Neutrinos and scalar dark matter

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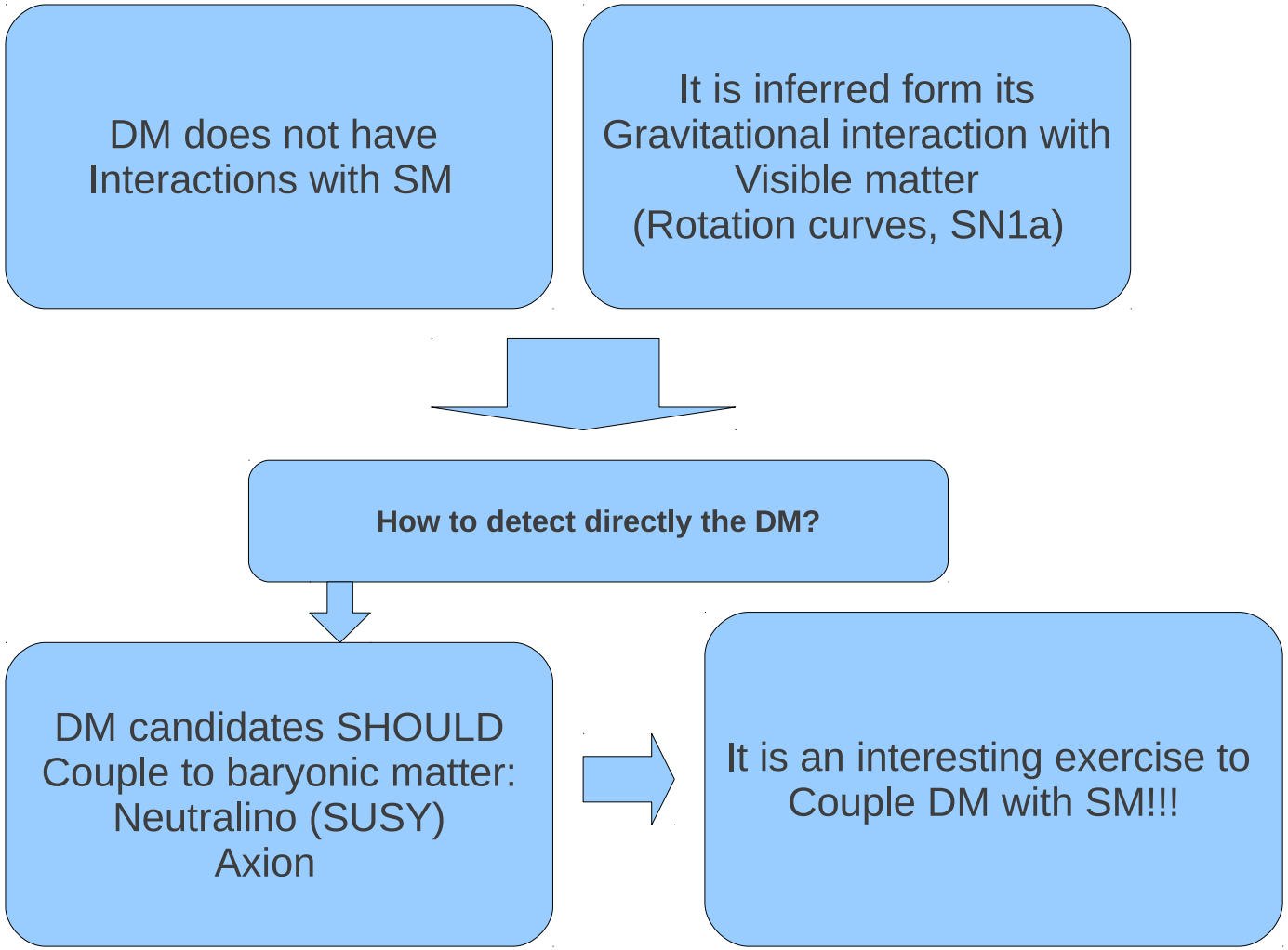
Essential Cosmology for the next generation

Cosmology on the Beach, Cancún México, 16-20 January 2012

Outline

- Motivation
  - Interaction ν-DM: Previous works
- Possible new suppression of extra-galactic ν's.
  - Mean free path
  - Cross section
  - The case of an ultra light spin zero boson ($m \sim 10^{-23}$ eV.)
- Possible suppression of the diffuse supernova neutrino background
- Conclusions

Motivation


DM does not have
Interactions with SM
It is inferred form its
Gravitational interaction with
Visible matter
(Rotation curves, SN1a)
How to detect directly the DM?
DM candidates SHOULD
Couple to baryonic matter:
Neutralino (SUSY)
Axion
It is an interesting exercise to
Couple DM with SM!!!

ν-DM interaction

- To add a ν-DM interaction
- In particular, add a new interaction with a scalar field

ν-ϕ_{DM} interaction

- J. F. Beacom, N. F. Bell and S. Dodelson,
  Neutrinoless universe, Phys. Rev. Lett. **93**, 121302 (2004)
- G. Mangano, A. Melchiorri, P. Serra, A. Cooray and M. Kamionkowski,
  Cosmological bounds on dark matter-neutrino interactions, Phys. Rev. D **74**, 043517 (2006)

ν-$\phi_{\rm DM}$ interaction

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This new interaction could suppress the flux of extragalactic neutrinos

Possible suppression

- The mean free path

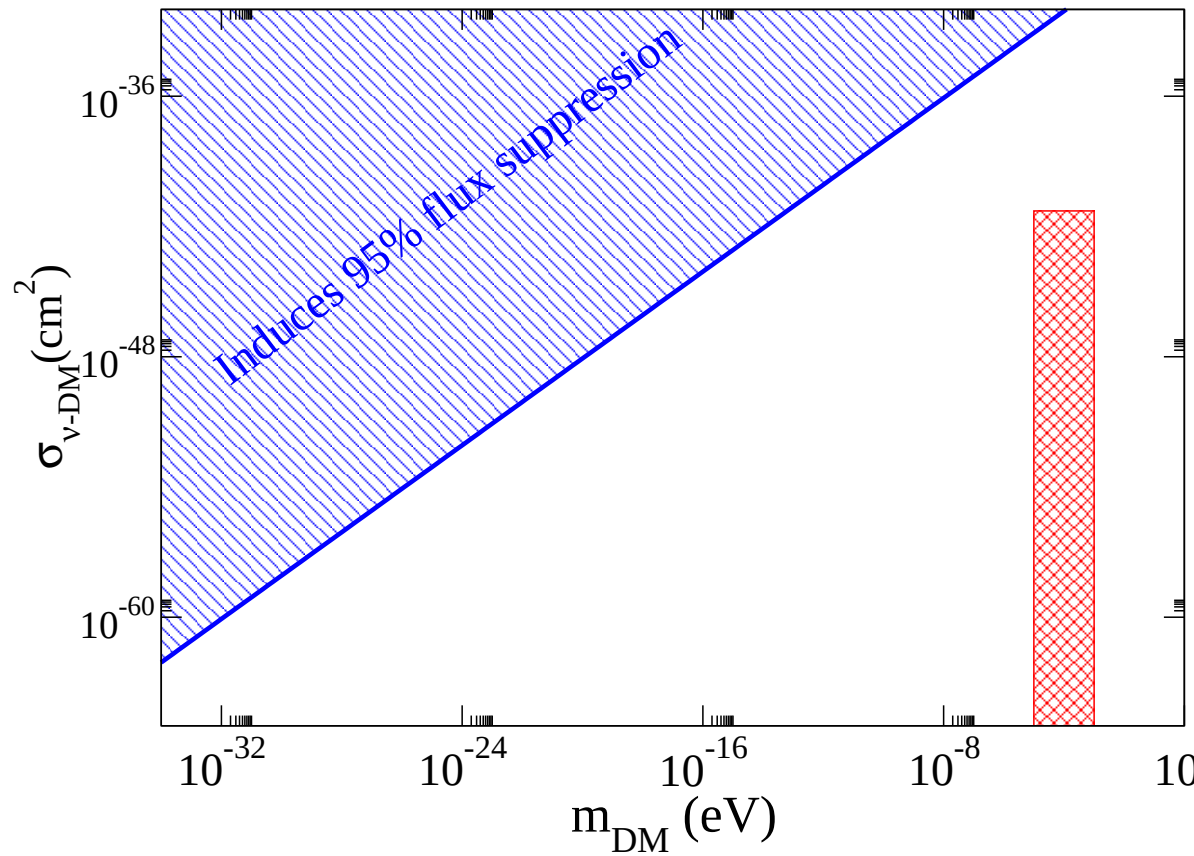
$$\lambda^{mfp} = (n\sigma)^{-1} = \frac{m_{DM}}{\rho_{DM}\sigma},$$

where n is the DM density and σ is the elastic cross section ν-DM, and m_{DM} is the mass of the DM particle.

- There will be a ν's UHE flux suppression given by

$$F(L) = F_0 e^{-L/\lambda^{mfp}},$$

where $F(L)$ is the suppressed flux and F_0 is the flux at the source.



SFDM as a viable model for DM

- Another approach: The Scalar Field Dark Matter model (SFDM) The Dark Matter is modeled by a scalar field with a ultra-light associated particle. ($m \sim 10^{-23}$eV)
  - At cosmological scales it behaves as cold dark matter
    T. Matos, L.A. Urena-Lopez, Class. Quant. Grav. **17** L75 (2000),

    V. Sahni and L.M. Wang, Phys. Rev D **62**, 103517 (2000).
  - At galactic scales, it does not have its problems: neither a cuspy profile, nor a over-density of satellite galaxies.

    A. Bernal, T. Matos, D. Nuñez, Rev. Mex. A.A. 44, 149 (2008)

    T. Matos, L.A. Urena-Lopez, Phys. Rev. D **63**, 063506 (2001)

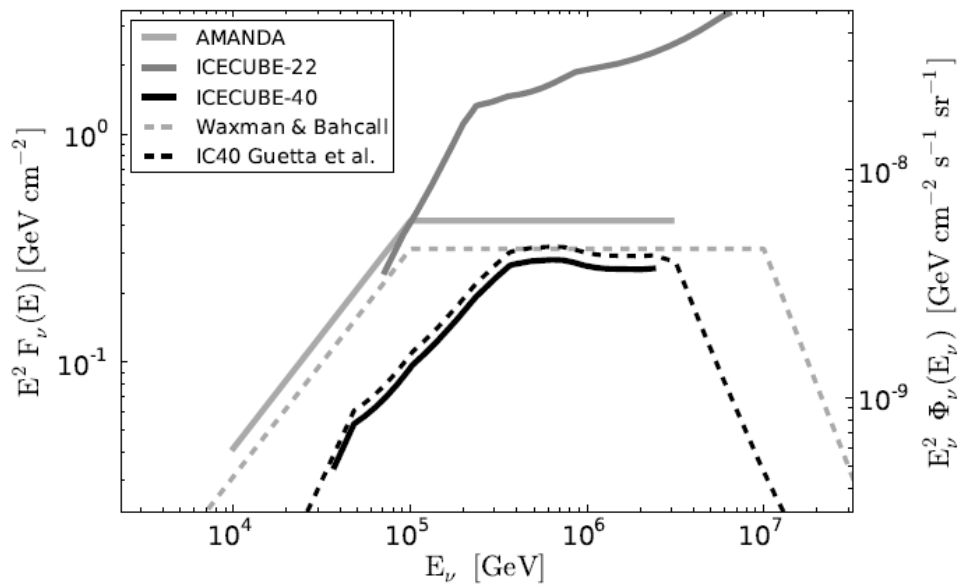
Could it be possible that we have already observed this interaction?

Phys.Rev.Lett. 106 (2011) 141101

Limits on Neutrino Emission from Gamma-Ray Bursts with the 40 String IceCube Detector

(IceCube Collaboration)

IceCube has become the first neutrino telescope with a sensitivity below the TeV neutrino flux predicted from gamma-ray bursts if GRBs are responsible for the observed cosmic-ray flux above 10^{18} eV. Two separate analyses using the half-complete IceCube detector, one a dedicated search for neutrinos from $p\gamma$-interactions in the prompt phase of the GRB fireball, and the other a generic search for any neutrino emission from these sources over a wide range of energies and emission times, produced no evidence for neutrino emission, excluding prevailing models at 90% confidence.



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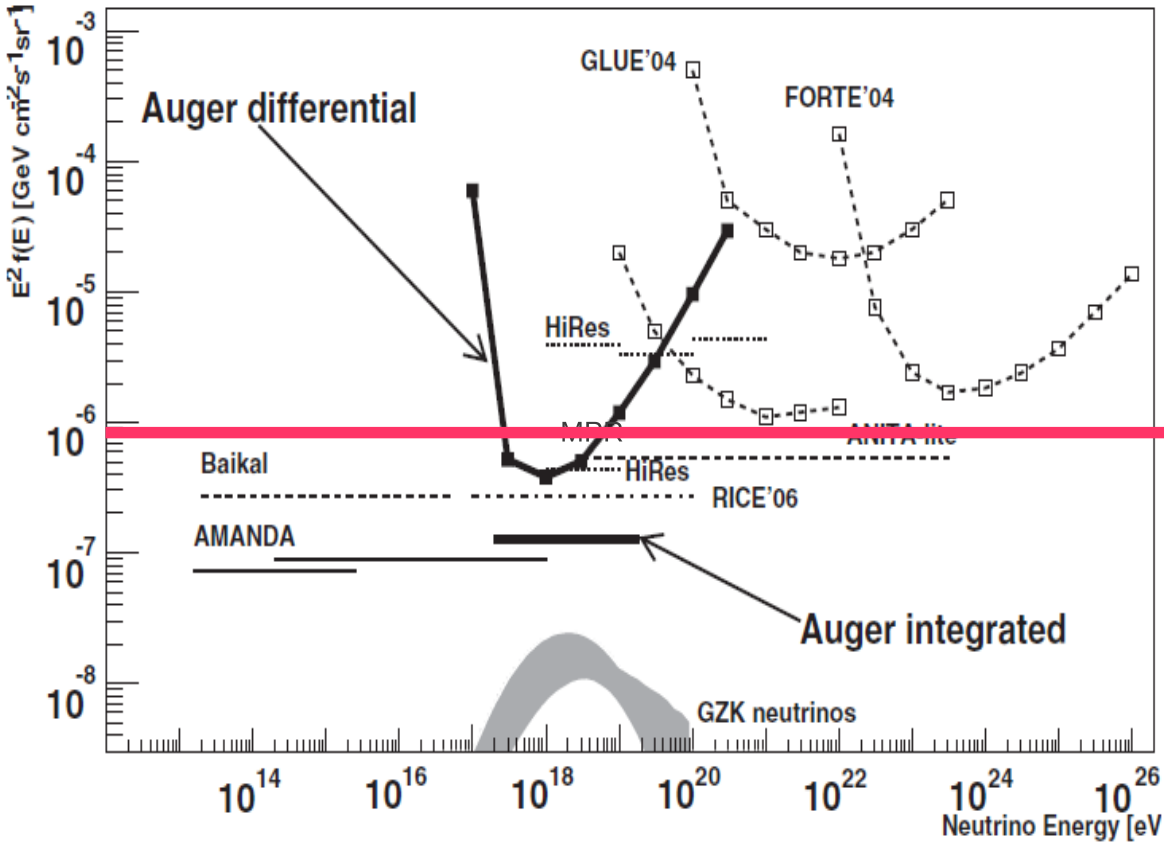


J. Abraham *et al.* [Pierre Auger Coll.],

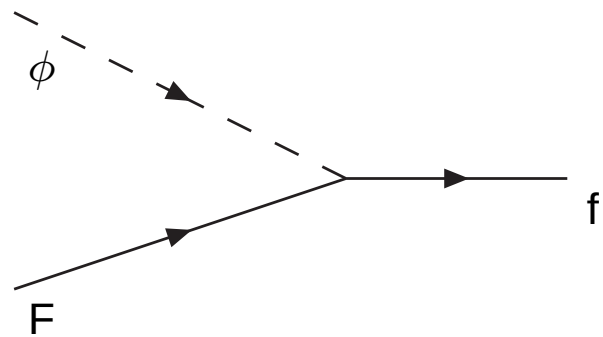
Upper limit on the diffuse flux of UHE tau neutrinos from the Pierre Auger Observatory,

Phys. Rev. Lett. **100** (2008) 211101

Flux computed by K. Mannheim, R. J. Protheroe and J. P. Rachen **MPR**,

Phys. Rev. D **63** (2001) 023003

A possible interaction model



$g_{\nu\phi} P_R$

$$\mathcal{L} = g_{\nu\phi}\, \bar{\nu}\, \phi\, P_R F + H.c.\,,$$

where $g_{\nu\phi}$ is the ν-DM coupling constant, P_R is a chiral projector $(1+\gamma^5)/2$ and F represents a NEW fermion.

D. Hooper *et al.* Phys. Rev. Lett. **93** (2004) 161302

C. Boehm *et al.* Phys. Rev. Lett. **92** (2004) 101301

C. Boehm and P. Fayet, Nucl. Phys. B **683** (2004) 219

The cross section

Self-conjugated ($\phi = \phi^*$)

$$\begin{aligned}
\frac{d\sigma}{d\Omega} &= \frac{g_{\nu\phi}^4}{32\pi^2}\Big[\frac{m_\nu^2}{4}\left(\frac{1-\cos\theta}{(s-M_I^2)^2}+\frac{1-\cos\theta}{(u-M_I^2)^2}\right) \\
&+ \left(\frac{1}{s-M_I^2}-\frac{1}{u-M_I^2}\right)^2\left(\frac{s}{4}(1+\cos\theta)-\frac{m_\phi^2}{4}(1-\cos\theta)\right) \\
&+ \left(\frac{1}{s-M_I^2}-\frac{1}{u-M_I^2}\right)m_\nu^2\left(\frac{1+\cos\theta}{2(s-M_I^2)}+\frac{1}{u-M_I^2}\right) \\
&+ \frac{2m_\nu^4}{s(u-M_I^2)(s-M_I^2)}\Big]\,.
\end{aligned}$$

$\frac{d\sigma}{d\Omega}$ is valid in the limit $m_\nu^2 << s$. If $m_\nu \sim 1$eV and $E_\nu \sim 10^{18}$ eV, the cross section is valid for $m_\phi >> \mathcal{O}\left(10^{-18}\right)$ eV.
Furthermore, in the limit $s, u \ll M_I$ and integrating over solid angle

$$\sigma \simeq \left(\frac{g_{\nu\phi}}{M_I}\right)^4 \frac{m_\nu^2}{16\pi}\,.$$

Mean free path

Self-conjugated ($\phi = \phi^*$)

$$\begin{aligned}\lambda &= 16\pi \times 10^{-6} \left(\frac{M_I/g_{\nu\phi}}{\mathrm{GeV}}\right)^4 \left(\frac{\mathrm{eV}}{m_\nu}\right)^2 \left(\frac{\mathrm{GeV/cm^3}}{\rho_\phi}\right) \left(\frac{m_\phi}{10^{-15}\mathrm{eV}}\right) \mathrm{GeV^2 cm^3} \\ &\simeq L_0 \left(\frac{M_I/g_{\nu\phi}}{\mathrm{GeV}}\right)^4 \left(\frac{\mathrm{eV}}{m_\nu}\right)^2 \left(\frac{\mathrm{GeV/cm^3}}{\rho_\phi}\right) \left(\frac{m_\phi}{10^{-18}\mathrm{eV}}\right) ,\end{aligned}$$

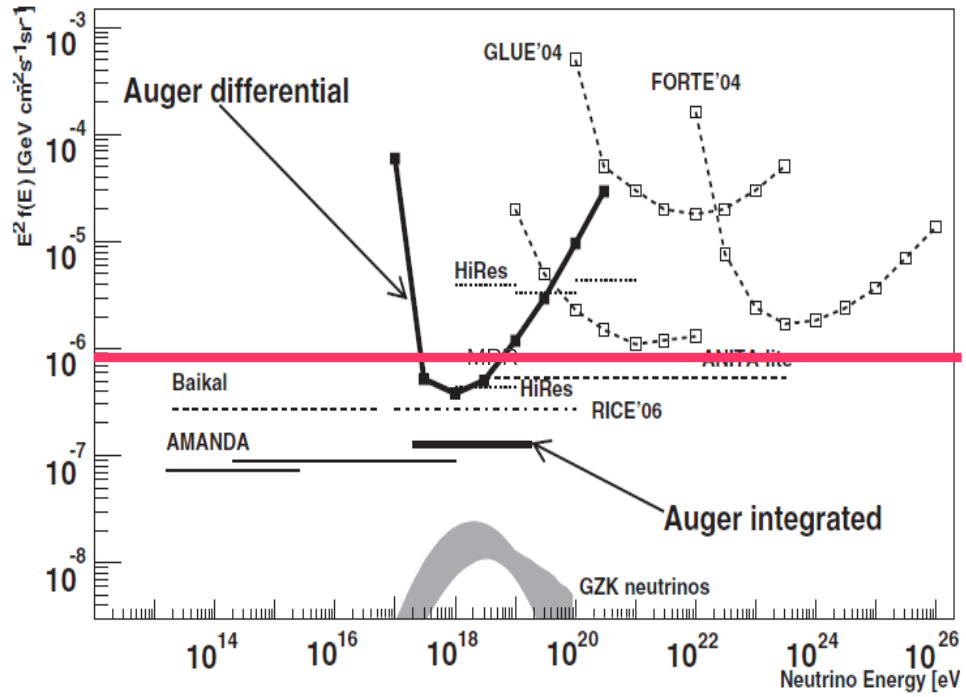
where $L_0 \simeq 42$ pc.

Possible suppression

- F_0 is the MPR's flux
- The flux measured at Earth:

$$F(L) = F_0 e^{-L/\lambda^{mfp}} ,$$

- $\lambda^{mfp}(\phi = \phi^*)$



Possible suppression

$$\frac{g_{\nu\phi}}{M_I} \gtrsim \left[\ln\left(\frac{F_0}{F}\right)\frac{L_0 m_\phi}{\rho_\phi m_\nu^2 L}\right]^{\frac{1}{4}} .$$

$L = 5 \times 10^2$ Mpc, $m_\nu \sim 1$ eV and $\rho_{\rm DM} = 1{,}2 \times 10^{-6}$ GeV/cm^3

J. Barranco, O. G. Miranda, C. A. Moura, T. I. Rashba, F. Rossi-Torres

Confusing extragalactic neutrino flux limit at the source with absorption by ultra-light scalar field dark matter,

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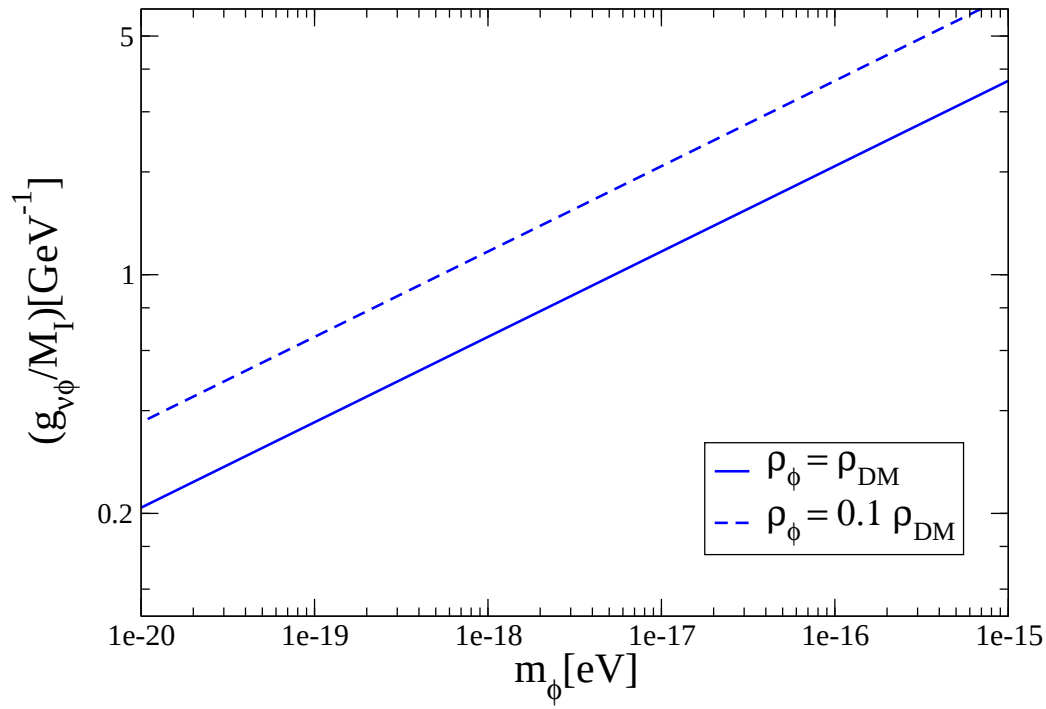
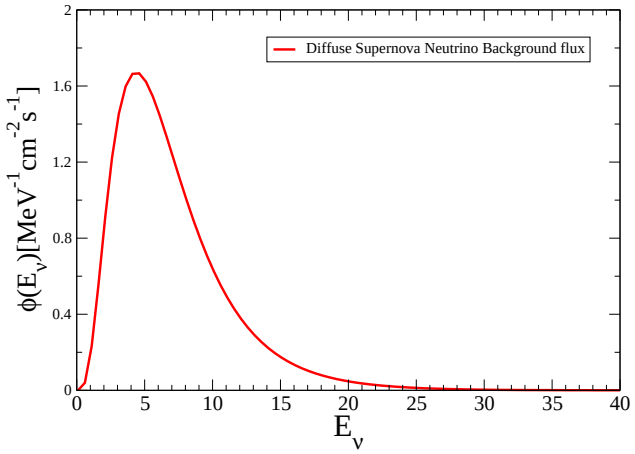
arXiv:1012.2476 [astro-ph.CO].



Diffuse supernova neutrino background

- The Diffuse Supernova Neutrino Background (DSNB) is the flux of neutrinos and antineutrinos emitted by all core-collapse supernovae in the causally-reachable universe
- It will appear isotropic
- Time-independent
- Its energy density is ~ 10 times less than that of the cosmic micro-wave background

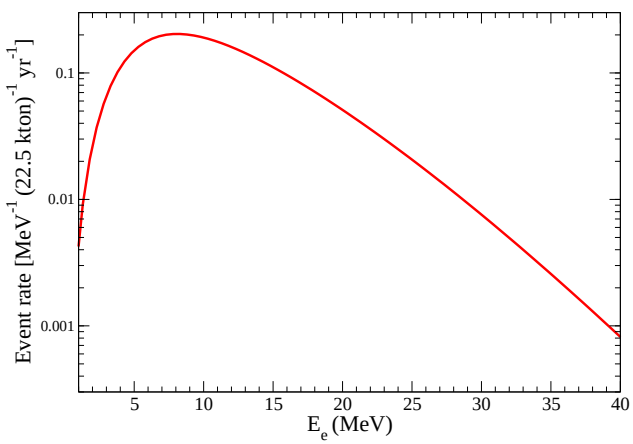
- $N(E_z)$ is the $\bar{\nu}_e$ spectrum of an individual SN,
- $R_{\rm SN}(z)$ the cosmic SN rate at redshift z,



$$\frac{d\phi_{\bar{\nu}}^{DSNB}}{dE} = \frac{1}{H_0}\int_0^{zmax} \frac{dN(E_z)}{dE_z} R_{SN}(z) \frac{dz}{\sqrt{(z+1)^3\Omega_M + \Omega_\Lambda}}$$

DSNB

The best prospects for DSNB detection are for $\bar{\nu}_e$ in SK, detected by $\bar{\nu}_e + p \rightarrow e^+ + n$, as it has both large size and low background rates.



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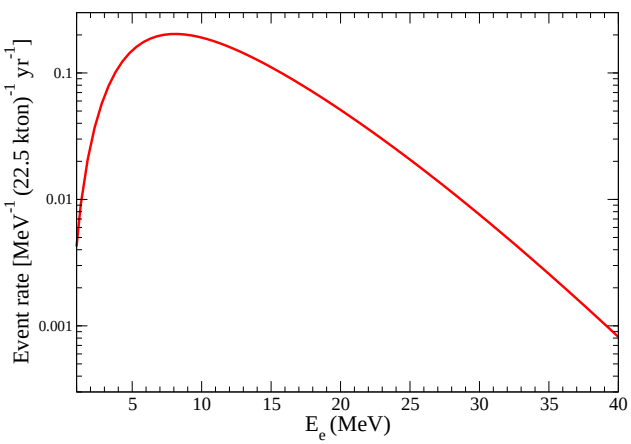
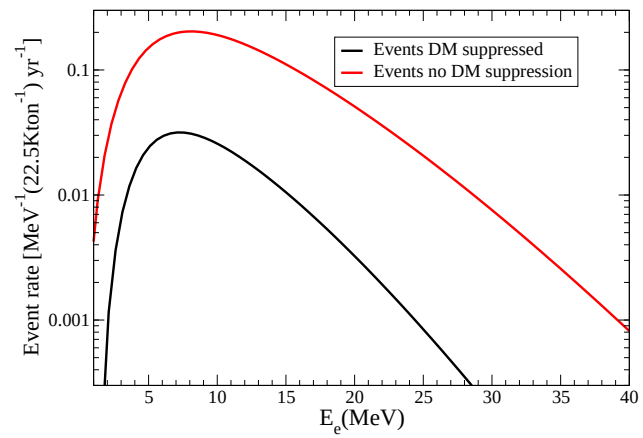


$$\frac{dN(E_z)}{dE_z} \rightarrow \frac{dN(E_z)}{dE_z} \times e^{-L/\lambda^{mfp}}$$



DSNB can be modified, and even completely suppressed!

Conclusions

- If UHE neutrinos are not detected, this could imply a possible ν-DM interaction and a way to determine properties of an extremely light boson.
- DSNB could also bring information on this type of interaction between the DM SM particles.