Diffuse supernova neutrino background and scalar dark matter

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Outline

- Diffuse supernova neutrino background (DSNB)
  - what is it?
  - First lesson: it will be hard to detect
    1. SK 22.5 Kton
    2. Coherent neutrino scattering?
- Motivation: DM and the SM
- Possible effects of ν-DM coupling
- DSNB and scalar dark matter
- Conclusions

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 microwave background

Diffuse supernova neutrino background

- Understanding supernovae is crucial to astrophysics and physics.
- We cannot understand supernovae without detecting neutrinos.
- Detecting bursts of neutrinos from nearby supernovae is difficult.
- The DSNB is a guaranteed steady source of supernova neutrinos.

How to compute it?

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

- $E_z = (1+z)\,E$ is the neutrino energy at redshift z,
- $N(E_z)$ is the $\bar{\nu}_e$ spectrum of an individual SN,
- $R_{\rm SN}(z)$ the cosmic SN rate at redshift z,
- H_0 the Hubble constant, $\Omega_{\rm M}$ and Ω_Λ, with values extracted from cosmology.

Diffuse supernova neutrino background

To be specific we parametrize the cosmic SN rate in the form

$$\begin{aligned} R_{\mathrm{SN}}(z) &= 4{,}1 \times 10^{-3}\,\mathrm{yr}^{-1}\ \mathrm{Mpc}^{-3}\, f_{\mathrm{SN}}\, h_{73} \\ &\times \frac{e^{3{,}4z}}{e^{3{,}8z}+45}\left[\Omega_{\mathrm{M}} + \frac{\Omega_{\Lambda}}{(z+1)^3}\right]^{1/2} \end{aligned}$$

where f_{SN} is a normalization factor of order of unity and h_{73} is H_0 in units of $73\,$km s^{-1} Mpc^{-1}.

Diffuse supernova neutrino background

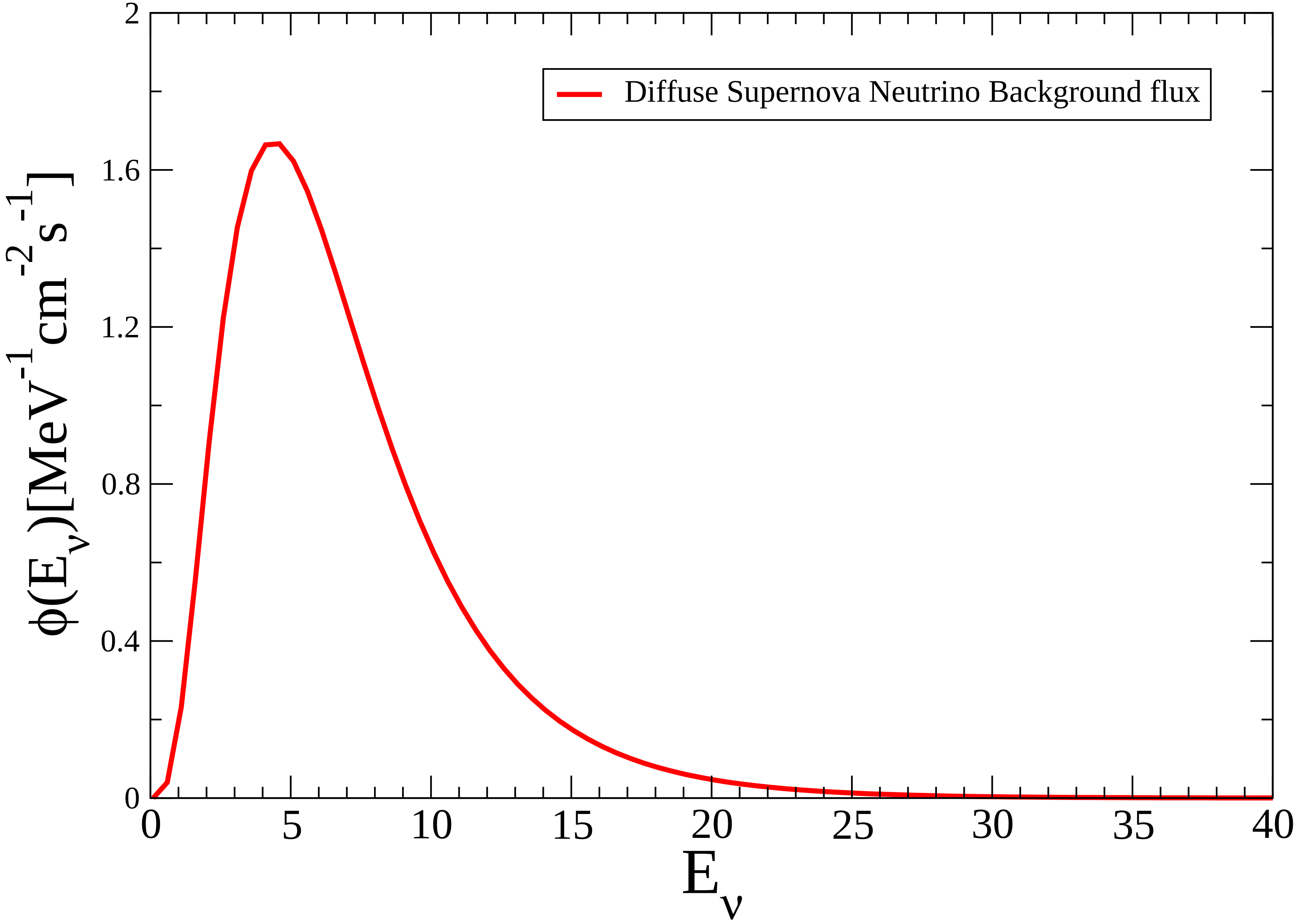
The average $\bar{\nu}_e$ spectrum emitted by a SN is expressed in the quasi-thermal form

$$\frac{dN(E)}{dE} = \frac{(1+\alpha)^{1+\alpha} E_{\rm tot}}{\Gamma(1+\alpha)\bar{E}^2} \left(\frac{E}{\bar{E}}\right)^{\alpha} e^{-(1+\alpha)E/\bar{E}} ,$$

- $\bar{E} = 15$ MeV for the average energy,
- $\alpha = 4$ for the pinching parameter
- $E_{\rm tot} = 5 \times 10^{52}$ erg for the
- The flavor-dependent is small

$H_0 = 73\,$km s^{-1} Mpc^{-1} the Hubble constant. $\Omega_{\rm M} = 0{,}27$ and $\Omega_{\Lambda} = 0{,}73$ are the matter and dark energy density, respectively

DSNB



Diffuse Supernova Neutrino Background flux
$\phi(E_\nu)[\mathrm{MeV}^{-1}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$
E_ν
0
0.4
0.8
1.2
1.6
2
0
5
10
15
20
25
30
35
40

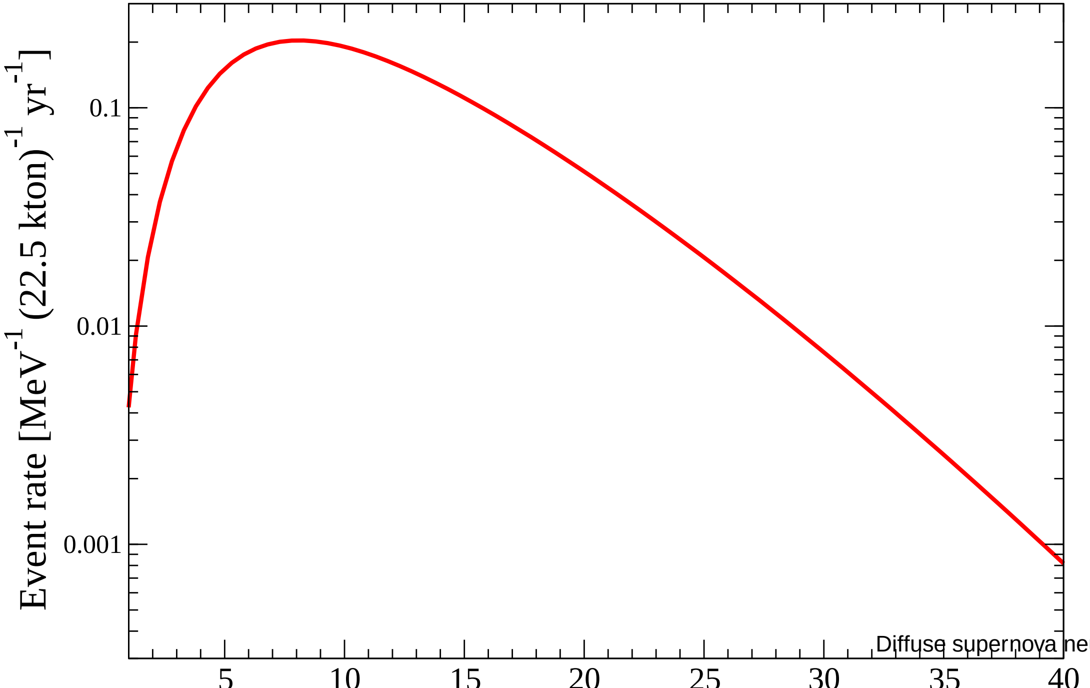
DSNB

The best prospects are for $\bar{\nu}_e$ in SK, detected by $\bar{\nu}_e + p \to e^+ + n$, as it has both large size and low background rates The total cross section for inverse beta decay is

$$\sigma(E_\nu) = \left[0{,}0952 \times 10^{-42}\ \mathrm{cm}^2\ (E_\nu - 1{,}3\ \mathrm{MeV})^2\right]\ (1 - 7E_\nu/M_p)\,,$$

above threshold, $E_\nu > 1{,}8$ MeV.

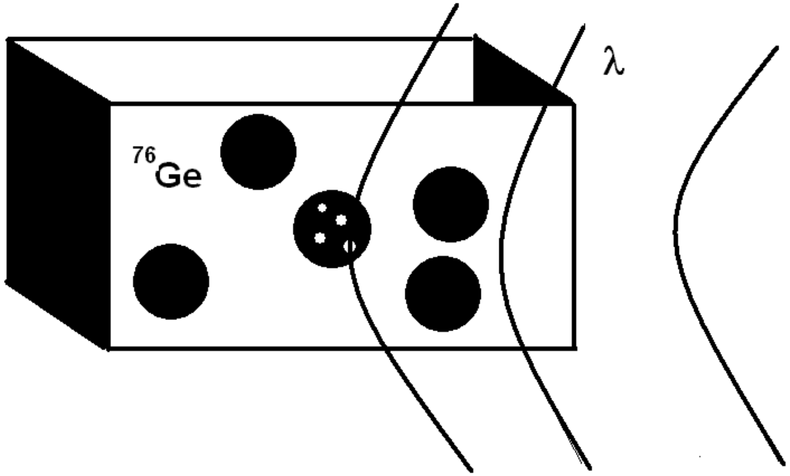
$$\frac{dN}{dE_e} = N_p \int dE_\nu \frac{d\phi}{dE_\nu}\frac{d\sigma}{dE_e}\,,$$



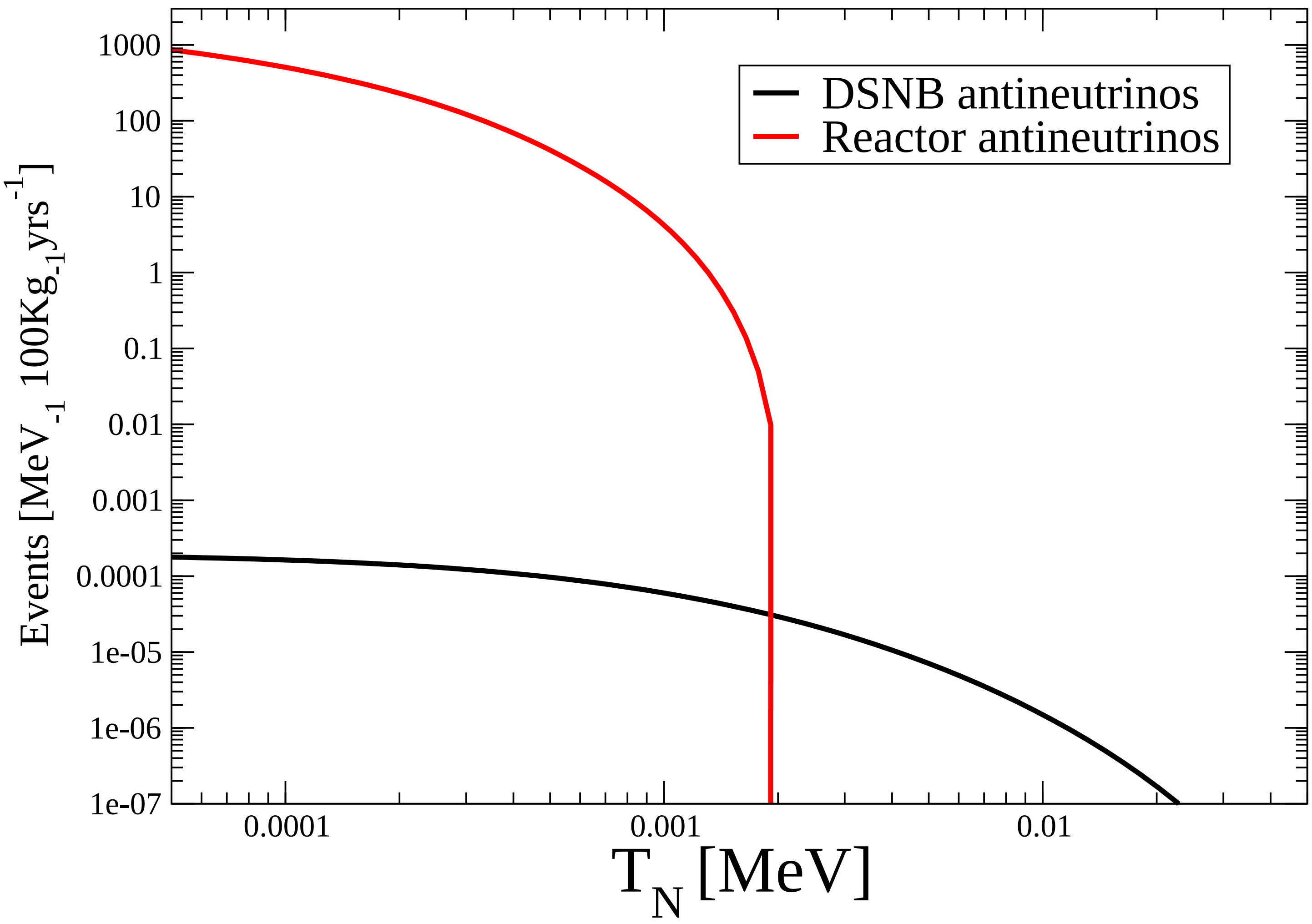
First lesson: it will be hard to detect

Coherent neutrino-nucleus scattering:

- If the momentum transfer is low, $qR < 1$ (R the núcleus radius): ν “sees” the nucleus as a point.
- For most of the nuclei: $1/R \sim 25 - 150$MeV
- It is fulfilled by most ν’s sources.
- TEXONO, NOSTOS are planning to observe it for the first time.
- Experimnetal difficulty: Very low threshold!!!

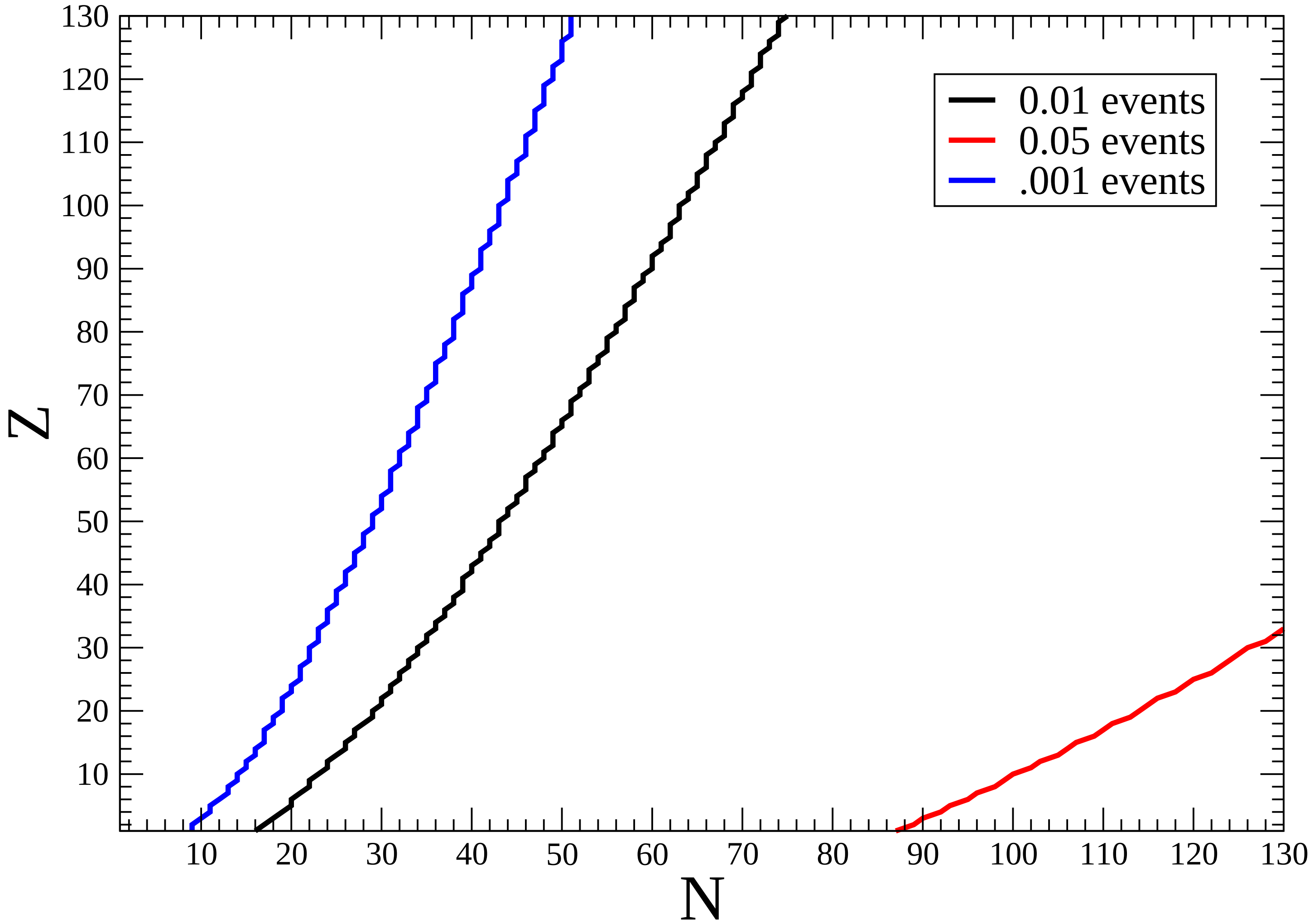


First lesson: it will be hard to detect



Germanium detector.

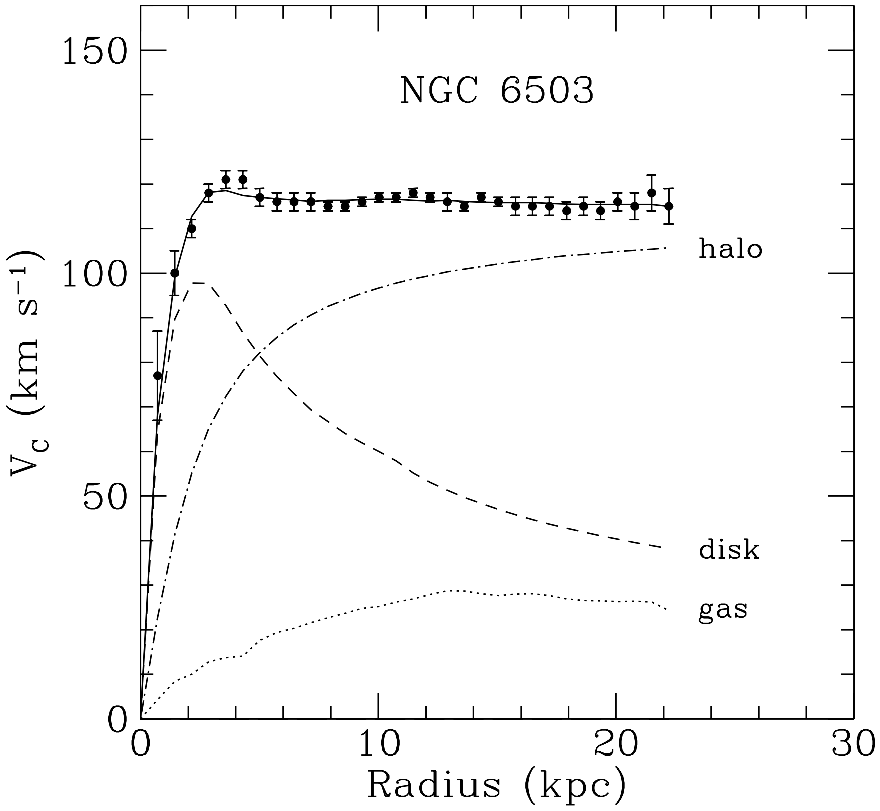
First lesson: it will be hard to detect



100 kg detector, 1 year.

Dark matter as a motivation

The most convincing and direct evidence for dark matter on galactic scales comes from the observations of the *rotation curves* of galaxies, namely the graph of circular velocities of stars and gas as a function of their distance from the galactic center.



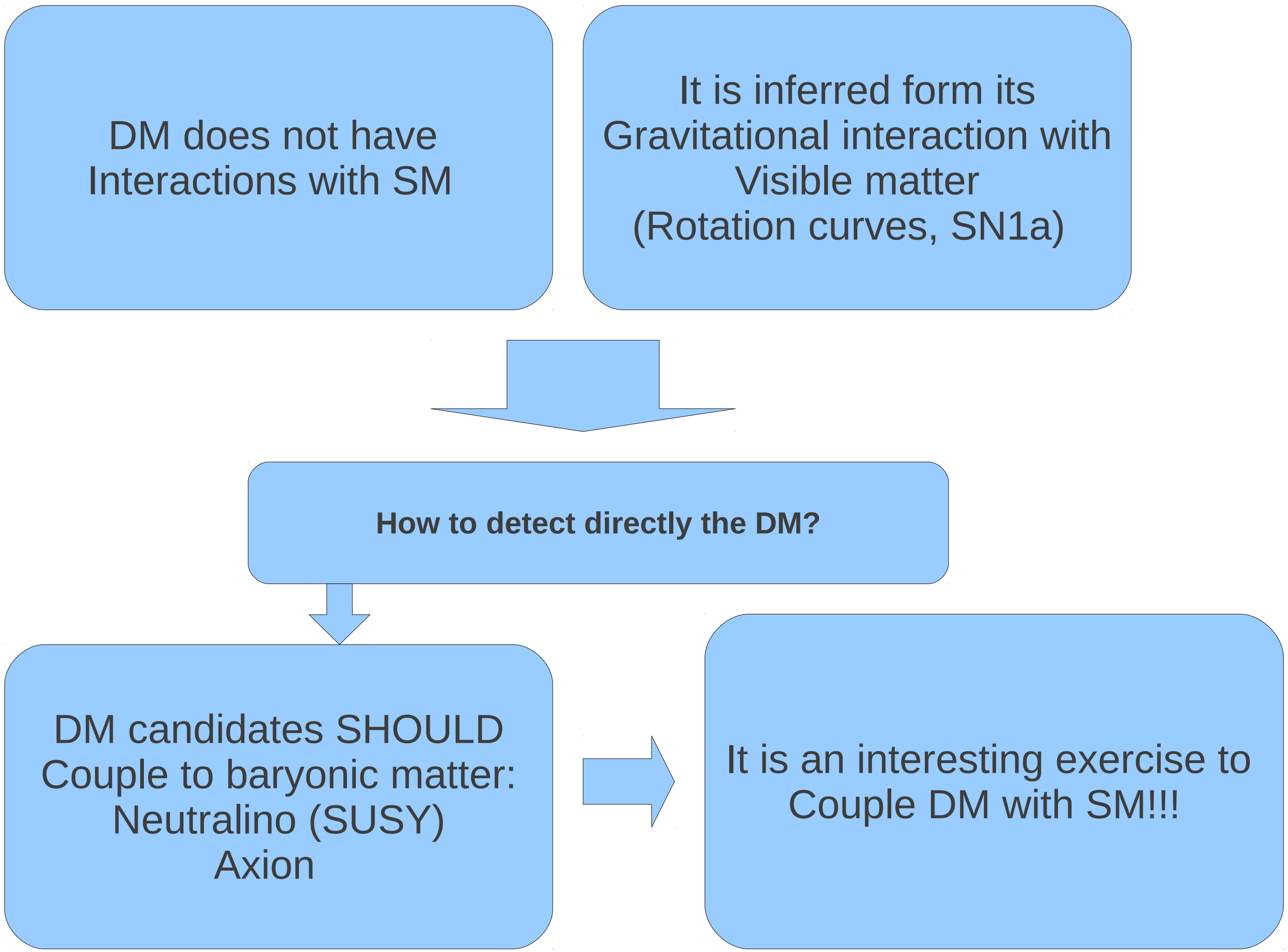
Dark matter as a motivation

- At galactic scales
  - *Weak modulation of strong lensing* around individual massive elliptical galaxies. This provides evidence for substructure on scales of $\sim 10^6 \mathrm{M}_\odot$
  - *Weak gravitational lensing* of distant galaxies by foreground structure
  - The *velocity dispersions of dwarf spheroidal galaxies* which imply mass–to–light ratios larger than those observed in our “local” neighborhood.
  - The *velocity dispersions of spiral galaxy satellites* which suggest the existence of dark halos around spiral galaxies, similar to our own, extending at galactocentric radii $\gtrsim 200$ kpc, i.e. well behind the optical disc. This applies in particular to the Milky Way, where both dwarf galaxy satellites and globular clusters probe the outer rotation curve.

Dark matter as a motivation

- At cosmological scales
  Starting from a cosmological model with a fixed number of parameters, the best-fit parameters are determined from the peak of the N-dimensional likelihood surface. From the analysis of the WMAP data alone:
  $\Omega_b h^2 = 0{,}024 \pm 0{,}001 \quad , \Omega_M h^2 = 0{,}14 \pm 0{,}02.$
  Including astronomical measurements of the power spectrum from large scale structure (2dFGRS) and the Lyman α forest:
  $\Omega_b h^2 = 0{,}0224 \pm 0{,}0009 \quad \Omega_M h^2 = 0{,}135^{+0{,}008}_{-0{,}009}.$

Materia oscura



DM does not have Interactions with SM

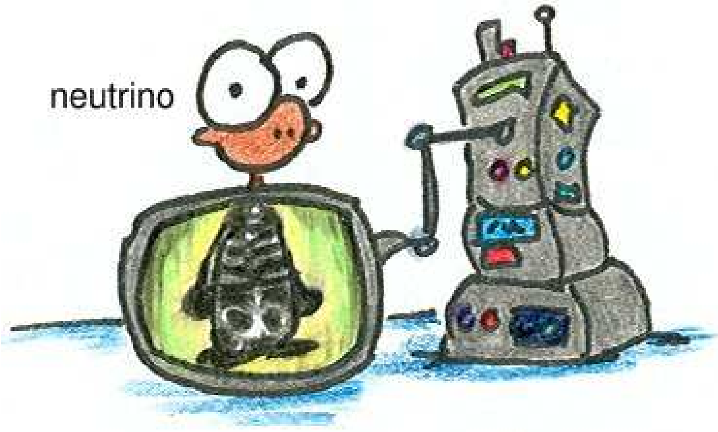
It is inferred form its Gravitational interaction with Visible matter (Rotation curves, SN1a)

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!!!

Remind neutrino characteristics



- Neutral particle
- Fermion
- Negative helicity
- Three flavors:

  ν_e, ν_μ, ν_τ.
- Mass:

$$|\nu_\alpha\rangle = \sum_a U^*_{\alpha a} |\nu_a\rangle$$

$$7{,}1 \times 10^{-5} (eV)^2 \leq \Delta^2 m_{12} \leq 8{,}9 \times 10^{-5} (eV)^2,$$

$$0{,}24 \leq sin^2\theta_{12} \leq 0{,}40,$$

$$1{,}4 \times 10^{-3} (eV)^2 \leq \Delta^2 m_{13} \leq 3{,}3 \times 10^{-3} (eV)^2,$$

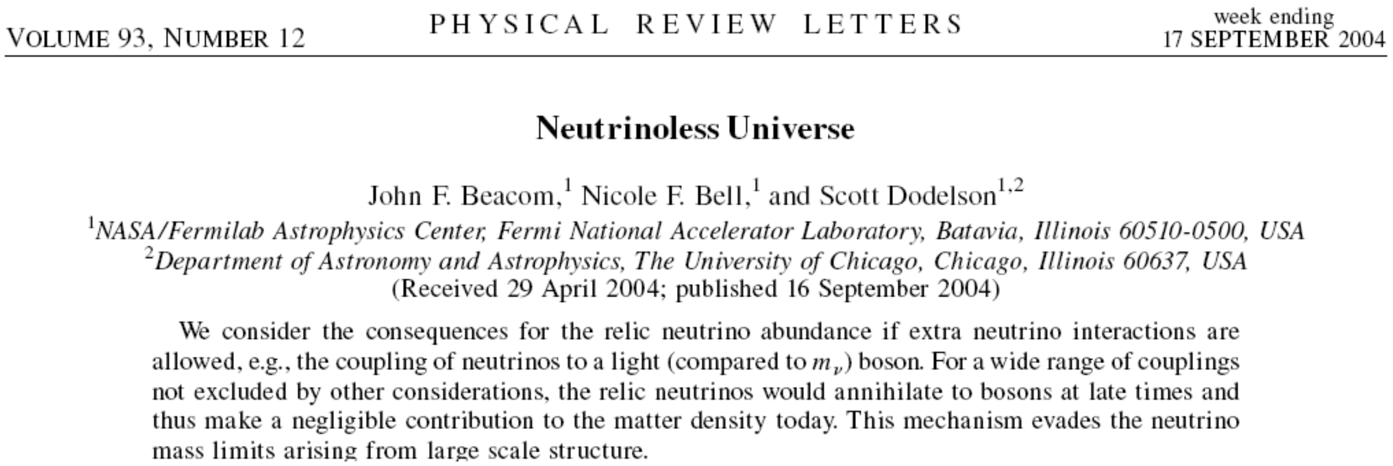
$$0{,}34 \leq sin^2\theta_{23} \leq 0{,}68,$$

- Magetic moment $\mu_\nu < 10^{-12} \mu_B$

ν-DM interaction

- To couple neutrinos to DM!
- In particular add an interaction with a scalar field ϕ

ν-DM interaction



VOLUME 93, NUMBER 12 PHYSICAL REVIEW LETTERS week ending 17 SEPTEMBER 2004

Neutrinoless Universe

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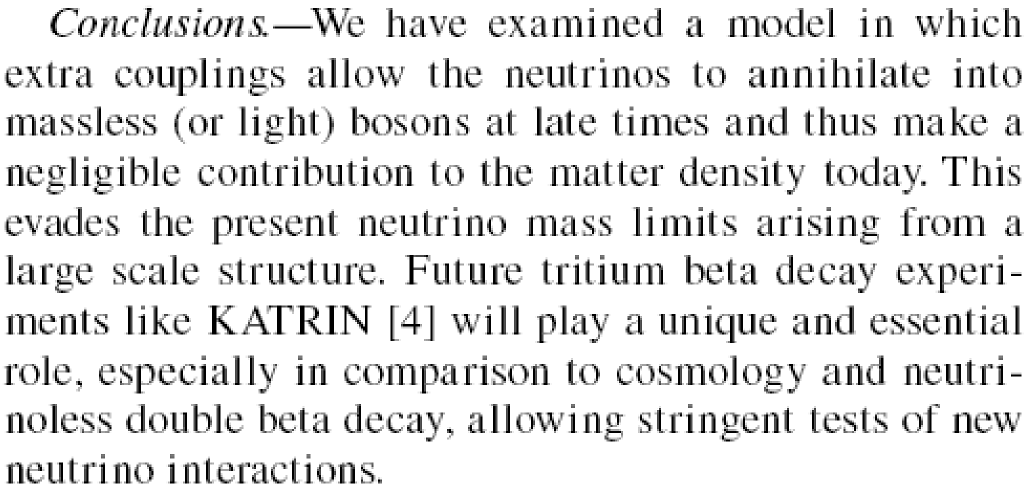
We consider the consequences for the relic neutrino abundance if extra neutrino interactions are allowed, e.g., the coupling of neutrinos to a light (compared to m_ν) boson. For a wide range of couplings not excluded by other considerations, the relic neutrinos would annihilate to bosons at late times and thus make a negligible contribution to the matter density today. This mechanism evades the neutrino mass limits arising from large scale structure.

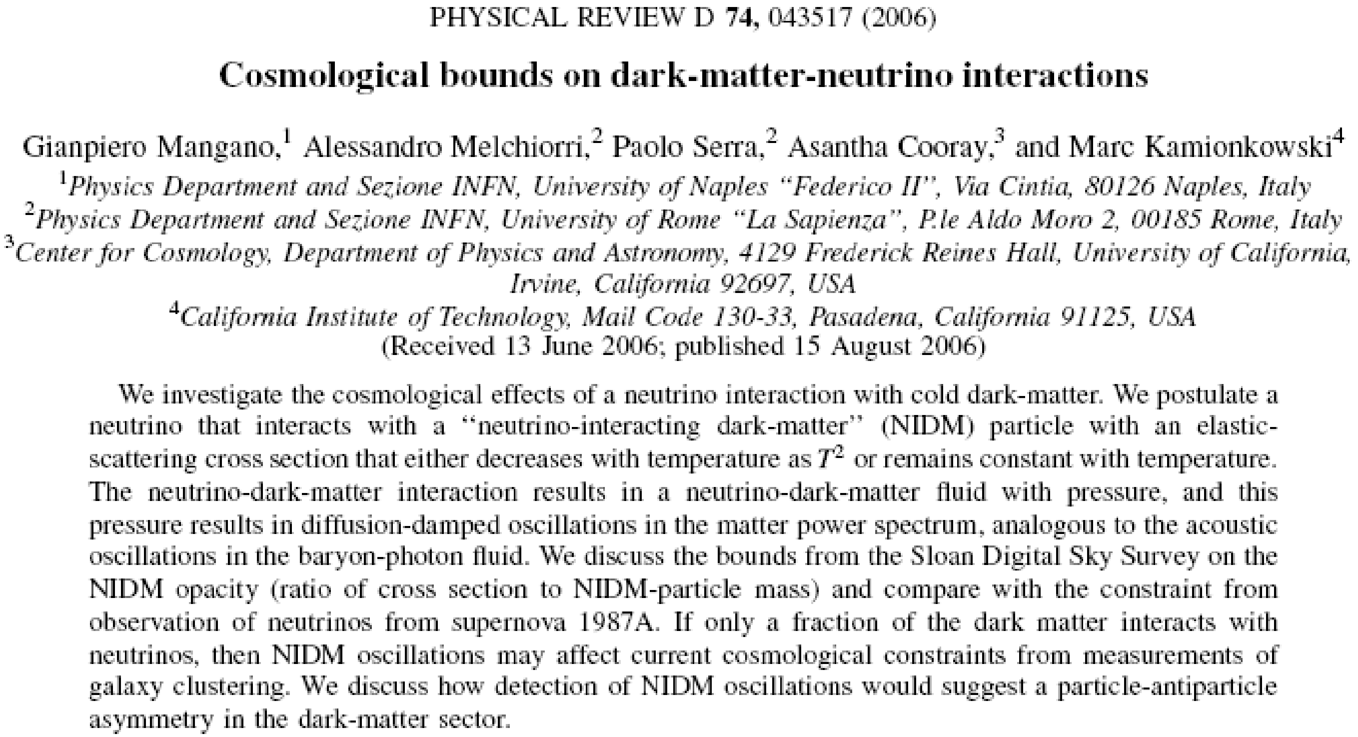
$$\mathcal{L} = h_{ij}\overline{\nu}_i \nu_j \phi + g_{ij}\overline{\nu}_i \gamma_5 \nu_j \phi + \text{H.c.},$$

$$\Gamma(T) = \frac{g^4}{64\pi} \frac{T}{m_\nu^3} \left(\frac{m_\nu T}{2\pi}\right)^{3/2} e^{-m_\nu/T}$$



Conclusions.—We have examined a model in which extra couplings allow the neutrinos to annihilate into massless (or light) bosons at late times and thus make a negligible contribution to the matter density today. This evades the present neutrino mass limits arising from a large scale structure. Future tritium beta decay experiments like KATRIN [4] will play a unique and essential role, especially in comparison to cosmology and neutrinoless double beta decay, allowing stringent tests of new neutrino interactions.

ν-DM interaction



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Cosmological bounds on dark-matter-neutrino interactions

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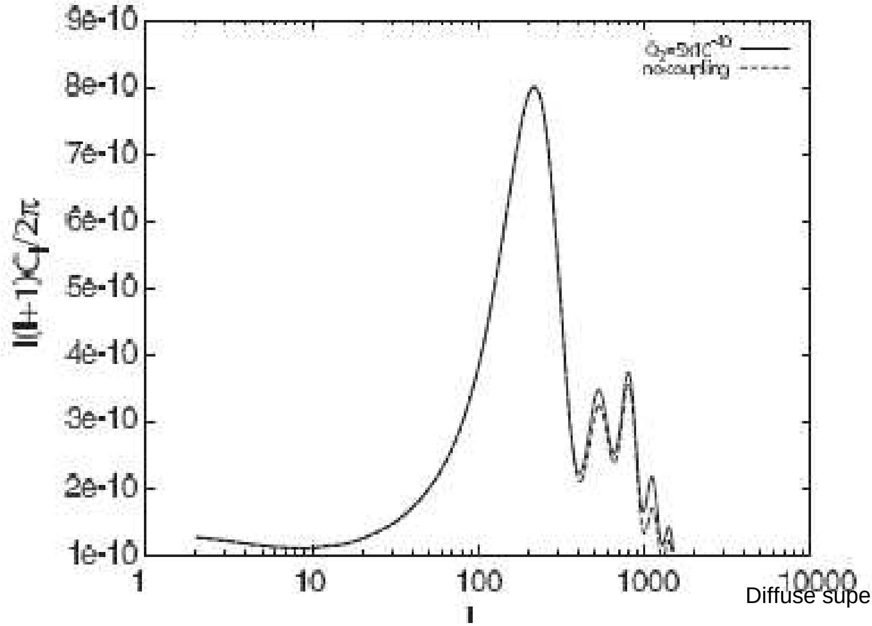
We investigate the cosmological effects of a neutrino interaction with cold dark-matter. We postulate a neutrino that interacts with a "neutrino-interacting dark-matter" (NIDM) particle with an elastic-scattering cross section that either decreases with temperature as T^2 or remains constant with temperature. The neutrino-dark-matter interaction results in a neutrino-dark-matter fluid with pressure, and this pressure results in diffusion-damped oscillations in the matter power spectrum, analogous to the acoustic oscillations in the baryon-photon fluid. We discuss the bounds from the Sloan Digital Sky Survey on the NIDM opacity (ratio of cross section to NIDM-particle mass) and compare with the constraint from observation of neutrinos from supernova 1987A. If only a fraction of the dark matter interacts with neutrinos, then NIDM oscillations may affect current cosmological constraints from measurements of galaxy clustering. We discuss how detection of NIDM oscillations would suggest a particle-antiparticle asymmetry in the dark-matter sector.



UHE ν's suppression

ν-DM could induce a suppression in the UHE ν's flux if the mass of ϕ is extremely low!

UHE ν's suppression

ν-DM could induce a suppression in the UHE ν's flux if the mass of ϕ is extremely low!

Celio Moura's talk next Monday

Possible suppression

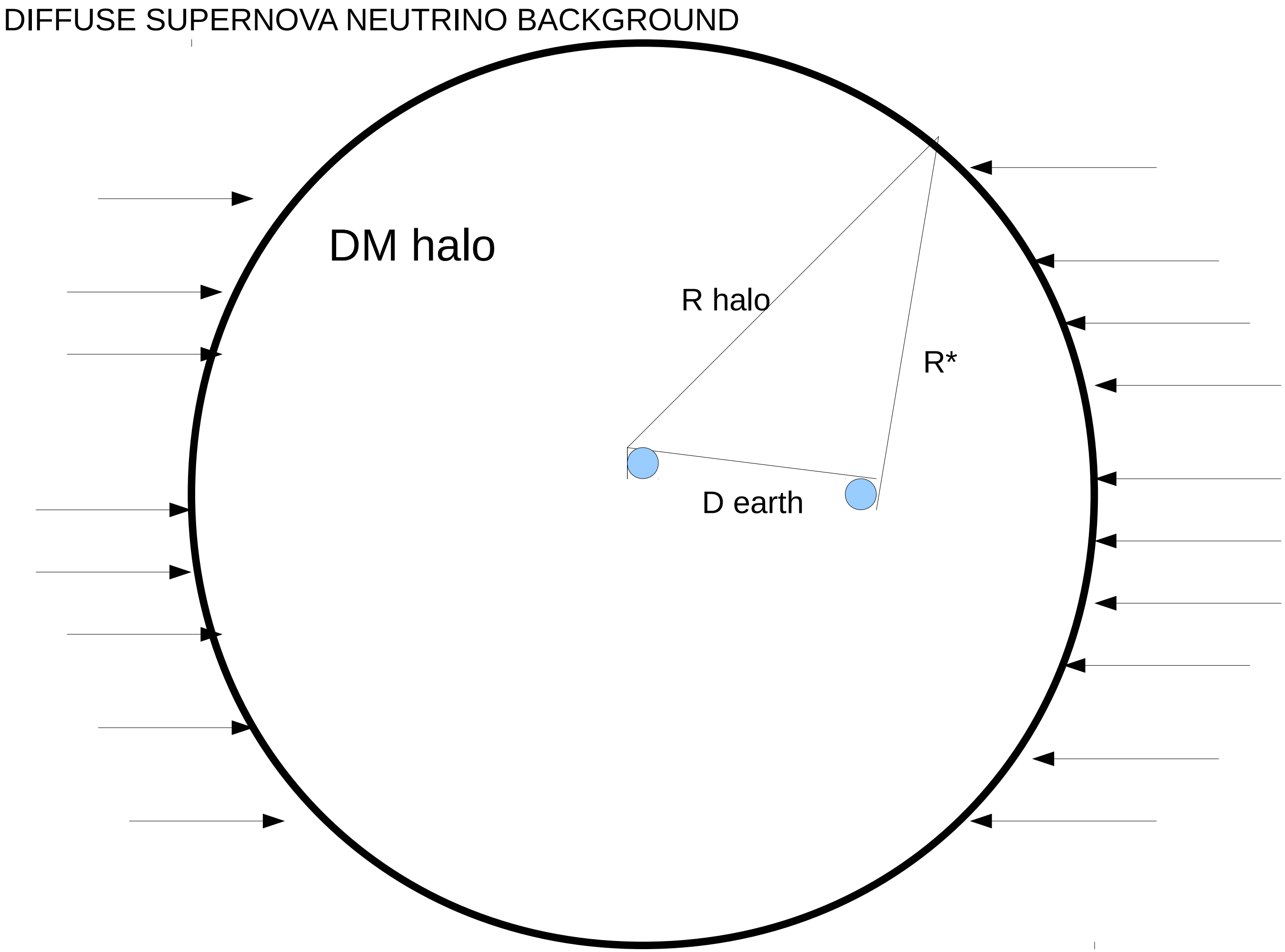
- The mean free path:

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

- There is a suppression in the flux:

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

Possible suppression



DIFFUSE SUPERNOVA NEUTRINO BACKGROUND

DM halo

R halo

R*

D earth

Possible suppression

$$R^*(\alpha) = r_\odot \cos\alpha + \sqrt{r_{halo}^2 - r_\odot^2 \sin^2\alpha}\,,$$

Now we can compute the DSNB neutrino flux

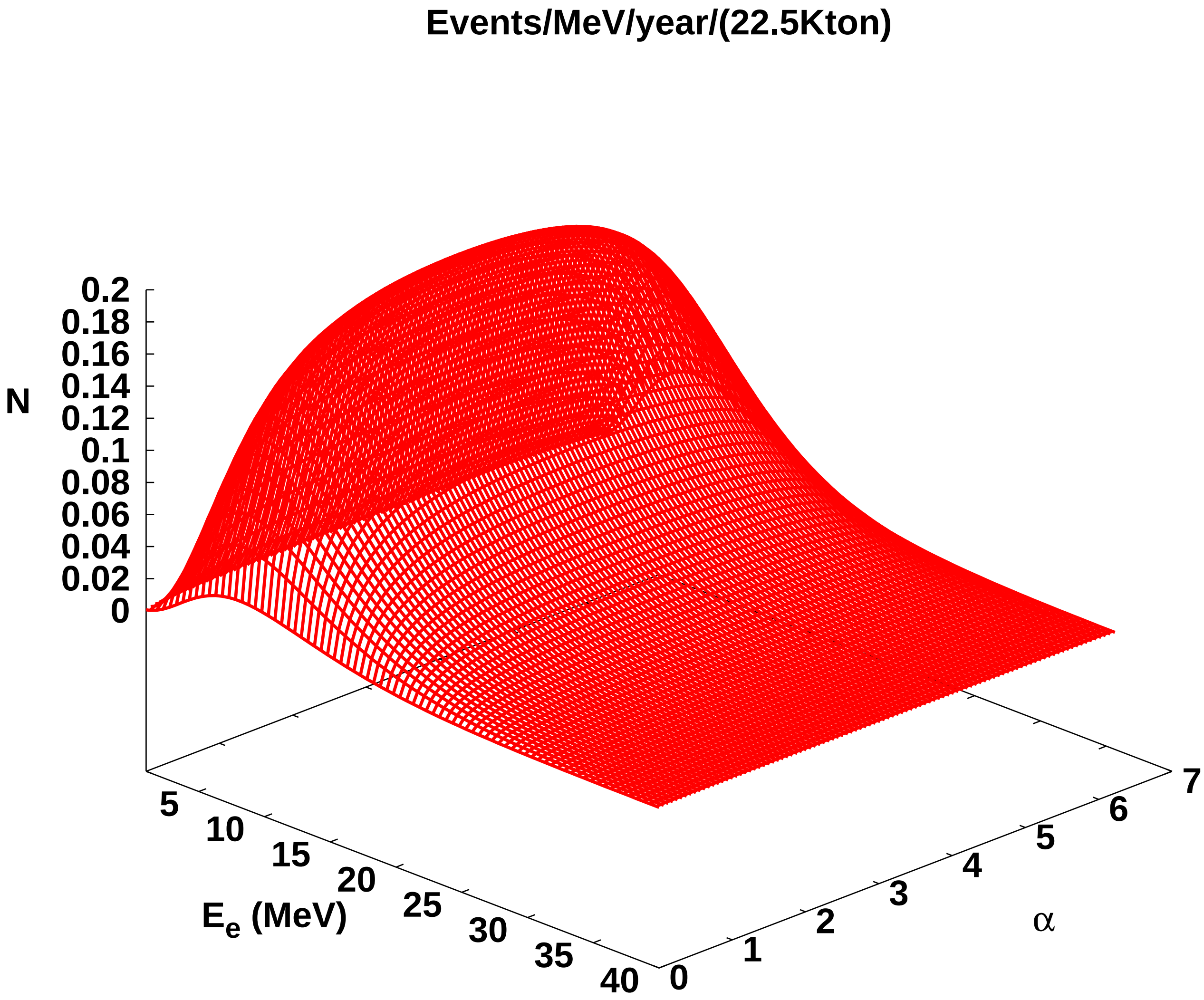
$$\phi(E_\nu, \alpha) = \frac{d\phi_{\bar\nu}^{DSNB}}{dE} \exp\left(-\lambda^{-1} \int\limits_0^{R^*(\alpha)} G_{DM}(R) dR \right) \;\; ; \quad G_{DM}(R) = f_{NFW}(R^*)\,,$$

$$f_{DM}(r) = \frac{1}{(r/a)^\gamma [1 + (r/R)^\alpha]^{(\beta-\gamma)/\alpha}}\,,$$

where the coefficients α, β, γ are

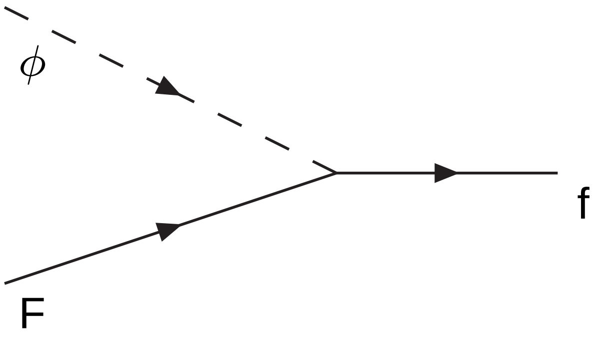
	α	β	γ	R(Kpc)
Kra	2.0	3.0	0.4	10.0
NFW	1.0	3.0	1.0	20.0
Moore	1.5	3.0	1.5	28.0
Iso	2.0	2.0	0.	3.5

Possible suppression



Typical mean free path $\lambda \sim 100$Mpc

Candidates



$g_{\nu\phi}P_R$

D. Hooper, F. Ferrer, C. Boehm, J. Silk, J. Paul, N. W. Evans and M. Casse,
MeV dark matter in dwarf spheroidals: A smoking gun?,
Phys. Rev. Lett. **93** (2004) 161302 [arXiv:astro-ph/0311150];
C. Boehm, D. Hooper, J. Silk, M. Casse and J. Paul,
MeV Dark Matter: Has It Been Detected?,
Phys. Rev. Lett. **92** (2004) 101301 [arXiv:astro-ph/0309686];
C. Boehm and P. Fayet,
Scalar dark matter candidates,
Nucl. Phys. B **683** (2004) 219 [arXiv:hep-ph/0305261];

Possible suppression?

$$\sigma \simeq \frac{g_{\nu\phi}^4}{32\pi}\frac{s}{(u-M_I^2)^2}\,,$$

and if $u << M_I^2$

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

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

where $L_0 \simeq 42$ pc.
If E_ν ~MeV then where $L_0 \simeq 4{,}2 \times 10^4$ Mpc!!!

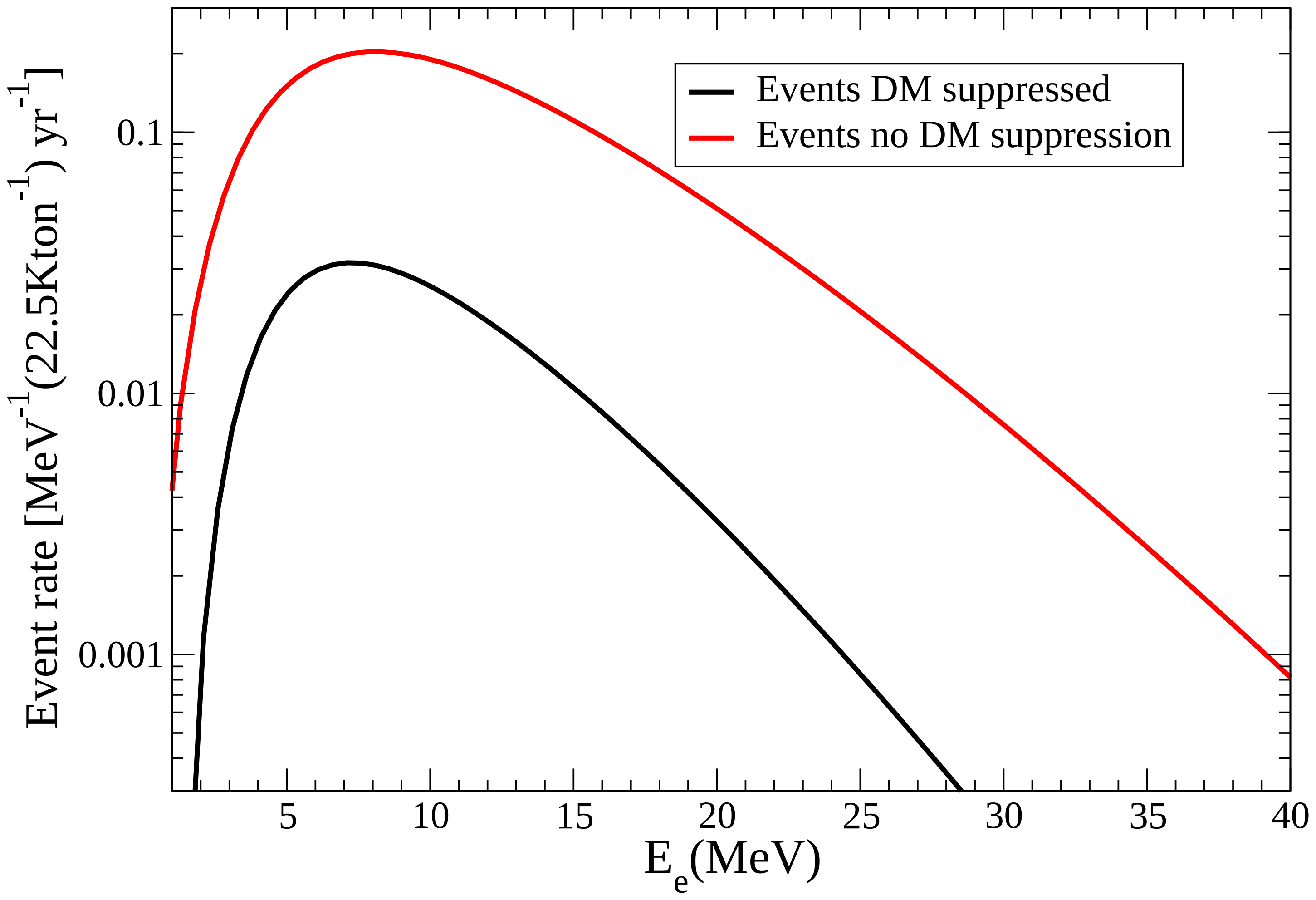
something?

$$\frac{dN(E)}{dE} = \frac{(1+\alpha)^{1+\alpha} E_{\mathrm{tot}}}{\Gamma(1+\alpha)\bar{E}^2} \left(\frac{E}{\bar{E}}\right)^{\alpha} e^{-(1+\alpha)E/\bar{E}} ,$$

Modify this flux!

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

DSNB is modified!!!!!



Conclusiones

- DSNB will bring very interesting information, but it will be difficult to observe.
- If we want to “directly” observe DM, we need to couple to SM particles
- DSNB could be modified by a new interaction of neutrinos with a scalar field dark matter candidate.