

PLANETARY SCIENCE WITH AN INTERSTELLAR PROBE. Kathleen E. Mandt¹, Kirby Runyon¹, Abigail Rymer¹, Ralph McNutt¹, Pontus Brandt¹, Michael V. Paul¹. ¹Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA. (Kathleen.Mandt@jhuapl.edu).

Introduction: The space science community has maintained an ongoing interest in exploration of interstellar space for several decades. In 2016, Congressional language encouraged NASA to take the enabling steps for an Interstellar scientific probe. In 2018, NASA began funding a study targeting 1000 AU within 50 years using current or near term technology. The ultimate goal of this study is to define a mission that would be feasible to launch in the 2030's, enabling NASA and humanity to take the first explicit step in to interstellar space scientifically, technically and programmatically. Although the primary goal of an Interstellar Probe would be to understand the heliosphere and the very local interstellar medium (VLISM), a probe designed to exit the solar system and explore interstellar space provides a prime opportunity for planetary science. During the time period while traveling to interstellar space, flybys of critical science targets should be planned to maximize the science outcome of such a mission.

Interstellar Probe Objectives: Most NASA missions fall under a single science division (e.g. Heliophysics) and funding for a mission is only allowed to be used in support of science objectives relevant to that division's decadal survey goals. However, a growing awareness is developing within the space science community of the need for cross-disciplinary efforts for NASA missions. A prime example of this is the exoplanet community, which has historically been supported by the Astrophysics Division, but which has natural overlap with the Planetary Division. In fact, as more information is obtained about exoplanets a critical need for collaboration and coordination between these communities is developing.

In order to maximize the science return of an Interstellar Probe, the objectives would need to be cross-divisional. The NASA-funded study is focused on designing a mission capable of addressing science objectives that fall into three categories:

- a) *The Heliosphere as a Habitable Astrosphere:* Characterize the heliosphere and the interstellar medium to understand other astrospheres harboring potentially habitable stellar-exoplanetary environments.
- b) *The Circum-Solar Disk:* Determine the three-dimensional dust distribution of the circum-solar disk to understand planetary formation in our solar system.
- c) *Kuiper Belt Objects and Planets (KBOPs):* Explore KBO worlds in the outer solar system to

understand the origin and evolution of outer solar system bodies and explore the giant planets to better understand their magnetospheres, atmospheres and satellites.

Kuiper Belt Objects: The New Horizons flyby of Pluto revealed unexpected complexity in Pluto's surface processes, the distribution of volatiles on the surface and atmospheric chemistry and loss. This has clearly demonstrated the need for future exploration of the Pluto system and of other KBOs, which is best done through an ongoing multi-mission program. With its high asymptotic speed, the Interstellar Probe enables a flyby of at least one, but ideally more than one, KBO dwarf planet.

The planetary Decadal Survey, *Visions and Voyages* [1] sets a priority objective of determining how matter in the solar system and interstellar medium originated and evolved. It calls for exploration of the outer solar system in search of clues to its origin and to the nature of other planetary systems. Questions that an Interstellar Probe could address during a planetary flyby include:

- 1) What do surface compositions (volatiles, organics, etc.) and geological landforms (faults, cryovolcanoes, crater depths, dunes, flows, etc.) reveal about the current state and evolution of the surfaces and interiors of large KBOs?
- 2) Do or did KBOs have a subsurface ocean or atmosphere and what can we tell of their characteristics?
- 3) What does the size-frequency distribution of KBOs and dwarf planets, together with their orbits, reveal about the collisional, orbital, geologic processes, and formation of Kuiper Belt worlds?

Exploration of KBOs with an Interstellar Probe would present unique challenges compared to New Horizons because the spacecraft would be travelling at much higher speeds. An adaptation of the LORRI instrument on New Horizons [2] could be the ideal approach for obtaining high resolution, multi-spectral images [3].

Giant Planet Flybys: The Decadal Survey outlines several objectives for exploration of the giant planets, including:

- 1) How did the giant planets and their satellite systems accrete, and is there evidence that they migrated to new orbital positions?
- 2) Why are the ice giant magnetic fields so complex? How do their unusual geometries affect

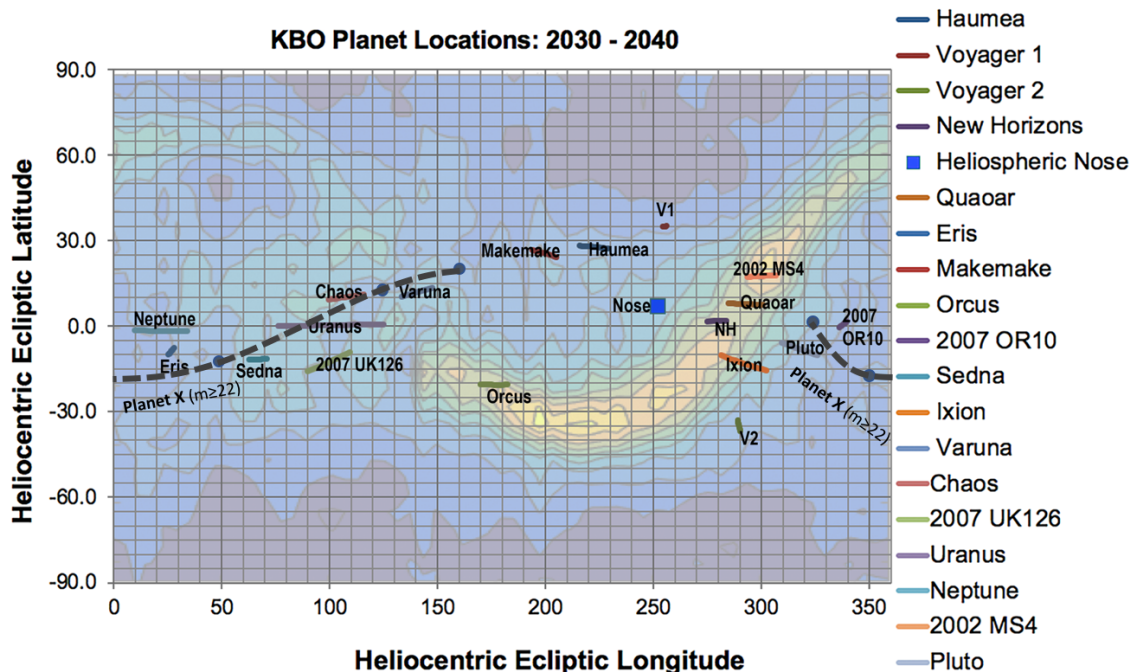


Fig. 1. Map in heliocentric latitude and longitude illustrating the locations of large KBOs compared to the location of the heliospheric nose and ribbon [4]. Also included is the calculated orbit of Planet X [5].

magnetospheric interactions with the solar wind and satellites as well as atmospheric escape?

- 3) How do the giant planets serve as laboratories to understand Earth, the solar system, and extrasolar planetary systems?

The Interstellar Probe, designed using current and near term technology, would require a gravity assist flyby of Jupiter. This provides opportunities to study the magnetosphere and atmosphere of Jupiter as well as to image Jupiter's moons and could include coordinated observations with other spacecraft in the Jupiter system at the time of the encounter.

The final flagship, or large strategic mission recommended by the Planetary Decadal Survey involves a mission dedicated to studying the ice giants. The ice giants are the only class of planet in our solar system that have not had a dedicated orbiting mission even though they are the most common class of detected exoplanets. They are fundamentally different from Jupiter and Saturn, being mostly composed of "ices" (unlike the gas giants, which are 90% hydrogen and helium) and they are also unique from each other. A trajectory past Uranus is more feasible than Neptune for the Interstellar Probe in the coming epoch. Uranus has a peculiar obliquity, puzzling interior structure, is unexpectedly colder than Neptune (releasing significantly less internal heat than Neptune) [6], and hosts an exotic magnetosphere with surprisingly energetic radiation belts but little

source plasma or intense wave activity that is often associated with robust radiation belts at other planets [A2].

Interstellar Probe Trajectories: Fig. 1 illustrates the position of KBOs and the ice giants in ecliptic latitude and longitude and their position in relation to the heliospheric nose and ribbon. The trajectory will be determined by the best direction for addressing heliosphere objectives and is likely to be ~45-90 degrees from the nose or into the ribbon to be able to image the heliosphere appropriately from the outside. Ensuring that targets of high interest for planetary exploration will play an important role in determining the trajectory. We highlight the fact that a flyby of the dwarf planet Quaoar would also permit an Interstellar Probe to explore the energetic neutral atom (ENA) ribbon, thus addressing fundamental questions in both planetary science and heliophysics.

References: [1] NRC (2011). [2] Cheng et al. (2007), *New Horizons*, 189-215. Springer, NY. [3] Runyon et al. (2018), *AGU Fall Mtg Abstracts*. [4] McComas et al. (2009), *Science*, 1180906. [5] Brown & Batygin (2016), *ApJL*, 824, L23. [6] Mousis et al. (2018). *PSS*, 155, 12-40. [7] Mauk (2014). *JGR*, 119, 9729-9746.