Assessing the Suitability of a Flyby for Planetary Defense Characterization.
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Introduction: A near-Earth object (NEO) that poses a threat to Earth must be characterized to understand the severity and consequences of the threat and to determine a course of action [1,2]. Time is critical in these scenarios, and could be the difference between a successful mitigation and a disaster. Flyby missions are faster and cheaper than rendezvous missions, but limited in scope. Questions have been raised about whether a flyby mission can adequately characterize the asteroid properties most essential for planetary defense purposes [3-5]. These properties are orbit, mass, presence of binary objects, shape, rotational state, composition, internal structure, material properties, surface topology, and presence of dust/coma (Table 1; [3,6]).

	Orbit	Mass	Binarity	Shape	Rotation	Composition	Structure	Strength	Volatiles
Earth Observatories									
Flyby Mission									
Rendezvous Mission									

Table 1: Comparison of NEO reconnaissance options. Priority decreases left to right, and lighter shading indicates less measurement capability. Table courtesy of Barbee et al. [3].

We are using data from recent missions to NEOs, as well as simulated spacecraft data based on a set of strawperson flyby trajectories, to assess how well a flyby could characterize the asteroid properties that are most important to planetary defense and mitigation. This work may challenge the notion that a flyby mission is inadequate for planetary defense reconnaissance.

Our objectives include:

(1) Generate real and simulated datasets that are representative of what an asteroid flyby mission would return under various encounter conditions.

(2) Analyze the datasets using the tools and methods that would be used in a real-life situation.

(3) Assess how well the analyses constrain asteroid properties relevant to planetary defense.

(4) Determine whether the results are sufficient to inform mitigation strategies.

In the context of Apophis, there are already plans for a rendezvous encounter. The OSIRIS-REx Extended Mission will arrive post-encounter and study Apophis in high resolution. This study helps assess the scientific value of a rapid flyby mission passing Apophis prior to its Earth encounter (e.g., [7]).

Methods: We focus specifically on Itokawa, Ryugu, and Bennu as examples of NEOs in this study. These small NEOs were visited by the Hayabusa, Hayabusa2, and OSIRIS-REx spacecraft, respectively. We selected subsets of imaging data from these missions that matched several representative flyby encounter scenarios (using the APL Small Body Mapping Tool [SBMT; 8]). The flyby velocity ranged from 5 to 20 km/s, the closest approach distance ranged from 25 to 100 km, and the phase angle at closest approach ranged from 0 to 120 degrees.

We simulated images of the asteroid shape models using two camera models to identify the dependence of the results to camera selection. The first is the New Horizons/Lucy LORRI camera [9] as a representative heritage imager (iFOV = 5 µrad). The second is a Malin Space Science Systems (MSSS) ECAM-C50 NFOV camera as a representative commercial off-the-shelf (COTS) imager (iFOV = 174.6 µrad). A heritage imager provides higher-resolution imaging, but a COTS imager might be the only viable option from a schedule perspective in the event that asteroid characterization is urgent. A potential rapid flyby mission to Apophis prior to the OSIRIS-REx rendezvous might use a COTS camera [7].

Future Steps: With these synthetic images (e.g., Figure 1), we will create shape models to calculate the asteroid's size/volume, and assess how well we can constrain the asteroid's mass using current and future gravity science methods [10]. We will conduct image analyses in the SBMT to identify surface properties, such as boulder distribution and roughness, to characterize the synthetic NEO. The results from our simulated flyby datasets will then be compared to the published findings from rendezvous missions to these asteroids. The analyses will be done by individuals who did not work on the Hayabusa, OSIRIS-REx, or Hayabusa2 missions to avoid their prior knowledge from influencing the analyses. This effort will inform the development of potential planetary defense reconnaissance missions to a potentially hazardous asteroid, and can be used to constrain the planetary defense objectives and return of a rapid flyby mission to Apophis.

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References:

[1] Mainzer et al. (2021), *Bulletin of the AAS*, 53(4).
[2] National Research Council (2010), *Defending Planet Earth: Near-Earth-Object Surveys and Hazard Mitigation Strategies.* The National Academies Press.
[3] Barbee et al. (2021), *Bulletin of the AAS*, 53(4).
[4] Abell et al. (2021), *Bulletin of the AAS*, 53(4).
[5] Rivkin et al. (2021), *Bulletin of the AAS*, 53(4).
[6] Miller et al. (2015), *IAA Planetary Defense Conference*, IAA-PCD-15-03-01.
[7] Ballouz et al. (2022), *this workshop*, submitted.
[8] Ernst et al. (2018), *49^{th} LPSC*, abstract #1043.
[9] Cheng et al. (2008), *SSR*, 140, 189.
[10] Bull et al. (2021), *P&SS*, 205, 105289.

Figure 1: Simulated LORRI (left) and Malin (right) images of a fictitious asteroid based on OSIRIS-REx imagery of Bennu (at half size). The three encounters represented in these image sets are (A,B): flyby speed=15 km/s, closest approach distance=25 km, phase angle at closest approach=30º; (C,D): flyby speed=10 km/s, closest approach distance=50 km, phase angle at closest approach=60º; (E,F): flyby speed=20 km/s, closest approach distance=100 km, phase angle at closest approach=90º.