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Neutrino Physics/Physique des neutrinos

High energy neutrino astronomy

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Abstract

Traditionally photons are used to study the Universe, but, at high energies, absorption of photons renders it opaque. Neutrinos, interacting only weakly, are good alternative candidates to probe the high energy Universe over cosmological distances. Pioneering experiments utilizing the neutrino as messenger have been taking data for about a decade, but so far no source of extraterrestrial high energy neutrinos could be identified. Detection requires km^3 detectors, planned to be operated deep underwater or under ice. While several projects are studying the feasibility of such a detector in the Mediterranean Sea, the construction of an Antarctic array has already started. ***To cite this article: S. Hundertmark, A. Kouchner, C. R. Physique 6 (2005).***

Résumé

Astronomie neutrino à haute énergie. L'Univers est traditionnellement étudié par l'intermédiaire de photons, mais, à haute énergie, ceux-ci sont absorbés au point que l'Univers devient opaque. Les neutrinos, parce qu'ils n'interagissent que faiblement, sont de bons messagers (alternatifs) pour l'exploration de l'Univers lointain à haute énergie. Plusieurs télescopes à neutrinos de première génération ont accumulé des données pendant une dizaine d'années, sans pour autant identifier de source. Pour ce faire, de nouveaux détecteurs d'environ 1 km^3 doivent être immergés au fond de l'eau ou de la glace. Tandis que plusieurs projets étudient la faisabilité d'un tel détecteur en mer Méditerranée, la construction d'un télescope kilométrique vient de débuter au Pôle Sud. ***Pour citer cet article : S. Hundertmark, A. Kouchner, C. R. Physique 6 (2005).***

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1. Scientific motivation

The fundamental questions that neutrino astronomy tries to answer is what and where the sources of the high energy cosmic rays (HECR) are. As discovered already in 1912 [1], the Earth is being continuously bombarded by an isotropic flux of charged particles of unknown origin. As early as in the 1960s the neutrino was proposed by Greisen, Markov and Reines as the ultimate astronomical messenger [2]. Indeed, neutrinos can escape from the core of the sources and travel with the speed of light

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through magnetic fields and matter without being deflected or absorbed. Therefore they can deliver direct information about the processes taking place in the core of the production sites and reveal the existence of undetected sources. Above several GeV, neutrinos are unmatched in their capabilities to probe the Universe.

The other candidate particles, neutrons, protons and photons, suffer limitations. Neutrons, as any neutral particle, pass undeflected through magnetic fields, but their short lifetime makes astronomy impractical. Protons, as the major component of cosmic rays (CR), suffer deflection by magnetic fields, which might be the cause for the measured isotropy of the CR. An accurate knowledge of the proton energy and of the extraterrestrial magnetic fields is required to trace them back to their sources. Above $\sim 10^{19}$ eV, protons point straight back to the production site, but they suffer an unknown delay with respect to neutral particles [3], preventing simultaneous detection with other messengers. In addition, because of the interaction with the relic radiation fields—the GZK effect [4]—the window for proton astronomy closes just above $\sim 10^{20}$ eV. The GZK effect is actually the source of a puzzle. As CR above this energy have been reported, it is implied that sources are close by, but no powerful enough close by source could be identified. This puzzle spurred the realization of the huge CR observatory AUGER [5], being designed to make a high statistics measurement of CRs with energies above $\sim 10^{19}$ eV.

Since the dawn of time, photons have been the most privileged particles used to explore the Universe and are undoubtedly the most successful. As photons interact electromagnetically with matter and with the relic radiation fields their mean free path decreases with energy and the Universe becomes opaque: at ~ 1 PeV (high energy γ-rays) the field of view is reduced to the dimension of our Galaxy.

For the above mentioned reasons, neutrinos appear not only as an interesting messenger able to inform about the underlying CR production mechanisms, but also as a unique probe to study astrophysical sources and explore the High Energy Universe over cosmological distances. Neutrino astronomy will certainly allow the opening of a new window on the Universe.

The neutrino's advantage, its weak coupling to matter is, at the same time, a big disadvantage. Huge volumes need to be monitored to compensate for the feeble signal expected from the cosmic neutrino sources. Efforts went into the development of detector technologies, both cheap and reliable. Currently most advanced is the water/ice Cherenkov technique, using photomultiplier tubes (PMT) to build neutrino telescopes (NT). The required size of these detectors has grown with time since the largest operating NT, AMANDA-II, has recently placed significant limits on the flux of extragalactic neutrinos. Theoretically founded arguments anticipate that at least a 1 km^3 NT is needed for the detection of astrophysical neutrinos. Consequently several projects, in different development stages and in both hemispheres of the Earth, aim at deploying such a detector.

2. Neutrino flux predictions

In the 'bottom-up' scenario the production of high energy neutrinos in astrophysical sources is inextricably related to proton acceleration through the Fermi mechanism. This mechanism generically produces a non thermal $\mathrm{d}N/\mathrm{d}E \propto E^{-\alpha}$ spectrum, with $\alpha \approx 2$. High energy neutrinos are produced in a beam dump scenario in dense matter via pion decay, when the accelerated protons interact with ambient matter or dense photon fields:

$$\begin{array}{llll} p/A + p/\gamma \longrightarrow & \pi^0 & + \ \pi^\pm & + N + \cdots \\ & \downarrow & \downarrow & \\ & \gamma+\gamma & \mu^\pm + \nu_\mu\ (\bar\nu_\mu) & \\ & & \downarrow & \\ & & e^\pm + \nu_e\ (\bar\nu_e) + \bar\nu_\mu\ (\nu_\mu) & \end{array}$$

According to this scheme, for each electron neutrino, two muon neutrinos are produced ($\nu_e : \nu_\mu : \nu_\tau = 1 : 2 : 0$). Even so, high energy γ-rays, if produced as described by π^0 decay, can also indicate a potential source of cosmic rays (see, for example, [6]); they can as well result from synchrotron self Compton scattering, not necessarily involving hadron acceleration. Only neutrinos can unambiguously determine the acceleration of protons.

An upper bound on the diffuse neutrino flux can be derived using the measured intensity of the HECR (or γ-ray fluxes [7]). The most stringent theoretical bound is the 'Waxman–Bahcall' bound [8] which is below the sensitivity of the currently operating NT and sets the scale for the next generation km^3 detectors. However, this bound is not universal. Alternative scenarios ('top-down scenarios') produce high energy neutrinos via the decay of relic heavy particles and could be the solution to the above mentioned puzzle in connection to the GZK effect. These particles are also good dark matter candidates [9]. So far, no such particles have been observed and their detection by a NT would be a revolution in particle physics.

2.1. *Extragalactic sources*

Good candidates for high energy neutrino production are active galactic nuclei (AGN). These objects, powered by a super massive black hole, are among the brightest astrophysical objects. The accretion of matter by the black hole leads to an accretion disk and may produce relativistic jets perpendicular to the disk. The production of neutrinos could take place in the disk [10] or in the jets [11].

Another potential source of high energy neutrinos are transient sources like gamma ray bursters (GRB). As many models [12] for GRB involve the collapsing of a star, acceleration of hadrons follows naturally. The diffuse flux of high energy neutrinos from GRB [13] is lower than that expected from AGN, but the background can be dramatically reduced by requiring a spatial and temporal coincidence with the short electromagnetic bursts detected by a satellite. Therefore GRB offer a great opportunity for the observation of high energy neutrinos.

2.2. Galactic sources

The galactic plane has a high concentration of potential neutrino emitters. Microquasars [14], for instance, are black holes of a few solar masses, accreting matter from a companion. They may be considered as a small scale model of AGN, mainly because of the recent detection of relativistic jets. Pulsars, which are rapidly spinning neutrons stars generating strong magnetic fields, can lead to electrostatic particle acceleration. Also likely to produce neutrinos are supernovae remnants. These are powerful blast waves driven to the interstellar medium by core collapse of massive stars (supernovae). For a more extensive review see [15]. More recently, a high energy non thermal activity has been reported by the HESS ground based γ-ray telescope from the Galactic Center itself [16]. As NTs mainly look downward through the Earth, a northern hemisphere NT is advocated for good coverage of the galactic plane.

3. Detection principles

Neutrinos are detected via the secondary products from their interactions with matter. Even so both muon and electron neutrinos are produced in the beam dump scenario described in Section 2, several factors favor the detection of high energy muon neutrinos. The ν_μ charged-current (CC) cross-section which produces a high energy muon ($\nu_\mu + N \to \mu + X$) grows with energy as well as the issued muon range. At high energy the range is up to several kilometers. As the energy loss is proportional to the muon energy, high energy muons produce more photons that can be detected. These factors compensate at least partly the fact that the flux of astrophysical neutrinos drops with energy. Moreover the angle between the neutrino and the daughter muon is reduced to less than a degree ($E_\nu >$ TeV), enabling the instrument to be used as a telescope.

A grid of optical modules (OM) is used to detect Cherenkov photons sent out by muons during their passage through the media. An OM consists out of a PMT enclosed in a pressure glass sphere. Depending on the design the OM can also house on board electronics to process data. Given a sufficient number of OMs are hit, one uses the known Cherenkov angle under which the photons are emitted, to reconstruct the muon direction. The optical properties of the medium (scattering and absorption of photons) determine the optimal distances between the OMs. Typically the OMs are arranged at vertical distances of 10–20 m and 50–130 m horizontally. Therefore the concept of an enclosed detector, accessible for maintenance, is not suitable at higher energies. The largest enclosed NT is the Super-Kamiokande experiment [17], a 50 000 ton (∼ 40 m diameter) cylindrical water Cherenkov detector, with a sensitivity up to a few GeV. Above this energy, one needs huge open detectors deployed in natural media like sea/lake water or ice.

3.1. Backgrounds to extraterrestrial neutrinos

The weak fluxes of extraterrestrial neutrinos have to be separated from backgrounds created by cosmic ray primary particle interactions in the atmosphere. The most abundant background is made of muons copiously produced in these air showers. If sufficiently energetic, these atmospheric muons penetrate to the underground detector. Two measures are used to reduce this large background. The first measure is to place the detector under as much overburden as feasible. The second is to use the Earth as filter and concentrate on upward going particles. Therefore, the field of view for NTs is restricted to the lower hemisphere. Along with atmospheric muons, atmospheric neutrinos are produced following a $\mathrm{d}N/\mathrm{d}E \propto E^{-3.7}$ spectrum. These neutrinos do come from all directions and represent an irreducible background. As extraterrestrial neutrinos are expected to exhibit a harder spectrum ($\mathrm{d}N/\mathrm{d}E \propto E^{-2}$), an excess of events above a certain energy would be attributed to extraterrestrial neutrinos.

For neutrinos above several PeV the Earth will be increasingly opaque and at ultra-high energies (UHE) the signal has to be searched at the horizon making large bundles of atmospheric muons the background. Nevertheless it was shown that neutrino induced events can be distinguished from atmospheric muon bundles [18] and NT are a viable tool to search for UHE neutrinos.

3.2. Neutrino oscillation effects and event topologies

The interaction of protons with protons or photons in the source will lead to pion production. As shown in Section 2 the decay chain of these pions leads to the naive neutrino flavor ratio expectation of $\nu_e : \nu_\mu : \nu_\tau = 1 : 2 : 0$ at the source. As these neutrinos propagate over cosmological distances, oscillations [19] between the different flavors could result in a ratio of $\nu_e : \nu_\mu : \nu_\tau = 1 : 1 : 1$ at the detector [20]. This democratic flavor distribution emphasizes the importance of all flavor sensitivity. Muon neutrinos produce, via CC interaction, muons that travel through the detector. In contrast to these track-like events, electrons from electron neutrinos will only travel short distances compared to the spacing of the array and leave a localized energy deposition. The achievable pointing resolution is worse compared to muons, but as the energy is deposited in a comparatively small volume a better energy determination is possible. Up to energies of $\sim$ PeV the same applies to taus from tau neutrinos. These events are called 'cascade' events. Given a sufficiently large detector, one can search for the specific 'double bang' signature of high energetic tau neutrinos. The tau from a tau-neutrino CC interaction travels distances above tens of meters before it decays, giving a distinct signature of two cascades connected by a dim tau track. In total NT could use these topologies for particle identification and consequently extract more information about the source of the neutrinos or the oscillation parameters [21].

3.3. Site considerations

The optimal site for a large NT combines a medium with very little scattering and absorption to enhance both the pointing accuracy and the effective detection volume. The site should be deep enough to shield the down-going atmospheric muon flux and easily accessible with all the needed infrastructure close by. In reality one has to compromise. Water is generally less diffusive than ice but absorbs more light. In lakes, absorption is much more important than in the ocean or sea, essentially because of the fouling and the presence of mud. On the other hand, sea water sites must fight against Cherenkov photons from electrons produced in ^{40}K β-decays and light emitted by bioluminescent bacteria or other living creatures, a background that needs to be filtered with causality based algorithms.

The field of view for a NT is related to its geographic latitude. For ice there is only one location deep enough and with the needed infrastructure: the South Pole. There, a NT is monitoring the northern hemisphere, while at mild latitudes the Earth rotation enables a detector to monitor, at least for part of the time, 3.5π of the sky. A configuration of two detectors would therefore provide both a complementary sky coverage and the possibility of cross exploration of parts of the sky. Finally, a detector in the northern hemisphere provides easier access to sources that might be found close to the Galactic Center which is located in the south hemisphere at a declination of $\delta = -29^\circ$.

4. Current projects and detectors

The first attempt to build a NT was made by the DUMAND collaboration [22], off the Hawaiian coast at the end of the 1970s. Due to technical problems, the project was canceled in 1995. New projects have been born since then, some in the ice providing the detector with mechanical stability and avoiding leakage problems, others persevering with water. A summary of their main features is presented in Table 1.

Table 1
Summary of the main features of the current NT projects

Experiment	Dimensions	# PMTs	Medium	Angular resolution	Status
AMANDA [23]	Cylinder (R × H) 100 m × 500 m	677	Ice	$\sim 3.0^\circ$	Running
ICECUBE [24]	Octagon 1 km^3	4800		$< 1.0^\circ$	Construction
BAIKAL [25]	Cylinder (R × H) 20 m × 72 m	192	Lake water	$\sim 4^\circ$	Running
NESTOR [26]	Cylinder (R × H) 16 m × 410 m	144	Sea water	$< 0.5^\circ$	Construction
ANTARES [27]	Octagon (l × H) 60–75 m × 350 m	900			
NEMO [28] KM3NET [29]	Array 1 km^3	~ 5000			Conception

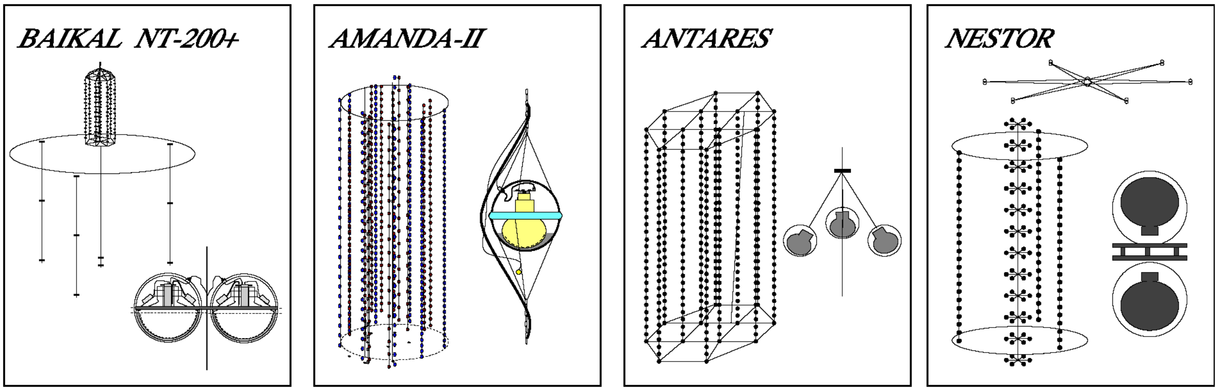

Fig. 1. Conceptual layouts of the current sub-kilometric neutrino telescopes as described in the text.

4.1. *The* BAIKAL *neutrino telescope*

The BAIKAL NT (NT-200) is located at 1100 m depth in Lake Baikal, Siberia. Deployment and repairs are made in winter, when the lake is covered by an ice shield, making ships unnecessary. The detector with a diameter of 40 m, consists of 192 OMs on eight 72 m long strings (see Fig. 1).

The best limit on the flux of diffuse extragalactic neutrinos is obtained with a data sample of 780 live days (see Fig. 2). The signal expected is an upward moving light front induced by isolated cascades. To increase the sensitivity, no containment

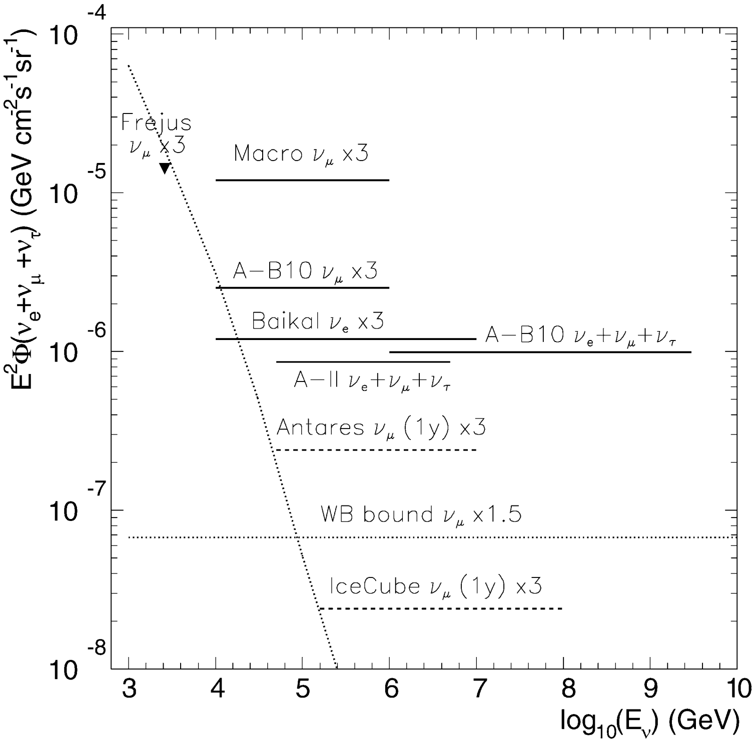

Fig. 2. Overview of current limits (solid lines) on extraterrestrial neutrino fluxes from different experiments: FREJUS limit on ν_μ [30], Macro limit on ν_μ [31], BAIKAL limit on ν_e [32], the AMANDA-B10 (A-B10) limits on ν_μ [33] and UHE (all flavors) [18], the AMANDA-II (A-II) all flavor limit [34]. Expected sensitivities for one year derived from simulations are shown as broken lines for ANTARES [35] and IceCube [36]. Both were derived for ν_μ only, as the detectors are sensitive to the other flavors, too, the real sensitivity to an all flavor flux is better. The dotted line marked WB represents the Waxman–Bahcall bound [8] as upper bound for the expected diffuse neutrino flux (see Section 2). Also shown is the background from the atmospheric neutrino flux. The factors give the scaling from a single flavor limit to an all flavor limit.

in the detector is required. The associated background is mainly bremsstrahlung showers initiated by high energy downward atmospheric muons. The final rejection criteria relies on the energy estimate of the event. Benefiting from a low energy threshold (because of the high OM density), the BAIKAL collaboration also reports interesting limits regarding dark matter [37].

The modest dimensions of the detector and the poor transparency of the lake water limits the sensitivity to predicted fluxes of cosmic neutrinos. An extension of the detector called NT-200+ has been proposed, and calls for a deployment of 36 additional OMs on 3 further 140 m long strings. It is expected that a factor of 4 in sensitivity can be reached by this modest extension. Two strings are already deployed and NT-200+ should be completed by the end of 2005.

4.2. The AMANDA *neutrino telescope*

The AMANDA collaboration has chosen the approximately 3 km thick antarctic ice cap below South Pole to deploy the detector. OMs on cables are lowered into holes drilled by hot water. Once the strings are deployed, the water freezes within two weeks, mechanically fixing the OMs. Deployment of the first four strings with 86 OMs took place 1995/96 and the detector was subsequently extended to AMANDA-II, 677 OMs on 19 strings commissioned in January 2000. The first published data used the array as of 1997 with 10 strings (AMANDA-B10). A series of analyses established the approach used by AMANDA as viable. Areas covered were the observation of atmospheric neutrinos [38], searches for diffuse fluxes of extraterrestrial neutrinos for energies from TeV up to 3×10^{18} eV [18,33,39], the search for point sources [40] and for a neutrino signal induced by dark matter candidates [41]. The unique combination of the AMANDA detector with the surface air-shower array SPASE allows a direct measurement of the directional accuracy of the reconstruction and a coincidence analysis resulted in a measurement of the cosmic ray composition [42].

Since then, the focus of the analyses shifted to the larger AMANDA-II array. The 2000 data was searched for cascades and a limit from 50 TeV to 5 PeV could be derived [34] (see Fig. 2). With an overall pointing resolution below 3°, several years of data are combined in different analyses to search for neutrinos from GRBs or other transient and steady point sources [43]. Fig. 3 shows the 3329 neutrino candidates extracted from four years of operation (2000–2003) projected on the sky.

Up to now all results are compatible with fluctuations as expected from the atmospheric neutrino background. The non-observation of a signal was translated into limits on individual sources or as a function of declination. As AMANDA is taking data and the detector was recently upgraded with a system to record the full wave-form information of the PMT pulses, improvements of the analyses are expected in the near future.

4.3. The NESTOR *project*

The NESTOR project started in 1989. The immersion site is located next to Pylos, on the Greek Ionian coast, at a depth of about 4000 m. The elementary part of the detector array is a tower rising 410 m from a sea-bed anchor. The tower consists of twelve 6 arm titanium stars of 16 m radius [45]. A pair of OMs is installed at the extremity of each arm, one OM facing down, the other up. The full tower will hold 144 PMTs. The associated electronics is stored in a titanium sphere housed in the center of the star. The electrical pulses of the PMTs are digitized locally thanks to an analog transient wave-form digitizer chip. The full

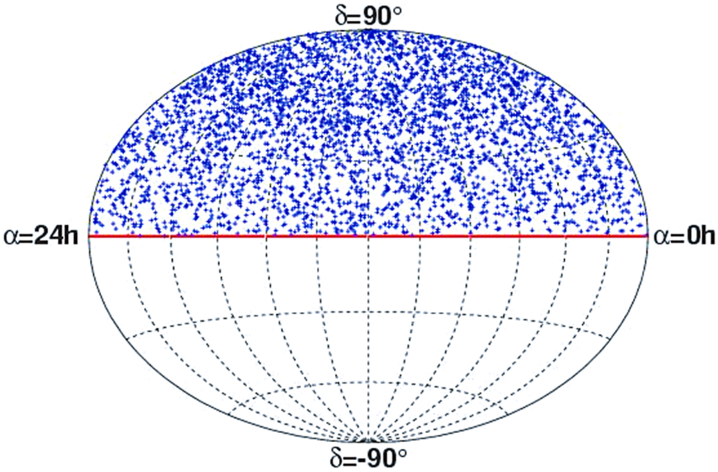

Fig. 3. The 3329 neutrino candidates collected during the years 2000–2003 with the AMANDA detector in a sky map with equatorial coordinates [44]. The distribution is compatible with expectations from atmospheric neutrinos.

sampled wave-form is sent to shore for signal analysis through a 31 km long cable deployed in June 2000. In January 2002 an electro-optical junction box and other devices dedicated to environmental survey were added. All cable connections are made on the boat during deployment.

The first NESTOR floor prototype—a reduced star (5 m radius) with 12 OMs—has been immersed in March 2003 [46]. More than 5 million triggers (4 fold coincidences) have been recorded. A reconstruction has been made to extract the zenithal dependency of atmospheric muons as well as a measurement of the muon flux. These results validate the chosen techniques, even if the collaboration still has to demonstrate its ability to deploy a full scale rigid tower.

4.4. The ANTARES *project*

The ANTARES collaboration follows a modular approach. The detector will consist of an array of 12 flexible individual mooring lines separated horizontally by 60–75 m. Each line will be equipped with 25 stories of 3 OMs each. The OMs [47] are inclined by 45° with respect to the vertical axis to ensure maximum sensitivity to upward moving Cherenkov light fronts. The line motion will be monitored by acoustic devices as well as inclinometers regularly spread along the line, ensuring partial redundancy. The system guarantees the knowledge of the location of each OM with a precision accurate enough to achieve an angular resolution better than 0.5° for TeV neutrinos. Timing calibration will be ensured by an additional network of laser and LED beacons [48]. The PMT signals will be treated off shore by a dedicated chip which discriminates single photo-electron like pulses from complex, fully sampled, wave-forms potentially important for background reduction and cascade analysis.

The ANTARES site is located at a depth of 2475 m, 40 km off La-Seyne-sur-Mer (Var, French Riviera) where the shore station is installed. It has been extensively studied revealing a long scattering length with scattering mainly in the forward direction [49]. The average optical background [50] produces 70 kHz readout for each OM. Nonetheless, this background is variable (depending on sea current) and recent immersions have shown an activity as high as 300 kHz per PMT which will saturate the readout bandwidth. In such severe conditions, local coincidences will be required from the local story electronics.

A first remote controlled demonstrator line (comprising 8 OMs) was deployed in November 1999. Reconstruction of down-going atmospheric muons tracks was done by asking for 7 fold coincidences.

Since then, two major milestones have been reached: first in October 2001, with the deployment of the main electro-optical cable; second in December 2002 with the connection of the cable to the junction box. In order to check the in-situ connection procedure to the junction box and to verify the functioning of the data transmission system, a prototype line and a mini-instrumented line (for monitoring of sea current, salinity, pressure, temperature, etc.) were launched early in 2003. A large amount of data was stored on disk, demonstrating the effectiveness of the acquisition and the remote run and slow control systems.

The collaboration feels now confident enough to immerse the first full ANTARES line in summer 2005, rapidly followed by two others. The ANTARES NT should be completed by the end of 2007.

5. Next generation neutrino telescopes

Even although the currently running NT still have discovery potential (see, for example, [51]), theoretical arguments call for a cubic kilometer NT to discover extraterrestrial neutrino sources. Several projects in different development stages have the goal to deploy such a next generation NT.

5.1. ICECUBE

The ICECUBE project [52] extends the current AMANDA detector with 4800 OMs on 80 strings plus a large air-shower array on the surface. Each string of the in-ice detector carries 60 OMs, spanning over the lower 1 km length. The detector technology is building on the experience gained by AMANDA. The OM has been equipped with an on-board processor, enabling a much more flexible software controlled data acquisition setup. The spacing between the strings has been enlarged to about 125 m and the vertical OM to OM distance is 17 m, well adapted to the optical parameters of the ice. Due to the long leverage arm and the large amount of additional information the reconstruction will achieve a pointing accuracy better than 1°. To facilitate the deployment of the 80 strings to a depth of 2500 m a new more powerful hot water drill was developed. This drill was successfully operated to deploy the first fully equipped string in the beginning of 2005. The next South Pole summer season will see the deployment of up to 10 strings. Data taking begins directly after deployment and analyses will use merged data from the AMANDA and ICECUBE detector. The array will be fully deployed and operational in 2010.

5.2. NEMO

The NEMO collaboration was formed in 2000 and has close ties to the ANTARES project. The collaboration has successfully located a suitable detector site at a depth of 3500 m, 80 km off the eastern coast of Sicily, featuring low concentration of bioluminescent bacteria [28]. The NEMO conceptual design for a cubic kilometer NT calls for 64 semi-rigid towers spaced by 200 m. This design takes the advantages of the flexible ANTARES string-like design and the rigid NESTOR tower structure which minimizes the number of in situ connections. Each of these towers would spread 16 stories by 40 m vertical to a total length of 750 m. Each story is composed of a 20 m long rigid arm that carries four OMs at each end. Communication to the shore is handled by one main and eight secondary junction boxes.

5.3. KM3NET

The three existing Mediterranean collaborations ANTARES, NEMO and NESTOR have formed the design study network KM3NET with the goal to design and locate the future Mediterranean cubic kilometer detector. A funding request to the European Community has been submitted. This project enlarges the scope to an international and multidisciplinary endeavor. It is foreseen to instrument the detector with specialized equipment for seismology, gravimetry, radioactivity, geomagnetism, oceanography and geochemistry, making KM3NET a complex laboratory for a large science community.

6. Conclusions

Several projects are concentrating their efforts on opening the high energy neutrino window on the Universe. Preparations are under way to deploy sub-kilometer arrays in the Mediterranean sea, while two of these detectors have been operating for several years: the BAIKAL detector in Siberia and the AMANDA detector at South Pole.

The sky has been searched for extraterrestrial neutrinos from steady or transient point sources and from (unresolved) diffuse sources. Up to now no signal has been found and limits have been derived that are constraining models of extraterrestrial neutrino sources. By searching for horizontal neutrinos the energy reach of NT was enlarged and the gap to radio and acoustic detection of neutrinos [53] closed.

These results and the advances in theoretical model building have shifted focus from the deployment of first generation telescopes to realization of cubic-kilometer neutrino observatories. Given the scale and costs of these detectors, the current efforts concentrate on two detectors, one in the Mediterranean and one at South Pole. While the Antarctic project ICECUBE has secured funding and started deployment of the detector, the Mediterranean project has ongoing feasibility and detector design studies. Exciting times are ahead with more detectors coming online and growing to the cubic kilometer scale.

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