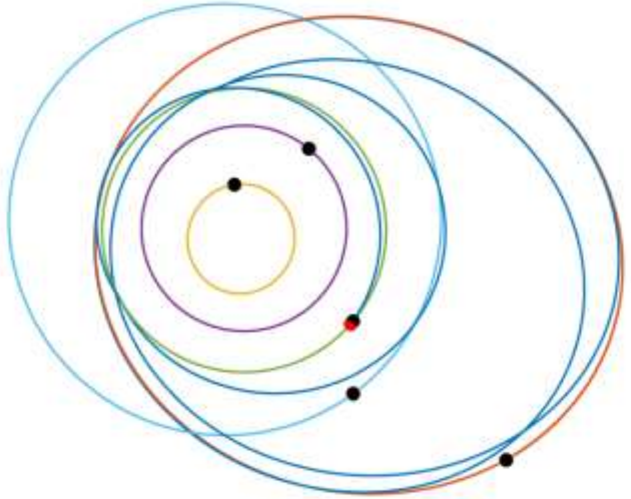
CARINA

Comet **A**steroid **R**elation **IN**vestiagion and **A**nalysis

«CARINA is a first of its kind sample return mission, with the aim to contribute to pending questions about the relationship between asteroids and comets, the origin of life, and the formation of our solar system.»



Team Green Summer School Alpbach 2018:
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Tutors: *Christian Gritzner and Özgür Karatekin*

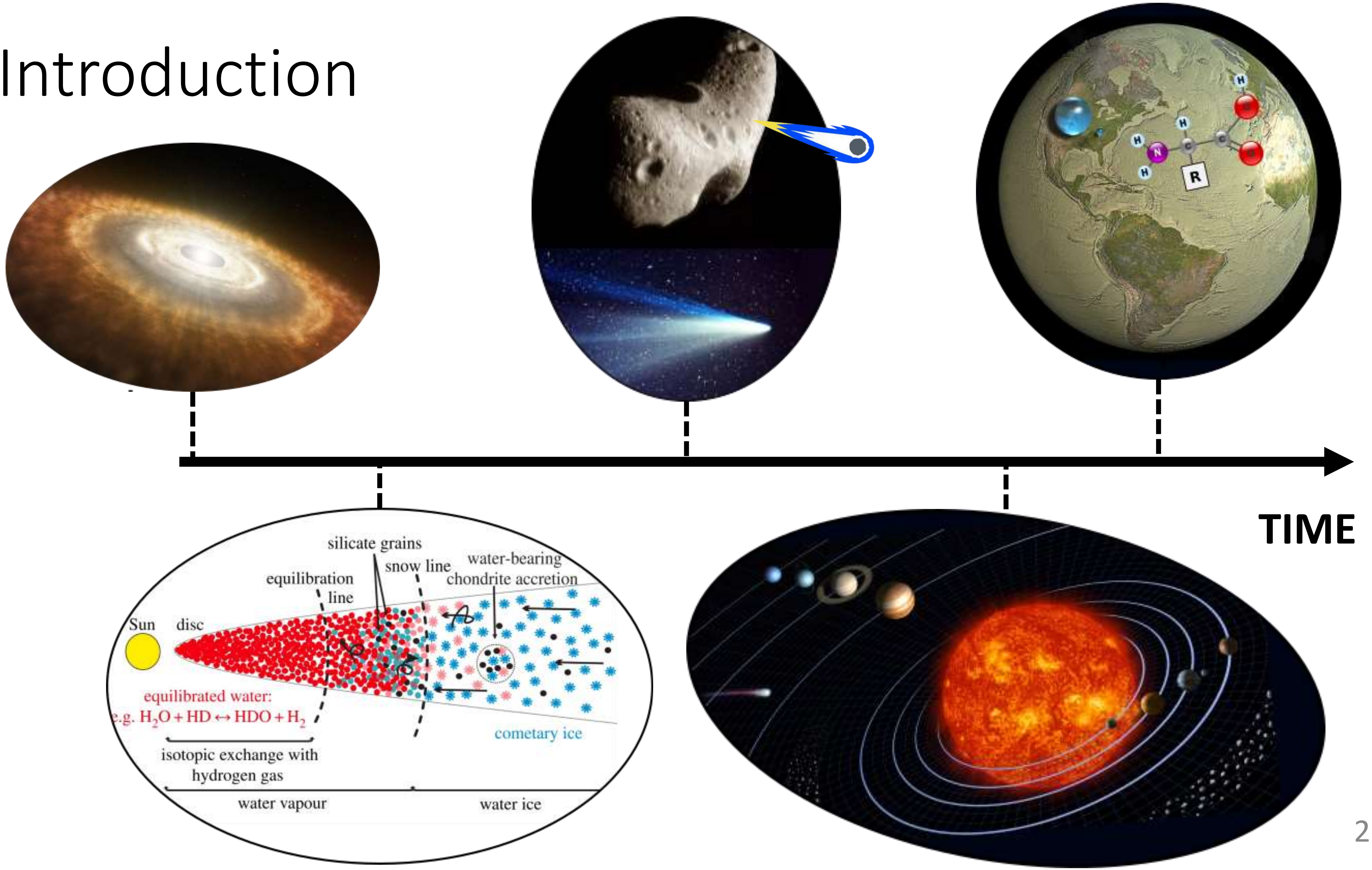
European Space Agency

FFG Österreichische Forschungsförderungsgesellschaft

INTERNATIONAL SPACE SCIENCE INSTITUTE

AUSTROSPACE

Introduction

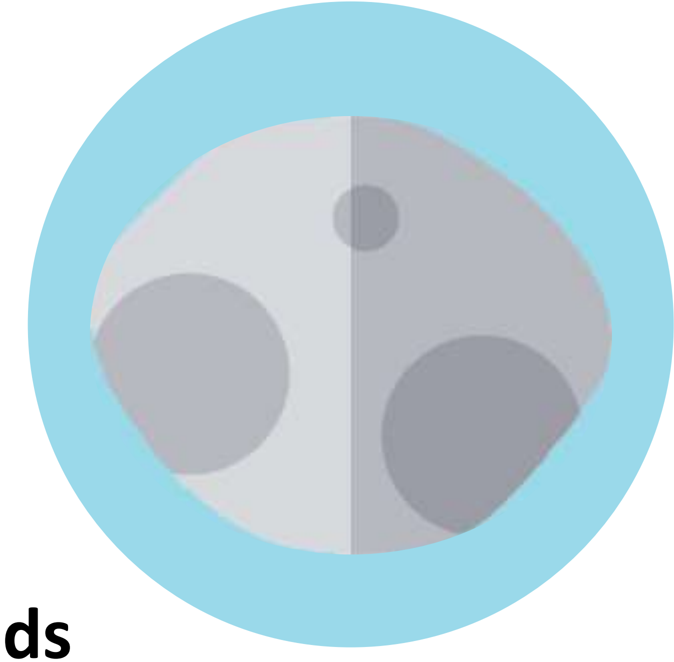


Scientific Questions

- How did the Solar System evolve and how did planetesimals form?
- What is the origin of water and life on Earth?
- Is there a relationship between asteroids and comets?

Mission overview

Small bodies in the solar system



Asteroids

- small **rocky** bodies
- orbiting the sun

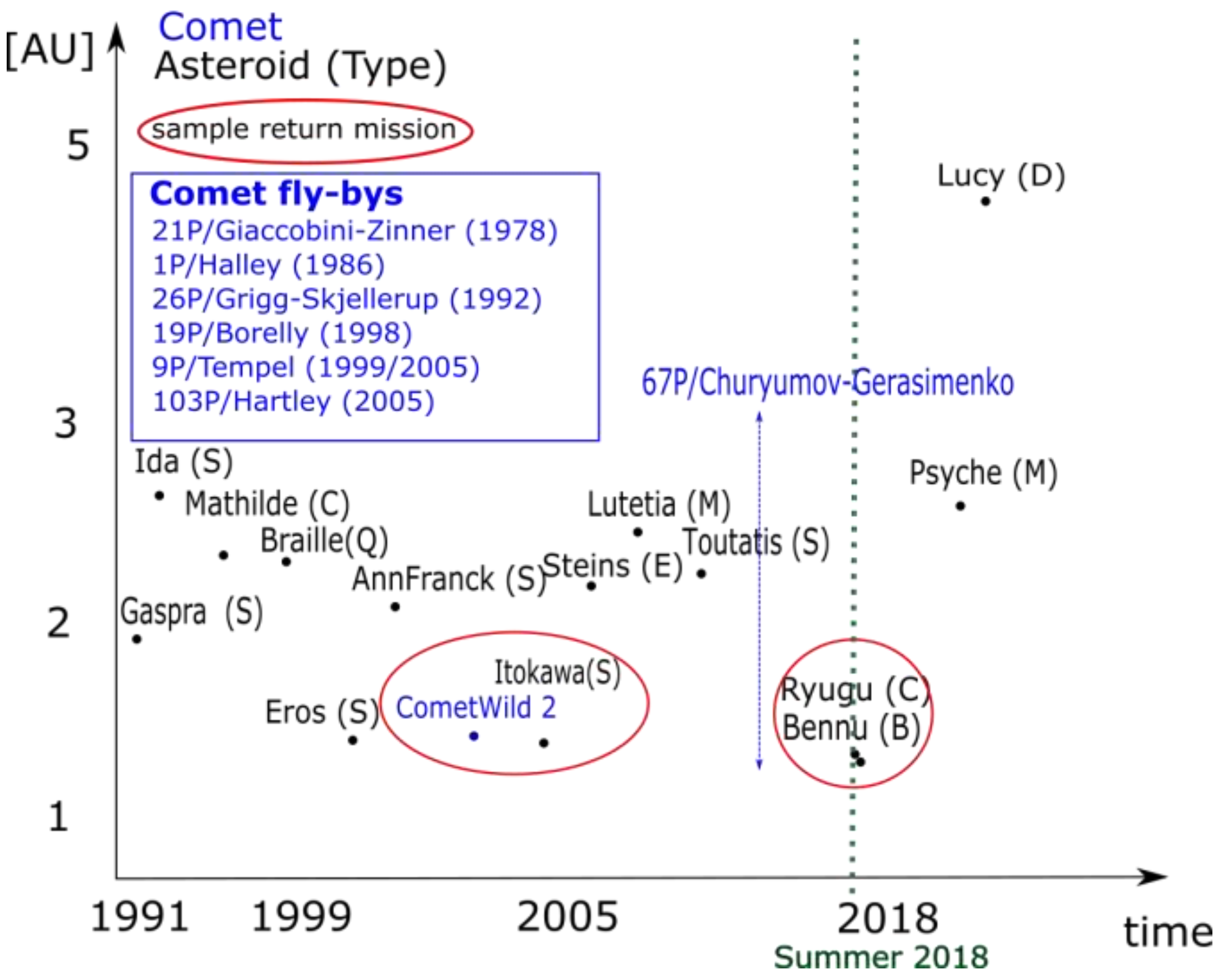
Biggest reservoir: Main Belt

Comets

- small **icy and dusty** bodies
- orbiting the sun
- **active**

Reservoirs: Kuiper belt, Oort cloud

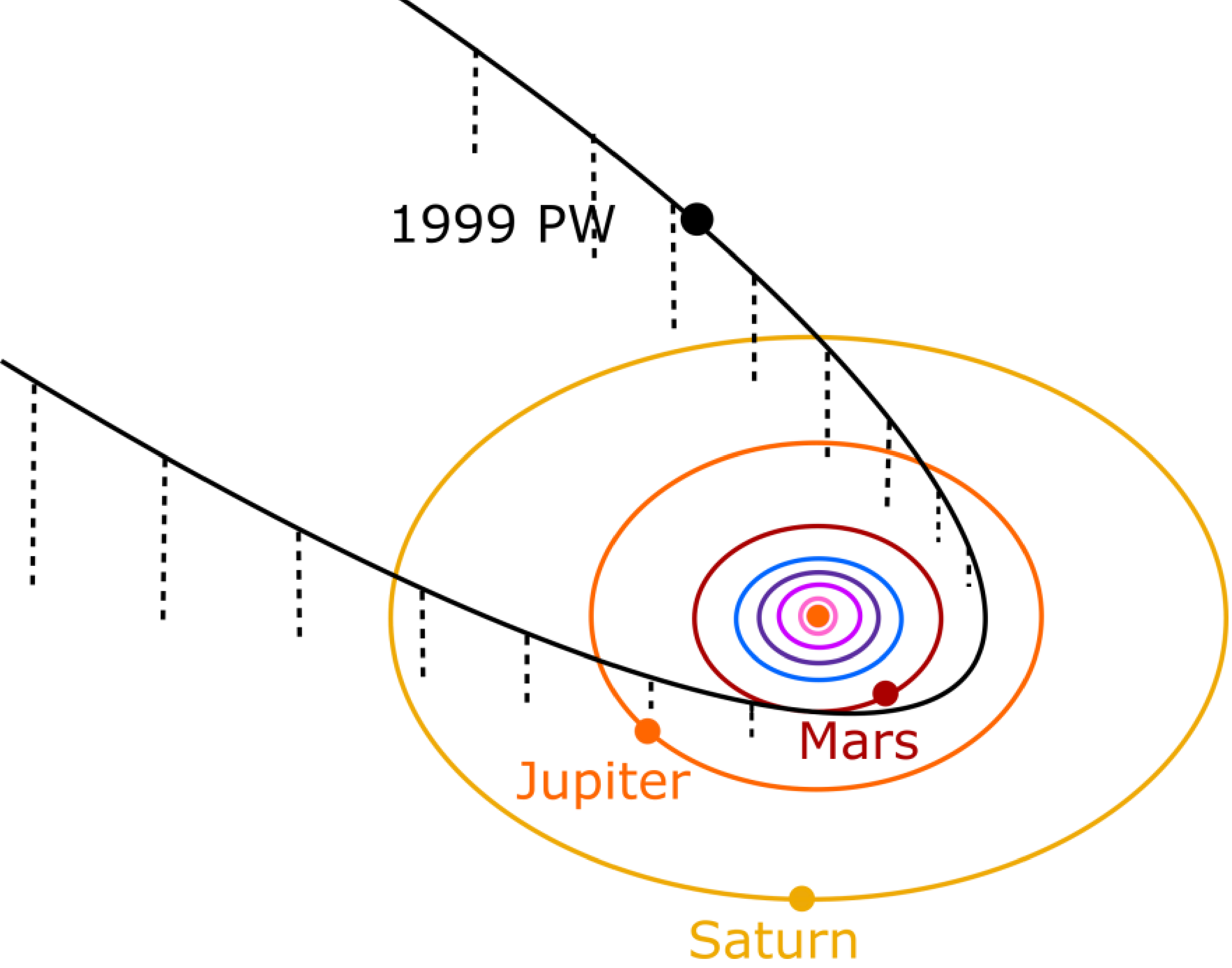
Previous small body missions:



European Main Contributions to Asteroidal Exploration:

Cassini/Huygens:
fly-by at asteroid 2685 Masursky on 23 January 2000
→ Mission dedicated to study Saturn system

Rosetta:
fly-by at asteroids Steins and Lutetia
→ Mission dedicated to study comet 67P/Churyumov-Gerasimenko



1996 PW

Comet – like orbit

D-type asteroid

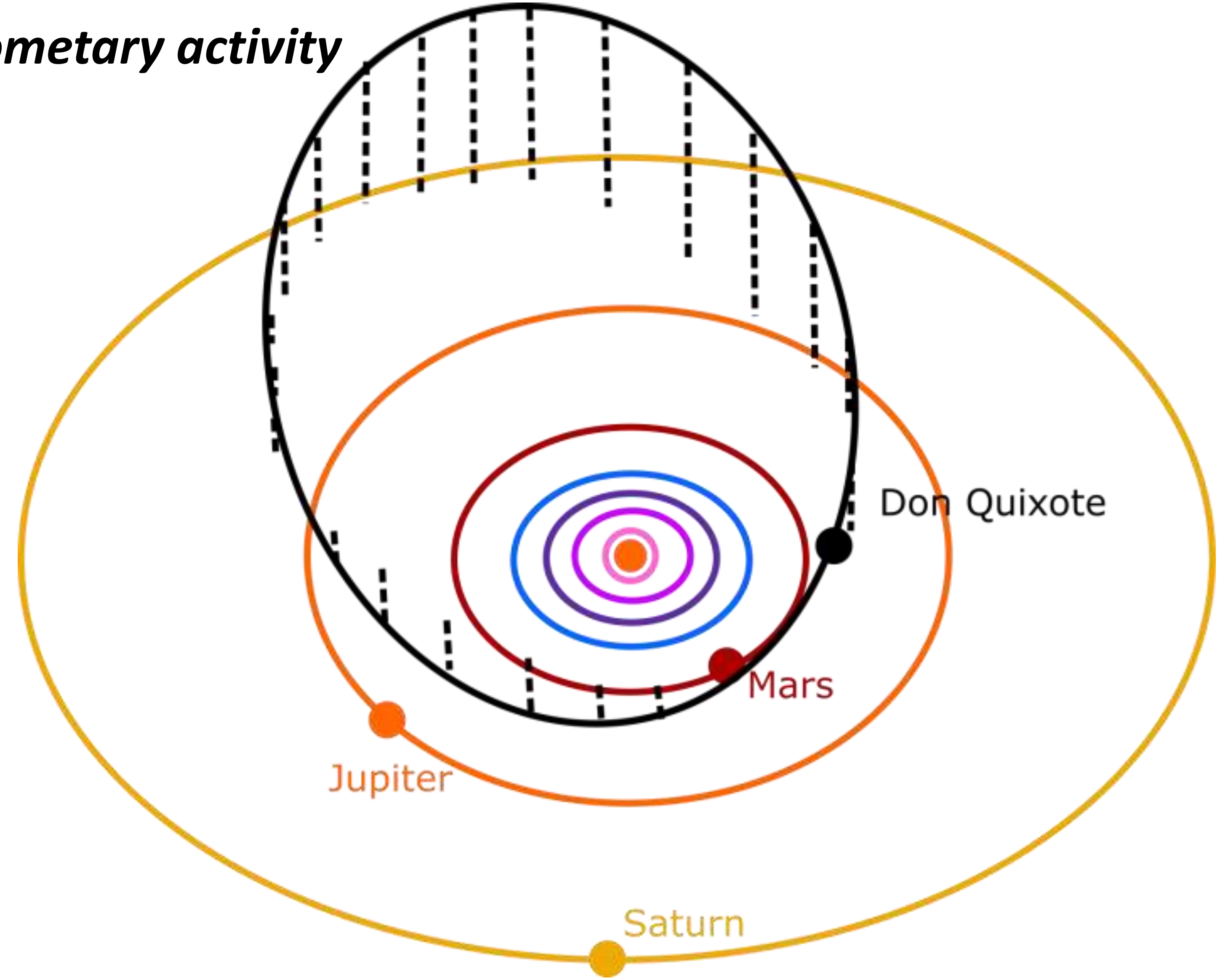
Inactive

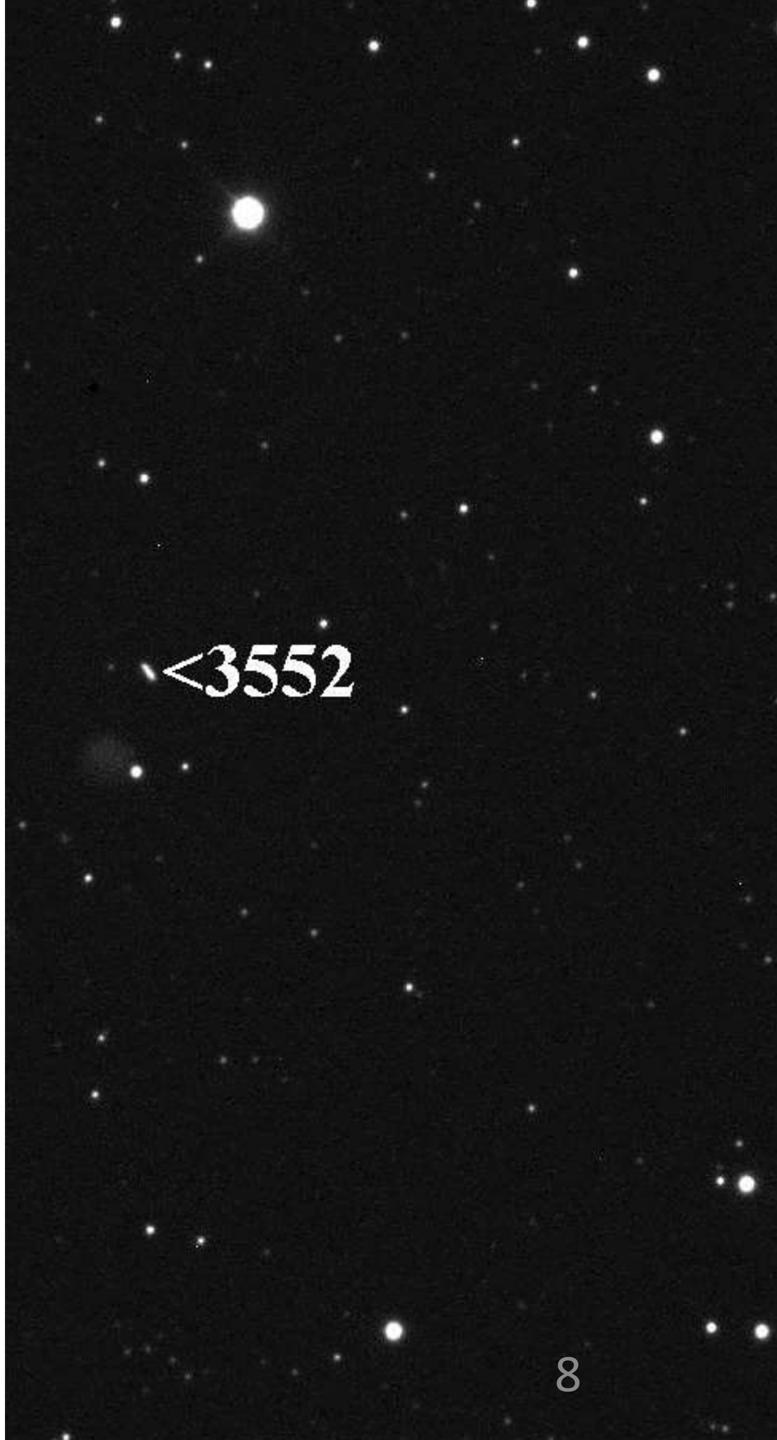
3552 Don Quixote

Amor ***asteroid - like*** orbit

D-type classification

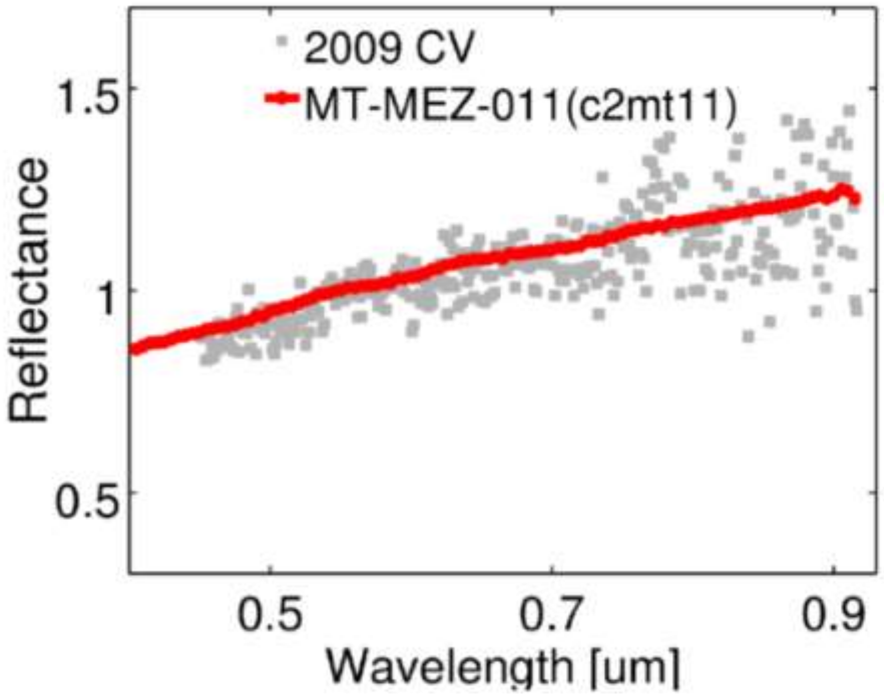
Shows cometary activity



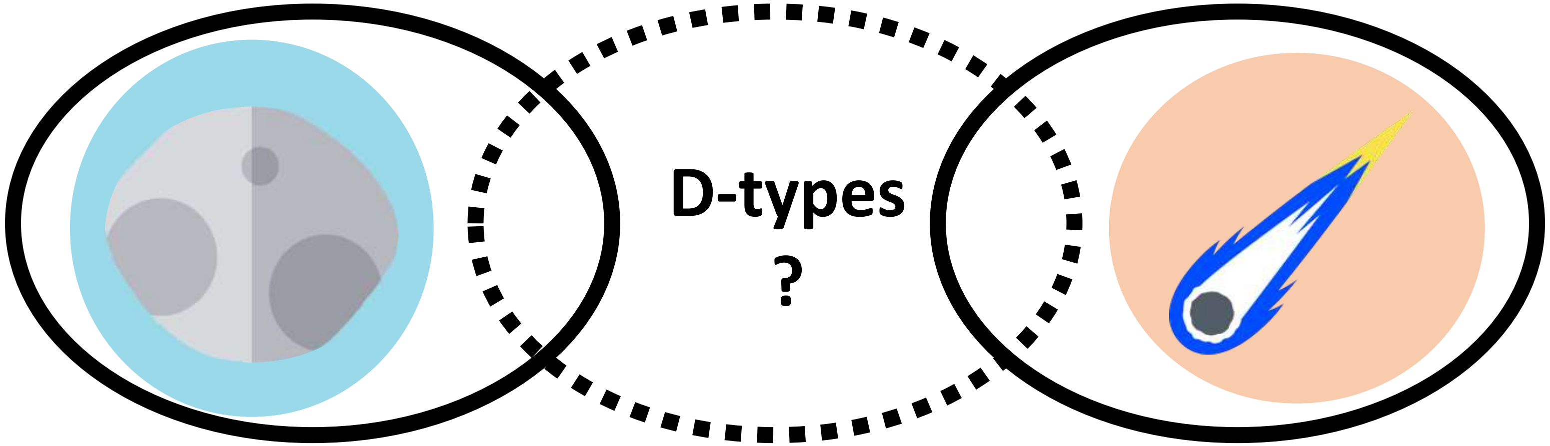


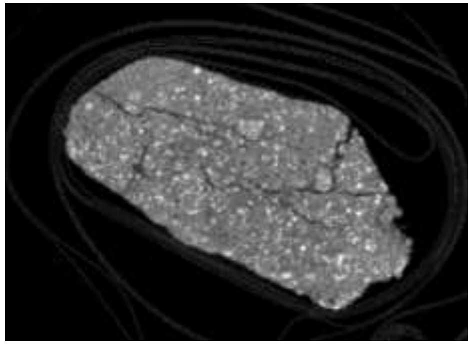
What are D-types?

- **most primitive** among asteroid population
- contain **organics and volatiles**
- most abundant **beyond outer edge of the main belt**
- but a **small population in NEO**
- **red featureless spectrum**
- **low albedo**



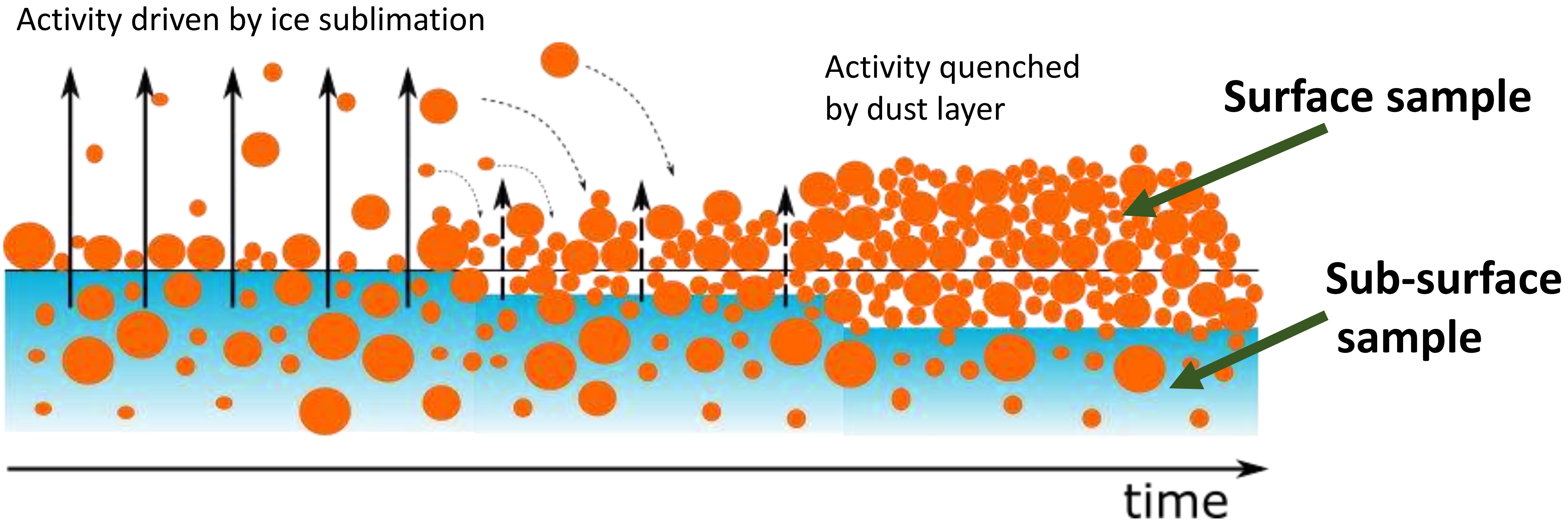
DeMeo et al. 2009





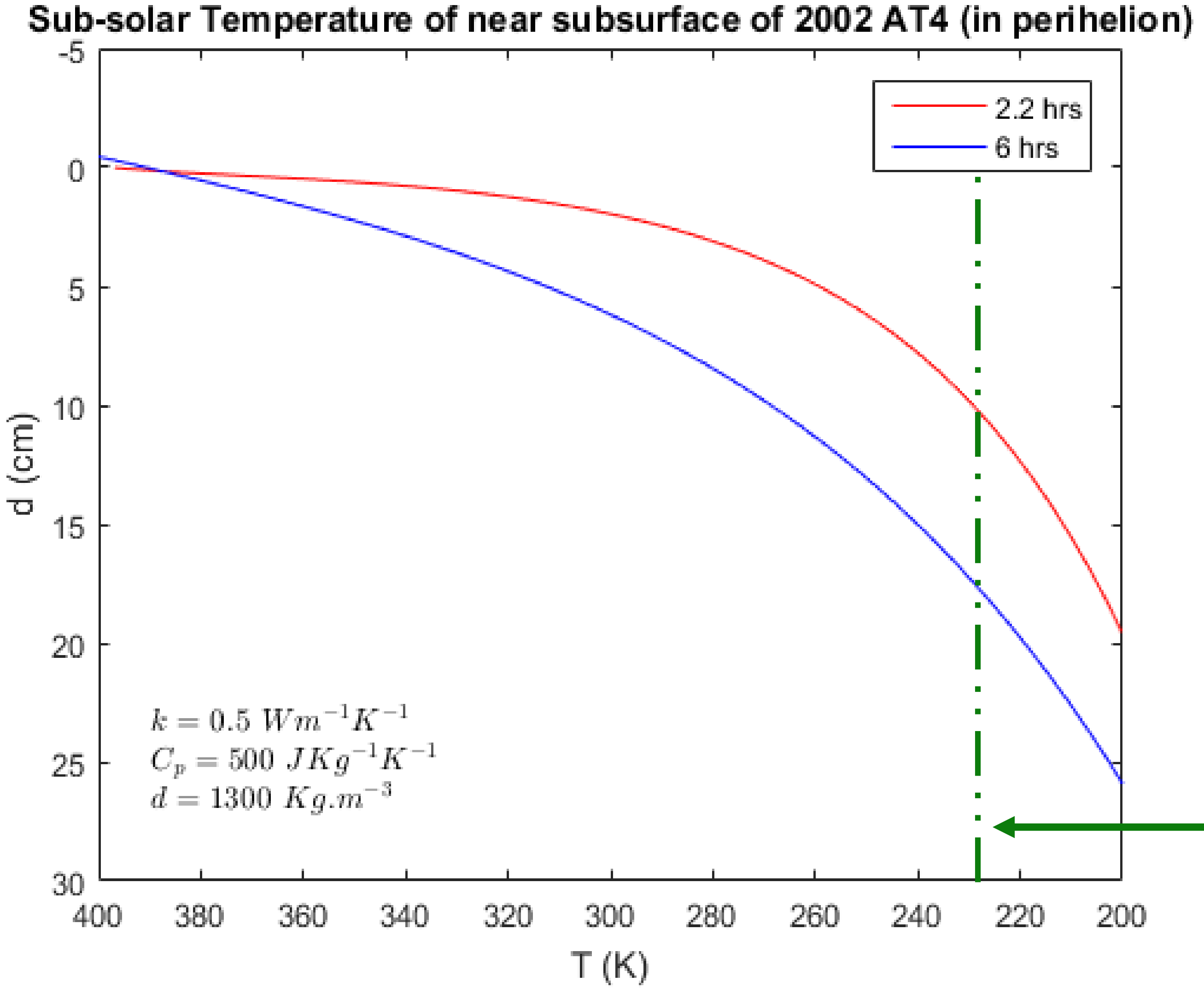
Tagish Lake Meteorite

What happens when a comet dies?

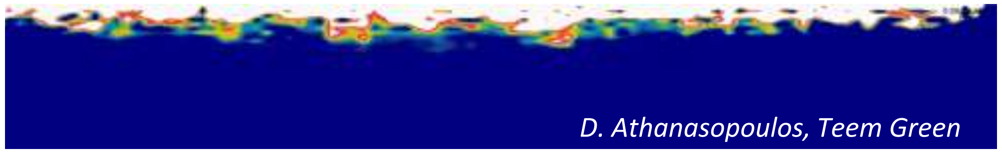


Is there some icy material left buried beneath the dust layer ?

How deep should we go?



Depending on the rotation, minimum sampling depth: **9 cm - 18 cm**.



Water in stable configuration trapped in molecules

Scientific Objectives

Is there a relationship between asteroids and comets?

1. Investigate the Asteroid-Comet relationship

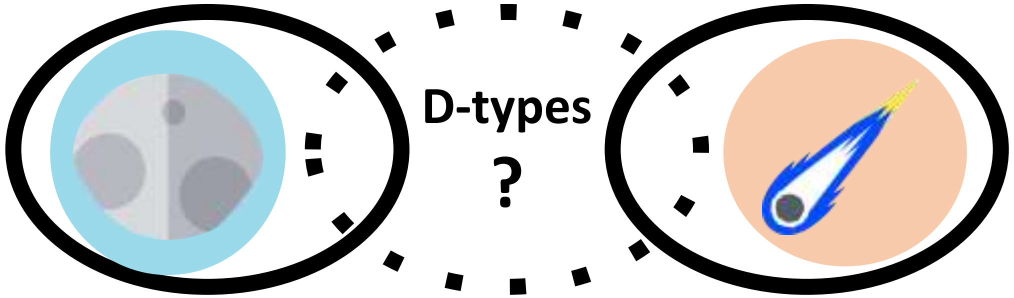
What is the origin of water and life on Earth?

2. Investigate the Origin of Life

How did the Solar System evolve and how did planetesimals form?

3. Characterise the conditions in the early Solar Nebula

1. Investigate the Asteroid-Comet relationship



- Evaluate if D-types can be related to extinct comet nuclei.
- Investigate activity quenching as a 'comet killer'.
- Do comets, D-type asteroids and C-type asteroids represent a continuum?

REQUIREMENTS

Composition

Physical Characteristics

Chemistry

METHOD

Imaging

Spectroscopy

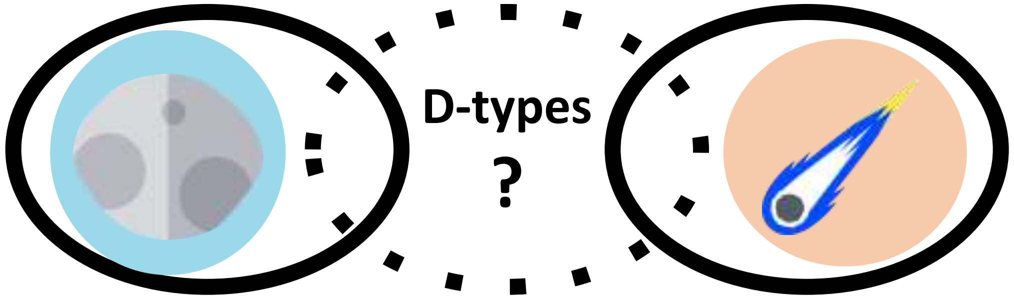
Radar Science

Magnetometry

Mass Spectroscopy (In situ)

Sample Analysis (Earth Laboratory)

1. Investigate the Asteroid-Comet relationship



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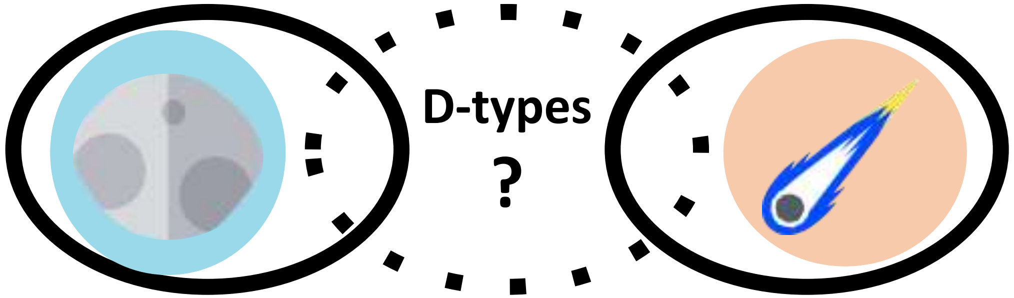

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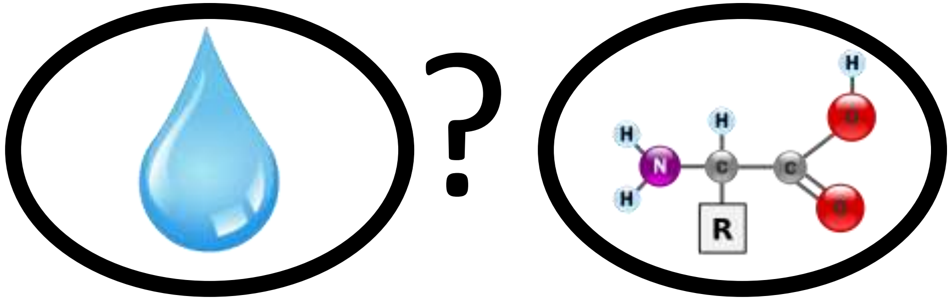
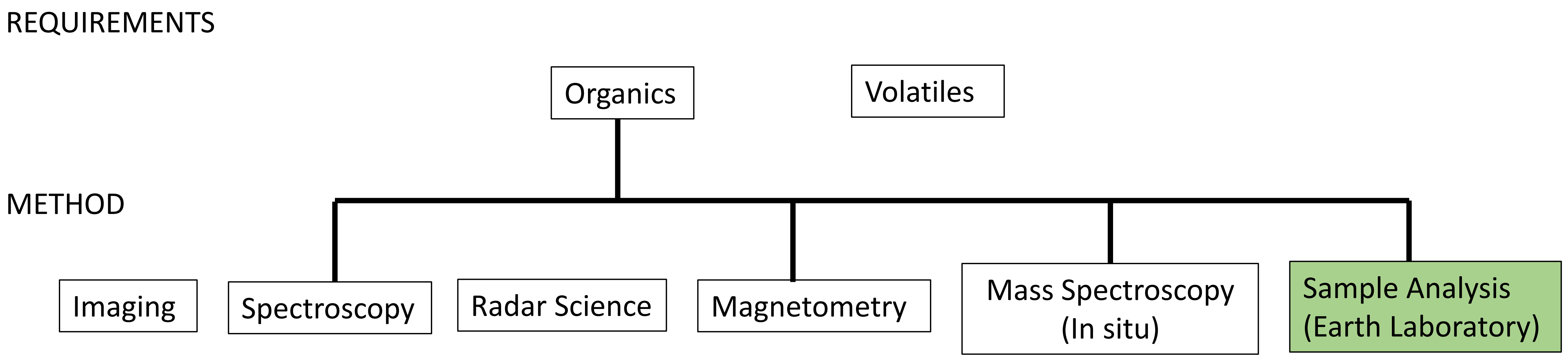


- Investigate chirality in the organic material
- Investigate D/H ration in the volatile content



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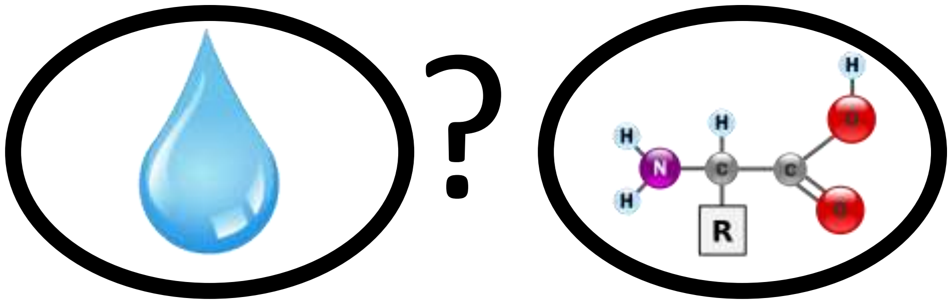

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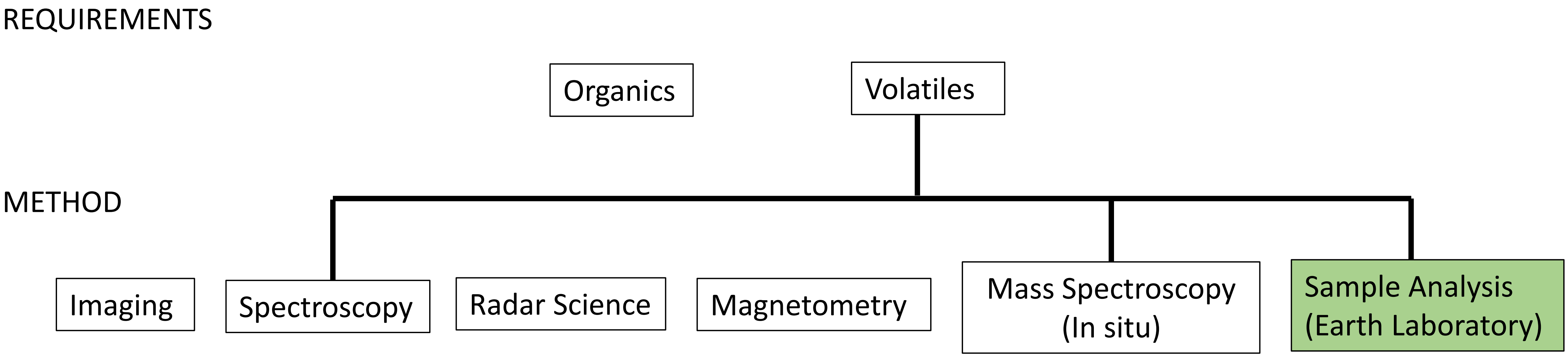
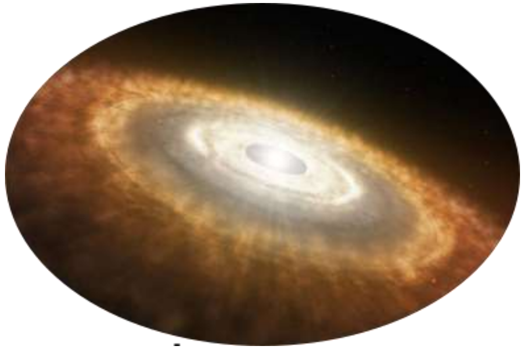


3. Characterise the early Solar Nebula



- Determine timescales of accretion and planetesimal formation
- Characterise mixing of elements in the protoplanetary disk
- Link characteristic properties to meteorite analogues

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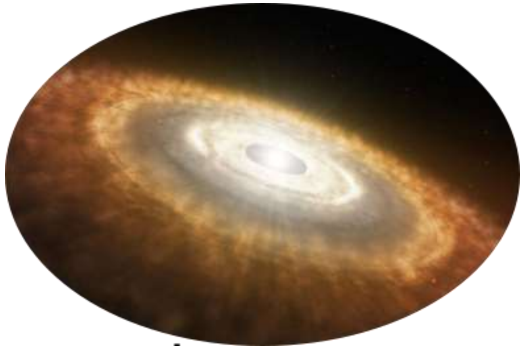

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REQUIREMENTS

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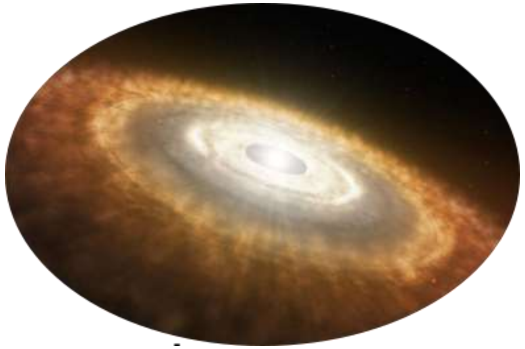

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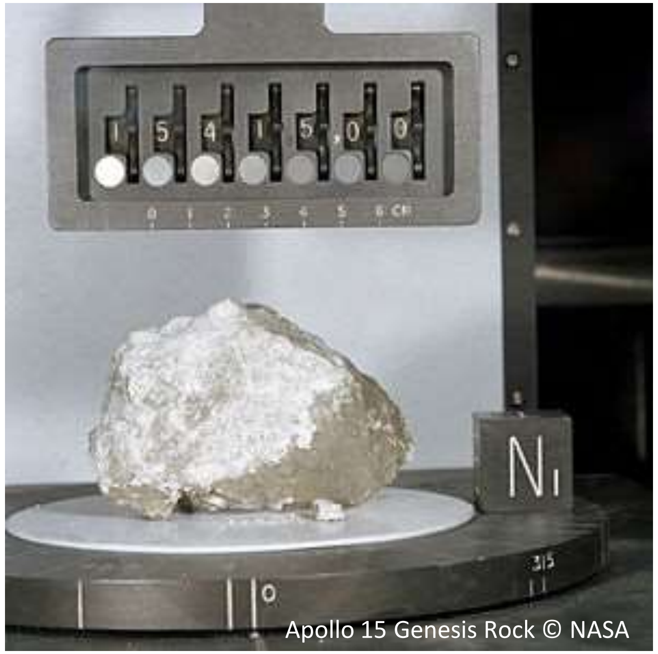
Mass Spectroscopy (In situ)

Sample Analysis (Earth Laboratory)

Mission goals

1. Rendezvous with a near-Earth D-type asteroid and escort it along a part of its orbit.
2. Return a regolith and a sub-surface sample and document the sampling site.
3. Characterize and map a D-type asteroid.

Sample return



Science case	Type of analysis	Key characterization techniques	Minimum amount of sample (g)	
			Regolith	Sub-surface
Asteroid-Comet Relationship	elemental and isotopic abundances; mineralogy	*SIMS, LA-ICP MS, GSMS, IRMS	3.5	3.5
Origin of life	chemical analysis; elemental and isotopic abundances	UV-VIS-NIR, (13C, 1H) NMR, Raman, XANES, HPLC, GC-MS, C D spectroscopy	2	2
Conditions in the early solar system	isotopes and mineralogy	SEM, TEM, EDS, Raman, SIMS, Auger spectr., X-ray CT	0.5	0.5

*Destructive methods

Minimum total amount of sample to perform scientific investigations once: **12 g**

Maximum expected total amount of return material: **2.2 kg**

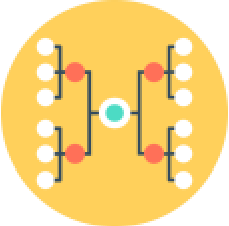
(~10% sample early characterization|~10% preliminary examination| ~20% scientific investigations| ~60% storage)

Key mission drivers

Sample return	
Sample mass:	Min. req.: 12 g Surface & sub-surface
Target selection:	D-type near-Earth asteroid
Landing capability and sampling:	S/C needs to reach asteroid surface
Re-entry:	Sample protection at impact and during atmosphere re-entry
Planetary Protection:	Isolate sample from Earth environment, avoid sample contamination

Payload Concepts

Scientific Payload - Identification

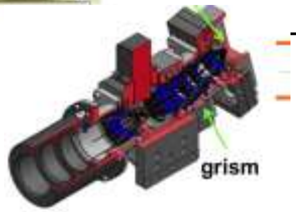
1. Sample Analysis	3. Spectroscopy	5. Mass Spectrometry
 **Sampler**	 **VNIR/TIR Spectrometer**	 **Mass Spectrometer**

2. Imaging	4. Radar/Radio measurements		6. Magnetic measurements
 **Camera System**			 **Magneto-meter**
	Radar	**Radio Science Instrument**	

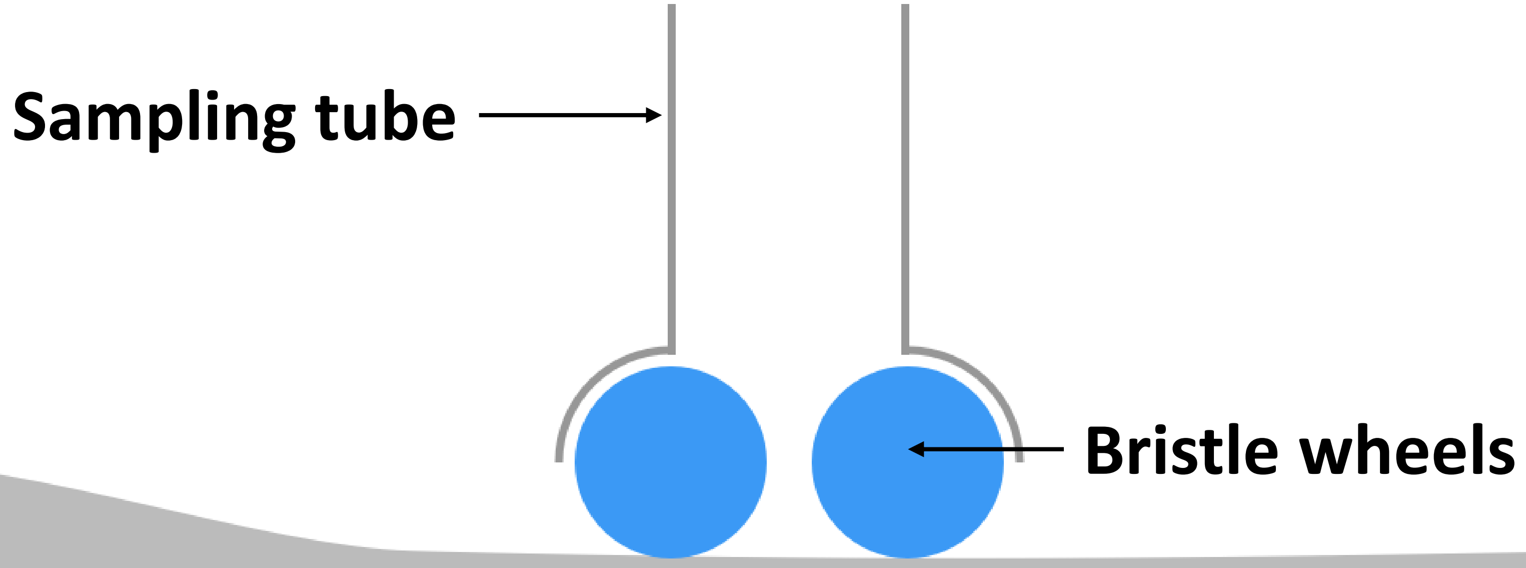
PAYLOADS

1- Sampling and in-situ analysis
2- Enable safe operations and facilitate sample site selection
3- Place the samples in their global and local context
4- Provide complementary science

Instrument	Investigation, Measurement Requirements	1	2	3	4	Priority
Global Mapping Camera	Global mapping, sampling site selection, Geology, Shape model, 20 cm resolution		●	●	●	1
Sampling Camera	Local mapping, 1 mm res.		●	●	●	1
Radio Science	Mass determination Doppler accuracy < 1 mm/s		●		●	1
Sampling Mechanism	Sampling	●				1
Magnetometer	M-field measurements of the sample 10 pT	●				4
Mass Spectrometer	Compositional characterisation of samples, Identification of volatiles, organics 5 ‰ detection limit, 5 - 60 m/z range	●				3
Visible/Near- Infrared Spectrometer/	Surface composition and minerology 0.4 - 4 um bandwidth, 10 cm-1 spec. res., 10 cm-1 spec. res.		○	●	●	2
HF Radar	near sub surface characterisation, ranging topography, 3 - 4 m penetration depth minimum, 1x1 m resolution		○	●	●	3
IR Thermal Spec	Temperature and thermal properties, 5 - 20 micron bandwidth, spectral resolution of 0.5 micron		○	●	●	2

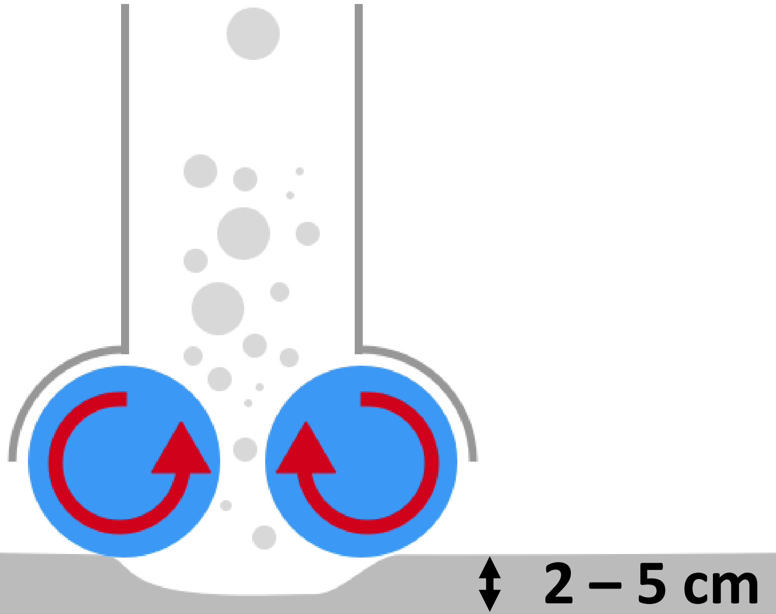
Instruments		Heritage	TRL	Mass/ Power
Global Mapping Camera		Rosetta (Osiris)	9	2000 g 11.5 W
Sampling Camera		Rosetta (Osiris)	9	820 g 12.5 W
Magnetometer		Rosetta Lander Magnetometer (Philae)	9	180 g 1 W
Mass Spectrometer		Rosetta Lander (Philae/Ptolemy)	9	4500 g 18 W
IR Thermal Spec		Compact Modular Sounder (CMS), UK's TechDemoSat-1	9	3000 g 4 W
Visible/Near-Infrared Spectrometer		MMX, MacrOmega MEXOmega NIRS3 on hayabusa2	4-9	3600 g 25 W
HF Radar	 	AIM, HF radar ExoMArs WISDOM	4	1700 g 88 W
Radio Science		Rosetta RSI	9	N.A

Sampling Procedure



Surface sample collection with bristle sampler

Brustling surface regolith
sample into spacecraft
trough sampling tube



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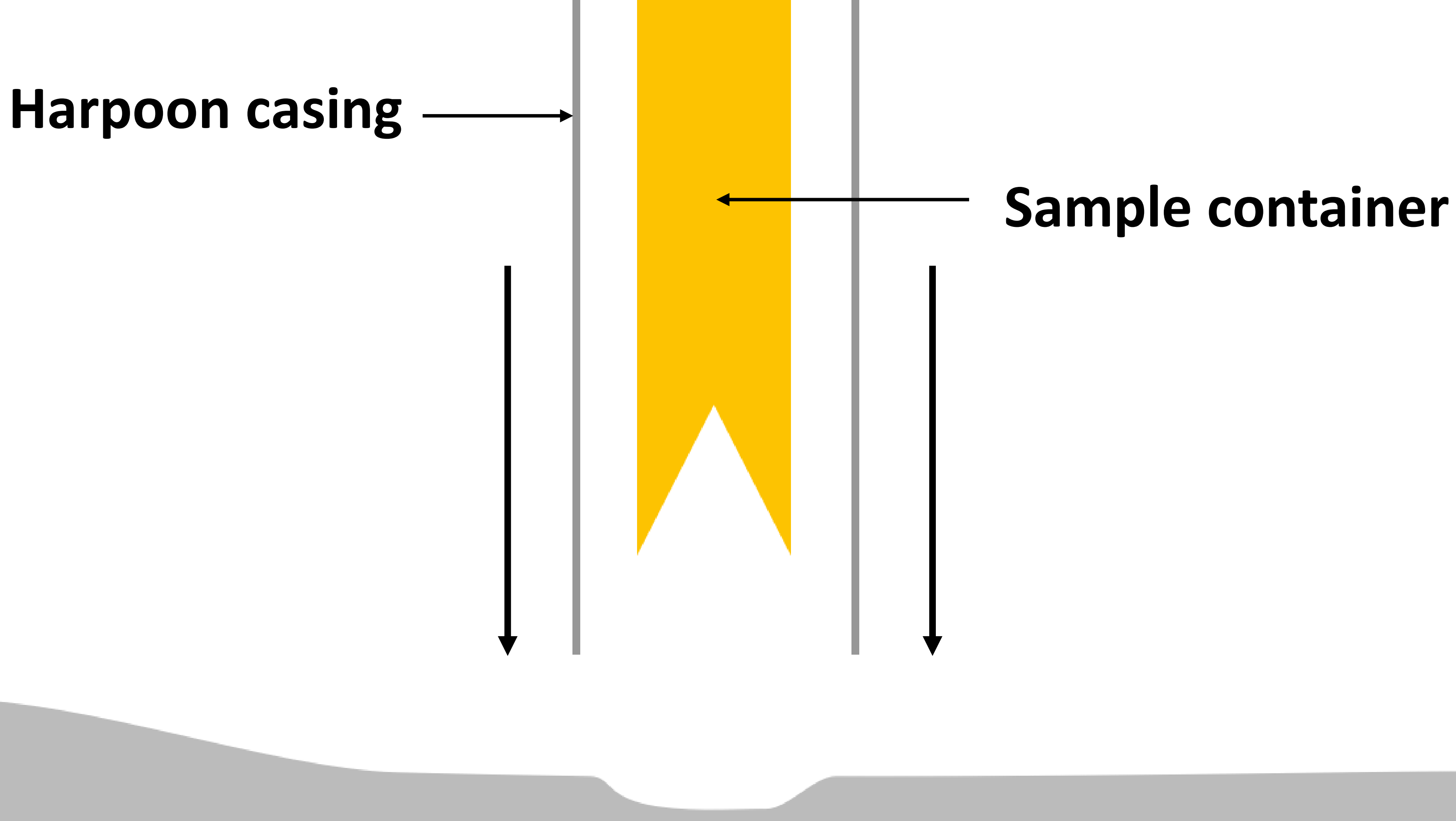
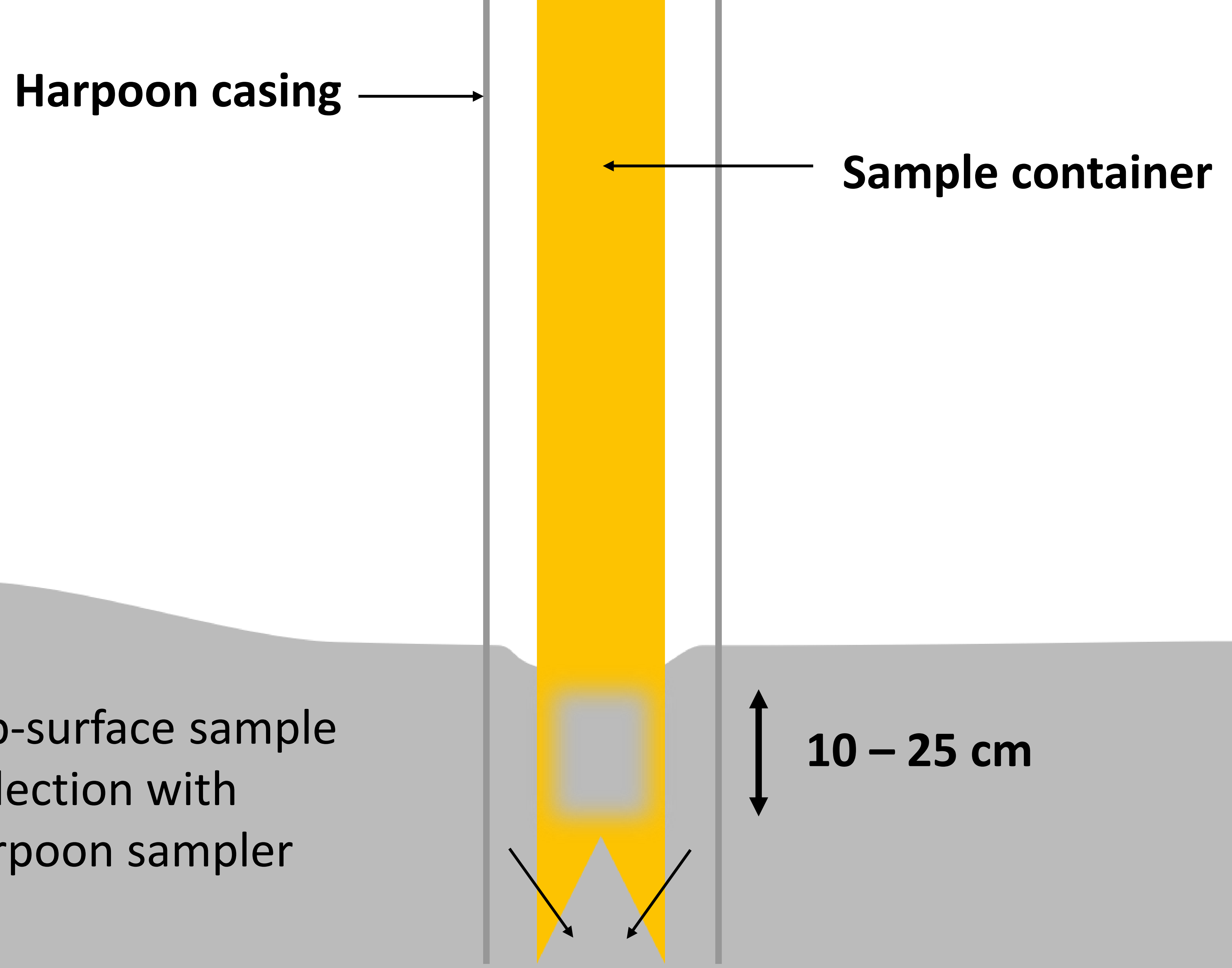
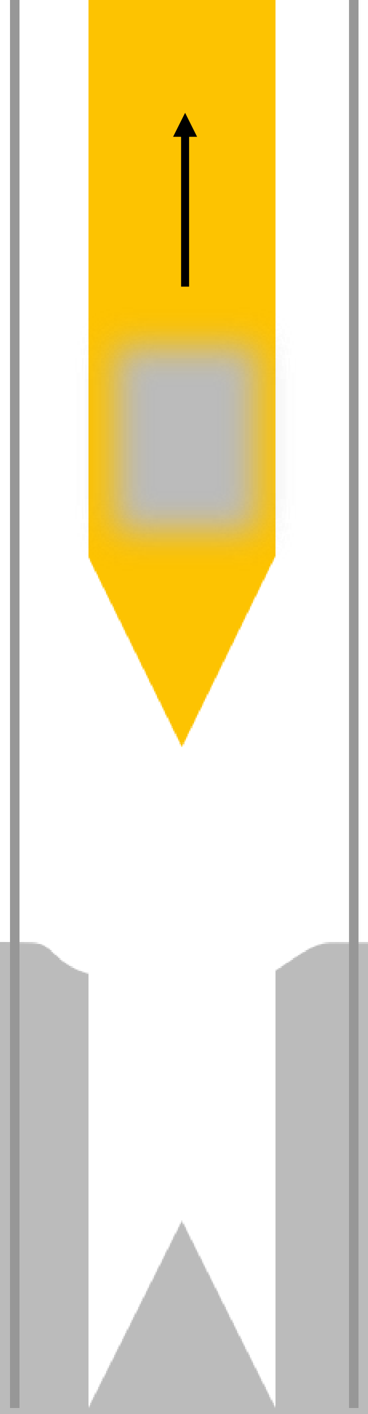


Sub-surface sample collection with Harpoon sampler



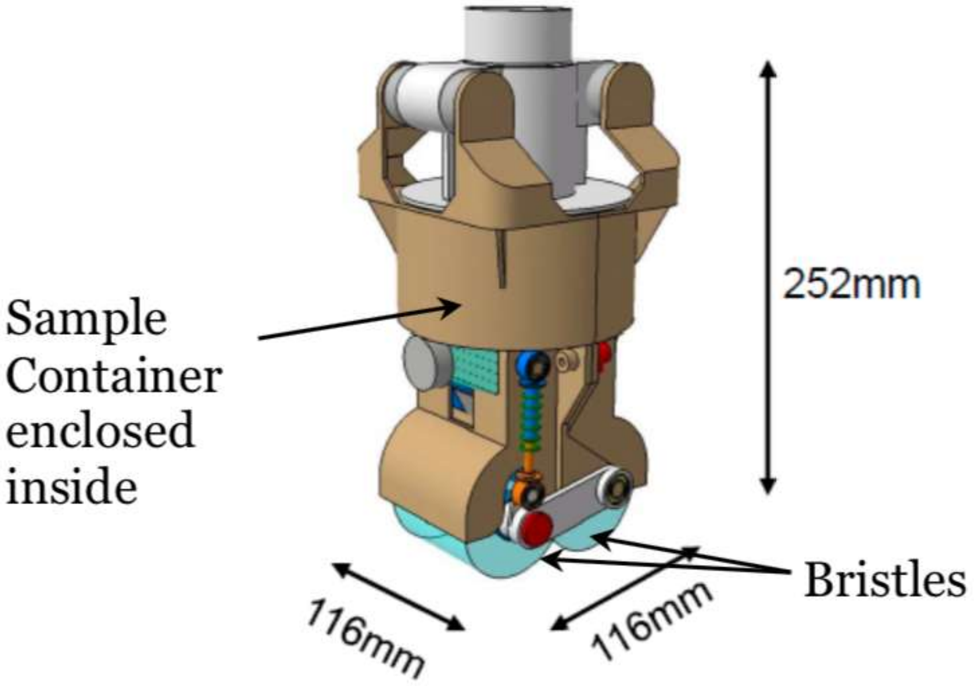
Sub-surface sample collection with Harpoon sampler

Retrieving sub-surface sample into spacecraft by pulling back harpoon sample container



Sub-surface sample collection with Harpoon sampler

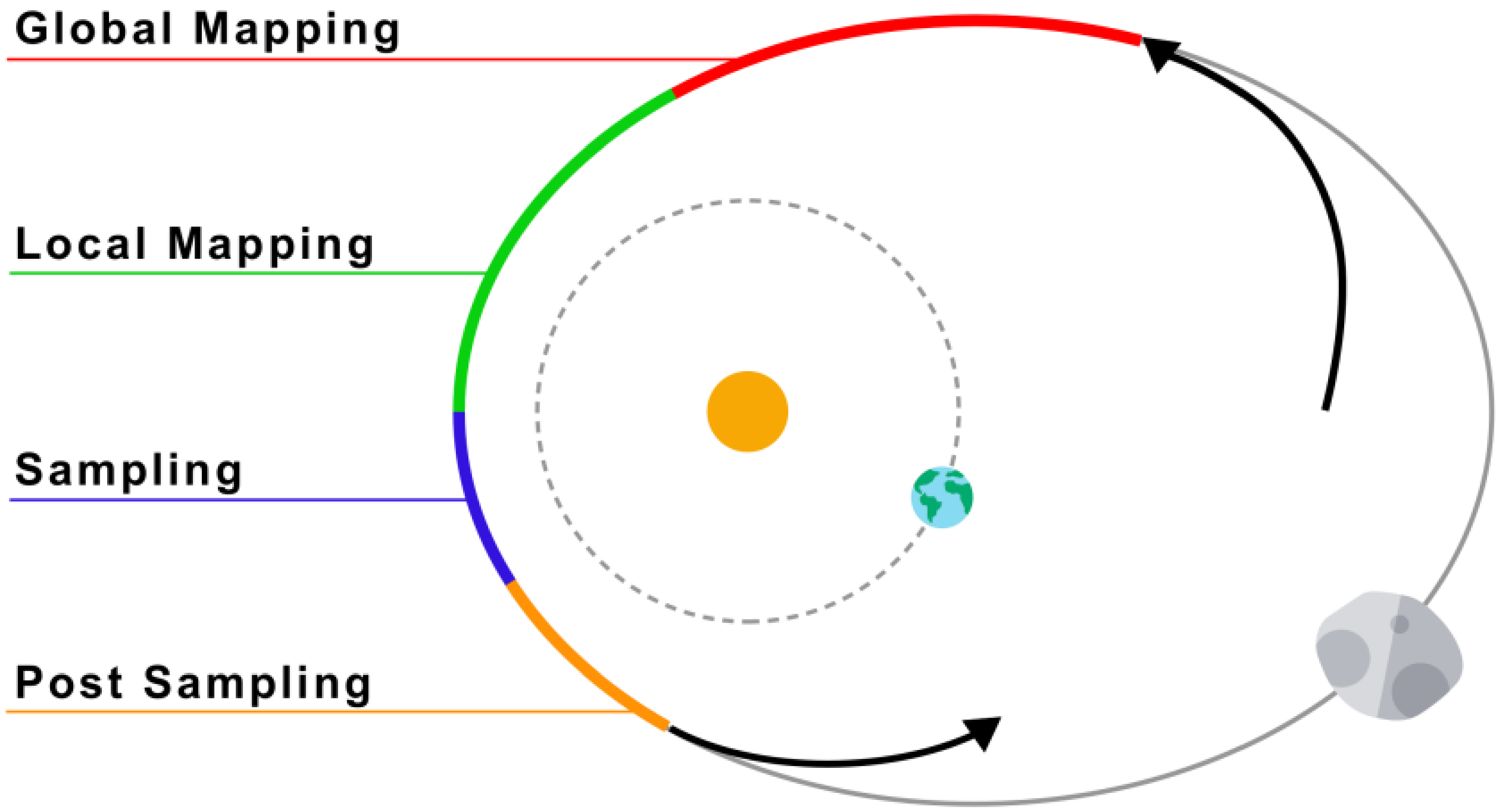
Sampling mechanisms



Surface Sampling: max. 300g

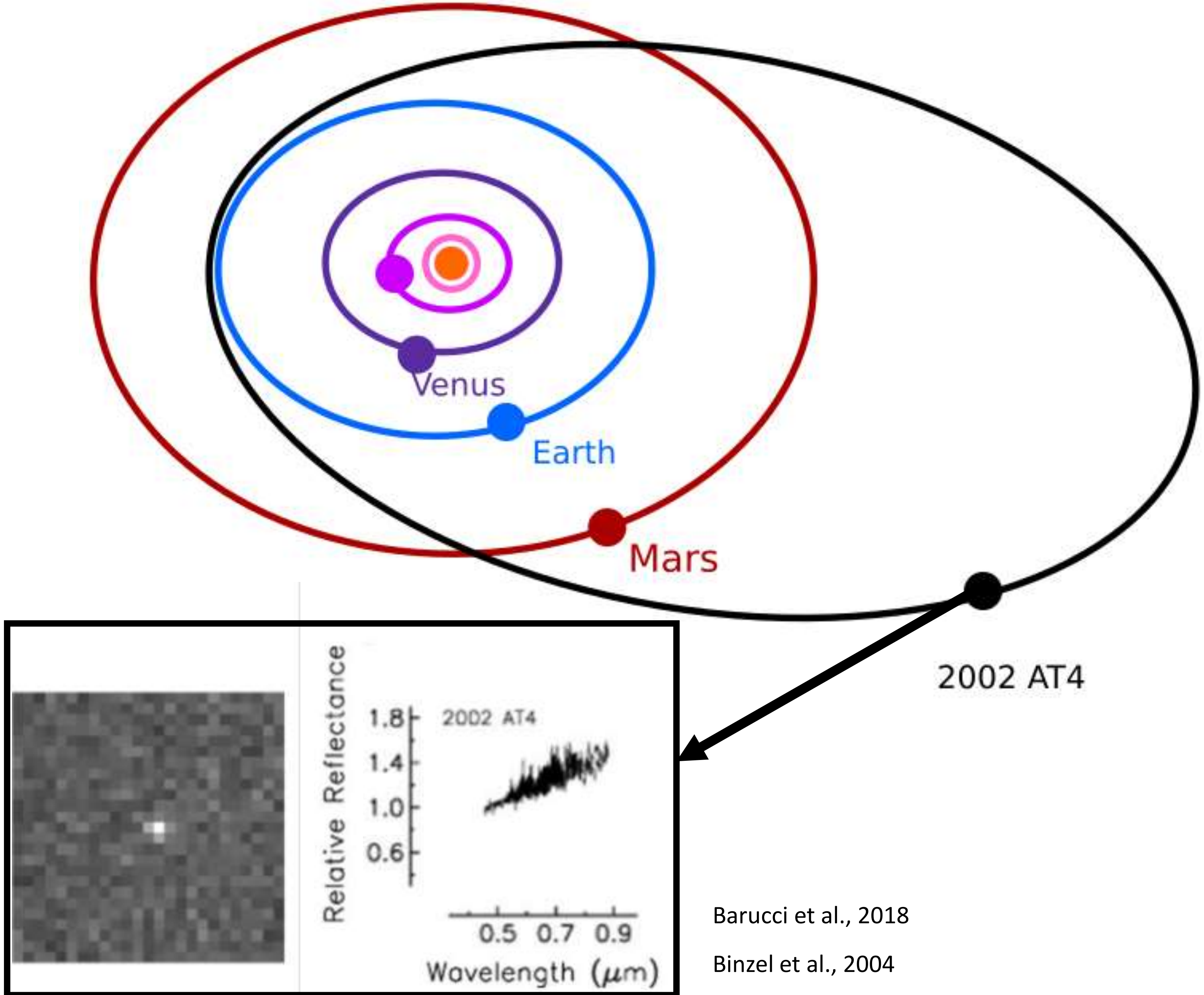
Sub-Surface Sampling: max. 840g

Observation strategy



Mission profile

Targets selection: 2002 AT4



Barucci et al., 2018

Binzel et al., 2004

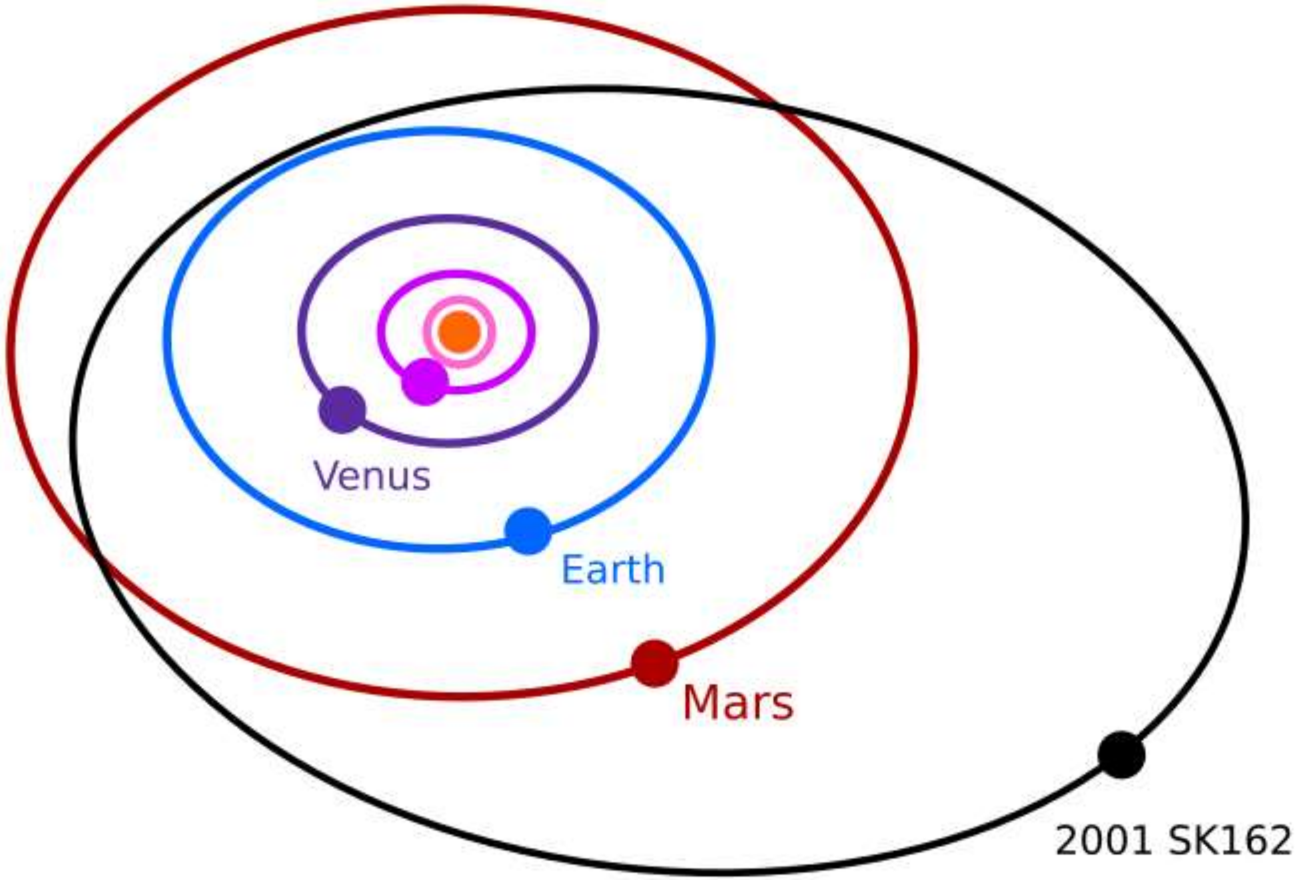
- D-Type asteroid
- Primitive composition
- Hydrated minerals
- Carbonaceous material
- diameter: ~160-350m
- Near Earth Orbit

Orbital parameters:

- i=1.5°
- a=1.8 AU

Launch window every 2 years

Plan B : SK162

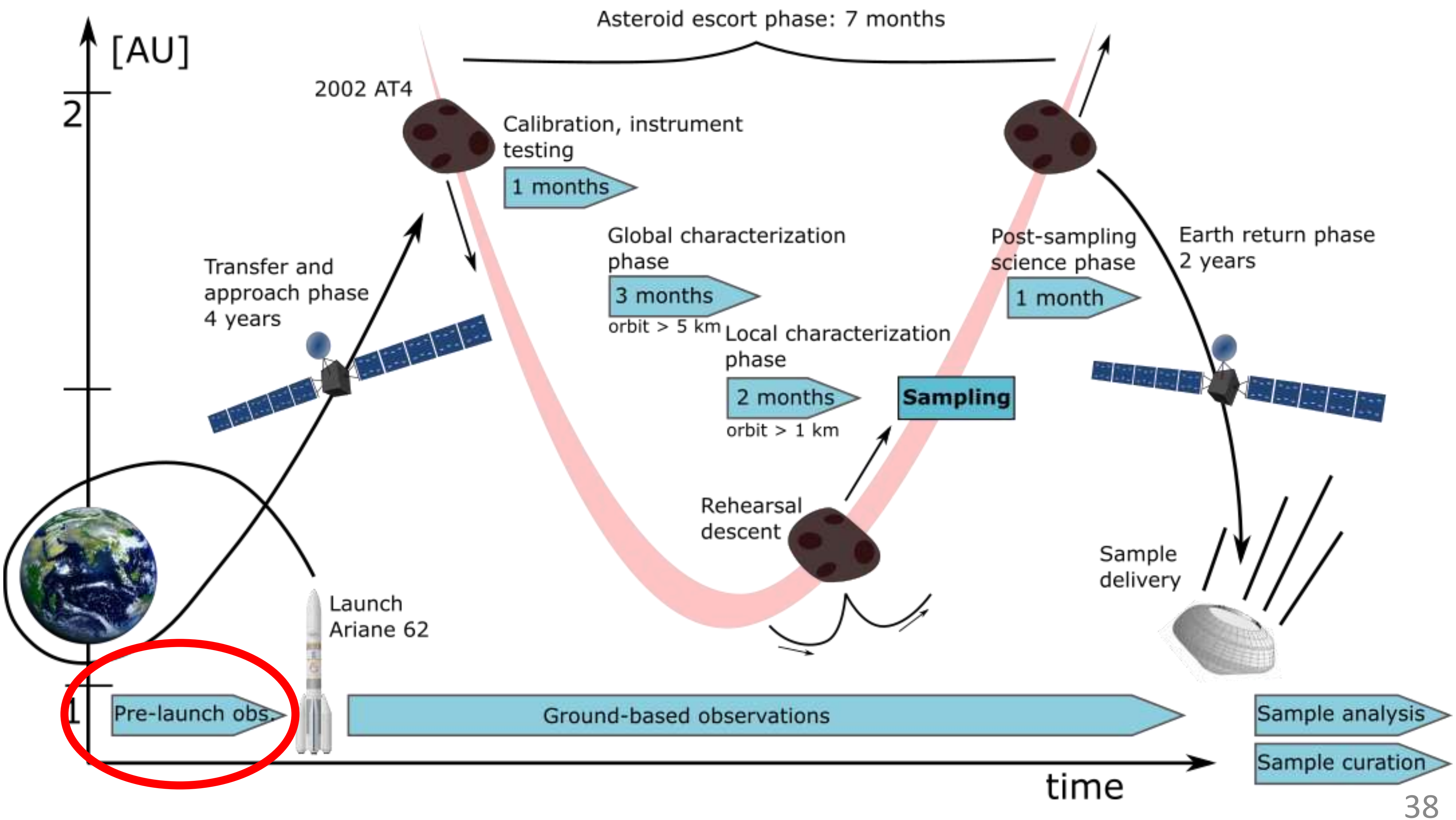


- D or T-Type asteroid
- Primitive composition
- Thought anhydrous
- Carbonaceous material
- 870m diameter

Orbital parameters:

- i=1.6°
- a=1.92 AU

Mission Phases



Pre-Launch Ground-based Observation

Objectives of observations

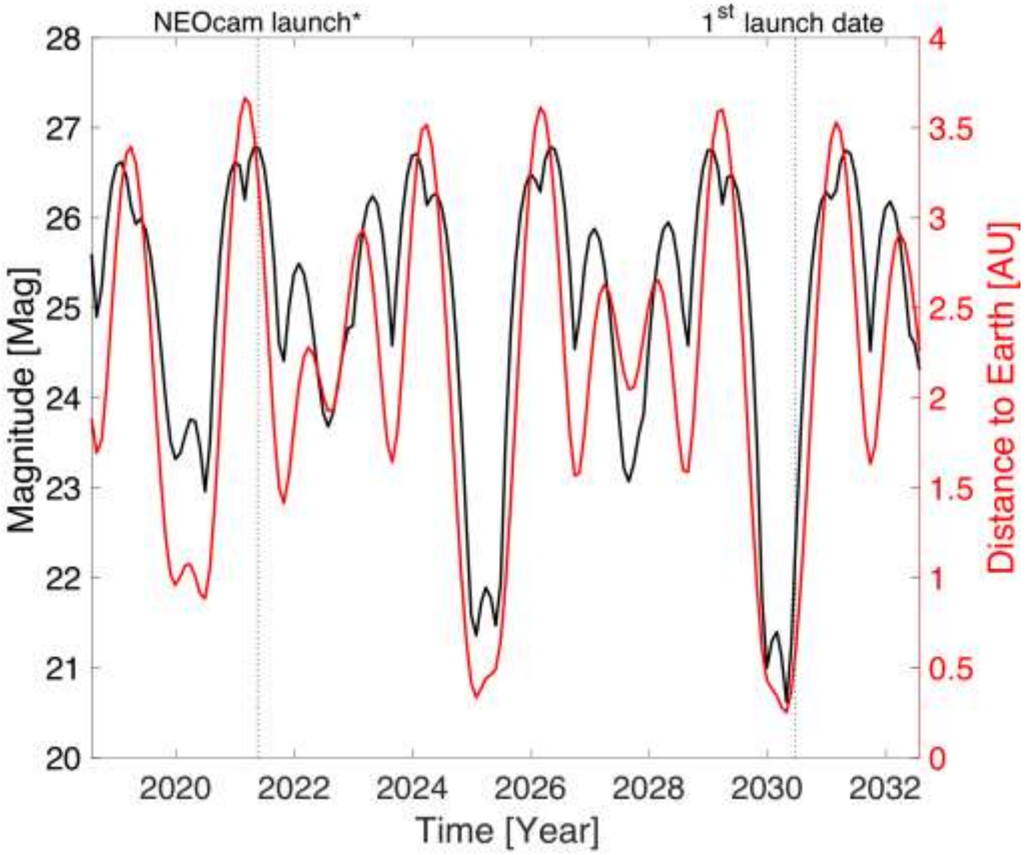
- Determine rotation period
- Improve diameter estimation
- Ensure taxonomy and do preliminary compositional analysis
- Search for binary

Primary observation stations

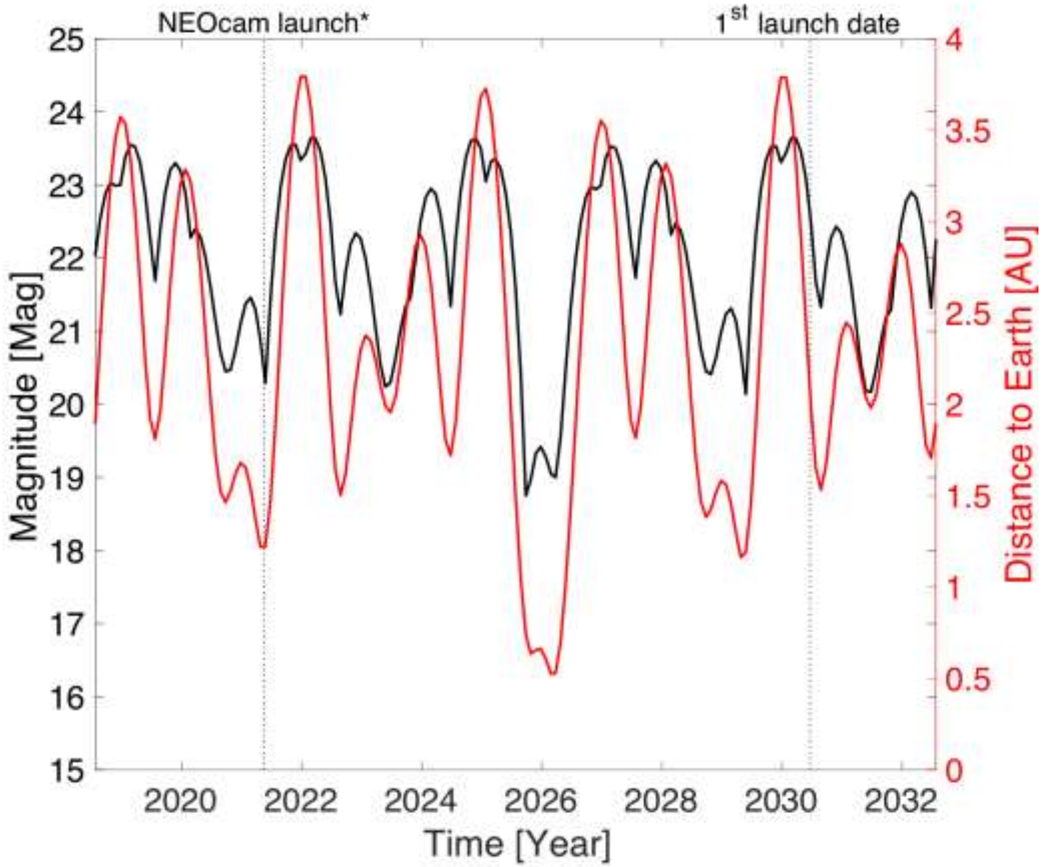
- Arecibo, Puerto Rico for radar observations
- Mauna Kea, Hawaii for visible and NIR spectra
- NEOcam (proposed to launch 2021) for IR observations above atmosphere

Ground-based Observation

2002 AT4



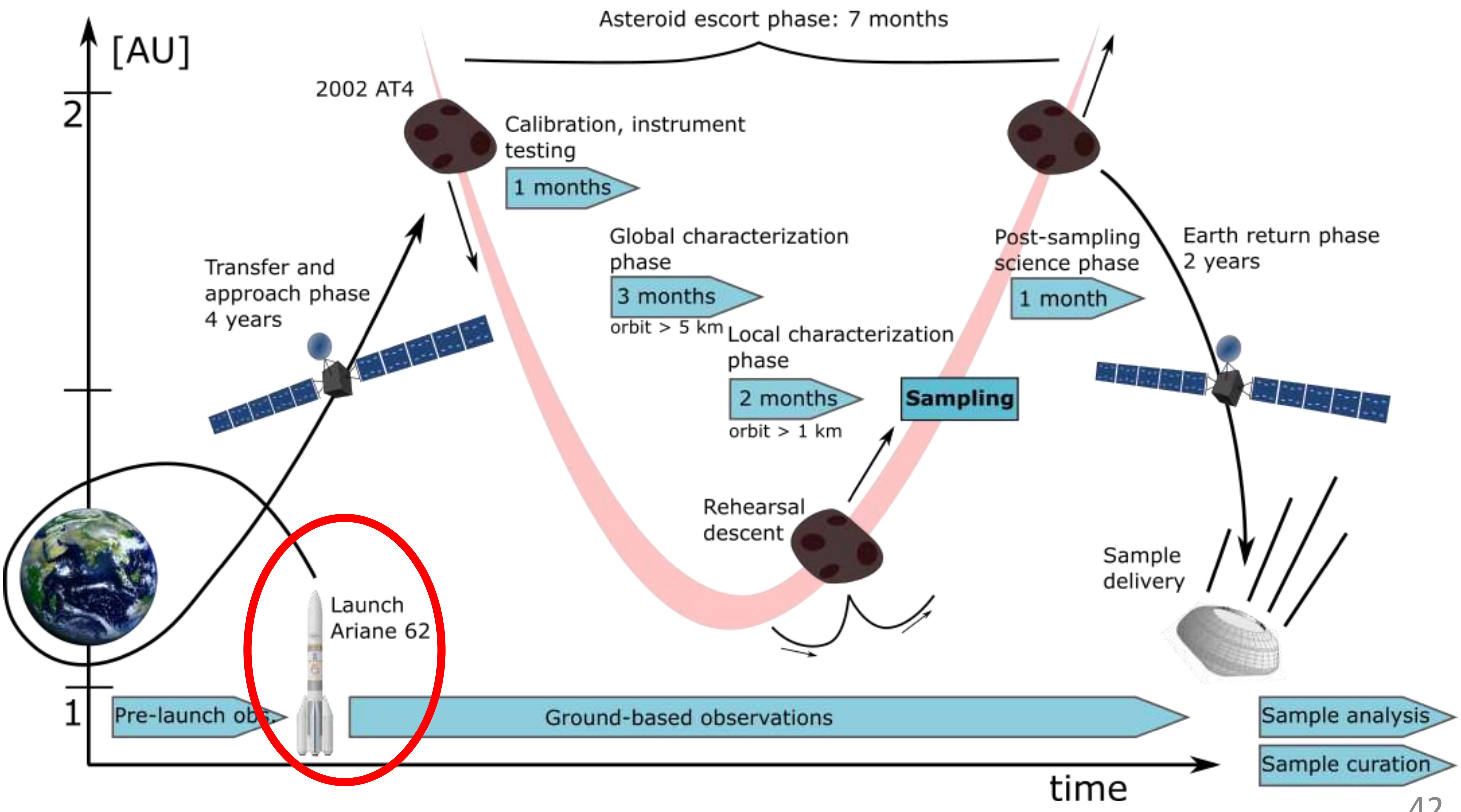
2001 SK162



Phase	Duration	Instruments	Data Volume	Data Rate (Max)
Launch				
Transfer and Approach	4 years	Global Camera 1 scan per day	7,2 Gbits per day max	83 kbits/s
Global Mapping	3 Months	Global Camera : 2 scans HF Radar : 2 scans VIS IR :100 scans NIR: 100 scans RSE	71 Gbits	8,9 kbits/s
Local Mapping	2 Months 2 Weeks	NearField Camera : 50 scans HF Radar :10 scans VIS IR:100 scans NIR: 100 scans RSE Magnetometer	72 Gbits	11 kbits/s
Sampling	2 Weeks	Bristle Sampler Dart Sample		
Post Sampling Phase	1 Month	NearField Camera : 25 scans HF Radar : 5 scans VIS IR : 50 scans NIR : 50 scans Mass Spectrometer	72 Gbits	27 kbits/s
Earth Return Phase	4 years			
Sample Capsule Return		Sample Return Capsule		

1 scan = 1 view of the complete target

Mission Phases

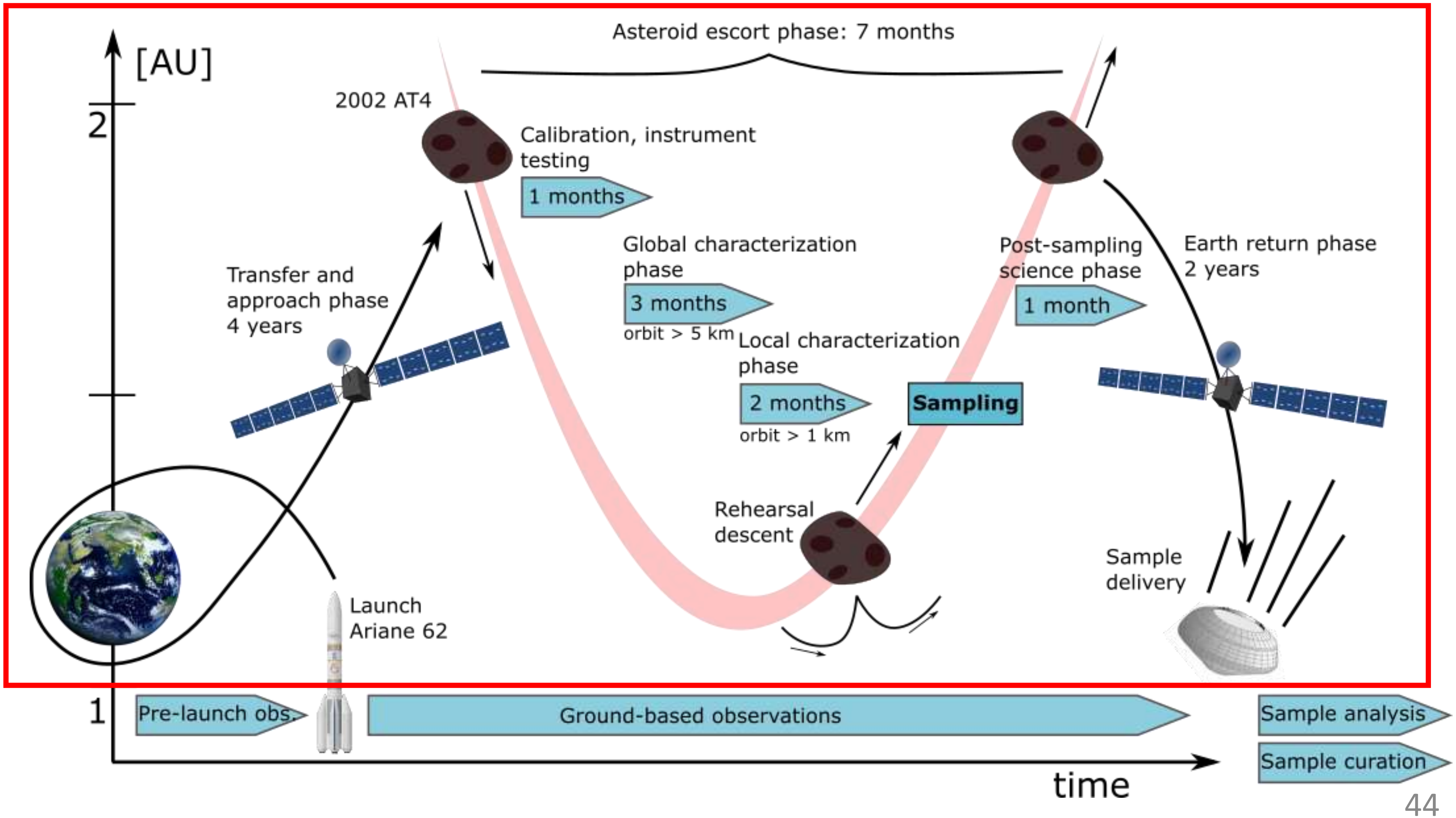


Launch

- Launcher: Ariane 62
- Launch base: Guyana Space Center (Kourou)
- Direct injection into heliocentric transfer orbit

TARGET	LAUNCH DATE	MAXIMUM MASS AT LAUNCH [kg]	MISSION DURATION [years]	STAY TIME [months]	TOTAL ΔV FOR THE MISSION [km/s]
2002AT4	29/06/2030	1825	6.95	7	9.43
2002AT4	12/08/2033	2012	6.45	22	9.68
2002AT4	31/08/2035	2039	6.73	7	13.55

Mission Phases

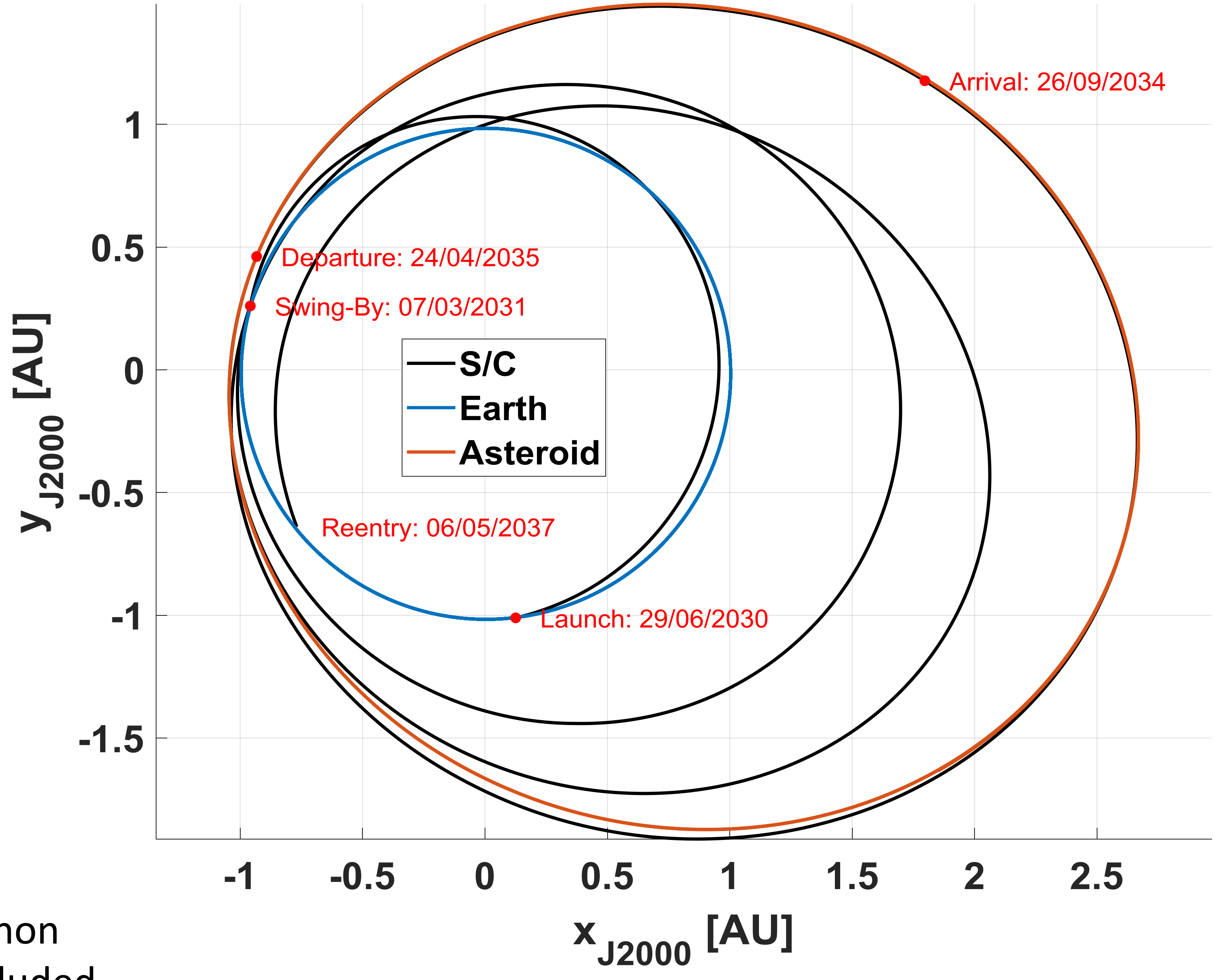


Orbit

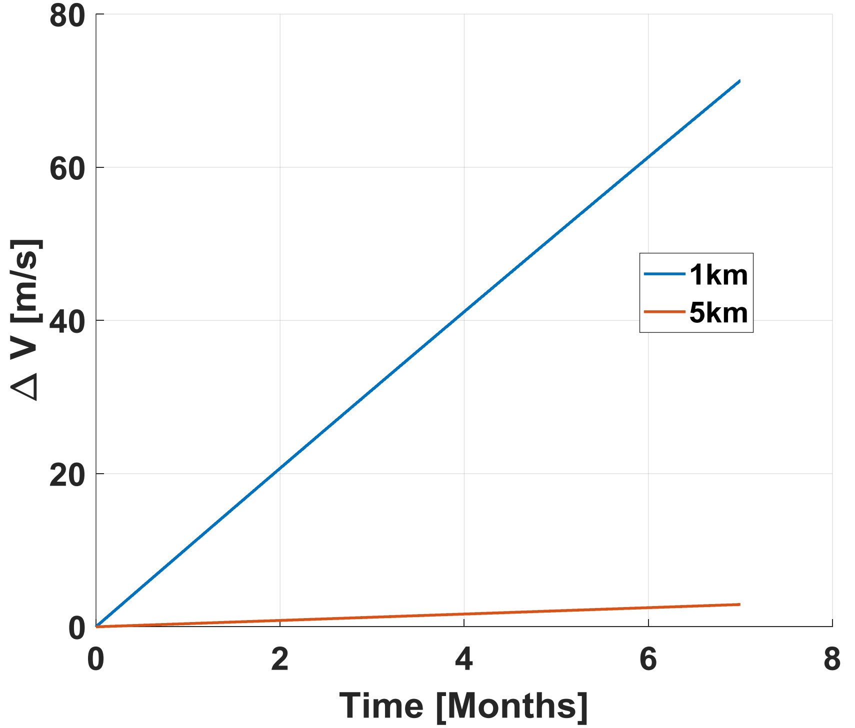
Launch date 1:
29/06/2030

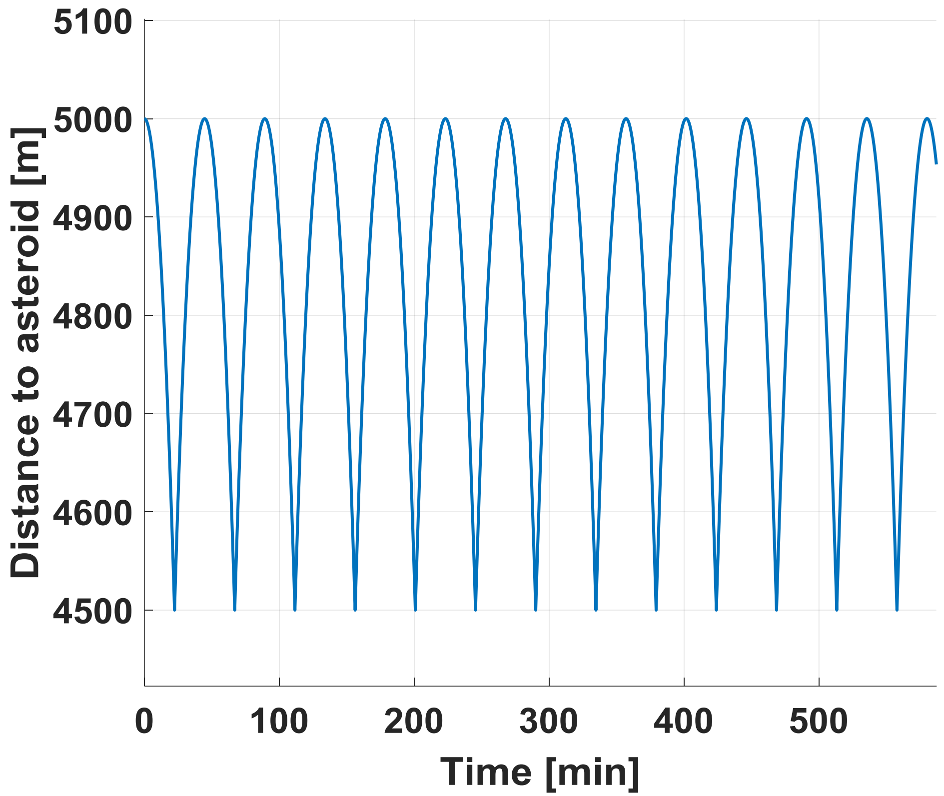
	ΔV (km/s)
Outgoing	5.28
Asteroid operations	0.05
Land & go	0.021
Return	4.08
Total	**9.431**

*Propellant safety factor of 5% for Xenon and 100% for Hydrazin have been included



Target Orbits



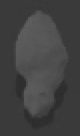


5km: Global Mapping

- **Shape model**
  - **Resolution for NAC: 20cm**
  - **Radar**
- **Science Operations**

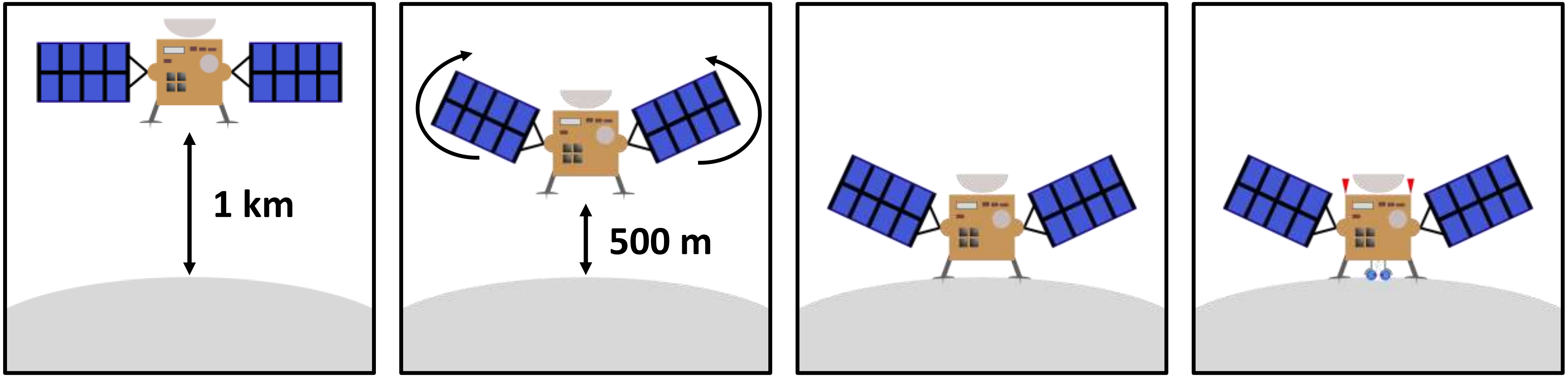
1km: Local Mappping

- **Radio science measurements**
  - **Gravity field determination**
- **Sampling site selection**
- **Science Operation**



Touch Down Sequence

Start | **14 min** | **6 min** | **5 min**



Mapping

Approach

- Solar panels tilted by 25°

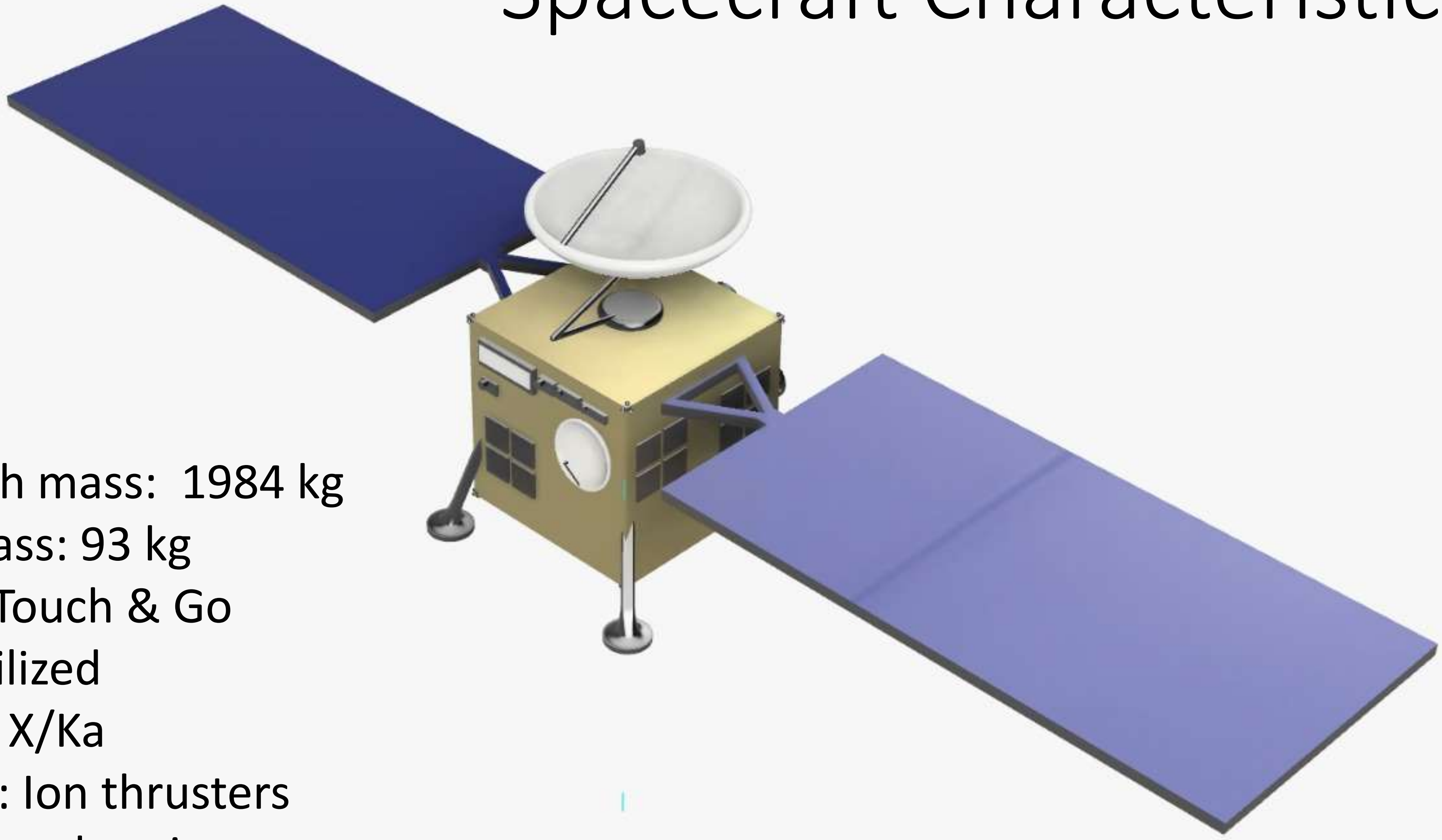
Touch Down

- Free fall from 8 m in 126 s
- Touch down velocity: 6 cm/s

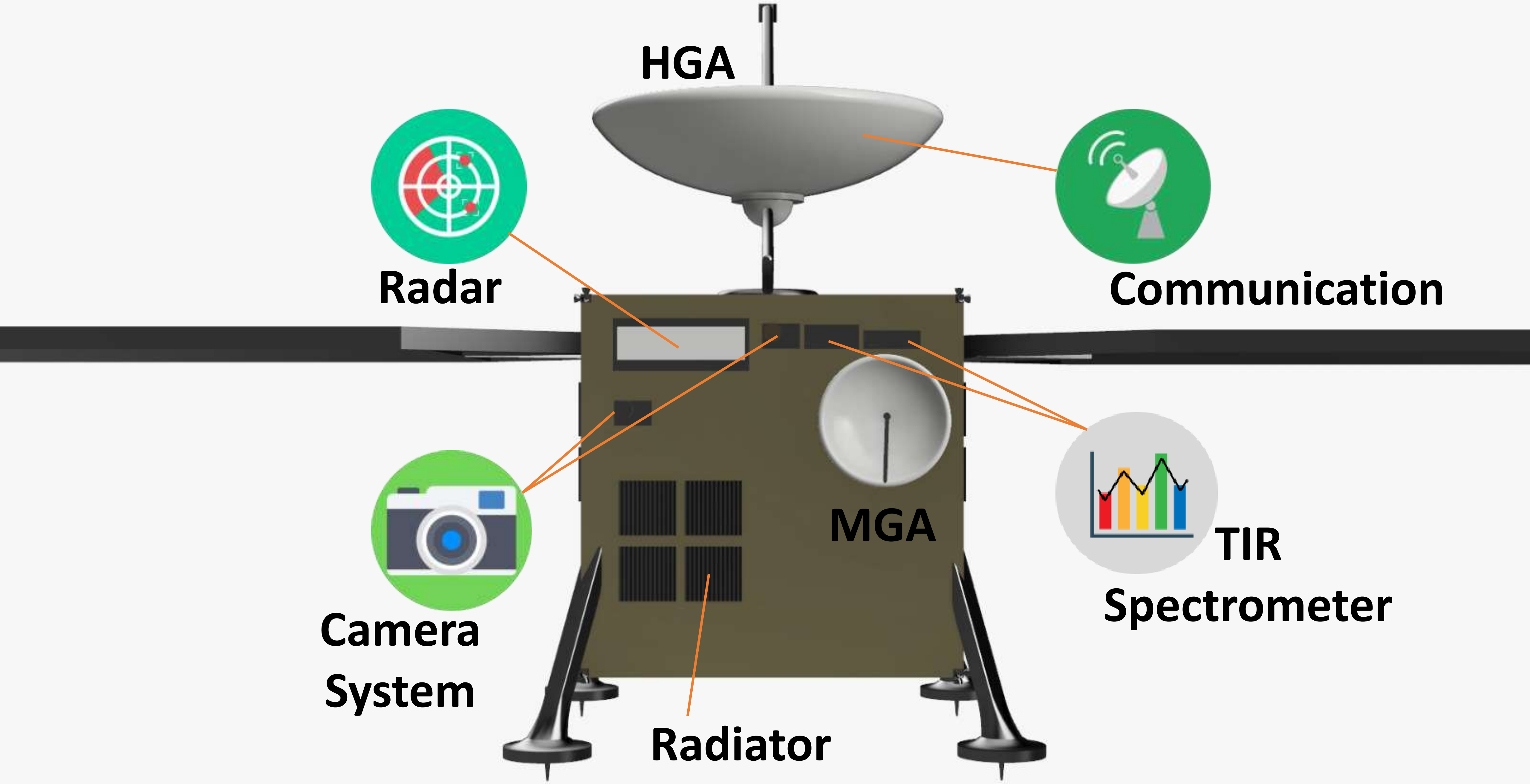
Sampling

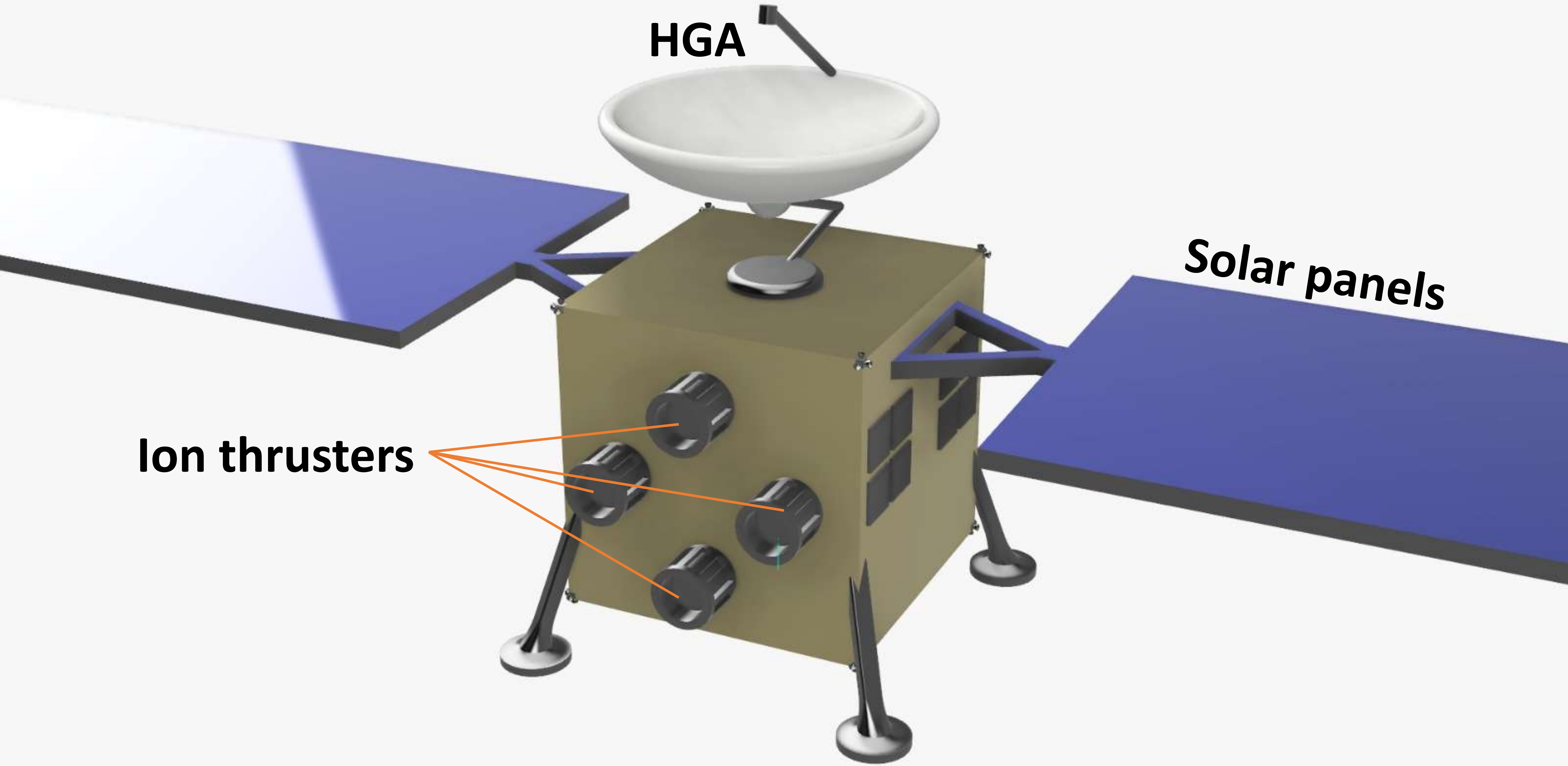
The Spacecraft

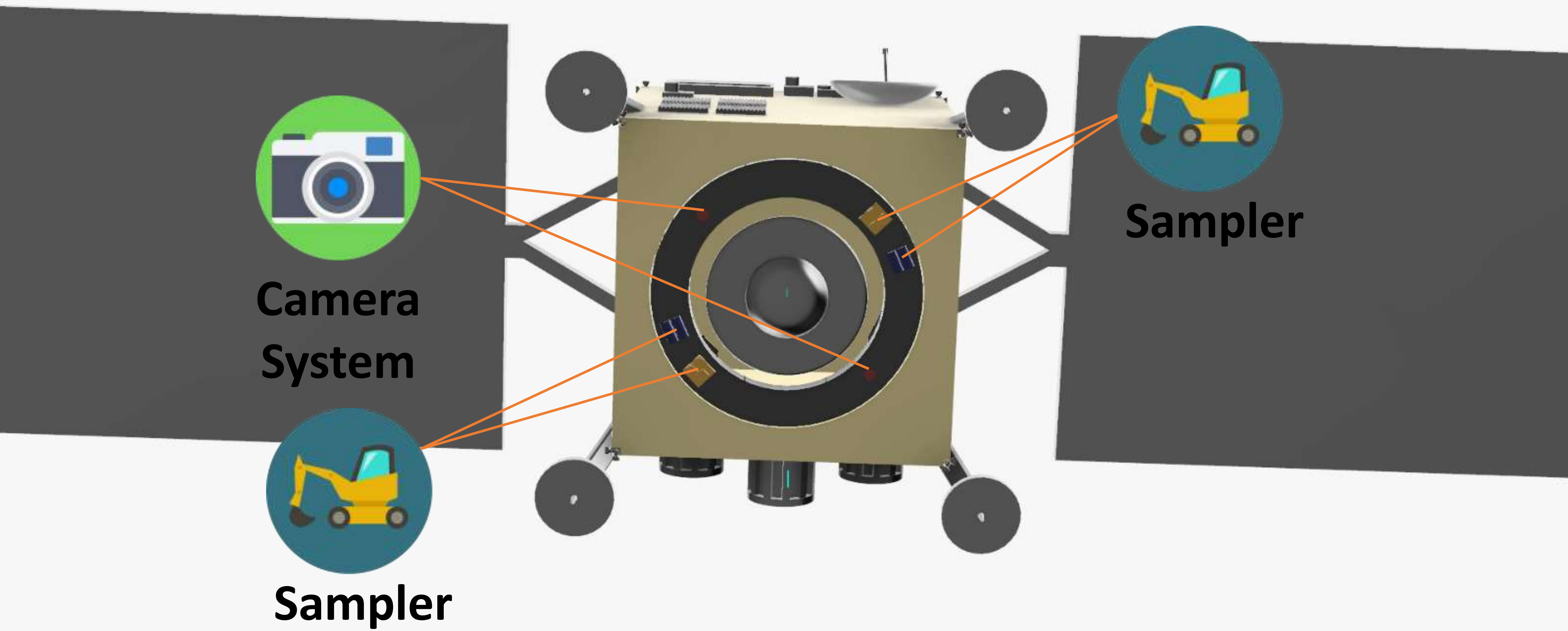
Spacecraft Characteristics



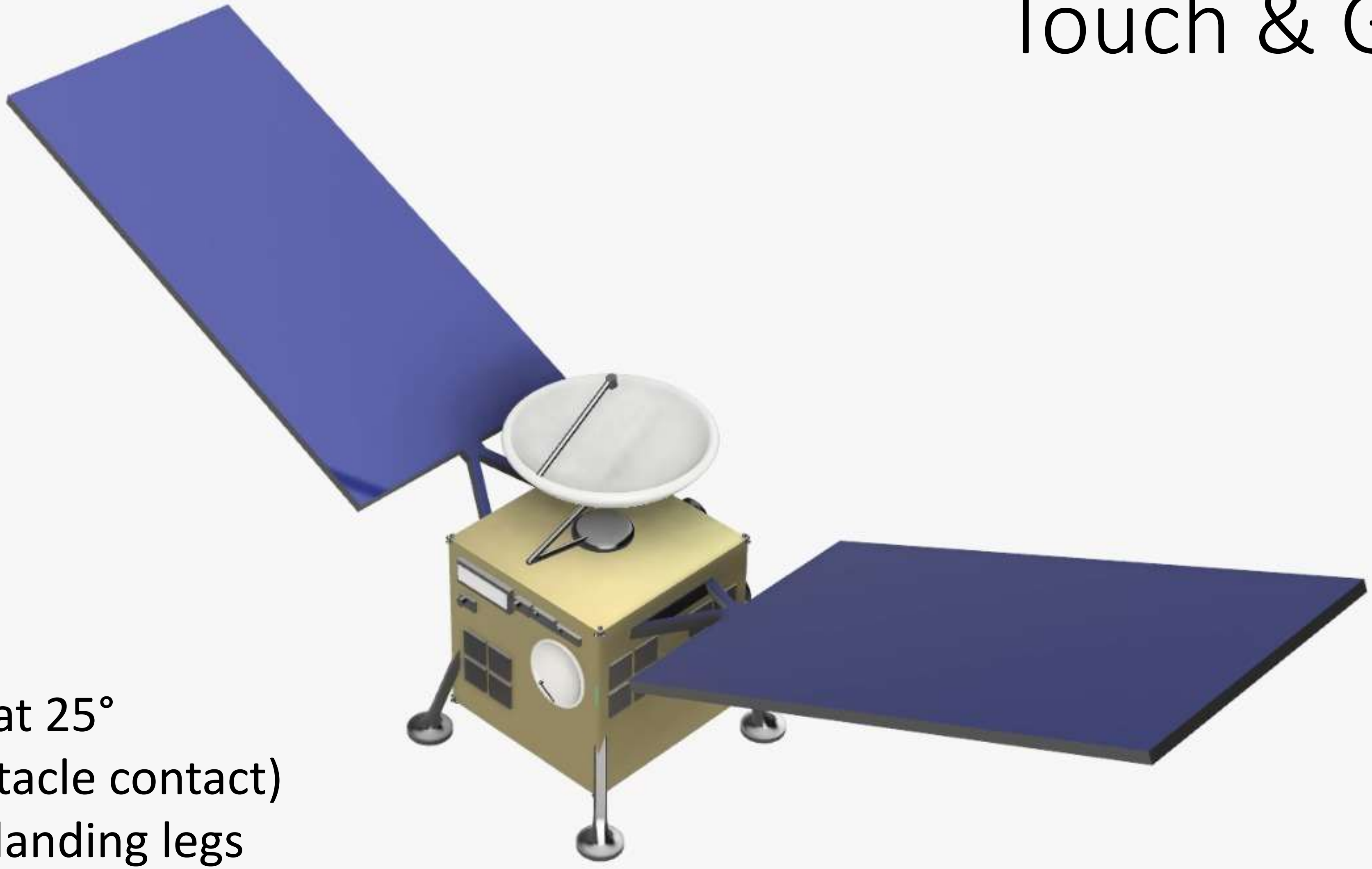
- Total launch mass: 1984 kg
- Payload mass: 93 kg
- Sampling: Touch & Go
- 3-axis stabilized
- Telemetry: X/Ka
- Propulsion: Ion thrusters
- Power: Solar electric


HGA
Radar
Communication
MGA
TIR
Spectrometer
Camera
System
Radiator


HGA
Solar panels
Ion thrusters

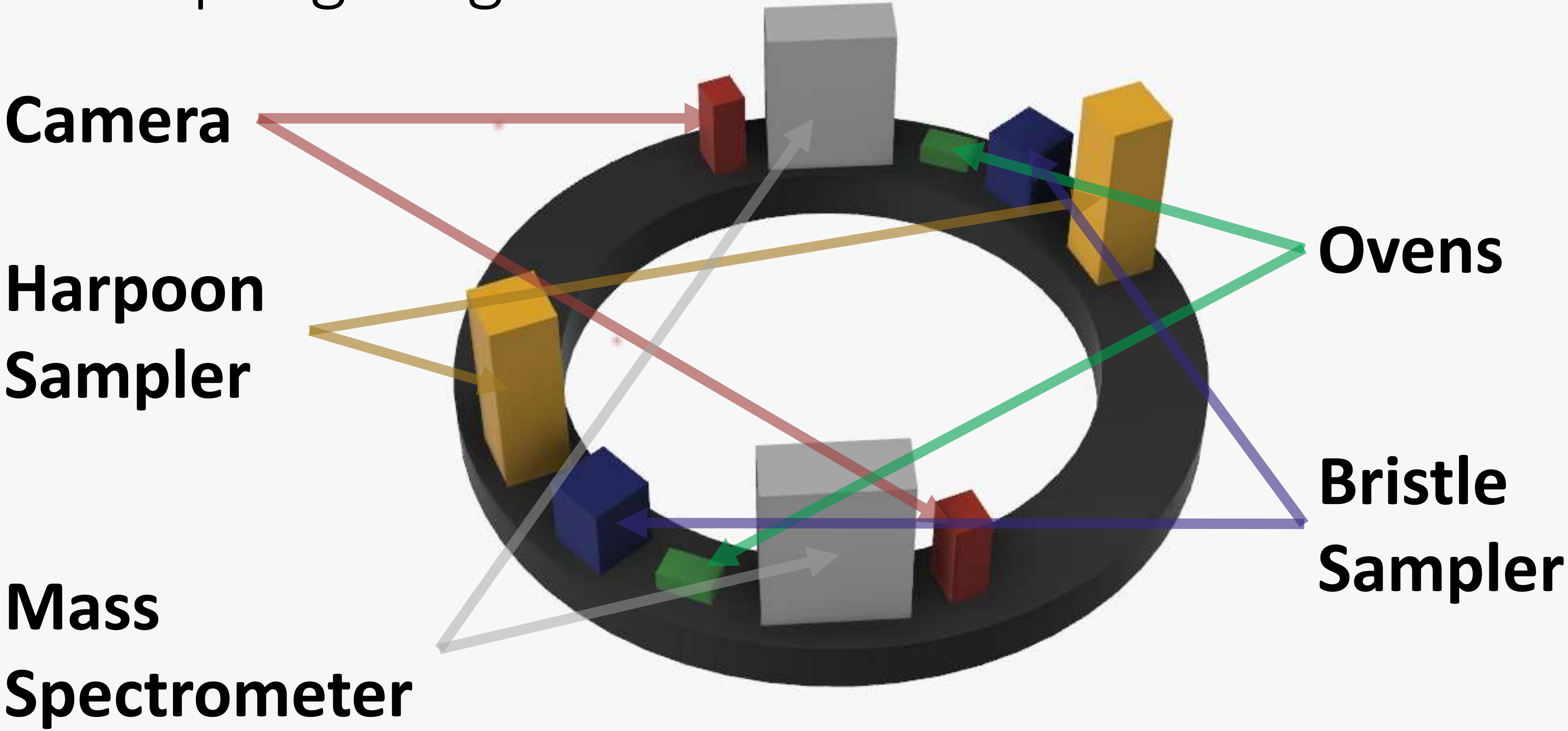

Camera
System
Sampler
Sampler

Touch & Go

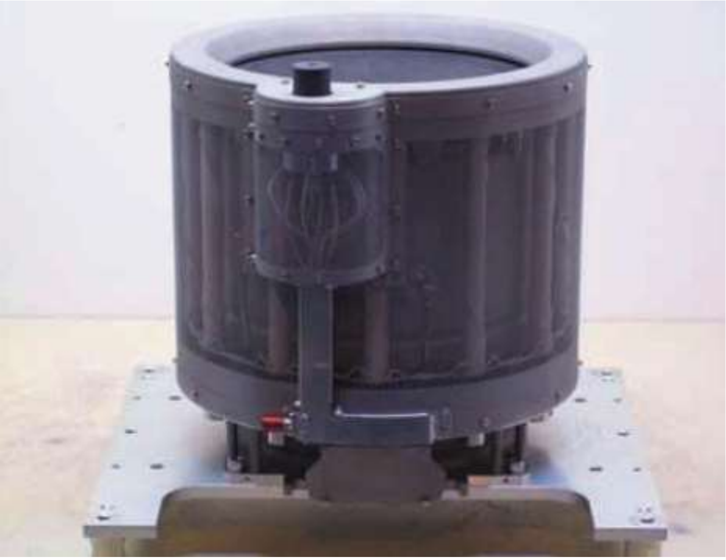


- Solar panels at 25°
  (to avoid obstacle contact)
- 4 body fixed landing legs
- Passive damping
- Anti momentum spikes

Sampling Ring



Propulsion



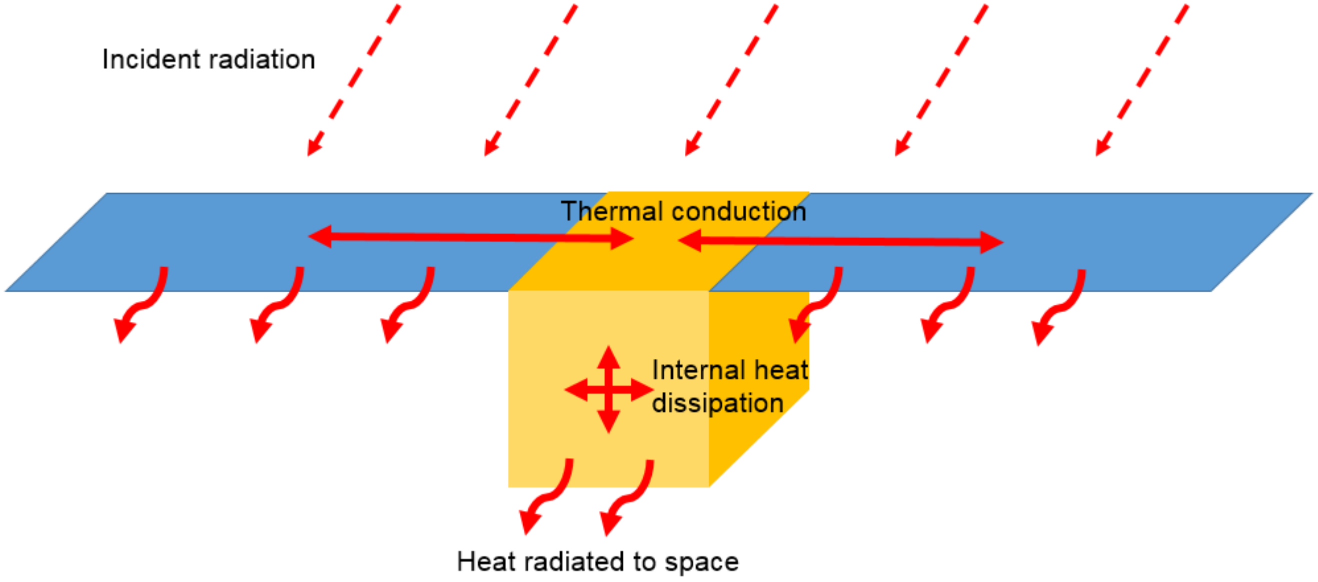
- Improved T6 engines (QinetiQ, UK)
- 4 engines
  (2 active, 2 for redundancy)
- TRL 8
- Heritage: BepiColombo

T6 Engine	Force (N)	Isp (s)	Power (kW)	Diameter (cm)	Width (cm)	System of 4 thrusters (kg)
State of Art	0.145	4.285	4.628	22.000	15.000	130.000
Assumed	0.200	4.000	4.000	22.000	15.000	130.000

Thermal System

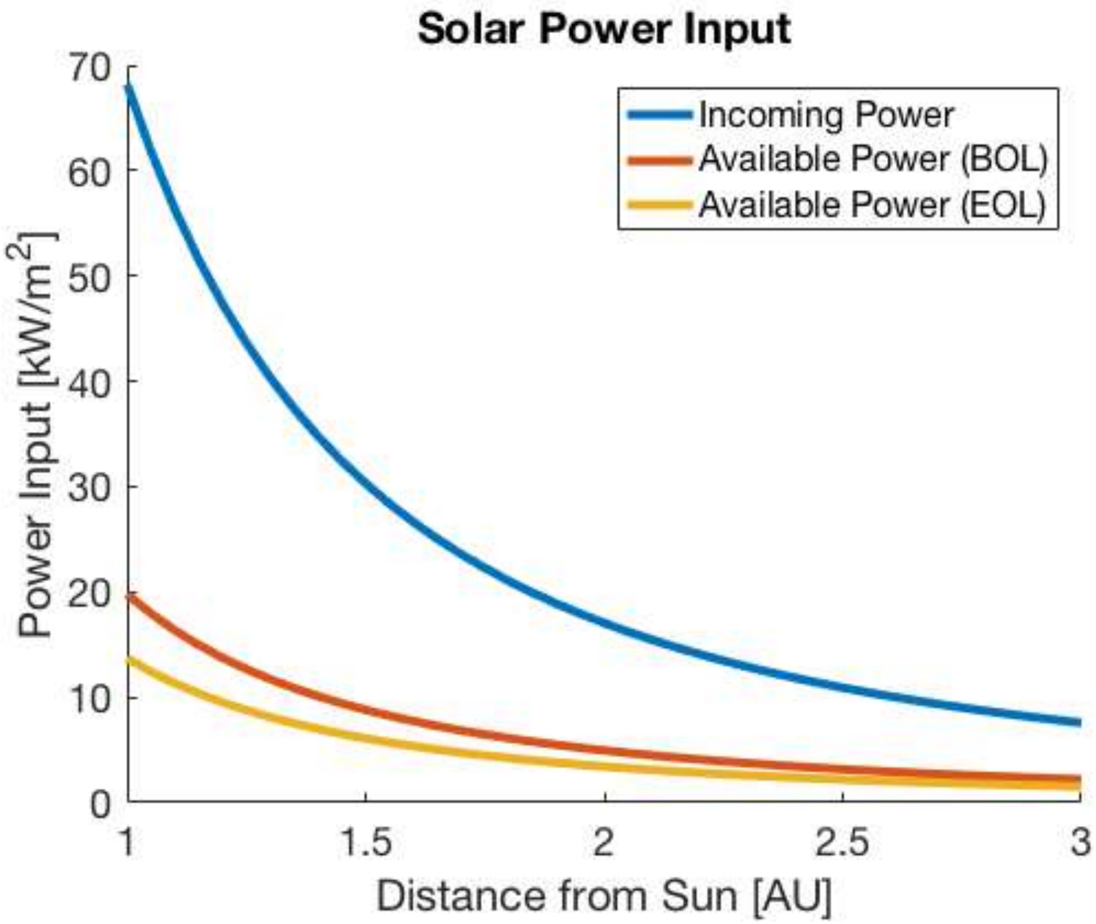
Mission Phase	Distance from the Sun [AU]	Internal Power dissipation [W]	Spacecraft Temperature [K]
Cruise	1 AU	2190	302
Cruise	3 AU	2190	272
Global Mapping	1.2 AU	638	314
Local Mapping	1.2 AU	639	313
Descent and Sampling	1.2 AU	581	312

- Two-node thermal model
- Main body covered in MLI
- 3.5 m^2 Radiator
- Louvres adjusting exposed radiator area
- 290 W Heater



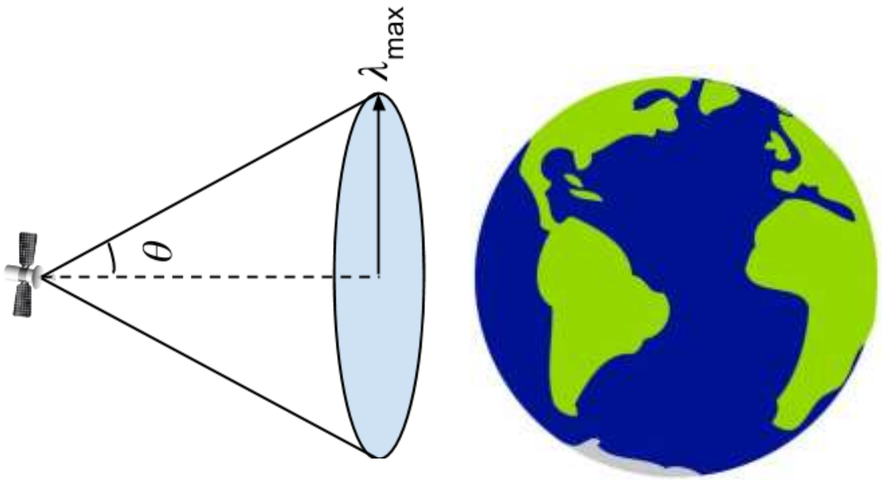
Power Subsystem

- Power requirement at launch: **9 kW**
- SA area (incl. 20% margin, 33% efficiency, 88% I_d degradation): **25 m^2**
- Available power at target (incl. 4 yrs of degradation): **0.9 kW**
- Battery capacity: **1.1 kWh**



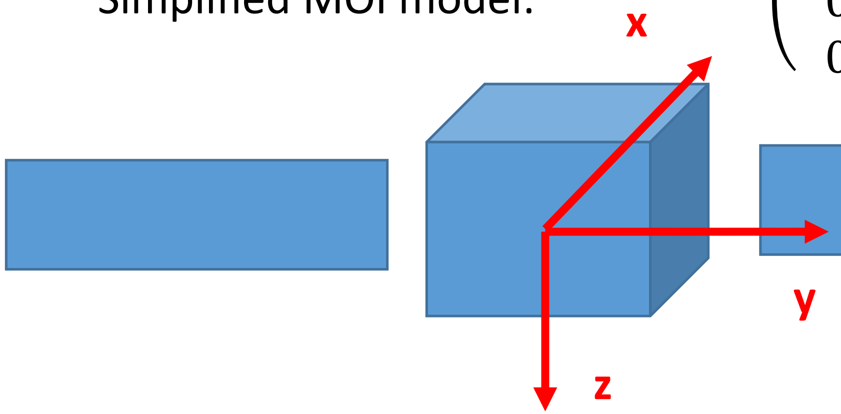
AOCS/GNC

Requirements	Value	Derived from
Pointing	**700 arcsec**	Communication: HGA FOV of 0.39 deg
	20000 arcsec	Global mapping: 5 km away from asteroid
Knowledge	**70 arcsec**	At least 10 % of pointing requirement
Disturbance (worst case)	$\approx \mathbf{0.1mNm}$	Solar radiation pressure ($c_{cog} - c_{com} = 0.3$ m) Gravity gradient (from MOI model)
Relative Navigation	**-**	Autonomy required due to communication delay



Simplified MOI model:

$$\begin{pmatrix} 600 & 0 & 0 \\ 0 & 225 & 0 \\ 0 & 0 & 600 \end{pmatrix} \mathrm{kgm}^2$$



AOCS/GNC

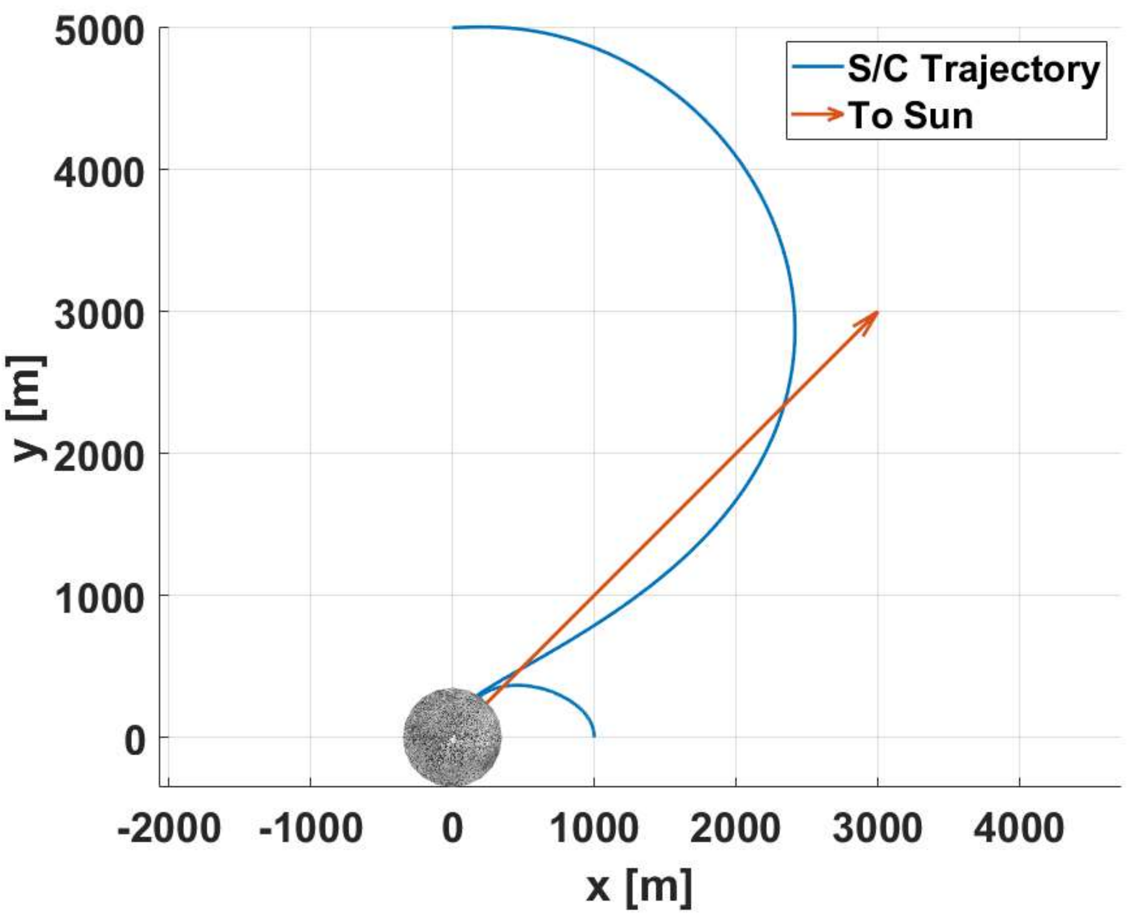
- Hardware

Sensor	Company	Performance	TRL
2x Star Tracker	Jenoptronik	4.5 arcsec (xy-plane) 36 arcsec (z-axis)	9
1x Gyro	Jenoptronik	ARW: 0.01 deg/sqrt(hr)	9
1x Laser Range Finder	Jenoptronik	Range: 1 km Accuracy: 0.5 m	9

Actuator	Company	Performance	TRL
4x Reaction wheels	Rockwell Collins	Angular Momentum: 12 Nms Torque: 75 mNm	9
2x8 Hydrazine Thrusters	ArianeGroups	20 N Isp = 230 s	9

Based on requirements

AOCS/GNC – Touch & Go manoeuvre



Phase	Duration [min]	DeltaV [m/s]	Propellant with 20% margin [kg]	Max Force [N]
Descend	20	1.4	0.91	4
Ascend	30	9.1	8.4	23

- LIDAR:
  - Allows precise relative navigation
- Thrusters:
  - 8x2: 20N hyrdazine thrusters
  - Isp = 230s
  - Thrust range: 7.9-24.6N

Data Handling

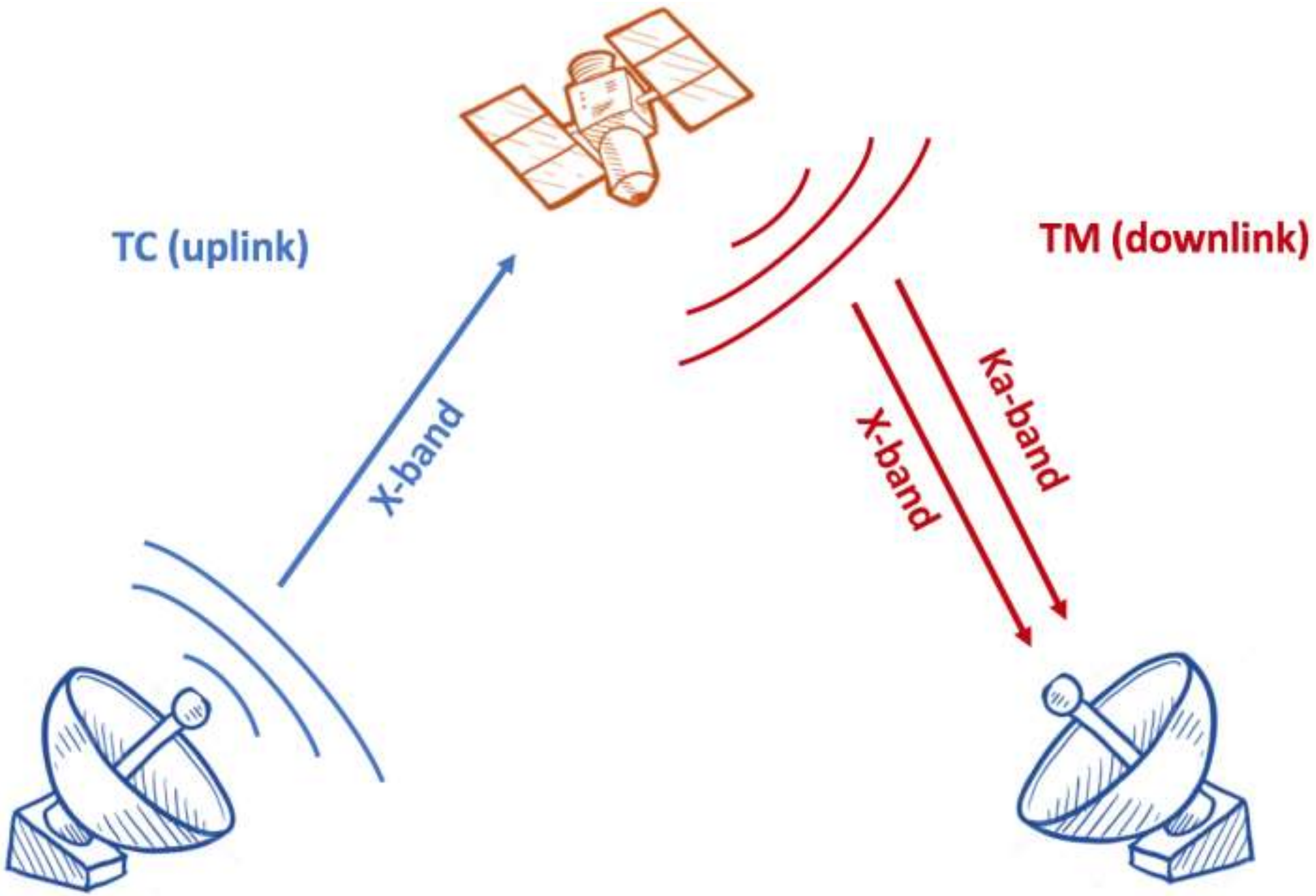
- Next Generation On Board Unit (RUAG)
- Processing, TC, TM, Time Handling, Data Storage on board
- 6.5 kg
- < 23 W
- 40 GB on board memory
- Up to 20 years of flight time

Heritage:

- > 2900 fail free years in orbit
- > 120 Satellite Data Handling Systems

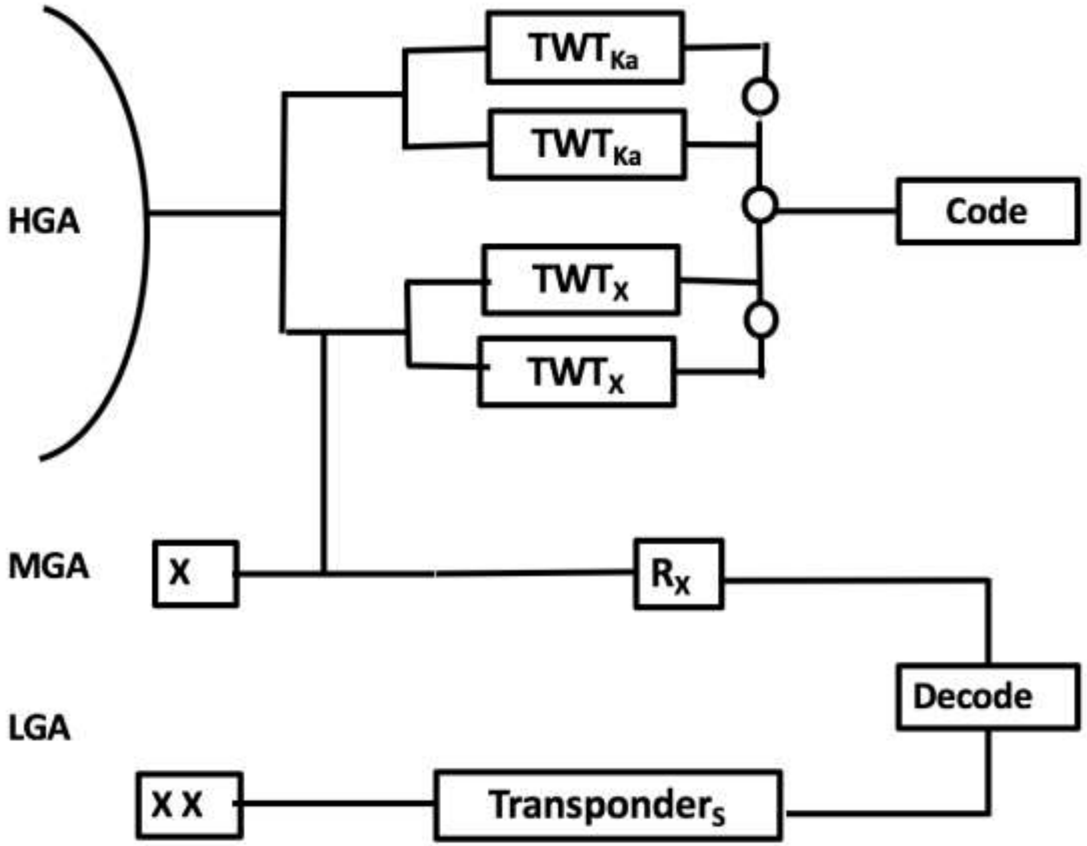
TTC/SS Drivers

Key Drivers	
Distance	3 AU (Longest distance)
Frequency	X (TC+TM) / Ka band(TM)
Data rate	60 - 300 kbps
Stations	ESA Track



TTC/SS Components

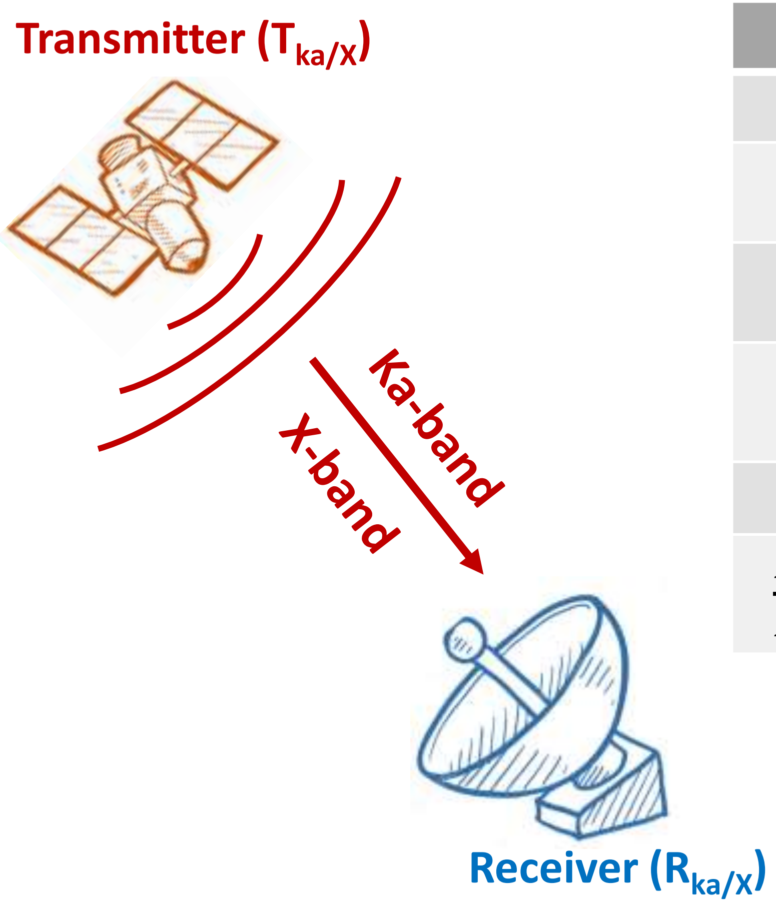
Component	Purpose
1x HGA (X/Ka)	For science data, telemetry, housekeeping
1x MGA (X)	For telemetry and housekeeping
2x LGA (S)	For emergency case and redundancy
2x Transponder	For S-band
4x TWTA (2 for redundancy)	2x for X-band 2x for Ka-band



Downlink Budget

Parameter	Unit	Value (Ka/X)
f	GHz	18/8.2
D_t	m	1.7
P_t	W	170 / 125
θ_t	deg	0.69/1.51
G_t	dB	48.2/41.4

Parameter	Unit	Value
D_R	m	35
η	-	0.90
θ_R	deg	0.03/0.07
G_R	dB	75.9/69.1
T_s	K	80



Link Budget		
Parameter	Unit	Value (Ka/X)
DR (req)	kbps	300/60
BER	bps	10^{-5}
$\frac{E_B}{N_0}$ (req)	dB	4.5
DR (Max achievable)	kbps	822/151
$\frac{E_B}{N_0}$ (Max achievable)	dB	7.4/7.0

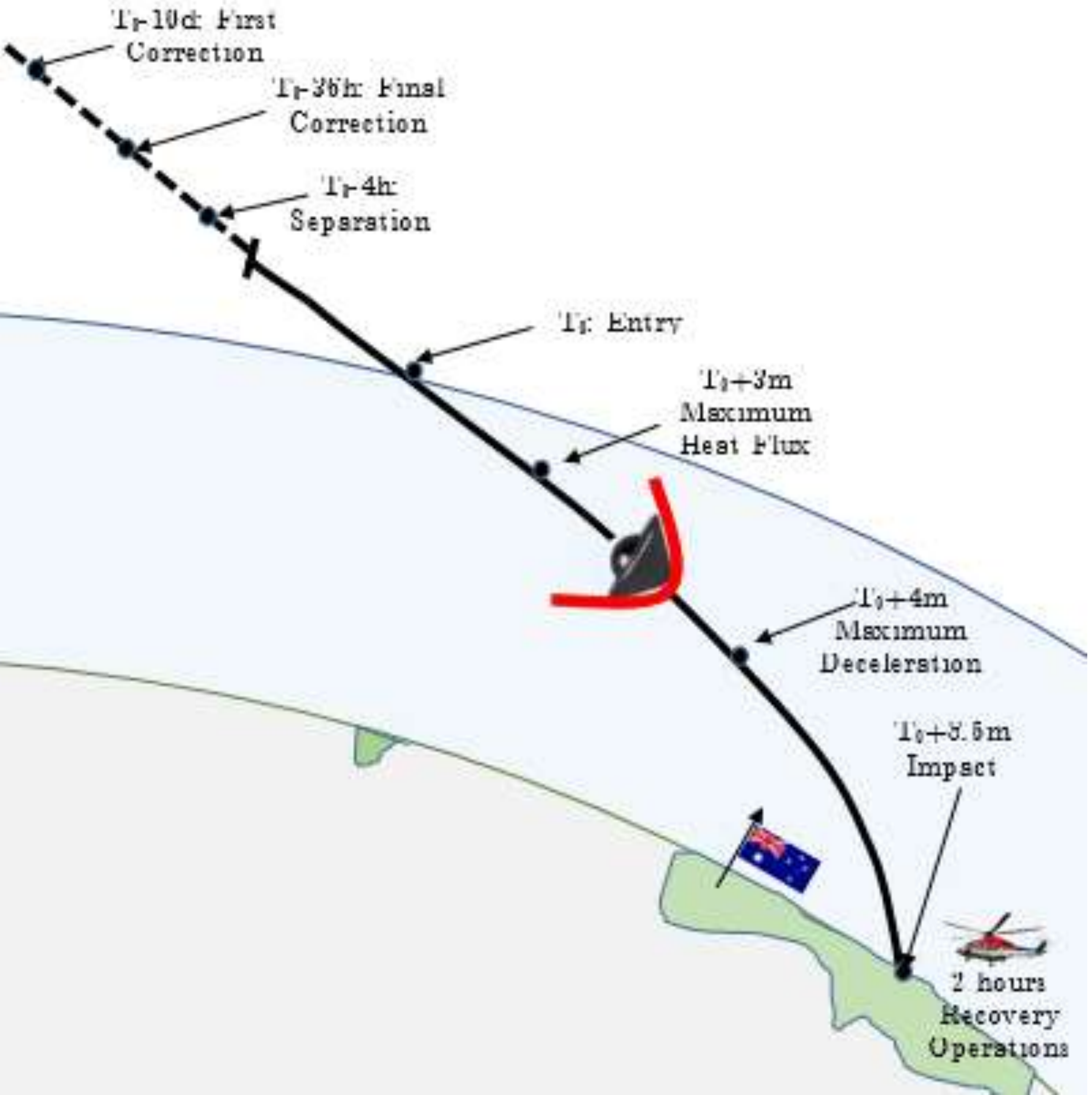
Operations & Ground Segment

Cebreros-1 (CEB1)
TX: X
RX: X/Ka
35 m diameter

New Norcia-1 (NNO1)
TX: X/S
RX: X/S
35 m Diameter

Malargue-1 (MLG1)
TX: X
RX: X/Ka
35 m diameter

Earth re-entry sequence



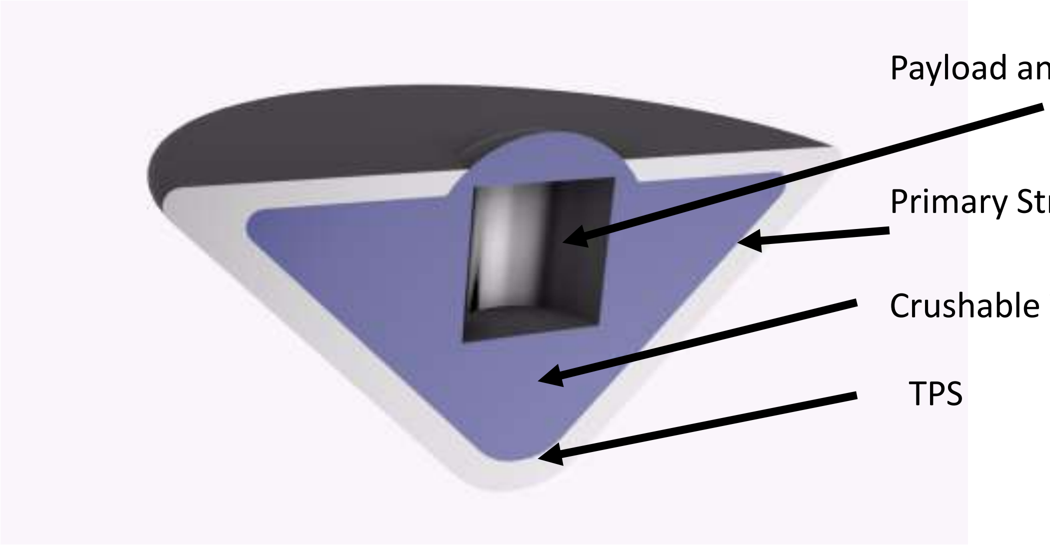
- Entry Velocity V_{entry} = 12 km/s
- Entry Flight Path Ange γ= -15^{o}

- Safe recovery and fast recovery of sampled.
- A small radio beacon as a backup to visual and radar tracking of the ERC to determine its location at landing.
- Night Entry
- Landing on Australia

Earth Re-entry Capsule

High reliability: the elimination of all active systems, a well-understood aerodynamic shape/ dynamic stability , flight heritage thermal protection system (TPS)

Mass= 36 kg, Diameter = 1m, Ballistic Coefficient =44 kg/m^2



Components	Mass [kg]
TPS (Pica)	13.4
Crushable TPS (PMI)	7.8
Max Payload Sample	2.64
Total	**35.6**

- Spin Stabilized
- Max heat flux < 11 MW/m2
- Max aerodynamic d loads ~ 80 g
- Crushable structure to ensure payload safety for ~500 g impact load.

Critical Technologies & Options :

- Crushable TPS
- Dynamic stability
- European TPS (ASTERM or ATLAS)
- Option ERC with Parachute

Components	Mass [kg]
TPS (Pica)	11.188
Parachute System + Stabilizer	2.5
Max Payload Sample	2.64
Total	**35.7**

Curation process

- After sample capsule returns:
  - Verification of containment integrity
  - Testing for Planetary Protection
  - Mapping, selection of preserved samples, LD/BH analysis, sterilization

Hayabusa return capsule

- Curation Facilities (Oxford, Nancy, Pisa):
  - Proximity to science centres

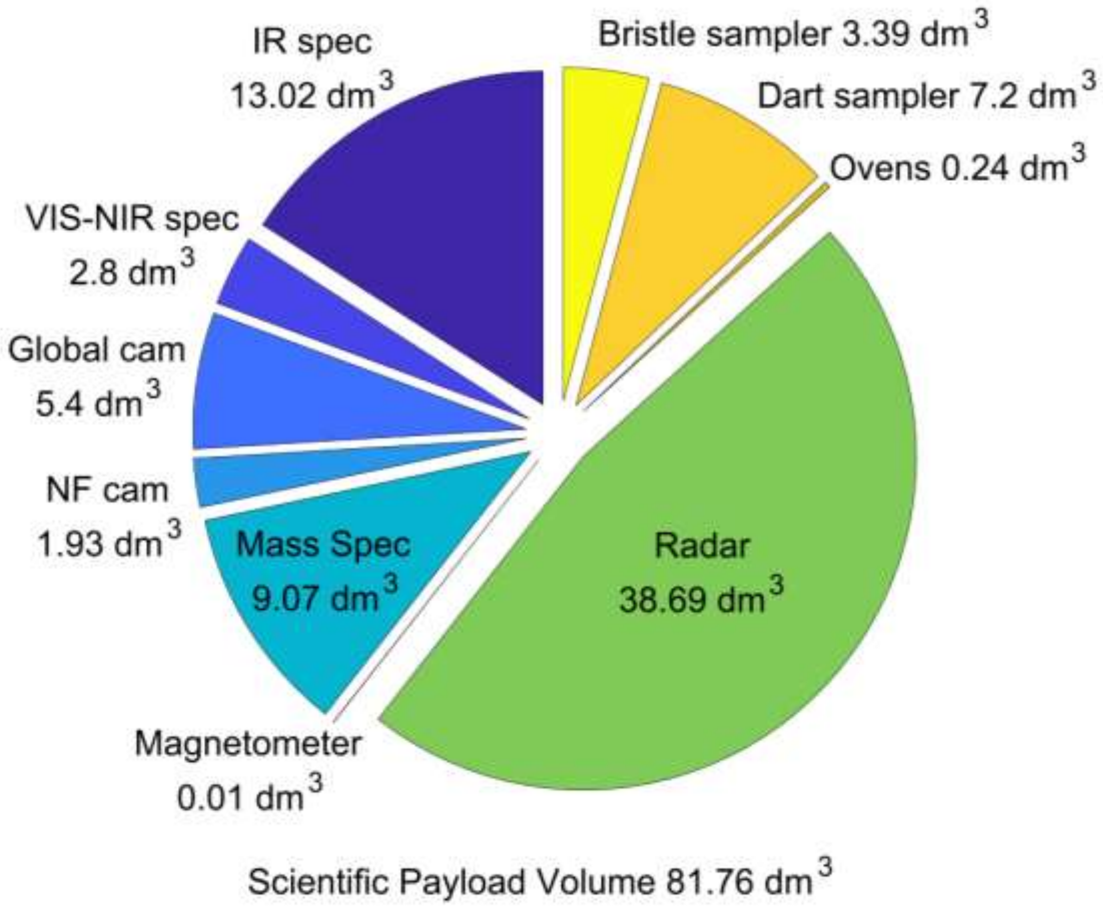
Mass Budget

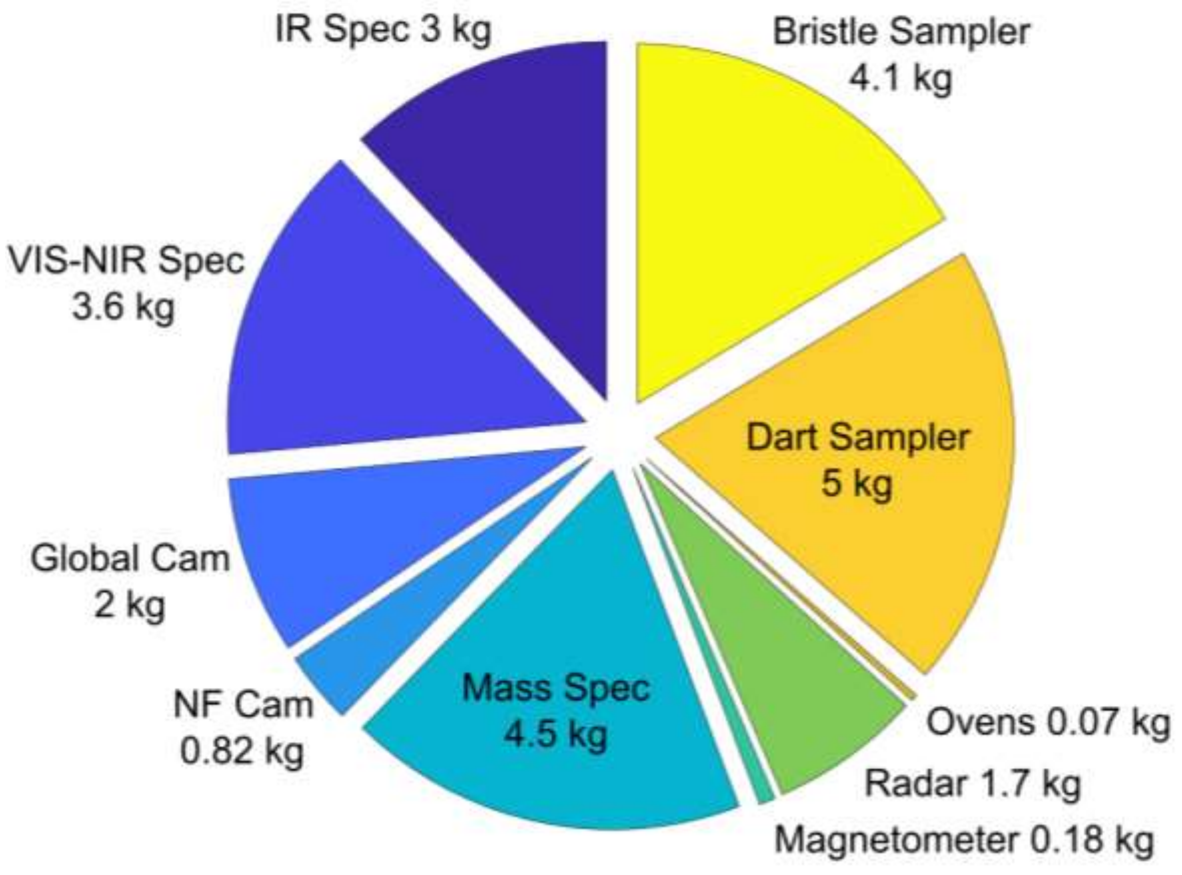
Subsystem	Without margin	Margin	With margin	% of total mass
Data handling	64.34 kg	5%	67.55 kg	9.62%
Communication	77.20 kg	5%	81.06 kg	11.54%
Thermal	57.26 kg	10%	62.99 kg	8.56%
AOCS/GNC	27.80 kg	5%	29.19 kg	4.16%
Power	130.00 kg	5%	136.50 kg	19.43%
Propulsion	138.80 kg	5%	145.74 kg	20.75%
Structure	99.08 kg	20%	118.89 kg	14.81%
Harness	49.54 kg	5%	52.02 kg	7.41%
Payload (incl. ERC)	77.32 kg	20%	92.78 kg	3.73%
Total dry mass with 20% margin			**1114 kg**	
Propellant			**870 kg**	
Total wet mass			**1984 kg**	

Power Budget

Subsystem	Without Margin	Margin	With margin	% of total power
Data handling	25.00 W	5%	26.25 W	0.29%
Communication	156.00 W	5%	163.80 W	1.81%
Thermal (via Data handling)	0.00 W	5%	0.00 W	0.00%
AOCS/GNC	67.00 W	5%	70.35 W	0.78%
Power	200.00 W	5%	210.00 W	2.32%
Ion Propulsion	8000.00 W	5%	8400.00 W	92.64%
Payload	188.00 W	20%	225.60 W	2.18%
Total power with 20% margin			**10915.20 W**	

Payload Volume and Mass



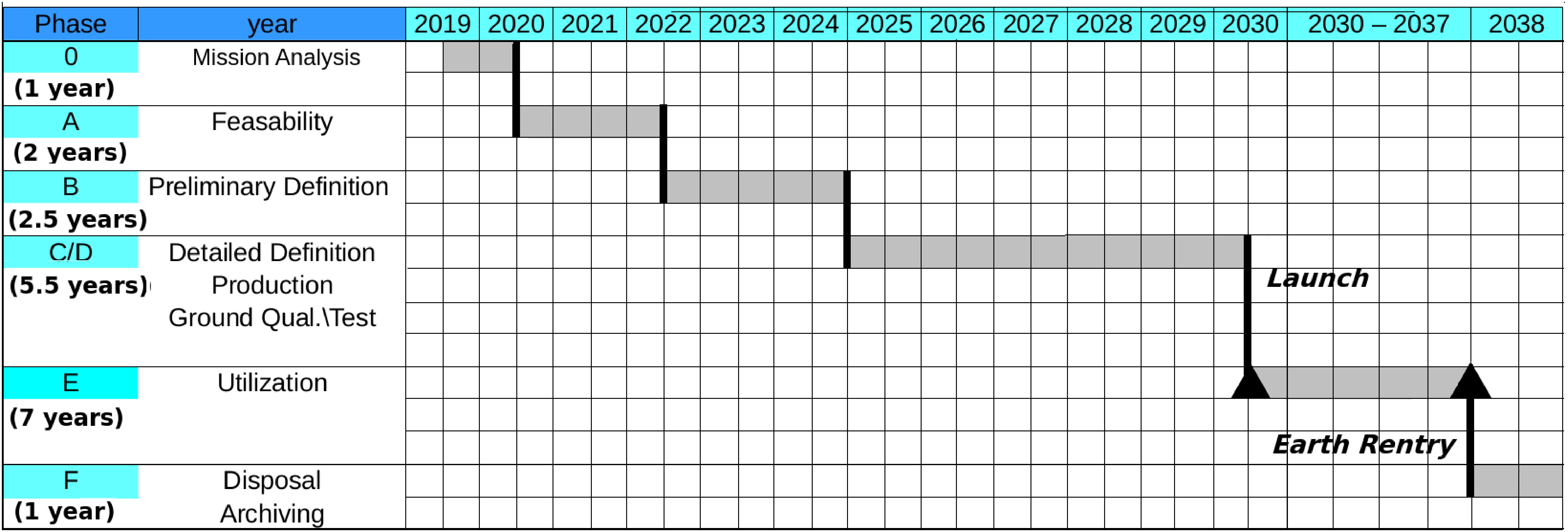


Critical Technologies

Component	TRL	Source	Heritage
Bristle sampler	3 - 4	CDF Study Report Phobos Sample Return (2014)	MarcoPolo R, Phobos Sample Return
Harpoon sampler	4	(RASARS) **RA**pid **SA**mple **R**etrieval **S**ystem for Comet Nucleus Sample Return (2012)	NASA Study
Re-entry capsule	5	Conceptual Design of a crushable thermal protection system for the ERC (2016), Dynamic stability	MarcoPolo R, Mars Sample Return Orbiter, Phootprint

Development schedule

Development schedule



Risk assessment

Risk assessment

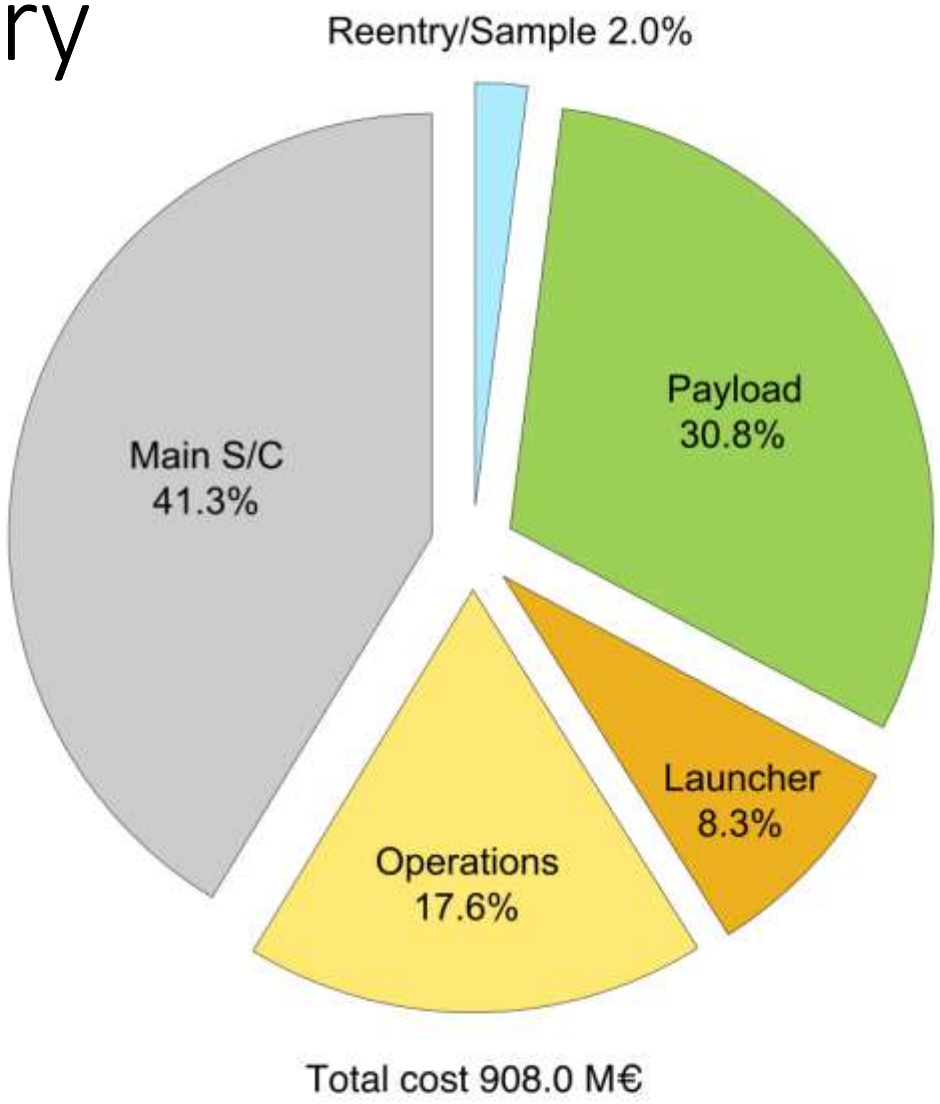
S: schedule, C: cost, M: mission, P: performance

Risk	Impact	Severity	Likelihood	Mitigation
Launcher 62 not available	S/C	6	E	Unavoidable risk
Bristle sampler mechanism not available	S	6	D	Unavoidable risk
Harpoon sampler mechanism not available	S	6	C	Unavoidable risk
Re-entry capsule not available	S/M/P	2	D	Other options (parachute)
Solar panel clearance (during Touch & Go)	S/M/P	5	D	Adjust sampling site, panels dimensioned to allow solar access at 25^{o}
Sampling mechanism failure	M	6	C	Redundancy
Re-entry capsule failure	M	6	D	Unavoidable risk
HGA failure	M	6	E	1 x MGA, 2 x LGA
Sampling ring failure	M	2	D	Unavoidable risk
Sample recovery issues	M	6	E	Multiple potential landing sites

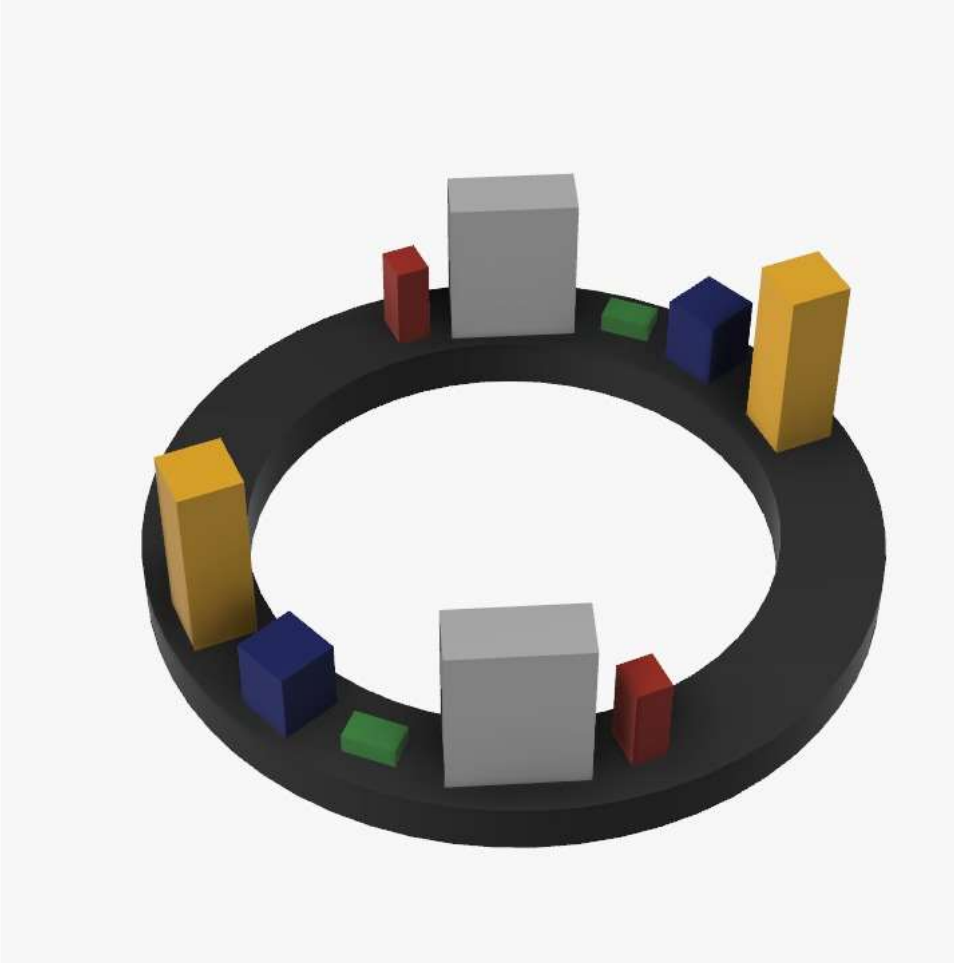
Cost Strategy / Descoping

Cost Assessment & Category

Object	Cost [M€]
Main S/C	375
Reentry / Sample Canister Module	18
Operations	160
Payload	280
Launcher	75
	908



Descoping Options

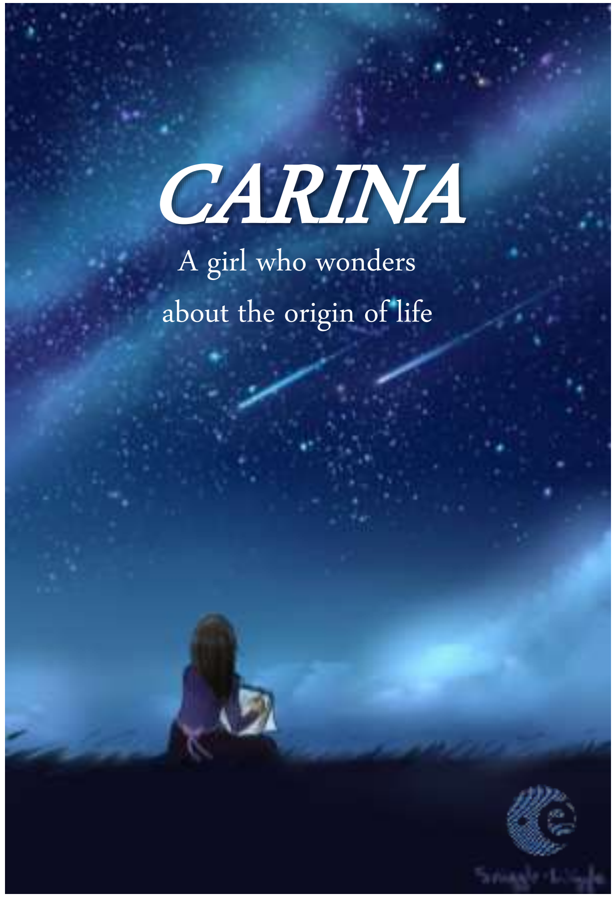


In Situ Measurements: Mass Spectrometer (GC/MS)
+ Mission goals intact
+ Reduced cost
+ Reduced complexity
- Unbound water identification impossible
- No initial characterization of sample
- Interaction with/contamination from sample container
- Effects of return trip and re-entry (vibrations, g-forces, temperature variations) on sample unknown

Public Outreach

- Live streams and mission progress updates on social media platforms

- Naming competition for asteroid
- Workshops for school teachers on small solar system bodies
- Spacecraft models for students
- «How to make an asteroid at home»
- Cartoons of Paxi travellig to 2002 AT4

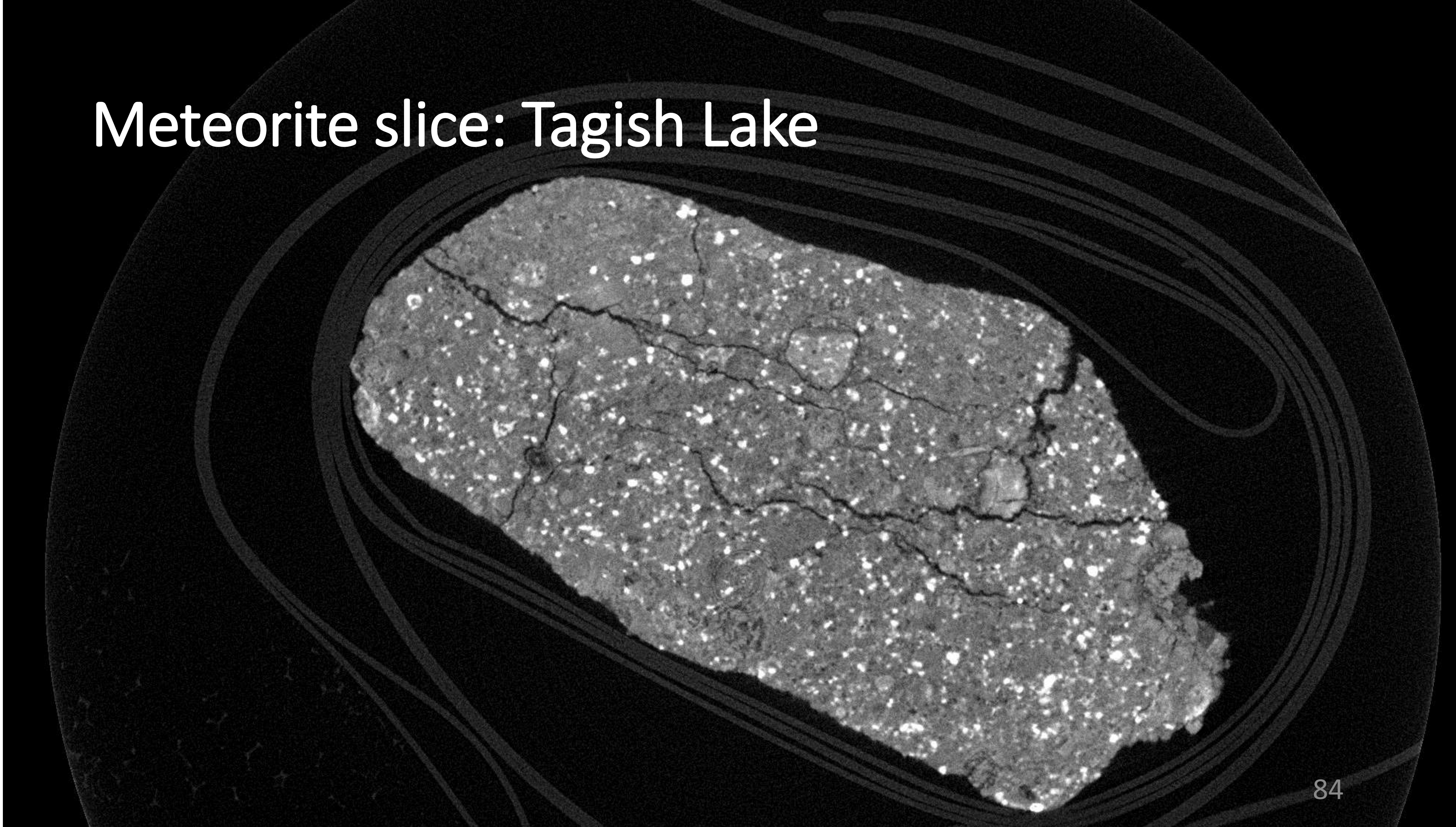


Comic Book of «Carina»

Summary

Appendix

Meteorite slice: Tagish Lake



Instrument	Heritage	Mass in g	Volume (mm)	Datarate in Mbits/s	Working Temperature (in obs °C)	Power (W) avergae
Global Camera	MarcoPolo-R	2000	273x172x115	1,69	[0,27]	11.5
Near-Field Camera	MarcoPolo-R	820	364x78x68	1,69	[0,27]	13.5
Visible/NIR Spectrometer	MarcoPolo-R	3600	260x128x84	0,1	-123	18
Mid-IR Spectrometer	MarcoPolo-R	3000	160x220x370	0,1	-10	2
Mass Spectrometer	Philae	4500	250x330x110	0,1	TBD	10
Magnetometer	Mascot	180	55 (d) x50	0,000101	[-80,80]	0.5W
HF Radar	AIM	1700	260x620x240	0,3	[-50,50]	16W
Radio Science Experiment	MarcoPolo-R	Contained in resources of radio system	Contained in resources of radio system	0,000101	[-20,60]	TBD

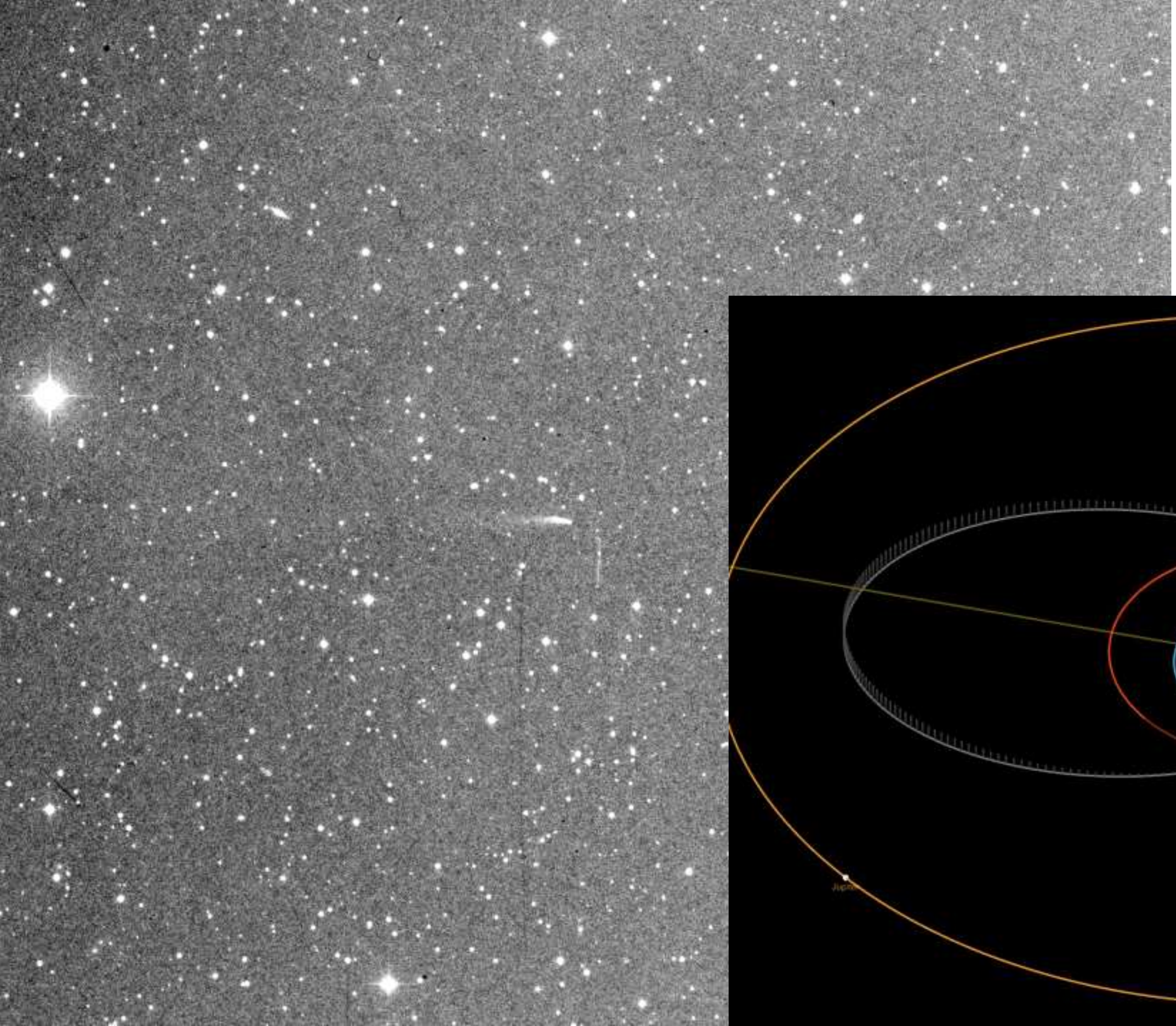
4015 Wilson-Harrington

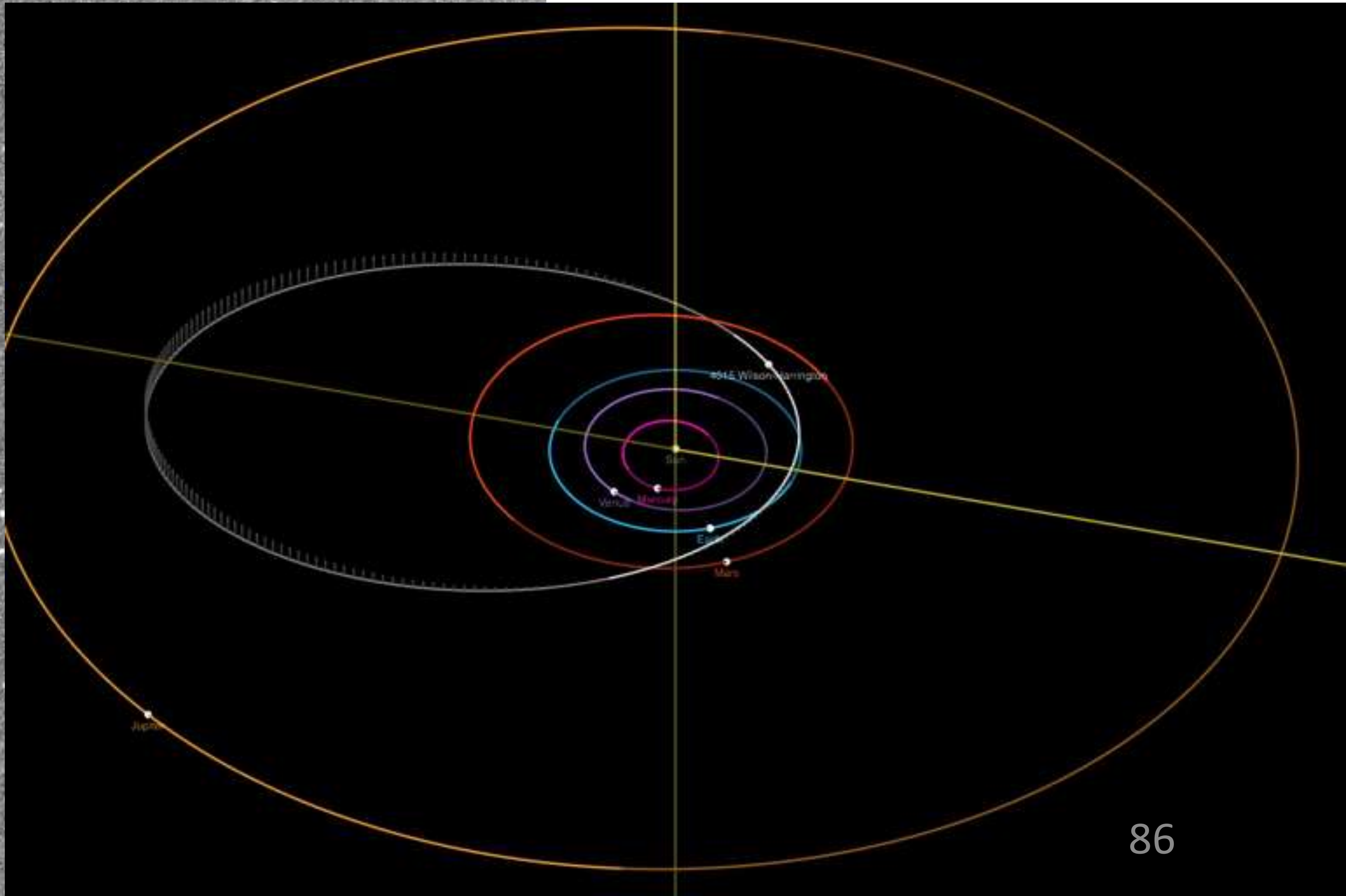
Apollo ***asteroid - like*** orbit

C-,P-,D-type classification

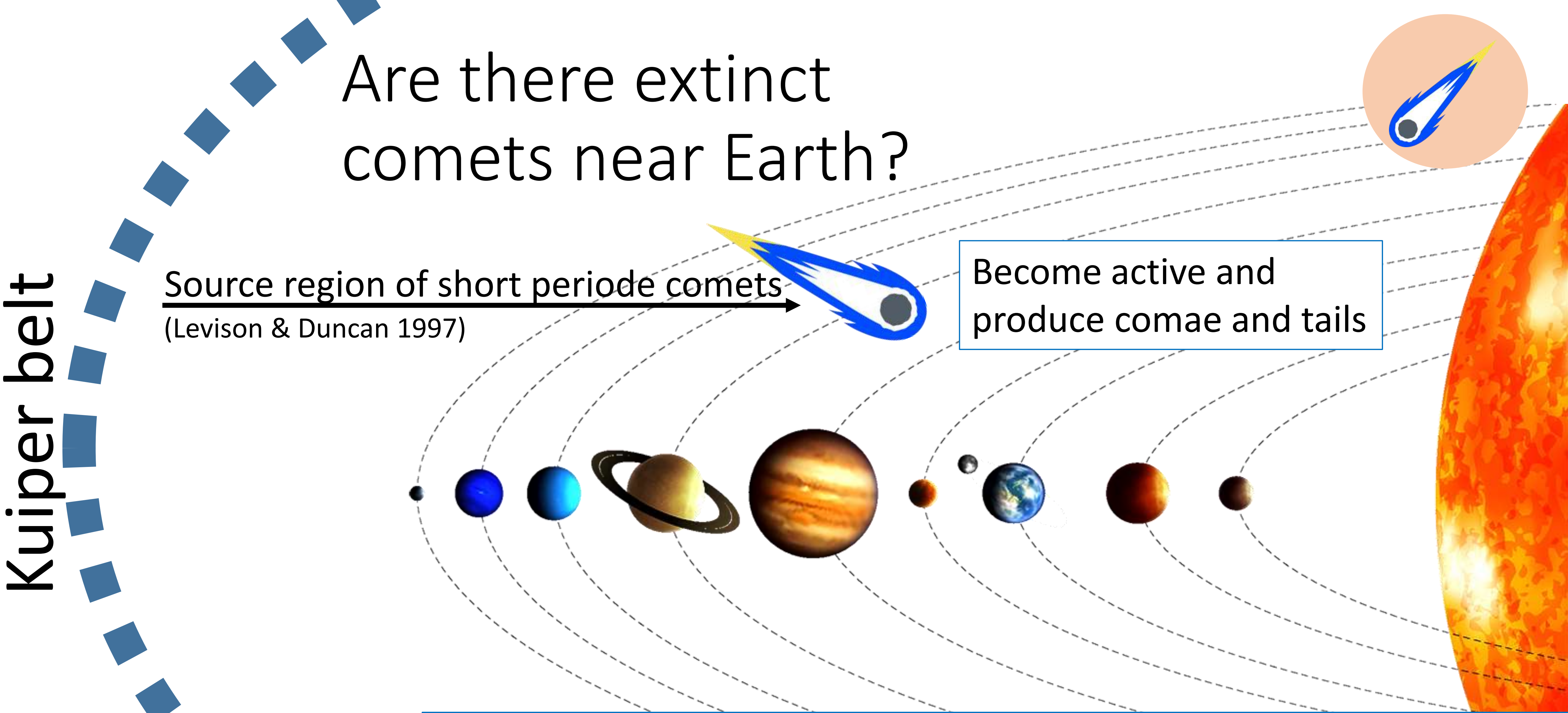
Low albedo

Shows cometary activity





Are there extinct comets near Earth?



Activity lifetime is shorter than the dynamical lifetime,
so NEO population likely includes some extinct or dormant comets !
(Levison & Duncan, 1997, Morbidelli & Gladman 1998, Weissman et al. 2002).

Measurement requirements

What measurement	What instrument	Instrument requirements	Environmental parameters
Global mapping	Global camera	Build global maps at a distance of 5 km with a resolution of 20 cm.	5km orbit above asteroid, months 1 – 5 of asteroid escort phase.
	VNIR spectrometer	Spectroscopic analysis over the wavelength ranges 0.3 - 4.3 µm at a precision of 10 cm-1. 20 m resolution.	
	TIR spectrometer	Spectroscopic analysis over the wavelength ranges 4 - 30 µm at a resolution of 10 cm-1. 20 m resolution	
	Radar	Build global map of the near sub surface using radar with a resolution of 1m at a depth of min 3-4 m	

Measurement requirements

What measurement	What instrument	Instrument requirements	Environmental parameters
Local mapping	Nearfield camera	Build localised maps of sampling site on descent with a resolution of maximum 1 mm.	1km orbit above asteroid, 6 – 8 months of asteroid escort phase.
	VNIR spectrometer	Spectroscopic analysis over the wavelength ranges 0.3 - 4.3 µm at a precision of 10 cm-1. 20 m resolution.	
	TIR spectrometer	Spectroscopic analysis over the wavelength ranges 4 - 30 µm at a resolution of 10 cm-1. 20 m resolution.	
	Radar	Build global map of the near sub surface using radar with a footprint of 1mx1m at a depth of 3-4 m	

Measurement requirements

What measurement	What instrument	Instrument requirements	Environmental parameters
Rehearsal descent			At month 8 of asteroid escort phase
Sampling	Bristle sampler		month 9 of asteroid escort phase
	Dart Sampler		
Post-sampling phase	Mass spectrometer	Mass spectrometer with a 10-200 m/z range, a detection limit of 5‰, and an accuracy ± 1‰	Month 10 of asteroid escort phase
	Nearfield camera (optional)		
	VNIR spectrometer (optional)		
	TIR spectrometer (optional)		

Calculation data Volume

- Camera : 200 images and 36 Mbits per image so 7.2 Gbits

- Spectrometers : 16 bits per value, 2466 values for one image, with a foot print of 20*20m to cover a whole 800m body (sphere) we need

:$2 * \frac{(\pi * 800)^2}{20*20} * 2466 * 16 = 396$ Mbits in total for one image of one body

40 Gbits for 100 images

- Radar : Body of 800m, PRF of 3.6 Hz, 2150 frequencies so one spectrum has $4.3 * 10^6$points, with 16 bits per point we have 69 Mbits per orbits $*$ 20 orbits if we want a tomography so 1,3 Gbits per tomography and with 10 tomography we have 13 Gbits

- Then we compute according to the time of the phase

Measurements on Earth

Technique	Potential Results
Scanning electron microscopy (SEM)	Mineralogy, composition <mm structures
Transmission electron microscopy (TEM)	Mineralogy, <µm structures, composition
Electron microprobe analysis (EMPA)	Elemental and chemical composition
Nano secondary ion mass spectroscopy (nanoSIMS)	Isotopic and elemental composition, dating
Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS)	Isotopic and trace elemental composition
Circular polarisation measurements	Chirality

Technique	Potential Results
Helium pycnometry	Porosity
Micro computed tomography (µ-CT)	Mineralogy
Gas chromatography mass spectroscopy (GC-MS)	Organics
Transmission infrared spectroscopy	Chemistry and mineralogy
X-ray fluorescence (XRF)	Elemental and chemical analysis
X-ray absorption (XAS) near edge structure (XANES)	Elemental analysis

COSPAR Planetary Protection Policy

Do we have a restricted Earth return?

1. Does the preponderance of scientific evidence indicate that there was never liquid water in or on the target body? YES
2. Does the preponderance of scientific evidence indicate that metabolically useful energy sources were never present? UNCERTAIN
3. Does the preponderance of scientific evidence indicate that there was never sufficient organic matter (or CO_2 or carbonates and an appropriate source of reducing equivalents) in or on the target body to support life? UNCERTAIN
4. Does the preponderance of scientific evidence indicate that subsequent to the disappearance of liquid water, the target body has been subjected to extreme temperatures (i.e., >160°C)? N/A
5. Does the preponderance of scientific evidence indicate that there is or was sufficient radiation for biological sterilization of terrestrial life forms? YES
6. Does the preponderance of scientific evidence indicate that there has been a natural influx to Earth, e.g., via meteorites, of material equivalent to a sample returned from the target body? YES

Need to answer no or uncertain to all 6 questions to qualify, so no we don't!

1 Investigate the Asteroid – Comet Relationship

Objective	Measurement	Phase
Evaluate whether D-types could represent extinct comet nuclei.	**Comparison** of **physical characteristics** and **compositional information** with **Rosetta** data, and a comparison of detailed **mineralogical, petrological and chemical data** to **Stardust** returned samples.	Orbital phase, ground based observations, sample return
Investigate activity quenching as an 'comet killer'.	**Characterisation** of a **regolith and sub-surface** sample from a D-type.	Sample return
Determine whether asteroids and other comets are related; are they separate bodies or do comets, D-type asteroids and C-type asteroids represent a continuum.	**Comparison** of **physical characteristics** and **compositional information** and a comparison of detailed **mineralogical, petrological and chemical data** with **OSIRIS-REx and Hayabusa2** data,	Orbital phase, ground based observations, sample return

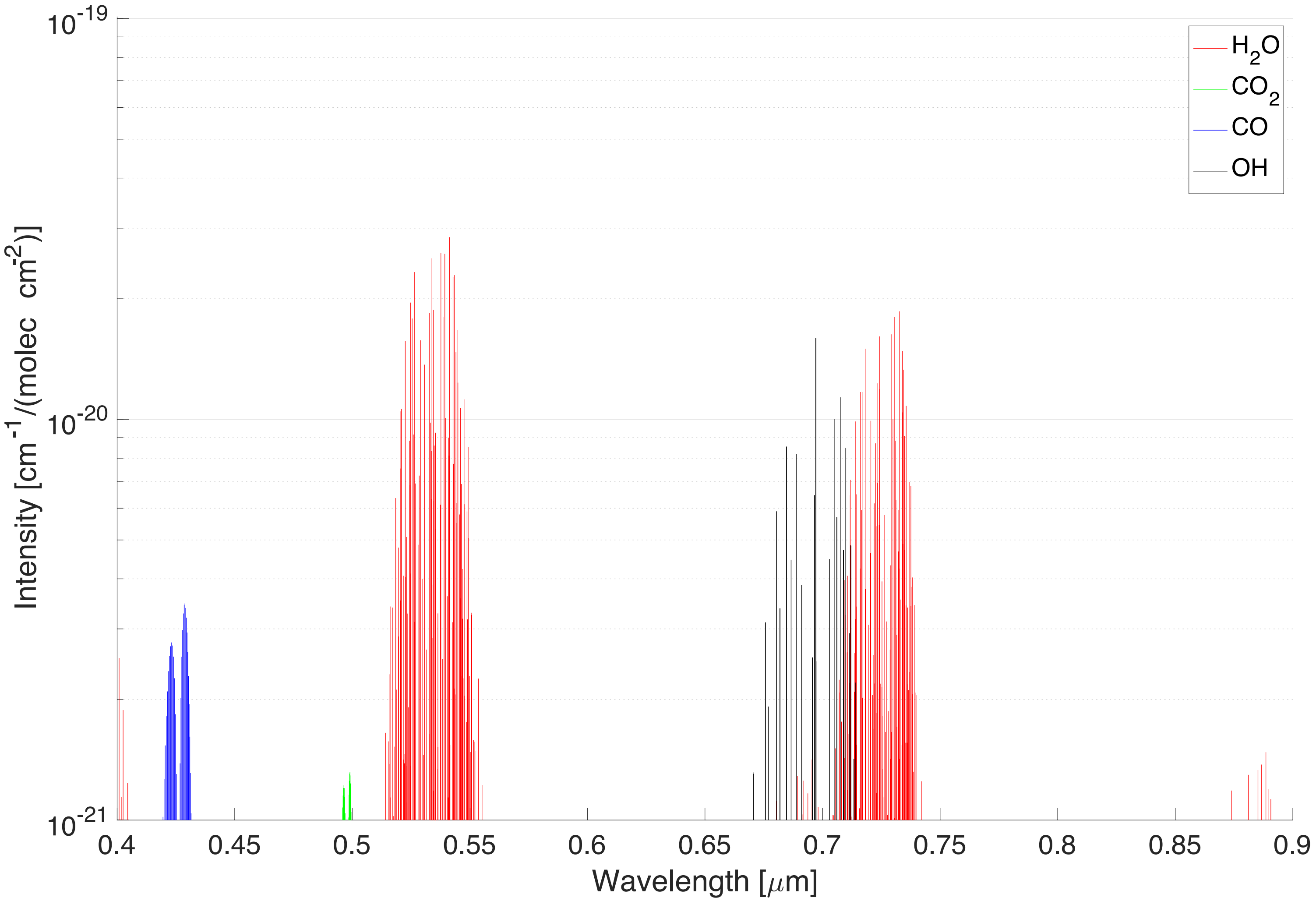
2 Investigate the Origin of Life

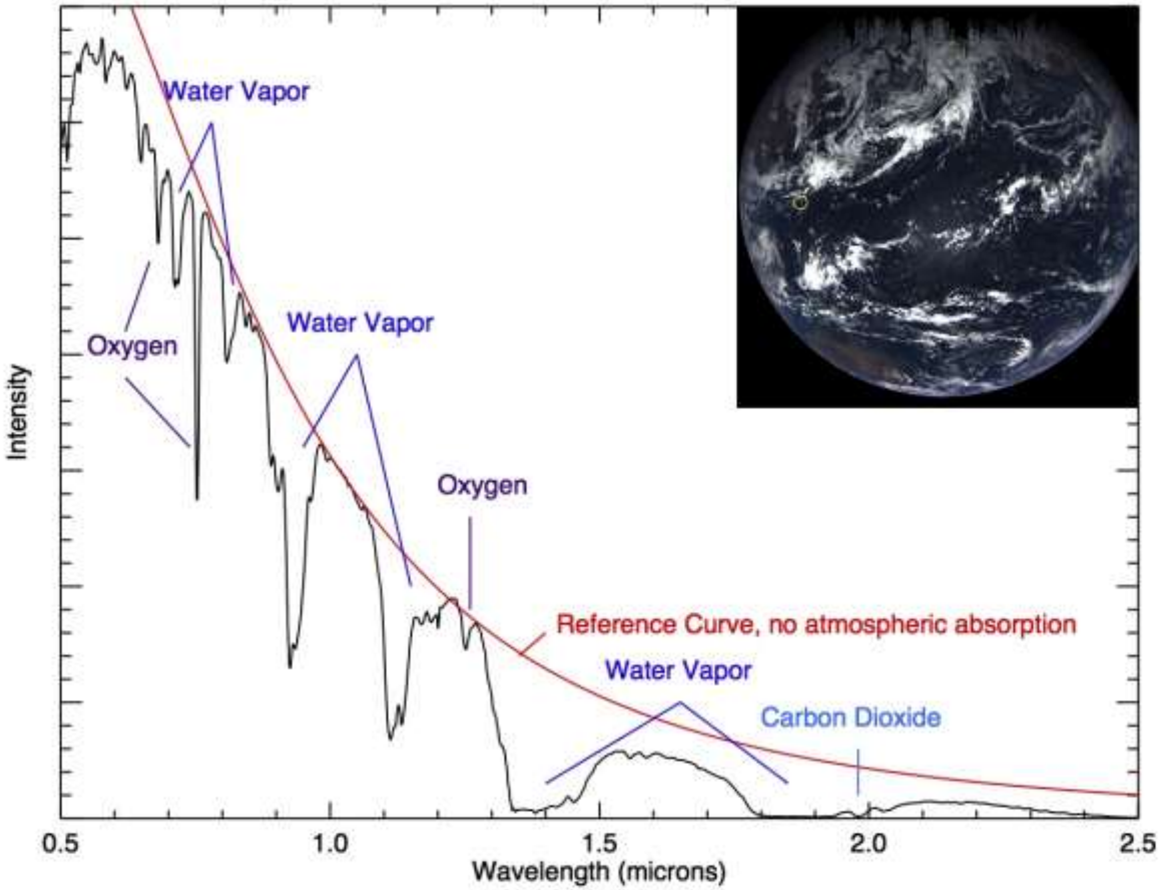
Objective	Measurement	Phase
Investigate the organic material (chirality)	The **content and composition of organic material**, including the **molecular asymmetry** (chirality)	Sample return
Investigate the volatile content (D/H ratios)	Establish the presence of **volatiles**, their **composition and abundance**, and **isotopic composition.**	Sample return, in-situ measurement

3 Determine Conditions in the Early Solar Nebula

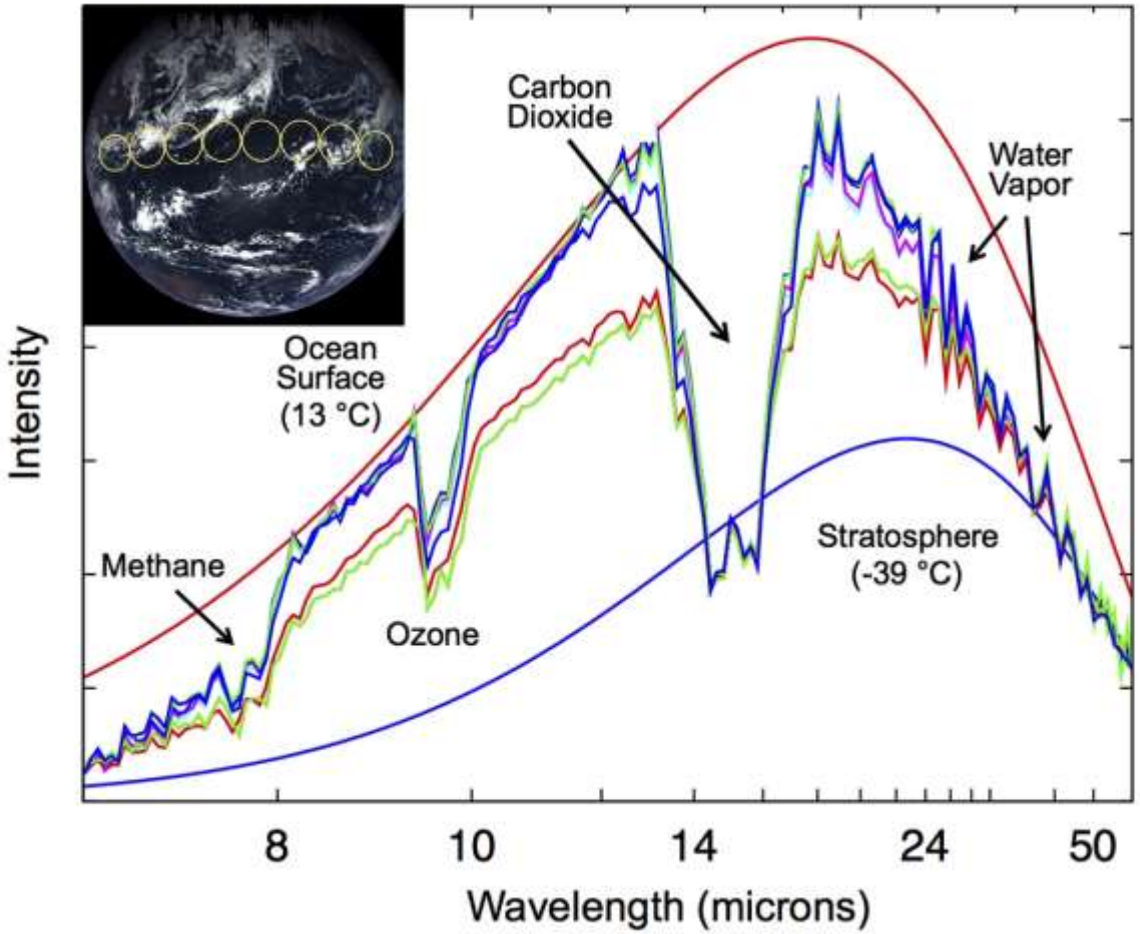
Objective	Scientific requirement	S
Characterise a near-Earth D-type asteroid.	**global surface compositional** **near sub-surface map** **volume, mass and density** **magnetic field measurement**	OS, GB, SR
Determine the timescales of accretion and planetesimal formation.	**Isotopic composition (dating)**	Sample return
Characterise the mixing of elements the protoplanetary disk.	**Comparison** of measurements to data from other objects hypothesised to form from other Solar Nebula reservoirs.	Sample return
Link characterisation to potential meteorite analogues.	**Comparison** of measurements to data from meteorites such as Tagish Lake and other carbonaceous chondrites	Sample return

Spectrum of possible volatiles



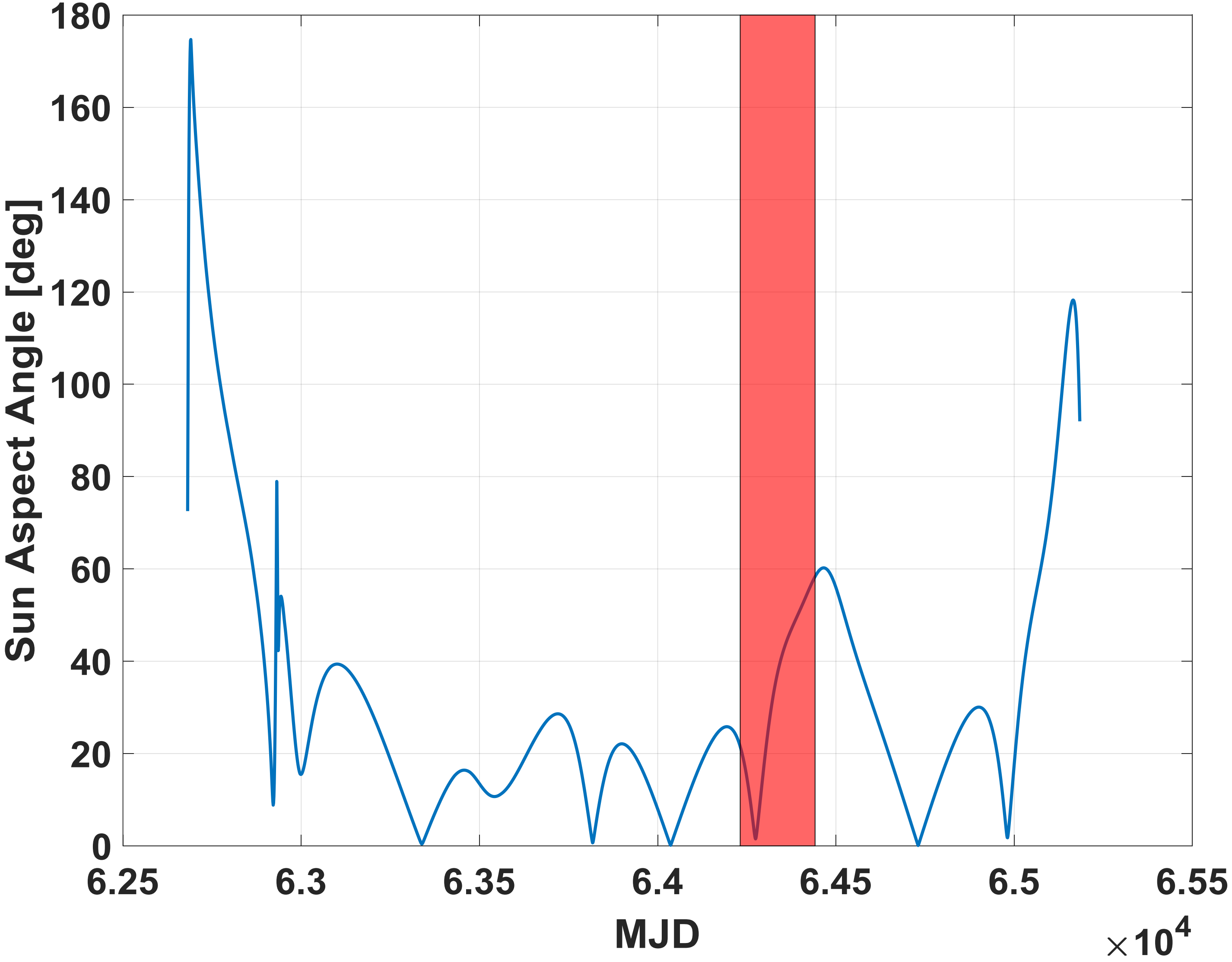

Water Vapor
Oxygen
Water Vapor
Oxygen
Reference Curve, no atmospheric absorption
Water Vapor
Carbon Dioxide
Intensity
0.5
1.0
1.5
2.0
2.5
Wavelength (microns)

NIR

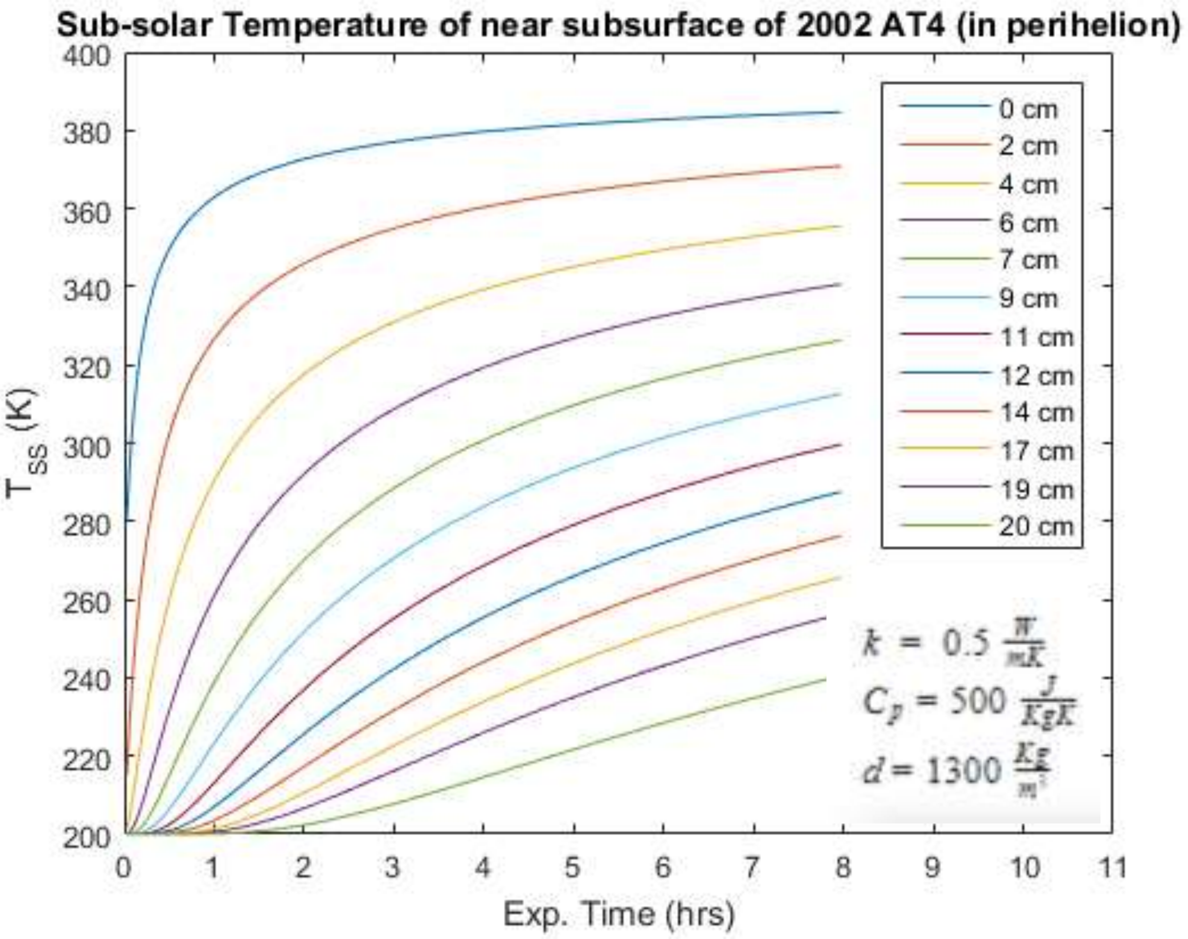

Carbon Dioxide
Water Vapor
Ocean Surface (13 °C)
Methane
Ozone
Stratosphere (-39 °C)
Intensity
8
10
14
24
50
Wavelength (microns)

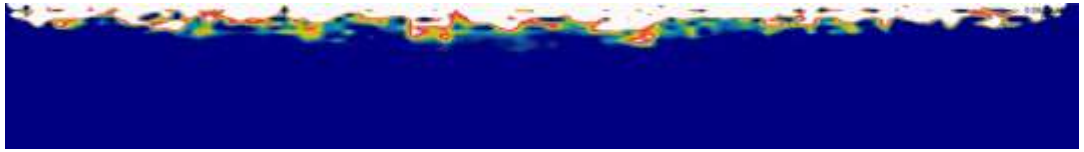
TIR

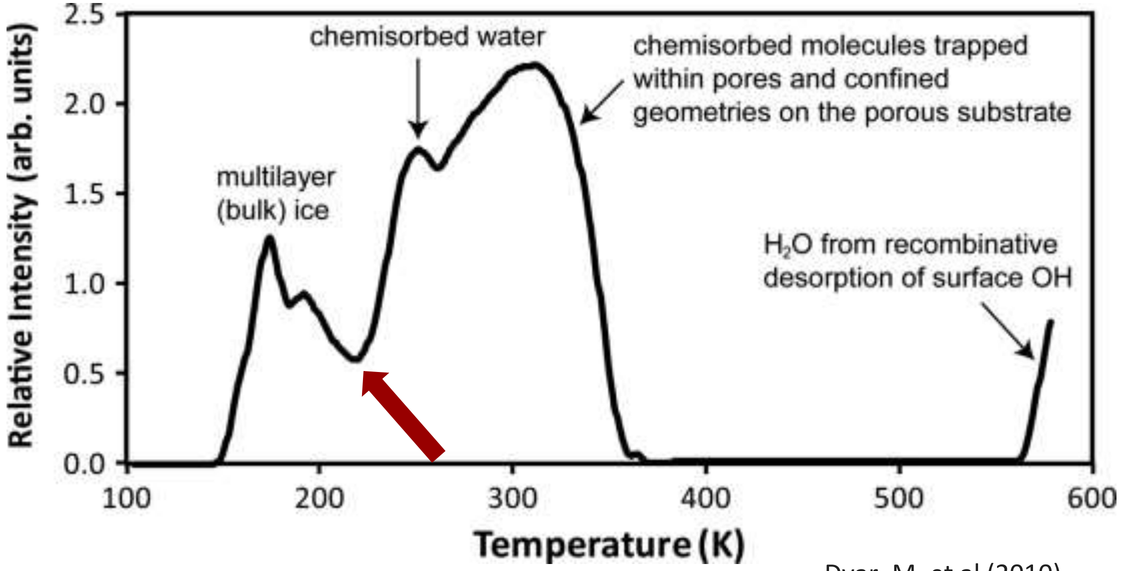
Sun Aspect Angle



How deep should we go?







Dyar, M. et al (2010).

Depending on the rotation, the minimum sampling depth could be approximately
from 9 cm to 18 cm.

Skin Depth:

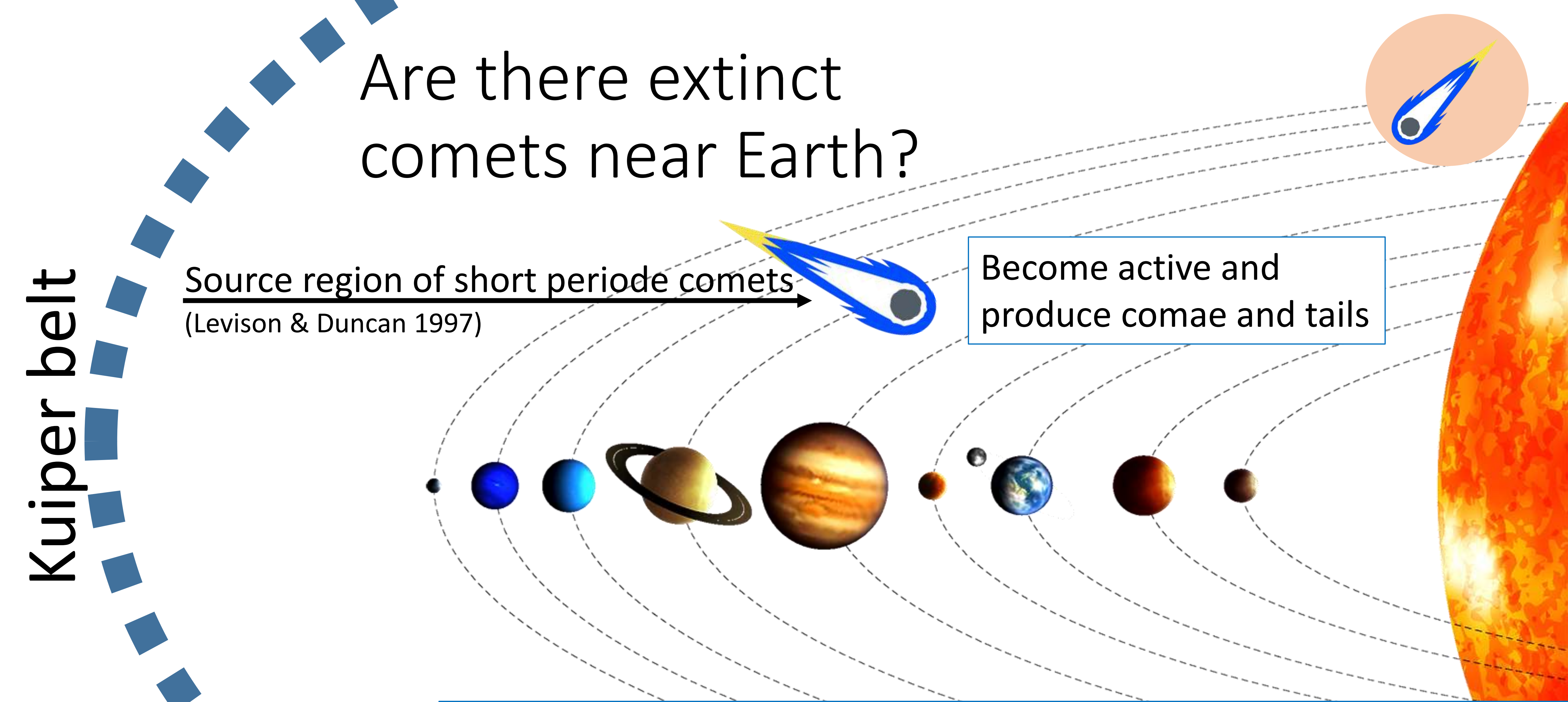
For **2.2 hrs** rotational period: **11 cm**

Summary

«CARINA is a first of its kind sample return mission, with the aim to contribute to pending questions about the relationship between asteroids and comets, the origin of life, and the formation of our solar system.»

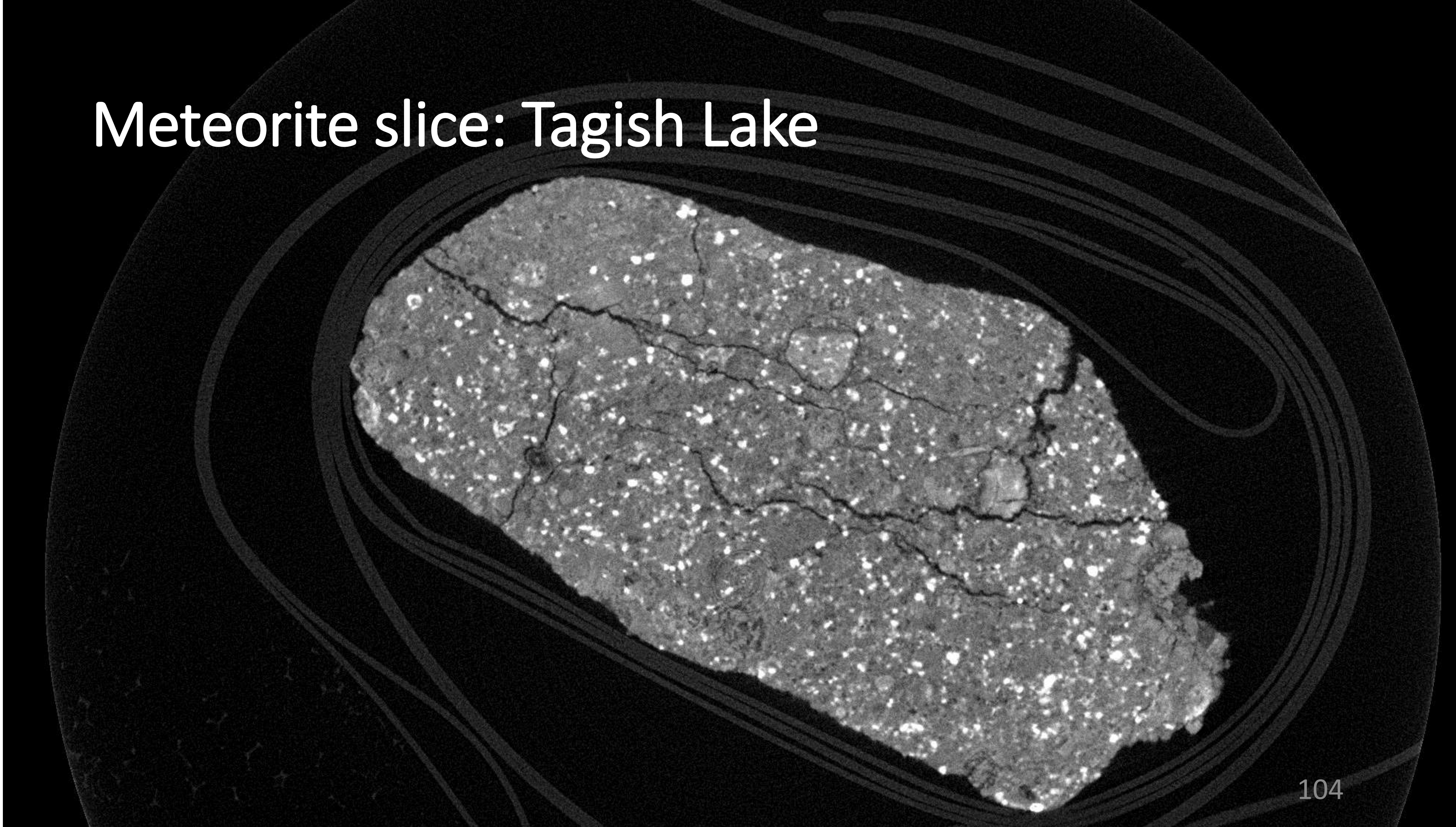
Appendix

Are there extinct comets near Earth?

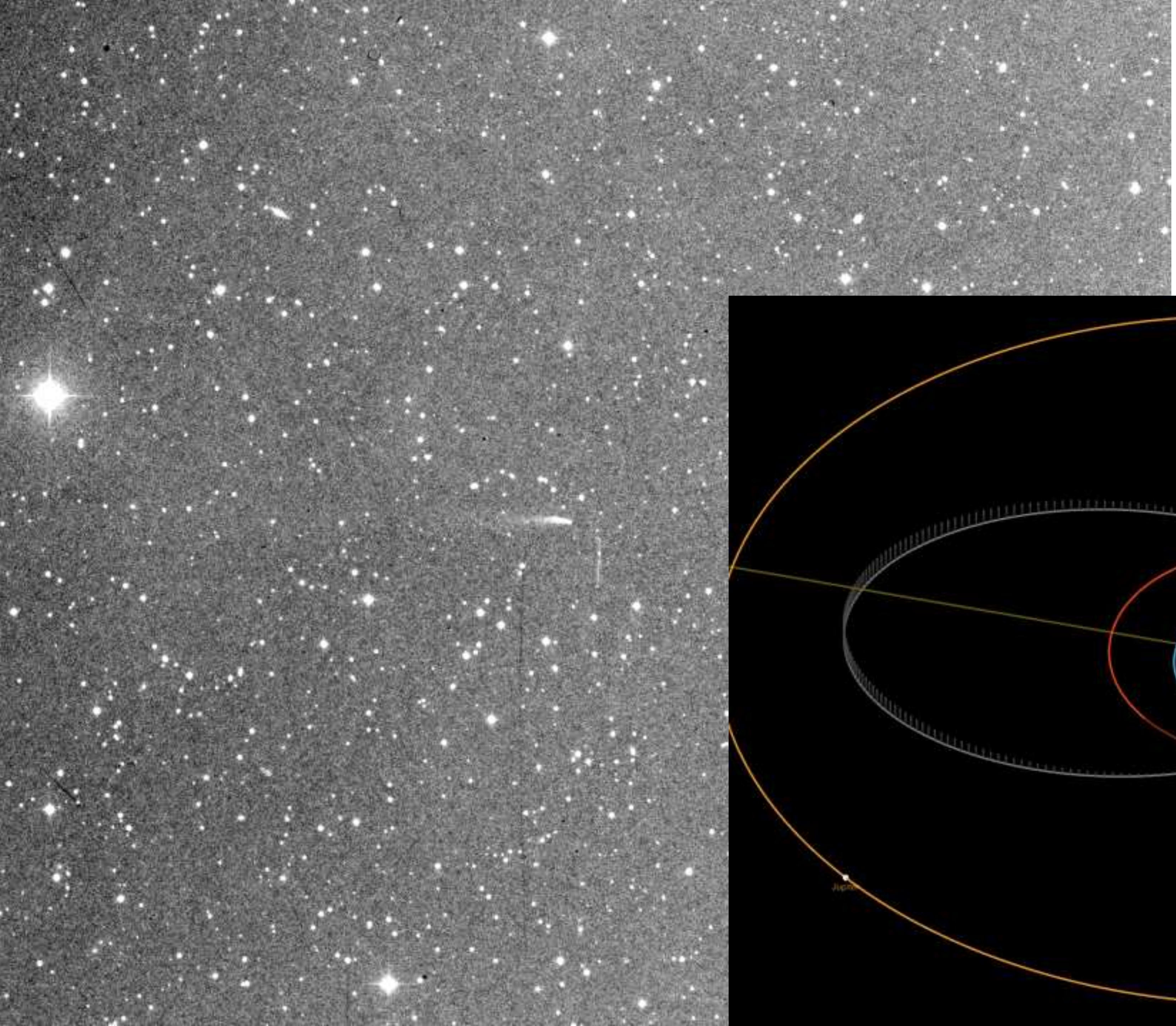


Activity lifetime is shorter than the dynamical lifetime,
so NEO population likely includes some extinct or dormant comets !
(Levison & Duncan, 1997, Morbidelli & Gladman 1998, Weissman et al. 2002).

Meteorite slice: Tagish Lake



Instrument	Heritage	Mass in g	Volume (mm)	Datarate in Mbits/s	Working Temperature (in obs °C)	Power (W) avergae
Global Camera	MarcoPolo-R	2000	273x172x115	1,69	[0,27]	11.5
Near-Field Camera	MarcoPolo-R	820	364x78x68	1,69	[0,27]	13.5
Visible/NIR Spectrometer	MarcoPolo-R	3600	260x128x84	0,1	-123	18
Mid-IR Spectrometer	MarcoPolo-R	3000	160x220x370	0,1	-10	2
Mass Spectrometer	Philae	4500	250x330x110	0,1	TBD	10
Magnetometer	Mascot	180	55 (d) x50	0,000101	[-80,80]	0.5W
HF Radar	AIM	1700	260x620x240	0,3	[-50,50]	16W
Radio Science Experiment	MarcoPolo-R	Contained in resources of radio system	Contained in resources of radio system	0,000101	[-20,60]	TBD



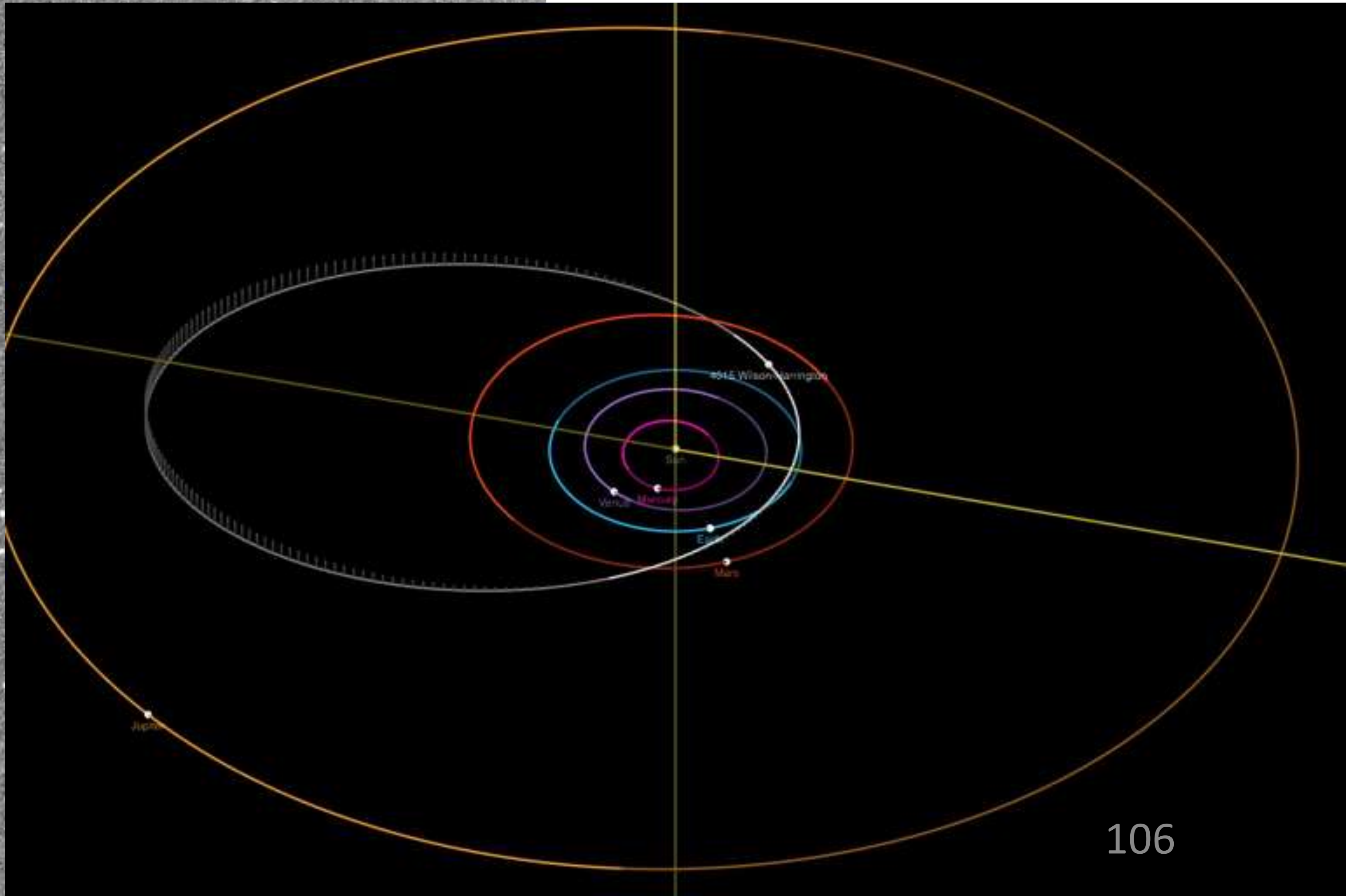
4015 Wilson-Harrington

Apollo ***asteroid - like*** orbit

C-,P-,D-type classification

Low albedo

Shows cometary activity



Measurement requirements

What measurement	What instrument	Instrument requirements	Environmental parameters
Global mapping	Global camera	Build global maps at a distance of 5 km with a resolution of 20 cm.	5km orbit above asteroid, months 1 – 5 of asteroid escort phase.
	VNIR spectrometer	Spectroscopic analysis over the wavelength ranges 0.3 - 4.3 µm at a precision of 10 cm-1. 20 m resolution.	
	TIR spectrometer	Spectroscopic analysis over the wavelength ranges 4 - 30 µm at a resolution of 10 cm-1. 20 m resolution	
	Radar	Build global map of the near sub surface using radar with a resolution of 1m at a depth of min 3-4 m	

Measurement requirements

What measurement	What instrument	Instrument requirements	Environmental parameters
Local mapping	Nearfield camera	Build localised maps of sampling site on descent with a resolution of maximum 1 mm.	1km orbit above asteroid, 6 – 8 months of asteroid escort phase.
	VNIR spectrometer	Spectroscopic analysis over the wavelength ranges 0.3 - 4.3 µm at a precision of 10 cm-1. 20 m resolution.	
	TIR spectrometer	Spectroscopic analysis over the wavelength ranges 4 - 30 µm at a resolution of 10 cm-1. 20 m resolution.	
	Radar	Build global map of the near sub surface using radar with a footprint of 1mx1m at a depth of 3-4 m	

Measurement requirements

What measurement	What instrument	Instrument requirements	Environmental parameters
Rehearsal descent			At month 8 of asteroid escort phase
Sampling	Bristle sampler		month 9 of asteroid escort phase
	Dart Sampler		
Post-sampling phase	Mass spectrometer	Mass spectrometer with a 10-200 m/z range, a detection limit of 5‰, and an accuracy ± 1‰	Month 10 of asteroid escort phase
	Nearfield camera (optional)		
	VNIR spectrometer (optional)		
	TIR spectrometer (optional)		

Calculation data Volume

- Camera : 200 images and 72 Mbits per image so 14.4 Gbits *2 for redundanct

- Spectrometers : 16 bits per value, 2466 values for one image, with a foot print of 20*20m to cover a whole 800m body (sphere) we need

:$2 * \frac{(\pi * 800)^2}{20 * 20} * 2466 * 16 = 396$ Mbits in total for one image of one body

40 Gbits for 100 images

- Radar : Body of 800m, PRF of 3.6 Hz, 2150 frequencies so one spectrum has $4.3 * 10^6$ points, with 16 bits per point we have 69 Mbits per orbits $*$ 20 orbits if we want a tomography so 1,3 Gbits per tomography and 2 tomography we have 2,6 Gbits

- Then we compute according to the time of the phase

Measurements on Earth

Technique	Potential Results
Scanning electron microscopy (SEM)	Mineralogy, composition <mm structures
Transmission electron microscopy (TEM)	Mineralogy, <µm structures, composition
Electron microprobe analysis (EMPA)	Elemental and chemical composition
Nano secondary ion mass spectroscopy (nanoSIMS)	Isotopic and elemental composition, dating
Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS)	Isotopic and trace elemental composition
Circular polarisation measurements	Chirality

Technique	Potential Results
Helium pycnometry	Porosity
Micro computed tomography (µ-CT)	Mineralogy
Gas chromatography mass spectroscopy (GC-MS)	Organics
Transmission infrared spectroscopy	Chemistry and mineralogy
X-ray fluorescence (XRF)	Elemental and chemical analysis
X-ray absorption (XAS) near edge structure (XANES)	Elemental analysis

COSPAR Planetary Protection Policy

Do we have a restricted Earth return?

1. Does the preponderance of scientific evidence indicate that there was never liquid water in or on the target body? YES
2. Does the preponderance of scientific evidence indicate that metabolically useful energy sources were never present? UNCERTAIN
3. Does the preponderance of scientific evidence indicate that there was never sufficient organic matter (or CO_2 or carbonates and an appropriate source of reducing equivalents) in or on the target body to support life? UNCERTAIN
4. Does the preponderance of scientific evidence indicate that subsequent to the disappearance of liquid water, the target body has been subjected to extreme temperatures (i.e., >160°C)? N/A
5. Does the preponderance of scientific evidence indicate that there is or was sufficient radiation for biological sterilization of terrestrial life forms? YES
6. Does the preponderance of scientific evidence indicate that there has been a natural influx to Earth, e.g., via meteorites, of material equivalent to a sample returned from the target body? YES

Need to answer no or uncertain to all 6 questions to qualify, so no we don't!

1 Investigate the Asteroid – Comet Relationship

Objective	Measurement	Phase
Evaluate whether D-types could represent extinct comet nuclei.	**Comparison** of **physical characteristics** and **compositional information** with **Rosetta** data, and a comparison of detailed **mineralogical, petrological and chemical data** to **Stardust** returned samples.	Orbital phase, ground based observations, sample return
Investigate activity quenching as an 'comet killer'.	**Characterisation** of a **regolith and sub-surface** sample from a D-type.	Sample return
Determine whether asteroids and other comets are related; are they separate bodies or do comets, D-type asteroids and C-type asteroids represent a continuum.	**Comparison** of **physical characteristics** and **compositional information** and a comparison of detailed **mineralogical, petrological and chemical data** with **OSIRIS-REx and Hayabusa2** data,	Orbital phase, ground based observations, sample return

2 Investigate the Origin of Life

Objective	**Measurement**	**Phase**
Investigate the organic material (chirality)	The **content and composition of organic material**, including the **molecular asymmetry** (chirality)	Sample return
Investigate the volatile content (D/H ratios)	Establish the presence of **volatiles**, their **composition and abundance**, and **isotopic composition.**	Sample return, in-situ measurement

3 Determine Conditions in the Early Solar Nebula

Objective	Scientific requirement	S
Characterise a near-Earth D-type asteroid.	**global surface compositional** **near sub-surface map** **volume, mass and density** **magnetic field measurement**	OS, GB, SR
Determine the timescales of accretion and planetesimal formation.	**Isotopic composition (dating)**	Sample return
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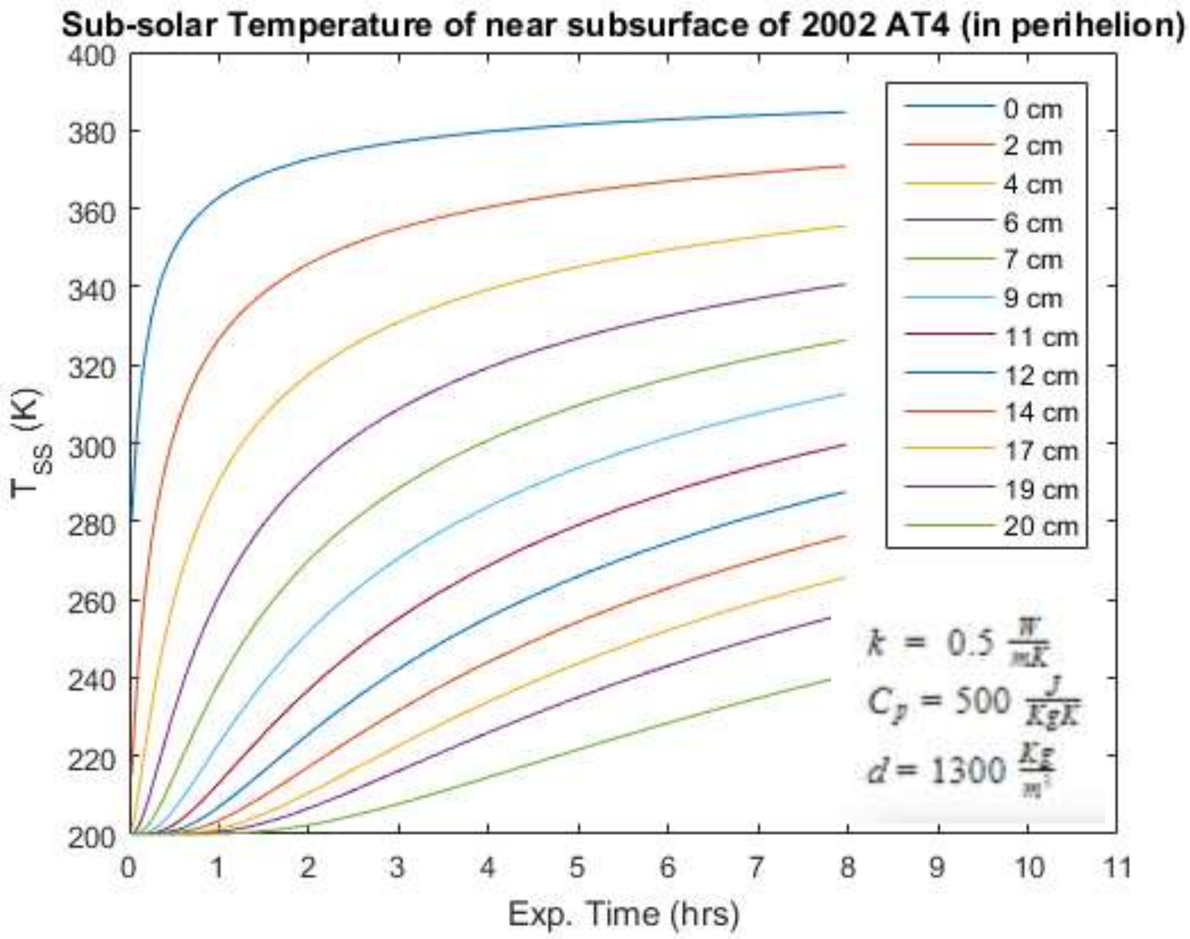
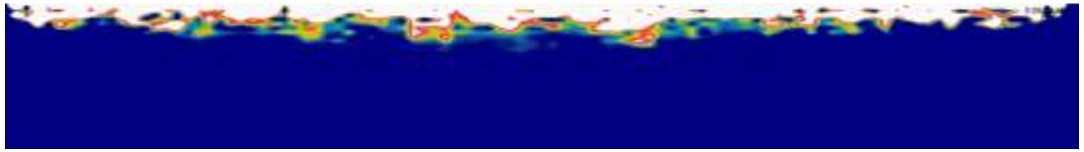
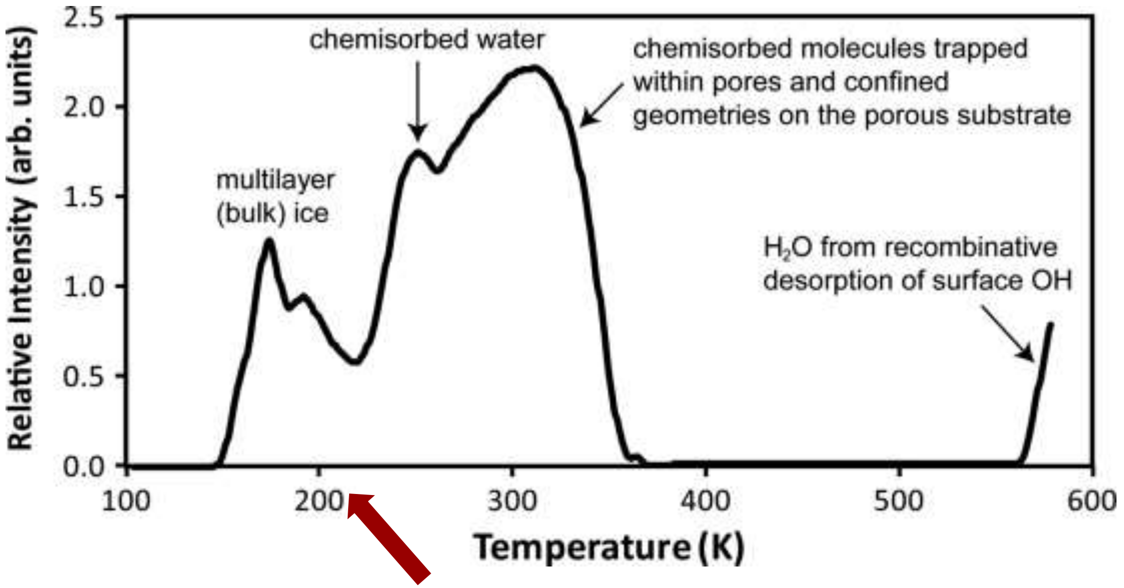
How deep should we go?







Dyar, M. et al (2010).

Depending on the rotation, the minimum sampling depth could be approximately **from 9 cm to 18 cm**.

Skin Depth:

For **2.2 hrs** rotational period: **11 cm**

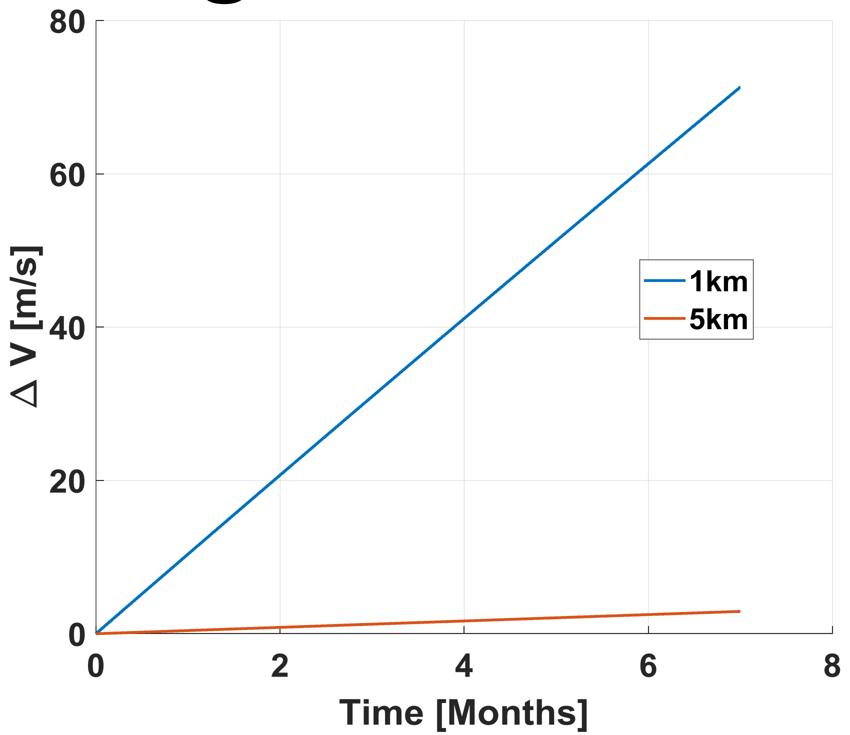
For **6 hrs** rotational period: **18 cm**

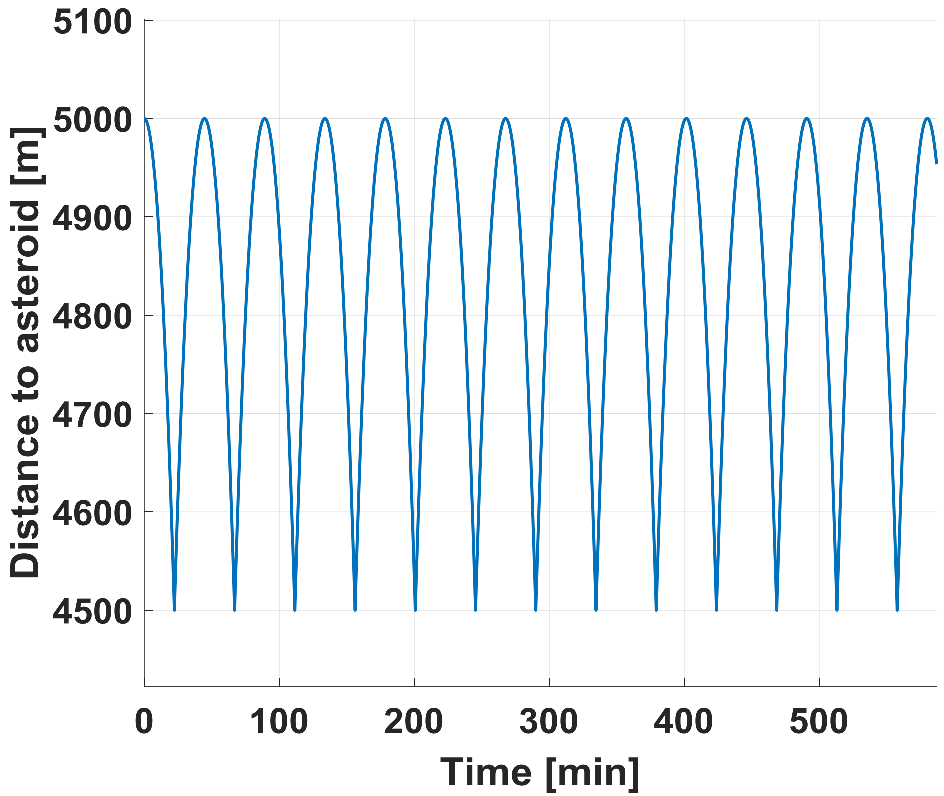
BACKUP SLIDES!

Mission	Year of Return	Target	Return material	Country
Chang'e 5	2018	Moon	2kg	China
Hayabusa2	2020	C asteroid	~g	Japan
Luna-Grunt	2020	Moon	<1kg	Russia
OSIRIS-REx	2023	B asteroid	60-2000g	USA
Mars Sample Return	2020s	Mars	500g	USA/Europe

"Sample curation : handling, analysis, storage", Vinciane Debaille (ULB)

Target Orbits





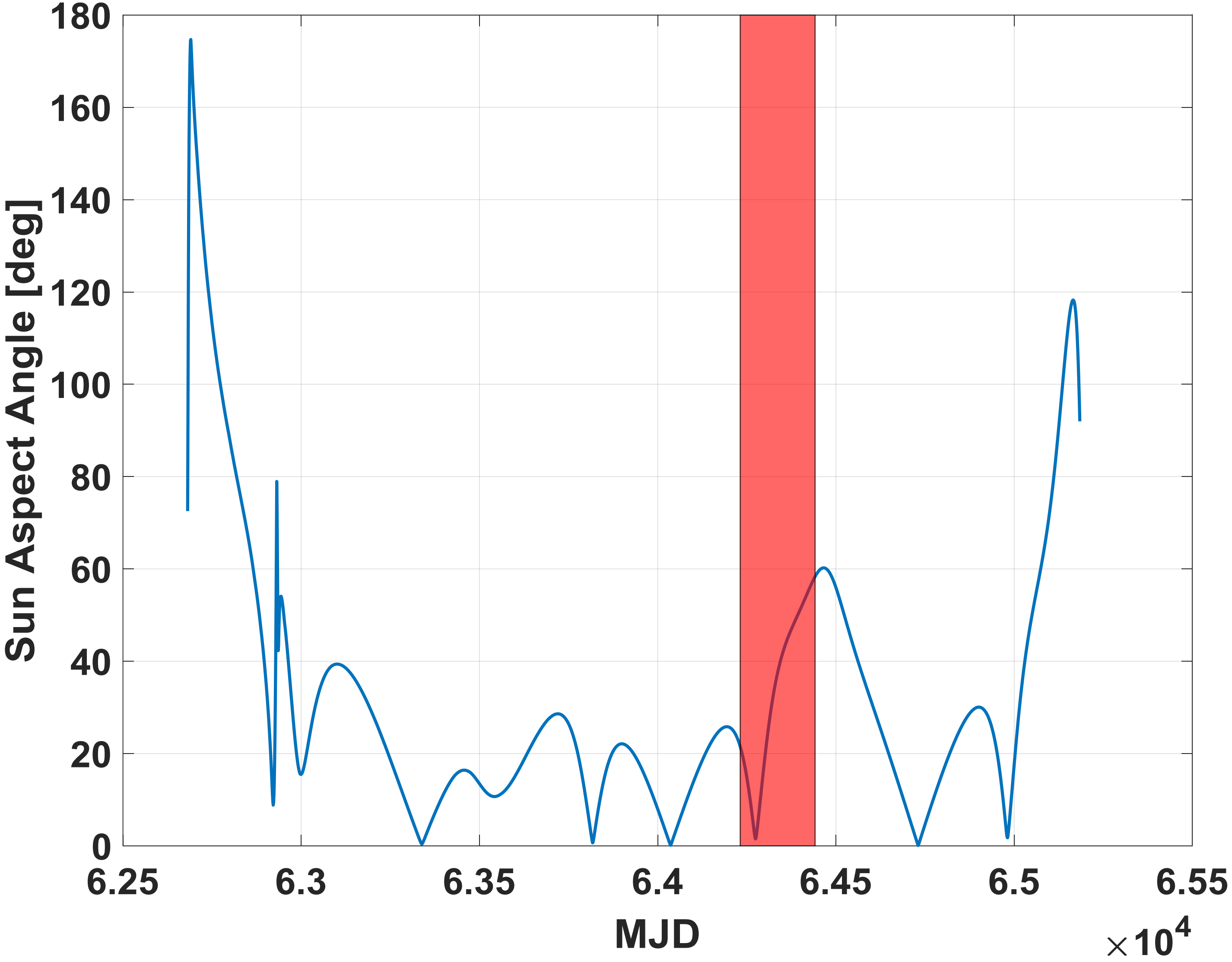
5km: Global Mapping

- **Shape model**
  - **Resolution for NAC: 20cm**
  - **Radar**
- **Science Operations**

1km: Local Mappping

- **Radio science measurements**
  - **Gravity field determination**
- **Sampling site selection**
- **Science Operation**

Sun Aspect Angle



Power Generation

Phase	Power generated [W]	Power consumed [W]
Departure to asteroid	8329	8059
At Asteroid	981	537 (Payload: 210W)
Departure to Earth	1784 [2AU] – 7139 [1AU]	8059