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Rapid-response Flyby Exploration using Deep Space Constellation deployed on Asteroid Flyby Cyclers

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ABSTRACT

The U.S. Decadal Survey [1] asserts the importance of rapid-response flyby exploration in planetary defense to understand the characteristics of hazardous asteroids and to develop effective mitigation strategies. One of the rapid-response mission architectures is to send spacecraft in a dedicated launch vehicle as quickly as possible when the target object is discovered. This approach requires a dedicated launch vehicle capable of rapid response, which poses a high technical and political hurdle for countries including Japan. Among various other architectures, this study proposes an approach of loitering dozens of micro-spacecraft in deep space, particularly in Earth-resonant flyby orbits, until a hazardous asteroid is discovered. In an Earth-resonant flyby orbit, the orbital period of the Earth and the spacecraft exhibit integer ratios, therefore allowing for repeated Earth flybys.

Dozens of micro spacecraft are inserted into the Earth-resonant flyby orbit in our proposed mission architecture, with the advantage that each spacecraft has the capability to perform an Earth flyby at a uniquely specified time. By making small trajectory correction maneuvers several weeks to a month before the Earth flyby, the spacecraft can drastically change its trajectory toward the target object utilizing the Earth's gravity assist. For this concept to work, at least one spacecraft would need to perform an Earth flyby on a month-to-month cadence; that is, this concept requires a large-scale deep space constellation. This constellation can be built through rideshare opportunities to deep space or the Moon without the need for dedicated launch vehicles. Figure 1 shows an overview of the Earth-resonant flyby architecture via the proposed deep space constellation. Earth-resonant flyby orbits expand the reachable region with lower ΔV requirements because the spacecraft has a higher V-infinity with respect to the Earth than low-energy orbits, such as at Lagrange points

[2]. These high-energy loitering orbits improve the probability of reaching interstellar objects and long-period comets [3].

This proposed mission architecture uniquely offers multiple flybys of NEOs while loitering in an Earth-resonant flyby orbit [Figure 2, 4-7], as will be demonstrated by JAXA's DESTINY^{+} mission [6]. Via order of magnitude calculations, we estimate that ~5-10 NEOs can be directly explored every year if ~10 micro spacecraft are deployed. The proposed multiple NEO flyby concept would bolster our collective planetary defense efforts while amplifying the scientific returns of in-situ exploration of this population. It would also solidify our overarching technology for asteroid flyby exploration.

This paper presents a statistical analysis of reachable hazardous asteroids and configuration options for deep space constellations. We also investigate the example of multiple NEO flybys in the loitering orbit. Mission design results indicate the amount of required fuel that can be used to estimate the size of the spacecraft system.

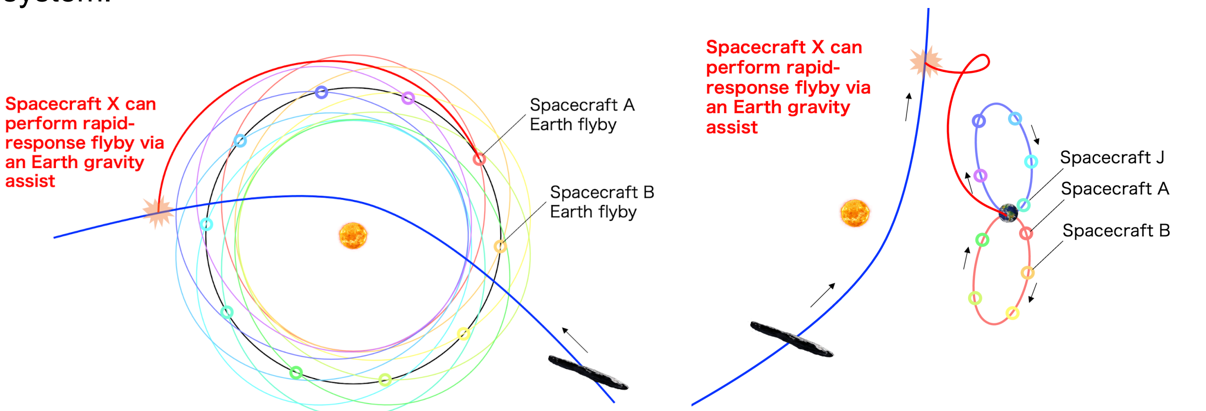

Figure 1. Earth-resonant flyby options (Left: Example orbit in the inertial frame, Right: Example orbit in Sun-Earth fixed rotational frame)

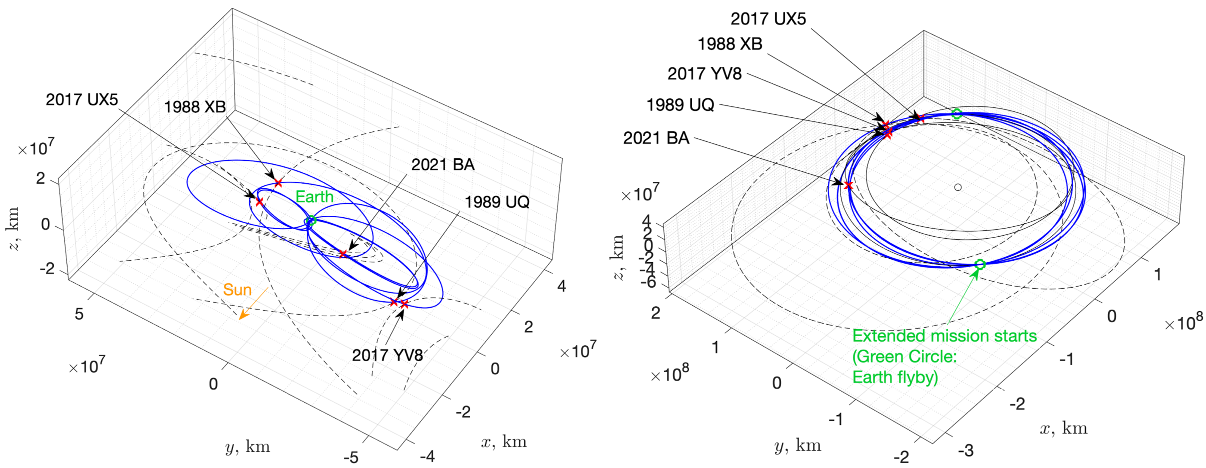

Figure 2. Example of asteroid flyby cycler trajectory[4]

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