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Simultaneous observations of the Moon at λ = 6.2 cm using 22-m radio telescopes at Pushchino and Simeiz during Leonid meteor shower in November 2001

The results of simultaneous observations of the Moon at λ = 6.2 cm in Pushchino and Simeiz on 17-19 November 2001 are presented. According to these observations, there are no evidences of influence of Leonid shower on the lunar radio flux. Correlation between fluctuations of lunar radio flux in Pushchino and Simeiz is absent. Impact-produced radio flashes are not detected; the upper limit for flux of such flashes is $2\cdot10^{-8}$ J/Hz at λ = 6.2 cm.

ОДНОЧАСНІ СПОСТЕРЕЖЕННЯ МІСЯЦЯ НА 22-М РАДІОТЕЛЕСКОПАХ У ПУЩИНО ТА В СИМЕЇЗІ ПІД ЧАС МЕТЕОРНОГО ПОТОКУ ЛЕОНІД В ЛИСТОПАДІ 2001 Р. НА ДОВЖИНІ ХВИЛІ λ = 6.2 СМ, Вольвач О. Е., Бережной О. А., Хаврошкін О. В., Коваленко А. І., Смирнов Г. Т. — Представлено результати одночасних спостережень Місяця під час максимуму метеорного дощу Леонід на однотипних радіотелескопах РТ-22 у Пущино та Симеїзі 17—19 листопада 2001 р. на довжині хвилі λ = 6.2 см. За даними спостережень немає підтвердження впливу метеорного потоку Леонід на радіовипромінювання Місяця. Відсутність кореляції між коливаннями місячного радіовипромінювання означає, що інтенсивність радіовипромінювання, що має сейсмічну природу, менша, ніж порогова чутливість обох радіотелескопів. Верхня межа реєстрації таких спалахів складала $2\cdot10^{-8}$ Ян/Гц на довжині хвилі λ = 6.2 см.

СОВМЕСТНЫЕ НАБЛЮДЕНИЯ ЛУНЫ НА 22-М РАДИОТЕЛЕСКОПАХ В ПУЩИНО И В СИМЕИЗЕ ВО ВРЕМЯ МЕТЕОРНОГО ПОТОКА ЛЕОНИД В НОЯБРЕ 2001 Г. НА ДЛИНЕ ВОЛНЫ λ = 6.2 СМ, Вольвач А. Е., Бережной А. А., Хаврошкин О. В., Коваленко А. И., Смирнов Г. Т. — Представлены результаты одновременных наблюдений Луны во время максимума метеорного дождя Леонид на однотипных радиоте-

лескопах РТ-22 в Пущино и в Симеизе 17—19 ноября 2001 года на длине волны λ = 6.2 см. Согласно данным наблюдений нет подтверждения влияния метеорного потока Леонид на радиоизлучение Луны. Отсутствие корреляции между колебаниями лунного радиоизлучения означает, что интенсивность радиоизлучения, имеющего сейсмическую природу, меньшая, чем пороговая чувствительность обеих радиотелескопов. Верхний предел обнаружения таких вспышек составлял $2\cdot10^{-8}$ Ян/Гц на длине волны λ = 6.2 см.

INTRODUCTION

Meteoroid impacts onto the Moon might be observable from the Earth. The meteoroid stream most likely to be detectable is the Leonids, remnants from the comet 55P/Tempel — Tuttle. Optical flashes from Leonid meteors hitting the dark side of the Moon were observed in 1999 [10]. An unsuccessful attempt to detect flashes of radio emission at λ = 3.6 cm during optical flashes caused by Leonid's impacts onto the Moon in 1999 was conducted by Osaki et al. [8].

The main component of the lunar radio emission is the thermal radiation. The lunar thermal radiation has been rather well investigated and it allowed the estimation of 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 seismic origin measured before earthquakes is in the kHz and MHz ranges [3]. There are several probable models on how a mechanic stress can be transformed in electromagnetic radiation: formation of new microcracks in the rock, charges arising at the peaks of existing cracks forming under the action of increasing load, the piezoelectric and piezomagnetic effects. Radio emission of seismic origin can be detected on the Moon also.

Fast variability of lunar radio emission at λ = 13 and 21 cm was detected on 29 July — 2 August 1999 [4]. There is a correlation between the variations of the lunar radio flux at both wavelengths, giving evidence of a common mechanism of radio emission. During the Leonid meteoroid shower in 2000 and 2001, variability of lunar radio flux at 2.46 cm was detected at Irbene in Latvia [2]. The increasing of amplitude of variations of the lunar radio flux during Leonid shower is interpreted as a result of excitation of seismic waves on the Moon and the transformation of seismic energy into the electromagnetic radiation. Another feature of variable radio emission is the existence of its oscillations with periods equal to some minutes. However, detected phenomena can have instrumental origin. For confirmation of lunar origin of variable lunar radio emission simultaneous observations of the Moon must be carried out with some radio telescopes. In this paper we present the results of simultaneous observations of the Moon in Russia and Ukraine during Leonid shower in 2001.

OBSERVATIONS

During 17-19 November 2001 simultaneous observations of the Moon at λ = 6 cm were conducted at Pushchino (55°N, 38°E) in Russia and at Simeiz (44°N, 35°E) in Ukraine. The frequency and the bandwidth of the receiver at Simeiz are 4.866 GHz and 2 MHz, respectively. The frequency and the bandwidth of the receiver at Pushchino are 4.830 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 centre of the lunar disk. The duration of interrupted observations of the Moon is 1 hour.

To verify if the variations are attributed to the Moon, we performed several tests that included recording signals from the 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

Results of observations of the Moon at $\lambda = 6.2$ cm are quite different from that at $\lambda = 2.46$ cm. McNaught [5] predicted three maxima of Leonid shower on the Moon in 2001 on 17 November, 16:03 UT (ZHR ~ 500), on 18 November, 14:16 UT (ZHR ~ 1000), and on 18 November, 16:28 UT (ZHR ~ 5000). The maxima of Leonid shower on the Earth were on 18 November, 10:39 UT (ZHR ~ 1600), and on 18 November, 18:16 UT (ZHR ~ 3400 [1]. Amplitude of variations of lunar radio flux at $\lambda = 6.2$ cm in Simeiz is equal to 1-2 K during 17—19 November 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 existence of periodicities of radio flux as from the Moon as from Cyg A and the sky. Values of periods vary chaotically versus time. All these facts confirm instrumental origin of detected variations.

Amplitude of variations of lunar radio flux in Pushchino is equal to 1-2 K before and after predicted second maximum of Leonid meteor shower on the Moon. But the amplitude of quasi-periodic fluctuations reached 3-4 K at 14—15 UT on 18 November 2001 (see Fig. 1). Intensities of spectral peaks of lunar radio flux were much weaker before and after Leonid's maximum than that at the time of maximum of the Leonid shower (see Fig. 2). Spectral analysis of lunar radio flux before maximum of Leonid shower shows periodicities with values between 2 and 13 minutes, but at the moment of Leonid's maximum spectral peaks with values between 30 and 120 s occur also. However, fluctuations of received signal from the sky and Cyg A with the same periods and amplitudes were detected at 15-16 UT. This means that detected fluctuations are caused by instrumental effects.

Analysis of simultaneous observations of the Moon shows the absence of correlation of fluctuations of lunar radio flux at both telescopes. The coefficient of correlation is equal to 0—0.05 for all data sets. The absence of correlation can be an evidence of instrumental or atmospheric origin of detected fluctuations. But observations were conducted on slightly different frequencies with different bandwidths of receivers. This fact can be interpreted also as existence of strong dependence of radio emission of seismic origin on frequency.

According to results of observations of the Moon in Kalyazin, after 9—12 hours from the Lunar Prospector impact with the Moon on 31 July 1999 the lunar radio flux at 13 and 21 cm increased by 20—40 %, but after 35 hours from the impact it returned to the value of 30 July [4]. However, measurements

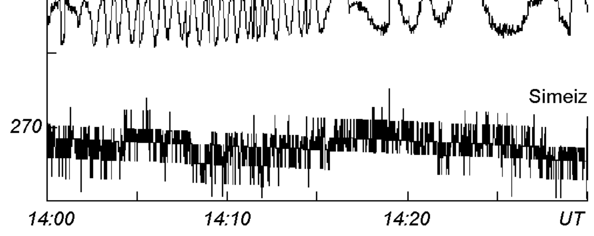

Fig. 1. Brightness temperature of the Moon at 6.2 cm at 14:00-14:30 UT on 18 November 2001. Curve *1* is for Pushchino data, curve *2* shows Simeiz data

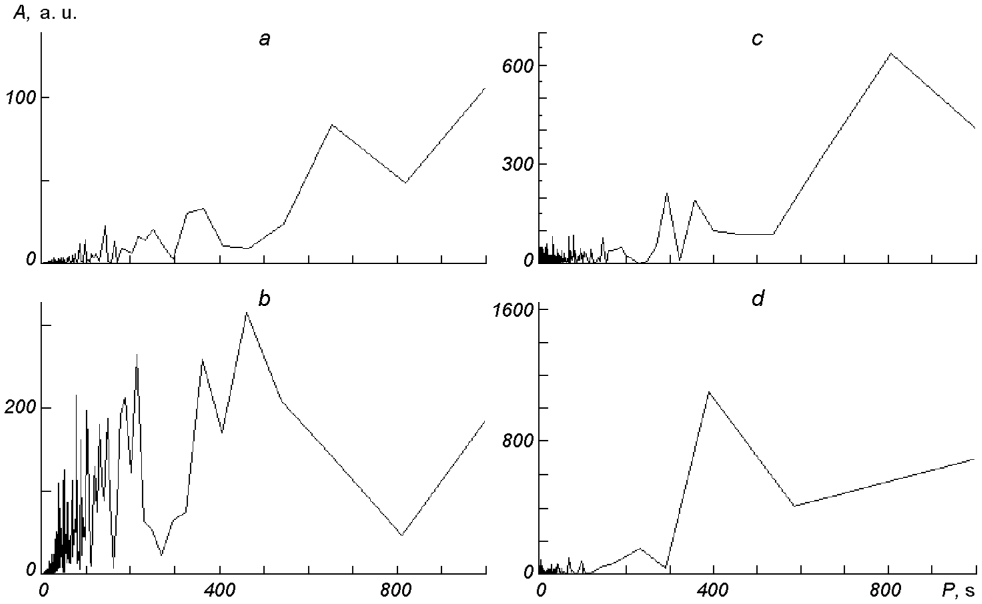

Fig. 2. Relative spectral amplitude of radio flux from the Moon at $\lambda = 6.2$ cm at 09:50—15:30 UT on 18 November 2001. Curve *a* represents Pushchino data at 9:50-10:45 UT, curve *b* illustrates Pushchino data at 14:00-14:55 UT, curves *c* and *d* show Simeiz data at 13:56-14:50 and 15:11-15:30 UT, respectively

of absolute brightness temperature of the Moon at $\lambda = 6.2$ cm in Simeiz and Pushchino with an accuracy of 5 % did not show increasing of brightness temperature with increasing intensity of meteoroid bombardment. To confirm surprising results obtained in Kalyazin, more accurate estimations of the absolute radio temperature of the Moon are needed.

DISCUSSION

Let us check the lunar origin of detected variations. Disturbed ionosphere can be responsible for variations of lunar radio signal detected on the Earth. Ionospheric oscillations at 12 and 20 GHz with peak-to-peak fluctuations of up to 20 % during 10-30 minutes occur at the times of geomagnetic storms at equatorial and polar latitudes [6]. Let us note that variations of lunar radio flux were detected in middle latitudes and under quiet geomagnetic conditions. Ionospheric oscillations are night-time phenomena and they become stronger with decreasing frequency, but variations of lunar radio flux does not show such a behaviour. This rules out ionospheric origin of detected variations.

Ionospheric oscillations of intensity of received lunar radio signal caused by formation of meteor plasma tails in the upper Earth's atmosphere were not detected at all radio telescopes. The detection of such pulses cannot be a very frequent event, because the antenna beam is so narrow. However, short-term oscillations of transionospheric signal from artificial satellite of the Earth at $\nu = 244$ MHz with a duration of 30—50 s were detected during Leonid shower in 1998 [9]. Ionospheric oscillations at $\lambda = 2.46$ cm with duration of about 30 s were detected also at 13:40 UT on 18 November 2001 [2]. But duration of fluctuations detected in Pushchino is more than 30 minutes and meteor plasma tails are unstable during such a long period of time.

Observations of the Moon at $\lambda = 6.2$ cm do not give support to lunar origin of detected variations, because correlation between these variations at two isolated radio telescopes is absent. This can be explained by a weak intensity

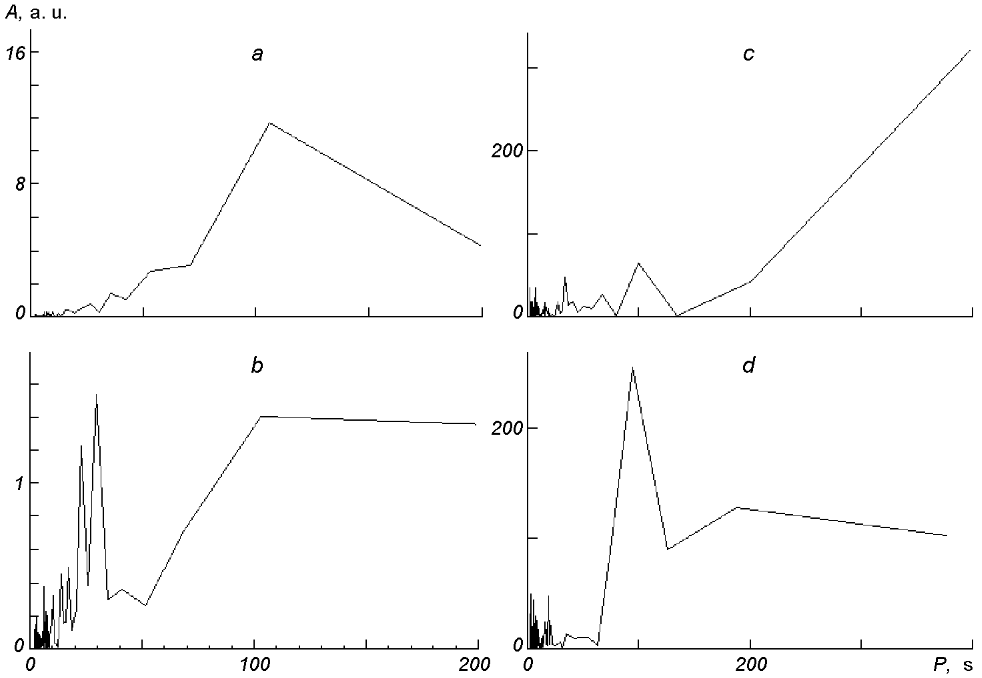

Fig. 3. Relative spectral amplitude of radio flux from Cyg A and the sky on 18 November 2001. Curve a represents observations of the sky in Pushchino at 9:40:30—9:46:00 UT, curve *b* illustrates Cyg A at 10:48:30—10:52:10 UT. Curve *c* shows results of observations of the sky in Simeiz at 8:32—8:38 UT, curve *d* is for Cyg A at 13:49—13:55 UT

of lunar radio emission caused by meteoroid bombardment at λ = 6.2 cm in comparison with that at 2.46 cm. For study of dependence of lunar radio emission of seismic origin on wavelength, simultaneous observations of the Moon at many frequencies during active meteor showers must be carried out.

An important feature of variable lunar radio flux is its periodicity. Values of periods are between 1.5 and 12 minutes at λ = 2.46, 13, and 21 cm [2]. A spectral analysis of the variations of radio signals from the sky, the Moon, and Cyg A at λ = 6.2 cm shows a general increase of the spectral density towards lower frequencies. The periods of oscillations of lunar radio flux at λ = 6.2 cm are in 1—15 minute range (see Fig. 2). Amplitude of spectral power of spectra at λ = 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 two minutes (see Fig. 3). Unfortunately, observations of the sky and Cyg A were conducted only during five minutes, which is not enough for study of possible periodicities at 3-15-minute range, where lunar radio flux shows periodicities. There is a fast variability of values and intensities of spectral peaks as from the Moon as from the sky and Cyg A. It is known that Cyg A has not variability of its radio flux in minute range. The values of detected periods of signal from the Moon at the same time in Pushchino and Simeiz are quite different (see Fig. 2). This means that instrumental effects can explain periodicities of lunar flux at λ = 6.2 cm. Thus, previously detected periodicities of lunar flux at other wavelengths must be checked again by simultaneous observations at two isolated antennas.

During impacts of meteoroids with the Moon thermal radiation emits from the impact-produced fireball. Just after an impact, seismic waves are excited, and a part of seismic energy is transformed to radio emission. An unsuccessful search for impact-produced radio flashes was performed. The upper limit for strongest radio flashes is equal to 3 K, based on Simeiz and Pushchino data. We can estimate the upper limit of intensity of impact-produced radio flashes as $2 \cdot 10^{-8}$ J/Hz at λ = 6.2 cm. The duration of optical flashes caused by meteoroid impacts does not exceed 0.1 s. We can suppose that radio flashes accompanying optical emission have the same duration. Flux of thermal radiation from impact-produced fireball is too low for detection by radio telescopes. Let us assume that the mass of biggest meteoroid collided with the Moon at the time interval of our radio observations is 2.5 kg as estimated by Ortiz et al. [7]. Using the model of Yanagisawa and Kisaichi [10] for thermal radiation from flash D', caused by impact of meteoroid with same mass, we can estimate that flux of thermal radiation from such an impact does not exceed $5 \cdot 10^{-15}$ J/Hz at λ = 6.2 cm.

CONCLUSIONS

Previously it was reported that strong oscillations of lunar flux at λ = 2.46 cm occurred at the moments of predicted maxima of Leonid meteor shower on the Moon in 2000 and 2001 [2]. But observations of the Moon at 2.46 cm were conducted at unique antenna. Absence of coincidence data on other radio telescopes means that instrumental origin of detected fluctuations cannot be ruled out. For study of instrumental effects simultaneous observations of the Moon at very similar frequencies in Pushchino and Simeiz were conducted. Correlation between fluctuations of lunar radio flux at ν = 4.866 and 4.83 GHz was absent. This means that intensity of radio emission of seismic origin is less than sensitivity of both telescopes. Radio flashes caused by collisions of kg-meteoroids with the Moon were not detected, and the upper limit for intensity of such flashes is estimated.

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