SEAFARE

Surveying Environments & cross the Saturnian System For habitability ResEarch



Summer School Alpbach 2024



Team Green

Science Team

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Mission Analysis Team

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- Anike Ohm Germany



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- Andras Baranyai Hungary
- Boris Baudel France
- David Placke Austria
- Colm Daly Ireland







Mission Engineering Science Case **Programmatics** Analysis Julia Wiltenburg Vincent Affatato **Colm Daly David Placke** esa Seafarer eesa +* Green Team – Mission SEAFARER

Science Case

Mission Analysis

Julia Wiltenburg

Vincent Affatato

David Placke

Engineering

Colm Daly

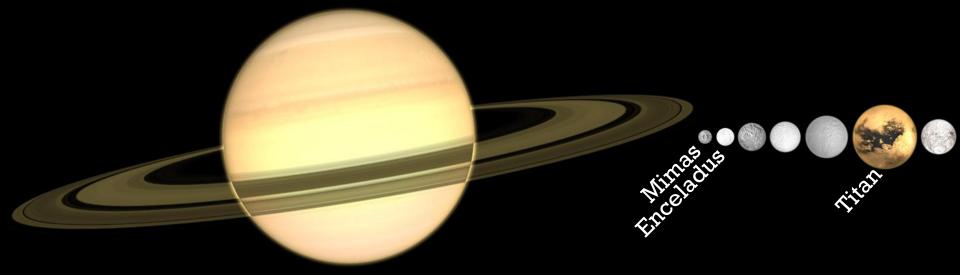
Programmatics





Our Destination

Saturn and its Moons



But why?





Our Destination

Saturn and its Moons

With 22

Planet Formation

History of Solar System

(Potential) Ocean Worlds

Early Earth Archetype

Habitability





Motivation



Heritage

- Characterized Saturn's atmosphere
- Discovered Enceladus' plume
 CHNOPS & organics
- Enceladus mapped
- Huygens landed on Titan
 - Atmosphere
 - Lakes
- Dragonfly to land on Titan
 - Dry equatorial land
 - Habitability

Open Questions

- Elemental composition poorly known
- Cassini scratched the surface \rightarrow SEAFARER designed for habitability
- Low resolution → higher resolution for future landers
- Large scale circulations to be addressed
- Complement Dragonfly
 - Lakes (properties remain unknown after Cassini)
 - Habitability



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Green Team – Mission SEAFARER

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Motivation



Report of the Expert Committee for the Large-class mission in ESA's Voyage 2050 plan covering the science theme "Moons of the Giant Planets"



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Expert Committee Report for the Large-class Mission "Moons of the Giant planets":

1) The issue of **habitability** of ocean worlds and the interaction between the surface and the interior

2) The issue of habitability of **oceans worlds** and the interaction with the external environments

3) The identification of **prebiotic chemistry** and the search for **biosignatures** on ocean worlds.

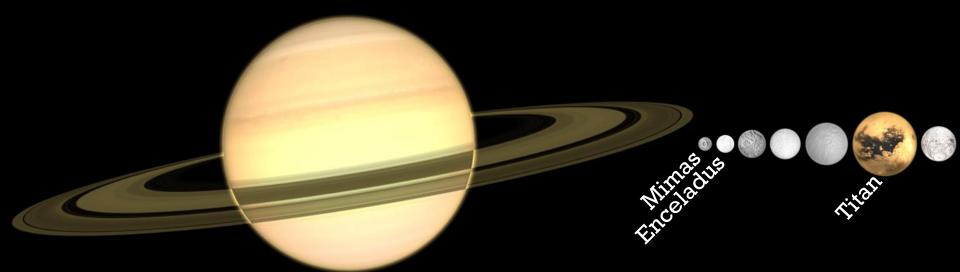
Most interesting target: Enceladus 2nd place: Titan Lander and Orbiter





Our Destination

Saturn and its Moons



"SEAFARER shall study and characterise the diversity of habitats in the Saturnian systems"





Science Objectives

Objective 1: How and where did **Saturn** form?

Objective 2: What is the nature and diversity of the **potential habitats**?

Objective 3: What is the peculiar nature of the **Titan climate** variability?





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SEAFARER: A mission to study Habitability in the Saturnian Syste

Scientific	Scientific	Scientific	Measurement	Mission	Instrument
Goals	Question	Measurements	Requirements	Requirements	
1. Understand Saturn's formation and orbital evolution	1.1. What is Saturn's formation history, composition and implications for the present-day Solar System architecture?	 I. I. In-situ isotopic ratios of noble gas and elements (II, IIe, Ne, Ar, Kr, Xe, C, N, O, and S) in Saturn's atmosphere. I. I. Z. In-situ mixing ratios of the species CO, C₂H₆, PH₃, NH₃ in Saturn's atmosphere. 	Abundances at a resolution of from 1 to > 150 ann, mass resolution > 1000 M/dM. The Tunable laser spectrometer shall have a resolving power of ${\sim}10^6~\lambda/{\Delta}\lambda$ at least.	Data retrieval from 1 nbar to 10 bar.	VESPUCCI Atmospheric Probe Quadrupole Mass spectrometer, Tunable Laser Spectrometer
	1.2. What is the geomorphology and composition of Encedand's andree, especially in the moon's south polar region?	1.2.1. Vanal and thermal mapping in the IR. 1.2.2. Topography mapping.	Presence and temperature manping every 2. A tablest systematic via 2.0 tables, and the viscous via 2.0 tables, and the viscous viscous viscous 2.0 tablest and the viscous vi	Data retrieval from 1 abar to 10 bar.	VESPUCCI Atmospheric Probe Atmospheric Probe Atmospheric package with generative and temperature sensors, Accelerometer, used fue factoristic and the temperature and the sensors and radio centrologies detector

EAFARER: /	A mission to study Habi	tability in the Saturnian Syst	em		Green Te
Scientific	Scientific	Scientific	Measurement	Mission	Instrument
Goals	Question	Measurements	Requirements	Requirements	
 Understand the nature and diversity of potential habitats in the Saturnian system. 	2.1. What is the origin and evolution of Saturn's medium-sited moons (Minux, Encolutus, Rhea, Dione, Tethys)?	2.1.1. Remote sensing of infrared absorption of H ₀ O between 1 – 5 µm one key surfares to find the D/H ratio of Enexcitains, Mimas, Rhex, Diones and Tethys from the surfare (absorption feature at 4.13 µm is representative for douterium in the ice and 2 µm absorption hased of H ₂ O). 2.1.2. Remote sensing of the Enexcludus plunnes	The wavelength coverage shall be 1–5µm, with a higher modulus of MSS, and a minimum resolution of 0.01 $\mu m.$	Perform > 5 flybys of the Saturnian mesons (Mimas, Rhou, Done, Tethys) at an abitute of < 7 fs len. Thin needs to be updated!	SEAFARER Orbiter Visible-Infrared Hyperspectral Imaging Spectrometer
	2.2. What is the geomorphology and composition of Enceladus' surface, namely in the moon's south polar region (Tiger Stripes)?	2.2.1. Visual and infrared (thermal) mapping of the South Polar Region of Enceladus. 2.2.2. Topography and altimetry mapping.	Image and analyse spectrally the ice surface, with a resolution of 100m/pixel. This needs to be expanded!	How many flybys would you need?	SEAFARER Orbiter Visible-Infrared Hyperspectral Imaging Spectrometer. Imaging System. Radar Altimet
	2.3. What is Encoladas' plumes' activity variability (location, composition, time, interaction with magnetosphere)?	2.3.1. Thermal mapping (location and intensity) in the South Tolar Region. 2.3.2. Magnetic field of Enceladus during the flyby of the moon.	Image and spectral analysis at least 10 m/pixel for the imager and spectrometer 500 m/pixel. We need magnetic measurement requirements.	Flybys	SEAFARER Orbiter Visible-Infrared Hyperspectral Imaging Spectrometer. Magnetometer. Sub- millimetre wave instrument. Imaging System.
2.4. What is the current state of water- rock interactions on Excelators and subsurface ocean longwity and composition?	2.4.1. Sample the salts, organics and volatiles from the plumes of Enceladus. 2.4.2. Add more.	Molecular weight distribution of organic matter from 16 Da (CH4) to \geq 1000 Da in plume vapour and icy particles. We need specifications here!	>9 Enceladus flybys at an altitude < 75 km to get to the plumes densest part. S/C velocity shall be 3– 5 km/s and 5–9 km/s.	SEAFARER Orbiter High Resolution Mass Spectrometer.	
	2.5. What is the nature of the potential subsurface ocean on Mimas?	2.5.1. Surface image of tectonism features 2.5.2. Spectral image for detection of endogenous signatures 2.5.3. Thermophysical properties (grain-size)	The spectrometer shall have a wavelength coverage of 0.5 – 5.5 μm, and 3– 6 nm spectral resolution.	Shall perform > 9 Mimas flybys at an altitude < TBD	SEAFARER Orbiter Imaging System. Visual and Infrared Spectrometer. Sub-mm wave instrument.?

Scientific	Scientific	Scientific	Measurement	Mission	Instrument
Goals 2. Understand	Question 2.6. What is the	Measurements 2.6.1. Image and spectral	Requirements	Requirements	SEAFARER (Intel
2. Understand the nature and diversity of potential habitats in the Saturnian system.	2.6. What is the nature and habitability potential of the medium- sized moons Dione, Tethys, Rhea?	2.6.1. Image and spectral analysis of the icy surface 2.6.2. thermophysical properties 2.6.3. Induced magnetic field.	Imager shall measure at a resolution of $< 10 m/pixis. The spectrometer shall measure at a < 500 m/pixel resolution, with a wavelength coverage of 0.5 – 5.5 \mu m, and 3–6 \mu m spectral resolution.$	Flyby requirements for each moon	SEAFARER Orbit Imaging System. Visual and Infrared Spectrometer. Magnetometer.
-	2.7. What is the current state of interior- methers presents as concernent state of interior textension, impact-forces liquid water melt pools, they ghold attendesion, height pool attendesion for implications for organic interior targets and the interior targets and t	2.1.1. Breface mapping of crymological different of the second of crymological difference of the second of their parameters (frees) and their parameters (frees) and their parameters (frees) 2.1.2. Strates mapping of discourse factorial second and and guident (scienceiso) and lateral guident (scienceiso) and lateral guident (scienceiso) and lateral guident (scienceiso) and lateral guident (scienceiso) and lateral parameters (scienceiso) and lateral guident (scienceiso) and lateral guident (scienceiso) and lateral (scienceison) and scienceison (scienceison) and scienceison (scienceison) (scienceison) and scienceison (scienceison)	Image them emission spatial multilexit of the spatial	The orbits must be at 2000 in or database in a light polar region. Loser allutions are accordingly and the second or the accordingly of the minimum.	SEAFARER Orbit Inaging System. Vinual and Infrared Dependence. Roho Of-andro microwave nationestry. *
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Scientific	Scientific	Scientific	Measurement	Mission	Instrument
Goals	Question	Measurements	Requirements	Requirements	
2. Understand the nature and diversity of potential habitats in the Saturnian system	2.8. What is the relative surface abundance of complex molecules on Titan and Enceladus?	2.8.1. Image and spectral analysis of the icy surface	Visual and Infrared Spectrometer (0.5.5.5 micrometers, 3-6 nm spectral resolution) lunger shall measure at a resolution of < 10m/pixel. The spectrometer shall measure at a < 500m/pixel resolution, while a wavelength coverage of 0.5 – 5.5 μm , and 3.6 nm spectral resolution.	Flyby requirements for each moon	SEAFARER Orbiter Imaging System. Visual and Infrared Spectrometer. Magnetometer.
	2.9. Are three biopenic three biopenics powers in the organic dennistry in Tiana, and, if an, what are third shundances and can be roluced and onlikely organic and onlikely organic and onlikely organic be detected?	2.9.1. Blamental chemistry (e.g., Phosphera, Sulphar) of organic molecules in Tialars stanophera, netrocks and in Nardem Mare. 2.9.2. Insentor of robust and unified organic species present in Knuten Mare. 2.9.3. Bostopic raiso determination "CP/PC (e.g., on chemically should species on Tanc. CPI2, C 2014, C218, CBI8,) and D/D parameters on Tanc. CPI2, C 2014, C218, CBI8,) and D/D parameters on Tanc. CPI2, C 2014, C218, CBI8,, and CPI parameters on CPI and CPI parameters 2.9.4. Abundances of solid processes (e.g. ⁴⁰ Ar, ²¹ Fe) in Knoben Mare.	Mar range Man abandare v., nobedia dipal don wigit bun 130 ma dipal don Kuler Mee, Essektize Mar robolisti, taka ter kuler a dipa se sektisi particular taka ter kuler a dipak sektisi particular a^{-1} and 10×10^{-10} atting radio.	Operation requisites: at TS K at least under surface pressure of 1.5 bar.	COLUMBUS Infler Gas Chromotography- Mass Sportrometer.

Septific:	Scientific	Scientific	Mountement	Mission	Instrument
rinda	Question	Measurements	Requirements	Requirements	
Understand e climate risbility Titan	3.1. How do the large- scale atmospheric features on Titas (experintation, polar works) and wave activity form and evolve and compare to those of Vesus (slow-rotator comparison)?	3.1.1. Doppler shift of spectral lines to directly necessary ward, resrictional and working winds at bigher balitades.	Boohtim sprification	A high inclination orbit is necessary to accomplish what measurements in the upper attracephere. Reported measurements across different seasons much be made across Titan's orbit phase.	SEAFARER Oriner Sub-millioneter spectrometer; Ultraviol Imaging Spectrograph; vidble and sene IR imager.
	3.2. How different are the thermal structure and mixing values of minur traceable species of the polar atmosphere of Than compared to the low latitudes?	3.2.1. Thermal structure in the mid atmosphere from CO and BCN lines. 3.2.2. Moorg ratio profiles of many molecules and their isotopen in the same abituale many Complex Mid.	Resolution specifications	Mountered specifications	SEAFARER Orisier Sub millimeter spectrometer). Ultravial Imaging Spectrograph; visible and near- IR imager.
	3.3. How do haves and clouds from on Titan, from the lower advantages from the lower advantages to the stratosphere?	3.3.1. Profile across estimation coefficient to remain the structures and ecceptotism of stratospheric in clouds. 3.3.2. UV singlese and reflected UV, 8.3.3. Cloud activity in the visible and move-Bt. 3.3.4. Cloud activity in the visible and move-Bt. 3.3.4. Cloud mechane (Clic) abundances and Cli, dropict also and cristal due from sour-Bt spectrometry, parallel during hasher discort, 3.3.4. Arrange activity and clinical activity model context.	The laster carers should have a wavelength survey in two characteristics of a 460 km strategy of the two characteristics of a 460 4.20° Table to Philase should then	We need association mapproximate for this	SEAPSREE Orbitor UV spectrometer; visible and near-fill imager, and millimeter near initiation in the second near initiation of the second near initiation of the second COLUMBUS Jander COLUMBUS Jander COLUMBUS Jander COLUMBUS Jander Nephalemeter

Scientific	Scientific	Scientific	Measurement	Mission	Instrument
Goals	Question	Measurements	Requirements	Requirements	
3. Understand the climate variability of Titan	3.8. What are the local physical and dynamical prioprities of Kraden properties of Kraden Barer as a proof for Thurs's lakes and result?	3.6.1. Son depth and sound speech frame SDNAR, sound speech frame SDNAR, sound speech frame SDNAR, source start of the index Cohanton. 3.4.5. Alson. Tumperature, pressure and deleteristic constant for Alson. Tumperature, pressure and deleteristic constant. Als. Tumperature, framework, alson. Tumperature, measure and deleteristic constant. S.A.4. Where activity, muffsee constant and index files. Source is a straffic images of lander camera and index index. Jona Libro Boking Hanching and Libro Schuller, Hansel Market, Jonaldo Libro Wern Sure Straffic in Libro Ischer Weithering, Jonald Janes Jack-Tumbelity from Libro Ischer Weithering, Jackan Janes Jack-Tumbelity from Libro Ischer Weithering, Jackan J	"Sensitivity (1) near speech shall be received with a 15 sensitivity in the result be nearestive with 8 sin accuracy of 1.5 m and over a second shall shares of 1.0 m 100 sensitivity be nearestived shares of 1.0 m 100 sensitivity of near second shares of 1.0 m 100 sensitivity of near second shares of 1.0 m 100 sensitivity of the distribution of 1.0 m 100 sensitivity of 1.1 k. The distribution shares are simplified with a sensitivity of 1.0 m 100 sensitivity of 1.0 m 100 sensitivity 0.0 m 100 sensitivity 0.0 m 100 sensitivity 0.0 m 100 sensitivity 0.0 m 100 sensitivity 0.0 m 100 sensitivity 0		SRAFAIRER Oblig Tadai, IR Spectrometer, IR canen COLUMBIUS <i>Lander:</i> upper long, keve long - i diling compartment).

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Scientific	Scientific	Scientific	Measurement	Mission	Instrument
Goals	Question	Measurements	Requirements	Requirements	
3. Understand the elimate variability of Titan	 What are the local physical and physical properties of Krahm and Krahm Titae's labor and near? 	3.4.1. Sies depth and sound speel from SNARL sound speel from SNARL of the lauder Cohanton. 3.4.2. Traperature, pressure and deleteric constant for the lack, to be gathered from lower large (for surface), surface of the desping comparison in the lower base currents, fushing films (foch-dage recognition of form new surface surface). Surface currents, fushing, films (foch-dage recognition of form new surface surfaces, sound in the upper lowy of the linet Chanton.	"Binativity: (1) sound speed adult is of (2016) 1220 million in the start of the start of the low manual with an accuracy of (2 h m form the 2010 million in the start of (2 h m form the 2010 million interaction of (2 h m form the 2010 million interaction of an abu- contain programment. For instrument and with a soundarial programment, for instrument and the documents with a soundary of (2 h H form the 2010 million interaction of the 1 h for the result (3 million accuracy of the 4.001 (2) means and the 2011 million interaction (3 million interaction) and the 2011 million interac- tion of the start of the start of the start (3 million interaction) and the start of the start (3 million interaction) and the start of the start light extinction under the waterflux.		SEAFARER Other Indue, III Spectrometer, III canera COLUMPIUS Lander: upper bary, lower boar 4 shing compartment).



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Green Team – Mission SEAFARER

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SEAFARER: A mission to study Habitability in the Saturnian System

Scientific	Scientific	Scientific	Measurement	Mission	Instrument
Goals	Question	Measurements	Requirements	Requirements	
1. Understand Saturn's formation and orbital evolution	1.1. What is Saturn's formation history, composition and implications for the present-day Solar System architecture?	1.1.1. In-situ isotopic ratios of noble gas and elements (II, IIe, Ne, Ar, Kr, Xe, C, N, O, and S) in Saturn's atmosphere. 1.1.2. In-situ mixing ratios of the species CO, C ₂ H ₆ , PH ₃ , NH ₃ in Saturn's atmosphere.	Aburdances at a resolution of from 1 to $>$ 159 ann, mass resolution $>$ 1000 M/AM. The Tunable laser spectrometer shall have a resolving power of ${\sim}10^6~\lambda/{\Delta}{\lambda}$ at least.	Data retrieval from 1 nbar to 10 bar.	VESPUCCI Atmospheric Probe Quadrupole Mass spectrometer, Tunable Laser Spectrometer
	1.2. What is the geomorphology and composition of Encedadar surface, especially in the moon's south polar region?	1.2.1. Vanal and thermal mapping in the IR. 1.2.2. Topography mapping.	Pressure and tomperature sampling every 2. A fibble solution to 2.0 to 10 km and 2.0 to 2.0 to 10 km and 2.0 to 2	Data retrieval from 1 nbar to 10 bar.	VESPUCCI Atmospheric Probe Atmospheric Probe Monopheric package with pressure and temperature sensors, Accelerometer, Nephelomster, lighting and radio emissions detector

Green Team

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SEAFARER:	A mission to study Habi	tability in the Saturnian Syst	em		Green Team
Scientific	Scientific	Scientific	Measurement	Mission	Instrument
Goals	Question	Measurements	Requirements	Requirements	
the nature and diversity of potential	2.1. What is the origin and evolution of Saturn's medium-sized moons (Minnes, Ezceladus, Rhea, Dione, Tethys)?	2.1.1. Remote sensing of infrared absorption of H ₄ O between $1 - 5 \mu m$ on key surfaces to find the D/H ratio of Enzekahns, Mimas, Bibes, Dione and Tethys from the surface (absorption feature at 4.13 μm is representative for deuterium in the ice and 2 μm absorptions hand of H ₄ O). 2.1.2. Remote sensing of the Enzelabus plurmes	The wavelength coverage shall be 1–5µm, with a higher resolution than VHMS, and a minimum resolution of 0.01 $\mu m.$	Perform > 5 flybys of the Saturnian moone (Mimas, Rhea, Done, Tothys) at an altitude of < 75 km. Thin needs to be updated!	SEAFARER Orkier Visibi-Infrared Hyperspectral Imaging Spectrometer
	2.2. What is the geomorphology and composition of Enceladus' surface, namely in the moon's south polar region (Tizer Stripes)?	2.2.1. Visual and infrared (thermal) mapping of the South Polar Region of Enceladus. 2.2.2. Topography and altimetry mapping.	Image and analyse spectrally the ice surface, with a resolution of 100m/pixel. This needs to be expanded!	How many flybys would you need?	SEAFARER Orbiter Visibio-Infrared Hyperspectral Imaging Spectrometer. Imaging System. Radar Altimetry.
	2.3. What is Enceladus' plumes' activity variability (location, composition, time, interaction with magnetoephere)?	2.3.1. Thermal mapping (location and intensity) in the South Polar Region. 2.3.2. Magnetic field of Enceladus during the flyby of the moon.	Image and spectral analysis at least 10 m/pixel for the imager and spectrometer 500 m/pixel. We need magnetic measurement requirements.	Flybys	SEAFARER Orbiter Visibio-Infrared Ihyperspectral Imaging Spectrometer. Magnetometer. Sub- millimetre wave instrument. Imaging System.
cii ro Ei	2.4. What is the current state of water- rock interactions on Enceladus and subsurface ocean longevity and composition?	2.4.1. Sample the salts, organics and volatiles from the plumes of Enceladus. 2.4.2. Add more.	Molecular weight distribution of organic matter from 16 Da (CH4) to \geq 1000 Da in plume vapour and icy particles. We need specifications here!	>9 Enceladus flybys at an altitude < 75 km to get to the plumes densest part. S/C velocity shall be 3– 5 km/s and 5–9 km/s.	SEAFARER Orbiter High Resolution Mass Spectrometer.
	2.5. What is the nature of the potential subsurface ocean on Mimas?	2.5.1. Surface image of tectonism features 2.5.2. Spectral image for detection of endogenous signatures 2.5.3. Thermophysical properties (grain-size)	The spectrometer shall have a wavelength coverage of $0.5 - 5.5 \ \mu m$, and $3 - 6 \ nm$ spectral resolution.	Shall perform > 9 Mimas flybys at an altitude < TBD	SEAFARER Orbiter Imaging System. Visual and Infrared Spectrometer. Sub-mm wave instrument.?

Scientific	Scientific	Scientific	Measurement	Mission	Instrument
Goals	Question	Measurements	Requirements	Requirements	
 Understand the nature and diversity of potential habitats in the Saturnian system. 	2.6. What is the nature and habitability potential of the medium- sized moons Dione, Tethys, Rhea?	2.6.1. Image and spectral analysis of the icy surface 2.6.2. thermophysical properties 2.6.3. Induced magnetic field.	Imager shall measure at a resolution of < 10m/pixt. The spectrometer shall measure at a < 500m/pixel resolution, with a wavelength coverage of 0.5 – 5.5 µm, and 3–6 nm spectral resolution.	Flyby roquirements for each moon	SEAFARER Orbite Imaging System. Visual and Infrared Spectrometer. Magnetometer.
	2.7. What is the current state of interior- surface presents on This (expressions), many line of the state of the state line of water methy people, their global distribution, geological history and mainful tamport across the sty crust?	2.1.1. Surface mapping of reproduction that and (hanne, address, pild) and and their parameters (many, address, parameters (many, address, parameters), how and address (parameters), how and fold (compression), and all in the isy errors of Thata, 2.7.3. Surface mapping of the statistical state of the state (horizon to horizon the state the statistical state of the state the state of the state of the state (horizon to horizon the state the state of the state of the state (horizon to horizon the state of the state of the state (horizon to horizon the state of the state of the state (horizon to horizon the state of the state of the state (horizon to horizon the state of the state of the state (horizon to horizon the state of the state of the state (horizon to horizon the state of the state of the state (horizon to horizon the state of the state of the state of the state (horizon to horizon the state of the state	Image thermal emission, spatial restrikes of 20 m logical, bear on manufactor 20 \pm m logical, bear on marking and the state of th	The orbits must be at 2000 to of adducts in a high indication orbit is cover the indication orbit is cover the one second second in the catended place of the minion.	SRAFARER Orbita Imaging Syndem. Visual and Infrared Spectrometer. Radar Off-andfr microwave radiometry. "

SEAFARER: A mission to study Habitability in the Saturnian System

SEAFARER: A mission to study Habitability in the Saturnian System

Green Team

Scientific	Scientific:	Scientific	Measurement	Mission	Trackrosmend.
Goals	Question	Measurements	Requirements	Requirements	
 Understand the climate suriability of Titan 	3.1. How do the large- scale atmospheric features on Titas (experimation, polar writer) and uses activity form and evolve and ecompare to those of Vesas (show-extatur comparison)?	3.1.1. Doppler shift of spectral lines to directly necessare ward, resrictional and working winds at bigher balitades.	Boohtim sprification	A high inclination orbit is necessary to accomplish what measurements in the upper attracephere. Reported measurements across different seasons much be made across Titan's orbit phase.	SEAFARER (Jointer Sub-enlinester spectrometer, Ultraviole Imaging Spectrograph, visible and sear- IR imager.
	3.2. How different are the thermal structure and mixing ratios of minur traceable species of the polar atmosphere of Than compared to the low latitudes?	3.2.1. Thermal structure in the mid atmosphere from CO and BCN lines. 3.2.2. Moorg ratio profiles of many molecules and their isotopen in the same abituale many Complex Mid.	Resolution specifications	Mountered specifications	SEAFARER Orisler Sab millimeter spectromoter, Ultravide Inoging Spectrograph; visible and near- IR imager.
	3.3. How do haves and clouds form on Titan, from the lower atmosphere to the stratosphere?	3.3.1. Profile served estimation coefficient to rewal the structure and composition of stratopheric ice clouds. 3.3.2. UV singlow and reflected UV. 3.3.3. Goal activity in	The lander camera should have a wavelength coverage in two character visible at 480– 900 me and 100 of 0.07–1.04 m. A resolution of 0.06–0.20° Talk to Fabian about this,	We need minister requirements for this	SEAFARER Ovision UV spectrumeter; visible and near-BR imager; sub-sufficiences wave inferenced; sear- IR spectrumeter.
		i.i.i.i. Chain activity in the visible and none-IR. 3.3.4. Could methane (CBL) absentiance and CHL dropiet size and cristal size from non-IR spectrometry. 3.3.5. Methane abundance public during lander doccerd. 3.3.6. Arrowed extinction coefficients during lander doccerd.			COLUMBUS Lander Lander camera. Nephakomter

SEAFARER: A mission to study Habitability in the Saturnian System Green Team Scientific Scientific Scientific Measurement Mission Instrument Question Measurements Reminente Requirements 2. Understand 2.8. What is the relative 2.8.1. Image and spectral Visual and Infrared Spectrometer (0.5-5.5 Flyby requirements SEAFARER Orbiter the nature surface abundance of analysis of the icy surface. micrometers, 3-6 nm spectral resolution) for each moon Impring System and disersity complex molecules on Imager shall measure at a resolution of Visual and Infrared of potential Titan and Enceladus? < 10m/nixel. The spectrometer shall Spectrometer. habitats in measure at a < 500m/pixel resolution, with Magnetometer the Saturnian a wavelength coverage of 0.5 - 5.5 µm, system and 3-6 nm spectral resolution. 2.9. Are there biogenic 2.9.1. Elemental chemistry Mass range: Mass abundance vs. molecular Operation requisites: at COLUMBUS Drifter elements present in the (e.g., Phosphorus, Sulphur) weight from 2-500 amu of liquid from 75 K at least under a surface Gas Chromatoeraphyorganic chemistry in of organic molecules in Kruken Mare. Resolution: Mass resolution pressure of 1.5 bar. Mass Spectrometer Titan, and, if so, what Titan's atmosphere, acrosols shall be 1×10⁻⁶ at 250 ann: Sensitivity: are their abundances and in Kruken Mare minimum 0.002 counts molecule-1 cm3 and can be reduced 2.9.2. Inventory of reduced s⁻¹ and 10× 10⁻¹⁰ mixing ratio. and oxidised organic and oxidised organic species species be detected? present in Kraken Mare. 2.9.3. Isotopic ratio determination 12C/13C (e.g. on chemically abundant species on Titan: C2H2, C2H4, C2H6, C3H8, ...) and D/H parameters from samples collected in the atmosphere and in Kraken Mare. 2.9.4. Abundances of noble gases produced by radiogenically processes (e.g. 40 Ar, 21 Nc)

Scientific	Scientific	Scientific	Measurement	Mission	Instrument
Goals	Question	Measurements	Requirements	Requirements	
3. Understand the climate variability of Titan	3.8. What are the local physical and physical and physical in the physical properties of Kraham are proved for the set of the set	3.6.1. Son depth and sound speed from SNAM, sound speed from SNAM, sound speed from SNAM, sound speed from SNAM, sound speed speed speed of the lander Columbia. Sound SA.5. Transpeeding, pressure and disfective constants for lower barry (for narfare). 3.8.4. Transpeeding the sound speed spe	"Semitricy (1) second speed shall be interpreted by the second speed shall be also be the second set of the second speed of the second between the second second speed speed speed to the second second speed by determined with a speed		SRAPARER Orbits Enda, III.Spectrometer, IR enorma COLUMNIUS Lander: upper long, isser boay 1- faling compartment).

n Team

Scientific	Scientific	Scientific	Measurement	Mission	Instrument
Goals	Question	Measurements	Requirements	Requirements	
3. Unforstand the climate variability of Titan	3.8. What are the local physical and dynamical properties of <i>Kralma</i> as a provy for <i>Mars</i> as a provy for <i>Theory in Mars</i> and nearly the state and nearly the state of th	3.6.1. See depth and sound proof from SOAML, sound proof from SOAML, or sound proof from SOAML, or sound proof from SOAML, and Electric constants for the hander Cohambon. 32. 3.2. Throppetation, pressure and distortic constants for locar loop (for nurface). 3.3.4. Throppetation (from locar loop (for nurface). 3.3.4. Where activity, multise comparison in the lower loop, 3.3.4. Where activity, multise (including recognition of floating islands) and debts from local and debts from local from lander attitude. 3.6.3. Threbieff from local local we suitching, located local constants.	"iteratives: (1) around speed shall be recorded with a $(3 + c)$ methods in the range behaviour of the state of the state of the state behaviour of the state of the state of the state of the state of the state of the state of the state semial requirement for instrument work at $< 3 \approx 0.01/9 \times 0.01$, (1) The sex and frequency of the state of the state of the state behaviour of the state into consideration and what it is the light extinction under the waterline."		SEAPAURC Orbitor Rudar, IR Spectrometer, IR caures COLUMBUS Lander: upper boxy, lower boxy + falling compartment).



Green Team – Mission SEAFARER

in Kraken Mare

mission to study Habitab	ility in the Saturnian System			Green Team
Scientific	Scientific	Measurement	Mission	Instrument
Question	Measurements	Requirements	Requirements	
1.1. What is Saturn's formation history, composition and implications for the present-day Solar System architecture?	1.1.1. In-situ isotopic ratios of noble gas and elements (II, He, Ne, Ar, Kr, Xe, C, N, O, and S) in Satarn's atmosphere. 1.1.2. In-situ mixing ratios of the species CO, C ₂ H ₆ , PH ₃ , NH ₃ in Satarn's atmosphere.	Abundances at a resolution of from 1 to $>$ 150 anu, mass resolution $>$ 1000 M/ ΔM . The Tunable laser spectrometer shall have a resolving power of ${\sim}10^5~\lambda/\Delta\lambda$ at least.	Data retrieval from 1 nbar to 10 bar.	VESPUCCI Atmospheric Probe Quadrupole Mass spectrometer, Tunable Laser Spectrometer
1.2. What is the geomorphology and composition of Encelaturi surface, especially in the moon's south polar region?	1.2.7. Vanal and thermal mapping in the IR. 1.2.2. Topography mapping.	Promess and temperature sampling every 2. A fibrale solution (2.5 to 0.6 kb and 2.5 to 0.0 kb and 2.5 to 0.0 kb and 2.5 to 0.0 kb and 2.5 there maps to 0.5 to 0.0 kb and 2.5 there follower angle to 0.5 to 0.0 kb and 2.5 there follower and 0.5 to 0.5 there are solved to 0.5 the output to 0.5 the out	Data retrieval from 1 ubar to 10 bar.	VESPUCCI Atmospheric Probe Atmospheric package with pressure and temperature sensors, Acceleronster, neuroscienter, lightaing detector detector
	Question 1.1. What is Saturn's formation history, composition and mplications for the operant-day Solar System architecture? 1.2. What is the geomorphology and composition of Enceladus' surface, especially in he moon's south	Question Measurements 1.1.1.7. Rein Sinderper ratike of solds pas and clearast (R) (R) (R) (R) (R) (R) (R) (R) (R) present day Starb System) 1.2.2. West Sinder System (R) (R) (R) (R) (R) (R) (R) (R) (R) (R)	Question Measurement. Respirements/ termation biotection, second second seco	Question Masses weakers Requirements Requirements L1.1.Wash is kindler, increasities history, research of your system 1.1.1.F. As its kindler, increasities history, research of your system 1.1.1.F. As its kindler, increasities history, history, increasing and history, history, increasing and history, history, increasing, increas

2.2.1. Visual and infrared Image and analyse spectrally the ice How many flybys would (thermal) mapping of the South surface, with a resolution of 100m/pixel. you need?

AFARER: A	mission to study Habit	ability in the Saturnian Syste	m		Green Tea
cientific Ionis	Scientific Question	Scientific Measurements	Measurement Requirements	Mission Requirements	Instrument
Understand or nature of diversity potential abitats in or Saturnian often.	2.6. What is the nature and habitability potential of the medium- sized moons Dione, Tethys, Rhea?	2.6.1. Image and spectral analysis of the icy surface 2.6.2. thermophysical properties 2.6.3. Induced magnetic field.	Imager shall measure at a resolution of < 10m/pixel. The spectrometer shall measure at a < 500m/pixel resolution, with a wavelength coverage of 0.5 – 5.5 μ m, and 3–6 nm spectral resolution.	Flyby requirements for each moon	SEAFARER Orbite Imaging System. Visual and Infrared Spectrometer. Magnetometer.
	2.7. What is the current state of interfor- soriar processes on line (expressions), more linguit water meth people, ther global distribution, guological biology and produced biology and material transport access the ky erant?	2.7.1. Surface supplies of crysochastic relificant (blaces, oblaces, jobd) and compared and the programmer (may), and their presenters (may), and their presenter (may), and their presenter (may), and their presenter (may), and their presenter (may), and their present (may), and fails (comparements), how and mappinging (comparements), how and fails (comparements	Image: thermal ministic spatial molecules of 20 m highest bootstand models at 6 \times 10 m highest bootstand models at 6 \times 10 m highest bootstand models in the 10 m highest bootstand models at 10 m highest highest bootstand models at 10 m highest bootstand highest bootstand models at 10 m highest bootstand highest bootstand models at 10 m highest bootstand highest bootstand highes	The orbiter routs he at 2000 in sof although in a high inclusion orbit is to over the inclusion orbit is to over the one is excernitioned in the entertheli plane of the minimum.	SEAFARER Order Imaging Systems. Visual and Inflared Spectrometer. Rolar Off and/r microwave radionetry. "

SI

lyst	em		Green Team	SEAFARER	A mission to study Habi	tability in the Saturnian Syste	m		Green Tear
	Measurement Requirements	Mission Requirements	Instrument	Scientific	Scientific	Scientific	Measurement	Mission	Instrument
	The wavelength coverage shall be 1–5µm, with a higher resolution than VIMS, and a minimum resolution of 0.01 µm.	Perform > 5 flybys of the Saturnian moons (Mimas, Rhea, Dione, Tethys) at an	SEAFARER Orbiter Visible-Infrared Hyperspectral Imaging	Goals	Question	Measurements	Requirements	Requirements	Instrument
9)).	a mananam resolution of 0.01 µm.	Idea, Doord, 19409) at an additude of c75 km. This needs to be updated!	Typerspectral maging Spectrometer	 Understar the nature and diversity of potential habitats in the Saturnian system 	d 2.8. What is the relative surface abundance of complex molecules on Titan and Enceladus?	2.8.1. Image and spectral analysis of the icy surface	Visual and Infrared Spectrometer (0.5.5.5 micrometers, 3-6 nm spectral resolution) lunger shall measure at a resolution of < 10m/pixel. The spectrometer shall measure at a $< 300m/pixel resolution, whilea wavelength coverage of 0.5 -5.5 µm,and 3.6 nm spectral resolution.$	Flyby requirements for each moon	SEAFARER Orbiter Imaging System. Visual and Infrared Spectrometer. Magnetometer.
ath	Image and analyse spectrally the ice surface, with a resolution of 100m/pixel. This needs to be expanded!	How many flybys would you need?	SEAFARER Orbiter Visible-Infrared Hyperspectral Imaging Spectrometer. Imaging System. Radar Altimetry.		2.9. Are there biogenic elements present in the organic chemistry in Titan, and, if so, what are their abundances	2.9.1. Elemental chemistry (e.g., Phosphorus, Sulphur) of organic molecules in Titan's atmosphere, acrosols and in Kraken Mare	Mass range: Mass abundance vs. molecular weight from 2–500 anns of liquid from Krakes. Mare. Resolution: Mass resolution shall be 1×10^{-6} at 250 ann; Sensitivity: minimum 002 counts molecule-1 cm ³	Operation requisites: at 75 K at least under a surface pressure of 1.5 bar.	COLUMBUS Drifter Gas Chromatography- Mass Spectrometer.
	Image and spectral analysis at least 10 m/joixel for the imager and spectrometer 500 m/joixel. We need magnetic measurement requirements.	Flybys	SEAFARER Orbiter Visibio-Infrared Hyperspectral Imaging Sportrometer. Magnetometer. Sub- millimetre wave instrument. Imaging System.		are tater automates and can be reduced and oxidised organic species be detected?	and in Artuch and a species and ordised organic species present in Kraken Mare. 2.9.3. Isotopic ratio determination ¹² C/ ¹³ C (e.g., on chemically abundant species)	minimum cone coulds more that c^{-1} and 10×10^{-30} mixing ratio.		
	Molecular weight distribution of organic matter from 16 Da (CH ₄) to \geq 1000 Da in plume vapour and icy particles. We need specifications here!	>9 Enceladus flybys at an altitude < 75 km to get to the plumes densest part. S/C velocity shall be 3- 5 km/s and 5-9 km/s.	SEAFARER Orbiter High Resolution Mass Spectrometer.			on Titan: C2H2, C2H4, C2H6, C3H8,) and D/H parameters from samples collected in the atmosphere and in Kruken Mare. 2.9.4. Abundances of noble			
	The spectrometer shall have a wavelength coverage of $0.5-5.5~\mu m$, and $3-6~nm$ spectral resolution.	Shall perform > 9 Mimas flybys at an altitude $< \mathrm{TBD}$	SEAFARER Orbiter Imaging System. Visual and Infrared Spectrometer, Sub-mm weave instrument.?			2.9.4. Abundances of noble gaves produced by radiogenically processes (e.g. ⁴⁰ Ar, ²¹ Ne) in Kraken Mare.			

SEAFARER: A mission to study Habitability in the Saturnian System

Scientific:	Scientific	Scientific	Measurement	Mission	Instrument
Gosla	Question	Measurements	Requirements	Requirements	
3. Understand the climate variability of Titan	5.1. How do the large- male atmospheric features on Titas (experimation, polar vortes) and usue activity form and evolu- and compart to those of Venus (else-rotator comparison)?	3.1.1. Doppler shift of spectral lines to discriby nearant small, meridianal and vertical winds at higher latitudes.	Emolution specifications	A high inclination orbit is measurements in the upper atmembers, Reported measurements across different seasons must be toolt across Titae's orbit phase.	SEAFARER Orbitor Sub-millimeter spectrumeter; Ultraviolet Imaging Spectrograph; visible and sear- IR imager.
	3.2. How different are the thermal structure and mixing values of minur traceable species of the polar atmosphere of Than compared to the low latitudes?	3.2.1. Thermal structure in the mid-atmosphere from CO and BCN lines. 3.2.3. Mixing ratio profiles of many redeniles and their isotops in the same altitude many Complete GMZ.	Resolution operfications	Mourners specifications	SEAFARER Orisier Sub-millimeter spectrometer). Ultraviolet Imaging Spectrograph; visible and near- IR imager.
	8.3. How do have and cleads form on Than, four the lower atmosphere to the stratosphere?	3.3.1. Profile across estimation coefficient to reveal the structure and ecceptotion of structuphetic in clouds. 3.3.2. UV singless and reflected UV, 3.3.3. Cloud activity in the visible and more-Br. 3.3.4. Cloud methans (ClL) absendence and ClL, droplet size and cristal size from row-Br. protramstry, 3.3.5. Methane absendance profile during lander document.	The larker cancers should have a wavelength of the second state state of the second state s	We and mining mysics for this	SEASPAREN Gristor UV spectrumster; visida sal asar-Ba image; sab stillimeter www instruction, same IR spectrumster. COLUMEUS Lander Lander sames. Nephekanster
SEAFAREE	: A mission to study Ha	bitability in the Saturnian Sy	stem		Green Ter

Scientific	Scientific	Scientific	Measurement	Mission	Instrument
Goals	Question	Measurements	Requirements	Requirements	
3. Understand the climate variability of Titan	3.8. What are the local physical and physical properties of <i>Krules</i> <i>Marrs</i> as a provy fac <i>Marrs</i> as a provy fac <i>Thurs's</i> halos and local?	3.6.1. Soa depth and somel speef from SUMARI, somel speef from SUMARI, source and speed from SUMARI, source and speed from SUMARI, and Sumari and Sumarian speed and distortic constants for share to any (for nucleos). 3.3. Theoperations of speed speed profiles for the dropping comparison in the hower basy. A cortext, fouring films (including recognitions of floating initiality) and defect from statistic states at the speed floating initiality of the speed floating of the speed speed speed speed speed floating index attitude. 3.6.3. Turbeliship true LiDs in the upper basy of the index Chimakan.	"Summitty, (i)) most good hall be conclusive in the fraction in the fraction of the second states of the second states of the second states of the second states are strength of the intermediate states are strength of the second states of the second states of the second states of the second states of the second states of the second states of the second states in the second states of the second state of the intermediate states of the second states		SRAPARRE Oblight Radar, IR Spectrometer IR easers COLUMIUS Lander: upper bosy, lower bosy + falling compartment).

Scientific	Scientific	Scientific	Measurement	Mission	Instrument
Goals	Question	Measurements	Requirements	Requirements	
3. Understand the elimate variability of Titan	 What are the local properties of Kraham properties of Kraham and Kraham And	3.0.1. Son depth and sound proof from SOMME sound proof from SOMME of the lasder Cohambon. 3.0.2.7. Trepresentative, pressure and disketic constants for the lasts, to be predicted from lower large (for surface), and the lasts, to be predicted from lower large (for surface), and disketic constant profiles for the dropping comparison in the lower lower corrects, finaling filess (forchange recognition of form new attribute, based for the strength of lander corrects, finaling, filess (forchange recognition, based for the strength of lander corrects, finaling, filess (for surface), and (for surface), form lander attribute, based in the upper lawy of the lander Chanaton.	"Sensitivity: (1) away speed and be determined by the sense of the sense of the sense of the 100 to 120 to		SRAFAIRER Other Rudu, III. Spectrometer, III: canera COLUMBER <i>Lander:</i> upper bacy, lower boyr + falling compartment).



SEAFARER: A mission to study Habitability in the Saturnian System

surface, namely in the 2.2.2. Topography and

2.4. What is the 2.4.1. Sample the salts,

Enceladus and subsurface 2.4.2. Add more

2.5. What is the nature of 2.5.1. Surface image the potential subsurface of tectonism features ocean on Mimas? 2.5.2. Spectral

moon's south polar region altimetry mapping.

2. Understand 2.1. What is the origin 2.1.1. Remote sensing of

and evolution of Satarn's medium-sized moons

(Mimus, Enceladus,

2.2. What is the

geomorphology and

(Tirer Strings)?

2.3. What is

Enceladus' plumes' activity variability

magnetoephere)?

flocation, composition,

time, interaction with

current state of water-rock interactions on

ocean longevity and composition?

Measurements

infrared absorption of H_2O between 1 – 5 µm on ky

surfaces to find the D/H ratio

2 am absorption band of H-O). 2.1.2. Remote sensing of the Enceladus plumes

2.2.1. Visual and infrared

2.3.1. Thermal mapping

(location and intensity) in the South Polar Region. 2.3.2. Magnetic field

of Engeladus during the

organics and volatiles from the plumes of Enceladus.

image for detection of

endogenous signatures 2.5.3. Thermophysical

flyby of the moon.

composition of Enceladus' Polar Region of Enceladus. This needs to be expanded!

of Enceladus, Mimas, Rhca, Dione and Tethys from the

surface (observation feature at 4.13 μ m is representative for deuterium in the ice and

Goals

the nature and diversity

of potential

the Saturnian

matem

Operation

habitats in Rhea, Dione, Tethys)?

Green Team – Mission SEAFARER

EAFARER: A mission to study Habitability in the Saturnian System Green Team								
Scientific Goals	Scientific Ouestion	Scientific Measurementa	Measurement	Mission Requirements	Instrument			
1. Understand Saturn's formation and orbital evolution	1.1. What is Saturn's formation history, composition and implications for the present-day Solar System architecture?	Attacurentinas I.1.1. I. nitáti siotopic ratios of noble gas and elements (II, IIe, Ne, Ar, Kr, Xe, C, N, O, and S) in Saturn's atmosphere. I.1.2. In-situ mixing ratios of the species CO, C ₂ H ₆ , PH ₃ , NH ₃ in Saturn's atmosphere.	requirementa Abundances at a resolution of from 1 to > 150 anu, mass resolution > 1000 M/AM. The Tunable laser spectrometer shall have a resolving power of ~10 ⁶ $\lambda/\Delta\lambda$ at least.	Data retrieval from 1 nbar to 10 bar.	VESPUCCI Atmospheric Probe Quadrupole Mass spectrometer, Tunable Laser Spectrometer			
	1.2. What is the gromorphology and composition of Enceldad's markace, especially in the moon's south polar region?	1.2.1. Varal and thermal mapping in the IR. L.2.2. Topography mapping.	Promote and temperature anapping every 2. A fitted workshow 50.10 0.0 H and 50.10 and 50.10 m s 10.10 m s	Data retrieval from 1 ubar to 10 bar.	VESPUCCI Atmospheric Pode Atmospheric package with persaure and lemperature sensors, Accelerometer, neif Bac Rakameter, Roghekonster, lightning and radio centasians detector			

AFARES: 7	mission to study flant	ability in the Saturnian Syste	m		Green Tea
icientific Joals	Scientific	Scientific	Measurement	Mission	Instrument
 Understand he nature and diversity of potential subitats in he Saturnian neutron. 	Question 2.6. What is the nature and habitability potential of the medium- sized moons Dione, Tethys, Rhea?	Measurements 2.6.1. Image and spectral analysis of the icy surface 2.6.2. thermophysical properties 2.6.3. Induced magnetic field.	Requirements Imager shall measure at a resolution of < : (lnu/pice). The spectrometer shall measure at a < 500m/pixel resolution, with a wavelength coverage of 0.5 – 5.5 $\mu m_{\rm c}$ and 3–6 nm spectral resolution.	Requirements Flyby requirements for each moon	SEAFARER Orbiter Imaging System. Visual and Infrared Spectrometer. Magnetometer.
g ======	2.7. What is the current state of interior- surface processes on Tital (expressions), mean liquid vater meth pools), their global distribution, geological history and history and history and material transport access the ky crust?	2.7.1. Instruce mapping of ergonomian (editors, ridd) and (ditors, ridd) and (ditors, ridd) and (ditors, ridd) and (ditors) and (dit	Image thermal emission paulo invalidates of the high-the bottom barries of the theory of the high-theory tensor of the high-theory of the high-theory of the high-theory of the high-theory of the high-theory of the high-theory duction moving to Lemma et al. 2000, the duction moving to Lemma et al. 2000, the duction moving the Lemma et al. 2000, the lemma et al. 2000, the lemma et al. 2000, the lemma et al. 2000, the duction moving the lemma et al. 2000, the lemma et al. 2000, the lemma et al. 2000, the lemma et al. 2000, the duction moving the lemma et al. 2000, the lemma et al. 2000, the duction moving the lemma et al. 2000, the lemma et al. 2000, the duction moving the lemma et al. 2000, the lemma et al. 2000, the duction moving the lemma et al. 2000, the lemma et al. 2000, the duction moving the lemma et al. 2000, the lemma et al. 2000, the duction moving the lemma et al. 2000, the lemma et al. 2000, the duction moving the lemma et al. 2000, the lemma et al. 2000, the duction moving the lemma et al. 2000, the lemma et al. 20	The orbits must be at 2000 km of allowing in a high inclusion orbit is cover the inclusion orbit is cover the one coverse of the second of the extended phase of the minimum.	SEAFABER Orkies Imaging Systems. Visual and Infrared Spectrometer. Radar: Off-andir microwave radiometry. *

Scientific	Scientific	Scientific	Measurement	Mission	Instrument
Goals	Question	Measurements	Requirements	Requirements	
 Understand the nature and diversity of potential habitats in the Saturnisa system. 	2.1. What is the origin and evolution of Saturn's medium-sized moous (Minnas, Ezceladus, Rhea, Dione, Tethys)?	2.1.1. Remote sensing of infrard absorption of H ₃ O between $1 - 5 \mu n$ cm kgr surfaces to find the D/H ratio of Enzekahus, Minasa, Rhea, Dione and Tethys from the surface (absorption feature at 4.13 µm is representative for deuterium in the ice and 2 µm absorptions hand of H ₂ O). 2.1.2. Remote sensing of the Enzekabus plurame	The wavelength coverage shall be 1–5µm, with a higher roution than WHSE, and a minimum resolution of 0.01 μm .	Perform > 5 flybys of the Saturnian moons (Mimas, Rhea, Dione, Tethys) at an abitude of < 75 km. This needs to be updated!	SEAFARER Orbiter Visible-Infrared Hyperspectral Imaging Spectrometer
	2.2. What is the gromorphology and composition of Enceladus' surface, namely in the moon's south polar region (Tiger Stripes)?	2.2.1. Visual and infrared (thermal) mapping of the South Polar Region of Enceladus. 2.2.2. Topography and altimetry mapping.	Image and analyse spectrally the ice surface, with a resolution of 100m/pixel. This needs to be expanded!	How many flybys would you need?	SEAFARER Orbiter Visible-Infrared Hyperspectral Imaging Spectrometer. Imaging System. Radar Altimetry.
	2.3. What is Enceladus' plumes' activity variability (location, composition, time, interaction with magnetoephere)?	2.3.1. Thermal mapping (location and intensity) in the South Polar Region. 2.3.2. Magnetic field of Enceladus during the flyby of the moon.	Image and spectral analysis at least 10 m/pixel for the imager and spectrometer 500 m/pixel. We need magnetic measurement requirements.	Plybys	SEAFARER Orbiter Visibio-Infrared Hyperspectral Imaging Spectrometer. Magnetometer. Sub- millimetre wave instrument. Imaging System.
	2.4. What is the current state of water- rock interactions on Enceladus and subsurface ocean longevity and composition?	2.4.1. Sample the salts, organics and volatiles from the plumes of Enceladus. 2.4.2. Add more.	Molecular weight distribution of organic matter from 16 Da (CH4) to \geq 1000 Da in plume vapour and icy particles. We need specifications here!	>9 Enceladus flybys at an altitude < 75 km to get to the plumes densest part. S/C velocity shall be 3– 5 km/s and 5–9 km/s.	SEAFARER Orbiter High Resolution Mass Spectrometer.
	2.5. What is the nature of the potential subsurface ocean on Mimas?	2.5.1. Surface image of tectonism features 2.5.2. Spectral image for detection of endogenous signatures 2.5.3. Thermophysical properties (grain-size)	The spectrometer shall have a wavelength coverage of 0.5 – 5.5 µm, and 3– 6 nm spectral resolution.	Shall perform > 9 Mimas flybys at an altitude $< \mathrm{TBD}$	SEAFARER Orbiter Imaging System. Visual and Infrared Spectrometer, Sub-mm wave instrument.?

Green Team

SEAFARER: A mission to study Habitability in the Saturnian System

2. Understand 2.8. What is the relative 2.8.1. Image and spectral

Scientific

surface abundance of analysis of the icy surface

2.9. Are there biogenic 2.9.1. Elemental chemistry

elements present in the (e.g., Phosphorus, Sulphur)

Titan, and, if so, what Titan's atmosphere, acrosols

and in Kruken Mare

and oxidised orratic species

on Titan: C2H2, C2H4, C2H6,

C3H8, ...) and D/H parameter

present in Kraken Mare. 2.9.3. Isotonic ratio determination 12C/13C (e.g., on chemically abundant species

organic chemistry in of organic molecules in

Measurements

Scientific Scientific

the nature

of potential

habitats in

system

the Saturnian

Question

and diversity complex molecules on

Titan and Enceladus?

are their abundances

and can be reduced

and oridised organic

species be detected?

Goals



Measurement

Requirements

2.9.2. Inventory of reduced s⁻¹ and 10x 10⁻³⁰ mixing ratio.

Mission

Mass range: Mass abundance vs. molecular Operation requisites: at COLUMBUS Drifter

weight from 2-500 anu of liquid from 75 K at least under a surface Gas Chromatography-Kraken Mare. Resolution: Mass resolution pressure of 1.5 bar. Mass Spectrometer.

Visual and Infrared Spectrometer (0.5-5.5 Flyby requirements

micrometers, 3-6 nm spectral resolution) for each moon

Imager shall measure at a resolution of

measure at a < 500m/pixel resolution, with

< 10m/pixel. The spectrometer shall

a wavelength coverage of 0.5 - 5.5 am.

shall be 1×10-6 at 250 amu; Sensitivity:

minimum 0.002 counts molecule-1 cm³

and 3.6 nm spectral resolution.

Requirements

SEAFARER: /	AFARER: A mission to study Habitability in the Saturnian System							
Scientific	Scientific	Scientific	Measurement.	Mission				
Goals	Question	Measurements	Requirements	Requirement				
3. Understand the climate variability of Titan	5.1. How do the large- scale atmospheric features on Than (experimation, policy writes) and wave	3.1.1. Doppler shift of spectral lines to directly measure smal, meridional and vertical winds at higher latitudes.	Resolution specifications	A high inclu- is memory wind menory upper almost				

-Guate bility Ran	ande atmospheric fastures on Titas (experimation, polar wates) and wase activity form and evolve and compare to those of Vesas (slow-rotator comparison)?	lines to directly measure mush, meridional and vertical winds at higher hattoales.		is messaway to accouplibly wind measurements in the upper atmosphere. Repeated measurements across different seawers must be reade across Titan's orbit phase.	Sub-millionter spectrumeter; Ultraviolet Imaging Spectrograph; visible and assa- R. imager.
	3.2. How different are the thermal structure and mixing ratice of minur traenable species of the polar atmosphero of Titan compared to the low latitudes?	3.2.1. Thermal structure in the mid-atmosphere from CO and HCN lines. 3.2.2. Mining ratio profiles of many molecules and their isotopes in the same altitude many Complex OM2.	Honolation specifications	Mountered specifications	SEAFARER Orisier Sub millimeter spectrometer, Ultraviolet Imaging Spectrograph; visible and near- IR imager.
	3.3. How do haves and clearly invo on Than, from the lower adrouphere to the stratosphere?	3.3.1. Profile served estimation coefficient to remain the structures and composition of etaxophyteric in clouds. 5.3.3. UV alrgium and reflected to two-file. 3.3.4. Cloud activity in the visible and nors-file. 3.3.4. Cloud activity in the visible and nors-file. 3.3.4. Cloud methane (Clin) abundances and Clin, droptet size and critical size profile during lander doccest. 3.3.5. Advances distinction coefficients during lander downet.	The hadre canons should have a wavelength sourcept in two should will all all 400 sources of the source of the source of the source of the of 0.06 0.20° Table to Fallen about this.	We seed taking measurements for this	SRAFARER Orbain UV spectrometer; visible and near-Bi imager, mh millimeter wave indirected, mar- lik spectrameter, COLUMBUS Lander Lander canters, Neglackmeter

SEAFARER: A mission to study Habitability in the Saturnian System

Scientific	Scientific	Scientific	Measurement	Massion	Instrument
Goals	Question	Measurements	Requirements	Requirements	
 Understaad the clinical variability of Titan 	3.8. What are the local physical and dynamical physical set dynamical physics are a proxy for Titan's lakes and seus?	B.A.T. Sies depth and the second as the spectrosy of the inder Columbus. Also: Texpercedues provide the spectra of the inder Columbus. B.A.T. Texpercedues provide the spectra permittivity assessment of the lark, where spectra is the spectra of the spectra of the spectra of disketic consistency is and disketic consistency is comparison of the spectra of the spectra of the spectra of the spectra of the spectra (including recognition of the spectra of the spectra constraints of the spectra of the	"Similarity: (1) around speed table by "Similarity: (1) around speed table by (1) (2) (2) (2) (2) (2) (2) (2) (2) (2) (2		SEAPARRE Obtion Radar, R. Byertennete III: easers COLUMIUS Jander: upper basy, issue basy, falling compartment).

SEAFARER: A mission to study Habitability in the Saturnian System

Green Team

SEAFARER Orbiter

Imaging System.

Spectrometer,

Marnetometer

Visual and Infrared

Scientific	Scientific	Scientific	Measurement	Mission	Instrument
Goals	Question	Measurements	Requirements	Requirements	
 Understand her elimate arability of Titan 	3.8. What are the local physical and dynamical properties of Kindan properties of Kindan Mare as a proxy for Thurs's lakes and reas?	3.4.1. Son depth and sound speed from SNMAR, located in the report basy basis of the second second second second second second second second second second and district constants for JASA. Trupperstance, pressure and district constants for locate location of the second second locate location of the second s	"Similarly, (1) such good half be conclude in a 16 showing the first parameters in the first parameters in the second star of the second star of the lensement with an accuracy of 1 s and the second star of the second star of the second star of the second star of the second star of the second star of the second star of the second star of the second star of the second star of the second star be determined with a second star of the second star the determined with a second star of the second star star of the second star of the second star of the second star of the second star of the second star of the second star of the second star of the second star of the second star of the second star of the second star star of the second star of the second star of the second star of the second star of the second star star of the second star of the second star of the second star of the second star of the second star of the second star of the second star of the second star of the second star of the second star of the second star of the second star of the second star of the second star star of the second star of the second star of the second star of the second star of the second star of the second star of the second star of the second star of the second star of the second star of the second star of the second star star of the second star of the second star of the second star of the second star of the second star of		SRAPAURR Other Rudar, IR Spectrometer, IR canora COLUMIUS Jander: upper long, lower boy + falling computment).



SEAFARER: A mission to study Habitability in the Saturnian System

Green Team – Mission SEAFARER

Green Team SEAFARER Orbiter

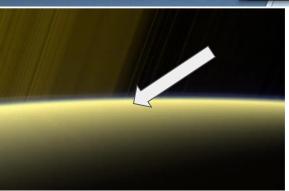
Green Team

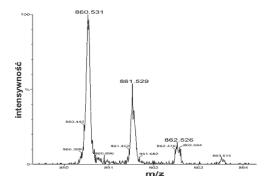
Science Questions

Science objectives	Science questions
SO1: How and where did Saturn form?	• Q1.1: What is Saturn's formation history, composition and implications for the present-day Solar System architecture?
	 Q1.2: What are the physical, dynamical and radiative conditions of the upper atmosphere of Saturn in the pressure range between <1 bar and 10 bar?



Q1.1: What is Saturn's formation history, composition and implications for the present-day Solar System architecture?





- Measure in situ isotopic ratios of noble gases and elements (H, He, Ne, Ar, Kr, Xe, C, N, O, and S)
- Quadrupole mass spectrometer
 - Mass range [1,150] amu
 - \circ Resolution >1000 M/ Δ M
- Measure in situ mixing ratios of CO, C₂H₆, PH_{3.}, NH₃
- Tunable Laser Spectrometer
 - $\circ \quad \text{Resolution } 10^5 \, \lambda / \Delta \lambda$
- Measurements <1-10 bar
- \rightarrow Atmospheric probe VESPUCCI





Science Questions

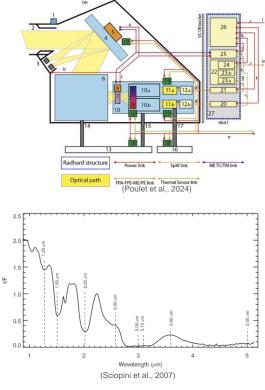
Science objectives	Science questions
SO2: What is the nature and diversity of potential habitats in the Saturnian system ?	 Q2.2: What is the geomorphology and composition of Enceladus' surface, namely in the moon's south polar region (Tiger Stripes)? Q2.3: What is Enceladus' plume activity variability (location, composition, time, interaction with magnetosphere)? Q2.5: What is the nature of the potential subsurface ocean on Mimas? Q2.7: What is the current state of interior-surface processes on Titan, their global distribution, geological history and implications for organic material transport across the icy crust? Q2.9: Are there biogenic elements present in the organic chemistry in Titan, and, if so, what are their abundances?

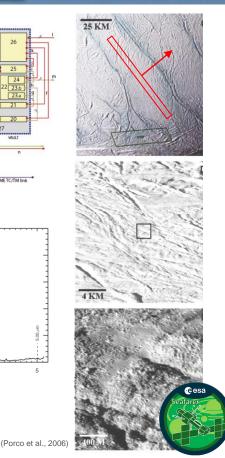


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Q2.1: What is the geomorphology and composition of Enceladus' surface namely in the moon's south polar region?

- Measure spectra of the south polar terrain to extract composition and physical properties of water ice
 - $\circ \quad \mbox{resolve smallest feature} \rightarrow \mbox{spatial} \\ \mbox{resolution of 100 m/pixel} \\$
- Visual and Infrared Spectrometer
 - range 0.5-5µm (two multi-band spectrometers: VIS & IR)
 - \circ spectral resolution ~10nm
- Minimum of 10 flybys to cover the whole south polar area at an altitude of 100km
 - \rightarrow Orbiter







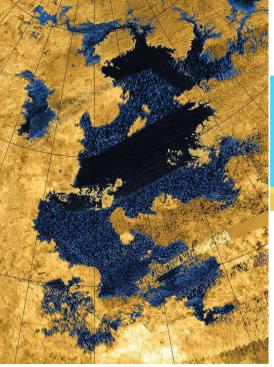
Science Questions

Science objectives	Science questions
SO3: What is the peculiar nature of the Titan climate variability?	 Q3.1: How do the large scale atmospheric features on Titan(superrotation, polar vortex) evolve? Q3.2: What is the meteorology (temperature, surface winds, pressure, methane humidity precipitation, heat flux) in the northern polar region of Titan? Q3.6: What is the complete distribution, physical and dynamic properties of lakes and river networks on Titan and their temporal variability across different latitudes? Q3.8: What are the local physical and dynamical properties of Kraken Mare as a proxy for Titan's lakes and seas?





Q3.8: What are the local physical and dynamical properties of Krake_b Mare as a proxy for Titan's lakes and seas?

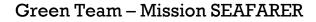




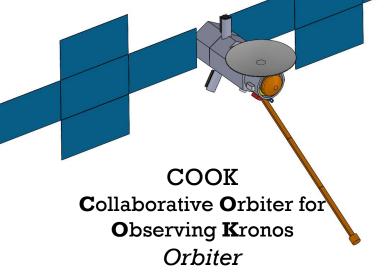
Credit: Americanoceans.org

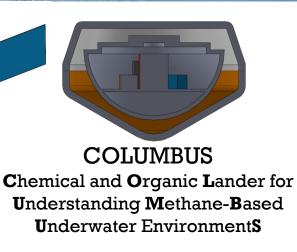
- Measure the sea depth and sound speed
- 1% sensitivity with 1000 to 2000 m/s range
- Depth accuracy of <5m at nominal distances of 10 to 500m from instrument
- Operate at <50 dB/Pa²/Hz
- SONAR
 - \rightarrow Lander COLUMBUS



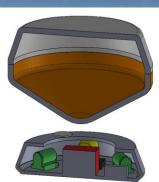


SEAFARER





Lander





VESPUCCI

Vertical Entry probe for Saturn's Upper Cloud Chemistry and habitability Investigation

Probe





COOK Orbiter Instruments

Science Objective	Science Question	UV-Spectro- meter	Infrared Spectro- meter	Mass Spectro- meter	Camera	Magneto- meter	Radar	Sub-mm Wave Instrument	Dust Analyzer	Gravity Science Experiment
Formation	Q1.1 Atmospheric Composition		Х					x		
Composition of Saturn	Q1.2 Atmospheric Dynamics and Properties	X	X		X			X		
	Q2.2 Enceladus Surface		Х		X		Х	x		
	Q2.3 Enceladus Plumes		Х	Х	X	X		x	X	
Nature and Diversity of Potential	Q2.5 Mimas Subsurface Ocean		X		X		X			
Habitats	Q2.7 Titan Interior-Surface Processes		X				X			Х
	Q2.9 Titan Organic Chemistry		X	X			Х			
Titan's Climate	Q3.1 Large-scale Atmospheric Features	X	X		X	X		X		
	Q3.5 Meteorology Polar Regions		X		X	2	3	X	:	
	Q3.6 Lake and River Networks		X				х			





VESPUCCI Probe Instruments

Science Objective	Science Question	Temperature Sensor	Pressure Sensor	Mass Spectro- meter	Nephelo- meter	Accelero- meters	Net Flux Radio- meter	Lightning and Radio Emissions Detector	Laser Spectro- meter
Formation	Q1.1 Atmospheric Composition			х		х			х
and Composition of Saturn	Q1.2 Atmospheric Dynamics and Properties	x	x		x	х	x	X	





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COLUMBUS Lander Instruments

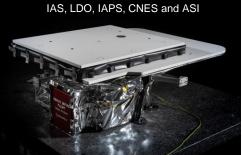
				Upper Bu	ıoy		Lower Buoy		
Science Objective	Science Question	Sonar	Nephelo meter	Camera	GC-Mass Spectro- meter	Atmopsheric Structure Instrument	Thermo- meter	Dielectric Sensor	Pressure Sensor
Nature and Diversity of Potential Habitats	Q2.9 Titan Organic Chemistry		х	х	х				
Titan's	Q3.5 Meteorology Polar Regions		Х	Х	Х	X			
Climate	Q3.8 Properties of Kraken Mare	X		X	x		Х	х	Х





Instrument Heritage

NASA/Ames Research Center



MAJIS (JUICE)

SWI (JUICE)

JANUS (JUICE)

Galileo Atmospheric Probe



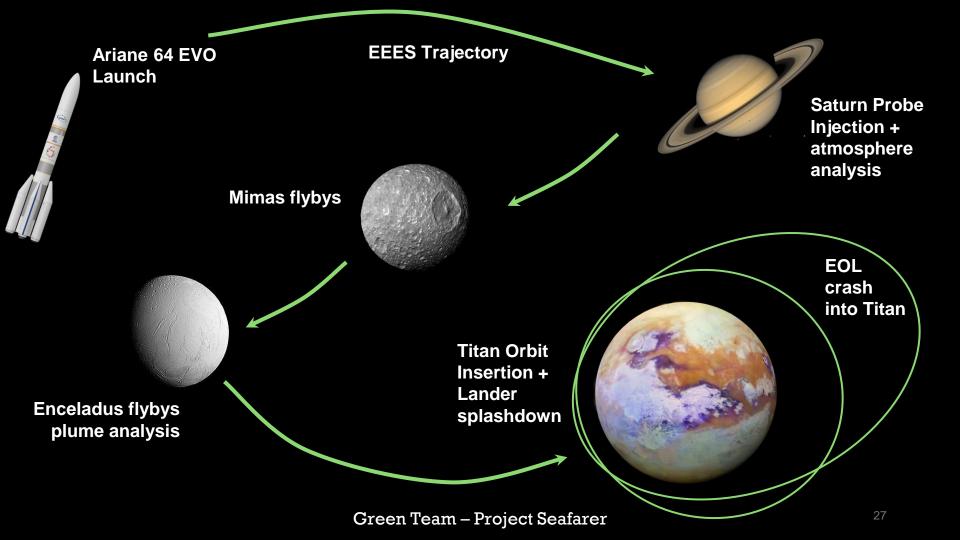


Green Team – Mission SEAFARER



dit: LDO

Mission Science case Engineering **Programmatics** Analysis Julia Wiltenburg Vincent Affatato **Colm Daly David Placke** esa Seafarer eesa 1+米





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esa

-Interplanetary Cruise

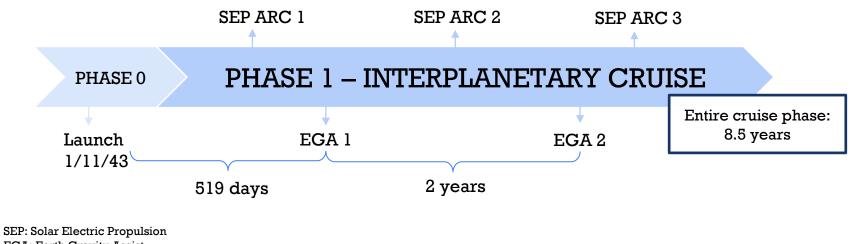


Interplanetary Cruise

- Proved by CDF studies
- Launch with an ARIANE 64 EVO

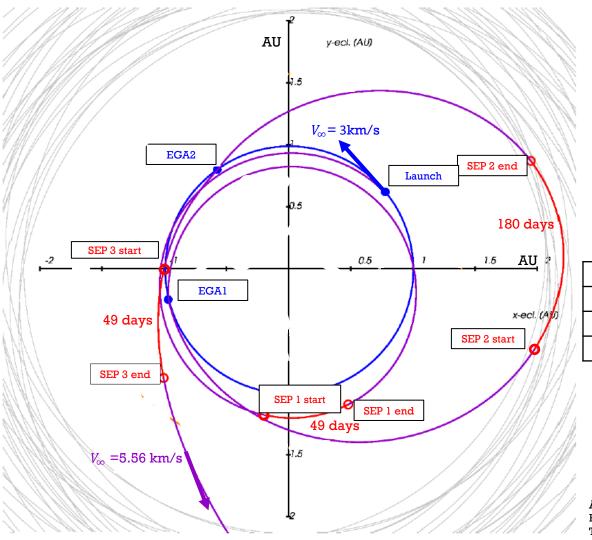
Phase

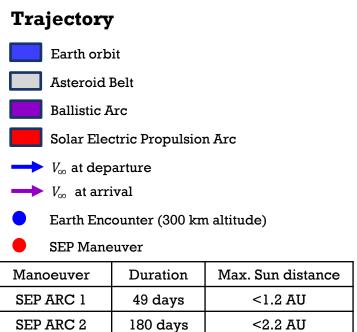
- Solar electronic propulsion (SEP)
- Launch window of \sim 21 days, with limited to no variations of V_{∞} , and launch opportunities every 12.5 months



EGA: Earth Gravity Assist CDF: Concurrent Design Facility

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49 days

SEP ARC 3

<1.2 AU

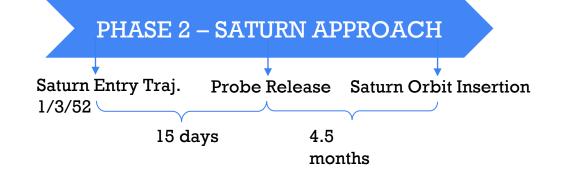


Phase 2 – Saturn Approach

Action Sequence

- Jettison of the SEP → Switch to RTGs
- Entry Trajectory to Saturn with a 55° inclination
- Probe Release 5 months before perikrone
- SOI in a safe orbit with perikrone at 2000 km altitude from 1-bar level





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Cesa

Phase 2 – Saturn Approach

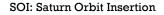


- The SOI shall also:
- reduce the velocity of the spacecraft
- 2) increase the altitude

 \rightarrow wait for the entry of the probe into the atmosphere and maximise the communication window

- The early close approach has been proved safe by Cassini but still needs particular attention for communication overload

Seafarer trajectory
 VESPUCCI trajectory
 Altitude: 2000 km



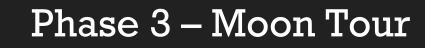
Side View

Ph

Phase 3 – Moon Tour



PHASE 1 -PHASE 2 – **Action Sequence** PHASE 0 **INTERPLANETARY** SATURN PRM at the apoapsis of CRUISE **APPROACH** the first Saturn orbit to enlarge the periapsis at Mimas Titan Flybys (8) Encel. Flybys (10) Mimas Flybys (5) Flybys to Mimas at 70 days 96 days 20 months different altitudes PHASE 3 – MOON TOUR Inject in 7:1 resonance flyby sequence of Enceladus using Titan Periapsis Raising Man. 2 Periapsis Raising Man. 1 swingbys for the second 24/10/52 30/11/54 PRM



Top View

Saturn

Enceladus Orbit

COOK Orbit

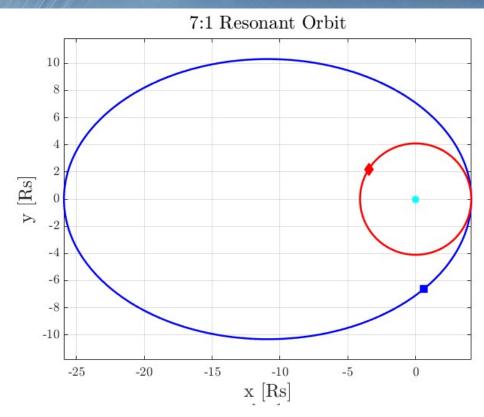
Titan Transfer



Key Aspects

eesa

- Mimas flybys require 4 months each due to the high initial V_{∞} from the cruise
- Possible visit to other medium-size moons is based on opportunity windows
- Reduction of the inclination wrt equatorial plane to <20°

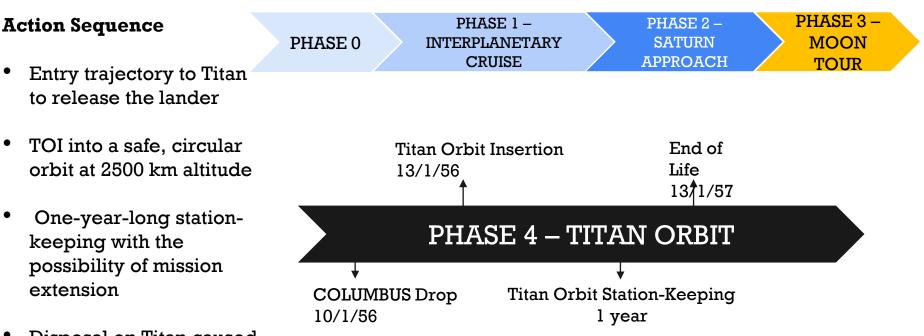


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Phase 4 – Orbiting Titan





 Disposal on Titan caused by Saturn perturbations

Cesa

Phase 4 – Orbiting Titan

-100

-150

-100

-50

0

Longitude [deg]



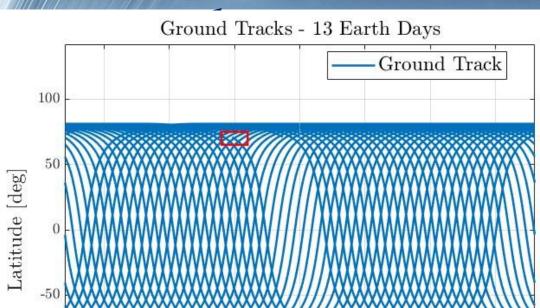
100

50

150

Lander Key Aspects

- Lander drop \sim 3 days before orbit insertion
- Landing site constraints:
- Cassini mapped three large lakes within 70° and 78° N latitude
- 2) DeltaV budget and mitigation of perturbations
- Final Choice: Kraken Mare (70° N, 50°E)
- The orbit provides coverage to the lander for operative life





ΔV budget and dimensioning



PHASE	ΔV [km/s] (5% margin)	Propellant Mass [kg]	Propellant Mass [kg] 10% margin
l – Interpl. Cruise	3,11	520	572
2 – Saturn Approach	0,72	1107	1218
3 – Moons Tour	0,45	676	744
4 – Titan Orbit	0,81	986	1084
AOCS allocation	0,1	198	218
TOTAL	TOTAL 5,1		3838

Dimensioning constraints

- ΔV for SEP cruise \rightarrow Solar panel size 110m²
- ΔV for Saturn Tour \rightarrow Total bipropellant mass
 - → Iteration on maximum initial spacecraft mass: 7.5t

Propellant System	Isp [s]		
Xenon propellant	4400		
$MMH+N_2O_4$	321		

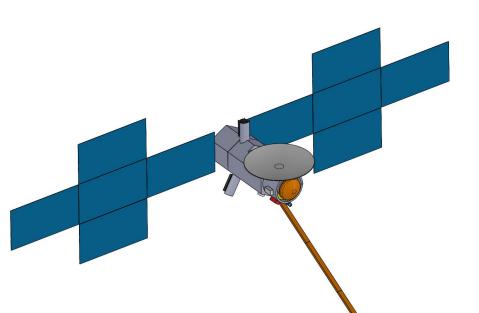


Systems

Mission Design

Key features:

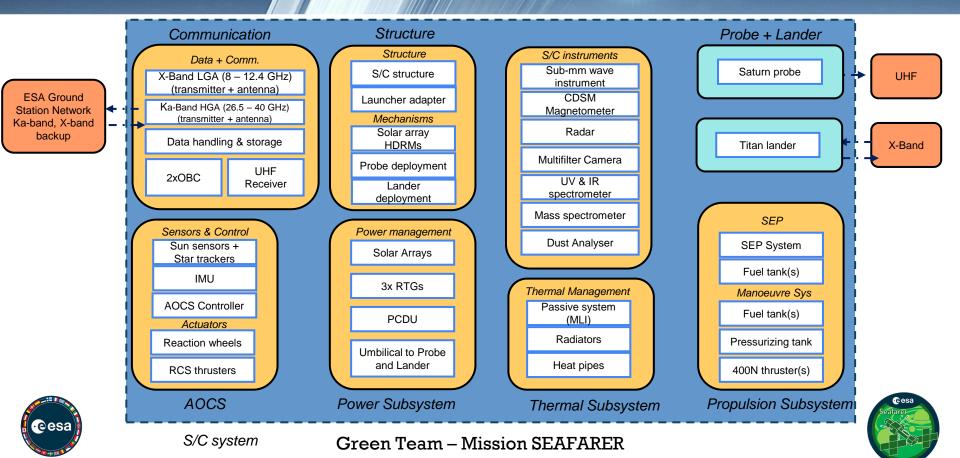
- 6,9 m height
- 10 m long magnetometer boom
- 3 GPHS-RTGs
- 110 m² SEP Solar Arrays
- 4 m stiff gimbaled High Gain Antenna (HGA)
- Gimballed low gain antenna (LGA)







Orbiter System Architecture



Orbiter Mass Budget

Subsystem total	Mass (kg)	Mass fraction to M_dry
Communication	216	7,9%
SC Instruments	297	10,8%
Titan lander	298	10,9%
Saturn probe	269	9,8%
AOCS	97	3,5%
Power	216	7,9%
Thermal	63	2,3%
Solarelectric prop.	394	14,4%
Chemical prop.	210	7,7%
Structure	679	24,8%
		Croon Toom Miga

Subsystem	Mass (kg)
Dry mass total	2739
Dry mass with 30% margin	3698
SEP propellant	573
Chemical propellant	3265
Total wet mass at launch	7538
Dry mass after array jettison	2849
Dry Mass after Probe Ejection	2519
Dry Mass after Titan Splasher Ejection	2220

All components tagged with margins depending on maturity (5%, 10%, 20%)



Orbiter Mission Modes

Phase/Mode	Mode description			
LEOP	Commissioning of the spacecraft, communication with Earth using X-band.			
Safe mode	Spacecraft kept in safe state, pointing to Earth for comms.			
Recovery/Reboot mode	Recovery from safe mode.			
SEP cruise	SEP cruising using Solar arrays and SEP fuel			
Cruise	Cruising following SEP			
Probe Internal Checkhout	Biannual check of probe and lander instruments during cruise			
Standby	Instruments powered ON at low power.			
Science mode	Instruments powered ON at full power, data recorded to onboard storage			
Manoeuvre	Trajectory changes using chemical propulsion			
Earth Comms	Communication with Earth using Ka-band (or backup X-band)			
Science Comms	Communication with probe/lander using UHF and X-band respectively			



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eesa

Orbiter Power Budget

Power Budget	LEOP	Safe mode	Reboot	SEP cruise	Chem. cruise	PIC mode	Standby	Science	Man.	Earth comm.	Science comm.	
Communication										289	268	S
SC Instruments								372				E K
AOCS								82		64	64	
Thermal												5
Solar Electric Propulsion												ľ
Chemical Propulsion												l I u
Structure												ľ

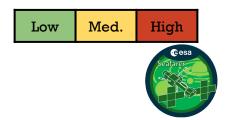
Driving modes: Science ~ 454W

Earth comms w/ Ka-band HGA ~353W

Science comms w/ probe and lander. Most power when using X-band MGA ~332W

Margins taken into account, according to ESA ECSS margin standards





Link Budget

Orbiter-Earth Budget		Orbiter-Payloads Budget		
Frequency (Ka-Band) [GHz]	32	Frequency (X-Band) [GHz]	8.5	
Maximum range [AU]	10.5	Maximum range [km]	~ 3000	
Orbiter Transmitter Power [W]	40	Lander Transmitter Power [W]	15	
Data rate [kbps]	0	Data rate [kbps]	40	
Final E _B /E _N [dB]	3.6	Final E _B /E _N [dB]	5.7	

- ESA DSN Network: 35m dishes at Cebreros, New Norcia, and Malargue
- Saturn moon tour: single 4-hour DSN pass per day
- Titan orbit: expect 5h to 8h DSN pass per day \rightarrow data downlink every 4 orbits.
- Min. datarate: 40 kbps (total between: 720 Mb/day and 1.15 Gb/day)





STR-1: Launch with Ariane 64 EVO. **COM-1**: Shall sustain Telemetry, Science downlink, and relay links.

Structure	
Structure material	Composite, Aluminium
# articulated structures	l HGA, 2 Solar Arrays
# deployed structures	2 solar arrays, 3 RTGs, 1 magnetometer boom, 1 radar antenna, Lander deployment mechanism, Probe deployment mechanism
Communications	
Antennas and gain	4m stiff gimballed HGA for Ka-band, 61dBi 16cm Horn MGA X-band , 22.6 dBi 25cm UHF Antenna
Data rates	50/40 kbps to Earth (40 W transmitter power) 40 kbps relay link (lander) 1000 bps relay link (probe)

Challenges:

Stow orbiter + SAs + SEP system + probe + lander + adapters in Ariane 64 EVO fairing.

Keeping sufficient data rate between Earth and Orbiter (to manage on-board science and relay links)

- When close to Earth (8.5AU) expect rate 50 kbps
- When at maximum distance (10.5AU) can only sustain rate of 40 kbps.

Inspiration: Mars Reconnaissance Orbiter, PEP probes, SPRITE, TSSM, EPIG

POW-1: Shall sustain the S/C during the SEP and nominal mission lifetime.

POW-2 : Shall provide power and charge the batteries of the probe and lander prior to release.

TC-1 : Maintain temperature of instruments between ~250 K and 280 K.

TC-2: Maintain temperature of batteries between 278 K and 298 K.

SEP Power	
Solar array type and size, m2	Ga-As, 110
Expected power generation, W/m2	375,75 (BOL) and 77,63 (EOL)
Expected power consumption, W	7500
Science Power	
Power Source	3 GPHS-RTGs (New Horizon, Cassini)
Battery type	LiSO2 to stabilise RTG power
Driving power mode, W	Science ~500W & Telecoms ~400W
Thermal Control	
Type of thermal control	MLI, Heat Pipes and RHUs
Heat output of RTGs, K	3 x 3850

Trade-off:

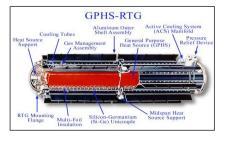
Solar Arrays vs Nuclear power vs RTGs (higher TRL & less moving parts)

Challenges:

Selection of duty cycles for Power Modes

GPHS-RTG heat dissipation with fins with a fin root temperature of approx. 200°C. Astroquartz insulation.

How to manage RTG booms and heat? Especially with temperature sensitive Instruments?



AOC-2 : Shall orient orbiter to ensure at least 13 min of Orbiter-Lander communication (after handshake).
 AOC-3 : Shall maintain ponting loss to less than 0.11 deg (same as Mars Reconnaissance Orbiter).
 OBDH-1: Shall handle, process, and store all Scientific data produced during 2 Orbits.

Attitude Control	
Control methods	3-axis (w/ Inertial, Nadir, Solar references)
Attitude knowledge limit	Sun sensors (radial accuracy $<\pm 0.5$ deg), Star trackers (pitch/yaw accuracy within ± 18 arcsec), IMUs (bias stability within ± 0.015 arcsec/sec)
Articulation #axes	2 axes for HGA
Sensor and actuator information	4 RWs with 25 Nms angular storage, 16 4,5-N RCs thrusters for desaturation of reaction wheels
Command and Data Handling	
Data storage capacity	3 Gbits (2 days worth of orbiter titan science & lander data)

Trade-off:

Current 100 m/s in delta-V budget to account for pointing requirements.

Issues:

Challenge in deriving pointing accuracy of instruments.

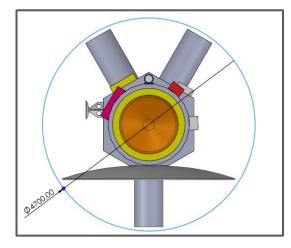
Pointing requirement for Earth & Science Comms (w/ Lander).

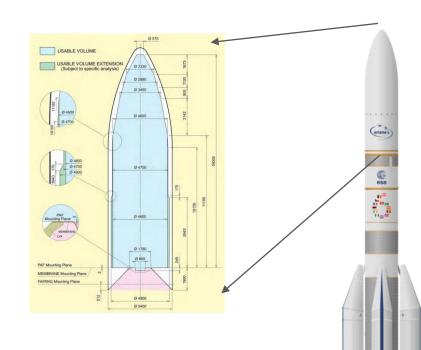
Prior to probe release, CoM expected to be unbalanced - increasing delta-V for manoeuvers and AOCS pointing.

Heritage/Inspiration: MRO, Enceladus Orbiter, TSSM

Launcher - Ariane 6.4 Evo

Fairing Diameter (Internal)	4.7 m
Fairing Height (Internal)	18 m

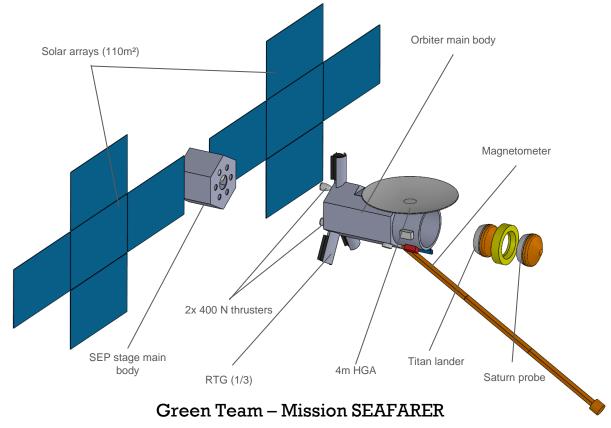








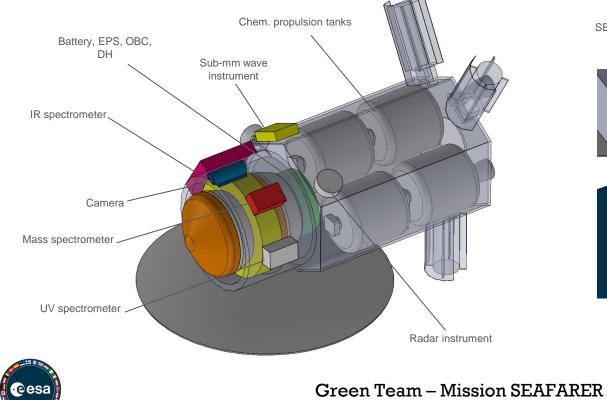
Orbiter model

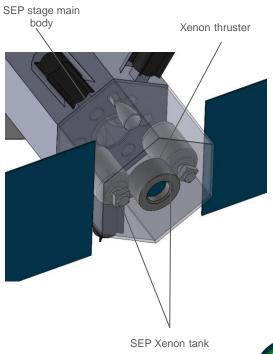






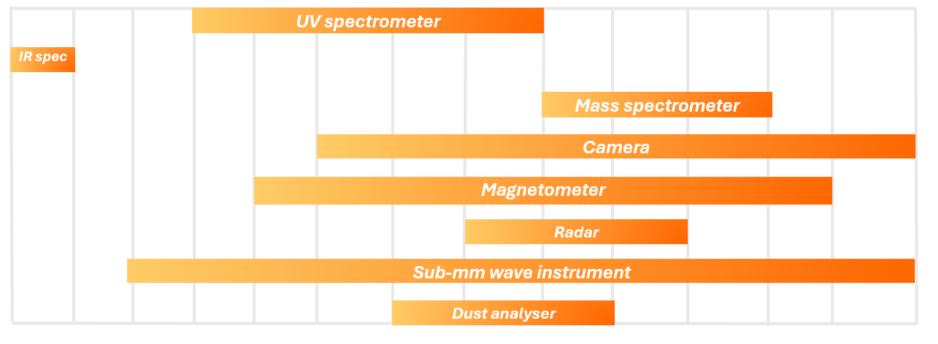
Orbiter model







Orbiter Thermal Envelope



90K 130K 232K 237K 247K 252K 257K 267K 272K 297K 302K 312K 317K 322K

Instrument Priority

Instrument	Complexity	Thermal score	Size score	Science score	Total score
Weight	2	2	5	10	190
UV-spectrometer	8	2	7	3	85
Infrared spectrometer	7	1	5	10	141
Mass spectrometer	7	7	5	7	123
Camera	8	8	5	9	147
Magnetometer	4	8	4	6	104
Radar	8	4	3	10	139
sub-mm wave instrument	7	9	7	10	167
Dust Analyser	7	4	7	3	87
Gravity science experiment	6	8	8	3	98
Average	6	5	6	7	128

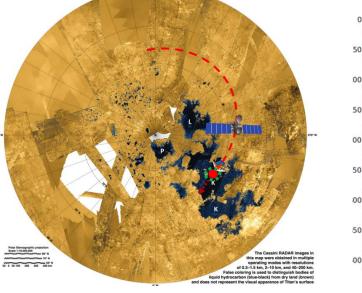




Lander

Lander Mission

Mission Concept: Land on Kraken Mare (70 deg inclination) and perform analysis of atmosphere and the liquid methane lake for ~10 days.



Landing location in Kraken Mare confidence: +/- 50 km Lander has no movement capabilities: Maximum possible drift shown above

200

К

300

400

500



65

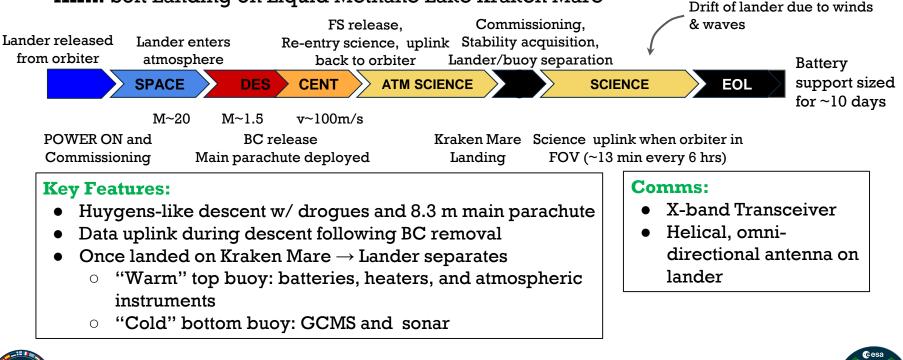
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100



Mission Timeline

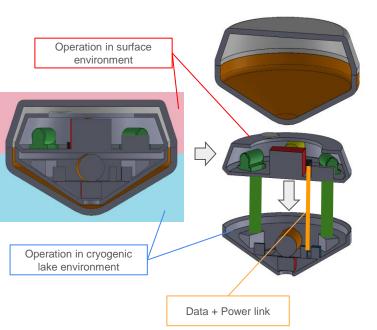
Aim: Soft Landing on Liquid Methane Lake Kraken Mare





Lander Design

STR-1: Shall survive Titan atmospheric re-entry (~18gs, 14,000K) & perform a soft landing on the Kraken Mare.
STR-2: shall stay upright (waves, wind, drift, landing)
TH-1: Shall resist a Titan's atmospheric (91 K) and liquid temperature (91 K), and hydrostatic pressure.
SCI-1: Shall drop sample sensor and collect the data from it.



Spec
297
Max 150
14000 Heat shield
40
1.3

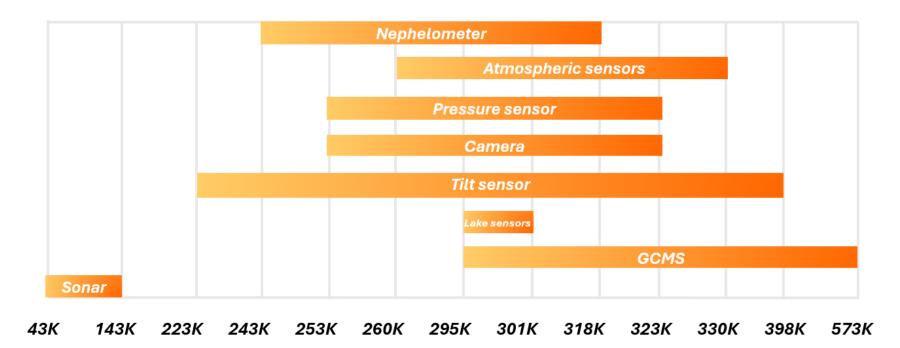
Trade-off:

- 5 m maximum deployment depth
- Can not measure the entire temperature profile

Challenges:

- Thermal management: warm batteries & instruments vs. cold outside.
- Impact of hot lander on environment being measured.
- Hoist mechanism for lowering the bottom "cold" buoy.
- Cryogenic temperatures \rightarrow compliance of material.

Lander Thermal Envelope





Lander Science Instrument Priority

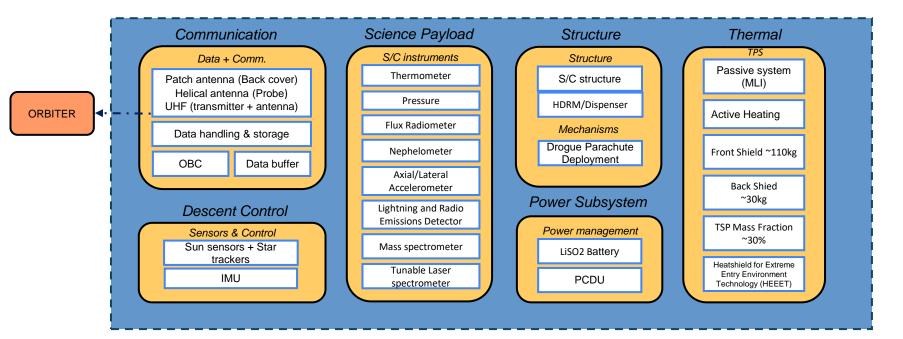
Instrument	Complexity	Thermal score	Size score	Science score	Total score
Weight	2	2	5	10	170
Upper buoy					
Sonar	8	8	9	8	141
Nephelometer	6	5	3	9	115
Camera	8	2	5	10	129
GCMS	7	6	3	10	127
Atmospheric Structure Instruments	10	4	4	7	98
Lower buoy					
Thermometer	10	10	10	7	140
Dielectric constant sensor	10	10	10	7	140
Pressure sensor	10	10	10	7	140
Average	8	6	7	8	133





Probe

Probe System Architecture







Probe Design

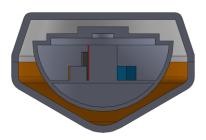
STR-1: The probe shall reach at a depth where the pressure is of at least 10 bar.

POW-1: Probes power system shall be able to **provide 140 W** throughout the measurement phase.

OBDH-1: The probe OBDH shall be able to **handle 32 bps.**

TH-1 : The probe shall survive a maximum temperature of 2000 K.

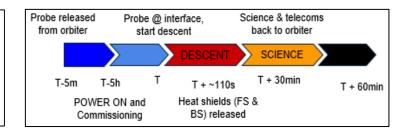
TH-2 : The internal temperature shall not exceed the instrumental temperature range of 253.15 K - 323.15 K.



Part	Spec
Mass (kg)	270
Power (W)	Max 140
Thermal (k)	14,000
Parachute Diameter (m)	2.5
Base Diameter (m)	1.3

Challenge:
Thermal shielding as probe descends through Saturn's cloud
Communication window with S/C
through Saturn's cloud

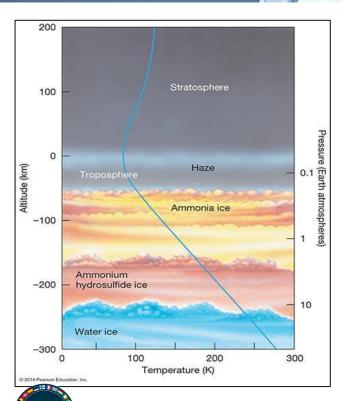
Heritage/Inspiration: PEP probes & Galileo



Components:

Descent: 2 parachutes with main parachute D=2.5 m **Communication:** UHF transceiver to orbiter, 0.5 m patch antenna on back cover and helix antenna during descent. **Thermal:** expected at entry: 2000 K

Probe - Instruments

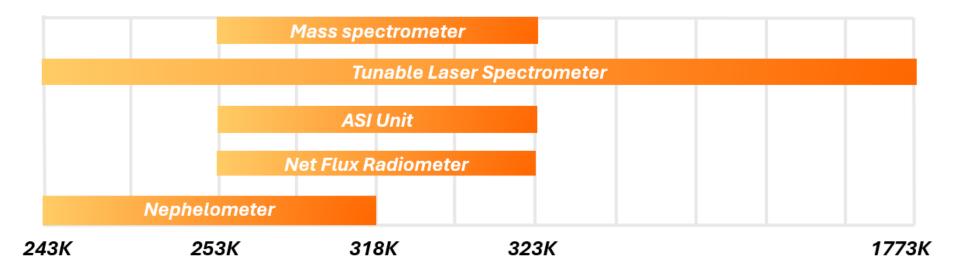


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Payload Instrument	Instrument Requirement
Mass spectrometer	Shall have a resolution of >1000 M/ Δ M
	Shall measure in a mass range between 1-150 amu
Tunable Laser Spectrometer (TLS)	Shall have a resolving power of ${\sim}10^5\lambda/{\Delta}\lambda$
ASI Unit (Temp. / Press. / Accel.)	Shall measure every 4&2, 6 seconds
Net Flux Radiometer	Shall measure every 4&2, 6 seconds
Nephelometer	Shall measure every 5 mins
Lightning and Radio Emissions Detector	Shall measure every 256 s



Probe Thermal Envelope





Green Team – Mission SEAFARER

Cesa Seafarer

Probe Instrument Priority

Instrument	Complexity	Thermal score	Size score	Science score	Total score
Weight	2	2	5	10	190
Temperature sensor	10	8	10	4	126
Pressure sensor	10	4	10	5	128
Mass spectrometer	6	4	3	8	115
Nephelometer	6	8	5	6	113
Accelerometers	10	7	5	5	109
Net Flux Radiometer	7	4	5	3	77
Lightning and Radio Emissions	9	7	10	5	132
Tunable Laser Spectrometer	6	10	8	7	142
Average	7	6	7	6	126







Technology Readiness Level

All components TRL >6 except:

Payload Component	TRL
Sonar (Lander)	4
Tunable Laser Spectrometer (Probe)	4

System Component	TRL
Thermal Control System (Lander)	1
Structure	2

Level	Technology Readiness
4	Component and/or broadband functional verification in laboratory environment
5	Component and/or broadband critical functional verification in laboratory 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



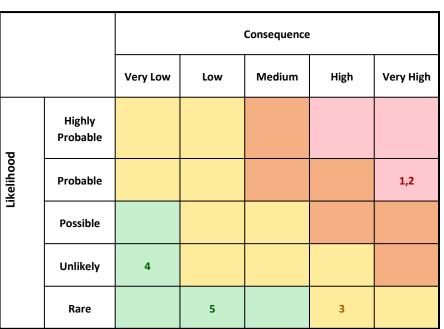


Risk Matrix

Risk Inventory

Risk ID	Risk	Likelihood	Severity	Mitigation	
1	Communication system failure on S/C	Possible	Very High	Test all subsystem on Earth	
2	No power (lost of solar array, RTG problems)	Possible	Very High		
3	Planetary Contamination	Rare	Impact	Follow Deep Space build requirement (ISO3)	
4	Communication issues at ground station	Unlikely	Very Low	Fix or use another Ground Station	
5	Collision with micro meteoroid	Rare	Low	Use proper MLI on S/C	

Risk Matrix





Planetary Protection

Mission SEAFARER = Category II

Spacecraft Protection

• ISO 3 cleanroom (Fed. Class 1)

Planetary Protection

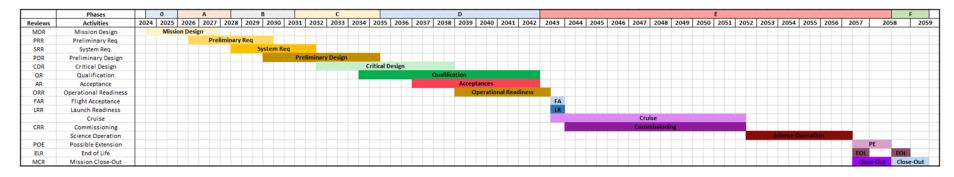
- <u>Titan</u>: Harsh environment kills microorganisms
- <u>Enceladus</u>: Fly By
- <u>Saturn</u>: Disintegrate Upon Entry







Development Schedule



Key D	lates		Dura	ations
Begin: 2024	Launch: 2043	30% Safety Margin Mission Duration	Phase A: 2.5 Years	Phase D: 6.5 Years
Requirements: 2032	Science: 2052	33 Years	Phase B: 3 Years	Phase E: 15.5 Years
Design: 2039	End Mission: 2057	Ready to Launch 20 Years	Phase C: 4 Years	Phase F: 1 Years
Qualified: 2042				



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Finances

Cassini-Huygens: €3.6 Billion L Mission Costs Juice = €1.6 Billion Athena = €1.9 Billion

Instrument Cost: €200 Million

Total Cost: €2.7 Billion

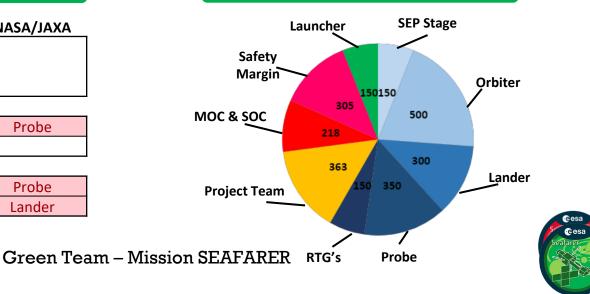
Options

Cost (€)	ESA	NASA/JAXA
	Orbiter	
€2.5 Billion	Lander	
	Probe	

€2.0 Billion	Orbiter	Probe
	Lander	

€1.5 Billion	Orbiter	Probe
		Lander

Mission Cost Breakdown





Descoping Options

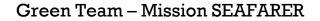
1. De-Scope probe instruments

De-Scope Probe Save €500 Million 25% Science Lost

Probe De-Scoping Options

Instrument	Measures	Probe Science Fraction	Saving (kg)
Lightning Detector	Storm Activity	10%	2.5
Radiometer	Atmospheric Dynamics	20%	3.15
Nephelometer	Wind Speed + Cloud Properties	20%	4.4
Laser Spectrometer	Heavy Molecules	50%	3.5







Descoping Options

De-Scope Lander Instruments De-Scope Lander Save €500 Million

25% Science Lost

Lander De-Scoping Options





Outreach

• Scientific Community

Publications & attending scientific conferences Different calls for observation proposals Invite Students to participate in mission meetings

• General Public

Social Media, website & press releases Provide educational resources

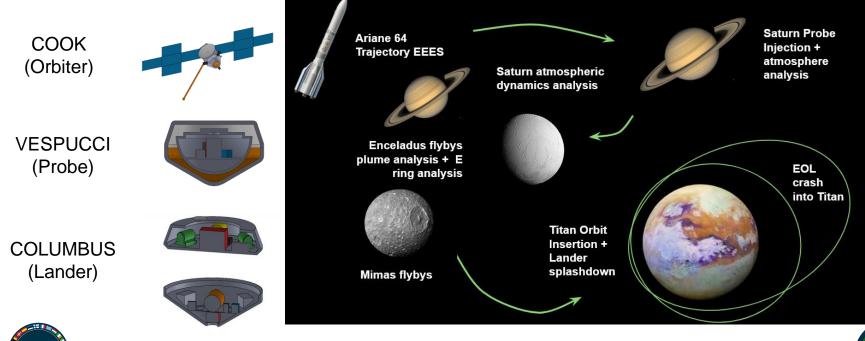






Mission Overview

"To study and characterise the diversity of habitats in the Saturnian systems"



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Extra Slides

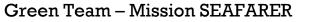






Extra Slides

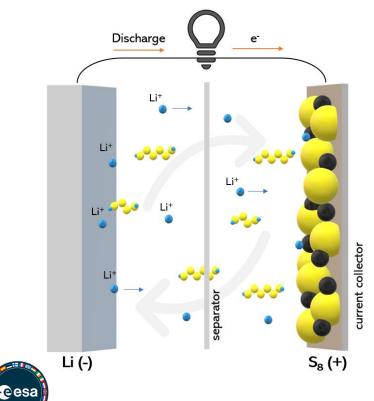








Lander batteries



Battery type	LiSO2
Specific energy	450 Wh/kg
Energy density	550 Wh/L
Capacity	2900 Wh
Mass	6.5 kg
Science Mode	5% duty cycle



Thermal

Thermal -RTGS

RTGs	ASRG
efficiency of 6 - 7 %	efficiency 22 - 30 %
lifetime >= 25 years	lifetime >= 14 years
much heritage	ease of assembly
no moving parts	less complex interface
	slower surface temperature
	greater flexibility
	lower mission cost
	decreased mass





Green Team – Project Seafarer

Thermal -RTGS - Heritage

	Cassini	Galileo
Number of RTGs	3	2
typical housing temperature while		
rejecting 4000 W	240 °C	240 °C
thermal radiation to warm components	140 W + electrical heaters + 157 RHUs	relied solely on elec. heaters, +
(usually up to 500 W)	(35 for Huygens)	120 RHUs

 \rightarrow estimate that most planetary spacecraft would use at most 500 W of heat for thermal management





Green Team – Project Seafarer

RTGs - Fin Sizing

- Fin heat dissipation Q through radiation: $Q_{\mathrm{fin}} = \epsilon \sigma A_{\mathrm{fin}} (T_b^4 T_\infty^4)$
- Assuming rectangular fin shape with width w and thickness t: $A_{\text{fin}} = 2(Lw + Lt + wt)$
- Given total heat dissipation we can calculate the number N of fins needed: $N = \frac{Q_{\text{total}}}{Q_{\text{fin}}}$
- Calculating the thickness of astroquartz-insulation needed: $R = \frac{\Delta T}{Q}$ $R = \frac{\ln(r_1/r_i)}{2\pi\lambda_2 \cdot L}$ $\lambda_a = 1.0 \frac{W}{mV}$

$Q_{RTG,dissipated}$	$\epsilon_{aluminium}$	σ	L	w	t	$T_{b,fins}$	T_{∞}	T _{RTG}	\mathbf{r}_1
4285 W	0.6	$5.67 \cdot 10^{-8} \frac{W}{m^2 K^4}$	0.35 m	1.0 m	0.01 m	473 K	2.7 K	870 K	0.2

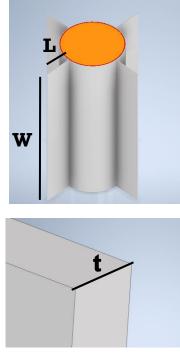
Four aluminium fins with a 8 cm astroquartz insulation layer of 2 kg.

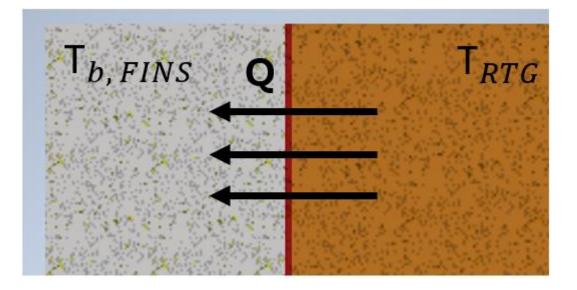




RTGs - Fin Sizing

L = 35 cmw = 1 m t = 10 mm



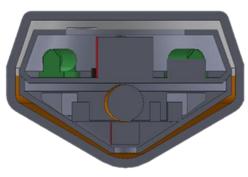


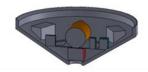
Aluminium fin

Astroquartz III ® insulation layer

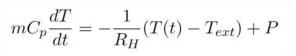


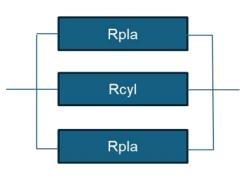
Thermal protection





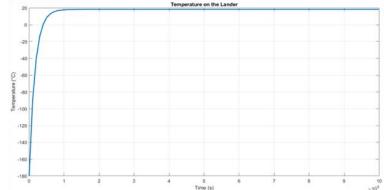
Power estimation : **30 W** Isolation : 20 cm MLI : 0.0004W/m2 L =1 m





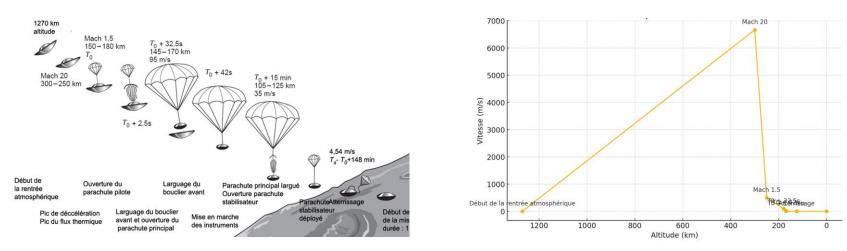
 $R_{
m pla} = rac{e}{\lambda\,S}$

 $R_{cyl}=rac{\ln(r_2/r_1)}{}$



$$T(t) = (T_i - T_{\text{ext}} - PR_H) e^{-\frac{1}{R_H C}t} + T_{\text{ext}} + PR_H$$

Track Lander trajectory



$$\begin{cases} m\frac{d^2x}{dt^2} = mg\cos(\theta) - D\left(\frac{dx}{dt}\right)^2, \\ m\frac{d^2y}{dt^2} = -mg\sin(\theta) + D\left(\frac{dy}{dt}\right)^2. \end{cases}$$





Protection



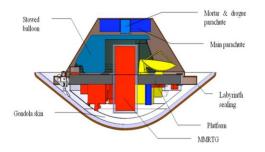
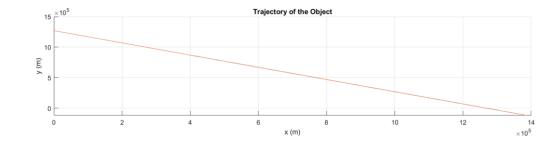


Figure 5 : montgolfière configuration (ESA TSSM assessment report).

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$$\begin{split} v_x(t) &= \sqrt{g\cos(\theta)/k} \tanh\left(\sqrt{g\cos(\theta)k}t + \tanh^{-1}\left(\frac{kv_x(0)}{g\cos(\theta)}\right)\right) \\ v_y(t) &= \sqrt{g\sin(\theta)/k} \tanh\left(\sqrt{-g\sin(\theta)k}t + \tanh^{-1}\left(\frac{kv_y(0)}{g\sin(\theta)}\right)\right) \end{split} \quad k = \frac{\rho C_d A}{2m} \end{split}$$





Structure

Mechanisms

Orbiter	Lander	Probe		
- Solar arrays deployment x2	- Lander separation	- Probe separation		
- Boom for the RTG x3	subsystem	subsystem		
- Boom for the magnetometer	- Parachutes deployment	- Parachutes deployment		
(10m)	- Upper cover			
- Radar antenna deployment (4m)	deployment			
- Probe separation subsystem	- Heat shield deployment			
- Lander separation subsystem	- Drop de lower buoy part			

Cameras are used on the **orbiter** to **confirm the deployment**.





Outreach

Scientific Community

Publications & attending scientific conferences Different calls for observation proposals Invite Students to participate in mission meetings

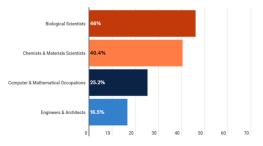
General Public

Social Media, website & press releases Podcast VR/App design to follow the orbiters observations Provide educational resources Touring, interactive exhibition

Call and Inspiration for Minorities in STEM

Ambassadors engage young students









Planetary Protection

Planetary protection

Risk of carrying bacteria from Earth or pollute Titan?

• Given the fact that Titan is too cold and that there is no liquid water for life as we know it to evolve, the **risk of contamination is practically non-existing**. The harsh environment is expected to kill microorganisms that may have hitchhiked from Earth on board the clean space probe.

Risk of carrying bacteria from Earth or pollute Enceladus?

- Care has been taken to ensure that the orbiter does not crash into a body which has a significant chance for hosting life, such as Enceladus.
- Enceladus' plumes will be studied with **fly-bys** (no lander or probe).

Risk of carrying bacteria from Earth or pollute Saturn?

- Scientists have decided to impact the probe into the atmosphere of Saturn to ensure biological contamination will not occur. Although the possibility that Saturn might host life is unlikely, the spacecraft will not risk even that unlikely scenario.
- The **probe will disintegrate** and be scattered into the giant gaseous planet's atmosphere, preventing possible contamination from Earth

Cleanroom Design for Deep Space Satellites

Deep Space satellites demand greater consideration for microbe counts. **The requirement is ISO 3 cleanroom (Fed. Class 1) or better**: partitioned cleanrooms with air lock entry systems, HIPA filters, special protective clothing for people assure that entry and exit does not introduce contamination.

Tools, raw materials and packaging must be wiped down and enter through integrated passthrough chambers. Items are sterilized with IPA wipedowns, autoclaves or by gamma sterilization.

Reason

It's possible that rogue earth microbes (fungus, bacteria, viruses) could colonize or even cannibalize other life on distant planets and spacecraft.

CONTAMINANT: any unwanted molecular or particulate matter (including microbiological matter) on the surface or in the environment of interest, that can affect or degrade the relevant performance or life time.

CONTAMINATION: An unwanted material or substance that causes degradation in the desired function of an instrument or flight hardware.

ISO Class number (N) Maximum allowab 0.1 μm 0 1 10^b 2 100 3 1 000 4 10 000 0 5 100 000 0 6 1 0000 000 7 c 9ε c * All concentrations in the table are cun particles equal to and greater than this size. b These concentrations will lead to large applied; see Annex D. c Concentration limits are not applicable 4 Sampling and statistical limitations for

Table 1 — ISO Classes of air cleanliness by particle concentration

ISO Class number (N)	Maximum allowable concentrations (particles/m ³) for particles equal to and greate than the considered sizes, shown below ^a					
	0,1 µm	0,2 μm	0,3 µm	0,5 μm	1 µm	5 µm
1	10 ^b	d	d	d	d	е
2	100	24 ^b	10 ^b	d	d	e
3	1 000	237	102	356	d	e
4	10 000	2 370	1 0 2 0	352	83 ^b	e
5	100 000	23 700	10 200	3 520	832	d, e, f
6	1 000 000	237 000	102 000	35 200	8 320	293
7	c	c	с	352 000	83 200	2 930
8	с	c	с	3 520 000	832 000	29 300
9g	c	c	с	35 200 000	8 320 000	293 000

a All concentrations in the table are cumulative, e.g. for ISO Class 5, the 10 200 particles shown at 0,3 μm include all particles equal to and greater than this size.

^b These concentrations will lead to large air sample volumes for classification. Sequential sampling procedure may be applied; see <u>Annex D</u>.

^c Concentration limits are not applicable in this region of the table due to very high particle concentration.

d Sampling and statistical limitations for particles in low concentrations make classification inappropriate.

^e Sample collection limitations for both particles in low concentrations and sizes greater than 1 μm make classification at this particle size inappropriate, due to potential particle losses in the sampling system.

f In order to specify this particle size in association with ISO Class 5, the macroparticle descriptor M may be adapted and used in conjunction with at least one other particle size. (See <u>C.Z.</u>)

This class is only applicable for the in-operation state.

HEPA Filter Filtering Power



Preventing Extra-Terrestrial Contamination

A satellite cleanroom prevents earth-borne contamination from invading extraterrestrial environments, so the project must undergo a review to establish a threshold of allowed microbial counts based on a risk assessment. See: <u>COSPAR Planetary Protection Policy</u>

Committee on Space Research







Lander Mission : Protection

Category II missions comprise all types of missions to those target bodies where there is significant interest relative to the process of chemical evolution and the origin of life, but where there is only a remote 1 chance that contamination carried by a spacecraft could compromise future investigations. The requirements are for simple documentation only.

Preparation of a short planetary protection plan is required for these flight projects primarily to outline intended or potential impact targets, brief Pre- and Post-launch analyses detailing impact strategies, and a Post-encounter and End-of-Mission Report which will provide the location of impact if such an event occurs.

Category II Flyby, Orbiter, Lander: Venus; Moon; Comets; Carbonaceous Chondrite Asteroids; Jupiter; Saturn; Uranus; Neptune; Ganymede*; Callisto; **Titan***; Triton*; Pluto/Charon*; Ceres; Kuiper-belt objects > ½ the size of Pluto*; Kuiper-belt objects < ½ the size of Pluto; others TBD

https://cosparhq.cnes.fr/assets/uploads/2021/07/PPPolicy 2021 3-June.pdf





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