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Planetary imaging during fast flybys by Interstellar Probe

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Abstract

Imaging planetary targets during fast flybys by an Interstellar Probe on its way out of the solar system present opportunities for dwarf planet reconnaissance but with unique imaging challenges. Studying the geology of, e.g., Quaoar, via flyby imaging, is possible.

1. Introduction

An interstellar probe leaving the solar system could make opportunistic flybys of planets and Kuiper Belt Objects (KBOs) to conduct novel planetary science and exploration [e.g., 1]. Here, we explore types of targets and the concept of operations (ConOps) for planetary reconnaissance.

2. Mission Architecture

As detailed by [1], APL's Interstellar Probe mission concept mission would notionally launch a lightweight (~half ton) New Horizons (NH)-like spacecraft in circa 2030 on a fast escape trajectory away from the Sun. It would likely launch on a very heavy-lift rocket (e.g., the Space Launch System; SLS) and use a rocket-assisted prograde Jupiter gravity assist to fly outward at a speed of 9-20 AU per year (i.e., 3-6 times faster than New Horizons). Flyby science of Jupiter [1] would be a secondary priority after successfully executing the maneuver. Visible and near-IR imaging of planetary surfaces and atmospheres during flybys allows geological, compositional, and geophysical investigations (Figure 1). The extremely fast flyby speeds (>50 km/s) provide both challenges and opportunities.

2.1 Imaging ConOps

The ConOps for imaging a planet during a fast flyby benefits from the experience of the New Horizons (NH) team during the flybys of the Pluto-Charon system and KBO 2014 MU_{69}. The main constraint is angular acceleration of the apparent motion of the target along the focal plane of the camera, and that is more a function of spacecraft slew rate and rate change than proper motion. NH can slew at 1.5 deg/s, and accelerating the spacecraft to that rotation rate takes on the order of a few seconds. Time-Delay Integration (TDI) for NH's Ralph multispectral imager must occur at slew rates no faster than 1000 μrad/sec, or ~0.06 deg/s and not change during an image acquisition. This imaging slew rate can be increased by enhancing the imaging detector sensitivity, such as by co-adding more pixels in the direction of the image scan, and software modifications can enable variable-rate TDI imaging. Angular rate and rate acceleration is not a problem for a NH-like spacecraft: NH traveled at 14.44 km/s at a distance of 3500 for the flyby of MU_{69} with an instantaneous radial velocity of 0.24 deg/s. This was said by the engineers [Gabe Rogers, personal comm.] to be at the limit of capability for the panchromatic LOng-Range Reconnaissance Imager (LORRI) framing camera, which does not use TDI.

Consider Interstellar Probe flying by a planet (e.g., Quaoar) 3500 km from the surface moving 50 km/s. The proper motion of the planet would be 0.82 deg/s, which is within a New Horizons-like spacecraft's ability to compensate for by slewing (1.5 deg/s maximum) against the spacecraft motion. To build up a multispectral TDI image at a NH-like rate of 0.06 deg/s, the spacecraft must slew at 0.76 deg/s against the velocity vector, though this does not account for angular acceleration produced by changing spacecraft-target distance. The spacecraft can conduct multiple such scans by slewing near the maximum rate parallel to the velocity vector to once again point the cameras ahead of the planet, thus resetting for another imaging scan. To a casual observer, the spacecraft would thus appear to wobble; this was done for NH's encounter with Pluto and MU_{69}. In this way, multiple imaging scans can be acquired leading up to, during, and after closest approach to provide stereo views, global coverage at high resolution, and views at variable phase angles. However, other considerations should inform imaging operations, such as desiring global, high-phase angle imaging over the planet's terminator, which would occur near closest approach when a LORRI-like camera field of view would span only a few km on the surface.

2.2 Camera Design

The advantages of TDI imaging over a framing camera for a fast flyby are two-fold. Firstly, the camera scans across the scene to build up the image one row at a time, analogous to the scanner on a photocopy machine; this takes advantage of fast spacecraft motion instead of fighting it to prevent smear. Secondly, given the camera's scan motion, is the ability to image through multiple visible and near-IR color filters for multispectral imaging while achieving the same pixel scale as a framing camera.

3. Target Planets

Known Kuiper belt dwarf planets number near 130 [2], though several stand out as particularly interesting. Quaoar's size (D ~ 1092 km; roughly the same size as Charon) and spectral characteristics suggest that it is a complex planet, especially as it appears to have an intermediate amount of surface volatiles (CO, N_2, CH_4; e.g., [3]) between volatile poor small KBOs and volatile-rich planets Pluto and Eris. The types, distributions, and albedos of landforms on the encounter hemisphere will constrain their formation processes.

As discussed by [3,4], Makemake, like Quaoar, is also transitional between volatile rich and poor. Haumea, while volatile depleted, is rotating quickly enough (4-hr) to be oblong in dimensions while still resting in hydrostatic equilibrium. In contrast to these planets, Pluto, Triton, Eris, and Sedna are volatile rich. While flying by any one of these planets is possible, the ultimate trajectory will be constrained by Interstellar Probe's primary science goals of heliophysics and studying the interstellar medium [1]. In the decade of 2030-2040, Quaoar and Ixion are opportunistically aligned in front of the Heliospheres energetic neutral atom ribbon, enabling dwarf planet reconnaissance and unique heliophysics investigations.

References

[1] Mandt, K.D., et al.: Planetary Science with an Interstellar Probe. Joint DPS-EPSC, Geneva, Switzerland, this Congress, 2019.

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[4] Brown, M.E.: The Compositions of Kuiper Belt Objects. Annu. Rev. Earth Planet. Sci. 2012. 40:467–94. Doi: 10.1146/annurev-earth-042711-105352 (2012).

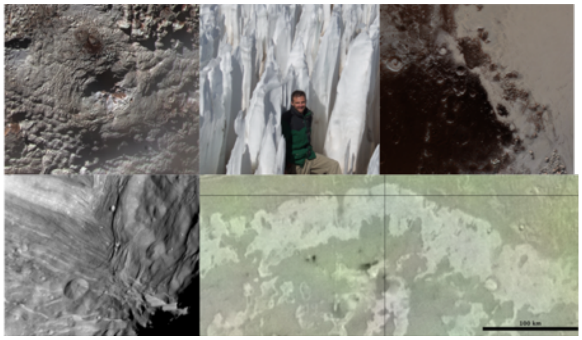

Figure 1. Top-left: Cryovolcanic edifice of Wright Mons, Pluto (NASA PIA11707). Top-center) Sublimation-driven penitentes on Earth (S. de Silva). Top-right: N_2 glaciation and organics-rich cratered higlands on Pluto (NASA PIA11707). Bottom-left) Extensional grabens and a possible mantle convection corona on Miranda (NASA PIA01354). Bottom-right) Triton's sublimation-eroded cliffs (JMARS/P. Schenk).