Capabilities of Past, Present, and Future Radar Systems for Observations of Near-Earth Objects

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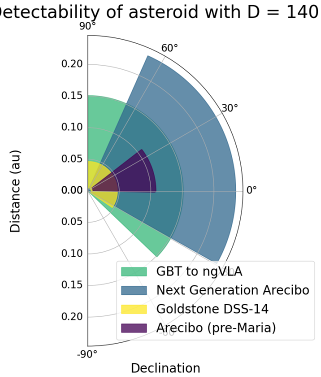
Introduction

Ground-based radar systems have unique capabilities for physical and dynamical characterization of near-Earth objects (NEOs – asteroids and comets). Radar astrometry enables fast and accurate determination of an NEO's orbital parameters and future trajectory. Radar is also very useful for physical characterization of NEOs, providing information on size, shape, surface properties, rotation state, and binarity, which aids planning of potential impact mitigation missions [1].

Building upon the work of Naidu et al. 2016 [2], Roshi et al. 2021 [3], and Venditti et al. 2022 [4], we investigate how many near-Earth asteroids (NEAs) and potentially hazardous asteroids (PHAs) could be detected with past, present, and potential future planetary radar systems. We consider radar transmissions from Arecibo Observatory, Goldstone Deep Space Communications Complex DSS-14 [2], and two radar facility concepts that have been proposed for the future: the Next Generation Arecibo Telescope (NGAT, modified from [3]) and the Green Bank Telescope (GBT) transmitting [5] to the Next-Generation Very Large Array (ngVLA) [6].

Facility	Transmitter frequency (GHz)	Transmitter power (MW)	Transmitter gain	Maximum zenith angle	Receiver sensitivity (m^2/K)
Goldstone DSS-14	8.56	0.45	74.0 dB	70°	140
Arecibo	2.38	0.90	73.4 dB	20°	1150
NGAT	5.00	2.00	82.7 dB	48°	1900
GBT to ngVLA	13.70	0.50	81.4 dB	78°	2050

Detectability of asteroid with D = 140 m



Counting potential radar detections

We used the Minor Planet Center's database of NEA orbital elements [7] to calculate all NEAs' positions at one-day intervals during the one-year period from 2022 March 1 through 2023 February 28. For each NEA and each radar facility, we calculated the NEA's signal-to-noise ratio (SNR) for hypothetical radar observations [8], during the dates at which the NEA would appear within the facility's range of observable declinations.

The MPC database lists every known NEA's orbital elements and absolute magnitude. For radar SNR calculations, we converted that absolute magnitude to a diameter and a radar cross section by assuming an optical albedo of 0.18 and a radar albedo of 0.10.

On a given date, we define an NEA to be detectable if its SNR after 30 minutes of observations would be at least 5. We use 30 minutes based on past experience, since radar observers rarely would spend more than 30 minutes trying to observe an object if there is no clear signal. In such cases, we normally would move on after about 30 minutes and try to observe another object instead.

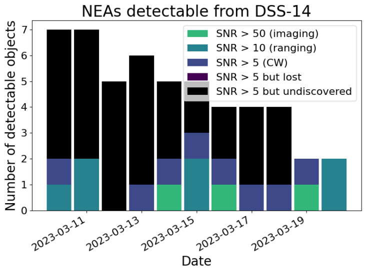
However, some potential detections (theoretically with sufficient SNR) had to be filtered out. In many cases, an NEA was only observed for a few days or a few weeks, at the time of its discovery. Without additional observations during later apparitions, such NEAs are effectively lost.

We also had to filter out objects that were only detectable (by radar) before they were actually discovered. For example, an object that was discovered in February could not have been observed with radar in January, no matter how close to Earth it may have been.

We kept track of lost and not-yet-discovered objects when doing the calculations, and they are shown in some figures for comparison purposes, but such objects are not counted as potential detections.

We also grouped the simulated detections based on their estimated SNR. SNR > 50 is bright enough to get well-resolved delay-Doppler images of a target. 10 < SNR < 50 is enough for a range measurement but not good images. 5 < SNR < 10 is a weak detection in which the target could be resolved only in Doppler frequency (called continuous-wave or CW observations).

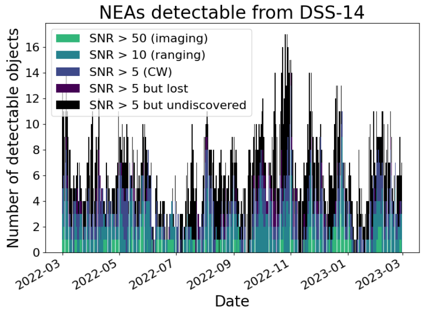
NEAs detectable from DSS-14



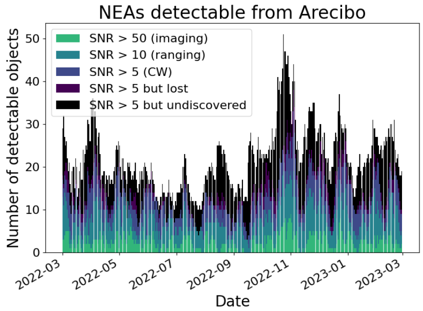
Above: Counts of NEAs that could have been detected by DSS-14 on each of 11 days in March 2023. On the first date (March 10), there was one NEA bright enough for ranging, one more NEA that was only bright enough for CW, and five others that would have been detectable but had not yet been discovered. On March 11, there were two known NEAs that were bright enough for ranging.

Below: Similar plots for DSS-14 and for Arecibo, covering 12 months

NEAs detectable from DSS-14

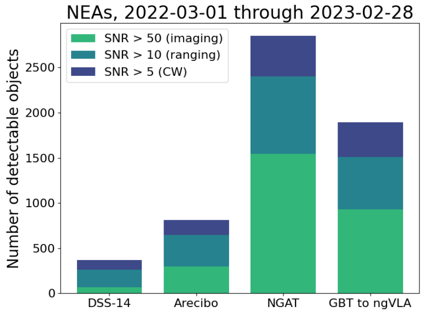


NEAs detectable from Arecibo

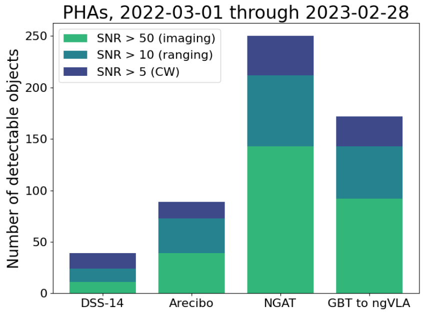


The final two plots show how many unique NEAs could have been detected by each of these four radar facilities during this twelve-month period. The first plot shows all NEAs: 368 for DSS-14, 810 for Arecibo, 2849 for NGAT, and 1892 for GBT to ngVLA. The NEA count includes many small objects. (The median estimated diameter for the potential Arecibo detections is just 23 m.) The second plot shows only PHAs, which by definition have absolute magnitude less than 22.0 (diameter greater than about 140 m) and also can approach within 0.05 au of Earth's orbit – making them important for planetary defense.

NEAs, 2022-03-01 through 2023-02-28



PHAs, 2022-03-01 through 2023-02-28



We are interested in analyzing how many of the asteroids expected to be discovered by Vera C. Rubin Observatory (LSST) and NEO Surveyor would be detectable by radar. If you are involved with either of those programs, the first author would like to discuss this with you!

Acknowledgements

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