EVALUATING TRANS-NEPTUNIAN DWARF PLANETS AS TARGETS FOR AN INTERSTELLAR PROBE FLYBY. B. J. Holler[1] and K. D. Runyon[2], [1]Space Telescope Science Institute (Baltimore, MD, USA; bholler@stsci.edu), [2]Johns Hopkins University-Applied Physics Laboratory (Laurel, MD, USA; kirby.runyon@jhuapl.edu).

Introduction: A trajectory for NASA's Interstellar Probe (ISP) concept mission is beginning to coalesce around potentially leaving the heliosphere between roughly -20° and 20° ecliptic latitude and 300° to 330° ecliptic longitude. The goal of such a trajectory is to reduce the time needed to leave the heliosphere and ensure that the shape of the heliosphere can be confidently determined by viewing it in profile. The ISP mission concept presents a unique opportunity to fly by one or more trans-Neptunian Objects (TNOs). At the time of a potential flyby (~2040, ± a few years) there will be 5 trans-Neptunian dwarf planets within this region (Figure 1). Dwarf planets are generally considered to be objects greater than 400 km in diameter, and therefore in hydrostatic equilibrium (spherical or ellipsoidal in shape). These five dwarf-planet class TNOs are 2002 MS_4, Ixion, Pluto, Quaoar, and Gonggong. Pluto was previously visited by New Horizons [1], Ixion appears to be spectrally neutral with no detected satellites, and little is known about 2002 MS_4 due to its current position in front of a dense Milky Way star field. For these reasons, we consider Quaoar and Gonggong to be the most interesting potential targets for an ISP flyby. Their orbital and physical properties are discussed in more detail below.

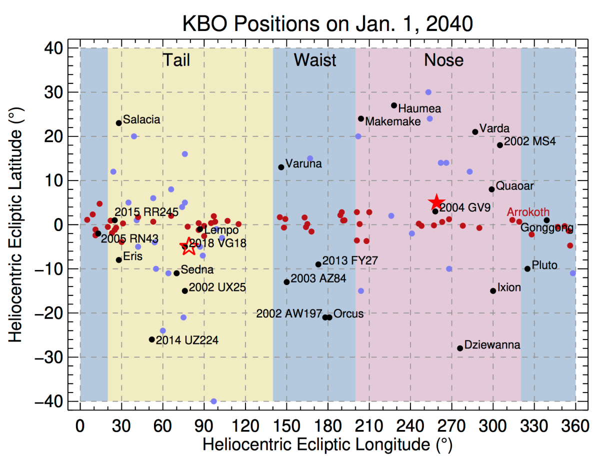

Figure 1: Ecliptic coordinates of a sample of trans-Neptunian Objects (TNOs) on January 1, 2040. The filled red star marks the approximate location of the heliospheric nose and the open star marks the tail. Dwarf planets are marked in black, cold classical TNOs in red, and extreme TNOs (perihelion >40 au, semi-major axis >150 au) in purple.

Orbital properties: With an inclination of 8°, Quaoar is a hot classical TNO, meaning it orbits between the 3:2 and 2:1 resonances (42-47 au) with Neptune and has an inclination >5°. The eccentricity is low at 0.04, so the orbital distance varies from 42-45.5 au over an orbit. At the time of a flyby, Quaoar would be 42.2 au from the Sun.

Gonggong is a scattered disk object that would be very distant during the time of a flyby, ~92.5 au from the Sun. With an eccentricity of 0.50, aphelion is at 101 au and perihelion is at 33 au (about the same as Pluto), meaning at its closest it is nearer to the Sun than Quaoar ever gets. Its orbital inclination is over 30°, but would be near the ecliptic around the time of a potential ISP flyby (Figure 1).

Physical properties: Quaoar's diameter was measured to be 1110±5 km from a stellar occultation [2]. Based on this diameter and the system mass, the density was calculated as 1.99±0.46 g cm^{-3}, which could make it one of the densest (rock-rich) TNOs, comparable to Eris [3]. The rotation period is on the shorter end at ~8.8 hours [4].

Thermal measurements indicate that Gonggong is 1230±50 km in diameter [5], which is half the size of Pluto and Eris, smaller than both Makemake and Haumea, and comparable to Pluto's largest satellite, Charon. Its density, 1.74±0.16 g cm^{-3}, is also comparable to that of Charon [1]. The rotation period is either 22.4 or 44.8 hours [6].

Satellites: Quaoar has one known satellite, Weywot, which has a diameter of 81±11 km from thermal measurements [7]. It has an eccentricity >0.10 [8]. The orbital period is ~12.5 days. Little else is known about Weywot, but a flyby would reveal an object in a size range rarely visited by robotic spacecraft. Such a flyby would be the first such object visited in the trans-Neptunian region.

Xiangliu is Gonggong's only known satellite and could be comparable in size to Weywot at <100 km in diameter [5]. Combined with Gonggong's slower rotation period, the high eccentricity of Xiangliu (~0.29) raises the possibility that Gonggong itself is a tidally-locked semi-contact binary [9].

Color and surface composition: NIR spectra of Quaoar show clear absorption features of H_2O ice and strongly suggest that both volatile methane and non-volatile ethane (a radiolytic by-product) are present as well [10]. This matches with Quaoar's red color [11].

An alternate explanation is that ammonia hydrates are present on Quaoar, which would point to ancient resurfacing, similar to Charon. Quaoar is firmly on the boundary for volatile retention over the age of the solar system [12].

Gonggong is one of the reddest objects in the solar system [13], but Xiangliu is much less red, resulting in one of the largest color dichotomies among the components of a TNO binary system. Gonggong's red color may arise from radiolytic processes acting on methane, but to-date there has only been a very tentative detection of this volatile ice species [14]. Gonggong is also on the boundary for volatile retention based on the model of [12].

Trajectory considerations: During the time frame considered, Quaoar will be just within the target region and ~10° out of the plane of the ecliptic. These factors have contributed to Quaoar frequently being mentioned as the best option for an ISP flyby for these reasons. Pluto is at a similar inclination below the ecliptic, but has already been visited so presents less of an opportunity to push the boundaries of comparative planetology among dwarf planets. Ixion and 2002 MS_4 are even further out of the plane of the ecliptic. The primary downside of a Quaoar flyby is the diminished opportunity for serendipitous flybys of cold classical TNOs, which reside in the ecliptic plane.

On the other hand, Gonggong is outside the target region by ~10° in ecliptic longitude, but is still very much in the flank of the heliosphere. Gonggong lies only a few degrees above the ecliptic during this time period, potentially providing the added bonus of serendipitous flybys of cold classical TNOs. The chance of a serendipitous flyby was calculated as 1 in 100,000, but only for trajectories exactly along the ecliptic [15]. The probability of a flyby decreases quickly with distance from the ecliptic plane. Figure 1 shows the locations of dwarf planets (black), cold classical TNOs (red), and extreme TNOs (purple) of interest on January 1, 2040.

Summary: A slight edge might be given to Gonggong because of its deep red color, the possibility that it is a semi-contact binary, and its location along the ecliptic. However, Quaoar would also be a fine target for an ISP due to potentially higher density compared to other TNOs and location along the seemingly preferred ISP trajectory. Both targets have smaller satellites on eccentric orbits and are on the boundary for retention of volatiles over the age of the solar system. Thus, a flyby of either dwarf planet by ISP would make a significant contribution to our understanding of the physical, chemical, geological, and dynamical processes at work on TNOs.

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