RADIO OBSERVATIONS OF THE MOON AT 3.6 CM BEFORE AND AFTER SMART-1 IMPACT

A.E. Volvach[1], A. A. Berezhnoy[2], B. Foing[3], P. Ehrenfreund[4], O.B. Khavroshkin[5], L.N. Volvach[1]
[1] Crimean Astrophysical Observatory RT-22, Katsively, Yalta, Crimea, 98688 Ukraine [2] Sternberg Astronomical Institute, Moscow State University, Moscow, Russia [3] European Space Agency, Noordwijk, the Netherlands [4] Leiden Institute of Chemistry, Leiden, the Netherlands [5] Institute of Earth Physics, Moscow, Russia

Introduction: The main component of the lunar radio emission is the thermal radiation. However, on Earth electromagnetic radiation of seismic origin in the kHz and MHz range was detected before earthquakes [1]. Theoretical study of electromagnetic radiation emitted by impact-formed micro cracks in the rocks show that this emission has a tail at high-frequency tail up to GHz range [2].

Massive impactors may significantly increase seismic activity on the Moon. Duration of such moonquakes may reach several hours; at this reason radio observations of the Moon after Lunar Prospector impact were conducted. Fast variability of lunar radio emission at 13 and 21 cm was detected on July 29 - August 2, 1999 [3]. Correlation coefficient between the variations of the lunar radio flux after Lunar Prospector impact at both wavelengths is about 0.6, it may be explained as by telescope vibrations as by the lunar origin of detected fluctuations. During the Leonid meteoroid shower in 2000 and 2001 variability of lunar radio flux at 2.46 cm was detected [4]. However, simultaneous observations of the Moon at 6.2 cm at similar RT-22 telescopes located in Pushchino (Moscow region, Russia) and Simeiz (Crimea, Ukraine) during Leonid 2001 shower do not confirm the lunar origin of detected fluctuations because correlation between variations of the lunar radio flux at both telescopes was absent [5].

Observations: European spacecraft SMART-1 collided with the Moon at grazing angle of about one degree at 5:42:22 UT on September 3, 2006. The mass and the velocity of the spacecraft were equal to 285 kg and 2 km/s at the time of impact. Observations of the Moon at 3.6 cm were conducted at 22-m radio telescope at Simeiz (44 N, 35 E) in Ukraine during 14-21 UT on September 2 and 15-21 UT on September 3, 2006. Angular resolution at these observations is about 5 arc minutes. Observations with time resolution of 1.2 s were conducted at 3.6 cm at 2 and 500 MHz bandwidths. The duration of interrupted observations of impact region (34S, 43W) of the Moon was equal to 30 minutes, and then seismic passive region (30S, 30E) was observed during 20 minutes. Last 10 minutes of each hour observations of the sky at several degrees off the Moon were conducted.

To verify if the variations are attributed to the Moon we performed several tests that included recording signals from a calibration source that is known to be without fast variations and recording the atmospheric radio emission, when the radio telescope tracked a position on the sky several degrees off the Moon.

Results: Raw observational data were calibrated, and then standard deviation of variations of received signal from the regression curve was determined. Amplitudes of variations of received signal from calibration source and the sky were equal to 0.5 K at 2 MHz bandwidth and 0.2 K at 500 MHz bandwidth as on September 2 as on September 3. Amplitudes of variations of received signal from calibration source, the sky, lunar radio flux at impact region and seismic passive region were equal to about 2 K and 0.7 K, respectively at both bandwidths. We did not detect any differences between variations of lunar radio flux before and after SMART-1 impact.

Correlation coefficient between variations of lunar radio flux at 3.6 cm with 2 and 500 MHz bandwidth after subtraction of polynomial fit curve (caused mainly by receiver instability) is high, about 0.9. This fact may be explained by lunar origin, Earth atmosphere noises, receiver instability, and by telescope vibrations. However, Earth atmosphere noises cannot explain higher values of amplitudes of variations of lunar radio flux in comparison with that from the sky. Receiver instability hypothesis cannot explain low correlation coefficient (about 0.1) between variations of received signal from the sky at 3.6 cm with 2 and 500 MHz bandwidths.

Additional observations were conducted on November 29-30 at the same age of the Moon for checking possible dependence of received variations of lunar radio flux from the age of the Moon and the distance of the center of the lunar disk caused by telescope vibrations. These observations show increasing of amplitude of fluctuations near the terminator and edges of the lunar disk where temperature gradients are maximal. Thus, telescope vibrations are suitable for explanation of quasi-periodic fluctuations of received lunar signal.

Discussion: Recent observations of the Moon 10-15 hours after SMART-1 impact show similar results in comparison with observations of the Moon at 13 and 21 cm 9-12 hours after Lunar Prospector impact. Let us note that for both impactors impact velocities, grazing angles, and masses are similar.

Observations of the Moon at 6.2 cm during 2001 Leonid meteor shower do not give support to the lunar origin of detected variations, because correlation between these variations at two isolated radio telescopes is absent [5]. Flashes of radio emission at 3.6 cm during optical flashes caused by 1999 Leonid's impacts onto the Moon with impact speed of 72 km/s were not detected also [6]. Unsuccessful attempts to detect radio flashes on the Moon cause by meteoroid impact may be explained by inefficient time resolution of 1 s used during these observations.

Study of differences between values of nearest pixels was performed for search for impact-produced radio flashes. Based on 3 σ criteria corresponding to 1 s flash intensity of about 5 Jy we did not detect any flashes occurred at 3.6 cm and at both 2 and 500 MHz bandwidth during 15 minutes of observations. For the whole dataset (10 hours of observations of the Moon) the upper limit of radio flashes is estimated as 20 Jy. For more accurate search for lunar impact radio flashes the receivers with quite different wavelengths and with time resolution of about 0.01 s at the same telescope must be used.

Small lunar brightness temperature variations at 3.6 cm during September 2-3, 2006 with amplitude of about 10 K may be explained by changes of conditions of the solar illumination of the Moon. These results agree well with measurements of the brightness temperature of the Moon at 6.2 cm during 2001 Leonid meteor shower [5].

Estimation of intensity and duration of SMART-1 impact radio flash: Let us estimate the intensity of radio emission during SMART-1 impact based on results of impact experiments and previous radio observations. Upper limit of Leonid 2001 radio impact flashes at 6.2 cm is estimated as 100 Jy if flash duration is about 0.02 s [5]. Let us note that kinetic energy of biggest Leonid meteoroids impacts [7] is similar to the kinetic energy of SMART-1 impact. Thus, upper limit of SMART-1 impact flash intensity at 6.2 cm is about 100 Jy also. During 4 km/s impacts of 1 g polycarbonate projectiles to different targets the duration of white noise emission was about $3*10^{-4}$ s, average emitted power and maximum power at 1.35 cm and 0.3 GHz bandwidth were equal $3*10^{-8}$ W and 10^{-5} W for Al target, respectively [8]. Assuming linear proportionality between duration of radio flash and size of impactors as well as between the emitted power and kinetic energy of impacts we can estimate the duration of SMART-1 impact radio flash as 0.03 s, intensity of sharp flashes as 0.1 Jy, and the average intensity as $3*10^{-4}$ Jy. Intensity of SMART-1 microwave impact flash may be significantly higher at the wavelength of SMART-1 radio signal equal to 13 cm based on theoretical study of dependency of intensity of such radiation on wavelength [2]. Estimation of upper limit of impact-produced radio emission during SMART-1 impact is possible based on interferometric observations of this event with time resolution of 10^{-6} s at other telescopes.

Conclusions: Special technique was developed for determination of the nature of detected variations of lunar radio flux. Previously strong oscillations of lunar flux at 13 and 21 cm were detected after several hours after Lunar Prospector collision with the Moon [3]. These results as well as other observations of quasi-periodic fluctuations of the lunar radio flux can be explained by telescope vibrations. Influence of SMART-1 impact on lunar radio flux at 3.6 cm was not detected during several hours after SMART-1 impact. Possibility of detection of SMART-1 impact radio flash is estimated.

References: [1] Gokhberg M.B. et al. (1995) Earthquake prediction - Seismoelectromagnetic phenomena, Amsterdam, Gordon and Breach Publishers, 195 p. [2] Grimalsky V. et al. (2004) *Natural Hazards and Earth System Sciences, 4*, 793-798. [3] Khavroshkin O.B. et al. (2001) *Doklady Earth Sciences, 376*, 90-92. [4] Berezhnoy A.A. et al. (2002) *Baltic Astronomy, 11*, 507-527. [5] Volvach A.E. et al. (2004) *Kinematics and Physics of Celestial Bodies, Suppl. Ser., 2*, 32-36. [6] Osaki H. et al. (2001), *Journal of the Communications Research Laboratory, 48*, 159-162. [7] Ortiz J.L. et al. (2002) *ApJ, 576*, 567-573. [8] Takano T. et al. (2005) *Proc. 4th European Conference on Space Debris,* ESA/ESOC, Darmstadt, Germany, p.501-505