REVISITING THE RELATIONSHIP BETWEEN NEAR-EARTH ASTEROID RADAR PROPERTIES AND TAXONOMIC CLASS. B. Aponte-Hernandez[1], E. G. Rivera-Valentín[1], P. A. Taylor[1]; [1]Lunar and Planetary Institute, USRA, Houston, TX 77058 (hernandez@lpi.usra.edu).

Introduction: Radar is a powerful tool for constraining the near-surface, wavelength-scale properties of near-Earth asteroids (NEAs) through the measurement of their scattering properties. Indeed, previous work indicated that a correlation exists between radar-derived properties and some visible-infrared taxonomic classes of NEAs [1]. Such a relationship may indicate distinct, near-surface material properties (e.g., dielectric properties, density) per taxonomic class, different near-surface evolutions, as well as other factors such as the geometric properties of the near-surface scatterers [1,2]. Here, we revisit this analysis in light of new radar observations of NEAs from the Arecibo Observatory in Puerto Rico through 2017, prior to Hurricane Maria, which significantly impacted the antenna gain at S band. We specifically address if radar-derived properties can be used as a diagnostic tool for taxonomic class, thereby resolving ambiguous classifications such as the X complex.

Methods: Over 650 NEAs were observed at Arecibo from 2008 to 2017. For each of these objects, disk-integrated radar properties are derived using radar backscatter from continuous wave (CW) experiments. During a typical CW radar observation of an NEA using the Arecibo Observatory S-band (12.6 cm) planetary radar, monochromatic, unmodulated, circularly polarized light is emitted. Because targets are not perfect reflectors and typically have surface irregularities on the order of the radar wavelength, the signal can undergo multiple scatterings, thereby changing its polarization. Echoes in both the opposite circular and same circular polarization as transmitted are received and power spectra per polarization are produced, leading to measurements of asteroid radar properties (e.g., circular polarization ratio (μ_c) and radar albedo) [3]. For NEAs with more than one observation, the weighted average of these values was used.

Of the 650 NEA Arecibo radar targets, 299 have compositional information as derived through their visible-infrared Tholen and Bus & Binzel taxonomy [1,4-13]. For the purposes of this study, we focus on S-, C-, M-, P-, V-, and E-type asteroids, as well as the ambiguous taxonomic group, the X types, which may be either M, P, or E types according to the Tholen classification. For our statistical analysis, the dataset is further restricted to objects with unambiguous taxonomy (i.e., NEAs consistently classified as the same taxonomy by multiple observers or with at least one observation). These filters resulted in a total of 167 asteroids for our analysis.

Results: Following [1], in Fig. 1, we plot radar circular polarization ratio as a function of absolute magnitude for our filtered dataset with colors representing visible-infrared taxonomic class. To resolve distinct data clusters with respect to μ_c, we conducted modality tests. First, agnostic to taxonomy, we apply an unsupervised, k-means clustering algorithm to μ_c and find three clusters with centers around μ_c = 0.88, 0.39, and 0.21. All E-type asteroids fall within the high-polarization cluster; however, this cluster also includes an S-type asteroid and three V-type asteroids. Furthermore, prediction limits of a least squares fitting to Fig. 1, indicate that to 95% confidence, NEAs with μ_c > 0.7 do not follow the general trend observed in Fig.1.

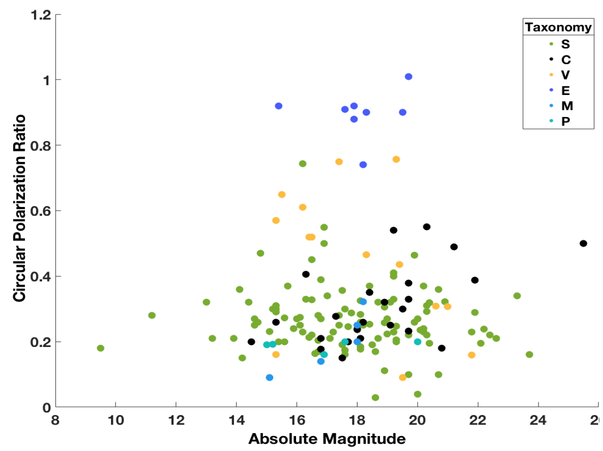

Figure 1: Circular polarization ratio as a function of absolute magnitude for the filtered dataset of near-Earth asteroids. Asteroid taxonomy is represented by the symbol color for S, C, V, E, M, and P types.

The average ($\bar{\mu}_c$), standard deviation (σ), median, maximum, and minimum circular polarization ratio per taxonomic class along with the total number of asteroids studied are shown in Table 1. Using a z-test, $\bar{\mu}_c$ values for the studied taxonomies were compared to test if these populations are distinguishable from each other and therefore associated with a typical circular polarization ratio. To 99% confidence, E-type asteroids are uniquely distinguishable from all other taxonomies. Due to their large spread, V-type asteroids are indistinguishable from C types, but distinguishable from all other taxonomies. C-type asteroids are only distinguishable from E and P types. M-type asteroids are only distinguishable from E and V types.

Table 1: Summary of near-Earth asteroid circular polarization ratio among the studied taxonomies.

Class	$\overline{\mu}_c$	σ	Median	Max	Min	N
E	0.90	0.07	0.90	1.01	0.74	8
V	0.45	0.22	0.49	0.76	0.09	14
C	0.31	0.12	0.27	0.55	0.15	24
S	0.28	0.10	0.26	0.74	0.03	110
M	0.20	0.09	0.20	0.32	0.09	5
P	0.18	0.02	0.19	0.20	0.16	6

The distinguishability between some taxonomic classes suggests that circular polarization ratio is associated with these compositional groups with a high degree of confidence. Within 2-σ E-type asteroids can be characterized by $\mu_c > 0.75$; again, providing confidence that μ_c can be used as a diagnostic tool for E types. Although polarization cannot be used as diagnostic for other taxonomies, these can be generally, at the 1-σ level, grouped into three clusters: M and P types are typically characterized by $\mu_c < 0.3$, S- and C-type by $0.2 < \mu_c < 0.4$, and V types by $0.4 < \mu_c < 0.7$.

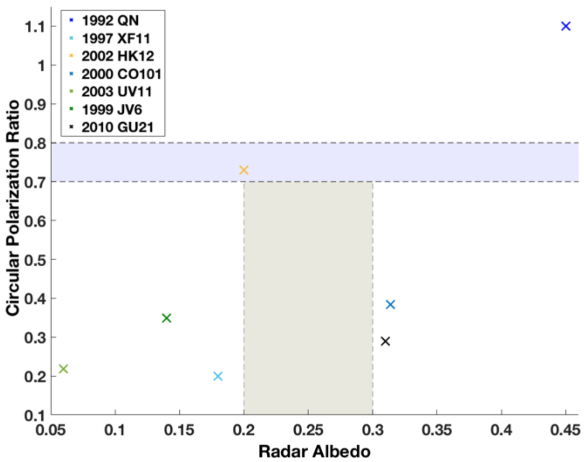

Figure 2: The radar albedo and circular polarization of X-type asteroids in our study with their names noted by color. The shaded regions, within $0.7 < \mu_c < 0.8$ and between 0.2 and 0.3 for radar albedo, represent ambiguous zones for taxonomic identification.

Discussion: Our results indicate that circular polarization ratio can be used as a diagnostic tool to identify E-type asteroids to a high degree of confidence. Furthermore, due to their metallic nature, M-type asteroids typically have high radar albedo [14]. This allows us to resolve ambiguous taxonomic detections. For example, X-type asteroids are an ambiguous group of NEAs with similar spectra but different compositions consisting of E-, M-, and P-type asteroids. Therefore, radar-derived NEA properties can be used to resolve this taxonomic class, especially without an estimate of the visible albedo either from a radar size or from near-IR spectra. In Fig. 2, we plot X-type asteroids as a function of these two radar-derived properties. We can confidently predict that 1992 QN is an E-type asteroid, 2000 CO101 and 2010 GU21 are M-type asteroids, and that 2003 UV11, 1999 JV6, and 1997 XF11 are P types. Additionally, 2002 HK12 is probably an E type, although it is in the ambiguous zone; however, this zone is only ambiguous with respect to V-type asteroids.

Conclusions: Using our base data set of M, P, S, C, V, and E types along with radar-derived properties up through 2017, our statistical analysis indicates that to a high degree of confidence the circular polarization ratio can be used as a diagnostic tool to identify E-type asteroids. Because the X complex is comprised of M, P, and E types, radar properties, including radar albedo, which is high for M-type asteroids, can be used to resolve into its subgroups of E, M, and P types.

Although the other taxonomic classes cannot be confidently identified by their radar properties, results indicate they can be grouped into three clusters characterized by circular polarization ratio; therefore, taxonomic classes are associated with this radar property. Such a relationship may indicate distinct, near-surface material properties (e.g., dielectric properties, geometric properties of the near-surface scatterers), which may be potentially derived from differences in their near-surface evolutions (e.g., through differences in formation ages or collisional histories) [1,2].

The derived relationships, though, are significant only over the studied parameter space (i.e., for the range of asteroid sizes studied). Additionally, the dataset may be biased by sample size and biases in observations. Further characterization of these relationships requires modeling efforts (e.g., [2]) and laboratory work in radar scattering processes.

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