THE POTENTIAL FOR UNIQUE AND TRANSFORMATIVE OBSERVATIONS OF THE SOLAR SYSTEM'S DEBRIS DISKS FROM THE INTERSTELLAR PROBE

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Introduction. Here we update the possibilities of using an Interstellar Probe (ISP) telescope traveling to 1000 AU from the Sun to observe the brightness, shape, and extent of our solar system's debris disk(s).

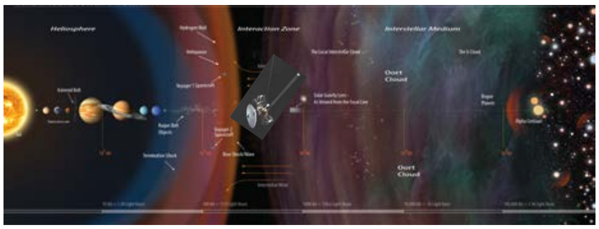

Figure 1 – Interstellar Probe Explorer payload at its design goal location of 1000 AU with respect to the planets, the heliopause, Alpha Centauri, and the Oort Cloud.

Planetesimal belts and dusty debris disks are known as the "signposts of planet formation" in exo-systems. The overall brightness of a disk provides information on the amount of sourcing planetesimal material, while asymmetries in the shape of the disk can be used to search for perturbing planets. The solar system is known to house two such belts, the Asteroid belt and the Edgeworth-Kuiper Belt (EKB), and at least one debris cloud, the Zodiacal Cloud, sourced by planetesimal collisions and comet evaporative sublimation.

However, these are poorly understood *in toto* because we live inside of them. E.g., it is not understood well how much dust is produced from the EKB since the near-Sun comet contributions dominate near-Earth space and only one s/c, New Horizons, has ever flown a dust counter through the EKB. Understanding how much dust is produced in the EKB would give us a much better idea of the total number of bodies in the belt, especially the smallest ones, and their dynamical collisional state. Even for the close-in Zodiacal cloud, questions remain concerning its overall shape and orientation with respect to the ecliptic and invariable planes of the solar system - they are not explainable from perturbations caused by the known planets alone.

Discussion: What Can ISP at 1000 AU achieve with Remote Imaging and *in Situ* Dust Measurements?

Enable Scientific Studies:

- Produce the 1st Exterior Imaging of the Solar System's Dust Cloud/Debris Disk
- Use the Solar System's known inventory & history as a Rosetta Stone for understanding Exosystem Disks
- Search for unknown/new Solar System objects like Planet X that perturb the cloud
- Improve measurements of cosmic background light originating from outside the Solar System

Using Interstellar Probe lookback remote sensing, we could measure the entire extent of the inner, near-Earth Zodiacal Cloud and whether it connects smoothly into an outer cloud, or if there is a second outer cloud sourced by the Kuiper belt and isolated by the outer planets, as predicted by Stark & Kuchner or Poppe et al. [1-5] (Figs 2-3). Using new technologies and passively cooled detectors, a suitable low size, weight and power system VISNIR spectrometer/FIR imager + 10 cm class primary has been specified using a CubeSat study baseline design [6]. FIR imagery will inform us about the dust cloud's density, while the VISNIR spectrometer will provide maps of the cloud's dust particle size and composition.

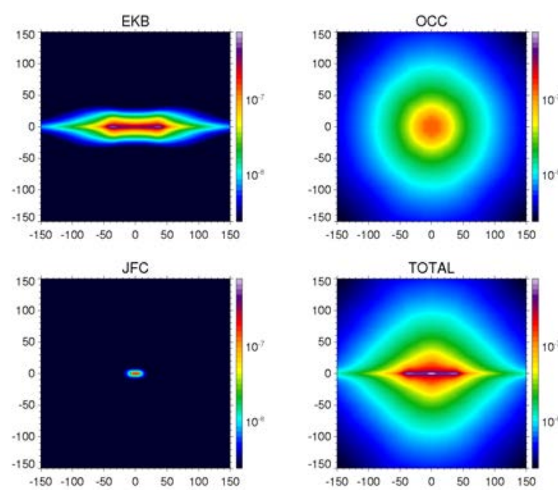

Figure 2 – Predicted dust cloud morphologies arising from solar system JFC and Oort Cloud (OCC) comets & Kuiper Belt (EKB) sources. After [5].

Observing at high phase angle by looking back towards the Sun from 1000 AU, we will be able to perform deep searches for the presence of rings and dust clouds around discrete sources, and thus we will be able to search for possible strong individual sources of the debris clouds - like Planet X, the Haumea family of collisional fragments, the rings of the Centaur Chariklo, or dust emitted from spallation off the six known bodies of the Pluto system. The same remote sensors will be used to map the surfaces of KBOs encountered along the way. Direct dust sampling will return the first ever *in situ* chemical analysis of EKB dust, the first ever *in situ* sampling of dust beyond 200 AU, and provide calibrated ground truth for cloud models produced from our imagery.

Large-scale structure determination of the cloud should help inform us of ancient events like planetary migration and planetesimal scattering (as in the LHB), and measurement of the cloud's total brightness will allow improved removal of its signal in near-Earth cosmological measurements looking out into the Universe.

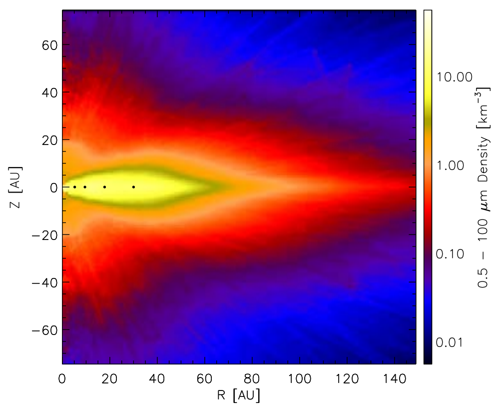

Figure 3 – Close-up of the expected total in-plane solar system dust cloud morphology. After [5].

Potential Solar System Resource Utilization:
- Dust, Collisional Family Locations
- Source Characterization - #'s, Masses, Velocities
- Source Loss Rates

At the same time these scientific endeavors are occurring, better understanding of the solar system's dust clouds will help characterize their sources, providing location information for potential future easily exploitable, organic, rocky dust (inner cloud) and icy, organic, rocky dust (outer cloud) materials. Examples of these are the sources of the inner cloud dust bands in the MBA, & the Haumea family members in the EKB.

Exploration:
- Understanding a G2V's Circumstellar Dust

Looking out to the future, the exploration of our first exosystem, our closest neighbor, the α Centauri system, beckons. This system also contains a close G2V solar twin of estimated age ~5 Gyr, old enough to have formed life as we know it. At 4.3 ly distance, the timescales for reaching this system are prohibitive unless we send probes at near lightspeed velocities, conversely dust particles impacts at these speeds can deliver very large amounts of energy per impact (e.g., a 1 mm particle hitting at 0.2c delivers 20 GJ = 5 Tons of TNT equivalent). Thus, a detailed knowledge of the dust cloud around **our** G2V star will help mitigate hazards for a High-Speed Interstellar Flyby (like Breakthrough Starshot) to our neighboring G2V in α Cen.

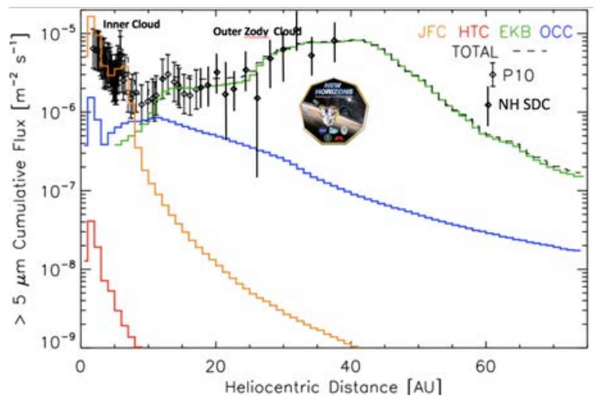

Figure 4 – Predicted dust flux contributions (colored curves) and in situ measurements (black data pts) for the solar system debris disk cloud [3,4,6]. Some care should be taken in interpreting this plot, as the PIONEER 10 fluxes are for 1-100 um grains while the NH grains are 0.2 – 10.0 um in size**. Regardless, the overall relative shapes scale well and** the predicted crossover at ~10 AU from JFC dominated to EKB dominated is seen. ISP will help us determine if another crossover from EKB dominated to OCC dominated occurs at ~100 AU, and if the EKB dust is ice, rock, & organics rich like KBOs and comets.

Conclusions. The expected scientific, resource utilization, and mission exploration support value of VISIR imaging of the solar system's dust cloud from 1000 AU remove is large. The contributions from the Edgeworth-Kuiper Belt and the Oort Cloud, normally obscured from the Earth by locally dominant JFC and asteroid belt contributions, should be easily imaged. Models of the inner + outer cloud produced from IP measurements will allow better understanding of the dust hazards we can expect around α Cen and better, safer mission designs to study that system *in situ*.

References: [1] Stark & Kuchner 2009, *ApJ* **707**, 543 [2] Stark & Kuchner 2010, *AJ* **140**, 1007 [3] Poppe+ 2010, *Geophys.Res.Lett.* **37**, L11101 [4] Poppe & Horányi 2012, *Geophys.Res.Lett.* **39**, 1 [5] Poppe 2016, *Icarus* **264**, 369 [6] Piquette+ 2019, *Icarus* **321**, 116 [7] Zemcov+ 2019, *American Astronomical Society*, AAS Meeting #**233**, id.#171.06