The Calathus Mission Concept to Occator Crater at Ceres: Science, Operations and Systems Design

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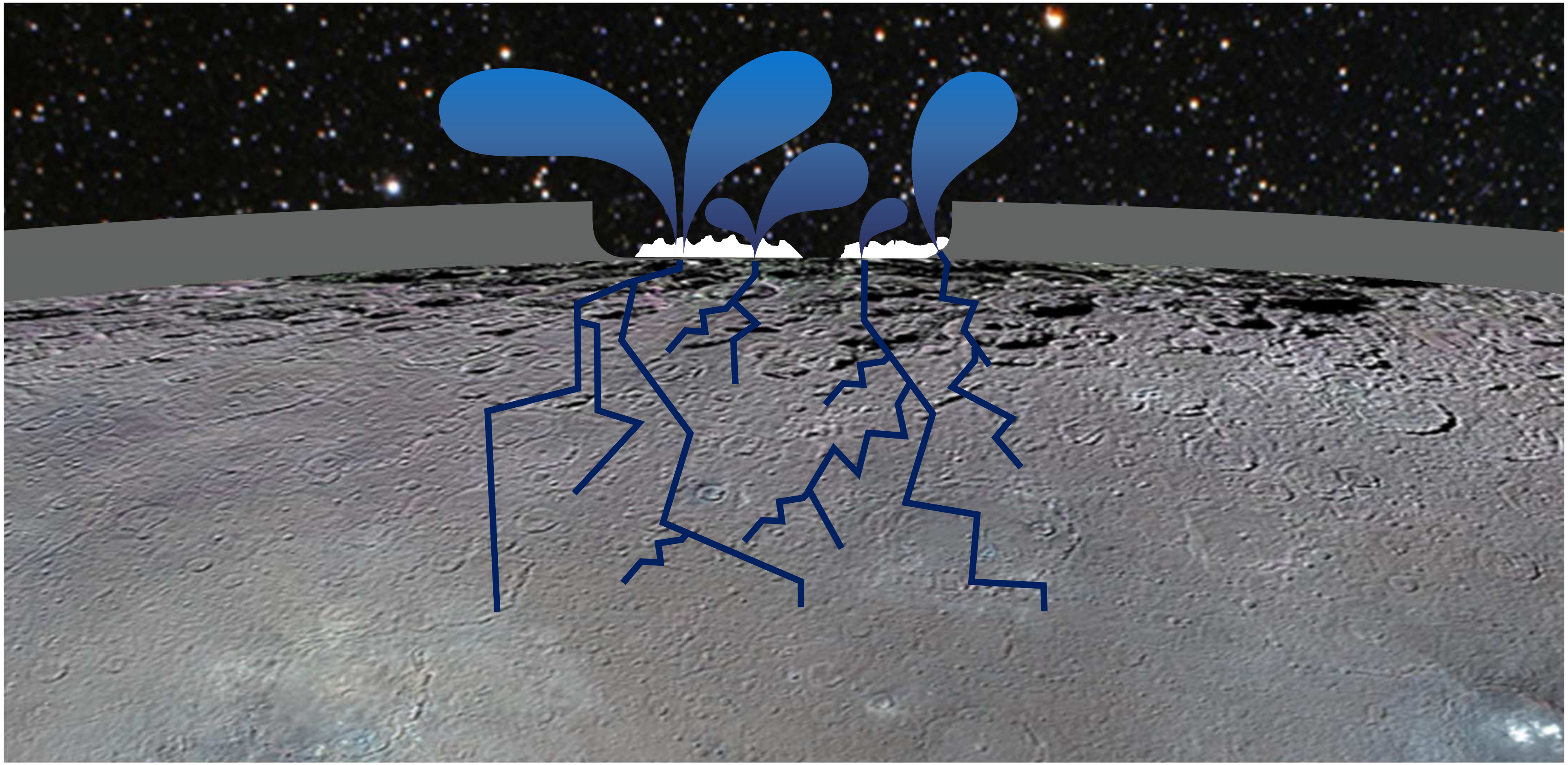
Introduction and Motivation

This mission concept has been designed under the supervision of noted European scientific and engineering experts during the Alpbach Summer School 2018 on the topic "Sample return from smalls Solar system bodies" and the Post Alpbach Summer School Event 2018, both co-organized by the Austrian Research Promotion Agency (FFG) and the European Space Agency (ESA)

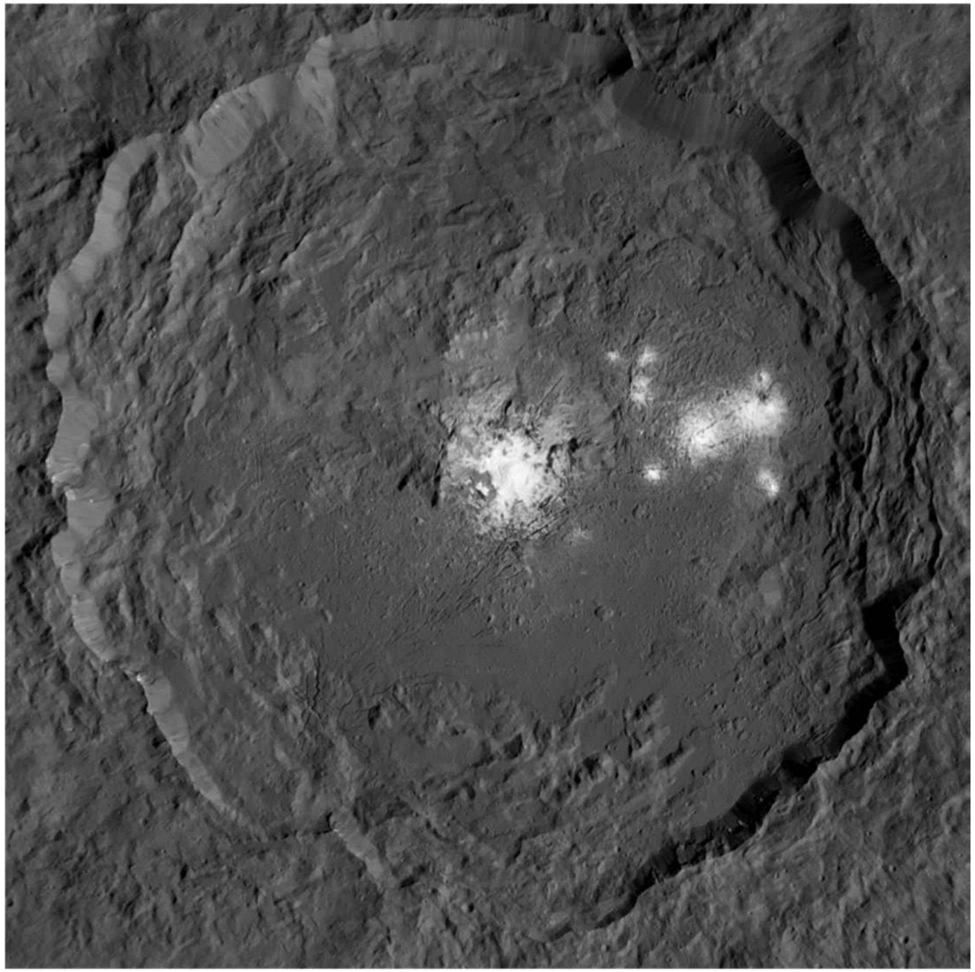
Introduction and Motivation

- Hydrostatic celestial body with two or three layers
- Brine spots composed of salt-rich carbonates believed to be residual of a internal reservoir
- Dawn revealed the presence of organics in Ernutet's crater



Introduction and Motivation

A sample return from Occator’s Crater would provide invaluable insight to understand the Ceres' origin and evolution in the Solar System, to characterize its composition, and its past habitability.



Credits: NASA/JPL-Caltech/UCLA/MPS/DLR/IDA/PSI

We propose here the Calathus mission concept to the Occator’s crater at Ceres

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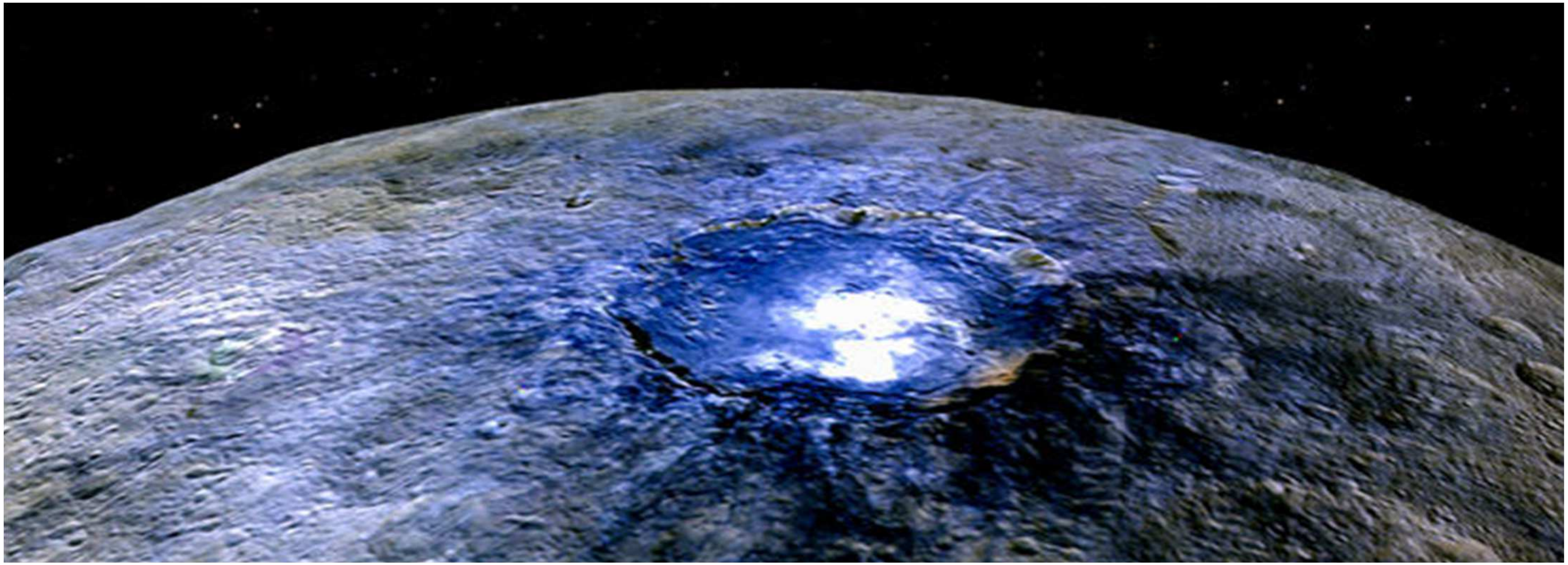
Scientific Questions

Astrobiology: Did Ceres' subsurface contained the ingredients for life?

Origins Of Solar System: Where does Ceres formed? Were asteroids like Ceres responsible for delivering water and organics to Earth?

Credits: NASA/JPL-Caltech/UCLA/MPS/DLR/IDA



Scientific Questions

Mission requirements have been identified:

- The mission shall perform a sample return of at least a total of 4 cm^3 of bright material from Ceres
- The sampling mechanisms shall be capable of taking samples from up to a depth of 5 cm
- Contamination of the surface of Ceres shall be limited to 180 ng/cm^2 of hydrazine during descent
- Four samples shall be collected
- At least one additional sample shall be collected and analysed in situ

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Instrumentation

- **Orbiter**
  - **Narrow-angle camera × 2:** 0.94 m/pixel @ 100 km | *OSIRIS, Rosetta heritage*
    - 1 UV – visible optimized
    - 1 visible - near-IR optimized
  - **Penetrating Radar:** 100 m depth | *SHARAD heritage*
  - **Thermal infrared mapper:** 600-1300 nm | *THEMIS heritage*

- **Lander**
  - **Descent camera** | *MARDI, MSL heritage*
  - **Arm camera** | *InSight heritage*
  - **Gas chromatography mass spectrometer** | *MODULUS Ptolemy, Rosetta heritage*
  - **Drill with cleaning device** | *Mars Exploration Rover heritage*

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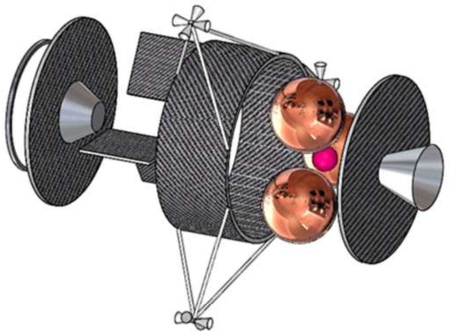
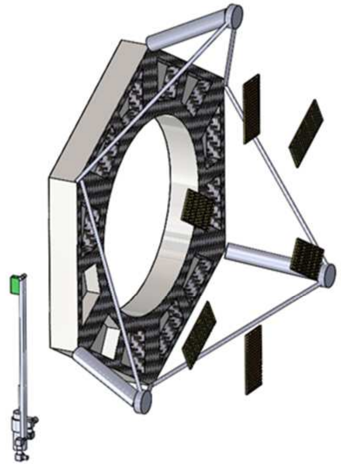
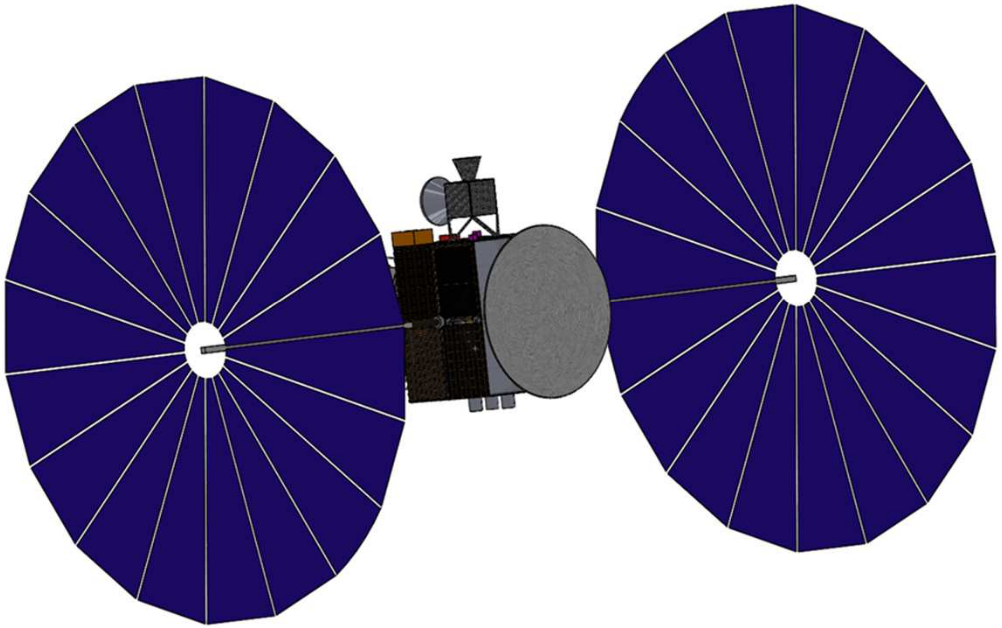
Mission Concept

The mission architecture is composed of two subsystems:

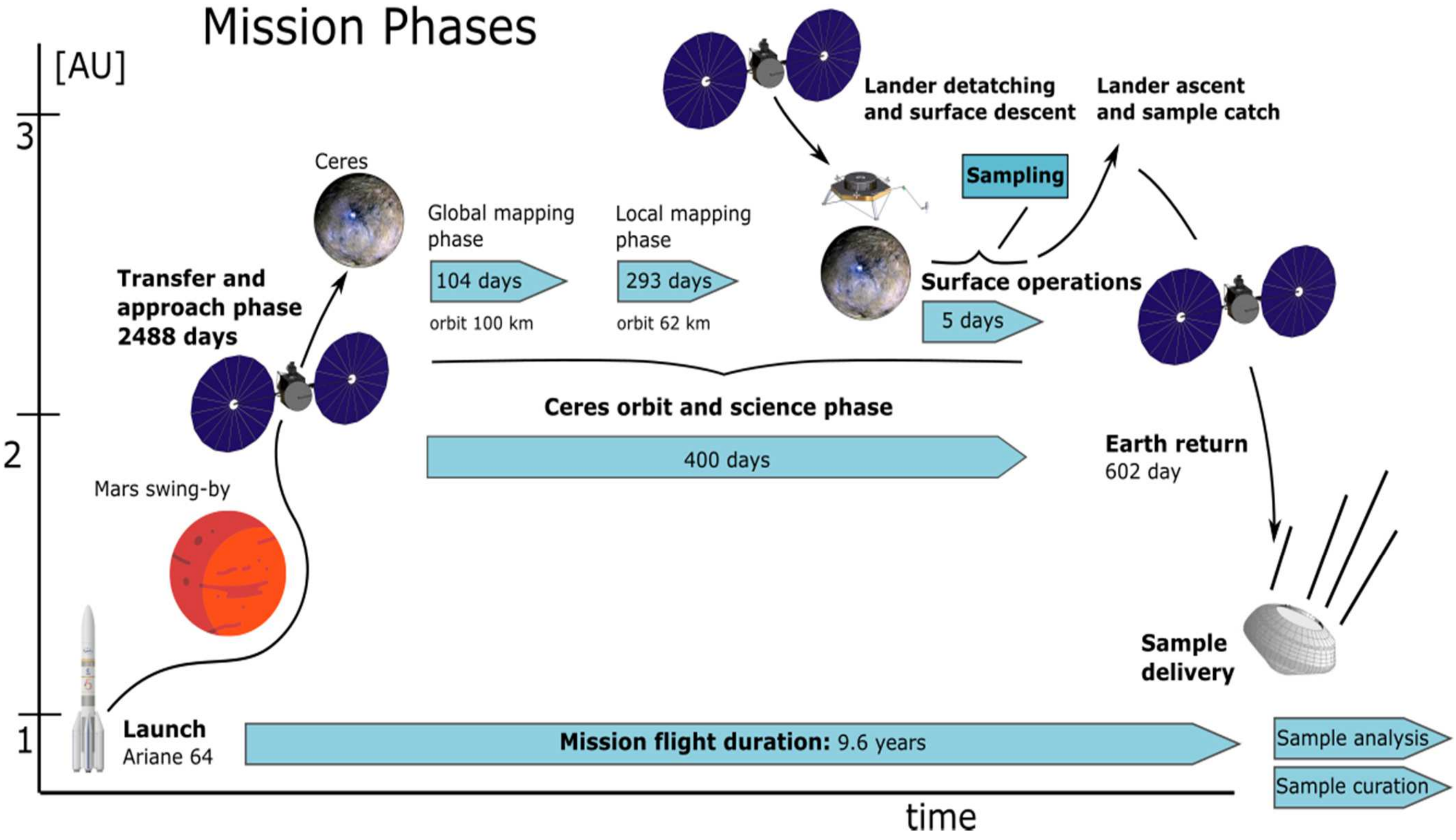
1. An orbiter (5600 kg)
2. A lander



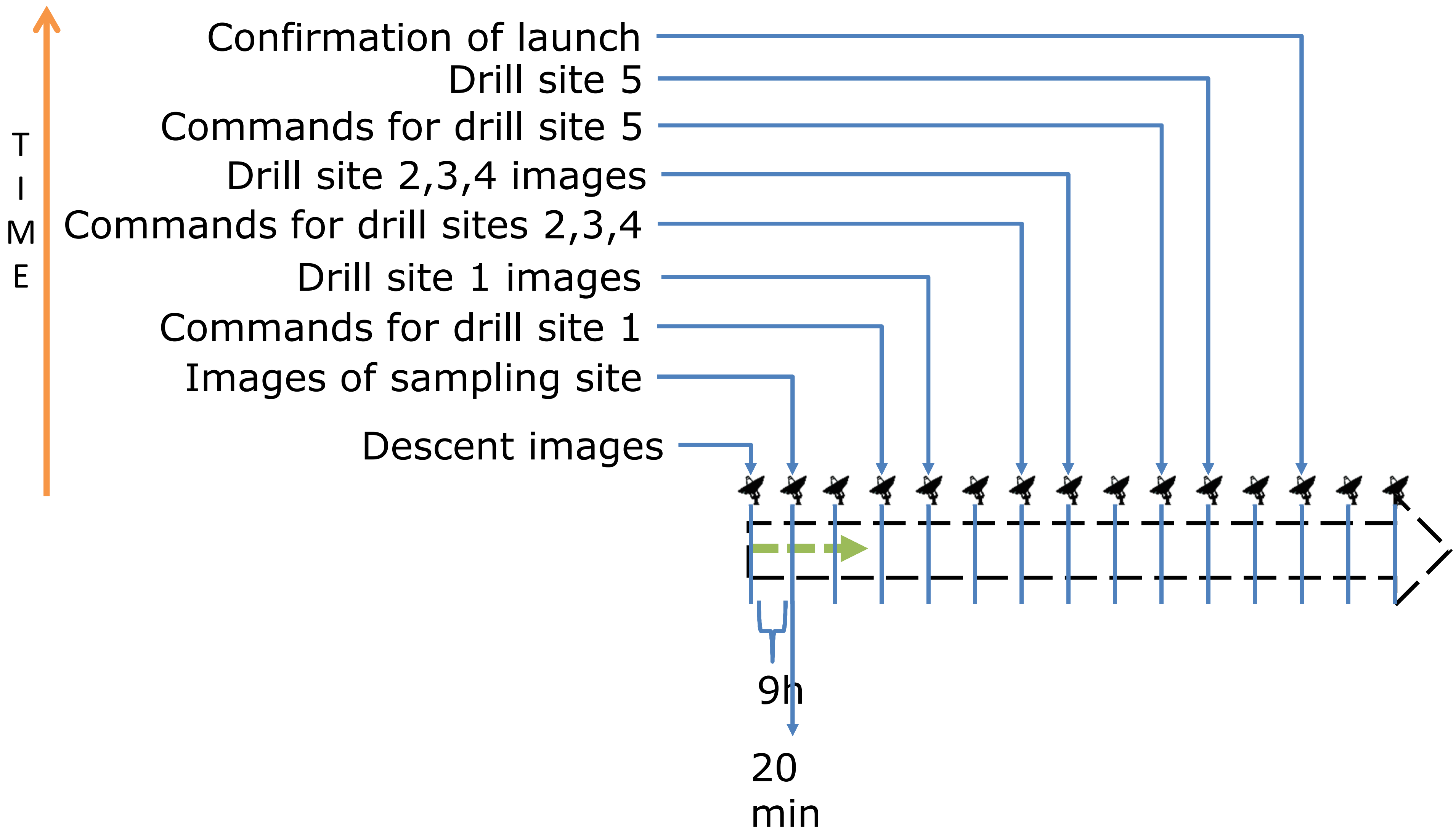




Mission Concept



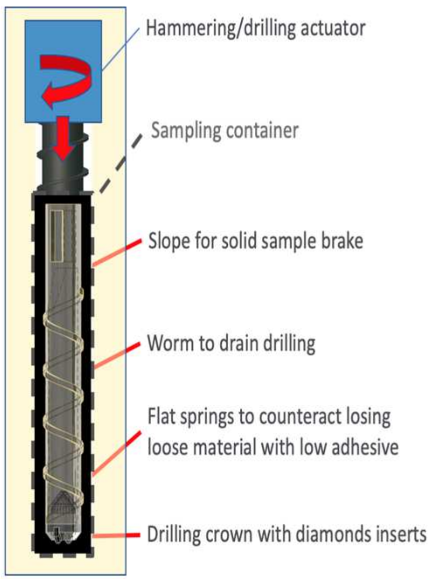
Mission Concept

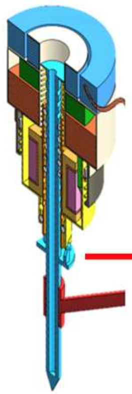


Mission Concept

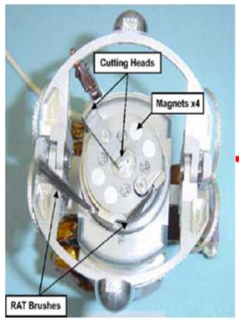
Sampling

- Concept:
  - Manipulator arm carries the instruments
  - Grinding device cleans the drilling area to 5 mm
  - Hammering Drill with 5 sample holding bits
  - 4 samples will be stored for return
  - TRL 3

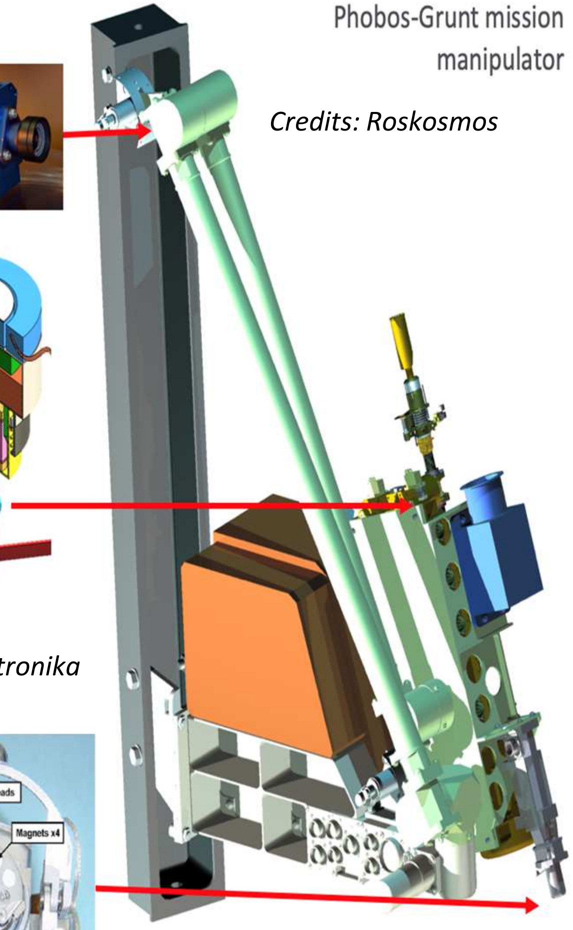




Credits: *Astronika*



Credits: NASA



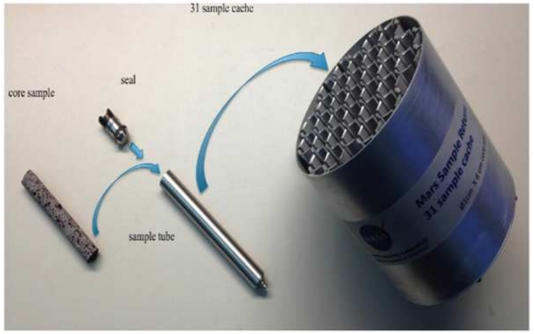
Phobos-Grunt mission manipulator

Credits: Roskosmos

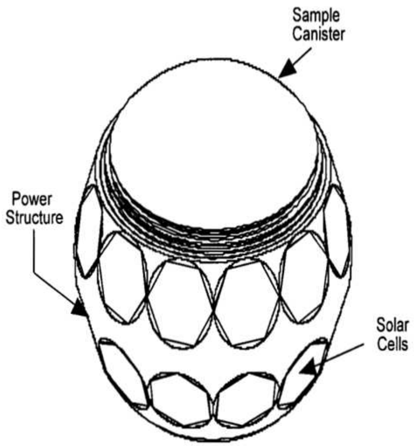
Mission Concept

Docking/Catching

- Concept:
  - Sample Capsule will be sent into orbit
  - Capsule will be released toward the Orbiter
  - Orbiter will catch the Capsule



Credits: NASA Mars Sample Return



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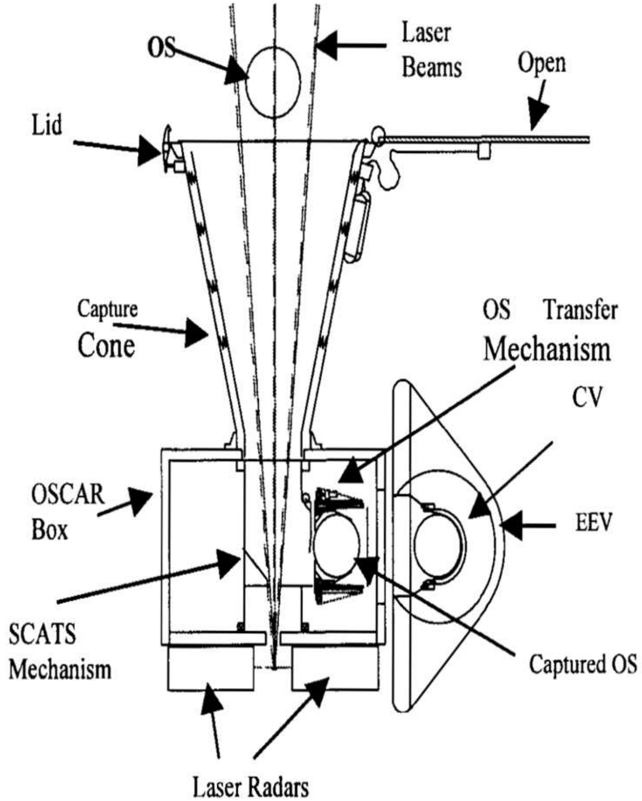

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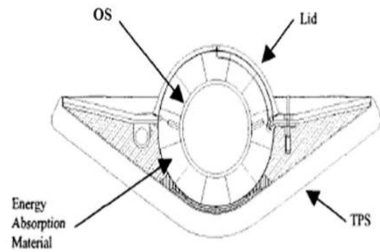
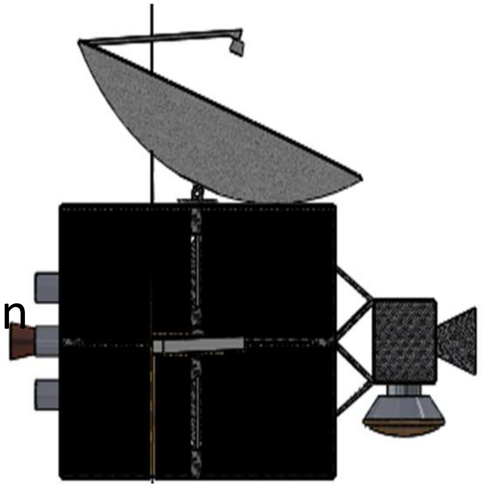


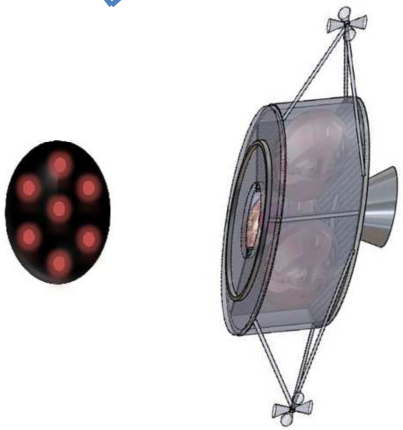
Mission Concept

Rendez-vous

Orbiter
- Visual navigation
- LiDAR



Ranging (3 ways)



Ascent Module
- 1 Transceiver
- 1 Patch antenna

250-500 m

Sample canister
- LED markers
- Mirrors

Curation plan

Collection of sample capsule → Transportation to EURO-CARES

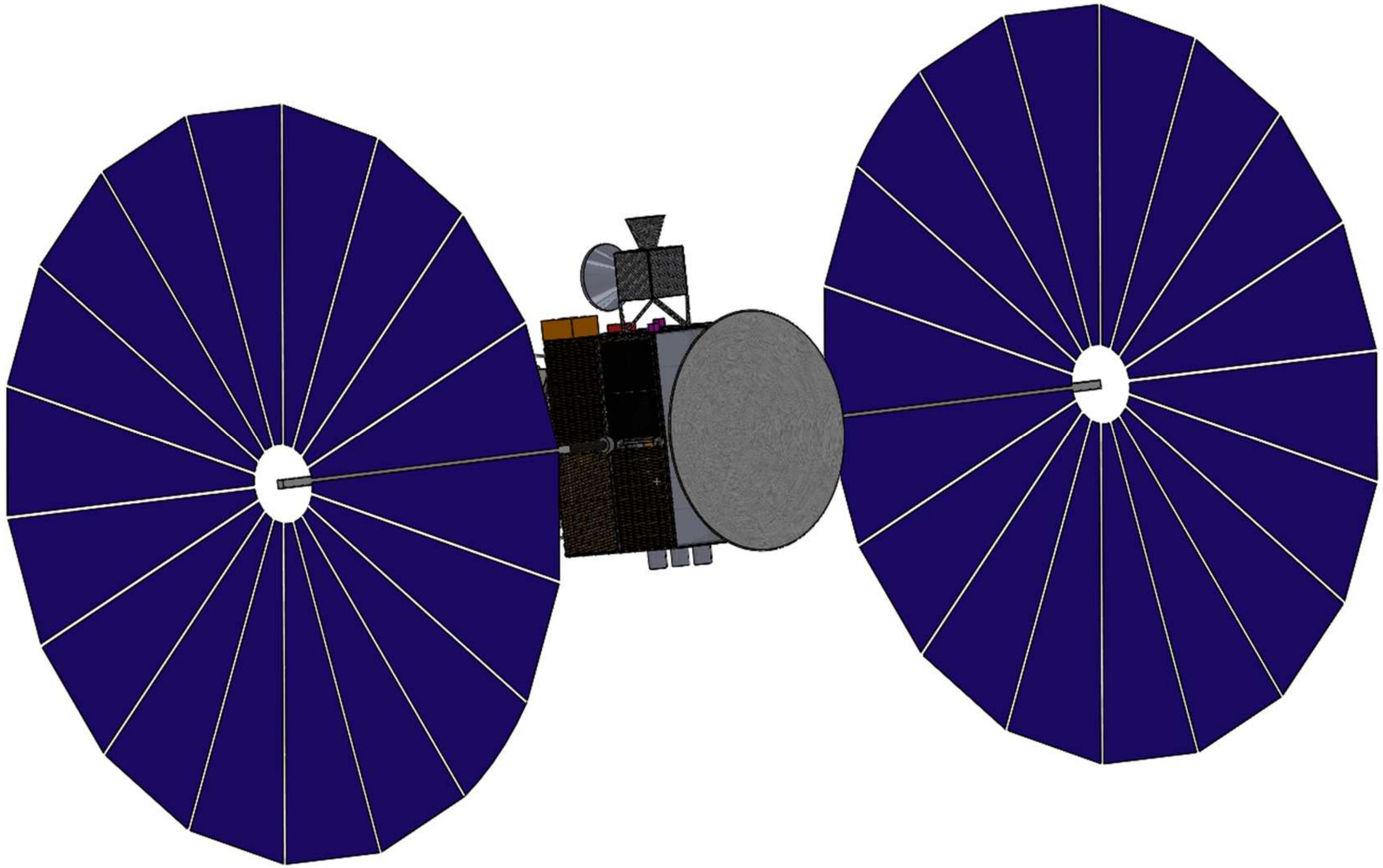
Receiving protocol: sterilisation, opening drill bit in sterile, clean, secure environment

Sample early characterisation: life detection, EDX, mass and size measurement, creation of a database

Characterization by ESA team: 20%	Characterization by international team: 10% NASA + 10% JAXA 10% distribution on proposals	Storage: 50% for future measurements

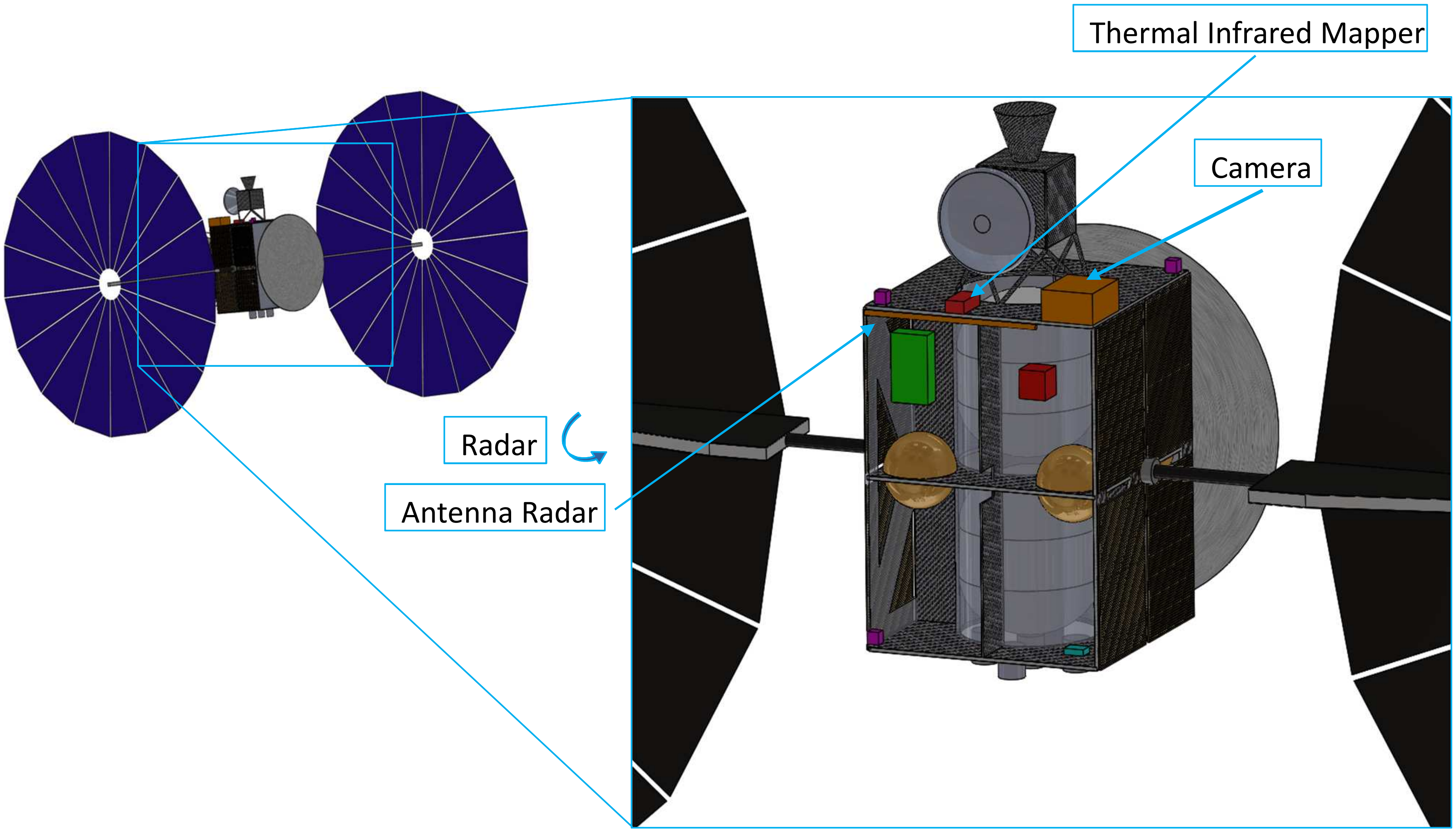
Mission Concept

Orbiter



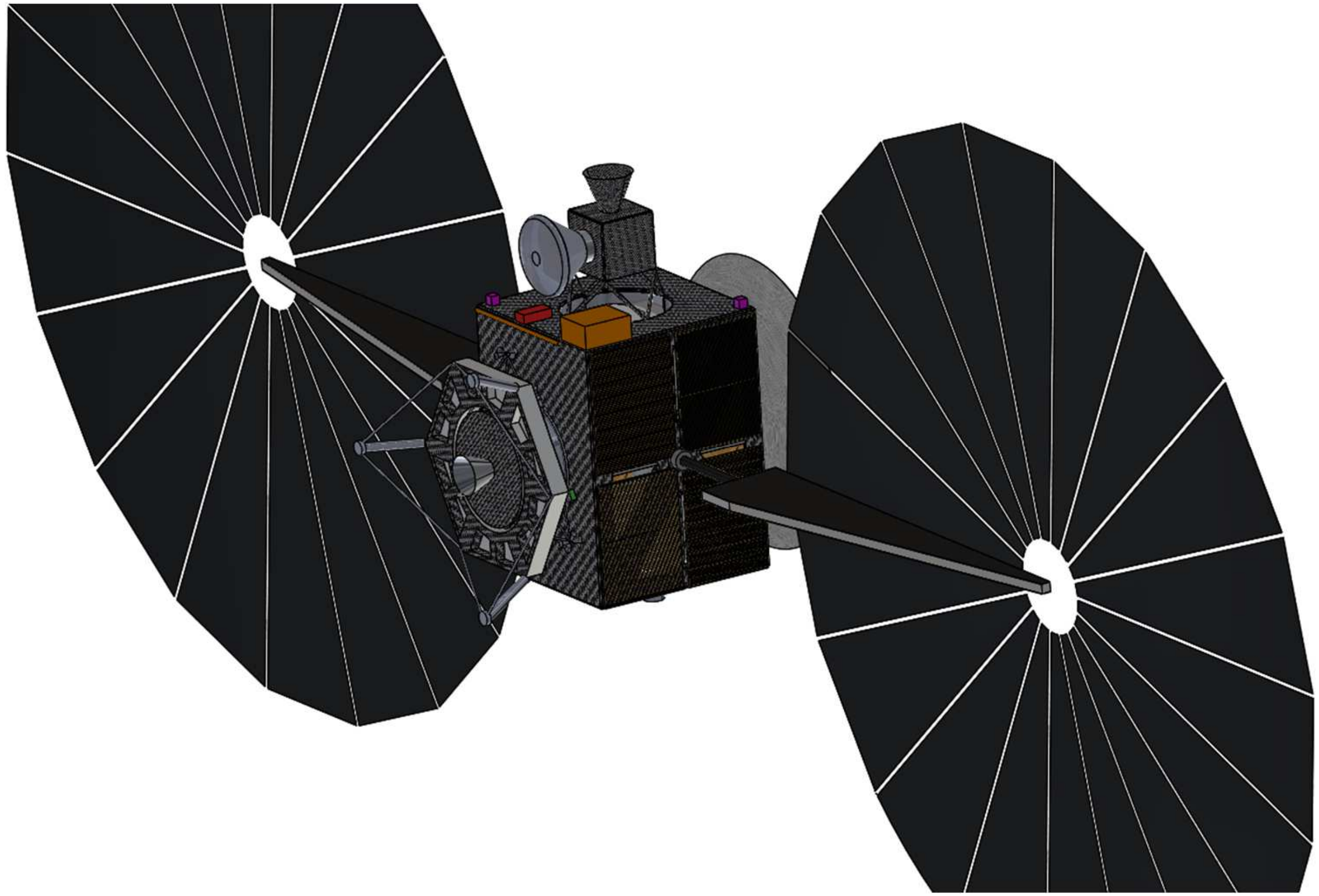
Mission Concept

Orbiter



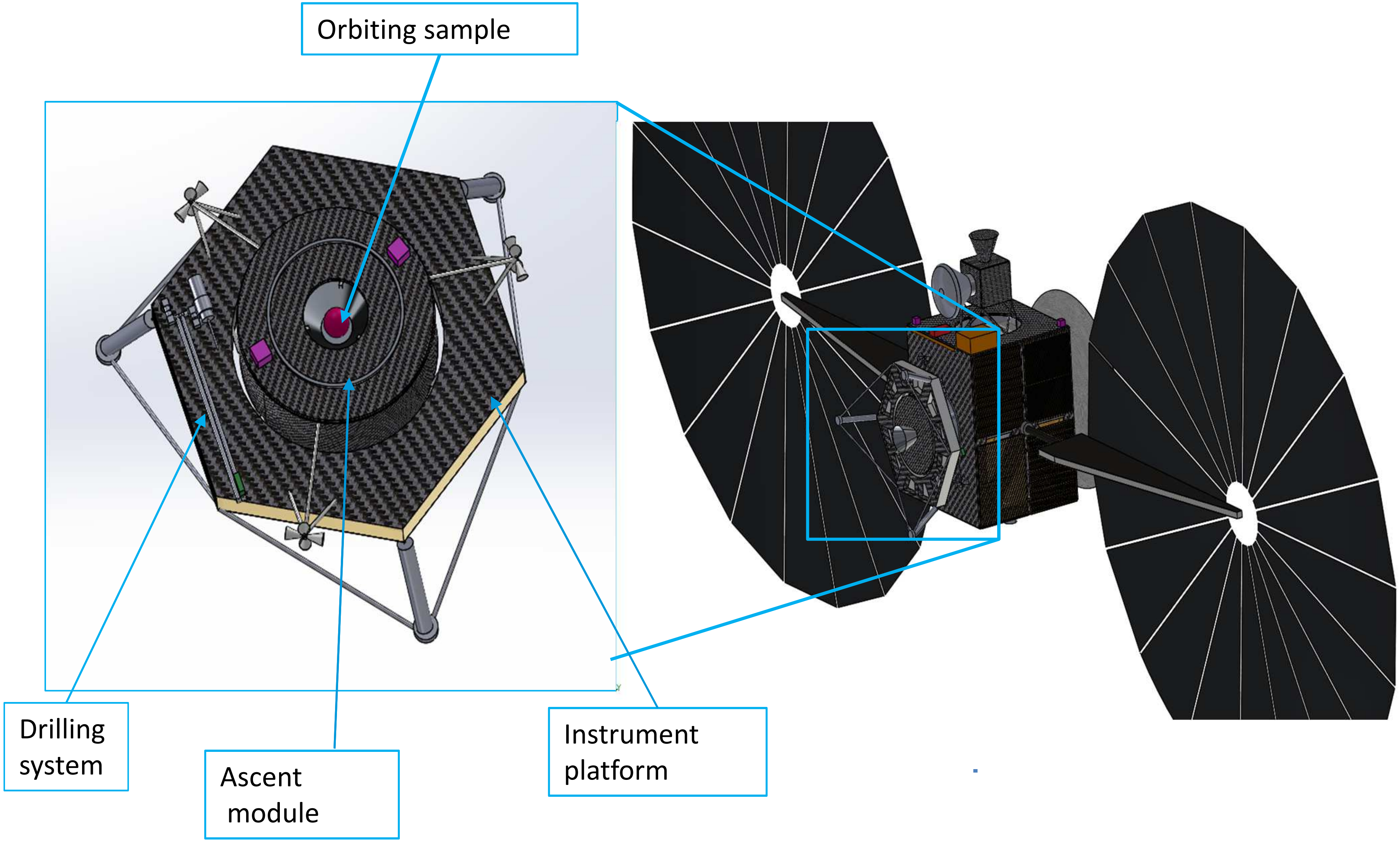
Mission Concept

Lander



Mission Concept

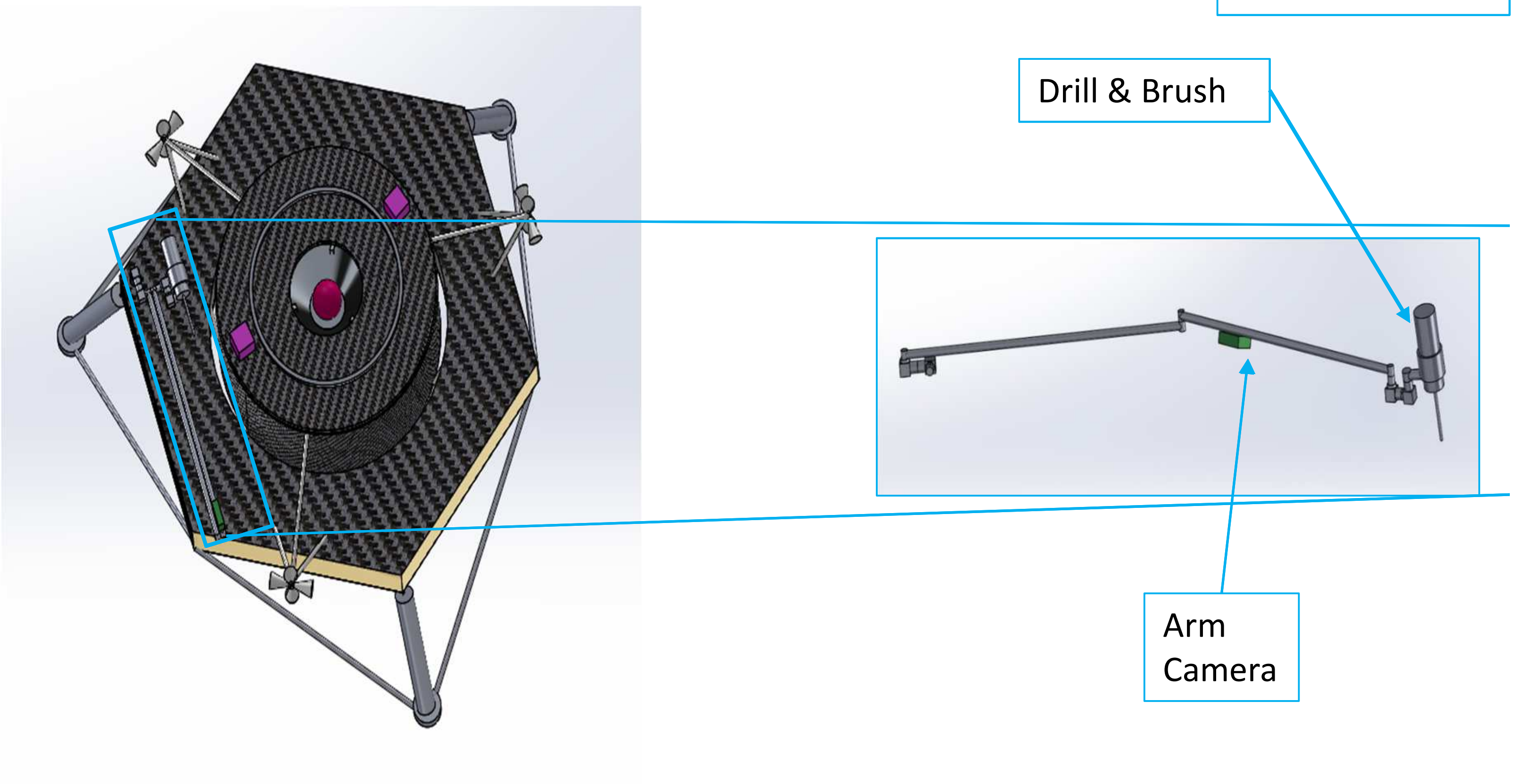
Lander



Mission Concept

Lander

Heritage
- Luna 27
- Phobos-Grunt



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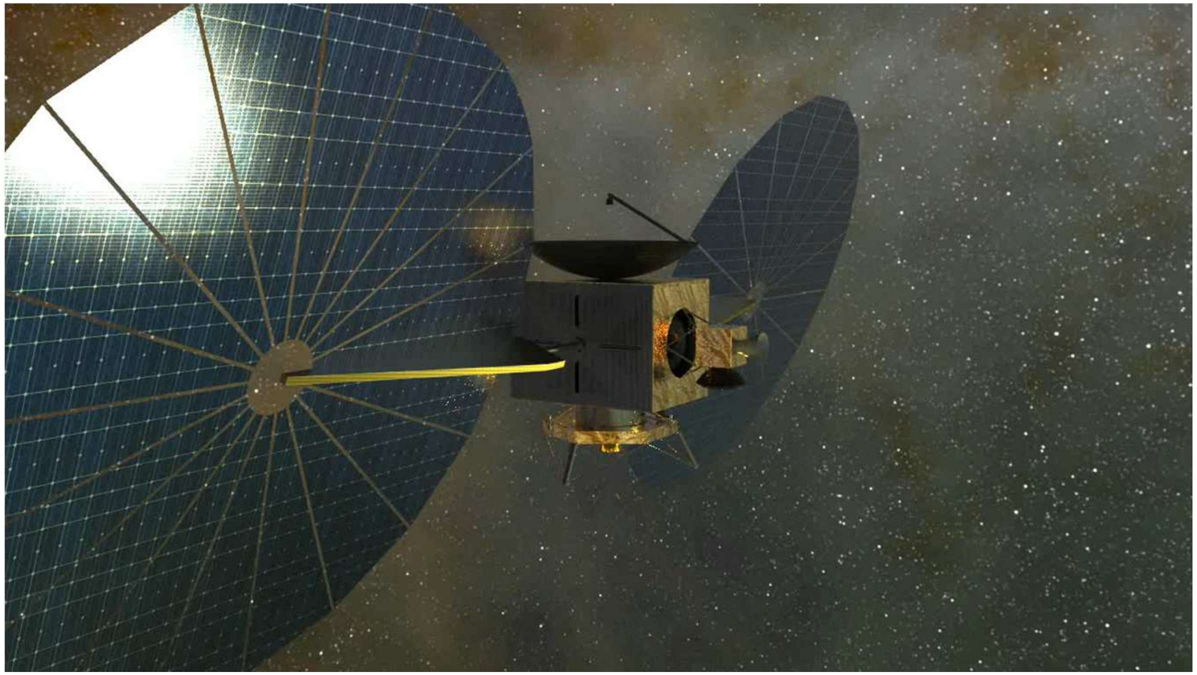
Conclusion

The Calathus mission concept is:

- Driven by compelling science
- Designed to understand the Solar System evolution and presence of life in the Solar System
- Conceived in an orbiter and a lander carrying a set of instruments to maximize scientific return



Conclusion

A special thanks to

Conclusion

Thank you for the attention
Any questions?

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Mission requirements

- **The mission shall perform a sample return of at least a total of 4 cm^3 of bright material from Ceres**
- The system shall be composed of a lander and orbiter
- The samples shall be collected and stored without cross contamination
- **The sampling mechanisms shall be capable of taking samples from up to a depth of 5 cm**
- **Contamination of the surface of Ceres shall be limited to 180 ng/cm^2 of hydrazine during descent**
- There shall be a cleaning tool for sample site preparation
- The cleaning tool shall be able to remove a minimum of 5 mm of material from the surface before drilling
- **Four samples shall be collected**
- **At least one additional sample shall be collected and analysed in situ**
- In situ measurements shall monitor chemical alteration during return phase

Appendix

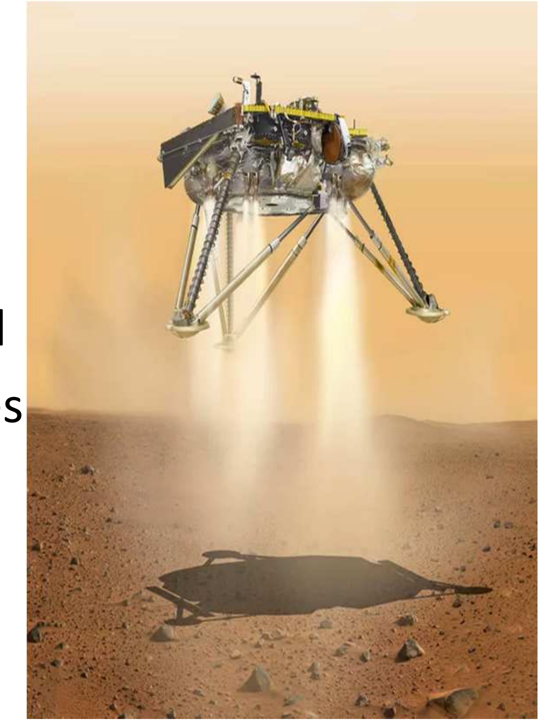
Mission requirements

- The landing site shall be located between a latitude of -40 and 40°
- The mapping of the specific landing site shall be able to resolve surface features of characteristic diameter 0.6 m
- **The lander shall be able to cope with boulders and surface features up to diameter 0.6 m**
- The lander shall be able to cope with slopes up to 15 %
- The mapping of bright spots shall be able to resolve surface features at 1 m^2/pixel
- **The system shall support selection of sampling location based on visual inspection**
- **The samples shall not be contaminated with terrestrial material or organics**
- The conditions in the interior of the sample capsule shall be monitored during return phase, re-entry and collection

Landing

- Concept:
  - Active landing with obstacle avoidance software
  - Landing gear can damp for ~2.5 m/s impact speed
  - Landing gear shall correct for certain obstacle sizes
  - Partial Thermal insulation from Ceres ground
  - TRL 4 (further investigation very much needed)

- Parameters:
  - Mass: 3 x 5 kg



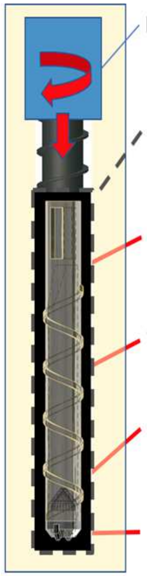
Credits: *NASA Insight*

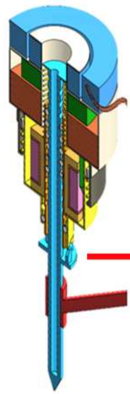
Credits: NASA Apollo Damper

Sampling

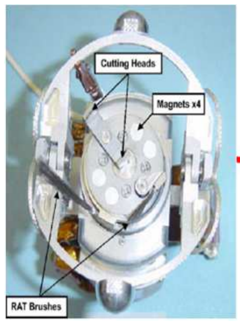
- Concept:
  - Manipulator arm carries the instruments
  - Grinding device cleans the drilling area to 5 mm
  - Hammering Drill with 5 sample holding bits
  - 4 samples will be stored for return
  - TRL 3

- Parameters:
  - Mass: 8 kg
  - Power:
    - Arm: 60 W
    - Drill: 10 W
  - Drilling time: max. 8 h

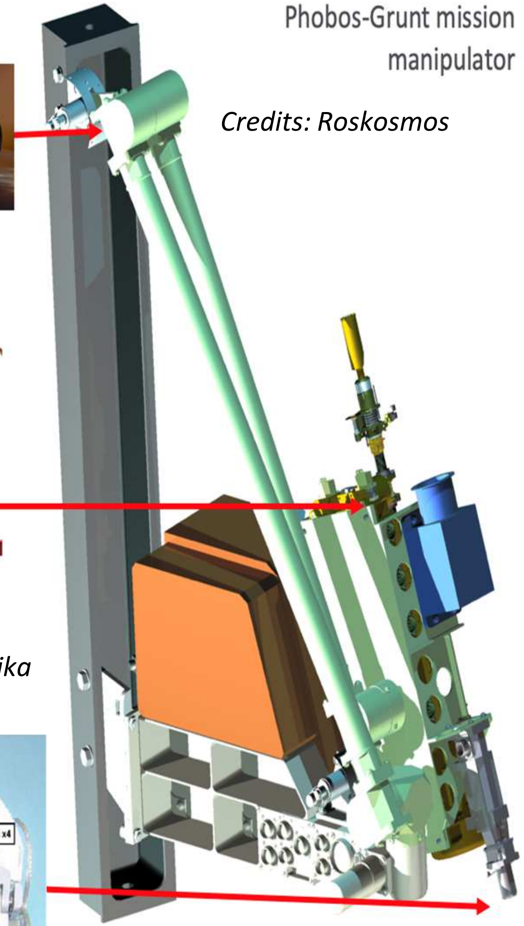




Credits: Astronika



Credits: NASA

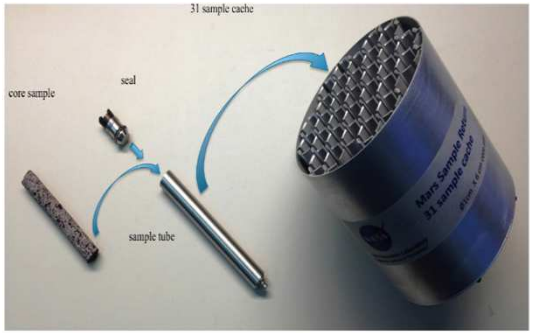


Phobos-Grunt mission manipulator

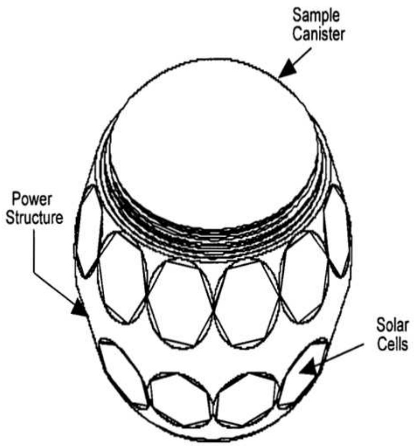
Credits: Roskosmos

Docking/Catching

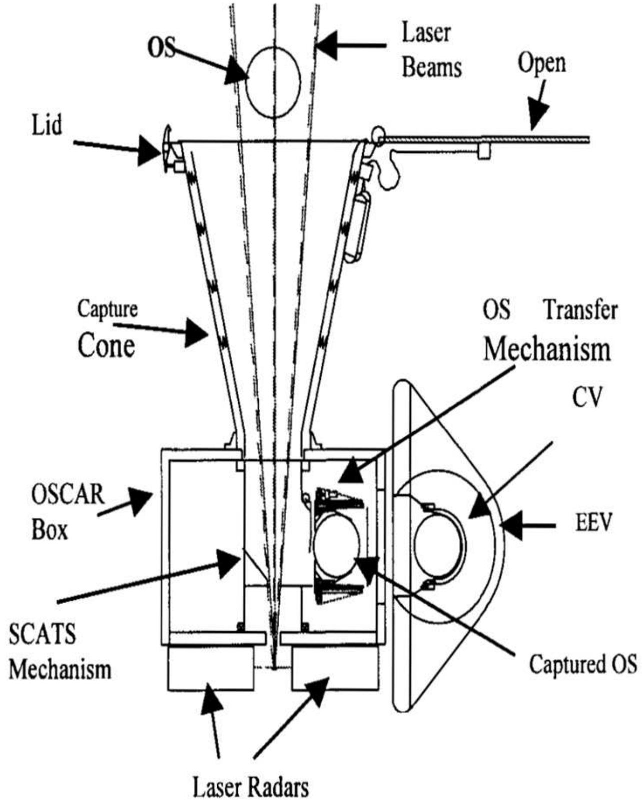
- Concept:
  - Sample Capsule will be sent into orbit
  - Capsule will be released toward the Orbiter
  - Orbiter will catch the Capsule
- Parameters:
  - Mass:
    - On Orbiter: 30 kg
    - Capsule: 6 kg



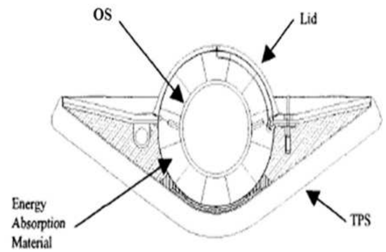
Credits: NASA Mars Sample Return



Credits: NASA Mars Sample Return

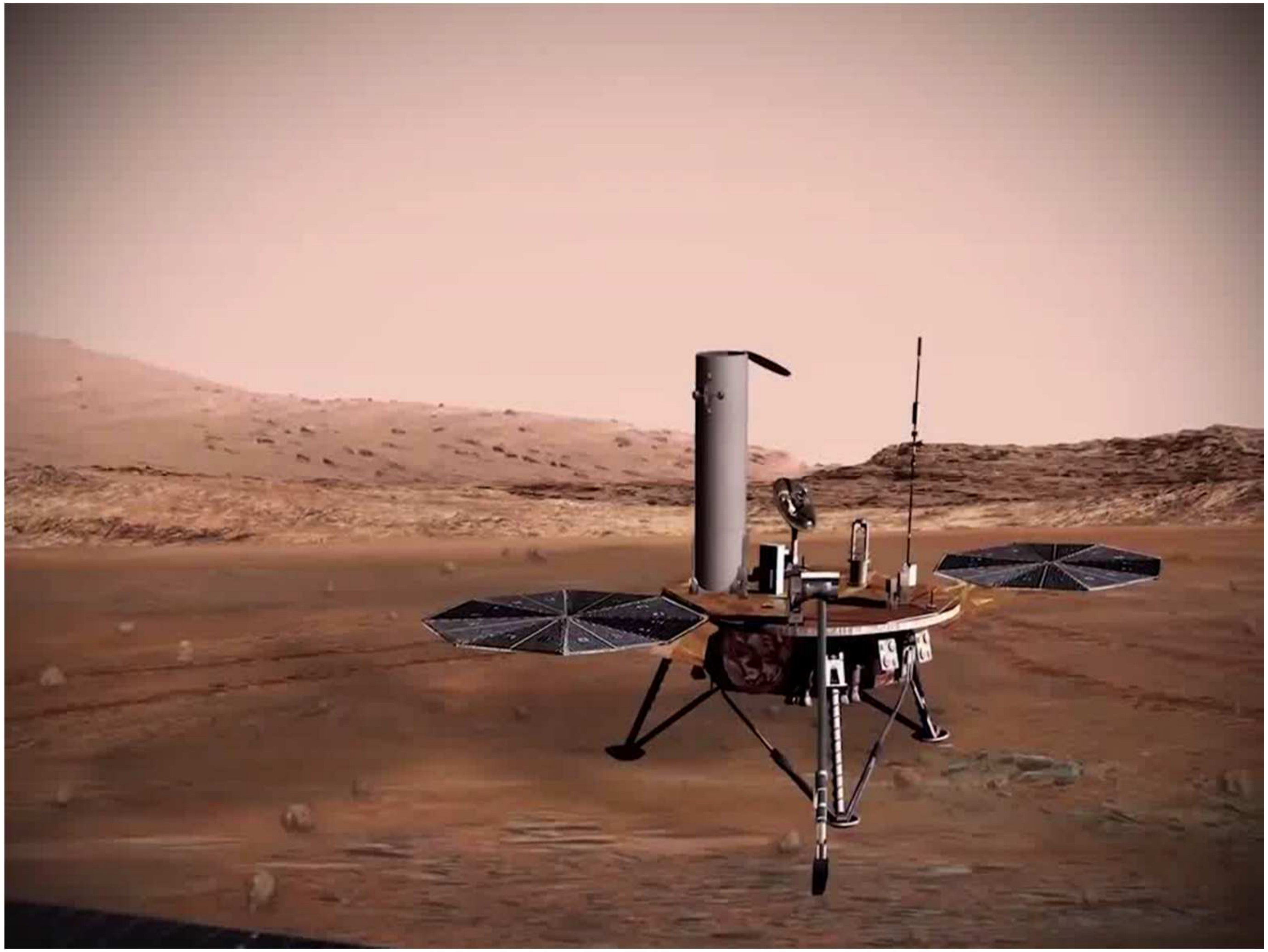


Credits: NASA Mars Sample Return



Mars Sample Return Catcher

Credits: NASA



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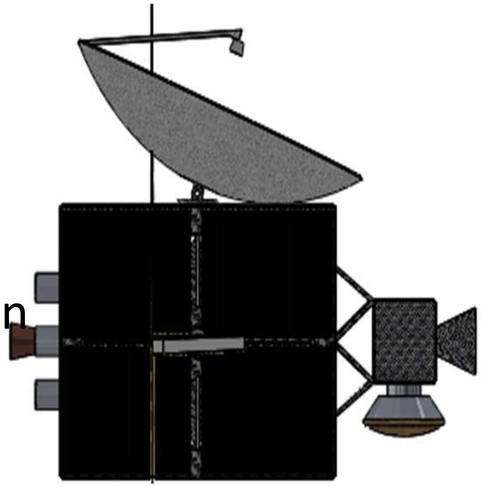
Rendez-vous

Orbiter
- Visual navigation
- LiDAR



Ranging (3 ways)

Ascent Module
- 1 Transceiver
- 1 Patch antenna

250-500 m

Sample canister
- LED markers
- Mirrors

Appendix

Ceres is a class V restricted body

- Potential of liquid water in the past
- Metabolically useful energy sources and large quantities of organic material
- Faculae is too young to have been completely sterilized by interplanetary radiation and has not been exposed to temperatures >160°C
- No provable natural influx of material from Ceres to Earth equivalent to the sample

Forward and backward protection actions to be taken

- Sterilization of s/c before launch to avoid false-positives life-detection
- Approval from planetary protection officer before launch from Earth, Ceres, and before re-entry
- Everything that has been in contact with Ceres must be tightly contained or sterilized before and after re-entry

Power Budget: orbiter

Orbiter Modes	AOCS	COMS	DH	INS	MEC	POW	TC	PROP	TOTAL [W]
Cruise	36	0	23.17	0	12.4	350	22.3	10000	10443.87
Mapping	36	0	23.17	45	12.4	17.5	22.3		156.37
Comm	36	503	23.17	0	72.4	17.5	22.3		674.37
Relay	36	523	23.17	0	72.4	17.5	22.3		694.37
Sample Catch	36	0	23.17	0	42.4	17.5	22.3		141.37
Return	36	0	23.17	0	12.4	350	22.3	10000	10443.87
Eclipse	36	0	23.17	18	12.4	17.5	22.3		129.37
Safe	36	80	23.17	0	12.4	17.5	22.3		191.37

Power Budget: lander

Lander Modes	AOCS	COMS	DH	INS	MEC	POW	PROP	TC	TOTAL [W]
Descent	37.4	0	6.5	7.7	0	3	58	5.1	117.7
SciOps	0	0	6.5	2.15	70	3	0	5.1	86.75
idle	0	0	1.3	0	0	3	0	5.1	9.4
Ascent	37.4	0	6.5	0	0	3	58	5.1	110
In Situ	0	0	6.5	10	0	3	0	5.1	24.6
Transmission	0	55	6.5	0	0	3	0	0	64.5

Appendix

Mass Budget: orbiter

Mass Budget	Margin	Mass [kg]
Orbiter		
Attitude, Orbit, Guidance, Navigation Control		34.7
Communications		99.7
Data-Handling		19.2
Instruments		44.6
Mechanisms		64.4
Propulsion		352.2
Power		673.0
Structures		312.0
Thermal Control		77.4
Subsystems total Orbiter dry mass		1677.4
Harness estimate	5.0%	83.9
Dry mass without system margin		1761.2
System margin	20.0%	352.2
Dry mass including system margin		2113.5
Chemical propellant (+2 % margin)		933.3
Xe propellant (+2 % margin)		2142.0
He pressurant (+2 % margin)		2.9
Subtotal mass consumables		3078.1
Wet mass		5191.6

Mass Budget: lander

Mass Budget	Margin	Mass [kg]
Lander		
Attitude, Orbit, Guidance, Navigation Control		10.8
Communications		3.3
Data-Handling		1.2
Instruments		5.9
Mechanisms		32.9
Propulsion		22.8
Power		55.2
Structures		67.2
Thermal Control		5.7
Subsystems total Lander dry mass		204.9
Harness estimate	5.0%	10.2
Dry mass without system margin		215.2
System margin	20.0%	43.0
Dry mass including system margin		258.2
Chemical propellant (+2 % margin)		71.4
He pressurant (+2 % margin)		0.4
Subtotal mass consumables		71.8
Wet mass		330.0

Total Mass Budget

Mass Budget	Mass [kg]
Spacecraft	
Dry mass including system margin (20%)	2371.7
Mass consumables	3149.9
Wet mass	5521.6
Launcher Adapter	100.0
Total wet mass + Launcher Adapter	5621.6
Ariane 64 launch capacity Earth escape	7400.0
Below target	1778.4

Appendix

Budgets

	Mass (kg)	ROM multiplier: development	ROM multiplier: manufacturing	Inflation	Cost (Million €)
S/C dry mass	2440.8	1022	84	1.14	2.7
Lander Dry Mass	231	2390	317	1.14	0.63
Development and manufacturing total	-	-	-	-	3335

	Number of years	ROM multiplier		
Ground segment costs	12	14000000		148
Launcher costs	-	-	-	132
Grand total	-	-	-	3600

Appendix

Curation plan

Collection of sample capsule → Transportation to EURO-CARES

Receiving protocol: sterilisation, opening drill bit in sterile, clean, secure environment

Sample early characterisation: life detection, EDX, mass and size measurement, creation of a database

Characterization by ESA team: 20%	Characterization by ESA team: 10% NASA + 10% JAXA 10% distribution on proposals	Storage: 50% for future measurements

Analysis on Earth

Methods	Measurement
X-ray diffraction	Mineral/chemical structure
Gas chromatography mass spectrometry	Identification of the insoluble organic phase
X-ray IR spectroscopy	Spatial distributions of organics and minerals and link between them
Electron Microprobe	Elemental composition
Scanning Electron Microscopy	Sample microstructure
Thermal ionization mass spectrometry	Ratios of radioactive isotopes, age of the components

Are the ingredients of life present in the subsurface of Ceres?

Were asteroids like Ceres responsible for the delivery of organics and volatiles to Earth?

Appendix

Instrument	Question 1	Question 2
Orbiter Mapping Camera	✓	
Subsurface Radar	✓	
Thermal IR Mapper	✓	
Lander Sample	✓	✓
Lander Mapping Camera	✓	
Mass Spectrometer	✓	✓
Sampling Module	✓	✓

Question 1: Did Ceres' subsurface contain the ingredients for life?

Question 2: Were asteroids like Ceres responsible for delivering water and organics to Earth?