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The Potentially Hazardous Binary and Triple Near-Earth Asteroids Observed with the Arecibo Planetary Radar System

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Potentially hazardous asteroids (PHAs) are near-Earth objects (NEOs) that are larger than 140 meters and that can come closer to Earth than 0.05 au (~20 Lunar Distances). Radar can help to discover or confirm asteroid satellites, and delay-Doppler images provide a unique way to characterize multiple asteroid systems, allowing us to extract information about the physical and dynamical properties of the system. The population of binary and triple near-Earth asteroids (NEAs) observed with the Arecibo's S-band planetary radar system (2.38 GHz, 12.6 cm) includes 58 objects, which represent approximately 7% of a total of 867 NEAs observed. Among these NEAs, 345 are classified as PHAs, 42 of them are binary/triple systems, which is about 12% of the PHAs observed at Arecibo. Table 1 shows the total numbers of binary, including equal mass binaries, and triple NEAs.

Table 1: Binary and triple NEAs observed with the Arecibo's planetary radar system.

Binary/Triple	58
Binary	54
Triple	4
Equal mass binary	4
PHA	42

The binary and triple population observed at Arecibo

The binary PHA observed with Arecibo's radar with the lowest minimum orbit intersection distance (MOID), which is minimum separation between the osculating ellipses, was 2020 BX12 [1], observed on February 4th and 5th, 2020, with a MOID of 0.0024 au (see Zambrano-Marin et al. abstract); followed by 164121 (2003 YT1) [2] and 143649 (2003 QQ47) [3], with a MOID of 0.0026 au and 0.0038 au, respectively. Three out of four triple near-Earth asteroid systems observed at Arecibo are classified as PHAs: 3122 Florence, 136617 (1994CC) [4], and 348400 (2005JF21). In addition, also three out of four equal mass binary systems observed at Arecibo are PHAs: 69230 Hermes [5], 1994CJ1 [6], and 2017 YE5 [7]. The NEA system with the lowest upcoming close approach to Earth is 164121 (2003 YT1), passing at a distance of 0.01133 au (4.4 Lunar Distances) on April 29th 2073. The system with the next known approach within 0.05 au is 488453 (1994 XD), which will fly by Earth at a distance of 0.02 au (~8 Lunar Distances) on June 12th 2023.

Figure one shows the rotation period and absolute magnitude for the multiple NEA systems observed at Arecibo, with the PHAs marked in red.

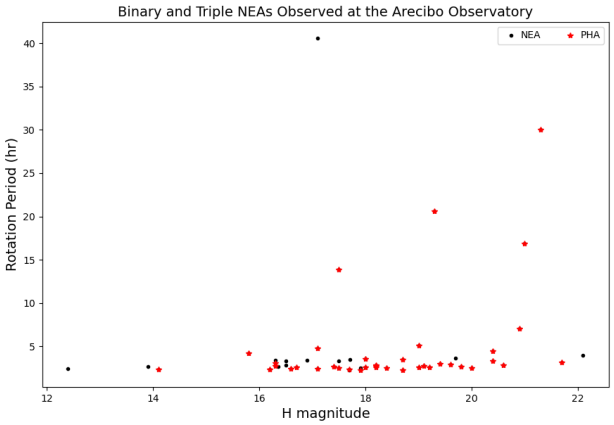

Figure 1: Rotation period and H for binary/triple NEAs observed at Arecibo.

Table 2 shows the dynamical properties for all binary and triple PHAs observed at Arecibo. Highlighted in magenta are the objects with the highest delay-Doppler resolution data, which are more suitable for 3D shape reconstruction. Marked in red are the triple PHAs, and in yellow are the equal mass binaries, where the center of mass is halfway between the two components.

Table 2: Binary and triple (in red) PHAs observed at Arecibo.

ASTEROID	MOID (AU)	Close ap. <0.05 (AU)	P (hours)	Close ap. Date	a(AU)	e	i(deg)	H (mag)	Q(AU)	q(AU)	Radar obs. YY
2020BX12	0.001295	0.0445	2.8	2101-Jan-31	1.599	0.527	40.1	20.6	2.442	0.757	2020
164121 2003YT1	0.003093	0.01133	2.343	2073-Apr-29	1.11	0.292	44.1	16.2	1.434	0.785	2004
143649 2003QQ47	0.003799	NA	2.6446	NA	1.085	0.187	62.1	17.4	1.288	0.882	2021
69230 Hermes	0.004403	0.0282	13.894	2040-Apr-25	1.654	0.624	6.1	17.5	2.686	0.622	2003
2003SS84	0.005106	0.04602	NA	2054-Oct-04	1.932	0.572	5.5	21.7	3.037	0.827	2003
461852 2006GY2	0.007576	0.43341	2.25	2039-Apr-21	1.853	0.494	30.6	18.7	2.768	0.938	2006
399774 2005NB7	0.008368	0.47649	3.4882	2043-May-29	2.042	0.516	12.7	18.7	3.096	0.988	2008
311066 2004DC	0.008874	0.1901	2.5709	2029-May-13	1.634	0.4	19.4	18	2.288	0.981	2006
162000 1990OS	0.008999	0.02038	2.536	2053-Nov-16	1.68	0.463	1.1	20	2.458	0.902	2003
357439 2004BL86	0.00943	0.02388	2.6205	2096-Jan-25	1.502	0.403	23.7	19	2.107	0.896	2015
494658 2000UG11	0.010184	0.01994	4.44	2142-Nov-12	1.934	0.573	8.9	20.4	3.042	0.826	2000
374851 2006VV2	0.010223	0.36507	2.425	2055-Apr-20	2.388	0.602	23.6	16.6	3.826	0.949	2007
363027 1998ST27	0.010293	0.0238	3	2024-Oct-12	0.819	0.53	21	19.4	1.253	0.385	2001
2018EB	0.010421	0.03364	3.16	2059-Apr-04	1.017	0.012	29.4	21.7	1.029	1.005	2018
450894 2008BT18	0.011056	0.18701	2.5702	2051-Jul-31	2.222	0.598	8.1	18.2	3.551	0.894	2008
66391 1999KW4	0.013376	0.01553	2.7645	2036-May-25	0.642	0.688	38.9	16.3	1.084	0.2	2001
185851 2000DP107	0.015048	0.04239	2.7754	2067-Sep-20	1.365	0.377	8.7	18.2	1.88	0.85	2000
226514 2003UX34	0.015114	0.04355	NA	2149-Jan-05	1.095	0.616	2.6	20	1.77	0.421	2017
136617 1994CC	0.015924	0.01702	2.3886	2074-Jun-11	1.638	0.417	4.7	17.7	2.321	0.955	2009
2005YQ96	0.017767	0.03731	NA	2040-Jan-03	0.744	0.333	22.2	20.4	0.992	0.496	2014
385186 1994AW1	0.019498	NA	2.5193	NA	1.105	0.075	24.1	17.5	1.188	1.105	2015
488453 1994XD	0.020118	0.02114	2.7365	2023-Jun-12	2.356	0.73	4.3	19.1	4.076	0.637	2005
363599 2004FG11	0.020554	0.01815	7.021	2134-Nov-25	1.589	0.724	3.1	20.9	2.739	0.438	2012
2017YE5	0.021511	NA	20.6	NA	2.82	0.71	6.2	19.3	4.822	0.817	2018
85938 1999DJ4	0.021758	NA	2.5141	NA	1.851	0.483	9.2	18.4	2.745	0.957	2004
363067 2000CO101	0.022657	0.02522	5.12	2057-Sep-16	1.075	0.09	15.3	19	1.172	0.979	2009
1862 Apollo	0.025812	0.03529	3.065	2046-Nov-13	1.471	0.56	6.4	16.3	2.295	0.647	2005
35107 1991VH	0.025992	0.0445	2.6236	2065-Aug-06	1.136	0.144	13.9	16.7	1.3	0.973	2008
2014WZ120	0.027745	0.04919	3.361	2149-Nov-28	2.354	0.571	20.9	20.4	3.62	0.8	2014
175706 1996FG3	0.028302	0.03076	3.5942	2166-Nov-27	1.054	0.35	2	18	1.423	0.685	2011
2016AZ8	0.029003	0.03286	16.897	2151-Jan-10	1.32	0.355	5.6	21	1.79	0.852	2019
2002KK8	0.029796	NA	NA	NA	1.967	0.469	24.6	20.5	2.889	1.045	2002
2002BM26	0.031361	NA	2.7	NA	1.832	0.444	16.2	19.8	2.645	1.019	2002
153958 2002AM31	0.031671	0.03406	2.8174	2032-Jul-29	1.705	0.452	4.6	18.2	2.475	0.935	2012
1994CJ1	0.031783	NA	30	NA	1.489	0.325	2.3	21.3	1.973	1.005	2014
285263 1998QE2	0.032949	0.49027	4.749	2028-Jul-12	2.421	0.571	12.9	17.1	3.805	1.039	2013
2013WT44	0.036429	0.02033	2.8849	2133-Mar-23	2.259	0.568	12.2	19.6	3.542	0.975	2014
65803 Didymos	0.040448	0.04965	2.2593	2062-Oct-20	1.642	0.383	3.4	17.9	2.275	1.013	2003
3122 Florence	0.043366	0.04996	2.3581	2057-Sep-02	1.768	0.423	22.2	14.1	2.516	1.02	2017
481532 2007LE	0.045633	NA	2.603	NA	1.839	0.517	29.5	19.2	2.79	0.889	2012
348400 2005JF21	0.046433	NA	2.4149	NA	2.224	0.535	10.9	17.1	3.415	1.034	2015
138095 2000DK79	0.049978	0.04775	4.243	2103-Nov-07	1.777	0.414	60.7	15.8	2.513	1.04	2013

Radar detection of an asteroid satellite in radar images can provide information such as the separation distance between two components and mutual orbital period, and also makes it possible to estimate the mass of the system and density. This information is valuable to support our understanding of asteroid formation and evolution, as well as planning for small bodies space missions. An example of mission to a binary asteroid system supported by Arecibo radar observations is NASA's Double Asteroid Redirection Test (DART) to the 65803 Didymos system, the first planetary defense test mission.

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References:

[1] Zambrano Marin, L. *et al.*, 2021, October. 2020 BX12: The Last Binary Asteroid Discovered by Arecibo Observatory. In AAS/Division for Planetary Sciences Meeting Abstracts (Vol. 53, No. 7, pp. 207-01).

[2] Nolan, M.C., *et al.*, 2004, November. Radar images of binary Asteroid 2003 YT1. In AAS/Division for Planetary Sciences Meeting Abstracts# 36 (Vol. 36, pp. 28-08).

[3] Brozovic, M., *et al.*, 2022, December. Goldstone radar observations of ten binaries and one triple NEA system in 2021-2022. In AAS/Division for Planetary Sciences Meeting Abstracts (Vol. 54, No. 8, pp. 514-02).

[4] Brozović, M., *et al.*, 2011. Radar and optical observations and physical modeling of triple near-Earth Asteroid (136617) 1994 CC. Icarus, 216(1), pp.241-256.

[5] Rivkin, A.S., *et al.*, 2004. Infrared spectroscopic observations of 69230 Hermes (1937 UB): Possible unweathered endmember among ordinary chondrite analogs. Icarus, 172(2), pp.408-414.

[6] Taylor, P.A., *et al.*,2014, November. The smallest binary asteroid? The discovery of equal-mass binary 1994 CJ1. In AAS/Division for Planetary Sciences Meeting Abstracts# 46 (Vol. 46, pp. 409-03).
[7] Taylor, P.A., *et al.*, 2018, October. Radar and optical observations of equal-mass binary near-earth asteroid 2017 ye5. In AAS/Division for Planetary Sciences Meeting Abstracts# 50 (Vol. 50, pp. 508-07).
[8] Rivkin, A.S. and Cheng, A.F., 2023. Planetary defense with the Double Asteroid Redirection Test (DART) mission and prospects. nature communications, 14(1), p.1003.