RADAR IMAGES OF THE MOON AT 4.2-CM WAVELENGTH.

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Introduction: Radar observations are one of the most effective methods of Earth-based remote sensing of the Moon, allowing high spatial resolution mapping and exploration of surface and subsurface physical properties. These data can be used to study the history of the geological formation of the Moon, prospecting, and mining, and choosing landing sites for spacecraft. We report the results of intercontinental bistatic radar observations of the Moon conducted by the Institute of Applied Astronomy of the Russian Academy of Sciences (IAA RAS) and the National Commission on Space Activities of Argentina (CONAE). The observations involved the 35-m antenna (DSA 3) of the European Space Tracking (ESTRACK) network at Malargüe station in Argentina and the 13.2-m radio telescope (RT-13) at Svetloe radio astronomical observatory of the Russian VLBI network (Quasar).

Radar Observations: The observations were carried out on September 7, 2021, from 13:30 to 14:30 UT while the Moon was in sight of both antennas. Three sites on the lunar surface were chosen as radar targets: Rima Hadley and Mare Serenitatis in the northern hemisphere and Tycho crater in the southern hemisphere. Since the Moon is close enough to the Earth, we used bistatic radar observations mode with transmission from DSA 3 and reception at RT-13. The DSA 3 antenna alternately irradiated selected targets with a 2 kW circularly polarized signal at a carrier frequency of 7190 MHz (4.2 cm) modulated with a repeating pseudo-random code using binary phase shift keying. At the same time, the RT-13 antenna received echoes simultaneously in the same circular (SC) and opposite circular (OC) polarizations as transmitted, sampled them and recorded [1]. The modulated signal was used to resolve the target in two dimensions – time-delay (or range) and frequency (or Doppler shift) forming a range-Doppler radar image. The range resolution along the time-delay axis depends on the selected duration of each code element (or baud) and the frequency resolution depends on the fast Fourier transform (FFT) length or integration time. We cross-correlated the echo time series with a replica of the transmitted code and considering the Doppler frequency as a function of time we applied FFT in each range bin to obtain range-Doppler images. We used 0.5 µs baud duration which allowed us to achieve a spatial resolution of lunar surface up to 75 meters.

Radar Images: For each of the three target regions on the lunar surface, radar images were obtained in OC and SC polarizations, respectively. 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 is received in the SC polarization, due to multiple reflections or scattering by surface or subsurface interfaces between materials with different electrical properties, such as rocks or cracks. Therefore, a higher circular polarization ratio (CPR) or SC/OC indicates a greater degree of near- or sub-surface wavelength-scale roughness or multiple scattering and provides important information about the physical properties of the target region [2]. Figures 1-4 show the obtained radar images of the Rima Hadley, Mare Serenitatis and Tycho crater regions overlaid with the color values of the CPR. The images are in delay-Doppler coordinates, with range (distance from the observer) increasing to the bottom, and Doppler frequency increasing to the right (to the left for Fig. 3 and 4). These images clearly detect high CPR values of the young craters ejecta, basaltic lava flows boundaries, and bedrocks, allowing us to investigate the surface and subsurface physical properties not evident in visible imaging or infrared spectroscopy data sets.

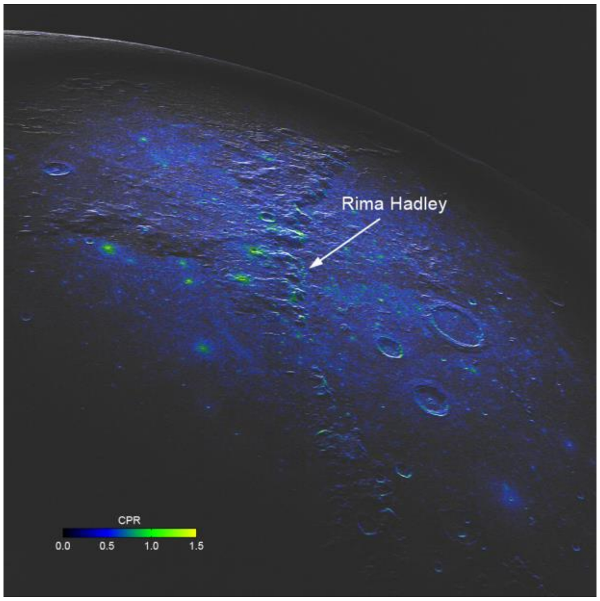

Fig. 1. Radar image of Rima Hadley region at a radar wavelength of 4.2 cm overlaid with the color values of the circular polarization ratio (CPR).

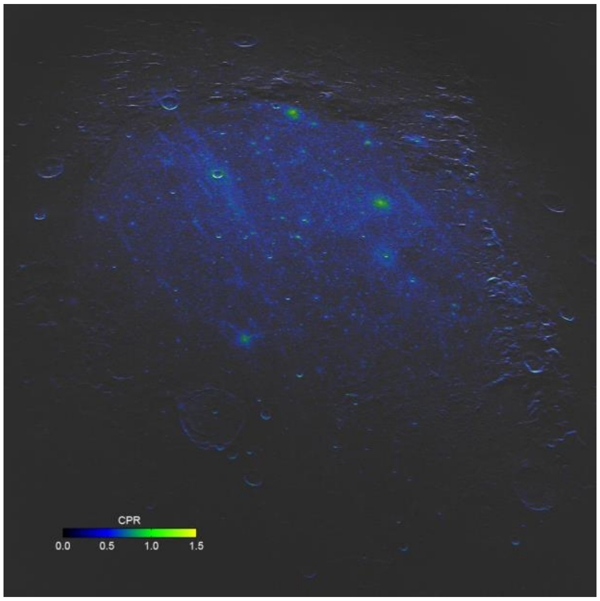

Fig. 2. Radar image of Mare Serenitatis region at a radar wavelength of 4.2 cm overlaid with the color values of the circular polarization ratio (CPR).

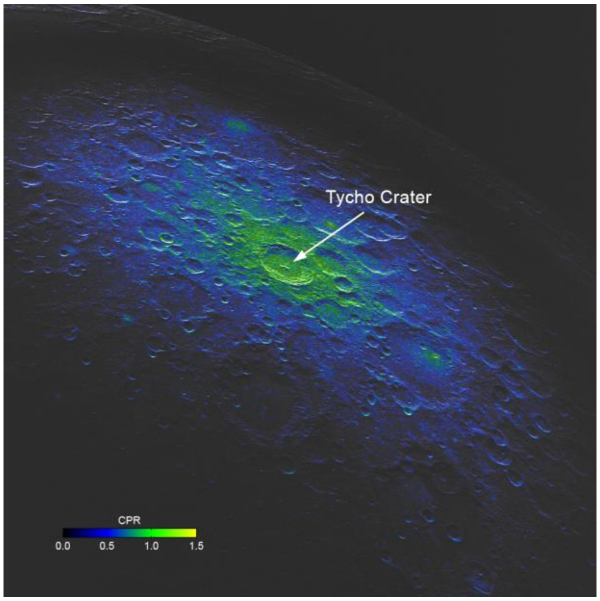

Fig. 3. Radar image of Tycho crater region at a radar wavelength of 4.2 cm overlaid with the color values of the circular polarization ratio (CPR).

Conclusion: Radar images of the Rima Hadley, Mare Serenitatis and Tycho crater regions at 4.2 cm wavelength with a spatial resolution up to 75 meters were obtained as a result of intercontinental bistatic radar observations of the Moon. Derived values of circular polarization ratio revealed hidden from visible images surface and subsurface physical properties. Such results can be useful for planets formation study, constructing high-resolution radar maps of the lunar surface, prospecting, and mining, choosing landing sites for spacecraft.

This work also shows that modern digital signal processing capabilities make it possible to carry out radar observations of the Moon without the use of specially designed "planetary" radars or highly sensitive radio telescopes.

More details about our work can be found at http://iaaras.ru/en/observations/echo/.

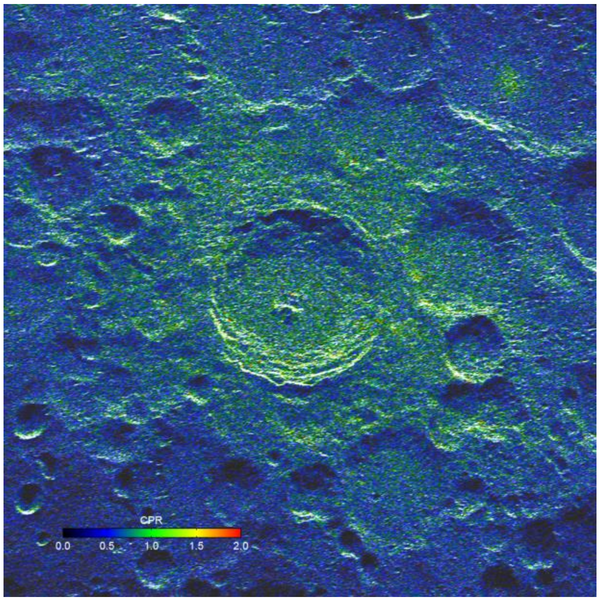

Fig. 4. Detailed radar image of Tycho crater region without spherical distortion.

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References: [1] Marshalov D. A. et al. (2018) *Instrum. Exp. Tech.*, *61*, 577–582. [2] Campbell B. A. (2016) *PASP*, *128:062001*.