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RADAR OBSERVATIONS OF NEO BY QUASAR VLBI NETWORK

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Radar is one of the most effective methods for determining the physical properties of near Earth objects (NEO). Radar observations allow us to determine the size, shape, features of rotation, to study the properties of the surface, as well as to improve the elements of the orbits [2].

From 2015, the Institute of Applied Astronomy of the Russian Academy of Sciences together with the Goldstone Observatory (USA) has conducted periodically intercontinental radar observations of NEOs using the 70-meter antenna of Goldstone Observatory (DSS-14) as a transmitter and the 32-meter radio telescopes of the Russian Quasar VLBI network as receivers. This method of radar observations is called "bistatic", in which the transmitter and the receiver are located in different antennas. Bistatic observations have several advantages..The interferometric reception of radio echo by several antennas is possible. The bistatic method allows one to continuously observe rapidly spinning celestial bodies, and to determine the spin axis.

The stationary Quasar VLBI network comprise three radio observatories: Svetloe, Zelenchukskaya and Badary. The observatories are located in the Leningrad region, the Karachaevo-Circassian republic and the Buryatiya republic respectively and are connected with the IAA Collation Processing Center in St. Petersburg.

The main purpose of Quasar VLBI network is to carry out radiointerferometric observations of extragalactic radio sources (quasars) and to process the observations obtained to determine the parameters of the Earth's rotation.

Radar observations of NEOs are carried out as follows. The DSS-14 radar transmits a right circularly polarized continuous wave (CW) signal at 8560 MHz (3.5 cm). RT-32 radio telescopes in Zelenchukskaya, Svetloe and Badary observatories receive the reflected signal. When processing the obtained data, the power spectra of the signals reflected from the asteroid with a given frequency resolution are calculated. As an example, Fig. 1 shows the spectra of 2011 UW158 and 2003 YT1 asteroids in the observatory Badary. Echo power is plotted in terms of noise standard deviations as a function of Doppler frequency relative to the estimated frequency of echoes from the asteroid's center of mass. Solid and dashed lines denote echo power in the OC and SC polarizations. Circular polarization of the signal is reversed after reflection from the plane surface and the maximum power of the reflected signal is expected in the OC polarization, though some of the signal, due to secondary reflections, is received with the same polarization. The ratio of SC to OC is a measure of near-surface wavelength-scale roughness [1].

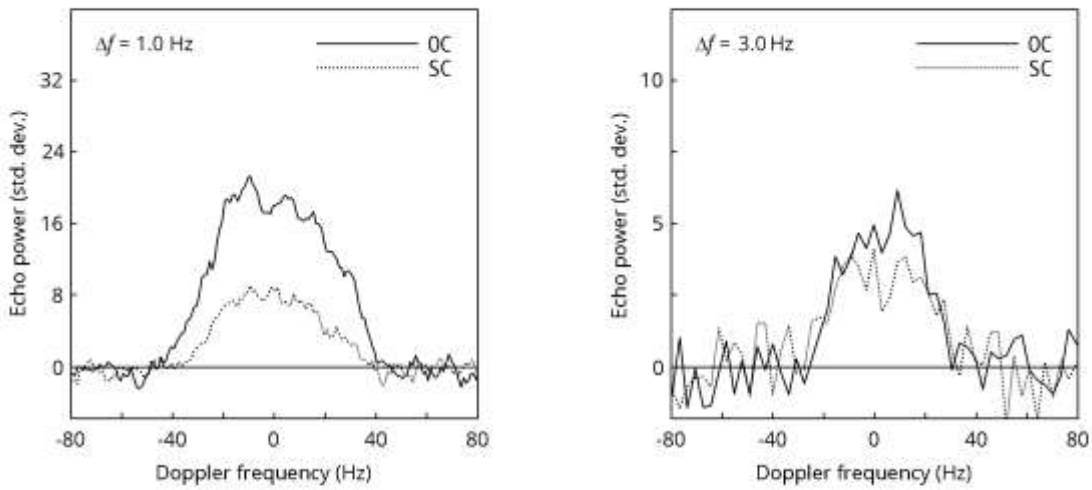

Fig1. Echo power spectra of asteroids 2011 UW158 и 2003 YT1 obtained at Badary observatory

Taking the geometric relation between echo power spectrum and the shape of rotating asteroid into account, we can estimate polar silhouette of an asteroid. Knowing the obtained spin period and assuming that the spectrum bandwidth is a continuous vector function of rotation phase we use least squares to fit 3-harmonic Fourier series to the data vector. The result is a two-dimensional convex hull which is a projection of the asteroid onto its equatorial plane. To convert Hz to meters we assumed that the asteroid-centered declination of the radar is equal to zero. We have considered solutions for each of the observatories separately and a joint solution for both observatories shown in Fig. 2. The solid profile represents the joint solution and the dotted profiles correspond to the observatories individually [4]. The figure shows that the body has an elongated shape 350 × 520 meters, which is consistent with the radar observations of the Arecibo Observatory, Green Bank and Goldstone [3].

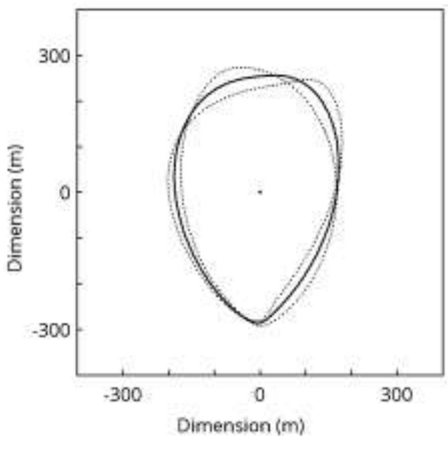

Fig. 2 Convex hull of 2011 UW158 polar silhouette

To obtain radio images of NEOs a phase-modulated signal are used. The phase modulation code sequence typically contains 511 elements, a length of 0.125 microseconds each. Then, using the original code sequence, the power spectra of the signals reflected from the asteroid with a given frequency resolution for different time delays are calculated. We are developing algorithms for radar-based reconstruction of asteroid shapes. Fig. 3 presents an ensample of reconstruction of asteroid shape from the radio images of an ellipsoidal model body.

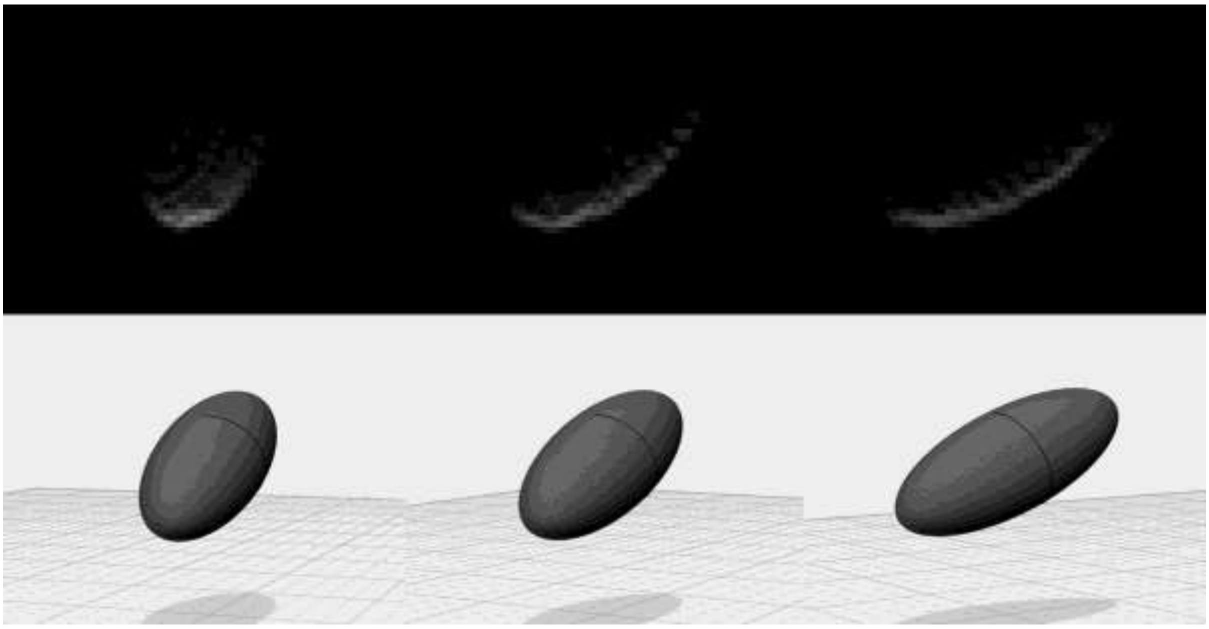

Fig. 3 Radio images of the asteroid (the top three figures) in comparison with the rotating model.

In conclusion we can say that the radar echo of signal transmitted from the 70 m antenna of the Goldstone Observatory was successfully detected. Obtained results confirm the possibility and effectiveness of the bistatic radar observations of near-Earth Asteroids using 32 m radio telescopes of Quasar VLBI network as receiving part of a bistatic configuration. It was shown that receiving and processing of the continuous wave echo allows to estimate the value of the Doppler frequency with sufficient accuracy which can be used to obtain the spin period and size of Near-Earth Object as well as improve the accuracy of prediction ephemerides. Following this positive experience we plan to continue bistatic radar experiments for obtaining continuous wave spectra and range-Doppler images in the near future.

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