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Sergio Palomares-Ruiz

March 06, 2008

Testing Dark Matter with neutrino detectors

Rencontres de Moriond EW 2008

RENCONTRES

La Thuile (Italy) March 01-08, 2008

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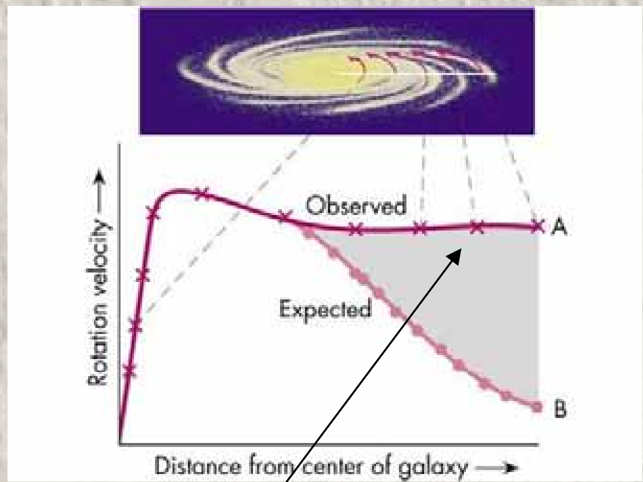
Evidences of DM

- **Rotation curves of galaxies and clusters**



Need non-luminous matter

Black-holes, brown dwarfs, white dwarfs, giant planets, neutron stars ...?

- **Weak modulation of strong lensing, Oort discrepancy, weak gravitational lensing, velocity dispersions of dwarf spheroidal galaxies and of spiral gallaxy satellites…**

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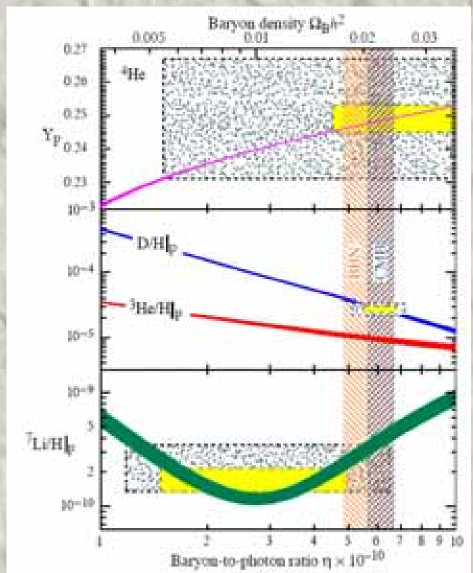
Cosmological evidences

- **WMAP Best-fit for a flat ΛCDM model:**

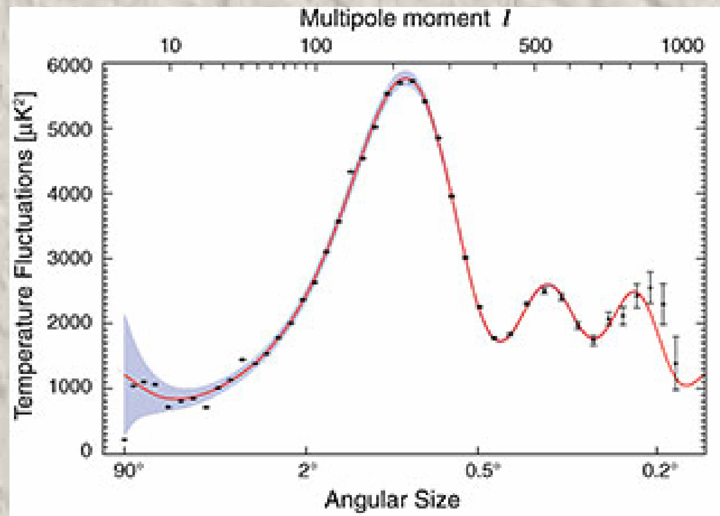
$\Omega_m h^2 = 0.1326 \pm 0.0063$

Non-baryonic Dark Matter

But… $\Omega_b h^2 = 0.02229 \pm 0.00073$



B. D. Fields and S. Sarkar, PDG



NASA / WMPA Science Team, WMAP 5-year results

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What do we know about Dark Matter?

- **Astrophysicist view:**

"You both have something in common. Dr. Davis has discovered a particle which nobody has seen, and Prof. Higbe has discovered a galaxy which nobody has seen."

"Ill tell you what's beyond the observable universe -- lots and lots of unobservable universe."

- **Particle Physicist view:**

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Some DM properties

- How big is the annihilation cross section?
- For a thermal relic: $<\sigma v> \sim 3 \times 10^{-26}\ cm^3/s$
- But…DM might only exist in the late Universe
- $<\sigma v>$ sets the rate of DM annihilation in DM halos

- If DM is unstable, how long does it live?
- τ would set the rate of DM decay in DM halos

Can we test them with neutrino detectors?

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Annihilations from the halo

Model-independent bound

- Neutrinos are the least detectable particles of the SM

- From the detection point of view the most conservative assumption (the worst case) is that DM annihilates *only* into ν's: $\chi\chi \rightarrow \nu\nu$

- Anything else would produce photons, and hence would lead to a stronger limit

Strategy

- Calculate neutrino flux: proportional to annihilation cross section and ρ_{DM}^2
- For E ~ 100 MeV – 100 TeV the main background: atmospheric neutrino flux
- Consider angle-averaged flux in wide energy bins
- Compare potential signal with the well known and measured background: set upper bound on the DM annihilation cross section

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Signal

$$\frac{d\Phi}{dE} = \frac{\Delta\Omega}{4\pi} \frac{\langle \sigma \upsilon \rangle}{2m_\chi^2} \frac{dN}{dE} R_{sc} \rho_0^2 J_{\Delta\Omega}^{ann}$$

Experiment — $\frac{\Delta\Omega}{4\pi}$

Particle Physics — $\frac{\langle \sigma \upsilon \rangle}{2m_\chi^2} \frac{dN}{dE}$

Astrophysics — $R_{sc} \rho_0^2 J_{\Delta\Omega}^{ann}$

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Field of View

$$\Delta\Omega = 2\pi\left(1-\cos\psi\right)$$

Neutrino Spectrum: Flavor democracy

$$\frac{dN}{dE} = \frac{2}{3}\delta\left(E - m_\chi\right)$$

Average of the Line of Sight Integration of ρ^2

$$J_{\Delta\Omega}^{ann} = \frac{1}{\Delta\Omega}\int_{\cos\psi}^{1}\left(\frac{1}{R_{sc}\rho_0^2}\int_0^{\ell_{\max}}\rho^2(r)d\ell\right)2\pi\, d\cos\psi$$

$$r = \sqrt{R_{sc}^2 - 2\ell R_{sc}\cos\psi + \ell^2} \qquad \ell_{\max} = \sqrt{R_{halo}^2 - R_{sc}^2\sin^2\psi} + R_{sc}\cos\psi$$

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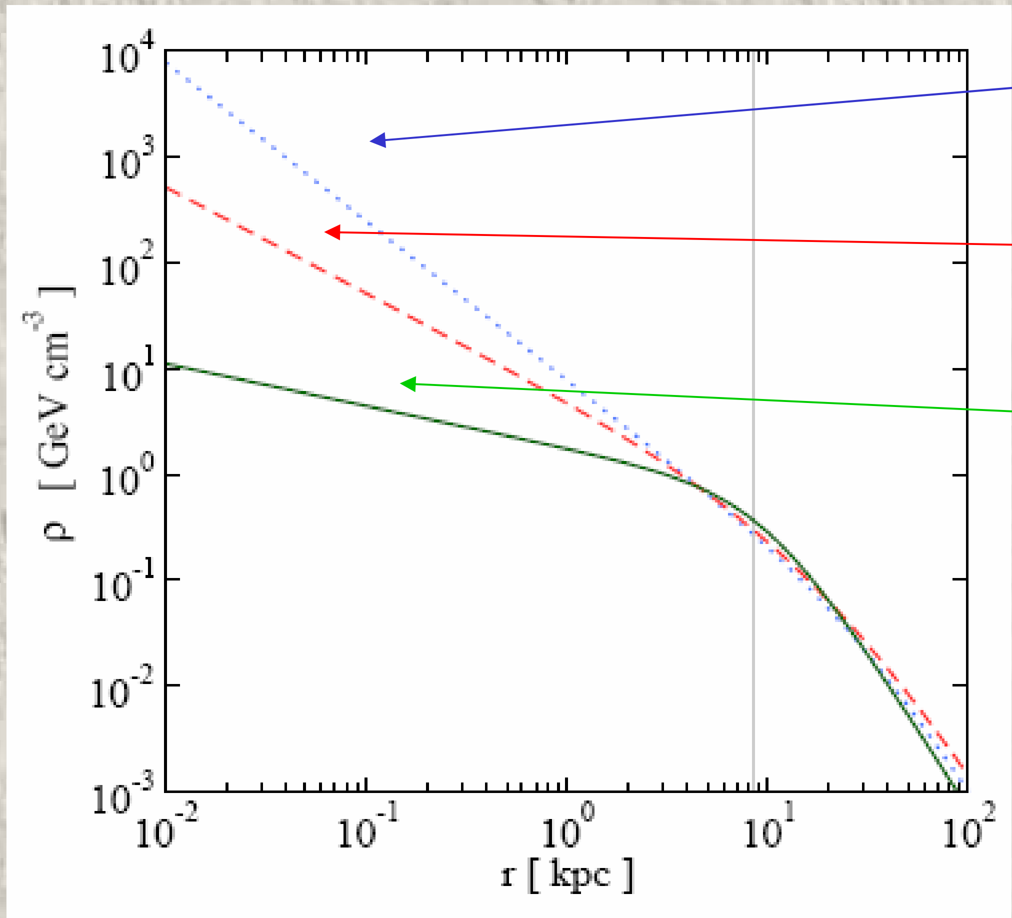
Dark Matter Profiles

$$\rho(r) = \rho_{sc}\left(\frac{R_{sc}}{r}\right)^{\gamma}\left[\frac{1+\left(R_{sc}/r_s\right)^{\alpha}}{1+\left(r/r_s\right)^{\alpha}}\right]^{(\beta-\gamma)/\alpha}$$



Moore et al.

NFW

Kravstov et al.

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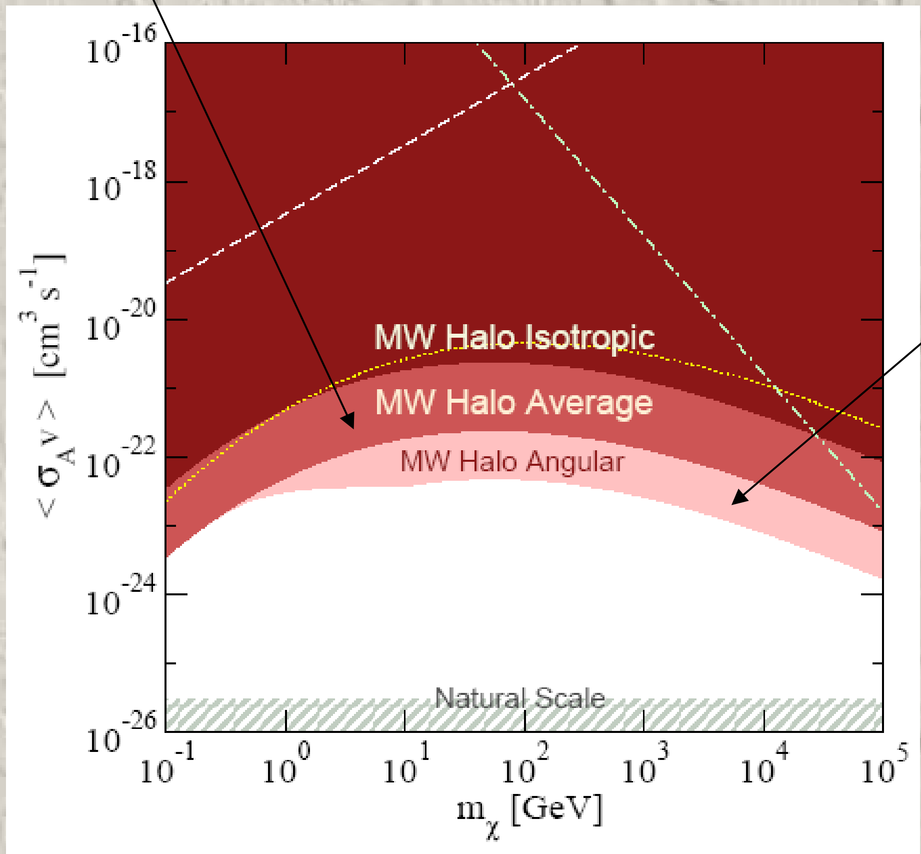
Energy bin: $\Delta \log E = 0.3$

$$\Delta\Omega = 4\pi$$



$$\Delta\psi = \begin{cases} 30^o \sqrt{\dfrac{10\,\mathrm{GeV}}{E}} & E < 10\,\mathrm{GeV} \\ 30^o & E > 10\,\mathrm{GeV} \end{cases}$$

H. Yüksel, S. Horiuchi, J. F. Beacom and S. Ando , Phys. Rev. D76:123506, 2007

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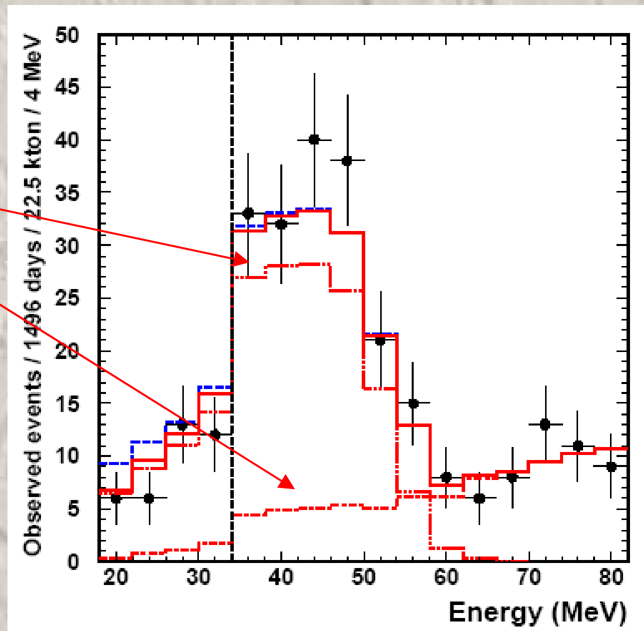
Can we do better?

- Careful treatment of energy resolution and backgrounds: eg. limits on MeV DM
- We use SK data for E = 18-82 MeV
- Detection: $\overline{\nu}_e + p \rightarrow e^+ + n$
- Two main backgrounds:
  - Invisible muons
  - Atmospheric neutrinos



M. S. Malek, Ph.D thesis
M. S. Malek *et al.*, Phys. Rev. Lett. 90:061101, 2003

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Analysis

16 4-MeV bins in the range [18,82] MeV

N_l = Number of events in bin l
A_l = fraction of signal events
B_l = fraction of Michel electrons (positrons)
C_l = fraction of atmospheric electron (anti)neutrinos

$$A_l = A_s \int \left[\frac{d\sigma_{\rm f}^{\overline{\nu}}}{dE_e}(m_\chi, E_e) + \frac{1}{2}\left(\frac{d\sigma_{\rm b}^{\nu}}{dE_e}(m_\chi, E_e) + \frac{d\sigma_{\rm b}^{\overline{\nu}}}{dE_e}(m_\chi, E_e) \right) \right] dE_e \times \int_{E_l}^{E_{l+1}} \epsilon(E_{\rm vis})\, R(E_e, E_{\rm vis})\, dE_{\rm vis}$$

$$\chi^2 = \sum_{l=1}^{16} \frac{\left[(\alpha \cdot A_l) + (\beta \cdot B_l) + (\gamma \cdot C_l) - N_l\right]^2}{\sigma_{stat}^2 + \sigma_{sys}^2}$$

$$P(\alpha) = K\, e^{-\chi^2/2} \quad \Rightarrow \quad \int_0^{\alpha_{90}} P(\alpha)\, d\alpha = 0.9$$

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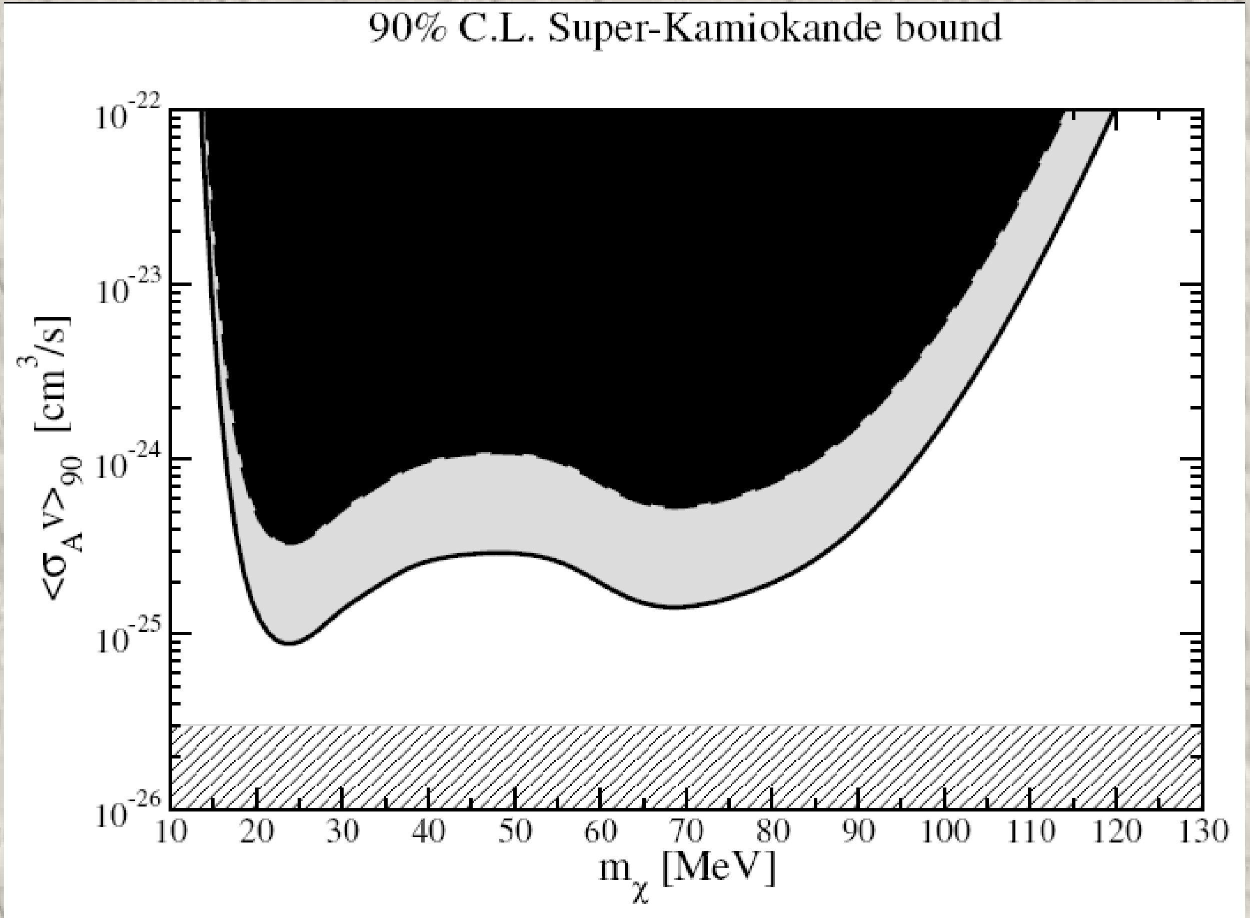
We perform a similar χ^2 analysis as that done by SK to limit the flux of DSNB and we set an upper bound on the DM annihilation cross section



SPR and S. Pascoli, Phys. Rev. D 77, 025025 (2008)

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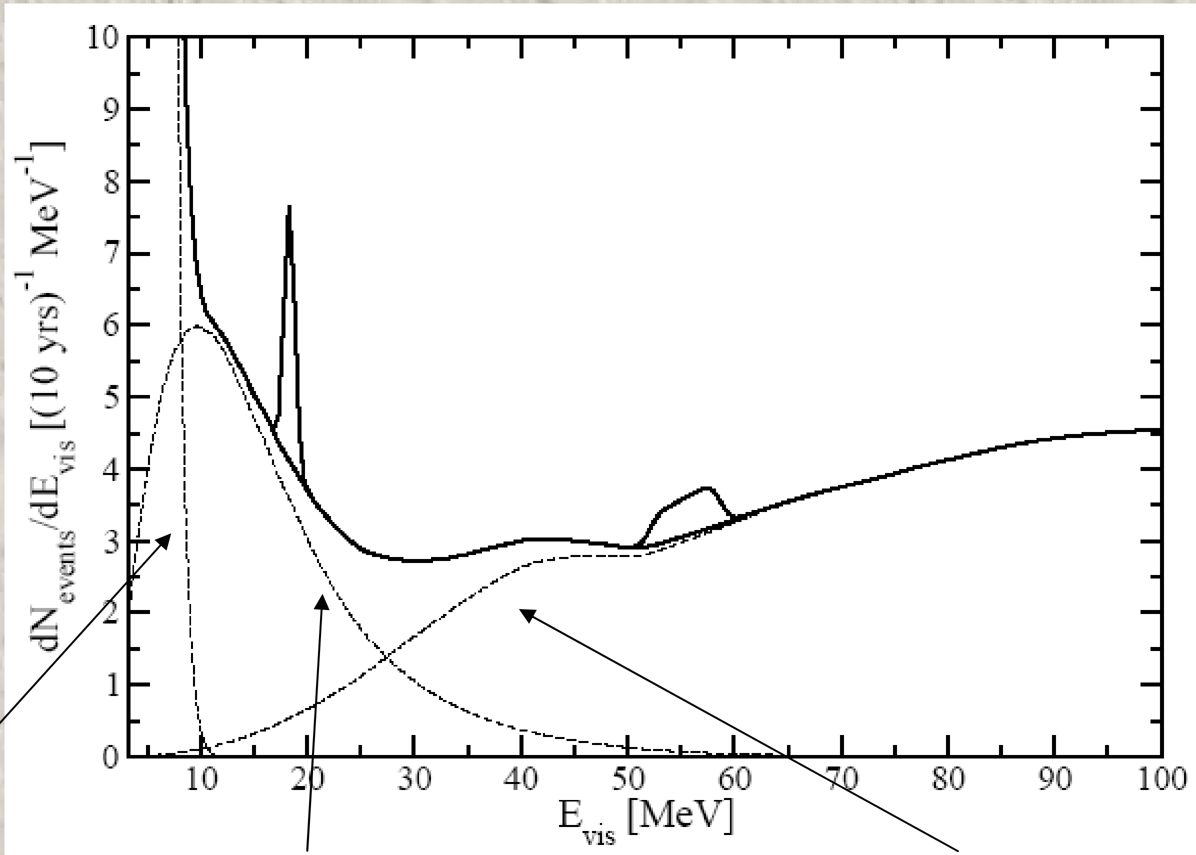
What if this is actually the case and DM only annihilates into neutrinos?

C. Boehm, Y. Farzan, T. Hambye, SPR and S. Pascoli, Phys. Rev. D 77, 043516 (2008)

LENA: 50000 m^3 scintillator after 10 years



Reactor BG DSNB Atmospheric BG

SPR and S. Pascoli, Phys. Rev. D 77, 025025 (2008)

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Decays from the halo

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- **Neutrinos are the least detectable particles of the SM**

- **From the detection point of view the most conservative assumption is that DM decays *only* into ν's : $\chi \to \nu\ \nu$**

- **Flux proportional to the inverse of the DM lifetime and ρ_{DM}**

- **For E ~ 100 MeV – 100 TeV the main background: atmospheric neutrino flux**

- **Compare potential signal with the well known and measured background: set lower bound on the DM lifetime**

Signal

$$\frac{d\Phi}{dE} = \frac{\Delta\Omega}{4\pi} \; \frac{1}{m_\chi \tau_\chi} \frac{dN}{dE} \; R_{sc}\,\rho_0\, J^{dk}_{\Delta\Omega}$$

Experiment

Particle Physics

Astrophysics

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Field of View

$$\Delta\Omega = 2\pi\left(1 - \cos\psi\right)$$

Neutrino Spectrum: Flavor democracy

$$\frac{dN}{dE} = \frac{2}{3}\delta\left(E - m_\chi / 2\right)$$

Average of the Line of Sight Integration of ρ

$$J_{\Delta\Omega}^{dk} = \frac{1}{\Delta\Omega}\int_{\cos\psi}^{1}\left(\frac{1}{R_{sc}\rho_0}\int_0^{\ell_{\max}} \rho(r)\, d\ell\right) 2\pi\, d\cos\psi$$

$$r = \sqrt{R_{sc}^2 - 2\ell R_{sc}\cos\psi + \ell^2}$$

$$\ell_{\max} = \sqrt{R_{halo}^2 - R_{sc}^2\sin^2\psi} + R_{sc}\cos\psi$$

$$\rho(r) = \rho_{sc}\left(\frac{R_{sc}}{r}\right)^{\gamma}\left[\frac{1+\left(R_{sc}/r_s\right)^{\alpha}}{1+\left(r/r_s\right)^{\alpha}}\right]^{(\beta-\gamma)/\alpha}$$

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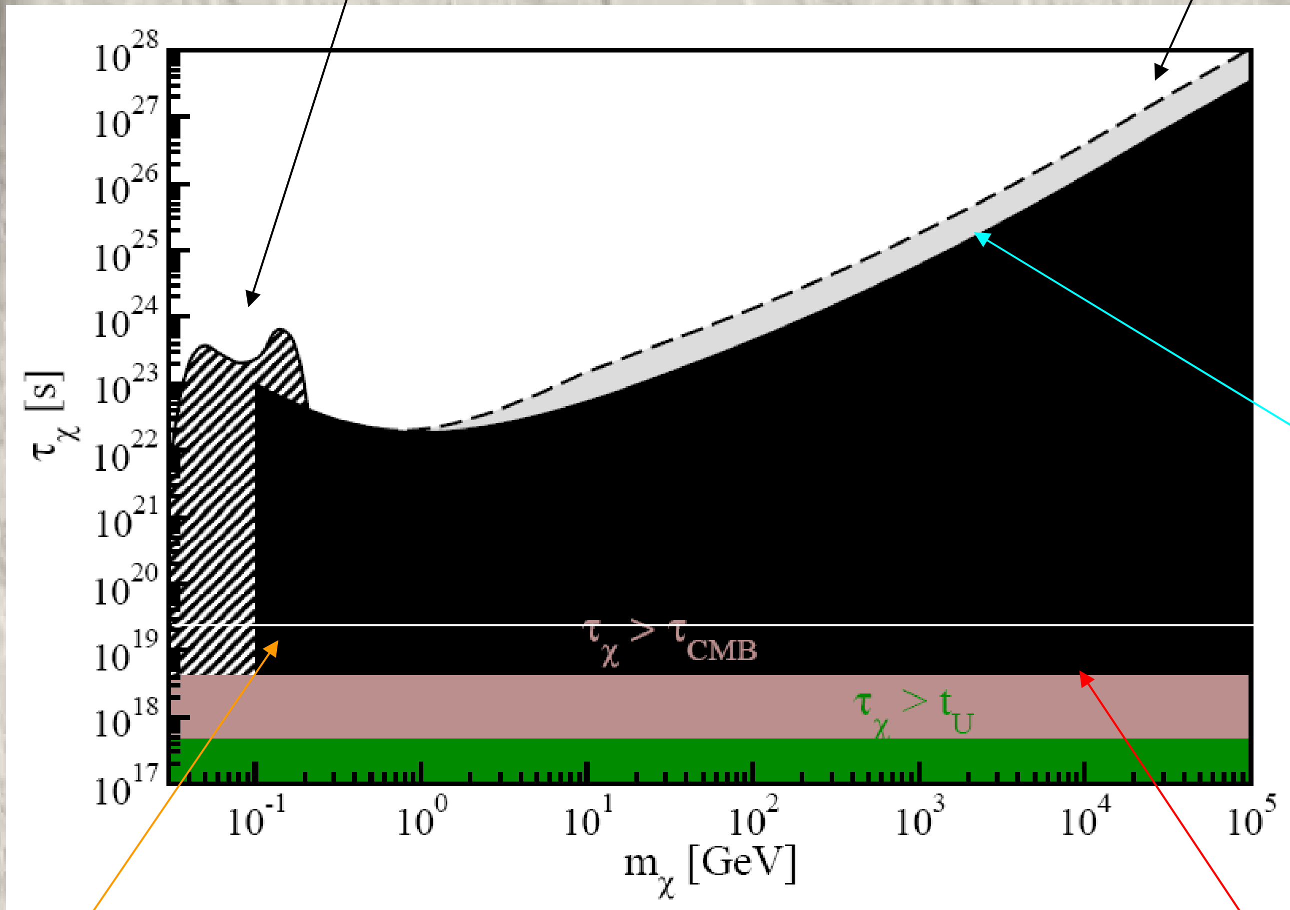
Using SK data from DSNB search:
Detailed analysis of background and energy resolution

$$\Delta\psi = \begin{cases} 30^{\circ}\sqrt{\dfrac{10\mathrm{GeV}}{E}} & E < 10\mathrm{GeV} \\ 30^{\circ} & E > 10\mathrm{GeV} \end{cases}$$



$$\Delta\Omega = 4\pi$$

New model-independent bound from CMB and SN observations

Y. Gong and X. Chen, arXiv:0802.2296

SPR, arXiv:0712.1937

Model-independent bound from CMB observations

K. Ichiki, M. Oguri and K. Takahashi, Phys. Rev. Lett. 93, 071302 (2004)

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Conclusions

- Neutrino detectors can test DM properties
- Searches for neutrinos from DM annihilations/decays in the galactic halo could constitute powerful probes of DM properties
- Neutrino detectors can set model-independent bounds on the DM annihilation cross section and on the DM lifetime
- Future detectors (LENA) might be able to detect a signal from DM annihilations/decay