COMETS SOURCED BY KBOS - COMPARISON OF SFDS DERIVED FROM SPITZER/WISE JFC IMAGING & PLUTO/CHARON KBO CRATERING RATES

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Introduction. Today's Jupiter-family comet population in the inner Solar System is likely the dynamical progeny of KBOs that were once in the trans-Neptunian region. As shown by the just-released images of Ultima-Thule in January 2019 that suggest there are morphological analogs with observed cometary nuclei amongst the TNO population (cf. Fig. 1 [1] & [2]). The evolution of the cometary nuclei is an ongoing topic of study, since cometary activity drives many changes to the nuclei (e.g. resurfacing, fragmentation) on timescales that are short compared to dynamical lifetimes. The size-frequency distribution (SFD) of nuclei is one measurable that can be used to understand some of this evolution. The current SFD is a combination of the SFD of the source population, i.e. the bodies injected into the inner Solar System, with whatever evolutionary effects have happen since their injection until the present day.

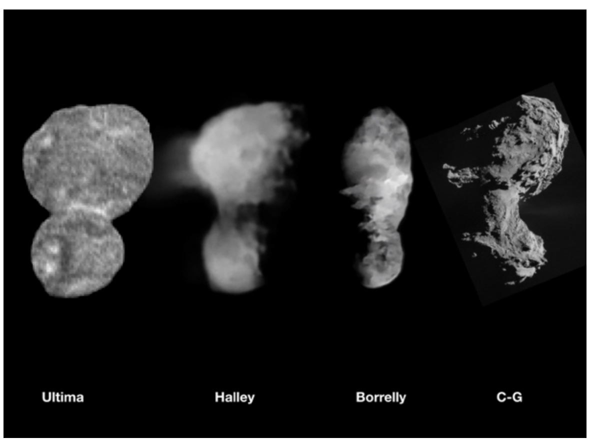

Figure 1 – Morphology of Ultima Thule & 3 Bilobate SP Comet Nuclei. UT appears to be a less processed, almost no-neck version of the SP comets. 2 other SP comet nuclei (not shown) of the 7 resolved to date are also bilobate - 103P/Hartley 2, which matches 19P in gross morphology, and 8P/Tuttle, radar imaged during its close perigee approach in 2009.

Comet SFDs. There have been several recent attempts at measuring the JFC SFD. For example, Meech+ (2004) [3] used visible-wavelength observations to constrain the observed SFD, assuming an albedo, and then debiased the population to obtain the true SFD. Their true SFD shows that there is a real dearth in sub-kilometer scale JFCs. Fernandez+ (2013) [4] and Bauer+ (2017) [5] used infrared imaging photometry from Spitzer and WISE, respectively, to independently measure the SFD. A major benefit of the direct infrared imaging observations is that one need not assume an albedo in order to obtain a nucleus diameter, so these results were truly independent of all previous visible-wavelength studies. [4] measured nucleus diameters for 89 JFCs, the largest sample to date, and since the observed SFD was in agreement with that of [3], they concluded that this was further evidence of missing sub-kilometer JFCs.

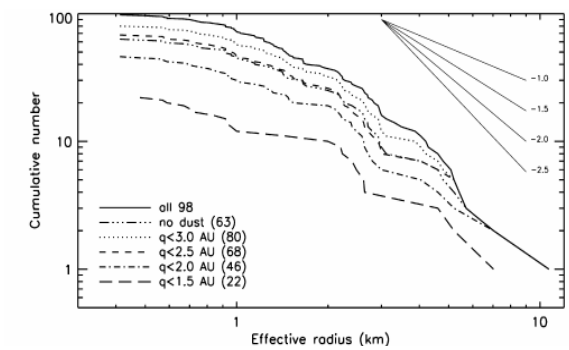

Figure 2 - Cumulative SFD for 98 JF comets using coma removed Spitzer nuclear infrared fluxes. After [4].

Bauer+ 2017 [5] measured diameters for **94** JFCs to obtain the SFD, but also did an independent debiasing of their sample, which was doable since WISE was an all-sky survey, and found a good power law fit down to ~1 km diameters. Because the WISE sensitivity limit precluded the measurement of many sub-kilometer comets, the most robust statement that can be made from the WISE data is that any break in the comet SFD, if present, occurs below 1 km diameter.

While the evidence for the lack of sub-kilometer JFCs is tantalizing, if those comets truly are underrepresented in the current population, it has implications for the evolution of these bodies. One interpretation is that these small comets could more quickly catastrophically disrupt (e.g. [6,7]), another is that they could more readily "turn off" due to volatile exhaustion and/or thick mantle growth & encasement [8].

KBO SFDs. The flyby of Pluto and Charon in July 2015 by the New Horizons spacecraft provided a new opportunity to understand the km-scale population of TNOs, thanks to impact crater measurements on the surfaces of those bodies. Singer *et al.* [9] have recently published a new study of the Pluto/Charon cratering SFD obtained by detailed analysis of all of the mid-to-high resolution image sets returned from the flyby. The craters were formed by TNOs ranging in diameter from ~40 km down to ~100 m, smaller than most KBOs observed directly by telescopes. The larger craters on Charon's encounter hemisphere range in diameter from ~10 km to 225 km and correspond to impactors ~1–40 km in diameter. The average differential slope for craters in this size range is approximately -3 (or -2 cumulative), although a range from -2 to -4 differential is within 1σ error. 1 to 10 km diameter craters (made by impactors of 0.1 – 1.0 km diameter) have an average differential slope of -1.7 and are all shallower than -2 within 1σ. Scaling from the size of craters on Charon to the size of KBO impactors that made them may introduce a slight slope change (*e.g.* [10]) that makes the KBO SFD slightly shallower than the crater SFD, but we consider this scaling slope change negligible compared to the error bars on the fits to the data.

Like the comet SFDs, the Singer+ KBO SFD [9] shows evidence for a 3-part broken power law structure in the 0.1 – 40 km diameter range. By contrast, their SFD does not look like the asteroid belt at these sizes and is not consistent with traditional collisional equilibrium slopes. The break in SFD slope described above, to a shallower slope for smaller craters/impactors, occurs on both Pluto and Charon at a similar crater diameter. Various geologic mechanisms for potential erasure of small craters are considered in [9], but no mechanisms was found that would erase small craters on all terrains on Pluto and Charon. Thus the shallow slope for smaller craters does not appear to be an effect of geological resurfacing, and implies a relative deficit of small Kuiper belt objects (< ~1-2 km in diameter).

Discussion. Detailed investigation of the evolution of the JFCs requires knowing the source population, *i.e.* the SFD of objects in the trans-Neptunian region. In the past, modelers like Belton [7] attempted to reconcile the JFC SFD with that of the trans-Neptunian objects (TNOs) by postulating a TBD mechanism that preferentially removes sub-km sized JFCs, but this was done without fully understanding the TNO SFD. *I.e.,* the main difficulty in the past has been that in order to truly compare the JFCs with the TNOs, there needed to be size-matching, and there have been few concrete measurements of TNOs at km-scales, while the New Horizons data has provided the first look ever at the structure of the sub-km diameter KBO population SFD [9].

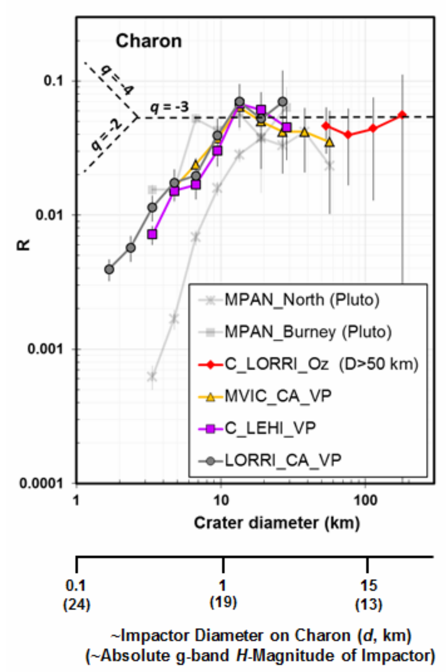

Figure 3 – The differential KBO SFD derived from Pluto/Charon crater counts, after division by D^{-3} [9]. (N.B. - to obtain equivalent cumulative dN/dD slopes as in Fig. 1, form q + 1.0)

In this paper we compare the strong similarities seen in the broken power law structure of the JFC and Pluto/Charon TNO SFDs in the 0.1 – 20 km body radius range, in light of the New Horizons 2019 Ultima Thule KBO flyby results genetically linking the populations. Allowing for the systematic uncertainties inherent in formulating each of the distributions, we will then pay particular attention to any significant mismatches, interpreting them as caused by differential thermal evolution of the populations.

References: [1] http://pluto.jhuapl.edu/Galleries/Featured-Images/index.php [2] A'Hearn+ 2011, *Science* **332**, 1396 [3] Meech+ 2004, *Icarus* **170**, 463 [4] Fernandez+ 2013, *Icarus* **226**, 1138 [5] Bauer+ 2017, *AJ* **154**, 53 [6] Chen & Jewitt 1994, *Icarus* 108, 265 [7] Belton 2015, *Icarus* **245**, 87 [8] Jewitt 2004, in Comets II, Univ Ariz. Press, Tucson, p.659 [9] Singer+ 2019, DOI: 10.1126/science.aap8628 [10] Holsapple 1993, *Ann. Rev. Earth & Planetary Sci* **21**, 333

Acknowledgements. This work was funded by NASA. We thank NASA, the Deep Space Network, JPL, KinetX Corporation, and the entire present and past New Horizons team for making the flyby of MU69 successful.