Occultation studies of primitive and small bodies

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The recent flyby of the cold-classical Kuiper Belt object, Arrokoth, by New Horizons has already opened an entirely new chapter into the study of solar system formation. The obvious contact binary nature has provided fundamentally new constraints on the accretion process. Prior to that flyby, the contact binary nature of Arrokoth had already been determined through the use of stellar occultations. By itself, the occultation result was already tremendously important but having a spacecraft flyby and the much more detailed view has now provided a fundamental legacy of information and fulfilled goals from the past two Planetary Astronomy Decadal Surveys.

In the wake of the results on Arrokoth, an obvious follow-on question is to understand the diversity of shapes for these small primitive bodies as the need to understand other dynamical populations in the solar system with similar measurements. Clearly, a large-scale survey of small body shapes in the outer solar system by spacecraft exploration is infeasible due to its prohibitive cost. We should certainly target as many small-bodies as we can as part of our continued mission profiles but gaining the insight provided by a large number of studied objects will have to come elsewhere.

The reason the occultation result on Arrokoth was even possible is due to the incredible scientific gift and legacy of the ESA Gaia mission. From this mission we now have a positional catalog of stars that all but eliminates stellar position errors from the task of obtaining stellar occultation profiles of small bodies. Prior to Gaia, occultations were difficult to achieve with the largest objects, primarily limited to the dwarf planets. With the Gaia catalog, we now have the means to routinely target and collect occultation profiles on bodies down to a diameter of 10 km, perhaps even lower in special circumstances. This capability is already in use to help with characterization of Lucy Mission targets and with mission planning of the JAXA DESTINY+ mission that would investigate Phaethon.

Occultation studies also provide extremely high-precision astrometry of objects for more precise orbit estimates, on par with that possible with radar ranging. Occultation astrometry is very complementary to radar since it is more effective at larger distances while radar is limited to just nearby targets.

The problem we face now is one of how to capitalize on this new capability. Getting robust shapes on small bodies and constraints on contact or near-contact binaries requires a large number of deployed stations. The mission support efforts to date typically deploy twenty or more mobile observing stations. Such efforts require funding support that is well beyond what would be considered a reasonable level for the typical research grants that could come out of the Solar System Observations program at NASA or the regular Astronomy and Astrophysics Grant program at NSF. These existing, non-mission, programs might be able to at most a few such campaigns in a typical 3-year grant. More can be done with mission funding but that is always

going to be targeted directly at what a particular mission needs. The ability to pursue an occultation-based survey of sizes and shapes is completely untenable given the current funding structure. The problem is very similar to the so-called “TRL valley of death” that was addressed in past Decadal surveys. This situation refers to the Technology Readiness Level (TRL) which ranges from 1-9 and grades the readiness for an instrument or technology to be included on a flight mission. At the low end, a 1 signifies nothing more than an idea for something that might work. At the high end, a 9 indicates something that is currently on an active flight mission. Historically, there has been small amounts of development money for working on ideas at a level of 1-3. These projects are similar in scale to normal research grants. Work in instruments in the range of 7-9 comes under actual mission budgets with significant levels of support to ensure mission success. The “valley” occurs at a level of 4-6 where the work needed to advance a concept is beyond the scope of the initial development program but the concept is still considered too risky for inclusion in a flight program.

Scientific studies using occultations are now in a similar situation to flight instrument development. Limited scope investigations are possible but will require many compromises to stay in the funding envelope of existing programs. Such compromises could entail fewer observing stations, highly selective regions for deploying stations, restrictions to events with very bright stars or large objects, and so on. A project such as one to answer the question: “How common are contact binaries in the cold-classical Kuiper Belt population?” is one that is not at all likely to be addressed by a mission nor can it be funded through the current research program structure.

The answer lies in an adjustment of the balance of the research portfolio maintained by NASA and NSF. Both agencies have good support for smaller research programs and both have good support for legacy activities such as flight missions or very large programs (eg., Rubin/LSST, ALMA, Gemini). Occasionally, there is support provided by NSF for intermediate level surveys. However, this level between typical scientific research grants and mission proposals is missing from the NASA portfolio and with the recent cut back in funding scope for Planetary Major Equipment (PME) the situation is even worse. Providing such support will clearly provide a means for the scientific community to help NASA reach its overarching agency goals more quickly and effectively. This timing on this is particularly important given that we now have the Gaia catalog and the upcoming LSST survey on the Rubin Observatory that will soon reap a windfall of scientific discoveries that will also provide a vastly increased set of occultation opportunities. With adequate support, occultation-based studies stand poised to provide a scientific contribution equal to any major flight mission or observatory development program at a fraction of the cost of either.