Prochaine mission planétaire classe Large ESA – L4
Explorer l’habitabilité d’Encelade

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Membre du groupe de définition de la charge utile L4

06 nov 2025
Journée de la science du CNES
Paris

Motivation scientifique et recommandations

Motivation:

• 2019: « Topical Teams » pour discuter du plan à long terme **Voyage 2050.** Liste des white papers de l'AO: *https://www.cosmos.esa.int/web/voyage-2050/white-papers*

→ *Lunes des planètes géantes*

• 2022: le groupe ESA **external L4 Science Expert Team** a été nommé. Rapport: *https://www.cosmos.esa.int/documents/1866264/1866292/ESA_L4_Expert_Committee_report_Voyage_2050_Moons_of_the_Giant_Planets.pdf*

→ *Encelade et Titan sont les deux plus intéressantes pour leur caractéristique de mondes océans. La destination principale est le pôle sud d'Encelade*

• 2025: le groupe ESA de **définition d'une strawman payload (L4PWG)** a été nommé.

Recommandations:

- Orbiteur nécessaire mais non suffisant : après JUICE nous aurons besoin d'un atterrisseur.
  Les opérations de surface devront durer au minimum 4 semaines
- Accès à la sous-surface par échantillonnage des panaches
- Tour des autres lunes de Saturne

Members of the Science Expert team

Z. Martin, CQE, Instituto Superior Tecnico, Lisbon, Portugal
E. J. Bunce, Univ Leicester, UK
O. Grasset, Univ. Nantes
R. Hamp, Open University, UK
G. H. Jones, UCL Mullard Space Science, UK et Intl Space Science Institute Switzerland.
A. Le Gall, LATMOS, Sorbonne U., France
A. Lucchetti, INAF-OAPD, Padova, Italy
F. Postberg, Freie Universitaet Berlin, Germany
O. Prieto-Ballesteros, Centro de Astrobiologia, INTA, Torrejon de Ardoz, Spain
L. Roth, Space and Plasa Physics, Stockholm, Sweden
P. Tortora, Alma Mater Studiorum Univ. Bologna, Italy
A. Vorbuger, Space research & planetary sicences, Bern, Switzerland

Members Payload Working Group

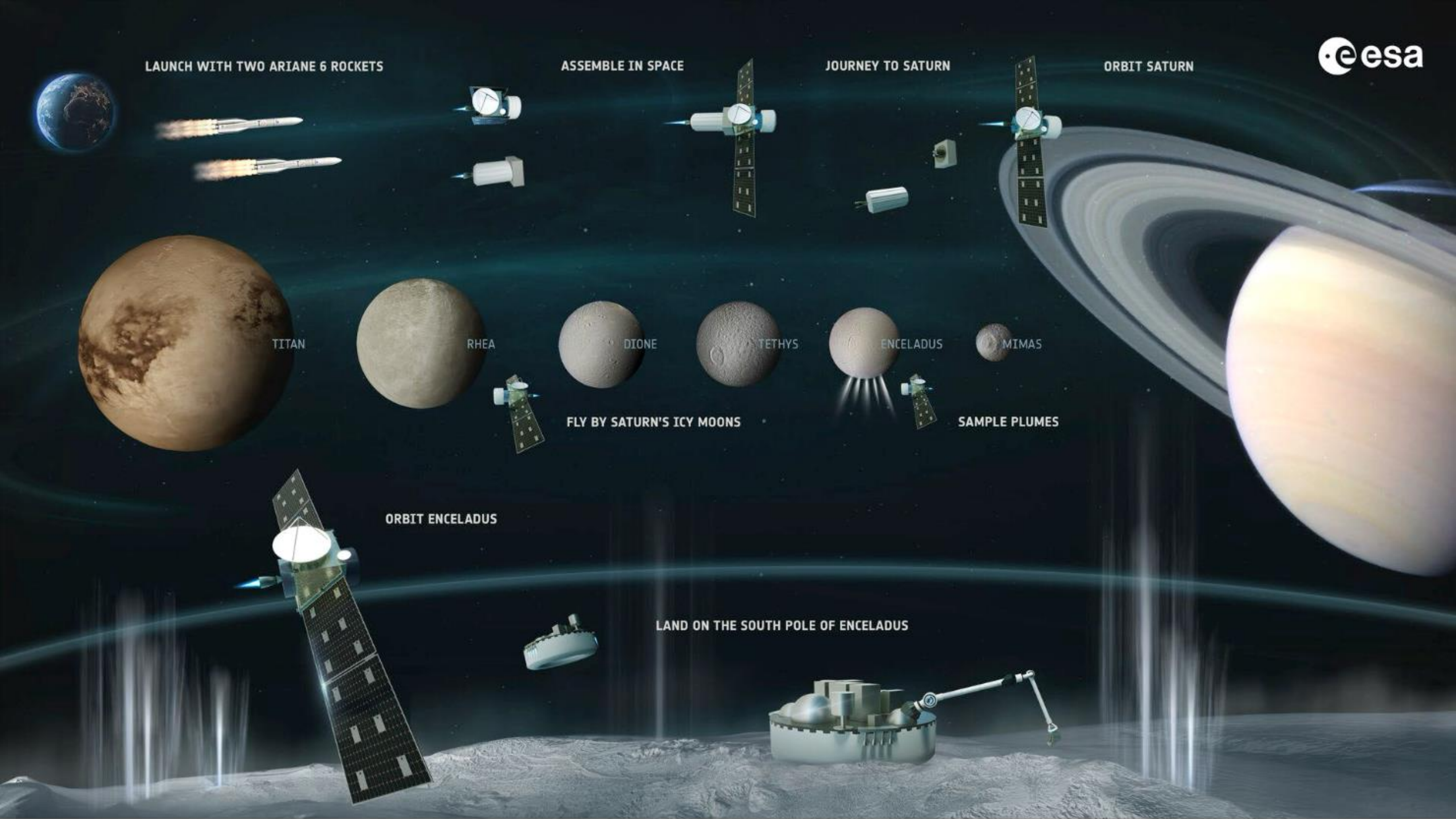
Vania Da Deppo, CNR-IFN, Italy
Caroline Freissinet, LATMOS/CNRS, France
Axel Hagermann, Lulea University of Technology, Sweden
Maximilian Hamm, Freie Universität Berlin, Germany
Quang Hung Hoang, Luxembourg Institute of Science and Technology
Carly Howett, University of Oxford, United Kingdom
Florian Kehl, University of Zurich (CH)/ETH Zurich, Switzerland
Pawel Knapkiewicz, Wroclaw Univ of Science and Techno, Poland
Niels Ligterink, Delft University of Technology, The Netherlands
Andoni G. Moral Inza, Inst. Nacional de Técnica Aeroespacial, INTA, Spain
Robert Prevedel, European Microbiology Laboratory
Vassilia Spathis, University of Leicester, United Kingdom
Stephan Ulamec, DLR, Germany
Antti Nasila, VTT, Finland

2.3. Meetings

Table 6: L4 PWG Meeting Schedule

Date	Event	Format	Goals
March 26-27th, 2205	PWG KO	In Person/Hybrid	Kick Off
April 7th, 2025	PWG Catch Up	Remote	Catch up
May 12th, 2025	Monthly Meeting #1	Remote	Catch up
June 3rd, 2025	Monthly Meeting #2	Remote	Catch up
September 17-18th, 2025	Colocation Meeting	In Person/Hybrid	STM Consolidation
November 2025	Monthly Meeting	Remote	Catch up
2-3 déc 2025	**Colocation**	**ESTEC**	**STM**
End January/Early February 2026	1-day Colocation Meeting	In Person/Hybrid	Payload Trade off Consolidation
March 2026	Monthly Meeting	Remote	Catch up
April 2026	2-day Colocation Meeting	In Person/Hybrid	Strawman Payload Consolidation
May 2026	Monthly Meeting	Remote	Catch up
June 2026	Monthly Meeting	Remote	Catch up
September 2026	2-day Progress Meeting	TBD	Deliverables Consolidation
October 2026	Monthly Meeting	Remote	Catch up
November 2026	Monthly Meeting	Remote	Catch up
December 2026	2-day L4 Community Workshop	Colocation at ESTEC	Close out, Community engagement

Note that the format may be changed depending on availability of meeting space at ESTEC.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THE MISSION TIMELINE(s)

Today
2025

Member states approval (CMIN25)
End 2025

Mission definition phase
2026 - 2034

Mission adoption
2034

Implementation phase
2035 - 2042

Launch
~2042

Arrival at Saturn
2053

Tour of Saturn moons, plume sampling
2053 - 2058

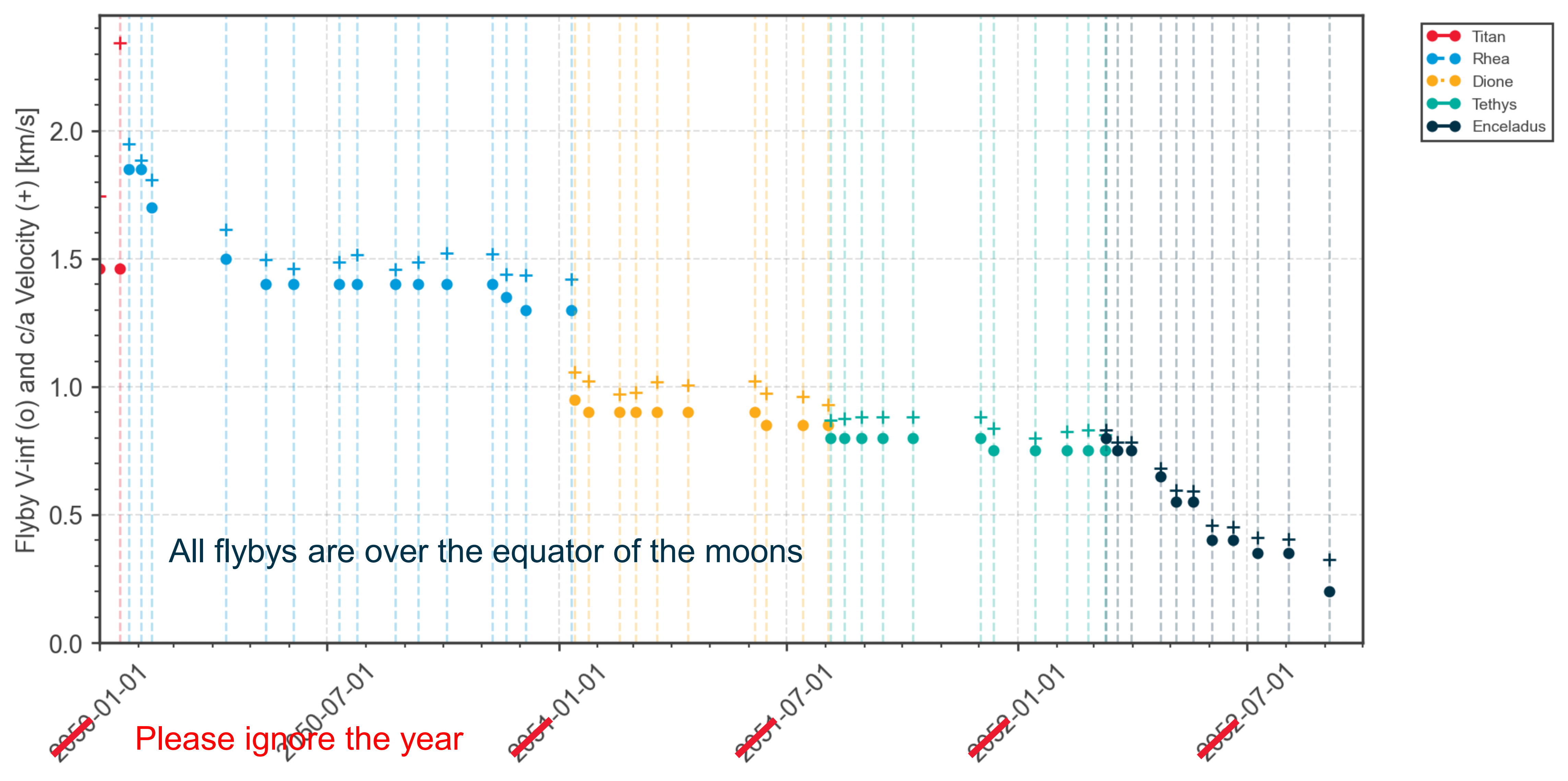
Landing on Enceladus
2058

Launch ~2042

RDV phase	Interplanetary transfer	SOI & PRM	TGAs & Enc. flybys	Moon Tour	Landing site reconnaissance	Surface operations	Disposal
0.5 – 1.5 yr	< 10 yrs	0.9 yrs	1.3 yrs	2.7 yrs	1 month	1 month	TBD

PRELIMINARY TIMELINES

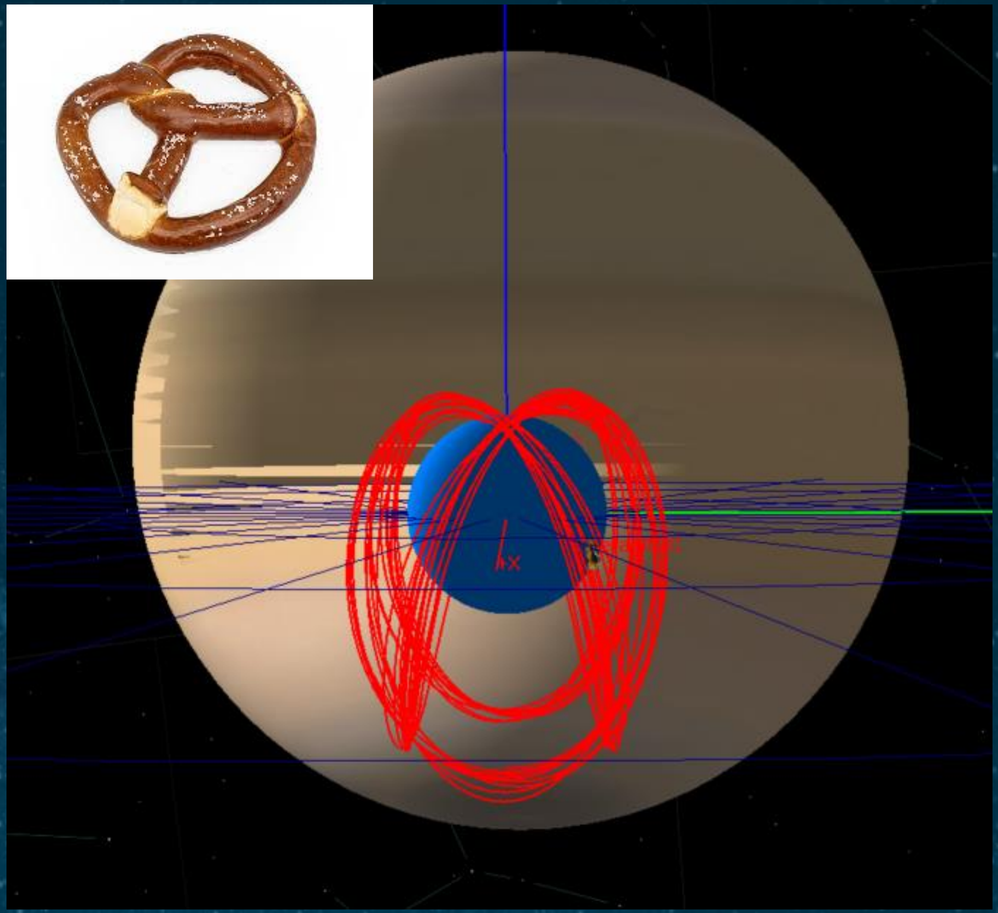
Moon tour – flyby velocities



Search for "safe-hold points" orbits

Search for "safe-hold points" orbits:

- A new stable "Pretzel" orbit , recently found by the ESOC L4 team!
  - Southern and northern version exist
- Delta-V needed to reach it, stability, ground track, etc. is currently being investigated
- Unclear to what extent we fly through the plumes
- We can add flybys, through the plumes, at the end of the moon tour
  - ~5m/s and ~1 month for each flyby



Charge utile conceptuelle

Orbiter (78 kg):

- Mass spectrometer
- Plume dust analyser
- Camera (VIS, high res.)
- Magnetometers
- Radio science
- Infrared Spectrometer
- (Ice-penetrating) radar
- Energetic Particle Detectors

Lander (23 kg):

- Mass spectrometer (+ separation system)
- Camera
- Lab-on-a-Chip/sample handling
- Physical, geophysical and chemical sensors

Small instruments (hundred to few 100s g)

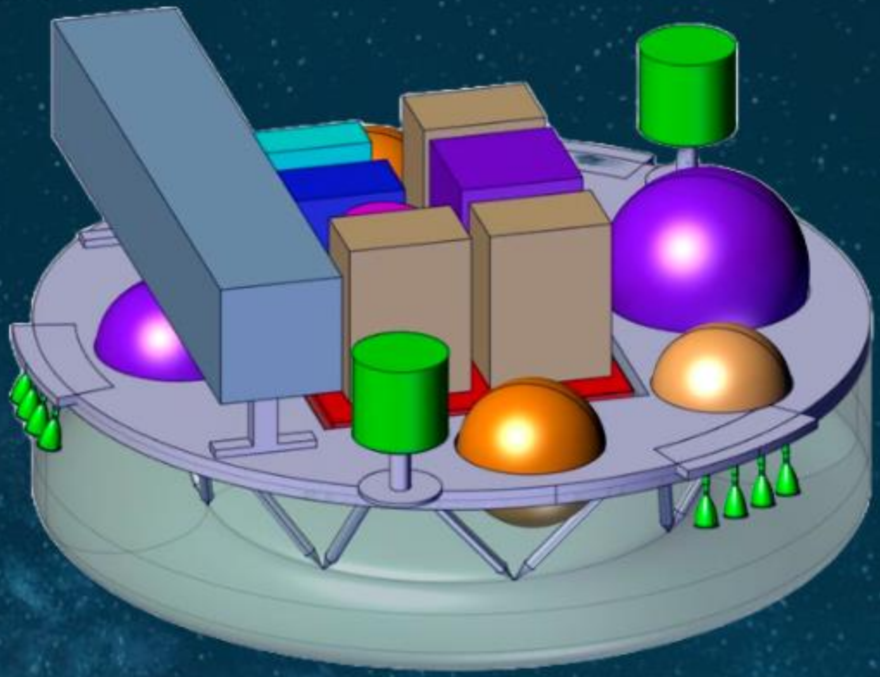
E.g. Idefix rover: miniRAD (radiometer), cameras
Huygens: density measurement
Permittivity sensors

L'atterrisseur

Design préliminaire

<u>31 jours d'opérations en surface</u>

- 6.5 h de la séparation à l'atterrissage
- 2 h commissioning
- ~23 h science / jour
- 1 h de communication avec l'orbiteur/jour



- **<u>~23 kg de charge utile (seulement)</u>**

Alimenté par batteries

- Batteries conventionnelles: ~230 kg! → 4 semaines à la surface d'Encelade
- Masse humide : ~1000 kg (trop?)
- Besoin d'une grosse structure comprimable pour un atterrissage doux sur un terrain inconnu avec des propriétés de surfaces inconnues.

Science Traceability Matrix (doc. évolutif)

esa

Science				
Scientific Themes	Scientific Questions	Scientific Objectives	Payload Requirements	Current Known Payload Technology (Heritage)
A: Habitability of Enceladus & surface–interior interaction	A1: What are the structure, dynamics and composition of the interior of Enceladus?	A1.1: Define the moons' interior structure including the properties of the core		
		A1.2: Determine the structure and dynamics of the ice shell		
		A1.3: Define the depth, dimensions and dynamics of aqueous reservoirs (e.g., global ocean, brine pockets)		
		A1.4: Characterize the exchange between the liquid environment and the rocky layer. Comments added		
		A1.5: Define the thermal state and heat budget of the interior (Potential sources of planetary energy may include, e.g., tides, geochemical processes, and isotopic decay)		
		A1.6: Define the evolution of the orbit of Enceladus over geological periods		
	A2: What is the physical-chemistry of the liquid water environment(s) including its hydrothermal systems?	A2.1: Characterize the chemical composition (gradients, nutrients, elements, chemical energy sources)		
		A2.2: Characterize physical–chemical parameters (salinity, redox, pH, temperature, pressure)		
		A2.3: Identify forms of energy available to support life		
		A2.4: Assess the long-term evolution of the liquid ocean		
	A3: How does surface geology and composition inform the current state and evolution of Enceladus?	A3.1: Characterise the geological history and evolution (constrain stress history, deformation evolution and resurfacing mapping and characterizing geological features, e.g. craters, boulders, fractures, ridges, fine particle deposits, landslides)		
		A3.2: Identify surface distribution of ices, salts, organics, and silicates to trace internal vs. external material sources. Detect cryovolcanic features and relate them to subsurface ocean chemistry.		
		A3.3: Detailed characterization of the south pole terrain (tiger stripes, venting activity, connecting fracture system, physical properties)		
		A3.4: Characterize plume deposition		
	A4: What is the mechanism driving plume formation and	A4.1: Characterize plume vents	→ Add your favorite instrument here	
		A4.2: Characterise the energy balance driving plume activities (tidal vs internal heat, seismic activity)		
B: Enceladus & its external environments and the Saturnian system	B1: How does space weathering affect the surface of Enceladus?	B1.1: Characterise how the dust environment interacts with the surface		
		B1.2: Characterise effects of micrometeorite bombardment		
		B1.3: Characterise how the electro-magnetic field and charged particles interact with surface materials		
	B2: What is the structure and composition of the plume and its interactions with external	B2.1: Characterise plume morphology, structure, and temporal variability		
		B2.2: Characterise gaseous and particle components of plumes		
		B2.3: Define how plume material interacts with the Saturn system (E-ring, torus)		
	B3: What is the history of the Saturian system?	B.3.1 Constrain the interior of other Saturnian moons		
		B.3.2 Identify and characterize the liquid environements (if any) of other Saturnian moons		
		B.3.3 Characterize the geological history and evolution of other Saturnian moons		
		B.3.4 Characterize the surface composition of other Saturnian moons		
		B.3.5 Constrain the orbit of other Saturnian moons		
		B.3.6 Characterize the dust distribution and composition in the Saturnian system		
		B.3.7 Characterize the Saturn's magnetosphere and its interaction with other Saturnian moons		
C: Prebiotic chemistry & biosignatures	C1: What is the inventory of prebiotic chemistry available at Enceladus?	C1.1: Determine and characterize the inventory (abundance and distribution) of organic molecules		
		C1.2: Determine the origin of organic molecules		
		C1.3: Determine and characterize the inventory of inorganics related to prebiotic chemistry		
		C1.4: Determine the molecular complexity of organic molecules		
	C2: Are there signatures of life (as we know it) at Enceladus?	C2.1: Determine and characterize the inventory of putative chemical biosignatures (e.g., from monomers to polymers)		
		C2.2: Search for any other detectable non-chemical biosignature such as biological textures and morphologies.		
		C2.3: Determine metabolic pathways, if biosignatures are present		
		C2.4: Determine local influences on the preservation state of biosignatures		

Développements technologiques nécessaires

Développements techno nécessaires avant l'adoption en 2034. Idéalement TRL6 avant adoption pour dérisquage

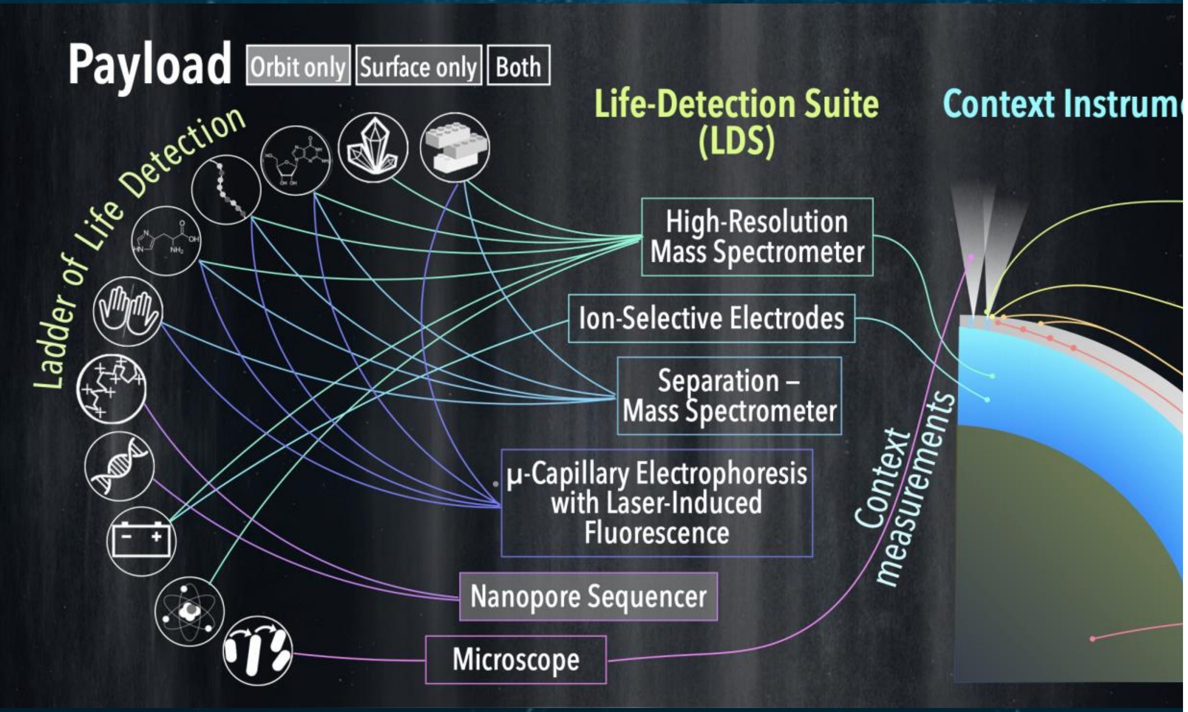
➔ Miniaturisation et efficacité en puissance

ESA L4 Study team ready to support you on all aspects regarding the technology development

- Understanding ice material
- Passive snow sampling
- Desalination
- **Speed up TRL increase for Orbitrap**
- Impact survivability of biomarkers
- Lab on a chip receptor chemistry (stability derivatization reagents etc)
- Miniaturized MS (Univ Wroclax, PL), MEMS GCs (UK, Swiss, France)

Enceladus Orbilander

2nd priority in decadal survey 2023-2032
Determine whether or not Enceladus is inhabited and
Obtain geochemical and geophysical **context for life**
Concept study - MacKenzie *et al.* 2022 Astrobio



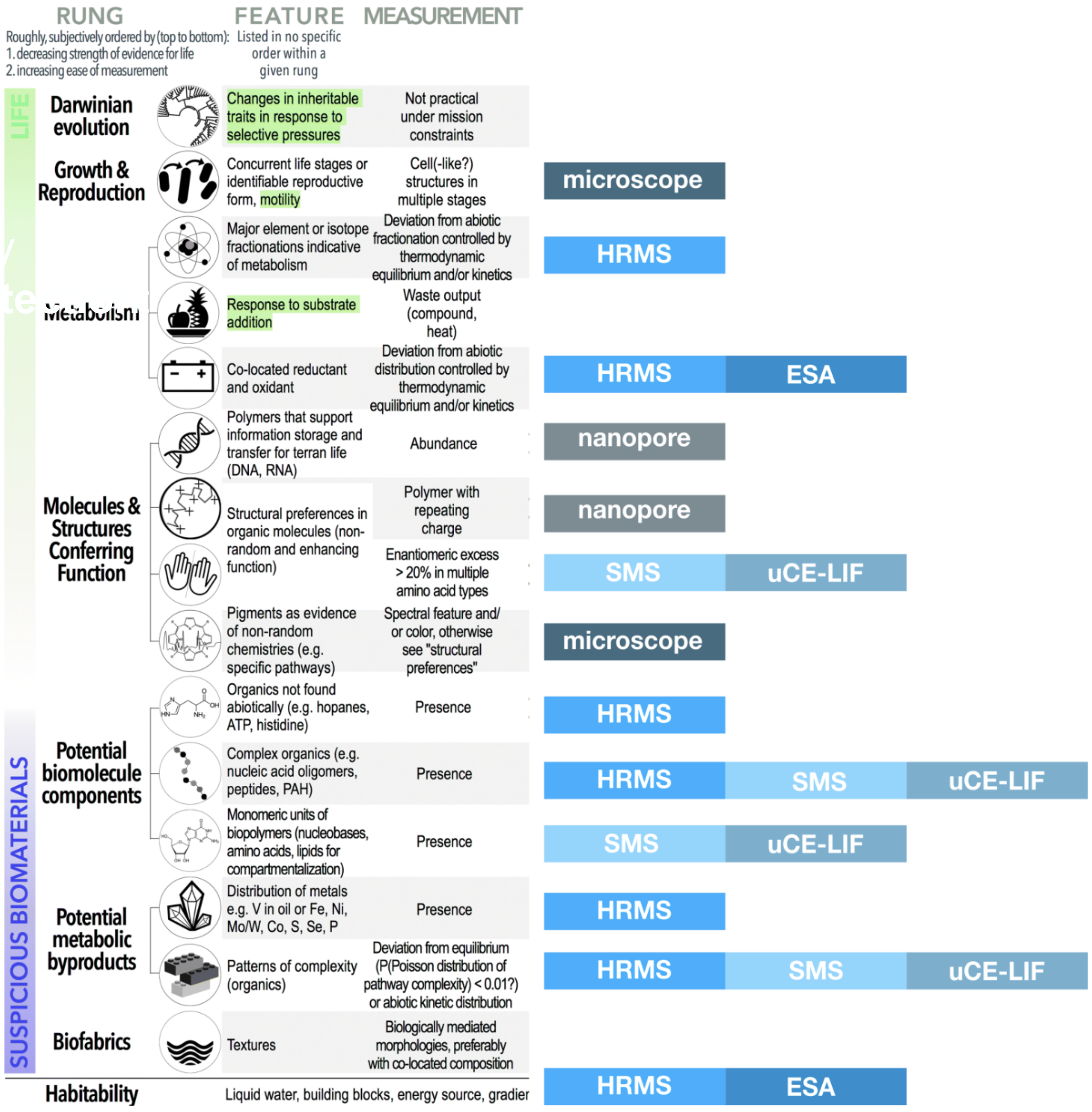


Exhibit B-1. Complementarity of the life detection investigations. Left-hand side modified from Neveu et al. (2018). HRMS, high-resolution mass spectrometer; µCE-LIF, microcapillary electrophoresis with laser-induced fluorescence; ESA, electrochemical sensor array; SMS, separation mass Spectrometer; TES, thermal emission spectrometer; NAC, narrow angle camera; WAC, wide angle camera (either of the two navigation cameras; co-boresighted with the NAC).

Encelade, une cible populaire – NASA New Frontiers 5

- ***EAGLE*** *: Enceladus Astrobiology and Geology Landed Explorer (Penn State). Sera proposé en NF5*

  → Proposition pour synergie avec L4 ESA. Co-Is et instruments CNES proposés

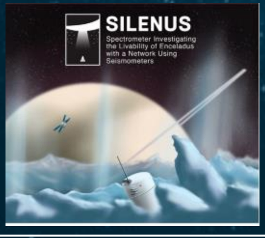
- ***BRINE/ELSAH*** *: Enceladus Life Signatures And Habitability (GSFC) – « Fly low and fly slow ». Proposé en NF4*

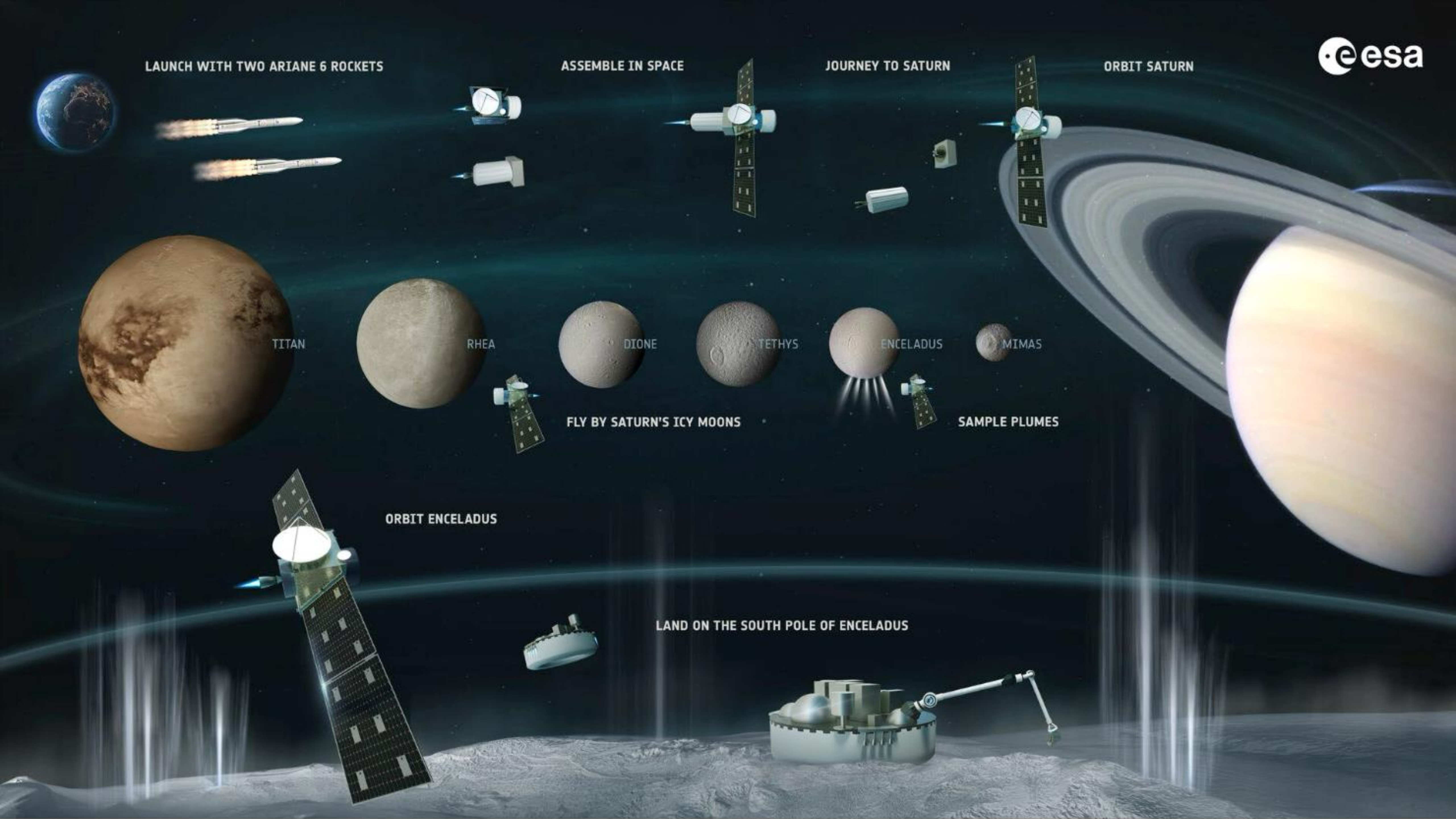
- ***ELF*** *(Enceladus Life Finder)/* ***Nightingale*** *(JPL) (Reh et al. 2016 – Proposé en NF4 (2017). Sera reproposé en NF5. Co-Is CNES proposés*

- *Autres proposal du JPL ? (Sélection interne envisagée, 6 propositions pour NF5, downselect à 3 (?))*

- ***Tiger*** *(Spiers et al. 2021)*

- ***SILENUS*** *(Nathan et al. 2022)*

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High speed flybys

- Removing the high-speed flybys (HSF) would save >500 kg wetmass and 10 months of the mission
    - Frees up propellant
        - Addition of Mimas flyby(s)
        - Targeted flybys of the other moons
        - More time spent in orbit around Enceladus → longer recognizance phase!
    - Enable other mission architectures
        - potential for substantial reduction in mission complexity and cost
        - drawback of increasing the overall mission duration (~1 year)

Questions for L4 PLWG

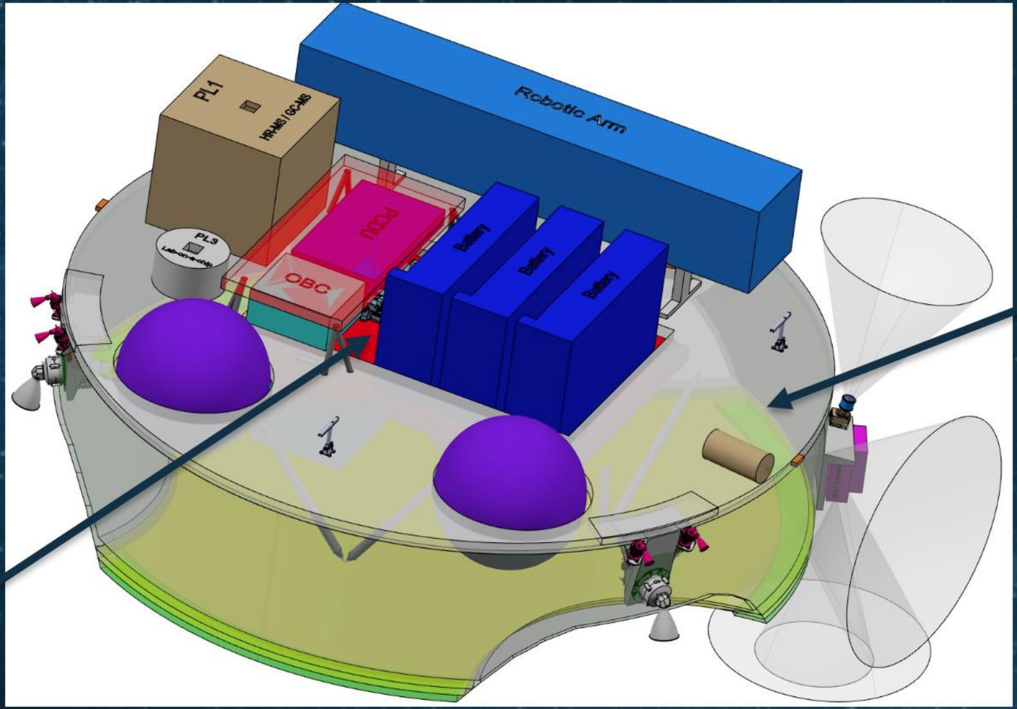
- Are there any strong scientific reasons NOT to remove the high-speed flybys?

- If we select the “Pretzel”-orbit, how do we make sure we comply with the scientific requirement:

  “We require the spacecraft to execute some high velocity flybys through the plume while still being in a Saturn resonant orbit (Figure 6). At least 10 such flybys should be executed, targeting plume sampling with the spacecraft’s in situ instrumentation at altitudes ideally below 50 km.”

- What constitutes a flyby?
  - What min/max velocity?
  - What maximum altitude?
  - What is the required minimum density of the plumes?

Lander design - ADS



Cold Deck

- Payloads (Mass Spectrometer, Lab-on-a-chip, camera, sensors on booms)
- Propulsion Tanks
- Thrusters
- GNC Equipment

Additional Constraints
Lander height restricted to height of robotic arm
Lander diameter capped at 2.4 m (SBAS) to avoid orbiter accommodation knock-on effects
CoG as central as possible

Warm Deck

- OBC
- PCDU
- UHF Transceivers
- Payload E-boxes
- **<u>Batteries</u>**
- IMU

L4 main design drivers

Launch capability of Ariane 64 (and evolutions) estimated to be ~10.7 tons into HEO orbit

- One launch to carry a first stack with the orbiter (~80kg payload) and the Enceladus lander
- Second launch with the chemical propulsion stage and the solar electric propulsion stage
- Limited solar power available in the outer solar system requires use of large solar arrays and primary batteries:
- Low solar flux (~14 W/m2) at Saturn **≥180 m2 solar arrays** on the orbiter
- **~700 W generated EOL**
- Large solar arrays enable electric propulsion in inner solar system
- **Primary battery for the Enceladus lander** (High TRL, with further improvement being investigated)
- Low TRL solutions with European equipment: high energy density fuel cells, and/or RHUs
- The thermal control system is driven by a highly variable thermal environment
- Extremely low temperatures in the outer solar system and high temperatures generated by the SEP stage at ~0.8 AU
- Telecommunication (orbiter to ground) requires large high-gain antennas (~2 to 3 m) and arrayed (35 m) ground stations
- Only possible to transfer a limited amount of data (~22 kbps)

MASS SPEC IN SPACE EXPLORATION

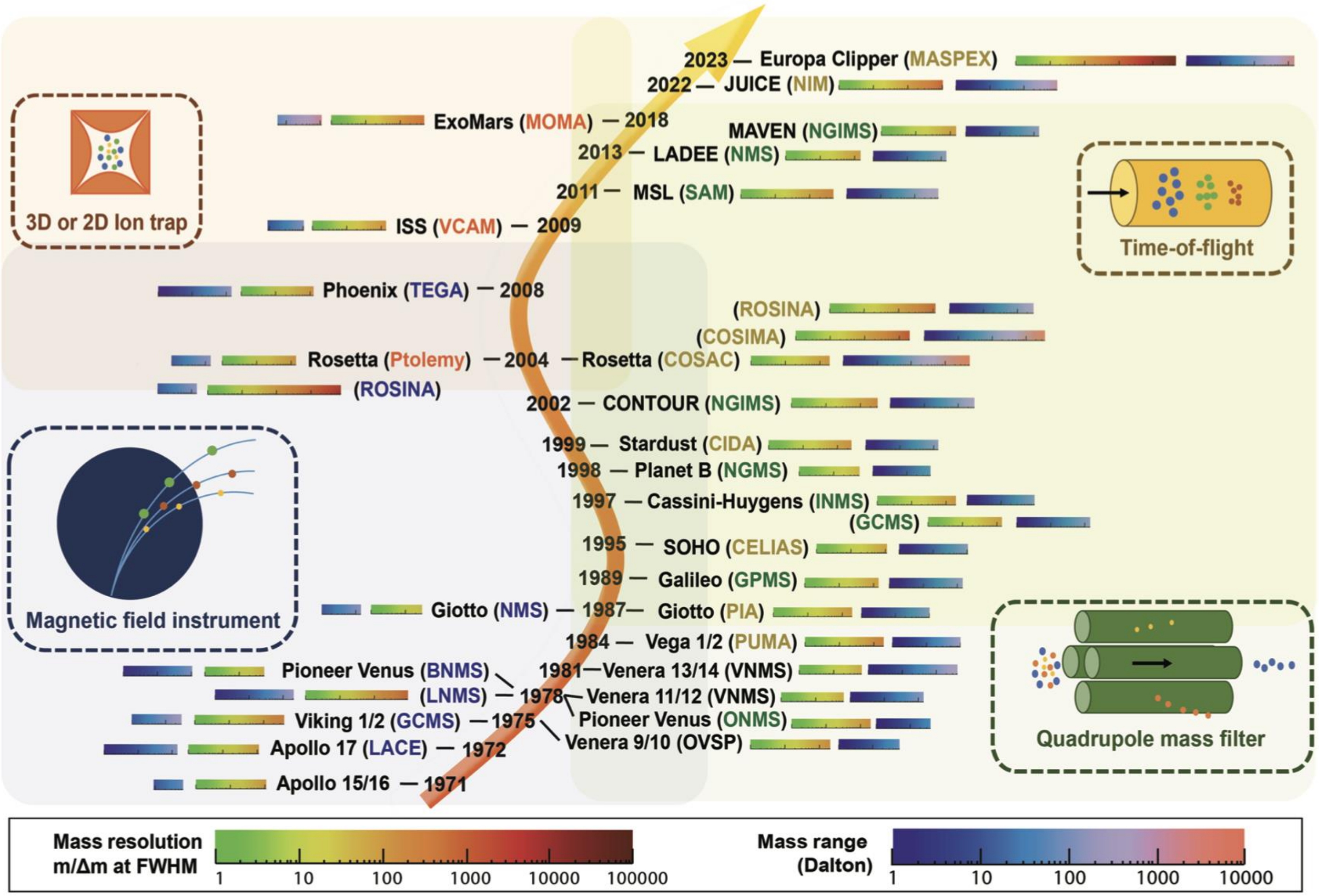


FIGURE 2 Major milestones in the evolutionary history of mass spectrometry, applied for planetary exploration, show the variety of mass analyzers exploited to date and the progression from instruments offering limited analytical performance to those capable of enhanced science return (expanded mass ranges, higher mass resolving powers, etc). For an even more detailed history than that provided here, the reader is referred to Ren et al[16]

Bonus slide: Blue Ghost payload inspiration