EXCLUSION LIMITS on DM-ν scattering cross-section

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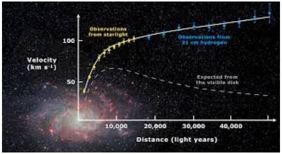
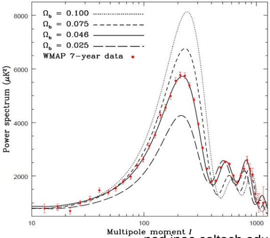
State of the Universe Seminar @ TIFR

DM Overview



Wikipedia



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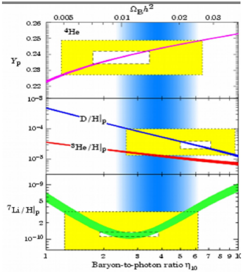
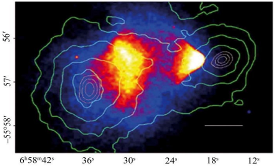


Fields & Sarkar, 2004

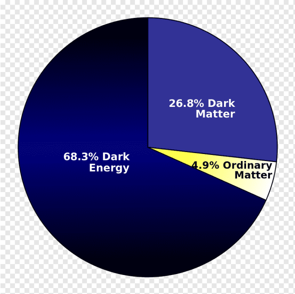


astrobites.org

These observations are indirect and, it is difficult to ascertain whether it is a Particle DM, signature of Modified gravity or some exotic object.

What do we know about DM?

- **Dark matter neither emits nor absorbs light or any other electromagnetic radiation to a significant level.**
- **It should be non-relativistic (typical velocities - $10^{-3}c$) to accumulate and grow in the galactic halos of galaxies.**
- **Local DM energy density** $\rho_{\mathrm{DM}} \sim 0.4\mathrm{GeV}/\mathrm{cm}^3$



Wikipedia

Methods of probing DM

Indirect ways

- Effect on early Universe observables like relativistic degrees of freedom, CMB power spectrum, matter power spectrum.
- Astrophysical probes like cooling of white dwarfs, red giants, Supernovae etc.
- Rare cosmic ray spectrum due to the annihilation of a pair of DM particles into SM particles.
- Producing DM in the accelerators.

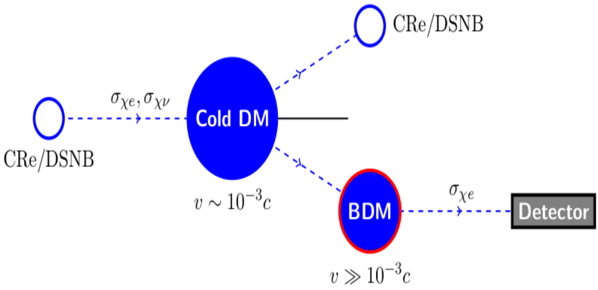
Direct ways

Identify the nuclear or electronic recoils produced by the scattering between DM and the detector material.

Current constraints on DM-e^- and DM-ν scattering cross-section

- DM-e^-:
    - $\sigma_{\chi\, e} \sim 10^{-28}\mathrm{cm}^2$ for $m_\chi \lesssim 0.1\,\mathrm{MeV}$ — CMB spectral distortion.
      Y. Ali-Hamoud, 2021
    - $\sigma_{\chi\, e} \lesssim 10^{-34}\,\mathrm{cm}^2$ for $m_\chi > 5\,\mathrm{MeV}$ — SENSEI experiment.
      O. Abramoff et al. (SENSEI), 2019
    - $\sigma_{\chi\, e} \sim 10^{-34}\mathrm{cm}^2$ for $m_\chi \lesssim 0.1\,\mathrm{MeV}$ — Boosted DM via Super-K experiment data.
      C. V. Cappiello and J. F. Beacom, 2019
- DM-ν:
    - $\sigma_{\chi\nu} \lesssim 10^{-33}(m_\chi/\mathrm{GeV})\,\mathrm{cm}^2$ if the cross section is momentum independent — Planck and large scale structure experiments.
      R. J. Wilkinson et al,2014

Boosted DM scenario



DM is boosted to higher velocity due to scattering with various cosmic ray components from various astrophysical sources. Such upscattered low-mass DM can leave interesting signatures in DD and neutrino experiments.

$\Longrightarrow$ DD experiments can constrain these interactions. Though they can't constrain $\sigma_{\chi\nu}$ independently but can put a bound on a function of $\sigma_{\chi\nu}$ and $\sigma_{\chi e}$ only since matter is not made of neutrinos.

Y. Jho et al., 2021, A. Das and M. Sen, 2021

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2. Probing Boosted DM via DD and Neutrino Experiments

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4. Conclusion

Diffuse Supernovae ν Background and CR e^-s

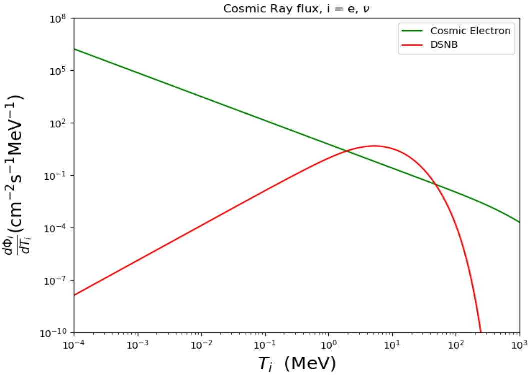


Figure: Fluxes of cosmic ray electrons and the diffuse supernova neutrino background (summing over all flavours of neutrinos).

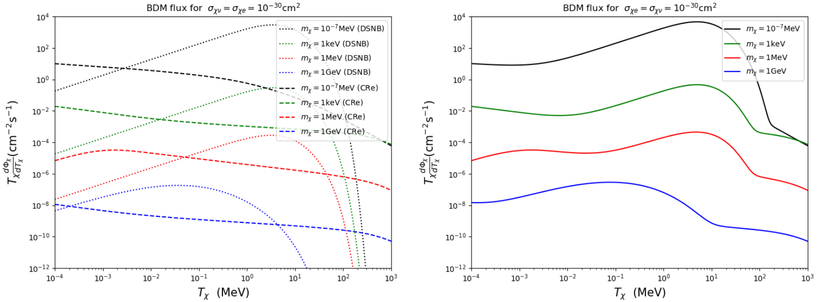
M. J. Boschini et al., 2018, C. Lunardini, 2016, A. Das and M. Sen, 2021

For $1\,\mathrm{MeV} < \mathrm{T_i} < 50\,\mathrm{MeV}$, both the fluxes are of similar order and this range is crucial for boosting DM with mass below MeV. This fact inspire us to consider both the fluxes to derive bounds on $\sigma_{\chi\nu}$ and $\sigma_{\chi e}$ for light DM case considered here.

In this work

WE CONSIDER

DM in the Milky Way halo experiences scattering with the DSNB νs as well as the cosmic e^-s, and gets boosted to velocities $v \gg 10^{-3}\,\mathrm{c}$.



CR electrons and DSNB induced BDM flux for $\sigma_{\chi e} = \sigma_{\chi\nu} = 10^{-30}\ \mathrm{cm}^2$. (Left) BDM flux due to the individual boost by CR e^-s (dashed lines) and DSNB νs (dotted lines). (Right) BDM flux due to the combined effect.

Rate Equation

The differential recoil rate for Xenon1T and Super-Kamiokande (SK) is given as

$$\frac{dR}{dE_R} = A\sigma_{\chi e}\sigma_{\chi\nu} + B\sigma_{\chi e}^2 \tag{1}$$

with

$$A = \aleph \ D_e^{\nu} ff \ \frac{\rho_\chi}{m_\chi} \int\limits_{T_\chi^{min}(E_R)}^{\infty} \frac{dT_\chi}{E_R^{max}(T_\chi)} \int\limits_{T_\nu^{min}}^{\infty} \frac{dT_\nu}{T_\chi^{max}(T_\nu)} \frac{d\Phi_\nu}{dT_\nu}$$

and

$$B = \aleph \ D_e^{e} ff \ \frac{\rho_\chi}{m_\chi} \int\limits_{T_\chi^{min}(E_R)}^{\infty} \frac{dT_\chi}{E_R^{max}(T_\chi)} \int\limits_{T_e^{min}}^{\infty} \frac{dT_e}{T_\chi^{max}(T_e)} \frac{d\Phi_e}{dT_e}$$

where $\aleph^{\mathrm{XN1T}} = Z_{Xe}/m_{Xe}$, $\aleph^{\mathrm{SK}} = 7.5 \times 10^{33}$, A and B are functions of DM mass and electron recoil energy. .

χ^2 analysis and Experimental data

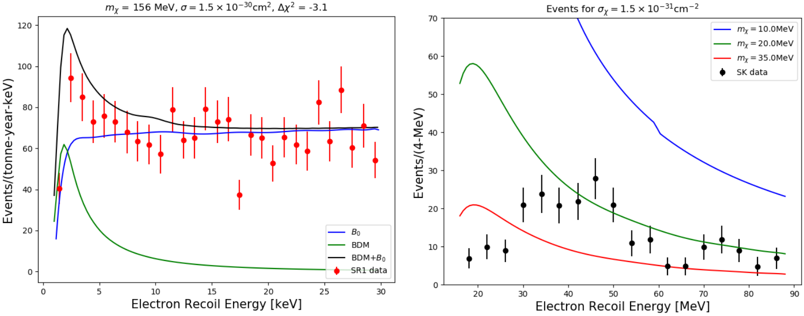


Figure: (Right) Scientific Run 1 (SR1) data (in red) along with the estimated background, B_0 (in blue) reported by the XENON collaboration. (Left) Event rate as a function of the recoil energy is given for different values of m_χ at fixed $\sigma = 1.5 \times 10^{-31}\,\mathrm{cm}^2$.

E. Aprile et al. (XENON), 2020
K. Bays et al. (Super-Kamiokande), 2012

We define

$$\Delta\chi^2 = \chi^2(BDM + B_0) - \chi^2(B_0 \text{ only})$$

where we demand $\Delta^{27}\chi^2 > 40.1$ and $\Delta^{16}\chi^2 > 26.3$ to derive exclusion limit at 95% C.L.

Xenon1T results

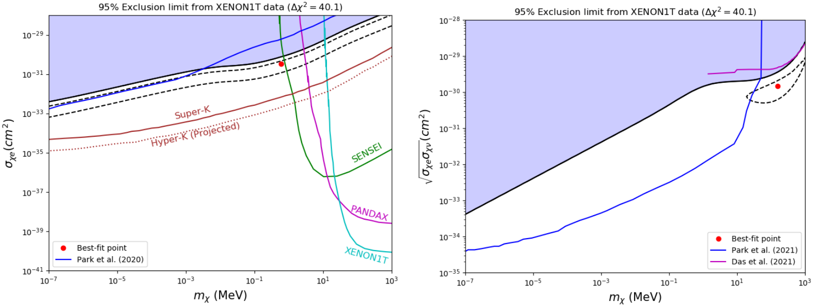


Figure: Blue shaded exclusion region in the $(m_\chi\,, \sigma_{\chi e})$ and $(m_\chi\,, \sqrt{\sigma_{\chi e}\sigma_{\chi\nu}})$ plane derived from the XENON1T data at the 95% confidence level for boosted DM. The region between the two dashed lines satisfy $\Delta\chi^2 < 0$.

Xenon1T results

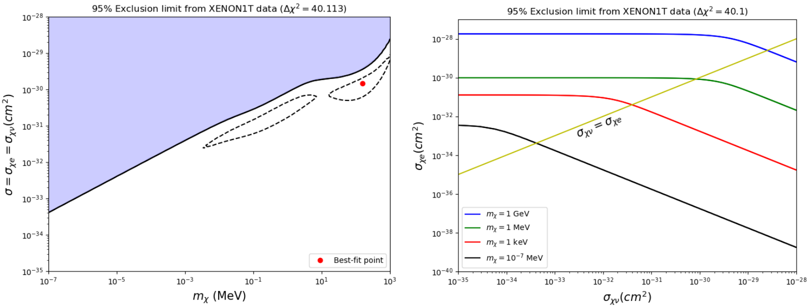


Figure: Exclusion region in the $(m_\chi\,, \sigma_{\chi\nu} = \sigma_{\chi e})$ plane derived from the XENON1T data at the 95% confidence level for DM boosted by both CRe and DSNB, corresponding to $A \neq 0$ and $B \neq 0$. For all points inside the dashed line $\Delta\chi^2 < 0$ and the best fit point $(156 \text{ MeV}, 1.5 \times 10^{-30}\mathrm{cm}^2)$ marked with red point correspond to $\Delta\chi^2 = -3.1$.

Super Kamiokande results

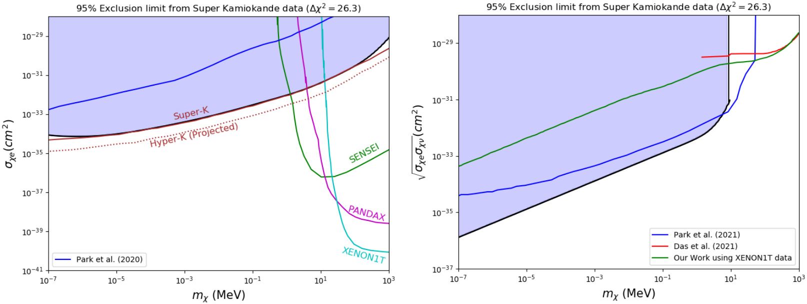


Figure: Exclusion region in the $(m_\chi\,,\sigma_{\chi e})$ and $(m_\chi\,,\sqrt{\sigma_{\chi e}\sigma_{\chi\nu}})$ plane derived from the SK I data at the 95% confidence level for CRe boosted DM.

Super Kamiokande results

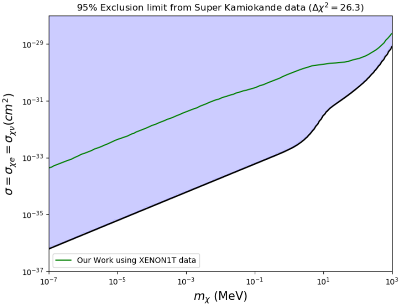


Figure: Exclusion region in the $(m_\chi\,, \sigma_{\chi\nu} = \sigma_{\chi e})$ plane derived from the SK I data at the 95% confidence level for DM boosted by both CRe and DSNB, corresponding to $A \neq 0$ and $B \neq 0$ in Eq. (1).

Conclusion

- To register events in the detectors of DM particles in- teracting with neutrinos, obviously, we need to assume non-zero interaction strength between DM and the elec- trons. Therefore we can not ignore the boost due to scat- tering of DM with CRe while constraining DM-neutrino interactions.
- We found that Super-Kamiokande sets the strongest bound on $\sigma_{\chi\nu}$ for $m_\chi < 10$ MeV.

Back Up

A & B coeffiients for XENON1T & SK for $m_\chi = 1$eV

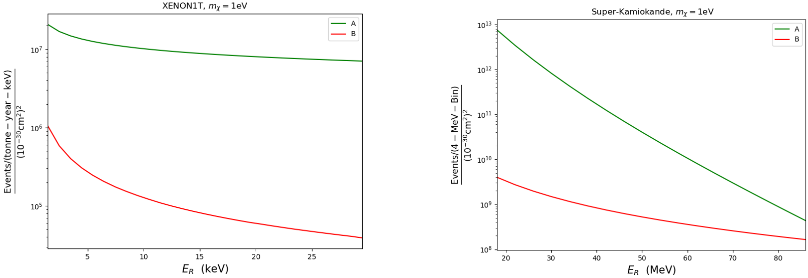
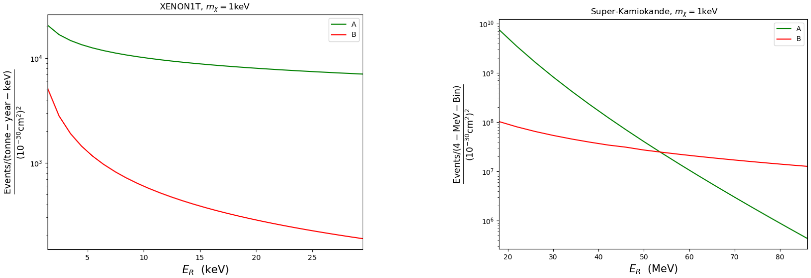


Figure: Variations of A and B as a function of the recoil energy for $m_\chi = 1\ \mathrm{eV}$.

A & B coeffiients for XENON1T & SK for $m_\chi = 1$keV



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A & B coeffiients for XENON1T & SK for $m_\chi = 1$MeV

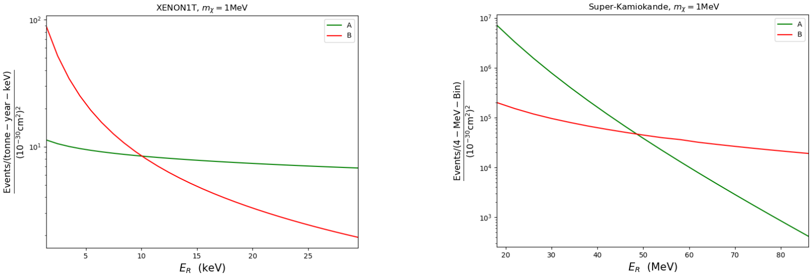

Figure: Variations of A and B as a function of the recoil energy for $m_\chi = 1\ \mathrm{MeV}$.