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NEO Radar Observations in Europe

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We describe here some results of NEO radar observations conducted in Europe in recent years, as part of the ESA project 'NEO observation concepts for radar systems'. The project aimed to derive the requirements for performing NEO observations, focusing on present and future European assets for such observations.

Here, we present two of the targets observed within and in the wake of this project: (4660) Nereus and 2005 LW3. For each asteroid, we obtained echoes that allowed us to derive measurements of polarization ratio and rotation period, along with astrometric information.

Why radar observations of NEOs?

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.

Observation planning and involved assets

The observing campaign began with consulting the list of known close approaches, considering those expected within the desired timeframe. This information was sourced from the NEODyS database. Concurrently and iteratively, we assessed the suitability and availability of both the transmitting and receiving antennas to determine the exploitable combinations and evaluate their performance on various potential targets. We sought asteroids with a common Tx–Rx visibility window and SNR estimates suitable for detection, as determined by our developed software tools. According to these requirements briefly explained before, we selected the 70-m DSS-14 JPL antenna in Goldstone (US), the 70-m DSS-63 antenna in Madrid (Spain), the 100-m radio telescope at Effelsberg (Germany), the 64-m Sardinia Radio Telescope (SRT/SDSA) in San Basilio (Italy) and the 32-m radio telescopes "G. Grueff" at Medicina, near Bologna (Italy) and the one at Noto, in the southern part of Sicily (Italy).

All the recent results, including the observations illustrated in this poster, are presented in Pupillo et al. 2024 [6], reachable via the QR code provided below.

References

[1]] Yeomans D. L. et al. (1992), The Astronomical Journal, 103, n.1, 303-317. [2] Del Vigna A. et al., (2018) A&A 617, A61. [3] Hudson, R.S. and S.J. Ostro (1999), Icarus, 140, 369-378. [4] Ostro S.J. et al. (1991), The Astronomical Journal, 102, n.4, 1490-1502. [5] Naidu S. P. et al. (2015) Tech. rep., Central Bureau for Astronomical Telegrams, 419. [6] Pupillo G. et al. (2024) Remote Sens., 16 (1), 1-23. [7] Molera Calvés G. et al. (2014) A&A, 564, 1-7. [8] Jurgens R.F. and Goldstein R.M. (1976) Icarus, 28, 1-15. [9] Green D.W.E. (2022), IAU Circular No. 5198, 2022 Dec. 10. [10] Virkki A. and Muinonen K. (2016) Icarus, 269, 38-49.

Observation of the targets

The observation of Nereus was conducted in December 2021 using the bistatic radar system DSS14-Medicina, in which the transmitter DSS-14 was involved in a Speckle interferometry experiment with the Very Long Baseline Array (VLBA). In this transmitting mode, Doppler compensation was centered on the Earth rather than on a specific antenna, resulting in a residual Doppler shift in the received signal. This shift was subsequently removed in post-processing using the phase-stopping method [7]. High-resolution power spectra at 0.1 Hz (Fig. 1) enabled the measurement of both the frequency at the center of mass (COM) for astrometry computations and the rotation period of the asteroid. To further increase the signal-to-noise ratio (SNR), each integrated spectrum was obtained by combining the individual power spectra acquired in both polarizations.

In estimating the echo broadening, we also employed a multi-parametric fitting approach with a simple echo profile model [8]. This method involved accurately removing the noise baseline and then expressing the signal in terms of standard deviation units of the background noise. We used a least-squares method to fit the linear baseline and a signal profile model defined by four parameters: echo width and amplitude, peak position, and shape parameter.

2005 LW3 was observed on November 23, 2022. Thanks to JPL/DSN, the DSS-63 antenna in Madrid was used, in the first full-European experiment, as the transmitting element 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 radio telescope, permitted us to achieve suitable SNR and accuracy in the measurements. Both the receiving dishes detected the radar echo, well resolving it in the frequency domain.

Fig. 2 illustrates the spectrogram of the asteroid pre- and post-compensation for the Doppler frequency drift induced by the target radial motion.

Fig. 3 shows the high-resolution spectra of the echoes recorded at Effelsberg and Medicina. It allowed us to estimate a rotation period of about 4 h (assuming an equatorial view) and a slight offset of 1.0±0.1 Hz in the received frequency with respect to the ephemeris-based expectations, a measurement that can be used to further refine the orbit knowledge.

The delay-Doppler radar images obtained at Goldstone from NASA-JPL (Fig. 4) revealed that 2005 LW3 is a binary system with a 50-100 m diameter satellite orbiting at a distance of about 4000 m [9]. The satellite was clearly detected as a secondary peak in the high-resolution echo profiles from the data acquired at Effelsberg and Medicina (Fig. 3).

Finally, Medicina detected the 2005 LW3 echo in both the same (SC) and opposite (OC) circular polarization sense as transmitted (Fig. 5), so it was possible to measure a low circular-polarization ratio between 0.1 and 0.2. This ratio, a very important observable in NEO radar techniques, is related to the NEO surface and sub-surface roughness at the wavelength scale [10]

We are working to extract additional information from these data and aim at derive the shape of the asteroid from power spectra profiles.

These observations highlight the significant potential of European radio telescopes, utilized as receivers albeit with a limited availability in time, to substantially contribute to the establishment of a comprehensive European network for NEO monitoring. The availability of a suitable transmitter is crucial for the creation of such a network and could greatly increase the possibilities to perform this type of observations.

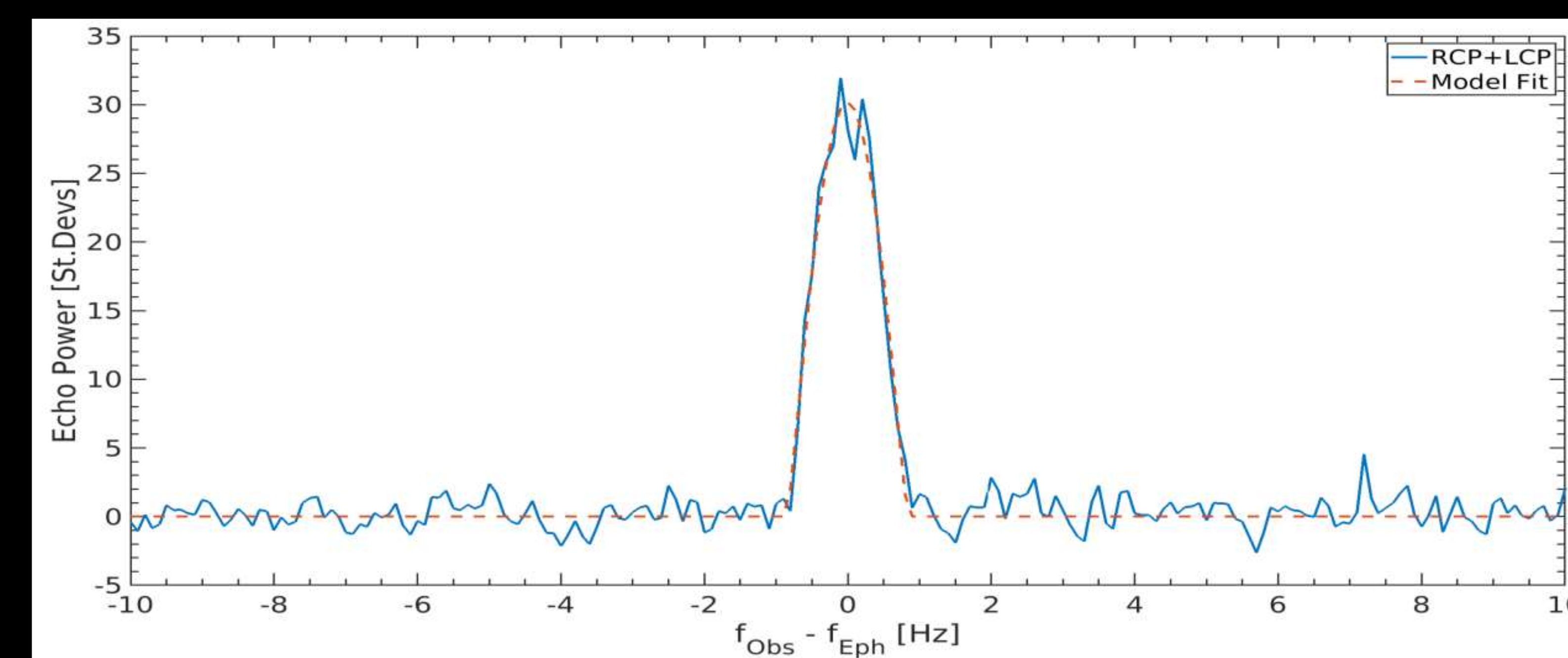

Fig. 1 - Integrated power spectrum at 0.1 Hz frequency resolution of the Nereus radar echo recorded at Medicina on 2021 December 10 (blue curve). Echo power is plotted in standard deviations of the background noise versus the estimated frequency of the echo from the asteroid's COM. The echo model fit is superimposed on the spectrum (dashed red curve)

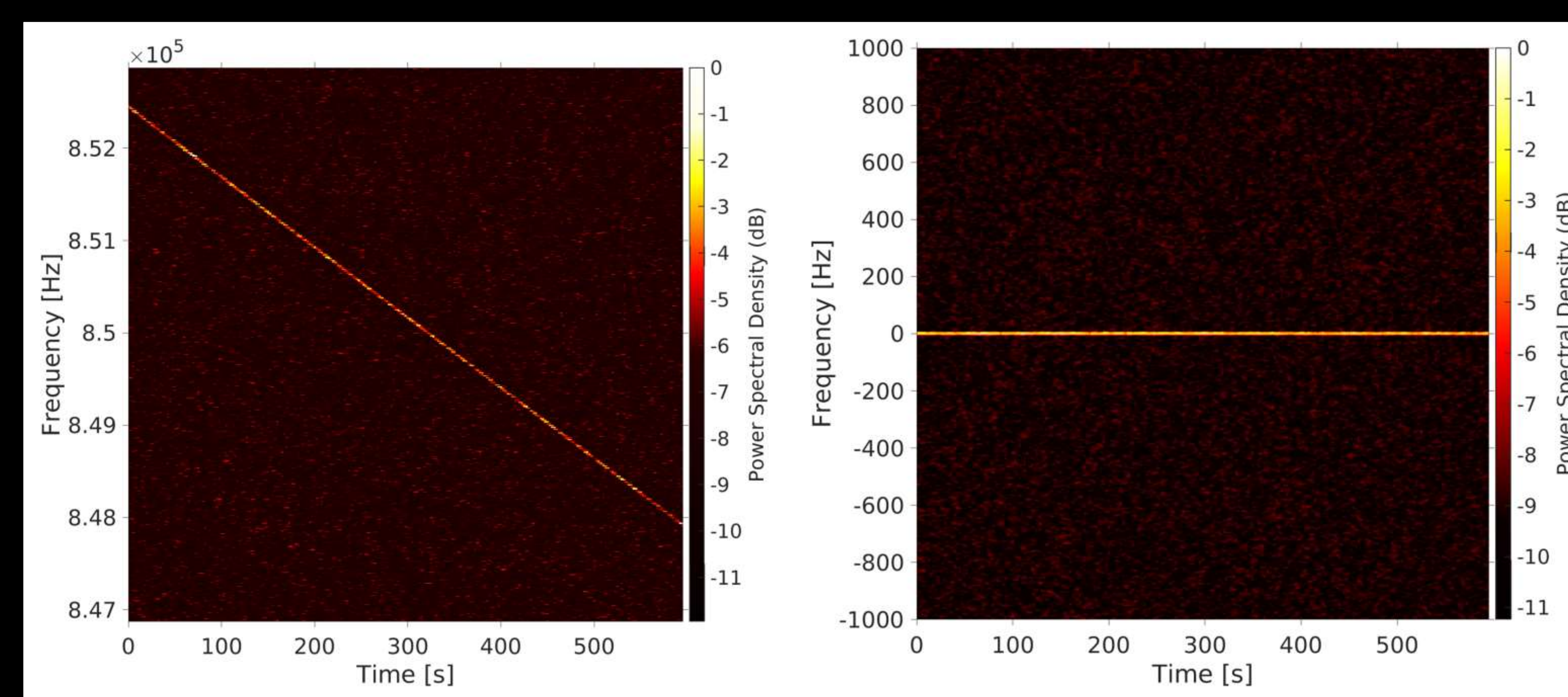

Fig. 2 - Spectrogram of the asteroid radar echo acquired at Effelsberg before and after the Doppler compensation (5 Hz spectral resolution, 5 s integration time). Color scale represents the power spectral density in dB-scaled arbitrary units

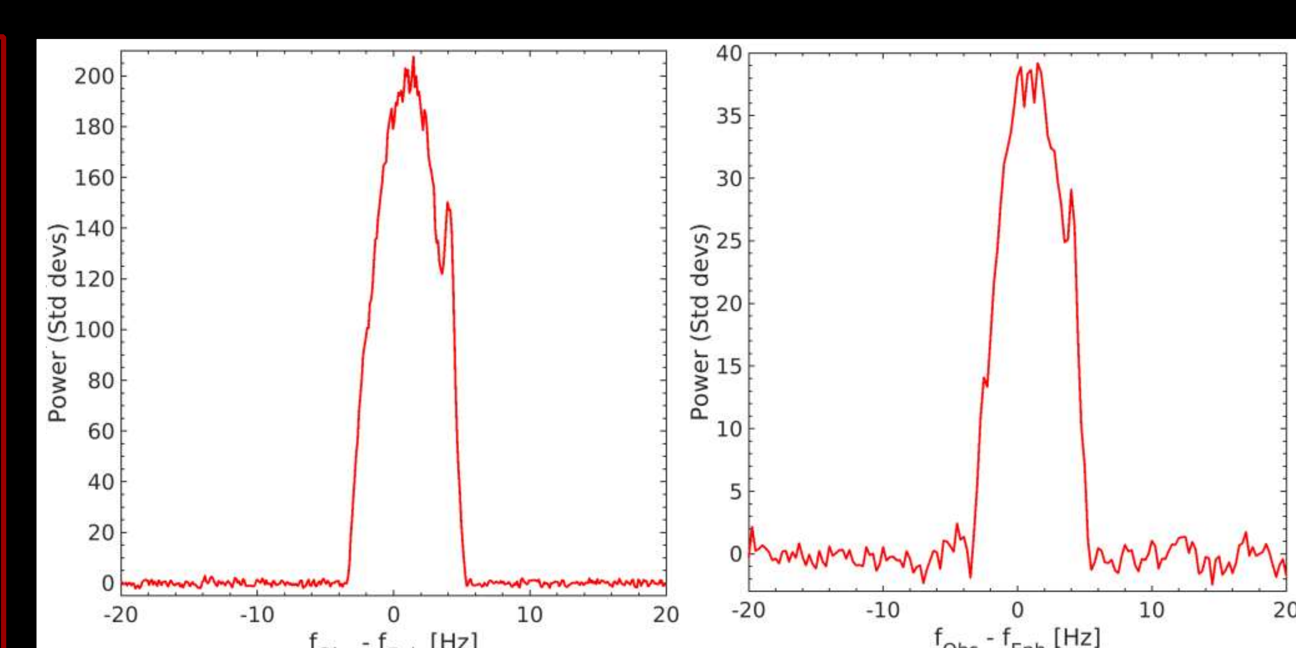

Fig. 3 - Full-track integrated power spectra of radar echoes produced with Effelsberg (left) and Medicina (right) data, at resolution 0.1 Hz and 0.25 Hz, respectively. Zero frequency is the expected center of mass (COM) frequency of the asteroid. The spike at ~4 Hz is the echo from the asteroid's satellite.

Fig. 4 - Delay-Doppler image of 2005 LW3 and its satellite obtained at Goldstone.

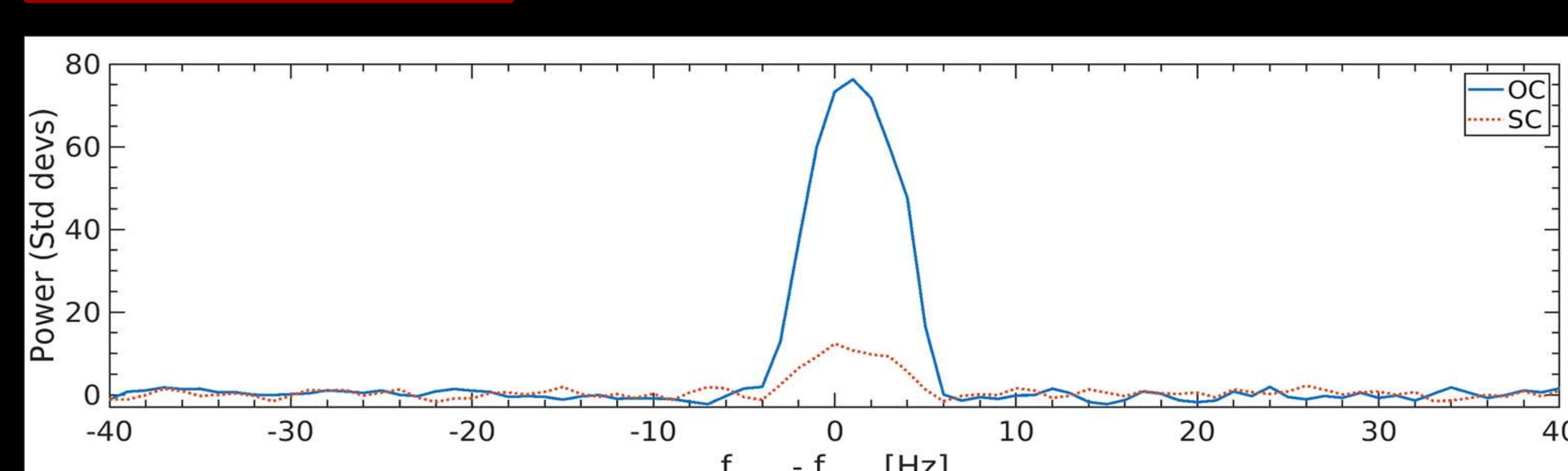

Fig. 5 - Radar echo power in the OC polarization (blue line) and in the SC polarization (dotted red line) obtained from Medicina data. Spectral resolution 1 Hz, full-track integration time.