Neutrinos from the Sun can discover Dark Matter-Electron scattering

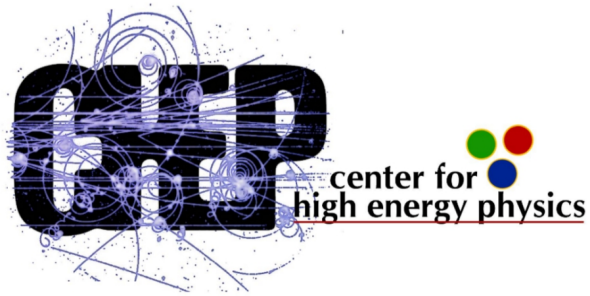
Akash Kumar Saha

Based on

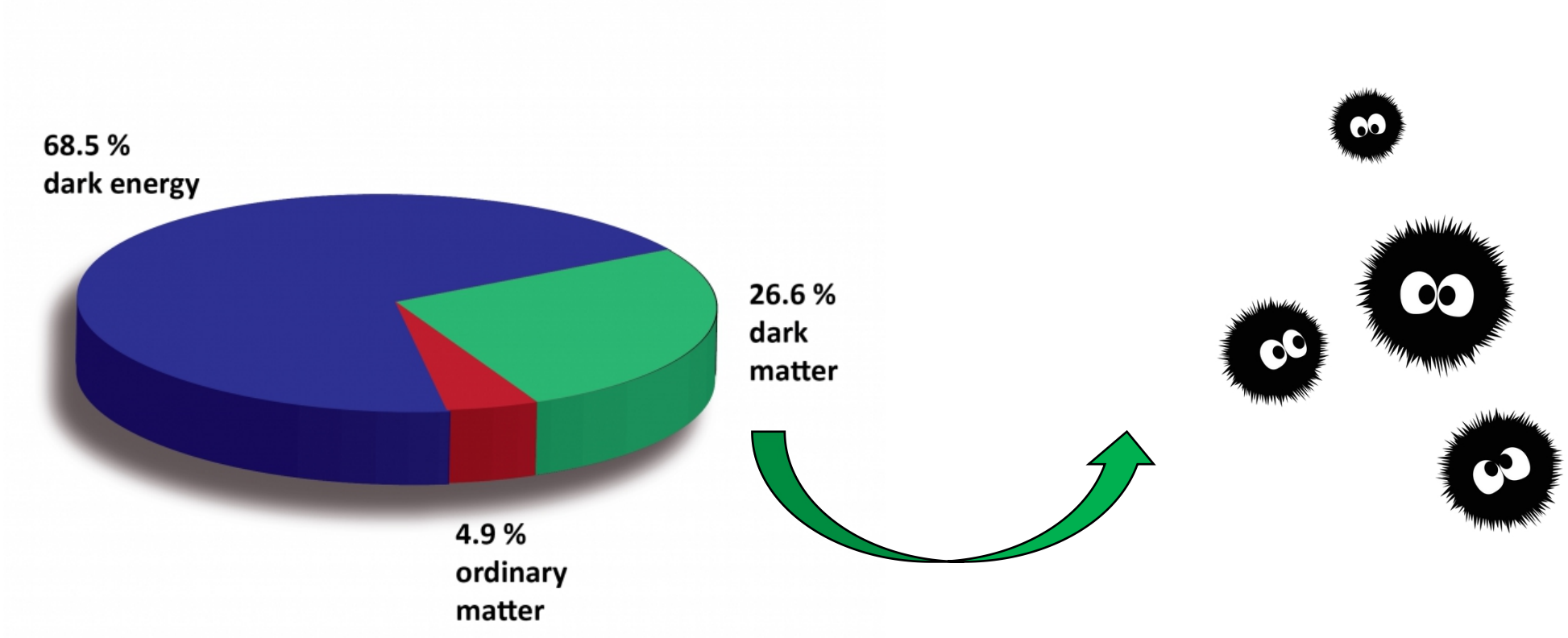
arXiv: 2308.12336

Tarak Nath Maity, AKS, Sagnik Mondal, Ranjan Laha

Centre for High Energy Physics
IISc Bangalore



Reality Check

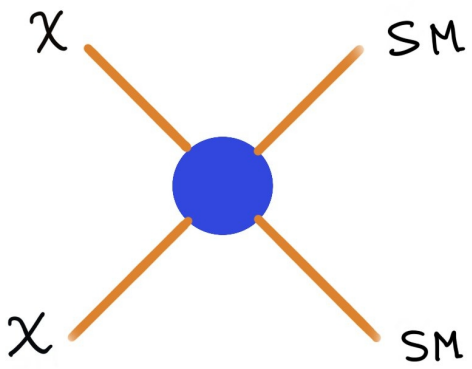


Credit: NIST

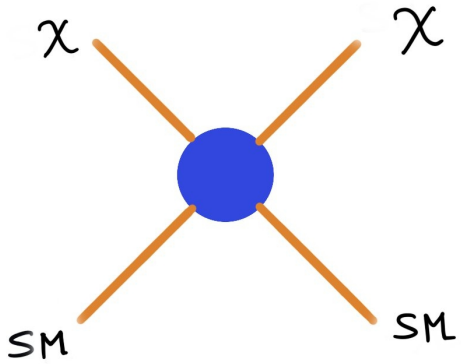
https://pngio.com/images/png-a2696042.html

Dark Matter detection

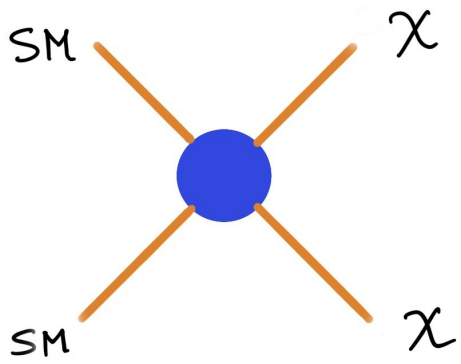
Indirect Detection



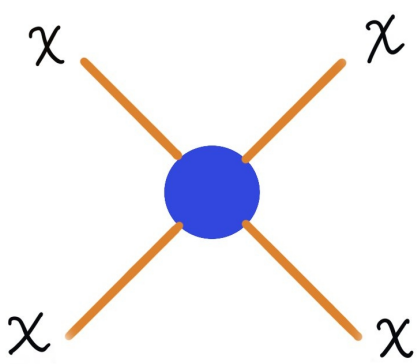
Direct Detection



Collider Search



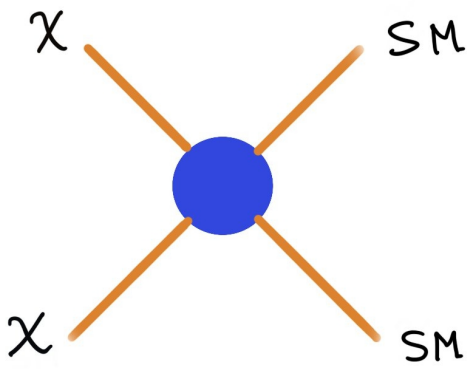
Astrophysical Search



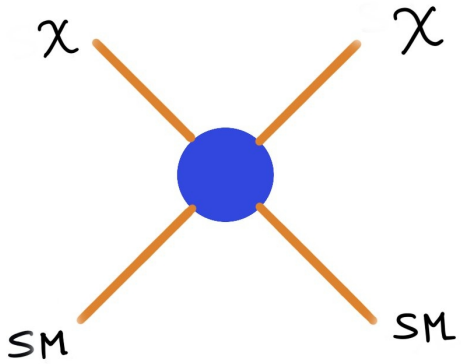
time

Dark Matter detection

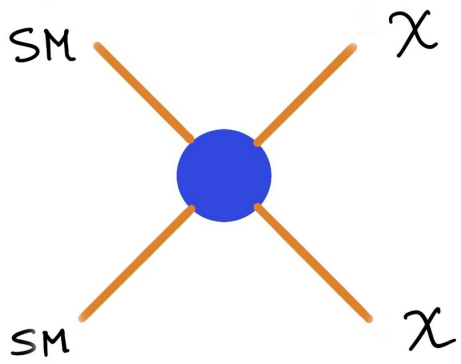
Indirect Detection



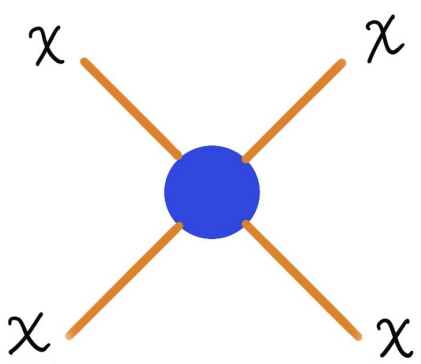
Direct Detection



Collider Search



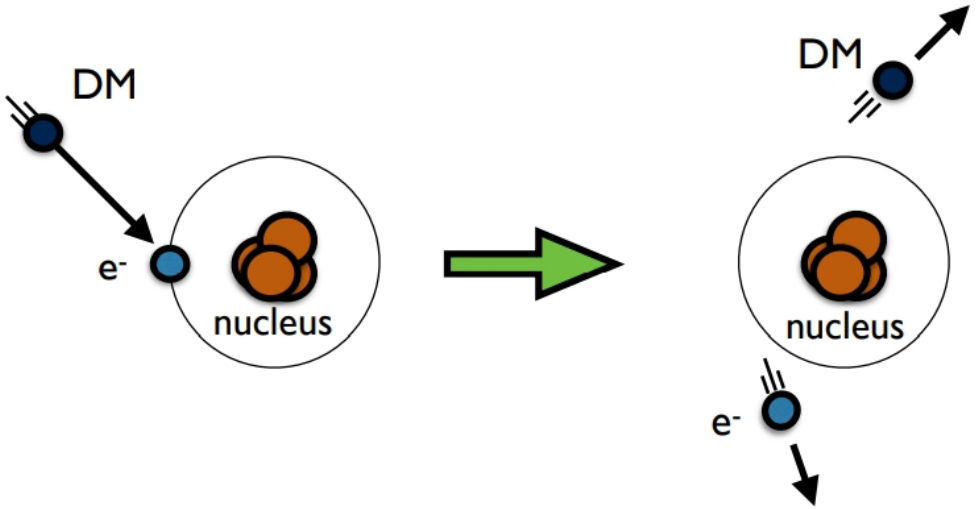
Astrophysical Search



This work

time

Dark Matter-electron scattering status



Rouven Essig, Mainz (2019)

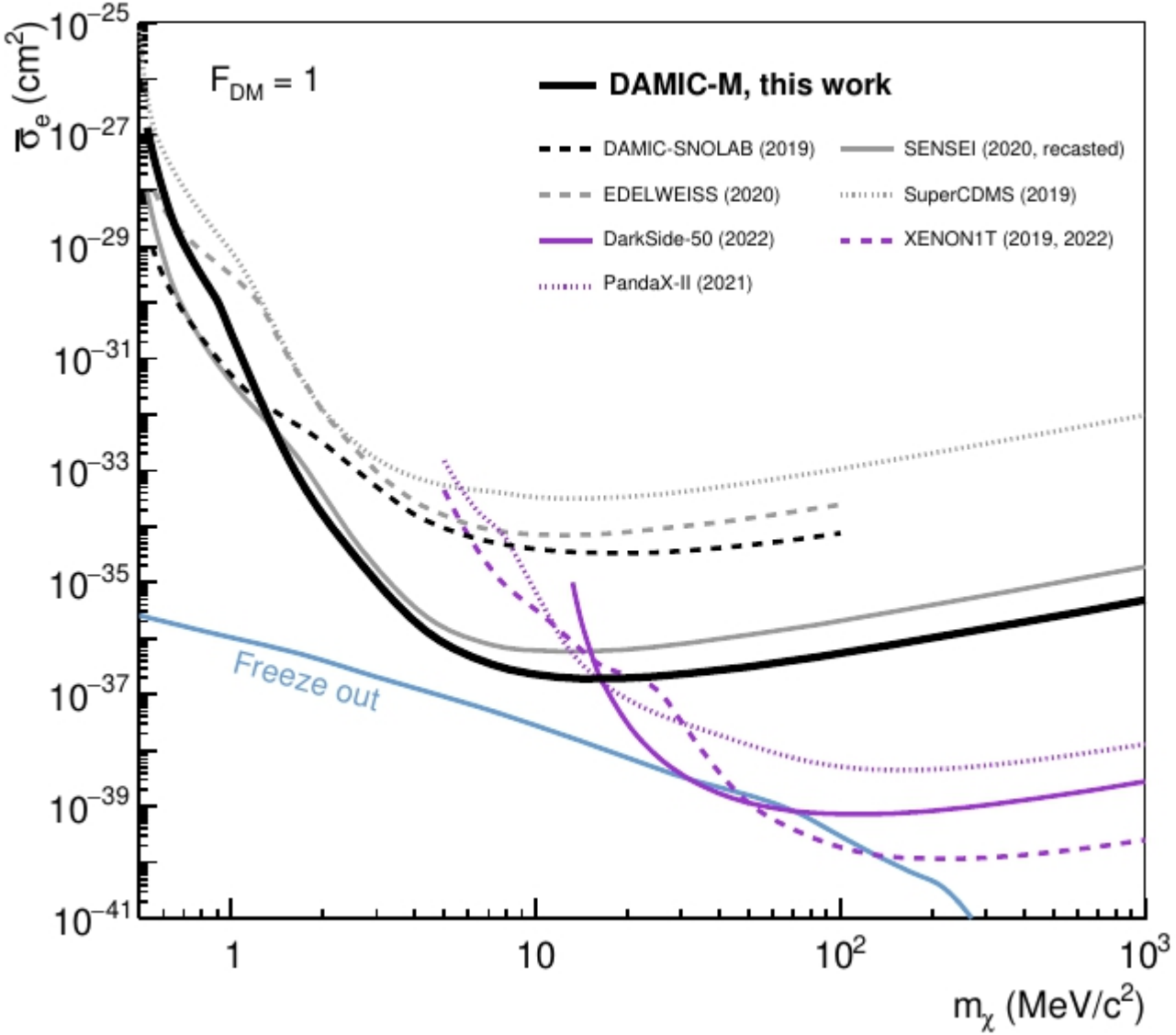
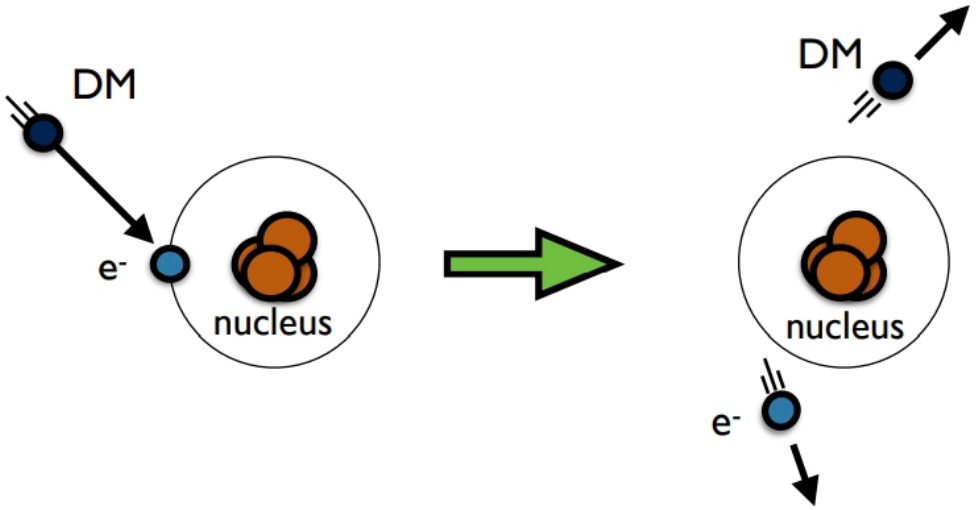


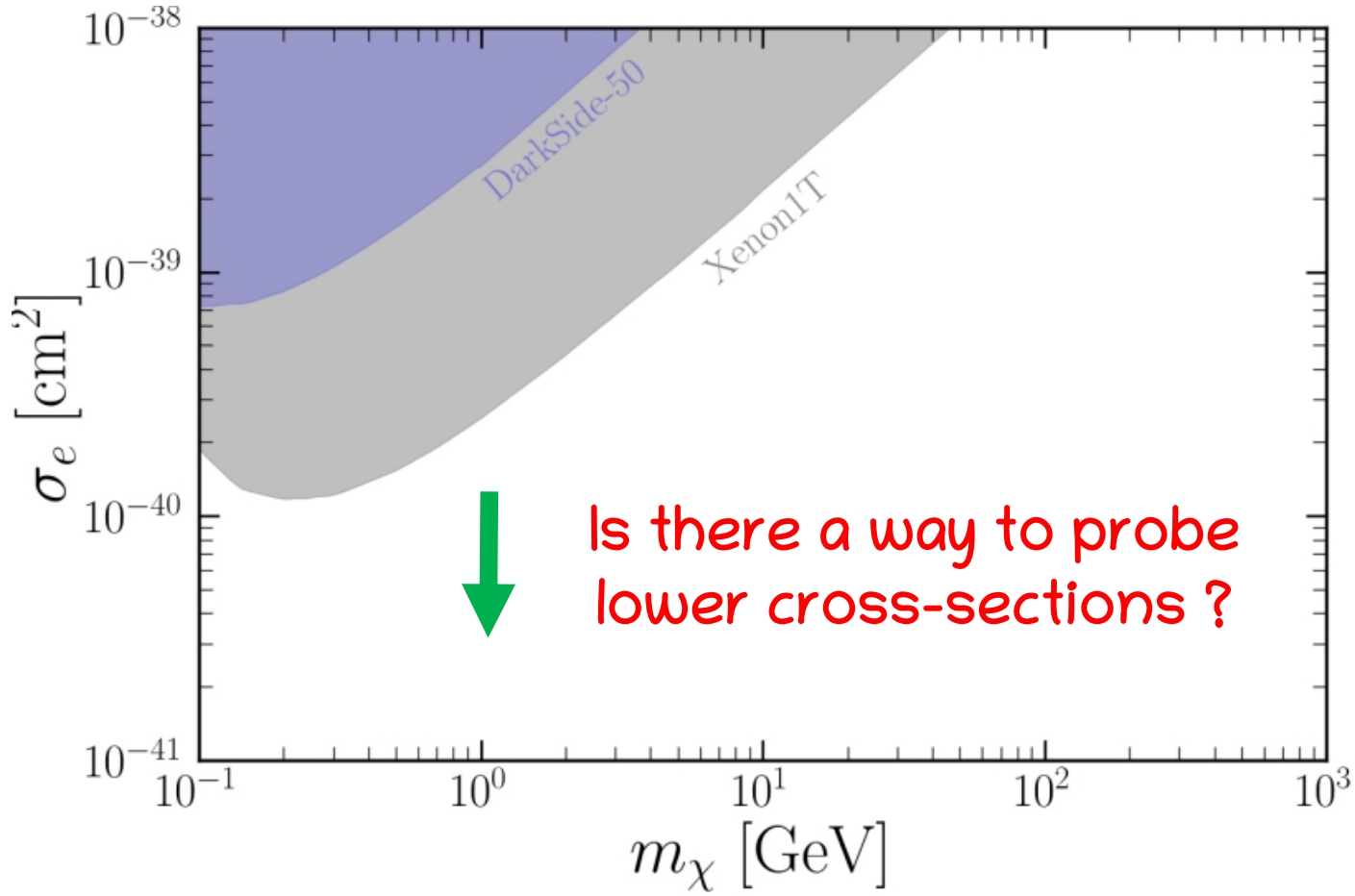
Fig.: 2302.02372

Dark Matter-electron scattering status



Rouven Essig, Mainz (2019)

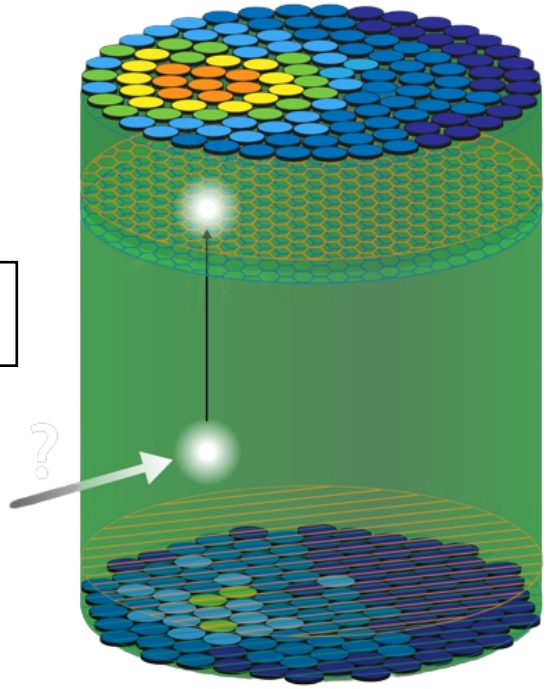
$$N = \frac{\rho_\chi}{m_\chi} \times V$$



Is there a way to probe lower cross-sections ?

So whats the solution ?

Xenon1T



Exposure: ~ 22 tonne-day

Fig.: APS/Alan Stonebraker

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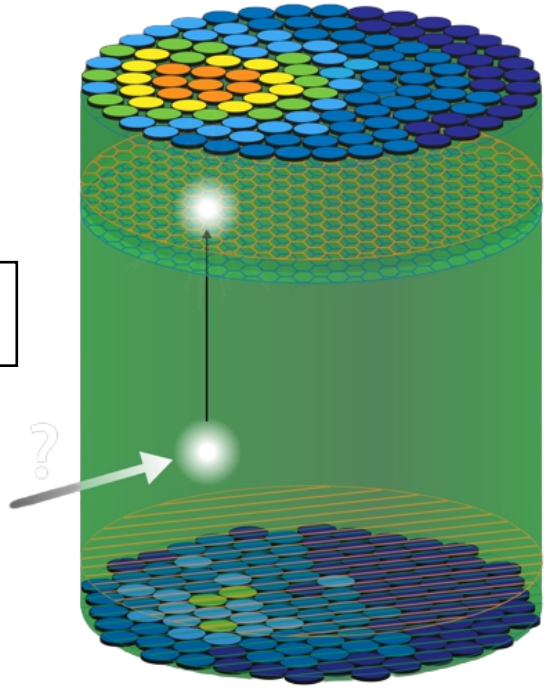
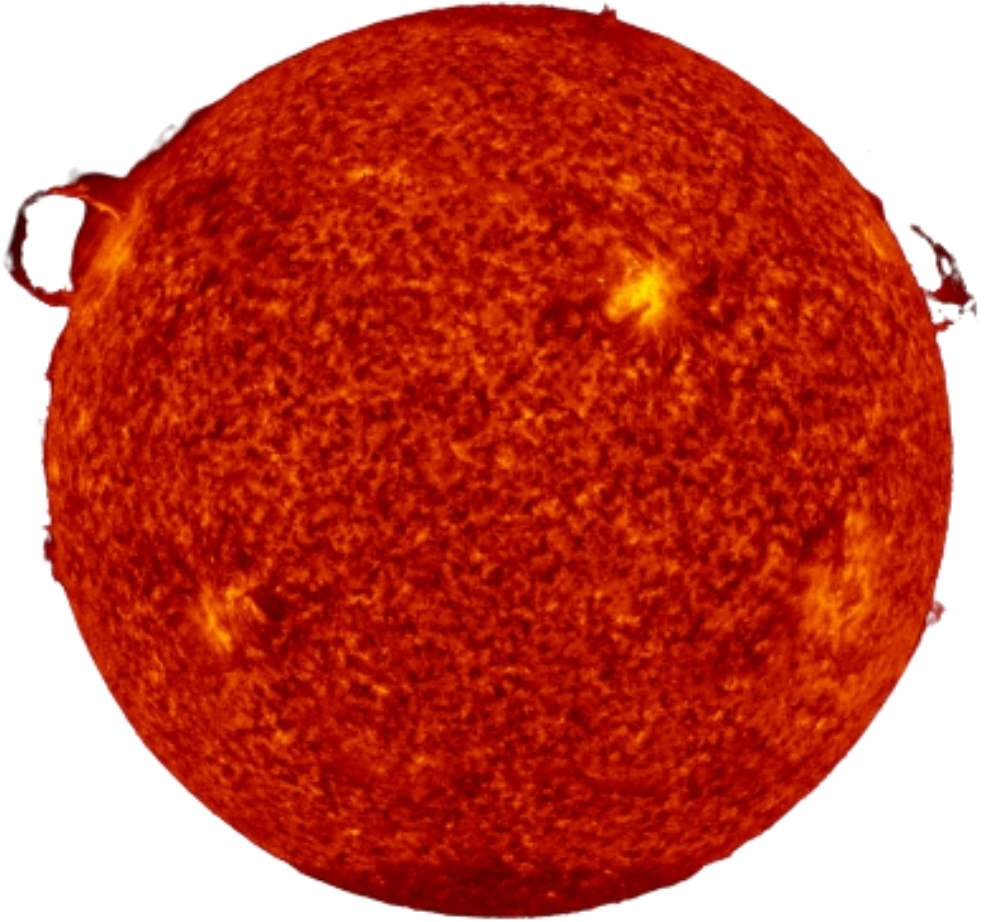


The Sun



Exposure: ~ 22 tonne-day

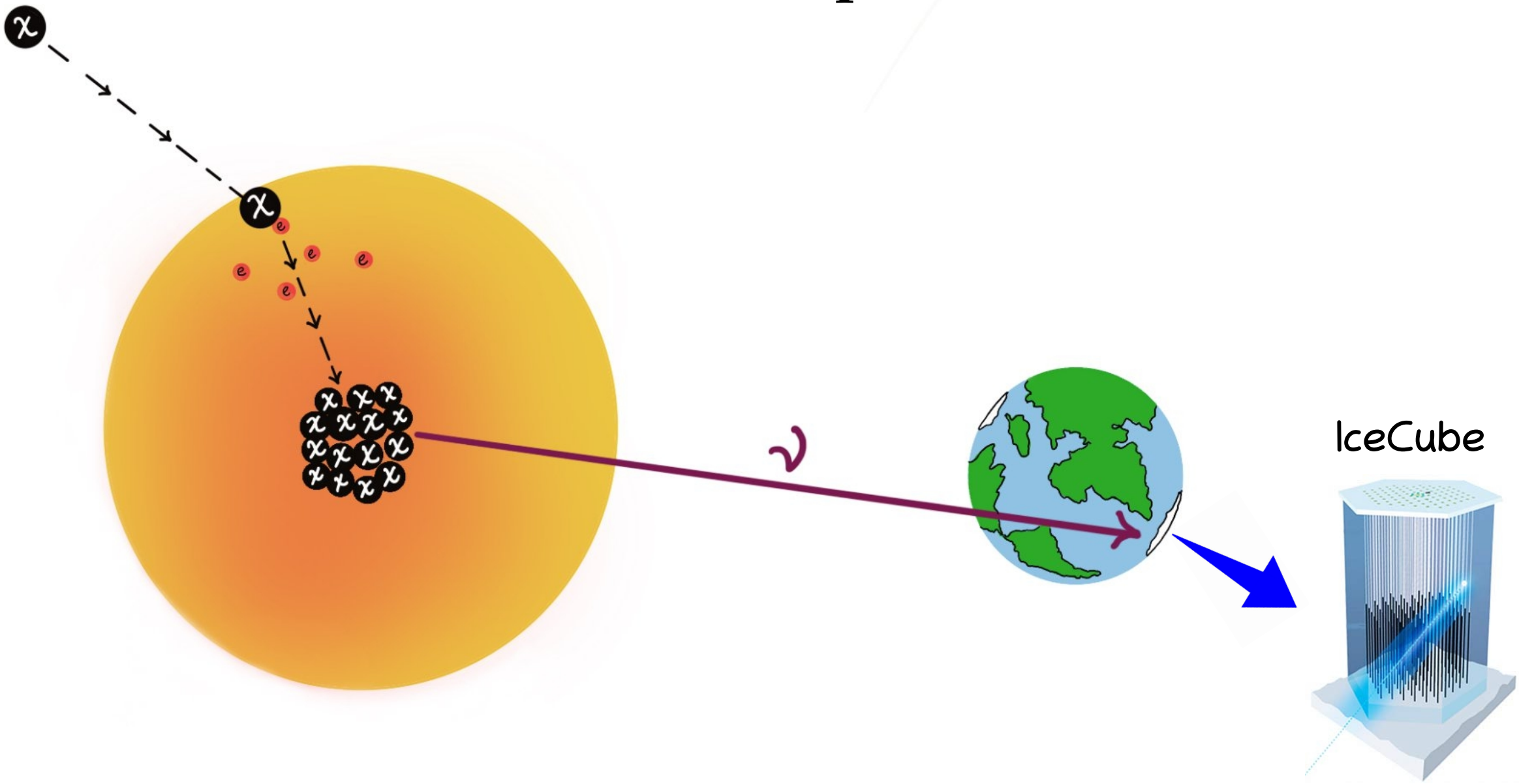
~ 10^{28} tonne-Gyr

Fig.: APS/Alan Stonebraker

Fig.: https://svs.gsfc.nasa.gov/10610

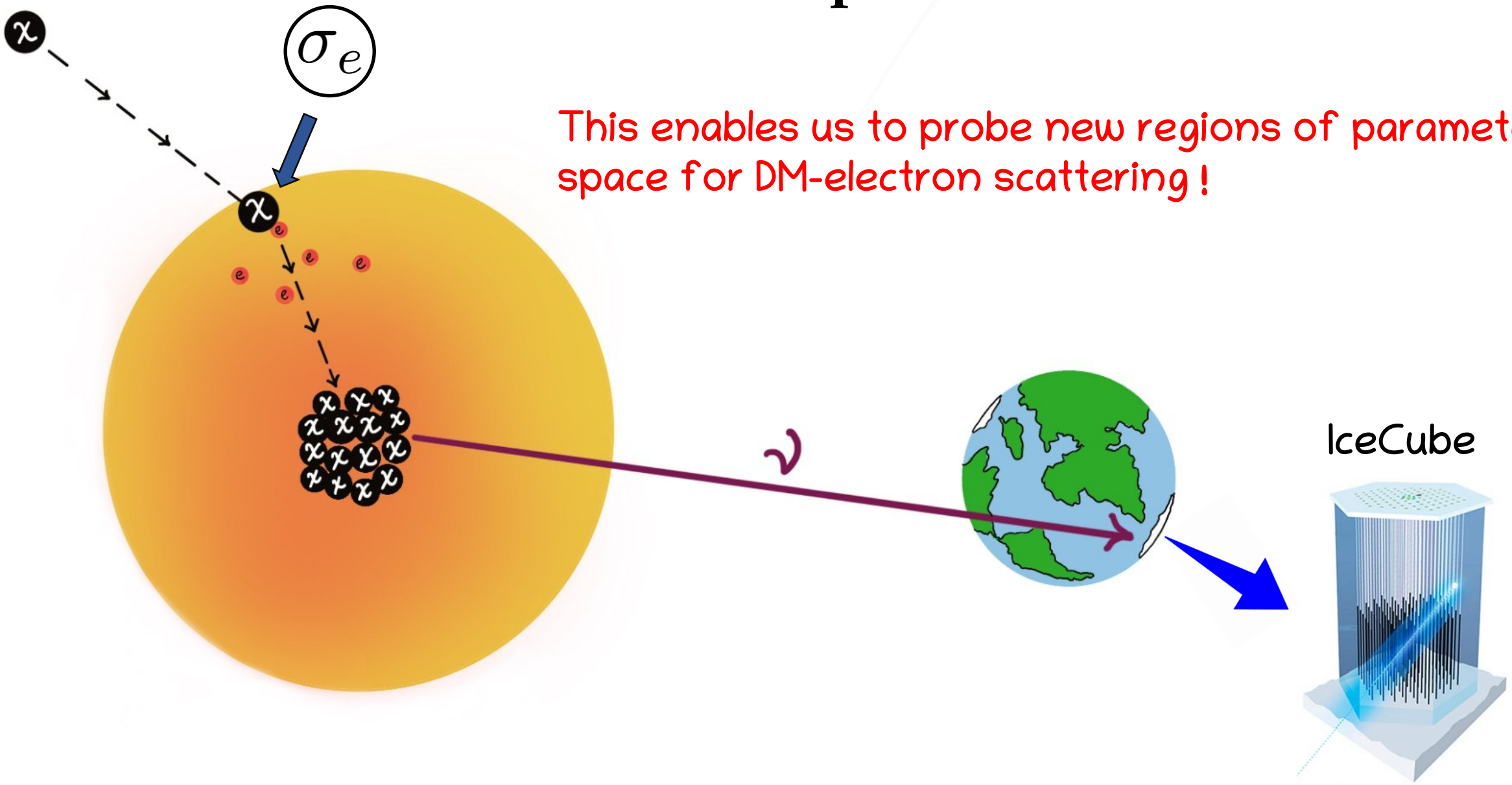
Can we use the Sun as our DM detector ?

Our Proposal



https://skyandtelescope.org/wp-content/uploads/IceCube-detection_300px.jpg

Our Proposal



This enables us to probe new regions of parameter space for DM-electron scattering !

https://skyandtelescope.org/wp-content/uploads/IceCube-detection_300px.jpg

Dark Matter capture in the Sun

$$C_\odot = \int_0^{R_\odot} 4\pi r^2 n_e(r) dr \int_0^\infty du_\chi \left(\frac{\rho_\chi}{m_\chi}\right) \frac{f_{v_\odot}(u_\chi)}{u_\chi} (u_\chi^2 + v_e^2(r)) g(w) \sigma_e$$

Capture rate of DM inside the Sun

Total number of Solar electrons

Incident DM flux

Capture probability

See Kopp et al. (0907.3159), Garani et al. (1702.02768)

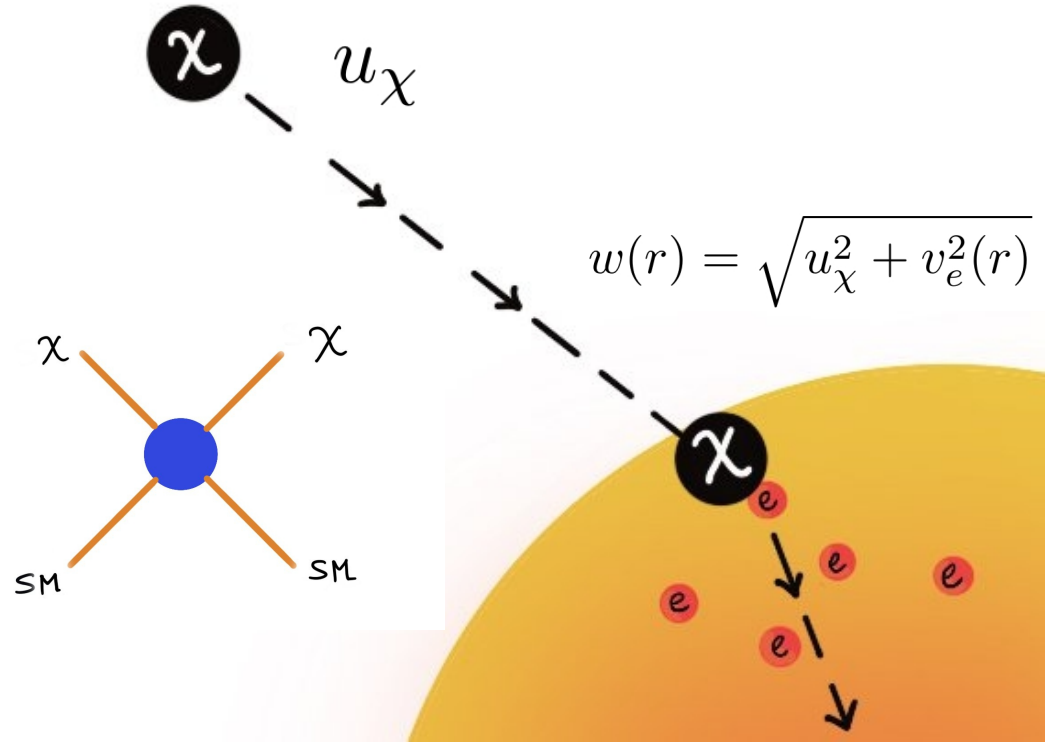
$n_e(r)$ → Number density of Solar electrons

ρ_χ → DM density at Solar neighbourhood

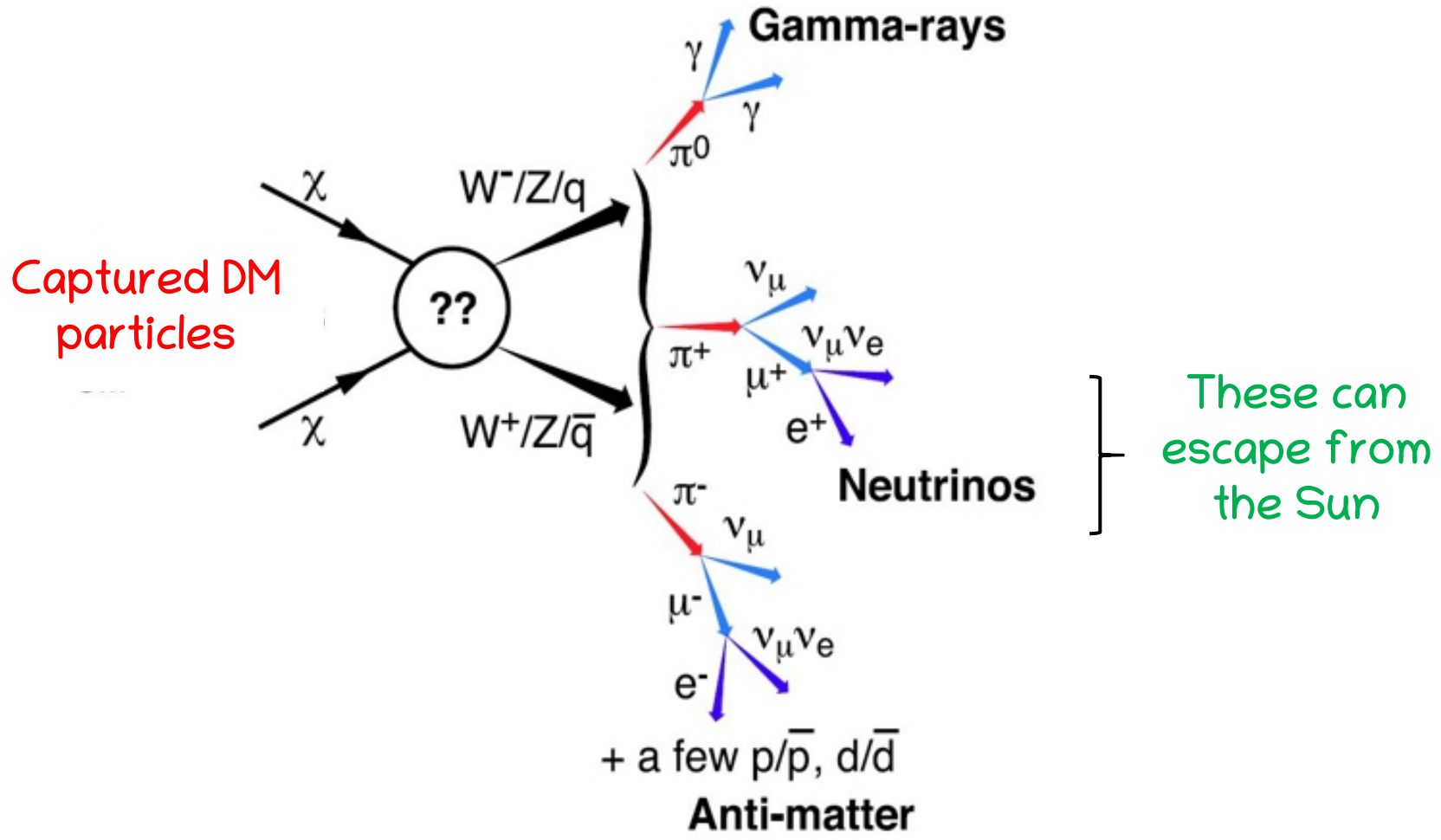
m_χ → Mass of DM particle

$f_{v_\odot}(u_\chi)$ → DM velocity distribution at Solar position

σ_e → DM-electron cross-section



Captured Dark Matter annihilation



Captured DM particles

These can escape from the Sun

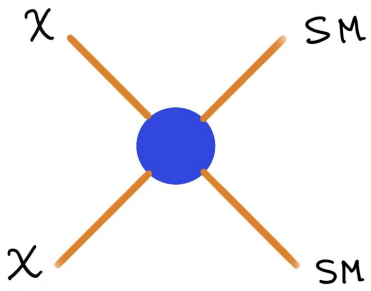


Fig: https://fermi.gsfc.nasa.gov/science/eteu/dm/

Neutrino detection by IceCube and DeepCore

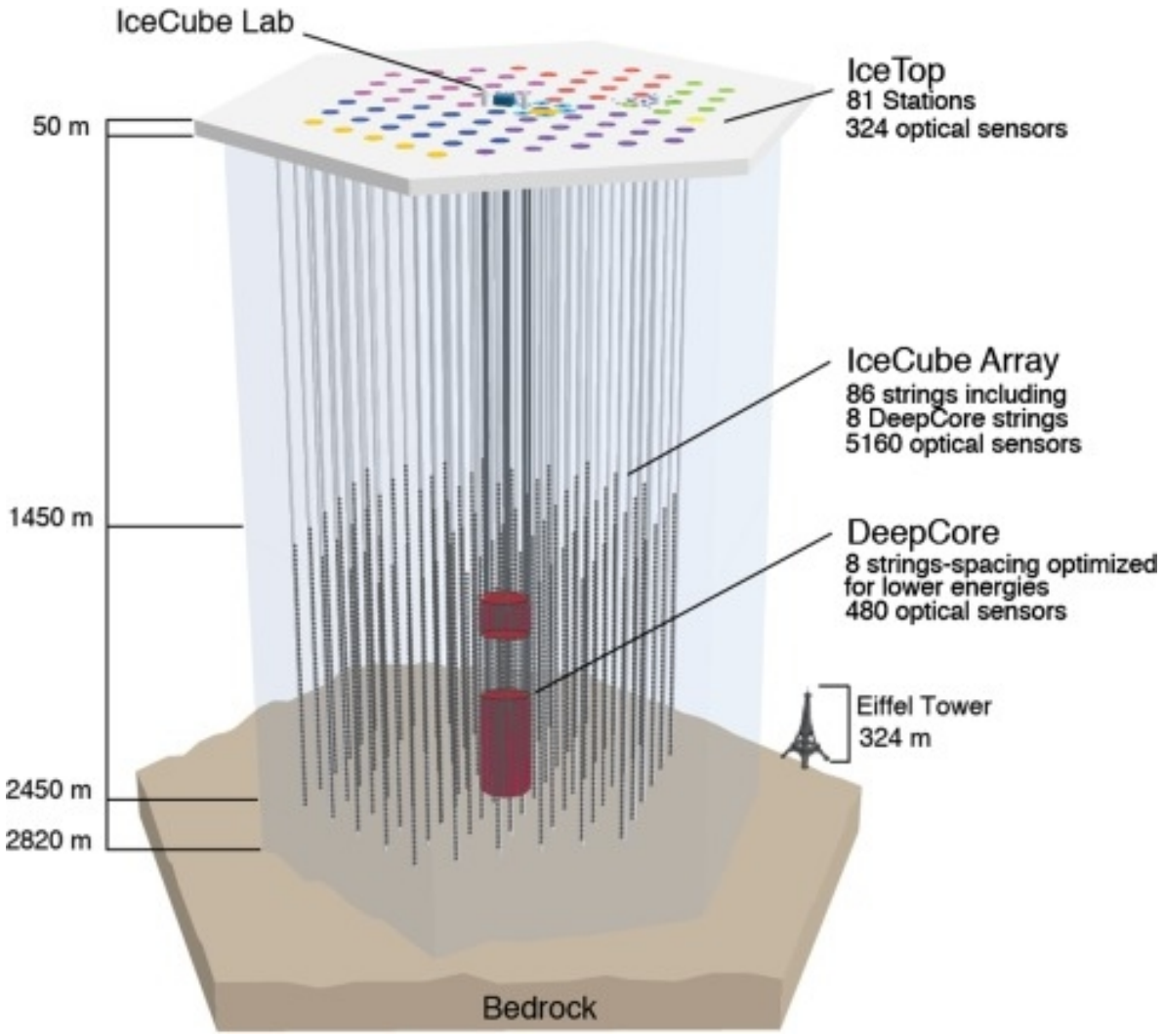


Fig. credit: IceCube Collaboration

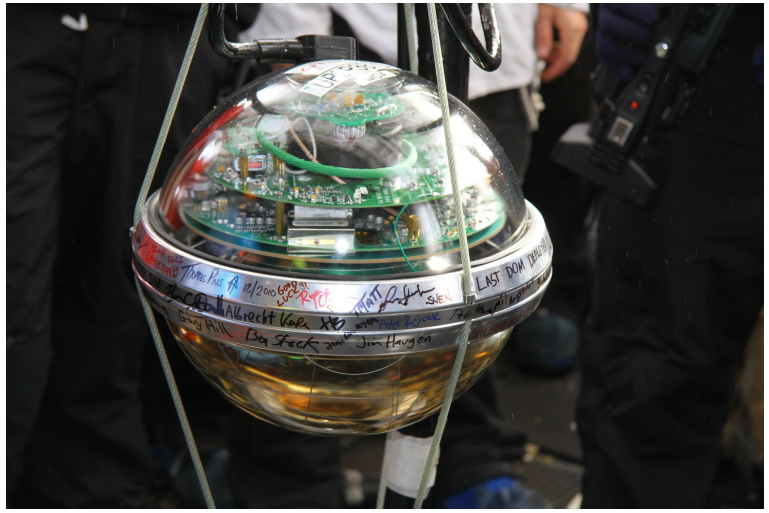


Photo: R. Schwarz

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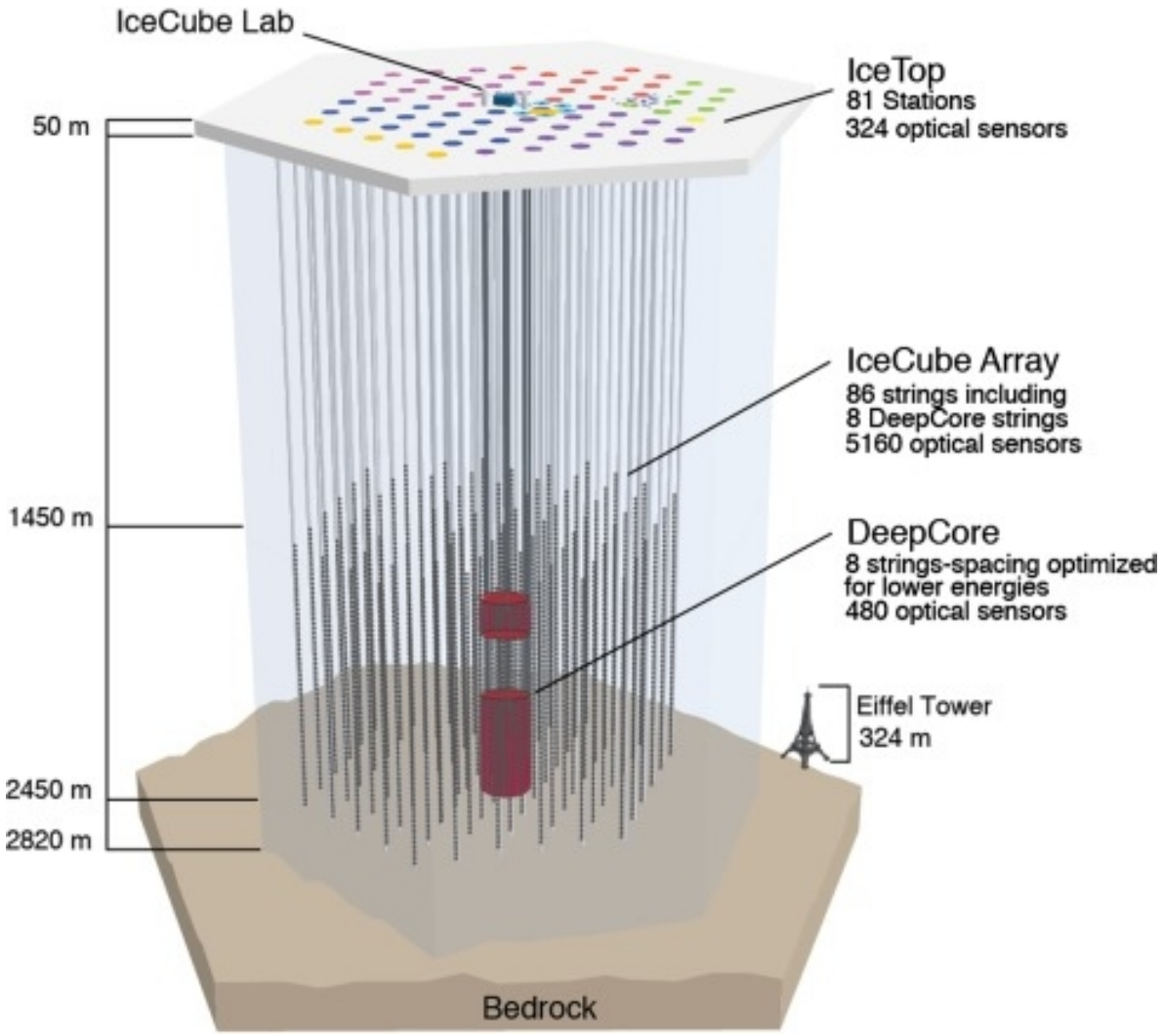

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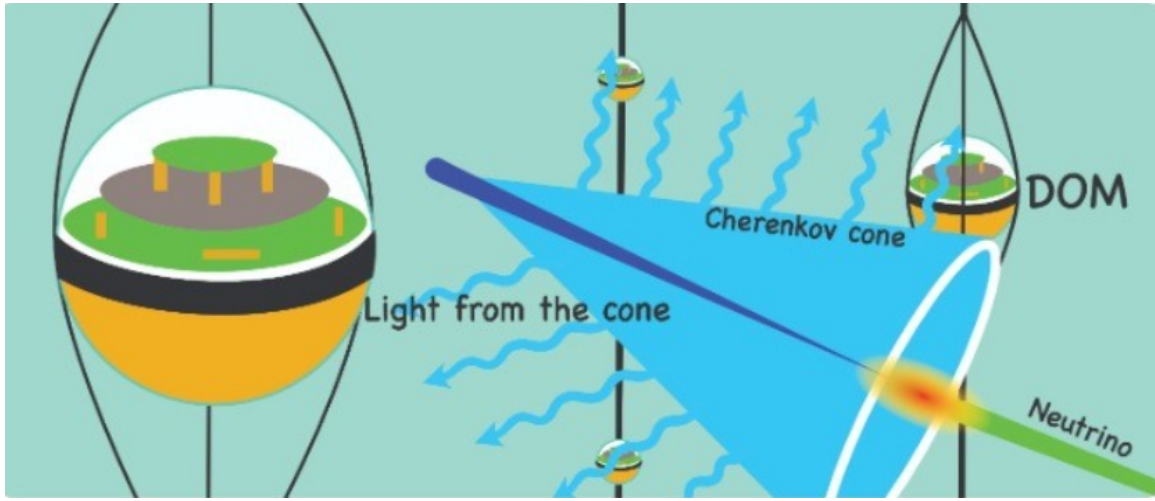
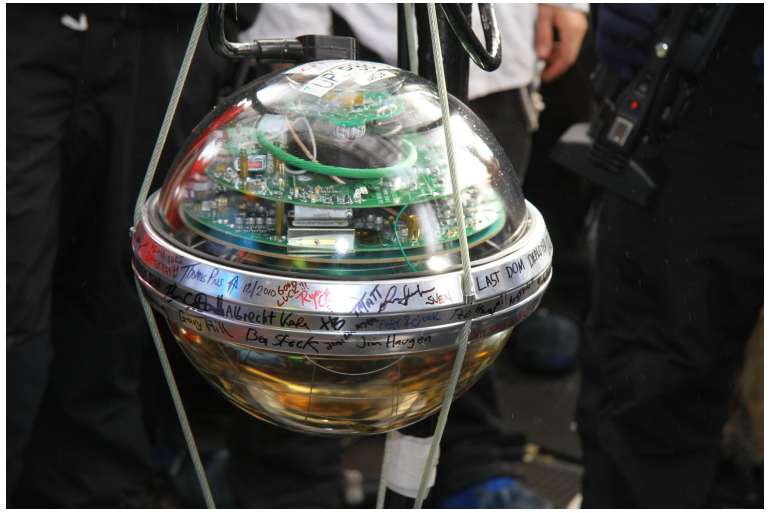


Fig. credit: Kunal Deoskar



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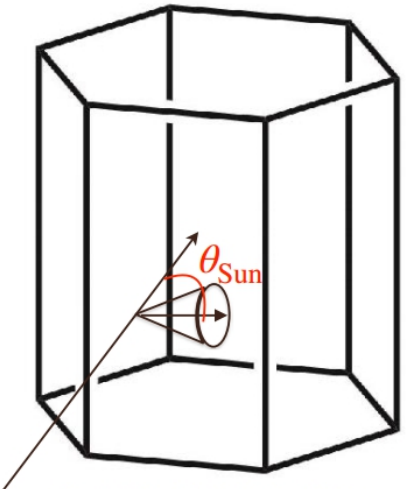
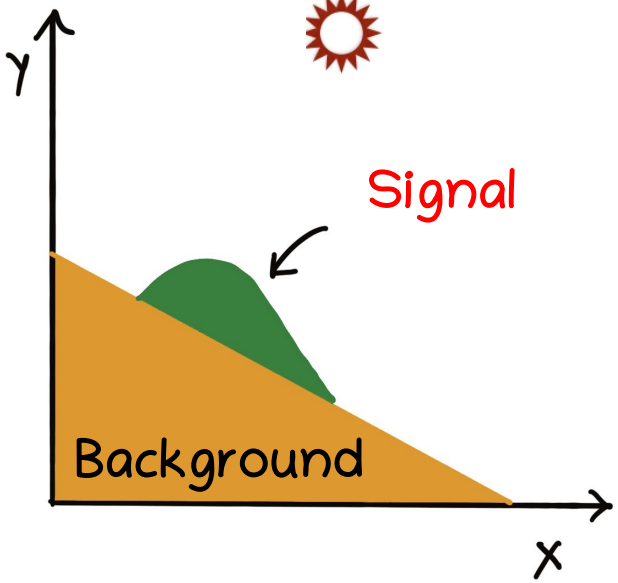
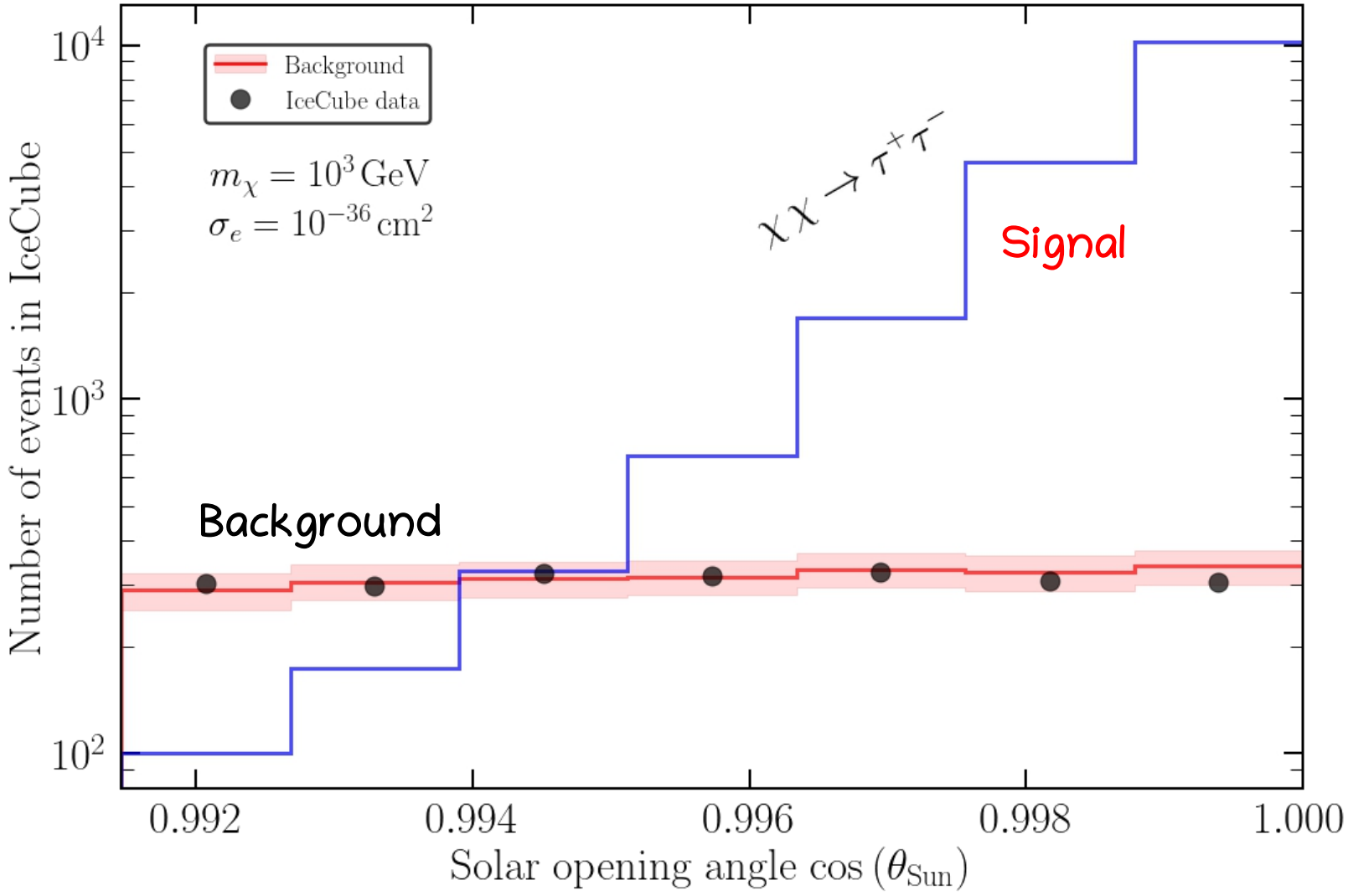
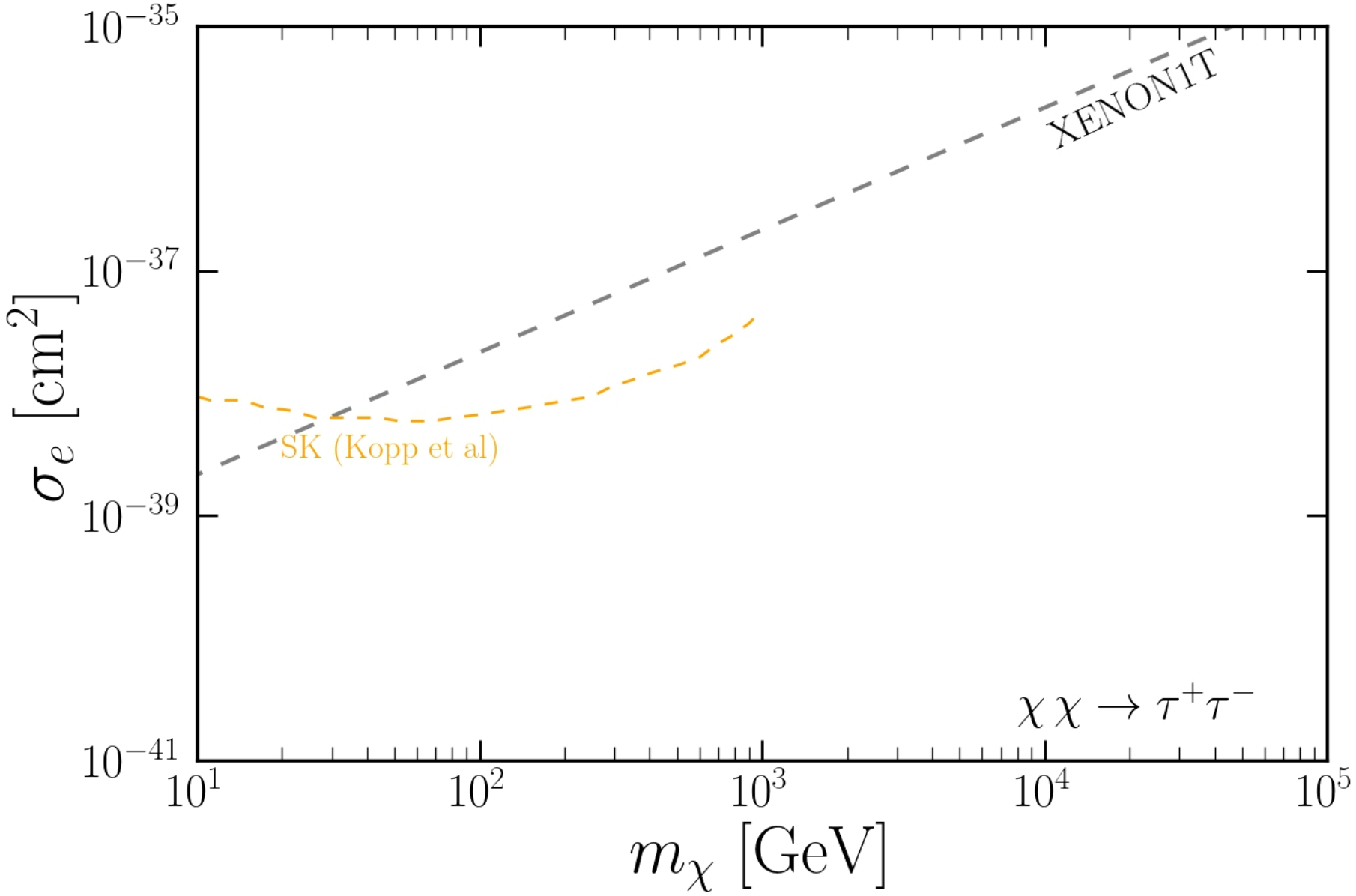


fig. credit: Tarak Nath Maity



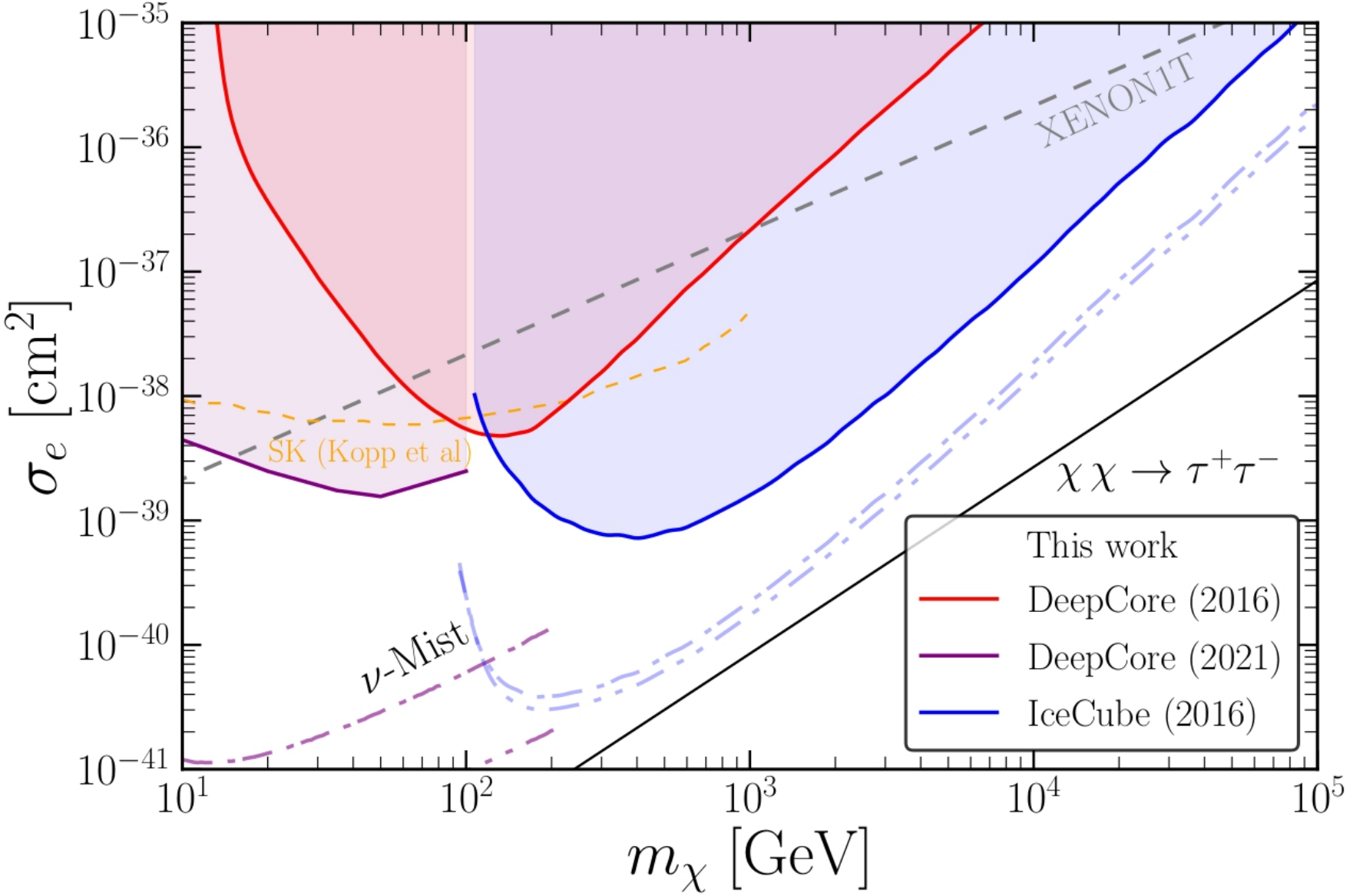


Our result



Previous limits in the parameter space

Our result



Tarak Nath Maity, AKS, Sagnik Mondal, and Ranjan Laha

(arXiv: 2308.12336)

Conclusion

- Due to DM-electron scattering, local DM particles can get captured inside the Sun.
- These captured DM particles can annihilate and produce neutrinos that can be detected by terrestrial experiments like IceCube, DeepCore. Using the latest data-sets from these experiments we obtain world-leading bounds on DM-electron scattering cross-section.
- In future, IceCube and other neutrino experiments like KM3NeT, Hyper-Kamiokande will be able to discover DM-electron scattering.

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Thank You

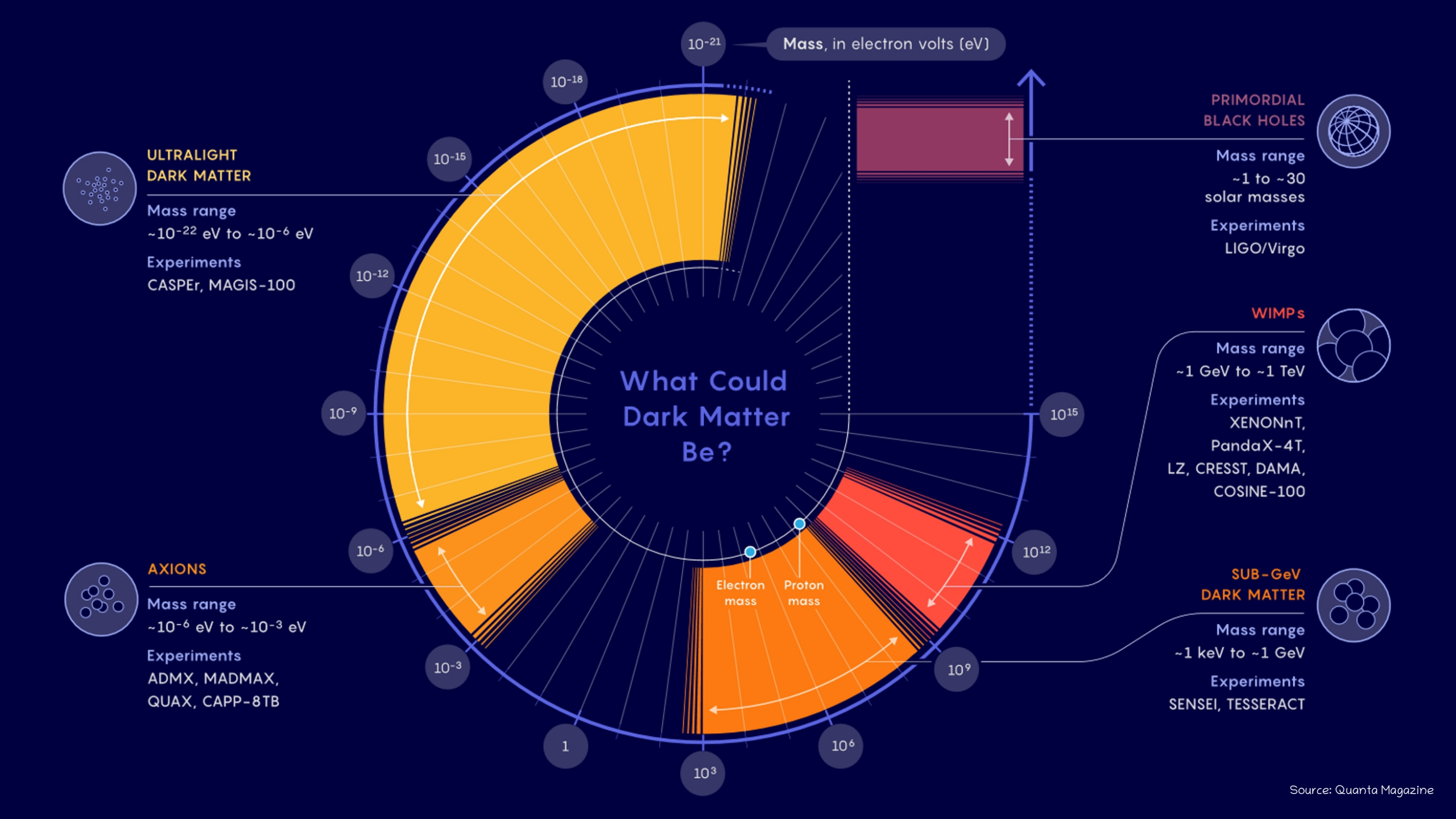
Extra Slides

Target materials for electron recoils?

Type	Examples	mass threshold	ΔE
Noble liquid	xenon	~5 MeV	~10 eV
Semiconductor	silicon	~500 keV	~1 eV
Scintillator	gallium-arsenide	~500 keV	~1 eV
Many other ideas	Graphene, superconductors, Dirac materials, polar crystals	various (> keV)	various (> meV)

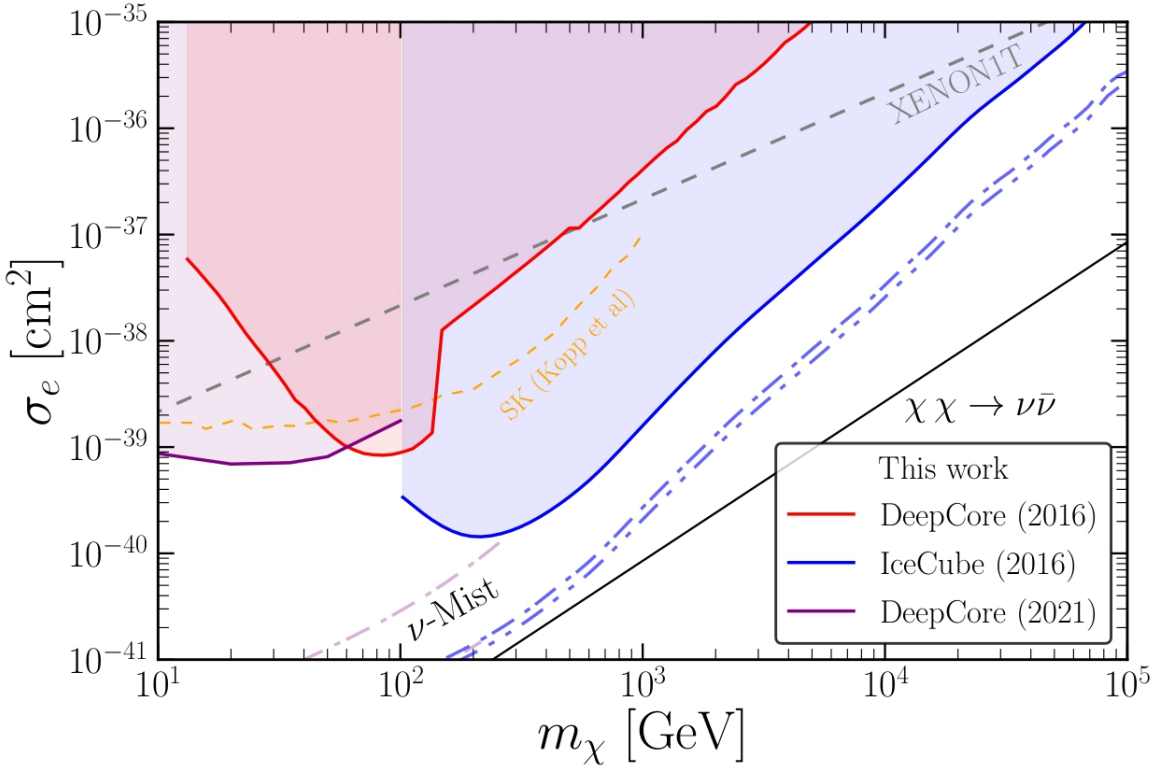
Hochberg, Kahn, Lisanti, Tully, Zurek
Hochberg, Zhao, Zurek
Hochberg, Pyle, Zhao, Zurek
Hochberg, Lin, Zurek
Hochberg, Kahn, Lisanti, Zurek, Grushin, Ilan, Griffin, Liu, Weber, Neaton
Knapen, Lin, Pyle, Zurek
Griffin, Knapen, Lin, Zurek

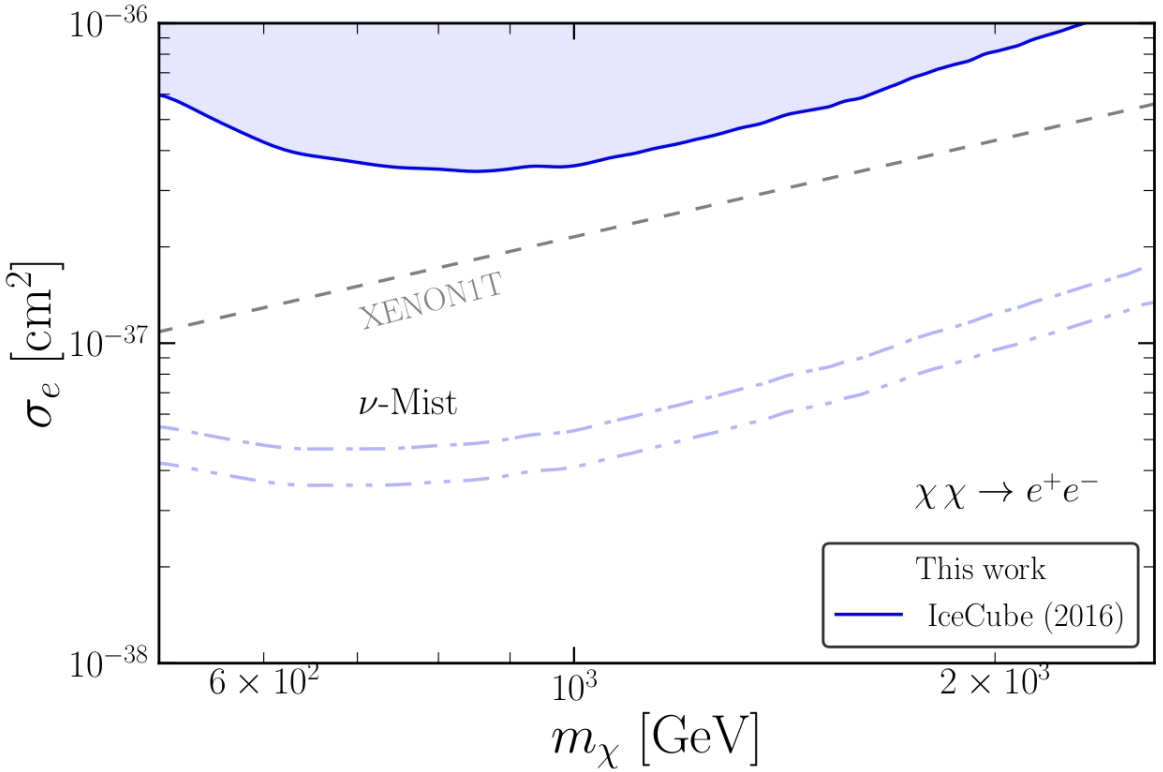
Slide credit: Rouven Essig



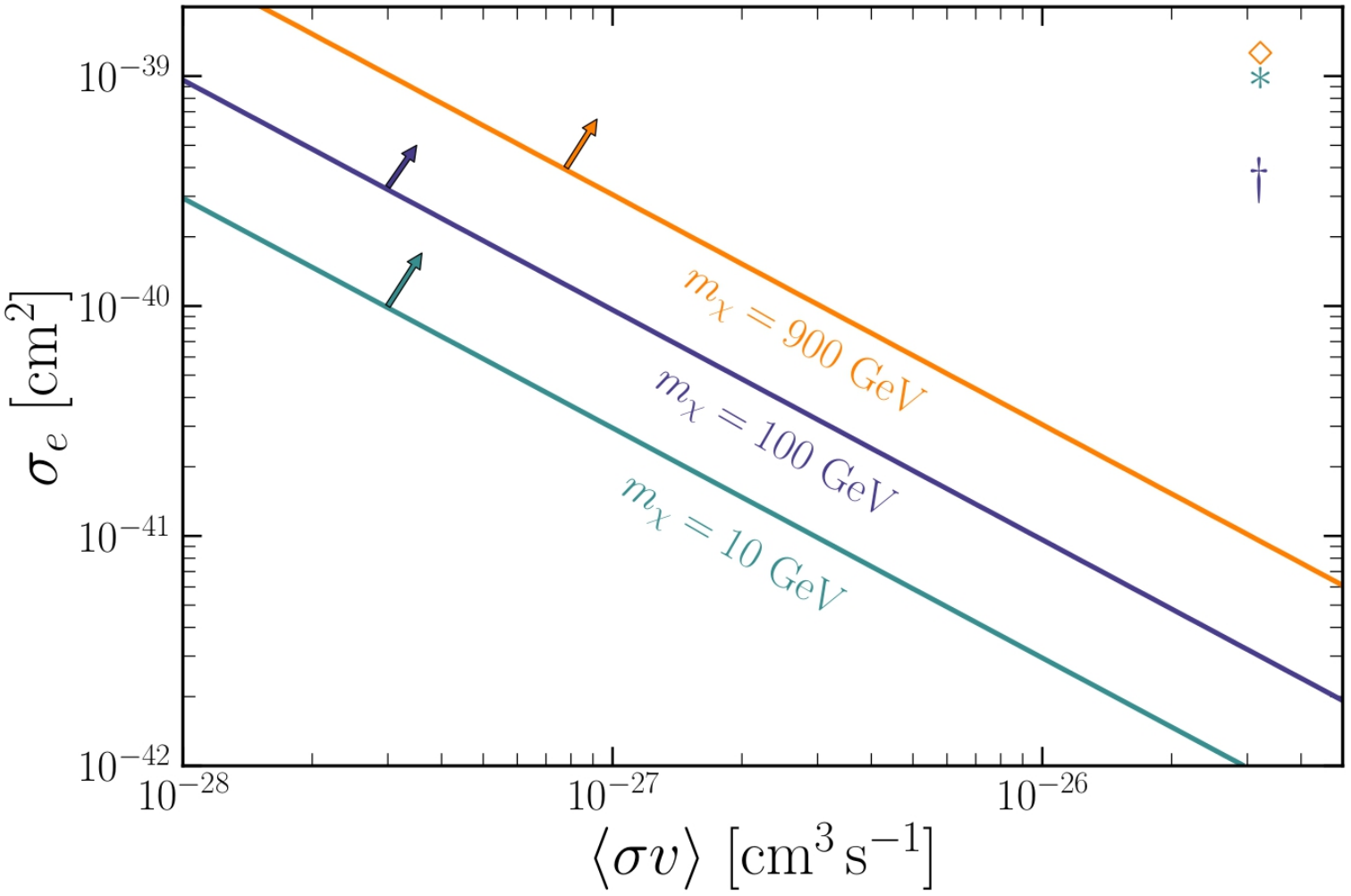
Source: Quanta Magazine

Other final states

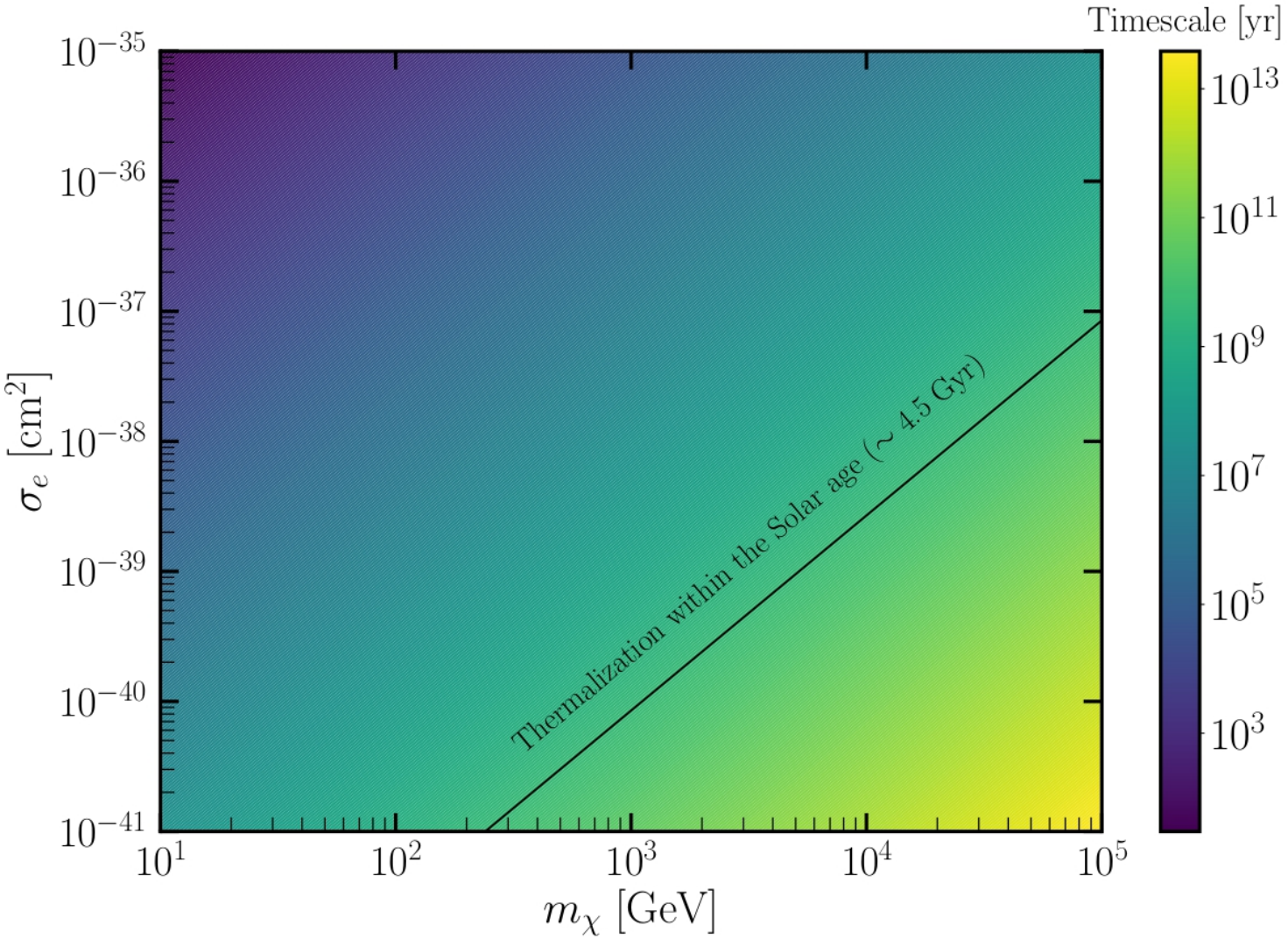




Equilibrium timescale

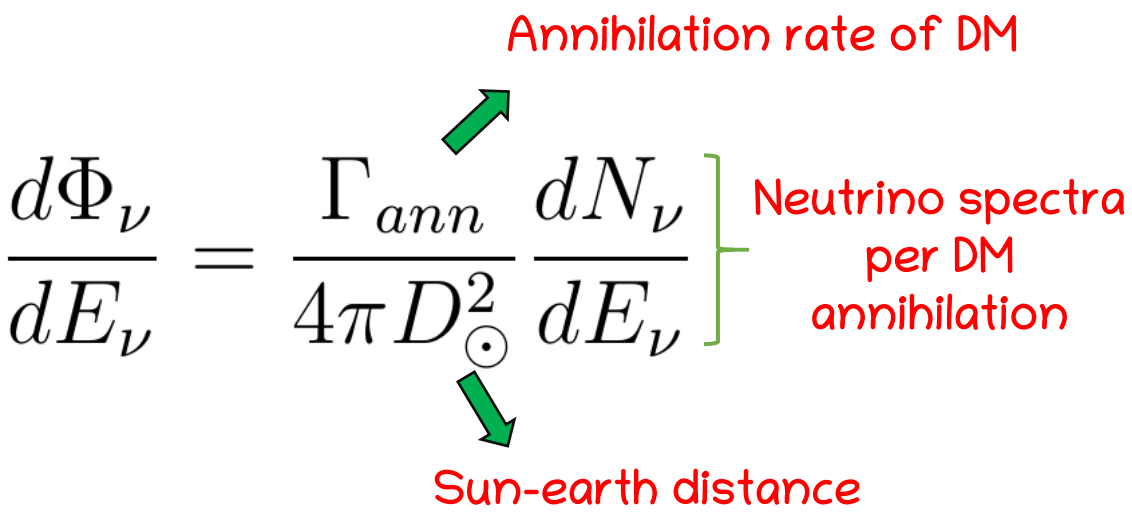


Thermalization timescale



Neutrino flux at terrestrial detectors

Flux of these neutrinos at a ground-based detector,



Neutrino flux at terrestrial detectors

Flux of these neutrinos at a ground-based detector,

Annihilation rate of DM

$$\frac{d\Phi_\nu}{dE_\nu} = \frac{\Gamma_{ann}}{4\pi D_\odot^2} \frac{dN_\nu}{dE_\nu}$$

Neutrino spectra per DM annihilation

Sun-earth distance

For our range of parameters the DM capture and annihilation rates are in equilibrium,

$$\boxed{\Gamma_{ann} = \frac{C_\odot}{2}}$$

!!

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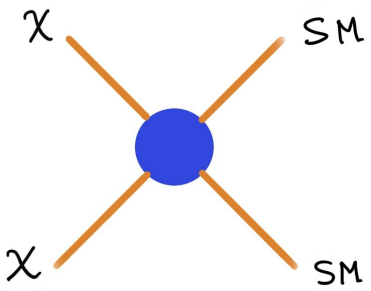
Captured Dark Matter annihilation



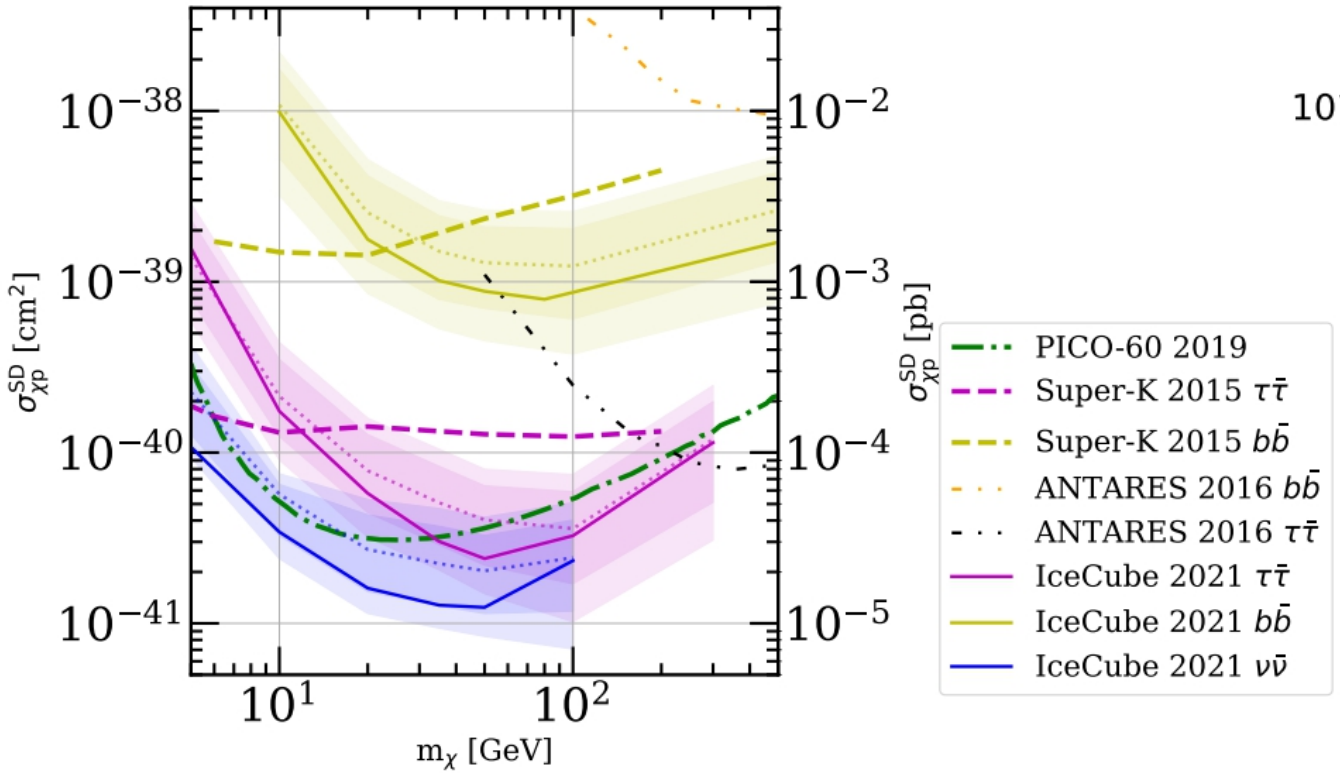
Neutrinos produced inside the Sun

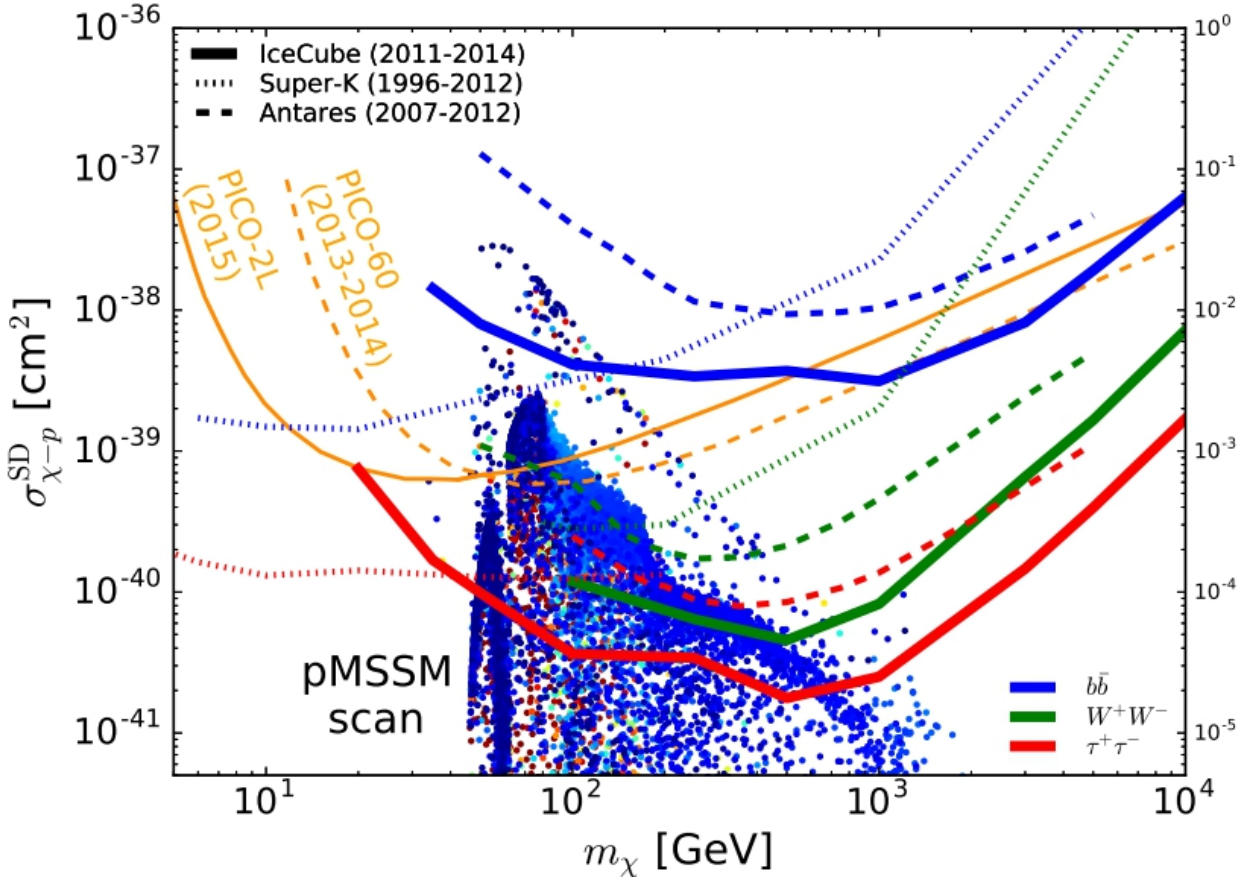
- Neutrino trapping in dense solar medium
- Tau regeneration
- Neutrino oscillation

χaron	(arXiv: 2007.15010)
nuSQuIDS	(arXiv: 2112.13804)

Leading limits for SD DM-proton interaction

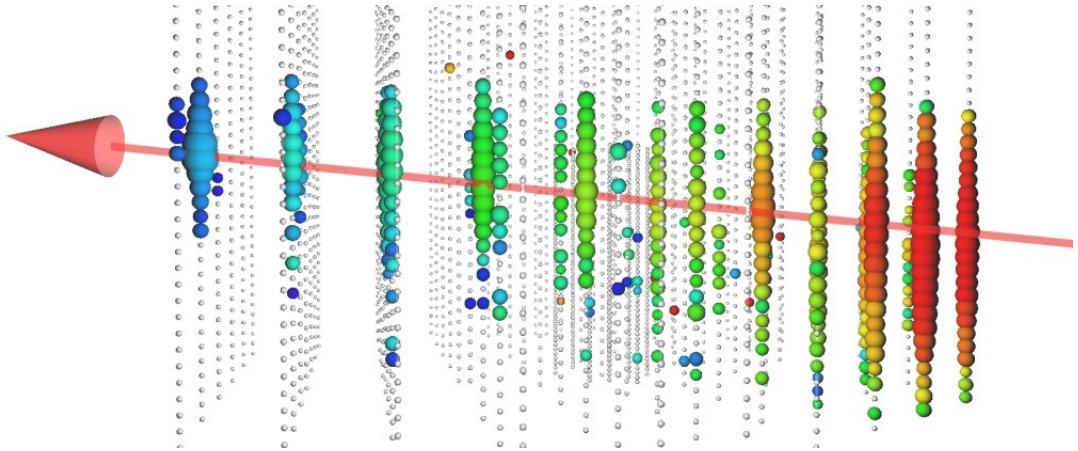
arXiv: 2111.09970





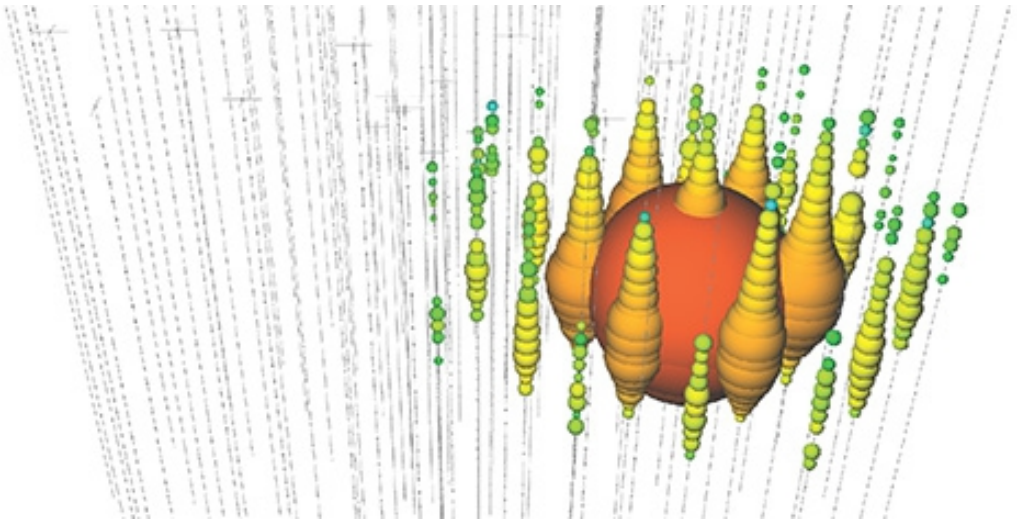
arXiv: 1612.05949

Neutrino signatures at IceCube and DeepCore



Track

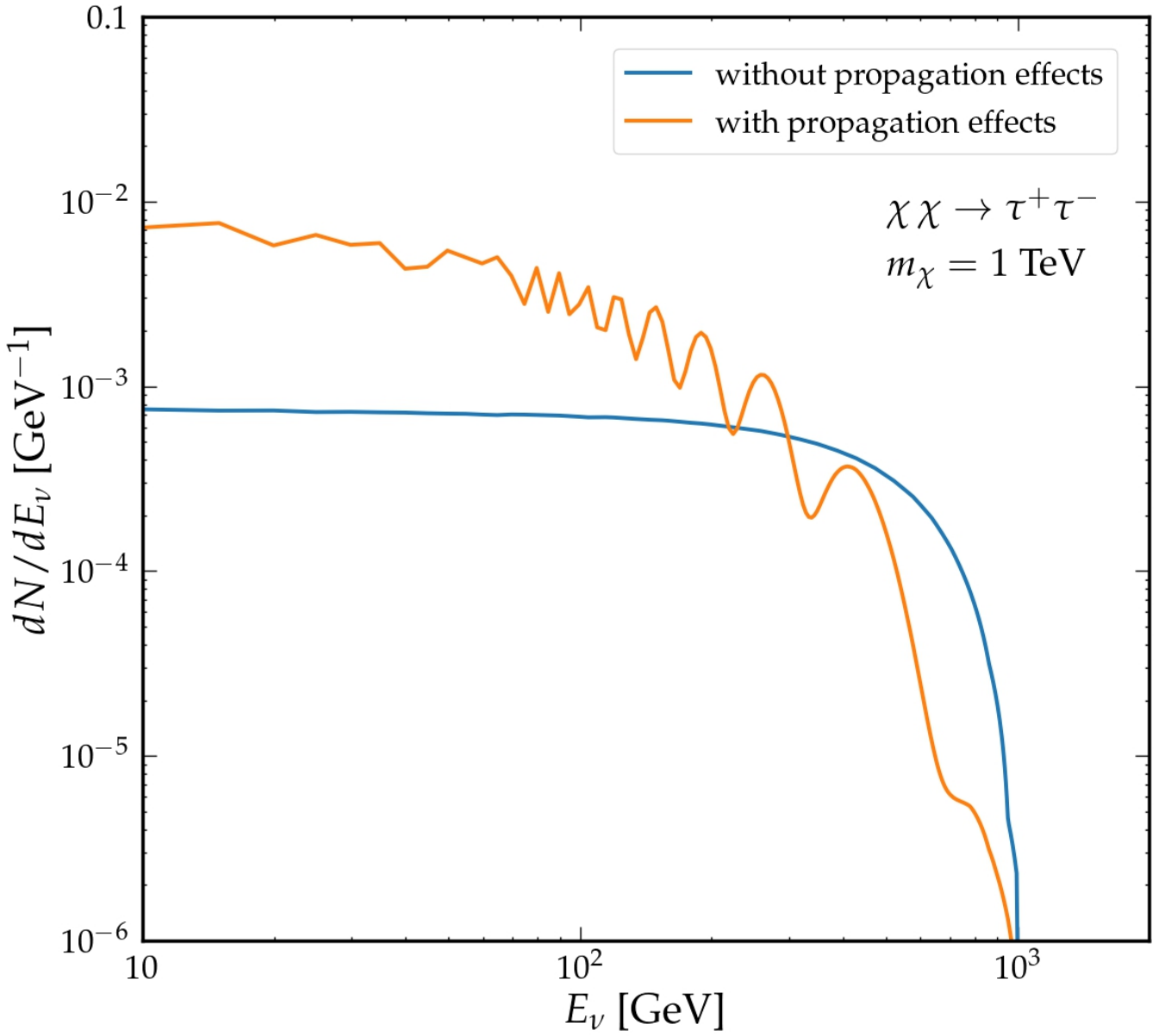
Cascade



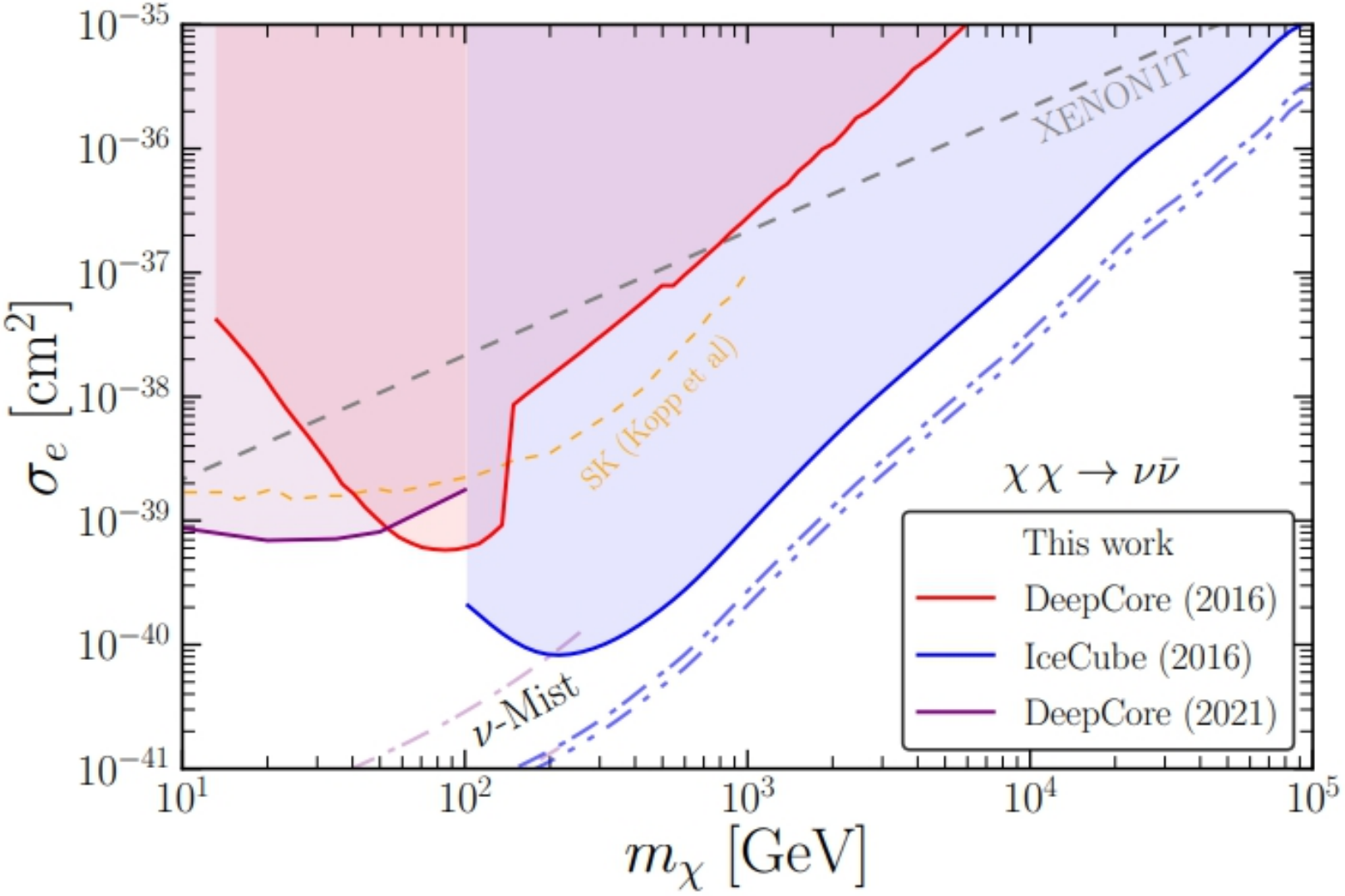
https://www.sciencealert.com/images/2019-10

https://nbi.ku.dk/english/research

Propagation of Neutrinos inside the Sun



Our result



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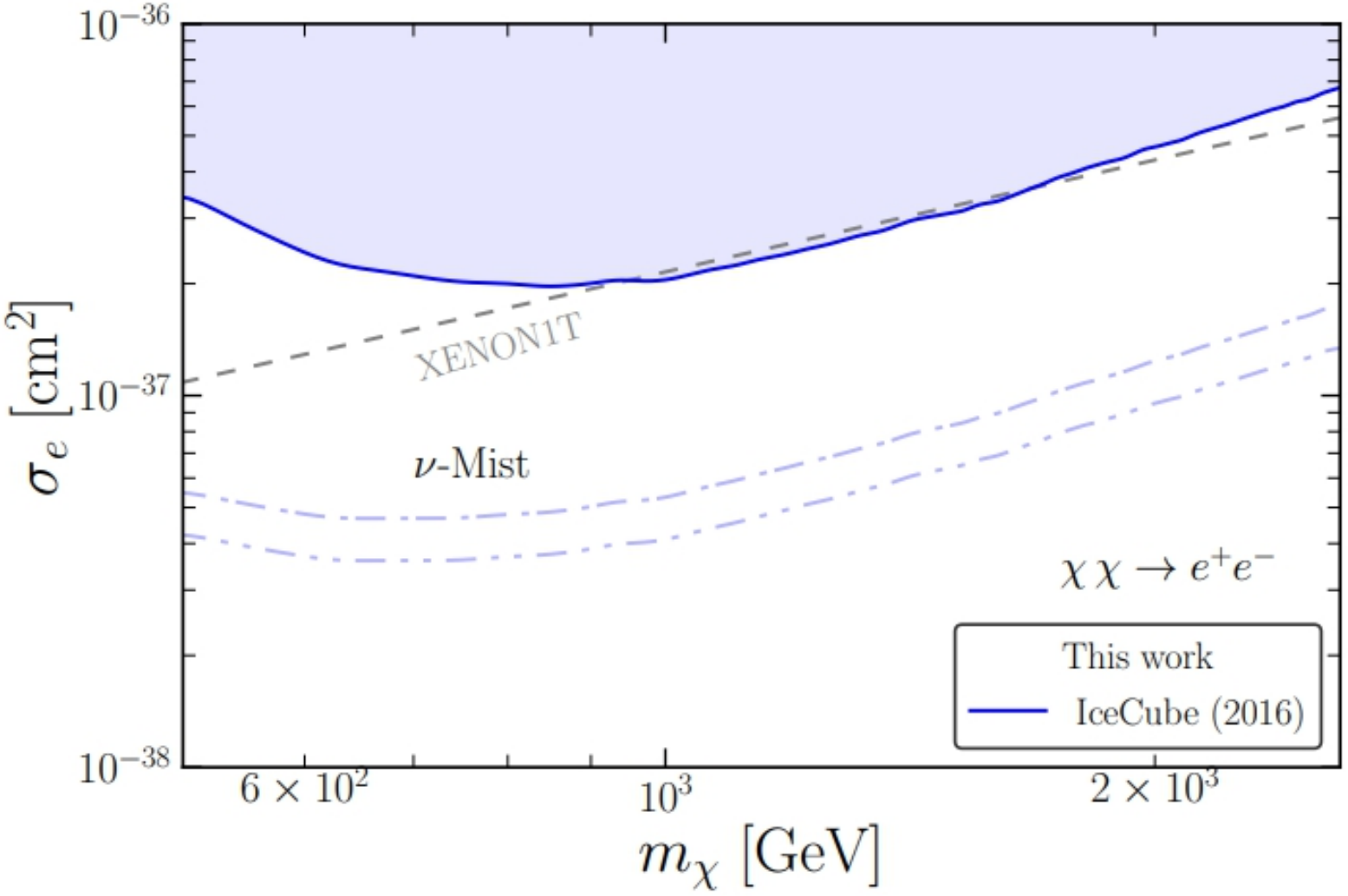

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Electroweak Bremsstrahlung

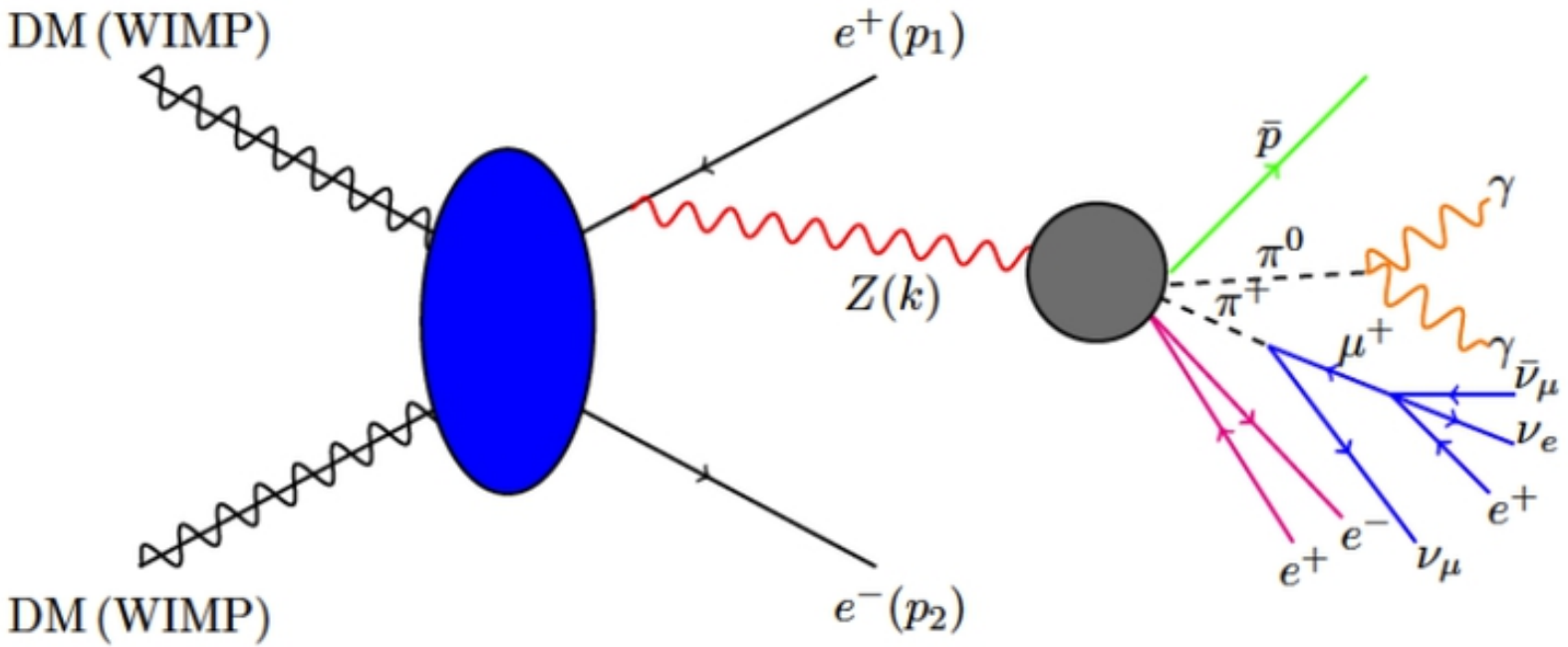

Fig. credit: Mathieu Pellen