The OWL Mission
Origin of Water and Life

TEAM RED


OWL-MISSION
Alpbach Summer School 2018 – Team Red

COM(ET)ING HOME

Mission Statement

Science Case

Payload Concept

Mission Profile & S/C

Project Envelope

Science Case

Payload Concept

Mission Profile & S/C

Project Envelope

Why are we interested in small bodies?

- Remnants of the early Solar System
- Building blocks
- Shaped life on Earth
  - delivered water and organics to Earth
  - extinction events
- Resource Exploitation

www.inverse.com

Why choose a comet?

- COMETS ARE COOL !

- Primordial objects from the outer solar system
  - as old as 4.6 billion years
  - contain water ice and other volatiles
  - less violent history than asteroids

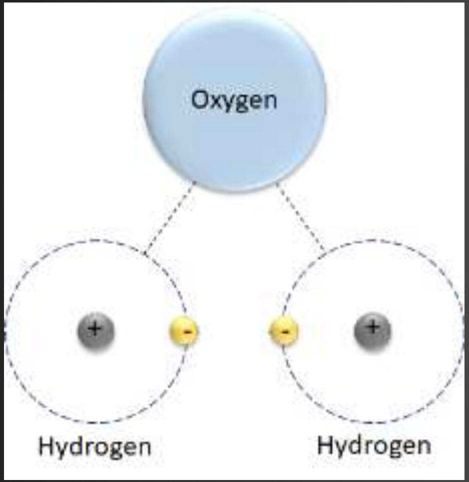
- More asteroid samples than comet samples

What we learned from previous comet missions

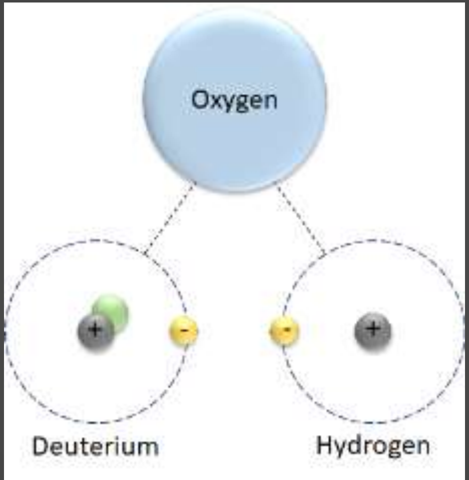
- High diversity of organic compounds
- Not “dirty snowballs” (dry and dark surface)
- Unexpected shape
- Gas drag is not completely predictable
- Wide range of D/H ratio for Jupiter Family Comets

www.esa-int

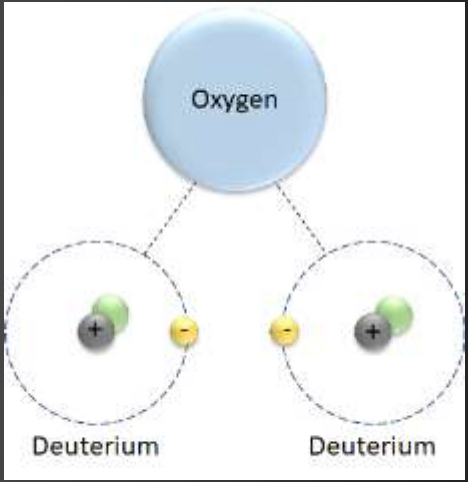
What is heavy water?



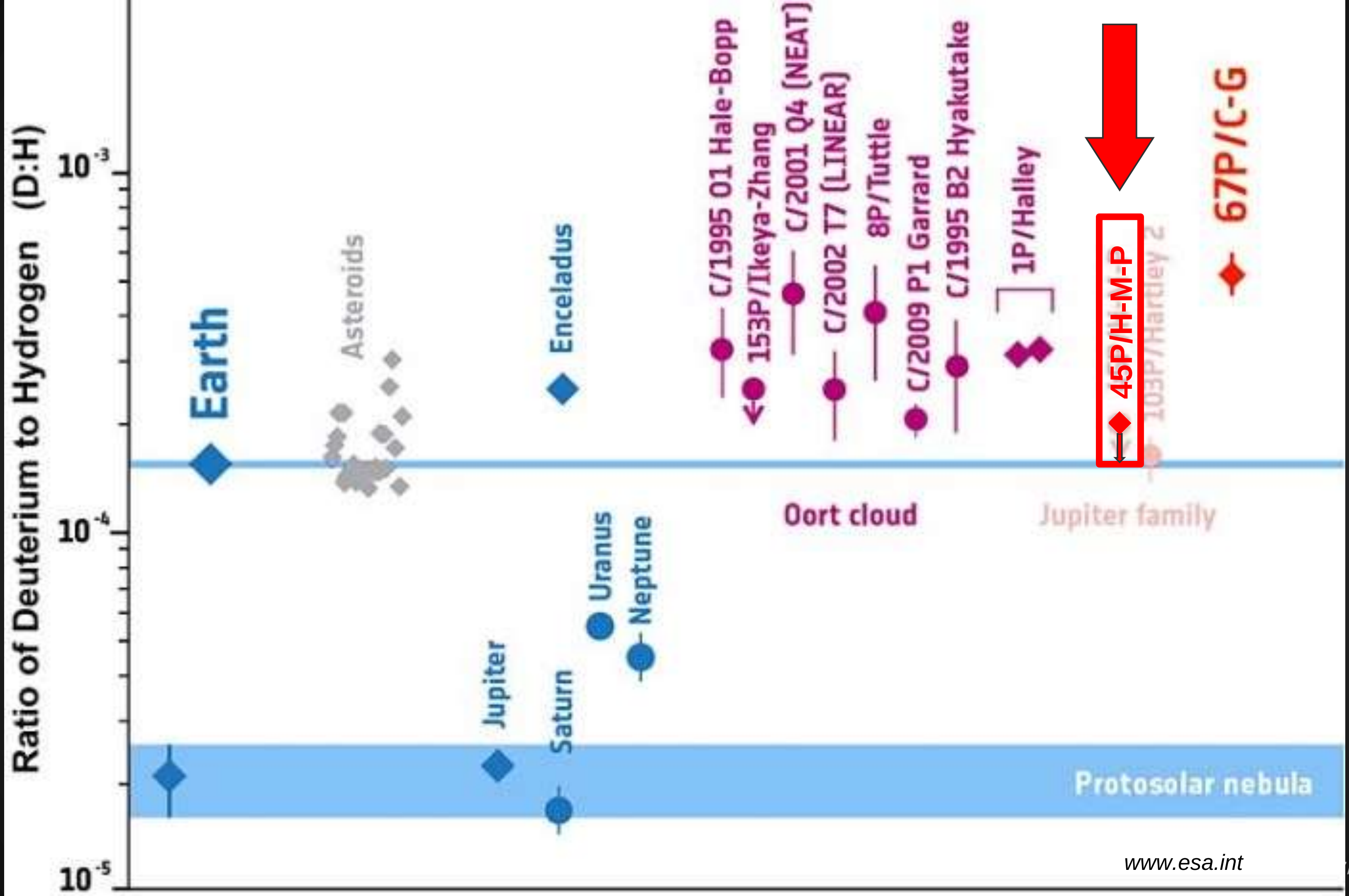
H_2O



HDO



D_2O

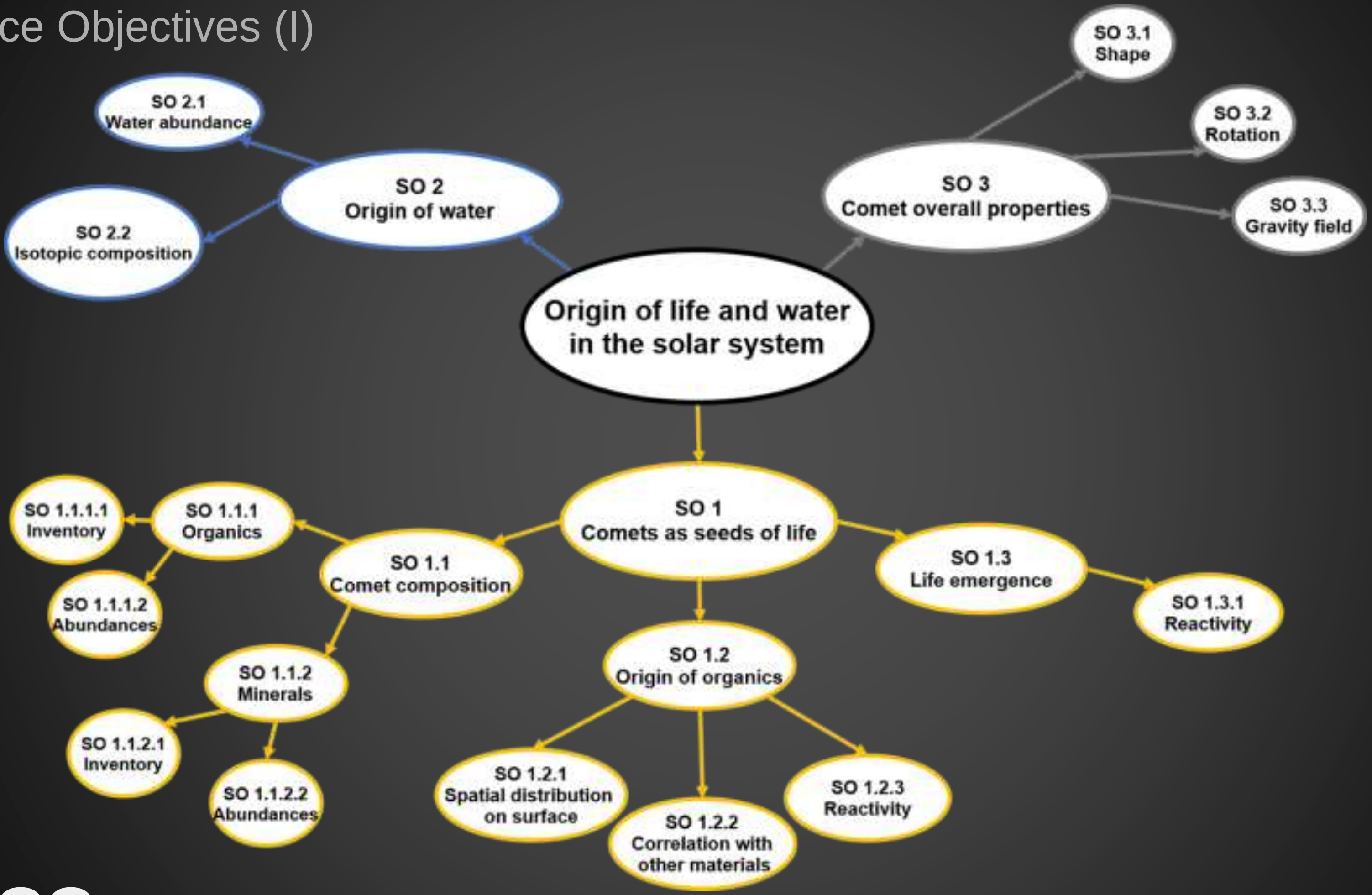

Ratio of Deuterium to Hydrogen (D:H)
10^{-3}
10^{-4}
10^{-5}
Earth
Asteroids
Enceladus
Jupiter
Saturn
Uranus
Neptune
C/1995 O1 Hale-Bopp
153P/Ikeya-Zhang
C/2001 Q4 (NEAT)
C/2002 T7 (LINEAR)
8P/Tuttle
C/2009 P1 Garrard
C/1995 B2 Hyakutake
1P/Halley
45P/H-M-P
103P/Hartley 2
67P/C-G
Oort cloud
Jupiter family
Protosolar nebula

www.esa.int

What questions are remaining?

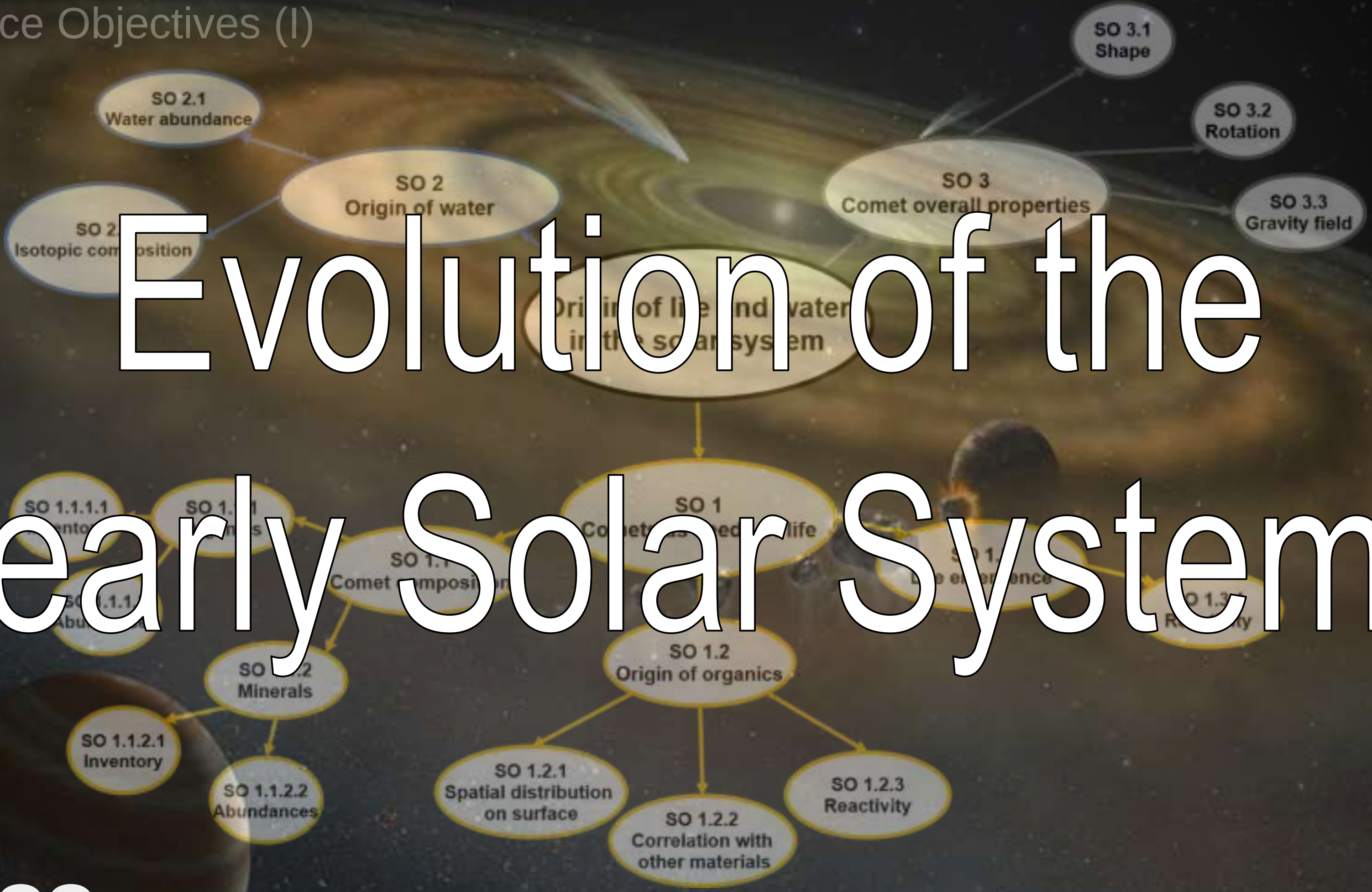
- Are dust agglomerates primitive pebbles?
- Does nucleus contain interstellar matter?
- Age of surface and subsurface material?
- Exact composition of complex organics?

Science Objectives (I)

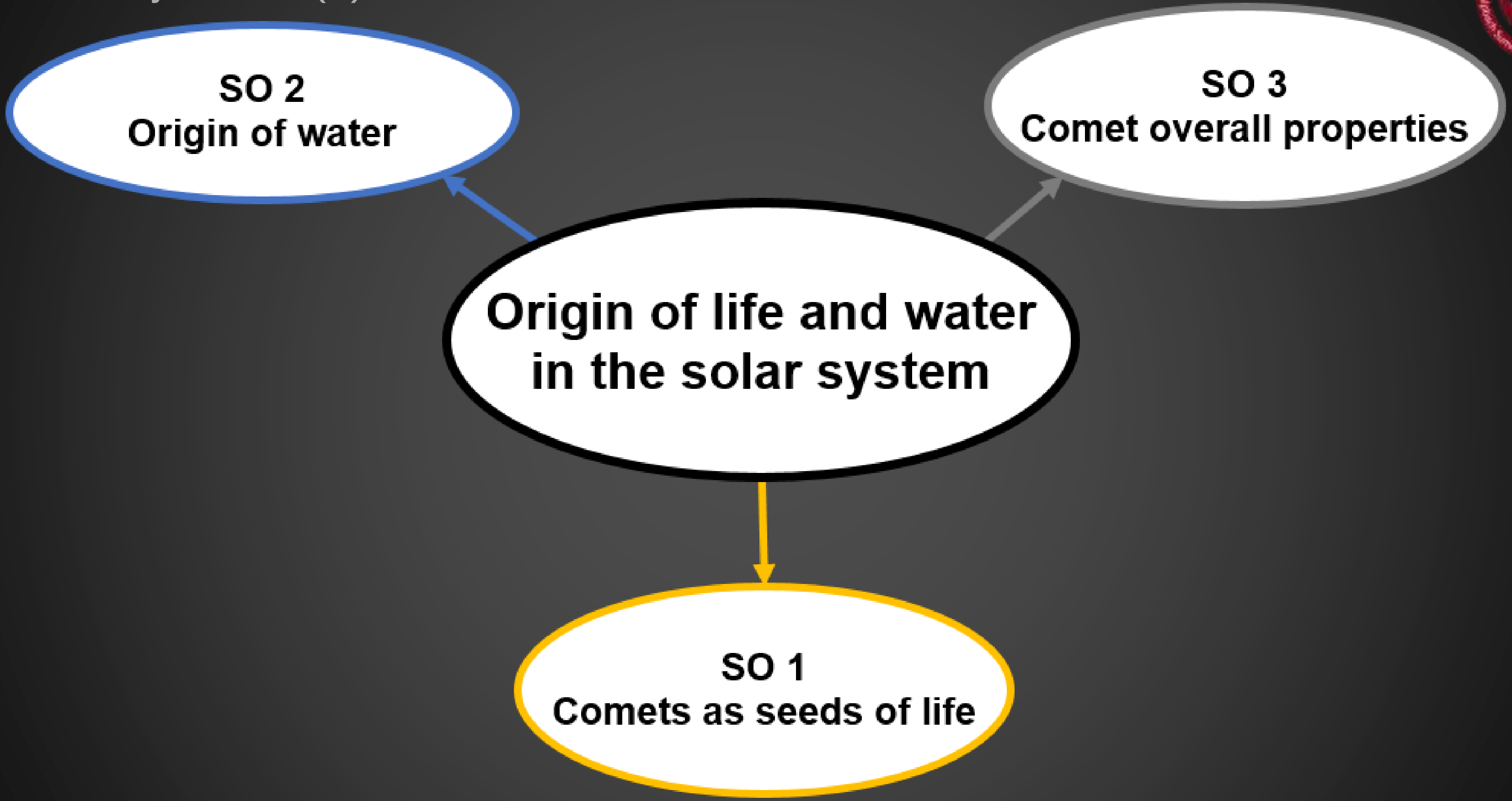


Science Objectives (I)

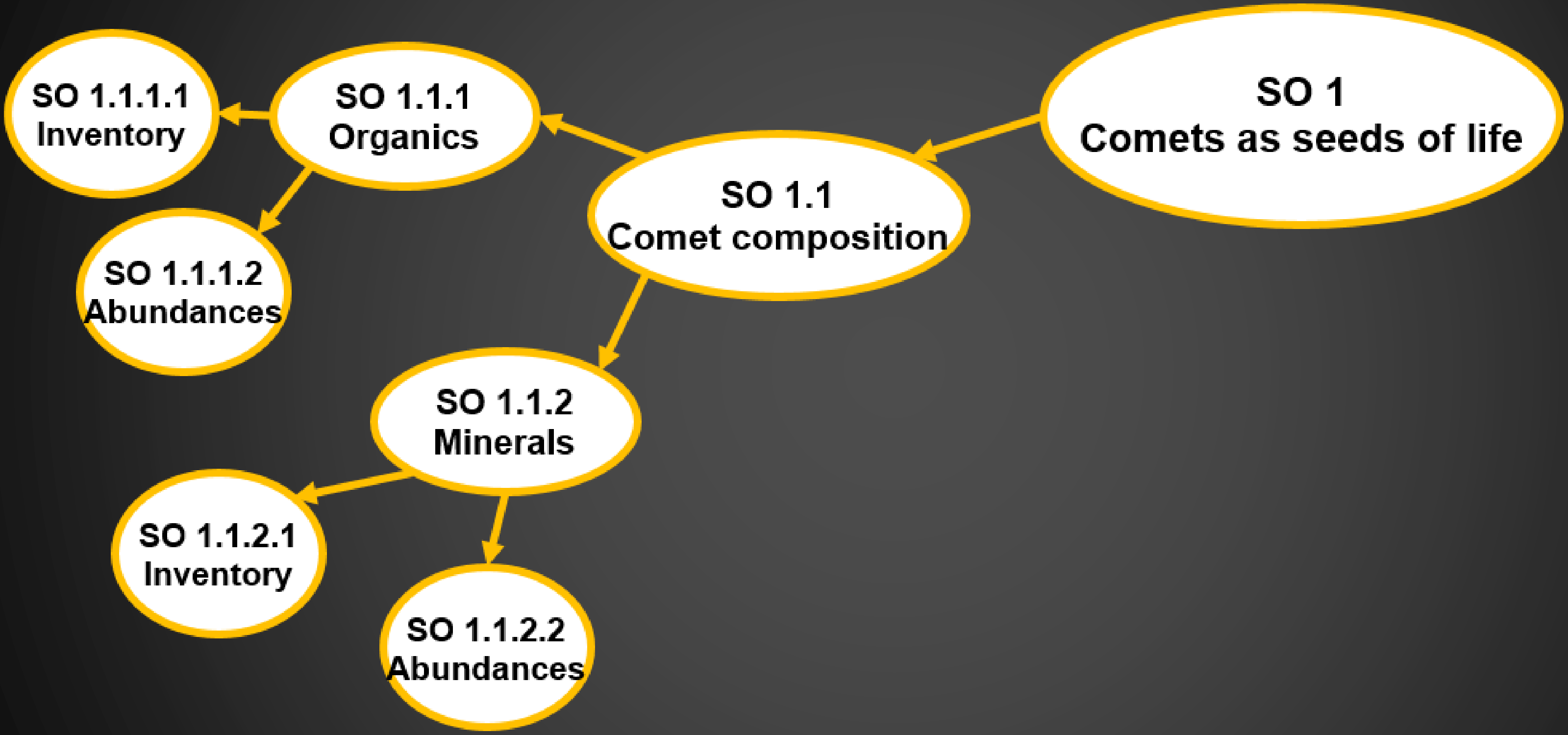
Evolution of the early Solar System



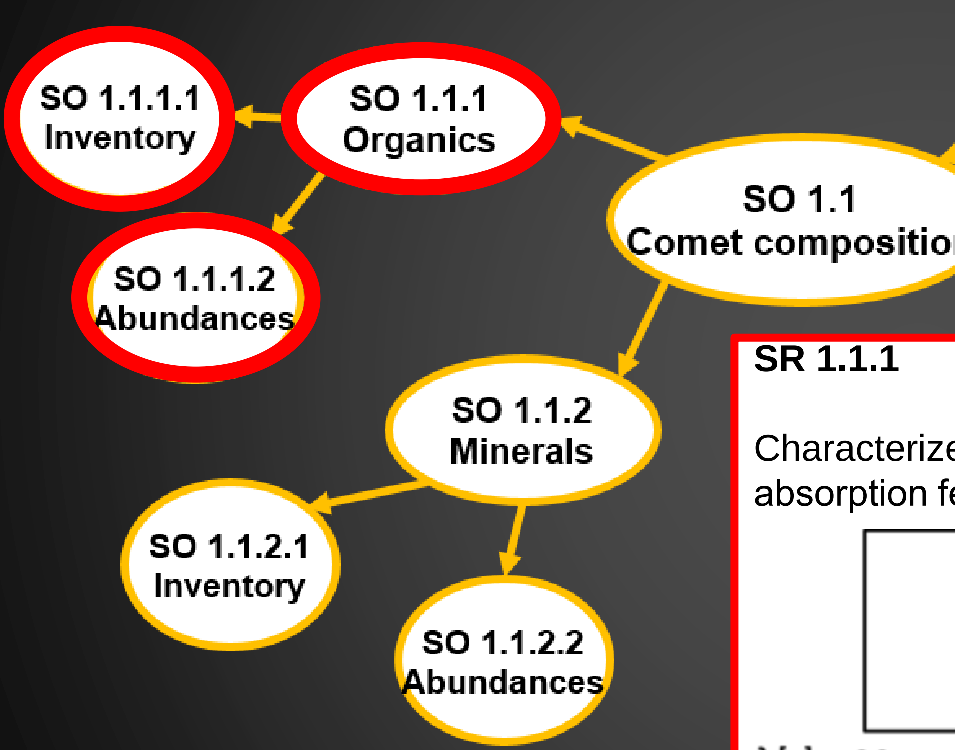
Science Objectives (II)



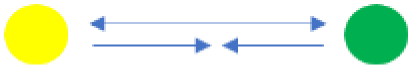
Science Objectives (III)



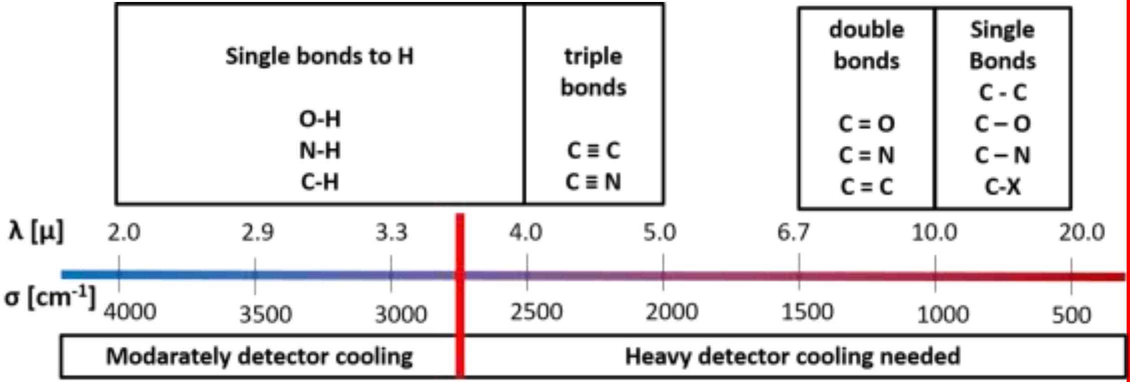
Science Objectives (III)



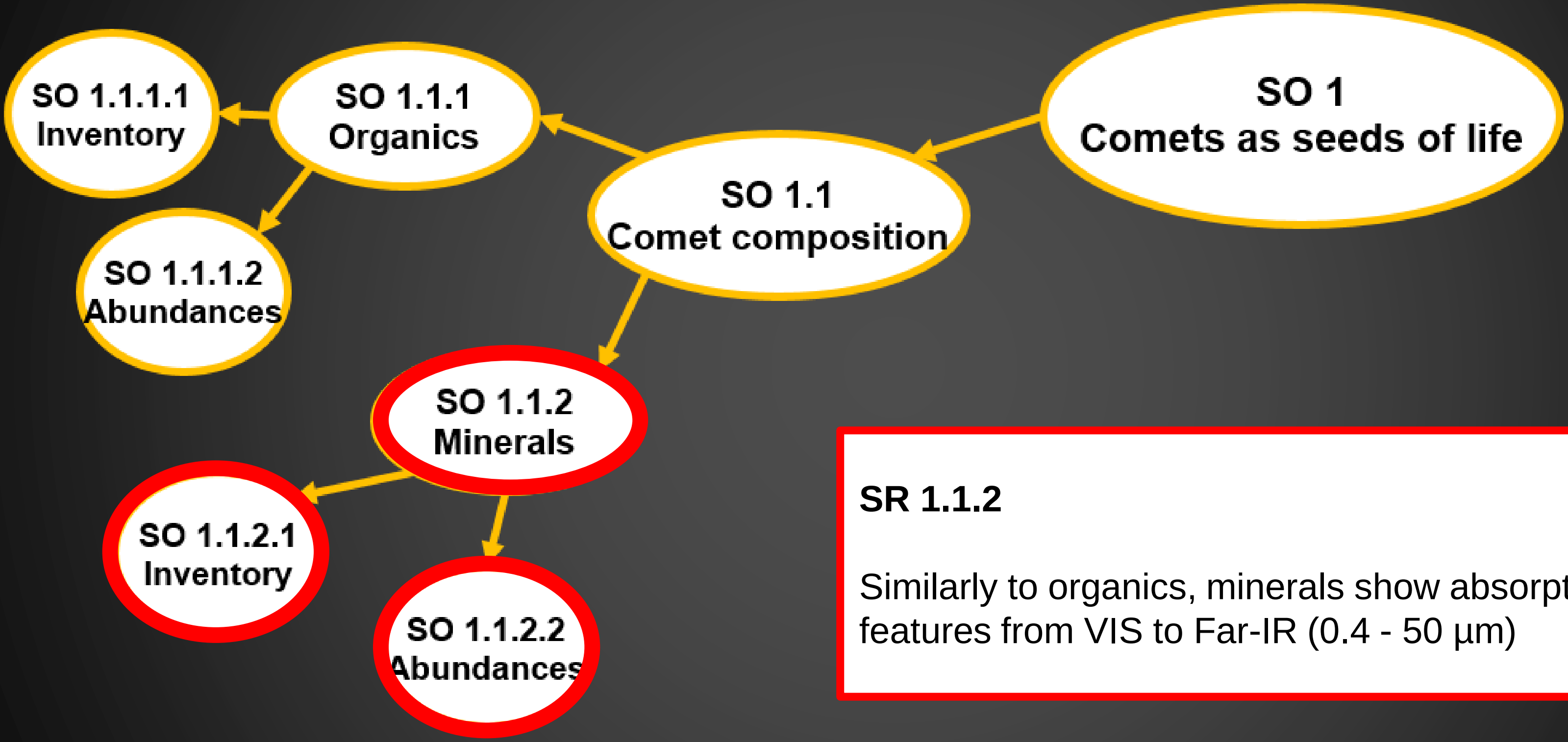
SR 1.1.1



Characterize the nature of organic molecules by measuring their IR absorption features from 2 to 20 µm



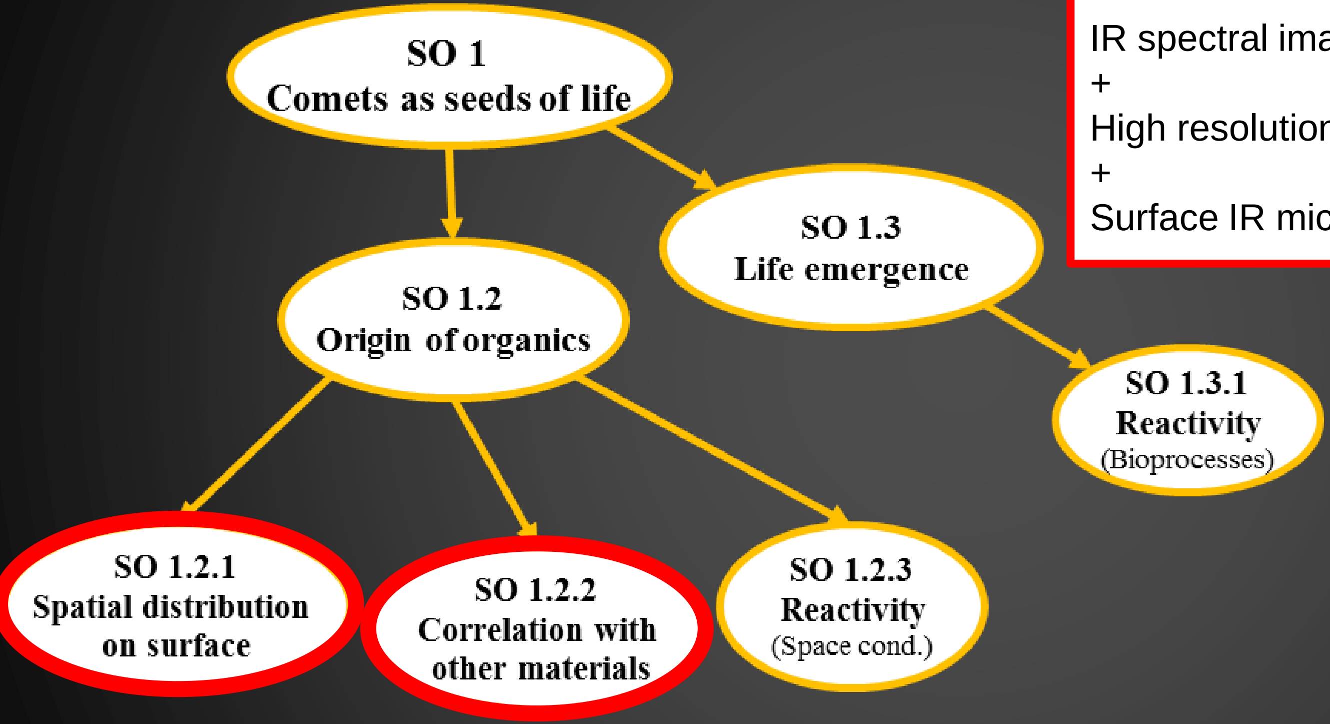
Science Objectives (III)



SR 1.1.2

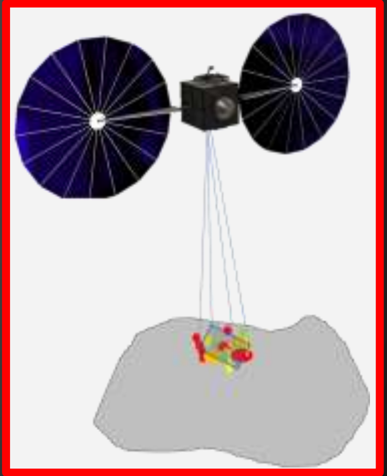
Similarly to organics, minerals show absorption features from VIS to Far-IR (0.4 - 50 μm)

Science Objectives (IV)

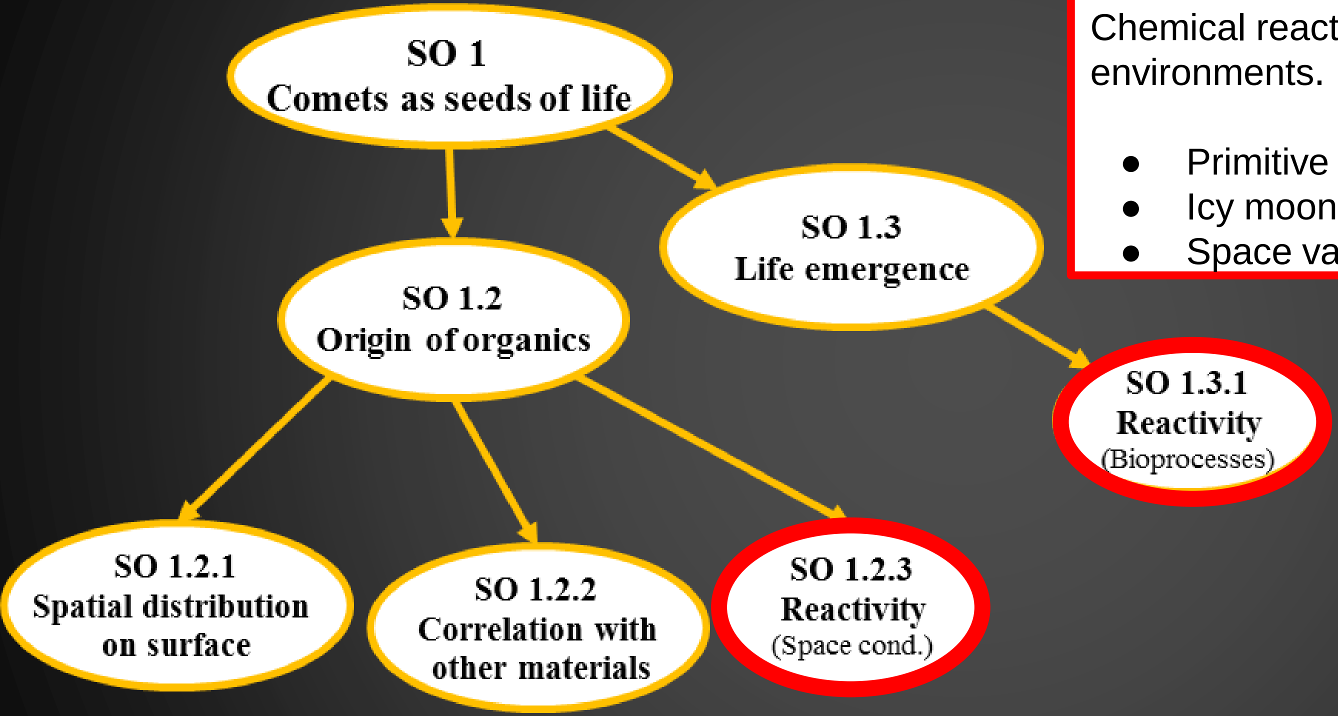


SR 1.2.1 & 1.2.2

IR spectral imagery of the surface: 1 - 3.6 µm
+
High resolution imagery: 0.1 mrad
+
Surface IR microscopy: 1 - 3.6 µm, 20 µm resol



Science Objectives (V)



SR 1.2.3 & 1.3.1

Chemical reactivity tests in various environments.

- Primitive planetary ocean
- Icy moon
- Space vacuum

Tandem accelerator, IPN, Orsay

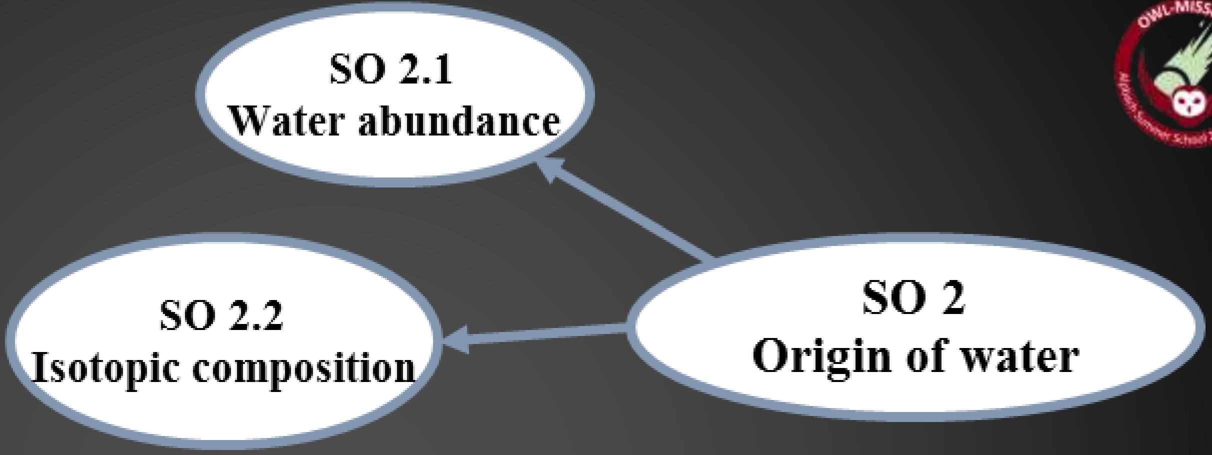
Science Objectives (VI)

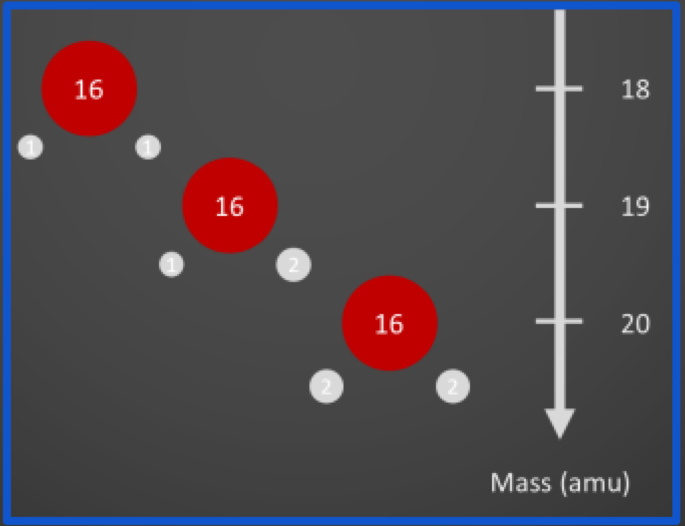
SR 2.1

Target 1.4 µm (hydratation) and 2.6 µm (O-H) band in IR spectra

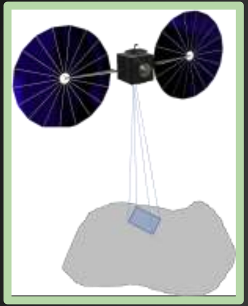
SR 2.2

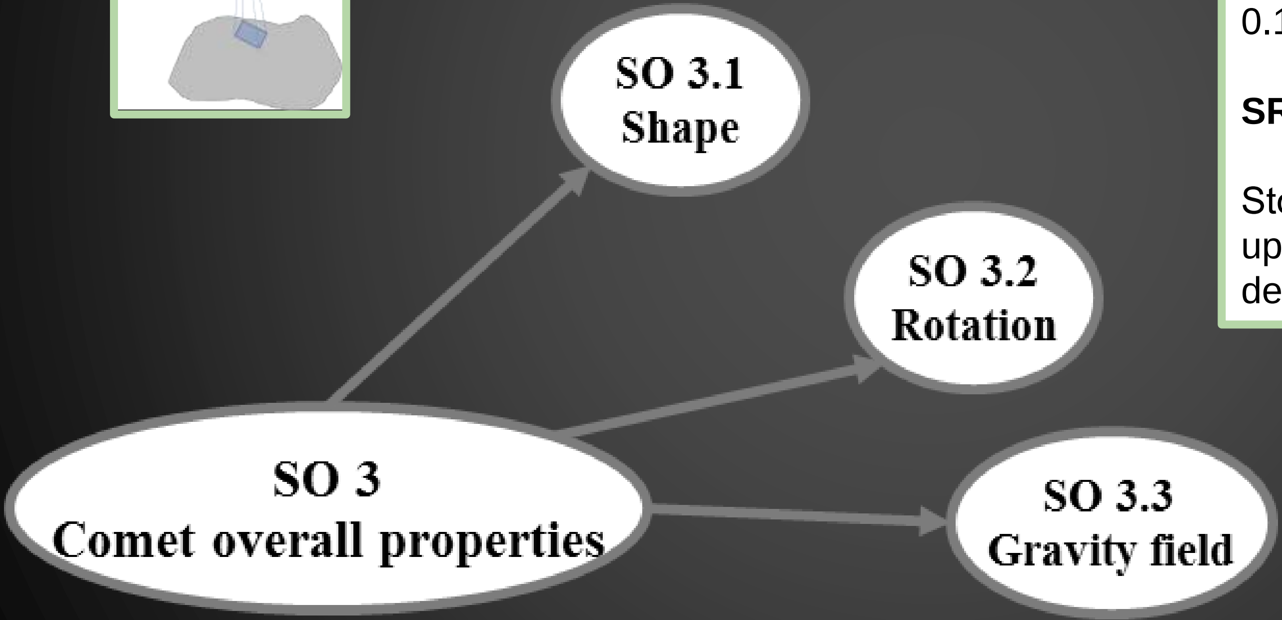
Mass spectra: H_2O, DHO, D_2O differentiation
from 18 to 22 amu





Science Objectives (VII)





SR 3.1 & 3.2

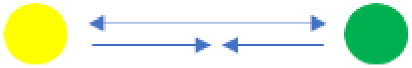
High resolution imagery:
0.1 mrad global coverage

SR 3.3

Stokes coefficients’ determination up to and including order and degree 2

Science Objectives (VIII)

SR 1.1.1



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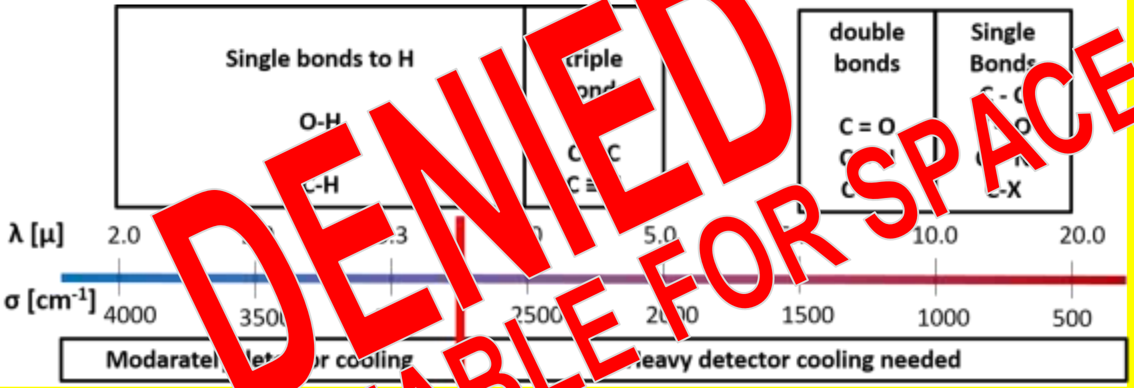

DENIED
NOT SUITABLE FOR SPACE

SR 1.1.2

Similarly to organics, minerals show absorption features from VIS to Far-IR (up to 50 μm)

SR 1.2.3 & 1.3.1

Chemical reactivity tests in various environments.

- Primitive planetary ocean
- Icy moon
- Space vacuum

SR 2.1

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SR 3.1 & 3.2

High resolution imagery:
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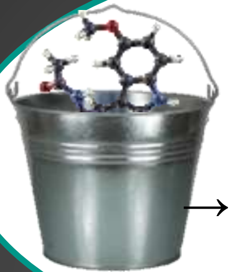
SR 3.3

Stokes coefficients' determination up to and including order and degree 2

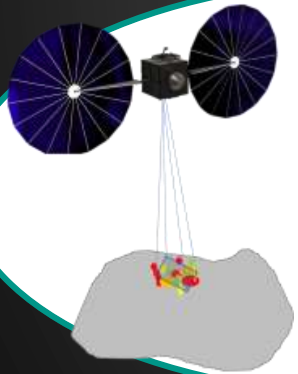
SAMPLE RETURN !

Mission Objectives



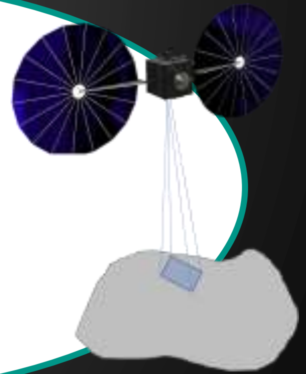
Return
+ analyze sample

→ chemical composition

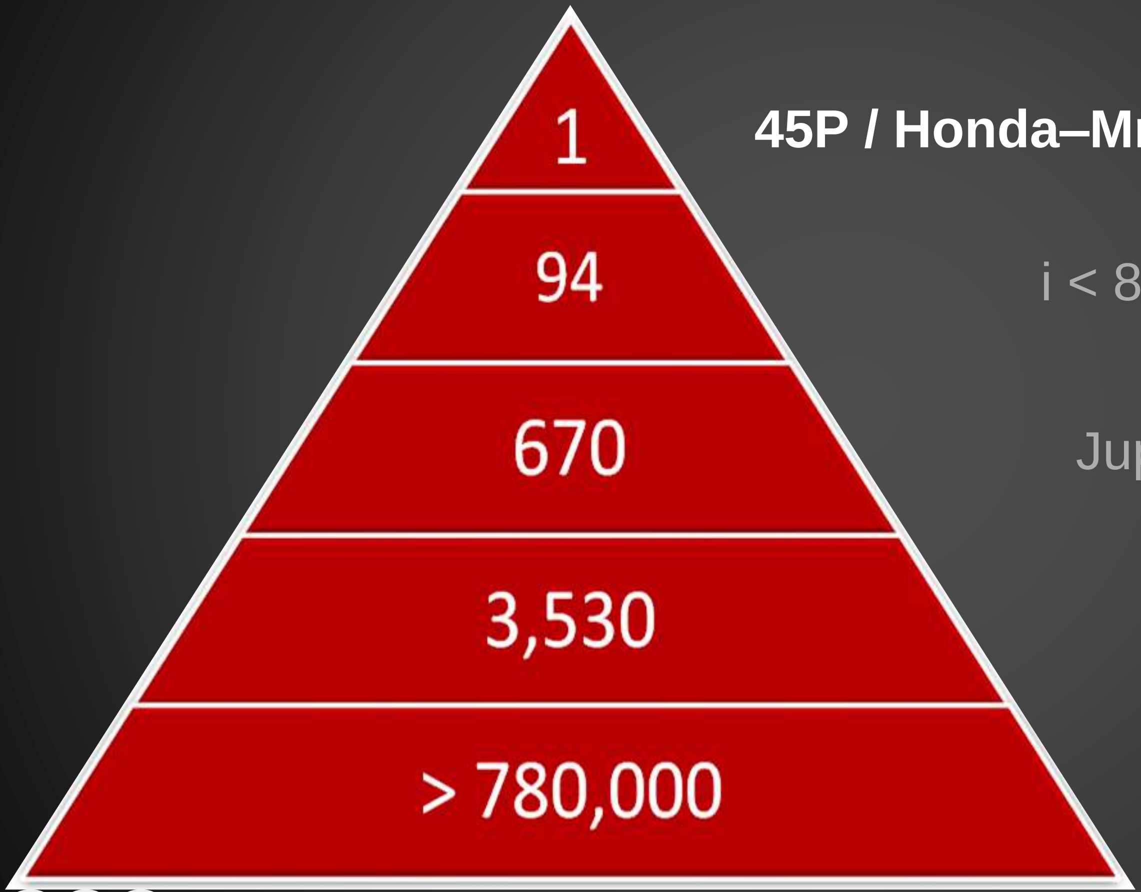


Map organics distribution on surface

Measure comet’s properties (shape, density, rotation, gravitation)



Mission Target



45P / Honda–Mrkos–Pajdušáková

i < 8 deg, period < 10 yr

Jupiter Family Comets

Comets

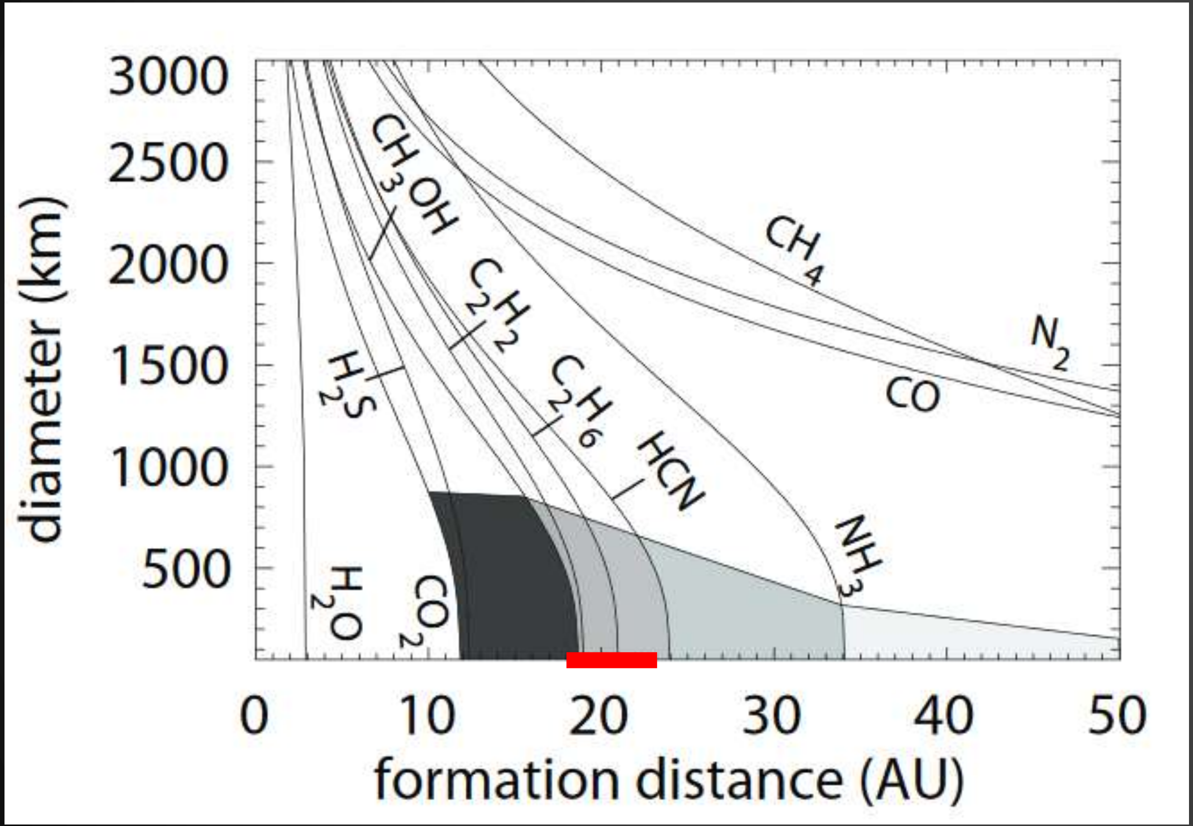
Small Bodies

JPL

45P / Honda–Mrkos–Pajdušáková

- Jupiter family comet (originate from Kuiper belt, influenced by Jupiter)
- Short orbital periods (< 20 years), low inclination and high eccentricity
- Two lobes and grains with a size of > 2 cm in the coma detected
- Composition:
  - strong depletion of CO (carbon monoxide) HCN (hydrogen cyanide) depletion
  - CH_3OH (methanol) enrichment
- Activity is expected to begin at Mars distance and peak at perihelion (lasting a year)

45P / Honda–Mrkos–Pajdušáková - Chemical Properties



Brown 2012

CO and HCN depletion

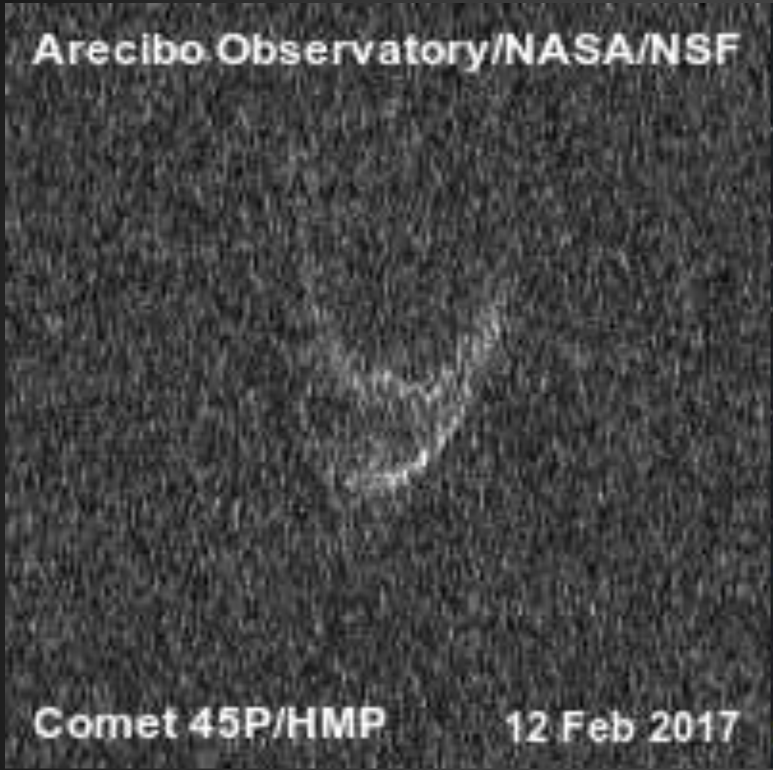
CH_3OH detection

→ formation distance

18 - 23 AU

~ Uranus's orbit

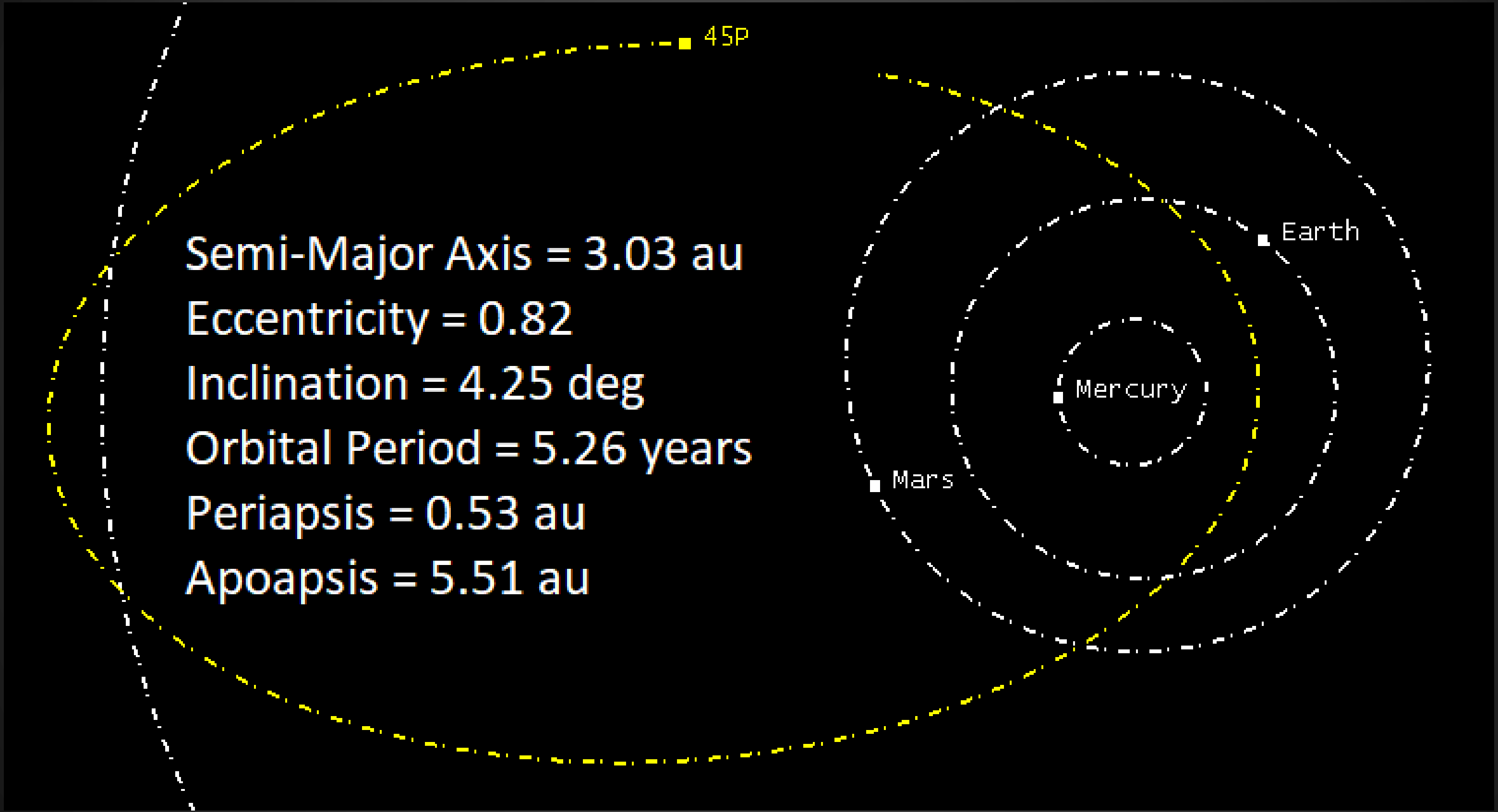
45P / Honda–Mrkos–Pajdušáková



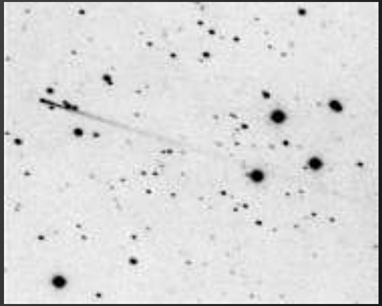
Arecibo radar observation of 45P

VIS image of 45P ‘the Green Comet’ (Gerald Rhemann, NASA)

Target Orbit



Alternative Targets

15P/Finlay	137P/Shoemaker-Levy 2	133P/Elst-Pizarro (MBO)
Radius: 1.8 km Abs. mag.: 15.1 mag Mass: $1.5*10^{12}$ kg Orbital period: 6.51 yr  *Damian Peach*	Radius: 2.9 km Abs. mag.: 15.2 mag Mass: $5*10^{13}$ kg Rot. period: 7.7 h Orbital period: 9.56 yr  *Kuma Kogen Astronomical Observatory*	Radius: 1.6 km Abs. mag.: 15.7 mag Mass: $3*10^{13}$ kg Rot. period: 3.47 h Orbital period: 5.63 yr  *ESO*

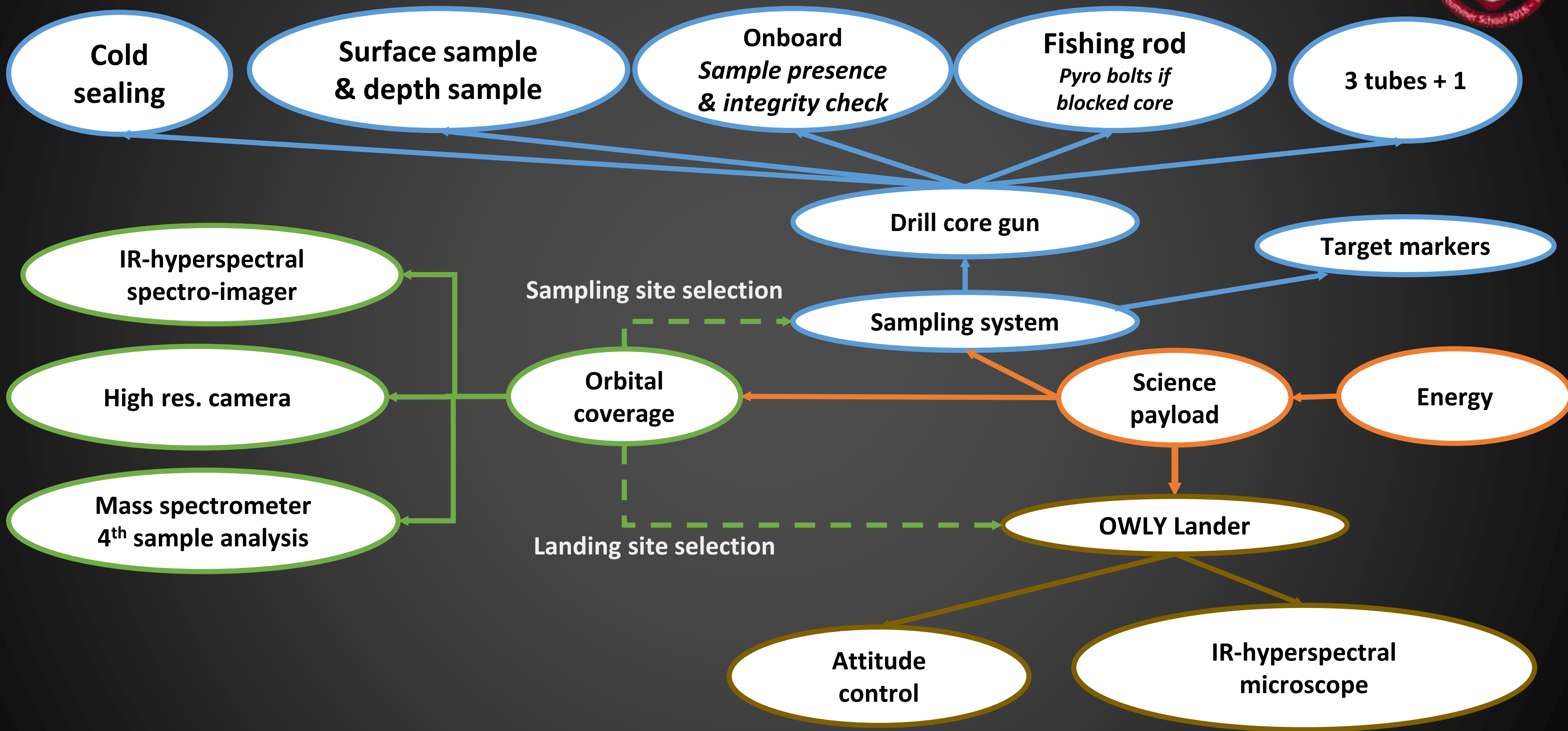
Science Case

Payload Concept

Mission Profile & S/C

Project Envelope

Payload overview



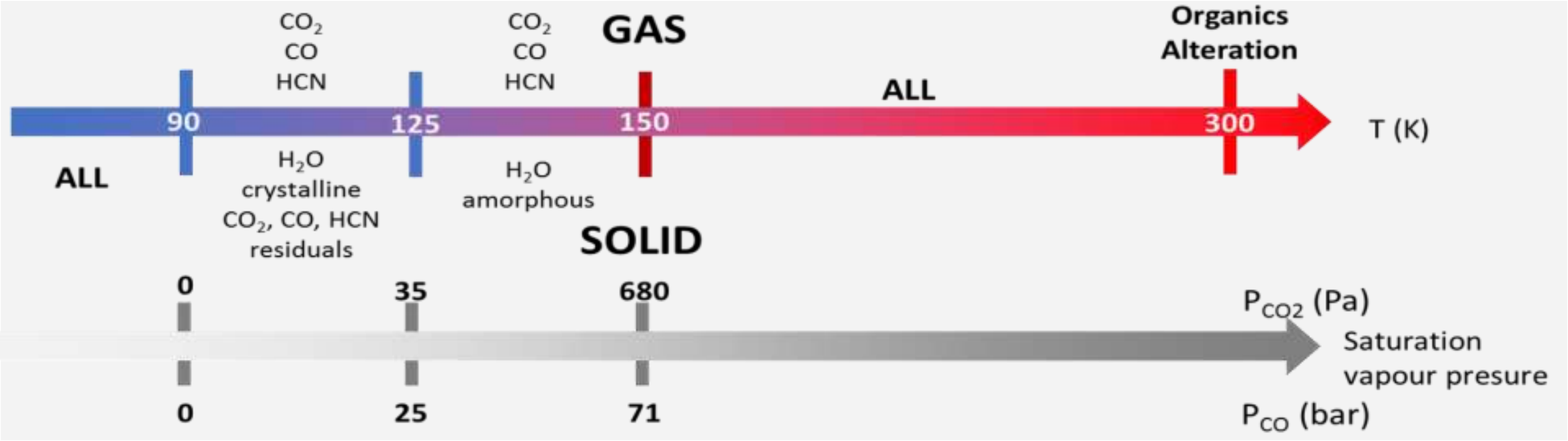
Sample Requirements - Mass

- 3 samples of comet returned to Earth
    - \+ possible cooperation
    - \+ same amount kept for later use
    - \+ margin for destructive experiments
    - \+ 100 % margin
    - 18 g min. mass for earth based experiments

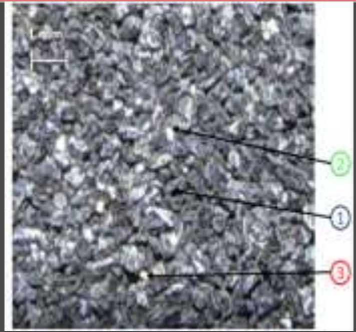
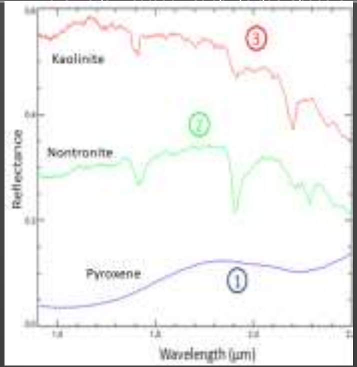
150 g
144 g
72 g
36 g
18 g

Sample Requirements - Condition

- Prevent sublimation of icy components (except CO which has presumably low abundance on 45P)
- The samples must be kept at a max. temperature of 120 K with tolerable, brief, peak of 140 K during Earth re-entry.
- Hermetic sealing, resist internal pressure of 3.5 Pa



Instruments Requirements (I)

Instrument type	Observation method		Specifications
IR hyperspectral imagery	Orbital mapping	 MicrOmega/Institut d'Astrophysique Spatiale	Spatial res = 1 mrad Spectral range = 1 – 3.6 µm Spectral res = 2 nm @ 1 µm - 25 nm @ 3.6 µm
	Microscopic imagery	 MicrOmega/Institut d'Astrophysique Spatiale	Spatial res = 20x20 µm² Spectral range = 1 – 3.6 µm Spectral res = 2 nm @ 1 µm - 25 nm @ 3.6 µm

Instruments Requirements (II)

Instrument type	Observation method		Specifications
High resolution imagery	Orbital mapping 2 FoV (narrow and wide)	 ESA/Rosetta/MPS for OSIRIS Team MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA	Spatial res = 0.1 mrad (wide) Spatial res = 0.02 mrad (narrow) FOV = 0.2 rad Spectral range = visible
Mass spectrometry	Orbital characterisation	 SAM / MSL / NASA	Mass range 2 - 535 amu

MicrOmega/Institut d'Astrophysique Spatiale

Instruments Requirements (III)

Instrument type	Purpose	Specifications
Sampling mechanism	Sample collection	100 mm surface penetration, pre-cooled to < 120 K, quick enough to keep the sample frozen
Sample Chamber	Sample transport to earth	Maintain temperature < 120 K (cruise) and < 140 K (brief peak during re-entry)

Instruments vs. Science Objectives

	Organics			Water		Comet props	
Payload	**SO1.1**	**SO1.2**	**SO1.3**	**SO2.1**	**SO2.2**	**SO3.1**	**SO3.2**
IR spectrometer (orbit)							
IR microscope (lander)							
High Resolution Camera							
Mass spectrometer							
Earth based facilities (sample)							
Earth based facilities (obs.)							

Science Case

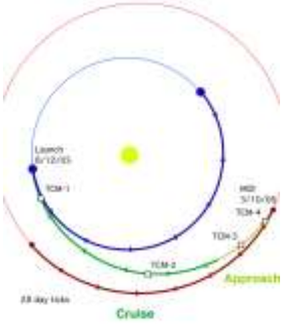
Payload Concept

Mission Profile & S/C

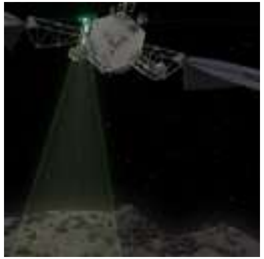
Project Envelope

Mission Timeline


ESA



NASA


NASA


NASA


ESA


ESA


ESA

Launch

Outbound Transfer

Observation Period

Sample Retrieval

Inbound Transfer

Re-entry

Post Analysis

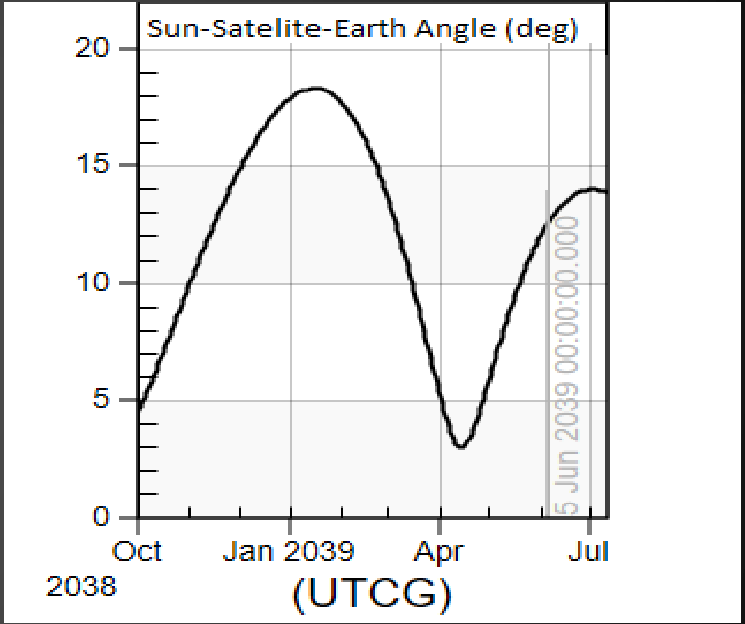
Launch Facility, Provider and Launcher

- Guiana Space Centre in Kourou
- Operator: Arianespace
- Latitude of 5 deg
- Facility ELA-4 intended for **Ariane 64** (under construction)

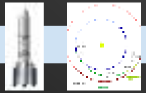
arianespace

System Drivers - Outbound

Launch Date	June 2032
Launcher Performance	5.3 t
Mission Manoeuvres	20 km/s
Gravity Assist	Mars
Propellant Mass	2.2 t
Travelling Time	6.57 yr



Sun-Satellite-Earth Angle at arrival = 17.8 deg



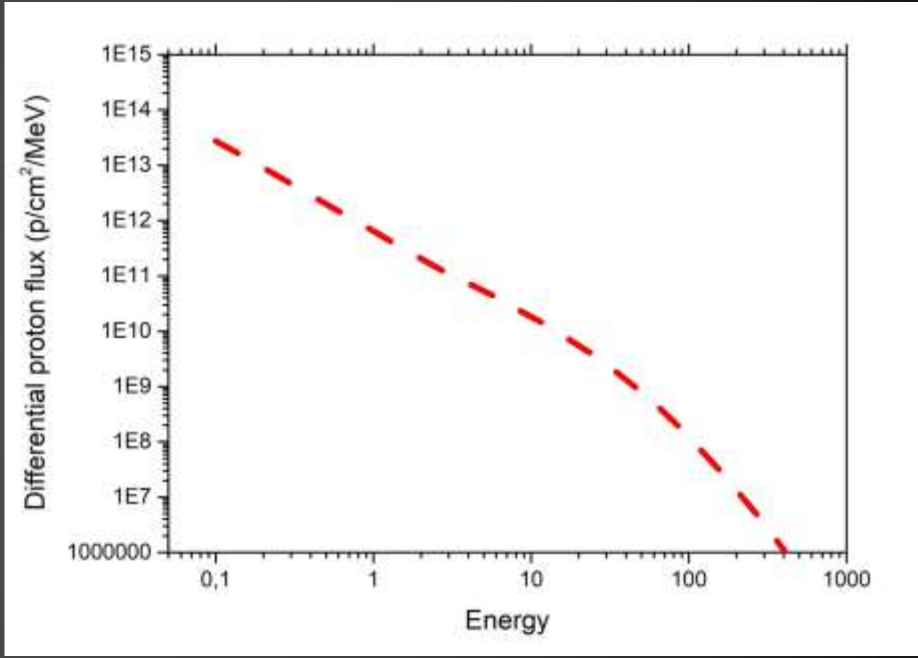
Radiation Environment

- **Solar protons**
- Galactic cosmic rays

Main concern:

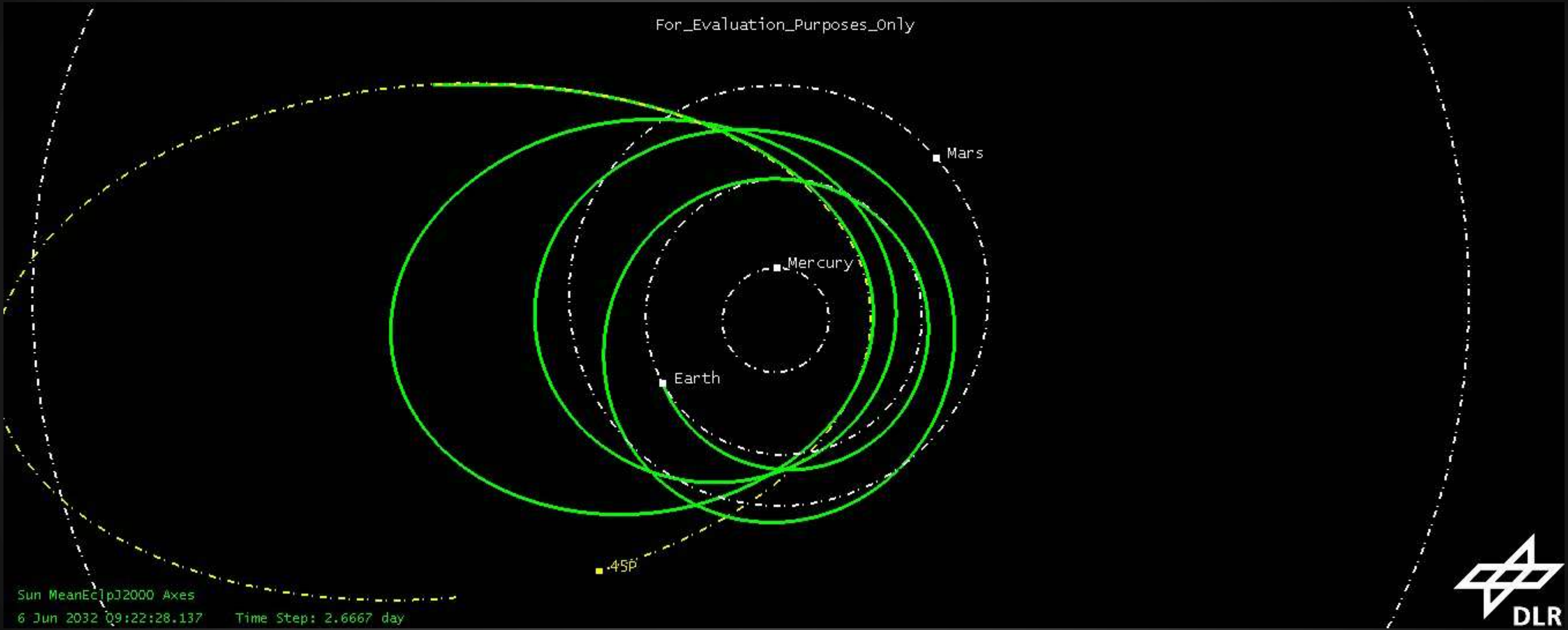
- TID in insulators
- SEE in memories
- **DDD in camera, solar cells**

Wikipedia

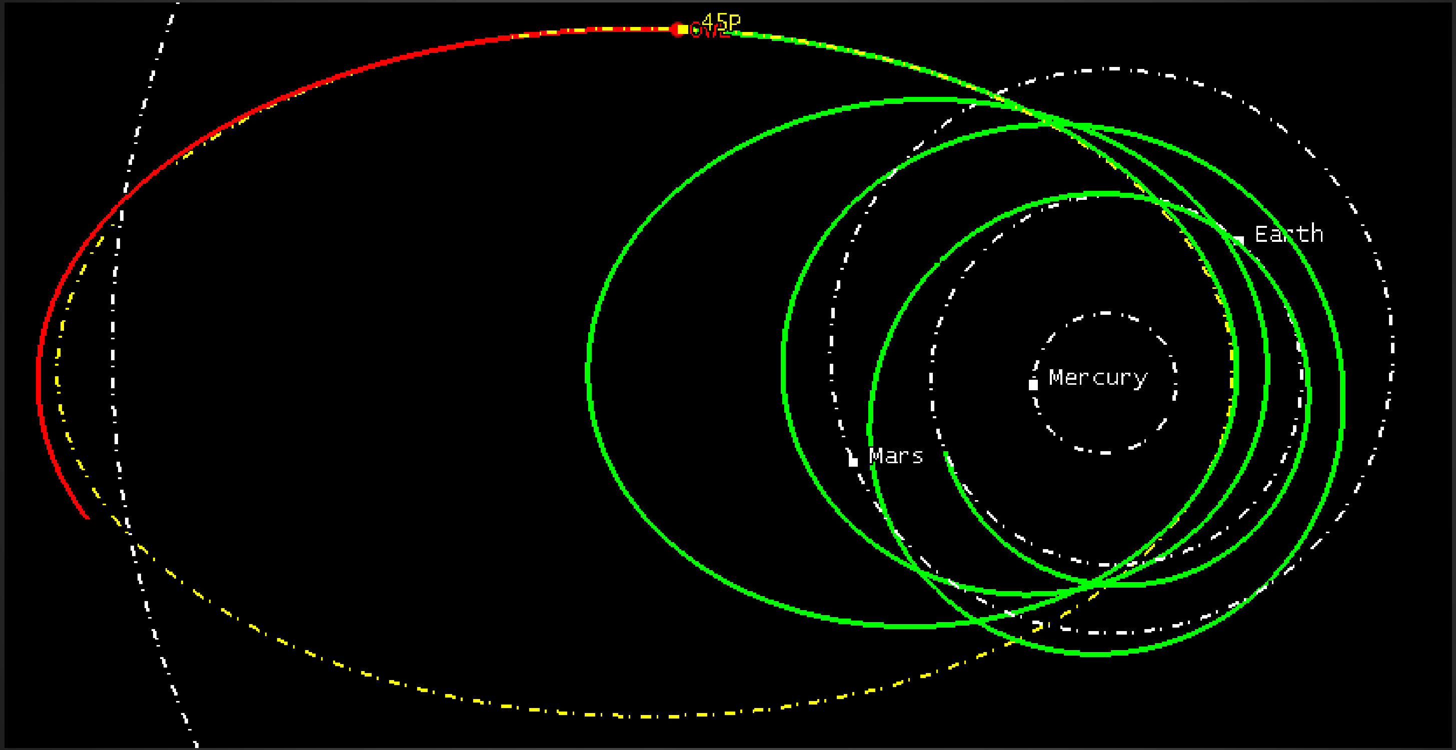


Solar proton flux during comet chasing manoeuvre
DDD: 1e11 MeV/g (SPENVIS)

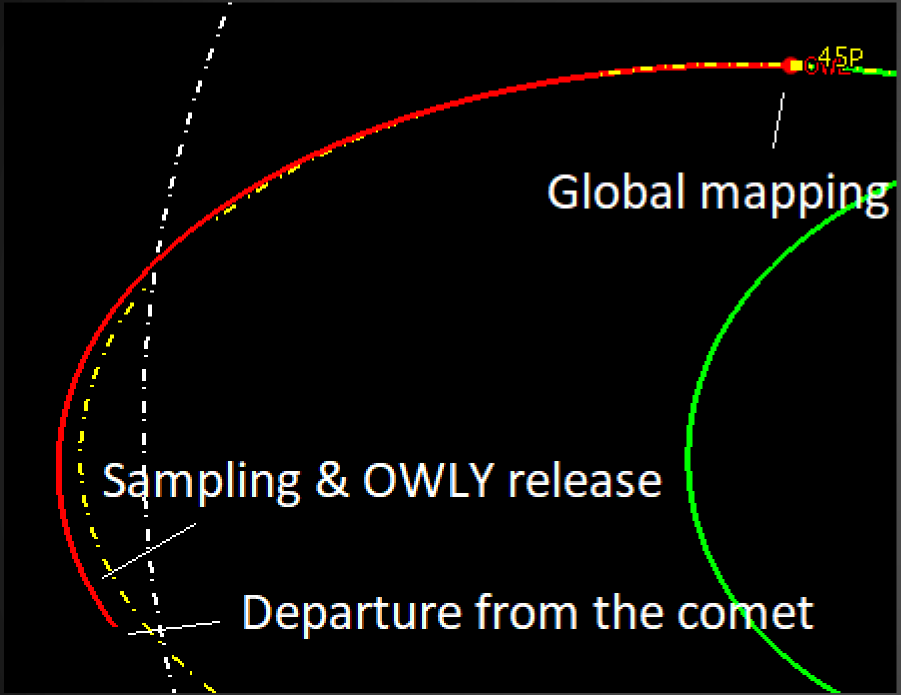
Transfer Outbound



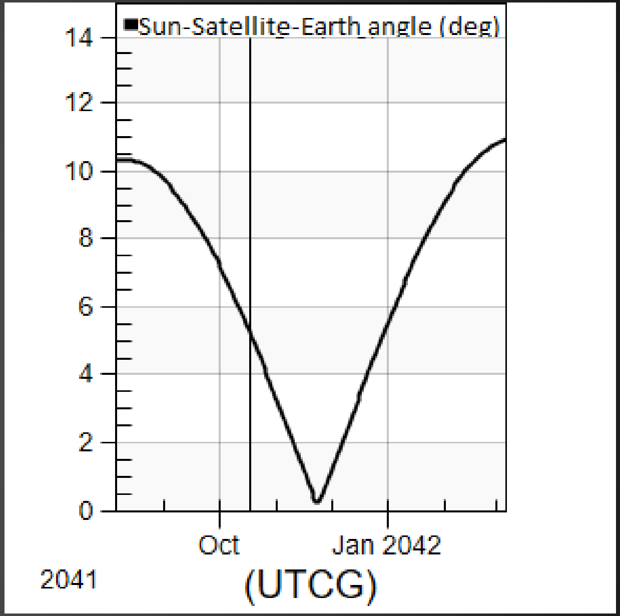
Target Operations (I)



Target Operations (II)

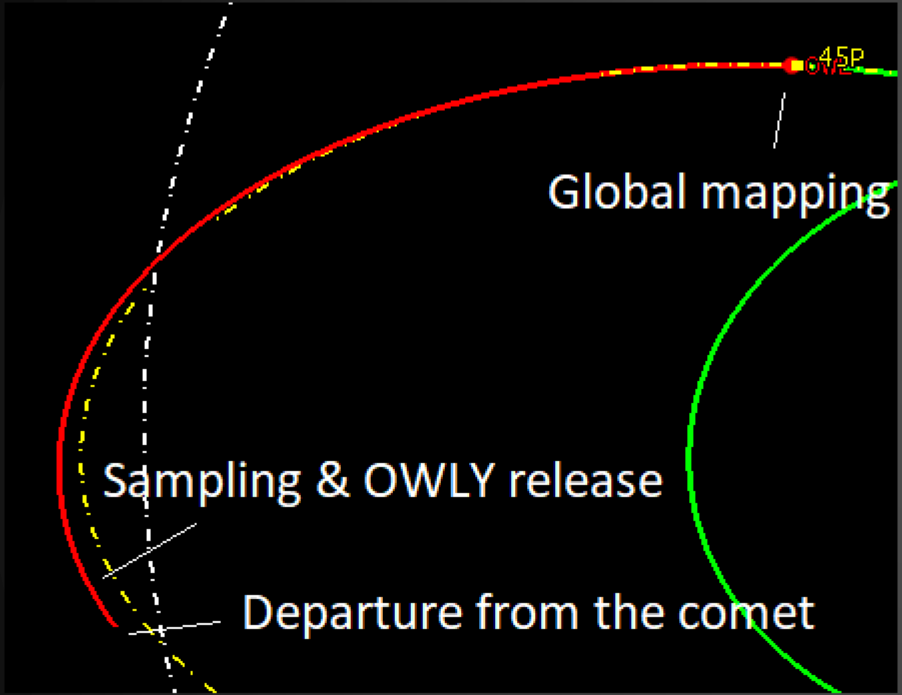


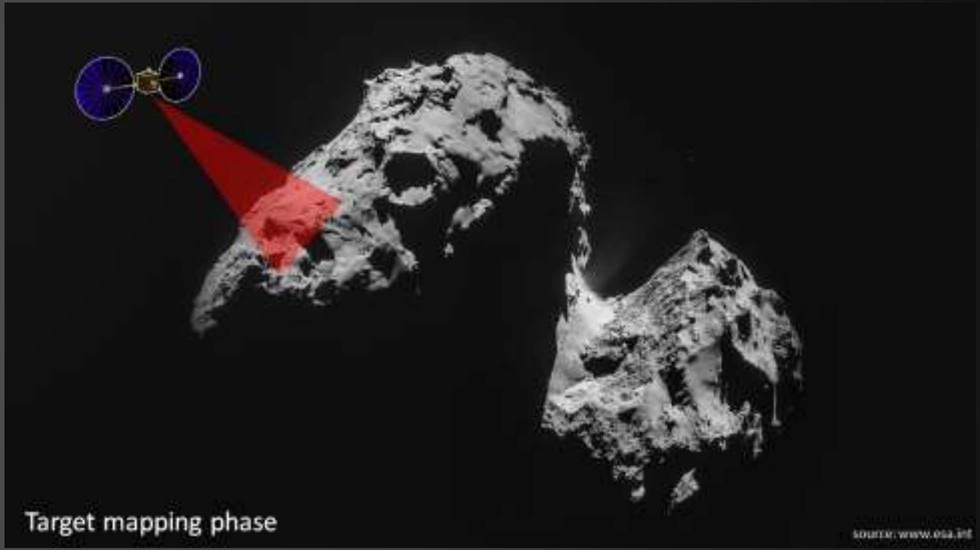
Time around the comet = 2.8 yr



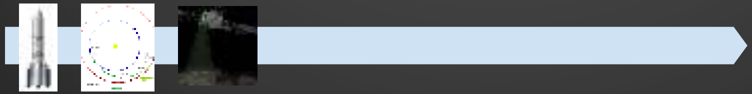
Sun-Satellite-Earth Angle at departure = 5.2 deg

Target Operations (II)

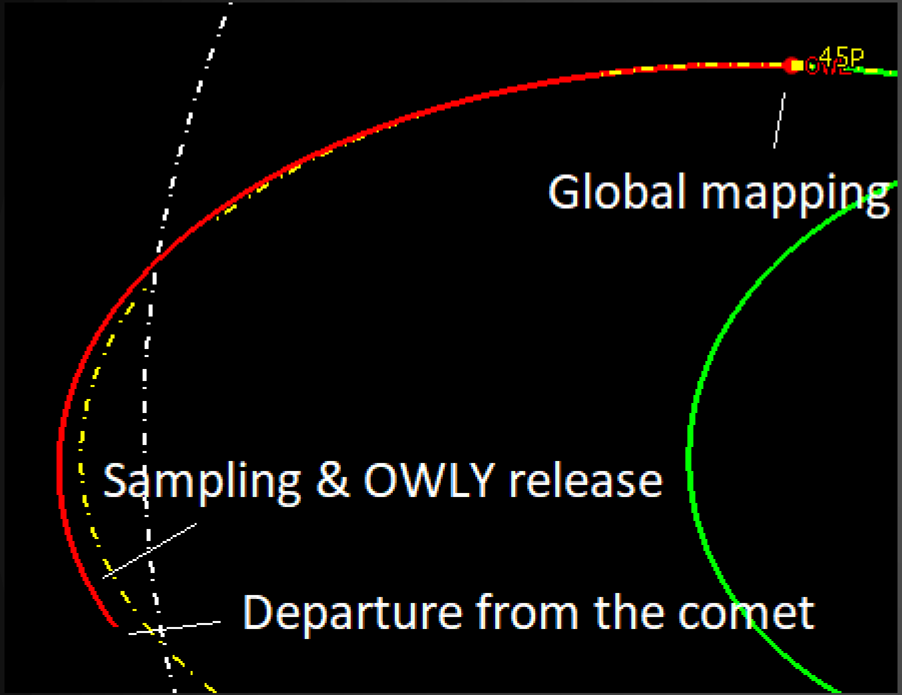


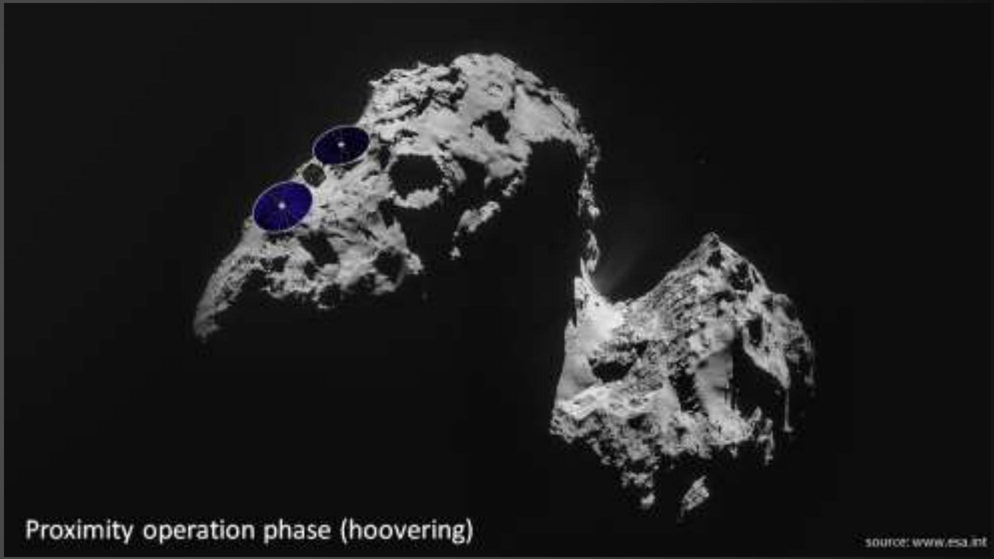


Time around the comet = 2.8 yr

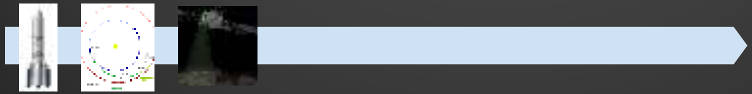


Target Operations (II)

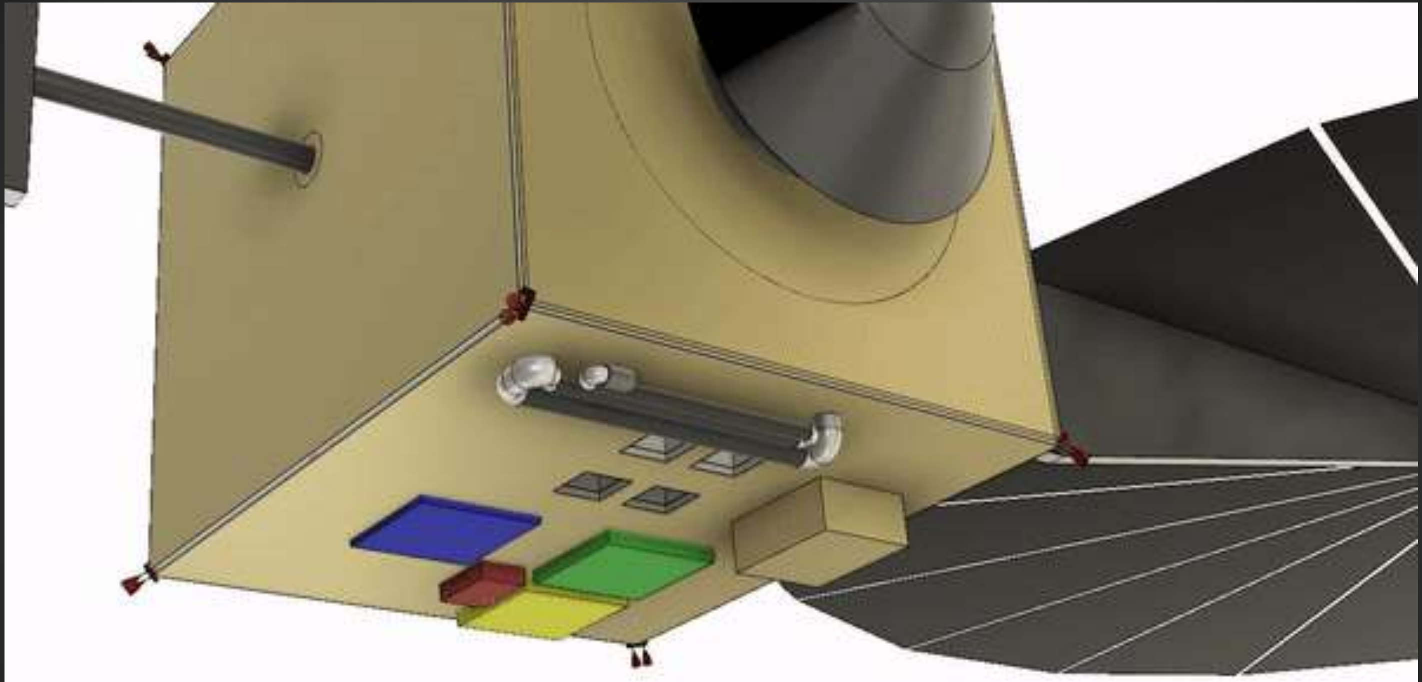




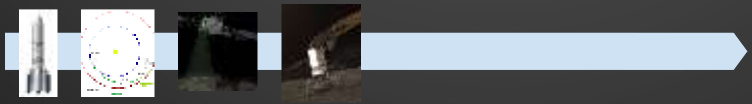
Time around the comet = 2.8 yr



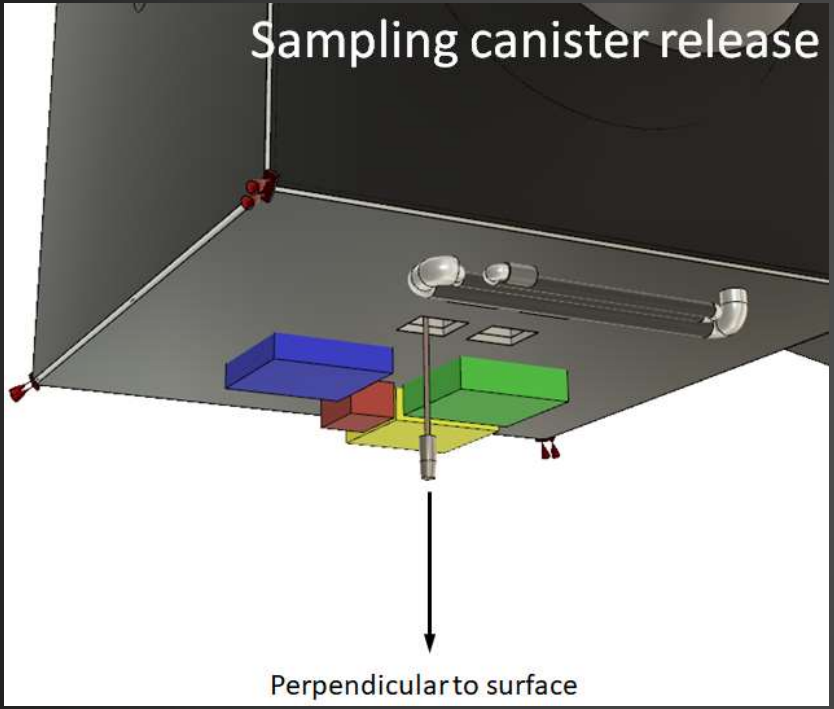
Lander Deployment

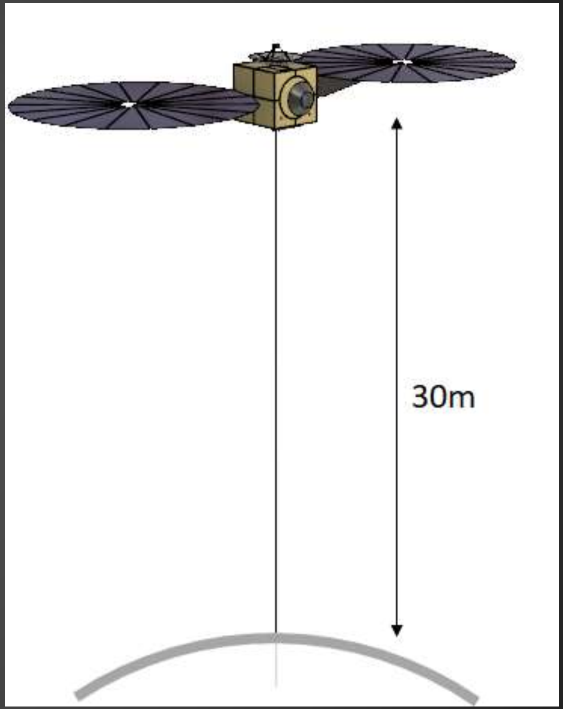


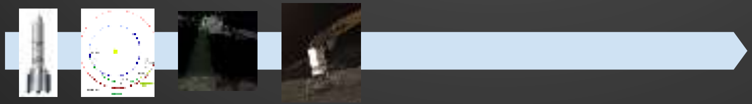
"OWLY" lander deployment



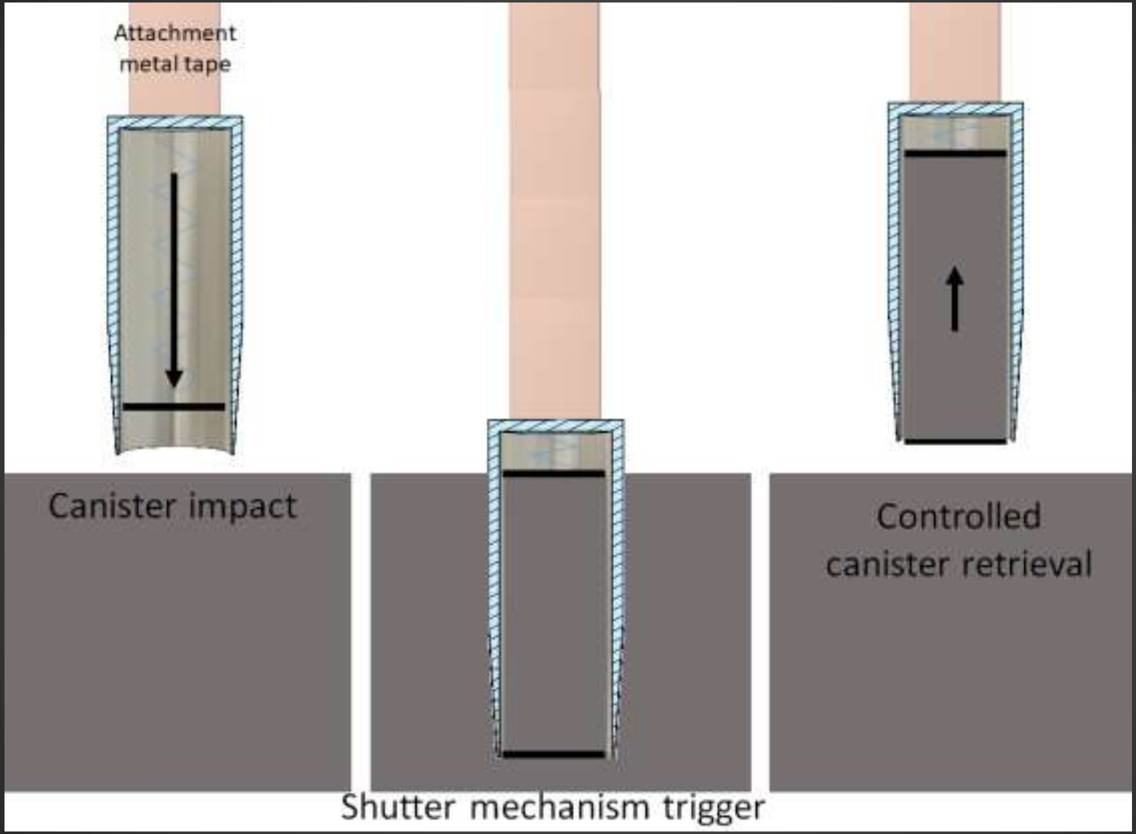
Sample Acquisition (I)

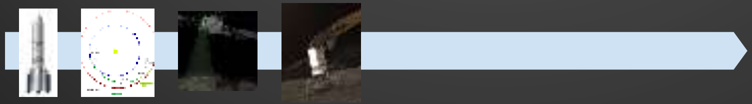




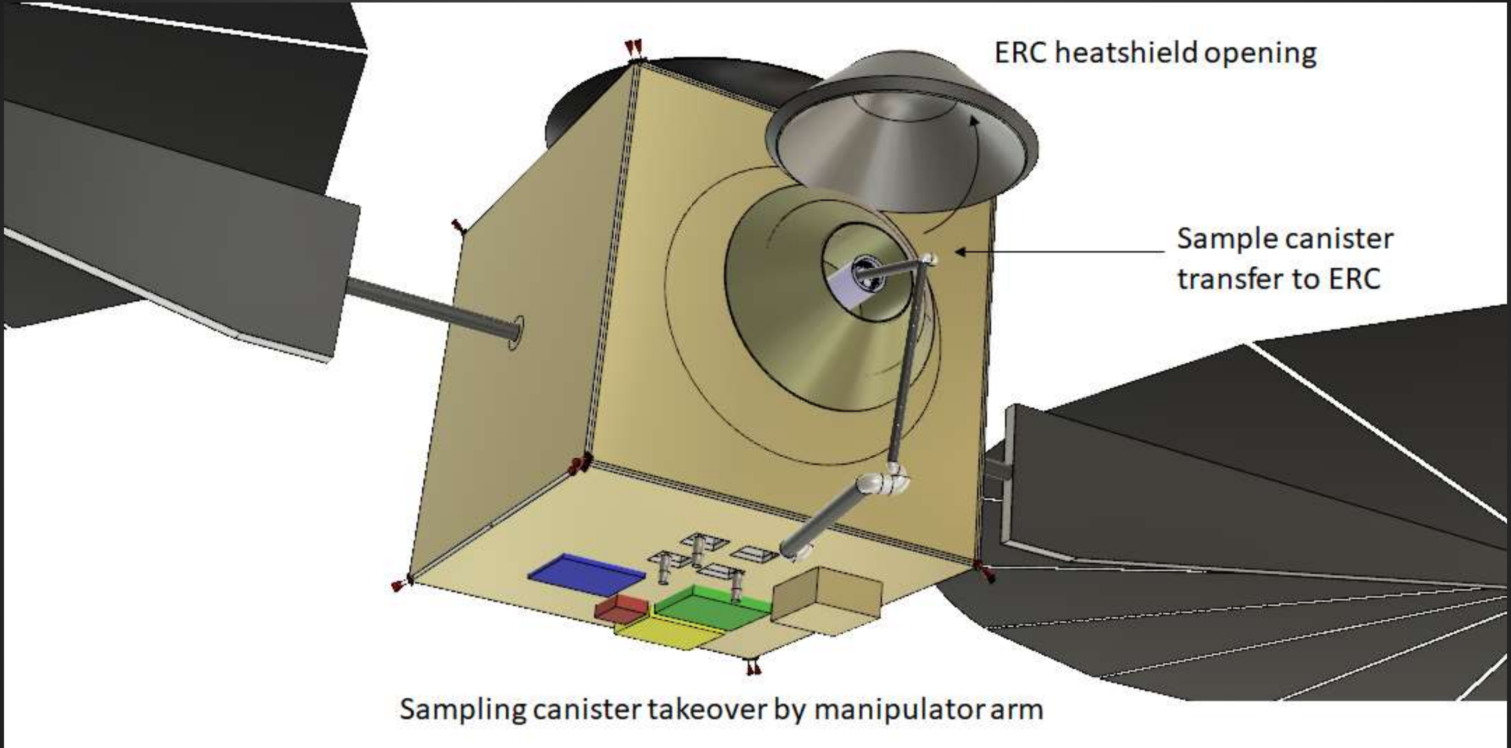


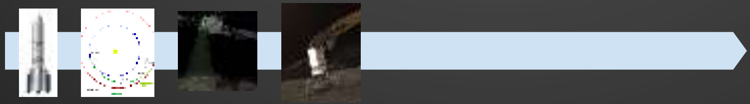
Sample Acquisition (II)





Sample acquisition (III)



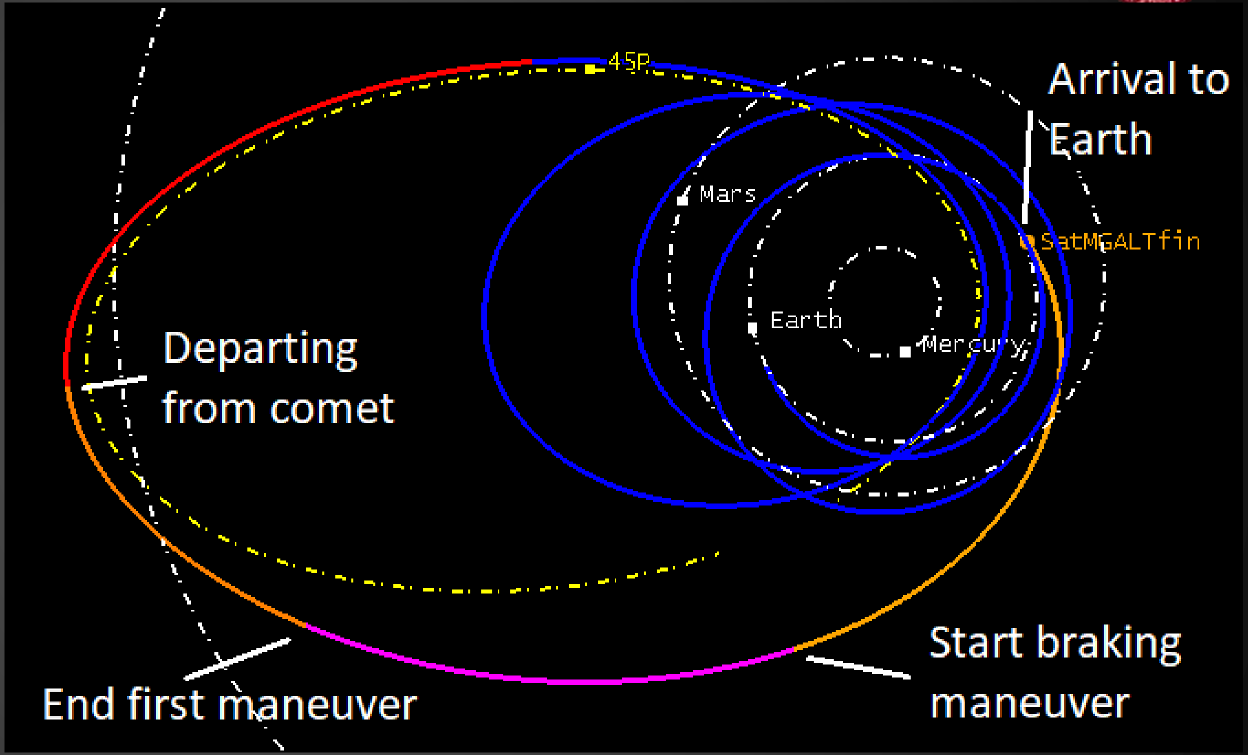


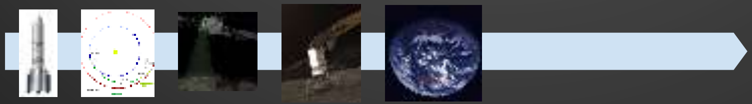
Transfer Inbound

Low thrust return trajectory
- *2.6 km/s & 190 kg*
- *1.79 km/s & 138 kg*

Separation of Earth Return Capsule

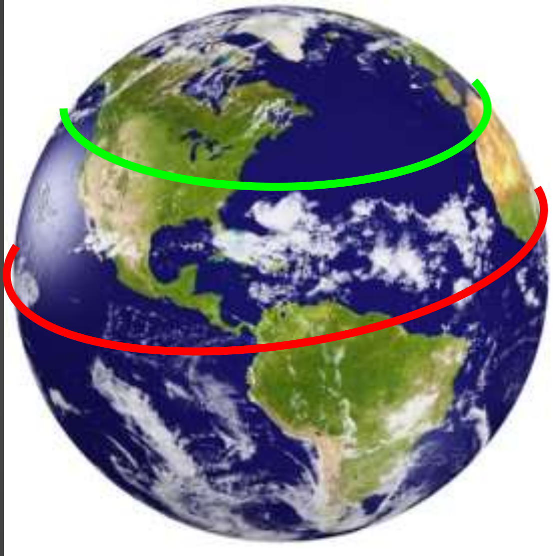
Earth re-entry: 13.15 km/s



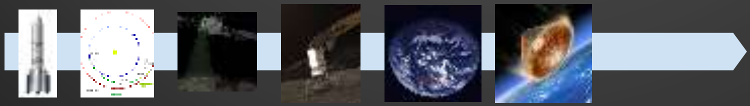


Re-entering Earth’s Atmosphere and Retrieval (I)

- In-air capture and transfer to lab
- **Baseline** re-entry landing location: Utah, USA
  - High heritage in Mid-Air Retrieval (1950s)
- **Backup** re-entry landing location: Woomera, Australia
- Entry at latitude of 19°, Utah is 39°, correction maneuver required



Planet Earth image via Shutterstock



Re-entering Earth’s Atmosphere and Retrieval (II)

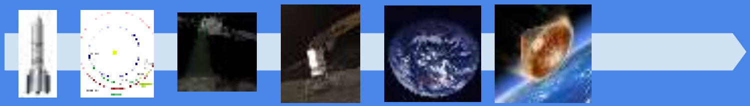
Entry to atmosphere at 120 km

-10deg

13 km/s

Max deceleration of 61 g
peak heat flux 14.8 MW/m2

Landing velocity of 41 m/s
Drogue chute released at
5 - 10km

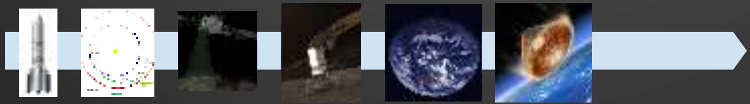


Re-entering Earth’s Atmosphere and Retrieval(III)

NASA/JPL. Artist interpretation of Genesis intended mid air retrieval

Mid Air Retrieval

- Required to keep the sample cool
- Sample cooling whilst transporting to curation facility
- Demonstrated previously many times and was intended for Genesis which had a similar landing velocity



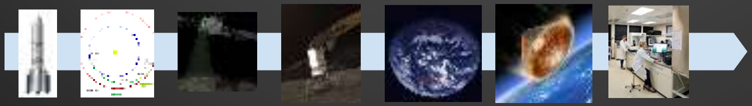
Curation Facility

Euro-Cares

Genesis curation materials, NASA

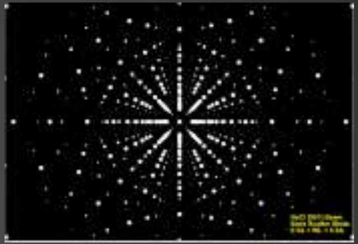
“Triple zero” environment

- Zero particle
- Zero molecular
- Zero biologic

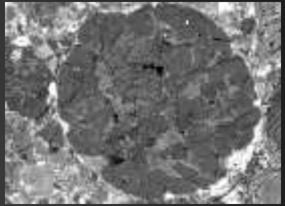


Sample Post Analysis - Measurements

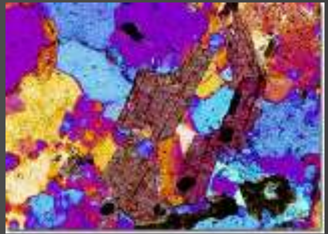
Objective	Measurement
Atomic/molecular structure	X- ray diffraction
For high resolving power	Electron microscopy
Calculation of sample age	Radiometric dating
Compositional analysis	Optical microscopy
Tomography of sample	CT scanner
Sample composition	Mass spectroscopy
Prebiotic reaction	PALS Laser



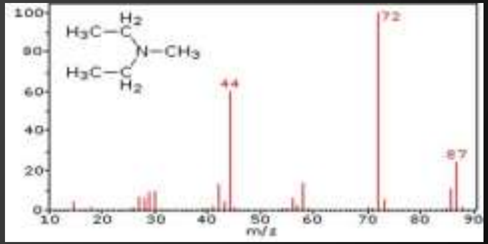
CrystalStudio



Steven Simon

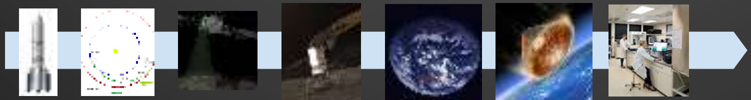


Florida State University



AssignmentPoint.com

pals.cas.cz



Space System

System Requirements

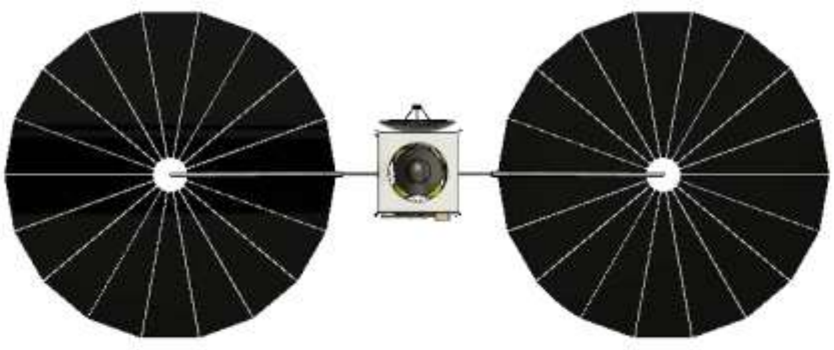
Requirement	Description
Earth Return Capsule & Biocontainer	The sample shall be kept at a temperature of 120 K ± 20 K at all phases of the mission, post sampling.
Science Measurements	The AOCS/GNC subsystem shall provide a precision required to ensure instrument resolution.
Lander	Data obtained from OWLY shall be transmitted to Earth through a communications relay with the spacecraft orbiter.
Sampling & Transfer Mechanism	150 g of sample must be obtained from a depth of 10 cm and stored inside a Biocontainer to meet planetary protection requirements.

System Architecture

OWLY Lander	Spacecraft Bus	Sampling & Transfer Mechanism

Payload Instruments	Earth Return Capsule

Spacecraft Bus - Structure (I)



Spacecraft Bus - Structure (II)

CFRP/Alu sandwich panels

ESA, www.esa.int

+

Full CFRP struts

Space Structures GmbH

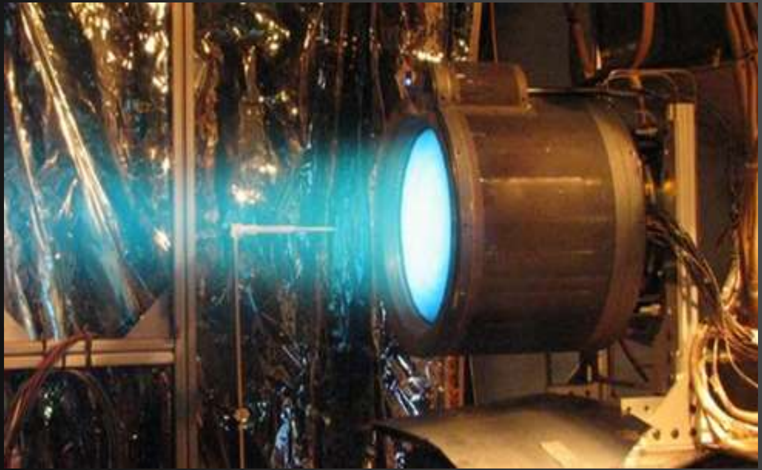
Spacecraft Bus - Structure (III)

OWL inside of ARIANE 6 single-launch-configuration fairing

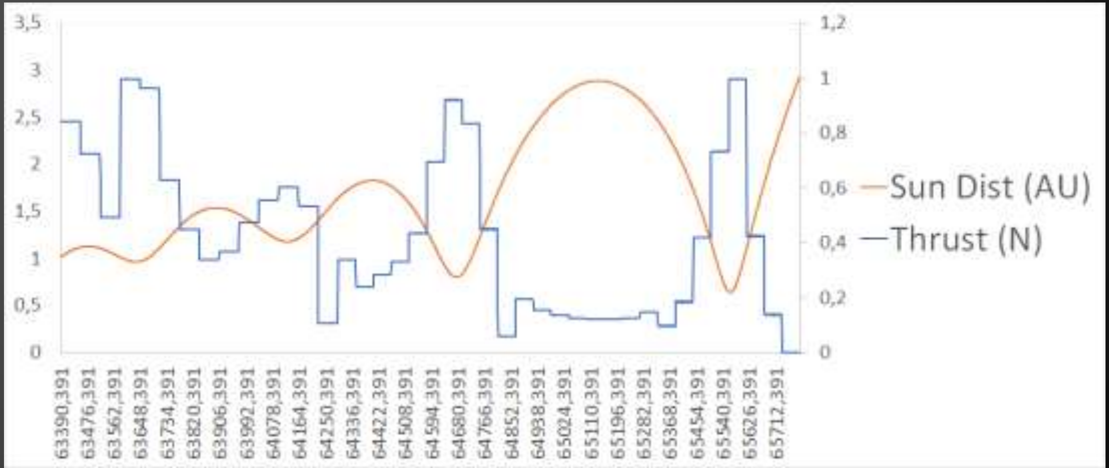
Spacecraft Bus - Propulsion

T6 ion engines:
- 7x Operational
- 1x Redundant
- Fuel Type: Xenon

Other subsystem elements:
- Power Processing Unit (4x)
- High Pressure Regulator System
- Harnessing
- Propellant tanks (4x)



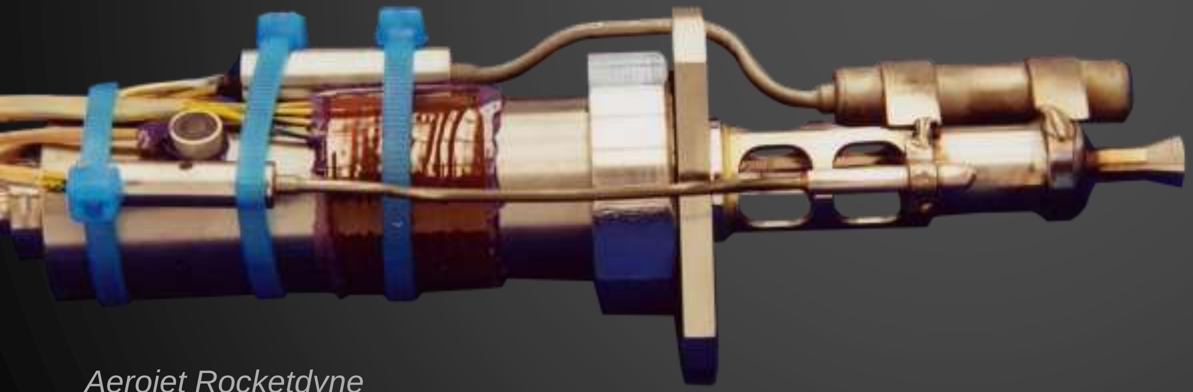
NASA



Spacecraft Bus - AOCS/GNC

Aerojet MR 103-M engine:

- 12x Operational
- Fuel Type: Hydrazine



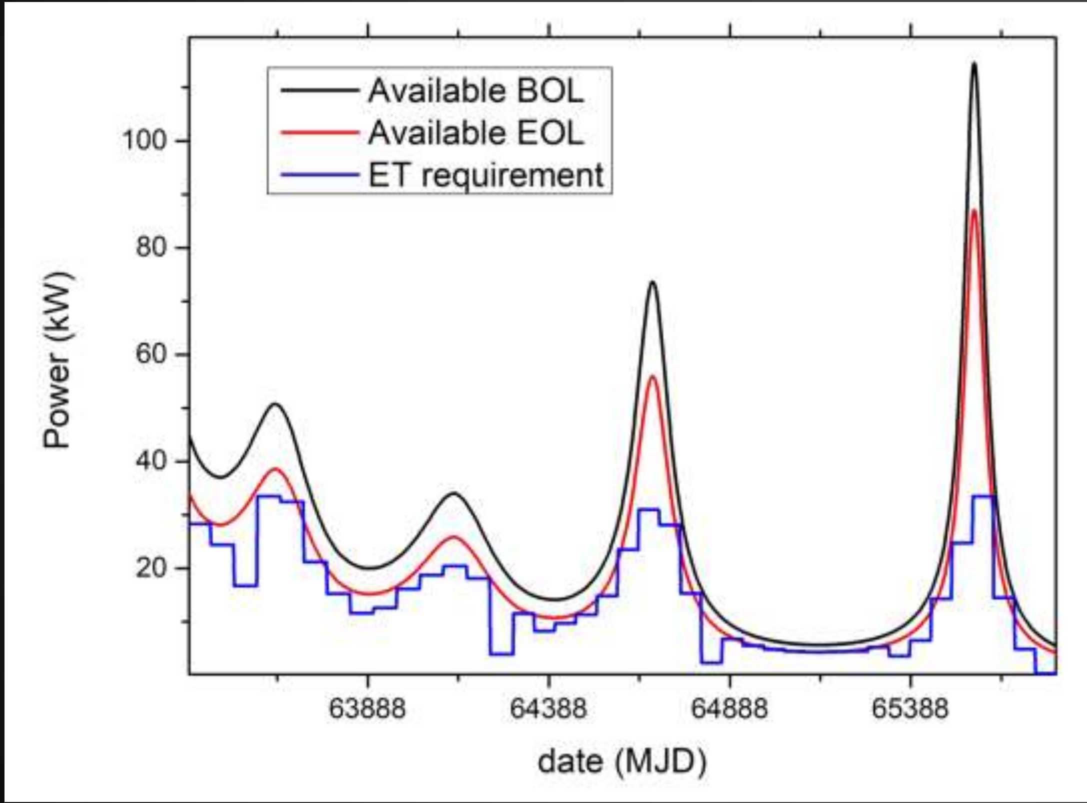
Aerojet Rocketdyne

Other subsystem elements:

- Star Tracker (3x)
- Sun Sensor (3x)
- Reaction Wheels (4x)
- IMU (1x)
- AOCS Control Unit (1x)
- Harnessing
- Propellant tank (1x)
- Laser Altimeter (1x)

Spacecraft Bus - Power

Criticality: Power demanded during the journey to the comet



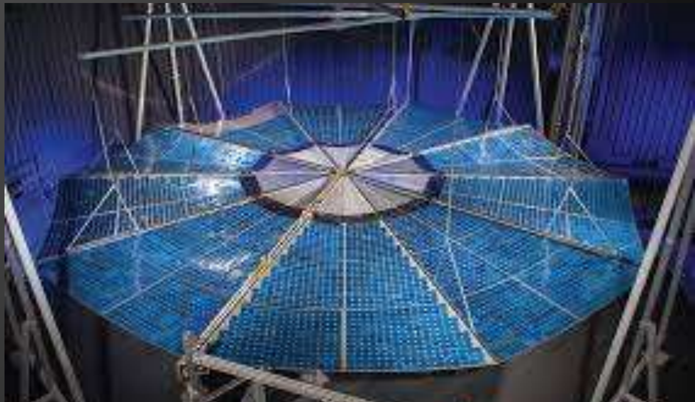
Power estimation:

- 30% average solar cell eff.
- Power conv. efficiency 90%
- Sun angle offset 20°
- EOL Power remaining factor: 0.75

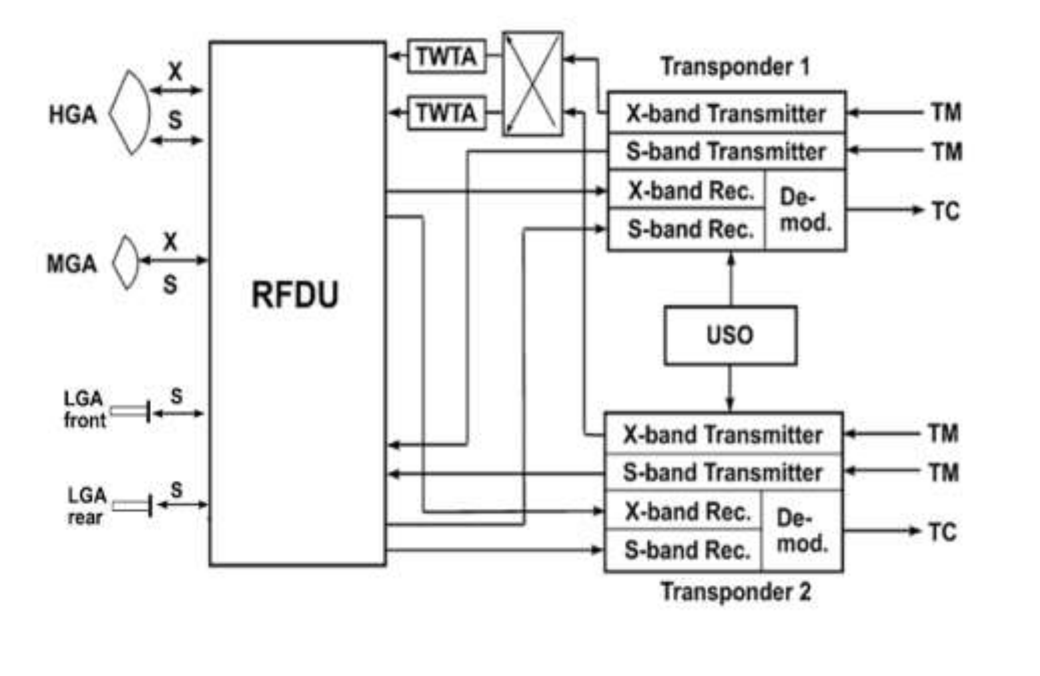
Solar Array sizing:

- **120 m^2 (2x MEGA Flex configuration)**
  Power/Weight ratio: 150 W/kg

Northrop Grumman Corporation



Spacecraft Bus - Communication



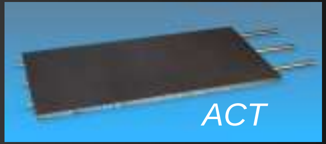
Thales Alenia Space

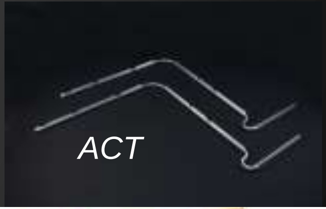
Antenna	Freq Band	Communication
HGA	X/S	Science data/telemetry (up to 50 Kbps in worst case)
MGA	X/S	Telemetry/Commissioning Phase/Emergency (2 - 8000 bps)
LGA (x2)	S	Lander Communication (16 Kbps)

Spacecraft Bus - Thermal

Device	Mass [kg]	Power [W]	Remarks
Multi - layer Insulation	27	-	
Radiators	10	-	w/ Thermal Switch
Heat Pipes	5	-	
Heaters	3	50	


RUAG





Spacecraft Bus - Mechanisms

- **Solar Array Drive Assembly**
  - Max power transfer per wing: 2 kW
  - Septa 31 - RUAG
- **High Gain Antenna Pointing Mechanism**
- **Separation Mechanism**
  - Spin Up & Eject Mechanism

RUAG

System Architecture

OWLY Lander

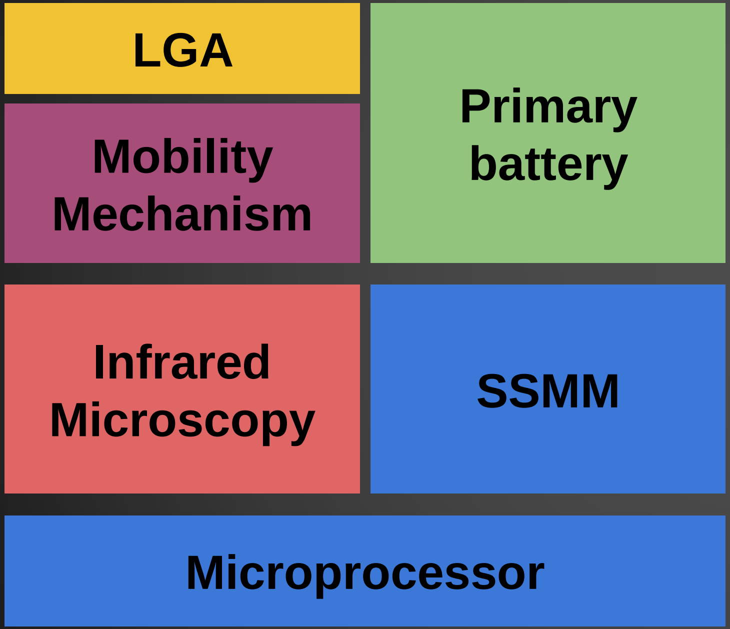
Spacecraft Bus

Sampling & Transfer Mechanism

Payload Instruments

Earth Return Capsule

OWLY Lander



Characterise the diversity and inhomogeneity at microscopic scale

SSMM required: ~ 2 Gbit

S-band link Orbiter Lander

Power required: 15 W

Operation time: ~ 10 h

System Architecture

OWLY Lander	Spacecraft Bus	Sampling & Transfer Mechanism

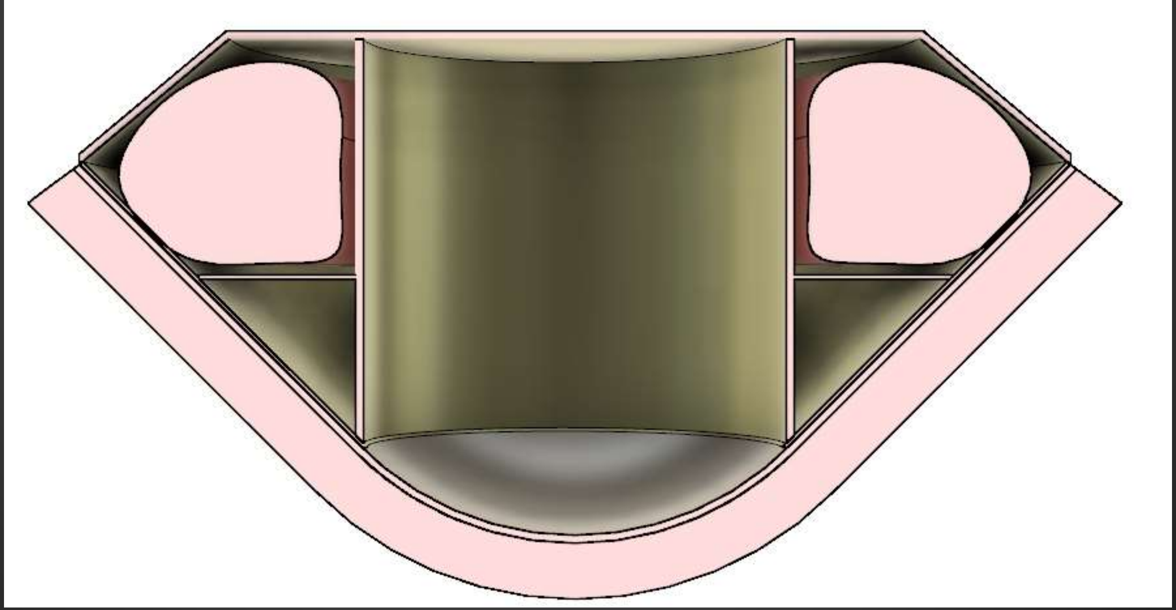
Payload Instruments	**Earth Return Capsule**

Earth Return Capsule

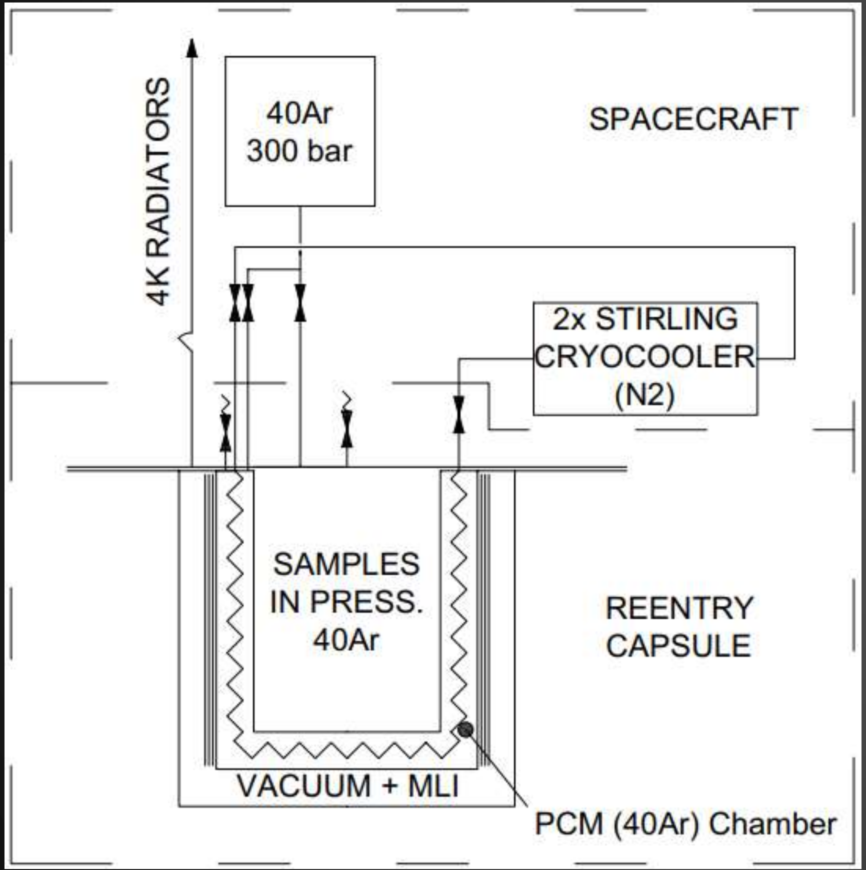
- Scaled from Hayabusa to maintain ballistic coefficient
- ERC required to accommodate sample and cryogenic cooling
- TPS selected based on peak flux
- Mid air retrieval necessary to maintain temperature so crushable design was not considered
- Estimated deceleration is higher than previous missions but similar to Marco-Polo and Marco-Polo 2, 60-70g

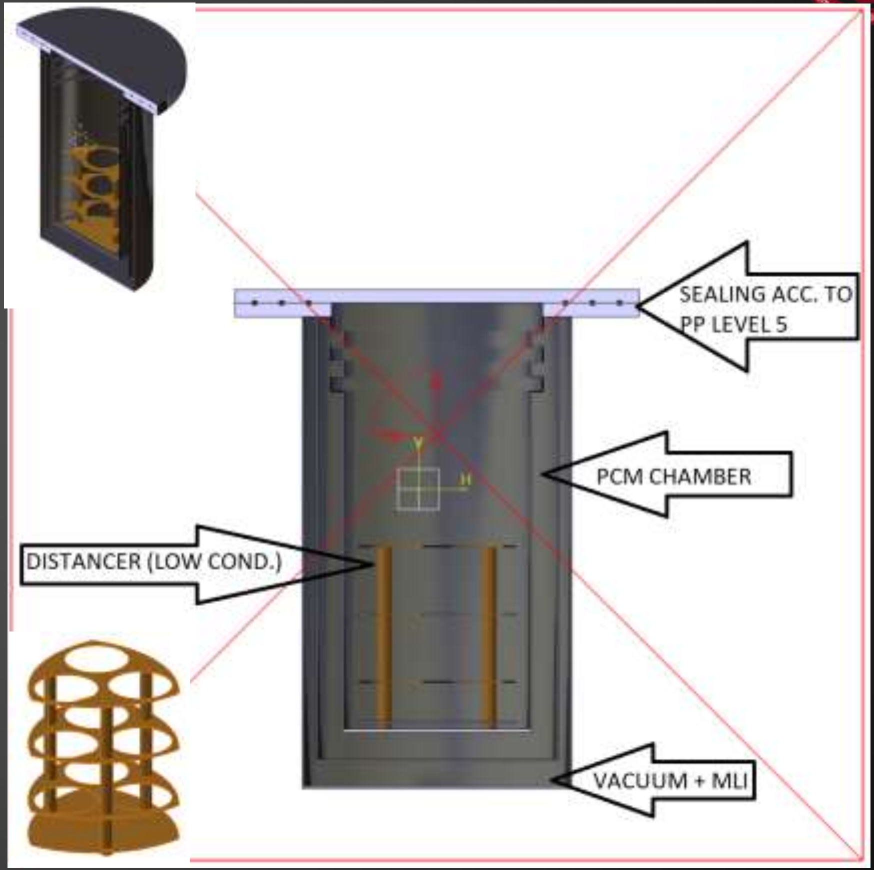
Earth Return Capsule

Peak Heat flux [MW/m²]	Heat Load [MJ/m²]	TPS thickness [mm]	TPS Material	Diameter [mm]	Height [mm]
14.8	391.1	63.9	Pica X	780	422



Earth Return Capsule - Biocontainer





Ground Segment

Ground Segment - Ground Stations and Control

ESA DEEP SPACE NETWORK
S/X/Ka band - 120° spaced ca.

ESA

Possible cooperation network with NASA Deep Space Network - 70 m Antenna Goldstone, Madrid

European Space Operations Centre in Darmstadt, Germany

Budgets

Power Budget

Spacecraft operation around the comet (incl. system margin 20 %)

Subsystem	Maximum Power [W]
AOCS	120
TT&C	240
OBDH - PDU	40
PAY	120
THERMAL	80
OWLY Lander	15
S&R Mechanism	120
CRYO	120

Power Budget and Battery sizing

Configuration mode	Nominal	Safe	Science	Sampling
Power / W	**500**	**200**	**800**	**600**

48 h operation in safe mode without solar power Li-ion battery technology:

Battery Size: 10 kWh - ~ 50 kg

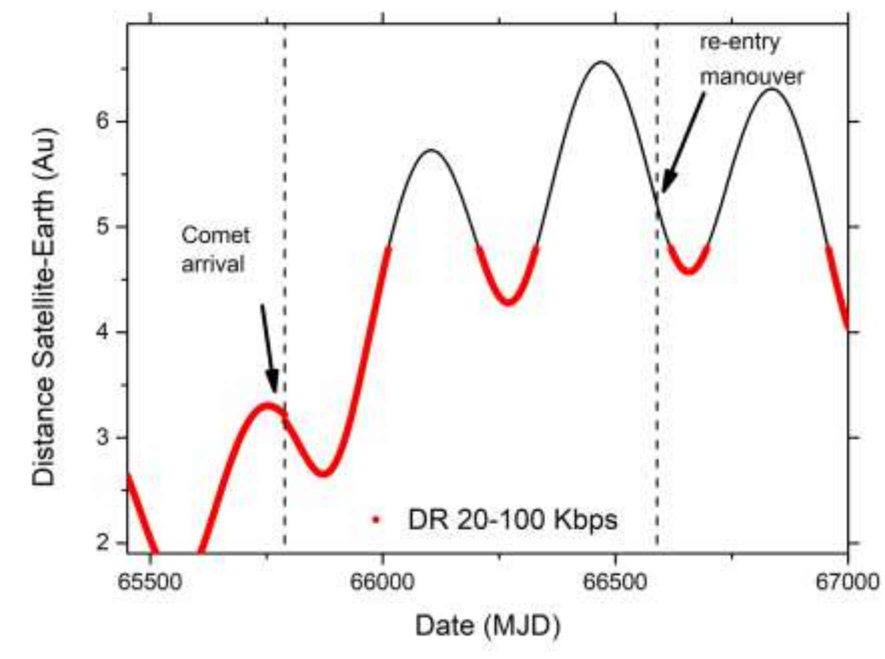
Mass Budget

Category	**Mass / kg**
Payload (excluding lander payload)	70
Spacecraft Bus	1715
OWLY Lander	10
System Dry Mass	1795
System Dry Mass (+ 20% margin)	2154
Propellant Mass (+ 12% margin)	2860
Wet Mass	**5014**

Link and Data Budget

Link Budget

Distance Sat-Earth [au]	< 4.8
Telemetry DR [Kbit/s]	8 - 10
Science DR [Kbit/s]	~ 100
X-Band HGA Diam [m]	**2.2**
Power required [W]	150
Eb/En	> 10
BER (QPSK)	~ 2E-6



Data Budget

Data required for comet mapping: ~ 1,5 GB

Worst case mapping time @ 4.8 au: **90 days**

Minimum SSMM Memory Size: 3 GB

(including redundancy)

Science Case

Payload Concept

Mission Profile & S/C

Project Envelope

Critical Technology (I)

Technology	TRL est.	Date of est.	Reference
Sampling Mechanism	2	2009	FFF
Earth Return Capsule	3	2016	MSR
Flexible Solar Arrays	3/4	2018	Thales Alenia Space
Bio-container	3/4	2016	MSR

Critical Technology (II)

Technology	TRL est.	Date of est.	Reference
Manipulator (DELIAN)	3/4	2015	Leonardo SPA
Phase Change Material	4	2012	(CNSR) NASA
Rendezvous Equipment Mid Air Retrieval	5	2018	Space Rider

Critical Risks (I)

Probability	
A	Extremely Unlikely
B	Remote
C	Occasional
D	Reasonably Possible
E	Frequent

Severity	
1	No relevant effect
2	Very minor effect
3	Minor effect
4	Moderate
5	Critical
6	Catastrophic

Critical Risks (II)

Prob/Sev	1	2	3	4	5	6
A		Sample Mechanism fail			Launch delay	Loss of ERC during re-entry
B				ERC development delay		
C		Sampling Mechanism development delay				
D						
E						

Article IX Outer Space Treaty

↓

COSPAR Planetary Protection Policy:

"**Category V** missions comprise all Earth - return missions. The concern for these missions is the protection of the terrestrial system, the Earth and the Moon."

Planetary Protection (II)

"Does the preponderance of scientific evidence indicate that there was never liquid water in or on the target body?"

= RESTRICTED EARTH RETURN

Planetary Protection (II)

"Does the preponderance of scientific evidence indicate that there was never liquid water in or on the target body?"

= RESTRICTED EARTH RETURN

Launch Date
June 2032

Arrival Date
Jan 2039

Departure Date
Oct 2042

Retrieval Date
Jan 2046

Phase 0-A-B1
2 to 3 years

Phase B2-C-D
5 to 6 years

Phase E
12 years

Phase F
10 min

Ground Based Observation Period

Data Analysis Dissemination and Exploitation

Cost Estimation

Main Spacecraft	1077 MEU
Lander	4 MEU
Re-entry/Sample Canister Module	20 MEU
Operations	192 MEU
Launcher	90 MEU
Member States	41 MEU
Total Cost	**1424 MEU**

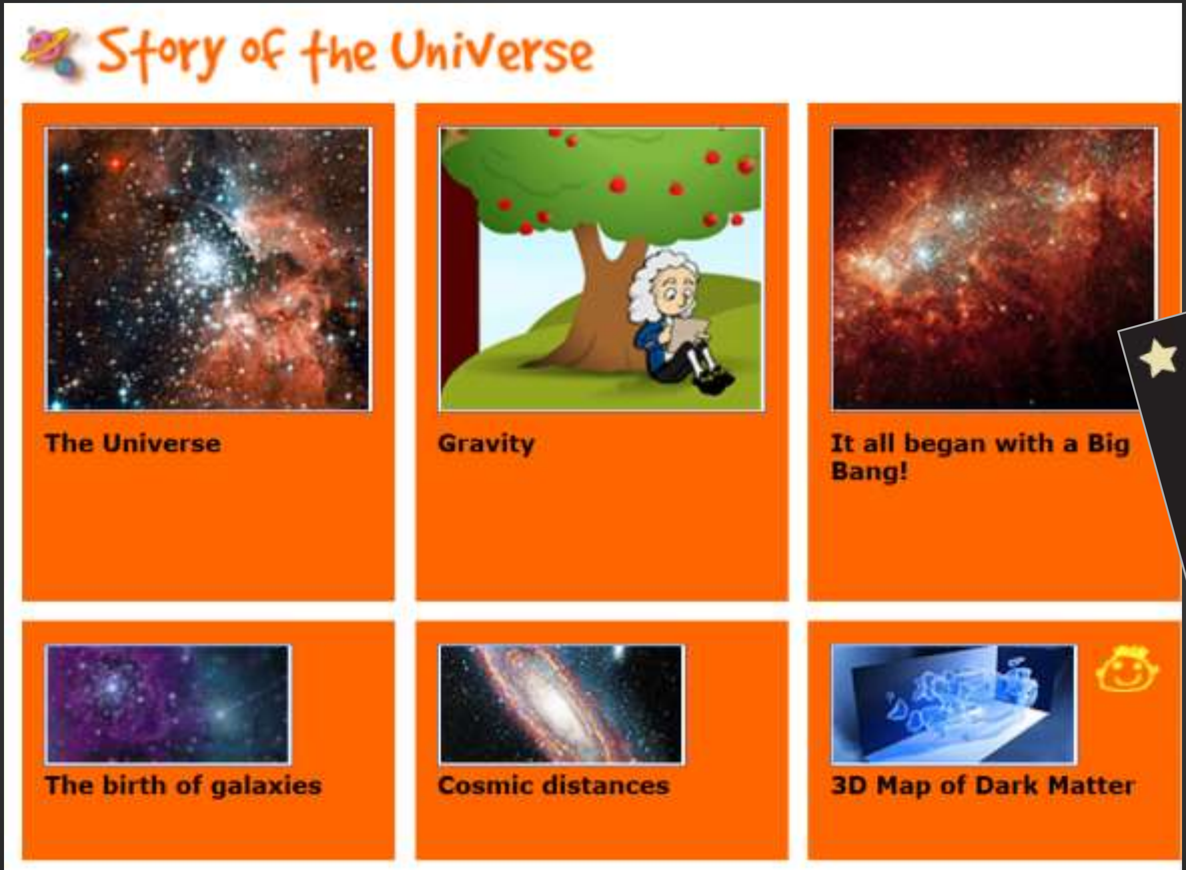
- Cosmic Vision 2015 - 2025
- What are the conditions for planet formation and the emergence of life?
- How does the Solar System work?

- Priority of ESA exploitation facilities
- Collected scientific data and results transferred to public archive for further analysis after first examination period (1 - 2 years)
- Processed data for future educational programmes and outreach activities

Public Outreach

Public Outreach

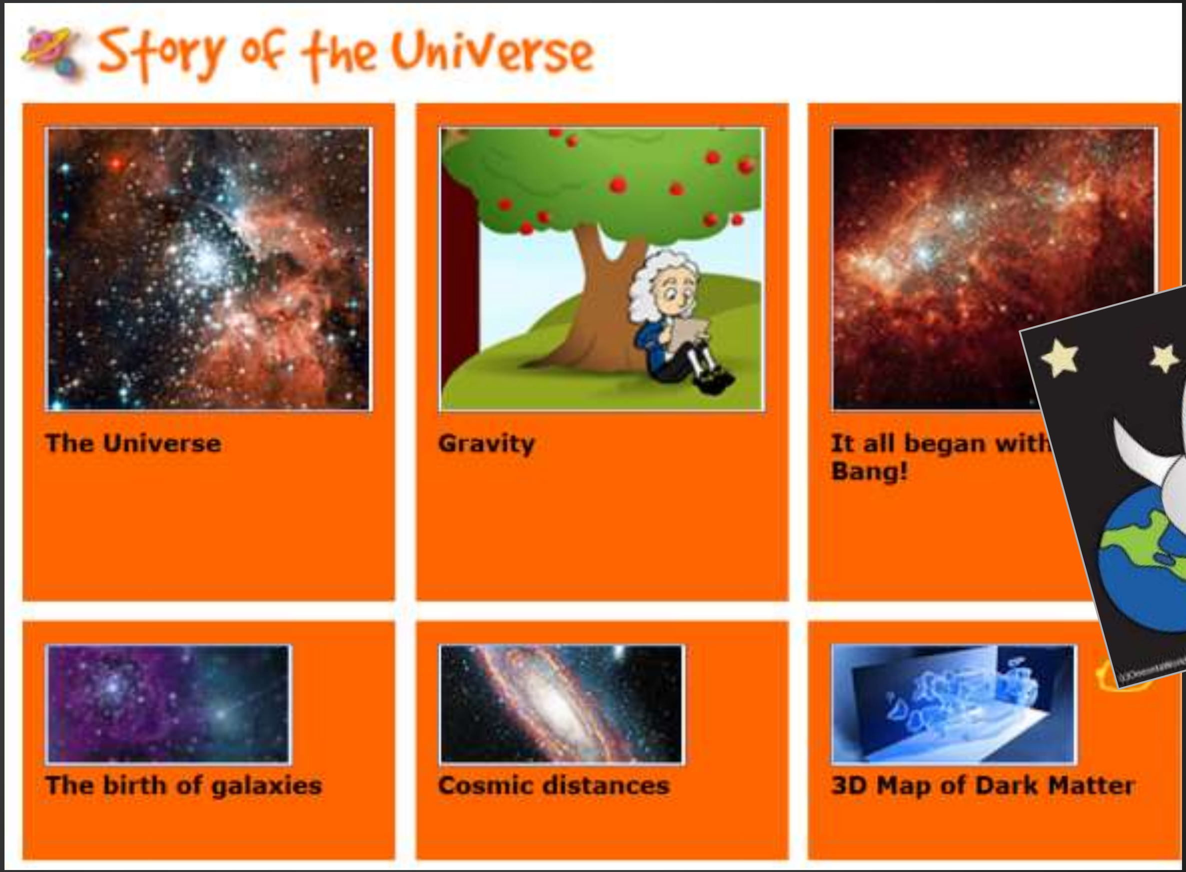
Public Outreach



ESA

Public Outreach

Water and Life



ESA

Public Outreach

esa academy

Sample Return Mission Design Training 2050

OWL Science Operations Scheduling Legacy Workshop 2050

THE OWL HAS LANDED

Thank you!