

# The Accessibility of Potentially Hazardous Asteroids for Ballistic Rapid Reconnaissance Flyby Missions

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## Objective

Rapid reconnaissance flyby missions are the fastest means of characterizing a potentially hazardous asteroid.

In these scenarios— the design, fabrication, & testing of the spacecraft is often the longest duration event in the overall timeline.

To prepare for this scenario, we ask:

Can we build a rapid reconnaissance flyby spacecraft in advance of a known asteroid threat?

What range of trajectory parameters would it need to accommodate?

## Approach

1. We take the existing population of 2340 potentially hazardous asteroids (PHAs) and *rephase* them so that they pass close to Earth in the early 2030's. This event is the Time-of-Close-Approach (TCA).

- Two of the 2340 asteroids have orbital periods greater than 30 years and are removed from the set.
- Though based on true asteroid data, this risks a biased population.

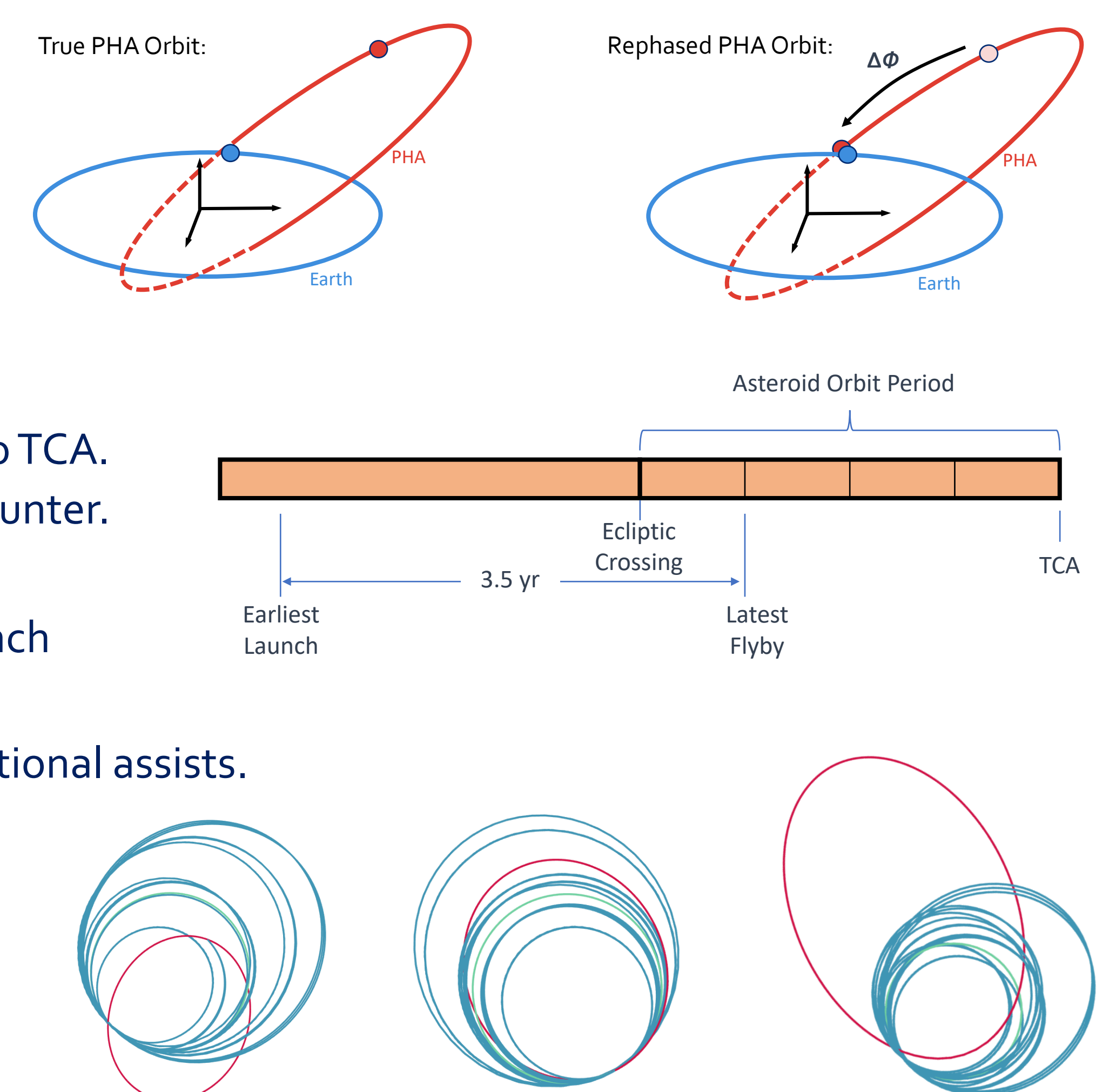
2. We then suppose that a flyby mission would need to encounter the PHA no later than 0.75 orbit periods prior to TCA.

3. We further suppose that a rapid response would need to launch no earlier than 3.5 years before this latest encounter.

4. We suppose that a viable flyby mission would not require a heavy-lift launch vehicle. We limit the available launch energy ( $C_3$ ) to  $30 \text{ km}^2/\text{s}^2$ , which supports up to a 500 kg spacecraft on at least two medium-lift launch vehicles.

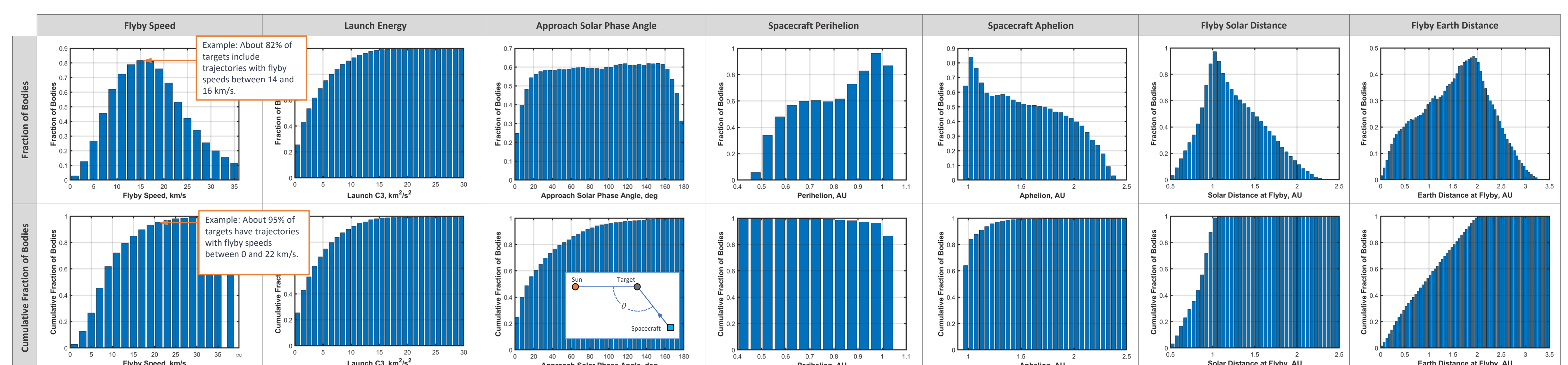
5. To reduce the trade-space, we only consider ballistic trajectories, which use no maneuvers or planetary gravitational assists.

6. We then compute trajectories (simplified two-body Lambert arcs) to each PHA, departing Earth every 5 days and passing the asteroid every 5 days. We remove any trajectories that violate the assumed constraints above. This leaves over 32M trajectories that we can sort and filter.

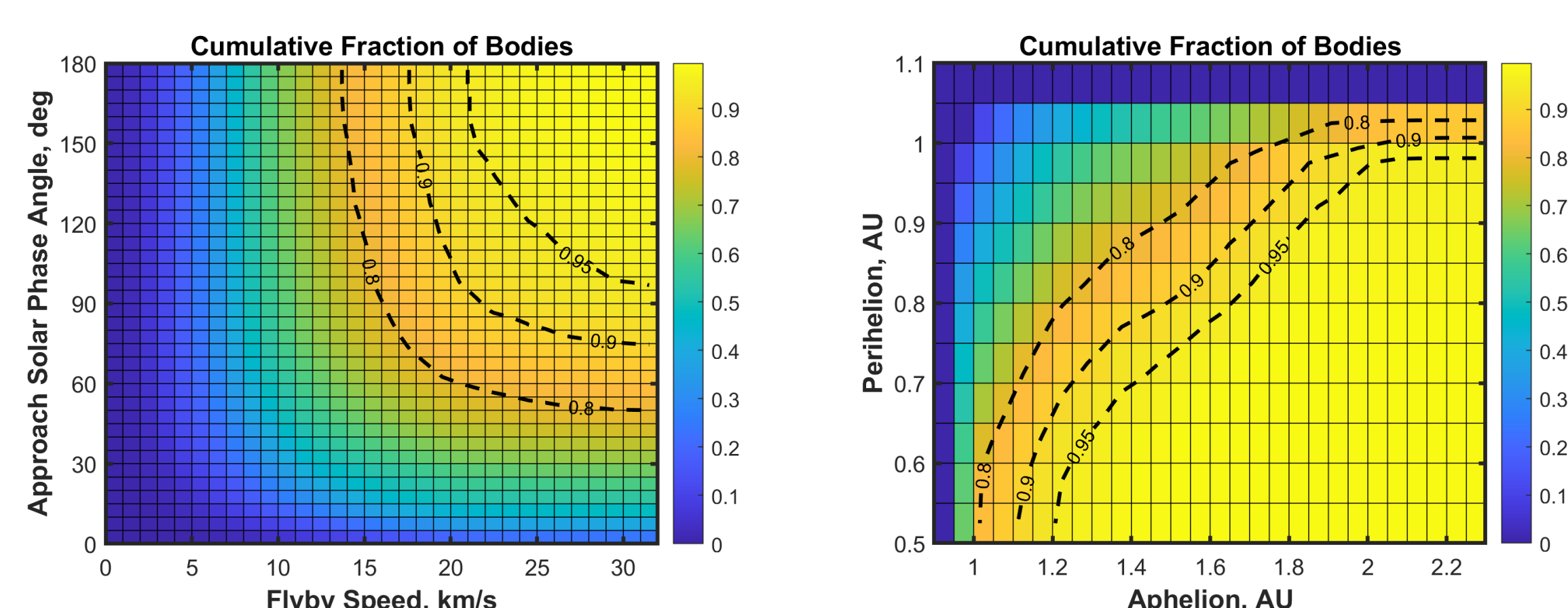


## Results

These 1D histograms show the distributions of relevant trajectory parameters. Each bar depicts the fraction of the PHA population that can be reached with the specified values.



However, 1D histograms are insufficient to define mission requirements because many of these parameters are correlated, as depicted in these 2D histograms. Dashed lines indicate contours containing 80%, 90%, and 95% of the population.



To determine viable requirements, we can filter the data to find combinations of parameters that permit access to specified fractions of the population (e.g. 90%).

*Highlighted entries indicate changes relative to the row above.*

| Max Time of Flight | Min Solar Distance | Max Solar Distance | Max Solar Phase Angle | Max Flyby Velocity | Percent Completeness |
|--------------------|--------------------|--------------------|-----------------------|--------------------|----------------------|
| 3.5 yr             | 0.72 AU            | 2.2 AU             | 120 deg               | 35 km/s            | 98.0%                |
| 2.5 yr             | 0.72 AU            | 2.2 AU             | 120 deg               | 35 km/s            | 97.7%                |
| 2.5 yr             | 0.90 AU            | 2.2 AU             | 120 deg               | 35 km/s            | 96.5%                |
| 2.5 yr             | 0.90 AU            | 1.8 AU             | 120 deg               | 35 km/s            | 94.5%                |
| 2.5 yr             | 0.90 AU            | 1.8 AU             | 90 deg                | 35 km/s            | 90.5%                |
| 2.5 yr             | 0.90 AU            | 1.8 AU             | 90 deg                | 25 km/s            | 88.5%                |
| 2.5 yr             | 0.90 AU            | 1.52 AU            | 90 deg                | 25 km/s            | 84.3%                |
| 2.5 yr             | 0.90 AU            | 1.52 AU            | 75 deg                | 20 km/s            | 78.6%                |

Proposed design point, which mitigates outliers while satisfying 90% of simulated population:

|        |         |        |        |         |       |
|--------|---------|--------|--------|---------|-------|
| 2.5 yr | 0.90 AU | 2.0 AU | 90 deg | 25 km/s | 90.5% |
|--------|---------|--------|--------|---------|-------|

## Next Steps

- Consider different suppositions for trajectory search constraints, including a wider range of launch dates, higher launch energies, and inclusion of maneuvers & gravity assists.
- Assess if the conclusions change when applied to an unbiased synthetic population.
- Iterate with systems and payload engineers to select a requirement set that is feasible and low-cost.

## Acknowledgements

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