Interstellar Probe Measurements of Dust in the Heliosphere, HelioSheath, and the Nearby Galaxy

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ABSTRACT.

Micron sized dust grains are present throughout the heliosphere and in the nearby galaxy as both interplanetary dust (IPD) and interstellar dust (ISD) particles. Dust sources include grinding main belt asteroids, sputtered KBOs in the EKB, and sublimating comets throughout, while sinks include solar radiation pressure and evaporation. The full shape and structure of the solar system's dust disks are poorly understood because we live inside of them; we especially do not understand the outer disks regions since near-Sun cometary contributions dominate near-Earth space and only 1 spacecraft, New Horizons, has ever flown a dust counter through the EKB. The ability to map the radial gradient of interplanetary dust grain composition (s) provides strong constraints on the masses, compositions, and origins of their parent relic bodies.

ISD grains from the local galactic environment continuously flow through our heliosphere after passing through the ISM–heliosphere boundary. Each ISD grain carries critical compositional information, delivering matter that may resemble the original solid building blocks of our solar system. Despite decades of observations, understanding the ISD flux and its directional variability remains an unfinished and challenging task. *In-situ*measurements of ISD grains from 1 to 1000 au are critical to understand the flux and composition of ISD, and how the heliosphere filters and interacts with this material.

Using a dust analyzer instrument onboard an Interstellar Probe (ISP) to perform *in situ* dust collection as the s/c exits the solar system, we will measure the extent of the inner, near-earth zodiacal cloud and the outer second cloud sourced by the EKB. *In situ* sampling will inform about the cloud's run of dust particle size and composition. It will help calibrate 3D cloud models produced by remote ISP VISIR imaging, determine if the dust in the outer system is icy or rocky or both, and help solve the current disconnect between remote imaging models of ISM dust in the galaxy near the Heliosphere and ISD measurements made by the Ulysses and Cassini s/c. It will carry a dust analyzer for the 1st time ever through the heliopause, producing our 1st understanding of the role a dusty plasma plays in the boundary interaction regions between our habitable astrosphere and the galaxy.

Figure 1 (at bottom right of main page) – Interstellar Probe Explorer payload at 1000 AU with respect to the planets, the heliopause, Alpha Centauri, and the Oort Cloud. The Interstellar Probe studied by JHU/APL would have a nominal design lifetime of 50 years, achieve more than twice the speed wrt the Sun than Voyager 1, and have the ability to operate out to 1000 AU.

PLANETESIMAL BELTS AND DUSTY DEBRIS DISKS.

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 inner Jupiter Family Comet (JFC) + Asteroid belt and the outer 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 the inner cloud and only one s/c, New Horizons (NH), has ever flown a dust counter through the EKB. New estimates from the NH results put the EKB disk mass at at 30 – 40 times the inner disk mass [1]. Better understanding how much dust is produced in the EKB will improve our estimates of the total number of bodies in the belt, especially the smallest ones, and their dynamical collisional state. Even for the innermost 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.

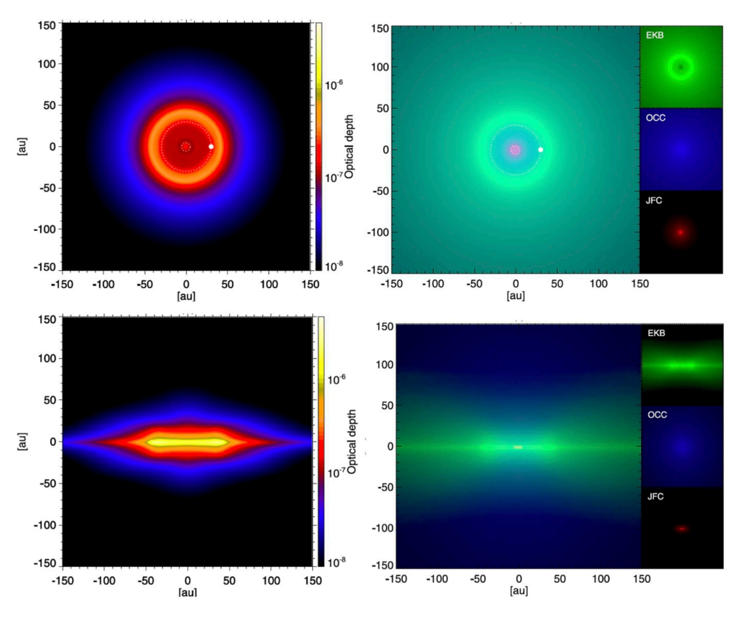


Figure 2 – In situ measurements (black data pts) and predicted dust flux contributions (colored curves) for the solar system's debris disks [1,8]. The overall relative shapes of the inner & outer disks scale well and the predicted crossover at ~10 AU from JFC dominated to EKB dominated is seen. ISP will help 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.

UNDERSTANDING THE SUN' ASTROPAUSE / ISM BOWSHOCK REGION.

At the outermost edges of our solar system, the ram pressure of the expanding solar wind (SW) outflow becomes comparable to the pressure of inflowing ISM material. The SW dominated heliosphere gives way to a transition region demarcated by the Transition Shock on the inner edge and the Heliopause on the outside (Fig. 1). The role that dust plays in shaping and energizing the heliosphere's boundary with the local galactic medium is almost completely unknown. Estimates range up to 1/3 of the energy density in the heliopause and heliosheath to be in the dust. Current models of the heliopause & sheath do not allow for the physics of a dusty plasma because the dust component is so poorly known. We do know that submicron sized dust is streaming into the solar system from the ram direction the solar system is taking through the local ISM, and the discrepancy between remote sensing models of local ISM dust and ISM dust measured inside the solar system suggests a large amount of energy is involved in diverting much of the impinging dust around the edges of the solar system in the helio-sheath.

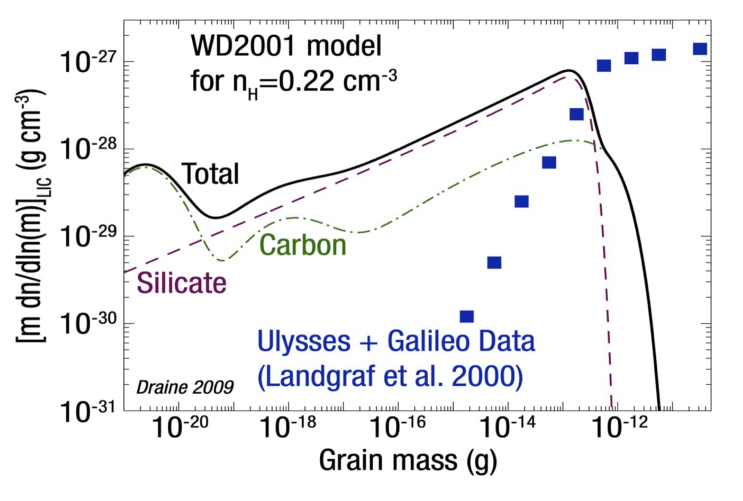
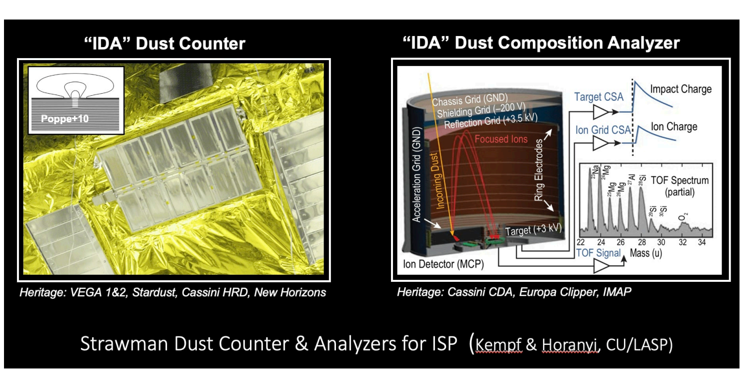


Figure 3 – Disconnect between the nearby ISM dust size distribution pre dicted from remote sensing measurements (black) & ISM dust counts measured inside the solar system (blue) [11, 12]**.** Further, only evidence for silicaceous ISM derived dust has been found to date inside the heliosphere, suggesting some process has preferentiaslly removed carbonaceous solids from dust instreaming from the VLISM.

References: [1] Poppe, Lisse, *et al.* 2019, *ApJ Lett* **881**, L12 [2] Zemcov+ 2019, *American Astronomical Society*, AAS Meeting #**233**, id.#171.06 [3] Stark & Kuchner 2009, *ApJ* **707**, 543 [4] Stark & Kuchner 2010, *AJ* **140**, 1007 [5] Poppe *et al.* 2010, *Geophys.Res.Lett.* **37**, L11101 [6] Poppe & Horányi 2012, *Geophys.Res. Lett.* **39**, 1 [7] Poppe 2016, *Icarus* **264**, 369 [8] Piquette *et al.* 2019, *Icarus* **321**, 116 [9] Greaves & Wyatt 2010, *MNRAS* **404**, 1944 [10] Kempf *et al.* 2014, *EPSC Abstracts* **9**, EPSC2014-229 [11] Wein-gartner & Draine 2001, *ApJ* **548**, 296 [12] Draine & Hensley 2016, *ApJ* **831**, 59

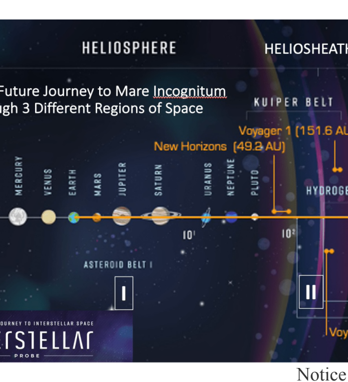
FIRST EVER OUTER SOLAR SYSTEM IN SITU DUST CHARACTERIZATION.

ISP will carry the first ever *in situ* dust chemical analyzer past the orbit of Saturn. Based on the *Europa Clipper* SUDA instrument [10], it will compositionally and directionally characterize the solar system's dust clouds and will help isolate their sources, like the rocky asteroidal dust bands and the icy Haumea family fragments. Using measured dust particle masses and velocities, dust input & loss rates from these sources will be derived. Direct dust sampling will return the first ever *in situ* chemical analysis of dust in the EKB, the first ever *in situ* sampling of dust beyond 50 AU, and provide calibrated ground truth for cloud models produced from our imagery. It should also resolve the tension between the expected makeup of inflowing ISM dust as determined by remote sensing and the mesasured ISM dust component found at Jupiter and Saturn by Galileo, Ulysses, and Cassini [11, 12] & Figure 4.

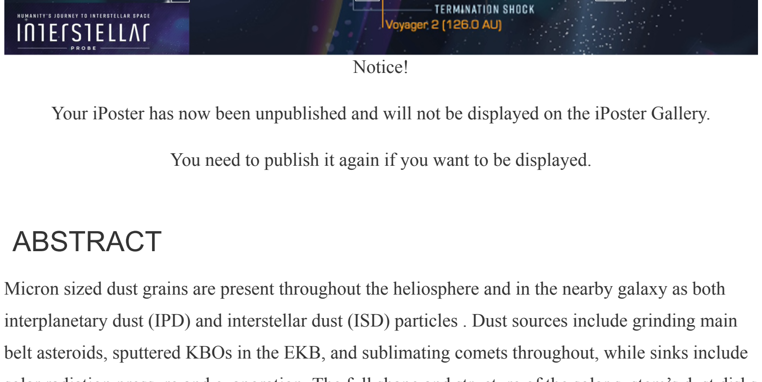


IMAGING STUDIES.

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 [2]. The VISNIR spectrometer could provide maps of the cloud's dust particle size and composition, while FIR imagery would map the dust cloud's density. 3-D cloud Mapping would occur during flythrough via tomographic inversion, and via lookback imaging once the s/c is beyond 200 AU. The lookback imaging will allow ISP to measure for the first time in history the entire extent of the Zodiacal Cloud, and determine whether its inner JFC/asteroidal & outer KBO parts connect smoothly, as predicted by Stark & Kuchner [3-4] and detected by Poppe, Horányi, & Piquette using NH dust counts along 1 chord [5-8] (Figs. 2-3). This would also allow direct comparison of the solar system's debris disks with those observed around other nearby stars, and test theories that suggest that our solar system is planet rich but dust-poor [9]. Observing at high phase angle by looking back towards the Sun from >400 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 icy collisional fragments, the rings of the Centaur Chariklo, or dust emitted from spallation off the larger KBOs. The same remote sensors will be used to map the surfaces of KBOs encountered along the way. 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.



	SP-LEISA 0.5 – 8.0 µm + 1 FIR Beam
$PixSize_{0.55\ \mu m}$	0.5"-2" (2-10 urad)
VISNIR Binning	Up to 50 x 50
$PixSize_{100\ \mu m}$	3.5'
Min Elong	70
Primary Diameter	7-30 cm
Mass	~4 kg (w/o gimbal)
T_det	< 8 K passive
Ch 1 (VISNIR)	Y
Ch 2	Y
Gimbal	Y
Beam Splitter	Y
Filter Set	0.5 – 8 um + 100 um
Observe Off Sun?	Y
Zody Science	< 40 AU
Planet X Science	Y
KBO Flyby Science	Y
Exoplanet Science	Y, w/ Gimbal
Lookback Mask	Y



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