RISK ESTIMATION OF THREATENING ASTEROIDS

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Premise

When faced with the question of designing an asteroid deflection mission or with the decision of launching it, significant uncertainties are present in the asteroid's physical properties, and its orbit solution. The success of the deflection mission relies heavily on these aspects. For example, a heavier than expected asteroid will reduce the imparted deflection DV. So will a larger porosity value by reducing the beta factor [1]. Here, we present a new capability that estimates asteroid impact risk under consideration of these uncertainties. The new method samples the uncertainty space along multiple dimensions, performs a predetermined deflection, propagates the deflected samples to the Earth, models the impact damage, and estimates the overall risk outcome. The work builds on the Probabilistic Asteroid Impact Risk (PAIR) assessment tool [2] by including orbital uncertainty and deflection capabilities. We demonstrate this risk estimation approach for threatening asteroids using the example of the fictitious impactor 2019 PDC. Such analysis provides a quantitative basis for the work of decision makers and disaster managers. It may further find application in areas such as mitigation mission planning where projected post-mitigation risk can be compared to pre-mitigation levels as a means of cost-benefit analysis for mitigation options.

Setup

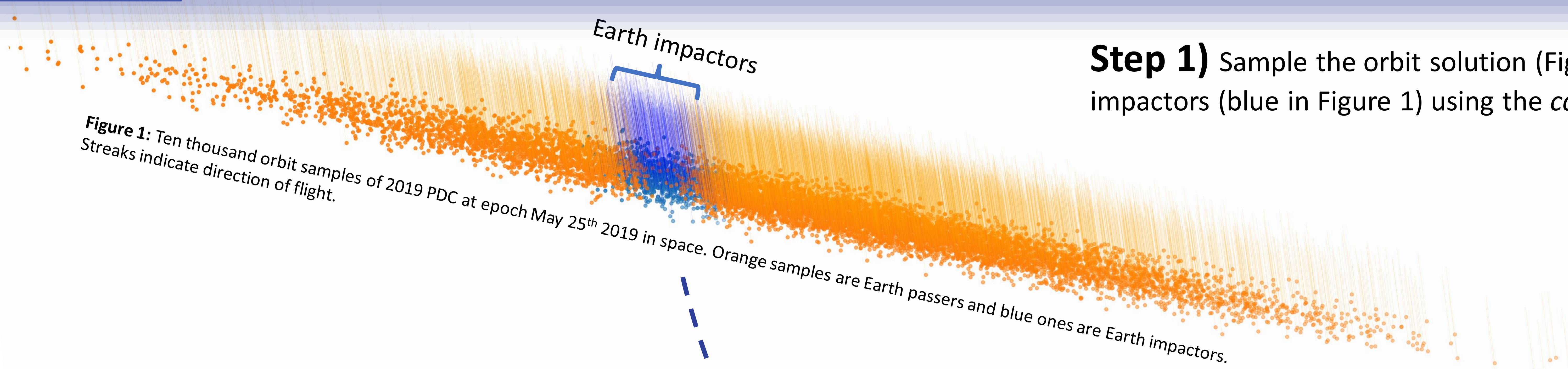

Figure 1: Ten thousand orbit samples of 2019 PDC at epoch May 25th 2019 in space. Orange samples are Earth passers and blue ones are Earth impactors. Streaks indicate direction of flight.

Step 1) Sample the orbit solution (Figure 1) and identify Earth impactors (blue in Figure 1) using the *camonti* software.

Step 2) Propagate orbit sample to time of deflection. Here we use deflection mission "East 2" as a case study.

Step 3) Sample property distributions (Figure 2) for subsequent deflection and impact analysis.

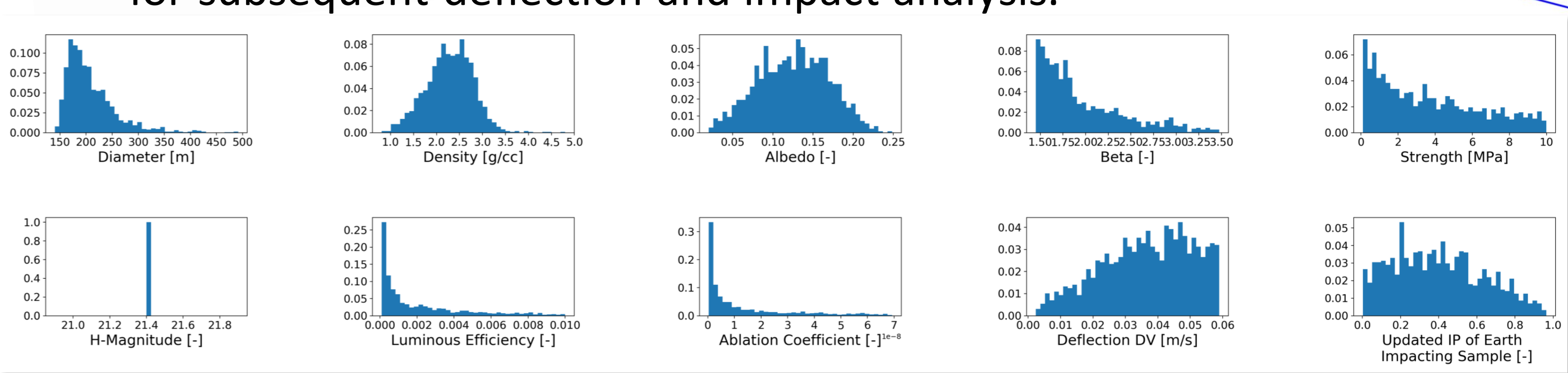

Figure 2: Property distributions for 2019 PDC

Step 4) Impart deflection impulse on Earth impactor sample (Figure 3). The deflection impulse varies based on the physical properties sampled in step 3.

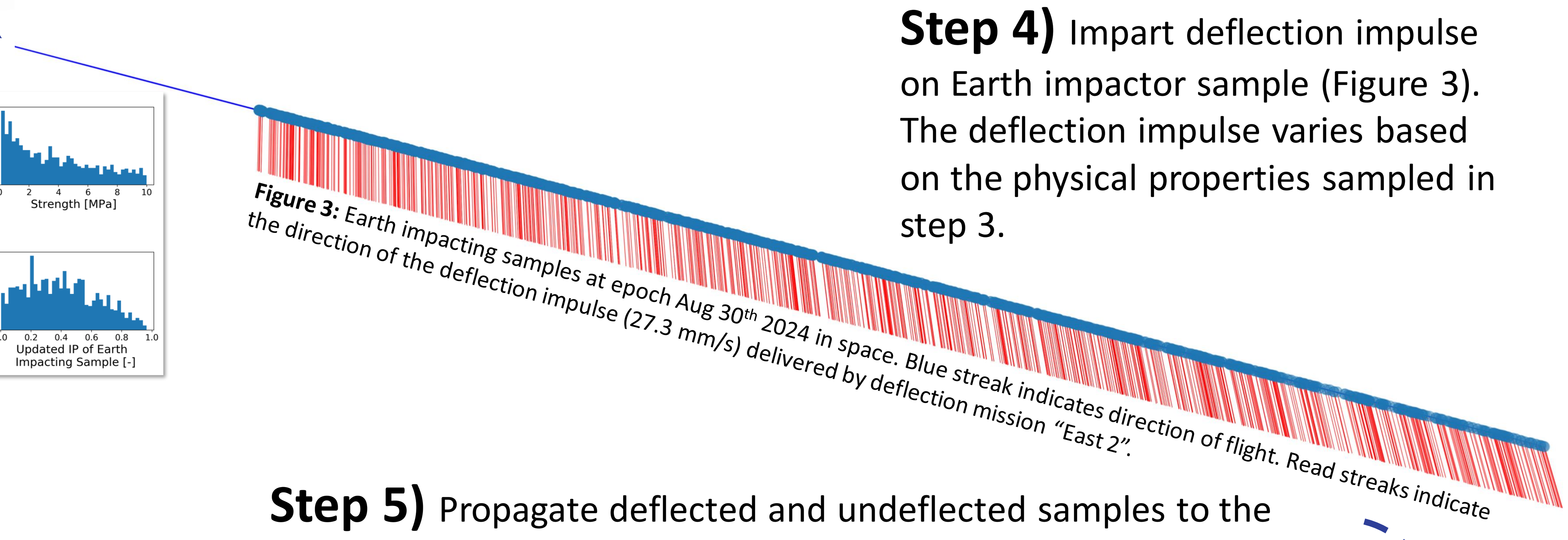

Figure 3: Earth impacting samples at epoch Aug 30th 2024 in space. Blue streak indicates direction of flight. Read streaks indicate the direction of the deflection impulse (27.3 mm/s) delivered by deflection mission "East 2".

Step 5) Propagate deflected and undeflected samples to the ground. Calculate the number of affected population. Compare risk outcomes.

Results

The deflection mission reduces risk by 71.8% from 35,340 expected fatalities to 9,980, but fails to eliminate it. Likewise, the impact probability is reduced from 10.7% to 1.7%.

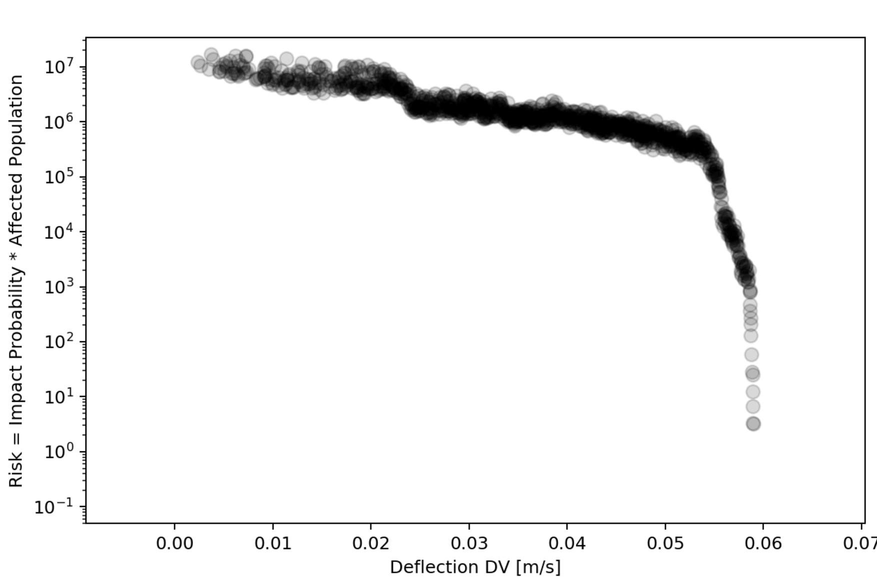

Figure 7: Risk scatter plot as a function of deflection DV. Risk reduces with stronger deflection DV. Achieving a DV of 0.06 m/s guarantees complete deflection of the asteroid.

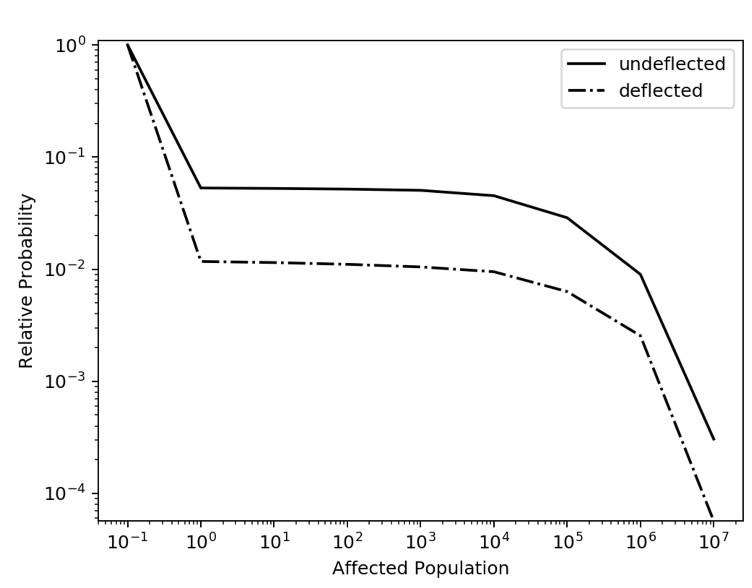

Figure 6: Damage exceedance plot for deflected and undeflected scenario. Shows probability of incurring the inquired damage level or less. The deflected case reduces the damage probability consistently.

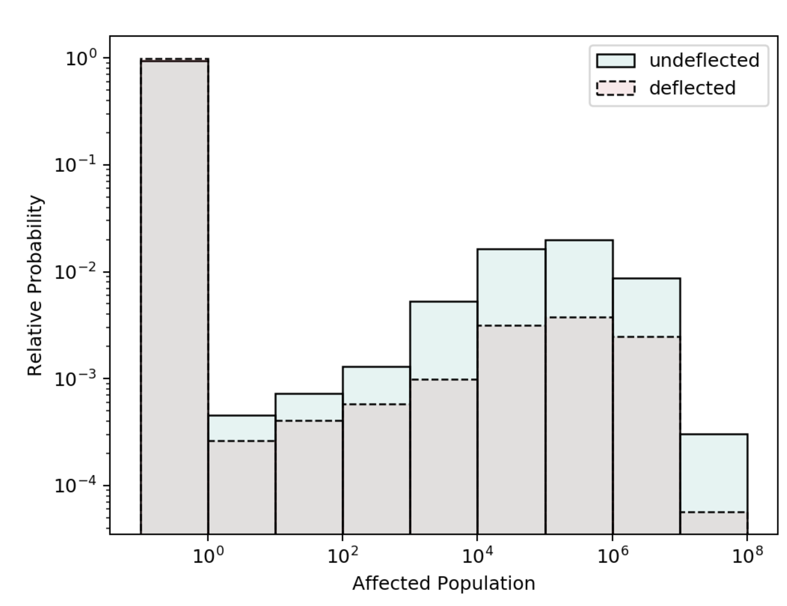

Figure 5: Affected population histogram for the undeflected and deflected impact scenario. Values <1 equate to zero casualties and largely represent samples that miss the Earth entirely. The deflection mission reduces the affected population in each bin and increases the asteroid's Earth miss probability.

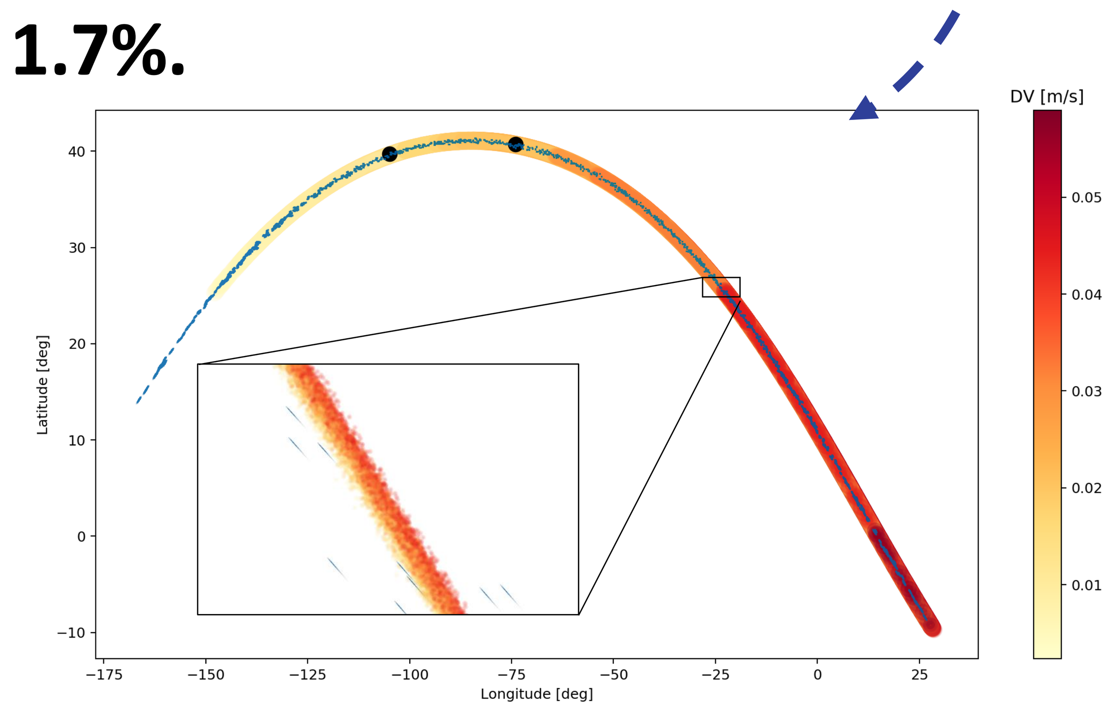

Figure 4: Impact corridor plot. The undeflected corridor is shown in blue points. The yellow/red shaded regions show impact points (see inset) of deflected orbits. The deflected impact points are colored with the applied deflection DV. A larger deflection DV moves the corridor eastwards.

Conclusions

Conclusions: We demonstrate a new capability for asteroid impact risk assessment. Utilizing large Monte Carlo simulations that sample physical as well as orbit uncertainties of the asteroid, we demonstrate that a deflection mission is not binary in its mission outcome. Rather, the remaining risk depends strongly on the uncertain physical properties of the asteroid, its orbital uncertainty, and the deflection mission itself. Typically, the impact risk is not completely removed when asteroid and deflection uncertainties are taken into account. The new capability quantifies the post-mitigation risk situation (Figure 4-6). It can also help in the design of deflection missions by estimating a minimum DV required to completely remove risk (Figure 7).

Future work: We will explore dependencies between individual physical characteristics and their influence on risk outcome to inform reconnaissance mission science priorities. Additional uncertainty dimensions such as deflection spacecraft uncertainties including S/C failure probability, and NAV instrumentation measurement errors will expand the analysis. We will also explore additional uncertainties in the momentum exchange between deflection S/C and the asteroid.

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[2] D.. L. Mathias, L. F. Wheeler, and J. L. Dotson, "A Probabilistic Asteroid Impact Risk Model: Assessment of Sub-300 m Impacts," Icarus, vol. 289, 2017.