Astronomical and Astrophysical Transactions (*AApTr*), 2025, Vol. 35, Issue 4, pp. 393–398,
ISSN 1055-6796, Photocopying permitted by license only, ©Cambridge Scientific Publishers

Search for sub-microsecond bursts of Cherenkov radio emission caused by the interaction of high-energy neutrinos with lunar regolith

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Received 18 June, 2025; accepted 17 July, 2025

Works by G.A. Askaryan in the 1960s [1,2] have shown the interaction of high-energy particles (including neutrinos) with dense dielectric matter lead to the formation of cascades with an excess of electrons moving in a medium at superluminal speed. The radio astronomy method for detecting ultrahigh-energy neutrinos, proposed in the work of R.D. Dagkesamansky and I.M. Zheleznykh, is based on the Askaryan effect [3]. This article provides a brief overview of the application of the radio astronomy method to search for Cherenkov radio bursts from the Moon. Some results of the search for such radio bursts on the BSA meter-wavelength radio telescope are presented.

Keywords: Cherenkov radio bursts

1 Introduction

It is believed that the energy of charged particles accelerated in active galaxies can reach values obviously higher than 10^{21} eV, however, a blockage is observed in the spectrum of detected particles at energies of 10^{19} eV. The fact is that the cross-section of the interaction of cosmic rays with photons of the microwave background increases markedly with the energy of the particle, so that at energies of the order of 10^{19} eV, cosmic rays have an effective free path of only about 50 Mpc (the so-called Greisen–Zatsepin–Kuzmin effect [4]). This means that extremely high-energy cosmic rays do not reach the Earth from farther distances, and there are not many powerful galaxies with active nuclei within a radius of 50 Mpc. On the other hand, as a result of the interaction of high-energy cosmic ray nuclei with photons of cosmic microwave background radiation, neutrinos with energies about an order of magnitude lower than the energy of the primary particle are generated. So, in the range of $10^{19–20}$ eV, we can expect the appearance of a multitude of isotropically directed GZK neutrinos, against which neutrinos propagating directly from active galactic nuclei should be

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detected. It is quite obvious that the registration of extremely high-energy neutrinos would bring very important information both about the processes occurring in the cores of active galaxies and about the conditions of cosmic ray propagation in the intergalactic medium. However, the small flux of high-energy neutrinos, as well as the very small cross-section of the interaction of these particles with the surrounding matter, greatly complicate this task.

The basis for the development of the radio astronomy method is the theoretical work of G. A. Askaryan [1], which determines the amount of excess electric charge in an electromagnetic shower formed in the lunar soil during interaction with a particle with energies of $10^{19–20}$ eV, which is the source of Cherenkov bursts of coherent radiation in the radio range. For the first time, the idea of using ground-based radio telescopes to detect short radio bursts from the lunar surface was discussed in the works of R.D. Dagkesamansky and I.M. Zheleznykh (1989) [3].

2 Observations at the BSA

To register the signal coming from the radio telescope, the observatory's radio engineer A.A. Salnikov [5] developed and manufactured a rapid registration system. This system registers the voltage coming from the radio telescope in the band from 110 to 112 MHz, with a time resolution of 0.25 microseconds. In other words, the voltage values at the output of the receiving device are taken with an interval of a quarter of a microsecond. Each observation session has a duration of about 0.5 hours (+/–15 minutes from the moment of the Moon's upper climax). The information was collected with a time resolution of a quarter of a microsecond for about 18 seconds, after which the received information was flushed from the flash card to the hard disk. Then the procedure for removing information was repeated. During a half-hour observation session, about a hundred 18-second recording segments were obtained, which were later processed offline. The duration of the session was chosen to be significantly longer than the time spent by the Moon in the main beam of the radiation pattern (which, as noted above, is only about 7 minutes) in order to compare the frequency of bursts of significant amplitude when the Moon is in the main beam of the diagram and when the Moon is outside the main beam.

Pre-processing of records

The procedure for processing off-line each of the 18-second recording segments was as follows:

1. Fourier transform of a data array including 72 million samples.
2. Correction of the phase of the Fourier transform in order to compensate for the measure of dispersion that occurs when a signal passes through the ionosphere; this adjustment consisted of adding a linear frequency function to the phase of the Fourier transform.
3. Reverse the Fourier transform and find the maximum value of the amplitude of the corrected signal.

Procedures 2 and 3 were performed for 20 different values of the dispersion measure, after which the value of the dispersion measure (DM) was selected for which

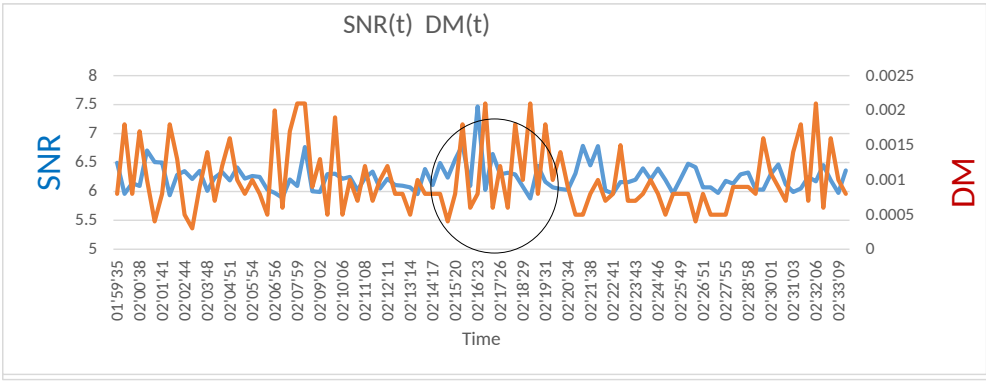


Figure 1 The dependence of SNR ¿5 on time, and the corresponding DM values, date February 17, 2021.

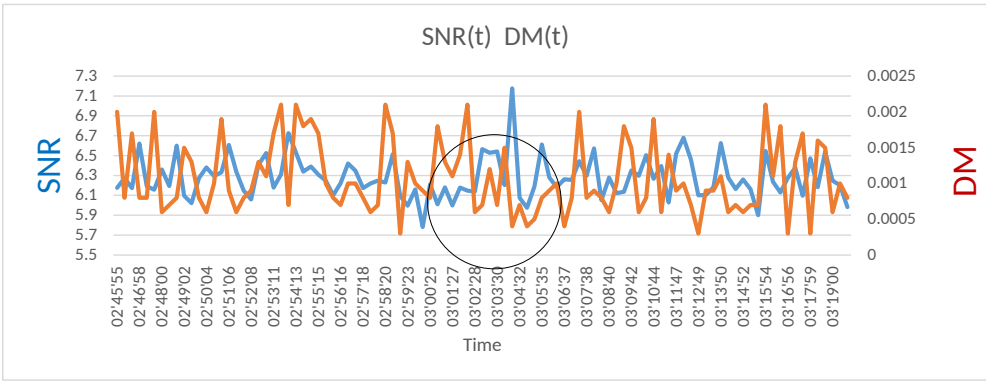


Figure 2 The dependence of SNR ¿5 on time, and the corresponding DM values, date February 18, 2021.

the maximum value of the SNR signal amplitude, expressed in RMS units (RMS noise level), was the largest. Since dispersed bursts that have passed through the ionosphere are of interest to us, signal processing included a dispersion compensation procedure. The value of the compensated dispersion measure ranged from 10^{-4} to 2×10^{-3} pc/cm^3, which by a margin exceeds the limits of possible values of the dispersion measure in the Earth's ionosphere.

The results of observation data processing are shown in the graphs of Figures 1–4, where the dependences of SNR > 5 on the observation time (stellar time) are shown, the circle is the Moon at the moment of culmination and its location in the main lobe of the radiation pattern, and the graphs also show the dispersion measure, which corresponds to the maximum SNR value at a given reference point. Graphs with "suspicious" bursts with noticeably high SNR at the moment of the Moon's culmination are shown, as well as graphs in which no correlation of SNR from the position of the Moon relative to the main lobe is observed.

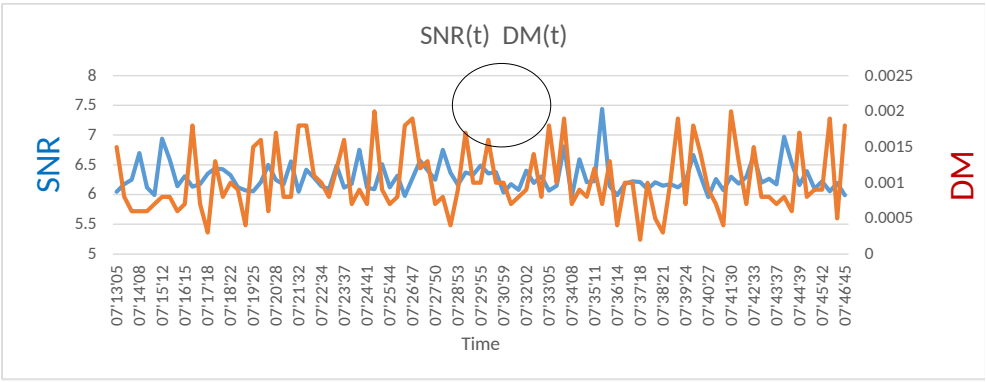


Figure 3 The dependence of SNR ¿5 on time, and the corresponding DM values, date February 24, 2021.

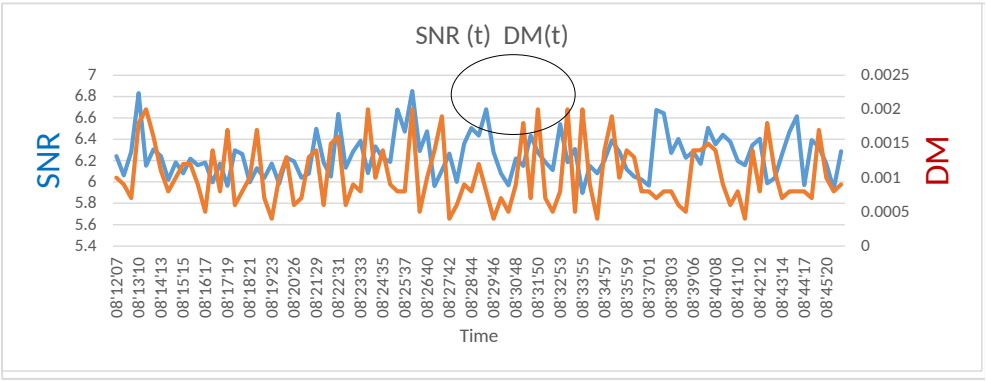


Figure 4 The dependence of SNR > 5 on time, and the corresponding DM values, date February 24, 2021.

3 Conclusions

In Figures 1 and 2, you can see a noticeable increase in SNR when the Moon was in the lobe of the directional pattern, but Figures 3 and 4 show no clear correlation of SNR with the passage of the Moon through the main lobe of the directional pattern. Despite the fact that significant bursts of radio emission have been detected at the time of the Moon's passage through the main lobe of the radiation pattern, it is too early to judge their nature related to the interaction of ultrahigh-energy neutrinos with the lunar regolith. Firstly, sufficient observation statistics are needed, which is not easy, because the BSA is a passage instrument, the Moon is observed only once a year a day, no more than 30 minutes, and secondly, noise fluctuations of SNR > 7 also occur, simple calculations show that they will appear at least once every 50 observations. Therefore, we have high hopes for the SKA program to search for ultrahigh-energy neutrinos using the radio astronomy method.

Acknowledgements

I would like to express my gratitude to my scientific supervisor R.D. Dagkesamansky, as well as to A.A. Sal'nikov.

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