Dark Matter & Strong Interactions: Capture in Celestial Bodies

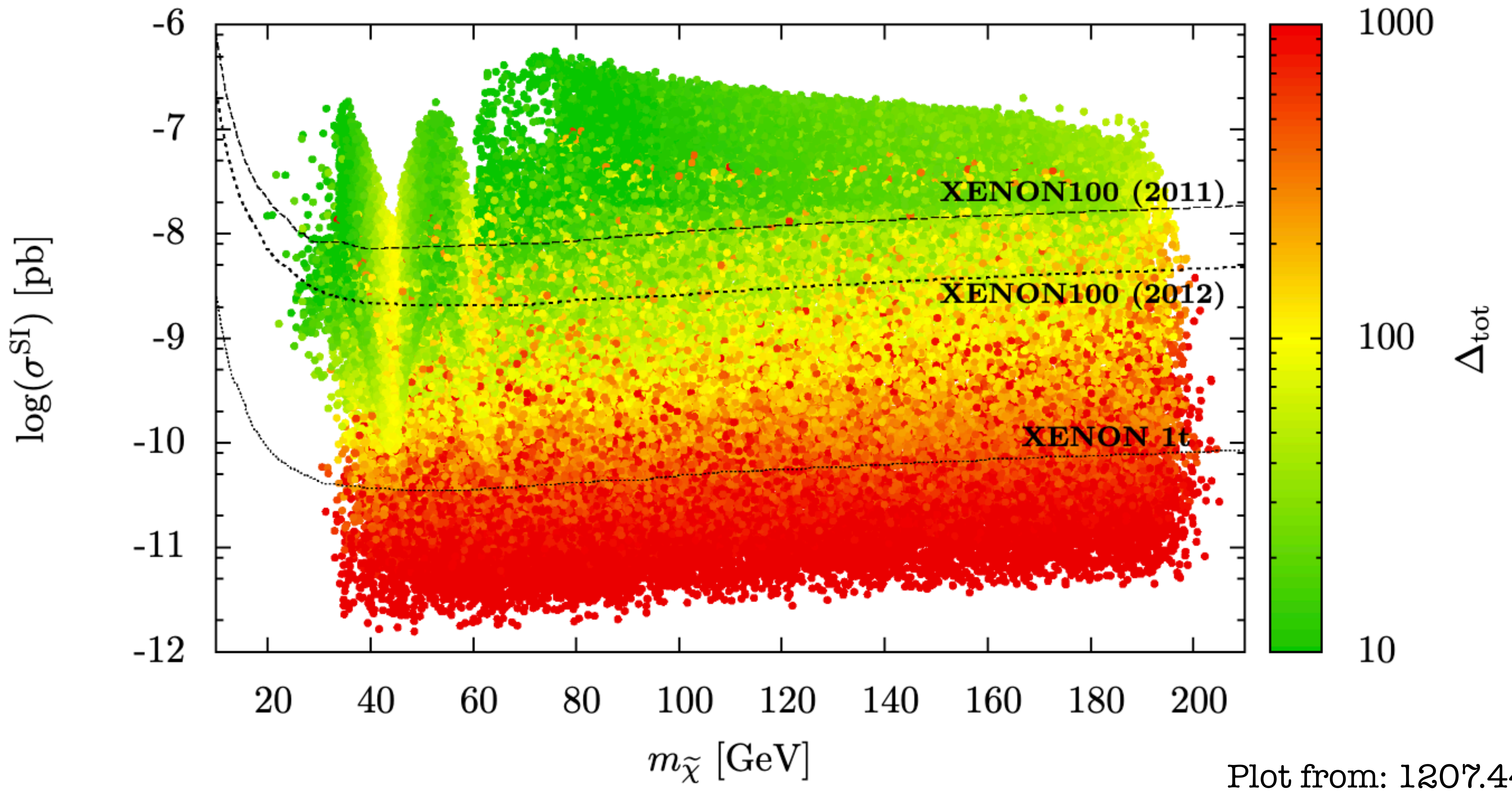
Juri Smirnov, University of Liverpool,
UKRI Future Leaders Fellow

BLV

Karlsruhe: 10/10/24

Many thanks to my collaborators: John Beacom, Djuna Croon, Rebecca Leane, Jeremy Sackstein, ...

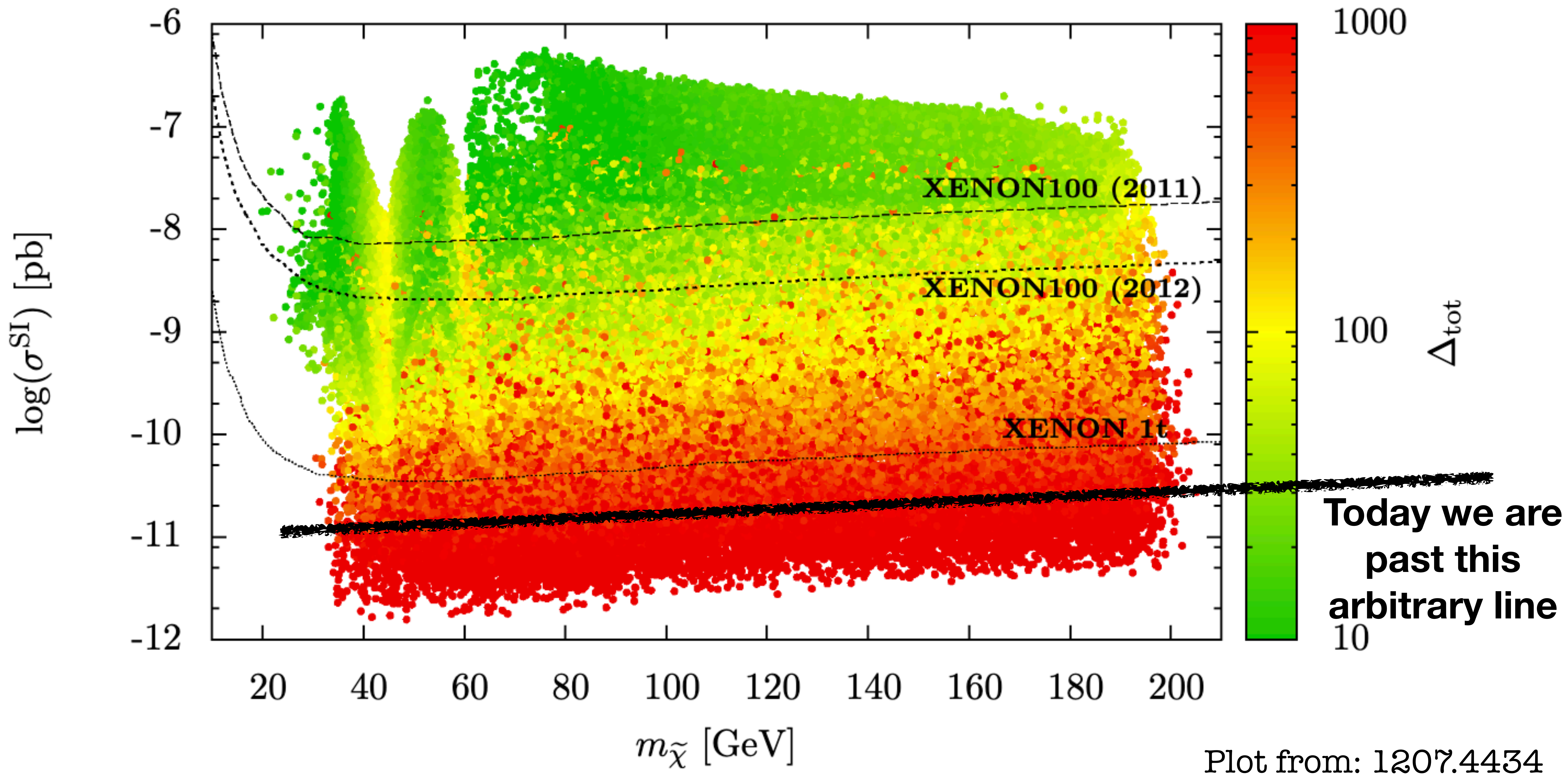
In Search of Lost Naturalness



Plot from: 1207.4434

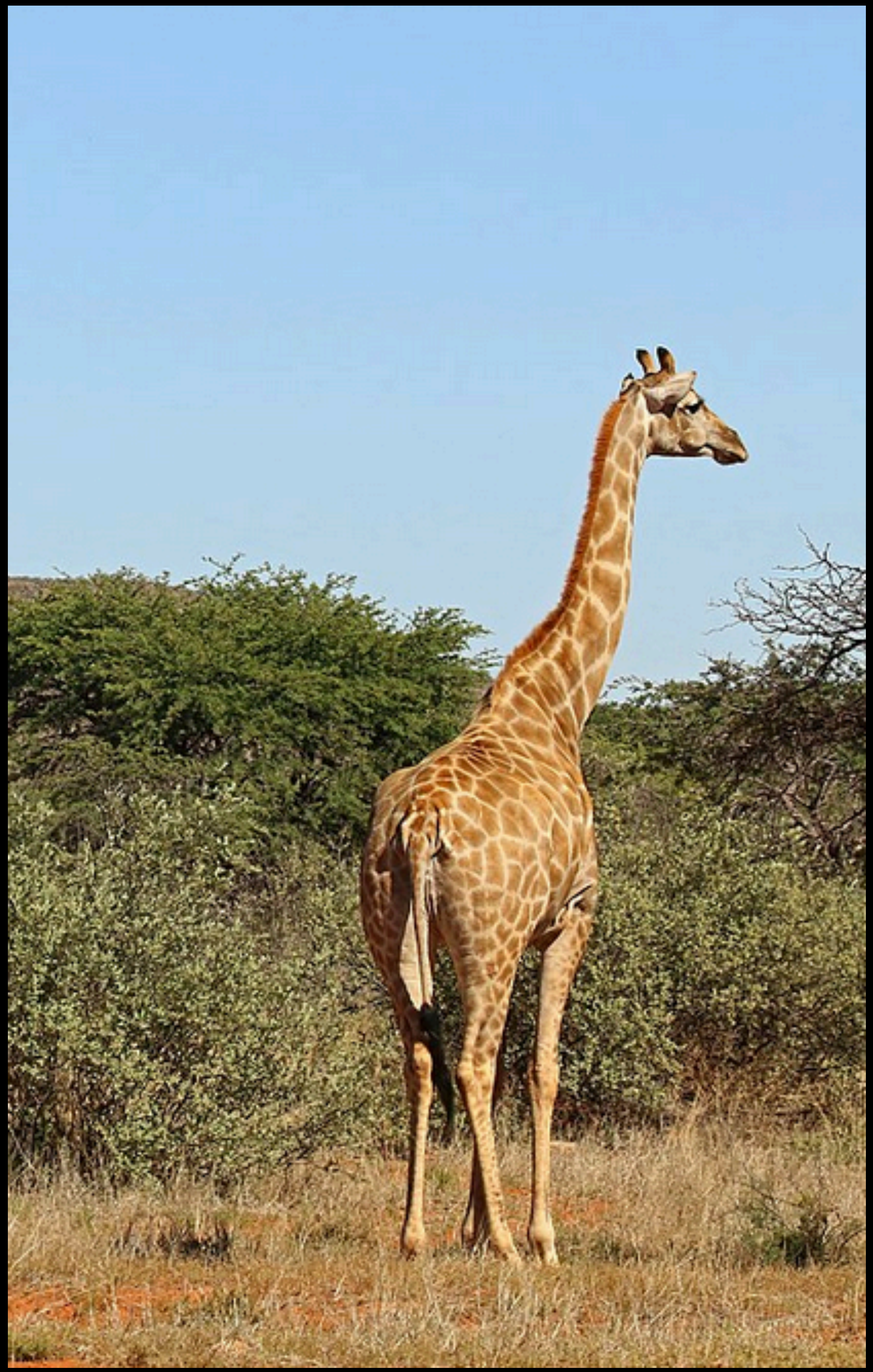
Juri Smirnov, juri.smirnov@liverpool.ac.uk; 10/10/24

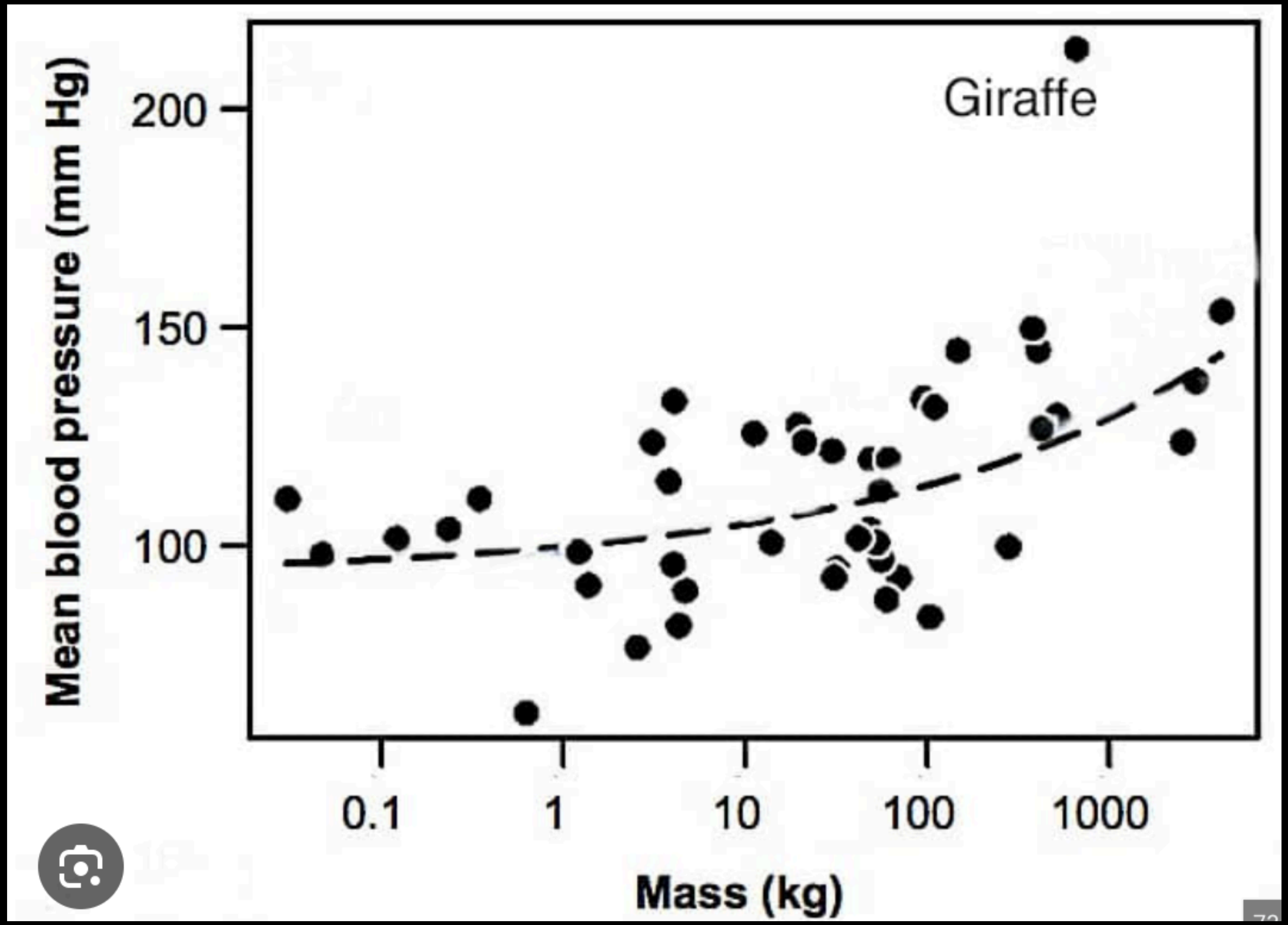
In Search of Lost Naturalness



Plot from: 1207.4434

Naturalness and Spherical Cows





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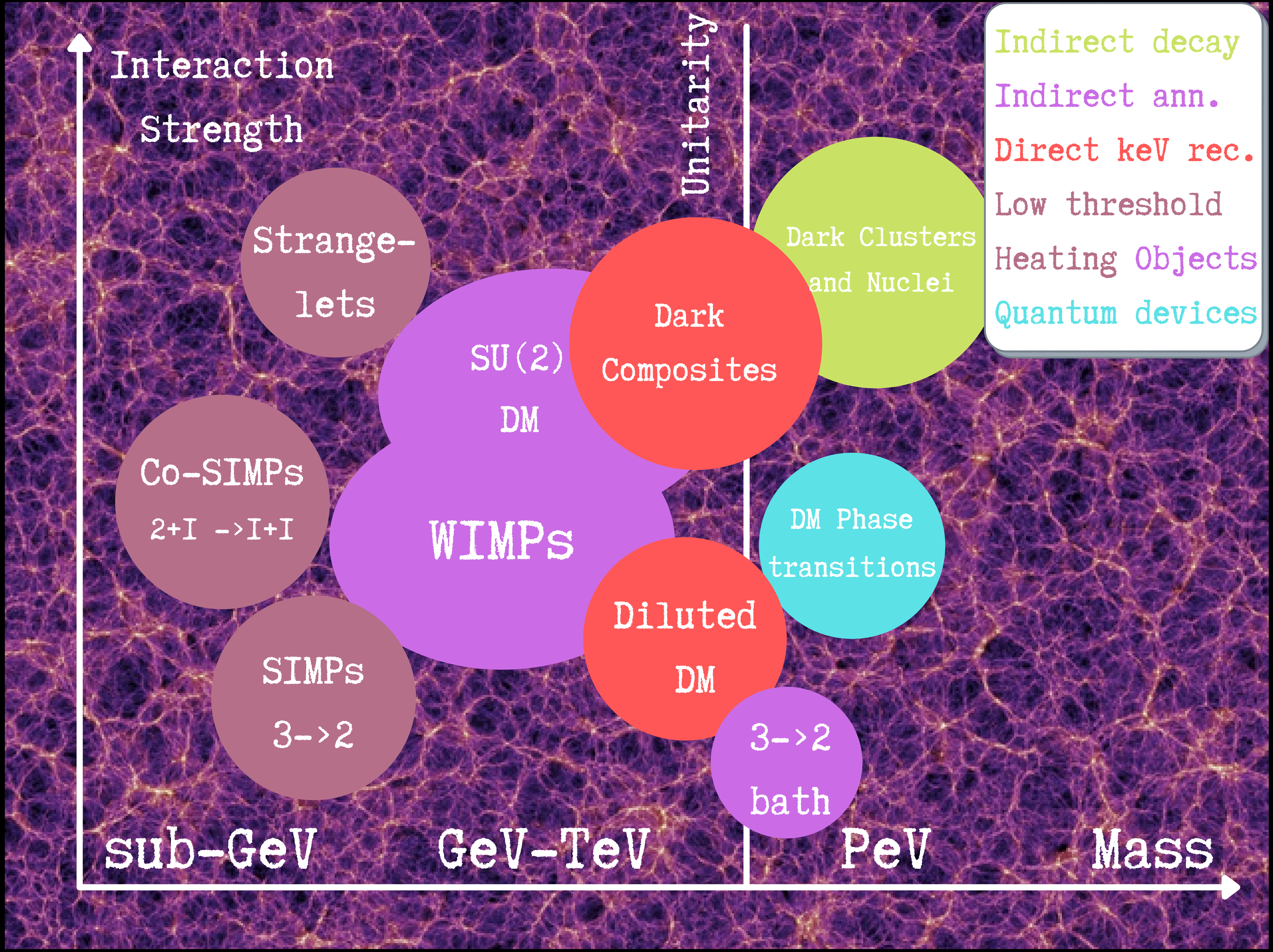
Naturalness and Spherical Cows

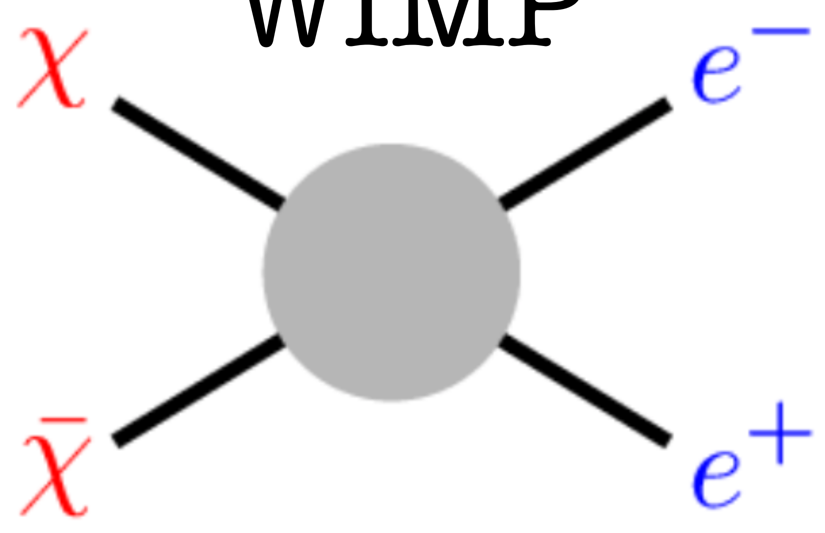
Dark Matter Scenario Space



Thermal Production

Types of Freezeout

WIMP

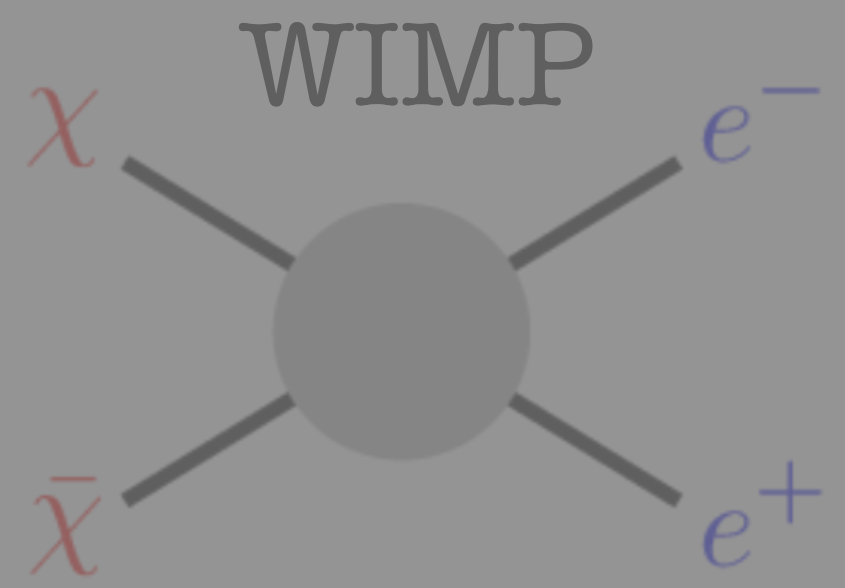


Zeldovich, Lee, Weinberg, Steigman, Turner,...

$$\Gamma_{\rm DM} = \langle \sigma v_{\rm rel.} \rangle \, n_{\rm DM} > H(T)$$

$$\Omega_{\rm DM} \, h^2 \approx \frac{0.12}{\langle \sigma v_{\rm rel.} \rangle \, [25 \rm TeV]^2}$$

Types of Freezeout



Zeldovich, Lee, Weinberg, Steigman, Turner,...

$$\Gamma_{\mathrm{DM}} = \langle \sigma v_{\mathrm{rel.}} \rangle \, n_{\mathrm{DM}} > H(T)$$

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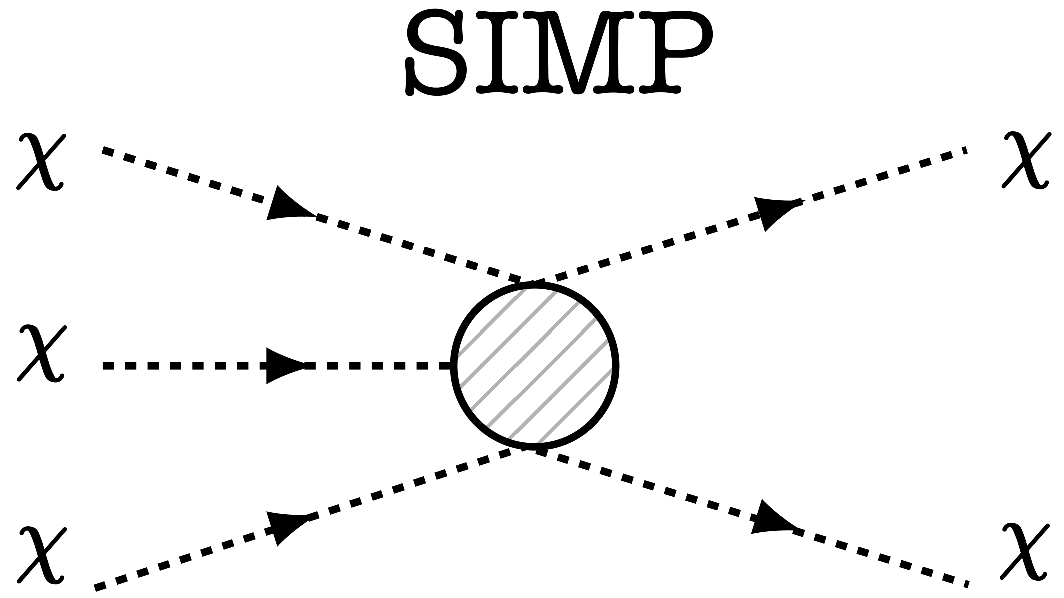


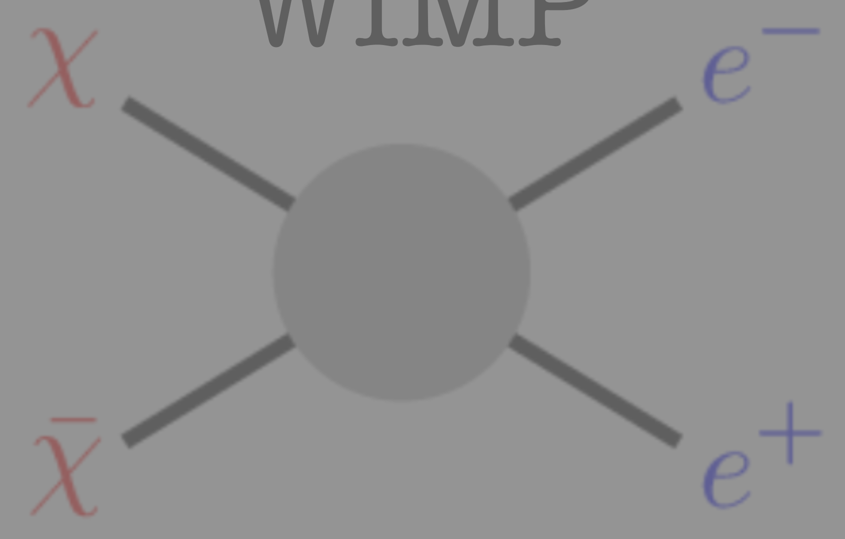
Hochberg, Kuflik, Volansky, Wacker

$$\Gamma_{\mathrm{DM}} = \langle \sigma_{3\to 2} v_{\mathrm{rel.}}^2 \rangle \, n_{\mathrm{DM}}^2 > H(T)$$

$$\Omega_{\mathrm{DM}} \, h^2 \approx \left(\frac{\mathrm{MeV}}{m_{\mathrm{DM}}} \right) \frac{0.12}{\sqrt{\langle \sigma_{3\to 2} v_{\mathrm{rel.}}^2 \rangle \, [3\mathrm{MeV}]^5}}$$

Types of Freezeout

WIMP



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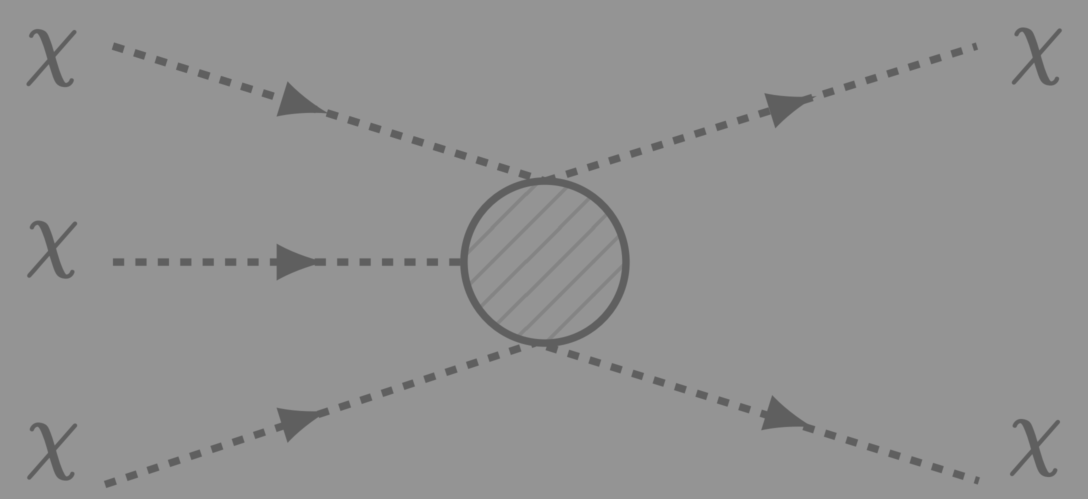
SIMP

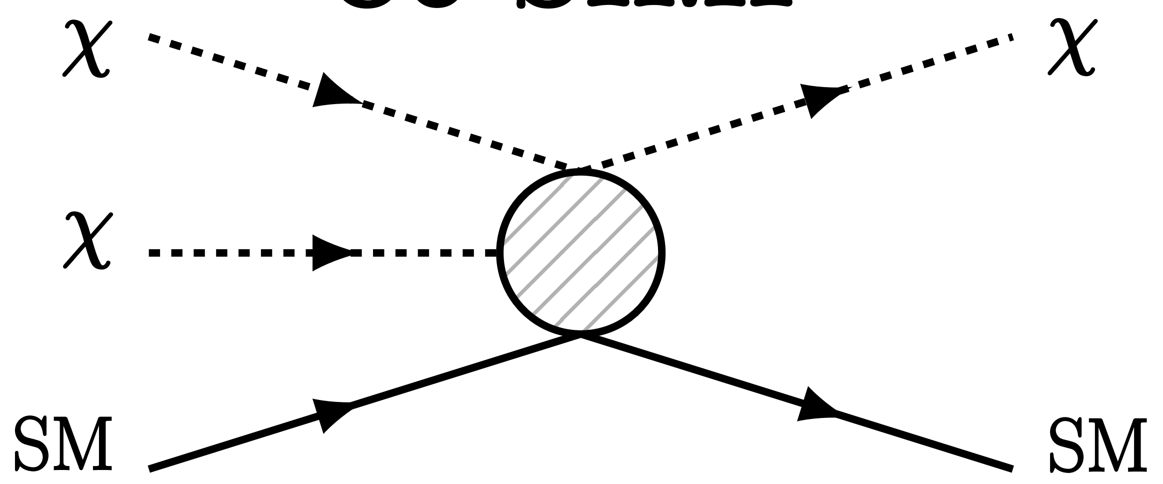


Hochberg, Kuflik, Volansky, Wacker

$$\Gamma_{\rm DM} = \langle \sigma_{3\to 2} v_{\rm rel.}^2 \rangle \, n_{\rm DM}^2 > H(T)$$

$$\Omega_{\rm DM} \, h^2 \approx \left(\frac{\rm MeV}{m_{\rm DM}} \right) \frac{0.12}{\sqrt{\langle \sigma_{3\to 2} v_{\rm rel.}^2 \rangle \, [3 {\rm MeV}]^5}}$$

Co-SIMP

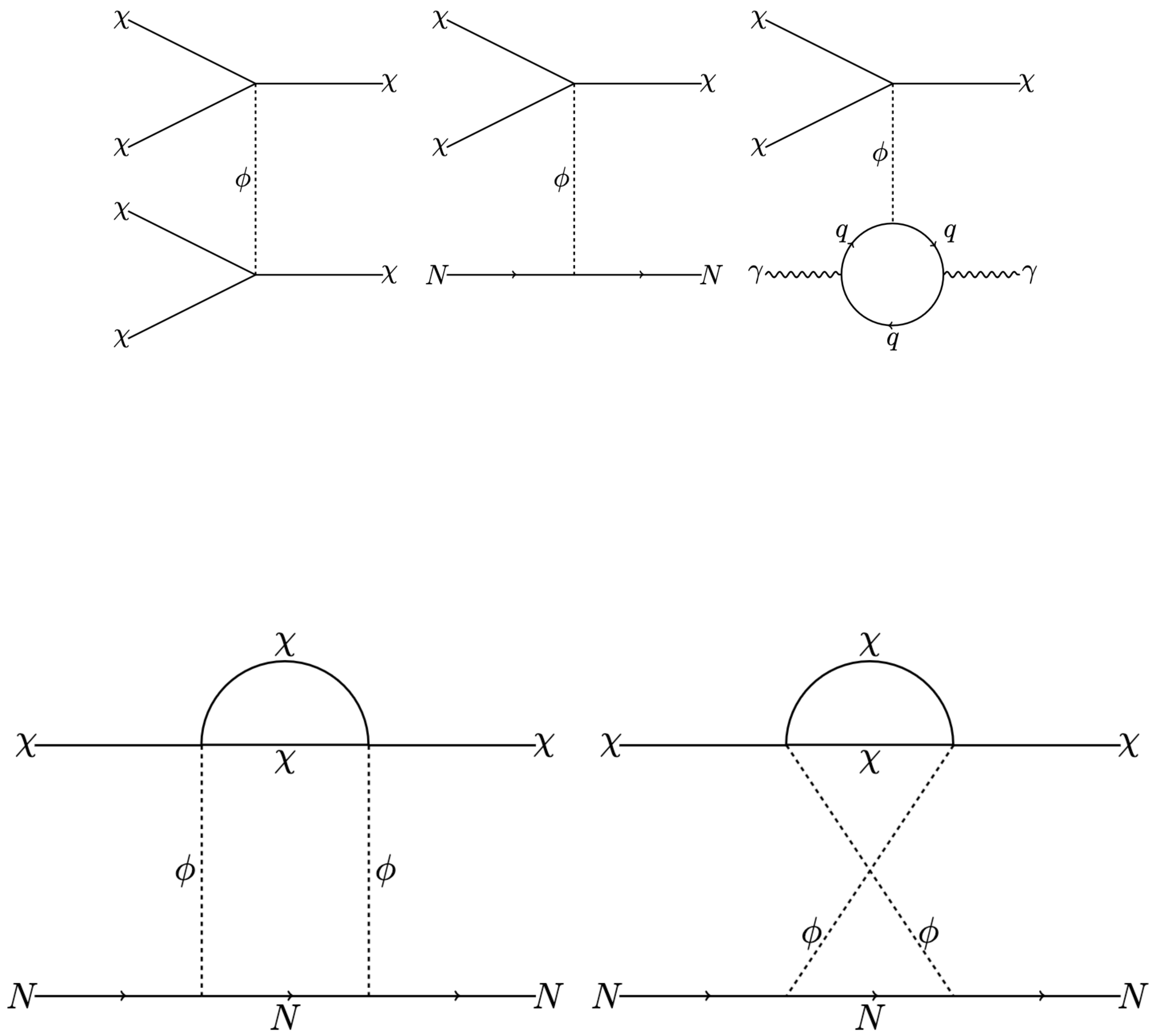


Smirnov, Beacom

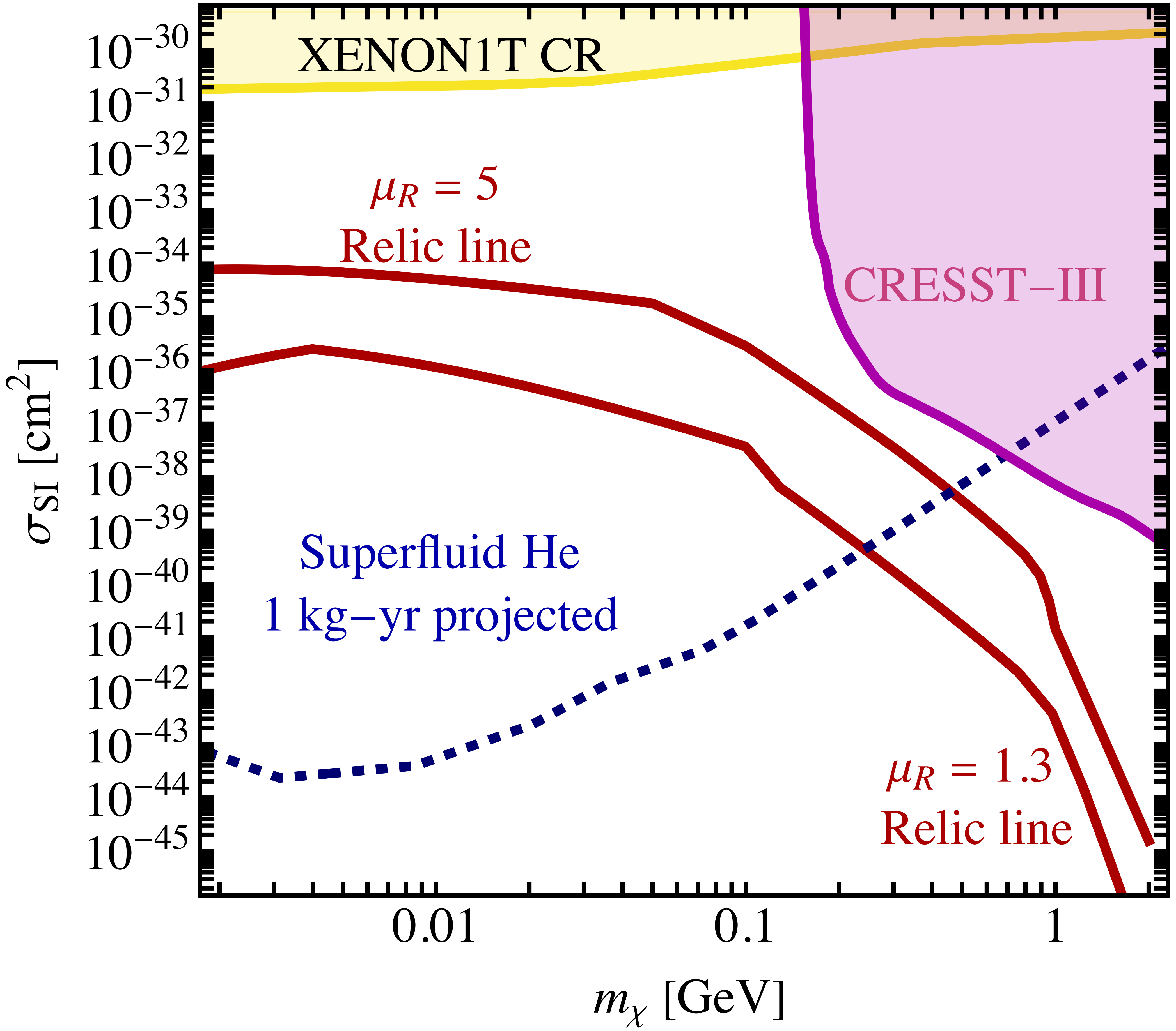
$$\Gamma_{\rm DM} = \langle \sigma_{3\to 2} v_{\rm rel.}^2 \rangle \, n_{\rm DM} n_{\rm SM} > H(T)$$

$$\Omega_{\rm DM} h^2 \approx \left(\frac{\rm MeV}{m_{DM}} \right)^3 \frac{0.12}{\langle \sigma_{3\to 2} v_{\rm rel.}^2 \rangle [100 \, {\rm MeV}]^5}$$

Co-SIMP Scattering off Nucleons



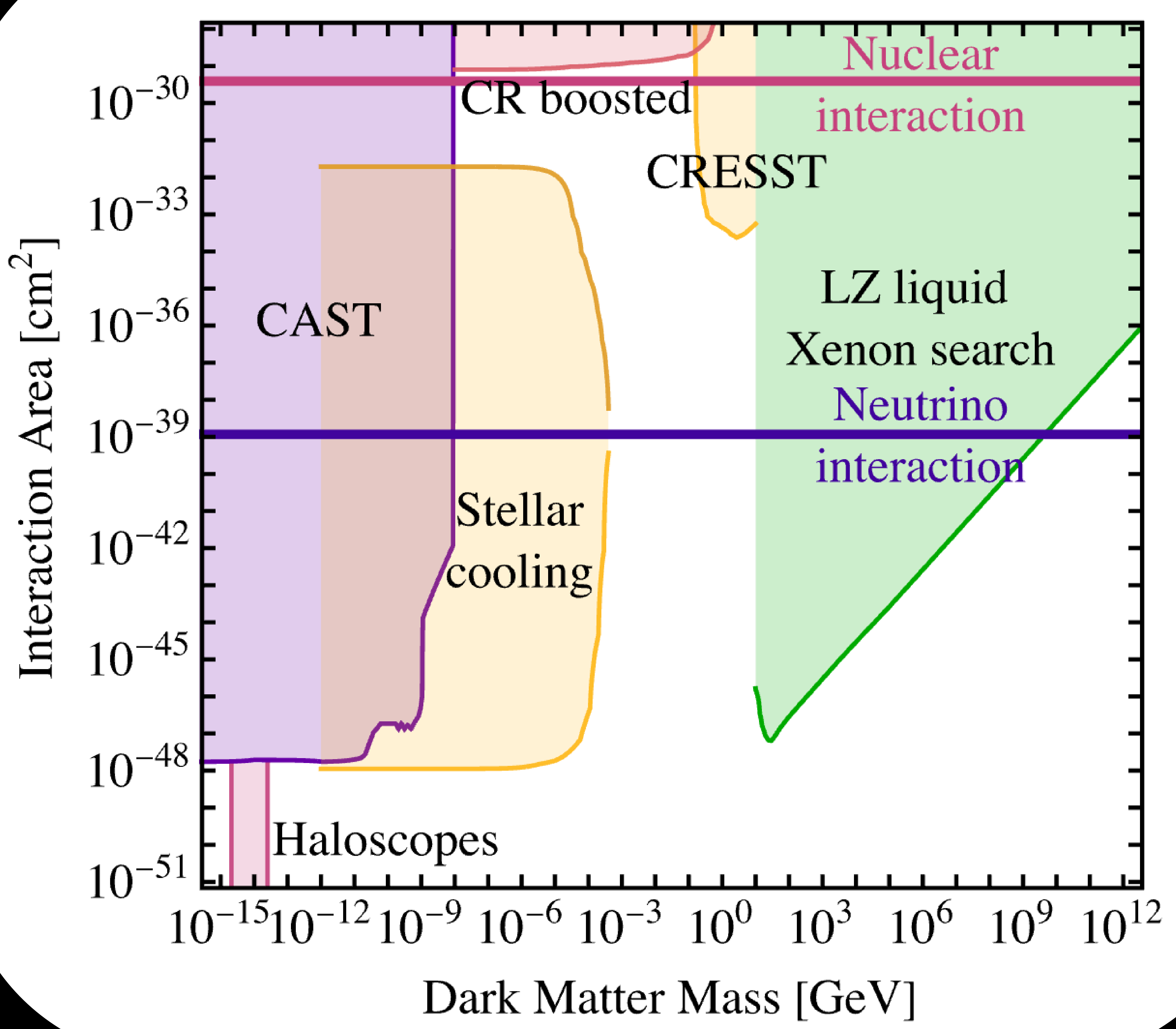
DD cross section expectation nucleons

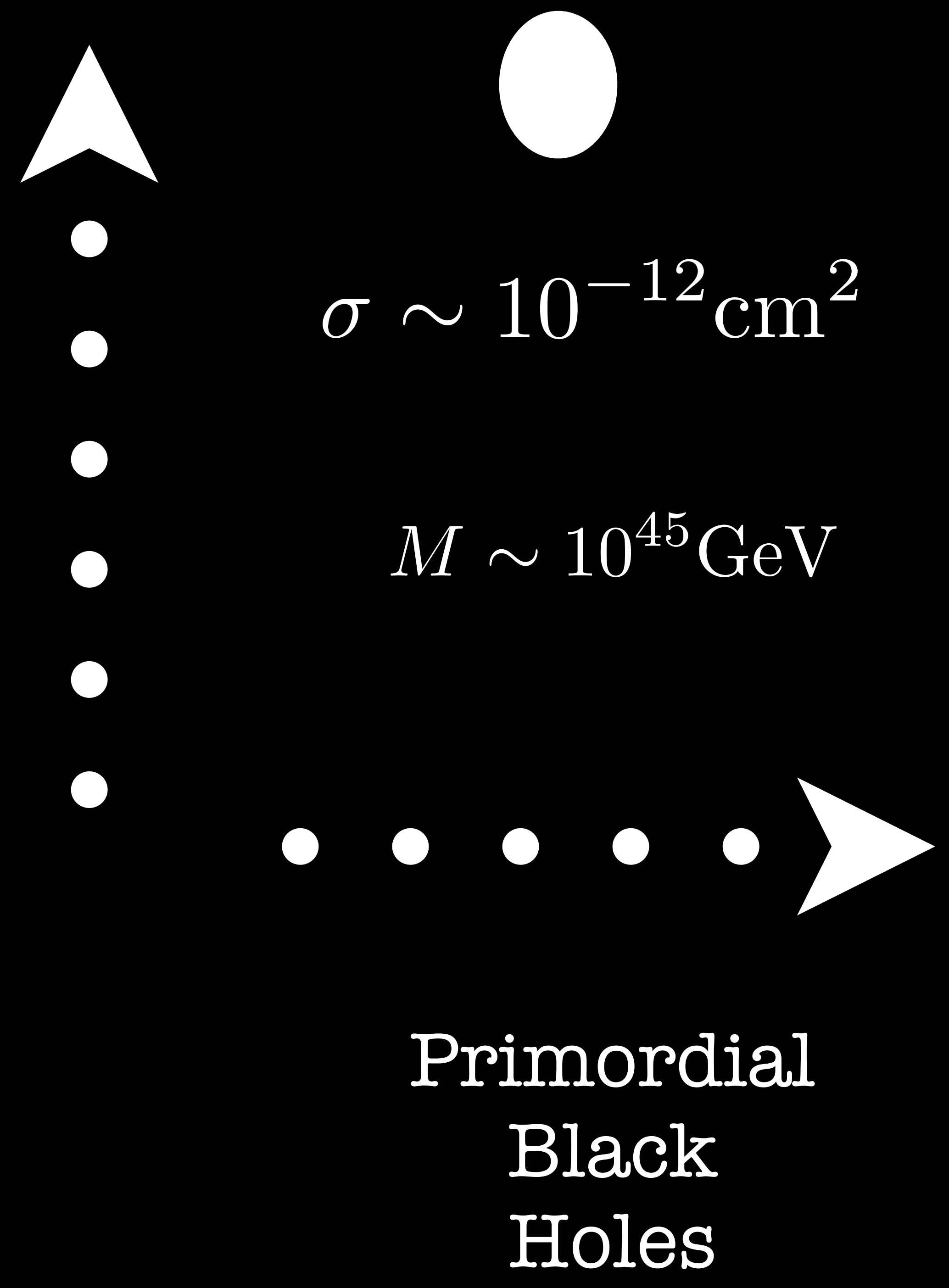


arXiv: 2302.00008; Parikh, Smirnov, Xu, Zhou

Cartoon of Interaction Space

+ SIMPs
+ CoSIMPs
+ DM from PTs
+ Inflation
+ ...





Cartoon of Interaction Space

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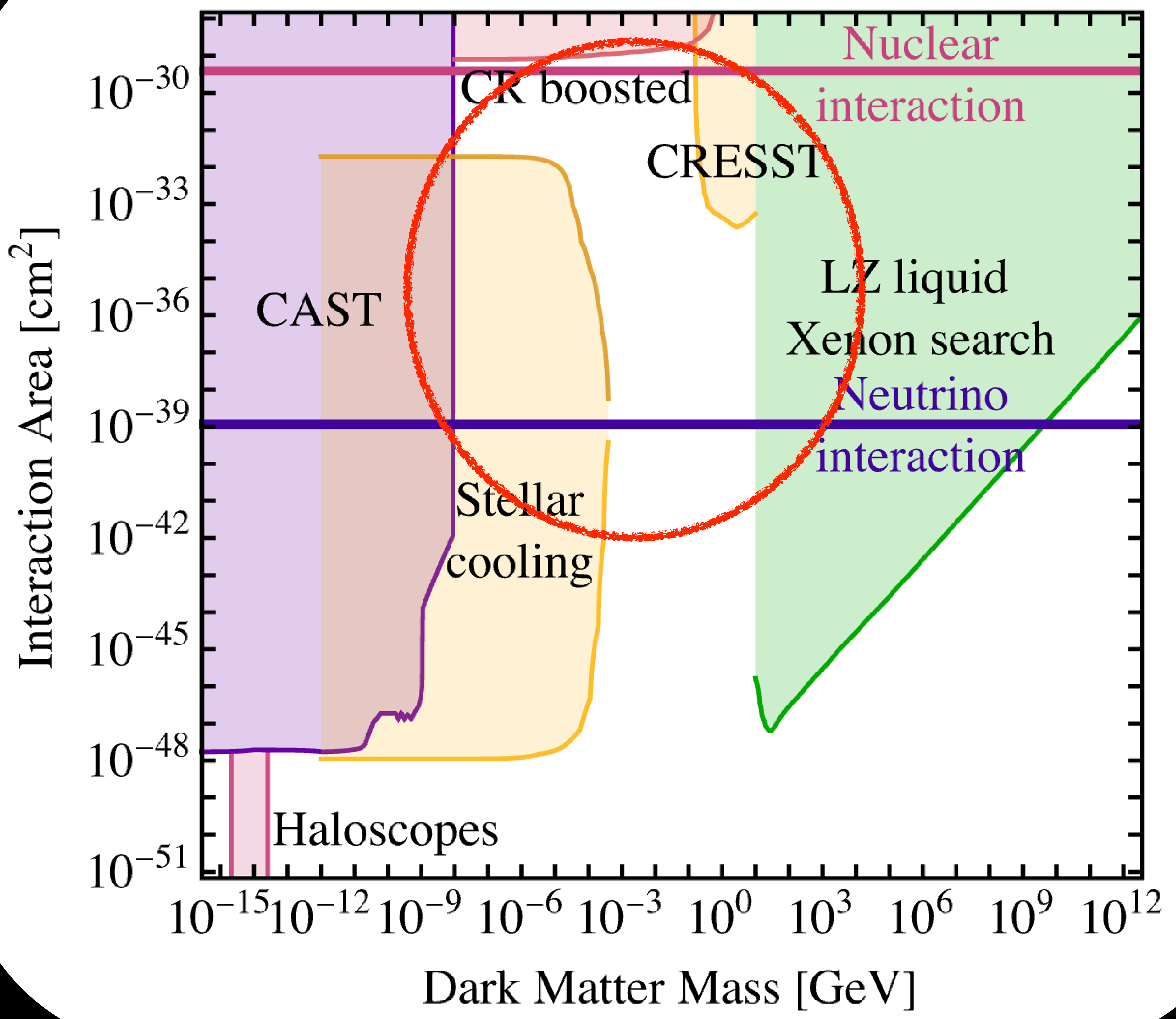


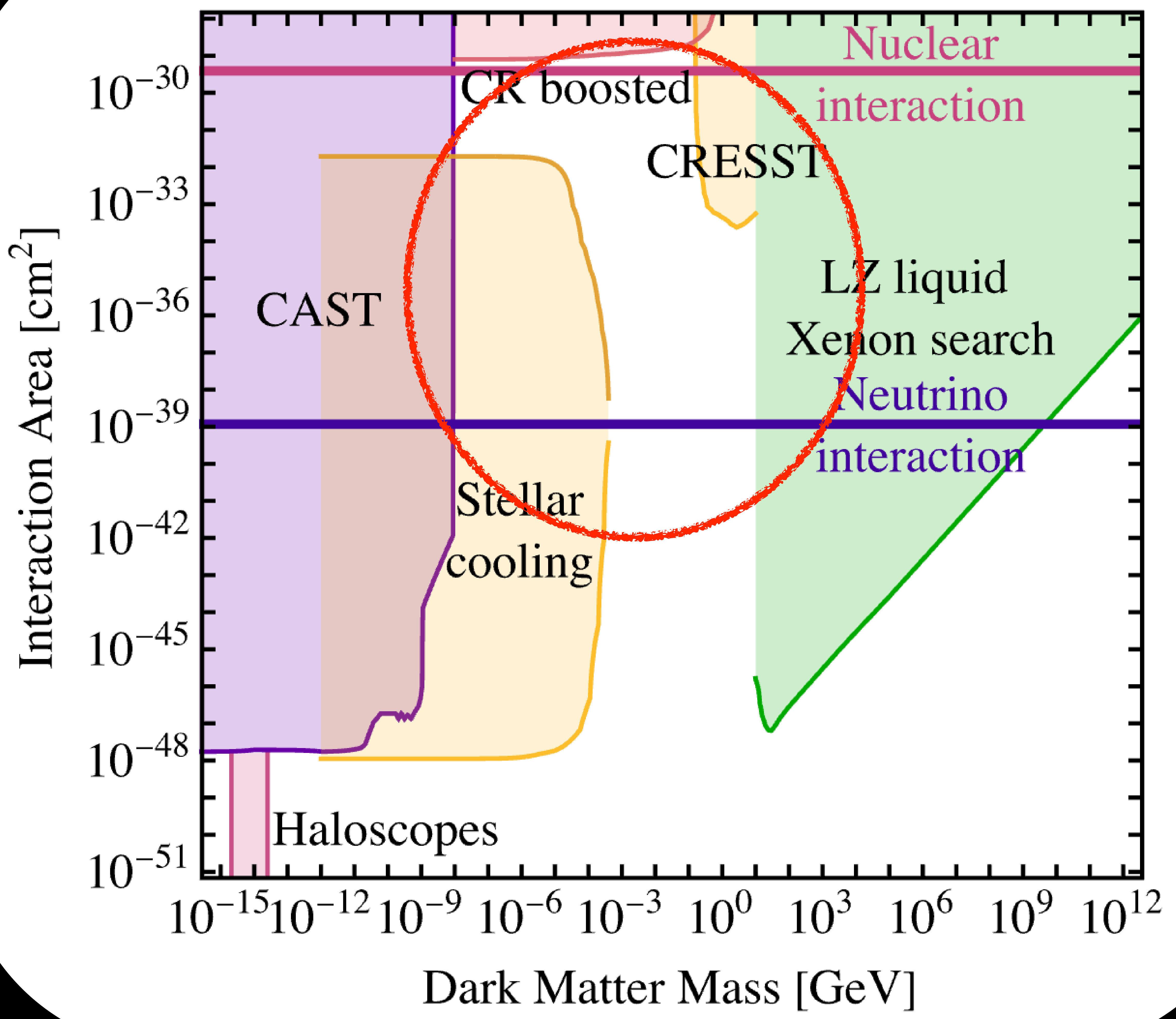
$\sigma \sim 10^{-12}\text{cm}^2$

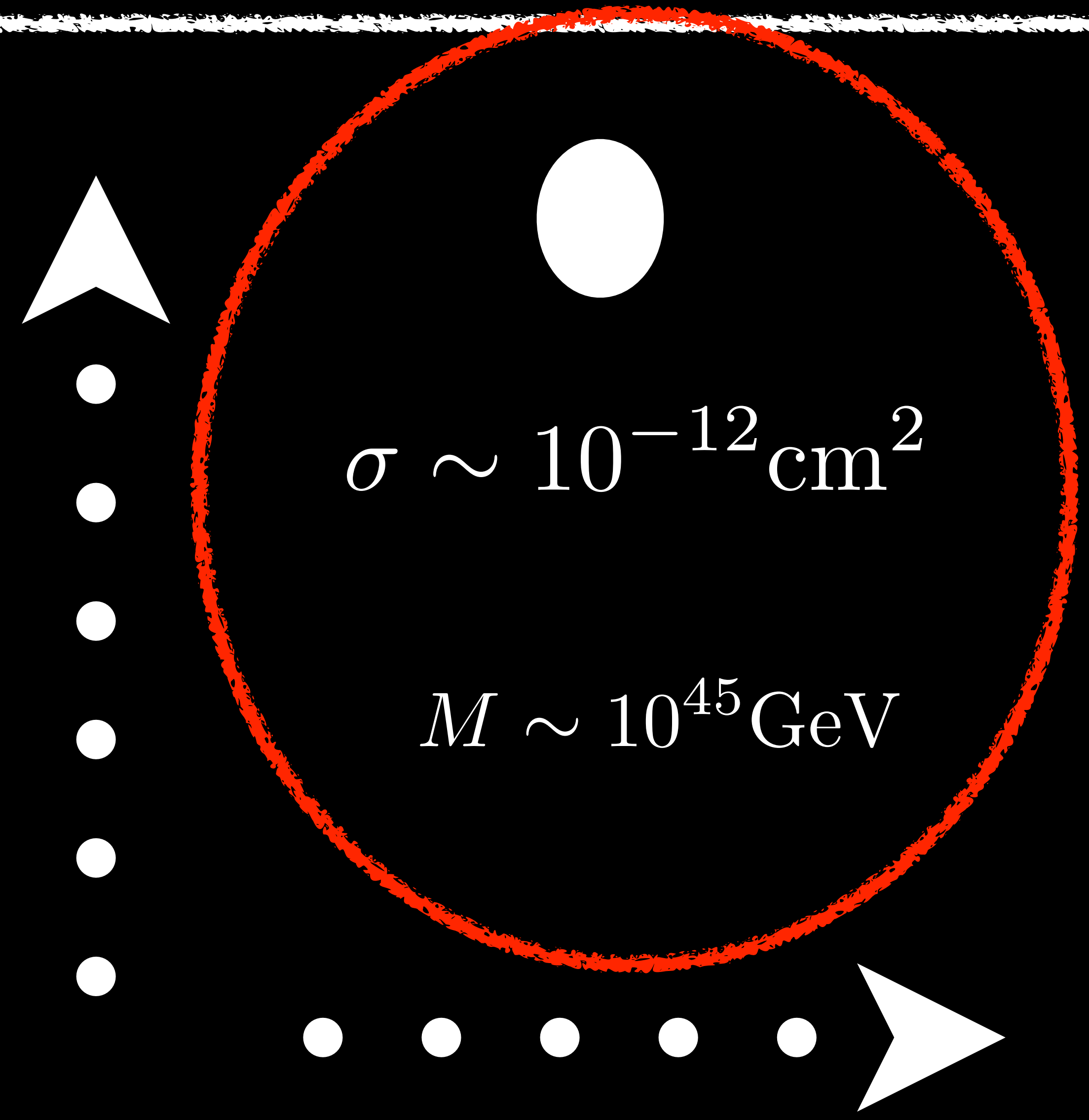
$M \sim 10^{45}\text{GeV}$

Primordial Black Holes

Cartoon of Interaction Space

+ SIMPs
+ CoSIMPs
+ DM from PTs
+ Inflation
+ ...





Primordial Black Holes

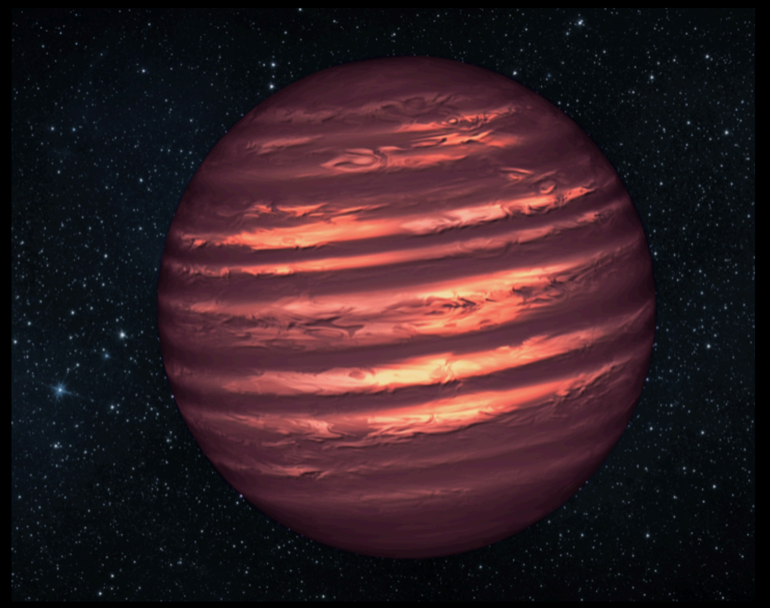
Old Objects / New Searches

Stuff in Space

Accessibility

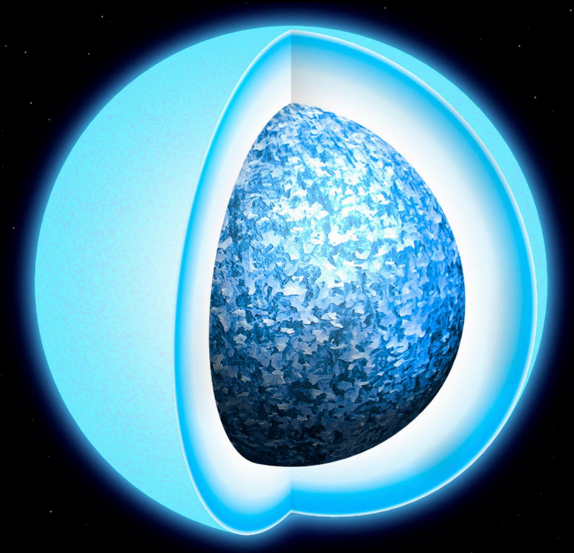
$M \sim 3 \times 10^{-6} M_{\text{Sol}}$

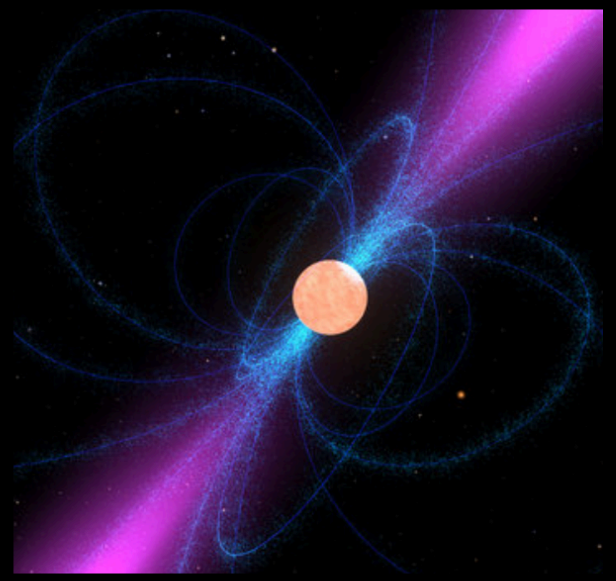
$M \sim 10^{-3} M_{\text{Sol}}$



$M \sim \times 10^{-1} M_{\text{Sol}} - 10^{-2} M_{\text{Sol}}$

$M \sim M_{\text{Sol}}$





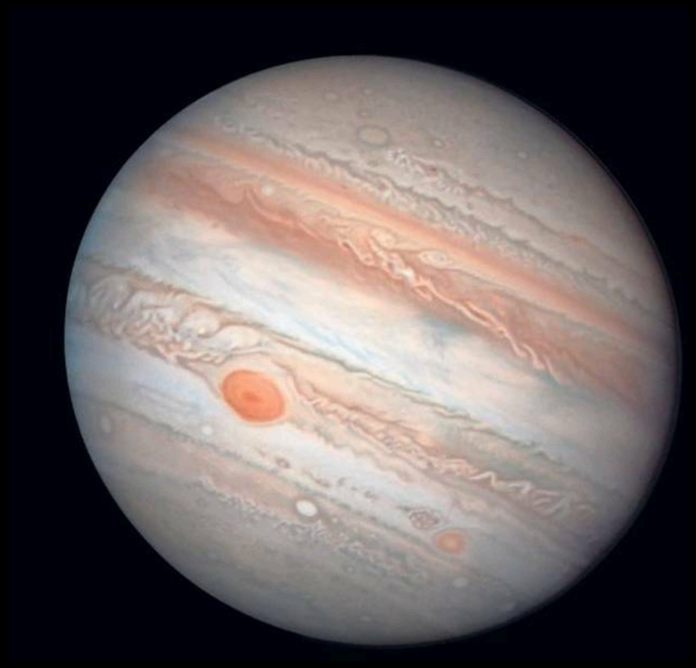
$M \sim 1.4 \times M_{\text{Sol}}$

Efficient Capture

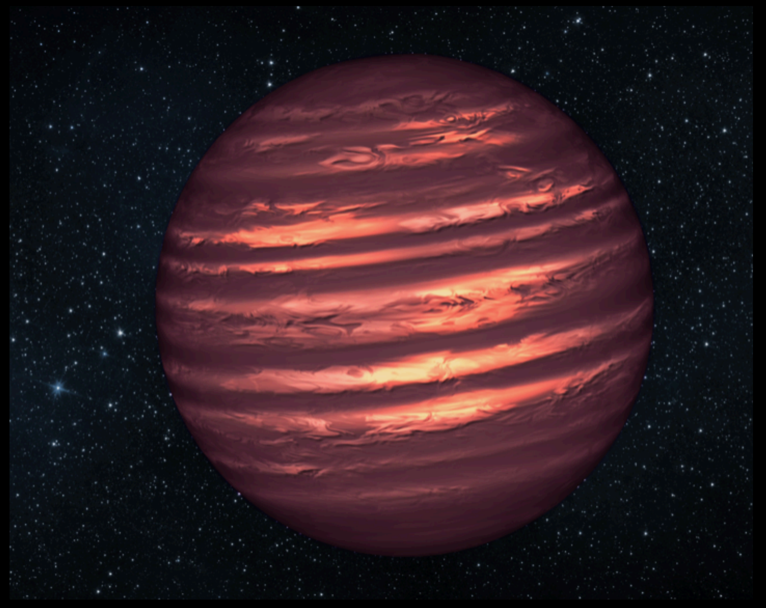
Stuff in Space

Accessibility

$M \sim 3 \times 10^{-6} M_{\text{Sol}}$



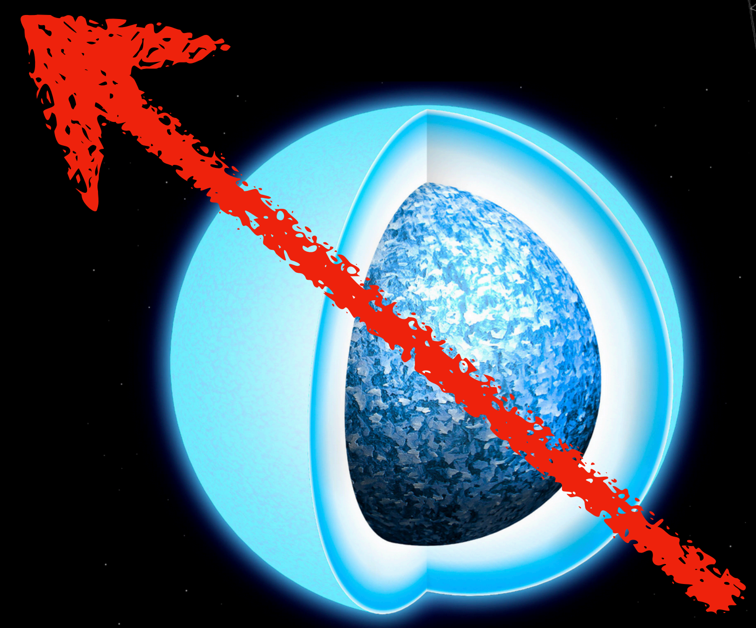
$M \sim 10^{-3} M_{\text{Sol}}$

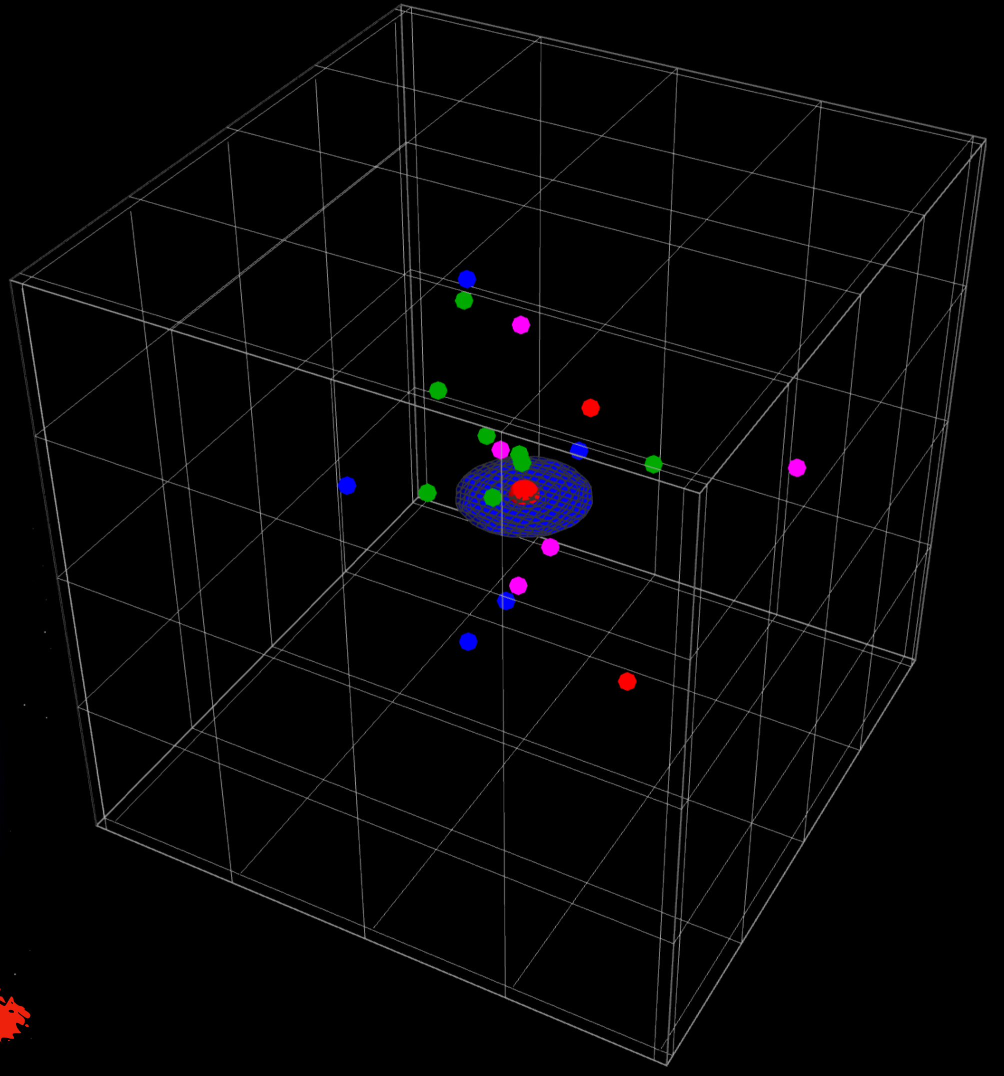


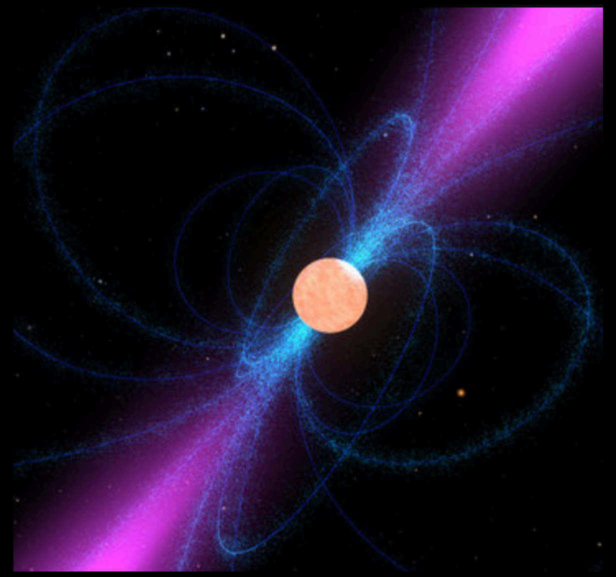
$M \sim \times 10^{-1} M_{\text{Sol}} - 10^{-2} M_{\text{Sol}}$

2211.00013 : **JS,** Goobar, Linden, Mörtsell

$M \sim M_{\text{Sol}}$







$M \sim 1.4 \times M_{\text{Sol}}$

Efficient Capture

Dark Matter Heating

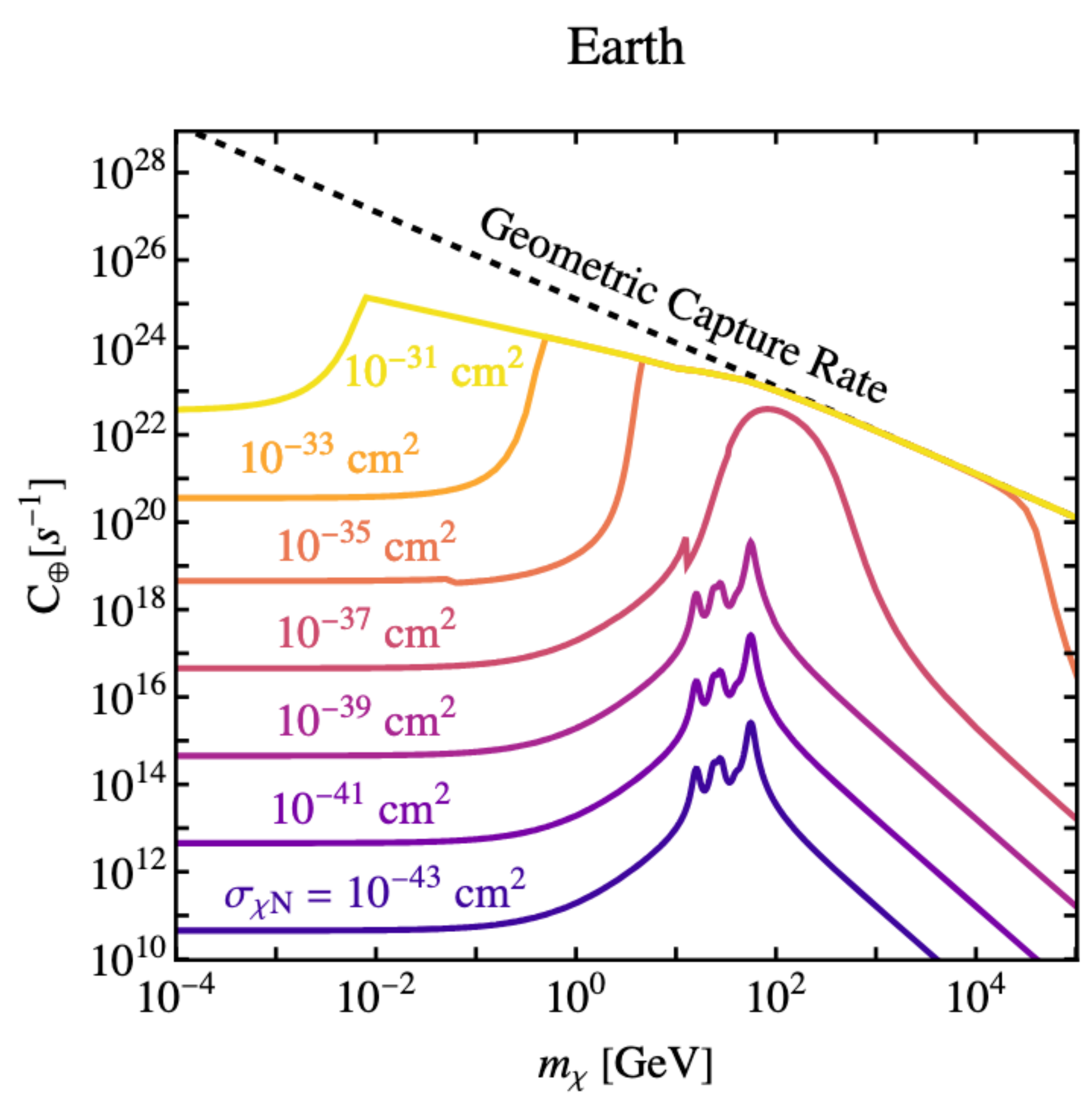
1) Capture Rates

$$C_{\rm cap} \approx v_{\rm DM} \pi R^2 \left(1 + \frac{3}{2}\frac{v_{\rm esc}^2}{v_{\rm DM}^2}\right)$$

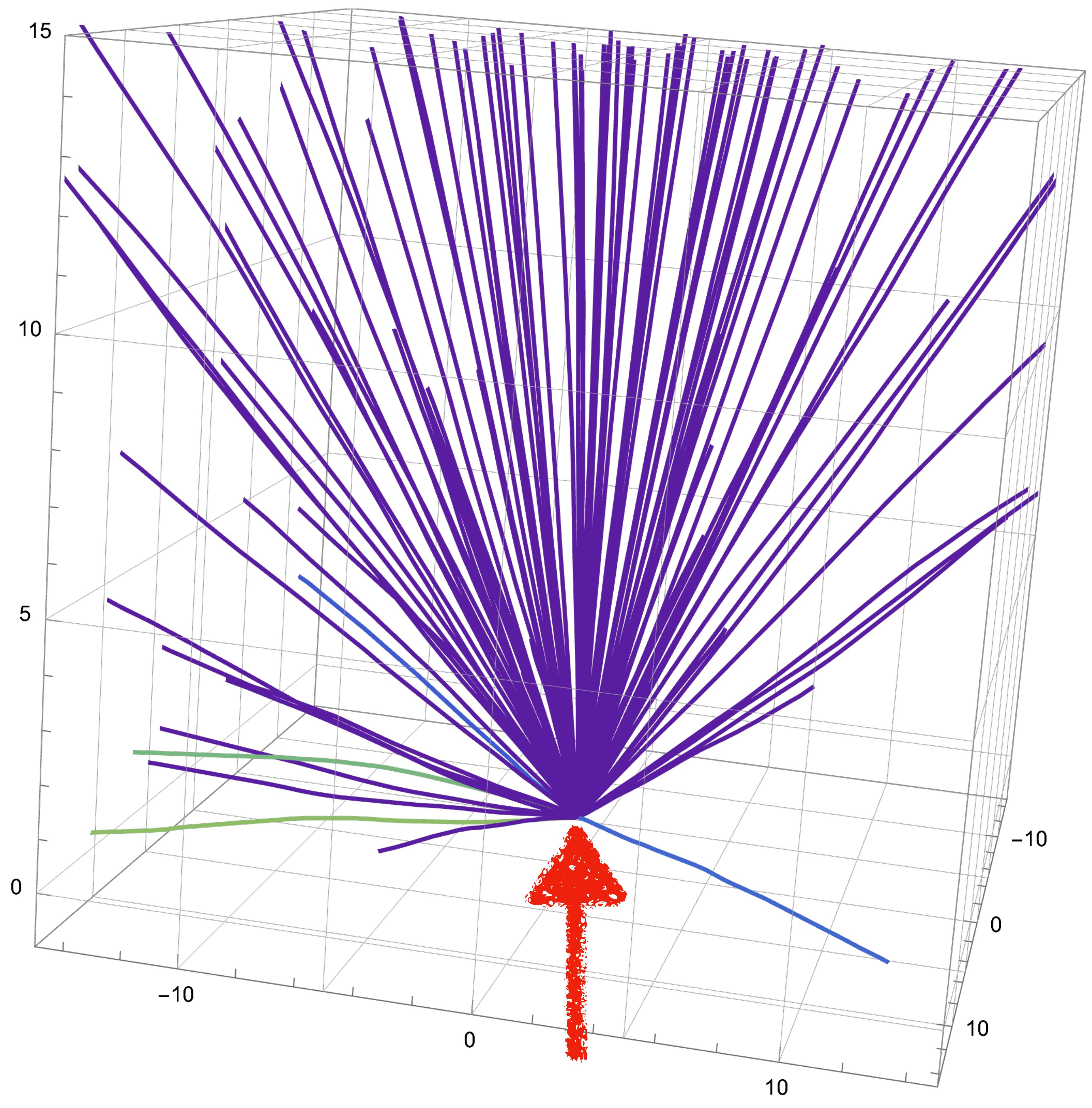
$$\times \sum_{N=1}^{\infty} f_N(\tau) g_N(v_{\rm DM}, v_{\rm esc})$$

$$= \phi_{\rm DM}\, f_{\rm cap}$$

Asteria Package
2309.00669
R. K. Leane, **JS**



Reflection Correction Possible



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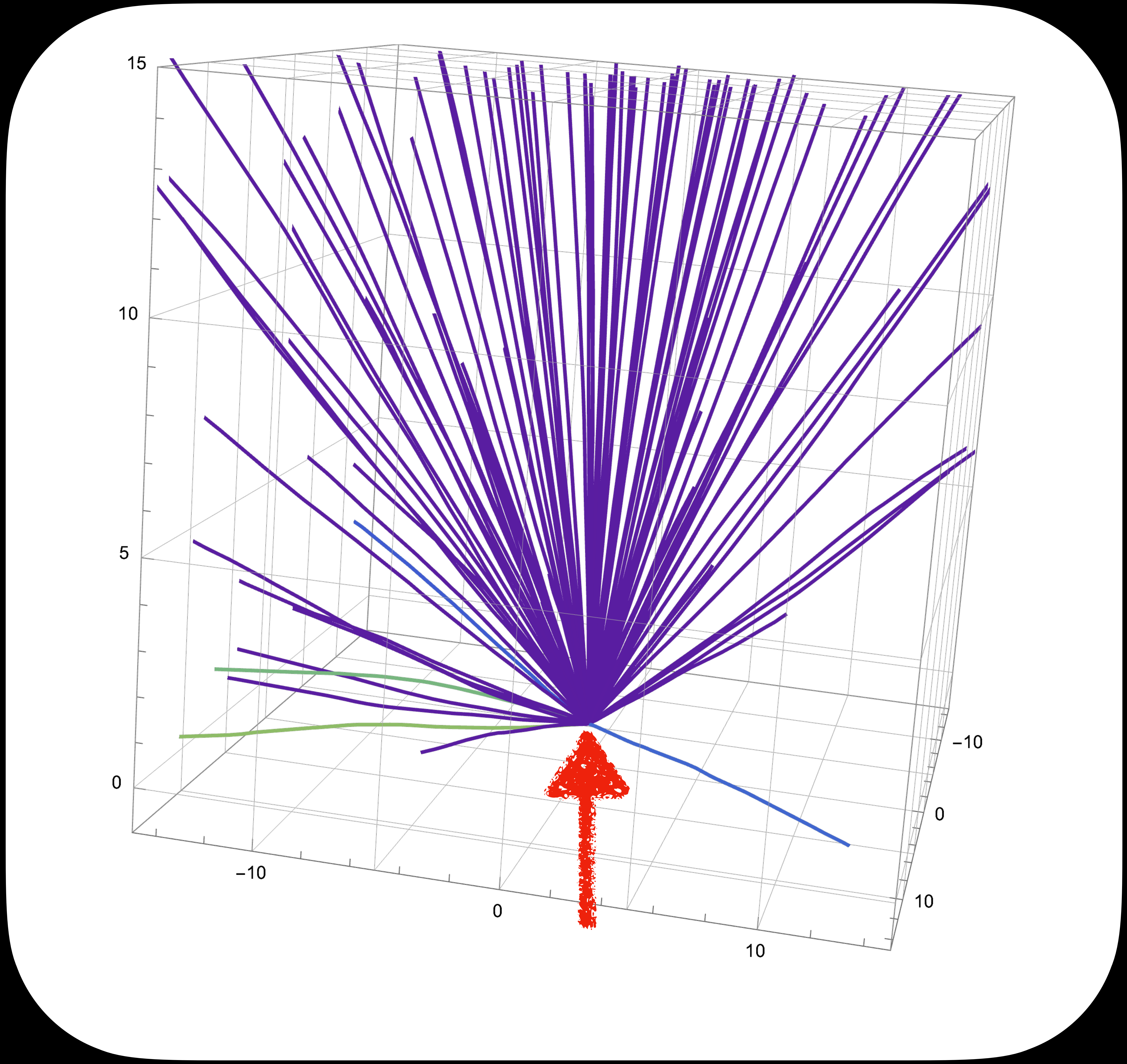
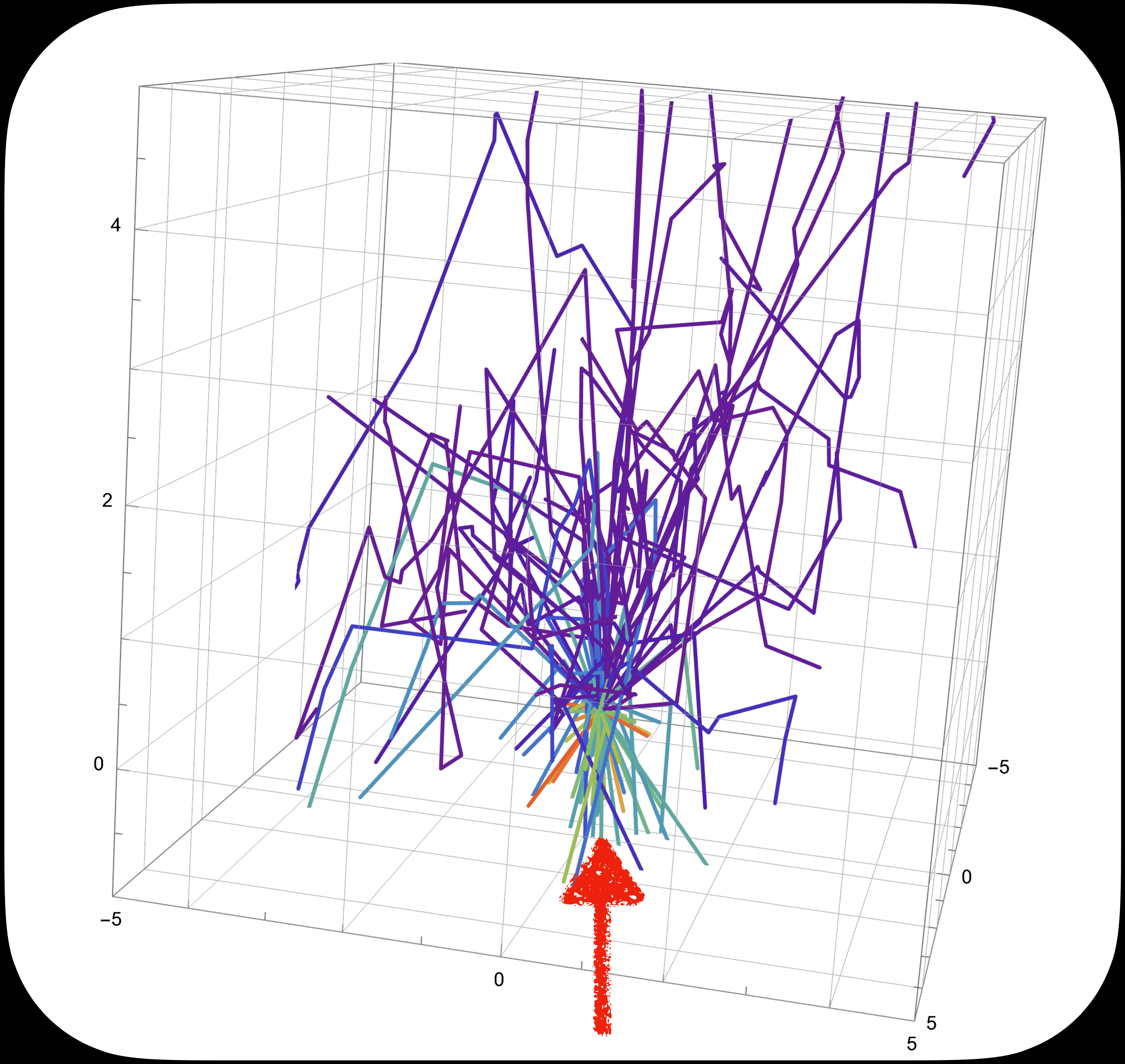




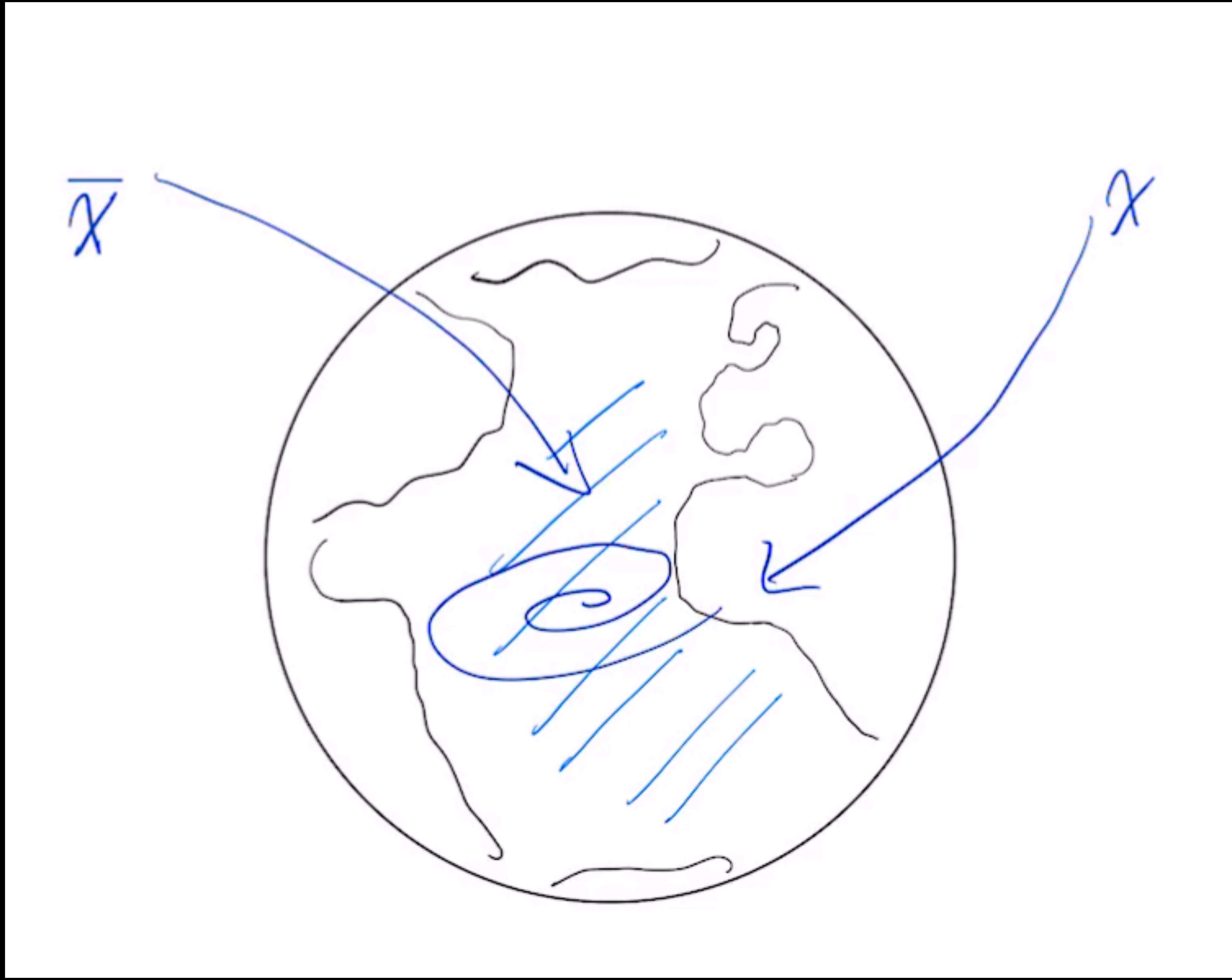
2) Annihilation Equilibrium

$$\langle \sigma_{\rm ann} v_{\rm rel} \rangle \geq \frac{V_{\rm eff}^{2\to 2}}{C_{\rm cap}\tau^2}$$

$$\langle \sigma_{3\to 2} v_{\rm rel}^2 \rangle \geq \frac{V_{\rm eff}^{2\to 2}}{n_{\rm SM} C_{\rm cap}\tau^2}$$

Co-SIMP process

Phys.Rev.Lett. 125 (2020) 13; **JS**, J. Beacom (OSU)



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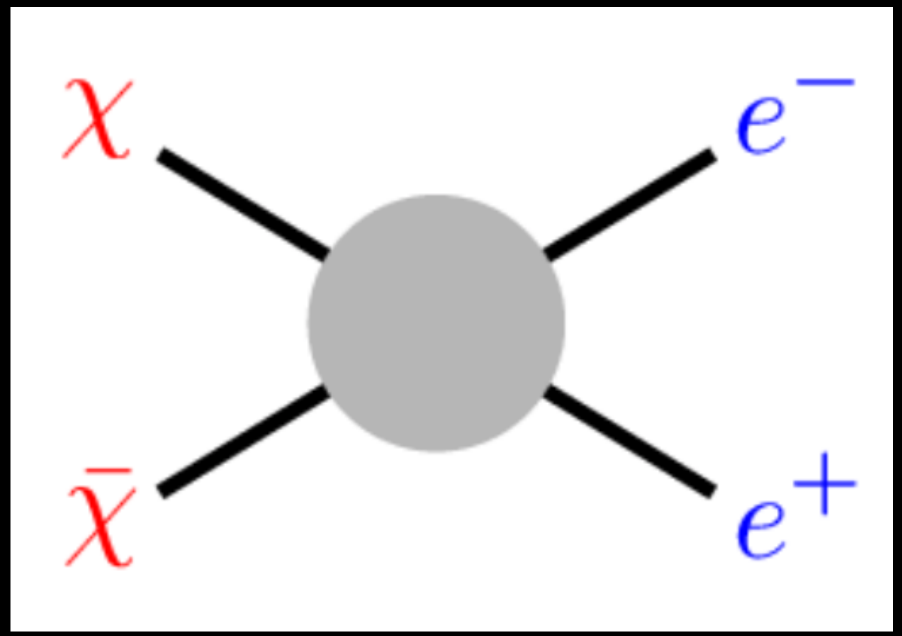

$$\geq \frac{V_{\rm eff}^{2\to 2}}{C_{\rm cap}\tau^2}$$

$$\langle \sigma_{3\to 2} v_{\rm rel}^2 \rangle \geq \frac{V_{\rm eff}^{2\to 2}}{n_{\rm SM} C_{\rm cap}\tau^2}$$

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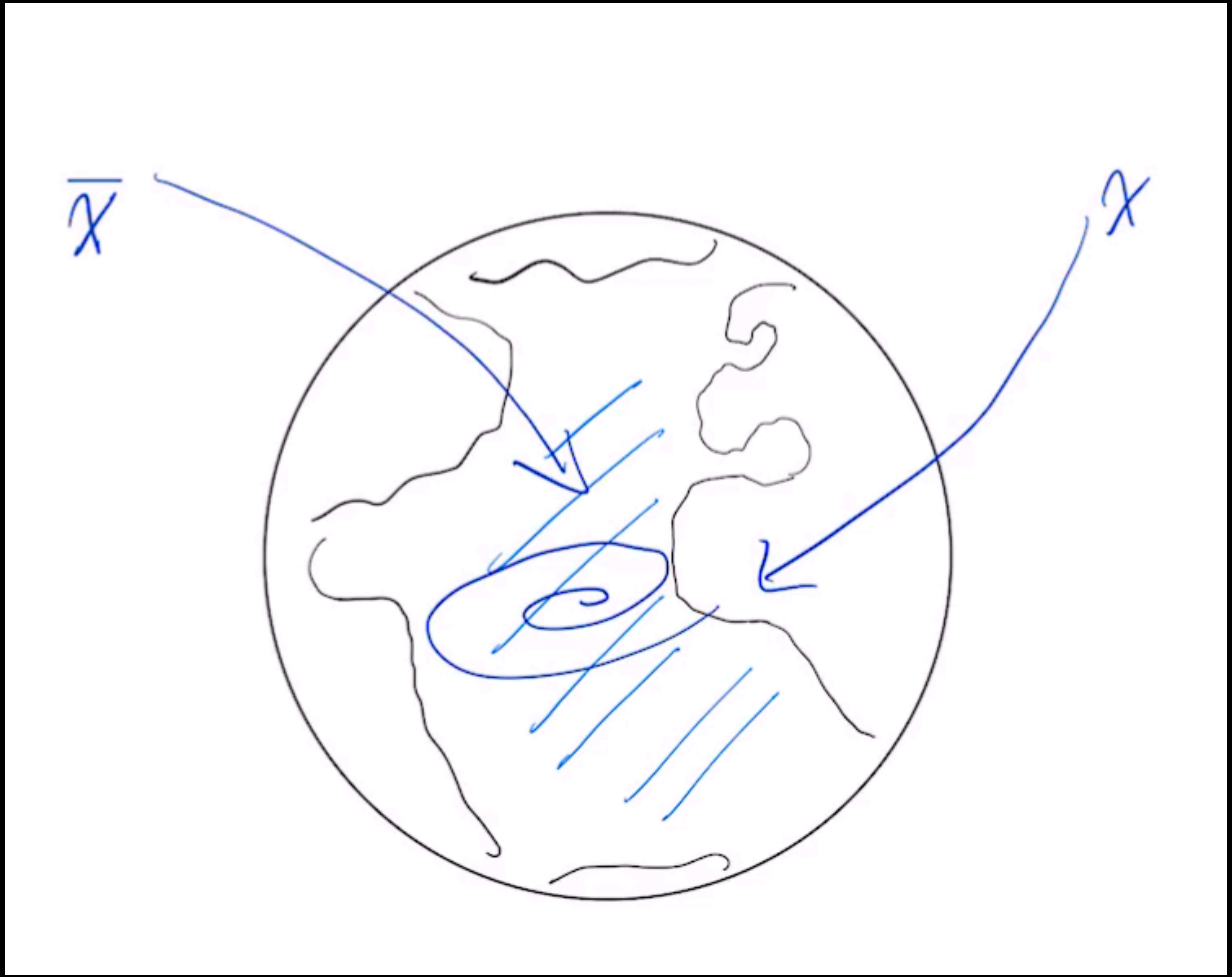

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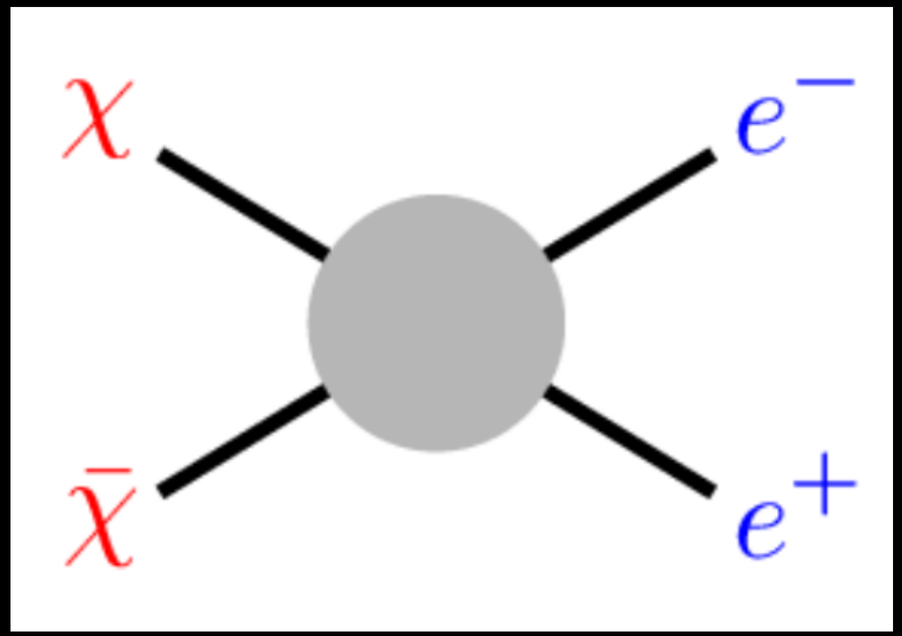

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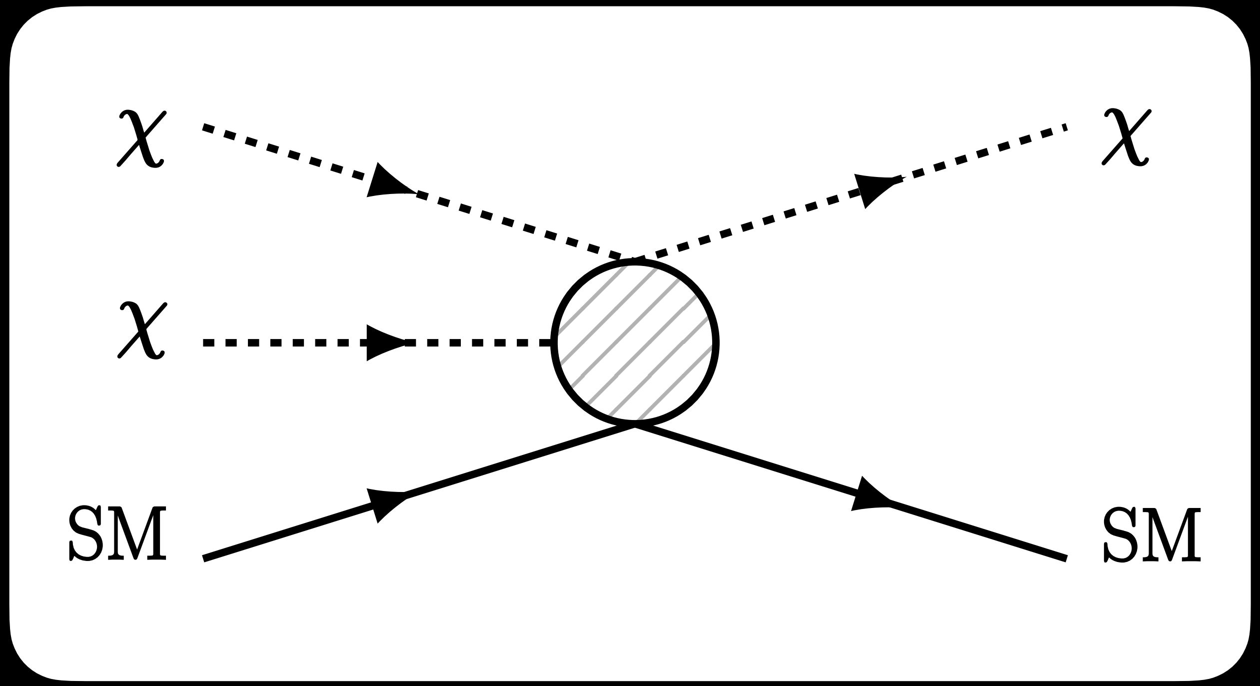

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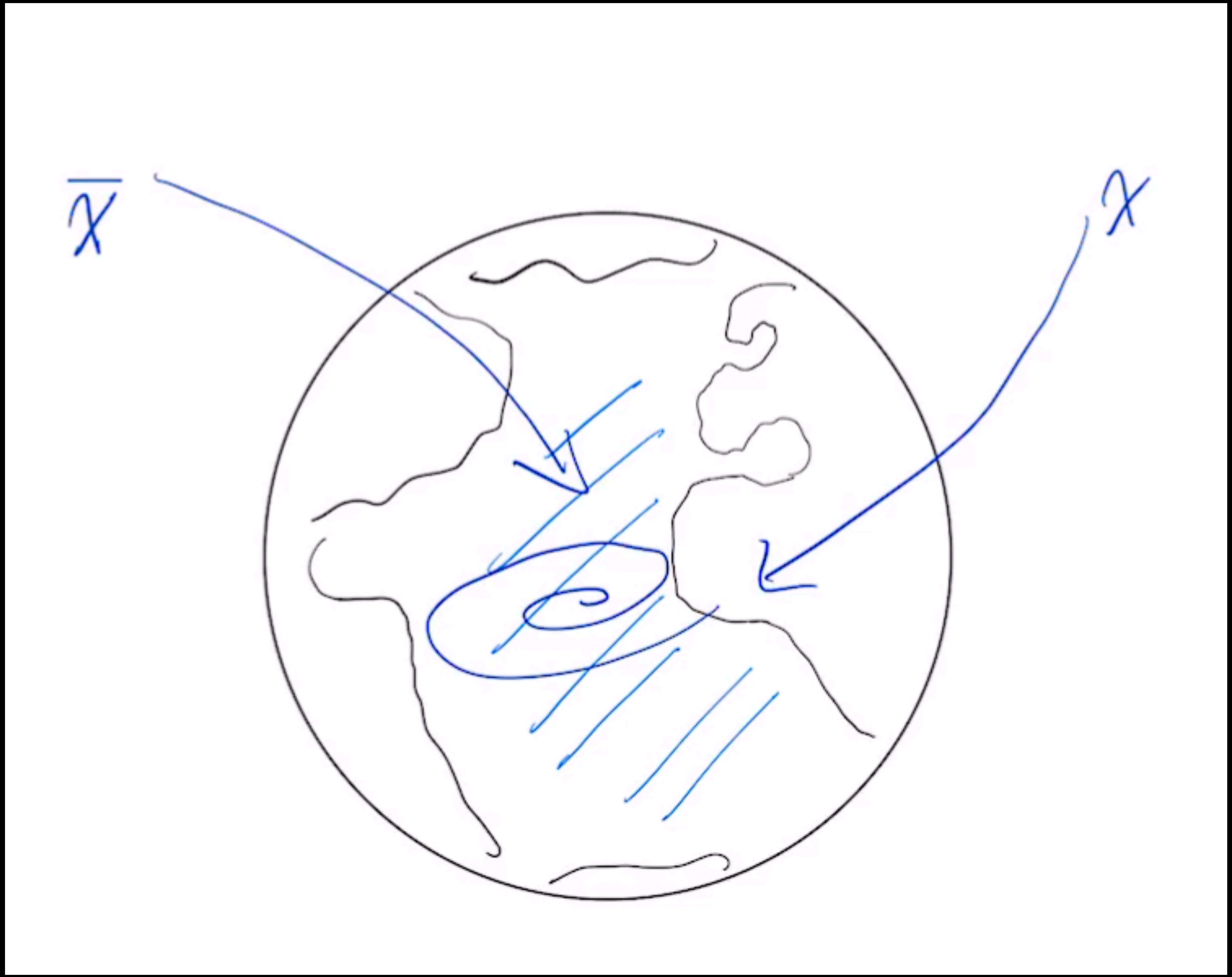
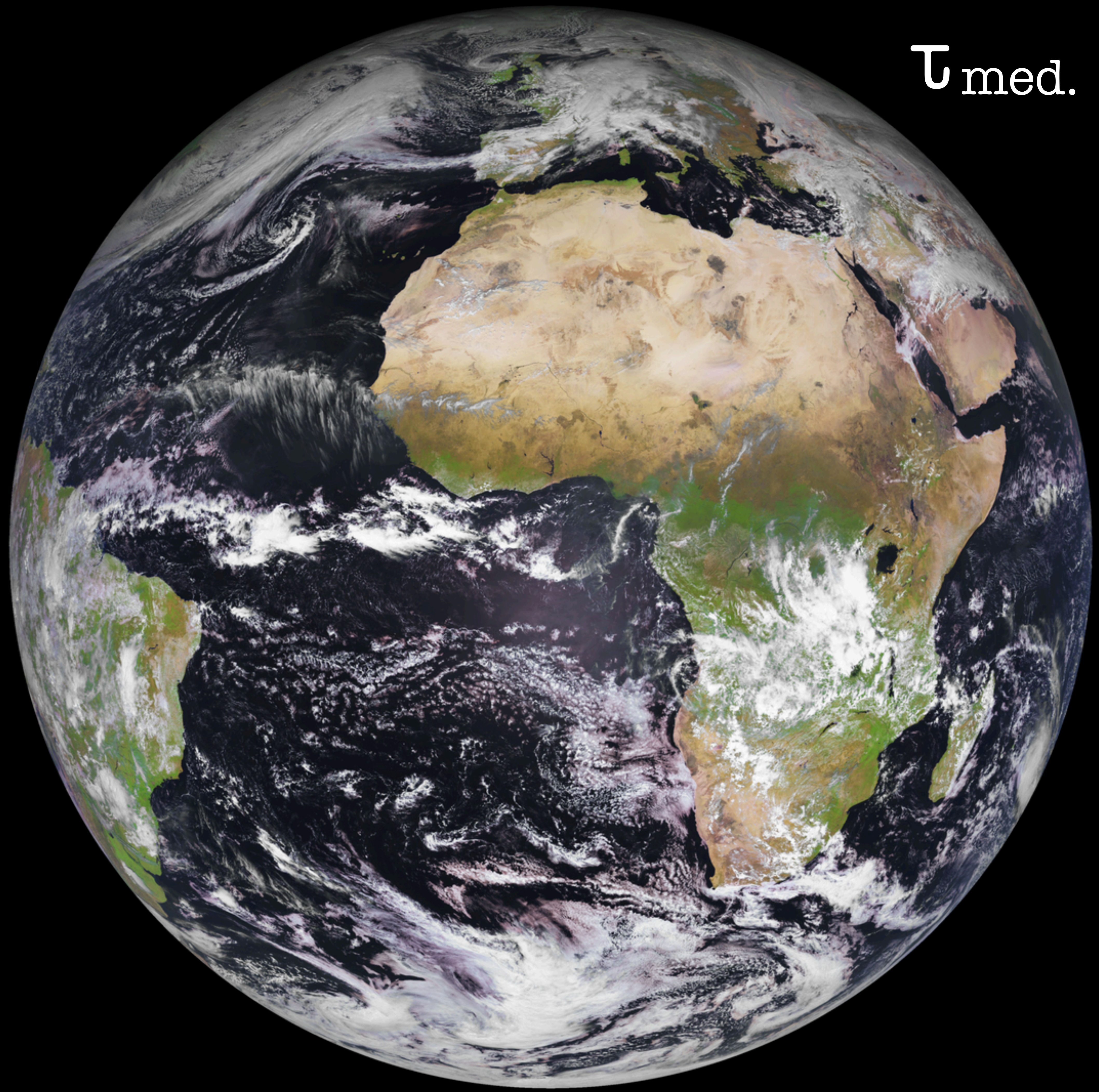


Limits from the Earth Heat Flow



$\tau_{\text{med.}} < 0.01$ s

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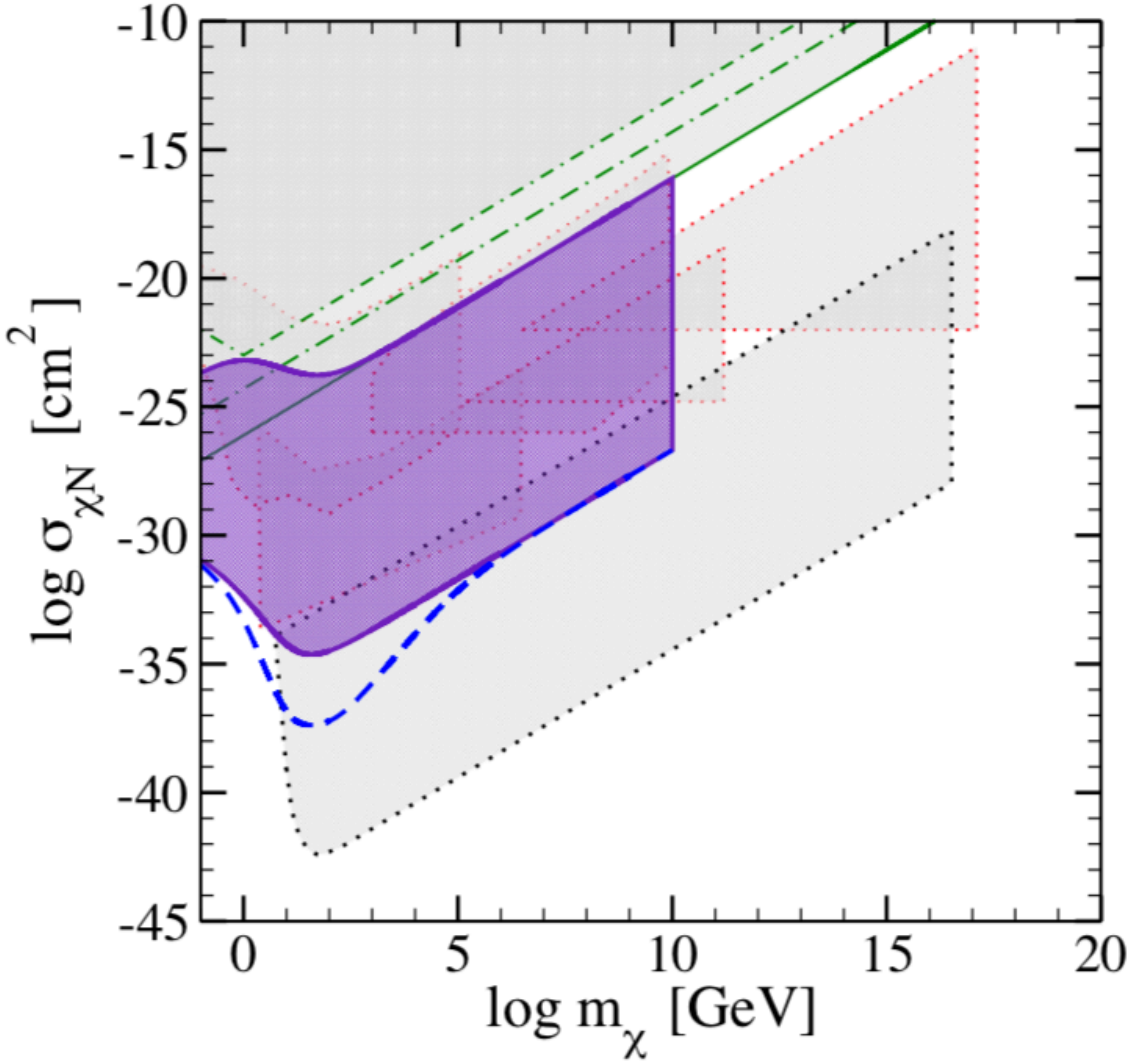
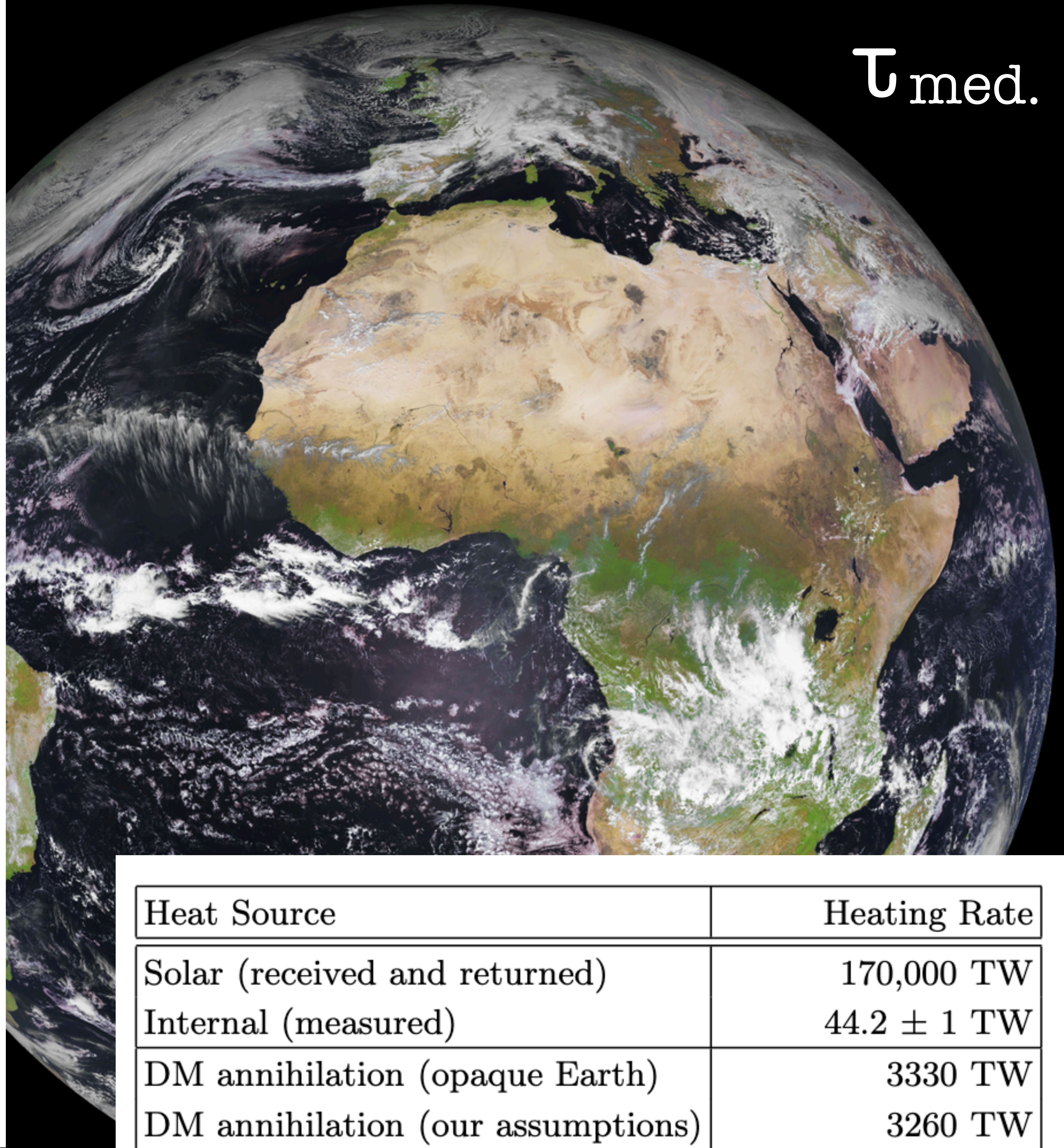


J. Beacom (OSU) et al. 2007



$\tau_{med.} < 0.01$ s

Heat Source	Heating Rate
Solar (received and returned)	170,000 TW
Internal (measured)	44.2 ± 1 TW
DM annihilation (opaque Earth)	3330 TW
DM annihilation (our assumptions)	3260 TW
DM kinetic heating	$\sim 3000 \times 10^{-6}$ TW

What about Jupiter?

What about Jupiter?

Article | Open Access | Published: 13 September 2018

Less absorbed solar energy and more internal heat for Jupiter

Liming Li, X. Jiang, R. A. West, P. J. Gierasch, S. Perez-Hoyos, A. Sanchez-Lavega, L. N. Fletcher, J. J. Fortney, B. Knowles, C. C. Porco, K. H. Baines, P. M. Fry, A. Mallama, R. K. Achterberg, A. A. Simon, C. A. Nixon, G. S. Orton, U. A. Dyudina, S. P. Ewald & R. W. Schmude Jr.

Previous: $F = 5.4 \pm 0.4 \text{ Watt}/m^2$

New: $F = 7.5 \pm 0.2 \text{ Watt}/m^2$

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Previous: $F = 5.4 \pm 0.4$ Watt$/m^2$

New: $F = 7.5 \pm 0.2$ Watt$/m^2$

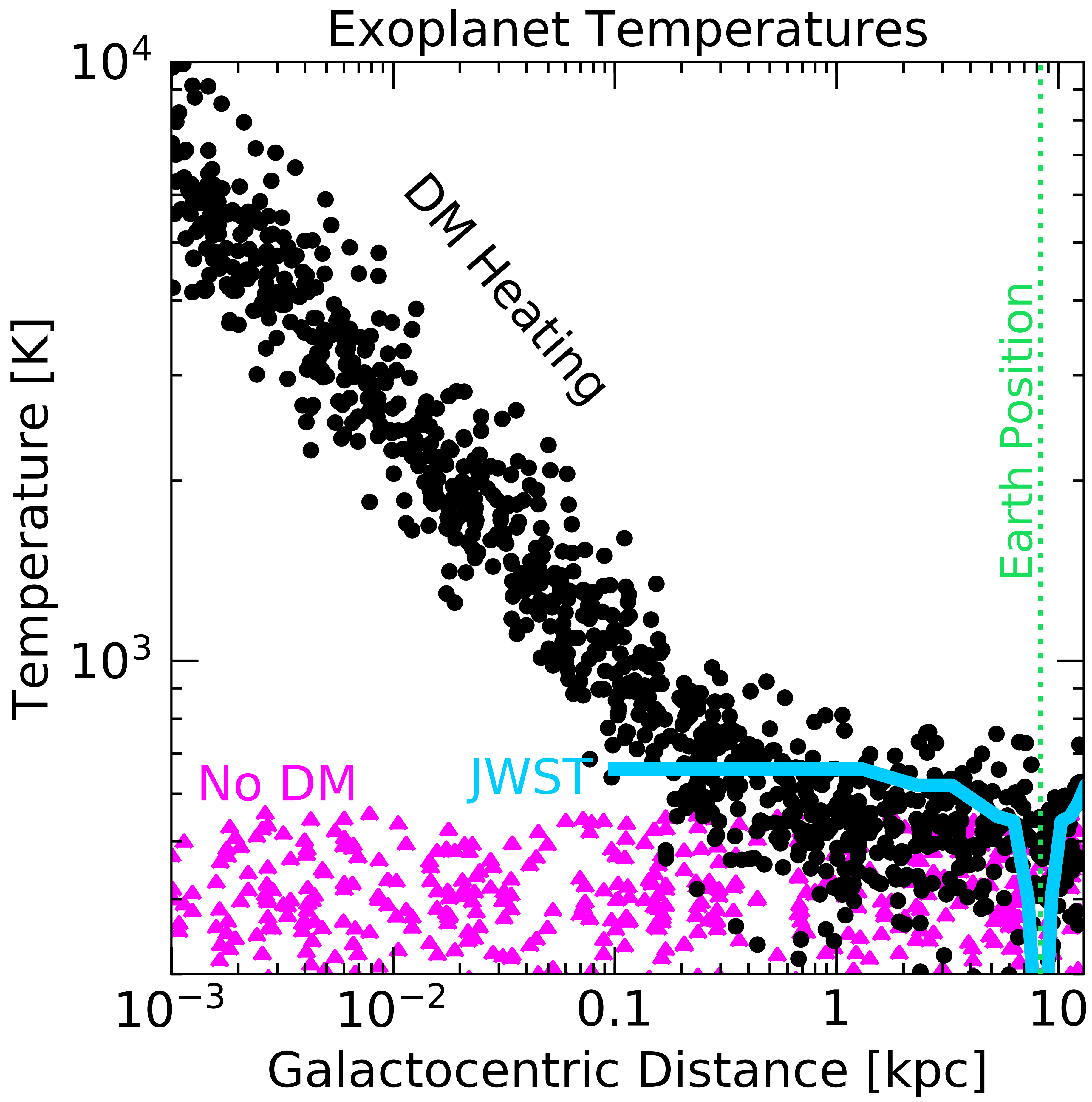
Expected w/o heating: $F \approx 4$ Watt$/m^2$

Expected with heating: $F \approx 8$ Watt$/m^2$

$\Delta F \approx 1 - 1.5$ Watt$/m^2$

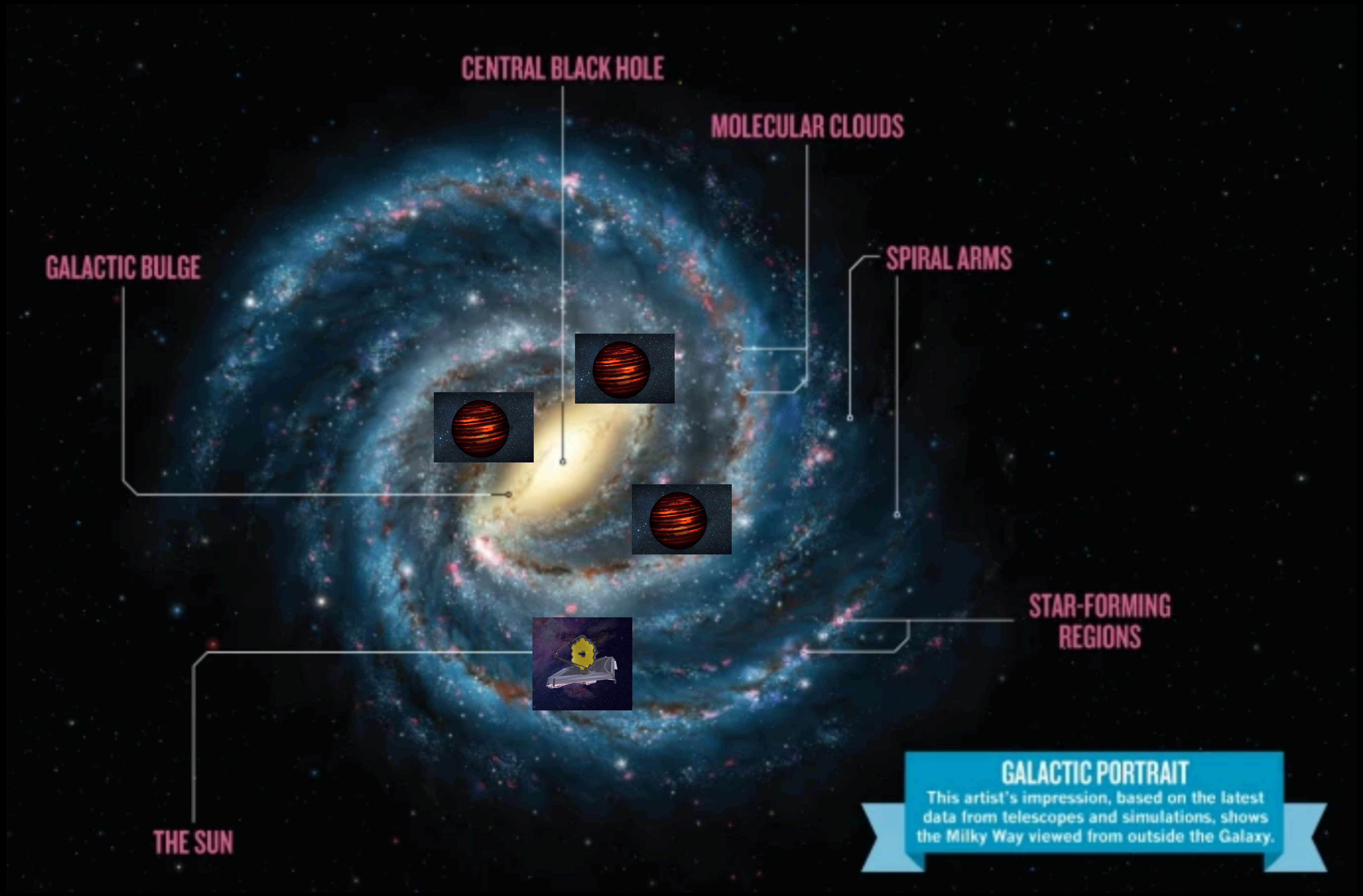
Go to Large Numbers

A Position Dependent Signal



arXiv: 2010.00015; R. K. Leane, **JS**

Modeling Our Galaxy



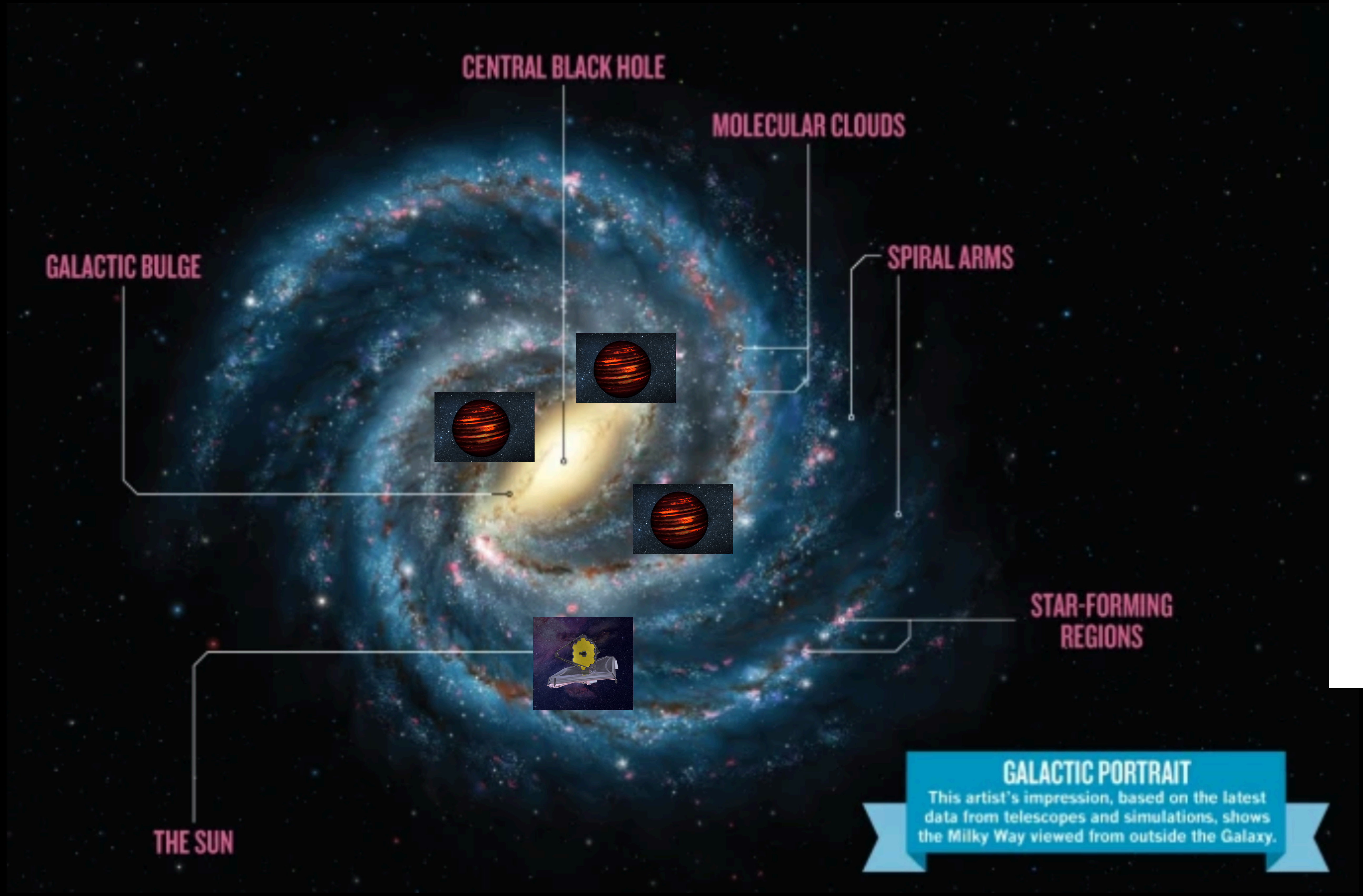
- Old population in the Bulge: t > few Gyr
- E2 Bulge Profile (astro-ph/9605162)
- Power law Mass function

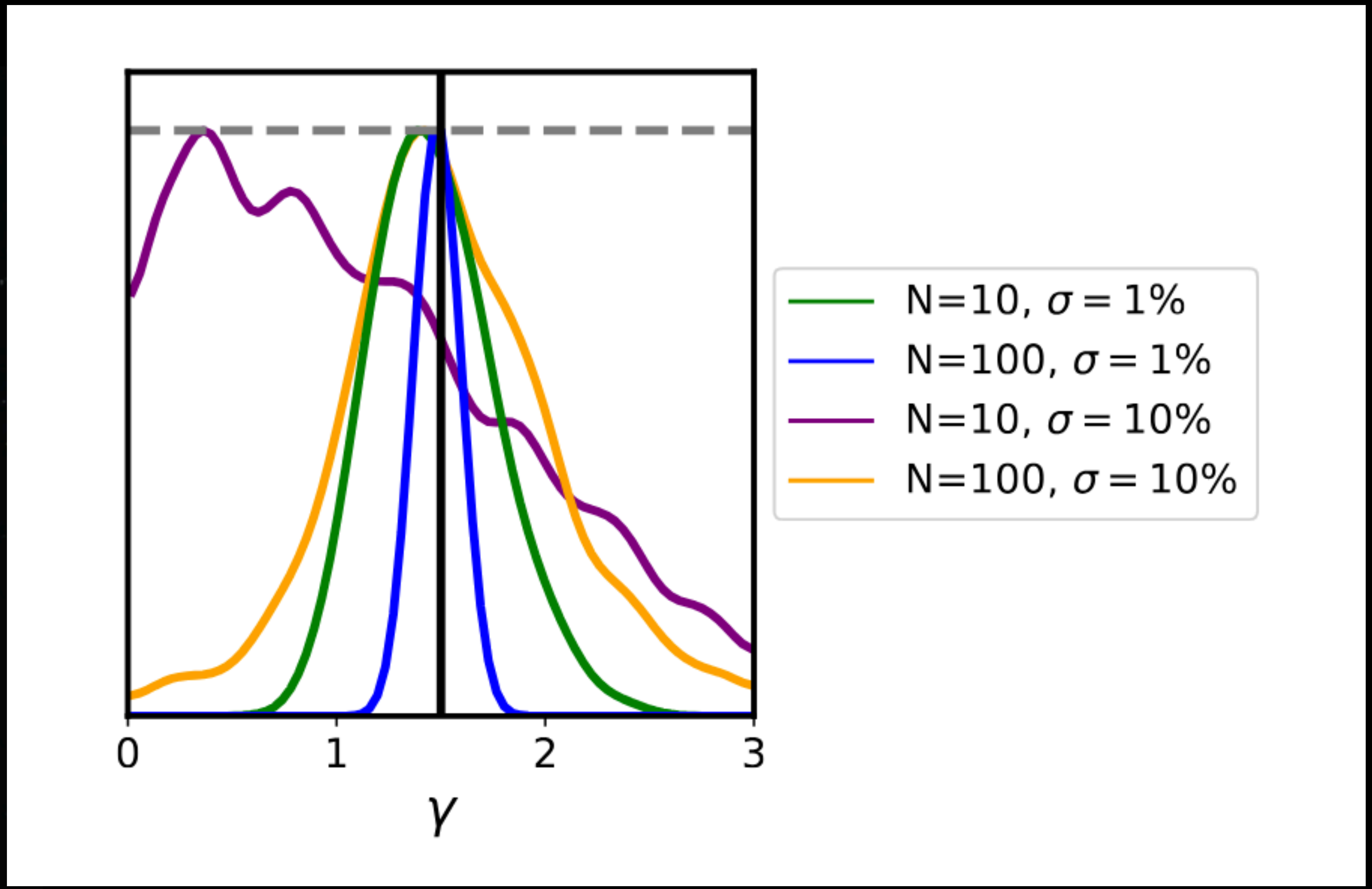
$$\frac{dN_{\rm BD}}{dM} = \frac{1}{M^\alpha}$$

$$\alpha \approx 0.6$$

2405.09578: M. Benito, K. Karchev, R. K. Leane, S. Podar, **JS**, R. Trotta

Modeling Our Galaxy





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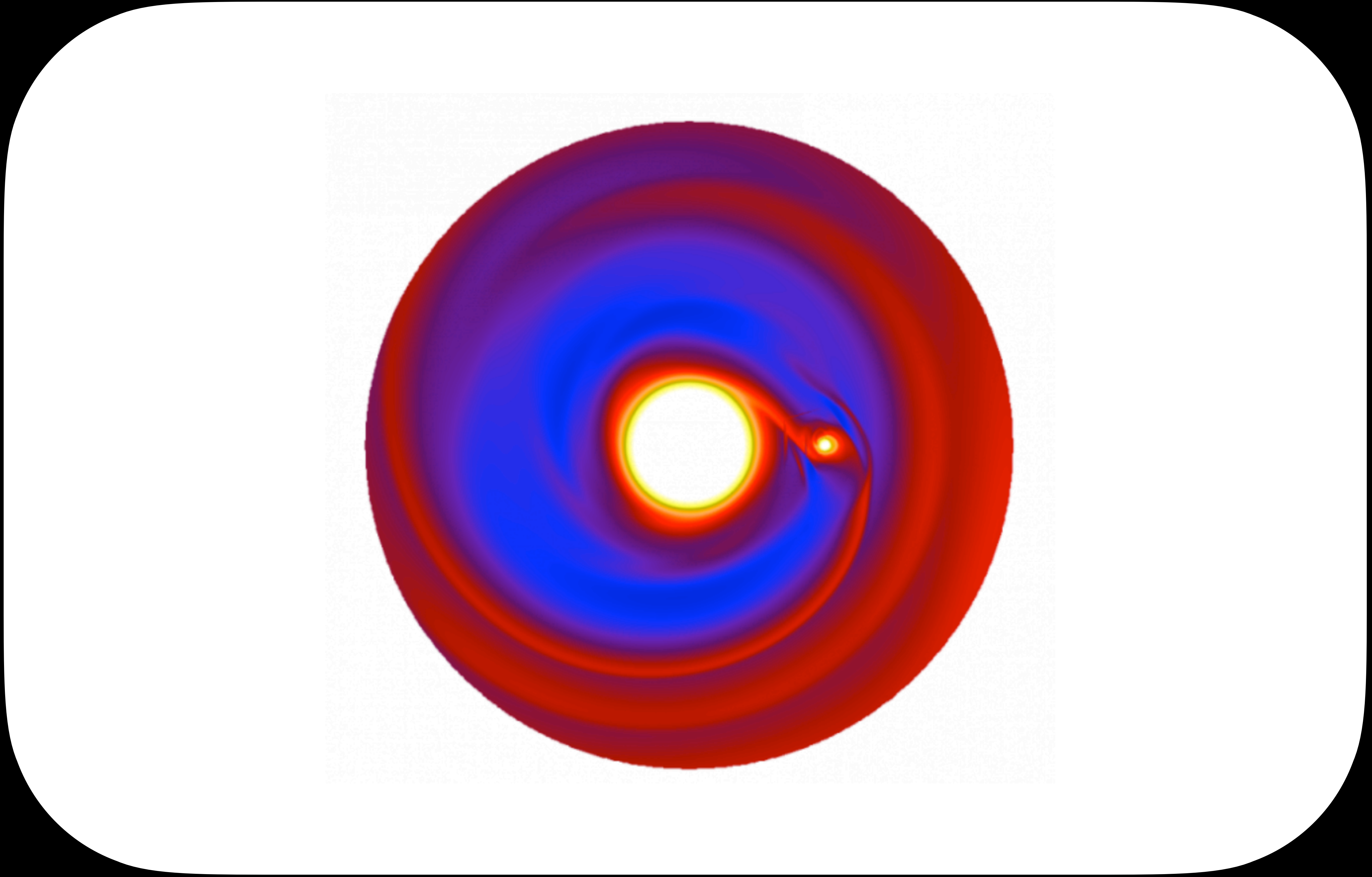
2405.09578: M. Benito, K. Karchev, R. K. Leane, S. Podar, **JS**, R. Trotta

More Effects

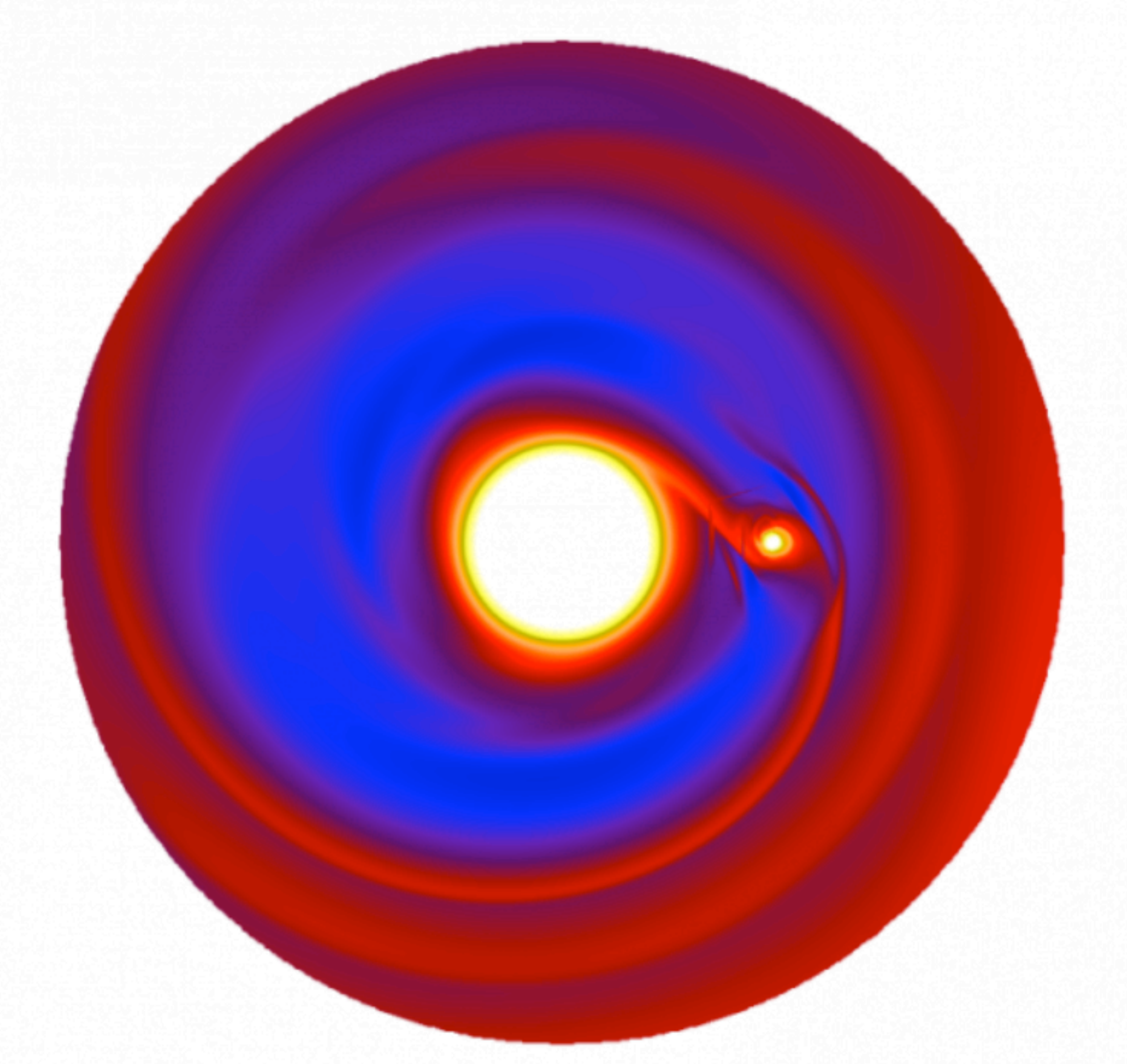
Extreme...



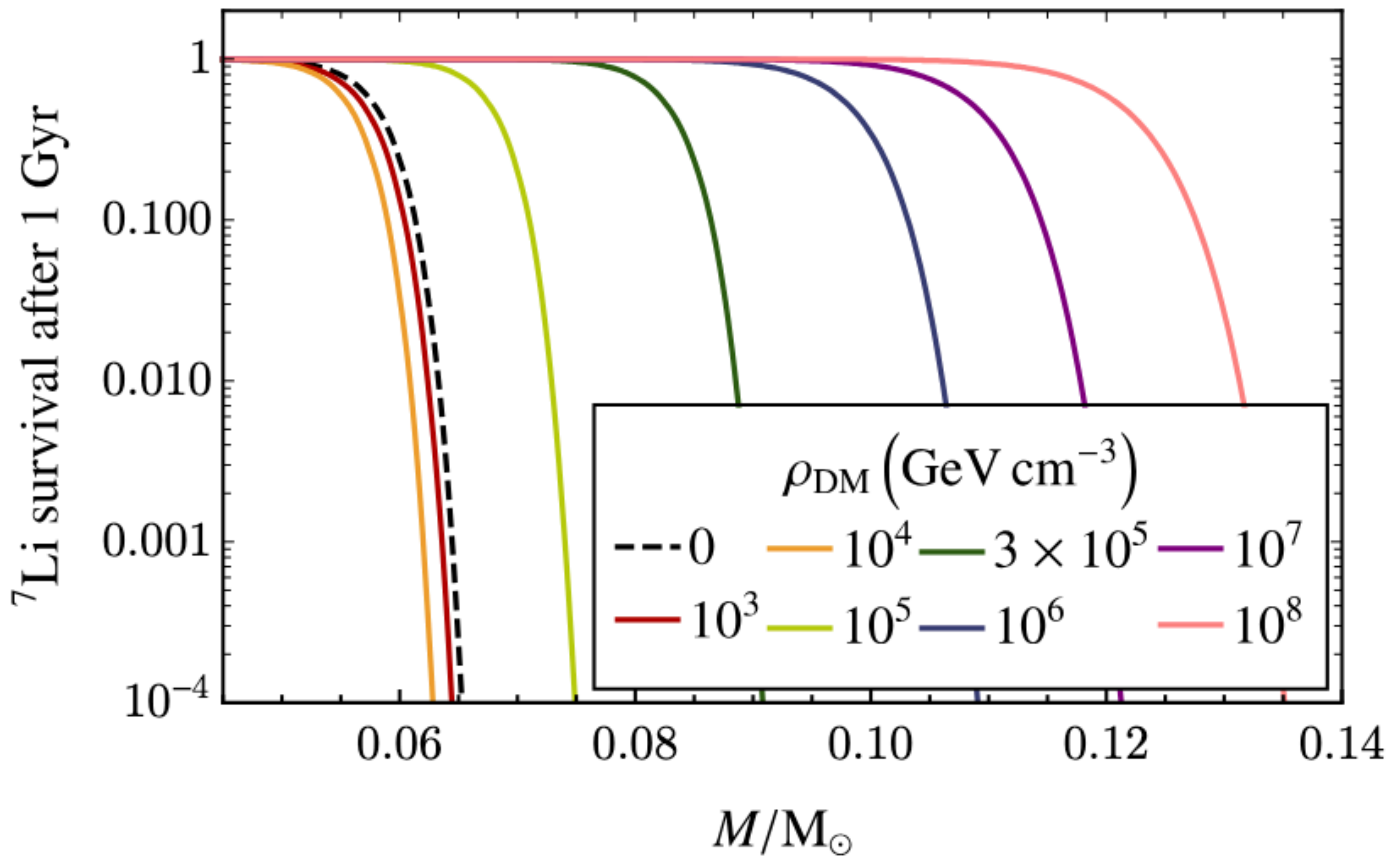
2309.02495: D. Croon, **JS**

More Effects

Extreme...



Or subtle...



2309.02495: D. Croon, **JS**

2408.00822: D. Croon, J. Sackstein, **JS**, J. Streeter

Reach in Target Space

Model dependence of evaporation

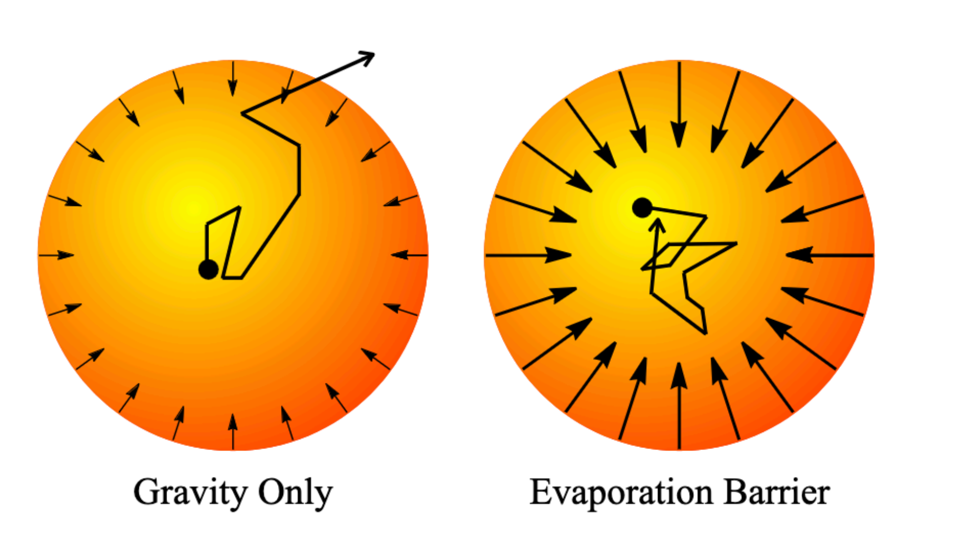
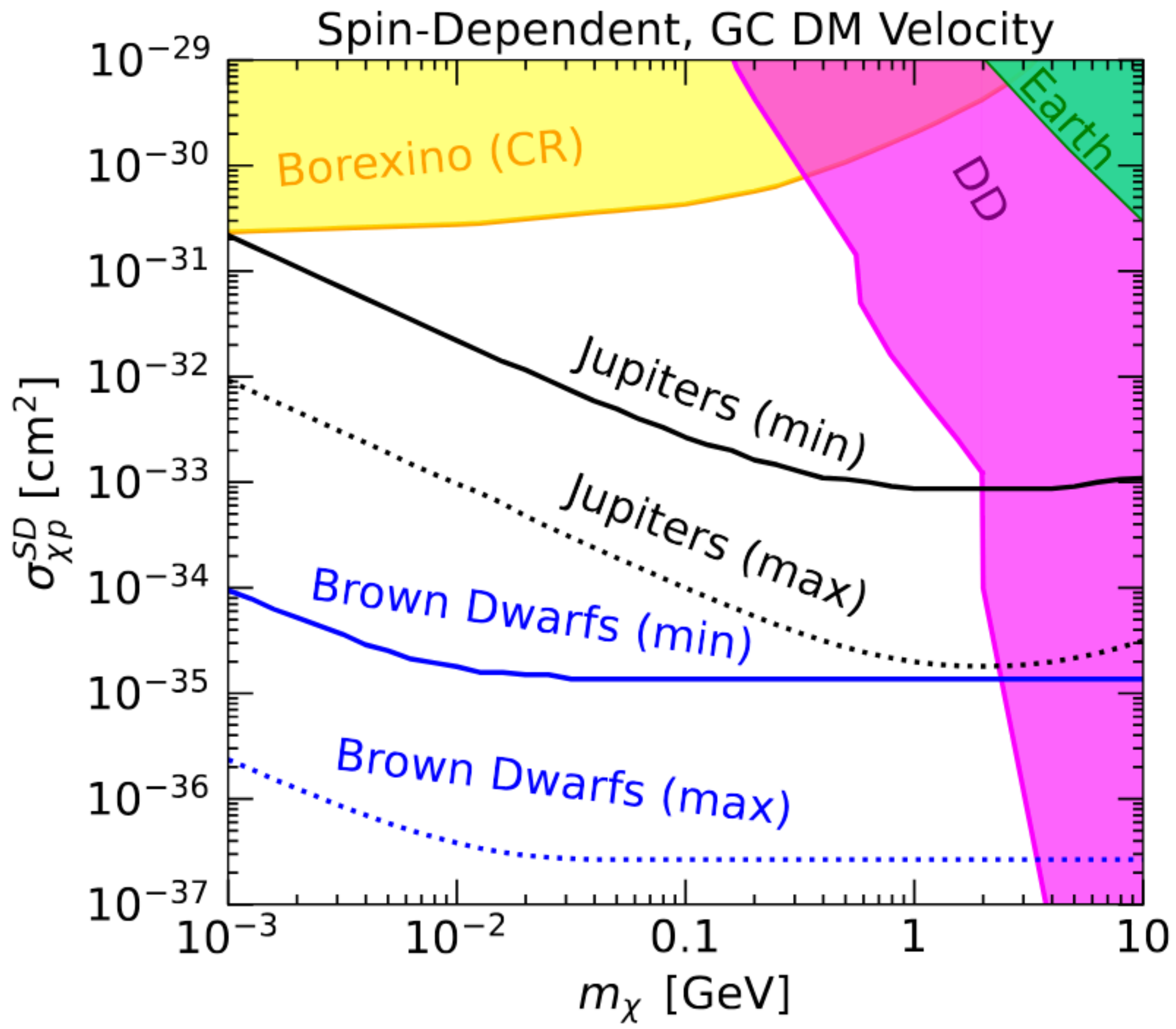


FIG. 1. Schematic representation of the evaporation barrier. **Left:** Gravity only (previous assumption). Evaporation of upscattered light DM particles is not suppressed. **Right:** The evaporation barrier blocks evaporation (this work).

arXiv: 2303:01516;
J. Acevedo, R. K. Leane, **J.S.**

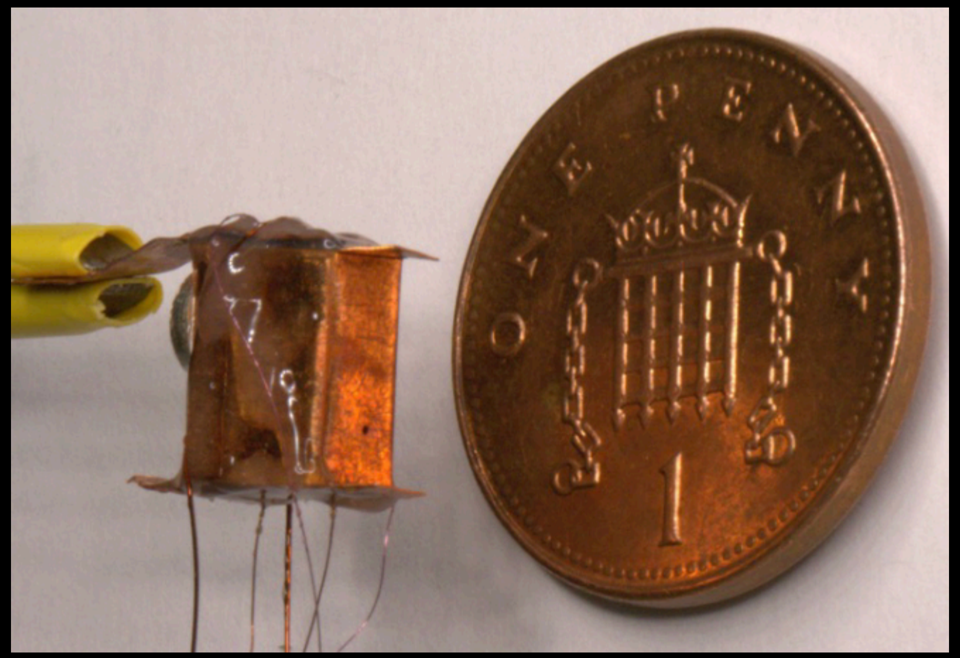


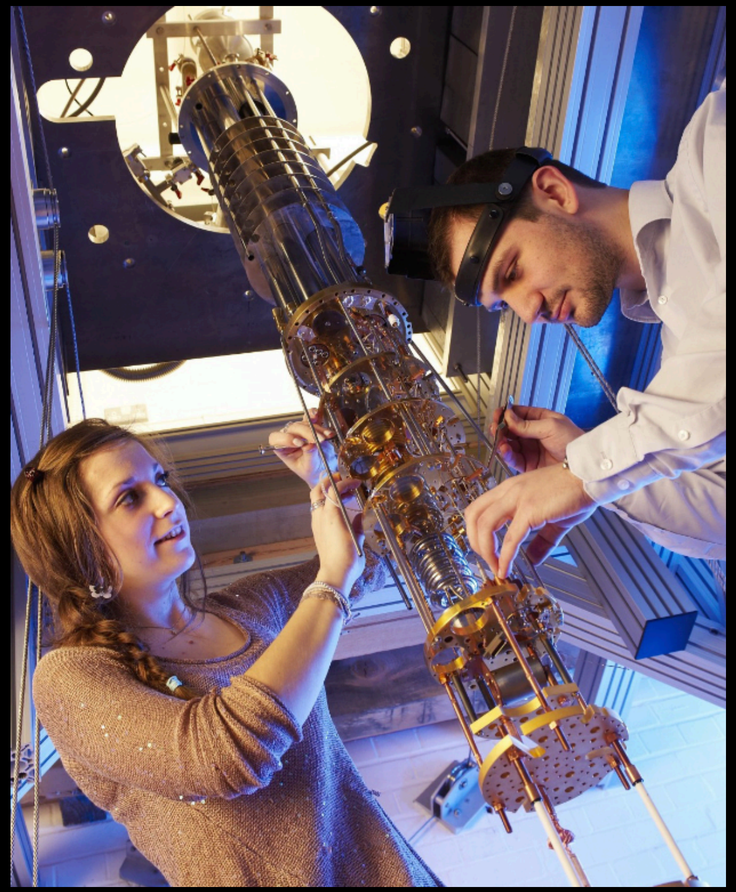
arXiv: 2010.00015; R. K. Leane, **J. Smirnov**

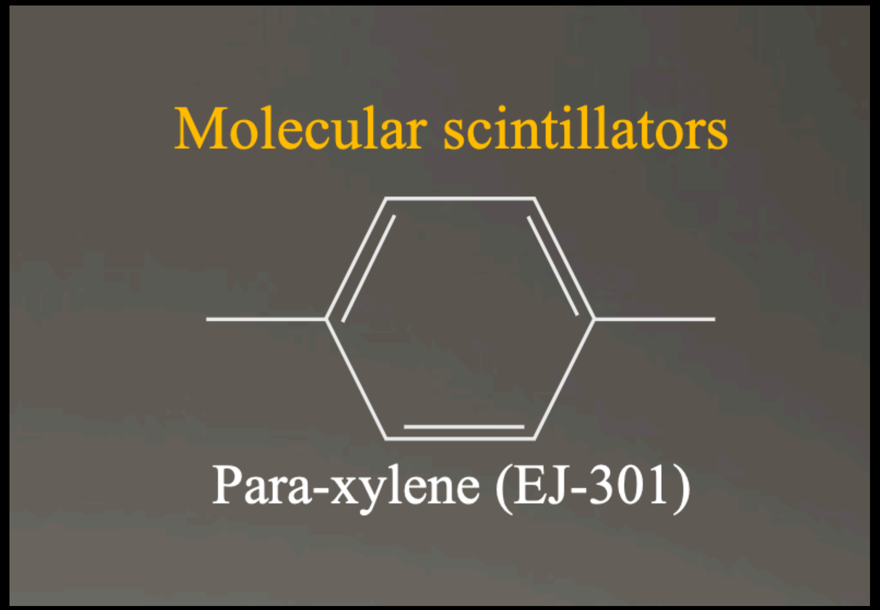
UK Research and Innovation

Complementary Program

QUEST DMC

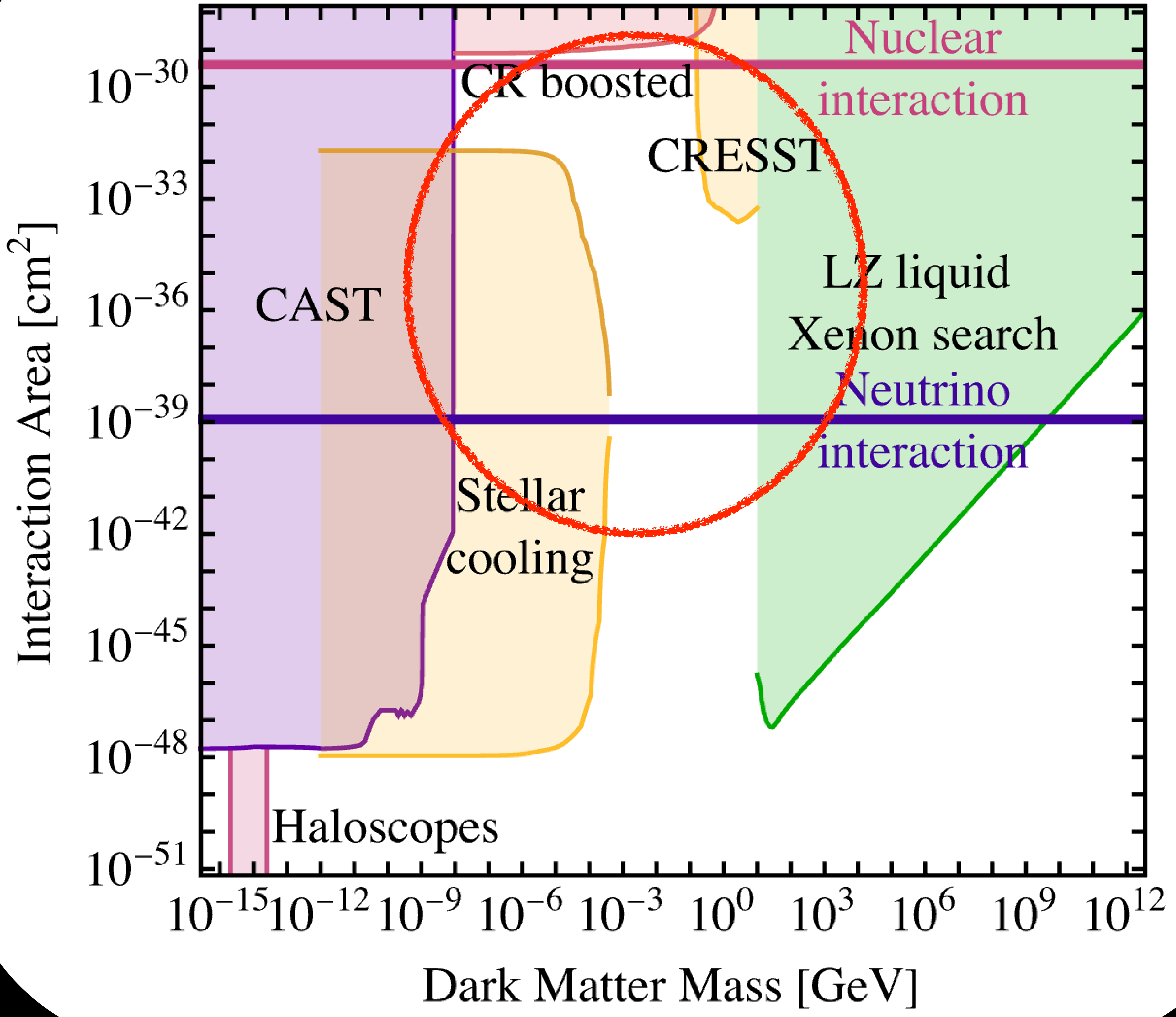






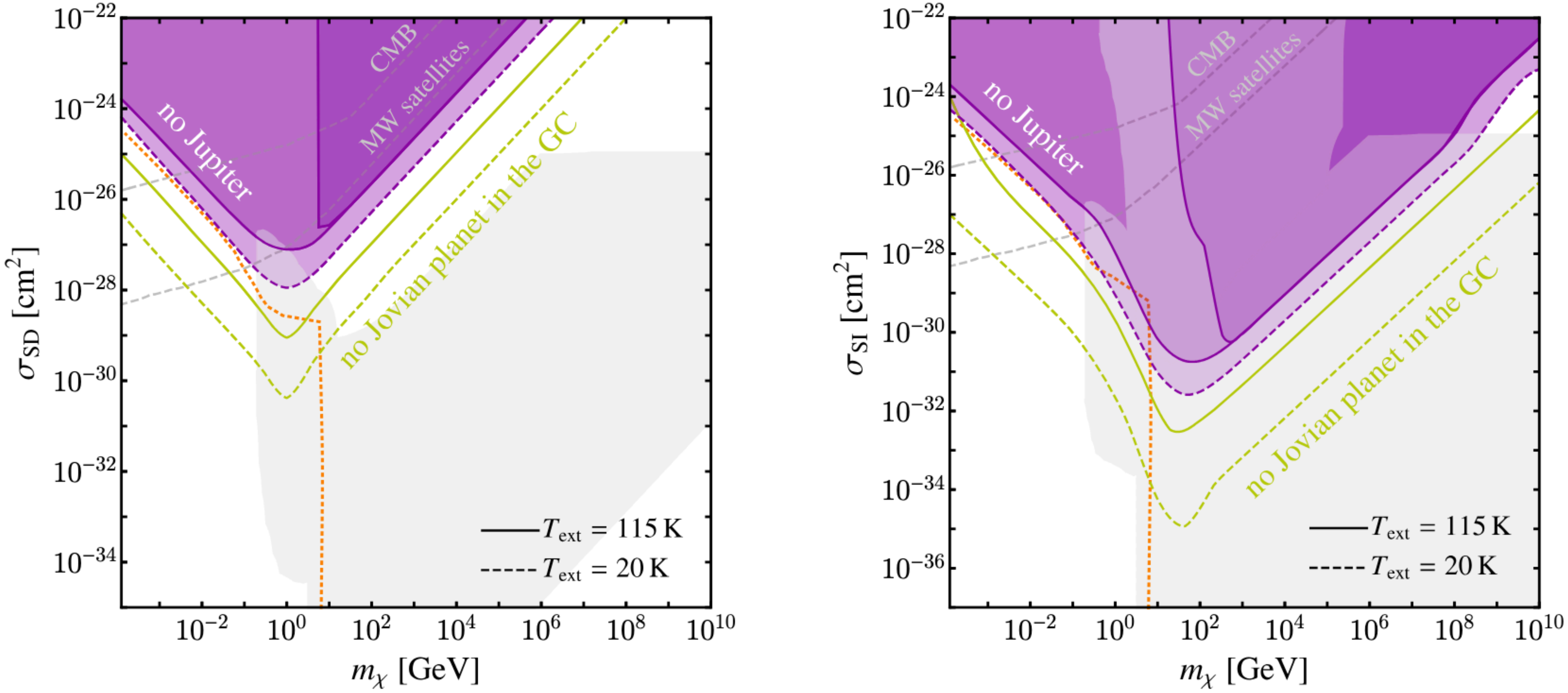
2 Post Doc openings
in my group

https://inspirehep.net/jobs/2834057



Backup

Sensitivity to Elastic Scattering



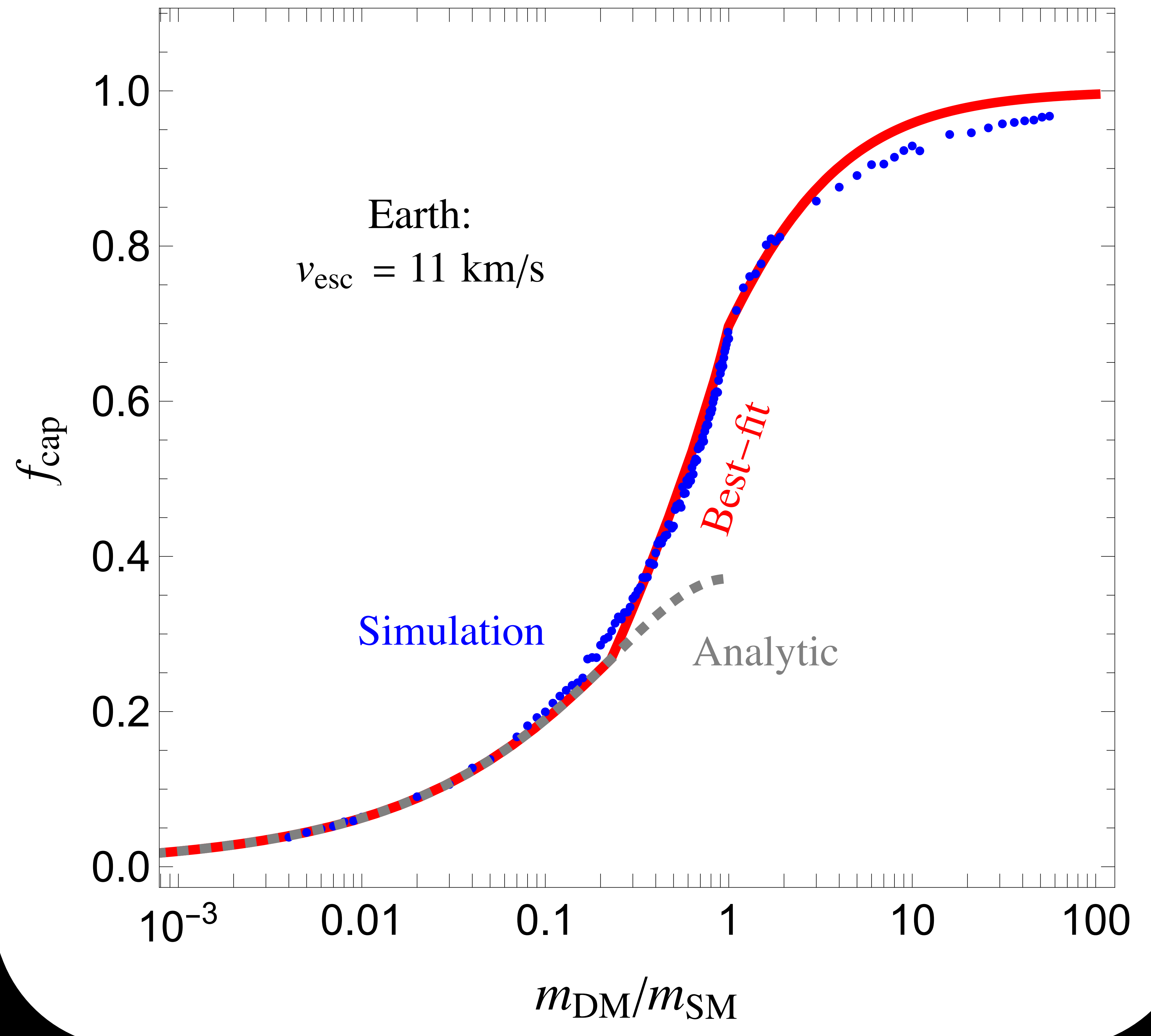
arXiv: 2309.02495; D. Croon (IPPP), **J. Smirnov**

Simulation and Analytic Result

$$f_{\rm ref} \approx 1 - \frac{2}{\sqrt{\pi}} \frac{1}{\sqrt{N_{\rm cap}}}$$

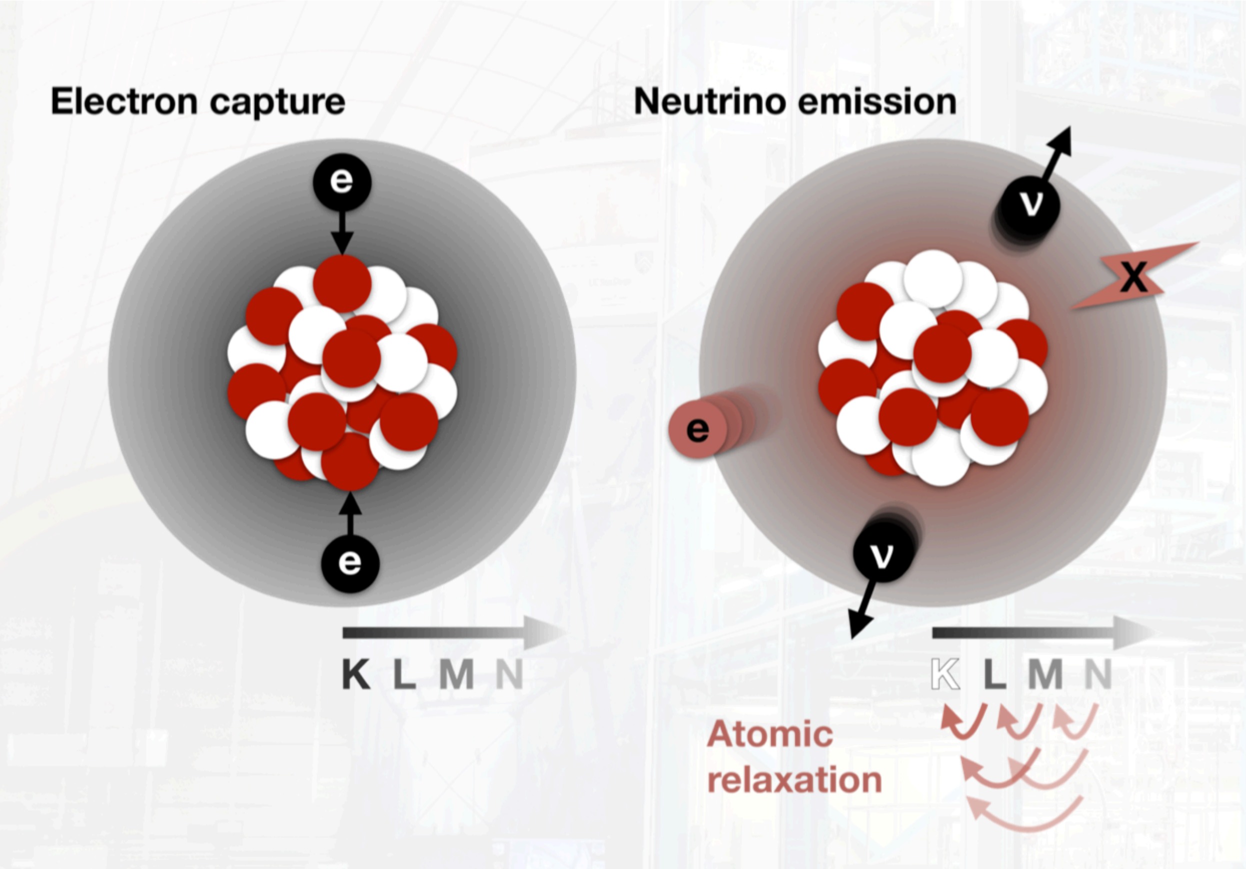
$$N_{\rm cap} \approx \frac{\log\left(\frac{v_{\rm DM}^2}{v_{\rm esc}^2}\right)}{\log\left(1 - \langle z \rangle \beta\right)}$$

$$\langle z \rangle \sim \frac{1}{2} \text{ and } \beta = \frac{4 m_{\rm DM} m_{\rm SM}}{(m_{\rm DM} + m_{\rm SM})^2}$$



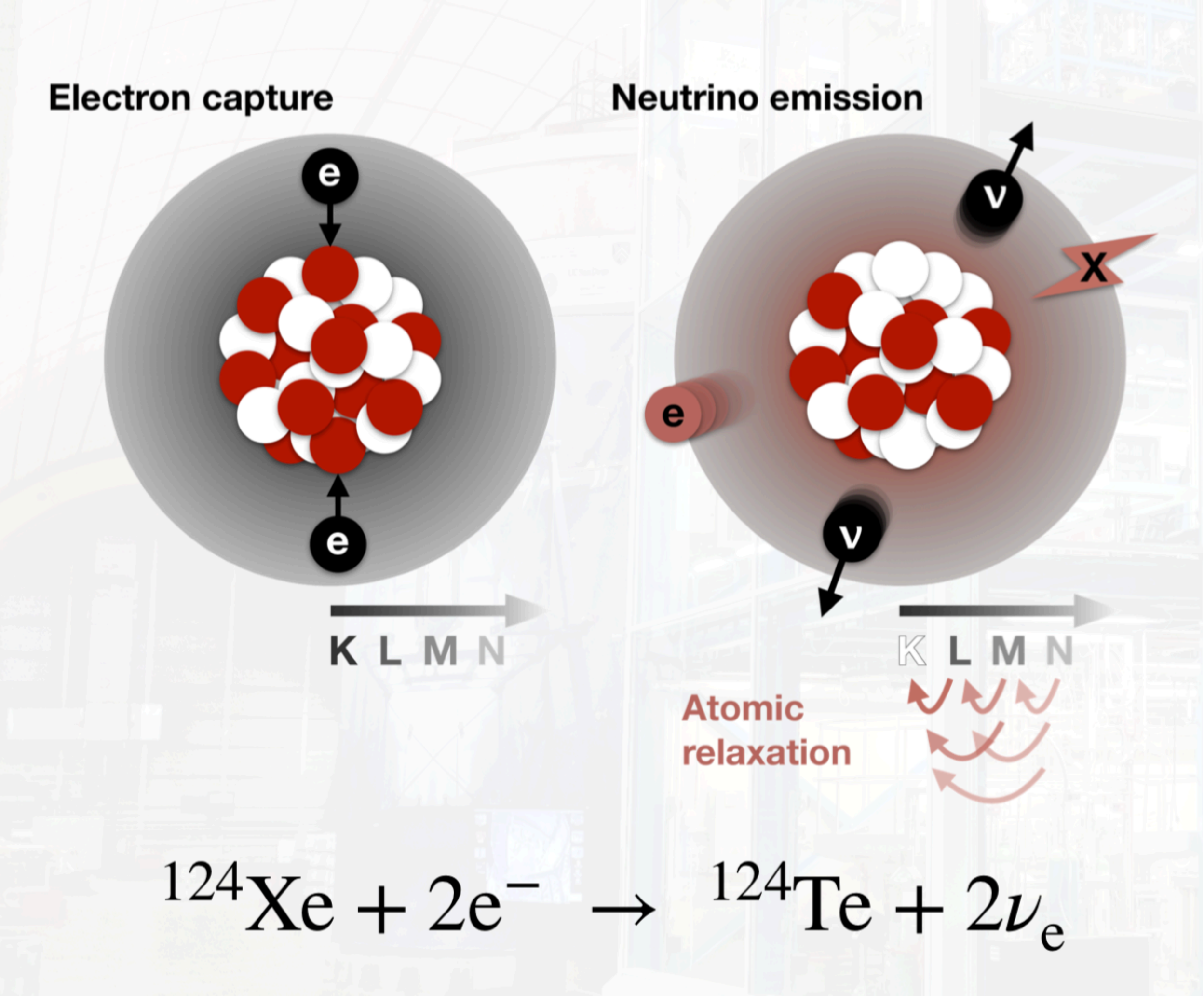
Asteria Package
2309.00669
R. K. Leane (SLAC),
J.Smirnov

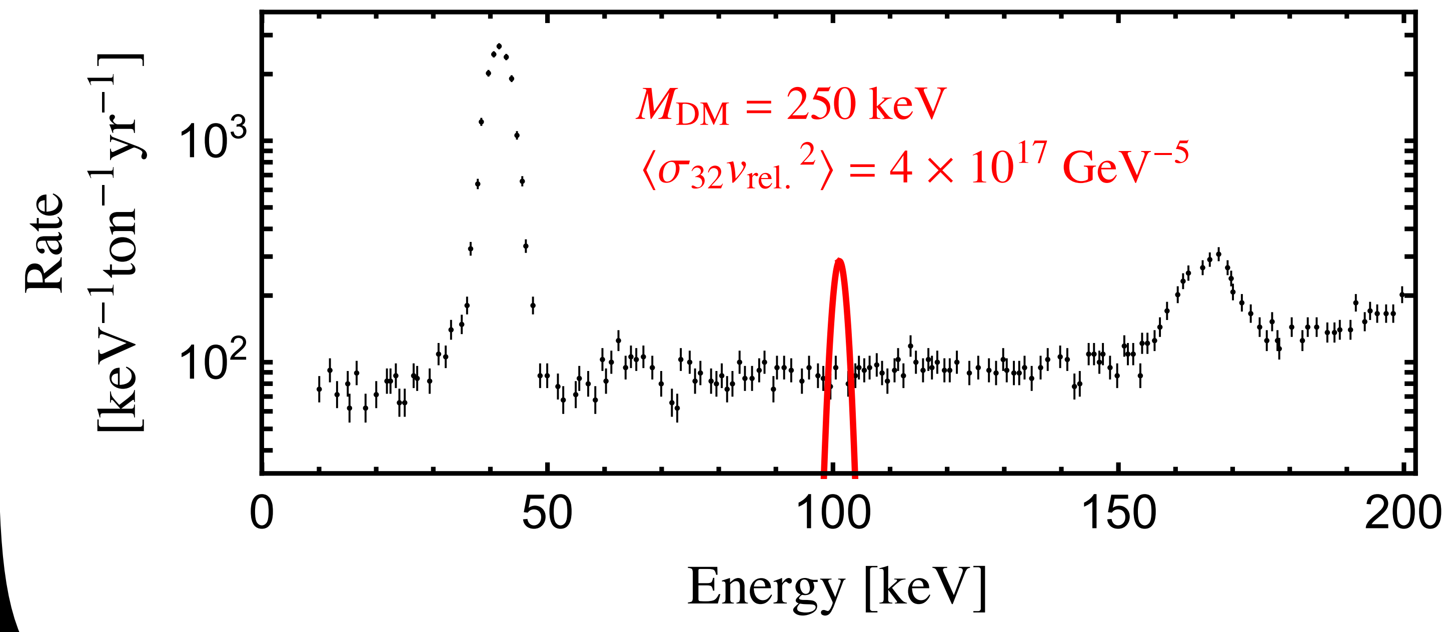
Co-SIMPs and Double Electron Capture



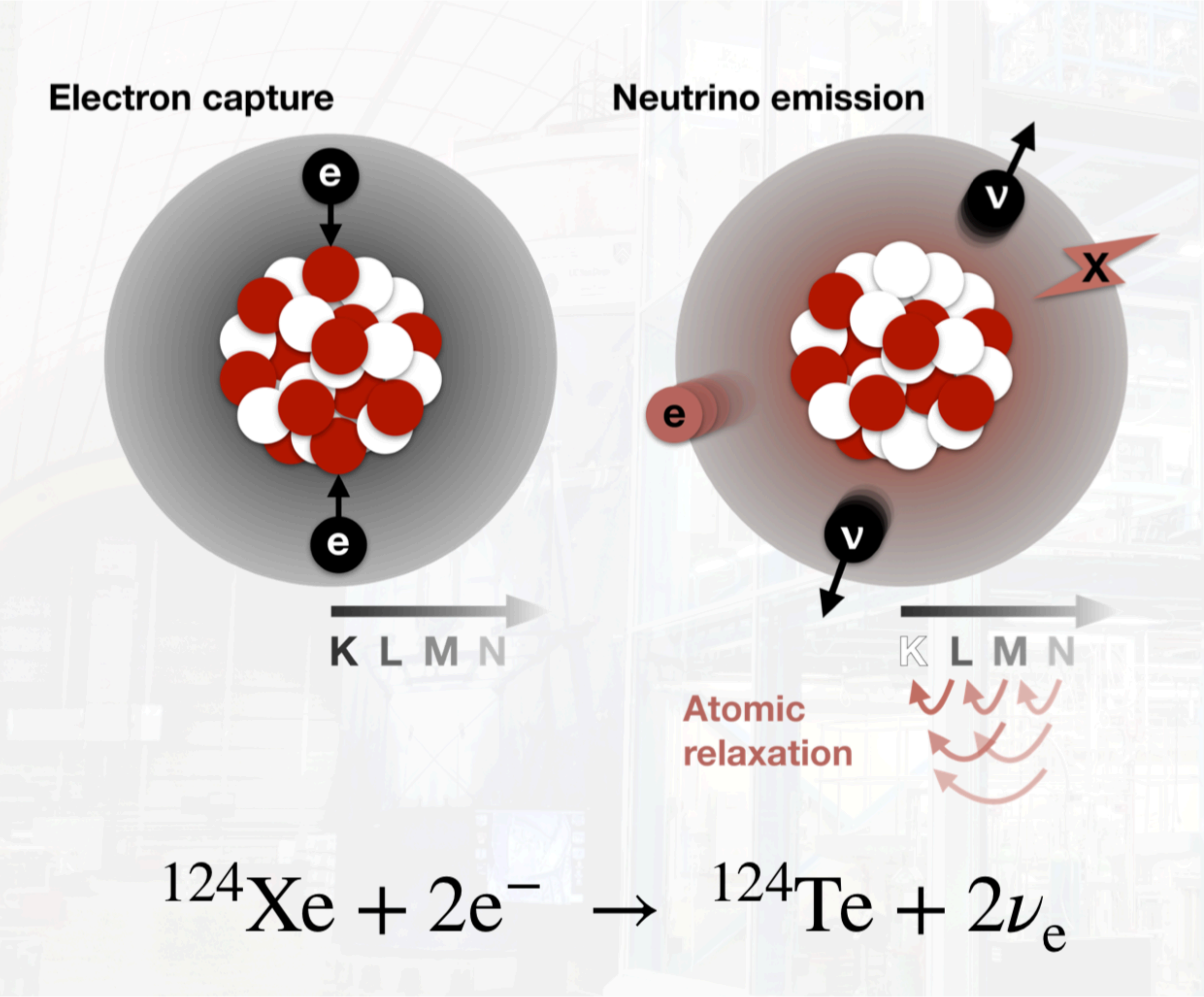
$$^{124}\mathrm{Xe} + 2e^- \rightarrow {}^{124}\mathrm{Te} + 2\nu_e$$

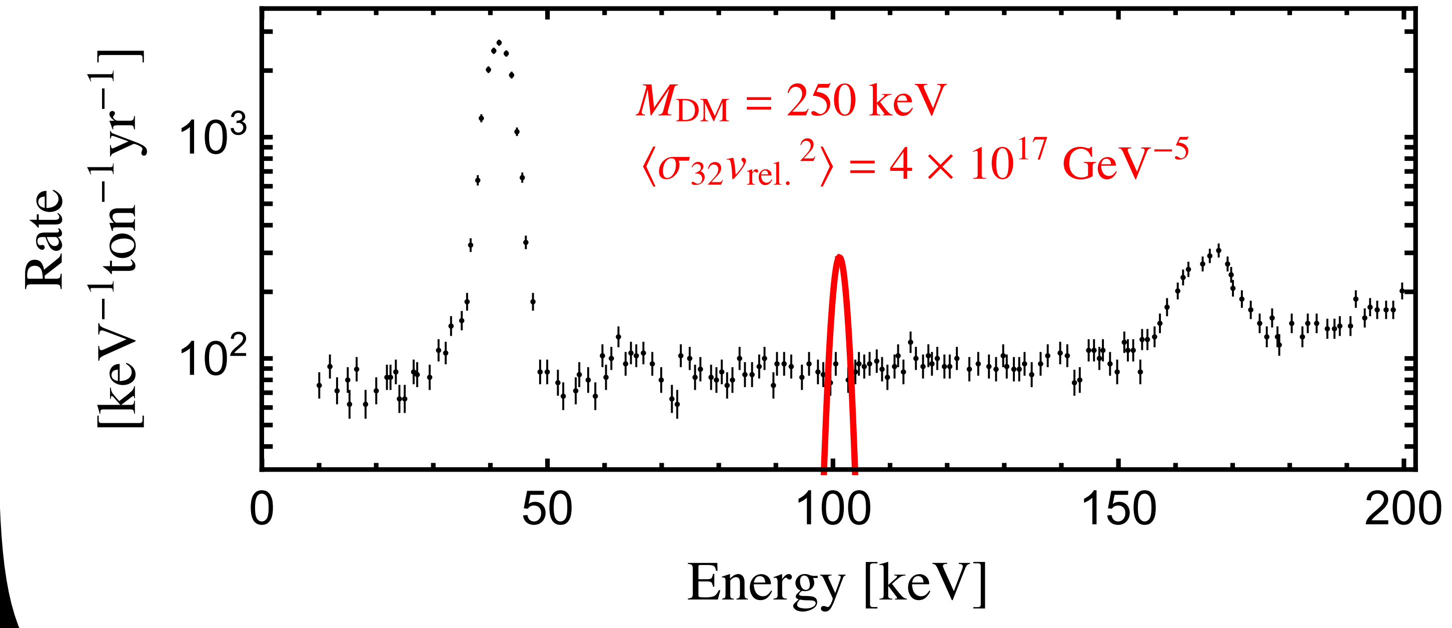
Co-SIMPs and Double Electron Capture

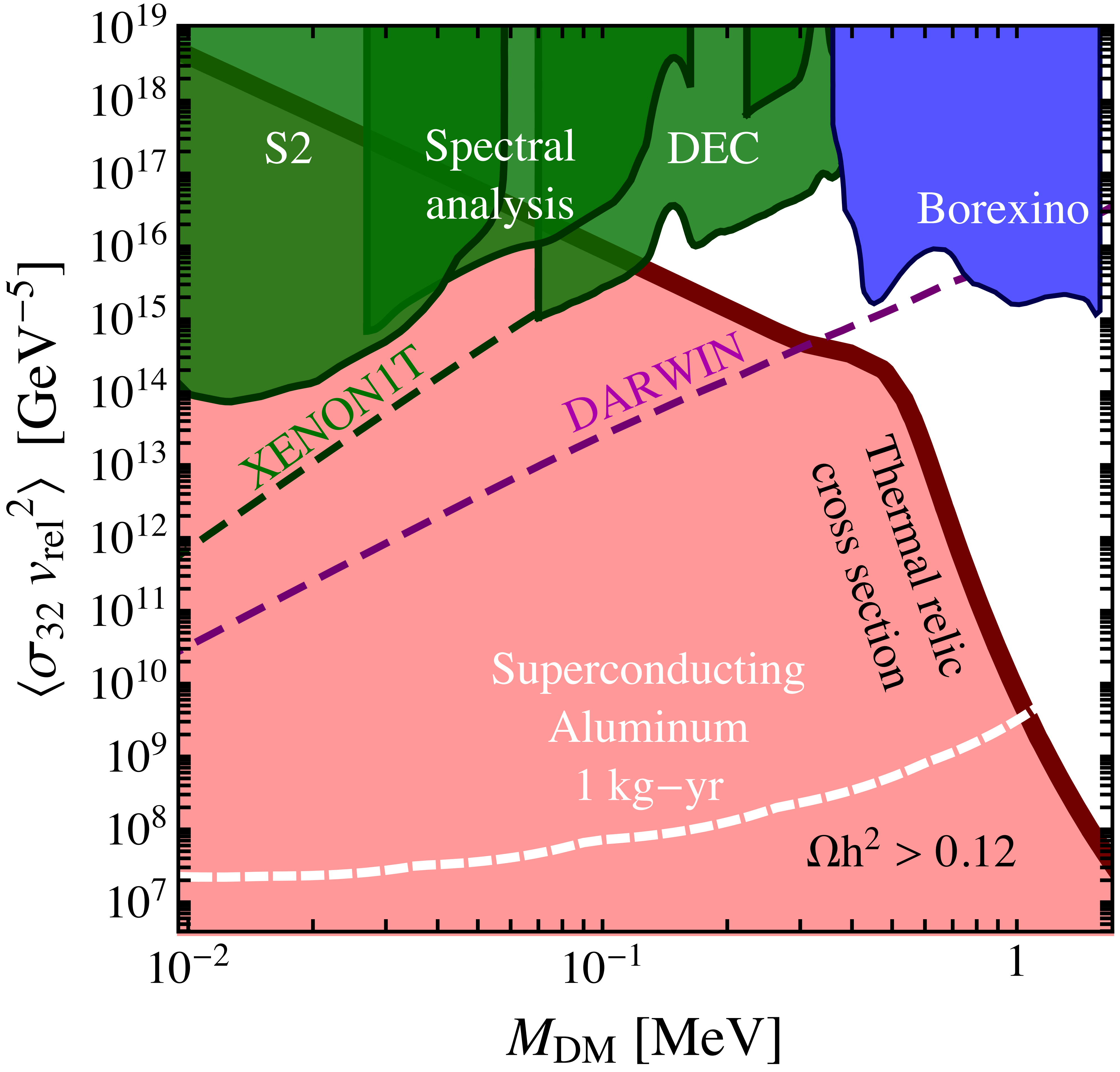




Co-SIMPs and Double Electron Capture







arXiv: 2002.04038; J. Smirnov, J. Beacom