

RADAR AND NEAR-INFRARED CHARACTERIZATION OF NEAR-EARTH ASTEROID (163899) 2003

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Introduction: Near-Earth asteroid (163899) 2003 SD220, hereafter SD220, was discovered on 29 September 2003 by the Lowell Observatory Near-Earth Object Search (LONEOS). NEOWISE thermal-infrared observations suggested an effective diameter of 0.8 ± 0.2 km [1]; however, radar results from Arecibo and Goldstone in December 2015 revealed SD220 is elongated with a long axis exceeding 2 km with an extremely slow rotation period of ~ 12 days. A period of 285 hours was verified with light curve data and hints of tumbling motion were identified [2], which is not unexpected for such a slow rotator [3].

SD220 recently made an extremely close approach to Earth on 22 December 2018, when it passed by at 7.4 lunar distances (LD), the closest it will come to Earth until 2070; the next close approach (17 December 2021) will be at 14.2 LD. Multi-instrument observations were coordinated between Arecibo Observatory (AO), Goldstone, the Green Bank Telescope (GBT), and the NASA Infrared Telescope Facility (IRTF). Here we present our preliminary results.

Radar Observations: Bistatic observations, where the radar transmitter and receiver are not collocated, were coordinated from Goldstone's DSS-14 to GBT at X-band (8560 MHz, 3.5 cm) and DSS-13 to GBT at C-band (7190 MHz, 4.2 cm), as well as AO to GBT at S-band (2380 MHz, 12.6 cm) to obtain high spatial resolution (as fine as 1.9 m/pixel) range-Doppler images of SD220 well-resolved in Doppler frequency. Furthermore, monostatic, continuous wave (CW) experiments were conducted at Arecibo and Goldstone. Because radio waves attenuate in a solid

medium by a factor of e at a wavelength dependent absorption depth [4], our multi-band radar campaign sampled different depths [5].

Results: Bistatic data with Goldstone transmitting were collected from 15 December – 23 December 2018 and from 18 December – 22 December 2018 with AO. In Figs. 1 and 2, we show a sample of range-Doppler images from Goldstone DSS-14 to GBT (Fig. 1) and AO to GBT (Fig. 2) with the radar beam illuminating SD220 from the top of the frame and Doppler frequency increasing to the right. These radar images, which cover $\sim 3/4$ of the rotation phase, are $20\times$ finer than those from 2015.

Several features are clearly distinguishable in the image set. In Fig. 1, a prominent ridge protruding from the middle of the shape in the leftmost frame and traversing the middle of the shape in the rightmost frame is clearly visible; the ridge extends some 100 m above the surrounding terrain. However, as seen in Fig 2, which shows nearly the opposite face as in Fig. 1, the ridge is not as prominent, suggesting it is hemispherically asymmetric. A large, radar-dark region (i.e., absence of radar echo) in the center frame of Fig. 2 that persists as it rotates head-on to the radar beam on 22 December (right frame), as indicated by the horizontal asymmetry of the echo, may be interpreted as a km-scale concavity spanning a significant fraction of the body. Such a large-scale, radar-dark region or concavity is very unusual among the hundreds of asteroids observed with radar. Visible bright spots in images may be due to boulders and clustered, dark, circular features may be small craters.

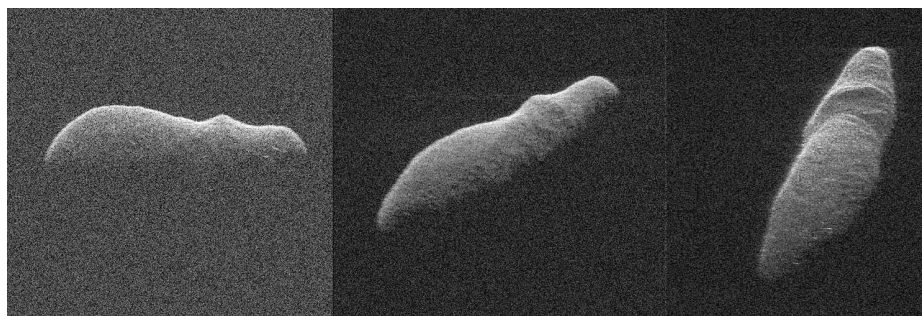


Figure 1. Range-Doppler images of SD220 taken on (left to right) 15 – 17 December 2018 at a range (vertical axis) resolution of 3.75 m/pxl and Doppler frequency (horizontal axis) resolution of 0.0025 Hz using Goldstone as the transmitter (X-band) and GBT as the receiver.

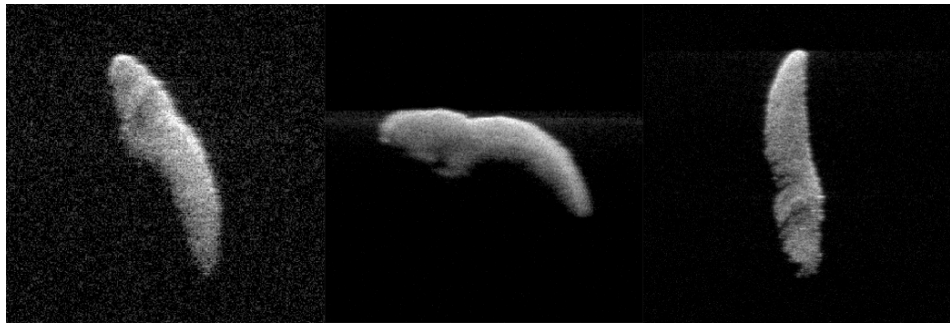


Figure 2. Range-Doppler images of SD220 taken (left to right) 18, 19, and 22 December 2018 at a range resolution of 7.5 m/pxl and Doppler frequency resolution of 0.0011 Hz transmitting from AO (S-band) and receiving at GBT.

The visible extent on 22 December (Fig. 2), when the length of SD220 was nearly fully illuminated by the radar, suggests the long axis is at least 2.5 km. The visible extent on 19 December, when SD220 was broadside and partially illuminated, places a lower bound on the intermediate axis of 0.5 km and roughly 1 km if SD220 was half illuminated as expected.

Furthermore, CW experiments during the 2015 and 2018 apparition revealed a circular polarization ratio of $\mu_c \sim 0.2$, which is typical for asteroids in the S and C taxonomic complexes [5].

Near-infrared Observations: Near-infrared observations (0.7-2.55 μm) of SD220 were carried out using the SpeX instrument on the NASA IRTF on 13 December 2018. Forty spectra of the asteroid were obtained along with twenty spectra of telluric extinction star SAO95279 and another ten spectra of solar analog star SAO93936. The spectra were reduced using Spextool provided by the NASA IRTF [7]. Spectral band parameters (band centers, band area ratio) were calculated using methods described in [8].

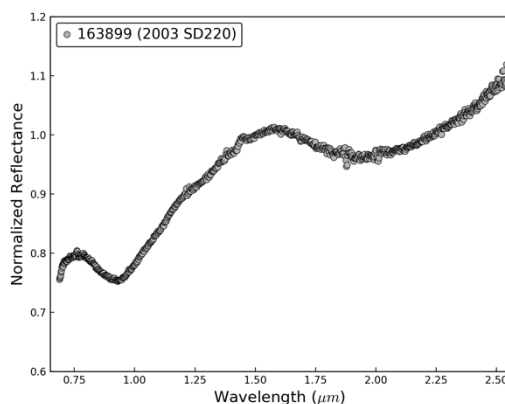


Figure 3. Near-IR reflectance spectrum of 2003 SD220 obtained using the NASA IRTF on Mauna Kea, Hawaii, on 13 December 2018.

Results: Fig. 3 shows the average spectrum of SD220 from the NASA IRTF. The spectrum shows deep absorption bands centered around 1 and 2 μm

due to the presence of pyroxene. The spectrum shows an overall red slope (increase in reflectance with increasing wavelength) beyond 2.25 μm . The Band I center and band area ratio fall within the S(V) region of the S-complex subtypes plot from [9]. These asteroids are thought to contain clinopyroxene apart from olivine and orthopyroxene in their surface assemblages. They fall roughly between the S(IV) types, which are analogs to ordinary chondrites and taxonomically similar to Q-types in the Bus-DeMeo system [10], and the basaltic achondrites represented by the V-types.

Conclusions: Radar and near-infrared observations of near-Earth asteroid 2003 SD220 during the 2015 and 2018 apparitions revealed that it is an elongated (batata-like), slowly rotating, S-complex asteroid. The high-resolution radar images and rotation phase coverage will allow for detailed spin-state and shape reconstruction as well as thermal modeling. If SD220 is a non-principal axis rotator, then we will obtain estimates of its moment of inertia ratios, allowing for important constraints on the mass and density of the interior, such as was done for 4179 Toutatis [11]. Because SD220 is classified as NHATS (Near-Earth Object Human Space Flight Accessible Targets of Study), detailed characterization is important to facilitate possible future human exploration.

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