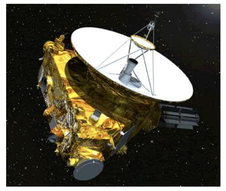

Potential Orbital Capture Missions to Trans-Neptunian Objects

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BACKGROUND

To date, New Horizons has been the only interplanetary mission undertaken with the exploration of a trans-Neptunian object (TNO) as its primary objective (Ref. 1). This remote region of the Solar System contains a large number of minor planets, at least one of which (Eris) is larger even than Pluto. Our group has previously analyzed high thrust missions using a single Jovian Gravity Assist (JGA) to several TNOs (Ref. 2-4). In the current study, we extend our previous work by examining the potential for the orbital capture of a probe. We also evaluate the possible benefits of using a Jupiter -Saturn Gravity Assist (JSGA) instead of a JGA.

Critical mission performance parameters include transit time to the target, potential flyby mass or orbital capture mass for launch on a given booster, arrival excess velocity at the target (which determines target observation time for flyby missions), and spacecraft radiation dose during the Jovian flybys. The last of these is important because of potential damage to electronics and the resulting shielding mass requirements.

OBJECTIVES

The main objectives of this project are:

- To design Jupiter Gravity Assist and Jupiter-Saturn Gravity Assist trajectories to several TNOs including Huya, Huamea, Ixion, Pluto, Quaoar, Varuna and Sedna;
- To identify the most favorable targets and opportunities for TNO orbital capture missions;
- To compare JGA and JSGA missions with regard to Jovian passage distances (a simple surrogate for spacecraft radiation exposure), arrival planet hyperbolic excess velocity, potential orbital capture mass, etc.
- To compare our results with historical missions in terms of transit time to the target, payload capability, Jovian flyby radiation exposure, etc.

METHODS

Interplanetary trajectory modeling was accomplished using Mission Analysis Environment (MAnE), a commercial software package developed by Space Flight Solutions (Ref. 5). Jupiter proximity trajectories were calculated using the Program to Optimize Simulated Trajectories (POST 3D, Ref. 6), and the Jovian radiation environment was analyzed using the European Space Agency code SPENVIS (Ref. 7). The calculated radiation environment is expressed via dose/depth curves, indicating the dose of radiation which would be experienced as a function of the equivalent thickness of aluminum shielding.

JGA trajectories are constructed by planning the second leg (Jupiter to the TNO) first, using a "pork-chop" plot which shows Jupiter departure and target arrival excess velocities; a near Hohmann Transfer from Earth to Jupiter in then added. This yields departure opportunities to a given TNO approximately every twelve years, corresponding to Jupiter's orbital period. Opportunities for JSGA trajectories to a given TNO occur less frequently due to the synodic period of Jupiter's and Saturn's orbits, with the Jupiter encounter typically occurring shortly before or near the time of those two planets' conjunction. Two such conjunctions occur in 2040 and 2060.

As an initial guess for JSGA trajectories, we set the Jupiter to Saturn transit time equal to 3.5 years (similar to that for Cassini) and use a near Hohmann transfer from Earth to Jupiter. MAnE is then allowed to optimize the encounter dates and distances. Potential TNO targets are limited for JSGA trajectories since the first two legs influence where a satellite can travel in an efficient manner.

Launch is accomplished on either a Delta IV HLV or an Atlas V, 551 with a Star 48 upper stage (analysis was done for both vehicles, and the better option was chosen). The performance of the launch vehicles is shown in Figure 1, taken directly from Ref. 10. Orbital capture is simulated assuming an impulsive burn. The interplanetary trajectories typically yield arrival excess speeds of 6 to 10 km/s, necessitating a two stage propulsive capture. The first stage assumes a solid rocket motor with an ISP's of ~286s and a tankage fraction of 0.05 (based on an average of ATK solid engine specs). The second stage is a liquid-fuelled HiPAT engine using mono-methyl hydrazine (MMH) and nitrogen tetroxide (N2O4). The engine is an upgraded version of the one used for Cassini orbital insertion and provides an ISP of 323s and tankage fraction of 0.113.

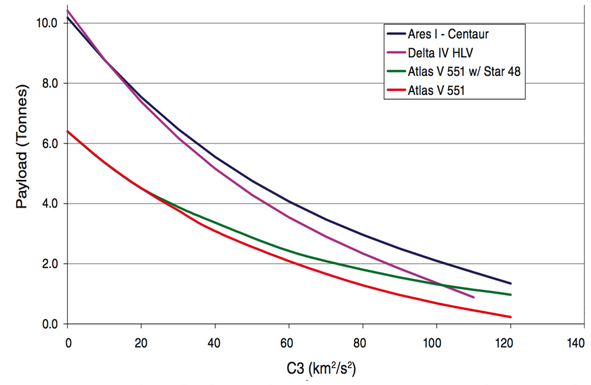

Figure 1. Launch Vehicle Performance Comparison for Interplanetary Missions (Ref. 10)

RESULTS

Table 1 shows potential orbital capture masses and other critical parameters for JGA missions with a time of flight of approximately 25 years to various TNOs. It is apparent that Huya, Pluto and Ixion are the most promising targets in terms of potential capture mass. These results assume departure at the minimum C3 and do not allow for schedule slippage (however, that issue is addressed below). The table also shows the impact of using a JSGA trajectory to Huya rather than a JGA. For the cases considered here, the JSGA permits a much more distant Jupiter flyby maneuver, but increases the arrival excess speed at the target, thereby reducing the time available for observation for a target flyby or making orbital capture less feasible.

	Earth Departure	Departure C3	Departure Mass (kg)	Jovian Periapsis Radius	Arrival V-Inf (km/s)	Capture Mass (kg)
Haumea	9-21-2025	103.14	1314	14.38	8.06	69.13
Huya (JGA)	10-28-2026	91.179	1560	9.28	3.93	380.6
Huya (JSGA)	9-28-2037	91.263	1558	33.08	6.54	133.4
Ixion	10-25-2026	88.6	1619	18.93	5.58	239.8
Pluto	12-19-2028	88.64	1618	18.25	5.22	295.6
Quaoar	11-21-2027	90.511	1575	17.64	6.5	149.4
Varuna	6-6-2022	88.2	1628	14.46	8.12	126.3

TABLE 1. Mission Comparison

Figure 2 shows the radiation dose/depth curves predicted to occur during the Jupiter flyby for several JGA trajectories to Huya, departing Earth in October of 2026. For comparison, the radiation encountered by the Voyager 1 and 2 probes is also shown (calculated using the same methodology). Figure 3 shows the potential orbital capture mass at Huya as a function of transit time for a mission departing Earth in 2026. The capture masses are shown both for the optimum departure date and for a 20% C3 margin above the minimum value to provide for schedule slippage The Jupiter flyby radiation dose behind 3 mm of aluminum shielding is also shown. This shielding depth was chosen as a point of reference since it is the value given in previous studies for the interior of the Pioneer probes (Ref. 11), where radiation doses were 4.5 (10^5) and 1.2 (10^5) rads for Pioneer 10 and 11 respectively.

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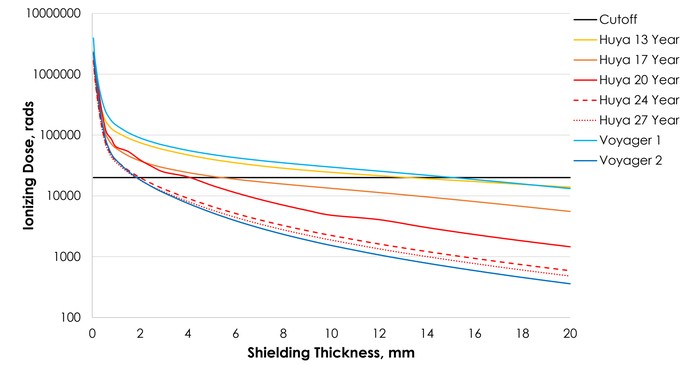

Figure 2. Jovian flyby radiation environment for 2026 departure to Huya with Voyager flyby radiation for comparison

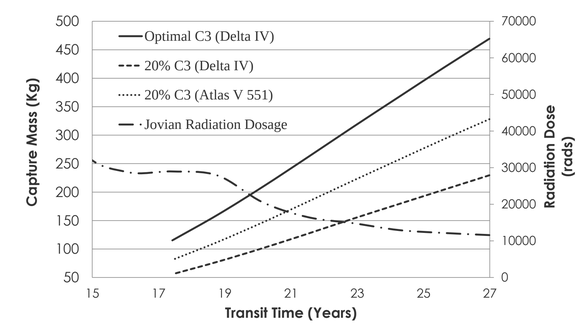

Figure 3. Transit time vs capture mass and Jovian flyby radiation for a mission to Huya departing in 2026

CONCLUSIONS

For selected TNOs, orbital capture of a small interplanetary probe appears feasible using a two-stage, traditional chemical propulsion system. The best targets identified to this point are Huya, Pluto and Ixion. Capture missions will typically require interplanetary transit times of approximately 25 years to have the low arrival excess speeds necessary to capture of a probe of reasonable mass. The interplanetary trajectory can incorporate either a Jupiter Gravity Assist or a Jupiter-Saturn gravity assist. For a wide range of Huya missions using a JGA, radiation exposure of the spacecraft during the Jovian flyby should be less severe than that encountered during previous missions including Voyager 1 and Pioneer 11. Use of a JSGA would allow more distant flybys of Jupiter and less intense radiative environments.

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