Indirect search for Dark Matter with the ANTARES Neutrino Telescope

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Indirect detection of WIMPs in a neutrino telescope

Relic WIMPs captured in celestial bodies

Potential \( \chi \chi \rightarrow \nu \) sources are Sun, Earth & Galactic Centre

Signal less affected by astrophysical uncertainties than \( \gamma \)-ray indirect detection

\( \chi \chi \) self-annihilations into c, b, t quarks, \( \tau \) leptons or W, Z, H bosons can produce significant high-energy neutrino flux
Indirect search towards the Sun with ANTARES

- **ANTARES neutrino telescope** located by 2500m depth in Mediterranean Sea in South of France (Toulon)
  → See J.J.Hernandez talk in Astro. Messenger session (Tuesday 6/09) for ANTARES results overview

- **Detector** building started in 2006, **completed in May 2008**
- **Current analysis** based on **2007** (5-lines) + **2008** (9-10-12 lines) data
  → about **1000 upgoing neutrino candidates** (in ~295 effective days)
- **Event selection** based on fast and robust track reconstruction algorithm (Astroparticle Physics 34 (2011) 652)

- **Binned search** towards the direction of the **Sun** (visibility below horizon)
- **Background** from atm. neutrinos and muons estimated from MC simulation and **scrambled data**
- **Signal energy spectrum** derived from WIMPSIM simulation package for different **WIMP masses** and **annihilation channel** hypotheses
Event selection: fit quality

Quality parameter of the track reconstruction for upgoing events:
→ very good agreement data vs. Monte Carlo events
→ good separation between neutrino and muon events
Selected events: zenith angle

Zenith distribution of selected events (Tchi2 < 1.6)

→ strong reduction of the atmospheric muon background
Background in the Sun direction

- Background estimated from data scrambled in time and \((\theta, \varphi)\)
- Using the Sun visibility at the ANTARES location

- Background due to neutrinos coming from CR interactions in the Sun corona negligible \((<1\% \text{ of atmospheric neutrinos})\)

All up-going events from 2007-2008 data  
Example of Sun tracking in horizontal coordinates
Neutrino signal from WIMP annihilations

- The WIMPSIM package (Blennow, Edsjö, Ohlsson, 03/2008) used to generate events in the Sun in a model-independent way
- Large statistics with $3 \times 10^6$ WIMPs annihilations
- Capture rate and annihilations in equilibrium at the Sun core
- Annihilations in c, b and t quarks, $\tau$ leptons, WW/ZZ bosons and direct channels
- Neutrino interactions in the Sun medium taken into account
- Three flavor oscillations, regeneration of $\tau$ leptons in the Sun medium (Bahcall et al.)
- Available parameters: WIMPs mass, oscillation parameter values...
Neutrino spectrum of main decay channels

$\nu_{\mu} \bar{\nu}_{\mu}$ from the $WW$ channel (at Earth)

$\nu_{\mu} \bar{\nu}_{\mu}$ from the $b\bar{b}$ channel (at Earth)

$\nu_{\mu} \bar{\nu}_{\mu}$ from the $\tau\tau$ channel (at Earth)

$\nu_{\mu} \bar{\nu}_{\mu}$ from all channels (at Earth)

"Hard" spectrum

"Soft" spectrum

$M_{\text{WIMP}} = 350$ GeV

Important contributions from $\tau$ leptons regeneration in the Sun $\rightarrow$ neutrino oscillations visible

mUED particular case!
Selection optimization and signal efficiency

- **Neutrino fluxes** at the Earth produced by Dark Matter coannihilation are **convoluted** with the **detector efficiency** for given selection parameter sets (track fit quality, cone size)

- **Neutrino background** given by **scrambled data in the Sun direction** is evaluated for the same selection set

- **Optimization of sensitivity** performed by minimizing

\[
\text{Sensitivity} = \frac{\bar{\mu}_{90}}{A_{\text{eff}}(M_{\text{WIMP}}) \times T_{\text{eff}}}
\]

Effective area estimated for all selection cuts (Tchi2,cone)

Background in Sun direction and Average upper limit (Feldman-Cousins)
Sensitivity to neutrino flux for ANTARES 2007-2008 data

For CMSSM:
Branching ratios $= 1$
(for WW, bb, $\tau\tau$)
(Large variation of branching ratios over CMSSM parameter space)

For mUED:
Theoretical branching ratios taken into account
Sensitivity to muon flux

Sensitivity to muon flux for ANTARES 2007-2008 data

Flux $\Phi_\mu$
Annihilation rate $\Gamma$
Capture rate C
Cross-section $\sigma_{SD}$
Sensitivity to Spin-Dependent cross-section for ANTARES 2007-2008 data

Compare SUSY predictions to observables such as sparticles masses, collider observables, Dark Matter relic density, direct detection cross-sections, …

SuperBayes (arXiv:1101.3296)
Sensitivity to Spin-Dependent cross-section for ANTARES 2007-2008 data

Compare mUED predictions to observables such as KK masses, collider observables, DM relic density, direct detection cross-sections, ...

SuperBayes modified version (Physical Review D 83, 036008 (2011))
Summary and Outlook

- **Indirect search for Dark Matter** is a major goal for neutrino telescopes (important complementarity to direct detection experiments)

- **Indirect search** towards the Sun performed by ANTARES within framework of two common Dark Matter models (CMSSM, mUED), unblinding of data will happen **soon**

- **Study of other sources** (Earth, Galactic Centre, dwarf galaxies…) in **progress** or to be done

- Analyses on **2007-2010 data** are in **progress**, > 3000 neutrino candidates already collected today!

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**Stay tuned for the BIG DARK DISCOVERY !!**