**D-TYPE ASTEROIDS: PRIMORDIAL ORGANIC RESERVOIRS, COMPOSITIONAL COUSINS, OR ORDINARY BLACK ROCKS?** G. M. Gartrelle[1], [1]University of North Dakota (gmgartr@gmail.com); P. S. Hardersen[2], [2]Planetary Science Institute (phardersen@psi.edu); M. R. M. Izawa[3], [3]Institute for Planetary Materials, Okayama University (matthew.izawa@gmail.com); M. C. Nowinski[4], [4]The Boeing Company mcnowinski@gmail.com

**Introduction:** D-type asteroids remain an intriguing mystery of asteroidal science. Their origin, dynamic evolution, and mineralogical makeup remain unknown. Due to their low albedos, they are difficult to detect and observe from Earth. No spacecraft has ever visited one. We have no confirmed D-type samples in the terrestrial meteorite collection. They may or may not be related to comets, Trans Neptunian Objects (TNO), irregular satellites of the outer planets, Kuiper Belt Objects (KBO), Interplanetary Dust Particles (IDP), or the recently discovered interstellar object (1I/2017 U1) Oumuamua. Many D-types may be virtually unchanged compositionally since formation and rich in primordial organics. They could have pure crystalline water-ice beneath their dark crusts, or they may be completely anhydrous. We just do not know.

**Research Focus & Methodology:** The purpose of this work is to understand how D-types differ spectrally in the near-infrared (NIR) at varying heliocentric distances. The effort began with a review of literature related to asteroidal physical characteristics, mineralogy, taxonomy, asteroid spectroscopy, analysis of asteroid spectra, compositional modeling of asteroidal surfaces, connections between asteroids and meteorites as related to D-types, and possible relationships between D-types and other small Solar System bodies. Our work also included construction of a synopsis of previous ground based NIR observations (~215) of D-types over four decades. A repository of spectral data from approximately half of these efforts has been collected and analyzed.

An observing program, begun in 2017, was tasked to use NIR spectroscopy from 0.7 to 2.5µm on D-type targets to identify surface minerals and determine if correlations exist between physical characteristics and location. To date, spectra from twenty-eight targets have been acquired from NASA/IRTF. Characterization of slope data as well as correlations to physical and observational parameters are ongoing. Laboratory comparisons of our obtained D-type spectra to known meteorite types are underway to establish possible connection between D-types and terrestrial samples. Mathematical compositional modelling will be applied to estimate possible surface mineralogical composition. Finally, a model of spectral gradient by heliocentric distance will be developed and interpreted. While several theories regarding the relationship between spectral variations of D-types and geophysical properties have been submitted over the years, none have been conclusively validated. Our investigation will test these theories and develop new constraints about the geochemical state of D-types and detected variations.

**D-Type Asteroids:** Taxonomic definitions of D-types are consistent across the major asteroid classification schemes of Tholen [1], Bus & Binzel [2], DeMeo et al [3] and Carvano et al [4]. D-types are characterized by low albedos and steep, red spectral slopes. D-type spectra do not exhibit an absorption feature at 1µm [4], although some spectra exhibit a slight kink at 1.5µm [3]. D-types comprise ~2% of the mass of the asteroid population [5]. Modeling estimates suggest D-types dominate the region beyond 3.5AU, with a large cluster at the Jupiter Trojan points, and another between ~3.0 - 3.2AU [4]. It is theorized several hundred D-types exist in the middle and inner asteroid belt [4, 6], with several dozen in near-Earth orbits [7, 8].

*Spectral properties.* Spectroscopic surveys of D-types confirm steep red spectra with virtually no discernable absorption features [6, 9-20]. Spectral reddening in D-type asteroids appears to increase with increasing heliocentric distance [4, 11, 19, 21, 22]; extends through the wavelength range [10]; may correlate directly to formation location [11]; and may be inversely correlated to material strength [23]. Spectral reddening of D-types may be the result of contamination of water-ice by carbon and/or tholin [24-26] or the result of Titan tholin processing of silicates [10] or some other darkening agent.

Although D-types appear to be spectrally featureless in the infrared, visible spectrum observations as well as modelling have revealed surprising diversity within the class. This includes the detection of rings comprised of water-ice [27], cometary activity [28], binary systems in the Jovian Trojans [29], and collisional families [13, 30, 31].

*Mineralogical Hypotheses.* Multiple studies [8, 10, 20, 32, 33] were unable to find direct spectral evidence of silicates on D-type surfaces. The spectra produced so far in this work are also featureless. If silicates are present on the surface, they could be impact deposits [21], depleted in iron [34], or space weathered [11]. Early work implied surface material on D-types may be similar to CM2 chondrites [16] or certain iron meteorites [35], but only three specific meteorite samples, WIS 91600 [36], Tagish Lake (TLM) [37], and MET 00432 [38], are suggested to originate from D-type parent bodies. Samples from TLM have spectral similarities to D-types in multiple regions of the asteroid belt [37, 39, 40]. Our initial results have produced several possible parent candidate suspects for Tagish Lake and WIS 91600.

*Possible Connections to Other Bodies.* The appearance of dark, red spectral material in multiple classes of small bodies implies some unknown geochemical and/or evolutionary connection(s) may exist between them. Multiple workers have discerned similarities between D-types and Jovian Trojans in formation location, albedo, material strength, and spectral reddening correlated with increasing distance, as well as decreasing diameter [11, 14, 41, 42]. Similar comparisons have been drawn between D-types and comets regarding spectral [14, 21] as well as dynamic properties [43-45], formation location [46], and activity [28]. The dark material covering D-type surfaces spectrally resembles material observed on smaller satellites of Jupiter and Saturn as well as TNO's, KBO's, and IDP's [47-53]. Oumuamua, the recently discovered interstellar object, displayed spectral characteristics similar to D-types [54] and other classes of small bodies spectrally linked to D-types [55-59].

**Potential Significance of This Research:** If a relationship exists between spectral characteristics of D-type asteroids and their current heliocentric locations, it may provide clues to understanding how and where D-types formed along with their compositional and dynamical relationship to other Solar System objects. The absence of such a relationship may also be significant.

If mineral absorption features are not revealed from our obtained spectra, mathematical modeling of a hypothetical D-type surface composition is still possible. The discovery of mineral absorption features in D-type spectra and/or the development of a viable compositional model of surface material may better explain the paucity of D-type meteorite samples on Earth and establish spectral links to potential parent bodies for the few analog D-type samples on hand. Successful results from this study should also be useful input for the Lucy mission D-type flybys [60].

**References:**

[1] D.J. Tholen, Planetary Sciences, University of Arizona, Tucson, AZ, 1984. [2] S.J. Bus, R.P. Binzel, Icarus, 158 (2002) 146-177. [3] F.E. DeMeo, et al., Icarus, 202 (2009) 160-180. [4] J.M. Carvano, et al., Astronomy & Astrophysics, 510 (2010) A43. [5] F.E. DeMeo, B. Carry, Icarus, 226 (2013) 723-741. [6] F.E. DeMeo, et al., Icarus, 229 (2014) 392-399. [7] R.P. Binzel, et al., Asteroids, Comets, Meteors Conference 2014, Helsinki, FL, 2014. [8] M.A. Barucci, et al., Monthly Notices of the Royal Astronomical Society, 476 (2018) 4481-4487. [9] M. Dahlgren, et al., Astronomy & Astrophysics, 323 (1997) 606-619. [10] J.P. Emery, R.H. Brown, Icarus, 164 (2003) 104-121. [11] J.P. Emery, et al., Astronomical Journal, 141 (2011) 1-18. Article ID: 25. [12] A. Fitzsimmons, et al., Asteroids, Comets, Meteors Conference 1991, Flagstaff, AZ, 1991. [13] S. Fornasier, et al., Icarus, 172 (2004) 221-232.
[14] D. Jewitt, J.X. Luu, Astronomical Journal, 100 (1990) 933-944. [15] J.X. Luu, et al., Icarus, 109 (1994) 133-144.
[16] F. Vilas, M.J. Gaffey, Science, 246 (1989) 790-792. [17] F. Vilas, et al., Icarus, 105 (1993) 67-78. [18] F. Vilas, L.A. McFadden, Icarus, 100 (1992) 85-94. [19] F. Vilas, B.A. Smith, Icarus, 64 (1985) 503-516. [20] M.N. DePrá, et al., Icarus, 311 (2018) 35-51. [21] A. Fitzsimmons, et al., Astronomy & Astrophysics, 282 (1994) 634-642. [22] C.-I. Lagerkvist, et al., Monthly Notes of the Royal Astronomical Society, 260 (1993) 679-680. [23] C.-I. Lagerkvist, et al., Astronomy & Astrophysics, 423 (2005) 349-354. [24] C.M. Dalle Ore, et al., Icarus, 252 (2015) 311-326. [25] F. Poulet, et al., Icarus, 160 (2002) 313-324. [26] A. Guilbert-Lepoutre, et al., Astronomy & Astrophysics, 501 (2009) 777-784. [27] F. Braga-Ribas, et al., Nature, 508 (2014) 72-75. [28] M. Mommert, et al., The Astrophysical Journal, 781 (2014) 25.
[29] R.D. Stephens, et al., Minor Planet Bulletin, 45 (2018) 341-342. [30] C. Beaugé, F. Roig, Icarus, 153 (2001) 391-415. [31] J. Rozehnal, et al., Monthly Notes of the Royal Astronomical Society, 46 (2015) 2319-2332. [32] D.P. Cruikshank, et al., Icarus, 153 (2001) 348-360. [33] L.A. Lebofsky, Reports of Planetary Geology and Geophysics Program, Lunar and Planetary Lab, National Aeronautics and Space Administration, Tucson, AZ, 1991, pp. 271-273. [34] B. Yang, D. Jewitt, Astronomical Journal, 141 (2011) 1-8. Article ID: 95. [35] J.M. Carvano, et al., Icarus, 161 (2003) 356-382. [36] T. Hiroi, et al., 36th Lunar and Planetary Science Conference, Houston, TX, 2005. [37] T. Hiroi, et al., Science, 293 (2001) 2234-2236. [38] T. Nakamura, et al., Meteoritics & Planetary Science, 48 (2013) A258. [39] M.R.M. Izawa, et al., Icarus, 254 (2015) 324-332. [40] P. Vernazza, et al., Icarus, 225 (2013) 517-525. [41] T. Grav, et al., The Astrophysical Journal, 759 (2012) 1-10. [42] F. Roig, et al., Astronomy & Astrophysics, 483 (2013) 911-931. [43] W.F. Bottke Jr, et al., Icarus, 156 (2002) 399-433. [44] Y.R. Fernández, et al., The Astrophysical Journal Letters, 553 (2001) L197. [45] Y.R. Fernández, et al., The Astronomical Journal, 130 (2005) 308. [46] R.P. Binzel, et al., The near-Earth object population: Connections to comets, Main-Belt asteroids, and meteorites, in: P. Michel, et al. (Eds.) Asteroids IV, The University of Arizona Press, Tucson, AZ, 2015, pp. 243-256. [47] J.F. Bell, et al., Icarus, 61 (1985) 192-207. [48] J.F. Bell, et al., Lunar and Planetary Science, XV (1984) 46-47. [49] R.H. Brown, et al., Science, 280 (1998) 1430-1432. [50] B.J. Buratti, et al., Icarus, 175 (2005) 490-495. [51] B.J. Buratti, J.A. Mosher, Icarus, 115 (1995) 219-227. [52] F. Vilas, et al., Icarus, 180 (2006) 453-463. [53] P. Vernazza, et al., The Astrophysical Journal, 806 (2015) 204. [54] K.J. Meech, et al., Nature, 552 (2017) 378. [55] A. Fitzsimmons, et al., Nature Astronomy (In Press), 0 (2018) 0. [56] D. Jewitt, et al., The Astrophysical Journal Letters, 850 (2017) L36. [57] J. Masiero, Astrophysical Journal (In Press), 0 (2017) 0. [58] Y. Quan-Zhi, et al., The Astrophysical Journal Letters, 851 (2017) L5. [59] D.E. Trilling, et al., The Astronomical Journal, 156 (2018) 261. [60] H.F. Levison, et al., 47th Lunar and Planetary Science Conference, Houston, TX, 2016.