Dark Tools workshop @ Dipartimento di Fisica, Turin

Celestial Objects as Leptophilic Dark Matter detectors

Thong T. Q. Nguyen
Stockholm University and the Oskar Klein Centre, Sweden

Based on

- **TTQN**, Tim Linden, Pierluca Carenza, Axel Widmark, *Super-Kamiokande Strongly Constrains Leptophilic Dark Matter Capture in the Sun*, submitted to PRL (2501.14864)

- **TTQN**, Carlos Blanco, Tim Linden, *Jupiter Metallic Hydrogen as Dark Matter Refrigerator: Probing sub-GeV Dark Matter-Electron Theory target with the Jovian Airglow*, in preparation for PRL.

- Tim Linden, **TTQN**, Tim Tait, *Indirect Searches for Dark Photon-Photon Tridents in Celestial Objects*, submitted to PRD (2402.01839)

- **TTQN**, Tim Tait, *Bounds on long-lived dark matter mediators from neutron stars*, PRD (2212.12547)

The Sun

Dark Matter Detector = Neutrino Detector

Xenon1T vs Super-Kamiokande

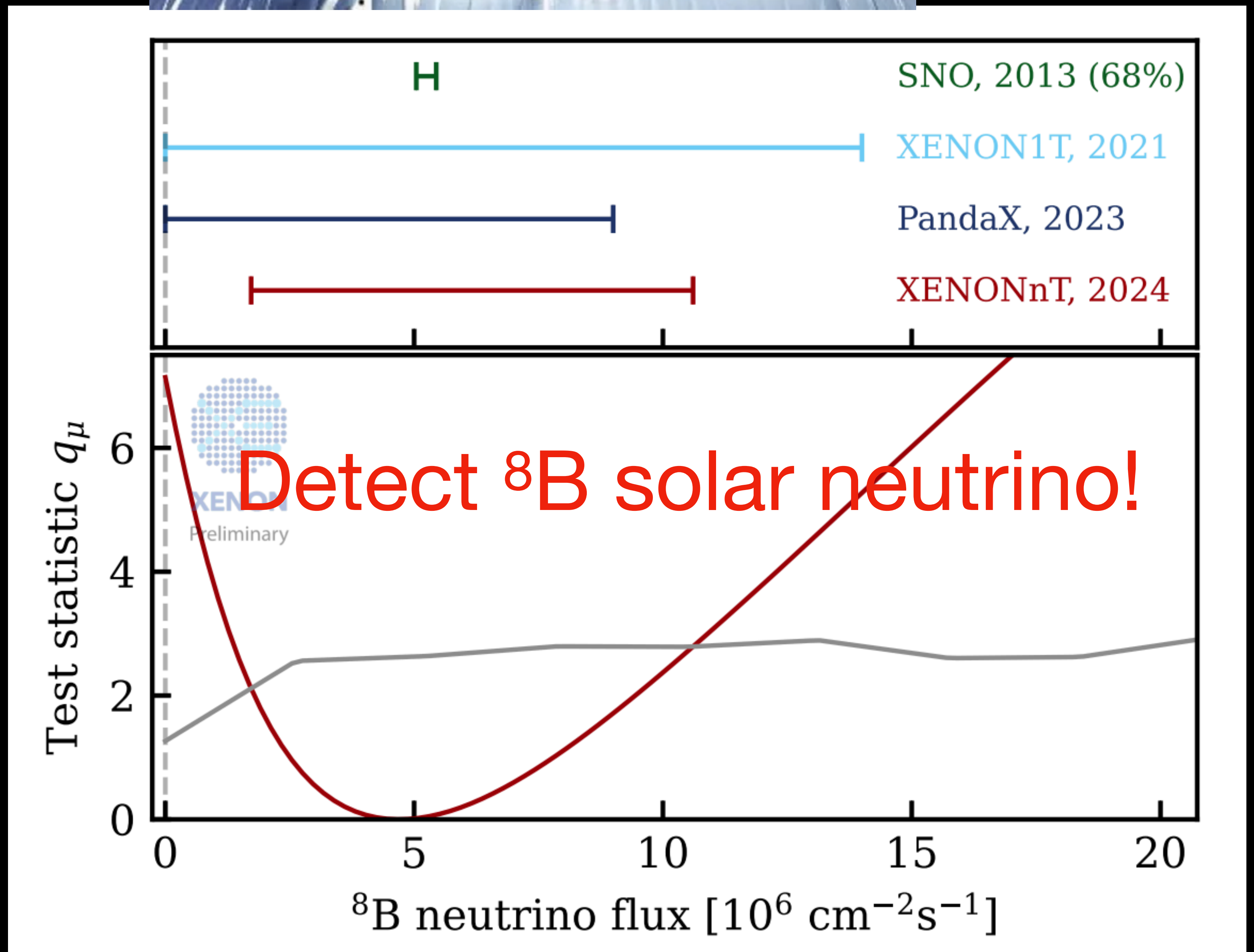
Sweden loves me!

Dark Matter Detector = Neutrino Detector

Xenon1T vs Super-Kamiokande

ν ←

Sweden loves me!

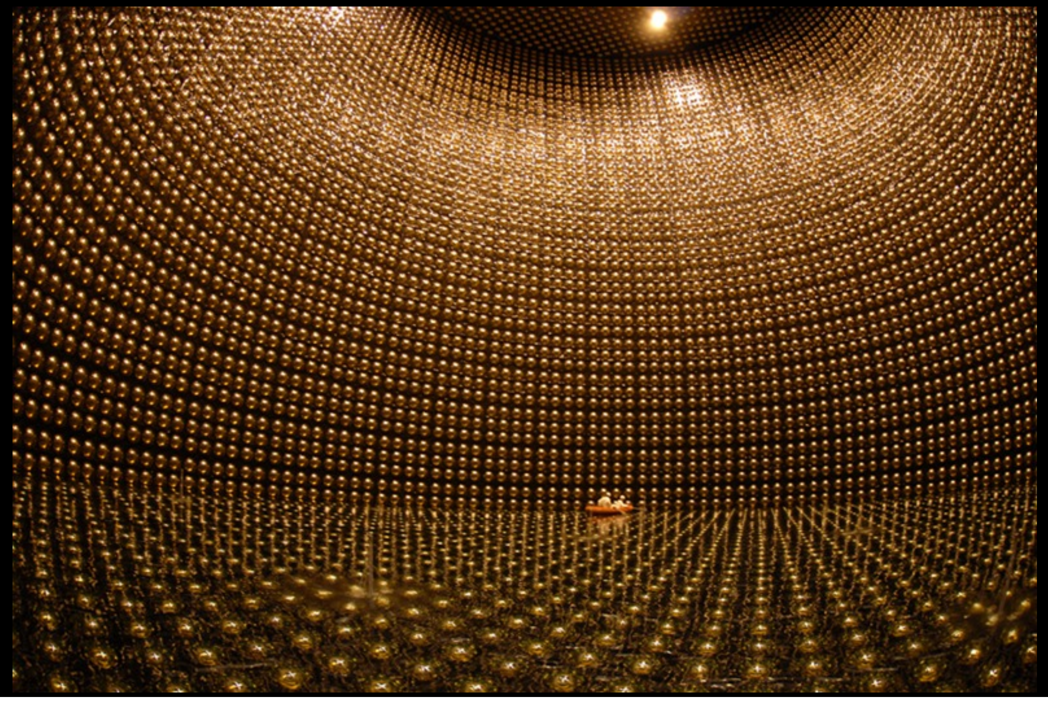


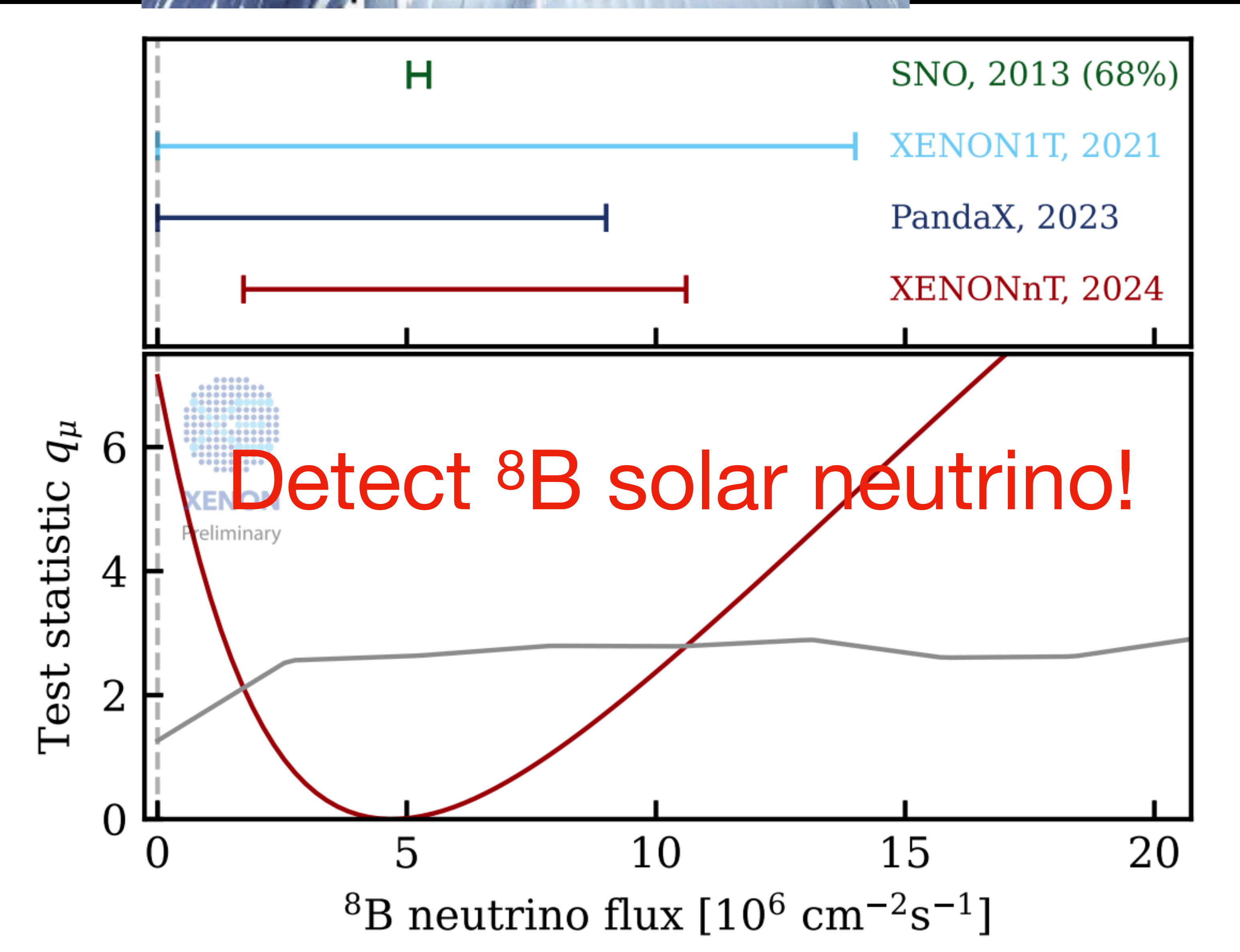
XENON collaboration, *PRL 2024*

Dark Matter Detector = Neutrino Detector

Xenon1T vs Super-Kamiokande

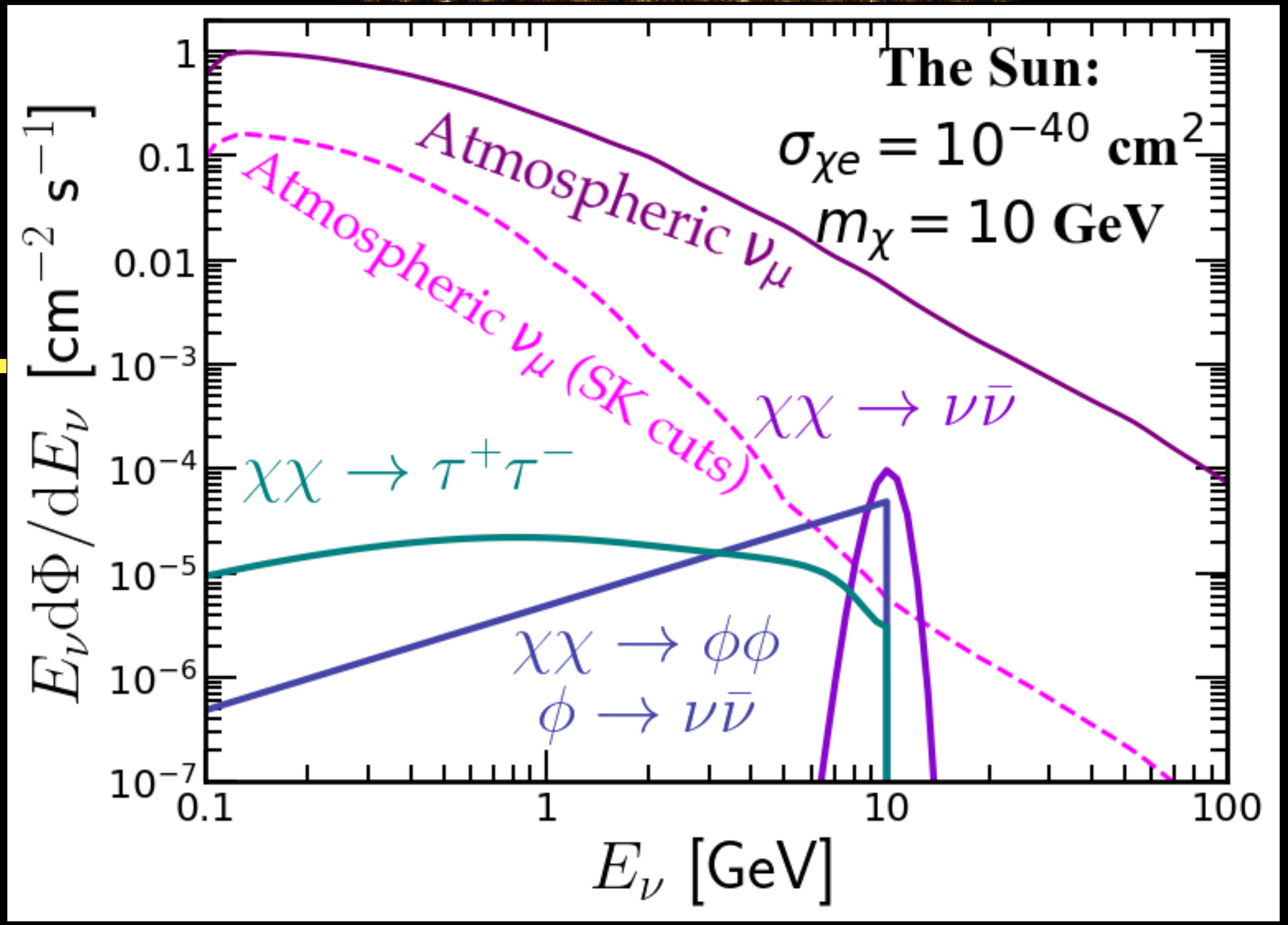
Sweden loves me!





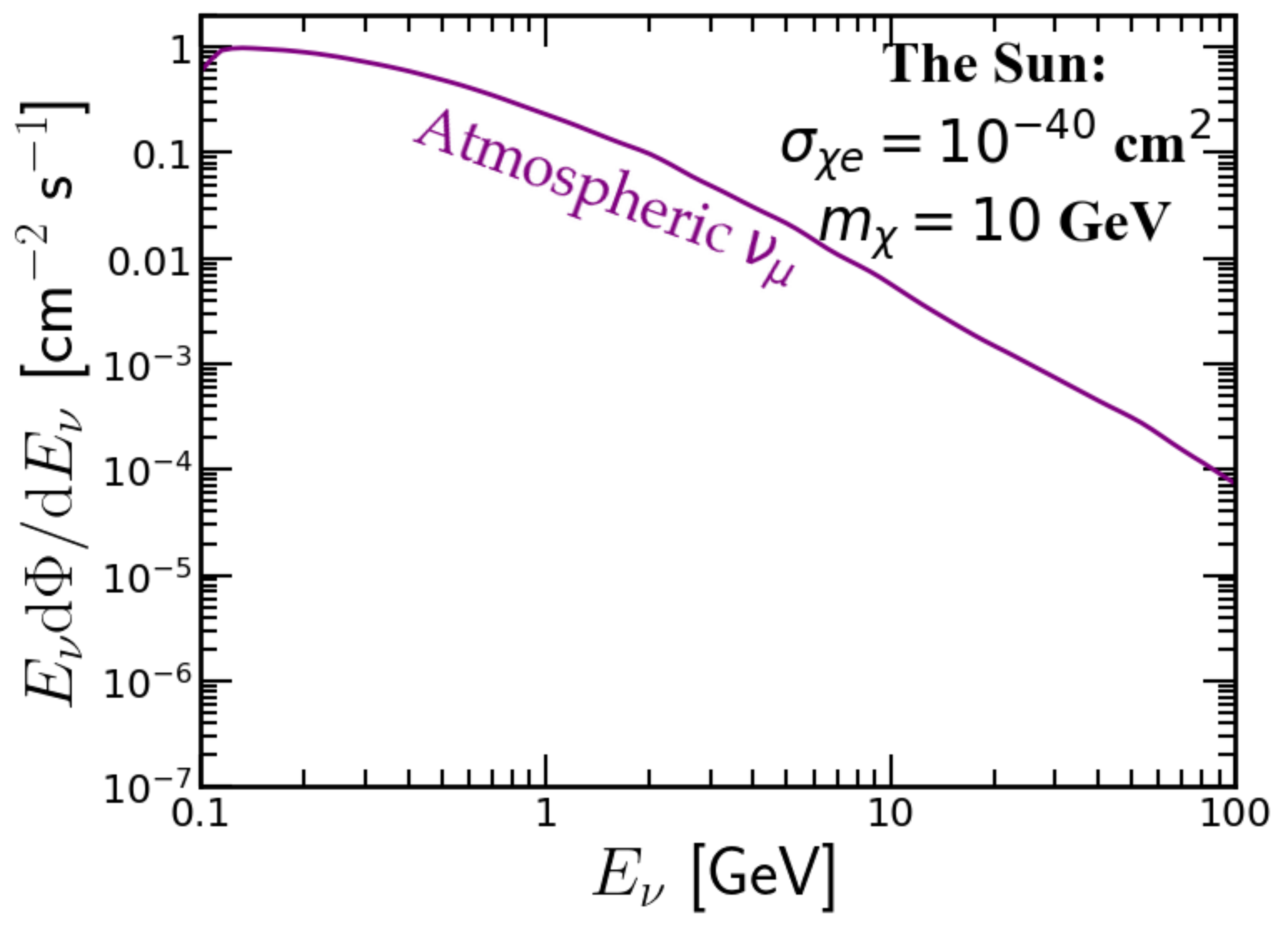
XENON collaboration, *PRL 2024*

Super-K can observe neutrinos from DM annihilation inside the Sun!



Reduce Atmospheric Neutrino Background

Using Super-K angular resolution



Reduce Atmospheric Neutrino Background

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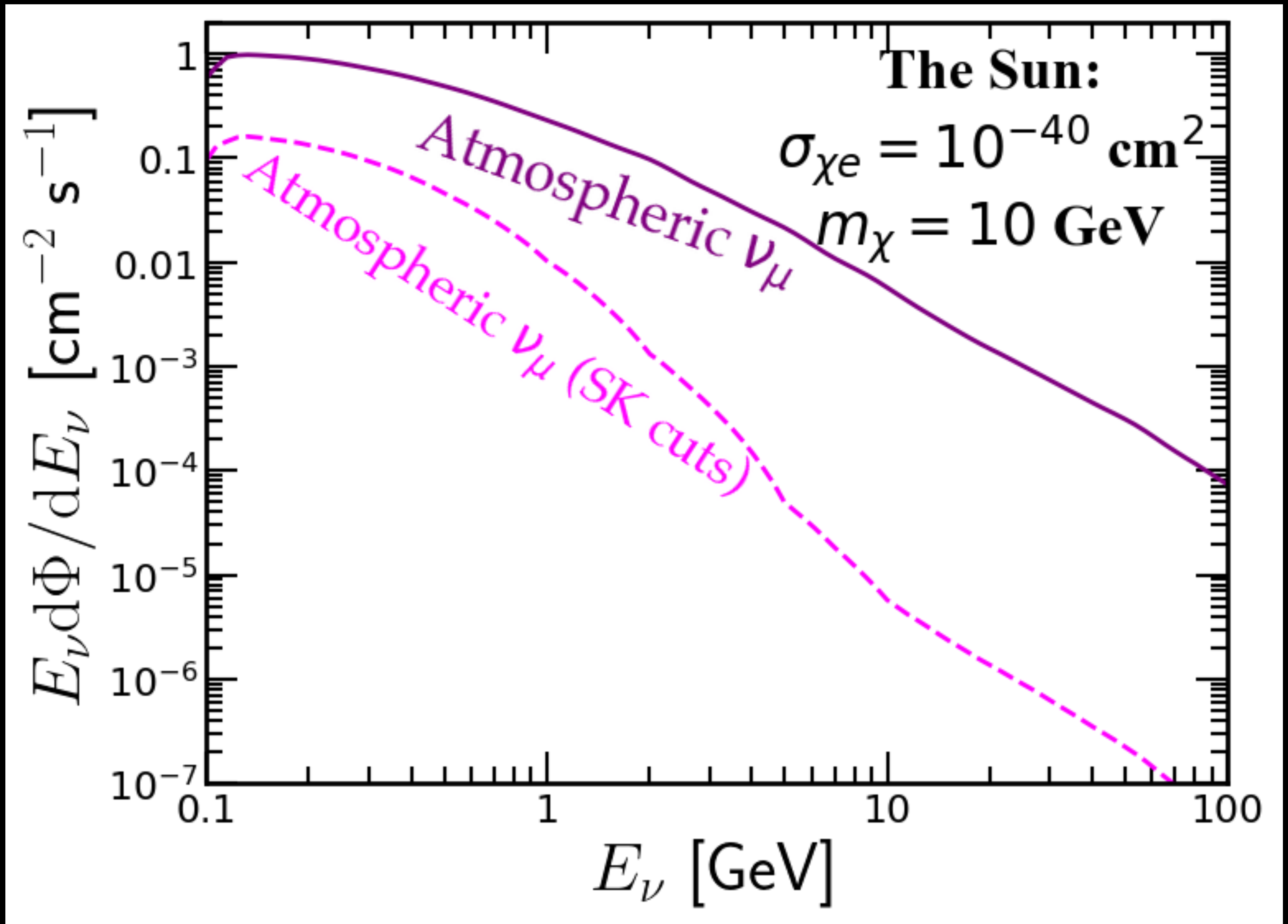
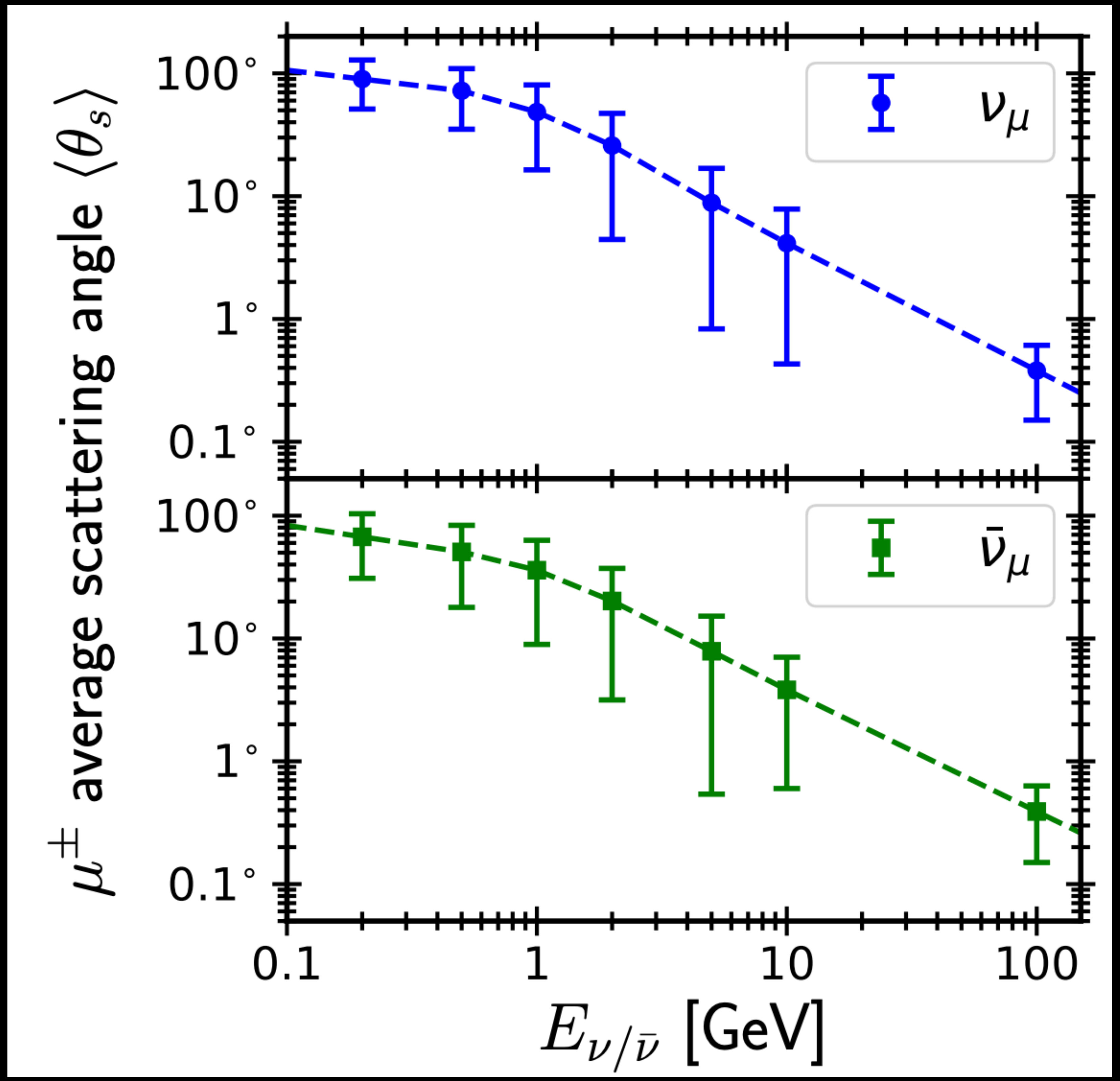
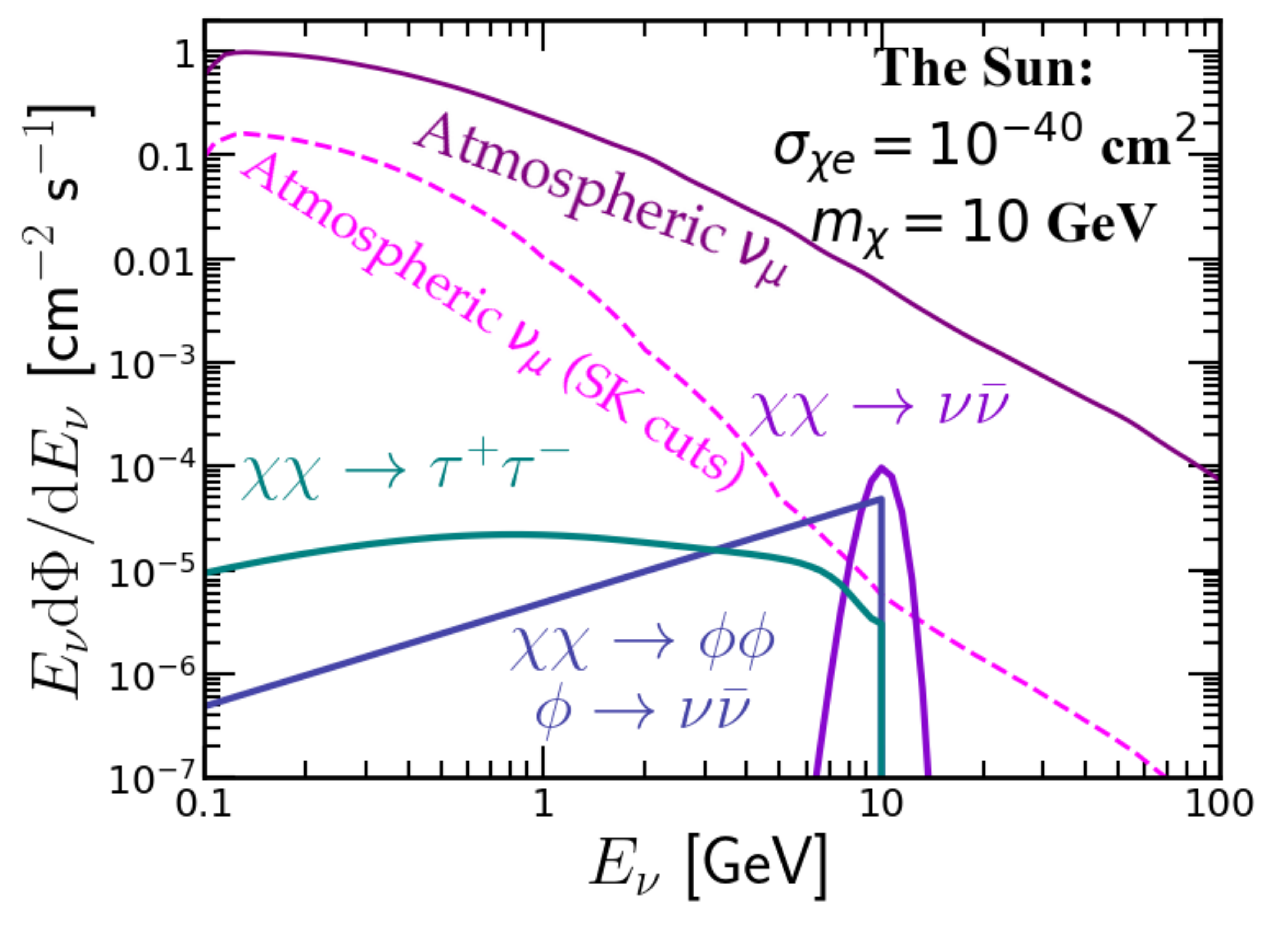


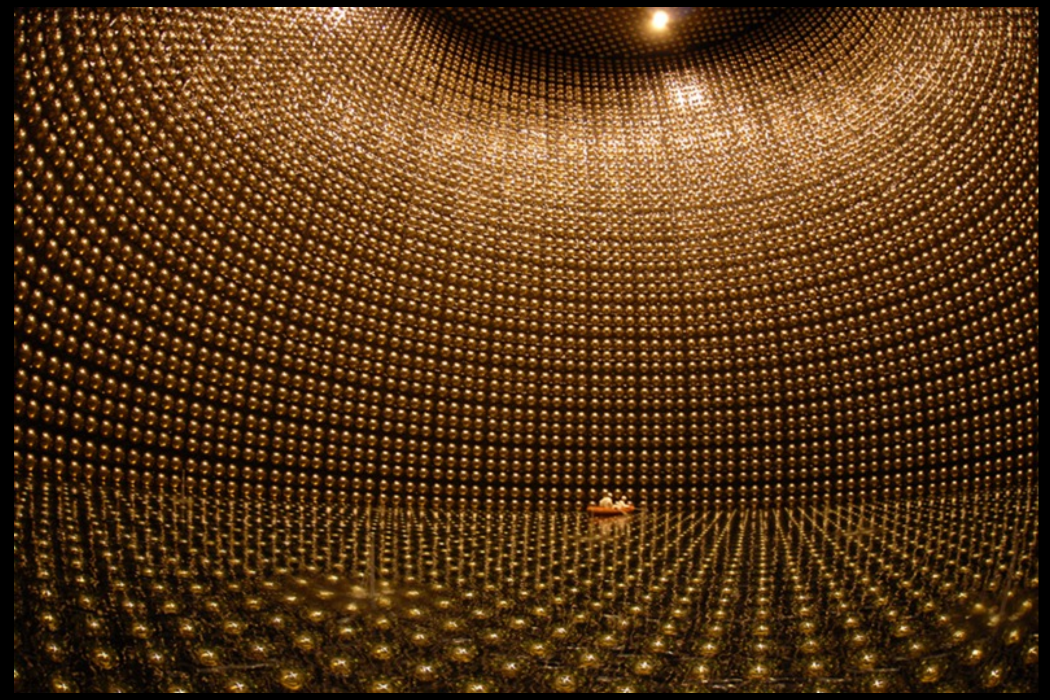


Neutrinos from leptophilic DM annihilation inside the Sun

Consider leptophilic annihilation channels



- Leptophilic DM scattering with electrons inside the Sun
- Loose KE, then being captured!
- Trapped DM annihilate to produce Neutrinos.
- Observe them with Super-K!



Neutrinos from leptophilic DM annihilation inside the Sun

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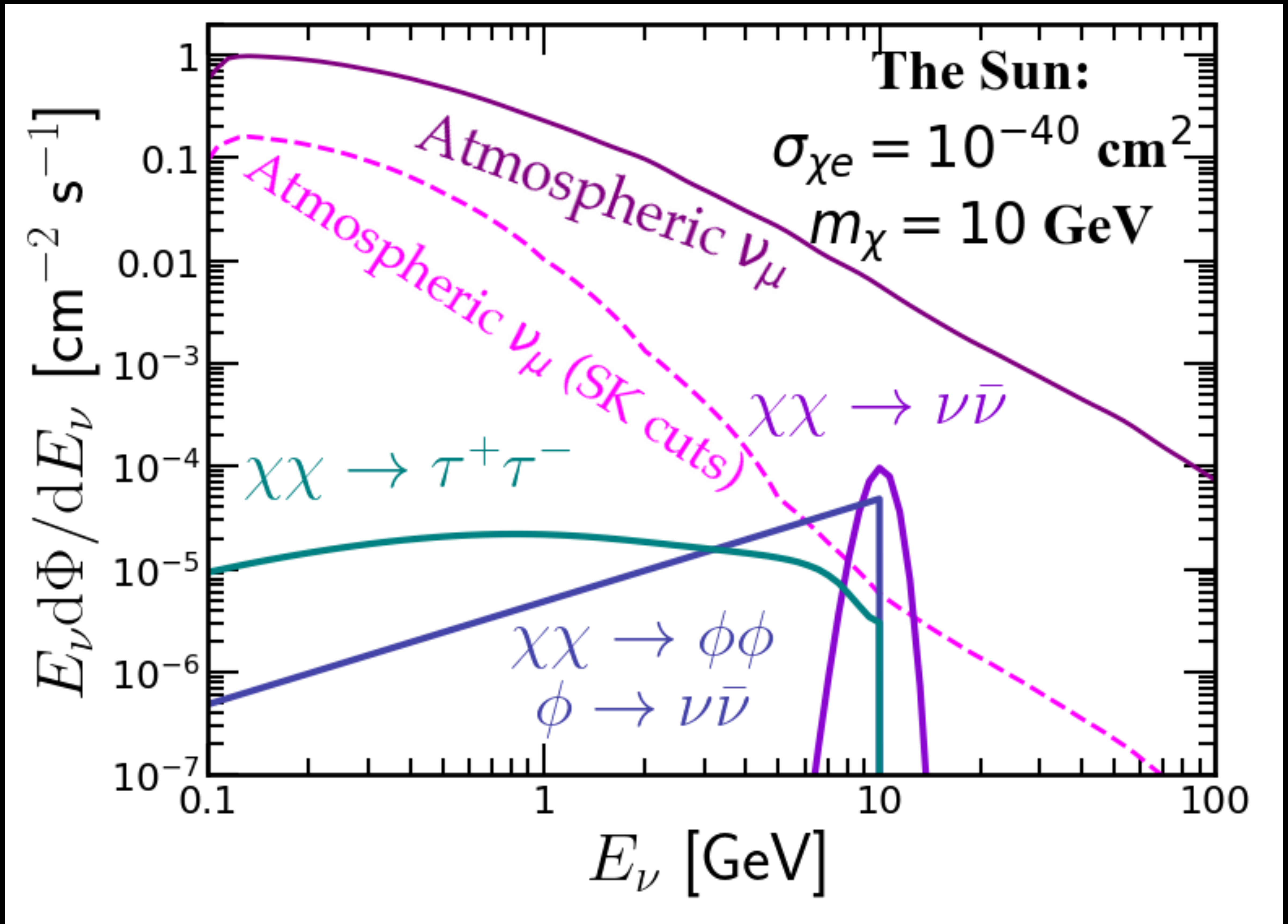
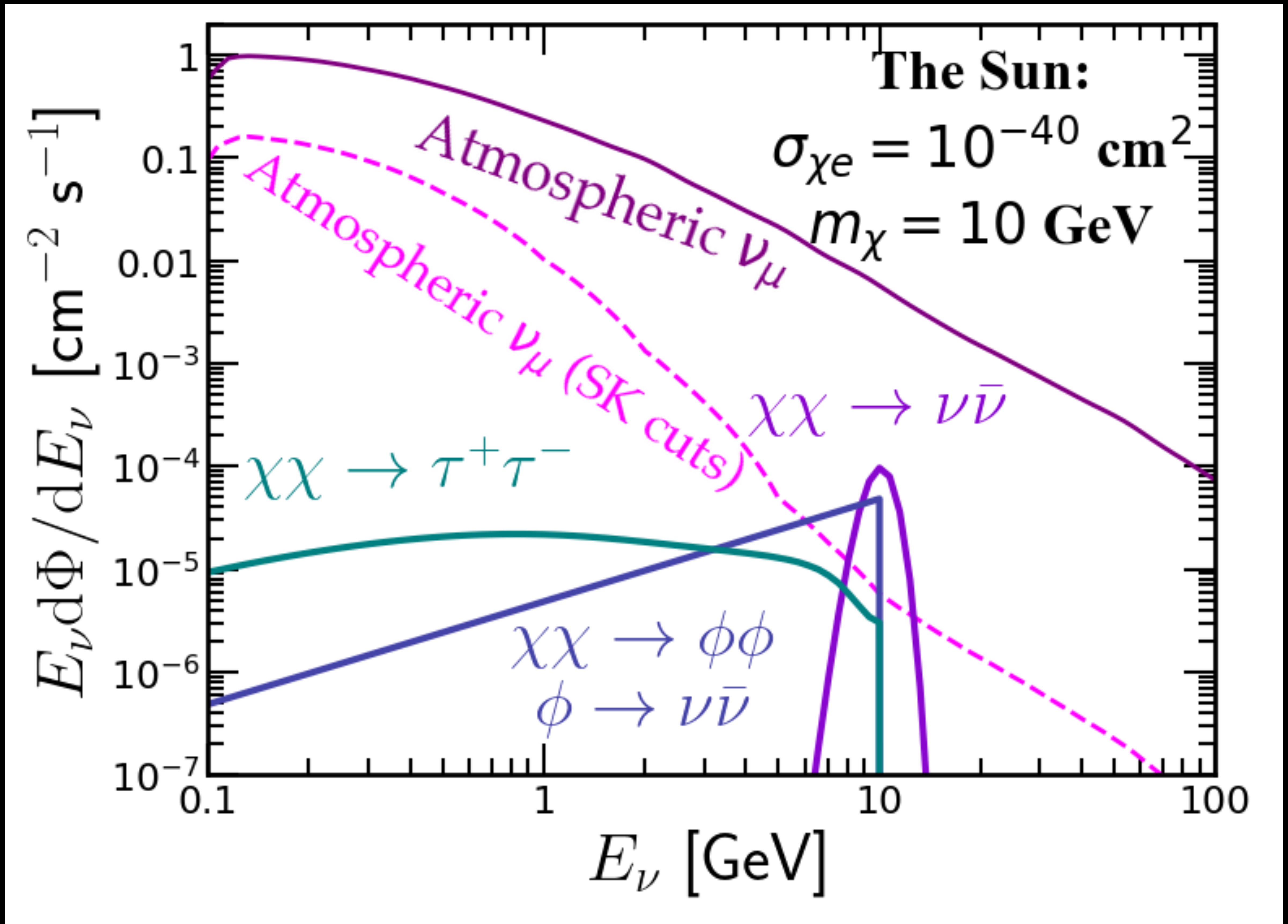


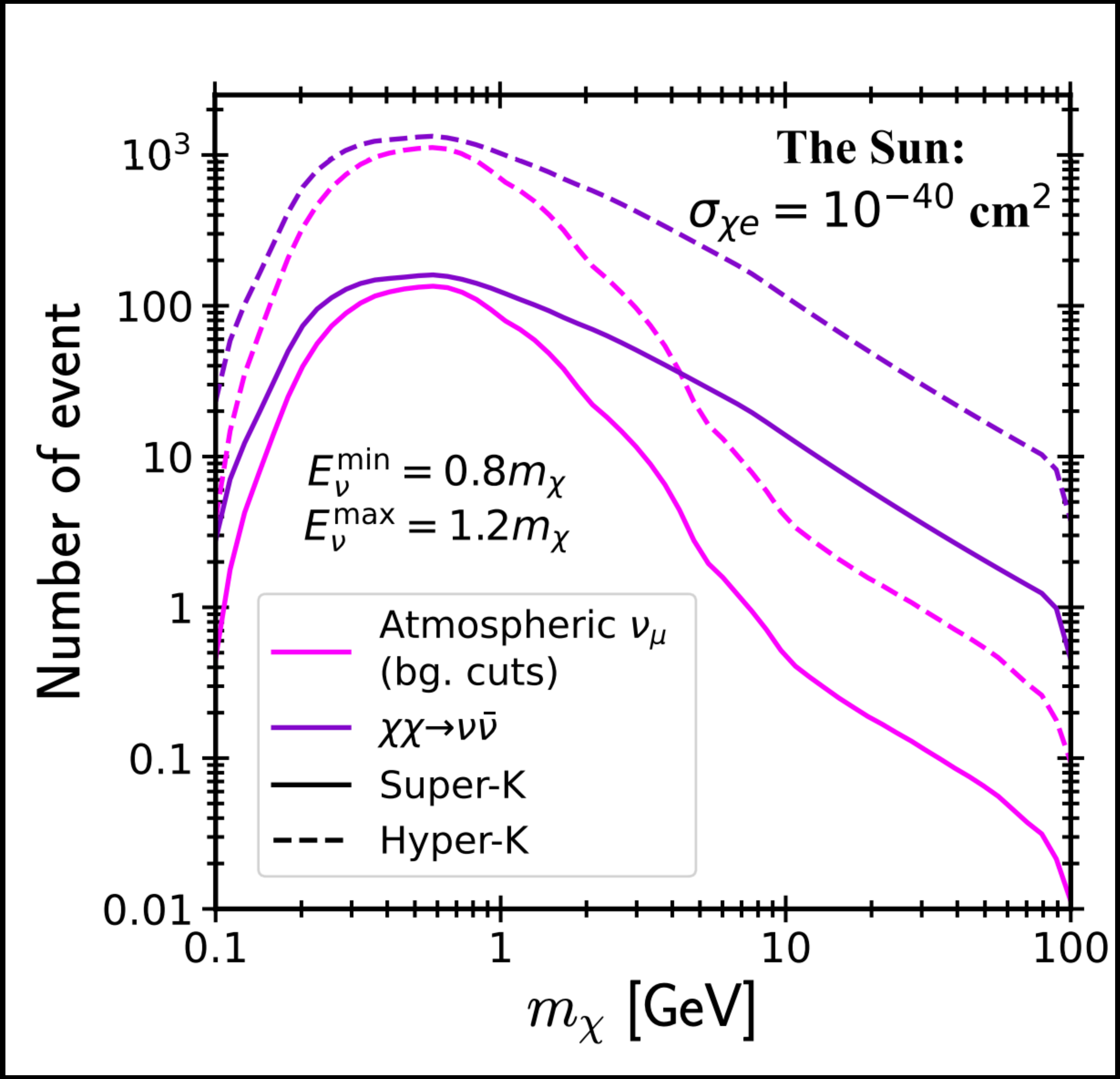
Tools to generate neutrino spectra inside the Sun:

- **PPPC4DMv**, *Baratella et al.* (1312.6408)
- **Xarov (Charon)**, *Liu et al.* (2007.15010)
- **DarkSUSY**, *Bringmann et al.* (1802.03399)

Neutrinos from leptophilic DM annihilation inside the Sun

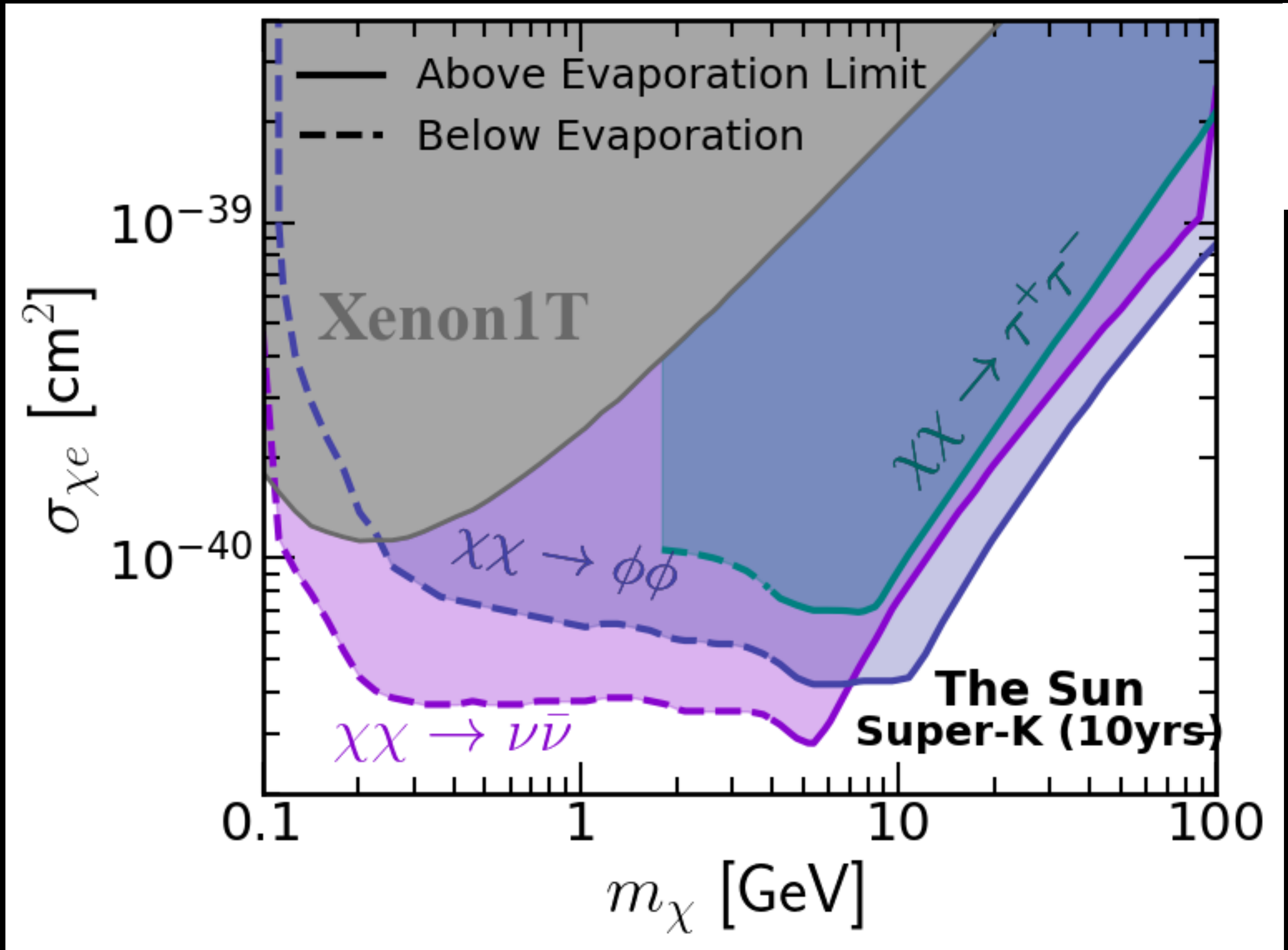
Consider leptophilic annihilation channels





Constraints on Leptophillic Dark Matter

Using 10-year Super-K observation on atmospheric muon neutrino



Super-Kamiokande Strongly Constrains Leptophilic Dark Matter Capture in the Sun

Thong T.Q. Nguyen,[1,*] Tim Linden,[1,†] Pierluca Carenza,[1,‡] and Axel Widmark[1,2,§]
[1] *Stockholm University and The Oskar Klein Centre for Cosmoparticle Physics, Alba Nova, 10691 Stockholm, Sweden*
[2] *Columbia University, 116th and Broadway, New York, NY 10027 USA*

Arxiv: 2501.14864 (submitted to PRL)

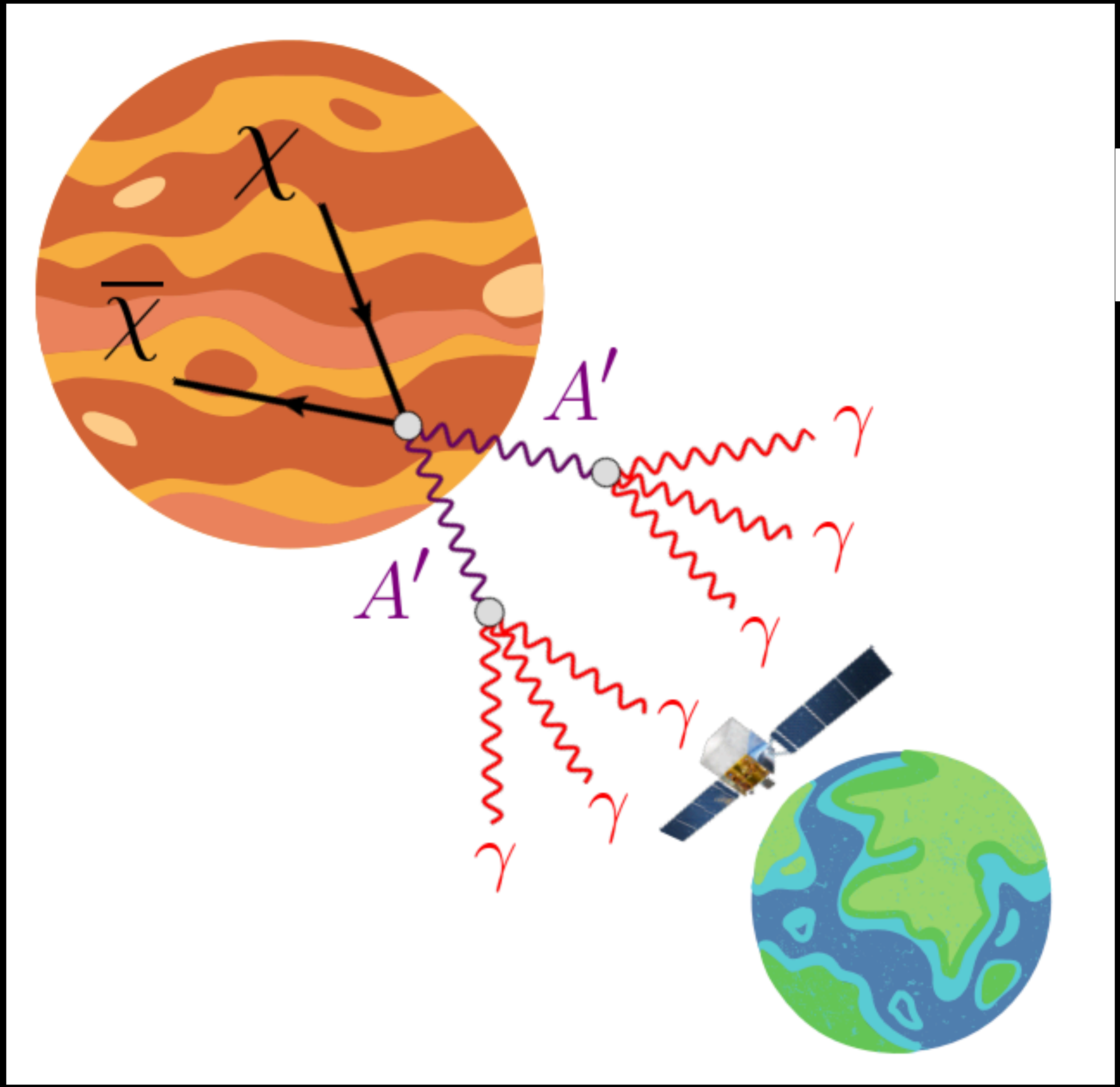
Tim Linden
(Stockholm U.)

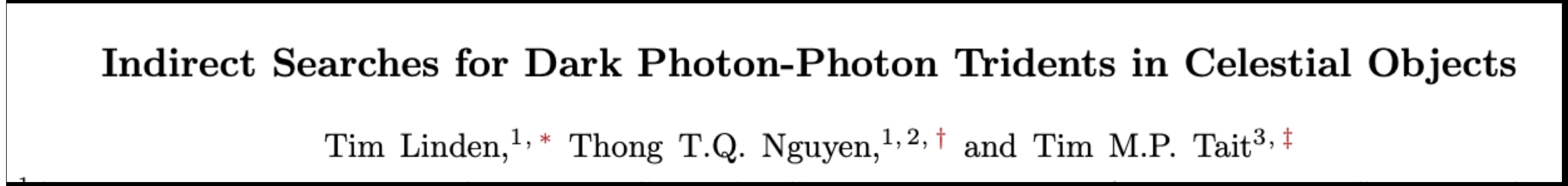
Pierluca Carenza
(Stockholm U.)

Axel Widmark
(Columbia U.)

How about gamma-rays?

DM annihilate to long-lived meditors, producing gamma-rays




Indirect Searches for Dark Photon-Photon Tridents in Celestial Objects

Tim Linden,[1,*] Thong T.Q. Nguyen,[1,2,†] and Tim M.P. Tait[3,‡]

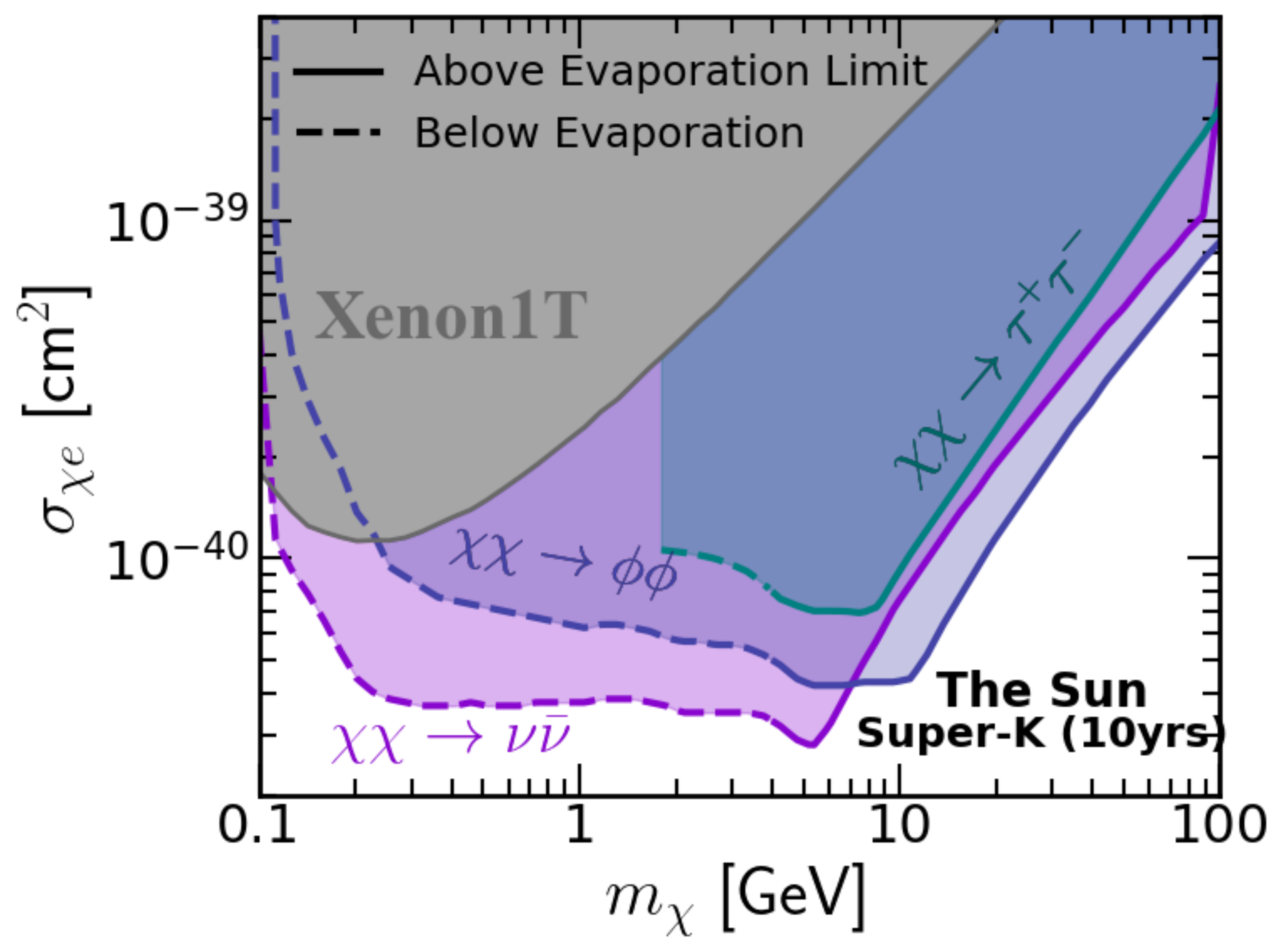
arXiv:2402.01839

Tim Linden
(Stockholm U.)

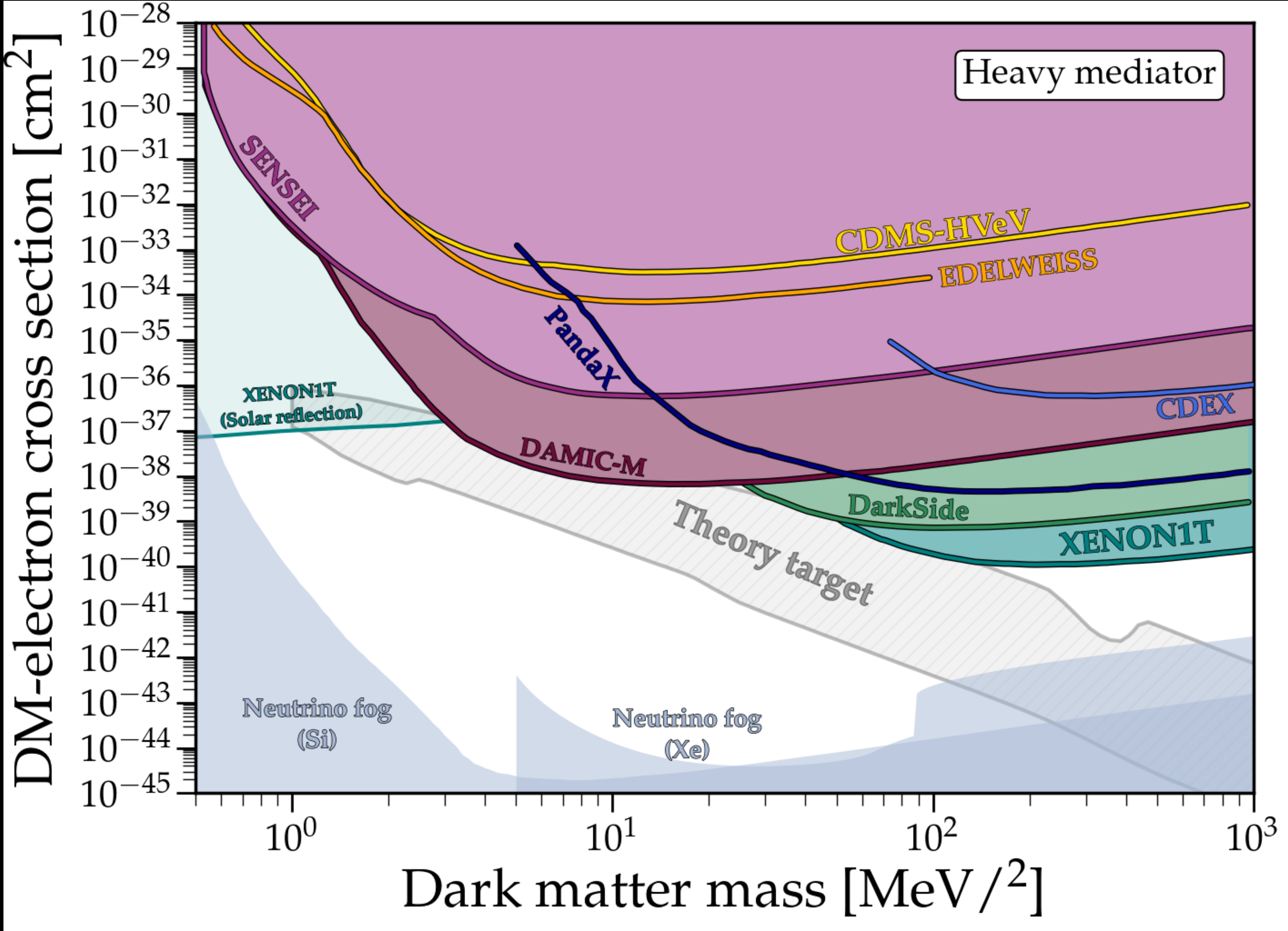
Tim Tait
(UCI)

Below 4 GeV: DM evaporation

A challenge in DM capture in the Sun!



Sub-GeV DM-electron cross section



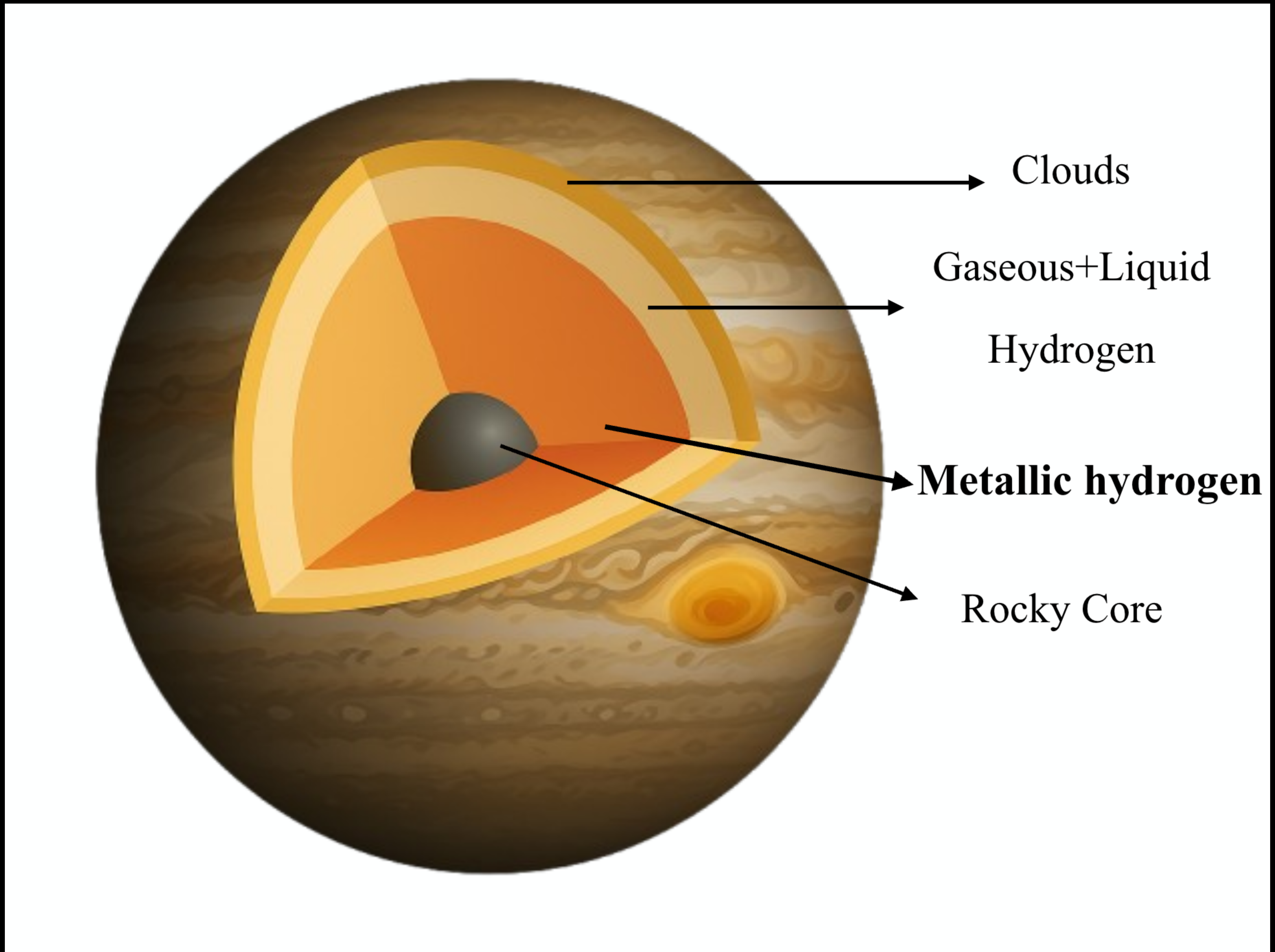
Ciaran O'Hare

(The artist!)

Is Jupiter the solution?

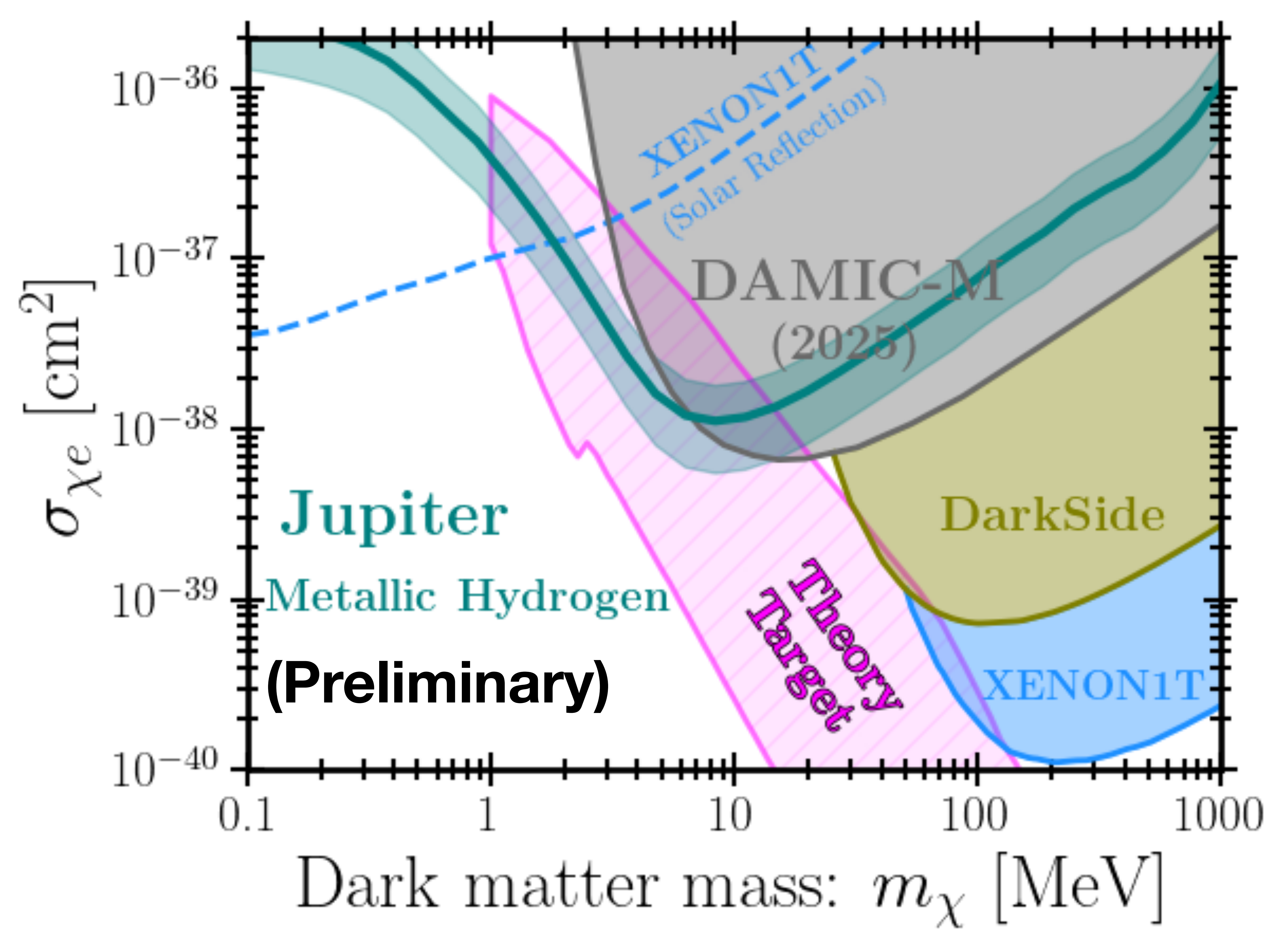
Jupiter with Metallic Hydrogen core

Electrons are cold and cannot kick (evaporate) sub-GeV DM out!



Jupiter as Dark Matter Refrigerator

Probing theory-target parameter space of sub-GeV Leptophilic DM



Jupiter Metallic Hydrogen as Dark Matter Refrigerator: Probing sub-GeV Dark Matter-Electron Theory target with the Jovian Airglow

Thong T.Q. Nguyen,[1,*] Carlos Blanco,[2,3,4,1,†] and Tim Linden[1,5,‡]

[1] *Stockholm University and The Oskar Klein Centre for Cosmoparticle Physics, Alba Nova, 10691 Stockholm, Sweden*
[2] *Department of Physics, The Pennsylvania State University, University Park, PA 16802, USA*
[3] *Institute for Gravitation and the Cosmos, The Pennsylvania State University, University Park, PA 16802, USA*
[4] *Institute for Computational and Data Sciences, The Pennsylvania State University, University Park, PA 16802, USA*
[5] *Erlangen Centre for Astroparticle Physics (ECAP), Friedrich-Alexander-Universität Erlangen-Nürnberg, Nikolaus-Fiebiger-Str. 2, 91058 Erlangen, Germany*

Letter in preparation!

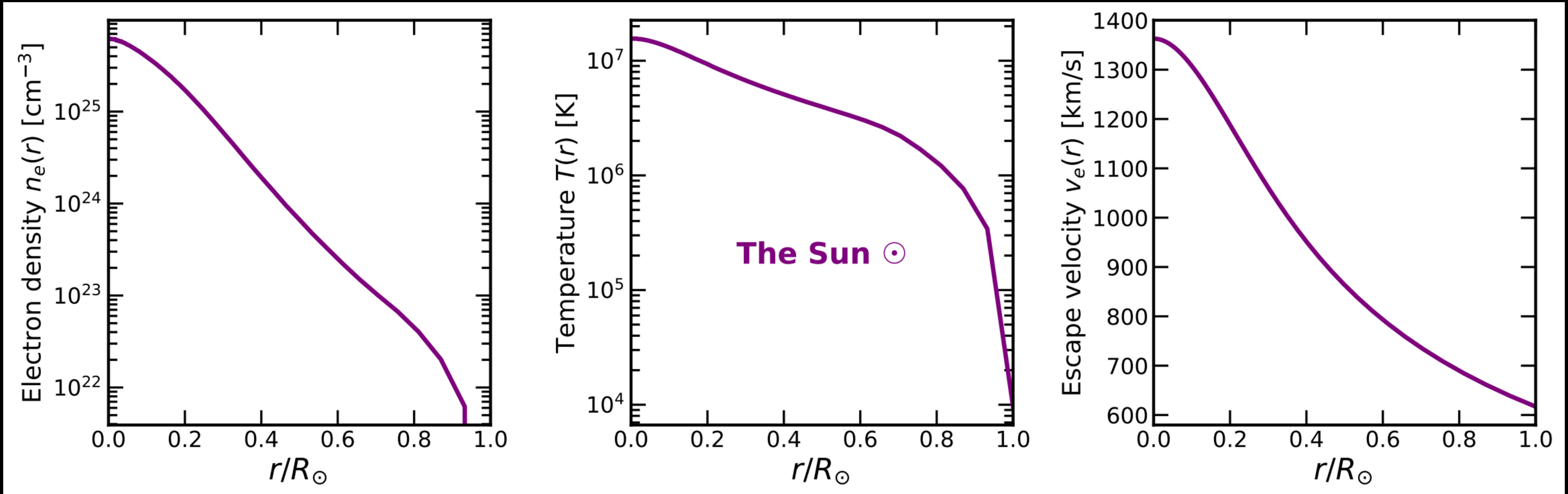
Carlos Blanco
(Penn State U.)

Tim Linden
(Stockholm U.)


Thank you for listening!
Chiao is searching for Dog-matter too!

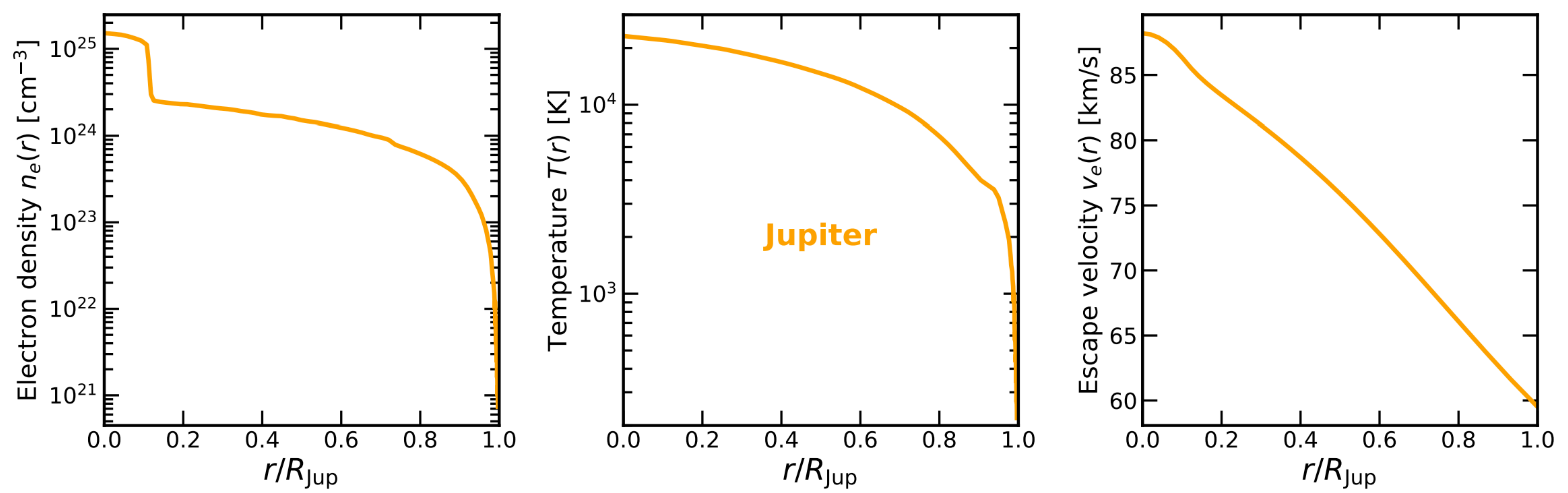
Backup Slide

The Solar model



Jupiter model

Jovian J11-4a



Metallic Hydrogen

Inside Jupiter

Metallic hydrogen

38 languages

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From Wikipedia, the free encyclopedia

Metallic hydrogen is a phase of hydrogen in which it behaves like an electrical conductor. This phase was predicted in 1935 on theoretical grounds by Eugene Wigner and Hillard Bell Huntington.[1]

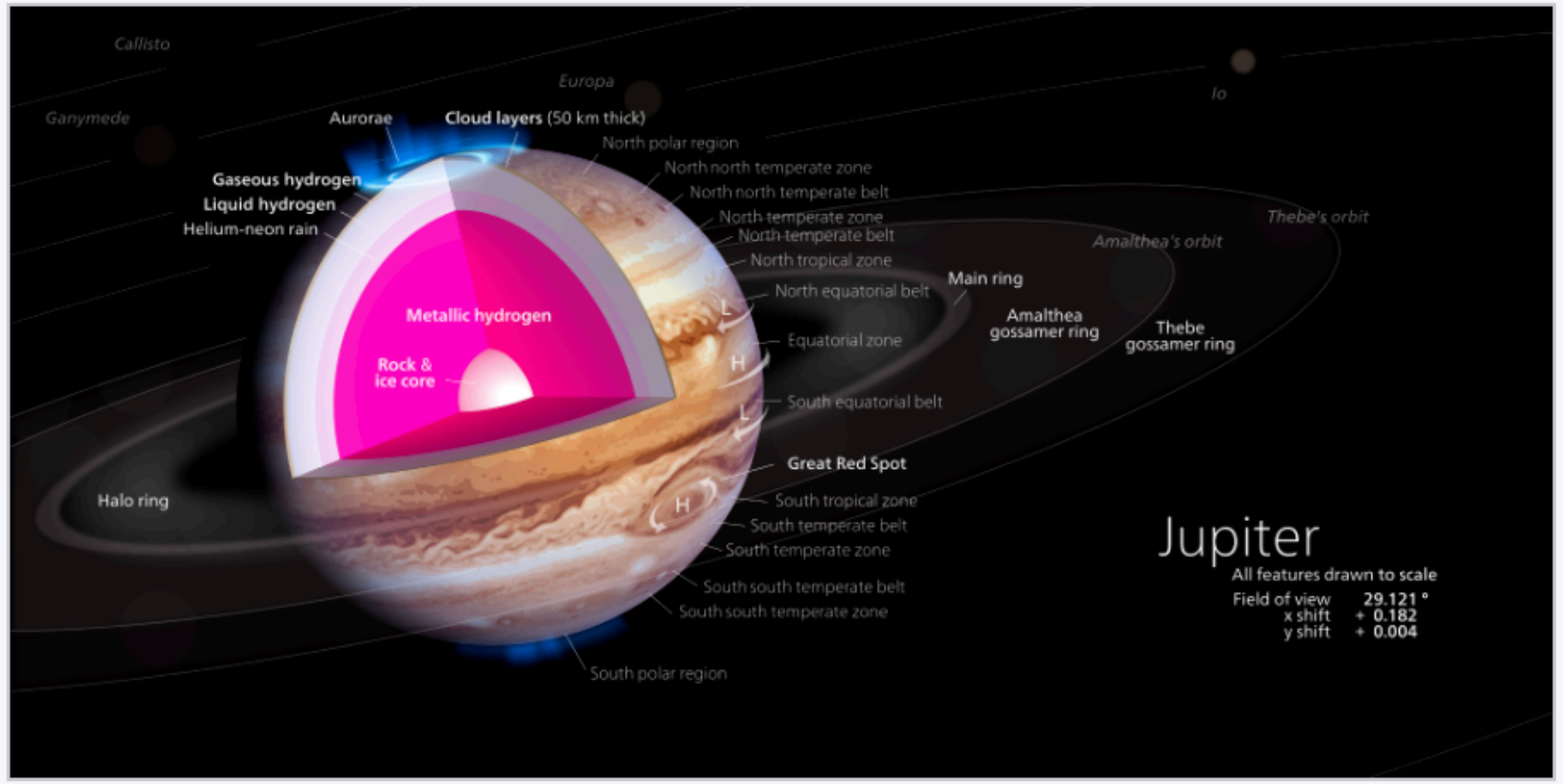
At high pressure and temperatures, metallic hydrogen can exist as a partial liquid rather than a solid, and researchers think it might be present in large quantities in the hot and gravitationally compressed interiors of Jupiter and Saturn, as well as in some exoplanets.[2]

Theoretical predictions [edit]

Hydrogen under pressure [edit]

Though often placed at the top of the alkali metal column in the periodic table, hydrogen does not, under ordinary conditions, exhibit the properties of an alkali metal. Instead, it forms diatomic H_2 molecules, similar to halogens and some nonmetals in the second period of the periodic table, such as nitrogen and oxygen. Diatomic hydrogen is a gas that, at atmospheric pressure, liquefies and solidifies only at very low temperature (20 K and 14 K respectively).

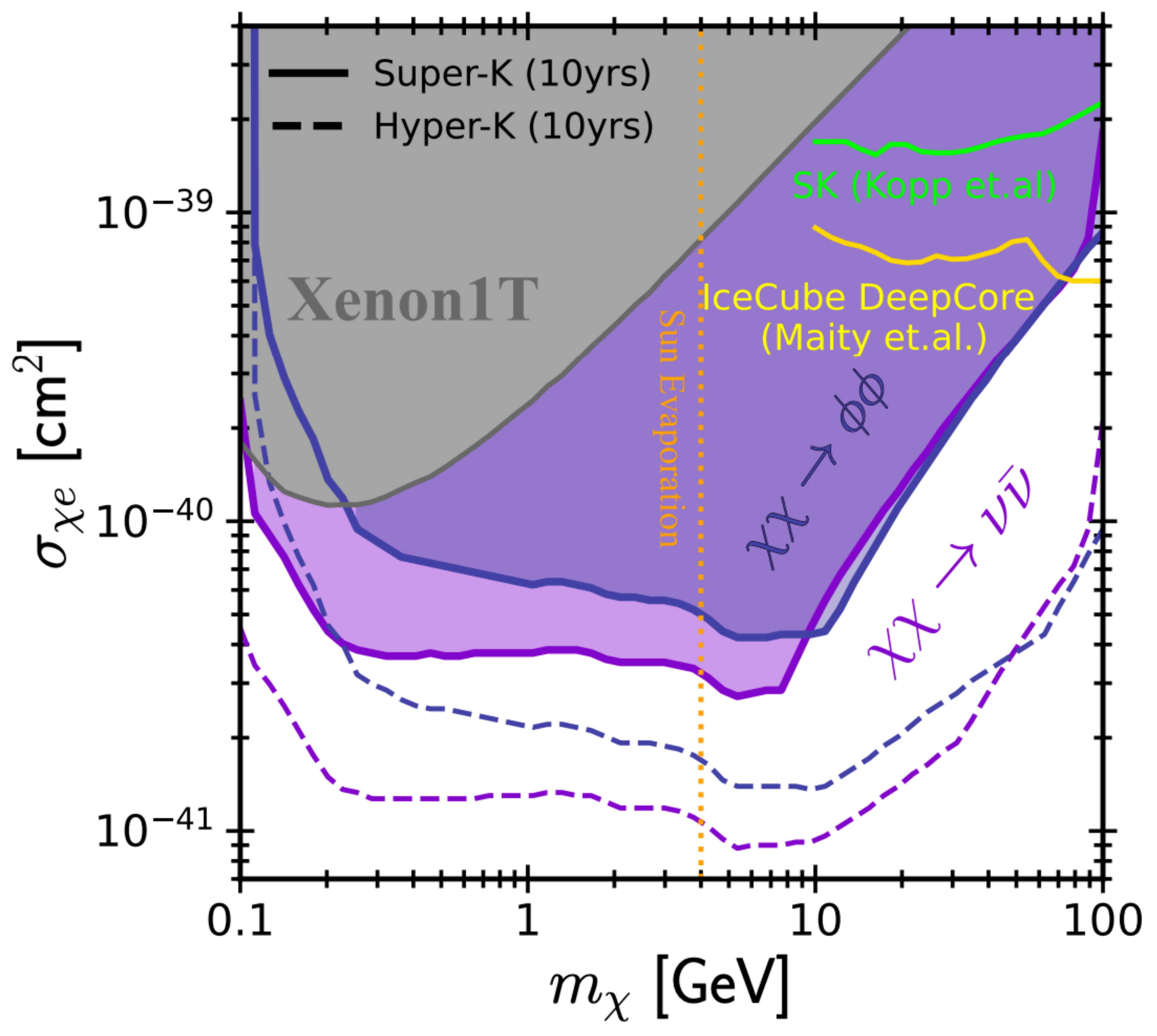
In 1935, physicists Eugene Wigner and Hillard Bell Huntington predicted that under an immense pressure of around 25 GPa

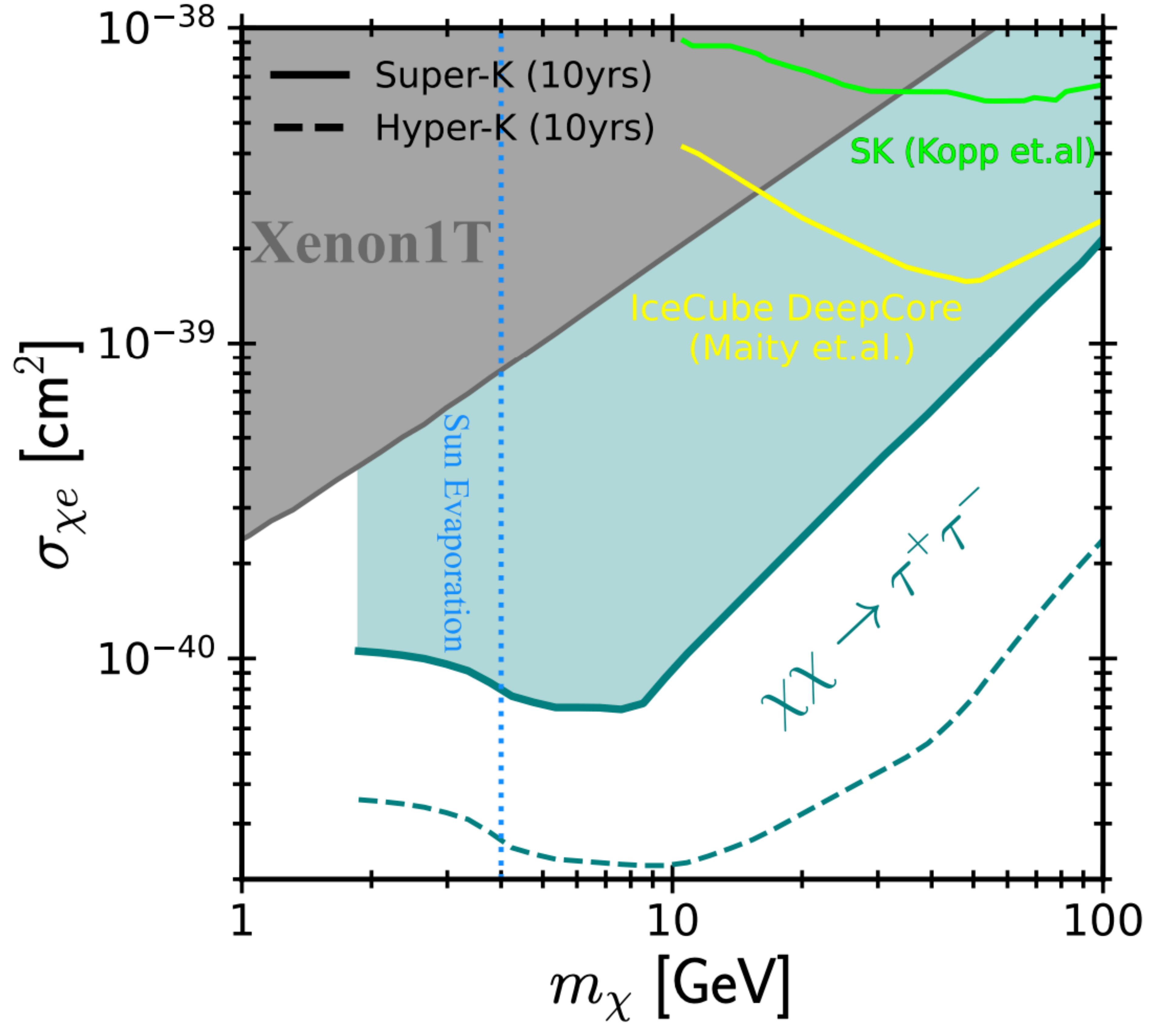


A diagram of Jupiter showing a model of the planet's interior, with a rocky core overlaid by a deep layer of liquid metallic hydrogen (shown as magenta) and an outer layer predominantly of molecular hydrogen.

Super-K and Hyper-K

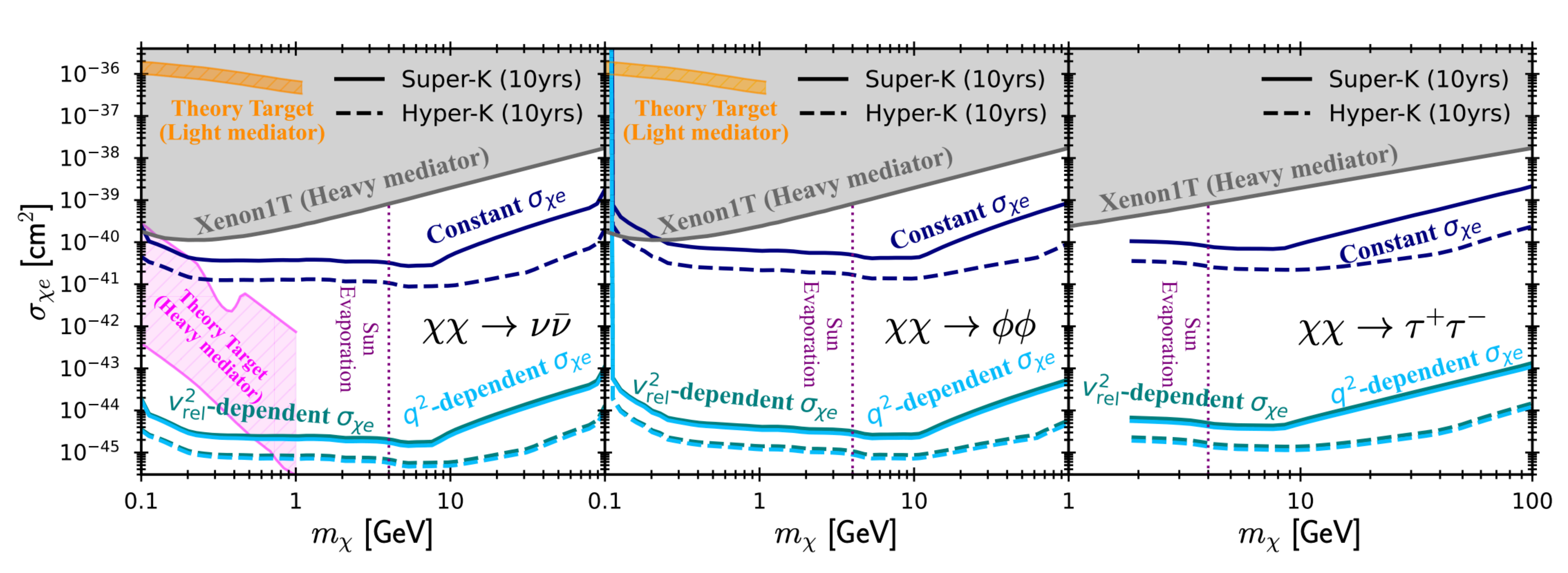
Maybe Super-Duper-Kamiokande in the future?





Velocity and Momentum-dependent cross sections

Too fast too furious!



Comment on 2503.07713

ν limits from Super-Kamiokande on dark matter-electron scattering in the Sun

Dhashin Krishna [1,*] Rinchen Sherpa [1,†] Akash Kumar Saha [1,‡] Tarak Nath Maity [2,§] Ranjan Laha [1,¶] and Nirmal Raj [1,**]

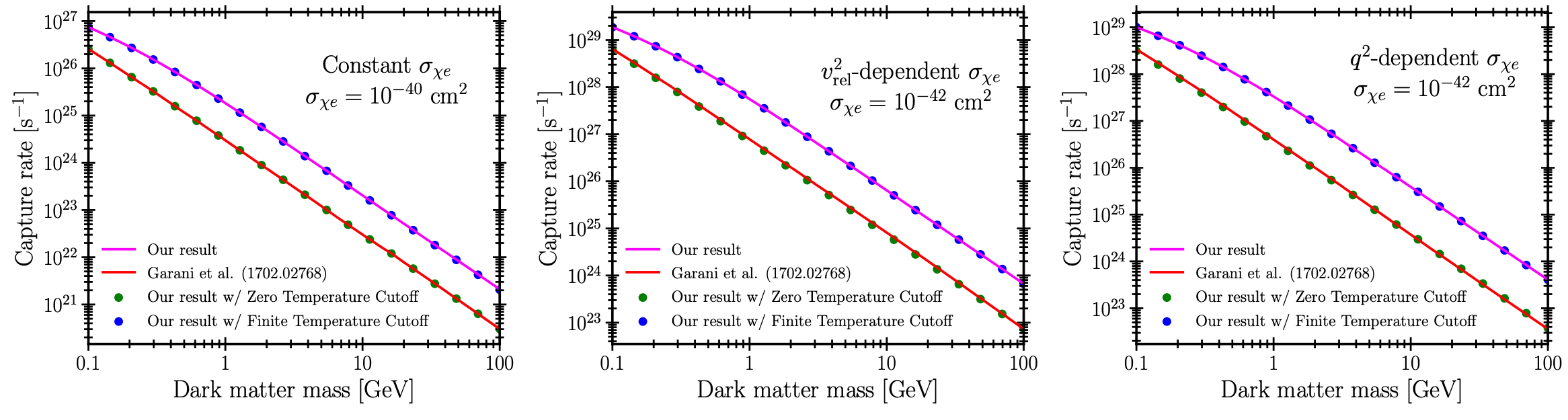
[1] *Centre for High Energy Physics, Indian Institute of Science, C. V. Raman Avenue, Bengaluru 560012, India*
[2] *School of Physics, The University of Sydney, ARC Centre of Excellence for Dark Matter Particle Physics, NSW 2006, Australia*

(Dated: March 12, 2025)

this discrepancy is the DM solar capture rate obtained in Ref. [147]. While Ref. [147] uses expressions for the capture rate derived in Ref. [107], the capture rates plotted in Fig. S3 exceed those plotted in Fig. 1 of Ref. [107] by a factor of about 7 for the relevant DM mass range. Our capture rates match those in Ref. [107]. Further, we also differ in our estimates of the angular cut used to reduce the atmospheric neutrino background. Whereas we use Eq. (4), Ref. [147] mentions following Ref. [44], which has used the square of the net angular resolution that underestimates the backgrounds by roughly a factor of 3. The cut in Ref. [147] is stronger than ours also

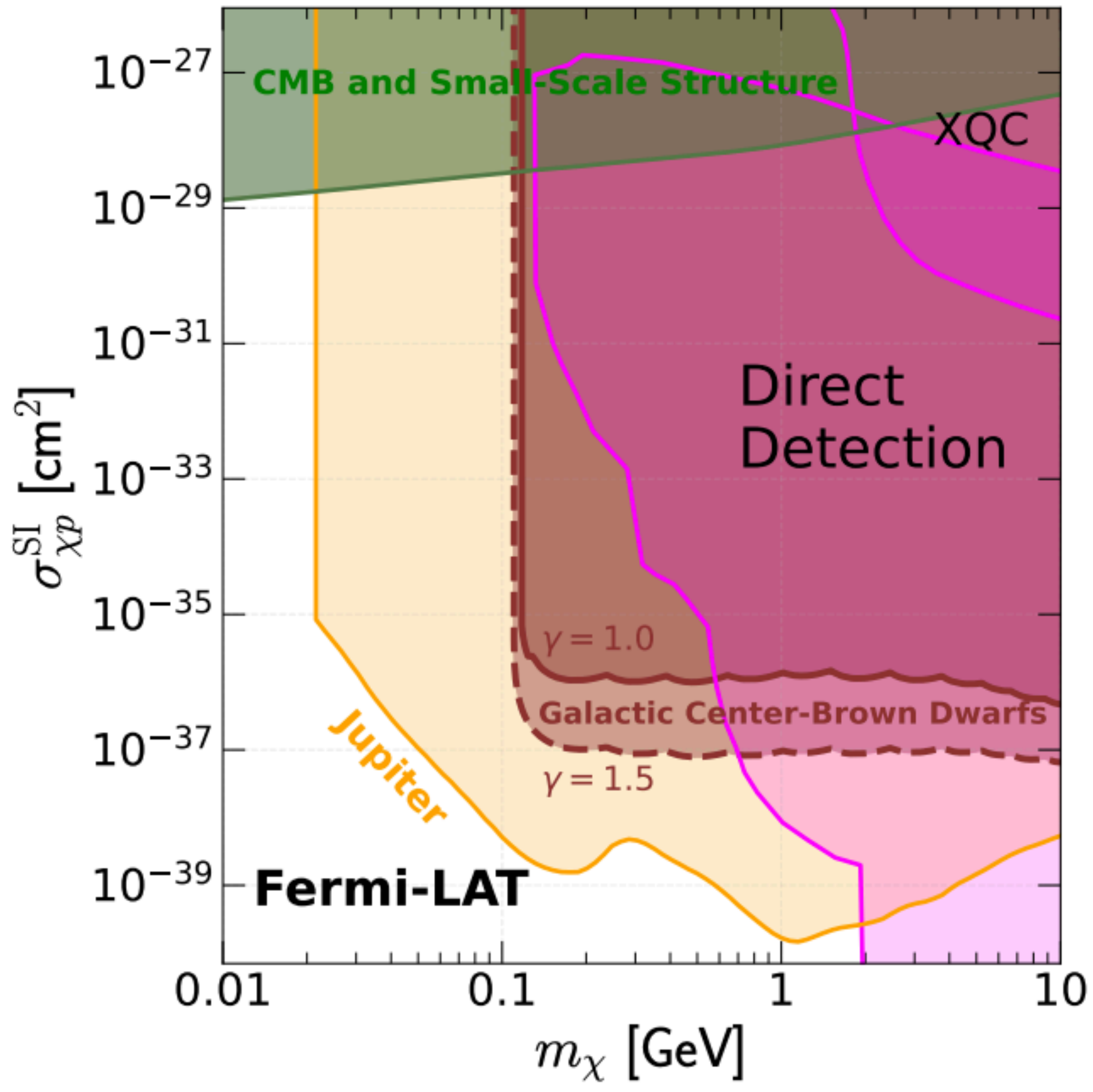
Compare with previous capture rate results

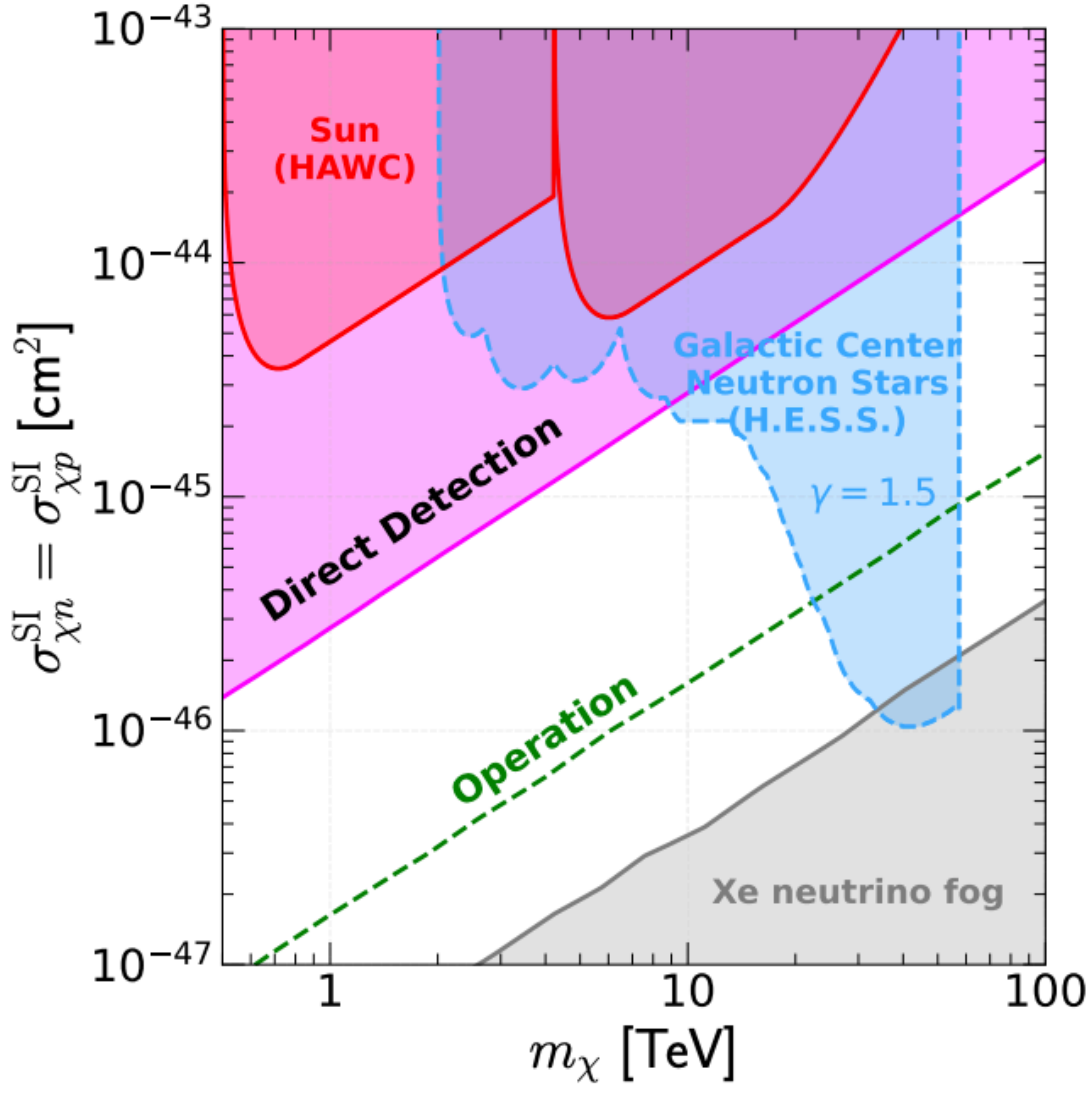
We are confident that we have obtained the correct finite-temperature capture rate!



DM-nucleon bounds with gamma-ray

DM annihilate to long-lived vector mediators, that decay into 3 photons





DM-nucleon bounds with VHE neutrinos

From Galactic Center Neutron Stars, observe with IceCube!