DESIRE

D-Type Explorer for Subsurface Interior sample REturn

Team Orange

First sample return from a D-type Near Earth Asteroid!

Mission statement:

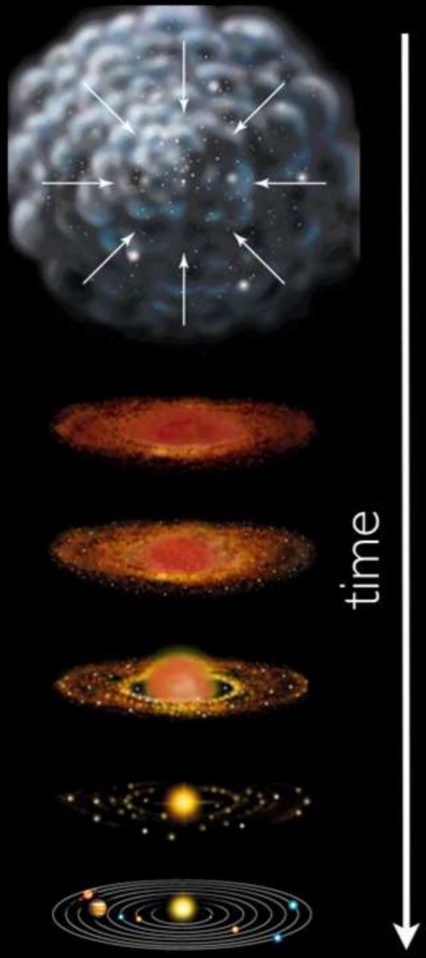
The DESIRE mission will return surface and subsurface material from a D-type asteroid in order to widen our understanding of the formation of the Solar System and how the building blocks of life were transported in it.

First sample return from a D-type Near Earth Asteroid!

- First mission to a Near Earth D-type asteroid
- First asteroid **subsurface** sample return
- Spacecraft + lander

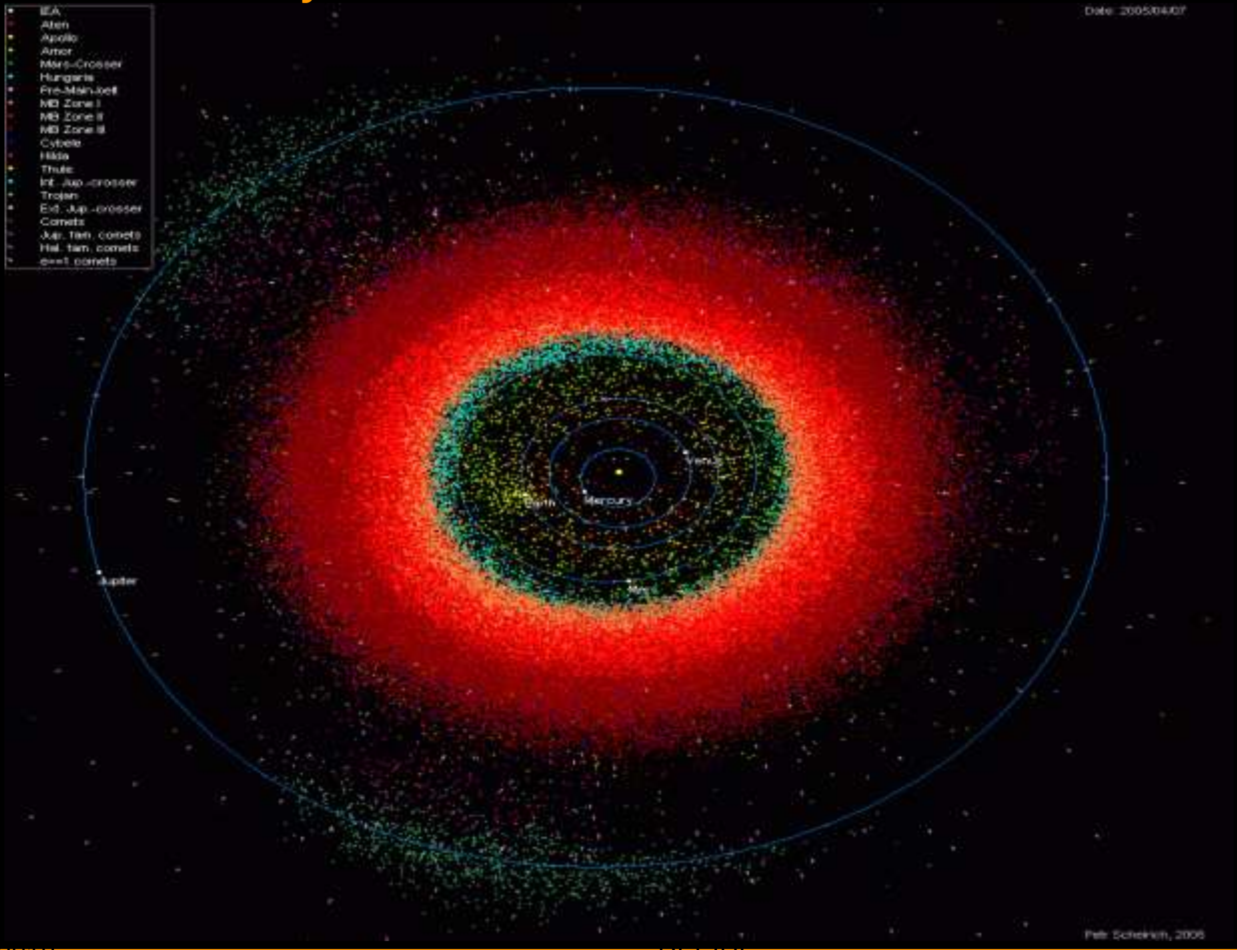
Formation of the Solar System

Scientific Background



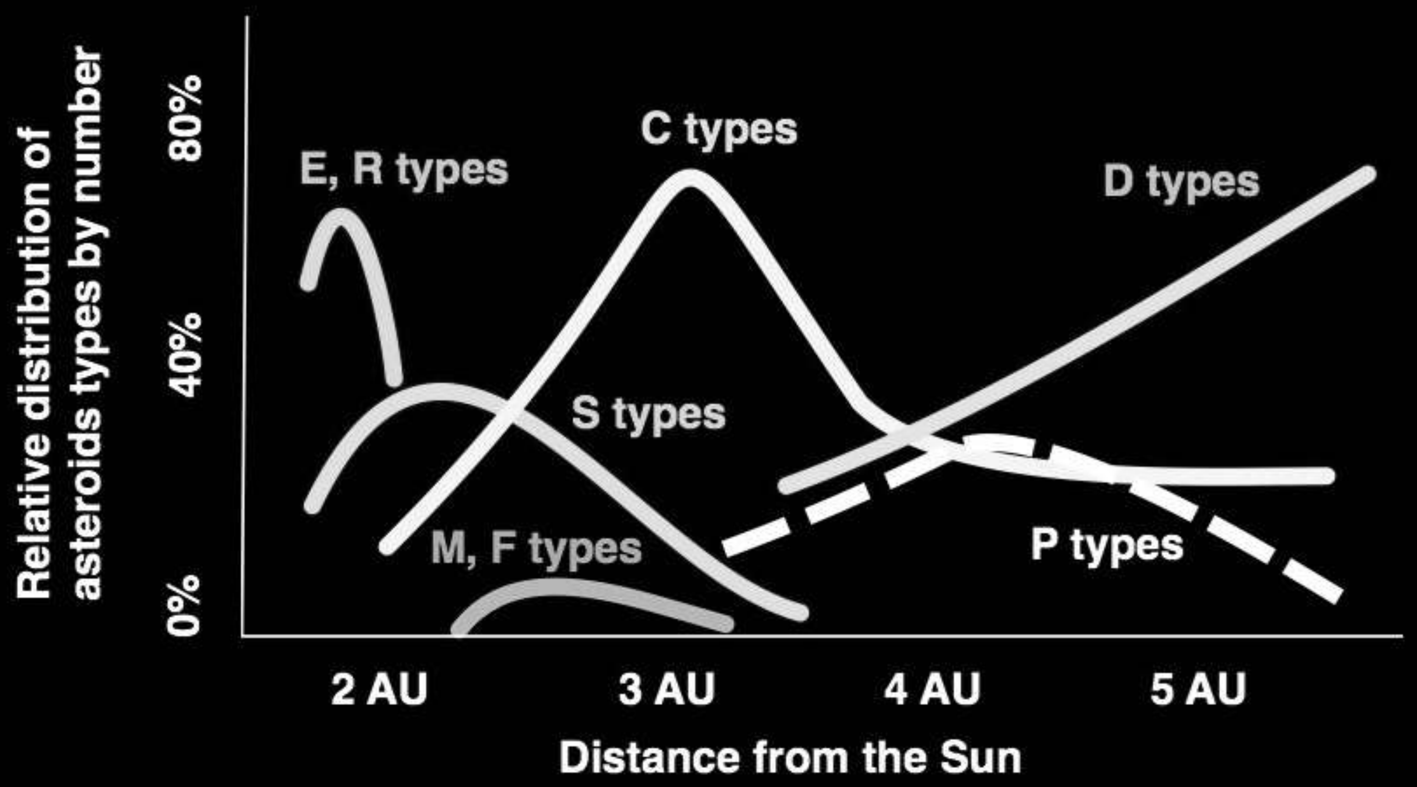
- Gravitational collapse of gas and dust particles
- Disk formation from gas and dust
- Rotation and accumulation of material in the centre
- Formation of the Sun
- Accretion within the disk
- Planetesimal formation
- Present Solar System structure

Asteroids in the Solar System



Taxonomic Classification

Asteroid Distribution in the Solar System



Three approaches to understand the formation of our Solar System:

1. Earth based remote sensing

Remote Sensing

- Mineralogical composition and taxonomy
- Shape and rotation
- Size and albedo
- Position

Three approaches to understand the formation of our Solar System:

1. Earth based remote sensing

1. Data from space missions

Past missions to asteroids

NEAR-Shoemaker (1996)

Flyby/Orbiter

S-type general characteristics of asteroids

Past missions to asteroids

NEAR-Shoemaker (1996)

Flyby/Orbiter

S-type general characteristics of asteroids

Hayabusa (2003)

Orbiter/Lander/Sample Return

Surface sample Itokawa (S-type)

Past missions to asteroids

NEAR-Shoemaker (1996)

Flyby/Orbiter

S-type general characteristics of asteroids

Hayabusa (2003)

Orbiter/Lander/Sample Return

Surface sample Itokawa (S-type)

Dawn (2007)

Orbiter

Orbit Vesta (V-type) and Ceres (C-type) by Remote sensing

Present missions to asteroids

Hayabusa 2 (ongoing)

Orbiter/Lander/Sample Return

Surface sample Ryugu (C-type)

Present missions to asteroids

Hayabusa 2 (ongoing)

Orbiter/Lander/Sample Return

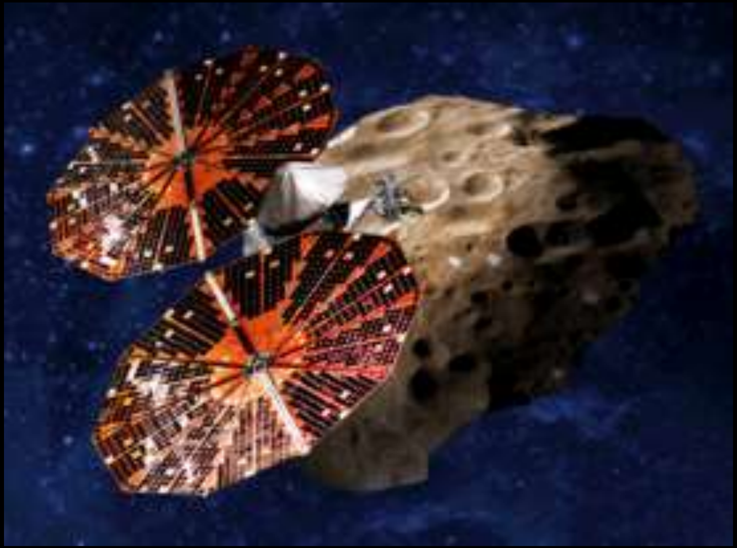
Surface sample Ryugu (C-type)

OSIRIS-REx (ongoing)

Orbiter/Lander/Sample Return

Surface sample Bennu (B-type)

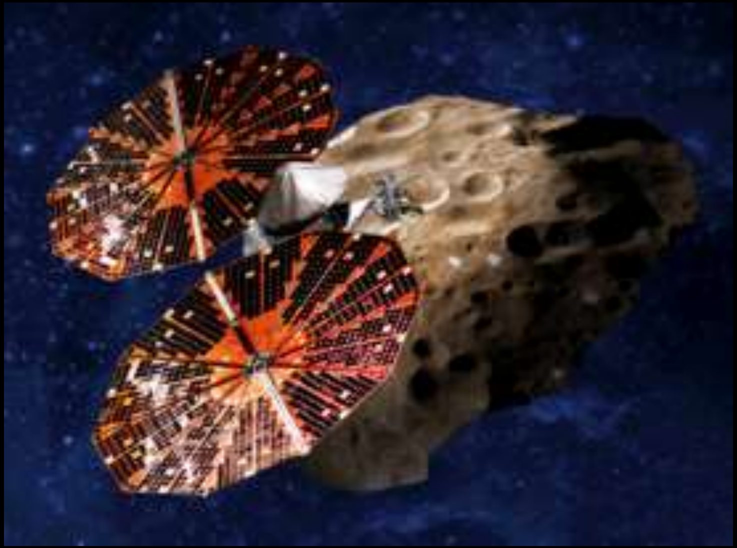
Future missions to asteroids



Lucy (2021)
Jupiter Trojan Asteroids

Fly-by of C-, D- and P-type asteroids

Future missions to asteroids



Lucy (2021)
Jupiter Trojan Asteroids

Fly-by of C-, D- and P-type asteroids

Psyche (2022)
Asteroid Orbiter

M-type asteroid

Three approaches to understand the formation of our Solar System:

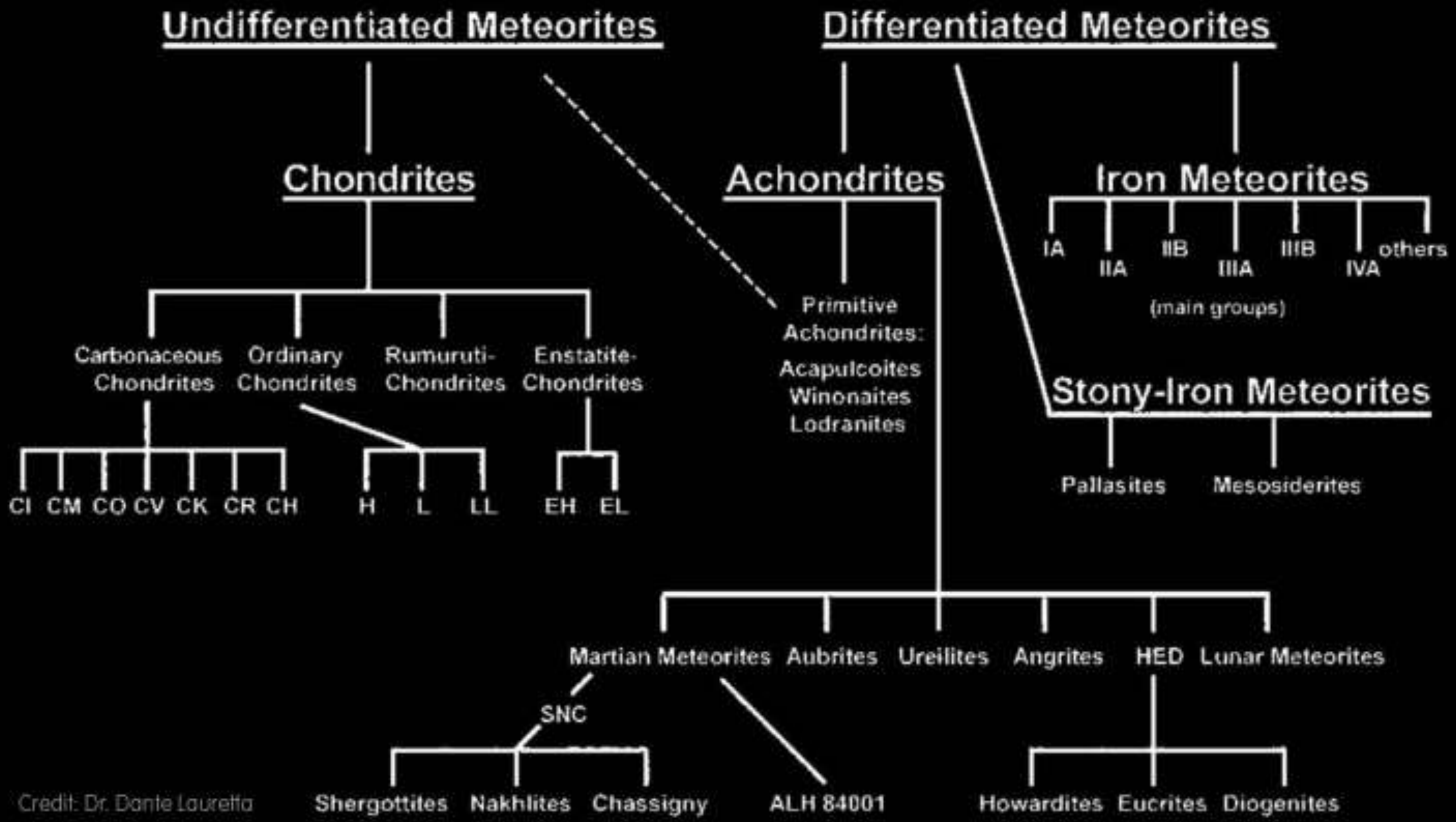
1. Earth based remote sensing

1. Data from space missions

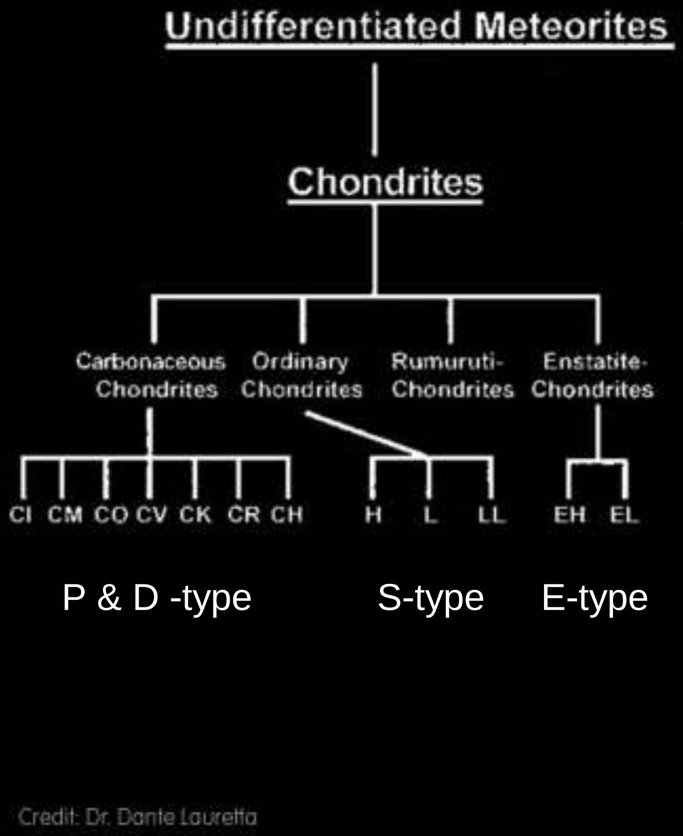
1. Meteorites

(Image courtesy of Mike Zolensky, NASA JSC)

Insights from the study of meteorites



Insights from the study of meteorites



P & D -type S-type E-type

Unprocessed and mixed early Solar System matter

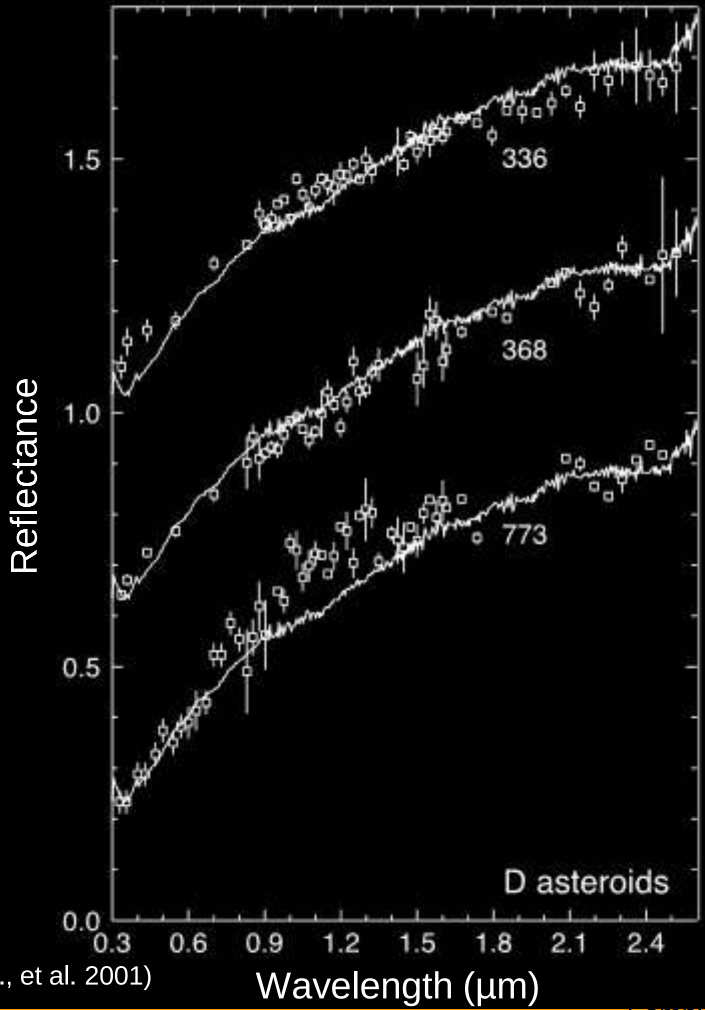
Ca, Al-rich inclusions (CAIs) in some chondritic meteorites

CAIs constrain the timing of Solar System formation

CAIs contain short lived radionuclides

- Chronology of the Solar System
- Heat source of the building blocks of planetesimal

Analogue material - Tagish Lake meteorite



(Hiroi, T., et al. 2001)

Analogue material - Tagish Lake meteorite

Tagish Lake

- Physical properties
  - Low albedo
  - Low bulk density
  - Porosity: 35-45%
- Composition
  - Carbon-rich
  - Presolar grains
  - CAI
  - Chondrules
  - Organics (Aminoacids)

Why is it important to go to a D type?

- Confirm/discard parent body
- Meteorite collection not representative
- Test theoretical model on early solar system formation
- Learn disk dynamic small body migration and processes in solar system
- Chemical and chronological properties
- The study of organics and presolar grains

Scientific Objectives

Scientific objectives	Scientific requirements	Measurements	Method	Instrument on orbiter/lander	Instrument requirements
Primary Objectives					
Q1: What were the building blocks of the Solar System and how did they evolve?	SR1: Determine the chemical composition and morphology of the building blocks at the time of early Solar System formation	Elemental composition	Spectroscopy	LIBS	Spectral resolution of 10 cm^{-1}
		Particle size and shape	**Sample analysis**	-	-
	SR2: Characterize collisional history of primitive bodies	Mineralogy (shock metamorphism)	**Sample Analysis**	-	-
		Internal structure	Radars	Low-Frequency Range radar (bistatic)	Res: 10-30m Penetration depth: 170 m Nominal Frequency: 50-70 mHz External Frequency: 45-75 Mhz
	SR3: Determine the initial spatial distribution and migration of small bodies across the Solar System	Chemistry Isotopes ratios	**Sample analysis**	-	-
Q2: What are the physical properties of NEAs?	SR4: Characterize D-Type asteroids	Global surface topography	Mapping Imaging	Wide Angle Camera	Resolution: 10 cm/pixel from 5km distance
				Narrow Angle Camera	Resolution: 10 cm/pixel from 5km distance
		Composition and mineralogy	Spectroscopy	Visible Near Infrared Spectrometer	Spectral resolution: 5nm Wavelength range: 0.4-3.3 um
				Mid Infrared Spectrometer	Resolution: 1 um Spectral range: 5-15 um
			Sample analysis	-	-
		Internal structure	Radars	High frequency radar (monostatic)	Res: 2 m Penetration depth: 10-20 m Nominal Frequency: 300-800mHz External Frequency: 300-2500 Mhz
				Low-Frequency Range radar (bistatic)	Res: 10-30m Penetration depth: 170 m Nominal Frequency: 50-70 mHz External Frequency: 45-75 Mhz
Q3: How were the building blocks of life formed and transported inside the Solar System?	SR5: Characterize organic compounds present in primitive bodies	Identification of organic compounds	Spectroscopy	Raman spectrometer	Raman shifts: 4000 cm^{-1} -1000 cm^{-1}
			Sample analysis	-	-

Primary Objectives

What were the building blocks of the Solar System and how did they evolve?

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What are the physical properties of Solar System bodies?

Primary Objectives

What were the building blocks of the Solar System and how did they evolve?

What are the physical properties of Solar System bodies?

How were the building blocks of life transported inside the Solar System?

Secondary Objectives

Q4: What was the astrophysical context at the time of Solar System formation?	SR6: Determine the presolar grain sources	Isotopic ratios	**Sample analysis**	-	-
	SR7: Characterize the stellar environment in which the Solar System formed	Isotopic and chemical characteristics of presolar grains	**Sample analysis**	-	-
	SR8: Characterize stellar processes				
Q5: Can the Tagish Lake meteorite be linked to a specific spectral class of asteroids?	SR9: Testing if D-types asteroids are the parent body type of the Tagish Lake meteorite	Chemical composition	Spectroscopy	LIBS + Raman	Spectral resolution of 10 cm^{-1} Raman shifts: 4000 cm^{-1} -100 cm^{-1}
		Isotopic ratios	**Sample analysis**	-	
Q6: What are the processes which are affecting the physical properties of asteroids today?	SR10: Characterize the interaction between the solar wind and asteroid surfaces	Low Energy Neutral Atoms	Neutral imaging	Neutral Particle Detector	Mass resolution: H, Heavy Energy range: 10eV to 3keV
	SR11: Determine the collisional record of D-type asteroids	Imaging	Cameras	Wide angle camera	Resolution: 10 cm/pixel from 5km distance
		Mineralogy	**Sample analysis**	-	-
Q7: Asteroid impact avoidance	SR12: Characterize Near Earth Asteroids in order to plan a defence strategy	Chemical and physical properties	Cameras	Wide Angle Camera	Resolution: 10 cm/pixel from 5km distance
				Narrow Angle Camera	FoV: 1.7 degrees Resolution: 18.6 urad px-1 (1.86 m/pixel from 100 km distance)
			Radar	High Frequency Radar	Res: 2 m Penetration depth: 10-20 m Nominal Frequency: 300-800mHz External Frequency: 300-2500 Mhz
				Low-Frequency Range Radar	Res: 10-30 m Penetration depth: 170 m Nominal Frequency: 50-70 mHz External Frequency: 45-75 Mhz
			Spectroscopy	LIBS + Raman	Spectral resolution of 10 cm^{-1} Raman shifts: 4000 cm^{-1} -100 cm^{-1}

Secondary Objectives

What was the astrophysical context at the time of Solar System formation?

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Secondary Objectives

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Can the Tagish Lake meteorite be linked to a specific spectral class of asteroids?

What are the processes which are affecting the physical properties of asteroids today?

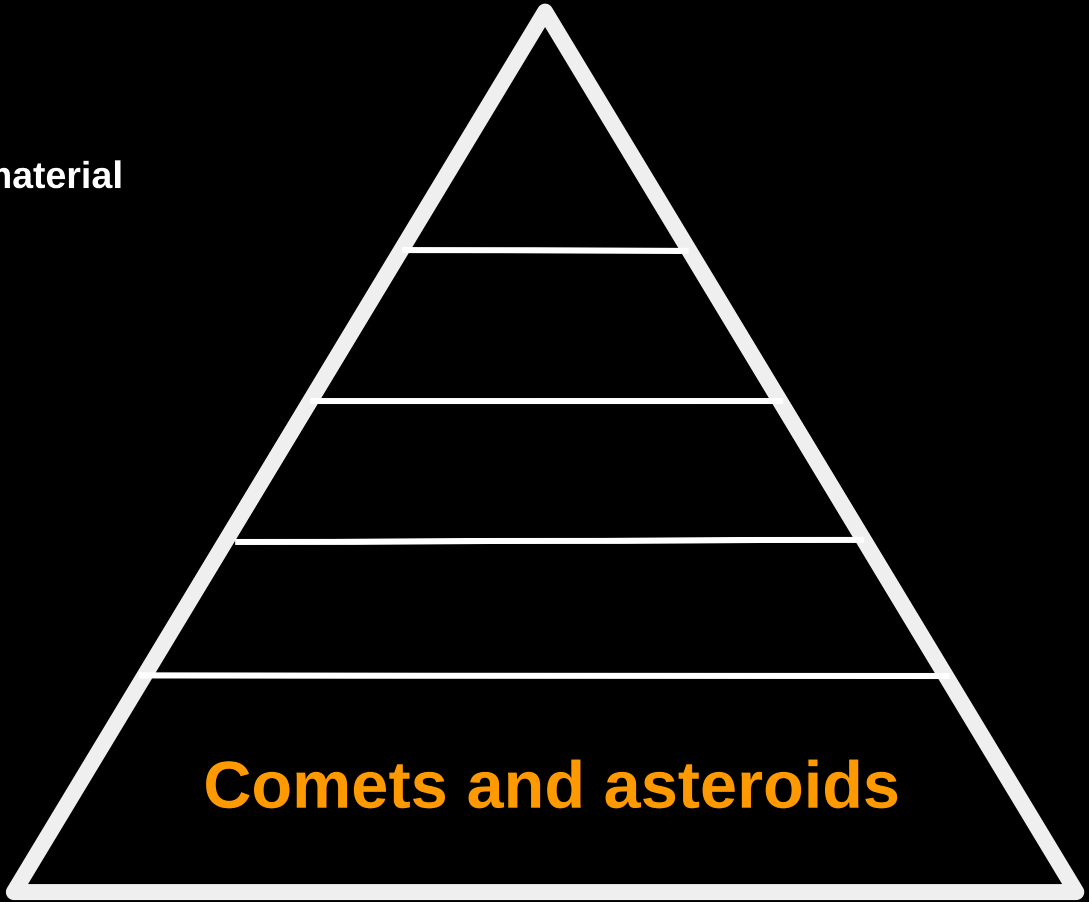
Asteroid impact avoidance

Where do we need to go?

Target Selection

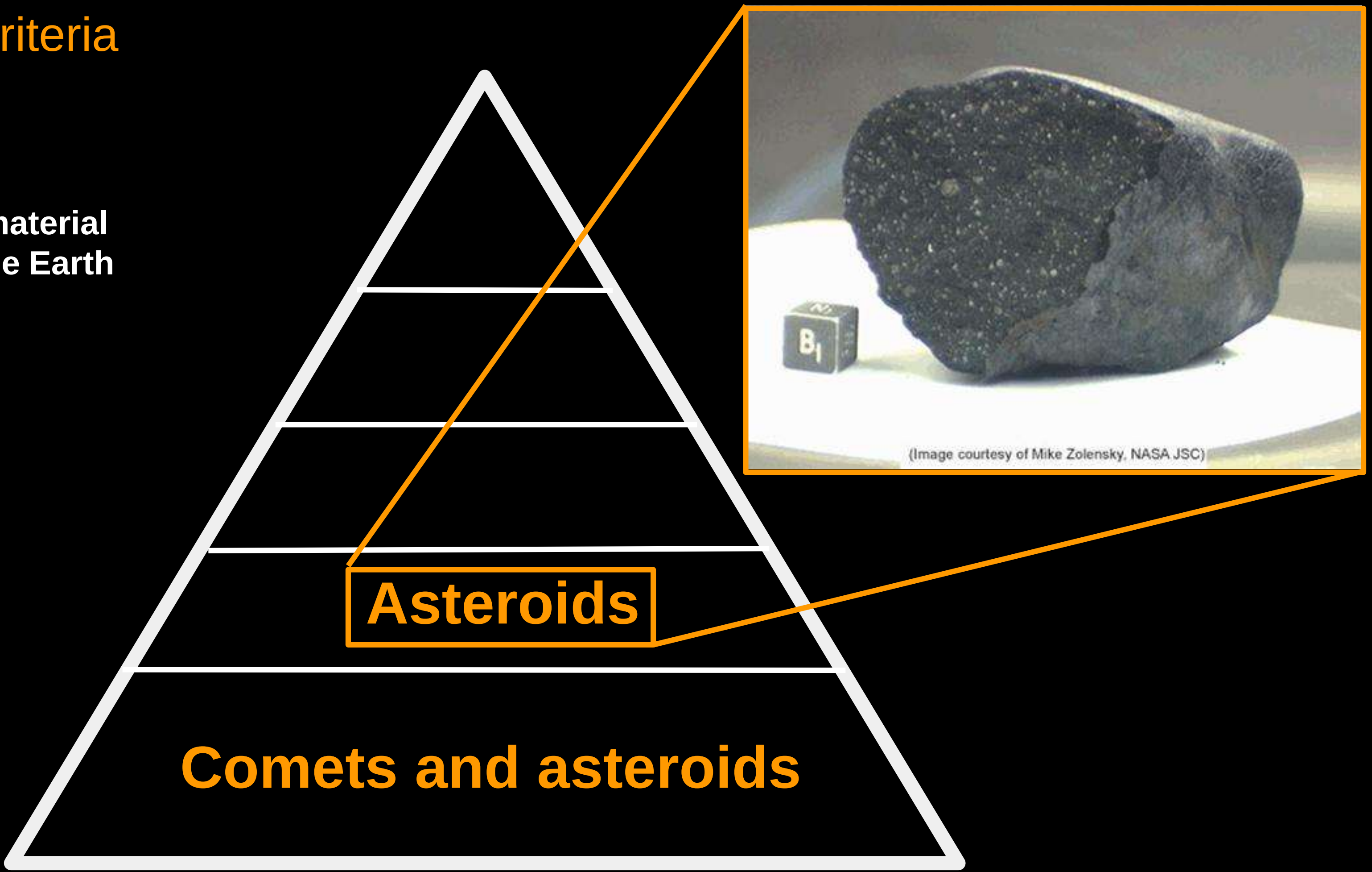
Selection Criteria

- **Primitive material**



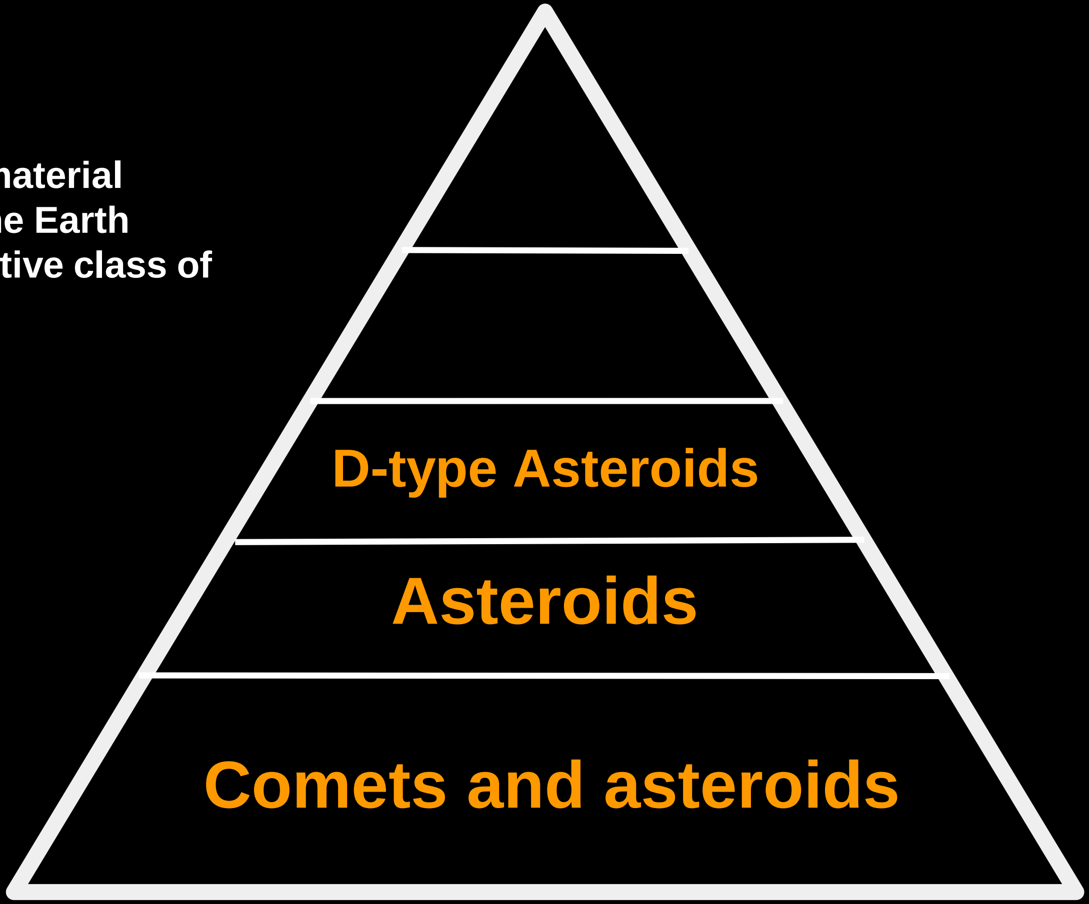
Selection Criteria

- Primitive material
- Close to the Earth



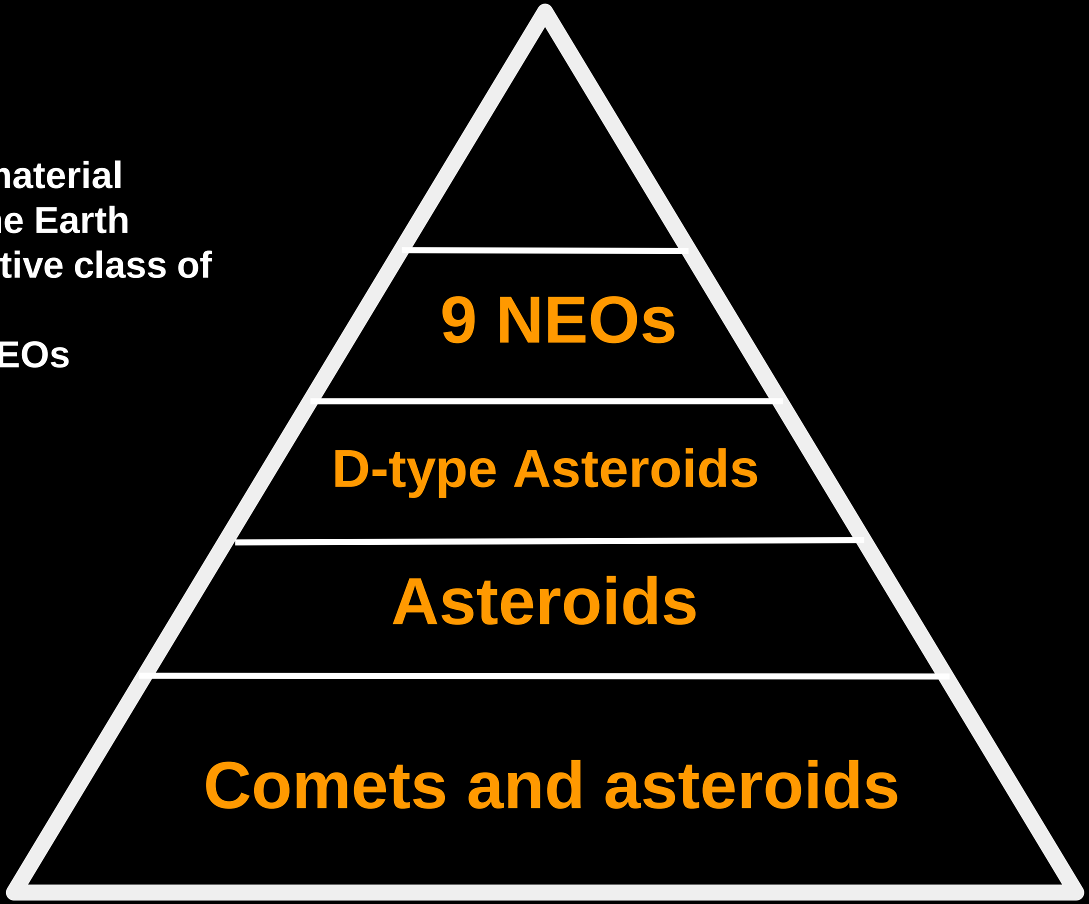
Selection Criteria

- **Primitive material**
- **Close to the Earth**
- **Most primitive class of asteroid**



Selection Criteria

- **Primitive material**
- **Close to the Earth**
- **Most primitive class of asteroid**
- **9 D-type NEOs**



Selection Criteria

- **Primitive material**
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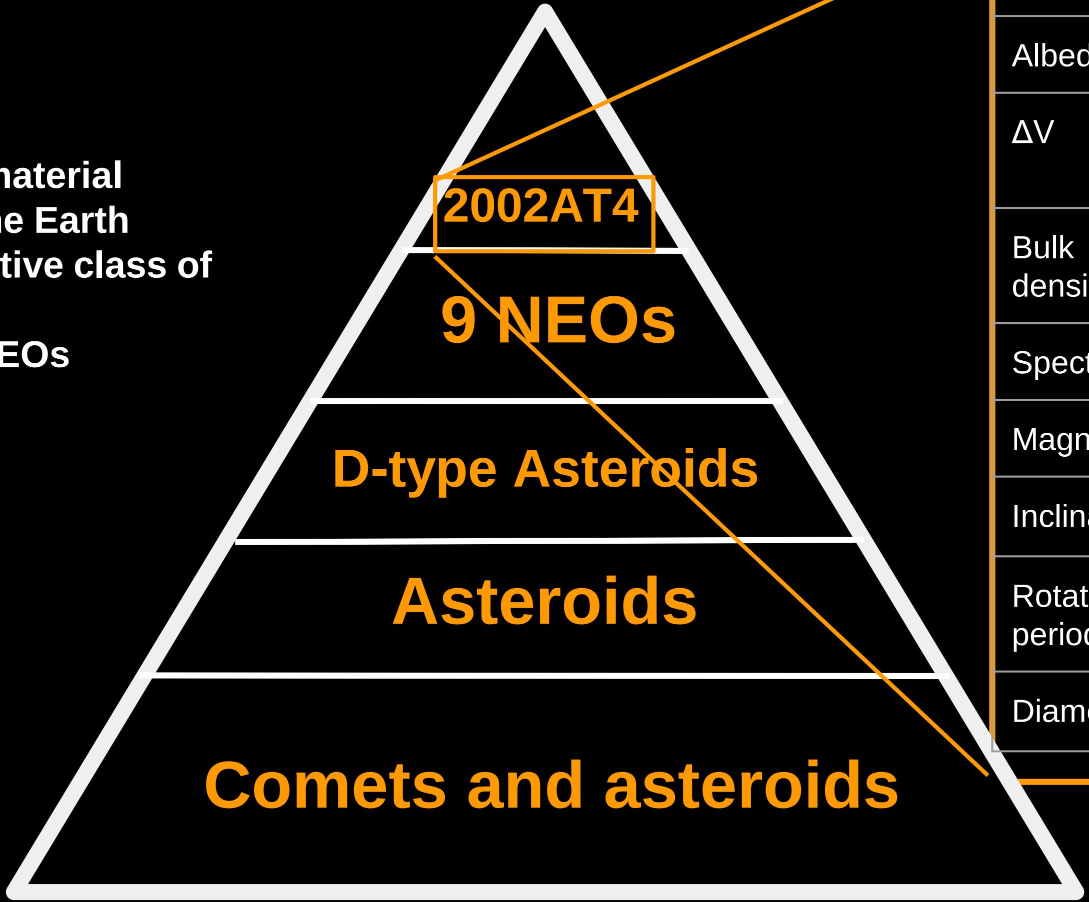
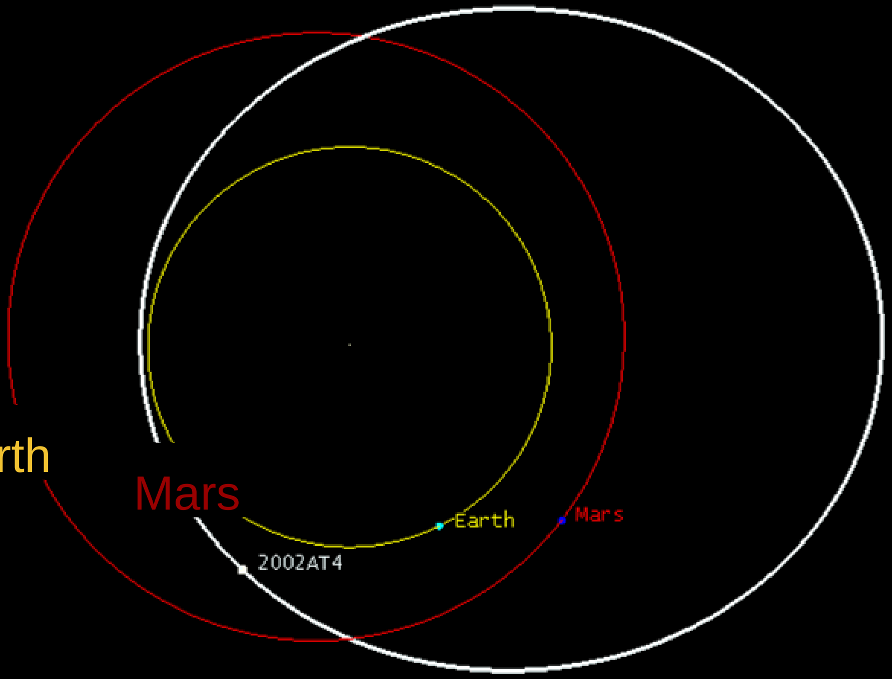


	Selection criteria	2002AT4
Albedo	3%-9%	7%
ΔV	<7 km/s	5.3 km/s
Bulk density	1.3<ρ<2.7	2
Spectrum	D-type	D-type
Magnitude	18<H<24	21.2
Inclination	low	1.5001°
Rotational period	≈ 6 hours	6 hours
Diameter	>200 m	320 m

Desired Primary and Secondary Targets



Earth

Mars

2002AT
4

Instrumentation

Orbiter instruments

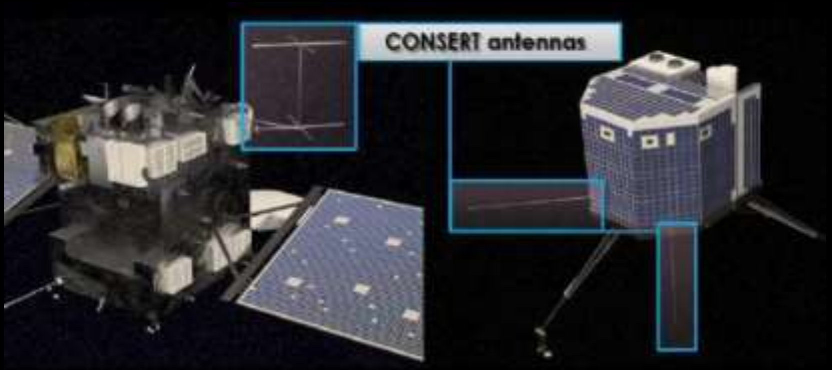
Narrow Angle Camera

Wide Angle Camera

- Mapping
- Landing site selection
- Morphology
- Collisional history

Heritage: Rosetta

Orbiter instruments



High Frequency Radar

- Physical properties
- Internal structure

Low Frequency Radar

Credits: ESA

Heritage: ExoMars, Rosetta

Orbiter instruments

Credits: CSEM

Mid Infrared Spectrometer

Near Infrared Spectrometer

Global physical properties

Heritage: Rosetta

Orbiter instruments

Credits: IRF

Neutral Particle Analyzer

Space weathering

Heritage: Chandrayaan-1

Lander instruments

Descent cameras

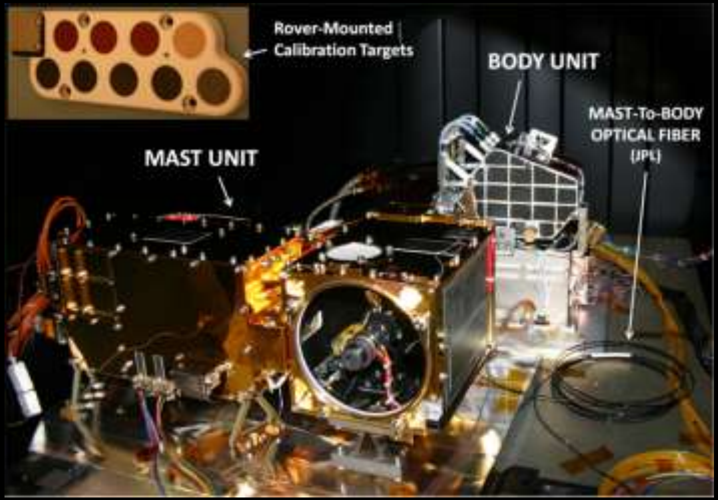
Credits: CSEM

Panoramic cameras

Geological context for the sampling site

Heritage: Philae

Lander instruments



Credits: LANL/CNES

LIBS* + Raman

*Laser Induced Breakdown Spectroscopy

- Elemental abundance
- Organics

Heritage: MSL/Mars2020

Sample Requirements

Property	Requirement	Reasons
Depth	> 20 cm	Value below skin depth with margin; likelyhood to get lithology intact
Mass	> 10 g	Ground-based instrument mass requirements to fulfill scientific goal
Temperature	< 313 K	To preserve organic material
Sample retrieval	Surface and subsurface	Context to time domain, impact gardening and space weathering effect

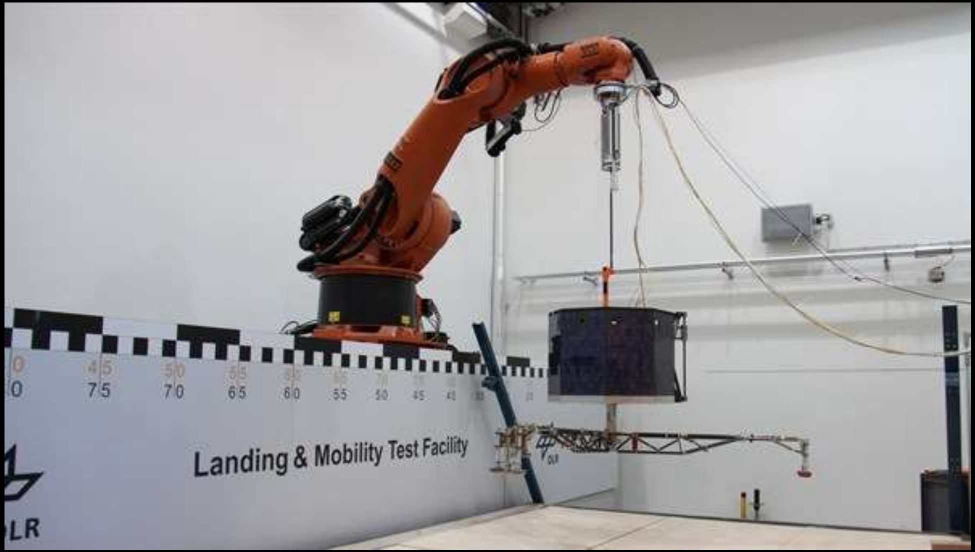
Mission Approach

Preparation

2018

Preparation

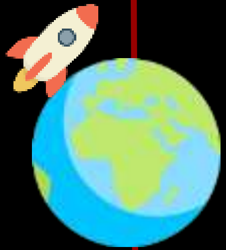
- Preliminary focus on observations
- Ground and space based
- Developing of scientific instruments
- Developing of technical solutions
- Setup sample curation facility



Mission Phases

Launch

Preparation

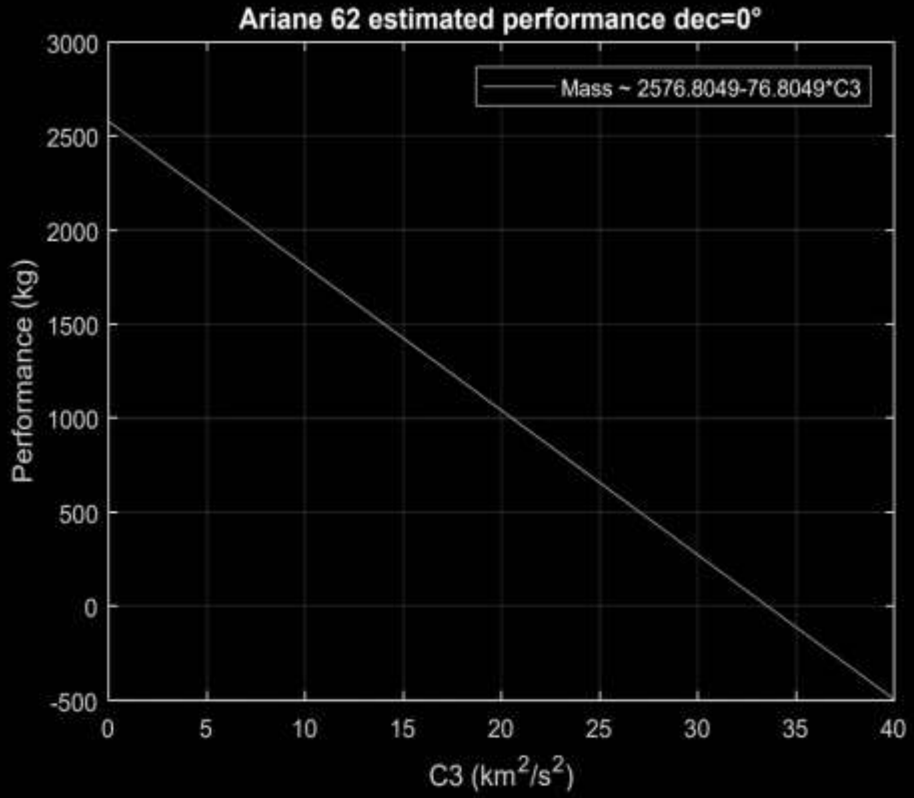


03/2029

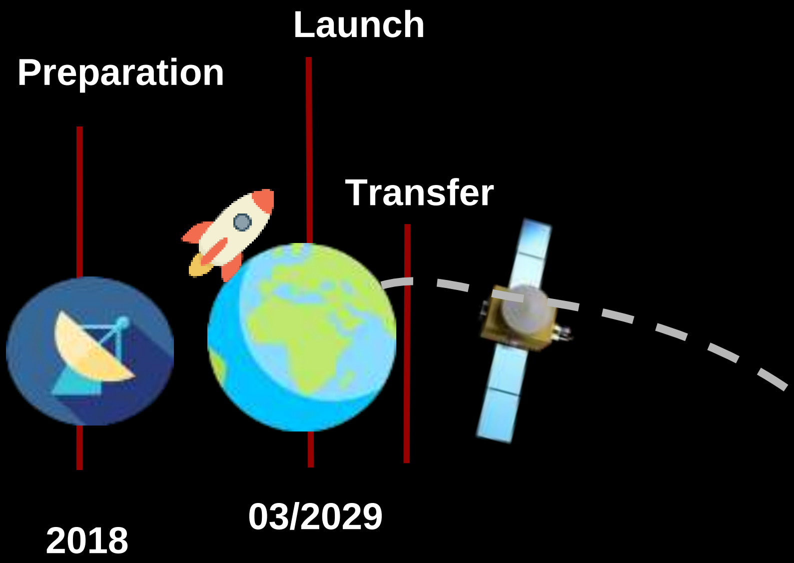
2018

Launch System

- Capability to transfer < 2.5 t
  Total Mass : 1839 kg
- Min natural vibration frequency: 30 Hz
- C3 =2.7 Km^2/s^2



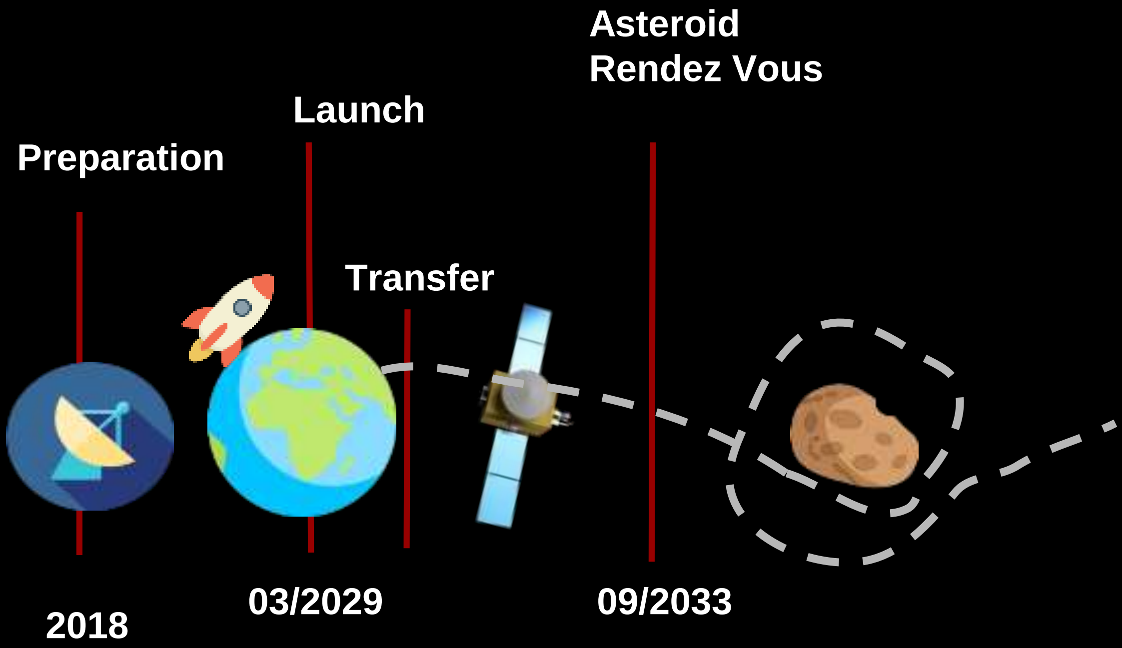
Mission Phases

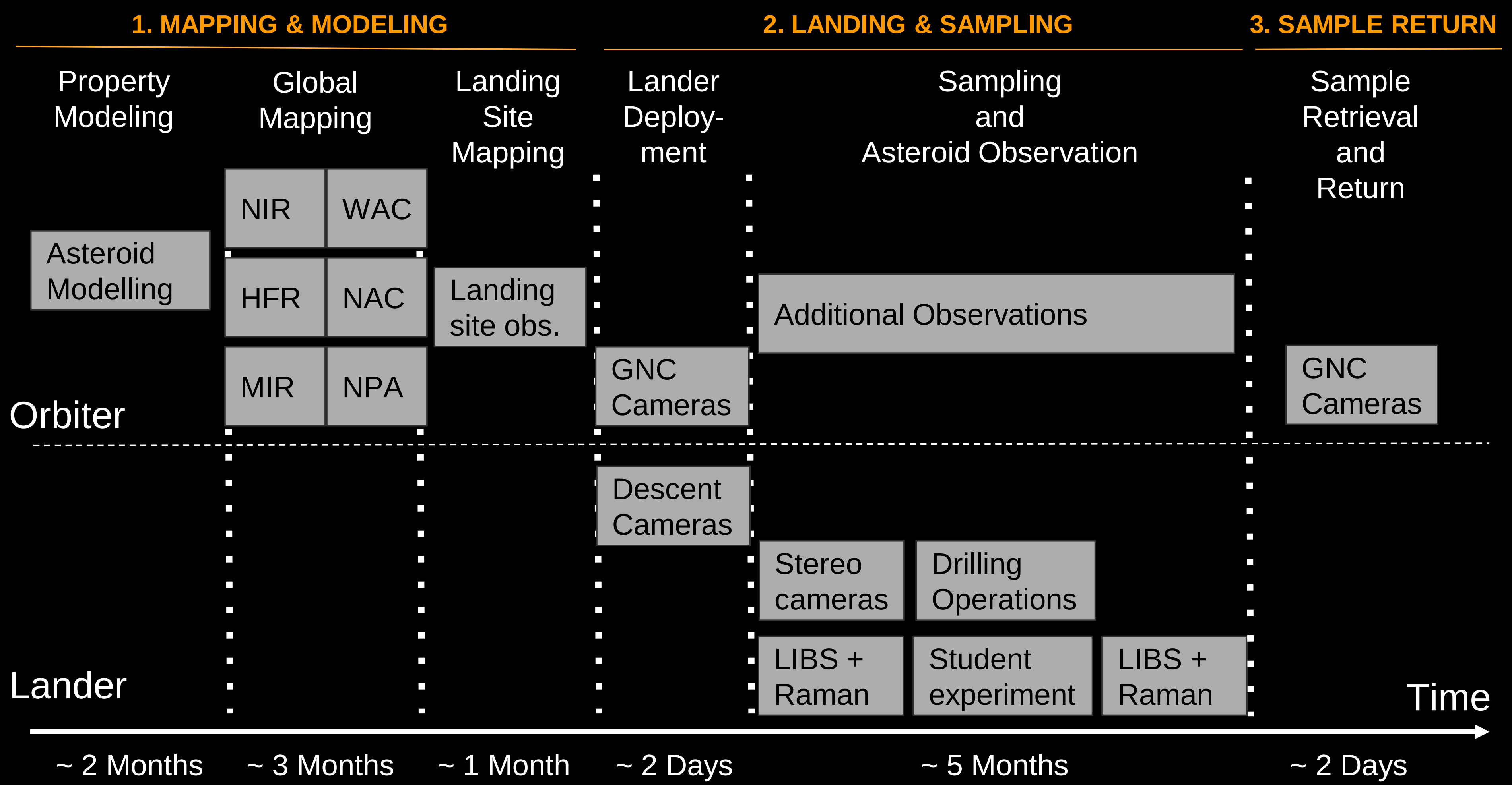


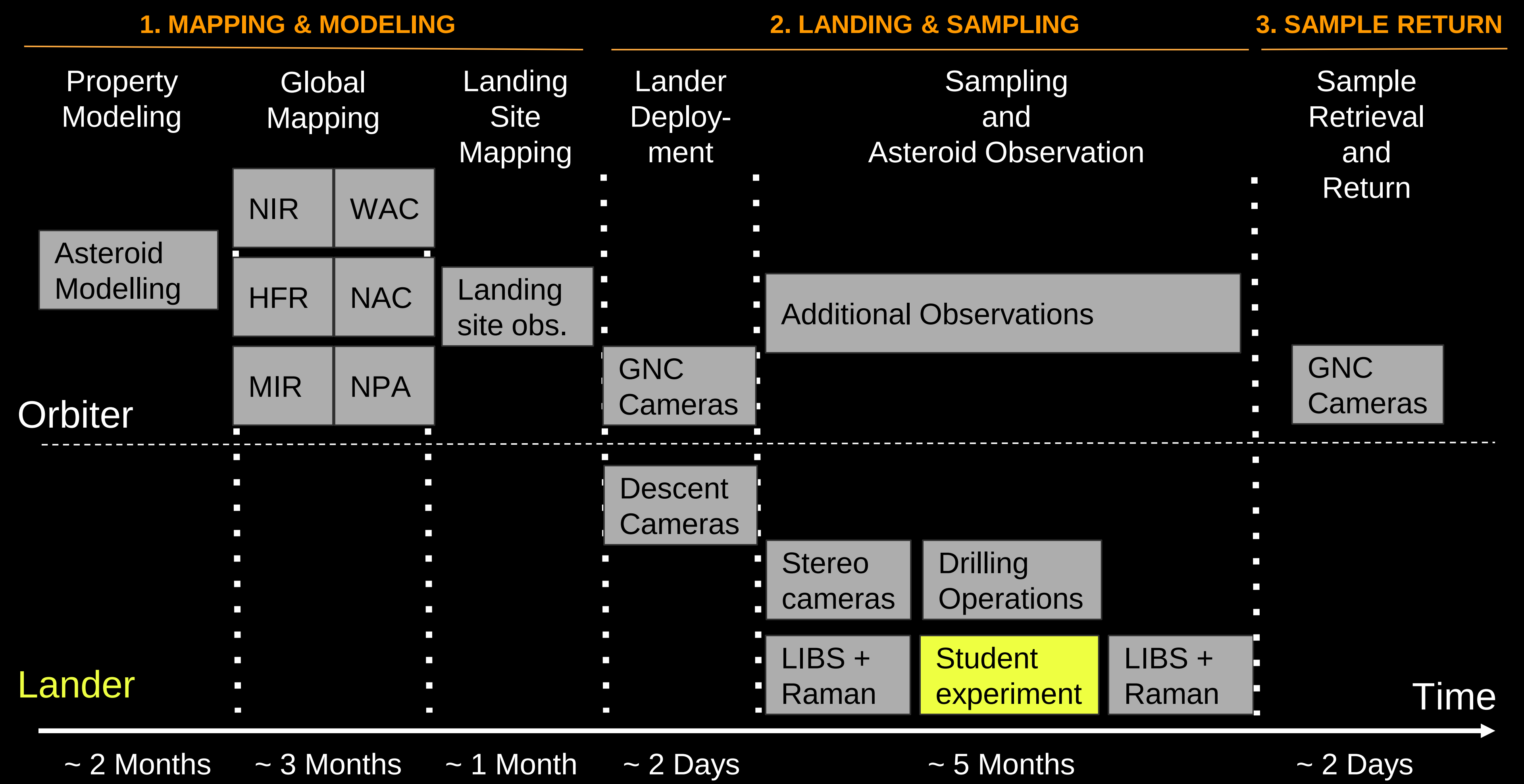
Orbit animation

Target	2002 AT4
Earth Departure	03/2029
Asteroid Arrival	09/2033
Asteroid Departure	08/2034
Earth Re-entry	06/2035
Outbound Delta V	7.0 km/s
Return Delta V	3.7 km/s
Re-entry velocity	11.8 km/s

Mission Phases




1. MAPPING & MODELING
2. LANDING & SAMPLING
3. SAMPLE RETURN
Property Modeling
Global Mapping
Landing Site Mapping
Lander Deploy-ment
Sampling and Asteroid Observation
Sample Retrieval and Return
Asteroid Modelling
NIR
WAC
HFR
NAC
MIR
NPA
Landing site obs.
Additional Observations
GNC Cameras
GNC Cameras
Orbiter
Descent Cameras
Stereo cameras
Drilling Operations
LIBS + Raman
Student experiment
LIBS + Raman
Lander
Time
~ 2 Months
~ 3 Months
~ 1 Month
~ 2 Days
~ 5 Months
~ 2 Days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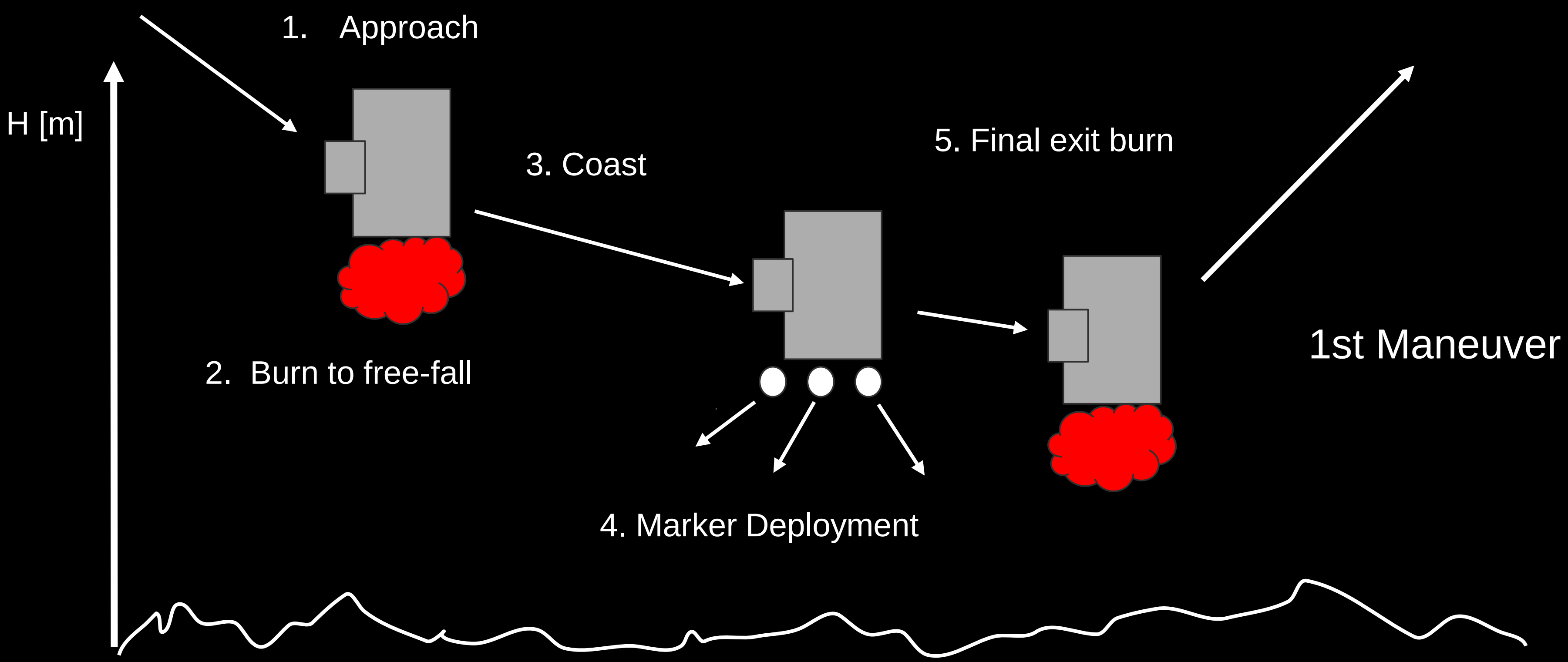
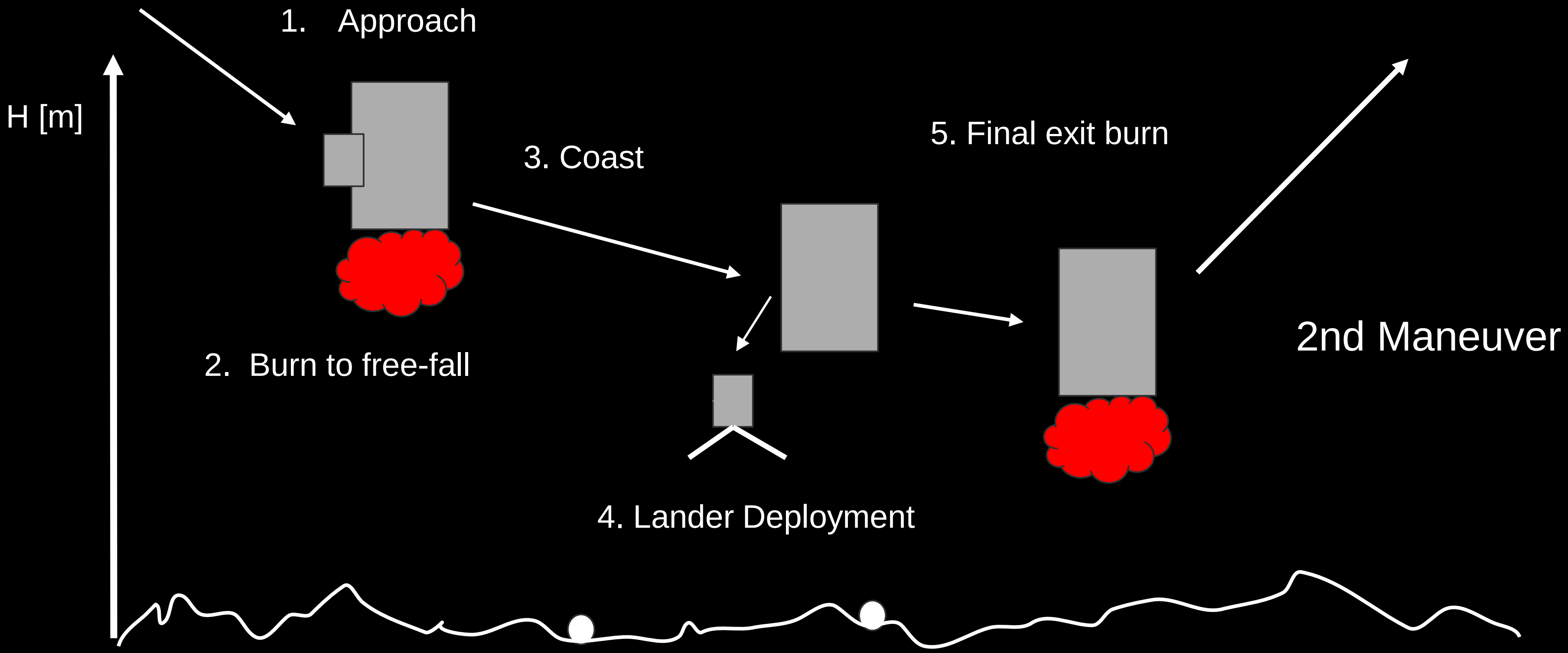
Landing & Sampling

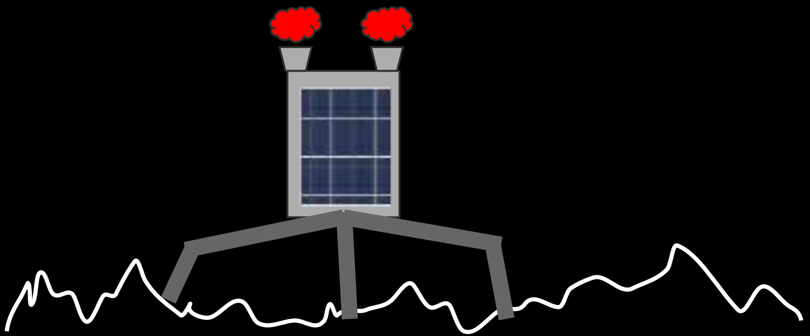
Landing Approach and Contamination Avoidance Maneuver (LACAM)



Landing Approach and Contamination Avoidance Maneuver (LACAM)



Sampling - Lander



- Principle: harpoons for anchoring (4) + cold gas thrusters + feet screws.
- Harpoons to attach to the surface.
- Anchoring at touchdown (screws).

Lessons Learned from Philae

Philae heritage → experiences

- Harpoons didn't fire
    - Heating Pyro wrong?
    - Degrading of Pyro?
    - No current in wire?
    - Leakage?

- Cold-gas thruster didn't work
    - Nail didn't penetrate membrane?

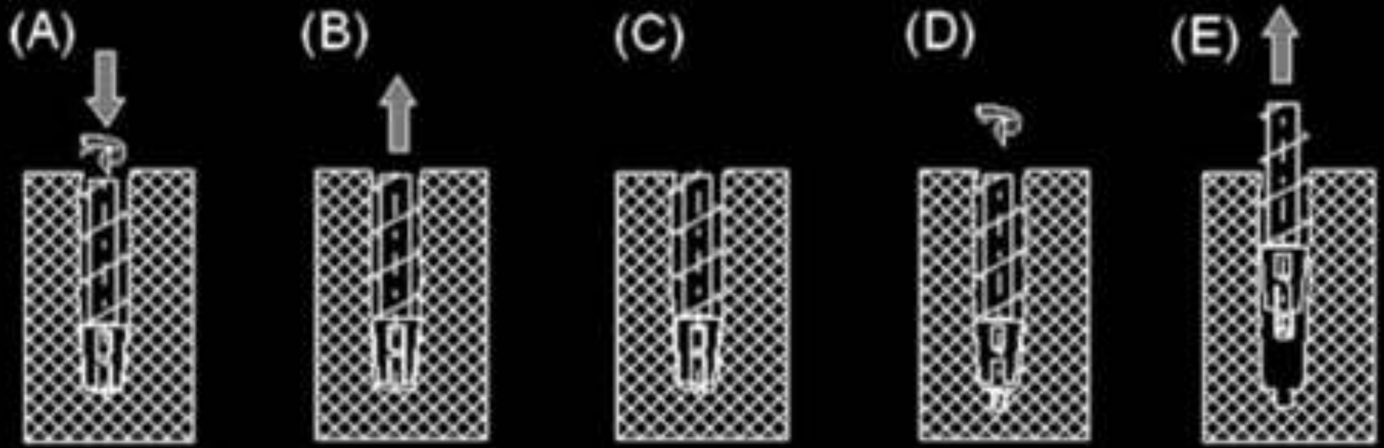
Lessons Learned from Philae

Philae heritage → improvement

- Two different pyro materials
  - For each harpoon
  - Avoid degradation
  - Seal chamber
- COTS Thrusters
  - Flight tested
- Decreased Development Cost
  - Test data available

Sampling - Drilling

- Several samples (same site) at known depths
- Use thermal probe for temperature profile
- Slow drilling to avoid cohesion
- Drilling depth: 20 cm

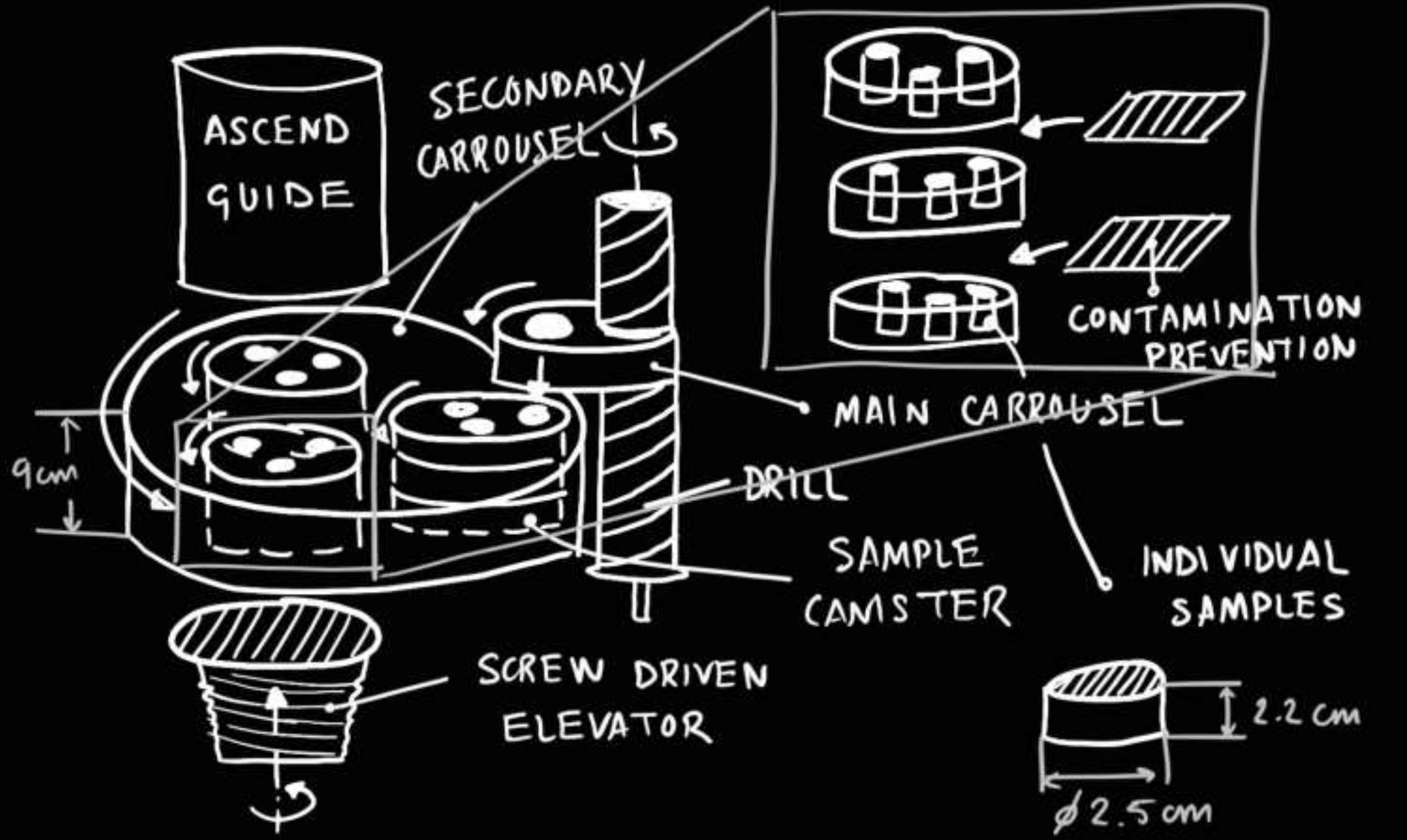


Drilling Phase | 1mm up | Sampling tube release | Drill rotation | Sample transport

Sample Drilling Risk Mitigation

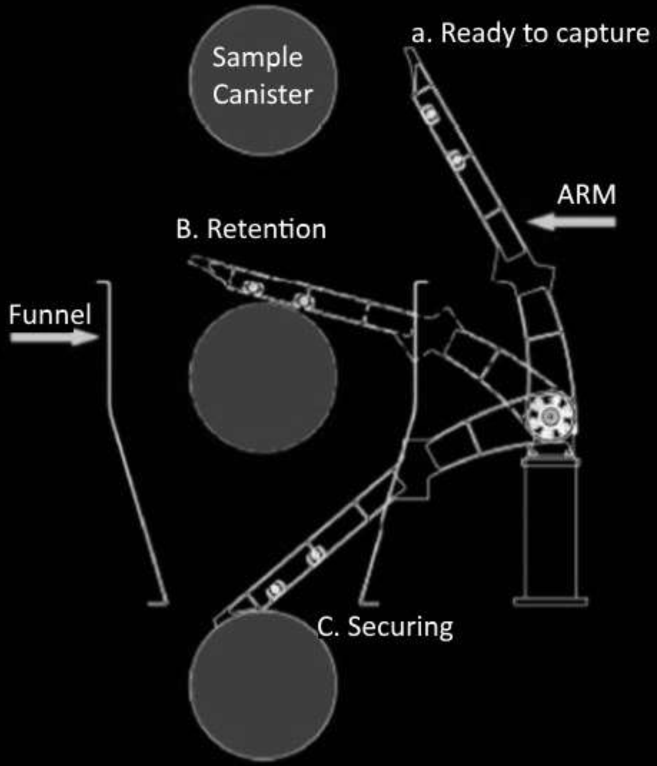
- Lander body rotates on base
- Allows multiple drilling sites
- Mitigate drilling obstacle risk

Sampling - Drilling



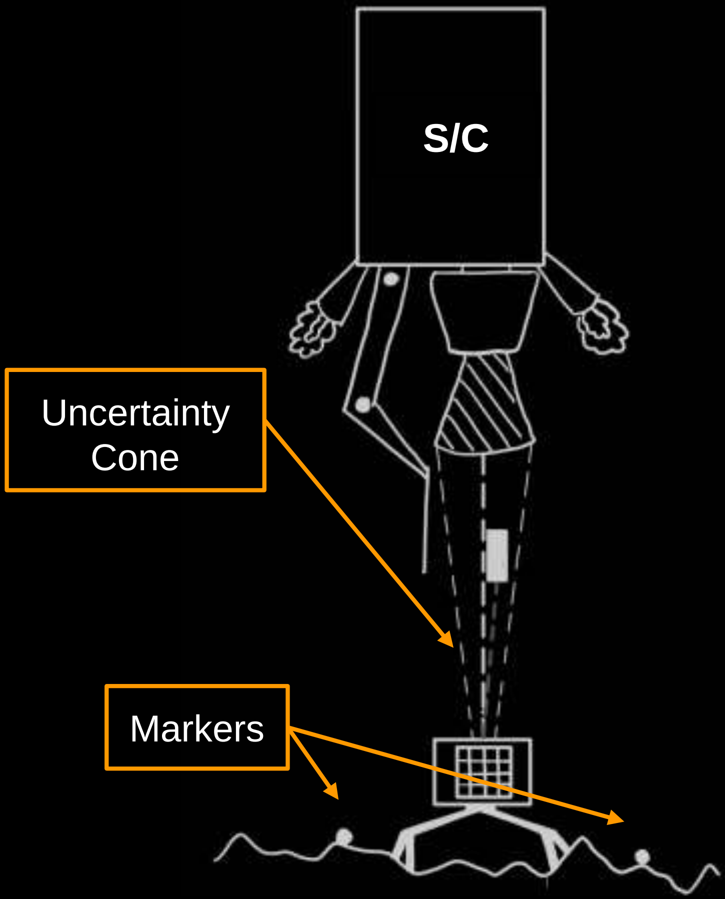
Sample capture

- Sample Canister Capture Mechanism (Carta et al. 2015)



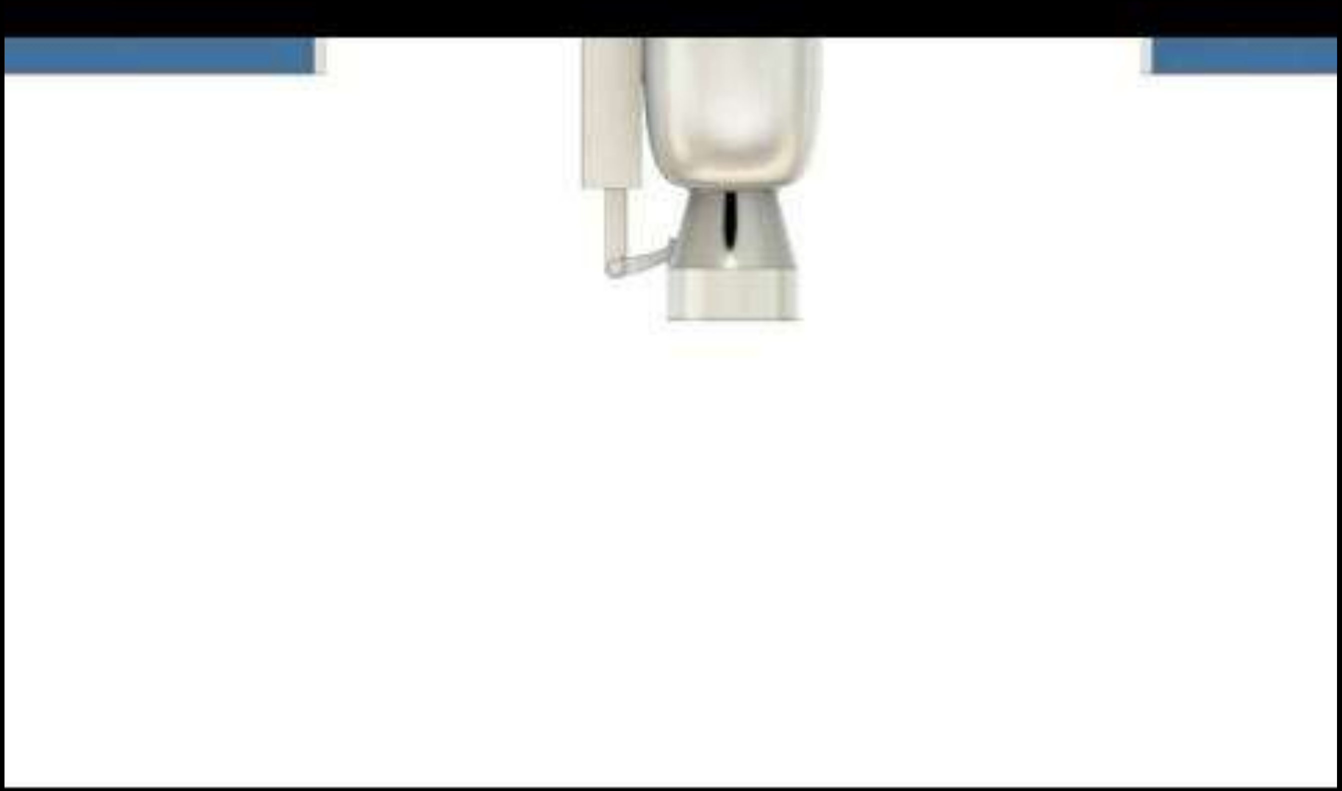
Adapted from Carta et al. 2015

Sample Capture

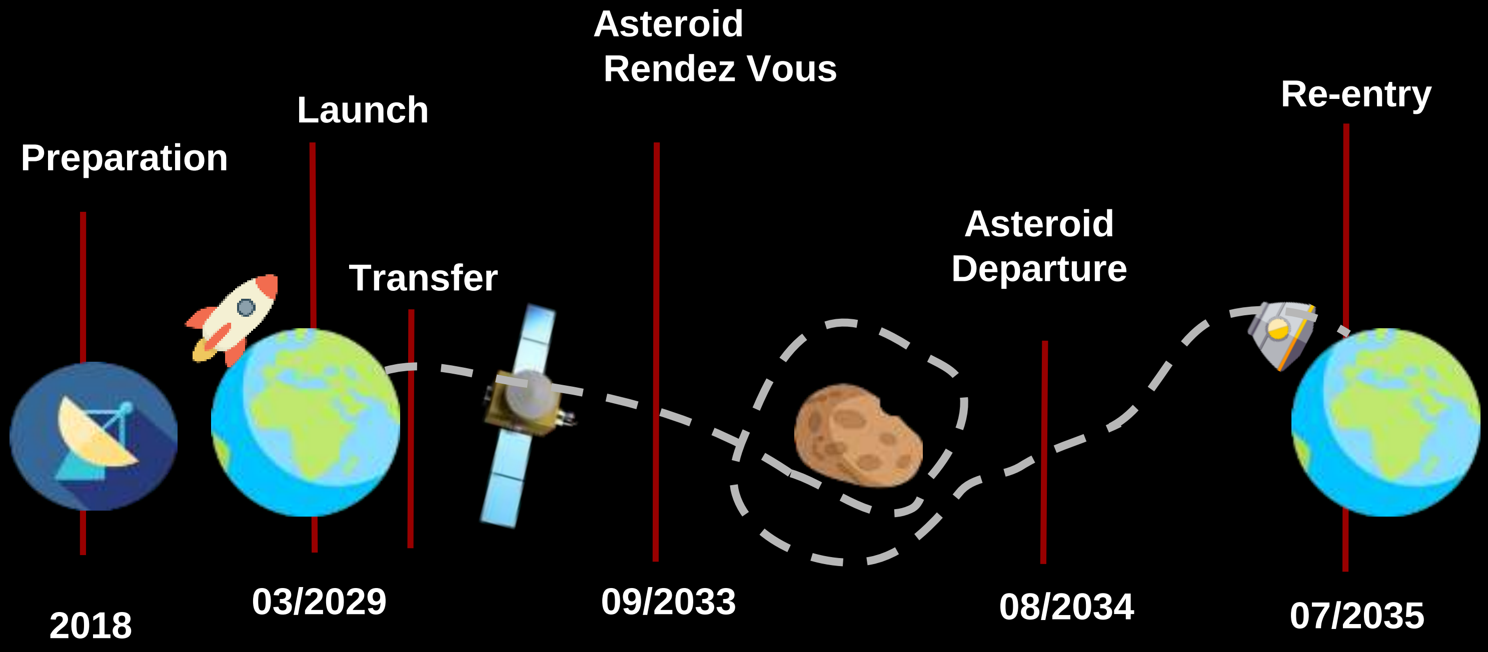


- Optical camera tracks the Sample Return Vehicle
- S/C hovers (body-fixed) at 20 m
- 5 - 15 cm/s docking speed
- Perform test maneuvers before
- Orbiter-Lander Horizon Synchronization
- TRL 6 (Carta et al. 2015)

Sample Capture



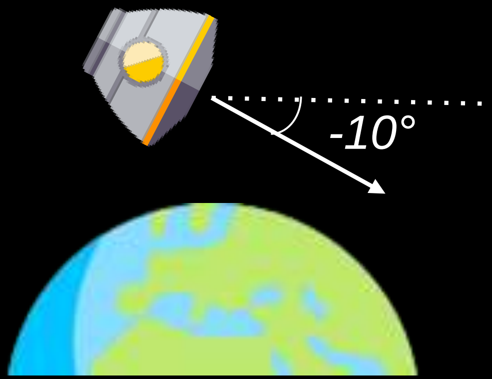
Mission Phases



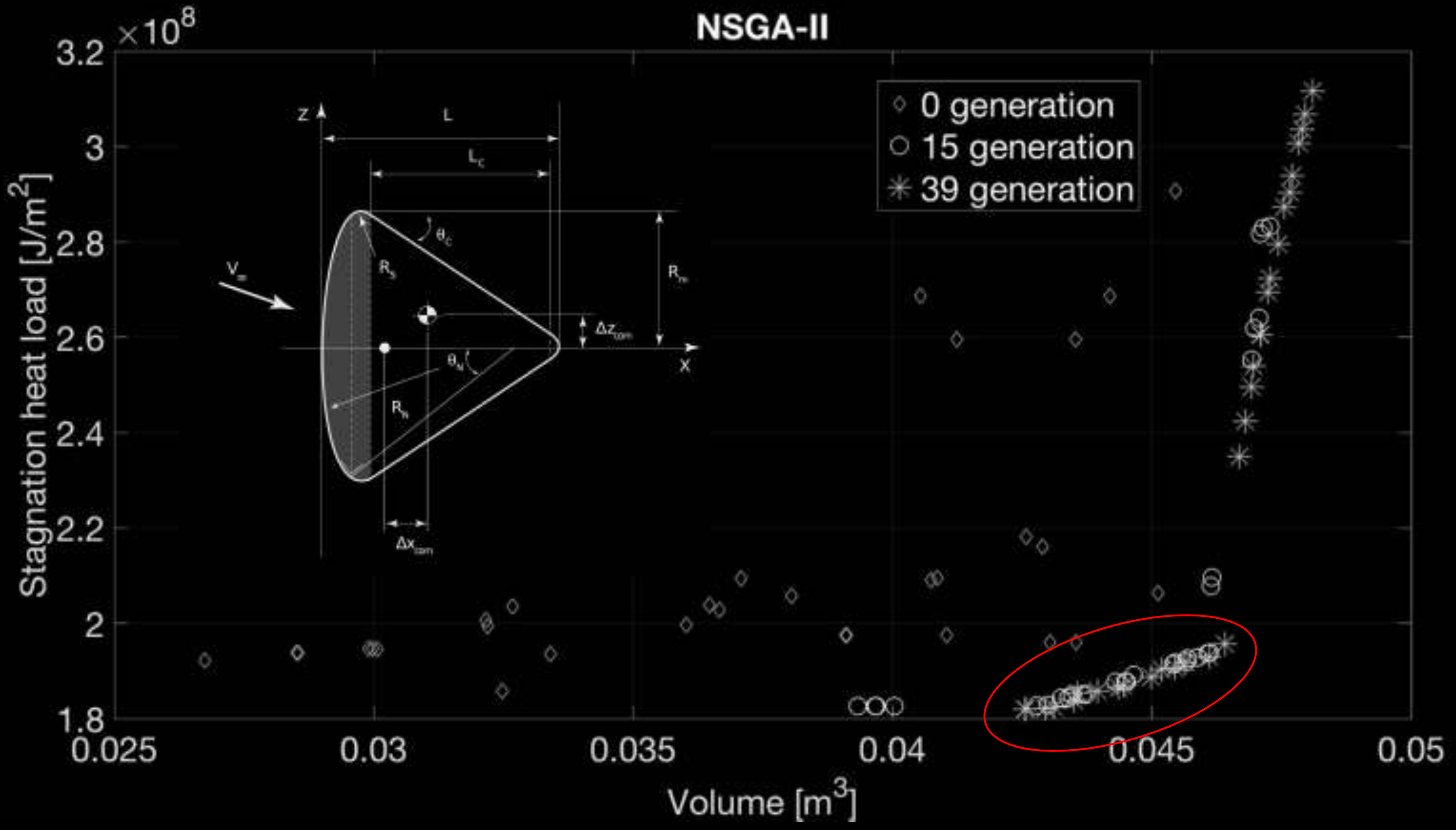
Entry Conditions:

- Precise landing site → Entry Flight Path Angle: *-10°*
- Maximum stag. heat flux: 10^7 W/m^2
- Max G-Load: *50 g*

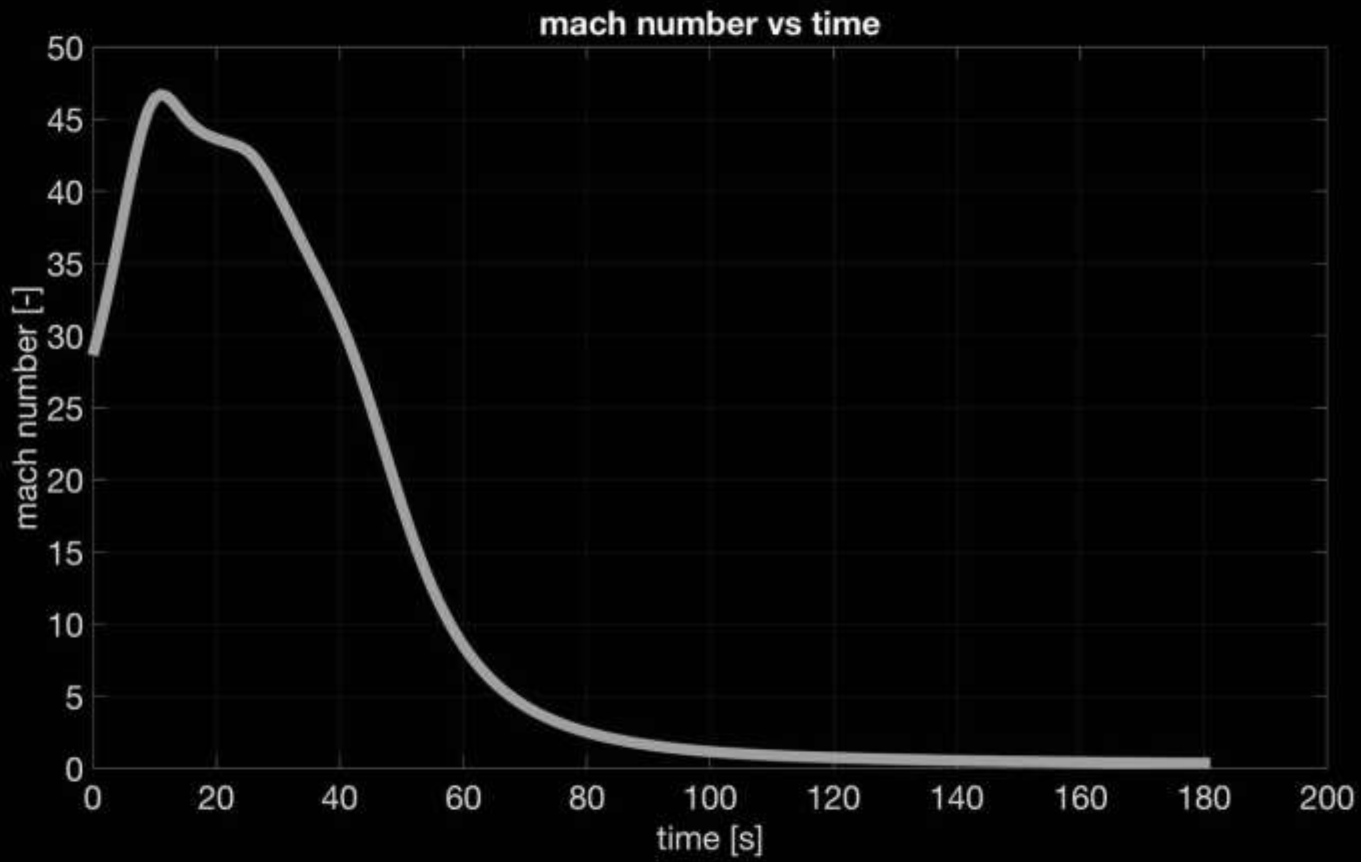
Max Entry Velocity of *12.3 km/s*



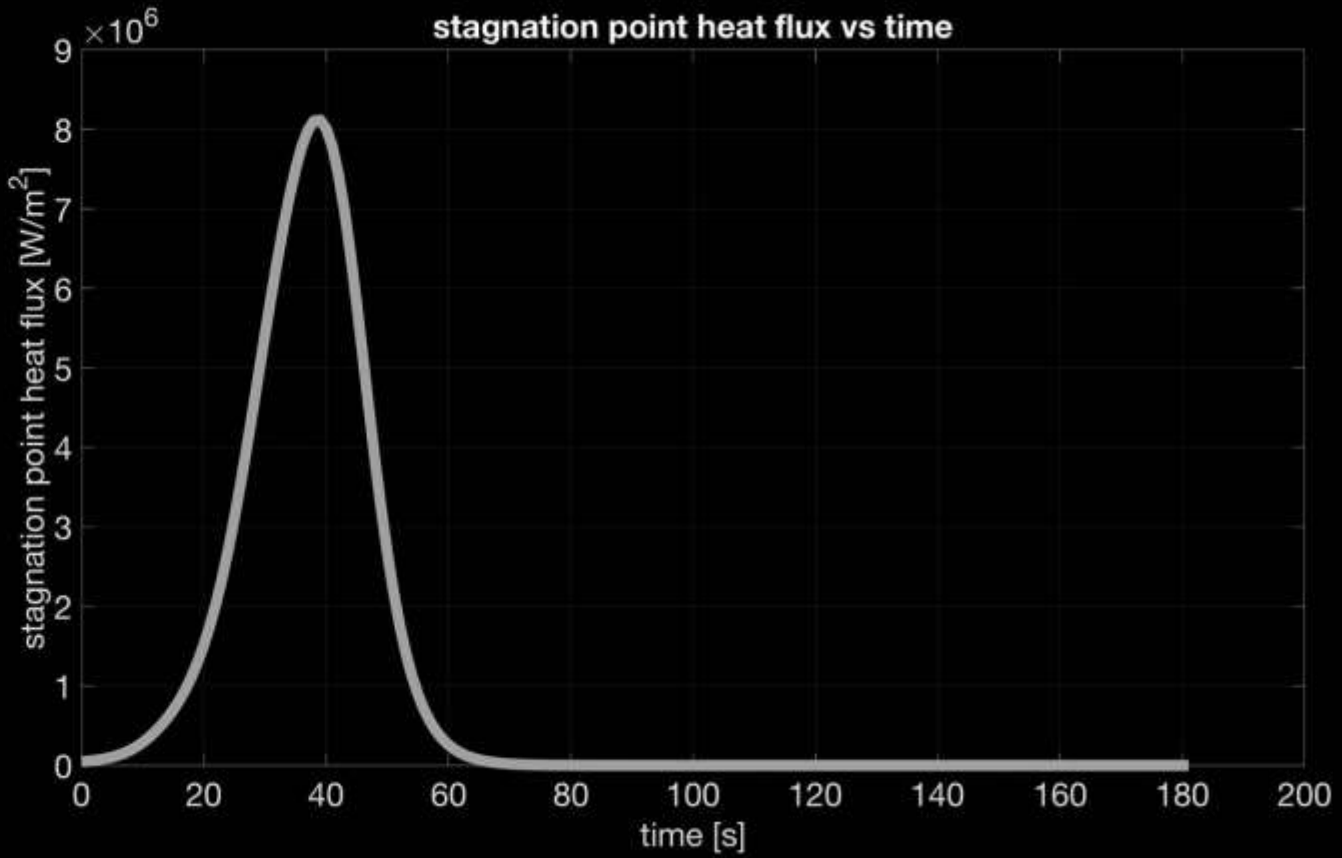
Re-Entry: Optimization procedure (NSGA-II)



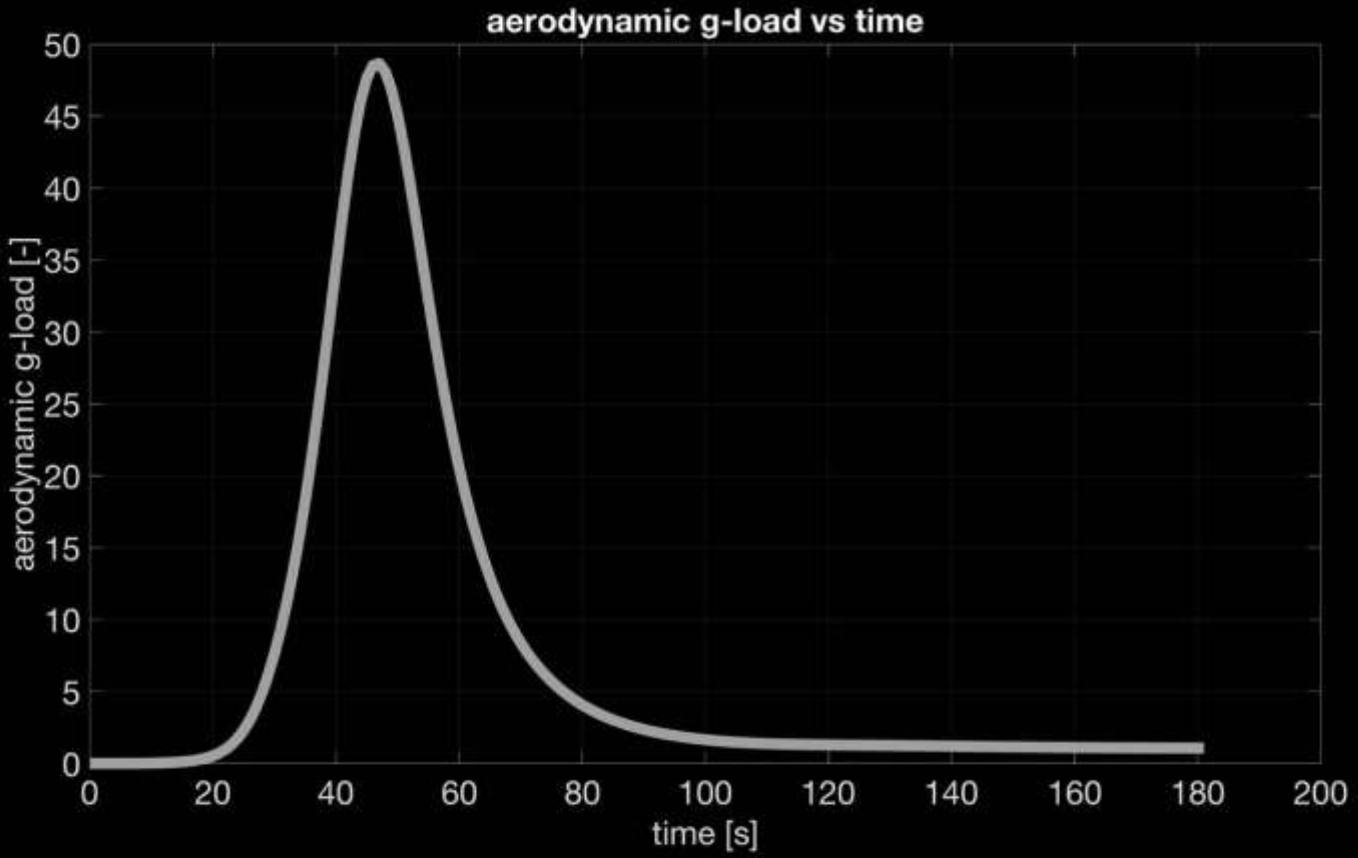
Re-Entry Trajectory Simulation: Mach Number



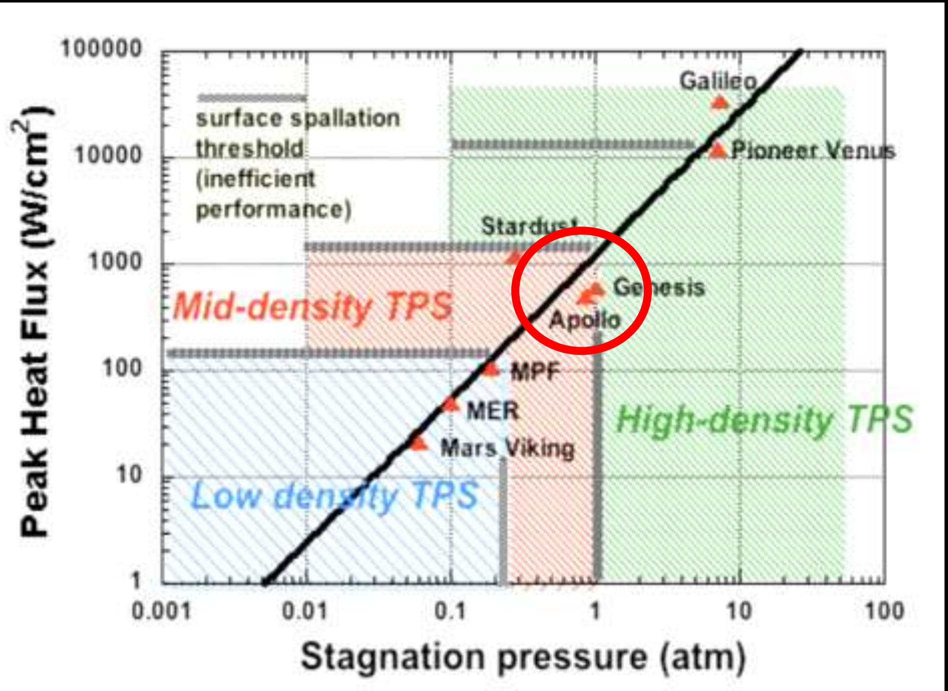
Re-Entry Trajectory Simulation: Stagnation Point Heat Flux



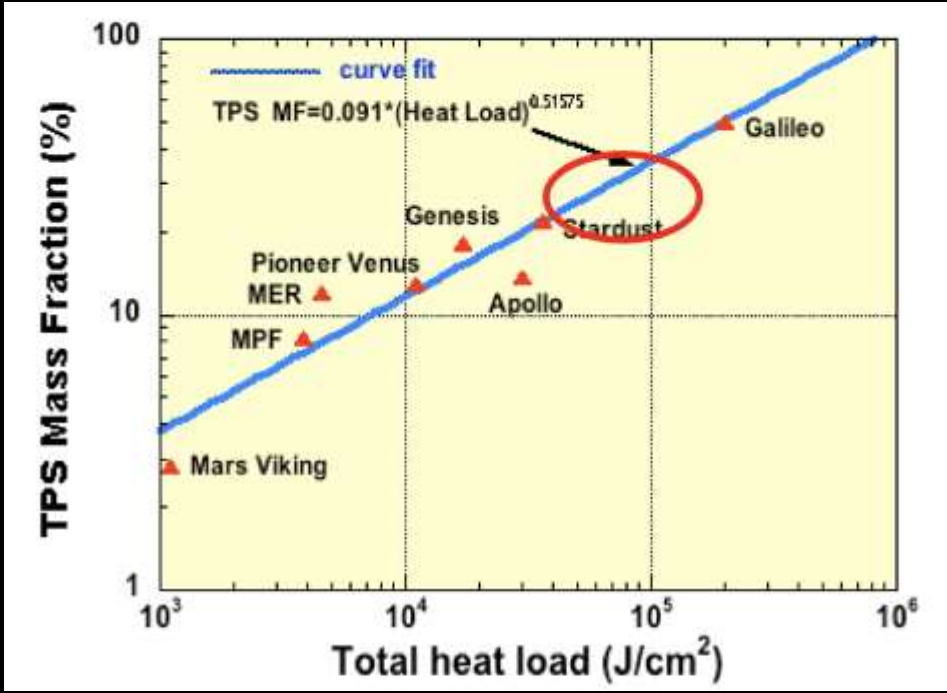
Re-Entry Trajectory Simulation: Aerodynamic g-Load



TPS design



surface spallation threshold (inefficient performance)
Galileo
Pioneer Venus
Stardust
Genesis
Apollo
MPF
MER
Mars Viking
Mid-density TPS
High-density TPS
Low density TPS
Peak Heat Flux (W/cm²)
Stagnation pressure (atm)
100000
10000
1000
100
10
1
0.001
0.01
0.1
1
10
100



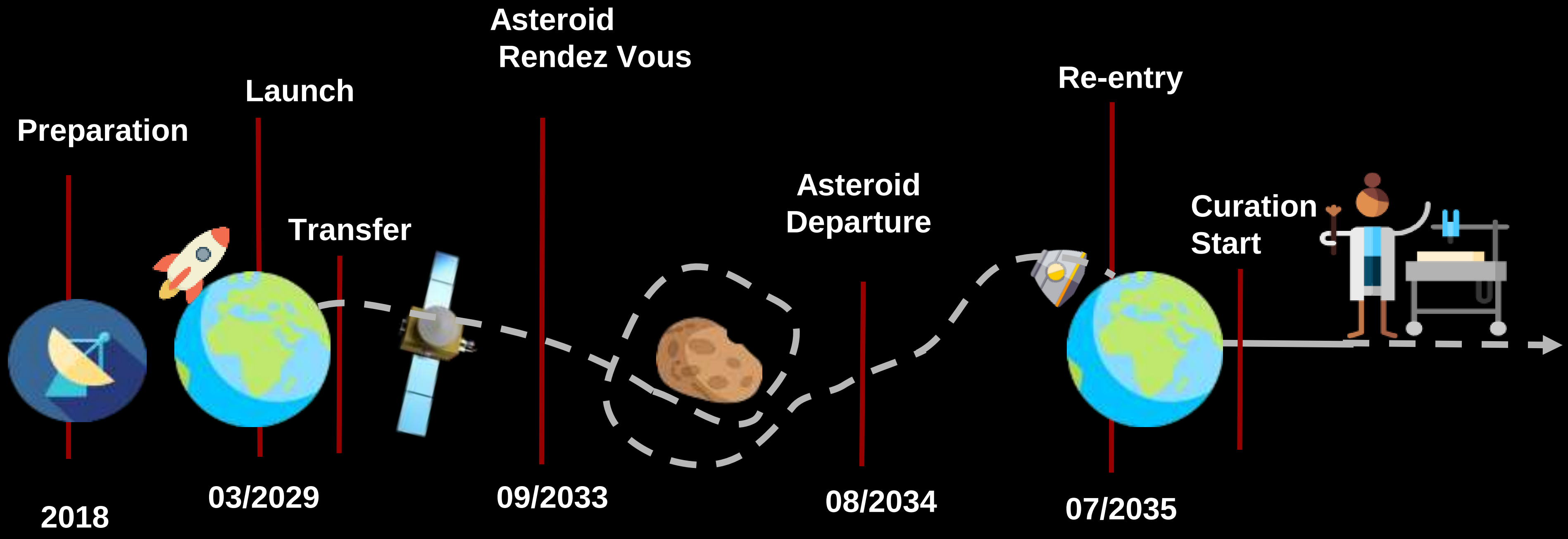
curve fit
TPS MF=0.091*(Heat Load)^0.51575
Galileo
Genesis
Stardust
Pioneer Venus
MER
Apollo
MPF
Mars Viking
TPS Mass Fraction (%)
Total heat load (J/cm²)
100
10
1
10³
10⁴
10⁵
10⁶

Parachute

- Used for soft landing
- Opens at 11 km altitude and Mach number of 0.34
- Impact speed 3 m/s
  → area of main parachute: 7 m^2

Source: NASA

Mission Phases



Curation Phase on Earth

Sample Catalogue

↓

Sample preparation

↓

Contamination markers

↓

Sample Analysation

Microscope (Brunnel)

High precision balances

Integrated prep systems

Grind and polish system

X-Ray Photoelectron Spectroscopy (XPS)

Clean Room (ISO 14644-1)

Residual Gas Analyzer

RTF/Raman spectrometer

Spacecraft - Preliminary Design

Margins Concept

Name	Specifications	Margins
Equipment	off-the-shelf items (no changes)	5%
	off-the-shelf items (minor changes)	10%
	off-the-off-the-shelf items (major changes)	15%
Systems (at least 20%)	Equipments System	20%
	Propellant System	10% Margin+2%residual
		Margin on maximum separated mass

Mass and power Budget - Total Spacecraft

	Mass (kg)	Power cons. (W)	Margin (%)	Final mass (kg)	Final power cons. (W)
1 Spacecraft	**1199**	**10286**	**20**	**1438**	**12343**
1.1 Main propulsion system	171	9450	0	171	9450
1.1.1 Engine + PPU	130	9000	5	137	9450
1.1.2 Tanks	41	0	10	45	0
1.2 Attitude orbit control system (dry)	86	50	5	90	53
1.3 Thermal control system	76	250	20	91	300
1.4 Power	245	0	0	245	0
1.4.1 Solar arrays + PPU	229	0	5	240	0
1.4.2 Batteries	5	0	5	5	0
1.5 Onboard computer + PL data handling	10	20	10	11	22
1.6 Rendezvous device	40	10	20	48	12
1.7 Reentry capsule	50	20	20	60	24
1.8 Telemetry, tracking and commanding	90	220	5	95	231
1.9 Payload / instrumentation	23	162	20	27	194
1.10 Structure & mechanisms	300	0	20	360	0
2 Propellant					
2.1 Xenon	378	0	10	416	0
2.2 Hydrazine (AOCS)	95	0	10	104	0

Mass and power Budget - Lander

	Mass (kg)	Power cons. (W)	Margin (%)	Final mass (kg)	Final power cons. (W)
3 Lander	**122**	**236**	**20**	**146**	**283**
3.1 Structure	28	0	20	34	0
3.2 Attitude orbit control system	3	10	5	3	11
3.3 Thermal control system	4	10	20	5	12
3.4 Drill	5	12	20	6	14
3.5 Balancing mechanical support	4	6	20	5	7
3.6 On board computer	1	5	20	1	6
3.7 Electrical power supply	12	100	20	14	120
3.8 Communication	7	15	20	8	18
3.9 Payload / instrumentation	32	58	20	39	69
3.10 Return capsule	26	20	20	31	24

Mass, power and data Budget - Instrumentation

	Mass (kg)	Power cons. (W)	Margin (%)	Final mass (kg)	Final power cons. (W)	Data volume (Mbit/day)	Data volume w/ margin (Mbit/day)
1.9 Spacecraft instrumentation	**23**	**162**	**20**	**27**	**194**	**4399**	**5278**
1.9.1 Wide Angle Cam	2,0	12	5	2	12	1125	1181
1.9.2 High freq radar	0	88	5	0	92	0	0
1.9.3 Narrow angle cam	9	14	5	9	14	134	141
1.9.4 Low freq radar	2	10	5	2	11	36	38
1.9.5 Mid Infrared Spectrometer	3	2	5	3	2	2880	3024
1.9.6 Vis near Infrared	4	18	5	4	19	14	14
1.9.7 Neutral particle analyzer	2	11	5	2	12	1	1
1.9.8 LASER altimeter	4	22	5	4	23	10	11
2.8 Lander instrumentation	**32**	**58**	**20**	**39**	**69**	**132**	**159**
2.8.1 Low freq radar (passive)	0	10	5	0	11	36	38
2.8.2 Panoramic camera	13	11	5	14	12	12	13
2.8.3 LIDAR (based on BELA)	7	14	5	7	14	0	0
2.8.4 Descent Cam	0	2	5	0	2	73	77
2.8.5 LIBS+Raman	11	18	5	11	19	4	4
2.8.6 Student experiment	1	5	20	1	6	0	0

Total masses

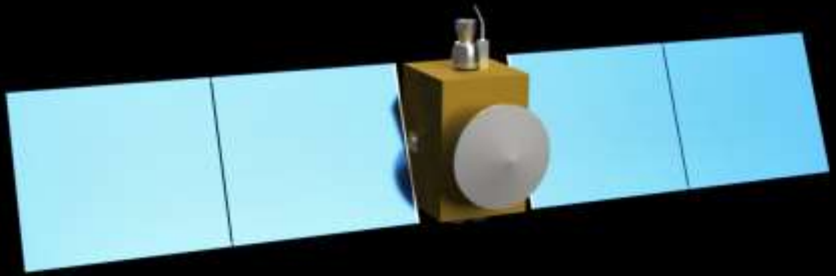
Total mass (kg)	1958
Total dry mass (kg)	1438
Total propellant mass (kg)	520

Public Outreach and University Project

- Space left for additional experiment(s) on Lander
  - Volume: 40cm x 15cm x 15cm
  - Power: 5 W
  - Mass: 1 kg

Preliminary S/C Design - Structure & Mechanism - Requirement

1. Survive launcher vibration and acoustic environment - acceleration and frequency values in launcher user guide
2. Support spacecraft subsystems



Preliminary S/C Design - Propulsion

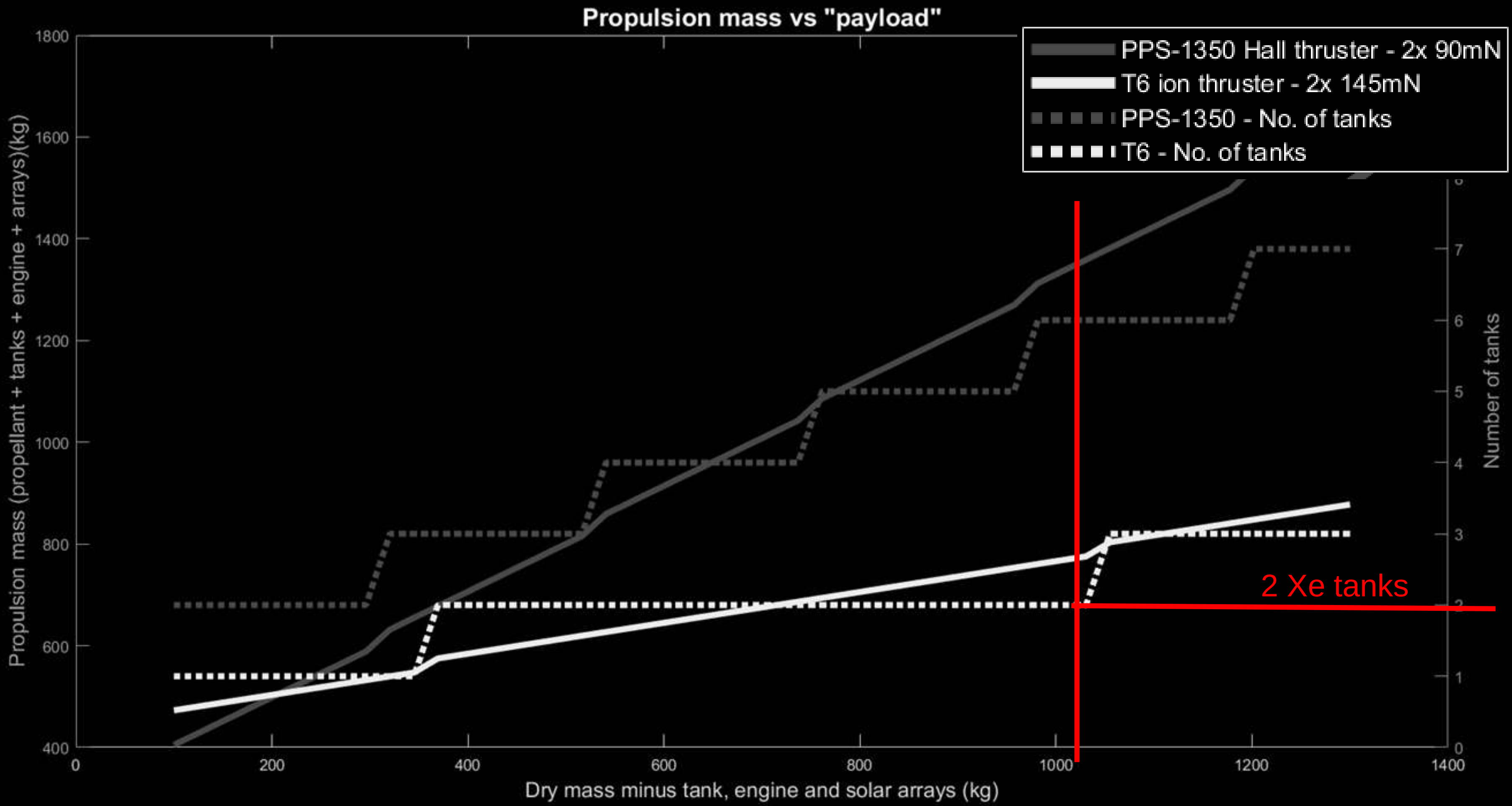
European electric thrusters chosen for study: T6 and PPS-1350

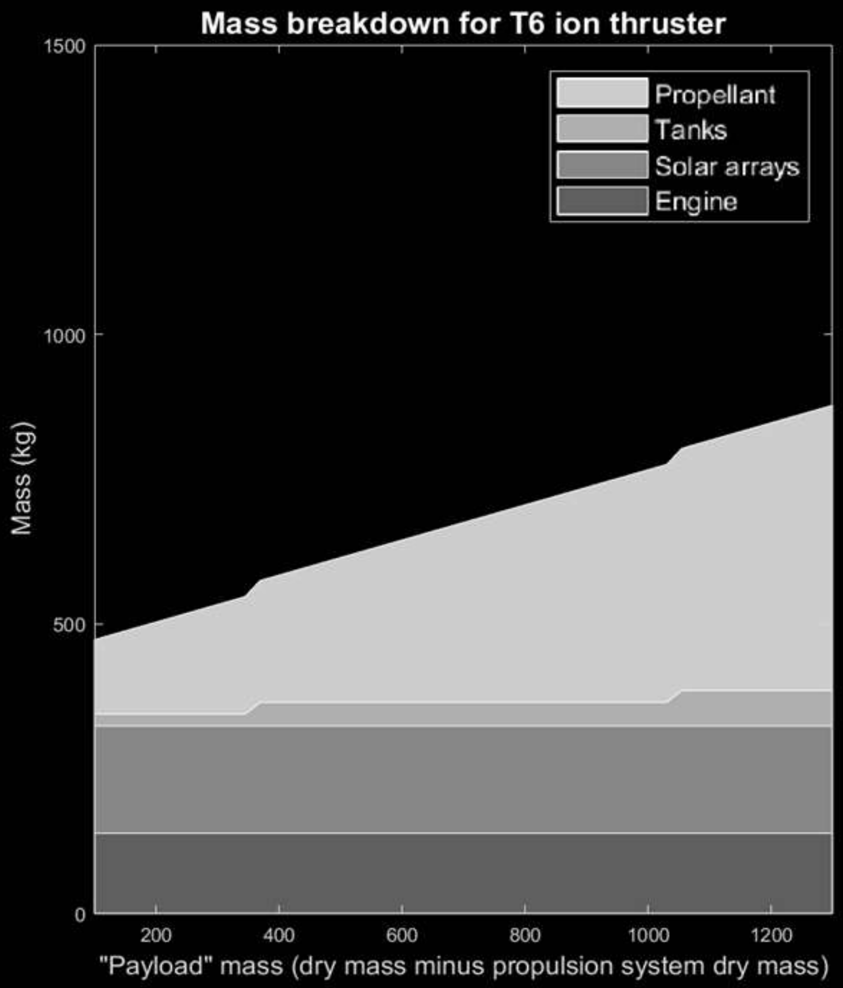
	T6 ion thruster	**PPS-1350 Hall thruster**
Thrust per engine	145 mN	90 mN
Nominal power	5 kW	1.5 kW
Specific impulse	4120 s	1650 s
Missions using thruster	BepiColombo (Mercury)	SMART-1 (Moon)
Mass of 4 engines	~ 130 kg	~ 84 kg

Preliminary S/C Design - Propulsion

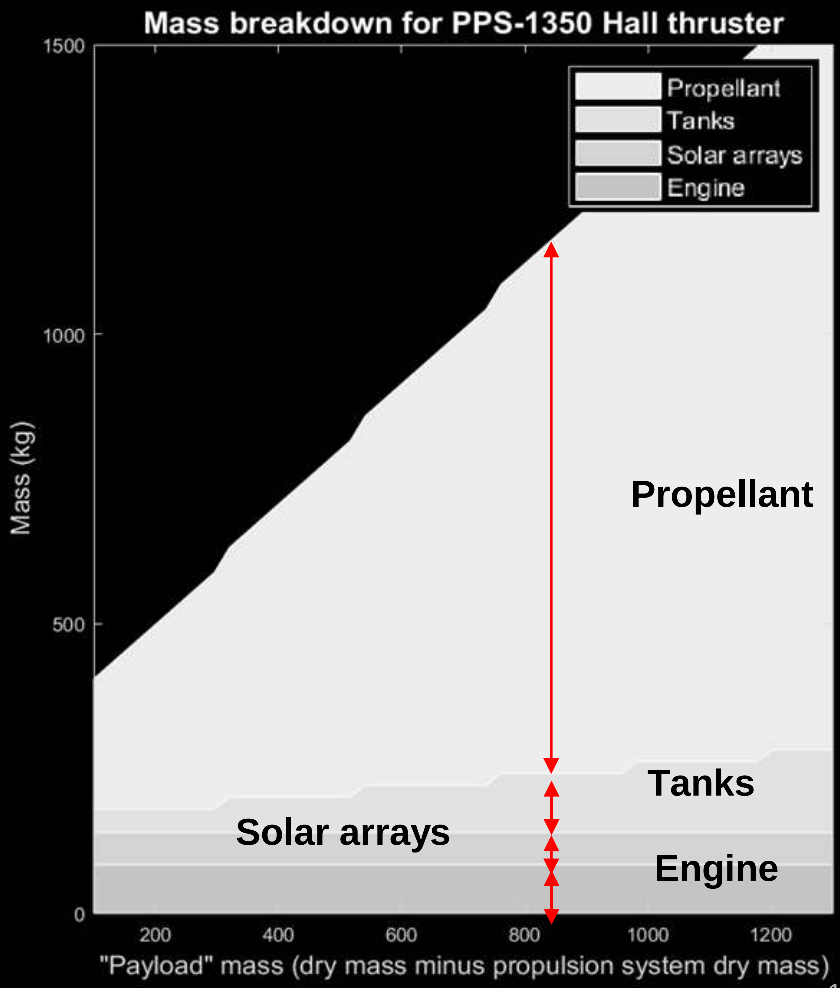
European electric thrusters chosen for study: T6 and PPS-1350

- Simulated and studied 2 engines working at a time
- S/C has 4 engines for redundancy
- Simulations suggest PPS-1350 more efficient in overall mass when:
  - Δv is low
  - Payload mass is low


Propulsion mass vs "payload"
PPS-1350 Hall thruster - 2x 90mN
T6 ion thruster - 2x 145mN
PPS-1350 - No. of tanks
T6 - No. of tanks
2 Xe tanks
Propulsion mass (propellant + tanks + engine + arrays)(kg)
Number of tanks
Dry mass minus tank, engine and solar arrays (kg)
1800
1600
1400
1200
1000
800
600
400
0
200
400
600
800
1000
1200
1400
7
6
5
4
3
2
1
0



Mass breakdown for T6 ion thruster
1500
1000
500
0
Mass (kg)
Propellant
Tanks
Solar arrays
Engine
200
400
600
800
1000
1200
"Payload" mass (dry mass minus propulsion system dry mass)



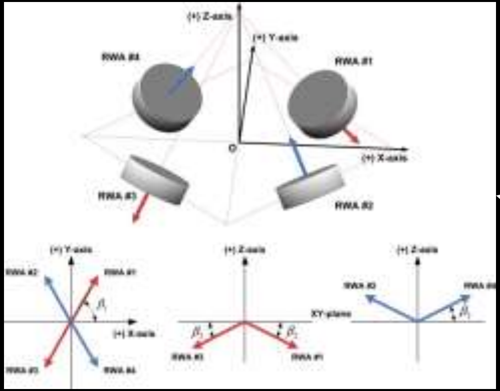
Mass breakdown for PPS-1350 Hall thruster
1500
1000
500
0
Mass (kg)
Propellant
Tanks
Solar arrays
Engine
Propellant
Tanks
Solar arrays
Engine
200
400
600
800
1000
1200
"Payload" mass (dry mass minus propulsion system dry mass)

Propulsion system mass budget

	Mass (kg)	ESA margin (%)	Final mass (kg)
4 engines	130	5	136.5
2 Xe 208 litre tanks	40,8	5	42.8
Xe	378	10	416

Preliminary Orbiter Design
GNC/AOCS

Yoon et al. 2014



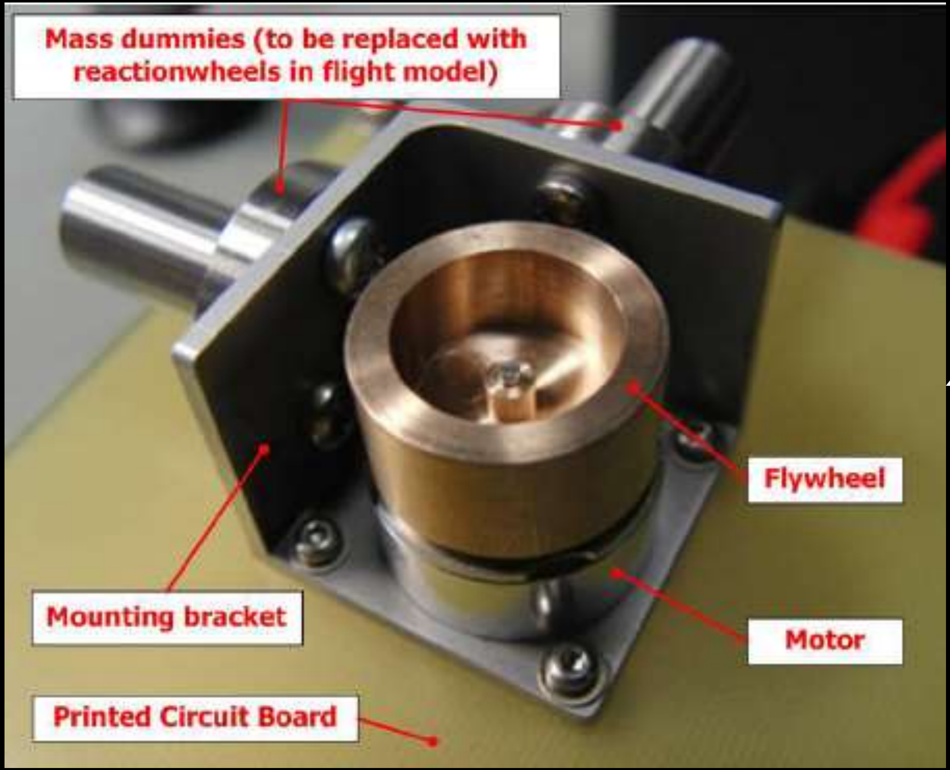
Actuators

- 4 Reaction Wheels
- 16 monopropellant thrusters
- 4 low thrust monopropellant thrusters for hovering

Sensors

- 2 Optical Navigation Cameras
- 2 star trackers
- 4 Sun Sensors
- 2 laser ranger
- 3 IMU
  - 3 Laser Ring Gyros
  - 3 Accelerometers

Preliminary Lander Design - GNC/AOCS



Actuators

- 1 flywheel
- 2 cold gas thrusters

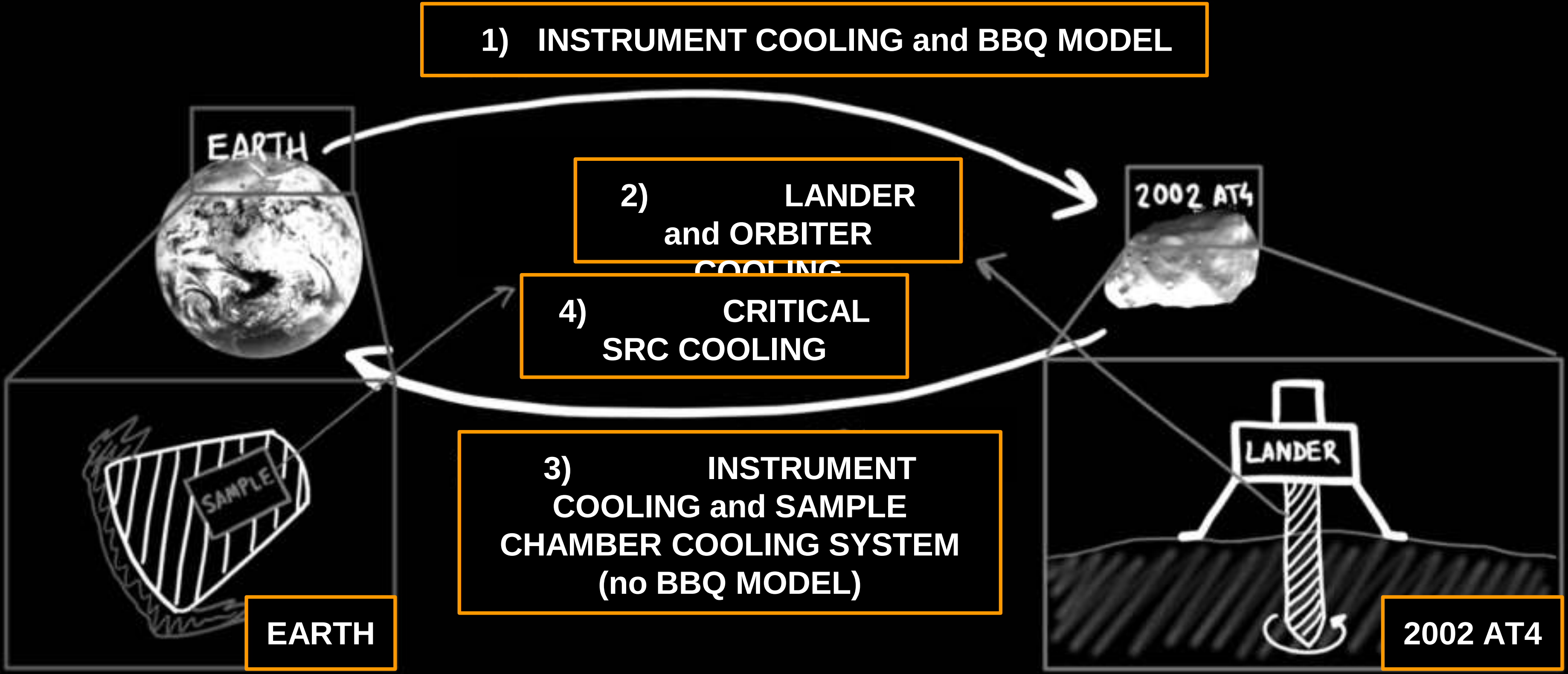
Thermal Control System Requirements:

- **TCS-001:** The TCS shall maintain the temperature inside the spacecraft bus between **263K (-10ºC)** and **293K (20°C)**, with an optimal temp of **278K (5ºC)**

- **TCS-002:** The TCS shall maintain the temperature of the sample at optimal of **263K (-10ºC)** and absolute maximum of **313K (40ºC)**. Exceptionally, it can be heated **323K (50ºC)** during the reentry for a max period of 2 hours.

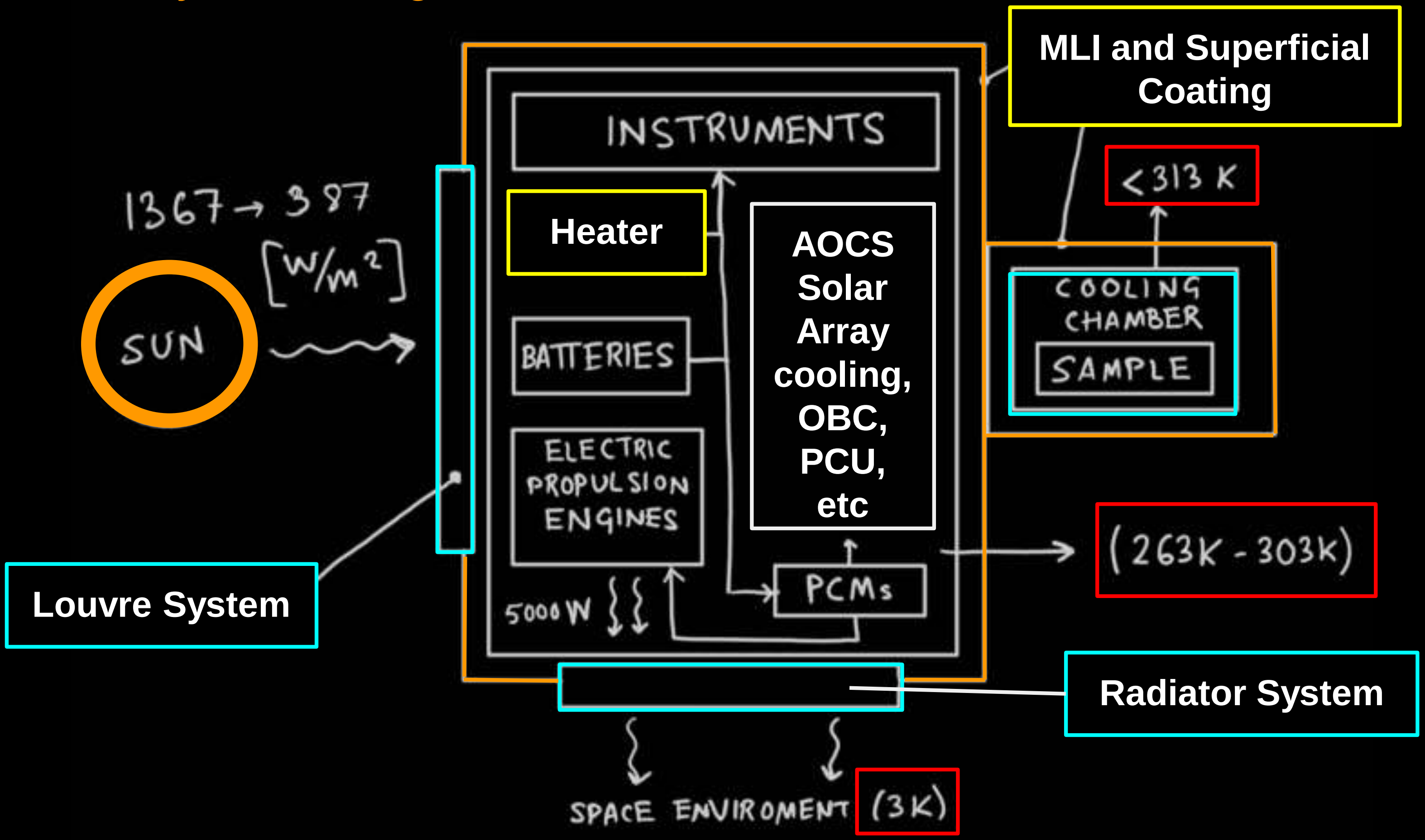
Preliminary S/C Design - TCS

CONCEPTUAL DESIGN



Preliminary S/C Design - TCS

CONCEPTUAL DESIGN

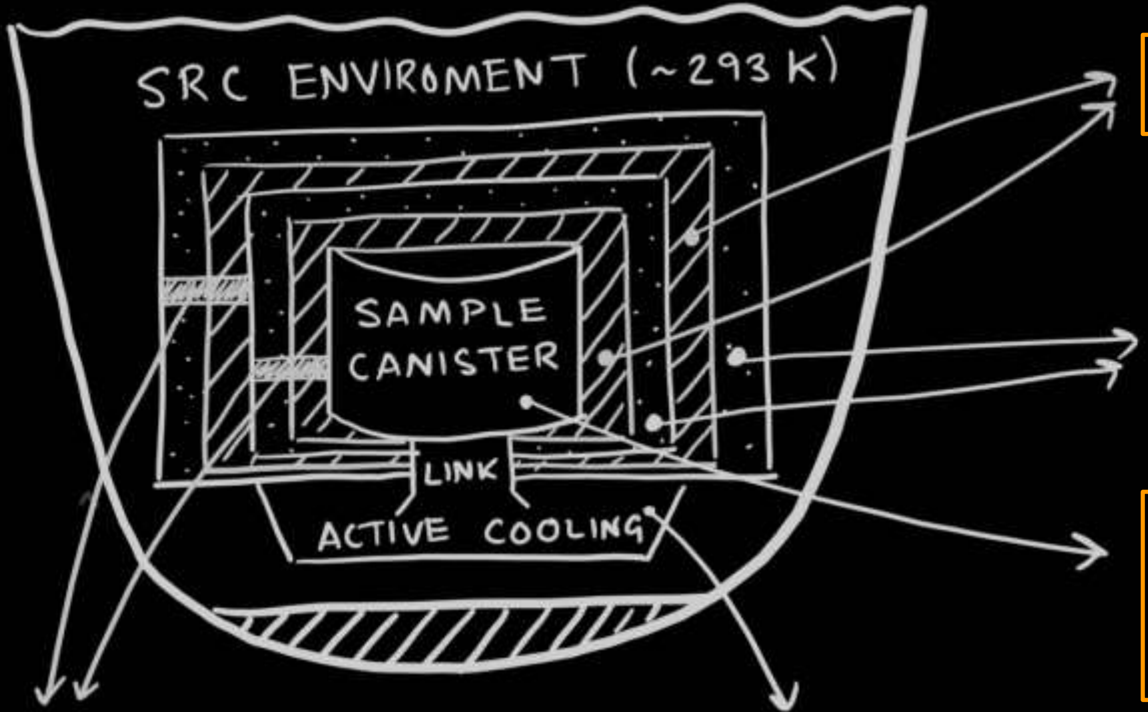


Preliminary S/C Design - TCS

TCS for the spacecraft

S/C Component	Mass Budget	Power Budget
Heaters	33kg	200W
Loop Heat Pipe (LHP)	7kg	N/A (heat switch by Heaters)
Radiator (Prop. system)	12kg (12 kg/m^2)	42W
MLI (15 layers)	17kg (0.73 kg/m^2)	N/A
Louvres	7kg	5W (when used)
Thermal Straps	0.12kg	N/A
Totals	**76.12kg**	**247W**

Preliminary S/C Design - TCS



PCM

Radiation Insulation (Aerogel)

Titanium flexure mount with Kevlar and Gold

Conduction Insulation

Battery, Valve, Sensor and Radiator

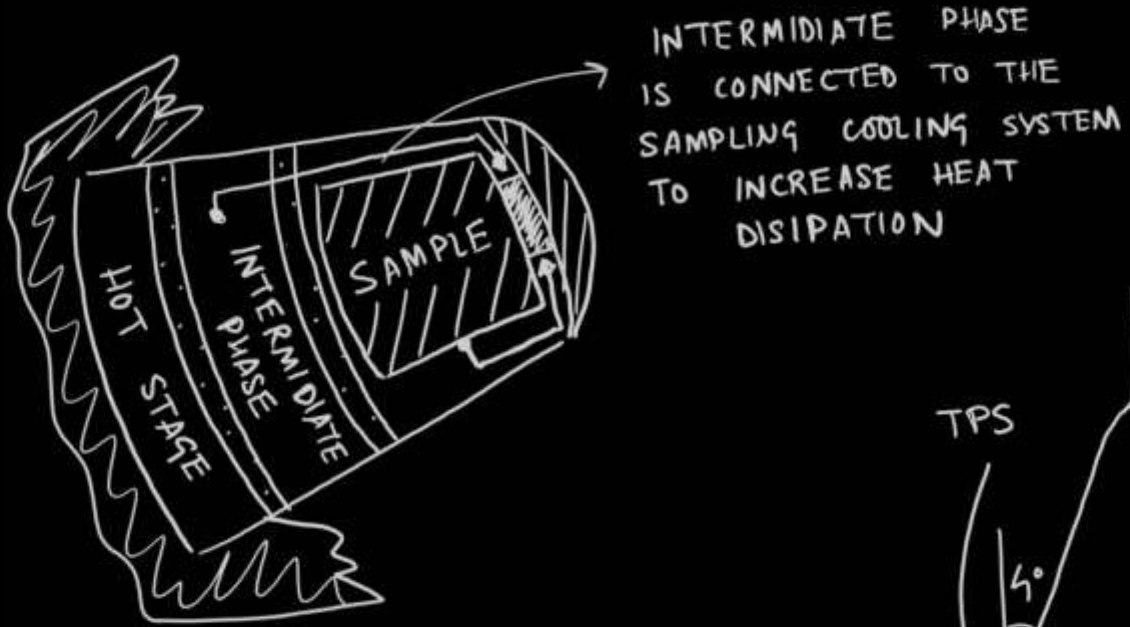
DESIGN from "*CNSR Mission Technology Study*" by Joe Veverka and "*Triple F - A Comet Nucleus Sample Return Mission*" by Michael Kueppers

Preliminary S/C Design - TCS

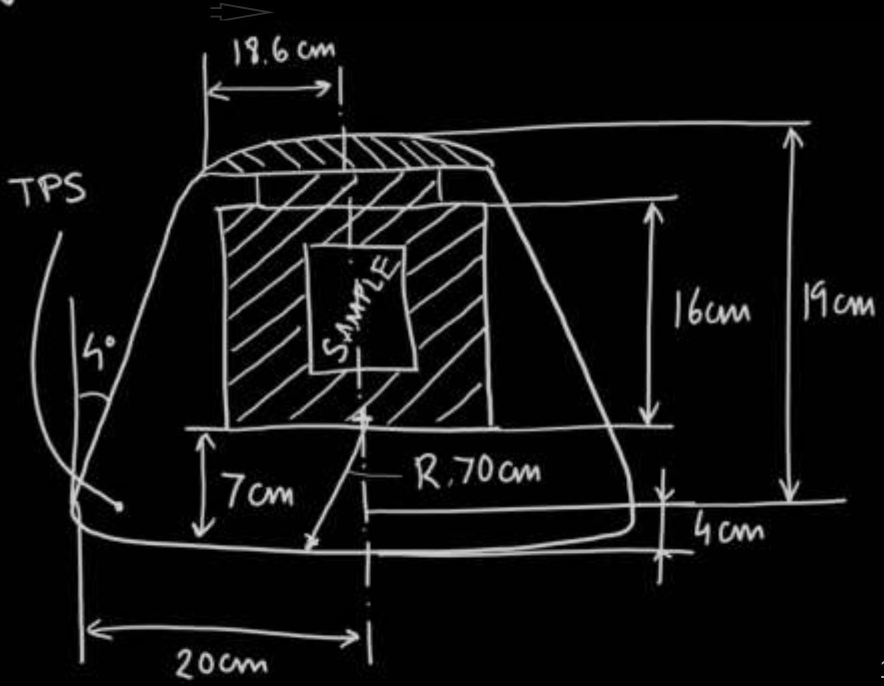
TCS for the Sample Reentry Capsule (SRC):

SRC Component	Mass Budget	Power Budget
Active Cooling Radiator	12kg	20W
Phase Change Material	7kg	N/A
Aerogel	Negligible	N/A
Titanium and Kapton	2kg	N/A
TPS	15kg	N/A
Totals	**26kg**	**20W**

Preliminary S/C Design - TCS

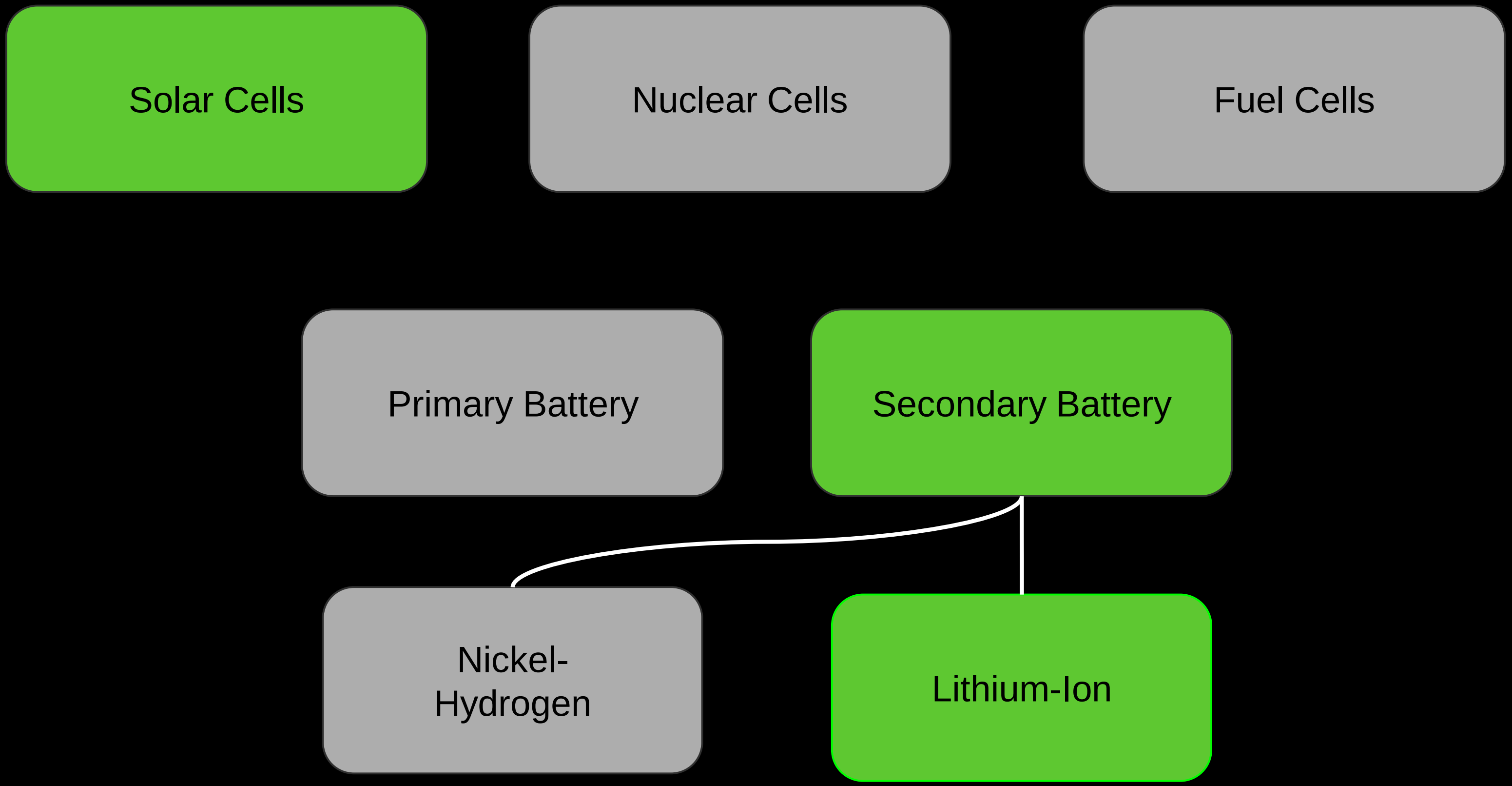


TPS mass: ~15 kg



TPS material: carbon phenolic and resin ablating

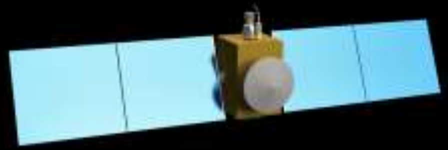
Preliminary S/C Design - Power



Preliminary S/C Design - Power

Satellite:

a. Max Power: 11 kW
b. Solar Cells:
   i. Size: 44 sqm
   ii. Mass: 206 kg
c. Battery:
   i. Volume: 2.5 L
   ii. Mass: 6 kg

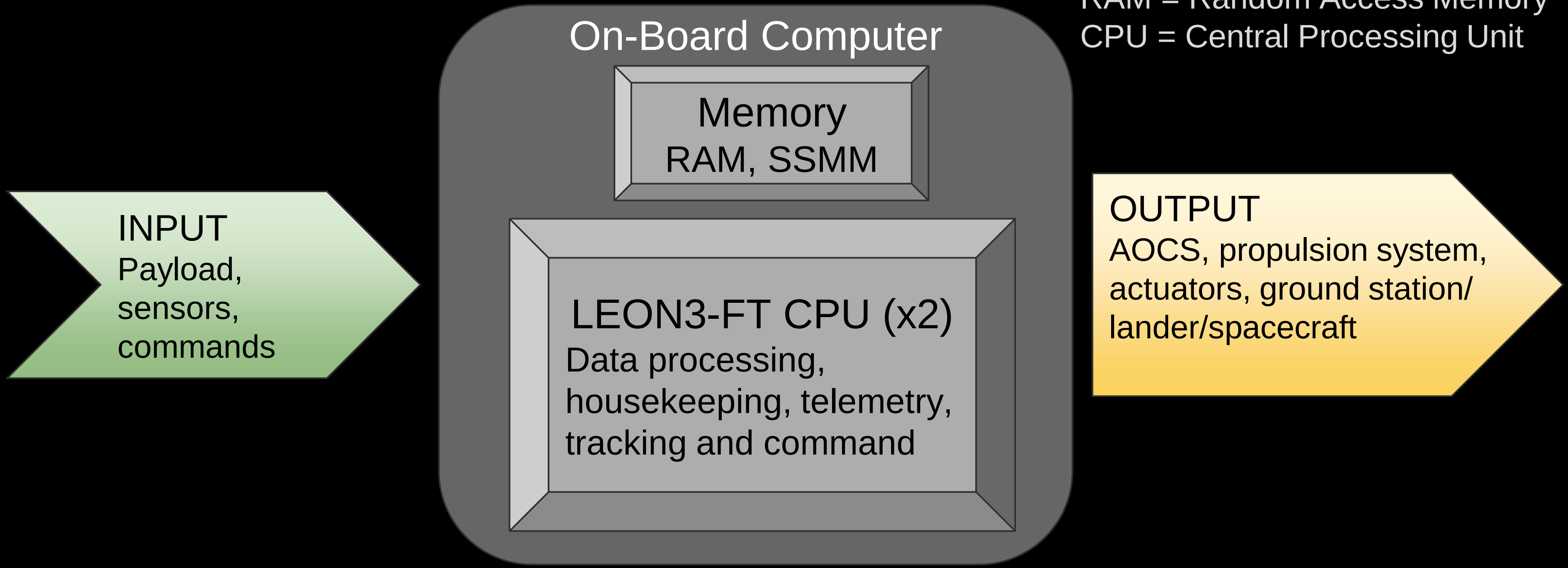


Lander:

a. Max Power: 100 W
b. Solar Cells:
   i. Size: 0.4 sqm
   ii. Mass: 2 kg
c. Battery:
   i. Volume: 1.5 L
   ii. Mass: 3.5 kg

Preliminary S/C Design - On-Board Computer

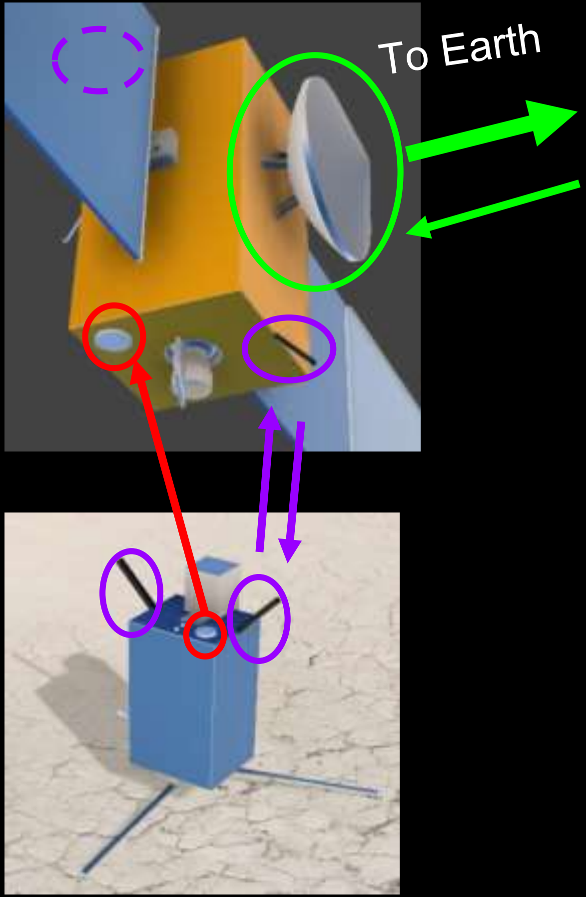
SSMM = Solid State Mass Memory
RAM = Random Access Memory
CPU = Central Processing Unit



- S/C and lander OBC
  - Mass storage units: 200+10 Gbit (+ RAM and additional storage within the payload)
  - Software infrastructure: SCOS 2000

Preliminary S/C Design - Telemetry, tracking, and commanding (TT&C)

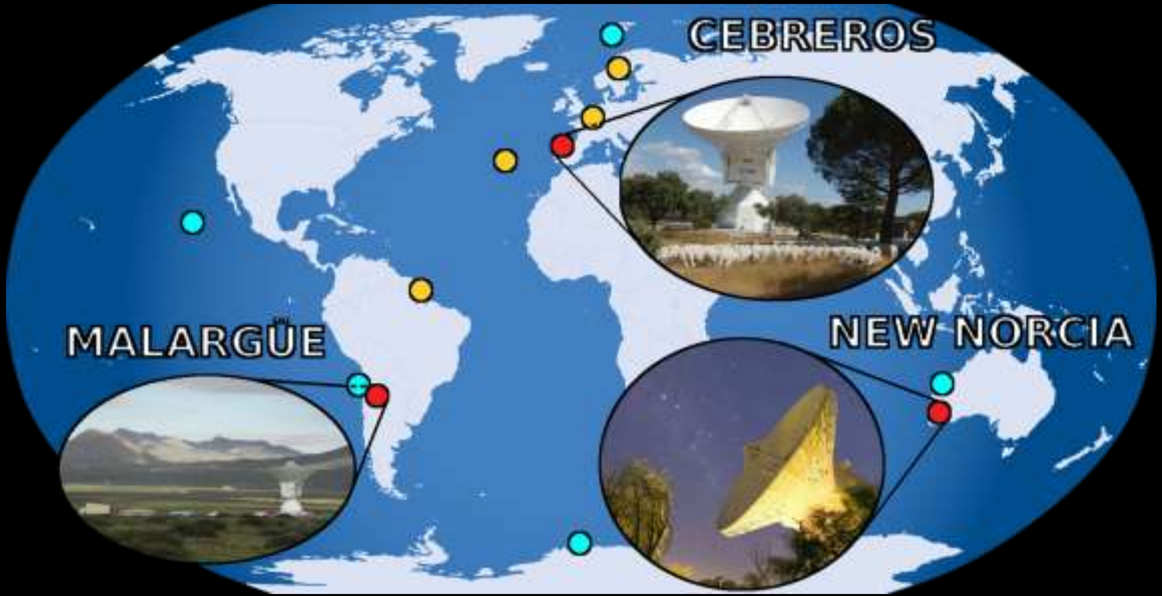
- For large data transfer (s/c):
  - gimbaled 2.2 m high-gain parabolic antenna
  - 8.5 GHz (X-band)
  - 200 W for the S/C transmitter
  - 0.22 Mbit/s data rate
- For telemetry, commands (ground stations and/or lander) and as a backup:
  - medium-gain 2 GHz S-band antenna
  - low-gain 2 GHz S-band antennas (x2)



Ground Segment

Ground station Network

- 8.5 GHz (X-band)
- ESA Tracking Stations (ESTRACK)
  - 35 m diameter (x3) parabolic antennas
  - <15 m parabolic antennas (part of the core network)
  - +augmented and cooperative network



Risk Assessment

Risk Map Before Mitigation

Consequences \ Likelihood	1 - Low	2 - Moderate	3 - Intermediate	4-High	5 – Very High
5 – Catastrophic	**G.6**		**G.1, G.4**		
4 – Critical	**L.4, L.7**		**L.1, L.2, L.3, L.5, L.8**	**G.7, G.5, G.9, G.10**	
3 – Major	**G.3**	**G.2, L.6**	**G.8**	**O.8**	
2 – Medium					
1 – Minor					

Risk Map After Mitigation

Likelihood / Consequences	1 - Low	2 – Moderate	3 - Intermediate	4-High	5 – Very High
5 – Catastrophic	G.6				
4 – Critical	G.5, G.7, L.1,L.4, L.7	L.3, L.5	L.2, L.8	G.9, G.10	
3 – Major	G.3, O.1	L.6	G.8		
2 – Medium			G.1, G.4		
1 – Minor		G.2			

G.7: The asteroid is not detected → (L=4, C=4)

mitigation: a wide angle camera is mounted on the spacecraft → (L=1, C=4)

Development Schedule

Development Schedule

MDR: Mission Definition Review
PRR: Preliminary Design Review
SRR: System Requirement Review
PDR: Preliminary Design Review
CDR: Critical Design Review
QR: Qualification Review

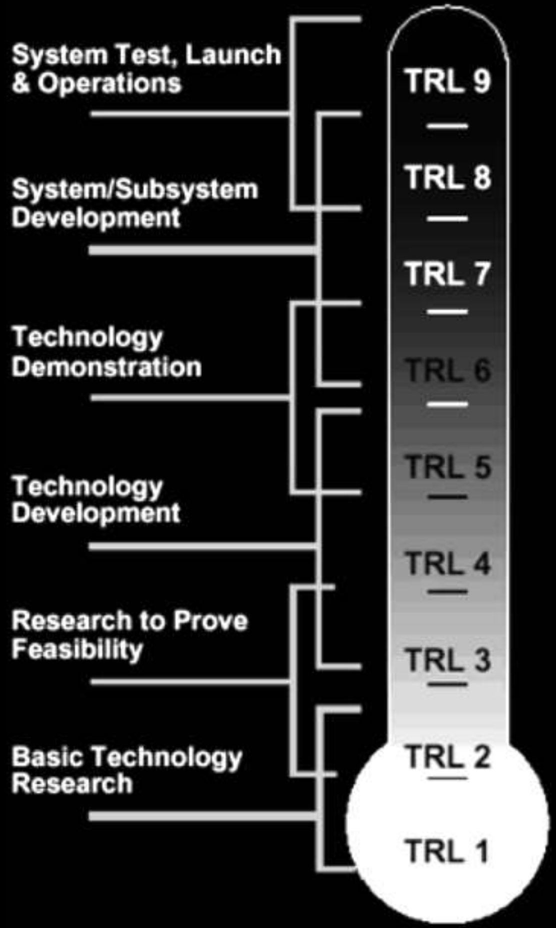
AR: Acceptance Review
ORR: Operational Readiness Review
FAR: Flight Acceptance Review
LRR: Launch Readiness Review
CRR: Commissioning Result Review
ELR: End of Life Review
MCR: Mission Close-out Review

Technological Readiness Level

Technical Readiness Level

- Heritage based approach
- Most subsystem will need minimal adaption
- High level of readiness, 6 or higher

- Subsystems that have limited heritage
  - Sample storing mechanism
  - Sample release mechanism
  - LIBS+Raman (Lander Instrument)



Cost Evaluation

Rough order of magnitude cost evaluation

Launcher (Ariane 62): 75 M€

ESA Project cost: 179 M€

MOC+SOC: 154 M€

Industrial cost: 810 M€

Payload: 83 M€

Contingency: 195 M€

TOTAL CaC: 1.496 B€

Thank you for your attention.

Appendix

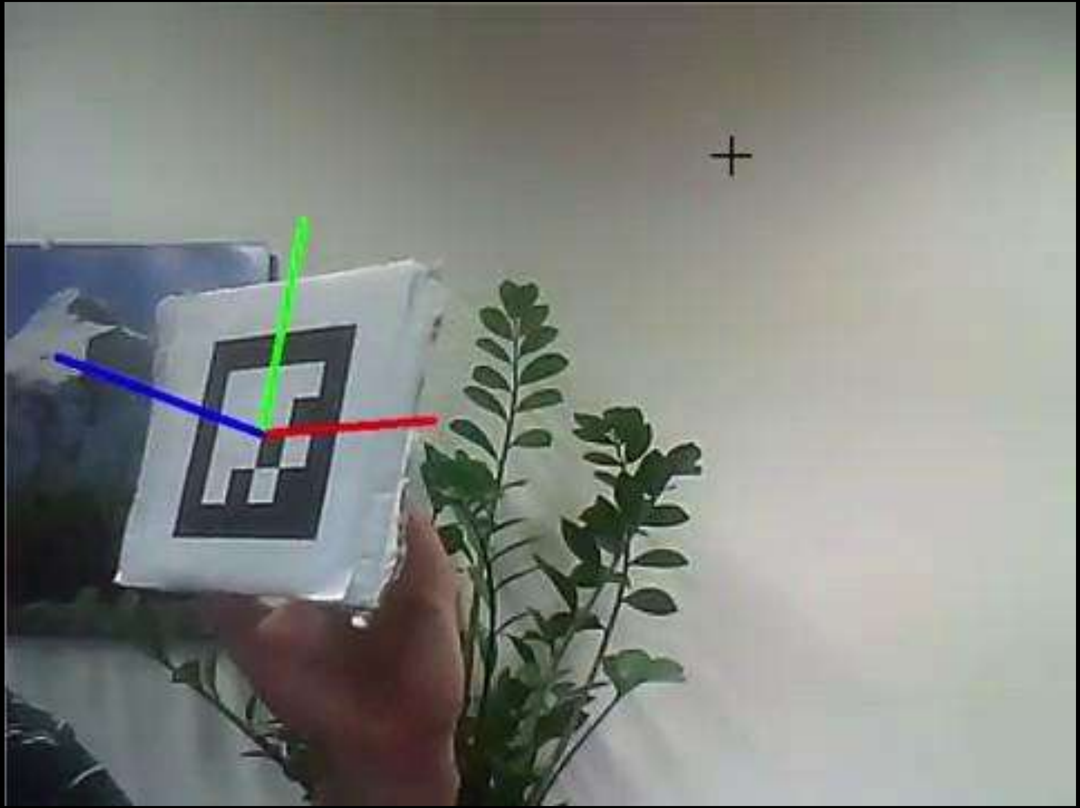
Appendix index

Primary and secondary target launch windows

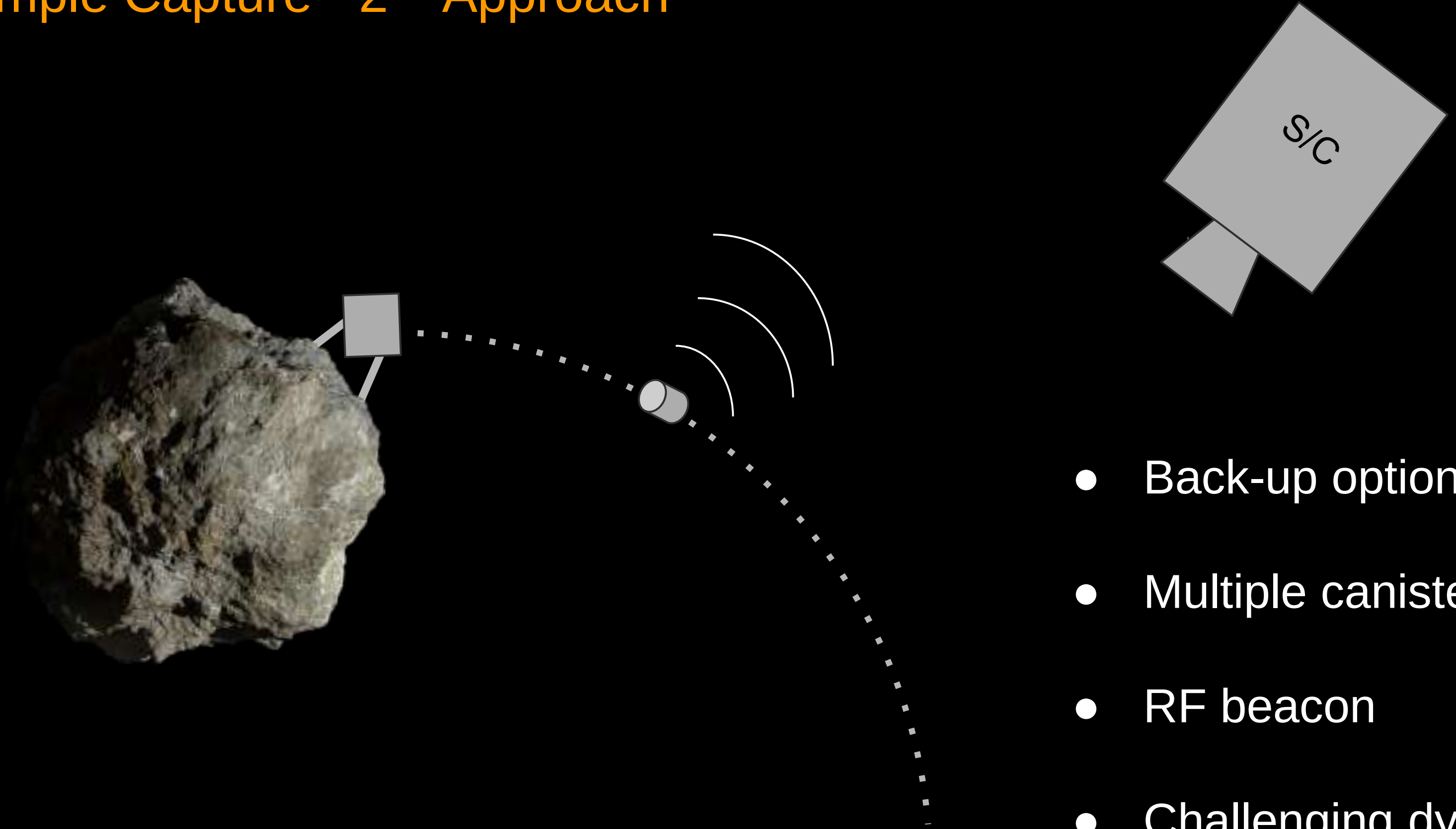
Target	Earth departure	Asteroid arrival	Asteroid departure	Earth re-entry	Outbound delta-v	Return delta-v	Re-entry velocity
2002 AT4	2029 MAR	2033 SEP	2034 AUG	2035 JUL	7.0	3.7	11.8
2002 AT4	2030 SEP	2033 May	2034 JUL	2036 JAN	8.1	3.3	11.7
2001 SG286	2031 JUL	2034 OCT	2036 JUN	2039 MAY	7.4	3.1	12.1
2002 AT4	2034 SEP	2038 MAY	2039 JUL	2040 APR	7.3	3.1	11.5
2001 SG286	2034 DEC	2037 DEC	2038 NOV	2039 Sep	8.38	2.6	11.2

Delta- V Budget

Delta V [m/s]	
Transfer Orbit:	7000
AOCS Maneuvers:	300
Return Orbit	3700
Total	11000



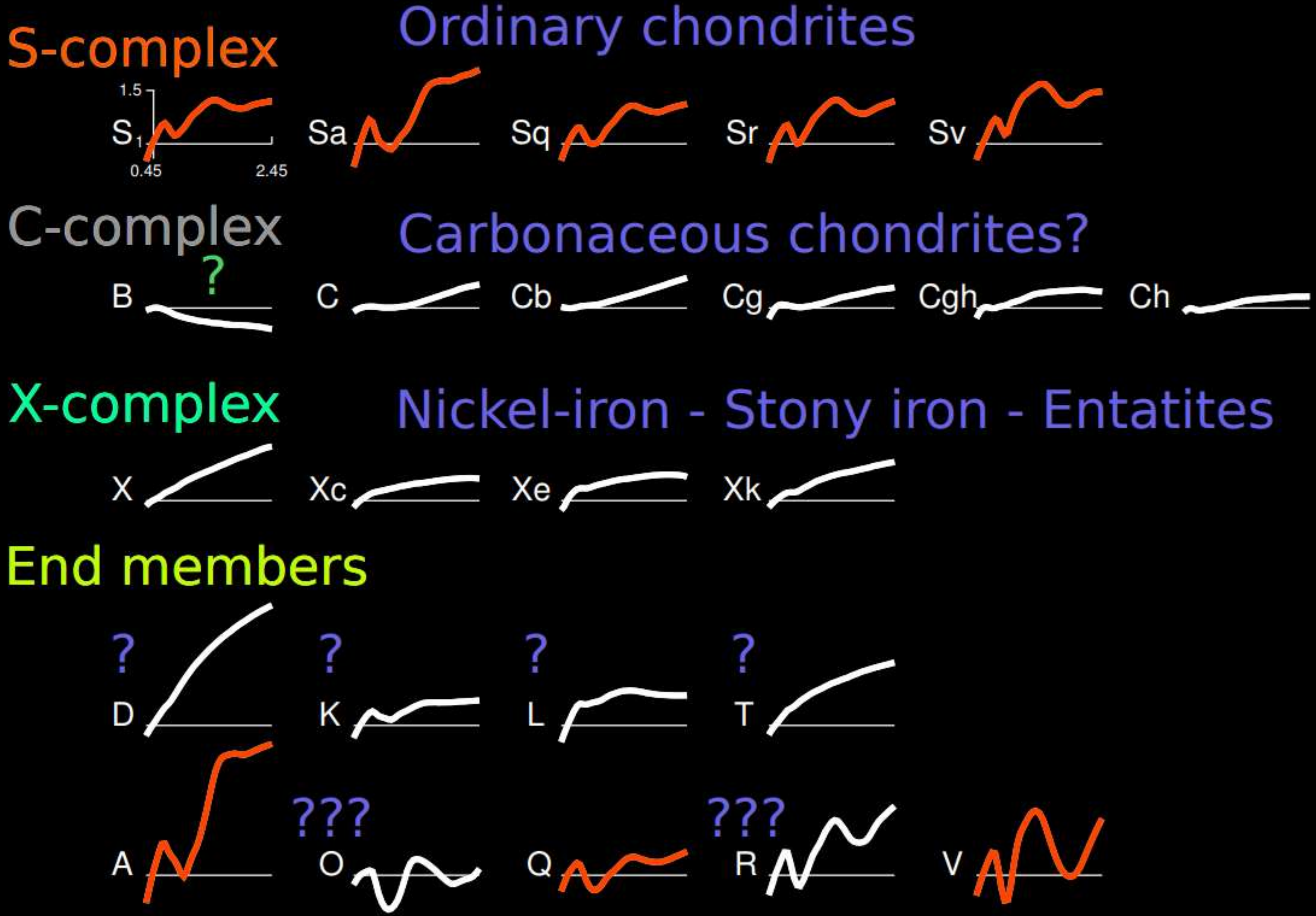
Sample Capture - 2nd Approach



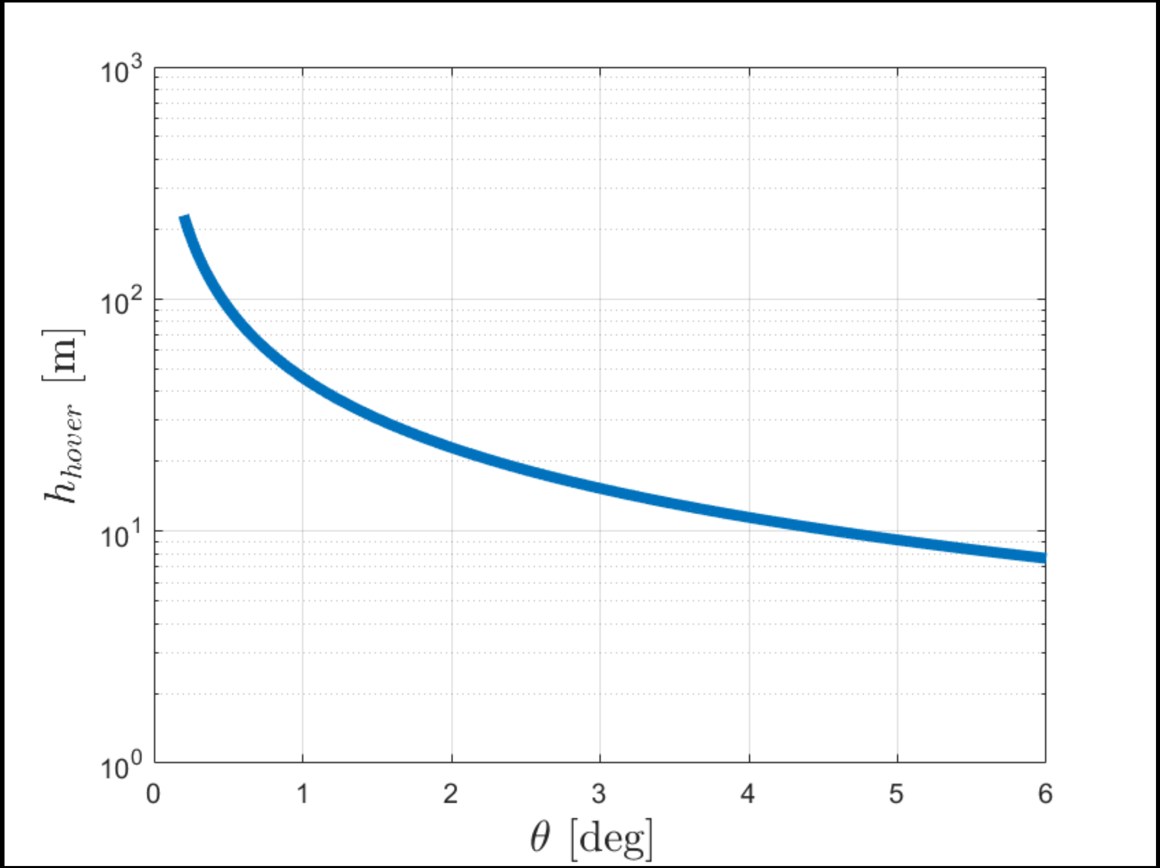
- Back-up option
- Multiple canisters available
- RF beacon
- Challenging dynamics

Scientific objectives	Scientific requirements	Measurements	Method	Instrument on orbiter/lander	Instrument requirements
Primary Objectives					
Q1: What were the building blocks of the Solar System and how did they evolve?	SR1: Determine the chemical composition and morphology of the building blocks at the time of early Solar System formation	Elemental composition	Spectroscopy	LIBS	Spectral resolution of 10 cm^{-1}
		Particle size and shape	**Sample analysis**	-	-
	SR2: Characterize collisional history of primitive bodies	Mineralogy (shock metamorphism)	**Sample Analysis**	-	-
		Internal structure	Radars	Low-Frequency Range radar (bistatic)	Res: 10-30m Penetration depth: 170 m Nominal Frequency: 50-70 mHz External Frequency: 45-75 Mhz
	SR3: Determine the initial spatial distribution and migration of small bodies across the Solar System	Chemistry Isotopes ratios	**Sample analysis**	-	-
Q2: What are the physical properties of NEAs?	SR4: Characterize D-Type asteroids	Global surface topography	Mapping Imaging	Wide Angle Camera	Resolution: 10 cm/pixel from 5km distance
				Narrow Angle Camera	Resolution: 10 cm/pixel from 5km distance
		Composition and mineralogy	Spectroscopy	Visible Near Infrared Spectrometer	Spectral resolution: 5nm Wavelength range: 0.4-3.3 um
				Mid Infrared Spectrometer	Resolution: 1 um Spectral range: 5-15 um
			Sample analysis	-	-
		Internal structure	Radars	High frequency radar (monostatic)	Res: 2 m Penetration depth: 10-20 m Nominal Frequency: 300-800mHz External Frequency: 300-2500 Mhz
				Low-Frequency Range radar (bistatic)	Res: 10-30m Penetration depth: 170 m Nominal Frequency: 50-70 mHz External Frequency: 45-75 Mhz
Q3: How were the building blocks of life formed and transported inside the Solar System?	SR5: Characterize organic compounds present in primitive bodies	Identification of organic compounds	Spectroscopy	Raman spectrometer	Raman shifts: 4000 cm^{-1} -1000 cm^{-1}
			Sample analysis	-	-

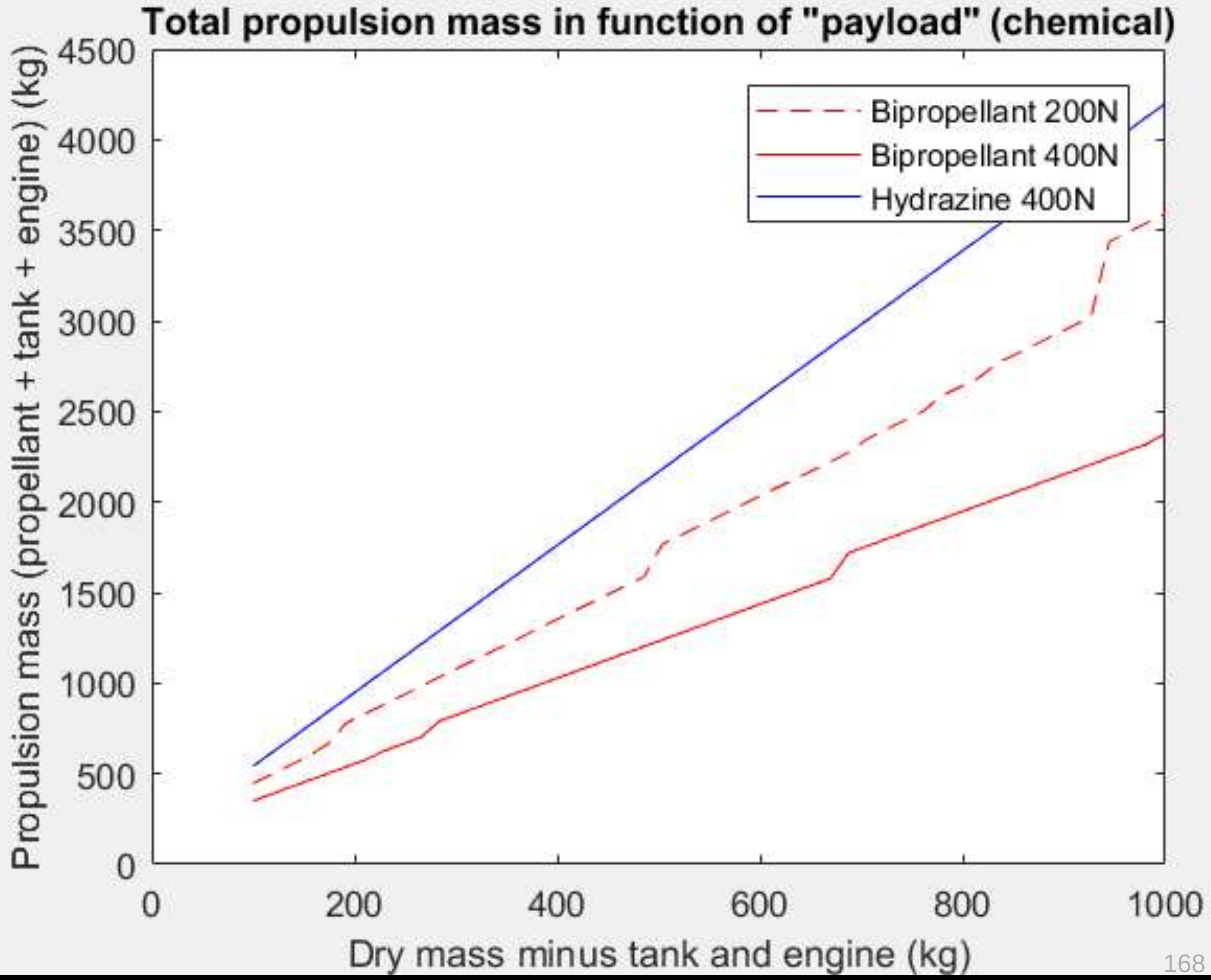
Secondary Objectives					
Q4: What was the astrophysical context at the time of Solar System formation?	SR6: Determine the presolar grain sources	Isotopic ratios	**Sample analysis**	-	-
	SR7: Characterize the stellar environment in which the Solar System formed	Isotopic and chemical characteristics of presolar grains	**Sample analysis**	-	-
	SR8: Characterize stellar processes				
Q5: Can the Tagish Lake meteorite be linked to a specific spectral class of asteroids?	SR9: Testing if D-types asteroids are the parent body type of the Tagish Lake meteorite	Chemical composition	Spectroscopy	LIBS + Raman	Spectral resolution of 10 cm^{-1} Raman shifts: 4000 cm^{-1} -100 cm^{-1}
		Isotopic ratios	**Sample analysis**	-	
Q6: What are the processes which are affecting the physical properties of asteroids today?	SR10: Characterize the interaction between the solar wind and asteroid surfaces	Low Energy Neutral Atoms	Neutral imaging	Neutral Particle Detector	Mass resolution: H, Heavy Energy range: 10eV to 3keV
	SR11: Determine the collisional record of D-type asteroids	Imaging	Cameras	Wide angle camera	Resolution: 10 cm/pixel from 5km distance
		Mineralogy	**Sample analysis**	-	-
Q7: Asteroid impact avoidance	SR12: Characterize Near Earth Asteroids in order to plan a defence strategy	Chemical and physical properties	Cameras	Wide Angle Camera	Resolution: 10 cm/pixel from 5km distance
				Narrow Angle Camera	FoV: 1.7 degrees Resolution: 18.6 urad px-1 (1.86 m/pixel from 100 km distance)
			Radar	High Frequency Radar	Res: 2 m Penetration depth: 10-20 m Nominal Frequency: 300-800mHz External Frequency: 300-2500 Mhz
				Low-Frequency Range Radar	Res: 10-30 m Penetration depth: 170 m Nominal Frequency: 50-70 mHz External Frequency: 45-75 Mhz
			Spectroscopy	LIBS + Raman	Spectral resolution of 10 cm^{-1} Raman shifts: 4000 cm^{-1} -100 cm^{-1}


S-complex
Ordinary chondrites
1.5
S
1
0.45
2.45
Sa
Sq
Sr
Sv
C-complex
Carbonaceous chondrites?
B
?
C
Cb
Cg
Cgh
Ch
X-complex
Nickel-iron - Stony iron - Entatites
X
Xc
Xe
Xk
End members
?
D
?
K
?
L
?
T
A
???
O
Q
???
R
V

Uncertainty Cone Sample Capture



Chemical propulsion

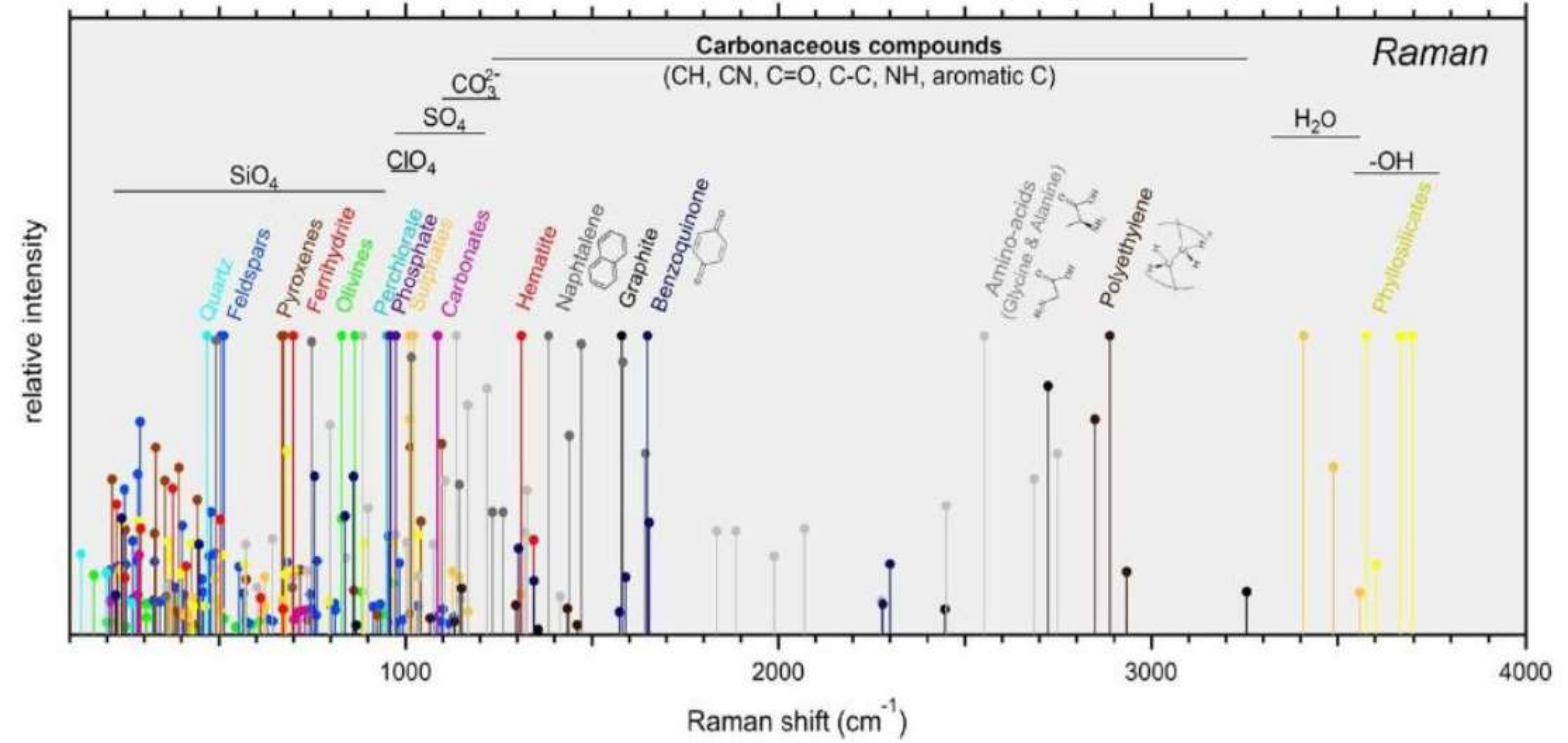


AOCS mass breakdown

Sensor	Mass (kg)	Amount	Sub Total (kg)
Star Tracker	5	2	10
Sun Sensor	2	4	8
Camera	2	2	4
IMU	10	3	30
LIDAR	6,5	2	13
Actuator			
Reaction Wheels	5	2	10
Thruster (hot gas)	0,29	16	4,64
Hydrazine tank	6,4	1	6,4
Hydrazine tank	104	1	104
		Total (kg):	190,04

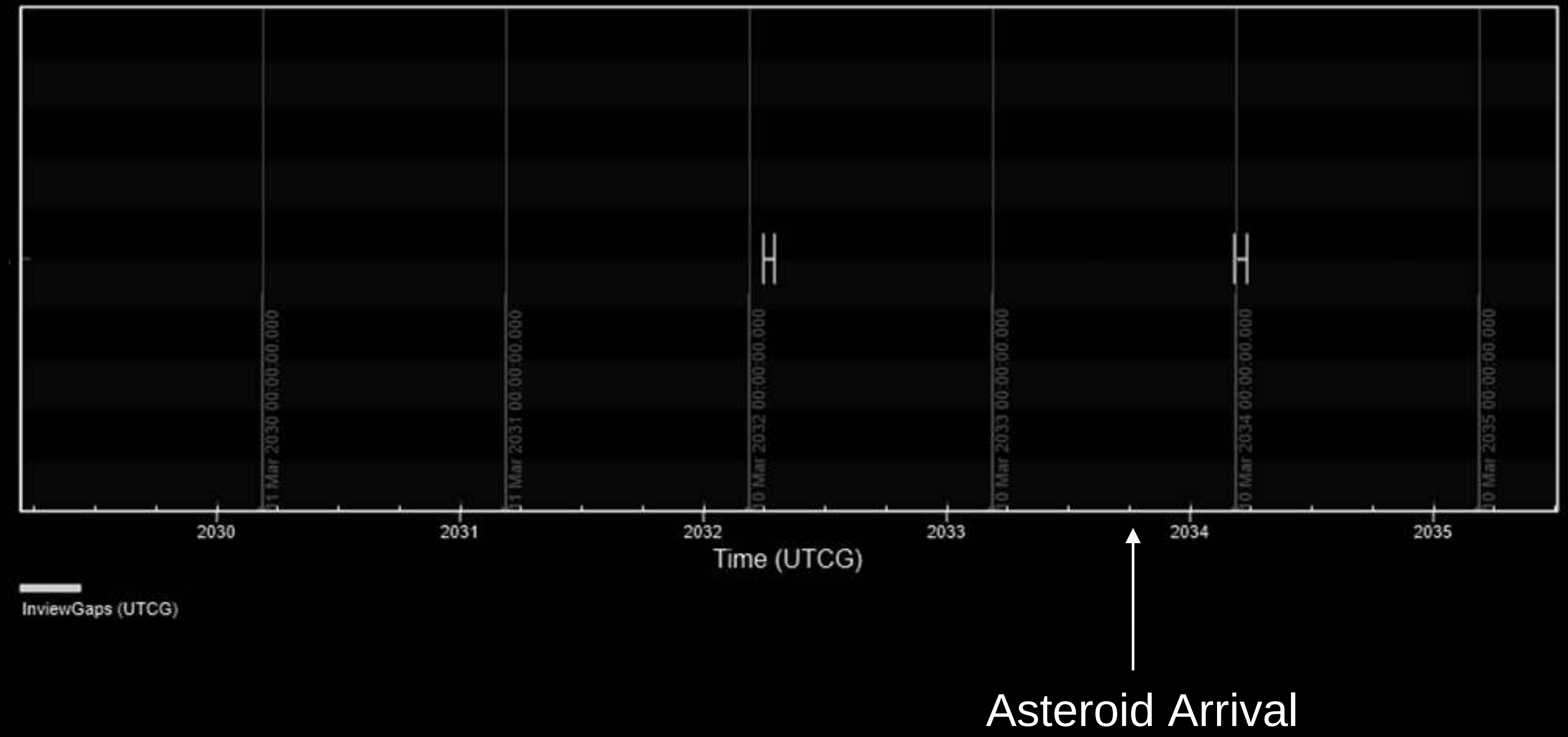
Name	Orbit	D (m)	deltaV (km/s)	H (mag)	Type	MOID (AU)	Rotation period [h]
2009CV	AP	80	4.26	24.3	D	0.01154	?
2016WZ8	AP	10	4.81	28.4	D	0.01147	?
2017 DL34	AM	40	4.96	25.9	D	0.04691	?
2011 AM24	AM	505	5.02	20.4	D?	0.00989	?
2009 DL46	AM	240	5.08	22.0	D	0.01233	?
1993 HA	AM	607	5.30	20.0	D	0.016887	4.107 +-0.002
2002 AT4	AM	349	5.55	21.2	D	0.04220	6
2001 SK162	AM	872	5.57	17.9	T/D	0.03005	?
2001 SG286	AP	401	5.60	20.9	D	0.00512	?
2001 YE1	AP	449	5.84	20.8	T	0.05938	?
2001WL7	AP	80	6.05	24.3	D	0.01488	?

Example of Raman spectra



Muriel Saccocio, ISSO, ESA/ESTEC 2-6 October 2017

Solar Conjunction



Costs

S/C	dry mass [kg]	Correcting factor	Cost [M€]
Mech&thermal architecture	622	1,4	218
Electrical	489	1,4	513
Payload	27	1,2	33
	SUM		764

Lander			
Mech&thermal architecture	40	1,6	16
Electrical	37	1,2	33
Payload	39	1,3	51
	SUM		99

Reentry			
Mech&thermal architecture	60	2	30

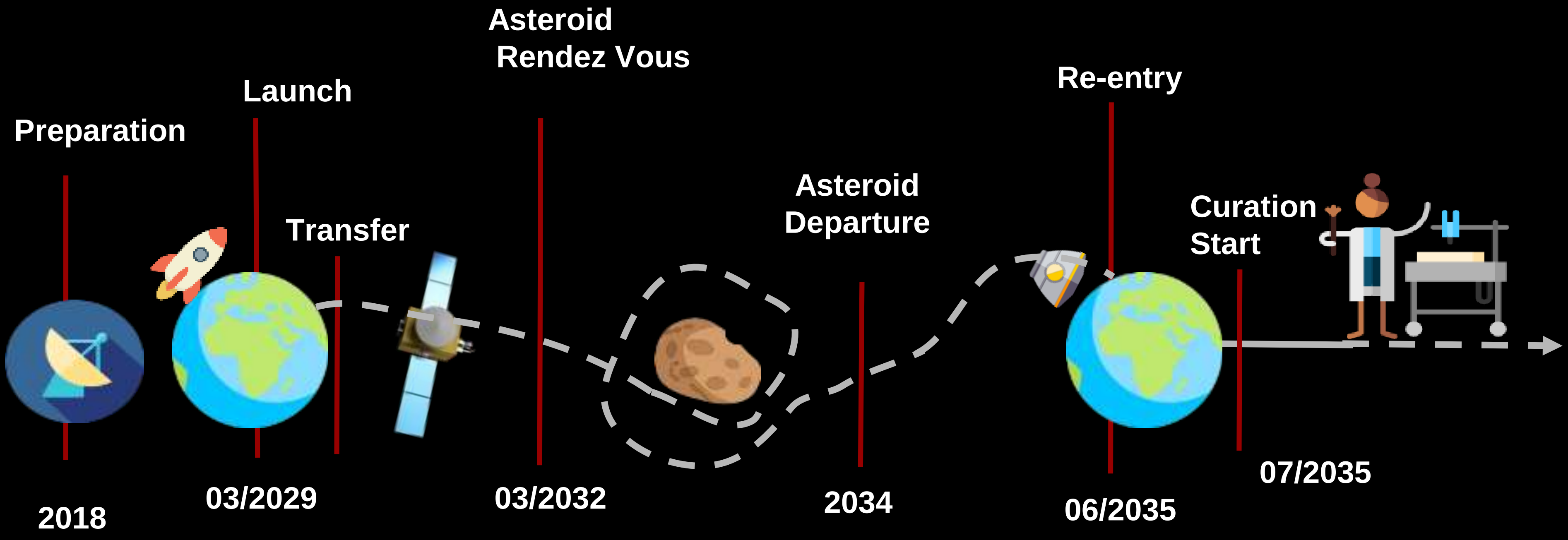
Data budget

Payload		Data Volume [Mbit/s]	Data Volume [Mbit/sample]	Seconds or samples per 24h (for one tough day)	Amount of data [Mbit]	Usage		
Instrument	Wide Angle Cam		75	15	1125	overall mapping		
	High freq radar	0,3		0	0	landing site	not used at the same time with others	
	Narrow angle cam		67	2	134	mainly landing site		
	Low freq radar	0,005		7200	36	overall mapping		
	Mid Infrared Spectrometer		360	8	2880	overall mapping		
	Vis near Infrared		0,45	30	13,5	overall mapping		
	Neutral particle analyzer		0,00072	1000	0,72	overall mapping		
	Student experiment			xxx	10			
				SUM:	4199,22			
Lander	Low freq radar (passive)	0,005		7200	36			
	Panoramic camera		1,2	10	12			
	LIDAR (based on BELA)	0,02	0,002	100	0,2			
	Descent Cam		7,3	10	73,40032			
	LIBS+Raman	15		xxx	4,2			
	Student experiment			4	0			
				SUM:	0	not used at the same time as s/c		125,80032
				Total SUM:	4199,22	Mbit		
				Amount of data with margin	5998,885714	Mbit	70-80% is the real usable data	
				Time to transfer data per 24 h	8	h		
				Data rate	0,2082946429	Mbit/s		

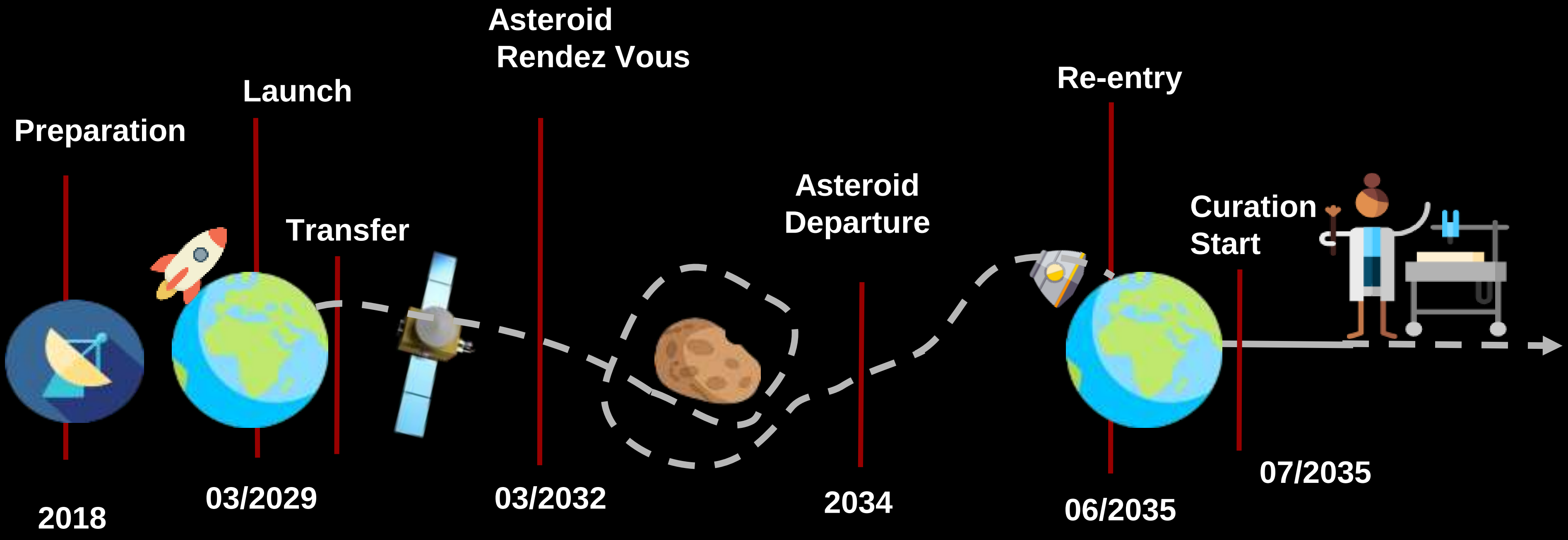
Recycling bin

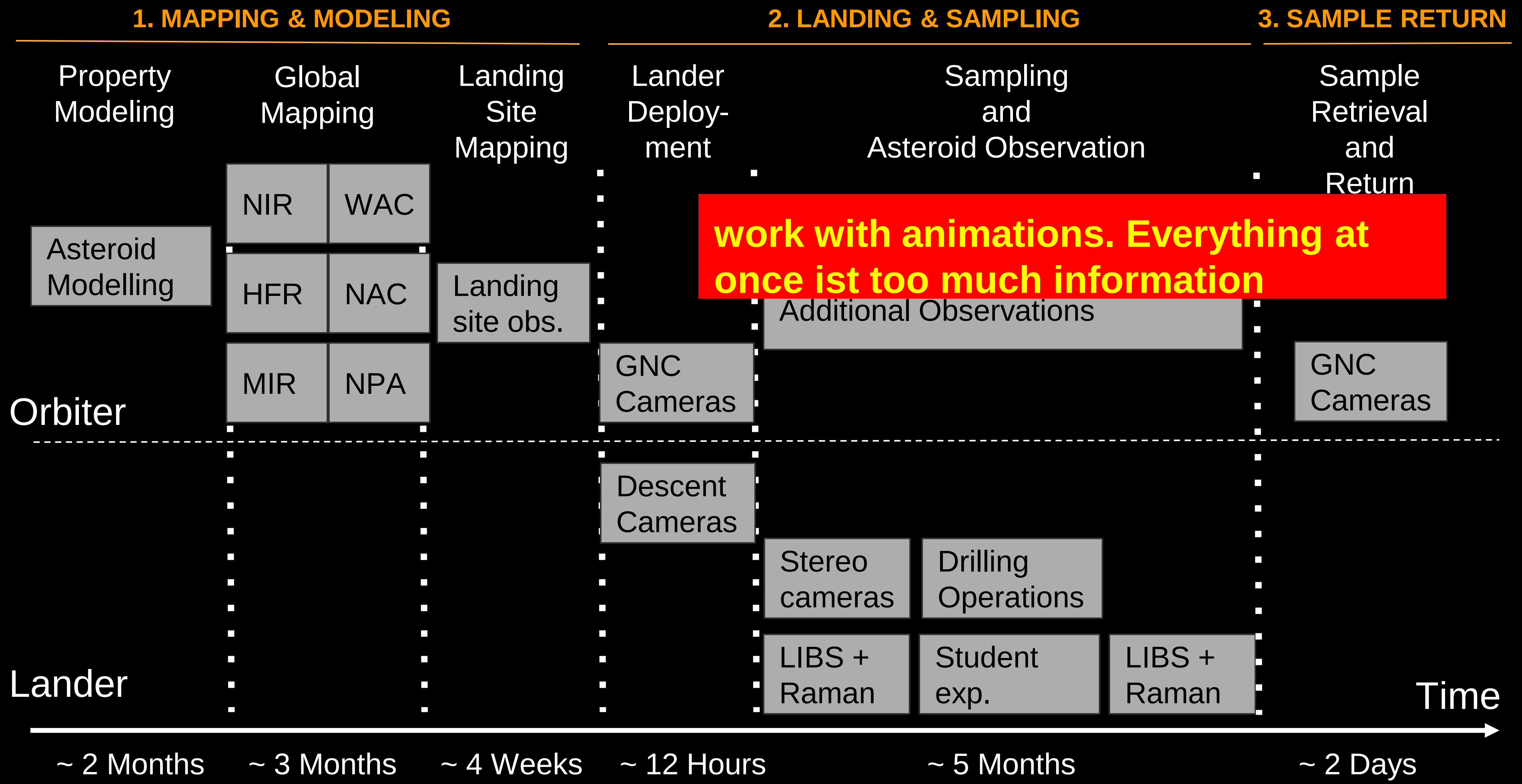
(Not appendix/backup slides)

Mission Phases

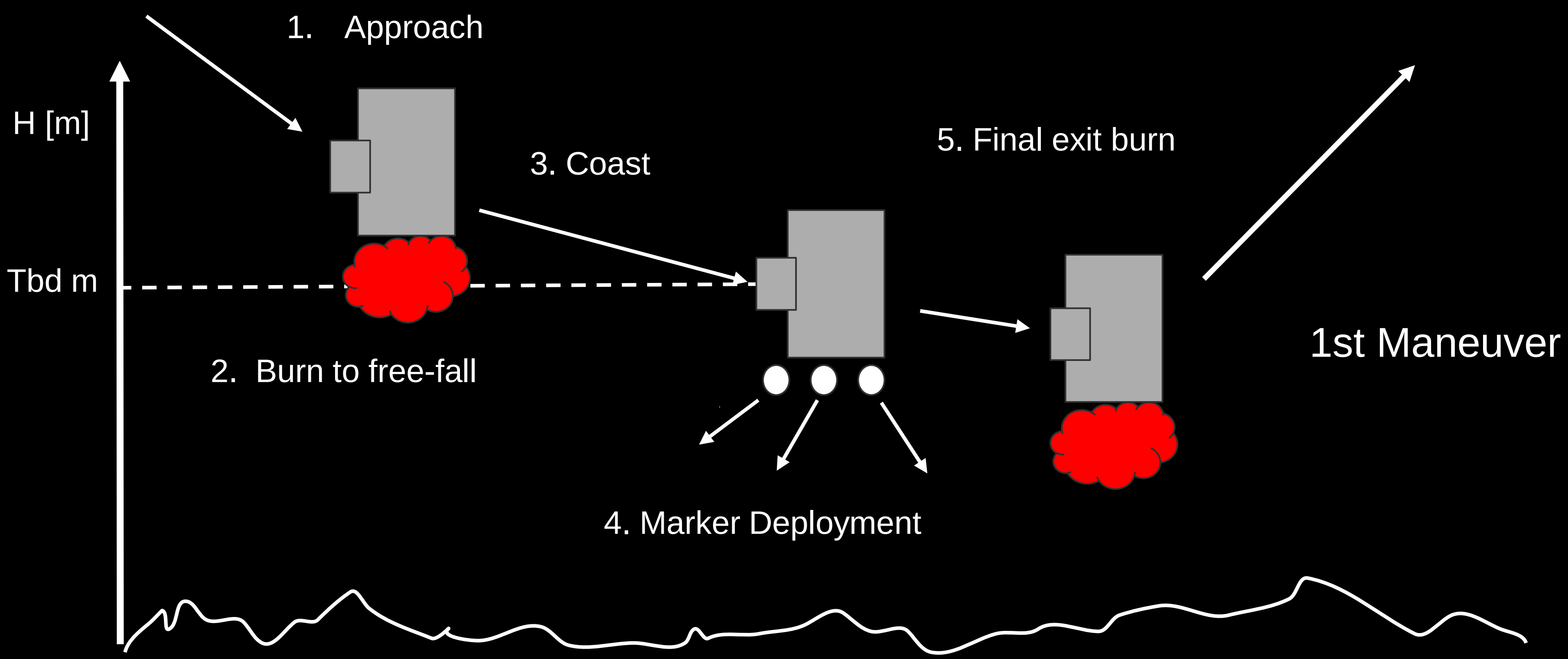


Mission Phases

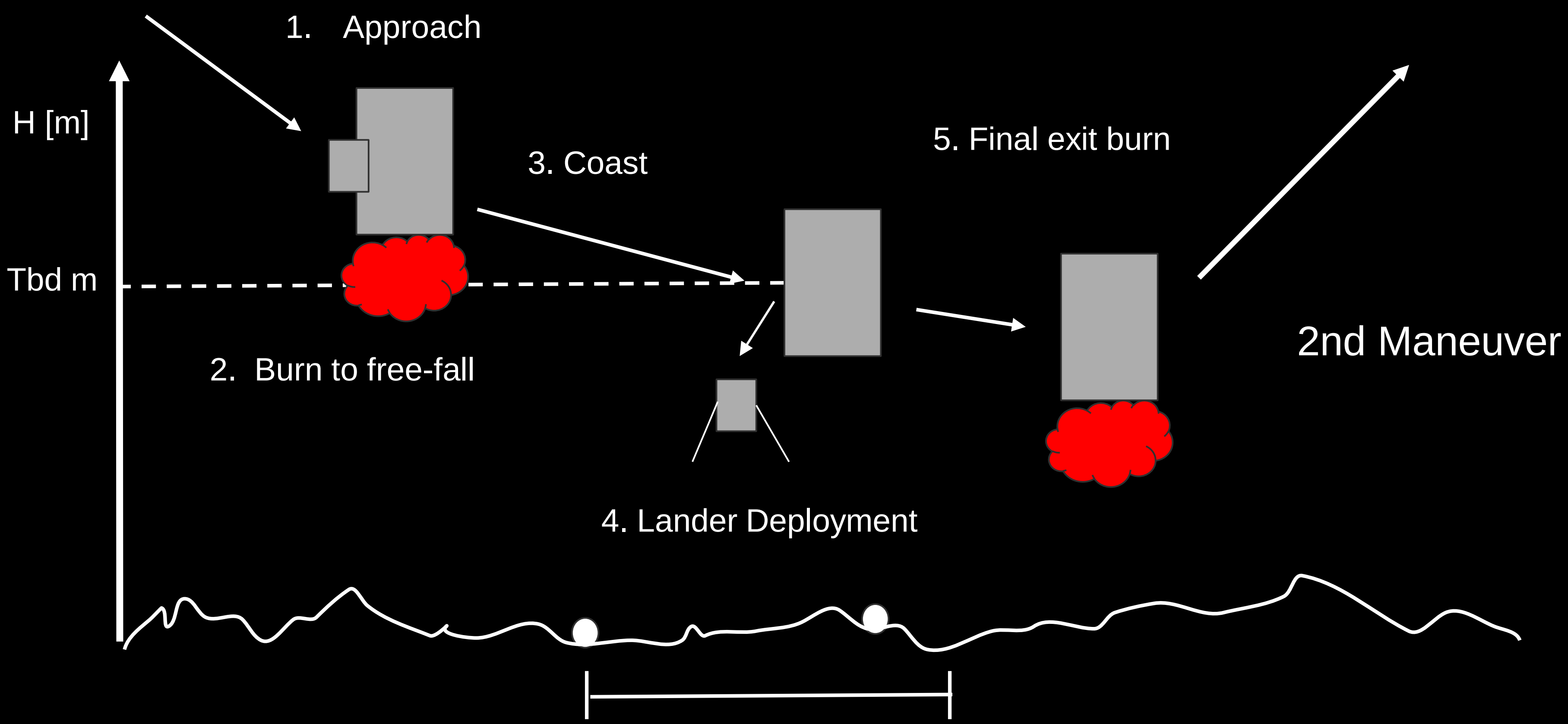



1. MAPPING & MODELING
2. LANDING & SAMPLING
3. SAMPLE RETURN
Property Modeling
Global Mapping
Landing Site Mapping
Lander Deploy-ment
Sampling and Asteroid Observation
Sample Retrieval and Return
NIR
WAC
Asteroid Modelling
HFR
NAC
Landing site obs.
work with animations. Everything at once ist too much information
Additional Observations
MIR
NPA
GNC Cameras
GNC Cameras
Orbiter
Descent Cameras
Stereo cameras
Drilling Operations
LIBS + Raman
Student exp.
LIBS + Raman
Lander
Time
~ 2 Months
~ 3 Months
~ 4 Weeks
~ 12 Hours
~ 5 Months
~ 2 Days

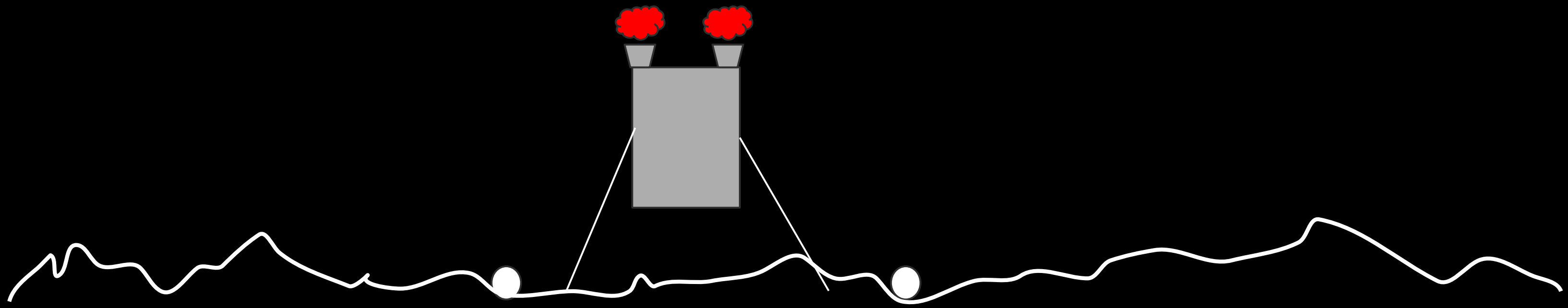
Landing Approach and Contamination Avoidance Maneuver (LACAM)



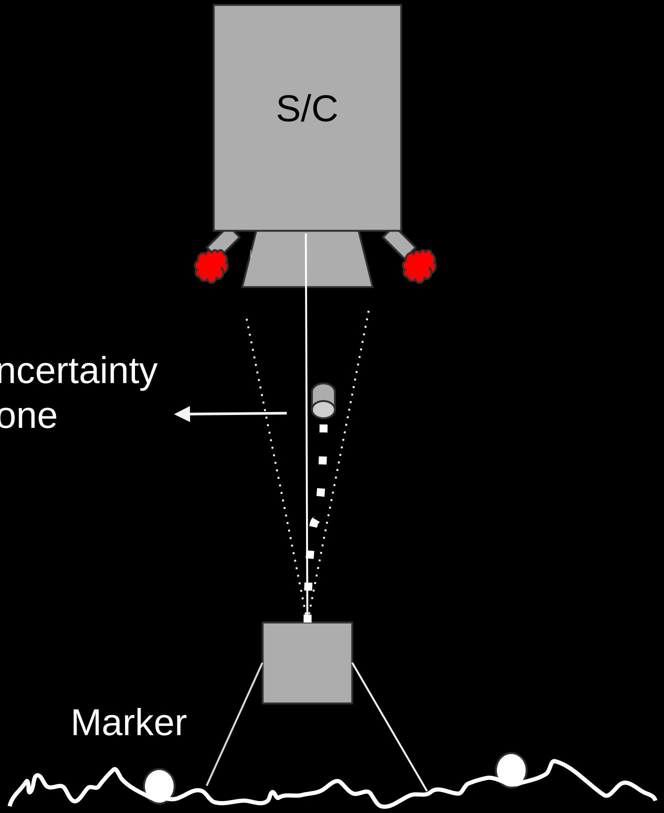
Landing Approach and Contamination Avoidance Maneuver (LACAM)



Landing



Sample Capture



- Optical camera tracks the SRV + 4 markers
- S/C hovers (body-fixed) at 20 m
- 5 - 15 cm/s docking speed
- Perform test maneuvers before
- Orbiter-Lander Horizon Synchronization
- RF-beacon on SRV

Sample Capture - 2nd Approach

Multiple shots = risk reduction
But need beacon or radar reflector