Monitoring of Cherenkov Emission Pulses with Kalyazin Radiotelescope: real sensitivity and prospective program

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Abstract. Possibilities of searching for the Cherenkov emission pulses from super-high-energy particle cascades by monitoring of the Moon with Kalyazin 64-meter radiotelescope are considered. Sensitivity of the available facilities and a level of man-made interference at the radiotelescope site are estimated. Some details of a proposed experiment are described.

INTRODUCTION

In the mid-1980s Igor Zheleznykh and the people of his team from Institute for Nuclear Research of Russian Academy of Sciences actively worked out the RAMAND (Radio Antarctic Muon and Neutrino Detector) project [1,2]. The project was based on one of the brightest idea by Gurgen Askaryan [3,4] to detect high-energy cosmic rays by detection of Cherenkov emission pulses produced by the negative charge excess of cascades generated in relatively dense dielectric medium when the high energy particle interacts with atoms of the dielectric. The properties of Antarctic ice make it possible to use an effective target of 10^9 or even 10^{11} m^3 [5].

To discuss the possible ways of improving the efficiency of the experiment Igor Zheleznykh and his colleagues contacted me and some other people from Pushchino Radio Astronomy Observatory. It seems that our discussion was rather fruitful and during the discussion Igor formulated his new idea to enlarge the target volume by observing the Cherenkov emission pulses from the Moon. First estimates had shown that the large meter-wavelength radiotelescopes of Pushchino Radio Astronomy Observatory (DKR-1000 and BSA FIAN) were not suitable for such observations because they could track the Moon for only few minutes around its culmination and their frequency ranges were too far from the expected maximum. On the other hand, the estimates revealed that using the already existing fully-steerable radiotelescopes of 70-meter (and more) diameter we could hope to detect at decimeter and centimeter wavelengths the Cherenkov pulses from 10^{20} eV cascades.

RAMHAND PROJECT

The following more careful considerations confirmed, in general, the rather optimistic estimates mentioned above. The new project was named RAMHAND — RAdio Moon Hadron And Neutrino Detector [5,6] because Cherenkov emission pulses have to be emitted after interactions of hadrons with the atoms of lunar regolith and the corresponding events could be observed near outer ring of the lunar disk. Sensitivity of this giant neutrino telescope is determined mainly by effective area of the ground-based antenna used as a detector and by the wavelength of observations. The power of the coherent Cherenkov emission pulse should be proportional to E^2, where E is the energy of the cascade. The expected rate of the events depends on the spatial density of particles in corresponding energy range and from the effective total mass of the target.

Using a predicted spectrum and some other parameters of the Cherenkov emission pulses it had been shown [5–8] that the pulses arising from interaction between particles of 10^{20} eV with the Moon's regolith should be about 5 times the r.m.s. noise level when observed with 70-meter ground-based radiotelescope. However, the expected rate of such events is very low and all *a priori* information about the pulses should be used to separate the real signal from noise fluctuations and the interference. For example, predicted short duration (several nanoseconds) of expected pulse could help to extract it from some types of man-made interference. The continuous spectrum of the predicted emission provides efficiency for multi-frequency observations together with coincidence schemes. Taking into account a dispersion delay of the signal in the Earth's ionosphere and using multi-frequency observations it could be possible to reject many sources of narrow-band and wide-band interference. Finally, spatial correlation of the signal enables using the simultaneous monitoring with several radiotelescopes separated by large distances.

A small variation of the RAMHAND project was suggested in the mid-1990s [9,10]. The possibility to use an on-board antenna orbiting the Earth or even a lunar satellite was considered. It was pointed out that neutrinos of somewhat lower ($\approx 10^{18}$ eV) energy could be detected in these cases.

To realize the main RAMHAND project one or several large fully-steerable radiotelescopes equipped with rather good receivers and special terminals of very high ($\approx$10 nsec) time resolution were needed. By the end of the 1980s and in beginning of the 1990s, there were no such terminals at our radiotelescopes and we could not start the monitoring of pulses from the Moon.

IMPORTANT RESULTS OF 1990S

Already the first discussions of the RAMHAND project with physicists and astronomers at "Neutrinos-88" [5], "Quarks '88" [6], USSR-USA Seminar on High Energy Astrophysics (Tbilisi, 1999) and other meetings showed that some of our colleagues did not believe the Cherenkov emission pulse monitoring would succeed because of several far extrapolations and rather rough estimates that were used in calculations of the pulse intensities and the rate of the observable events. New and more careful theoretical considerations as well as computer simulations were needed to overcome this scepticism. In the beginning of the 1990s besides Zheleznykh's team [11] the theoretical aspects of the problem were studied by Halzen, Zas and Stanev [12,13] and later by Alvarez-Muniz and Zas [14,15]. The results of computer simulations described in these papers confirmed as a whole preliminary optimistic RAMHAND project estimates and predicted duration, spectrum and some other parameters of Cherenkov pulse emission. For example, calculated the spectrum maximum position $\nu_{\max} = 2$ GHz or higher (compare with $\nu_{\max} = 1$ GHz used for earlier estimates).

The first attempt to detect the Cherenkov emission pulses from the Moon was made by T. Hankins, R. Ekers and J. O'Sullivan [16]. Using the Parkes 64-meter radiotelescope with a wideband (1187-1662 MHz) receiver and high time-resolution (of few nanoseconds) oscilloscope they observed the Moon for about 10 hours. No pulses of 1 nanosecond duration with flux density above 4000 Jy were detected during the observations.

Another attempt was made by P. Gorham, K. Liewer and C. Naudet [17] using the NASA Goldstone 70 m and 34 m antennas. The observations were made at S-band ($2.2 - 2.3$ GHz) for a total of 12 hours: 8 hrs in dual-antenna and 4 hrs in single-antenna mode. An L-band (1.6 GHz) receiver was used at 70 m antenna simultaneously with S-band receiver. During the observations the 1.6 GHz beam was pointed 0.5° away from the 2.2 GHz beam. Coincidences and anti-coincidences (between S- and L-band receivers) scheme were used during observations and processing so that almost all interference was rejected. So only the system noise of 400 Jy r.m.s. fluctuations limited the final sensitivity. No pulses of expected duration with flux density more than 6 r.m.s., i.e. 2400 Jy, were detected in 12 hours. The corresponding neutrino energy threshold was 5×10^{19} eV.

The negative results of both experiments are not surprising. Indeed, the upper limits to the event rates found in the experiments are above most theoretical estimates, and exclude only very exotic theoretical models like a Universe with super-conducting strings and so on. It was obvious, to test more real models, the observations of hundreds hours with sensitivity which was realized already were needed. Nevertheless, the scepticism mentioned above could be increased after these negative results. Fortunately, two excellent laboratory experiments [18,19] were fulfilled by UCLA/NASA group of physics shortly after the publication of Goldstone results. Using Argonne Wakefield Accelerator and Stanford Linear Accelerator authors of [18,19] have modeled the cascades of 10^{18-19} eV in silica sand target and showed that they had the expected negative excess and measured the radio pulses from the cascades. It turned out that measured energy dependence of the pulse amplitude is very close to that predicted before. On the other hand, the maximum of the pulse emission spectrum is at least at 8 GHz or even higher frequency. So, nothing is left for scepticism after the last two papers and the flux of neutrinos with energy $E \geq E_0$ can be directly found from the measured (or estimated) rate of the pulses with flux densities S above corresponding limit $S \geq S_0$.

PREPARATIONS TO MONITORING WITH KALYAZIN RADIOTELESCOPE

The 64-meter fully-steerable dish of OKB MEI (Special Construction Bureau of Moscow Power Institute) near Kalyazin town, which is about 200 km to north of Moscow, was constructed in 1992 for the deep space network service and for radioastronomical observations. Now this radiotelescope is equipped with receiving and recording complex mainly for pulsars and VLBI observations [20]. (see Figure 1). There is Kalyazin laboratory of Pushchino Radio Astronomy Observatory supporting most of these observations.

Today the Kalyazin 64 m radiotelescope is one of the most suitable tool for searching the Cherenkov emission pulses from the Moon in Russia. The radiotelescope

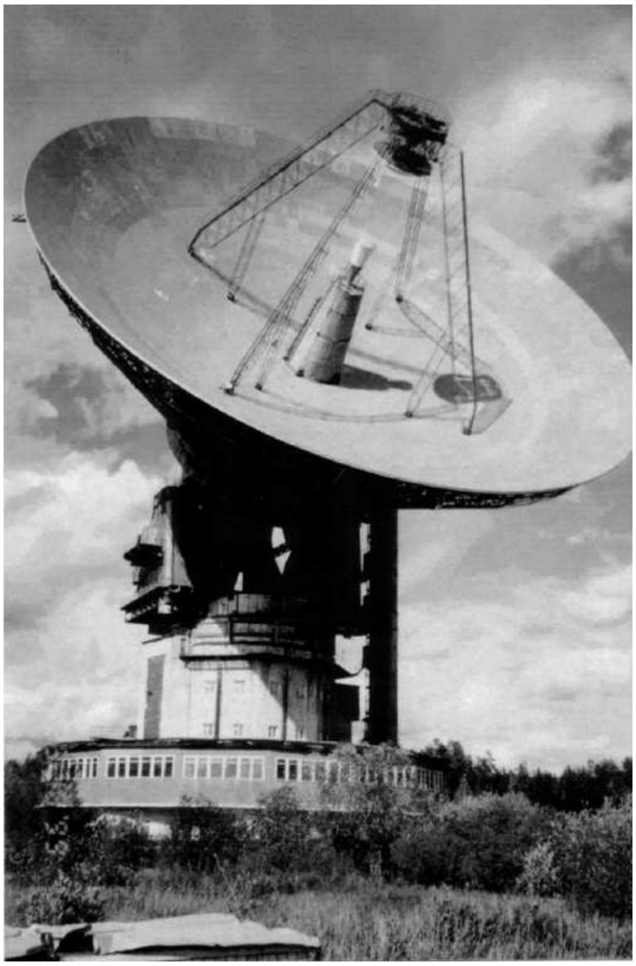

FIGURE 1. Kalyazin 64-meter radiotelescope.

is of alt-azimuth mount. There is a 6 m secondary reflector and a multi-frequency feed placed at a Cassegrain focus. There are five dual- channel (LCP/RCP) receivers for 0.6, 1.4, 2.3, 4.8 and 8.3 GHz frequency bands. Four of them (except 4.8 GHz receiver) can be used in simultaneous observations. System noises are less than 100 K at all mentioned frequencies, so the Moon brightness temperature will determine the noise fluctuations during proposed observations. The radiotelescope is equipped with Canadian S2 VLBI terminals of 32 MHz bandwidth. There is precise time service at radiotelescope.

There is a good experience in using the Kalyazin radiotelescope in pulsar and VLBI observations. Most observations are free from any strong interference. Figure 2 shows the short pieces of records during observations of two pulsars with Kalyazin radiotelescope.

The observations were made with S2 recording terminals in LCP-channels. Original time resolution was 30 nsec. Total duration of each Fig.2 piece is 10 seconds and the all three are averaged over 10 milliseconds. The spike near the beginning of Fig.2a record is one of giant pulses of Crab nebulae pulsar. Most of spikes at Fig.2c are the pulses of PSR 0329+54. After subtraction of these spikes from the original (non averaged) records the distributions of fluctuations at both frequencies are very close to Gaussian with standard deviations corresponding to expected system noise level.

We are planning to start the monitoring of the Moon with Kalyazin 64m radiotelescope at two or three frequencies before mid-2001. For the beginning we are going to use S2 recording systems as terminals.

CONCLUSIONS

It seems that now radio astronomers are close to getting the real estimate of extremely-high-energy neutrinos flux or at least a very strong upper limit of it. However, the rate of Cherenkov emission pulses from the Moon should be very low, and may be not more than one or two per month. To increase the reliability of such estimates and perhaps to determine the position of the cascade at lunar disk the simultaneous monitoring with two or three radiotelescopes separated by hundreds or thousand kilometers is very desirable. Several European radiotelescopes could be joined in such program. Close collaboration between radio astronomers from different countries should help us to solve this task.

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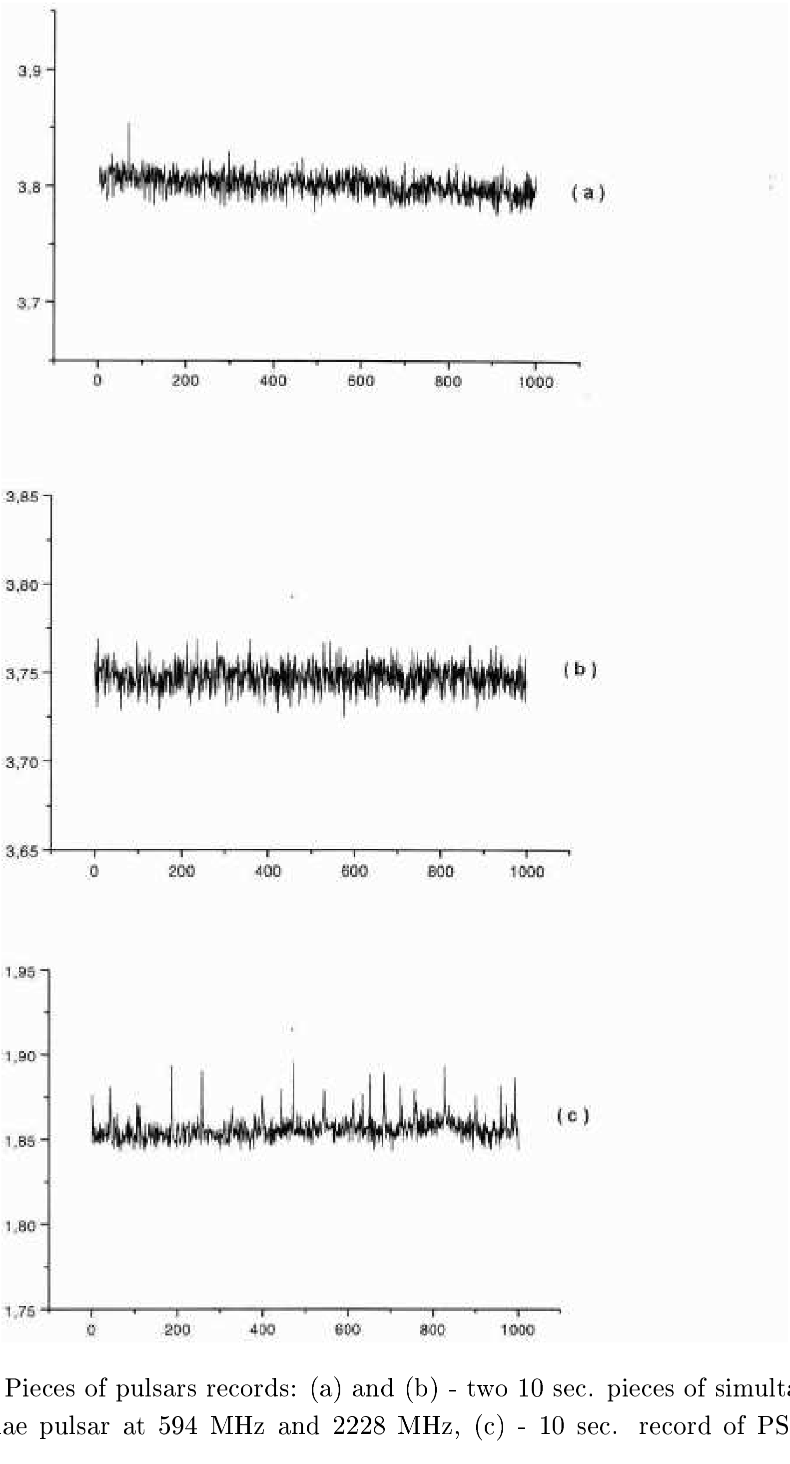

FIGURE 2. Pieces of pulsars records: (a) and (b) - two 10 sec. pieces of simultaneous records of Crab nebulae pulsar at 594 MHz and 2228 MHz, (c) - 10 sec. record of PSR 0329+54 at 2244 MHz

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