Radar Observation of Asteroids 2005 LW3 and 2006 WB with European Radio Telescopes

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We here describe the results of NEO radar observations of asteroids 2005 LW3, carried out on November 23, 2022, and 2006 WB, conducted on November 25-26, 2024, employing European radio telescopes as receivers and JPL/NASA antennas as transmitters, in the wake of the ESA project "NEO Observation Concepts for Radar Systems".
The observations allowed us to derive important physical properties of both the targets, such as polarization ratio and rotation period, together with astrometric information. We also obtained a preliminary pole-on silhouette of 2003 LW3 and confirmed its binary nature.

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) [1]. Subsequent experiments included the observation of (163899) 2003 SD220 in 2018 with SRT/SDSA, Medicina and Goldstone and the participation in interferometric radar campaigns (VLBR) dedicated to asteroids and inner planets, together with other antennas [2].

In 2020, an ESA tender assigned a feasibility study to SpaceDyS, INAF and the University of Helsinki, "SSA P3-NEO-XXII – NEO Observation Concepts For Radar Systems", 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 [3]. The Italian Space Agency ASI was also involved with the SRT/SDSA for test observations. In more recent observations, the 70-m DSS-63 transmitting antenna in Madrid, the 100-m Effelsberg radio telescope (Germany) and the 76-m Lovell dish at Jodrell Bank (UK) were also employed. Fig. 1 shows the facilities involved in the observations.

Some of the results of these observations are presented in Pupillo et al. 2024 [4], reachable via the QR code provided below.

Observing 2006 WB

2006 WB was one of the strongest radar targets in 2024, reaching a minimum distance of about 2.3 Lunar Distance from Earth. Our observations were conducted on 25-26 November 2024, during its close approach. This campaign employed the 64-m SRT/SDSA (in X- and C-high band) and the 76-m Lovell radio telescope (in C-high band) as receivers and the Goldstone DSS-14 and the Madrid DSS-63 antennas as transmitters operating in X- and C-high band, respectively.

The delay-Doppler radar images obtained at Goldstone from NASA-JPL (Fig. 6) revealed that 2006 WB is an elongated asteroid with a double-lobed shape [9].

About a third of the high-resolution echoes acquired at the SRT showed a double peak profile that can be related to this shape.

A rotation period of approximately 12-14 h (assuming an equatorial view) was estimated from the echo broadening, consistent with the Goldstone observations.

Finally, the SRT and Lovell dishes detected the 2006 WB echo in both polarizations (Fig. 7), allowing us to measure a circular-polarization ratio ranging between 0.2 and 0.3.

The data reduction of the 8-GHz portion of the experiment, aimed to produce Delay-Doppler images, is still underway.

Fig. 6 - Delay-Doppler images of 2006 WB obtained at Goldstone (NASA/JPL)

Observing 2005 LW3

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 "Grueff Radio Telescope", permitted us to achieve suitable SNR and accuracy in the measurements. The experiment was carried out on November 23, 2022 on 2005 LW3, a PHA roughly 400 m in size, observed at a distance of about 3.1 Lunar Distance. Both the receiving dishes detected the radar echo, well resolving it in the frequency domain.

The Doppler frequency drift due to the radial motion of the target was removed by using the phase-stopping technique [5] on the time-domain data.

Fig. 2 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. 3) revealed that 2005 LW3 is a binary system with a 50-100 m diameter satellite orbiting at a distance of about 4000 m [6].

The satellite was clearly detected as a secondary peak in the high-resolution echo profiles from the data acquired at Effelsberg and Medicina (Fig. 2).

Medicina detected the 2005 LW3 echo in both the same (SC) and opposite (OC) circular polarization sense as transmitted (Fig. 4), 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 [7].

Finally, we aim to extract additional information from radar data by deriving the asteroid's shape from power spectrum profiles. We implemented an algorithm to estimate the hull—i.e., the pole-on projection of the asteroid's convex envelope—for LW3 (Fig. 5) based on [8]. After removing the satellite's spectral contribution, we identified the echo edge as the zero crossing nearest to the central frequency. The asteroid's radial profile was modeled using a truncated Fourier series under convexity constraints. Measurement uncertainties were incorporated via a weighted least squares optimization. This approach is feasible only with adequate orientational coverage of the target. In our case, the data covered approximately 88% of the 2005 LW3 rotation period.

The current convex hull estimation relies on the variation of edge frequencies with rotation, but disregards the full spectral shape, leaving much of the data unused. We are therefore developing more advanced techniques to enable a full 3D convex reconstruction of the asteroid's radar profile.

	2006 WB	2005 LW3
Observation date	25-26 Nov 2024	23 Nov 2022
Target distance	2.3 LD	3.1 LD
Target size	80 m x 300 m	400 m
TX	DSS-14, DSS-63	DSS-63
RX	SRT/SDSA, Lovell	Grueff, Effelsberg

Tab. 1 - Summary of the observations here presented

Fig. 1 - The involved facilities.

Fig. 3 - Delay-Doppler image of 2005 LW3 and its satellite obtained at Goldstone (NASA/JPL).

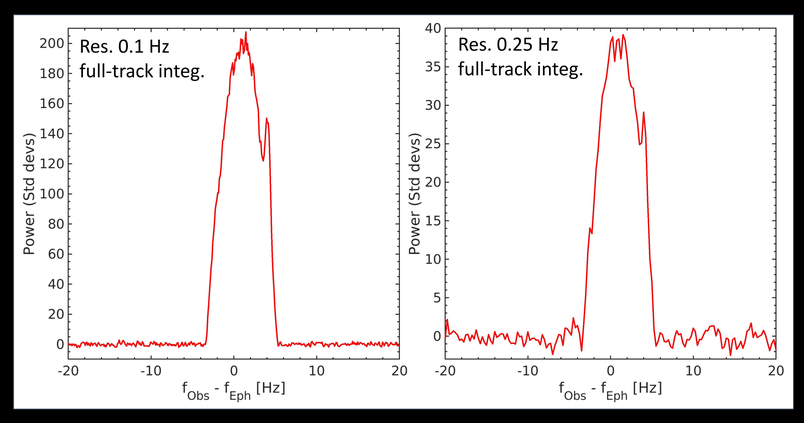

Fig. 2 - Full-track integrated power spectra of radar echoes produced with Effelsberg (left) and Medicina (right) data, at resolution 0.1 Hz and 0.25 Hz, respectively. Zero frequency is the expected center of mass (COM) frequency of the asteroid. The spike at ~4 Hz is the echo from the asteroid's satellite.

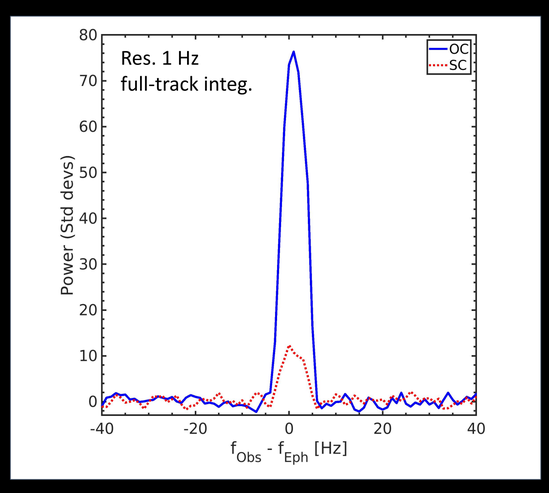

Fig. 4 - Echo power spectrum of 2005 LW3 in the OC polarization (solid blue) and in the SC polarization (dotted red) derived from Medicina data.

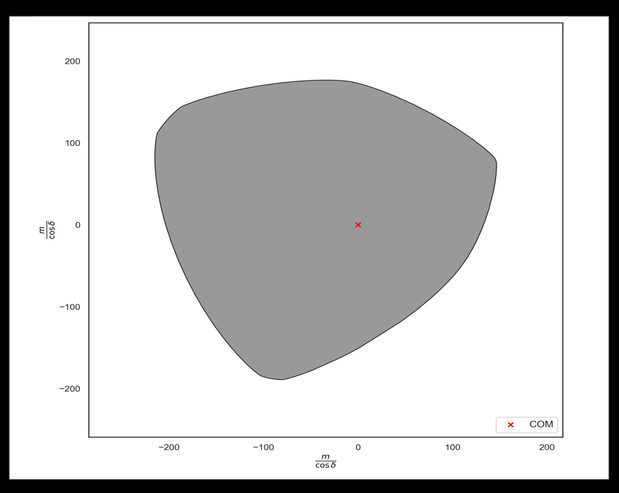

Fig. 5 - Pole-on projection of the 2005 LW3 convex envelope. The red cross marks the rotation center.

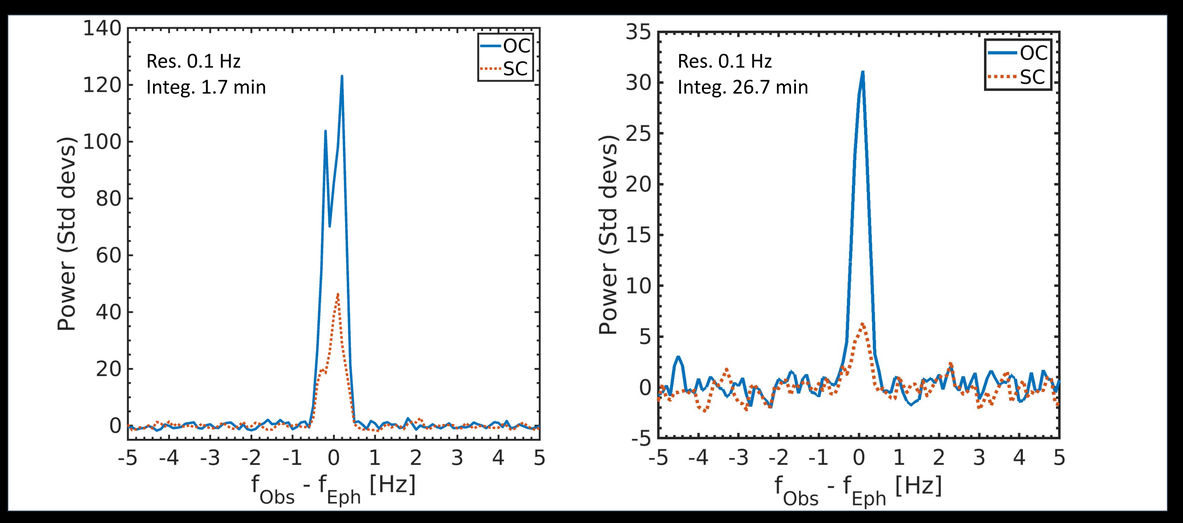

Fig. 7 - Echo power spectra of 2006 WB in the OC polarization (solid blue) and in the SC polarization (dotted red) obtained by the SRT/SDSA (left) and Lovell (right) dishes.

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