Don Quijote mission industrial assessment and roadmap

Ian Carnelli
Institutional Matters & Strategic Studies Office
ESA-ESTEC

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ESA addressing NEO impact risk

- Near Earth Objects (NEO): low impact probability but extremely severe effects
- Very limited practical knowledge on NEO threat and the best technology approach to tackle it
- Large public awareness of the issue

Meteor Crater, Arizona

Tunguska forest, Siberia

Manicouagan crater, Canada

ESA addressing NEO impact risk

UN COPUOS

Council of Europe

UK government task force

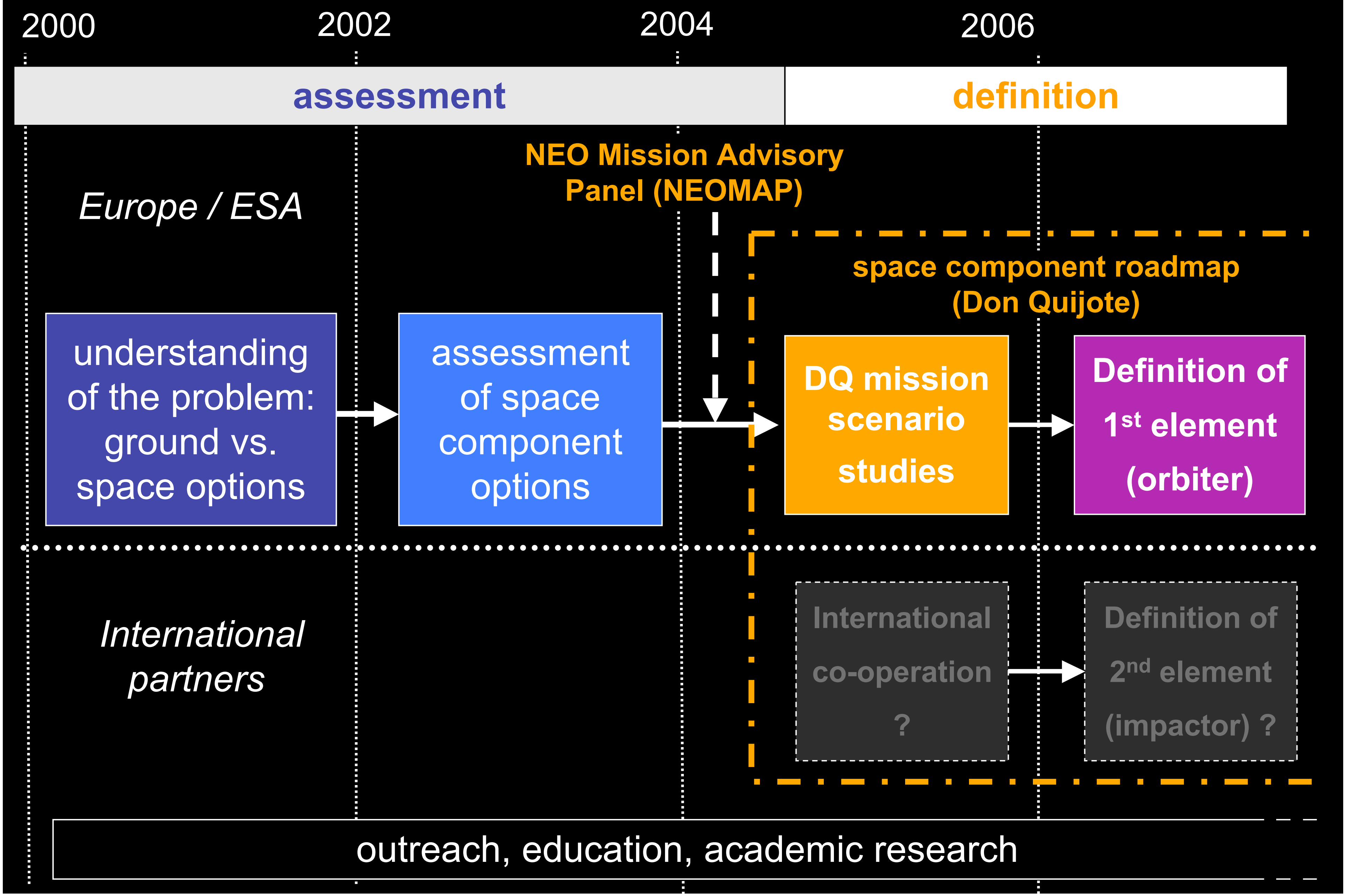
OECD

Organization for Economic Co-operation & Development

ESA to take action and identify the potential role of space missions

ESA long term plan 2000 and 2006

NEO Risk Space Mission Roadmap



Background

2000 | 2002 | 2004 | 2006

assessment

understanding of the problem: ground vs. space options

2000: studies on NEOs (number, distribution) integrated (ground + Space) assessment options

outreach, education, academic research

Space Component Options

2002 Early ESA scientific and system studies

6 parallel mission feasibility studies (GSP):

assessment of space component options

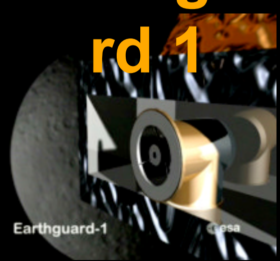
space component roadmap (Don Quijote)

NEO Mission Advisory Panel (NEOMAP)

Neró

Euneos

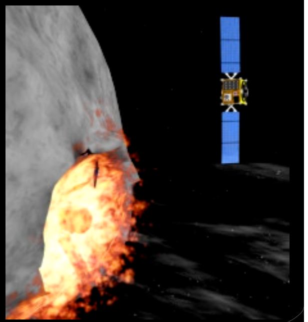
Earthguard 1



Simone

Ishtar

Don



Observatory missions

Rendezvous missions

Don Quijote concept

2004

NEO Mission Advisory Panel (NEOMAP)

space component roadmap (Don Quijote)

DQ mission scenario studies

2004 ESA's NEO Mission Advisory Panel (NEOMAP) ranks the DQ roadmap first in priority

1. **Prove the ability to detect any modifications on the trajectory of a NEO**, be it natural (e.g. Yarkowsky) or man-made

2. **Demonstrate ability to modify this trajectory**, e.g by means of a kinetic impact

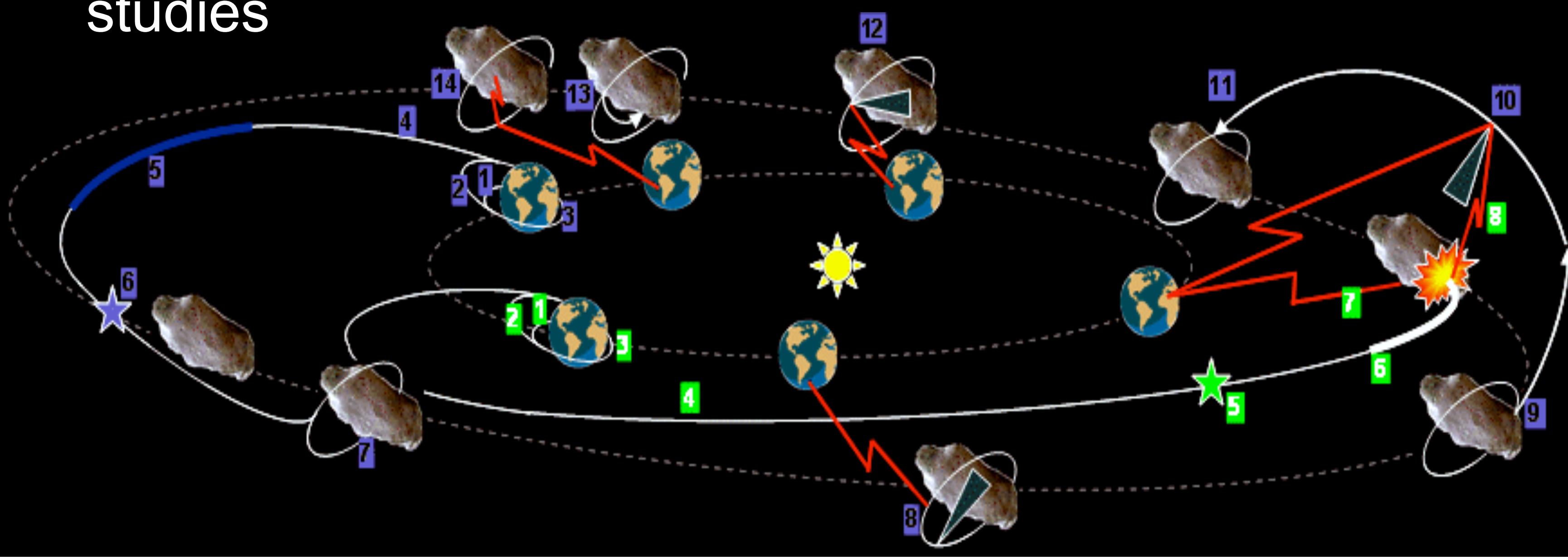
Don Quijote Scenario

2005 Internal studies:

- Review DQ mission concept
- Assess technical feasibility of several mission options
- Define a solid baseline mission scenario
- Identify requirements for the following industrial phase-A studies

space component roadmap (Don Quijote)

DQ mission scenario studies →



Don Quijote industrial studies

DQ mission scenario studies

April 2006 – 3 parallel industrial studies.

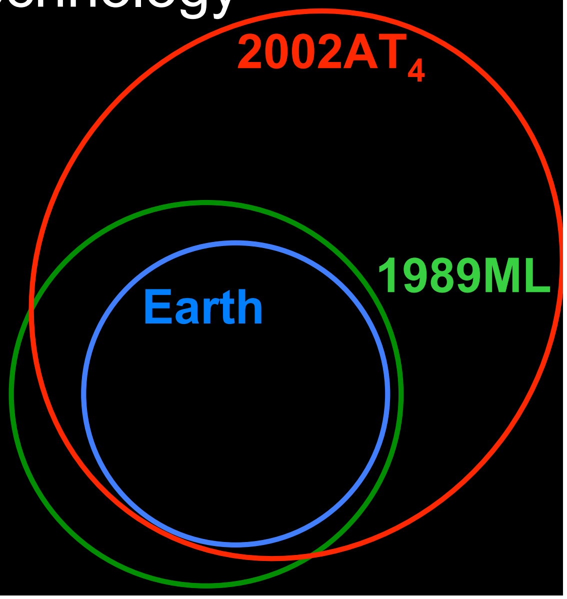
Study objectives:

- Assess the limitations in re-use of existing technologies, s/c bus, propulsion modules, …
- Identify the implications at system level of target choice and operational options
- Define performances (RSE, AutoNav …), technology developments and critical issues

Mission objectives:

DQ “light” (1) impact given NEO (Δa~100m)
(2) determine momentum transfer

DQ+ (1) + (2) + ASP-DEX + NEO properties



Don Quijote studies

DQ mission scenario studies

Mission constraints

System operations	2 s/c launched separately
	Impactor launched after Obiter successful rendezvous
	ASP-DeX to be carried out only at end-of-mission

Impactor	NEA CoG $\Delta a \geq 100$ m
	$\beta = 1$ (no ejecta)
	Target visual acquisition 2 days before impact
	Autonomous optical navigation 2 days before impact
	Impact accuracy 50 m from CoG

Technology	TRL ≥ 5 by mid-2008 for Orbiter autonomy & Impactor GNC
	TRL ≥ 6 by mid-2007 for all other system elements

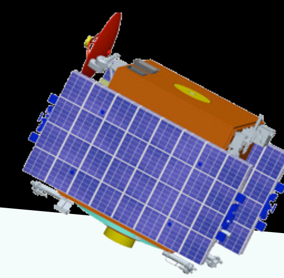
Don Quijote studies

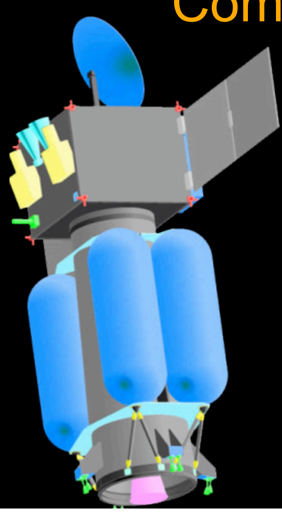
DQ mission scenario studies

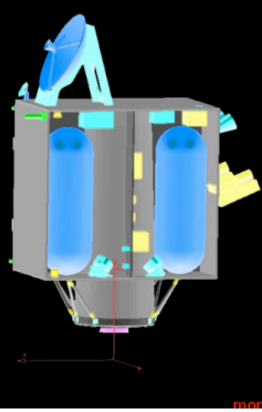
Orbiter	Δa measurement accuracy 10 m (10%)
	Measure at least NEA mass, size, gravity field, shape
	Back-up data relay for Impactor’s GNC
	Autonomous navigation while orbiting ≥ 4 orbits
	Autonomous optical rendezvous when distance ≤ 100 km

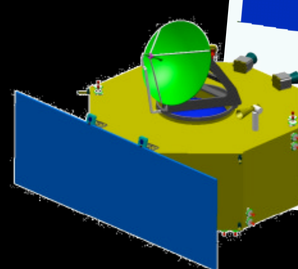
Alternative System Options:

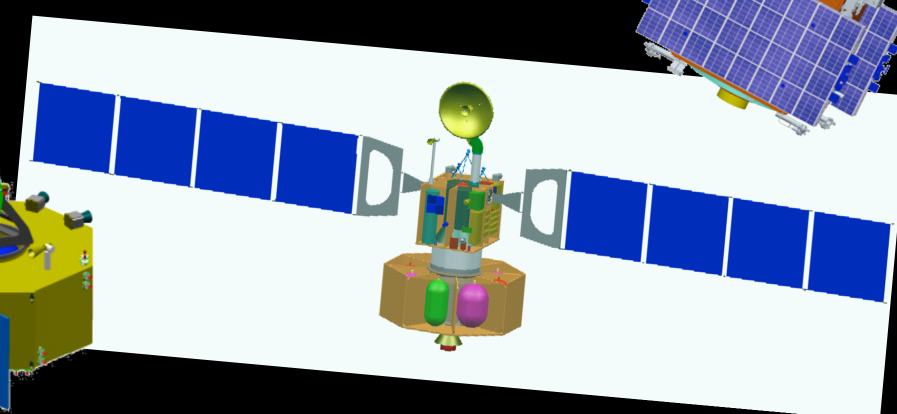
- Common Propulsion Module
- Impactor-PM integrated approach
- Common Orbiter-Impactor bus



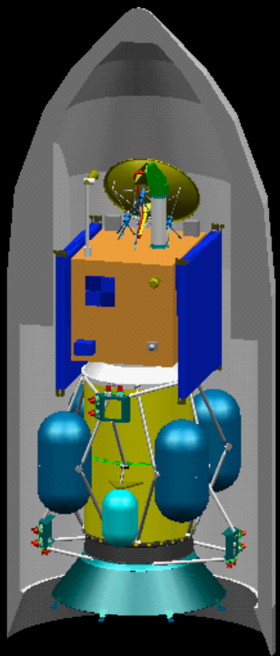




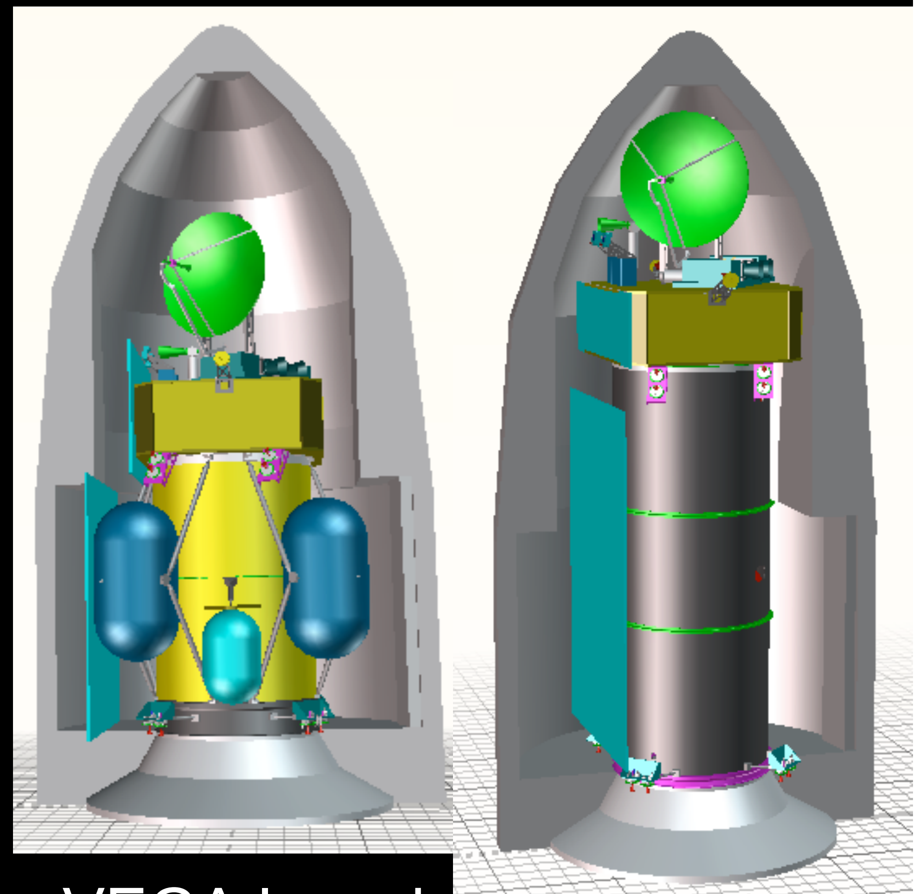




Alcatel Alenia Space

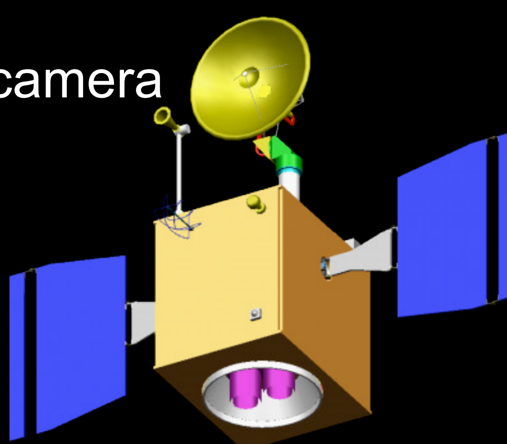


DNEPR launch
m_{dry} = 430 kg
m_{prop} = 70 kg
$m_{p/l}$ = 16.7 kg
Thermal radiometer
NIR spectrometer
X- and Ka-band TX



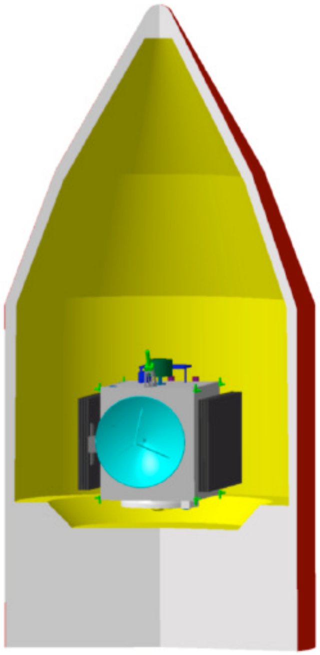
Orbiter navigation sensors

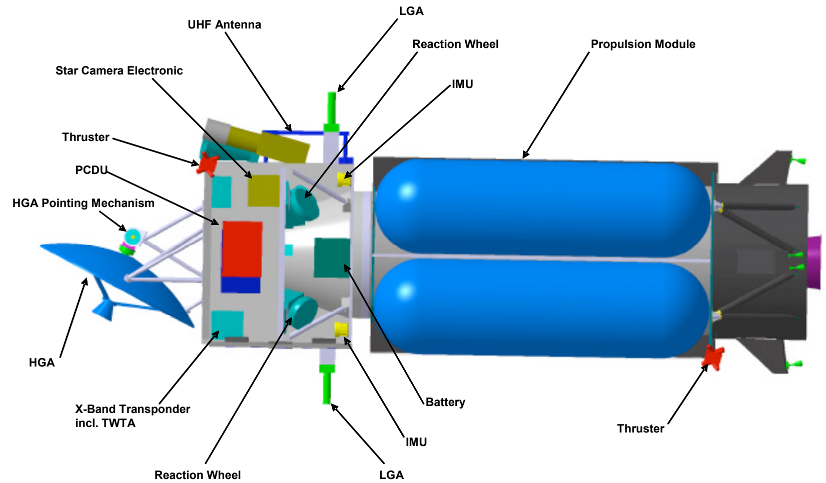
- NEAR Laser Range Finder
- Dawn NAC
- Wide angle camera

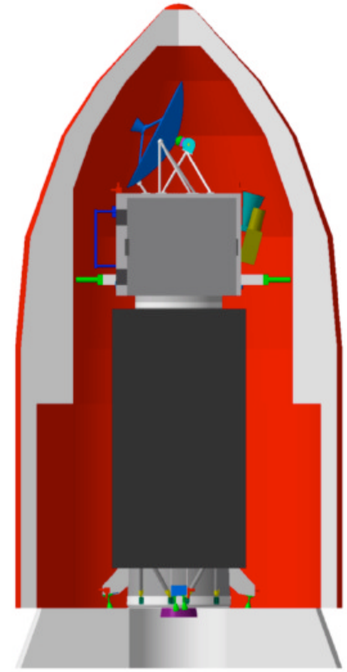


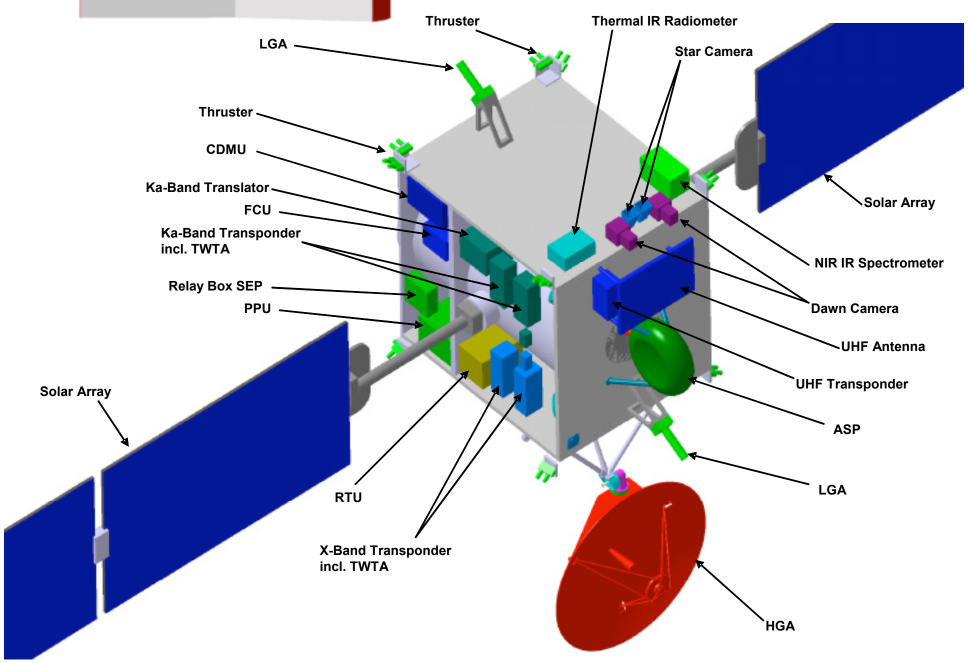
VEGA launch
m_{dry} = 440 kg
m_{prop}=1320 kg
Osiris camera
UHF link (GNC data)

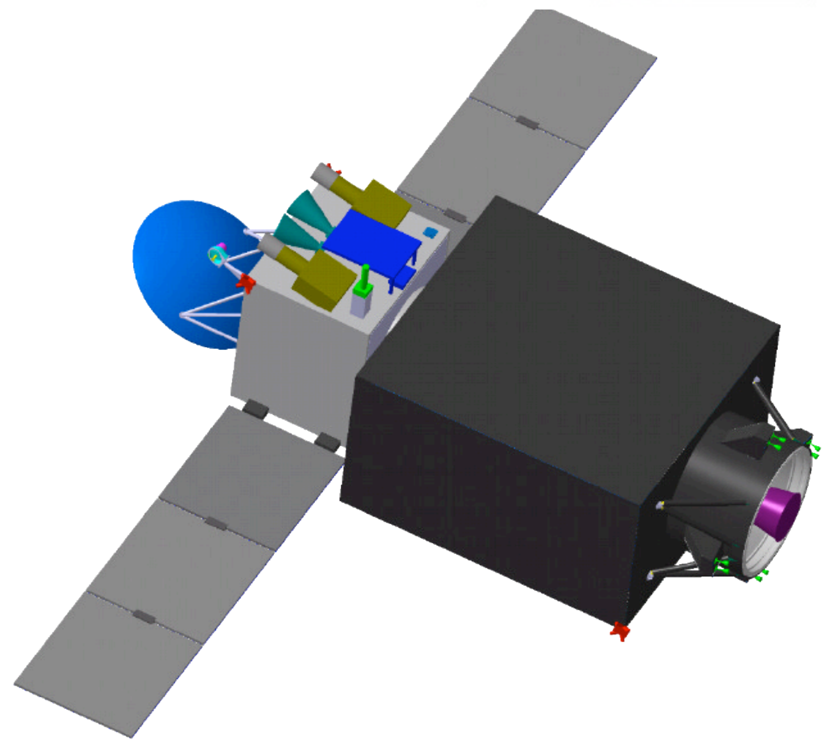
EADS Astrium





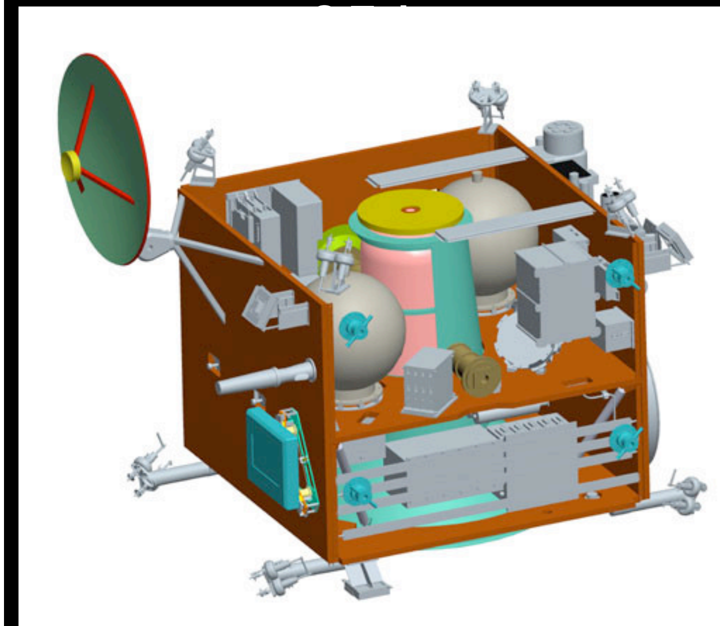




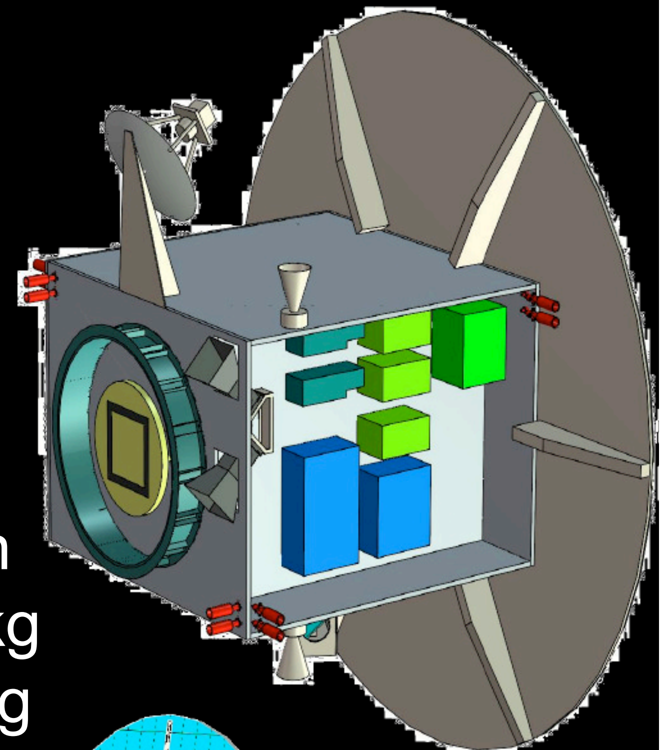


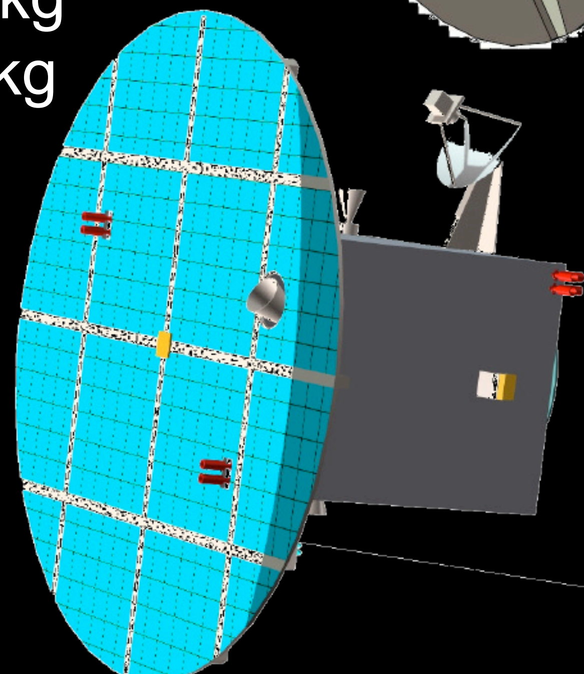
QinetiQ

PSLV launch
m_{dry} = 346 kg
m_{Xe} = 89 kg



VEGA launch
m_{dry} = 393 kg
m_{chem} = 34 kg
ballast = 3 kg





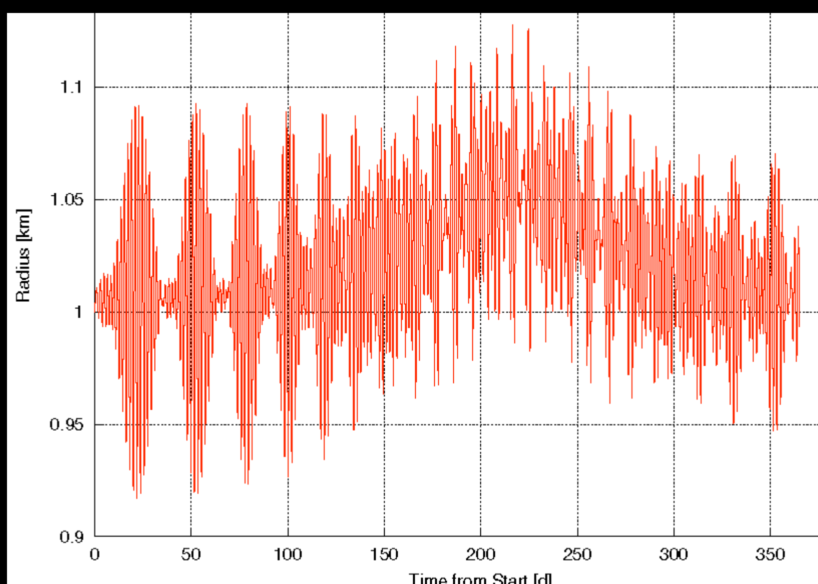
Payload: 10.7 kg, 30.5w
Camera – Amie2
Thermal IR spectrometer – Mertis
Laser altimeter – NEAR
NIR spectrometer – SIR-2
X- and Ka-band transponders

Orbit stability

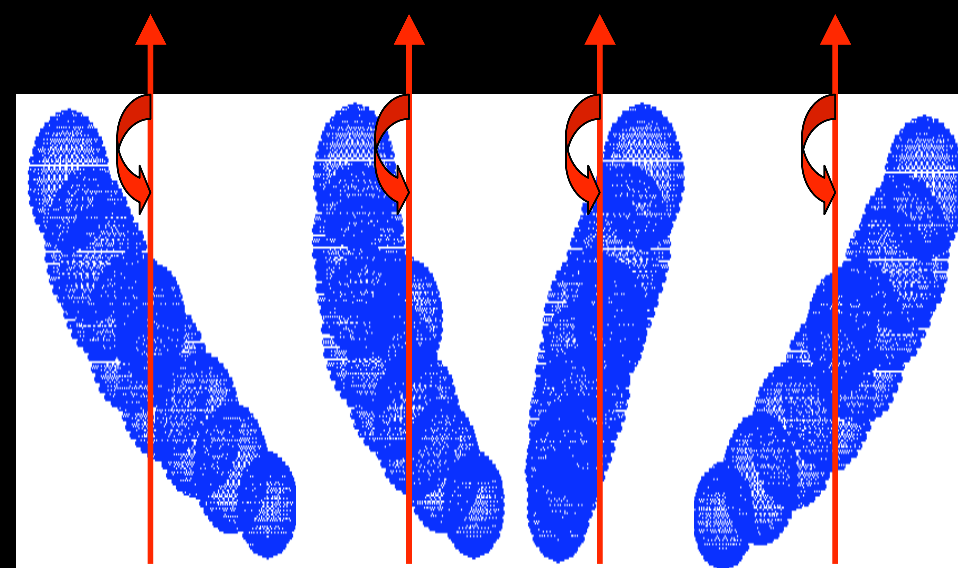
Long-term sun-synchronous orbits feasible

- Feasibility demonstrated for 1 year starting 15/11/2016
- Characteristics of this orbit:
  - Orbital radius around 1 km
  - No control maneuvers
  - No asteroid eclipses
  - Continuous Earth observability

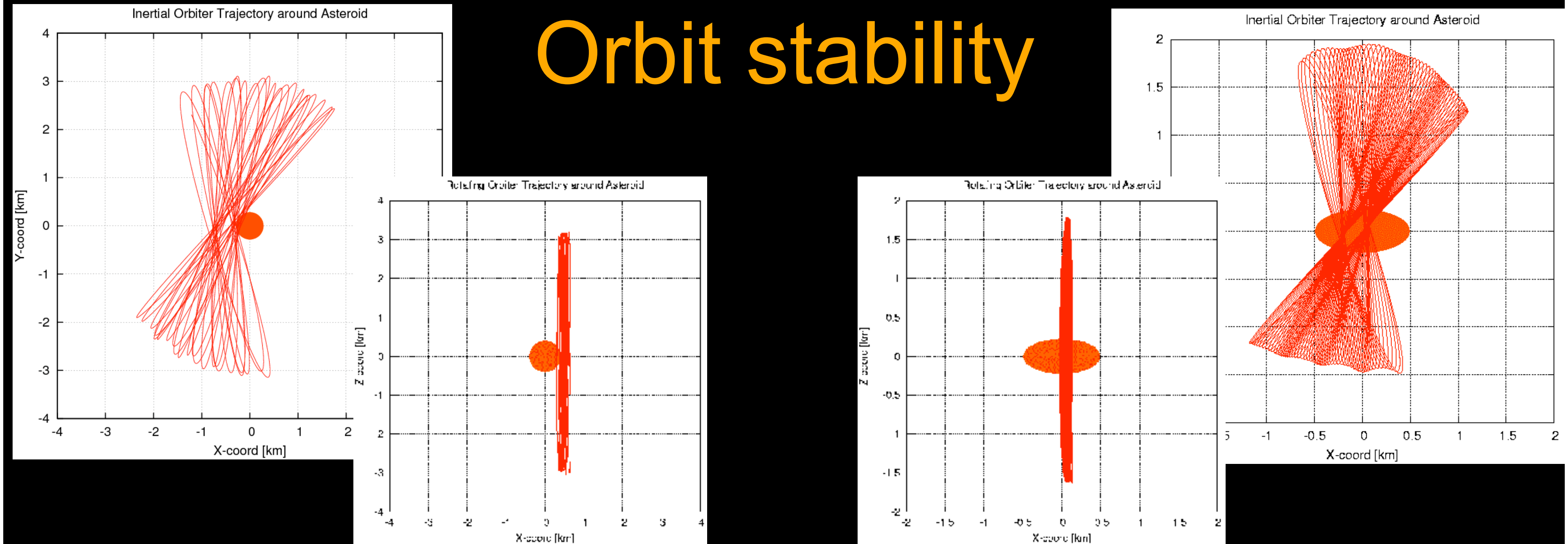
Orbit radius [km]



Time [day]



Orbit stability



Terminator orbits are robust and self-stabilizing through SRP if:

- Outside of ~1.5 x D resonance radii of the body
- Within the capture semi-major axis relative to SRP
- Terminator orbits nominally require minimal maintenance
- Deviations from the terminator plane can be allowed, but require a higher precision model to verify safety
- Orbits may not require correction maneuvers for weeks/months

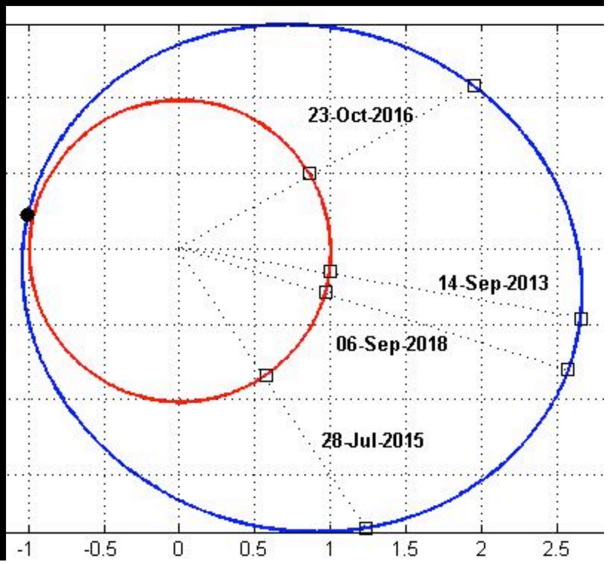
Non-terminator orbits require maneuvers ~ every few days

Radio science experiment

- Measurement goal: determine momentum transfer
- Requires two-step process:
  - Determine position of Orbiter (range & range-rate)
  - Infer position of asteroid CoM relative to Orbiter

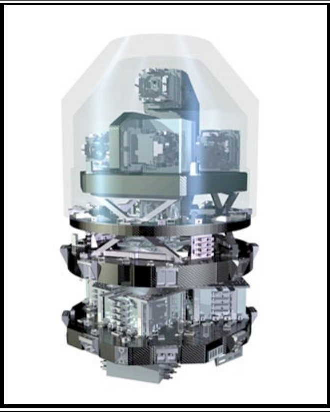
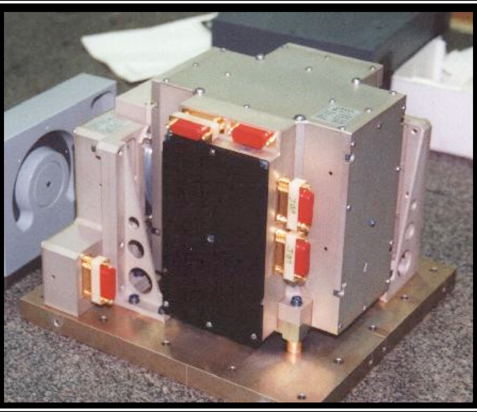
Solve for Orbiter heliocentric and asteroid-centric motion simultaneously!

- RSE benefits from:
  1. small Earth-asteroid distance → minimize the plasma effects → <u>solar opposition</u>
  2. <u>low angle</u> between the orbital plane of the Orbiter and the line of sight of the Earth → ensure a sufficient Doppler signal



Radio science experiment

- Challenges:
  1. Disentangle non-gravitational disturbances of the Orbiter (e.g. solar radiation pressure SRP, fuel leakage, WOL)
  2. Disentangle non-gravitational disturbances of the asteroid (e.g. Yarkowsky effect)

Three possible options to disentangle SRP		
High-performance accelerometer and conventional operations	Medium-performance accelerometer and clever operations	No additional equipment but clever operations
		Solve for solar radiation pressure and gravity field simultaneously

Radio science experiment

No additional equipment option

- Operational / design penalties
  - Plan for several SRP calibration phases during cruise
    - Verify force model
    - Verify aging properties
  - Maintain Sun-pointing attitude for solar arrays during RSE
  - Select Orbiter surface materials for their aging properties

Mass Configuration	Case	Uncertainty in SRP over the Asteroid	Uncertainty in Semi-major Axis (m)		Uncertainty in Δa (m)	Uncertainty in Δa (%Δa)
			Before the Impact	At the End of Mission Lifetime		
Minimum	1989ML-01-10	10%	16,24	13,81	21.32	4.12
Minimum	1989ML-01-5	5%	10,89	10,49	15.12	2.92
Minimum	1989ML-01-3	3%	8,90	8,88	12.57	2.43
Minimum	1989ML-01-1	1%	6,90	7,55	10.23	1.97
Maximum	1989ML-02-10	10%	8,22	6,86	10.71	11.15
Maximum	1989ML-02-5	5%	5,87	4,60	7.45	7.76
Maximum	1989ML-02-3	3%	4,63	3,76	5.96	6.21
Maximum	1989ML-02-1	1%	3,21	2,91	4.33	4.51

Don Quijote studies

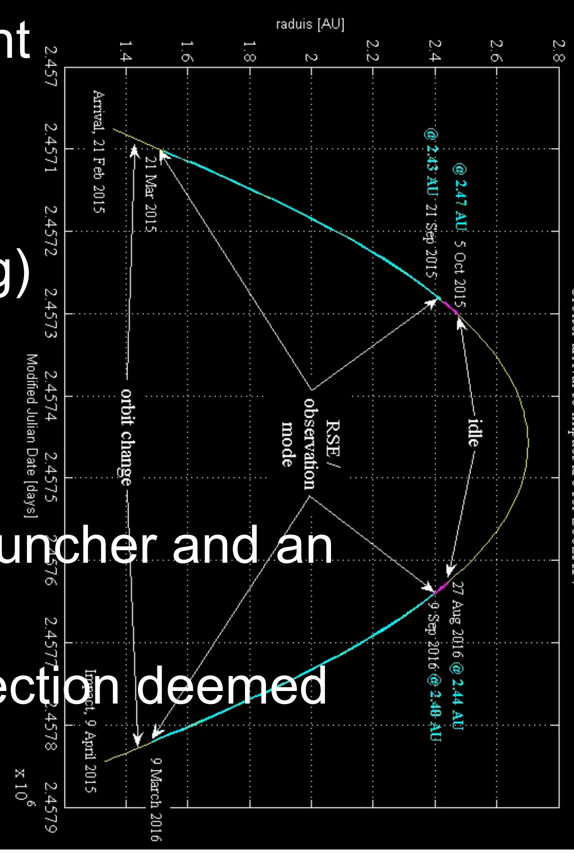
DQ mission scenario studies

System Drivers

1. high Δv of the given asteroids rendezvous trajectory
2. Operational scenarios at large Earth-distances
3. Increase of S/C complexity due to planetary swing-by (Venus)

Potential Solutions - Orbiter

1. Limit Orbiter's task on RSE and Camera → DQ light
2. Re-assess target selection criteria
3. Suspend RSE operations at larger AU
4. Use X-band RF only for RSE (Ka-band unit ~ 25 kg)



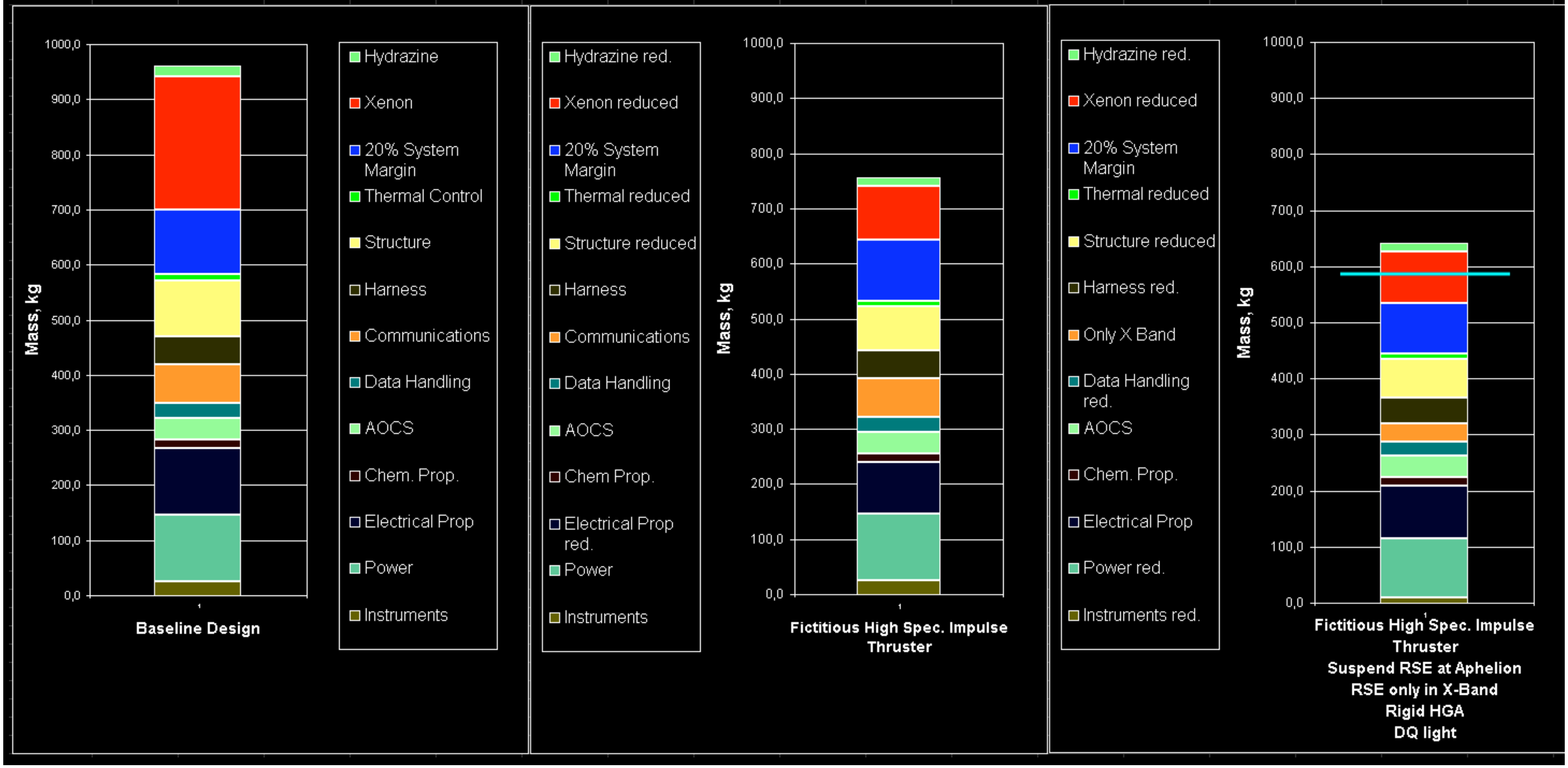
Impactor Conclusions

1. No single driver
2. Primary mission goal can be reached by a small launcher and an optimised propulsion module.
3. Minor reductions in impact precision and early detection deemed acceptable

Don Quijote studies

DQ mission scenario studies

Potential Implications - Orbiter



Definition of the first mission element

Don Quijote is **ESA's mid- term (2007-2017) roadmap**

- Studies prove that it provides **a meaningful demonstration** and even solution in certain cases e.g. resonant returns

space component roadmap
(Don Quijote)

→ Definition of 1st element (orbiter)

- **First action** definition of first DQ element:

  self-standing mini-satellite in the frame of in-orbit technology demonstrator

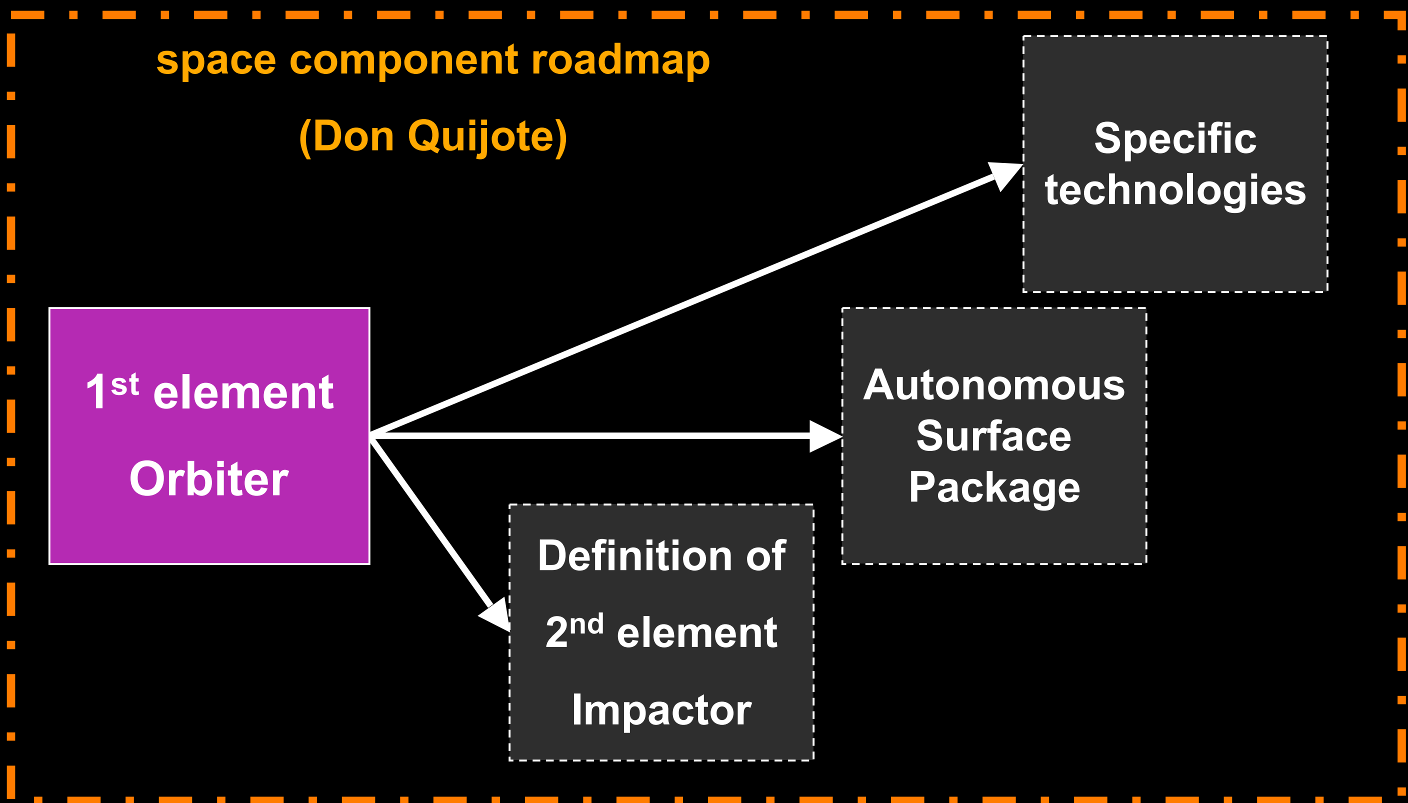
(1) High-accuracy s/c tracking & precise target orbit determination
(2) On-board autonomy → AutoNav techniques

(3) Constrain system to small launcher or secondary payload
(4) Choose target accordingly
(5) Minimize operation costs

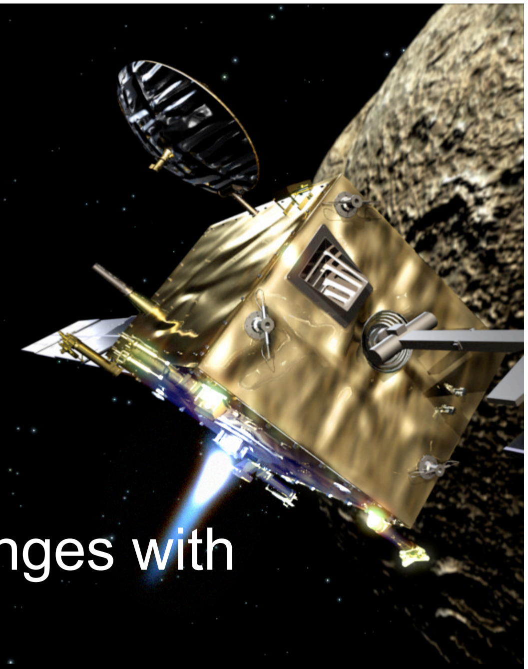
⇒ Minimize fixed costs

Future Space Component Options

- DQ provides a flexible scenario for future technology demonstration options in the context of a NEO risk mission.
- Depending on context i.e. ESA's Member States interests and international co-operation level, different mission extensions can be assessed and integrated.



Outlook



3rdQ 2007 Industrial study ITT release

- industrial assessment of the Orbiter element

Ongoing International cooperation

- Continue constructive discussions and exchanges with NASA and JAXA

Strong focus on Academic Research

- Continue ongoing research on mission optimization, mathematical modeling at ESA's Advanced Concepts Team
- Fostering research activities in the field, continuing partnerships with universities and research institutes (Ariadna scheme, G.O. competition etc)

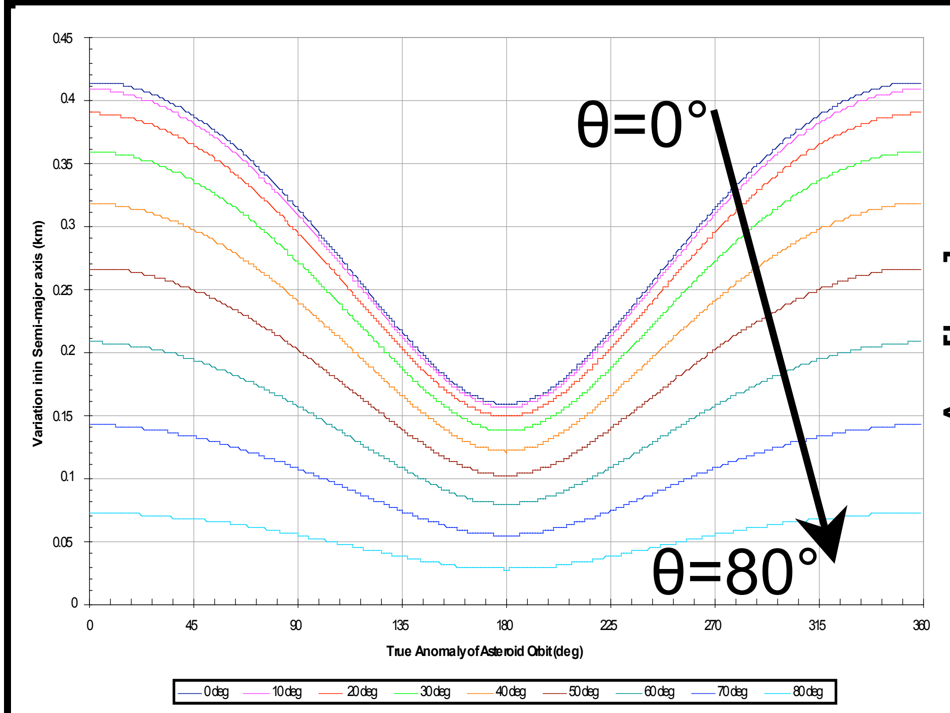
esa

Don Quijote Mission

Ian Carnelli
Institutional Matters & Strategic Studies Office
ESA-ESTEC
Ian.Carnelli@esa.int

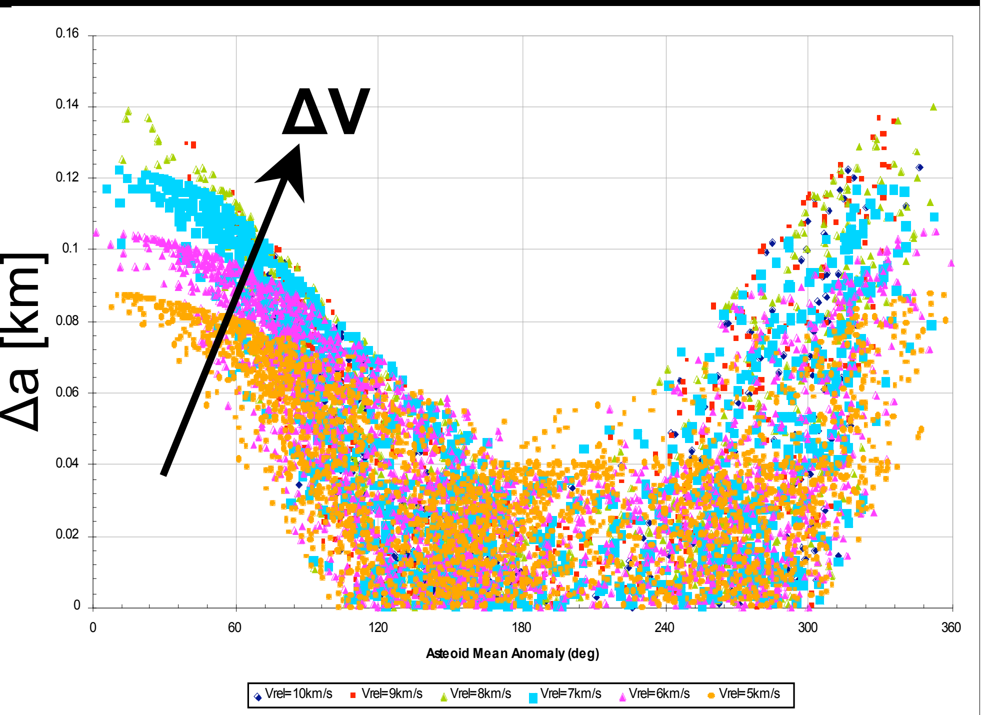
Impact modeling

2002AT4



Impact geometry
(ΔV fixed)

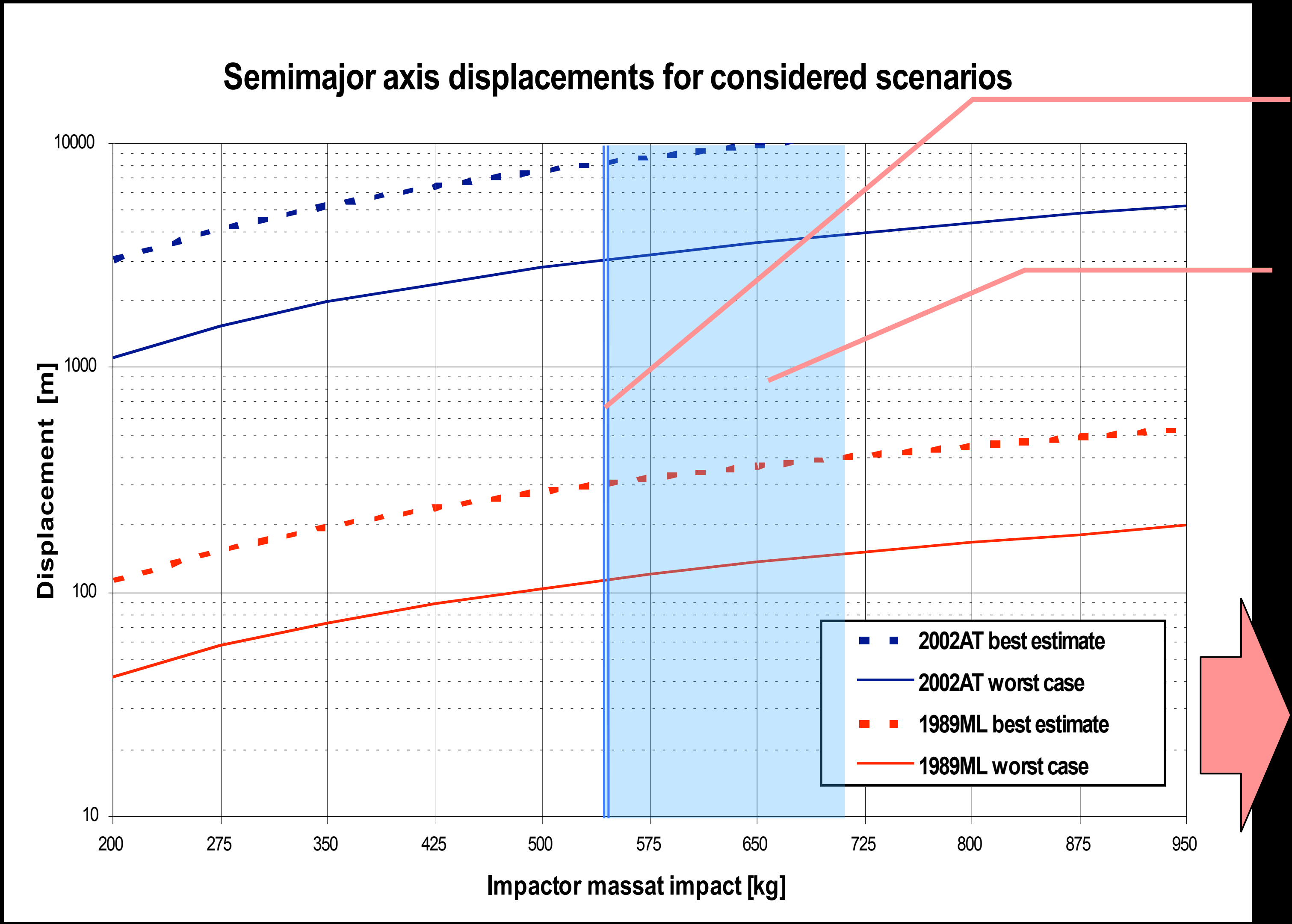
1989ML



true anomaly
(fixed impact geometry)

- Larger impact efficiency near perihelion
- Angle between Impactor and asteroid’s velocities should be parallel

Impact modeling



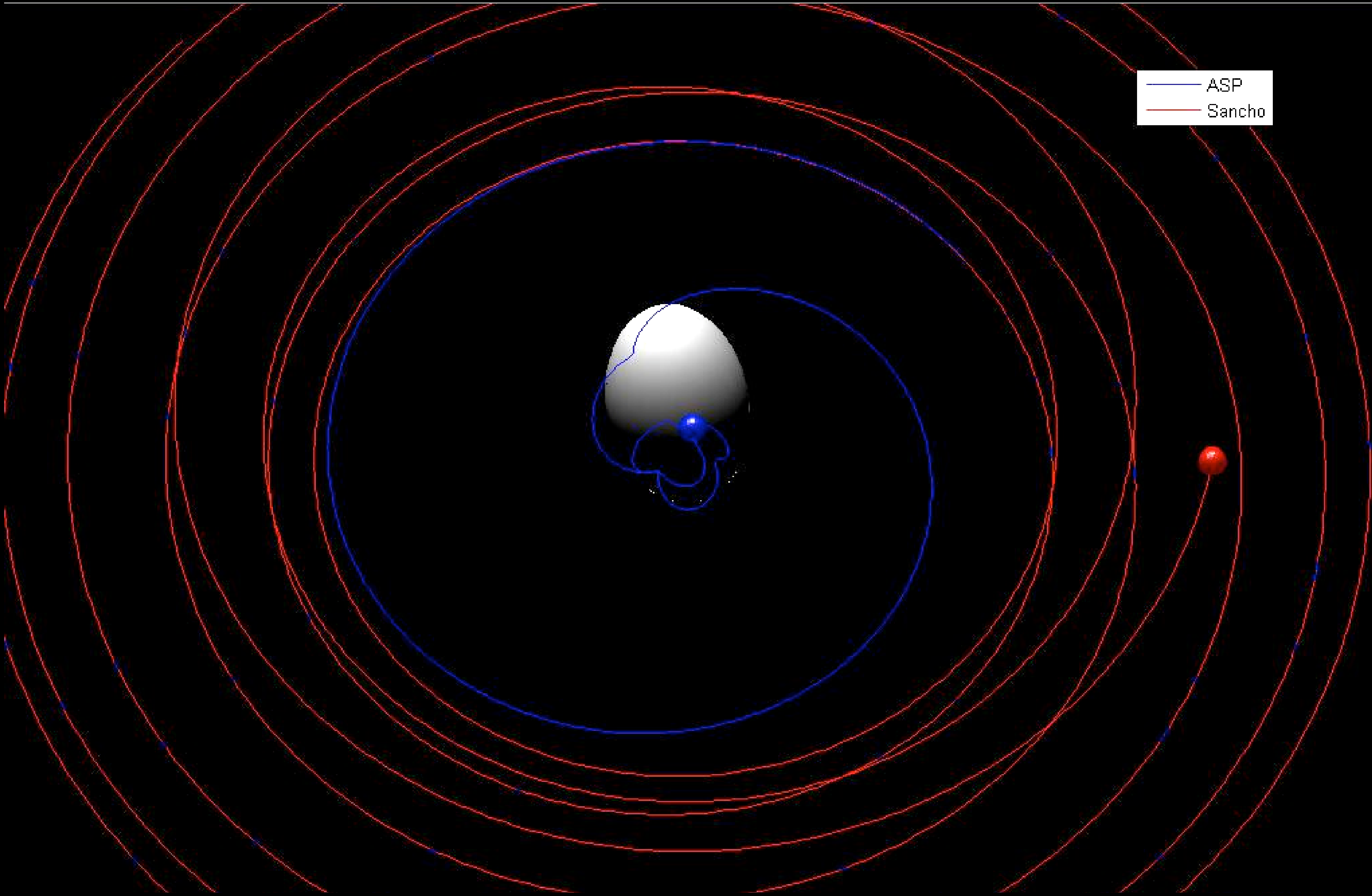
Impactor design mass

Impactor masses available from launcher performances

expected asteroid diameters

- worst case deflection (1989ML) achievable
- $2002AT_4$ deflection can be an order of magnitude higher

ASP deployment experiment



ASP deployment experiment