SIREN

Saturn atmosphere and Investigation of Rings and ENceladus

TEAM YELLOW

C. Cencia
M. Dannenmann
A. Dunne
V. Engesæt
S. Esparis Matanza
D. Grabowski
C. Libert
F. Martin
A. Mastropietro

D. McCloskey
M. Pinceloup
V. Saz Ulibarrena
R. Rianço-Silva
R. Steinhöfler
R. Wolfs

O. Dhuicque
D. Fischer

TABLE OF CONTENTS

01

Science Case and Objectives

Saturnian System Exploration

Pioneer 11 (1979)

First probe to encounter Saturn

Voyager 1 (1980)

Titan Flyby
Saturn Atmosphere

Voyager 2 (1981)

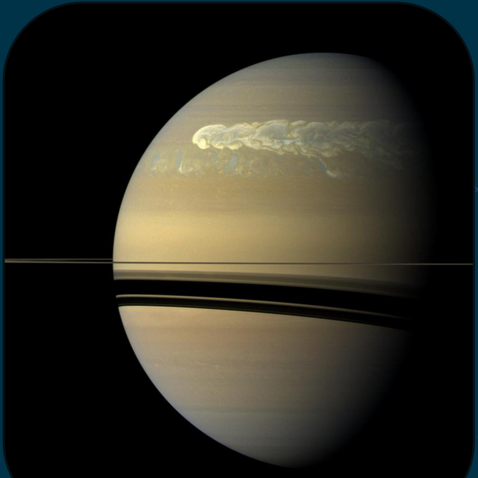
Continued atmosphere characterizations

Cassini-Huygens (2004-2017)

Titan probe
Ring transit

What do we know about Saturn’s atmosphere?

- Dynamic environment
- Extreme weather: Solar radiation and internal heat
- Chemistry should reflect interior composition and planetary formation



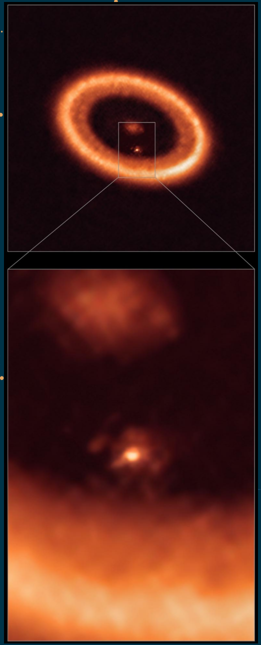
Saturn’s Great White Storm

Open Questions

- Abundance of volatile species, nobles gases and isotopic ratios
- Cloud vertical distribution
- Moist movement
- Interior Structure and Equation of State

A natural laboratory for Giant Planet Formation, Atmospheric Volatile Distribution and Extreme Atmospheric Physics

What do we know about Saturn’s Rings Environment?



Moon-forming disk around exoplanet PDS 70c

- Saturn’s rings
  - Instabilities and collisions by gravity waves
  - µm-km sized rocky/icy objects
- Plasma environment
  - Source Enceladus: E-ring
  - Charged particles interact with rings and Saturn’s atmosphere

?

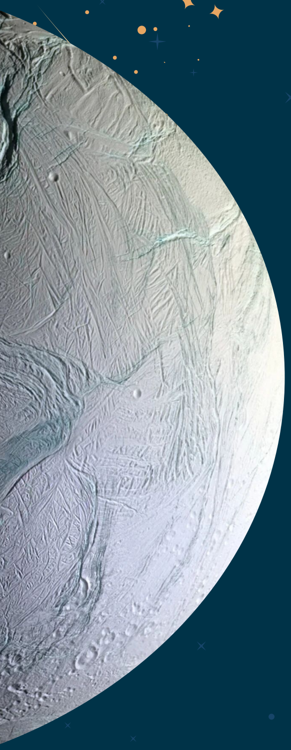
Open Questions

- Ring dynamics and lifetime
- Detailed gravity-plasma-radiation interaction
- Meter-size barrier problem in planetary formation

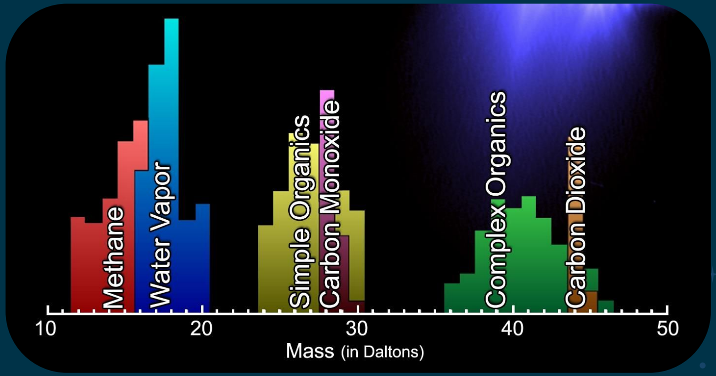
A natural laboratory for Gravity, Radiation and Plasma interactions in a protoplanetary disks

What do we know about Enceladus?

- Global liquid subsurface ocean
- Moderate salinity and pH 9-12
- Continuous water plume activity
- Evidence for hydrothermal activity
- Requirements for life as we know it



Enceladus



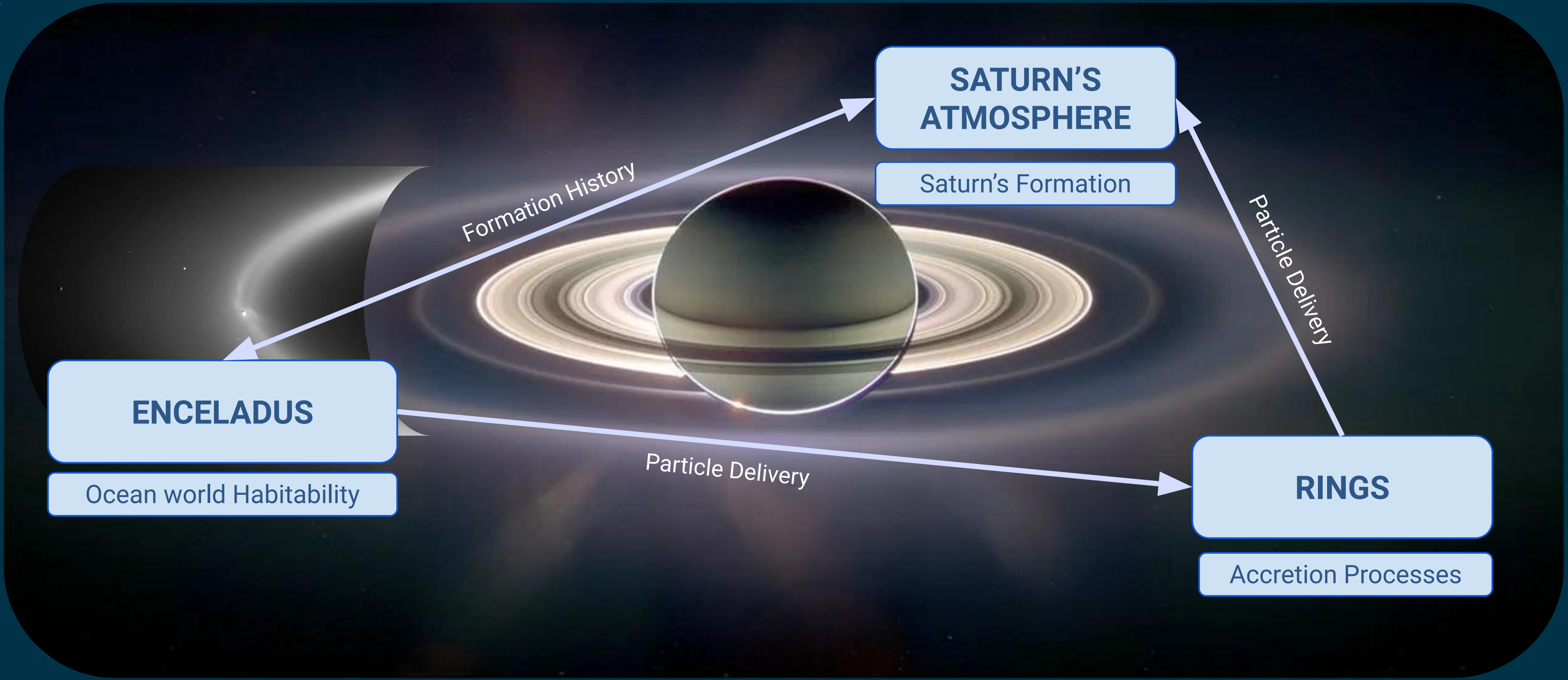
Cassini's Enceladus Plume Mass Spectra

Open Questions

- Unambiguous plume chemical composition
- Ocean's oxidation state
- Ice shell structure
- Surface composition
- Complex organics: Geo-/Biosignatures

A natural laboratory for Icy Moon Subsurface Ocean Geochemistry and Habitability

Science Case
Saturn atmosphere and Investigation of Rings and ENceladus

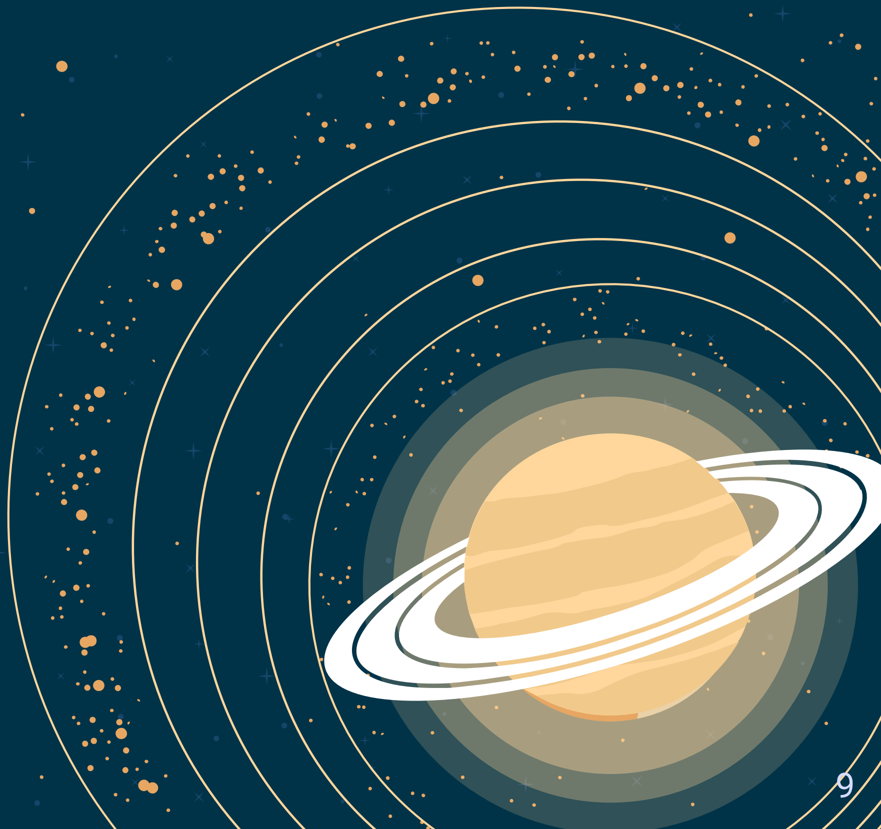


Mission Goals

G1: Study Saturn’s formation and evolution reflected in its atmospheric composition

G2: Study the Saturnian ring and moon formation and evolution as a proxy for accretion processes

G3 - Study what chemical processes shape Enceladus’ potentially habitable subsurface and surface environment

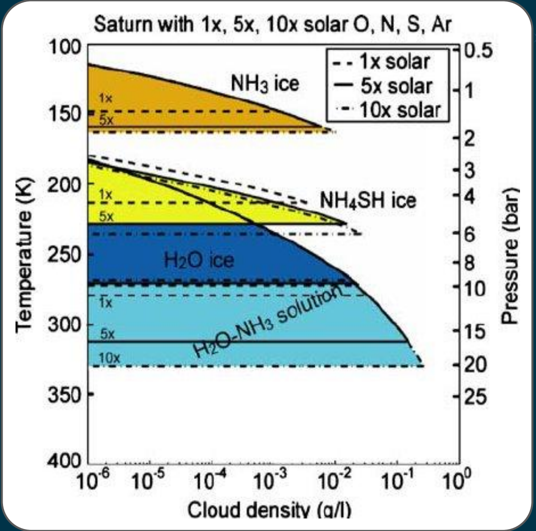


G1: Study Saturn's formation and evolution reflected in its atmospheric composition

G1S1 - What is Saturn's tropospheric volatile composition and vertical profile?

- In-situ vertical profiles of volatile and noble gas species
- In-situ vertical profiles of cloud structure and weather
  - From 0.5 bar to 20 bar (bottom of the H_2O cloud layer)

Mission	Vertical Profile	He fraction	CH_4	H_2O, H_2S, NH_3, Ne, Ar, Kr, Xe
Cassini	Unknown	0.11 - 0.16	450 ppm	Unknown
SIREN	0.5 km vertical resolution	Uncertainty < 100 ppm	Uncertainties < 1 ppm	



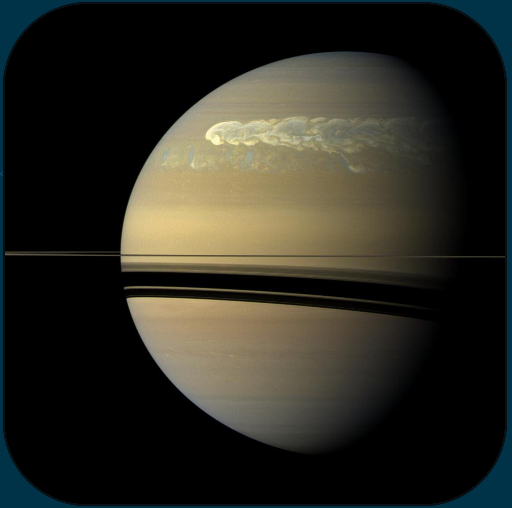
Model of Saturn's clouds structure

G1: Study Saturn's formation and evolution reflected in its atmospheric composition

G1S2 - What is the structure of Saturn's atmosphere?

- Gravity field and ionospheric science
- Context for in situ measurements: Correlating Ground Truth with Remote Sensing
- Monitoring temporal variability of weather layer
  - Imaging Saturn across distinct wavelengths (distinct atmospheric depths)

Mission	Spectral Resolution
Cassini in NIR	R ~ 100
SIREN in NIR	R > 1000



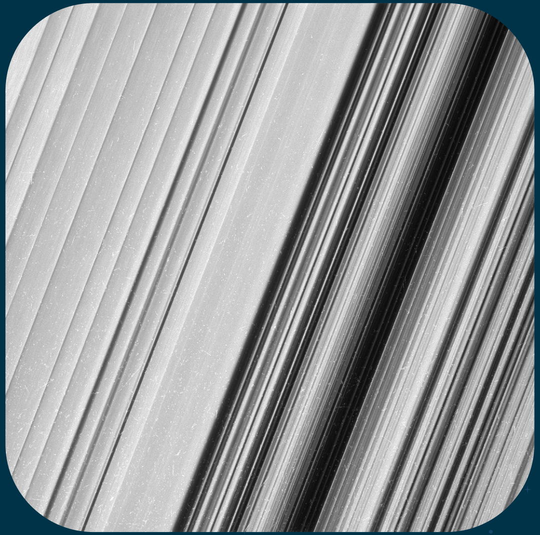
Saturn's Great White Storm

G2: Study the Saturnian ring and moon formation and evolution as a proxy for accretion processes

G2S1 - What are the processes behind small bodies formation within Saturn's rings?

- Address *Meter-size Barrier problem* by studying shepherd moons & ring system
  - Perform statistical survey of meter-sized ring material

Mission	B ring	A ring
Cassini	360 m/px	330 m/px
SIREN	≤ 10 m/px	

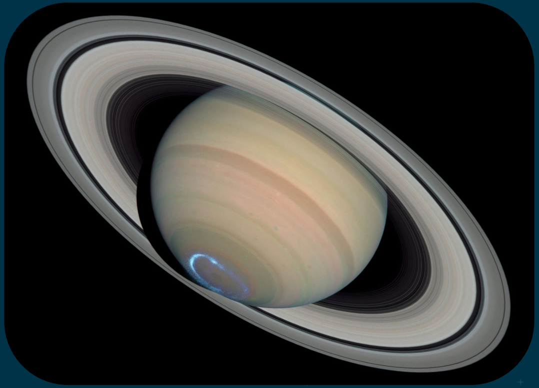


B ring at 360 meters per pixel from Cassini

G2: Study the Saturnian ring and moon formation and evolution as a proxy for accretion processes

G2S2 - What are the interactions of (charged) dust and particles from Enceladus within the Saturnian magnetosphere and ring system?

- Constrain the formation and evolution of the planetary environment
  - Measure the plasma environment, the electric field and the magnetic field of the Saturnian System
- Open Questions:
  - What are the plasma transport routes?
  - How does Enceladus' plume affect the plasma environment?
- SIREN's observations:
  - Energy, directions, density and fluxes of particles
  - Charged particles and dust

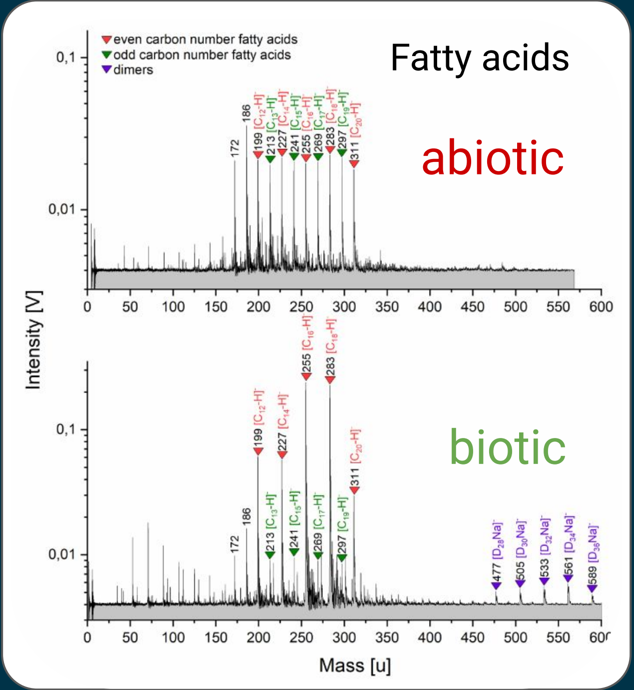


Saturn's Aurora

G3 – Study what chemical processes shape Enceladus' potentially habitable subsurface and surface environment

G3S1 - What is the structure and composition of the plume, including prebiotic chemistry, biosignatures, isotopic ratios and hydrothermal products?

- Biosignatures
- Isotopic ratios and noble gas abundances
- Geothermometer measurements
  - Composition of ice grains at < 1 Da resolution and up to > 500 Da mass
  - Composition of gas phase at < 1 Da resolution and up to > 200 Da mass
  - Composition of gas phase from UV occultations and NIR emission (R > 1000)
- Asymmetry of the plume
- Ice grain densities and size distribution



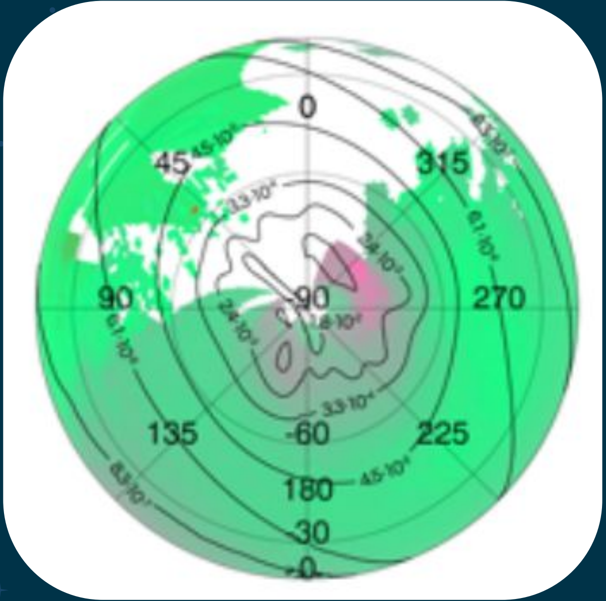
Klenner et al., 2020

G3 – Study what chemical processes shape Enceladus' potentially habitable subsurface and surface environment

G3S2 - What is the structure and composition of Enceladus' surface on a global and local scale?

- Terrain features and ground elevation mapping
- Surface chemical composition characterization
- Ice grains cohesiveness measurement for future landers
- Geomorphological survey

- Surface mapping at high resolution
  - CASSINI: 50 m/px
  - SIREN: 6 m/px



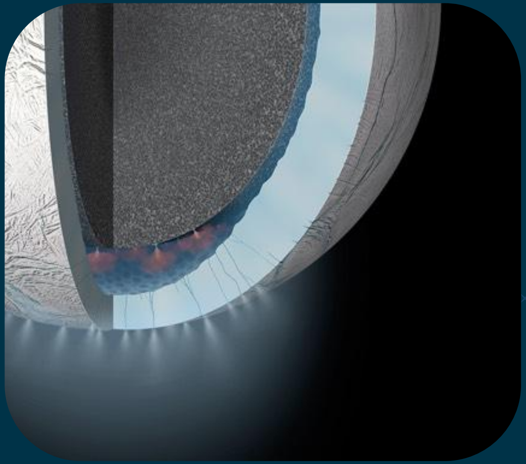
3.6 μm water ice reflectance map in Enceladus' south pole

G3 - Study what chemical processes shape Enceladus' potentially habitable subsurface and surface environment

G3S3 - How does Enceladus sustain a global liquid ocean?

- Cassini's observations indicates a global ocean
- Numerical models indicate insufficient tidal heating

- Measurement of tidal deformation
- Surface features indicating subsurface ocean (tilted blocks)
- Surface temperature mapping
- Measuring Ice shell thickness and structure
- Compositional differences of ice grains from individual jets



A model of Enceladus' subsurface

02

Measurements and Instruments

Generic Science Payload

Orbiter

- UV-VIS Spectrometer
- NIR Spectrometer
- Thermal Infrared Spectrometer
- VIS Camera
- Ion and Neutral Mass Spectrometer
- Impact Ionization Mass Spectrometer
- Ice Penetrating Radar
- Laser Altimeter
- Radio Science Experiment
- Magnetometer
- Top-Hat Analyser
- Electric Field Antenna

Atmospheric Probe

- Mass Spectrometer
- Nephelometer
- Net Flux Radiometer
- Atmospheric Sensing Instrument
- Helium Abundance Detector

Saturn's Atmospheric Probe Instruments

Instrument	What for?	Science Drivers	Traceability	Heritage
Mass Spectrometer	Atmospheric composition	Resolution: Isotopic ratios, Sensitivity to 1 ppm level	G1S1	NMS (Galileo)
Nephelometer	Cloud composition	Vertical resolution: 0.5 km Altitude range: 0.5 to 20 bar		NEP (Galileo)
Net Flux Radiometer				NFR (Galileo)
Atmospheric Sensing Instrument	Weather			HASI (Huygens)
Helium Abundance Detector	Origin	Sensitivity to 100 ppm level		HAD (Galileo)

MEASUREMENTS & INSTRUMENTS | PAYLOAD

Orbiter Optical Instruments

Instrument	What for?	Science Drivers	Traceability	Heritage
UV-VIS Spectrometer	Saturn's atmosphere Enceladus' plume & surface	Spectral resolution R >1000	G1S2 G3S1 G3S2	UVIS (Cassini)
NIR Spectrometer		Spectral Resolution: R > 1000 Spatial Resolution in Enceladus: 5 m/pix		VIRTIS (Rosetta)
Thermal Infrared Spectrometer	Saturn's atmosphere Enceladus' surface	Thermal Resolution: 0.1 K Spatial Resolution: <25km/px	G1S2 G3S2	OTES (OSIRIS-REx)
VIS Camera	Saturn's atmosphere & rings Enceladus' plume & surface	Spatial resolution at Ring particles: 10m/px	G1S2 G2S1 G3S2 G3S3	JANUS (JUICE)

Orbiter Mass Spectrometers, Radar, Altimeter and Radio Science Instruments

Instrument	What for?	Science Drivers	Traceability	Heritage
Ion and Neutral Mass Spectrometer	Enceladus’ plume	Resolution for isotopic ratios	G2S2 G3S1	NGIMS (MAVEN)
Impact Ionization Mass Spectrometer	Enceladus’ plume and surface, Particle Flows	Resolution/Range for complex organics Orientation in flight direction	G2S2 G3S1 G3S2 G3S3	SUDA (Europa Clipper)
Ice Penetrating Radar	Enceladus’ surface, Particle Flows	Penetration depth >18 km	G3S2 G3S3	RIME (JUICE)
Laser Altimeter		Spatial resolution of 5m/px for future lander	G3S2	GALA (JUICE)
Radio Science Experiment	Saturn and Enceladus gravity field	Precise position tracking	G1S2 G3S3	3GM (JUICE)

Orbiter Plasma Instruments

Instrument	What for?	Science Drivers	Traceability	Heritage
Magnetometer	Magnetic field	Dust and plasma transport mechanisms	G2S2 G3S1	JMAG (JUICE)
Top-Hat Analyser	Plasma field	Three-dimensional and energy ion distribution	G2S2	MIA (BepiColombo)
Electric Field Antenna	Electric field	Larger antennas to reach larger Debye length		LP-PWI (JUICE)

03

Mission Design

KEY System Drivers

Orbit

- Saturn rings - must be close enough to observe
- Far from the rings - spacecraft protection
- Planetary protection

Power generation

- Solar intensity ~ 100 times less than at Earth
- Management of high power needs via RTGs

Mission Phases

5 months — 8.8 years — ~4 years — ~6 months

LEOP + Commissioning → Interplanetary Transfer → Science Operations → Decommissioning

Phase 1
Probe Science

30 days
Orbital Insertion

Phase 2
Enceladus Science

~720 days
75 orbits

Phase 3
Ring Science

~640 days
100 orbits

Phase X
Additional Objectives

Mission Phases

5 months | 8.8 years | ~4 years | ~6 months

LEOP + Commissioning → Interplanetary Transfer → Science Operations → Decommissioning

Phase 1
Probe Science

30 days
Orbital Insertion

Phase 2
Enceladus Science

~720 days
75 orbits

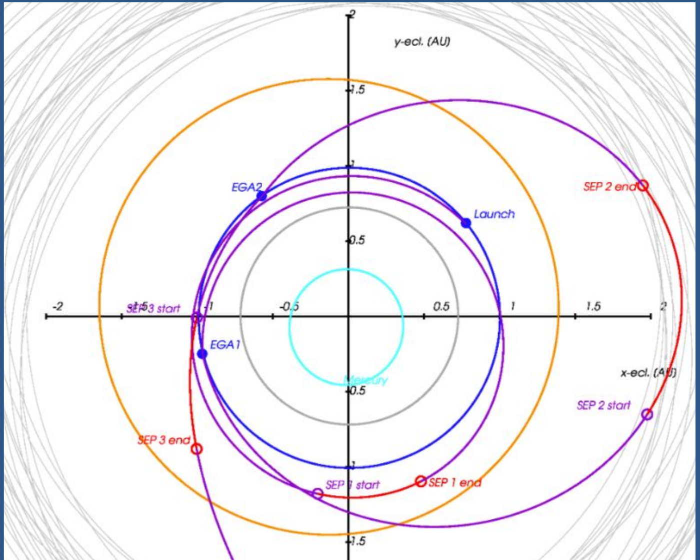
Phase 3
Ring Science

~640 days
100 orbits

Phase X
Additional Objectives

Mission Phases

LEOP + Commissioning → **Interplanetary Transfer** → Science Operations → Decommissioning

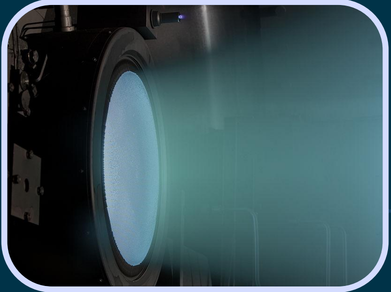


Saturn transfer in ecliptic frame
Solar Electric Propulsion Boosted Transfers To The Outer Solar System
A. Rocchi, M. Khan

Interplanetary Transfer
Solar Electric Propulsion (SEP)

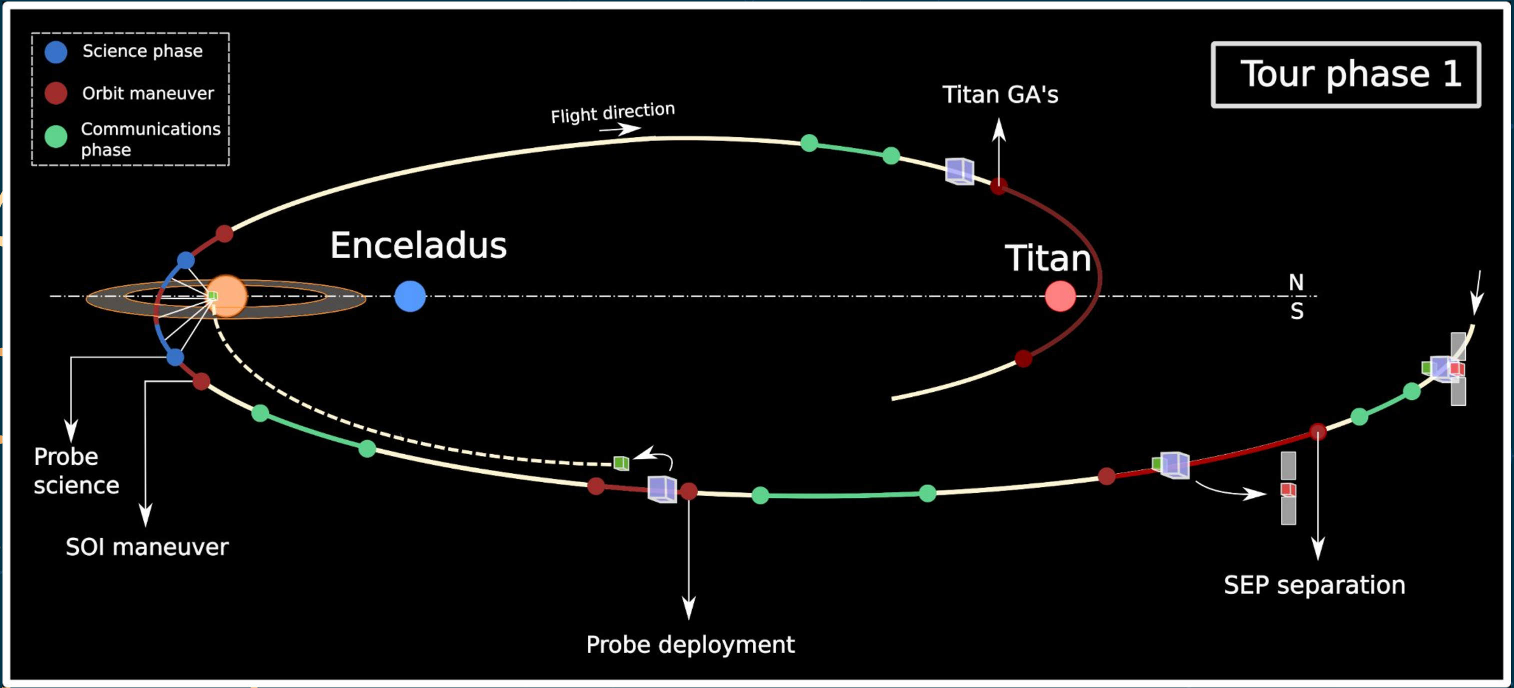
- NASA Evolutionary Xenon Thruster
- Heritage missions using SEP
- Proposed transfer orbit avoids interior Solar System (less radiation/heat)
- Launch windows annually

ΔV	= 3138 m/s
t	= 8.8 years



Mission Phases

LEOP + Commissioning → Interplanetary Transfer → **Science Operations** → Decommissioning



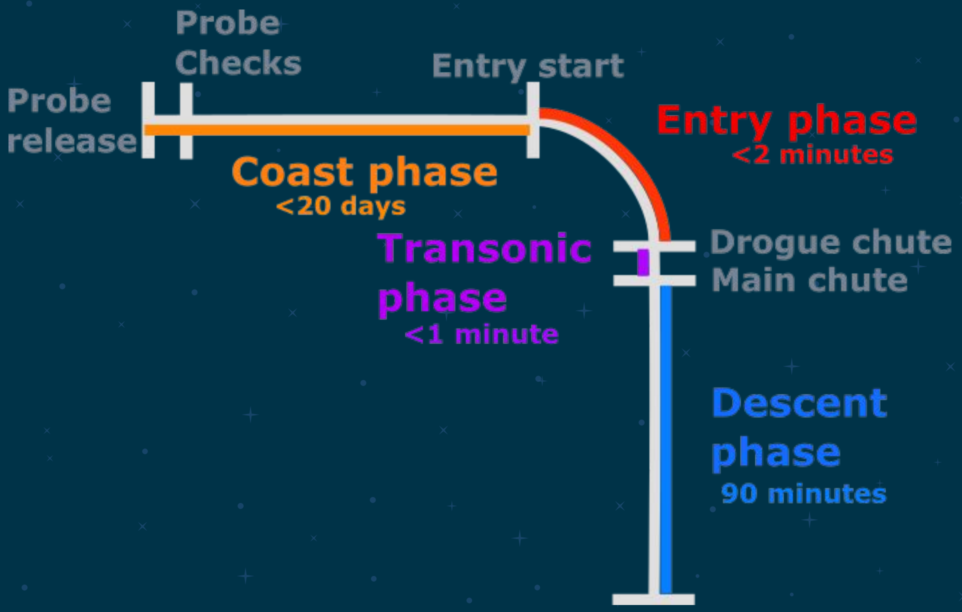
ΔV (m/s)	
Probe	15.75
SOI	664.6
PRM	315.1
Total	**995.4**

MISSION DESIGN → SCIENCE OPERATIONS

Mission Phases - Science Operations

LEOP + Commissioning → Interplanetary Transfer → Science Operations → Decommissioning

Phase 1
Probe Science



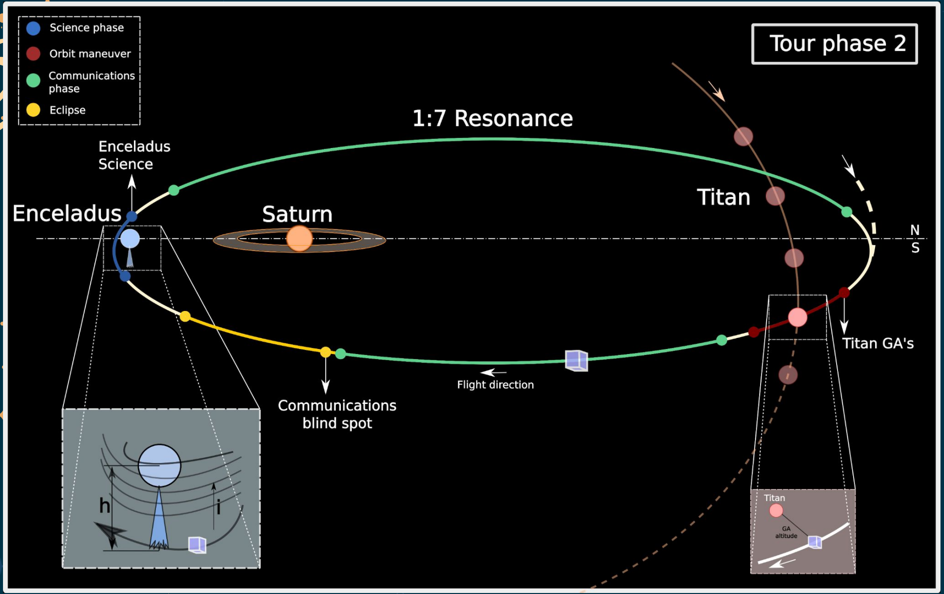
Objectives & Statistics

- Entry phase: 700 km above 1 bar altitude
- Entry angle: -25 deg
- Entry velocity: 36 km/s
- Descent phase: 0.5 bar
- 360 - 540 measurements

Mission Phases – Science Operations

LEOP + Commissioning → Interplanetary Transfer → Science Operations → Decommissioning

Phase 2
Enceladus Science

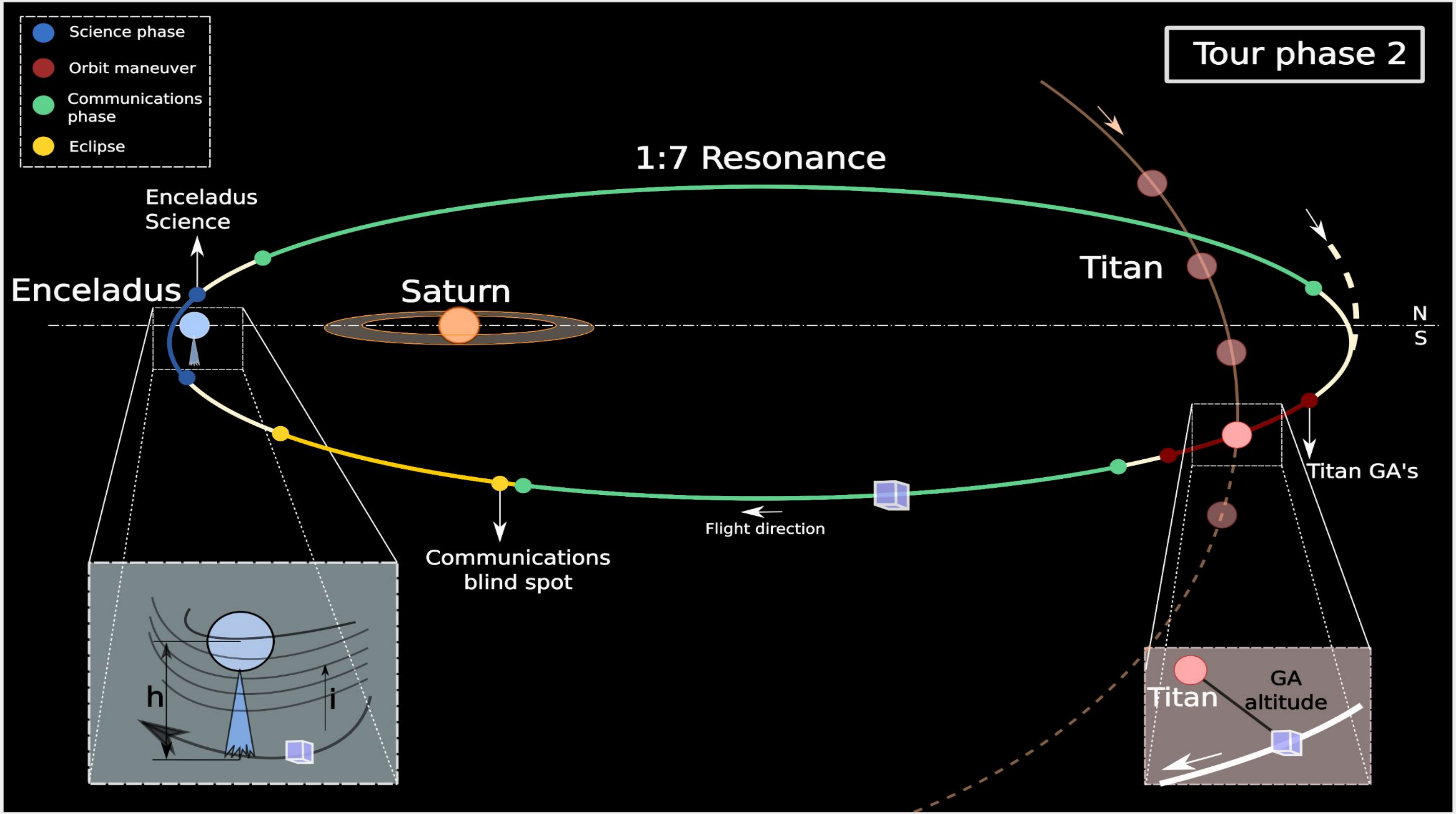


Enceladus Science
Goal 3:
Enceladean Plume Studies & Chemistry

h = [1000, 500, 100, 25] km

ΔV = 373 m/s
T = 9.62 days
N_{orbits} ≈ 75

MISSION DESIGN → SCIENCE OPERATIONS

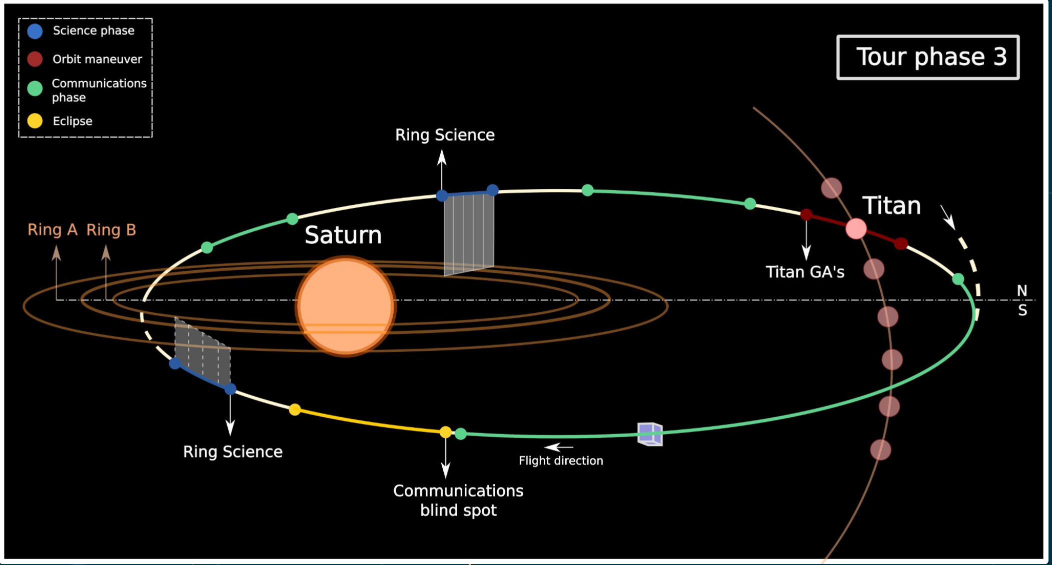


Science phase
Orbit maneuver
Communications phase
Eclipse
Tour phase 2
1:7 Resonance
Enceladus Science
Enceladus
Saturn
Titan
N
S
Titan GA's
Flight direction
Communications blind spot
h
i
Titan
GA altitude

Mission Phases - Science Operations

LEOP + Commissioning → Interplanetary Transfer → Science Operations → Decommissioning

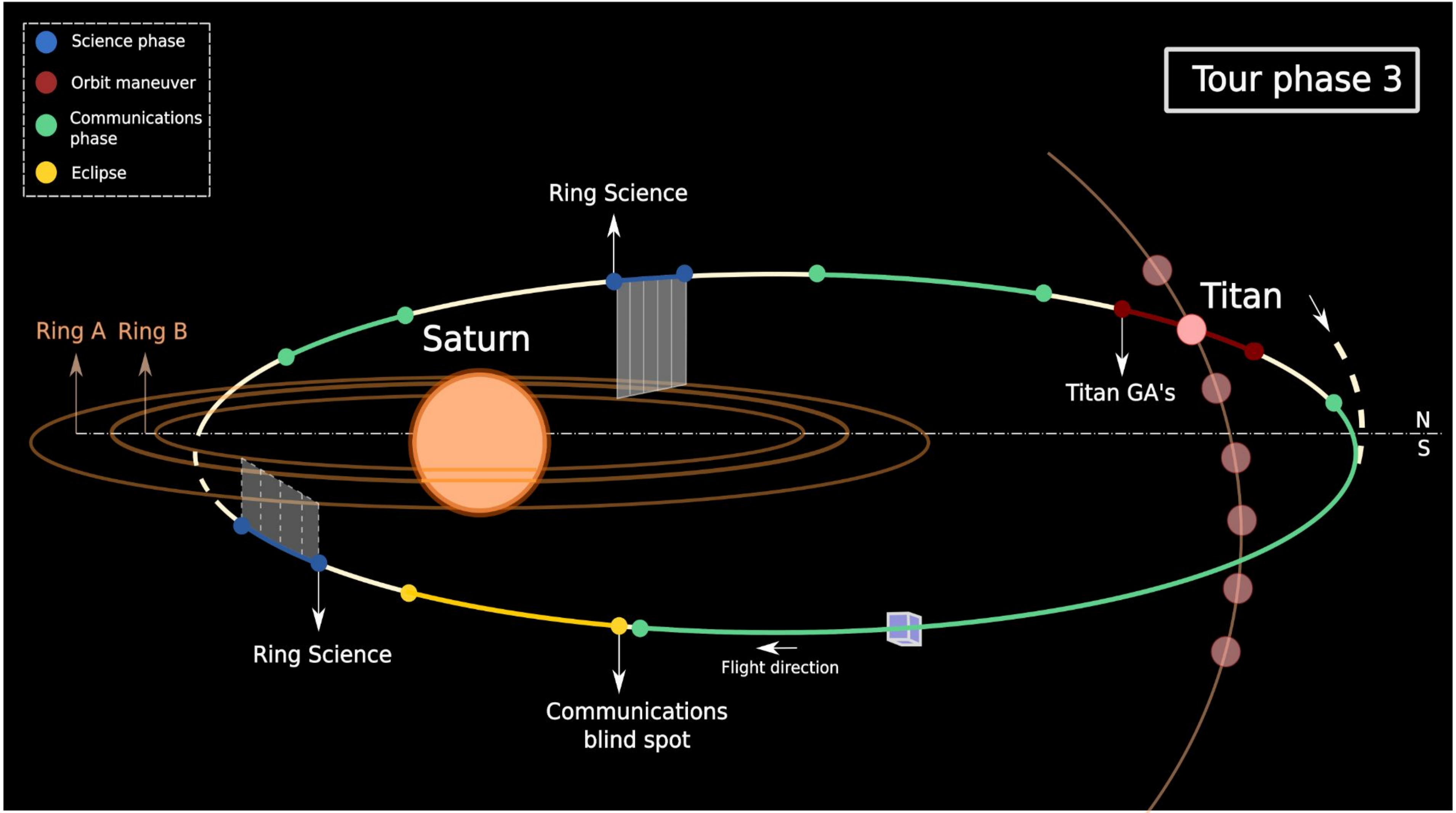
Phase 3
Ring Science



Ring Science
Goal 2:
Saturnian Ring and Moon formation processes

h = ~600 km

ΔV = 745 m/s
T = 6.4 days
N_{orbits} ≈ 100



Science phase
Orbit maneuver
Communications phase
Eclipse
Tour phase 3
Ring Science
Ring A
Ring B
Saturn
Titan
Titan GA's
N
S
Ring Science
Communications blind spot
Flight direction

Mission Phases

LEOP + Commissioning → Interplanetary Transfer → Science Operations → Decommissioning

Phase X
Additional Objectives

Additional Objectives

Extended ring analysis duration

Casual encounters with other Saturnian moons
- Mapping
- Composition analysis

Decommissioning

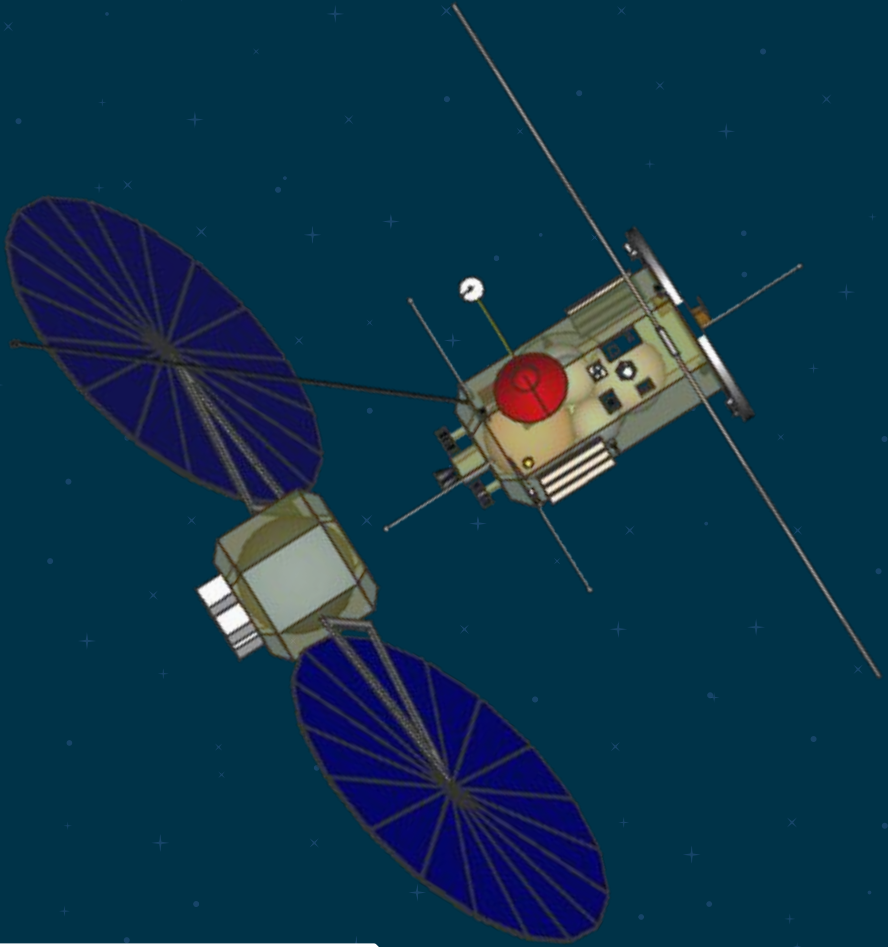
Planetary Protection: Spacecraft Disposal Restrictions

- Chance of impact at LoC
- Avoid impact with:
  - Moons
  - Ring systems

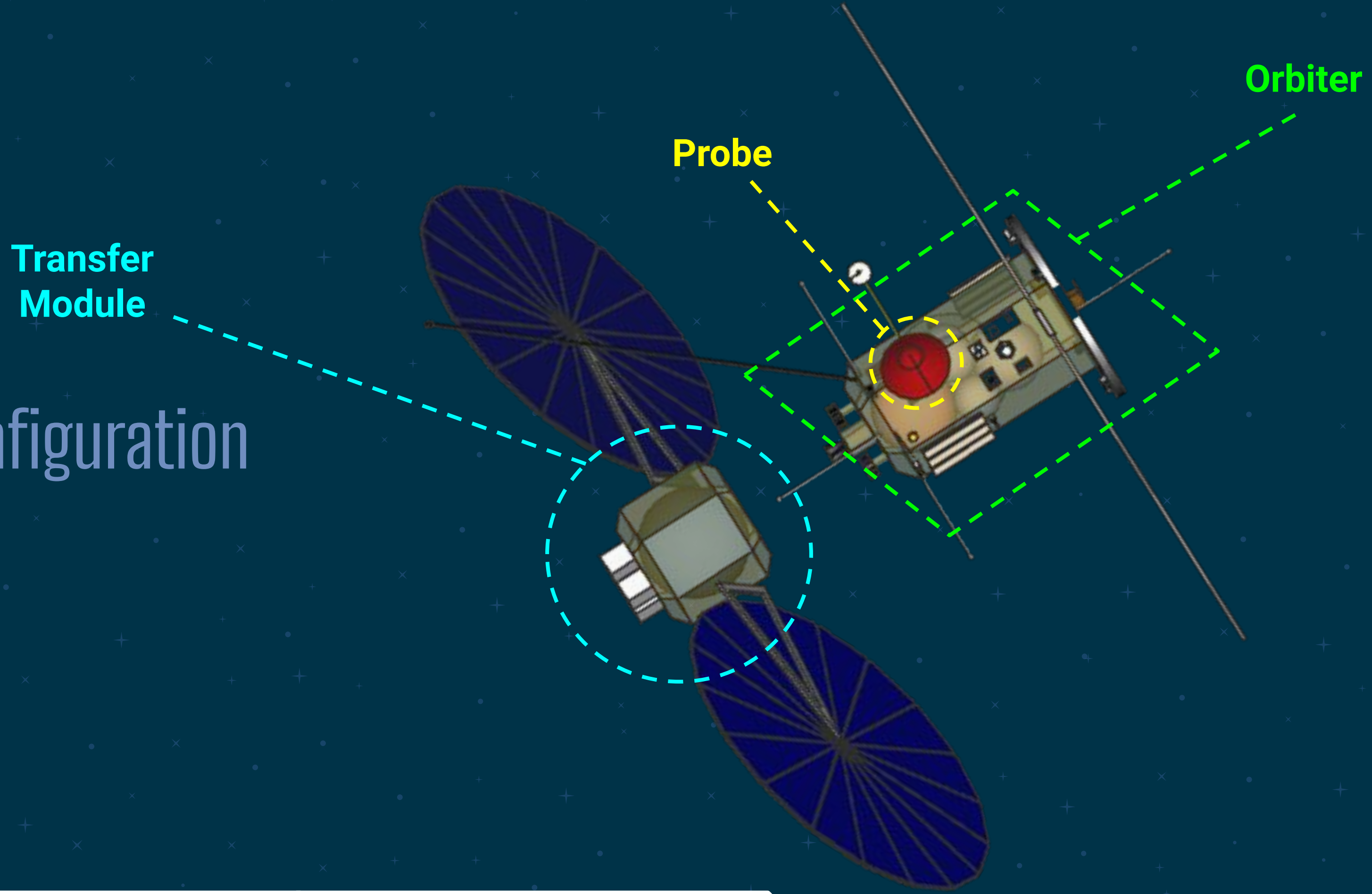
04

Mission Segments

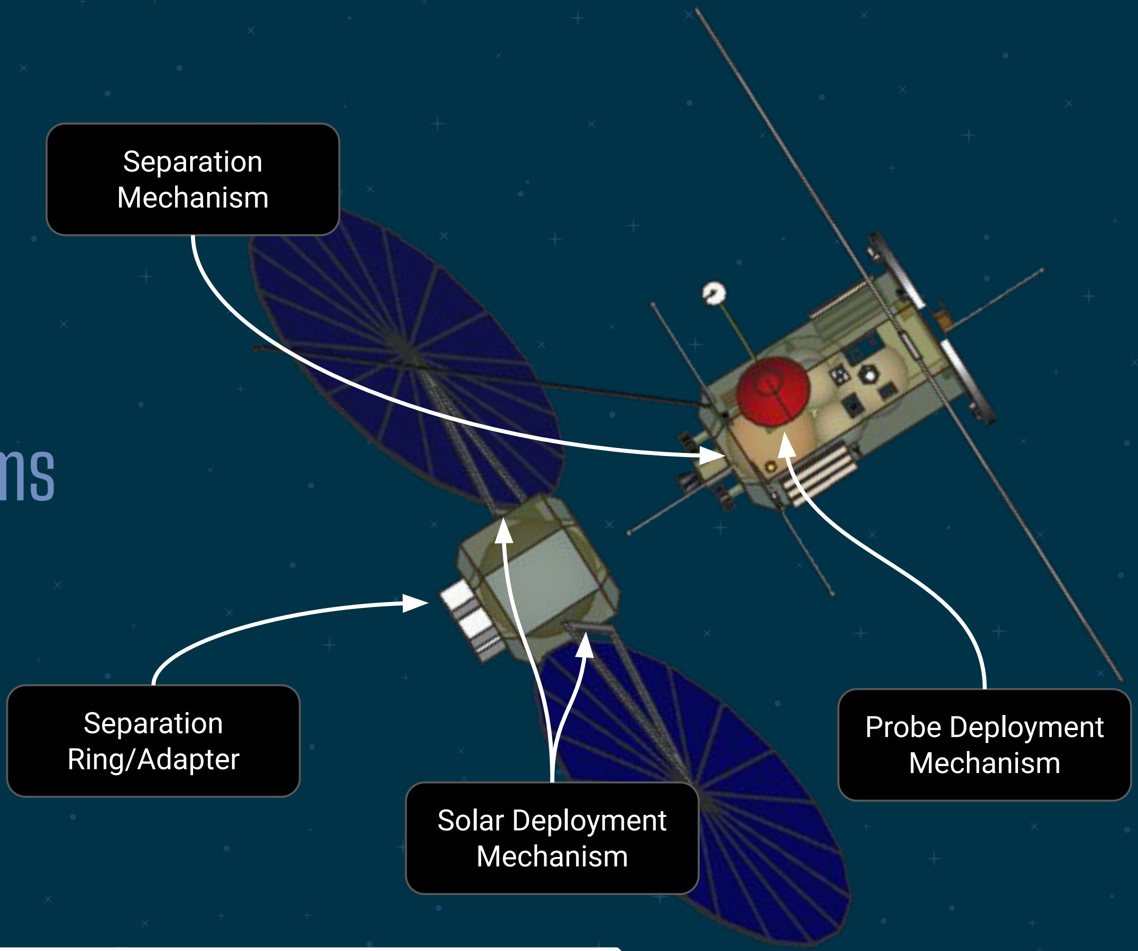
Configuration



Configuration



Mechanisms

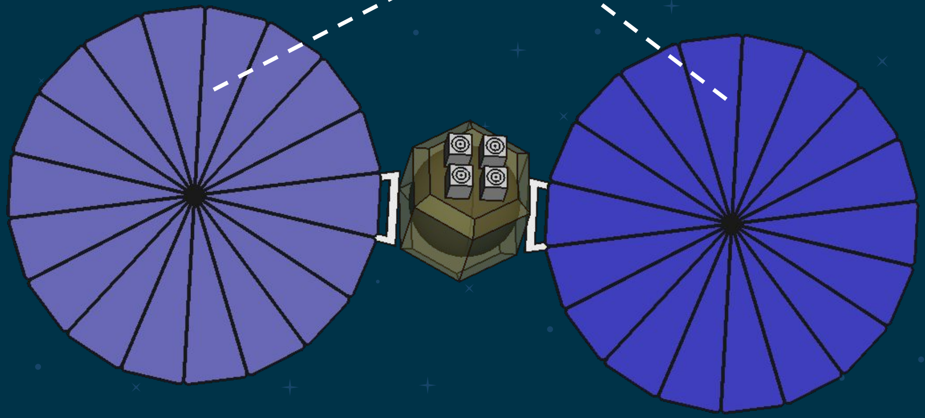


Separation Mechanism
Separation Ring/Adapter
Solar Deployment Mechanism
Probe Deployment Mechanism

TRANSFER MODULE

- Ionic Propulsion (DART)
  - Power = 26.7 kW
- Folding solar panels (LUCY)
  - Area = 83 m^2
- Minimal subsystems - jettisoned

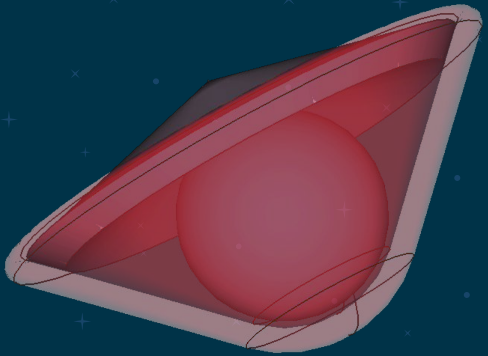
Solar Arrays



Probe

ARGO

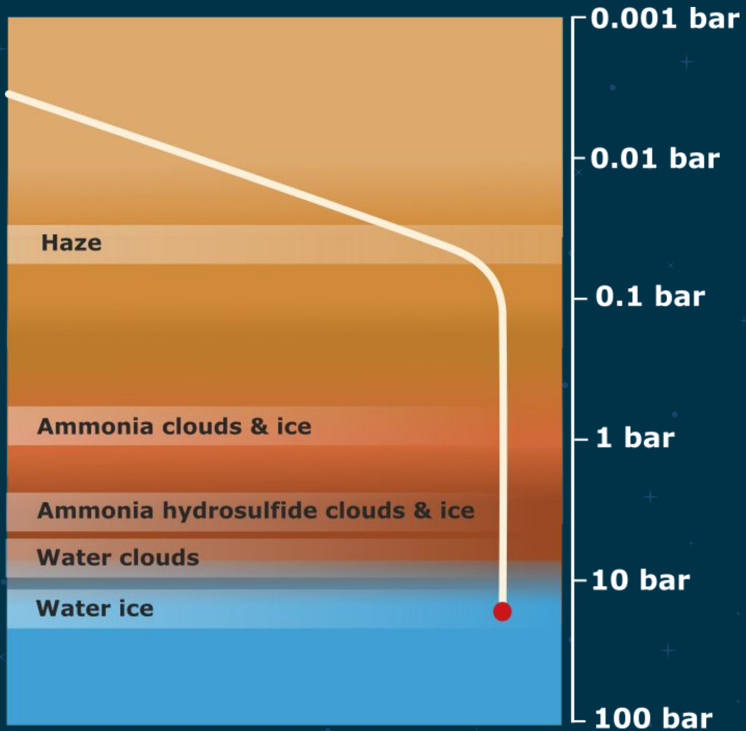
Atmospheric Research and Gas composition Observer



ARGO - Requirements

Scientific requirements

- Measure Saturn's atmosphere:
  - Resolution: every 500 m
  - Between altitudes from ~0.5 bar till 20 bar
- Key design drivers:
  - Dive into Saturn's atmosphere
  - Survive to 20 bar
  - Relay data to orbiter

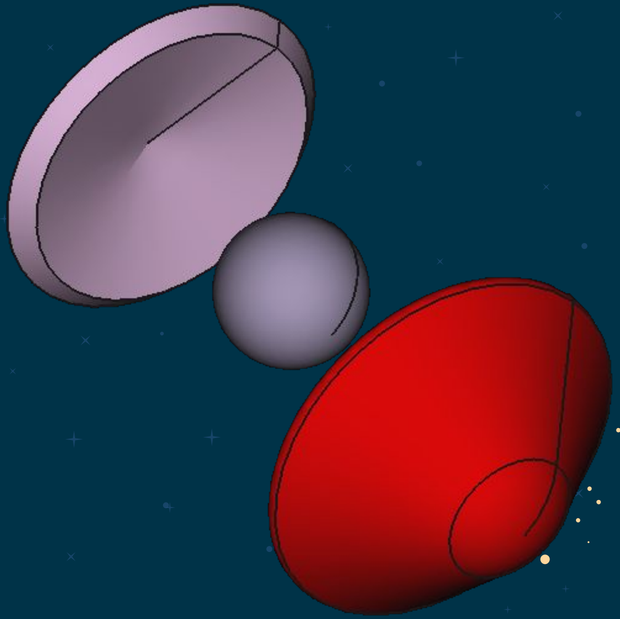


ARGO - Design

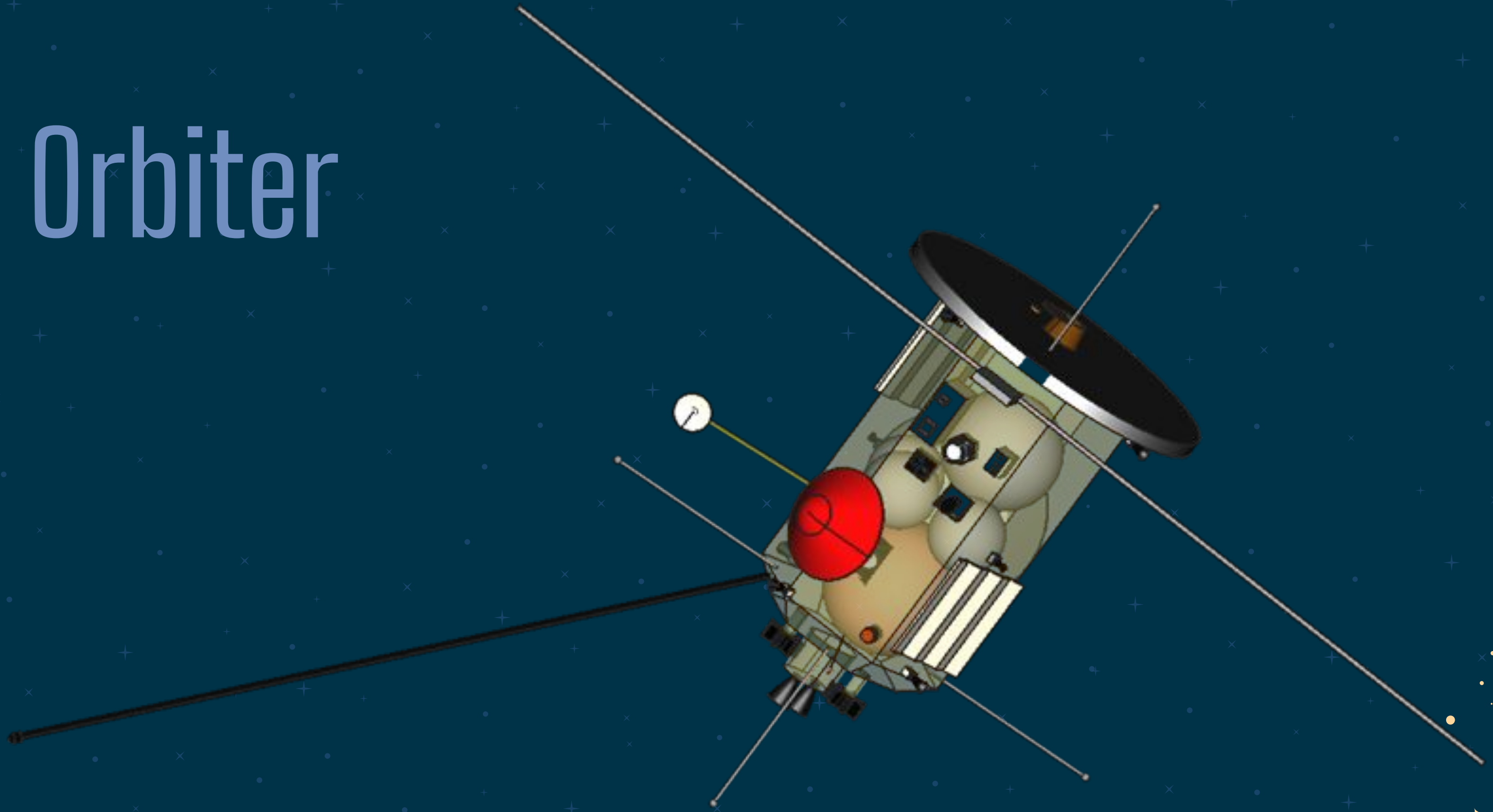
- Key parts:
    - Pressure vessel
    - Heat shield (HEEET)
    - Link: UHF direct to orbiter
    - Parachutes

- Total mass = 420 kg
    - Payload: 24.5 kg (~6% of total mass)
    - TPS mass: 210 kg: (~50%)

- Data budget = 3 MB



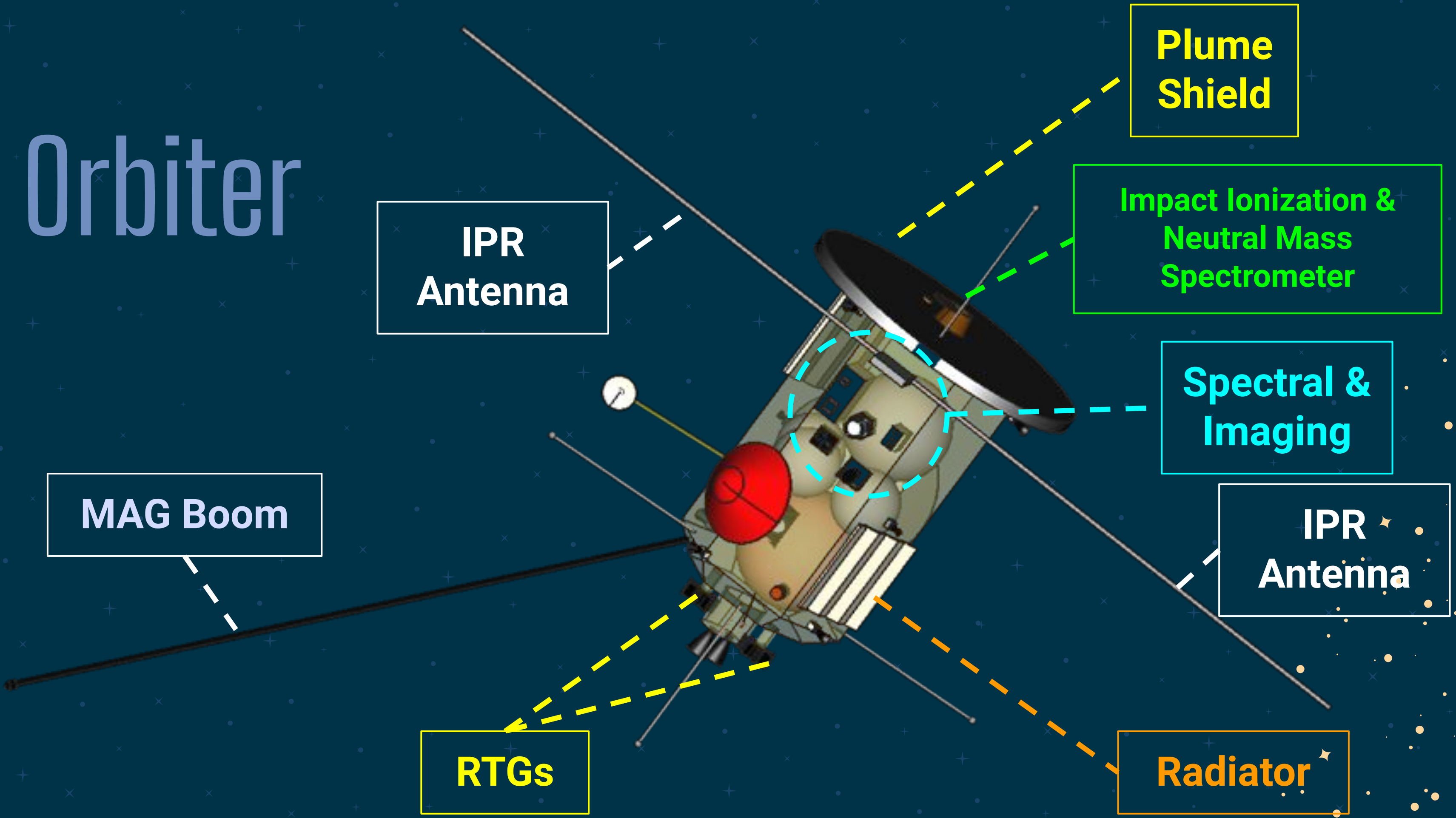
Orbiter



MISSION SEGMENTS

SPACE SEGMENT

Orbiter


Plume Shield
IPR Antenna
Impact Ionization & Neutral Mass Spectrometer
Spectral & Imaging
MAG Boom
IPR Antenna
RTGs
Radiator

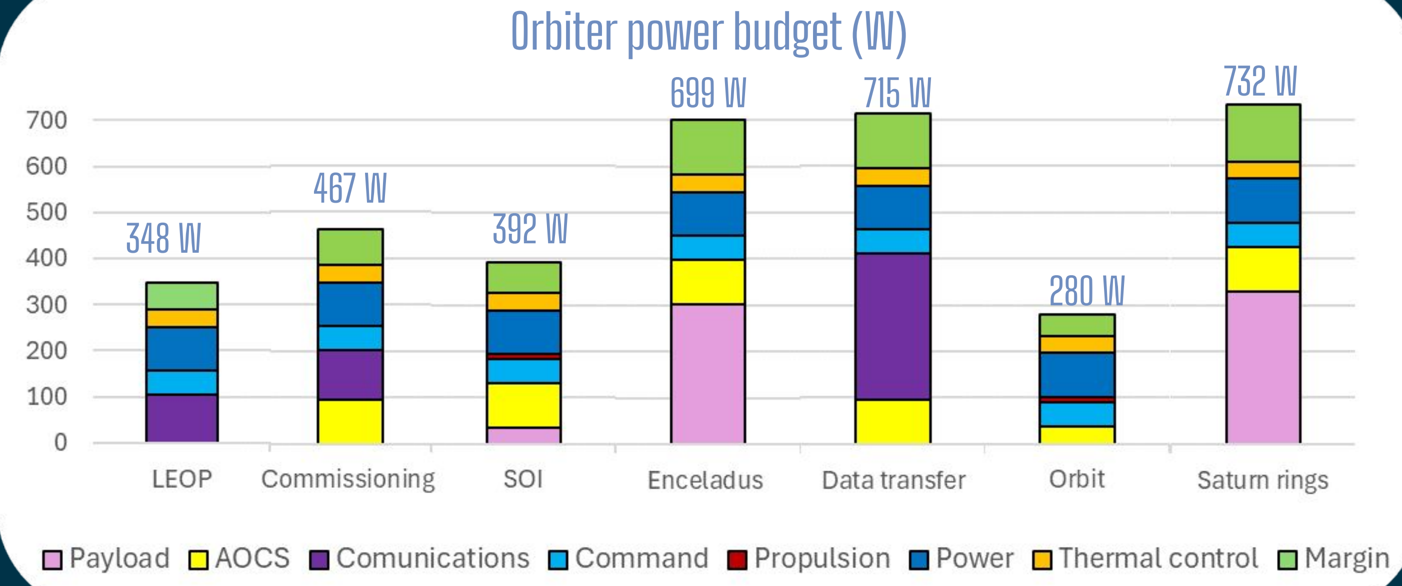
Power

Primary source

Am-241 RTG
6 x 50 W modules
300 W (BOL)
293 (EOL)

Secondary source

Li-ion batteries
Energy = 12.5 kWh



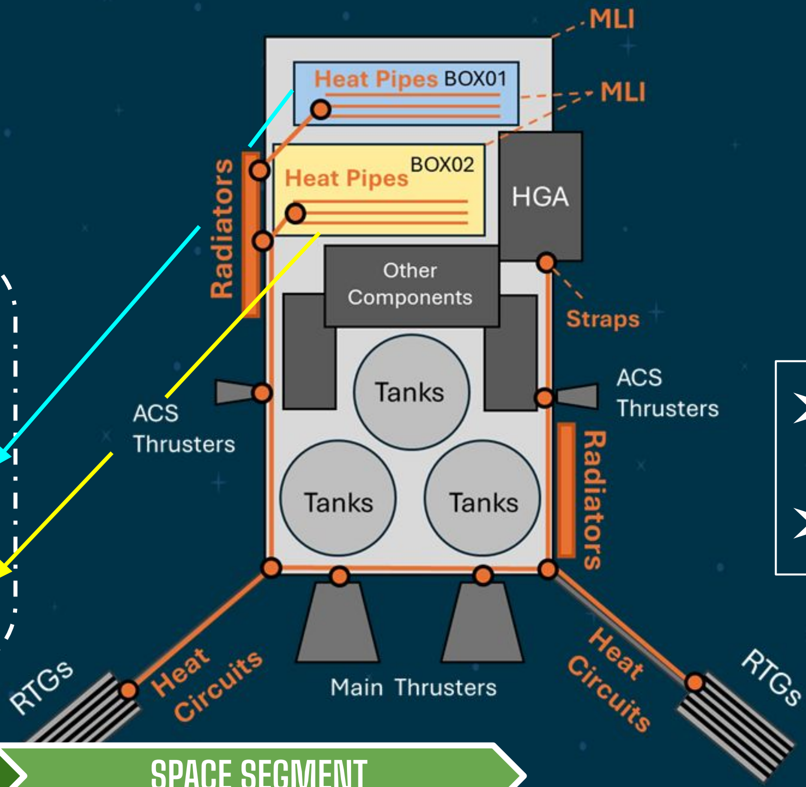
Thermal Control Subsystem

Instruments Thermal Requirements

Operational Temperature Ranges

150K - 160.15 [K]

280.15 - 290.15 [K]



- 6 RTGs → 6 × 1000 [W] → 6000 W thermal
- Thermal Radiators Area: **3.08 [m²]**

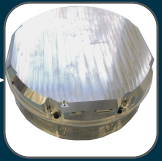
➢ **~ 132 [kg]**

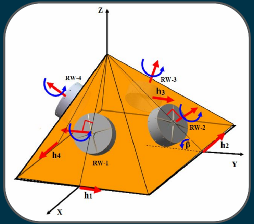
➢ **~ 38 [W]**

Attitude Determination & Control Subsystem

Actuators

- 4× Reaction Wheels
- 12× ACS Thrusters (~20N)





Sensors

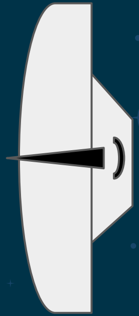
Sensors	Qty	Typical Performance Range
Sun sensors	6	0.005 - 3 [deg]
Star Trackers	2	0.0003 - 0.01 [deg]
IMU	2	0.003 - 1 [deg/hr]

- ~ 97 [kg]
- ~ 96 [W]

Data Budget

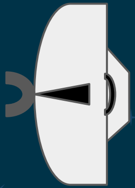
Mission Phase	Data Gathered 10% Margin	Lossless Compression Rate	Memory Budget
Atmospheric Probe **Total Phase 1**	3.02 Mbit	1.25	10 MB
Saturn + Enceladus **Per Orbit** in Phase 2	5.01 Gbit	1.6	1.2 TB
Saturn + Rings **Per Orbit** in Phase 3	5.03 Gbit		

Link Budget



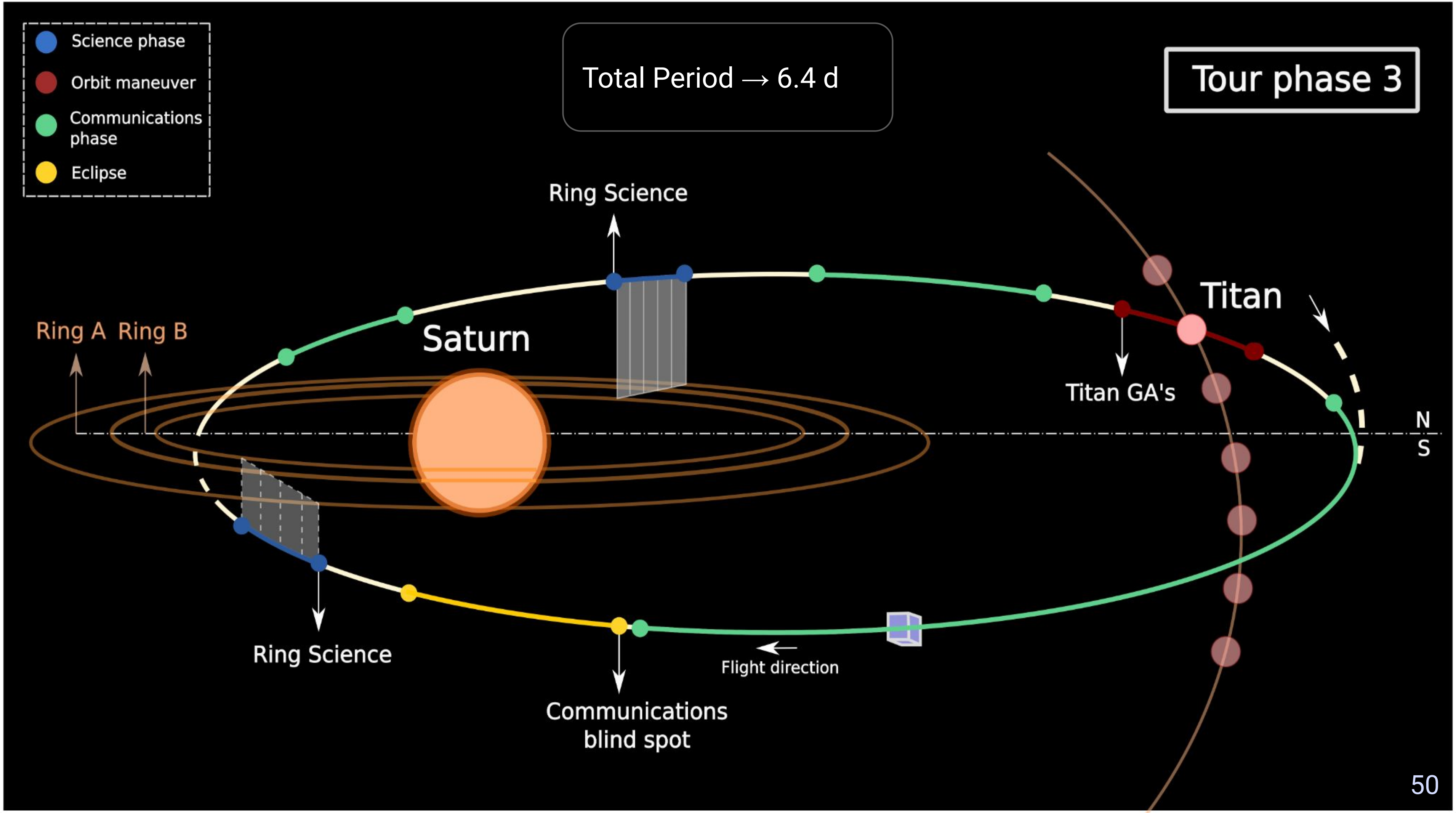
Fixed High Gain Antenna → 2.5 m

- UHF-Band ↑ Data rate → 1 - 16 kbps
- X-Band ↑↓ Data rate → 8.6 - 32.3 kbps
- Ka-Band ↑↓ Data rate → 80.2 - 421.3 kbps



Movable Mid Gain Antenna → 0.5 m

- X-Band ↑↓ Data rate → 0.42 - 1.06 kbps



Science phase
Orbit maneuver
Communications phase
Eclipse
Total Period → 6.4 d
Tour phase 3
Ring Science
Ring A
Ring B
Saturn
Titan
Titan GA's
N
S
Ring Science
Communications blind spot
Flight direction

Space Segment Summary

Power

Orbiter Subsystem Power	Power Budget in Phases [W]		
	Enceladus	***Orbit***	***Rings***
Payload	302	0	330
AOCS	96	39	96
Communications	0	0	0
Command	53	53	53
Propulsion	0	11	0
Power Conditioning and Distribution Unit (PCDU)	95	95	95
Thermal Control	38	38	38
System Margin (20%)	117	47	122
Total	**699**	**218**	**732**

Subsystem margin - 5%

Space Segment Summary

Mass

Mass Budget	Basic Mass [kg]	Margin	Total Mass [kg]
ARGO Probe Mass	420	20%	504
Transfer Module Dry Mass	1009,30	20%	1211,16
Propellant Mass (Electric)	497,80	10%	547,58
Transfer Module Wet Mass	1758,74	n/a	
Orbiter Dry Mass	1847,05	20%	2216,46
Propellant Mass (Bipropellant)	2129,38	10%	2342,32
Orbiter Wet Mass	4558,78	n/a	
Overall Spacecraft Dry Mass	3931,62	n/a	
Launch Mass	6821,53		

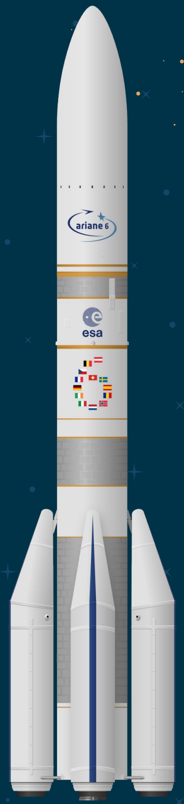
Mean component margin - 14 %
Mean subsystem margin - 17 %

Launch Segment

Mass is budgeted for Earth Escape

Launcher: Ariane 64
Launch Site: Kourou, French Guiana
Launch Windows: ~1 per year

Launchers	Infinite Velocity [m/s]	Mass limit [kg]
Ariane 64	2500	6900
Ariane 64 Block II	3000	9000



Ground Segment

ESTRACK Deep Space Antennae (DSA):

- DSA 1 - New Norcia (Australia)
- DSA 2 - Cebreros (Spain)
- DSA 3 - Malargüe (Argentina)
- *DSA 4 - Perth (Australia) soon*

Note: NASA's DSN can be used as support or backup

Operations:

- Science Data Downlink → ~ 19h / week
  - Routine Operations → ~ 3h / day

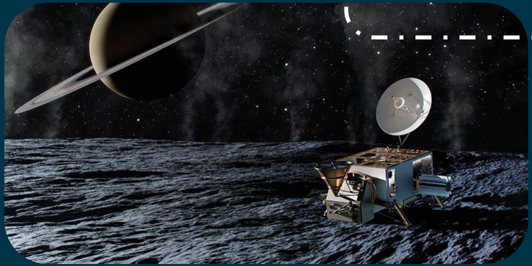
05

Programmatics

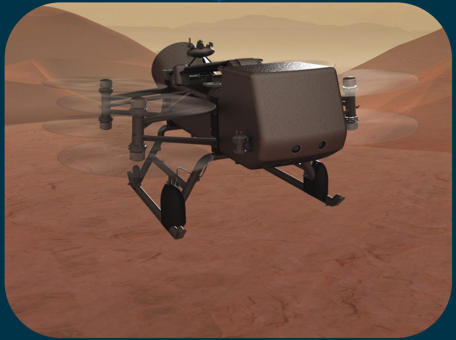
Synergies

- Proposed Mission

NASA Enceladus OrbiLander



Planetary Science and Astrobiology Decadal Survey 2023-2032



NASA DragonFly

- Planned Missions
  - Saturn
    - NASA Dragonfly to Titan
  - Jupiter
    - Juice (ongoing)
    - Europa Clipper

ESA's Voyage 2050 L4 Missions

- Science Questions related to Habitability
- **Enceladus**
  - Contact between ocean and rocky core
  - Dust environment
  - Hydrothermal vents
- Mission Profile Priority
  - Saturn orbiter + plume sampling

Technology Development

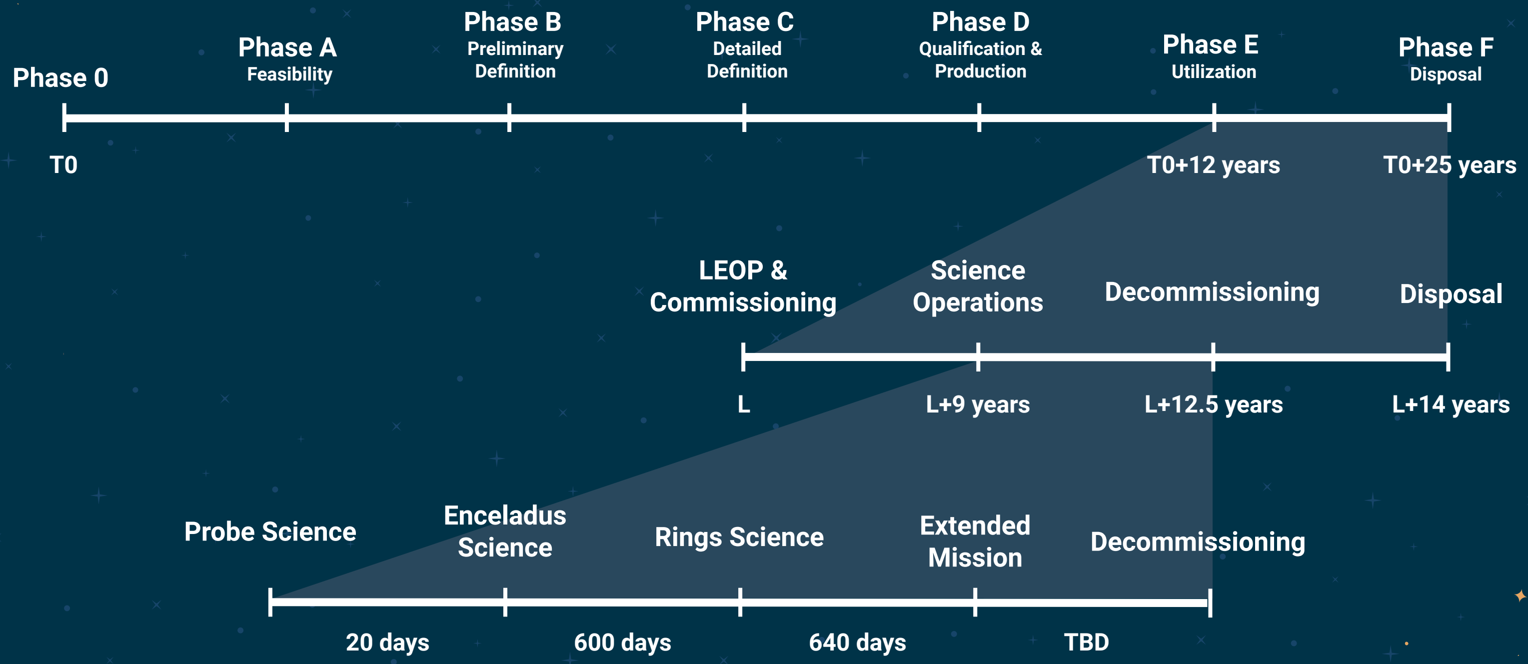
Current Components

- Existing Components: Adapted from previous missions
- Current TRLs: TRL 4 - 5
  - Expected to reach TRL 7 - 8 by mission development through planned advancements

Critical Elements:

- RTGs
  - Americium RTGs used as a safer, more responsible source of nuclear energy for deep space missions
- Instruments requiring development from their heritage references
  - Spectrometers: UV-VIS & NIR
  - Impact Ionization Mass Spectrometer
  - Ice Penetrating Radar

Mission Schedule



Cost Analysis

Item	Cost [M€]
Industrial Cost	1200
Project Team ESA	300
Mission Operations (MOC) Science Operations (SOC)	180
Launch	150
Contingency	252
Total	2082
+10% Inflation	2290

Risk Matrix

Severity \ Likelihood	1	2	3	4	5
5	R-01 RTG environmental damage R-16 Instruments development not ready	R-05 Spacecraft impact on Enceladus			
4	R-09 Launcher unavailable R-12 Probe does not turn on R-13 Failure of drogue chute deployment	R-03 RTG technology not mature enough R-08 Electronics failure due to radiation R-15 Deployment of Solar Array not complete			
3	R-14 Failure of main parachute deployment	R-04 Negative dV budget R-11 Long-lead items availability	R-02 Radioisotope acquisition R-17 Spacecraft AOCS failure		
2	R-06 Spacecraft is influenced by Enceladus plume during flyby R-10 Micrometeoroid strike	R-07 Deployment mechanism failure			
1					

Severity

Likelihood

Descoping

Priority	1	2	3	4
Instrument	Top Hat Analyzer	Electric Field Probe	UV-VIS Spectrometer	Atmospheric Probe
Consequence	Energy, directions, density and fluxes of plasma particles on Saturn's environment are less well-characterized		Incomplete Enceladus Plume chemical characterization	Loss of in-situ measurements of Saturn's atmosphere
Action	Remove Instrument			Remove

Outreach

Schools and universities: Workshops, colouring books for children, involvement in data analysis with supporting scientists (early access to data)

General public: Social media presence, websites, live streaming, public science events (exoplanet of the week), VR platform

Science community: Dedicated events for early-career scientists

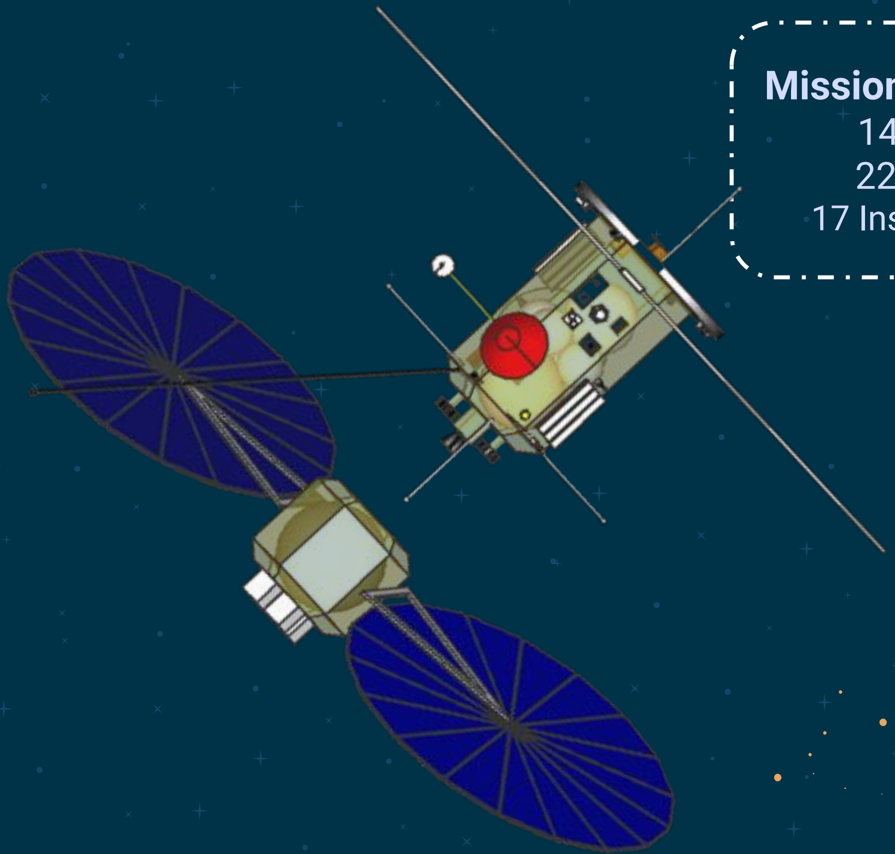
Conclusion

SIREN
Saturn atmosphere and Investigation of Rings and ENceladus

Transfer Vehicle
Orbiter
12 instruments

ARGO
Atmospheric Research and Gas composition Observer

Atmospheric Probe
5 instruments



Mission Key Facts
14 years
2290 M€
17 Instruments

Thank you

Saturn atmosphere and Investigation of Rings and ENceladus

TEAM YELLOW

Bibliography

Ando, H. et al. (2018). Local time dependence of the thermal structure in the Venusian equatorial upper atmosphere: Comparison of Akatsuki radio occultation measurements and GCM results. Journal of Geophysical Research: Planets, 123(9), 2270-2280.

Arianespace. (2021). Ariane 6 user's manual, issue 2 rev 0.

Birnstiel, et al. (2011). Growth and Transport of Dust Grains-How to Cross the Metre Size Barrier. In Workshop on Formation of the First Solids in the Solar System.

Buratti, et al. (2019). Close Cassini flybys of Saturn's ring moons pan, daphnis, atlas, pandora, and epimetheus. Science, 364(6445).

Čadek, et al. (2019). Long-term stability of Enceladus' uneven ice shell. *Icarus*, *319*, 476-484.

Choblet, et al. (2017). Powering prolonged hydrothermal activity inside Enceladus. *Nature Astronomy*, *1*(12), 841-847.

Crow‐Willard et al. (2015). Structural mapping of Enceladus and implications for formation of tectonized regions. *Journal of Geophysical Research: Planets*, *120*(5), 928-950.

Deschamps S., Rouchit P. (2023). Juice: Thermal Control Interface Document, Airbus.

ESA. (2010a). Planetary Entry Probes (PEP) for Venus and the Outer Planets. CDF Assessment study.

ESA. (2019a). EPIG CDF Study Summary Report. Report: ESA-SCI-F-ESTEC-RP-2019-001.

ESA. (2019b). CDF Study Report_Ice Giants_A Mission to the Ice Giants – Neptune and Uranus. Report: CDF-187(C).

Garcia-Melendo, (2011), Saturn's zonal wind profile in 2004-2009 from Cassini ISS images and its long-term variability, *Icarus*, 215, 1, 62–74.

Gibbs, R. (1996). Cassini spacecraft design. Cassini/Huygens: A Mission to the Saturnian Systems.

Glein, et al. (2015). The pH of Enceladus' ocean. *Geochimica et Cosmochimica Acta*, *162*, 202-219.

Gombosi, T. I., and A. P. Ingersoll, (2010), Saturn: atmosphere, ionosphere, and magnetosphere, *Science*, 327, 5972,

Hanel, R. et al (2003), Exploration of the Solar System by Infrared Remote Sensing, Cambridge University Press, Cambridge, UK.

Holmberg. (2015). A study of the structure and dynamics of Saturn's inner plasma disk. Doctoral dissertation.

Hsu et al. (2015). Ongoing hydrothermal activities within Enceladus. *Nature*, *519*(7542), 207-210.

Irwin. (2009). Giant Planets of Our Solar System, Springer Berlin, Heidelberg, Germany

Khawaja, et al. (2019). Low-mass nitrogen-, oxygen-bearing, and aromatic compounds in Enceladean ice grains. *Monthly Notices of the Royal Astronomical Society*, *489*(4), 5231-5243.

Machado, P., et al, (2017). Venus cloud-tracked and Doppler velocimetry winds from CFHT/ESPaDOnS and Venus Express/VIRTIS in April 2014. *Icarus*, 285, 8-26.

Markley F. L., Crassidis J. L. (2014). Fundamentals of Spacecraft Attitude Determination and Control, Space Technology Library - Springer.

Matson, et al. (2002). The Cassini/Huygens mission to the Saturnian system. Space Science Reviews, 104(1), 1-58.

Postberg, et al. (2011). A salt-water reservoir as the source of a compositionally stratified plume on Enceladus. *Nature*, *474*(7353), 620-622.

Bibliography

Peter et al. (2024). Detection of HCN and diverse redox chemistry in the plume of Enceladus. *Nature Astronomy*, *8*(2), 164-173.

Postberg, et al. (2009). Sodium salts in E-ring ice grains from an ocean below the surface of Enceladus. Nature, 459(7250), 1098-1101

Postberg et al. (2018a). Macromolecular organic compounds from the depths of Enceladus. *Nature*, *558*(7711), 564-568.

Postberg, F. et al. (2018b). Plume and Surface Composition of Enceladus, In: Enceladus and the Icy Moons of Saturn, University of Arizona Press, pp. 129-162.

Porco, et al. (2006). Cassini observes the active south pole of Enceladus. *science*, *311*(5766), 1393-1401.

Ray, et al. (2021). Oxidation processes diversify the metabolic menu on Enceladus. *Icarus*, *364*, 114248.

Robinson et al. (2023). Ethene-ethanol ratios as potential indicators of hydrothermal activity at Enceladus, Europa, and other icy ocean worlds, *Icarus,* 406, 115765

Rocchi, A. and Khan, M. (2023). Solar electric propulsion boosted transfers to the outer solar system. *AAS*, 23-263.

Sánchez-Lavega (2011). Introduction to Planetary Atmospheres, CRC Press, Boca Raton, Florida, USA

Shastry et al. (2017). Current Status of NASA's NEXT-C Ion Propulsion System Development Project, 68th International Astronautical Congress, Adelaide, Australia

Spencer J. et al. (2010). Mission Concept Study: Planetary Science Decadal Survey Enceladus Orbiter, NASA.

Thomas et al. (2016). Enceladus's measured physical libration requires a global subsurface ocean. *Icarus*, *264*, 37-47.

Villanueva et al (2023), JWST molecular mapping and characterization of Enceladus' water plume feeding its torus, *Nature Astronomy*, 7, 1056–1062

Waite et al.. (2006). Cassini ion and neutral mass spectrometer: Enceladus plume composition and structure. *science*, *311*(5766), 1419-1422.

Waite et al. (2017). Cassini finds molecular hydrogen in the Enceladus plume: evidence for hydrothermal processes. *Science*, *356*(6334), 155-159.

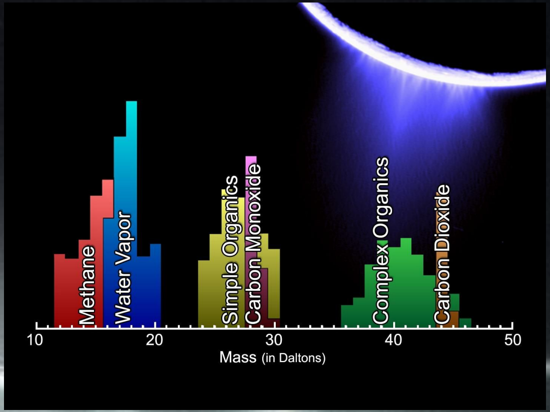
Wertz J.R. et al. (2003). Space Mission Analysis and Design, 3rd ed., Space technology Library.

Appendix

Probe instruments

[Instruments - Google Sheets]

What do we know about Enceladus?



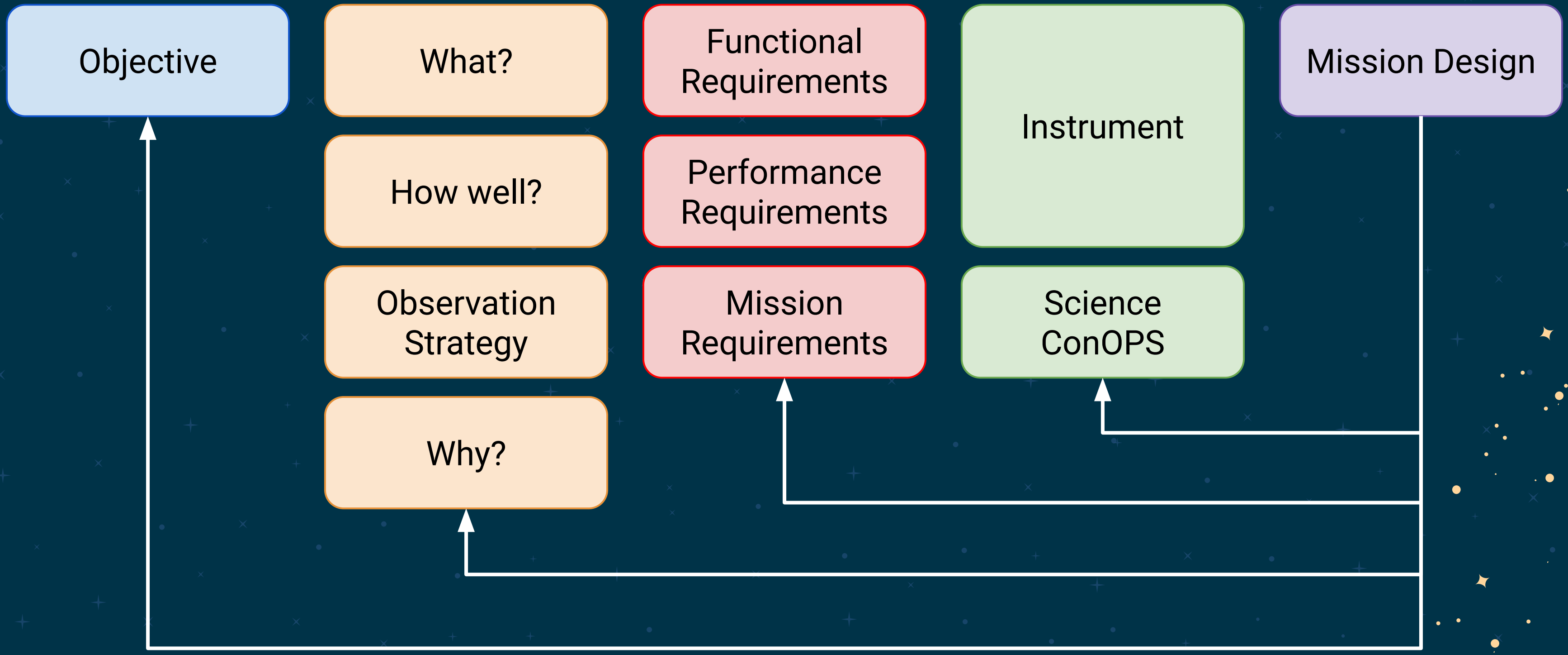
- Warm interior with liquid ocean of pH 9 -12
- Ice particles and gas continuously plume ejected at South pole
- Requirements for life as we know it on Earth

Gas (INMS)		Solids (CDA)	
H_2O	96 - 99 %	NaCl	0.5 - 2 M
CO_2	0.3 - 0.8 %	NaCO3	0.01 – 0.1 M
CH_4	0.1 - 0.3 %	KCl	$0.5*10^{-3}$ – $2*10^{-3}$ M
NH_3	0.4 - 1.3 %	Na3PO4	$1*10^{-3}$ – $20*10^{-3}$ M
H_2	0.4 - 1.4 %	SiO2	~ 0.001
C_2, C_3 organics	~ 0.1 %	Simple and complex organics (unidentified)	

- Cassini/INMS mass degeneracy, low spectral resolution in Cassini/UVIS and VIMS prevent complete plume chemical characterization.
- Plumes allow probing Ocean World Interiors, allowing search for ***Geosignatures*** and ***Biosignatures*** (given enough spectral resolution).
- Extent of the subsurface Ocean, Ice Shell structure and radiolytic chemistry poorly constrained.

A natural laboratory for Icy Moon Subsurface Ocean Geochemistry and Habitability.

System Engineering Plan



System Engineering Plan – Example

G3S1
What is the **structure** and **composition** of Enceladus' **plume**?

What?

Functional Requirements

For Enceladus' plume ejected at its South pole the mission shall measure:

1. Composition of ice grains
2. Composition of charged and neutral gaseous
3. Spatial differences in the plume composition (solids, gas).
4. Reflectance at UV-VIS-NIR wavelengths [100 nm to 5 μm] with R > 1000.
5. Density distribution of dust particles.
6. Dust particles size distribution.
7. Plume's asymmetry and migration.

During all flybys at Enceladus

System Engineering Plan – Example

G3S1
What is the **structure** and **composition** of Enceladus' **plume**?

How well?

Performance Requirements

How well?	**Why?**
Up to at least 500 Da.	Biosignatures: Amino acids, fatty acids Hydrothermal products: Ethane/Ethanol
Down to ppm levels.	Salinity, low abundances (S, Fe), Oxidation state, pH
Resolution of 1 Da.	Isotopic ratios: 13C/C12, 15N/14N, 18O/16O, 17O/16O

System Engineering Plan – Example

G3S1
What is the **structure** and **composition** of Enceladus' **plume**?

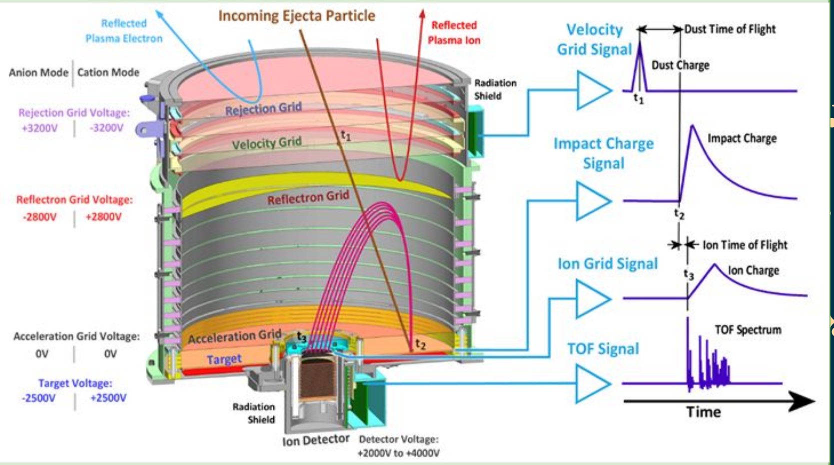
Observation Strategy

Mission Requirements

Instrument

Impact ionization mass spectrometer

- Composition of single ice grains
- Measuring the mass-to-charge ratio of molecules present in a sample.
- Ionization by impact, TOF of charged fragments
- Sensitive to cations and anions
- Mass resolution: 150 – 300 m/Dm
- Maximum recorded mass: ~500 u



System Engineering Plan – Example

G3S1
What is the **structure** and **composition** of Enceladus' **plume**?

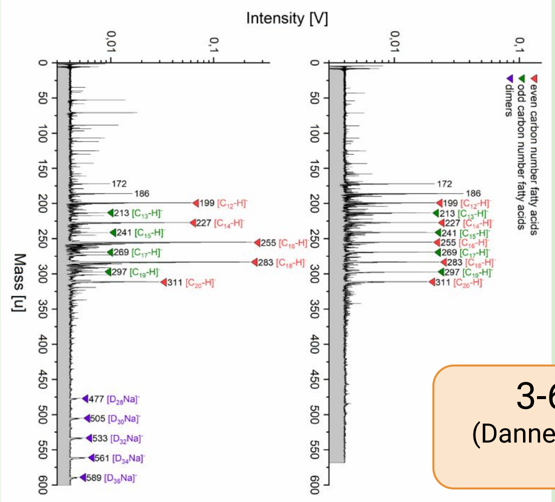
Observation Strategy

Mission Requirements

Instrument

Impact ionization mass spectrometer

- Fragmentation and detection of compounds depend on impact speed: Optimal detection of certain compounds can be simulated



Klenner et al., 2020

3-6 km/s
(Dannenmann et al., 2023)

System Engineering Plan – Example

G3S1
What is the **structure** and **composition** of Enceladus' **plume**?

Observation Strategy

Mission Requirements

The mission shall:

1. Measure the ice grains ejected at Enceladus south pole at an impact velocity of 4-6 km/s.
2. Measure the ice grains ejected at Enceladus south pole at altitudes of 25, 50, 100, 500, and 1000 km from the surface.
3. Pass Enceladus' plume during at least 3 flybys per altitude.

Saturn's Atmospheric Probe Instruments

Instrument	What for?	Mass (Kg)	Power (W)	Dimensions (cm x cm x cm)	Data Rate (kbps)	Operational Temperature (K)	Heritage
Mass Spectrometer	Atmospheric composition	13.2	25	18.5 x 18.5 x 45.2	32	240 - 260	NMS (Galileo)
Nephelometer	Clouds composition	2.76	3.6	13 x 19.5 x 16	10	240 - 260	NEP (Galileo)
Net Flux Radiometer	Clouds composition	2.88	7.56	11 × 14 × 28	60	240 - 260	NFR (Galileo)
Atmospheric Sensing Instrument	Weather	3	12	20 x 20 x 20	2	240 - 260	HASI (Huygens)
Helium Abundance Detector	Origin	1.4	0.9	10 x 10 x 10	4	240 - 260	HAD (Galileo)

Orbiter Optical Instruments

Instrument	What for?	Mass (Kg)	Power (W)	Dimensions (cm x cm x cm)	Data Rate (kbps)	Operational Temperature (K)	Heritage
UV-VIS Spectrometer	Saturn's atmosphere Enceladus' plume & surface	14.46	11.83	48 x 30 x 23	32.096	150 - 190	UVIS (Cassini)
NIR Spectrometer	Saturn's atmosphere Enceladus' plume & surface	33	50	91,2 x 76,5 x 35,6	TBD	65 - 90 (IR) 150 - 190 (VIS)	VIRTIS (Rosetta & Venus Express)
Thermal Infrared Spectrometer	Saturn's atmosphere Enceladus' surface	6.27	10.8	37.5 x 28.9 x 52.2	5.7	TBD	OTES (OSIRIS-REx)
VIS Camera	Saturn's atmosphere & rings Enceladus' plume & surface	29	43.2	67.2 x 60.2 x 31.5	10000 TBC	280.15 - 290.15	JANUS (JUICE)

Orbiter Mass Spectrometers

Instrument	What for?	Mass (Kg)	Power (W)	Dimensions (cm x cm x cm)	Data Rate (kbps)	Operational Temperature (K)	Heritage
Ion and Neutral Mass Spectrometer	Saturn's rings Enceladus' plume	8.8	22.6	TBD	TBD	248.15 - 298.15	NGIMS (MAVEN)
Impact Ionization Mass Spectrometer	Saturn's rings Enceladus' plume and surface	16	58.7	26.8 x 25.0 x 17.1	TBD	TBD	SUDA (Europa Clipper)

Orbiter Radar, Altimeter and Radio Science Instruments

Instrument	What for?	Mass (Kg)	Power (W)	Dimensions (cm x cm x cm)	Data Rate (kbps)	Operational Temperature (K)	Heritage
Ice Penetrating Radar	Enceladus' surface	16.8	30.1	25.6 x 18 x 14	TBD	TBD	RIME (JUICE)
Laser Altimeter	Enceladus' surface	19.6	56.8	38 x 28 x 31.1	TBD	TBD	GALA (JUICE)
Radio Science Experiment	Saturn, rings and Enceladus orbits	7	46.5	23.6 x 20.8 x 15	TBD	253.15 - 323.15	3GM (JUICE)

Orbiter Plasma Instruments

Instrument	What for?	Mass (Kg)	Power (W)	Dimensions (cm x cm x cm)	Data Rate (kbps)	Operational Temperature (K)	Heritage
Magnetometer	Magnetic field	5.9 30 boom	11.1	29.9 x 18.2 x 17.55 10m boom	TBD	TBD	JMAG (JUICE)
Top-Hat Analyser	Plasma field	5.4	7.8	40 x 13 x 20	1.2	TBD	MIA (BepiColombo)
Electric Field Antenna	Electric field	0.9 6.3 boom	5.4	10 x 10 x 10 2.5m boom	TBD	TBD	LP-PWI (JUICE)

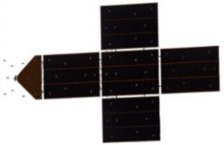
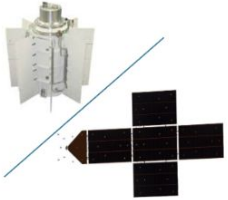
Instruments Traceability

Goals	Objectives	Functional Measurements	Part of the mission	Instrument	Requirements	Physical Instrument
G1: Study Saturn's formation and evolution reflected in its atmospheric composition	G1S1: What is Saturn's atmospheric volatile composition?	Measure molecular composition vertical abundance profiles on Saturn's atmosphere	ATM probe	Mass spectrometer	SR-20, SR-40, SR-50, SR-70, SR-80	NMS (Galileo)
		Measure cloud composition vertical abundances on Saturn's atmosphere	ATM Probe	Nephelometer/ Net Flux Radiometer	SR-30, SR-70, SR-80	NEP (Galileo) NRF (Galileo)
		The mission shall measure the temperature, pressure, winds speeds, He content, downward velocity (atmospherics sensing intruments)	ATM Probe	Atmospheric sensing instrument (miniaturised weather station)	SR-60, SR-70, SR-80	HASI (Huygens)
		The probe shall mesure the He content	ATM Probe	Helium abundance detector	SR-41	HAD (Galileo)
	G1S2: What is the structure of Saturn's atmosphere?	Observe Saturn's atmosphere in high spatial resolution allowing cloud tracking	Saturn orbiting	UV VIS spectrometer	SR-110	UVIS Cassini
		estimation of vertical profiles of the planetary atmosphere, tracking Temperature, Density and Static Stability/ Cloud Tracking measurements allow atmospheric dynamics studies by providing wind speed measurements at distinct latitudes and altitudes	Saturn-spacecraft -earth occultation (when the saturn atmosphere is between the sc and ground)	Radio tracking (Movable radio antenna)	SR-90, SR-100, SR-120	3GM (JUICE)
		Measure gravity	Saturn orbiting	Radio tracking (Movable radio antenna) + ultrastable oscillator	SR-120	3GM (JUICE)
G2: Study the Saturnian ring and moon formation and evolution as a proxy for accretion processes	G2S1 - What are the processes behind small bodies formation within Saturn's rings?	Observe Saturn's ring in high spatial resolution	Close Rings flyby	VIS camera	SR-130, SR-140, SR-150, SR-160, SR-170, SR-180	JANUS (JUICE)
	G2S2 - What are the interactions of charged particles and (charged) dust from Enceladus within the Saturnian magnetosphere and rings system?	Measure the Saturn environment magnetic field	Saturn orbiting	Magnetometer	SR-190, SR-200	JMAG (JUICE)
		Measure the Saturn environment electric field	Saturn orbiting	Electric field antenna	SR-250, SR-260	LP-PWI (JUICE)
		Measure plasma density, energy (velocity), composition (particle size, type)	Saturn orbiting	Top Hat Analyser + Impact ionization Mass Spectometer + Ion and neutral mass spectrometer	SR-210, SR-220, SR-230, SR-270	MIA (BepiColombo) SUDA (Europa Clipper) NGIMS (MAVEN)

Instruments Traceability

Goals	Objectives	Functional Measurements	Part of the mission	Instrument	Requirements	Physical Instrument
G3 - Study what chemical processes shape Enceladus' potentially habitable subsurface and surface environment	G3S1 - What is the structure and composition of the plume, including prebiotic chemistry, biosignatures, isotopic ratios and hydrothermal products?	Measure the composition and density of the solid particles of Enceladus plume	Enceladus Flyby	Impact Ionization Mass Spectrometer	SR-280, SR-290, SR-320, SR-550, SR-490, SR-500, SR-550	SUDA (Europa Clipper)
		Measure composition of volatile fraction of Enceladus plume	Enceladus Flyby	Ion and neutral mass spectrometer + magnetometer	SR-310, SR-550, SR-490, SR-500, SR-520, SR-530, SR-550	
		Measure composition, structure and migration of Enceladus plume	Enceladus Flyby	UV VIS spectrometer, NIR spectrometer	SR-300, SR-340, SR-490, SR-510, SR-520, SR-330	
	G3S2 - What is the structure and composition of Enceladus' surface on a global and local scale?	Measure the composition of Enceladus surface material (reflectance + composition of ice grains ejected from the surface)	Enceladus Flyby	UV VIS spectrometer + Impact Ionization Mass Spectrometer	SR-370, SR-380, SR-410, SR-411	SUDA (Europa Clipper)
		Measure the ice shield thickness, detect liquid pocket within the ice shield, level of water in the ice cracks, and map the terrain features, elevation, particle sizes, cohesiveness particles, and ground slopes of Encelauds' surface	Enceladus Flyby	Radar	SR-360, SR-390, SR-420, SR-450, SR-460, SR-470, SR-480	RIME (JUICE)
		Map the temperature variation of Enclados surface'	Enceladus Flyby	Infrared camera, NIR spectrometer	SR-350, SR-410	OTES (OSIRIS-REx) VIRTIS (Rosetta & Venus Express)
	G3S3 - Does Enceladus sustain a global liquid ocean?	Measure the extent of the subsurface liquid ocean	Enceladus Flyby	Radio tracking (Movable radio antenna) + ultrastable oscillator	SR-440	3GM (JUICE)
		Measure compositional differences in ice grains ejected from individual jets at Encedalus	Enceladus LOW Flyby	Impact Ionization Mass Spectrometer	SR-290, SR-540, SR-550	SUDA (Europa Clipper)

Power source trade-off study

		Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
		MMRTG	**GPHS-RTG**	**Am-241 RTG**	**Solar Arrays**	**Fuel Cells**	**Hybrid**
Layout/Picture							
Remarks		NASA developed Pu-238 Used on: Dragonfly, MSL, Perseverence	GE developed Pu-238 Used on : Cassini, Galileo, New Horizons	European developed Am-241 TRL 4 (bench tested)	Based on Juice solar cells but with 4X less solar intensity	Very early concepts in development for HERACLES lunar lander mission, flight heritage with NASA on STS and Apollo	Combination of small RTG (either MMRTG or Am-241 RTG) and solar arrays to reach required power numbers
Criteria	**Weight (1-5)**	**Grade (0-10)**					
Mass	5	8	9	5	3	6	5
Performance	2	6	9	6	3	8	5
Longevity	3	4	4	8	7	5	8
Price	1	3	3	6	7	6	5
Acquisition	4	4	2	6	10	3	6
Total		**83**	**86**	**91**	**89**	**79**	**88**

Specific power	2.4	5.5	1.5	0.9 - 1.3	?

Mission Phases

~5 months → ~8.8 years → ~3.5 years → ~6 months

LEOP + Commissioning → Interplanetary Transfer → Science Operations → Decommissioning

Launch and Early Operations Phase (LEOP)

1. Pre-launch operations
2. Launch (ascent and injection phase)
3. Autonomous Detumbling
4. Sun Acquisition
5. Telemetry Downlink
6. Nominal operations mode

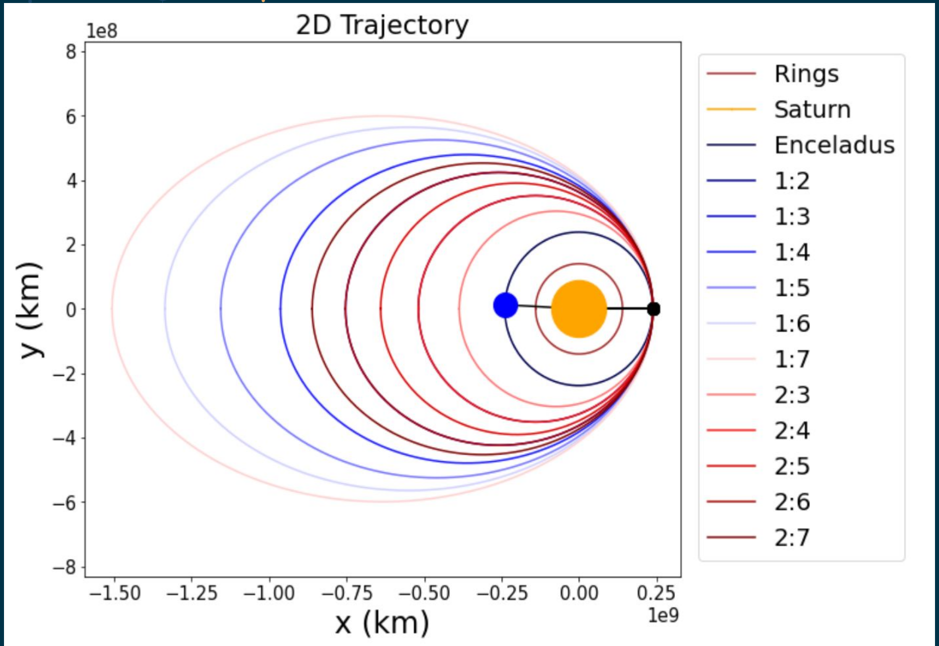
Commissioning Phase

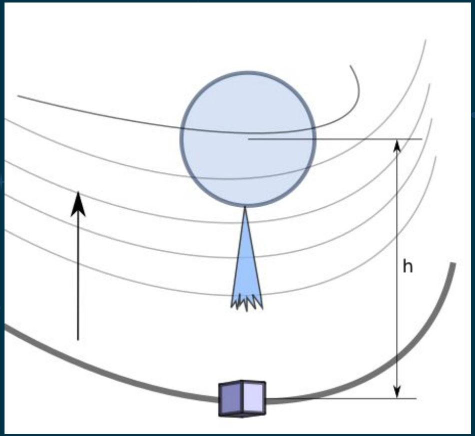
- SC Commissioning
  - Mechanisms Deployment
- SEP Commissioning
  - Solar Panels Deployment
  - Thruster Pointing
- Payloads activation, functional checkout and in-flight validation

ΔV Budget

Delta V Budget	Maneuver	Delta v (m/s)	Delta v + 5% (m/s)	Delta v_cumul (m/s)	Delta mass (kg)	Mass (kg)	Mass consumed (kg)	Propellant
Launch	Launch	0	0	0	0	6,900	0	-
E-S transfer	Arc 1 Earth	939.00	985.95	985.95	0	6,744	156	Xenon
	Arc 2 Earth	1,150.00	1,207.50	2,193.45	0	6,558	342	Xenon
	Boost	900.00	945.00	3,138.45	0	6,416	484	Xenon
	TOTAL			**3,138.45**		**6,416**	**484**	
Transition phase	Propulsion separation	0.00	0.00	0.00	1000	5,416	1,000	Chemical
	Probe deployment	15.00	15.75	15.75	380	5,010	1,406	Chemical
	SOI	633.00	664.65	680.40	0	4,095	2,321	Chemical
	PRM	300.00	315.00	995.40	0	3,722	2,694	Chemical
Enceladus observation	Titan GA's	150.00	157.50	1,152.90	0	3,548	2,868	Chemical
	Enceladus South Pole i sweep	125.00	131.25	1,284.15	0	3,410	3,006	Chemical
	Enceladus South Pole resonance	50.00	52.50	1,336.65	0	3,356	3,060	Chemical
	Inclination change to Enc. N-Pole	5.00	5.25	1,341.90	0	3,351	3,065	Chemical
	Resonant orbit h_E = 50 km (N-pole)	25.00	26.25	1,368.15	0	3,324	3,092	Chemical
Ring study	Change to ring orbit	10.00	10.50	1,378.65	0	3,313	3,103	Chemical
	Ring orbit	700.00	735.00	2,113.65	0	2,651	3,765	Chemical
Decomission	Move into decomission orbit	0.00	0.00	2,113.65	0	2,651	3,765	Chemical
	Crash with Saturn	0.00	0.00	2,113.65	0	2,651	3,765	Chemical
	TOTAL			**2,113.65**	**1380**	**2,651**	**3,765**	

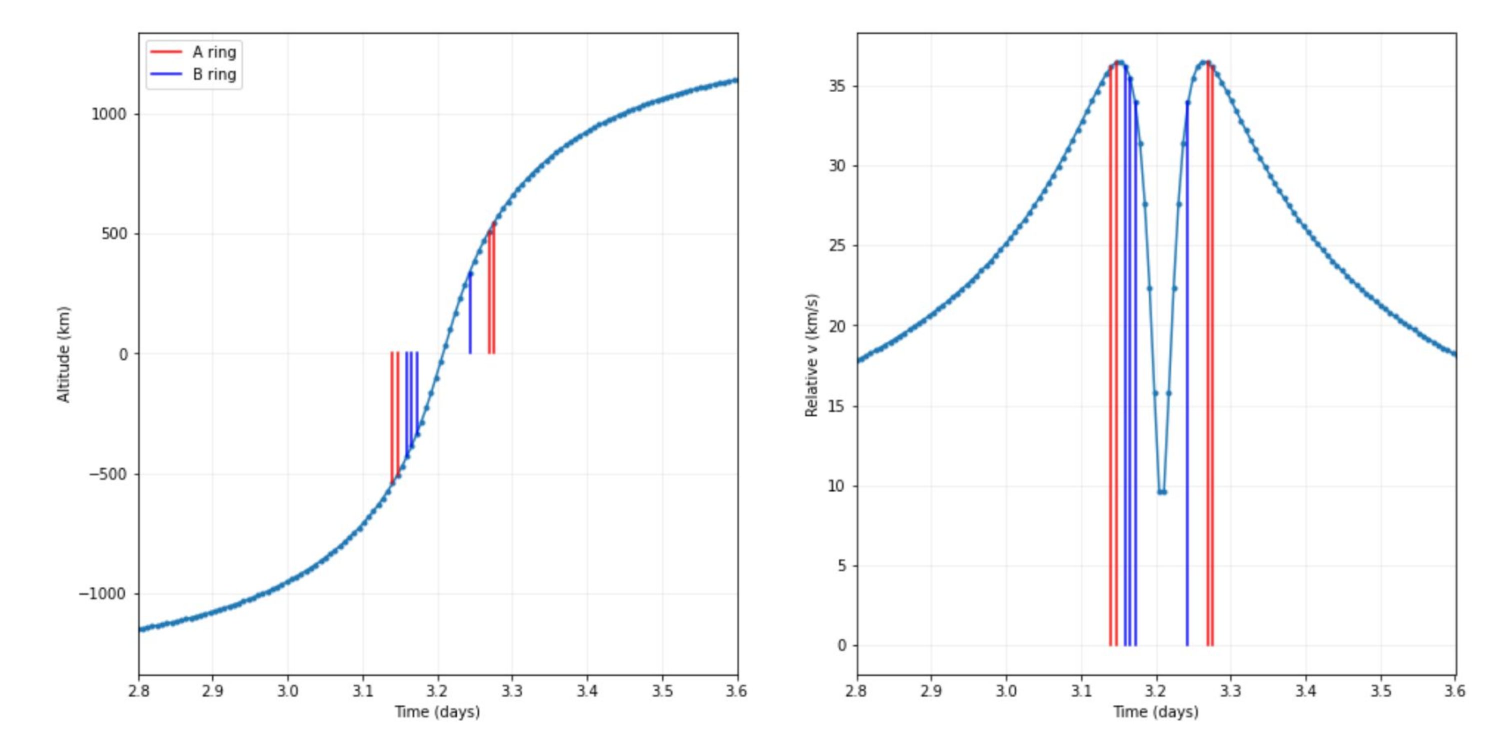
Mission Analysis: Resonant orbit






```
Resonance O:E 1:2, T = 2.75 days, a = 3.78E+05 km, e = 0.37, v_rel = 2.95 km/s, r_a = 518472.82 km
Resonance O:E 1:3, T = 4.12 days, a = 4.96E+05 km, e = 0.52, v_rel = 4.06 km/s, r_a = 753383.97 km
Resonance O:E 1:4, T = 5.50 days, a = 6.01E+05 km, e = 0.60, v_rel = 4.66 km/s, r_a = 963060.71 km
Resonance O:E 1:5, T = 6.87 days, a = 6.97E+05 km, e = 0.66, v_rel = 5.04 km/s, r_a = 1155771.66 km
Resonance O:E 1:6, T = 8.25 days, a = 7.87E+05 km, e = 0.70, v_rel = 5.31 km/s, r_a = 1335958.91 km
Resonance O:E 1:7, T = 9.62 days, a = 8.72E+05 km, e = 0.73, v_rel = 5.51 km/s, r_a = 1506356.96 km
Resonance O:E 2:3, T = 2.06 days, a = 3.12E+05 km, e = 0.24, v_rel = 1.91 km/s, r_a = 386384.75 km
```

Mission Analysis: Ring study



Spacecraft - Modes

LEOP + NECP + Interplanetary Transfer	**Phase 1** SOI and Probe Science	**Phase 2** Enceladus Science	**Phase 3** Ring Science
• BOOT • Stabilization • Telecom • Hibernation • Burn	• Pointing • Telecom • Safe • Burn		

Safe Mode	• On-board issues with need of Ground Segment action -> link availability requested • Power required to orient and communicate with the Earth
Decommissioning	• Use as much as possible the spacecraft for science in the Saturnian system • Planetary protection -> de orbiting on saturn atmosphere

Cost Analysis

Code	Item	Percent	Cost [M€]
#1	Industrial Cost ● Orbiter ● SEP ● Probe ● RTGs	~40-50% of total	1200 ● 500 ● 150 ● 350 ● 200
#2	Project Team ESA	15% of Industrial Cost	300
#3	Mission Operations (MOC) Science Operations (SOC)	15% of Industrial Cost	180
#4	Launch ● Launcher ● RTG factor	Mission Class Ariane 64	150 ● 130 ● 20
#5	Contingency	15% (1+2+3)	252
	Total	**Sum (1-5)**	2082
	+10% Inflation		2290

Lossless Compression

CCSDS 120.0-G-4

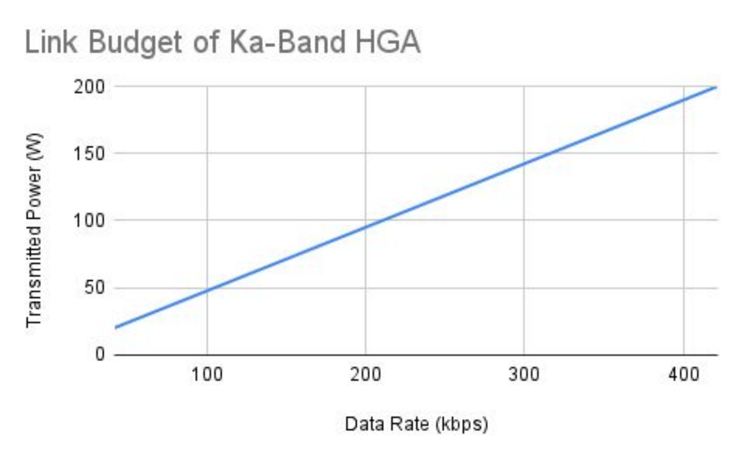
Table 6-1: Summary of Data Compression Performance for Different Scientific Data Sets

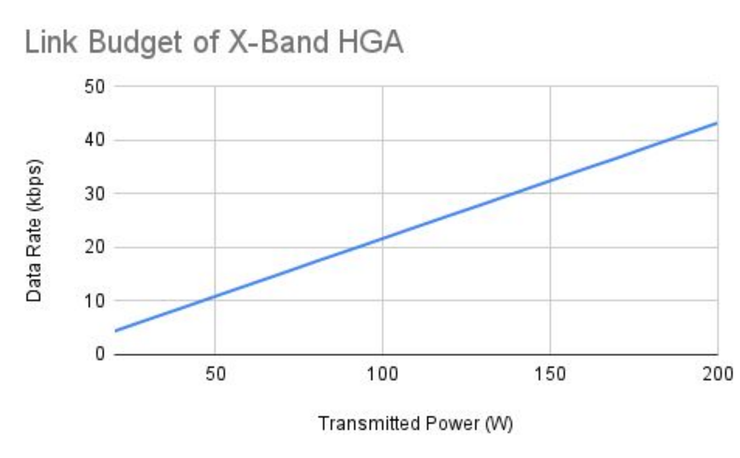
Paragraph	Instrument Data Set	Compression Ratio
Imaging	a) Thematic Mapper	1.83
	b) Hyperspectral imager (HSI)	2.6
	c) Heat Capacity Mapping Radiometer	2.19
	d) Wide Field Planetary Camera	2.97
	e) Soft X-Ray Solar Telescope	4.69
Non-Imaging	f) Goddard High Resolution Spectrometer	1.72
	g) Acousto-Optical Spectrometer	2.3
	h) Gamma-Ray Spectrometer	5 to 26[1]

[1] depending on integration time

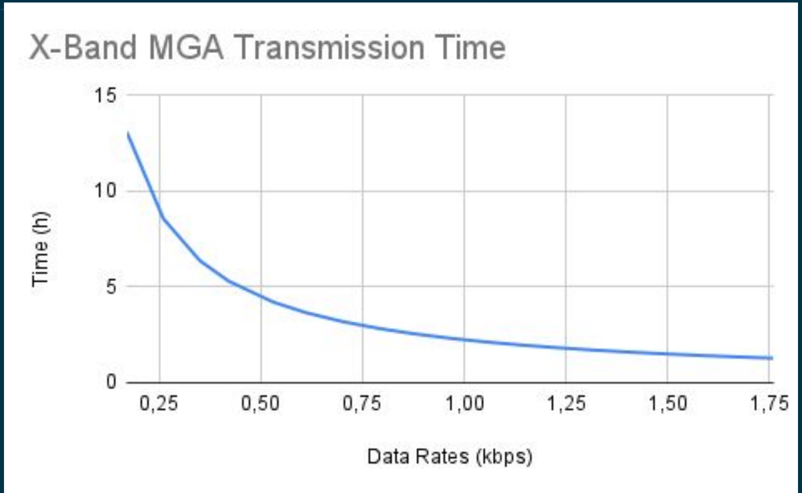
a) **Thematic Mapper (TM)**

Transmission Rates – HGA





Transmission Rates - MGA



ARGO- Mission Profile (backup)

Probe Mission Profile

- Probe coast < 20 days

- Interface at around 700 km above 1 bar altitude
- Entry angle: -25 deg
- Entry velocity: 36 km/s

- Drogue chute remove back cover at ~1 Mach
- Main chute limits speed to 50 m/s
- Drop heat shield

- Measure and relay data from 0.5 bar till 20 bar

Probe Design

- Total mass ~420 kg
  - Payload ~24.5 kg (~6% of total mass)
  - TPS mass ~210 kg:
    - Total heat load ~1.70E+09 J/m^2
    - Maximum heat flux ~115 MW/m^2
    - Added 25% mass margin

- Power capacity ~1550 Wh

- Data budget (D2Sat) : ~ 4MB

Mass Budget – Orbiter

Propellant (chemical)	2129,38	10%	2342,32	34,34%	34,34%
Orbiter Dry Mass	1847,05	20%	2216,46	32,49%	32,49%
Power Subsystem	345,6	10%	380,16	5,57%	17,15%
RTG	200	20%	240	3,52%	63,13%
Batteries	50	20%	60	0,88%	15,78%
PCDU	38	20%	45,6	0,67%	11,99%
Structure	250	20%	300	4,40%	13,54%
Mechanisms	57,6	20%	69,12	1,01%	3,12%
Antennas Boom Deployment Mechanism	35	20%	42	0,62%	60,76%
Probe Deployment Mechanism	13	20%	15,6	0,23%	22,57%
AOCS	88	10%	96,8	1,42%	4,37%
Propulsion (Bipropellant)	300	20%	360	5,28%	16,24%
OBC & OBDH	10	20%	12	0,18%	0,54%
Communication	134	20%	161	2,36%	7,25%
HGA	66	20%	79	1,16%	49,25%
MGA	28	10%	31	0,45%	19,15%
LGA	20	20%	24	0,35%	14,93%
Payload	212,88	10%	234,17	3,43%	10,57%
Ion and Neutral Mass Spectrome	8,8	10%	9,68	0,14%	4,13%
Impact Ionization Mass Spectror	16	10%	17,6	0,26%	7,52%
NIR Spectrometer	33	10%	36,3	0,53%	15,50%
Thermal Infrared Spectrometer	6,27	10%	6,897	0,10%	2,95%
UV-VIS Spectrometer	14,46	10%	15,91	0,23%	6,79%
VIS Camera	29	10%	31,9	0,47%	13,62%
Radio Science Experiment	7	10%	7,7	0,11%	3,29%
Magnetometer	30	10%	33	0,48%	14,09%
Electric Field Antenna	7,2	10%	7,92	0,12%	3,38%
Ice Penetrating Radar	16,8	10%	18,48	0,27%	7,89%
Altimeter	19,6	10%	21,56	0,32%	9,21%
Top-hat Analzyer	5,4	10%	5,94	0,09%	2,54%
Thermal Control Subsystem	110	20%	132	1,94%	5,96%
Harness	85	20%	102	1,50%	4,60%

Mass Budget – Transfer Module

Transfer Module Dry Mass	1009,30	20%	1211,16	17,75%	17,75%
Power Subsystem	215	10%	236,5	3,47%	19,53%
Solar array	154	10%	169,4	2,48%	71,63%
PCDU	38	20%	45,6	0,67%	19,28%
Structures	150	20%	180	2,64%	14,86%
Mechanisms	276	10%	303,6	4,45%	25,07%
Solar Array Deployment Mechar	30	20%	36	0,53%	2,97%
Separation Mechanism	100	20%	120	1,76%	9,91%
Separation Adapter	100	20%	120	1,76%	9,91%
AOCS	31	20%	37,2	0,55%	3,07%
Thermal Control Subsystem	25	20%	30	0,44%	2,48%
Propulsion (Electric)	135	20%	162	2,37%	13,38%
Harness	50	20%	60	0,88%	4,95%

Thermal Control Subsystem

Detailed Thermal Requirements

Worst case considered

		Temperature Ranges (op.) [K]		Heat Dissipation [W]
		Min.	Max	
ORBITER	Ion and neutral mass spectrometer	248.15	298.15	88.2
	Impact ionization mass spectrometer	?	?	?
	UV VIS spectrometer	150	190	70
	NIR spectrometer	120.15	160.15	24.7
	UV-VIS Camera	280.15	290.15	8
	Infrared camera	?	?	10
	Ice penetrating radar	253.15	323.15	30.1
	Laser Altimeter	273.15	313.15	56.8
	Radio tracking + Ultra Stable Oscillator	253.15	323.15	46.5
	Magnetometer	253.15	323.15	11.1
	Top-hat analyser	223.15	323.15	?
	Electric field antenna	253.15	323.15	20.3

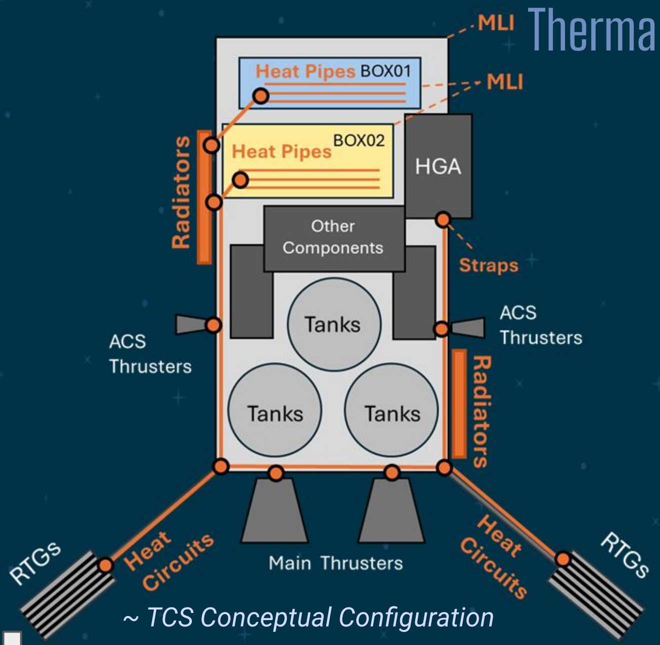
BOX01 Instruments (“cold” chamber): [150; 160.15]

BOX02 Instruments (“hot” chamber): [280.15; 290.15]

No available data

Thermal Control Subsystem

Thermal Preliminary Detailed Configuration



~ TCS Conceptual Configuration

6 RTGs → 6 × 1000 [W]

Thermal Radiators Area: **3.08 [m²]**

	Components	Margin [%]	Total weight [kg]	Power Consumption [W]
Orbiter	**PASSIVE**			
	MLI	20%	45.97	0
	Thermal Surfaces	20%	1.71	0
	Thermal Traps	20%	18.96	0
	Heat Pipes	20%	25.68	0
	Thermal Radiators	20%	12.96	0
	ACTIVE			
	Thermistors	20%	1.848	12
	Heaters	20%	3.024	31.2
	TOTAL		**110.15**	**43.2**
		20%	**132.18**	**51.84**

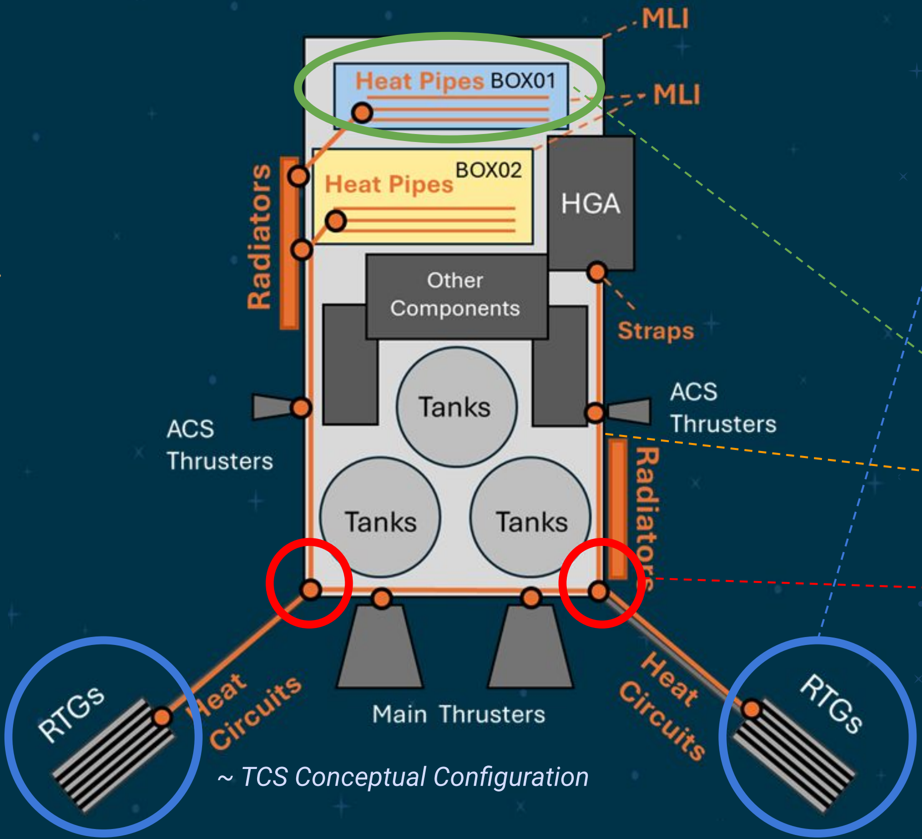
Risk Matrix & Assessment

Risk ID	Title	Cause	Effect	Likelihood	Cost impact	Schedule impact	Severity	Risk Rating
R-01	RTG environmental damage	Launch vehicle failure, Earth fly-by failure.	Thousands of humans exposed to high levels of radiation.	1	Incalculable	None	5	5
R-02	Radioisotope acquisition	Limited quantities available, difficult to manufacture and expensive.	Launch date slippage, delay in subsystem integration.	3	High	Depends on launch window	3	9
R-03	RTG technology not mature enough	The RTG selected for the mission is not avaiable on time.	Launch delay	2	Significant	Might be critical	4	8
R-04	Negative dV budget	Launch vehicle reaches lower orbit than required.	The mission plan cannot be completed, as the delta budget is not sufficient	2	None	None	3	6
R-05	Spacecraft impact on Enceladus	Spacecraft performs too close flyby to Enceladus. Invalid maneouver.	Loss of mission. Violation of Planetary Protection.	2	None	None	5	10
R-06	Spacecraft is influenced by Enceladus plume during flyby	Spacecraft performs too close flyby to Enceladus.	Possible orbit change	1	None	None	2	2
R-07	Deployment mechanism failure	Environmental conditions cause mechanism to fail.	Mechanism is unable to deploy desired configuration of spacecraft	2	None	None	2	4
R-08	Electronics failure due to radiation	Radiation dose is too high for selected components.	Some of the subsystems may fail.	2	None	None	4	8
R-09	Launcher unavaiable	Selecter launcher vehicle is unavaible at selected launch date.	Launch is delayed, possibility of missing launch window	1	Significant	Might be critical	4	4
R-10	Micrometeroid strike	Spacecraft is hit bz micrometeroid	Possible damage to spacecraft subystems	1	None	None	2	2
R-11	Long-lead items avaiability	Sub-contractor is unable to provide long-lead item on time.	Possible delay	2	None	Depends on launch window	3	6
R-12	Probe does not turn on	Failure of the Probe electric system	Probe mission is lost, no atmospheric measurements acquired	1	None	None	4	4
R-13	Failure of drogue chute deployme	Failure in either command execution, mechanical or electical failure	Probe will be unable to eject back cover, and blocks further deployment of main chute.	1	None	None	4	4
R-14	Failure of main chute deployment	Failure in either command execution, mechanical or electical failure	Probe will not be stable during descent and freefall instead of controlled descent. Heat shield might hit descent module.	1	None	None	3	3
R-15	Deployment of Solar Array not complete	Jammed components, failing hardware	Power not quaranteed, affects mission lifetime	2	Significant	Might be critical	4	8
R-16	Spacecraft is influenced by Saturn's rings	Spacecraft collides with Saturn's rings material	Possible damage to the spacecraft	2	None	None	4	8
R-17	Spacecraft AOCS failure	AOCS is unable to control orientation of the spacecraft	Spacecraft is unable to fulfill poinitng requirements	3	None	None	3	9

Severity	Likelihood 1	Likelihood 2	Likelihood 3	Likelihood 4	Likelihood 5
5	R-01 RTG environmental damage	R-05 Spacecraft impact on Enceladus			
4	R-09 Launcher unavaiable R-12 Probe does not turn on R-13 Failure of drogue chute deployment	R-03 RTG technology not mature enough R-08 Electronics failure due to radiation R-15 Deployment of Solar Array not complete R-16 Spacecraft is influenced by Saturn's rings			
3	R-14 Failure of main parachute deployment	R-04 Negative dV budget R-11 Long-lead items avaiability	R-02 Radioisotope acquisition R-17 Spacecraft AOCS failure		
2	R-06 Spacecraft is influenced by Enceladus plume during flyby R-10 Micrometeroid strike	R-07 Deployment mechanism failure			
1					

Thermal Control Subsystem

Preliminary Design



~ *TCS Conceptual Configuration*

- 6 RTGs → 6 × 1000 [W] ~ Heat Dissipation
- Infrared Instruments Cooling
- Passive Heat Circuit
- Control of Heat Fluxes from RTGs

Mission Analysis: ΔV Budget

Isp = 4190 s
M_wet = 6.9 tons

Delta V Budget	Maneuver	Delta v (m/s)	Delta v + 5% (m/s)	Delta v_cumul (m/s)	Delta mass (kg)	Mass (kg)	Mass consumed (kg)	Propellant
Launch	Launch	0	0	0	0	6,900	0	-
E-S transfer	Arc 1 Earth	939.00	985.95	985.95	0	6,744	156	Xenon
	Arc 2 Earth	1,150.00	1,207.50	2,193.45	0	6,558	342	Xenon
	Boost	900.00	945.00	3,138.45	0	6,416	484	Xenon
	TOTAL			**3,138.45**		**6,416**	**484**	
Transition phase	Propulsion separation	0.00	0.00	0.00	90	6,326	90	Chemical
	Probe deployment	15.00	15.75	15.75	380	5,916	500	Chemical
	SOI	633.00	664.65	680.40	0	4,836	1,580	Chemical
	PRM	300.00	315.00	995.40	0	4,395	2,021	Chemical
Enceladus observation	Titan GA's	150.00	157.50	1,152.90	0	4,190	2,226	Chemical
	Enceladus South Pole i sweep	125.00	131.25	1,284.15	0	4,026	2,390	Chemical
	Enceladus South Pole resonance	50.00	52.50	1,336.65	0	3,963	2,453	Chemical
	Inclination change to Enc. N-Pole	5.00	5.25	1,341.90	0	3,956	2,460	Chemical
	Resonant orbit h_E = 50 km (N-pole)	25.00	26.25	1,368.15	0	3,925	2,491	Chemical
Ring study	Change to ring orbit	10.00	10.50	1,378.65	0	3,912	2,504	Chemical
	Ring orbit	700.00	735.00	2,113.65	0	3,130	3,286	Chemical
Decomission	Move into decomission orbit	0.00	0.00	2,113.65	0	3,130	3,286	Chemical
	Crash with Saturn	0.00	0.00	2,113.65	0	3,130	3,286	Chemical
Extended mission		0.00	0.00	2,113.65	0	3,130	3,286	Chemical
		0.00	0.00	2,113.65	0	3,130	3,286	Chemical
	TOTAL			**2,113.65**		**3,130**	**3,286**	

ESOC (European Space Operations Centre)

ESA's European Space Operations Centre, in Darmstadt, Germany

a. Technical management of a mission operations (Spacecraft and Payload)

b. Data links between ground controllers and their satellites in orbit.

ESAC (European Space Astronomy Centre)

ESA's centre for space science (astronomy, Solar System exploration and fundamental physics)

a. Hub for operating planetary and astronomy missions

b. Experts in the mission science areas

Trade-off matrix

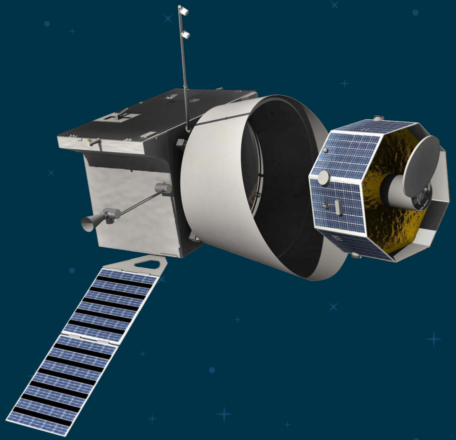
	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7	Option 8	Option 9	Option 10	Option 11	Option 12
Spacecraft	-	-	-	-	-	-	-	-	-	-	-	-
Power Subsystem	-	-	-	-	-	-	-	-	-			
Primary Power Source	MMRTG	GPHS-RTG	Am-241 RTG	Solar Arrays	Fuel Cells	Hybrid	-	-	-			
Secondary Power Source	Li-ion batteries	Fuel Cells	-	-	-	-	-	-	-			
PCDU	-	-	-	-	-	-	-	-	-			
Structures & Mechanism	-	-	-	-	-	-	-	-	-			
Primary Structure	-	-	-	-	-	-	-	-	-			
Secondary Structure	-	-	-	-	-	-	-	-	-	-	-	-
Mechanisms	-	-	-	-	-	-	-	-	-			
Antennas Boom Deployment Mechanism	Coiled Rods	Coiled Mast	Flexible Shell	Wire Cutter + Telescopic antenna deployment	Rigid Beam Deployment (similarly as SADM)	Rigid Tubular Segment + Tape spring	Fast Mast	-	-			
Probe Deployment Mechanism	Huygens	NASA pneumatic	-	-	-	-	-	-	-			
AOCS	-	-	-	-	-	-	-	-	-	-	-	-
Sensors	Sun Sensors	Star Trackers	Star Scanners	Horizon Sensors (staring sensors)	Horizon Sensors (Pippers)	Magnetometers	IMU	-	-			
Actuators	Reaction Wheels	Thrusters ACS	Magnetorquers	CMGs	-	-	-	-	-			
Propulsion	Electric Propulsion (Hall)	Monopropellant Propulsion	Bipropellant Propulsion	Solid Propulsion	-	-	-	-	-			
OBC & OBDH	GVSC-1750 A	Beyond gravity OBC NG	-	-	-	-	-	-	-			
Communications	Cassini Based	Juno Based	-	-	-	-	-	-	-	-	-	-
TM & TC	-	-	-	-	-	-	-	-	-	-	-	-
Science Data	-	-	-	-	-	-	-	-	-	-	-	-
Payload	-	-	-	-	-	-	-	-	-	-	-	-
G1 S2	UV-VIS Spectrometer - UVIS (Cassini)	UV-VIS Spectrometer - UVS (JUICE)	Radio Science Experiment - 3GM (JUICE)	Radio Science Experiment - Gravity/Radio Science (Europa Clipper)	-	-	-	-	-	-	-	-
G2 S1	VIS Camera - OSIRIS (Rosetta)	VIS Camera - JANUS (JUICE)	-	-	-	-	-	-	-	-	-	-
G2 S2	Magnetometer - J-MAG (JUICE)	Magnetometer - ICEMAG (Europa Clipper)	Impact ionization mass spectrometer - SUDA (Europa Clipper)	Impact ionization mass spectrometer - CIDA (Stardust)	Top-hat analzyer - MIA/SERANA (BepiColombo)	Top-hat analzyer - HPCA (Magnetospheric Multiscale)	Electric Field Antenna - LP-PWI (JUICE)	Electric Field Antenna - RPWS (Cassini)	-	-	-	-
G3 S1	UV-VIS Spectrometer - UVIS (Cassini)	UV-VIS Spectrometer - VIRTIS-M (Rosetta/Venus Express)	Impact ionization mass spectrometer - SUDA (Europa Clipper)	Impact ionization mass spectrometer - CIDA (Stardust)	Ion and neutral mass spectrometer - MASPEX (Europa Clipper)	Ion and neutral mass spectrometer - NGIMS (MAVEN)	NIR Spectrometer - MAJIS (JUICE)	NIR Spectrometer - VIRTIS-M/H (Rosetta/Venus Express)	-	-	-	-
G3 S2	UV-VIS Spectrometer - UVIS (Cassini)	UV-VIS Spectrometer - VIRTIS-M (Rosetta/Venus Express)	Impact ionization mass spectrometer - SUDA (Europa Clipper)	Impact ionization mass spectrometer - CIDA (Stardust)	Ice Penetrating Radar - REASON (Europa Clipper)	Ice Penetrating Radar - RIME (JUICE)	NIR Spectrometer - MAJIS (JUICE)	NIR Spectrometer - VIRTIS-M/H (Rosetta/Venus Express)	Thermal Infrared Spectrometer - E-Themis (Europa Clipper)	Thermal Infrared Spectrometer - OTES (OSIRIS-Rex)	Laser Altimeter - GALA (JUICE)	Laser Altimeter - MOLA (MGS)
G3 S3	Radio Science Experiment - 3GM (JUICE)	Radio Science Experiment - Gravity/Radio Science (Europa Clipper)	Impact ionization mass spectrometer - SUDA (Europa Clipper)	Impact ionization mass spectrometer - CIDA (Stardust)	-	-	-	-	-	-	-	-
Thermal Control Subsystem	MLI Blanket	Surface Finishes	Heaters	Radiators	Heat Pipes	Louvers	-	-	-	-	-	-
Probe	-	-	-	-	-	-	-	-	-	-	-	-
Probe Deployment mechanism	Mortar	Slug gun	Springs	-	-	-	-	-	-	-	-	-
G1 S1	Mass Spectrometer - NMS (Galileo)	Mass Spectrometer - ?	Nephelometer (Galileo)	Nephelometer - ?	Net Flux Radiometer (Galileo)	Net Flux Radiometer - LIR (Venus Probe)	Atmospheric sensing instrument (Huygens)	Atmospheric sensing instrument - ASI (Galileo)	Helium abundance detector (Galileo)	Helium abundance detector - ?	-	-

Solution Selected

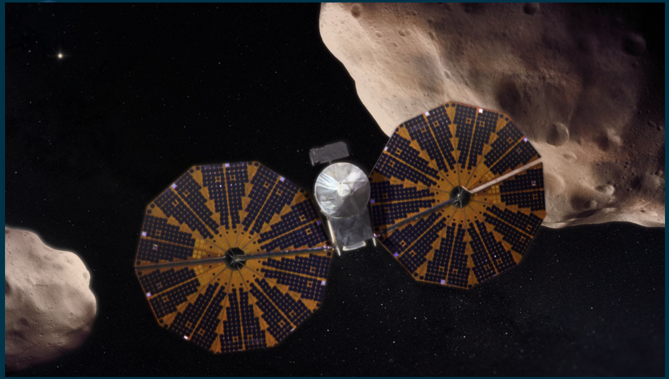
Identified Alternatives

Only One Option Available

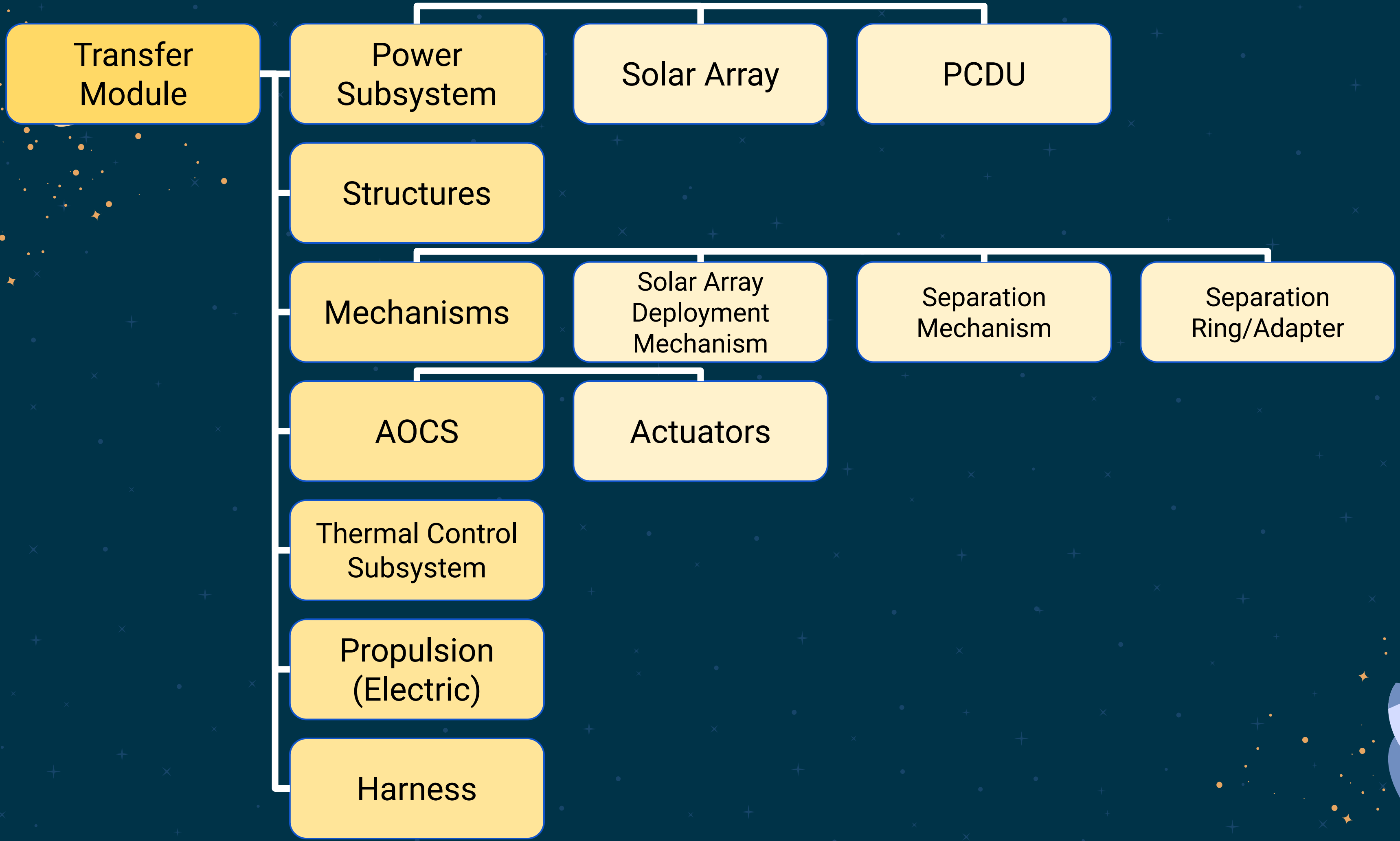
Transfer Module



Bepi Colombo - Wikipedia



Lucy (NASA) - Wikipedia


Transfer Module
Power Subsystem
Solar Array
PCDU
Structures
Mechanisms
Solar Array Deployment Mechanism
Separation Mechanism
Separation Ring/Adapter
AOCS
Actuators
Thermal Control Subsystem
Propulsion (Electric)
Harness

- Orbiter
  - Power Subsystem
    - RTG
    - Batteries
    - PCDU
  - Structures
  - Mechanisms
    - Antennas Boom Deployment Mechanism
    - Probe Deployment Mechanism
  - AOCS
    - Actuators
    - Sensors
  - Propulsion (Bipropellant)
  - OBC & OBDH
  - Communication
    - HGA
    - MGA
    - LGA

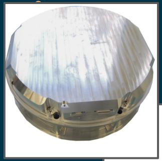
- Orbiter
  - Payload
    - Ion and Neutral Mass Spectrometer
    - Impact Ionization Mass Spectrometer
    - NIR Spectrometer
    - Thermal Infrared Spectrometer
    - UV-VIS Spectrometer
    - VIS Camera
    - Radio Science Experiment
    - Magnetometer
    - Electric Field Antenna
    - Ice Penetrating Radar
    - Altimeter
    - Top-hat analyzer
  - Thermal Control Subsystem
  - Harness

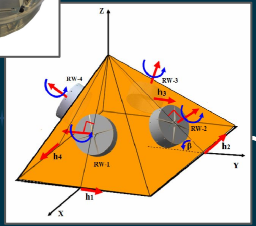
Link Budget – What do we need?

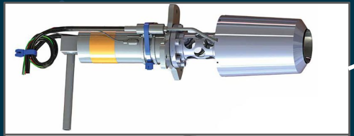
- Science Data → Ka-Band 26.5 - 40 GHz
- TM & TC → X-Band 8 - 12.4 GHz
- Atmospheric Probe → UHF-Band 0.2 - 0.45 GHz
- Orbital Manoeuvres → Movable Antenna

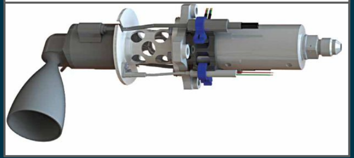
Attitude Determination and Control Subsystem

Preliminary Configuration









	Nbr [-]	Margin [%]	Total weight [kg]	Power Consumption [W]
Actuators				
RWs	4	10%	51.04	59.95
ACS Thrusters	12	10%	8.25	0
Sensors				
Sun sensor	6	10%	0.43	0
Star tracker	2	10%	0.99	1.54
IMU	2	10%	27.5	119.46
Total		**10%**	**97.03**	**199.05**

Mechanisms

Preliminary Configuration

Probe Deployment

Based on Cassini-Huygens mission.

- Pyrotechnic explosive bolt
- Stainless steel spring
- Axial rollers running along a helical track

Weight: ~ 23 [kg]
Power: ~50 [W]

Antennas/Booms Deployment

Considered options dependent on the selected antennas:

- Rigid beam deployment (JUICE)
- Tape spring with rigid tubular segment

Weight: ~ 35 [kg]
Power: ~TBD [W]

Solar Array Deployment

Based on CDF EPIG 2019, CDF-77

- *Based on LUCY mechanism*

Weight: ~ 30 [kg]
Power: 20 [W]

Separation Mechanisms

- *Pyro nuts, Springs*

Design considerations:

- *Safety margin, Fretting, shock loading, ..*

Weight: 2x 100 [kg]
Power: 10 [W]

Propulsion

Preliminary Configuration

Transfer Module

- Electric Propulsion - Ion engine
- Xenon
- Isp = 4190 s
- Propellant mass: 550 kg
- Thrust: 4x 0.25 N
- Expected dry mass: 135 kg

Orbiter

- Bipropellant Propulsion
- Monomethylhydrazine (MMH)
  +
  MON-3 (Mixed Oxides of Nitrogen)
- Baseline: Ariange Group Bipropellant Apogee Motor
- Isp = 320 s
- Propellant mass: 2370 kg
- Thrust: 420 N
- Expected dry mass: 300 kg TBC

Technology Development

- (Mostly) Already existing components (~ Heritage)

ISO Technology Readiness Level Summary	
TRL	Level Description https://www.iso.org/obp/ui/en/#iso:std:iso:16290:ed-1:v1:en
1	Basic principles observed and reported
2	Technology concept and/or application formulated
3	Analytical and experimental critical function and/or characteristic proof-of-concept
4	Component and/or breadboard functional verification in laboratory environment
5	Component and/or breadboard critical function verification in relevant environment
6	Model demonstrating the critical functions of the element in a relevant environment
7	Model demonstrating the element performance for the operational environment
8	Actual system completed and accepted for flight ("flight qualified")
9	Actual system "flight proven" through successful mission operations

➡ **No Recent Saturn Environment Verification**

TRL < 5

		Component Name	Qty	TRL	Dev. Level	Ready in 12 years ?
Orbiter	Payload	UV-VIS Spectrometer	1	3		y
		NIR Spectrometer	1	3		y
		Thermal Infrared Spectrometer	1	3		y
		Ice Penetrating radar	1	3		y
	Structure & Mechanism	Structure	1	1		y
		Probe Separation Mechanism	1	3		y
		Tranfer Vehicule Separation Mechanism	1	4		y
Tranfer Module	Structure & Mechanism	Solar Panel Deployment Mechanism	2	3		y
		Separation Adapter	1	3		y
		Separation Mechanism	1	3		y
		Structure	1	1		y
Probe	Structure & Mechanism	Parachutes deployment mechanism	2	3		y
	Thermal Protection System (TPS)	Heatshield	1	3		y

Power budget

		Saturn ring science			Enceladus science			Orbit		
Element	**Component**	**Mode**	**Power (W)**	**Total power (W)**	**Mode**	**Power (W)**	**Total power (W)**	**Mode**	**Power (W)**	**Total power (W)**
Payload				329.8365			302.19			0
	Magnetometer	ON	11.1		ON	11.1		OFF	0	
	Impact ionization Mass Spectrometer (IMS)	ON	58.7		ON	58.7		OFF	0	
	Ion and neutral mass spectrometer	ON	88.2		ON	88.2		OFF	0	
	Ice penetrating radar	OFF	0		ON	61		OFF	0	
	Hyperspectral imaging (vis to near IR)	ON	50		OFF	0		OFF	0	
	Radio science experiment: Radio tracking (Movable radio antenna) + Ultra Stable Oscillator (USO)	ON	46.5		OFF	0		OFF	0	
	Electric field antenna	ON	6		OFF	0		OFF	0	
	Visable camera	ON	34		ON	34		OFF	0	
	Top Hat Analyser	ON	7.8		OFF	0		OFF	0	
	UV VIS spectrometer	ON	11.83		OFF	0		OFF	0	
	Thermal Infrared Spectrometer	ON			ON	34.8		OFF	0	
	Margin (5%)	n/a	15.71		n/a	14.39		n/a	0	
AOCS				95.76			95.76			38.535
	Reaction wheel	ON	54.5		ON	54.5		ON	0	
	IMU	ON	27.2		ON	27.2		ON	27.2	
	Star trackers	ON	9.5		ON	9.5		ON	9.5	
	Margin (5%)	n/a	4.56		n/a	4.56		n/a	1.84	
Comunications				0			0			0
	High Gain antenna	OFF	0		OFF	0		OFF	0	
	Medium gain antenna	OFF	0		OFF	0		OFF	0	
	Margin (5%)	n/a	0		n/a	0		n/a	0	
Command				52.5			52.5			52.5
	On board computer (OBC)		50			50			50	
	Margin (5%)	n/a	2.5		n/a	2.5		n/a	2.5	
Propulsion				0			0			10.5
	SEP	OFF	0		OFF	0		OFF	0	
	Main engines (chemical)	OFF	0		OFF	0		ON	10	
	Margin (5%)	n/a	0		n/a	0		n/a	0.5	
Power				94.5			94.5			94.5
	PCDU	ON	90		ON	90		ON	90	
	Margin (5%)	n/a	4.5		n/a	4.5		n/a	4.5	
Thermal control				37.8			37.8			37.8
	Thermistor	ON	10		ON	10		ON	10	
	Heaters	ON	26		ON	26		ON	26	
	Margin (5%)	n/a	1.8		n/a	1.8		n/a	1.8	
System margin (20%)				122			117			47
Total				732			699			281

Net power across orbit

+ 420 W total