SPATS - A SOUTH POLE ACOUSTIC TEST SETUP

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FOR THE SPATS GROUP

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Due to its large Greeneisen coefficient ice is of special interest for the acoustic detection of ultra-high energetic neutrino-induced cascades. The abundant homogeneous volume and an existing neutrino observatory make the south polar ice cap a favourable location for this purpose. Theoretical calculations yield absorption lengths of ~ 10 km, but no measurements at all are available in the frequency range of interest. We present an experimental setup to measure the key parameters of the antarctic glacial ice.

1. Motivation

Despite its remote location, the south polar ice cap has proven to be a well-suited place for the neutrino telescopes IceCube¹ and AMANDA² detecting ultra-high energetic neutrinos by Cherenkov light emitted from neutrino interactions in the ice. Extensive investigations³ have shown that the ice is very clear and homogeneous for light transmission with absorption lengths of ~ 100 m. Similar promising results were obtained by the RICE experiment⁴ investigating the possibility of detecting neutrino induced cascades by their radio emission. Absorption lengths for radio waves were measured to be ~ 1 km, making this technique designated for a large-volume detector with correspondingly larger spacing and good sensitivity on the $\gtrsim$ PeV scale.

The detection of acoustic waves generated in the same neutrino interactions has only recently gained in interest again. Many km³ of target material

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will be needed to detect the feeble fluxes expected in the even higher energy range accesible with this technique. With larger signals than in water and expected absorption lengths of $\sim 10 \text{ km}$ ⁷, the south polar ice seems to be a promising medium also for an acoustic detector, allowing larger instrumented volumes and thereby suitable sensitivities on the EeV scale.

The possibility of combining the three detection methods makes the location even more favourable. A simulation of a hybrid optical – radio – acoustic array⁵ yields event rates of $\gtrsim 10/\text{yr}$ with about 40 % percent of the events detected by at least two techniques in coincidence.

However, in contrast to optical and radio detection, the assumptions for acoustic properties of the ice are purely based on theoretical calculations⁷. For a proper evaluation of the potential of such a detector, therefore a dedicated setup will be needed to measure the four key parameters:

- **Scattering length**

Scattering of phonons in the ice is assumed to be dominated by Raleigh scattering at the grain boundaries, and therefore dependant on crystal size a and frequency f

$$\lambda_s \propto a^{-3} \times f^{-4} \quad (1)$$

as shown in Fig. 1. Using an estimated grain size of 0.2 cm, values of $\lambda_s(10 \text{ kHz}) \approx 2000 \text{ km}$ and $\lambda_s(100 \text{ kHz}) \approx 0.2 \text{ km}$ are obtained⁷. Since the spectral peak frequency for a neutrino-induced acoustic wave is $\sim 50 \text{ kHz}$ in ice where $\lambda_s(50 \text{ kHz}) \approx 3.2 \text{ km}$ scattering can probably be neglected for sensor spacings closer than $\sim 1 \text{ km}$.

- **Absorption length**

For phonon absorption, the energy loss in the relaxtion of molecular reorientations is assumed to be dominant, which is therefore also a temperature dependant effect. Using laboratory measurements on the relaxation process, a value of $\lambda_a(-51^\circ \text{C}) = 8.6 \text{ km}$ is predicted⁷ for the coldest temperatures expected. Combined with a temperature profile, the depth dependant absorption can be determined as shown in Fig. 1⁷.

- **Velocity of sound**

Velocity of sound depends only weakly on the temperature via the elastic modulus $\bar{E}(T)$, but strongly on the density of the ice ρ

$$\vec{v}_s = \sqrt{\frac{\bar{E}(T)\vec{e}}{\rho}} \quad (2)$$

Figure 1. Absorption length vs. depth(left) and frequency(left, inset) and scattering length vs. frequency(right) in the south polar ice cap, taken from ⁷

This results in a very distinct profile, with strong variation in the upper ~ 200 m, where density increases strongly, and small variation below, where only temperature effects are important. Therefore, acoustic waves in the upper part will always be strongly bent towards the surface, whereas propagation will be nearly linear in the lower part.

• Background noise

With only a few signal events per year, ambient noise will be of special importance for an acoustic neutrino detector. Although the south pole is known to be among the most quiet places on earth in the seismic frequency range, neither measurements nor theoretical estimates are available for the ultrasonic regime. Some possible sources may include

- **anthropogenic** noise that should not only be damped by the firn layer, but as well be mostly refracted back to the surfaces
- noise from **micro cracks** in the ice, similar to what is observed in the vicinity of salt mines⁶
- noise generated in the **slip-stick motion** of the glacier over the continental bedrock

However, it is strongly assumed that the average noise level will be well below what is observed in oceans, where not only wind and waves contribute strongly, but also natural (e.g. dolphins and

sperm whales) and anthropogenic (e.g ships and oil drilling platforms) sources generate many transient events.

2. SPATS

In order to access all these parameters, an experimental setup — *SPATS, the South Pole Acoustic Test Setup* — was designed. Measuring the desired quantities implies signal transmission over distances of a few hundred meters for absorption to become relevant. To confirm the assumptions on temperature and density dependance, instrumentation of the upper few hundred meters is sufficient, as variation of both is small below.

2.1. General setup

Figure 2. Schematic of the SPAT Setup(left) and acoustic sensor(right)

Therefore a transmitter–receiver array with three strings in unequal spacing of 125 m to ~ 500 m is proposed, allowing redundant absorption

measurements. For solving the depth-dependance, seven levels from 80 m to 400 m will be equipped with acoustic stages, each of them holding as well a sensor and a transmitter as shown in Fig. 2. With hole drilling as the major cost factor, it is suggested to use the upper part of the holes of the IceCube project, which itself instruments only the depth range of 1500 m – 2400 m. Each acoustic string is read out by a *String-PC* at the top of the hole, which then passes the data to a *Master-PC* in the counting house. The data is stored on a local disk, with a small part of it being transmitted via satellite to the northern hemisphere for immediate analysis. This same link will also allow to log on to the system from the north for control and software updates.

2.2. Acoustic Stages

Each acoustic stage consists of a sensor module (see Fig. 2) and a transmitter module, both of them in a custom pressure housing to withstand the static pressure and additional pressure generate in the refreezing process. Each sensor module hosts three channels arranged in a star-like pattern. While no control over the azimuthal orientation is possible in the deployment, this improves the omnidirectional sensitivity of the device, but will also allow to look for coincidences within the module and a first estimate of the direction of the incoming pressure wave.

In the transmitter housing, a HV pulse generator drives $\sim 10 \mu\text{s}$ pulses with an externally adjustable peak voltage of up to 1 kV. A ring-shaped piezoelectric ceramic outside the pressure housing, molded into epoxy resin for stability, converts the electrical signal to an acoustic pulse. Peak currents of 8 A are reached due to the large capacitance of the ceramics. Bleeder resistors allow a read-back of the electrical signal scaled by a factor 1:100. In addition, temperature sensors are installed at each depth level but the lowest one, which contains pressure sensors for depth measurement and monitoring of the freeze-in process.

2.3. DAQ, Communication and Timing

The heart of the *String-PC* is an industrial standard PC/104 embedded CPU module running at 600 MHz clock frequency. Together with three 12-bit A/D sampling modules of 1.25 MHz and power supplies it is mounted in a waterproofed container, which will be buried in the snow for insulation to the strong climatic changes. The *String-PC* communicates to the *Master-PC* via a 2.2 MBit DSL connection over the ~ 1 km surface cables shared

with the IceCube project. DC-Power to the system is supplied via the same cable. In addition, an IRIG-B time coding sequence is used to keep the *String-PCs* synchronized on a sub-millisecond level.

3. Status

All sensor and transmitter modules for the SPATS setup were produced at DESY Zeuthen. Each of them has been individually calibrated to a reference hydrophone using a spectral comparison method ⁸. The variation in sensitivity of ~ 20 dB is probably a result from the mechanical setup of the sensor. Calibration of peak amplitudes and azimuthal response was also performed for all the transmitter modules. Extensive system testing has been started, with all parts that are subject to cold temperatures undergoing a freezing test at -55°C .

The system is planned to be installed in polar season 05/06. After a re-freezing time of several weeks, first results are expected in march 2006. Once the key parameters are resolved and the suitability of glacial ice is confirmed, the ground is laid for the design and developement of a several ten km^3 array.

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