Searches for dark matter signatures in high energy neutrinos

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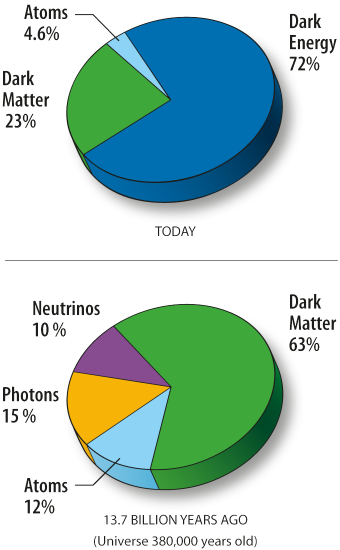
Motivation

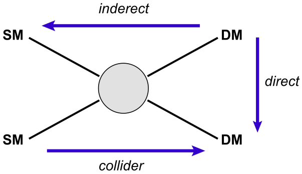
Dark matter

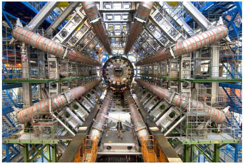


- A variety of observations, ranging from velocity distributions in galaxies to the CMB, indicate the presence of a large quantity of nonbaryonic matter in our universe.
- Today there is a large variety of experiments that try to examine the nature of dark matter in a variety of ways

Motivtion of indirect searches

Experiments include general astrophysics experiments that look for DM in the Sun, Earth, Milky way and extragalactic objects.

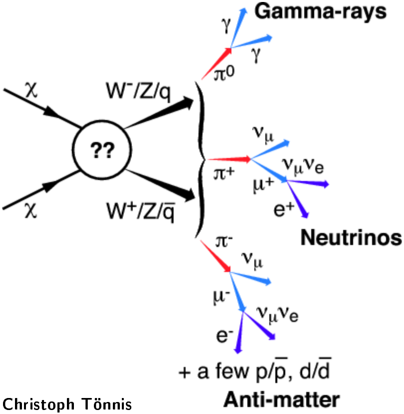




XENON, LUX, PICO and others constitute the current direct search experiments
For the moment the main collider experiment is the LHC

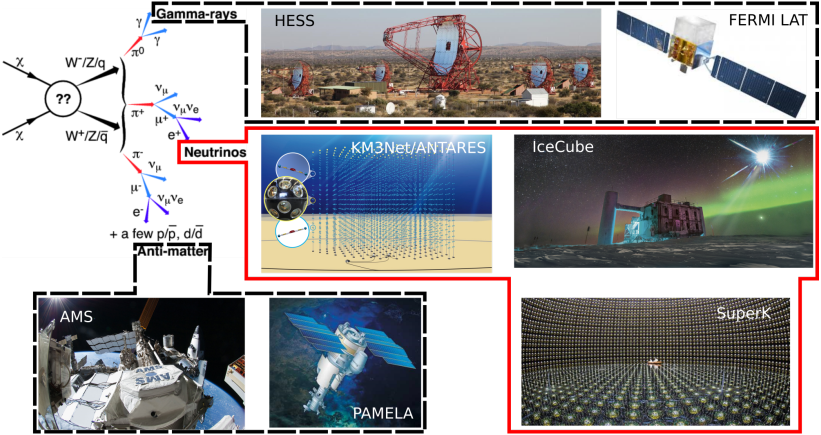
Indirect searches

- Indirect searches look for the products of dark matter annihilations/decays
- Depending on the particle model for dark matter different end products will come from the annihilations/decays



- The immediate products of the annihilations/decays decay further yielding stable messenger particles like leptons, baryons and photons
- Different detectors the look for different messengers

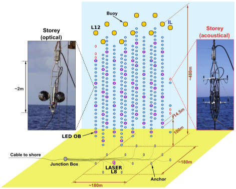
Types of indirect searches

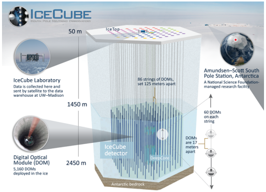


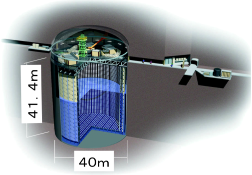
The benefits of using neutrinos

- A lack of interactions with other matter reduces systematics
- Searches in the Sun and Earth are sensitive to Spin dependent scattering cross-sections
- Unlike most other detectors neutrino detectors intrinsically scan the entire sky
- At higher neutrino energies interaction cross sections and angular resolutions increase, yielding improved sensitivities

Neutrino detectors







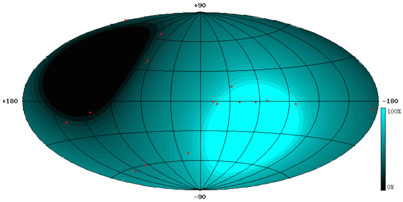
- Located 40 km off the southern French coast near la seyne sur mer
- 885 10-inch PMTs installed to 12 lines with 25 storeys each with 3 PMTs each
- Data taking started in 2007

- Located at the South Pole
- 5160 10-inch PMTs in Digital optical modules installed to 86 strings instrumenting km^3
- Data has been recorded since 2007, deep core was completed in december 2010

- Located at the former Kamioka mine in Japan
- 11000 20-inch PMTs are used to instrument a 50kt pure water (22.5kt fiducial) tank
- The experiment has been operating since 1996

Visibility

- Neutrino telescopes commonly use the earth as a shield against atmospheric muons
- This limits the visibility of various positions on the celestial sky to each detector



- Larger detectors, like IceCube, can use the outer layer of the detector as a veto against atmospheric muons
- This increases the visibility, but severely reduces effective volume of the detector, especially at high energies (muon range)

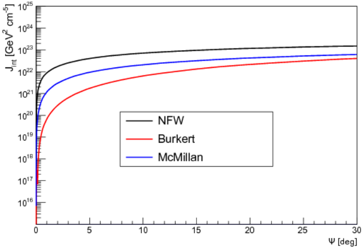
Galactic Centre

Search types

- There are two main types of neutrino-based dark matter searches: Searches for dark matter annihilations and searches for dark matter decays
- For annihilation searches the signal flux is calculated via:

$$\frac{d\Phi}{dE} = \frac{1}{4\pi}\frac{\langle\sigma v\rangle}{2m_\chi^2}\frac{dN_\nu}{dE} \times \int_{\Delta\Omega}\int_{LOS}\rho_\chi^2(l,\theta,\phi)dl(\theta,\phi)d\Omega$$

- The red term is the particle physics term and depends on the particle model for dark matter
- The blue term is called J-Factor. It takes the distribution of dark matter into account

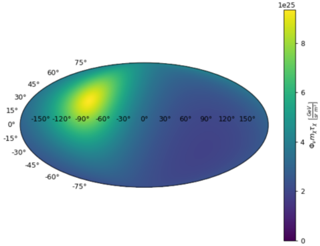


Search types

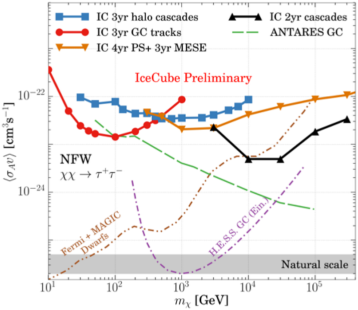
- For decay searches the signal flux is calculated via:

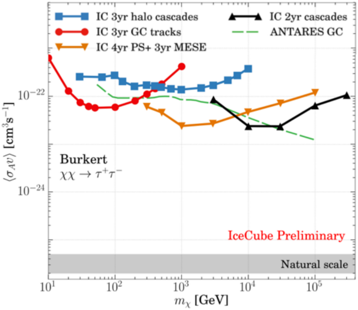
$$\frac{d\Phi}{dE} = \frac{1}{4\pi}\frac{1}{m_\chi \tau_\chi}\frac{dN_\nu}{dE} \times \int_{\Delta\Omega}\int_{LOS} \rho_\chi(l,\theta,\phi)\,dl(\theta,\phi)\,d\Omega$$

- Again, the red term is the particle physics term and depends on the particle model for dark matter
- The blue term is called D-Factor. It takes the distribution of dark matter into account



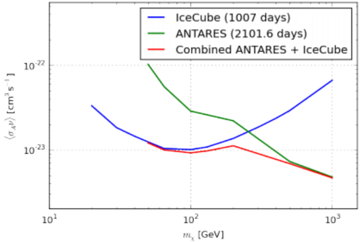
Annihilations

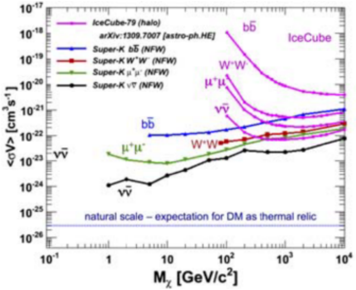




- There are currently 4 main analyses for the dark matter mass rang of 100 GeV to 300 TeV
- ANTARES 2007-2015, IceCube 2yr Cascade, IceCube 4yr tracks + 3 yr MESE, IceCube 3yr track low-energy [1-2]

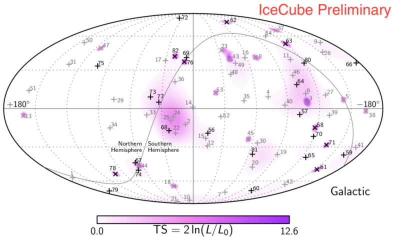
Annihilations





- At the region between 50 and 100 GeV a combined analysis between ANTARES and IceCube is in progress [3]
- The region below 100 GeV is covered by SuperK yielding very competitive results [4]

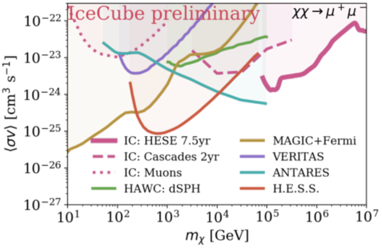
High energy starting events



- The IceCube collaboration has released analyses of high energy neutrino events
- 80 events were observed at an expected background of 41 events [5]

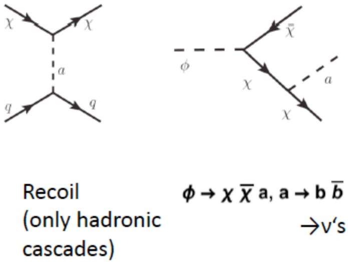
- One conjecture is that this high energy flux, or a part of it is generated from heavy dark matter
- However there are systematic effects in the modelling of the background and the absorption of neutrinos in the earth that make any inference difficult

High energy starting events



- There is one recent analysis of this topic [6]
- Their conclusion is that dark matter alone can not explain the HESE flux and this can not be considered direct evidence for dark matter at a sufficient level of significance
- After the discovery of multi-PeV neutrinos the case for PeV dark matter as an explanation has become even less favourable
- Limits have been placed on the annihilation cross section and decay lifetime for the respective cases

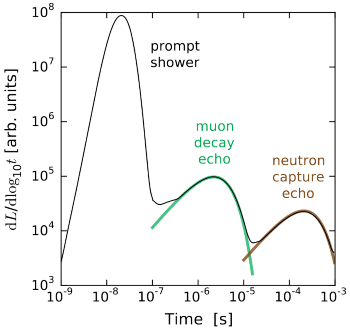
Boosted dark matter

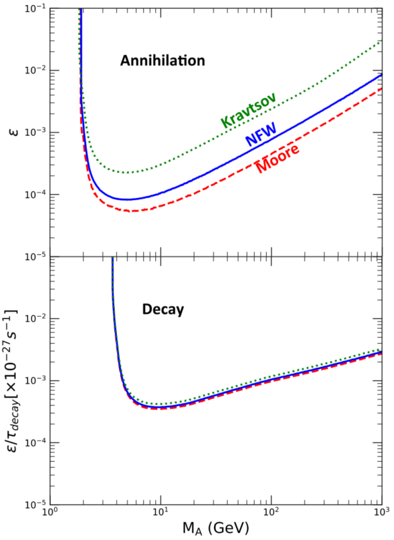


- Boosted dark matter is a model where there are two dark matter particles: a heavy and a lighter particle
- The heavier particle can decay into the lighter particle giving it a boosted kinetic energy

- Neutrino detectors can look for recoils from these boosted dark matter particles or signals from their annihilations/decays
- Both the SuperK and the IceCube collaborations have been investigating boosted dark matter [7-8]

Boosted dark matter

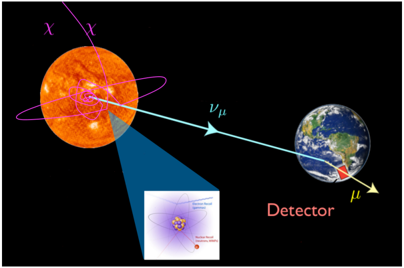




In IceCube recoils of boosted dark matter can be found using a delayed light echo from neutron capture, SuperK is looking for annihilations/decays

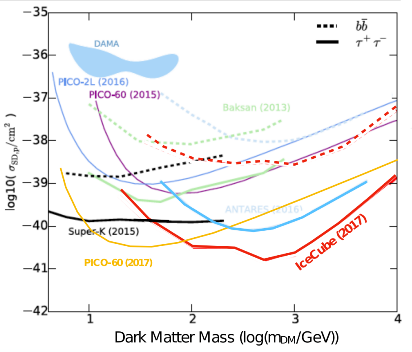
Sun

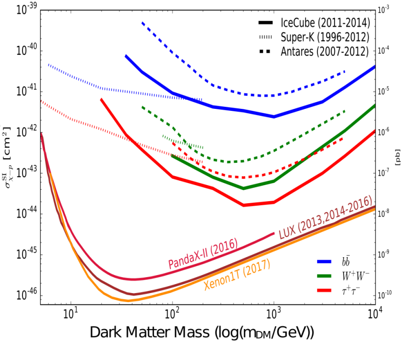
Dark matter in the Sun



- Dark matter can be gravitationally captured in the sun after it looses energy in scattering processes
- Over time an equilibrium between capture and annihilation will establish itself
- This equilibrium allows to relate neutrino signal fluxes to dark matter accumulation rates and dark matter scattering cross sections

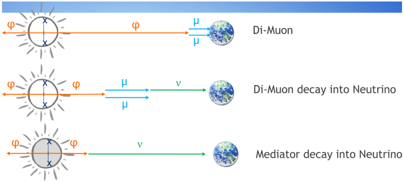
Dark matter in the Sun





- Limits and sensitivities are expressed as Spin independent and Spin dependent scattering cross sections [9-10]
- Direct detection experiments tend to be more sensitive to spin independent scattering,indirect searches with neutrinos to spin dependent scattering

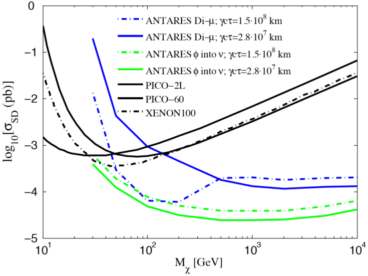
Secluded dark matter

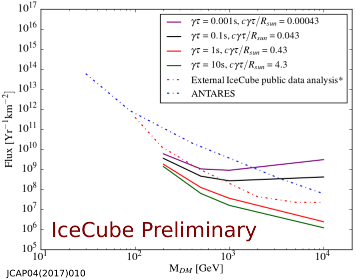


- Secluded dark matter is a particle model for dark matter in which the dark matter particles only decay into metastable mediator particles
- These mediators have a lifetime between a few microseconds and several seconds.

- For longer lifetimes the mediator can escape the Sun before decaying and avoid absorption in the Solar plasma. This increases the signal flux at high energies
- For very long lifetimes the mediator can decay close to the detector and yield a dimuon track

Secluded dark matter





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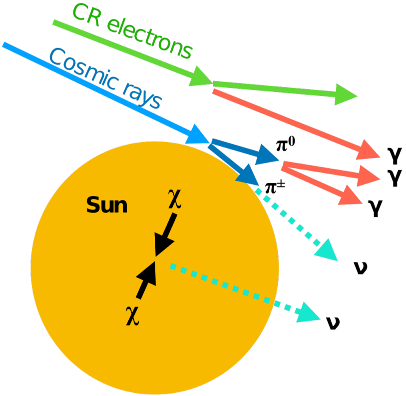
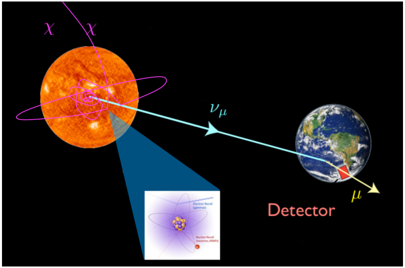
- Due to the enhanced high energy flux neutrinos are more sensitive to Secluded dark matter than to WIMP dark matter [11]
- Currently a new IceCube analysis is in progress [12]

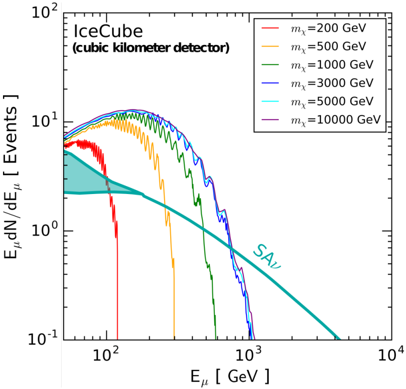
Solar atmospheric neutrinos

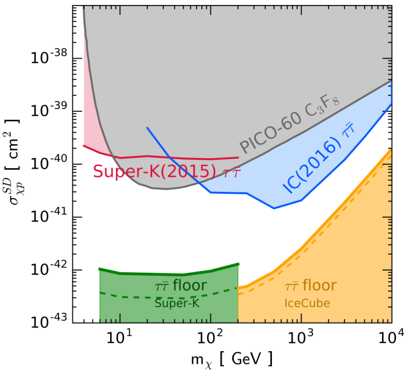




- Cosmic rays interacting with the solar atmosphere produce gamma rays that have been detected by FERMI LAT [13]
- It is expected that there is a corresponding flux of solar atmospheric neutrinos that can be investigated by neutrino detectors [14-15]

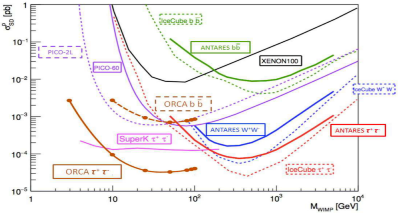
Solar atmospheric neutrinos

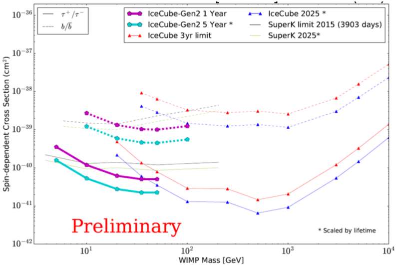


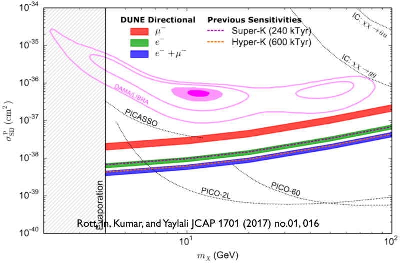


- Solar atmospheric neutrinos form a background to solar dark matter searches
- This generates a neutrino floor for this type of searches [16]

Outlook







There are several new experiments and extensions with promising sensitivity projections: KM3Net, Orca, IceCube GEN2/PINGU, DUNE [17-18]

Summary

Summary

- Distinctive signatures of dark matter decays and annihilations provide a good sensitivity for indirect dark matter searches
- Neutrino telescopes provide the most strict limits at high dark matter masses for self annihilations in the galactic centre
- Decaying heavy dark matter lifetimes are now restricted to 10^{28} s
- Searches in the sun provide the most stringent on spin dependent scattering
- Non-WIMP dark matter searches are also being pursued

References

[1] IceCube Eur. Phys. J. C (2017) 77: 627
[2] ANTARES Physics Letters B 769 (2017) 249–254
[3] ANTARES & IceCube ICRC2017 (911)
[4] K. Frankiewicz and Super-Kamiokande 2017 J. Phys.: Conf. Ser. 888 012210
[5] IceCube Science 342, 1242856 (2013)
[6] Y. Tianlu & H. Dujmovic NEUTRINO 2018 poster https://zenodo.org/record/1300506#.W2pUwNIzZPY
[7] A. Steuer, L. Koepke IceCube PoS(ICRC2017)1008
[8] C. Kachulis et al Super-K arXiv:1711.05278
[9] ANTARES Phys.Lett. B759 (2016) 69-74
[10] IceCube Eur.Phys.J. C77 (2017) no.3, 146
[11] ANTARES JCAP 1605 (2016) no.05, 016
[12] IceCube ICHEP 2018
[13] Fermi-LAT The Astrophysical Journal 734 (2011) 116
[14] Ng, Beacom, Peter, Rott Phys.Rev. D96 (2017) no.10, 103006
[15] C. Argüelles, G. de Wasseige, A. Fedynitch, B. Jones JCAP 1707 (2017) no.07, 024 [16] J. Edsjö, J. Elevant, R. Enberg, and C. Niblaeus, JCAP 2017 06 (2017), p. 033 [17] IceCube Gen2 LOI arXiv:1412.5106
[18] KM3NeT LOI J.Phys. G43 (2016) no.8, 084001