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Risk-Informed Spacecraft Mission Design for the 2021 PDC Hypothetical Asteroid Impact Scenario

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ABSTRACT

The 2021 PDC hypothetical asteroid impact scenario involves a fictitious near-Earth object (NEO) designated 2021 PDC, which is discovered on April 19, 2021 and may impact Earth only 6 months later, on October 20, 2021. This is a very short warning scenario and 2021 PDC's physical properties are not well known due to the lack of observational opportunities. Only the object's absolute magnitude of H = 22.4±0.3 (1σ) is available, meaning that its diameter could be between 35 m and 700 m. If

2021 PDC's albedo is around the average, e.g., about 0.13, then 2021 PDC's size would be about 120 m.

Launching a mission to an NEO with only a few weeks to perhaps a month of launch preparation time is not possible with current infrastructure. However, we analyze mission trajectories to 2021 PDC to understand what mission options could be enabled by hypothetical future rapid response spacecraft launch capabilities.

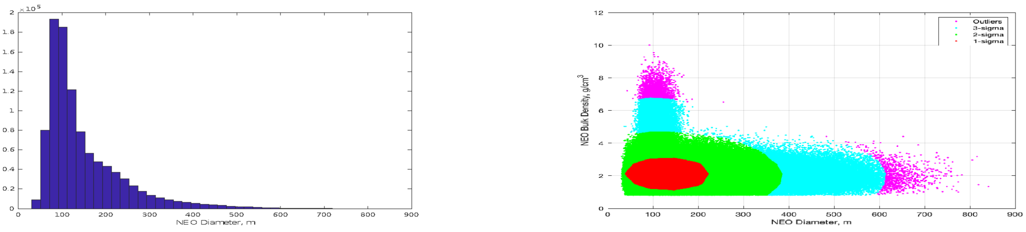
In this study, we consider mitigation missions designed to robustly disrupt the NEO via standoff detonation of a nuclear explosive device (NED). With only a few months between the potential spacecraft arrival and the Earth impact date, it is not practical to deflect the NEO as a whole because the required ΔV would be unreasonably high, and would almost certainly fragment the NEO. We also examine trajectory options for reconnaissance missions to assess how the knowledge gained about the asteroid size and properties could better inform mitigation mission criteria or damage and risk estimates for disaster response.

Our mitigation mission designs are informed by modeling of the uncertainties in the NEO's properties, which are produced by the Asteroid Threat Assessment Project (ATAP) team at NASA's Ames Research Center (ARC). Figure 1 shows the substantial property uncertainties for 2021 PDC.

NASA's Goddard Space Flight Center (GSFC) and the Jet Propulsion Laboratory (JPL) have calculated optimal spacecraft mission trajectories to 2021 PDC. Figures 2 and 3 show example ballistic intercept trajectories and solar electric propulsion (SEP) trajectories . It is notable that SEP could enable the rendezvous of a several-hundred-kilogram spacecraft about a month before Earth encounter, despite the extremely short warning and high inclination of the orbit. For the maximum spacecraft mass intercept solutions, SEP appears to offer a ~2% increase in delivered mass performance.

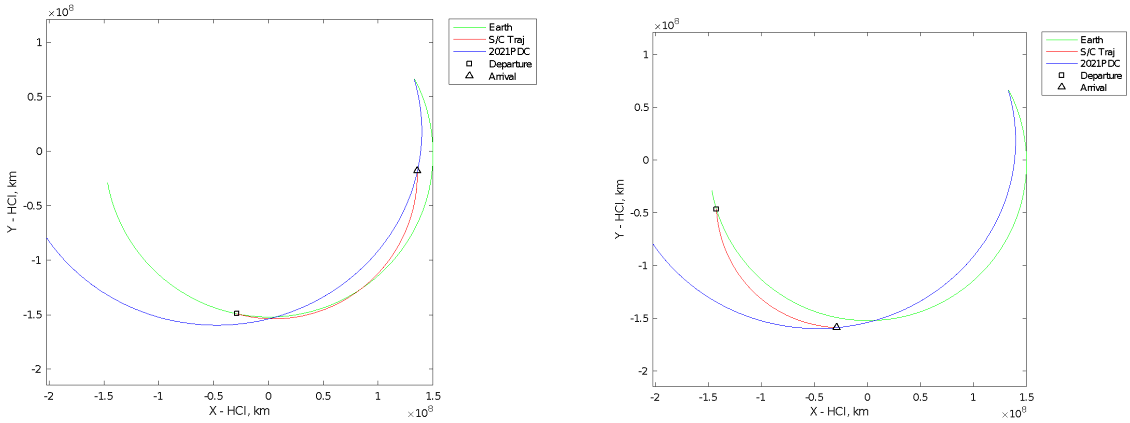
Intercept trajectories are generally capable of delivering several thousand kg of spacecraft mass (including an NED) to high-speed intercept with the NEO. Lawrence Livermore National Laboratory (LLNL) has provided an analytical model for standoff NED performance, and Los Alamos National Laboratory (LANL) has provided heuristics for robust disruption of NEOs and NED payload mass sizing. As shown in Figure 4, the maximum deliverable NED size could enable robust disruption of the NEO if it is no larger than ~150-200 m in diameter (assuming a nominal bulk density). However, because of the large uncertainties in the NEO properties, confidence in successful disruption is below the 1σ level. That confidence could be improved by rapid characterization of the NEO.

In our presentation, we will provide updated summaries of the analysis methodologies and results for risk-informed reconnaissance and mitigation mission options for 2021 PDC, accounting for uncertainties. We will also recommend potential improvements to technologies, procedures, or infrastructure that could enhance planetary defense readiness, responsiveness, and mission effectiveness.



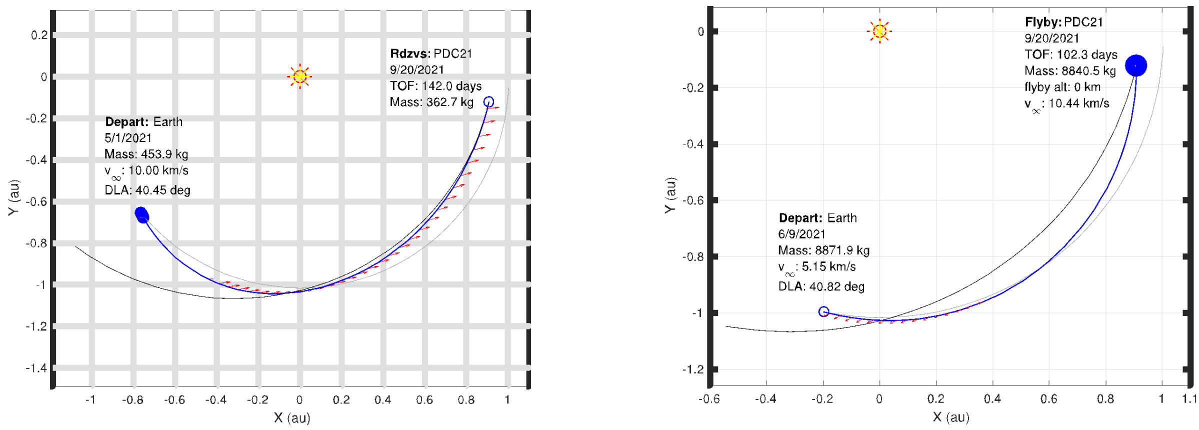
(a) (b)

Figure 1. (a) Diameter distribution for the 2021 PDC hypothetical threat NEO. (b). 1 σ, 2 σ, and 3 σ spreads of correlated 2021 PDC diameter and bulk density distributions.



(a) (b)

Figure 2. (a) Example maximum delivered mass ballistic spacecraft trajectory to 2021 PDC, launching 2021-06-10 (~7 weeks after discovery) aboard a Falcon Heavy Expendable and delivering 8651 kg to intercept the NEO 1 month before Earth encounter. (b) Example rapid-response flyby reconnaissance trajectory launching 2021-05-01 (~1.5 weeks after discovery) aboard a Falcon Heavy Expendable and flying by the NEO at 6.7 km/s relative speed 2 months before Earth encounter.



(a) (b)

Figure 3. (a) Example maximum delivered mass low-thrust SEP spacecraft trajectory to 2021 PDC, launching 2021-05-01 (~1.5 weeks after discovery) aboard a Falcon Heavy Expendable and rendezvousing a 362-kg spacecraft with the NEO 1 month before Earth encounter. (b) Example maximum delivered mass low-thrust SEP spacecraft trajectory to 2021 PDC launching 2021-06-09 (~7 weeks after discovery) aboard a Falcon Heavy Expendable and delivering 8840 kg to intercept the NEO 1 month before Earth encounter.

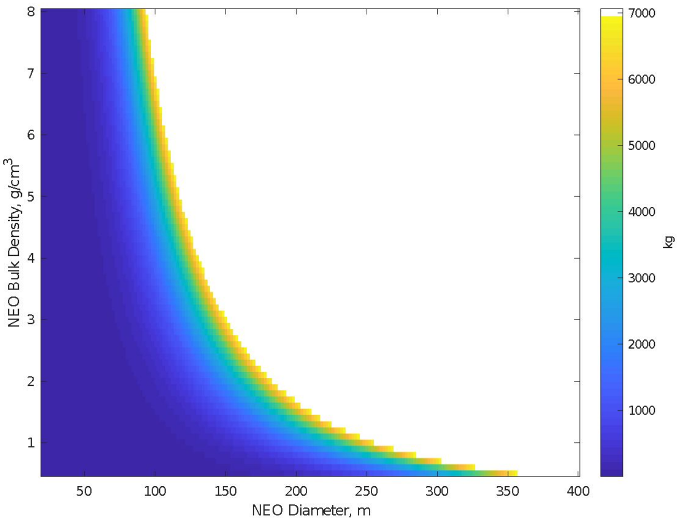


Figure 4. NED mass required to disrupt NEOs of given diameter and bulk density. The maximum NED mass shown here is 7000 kg, which is approximately the largest payload mass that could be delivered to 2021 PDC, based on the preliminary trajectory optimization results. The 7000-kg NED would notionally have a yield of approximately 12.6 MT.