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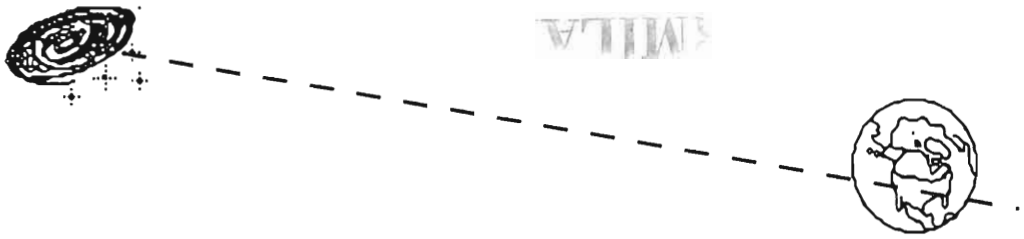

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AMANDA South Pole Neutrino Detector

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AMANDA SOUTH POLE NEUTRINO DETECTOR

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Abstract

High energy neutrino radiation provides us with a tomographic tool to scan the Universe. Sites shielded by a few hundred grams of matter are not revealed by light, whatever its wavelength. High energy neutrinos are decay products of pions and therefore are a signature of the most energetic cosmic processes. It is proposed to instrument the polar ice cap as a low-noise particle detector sensing the Cherenkov light from neutrino-induced muons. This paper describes the successful operation of a prototype string of optical modules that where deployed on January 17, 1992 at the South Pole. The advantages of the method are intriguing. The ice has good optical transmission and provides a mechanical structure to support the instrument. Ice is a quiet, sterile medium where photomultiplier tubes experience low background counting rates. The low background allows us to develop electronics and triggering schemes that are simple and can be installed at the surface and thus remain accessible after deployment of the PMTs under 1 km of ice. NSF has recently approved our proposal to construct a detector that will have an area over one order of magnitude larger than the largest of the present generation of underground detectors.

INTRODUCTION

The reasons for commissioning the high energy neutrino telescope AMANDA (Antarctic Muon and Neutrino Detector Array) are intriguing:

-- as photons carry little information on cosmic sites shielded from our view by more than a few hundred grams of intervening matter, the possibility of using weakly interacting neutrinos as a window on the Universe should be explored,

-- neutrinos are the decay products of pions and therefore they are a signature of the most energetic cosmic processes,

-- the neutrino sky could contain objects with no observational counterpart in any wavelength of light.

The AMANDA detector will concentrate on neutrino astronomy at the smallest wavelengths, detecting particles in the 100 GeV to 1 PeV energy range. In this energy range the flux of background neutrinos, generated by pion decay in cosmic ray-induced atmospheric cascades, is extremely small and the fluxes of anticipated sources dominate the neutrino sky[1]. AMANDA will use the large volumes of the polar ice cap as a low-noise particle detector sensing the Cherenkov light from neutrino-induced muons. The detector is based on techniques which have been tested *in-situ* and for which the technology and the cost is understood. A complete

description of the detector can be found in the papers listed in reference 1.

NEUTRINO TELESCOPES USING ICE AS A PARTICLE DETECTOR

At present, we believe the most cost-effective method to commission neutrino telescopes with effective area of order 0.1 km^2 is to use south polar ice.[2]. The AMANDA detector will reach this goal by instrumenting a large volume of South Pole ice. The experimental challenge of neutrino astronomy is to conceive of large-area particle detectors in an environment shielded from the large cosmic ray backgrounds at the surface of the Earth. We have demonstrated the possibility of taking advantage of the clear optical characteristics of deep polar ice in order to use it as a medium in which to sense the Cherenkov light generated by muons produced by cosmic neutrinos. Since TeV neutrinos will produce muons that travel over a kilometer in ice, the effective volume of such a detector is enormous even for a relatively modest volume of active detector which would consist of photomultipliers identifying muons by mapping their Cherenkov cone. The muon trajectory determines the parent neutrino arrival direction to a precision of order 1 degree. A simple procedure to construct a neutrino telescope uses hot water to create a water-filled hole that is 1 km deep. Since it is not practical to remove the water from the borehole, a string of photomultiplier tubes must be lowered to depth before the water refreezes (which takes about 4 days). Good optical contact is achieved as the water slowly refreezes thus insuring that an insignificant number of bubbles will form locally near the sensors.

There are significant science advantages to performing such experiments in the South Pole ice:

1. Ice is a quiet, sterile medium. There are no sources of background photons such as ^{40}K or bioluminescence. The PMT background counting rate is dominated by dark noise which is typically 2.5 kHz (for 8 inch PMTs at 0.3 pe discrimination) in the constant -55C temperature. Since the background rates are small, extremely simple trigger schemes can be implemented with off-the-shelf, inexpensive electronics.

2. Tests we performed are consistent with the expectation that the optical properties of *in-situ* ice are comparable to pure polycrystalline ice grown in the laboratory. Such ice has good optical transmission with attenuation length of 25 m around 470 nm. It is known that ice cores retrieved from a depth of 1 km are bubble-free and photographs show them to be optically transparent. Gow *et al.*[3] have mapped bubble structure of the Antarctic ice. At depth between 800 to 1100 meters trapped air is forced into the ice lattice. Moreover, our tests of *in-situ* ice show that bubbles trapped locally in the ice during the installation of PMTs do not have significant impact on the optical sensitivity, as the light is mostly scattered forward with negligible absorption.

3. The ice forms a mechanical structure for the instrument, enabling all active electronics to be placed directly above at the surface, putting them within reach for adjustment and maintenance. The deployment of the optical sensors is a straightforward procedure because the strings can be pre-assembled and stretched along the ground. It is then easy to check electrical and mechanical integrity of the system prior to deployment.

4. A cosmic source is observed continuously and remains at fixed zenith angle, making the subtraction of cosmic ray backgrounds extremely simple. The unique opportunity of uninterrupted observation of sources, not possible with gamma ray detectors, should be emphasized because some sources are expected to be impulsive and episodic with variations on perhaps several different time scales as is the case for X-ray binaries.

5. Instrumenting polar ice with phototubes allows the experiment to follow science: the array can be filled in to increase resolution and up/down rejection, and/or expanded over the

essentially unlimited expanse of the stable icefields.

6. There is a year-round station with adequate power (>10 kW) and communication (3 MB/week) as well as an operating air shower array (SPASE) which can be used for calibration and pointing. Station support for experimental activities is excellent. Large fork lifts, cranes, and plows are available to move heavy equipment around the station. Electronic mail facilities permit interaction with specialists who spend the winter at the pole maintaining scientific experiments.

SOUTH POLE 91-92

During the last austral summer (Nov. 1991--Feb 1992) hot water drilling was used to position several strings with different PMT sizes and at different depths for further tests of ice quality and for gaining experience in string deployment and operation.

The following detectors are now operating in South Pole ice:

- 2 PMTs of 8 inch diameter at 115 m, separation 2m
- 4 PMTs of 8 inch diameter at 150 m, separation 5m
- 4 PMTs of 3 inch diameter at 800 m, separation 1m

Also a set of 19 PMTs were frozen in 0.5 m of ice in a light-tight backyard swimming pool, constituting a prototype air shower detector of 45 m^2 area.

After spending two months at the south pole, we obtained the following conclusions.

Physics

-- there is no background of beta emitters such as potassium, the dark current of the tubes determines the background counting rate. As a consequence, a two-fold coincidence is sufficient to observe a real muon signal at all depths.

-- optical contact between the pressure vessel and refrozen ice is comparable to the water-module interface. We actually observed a gradual increase of muon counting rates as the ice refreezes (Figure 1). This suggests that the optical contact with the PMT improves as the ice refreezes.

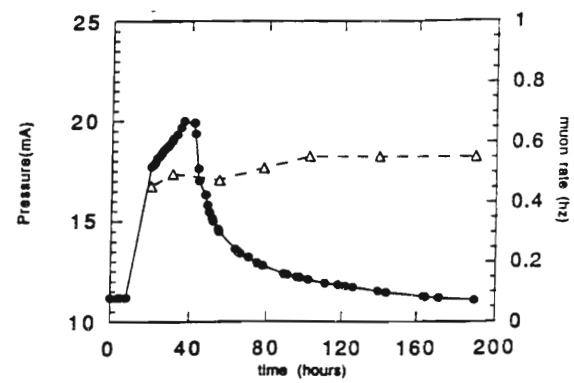

Figure 1: Measured muon rate (triangles) and ambient pressure (circles) at 800m as a function of time after deployment.

-- muon counting rates at 800 m are consistent with Monte Carlo (MC) predictions assuming bubble-free laboratory ice (see Figure 2). The solid line is generated by assuming that the attenuation length of the ice is 50% of the value measured in the lab. The error bars on the solid line indicate the statistical uncertainty of the MC. The MC calculation is also subject to systematic errors of 10% due to uncertainties in the photoelectron collection effeciciency.

We conclude that 800 m deep ice is free of bubbles and has attenuation length larger than 80% of laboratory ice. Furthermore, the rate of coincidence between SPASE triggers and AMANDA triggers provides an independent check of the optical clarity of the ice. These results are consistent with our conclusions based on the observed muon rates alone.

It is also important to realize that at 1 km depth any residual bubbles are less than 1 micrometer in diameter (Gow, private communication). We computed that the Mie scattering length exceeds the absorption length and should not affect our experiment.

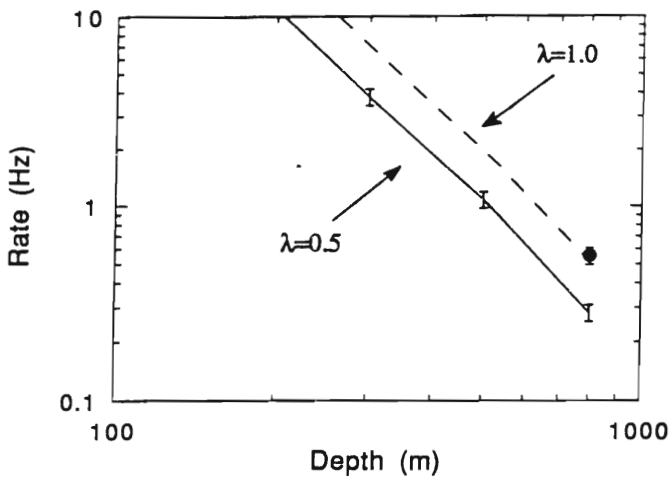

Figure 2: Measured muon rate at 800m (dot) is compared with Monte Carlo rates for two models of ice transparency.

-- a 4 nanosecond FWHM precision in timing resolution is achieved with the prototype AMANDA electronic system.

Technology

-- equipment survives refreezing. The refreezing process lasts a few days and good optical contact between PMT and ice is established.

-- during refreezing, the pressure at 800 m increased to 170 atmospheres before dropping to equilibrium pressure (70 atm). The Benthos spheres used in the present design are tested and guaranteed for 250 atmospheres.

-- the AMANDA prototype string of 8 inch PMTs was deployed 4 times and continued to function after a substantial amount of abuse. Thus, the mechanical design of string and PMT housing is sufficient as a final detector design.

-- the hole reached a depth of 2500 feet and was 14 inches wide. It is now clear that drilling with improved equipment will be routine.

CONCLUSION

Two strings of optical sensors were deployed during the '91-'92 austral summer at the south pole. The were lowered down water-filled holes that reached a depth of 800 meters. The sensors survived the subsequent refreezing of the water and continue to operate reliably. We have found that the noise rates from the buried PMTs are comparable to the intrinsic noise rates of these detectors. The observed muon rates at a depth of 800 meters is consistent with the assumption that the ice is bubble-free and transparent. Our conclusions about the ice transparency has been independently verified by measuring the coincidence rate between events observed by the SPASE air shower array and muon events observed by the AMANDA strings. Also, we determined that the sensitivity of the optical modules did **not** degrade as the ice refroze around them.

In short, we have demonstrated that south polar ice can be used as part of a large-area neutrino telescope and we have developed an inexpensive and reliable technology that can take advantage of this optically clear ice.

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