PLANETARY DEFENCE CONFERENCE 2015

NEOShield: Design of a Gravity Tractor Demonstration Mission

N.T. Faber(1,2) , M. Busch(3) , D. Morrison(2,3)

(1) SGT Inc.

(2) NASA Ames Research Center
(3) SETI Institute, Carl Sagan Center

Preparing to Protect the Planet

SEVENTH FRAMEWORK PROGRAMME

Overview

☐ **Need**

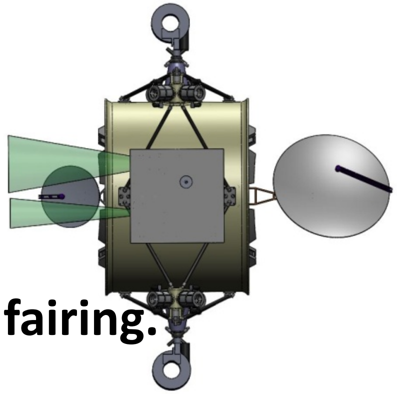
1. **Mission to demonstrate the Gravity Tractor (GT) concept.**

☐ **Goals**

1. **Demonstrate that the orbit deflection caused by a GT is detectable.**
2. **Obtain a knowledge base of operational techniques and best practices of relevance for future GT missions.**
3. **Demonstrate the GT concept in an effective and efficient way within constraints of cost, schedule and scope.**

#	Key Technical Challenges
1	Determine the physical parameters of the asteroid at an accuracy that is sufficient to carry out the GT experiment in safe and controlled conditions.
2	Detect the change in the asteroid’s orbit imparted by the GT and quantify that change.
3	Design an efficient thruster configuration and a robust control algorithm for safe hovering.

Mission Design: Baseline



❑**Asteroid Selection:**

- ▪**Target: 2000 FJ10.**
  - ▪**Mass ≈ 3. 5 10^9 kg (CBE). Diameter: between ≈120m and ≈210m.**

❑**Dedicated launch in 4rth quarter 2026 on Falcon 9, standard 4.6 m fairing.**

❑**S/C**

- ▪**Mass: ≈1160 kg at launch, >1100 kg at asteroid arrival using Mars gravity assist.**
- ▪**All-electric S/C based on SEP with RCS thrusters used for both attitude control and hovering.**

❑**Key operational aspects**

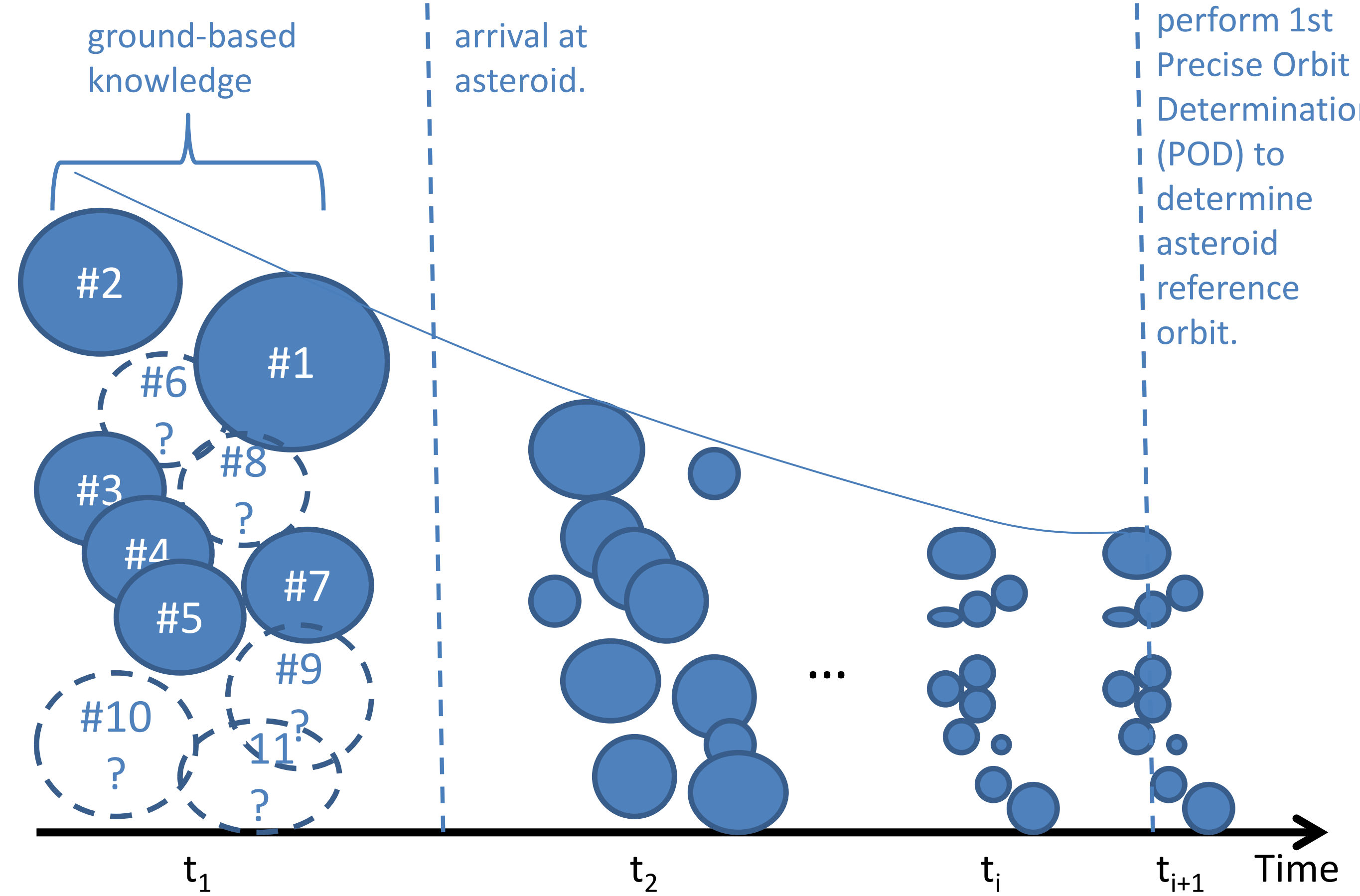
- ▪**Hover at fixed operational standoff distance as close as possible to optimal standoff distance (CBE: ≈125m).**
- ▪**Detect and quantify asteroid deflection using two dedicated Precise Orbit Determination (POD) campaigns.**
- ▪**Nominal mission duration: ≈6 yrs (of which ≈2 yrs of tractoring)**

KTC 1: Refine understanding of asteroid environment

Method: increase knowledge iteratively using measurements and radio science results.

#	Key parameters
1	Mass
2	Size
3	Spin pole, body-fixed frame
4	Shape, surface morphology
5	Rotation period
6	Thermal inertia
7	Albedo
8	Mineralogy, chemical composition
9	Dust movement or gaseous exosphere
10	Presence of a satellite
11	Presence of debris

bubble size shows magnitude of uncertainty on parameters



ground-based knowledge

arrival at asteroid.

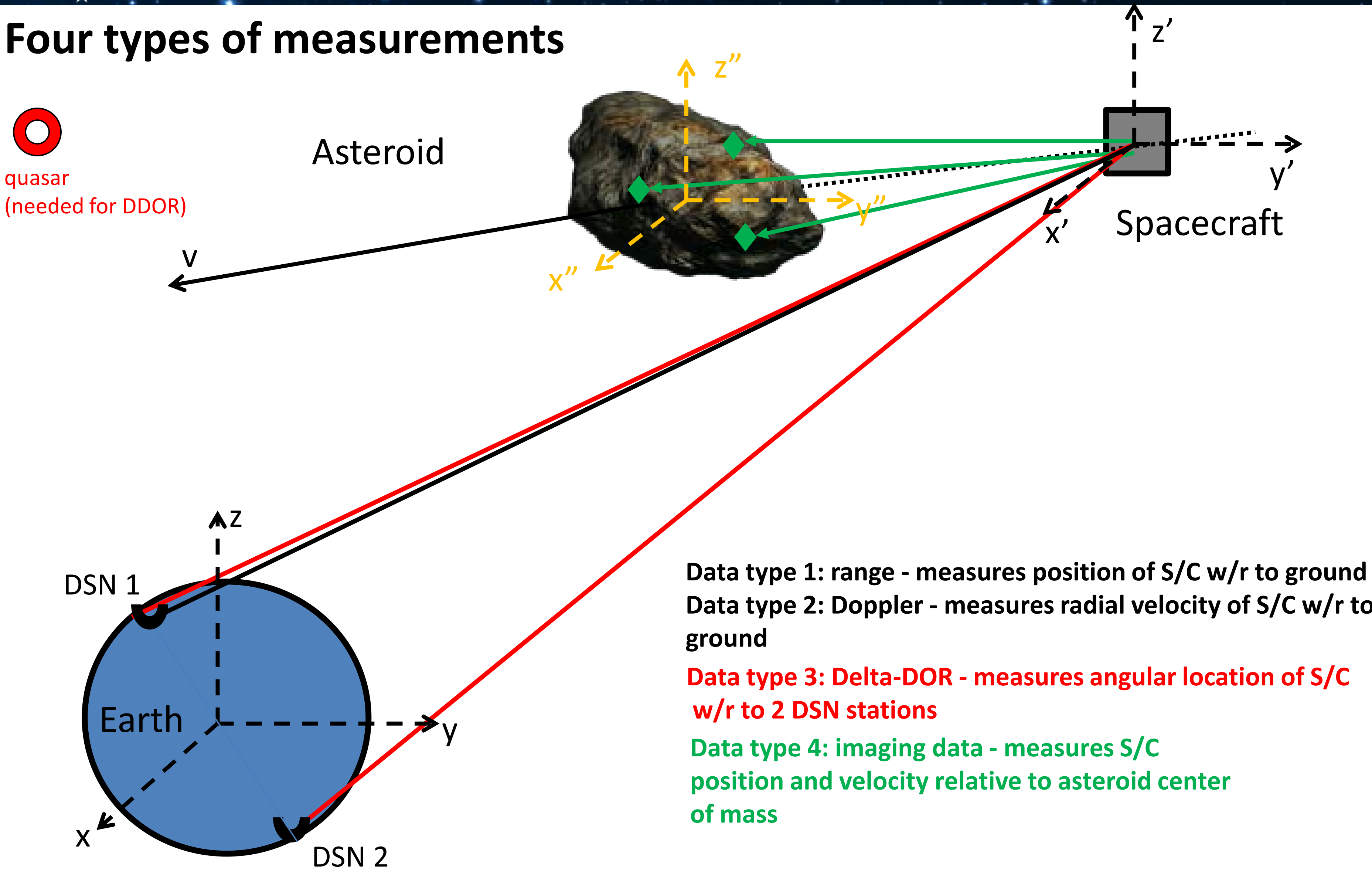
perform 1st Precise Orbit Determinatio (POD) to determine asteroid reference orbit.

Estimated time until sufficient knowledge about asteroid is reached: <6 months

Instrumentation:
X-band transponder
2 visible-wavelength cameras
Lidar
Optionally: VIR spectrometer

KTC 2: Detect and quantify orbit deflection

Four types of measurements



Data type 1: range - measures position of S/C w/r to ground

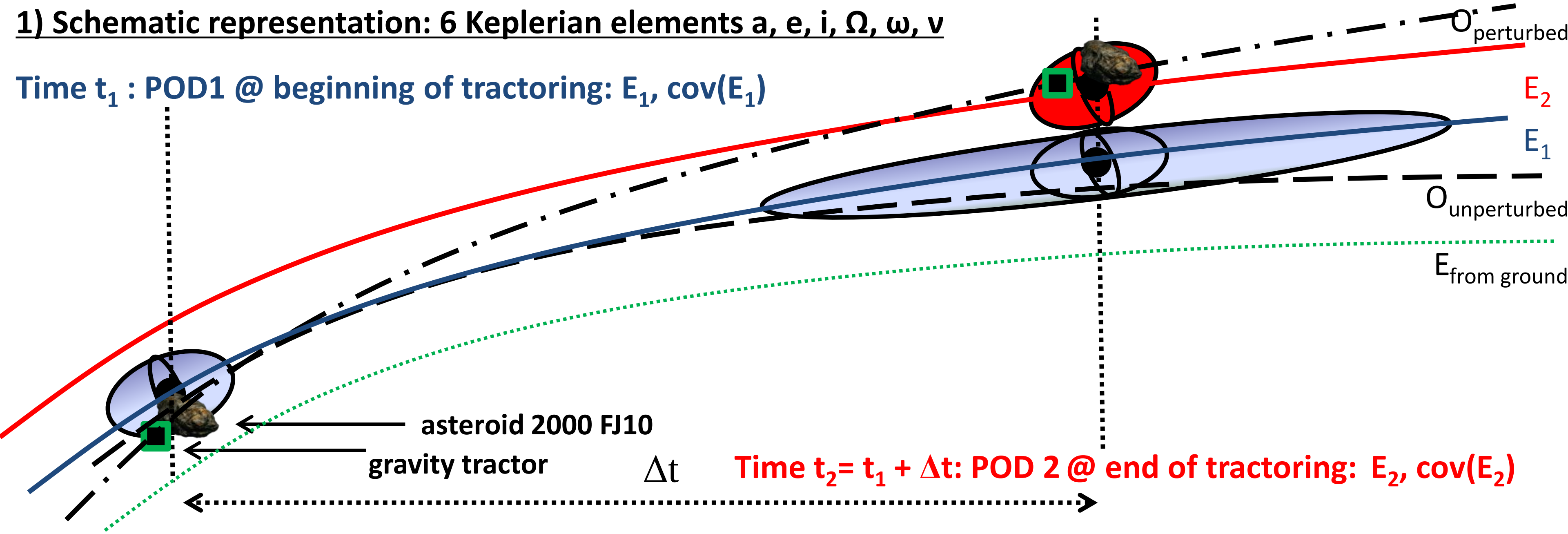
Data type 2: Doppler - measures radial velocity of S/C w/r to ground

Data type 3: Delta-DOR - measures angular location of S/C w/r to 2 DSN stations

Data type 4: imaging data - measures S/C position and velocity relative to asteroid center of mass

KTC 2: Detect and quantify orbit deflection

1) Schematic representation: 6 Keplerian elements a, e, i, Ω, ω, ν



Time t_1 : POD1 @ beginning of tractoring: E_1, cov(E_1)

Time $t_2 = t_1 + \Delta t$: POD 2 @ end of tractoring: E_2, cov(E_2)

2) Case study: using parameters of nominal mission and the semi-major axis *a* as figure of merit

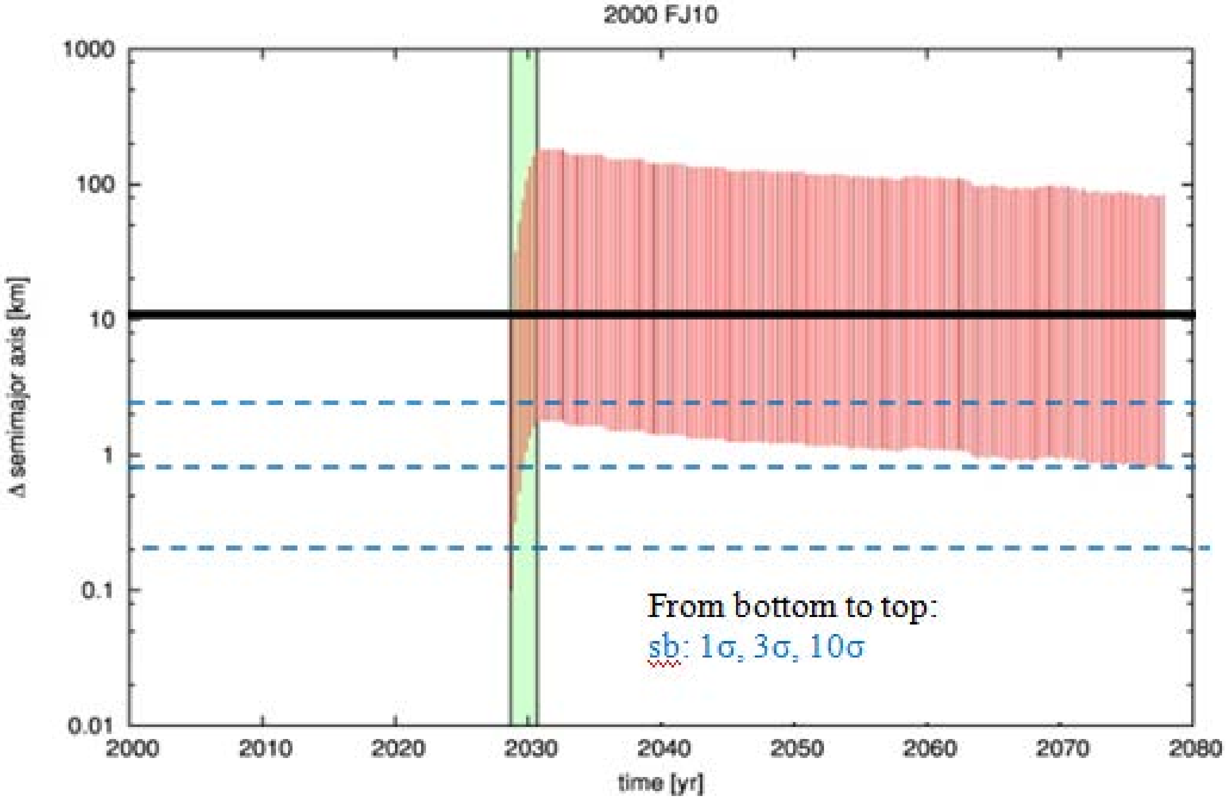
Table 1: accuracy on semi-major axis knowledge.

When	Expected accuracy on semi-major axis knowledge (1 sigma)
Prior to launch: using only ground-based measurements.	532 m or better
Prior to tractoring: using *in-situ* measurements (POD 1)	266 m or better
After tractoring: using *in-situ* measurements (POD 2)	266 m or better

Table 2: magnitude of semi-major axis change as a result of tractoring

Time Δt since beginning of tractoring	Lower bound for semi-major axis change imparted	Detectable at 1 sigma LOC	Detectable at 3 sigma LOC
12 months	≈5 km	Yes	No
24 months (POD 2)	≈10 km	Yes	Yes

Result of Monte-Carlo analysis:



From bottom to top:
sb: 1σ, 3σ, 10σ

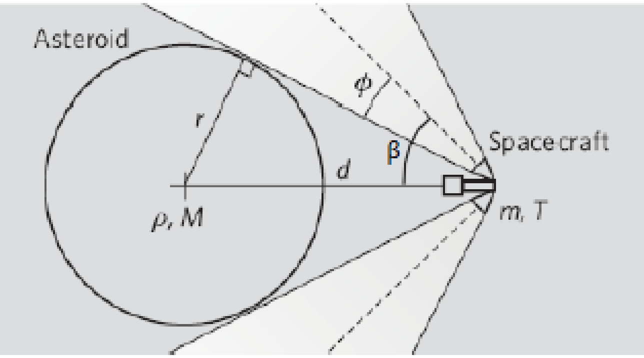


Figure 3: Geometry of the gravity tractor and NEO (16)

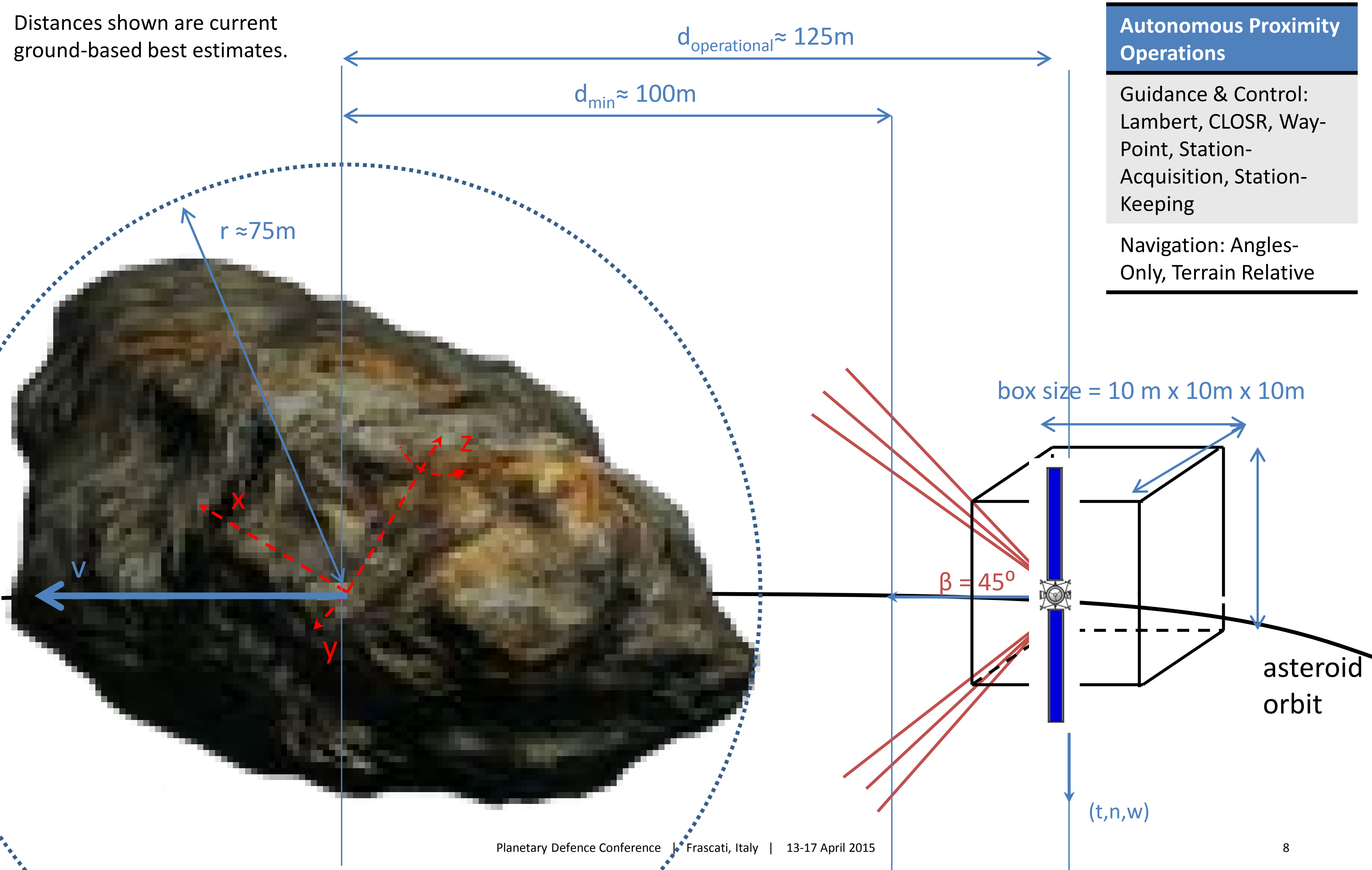
<u>11-dimensional random sampling:</u>
uncertainty on 6 asteroid orbital parameters
asteroid size: 47.5 m < r < 150 m
asteroid density: 1 < ρ < 4
standoff distance: 60m < d < 580m
exhaust plume half angle: 15º< φ <30º
S/C mass: 500 kg < 1500 kg

produces:
10^{-13} (m/s²)< a_{NEO} < 10^{-11} (m/s²)

Work performed in collaboration with NEOShield partner ObsParis-IMCCE.

KTC 3: Fuel efficient and fail-safe hovering

Distances shown are current ground-based best estimates.



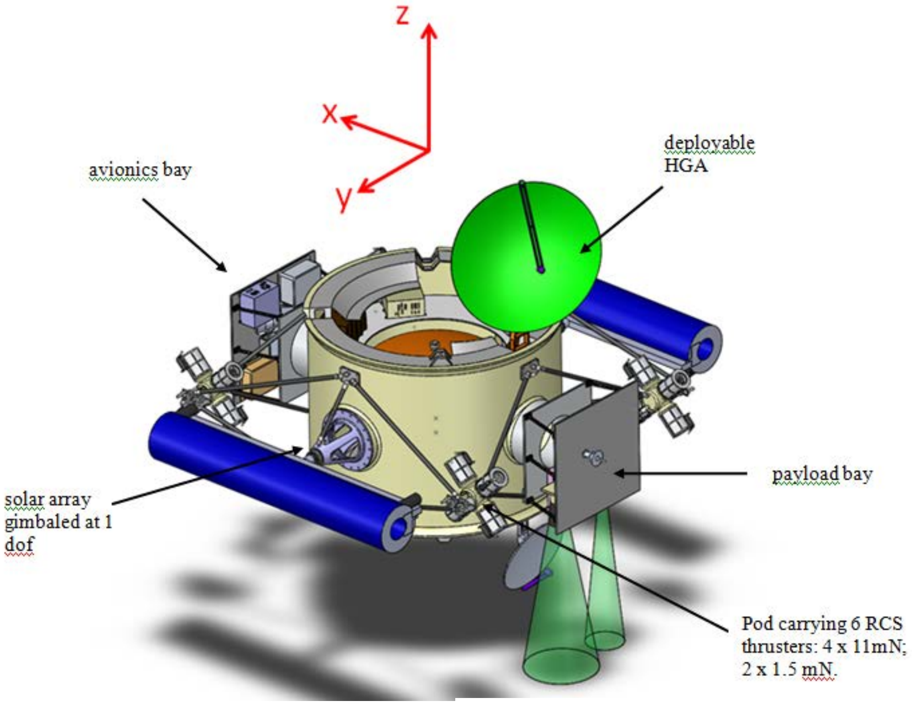
Autonomous Proximity Operations

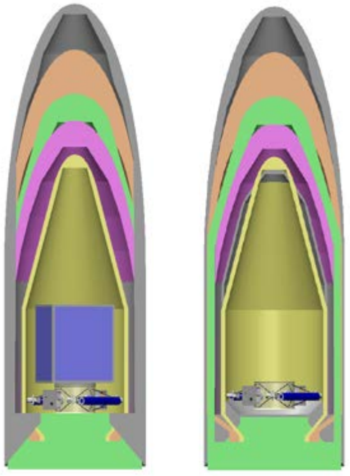
Guidance & Control: Lambert, CLOSR, Way-Point, Station-Acquisition, Station-Keeping

Navigation: Angles-Only, Terrain Relative

S/C Configuration

Subsystem	Mass (kg)	Margin (%)	Mature Mass	Power (W)
Propulsion	80	25	100	3333
ADCS	23	25	28	31
Power	150	20	180	153
Structure	322	10	355	27
Communications	15	5	16	87
Avionics	25	5	26	73
Thermal	23	5	24	253
Payload	10	5	11	67
Total Dry	**648**		**739**	**4023**
Propellant (Xe)	425		425	
Total Wet	**1073**		**1164**	





Main design advantages:

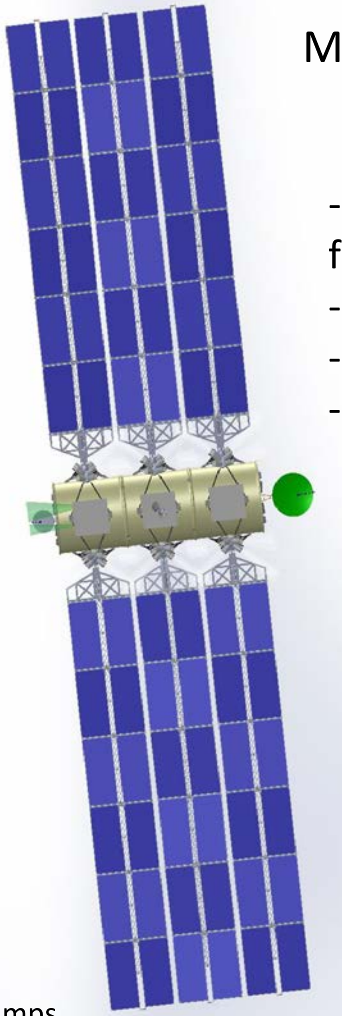
1. **Heritage: flight-proven platform, in-house mission designs using platform for ARPO at asteroids**
2. **Launch flexibility: Atlas 5, Ariane 5, Delta 4, Falcon 9, Soyuz. Possibility to be the primary or the secondary payload.**
3. **Adaptability to broad range of asteroid deflection missions**
4. **Compatibility with multiple-GT mission scenarios**

[NF1]Rationale: NCROSS ARPO calls for combination of those 2 cams

S/C Configuration (cont')

Subsystem	Configuration	Heritage leveraged
System	Mass at launch: ≈ 1160 kg. Mass at beginning of Hovering Phase ≈ 1110 kg Power: 4 kW @ 1.6AU Size (stoved): 2.4m x 2.4m; height = 1.07m	LCROSS
Propulsion	All-electric Solar Electric Propulsion (SEP) system 1 main NSTAR thruster for heliocentric transfer (90mN, I_{sp} = 3100s, 2.3 kW). 24 RCS thrusters for hovering and attitude control: 16 x(11mN, I_{sp} = 3850s, 400W), 8x(1.6 mN, I_{sp} = 2800s , 80W). Up-scope to include gimbaled thrusters for polyhedron tracking is possible (see RD-12). Xe tank capacity: ≈425 kg . Total DV: ≈17 km/s	DAWN, ARC SEP Demo
ADCS	AD: 2 star trackers, TBD coarse sun sensors, 1 IRU. AD capability: < 50 arcsec/axis (TBC) in Roll, Pitch and Yaw AC: 24 RCS thrusters (see above). AC capability: TBD deg per axis in Roll, Pitch and Yaw Slew rate: < TBD mins for 180 degs slew in Roll, Pitch and Yaw	LCROSS, TOPEX, LRO
GNC	Autonomous Rendezvous and Proximity Operations (ARPO) System H/W: OpNav camera, ProxOps camera, ARPO Flight Processor, DHU S/W: ARPO mission manager and FSW	ARC NCROSS proposal
Power	2x13 m2 deployable, low density, flexible solar arrays. Efficiency: 29%. Gimbaled with 1 dof. Battery: 35 A/h NiH2 (TBC)	ARC SEP Demo, DAWN
Structure	1 standardized ESPA Grande ring: diameter = 1.57m (62"); height = 1.07m (42")	LCROSS
Communications	(X-X) -band system: SDST + 200W TWTA HGA: 2 dof steerable at 0.95m diameter; 1 MGA; 2 Omnis	JWST, MRO, Landsat, EOS
Avionics	RAD 750 CPU, 1 GB SSMB onboard storage (TBC) FSW: Spacewire I/F, ARPO I/F via 1553B	LCROSS, EO-1, WMAP
Thermal	Thermostatic controlled heaters, MLI, Paint	LCROSS, EOS, Chandra
Payload	2 visible wavelength cameras (see above): 1) Narrow-Angle Camera for OpNav: FOV=5°x5°, SNR=7, res<0.2m@1km (DAWN Framing Camera); 2) SAIC ANGELS for ProxOps: FOV=9.8x9.8, SNR=6, res<0.2cm@1km and < 0.2.@100km LiDAR: dynamic range 50m – 50km Optionally: 1visible-to-near IR spectrometer	DAWN, Hayabusa, NCROSS prop., MarcoPolo-R

Work in Progress: Multiple GTs



Main focus points:

-) end-to-end strategy: from rocket fairing to docked configuration
-) control strategy for stacked GTs
-) S-S, S-G communications
-) TBD

image credit: Arthur Descamps

See also: Foster, Bellerose, Mauro, Jaroux (2011): Mission Concepts and Operations Involving Multiple GTs, PDC 2011, Bucharest, Romania

Summary

- ☐ **Presented baseline for the design of a gravity tractor demonstration mission.**

- ☐ **Baseline is to launch a ≈1160 kg ESPA ring based S/C to asteroid 2000 FJ10 in 2026 using a Falcon 9. Nominal mission duration is 6 years of which ≈2 years are dedicated to hovering and validating the deflection.**