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Hazardous near Earth asteroid mitigation campaign planning based on uncertain information on fundamental asteroid characteristics

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ABSTRACT

During the early stages of hazardous near Earth asteroid mitigation campaign planning, the fundamental characteristics (e.g. composition, dimension, mass, density, porosity, etc.) of the target object should be accurately determined to increase the likelihood of success. In-situ characterization by spacecraft becomes therefore preferable to remote observations by ground-based telescope, radar or IRAS. The latter often result in considerable measurement errors and the possibility of incorrect assumptions of the physical properties – a crucial prerequisite to a successful mitigation. Sending a precursor mission, however, may not always be feasible, particularly when the available warning time is only a few years to a decade. Given such a limited warning time, we would likely plan a mitigation campaign which could hinge on uncertainty-based information consisting of distant observational data of the target object, general knowledge on near Earth asteroids, and engineering judgment. There are a number of asteroid deflection concepts that have been closely studied and compared with each other in regard to their deflection capability as well

as technological feasibility [1]. Among them, kinetic impactor, nuclear interceptor, and solar collector turned out to be, in principle, capable of deflecting a modest-sized (i.e. ~150 meters in diameter) asteroid given the interception about a decade prior to the Earth impact. More recent work has however revealed that, to a greater or lesser extent, all these approaches would suffer a lack of precision due to the epistemic uncertainties in the asteroid physical properties [2]. Figure 1 illustrates a kinetic impactor on a 140-meter sized, S-type asteroid characterized at the ground-based level, aiming for 2.5 Earth-radii of deflection on the b-plane. It represents cumulative probabilities of achieving respective deflections (0.0-6.0 Earth-radii), where the probabilities (0.0-1.0) are prescribed by two probabilistic measures – belief and plausibility. The worst possible deflection scenario can be found on the point where the belief measure becomes non-unity. In this case, the deflection credibility is profoundly compromised, which might possibly result in placing the target object on a subsequent Earth impact trajectory due to unanticipated keyhole passage or, at the worst, complete mission failure. To complement such inherent limitations of primary deflection, we have considered the use of three different slow-push deflection techniques – gravity tractor, asteroid tugboat, and ion beam shepherd – following the primary deflection (see Fig. 2). The credibility of a mitigation campaign that combines a given primary and secondary deflection attempt is thoroughly assessed here. Instantaneous techniques have an advantage in fast-acting deflection and disadvantage in uncontrollability whereas slow-push ones are controllable but often take years to achieve reasonable deflections. There would be, therefore, a trade-off between these competing aspects, wherein the mitigation campaign is optimized to minimize the initial interceptor mass, total interception time while to maximize the final deflection. A multi-objective optimization algorithm is used to obtain Pareto-optimal solutions. Given a premise that the asteroid deflection techniques considered here are technologically feasible, this optimization approach will allow us to plan a mitigation campaign based on the uncertain information on the asteroid, selecting the best possible combination of deflection acts from a catalogue of various mitigation campaign components while the campaign credibility is uncompromised.

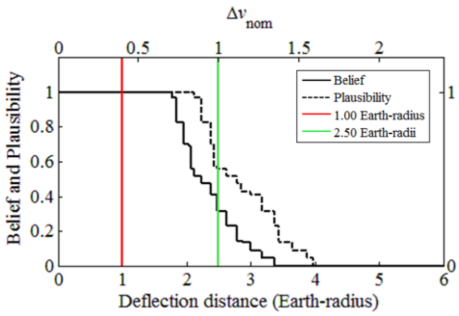

Fig. 1 Deflection by kinetic impactor and corresponding probability.

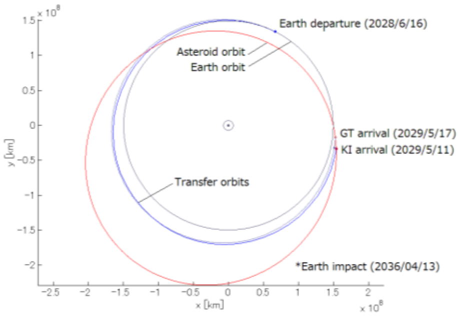

Fig. 2 Dual-deflection mitigation campaign of kinetic impactor and gravity tractor.

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