Overview of ANTARES results on Dark Matter Searches

J.D. Zornoza
IFIC (Univ. of Valencia - CSIC, c/Catedrático José Beltrán, 2, 46980, Paterna, Valencia, Spain

The search for dark matter is one of the most important goals of neutrino telescopes. The ANTARES detector, installed in the Mediterranean Sea, is taking data since 2007. Neutrino telescopes have interesting advantages for this kind of searches, as it will be discussed. In this talk we will review the status and results of the analyses performed in ANTARES for several sources: the Sun, Galactic Centre and the Earth.

1 Introduction

There is compelling evidence that a large part of the matter content of the Universe is made of something beyond the Standard Model of particle physics. Among these experimental proofs we can mention the observations from Planck, the results on the Big Bang Nucleosynthesis, the rotation curves of galaxies and the studies of highly red-shifted Ia supernovae. The conclusion from these experimental results is that about about 85% of the matter of the Universe is non-baryonic. In the most studied scenarios, it is assumed that the properties of this matter are the following: weak interaction with matter, no interaction with photons, non-zero mass and stability. The list of possible candidates for explaining this component is large, but one of the most appealing frameworks is SuperSymmetry, in particular in the models which offer neutralino as a dark matter candidate. The stability of neutralino would be preserved by the R-parity conservation.

The search for dark matter is one of the main goals of neutrino telescopes like ANTARES. The potentially interesting sources include the Sun, the Galactic Centre, the Earth, dwarf galaxies and galaxy clusters. Each source has advantages and disadvantages. The same applies to the different detection techniques (direct, indirect, accelerators), as it will explained.

If dark matter is made of weakly interacting particles (WIMPs), like neutralinos, they can scatter in astrophysical objects like the Sun or the Earth and become gravitationally trapped. Their self annihilation would produce, directly or (more commonly) indirectly high energy neutrinos. Dark matter forming part of the halo of the Galaxy can also annihilate and produce a signal, in particular in the direction of the Galactic Centre.

*on behalf of the ANTARES Collaboration
2 The ANTARES detector

The ANTARES collaboration finished the installation of a neutrino detector in the Mediterranean Sea in 2008. By 2007, five of the final twelve lines were already taking data. The detector is deployed at a depth of 2500 m and about 40 km of the French coast, near Toulon. It consists of 885 photomultipliers installed along twelve vertical lines anchored to the sea bed. The operation principle is based on the detection of the Cherenkov light induced by the relativistic muons produced after the charged-current interaction of high energy muon neutrinos close/inside the detector.

In the analyses presented in this paper, about 1300 days of data are used, corresponding to the period from 2007 to 2012. As mentioned before, only five lines were installed during 2007.

There are two sources of background. On the one hand, the so-called atmospheric muons, which are produced by the interaction of cosmic rays in the atmosphere. This is a huge background that can be partially reduced by installing the detector at a large depth, as it is the case for ANTARES. Even at a depth of 2000-2500 m, the atmospheric muon background is quite important, so only upgoing events are selected for the analysis, so that the Earth acts as a shield stopping atmospheric muons. An additional cut in the quality of the events is also needed in order to reject down-going atmospheric muons which are badly reconstructed as upgoing. The second kind of background are the atmospheric neutrinos produced also by cosmic rays. This is an irreducible background, but expected to be distributed diffusely in the sky, while the signal would be concentrated around the source.

3 Analysis method and results

Different methods have been used for reconstructing the muon track. For low masses (below \(\sim 250\) GeV), an algorithm called BBFit has been used, which offers a better response for low energies. In particular, it is used for the events reconstructed with only one line. For these events, the azimuth information is not available, but the information on the zenith angle helps to distinguish between signal and background. For higher masses, a likelihood algorithm is used.

The analyses presented in this paper have been done using a binned method. The strategy consists in finding the optimum selection in terms of neutrino flux sensitivity. The selection variables are the opening cone angle (i.e. the maximum angular distance to the source) and a cut in a parameter which describes the quality of the track reconstruction. All these cuts are chosen following a blind procedure.

3.1 The Sun

For the Sun, the signal is simulated with WIMPSim, which takes into account the main ingredients of the neutrino production and propagation. Since the composition of the neutralino is not known, we consider several channels (pessimistic and optimistic) assuming a branching ratio of one. The real situation should be between these extreme cases. One of the advantages of the searches for dark matter in the Sun, compared with other indirect searches, is that a potential signal would be free of astrophysical background. Neutrinos from nuclear reactions in the Sun are of much lower energies. The background from cosmic rays interacting in the Sun corona is very low. Concerning the atmospheric background, it can be accurately estimated from scrambled data.

After unblinding the data, no excess of data over expected background is found, so limits on the neutrino flux limit and on the WIMP-nucleon cross section can be set (see for a previous search with 2007-2008 data). The results from the search can be seen in Figure 1 (top), where the limits of the WIMP-proton scattering cross section are shown. It is important to note that neutrino telescopes offer the best limits for spin-dependent cross section (since the Sun is made
basically of protons), better than those from direct searches (other indirect searches set limits on $<\sigma v>$).

### 3.2 The Galactic Centre

The Galactic Centre is also a very promising source for neutrino telescopes. The distance is much larger, but the total mass involved is also larger. Moreover, there is no absorption of neutrinos, contrary to what happens in the Sun, which is particularly relevant for high energy/masses, where the angular resolution improves. The signal is simulated using the simulation by Cirelli et al. The profile of the dark matter halo has been simulated with the package CLUMPY. The background, as in the case of the Sun, is evaluated by scrambling real data. After unblinding the data, no significant excess is found so limits are set in $<\sigma v>$, as shown in Figure 1 (bottom) for a NFW halo profile and the $\tau^+\tau^-$ channel. These limits exclude the leptophilic dark matter interpretation of the Fermi+PAMELA+HESS excess. It can also be seen that above $\sim$150 GeV the limits set by ANTARES are the best limits from neutrino telescopes, since the visibility of ANTARES of the Galactic Centre and its angular resolution are better than those of IceCube.

### 3.3 The Earth

Dark matter would also accumulate in the Earth after scattering, like in the case of the Sun. However, in this case we cannot assume that an equilibrium between capture and annihilation has been reached. Moreover, since the scattering is mostly on the heavy elements in the Earth core, the limits are set on the spin-independent cross section of WIMP scattering. These limits are particularly interesting for WIMP masses close to the masses of scattering nuclei (iron and nickel). The signal is evaluated with WIMPSim and the background is calculated from the background in the zenith angle band between 160° and 170° degrees ($>95\%$ of the signal is found at zenith $>170^\circ$). The sensitivity of ANTARES is shown in Figure 2.

### 4 Conclusions

The search for dark matter is one of the main scientific goals of neutrino telescopes. ANTARES, installed in the Mediterranean Sea, has been taking data since 2007. Several sources have been studied. In this paper we have presented the results of the analysis for the Sun and the Galactic Centre (in terms of limits) and the Earth (in terms of sensitivity). Although no significant excess has been seen in the unblinded data, competitive limits have been set.

### Acknowledgments

The authors acknowledge the financial support of the Spanish Ministerio de Ciencia e Innovación (MICINN), grants FPA2009-13983-C02-01, FPA2012-37528-C02-01, ACI2009-1020, Consolider MultiDark CSD2009-00064 and of the Generalitat Valenciana, Prometeo/2009/026.

### References

1. M. Ageron et al., Nucl. Inst.. and Meth. in Phys. Res. A 656 (2011) 11-38, arXiv:1104.1607 [astro-ph.IM]
2. S. Adrián-Martínez et al., arXiv:1302.6516v1 [astro-ph.HE]
3. J. Edsjo, http://www.physto.se/edsjo/ wimpsim
4. J.A. Aguilar et al., ANTARES collaboration Astropart. Phys. 34 (2011) 652-662, arXiv:1105.4116 [astro-ph.IM]
5. A. Heijboer, Ph.D. thesis, University of Amsterdam, 2004.
6. M. Cirelli et al., arXiv:1012.4515 [hep-ph].
Figure 1 – Top: Spin-dependent cross-section limits for the search on the Sun: ANTARES 2007-2012 (thick solid lines): $\tau^+\tau^-$ (red), $W^+W^-$ (blue), $b\bar{b}$ (green), IceCube-79 (dashed lines), SuperKamiokande (colored dash-dotted lines), SIMPLE (black short dash-dotted line), COUPP (black long dash-dotted line) and XENON-100 (black long dashed line). The results are compared with a scan in MSSM-7. (Preliminary). Bottom: Limits on $<\sigma v>$ for the Galactic Centre for the $\tau^+\tau^-$ channel (red solid line) with IC40 for the GC (brown solid line), IC59 for dwarf galaxies (dashed black line), IC79 for the Galactic Halo (magenta solid line), IC59 for the VIRGO cluster (black solid line), DeepCore+IC79 for the GC (blue solid line) and Fermi for dwarf galaxies (green solid line). The grey/green area represent leptophilic dark matter models which would explain the PAMELA (grey) and Fermi+PAMELA+HESS (green) excess in the Galactic Centre. (Preliminary).

Figure 2 – Spin-independent cross section sensitivity (90% CL) for the Earth analysis, assuming $<\sigma v> \sim 3 \times 10^{-26}\text{cm}^2\text{s}^{-1}$ for three different channels: $\tau^+\tau^-$ (dash, blue), $W^+W^-$ (dot, green) and $b\bar{b}$ (dash-dot, magenta). This sensitivity is also compared with the results of XENON-100 (solid, red). (Preliminary).