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# DUMAND: A DEEP UNDERWATER MUON AND NEUTRINO DETECTOR --PRESENT STATUS--

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ABSTRACT

The DUMAND project is halfway through a three year feasibility study. The results so far indicate that an array can be built and deployed at modest cost which will be capable of doing important high energy neutrino physics and astronomy. The current status and future plans for DUMAND are briefly discussed and the results of simulated experiments presented. The array currently under consideration should be able to detect the flattening of the νN cross section expected for an 80 GeV W-boson and search for neutrino oscillations in a unique region. It will also be sufficiently sensitive to observe extraterrestrial neutrino sources if they are present at levels expected in some calculations.

DUMAND[1] is a project to build a deep underwater laboratory for the study of: (1) neutrino physics above 1 TeV, (2) high energy neutrino astronomy, (3) cosmic ray physics, (4) geophysics and ocean science. The proposed site for this laboratory is approximately 100 km south of NEUTRINO '81 in Wailea, Maui and 45 km west of Keahole point on the Big Island, at a depth of 4.5 km. The Hawaii DUMAND Center (HDC), a unit within the University of Hawaii High Energy Physics Group, is currently in the middle of a three year Feasibility Study, in collaboration with groups from U.C. Irvine, U. Wisconsin, Scripps Institution, the Naval Ocean Systems Center, the Naval Research Lab, and the Japanese Institute for Cosmic Ray Physics. Other groups which are making plans to join this international effort include U. Kiel, U. Aachen, U. Siegen, and U. Bern. The USSR has formed its own DUMAND group, which has already made some in-water tests (to be reported later), and it is to be hoped that they can join our collaboration.

## STATUS AND PLANS

The Feasibility Study has encompassed the following areas: site measurements, including water clarity; array studies; signal processing techniques; detector design; fiber optic cable design; deployment concepts; computer simulations; scientific capabilities. The first DUMAND experiment, the Muon String, is almost assembled and ready for deployment (see report by J.G. Learned).

So far the results of the Feasibility Study indicate that DUMAND is indeed feasible--technologically, scientifically and economically. The water at the DUMAND site is clearer than expected[2]. Because of this, and other factors which have become evident in detailed Monte Carlo simulations, the detectors need not be as sensitive and can be placed much further apart than was originally anticipated[3]. Signal processing[4] and deployment[5] studies indicate no fundamental problems requiring solutions beyond current technological capabilities. We believe enough is now known to begin designing the first array.

Our guiding principle for the first DUMAND array is to build the simplest, lowest cost array which can still do important physics. This has led us to a current design involving 756 phototube detectors spaced 25 m apart vertically on 36 strings, the strings being deployed 50 m apart horizontally. The volume of water enclosed by this array is $1.25 \times 10^8$ $m^3$ (tons). The effective volume, as we will see, is much larger. The cost is estimated at $3–7M. For more details on the specifications of this array see the following report by A. Roberts. In the remaining part of this report the physics and astronomy capabilities of these early DUMAND experiments will be described.

## NEUTRINO EVENT RATES

The DUMAND array described above is designed to detect and measure the direction (to better than $0.5^0$) of muons of energy greater than about 100 GeV. For muons above 1000 GeV DUMAND can use dE/dx to determine the energy to about 50%. An electromagnetic or hadronic cascade of comparable energy will light up only a few detectors so no directional information is possible, but energy above a few TeV should be measurable from total pulse height to about the same precision as for muons. These observations are confirmed by Monte Carlo simulations[3].

Cosmic ray muon physics at TeV energies will thus be a significant component of DUMAND. Of greater interest to this conference is the possible neutrino physics and astronomy.

Charged current $\nu_\mu N$ interactions both inside <u>and outside</u> the array can be detected. In the latter case the muon passes through the array from outside. Thus the effective volume for neutrino interactions is larger than the enclosed volume[6]. For example, the effective volume for a 2 TeV neutrino is $4 \times 10^8$ $m^3$, corresponding to a target mass of 400 megatons!

Thus, in calculating event rates, an <u>energy-dependent volume</u> must be used. Doing this, and using the best current estimations for the flux of atmospheric neutrinos and the cross section predicted by the standard model, we obtain the predicted event rates shown in Fig. 1. The DUMAND array is compared with the Case-Wittwatersrand-Irvine (CWI) underground detector[7], as typical of what may be achieved in mines. Also shown is the neutrino event rate for the Muon String, where approximately half (those going upward) should be identified as being from neutrinos. Amazingly, the Muon String, as of now, will be the most sensitive neutrino detector ever built! Unfortunately, because of ship costs, it cannot be deployed for the length of time that a fixed installation can operate, but this at least illustrates the power of the DUMAND technique. With an array connected by cable to shore we can expect thousands of events per year above 1 TeV. The big question is: what can be done with these events?

## NEUTRINO PHYSICS WITH DUMAND

Everyone expects that the W-boson will shortly be found in $\bar{p}p$ machines, at the predicted mass of 80 GeV. This will imply that the $\nu N$ cross section will begin to flatten out above 1 TeV. There is no accelerator currently under consideration which will provide a beam of TeV neutrinos. Thus DUMAND has the unique opportunity to make this important experimental test and look for other new phenomomena which might become evident when the weak interaction is no longer point-like.

A 10 TeV neutrino beam passing through the center of the earth will be attenuated to 76% if the cross section is a linear extrapolation from lower energies, but only by 82% for the cross section predicted by the standard model. This difference is, in principle, detectable by an underground or undersea high energy muon detector with at least crude energy and angular resolution. At lower energies where there are more events, the effect is smaller. It just becomes a practical matter of statistics and the background of downward cosmic ray muons. The downward muons can be removed with a zenith angle cut, but this will reduce the statistics if one has no independent measurement of the unattenuated flux. These muons, on the other hand, provide a good statistics handle ($> 10^6$ per year above 1 TeV) on the high energy neutrino flux. By putting all this together, it should be possible to determine whether or not the neutrino cross section is continuing to rise at TeV energies with 1-2 years operation of the array.

By using the variation in neutrino path length L through the earth DUMAND will also be able to make some useful statements about neutrino oscillations[8]. In one year DUMAND will have about 1700 events with $E_\mu > 1$ TeV from all zenith angles $\theta$. The path length for these events will range from about 20 km for $\theta = 0^0$ to 12,000 km for $\theta = 180^0$. This implies a sensitivity in neutrino mass square difference $0.1 < \delta < 1000$ eV$^2$. We have simulated what such an experiment would look like for one year's operation of DUMAND. In order to best illustrate the effect of oscillations, we study the distribution of events as a function of a variable $\eta$ which has a flat distribution if there are no oscillations. Fig. 2 shows the result of the simulation as a function of $\eta$, and zenith $\theta$, for maximal oscillations. Such oscillations in the $\delta$ range considered would be detectable. The actual limits which can be placed on the mixing angle would depend on statistics. From Fig. 2 it appears that perhaps a 20% effect would be detected in a year. It is to be noted that DUMAND would be exploring unique regions of L and E so effects, such as matter oscillations[9] which depend on these separately, could be studied.

## HIGH ENERGY NEUTRINO ASTRONOMY

The astrophysical role of high energy neutrinos is discussed in several papers at this conference. Since there is virtually no observational information on extraterrestrial high energy neutrinos, flux estimates are necessarily speculative. Taking the calculated numbers at face value, DUMAND is the only project currently under consideration which will have the sensitivity to observe these sources. For example, any events seen in the large proton decay detectors would be a (pleasant) surprise.

The Minimum Detectable Flux (MDF) for extraterrestrial neutrinos, normalized to 1 TeV[10], has been calculated for the DUMAND array and the Muon String, and again compared with the CWI experiment as an example of what can be accomplished underground. This is basically the flux which would give 10 events per year when the atmospheric background is negligible in the angular region of the sky being considered, usually the case for point sources. When the background is above one event per year, as it is when one is looking at more diffuse sources such as the galactic disk, then a $5\sigma$ effect is required. In Fig. 3 the results are shown in terms of the number of neutrinos above 1 TeV which would have to be (isotropically) emitted from a source at a distance R (this turns out to be roughly the luminosity of neutrinos in ergs/sec). Shown are the fluxes which might be expected from various sources, depending on the fraction of energy which appears as TeV neutrinos.

We again see that even the early phases of DUMAND represent orders of magnitude improvement over what may be accomplished in mines. If a supernova were to occur in our galaxy while the Muon String is deployed (very unlikely), it might be detected. Supernovae in our local cluster of galaxies out to M31, perhaps one every five years, could be seen by DUMAND. The array is about at the limit for detecting the diffuse flux expected, with some reliability, from the central regions of our galaxy[11]. Active galaxies, if powered by black holes, are predicted to be sources of high energy neutrinos[12]. The possible signal from the weak but close active galaxy, Centaurus A, is shown in Fig. 3. The quasar 3C273 is $\sim 10^4$ times as powerful but ~100 times farther away, so its flux will be similar[13]. Other sources such as SS433 are candidates for strong neutrino signals[14].

Until we look, we will not know if these signals are there, nor any others of unknown origin. The astrophysical calculations will remain speculative until there are some data to hang them on. Some idea of the magnitude of fluxes which are possible at TeV energies can be obtained from $\gamma$-ray observations. The $\gamma$ fluxes from several sources are also shown in Fig. 3. While the possibility of hidden sources, opaque to e-m radiation, represents the most exciting prospect for DUMAND, we note that there is at least one $\gamma$ source, Cyg X-3, which is emitting particles at TeV energies in detectable numbers and DUMAND, as a neutrino telescope, would be comparable to $\gamma$ detectors in sensitivity.

## CONCLUSIONS

A DUMAND array which can do important neutrino physics and astronomy can be built and deployed at reasonable cost. The array should see the predicted turnover in the $\nu N$ cross section above 1 TeV. A search can be made for neutrino oscillations with $0.1 < \delta < 1000$ eV$^2$ with atmospheric neutrinos. Should extraterrestrial neutrinos be observed the limits can be correspondingly extended. The sensitivity to extraterrestrial sources is orders of magnitude higher than other detectors and in the range where sources might be expected to produce the required flux of neutrinos.

## REFERENCES

1. An extensive literature on DUMAND exists, especially in the proceedings of workshops and symposia held since 1975. Copies of proceedings since 1978 are available from the Hawaii DUMAND Center. See, for example, Proceedings of the 1980 International DUMAND Symposium, "DUMAND 80", V.J. Stenger, ed., Hawaii DUMAND Center (1980).

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3. A. Roberts and V.J. Stenger, ibid, p. 136.

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13. R. Silberberg, private communication.

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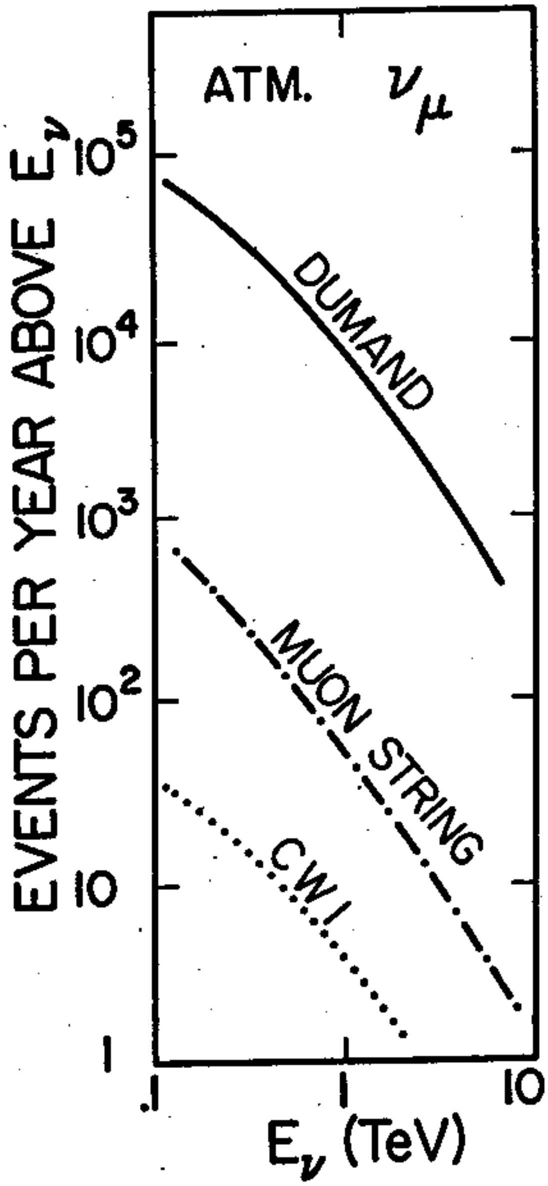


Fig. 1. Integral event rate spectrum for $\nu_\mu$ charged current events in DUMAND compared with the Muon String and CWI experiments.

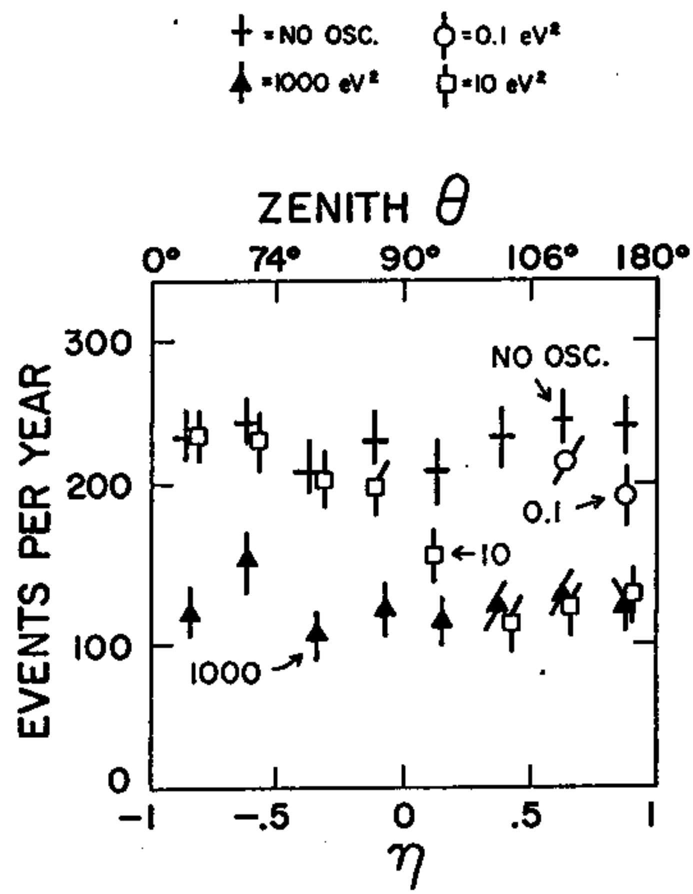


Fig. 2. The distribution in $\eta$ (see text) and zenith $\theta$ if there are no oscillations in the detectable range and for maximal oscillations for mass square differences $\delta$ = 0.1, 10 and 1000 $eV^2$.

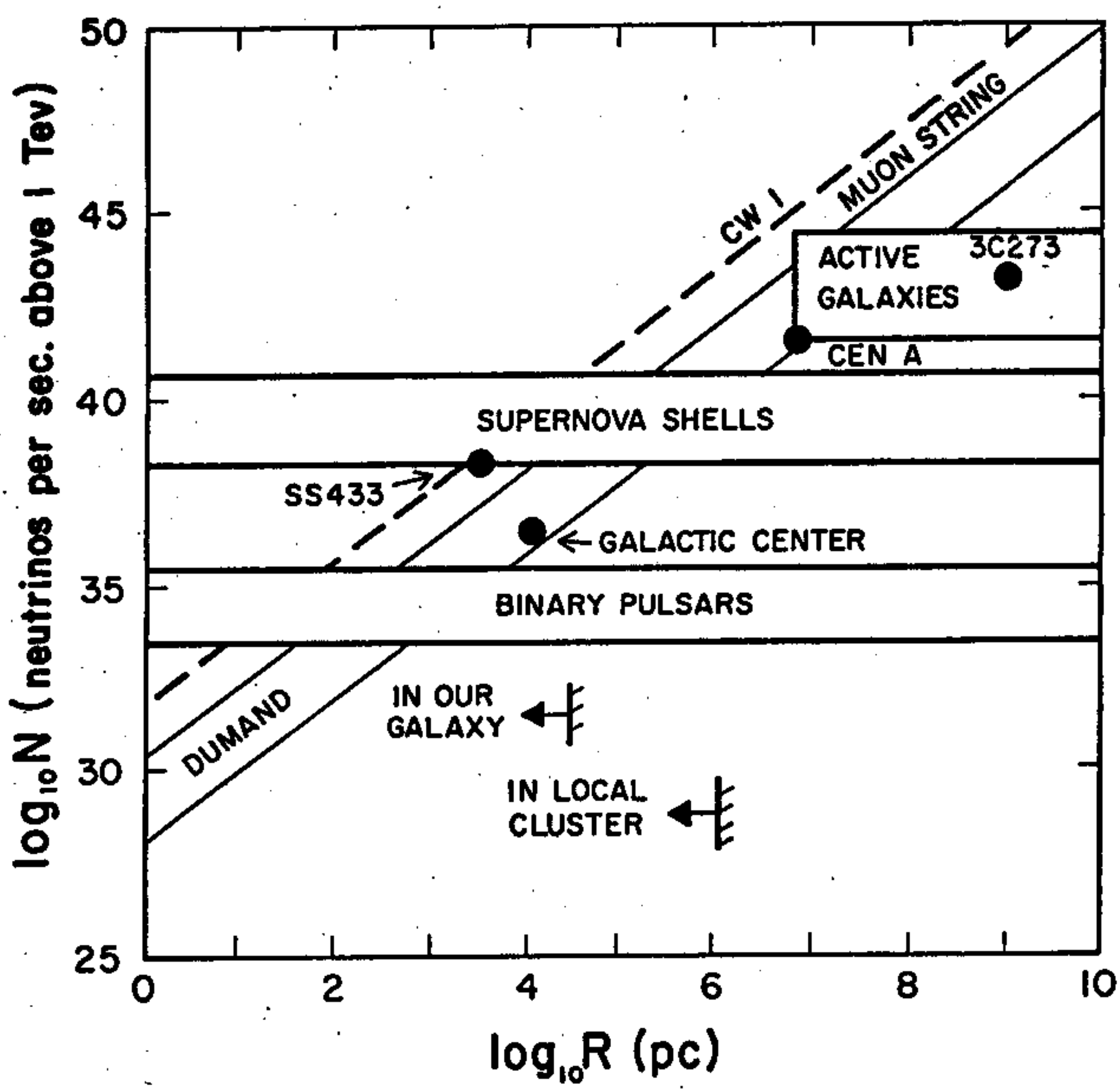


Fig. 3. The sensitivity of DUMAND and other experiments to the source luminosity of TeV neutrinos as a function of source distance. The bands indicate the range expected from certain source types at the distances indicated. The points are estimates for some specific sources.