

IAA-PDC-23-02-26
NEO RADAR OBSERVATIONS IN EUROPE

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Keywords: Radar, NEO, Observations

Extended Abstract—

Introduction

In this work, we present some preliminary results of NEO radar observations carried out by European radio telescopes in the wake of the ESA project “NEO observation concepts for radar systems”, in which INAF, SpaceDyS, and the University of Helsinki were involved. The project was aimed to derive the functional requirements of a radar system, evaluate the available European assets to perform NEO radar observations and carry out some test radar campaigns, with successful experiments performed on asteroids such as 2021 AF8, 2016 AJ193 and 4660 Nereus - all in collaboration with JPL (DSS-14, Goldstone). After the completion of this pilot project, further observations were planned to test a fully Europe-based system. The Madrid MDSCC station was involved, the DSS-63 antenna was employed as the transmitting element. Notwithstanding the low transmitted power, the involvement of the large Effelsberg radio telescope, together with the Medicina 32-m antenna, allowed to carry out a successful experiment on November 23, 2022 on 2005LW3, a binary Potentially Hazardous Asteroid (PHA), during its close approach to Earth.

Why Radars for NEO Observations

Ground-based planetary radars provide the most accurate estimates of the distance and velocity of the target and allow to significantly refine the knowledge of its orbit [1]. In certain cases, it is possible to determine subtle non-gravitational perturbations directly from a fit to the astrometry, as for the Yarkovsky effect [2].

Moreover, several physical characteristics of asteroids [3], such as size, shape, surface composition, rotation state [4], can be measured. Even the occurrence of a binary system can be assessed - as for NEA (410777) 2009 FD [5]. Radar and optical measurements are complementary, the former providing information on the radial distance and radial velocity, the latter on the direction of the target and its angular motion. Radar delay-Doppler imaging produces higher-resolution measurements to physically characterize the targets, with respect to light curves. A benefit of radar observations is that they can be performed 24 h per day and under most weather conditions.

Background and involved assets

The Italian 32-m radio telescopes of Medicina and Noto and the 64-m Sardinia Radio Telescope/Sardinia Deep Space Antenna (SRT/SDSA) have taken part in several radar observations of NEOs over the years. The

first attempt, which was successful, dates back to 2001, with the observation from Medicina of asteroid 33342 in a bistatic configuration with the 70-m transmitting antennas JPL DSS-14 in Goldstone (US) and RT-70 in Evpatoria (Ukraine) [6]. Subsequent experiments included the observation of (163899) 2003 SD220 in 2018 with SRT/SDSA [7], Medicina and Goldstone and the participation in interferometric radar campaigns (VLBR) dedicated to asteroids and inner planets, together with other antennas [8].

In 2020, an ESA tender assigned a feasibility study to SpaceDyS, INAF and the University of Helsinki, aimed at investigating the European potential for the future constitution of a planetary radar system able to perform NEO observations both for planetary defense and scientific goals [9]. The Italian Space Agency ASI was also involved with the SRT/SDSA as it agreed on offering its X-band receiving chain on board the SRT/SDSA for test observations. In the most recent observations, the 70-m DSS-63 transmitting antenna in Madrid and the 100-m radio telescope at Effelsberg (Germany), one of the largest single dish antennas in the world, were also employed.

Some experiments and results

In recent years we carried out radar observations of several asteroids, such as 2021 AF8, 2016 AJ193, and (4660) Nereus. The experiment on 2021 AF8 was performed on 3 May 2021. It produced interesting results, thanks to the high sensitivity of the employed system, involving DSS-14 (Goldstone) for transmission and SRT/SDSA on the receiving side. JPL scheduled this radar observation for the DSS14 in monostatic configuration and agreed to let us to "eavesdrop" the echo signal. For this reason, the received signal at SRT/SDSA were affected by a residual Doppler drift (see Fig.1) that was compensated offline in the post-processing phase.

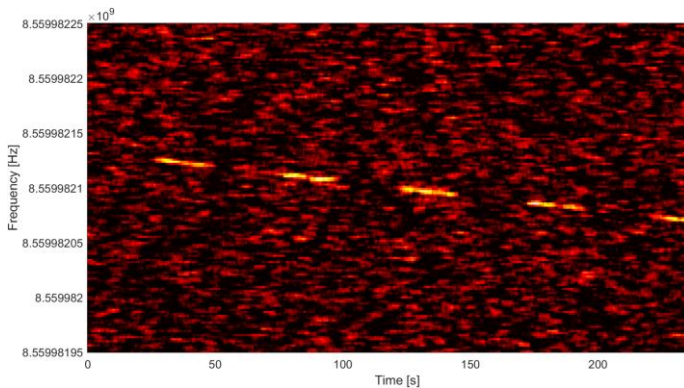


Fig. 1 - Spectrogram at 1.9 Hz/ch resolution, before the Doppler compensation. Color scale is the power spectral density in dB-scaled arbitrary units.

After the Doppler compensation, spectra with sub-Hz resolution (Fig. 2) were obtained. Measurements of the Doppler broadening yielded an estimate of the asteroid rotation period (~8.5 h, assuming an equatorial view).

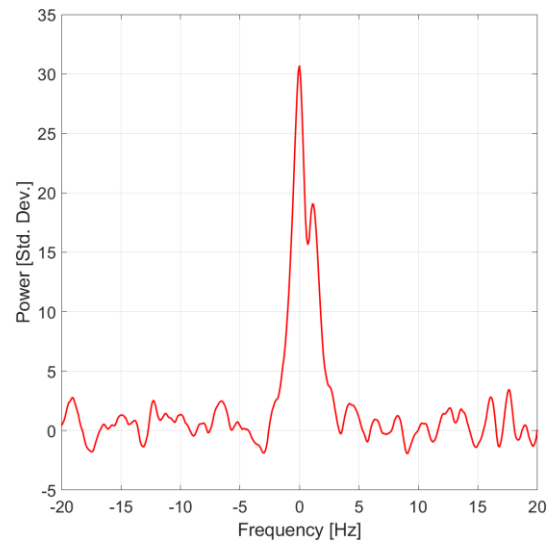


Fig. 2 - High-resolution integrated and smoothed echo power spectrum of 2021AF8 (resolution 0.1 Hz/ch).

The observation of Nereus, performed on 10 and 15 December 2021 by the bistatic radar system DSS14-Medicina, allowed us to confirm the high value of the circular polarization ratio, typical of the E-class spectral type asteroids, consistent with the measurements performed at Arecibo and Goldstone [10]. Figure 3 shows the radar echo of Nereus recorded in Medicina on 15 December 2021, both in SC (same circular) and OC (opposite circular) polarization.

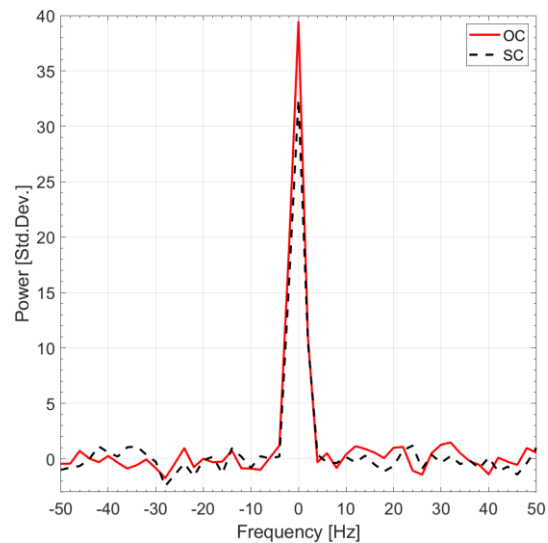


Fig. 3 – OC and SC power spectra of (4660) Nereus, recorded in Medicina.

The first fully Europe-based observation

Thanks to JPL/DSN, the DSS-63 antenna in Madrid was used as the transmitting element (at 7167 MHz) in a multi-static radar configuration. Despite the limited power available at this facility (20 kW), the possibility to exploit the large Effelsberg radio telescope on the receiving side, together with the Medicina 32-m antenna, permitted us to achieve higher SNR and accuracy in the measurements. The experiment was carried out on November 23, 2022 on 2005 LW3, a binary PHA roughly 400 m in size, observed at a distance of about 1.2×10^6 km (3.1 Lunar Distance). Both the receiving dishes detected the radar echo, well resolving it in the frequency domain. Figure 4 shows the echo recorded at Effelsberg. It allowed us to estimate a rotation period of about 4 h (assuming an equatorial view) and a slight offset in the received frequency, with respect to the ephemeris-based expectations, which can be used to further refine the orbit knowledge.

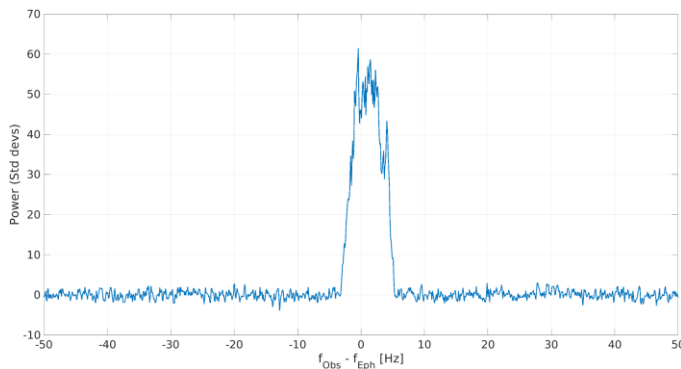


Fig. 4 – High resolution power spectrum (0.1 Hz/ch) of the 2005 LW3 radar echo acquired at the Effelsberg radio telescope.

Conclusions

These experiments demonstrated that European radio telescopes, although employed only as receivers (in bi- or multi-static configurations) and for a limited amount of time, can provide a significant contribution to the constitution of a European network for NEO monitoring, if a transmitting antenna - equipped with a suitable high-power transmitter - is made available.

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Acknowledgments

This work was carried out within the project SSA P3-NEO-XXII – NEO Observation Concepts For Radar Systems, ESA contract n. 4000130252/20/D/CT. We thank L. A. Benner, M. Brozovic, N. Rodriguez Alvarez and the staff at Goldstone and Madrid DSN complex for their assistance with the observations.