NEO Radar Observations in Europe

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We here describe some results of NEO radar observations carried out in Europe during the recent years in the wake of the ESA project "NEO observation concepts for radar systems" that was aimed to:

- **derive the functional requirements of a planetary radar system for NEO observations;**
- **evaluate the present and future capabilities of European assets for such observations;**
- **perform test campaigns exploiting European facilities.**

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.

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 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.

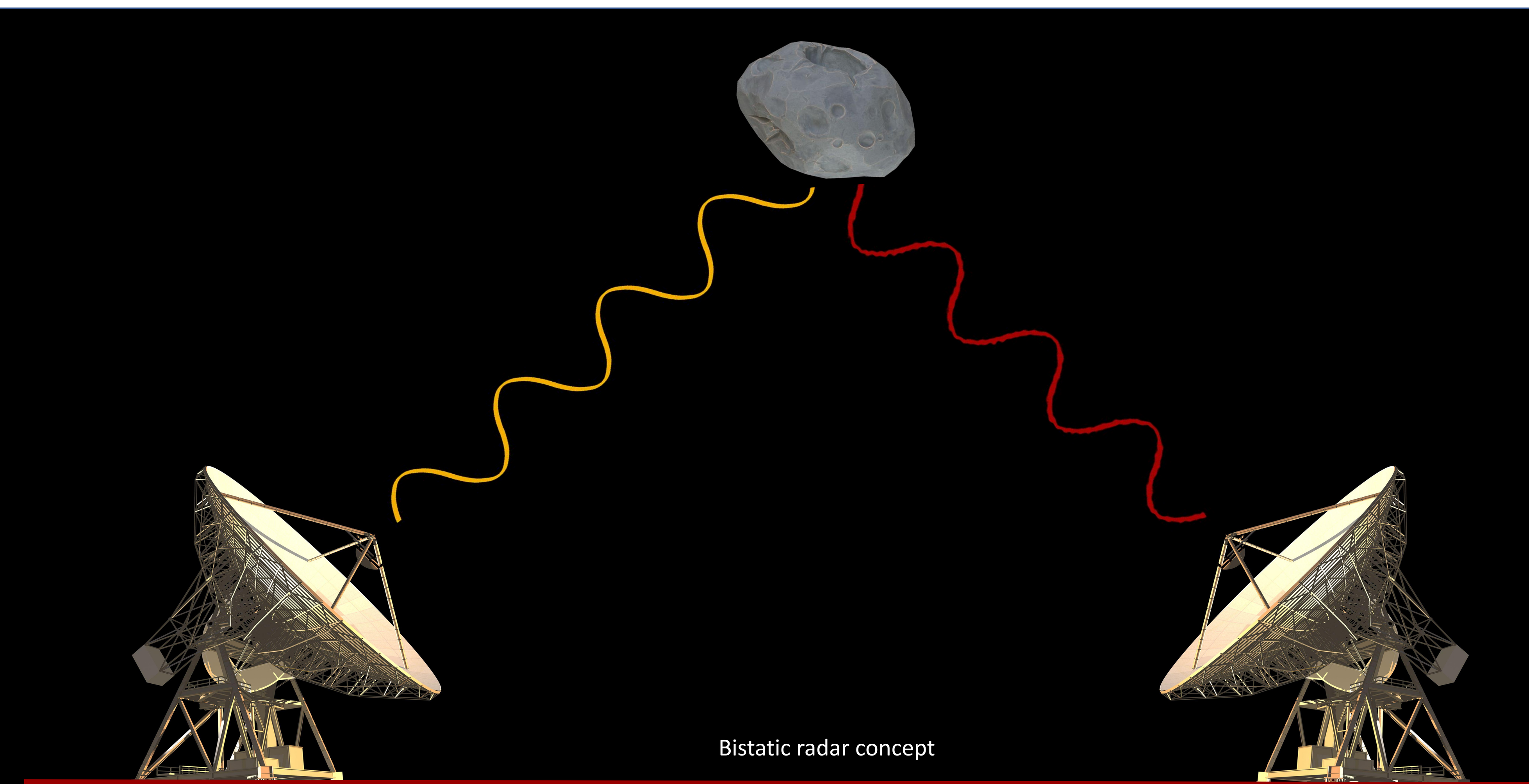
Some experiments and results

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. Spectra with sub-Hz resolution (Fig. 2 left) were achieved via the SDSA X-band devices. Measurements of the Doppler broadening yielded an estimate of its rotation period (~8.5 h, assuming an equatorial view). The observation of Nereus, performed in 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]. Fig. 2 (right) shows the radar echo of Nereus recorded in Medicina on 15 December 2021, both in SC (same circular) and OC (opposite circular) polarization.

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. Fig. 3 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.

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.



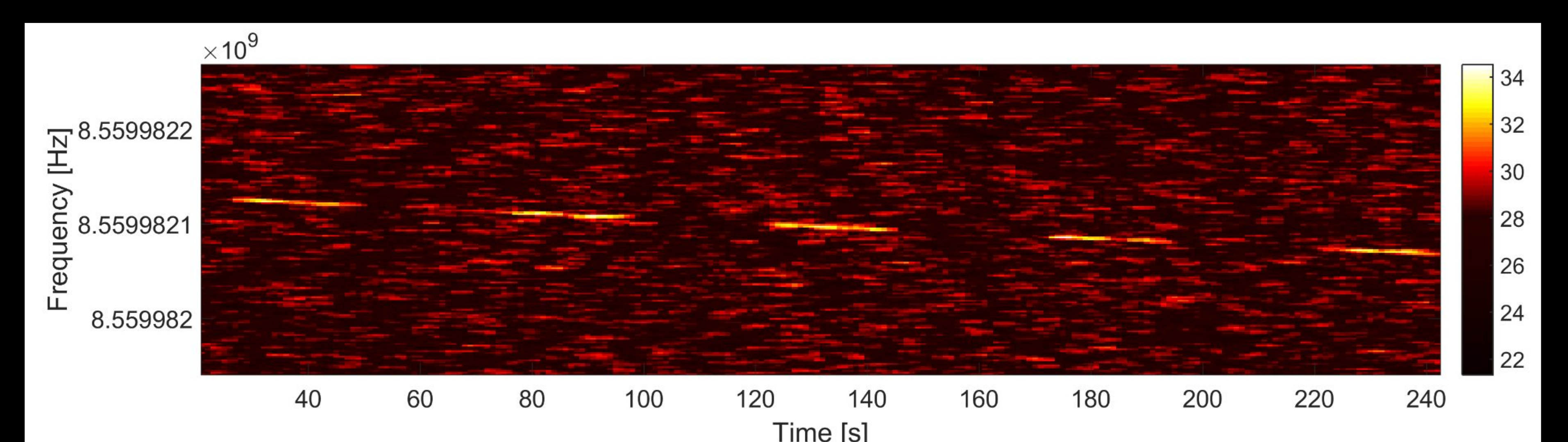


Fig. 1 - Spectrogram of asteroid 2021 AF8 echo before the Doppler compensation (1.9 Hz spectral resolution).

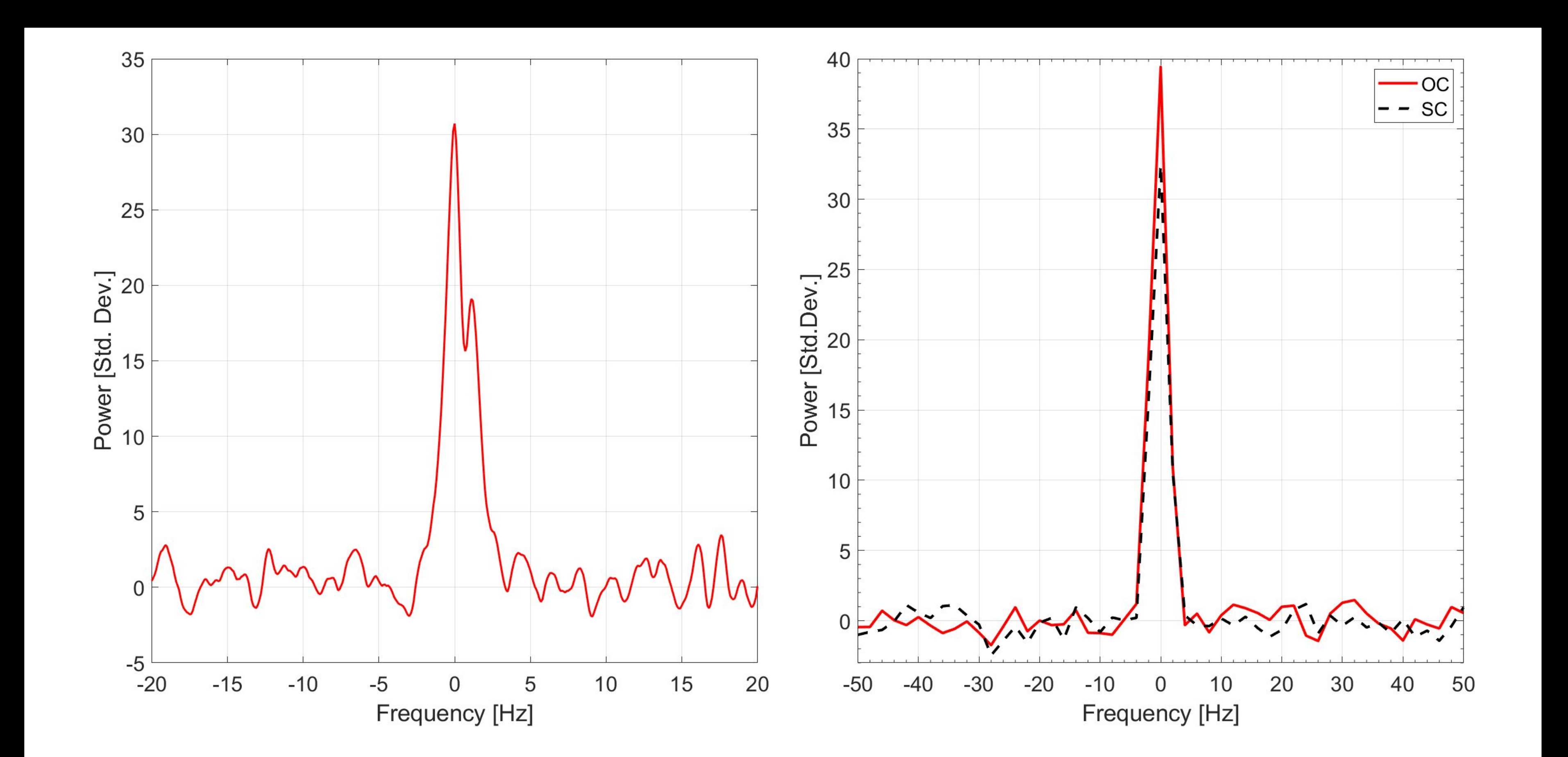


Fig. 2 - (left) Sub-Hz-resolution power spectrum of the radar echo produced by asteroid 2021 AF8, obtained with the SRT/SDSA antenna; (right) OC and SC power spectra of (4660) Nereus, recorded in Medicina.

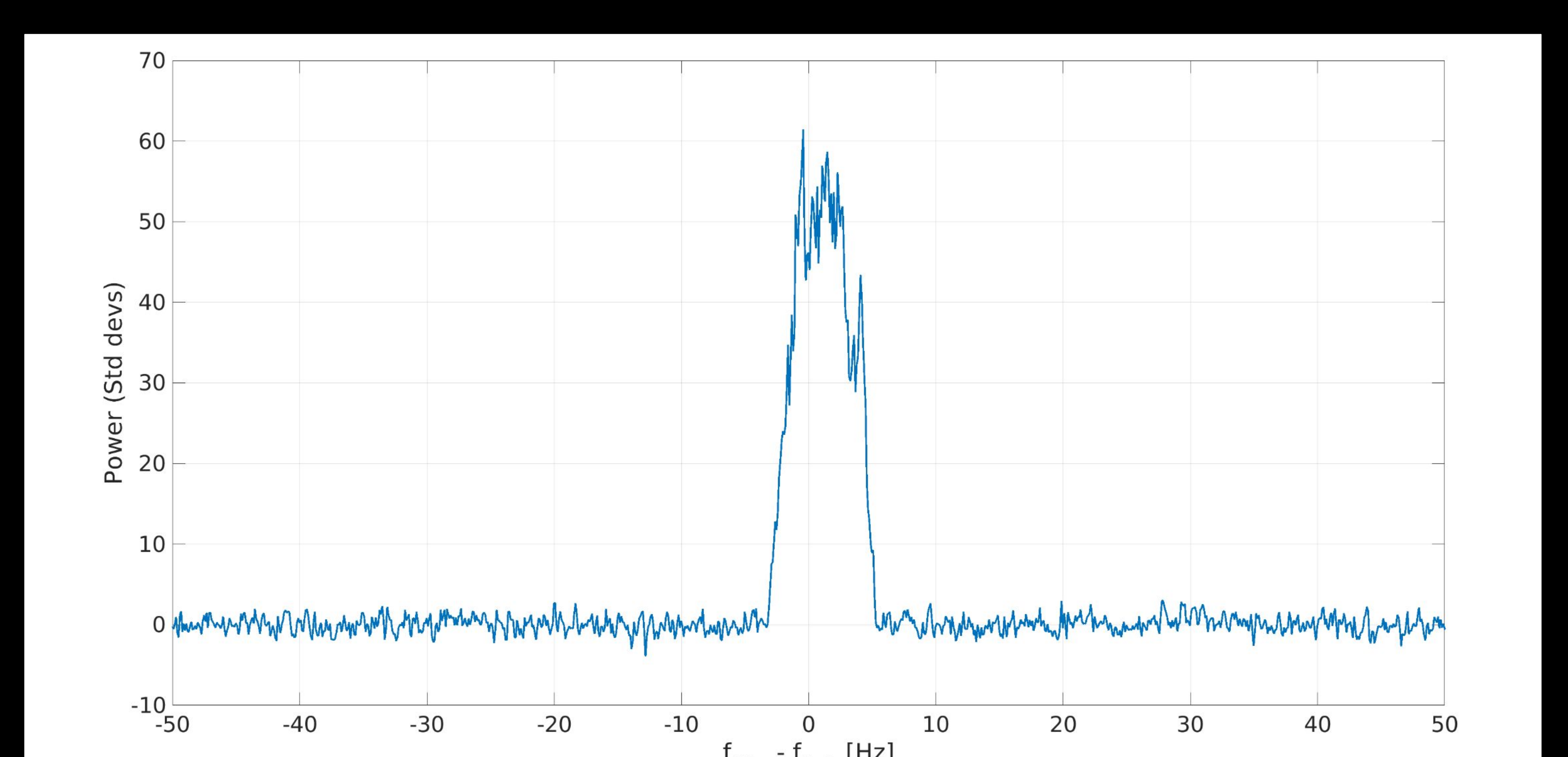


Fig. 3 - High resolution power spectrum (0.1 Hz/ch) of the 2005 LW3 radar echo acquired at the Effelsberg radio telescope.

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