SURVEYS OF SIZES AND BASIC COMPOSITIONS OF OUTER SOLAR SYSTEM POPULATIONS FROM INFRARED SPACE-BASED PLATFORMS. J. M. Bauer[1,2], S. Sonnett[3], E. Kramer[1], A. K. Mainzer[1], J. R. Masiero[1], T. Grav[3], [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA (James.M.Bauer@jpl.nasa.gov), [2]IPAC, California Institute of Technology, Pasadena, CA. [3]Planetary Science Institute, Tucson AZ.

Introduction: With the advent of the Infrared Astronomical Satellite (IRAS), statistically meaningful samples of asteroid sizes have been measured, and coupled with groundbased measurements, statistically large numbers of albedos [1-2]. For what was previously advanced by individual radar and occultation observations, IRAS measured thousands of sizes, and now NEOWISE [3-7] has provided hundreds of thousands of asteroid diameters which also yielded reflectance measurements. However, for outer solar system populations, namely long-period comets, Centaurs, Scattered Disk Objects (SDOs), and more generally Trans-Neptunian Objects (TNOs), the size distributions of these populations down to km sizes are only beginning to be constrained. Owing to the range of reflectances possible within these populations, from ~2% to ~90% [8, 9], thermal infrared measurements, in combination with reflected-light observations, have the best potential for revealing accurate sizes in these large numbers. Several future near, mid and far-infrared (IR) missions, well into their planning stages, have the potential to sample these more distant populations, and so trace primordial distributions of the quantity of material and volatiles in these bodies, relatively unaltered by insolation. We will discuss some of these platforms and the potential science cases associated with extending the reach of large-sample size surveys.

Comet Populations: Comets provide a special opportunity for the determination of size measurements of primordial populations from the outer solar system. These bodies are presumed to be less evolved as evidenced by the extant volatile reservoirs that drive their activity. However, as they may pass nearer to Earth they are more accessible to encounter missions and to space-based mid-IR (effective over the 3-25 micron wavelength range) measurements, whereby large numbers of nucleus diameters can be measured. Spitzer Space Telescope [10] and NEOWISE [11] have provided statistically meaningful constraints on the size distributions of Jupiter family comets (JFCs) and long period comets (LPCs), and NEOWISE's particularly regular cadence facilitates the debiasing of the sampled comets. Coma removal techniques in combination with debiasing have provided meaningful constraints on nucleus size distributions to within a factor of a few for the most distant Oort Cloud objects, the reservoir of LPCs [11]. In the near future, proposed and current missions undergoing fabrication may improve these constraints on size to within 25%.

Centaurs, SDOs, and TNOs: Farther out in the solar system, populations of objects that have undergone little or no de-volatilization present a means of separating the evolutional effects of near-solar approaches and the rate of change on bodies that such solar exposures induce. Near-IR survey missions, such as WFIRST and the proposed SphereX mission [12, 13], may provide information regarding volatile ice absorption features that indicate more primordial surface compositions, in large enough numbers to map distributions of these signatures across these outer-solar-system populations, while also assessing their reflected-light signals. These outer solar system populations are source regions of inner solar system populations. They serve as storehouses of volatiles, and may be the source of a significant fraction of the volatiles found in the terrestrial planet region, especially on Earth. Mapping spectral variations throughout these bodies can also constrain their formation and emplacement mechanisms, and so test models of early solar system evolution that involve, for example, giant planet migration. Broad-band far-IR surveys, such as the science studies outlined by the proposed Origins Space Telescope (OST) which span the wavelength ranges from several tens to several hundreds of microns, will afford the opportunity to explore the size distributions of SDO and TNO populations down to km sizes [14, 15] via radiometric methods. Such missions ultimately could map the outer solar system small bodies as NEOWISE did for the inner solar system, and move the number of size measurements from the hundreds, as provided by missions like Spitzer and Herschel [16], into the several thousands.

Target Selection for In-Situ Studies: Such missions, dedicated to surveying the outer solar system small bodies at wavelengths tailored to their detection and size characterization also facilitate future missions by providing multiple targets for in-situ study. A larger sample of TNOs and Centaurs with known sizes necessarily translates into a larger number of targets available for future in-situ studies, and the ability to exploit serendipitous opportunities, either with re-purposed spacecraft, as in the case of New Horizons, or with multiple lower-cost missions.

Special Case of an LPC "Constellation" Mission: One such example would be with the identification of targets for a multi-component cubesat or scout mission to image many LPC nuclei. At first it may seem surprising that no mission has yet imaged the nucleus of any LPC, with the possible exception of the Mars Reconnaissance Orbiter in the instance of the C/2013 A1 near-pass of Mars, and certainly none with sufficient detail to characterize the full shape or surface variegation. The range of JFC surfaces imaged by the missions to now six such comets show clear differences in topography, size, and activity, possibly attributable to the amount of time each of these comets have spent in the inner solar system [17]. This suggests the need for multiple comets to be sampled for any class of comets, but the LPCs are a particularly important class in that they are even less altered by the exposure to sunlight, and so provide a baseline of the evolutionary effects of insolation and a test for the origin of the variegated surfaces seen on JFCs.

The imaging of cometary nuclei is possible, as has been shown with the several JFC nuclei that have been imaged in detail, but the main problem lies in the delivery of the imaging instruments to particular targets. With Far-IR survey platforms dedicated to Centaur and TNO population mapping and size characterization, it would be possible to also identify LPCs at distances where missions can be planned and launched. LPCs detected at distances of 20-50 AU from the Sun allow for decade timescales for launch and cruise of the spacecraft to the target. This would facilitate the first line of LPC missions, simple modular and low-cost spacecraft which could fly by individual LPCs, one spacecraft per comet, and rapidly sample a number of comets within a decade, or even a few years, and possibly in preparation for more extended missions that may follow LPCs through their orbit, or even obtain samples from their surface. Such a multi-spacecraft "LPC constellation" mission, with modules launched simultaneously or in rapid succession, may be considerably less expensive and a more appealing first-line of investigation since it would avoid the necessity of matching the high Δv required for any more involved LPC in-situ study, while acquiring a statistically large number of imaged LPC nuclei in a relatively short interval of time.

Conclusion: An array of platforms of near-term and long-term missions being planned or built by both astrophysics and planetary divisions have the potential to sample and characterize the next region of solar system space. Mapping these most basic of properties, size and surface composition signatures, will likely deliver key information that will disentangle evolutionary effects from primordial composition in our solar system. In order to utilize these missions for this exploration, the possibilities for surveying more distant solar system bodies must be realized, and the necessary capabilities to facilitate these studies emplaced within platforms. This will require active participation in the development of these missions by the interested solar system communities. Alternatively, platforms would have to be dedicated and constructed separately. Such missions will both have considerable impact on our understanding of the formation and evolution of small bodies in the outer solar system, and will identify multiple targets for study, for example LPCs, for in-situ missions.

References: [1] Todesco et al. 2002. AJ 123, 1056. [2] Tedesco, E.F., et al. 2004. IRAS Minor Planet Survey V6.0. NASA Planetary Data System 12. [3] Mainzer et al. 2011. ApJ 731, 53. [4] Mainzer et al. 2011. 743, 156. [5] Masiero et al. 2011, 2011. ApJ 741, 68 [6] Grav et al. 2012. ApJ 744, 197. [7] Mainzer et al. 2016, 2016. NEOWISE Diameters and Albedos V1.0. NASA Planetary Data System 247. [8] Stansberry et al. 2008. The Solar System Beyond Neptune, ed. M. A. Barucci, H. Boehnhardt, D. P. Cruikshank, & A. Morbidelli (Tucson, AZ: Univ. Arizona Press), p. 161. [9] Bauer et al. 2013. ApJ 773, 22. [10] Fernandez et al. 2013. Icar. 226, 1138. [11] Bauer et al. 2017. Debiasing the NEOWISE Cryogenic Mission Comet Populations. (in prep), [12] Gehrels, N. & Spergel, D. 2015. Journal of Physics Conference Series 610, 012007. [13] Dore' et al. 2016.Science Impacts of the SPHEREx All-Sky Optical to Near-Infrared Spectral Survey: Report of a Community Workshop Examining Extragalactic, Galactic, Stellar and Planetary Science. arXiv:1606.07039. [14] Bauer et al. 2015. A FIR-Survey of TNOs and Related Bodies. arXiv:1505.04481., [15] OST SWG science cases https://firsurveyor.atlassian.net/wiki/display/FS/Science+Proposals+for+Architecture+Decision [16] Vilenius et al. 2014. A&A 564, A35. [17] Weissman, P. R. and the Rosetta Science Working Team 2016. The Nucleus of Comet 67P/Churyumov-Gerasimenko: Lots of Surprises. AAS/Division for Planetary Sciences Meeting Abstracts 48, 104.01.