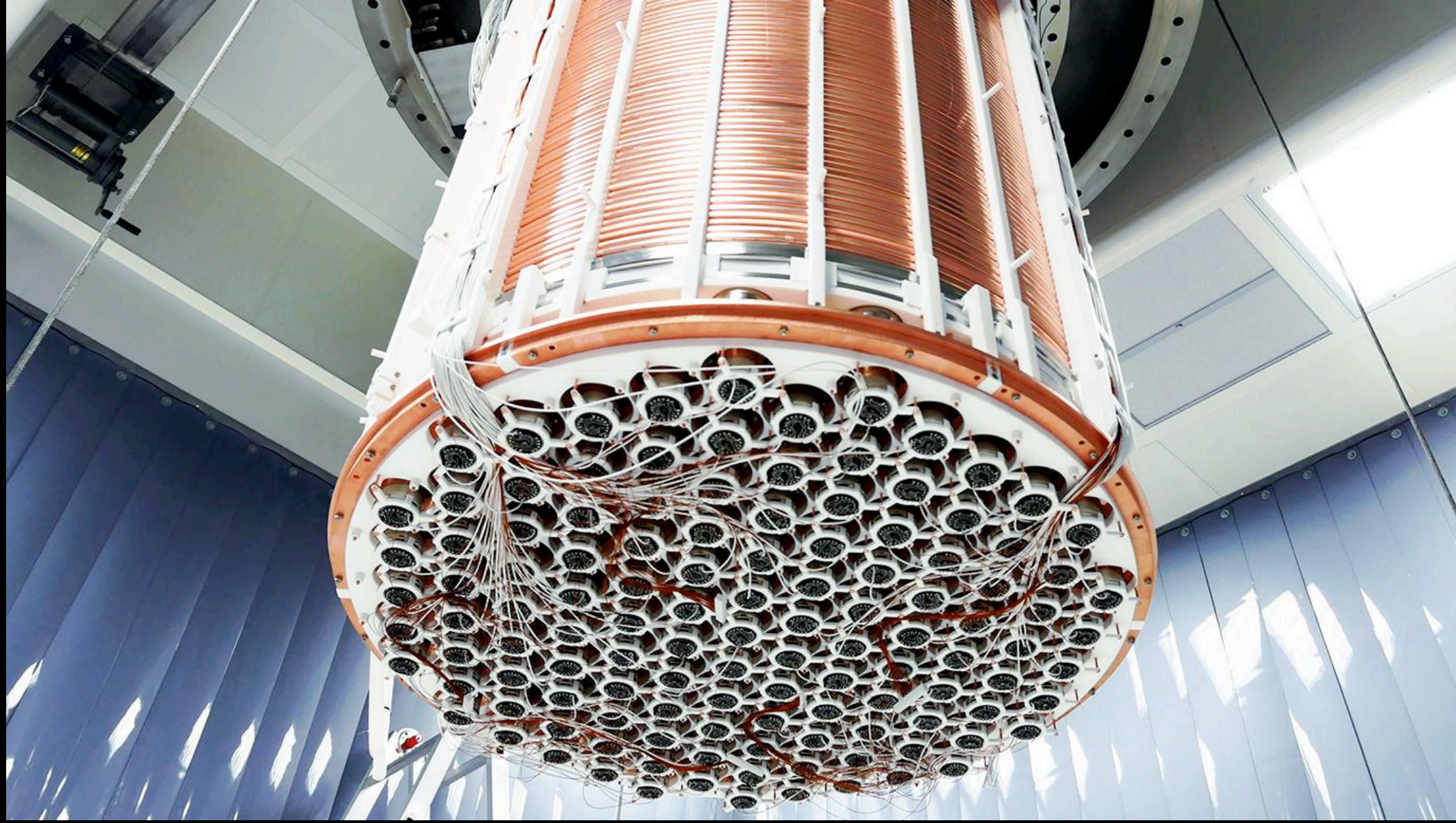




Celestial Bodies as Dark Matter Detectors

Tim Linden

Celestial Bodies vs. Direct Detection

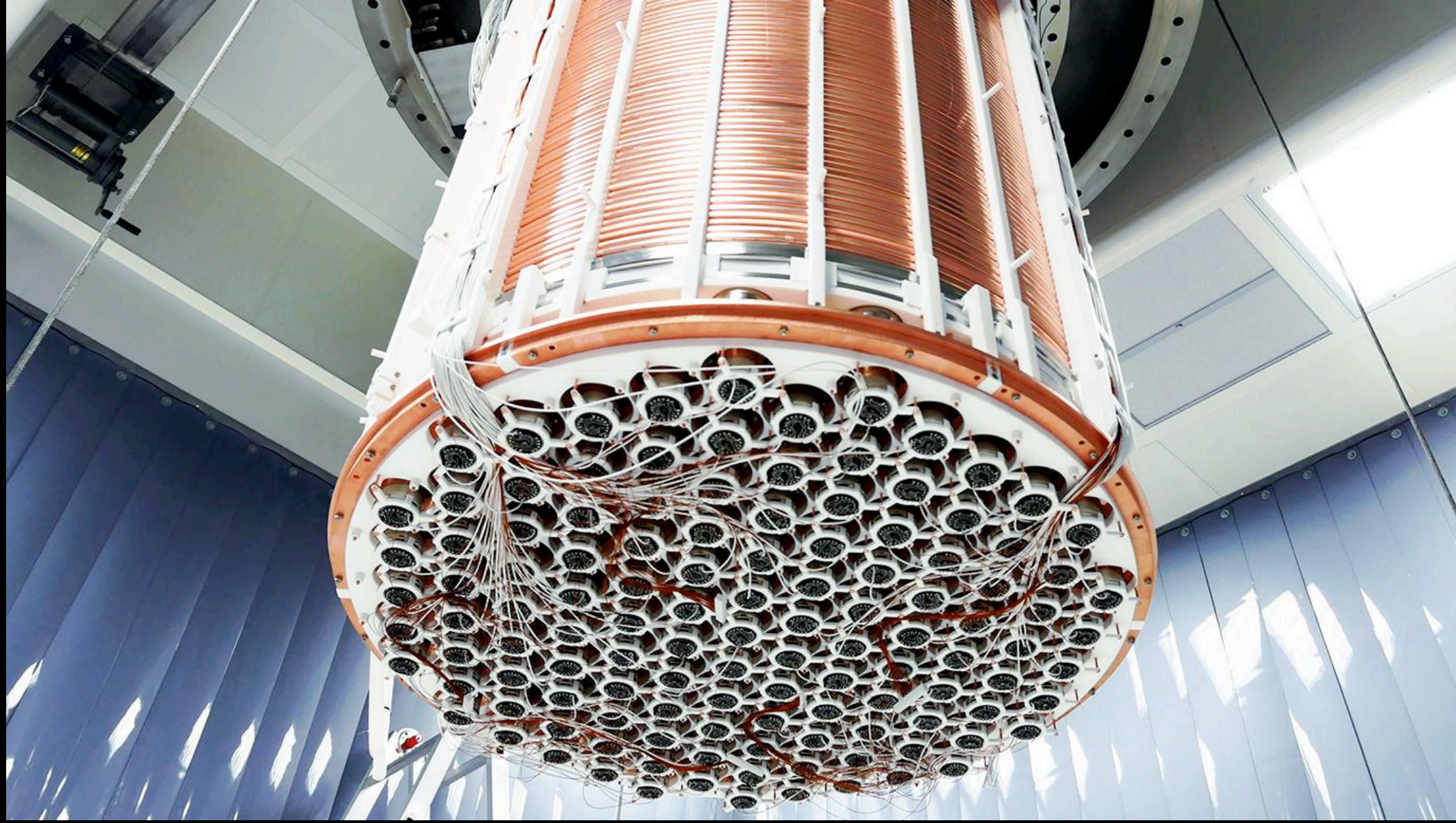


XENONnT

- 8600 kg
- 1000 days

8×10^6 kg day

Celestial Bodies vs. Direct Detection



XENONnT

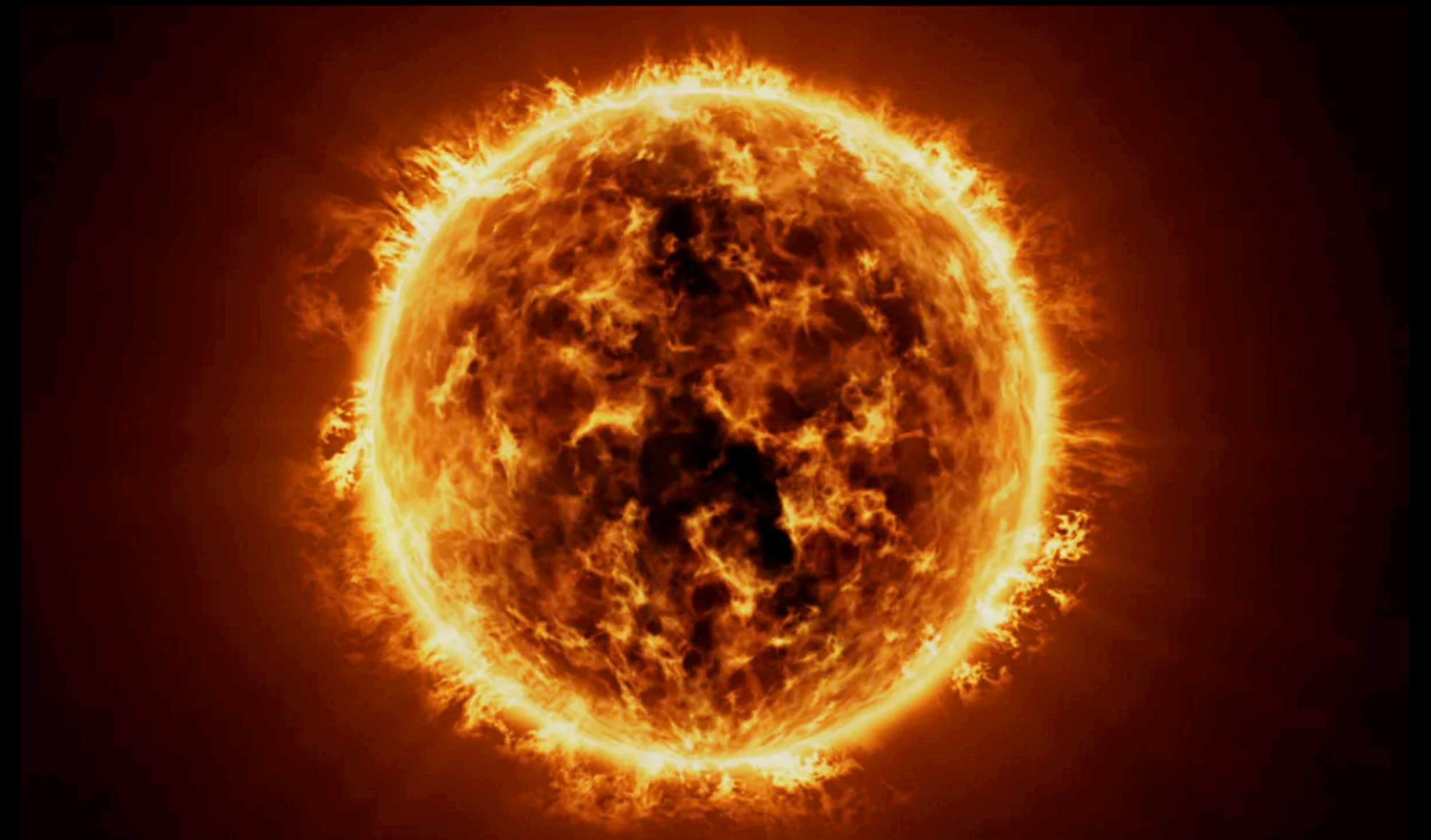
- 8600 kg
- 1000 days

8×10^6 kg day

Sun

- 3×10^{30} kg
- 2×10^{10} days

6×10^{40} kg day



Celestial Bodies vs. Direct Detection

$6 \times 10^{40} \text{ kg day}$ $>$ $8 \times 10^6 \text{ kg day}$

Precision Physics is Possible

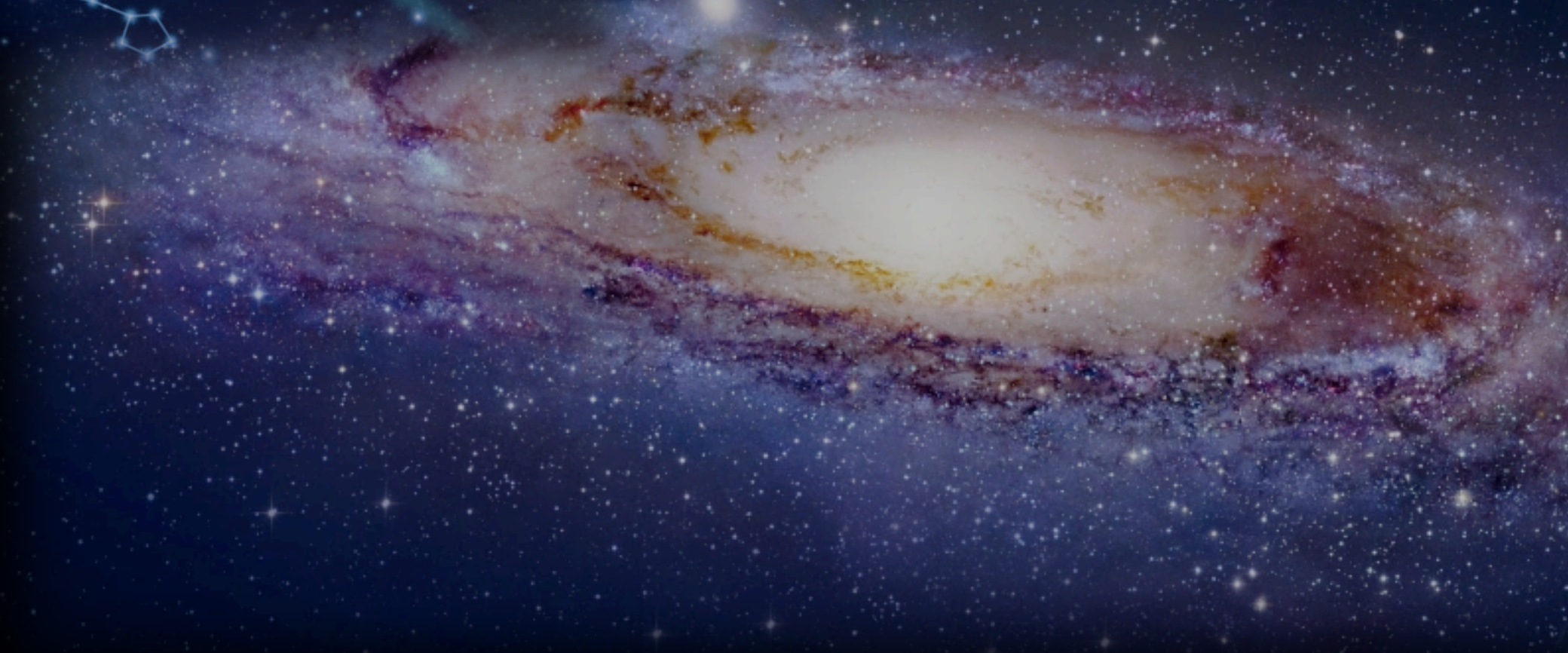
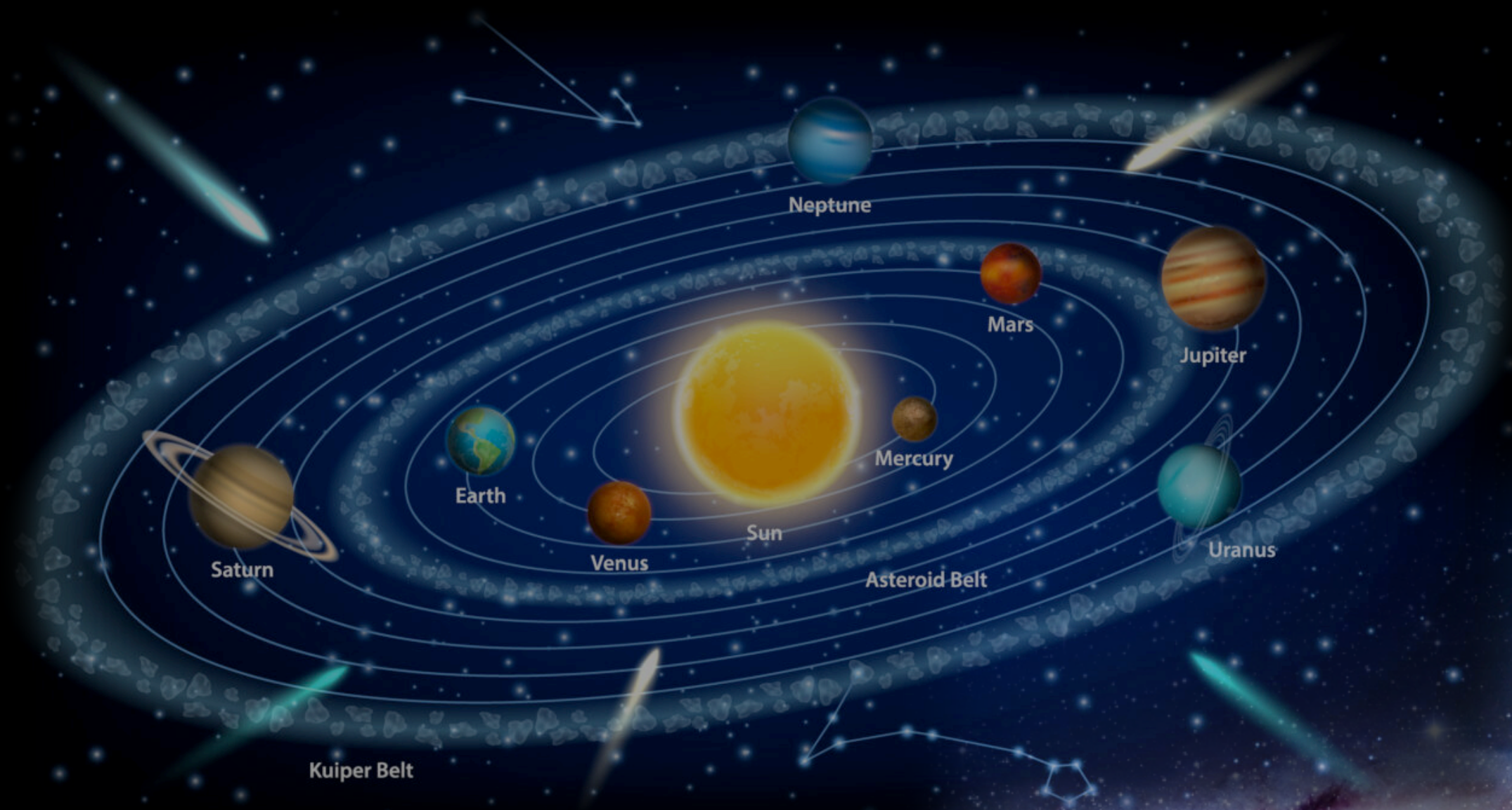
- Neutron star spin among the best measured quantities in physics.

PSR J1713+0747

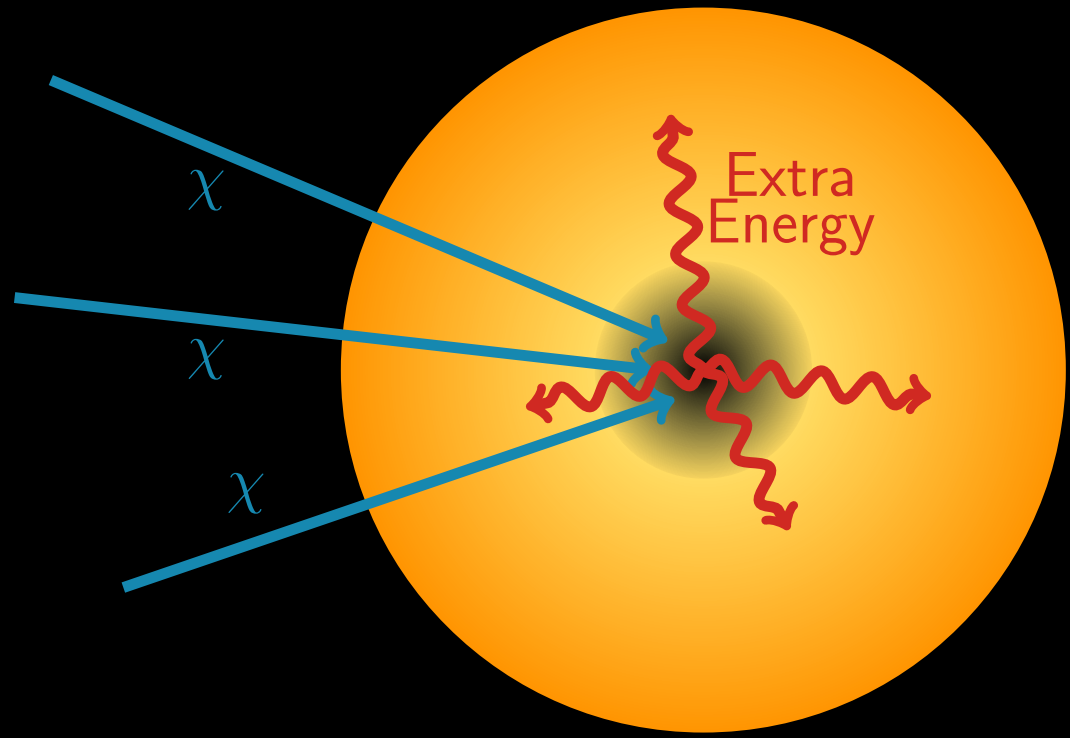
$$F = 218.8118437960826270 \pm 0.000000000000000988 \text{ s}^{-1}$$

$$F' = -4.083888637248 \pm 0.0000143324982645 \times 10^{-16} \text{ s}$$

A Multitude of Targets

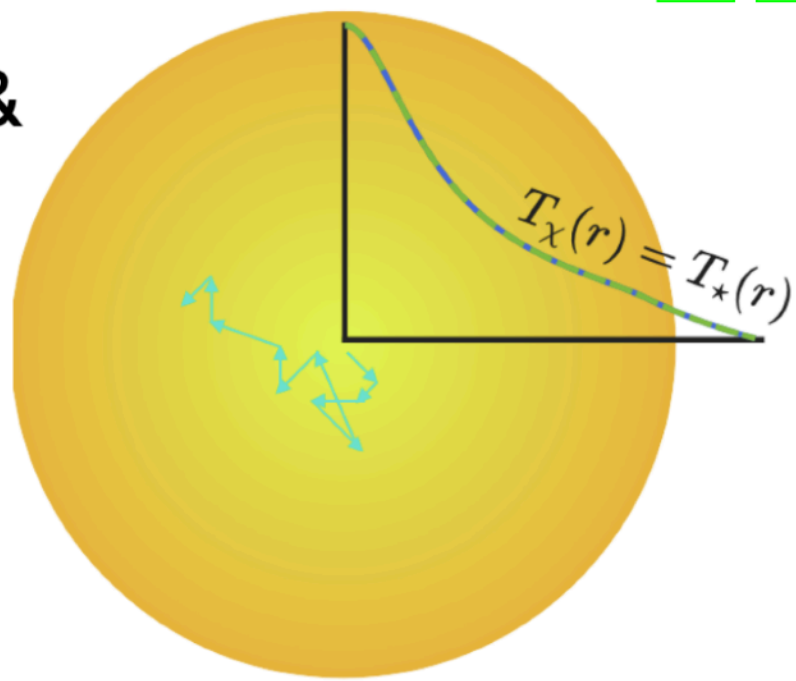


A Multitude of Signatures



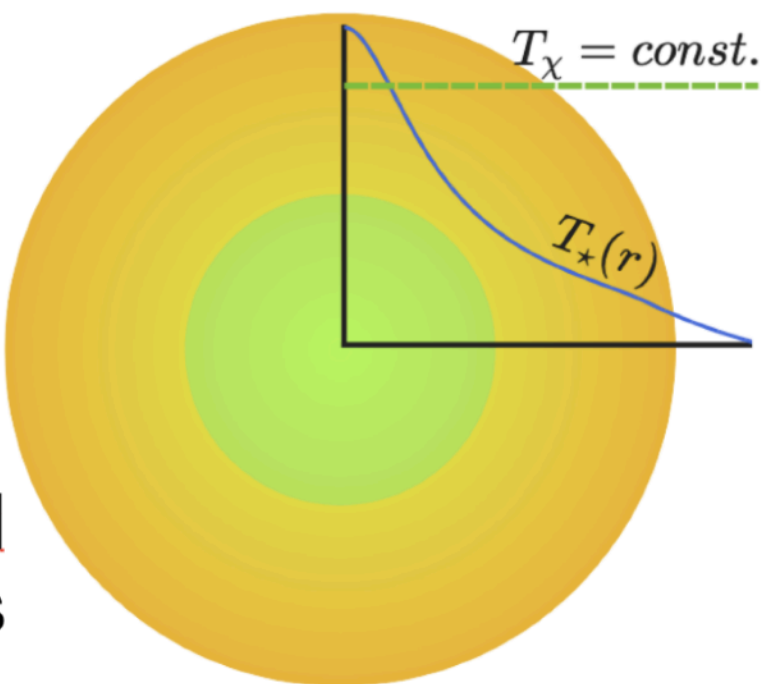
Gould &
Raffelt

$K \ll 1$



$K \gg 1$

Spergel
& Press



DM Heating

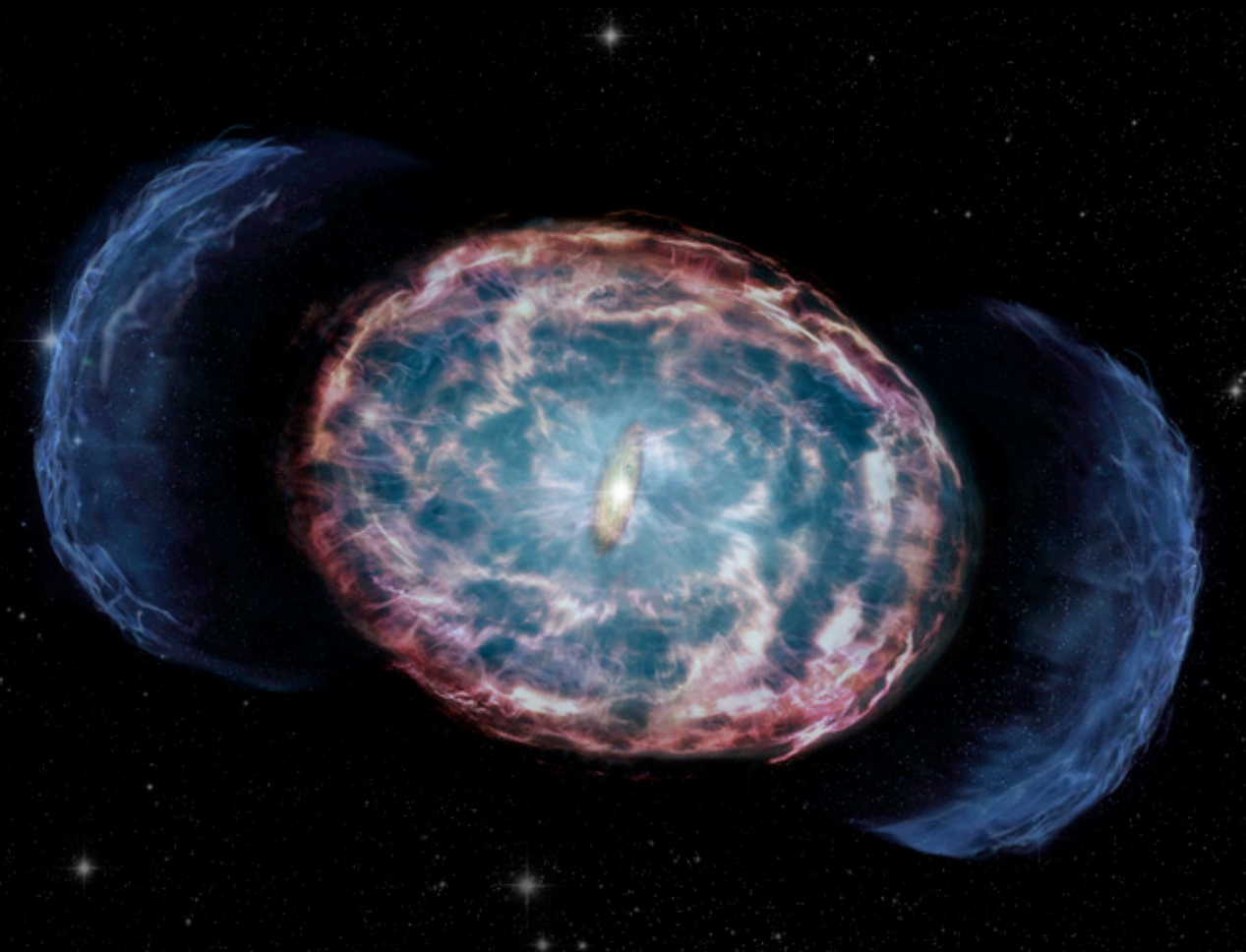
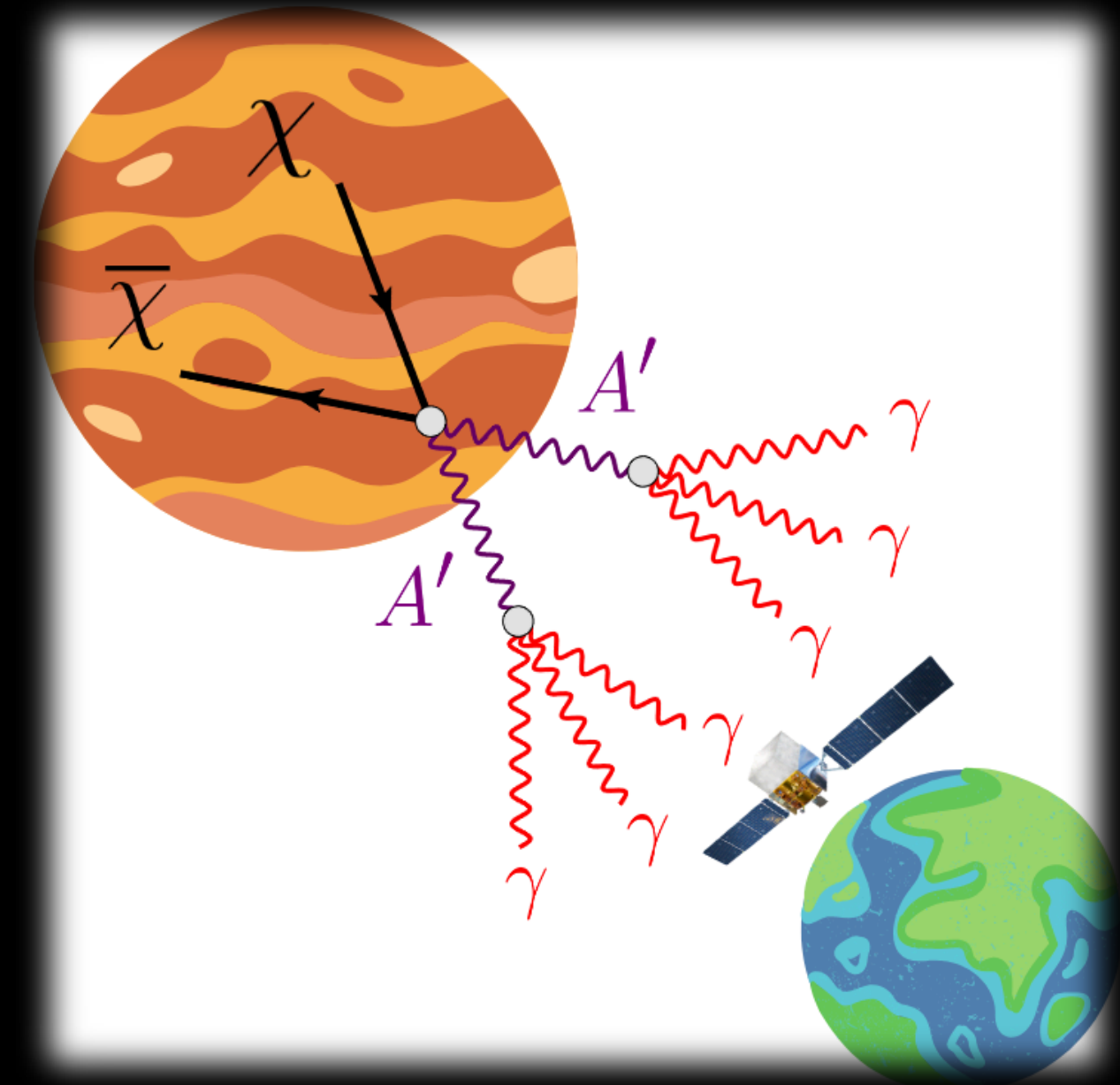
DM Signals

Energy

Transport

Explosive

Events

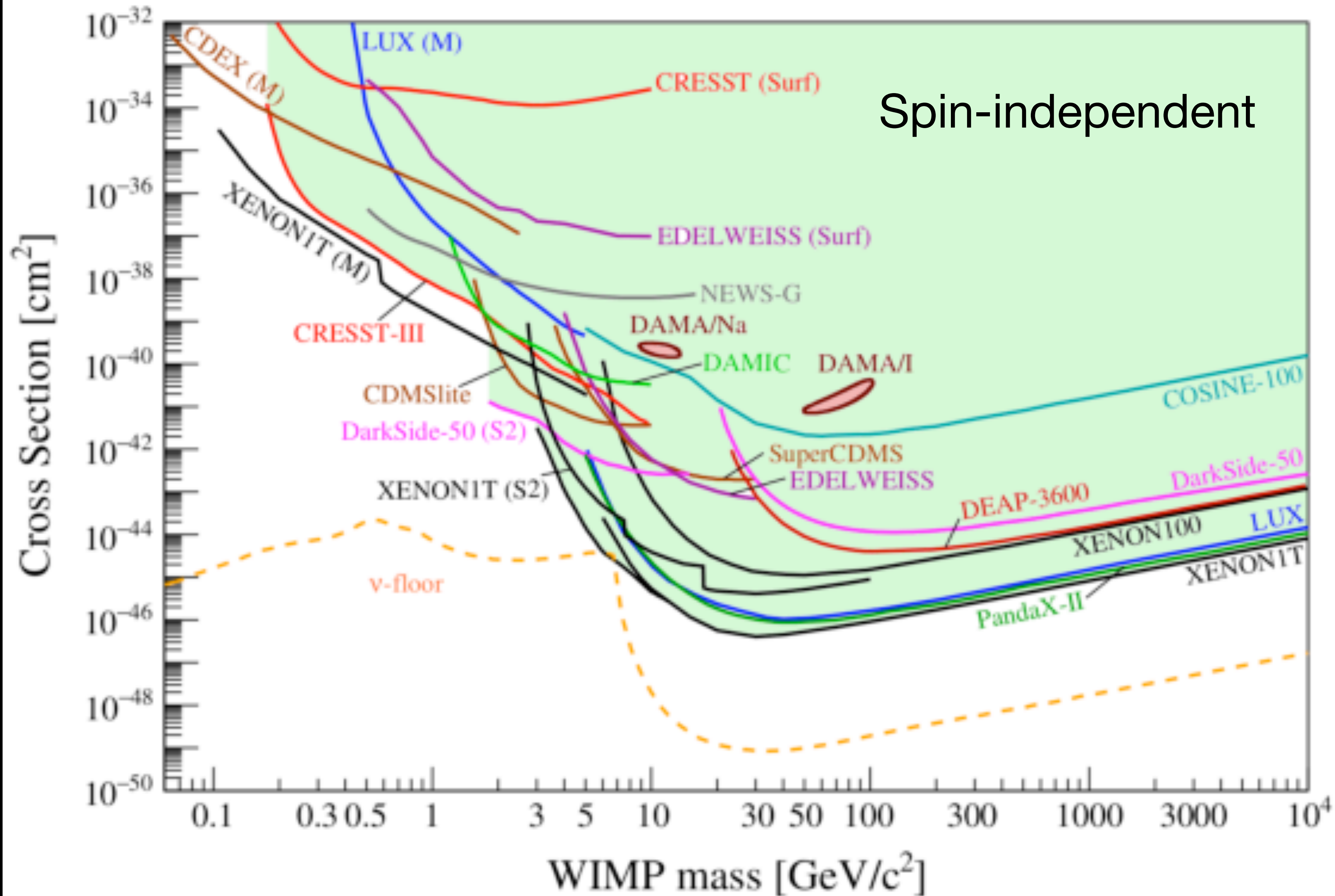


A Multitude of Dark Matter Models

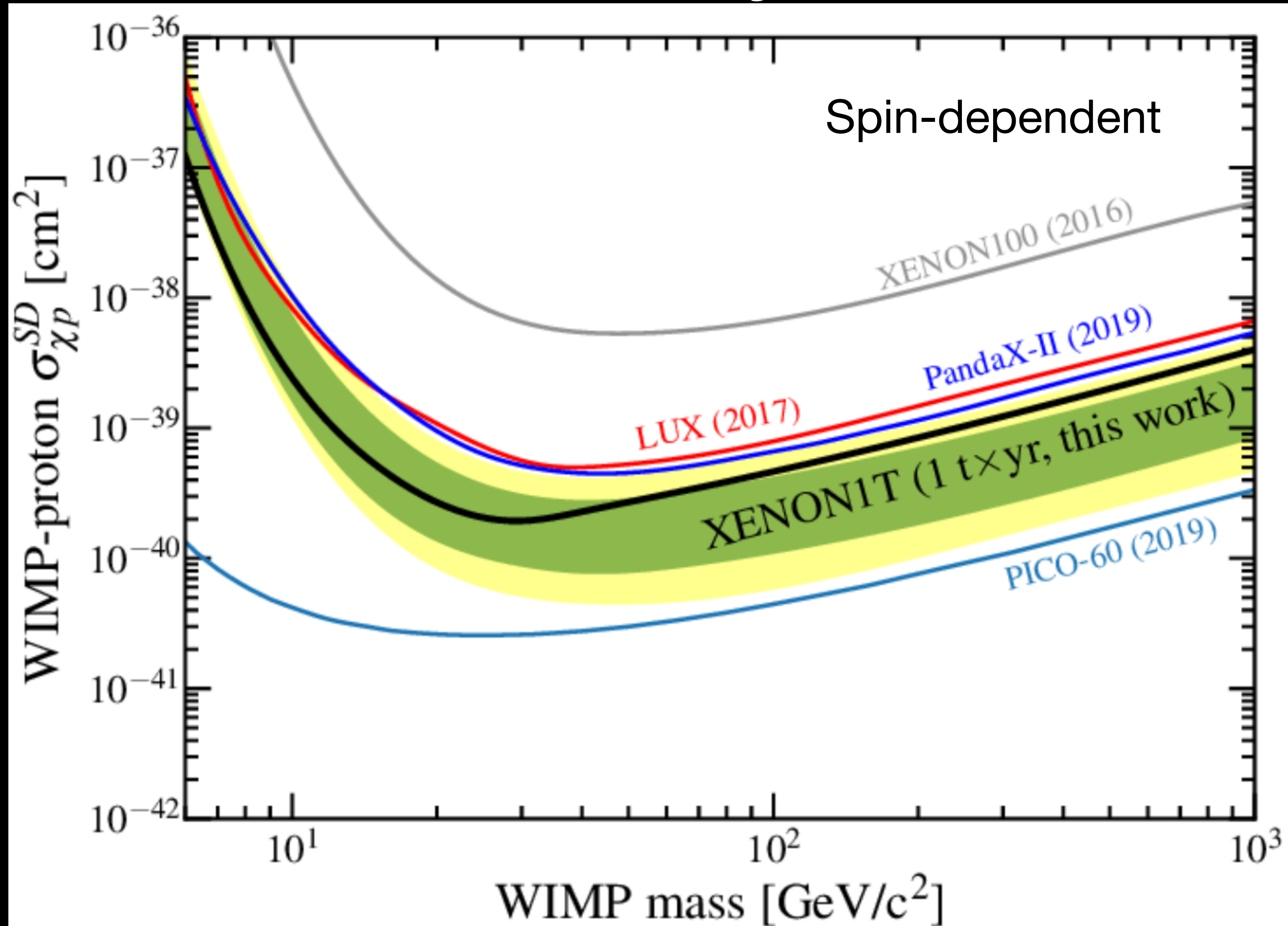




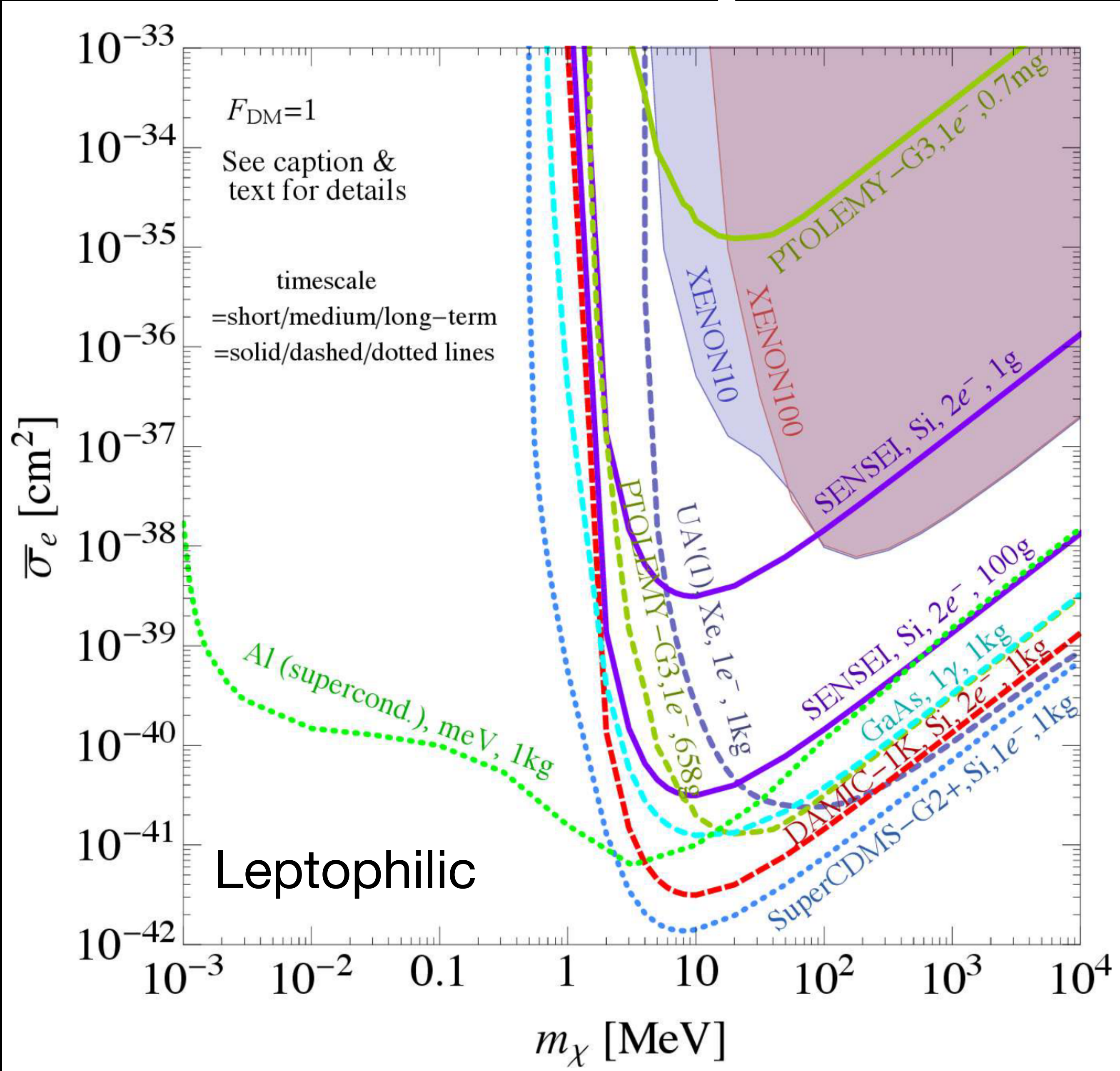
Standard Searches Fail in Many of These Scenarios












































Standard Searches Fail in Many of These Scenarios

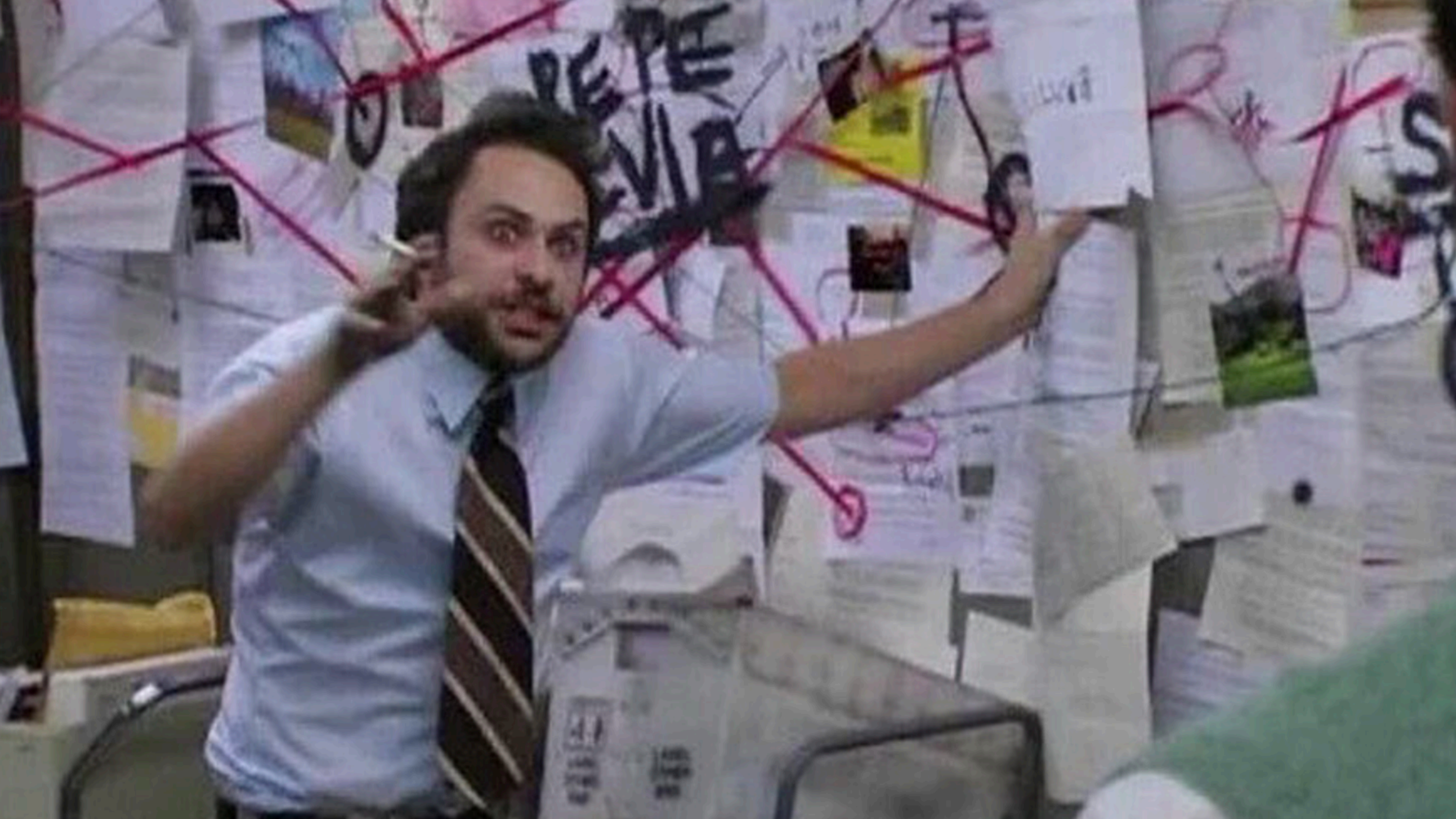


Standard Searches Fail in Many of These Scenarios



A Cacophony Of Studies

DD	GeV Scale	Sun		     	Heating Signatures (Thermal Spectra)
	Asymmetric	Jupiter		 	Thermal Transport (Seismology)
	Self-Interacting	S-Cluster			Thermal Transport (Affect on Neutrino Flux)
	Light Mediator	G-Objects		  	Thermal Transport (Cooling Curves)
				 	Escaping Signals (DM Neutrinos)
no DD	<GeV Mass	GC Brown Dwarfs		   	Escaping Signals (Cosmic Rays/ γ -Rays)
	>TeV Mass	GC White Dwarfs		   	Structural Changes (Longer Lifespan of CBs)
	Spin-Dependent			   	Structural Changes (Destruction of CBs)
	Inelastic			   	Structural Changes (Spectral Changes)
	Velocity-Dependent	Dark Stars		   	Structural Changes (Population Level)



How to Do Science in the High-Risk High-Reward Regime

1.) Avoid Two-Miracle Studies

- **Standard model miracles cost half.**
- **Miracles can be correlated**

2.) Focus on observables

- **When the risk is high, observers will not spend effort on studies.**

3.) Attack the biggest uncertainty, and then move on.

- **Every individual study is individually unlikely.**

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$$A - M \geq 0$$

Possible detections

How to Do Science in the High-Risk High-Reward Regime

“Wear your ~~character~~ theory as lightly as a cap.”



A Few Recent Studies

1.) SuperK Neutrino Searches in the Sun (2501.14864)

2.) Stellar Heating at the Galactic Center (2311.16228; 2405.12267)

3.) Missing Pulsars at the Galactic Center (1405.1031, 1706.00001)

Super-Kamiokande Searches for the Sun

- 1.) **Astrophysical Target:** The Sun
- 2.) **Dark Matter Target:** Annihilating Leptophilic Dark Matter
- 3.) **Detection Technique:** Escaping Signals (Neutrinos)



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,§}

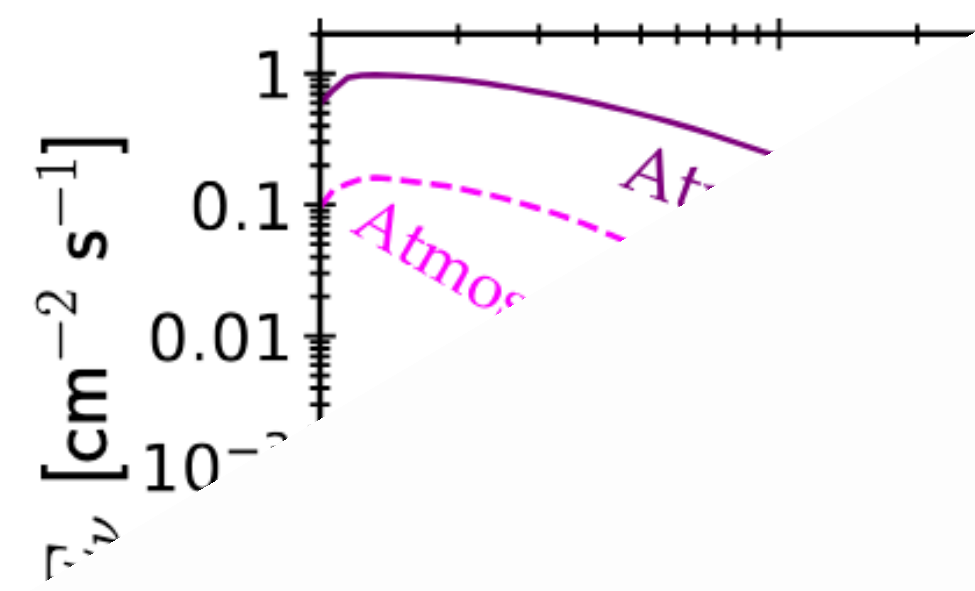
¹*Stockholm University and The Oskar Klein Centre for Cosmoparticle Physics, Alba Nova, 10691 Stockholm, Sweden*

²*Columbia University, 116th and Broadway, New York, NY 10027 USA*

The Sun can efficiently capture leptophilic dark matter that scatters with free electrons. If this dark matter subsequently annihilates into leptonic states, it can produce a detectable neutrino flux. Using 10 years of Super-Kamiokande observations, we set constraints on the dark-matter/electron scattering cross-section that exceed terrestrial direct detection searches by more than an order of magnitude for dark matter masses below 100 GeV, and reach cross-sections as low as $\sim 4 \times 10^{-41} \text{ cm}^{-2}$.

Abstract. — Detecting the particle interactions of dark matter is a cornerstone in our efforts to study beyond the Standard Model physics [1–3]. Many of the most powerful constraints depend on searching for rare scattering events between the dark matter particle and Standard Model particles [4–11].

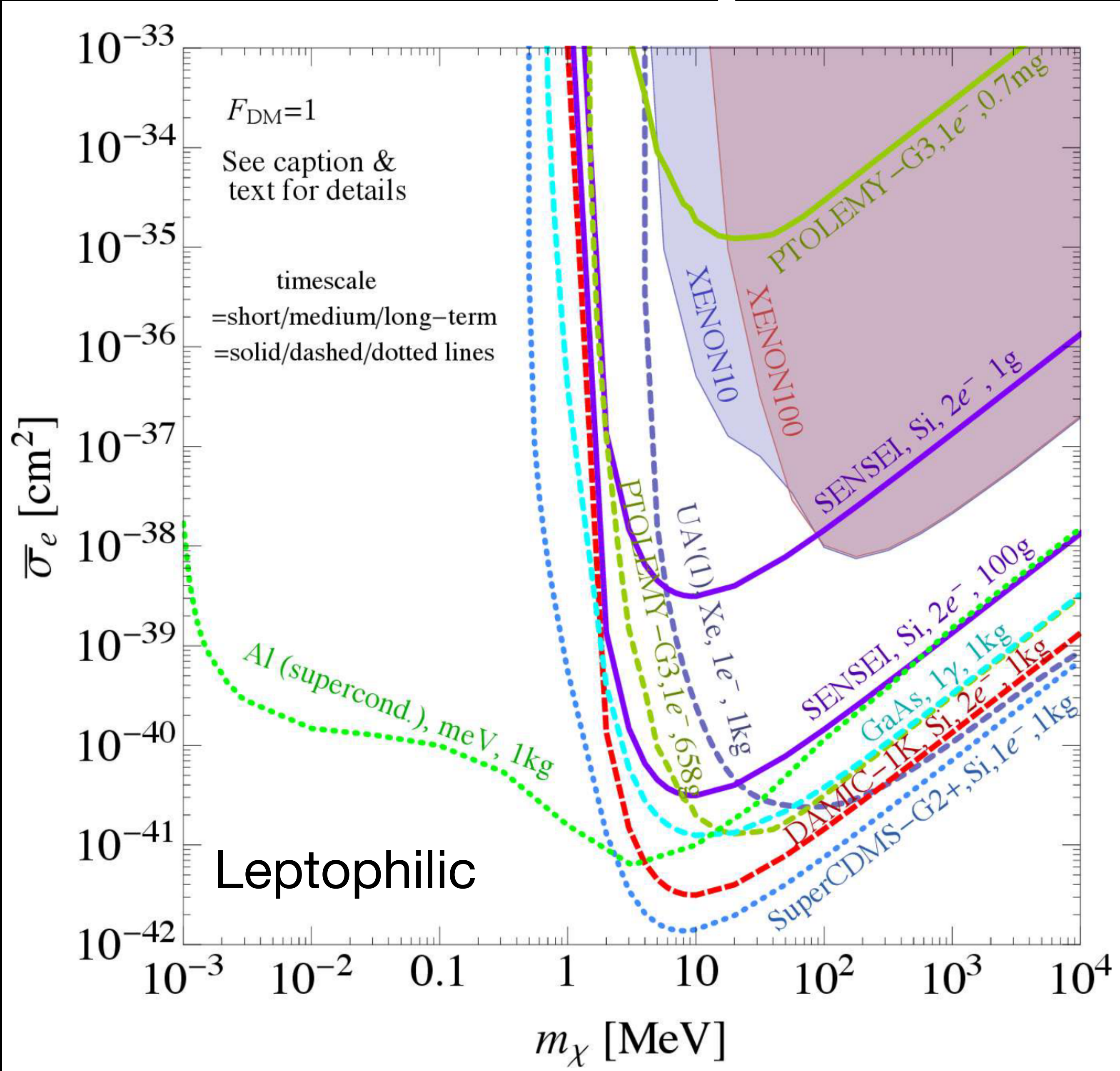
While terrestrial detectors, such as direct detection experiments, motivate current searches for dark matter, indirect searches, such as those using astronomical detectors, uses unmodelled astrophysical backgrounds and rely on the assumption of dark matter annihilation or interaction with Standard Model particles.



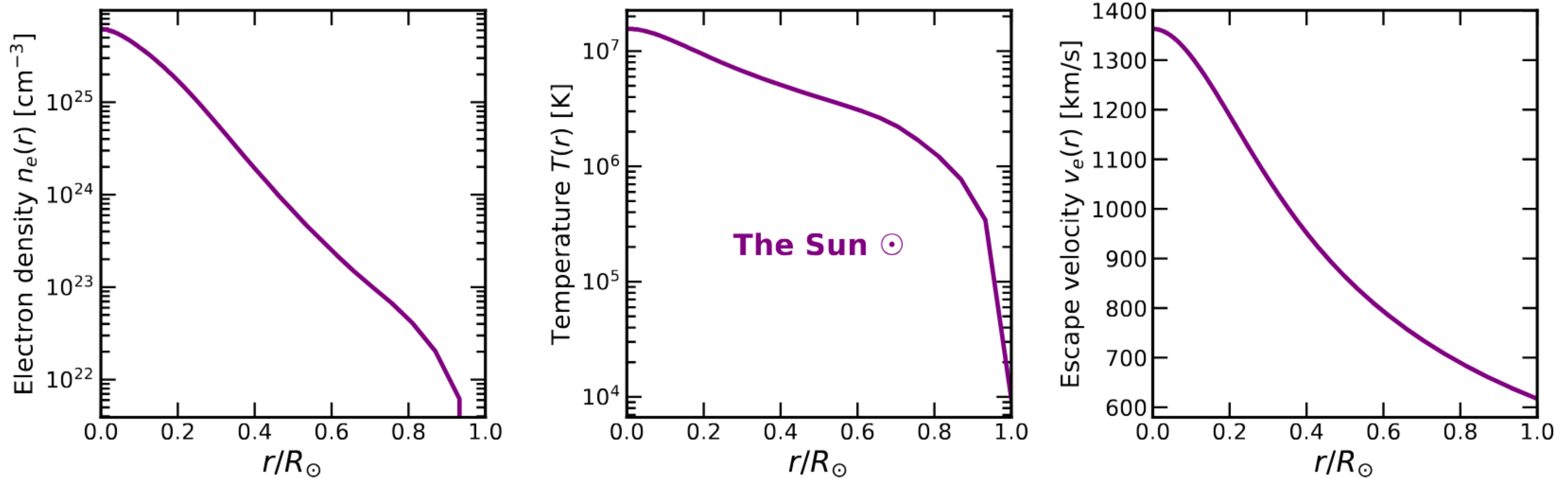
Dark matter in the Sun: constraints from Super-Kamiokande
Dark matter scattering off electrons vs nucleons
Thong T.Q. Nguyen¹ and Sergio Palomares-Ruiz²
¹Department of Physics and Physikalisches Institut, Universität zu Köln, 50924 Köln, Germany
²CSIC-Universitat de València, 46100 Burjassot, Spain
E-mail: thong.nguyen@fzj.kit.edu, sergio.palomares@uv.es

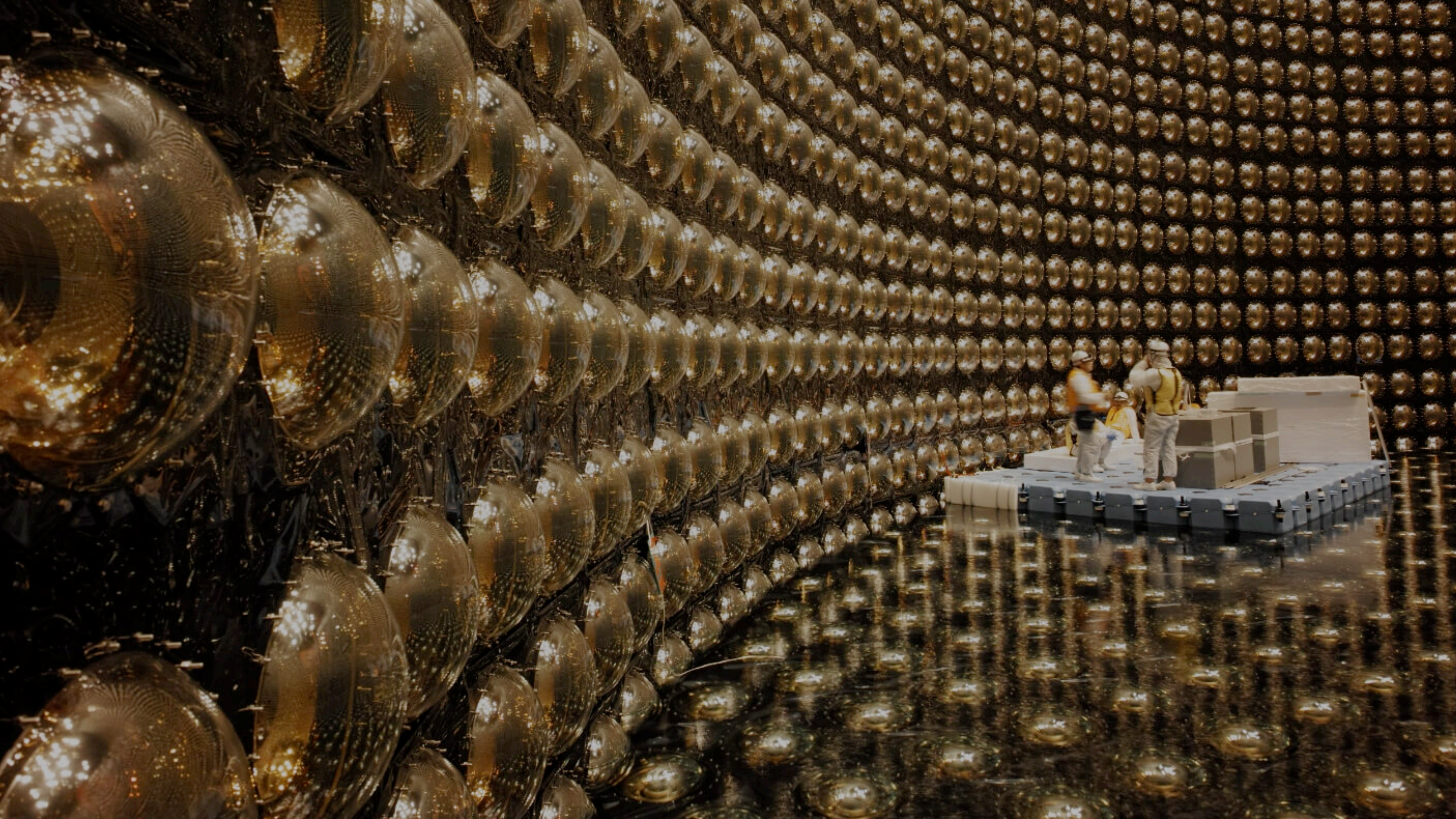
Neutrinos from the Sun can discover dark matter-electron scattering
Nath Maity^{1,2,3,*}, Akash Kumar Saha^{1,3,†}, Sagnik Mondal^{1,3,‡} and Ranjan Laha^{1,3,§}
¹Harish-Chandra Research Institute, A CI of Homi Bhabha National Institute, Chhatnag Road, Jhansi, Prayagraj (Allahabad) 211019, India
²Regional Centre for Accelerator-based Particle Physics, Harish-Chandra Research Institute, Prayagraj (Allahabad) 211019, India
³Energy Physics, Indian Institute of Science, C. V. Raman Avenue, Bangalore 560012, India
(Dated: August 25, 2023)
Dark matter-electron scattering using high-energy neutrinos can get captured in different Standard Model (SM) processes. We find that the current data from Super-Kamiokande observations of the solar neutrino flux can be used to constrain the dark matter-electron scattering cross-section. We find that the current data from Super-Kamiokande observations of the solar neutrino flux can be used to constrain the dark matter-electron scattering cross-section. We find that the current data from Super-Kamiokande observations of the solar neutrino flux can be used to constrain the dark matter-electron scattering cross-section.

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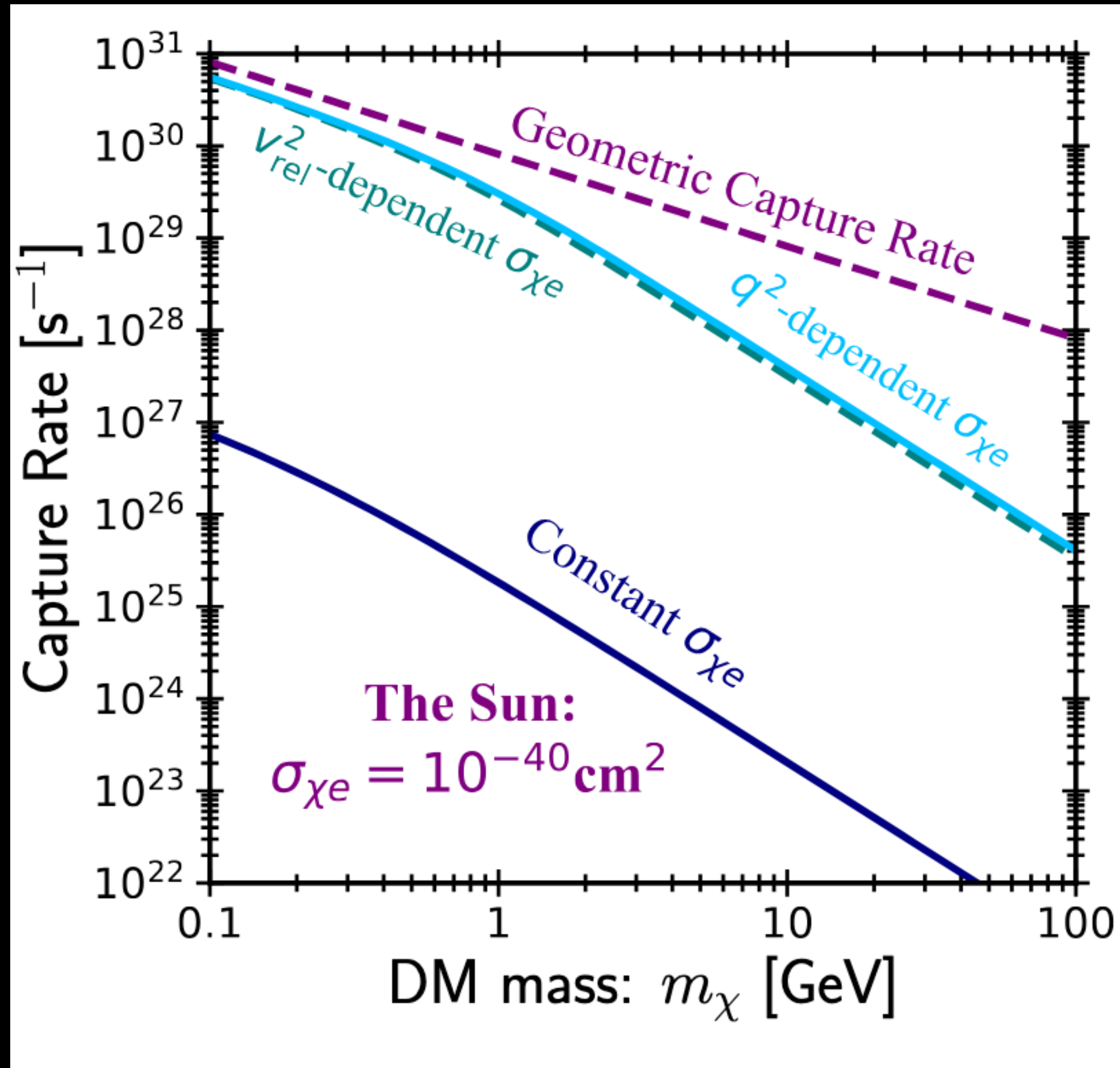


Super-Kamiokande Searches for the Sun

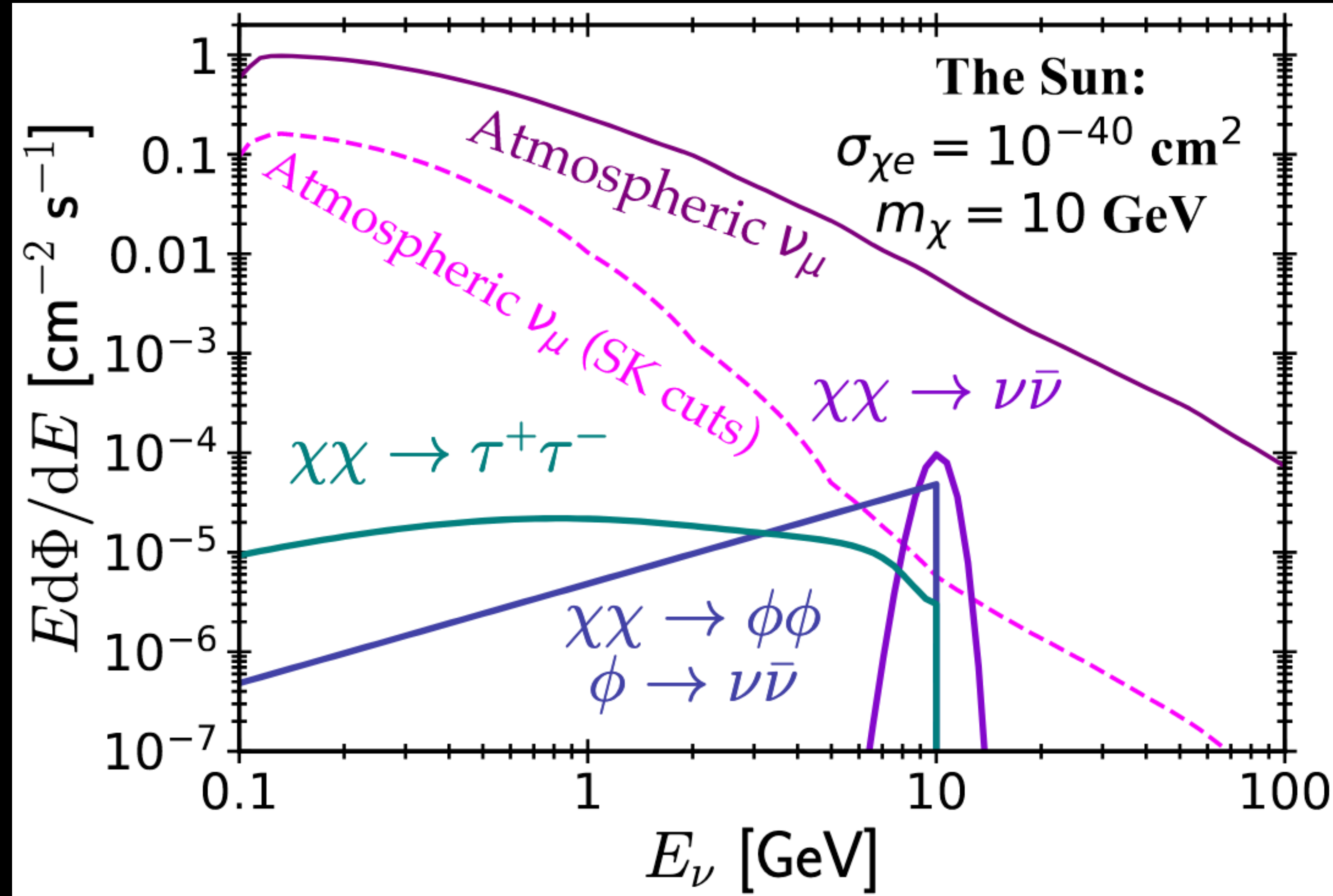




Dark Matter Capture in the Sun

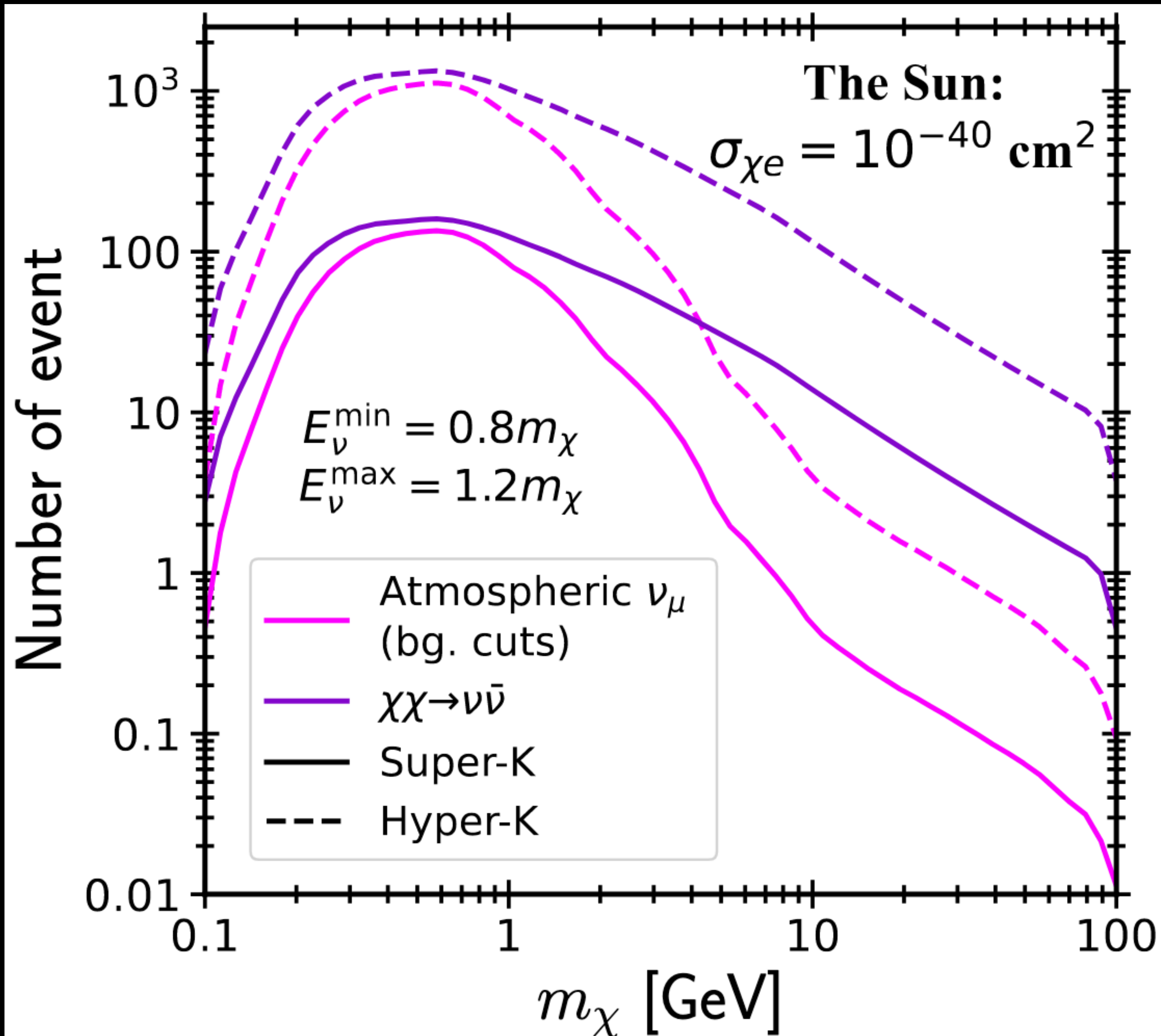


Super-Kamiokande



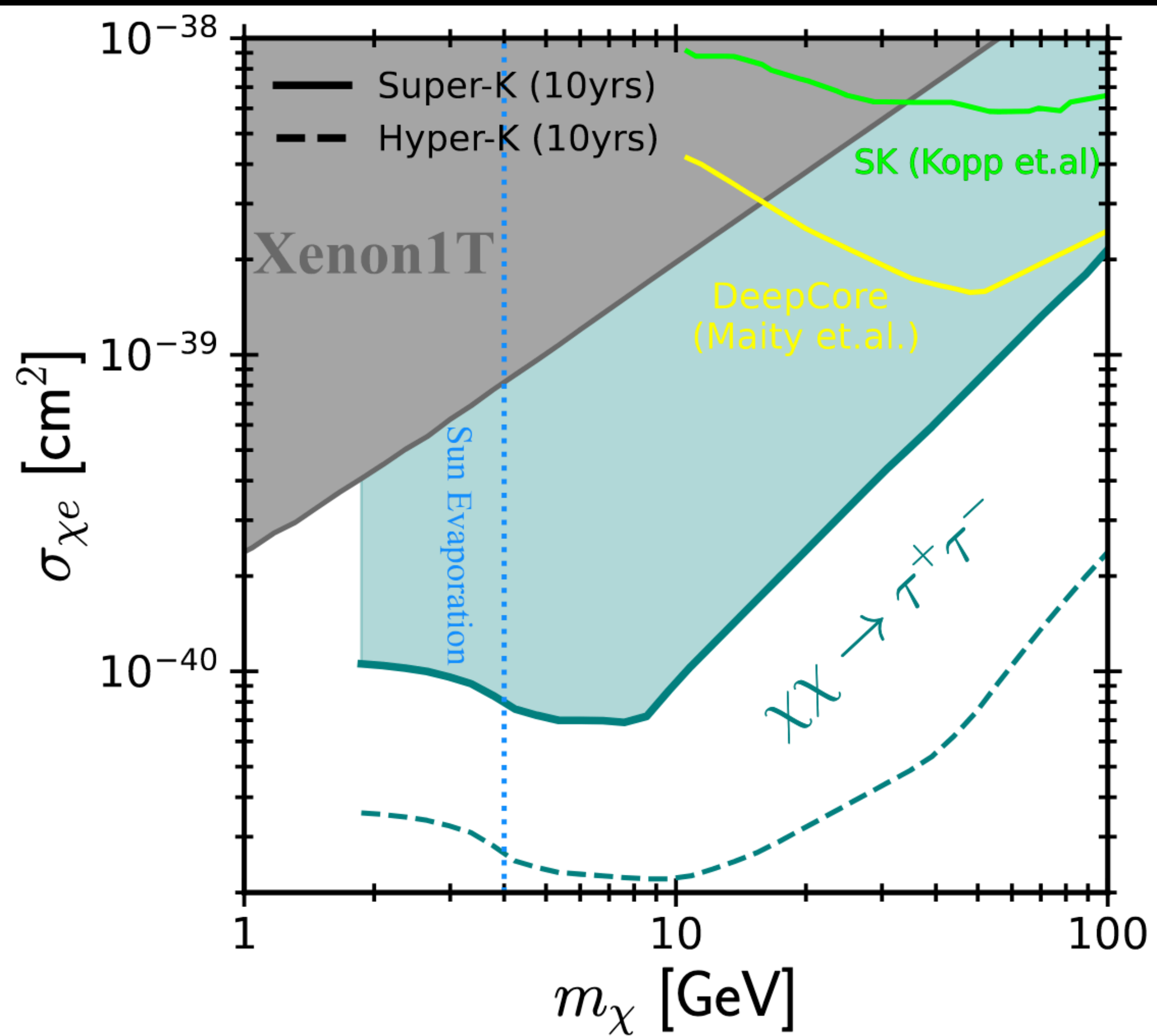
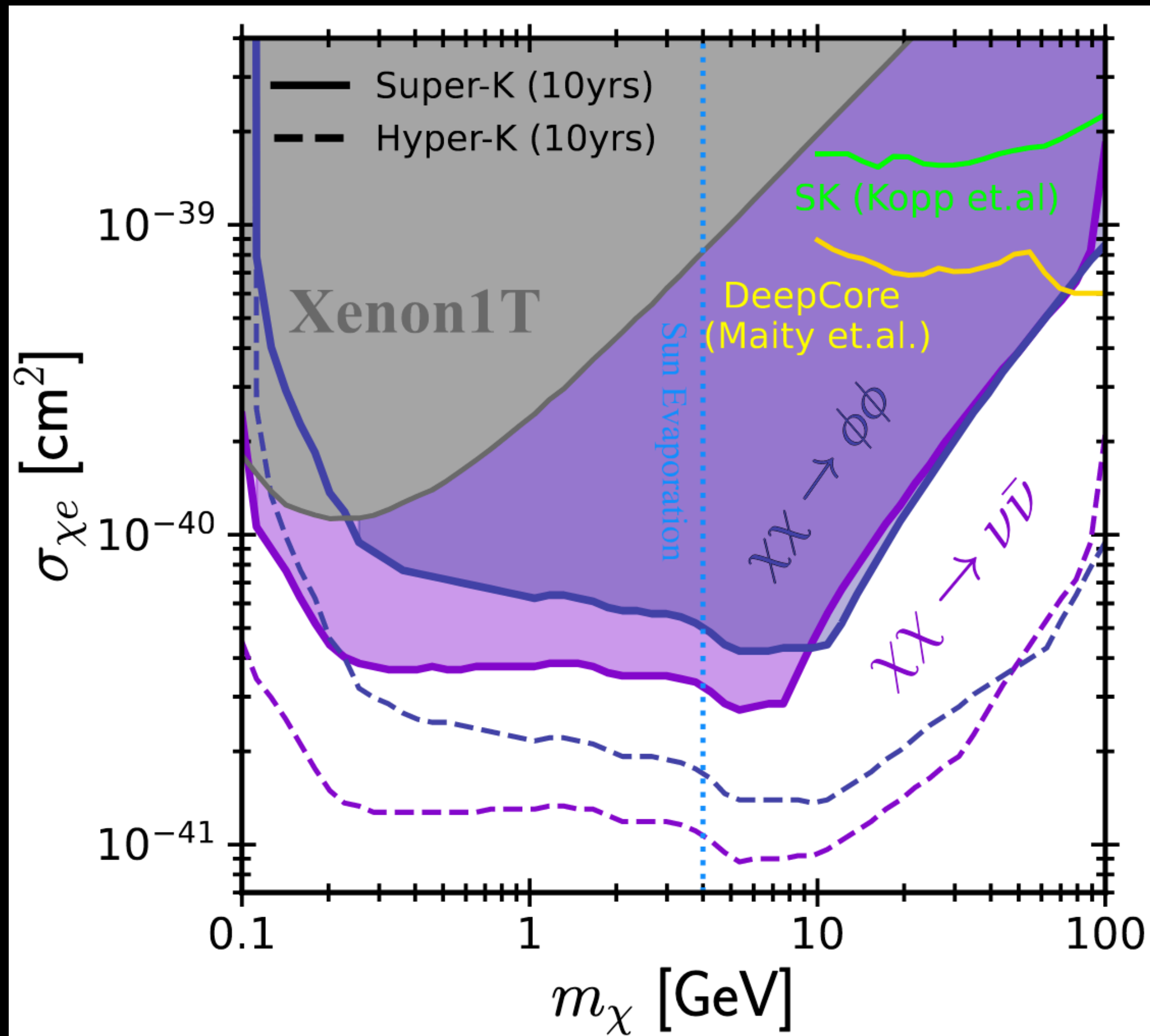
- **“Miracle” - Dark Matter must be leptophilic.**
- **Standard annihilation cross-sections and unconstrained scattering rate.**
- **Significant annihilation rate to neutrinos (or taus).**

Super-Kamiokande

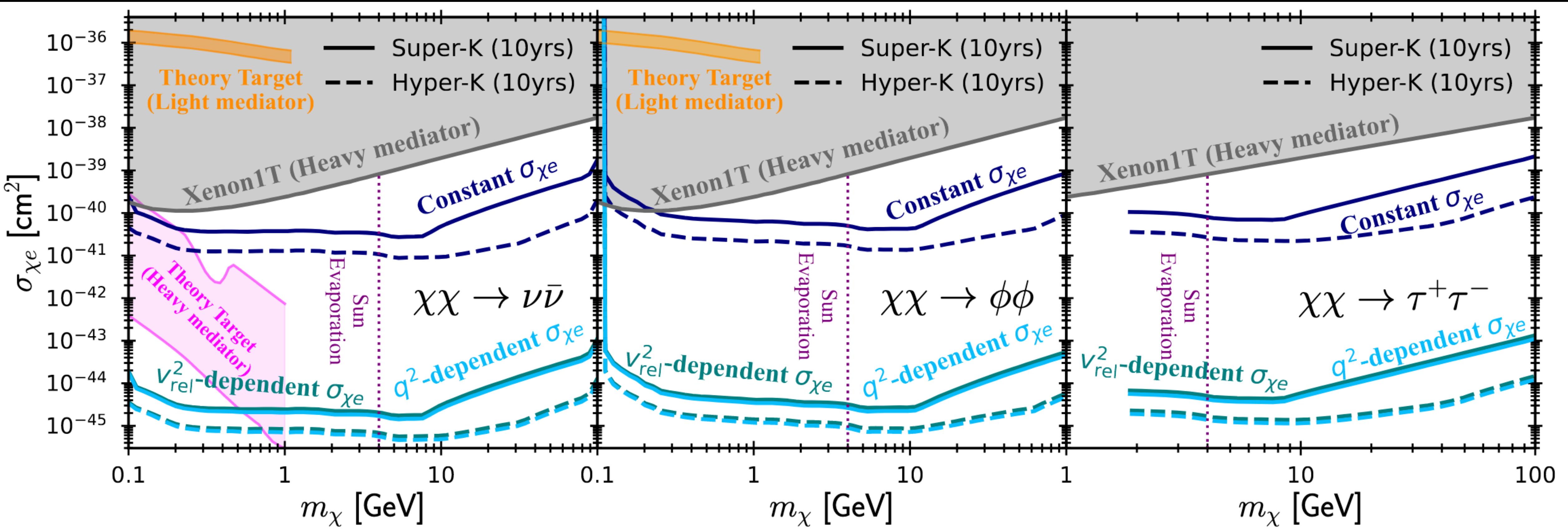


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Super-Kamiokande



Super-Kamiokande



- When the cross-sections are velocity or momentum dependent, the high velocity of electrons makes constraints much stronger, probing the theoretical targets for leptophilic DM.

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Immortal Stars at the Galactic Center

See also: work on Dark Stars (e.g., Spolyar & Freese)

SLAC-PUB-17770

Dark Branches of Immortal Stars at the Galactic Center

Isabelle John,^{1,*} Rebecca K. Leane,^{2,3,†} and Tim Linden^{1,‡}

¹*Stockholm University and The Oskar Klein Centre for Cosmoparticle Physics, Alba Nova, 10691 Stockholm, Sweden*

²*Particle Theory Group, SLAC National Accelerator Laboratory, Stanford, CA 94035, USA*

³*Kavli Institute for Particle Astrophysics and Cosmology, Stanford University, Stanford, CA 94035, USA*

We show that stars in the inner parsec of the Milky Way can be significantly affected by dark matter annihilation, producing population-level effects that are visible in a Hertzsprung-Russell (H-R) diagram.

We establish the dark HR diagram, where stars lie on a new stable *dark main sequence* with lower luminosities, but lower temperatures, than the standard main sequence.

The dark main sequence is continuously replenished by dark matter annihilation.

Upcoming telescopes could detect the dark main sequence.

Dark Matter Scattering Constraints from Observations of Stars Surrounding Sgr A*

Isabelle John,^{1,*} Rebecca K. Leane,^{2,3,†} and Tim Linden^{1,‡}

¹*Stockholm University and The Oskar Klein Centre for Cosmoparticle Physics, Alba Nova, 10691 Stockholm, Sweden*
²*Particle Theory Group, SLAC National Accelerator Laboratory, Stanford, CA 94035, USA*
³*Kavli Institute for Particle Astrophysics and Cosmology, Stanford University, Stanford, CA 94035, USA*

High resolution infrared data has revealed several young stars in close proximity to Sgr A*, favoring scenarios where dark matter annihilation produces stars. We examine the possibility that dark matter annihilation produces stars in the inner parsec of the Milky Way. We show that stars in the inner parsec of the Milky Way can be significantly affected by dark matter annihilation, producing population-level effects that are visible in a Hertzsprung-Russell (H-R) diagram. We establish the dark HR diagram, where stars lie on a new stable *dark main sequence* with lower luminosities, but lower temperatures, than the standard main sequence. The dark main sequence is continuously replenished by dark matter annihilation. Upcoming telescopes could detect the dark main sequence.

Dark stars at the Galactic centre – the main sequence

Pat Scott^{1*}, Malcolm Fairbairn^{2,3*} and Joakim Edsjö^{1*}

¹*Cosmology, Particle Astrophysics and String Theory, Department of Physics, Stockholm University & Oskar Klein Centre for Cosmoparticle Physics, AlbaNova University Centre, SE-106 91 Stockholm, Sweden*
²*Theory Division, CERN, CH-1211, Geneva 23, Switzerland*
³*Physics, Kings College London, Strand, London WC2R 2LS, UK*

2008 November 19. Submitted 2008 November 17; in original form 2008 October 5.

ABSTRACT

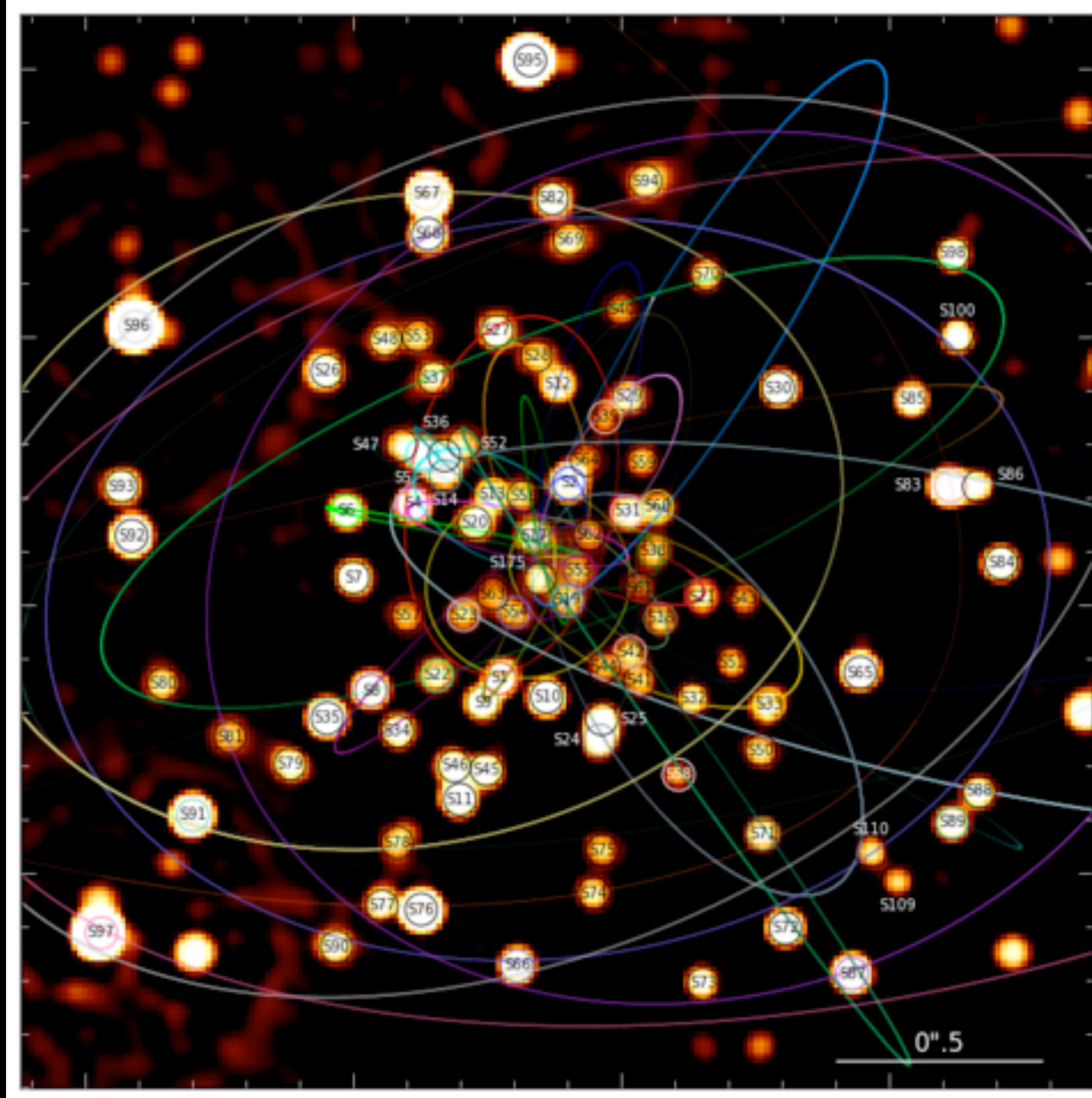
In regions of very high dark matter density such as the Galactic centre, the annihilation of WIMP dark matter by stars has the potential to significantly influence the dark stellar evolution code. We describe the dark stellar evolution code for main sequence stars, and show how it can be used to study the evolution of stars in the inner parsec of the Milky Way. We show that stars in the inner parsec of the Milky Way can be significantly affected by dark matter annihilation, producing population-level effects that are visible in a Hertzsprung-Russell (H-R) diagram. We establish the dark HR diagram, where stars lie on a new stable *dark main sequence* with lower luminosities, but lower temperatures, than the standard main sequence. The dark main sequence is continuously replenished by dark matter annihilation. Upcoming telescopes could detect the dark main sequence.

Immortal Stars at the Galactic Center

- 1.) **Astrophysical Target:** Galactic Center Stars
- 2.) **Dark Matter Target:** DM with Scattering and Annihilation Cross-Section
- 3.) **Detection Technique:** Stellar Heating (Optical)



Immortal Stars at the Galactic Center



**Many stars
within 0.016 pc**

Immortal Stars at the Galactic Center



Paradox of Youth: Spectroscopically middle-aged but bright as young stars

Conundrum of Old Age: Lack of very old stars



Top-heavy initial mass function: large abundance of massive stars

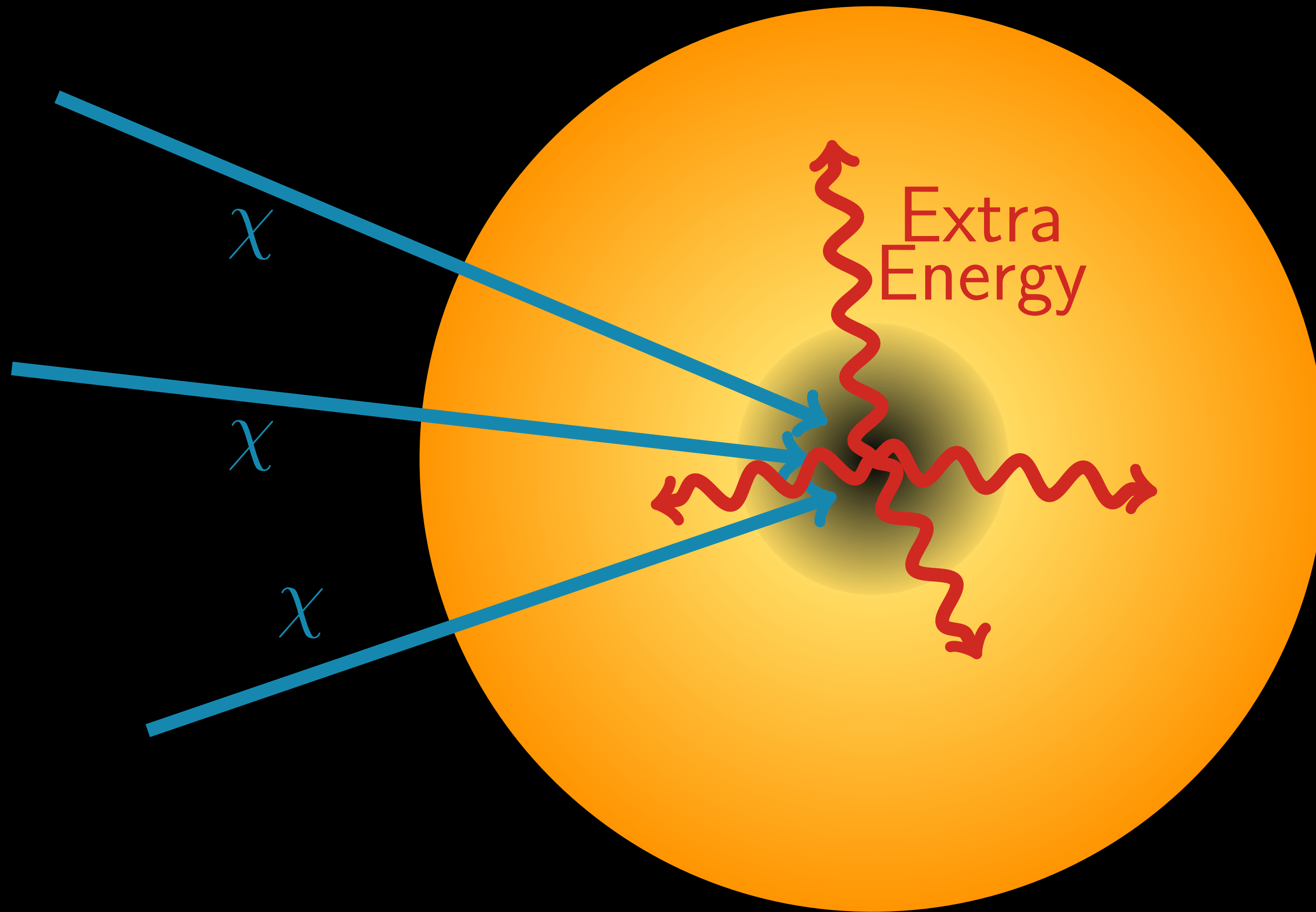
Massive Stars in Interacting Binaries
ASP Conference Series, Vol. 367, 2007
N. St-Louis & A.F.J. Moffat

Massive Young Stars in the Vicinity of our Galaxy's
Supermassive Black Hole: A Paradox of Youth

A. M. Ghez
Department of Physics & Astronomy and IGPP
University of California Los Angeles
12517 USA

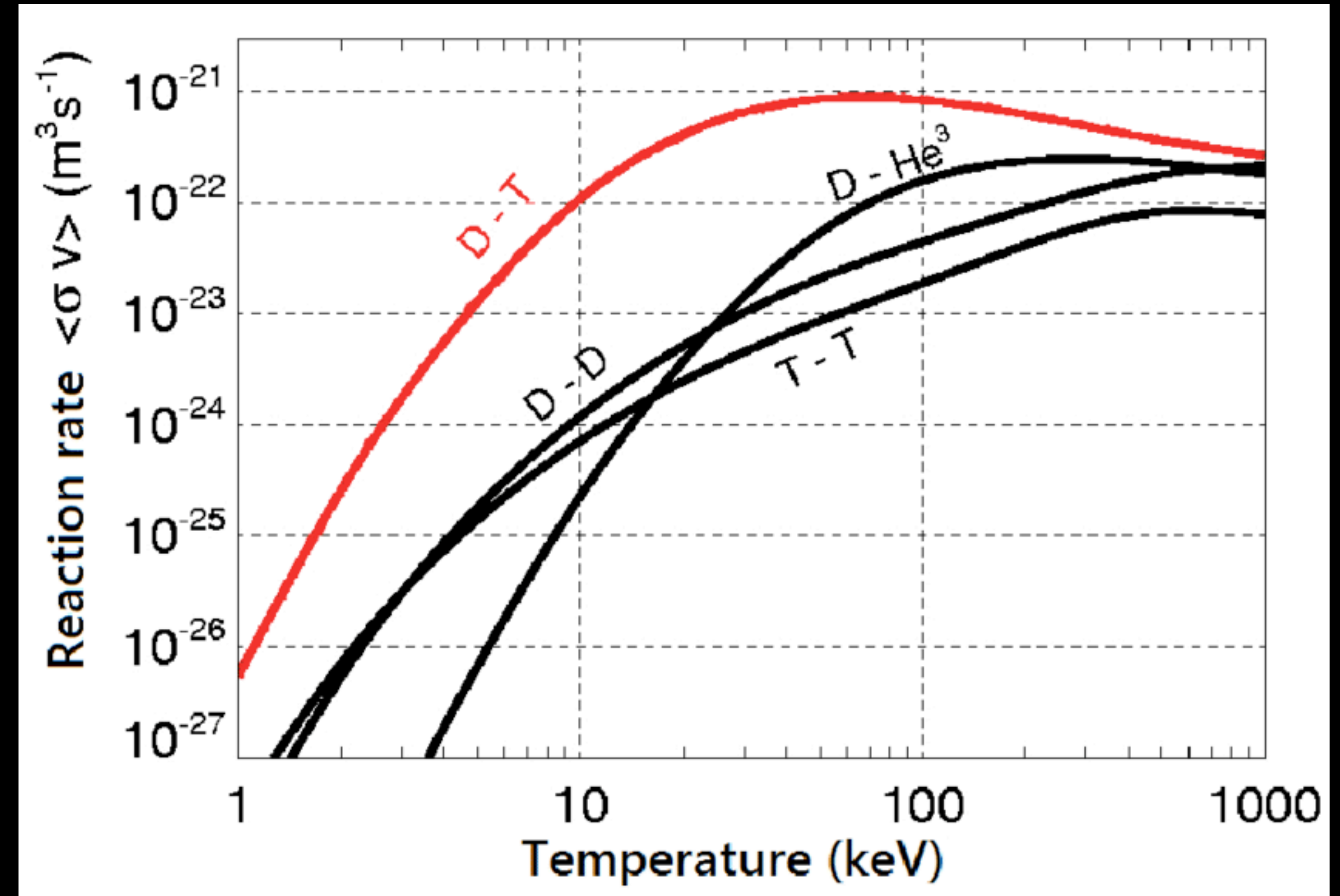
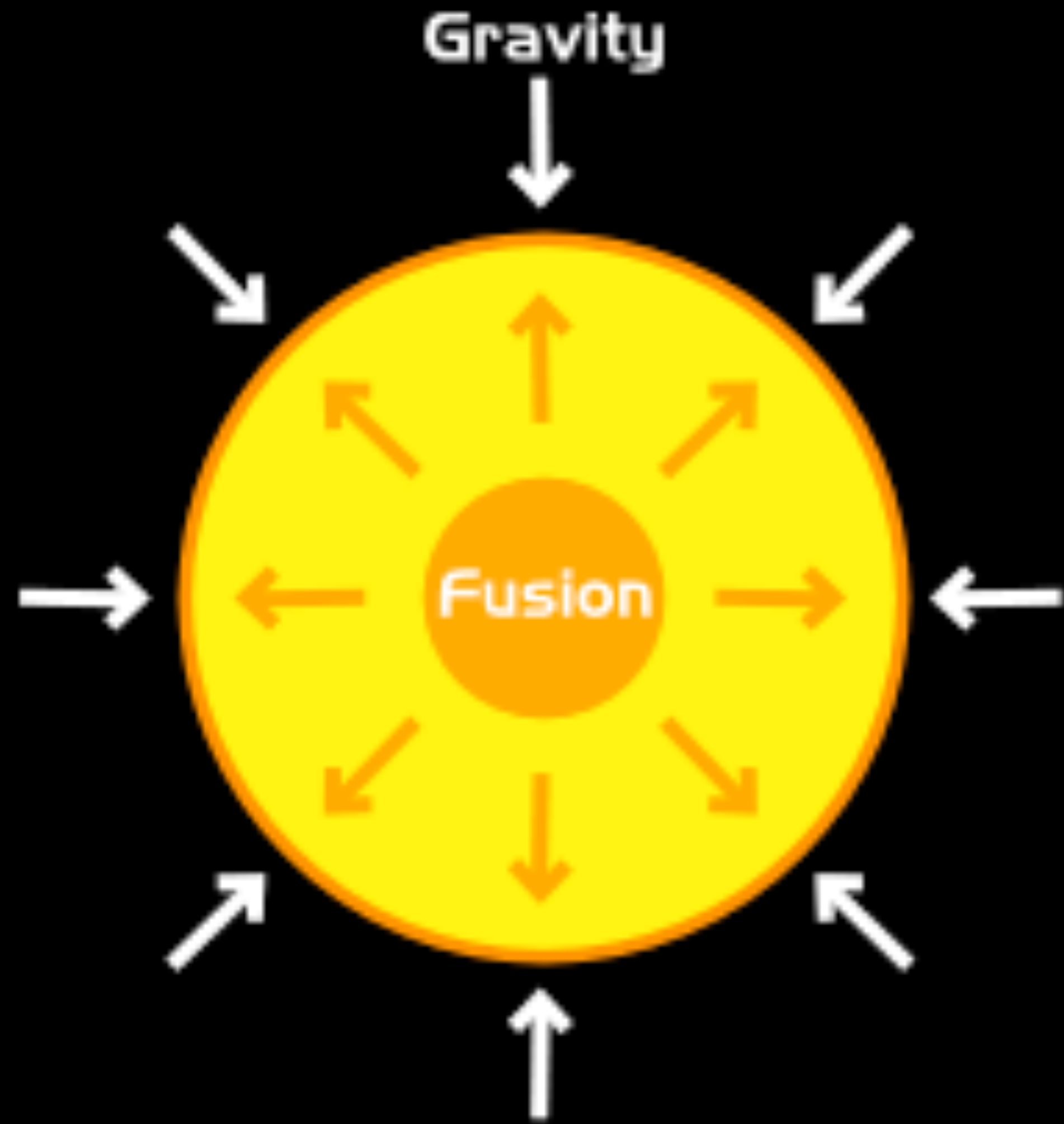
of our Galaxy hav
contrib

Immortal Stars at the Galactic Center

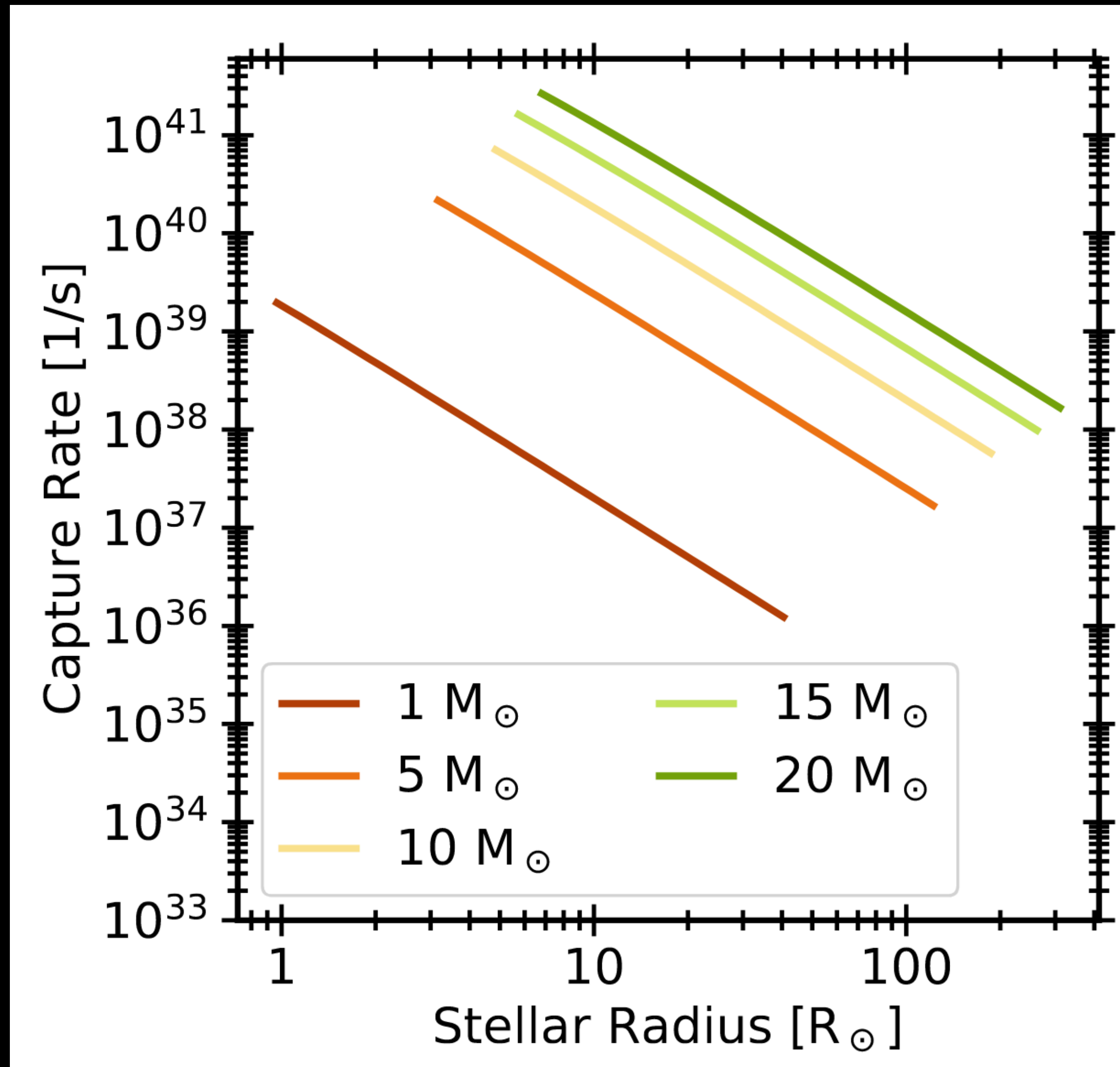


- **Dark Matter annihilation provides an additional power source that heats the star.**
- **The star maintains equilibrium - it expands if too much power is injected.**

Immortal Stars at the Galactic Center

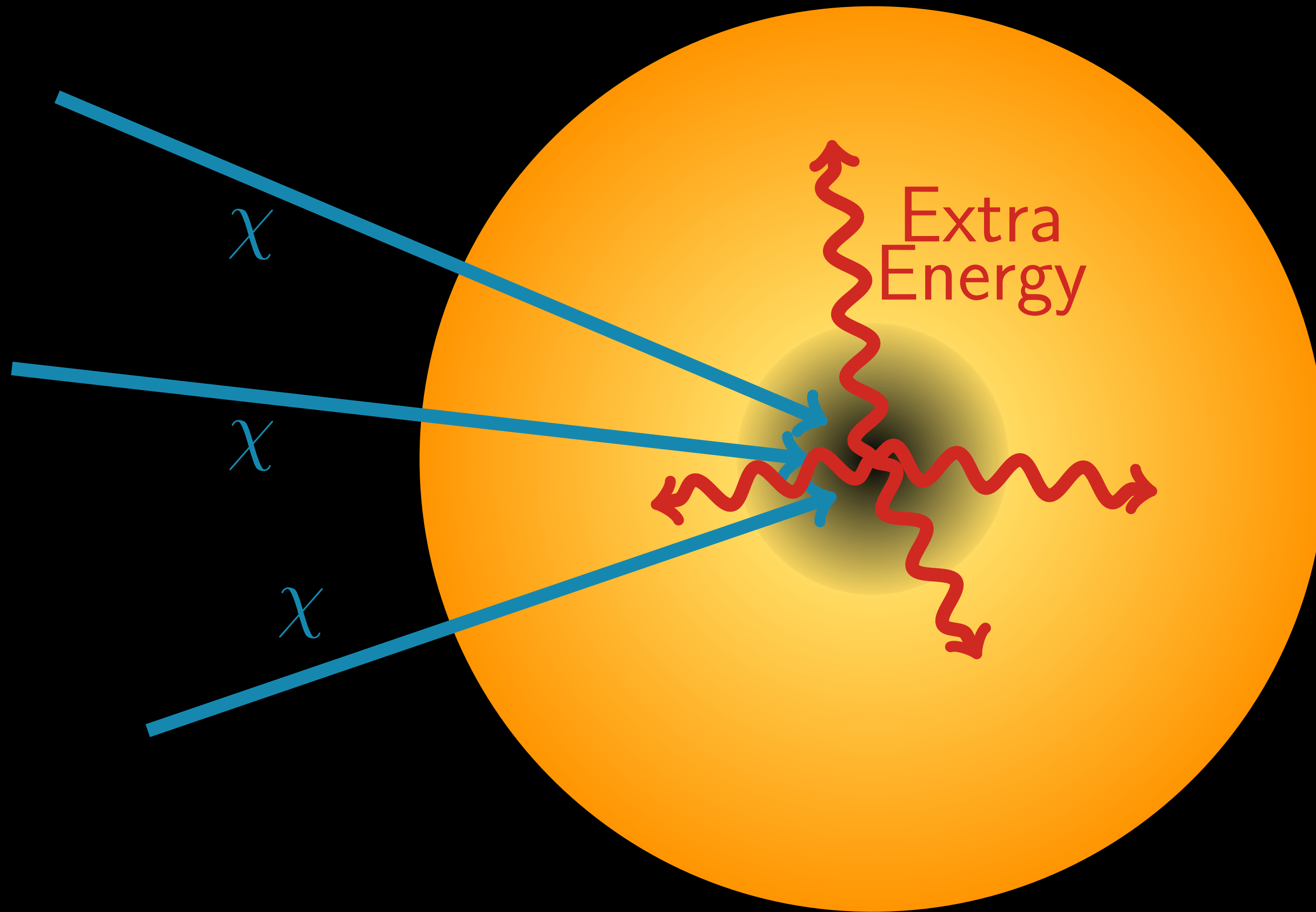


Immortal Stars at the Galactic Center



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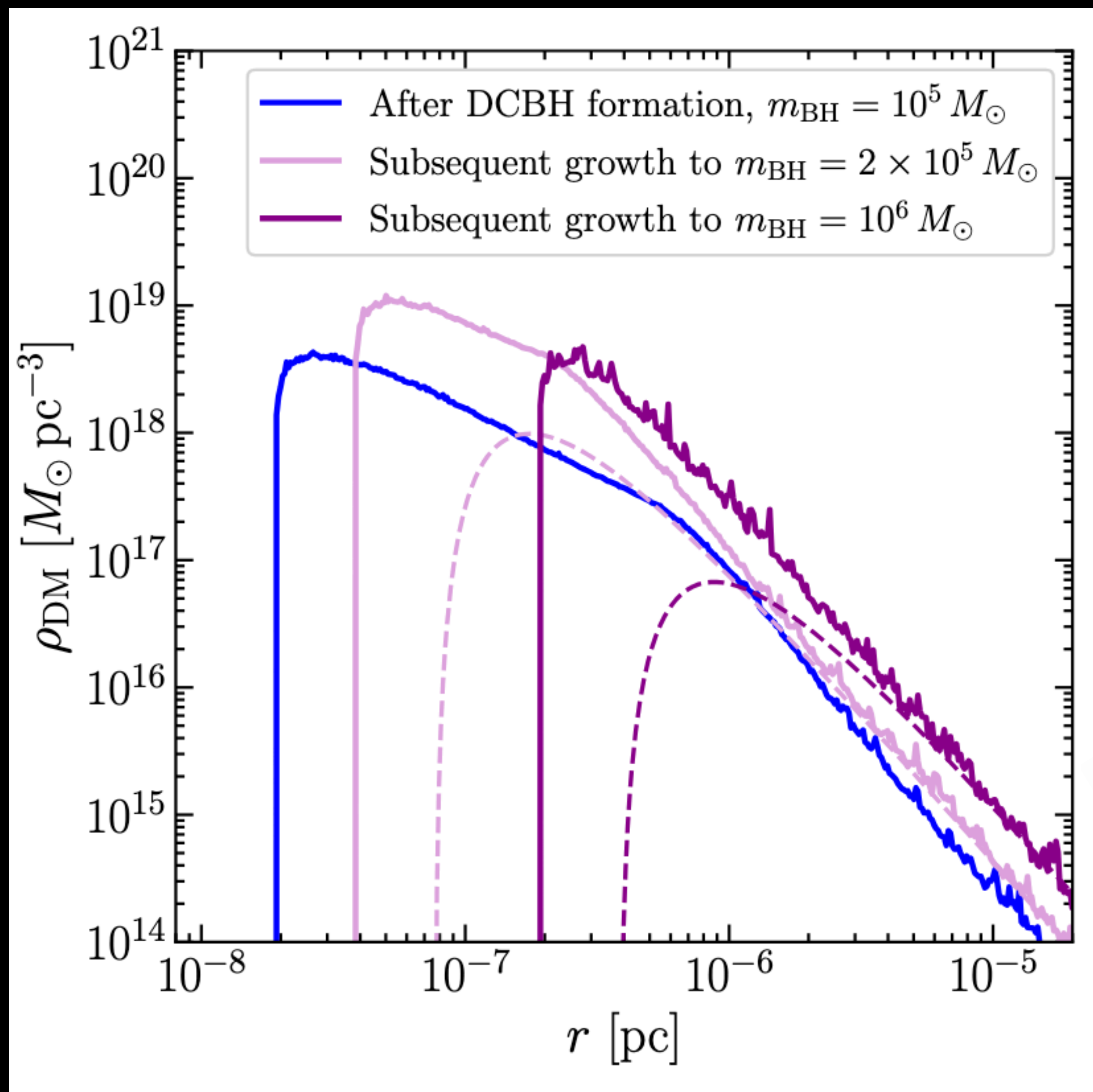
Immortal Stars at the Galactic Center



- “Miracle” - Very high dark matter densities at the galactic center.
- Standard WIMP DM
- Lower Mass WIMPs (to avoid direct detection constraints)



Immortal Stars at the Galactic Center



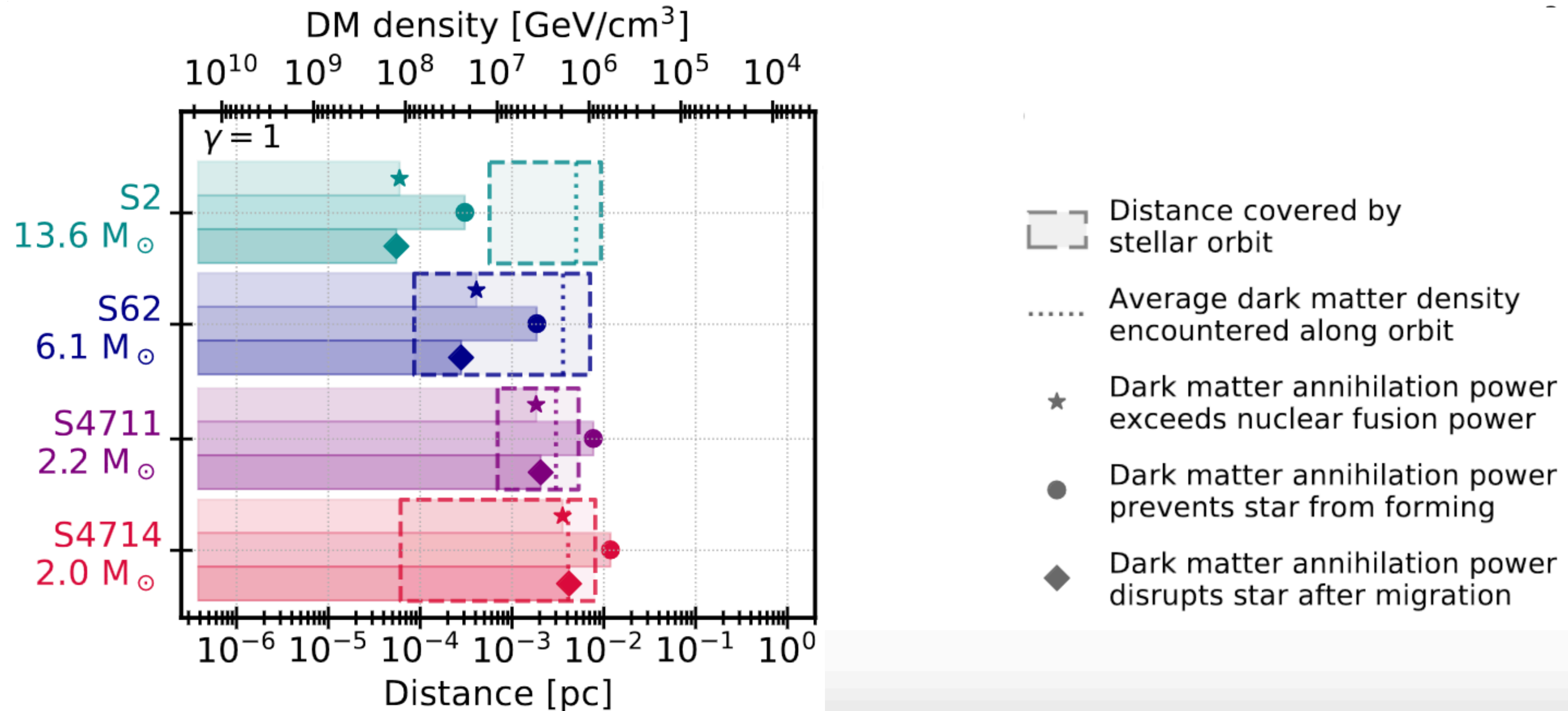
Dark Matter Mounds: towards a realistic description of dark matter overdensities around black holes

Gianfranco Bertone¹, A. Renske A. C. Wierda^{1,5}, and Naoki Yoshida^{6,7}
Bradley J. Kavanagh⁴, Marta Volonteri^{1,5} and Daniele Gaggero³

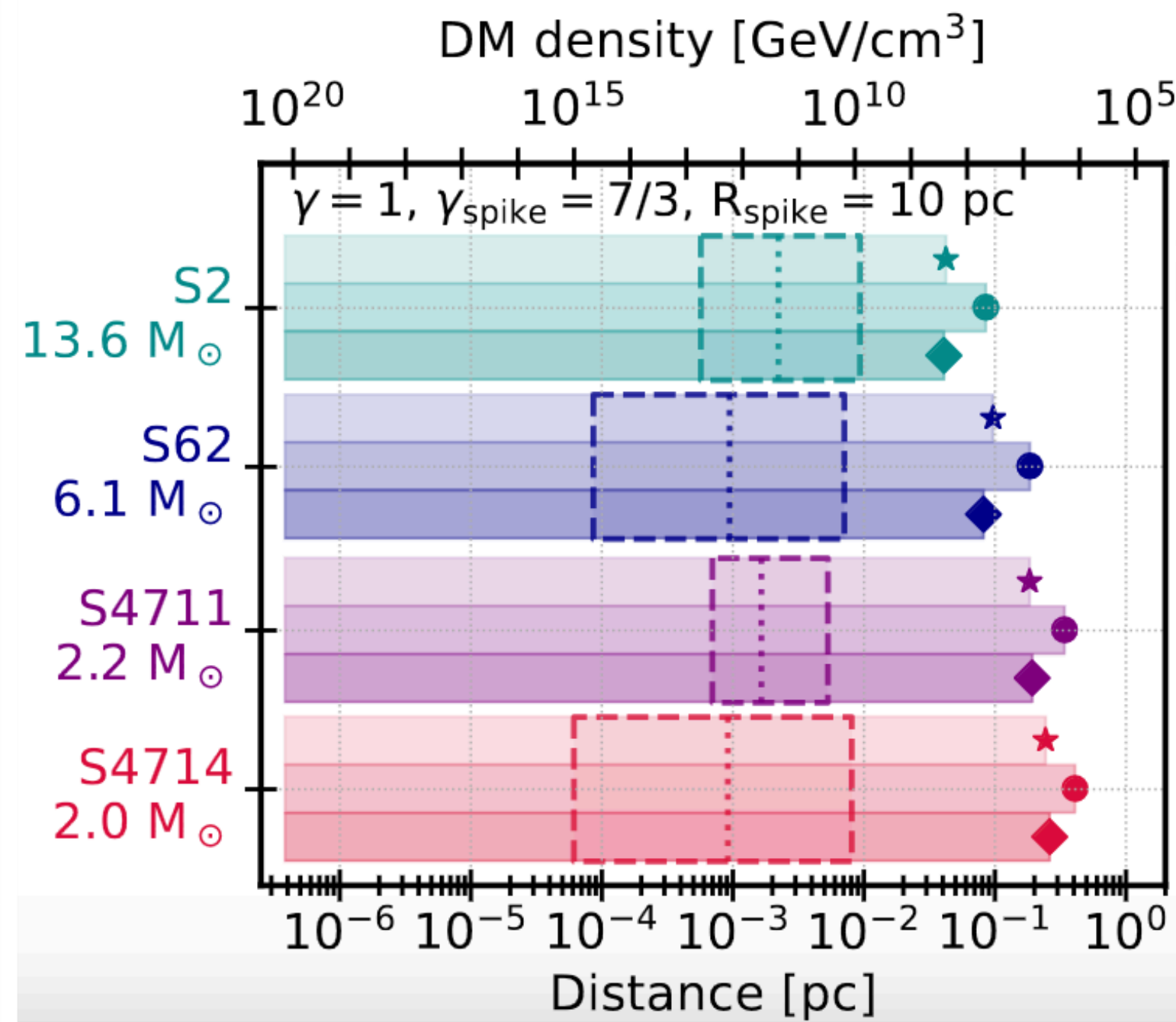
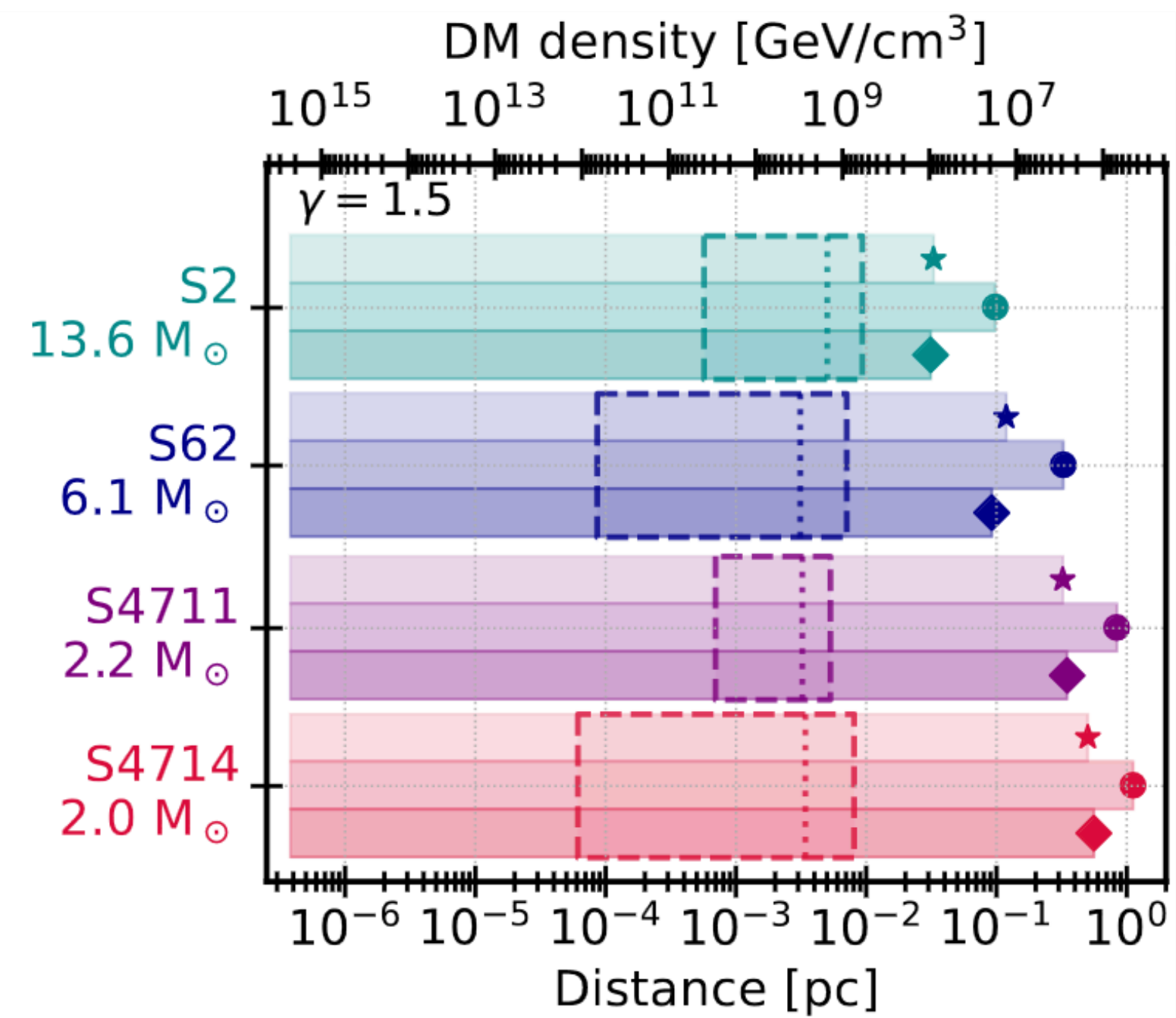
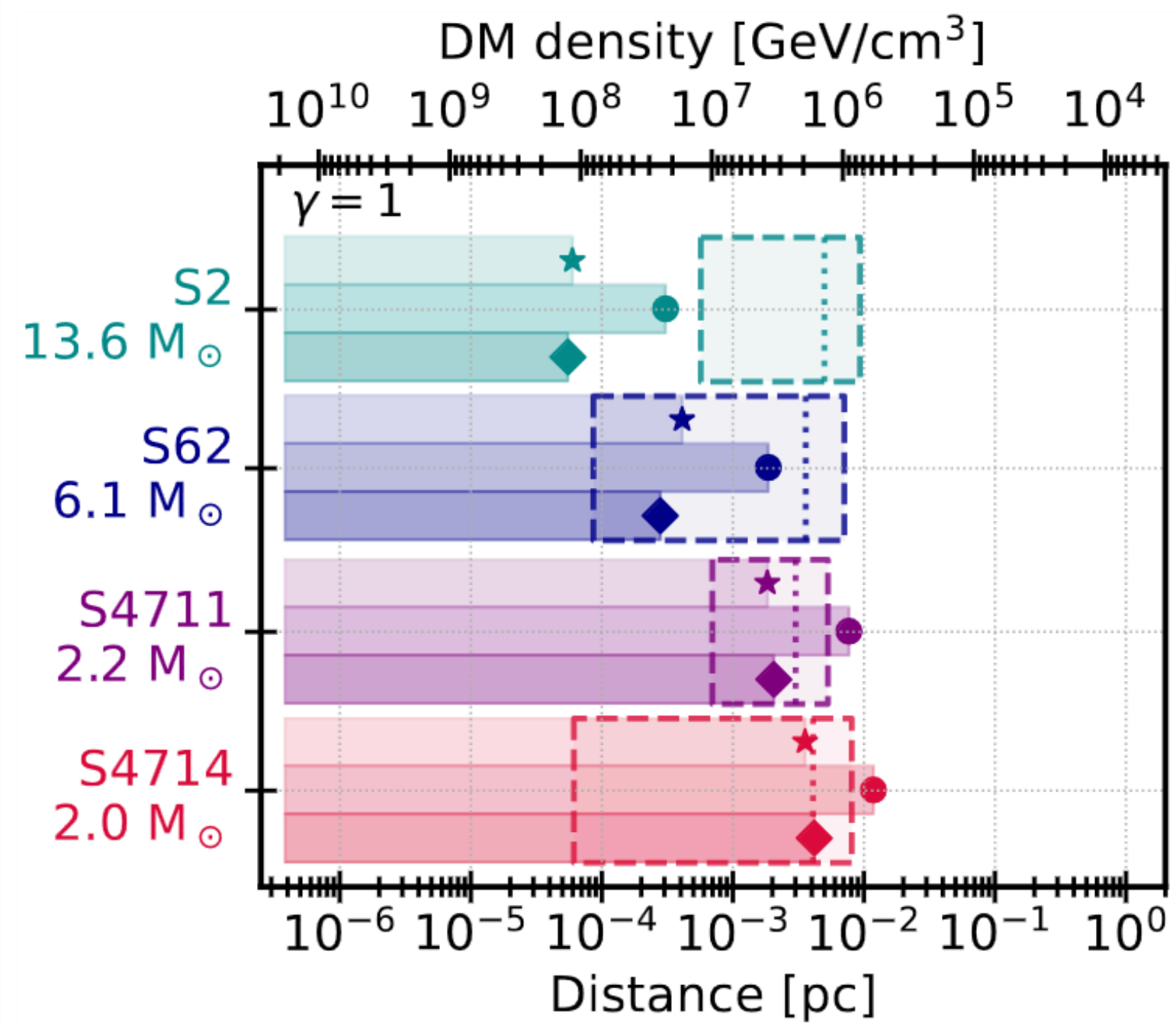
¹ Gravitation Astroparticle Physics Amsterdam (GRAPPA),
University of Amsterdam, Amsterdam, 1098 XH, Netherlands
² Department of Physics, KTH Royal Institute of Technology,
The Oskar Klein Centre, AlbaNova, SE-106 91 Stockholm, Sweden
³ INFN Sezione di Pisa, Polo Fibonacchi, Largo B. Pontecorvo 3, 56127 Pisa, Italy
⁴ Instituto de Física de Cantabria (IFCA, UC-CSIC),
Avenida de Los Castros s/n, 39005 Santander, Spain
⁵ Institut d'Astrophysique de Paris, Sorbonne Université,
CNRS, UMR 7095, 98 bis bd Arago, 75014 Paris, France
⁶ Department of Physics, The University of Tokyo, Chiba 277-8583, Japan
⁷ Kavli Institute for the Physics and Mathematics of the Universe (WPI),
UT Institute for Advanced Study, The University of Tokyo, Chiba 277-8583, Japan

Dark matter overdensities around black holes can be searched for by looking at the characteristic imprint they leave on the gravitational waveform of binary black hole mergers. Current theoretical predictions of the density profile of dark matter cusps at the center of galactic halos are based on highly idealised scenarios, in which black holes are assumed to grow adiabatically from an infinitesimal seed mass, compressing dark matter into very high densities, but they fail to capture the dark matter distribution scenarios where the gravitational wave signal is produced. We present here a realistic description of dark matter overdensities around black holes, where the dark matter forms shallower 'mounds', instead of 'cusps'. We discuss the implications of these mounds for the detection of supermassive stars, primordial BHs [27], and black holes [28].

Multiple Stars in DM-Dense Regions

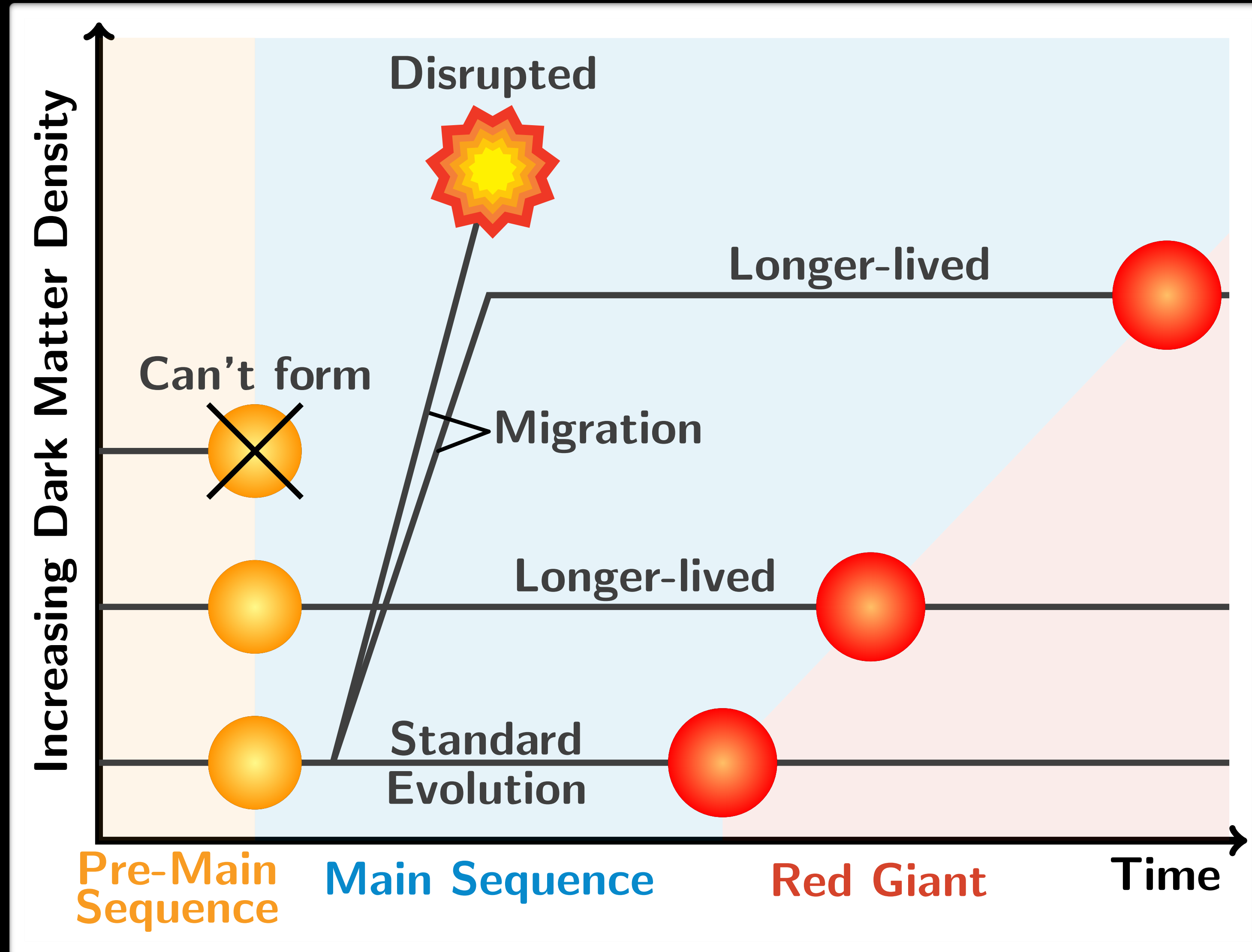


- (Assuming Geometric Capture cross-sections)



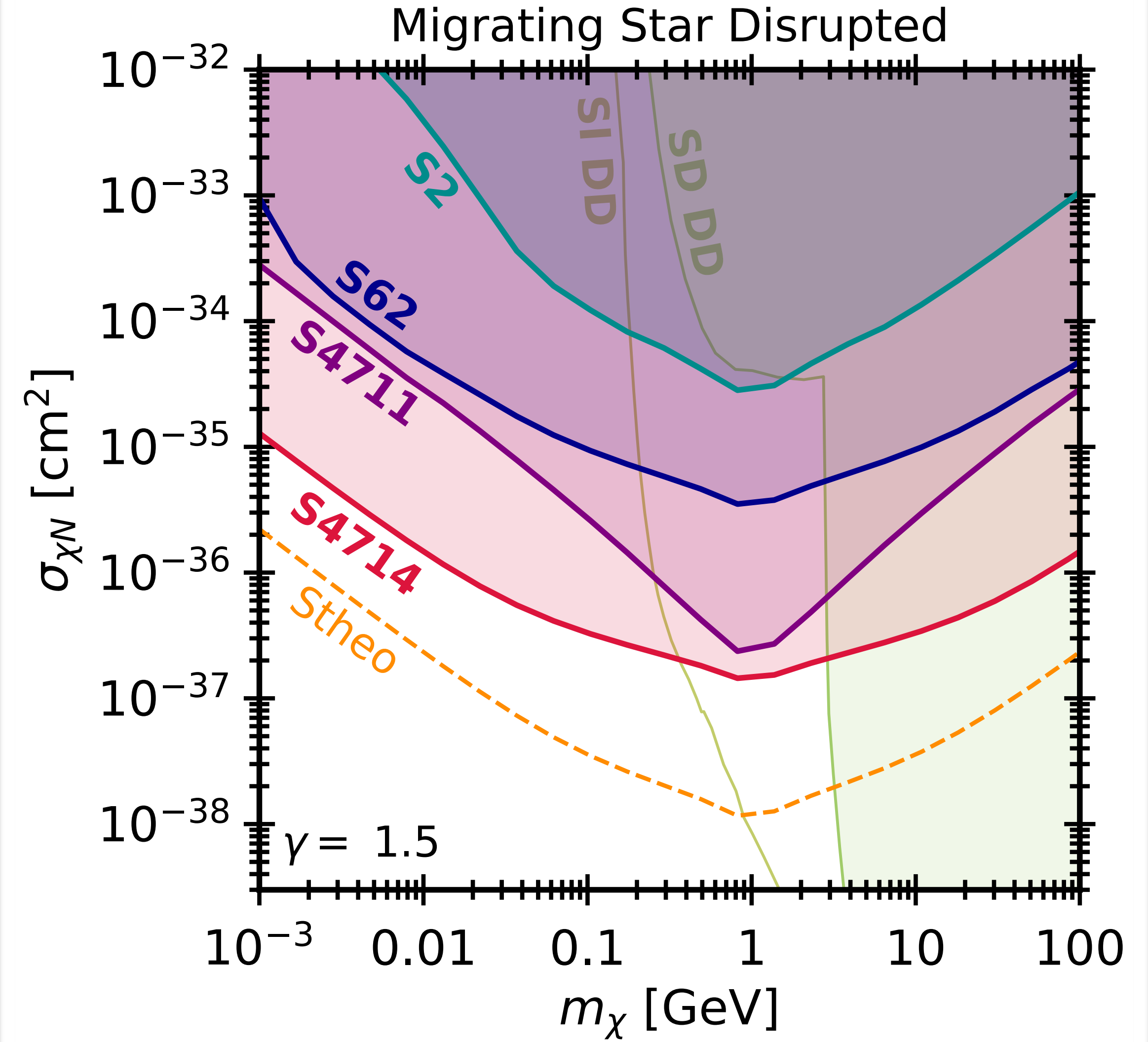
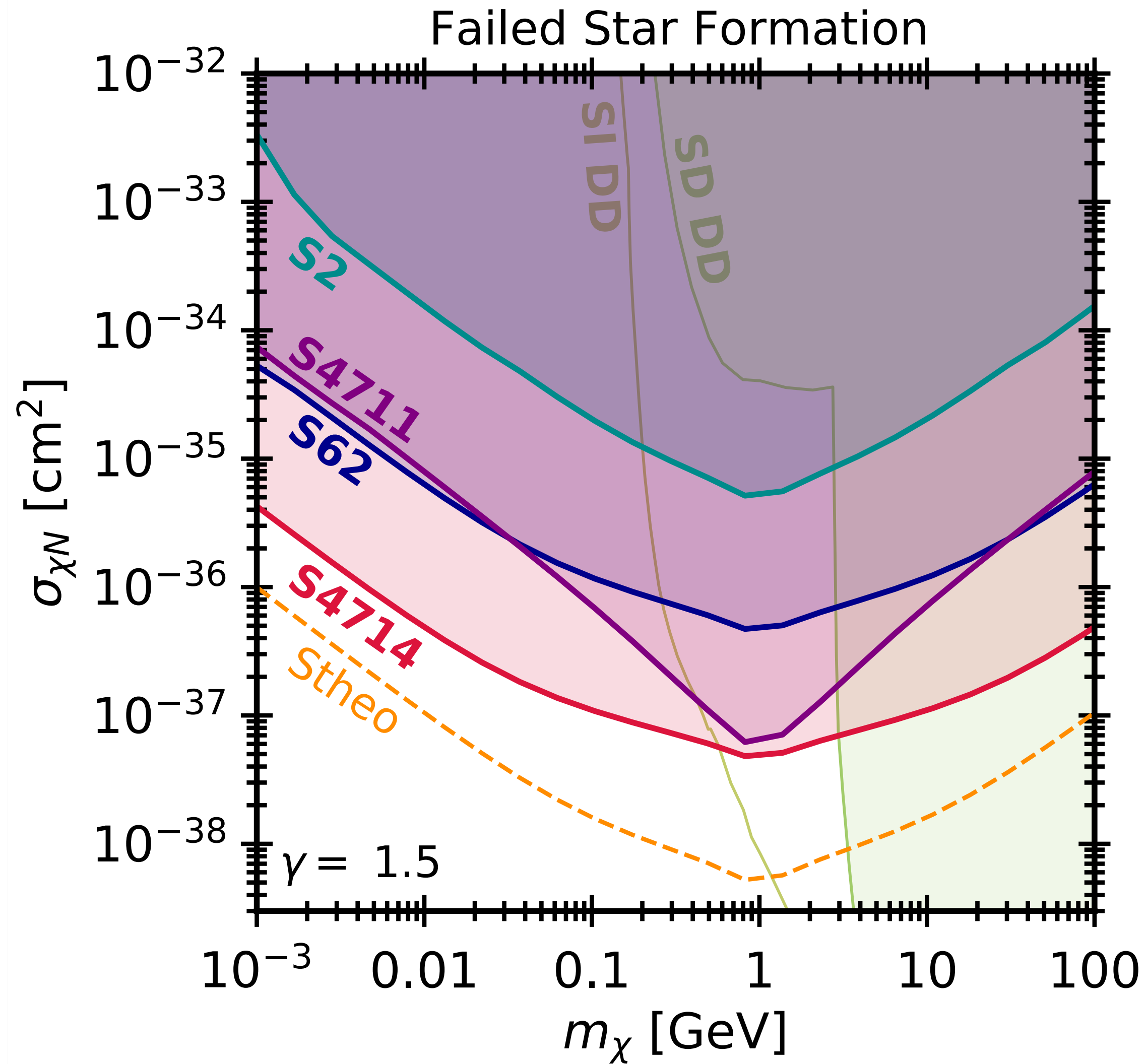
- Distance covered by stellar orbit
- Average dark matter density encountered along orbit
- Dark matter annihilation power exceeds nuclear fusion power
- Dark matter annihilation power prevents star from forming
- Dark matter annihilation power disrupts star after migration

Immortal Stars at the Galactic Center



- **“Miracle” - Very high dark matter densities at the galactic center.**
- **Standard WIMP DM**
- **Lower Mass WIMPs (to avoid direct detection constraints)**

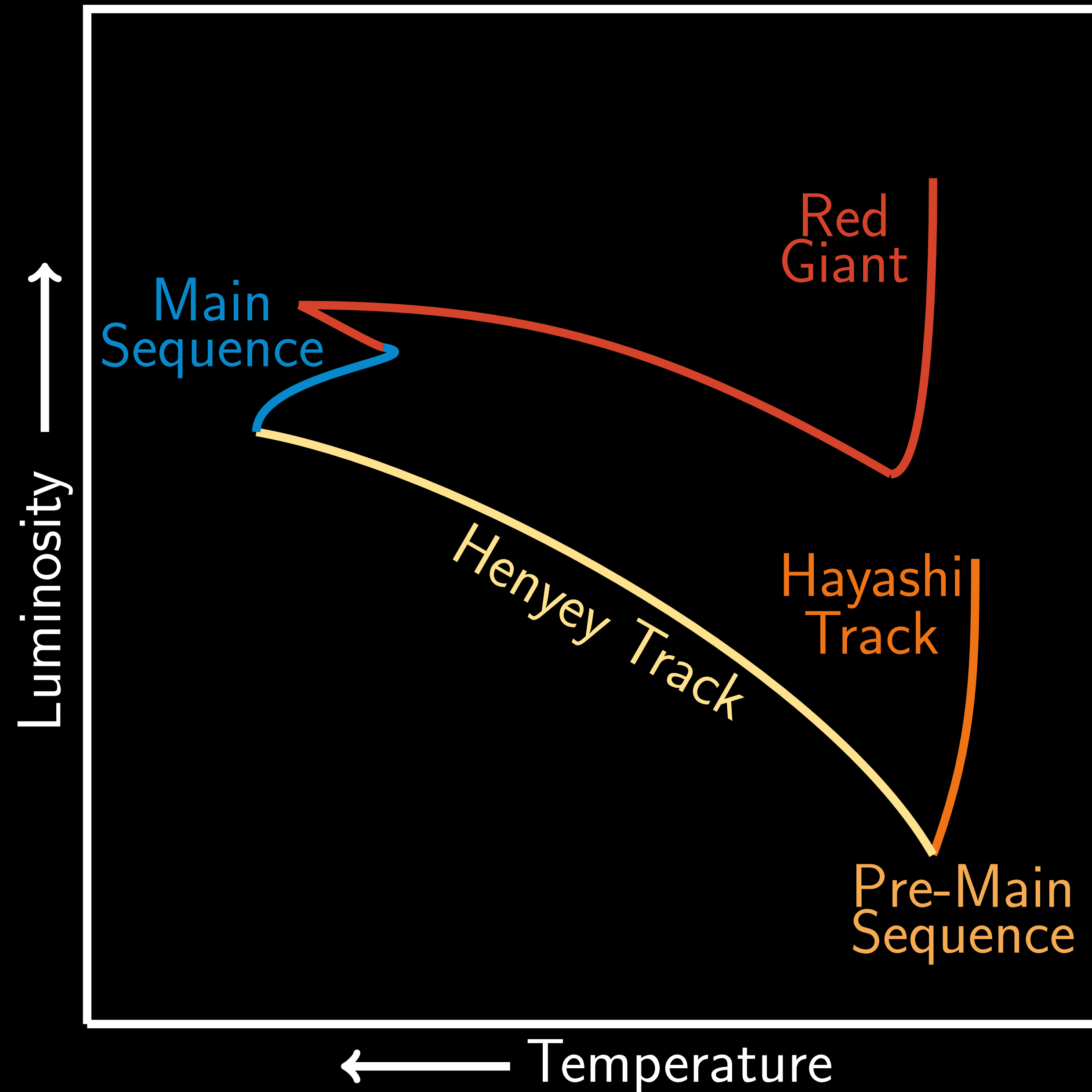
Immortal Stars at the Galactic Center

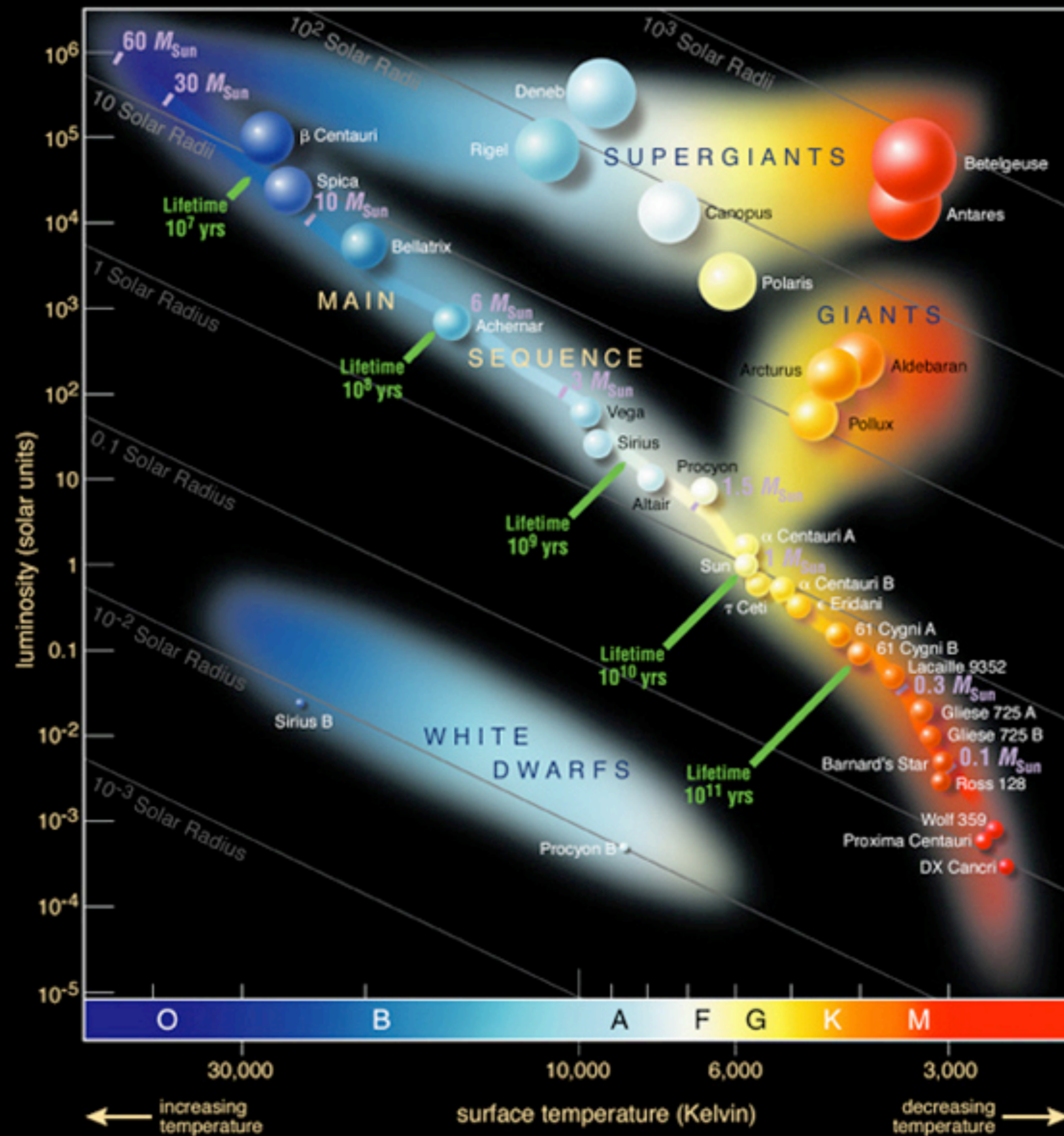


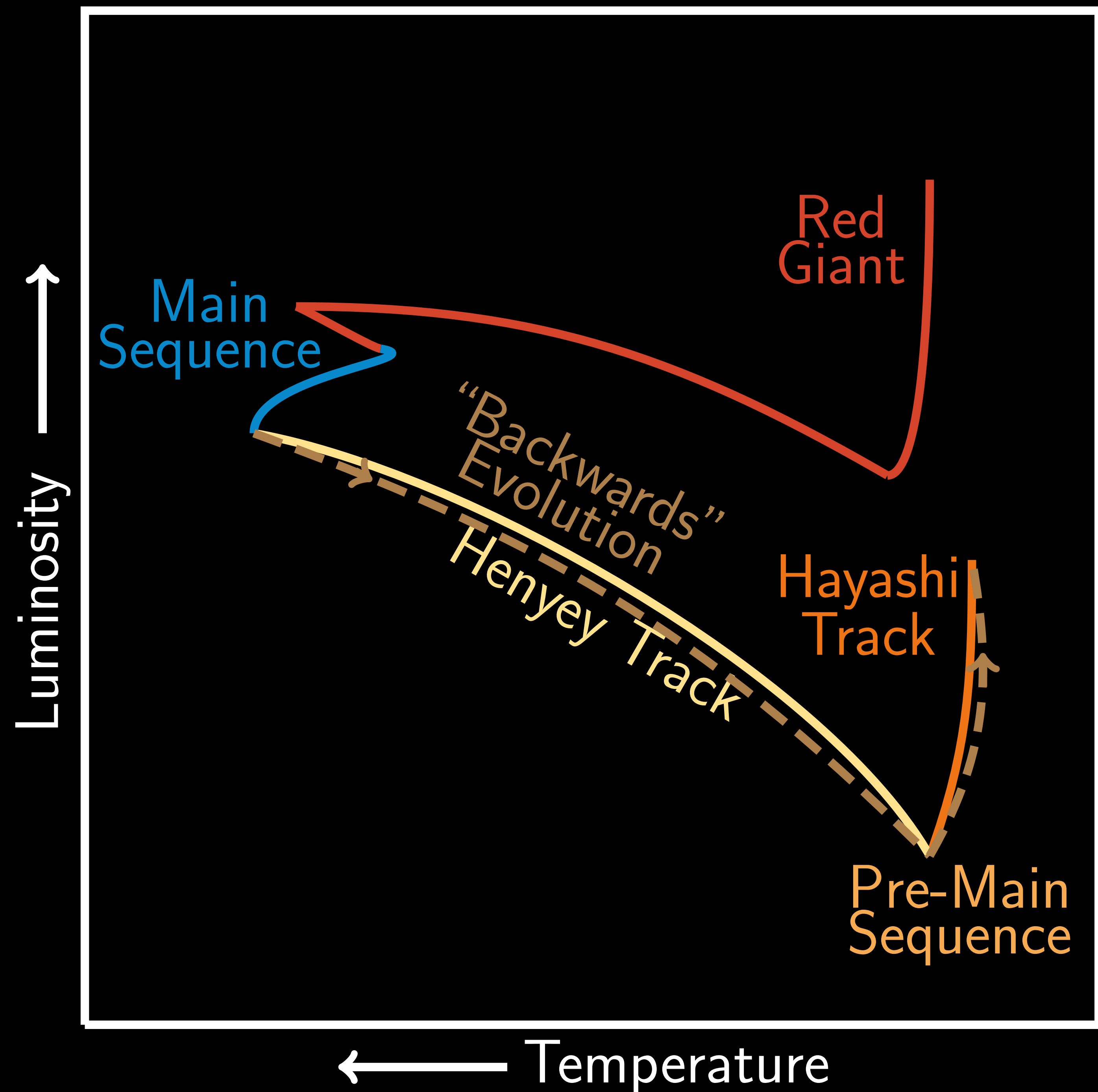
But:

How Can You Use the Absence of a Star to Detect Something?

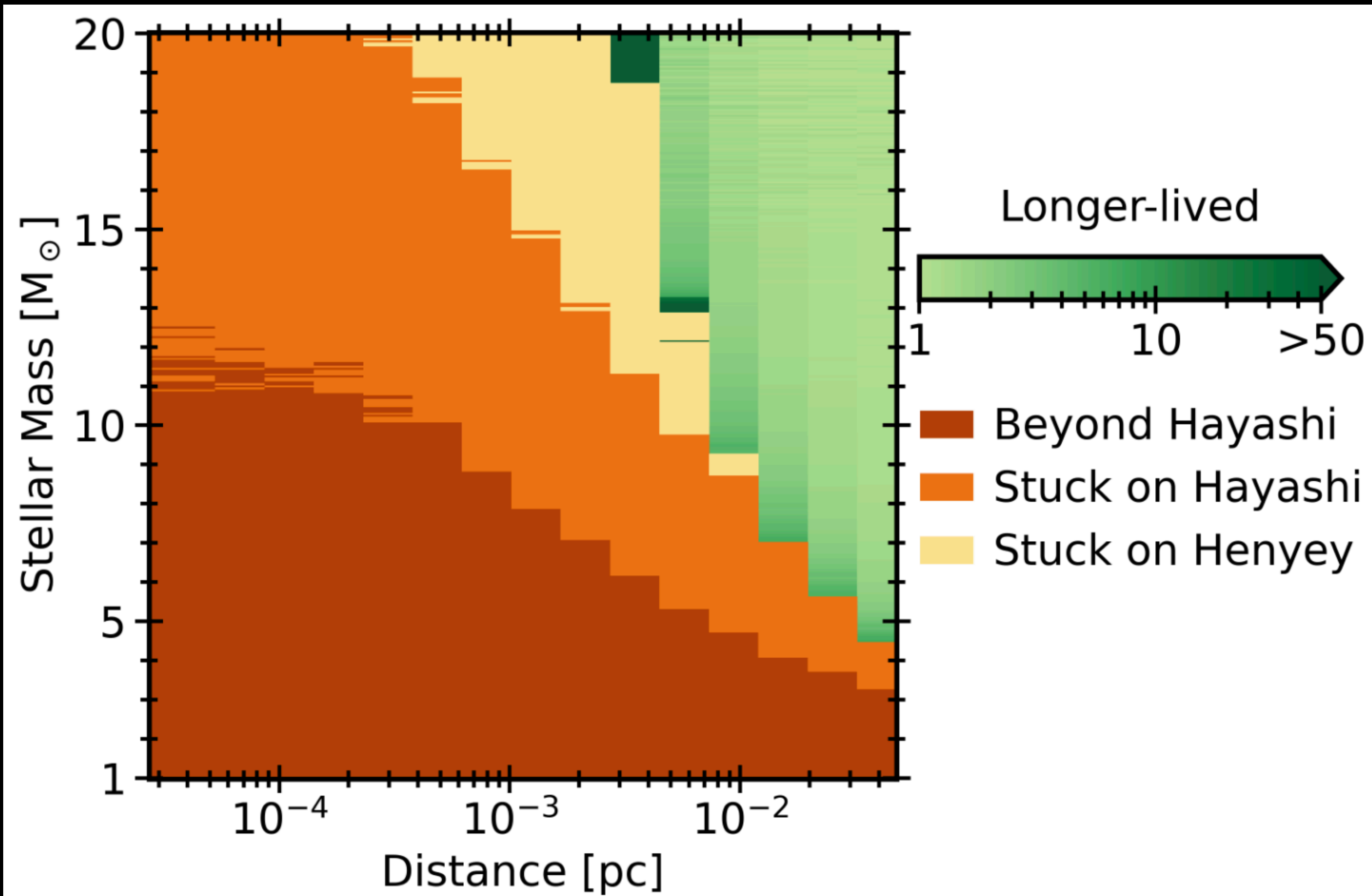
Immortal Stars



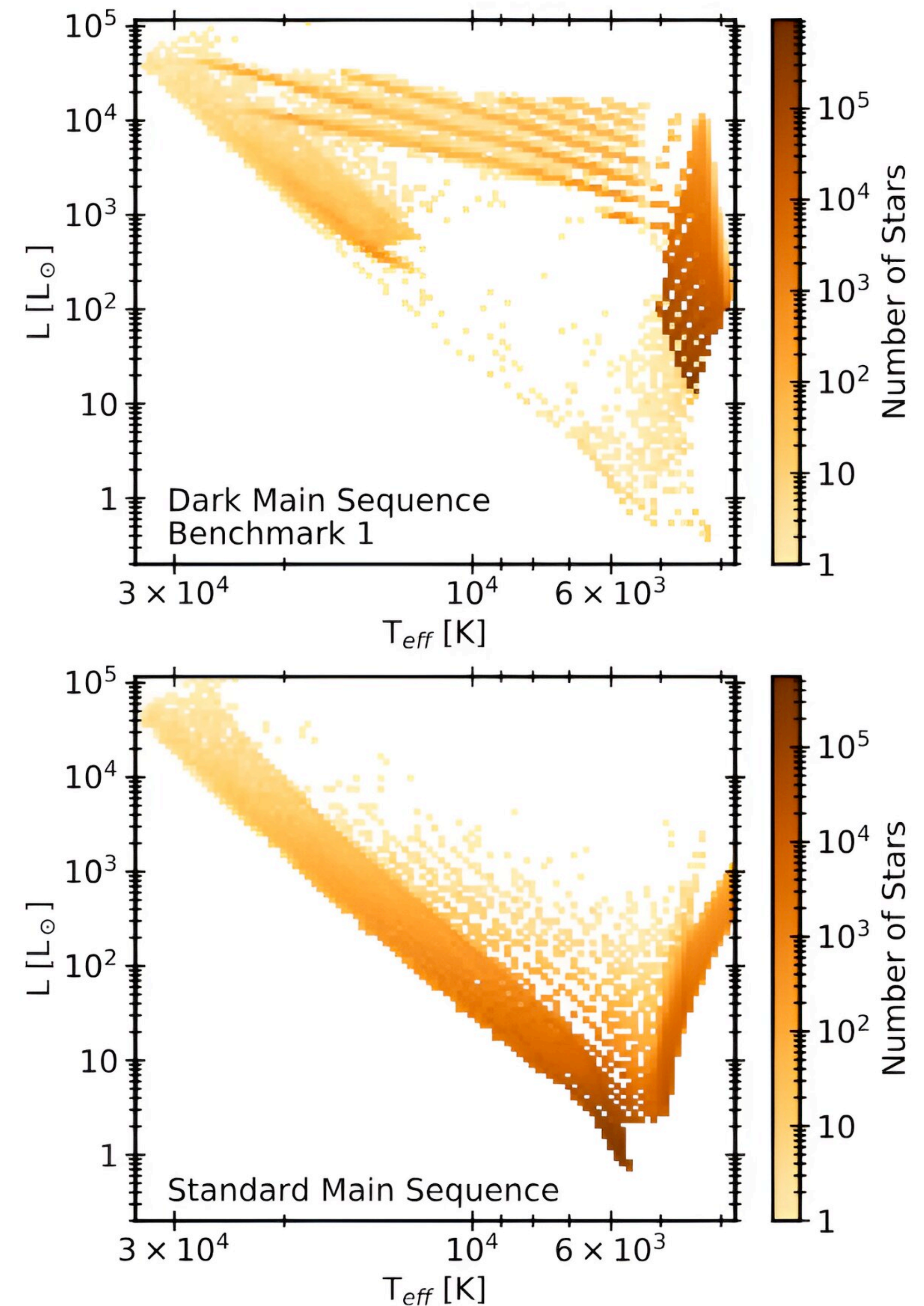




Immortal Stars



The type of signature observers can actually search for.



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Super-Kamiokande Searches for the Sun

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,§}

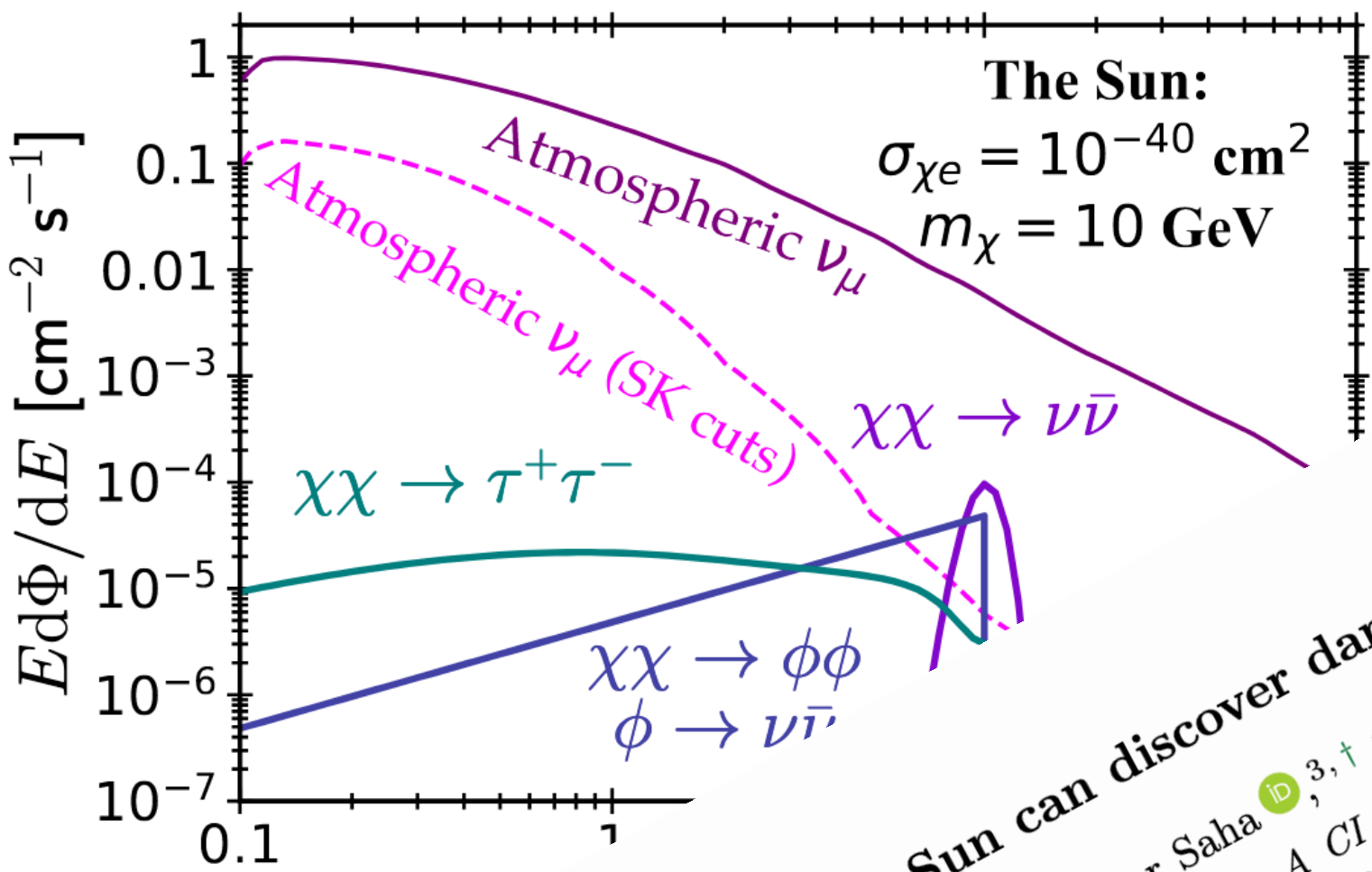
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²*Columbia University, 116th and Broadway, New York, NY 10027 USA*

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Introduction. — Detecting the particle interactions of dark matter is a cornerstone in our efforts to study beyond the standard model physics [1–3]. Many of the most sensitive constraints depend on searching for rare scattering interactions between the dark matter particle and standard model particles [4–11].

Current strategies motivate current searches. The standard approach, used in terrestrial detectors, uses underground experiments to avoid astrophysical backgrounds and relies on single dark matter interactions. However, to “go big”, using large-scale objects to constrain rare interactions, the scattering of dark



Neutrinos from the Sun can discover dark matter-electron scattering

Tarak Nath Maity^{1,2,3,*} Akash Kumar Saha^{3,†} Sagnik Mondal^{3,‡} and Ranjan Laha^{3,§}
¹Harish-Chandra Research Institute, A CI of Homi Bhabha National Institute, Chhatnag Road, Jhansi, Prayagraj (Allahabad) 211019, India
²Regional Centre for Accelerator-based Particle Physics, Harish-Chandra Research Institute, Prayagraj (Allahabad) 211019, India
³Indian Institute of Science, C.V. Raman Avenue, Bengaluru 560012, India
(Dated: August 25, 2023)

DAMA/LIBRA and leptonically interacting Dark Matter

Thim Kopp,^{1,†} Viviana Niro,^{1,‡} Thomas Schwetz,^{1,‡} and Jure Zupan^{1,§}
¹Max-Planck-Institute for Nuclear Physics, PO Box 103980, 69029 Heidelberg, Germany
²Theory Division, Physics Department, CERN, CH-1211 Geneva 23, Switzerland
Abstract

Detecting Dark Matter with Imploding Pulsars in the Galactic Center

Joseph Bramante

*Department of Physics, 225 Nieuwland Science Hall,
University of Notre Dame, Notre Dame, IN 46556, USA*

Tim Linden

*Kavli Institute for Cosmological Physics 5640 South Ellis Avenue
University of Chicago Chicago, IL 60637*

of old millisecond pulsars observed at the galactic center of the Milky Way. We study the possibility of matter accumulating in and destroying neutron stars. In regions where the density of matter clumped in a pulsar can exceed the Schwarzschild limit, a black hole is formed which destroys the pulsar. We examine what parameters of the pulsar and the environment find regions of parameter space where a significant fraction of the neutron star population within the central region of the galaxy could be destroyed. We find that millisecond pulsars in globular clusters and the galactic center could be destroyed by accretion of matter from the surrounding environment. Accretion of matter from the surrounding environment could cause the formation of a black hole and the destruction of the pulsar.

*Kavli Institute for Cosmology
University*

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THE PECULIAR PULSAR POPULATION OF THE CENTRAL PARSEC

JASON DEXTER
Department of Astronomy, University of California, Berkeley, CA 94720-3411

RYAN M. O'LEARY
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Draft version April 14, 2018

ABSTRACT

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ABSTRACT

Sgr A*, would be potentially used to test general relativity. Despite recent discovery of radio pulsars in the Galactic center, One explanation has been that the temporal variation shows that the ordinary pulsar emission mechanism in the ordinary pulsar population implies that the Galactic center black hole.

ABSTRACT

le, Sgr A*, would be potential probes of its mass, distance
Galactic center, none have been detected within 25
been that hyperstrong temporal scattering prevents
pulsations from a highly magnetized neutron
scattering is much weaker than predicted
populating the most likely reason for
the Galactic center. In contrast
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rdinary pulsars, their
could be caused
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The Galactic centre pulsar population

The Galactic centre pulsar population
 Jayanth Chennamangalam^{1*} and D. R. Lorimer^{1,2†}
¹ Department of Physics and Astronomy, West Virginia University, PO Box 6315, Morgantown, WV 26506, USA
² National Radio Astronomy Observatory, PO Box 2, Green Bank, WV 24944, USA

ABSTRACT

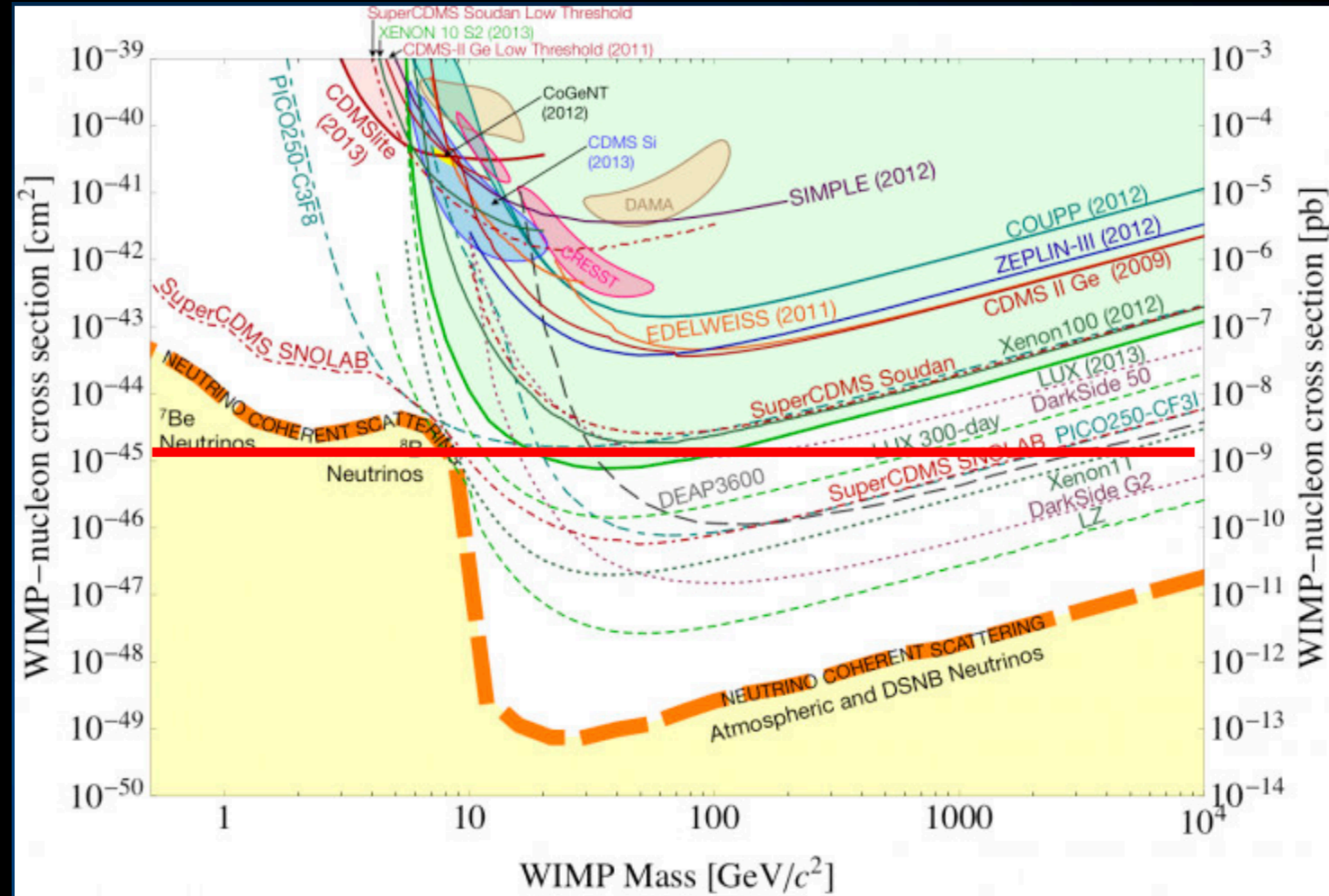
ABSTRACT
The recent discovery of a magnetar in the Galactic centre region (Spitler et al. 2006) has challenged the interstellar scattering model that the temporal broadening of the pulse profile of the magnetar is greater than that predicted by models of the electron density of that region. The question of what the plausible limits for the number of potential pulsars in the number of pulsars beaming towards the Earth – in the Milky Way, using reasonable assumptions – namely, (i) the number of pulsars in the Galactic centre region is the same as that in the rest of the Galaxy, (ii) the spin and luminosity of the pulsars are similar, and (iii) the scattering in the interstellar medium is similar, and (iv) the scattering in the interstellar medium is similar to that in the rest of the Galaxy, are addressed. The results suggest that the number of pulsars in the Galactic centre region is similar to that in the rest of the Galaxy, and that the number of pulsars in the Galactic centre region is similar to that in the rest of the Galaxy.

Neutron Stars are the Coolest Object in Physics

- $1.4 M_{\odot}$ compressed into a 10 km radius
- Spinning up to 700 s^{-1} (42000 rpm) \rightarrow velocity of $0.2c$ at the equator.
- Oblate spheroid to within 0.1 part in a million and spin-down power known to a part in 10^{20} .
- Magnetic field of 10^{10} T at the surface, electric field produces a potential of 1000 PV.

Neutron Stars as the Optimal Dark Matter Detectors

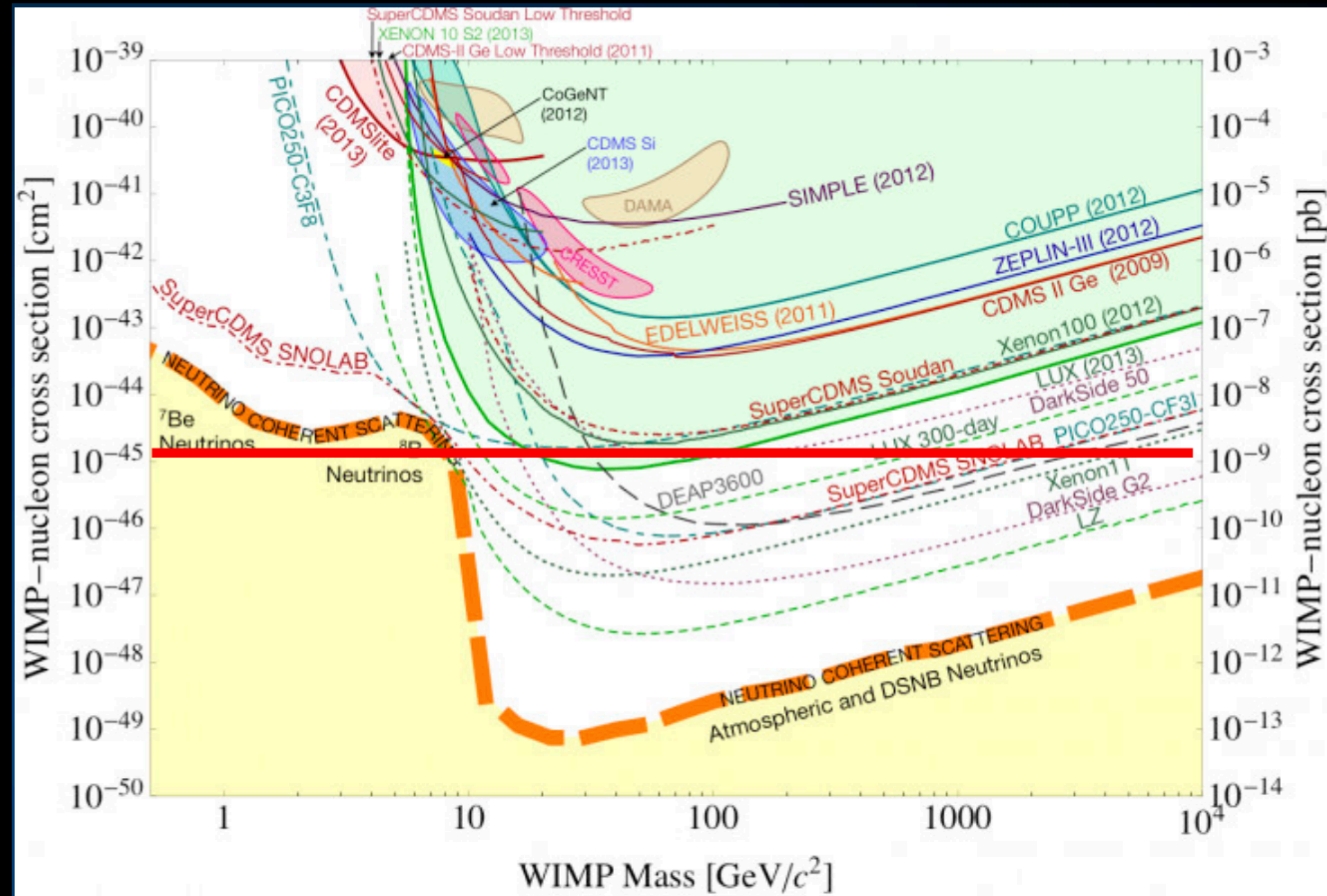
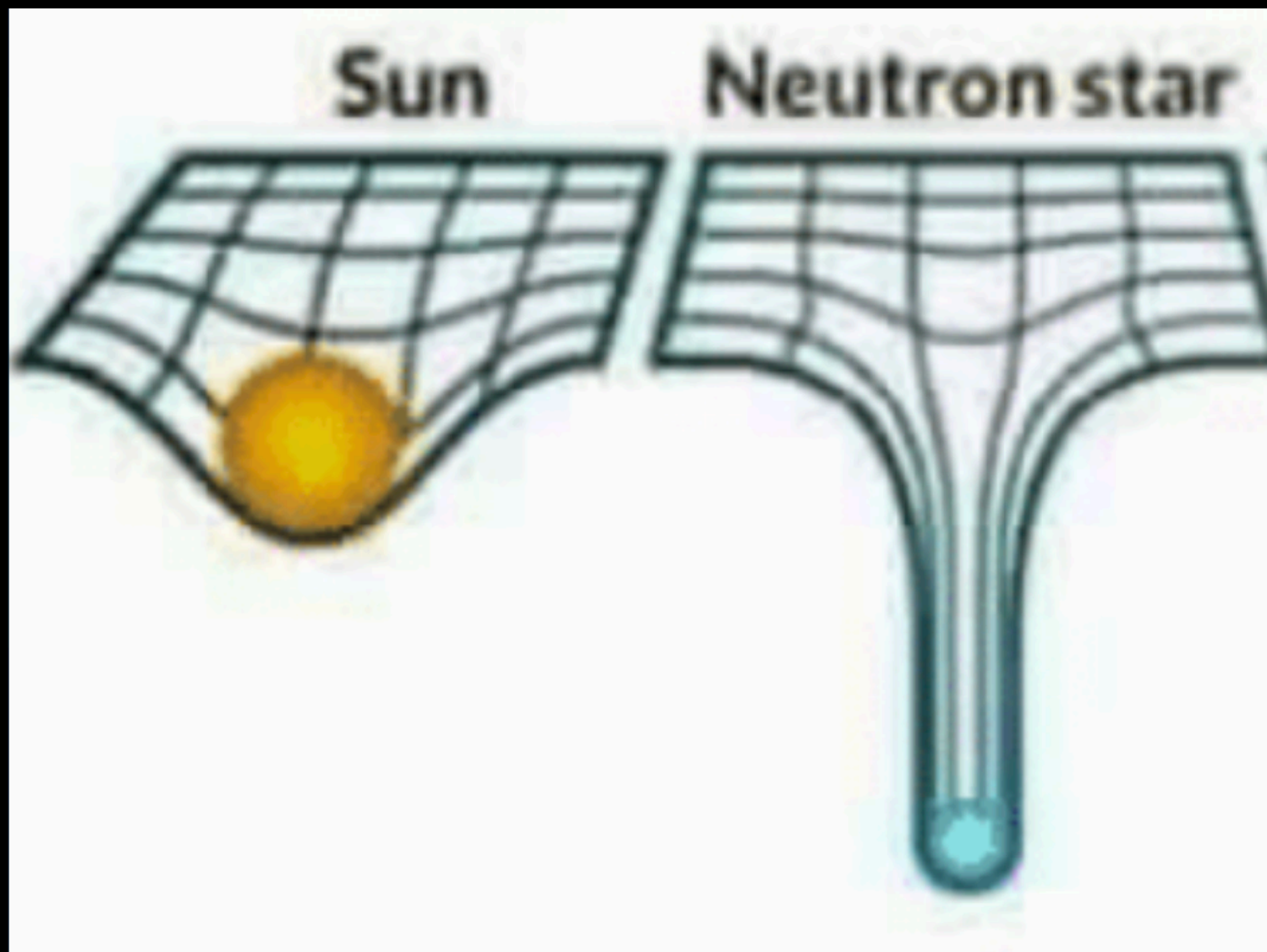
- Direct detection cross-sections near 10^{-46} cm^2 produce $\sim 1 \text{ event}/(\text{ton yr})$
- Sensitivity peaks near Xenon mass, and falls off significantly at higher or lower masses.



$$\sigma_{\text{sat}}^{\text{single}} \simeq \pi R^2 m_n / M \simeq 2 \times 10^{-45} \text{ cm}^2 \left(\frac{1.5 M_\odot}{M} \right) \left(\frac{R}{10 \text{ km}} \right)^2$$

Neutron Stars as the Optimal Dark Matter Detectors

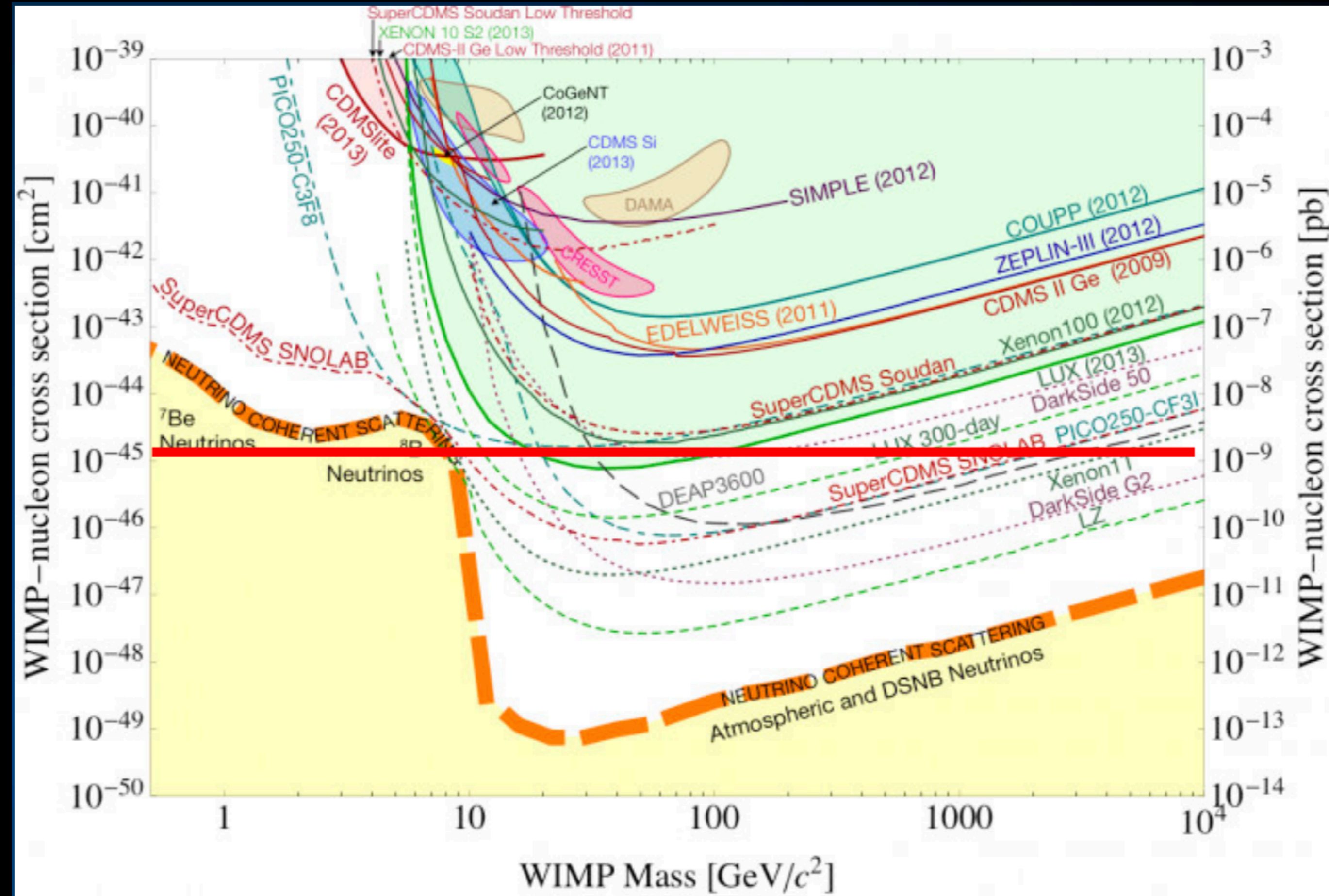
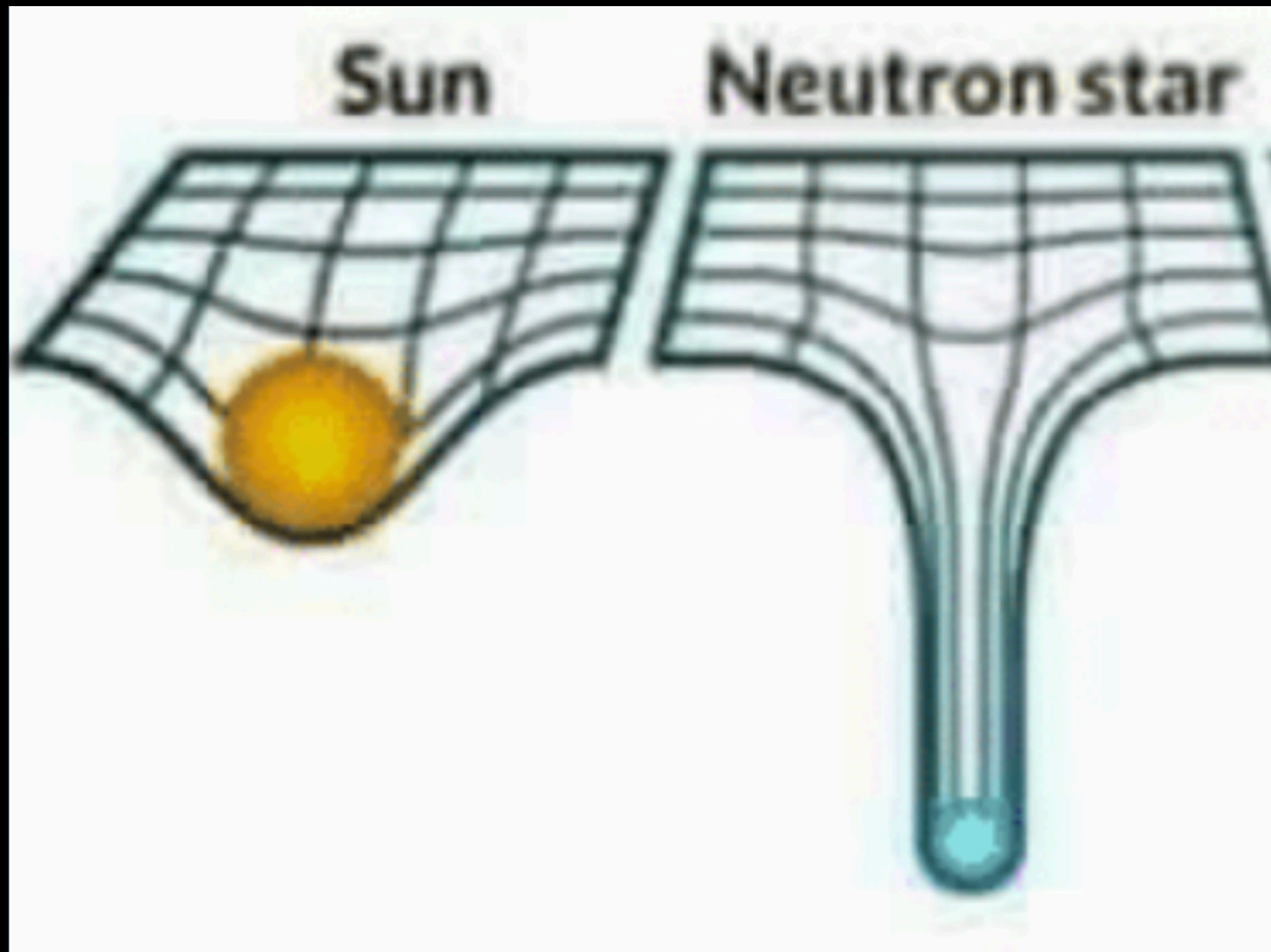
- Direct detection cross-sections near 10^{-46} cm^2 produce $\sim 1 \text{ event}/(\text{ton yr})$



$$b_{\text{max}} = \left(\frac{2GM R}{v_x^2} \right)^{1/2} \left(1 - \frac{2GM}{R} \right)^{-1/2}$$

Neutron Stars as the Optimal Dark Matter Detectors

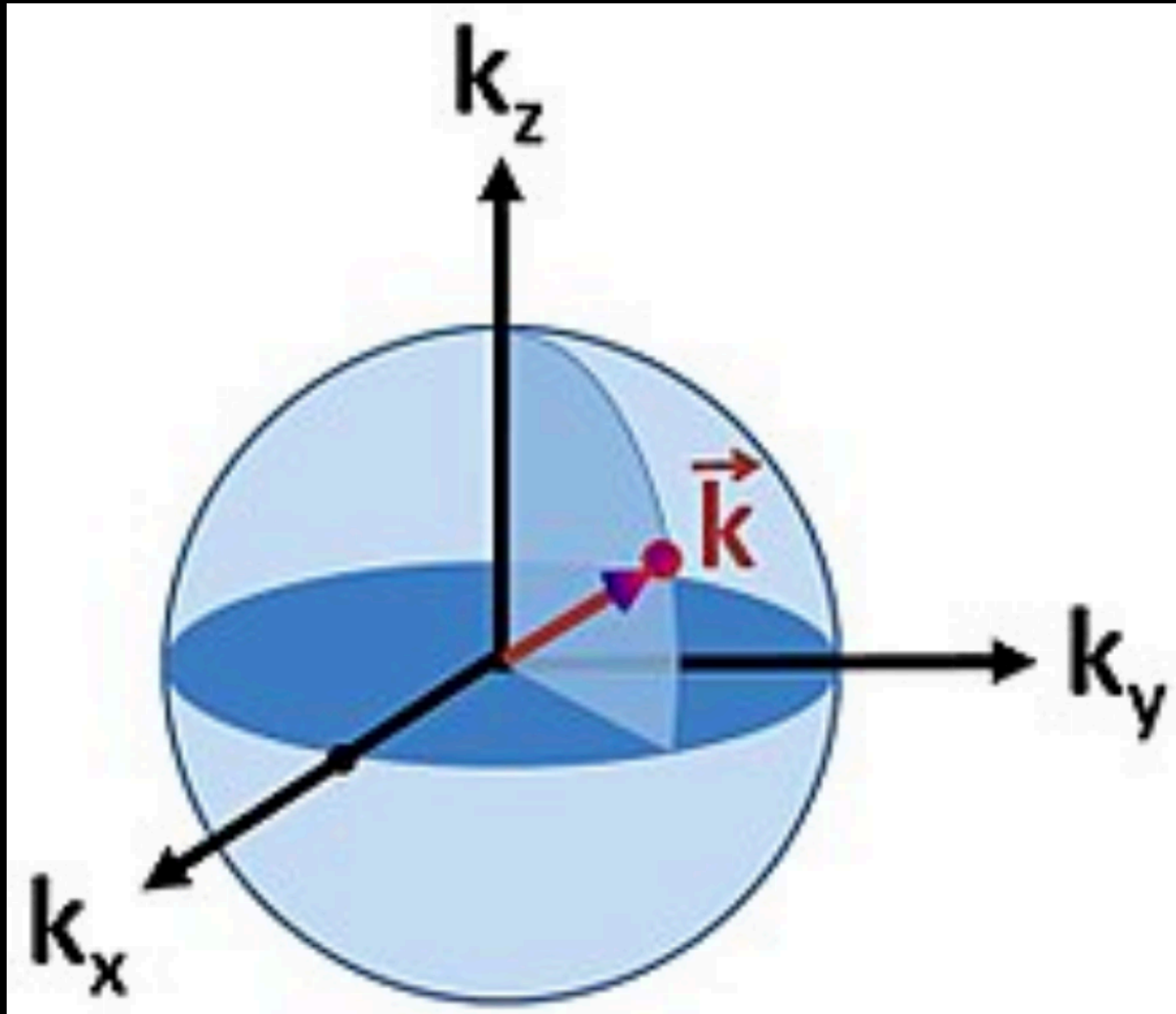
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$$v_{esc} = \sqrt{\frac{2GM}{r}} \sim 0.7c$$

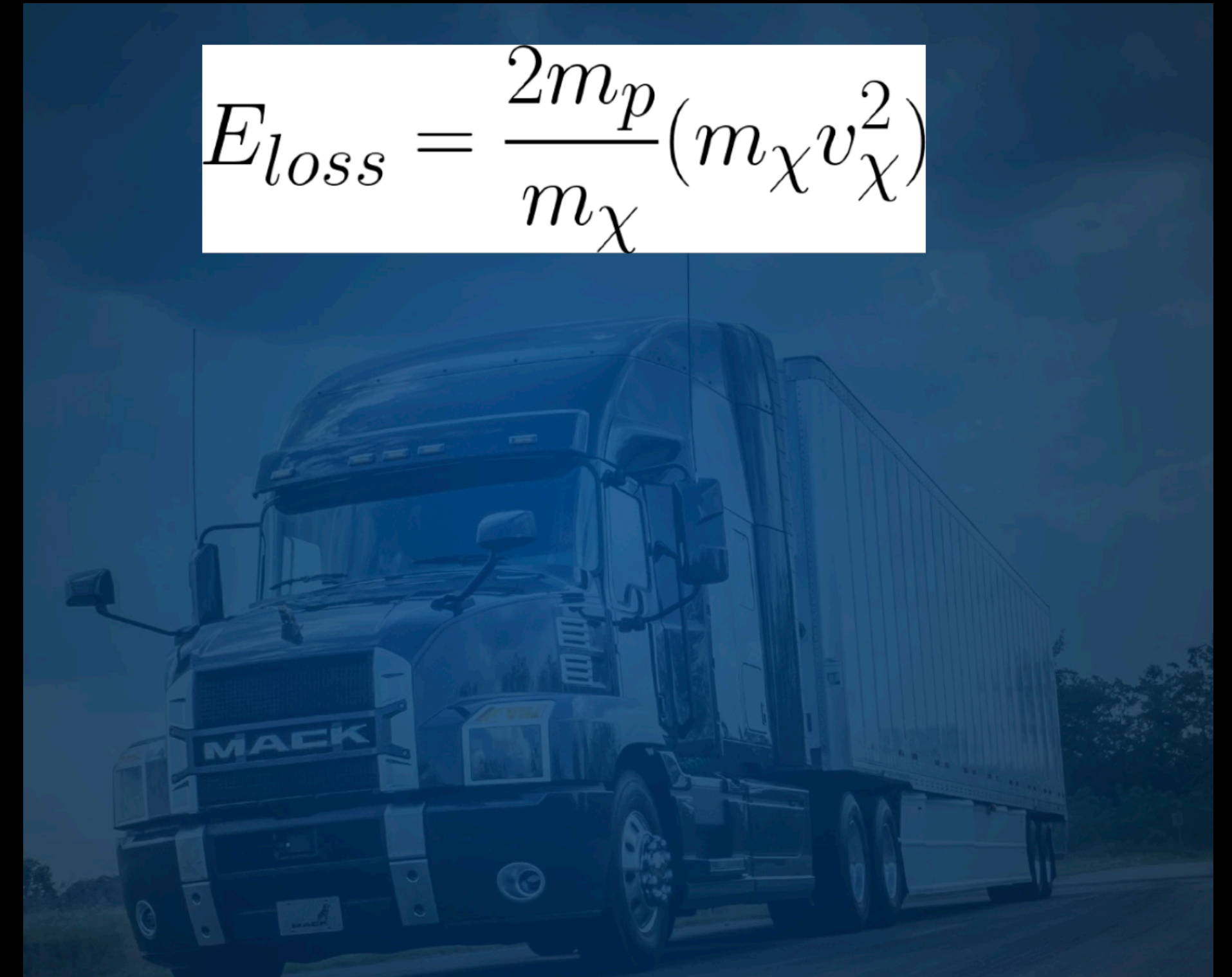
Energy Injection is Roughly Independent of Mass

Paul Blocking (< 1 GeV)



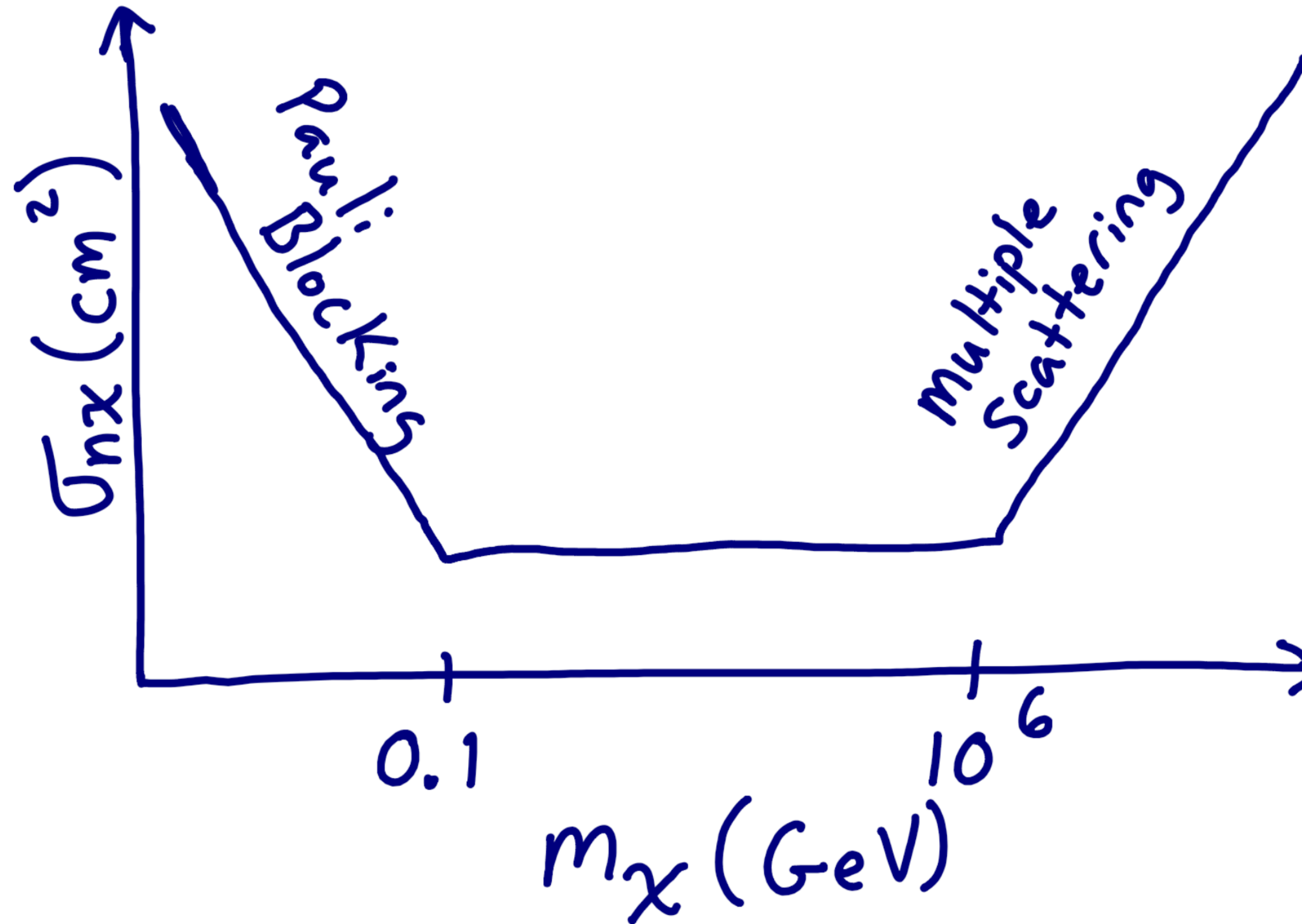
$$p_{F,n} \simeq 0.45 \text{ GeV} \left(\rho_{NS} / (4 \times 10^{38} \text{ GeV cm}^{-3}) \right)$$

Multi-Scattering (>1 PeV)



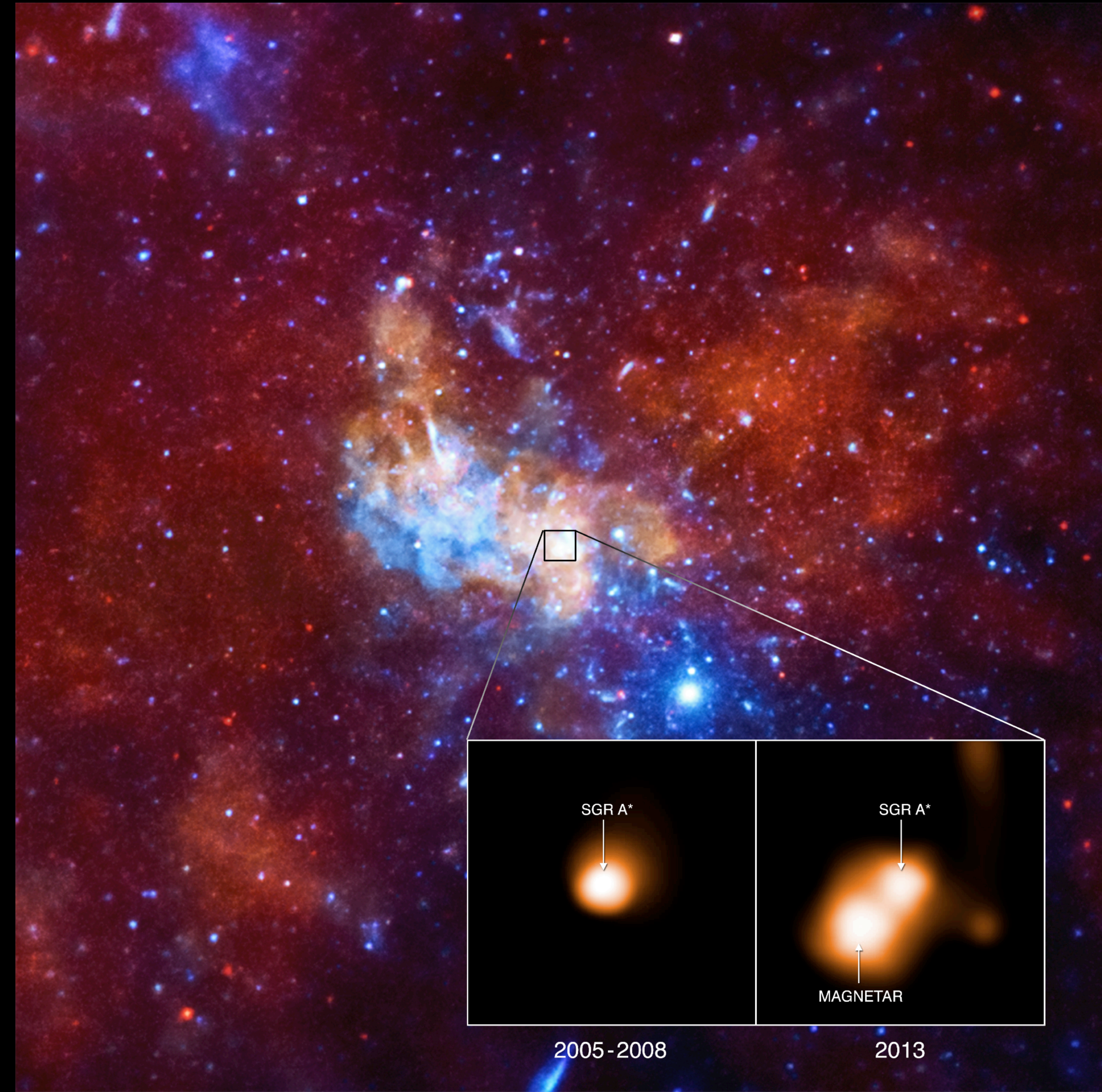
$$\sigma_{\text{sat}}^{\text{multi}} \simeq 2 \times 10^{-45} \text{ cm}^2 \left(\frac{m_\chi}{\text{PeV}} \right) \left(\frac{1.5 M_\odot}{M} \right) \left(\frac{R}{10 \text{ km}} \right)^2$$

Energy Injection is Roughly Independent of Mass



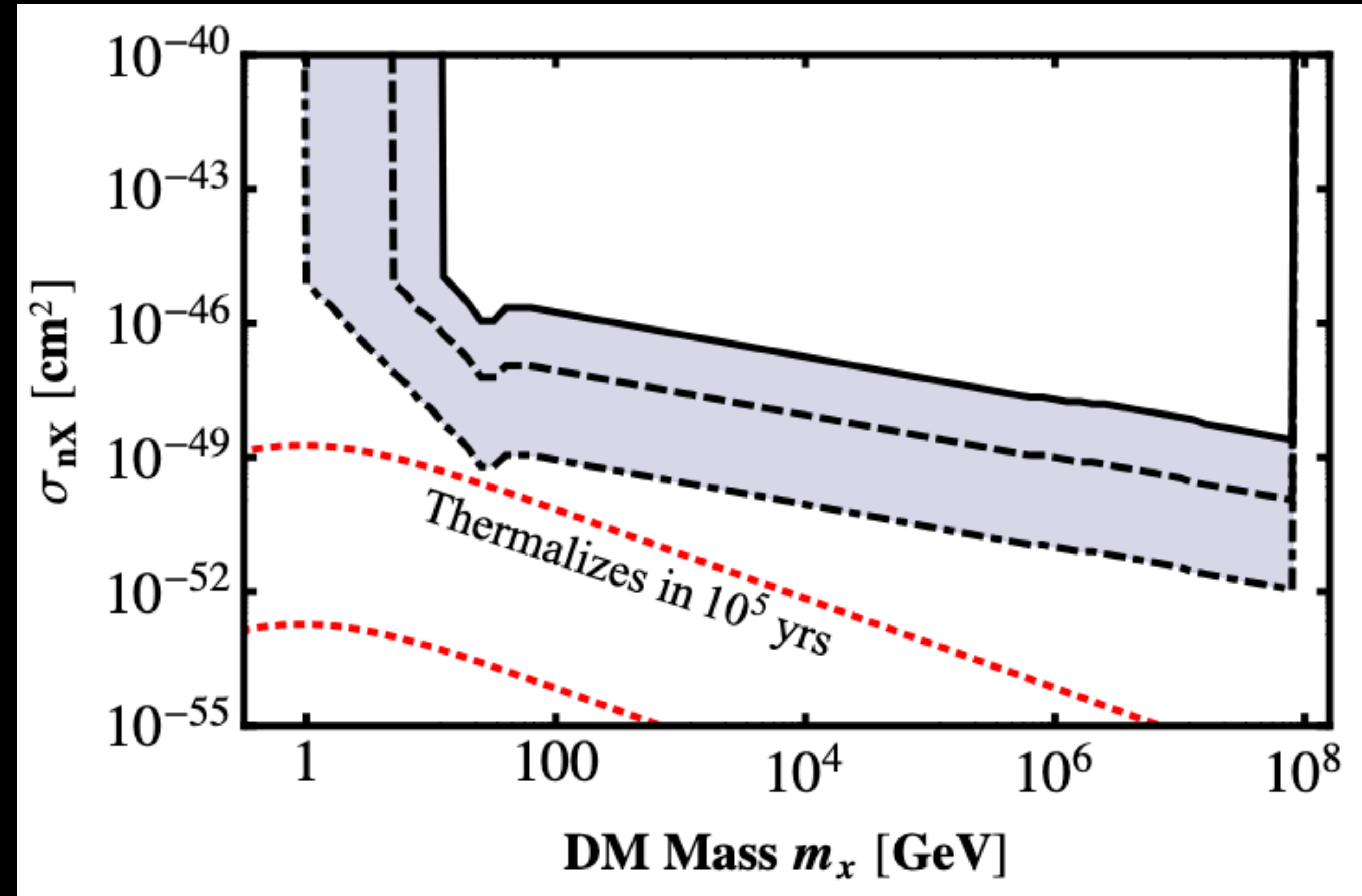
The 2013 GC Magnetar Detection

- Before 2013, it was thought that pulse dispersion made GC pulsars invisible.
- Magnetar observed (**First in X-rays!**) in 2013.
- Largest pulse dispersion of any existing pulsar, but not sufficient to make GC pulsars invisible.



Dark Matter interactions in NS

- Dark Matter accumulation can eliminate these pulsars:
- **Need DM to either be non-annihilating massive fermions or bosons (to avoid Fermi degeneracy pressure)**

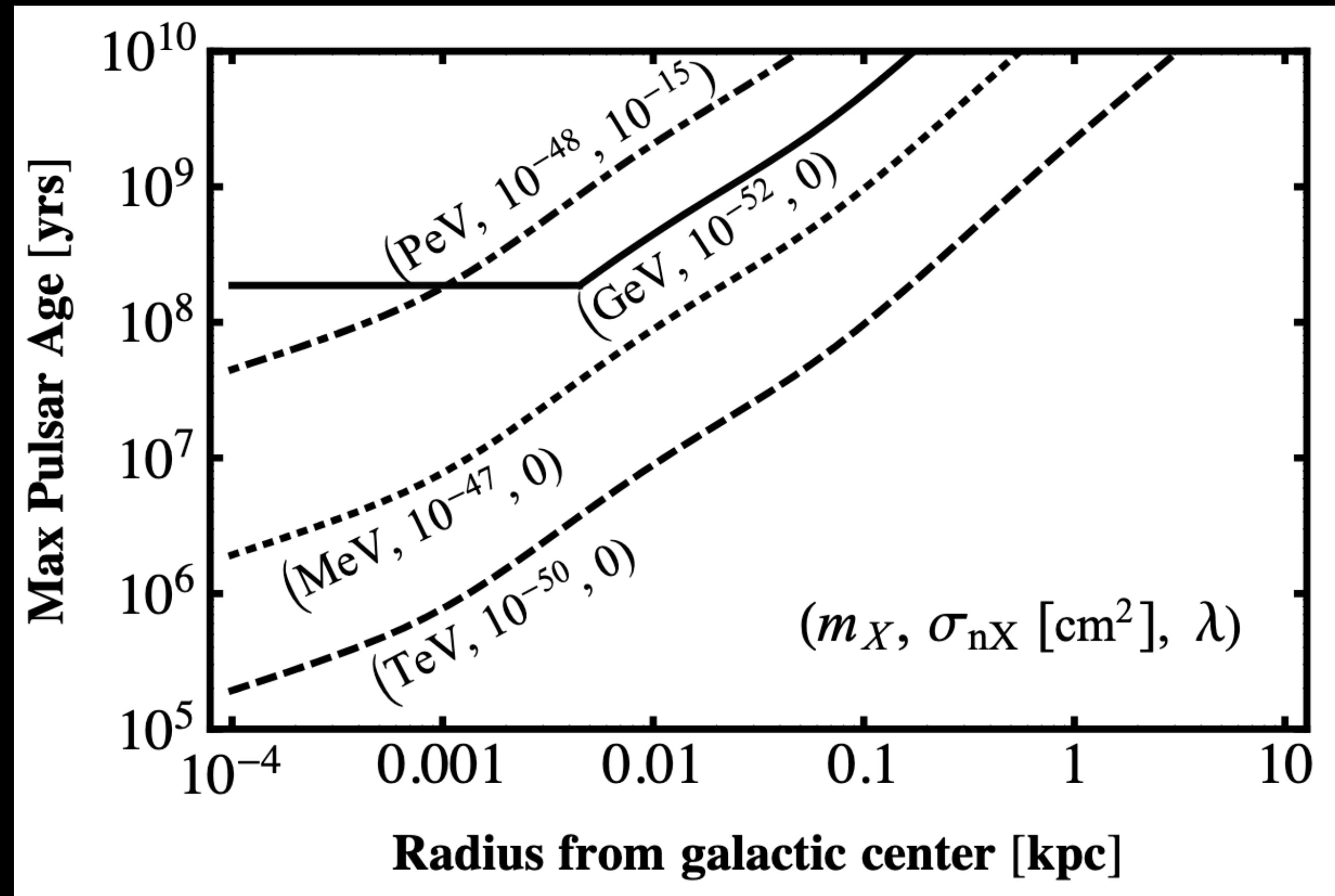


But:

How Can You Use the Absence of a Star to Detect Something?

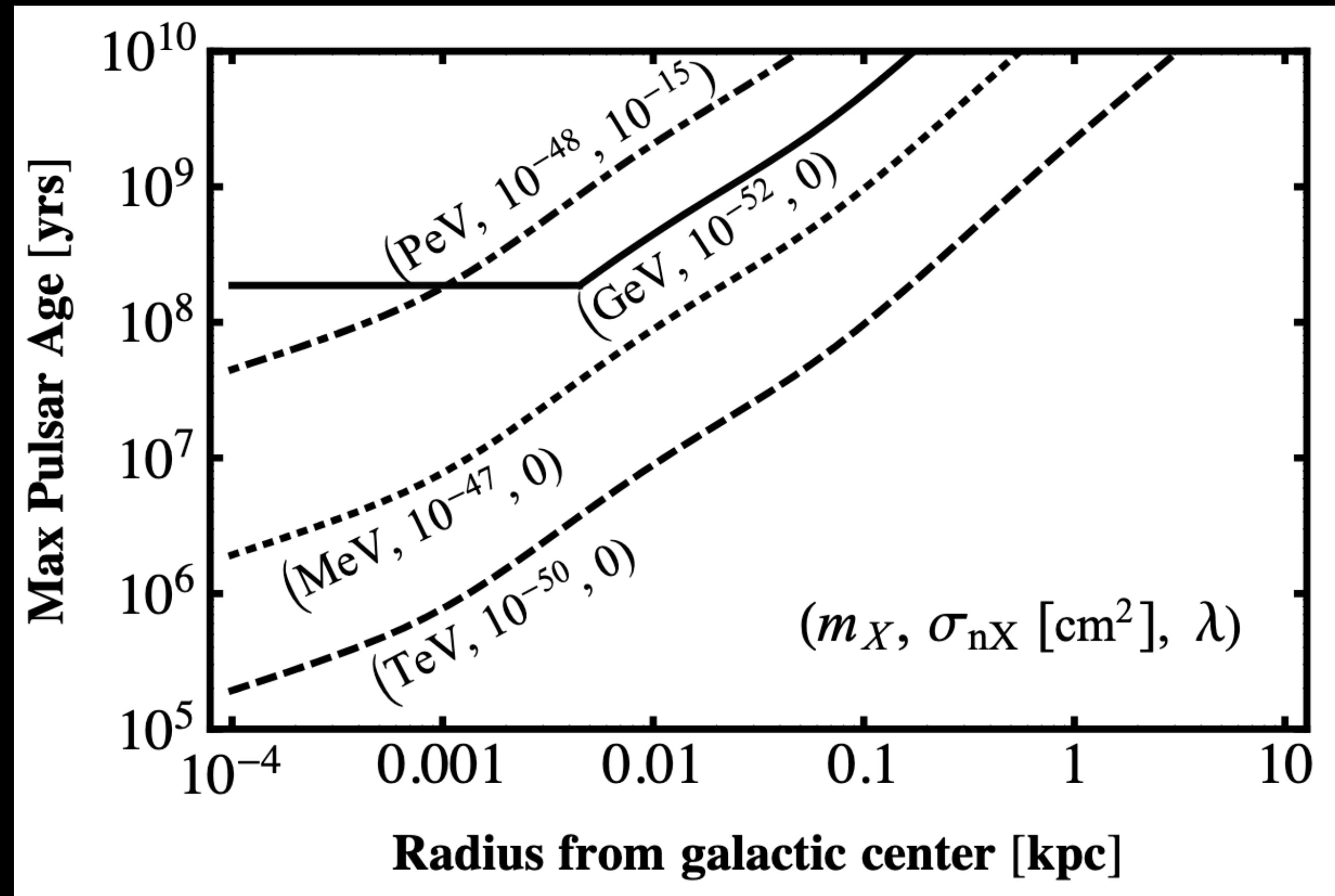
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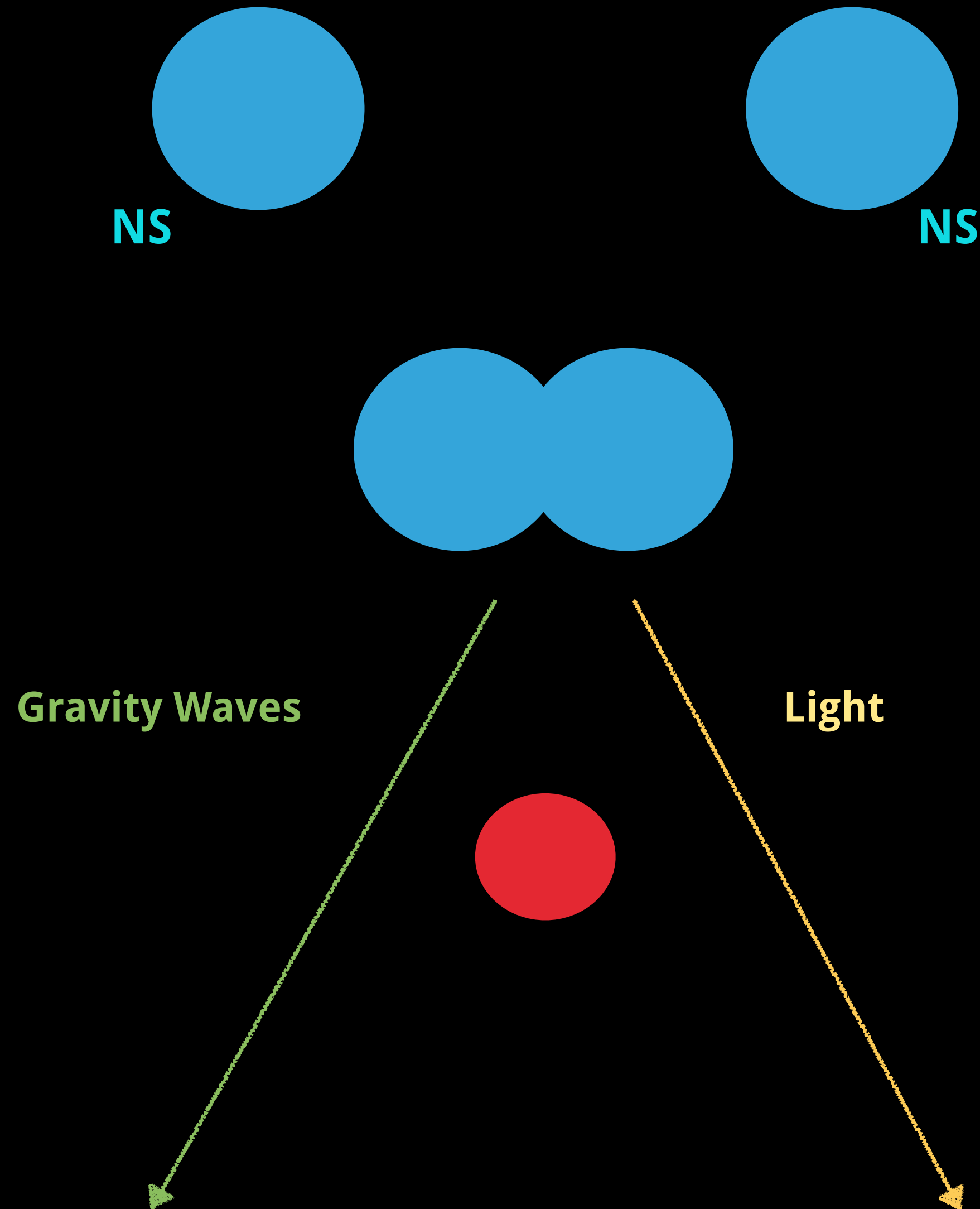
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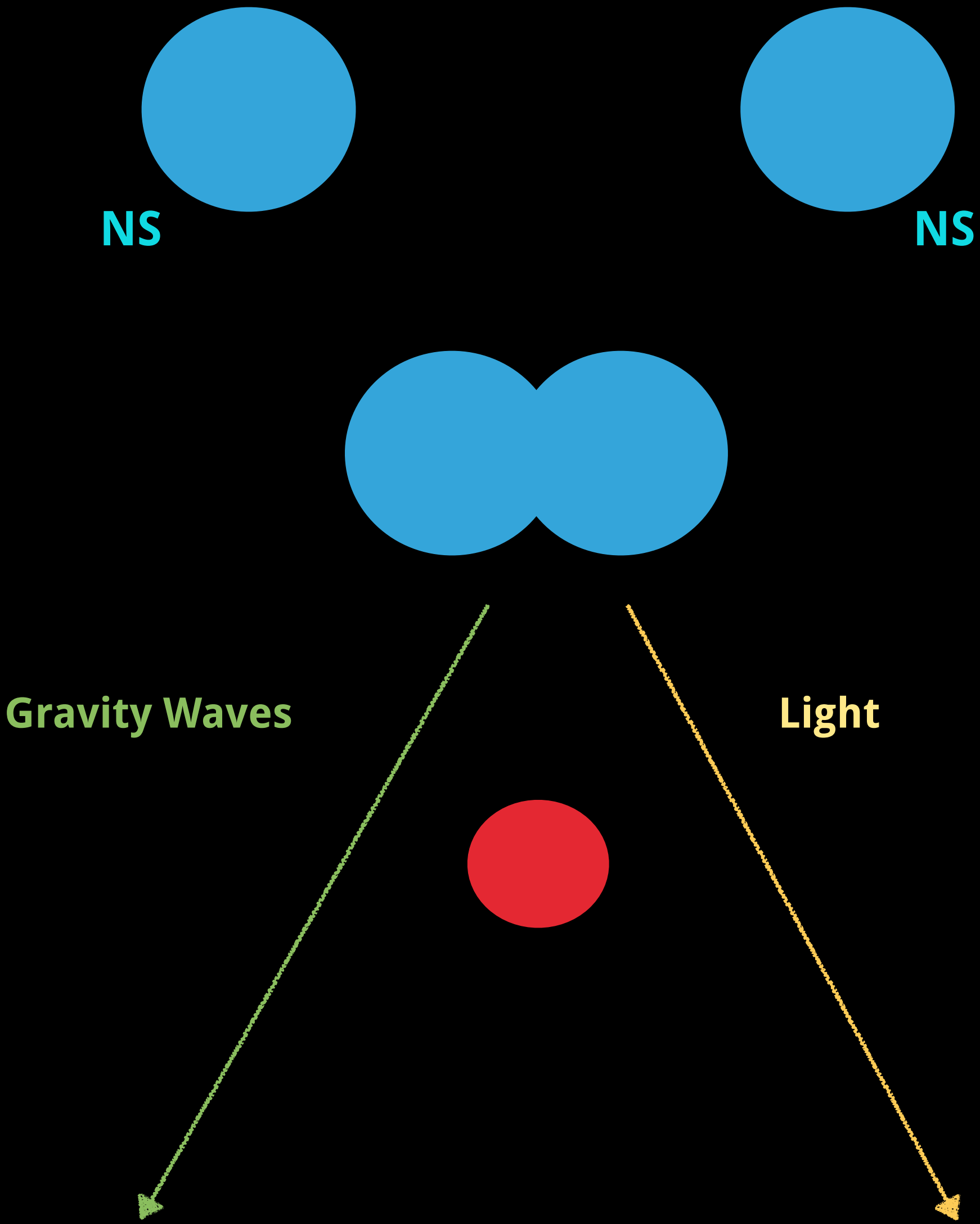
Separation of Electromagnetic and Gravitational Signals

Astrophysical Ligo Signals

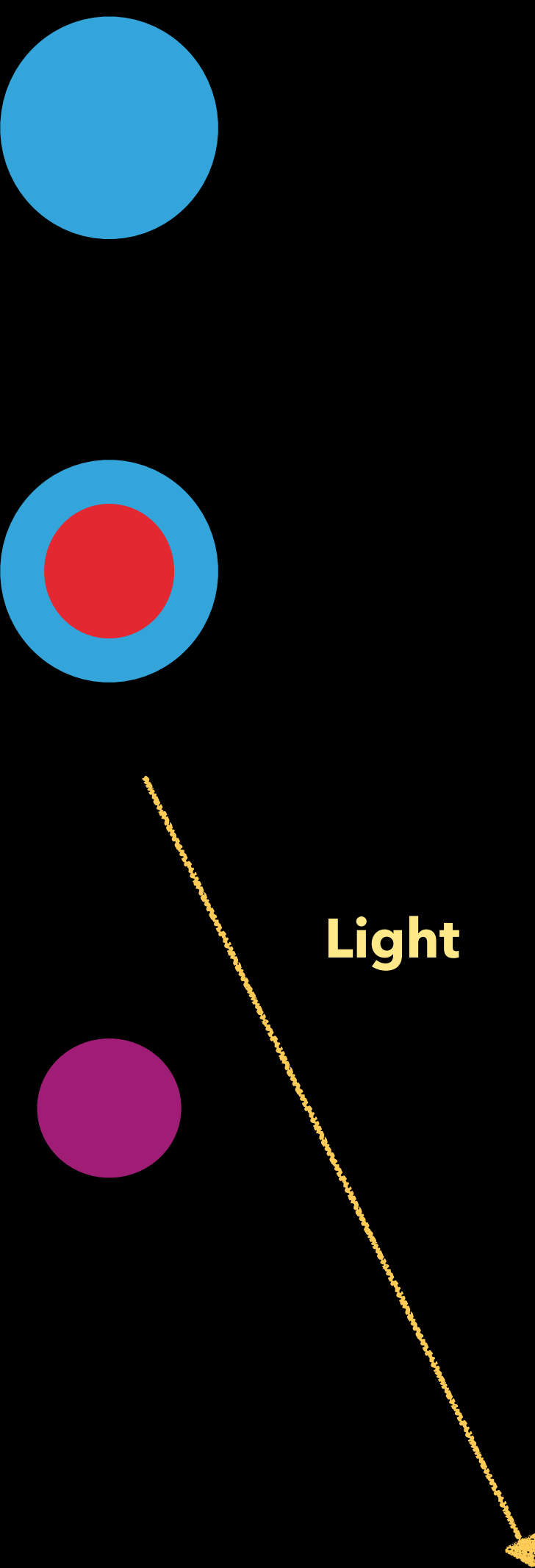


Separation of Electromagnetic and Gravitational Signals

Astrophysical Ligo Signals

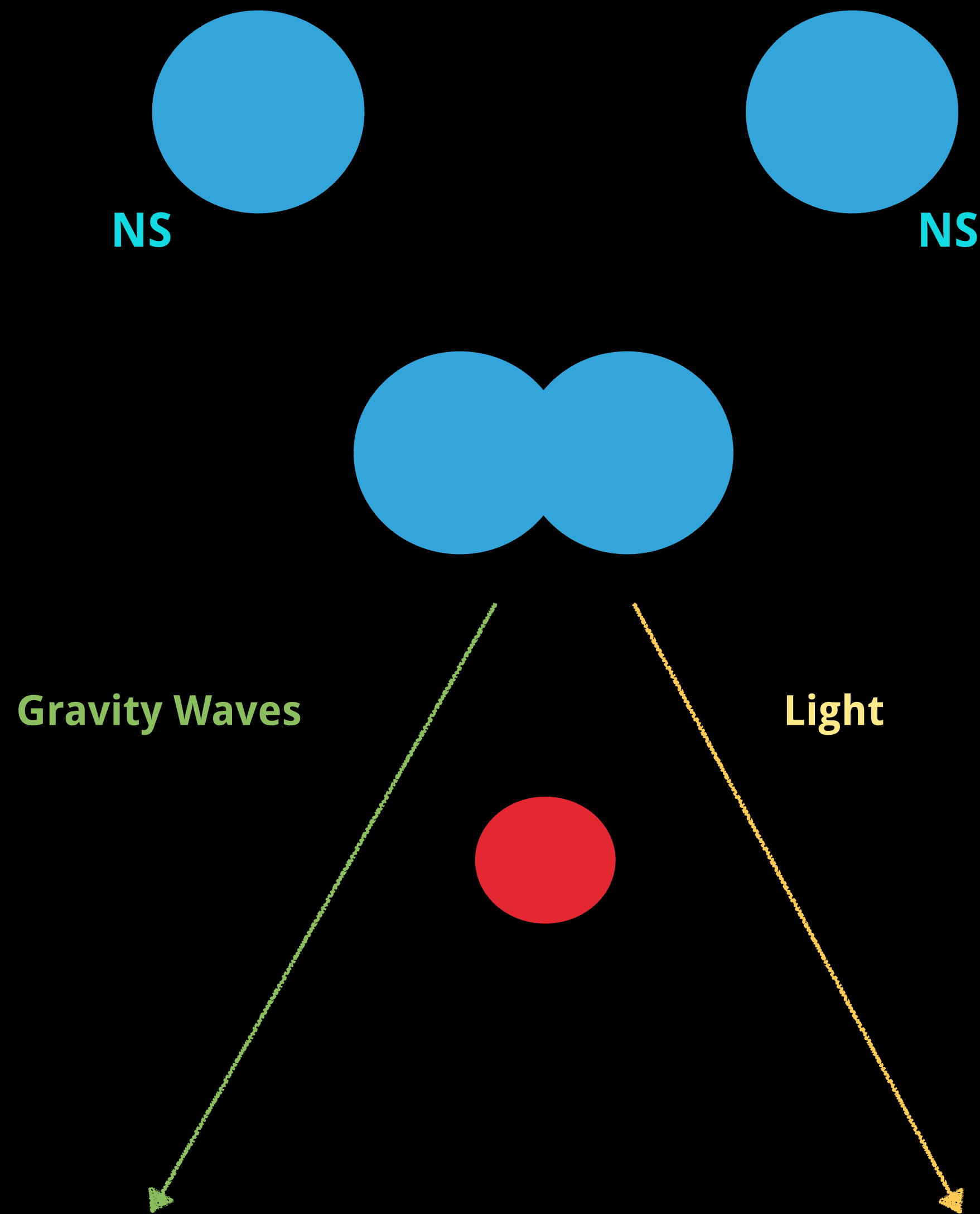


DM Induced Collapse

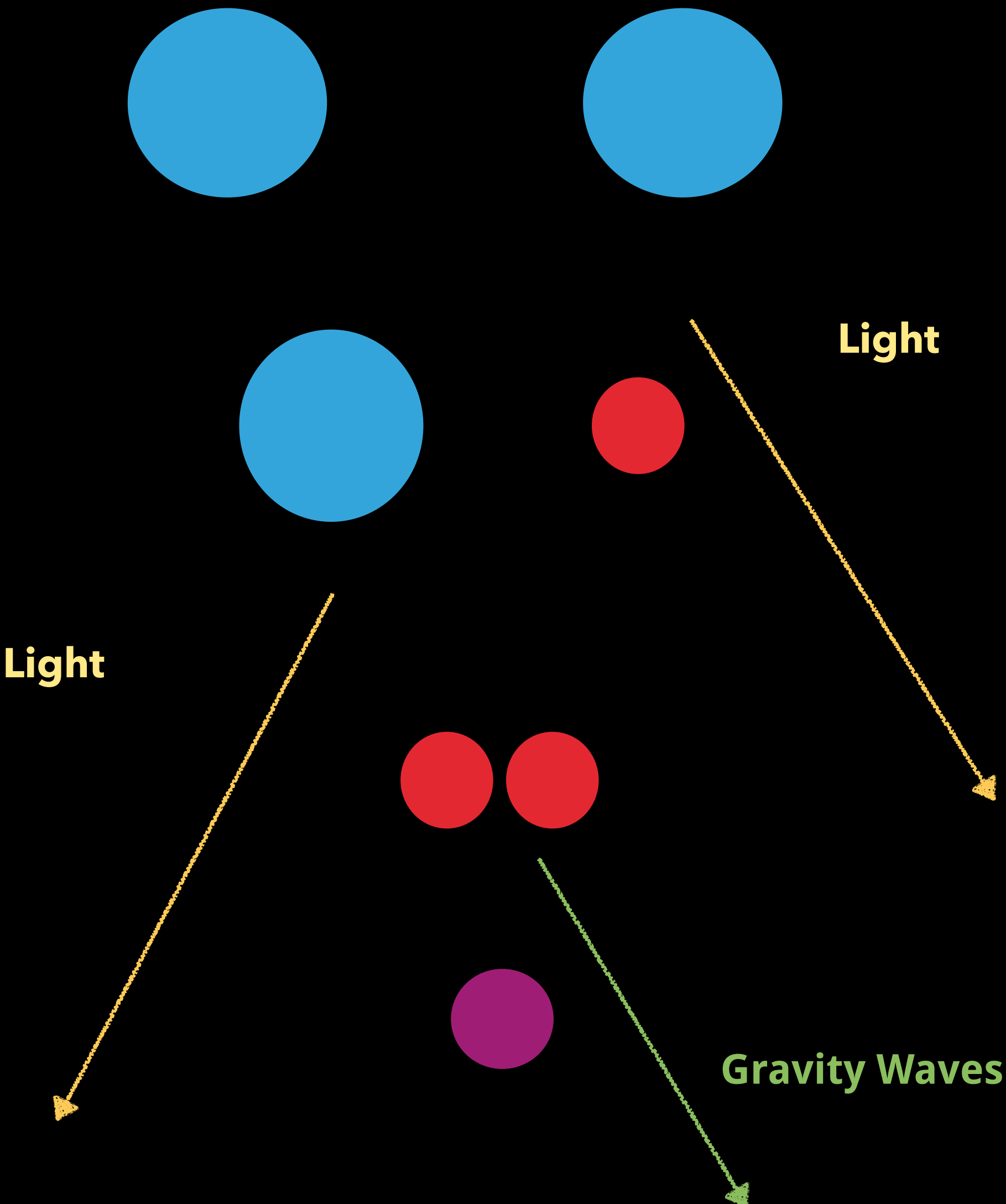


Separation of Electromagnetic and Gravitational Signals

Astrophysical Ligo Signals



DM Induced Collapse



How to Do Science in the High-Risk High-Reward Regime

1.) Avoid Two-Miracle Studies

- Standard model miracles cost half.
- Miracles can be correlated



2.) Focus on observables

- When the risk is high, observers will not spend effort on studies.










































3.) Attack the biggest uncertainty, and then move on.

- Every individual study is individually unlikely.



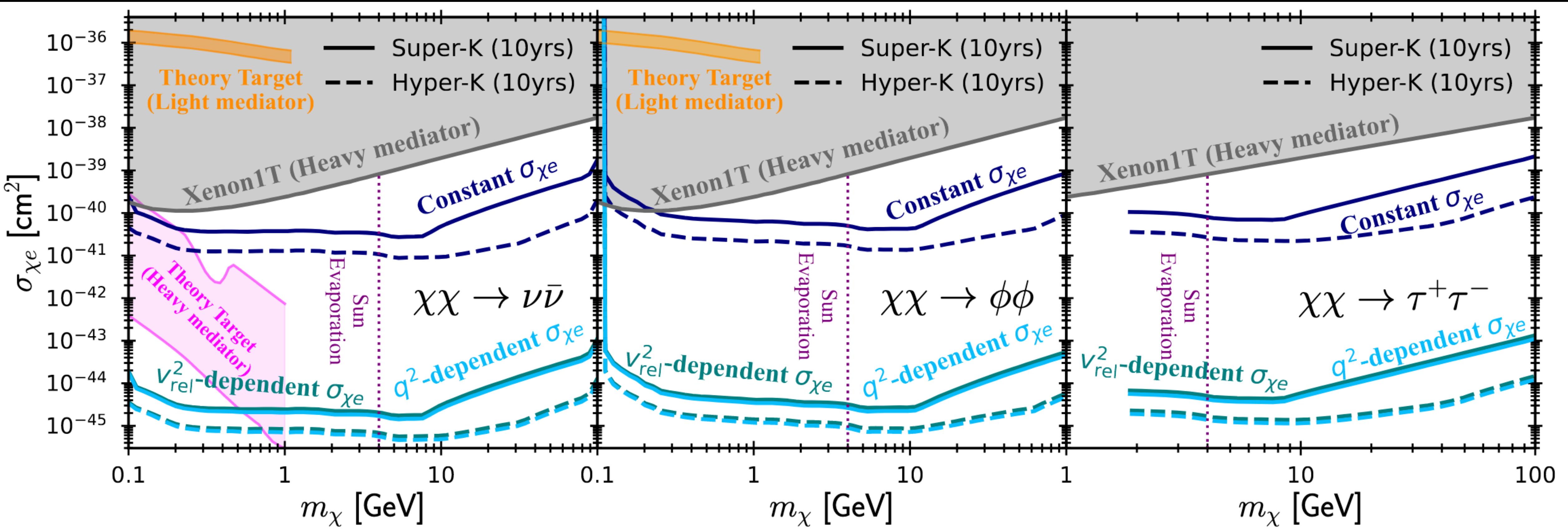
Conclusions

DD	GeV Scale	Sun		     	Heating Signatures (Thermal Spectra)
	Asymmetric	Jupiter		 	Thermal Transport (Seismology)
	Self-Interacting	S-Cluster			Thermal Transport (Affect on Neutrino Flux)
	Light Mediator	G-Objects		  	Thermal Transport (Cooling Curves)
				 	Escaping Signals (DM Neutrinos)
no DD	<GeV Mass			   	Escaping Signals (Cosmic Rays/ γ -Rays)
	>TeV Mass	GC Brown Dwarfs		 	Structural Changes (Longer Lifespan of CBs)
	Spin-Dependent	GC White Dwarfs		   	Structural Changes (Destruction of CBs)
	Inelastic			   	Structural Changes (Spectral Changes)
	Velocity-Dependent	Dark Stars		   	Structural Changes (Population Level)

Conclusions

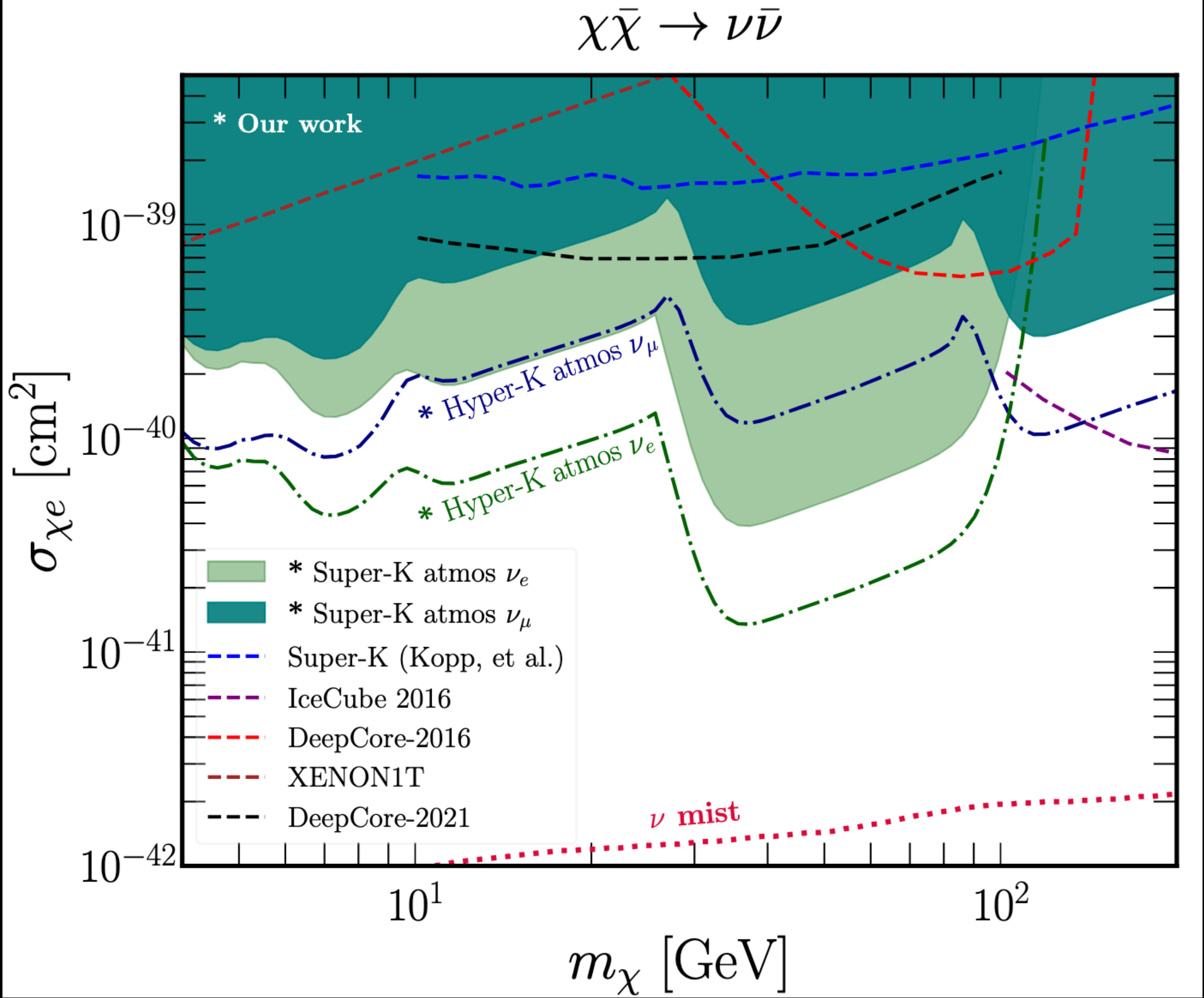


Super-Kamiokande



- When the cross-sections are velocity or momentum dependent, the high velocity of electrons makes constraints much stronger, probing the theoretical targets for leptophilic DM.

A Note Regarding 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,‡},
^{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 Physics, The University of Sydney, ARC Centre of Excellence for Dark Matter Particle Physics, NSW 2006,
(Dated: March 12, 2025)

Dark matter scattering on electrons in the Sun may gravitationally capture and self-annihilate into neutrinos and anti-neutrinos, or other final states that in turn decay to them. The most stringent limits on the fluxes of atmospheric electron-type and muon-type neutrinos by Super-Kamiokande of order 10^{-39} cm² over a mass range of 4–200 GeV. These outdo direct limits from IceCube and previously set limits at IceCube. We also derive limits on dark matter-electron scattering cross sections from atmospheric neutrino observations restricted to the mass range of 4–200 GeV.

A Note Regarding 2503.07713

Gould, 1987a (Astrophys.J. 321 (1987) 560)

$$R(w \rightarrow v) = \frac{4\mu_+^4}{\pi^{\frac{1}{2}}} N \sigma \frac{v}{w} \int_0^\infty dx \int_{-\infty}^\infty dy \kappa^3 (x+y) e^{-\kappa^2 u^2} \theta(v - |y|) \theta(x-w) \quad (\text{A11})$$

$$= \frac{2}{\pi^{\frac{1}{2}}} \frac{\mu_+^2}{\mu} N \sigma \frac{v}{w} [\chi(-\alpha_-, \alpha_+) + \chi(-\beta_-, \beta_+) e^{-\frac{M}{2T}(v^2 - w^2)}]. \quad (\text{A15})$$

Garani & Palomares-Ruiz (1702.02768)

$$\begin{aligned} R_i(w \rightarrow v) &= \int n_i(r) \frac{d\sigma_i}{dv} |\boldsymbol{w} - \boldsymbol{u}| f_i(\boldsymbol{u}, r) d^3\boldsymbol{u} \\ &= \frac{2}{\sqrt{\pi}} \frac{n_i(r)}{u_i^3(r)} \int_0^\infty du u^2 \int_{-1}^1 d\cos\theta \frac{d\sigma_i}{dv} |\boldsymbol{w} - \boldsymbol{u}| e^{-u^2/u_i^2(r)}, \end{aligned} \quad (\text{A.1})$$

A Note Regarding 2503.07713

$$C = \left[\left(\frac{8}{3\pi} \right)^{\frac{1}{2}} \sigma n_W \bar{v} \right] \left[\frac{M_B}{m} \right] \left[\frac{3v_{\text{esc}}^2}{2\bar{v}^2} \langle \hat{\phi} \rangle \right] [\xi_\eta(\infty)] \left\langle \frac{\hat{\phi}}{\langle \hat{\phi} \rangle} \left(1 - \frac{1 - e^{-A^2}}{A^2} \right) \frac{\xi_1(A)}{\xi_\eta(\infty)} \right\rangle, \quad (2.31)$$

Moreover, the distribution of energy loss is uniform over this interval. On the other hand, scattering from velocity w to a velocity less than v , requires an energy loss of *at least*

$$\frac{\Delta E}{E} \geq \frac{w^2 - v^2}{w^2} = \frac{u^2}{w^2}. \quad (2.11)$$

Combining expressions (2.9) and (2.11) gives the probability that a given scattering will leave the WIMP with less than escape energy,

$$\frac{\mu_+^2}{\mu} \cdot \left(\frac{\mu}{\mu_+^2} - \frac{u^2}{w^2} \right) \theta \left(\frac{\mu}{\mu_+^2} - \frac{u^2}{w^2} \right). \quad (2.12)$$

The rate of scattering from w to less than v is just the product of the total rate of scattering, $\sigma n w$, with the conditional probability (2.12). This result may be written,

$$\Omega_v^-(w) = \frac{\sigma n}{w} \left(v^2 - \frac{\mu_-^2}{\mu} u^2 \right) \theta \left(v^2 - \frac{\mu_-^2}{\mu} u^2 \right). \quad (2.13)$$

A Note Regarding 2503.07713

- **Incorrectly adding a zero-temperature kinematic cutoff significantly suppresses the leptophilic dark matter capture rate in the Sun (by a factor of ~7).**
- **Correcting this error leads to stronger limits in many studies.**

