Overview and Results from the ESA CDF Study on Small Planetary Platforms (SPP)

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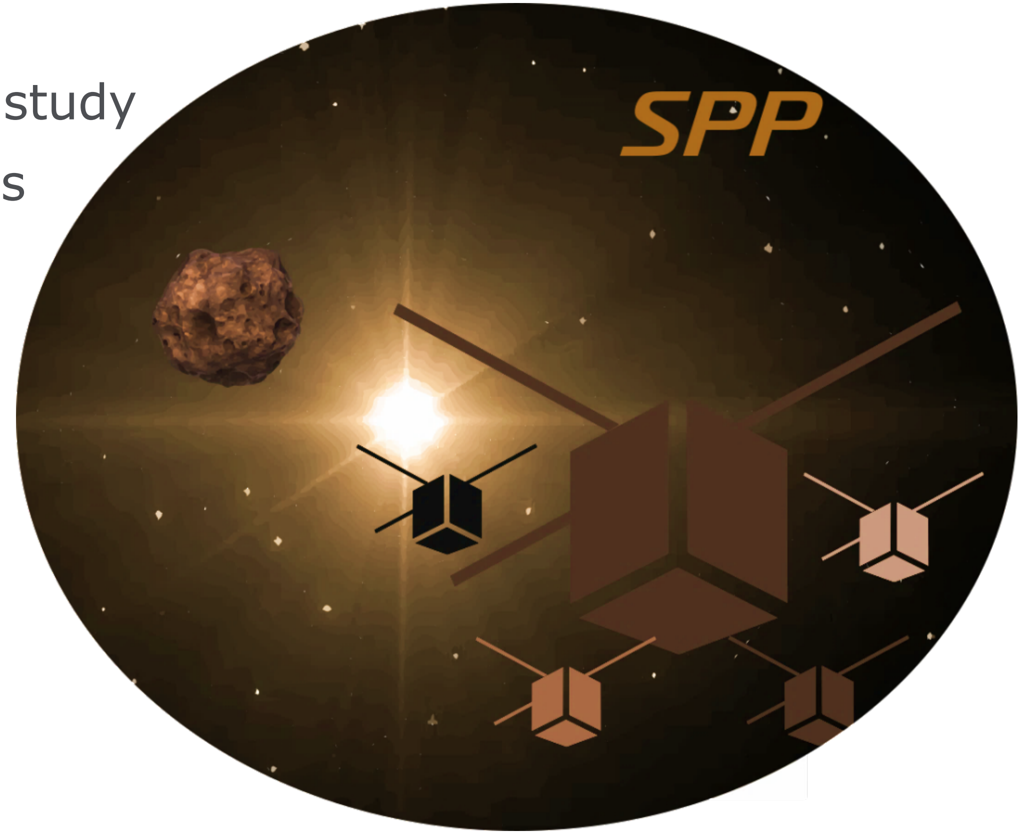
Presentation Overview

1. Setting the scene: Rationale for the SPP study
2. SPP CDF study overview and main results
3. Plans and future outlook



Setting the scene: Rationale for the SPP study

In 2016, ESA issued an open “Call for New Science Ideas”:

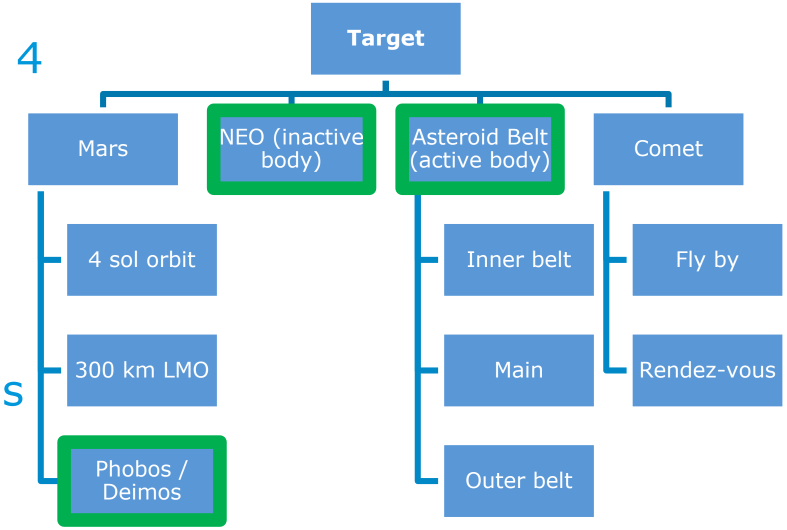
- Not a Call for Missions, but intended to scan for new ideas which could lead to new interesting future missions, possibly following some maturation time
- Out of the 26 proposals received, three themes were selected by the advisory committee:

1. High accuracy near IR astronomy
2. Quantum Decoherence
3. Planetary science with small platforms

A workshop with the scientific community confirmed the interest on smallsats for planetary science missions, with emphasis on the potential capability to provide “multipoint measurements” for a moderate cost.

Setting the scene: Rationale for the SPP study

- The big variety of potential mission options was not compatible with a single CDF study, so a smaller sub-set of 4 scenarios was agreed on and implemented via a baseline mission configuration consisting of a mother spacecraft and 4 small satellites, with different payload compliments depending on the target:
  1. Study the environment of an active main belt object
  2. Study the interior structure of an inactive Asteroid/NEO
  3. Study a planetary body satellite: Mars- Deimos or Phobos (potentially captured asteroids)
  4. Study multiple small bodies – a statistically significant number, which the science team defined as >10-100 (based on previously characterized bodies)



Note: Due to time constraints only scenarios 1 and 2 will be discussed in this overview

Setting the scene: Rationale for the SPP study

- The SPP study was then conducted at the ESA Concurrent Design Facility (CDF) at the end of 2017.
- The aim was to assess the set of mission concepts within the boundaries defined for M-Class or F-Class missions (F-missions being an evolution of S-missions, i.e. fast track small missions)
    - ➢ The reference mission concepts are not real missions or candidate missions.
    - ➢ The reference mission concepts are used for defining typical/envelope needs.
    - ➢ For each reference mission, a “strawman” payload was defined, with the support of the scientists, with the sole purpose of defining technical requirements for the small satellites.

SPP CDF Study Overview and Main Results – The “Strawman” Payload(s)

Active Main Belt body – Volatiles Investigation			
Sat 1	**Sat 2**	**Sat 3**	**Sat 4**
Mass spectrometer (EVITA, ITMS study)	Mass spectrometer (EVITA, ITMS study)	Camera (CUCorbiter/Exo Mars/ MarcoPoloR)	IR spectrometer (BIRCHES/NASA)
Pressure sensor (COPS/Rosetta)	Magnetometer (MAGIC/M-ARGO)	Magnetometer (MAGIC/M-ARGO)	
	Ion/electron spec (CHAP/M-ARGO)	Ion/electron spec (CHAP/M-ARGO)	
Radio Science	Radio Science	Radio Science	Radio Science

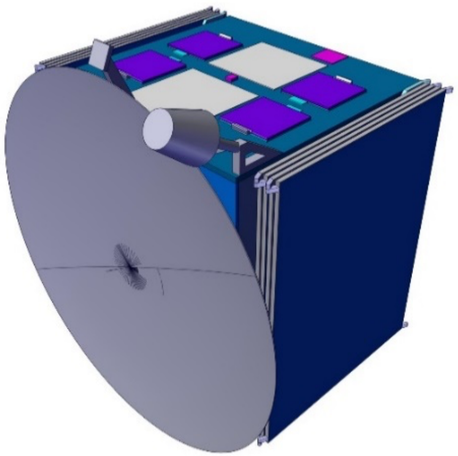
Inactive NEO– Interior Structure Investigation			
Sat 1	**Sat 2**	**Sat 3**	**Sat 4**
Low frequency radar (DISCUS study)	Low frequency radar (DISCUS study)	High frequency radar (AIM D1 study)	IR spectrometer (BIRCHES, LunaSat, NASA)
Camera (CUCorbiter)	Camera (CUCorbiter)	--	--
Radio Science	Radio Science	Radio Science	Radio Science

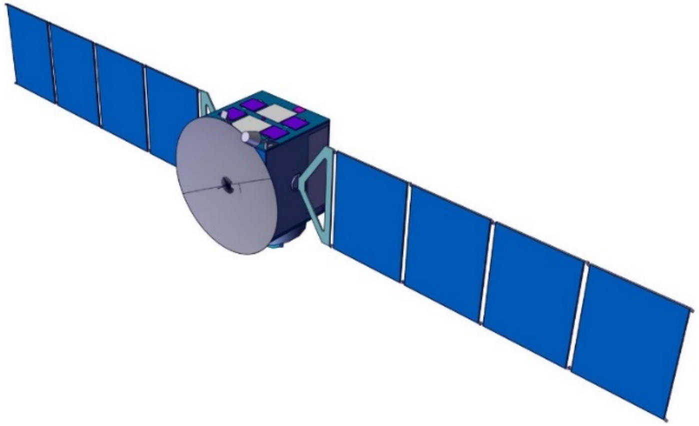
SPP CDF Study Overview and Main Results – Mission Requirements

- Multipoint mission with simultaneous science observations around small bodies (potentially extended to planets and their satellites)
-
- Mother spacecraft carrying 4 smallsats
- Consider a single launch with the Epsilon or Vega-C and a shared launch on Ariane 6.2
- Launch date between 2024 and 2034
- Selected final target to be reached after a maximum of 5 years (TBC) after launch
- 6 months (TBC) of science operations after deployment of the smallsats
- Total wet mass at launch shall not exceed 900 kg (TBC) – to remain compatible with the ARIEL mission
- Mother spacecraft and smallsats shall be compatible with storage on ground of at least 3 years (TBC)

SPP CDF Study Overview and Main Results – Mother Spacecraft Requirements

- The mother spacecraft shall not accommodate scientific payload (simplified approach for the purpose of the study)
- The mother spacecraft shall be able to carry the smallsats to the selected final target, providing to them thermal control and power during cruise and the data relay service to/from Earth after their deployment





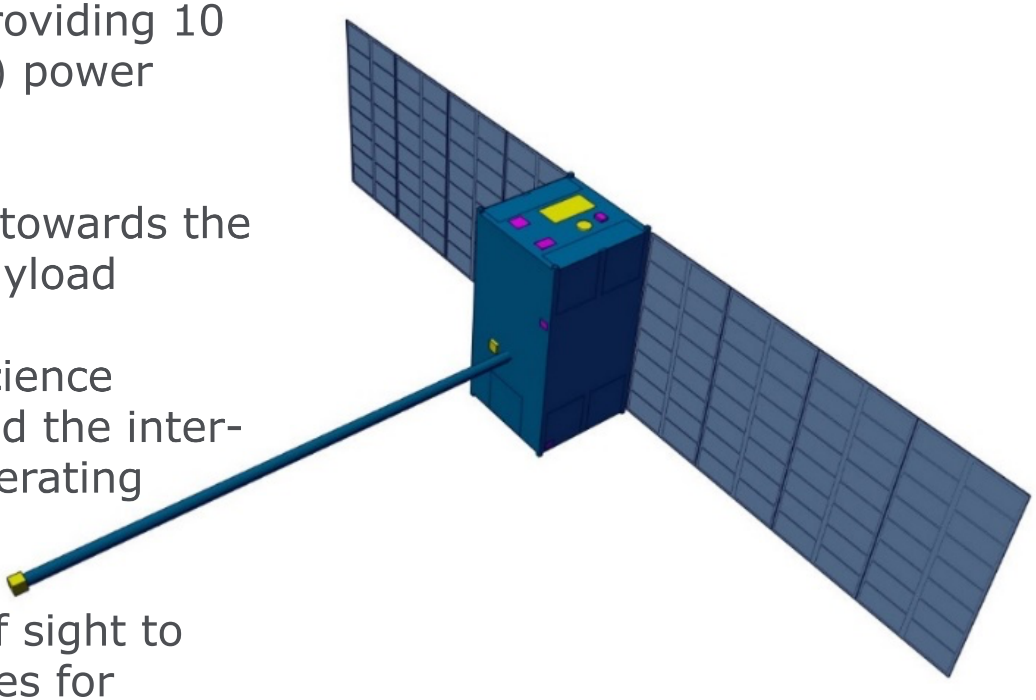
SPP CDF Study Overview and Main Results – Smallsat Requirements

- Each of the smallsats shall be able to accommodate a minimum of 3 kg (TBC) of scientific payload, providing 10 W (TBC) average electrical power and 5V (TBC) power interface

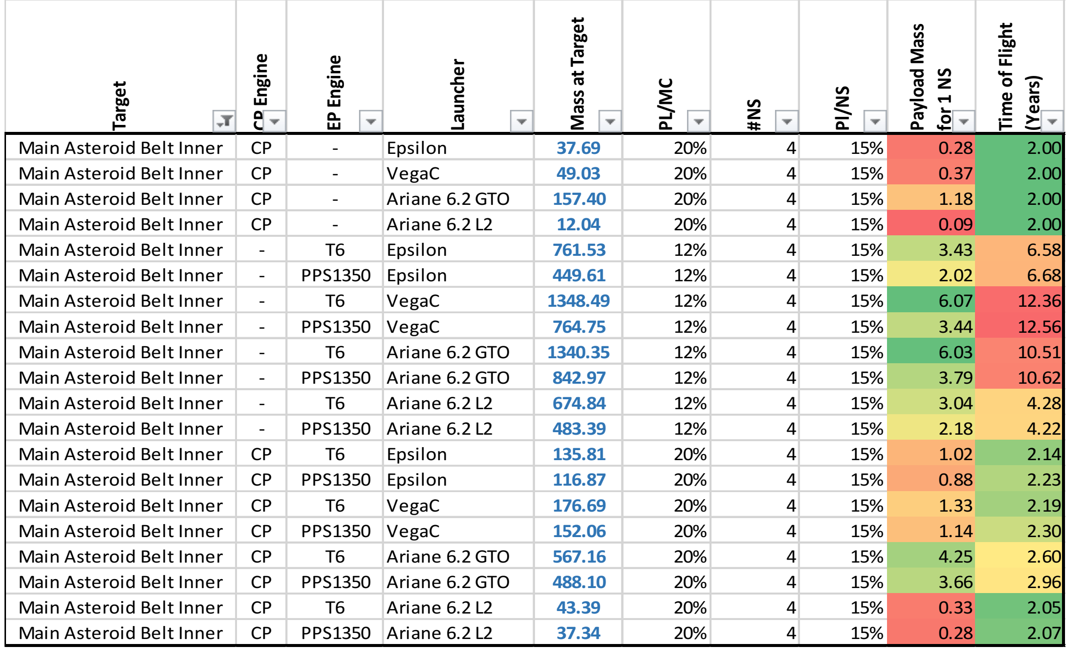
- All the smallsats shall have identical interfaces towards the mother spacecraft and towards the scientific payload

- The smallsats shall be capable of performing science operations with all the scientific instruments and the inter-satellite-link (ISL) communications package operating simultaneously

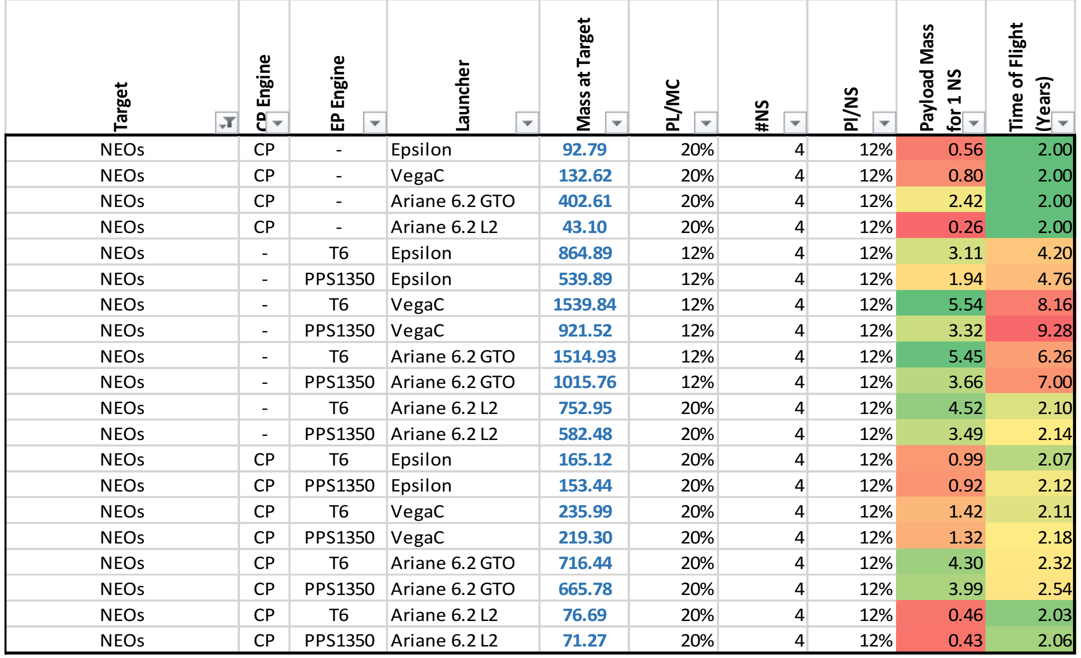
- The smallsats shall be able to maintain a line of sight to point of interest and shall have AOCS capabilities for station keeping after deployment from the MC



SPP CDF Study Overview and Main Results – Mission & System Level Trade-offs

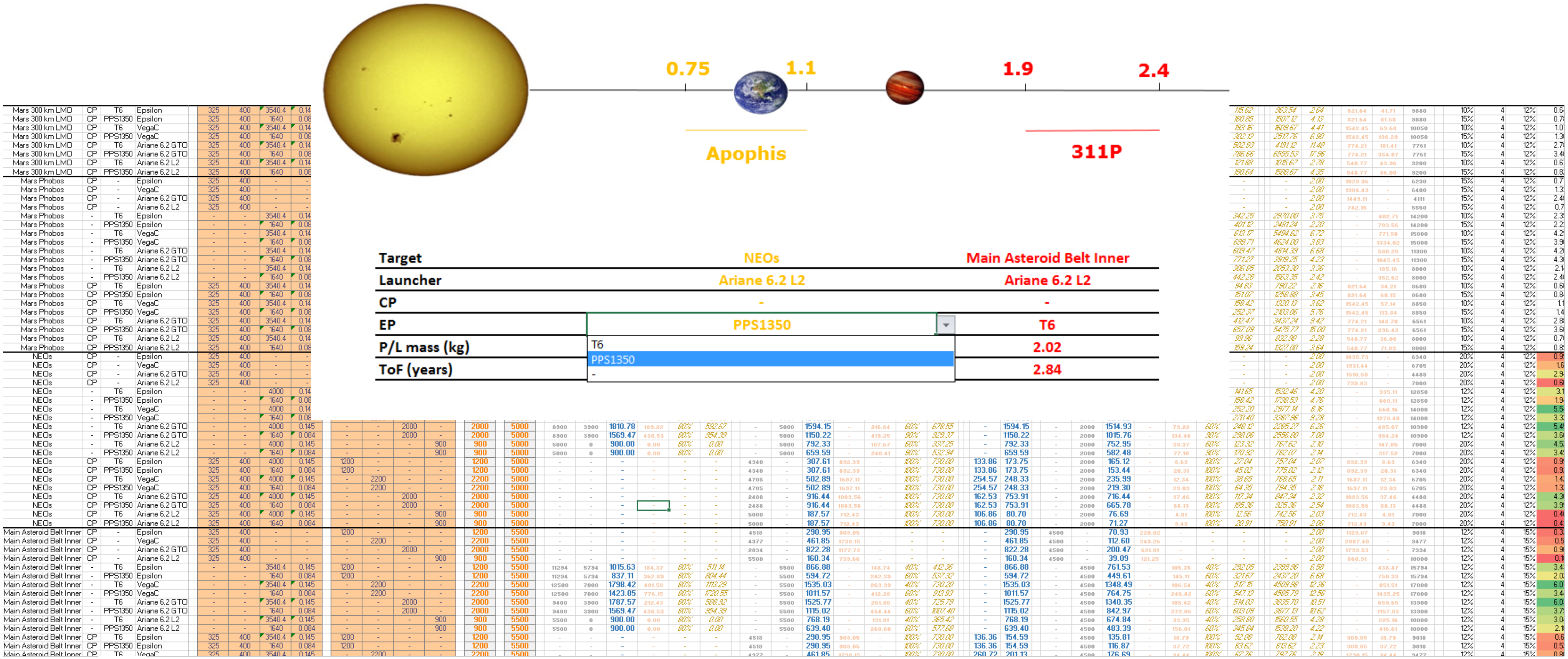


Target	CP Engine	EP Engine	Launcher	Mass at Target	PL/MC	#NS	Pl/NS	Payload Mass for 1 NS	Time of Flight (Years)
Main Asteroid Belt Inner	CP	-	Epsilon	37.69	20%	4	15%	0.28	2.00
Main Asteroid Belt Inner	CP	-	VegaC	49.03	20%	4	15%	0.37	2.00
Main Asteroid Belt Inner	CP	-	Ariane 6.2 GTO	157.40	20%	4	15%	1.18	2.00
Main Asteroid Belt Inner	CP	-	Ariane 6.2 L2	12.04	20%	4	15%	0.09	2.00
Main Asteroid Belt Inner	-	T6	Epsilon	761.53	12%	4	15%	3.43	6.58
Main Asteroid Belt Inner	-	PPS1350	Epsilon	449.61	12%	4	15%	2.02	6.68
Main Asteroid Belt Inner	-	T6	VegaC	1348.49	12%	4	15%	6.07	12.36
Main Asteroid Belt Inner	-	PPS1350	VegaC	764.75	12%	4	15%	3.44	12.56
Main Asteroid Belt Inner	-	T6	Ariane 6.2 GTO	1340.35	12%	4	15%	6.03	10.51
Main Asteroid Belt Inner	-	PPS1350	Ariane 6.2 GTO	842.97	12%	4	15%	3.79	10.62
Main Asteroid Belt Inner	-	T6	Ariane 6.2 L2	674.84	12%	4	15%	3.04	4.28
Main Asteroid Belt Inner	-	PPS1350	Ariane 6.2 L2	483.39	12%	4	15%	2.18	4.22
Main Asteroid Belt Inner	CP	T6	Epsilon	135.81	20%	4	15%	1.02	2.14
Main Asteroid Belt Inner	CP	PPS1350	Epsilon	116.87	20%	4	15%	0.88	2.23
Main Asteroid Belt Inner	CP	T6	VegaC	176.69	20%	4	15%	1.33	2.19
Main Asteroid Belt Inner	CP	PPS1350	VegaC	152.06	20%	4	15%	1.14	2.30
Main Asteroid Belt Inner	CP	T6	Ariane 6.2 GTO	567.16	20%	4	15%	4.25	2.60
Main Asteroid Belt Inner	CP	PPS1350	Ariane 6.2 GTO	488.10	20%	4	15%	3.66	2.96
Main Asteroid Belt Inner	CP	T6	Ariane 6.2 L2	43.39	20%	4	15%	0.33	2.05
Main Asteroid Belt Inner	CP	PPS1350	Ariane 6.2 L2	37.34	20%	4	15%	0.28	2.07



Target	CP Engine	EP Engine	Launcher	Mass at Target	PL/MC	#NS	Pl/NS	Payload Mass for 1 NS	Time of Flight (Years)
NEOs	CP	-	Epsilon	92.79	20%	4	12%	0.56	2.00
NEOs	CP	-	VegaC	132.62	20%	4	12%	0.80	2.00
NEOs	CP	-	Ariane 6.2 GTO	402.61	20%	4	12%	2.42	2.00
NEOs	CP	-	Ariane 6.2 L2	43.10	20%	4	12%	0.26	2.00
NEOs	-	T6	Epsilon	864.89	12%	4	12%	3.11	4.20
NEOs	-	PPS1350	Epsilon	539.89	12%	4	12%	1.94	4.76
NEOs	-	T6	VegaC	1539.84	12%	4	12%	5.54	8.16
NEOs	-	PPS1350	VegaC	921.52	12%	4	12%	3.32	9.28
NEOs	-	T6	Ariane 6.2 GTO	1514.93	12%	4	12%	5.45	6.26
NEOs	-	PPS1350	Ariane 6.2 GTO	1015.76	12%	4	12%	3.66	7.00
NEOs	-	T6	Ariane 6.2 L2	752.95	20%	4	12%	4.52	2.10
NEOs	-	PPS1350	Ariane 6.2 L2	582.48	20%	4	12%	3.49	2.14
NEOs	CP	T6	Epsilon	165.12	20%	4	12%	0.99	2.07
NEOs	CP	PPS1350	Epsilon	153.44	20%	4	12%	0.92	2.12
NEOs	CP	T6	VegaC	235.99	20%	4	12%	1.42	2.11
NEOs	CP	PPS1350	VegaC	219.30	20%	4	12%	1.32	2.18
NEOs	CP	T6	Ariane 6.2 GTO	716.44	20%	4	12%	4.30	2.32
NEOs	CP	PPS1350	Ariane 6.2 GTO	665.78	20%	4	12%	3.99	2.54
NEOs	CP	T6	Ariane 6.2 L2	76.69	20%	4	12%	0.46	2.03
NEOs	CP	PPS1350	Ariane 6.2 L2	71.27	20%	4	12%	0.43	2.06

SPP CDF Study Overview and Main Results – Quick Mission Design Tool

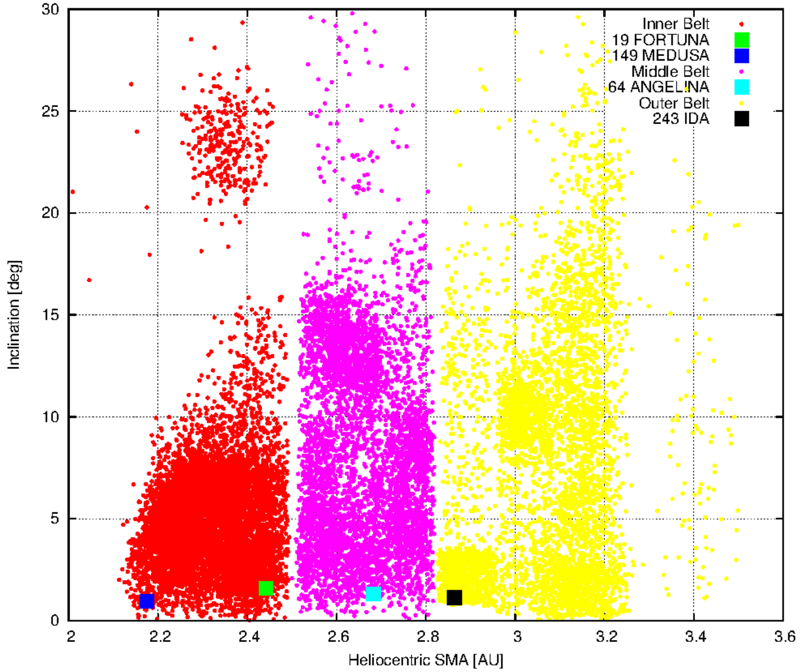


Target	NEOs	Main Asteroid Belt Inner
Launcher	Ariane 6.2 L2	Ariane 6.2 L2
CP	-	-
EP	PPS1350	T6
P/L mass (kg)		2.02
ToF (years)		2.84

SPP CDF Study Overview and Main Results – Databases of Small Bodies

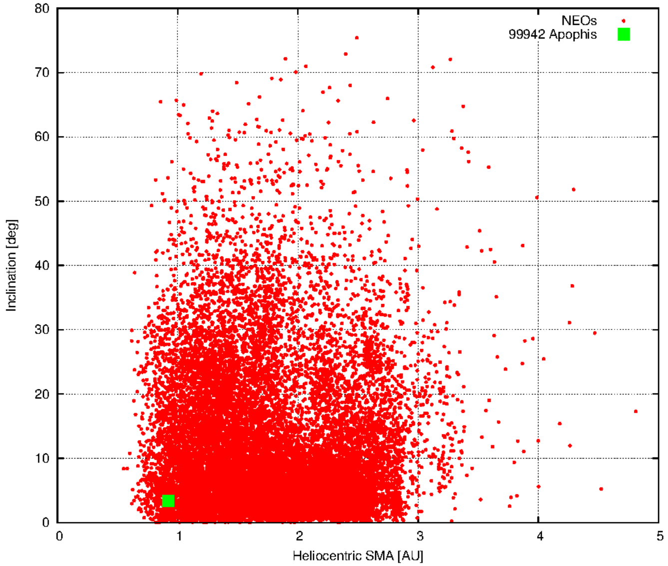
MBAs

- Huge database ~700,000 objects

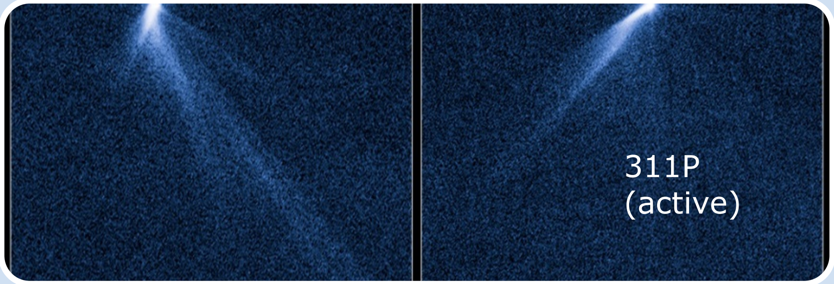


NEOs

- Perihelion < 1.3 AU
- Wide range of SMAs and inclination
- Wide range of DV
- 17,000+ objects in database



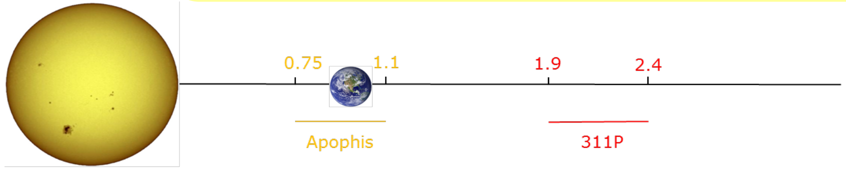
SPP CDF Study Overview and Main Results – Baseline Scenarios Overview



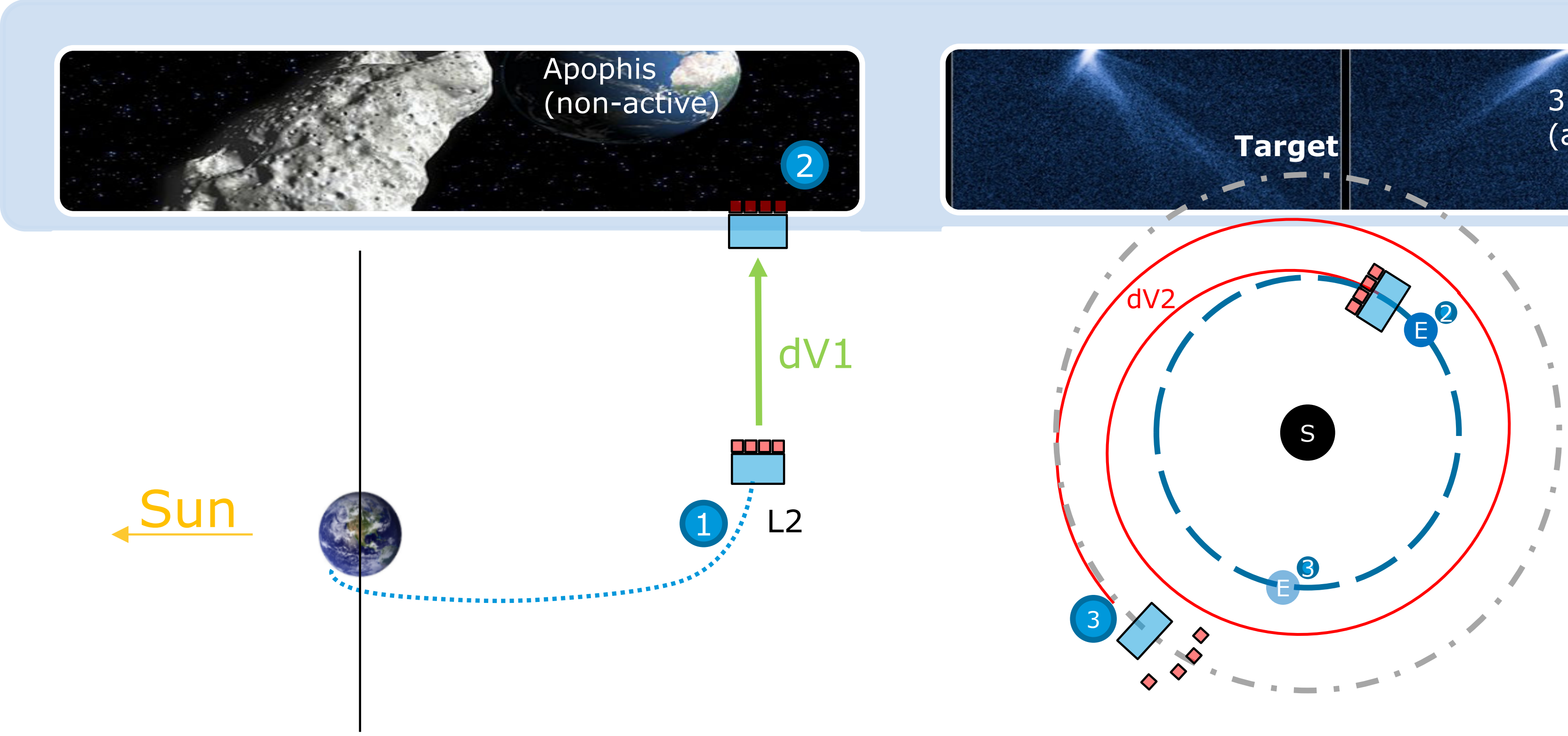
Target Diameter: 370 m
Target Distance:0.75-1.1 AU
NS SCI: radar tomography
DV ~ 4.5 km/s (with EP)

Strawman P/L **OPT 1 | OPT 2**
2.75 kg | 2.95 kg
88 W | 20 W
59 Gbit | 53 Gbit
3 U | 3 U

Target Diameter: 380 m
Target Distance: 1.9 - 2.4 AU
NS SCI: gases/volatiles
DV ~ 10-11 km/s (with EP)



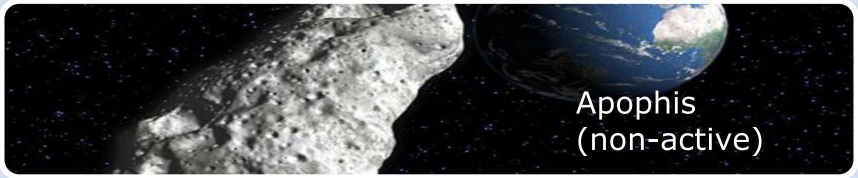
SPP CDF Study Overview and Main Results – Transfer Overview



① Launch into L2
Thrusting with EP to reach V_inf
② Escape with V_inf

② Heliocentric Orbit
Thrust with EP to reach target
③ RV with target

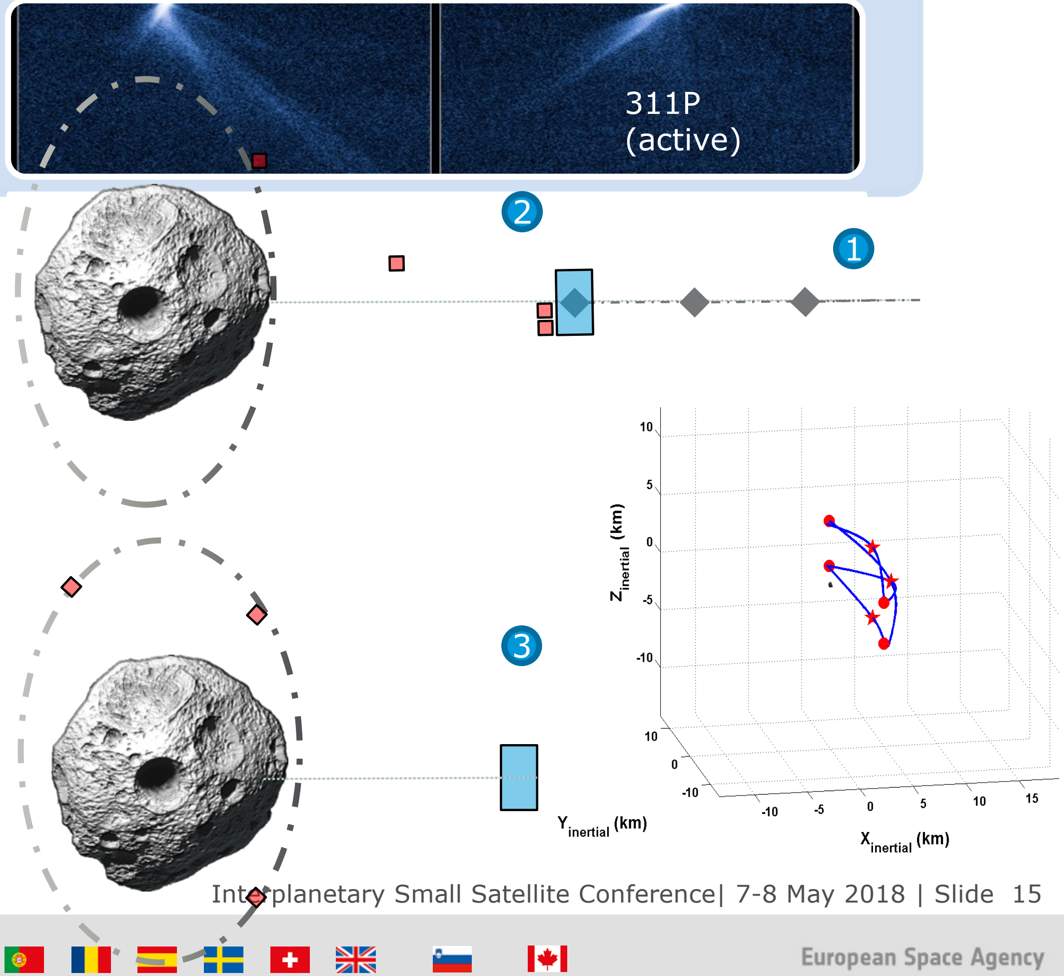
SPP CDF Study Overview and Main Results – Rendezvous Overview



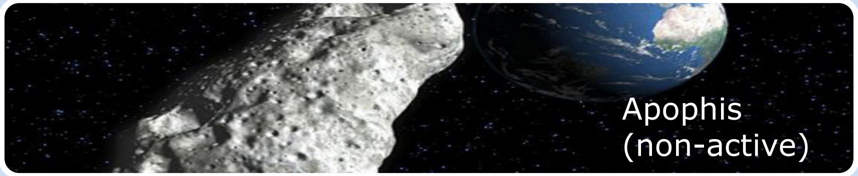
1. Mother spacecraft rendezvous and insertion in stable orbit in plane between the Earth and the target.
   - Slow stepped approach 4 to 6 weeks

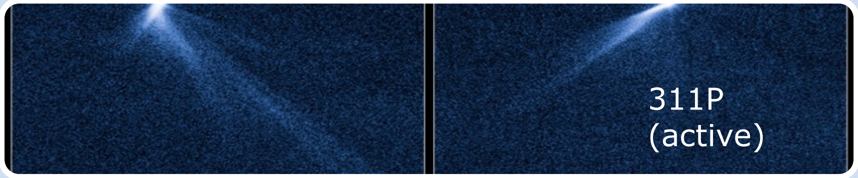
2. Deployment sequence of the smallsats individually with mother spacecraft in stable orbit.
   Smallsats maneuver to operational distance to the target

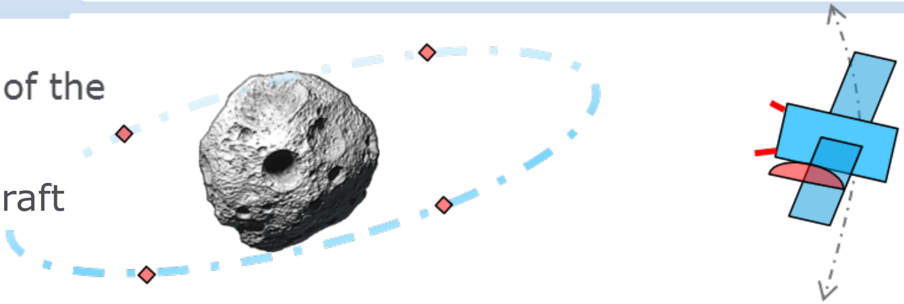
3. Mother spacecraft insertion in final trajectory in the trail of the target, with visibility of the whole constellation



SPP CDF Study Overview and Main Results – Rendezvous Overview







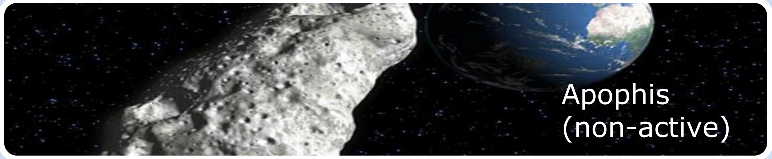
Mother spacecraft: ping-pong" trajectory in the trail of the target taken as baseline

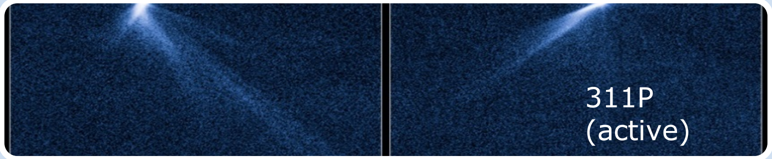
- No eclipses for mother spacecraft
- 1 correction every 7 days

Smallsats: 3-4 days arc hyperbola

- keeping an inclination that avoids eclipse while taking pictures of the "night side" for a small target - 5 km orbit >> 500m of the diameter of the target
- Baseline – No eclipses

SPP CDF Study Overview and Main Results – Smallsats Design Summary





Smallsat

- Dimensions: ~ 0.26 x 0.23 x 0.45
- Delta-V: 10 m/s at target
- Cprop: Butane Cold gas system
- Propellant mass: ~600 g Cold gas system

Smallsat

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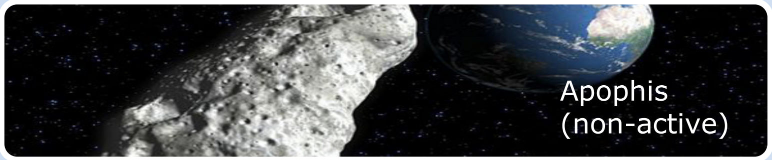
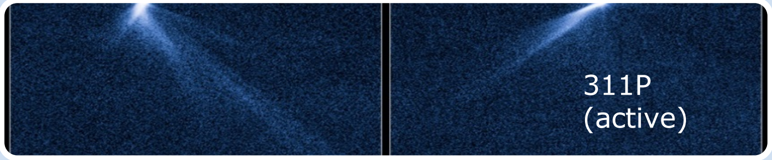
SPP CDF Study Overview and Main Results – Smallsats Design Summary



Apophis (non-active)



311P (active)

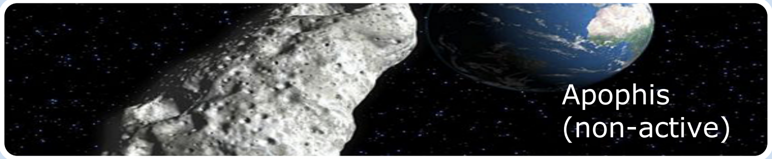
Smallsat

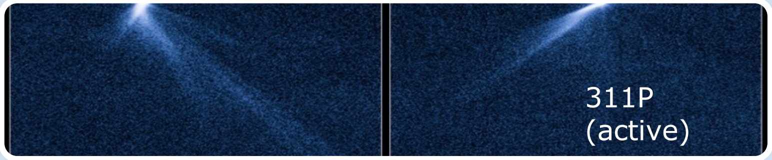
- Power Generation: ~0.64 m2 → 117 W 1.1 AU
- Batteries: 0.86 kg
- Thermal: Radiator area ~0.33 m2 Deployable radiators needed
- Thermal: Black MLI chosen to maximize absorption at the target
- Mechanisms: SADM

Smallsat

- Power Generation: ~0.64 m2 → 28 W 2.5 AU
- Batteries: 0.49 kg
- Thermal: No radiators
- Thermal: Black MLI chosen to maximize absorption at the target
- Mechanisms: SADM

SPP CDF Study Overview and Main Results – Smallsats Design Summary


Apophis
(non-active)


311P
(active)

Smallsat

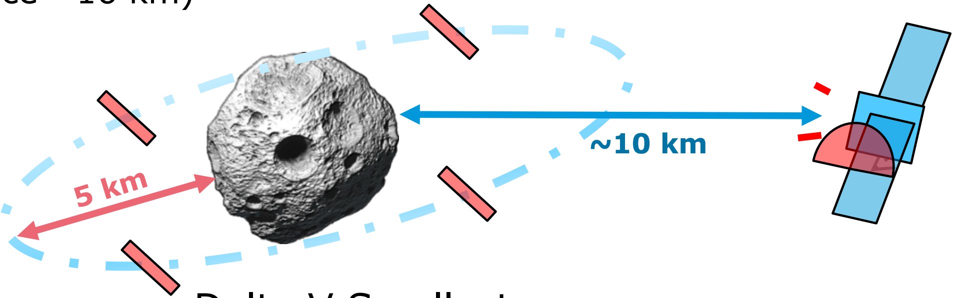
- Comms ISL:
  S-band: 2 Low Gain Antennas
  Higher duty-cycle
- DHS:
  OBC – Rad-Tolerant components
- AOGNC Sensors: SUN | STR | IMU| ALT |NAV CAM |
- AOGNC Actuators: RW | CG

Smallsat

- Comms ISL:
  S-band: 2 Low Gain Antennas
- DHS:
  OBC – Rad-Tolerant components
- AOGNC Sensors: SUN | STR | IMU| ALT |NAV CAM |
- AOGNC Actuators: RW | CG

SPP CDF Study Overview and Main Results – NEO Option DV Budget

Mother spacecraft: ‘ping-pong’ hyperbola 7 day arcs (pericentre ~12 km, max distance ~20 km)
Smallsats: 4-3-4-3 day hyperbolic arcs
3-day arc (pericentre ~5 km, max distance ~12 km)
4 day arcs (pericentre ~5 km, max distance ~16 km)



Delta V mother spacecraft:

Manoeuvres	Delta v (m/s)	margin	Total (m/s)
Transfer	4530	10% (EP)	4983
Orbit maintenance at target	2.4	-	10
Pointing & Attitude control	0.5	-	
Total		-	4993

Delta V Smallsats:

Manoeuvres	Delta v (m/s)	margin	Total (m/s)
Rendezvous & Insertion	1	100%	10
Hyperbolic arcs	6.7	5%	
Pointing & Attitude control	0.2	100%	
Total		-	10

SPP CDF Study Overview and Main Results – NEO Option Mass Budget

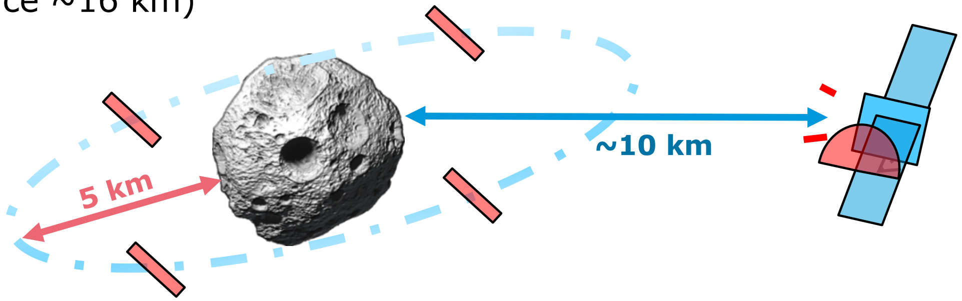
Smallsat Mass Budget		Mass [kg]
Attitude, Orbit, Guidance, Navigation Control		0.725
Communications		0.48
Chemical Propulsion		3.08
Data-Handling		0.31
Electric Propulsion		0.00
Instruments		3.30
Mechanisms		1.02
Power		5.42
Structures		2.70
System Engineering		0.00
Thermal Control		5.87
Harness	5%	1.15
Dry Mass w/o System Margin		**24.06**
System Margin	20%	4.81
Dry Mass incl. System Margin		**28.87**
CPROP Fuel Mass		0.52
CPROP Fuel Residual	2%	0.01
Total Wet Mass		**29.40**

x4

Mother Spacecraft Mass Budget		Mass [kg]
Attitude, Orbit, Guidance, Navigation Control		10.20
Communications		23.07
Chemical Propulsion		0.00
Data-Handling		3.60
Electric Propulsion		86.97
Instruments		0.00
Mechanisms		38.68
Power		67.12
Structures		81.00
System Engineering		0.00
Thermal Control		36.08
Harness	5%	17.34
Dry Mass w/o System Margin		**364.05**
System Margin	20%	72.81
Wet Mass Smallsat	**4.00**	**117.61**
Dry Mass incl. System Margin		**554.48**
EPROP Propellant Mass		225.38
EPROP Propellant Residual	2%	4.51
Total Wet Mass		**784.36**
Target Wet Mass		900.00
Below Target Mass by		115.64

SPP CDF Study Overview and Main Results – Main Belt Option DV Budget

Mother spacecraft: ‘ping-pong’ hyperbola 7 day arcs (pericentre ~12 km, max distance ~20 km)
Smallsats: 4-3-4-3 day hyperbolic arcs
    3-day arc (pericentre ~5 km, max distance ~12 km)
    4 day arcs (pericentre ~5 km, max distance ~16 km)



Delta V mother spacecraft:

Manoeuvres	Delta v	margin	Total
Transfer	10000	10% (EP)	11000
Orbit maintenance at target	2.4	-	10
Pointing & Attitude control	0.5	-	
Total		-	11010

Delta V Smallsats:

Manoeuvres	Delta v	margin	Total
Rendezvous & Insertion	1	100%	10
Hyperbolic arcs	6.7	5%	
Pointing & Attitude control	0.2	100%	
Total		-	10

SPP CDF Study Overview and Main Results – Main Belt Option Mass Budget

Smallsat Mass Budget		Mass [kg]
Attitude, Orbit, Guidance, Navigation Control		0.725
Communications		0.48
Chemical Propulsion		3.08
Data-Handling		0.31
Electric Propulsion		0.00
Instruments		3.54
Mechanisms		1.02
Power		4.74
Structures		2.70
System Engineering		0.00
Thermal Control		1.12
Harness	5%	0.89
Dry Mass w/o System Margin		**18.60**
System Margin	20%	3.72
Dry Mass incl. System Margin		**22.33**
CPROP Fuel Mass		0.52
CPROP Fuel Residual	2%	0.01
Total Wet Mass		**22.86**

x4

Mother Spacecraft Mass Budget		Mass [kg]
Attitude, Orbit, Guidance, Navigation Control		10.20
Communications		23.07
Chemical Propulsion		0.00
Data-Handling		3.60
Electric Propulsion		155.14
Instruments		0.00
Mechanisms		40.99
Power		136.78
Structures		81.00
System Engineering		0.00
Thermal Control		69.90
Harness	5%	26.03
Dry Mass w/o System Margin		**546.71**
System Margin	20%	109.34
Wet Mass Smallsat	**4.00**	**91.42**
Dry Mass incl. System Margin		**747.48**
EPROP Propellant Mass		243.69
EPROP Propellant Residual	2%	4.87
Total Wet Mass		**996.05**
Target Wet Mass		900.00
Above Target Mass by		96.05

SPP CDF Study Overview and Main Results – Some Conclusions

- The SPP CDF study has provided a ”tool-box” of elements for the design of planetary science missions involving multi-point observations of a body with small satellites

- The cubesat standard shape and form factors where assumed in the study for simplicity and availability of hardware (like the dispenser for example).
  - This choice heavily constraints the accommodation of scientific instruments (no protrusions)
  - Dedicated/tailored designs of the small satellites (not cubesats) will be consider in further steps to maximise payload mass and accommodation possibilities

- The size (mass/gravity field) of the selected target drastically impacts the mission and spacecraft designs
  - Missions to targets below ~ 1km in diameter can afford to have the mother in a ”ping-pong” orbit trailing the body and always in visibility of the smallsat network (in hyperbolic arcs) – there are no eclipses and the ISL can remain simple with patch LGAs
  - Missions to targets above ~ 1km would require the smallsats to go into orbit and the ISL to be a lot more complex in topology and hardware (MGA on mother spacecraft for example)

Plans and Future Outlook

- Strong interest both in the scientific community and within ESA to approach planetary science missions in a different, innovative way by considering small satellites with reduced and very focused science objectives.

- The use of smaller spacecraft can help in filling (as secondary passengers) the unused launcher capacity in larger missions, therefore reducing the overall cost.

- A call for proposals dedicated to planetary missions using small satellites (with a mother spacecraft) is expected to be released later this year.

Credits go to the ESA CDF team for their work on this study requested by the Science Future Missions department

Thank you for your attention!