Precise Orbital Tracking of an Asteroid with a Phased Array of Radio Transponders

Bernhard W. Adams
Advanced Photon Source, Argonne National Laboratory, 9700 S. Cass Ave., Argonne, Il. 60439

Impacts of large (>100 m) asteroids are rare but potentially devastating events. For this reason, the U.S. congress has tasked NASA with detecting, tracking, and characterizing all Near-Earth Objects (NEOs) larger than 140 m in size by the year of 2020 [1]. Optical observations in conjunction with celestial-mechanics computations can identify NEOs that may pose an impact risk many years in the future. Impact risks are hard to quantify due to the limited accuracy of optical observations and hard-to-model nongravitational orbital perturbations due to the Yarkovsky effect (sunlight pressure, which, over several years, can amount to microns per second velocity changes). Many NEOs have solar orbits that are resonantly locked to Earth’s. One example is Apophis [2], which comes close to Earth once in 7 years. In 2029 it will approach closer than the geostationary orbit. If, at that time, it should pass through a 100-meter “keyhole” in space, Earth’s gravity will set it up for an impact in 2036. Deflecting an asteroid from an Earth impact trajectory requires only small velocity changes, typically of the order of microns per second, if done many years ahead of time. In the case of Apophis, it is also much easier to deflect from the 100-m keyhole than from the entire planet after a keyhole passage. Therefore, a highly precise method of determining the need, magnitude, and direction of a deflection is required that goes beyond the range of ca. 0.1 astronomical units (1 AU = radius of Earth’s orbit) and cm/s in radial velocity possible with passive radar. One possibility is the use of a radio transponder near the asteroid for an active radar echo. For the highest, micron-per-second accuracies the transponder has to be fixed on the asteroid surface.

Challenges are landing on an unknown surface in low gravity, tracking the direction to Earth as the asteroid rotates, supplying power even in the shade, and survival in the space environment. To address these, the present proposal relies on a large number of solar-powered radio units operating a total of ca. 10000 antennae that constitute a phased array. The radio units are linked by thin cables that contain carbon fibers for mechanical strength, metal wires for electric-power distribution, and glass fibers for precision timing synchronisation. The array is made to collide slow-motion (cm/s) with the asteroid, entangling it in the process, and radio units that may initially bounce off will eventually settle into random but fixed locations. Then, by comparing a signal from Earth with a local clock distributed through the fibers, the exact locations of the antennae are determined, and the array becomes operational. The original proposal [3, 4] contains a sample design with detailed calculations of the radio power required (including spectral broadening due to interplanetary-plasma scintillations), the resulting power requirements, total mass to be delivered, and minimum-energy trajectories from Earth to destination. The same technology could be used for other applications such as gravitational-wave detection, radio astronomy with baselines the size of the inner solar system, or studies of the solar wind.

Figure 1: Left: orbits of Earth and Apophis (http://ssd.jpl.nasa.gov/sbdb.cgi?sstr=99942;orb=1); right: a phased array on an asteroid

References