Catching the highest energy neutrinos

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Ultrahigh energy neutrinos

Radio detection of neutrinos and other detection methods

Existing and planned experiments

Limits on ultrahigh energy neutrinos

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Ultrahigh energy neutrinos

Ultrahigh energy neutrino predictions are, in one way or the other related to ultrahigh energy cosmic rays. The first attempt to do it was by John Bahcall and Eli Waxman. they followed the proton energy loss in jets of AGN and similar astrophysical objects and calculated that a fraction of these energy losses will come out of the system in the form of neutrinos. If, however, protons lose all their energy inside the systems an upper limit of the neutrino flux would be

$$E_\nu^2 \, dN/dE = 5.10^{-8} \text{ GeV/cm}^2\text{/s/srad}$$

with a cosmological evolution of the sources as $(1+z)^3$ when the cosmic ray injection spectrum is E^{-2}.

this limit was criticized and better limits (MPR) were set. It is still very useful since it is a simple straight line to compare other models to.

Many other models are related to the TopDown models of UHECR production that were fashionable in the 1990's when they attempted to explain the lack of GZK cutoff in the data of the AGASA experiment. Interactiong or just long lived cosmic strings (remnants of the Big Bang) generate very massive X particles that decay. More than 90% of the decay products are gamma rays and neutrinos. Their spectra extend to the X particle mass that could be as high as 10^{23} GeV.

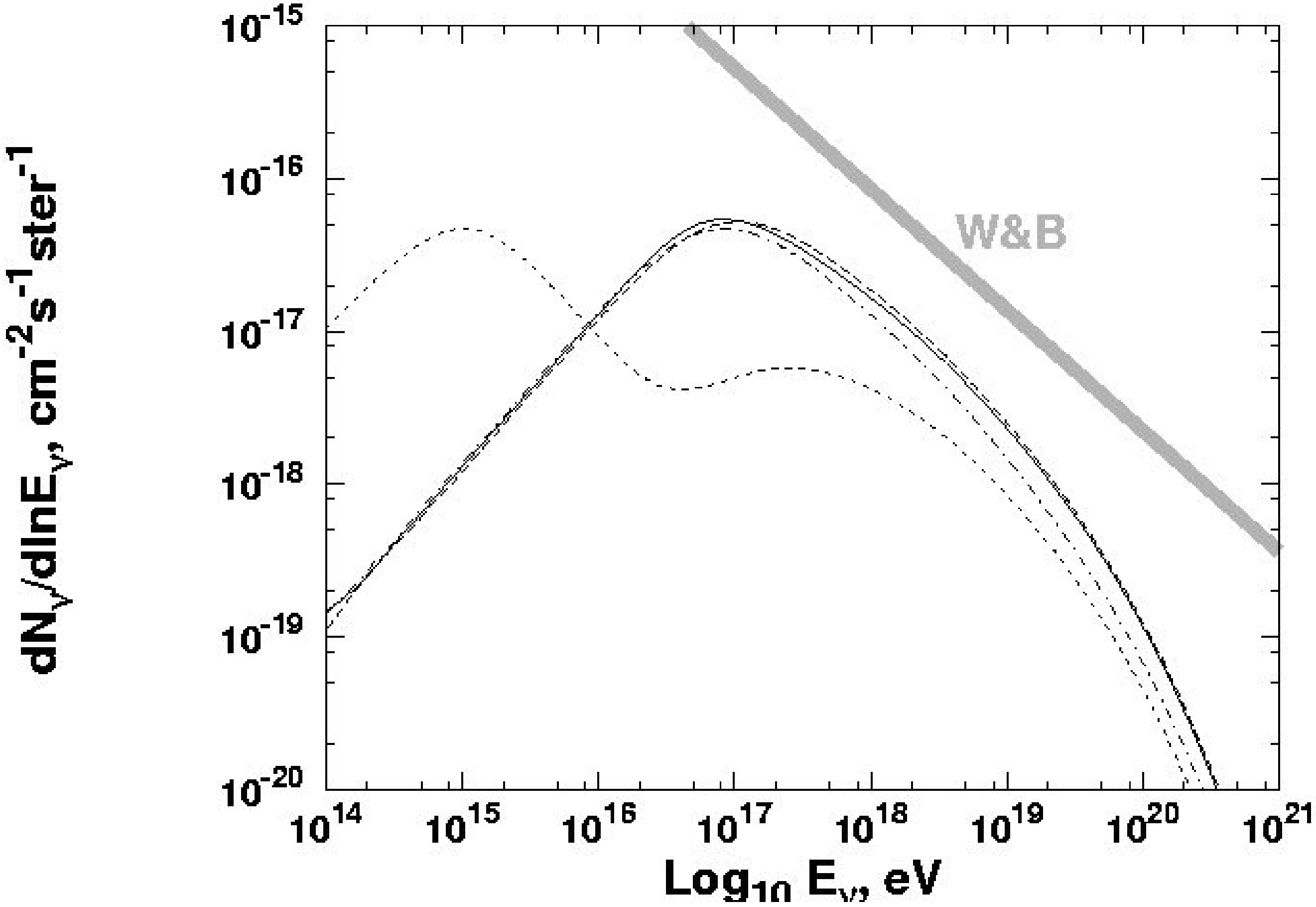
A special case is the Z burst model where ultrahigh energy neutrinos generated elswhere interact with cosmological neutrinos in the Galaxy or the local group of galaxies and produce Z_0s. The high energy neutrino energy has to significantly exceed 10^{21} eV to reach the interaction threshold.

Cosmogenic neutrinos (Berezinsky&Zatsepin, 1969; Stecker 1971) are the neutrinos generated by UHECR photoproduction interactions in the MBR. The energy threshold is determined by the requirement to mave one pion mass in CMS

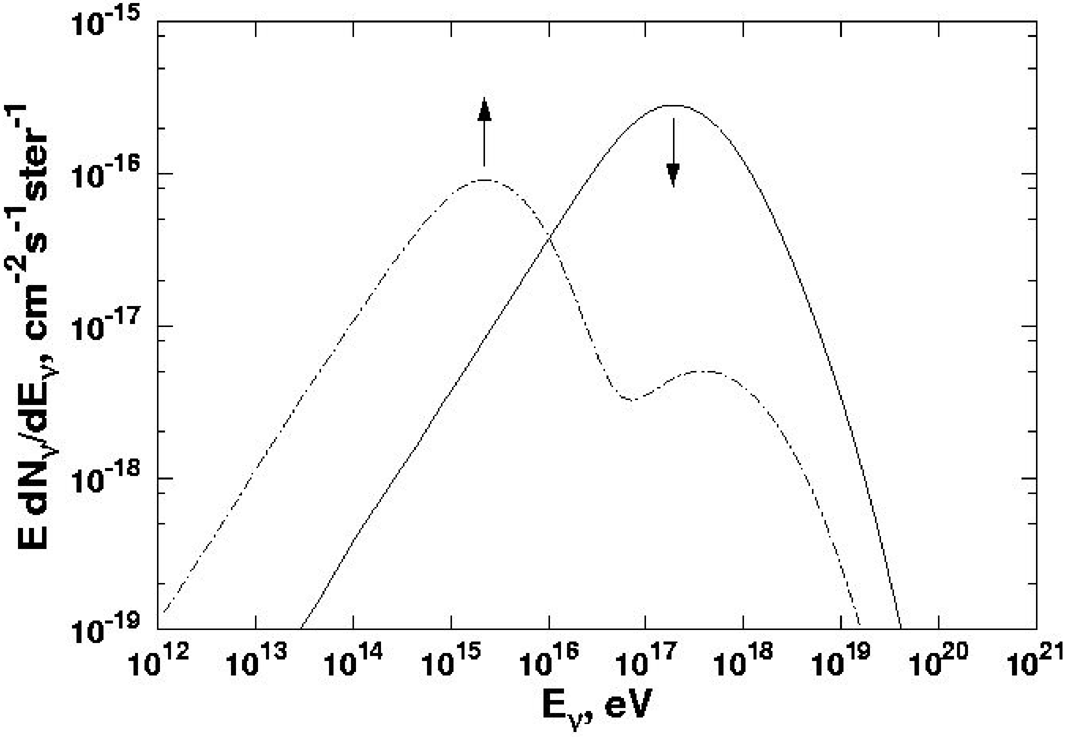
$$E = (m_\pi/4\varepsilon)(2m_p + m_\pi) = 10^{20}\ \mathrm{eV}$$

The actual energy threshold is at about 3.10^{19} eV.

Cosmogenic neutrinos are guaranteed but their flux is highly uncertain. It depends on the UHECR injection spectrum, its maximum energy, the cosmological evolution of the CR sources and the chemical composition of cosmic rays at injection.



We do not know what are the sources of UHECR and have no idea what their cosmological evolution is. The injection spectrum is also not known. We have, however, hints that their composition at Earth is heavy. That makes us wonder how big the cosmogenic neutrino flux may be. If all UHECR are protons the figure below is OK. If not, the high energy neutrinos would decrease and the low energy electron neutrinos would increase.



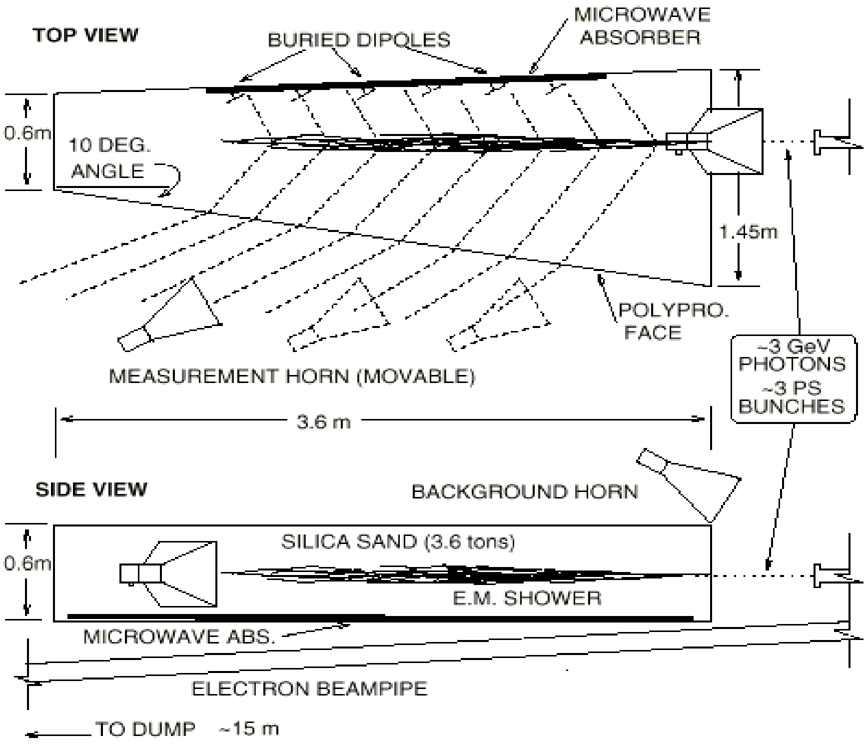
Right curve: spectrum of electron neutrinos and of muon neutrinos and antineutrinos.
Left curve: electron antineutrinos from neutron decay.

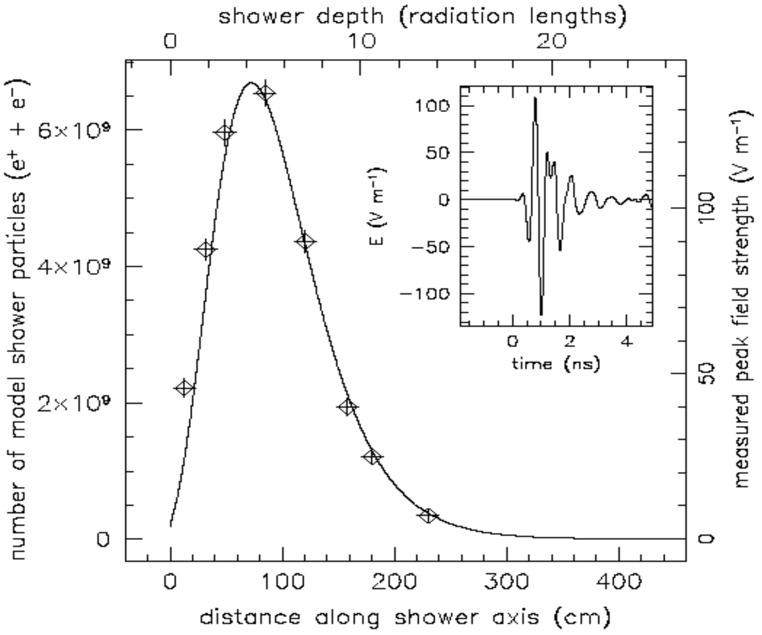
Radio detection of high energy neutrinos in solids (Askaryan effect). A small fraction of the Cherenkov radiation of the individual particles ($\sim 1/\lambda$) is in radio. The cascade, however, develops charge – a negative excess, because

-- Compton effect increases the electron energy/tracklength
-- positrons annihilate
-- the differences between Bhabha and Møller scattering

The electric field is created by the negative charge excess, which in turn increases linearly with primary energy. At wavelengths that are longer than the shower dimension the shower radiation is coherent and is thus proportional to shower energy Squared - E^2 . What matters is the lateral dimension of the cascade, expressed in the tracklength of the excess charge, projected on the shower axis. It is generally about 20% of the total shower tracklength. Five meters of ice equal 13 rad. lengths so even at frequences exceeding 1 Ghz the emission is coherent. At higher frequences the coherence and the power decrease to become proportional to E.

The radio detection method was proven by Gorham, Saltzberg and colleagues in experiments at SLAC. Bunch of electrons was dumped first in sand (below) and then in ice, and the developed electromagnetic cascade was detected with antennas (on the right). The total shower energy and the frequency dependence of the signal agreed with the predictions.

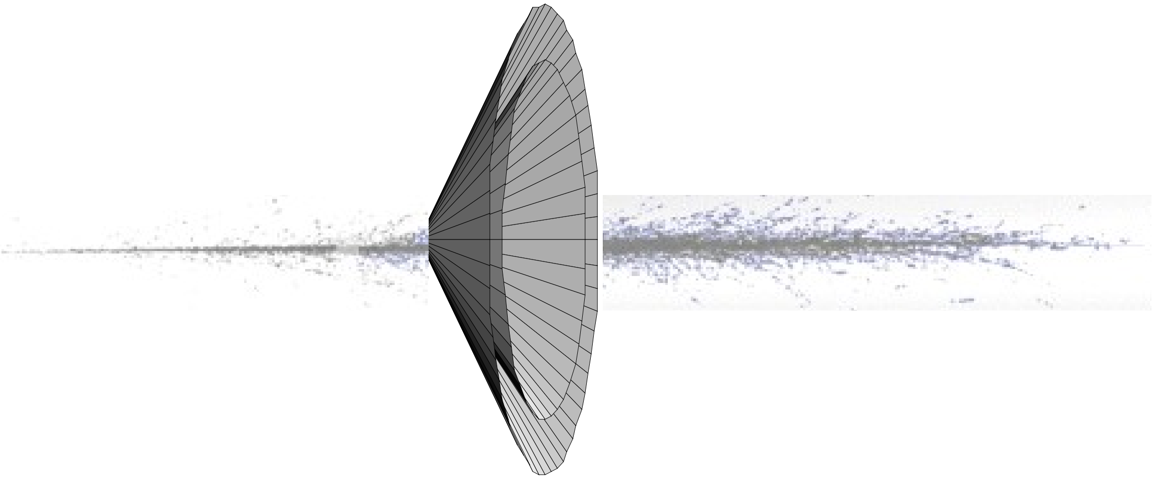


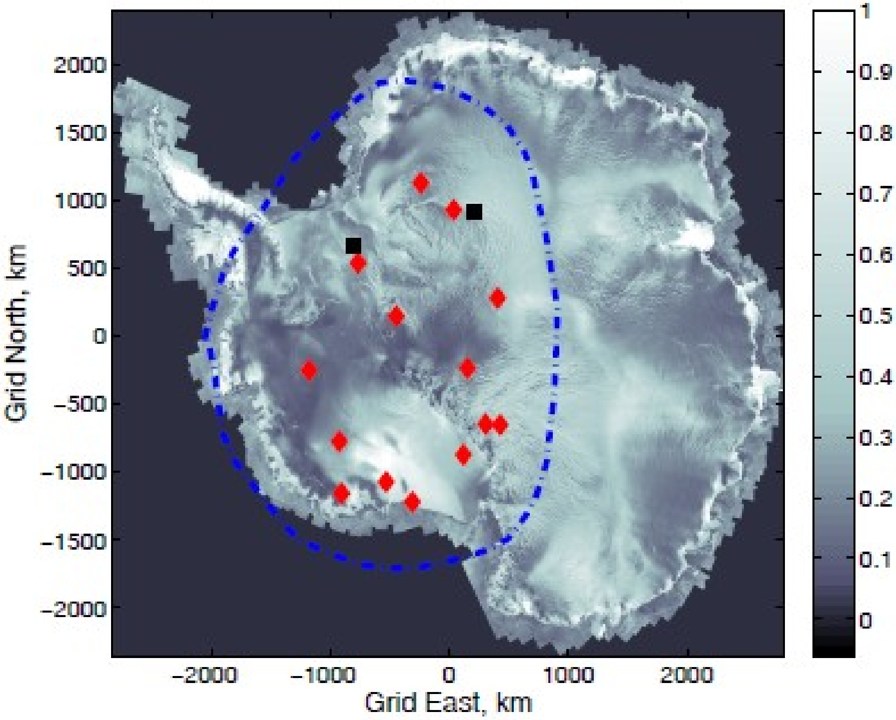


The radio power peaks at the Cherenkov angle ~ 1/n. The higher the frequency the narrow is the peak. It is thus important to match the antenna sensitivity to the effective area of the whole detector.

The RICE experiment consisted of 16 dipole antennas sensitive to 100-500 MHz buried under 100-400 m of ice at the South Pole. The antennas were calibrated as some of them were used as transmitters and others as receivers.

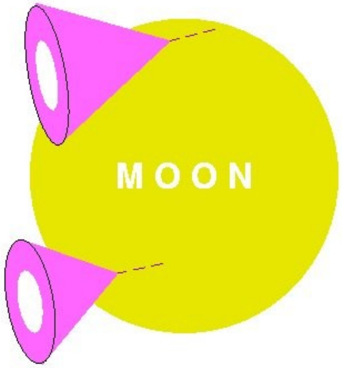
RICE did not detect any UHE neutrinos and set an upper limit of the diffuse fluxes of such neutrinos.





Anita is a balloon experiment that flew over Antarctica twice looking for UHE neutrino interactions in the antarctic ice. The field of view peaks for almost horizontal Neutrinos. Both the hardware and the electronics were different for the two flights but the wind pattern did not cooperate. A third flight is scheduled for December 2013. Anita still was able to set the best limit on UHE neutrinos and observed UHECRs.

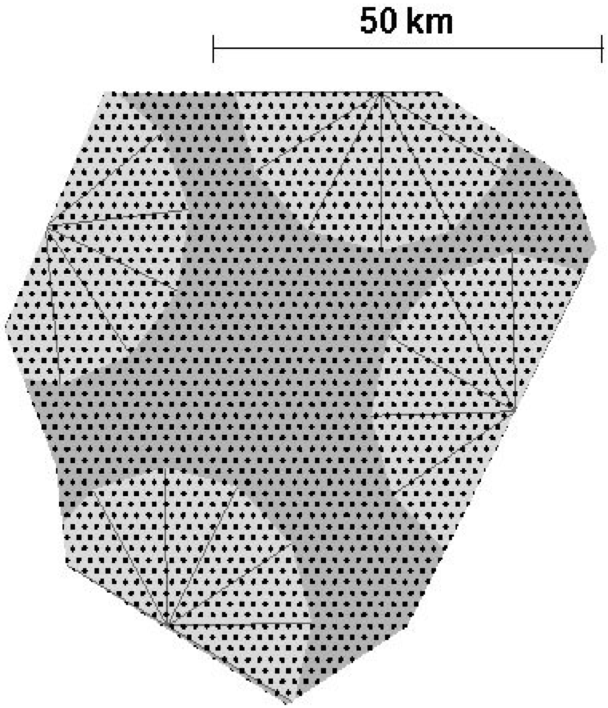
Observations of the Moon: UHE neutrinos interact in the lunar regolith and produce radio signals that can ve observed from the Earth. The first experiment was by Hankins,Ekers and O'Sullivan (1996) from the Parkes Observatory. The second one by Gorham, Saltzberg et al in 2000 at Goldstone: observation with two dishes.



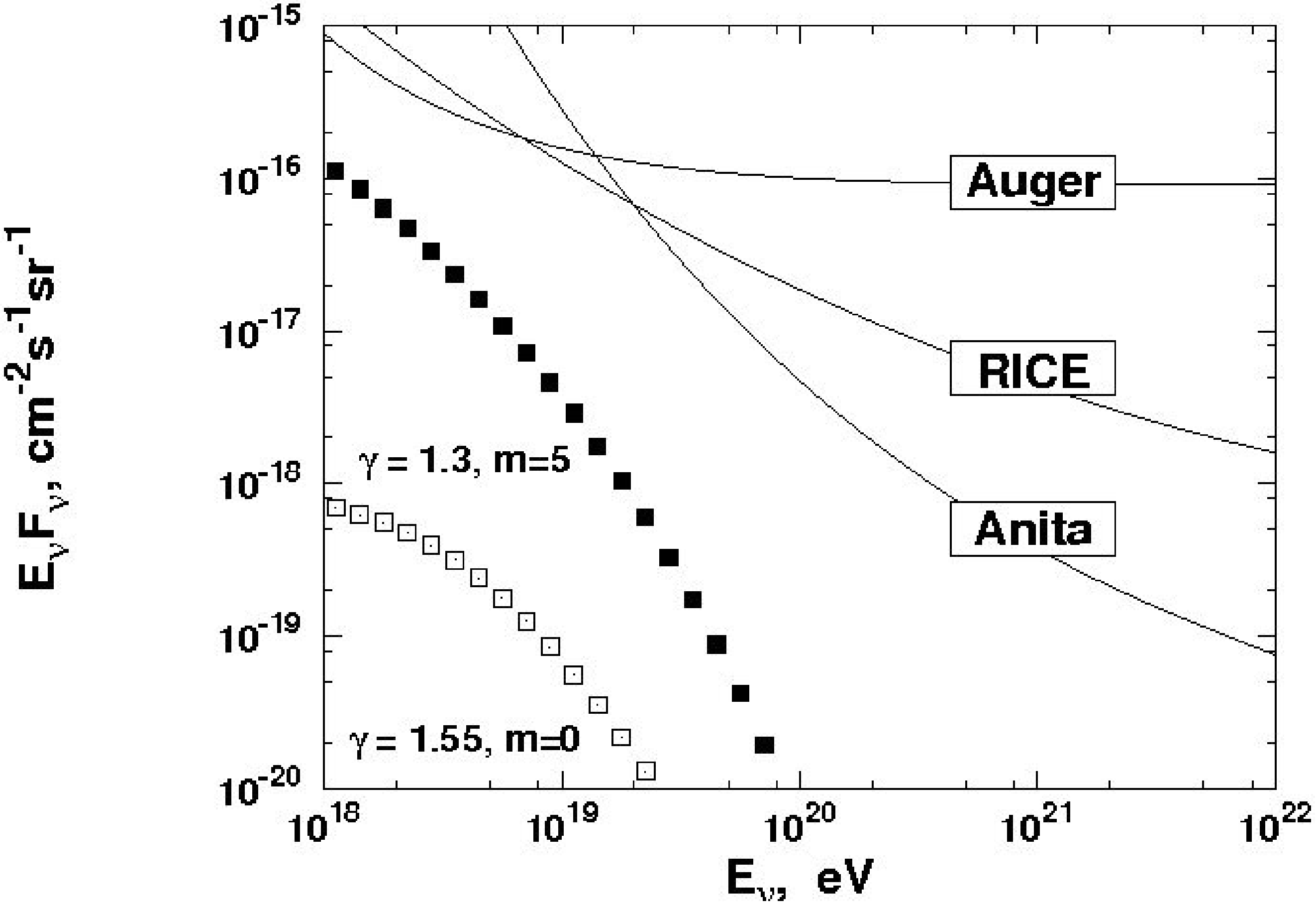
Although these two first attempts saw nothing, the experiments continue and become more sophisticated. Lunaska is also an Australian experiment using all Parkes radio antennas. RESUN uses four groups of four telescopes each of the Expanded Very Large Array to observe the limb of the Moon. The results are unfortunately only upper limits.

Air shower detection of UHE neutrinos

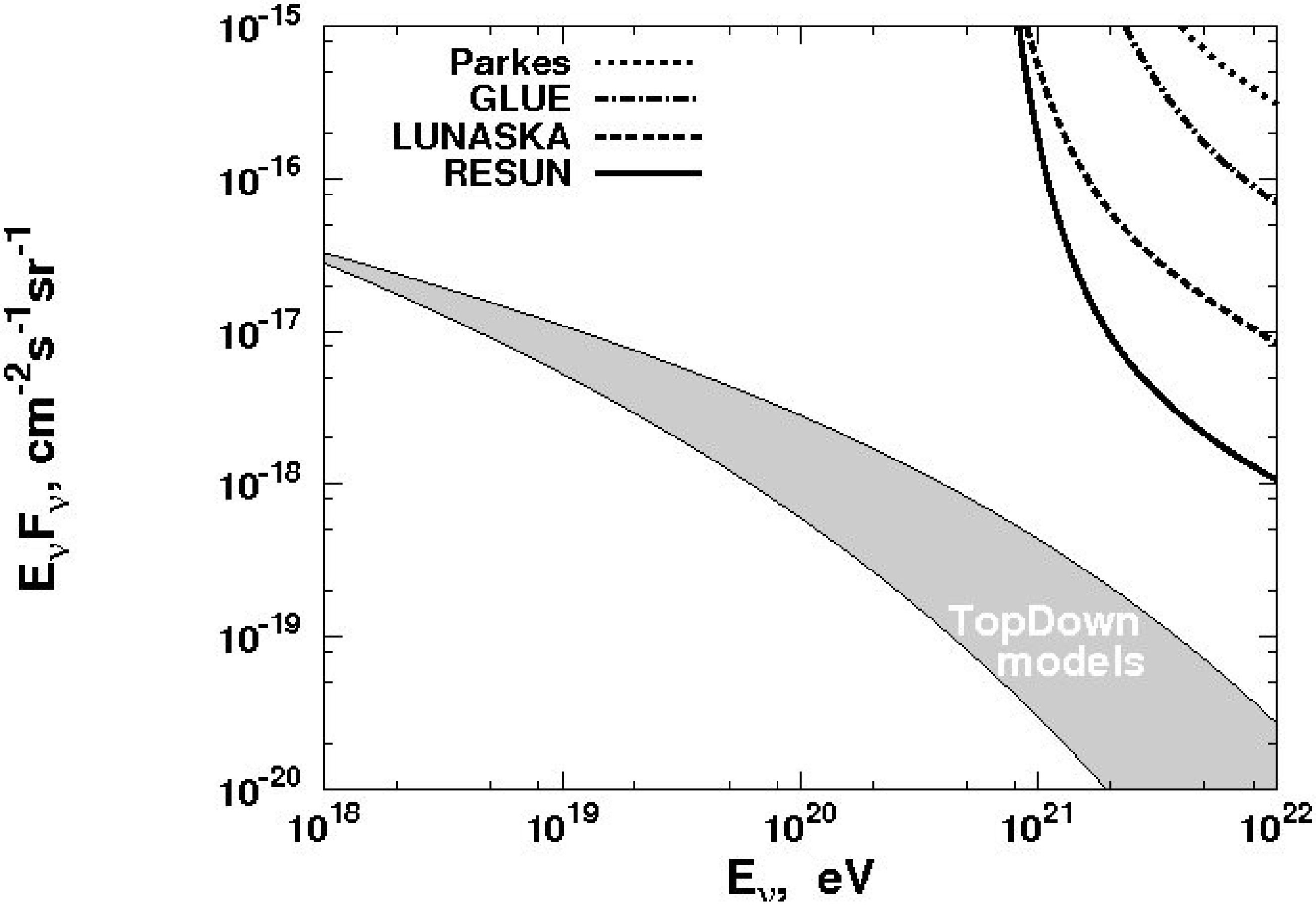
Both the HiRes and the Auger South detectors set limits on UHE neutrinos. HiRes looked for showers developing upward and did not see any. Auger looked for tau neutrinos coming from the Andes or just grazing the Earth. The assumption is that because of oscillations the flavor ratio is nearly 1:1:1.



Upper limits: RICE ,Auger (HiRes also has an upper limit) and ANITA. All limits are higher than the predicted cosmogenic neutrino fluxes from the Auger UHECR spectrum. Auger has the lowest energy threshold and ANITA has the best limit above 10^{20} eV. With increased statistics the air shower experiments will go deeper towards the predictions. RICE will be replaced by a new bigger experiment, ARA, at South Pole and ANITA will have a new flight in 2013.



Upper limits from observations of the Moon: all limits are well above the optimistic predictions of the TopDown models of UHECR. The sensitivity is only good for neutrinos of energy above 10^{21} eV. The hope is that observations with the Square Kilometer Array, when it exists, will be significantly better. The question is if 1000 EeV neutrinos exist in nature.



Conclusions:

Ultrahigh energy neutrinos are not easy to detect even if they exist

The current limits are one order of magnitude above all predictions.

All types of experiments not only continue, they become much more efficient: ARA aims at 10 km^2 area and sensitivity to 1 EeV electron neutrinos. SKA and its test sites will also be used. There are proposals for lunar orbiter observations.

The field is thus growing fast.