Dark Matter Search with the ANTARES Neutrino Telescope

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Neutrino telescopes are a promising tool for Astroparticle Physics. Neutrinos are neutral, stable and weakly interacting, so these telescopes will open a new window to observe astrophysical objects like AGNs, GRBs or micro-quasars and will allow to look for new Physics, such as dark matter candidates. WIMPs, weakly interacting massive particles, are a possible constituent of dark matter. WIMPs can scatter and become gravitationally trapped in massive objects like the Sun, the Earth or the Galactic Center. Supersymmetry offers several candidates for WIMPs. In the Minimal Supersymmetric Standard Model (MSSM), the lightest supersymmetric particle is stable in most scenarios because of R-parity conservation. In many MSSM models, the favorite candidate is the lightest neutralino. Their annihilation could give rise to detectable rates of high energy neutrinos. Other possible WIMPs, like the lightest Kaluza-Klein (LKK) particle occuring in scenarios with extra-dimensions, can also be investigated. Neutrino telescopes have complementary potential with respect to direct searches, particularly in the range of large neutralino masses. In this paper we will discuss the prospects for dark matter searches with the ANTARES neutrino telescope that is presently under construction in the Mediterranean Sea.

1. Introduction

There is solid evidence for the existence of cold dark matter in the Universe. The dynamical behaviour of galaxies does not agree with the mass inferred from the amount of luminous material: rotational curves point out the existence of a dark matter halo. On the scale of galaxy clusters, a disagreement is observed between the measured temperature and the value predicted by the equation of hydrostatic equilibrium. Also gravitational lensing provides support to the existence of dark matter at these scales. At cosmological scales, the measurements of the degree of flatness of the cosmic microwave background constrains the abundance of baryons and matter in the Universe.

The combination of the data available at different scales provide a constrain not only to the total dark matter density, but also to the relative density of different components. In this talk we will focus on the "cold" dark matter (CDM), i.e. non relativistic particles at decoupling, since these constitute the potential candidates in a neutrino telescope, as discussed below.

Recent analysis [1] estimate the CDM contribution to be

$$\Omega_{CDM} h^2 = 0.113^{+0.008}_{-0.009} \tag{1}$$

Weakly Interacting Massive Particles (WIMPs) are considered the main candidate for cold dark matter. One of the most prominent possibilities is the lightest neutralino [2]. Neutralinos are the lightest supersymmetric stable particle in most models due to the conservation of R-parity. Another interesting candidate is the lightest Kaluza-Klein particle, predicted in models with Universal Extra Dimensions [3].

In the following, we will describe the ANTARES detector and its capability for dark matter search, as well as the status of the project.

2. The ANTARES detector

The ANTARES neutrino telescope [4] will consist of a tridimensional array of 900 photomultipliers (PMTs) [5] set along 12 lines anchored in the bottom of the Mediterranean Sea (2400 m deep), 40 km southeast from Toulon (France). As shown in figure 1. The length of the lines is 450 m

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and the separation between lines is 60-75 m. The PMTs and their electronics are housed in high-pressure resistant glass spheres, which constitutes the Optical Modules (OMs) [6]. These OMs are grouped in triplets, for a more efficient background rejection and looking 45° downwards, in order to prevent the effect of bioufouling.

The detection principle is based on the measurement of the Cherenkov light emitted by the muons produced in the CC-interactions of neutrinos in the surroundings of the detector (water or rock). The information of the time and position of the hits detected by the PMTs allow to reconstruct the direction of the muon track.

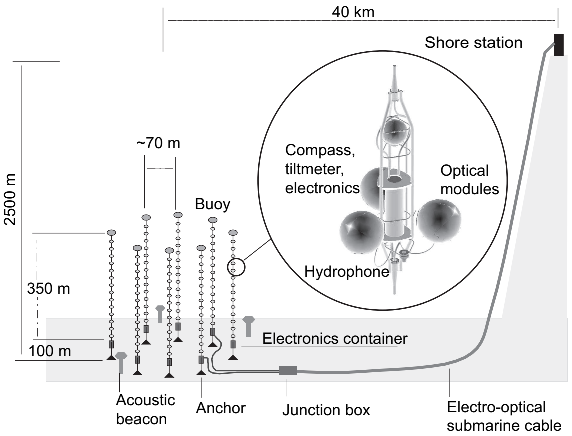

Figure 1. Sketch of the ANTARES telescope. It will consist of 900 PMTs distributed along 12 lines, anchored at the bottom of the Mediterranean Sea.

3. Dark matter search prospects

The detection of dark matter with neutrino telescopes is indirect, i.e. we would observe the products of the WIMP annihilation. WIMPs are expected to scatter elastically in massive objects like the Sun or the Earth and become gravitationally trapped. They would annihilate producing standard model particles. Among the annihilation products, only neutrinos can reach us. Neutralinos decay in pair-wise mode:

$$\chi\chi \to l^+l^-, W^+W^-, Z^0Z^0, H^0_{1,2}H^0_3, Z^0H^0_{1,2}, W^\pm H^\mp \quad (2)$$

Direct production is suppressed, since neutralinos are Majorana particles, but they are produced in the decay of the primary products. All three flavors of neutrinos are produced in the these decays. Typically, neutrinos get ~1/10-1/2 of the neutralino energy, which means ~GeV-TeV. This is in the low energy range in neutrino telescopes, but the energy threshold in ANTARES (~10 GeV) is lower than in its competitors [7].

On the other hand, the LKK particles would annihilate ~4% of the time directly to neutrinos, so the latter will have higher energy. The dominant decay channel in this case is the $\tau^+\tau^-$ mode, since offers higher fluxes [8].

The location of the ANTARES detector, at intermediate latitudes, is an important advantage for the detection of neutralinos in the Sun. In the South Pole, the Sun is never very low below the horizon.

Figure 2 shows the ANTARES sensitivity for neutralinos in the Sun, the best candidate source for neutralino detection. The scan in the parameter space has been performed with mSUGRA. Compared with direct searches, ANTARES will be more competitive in the high neutralino masses region. The background for these observations are the atmospheric neutrinos and the neutrinos produced in the interactions of cosmic rays with the Sun's corona.

The detection of neutralinos in the Earth is more difficult. Although the source of neutrinos is closer, the mass of the Earth is much smaller, so there is less target for neutralinos to interact and the gravitational well to trap them is weaker. Moreover, the effect of the gravitational field of the Sun depletes most of the neutralinos [9]. However, the WIMP velocity distribution in the Solar System is not accurately known yet.

Finally, the Galactic Center is also an interesting region for dark matter search with neutrino telescopes. In this case, other kind of signals (gamma rays and cosmic rays) are also possible. The neutrino emission would be enhanced by the

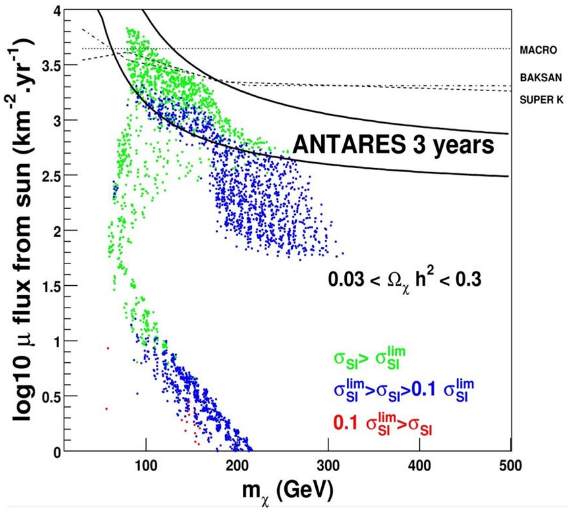

Figure 2. ANTARES sensitivity at 90%CL to muon fluxes produced by neutralinos in the Sun after three years. A muon threshold of 5 GeV has been assumed. The upper and lower curves correspond to a soft (bb) and hard (WW/$\tau\tau$) neutrino spectrum, respectively. σ_{SI} stands for the spin-independent cross-section predicted to be scanned by EDELWEISS-II in 5 years. The limits set by the experiments MACRO, BAKSAN and SUPER K are also shown.

presence of a super massive black hole. There is no consensus about the density profile of dark matter in the Galaxy. Some models [10] seem to agree with very "cuspy" profiles, for which the neutrino production is most favoured. Again, the location of the telescope in the Northern Hemisphere is advantageous with respect to the South Pole, where the Galactic Center in not visible.

4. Status of the project

Since the beginning of the project in 1996, several important steps have been realized by the ANTARES collaboration. The first years were devoted to R&D and site evaluation programs. The construction of the detector started with the deployment of the electro-optical cable (Oct 01) and the junction box (Dec 02). The first data came in Mar 03 after the connection of two test lines: the Mini-Instrumentation Line (MIL) and the Prototype Sector Line (PSL). The MIL contained several devices for environmental parameter monitoring and the PSL was a shorter version (1/5) of a complete line. These lines allowed to check the electronics and positioning systems, and to verify that the time calibration system worked within the specifications (<1 ns). Also the environmental parameters were monitored and minor technical problems were detected. In Mar 05, the so-called "Line Zero" was installed, which was a full-sized line without PMTs, to check the cables and mechanical structure in the most realistic conditions. An extended version of the MIL, with four optical modules, was also deployed [11]. The baseline measured with this line (called MILOM) is shown in figure 3 (top).

In Mar 06, a major milestone was reached with the connection of the first line of the detector. This allowed to reconstruct the first muon events and check that the angular resolution of ANTARES will be better than 0.3 deg. Figure 3 (bottom) shows the zenith angle distribution of atmospheric muon bundles, measured with Line 1.

The second line is expected to be installed by Sep 06 and by the end of the year, four of the lines are expected to be deployed. By the beginning of 2008, the 12 lines of the detector should be connected.

5. Conclusions

The ANTARES neutrino telescope will be able to explore regions of the WIMP space parameter which are not yet accessible with direct searches. Moreover, its low energy threshold, its size and its location at intermediate latitudes in the Northern Hemisphere, will make its results competitive with the search performed until now by AMANDA at the South Pole.

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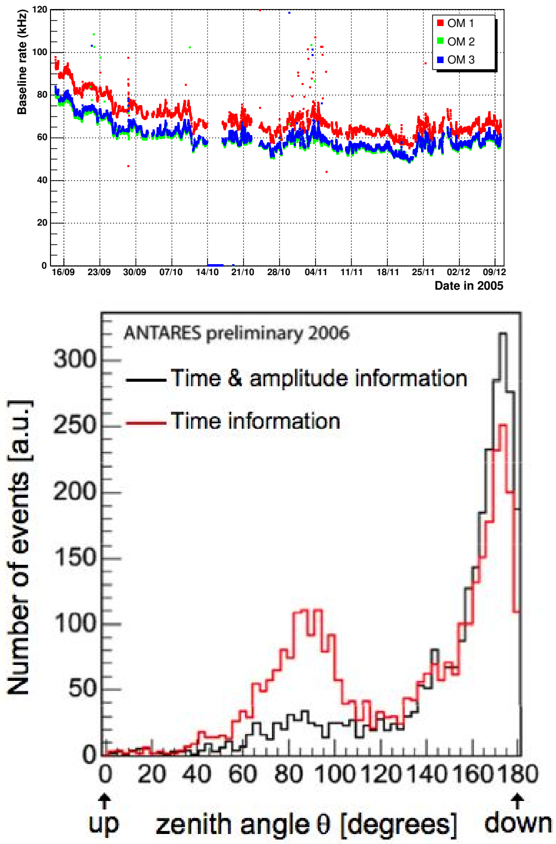

Figure 3. Top: Baseline rates measured by the MILOM. The fact that OM1 measures a rate 15% larger than the others is attributed to a lower threshold value of the PMT. Bottom: Zenith angle of atmospheric muon bundles with Line 1 (real data). It can be seen that the number of "ghost" solutions at twice the Cherenkov angle, inherent to the detection with one line, can be reduced using the amplitude information.