Cosmic-Neutrino-Boosted Dark Matter (νBDM)

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Based on **arXiv:2101.11262 [hep-ph]**
Collaboration with
Jong-Chul Park (Chungnam Natl. U.),
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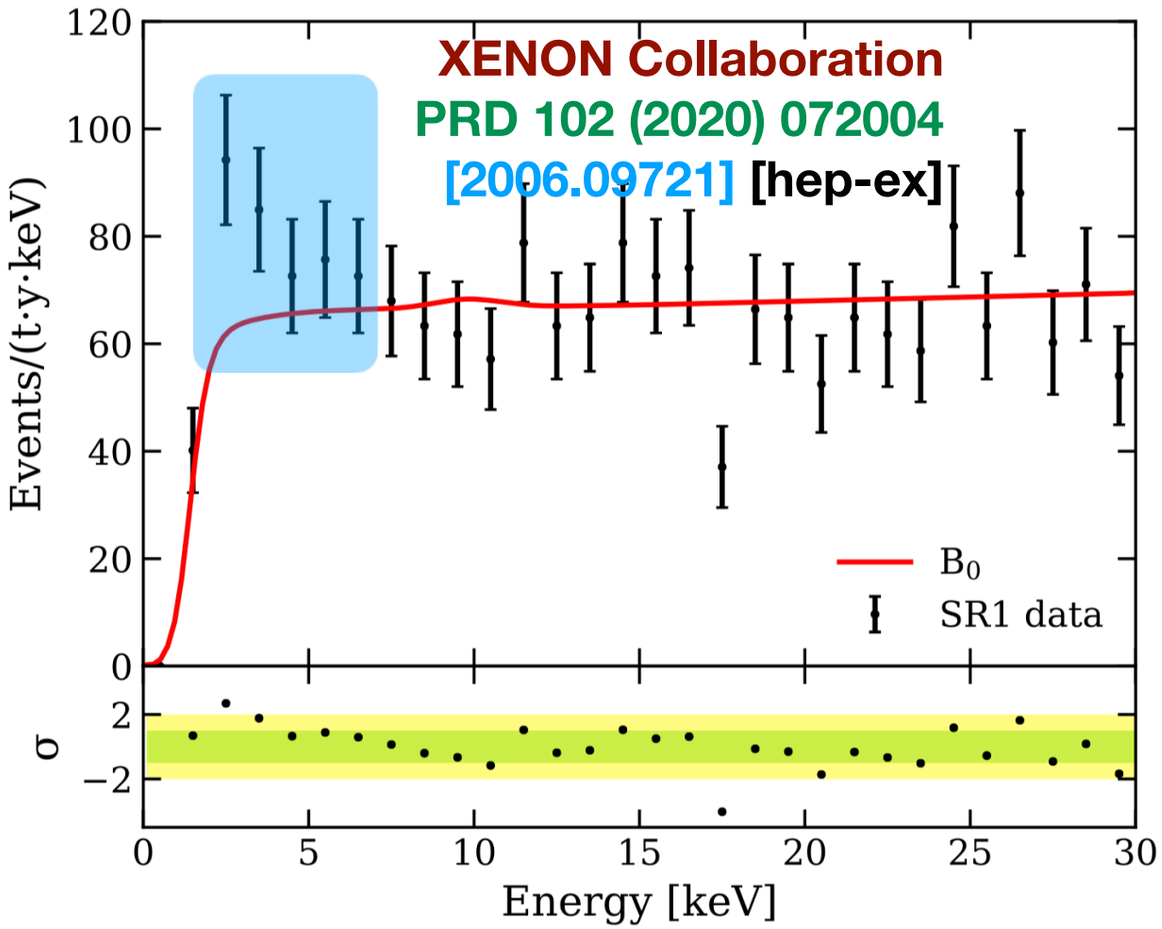
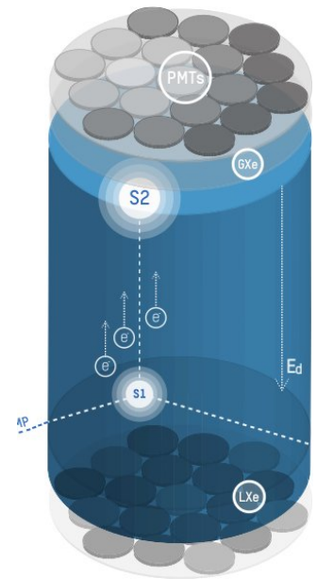
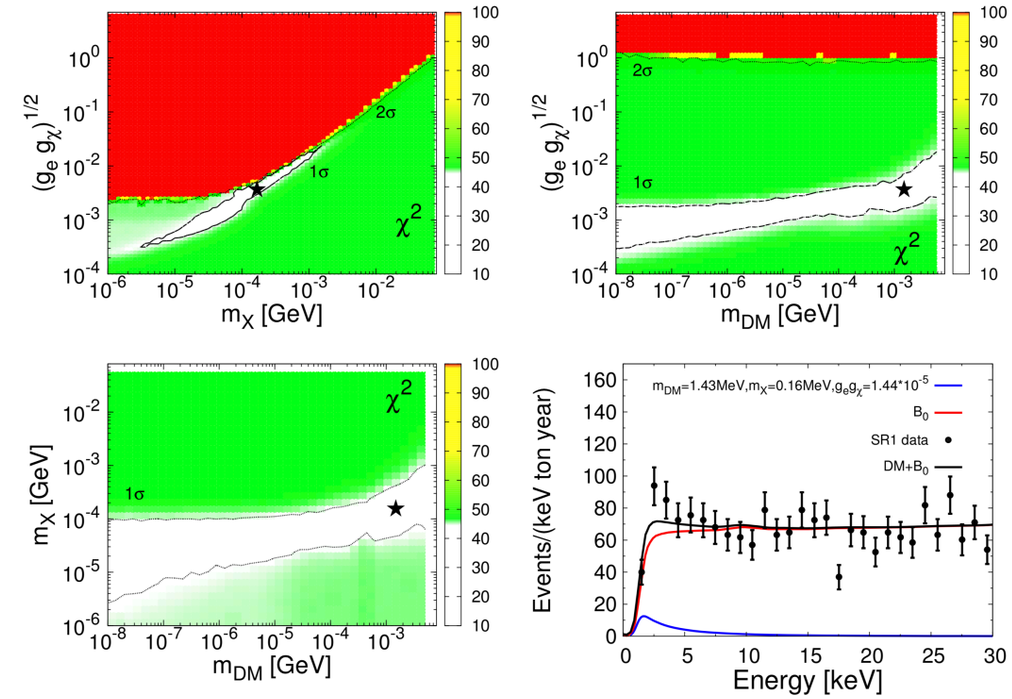
Aug 2nd, 2021
Asia-Pacific Workshop on Particle Physics and Cosmology 2021

Boosted Dark Matter (BDM) & Observation of BDM at DM Direct detection







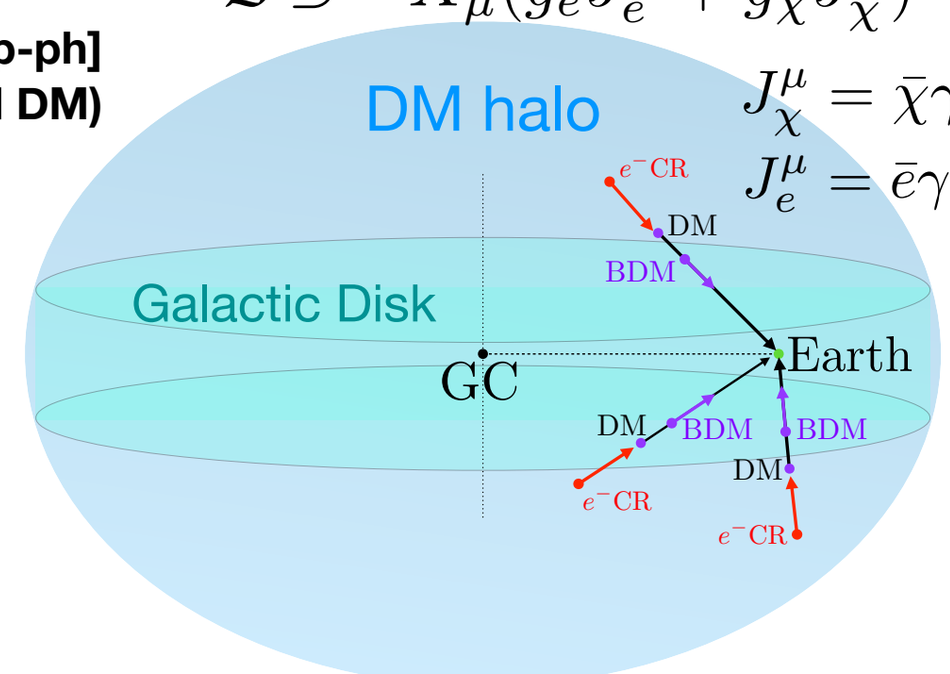
YSJ, J.-C. Park, S.-C. Park, P.-Y. Tseng, PLB 811 (2020) 135863 [2006.13910] [hep-ph]

cf) Q.-H. Cao et al, [2006.12767] [hep-ph] (electron CR Boosted DM)

$$\mathcal{L} \supset -X_\mu (g_e J_e^\mu + g_\chi J_\chi^\mu) + \ldots$$

$$J_\chi^\mu = \bar{\chi}\gamma^\mu\chi$$

$$J_e^\mu = \bar{e}\gamma^\mu e$$



Charged Cosmic ray (electron) BDM provides an interesting possibility in DM direct detection/neutrino observatories.

Q1: Can Cosmic "Neutrinos"
boost light Dark Matter in the halo?

Q2: Cosmic-Neutrino-Boosted Dark Matter
can be probed at
various ground experiments/observatories?

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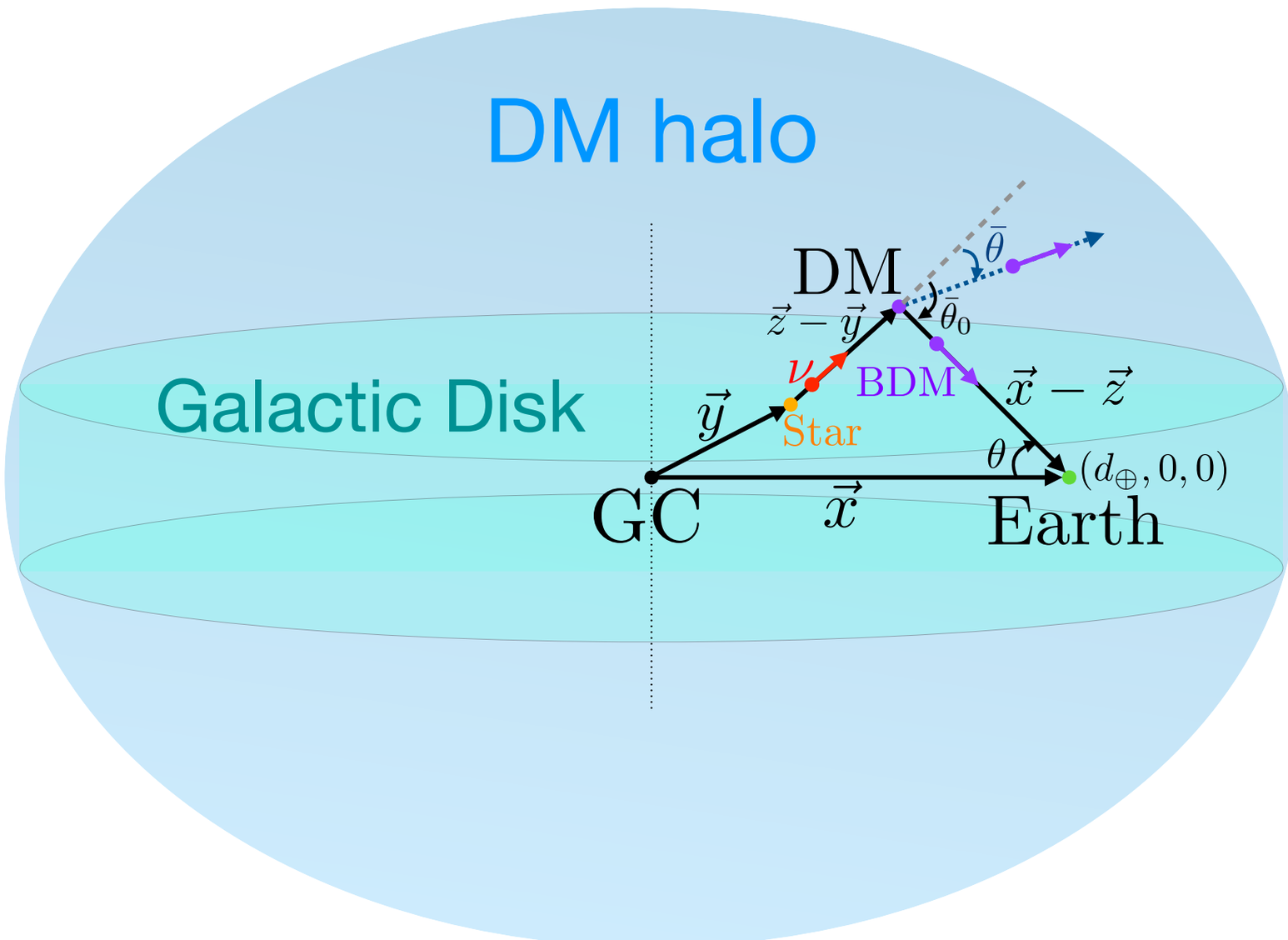
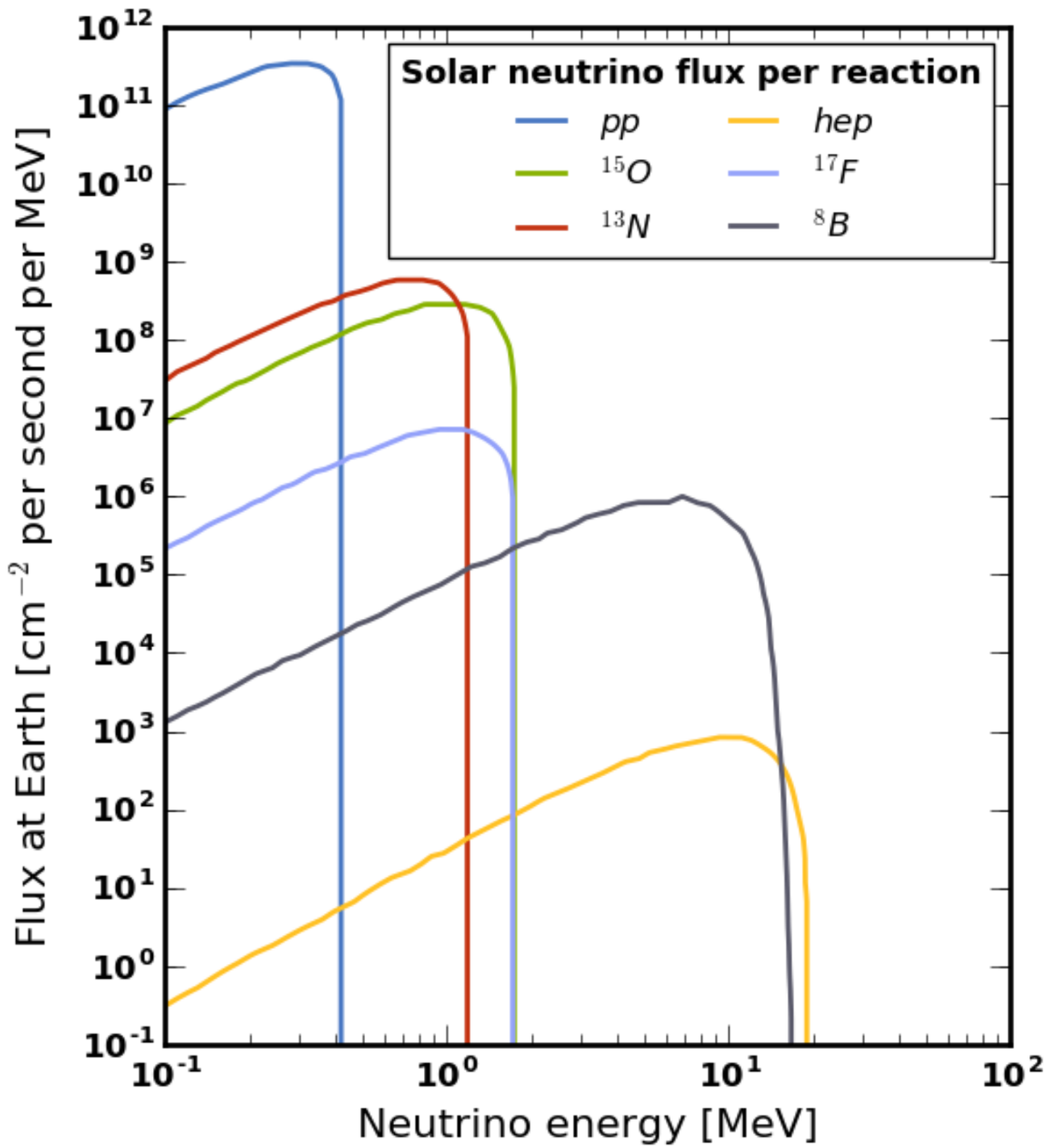


Cosmic-Neutrino-Boosted Dark Matter

I. Dark Matter boosted by neutrinos emitted from the Sun



Our Sun is the nearest source of keV-MeV energy neutrinos!

Various type of nuclear reactions induce several bump in the spectrum.

$$\Phi_{\mathrm{Solar}\nu} \simeq \mathcal{O}(10^8)[cm^{-2}s^{-1}keV^{-1}]$$

at $E_\nu \simeq 0.3$ MeV

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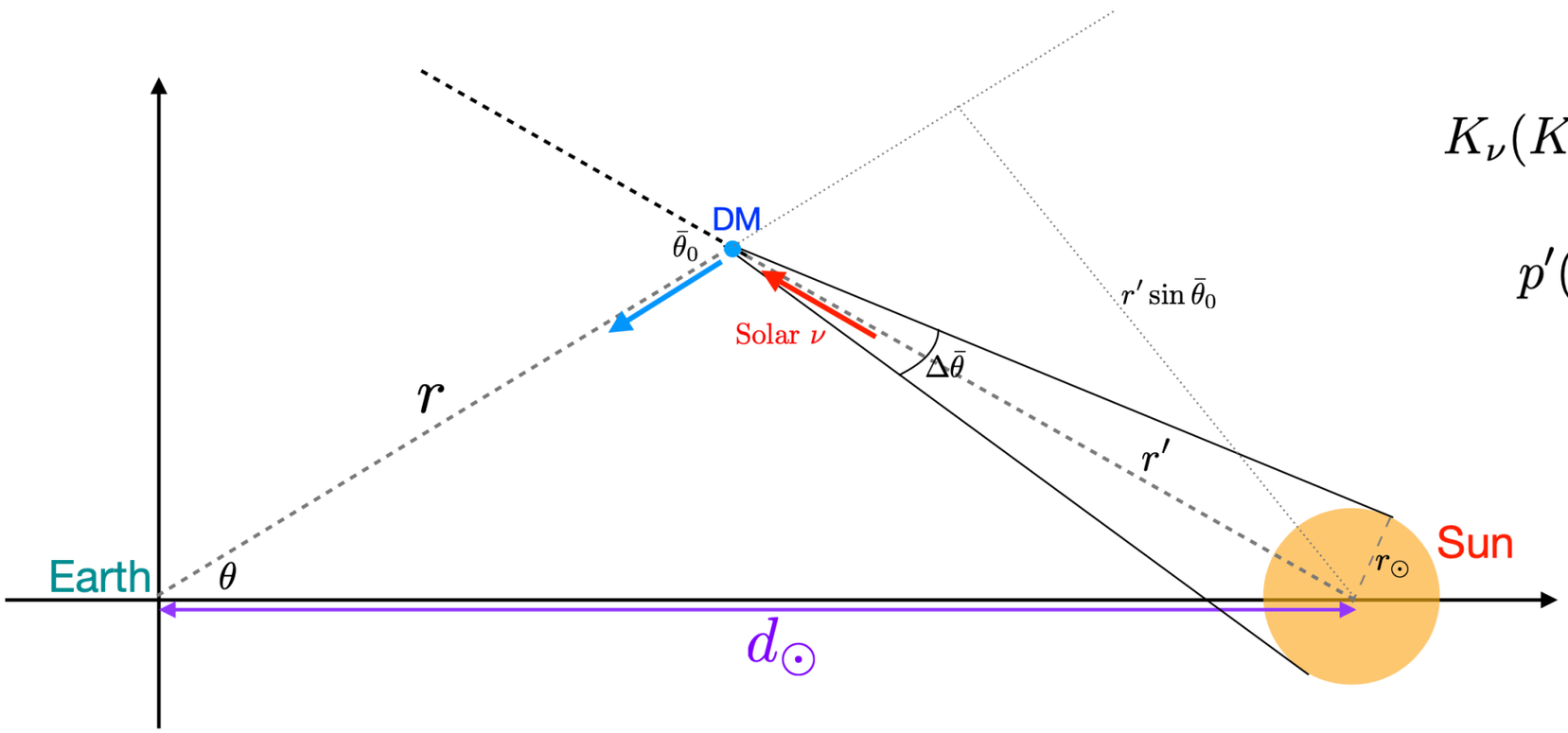

$$K_\nu(K_{\rm DM}, \bar{\theta}) = \frac{K_{\rm DM}^2 - p'^2}{2(K_{\rm DM} - p' \cos\bar{\theta})},$$

$$p'(K_{\rm DM}) = \sqrt{2 m_{\rm DM} K_{\rm DM} + K_{\rm DM}^2}.$$

$$\frac{d\Phi_{\rm DM}}{dK_{\rm DM}} = \int dV \frac{\rho_{\rm DM}}{m_{\rm DM}} \frac{1}{r^2} \int_{K_\nu^{\rm min}}^{K_\nu^{\rm max}} \underbrace{dK_\nu}_{\propto r_\odot} \frac{d\sigma_{\nu-{\rm DM}}(K_{\rm DM}, \bar{\theta})}{dK_{\rm DM}} \cdot \left(\frac{r_\odot}{4r' \sin\bar{\theta}}\right) \cdot \underbrace{\left(\frac{d^2\Phi^{\rm Solar\ \nu}}{d\Omega dK_\nu}\right) \cdot \left(\frac{d_\odot}{r'}\right)^2}_{\frac{\dot{N}_\nu}{4\pi r_\odot^2}}$$

(It is valid in the point source limit, $r_\odot \to 0$)

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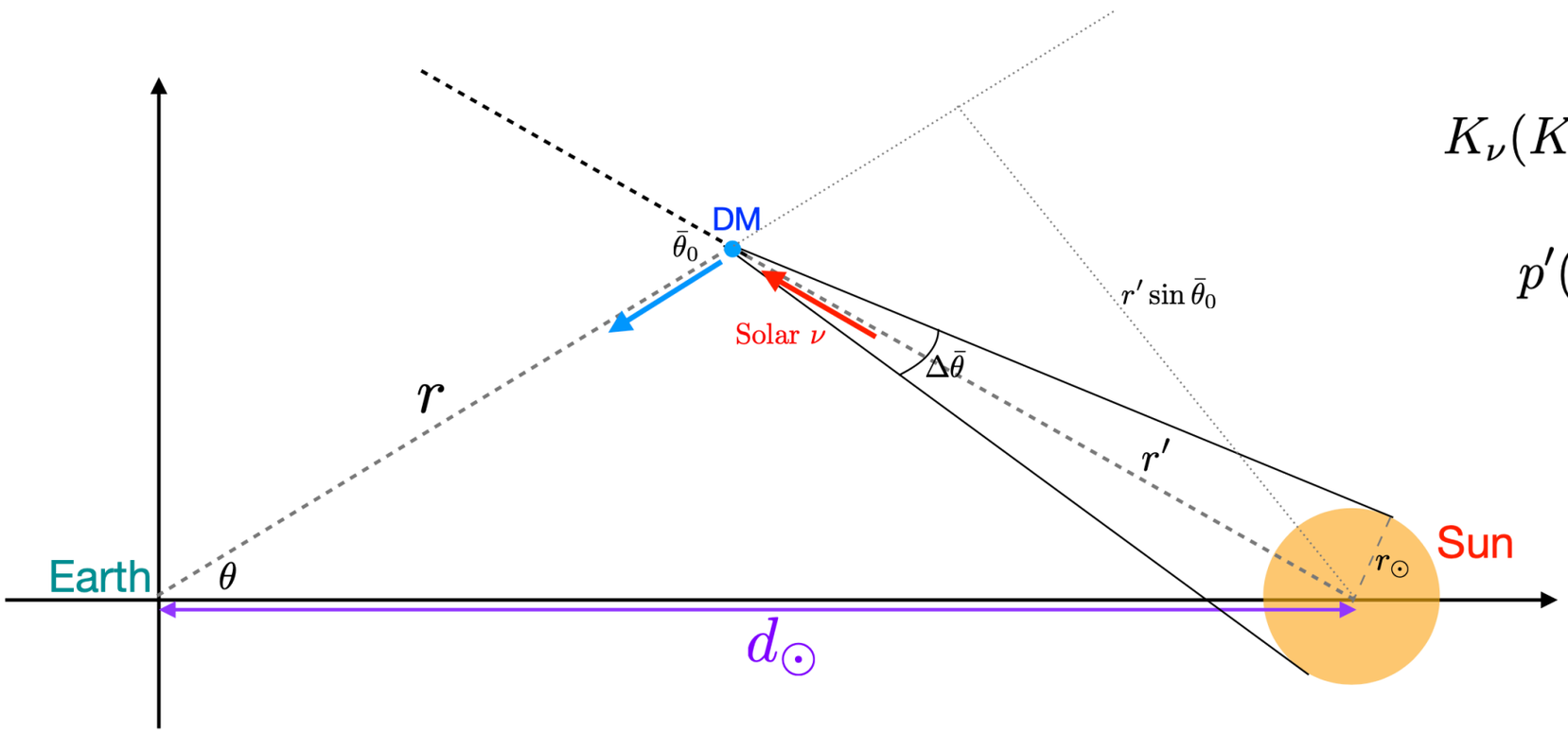


$$K_\nu(K_{\rm DM}, \bar{\theta}) = \frac{K_{\rm DM}^2 - p'^2}{2(K_{\rm DM} - p' \cos\bar{\theta})},$$

$$p'(K_{\rm DM}) = \sqrt{2 m_{\rm DM} K_{\rm DM} + K_{\rm DM}^2}.$$

$$\frac{d\Phi_{\rm DM}}{dK_{\rm DM}} \approx \frac{\dot{N}_\nu}{8\pi} \frac{\rho_{\rm DM}}{m_{\rm DM}} \int dV \frac{1}{r^2} \times \left(\frac{dK_\nu}{d\bar{\theta}}\bigg|_{\bar{\theta}=\bar{\theta}_0} \right) \times \left(\frac{d\sigma_{\nu-{\rm DM}}}{dK_{\rm DM}}\bigg|_{\bar{\theta}=\bar{\theta}_0} \right) \times \frac{1}{r'^2 \sin\bar{\theta}_0}$$

For a single neutrino source (here, our Sun) contribution!
(The volume integration for DM coordinates)

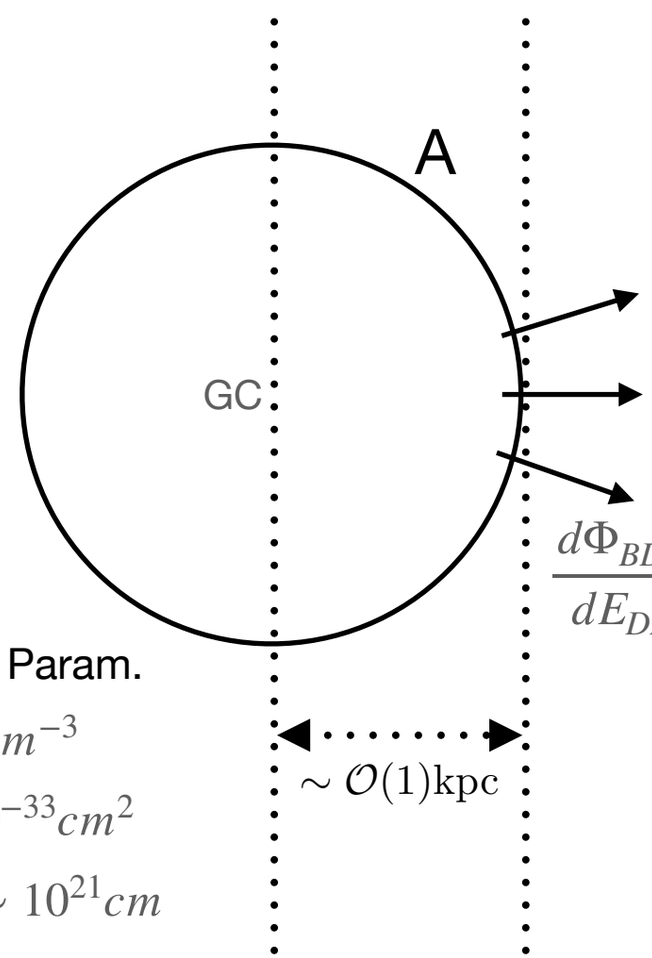
Cosmic-Neutrino-Boosted Dark Matter

II. A 'naive' estimation of Galactic Star neutrino BDM amounts

We know both the populations of Stars & DM is dominant within the O(1) kpc sphere centered at GC.

$$n_{\rm star}(R) \simeq 1.2 \times 10^{11}/(R/{\rm kpc})^3 \ [{\rm kpc}^{-2}]$$

The (planar) number density of stars from the observation.



If one assume a almost uniform production of neutrinos and scattering rate in the central region (with a set of benchmark parameters),

$$\left.\frac{d\Phi_{BDM}}{dE_{DM}}\right|_A \sim (n_{DM}\sigma_{\nu-DM}L)\cdot N_{star}\cdot\frac{d\Phi_{Solar\nu}}{dE_\nu}\cdot(\frac{1AU}{1kpc})^2$$

$$\sim (10^6\cdot 10^{-33}\cdot 10^{21}\cdot 10^{10}\cdot 10^{-18})\frac{d\Phi_{Solar\nu}}{dE_\nu} \sim 10^{-14}\cdot\frac{d\Phi_{Solar\nu}}{dE_\nu}$$

Benchmark Param.

$n_{DM} \sim 10^6 cm^{-3}$

$\sigma_{\nu-DM} \sim 10^{-33} cm^2$

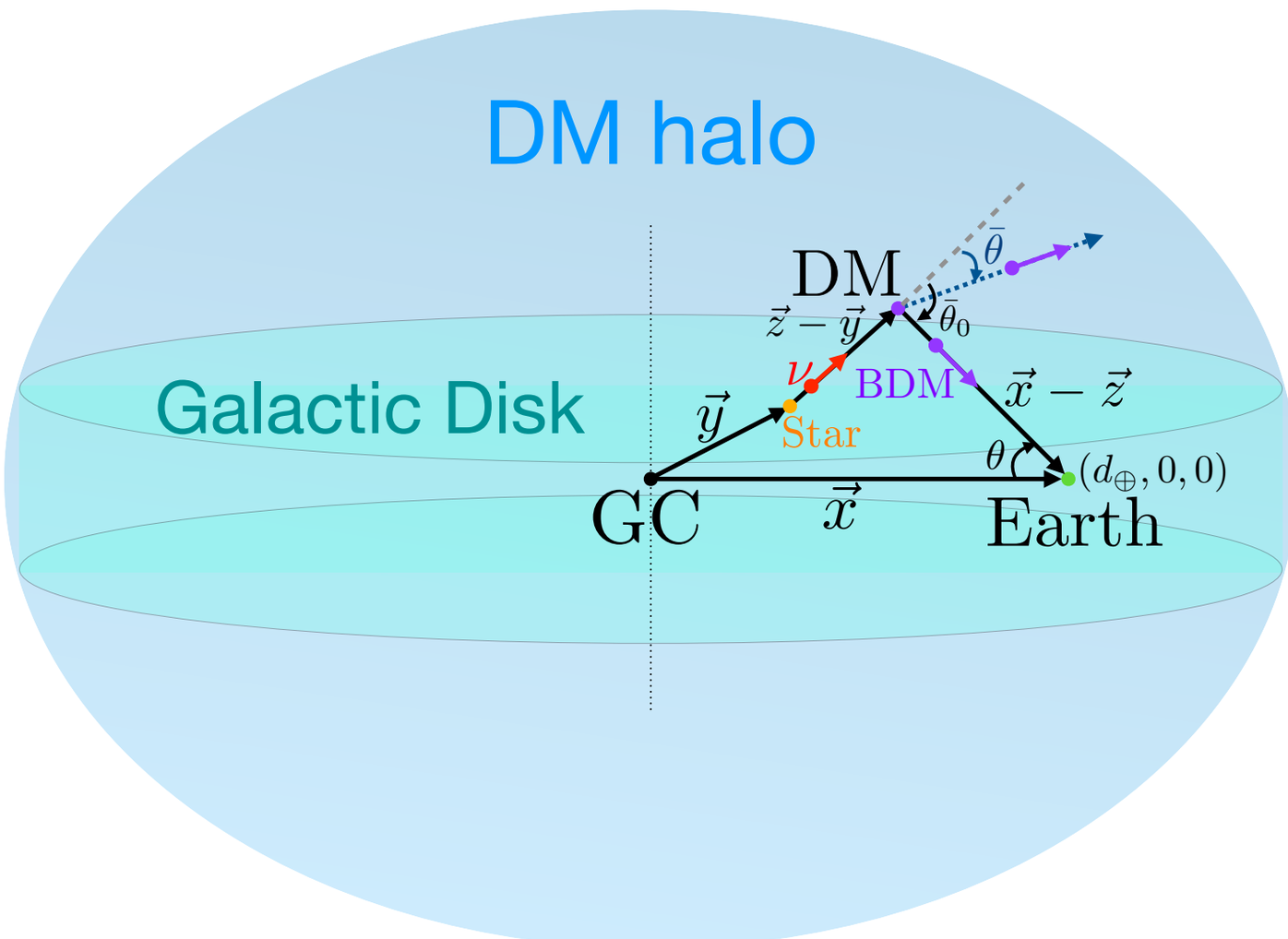
$L \sim 1kpc \sim 10^{21} cm$

$N_{star} \sim 10^{10}$

At the Earth, one can expect $\sim 10^{-15} - 10^{-16}\cdot\frac{d\Phi_{Solar\nu}}{dE_\nu}$

Cosmic-Neutrino-Boosted Dark Matter

III. The expectation of Galactic Star neutrino BDM



Individual star contribution

$$\frac{d\Phi^{(1)}_{\rm DM}(\vec{y})}{dK_{\rm DM}} \simeq \frac{1}{8\pi^2}\left(\tilde{f}_1 \frac{d\dot{N}^{\rm Sun}_\nu}{dK_\nu}\right)\int d^3\vec{z}\,\frac{\rho_{\rm DM}(|\vec{z}|)}{m_{\rm DM}}\frac{1}{|\vec{x}-\vec{z}|^2} \times \left(\frac{dK_\nu}{d\bar{\theta}}\bigg|_{\bar{\theta}=\bar{\theta}_0}\right)\left(\frac{d\sigma_{\nu\rm DM}}{dK_{\rm DM}}\bigg|_{\bar{\theta}=\bar{\theta}_0}\right) \times \frac{1}{\sin\bar{\theta}_0}\frac{1}{|\vec{z}-\vec{y}|^2} \times \exp\left(-\frac{|\vec{z}-\vec{y}|}{d_\nu}\right),$$

Total Galaxy contribution

$$\frac{d\Phi_{\rm DM}}{dK_{\rm DM}} = \int d^3\vec{y}\, n_{\rm star}(\vec{y})\frac{d\Phi^{(1)}_{\rm DM}(\vec{y})}{dK_{\rm DM}}$$

-Assumption in the evaluation-

1. Symmetric population of Stars&DM

2. All stars have same luminosity as the Sun

In a realistic estimation, Production of BDM is highly anisotropic, and depends on spectrum of injected neutrinos.

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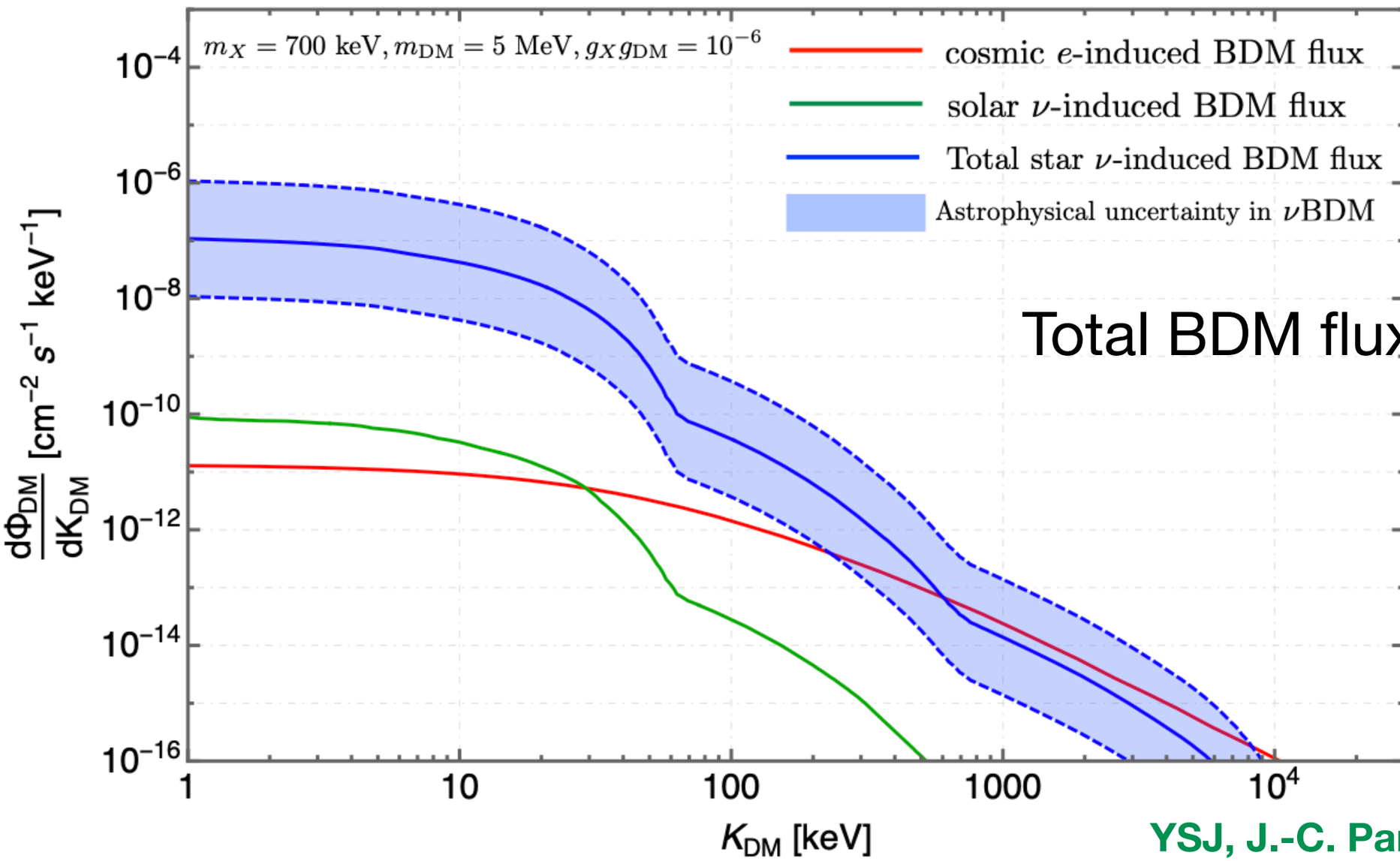

Total BDM flux at the Earth

YSJ, J.-C. Park, S.-C. Park, P.-Y. Tseng [2101.11262] [hep-ph]

Cosmic-Neutrino-Boosted Dark Matter

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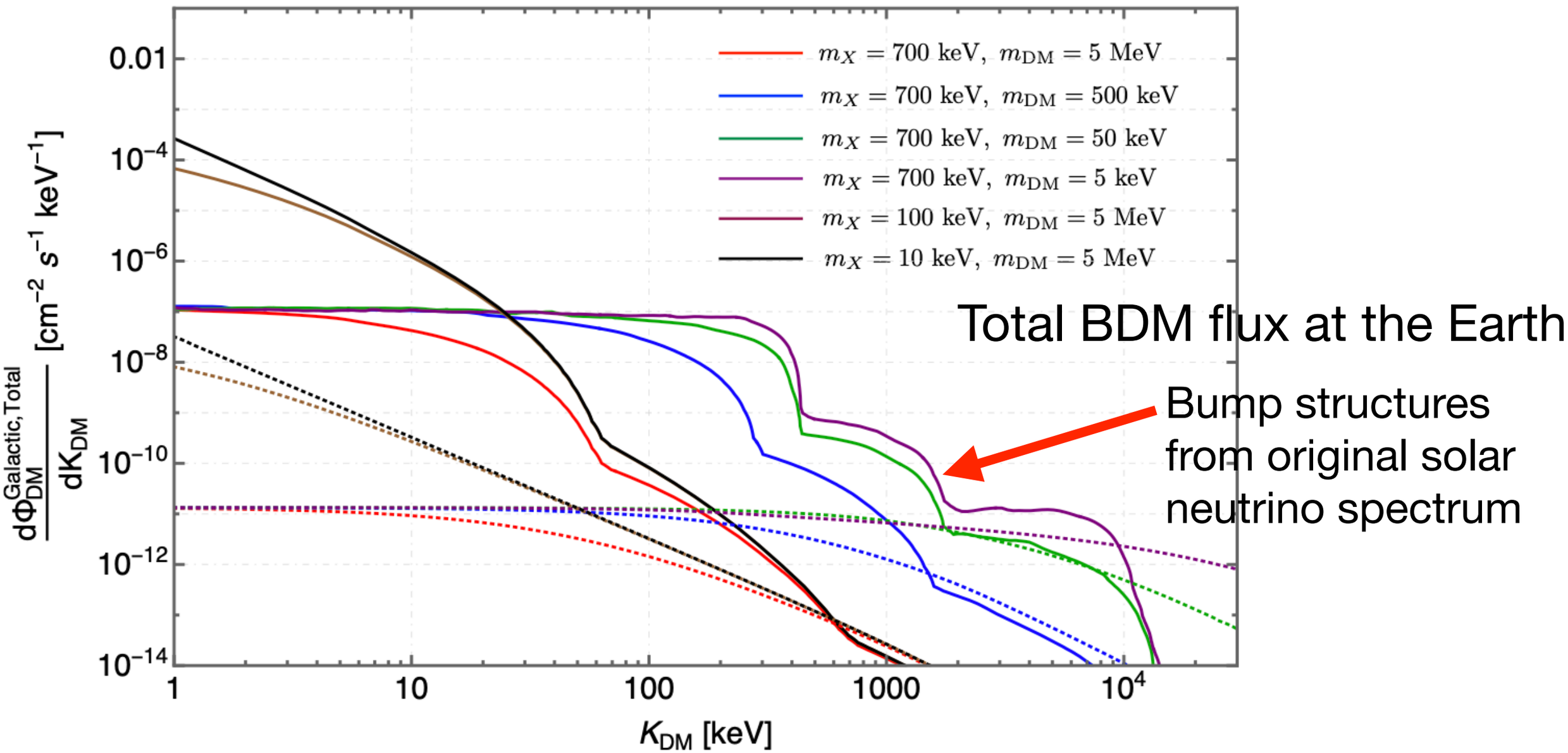

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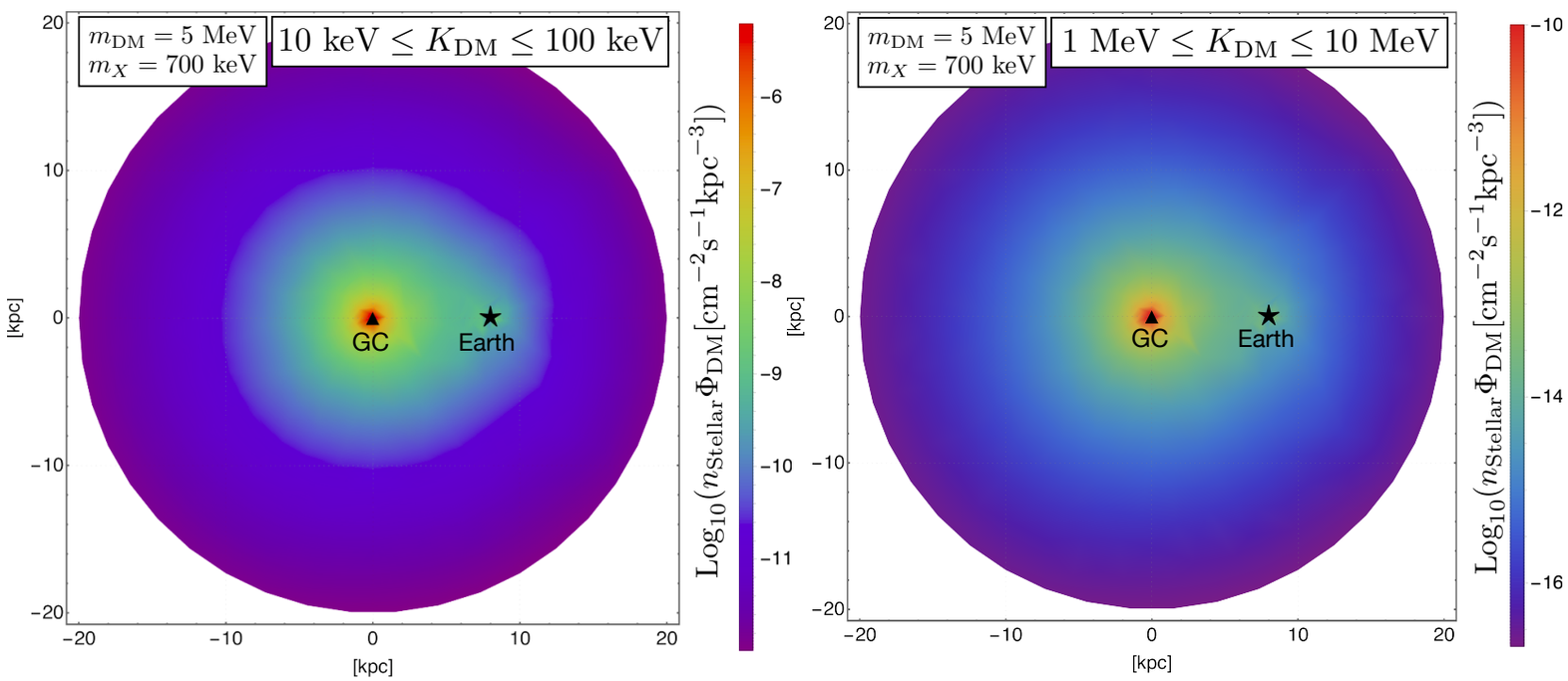
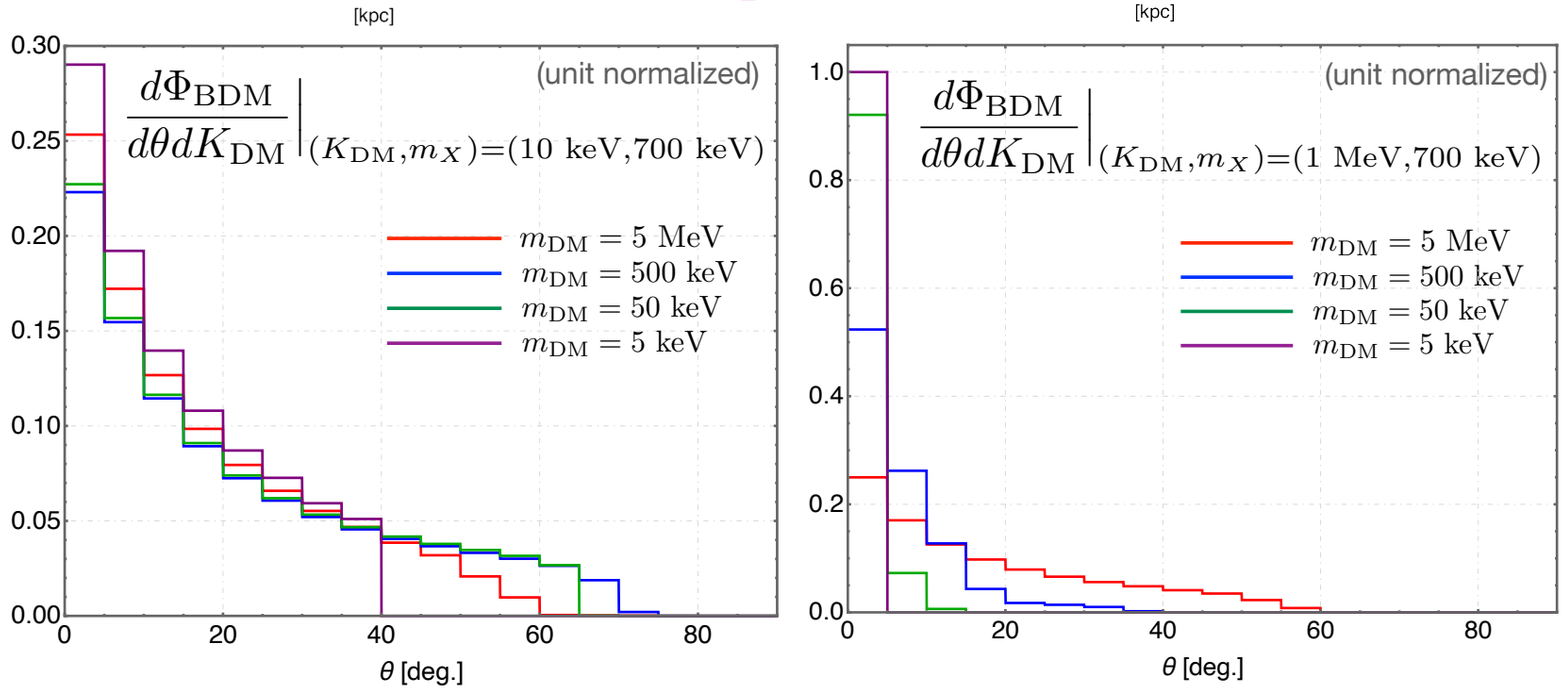


Galactic Disk distribution

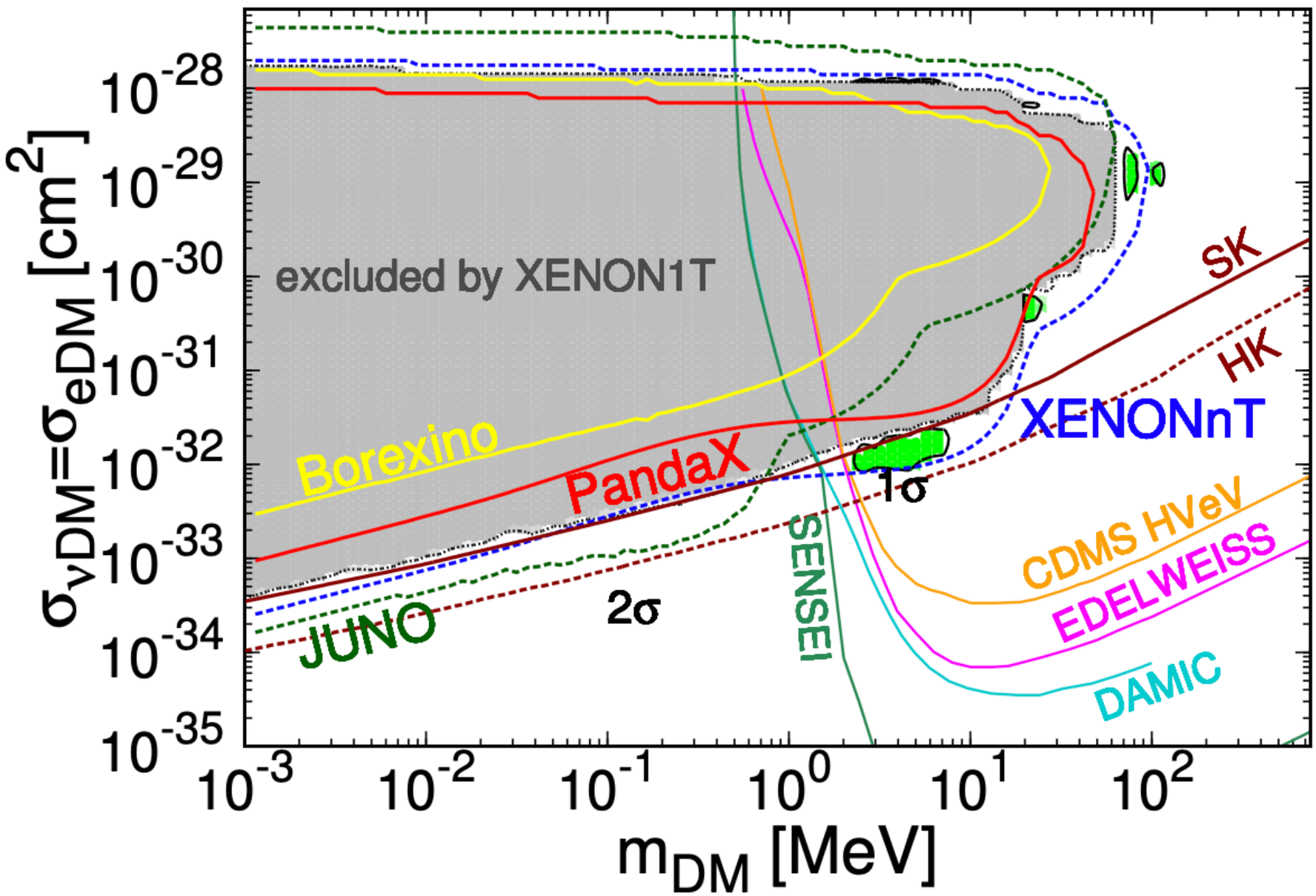


Arrival direction distribution of BDM

Non-trivial distribution of BDM arrival direction could help to probe nuBDM scenario.

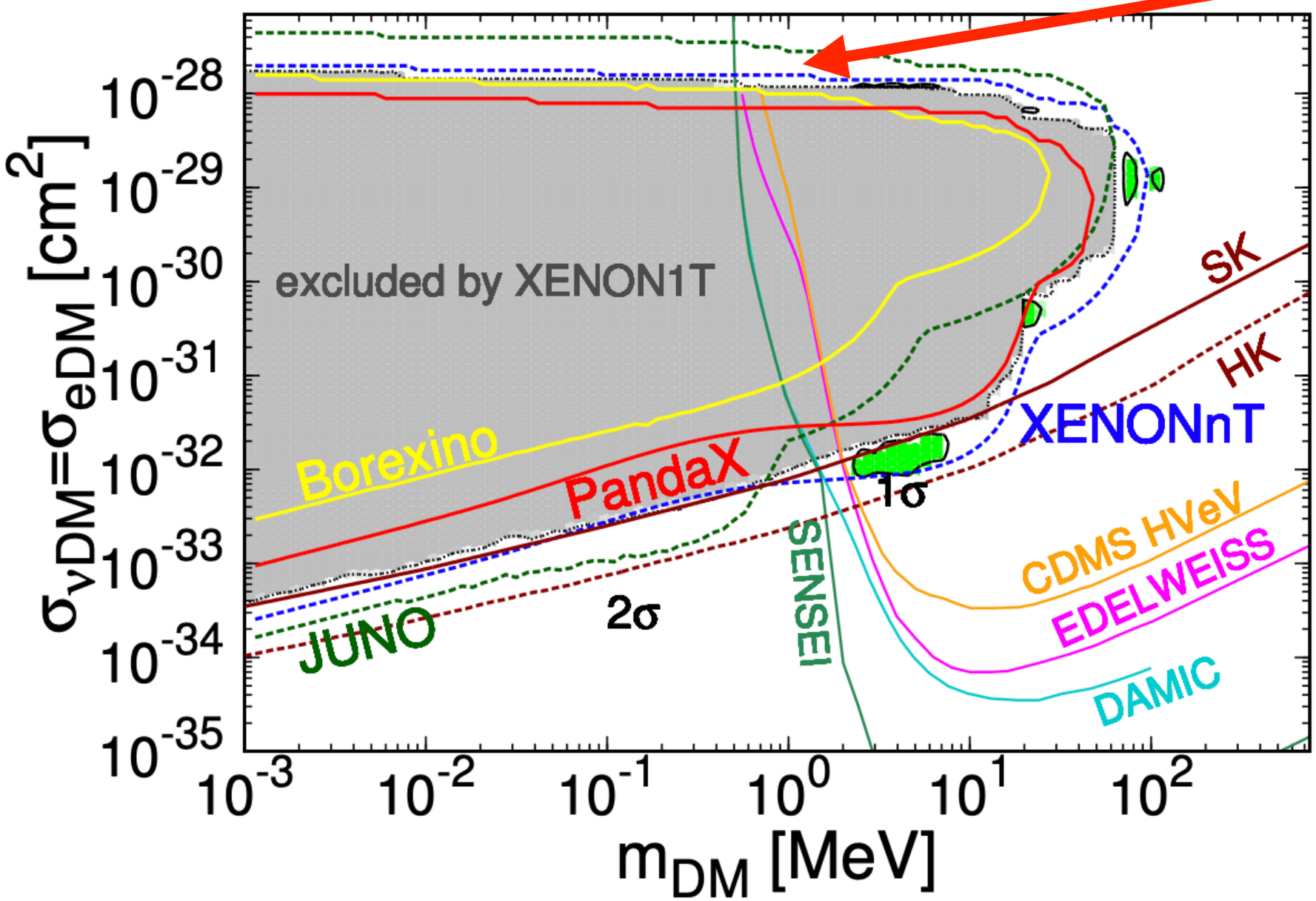
YSJ, J.-C. Park, S.-C. Park, P.-Y. Tseng [2101.11262] [hep-ph]

Constraints/Sensitivity limit for νBDM scenario



Constraints/Sensitivity limit for νBDM scenario

Shielding by Earth crust due to large nu-DM cross section



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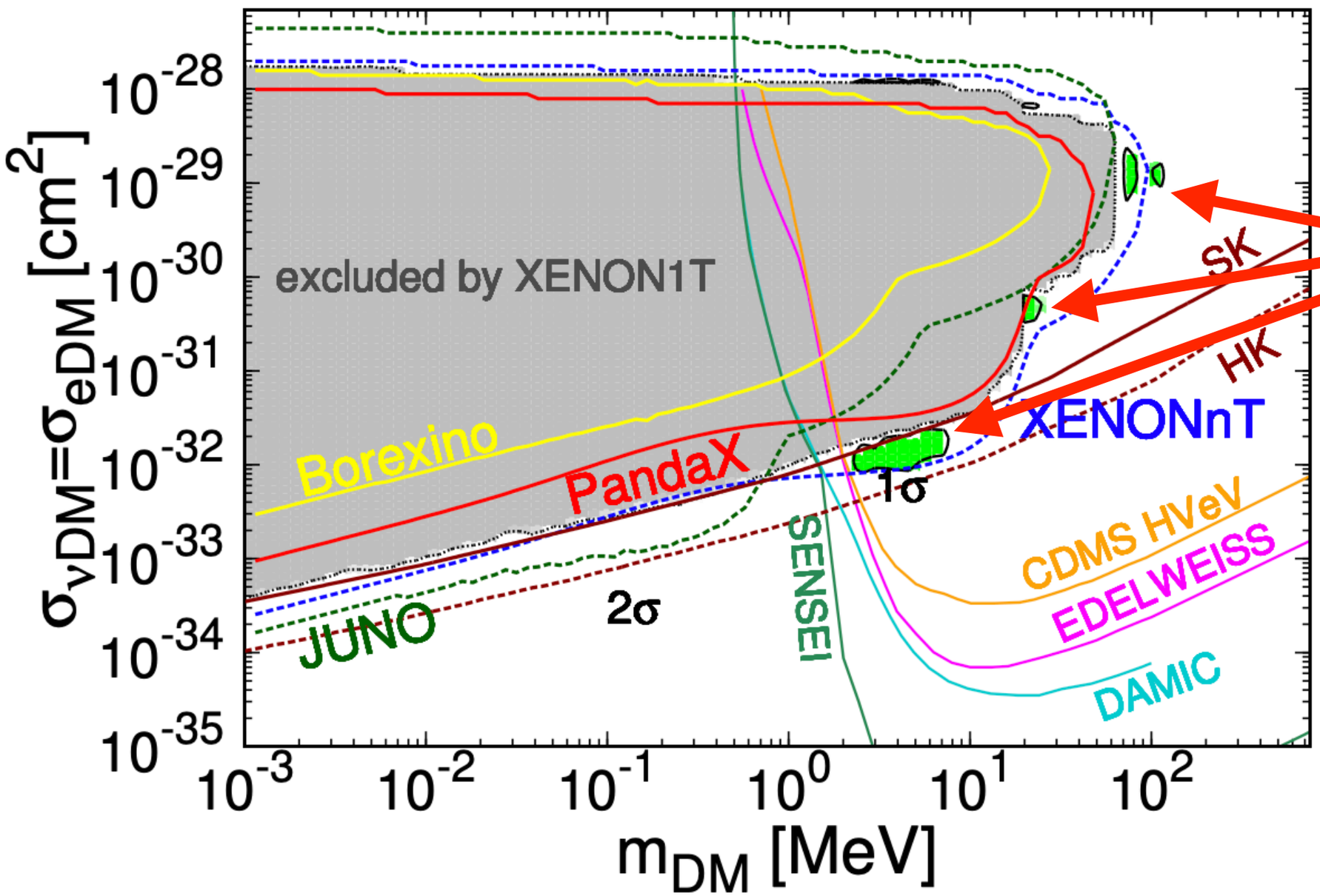
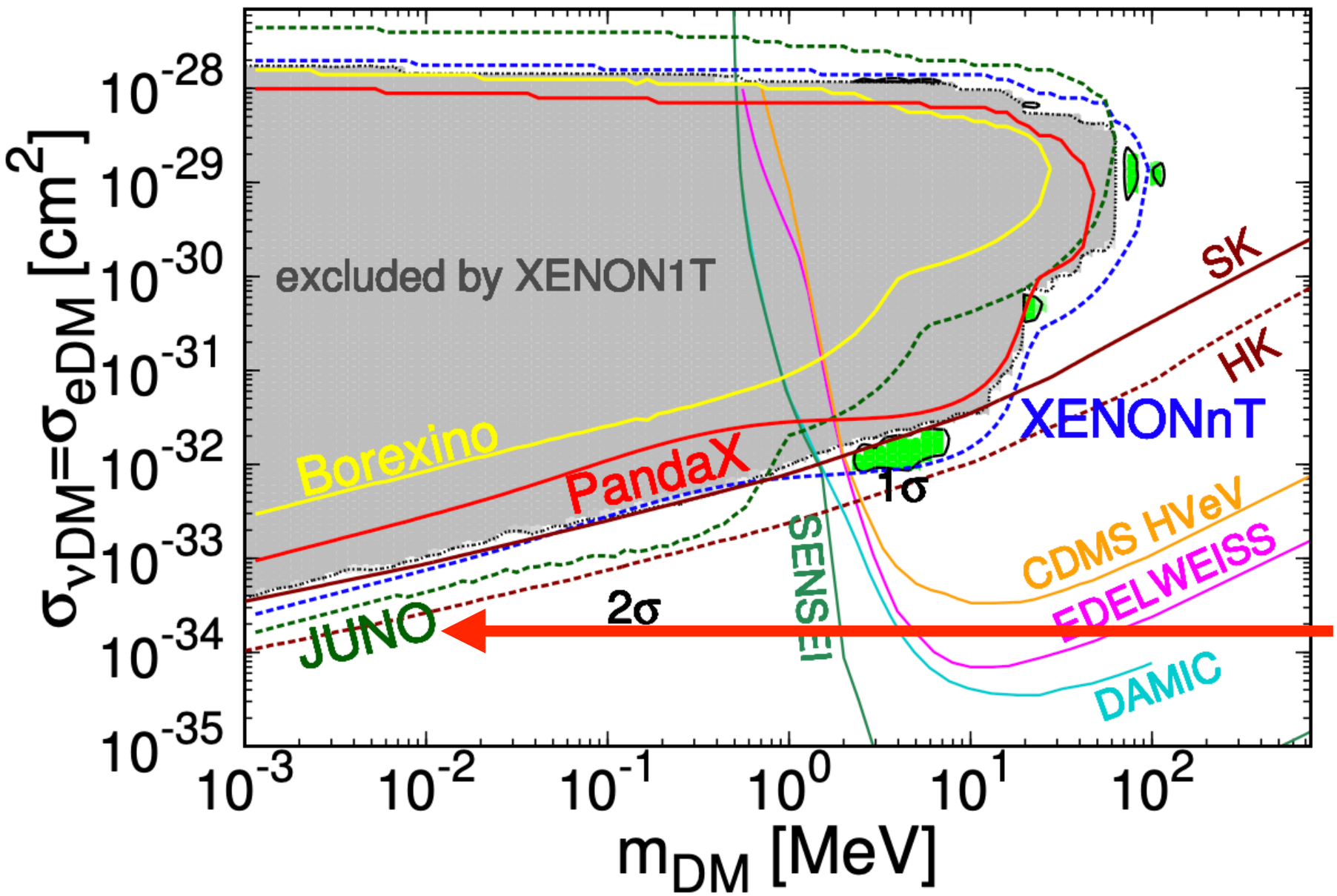


Bump structures from original solar neutrino spectrum

Constraints/Sensitivity limit for νBDM scenario

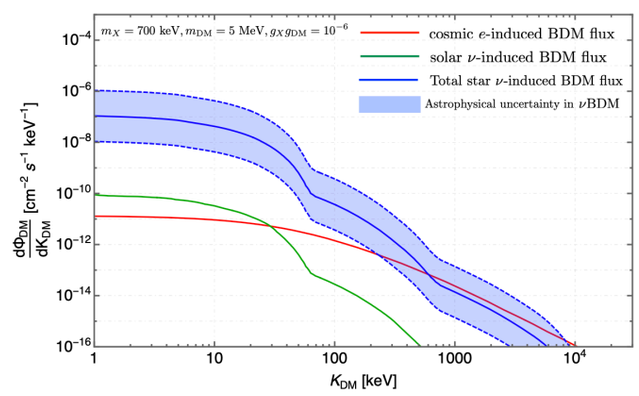


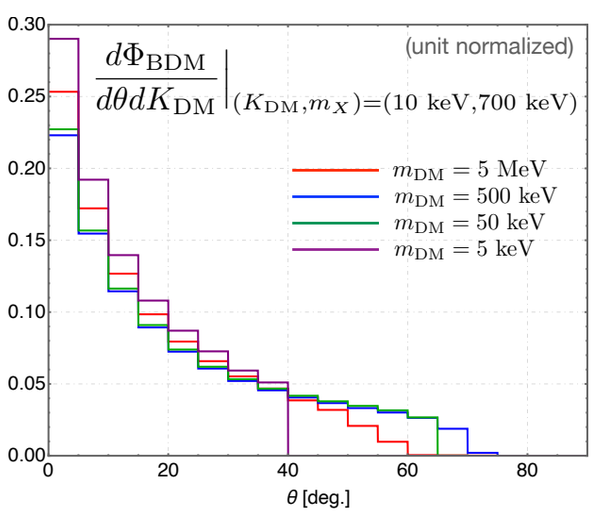
Future neutrino observatories (JUNO) with lower threshold Energies and Dark matter experiments (XENONnT/PandaX) can probe important parameters for nuBDM scenario.

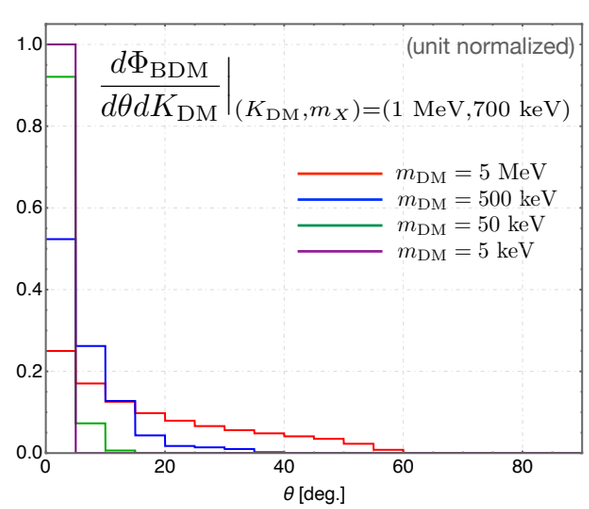
Conclusion

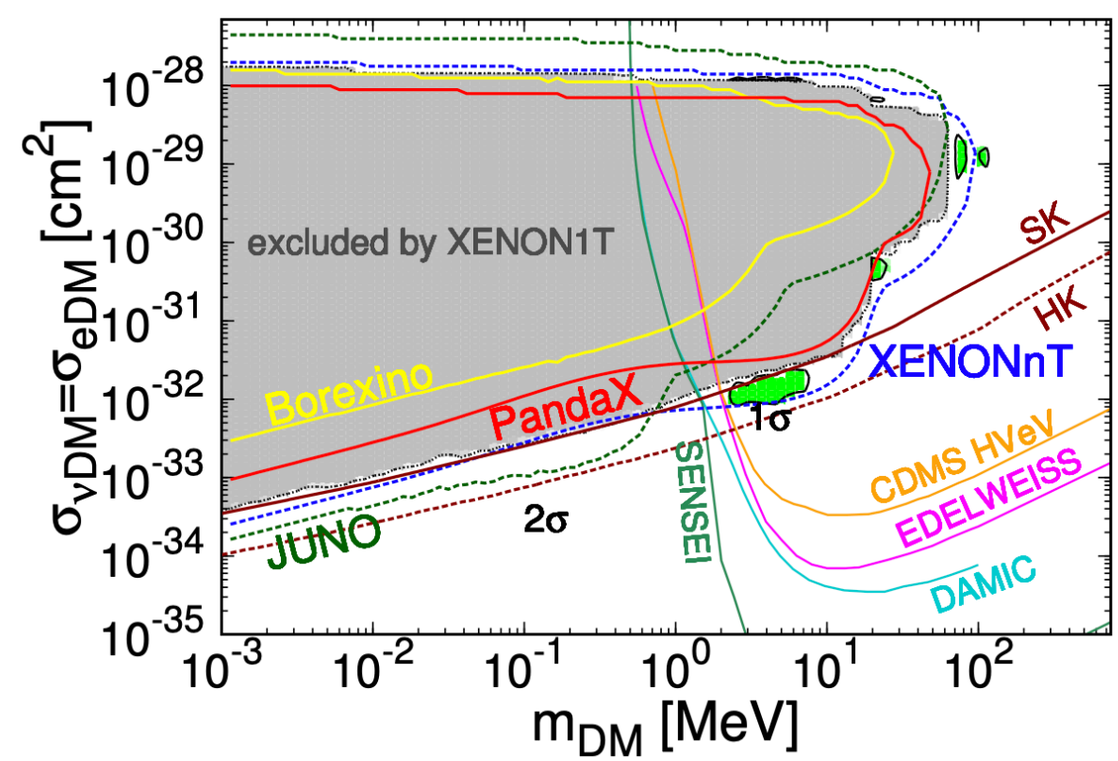
- We propose a novel mechanism to boost light dark matter particle by keV-MeV cosmic neutrinos emitted by stars in our galaxy.

- Improved sensitivities in future neutrino experiments (JUNO) and Dark matter direct detection experiments (XENONnT/ PandaX) & Non-trivial distribution of arrival direction and BDM spectrum could help to probe nuBDM scenario in near future.



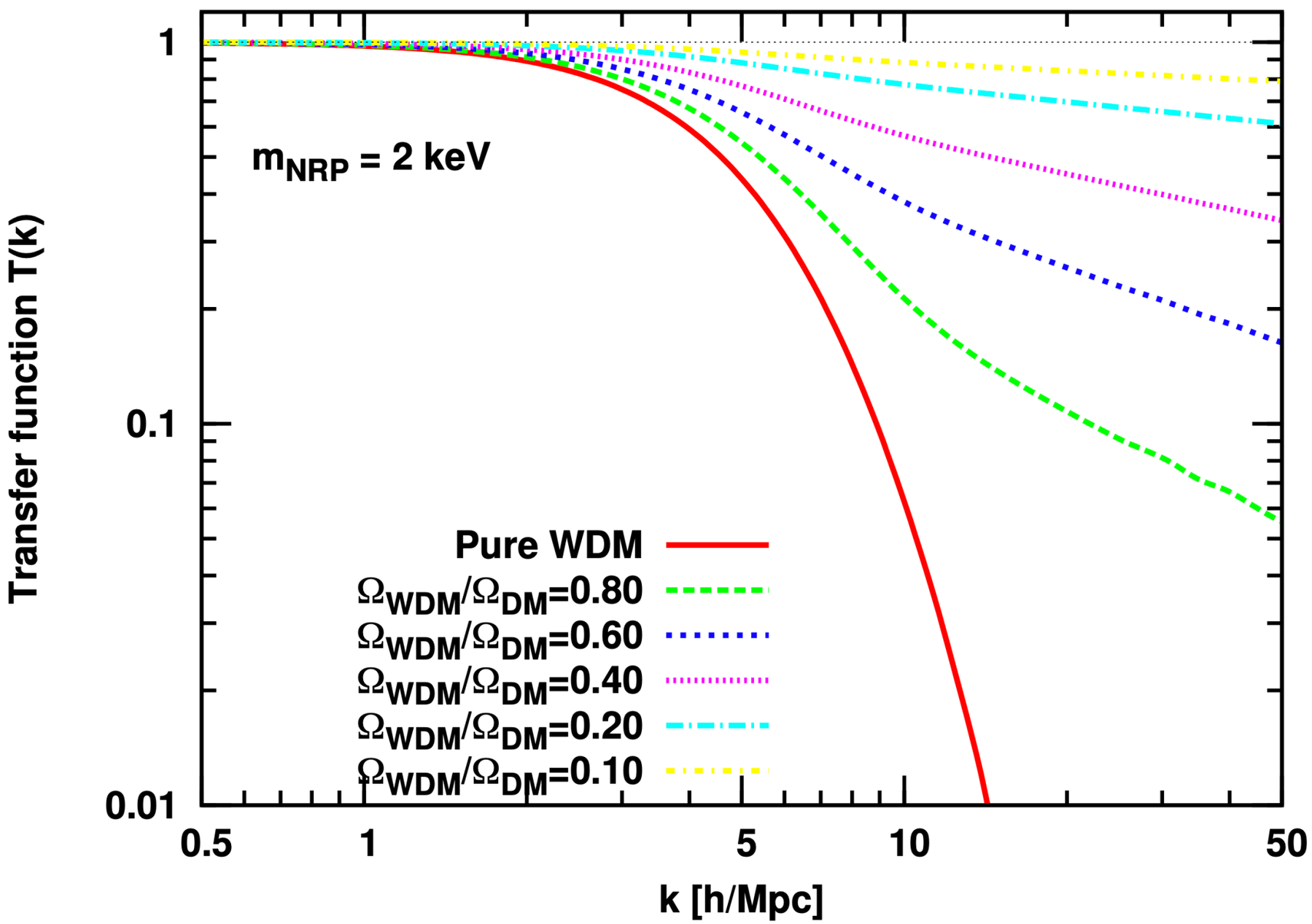






Thank you for your attention

Ly-alpha constraints on neutrino-DM interactions



[0812.0010] **[hep-ph]**

- >~10% fraction of light DM component can be constrained by Ly-alpha.