

Using a Gravity Tractor to Help Mitigate Asteroid Collisions with Earth. D.K. Yeomans¹, S. Bhaskaran¹, S.R. Broschart¹, S.R. Chesley¹, P.W. Chodas¹, M.A. Jones¹, T.H. Sweetser¹, E.T. Lu², R.L. Schweikart², ¹JPL/Caltech, 301-150, Pasadena, CA 91109, ²B612 Foundation, 760 Fifth St., East, Sonoma, CA 95476.

Introduction: A study was undertaken to determine the feasibility of using a gravity tractor as a mitigation measure when a Near-Earth Object (NEO) has been identified as a serious Earth impact threat [1]. In such a circumstance, a gravity tractor spacecraft with a transponder (t-GT), in residence with the threatening NEO, could provide accurate NEO tracking to verify that a deflection was needed. If a kinetic energy impact deflection is carried out, it would be necessary to verify afterwards that the primary impact threat had been eliminated and a subsequent impact had not been enabled by the NEO being deflected into a resonant Earth return keyhole that would allow a later Earth impact; in this latter case, the t-GT spacecraft could be used to tow the NEO to avoid this keyhole.

Study Description: To study the feasibility of the concept, three connected tasks were carried out. The first task selected a simulated impactor NEO and an associated mission timeline for the gravity tractor. Our simulated Earth impactor is discovered in July 2016, shortly after the initiation of the LSST survey, and collides with the Earth in Sept. 2049. This subject NEO is an Aten-class asteroid on an orbit that is very close to the 13:10 mean motion resonance with Earth and fairly close to the 4:3 resonance. Hence, the NEO is very well placed for ground-based observations every 10 years and also observable every 3 years following discovery. While simulations show that most discovered impactors would surpass 99% impact probability very early in their second apparition, our selected impactor does not reach this threshold until 10 years after discovery. The NEO itself has the following characteristics: bulk density of 2.0 g/cm³, obliquity of 135 degrees, rotation period of 6 hours, and the shape taken to be that of near-Earth asteroid Itokawa scaled down to an effective radius of 70 meters. By the end of 2023, the impact probability is about 85% and, with the incorporation of radar data, probably in excess of 99%. We assume that

a t-GT mission and a kinetic energy Impactor Deflection Mission (IDM) would share a launch in mid-2026. The t-GT spacecraft reaches the NEO in Dec. 2026 and is used to verify that the asteroid is headed for a 2049 Earth impact. Meanwhile, the IDM is put on a path that will take two years longer to gain momentum for a high velocity NEO impact (1150 kg @ 5 km/s) that will take place on July 4, 2028, a few weeks before the NEO's perihelion. As a result of the impact, the NEO will change its orbital velocity by 2 mm/s or more – depending upon the momentum enhancement provided by the blowback ejecta. We assume an unlikely worst case scenario whereby the IDM effectively prevents an Earth impact in 2049 but pushes the NEO into a keyhole (6:5 resonance) allowing an Earth collision 5 years later in Sept. 2054. After a year to redefine the orbit of the NEO, tractoring begins on July 4, 2029, about 20 years prior to the Sept. 2049 keyhole passage.

The second task determined the gravity tractor performance while station keeping and navigating in close proximity to a NEO for an extended period of time. A station-keeping control law was developed to keep the gravity tractor positioned close to the NEO and along its velocity vector while it tows the NEO by thrusting its ion engines in a direction to avoid impinging the NEO itself. The acceleration history of the NEO, due to the tractoring, was determined along with the amount of fuel required.

The third task was to study the use of t-GT spacecraft tracking data to reduce the NEO ephemeris uncertainties. We determined how long it would take to 1.) verify the primary NEO deflection maneuver succeeded and 2.) verify the gravity tractor towing had successfully moved the NEO out of the 2049 keyhole.

References: [1] Lu E.T. and Love S.G. (2005) *Nature*, 438, 177-178.

Acknowledgements: This work was carried out at JPL under a contract with the B612 Foundation.