DETECTION OF NEUTRINOS FROM ACTIVE GALACTIC NUCLEI

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A recent model[1] of neutrino production in Active Galactic Nuclei (AGNs) yields fluxes that verge upon detectability in present underground detectors, and would be eminently detectable in DUMAND II (20,000 m^2, scheduled to be operational in late 1993). The flux results from $\gamma + p \rightarrow \Delta^+$ in the dense photon field surrounding a supermassive black hole undergoing Eddington limited infall of matter. Proton acceleration in the accretion shock is invoked to explain various facets of the observed radiation in UV and X-rays. A particularly dramatic implication of their model is that the high flux of neutrinos could be the source of the observed broad line region in AGNs via neutrino induced stellar disruption, with the startling implication of the possible importance of neutrinos for galactic dynamics.

The idea for such neutrino production is not new, and traces back 15 years or more[2]. The present authors[1] however calculate neutrino fluxes from the sum of all AGNs, employing models for density and luminosity evolution. The resulting flux of muon neutrinos is of the order of 3500 muons per year through DUMAND II (2.35 π sr), but with the distinctive characteristic of having a mean energy of about 10 TeV at the detector, as compared to the muons from atmospheric neutrinos with mean muon energy <100 GeV (near minimum ionizing). We have used transport calculations[3] that include Earth attenuation and convert muon neutrino and anti-neutrino fluxes to muon rates in a detector. The attenuation includes both charged and neutral current cross-sections. This is illustrated in Figure 1, which shows the rate of muons traversing DUMAND II as a function of muon energy threshold[3]. The rate is so large that present day underground detectors may be able to discern the AGN flux.

In Figure 2 we present the predicted angular distribution of muons from the sum of AGNs and from the atmosphere (Volkova flux[3]). Three angular distributions are plotted for both AGN neutrino induced muons and atmospheric neutrino induced muons, with muon energy thresholds of 25 GeV, 1 TeV and 10 TeV. The strong attenuation for AGN neutrinos coming through the earth's core is particularly striking. While the statistics in one year's observation with DUMAND II are not impressive (25%), the multiplication due to the absorption being exponential would yield perhaps a 5% measurement of the core density in one year!

Are the ν_e's Detectable?

In the model of Stecker et al., the pions and muons are all said to decay. They further claim that the neutrons do not escape the photon field, which neutrons also get excited to Δ^o which yields $\pi^- p$ half the time (the π^o's from both Δ^+ and Δ^o yield γ's that add to the photon soup). Thus through $\pi^+ \rightarrow \mu^+ \nu_\mu \rightarrow e^+ \nu_\mu \nu_e$, and charge conjugate for π^-, one would get nearly equal fluxes of particle and anti-particle, but twice as many ν_μ as ν_e.

UHE electron neutrinos and anti-neutrinos will both interact inside a large detector and produce contained electron showers coming largely from the upper hemisphere. Electron anti-neutrinos have an additional detection channel through the resonant W^- production at a neutrino energy of 6.4 PeV. The signal would be a huge cascade, with roughly 10^5 times the light of the typical muon traversing the array! Additionally, the DUMAND II effective volume would be larger than the 2 megaton contained volume, since such events can be seen at some distance (though it is not clear how well they may be fitted). First estimates from a simple Monte Carlo calculation indicate an effective volume for DUMAND II in excess of 1/5 km^3 for triggering on such 6.4 PeV cascades, leading to a predicted rate of 2000 events/year. The predicted angular distribution of the resonant W^- shower events is shown in Figure 3.

One must consider backgrounds to such cascade observations, however, particularly for events that occur outside a DUMAND type of array where a nearby lower energy event might perhaps be mistaken for a more distant higher energy event. Ordinary downgoing muons may make electromagnetic cascades which mask these neutrino interactions. The various predicted AGN rates and expected atmospheric rates for comparison are summarized in the Table I.

Other Means of Detection?

We estimate that the ordinary UHE cosmic ray muon background would be relatively negligible even at the earth's surface compared to resonant W^- production, which suggests that one might search for the W^- cascade events in detectors of sufficient mass (megaton range), in such instruments as MILAGRO, NET or GRANDE. Even though events will be down or side-going and not upcoming, they would not resemble Extensive Air Showers, because of their point origin (EAS of these energies arrive as a nearly plane wave of lateral extent of order 100 m). Single unaccompanied hadrons or gammas are similarly unlikely at these energies.

The resonance energy is near the acoustic detection threshold calculated years ago for particle cascades[5], and a look at that work suggests that the signal-to-noise in the deep ocean would be near 0db for 100 m distances (near field, and assuming near thermal deep ocean high frequency noise background). Given the 52 hydrophones incorporated into DUMAND II, it may thus even be possible to hear the events. For such events occurring within 100 m or so of the array, the acoustic signal may perhaps be employed to reconstruct the interaction vertex.

Another tantalizing possibility is the employment of radio detection in ice, RAMAND, as a Soviet group has been pursuing at Vostok Station in the Antarctic over the last few years. New threshold calculations[6] indicate that 5 PeV would be detectable in microwaves at 1 km range in cold ice. The hypothesized AGN ν_e flux will doubtless encourage the the RAMAND group in their feasibility studies.

Summary

The new predictions of substantial muon neutrino fluxes from AGNs would yield readily detectable fluxes of >10 TeV muons in >10,000 m^2 neutrino detectors now under construction. While present generation detectors may just be large enough to detect the AGN flux, DUMAND II should be able to collect such events even if the predicted flux is high by several orders of magnitude. As a bonus, these AGN neutrinos, if they exist at the level suggested by the Stecker et al. model, will lead to such exotic opportunities as earth neutrino tomography, permitting us to measure the earth core density to a few percent by UHE neutrino absorption.

The model also predicts electron neutrino of 1/2 the flux of muon neutrinos, which may well lead to detection of cascades from W^- resonant production at 6.4 PeV in massive detectors. The predicted AGN UHE neutrino flux may also open the way for new techniques to enter neutrino astronomy.

Acknowledgements

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References

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Table I

Some estimated rates for AGN neutrinos and atmospheric background.

Event type Source (angle range)	Thresh Energy	Rate ($1/m^2/yr$)	IMB (1/yr)	DUMAND II (1/yr)
Muons			($400\ m^2$)	($20{,}000\ m^2$)
AGN $\nu_\mu \rightarrow \mu$ (90^o–180^o)	>2.5 GeV	0.17	70	
	>25 GeV	0.17	69	3500
	>1 TeV	0.14	60	3000
	>10 TeV	0.089	35	2000
AGN $\nu \rightarrow W^- \rightarrow \mu$ (80^o–94^o)	>10 TeV	0.274	110	50
Atm $\nu_\mu \rightarrow \mu$ (0^o–180^o)	>2.5 GeV	0.47	180	
	>25 GeV	0.22	90	4475
	>1 TeV	0.14	4	220
	>10 TeV	0.089	0.1	5
Cascades, contained	(E_{cas})	($1/10^9$ T yr)	(8000 T)	(2×10^6 T)
AGN $\nu_e \rightarrow$cas	1.0 PeV	15000		30
AGN $\nu^e \rightarrow$cas (0^o–120^o)	10.0 PeV	2000		4
AGN $\nu \rightarrow W^- \rightarrow$cas ($0^o$–$90^o$)	6.4 PeV	10000	0.1	20
uncontained				(2×10^8 T)
AGN $\nu \rightarrow W^- \rightarrow$cas ($0^o$–$90^o$)	6.4 PeV	10000		2000

Fig. 1: Integral spectrum of upcoming muons.

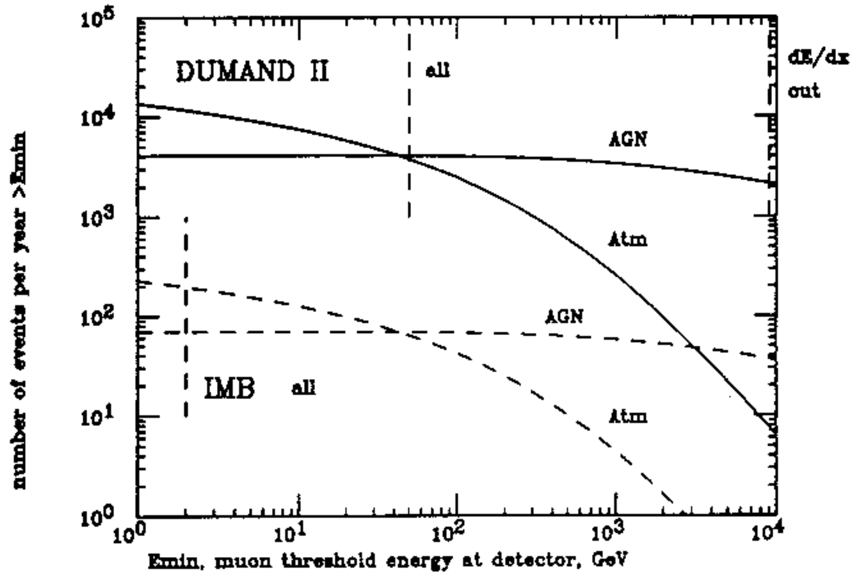

Fig. 2: Muon angular distributions.

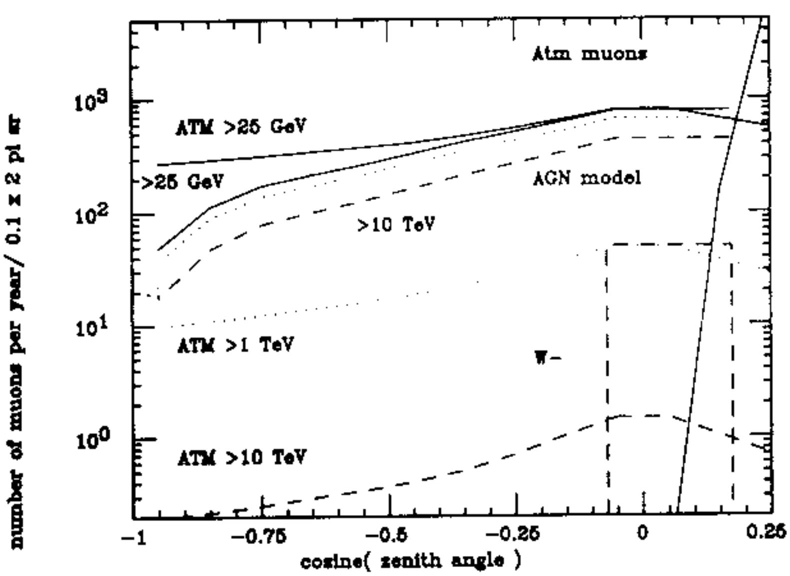

Fig. 3: Resonant nuebar -> W- rate