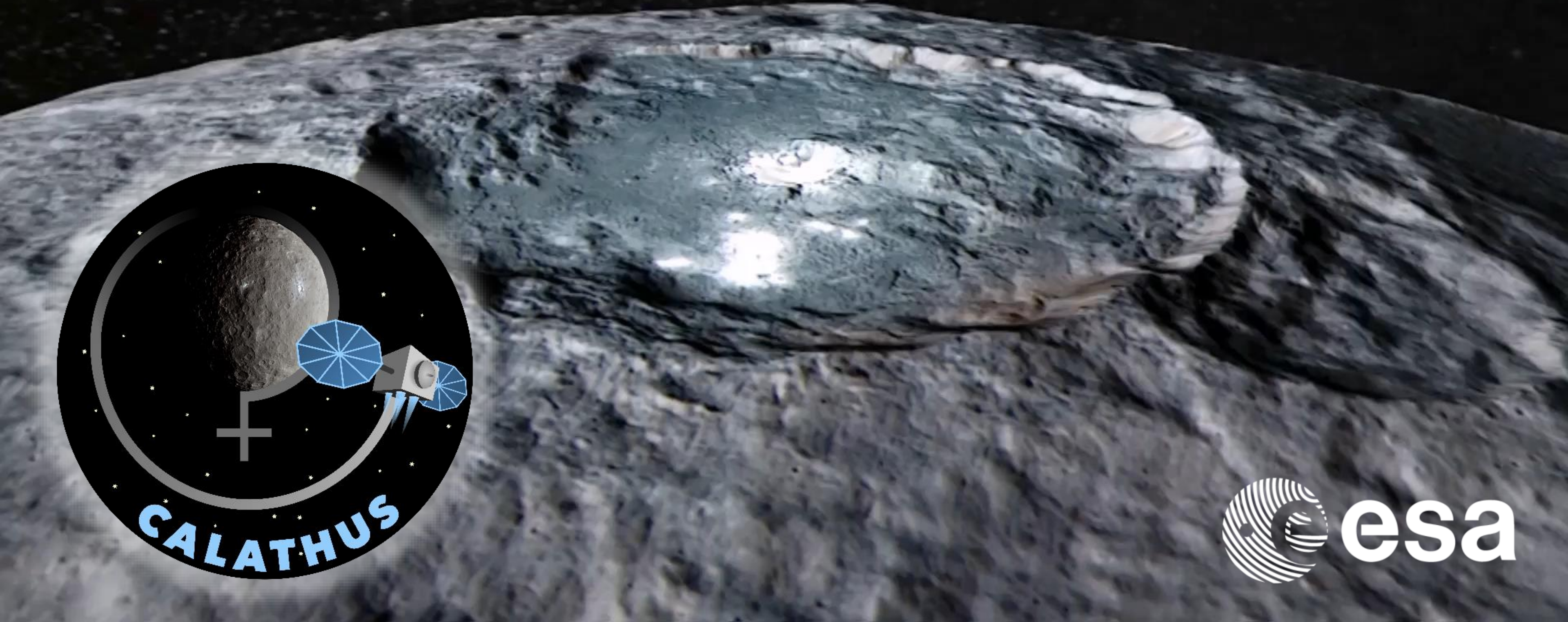
calathus

sample return from an evolving world



Science	Nini Berge, Zelia Dionnet, Gauthier Duvieusart, Florine Enengl, Grigori Fedorets, Lucy Kissick, Kristin Pump
Engineering	Denis Barros Caballero, Carlo Convenevole, Felix Hessinger, Bartosz Kędziora, Adam Kiss, Javier Navarro Montilla, Moritz Novak, Hannah Petersson

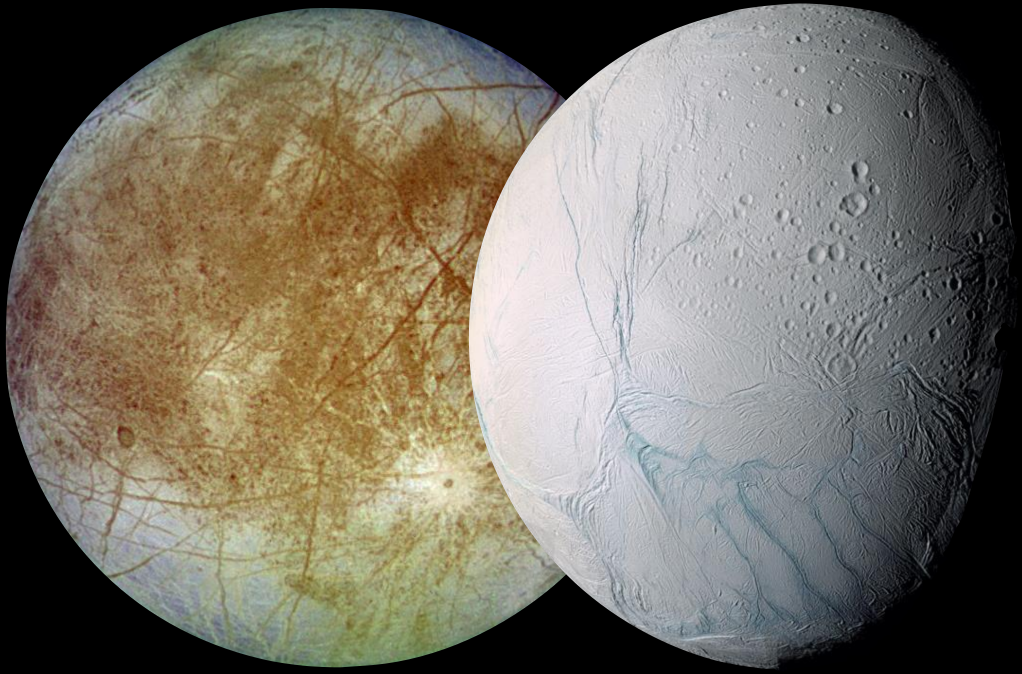
part i

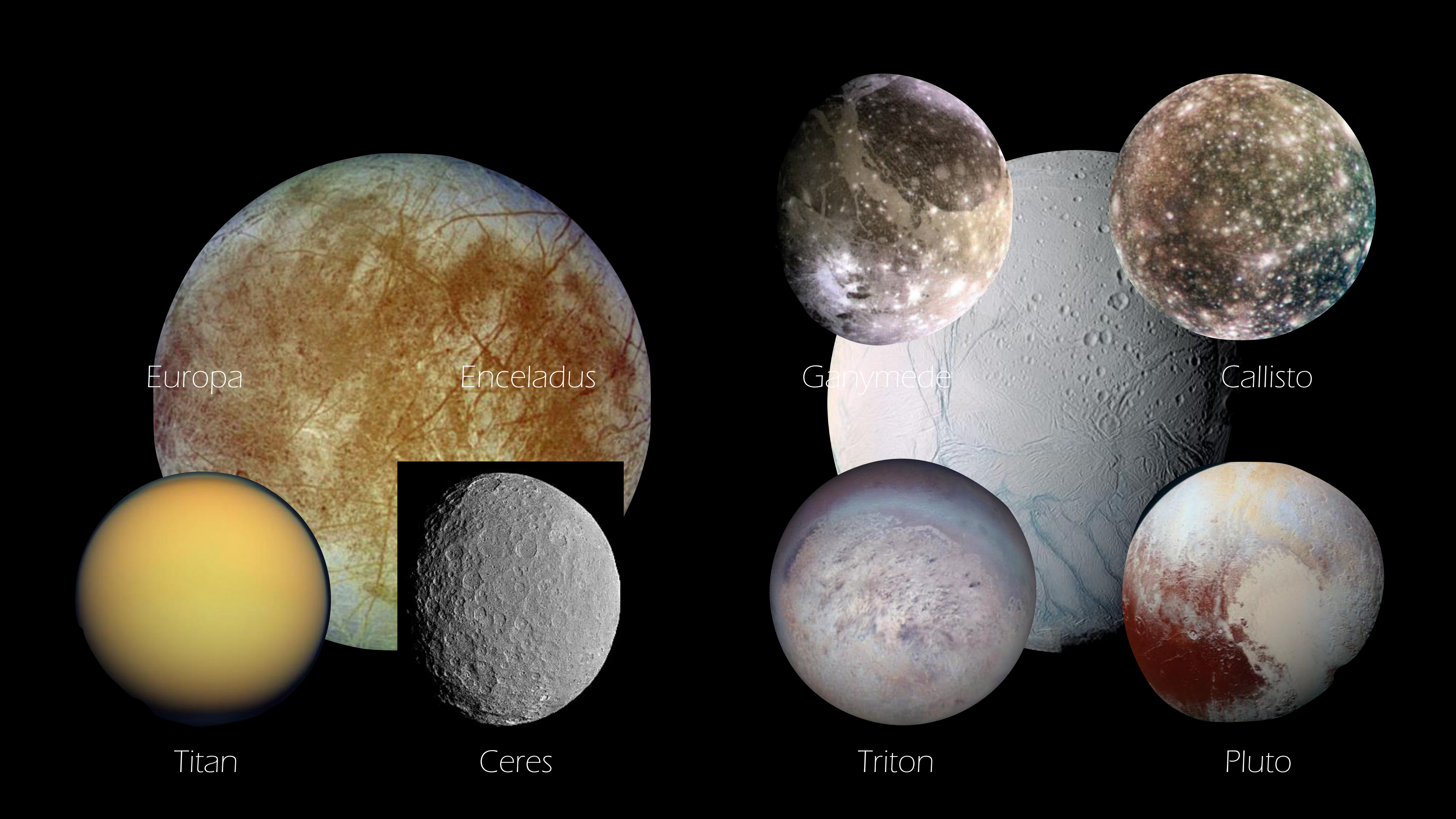
science rationale

Cosmic Vision question #1.3.

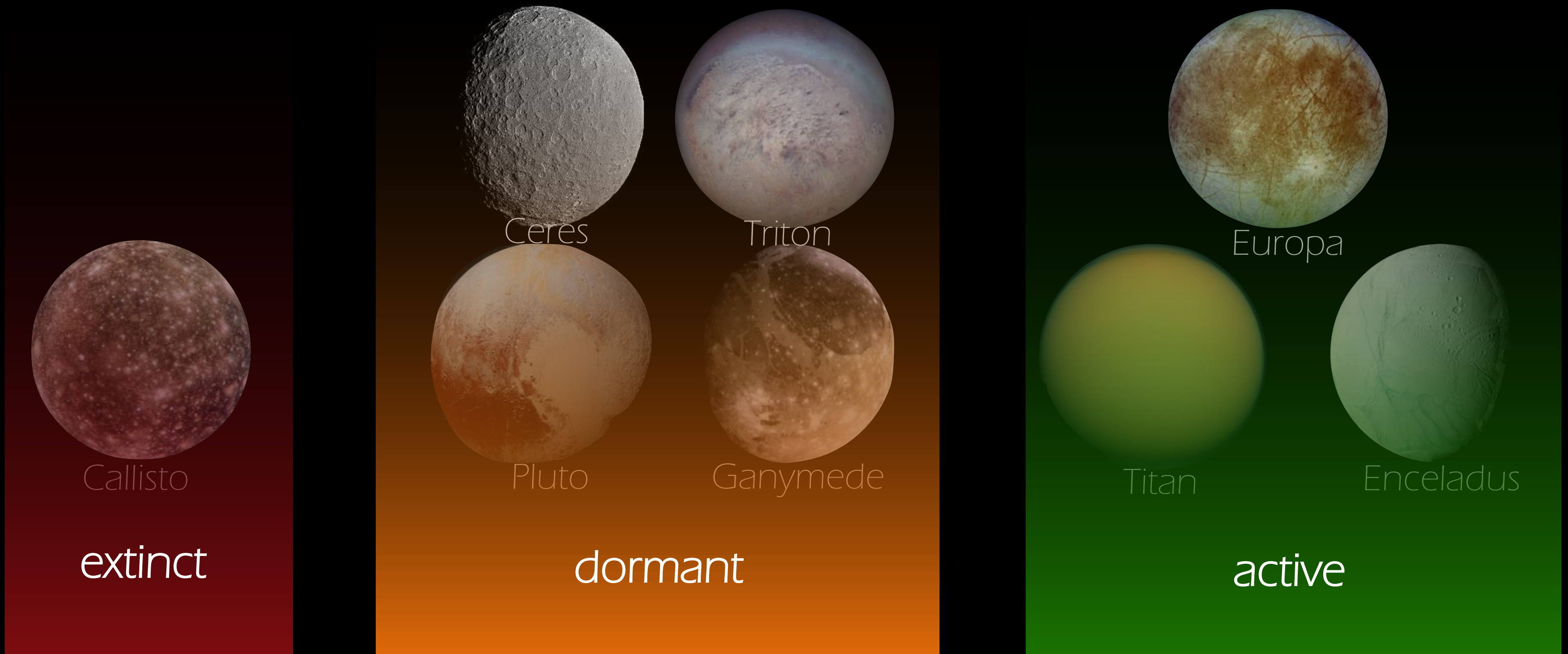
"Explore in situ the surface and subsurface of solid bodies in the Solar System most likely to host – or have hosted – life."

from Cosmic Vision page 9




Europa
Enceladus
Ganymede
Callisto
Titan
Ceres
Triton
Pluto

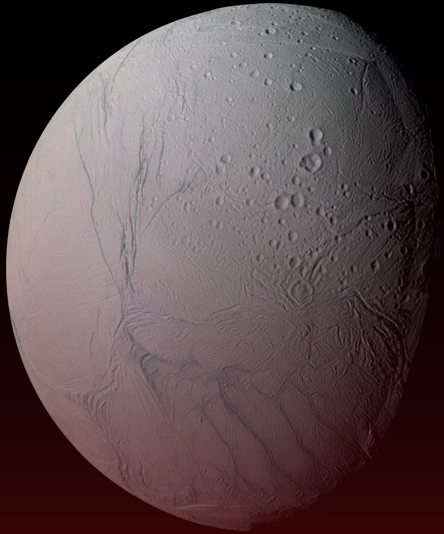
active


Ceres
Triton
Europa
Callisto
Pluto
Ganymede
Titan
Enceladus
extinct
dormant
active

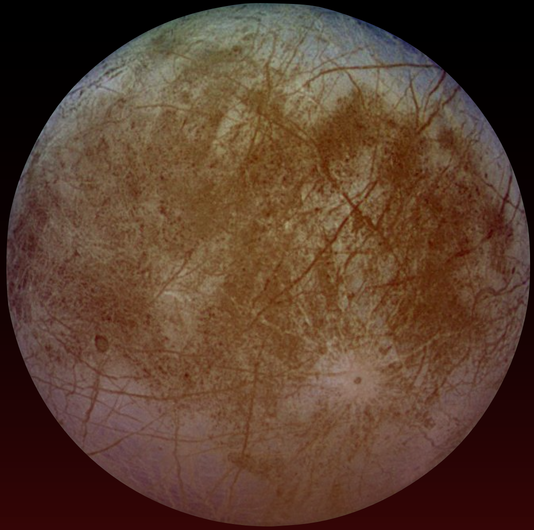
accessible

buried beneath thick icy shell

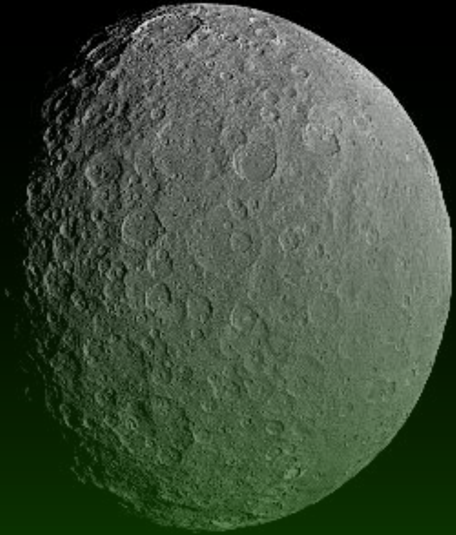
extruded to surface



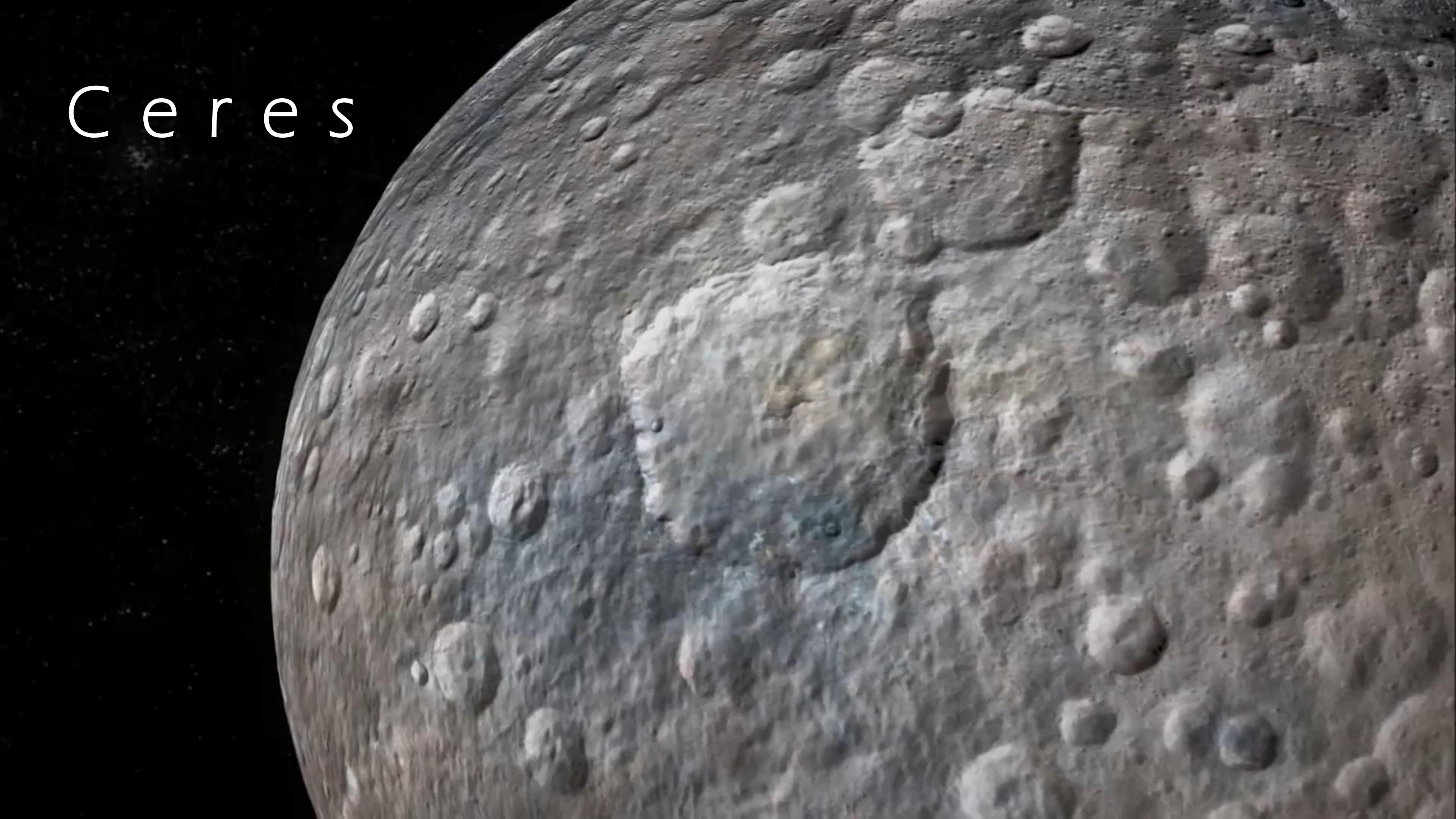
icy world



icy world



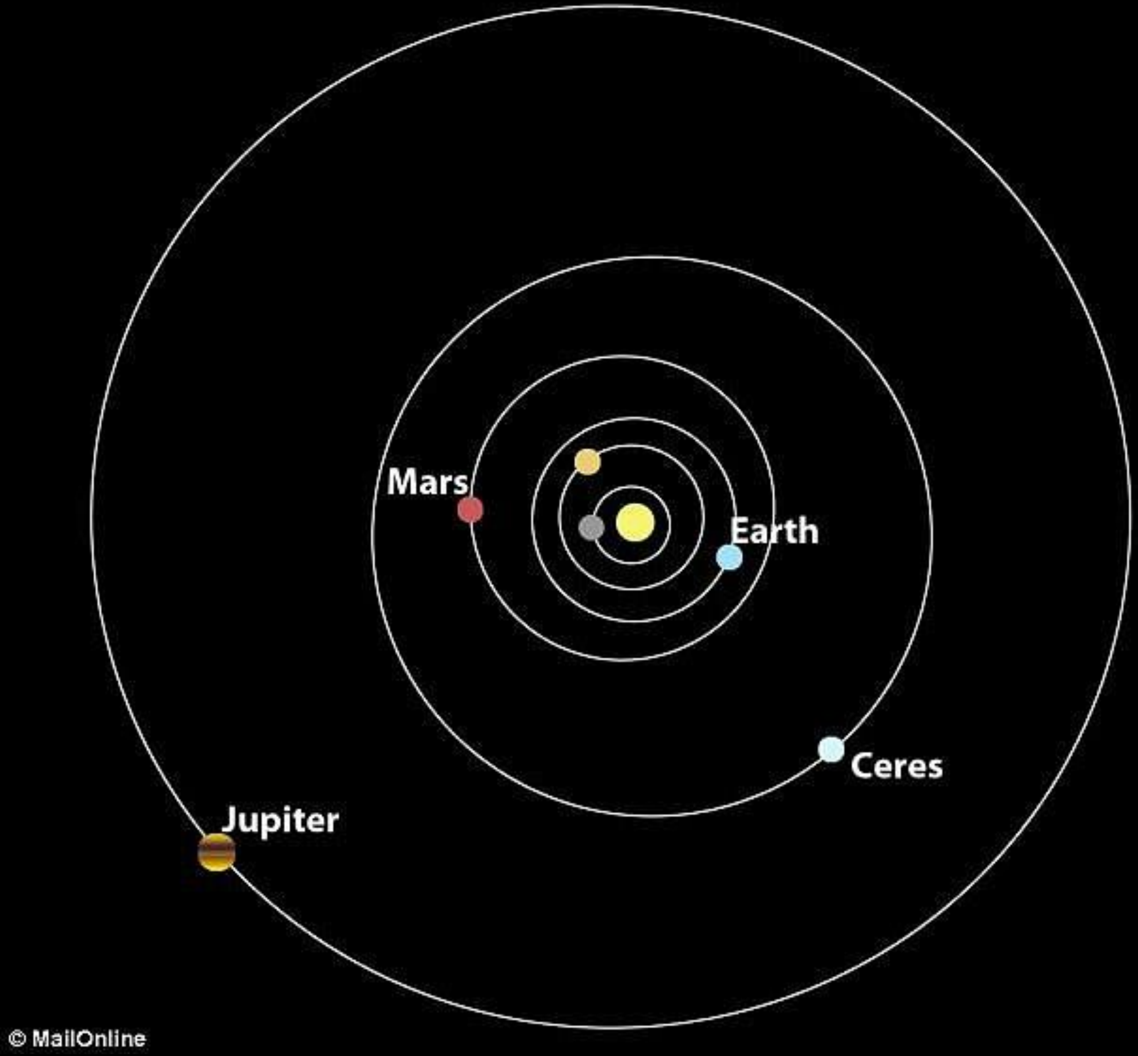
icy world
and
rocky surface


Ceres

C e r e s

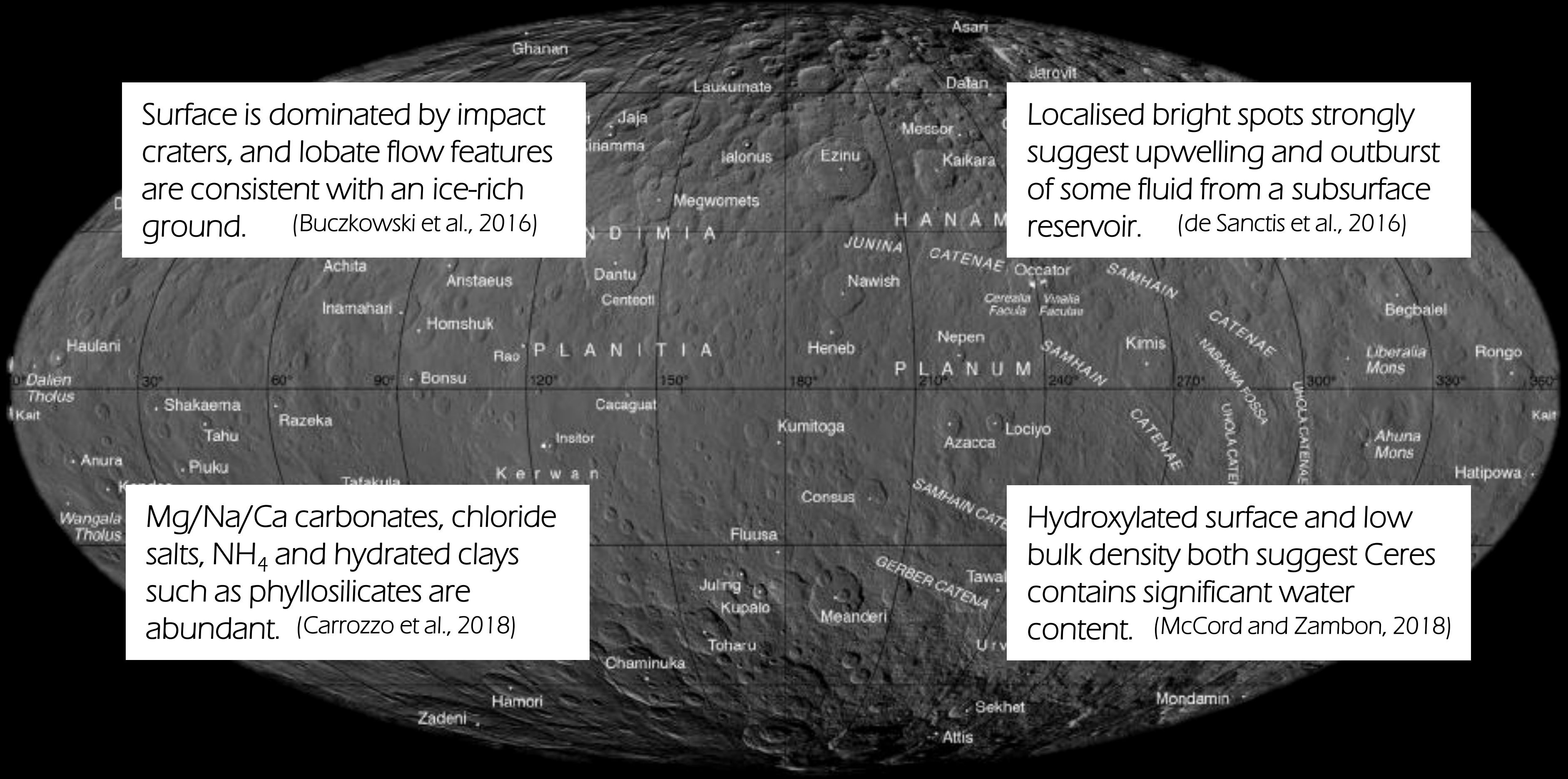
FACTS

Mass	9.393×10^{20} kg
Diameter	952 km
Aphelion	2.98 AU
Perihelion	2.56 AU
Orbital period	4.60 y



Surface is dominated by impact craters, and lobate flow features are consistent with an ice-rich ground. (Buczkowski et al., 2016)

Localised bright spots strongly suggest upwelling and outburst of some fluid from a subsurface reservoir. (de Sanctis et al., 2016)



Mg/Na/Ca carbonates, chloride salts, NH_4 and hydrated clays such as phyllosilicates are abundant. (Carrozzo et al., 2018)

Hydroxylated surface and low bulk density both suggest Ceres contains significant water content. (McCord and Zambon, 2018)

250 km

Map from Roatsch et al. (2016)

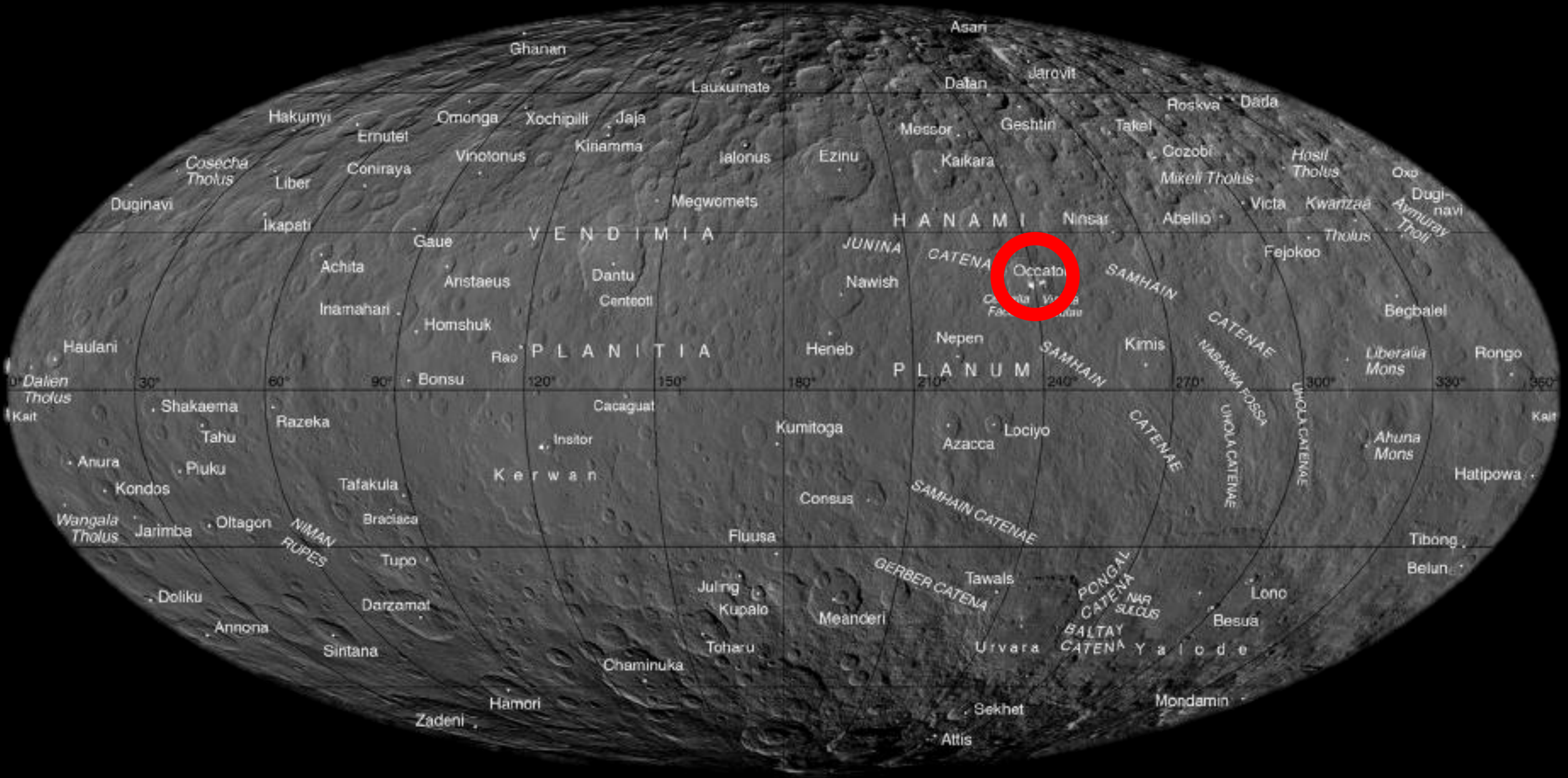
key science questions

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

2 **Origins:** *Did Ceres form in its present position?*

did Ceres' subsurface contain the ingredients for life?

a s t r o b i o l o g y

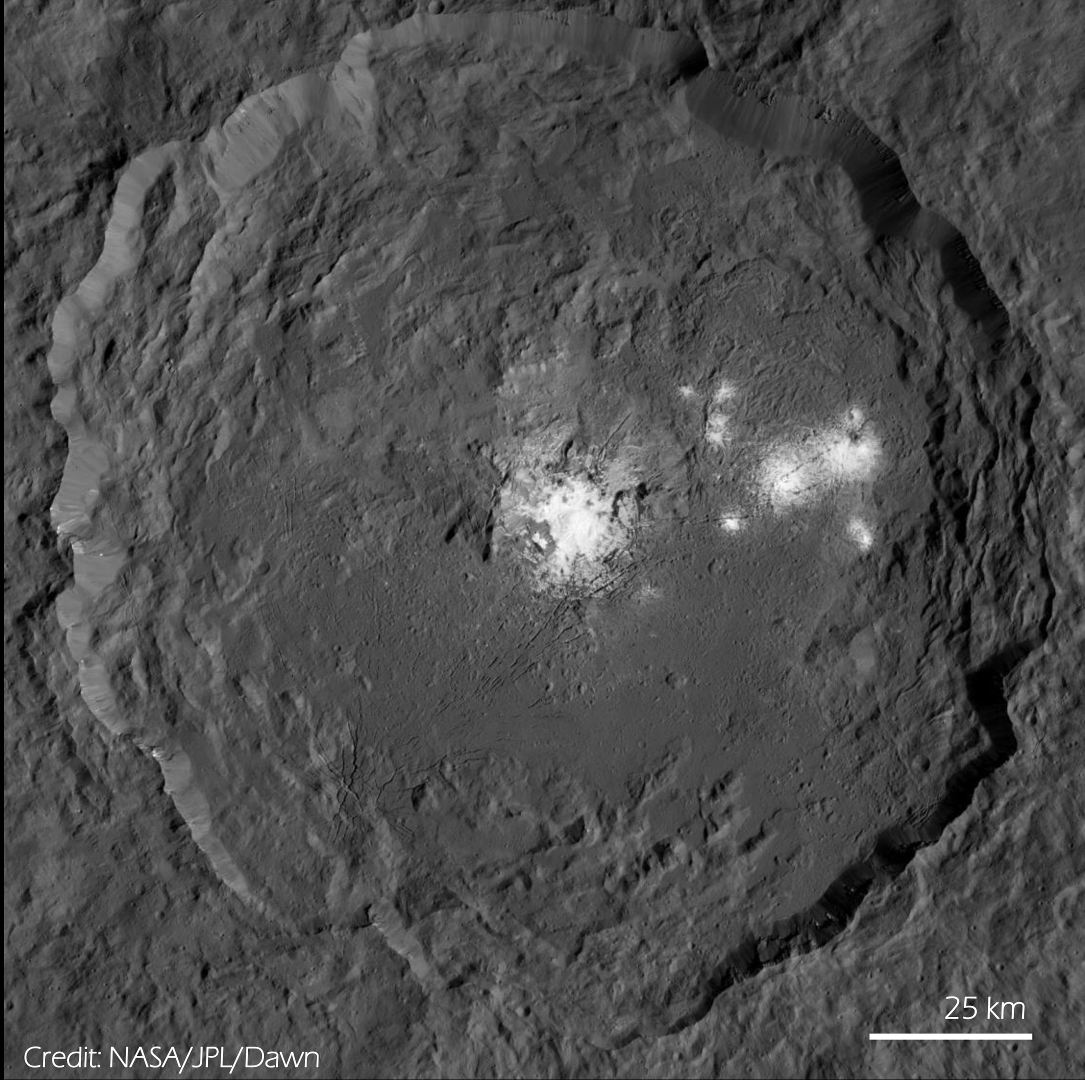


250 km

Roatsch et al. (2016)

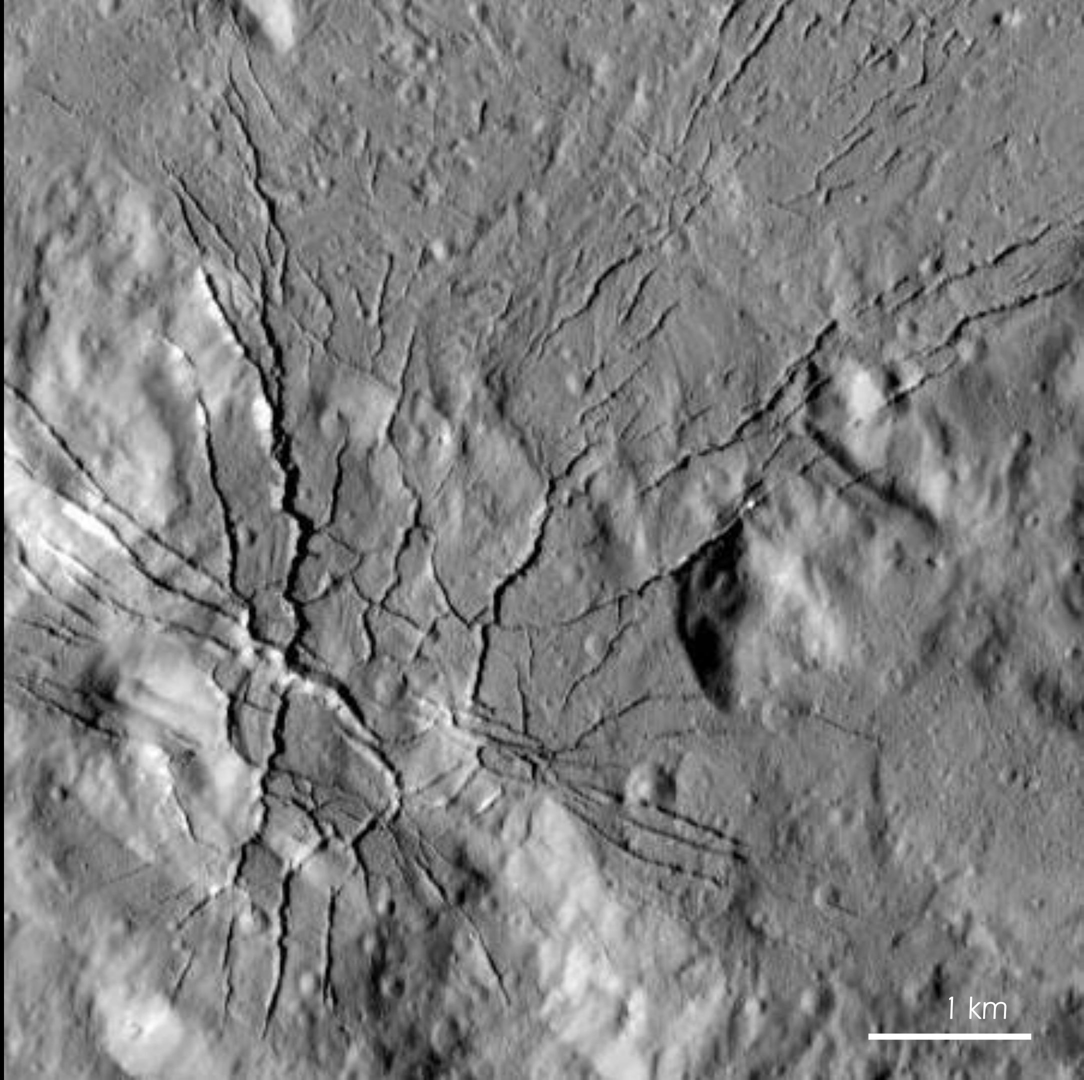
occator crater

- 92 km across
- 20 degrees N



occator crater

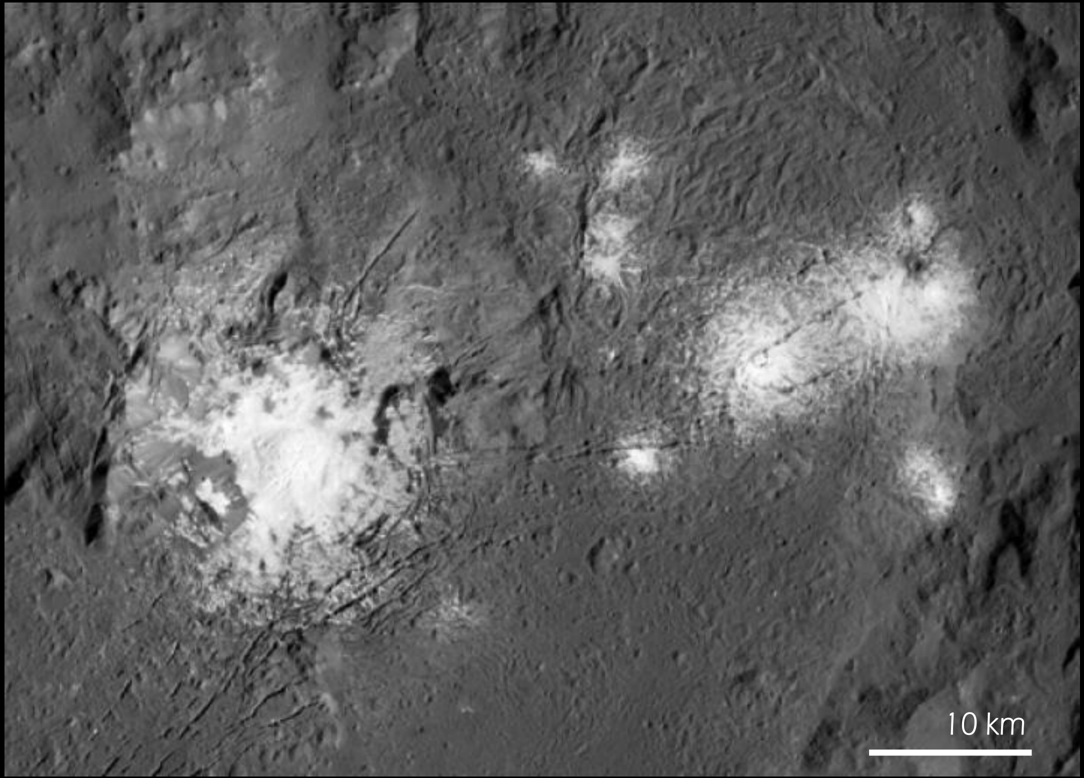
- 92 km across
- 20 degrees N
- fractured and domed



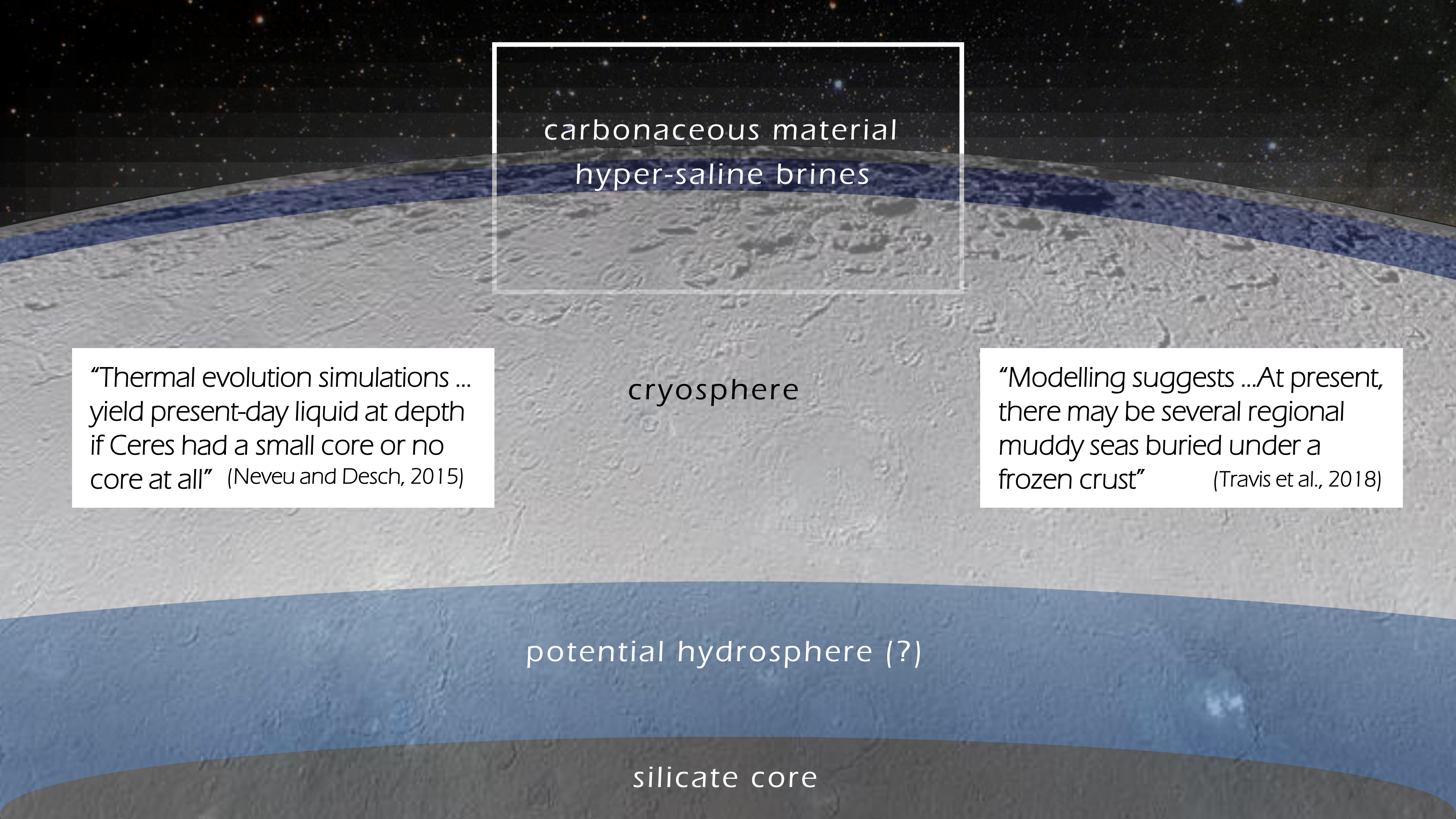
Credit: NASA/JPL/Dawn

o c c a t o r c r a t e r

- 92 km across
- 20 degrees N
- fractured and domed
- bright carbonate spots

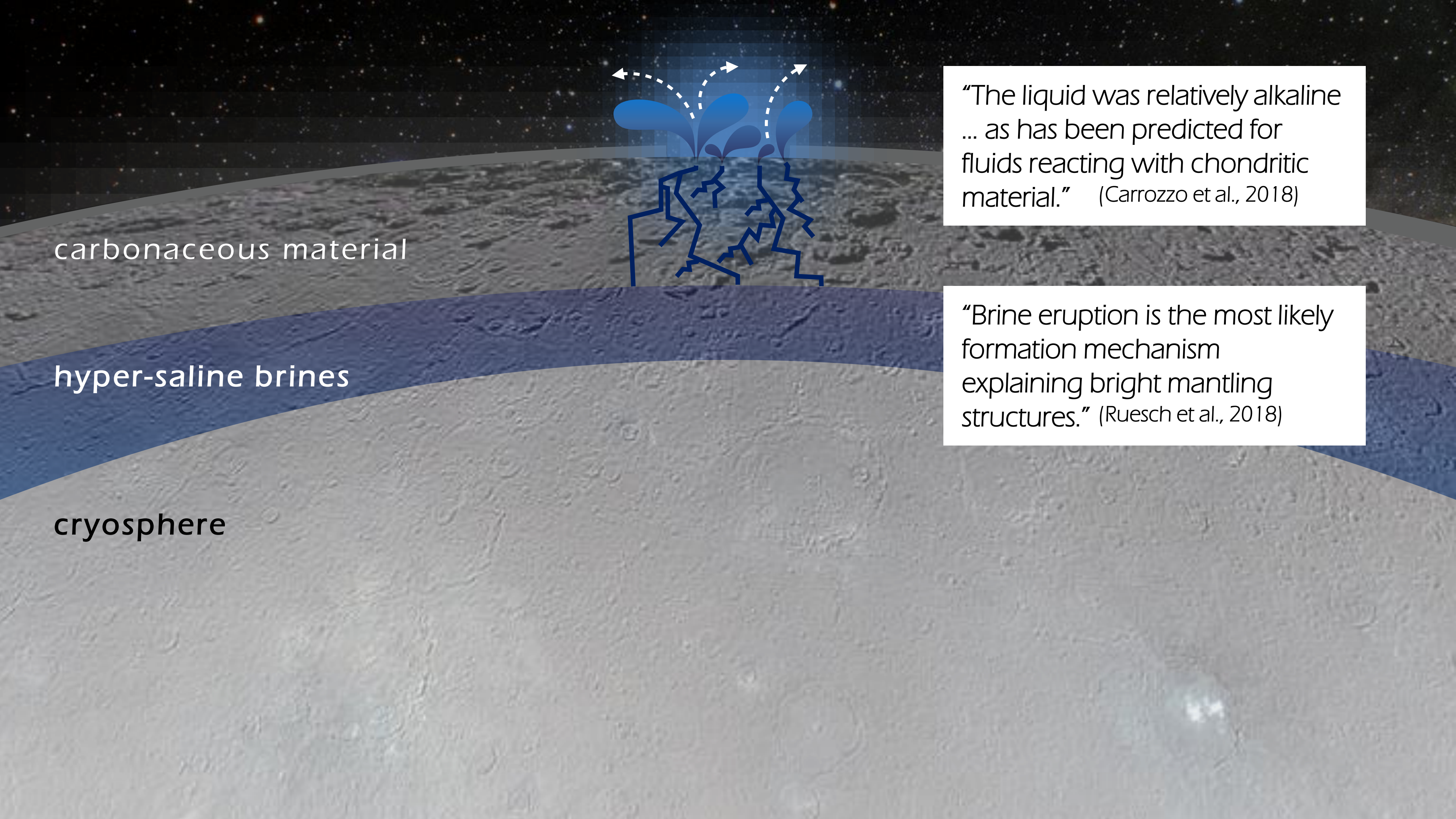


Credit: NASA/JPL/Dawn



"Thermal evolution simulations … yield present-day liquid at depth if Ceres had a small core or no core at all" (Neveu and Desch, 2015)

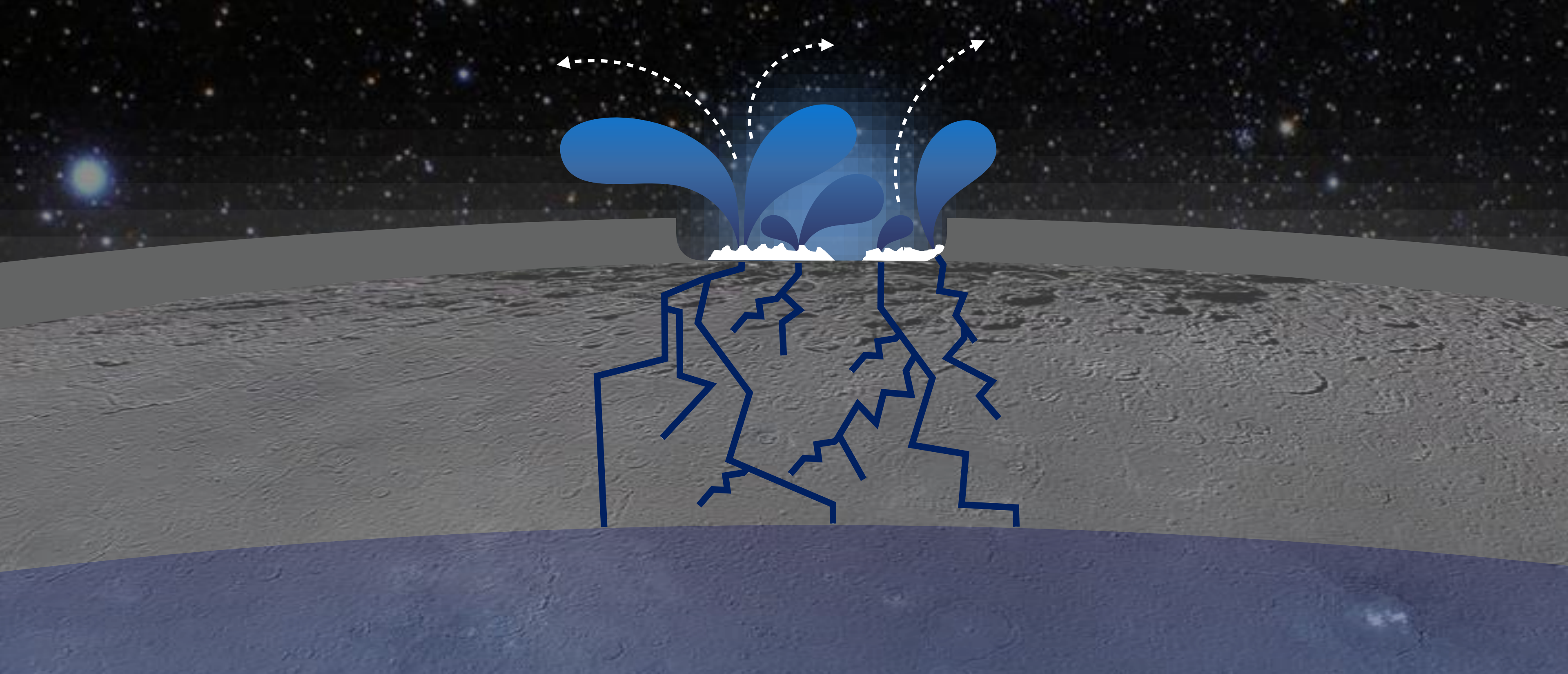
"Modelling suggests …At present, there may be several regional muddy seas buried under a frozen crust" (Travis et al., 2018)

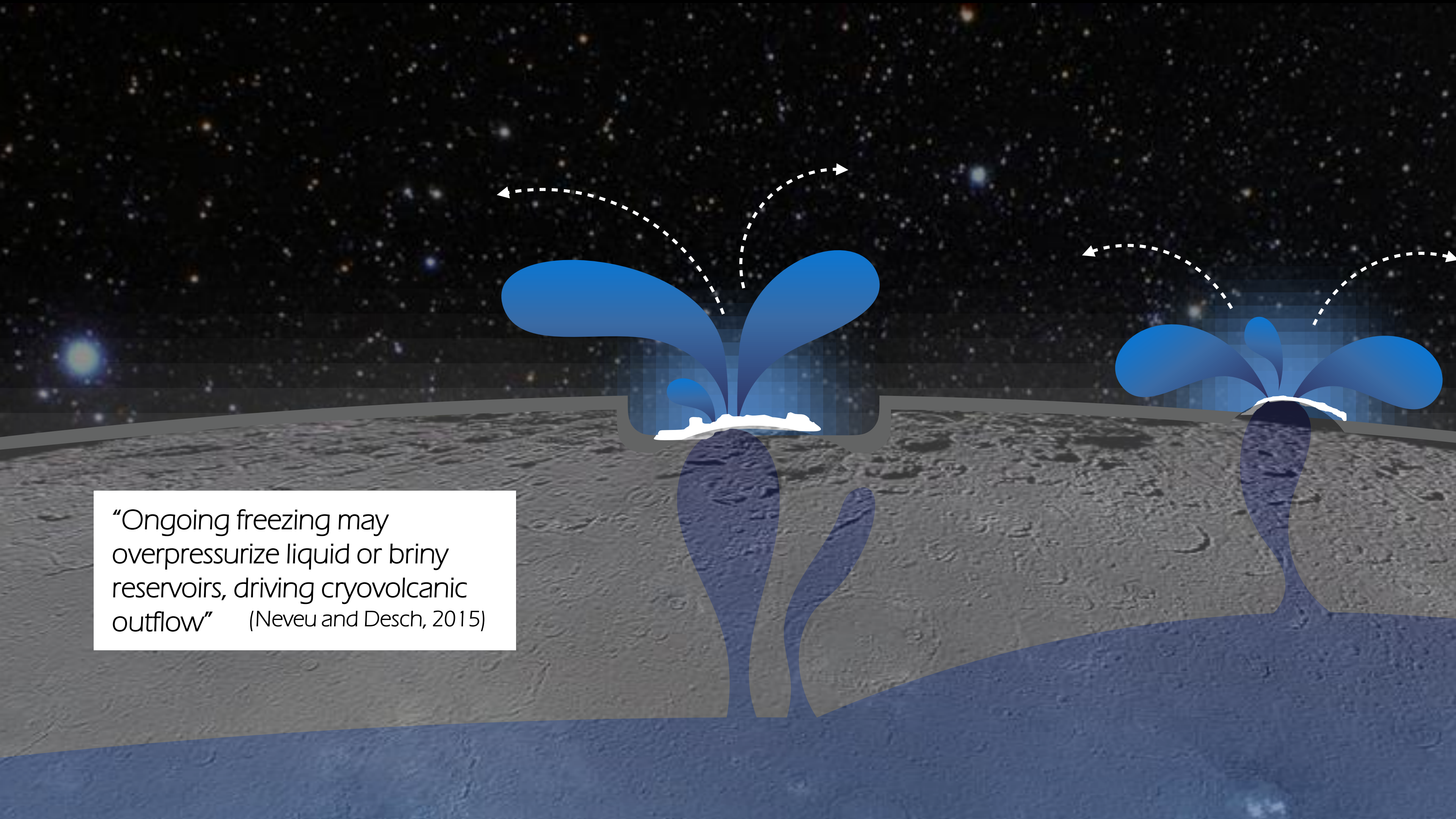


carbonaceous material
hyper-saline brines
cryosphere
"The liquid was relatively alkaline … as has been predicted for fluids reacting with chondritic material." (Carrozzo et al., 2018)
"Brine eruption is the most likely formation mechanism explaining bright mantling structures." (Ruesch et al., 2018)

Alkaline sodium-ammonium-chloride-carbonate brines = carbonates with these species.
(Thomas et al., 2017; Vu et al., 2017)

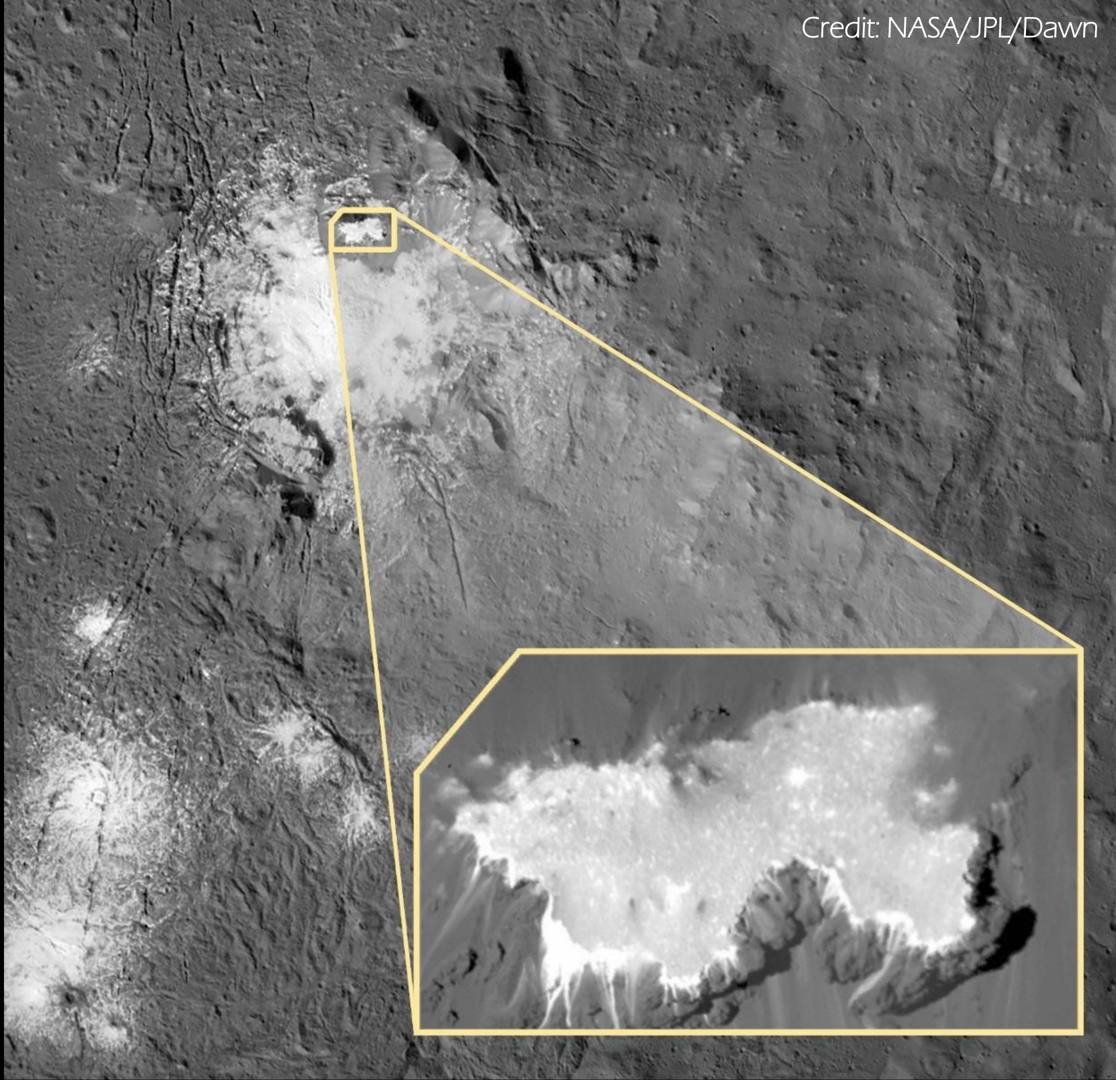
"The presence of hydrated carbonates indicates their formation/exposure ... is geologically recent and dehydration is ongoing, implying a still-evolving body." (Carrozzo et al., 2018)




"Ongoing freezing may overpressurize liquid or briny reservoirs, driving cryovolcanic outflow" (Neveu and Desch, 2015)

bright material

- diverse carbonate salts including sodium, calcium, magnesium, ammonia carbonate
- complex organic molecules also present in brine layer



astrobiology questions

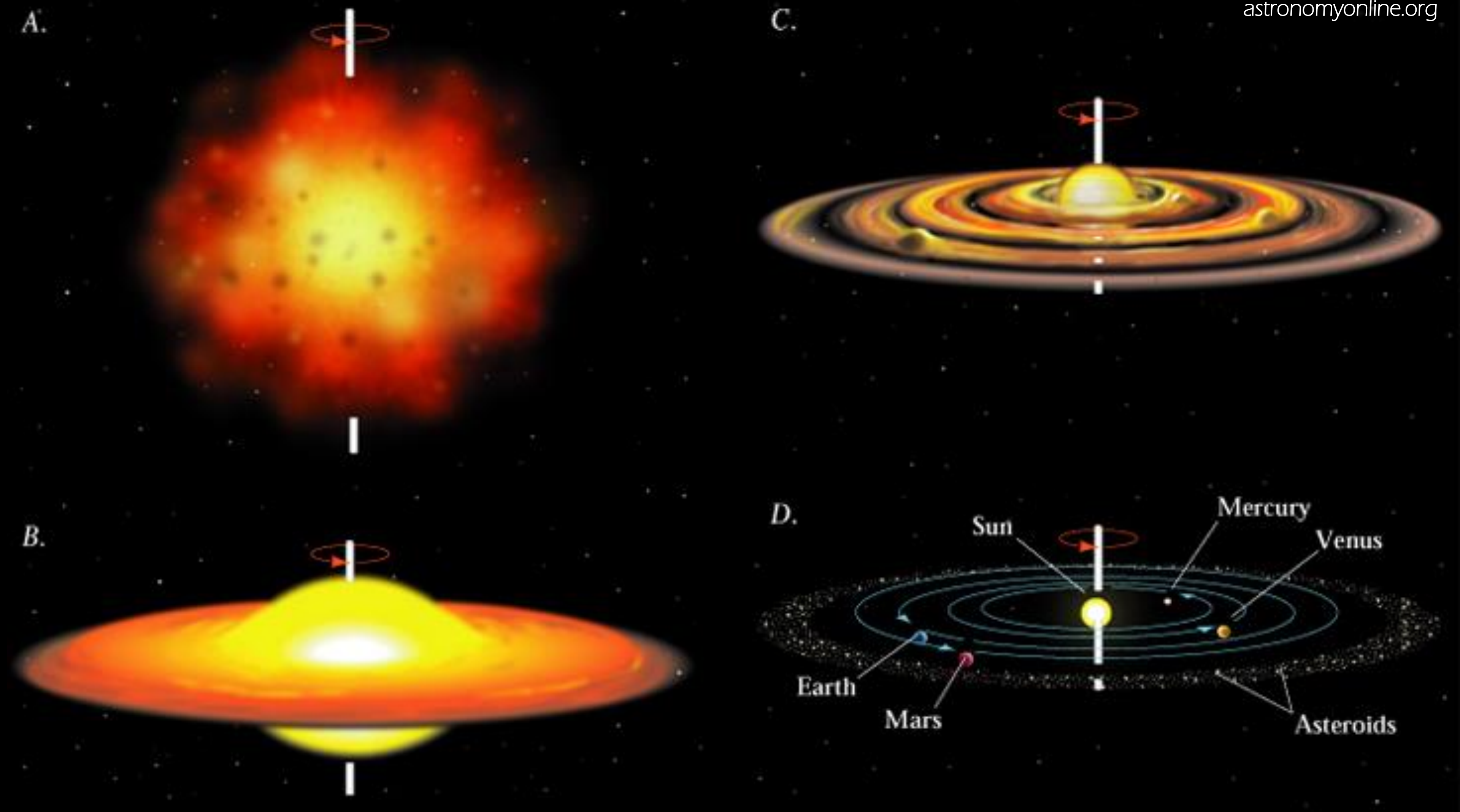
1 What is the nature of the bright material?

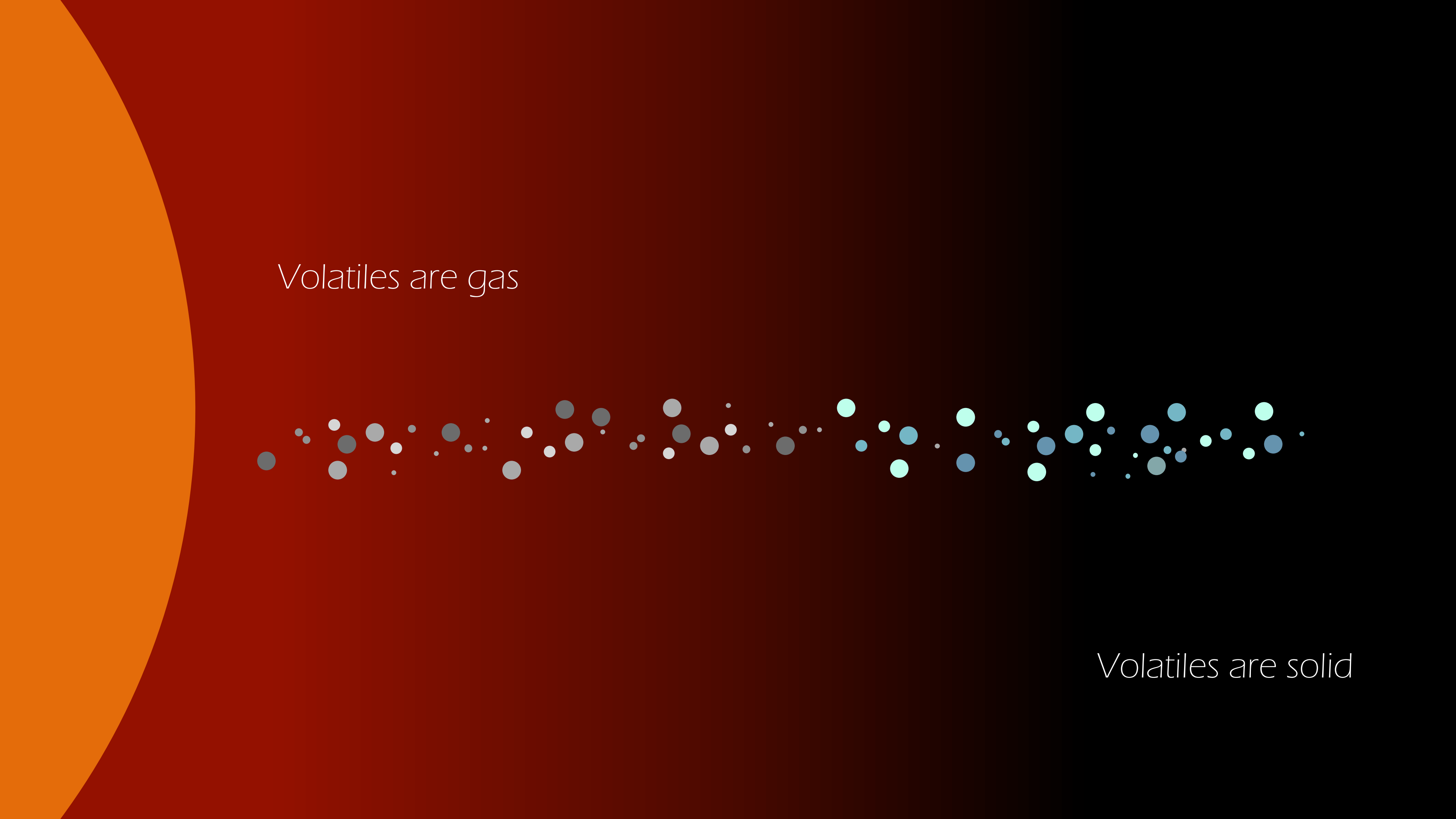
2 Were the ingredients for life present in the subsurface of Ceres?

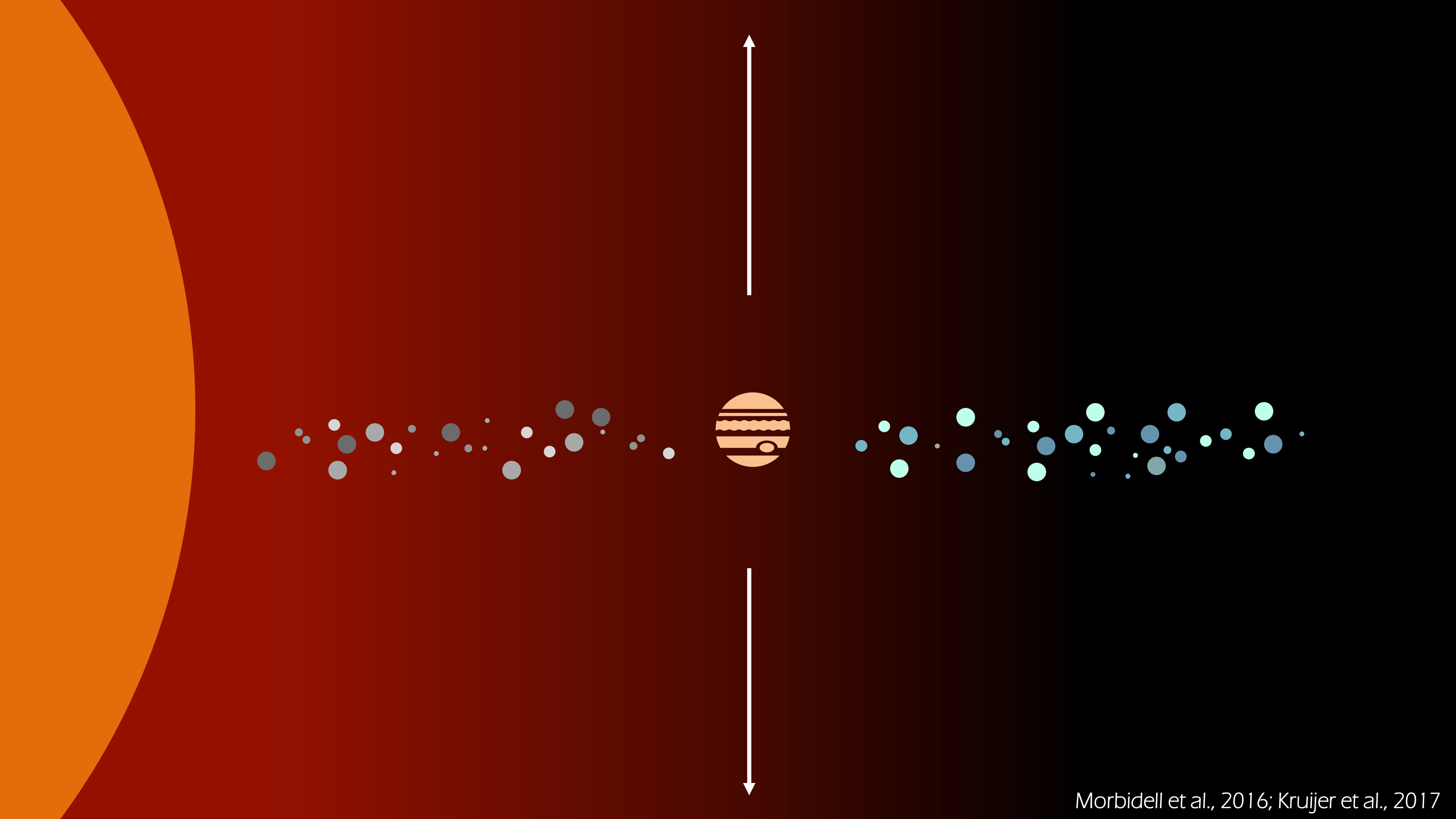
3 What role do small body hydrospheres play in the search for life?

did Ceres form in its present position?

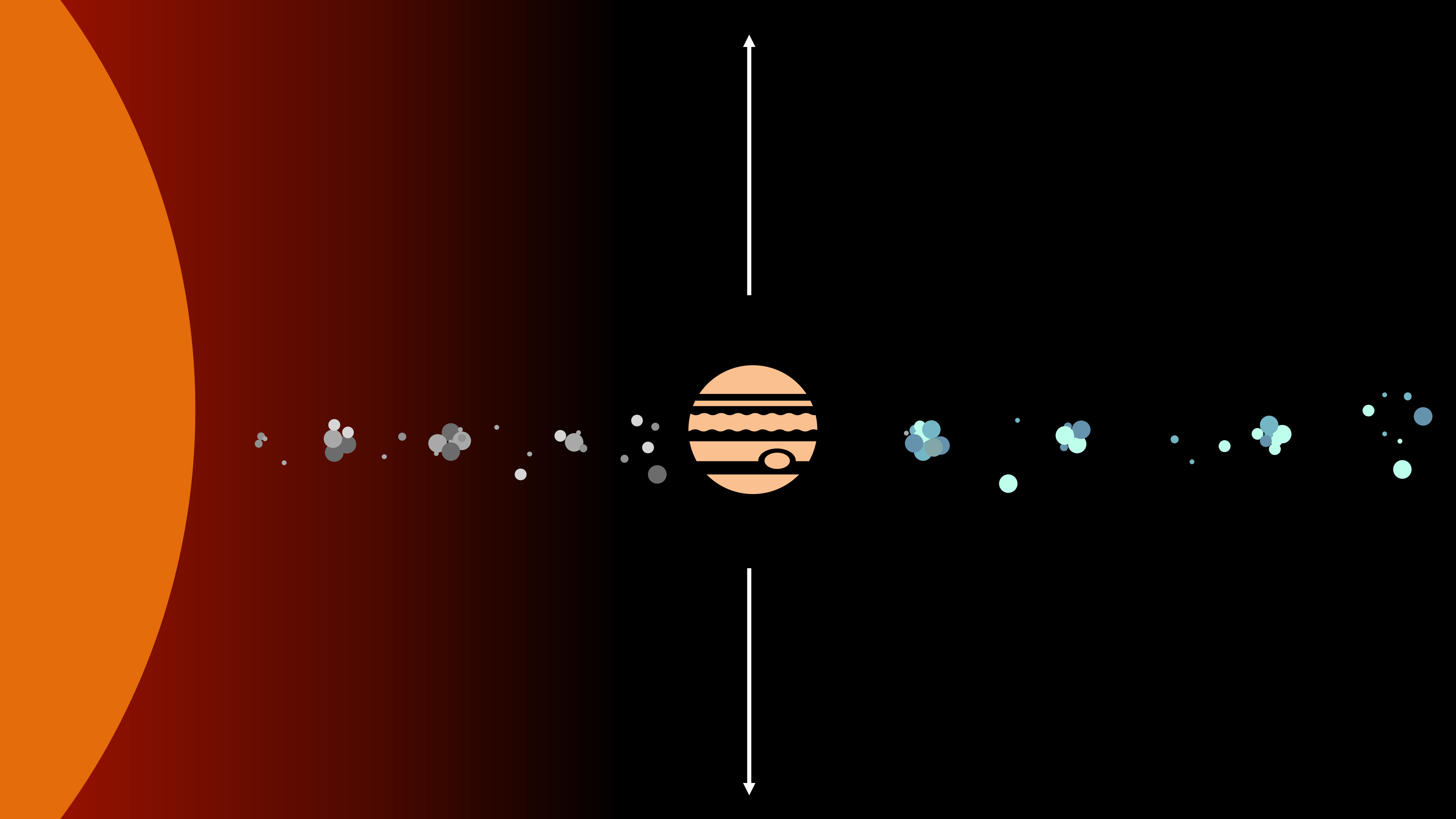
o r i g i n s

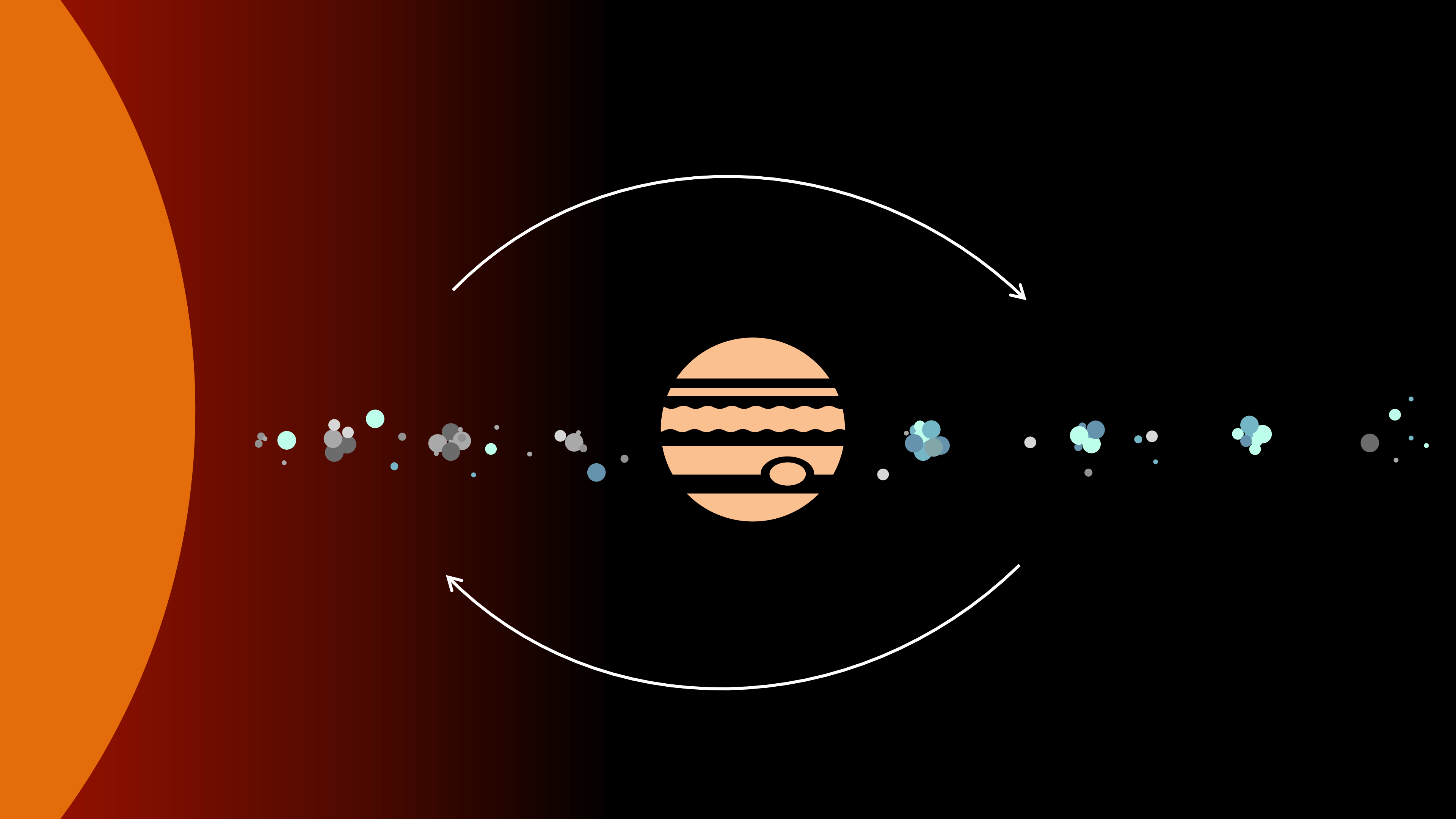

A.
B.
C.
D.
Sun
Mercury
Venus
Earth
Mars
Asteroids

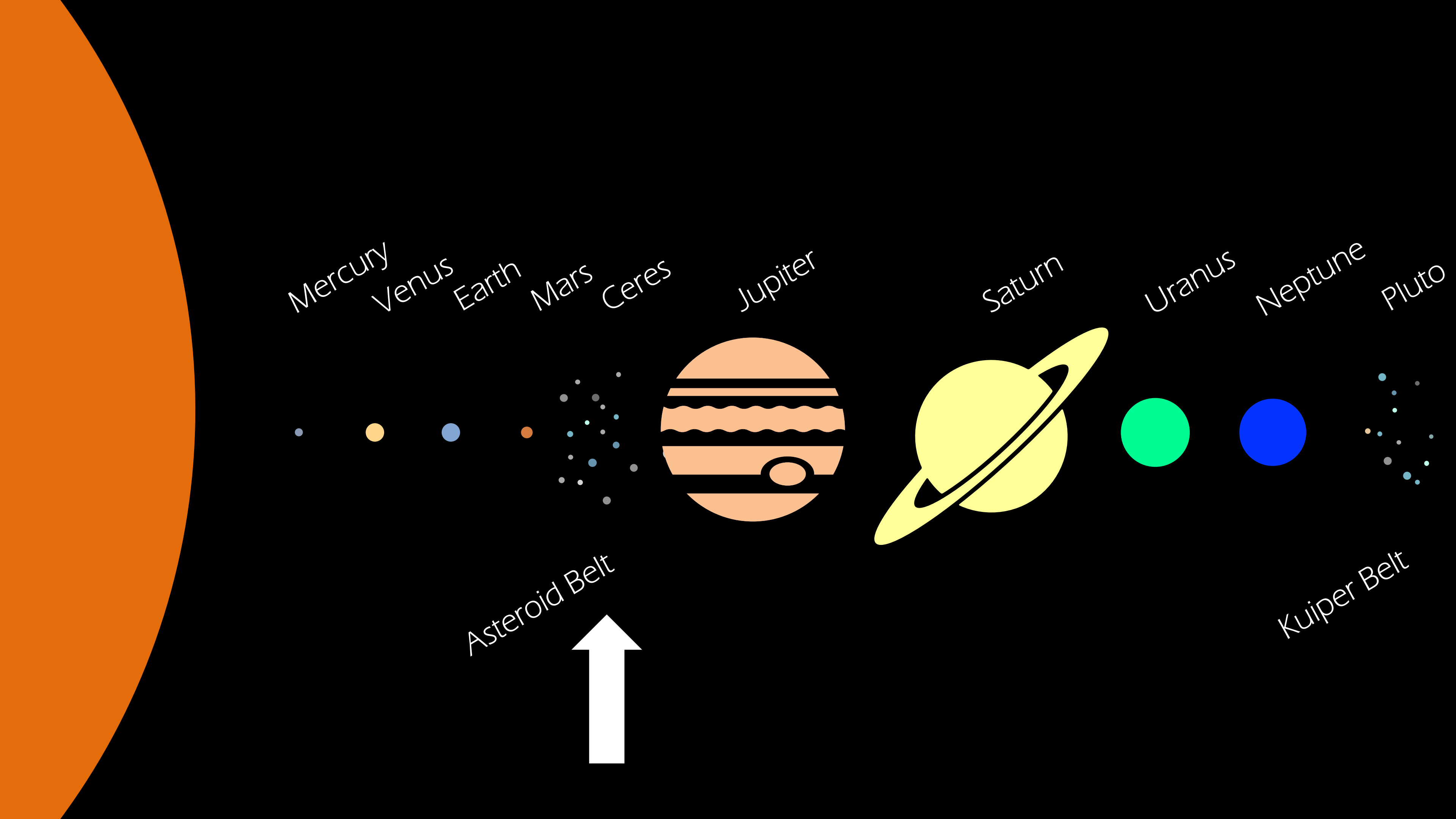

Volatiles are gas
Volatiles are solid



Morbidell et al., 2016; Kruijer et al., 2017

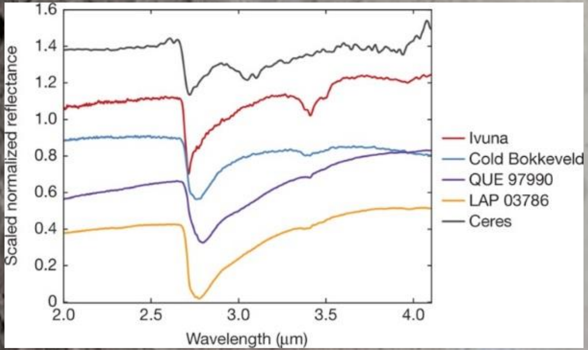





Mercury
Venus
Earth
Mars
Ceres
Jupiter
Saturn
Uranus
Neptune
Pluto
Asteroid Belt
Kuiper Belt

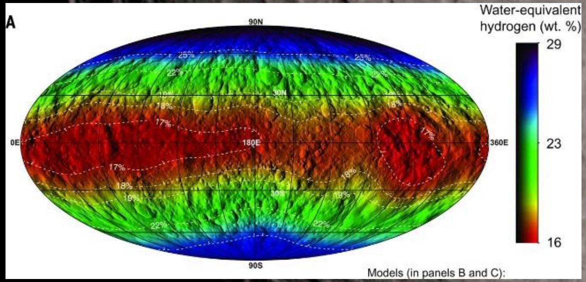
ammonia-rich crust

too volatile to condense in situ
in asteroid belt (Morbidelli et al., 2016)



carbonaceous surface

agrees with carbonaceous
chondrite spectra (De Sanctis et al., 2015)



high volatile content

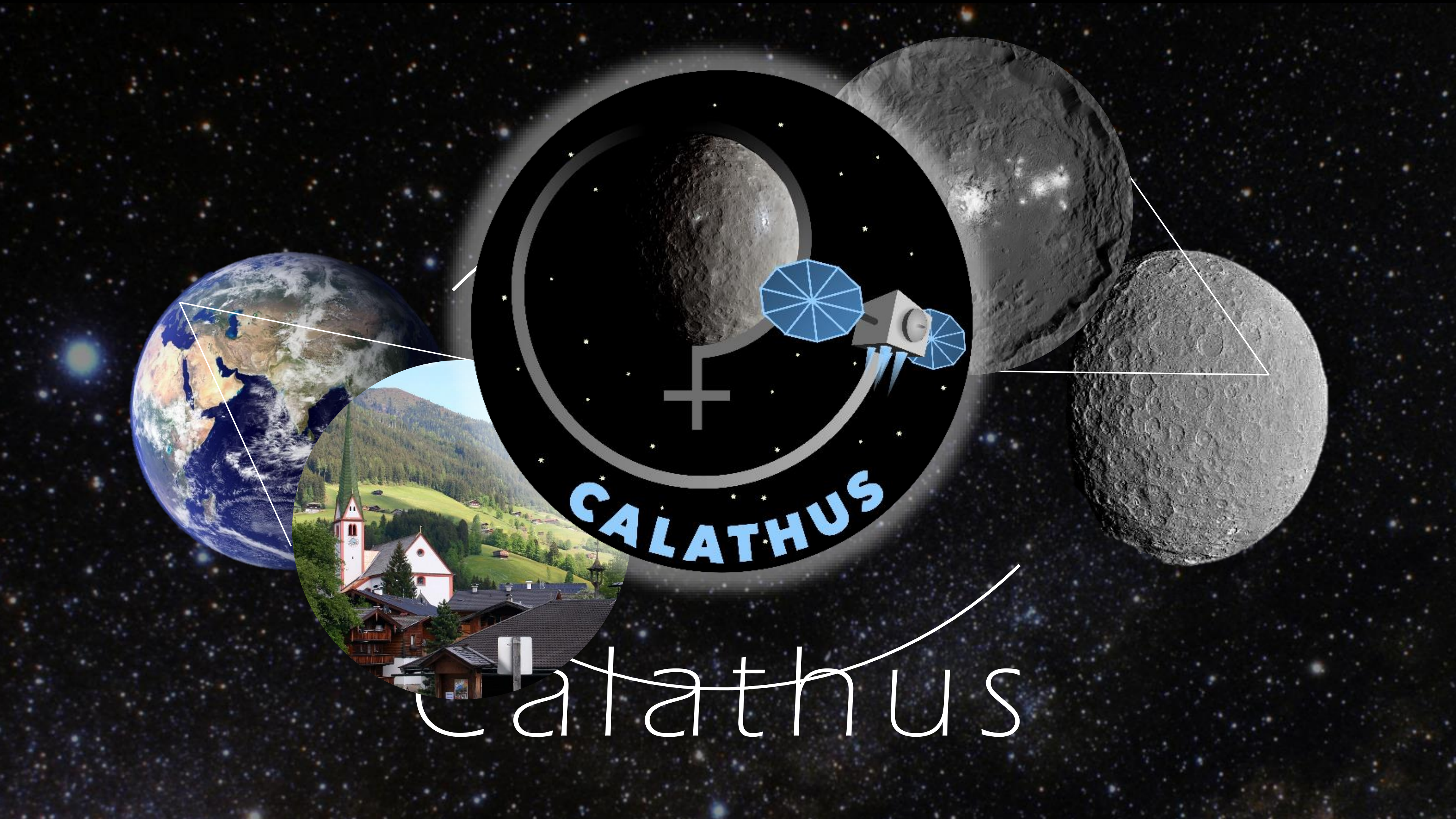
around 30% water (Prettyman et al., 2017)

origins questions

1. What is the nature of Ceres' carbonaceous material?

2. Where did Ceres and other C-type asteroids form?

3. Did C-type small bodies like Ceres contribute to the delivery of Earth's water?


CALATHUS
Calathus

why sample return?

1 Precise

2 Future-thinking

3 Provides context

4 Reproducible

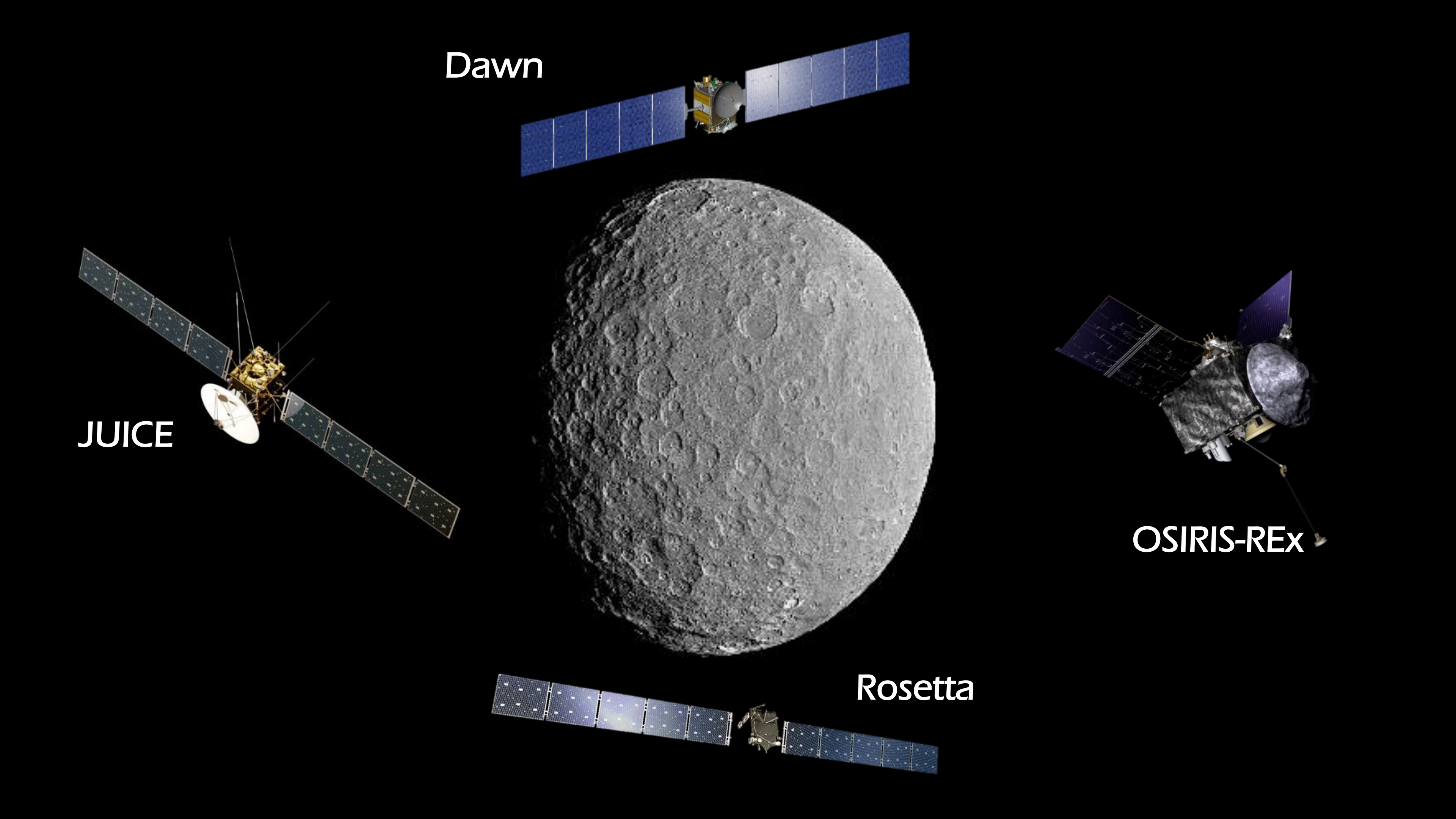
Credit: Vincianne Debaille

sample characterisation

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 for life present in the subsurface of Ceres?

Did Ceres originate beyond the main belt? - How much beyond (KBO, gas giant region)


Dawn
JUICE
OSIRIS-REx
Rosetta

“Jupiter’s moon Europa … has a **high priority** in the search for habitability in the Solar System.”

“These science goals could be achieved by a **dedicated Europa orbiter and/or lander.**”

“While highly desirable, a Europa lander **may not be technologically feasible within 2015-2025.**”

A sample return from Ceres is the ideal training ground to realise this goal

from Cosmic Vision page 25

traceability matrix

Science Question	Science Objective	Science Requirements	Observational Requirements	Instrument	Instrumental Requirements	System	System Requirements
Are the ingredients for life present in the subsurface of Ceres?	SO1: To determine how Occator crater carbonates in the faculae form.	SR1.1: The chemical composition shall be measured.	OR1.1: The minimum spatial resolution shall be 0.5 μm.	sample return (SR), X-ray diffracto-meter	IR1: A sample with a minimum volume of 4 cm^3 at a minimum depth of 50 mm below the surface of Ceres shall be taken while holding the samples temperature beneath 235 K.	Orbiting Sample (OS)	SysR1.1: The sample shall be returned safely to earth.

part ii

mission profile

mission objectives

1 To return carbonate samples from the surface of Ceres to Earth

2 To characterize the landing site to contextualize the returned samples

what will we do?

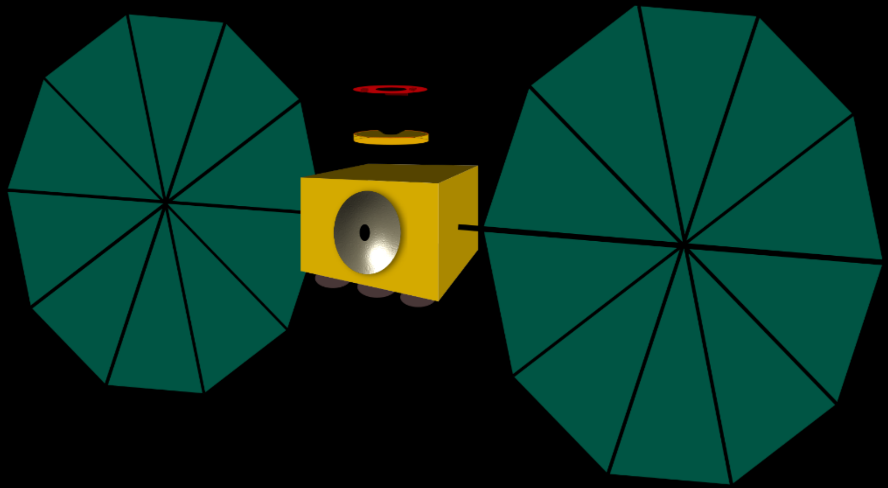
- Sample return
  - Retrieving 3 samples from within the reach of the arm for subsequent analysis on Earth

- In situ measurements
  - Temperature analysis of the surface
  - Mapping of the landing site during descent
  - Close-up imaging of the sampling site and panoramic view
  - Isotopic and composition analysis of one sample

- Surface mapping from orbit

how will we do it?

- Calathus
  - Orbiter
  - Piazzi
    - Bus
      * Ascent module
        - Propulsion platform
        - Orbiting sample
    - Surface module



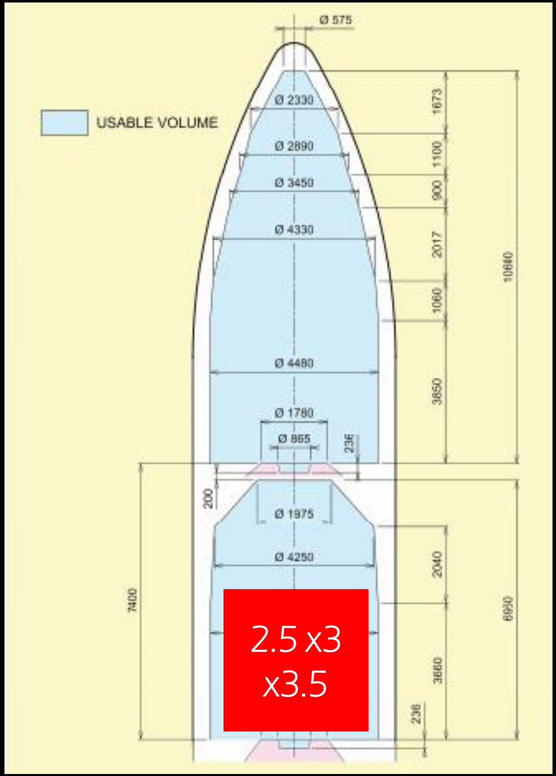
Layout of spacecraft

How will we do it?

Ariane 64

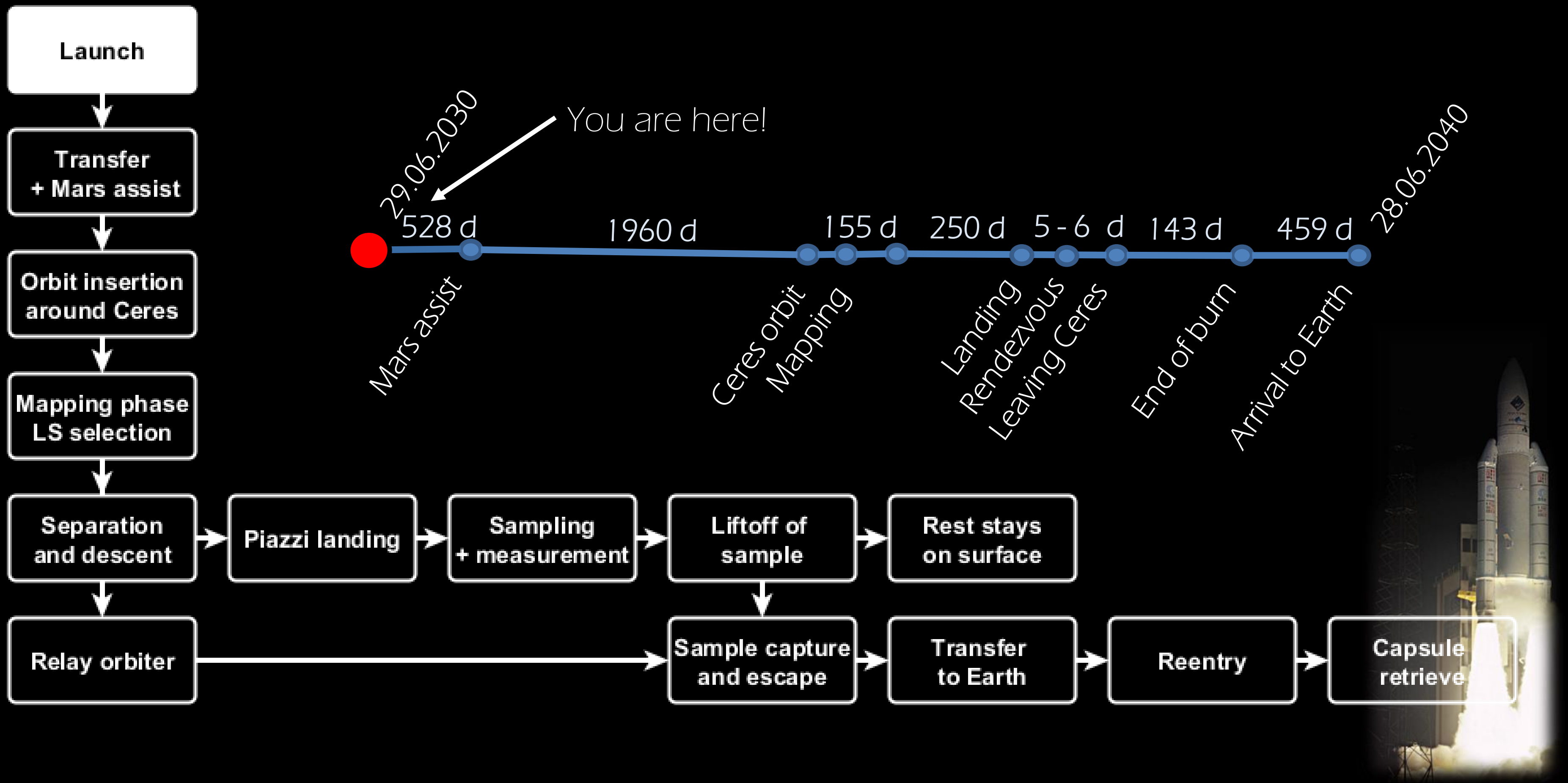
Mission systems		Wet mass (kg)
Orbiter		2500
Piazzi	Bus	57
	Surface module	200
Drymass		2757
Wetmass		5505

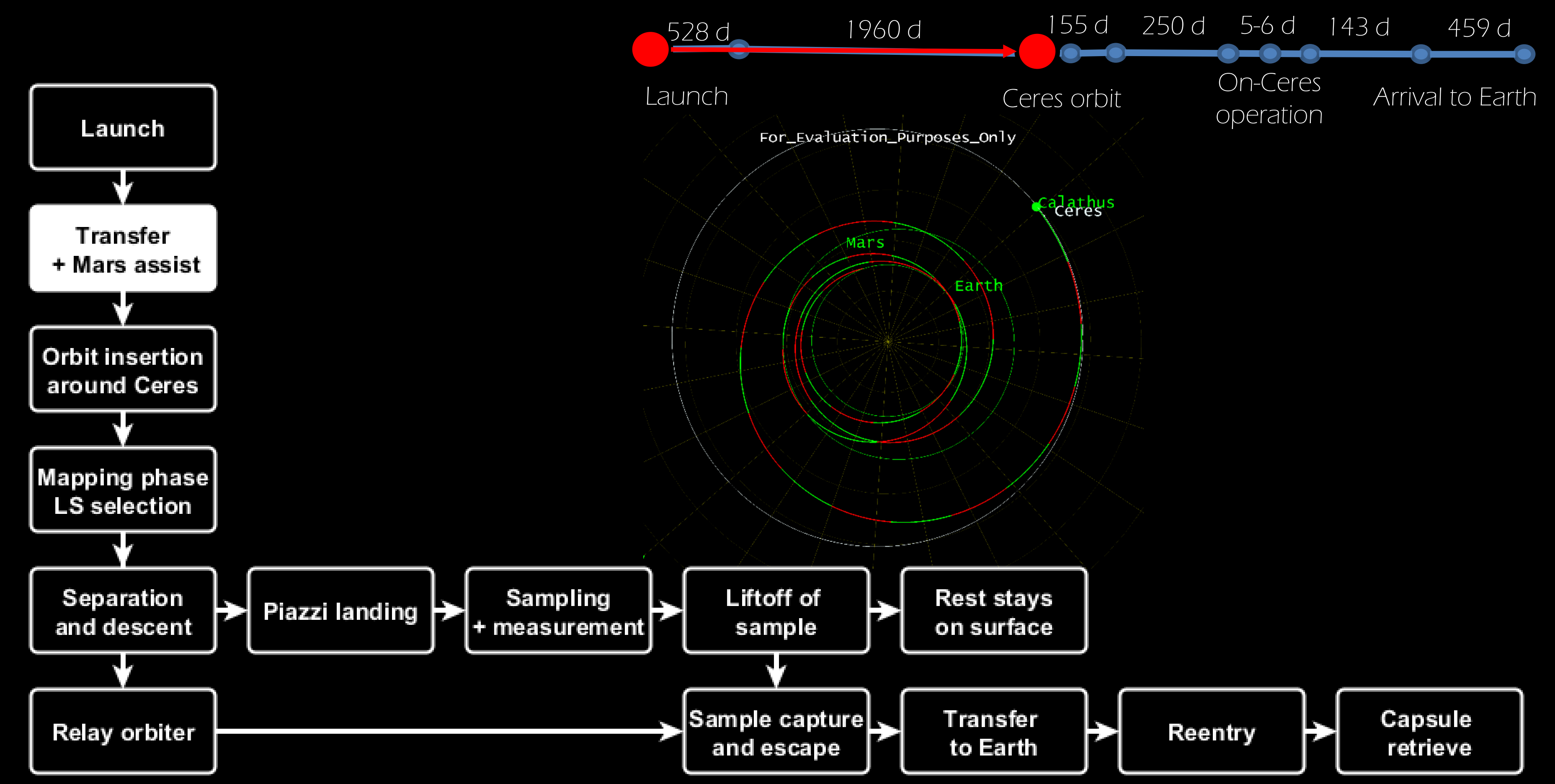
Ariane 64 capacity for Earth escape: 7400 kg



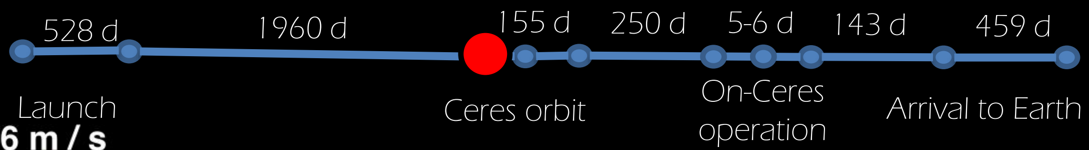
mission scenario

mission scenario

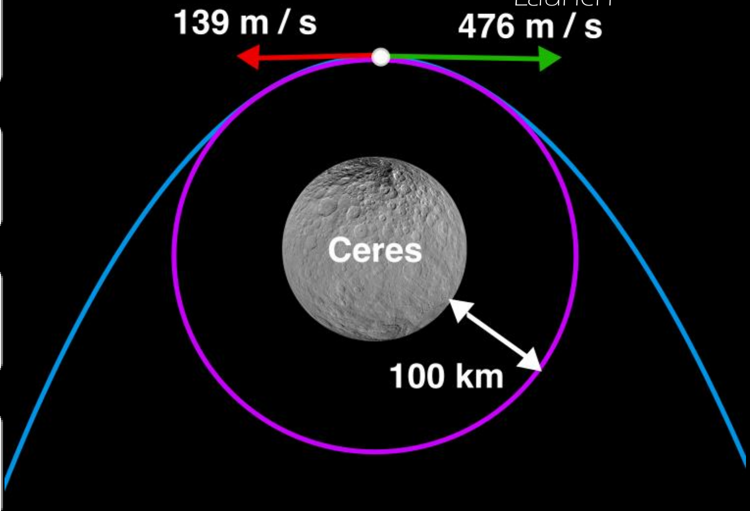




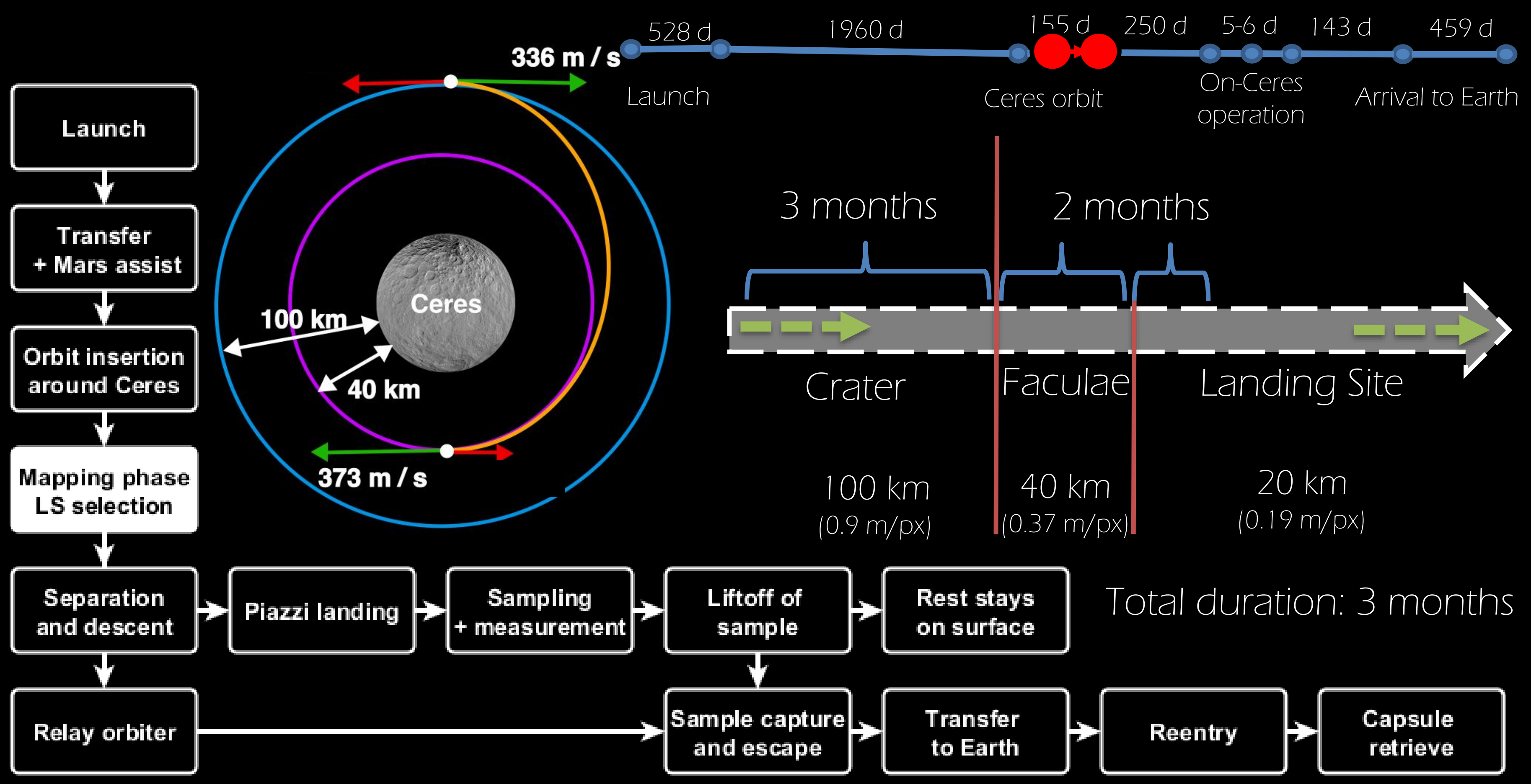
528 d
1960 d
155 d
250 d
5-6 d
143 d
459 d
Launch
Ceres orbit
On-Ceres operation
Arrival to Earth
For_Evaluation_Purposes_Only
Calathus
Ceres
Mars
Earth
Launch
Transfer + Mars assist
Orbit insertion around Ceres
Mapping phase LS selection
Separation and descent
Piazzi landing
Sampling + measurement
Liftoff of sample
Rest stays on surface
Relay orbiter
Sample capture and escape
Transfer to Earth
Reentry
Capsule retrieve



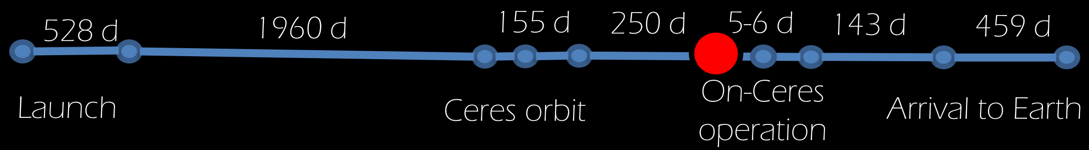
- Launch
- Transfer + Mars assist
- **Orbit insertion around Ceres**
- Mapping phase LS selection
- Separation and descent → Piazzi landing → Sampling + measurement → Liftoff of sample → Rest stays on surface
- Relay orbiter → Sample capture and escape
- Liftoff of sample → Sample capture and escape → Transfer to Earth → Reentry → Capsule retrieve

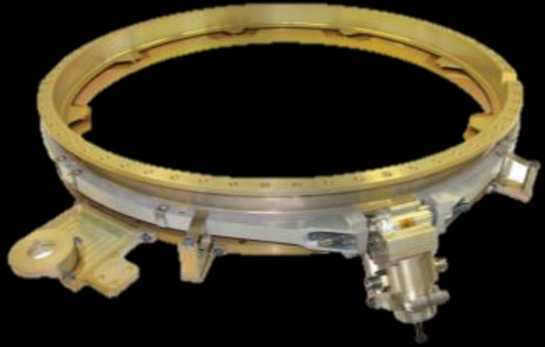


Orbit insertion	
dV (m/s)	139
Margin	1.1
Final dV (m/s)	153
Mass EOM (kg)	3200
Mass BOM (kg)	3364
Fuel Mass (kg)	163
Isp (s)	312
Engine Thrust (N)	490



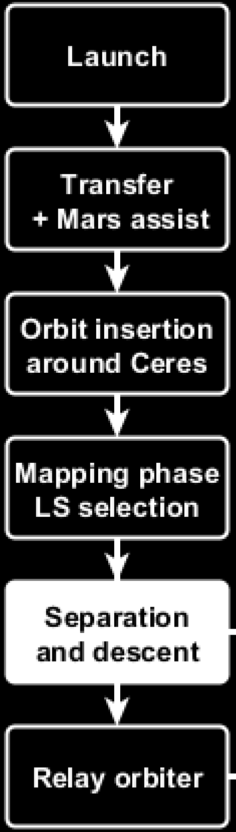
528 d
1960 d
155 d
250 d
5-6 d
143 d
459 d
336 m / s
Launch
Ceres orbit
On-Ceres operation
Arrival to Earth
Launch
Transfer + Mars assist
Orbit insertion around Ceres
Mapping phase LS selection
Ceres
100 km
40 km
373 m / s
3 months
2 months
Crater
Faculae
Landing Site
100 km (0.9 m/px)
40 km (0.37 m/px)
20 km (0.19 m/px)
Separation and descent
Piazzi landing
Sampling + measurement
Liftoff of sample
Rest stays on surface
Total duration: 3 months
Relay orbiter
Sample capture and escape
Transfer to Earth
Reentry
Capsule retrieve

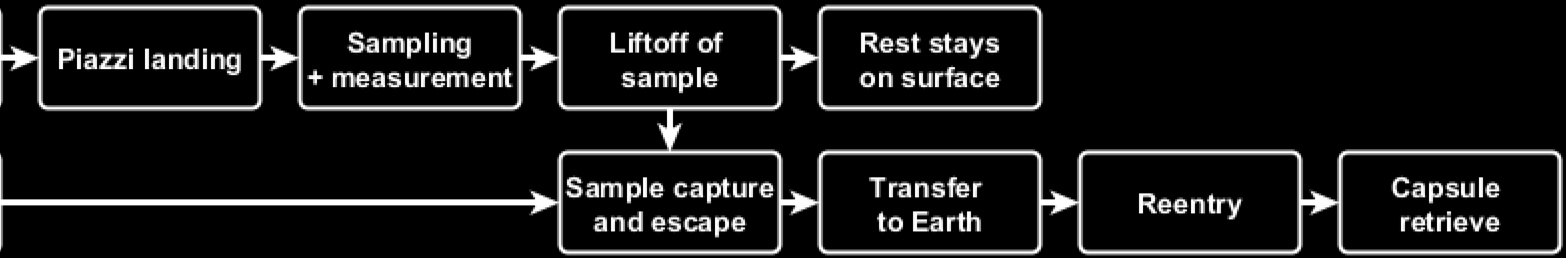


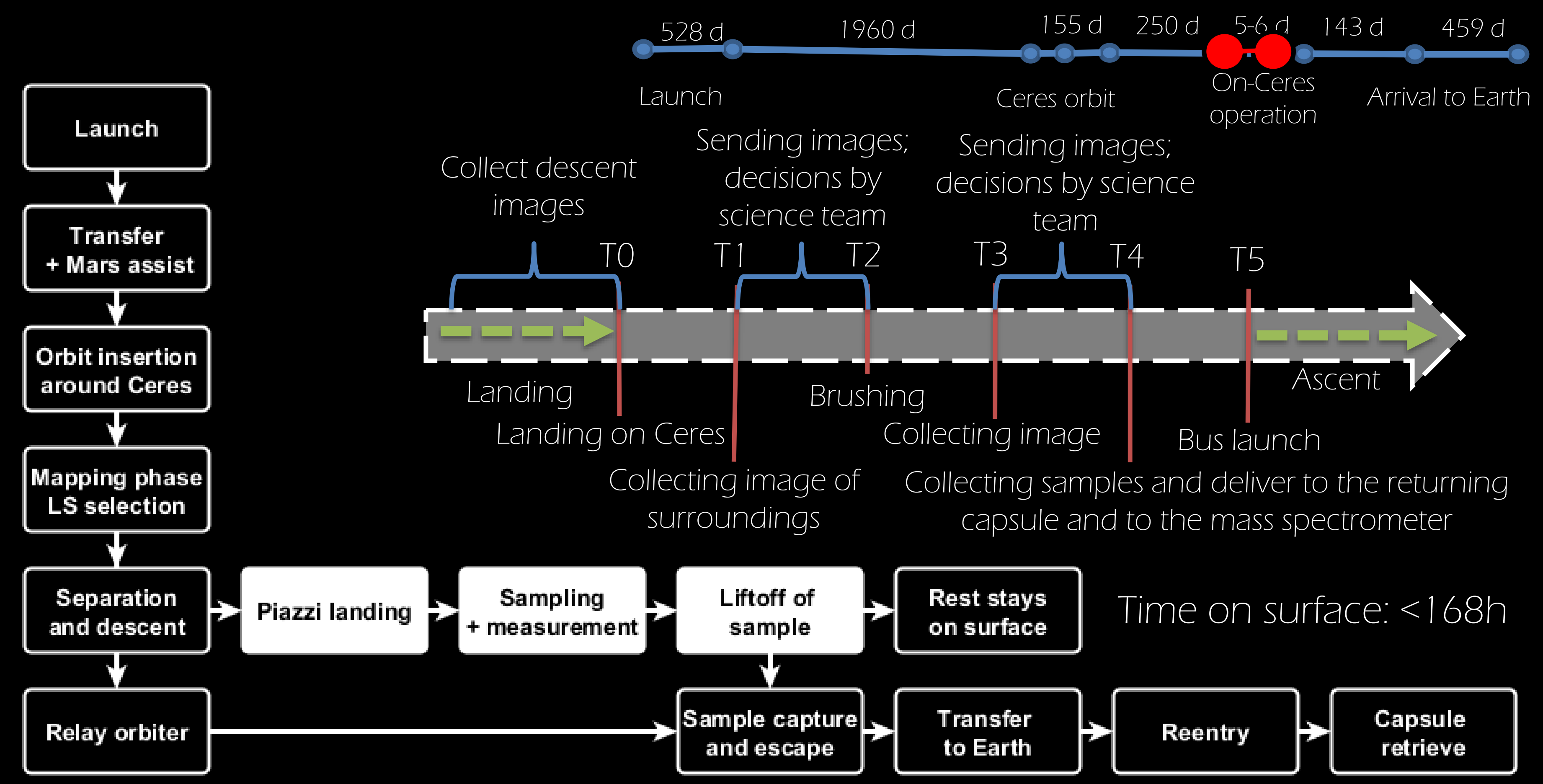


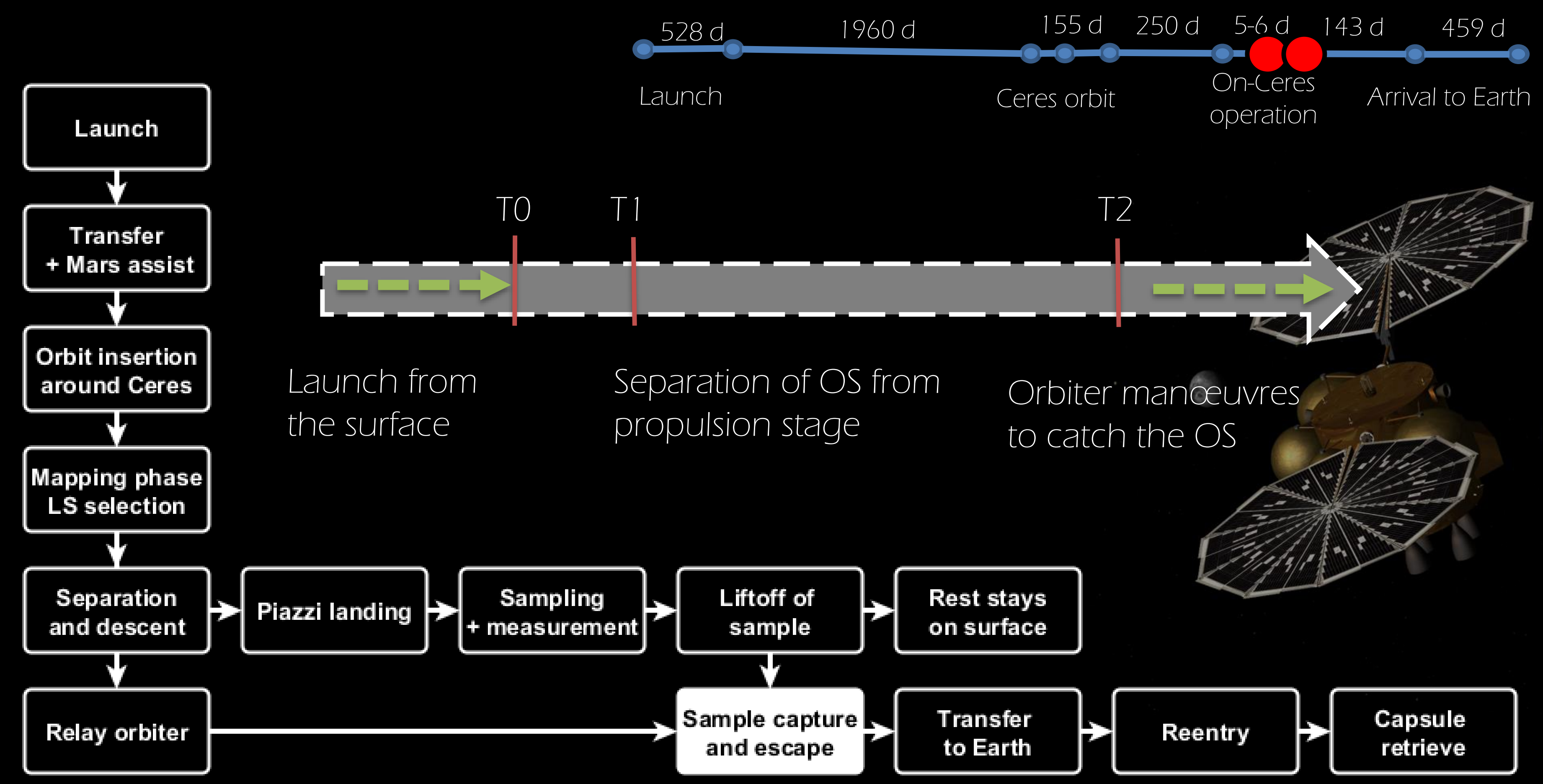
Descent

dV (m/s)	419
Margin	1.1
Final dV (m/s)	461
Mass EOM (kg)	300
Mass BOM (kg)	348.4
Fuel Mass (kg)	48.8
Isp (s)	312
Engine Thrust (N)	490

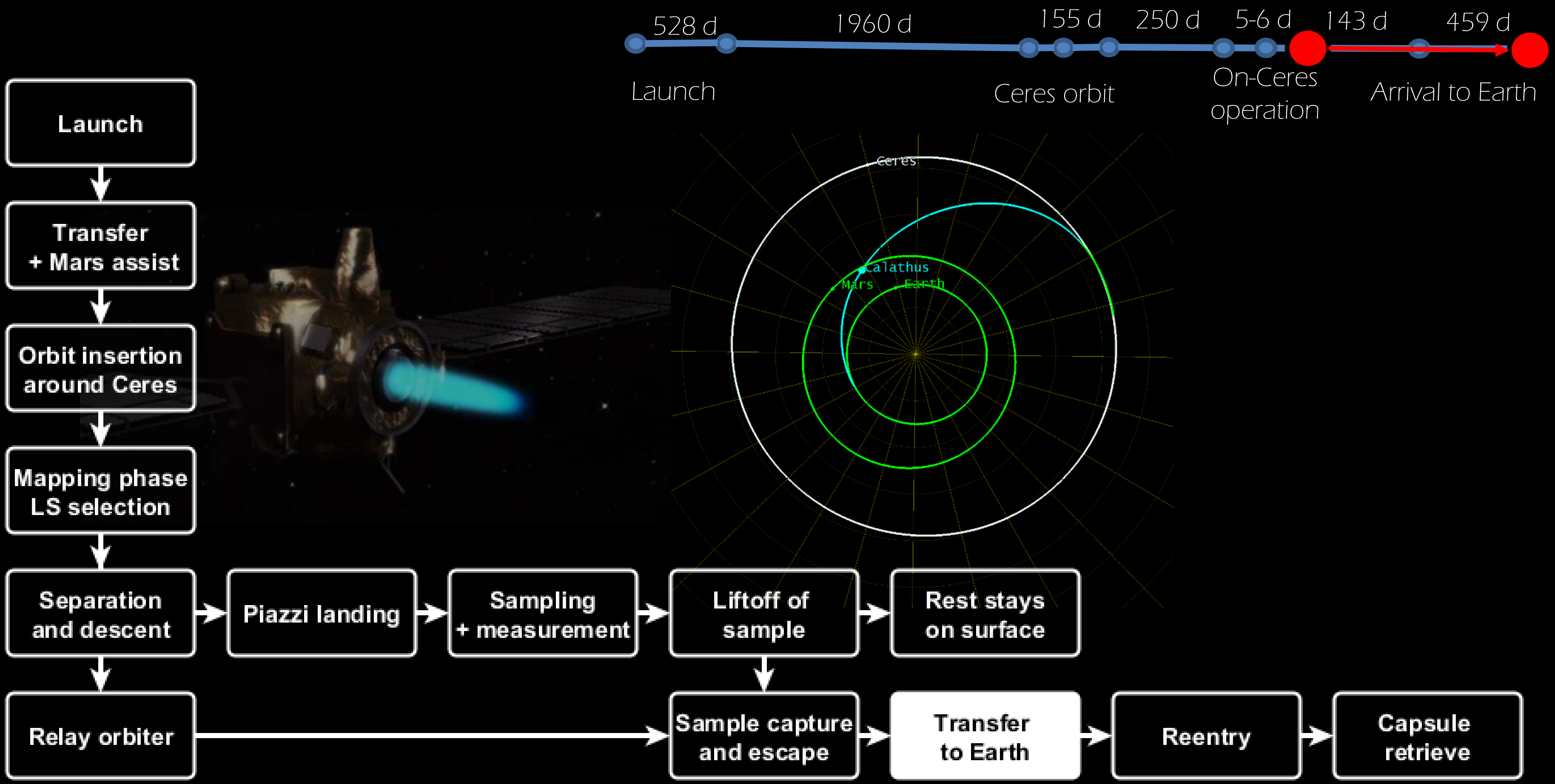




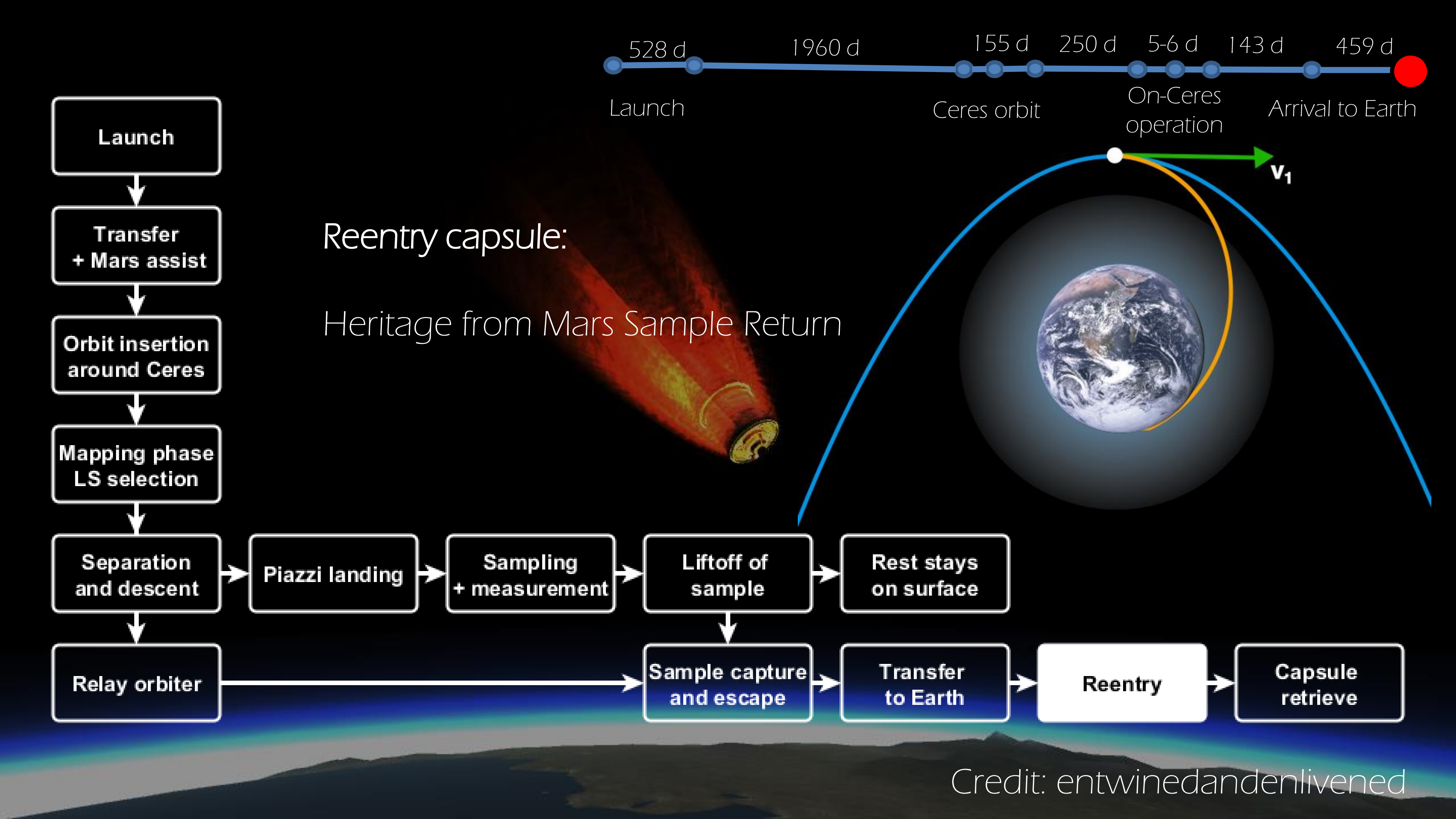

528 d
1960 d
155 d
250 d
5-6 d
143 d
459 d
Launch
Ceres orbit
On-Ceres operation
Arrival to Earth
Collect descent images
Sending images; decisions by science team
Sending images; decisions by science team
T0
T1
T2
T3
T4
T5
Landing
Ascent
Landing on Ceres
Brushing
Collecting image
Bus launch
Collecting image of surroundings
Collecting samples and deliver to the returning capsule and to the mass spectrometer
Launch
Transfer + Mars assist
Orbit insertion around Ceres
Mapping phase LS selection
Separation and descent
Piazzi landing
Sampling + measurement
Liftoff of sample
Rest stays on surface
Time on surface: <168h
Relay orbiter
Sample capture and escape
Transfer to Earth
Reentry
Capsule retrieve

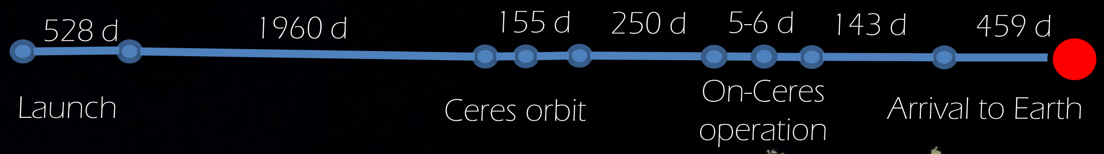

528 d
1960 d
155 d
250 d
5-6 d
143 d
459 d
Launch
Ceres orbit
On-Ceres
operation
Arrival to Earth
Launch
Transfer
+ Mars assist
Orbit insertion
around Ceres
Mapping phase
LS selection
Separation
and descent
Piazzi landing
Sampling
+ measurement
Liftoff of
sample
Rest stays
on surface
Relay orbiter
Sample capture
and escape
Transfer
to Earth
Reentry
Capsule
retrieve
T0
T1
T2
Launch from
the surface
Separation of OS from
propulsion stage
Orbiter manœuvres
to catch the OS

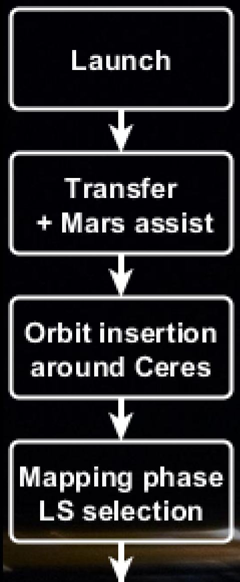
Credit: NASA

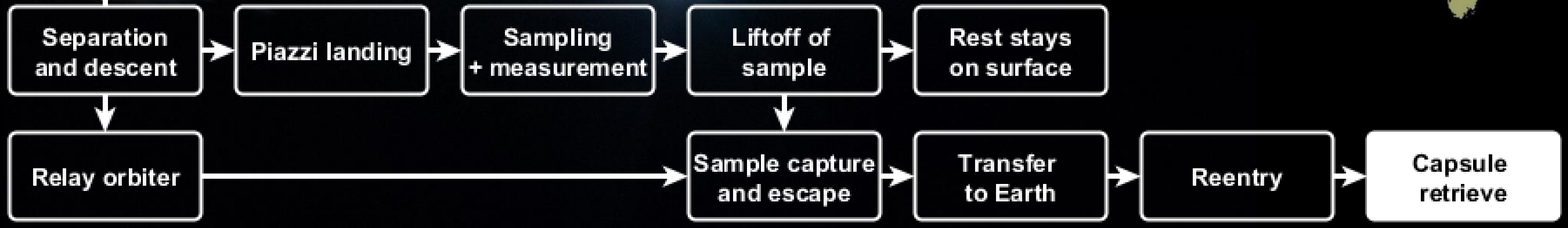


Credit: The watchers


528 d
1960 d
155 d
250 d
5-6 d
143 d
459 d
Launch
Ceres orbit
On-Ceres operation
Arrival to Earth
v_1
Launch
Transfer + Mars assist
Orbit insertion around Ceres
Mapping phase LS selection
Separation and descent
Piazzi landing
Sampling + measurement
Liftoff of sample
Rest stays on surface
Relay orbiter
Sample capture and escape
Transfer to Earth
Reentry
Capsule retrieve
Reentry capsule:
Heritage from Mars Sample Return
Credit: entwinedandenlivened

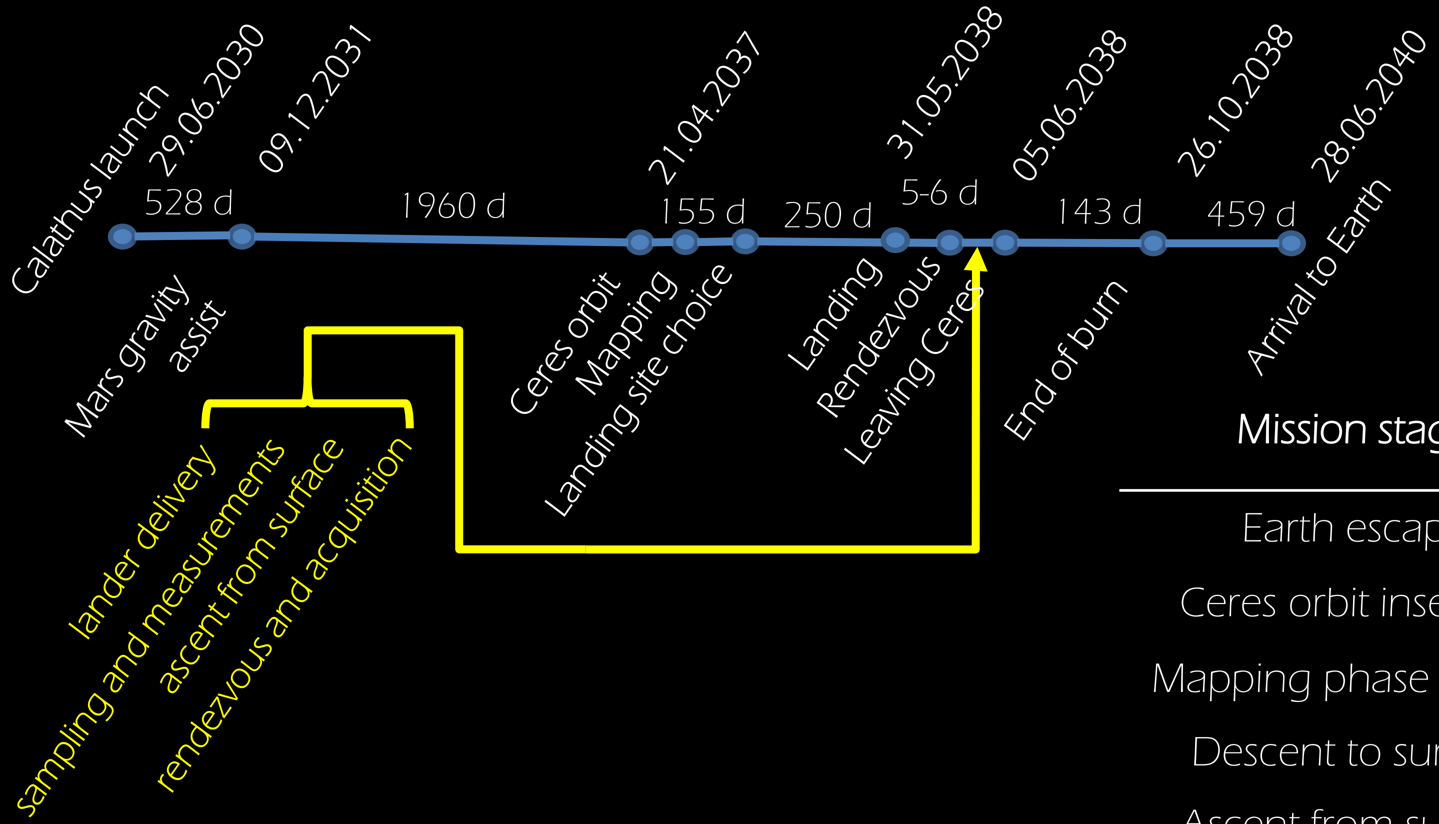






- *Landing site in Australia*
- Follow the reentry with cameras (preferentially by night)
- Transportation inside -20°C boxes to EURO-CARES

Credit: NASA



mission timeline

Mission stage	Time since launch
Earth escape	~3 h
Ceres orbit insertion	2488 d
Mapping phase begins	2490 d
Descent to surface	2893 d
Ascent from surface	2899 d
Ceres escape burn	2900 d
Arrival to Earth	3502 d

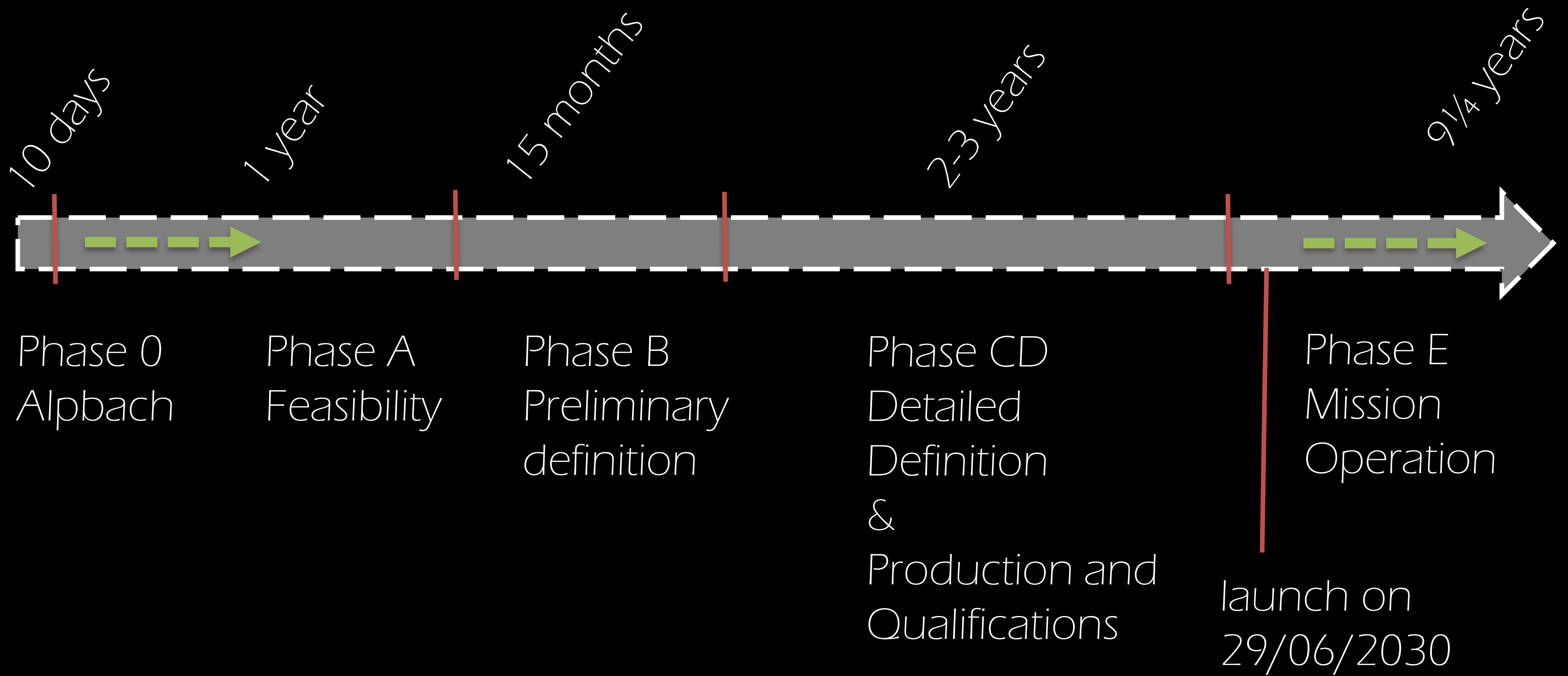
orbit

orbit budget

	dV (m/s)	Propellant mass (kg)	Propellant type
Outbound trajectory	17415	2327	Xenon
Orbit insertion	149	170	Hydrazine
Orbit manouvres	94	265	Hydrazine
Inbound trajectory	4410	397	Xenon

	dV (m/s)	Propellant mass (kg)	Propellant type
Landing	419	33	Hydrazine
Launch & rendezvous	371	7	Hydrazine

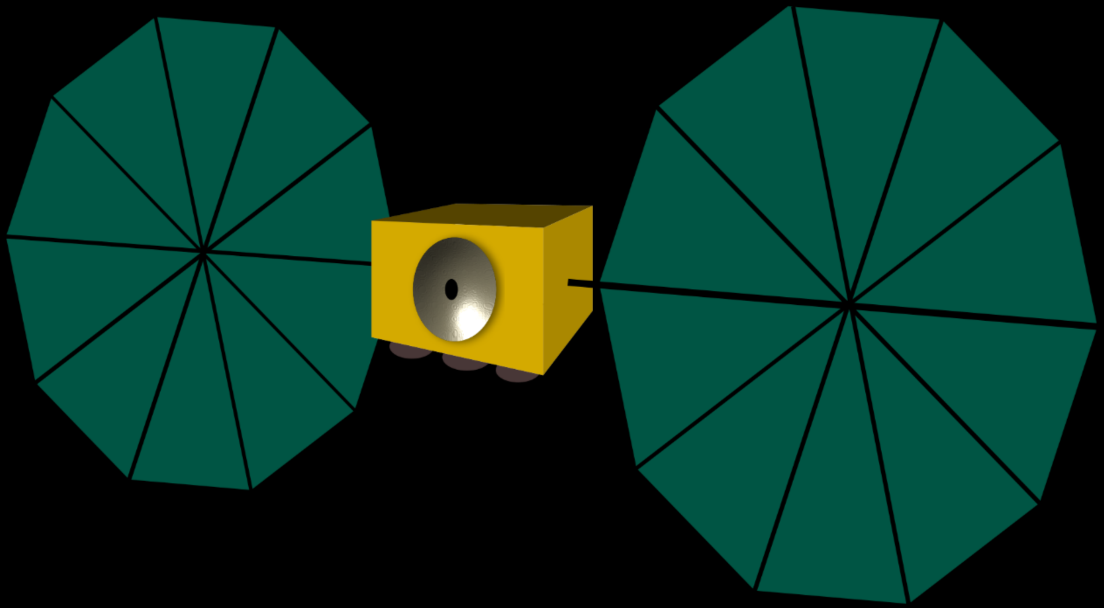
mission phases



Mission Phases

spacecraft design

orbiter

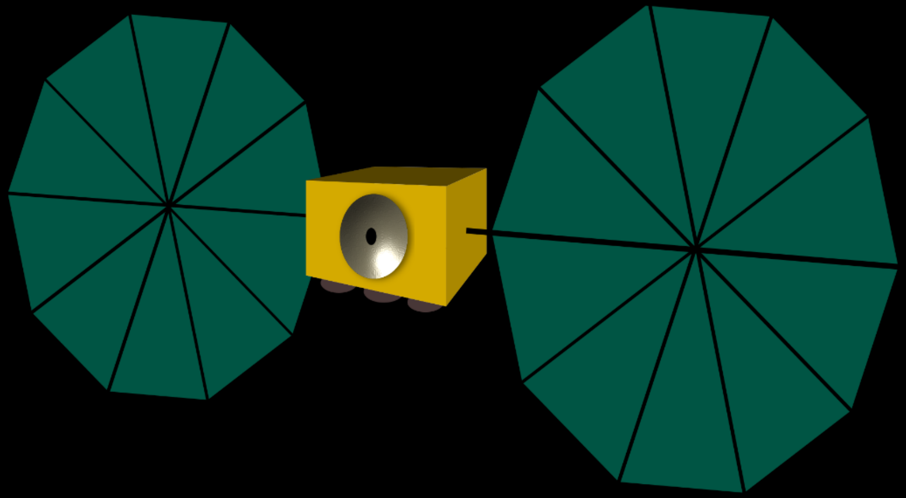


lander

lander ascent module

orbiter

Dimensions	Solar Panel Area
2.5 m x 3.0 m x 3.5 m	110 m^2



Subsystems

- On-board Computer
- Thermal Control
- Telecommunication
- Attitude Determination and Control
- Power
- Propulsion
- Payload

payload

orbiter camera

Derived from the OSIRIS Narrow Angle Camera onboard Rosetta

The OSIRIS NAC
Photo: Max Planck Institute

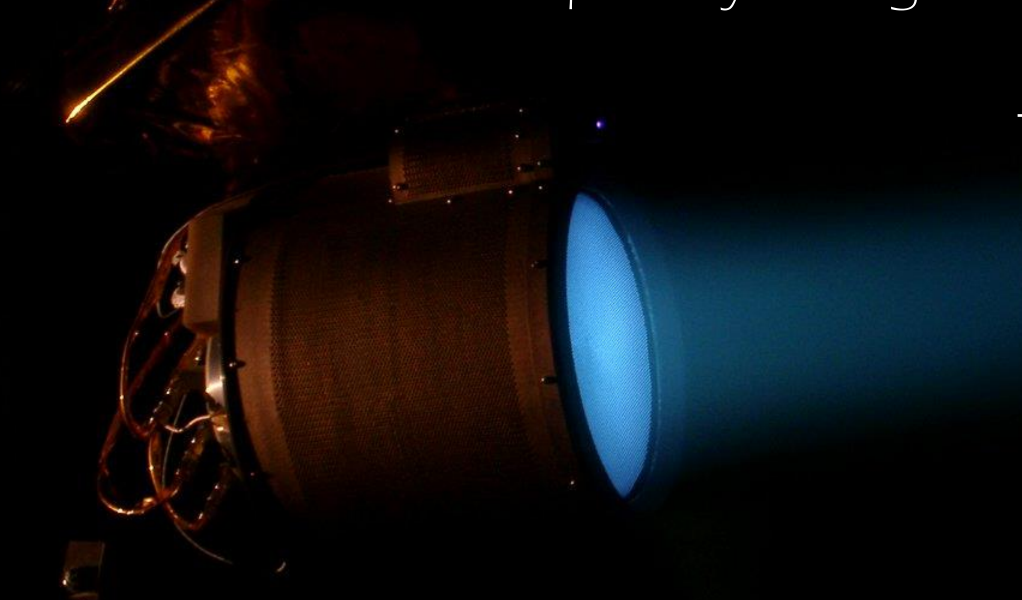
Narrow angle camera specifications	
Field of view	2.2° x 2.2°
Angular resolution	9.3 μradians / pixel
CCD	4096x4096
Shutter	<1 ms

i o n   p r o p u l s i o n

- Model: QuinetiQ`s T6
- Kaufman-type Ion Engine
- 2.5° Gimbal-capability along 2 axis

Heritage

Bepi Colombo

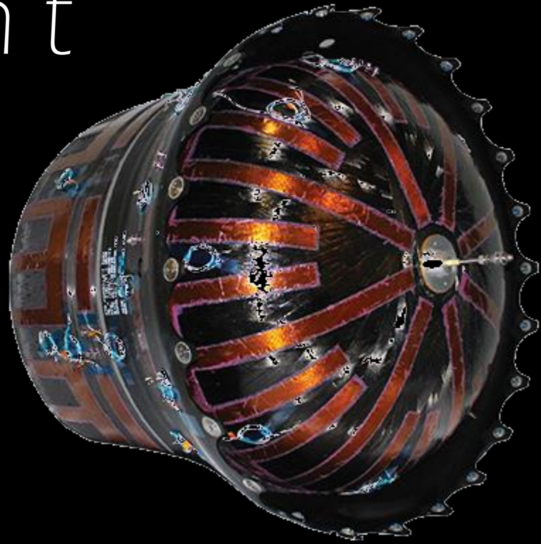


	Value	Unit
Thrust	110	mN
I_{sp}	4000	s
Power consumption	4000	W
Mass to power ratio	7	kg/kW

Credit: QinetiQ

xenon propellant

Medium	Xenon gas
Fill Pressure	86 bar
Water Volume	268 L
Dimensions	diameter 907 mm
Length	673 mm
Mass	max 22 kg

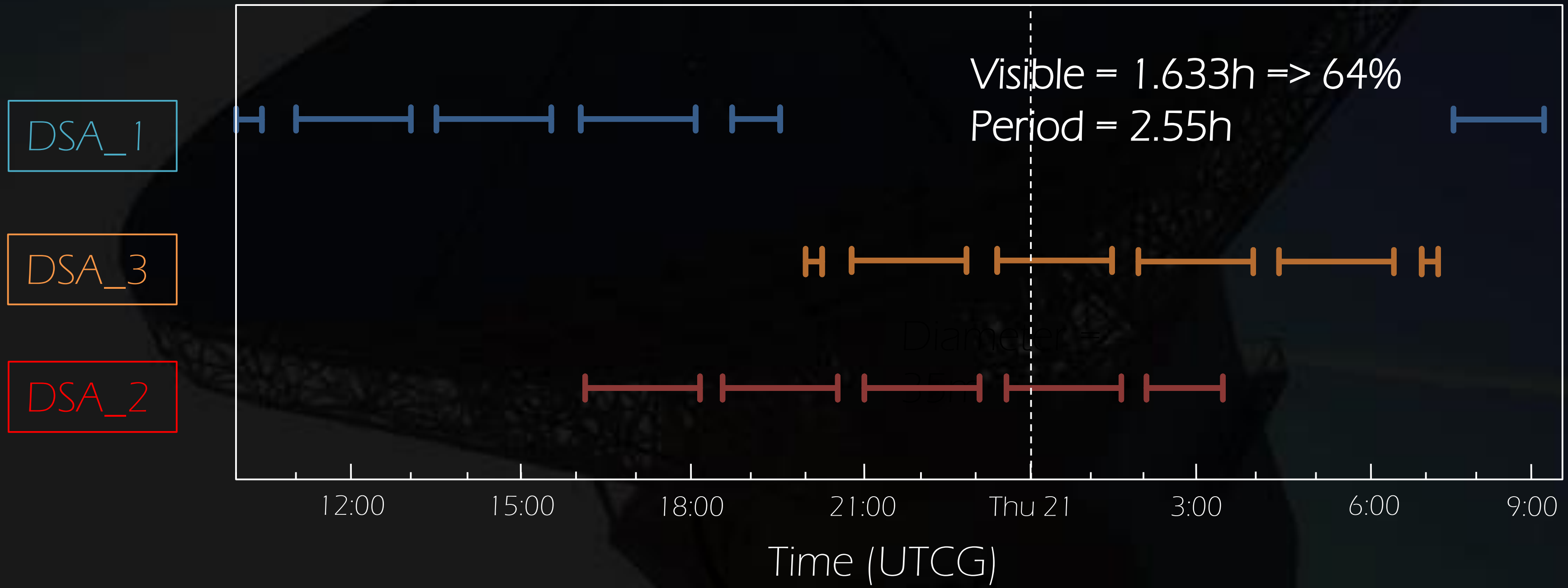


Credit; Cobham

telemetry

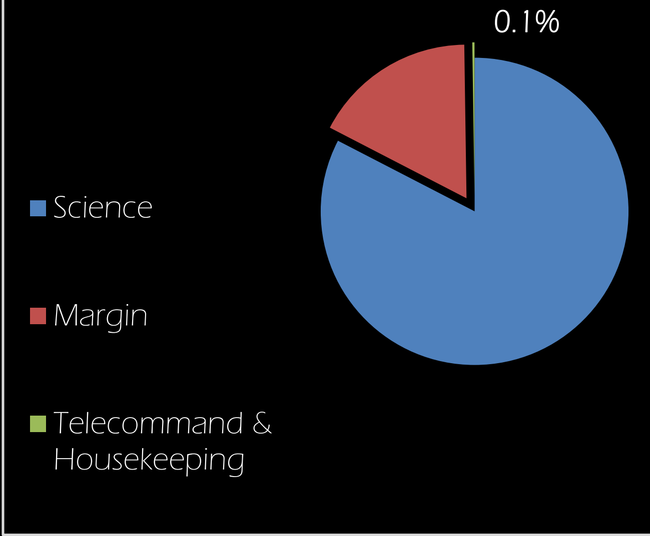
ground station - ESTRACK

- DSA1 - New Nordica
- DSA2 - Cebreros
- DSA3 - Malargüe



link budget

data distribution



Mission system	Instrument/ Usage	Data [kbit/s]	Margin [-]	Total [kbit/s]
Mapping & Science	Images (Orbiter)	1006	0.05	1.056
	Telecom. & Status	0.9	0.05	0.945
	Images (Sampling)	0.29	0.05	0.3045
	Mass-Spectrometer	0.37	0.1	0.3737
Total with margin			0.2	1267.3
Descent	Images (PIAZZI)	560	0.05	587.2
	Images (Orbiter)	461	0.05	484
	Telecom. & Status	1	0.05	1.05
Total with margin			0.2	1224.3

Telemetry Systems

		Downlink Comparison		
	X down (status & telecom.)	X down (science data)	Ka down (science data)	X down (PIAZZI to Orbiter)
Frequency [GHz]	8.42	8.42	32	8.44
Bandwidth [MHz]	5	5	100	10
Distance [km]	4.039E+08	4.039E+08	4.039E+08	60
Power [W]	150	225	150	1
Data Rate [Mb/s]	0.003	0.6	1.3	2
$D_{Antenna}$ [m]	0.2	2.2	1.3	0.1
Margin [dB]	6.001	5.477	5.722	32.543

Telemetry Systems

	X down (status & telecom.)	Downlink Comparison X down (science data)	Ka down (science data)	X down (PIAZZI to Orbiter)
Frequency [GHz]	8.42	8.42	32	8.44
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Margin [dB]	6.001	5.477	5.722	32.543

thermal control

t h e r m a l   c o n t r o l

Spacecraft: Calathus

Hot Case

Source	Heat flux
Electronics (W)	200
Sun (W)	138340
Radiation (W)	-85994
Sum (W)	52546

Cold Case

Source	Heat flux
Radiation (W)	-395

Solution

- 2.46 m² of radiators & louvres
- Electric heaters

other sub-systems

On board computer

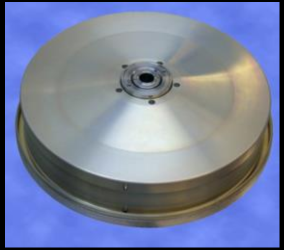
Bus-Speed	100.0 Mbit/s
Storage	4 GByte
Processor	RAD750

ADCS

Driving requirement:

Camera pointing = 0.53 mrad/sec
(angular momentum = 2.385 Nms)

→ RSI 4-75/60



- Star trackers
- Sun sensors
- 6 reaction wheels (redundancy)
- Reaction control thrusters

power budget

power budget - Calathus

Subsystem		Orbiter		Bus		Surface module	
	Margin [%]	Power [W]	Power + margin [W]	Power [W]	Power + margin [W]	Power [W]	Power + margin [W]
Telecomunication	5	220	231	20	21	-	-
Payload	20	20	24	-	-	Max. 90	108
Propulsion	10	23000	25300	10	11	-	-
Thermal control	5	395	415	41	43	41	43
OBC + ADCS + GNC	5	10	11	58	61	35	37
Beacon	5	-	-	0.7	0.74	-	-
SUM	-	23645	25981	130	137	166	188
System margin	20	4729	5196	26	27	33	38
SUM+system margin	-	28374	31177	156	164	199	226

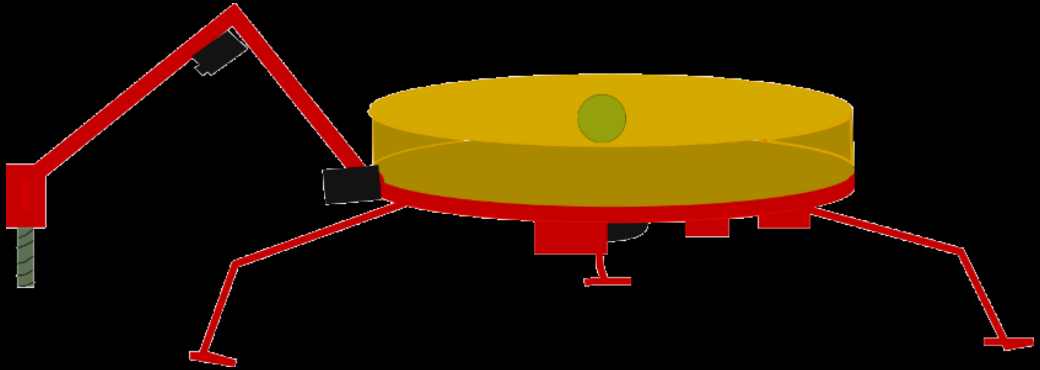
mass budget

mass estimate - Calathus mission

	Dry Mass without Margin	Margin		Total	%of Dry
	in kg	%	kg	in kg	in kg
Structure	300	20	60	360	20.15
Thermal Control	52	5	2.6	54.6	3.49
Mechanisms	26	20	5.2	31.2	1.75
Communication	37	5	1.85	38.85	2.49
Data Handling	4	20	0.8	4.8	0.27
GNC	54	5	2.7	56.7	3.63
Propulsion	158	5	7.9	165.9	10.61
Power	745	20	149	894	50.05
Harness	140	5	7	147	9.41
Payload (including Lander)	189	5	9.45	198.5	12.7
Total Dry Mass (excl. adapter)	1705		247	1952	
System margin		20		390	
Total Dry with margin (excl. adapter)				2342	
Reentry Capsule (RC)	40				
Total Dry with margin incl. RC (excl. adapter)	1745			2382	
Propellant - Xenon	2724	5		2860	
Propellant - Hydrazine	207	5		217	
Adapter mass (including seperation mechanism)	110			110	
Total wet mass (excl. adapter)	4676			5459	
Total wet mass (incl. adapter)	4786			5569	

orbiter

lander



lander ascent module

Piazzi lander

On board computer

Bus-Speed	77.2 Mbit/s
Storage	2 Gbyte
Processor	100 MHz

Properties

Wet Mass (kg)	194
Dimensions (m)	D1.5 x 0.6
Thrust (N)	400
Propellant	Hydrazine

ADCS

Driving Requirement:
Turn 90° shortly after separation
(angular momentum = 0.018 Nms)

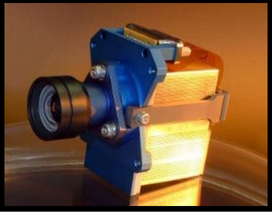
→ RWP050

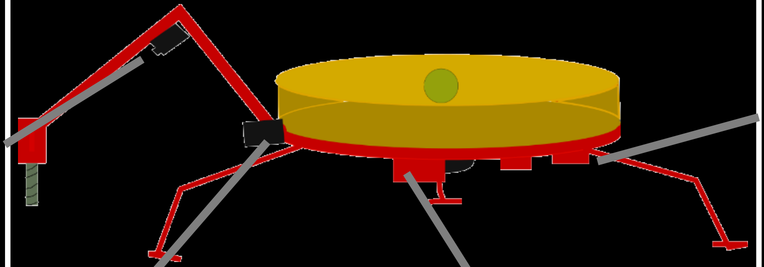
Feature	Value
Angular momentum (Nms)	0.050
Max Torque (Nm)	0.007
Mass (kg)	0.24
Volume (mm)	58 x 58 x 25
Max. Power (W)	<1.0

Piazzi lander

ARM CAMERA:

- Heritage of INSIGHT mission
- Arm camera: to image the sampling side

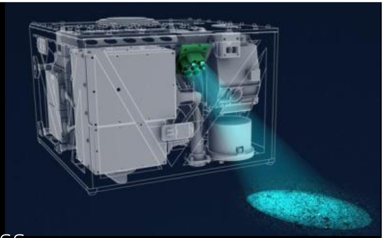




DESCENDING CAMERA:

- Heritage of ROLIS onboard Philae
- Bottom camera: to image the surface during descent

THERMAL MAPPER:



- Heritage of MARA from Hayabusa 2
- Determination of the brightness and temperature around the sampling site (10 cm spot)

MASS SPECTROMETER:

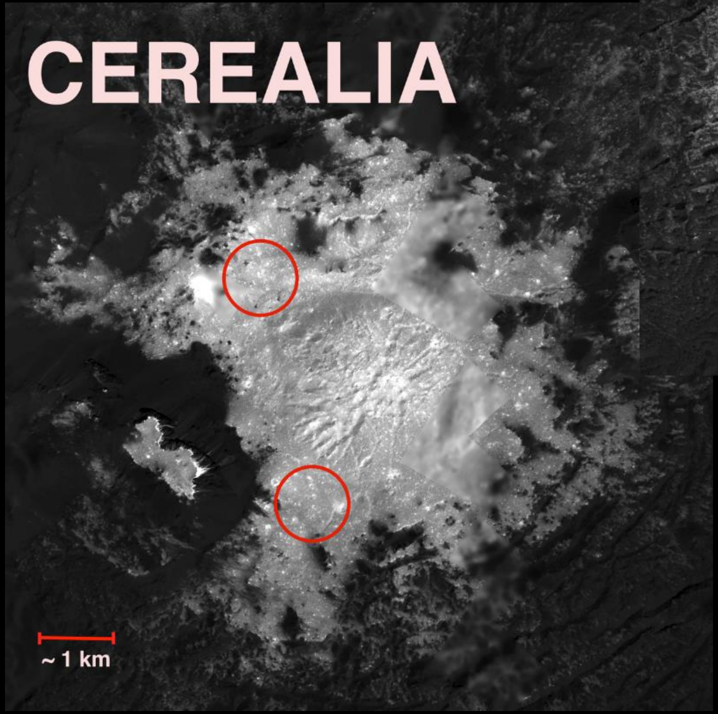
- Developed for exploration of Mercury
- analysis of light elements, volatiles as well as light organic components

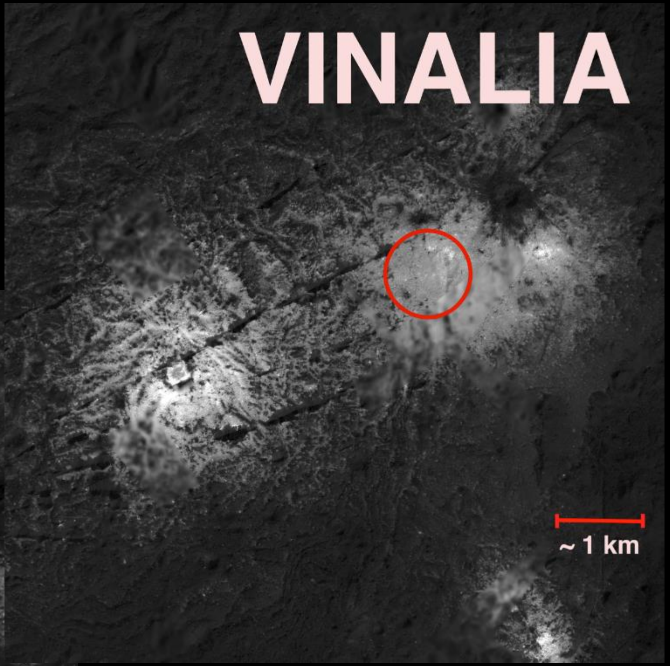
l a n d i n g   s i t e

Examples of possible landing sites

Have to avoid steep slopes and fractures

Dawn does not give sufficient resolution to make a definite choice





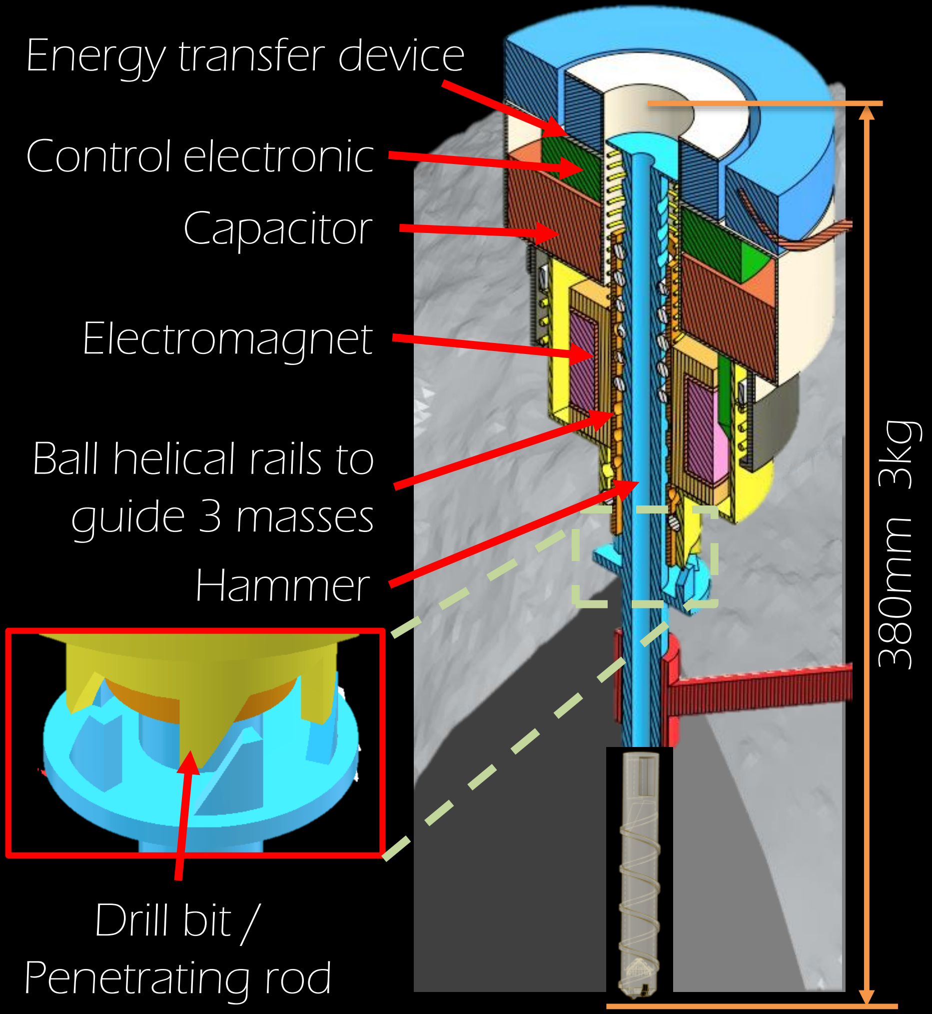
s a m p l i n g

requirements for the sampling process

- 4 samples (at different locations)
  - 3 samples back to Earth + 1 sample analyzed in situ
- Mass: 5 – 15 g for each sample
- Depth: 50 mm
- Temperature:

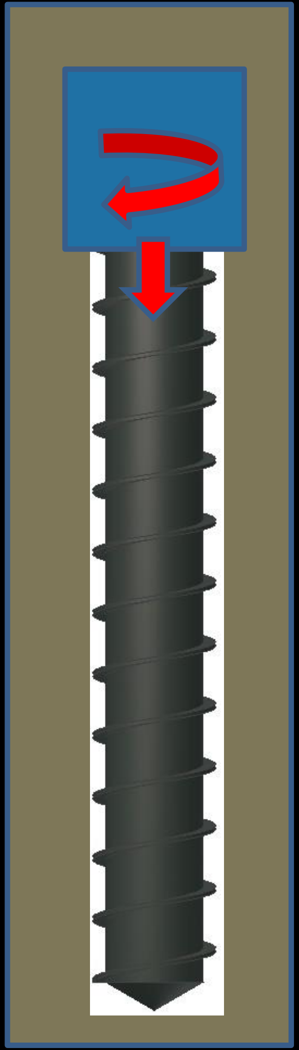
Assessment	Temperature range	Scientific justification
Optimal conditions	< -40 °C	Maximal temperature on Ceres
Fine	- 40°C to - 20°C	Almost no chemical or biological change below -20 °C
Acceptable	-20 °C to -5°C	
Critical	> -5 °C	Sublimation of the water

Driller/sampler



Principles of operation:

- The stroke generation bases on a modified reluctant electromagnetic principles
- The armature moves a hammer
- The core and coil are acting as counter-masses
- The hammer and the counter mass moves in opposite directions which reduces forces acting on a lander.
- The coil is powered by an electric impulses generated by a capacitor



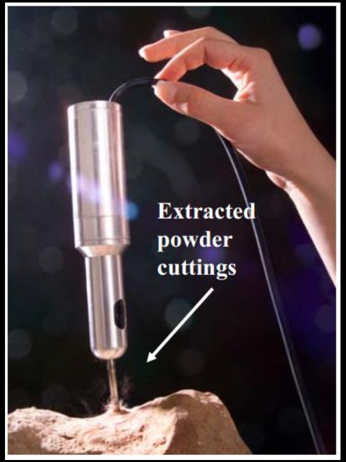
Advantages:

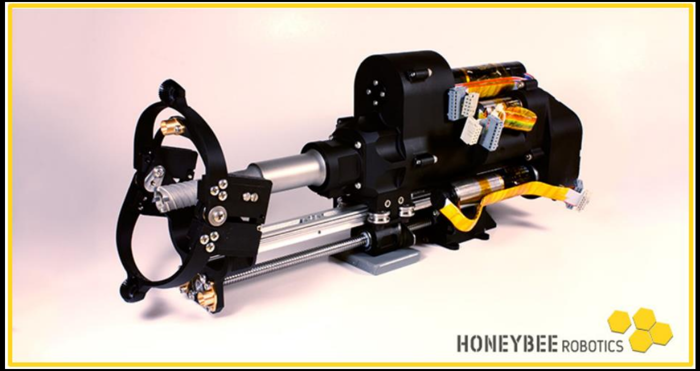
- No heat generation
- Low level of power consumption
- Able to penetrate highly compressed material
- Operating in microgravity - on planets, moons and asteroids,
- Well scalable

Key features:

- ~4 W of power consumption
- 3 kg weight
- 380 mm height
- 4 J of stroke energy

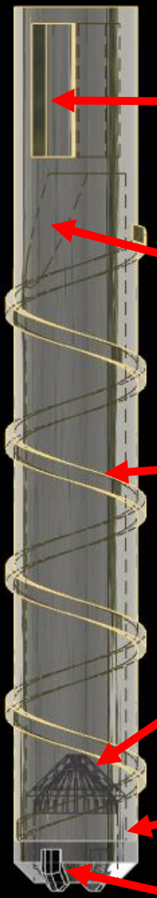
Credit: JPL
Leonardo S.p.A
Honeybee Robotics





Alternative solutions
(ultrasonic dril, drill, rotary precusive)
(make mission more feasible)

Drilling bit/sampling container



Actuator interface

Slope for solid sample brake

Worm to drain drilling

Flat springs to counteract losing loose material with low adhesive

Crown screwed with container for sample release

Drilling crown with diamonds inserts

Container material: hardened titanium

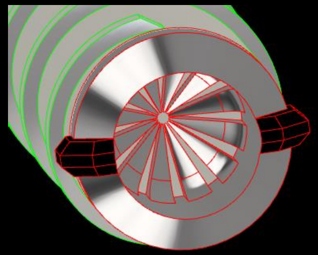
Crown material: hardened titanium with diamonds inserts

Dimensions:

- 60 mm in length
- 8 mm in diameter

Mass: 6g

Passive sampler with thin container walls provides more efficient drilling



r o b o t i c   a r m

Key features:

- 2m length
- 3kg of weight
- ~60W of power consumption
- Brush for decontamination

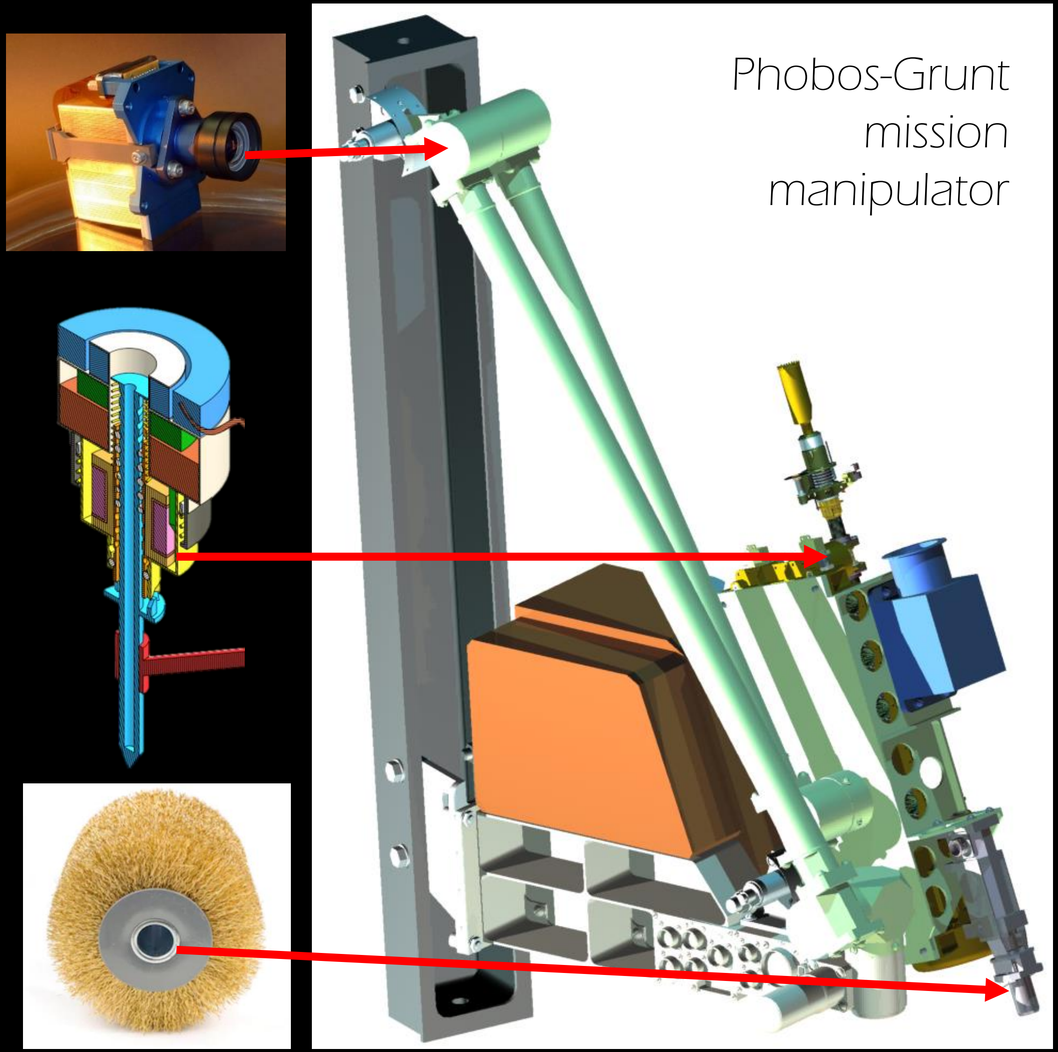
Main functions:

- Camera maneuver
- Brush maneuver
- Penetrator deployment
- Drilling support
- Depth measurement

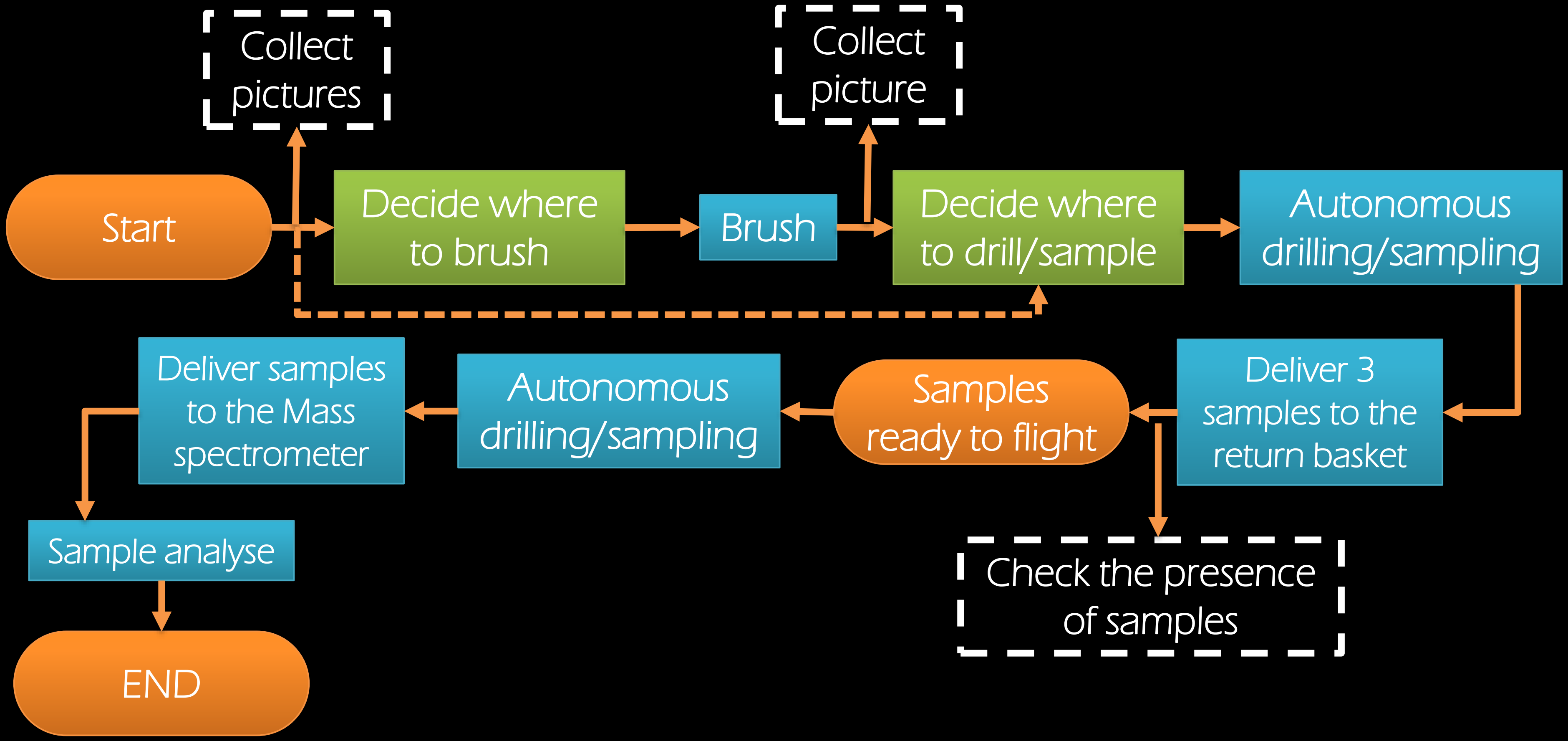
Heritage:

- Phobos-Grunt
- Luna27

Credit: CBK PAN

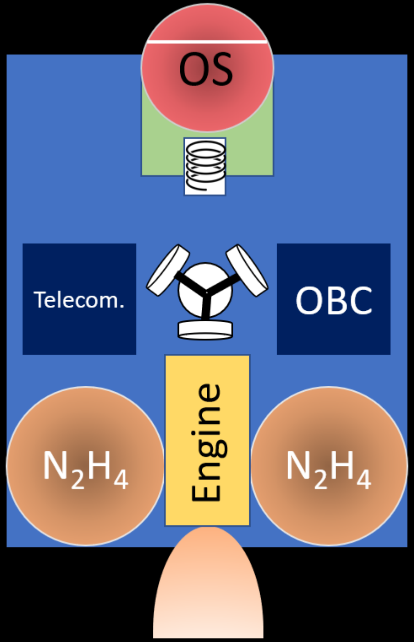


Drilling / sampling scenario



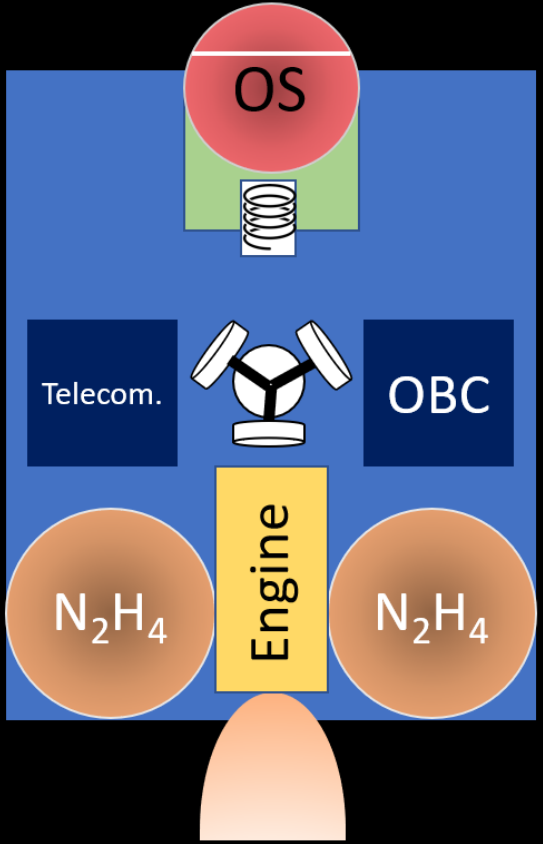
orbiter

lander



lander ascent module

Ascending module



Used for bringing the sample from the surface of Ceres to orbit for docking with the orbiter

Metrics	
Total height (m)	0.6
Dry mass during ascent (kg)	45.9
Wet mass during ascent (kg)	53.3

chemical propulsion

Pros:

- Long heritage
- Simple, reliable system
- Low-cost

Cons:

- Toxic propellant
- Relative low performance

400N Monopropellant Hydrazine Thruster	
Thrust range vac	120 to 420N
Isp range vac	212 to 220 sec
Mass:	P2 - design 3.8 kg
Propellant	Hydrazine

Credit: Space-propulsions.com

Pros:

- Long heritage
- Simple, reliable system
- Low-cost

Cons:

- Toxic propellant
- Relative low performance

SURFACE TENSION TANK OST 31/0

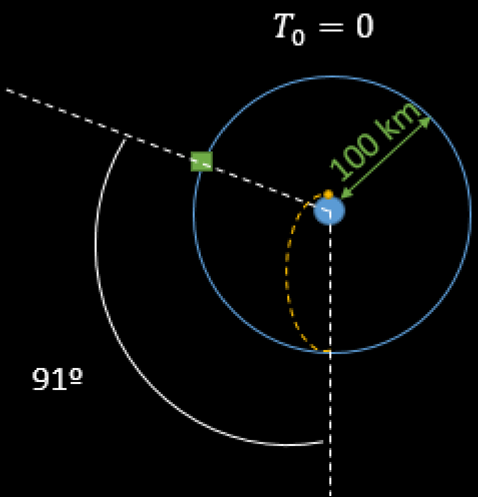
Max. Propellant Volume (l)	78
Propellant	Hydrazine
Pressurant Gas	Helium or Nitrogen
Expected Operating Pressure (bar)	24.6

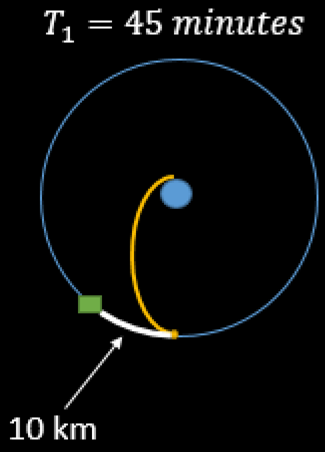
Credit: Space-propulsions.com

orbiting sample (OS)

orbiting sample

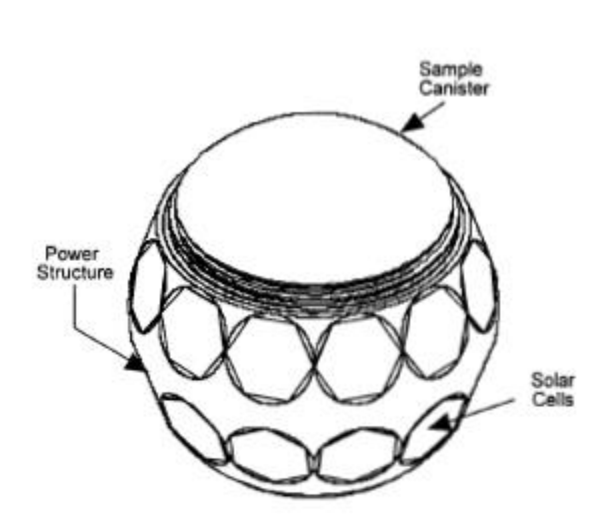
1. Launch from the surface into a 100 km circular orbit
2. Separation of Orbiting Sample (OS) and the propulsion stage, removal of propulsion stage
3. Orbiter manoeuvres to catch the OS





System design

Orbiting Sample (OS) → Technology proposed and tested for Mars Sample Return



Credit: "Mars Sample Return Spacecraft Systems Architecture"- H. Price, Jet Propulsion Laboratory

Physical caracteristics:

- Diameter: 16 cm
- Mass: 5.48 kg

system design

Orbiting Sample (OS)

Telecommunication

Radio beacon:

- Allow the orbiter to detect de OS in a range of at least 30 km
- UHF/VHF: 30-3000 MHz
- Transmiter+antennas

Power

- 25% of the surface covered by solar arrays producing 0.1 W when lighted up
- Lithium batteries: 52 Wh

Thermal control

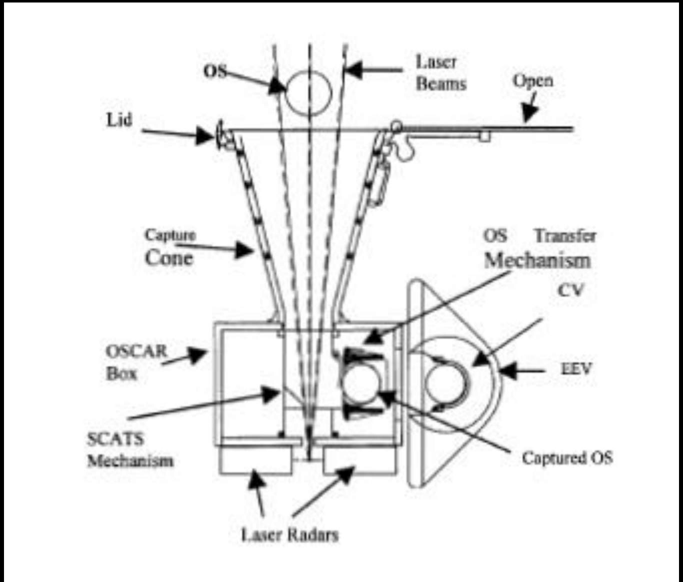
- Two separated volumes
- Heating
- The temperature should be less than $-5\ ^{o}C$

mass budget – orbiting sample

System	Element	Mass (kg)	Margin	Mass with margin (kg)
Telecom	Transciver	0.085	0.05	0.08925
	Antennas	0.0165	0.05	0.017325
Power	Battery	0.258	0.05	0.2709
	Solar arrays	0.32	0.2	0.384
Thermal	Heaters	0.1	0.05	0.11
OBC	OBC	0.094	0.05	0.099
Structure	Structure	3	0.2	3.6
TOTAL		3.77		4.57
TOTAL with margins	+20%			5.48

rendezvous system

Technology proposed and tested for Mars Sample Return



Credit:"Mars Sample Return Spacecraft Systems Architecture"- H. Price, Jet Propulsion Laboratory

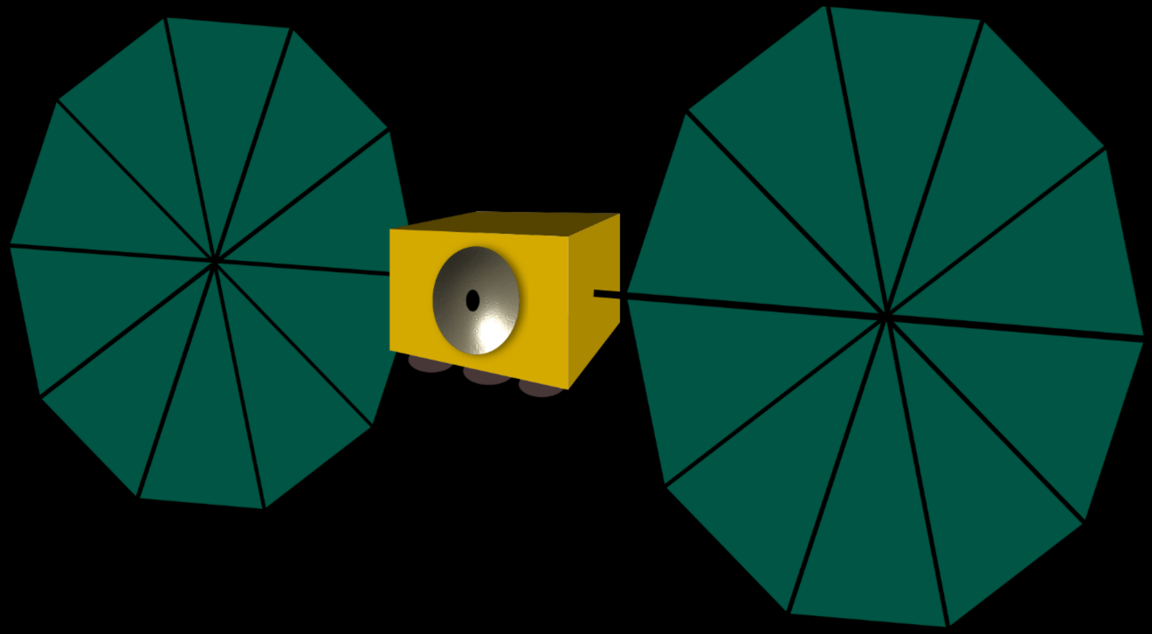
Physical characteristics:

- Capture cone: 0.5 m diameter entry, 0.2 m exit
- Estimated mass: 70 kg
- Power consumption between 27W and 34 W
- Less than 0.5 m accuracy lidar detection
- Blocking arm
- Transfer mechanism to fix the OS in the reentry capsule

orbiter

lander

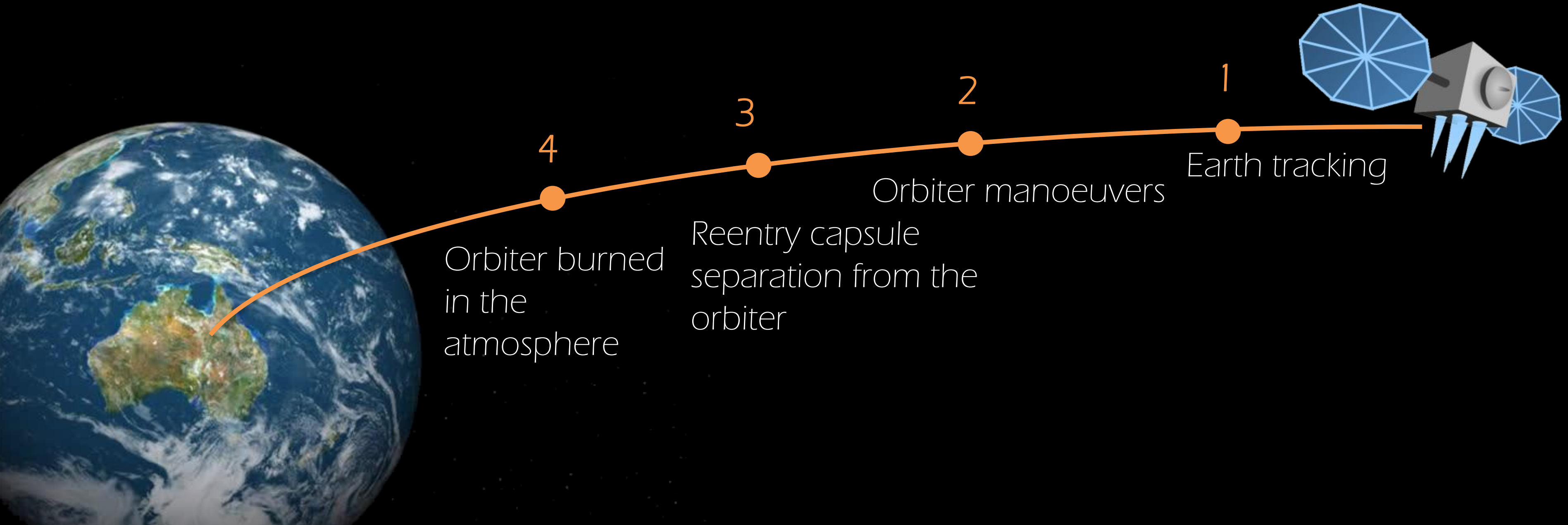
lander ascent module



Earth reentry scenario

Reentry scenario

Stages of the reentry:



Reentry scenario and requirements

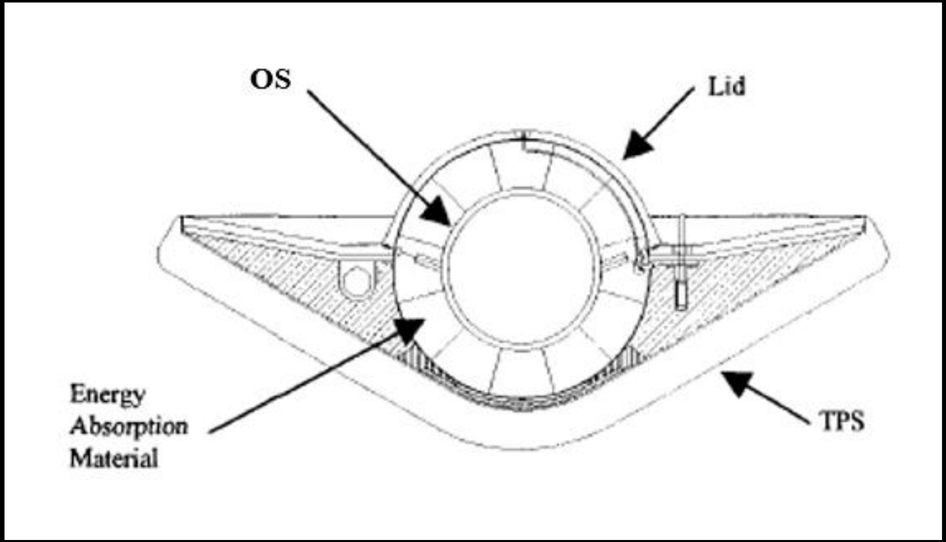
Landing spot Trade-off

		Utah dessert		Australia		Atlantic ocean		Kazakhstan	
Parameters	Weight factors	Ranking	Score	Ranking	Score	Ranking	Score	Ranking	Score
Population density	0.3	1	0.3	4	1.2	5	1.5	3	0.9
Accessibility	0.3	4	1.2	4	1.2	1	0.3	4	1.2
Soil hardness	0.15	3	0.45	3	0.45	4	0.6	2	0.3
Political situation	0.15	4	0.6	4	0.6	2	0.3	3	0.45
Feasability	0.1	4	0.4	5	0.5	1	0.1	2	0.2
TOTAL	1		2.95		3.95		2.8		3.05

ID	Requirement
SYS-O-RC-001	RC shall maintain the samples bellow -5 ºC
SYS-O-RC-005	Reentry velocity shall be less than 14.6 km/s for thermochemical equilibrium reasons

System design

Technology proposed and tested for Mars Sample Return



Credits: "Overview of the Mars Sample Return Earth Entry Vehicle"- Robert Dillman and James Corliss

Physical characteristics:

- Diameter: 0.8 m
- Mass: 41 kg
- spin-stabilized to maintain the proper orientation
- designed for a terminal velocity landing of 41m/s
- Hypersonic ballistic coefficient: 46.7 kg/m 2
- No parachute
- no on-board attitude control system

mass budget – return capsule

System	Element	Mass (kg)	Margin	Mass with margin (kg)
Orbiting sample	Orbiting sample	3.77	0.13	4.57
Telecom	Beacon (x2)	0.60	0.20	0.72
Power	Battery	0.26	0.05	0.27
Structure	Structure	8.2	0.2	9.84
Heat shield	Heat shield	14	0.2	16.8
Mechanisms	Latches and hinges	0.5	0.2	0.6
	Sealing	1	0.2	1.2
TOTAL		27.8		34
TOTAL with margins	+20%			40.8

Power budget – return capsule

Reentry capsule (RC) power consumption

System	Element	Power consumption (W)	Margin	Power with margin (W)
Telecom	Beacon	1.4	0.05	1.47
TOTAL		1.4		1.47
TOTAL with margins	+20%			1.76

Battery: 52 Wh

Estimation of RC electric power time: 47 hours
Estimation of RC reentry time: less than 10 hours

⇨ OK

part iii

b a c k o n E a r t h

planetary protection

Reasons to be careful

Ceres environment:

- 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

CLASS V: Restricted Earth Return

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 reentry
- Everything that has been in contact with Ceres must be **tightly contained** or **sterilized** before and after reentry

the curation plan

Collection of the basket box on Earth → Transportation to EURO-CARES

↓

Receiving protocol:
(sterilization, opening and collection of samples outside of the basket box)

↓

Sample early characterization:
(life detection, EDX, mass and size measurement) and creation of a database

Characterization by ESA team:
20 %

Distribution plan:
10 % NASA + 10 % JAXA
10 % distribution on proposals

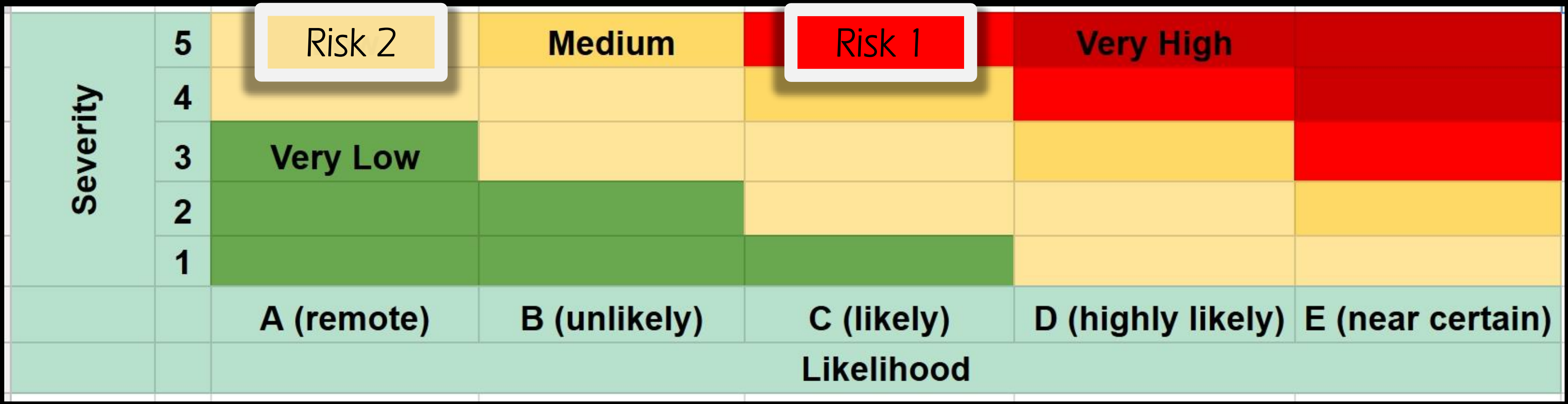
Storage:
50 % for future measurements

r i s k

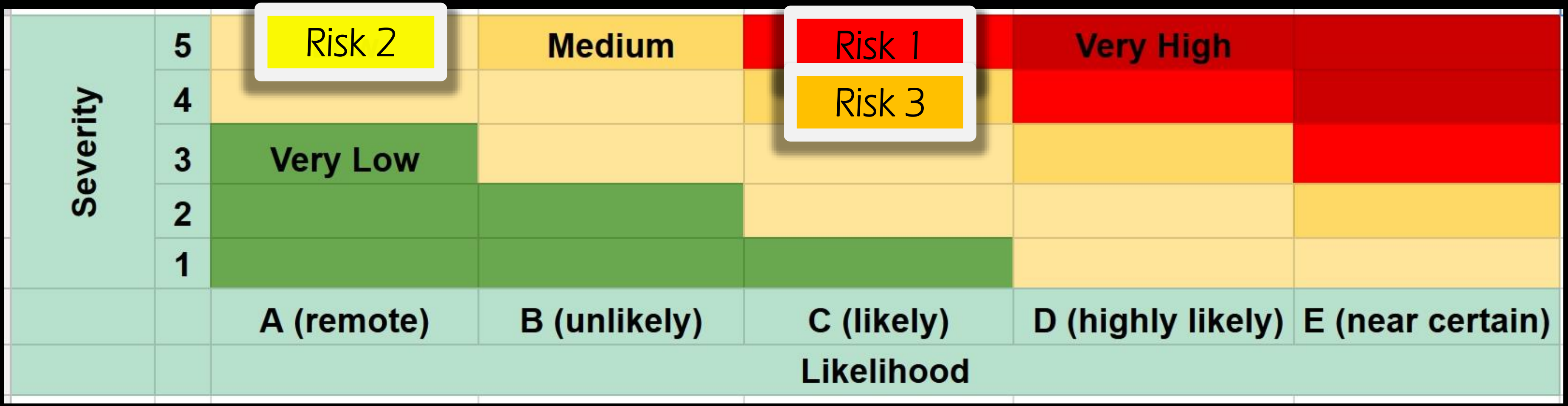
Severity						
	5	Low	Medium	High	Very High	
	4					
	3	Very Low				
	2					
	1					
		A (remote)	B (unlikely)	C (likely)	D (highly likely)	E (near certain)
		Likelihood				

Severity						
	5	Low	Medium	Risk 1	Very High	
	4					
	3	Very Low				
	2					
	1					
		A (remote)	B (unlikely)	C (likely)	D (highly likely)	E (near certain)
		Likelihood				

Risk 1:	Returning the sample
Severity:	5
Likelihood:	C
Mitigation:	ESA is working on Mars Sample Return, new technologies are developed.



Risk 2: Ion engines
Severity: 5
Likelihood: A
Mitigation: By the time Calathus is launched, other missions will have used this technology.



Risk 3:	Reentry
Severity:	4
Likelihood:	C
Mitigation:	Maturing required technology.

TRL estimation

System/subsystem	TRL	Comment
Separation mechanisms	5-6	Heritage from various space missions
Ion propulsion	6	
Thermal Control	8	
ADCS + GNC	8	
Rendezvous system	3	Principles of operation similar to solution that are going to be used on the Mars Sample Return mission
Reentry capsule	3-4	
Sampling device	2-3	Some components have space heritage, i.e.: from Rosetta
Manipulator arm	4	Heritage from various space science missions, e.g.: Rosetta, Phobos-Grunt, InSight.
NA Camera on Orbiter	5-6	
Cameras on lander	6-7	
Mass spectrometer	7	

estimation of costs

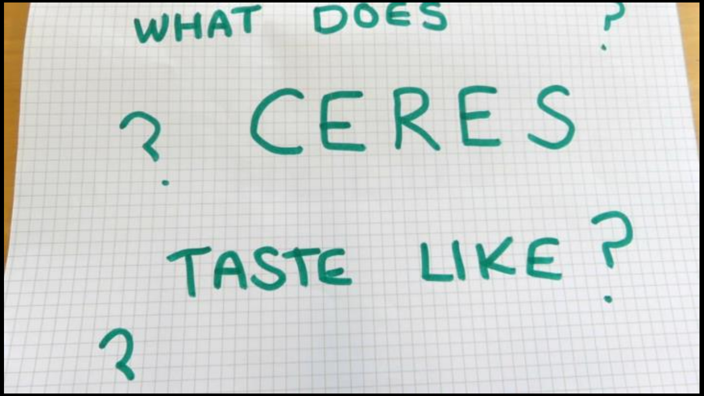
Estimated overall costs ~1.7 Billion €
- 1,6 Billion € ESA Costs
- 100 Million € member States

Assumptions for this estimation:

- Based on mass
- Calculation divided into mechanical, electrical and payload costs for each the orbiter, lander and re-entry
- The more complicated the part, the higher the multiplied factor

public outreach

outreach plans



- social media presence
- live messaging on important mission events (e.g. Twitter, TV, streaming)
- educational packages for schools and universities
- presence at public science events
- cooperation with ESA outreach

mission objectives

- To return carbonate and carbonaceous samples from the surface of Ceres to Earth
- To characterize the landing site to contextualize the returned samples

mission objectives

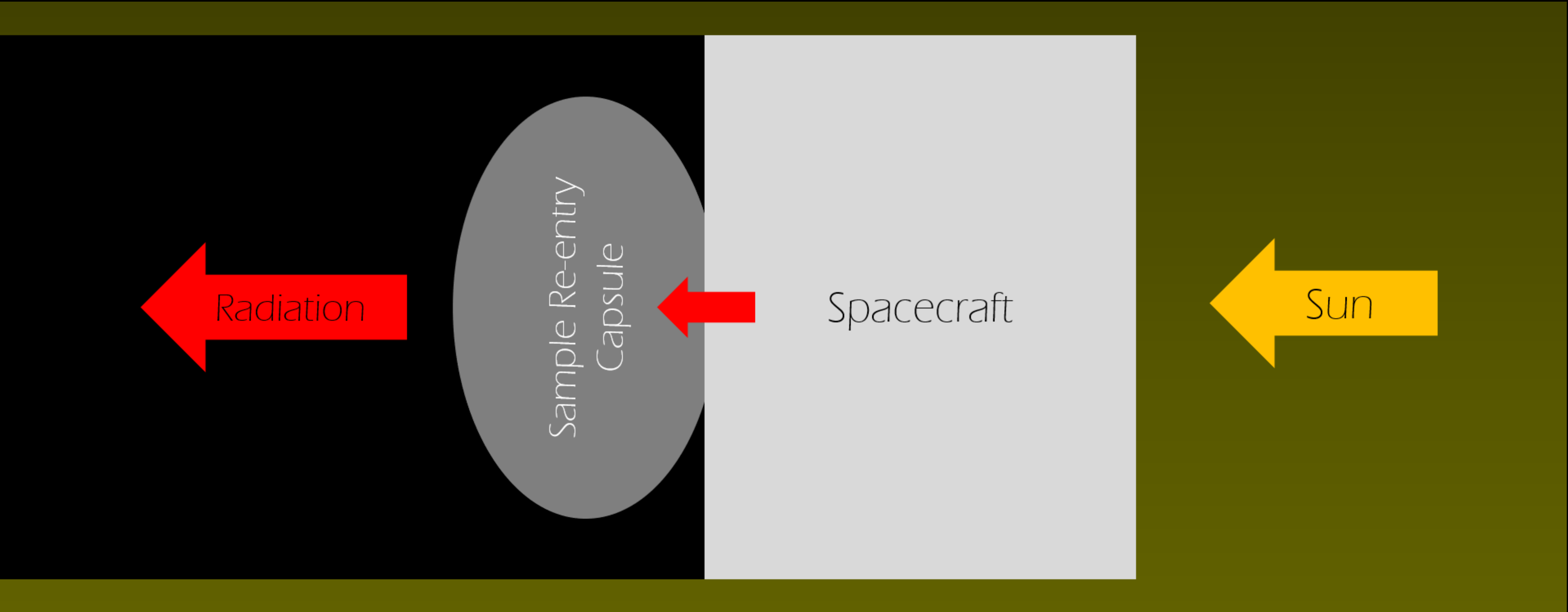
- To return carbonate and carbonaceous samples from the surface of Ceres to Earth

- To characterize the landing site to contextualize the returned samples

Backup slides

Thermal control

Sample preservation during transfer



Objective 1:

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

Science Objective	Science Requirements	Observational Requirements	Instrument	Instrumental Requirements	System	System Requirements
SO1: To determine how occator crater carbonates in the faculae form.	SR1.1: The chemical composition shall be measured.	OR1.1: The minimum spatial resolution shall be 0.5 μm.	sample return (SR), X-ray diffractometer	IR1: A sample with a minimum volume of 4 cm^3 at a minimum depth of 50 mm below the surface of Ceres shall be taken while holding the samples temperature beneath 235 K.	Orbiting Sample (OS)	SysR1.1: The sample shall be returned safely to earth.
		OR1.2: The minimum spectral resolution shall be 4 cm^(-1.)				
						SysR1.2:The sample shall be protected from hazards.
					lander(L)/drill(D)	SysR1.3: The sample shall be taken in the faculae (=the white spots) of the occater crator.
					Orbiter	see Orbiter Requirements
					Bus	see Bus Requirements
					Lander	see Lander Requirements

System Requirements	System Subrequirements	
SysR1.1: The sample shall be returned safely to earth.	SysR1.1.1:The sample shall be kept beneath 235K after recovery (still acceptable between 235 and 205K).	
	SysR1.1.2: The pressure in the Orbiting Sample shall remain 10^(-5) mbar.	
	SysR.1.1.3: The orbiting sampler shall be collected during the first hour after landing on earth.	
SysR1.2:The sample shall be protected from hazards.	SysR1.2.1: The sample shall be protected from organic contamination.	
	SysR1.2.2: The sample shall be protected from environmental hazards.	SysR1.2.2.1. Radiation energy (x-ray) on the sample shall not exceed 7keV in one hour.
		SysR1.2.2.2: The temperature inside the sample return basket shall not exceed 263K.
		SysR1.2.2.2: The temperature inside the sample return basket should not exceed 233K.
SysR1.3: The sample shall be taken in the faculae (=the white spots) of the occater crator.	SysR1.3.1: The sample shall be taken by drilling.	SysR1.3.1.1: The sample shall be taken 50 mm below the surface of Ceres.
	SysR1.3.2: The sample shall be put in a return basket upon collection.	SysR1.3.2.1: The return basket shall have a minimum volume of 4 cm^3.

Science Objective	Science Requirements	Observational Requirements	Instrument	Instrumental Requirements	System Requirements
SO2: To investigate what the occator crator carbonates are made of.	SR2.1: The chemical distributions of organics shall be measured.	OR1.1	SR, IR spectroscopy	IR1, all subrequirements	SysR1
	SR2.2: The chemical distributions of minerals shall be measured.	OR2.1	SR, IR spectroscopy	IR1, all subrequirements	SysR1
	SR2.3: The grain morphology shall be measured.	OR1.2	SR, Scanning Electron Microscopy	IR1, all subrequirements	SysR1
SO3: To characterize the bright material in the faculae to tell us about the conditions (as habitability, salinity, ph-value) within the unconstrained subsurface water-rich reservoir of Ceres.	SR1.1	OR1.1	SR, X-ray diffractometer	IR1, all subrequirements	SysR1
	SR1.2	OR1.2	SR, Scanning Electron Microscopy	IR1, all subrequirements	SysR1
	SR2.1	OR1.1	SR, IR spectroscopy	IR1, all subrequirements	SysR1
	SR3.1: The elemental composition shall be measured.	OR3.1: The elemental composition measurements shall be measured with a spatial resolution of 0.2mm with a level of precision of 100ppm.	SR, electron microprobe	IR1, all subrequirements	SysR1

Science Objective	Science Requirements	Observational Requirements	Instrument	Instrumental Requirements	System	System Requirements
	SR3.2: The temperature variations shall be measured.	OR3.2: The resolution of the thermal image shall be measured with an accuracy of 2K.	thermal mapper (TM)	IR3.1: The thermal mapper shall measure the wavelength between 5.5 and 7, 8-9.5μm, 9.5-11.5μm,13.5-15.5 μm, 5-100μm and between 8-14 μm with a rate of one measurement every 20 minutes in the same field of view as the lander camera.	lander	SysR3: The images shall be transmitted to the ground sation
SO4: To relate the characterization of SO3 to other water rich reservoirs such as Pluto, Ganymede.	SR4.1: The organic compounds, amonia - rich compounds, ions, minerals shall be identified.	OR4.1: The comparing techniques shall be done to be relateable to the triton and pluton fly-bys and the JUICE mission.	SR, Miscellaneous	IR1, all subrequirements		SysR1
SO5: To characterize organic material.	SR5.1: The chemical composition for organics shall be measured.	OR5.1: The abundance of the different components shall be measured with a precision of 10 ppb.	SR, Gas Chromatograph y Mass Spectrometer (GCMS)	IR1, all subrequirements		SysR1
	SR5.2: The chemical distributions of organics shall be measured.	OR2.1	SR, IR spectroscopy	IR1, all subrequirements		SysR1
	SR5.3: The chemical distributions of minerals shall be measured.	OR2.1	SR, IR spectroscopy	IR1, all subrequirements		SysR1

Science Objective	Science Requirements	Observational Requirements	Instrument	Instrumental Requirements	System Requirements
SO6: To investigate when the organic material formed.	SR5.1	OR5.1	SR, Gas Chromatography Mass Spectrometer (GCMS)	IR1, all subrequirements	SysR1
SO7: To investigate how the organic material has envolved under aqueous conditions. (=investigate types organic molecule)	SR5.1	OR5.1	SR, Gas Chromatography Mass Spectrometer (GCMS)	IR1, all subrequirements	SysR1
	SR5.2	OR5.2	SR, IR spectroscopy	IR1, all subrequirements	SysR1

Objective 2:

How representative is the sample of surrounding environment?

Science Objective	Science Requirements	Observational Requirements	Instrument	Instrumental Requirements	System	System Requirements
SO8: How does ceres relate to small bodies and protoplanets?	SR8.1: The faculae of the occator crater shall be mapped.	OR8.1: The resolution of the images taken shall be minimum 1 m/px with an exposure time under 5 ms.	orbiter camera	IR8.1: Images of the faculae of the occator crater shall be taken.	orbiter	SysR8.1: The images shall be transmitted to the ground station
		OR8.2: The resolution of the images taken shall be minimum 0.6 m/px.	orbiter camera	IR8.1: Images of the landing site shall be taken.	orbiter	SysR8.2: The images shall be transmitted to the ground station
		OR8.2: The resolution of the images taken shall be minimum 100mrad / px.	lander camera for descent, lander camera on arm	IR8.2: Images of the sample site shall be taken.	lander	SysR8
SO9: To investigate if ceres-like asteroids contribute to water delivery on earth.	SR9: The isotopical analysis shall be done.	OR9: The accuracy of the isotope ratios shall be better that 10^(-5).	mass spectrometer (MS) on the lander	IR9.1: The massspectrometer shall analyze material outside the sample site.	MS	SysR9.1: The data shall be transmitted to the ground station.
				IR9.2: The volume of the sample shall be minimum $1 cm^3$.		
	SR9: The compositional analysis shall be done.	OR9: The accuracy of the compositional ratios shall be better that 10^(-5).	mass spectrometer (MS) on the lander	IR9.1	MS	SysR9.1
				IR9.2		

Science Objective	Science Requirements	Observational Requirements	Instrument	Instrumental Requirements	System Requirements
SO10: What was the temperature under which minerals on Ceres (carbonates, ammoniae phyllosilicates..) were formed	SR1.1	OR1.1	SR, X-diffractometer	IR1, all subrequirements	SysR1
	SR1.2	OR1.2	SR, Scanning Electron Microscopy	IR1, all subrequirements	SysR1
	SR3.1	OR3.1	SR, electron microprobe	IR1, all subrequirements	SysR1
SO11: What was the pressure under which minerals on Ceres (carbonates, ammoniae phyllosilicates..) were formed	SR1.1	OR1.1	SR, X-diffractometer	IR1, all subrequirements	SysR1
	SR1.2	OR1.2	SR, Scanning Electron Microscopy	IR1, all subrequirements	SysR1
	SR3.1	OR3.1	SR, electron microprobe	IR1, all subrequirements	SysR1

Objective 3:

Did Ceres originate beyond the main belt? - How much beyond (KBO, gas giant region)

Science Objective	Science Requirements	Observational Requirements	Instrument	Instrumental Requirements	System Requirements
SO12: how does Ceres' properties compare to icy moons (e.g. Enceladus)	SR9	OR9	MS	IR9.1, IR9.2	SysR8
SO13: KBO case: how does ceres compare to D-type asteroids (- candidates for depleted KBO comets)	SR1.1	OR1.1	SR, X-diffractometer	IR1, all subrequirements	SysR1
	SR1.2	OR1.2	SR, Scanning Electron Microscopy	IR1, all subrequirements	SysR1
	SR3.1	OR3.1	SR, electron microprobe	IR1, all subrequirements	SysR1
SO14: What is the age of the carbonaceous material?	SR14.1: The ratios of the isotopes Mg26-Al26 shall be measured.	OR14.1: The accuracy of the isotope ratio measurements shall be 10^(-6).	SR, Thermal ionization mass spectrometry	IR1, all subrequirements	SysR1
SO15: What is the age of the carbonates?	SR15.1: The ratios of the isotopes Pb-Pb, U-Pb shall be measured.	OR14.1	SR, Thermal ionization mass spectrometry	IR1, all subrequirements	SysR1
SO16: What is the age of ammoniated phyllosilicates?	SR16.1: The ratios of the isotopes Rb87-Sr87, Mg26-Al26, Pb-Pb shall be measured.	OR14.1	SR, Thermal ionization mass spectrometry	IR1, all subrequirements	SysR1

WHAT DOES ?

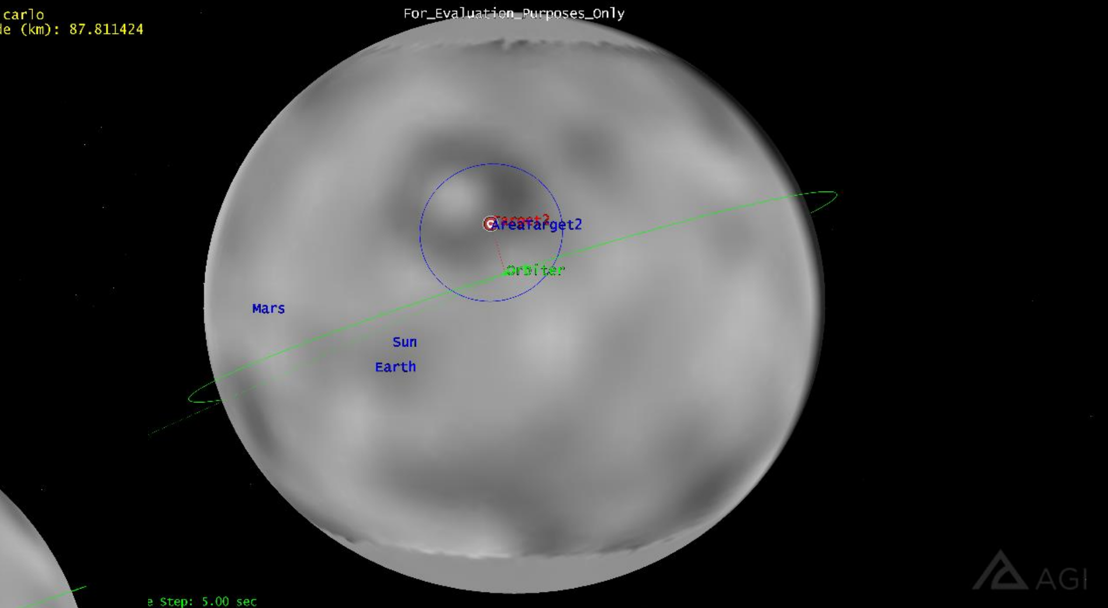
? CERES

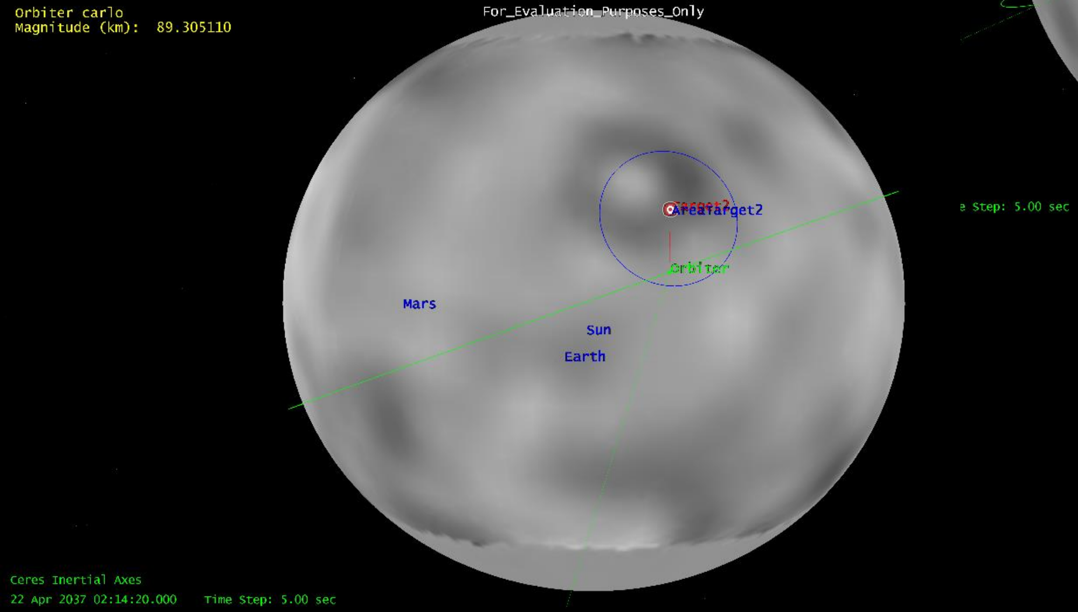
TASTE LIKE ?

?

BACKUP SLIDES

Mapping orbits





orbiter camera

We envision a narrow angle type camera.

Resolution similar to the OSIRIS Narrow Angle Camera (NAC) on Rosetta.

Field of view:	2.2° x 2.2°
Angular resolution:	18.6 μradians / pixel
CCD:	2000 x 2000 pixels

We will use a different shutter mechanism allowing exposures down to 1 ms and a newer CCD compared to the NAC.

m a p p i n g   p h a s e

We map the Cerealia and Vinalia faculae for potential landing sites from 43 km altitude.

First we map the entire faculae with 0.8 m / px,

Factor > 4 better than Dawn's resolution.

Then map a chosen landing site from 20 km altitude

at < 0.4 m / px.

We estimate that this can be done in 2 months.

Total power consuption budget

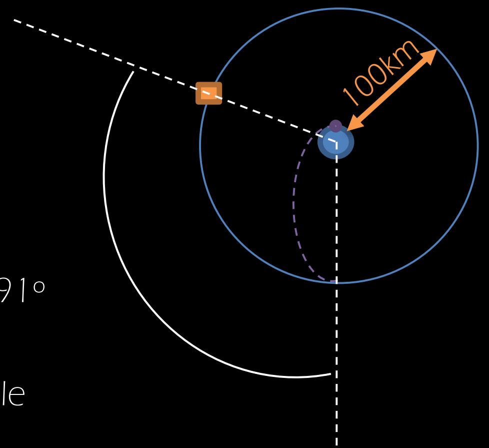
MODES	TOTAL POWER CONSUPTION (W)
CALATHUS	
Launch	120
Travel	32629
Operational mode 1	649
Launch Piazzi	681
Safe	405
Rendezvous	679
Re-entry	515
PIAZZI	
Launch from Orbiter	108
Operational mode 2	169
Take off	94

Rendezvous system(RS)

Rendezvous System (RVS)

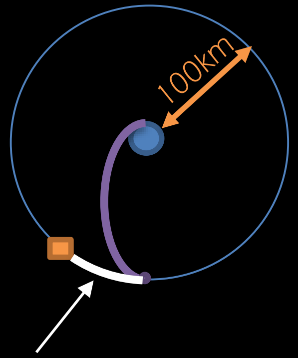
1. Launch from the surface into a 100 km circular orbit
2. Separation of Orbiting Sample (OS) and the propulsion stage, removal of propulsion stage
3. Orbiter manoeuvres to catch the OS

$T_0 = 0$



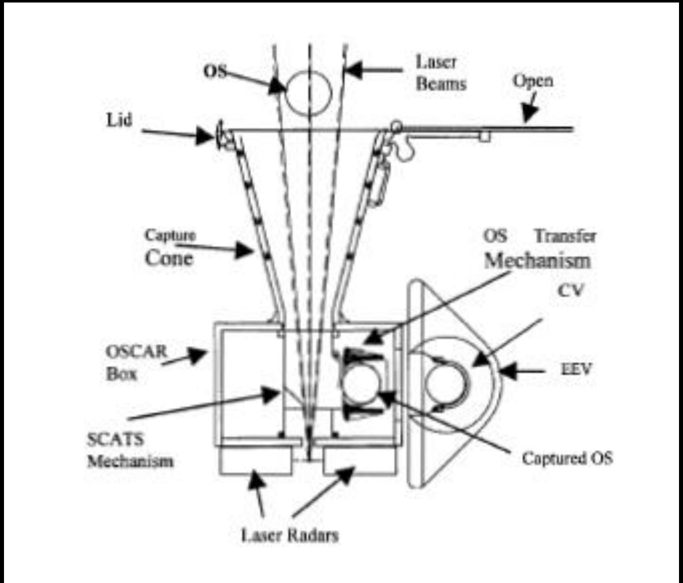
*Not to scale

$T_1 = 45\ minutes$



System design

Technology proposed and tested for Mars Sample Return



Credit:"Mars Sample Return Spacecraft Systems Architecture"- H. Price, Jet Propulsion Laboratory

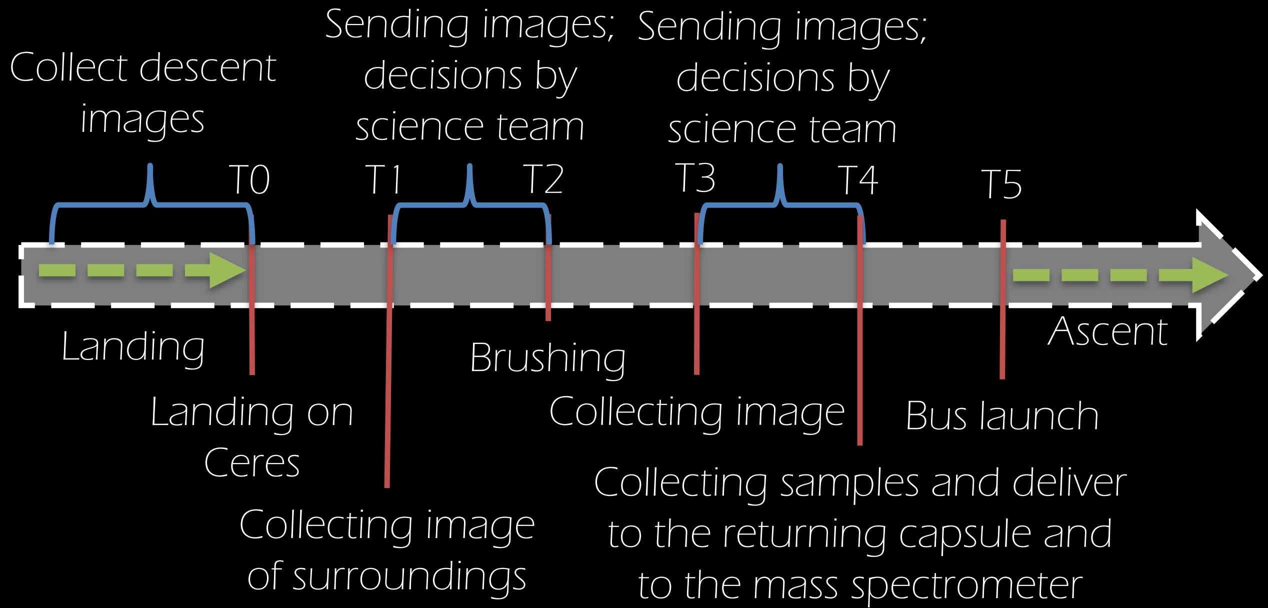
Physical characteristics:

- Capture cone: 0.5 m diamiter entry, 0.2 m exit
- Estimated mass: 70 kg
- Power consumption between 27W and 34 W
- Less than 0.5 m accuracy lidar detection
- Blocking arm
- Transfer mechanism to fix the OS in the reentry capsule

System design

Credits: esa.int

Timeline: sampling and measurements

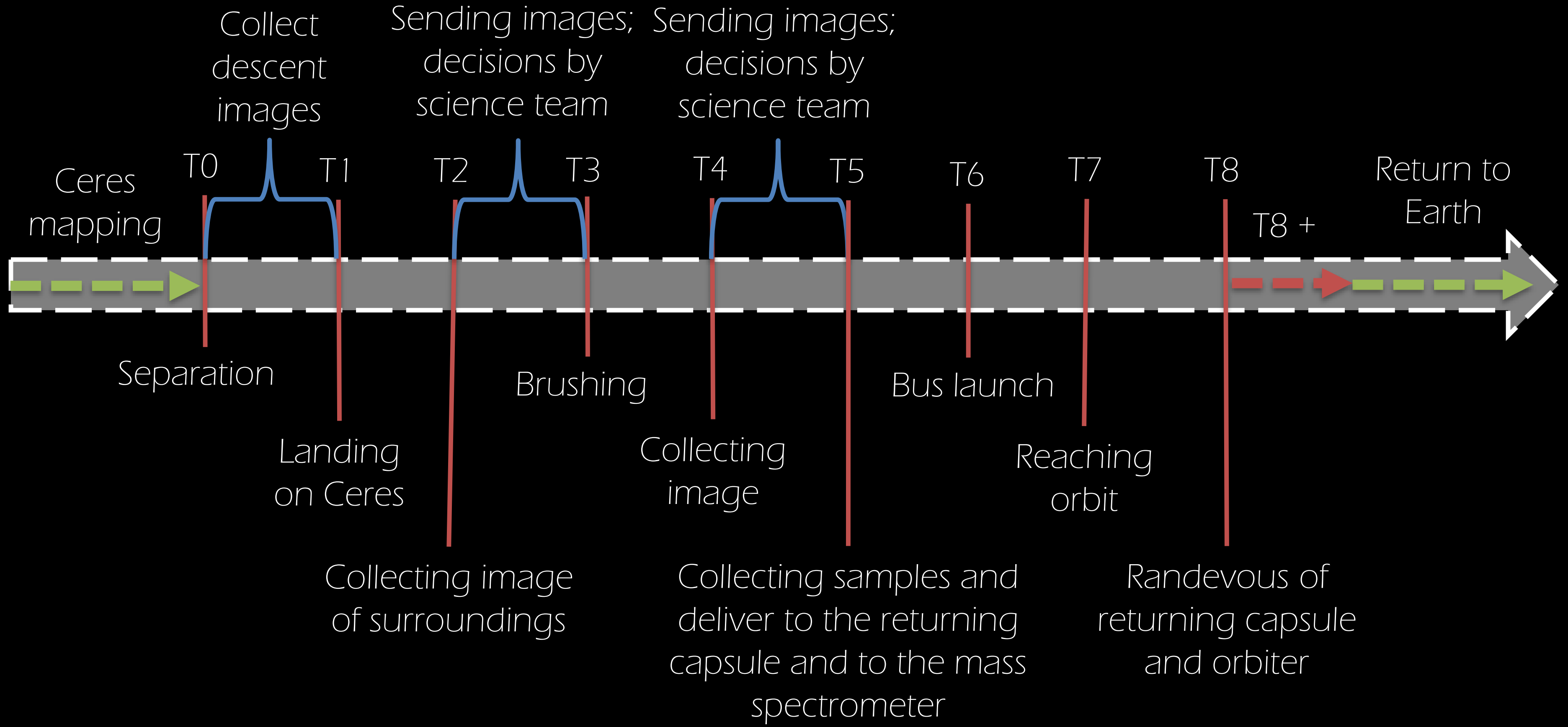


Collect descent images
Sending images; decisions by science team
Sending images; decisions by science team
T0
T1
T2
T3
T4
T5
Landing
Landing on Ceres
Collecting image of surroundings
Brushing
Collecting image
Collecting samples and deliver to the returning capsule and to the mass spectrometer
Bus launch
Ascent

Timeline: samplingand measurements

Time points	Action	Duration
T0	Landing on Ceres	1h
T0 -> T1	Collecting and send image of surroundings; decisions by science team	1d
T2	Brushing	0,5h (10 min / spot)
T2 -> T3	Collecting and send image; decisions by science team	1d
T4	Collecting samples and delivereing to the returning capsule and to the mass spectrometer	8h (max., depending on hardnes)
T5	Bus launch	1h

Timeline: sampling and measurements



Timeline: sampling and measurements

Time points	Action	Duration
T0	Separation	0
T0 -> T1	Collecting descent images	
T1	Landing on Ceres	1h
T2 -> T3	Collecting and send image of surroundings; decisions by science team	1d
T3	Brushing	0,5h (10 min / spot)
T4 -> T5	Collecting and send image; decisions by science team	1d
T5	Collecting samples and delivereing to the returning capsule and to the mass spectrometer	8h (max., depending on hardnes)
T6	Bus launch	1h
T7	Reaching orbit	1h
T8	Randevous of returning capsule and orbiter	2 d (max.)
T8+	Contingency time for randevous	1 week