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Combined search for dark matter with the ANTARES and IceCube neutrino telescopes

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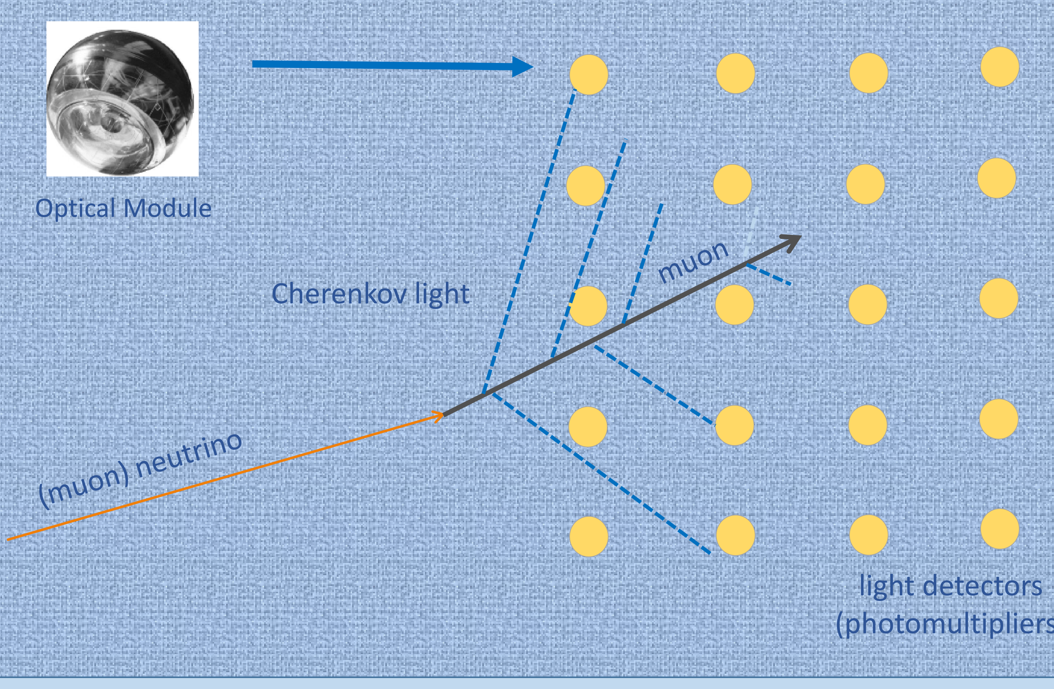
on behalf of ANTARES and IceCube Collaborations

Abstract

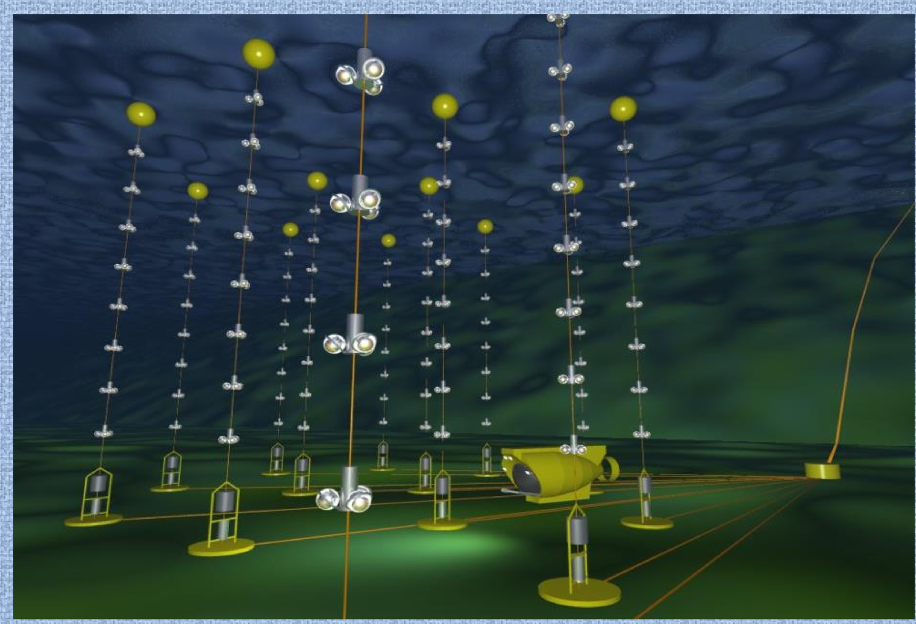
Most of the matter of the Universe appears to be "dark matter", the properties of which we know only very incompletely. The effort to identify this new kind of matter has to be multi-front, since we do not know which is the best way to proceed. An important player in this quest are neutrino telescopes, since they offer unique advantages that complement other searches. Examples of this are the limits of IceCube for the DM-nucleon spin-dependent cross section for searches in the Sun or the limits set by ANTARES for the DM annihilation cross section for the Galactic Centre, which in both cases are the best in the world for some mass ranges. In this presentation we will show an analysis carried out by these collaborations on the potential of combining data from both detectors to improve these limits.

Neutrino astronomy: ANTARES and IceCube

- Neutrino astronomy has become a mature field after years of operation of the two largest neutrino telescopes in the world: IceCube and ANTARES
- The search for dark matter is one of the most important goals of these detectors (see [1,2] for recent results)
- Neutrino telescopes consist of an array of photomulpliers (PMTs) deployed in water (ANTARES) or ice (IceCube) that collect the Cherenkov light induced by charged leptons produced by neutrinos

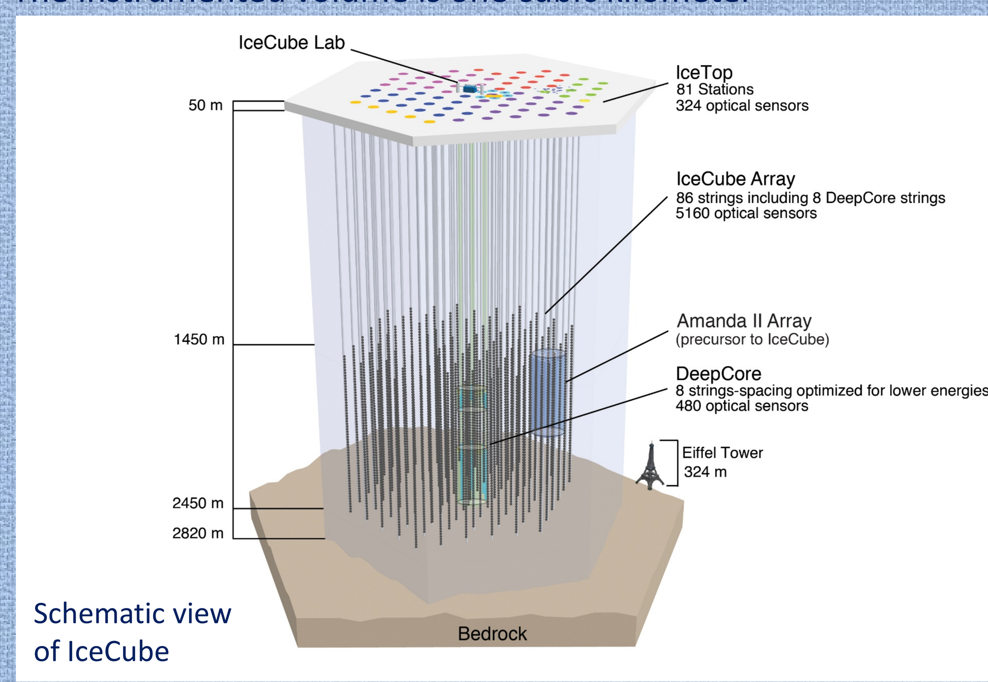


- The ANTARES detector [3] is located in the Mediterranean Sea, close to the French city of Toulon, and was completed in 2008
- It consists of 885 Optical Modules distributed on 12 lines anchored at 2500 m deep
- The length of the lines is 450 m and the separation among them is 60-75 metres



Artistic view of ANTARES

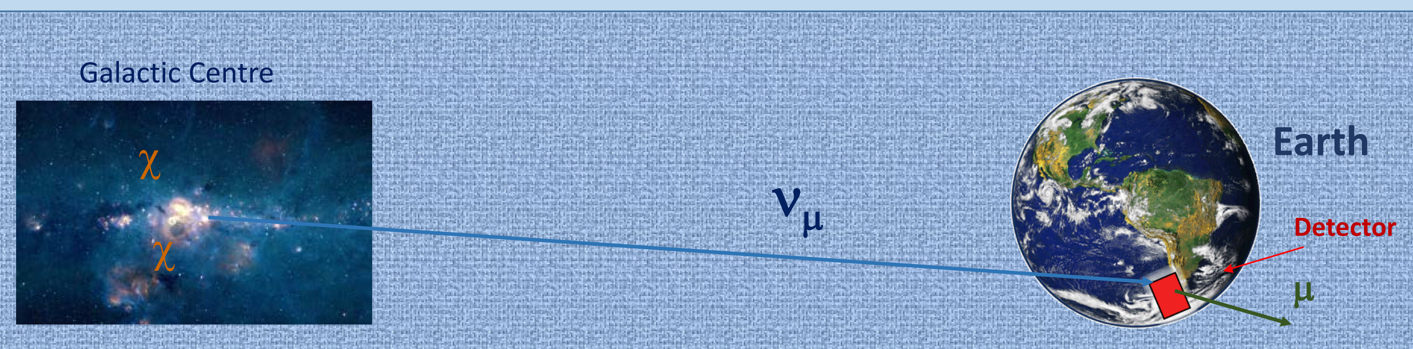
- The IceCube detector [4] is located at the South Pole and was completed in 2010 (although data taking with a partial configuration started in 2005)
- It consists of more than 5000 optical modules distributed along 86 lines installed in the South Pole at a depth of 1500-2500 m.
- The instrumented volume is one cubic kilometer



Schematic view of IceCube

Dark matter in the Galactic Center

- **Dark matter** makes up more that 80% of the matter of the Universe
- Because its nature is still unknown, a multi-front strategy is needed to search for it and determine its properties.
- Neutrino telescopes have specific advantages in this quest, given the unique properties of neutrinos (neutral, stable and weakly interacting)
- WIMPs gravitationally accumulate in the Galactic Centre and self-annihilate, giving rise to secondaries which in turn decay and produce neutrinos
- Neutrino fluxes are produced in the annihilation of $W^{\pm}$, Z, H bosons, c, b, t quarks, τ lepton. We consider the b and $W^{\pm}/\tau$ channels as **benchmarks.** We assume a 100% branching ratio for any considered cannel.
- The combination of ANTARES and IceCube data increases the sensitivity of the search, which is particularly relevant in the cases where the individual sensitivities are similar



$$\frac{d\phi_\nu(\Psi)}{dA\,d\Omega\,dt\,dE} = \frac{\langle\sigma_A v\rangle}{2}\frac{J_a(\Psi)}{4\pi m_\chi^2}\frac{dN_\nu}{dE}$$

$$J_a(\Psi) = \int_0^{l_{max}} \rho_\chi^2\left(\sqrt{R_{sc}^2 - 2lR_{sc}\cos(\Psi) + l^2}\right) dl$$

$$\rho_\chi(r) = \frac{\rho_0}{\frac{r}{r_s}(1+\frac{r}{r_s})^2}$$

- The **rate of neutrinos** is related to the dark matter profile and the energy spectrum
- J_a is the integrated J-factor, i.e. the integral of the DM density squared, along the line of sight *l*
- In this analysis, Navarro-Frenk-White profile as defined in [5] has been used, where ρ_s is the scale radius and ρ_0 is the characteristic dark matter density

Method

- ANTARES data **sample** includes 595 events from the period 2007-2015 (livetime: 2106.6 days)
- IceCube data **sample** includes 22,553 events gathered from May 15th 2012 to May 18th 2015 (livetime: 1007 days)
- The analysis is based on a **binned likelihood** with the two-component mixture model and masses ranging from 50 to 1000 GeV/c²
- In ANTARES, for low energy events only zenith angle is reconstructed
- The likelihood compares the **spatial distributions** of data and expected signal and background, given by the Probability Density Functions

$$\mathscr{L}(\mu) = \prod_{bin_i=bin_{min}}^{bin_{max}} \text{Poisson}\left(n_{obs}(bin_i)|n_{obs}^{tot} f(bin_i|\mu)\right)$$

$$f(bin_i|\mu) = \mu f_s(bin_i) + (1-\mu) f_{bg}$$

$$\mathscr{L}_{comb}(\mu) = \prod_{k=0}^{1}\mathscr{L}_k(\mu_k)$$

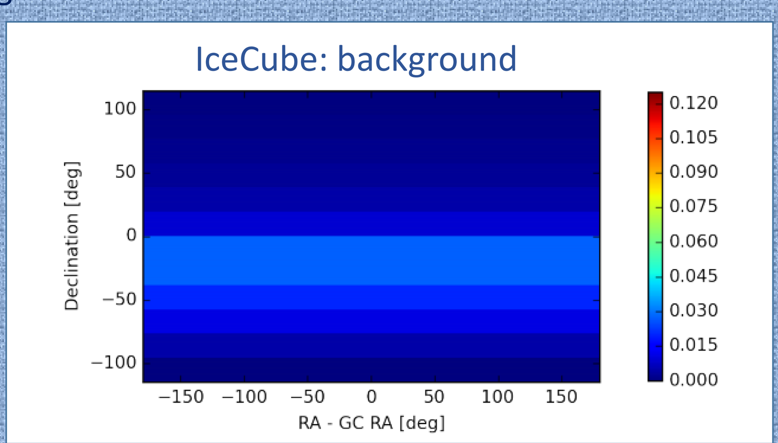
μ is the ratio of the number of signal events over the total number of background events n^{tot}_{obs}

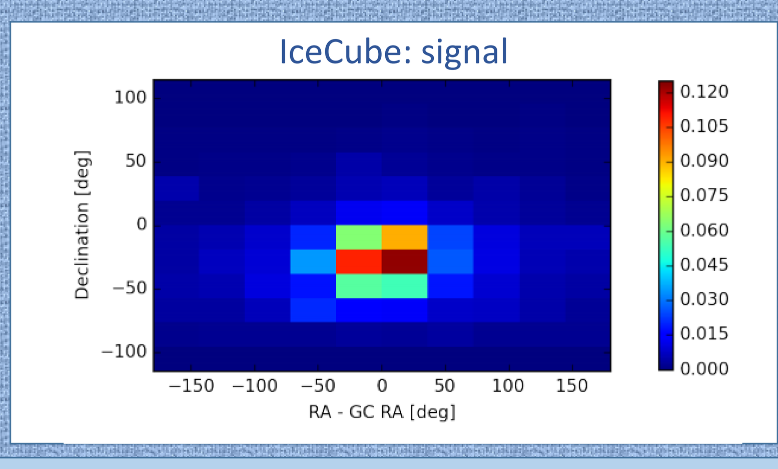
f is the fraction of events in the bin *i* with f_s and f_{bg} being

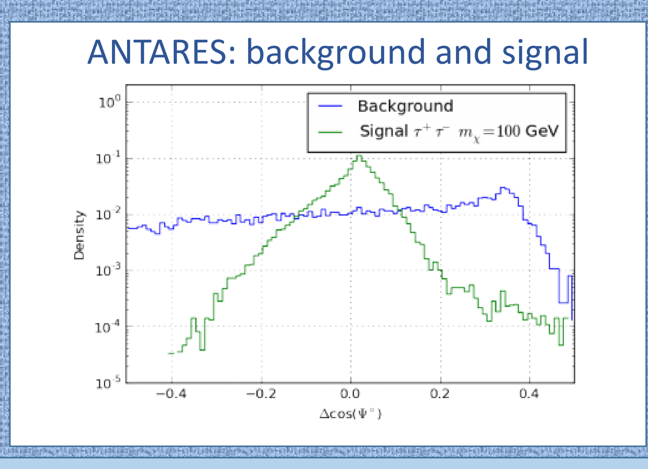
k runs for the two samples (ANTARES and IceCube)

Probability Density Functions

- Probability Density Functions for IceCube are two dimensional (declination and right ascension angular distance) while for ANTARES only the angular distance to the source is considered

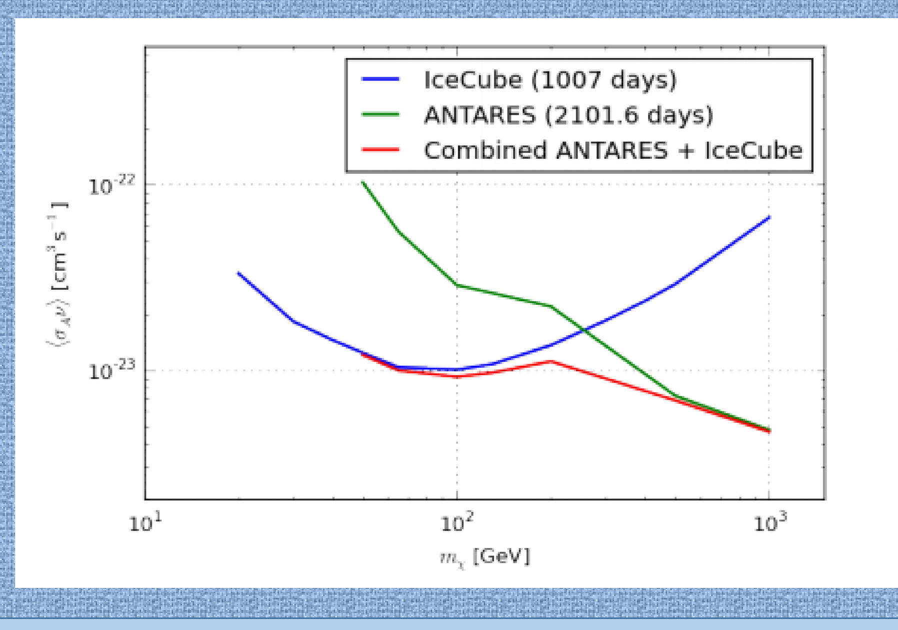






Results

- The **sensitivity** to the thermally averaged annihilation cross section has been calculated for tau-tau channel and NFW halo profile as a function of the WIMP mass.
- For the case under study here, there is an **improvement** in the energy range from 65 to 1000 GeV/c² with respect to the individual sensitivities of ANTARES and IceCube
- This study has also allowed to compare the analysis procedure of both collaborations
- This work will be **continued** with more channels and halo dark matter profiles



References

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[3] **ANTARES : The first undersea neutrino telescope,** M. Ageron et al., Nucl. Instrum. Meth. A 656 (2011) 11-38, arXiv:1104.1607

[4] **The IceCube Neutrino Observatory: Instrumentation and Online Systems,** M.G. Aartsen et al. JINST 12 P03012 (2017), arXiv:1612.05093

[5] **The dark matter halo of the Milky Way, AD 2013,** F. Nesti, P. Salucci, JCAP 07 016 (2013), arXiv:1304.5127

Conclusions

- The sensitivity of a combined search for dark matter in the Galactic Centre with combined data of ANTARES and IceCube is presented
- Combining data allows for an improvement in the performance, particularly important in cases where individual sensitivities are comparable (low WIMP masses for this case)
- This first study presents a show case for ττ and NFW profile, with 1007 days of IceCube data and 2101.6 days of ANTARES data.
- Unblinding of these data and interpretation within other scenarios (channels, dark matter profiles, etc.) is in preparation.