Indirect searches for Dark Matter with the IceCube neutrino telescope

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*for the IceCube collaboration*
- Geographic South Pole
- 5,160 Digital Optical Modules (DOMs)
- 86 string with 60 DOMs each
- 6 denser strings called DeepCore
From dark matter to neutrinos

Secondary production: annihilation, decay (with or without mediators)

Where to look for: Focus on large reservoirs of dark matter
Source regions

Dwarf spheroidal Galaxies
Cluster of Galaxies
Probe velocity-averaged DM annihilation cross section $\langle \sigma_A v \rangle$

Local Sources (Sun, Earth)
Only accessible with neutrinos
Under equilibrium they can probe $\sigma_{SI}$ and $\sigma_{SD}$

Galactic Halo
Probe velocity-averaged DM annihilation cross section $\langle \sigma_A v \rangle$

Galactic Center
Probe velocity-averaged DM annihilation cross section $\langle \sigma_A v \rangle$
The basic method (annihilation case)

\[
\frac{d\Phi_\nu}{dE_\nu} = \frac{1}{4\pi} \langle \sigma_A v \rangle \frac{dN_\nu}{2m^2_\chi} \int_0^{\Delta \Omega} d\Omega \int_{l.o.s.} \rho^2_\chi (s, \phi, \theta) \, ds
\]

**Measurement:**
Neutrino flux

**Constrain:**
anihilation cross section

**Theory input:**
Dark matter mass and final state energy spectra

**Astrophysical input:**
Dark matter density distribution along the line of sight
Galactic center

To date 4 different IceCube analyses with different event samples covering masses 10 GeV – 300 TeV

New analysis with improved event sample and more data in preparation!
Decaying dark matter in the galactic halo

\[ \frac{d\Phi_\nu}{dE_\nu} = \frac{1}{4\pi} \frac{1}{m_\chi \tau_\chi} \frac{dN_\nu}{dE_\nu} \int_0^{\Delta \Omega} d\Omega \int_{\text{l.o.s.}} \rho_\chi (s, \phi, \theta) \, ds \]

- Signal less concentrated on the Galactic Center
- Two independent data samples:
  - Track-like with 6 years of data
  - Cascade-like with 2 years of data
- Include also contributions from extra-galactic DM

[EPJC 78 (2018) 831]
Neutrino Lines from DM annihilation/decay

- Direct annihilation/decay neutrinos → spectral lines, “smoking-gun” signal
- Search for angular and spectral excess
- Covering masses 40 GeV – 40 TeV

First results upcoming early 2020!
Neutrino Lines from DM annihilation/decay

First results upcoming early 2020!
Capture and self-annihilation in the Sun

- Local density model independent $\sim 0.3 \text{ GeV/cm}^3$
- In equilibrium $\frac{dN}{dt} = 0$: probe SD cross section on H

\[ \frac{dN}{dt} = C_C - C_A N^2 \]

Capture $\sigma_{\chi-p}$  \hspace{2cm} Annihilation $\sigma_A$
Capture and self-annihilation in the Sun

- Two event samples for low and high energies
- Most sensitive for low masses due to neutrino escape from the sun

[EPJC 77 (2017) 146]
Capture and self-annihilation in the Sun

- Two event samples for low and high energies
- Most sensitive for low masses due to neutrino escape from the sun

Improved analysis extending to 7 years of data under development!
Assume superposition of streams with fixed velocity
→ conservative limits by choosing the stream with highest allowed cross section
Dark matter – neutrino scattering

DM – $\nu$ scattering leads to deviations in the isotropic cosmic neutrino flux
→ focus on high energies
→ 7.5 years of high energy starting events support isotropic flux
→ upper limit on allowed couplings
A glimpse to the future

Seven new strings in 2022/2023:
Better efficiency and reconstruction at low energies
An interesting detour

IceCube can search for sterile neutrinos
→ matter enhanced oscillations
→ at TeV energies
→ looking for a $\nu_\mu$ disappearance

Blue region is the best-fit from Diaz et al. arXiv:1906.00045

New analysis with 8 years of data and improved systematics out soon!
Summary

IceCube has a **lively** and **expanding** program of indirect searches for Dark Matter:

- No observation of a neutrino excess in IceCube compatible with dark matter expectations
- Results are competitive and complementary to other messengers
- More scenarios are being probed and constrained
- Many ongoing analyses with more data, improved event selection and reconstruction
Additional material
Galactic center

- First combination with ANTARES in common mass-range
- Combine different field-of-views
- Unify theoretical input and likelihood minimization
Secluded dark matter from the Sun

- DM annihilates into mediator $V$ which decays close to the sun surface
- No limitations due to neutrino attenuation in the sun
- Mediator mass and lifetime are free parameters
Capture and self-annihilation in the Earth

- Challenging analysis due to unique position of Earth
- No equilibrium assumed
  → limits on $\langle \sigma_A \nu \rangle / \sigma_{SI}$

[EPJC 77 (2017) 82]

S. Baur – Searches for DM with IceCube
Capture and self-annihilation in the Earth

- Challenging analysis due to unique position of Earth
- No equilibrium assumed → limits on $\langle \sigma_A v \rangle / \sigma_{SI}$

[EPJC 77 (2017) 82]
Capture and self-annihilation in the Earth

Annihilation rate, $\chi\chi \rightarrow W^+ W^-$

- IceCube 8 yrs 90% C.L. sensitivity
- IceCube 1 yr 90% C.L. upper limit
- ANTARES (2017) 90% C.L. upper limit

Improved analysis extending to 8 years of data under development!

IceCube work in progress