THE LUNAR RADIO FLUX DURING LEONID METEOR SHOWERS AND LUNAR ECLIPSE

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Significance variations of lunar radio flux at the wavelength of 2.46 cm were detected in Irbene (Latvia) during the maxima of Leonid shower on the Moon in 2000 and 2001. These results were interpreted as detection of lunar radio emission of seismic origin. However, radio observations of the Moon at the wavelength of 6 cm in Ukraine did not show any signal enhancement of lunar radio flux on November 17–19, 2001. Except meteoroid impacts, the eclipses can lead to increasing of intensity of non-thermal radio emission due to formation of micro cracks in lunar regolith when the regolith temperature during eclipses is quickly changes. The results of simultaneous observations of the full lunar eclipse at the wavelengths of 18 cm and 1.35 cm in Simeiz (Ukraine) and Pushchino (Russia) on November 8–9, 2003 are presented. According to these observations the correlation between fluctuations of lunar radio flux at both wavelengths is absent. Thus, the previously detected fluctuations of lunar flux at the wavelength of 2.6 cm may have the instrumental origin. Lunar origin of detected fluctuations could be confirmed by simultaneous observations at two radio telescopes. Our future goal is try to detect the lunar radio emission of seismic origin at the lower frequencies, because the intensity of such emission during the earthquakes increases with a decreasing frequency.

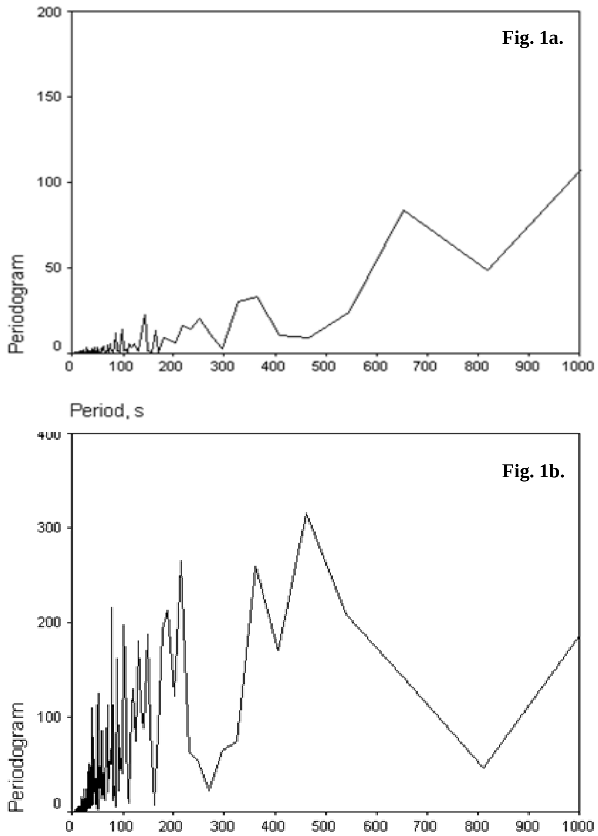
INTRODUCTION

Meteoroid impacts onto the Moon might be observable from the Earth. The meteoroid stream most likely to be detectable is the Leonids, remnants of the comet 55P/Tempel–Tuttle. Optical flashes from Leonid meteors hitting the dark side of the Moon were observed in 1999 [6]. An unsuccessful attempt to detect flashes of radio emission at the wavelength of 3.6 cm during optical flashes caused by Leonid's impacts onto the Moon in 1999 was carried out by [5].

The main component of the lunar radio emission is the thermal radiation. The lunar thermal radiation has been rather well investigated and it allowed us to estimate the density and electric properties of the porous lunar regolith, as well as the temperature regime of the surface layers. The frequency of electromagnetic radiation of the seismic origin measured before earthquakes ranges from 1 kHz to 1 MHz [3]. Radio emission of seismic origin can also be detected on the Moon.

Variability of lunar radio emission at 13 and 21 cm was detected on July 29 – August 2, 1999 [4]. During the Leonid meteoroid shower in 2000 and 2001 the variability of lunar radio flux at the wavelength of 2.46 cm was detected in Irbene (Latvia) [1]. The increasing of amplitude of the lunar radio flux variations during Leonid shower is interpreted as a result of excitation of the seismic waves on the Moon and the transformation of the seismic energy into the electromagnetic radiation. In this article we present the results of the Moon observations in Ukraine during Leonid shower in 2001 and in Japan in November 1999.

Except for meteoroid impacts, the eclipses can lead to increasing of intensity of non-thermal radio emission due to formation of micro cracks in lunar regolith when the regolith temperature quickly changes during eclipses.



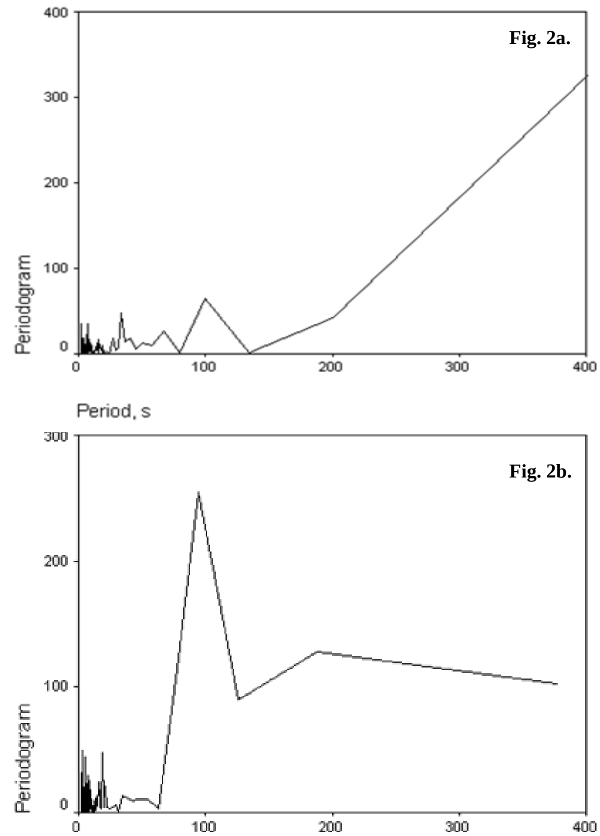


Figure 1. Periodogramms of radio flux from the Moon on November 18, 2001. Curve 1a shows the results of observations at 09:50–10:45 UT, curve 1b those of at 14:00–14:55 UT

Figure 2. Periodogramms of radio flux from Cyg A and the sky on November 18, 2001. Curve 2a shows the results of the sky observations in Simeiz at 8:32–8:38 UT, curve 2b those of Cyg A at 13:49–13:55 UT

The results of simultaneous observations of the full lunar eclipse are presented at the wavelengths of 18 cm and 1.35 cm in Simeiz and Pushchino on November 8–9, 2003.

OBSERVATIONS

During Leonid meteor showers

The observations of the Moon at the frequency of 8.2 GHz during Leonid meteor shower in 1999 were carried out using the 32 m radio telescope of the Kashima Space Research Center, Japan (36° N, 141° E) on November 15, 16, and 18. The bandwidth of the receiver is 800 MHz, the output time constant is 0.021 ms. Then the averaging of data was performed with a new output time constant equal to 1 s. The antenna was guided to the center of the lunar disc. The detailed description of the observations is given in [5]. The calibration sources and sky were not observed in Kashima. That's why the additional observations of the Moon at the frequency of 8.415 GHz were carried out on May 7, 2003 at RT-22 in Crimea (44° N, 35° E). The bandwidth of the receiver is 2 MHz, the output time constant is 1 s. The value of the sensitivity threshold for this time resolution is equal to 0.05 K. The antenna feed was left circular polarized. The antenna was guided to the center of the lunar disc. For calibration purposes the observations of the sky near the Moon and Vir A were also carried out. The duration of interrupted observations of each object is 20 min.

During November 17–19, 2001 the observations of the Moon at the wavelength of 6.2 cm were carried out in Simeiz. The frequency and the bandwidth of the receiver in Simeiz are 4.866 GHz and 2 MHz, respectively. The diameter of the radio telescope is 22 m, the output time constant is 1 s. The antenna feed was left circular polarized. The antenna was guided to the center of the lunar disc. The duration of interrupted observations of the Moon is 1 hour.

To verify whether the variations are attributed to the Moon we performed several tests that included recording signals from strong calibration source Cyg A and recording atmospheric radio emission, when the radio telescope tracked a position on the sky several degrees off the Moon and Cyg A.

During lunar eclipse

During November 8–9, 2003 the simultaneous observations of the Moon were carried out in Pushchino (55° N, 38° E) and in Simeiz (44° N, 35° E). The frequency and the bandwidth of the receiver in Simeiz are 1.666 GHz and 2 MHz, respectively. The frequency and the bandwidth of the receiver in Pushchino are 22.283 GHz and 6 MHz, respectively. The diameter of both radio telescopes is 22 m, the output time constant is 1 s. The antenna feed was left circular polarized in both cases. The antenna was guided to the center of the lunar disc.

To verify whether the variations are attributed to the Moon we performed several tests that included recording signals from strong source Cyg A 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 and Cyg A.

RESULTS

The mean amplitude of sporadic fluctuations of lunar radio flux at the frequency of 8.2 GHz was about five relative units on November 16 and 18, 1999. The amplitude of fluctuations of lunar radio flux did not increase at the time of predicted maximum of Leonid meteor shower on the Moon. The amplitude of fluctuations of lunar radio flux was equal to 200–300 relative units on November 16, 1999 at 9:20–10:50 UT. It can be explain by instrumental effects because Leonid activity was too low at that time interval.

The amplitudes of peak-to peak variations of signal from the Moon at the frequency of 8.4 GHz in Simeiz are equal to 2 K and comparable to those from the sky and Vir A. Fourier analysis shows the absence of periodicities of signal from all three objects.

The results of the Moon observations at the wavelength of 6.2 cm are quite different from those of at the wavelength of 2.46 cm. The amplitude of lunar radio flux variations at the wavelength of 6.2 cm in Simeiz is equal to 1–2 K during November 17–19, 2001 and did not increase at the time of predicted maxima of Leonid shower on the Moon. The amplitude of these variations is comparable with that of the sky and Cyg A. Spectral analysis shows the existence of periodicities of radio flux both from the Moon and from Cyg A and also from the sky. The values of periods vary chaotically versus time. All these facts confirm instrumental origin of detected variations.

According to simultaneous observations of the full lunar eclipse at the wavelengths of 18 cm and 1.35 cm in Simeiz and Pushchino on November 8–9, 2003 the correlation between fluctuations of lunar radio flux at both wavelengths is absent.

DISCUSSION

The Moon observations at the wavelengths of 3.6 and 6.2 cm do not give support to the lunar origin of detected variations. It can be explained by weak intensity of lunar radio emission caused by meteoroid bombardment at the wavelengths of 3.6 and 6.2 cm in comparison with that at the wavelength of 2.46 cm. To confirm the detecting seismic origin of lunar radio emission at the wavelength of 2.46 cm the additional simultaneous observations of the Moon at this wavelength are required by using two different radio telescopes.

The important feature of the variable lunar radio flux is its periodicity. The values of periods are situated between 1.5 and 12 min at the wavelengths of 2.46, 13, and 21 cm [1]. The spectral analysis of the radio signals variations from the sky, the Moon and Cyg A at the wavelength of 6.2 cm shows a general increase of the spectral density towards lower frequencies. The periods of oscillations of lunar radio flux at the wavelength of 6.2 cm range from 1 to 15 min (see Fig. 1). The amplitude of spectral power of the spectra at the wavelength of 6.2 cm from the sky and Cyg A is comparable with that from the Moon; the spectral maximum of the atmospheric fluctuations is at periods less than 2 min (see Fig. 2). Unfortunately, the observations of the sky and Cyg A have been carried out only during 5 min, but it is not enough to study of possible periodicities at 3–15 min range, where the lunar radio flux shows periodicities. There is fast variability of the values and intensities of spectral peaks from the Moon, from the sky, and also from Cyg A. It is known that Cyg A has not variability of its radio flux in 1 min range. This means that the instrumental effects can explain the periodicities of lunar flux at the wavelength of 6.2 cm. Thus, previously detected periodicities of lunar flux at other wavelengths must be checked again with simultaneous observations at two isolated antennas.

During impacts of meteoroids with the Moon the thermal radiation emits from the impact-produced fireball. Just after an impact, the seismic waves are excited, and a part of the seismic energy is transformed to the radio emission. The unsuccessful search for the impact-produced radio flashes was performed. The upper limit for the strongest radio flashes is equal to 3 K based on the Simeiz data. We can estimate the upper limit of intensity of the impact-produced radio flashes as $2 \cdot 10^{-8}$ J Hz^{-1} at the wavelength of 6.2 cm. We can suppose that radio flashes accompanying optical emission have the same duration as optical flashes (0.1 s). Let us assume that the mass of the biggest meteoroid collided with the Moon at the time interval of our radio observations is 2.5 kg as estimated by Ortiz *et al.* 2002. Using the model of Yanagisawa & Kisaichi [6] for thermal radiation from D$'$ flash, caused by the impact of 2.5 kg meteoroid, we can estimate that the flux of thermal radiation from such impact does not exceed $5 \cdot 10^{-15}$ J Hz^{-1} at the wavelength of 6.2 cm. Thus, the flux of thermal radiation from the impact-produced fireballs is too low for detection by radio telescopes. This estimation is confirmed with the radio flashes absence at the frequency of 8.2 GHz at the moments of big meteoroids impacts detected by Yanagisawa & Kisaichi [6].

The further theoretical, observational, and experimental study of the radio emission of the Moon is necessary to better understand the nature of the detected variations of lunar radio flux. The future study of the seismic origin of lunar radio emission must be performed at a few radio telescopes for accurate determination of an influence of the atmospheric fluctuations and instrumental effects. Monitoring of the lunar radio flux can give information about the time of maximal intensity of the strongest meteoroid showers on the Moon. Unfortunately, these moments were not estimated independently with other techniques. For example, the time determination of Leonid shower maxima on the Moon based on detection of the optical flashes on the Moon is practically difficult due to poor statistics. For study of the meteoroid bombardment intensity on the Moon with optical techniques, the methods for detection of the weak flashes must be developed. The LUNAR-A and SELENE spacecrafts are planned to launch to the Moon in nearest years. The LUNAR-A penetrators with sensitive seismometers will be installed on the lunar surface; these instruments can determine the moments of strong moonquakes and the maxima of meteor showers on the Moon. As a correlation between seismic radio emission and earthquakes is verified by Diakonov & Ulitin on Earth [2], we can expect the appearance of radio emission of the seismic origin during moonquakes. During moonquakes the release of radioactive gases Rn and Po from lunar interiors can occur, the SELENE alpha particle spectrometer can detect such events.

Except for meteoroid impacts, the eclipses can lead to increasing of the intensity of non-thermal radio emission due to formation of micro cracks in lunar regolith when the regolith temperature during eclipses is quickly changes. According to these observations a correlation between the fluctuations of lunar radio flux at both wavelengths is absent. Thus, the previously detected fluctuations of the lunar flux at the wavelength of 2.6 cm may have instrumental origin. The lunar origin of detected fluctuations could be confirmed by simultaneous observations using two radio telescopes.

CONCLUSION

Previously, it was reported that the strong oscillations of the lunar flux at the wavelength of 2.46 cm occurred at the moments of the predicted maxima of Leonid meteor shower on the Moon in 2000 and 2001. But the observations of the Moon at the wavelength of 2.46 cm were carried out at the unique antenna. An absence of the coincidence data obtained with other radio telescopes means that the instrumental origin of the detected fluctuations can't be exclude. To confirm the lunar origin of the variable lunar radio emission the simultaneous observations of the Moon must be carried out at a few radio telescopes during the lunar eclipses and the strong meteor showers. The radio flashes caused by collisions of kg meteoroids with the Moon were not detected at the wavelengths of 3.6 and 6.2 cm, the upper limit for the intensity of such flashes is estimated. In the future it is highly desirable the simultaneous study of the meteoroid bombardment and the seismic activity of the Moon with LUNAR-A penetrators, SELENE alpha particle spectrometer, single dish radio observations, and by monitoring of the optical flashes.

Our future goal is try to detect the lunar radio emission of seismic origin at the lower frequencies, because the intensity of such emission during earthquakes increases with a decreasing frequency.

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