ARE B-TYPE ASTEROIDS DORMANT COMETS? Joseph A. Nuth III[1] Natasha Johnson[2], Neyda Abreu[3] [1]Solar System Exploration Division, Code 690 NASA's Goddard Space Flight Center, Greenbelt MD 20771 USA (joseph.a.nuth@nasa.gov), [2]Astrochemistry Branch, Code 691, NASA-GSFC, Greenbelt MD 20771. [3]The Pennsylvania State University, DuBois, PA 15801,

Introduction: It has become increasingly clear that comets and asteroids may not be distinct object classes established at the beginning of the solar system, but may in fact be a continuum of objects ranging from dry planetesimals formed close to the Sun to water-rich bodies formed well beyond Jupiter's orbit [1]. In addition, since the dynamical lifetime of a comet in the inner solar system is on the order of 200,000 – 500,000 years while the mean active lifetime of such a comet is only about 20,000 years (or ~1000 perihelion passages), there should be at least an order of magnitude more "dead" or dormant comets than active ones.

Dual-classified comet/asteroid 107P/Comet Wilson-Harrington/Asteroid 4015 (1979VA) [2,3] and 2060 Chiron (95P/Chiron) are B-type asteroids as is the asteroid Phaeton (1983TB) that has been observed to be a source of orbital debris from a comet-like tail. Other dual-class objects include Comet 133P/Elst–Pizarro (7968 Elst–Pizarro) [4,5] a C-type asteroid, 60558 Echeclus (174P/Echeclus), a Centaur of unknown spectral type, and asteroid 118401 LINEAR (176P /LINEAR) [6,7], a "main-belt comet" of unknown spectral type. While some of these objects may (or may not) be rubble piles, turned inside out repeatedly by close passages near the earth and possibly other large bodies, there is still the possibility that some of these objects retain an icy component. This potential is enhanced if at least some Type B asteroids are actually "dead" (or dormant) comets rather than "traditional" asteroids formed in the inner Solar System.

Comets could become dormant by being covered with a highly insulating and very porous mineral layer formed via sublimation of mineral bearing ices [8]. It is also possible that comets stop producing a coma once their near-surface volatile content (H_2O, CO_2, etc.) reaches a threshold value where the vapor pressure of the subliming volatiles is too low to drive vapor through lightly filled regolith voids. As H_2O residence time increases, the potential for reaction with primitive amorphous silicates and with cosmic-ray-defect-laden silicate minerals increases. Therefore, while the silicate dust emitted by active comets may contain mostly anhydrous minerals, the fraction of hydrous silicates should increase as active comets evolve into inactivity until their orbit is perturbed into a smaller perihelion.

Meteorites from Comets: Although many meteorites contain low quantities of water, there are others such as the CI chondrite Orgueil that show extreme levels of hydration or that contain significant levels of volatile hydrocarbons as well as water of hydration and salts, such as ungrouped carbonaceous chondrite (CC) Tagish Lake [9–13]. Gounelle et al. [14] have suggested that these volatile-rich CCs originate from the outer solar system or even from comets. Scott et al. [15] have also suggested that CR, CO, and ungrouped CCs may have formed beyond the orbit of Jupiter based on a number of significant isotopic differences between these meteorites and non-CCs.

Both comets and CCs (particularly CIs, CMs, and CRs) contain organic material in a variety of forms, both soluble and insoluble, as well as aromatic and nonaromatic [16]. In CI and CM chondrites, insoluble organic material (IOM) comprises 2 wt% of the matrix [16,17]. This IOM in chondrites shares a number of similarities with refractory organic material in CP IDPs, which are probably of cometary origin, and organics analyzed as emanating directly from comets. Alexander [18] notes that the bulk composition of the IOM normalized to 100 carbon atoms is $C_{100}H_{70\text{-}79}N_{3\text{-}4}O_{11\text{-}21}S_{1\text{-}5}$, which is similar to the average composition of Comet Halley CHON particles measured by the PUMA mass spectrometer on Vega 1 [19] of $C_{100}H_{80}N_4O_{20}S_2$. Furthermore, both share similar enrichments in D/H and $^{15}N/^{14}N$. Although Sandford et al. [20] suggested an interstellar or protostellar origin based on these isotopic enrichments, Alexander [18] notes that these isotopic enrichments are indicative of formation at very cold temperatures and, although favoring a protostellar or interstellar origin, cannot rule out formation in the outer solar system. This carbonaceous material is also much more abundant in comets. Based on Mg/C ratios, solar C is 7 wt% in CC IOM but ~30% in comet Halley CHON particles. Sandford et al. [21] found that Wild 2 particles exhibit a greater range of composition, include an organic component poor in aromatics, and contain a more labile fraction. In this sense, cometary organics from active comets are more "primitive" compared with those in meteorites

OSIRIS-REx arrives at Bennu: Preliminary data obtained by the instruments on the OSIRIS-REx spacecraft on approach to Bennu (a B-Type asteroid) has revealed a remarkably water-rich regolith with a deep absorption feature at 2.7 microns as recorded by the OVIRS instrument [22]. The water-rich character of Bennu has also been demonstrated by spectra taken at longer wavelengths by the OTES instrument [23] where the global spectrum of Bennu appears to match that of the Orgueil meteorite, previously suggested by

Gounell et al [14] to be derived from a comet. In addition, studies of the crater size-frequency distribution on Bennu suggest that the surface is much older than previously expected [24]. While this preliminary data is interesting, much more data will be available as the mission progresses and returns a sample to earth.

Orbital evolution of material into the Near Earth Object population: The mechanisms for delivery of material to the Near Earth Object (NEO) population have been studied for some time and it has been shown that collisional activity in the Main Belt followed by resonant interactions is capable of delivering a steady supply of fresh material to the NEO population [25-27] though the size distribution of such material is not consistent with observations and might suggest that Yarkovsky thermal drag could play a dominant role in delivery of fresh material. The evolution of comets into asteroids [28, 29] has shown that potentially 6 (+/- 4) % of the NEO population could be derived from Jupiter Family Comets (JFC) and has identified a number of candidate asteroids that might have originated as JFCs based on their Tisserand parameter [30], a measure of the strength of the orbital interaction of the body with Jupiter. The contribution of Long Period Comets to the NEO population is currently unknown [29].

Why is this important? Water and organics are some of the most valuable commodities that can be mined in space and the identification of the spectral characteristics of dead or dormant comets that should be rich sources of such materials is important for future in space resource utilization planning. This knowledge will also contribute to our understanding of the relationship between comets and asteroids as established at the origin of the Solar System. Comparison of Bennu samples with those returned by the Hayabusa2 mission to C-Class asteroid Ryugu will provide valuable data on the evolution of primitive bodies while comparison to Stardust samples could shed light on the evolution of the mineral content of comets as they age.

References: [1] Nuth, J.A., McCoy, T., Johnson. N.M. & Abreu, in *Primitive Meteorites and Asteroids* (N. Abreu, ed.) (Elsevier Inc., 2018) pp.409-439. [2] Fernandez, Y.R., McFadden, L.A., Lisse, C.M., Helin, E.F., Chamberlin, A.B., 1997. Icarus 128, 114-126. [3] Ishiguro, M., Ham, J.-B., Tholen, D.J., Elliott, G.T., Micheli, M., et al.,2011.Ap.J. 726. doi: 10.1088/0004-637X/726/2/101 [4] Hsieh, H.H., Jewitt, D.C., Fernández, Y.R., 2004. Ap.J., 127, 2997-3017. [5] Hsieh, H.H.,Jewitt,D.C., Fernández,Y.R., 2009a.Ap.J. Lett.. 694, L111-L114. [6] Hsieh, H.H., Jewitt, D.C., Ishiguro, M., 2009b. Ap.J., 137, 157-168. [7] de Val-Borro, M., Rezac, L., Hartogh, P., Biver, N., Bockelée-Morvan, et al. 2012. A.&A.546. doi.org/10.1051/0004-6361/201220169. [8] Storrs, A.D., Fanale, F.P., Saunders, R.S., Stephens, J.B., 1988. Icarus 76, 493-512. [9] Brown, P.G., Hildebrand, A.R., Zolensky, M.E., Grady, M., et al., 2000. Science 290, 320-325. [10] Pearson, V.K., Sephton, M.A., Franchi, I.A., Gibson, J.M., Gilmour, I., 2006. MAPS 41, 1899-1918. [11] Alexander, C.M.O.'D., Bowden, R., Fogel, M.L., Howard, K.T., Herd, C.D.K., Nittler, L.R., 2012. Science 337 (6095), 721-723. [12] Alexander, C.M.O.'D., Howard, K.T., Bowden, R., Fogel, M.L., 2013. GCA 123, 244-260. [13] Gounelle, M., Zolensky, M.E., 2014.. Planetary and Space Science 49, 1769-1794. [14] Gounelle, M., Morbidelli, A., Bland, P.A., Spurný, P., Young, E., Sephton, M., 2008. In: Barucci, M.A., Boehnhardt, H., Cruikshank, D.P., Morbidelli, A., Dotson, R. (Eds.), **The Solar System Beyond Neptune**. U. Ariz. Press, Tucson, pp. 525-541. [15] Scott, E.R.D., Krot, A.N., Sanders, I., 2017. In 80th MetSoc.,Abstract#6395. [16] Glavin, D.P., Alexander, C.M.O.'D., Aponte, J.C., Dworkin, J.P., Elsila, J.E., Yabuta, H., 2018. In: Abreu, N.M. (Ed.), **Primitive Meteorites and Asteroids**. 2018, Elsevier. 205-271. [17] Alexander, C.M.O.'D., Cody, G.D., De Gregorio, B.T., Nittler, L.R., Stroud, R.M., 2017, Chemie der Erde 77, 227-256. [18] Alexander, C.M.O.'D., 2011. Proc. IAU Symp. 280, 288-301. [19] Kissel, J., Krueger, F.R., 1987. Nature 326, 755-760. [20] Sandford,S.A., Aléon, J., Alexander, C.M.O.'D., Araki, T., Bajt, S., et al., 2006. Science 314, 1720-1724. [21] Sandford, S.A., Nuevo, M., Milam, S.N., Cody, G.D., Kilcoyne, A.L.D., de Gregorio, B.T., Stroud, R.M., 2011. In: 74th MetSoc. Mtg., Abstr. #5162. [22] Simon, A. A., Reuter, D., et al., 2018, AGU Abstr. P33C-3838. [23] Hamilton, V. E., Christensen, P.R. et al., 2018 AGU Abstr. P22A-01. [24] Bierhaus, B., Barnouin, O. S., et al., 2018 AGU Abstr. P22A-09. [25] Bottke, W.F., Jedicke, R., Morbidelli, A., et al., Science 288, 2190-2194. [26] Morbidelli, A., Bottke, W.F., Froeschle, Ch. & Michel., P. in *Asteroids III* (W.F. Bottke et al., eds.) (Univ. Ariz. Press, Tucson, 2002) 409-422. [27] Granvik, M. Morbidelli, A., Jedicke, R., et al., 2018 Icarus 312 181-207 [28] Weissman, P.R., Bottke, W.F. & Levison, H.F. in *Asteroids III*, op.cit., 669-686. [29] Michel, P., 2008 EPSC Abstr 3 EPSC2008-A-00092. [30] Carusi, A. & Valsecchi, G. 1987 in Interplanetary Matter (Z. Ceplecha & P. Pecina, eds.) (Czech.Acad.Sci., Ondrejov) 21-28.