ABOUT EXPANSION OF TERRESTRIAL RADIOPHYSICAL METHODS FOR DETECTION OF ULTRA-HIGH-ENERGY COSMIC RAY

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ABSTRACT. Low arrival density of the ultra-high-energy cosmic rays is one of the main obstacles of their experimental research.

Overcoming this problem was based on the increase in the sensitive area of terrestrial facilities. Currently, the area of such installations reached a practical limit. The further development of researches is connected with remote registration of accompanying electromagnetic radiation. The projects of remote sensor installation on space vehicles are known. In this work the opportunity of use of ground-based radio telescopes and Moon, as return reflector, for global remote detection of electromagnetic bursts caused by space ultra-high-energy cosmic rays in an atmosphere of the Earth is considered.

Key words: cosmic rays, extensive air showers, HF signal, Moon reflection, radio telescopes.

Result of interaction of cosmic ray (CR) with substance is the cascade shower of secondary particles The cascade shower in an atmosphere have the name of extensive air showers (EAS). The observation of EAS is the main method of CR study in case of kinetic energy $W > 10^{15}$ eV. The ground observatories with ionization and scintillation detectors have ensured study of CR with energy up to 10^{17} eV. The intensity of cosmic ray sharply decreases with increase of energy of particles. There are 10^7 events with $W > 10^{15}$ eV and only one event with $W > 10^{19}$ eV on the area 1 km^2 per one year. Therefore increase of the detector area is necessary for study of ultra-high-energy cosmic ray. Therefore for study of ultra-high-energy cosmic ray increase of the detector area is necessary. The modern ground installations have the area up to thousand square kilometers (for example Pierre Auger Observatory – 3000 km^2) That allows to register events with energy of particles up to 10^{20} eV. The following stage is connected to use of remote sensor placed on space vehicles. One of the projects is EM-EUSO. This is a new type of observatory that uses the transient luminous phenomena taking place in the earth's atmosphere caused by particles coming from space. The sensor will detect extreme energy particles with energy above 3×10^{19} eV. The EM-EUSO observation area exceed is exceeding 10^5 km^2.

One of remote methods of superhigh-energy cosmic ray study is the detection of shower radioemission (Filonenko, 2002). Radio signal generates by the secondary electrons and positrons of the shower.

In this paper we consider an opportunity of use of the Moon as reflector EAS radioemission from all terrestrial hemisphere. As remote sensors can be used decameter wavelength radiotelescopes of URAN VLBI.

Space diversity on hundred kilometers radiotelescopes are triangulation network for definition of EAS coordinates and angle of cosmic ray arrival. In a fig. 1 presents the plan of EAS observation with lunar radio reflections.

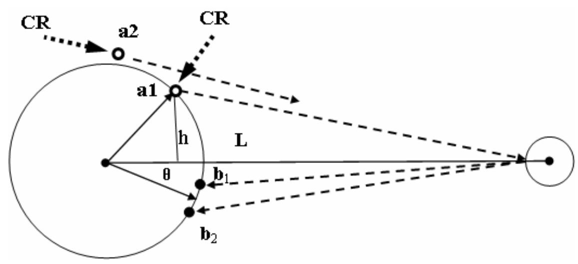

Figure 1: The plan of EAS observation with lunar radio reflections. **CR** and **dashed line** – transit and non transit cosmic ray way, **dashed line** – radio propagation paths, $\mathbf{a_1}$ and $\mathbf{a_2}$ – places of EAS radioemission, $\mathbf{b_1}$ and $\mathbf{b_2}$ – radiotelescopes, **L** – line connecting Earth with Moon, **θ** – the angle between **L** and direction to triangulation base of radiotelescopes.

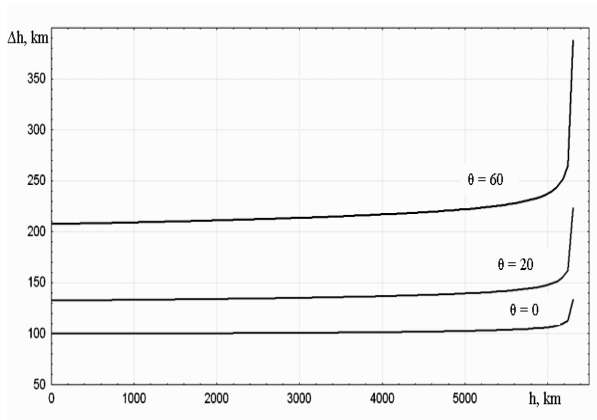

Figure 2: Absolute errors of EAS coordinates definition (triangulation base is 500 km, time resolution is 10^{-6} s)

After synchronic measurement of EAS radio signal lag on three telescopes we can calculate coordinates of EAS. Now afford calculate angle of cosmic ray arrival, if relative position Moon end Earth is known. In a fig. 2 presents absolute errors of EAS coordinates (Δh) definition as function of argument h (look fig.1). Three curves correspond to three sizes of a angle θ, degree.

The realization of this plan is possible if: radiowave power flux density will be sufficient; intensity of CR events will be sufficient. We shell estimate this conditions below.

The moving clot of EAS particles takes the form of a disk. Its thickness is about 2 meters and diameter from tens up to hundreds meters and more. Power of coherent radioemission of disk dominates among other type of EAS emission in high frequency range. Therefore directivity diagram of EAS radioemission define by directivity diagram of disk aperture.

Approximation of the directivity diagram in the field of the main lobe:

$$F(\alpha) = \exp\left[-1{,}38(\alpha/2\alpha_0)^2\right],$$

where α – angle between beam axis end emission direction, $2\alpha_0$ – beam width ($2\alpha_0 \approx 60\lambda/d$).

Me assume that the area of the disk is proportional *W*. Experimental result is d = 100 m, when $W = 10^{17}$. It is possible to write: $d = 2{,}16\cdot10^{-6}\sqrt{W}$. In a fig. 3 presents directivity diagram of EAS radioemission.

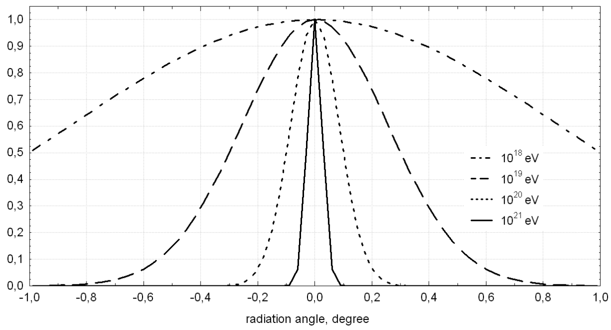

Figure 3: Power pattern of EAS radioemission. Frequency 30 MHz, X-axis radiation angle α, degree.

For estimation of radiowave power flux density me are used next formulas $\left|\overline{\Pi}_0(\alpha,\beta)\right| = (P'G_1/4\pi R_L^2)F(\alpha)^2$, where $G_1 = 1{,}98\cdot10^{-12}\,W/\lambda^2$, P' – EAS radioemission power, R_L – distance between the Earth and the Moon. For estimation of P' me are used theoretical and experimental data from Filonenko (2002). It was assumed, that $P' = b\cdot W$. For $W = 10^{21}$ and frequency band 1 MHz estimation is $P' = 80\ Watt$. Appropriate power flux density near the radiotelescope is $5\cdot10^6\,Jn$. It considerably is exceed power flux density of cosmic sources and solar bursts in decameter wavelength.

The estimation of intensity of EAS-events which can be registered by ground-base radiotelescopes is carried out. The results presents in Table 1.

Table 1: Intensity events in EAS-Moon reflection method

particle energy, lgW eV	angle of aspect, steradian	number of events	
		per annum	per diem
19	$3\cdot10^{-4}$	71154	195
20	$3\cdot10^{-5}$	7906	21.66
21	$3\cdot10^{-6}$	1	

References

Filonenko A.: 2002, *Uspehi fizicheskih nauk*, **172**, 439.