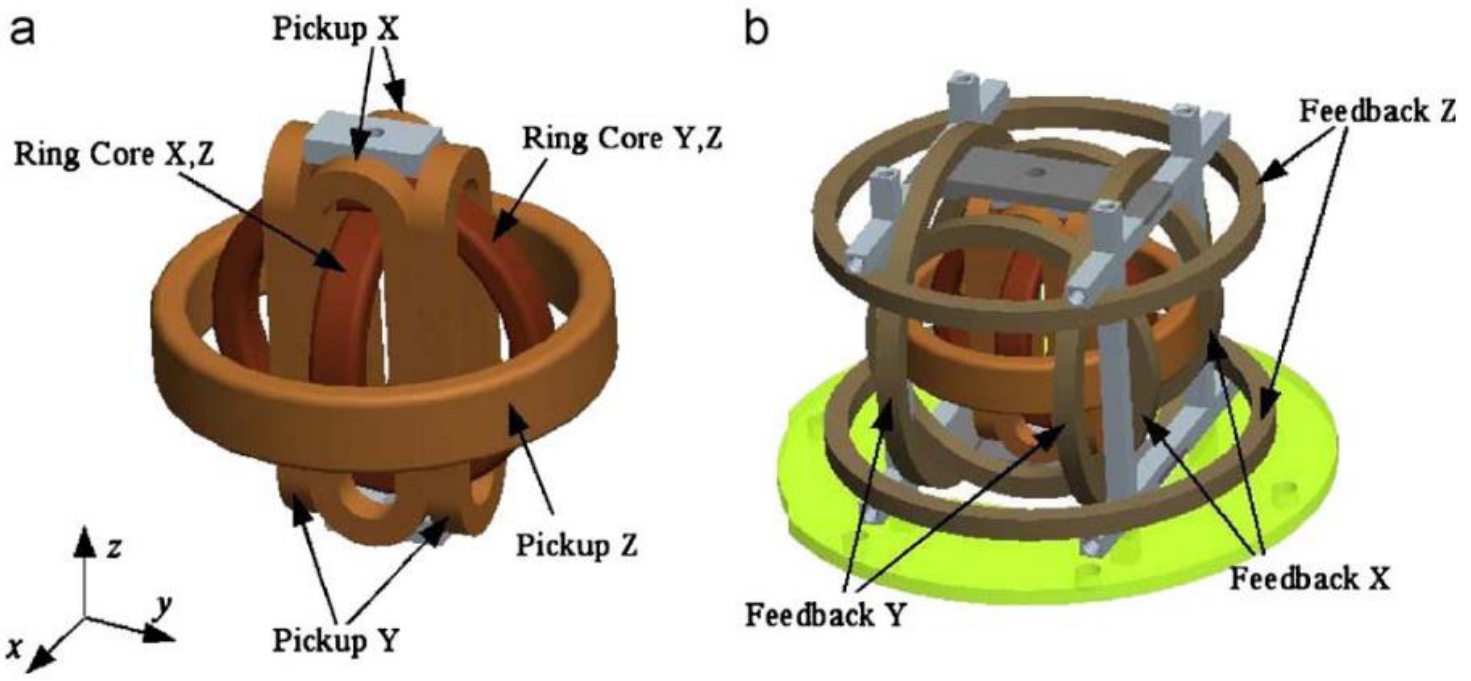
TEAM YELLOW

FLUXGATE MAGNETOMETER (FGM)

- Background magnetic field

- Range: +/- 2000 nT
- Time resolution: 128 Hz

- Satisfies IR1



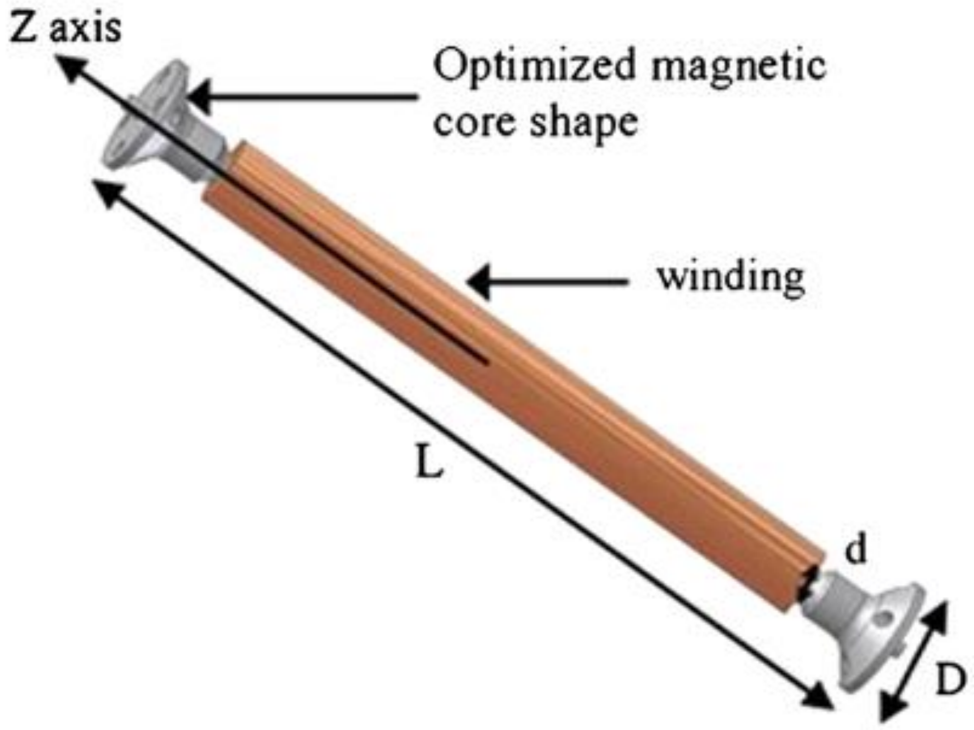
Glassmeier et al. 2010

SEARCH COIL MAGNETOMETER (SCM)

- High frequency magnetic field

- Range: +/- 5 nT
- Time resolution: 6kHz

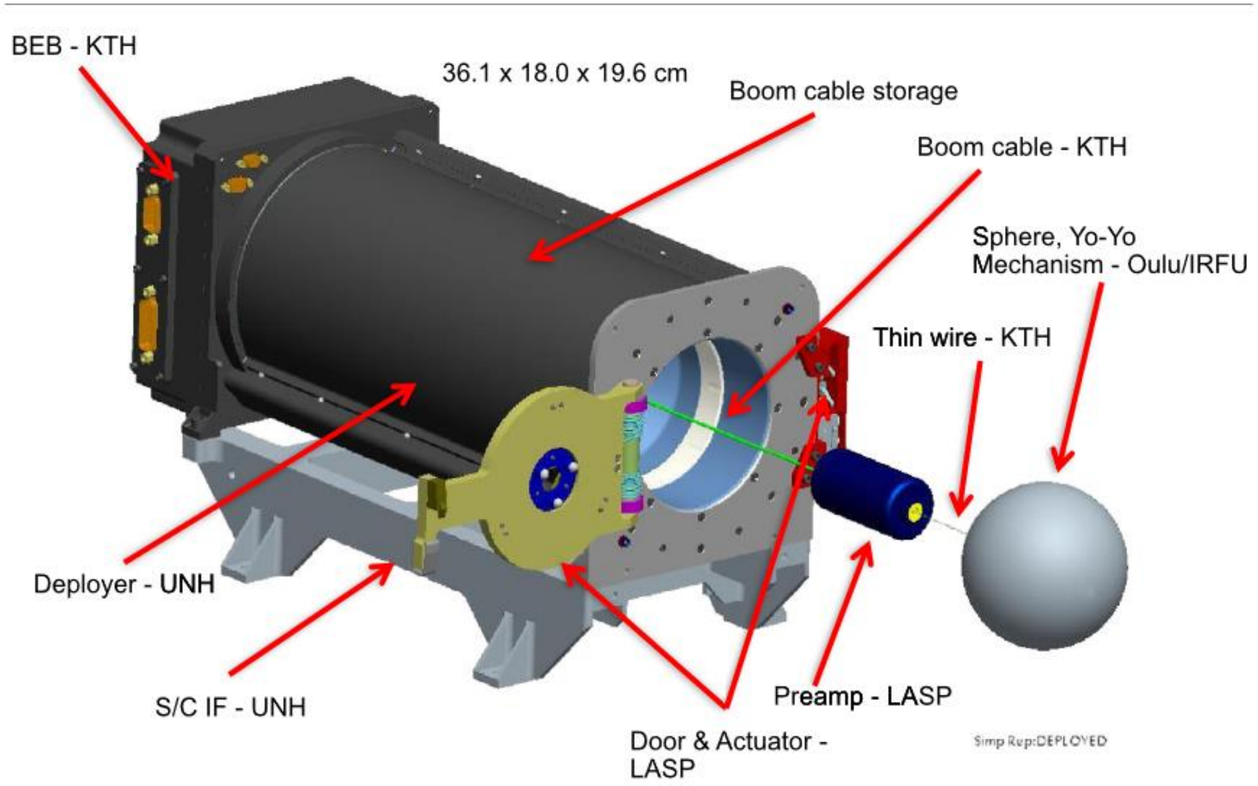
- Satisfies IR1



Le Contel et al., 2014

SPIN-PLANE DOUBLE PROBE (SDP)

- AC and DC electric field
- Range: **+/- 500 mV/m**
- Time resolution: **32kHz**
- Satisfies IR2

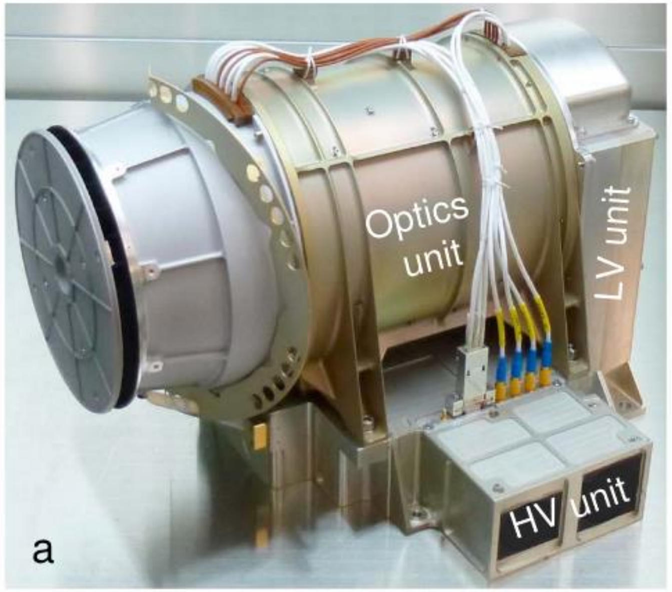


Lindqvist et al. 2014

MASS SPECTRUM ANALYZER (MSA)

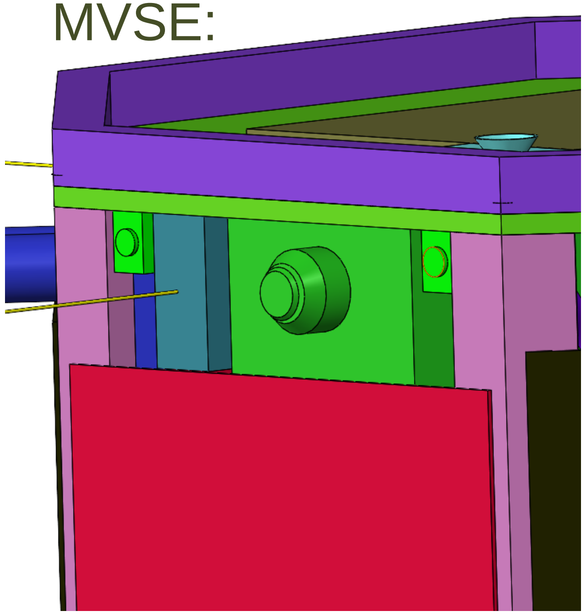
- Ion composition
- Mass resolution: **40**
- Time resolution: **8 s**
- Satisfies **IR4**

- Instrument configuration:



Delcourt et al., 2016

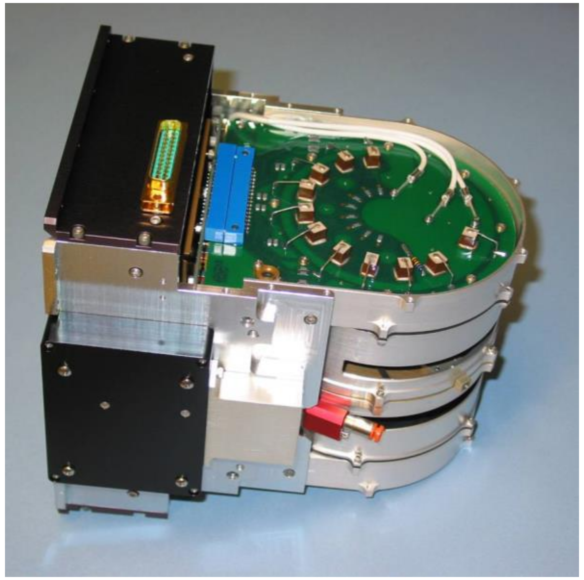
- Implementation in MVSE:



ELECTROSTATIC ANALYZER (ESA)

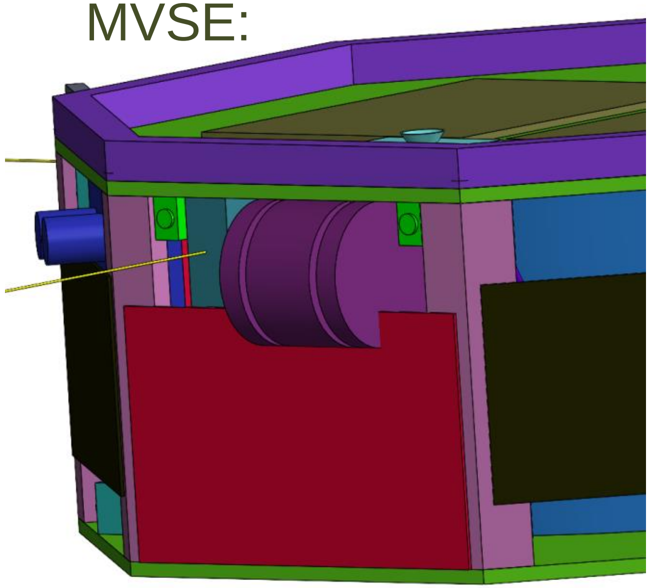
- Ion composition
- Ion Range: **1.6 eV – 50 keV**
- Electron Range: **2 eV – 36 keV**
- Time resolution: **4s**
- Satisfies IR3

- Instrument configuration:



McFadden et al., 2008a

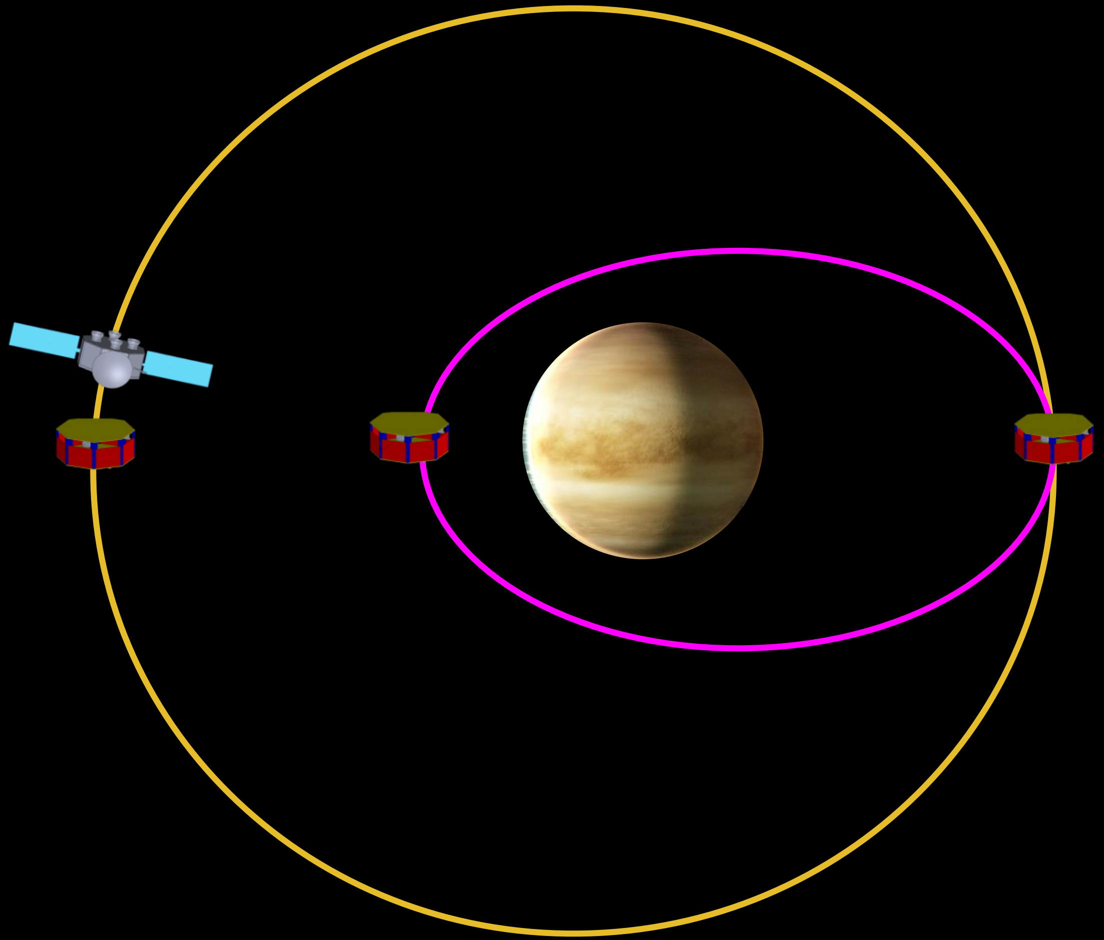
- Implementation in MVSE:



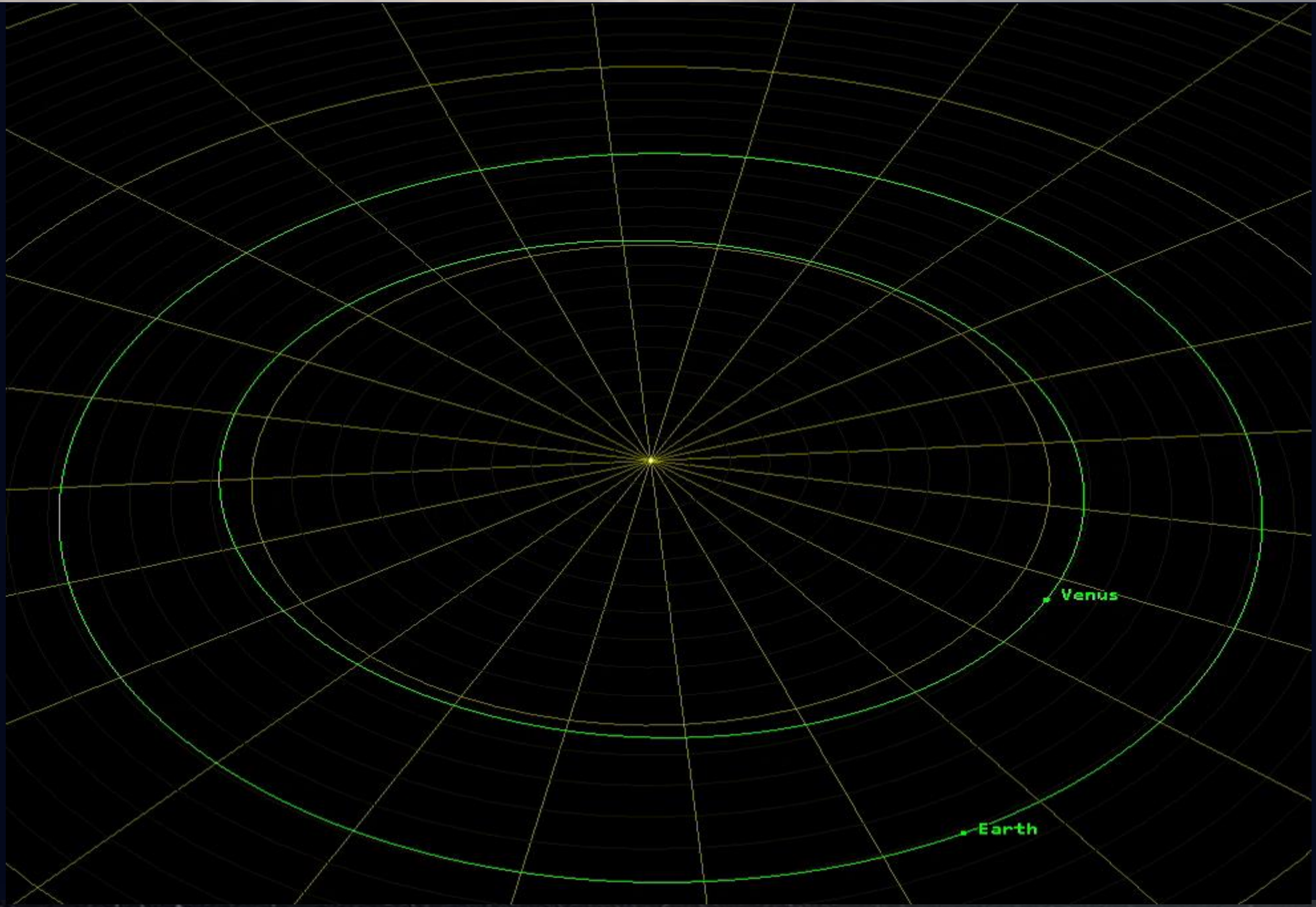
INSTRUMENT OVERVIEW

Instrument	m (kg)	P (W)	Data rate (kb/s)	Heritage
FGM	2.5	5.7	13	BepiColombo
SCM	0.42	0.13	400	MMS
SDP	4.3	0.4	400	MMS
ESA	1.6	2.5	12.3	THEMIS
MSA	4.46	9.1	20	BepiColombo
ASPOC	1.9	2.7	0.1	Cluster
TOTAL	**28**	**21.7**	**~ 830**	

ORBITS EXPLANATION



TRANSFER– EARTH TO VENUS (ANIMATION)

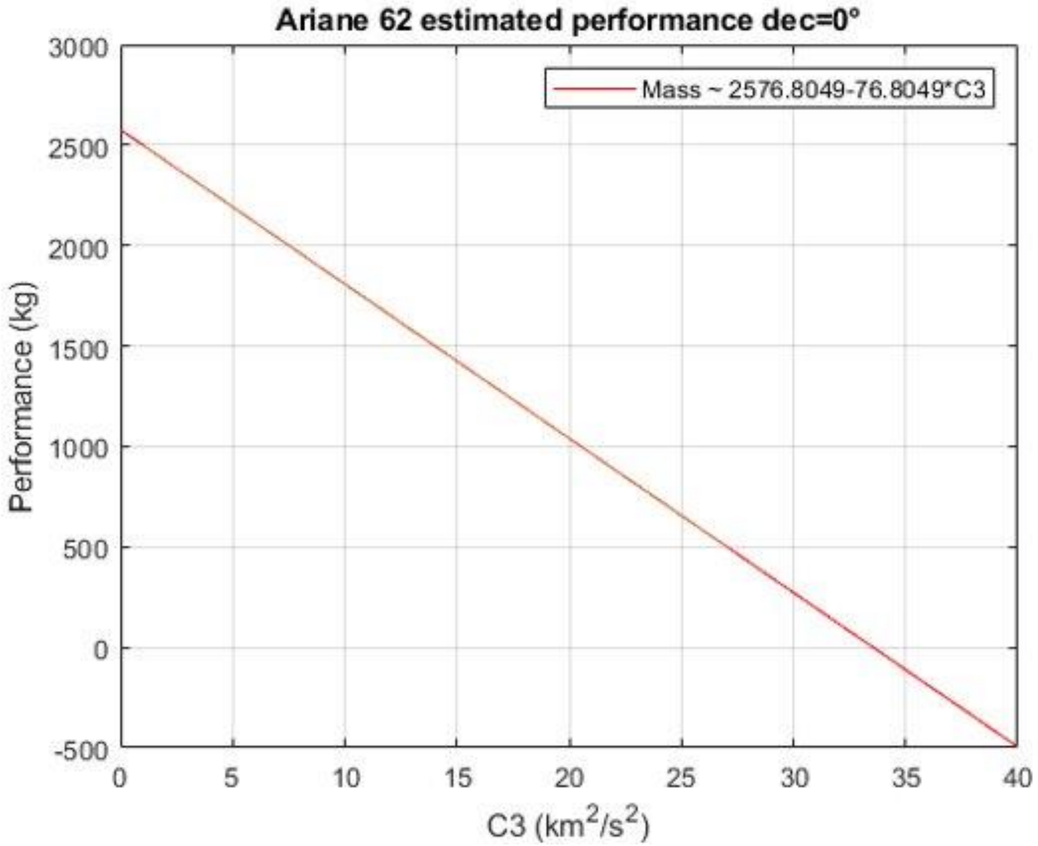


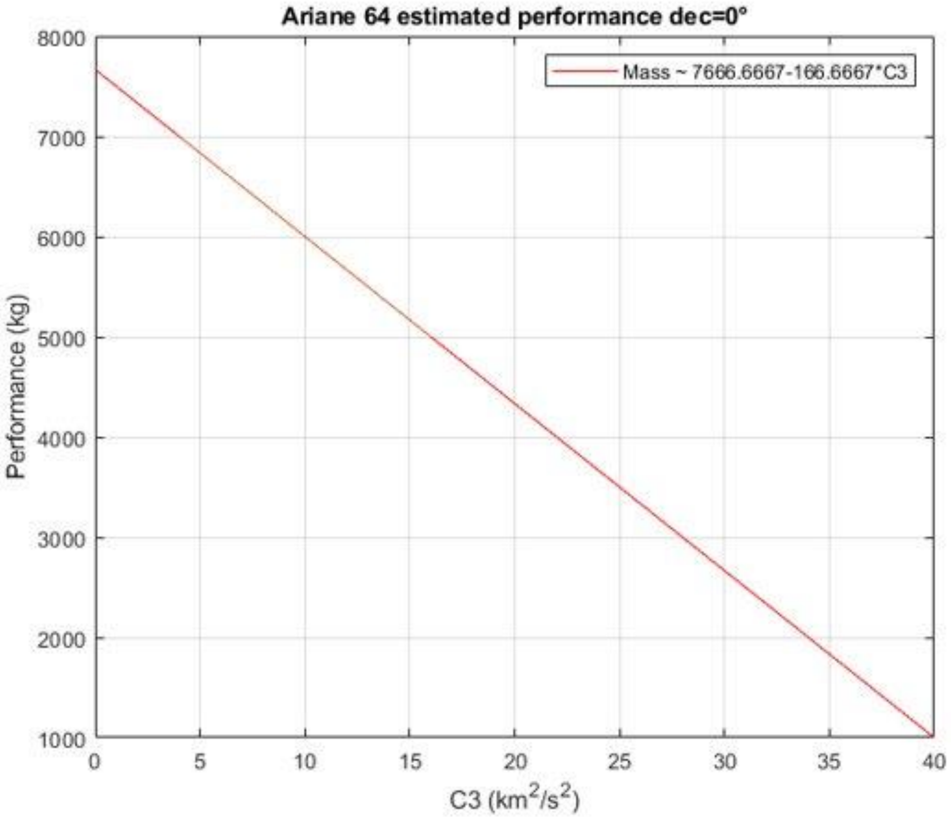
LAUNCH WINDOW AND TRANSFER TIME

- Optimal departure date: **6/12/2032**
- Arriving 157.53 days later, on 11/05/33
- Δv Launcher **= 3176.94 m/s**
  - C3 = **10.09 km²/s²**

Credits: DLR

LAUNCHER SELECTION





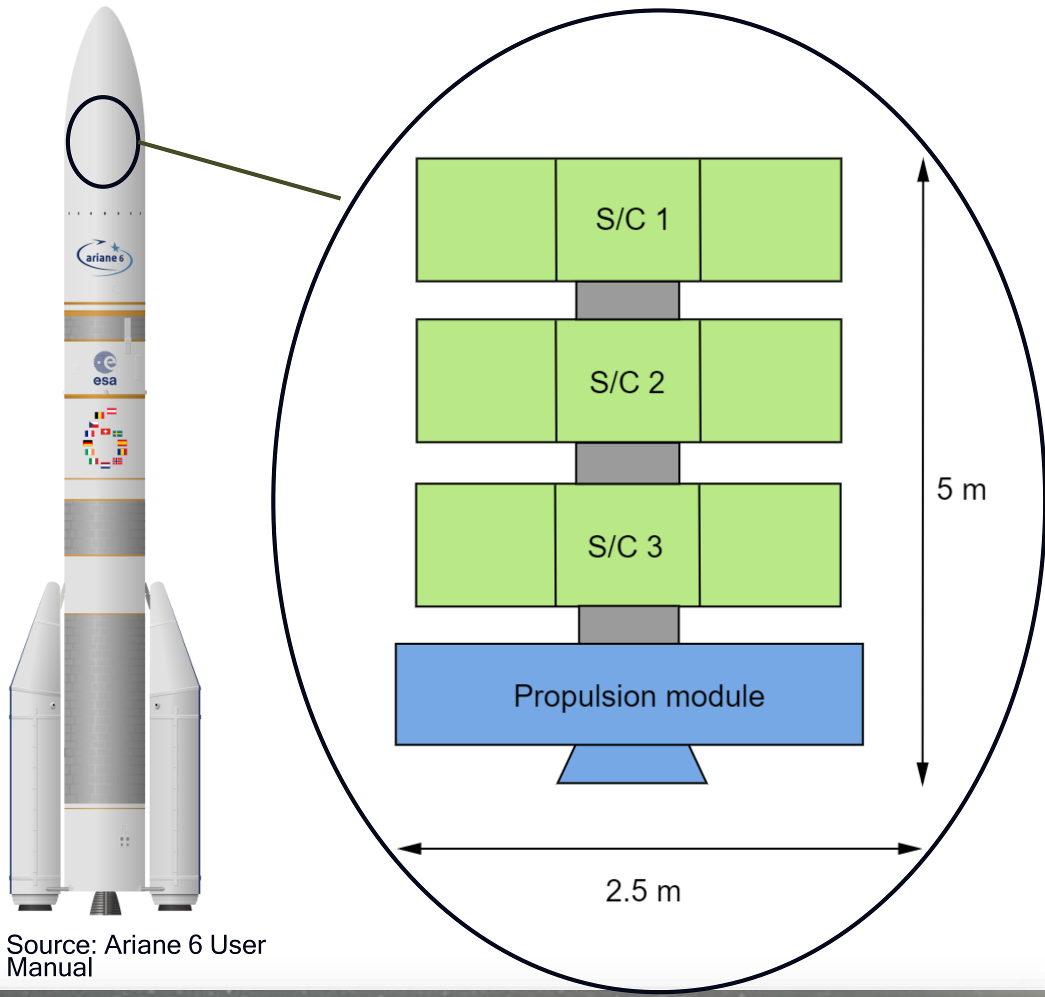
Optimal Performance with Ariane 62: **1801 kg**

Optimal Performance with Ariane 64: **5985 kg**

LAUNCHER

- **Fairing constraints:**
  - Max height: **14 - 20 m**
  - Max diameter: **5.4 m**
  - Launch adapter mass: **95 kg**

- Single launch containing **4 (3+1)** S/C.



Source: Ariane 6 User Manual

CHEMICAL PROPULSION

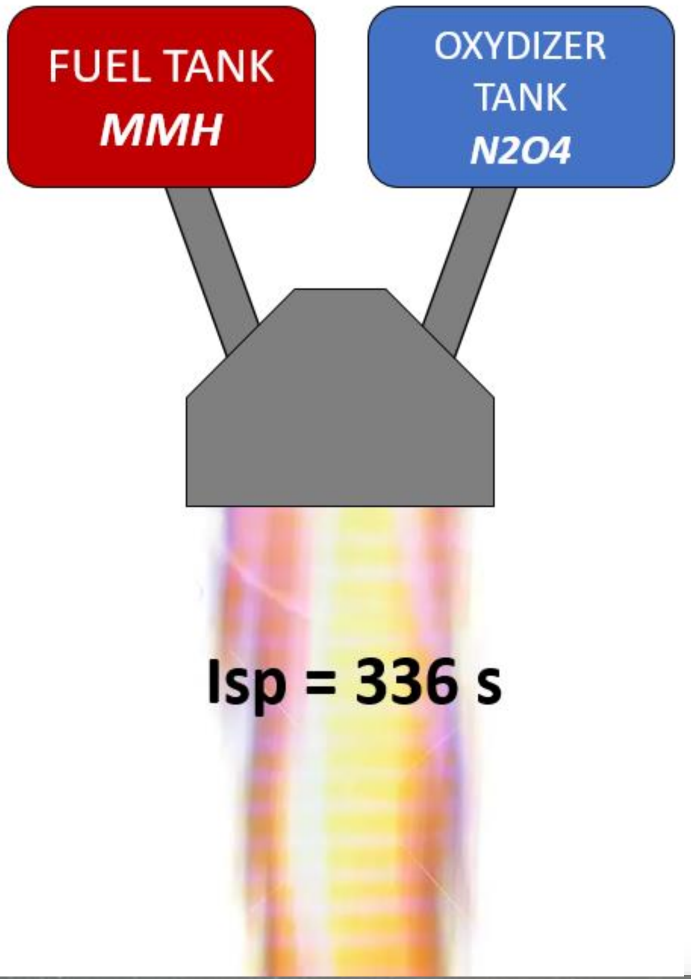
Chemical propulsion selected after **tradeoff** against electric propulsion.

Advantages:

- Lower transfer time with respect to electric propulsion

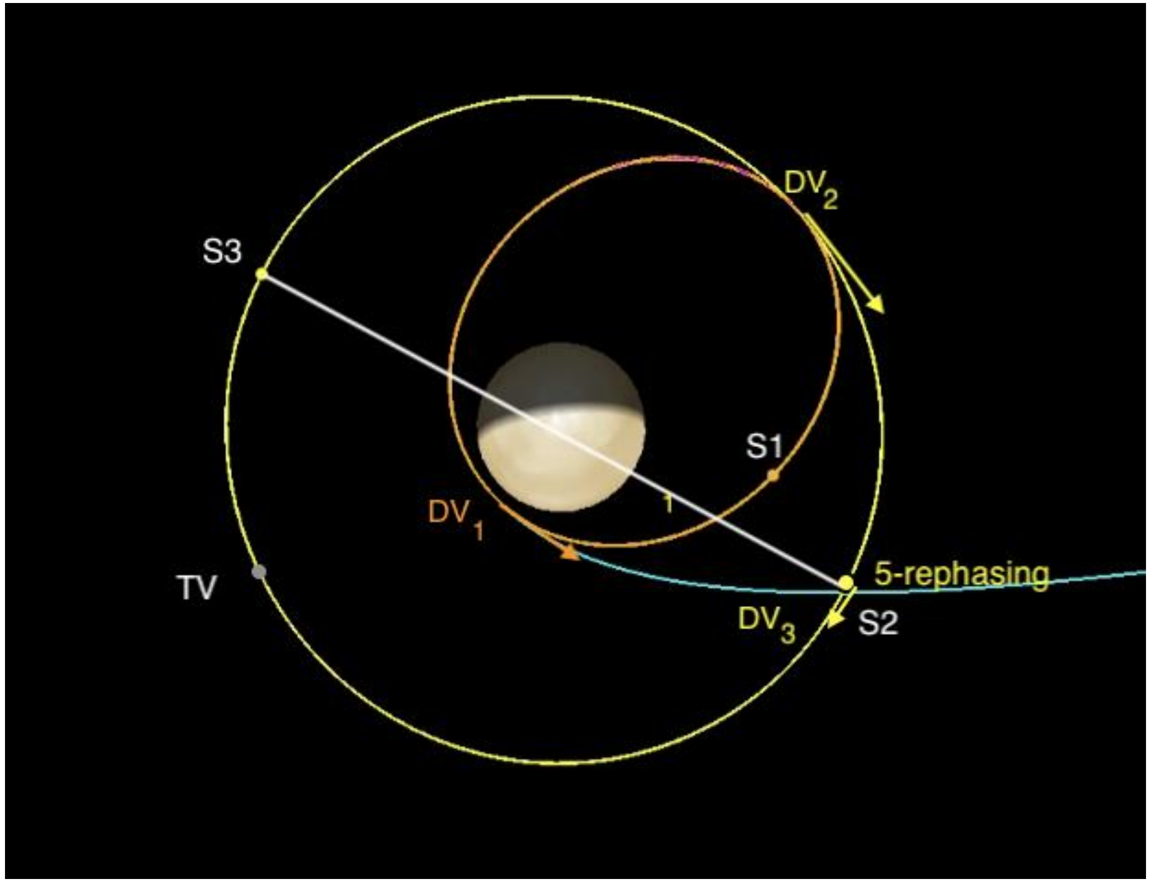
Selected propellant:

- Hypergolic → High Isp
- Widely used, flight proven technology



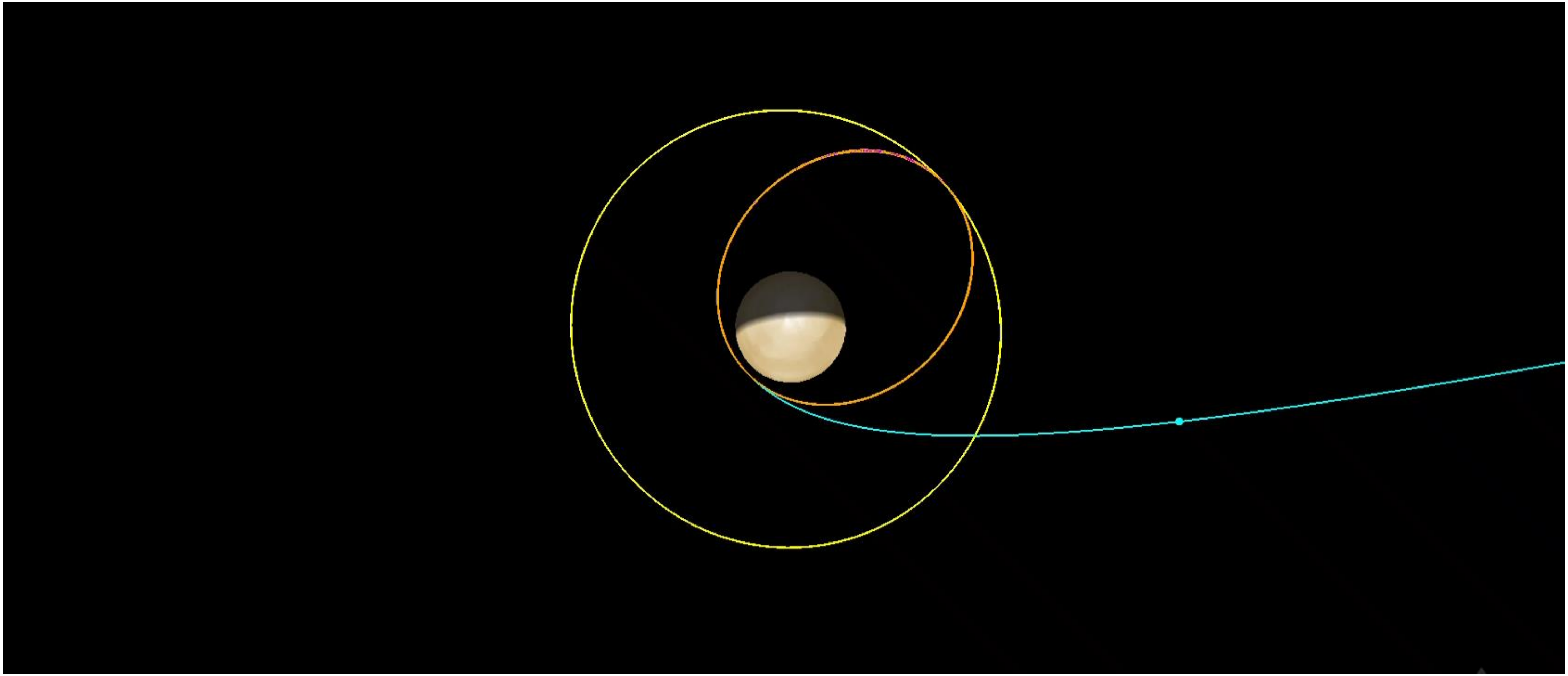
DELTA-V BUDGET

Date	Description	Delta-v (m/s)
15/12/32	small deep space correction ma nouver	0.17
11/05/33	insertion manouver into elliptical obit (e=0.55) at pericythe around venus	1534
12/05/33	circularization of sat 1 and sat2 at the apocythe of insertion ellipse	1200
	phasing manouver	200
througho ut mission lifetime	orbit mantainance and end of life	80 (20/year)
total dry mass (15% margin for propellent) for ariane62		***913 kg***



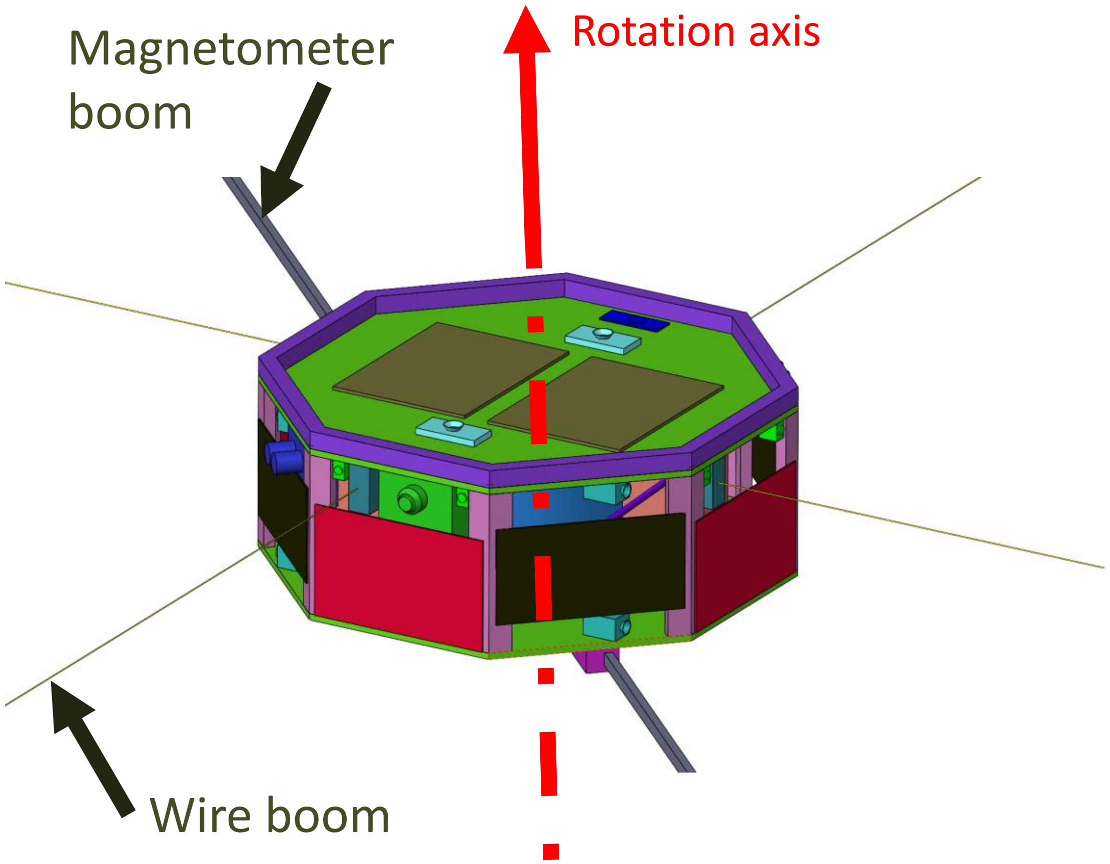
$$m_{prop} = m_0 \left[1 - \exp\left(- \frac{\Delta v}{g_0 I_{sp}} \right) \right]$$

ORBITS AROUND VENUS (ANIMATION)



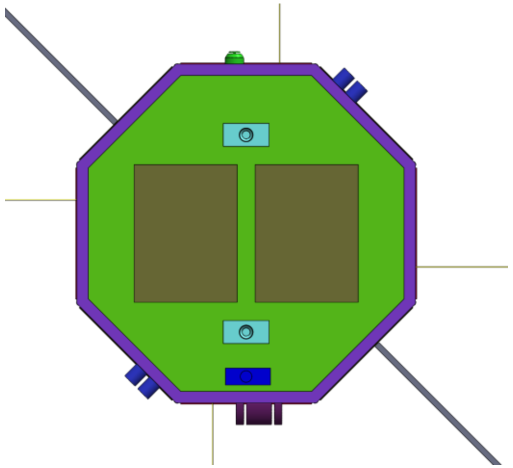
SCIENTIFIC SPACECRAFT CONFIGURATION

- **Spin-stabilized** spacecraft, octagonal layout.
  - Estimated rotation rate of ~10 rpm, according to previous missions (METHIS, MMO, MMS).
  - Enables 360º coverage of the solar wind.
- **2** stiff magnetometer booms + **4** wire electric field booms.
  - Horizontal separation to minimize electromagnetic interference.
- In figures:
  - Dry mass: 153 kg
  - Power consumption: 210 W
  - Dimensions: Ø1.6 x 0.7 m

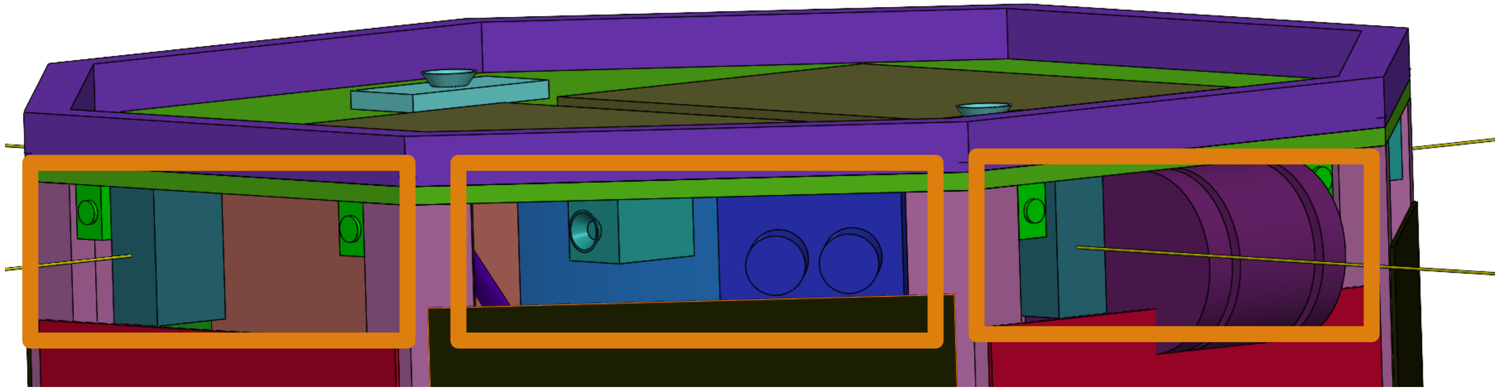


SCIENTIFIC SPACECRAFT CONFIGURATION

- **Lateral surface:** solar array + antenna array + instrument entrances.
- **Top surface (+z):** instruments attached to the lower deck, heat radiators on the upper deck.
- **Lower surface (-z):** extra electric field antenna (TBC).
- Payload, AOCS sensors and actuators located radially outwards.



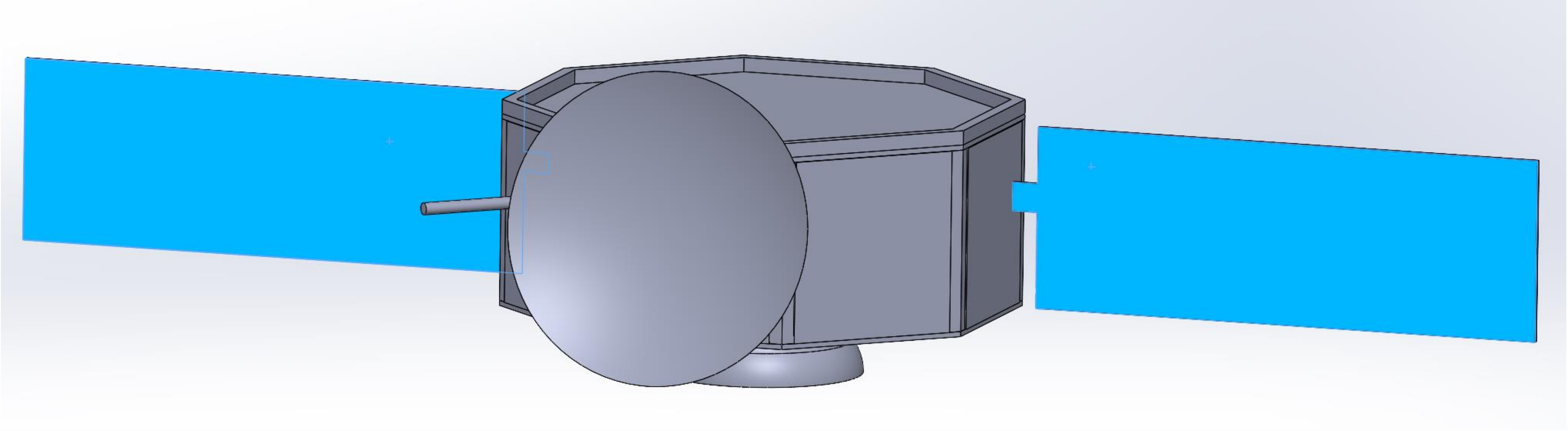
Instrument bays available at each of the 8 sides.



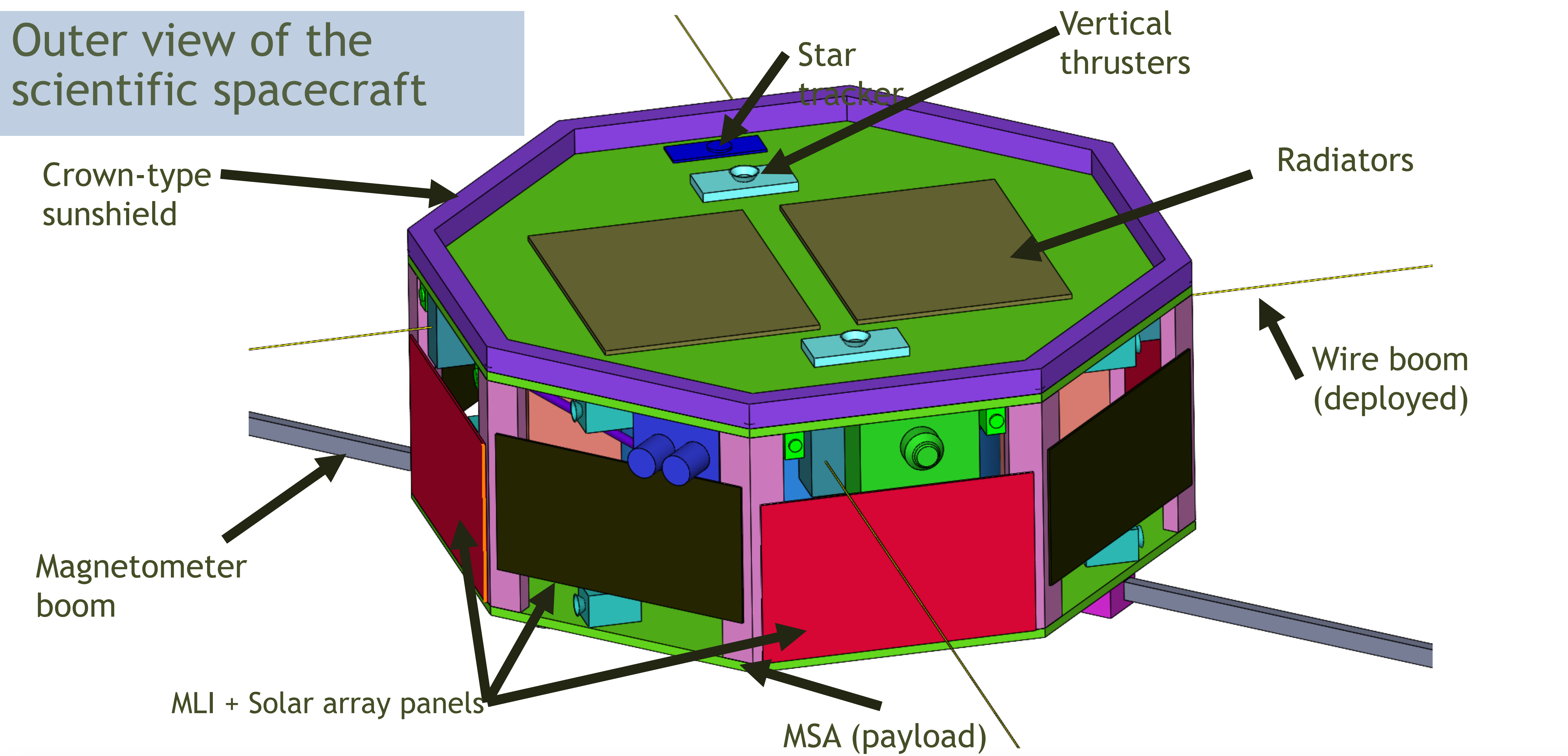
PROPULSION VEHICLE (RELAY) CONFIGURATION

- Functionalities:
  - Propulsion module during transfer and insertion.
  - Telecommunication relay during nominal operation.
- Antennas:
  - **High-gain antenna** for downlink data transfer.
  - **Low-gain antenna** for housekeeping operations.

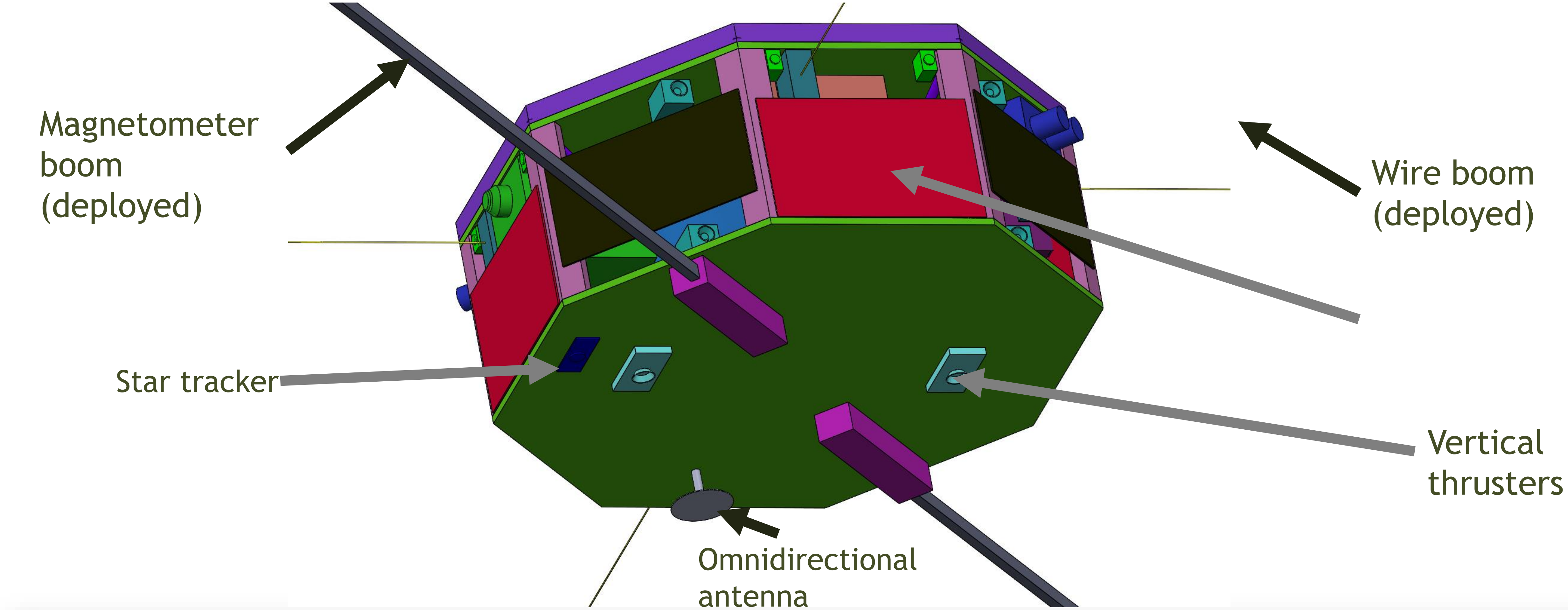
- In figures:
  - Dry mass: 250 kg
  - Power consumption: 470 W
  - Dimensions (folded): Ø2.1 x 1 m
  - Dimensions (extended): 6 x 2.1 x 0.9 m



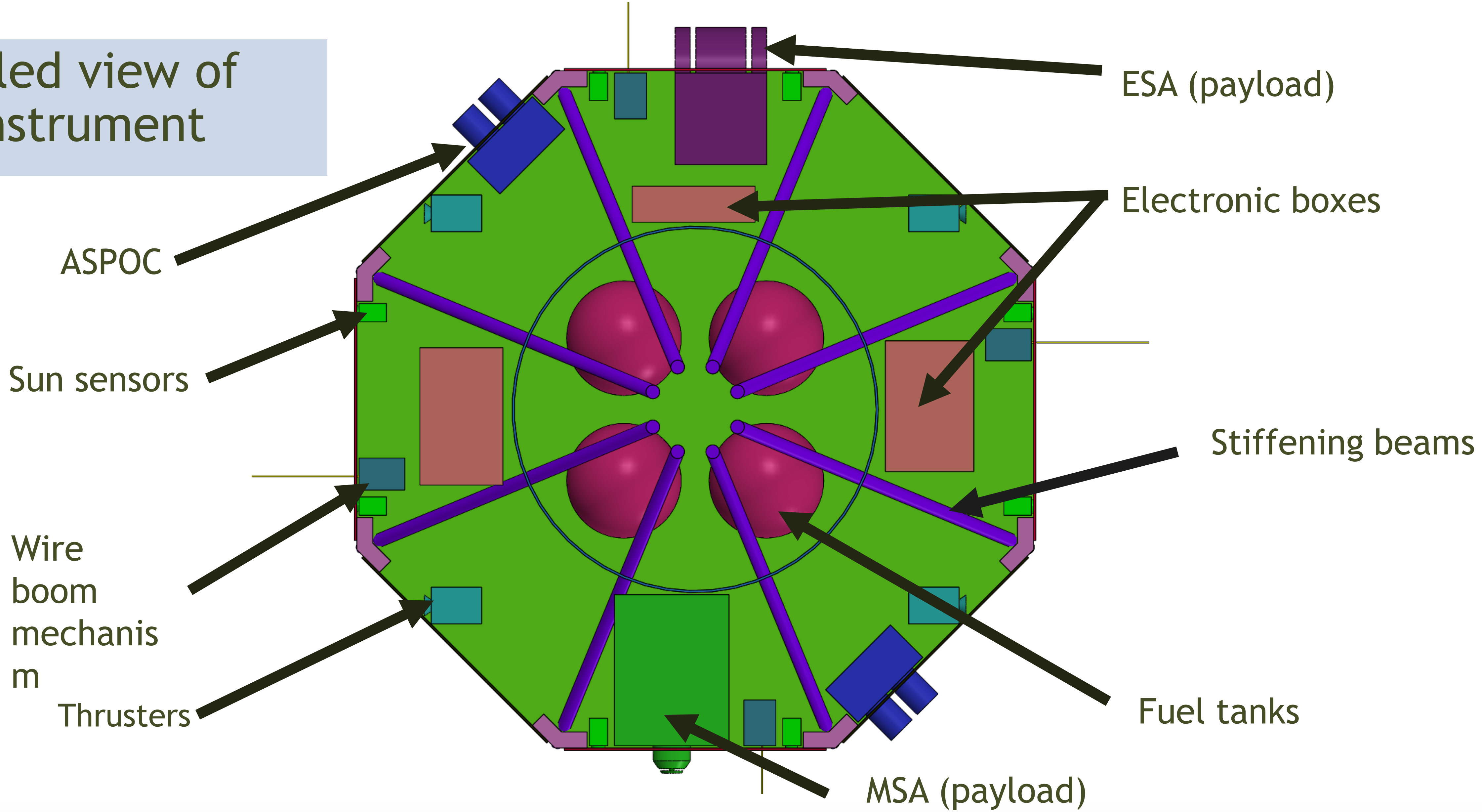
Outer view of the scientific spacecraft



Outer view of the scientific spacecraft

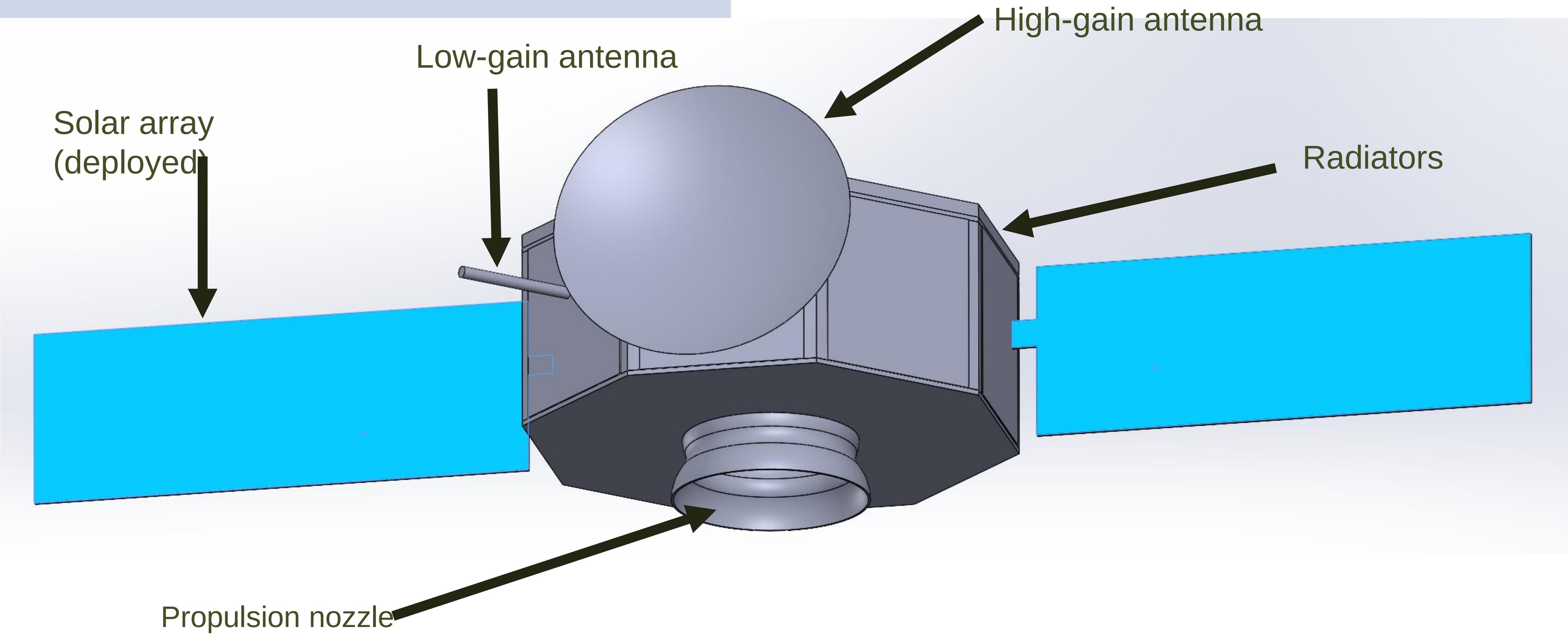


Detailed view of the instrument deck

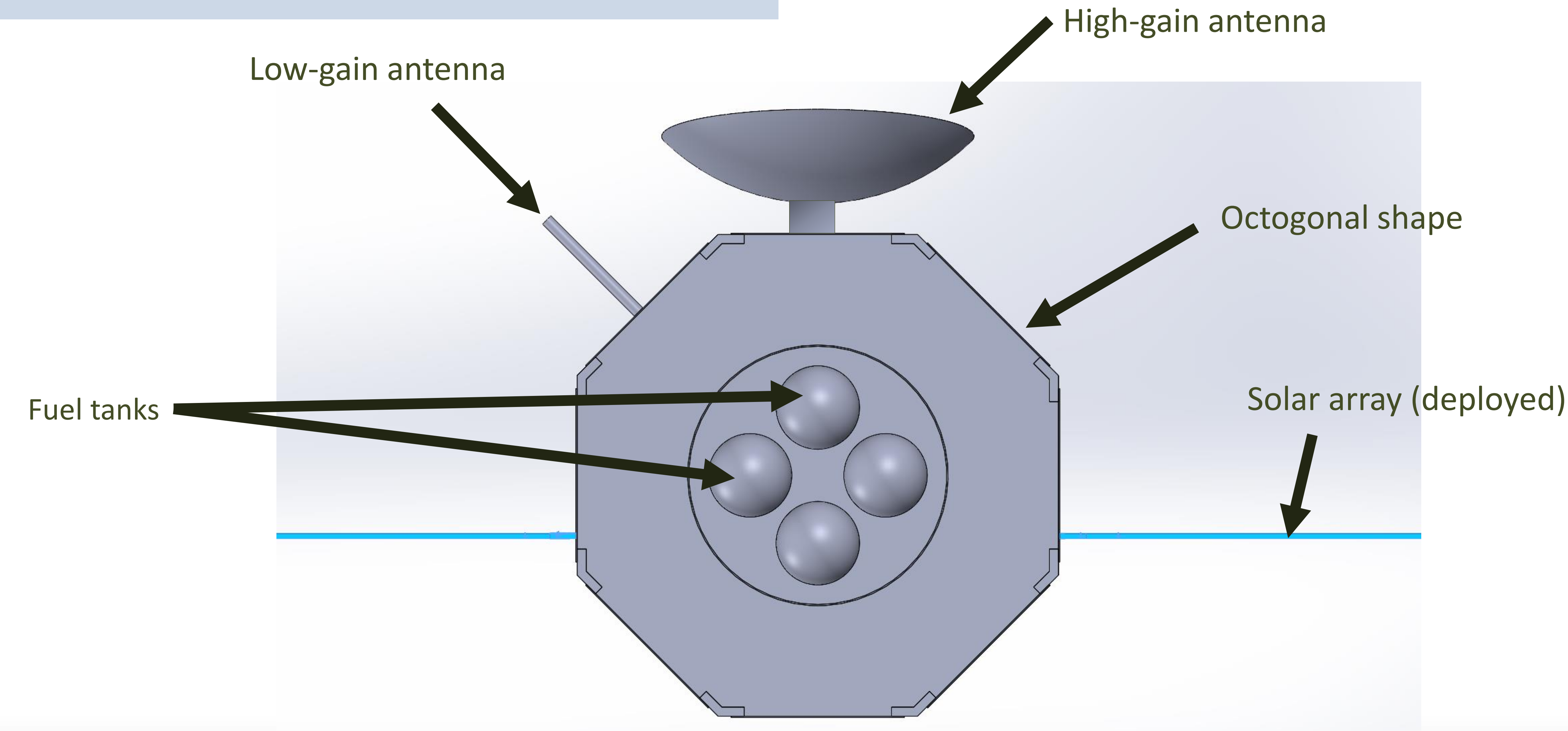


SCIENTIFIC SPACECRAFT CONFIGURATION

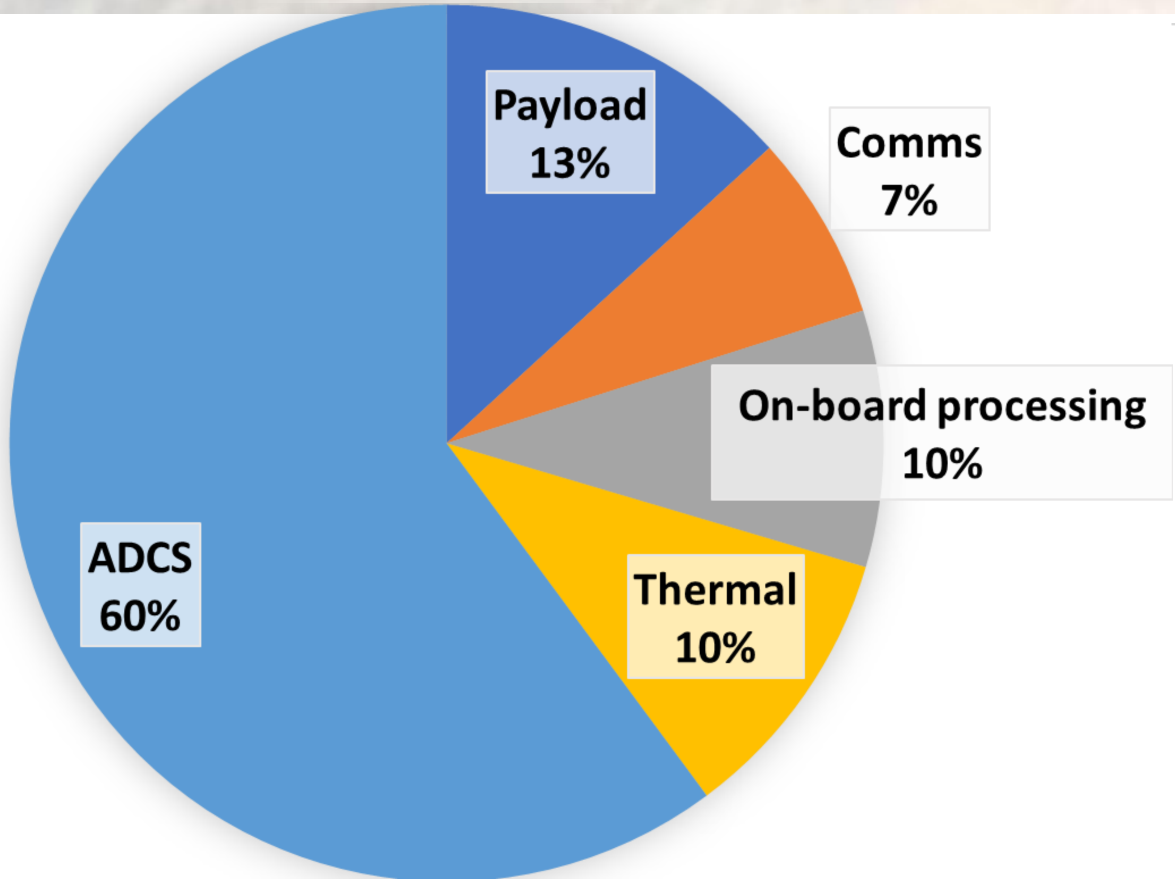
Outer view of the transfer vehicle

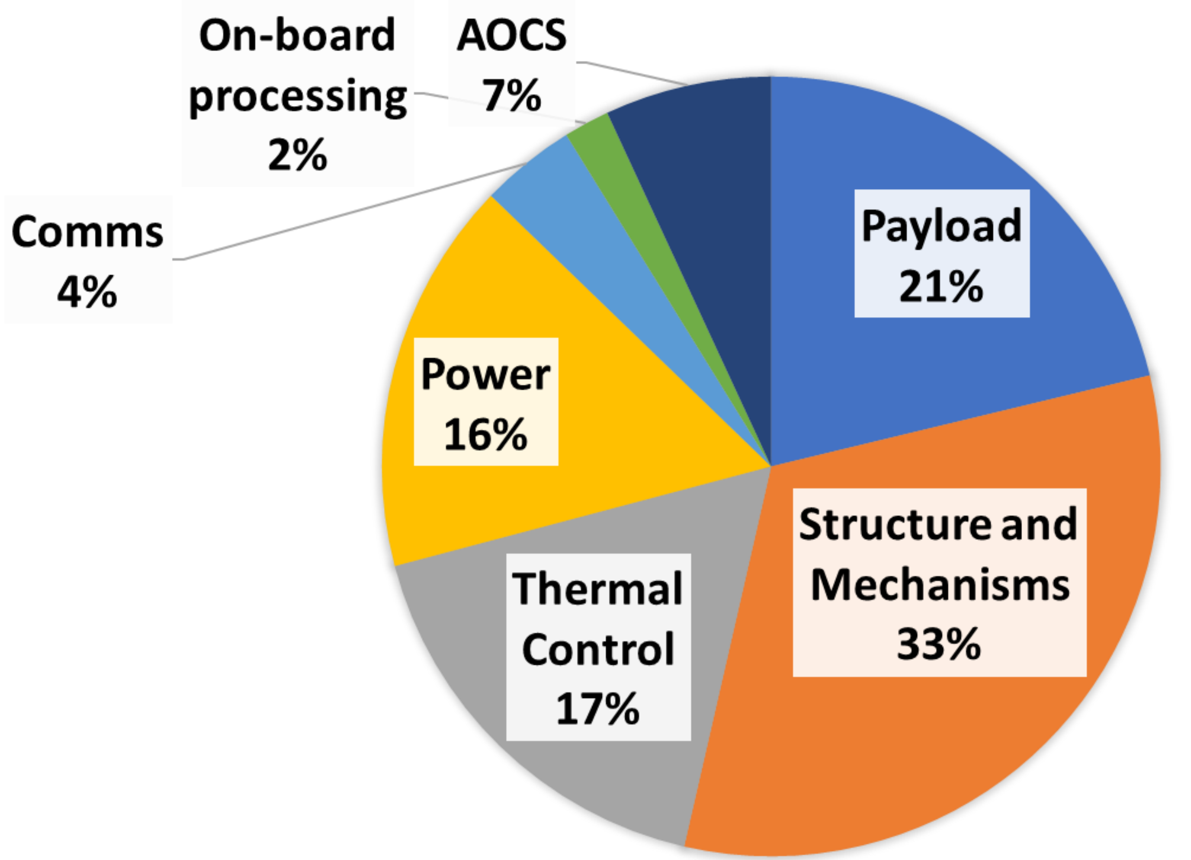


Inner view of the transfer vehicle



POWER AND MASS BUDGET– SCIENTIFIC S/C

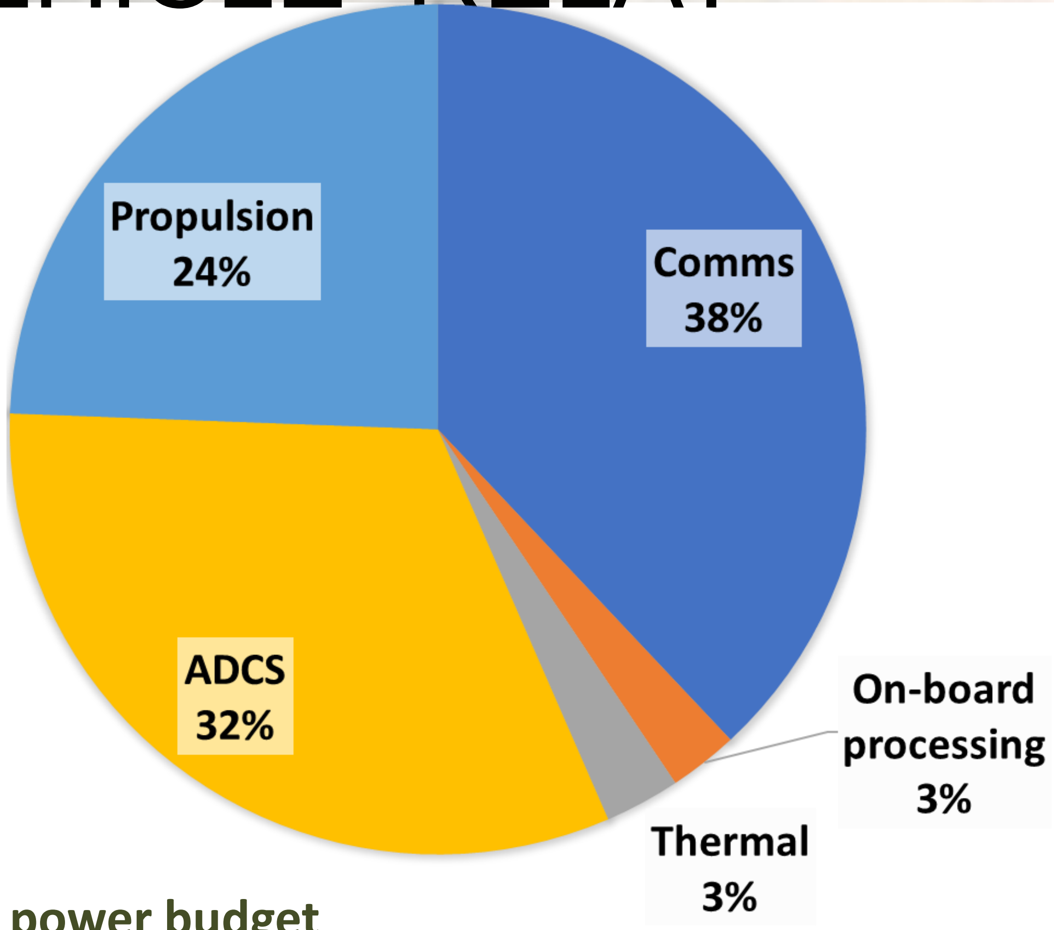


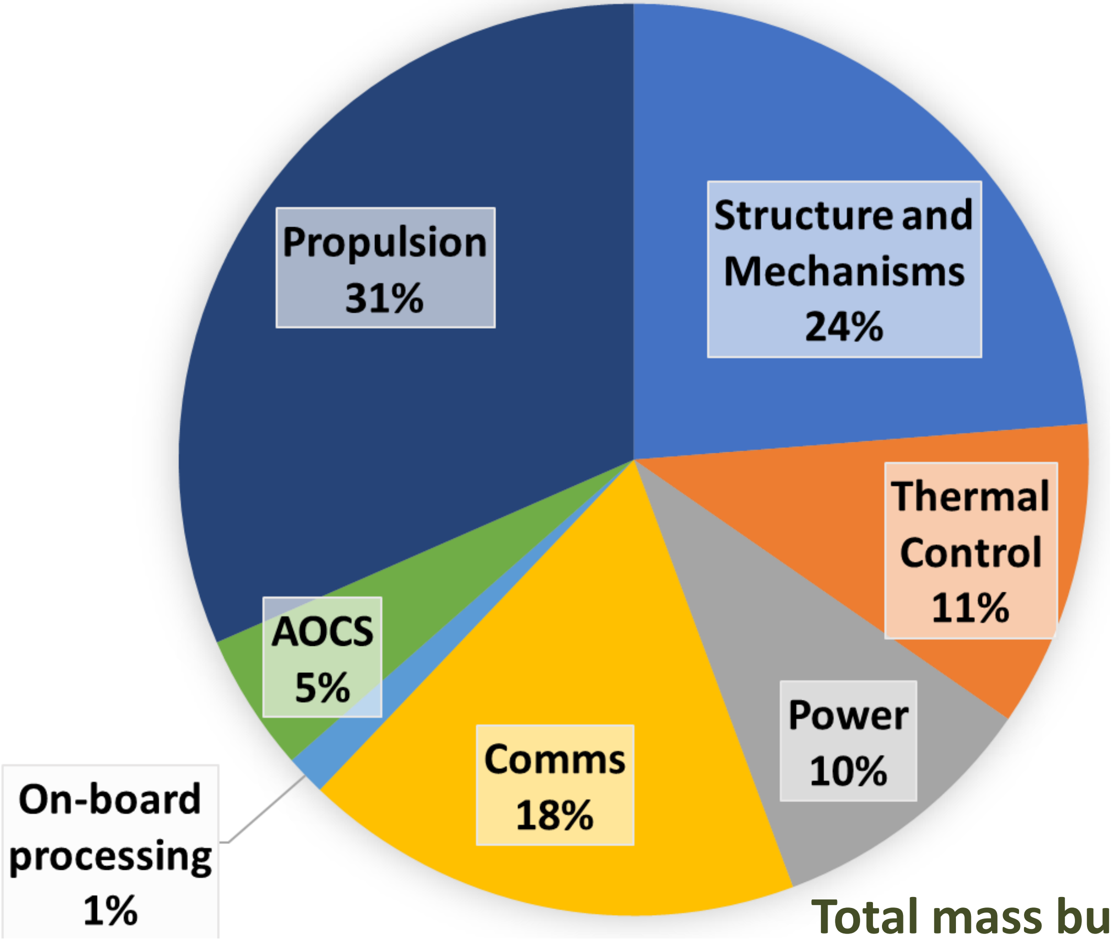


Total power budget (with 20% margin) : 174.563 W

Total mass budget (with 20% margin – no propulsion) : 166.52 kg

POWER AND MASS BUDGET– TRANSFER VEHICLE RELAY

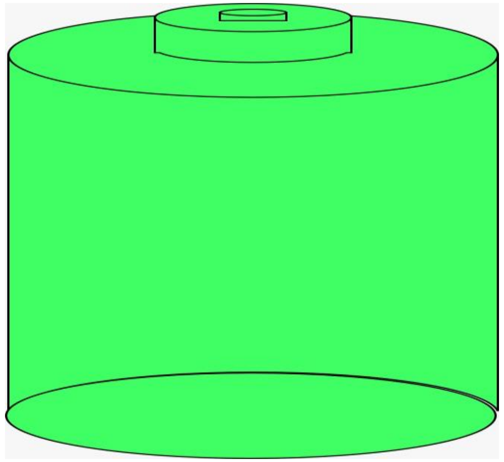




Total power budget (with 20% margin) : 469.3356 W

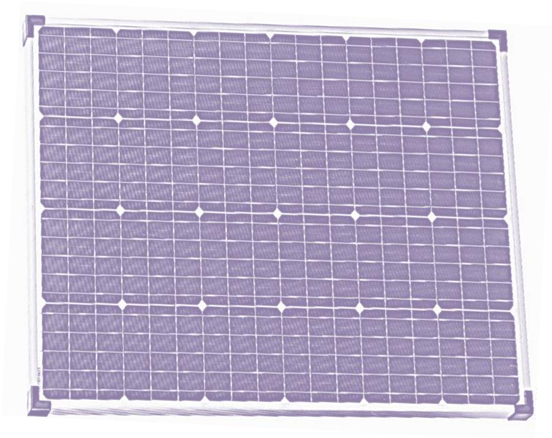
Total mass budget (with 20% margin – no propulsion) : 242.59 kg

POWER SUBSYSTEM– SCIENTIFIC SPACECRAFT



LITHIUM SULFUR CELLS USED FOR POWER STORAGE

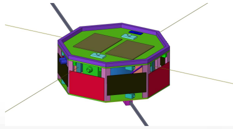
- Sized for 4 hour eclipse period (oversized), EOL performance not yet considered
- Power density: 152 Wh/kg
- Battery mass: 5.5 kg



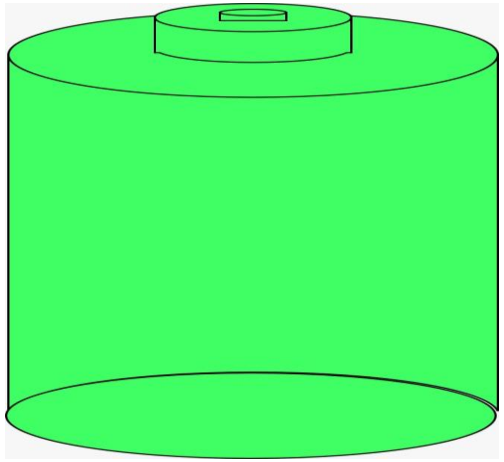
- **12**

SOLAR PANELS SIZED TO RECHARGE DEPLETED BATTERIES OVER REMAINDER OF ORBIT PLUS POWER DRAW

- **1.34 m2** 1.34m2 required for science spacecraft (EOL 8 years)
- This is the area needed on half of the spacecraft (rotation)
- **2.07 m2** 2.07m2 required for transfer spacecraft (EOL 8 years)
- Total mass: 15.1 kg

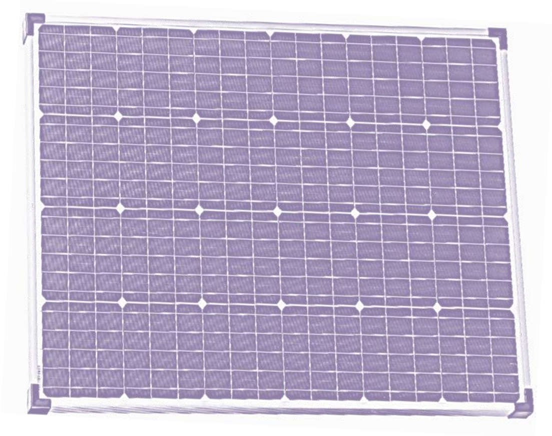


POWER SUBSYSTEM– TRANSFER VEHICLE



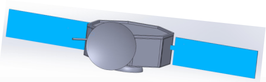
LITHIUM SULFUR CELLS USED FOR POWER ST ORAGE

- Sized for 4 hour eclipse period
- (oversized), EOL performance n ot
- yet considered
- Power density: **152 Wh/kg**
- Battery mass: **12 kg**



SOLAR PANELS SIZED TO RECHARGE DEPLETED BATTERIES OVER REMAINDER OF ORBIT PLUS POWER DRAW

- **2.07m^2** required for science spacecraft (EOL **8 years**)
- Total mass: **5.8 kg**



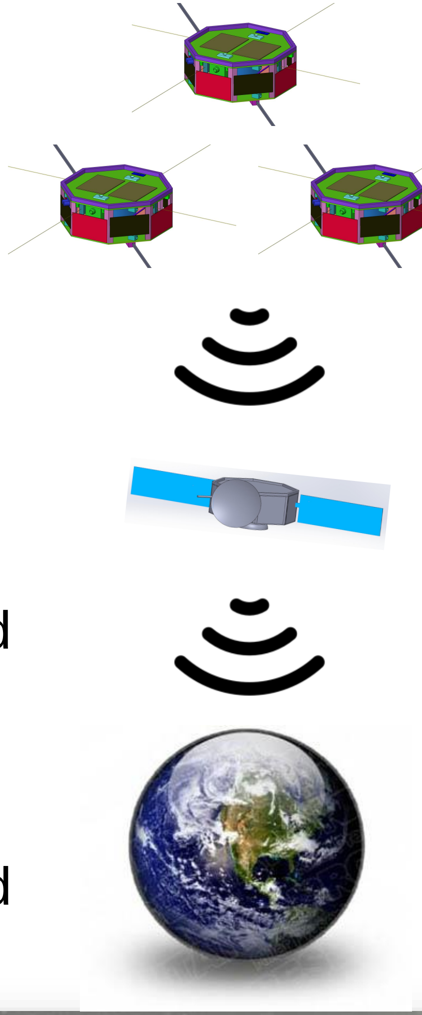
COMMUNICATION STRATEGY

SCIENCE REGION

DATA DUMP TO TV

SCIENCE REGION 2

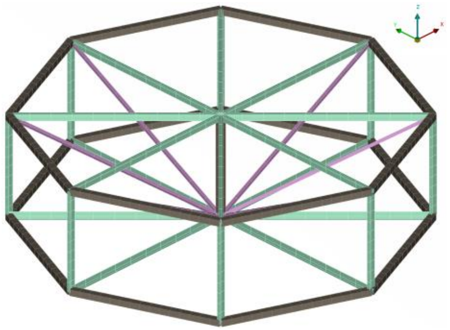
DATA DUMP TO TV EVERY ORBIT



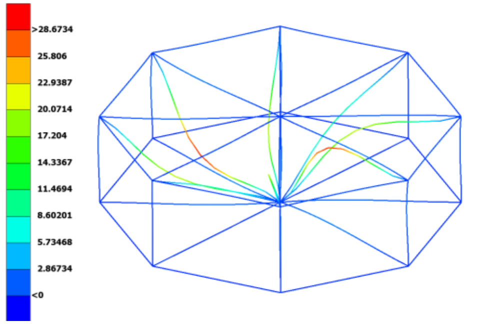
- Using the transfer vehicle as a comms relay reduces the mass and power budget of the science spacecraft
- **2 m** diameter HGA (**200W**) on transfer vehicle for earth link
- Resulting data rate: **13.34 Gb/h - 1.7** hours time required
- **22.94Gb** of data generated **every two days** (Assumed DSN availability every two d ays for downlink)

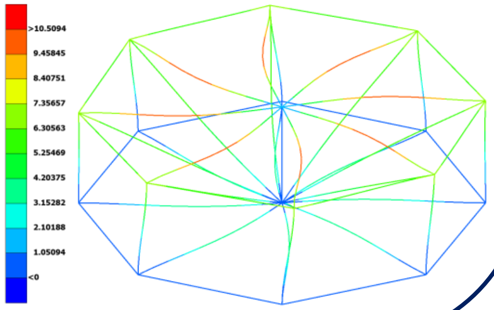
STRUCTURAL SUBSYSTEM

- Main aluminum truss structure.

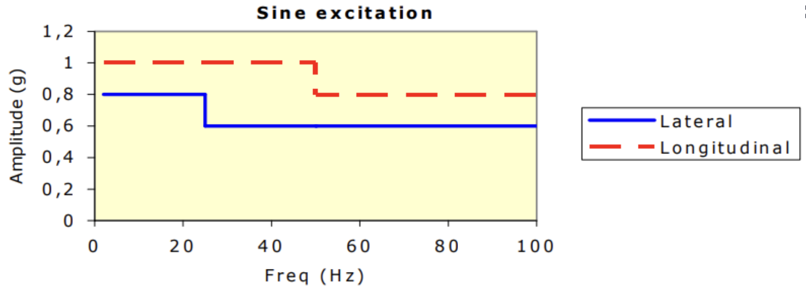


- Stiff, lightweight structure:
  - Lateral mode at **32 Hz**, axial mode at **73 Hz**.
  - Structural mass: **40 kg**

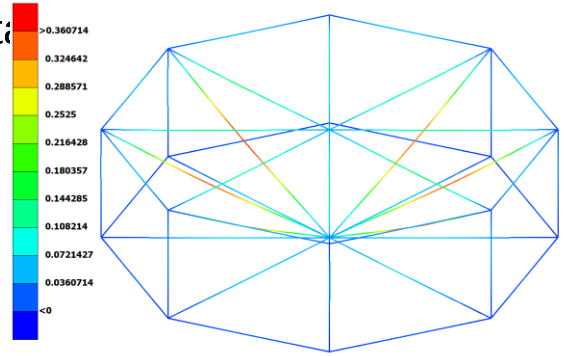




- Survival case conditions: Ariane 6 launch
  - Input acceleration, modes are stiff enough

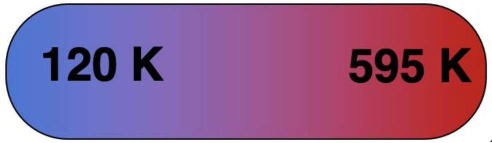


  - Sta lysis (6 g):



THERMAL AND RADIATIVE ENVIRONMENT

THERMAL BOUNDARIES

WORST COLD 

WORST HOT

RADIATIVE ENVIRONMENT

PASSIVE HEATING

- MLI layer
- Radiator on upper side of spacecraft

ACTIVE HEATING

Active heaters to maintain 0°C inside

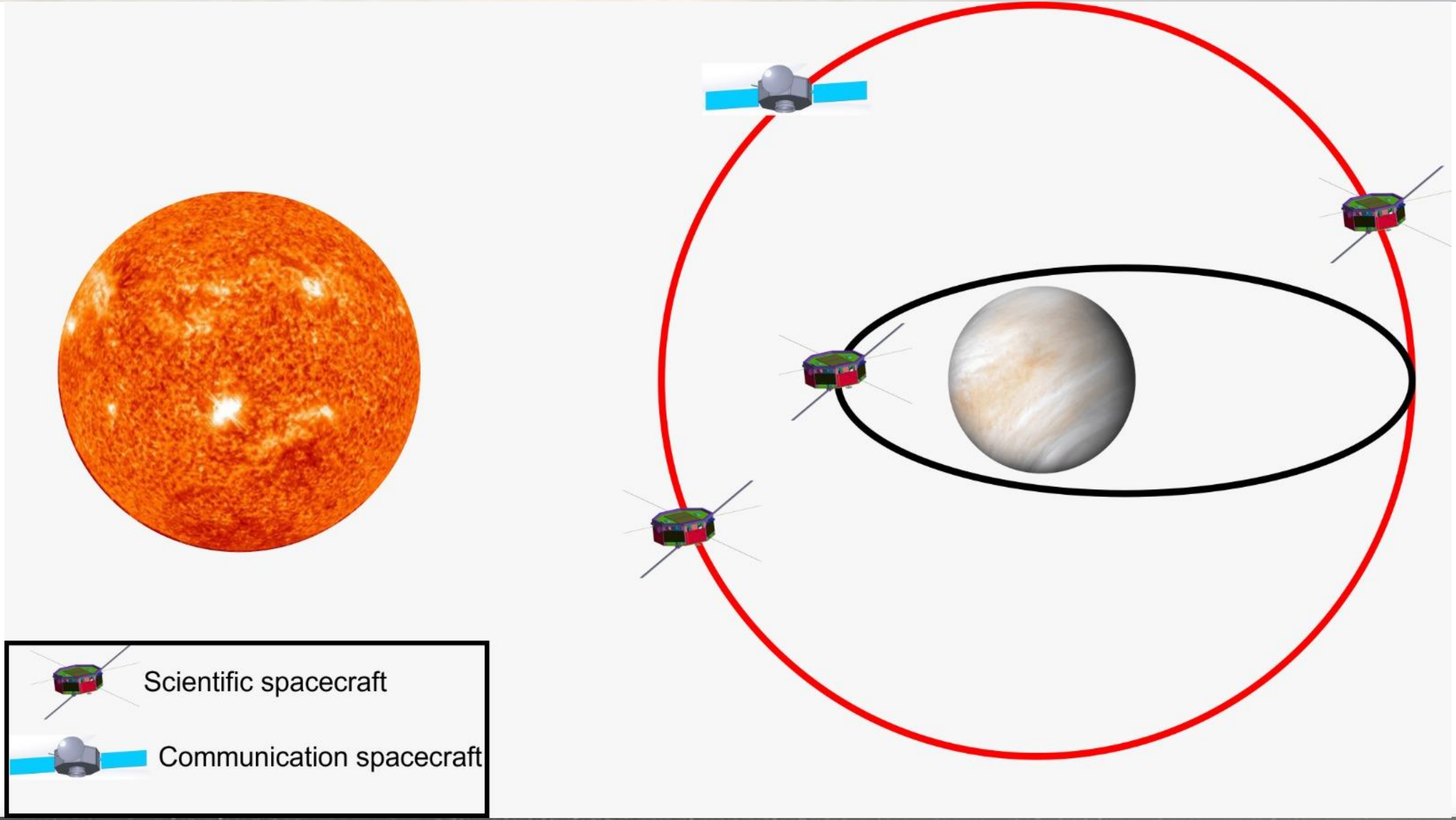
ALPBACH SUMMER SCHOOL 2022

MVSE

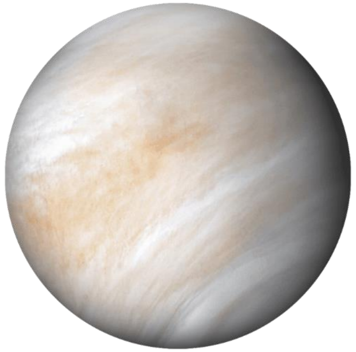
MAGNETOSPHERIC VENUS SPACE EXPLORERS

TEAM YELLOW

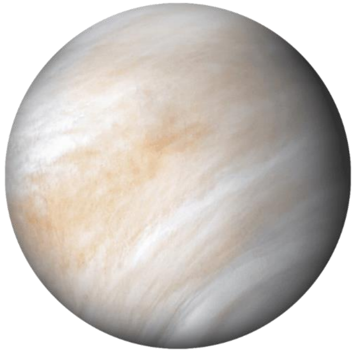
HOW DO WE GET IN THE FINAL ORBIT?

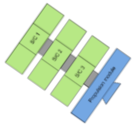


LAUNCH

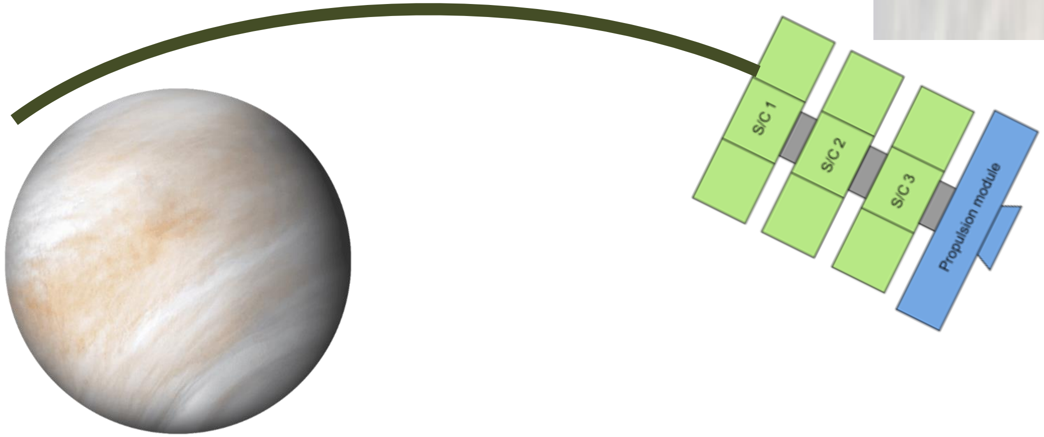


LAUNCH

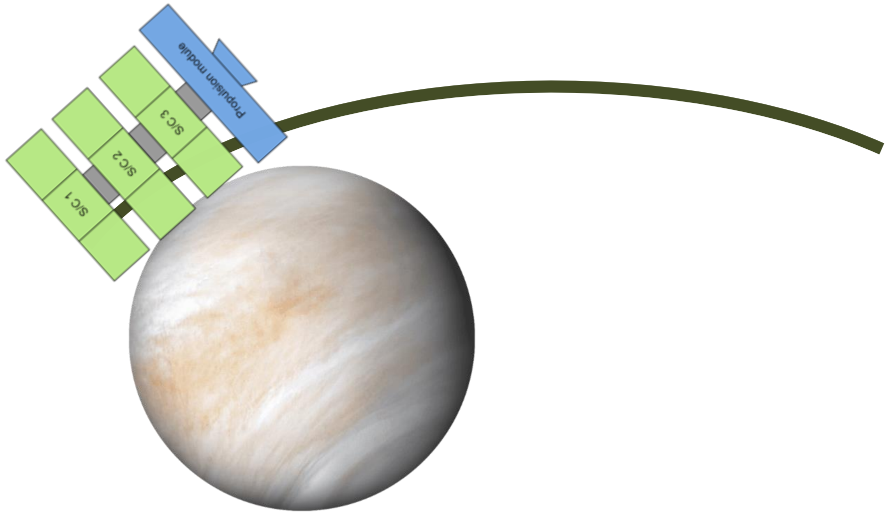




TRANSFER PHASE PHASE

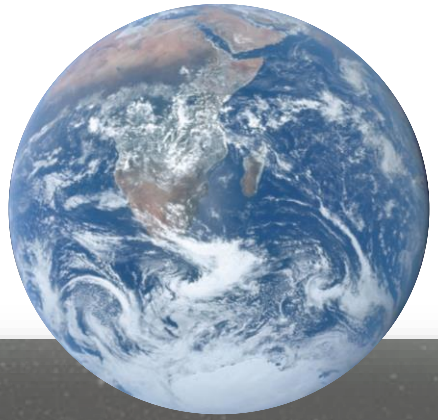


- Science s/c: stand-by
- Necessary orbit adjustments
- BBQ maneuver

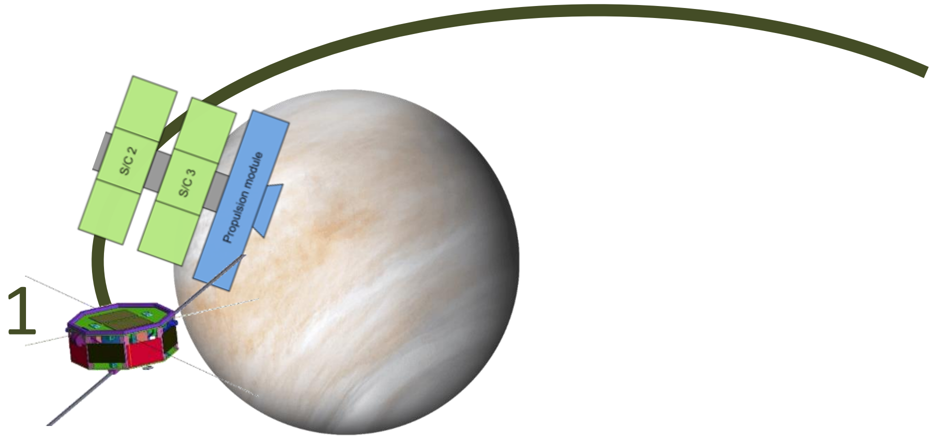


ARRIVAL

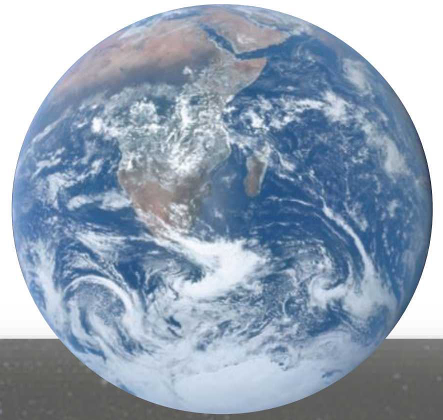
- Orbit insertion elliptical orbit
- Minor adjustment



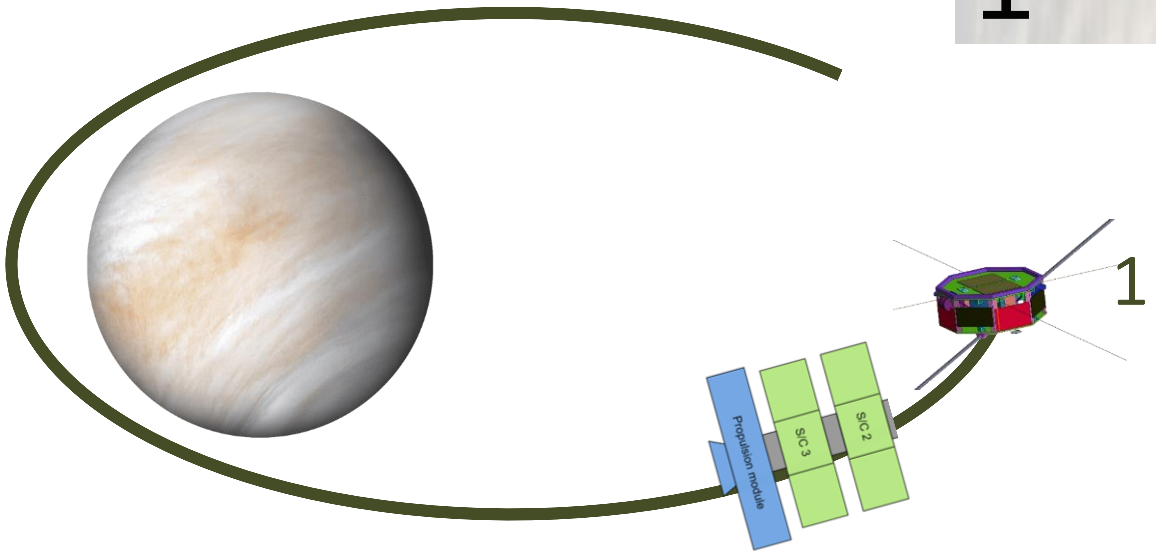
DEPLOYMENT OF SCIENCE SPACECRAFT 1



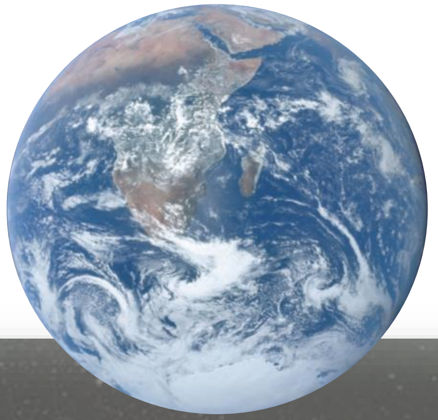
- Deployment position of transfer vehicle
- Deployment of s/c 1



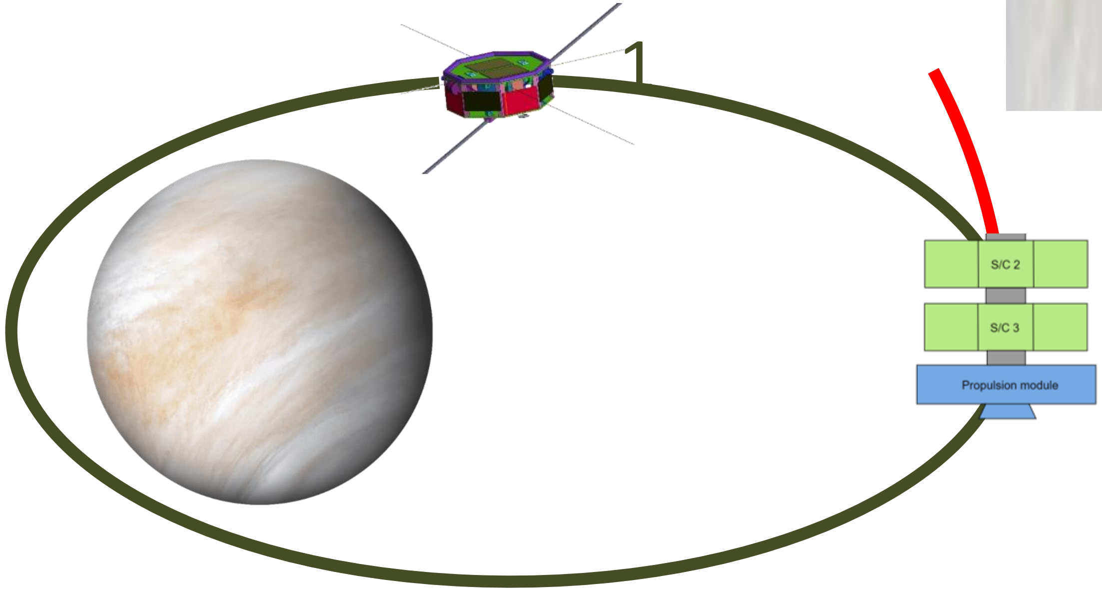
COMMISIONING OF SCIENCE SPACECRAFT 1



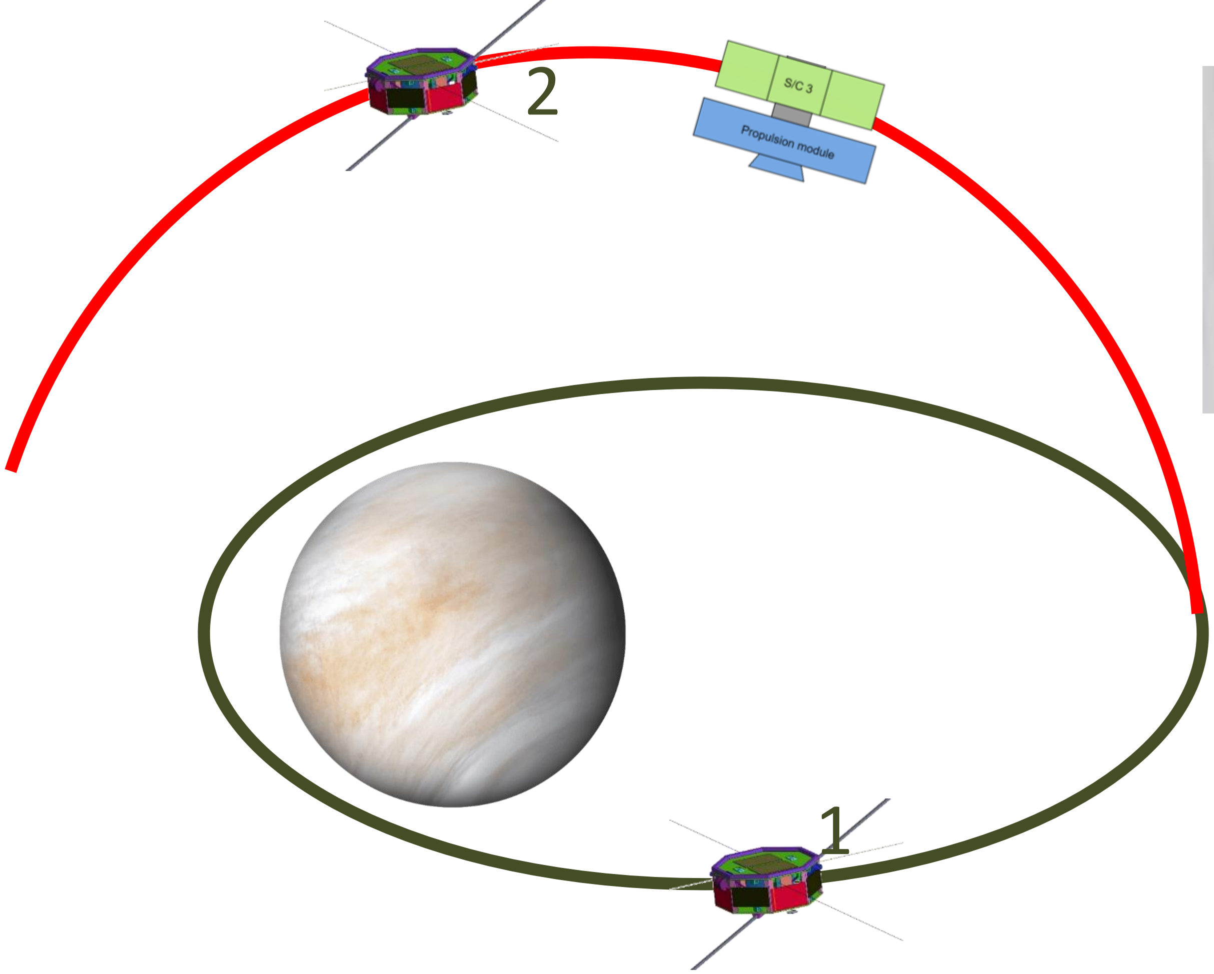
- Health check
- Spin-up
- Deployment of booms
- Spin-up



CIRCULARIZATION

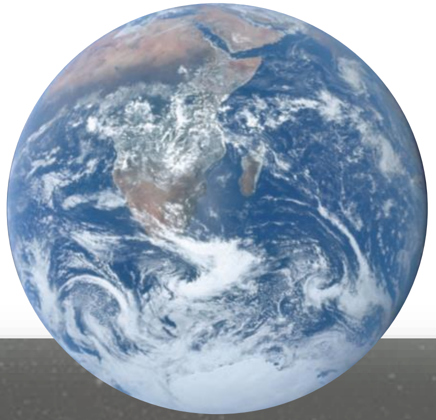


- Transfer position
- Burn up at apoapsis

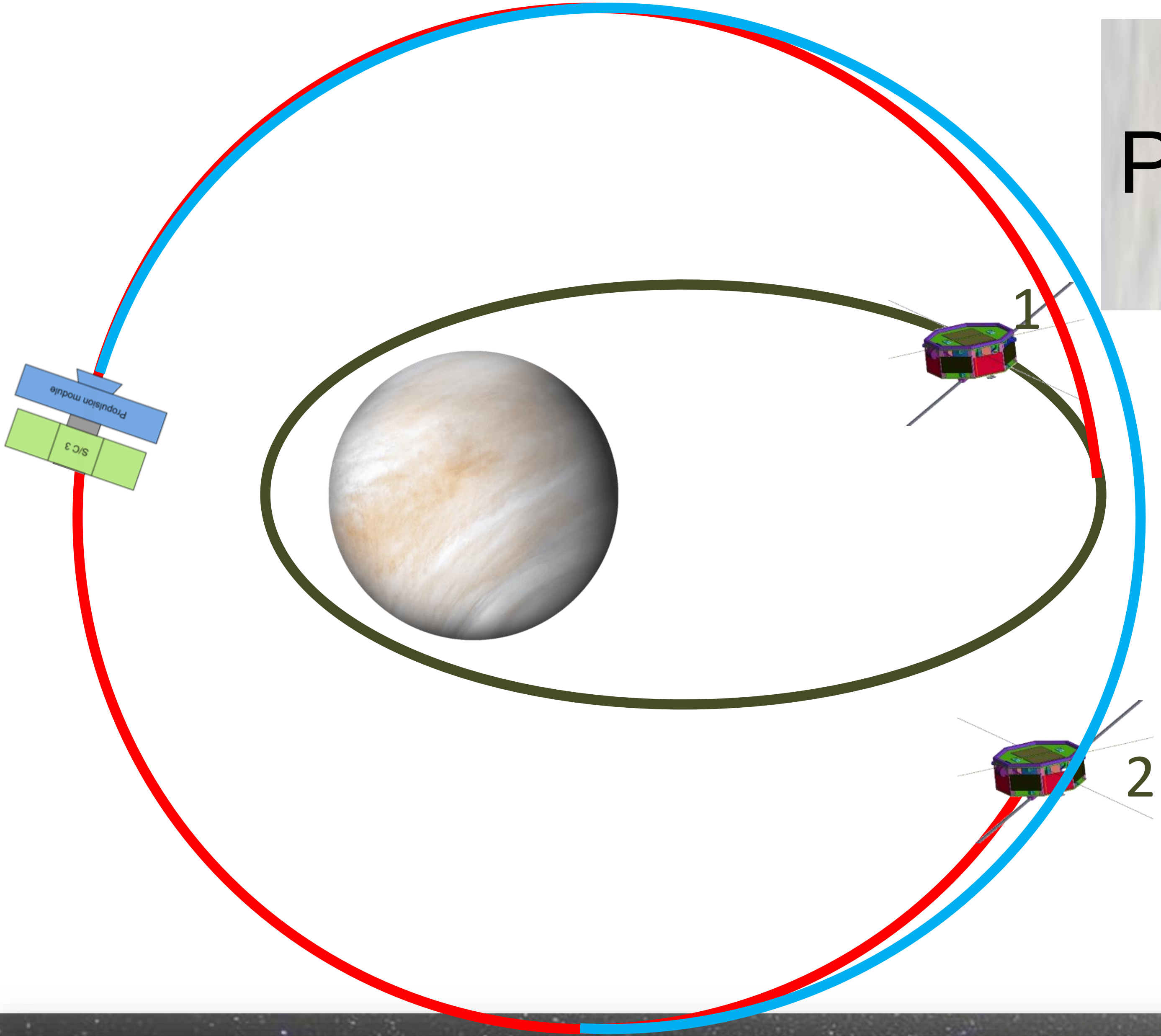


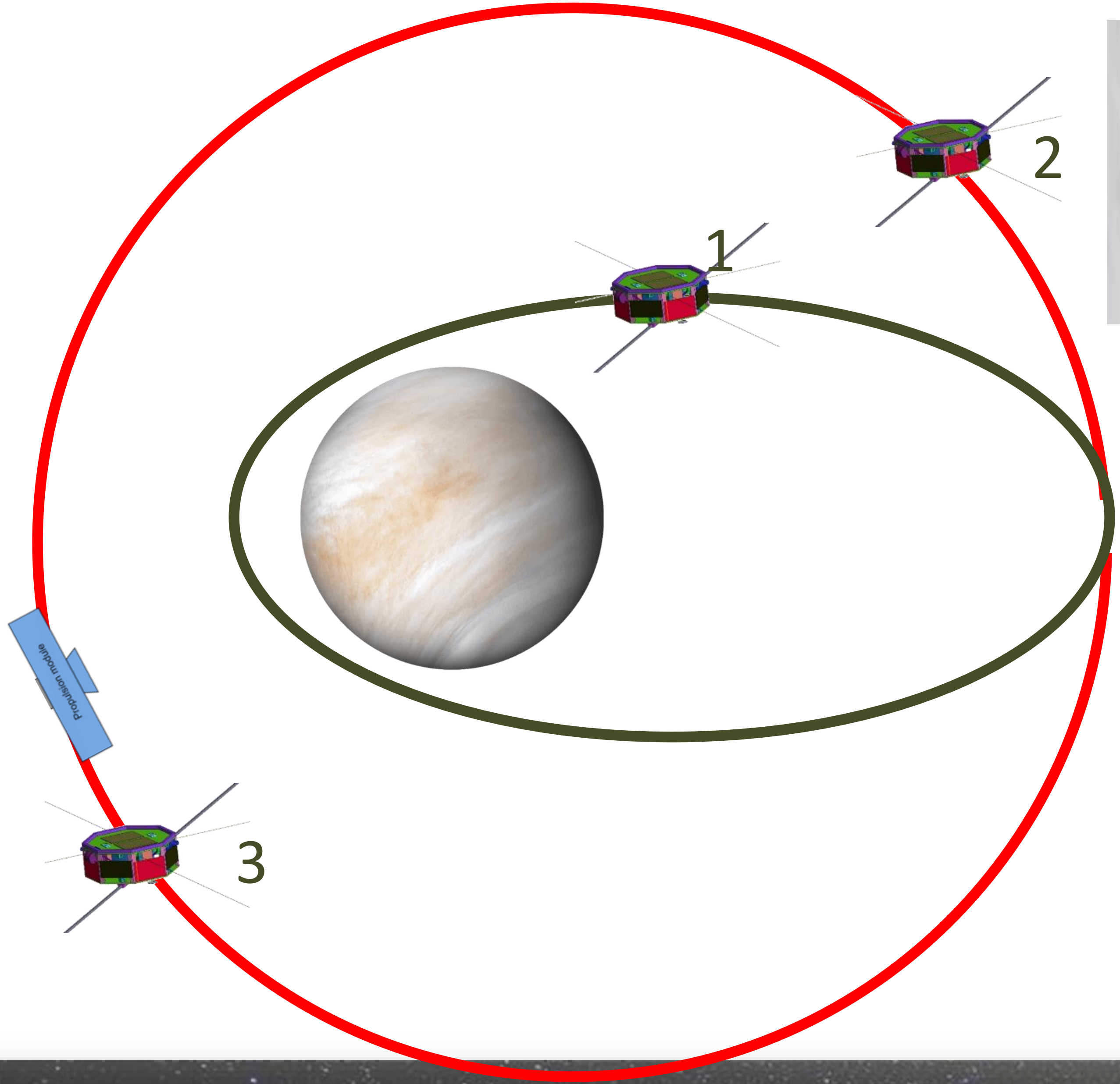
DEPLOYMENT/COMMISSIONING OF SCIENCE SPACECRAFT 2

- Deployment position of transfer vehicle
- Health check
- Spin-up and deployment

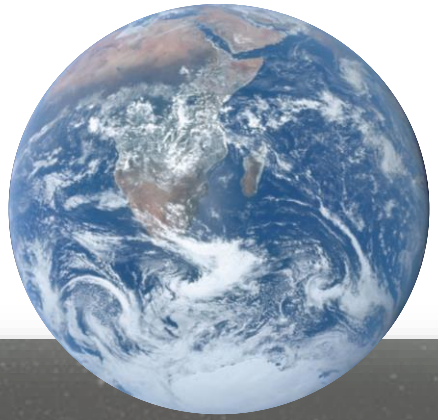


PHASING

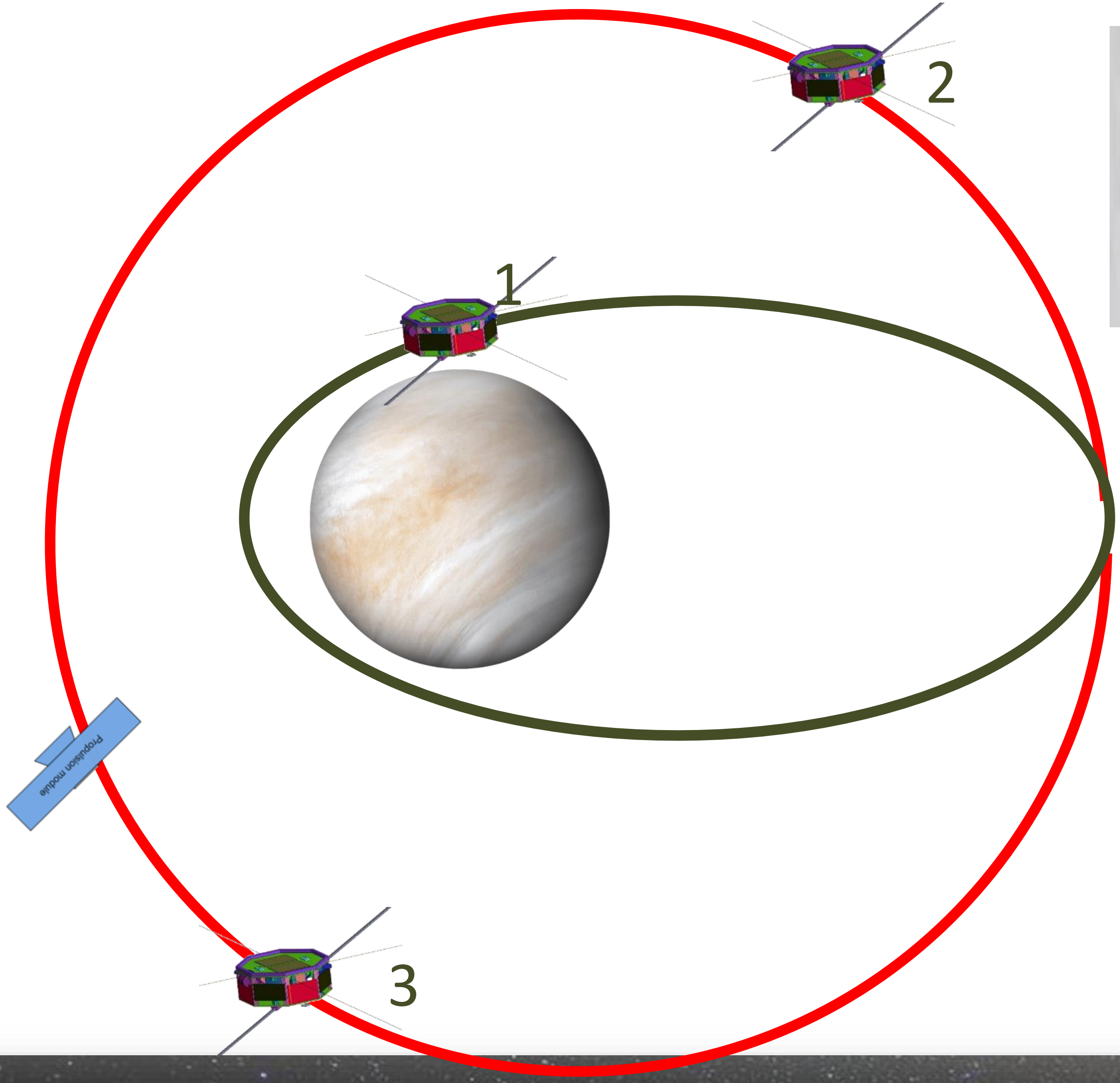


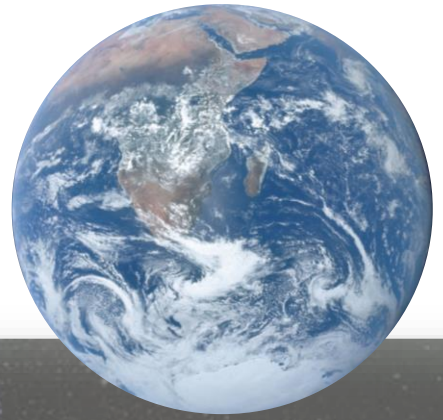


DEPLOYMENT/COMMISSIONING OF SCIENCE SPACECRAFT 3

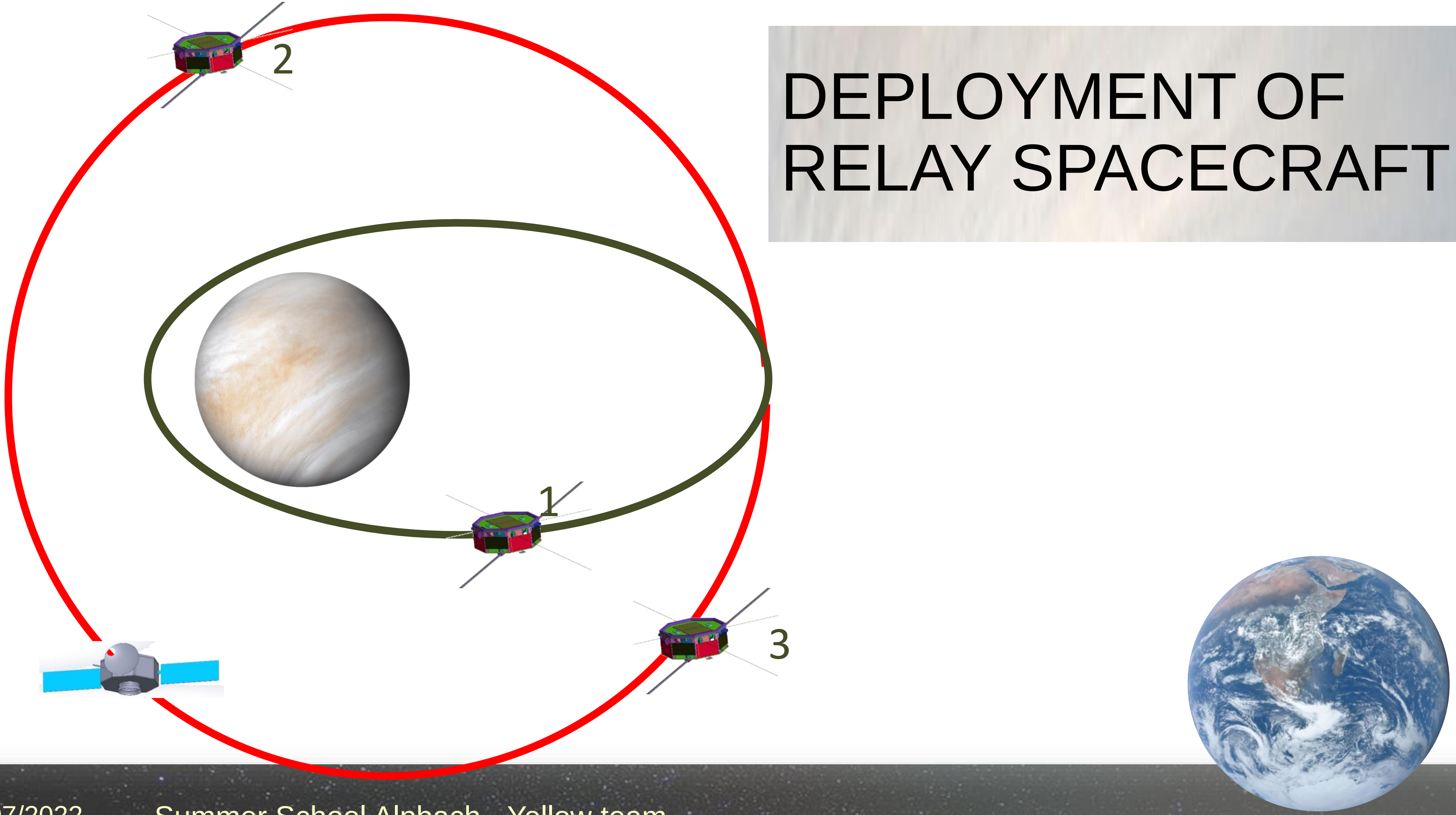


PHASING OF TRANSPORT VEHICLE





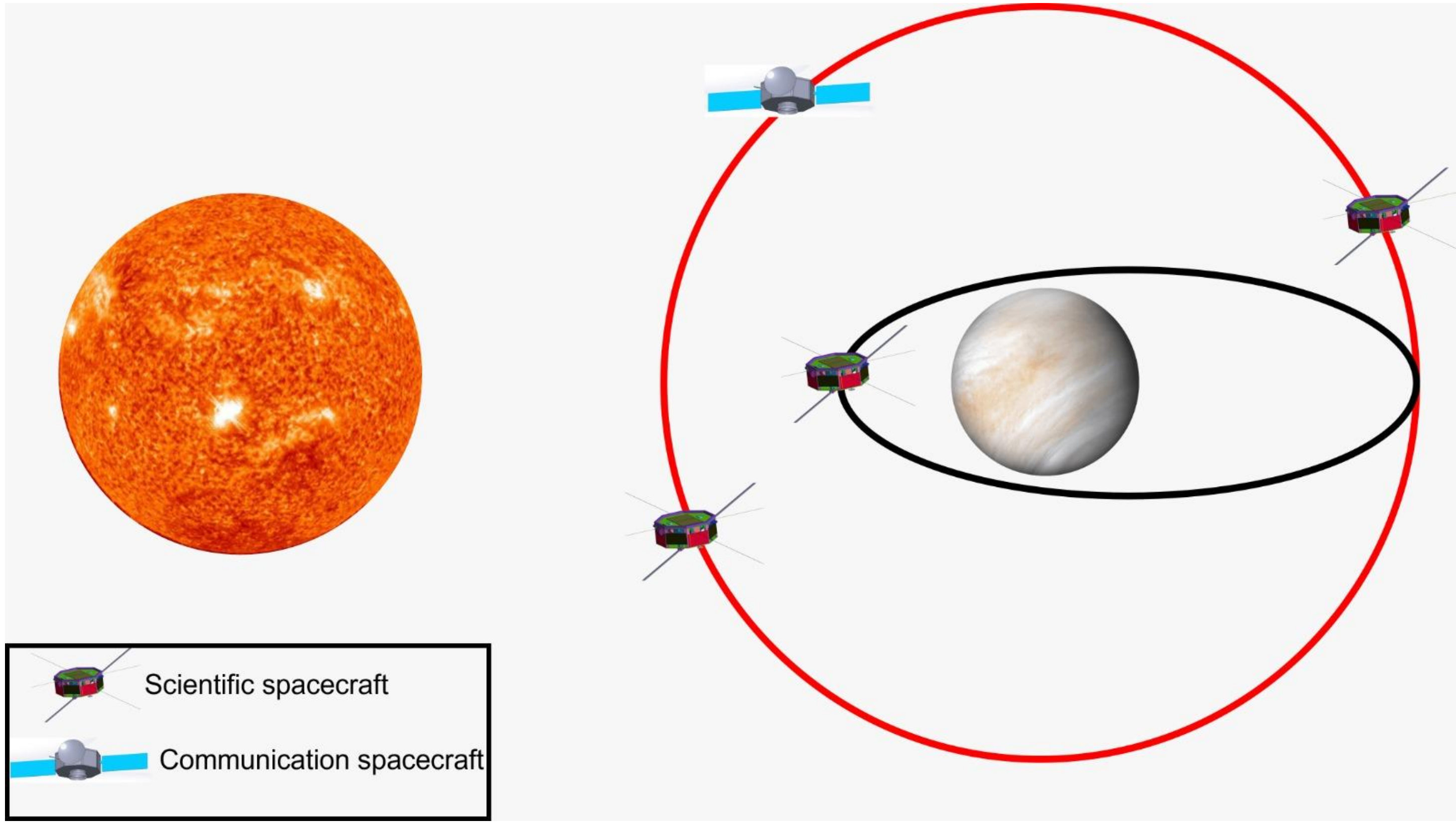
DEPLOYMENT OF RELAY SPACECRAFT



NOMINAL OPERATIONS

Science s/c modes:

- Measurement
- Transmission
- Safety



FUTURE

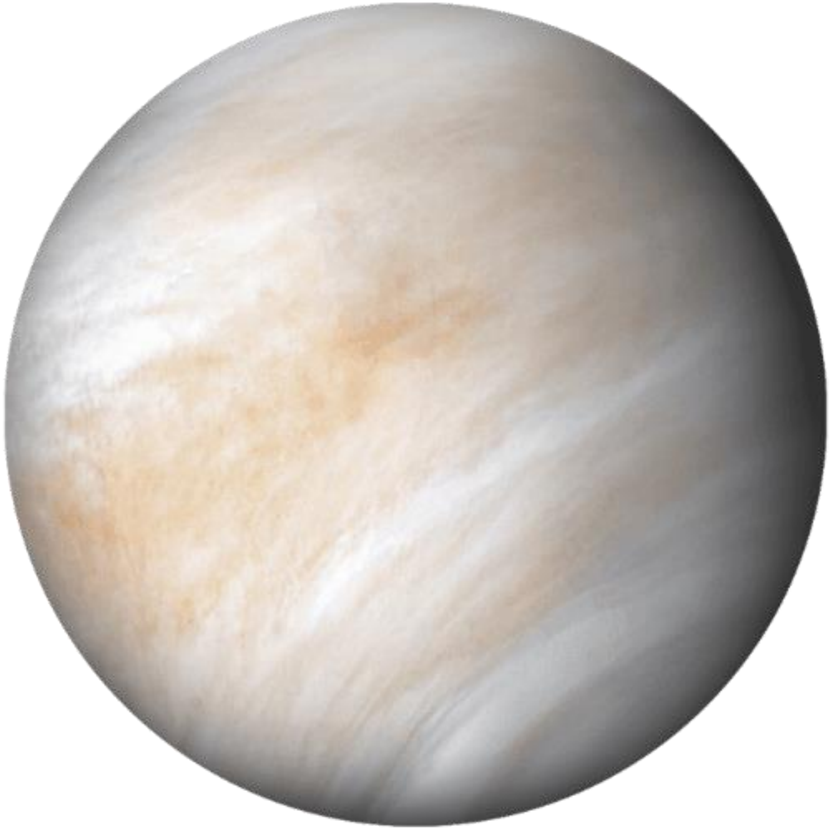
Mission timeline:

- 1 year orbit
- 2 year science operation

Spacecraft: max 8 year lif

Extension mission possible

END OF MISSION



VEX: burn up

End of mission:

- Planetary protection
- Graveyard orbits

RISK ASSESSMENT

Severity					
5	Relay failure Separation failure				
4					
3		Science satellite failure			
2			Satellite drift		
1					
	Remote	Unlikely	Likely	Highly Likely	Near Certain

COST BREAKDOWN ESTIMATION

	Million € (economic condition 2022)
Industrial costs	510
Internal costs ESA (25%)	128
Mission Operations	120
Subtotal	758
20% contingency	152
Launcher (Ariane 64)	115
Total	**1025**

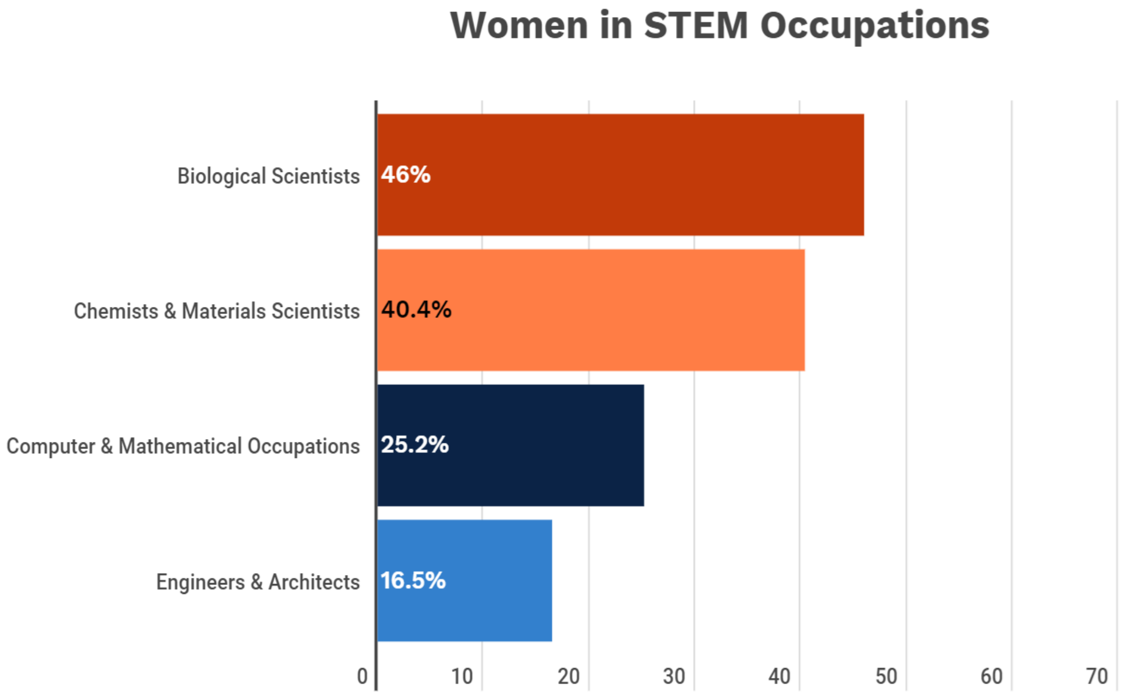
PUBLIC OUTREACH

Call and Inspiration for Minorities in STEM

Ambassadors engage young students

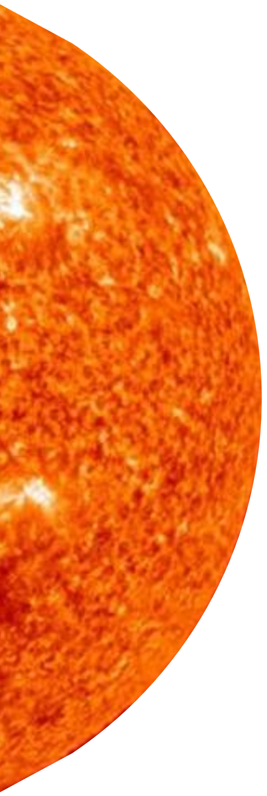
#ourMuseVenus

Regular mission & science updates for the public



SOURCE: U.S. Bureau of Labor Statistics, "Employed persons by detailed occupation, sex, race, and Hispanic or Latino ethnicity," Labor Force Statistics from the Current Population Survey, Table 11, 2020.

THE WAY FORWARD

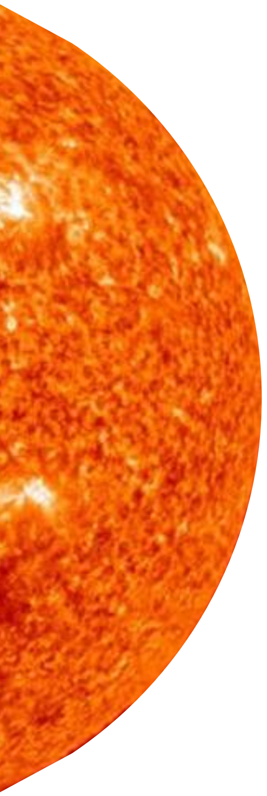


Explore other orbits

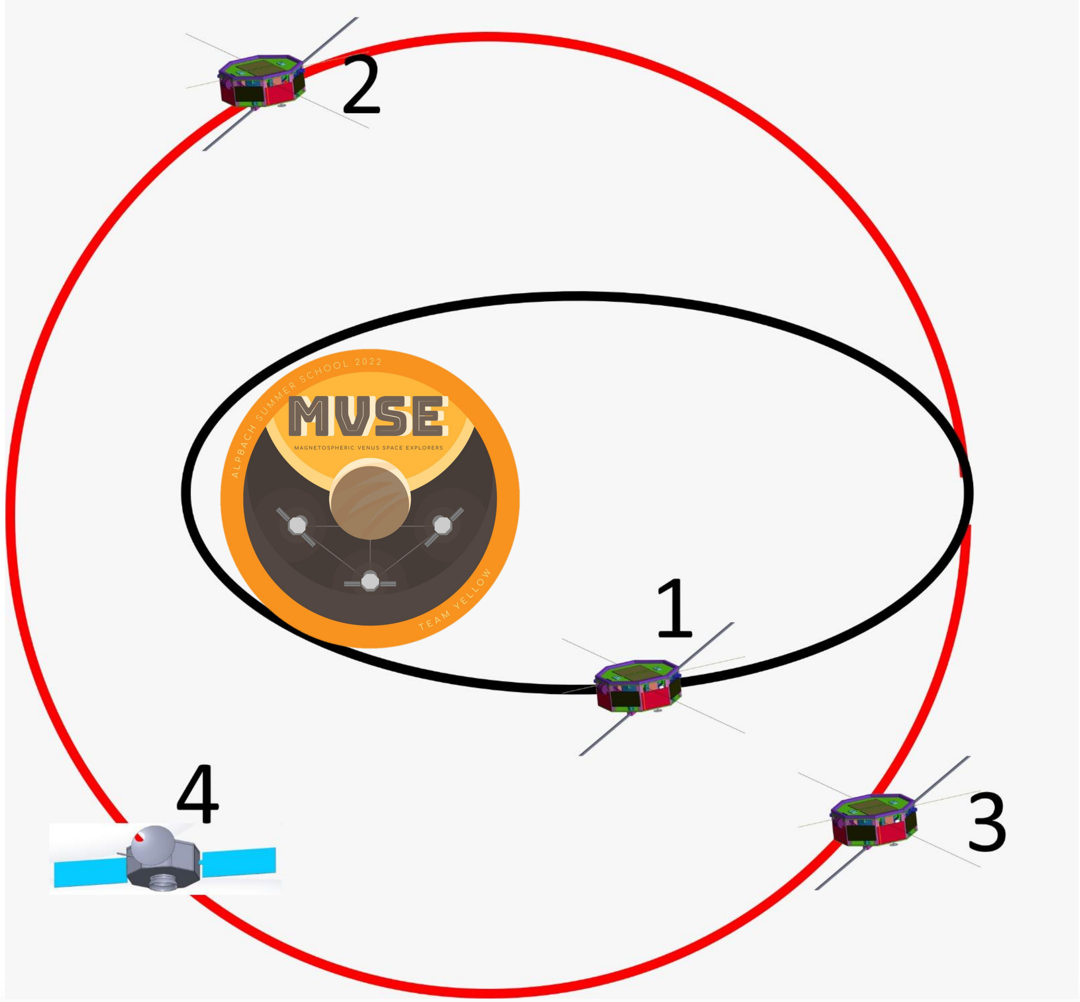
Optimize:

- Maneuvers
- Spacecraft sizing/Payload configuration -> Mass reduction
- Data transfer
- Antenna sizing

CONCLUSION



Understanding the plasma environment of induced magnetospheres



TEAM YELLOW – ALPBACH SUMMER SCHOOL 2022

Roland Albers, Henrik Andrews, Claire Baskevitch, Gabriele Boccacci, Francesca Covella, Luca Cressa, Juan Garrido Moreno, Joshua Hollowood, Eva Krämer, Sunny Laddha, Adel Malatinszky, Nadim Maraqten, Daiana Maria Alessandra Nidelea,
Luca Rigon