Astro2020 Science White Paper

Understanding Activity in Small Solar System Bodies

Thematic Areas: ☒ Planetary Systems ☐ Star and Planet Formation
☐Formation and Evolution of Compact Objects ☐ Cosmology and Fundamental Physics
☐Stars and Stellar Evolution ☐Resolved Stellar Populations and their Environments
☐Galaxy Evolution ☐Multi-Messenger Astronomy and Astrophysics

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Abstract (optional):

Gas and dust activity in small Solar System bodies is essential to understanding the clues that these objects hold concerning the conditions of the early Solar System and relevant formation mechanisms. However, many important questions remain about the mechanisms and conditions of activity, including outbursts. The list of bodies that show activity is expanding yearly and is increasingly diverse. We propose several research pathways to address this lack of knowledge and to make progress on understanding activity in small Solar System bodies that will assist in ascertaining relationships between these bodies, e.g., the proposed comet-asteroid continuum.

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Small bodies are believed to be the remnants - either fragments or survivors - of the swarm of planetesimals from which the planets formed. They are the leftover, primitive building blocks of the Solar System and offer clues to the chemical composition and conditions from which the planets formed some 4.6 billion years ago. By investigating the physical and chemical properties of asteroids, comets, Centaurs, and trans-Neptunian objects, one can characterize the conditions and processes of the Solar System's earliest epoch. This extends naturally also to some planetary satellites, which share, with small bodies and dwarf planets, similar properties and/or formation history and to studies of extra-solar systems. The scientific community has invested significant effort in past, ongoing, and future spacecraft missions and ground- and space-based observations in support of these goals. It has become increasingly evident that the differences between the small Solar System objects are much less sharply defined than previously believed so comparative studies of these objects are increasingly significant.

The important key to unlocking the secrets of these bodies is understanding their activity, the release of gas and dust to the surrounding environment that enables studies of their composition from ground- and space-based instruments. The list of bodies that show activity is expanding yearly and is increasingly diverse; including, short- and long-period comets in the inner solar system and at far (beyond Jupiter) heliocentric distances, active asteroids (including so-called Main Belt comets) at the far edge of the Main Belt, near-Sun bodies (e.g., sungrazers, Phaethon), Centaurs (e.g., Chiron, Echeclus, 166P/NEAT), Jupiter Trojans, and Kuiper Belt Objects. Occasionally transient events occur that suddenly increase activity (outbursts), characterized by timescale, duration, and magnitude, some by many orders of magnitude (e.g., Comet Holmes) while others are small enhancements of limited duration (e.g., Comet Hartley 2). Outbursts may include only gas (wet), only dust (dry), or both. Knowledge of the mechanisms that drive activity and outbursts is essential for tracing the origin of the materials released and possibly predicting outbursts to support observations and future spacecraft missions to small bodies.

Sublimation of volatiles, from surface, subsurface, and dust particles entrained in the gas flow, is essential for cometary activity. The specific volatile depends on heliocentric distance, dividing the planetary system into different sublimation regimes: H_2O (<2-3au, T_{subl}≈170K), CO_2 (Jupiter to Neptune, T_{subl}≈74), CO and CH_4 (trans-Neptunian), T_{subl}≈24 and 31, respectively). These molecules are the most abundant volatiles observed in comets. Compared to comet nuclei in the Kuiper Belt, like MU_{69} recently visited by New Horizons, where temperatures are low enough to preserve ices of CO_2, NH_3, and CH_3OH (but not N_2, O_2, CO, CH_4), Centaurs are found at distances where CO_2 (and NH_3, CH_3OH) can actively sublimate (but not water, of course).

A variety of outburst mechanisms have been proposed but none are conclusive. These include:

- Pressurized Obstructed Pores (POP) Model – blockage of near-surface pores by recondensation (sublimation from gas to solid) of volatiles as the surface cools either by diurnal or seasonal effects, resulting in increased gas pressure that can eventually rupture the surface (deAlmeida et al. 2016; related to Samarasinha 2001, Stevenson et al. 2014 and others).
- Coma Outburst Model by Avalanche (COMA) – mass wasting from sloped terrain, exposing fresh volatiles, which can lead to dry outbursts (Boice et al. 2002, Britt et al. 2004, deAlmeida et al. 2016, Steckloff and Samarasinha 2018).
- Exothermic phase change of amorphous to crystalline water ice (e.g., Patashnick et al. 1974, Yabushita and Hatta 1987). Amorphous water ice has never been directly detected in comets.
- Storage of hydrocarbons, especially methane, in the form of clathrates leading to explosive release (Whitney 1955, Gronkowski and Wesolowski 2016). Clathrates have never been directly detected in comets.
- Collisions with small, interplanetary asteroids or meteoroids (Sekanina 1974).
- Polymerization of hydrocarbons, especially HCN, leading to exothermic energy release (Rettig et al. 1992). Polymerized HCN has never been directly detected in comets.

In light of these uncertainties, detection of amorphous water ice, clathrates, and HCN polymers (all are possibly tens of meters below the surface) should be given top priority. *Why should we send a spacecraft hundreds of millions of kilometers to a comet and not go the next tens of meters in order to resolve these decades-old questions?*

Furthermore, connections of activity to surface features (active regions) and surface structures that would give us a window into the interior is not well established but is better known after progress of the Rosetta Mission to 67P/C-G (e.g., Vincent et al. 2015). Three-dimensional modeling of the mass and energy transport in a porous comet nucleus (see Huebner et al. 2006 for a summary), can potentially yield great insights into the interior, but results are not conclusive as too many parameters are poorly constrained.

More laboratory data are needed to support the investigation of activity including; studies of sublimation of cometary volatiles at very low temperatures; amorphous to crystalline water phase change under conditions appropriate to small Solar System bodies; studies of the formation, retention, and release of clathrates in cometary environments; and large-scale, laboratory simulations of cometary materials at low temperature appropriate to space environments [similar to the Kometensimulation (KOSI) experiments for Comet Halley but extended to lower temperatures, Huebner 1991].

Progress on understanding activity in small Solar System bodies will assist in ascertaining relationships between these bodies, e.g., connections between short- and long-Period comets – Trojans – Centaurs (transitional objects) – Kuiper Belt Objects and the proposed comet-asteroid continuum (instead of two separate groups as viewed historically, a spectrum of bodies with objects that bridge the gap between these groups).

References

1. Boice, D.C. et al. (2002) *EMP* **89**, 301.
2. Britt, D.T. et al. (2004) *Icarus* **167**, 45.
3. deAlmeida, A.A. et al. (2016) *ASR* **58**, 444.
4. Gronkowski, P. and Wesolowski, M. (2016) *EMP* **119**, 23.
5. Huebner, W.F. (1991) *GRL* **18**, 243.
6. Huebner, W.F. et al. (2006) Heat and gas Diffusion in Comet Nuclei, SR-004, June, 2006. ISBN 1608-280X. Published for The International Space Science Institute, Bern, Switzerland, by ESA Publications Division, Noordwijk, The Netherlands.
7. Patashnick, M. et al. (1974) *Nature* **250**, 313.
8. Rettig, T.W. et al. (1992) *Ap.J.* **398**, 293.
9. Samarasinha, N.H. et al. (2001) *Icarus* **154**, 540.
10. Sekanina, Z. (1974) in Proceedings of IAU Colloq. 22, held in Nice, France, 4–6 April 1972, ed. by C. Cristescu, W.J. Klepczynski, B. Milet (Academiei Republicii Socialiste, Romania, 1974), p. 307.
11. Steckloff, J. and Samarasinha, N.H. (2018) *Icarus* **312**, 172.
12. Stevenson, R. et al. (2014) *Ap.J.* **787**, 116.
13. Vincent, J.-B. et al. (2015) *Nature* **523**, 63.
14. Whitney, C. (1955) *Ap.J.* **122**, 190.
15. Yabushita, S. and Hatta, N. (1987) *EMP* **37**, 141.