4th IAA Planetary Defense Conference – PDC 2015
13-17 April 2015, Frascati, Roma, Italy

IAA-PDC-15-04-12
NEOShield: Mission Design for a Gravity Tractor Demonstration Mission

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

1SGT Inc., 7701 Greenbelt Road, Suite 400 Greenbelt, MD 20770, USA
2Carl Sagan Center, SETI Institute, 189 N Bernardo Ave, Mountain View, CA 94043, USA
3NASA Ames Research Center, Moffett Field 95035, Mountain View, CA, USA

Keywords: *gravity tractor, mission design*

Extended Abstract **– There are currently three primary techniques studied to deflect a near-Earth object (NEO) from an Earth impact trajectory: (i) the kinetic impactor (KI), (ii) nuclear blast deflection (NBD), and (iii) the gravity tractor (GT). The KI relies on transferring momentum to the NEO through a physical collision with a spacecraft. NBD relies on a nuclear explosion near the asteroid's surface to generate an impulsive push. The GT relies on the gravitational attraction between the target NEO and a hovering spacecraft, changing the object's trajectory slowly but continuously over months to years. These three techniques each have advantages and disadvantages depending on the physical characteristics of the asteroid and the time available before impact.**

The Mission Design Division at NASA Ames Research Center has begun a program to develop mission designs for planetary defense. Here we present a mission design for a gravity tractor demonstration mission completed in collaboration with the European NEOShield consortium.

We conducted a trade study to identify suitable target NEOs to demonstrate GT deflection, and identified 5 known asteroids with diameters between ≈100m and ≈500m that have been well studied in the past: 2000 FJ10, 2001 QC34, 2002 DU3, 2001 JV1 and 1998 VO. We selected 2000 FJ10 as the most suitable target to meet the requirements of a GT demonstration mission.

Our GT demonstration spacecraft is based on an ESPA ring main structure and solar electric propulsion (SEP, see Figure 1). The power budget is ≈4 kW and the spacecraft has an initial wet mass of ≈1,150 kg. The spacecraft would launch in the 3rd quarter of 2026 aboard a Falcon 9, arriving at 2000 FJ10 in early 2029 after an unpowered Mars gravity assist in 2027. The spacecraft mass at asteroid arrival would be ≈1,100 kg (see Figure 2).

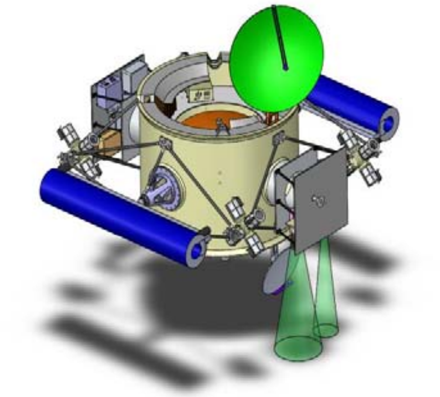

Figure 1: The gravity tractor as currently envisioned. Top: Overall configuration. The S/C is built around an ESPA ring main structure and features 4 pods of SEP based RCS thrusters canted at an angle $\beta = 45°$. The RCS thrusters are responsible for both attitude control and the translational hovering with respect to the asteroid. Bottom: impression of the gravity tractor during the hovering phase close to the asteroid.

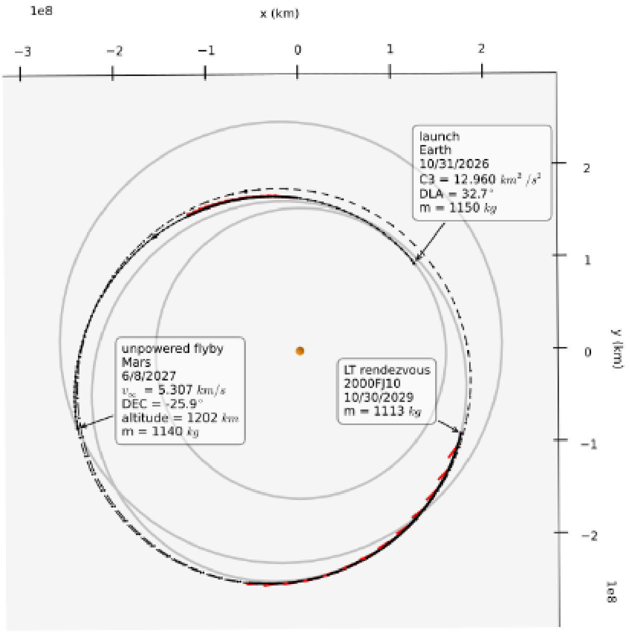

Figure 2: Heliocentric transfer. The gravity tractor is launched from Earth on 30 October 2026 using a Falcon 9 launch vehicle and C_3 = 12.9 km^2/s^2. The S/C arrives at 2001 FJ10 in October 2029 by taking advantage of an unpowered Mars flyby in June 2027. The total Xe consumption for the transfer is less than 50 kg.

We estimated the GT's performance based on current knowledge of 2000 FJ10's physical parameters. For a nominal asteroid mass of ≈3 x 10^9 kg, a diameter ≈150m, and an operational hovering altitude of ≈125 m from the asteroid's center-of-mass, the GT spacecraft would change the asteroid's semi-major axis by ≈10 km over a period of 2 years (see Figure 3). To ensure that the deflection is measured, and to permit safe hovering conditions for the GT at all times, a ≈6 month survey and characterization phase would take place after arrival at 2000 FJ10 and prior to tractoring. *In-situ* measurements would include the asteroid's mass, size, shape, spin state, albedo and potentially the properties of any satellites or orbiting debris. In addition to the X-band transponder needed to perform the radio science, the notional spacecraft instrument suite includes two visible-wavelength cameras and a LiDAR. To collect measurements on thermal inertia and chemical composition the instrument suite can be augmented to include a visible-to-near IR spectrometer.

We will present a concept of mission operations including (1) the sequence of operations during the pre-hovering asteroid survey and characterization phase, (2) the guidance, navigation and control strategy implemented for safe and fuel efficient hovering in proximity to the asteroid, and (3) the approach adopted to detect and quantify the deflection achieved, assuming orbit determination accuracy equal to previous asteroid missions.

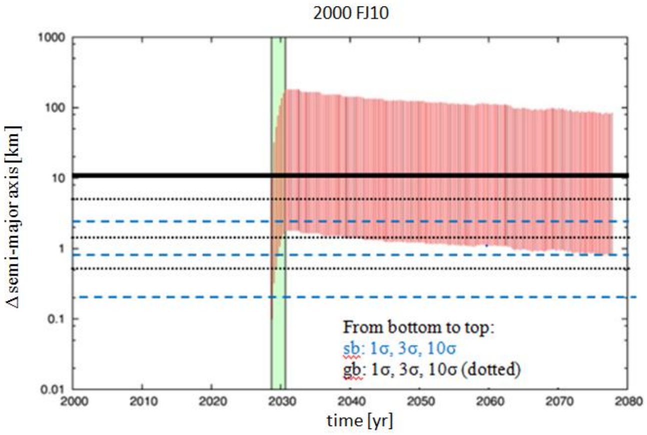

Figure 3: Distribution of semi-major axis changes imparted to 2000 FJ10 by the GT as a function of time (in km, shown in red). The distribution has been obtained using 9000 clones of 2000 FJ10 created by a 11-dimensional Monte Carlo random sampling that takes into account all the uncertainties related to the deflection attempt. The area marked in green delimits the 2 years' interval of time during which the GT is hovering close to the asteroid and is performing the tractoring. The 3 dotted lines in black show the 1σ, 3σ and 10σ uncertainty on the semi-major axis of 2000 FJ10 as determined from ground based measurements of the asteroid's orbit (labeled 'gb', see legend). The dashed lines in blue (labeled 'sb') show a conservative estimate of the accuracy that can be achieved when using in-situ measurements from space to improve the knowledge on the semi-major prior to tractoring. The deflection achieved nominally is Δa ≈ 10 km and plotted with the solid line in black. It follows from the plot that after ≈ 2 years of tractoring the deflection can be measured even if only the worst case deflection of ≈ 2 km is achieved by the GT. If the deflection validation campaign was performed from ground the deflection could be detected at 3σ level. In the currently envisioned case where the deflection validation campaign is performed from space by taking advantage of in-situ measurements and the radio science capabilities of the S/C the deflection can be detected at >7σ level. If this signal-to-noise ratio is considered insufficient there is sufficient fuel to increase the tractoring time by a few months.