Search for UHE neutrinos using a refurbished 25-m telescope

Peter M.W. Kalberla

Argelander-Institut für Astronomie, Universität Bonn, Auf dem Hügel 71, 53121 Bonn, Germany
Förderverein Astropeiler Stockert e.V., Am Astropeiler 2-4, 53902 Bad Münstereifel, Germany

Abstract

Lunar Cherenkov experiments with radio telescopes require large amounts of observing time but the competition with other astronomical projects leads usually to severe limitations in the observing time that can be allocated to the search for ultra high energy (UHE) neutrinos. To overcome this uncomfortable situation, we propose to dedicate a refurbished 25-m telescope to this kind of research. The aim is to track the Moon continuously over a period of at least three years. The 25-m Astropeiler Stockert, located close to Bonn, is currently under reconstruction. This industrial heritage will be back to operations early in 2009. An new 21-cm receiver will allow hands-on astronomy for amateurs and students. Only little efforts are necessary to upgrade the available hardware to perform state-of-the-art Cherenkov experiments. We briefly describe the achievable sky coverage and the expected sensitivity.

Key words: UHE neutrino detection, lunar Cherenkov technique, coherent radio emission

1. Introduction

The lunar Cherenkov technique allows to detect UHE particles with radio telescopes via the coherent Cherenkov radiation emitted upon their interaction in the outer layers of the lunar regolith. Excellent reviews of available radio astronomical strategies and the basic technology were given by Falcke et al. (2004) and Ekers (2008). Here we restrict the discussion to the case of a single dish telescope operated at λ21-cm and demonstrate that such a telescope could make a significant contribution in this field of research.

2. The Stockert Astropeiler

The 25-m telescope was inaugurated in 1956 after the prohibition of radar and wireless research was lifted in the Western Zones. This was the beginning of radio astronomy in Germany but at the same time radar research was taken up again after World War II. To allow both kinds of activities, the telescope was built on top of a hill known as "Stockert". At that time the Stockert project was the largest research project in Germany. The telescope was for a short time the largest in the world and remained for many years the most precise telescope. The Bonn University Observatory was also the base for the foundation of the Max-Planck-Institut für Radioastronomie with its 100-m radio telescope. A review of these early years was given by Wielebinski (2007).

The exposed position of the telescope on top of a hill caused increasingly problems with interferences at λ11-cm, where a continuum survey was in progress. Funding of other projects turned out to cause major difficulties in presence of the much more advanced 100-m telescope, so it was decided to shut down operations. The telescope was sold 1995 to a private investor. At the same time the registered association "Förderverein Astropeiler" was founded to support continuation of operations for

---

Email address: `pkalberla@astro.uni-bonn.de` (Peter M.W. Kalberla).

amateurs. The telescope got registered as an industrial monument and after the private investigator went bankrupt the foundation “Nordrhein-Westfalen-Stiftung Naturschutz, Heimat- und Kulturpflege” took care about the property. The activities of the Förderverein Astropeiler, together with major fundraising campaigns, led in the year 2008 to a successful refurbishment of the telescope. The aim of the reconstruction is to open the telescope to the general public and to allow hands-on astronomy for amateurs and students.

3. Available hardware

The telescope was previously equipped with a Cassegrain reflector and operated at λ11-cm. To improve the telescope performance it got a new prime focus mount with a dual channel receiver at λ21-cm for linear polarization. Major system components follow the design of the new Effelsberg multi-beam system but the receiver remains uncooled to ease maintenance. The system temperature is 50 K at a bandwidth of 140 MHz. The half power beam width is $0\overset{\circ}{.}6$. A state-of-the-art Field-Programmable-Gate-Array (FPGA) backend (Stanko et al., 2005) will allow to observe the 21-cm line emission of the Milky Way and alternatively Galactic and extragalactic continuum emission.

The size of the main beam ($0\overset{\circ}{.}6$) at λ21-cm matches pretty well the size of the Moon ($0\overset{\circ}{.}5$). This is very favorable for lunar Cherenkov experiments since it allows, when tracking the center of the Moon, to skim simultaneously all events that may originate from the observable part of the rim. For a single dish telescope of moderate size this is the most efficient way to search for lunar Cherenkov radiation (Ekers, 2008). Due to the high system temperature from the thermal emission of the Moon losses caused by an uncooled receiver are negligible. The Stockert telescope does not aim to serve as a prime instrument for “standard” radio astronomical applications. However the basic hardware components allow state-of-the-art research in the field of lunar Cherenkov radiation and plenty of observing time would be available for this purpose.

A higher telescope performance could be obtained by a larger single dish telescope equiped with a multi feed system. Alternatively, interferometers can be used, but science applications at such instruments are in any case highly competitive which immediately implies that the available observing time would be rather limited.

4. Proposed upgrades

The expected lunar Cherenkov signal at a frequency of 1.4 GHz is quite strong and easily detectable (James & Protheroe, 2008a), but the time resolution of the FPGA device, currently available at the Stockert telescope (Stanko et al., 2005), is insufficient to resolve nanosecond pulses. The new generation FPGA devices, currently in use at Effelsberg as spectrometers for a 21-cm line survey (Winkel et al., 2008), operate at a 3 GHz sampling rate and allow a sufficiently fast trigger data and dump strategy. A fast device of this kind is needed (Ekers, 2008).

Another limitation of the receiving system is the currently available bandwidth of 140 MHz. This bandwidth was chosen with respect to the local interference situation. Provision has been made to allow a larger bandwidth but it needs to be questioned whether the gain in sensitivity (formally proportional to the bandwidth) pays off. Benefits or shortcomings of an increase in bandwidth need to be explored in detail. The current setup has the advantage of a relatively low signal dispersion which implies a low degradation of the trigger signal.

Bandwidth limitations may be overcome by adding a second independent linearly polarized receiver system. Such a system may operate close to 400 MHz with a bandwidth of 40 MHz. The data stream should be recorded independently with a second FPGA device. However, in case that an event is recorded at 1.4 GHz also the data at the second frequency should be read out to check for coincidences. Signal timing, polarization, and Faraday rotation can be used to discriminate lunar Cherenkov signals from interference.

5. Sky coverage

Tracking the center of the Moon with a 25-m telescope at 1.4 GHz implies equal sensitivity for all parts of the observable rim of the Moon. Directional information, back-tracing the Cherenkov cones to the source position can be gained from the signal polarization, but an ambiguity remains. It can not be decided from which side of the Moon the signal originated, resulting in a 112° position ambiguity.

Figures 1 & 2 show the sky coverage for the Stockert telescope, assuming a continuous tracking of the

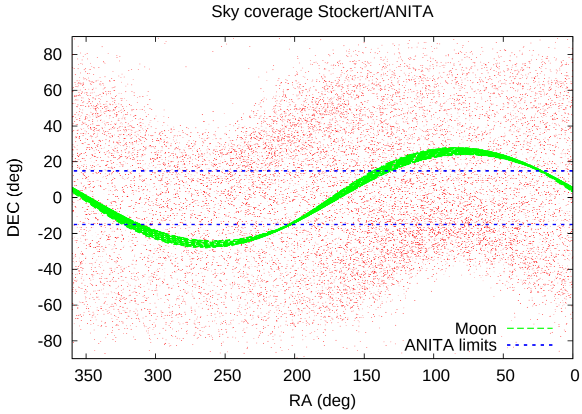

Fig. 1. Sky coverage in equatorial coordinates calculated for the Stockert telescope assuming a long term tracking of the Moon. The density of the red dots corresponds to the expected sensitivity obtained by projecting the Cherenkov cones to the celestial sphere. The green line indicates the lunar orbit. The blue lines represent the sky coverage by ANITA (Barwick et al., 2006).

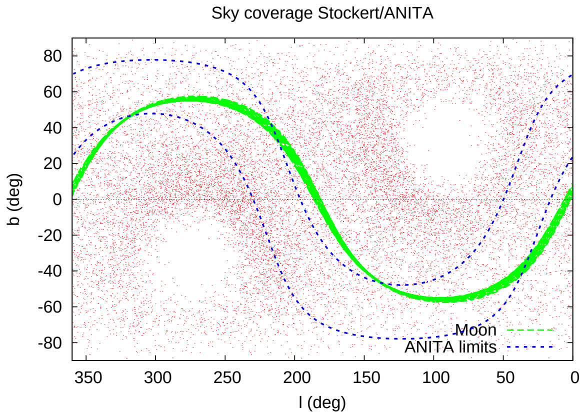

Fig. 2. Sky coverage corresponding to Fig. 1 in Galactic coordinates.

Moon. The proposed experiment covers most of the sky, except for two regions at the poles of the lunar orbit which are in principle not accessible. This coverage is quite an improvement over the limited coverage of the ANITA experiment (Barwick et al., 2006, blue). Also previous single dish experiments (James & Protheroe, 2008b) had a much more limited sky coverage.

One of the main advantages of the proposed Stockert experiment would be a systematical unbiased census of the whole sky, scanning continuously for all sources of UHE neutrinos which are acessible by the lunar Cherenkov method.

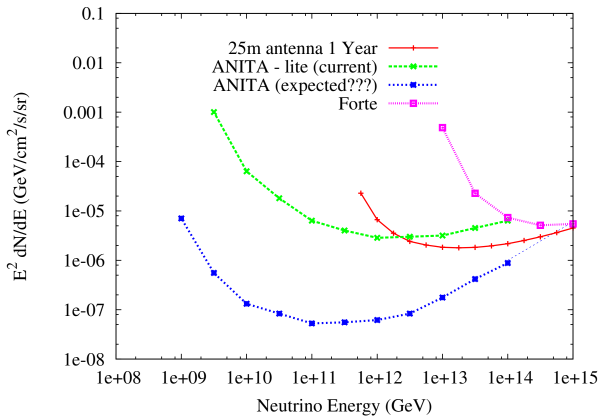

Fig. 3. Sensitivity limits reachable within 1 year of observations with the Stockert telescope in comparison to the pilot projects ANITA-lite (Barwick et al., 2006) and Forte (Lehtinen et al., 2004). The estimate is based on James & Protheroe (2008a) and was kindly provided by Clancy James.

6. Sensitivity

Next we consider sensitivity limits that can be reached with the Stockert telescope. Figure 3 is based on calculations by C. James (private communication), who used numerical simulations to estimate the expected radio signal for the detection of UHE cosmic ray and neutrino interactions in the Moon by radio-telescopes (James & Protheroe, 2008a). The simulations include interactions in the sub-regolith layer and apply to single dish and multiple telescope systems. For the calculation of the Stockert sensitivity limits in Fig. 3 it is assumed that during one calender year 90% of the time when the Moon is observable could be used to track the moon. This implies some limitations in scheduling, but 60% of the telescope time would still be available for other projects. We do not expect that this may cause major conflicts.

Figure 3 shows in comparison with Fig. 7 of James & Protheroe (2008a) that the proposed observations, even for a period of only a single calender year, could improve the current sensitivity limits for lunar Cherenkov experiments. The situation is different if one considers future radio astronomical instrumentation. Comparing Fig. 3 with Fig. 8 of James & Protheroe (2008a) indicates that a 25-m single dish telescope can not compete with major instruments like SKA or LOFAR. However this comparison, based on the assumption that all available observing time during a calender year could be used, is not fair. Astronomical projects need to compete for observing time at modern state-of-the-art radio telescopes. The telescopes are highly oversubscribed and it would be very optimistic to count on even weeks of observing time available exclusively for lunar Cherenkov experiments.

No such problems do exist for the Stockert telescope. Hence it is much easier to use this as a dedicated instrument. The experiment can easily be be run over several years, yielding much improved limits. Increasing the system bandwidth or installing a second receiver at longer wavelengths may lead to further improvements which are at present not taken into account.

7. International cooperation

Future synthesis telescopes like ASKAP, LOFAR or SKA will provide data buffer of sufficient size to look back in time once a transient event is detected. Rather then demanding a part of such an array to track the moon continuously it would be far more effective if external triggers could be used to “freeze” observations, read out the transient buffers and synthesize offline a proper beam, necessary for the analysis of a lunar Cherenkov event. Observations need to be interrupted for a few seconds only. The necessary trigger signal could be provided by a radio telescope that is dedicated to a continuous survey of the Moon.

We propose to use the Stockert telescope for this purpose. Such an application needs a fast Internet connection but also the development of reliable real-time detection algorithms. If other telescopes with a similar dedication would be available the reliability could be much improved by testing for coincidences.

8. Educative & interdisciplinary aspects

Lunar Cherenkov observations are very difficult. Instrumentation, observations, data registration and analysis require special care in comparison to “standard” radio astronomical observations. We consider the availability of a telescope which is dedicated to such an ambitious project as a unique chance for interdisciplinary cooperations. This includes problems such as automated telescope control and engineering but also data acquisition, signal detection, and interpretation of the observations. Each of these topics require careful considerations and innovative methods. The current experiences in discussing such problems with colleagues are very positive and we expect also to find students who are interested in outstanding topics for a master or diploma thesis. Last but not least, a lunar Cherenkov project may provide new impulses for astronomy outreach.

9. Funding

Major investments were necessary for a successful refurbishment of the telescope. By comparison, additional specialized instrumentation like bandpass filters, a second receiver, FPGAs, and data recorders imply minor investments only. However, the foundation “Nordrhein-Westfalen-Stiftung Naturschutz, Heimat- und Kulturpflege” by constitution can not support scientific activities. This applies to hardware as well as to maintenance or other running costs caused by a scientific research program. Other sponsors are needed.

Acknowledgments: This proposal gained broad support from the members of the Förderverein Astropeiler. During the the Arena 2008 conference many discussions and comments have helped considerably to clarify the current proposal. The constructive criticism from many participants has been taken into account. In particular I acknowledge help from Clancy James who also included the Stockert Telescope in his sensitivity calculations.

References

Barwick, S. W., et al. 2006, Physical Review Letters, 96, 171101

Ekers, R. D. 2008, Arena 2008

Falcke, H., Gorham, P., & Protheroe, R. J. 2004, New Astronomy Review, 48, 1487

James, C. W., & Protheroe, R. J. 2008a, arXiv:0802.3562

James, C. W., & Protheroe, R. J. 2008b, arXiv:0803.3653

Lehtinen, N. G., Gorham, P. W., Jacobson, A. R., & Roussel-Dupré, R. A. 2004, Physical Review D, 69, 013008

Stanko, S., Klein, B., & Kerp, J. 2005, A&A, 436, 391

Wielebinski, R. 2007, Astronomische Nachrichten, 328, 388

Winkel, B., Kerp, J., Kalberla, P. M. W., & Keller, R. 2008, The Evolution of Galaxies Through the Neutral Hydrogen Window, 1035, 259