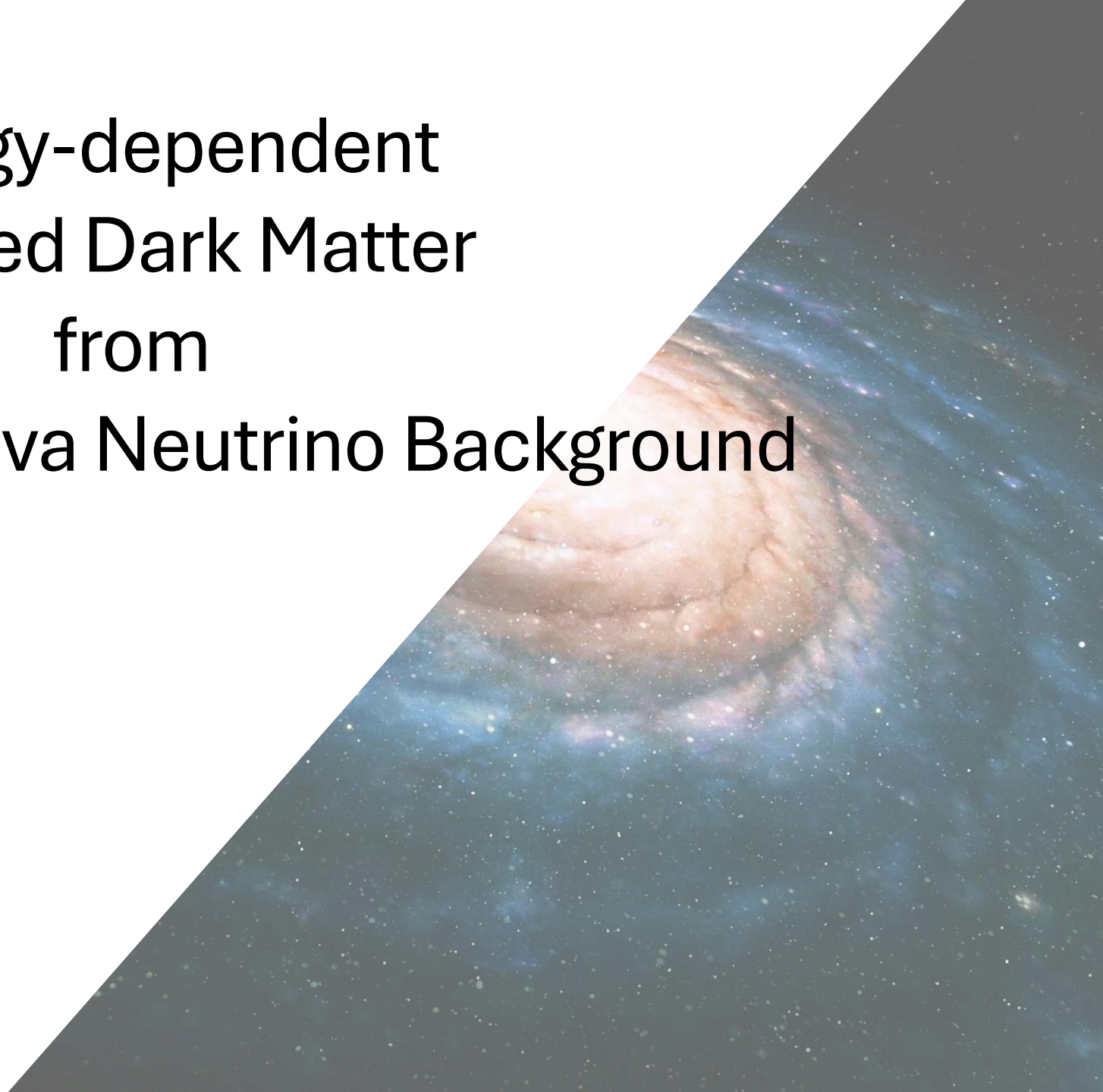
Energy-dependent Boosted Dark Matter from Diffuse Supernova Neutrino Background



Tim Herbermann

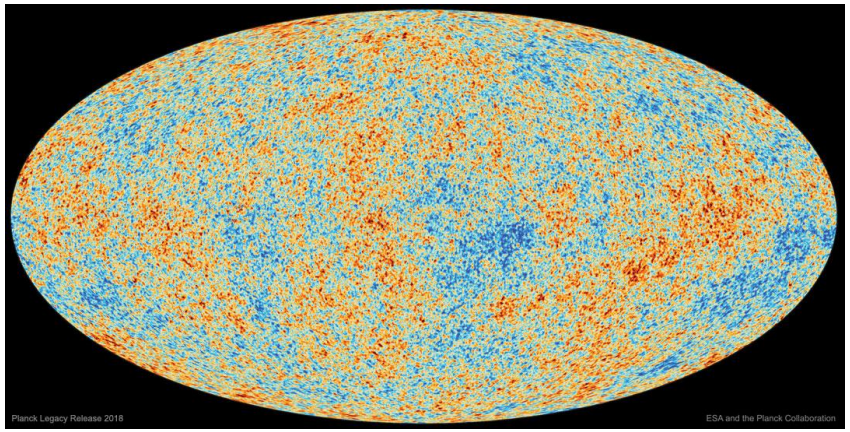
IMPRS seminar

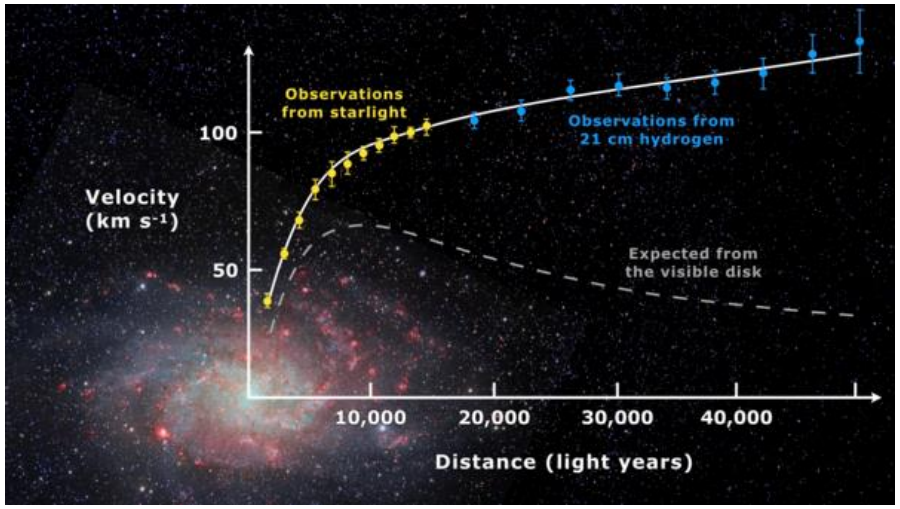
April 17th, 2024

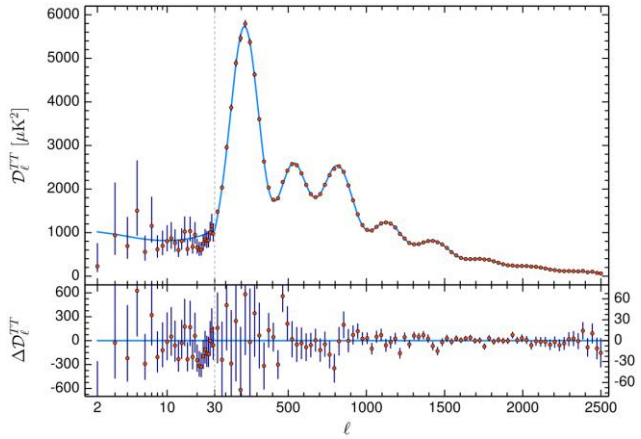
This talk

- DM and the limit of direct detection
- Boosted Dark Matter (BDM) to the rescue!
- Diffuse Supernova Neutrino Background (DSNB)
- BDM from the DSNB
- Conclusion

Dark Matter

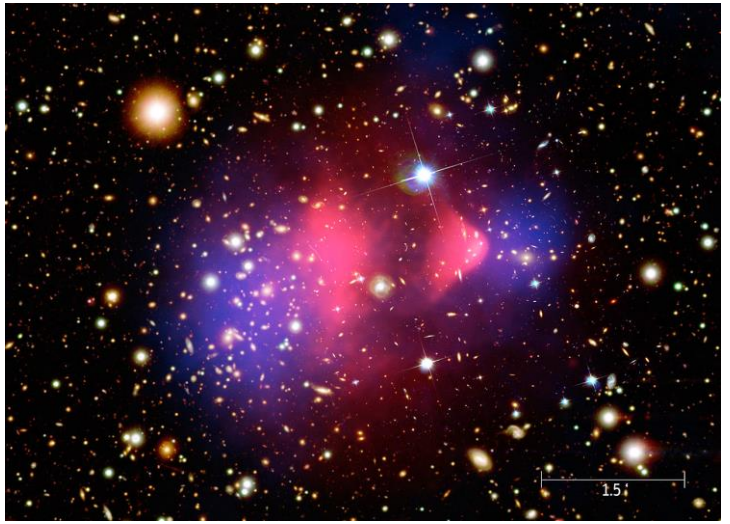






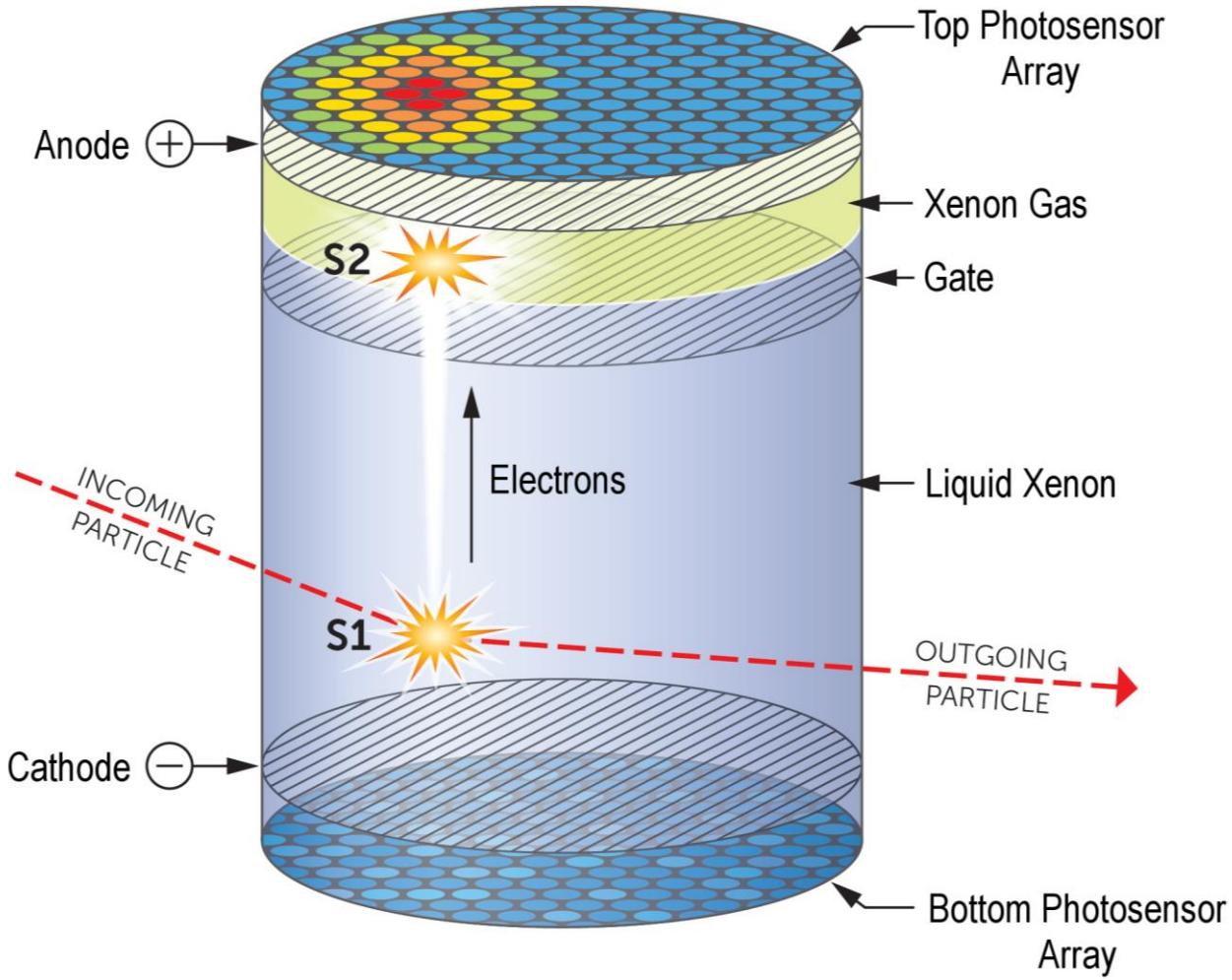
Planck2018

- Very abundant: $\Omega_{\mathrm{DM}} \sim 5 \times \Omega_b$
- Nearly collisionless
- Gravity?
- **New particle(s)?**



Direct Detection

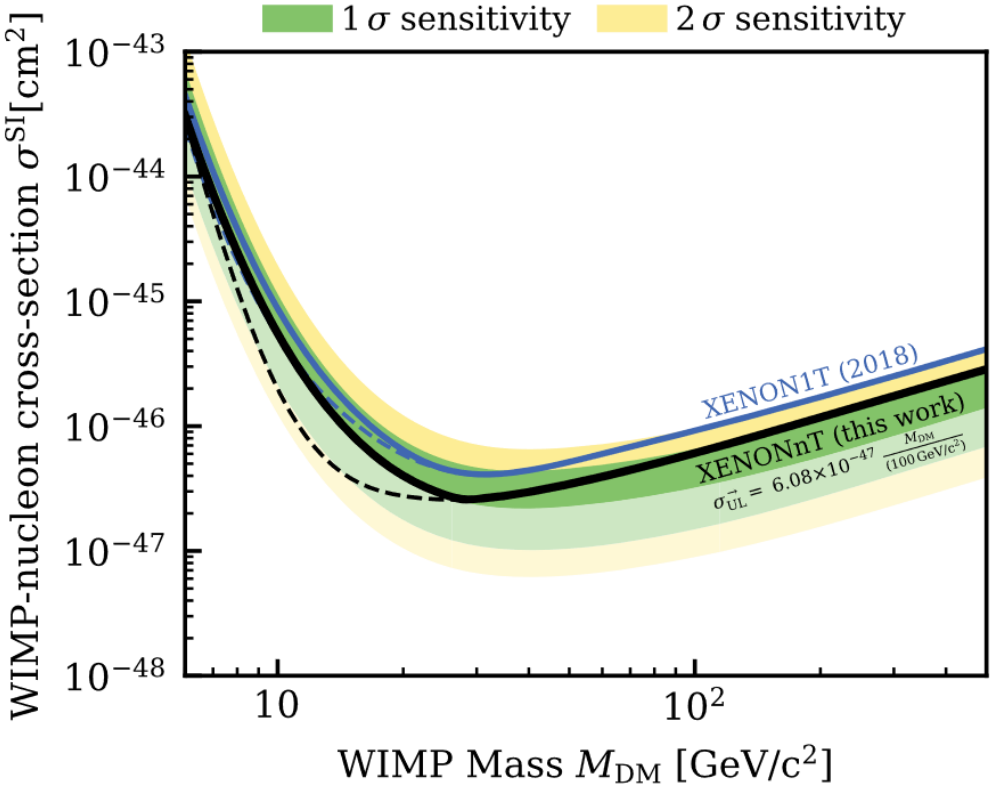
- Assuming DM is some new particle
- Virial motion $v \sim 10^{-3}c$
- Dark Matter can interact with detector material
- Ionization of atoms or nuclear recoil can be measured



https://cds.cern.ch/record/2803259/plots

Example: WIMP searches

- DM interaction induces nuclear recoil
- $E_{\mathrm{recoil}}^{\mathrm{max}} \approx \frac{2m_{\mathrm{DM}}^2 v_{\mathrm{esc}}^2}{m_{\mathrm{Xe}}}$
- Strong loss of sensitivity for small DM masses



E. Aprile *et al.* (XENON Collaboration) Phys. Rev. Lett. 131, 041003

Boosted Dark Matter to the rescue!

- Subdominant fraction of (relativistic) DM with kinetic energies

$$T_\chi \gg m_{\mathrm{DM}} v_{\mathrm{esc}}^2$$

- Flux of BDM necessarily small but we overcome $E_{\mathrm{recoil}}^{\mathrm{max}} \propto m_{\mathrm{DM}}^2$

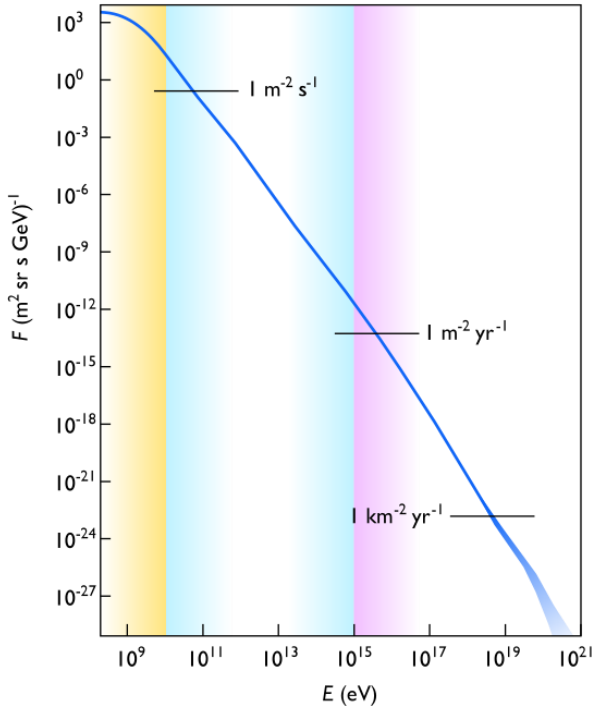
- How do we produce such a BDM component? → Energetic particles

Energetic particles are everywhere!

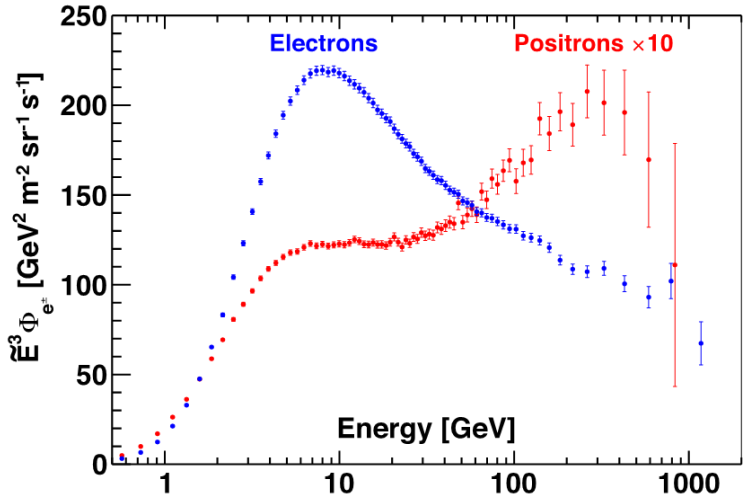
We already assume *some* interaction for detection.

Is there a suitable source of energetic particles to boost them?

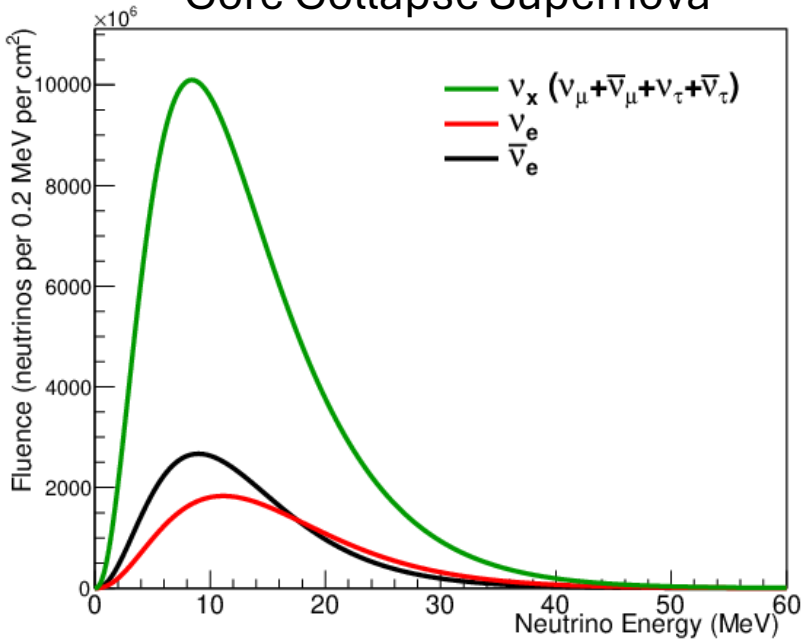
Cosmic rays



Cosmic ray electrons

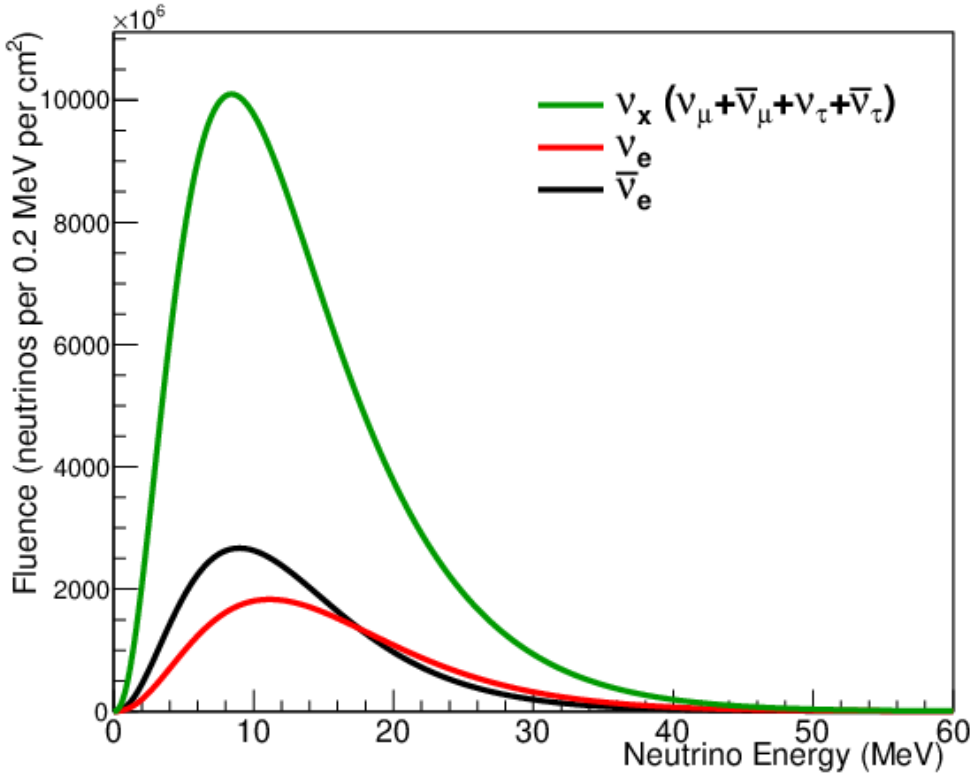


Core Collapse Supernova



Core Collapse Supernova (CCSN)

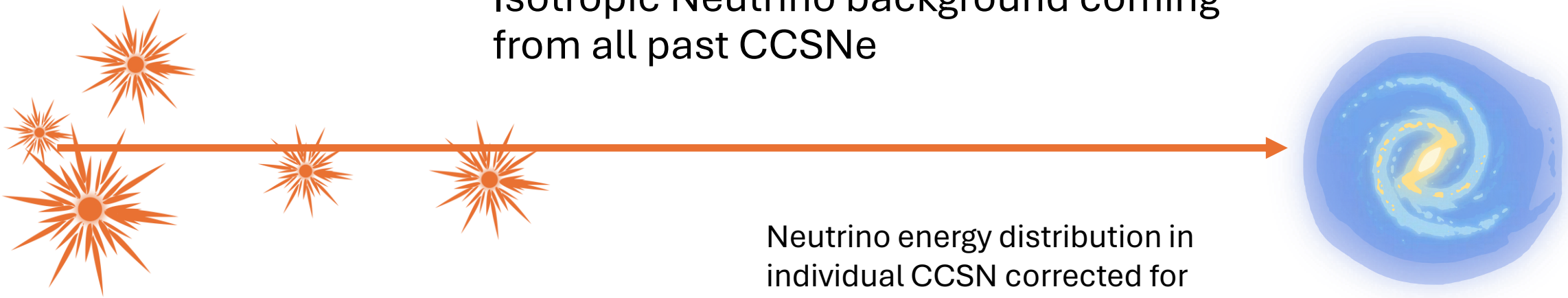
- Neutrino emission: $E_\nu^{tot} \sim 10^{53}\mathrm{erg}$
- Local rate about 1/century
- Up to 1/s in the observable universe



$$F_\alpha(E_{\nu_\alpha}) \approx \frac{E_\nu^{tot}}{6}\frac{120E_{\nu_\alpha}^2}{7\pi^4 T_\alpha^4}\frac{1}{1+\ e^{E_\alpha/T_\alpha}}$$

The DSNB

Isotropic Neutrino background coming from all past CCSNe



Neutrino energy distribution in individual CCSN corrected for redshifting

$$\frac{d\Phi_{\nu_\alpha}}{dE_\nu} = \int_0^{z_{\max}} \frac{dz}{H(z)} R_{\mathrm{CCSN}}(z)\, F_{\nu_\alpha}\left(E_{\nu_\alpha}, T_{\nu_\alpha}\right)\Big|_{E_\nu = E_\nu^S(1+z)}$$

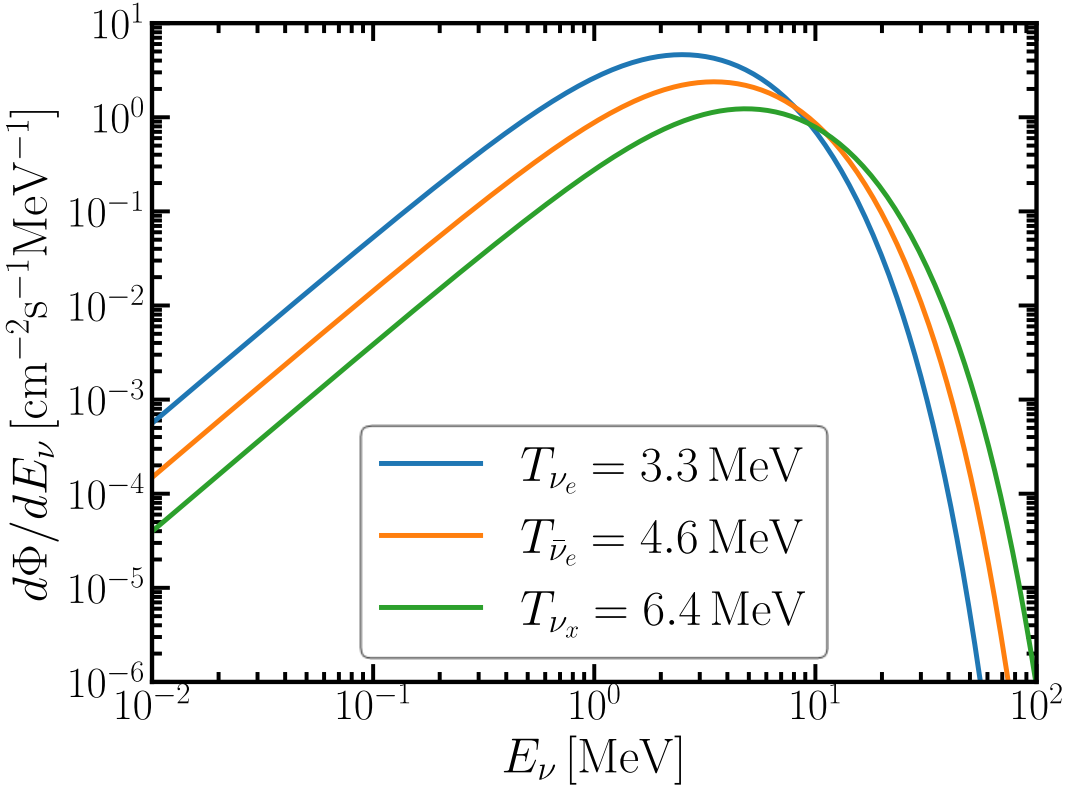
Adding up all past CCSNe

Rate of CCSN per comoving volume

DSNB for upscattering of DM?

Not the worst idea!

- MeV energies and abundant flux
- Isotropic background from cosmological distances
- Neutrino interactions arise naturally in many models



BDM flux at earth…

= flux of all DM particles upscattered by DSNB in the Milky Way halo

$$\frac{d\Phi_\chi}{dT_\chi} = \int_\Omega \frac{d\Omega}{4\pi} \int_{\text{l.o.s.}} dl\, \rho_{\text{MW}}\big(r(l,\Omega)\big) \int dE_\nu \frac{1}{m_\chi} \frac{d\sigma_{\nu\chi}}{dT_\chi} \frac{d\Phi_\nu^{\text{DSNB}}}{dE_\nu}$$

Calculate upscattering rate of DM by DSNB

&

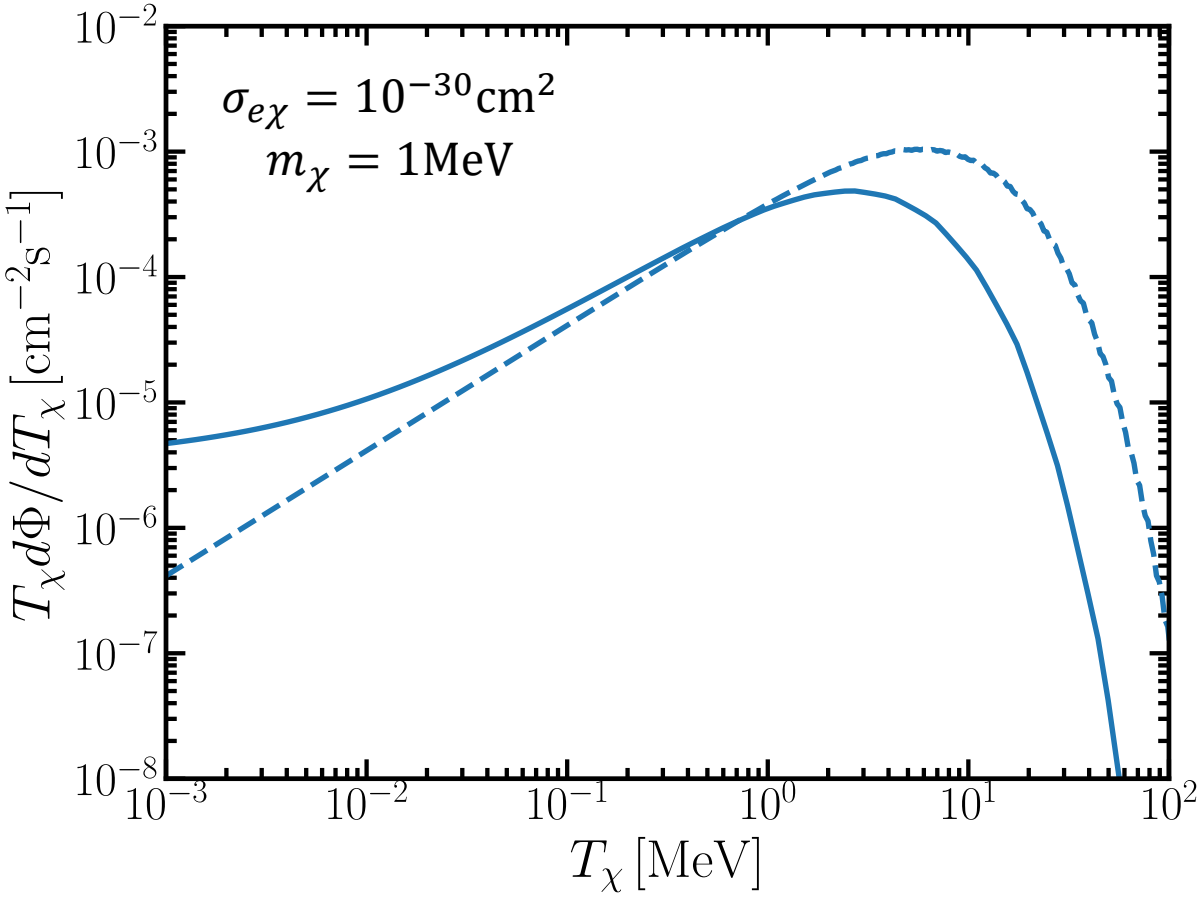
Integrate over all lines of sights and weight by DM density

… and at the detector?

- But also energy loss from elastic scattering

$$\frac{dT_\chi}{dz} = -n_e \int_0^{T_e^{\max}} \frac{d\sigma_{e\chi}}{dT_e} T_e dT_e$$

- Limited in scope: Average energy loss only, no multiple scattering



What did we do?

What people did before…

- Assume energy independent interaction
- Approximate solutions to energy loss equation

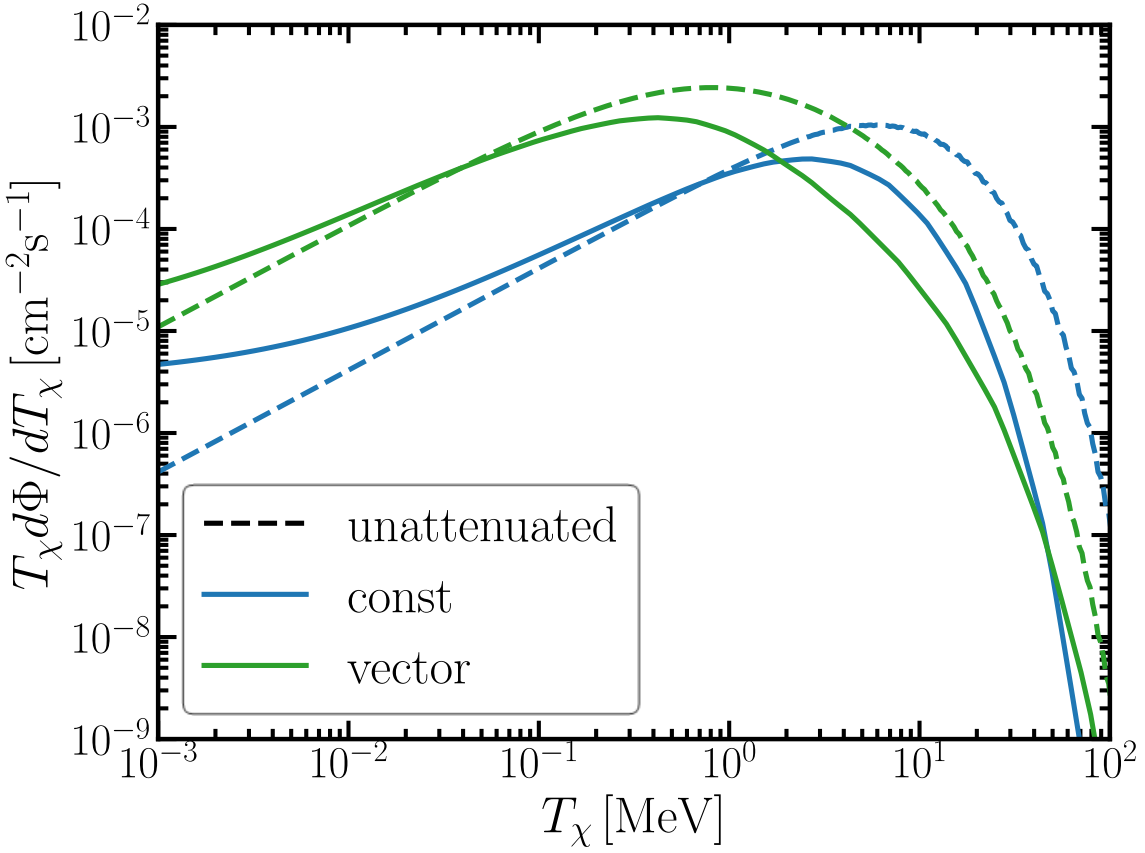
The problem is…

- Different energy scales & extended spectrum
- Approximations definitely not valid!

Overlooked and significant!

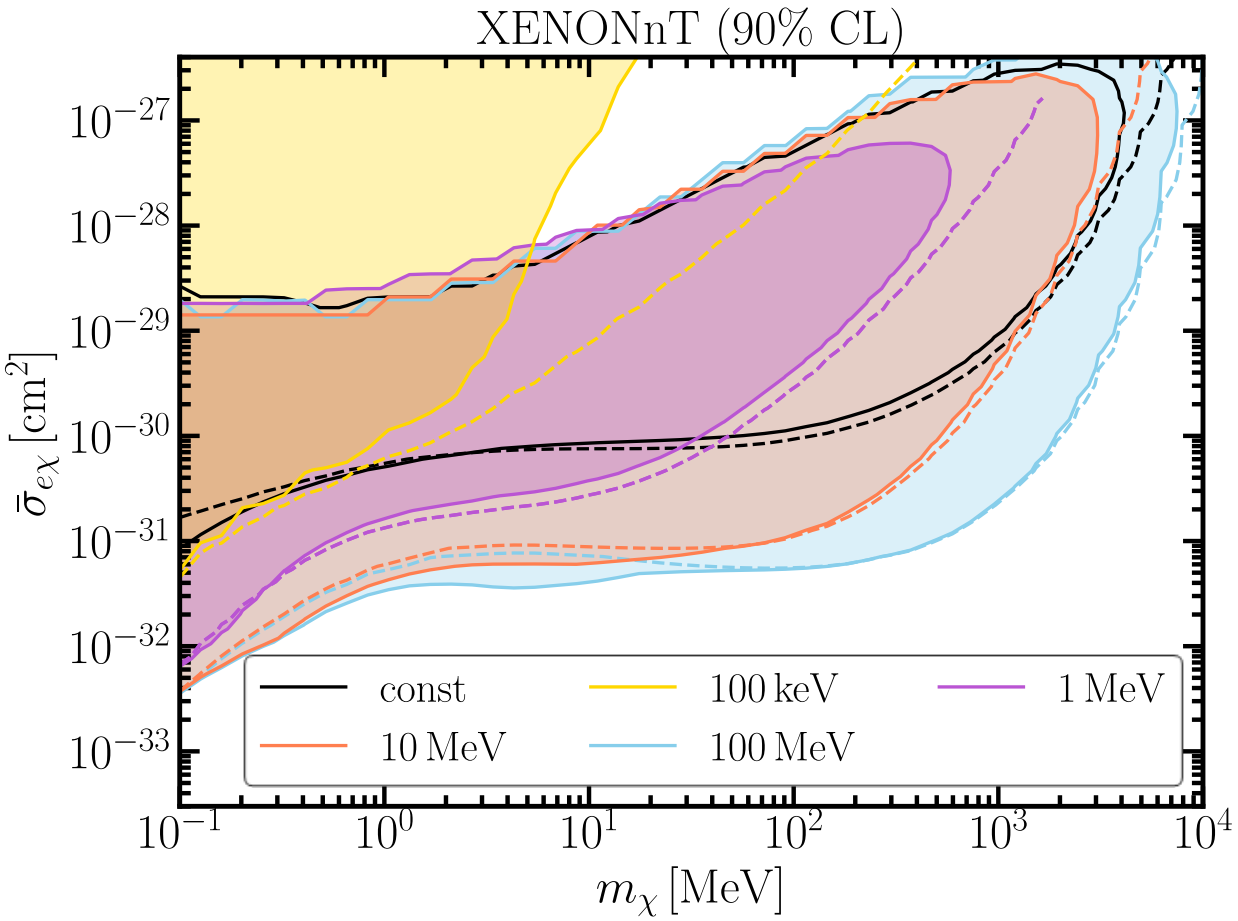
- We have implemented energy loss and energy-dependent cross-sections numerically
- Example of massive vector mediator (Z' with $g_e = g_\nu$)
- Energy-dependence affects upscattering, attenuation & detection in non-trivial way

$\sigma_{e\chi} = 10^{-30}\mathrm{cm}^2$
$m_{Z'} = 2m_\chi = 1\mathrm{MeV}$



Overlooked and significant!

- Large impact on DM model space
- Almost model independent attenuation ceiling
- More models & details see hep-ph:2403.15367



Conclusion – Take Home

- BDM comes for free & helps with direct detection
- DSNB for boosting is convenient and forgiving
- Overlooked or underappreciated: Energy-dependence and attenuation
- Implications beyond DSNB boosted DM