# Evaporation Barrier for Dark Matter in Celestial Bodies

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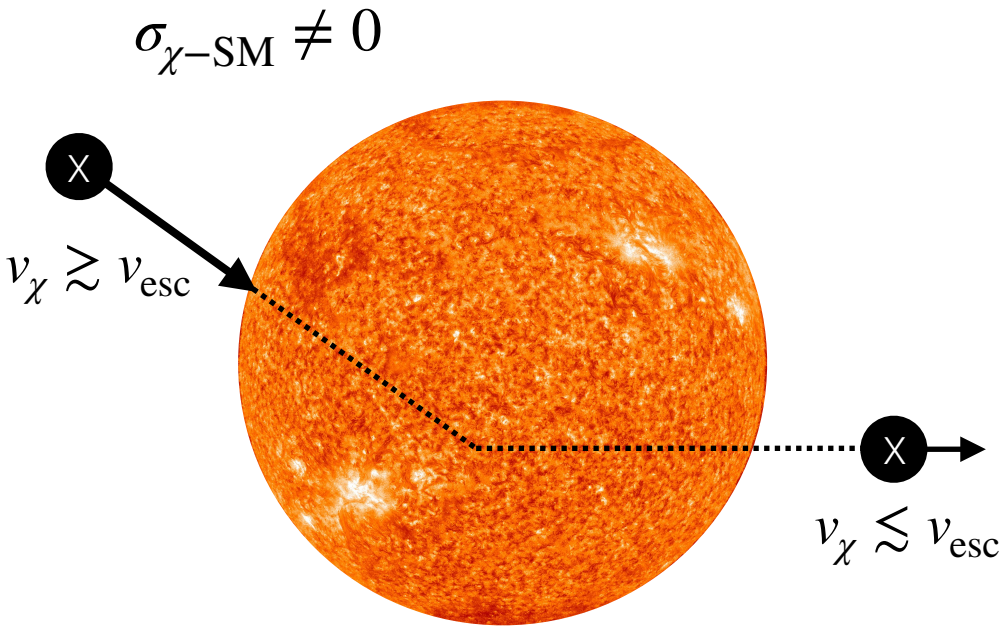
Based on: **2303.01516** w/ Rebecca Leane & Juri Smirnov

SLAC NATIONAL ACCELERATOR LABORATORY

Stanford University | U.S. DEPARTMENT OF ENERGY

# Celestial bodies as dark matter probes



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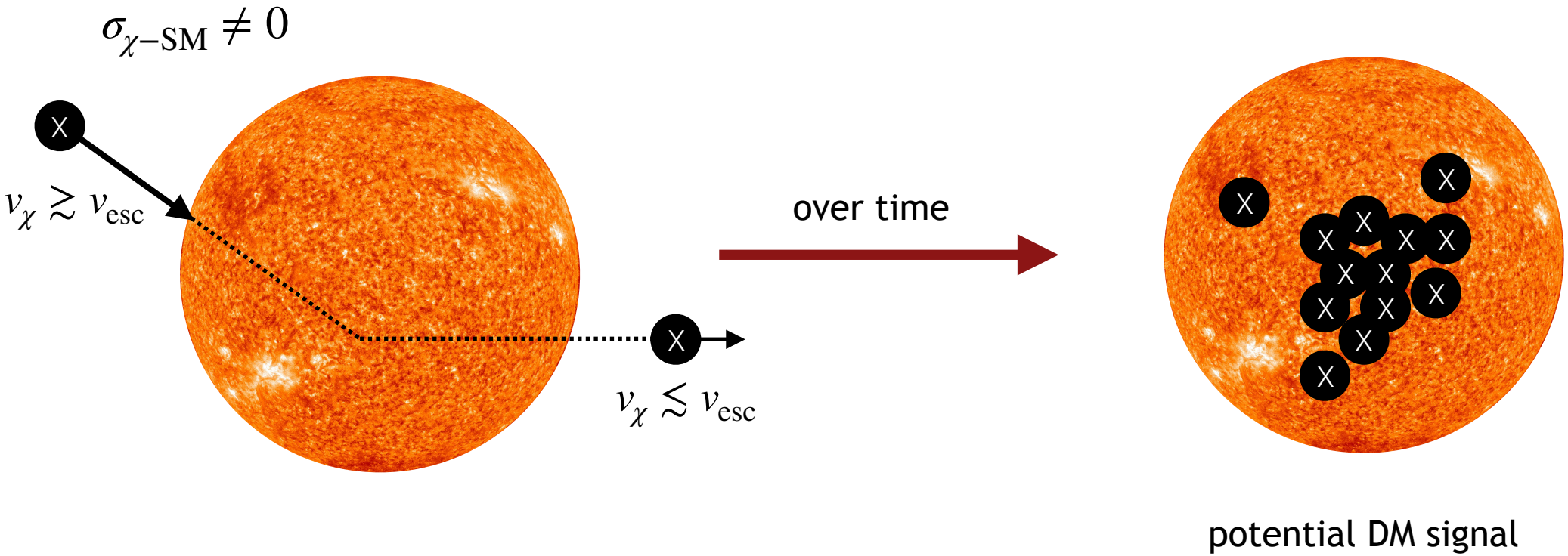

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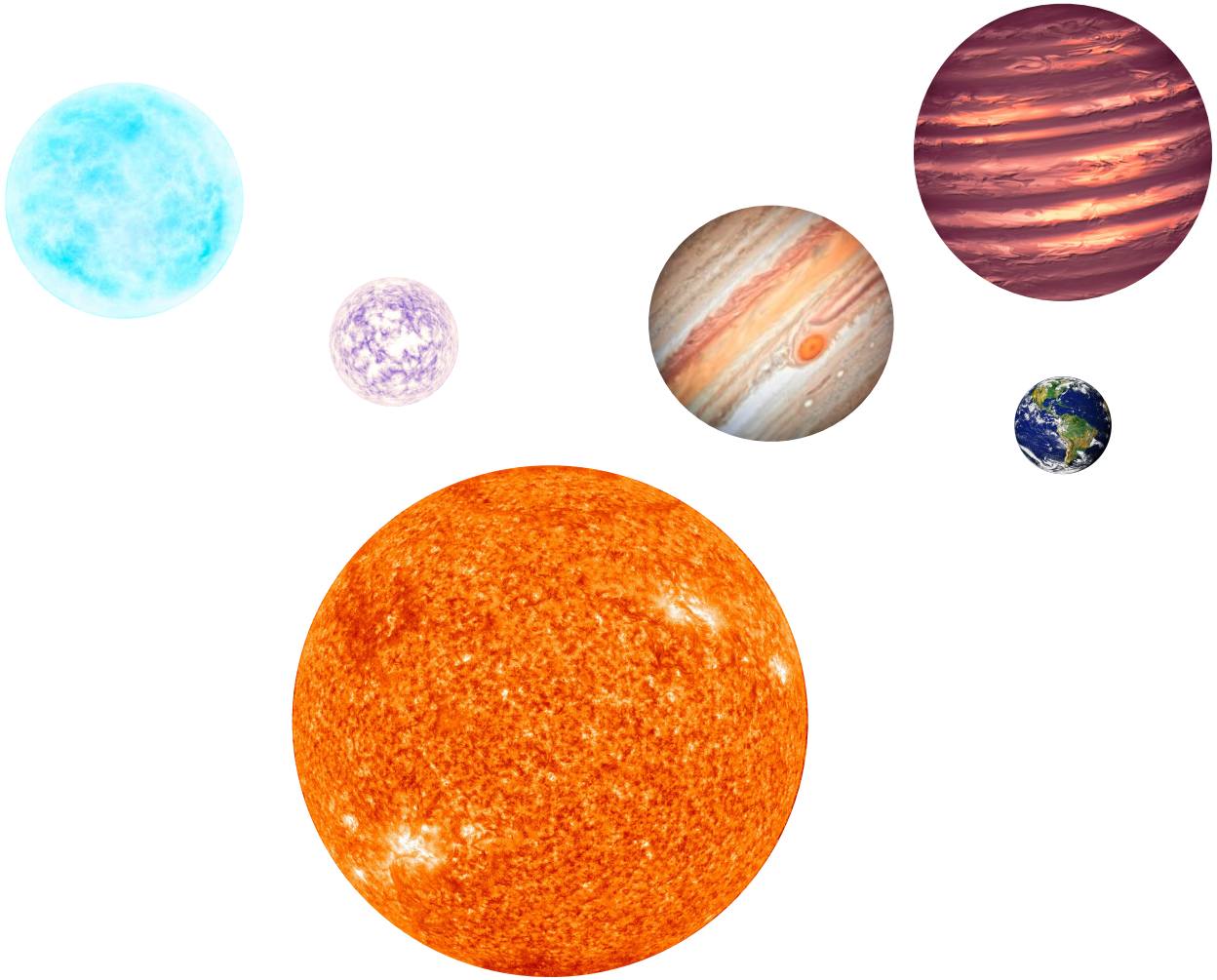
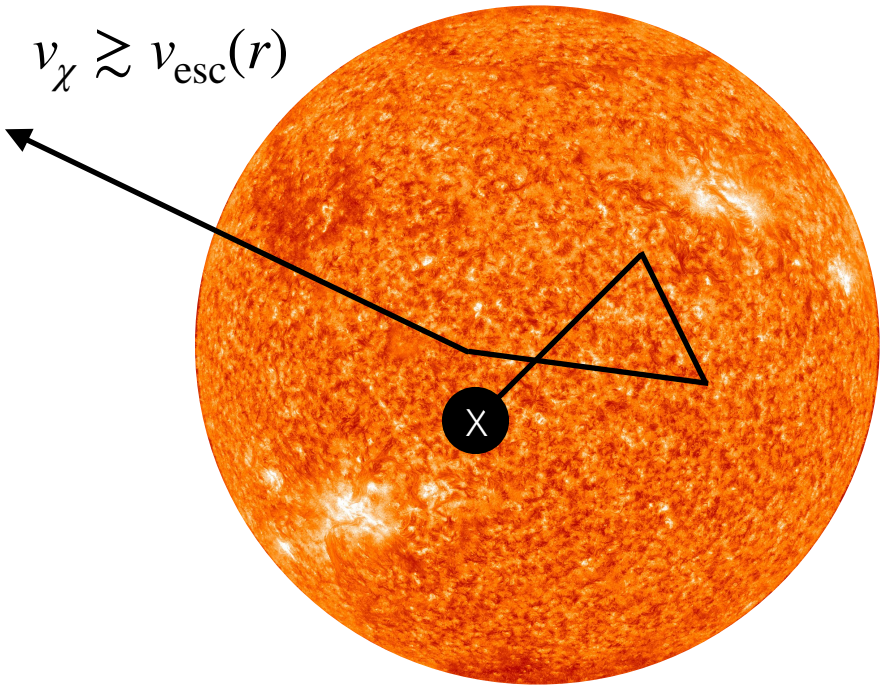


- Kinetic heating
- Stellar transients
- Type-Ia supernovae
- Annihilation to various states
- Transport processes
- Gravitational waves

# Dark matter evaporation

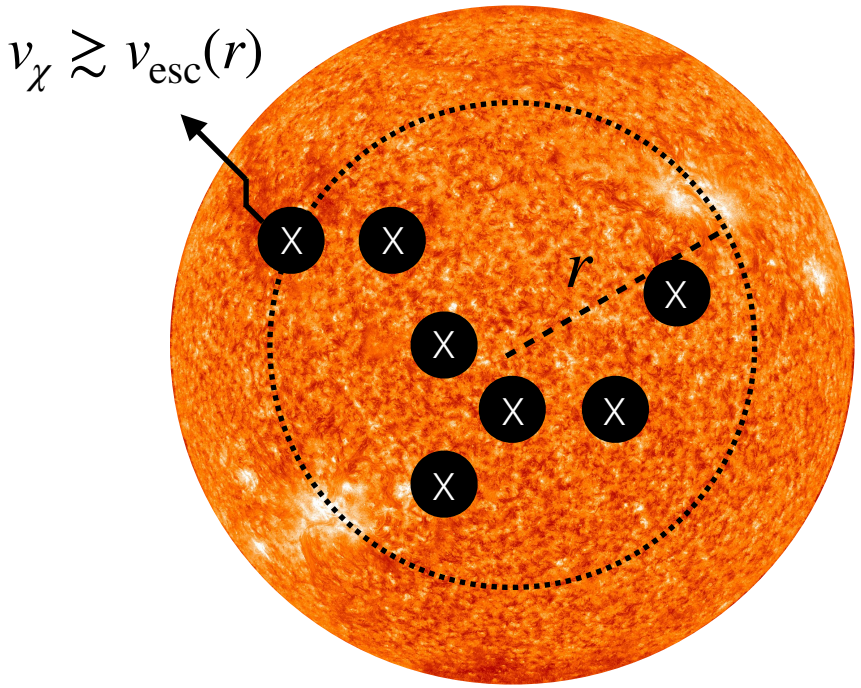



**Evaporation:** thermal upscattering of the DM to the escape velocity

e.g. for the Sun:

$$\frac{3}{2}T_{\rm central} \sim \frac{GM_* m_\chi}{R_*} \longrightarrow m_\chi \gtrsim 0.91\ \text{GeV}$$

# Dark matter evaporation




Accurate evaporation rate:

$$\Gamma_{\rm evap} \propto \exp\left(-\frac{\phi_{\rm grav}(r)}{T(r)}\right) \exp\left(-\tau(r)\right)$$

escape energy vs. temperature

optical depth to surface

Usual assumptions:

- DM-SM contact interactions
- Only gravity and temperature matters

# Computing the evaporation mass

Evolution of net DM number given by: $\frac{dN_\chi}{dt} = \Gamma_{\text{cap}} - \Gamma_{\text{evap}} N_\chi - \Gamma_{\text{ann}} N_\chi^2$

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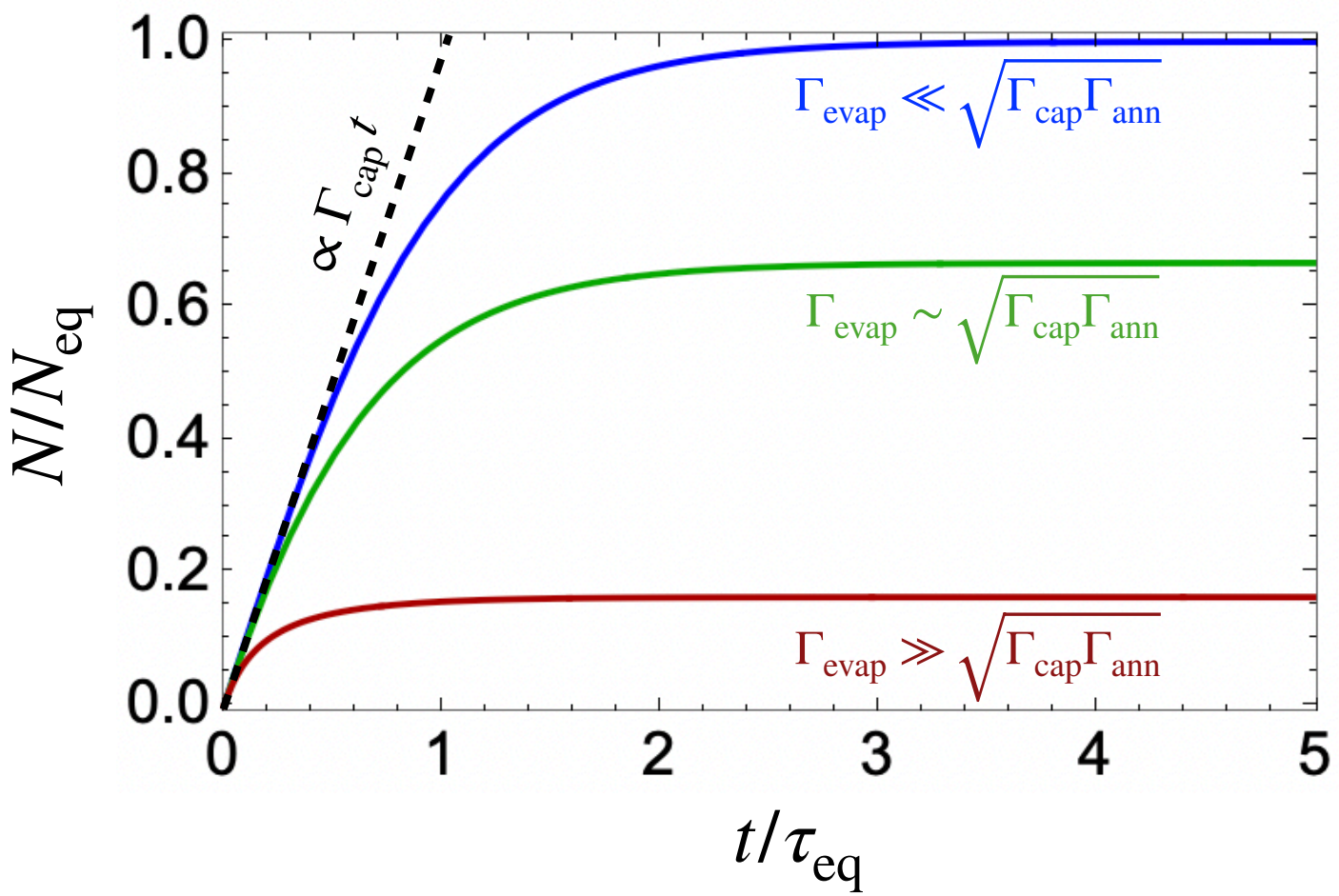

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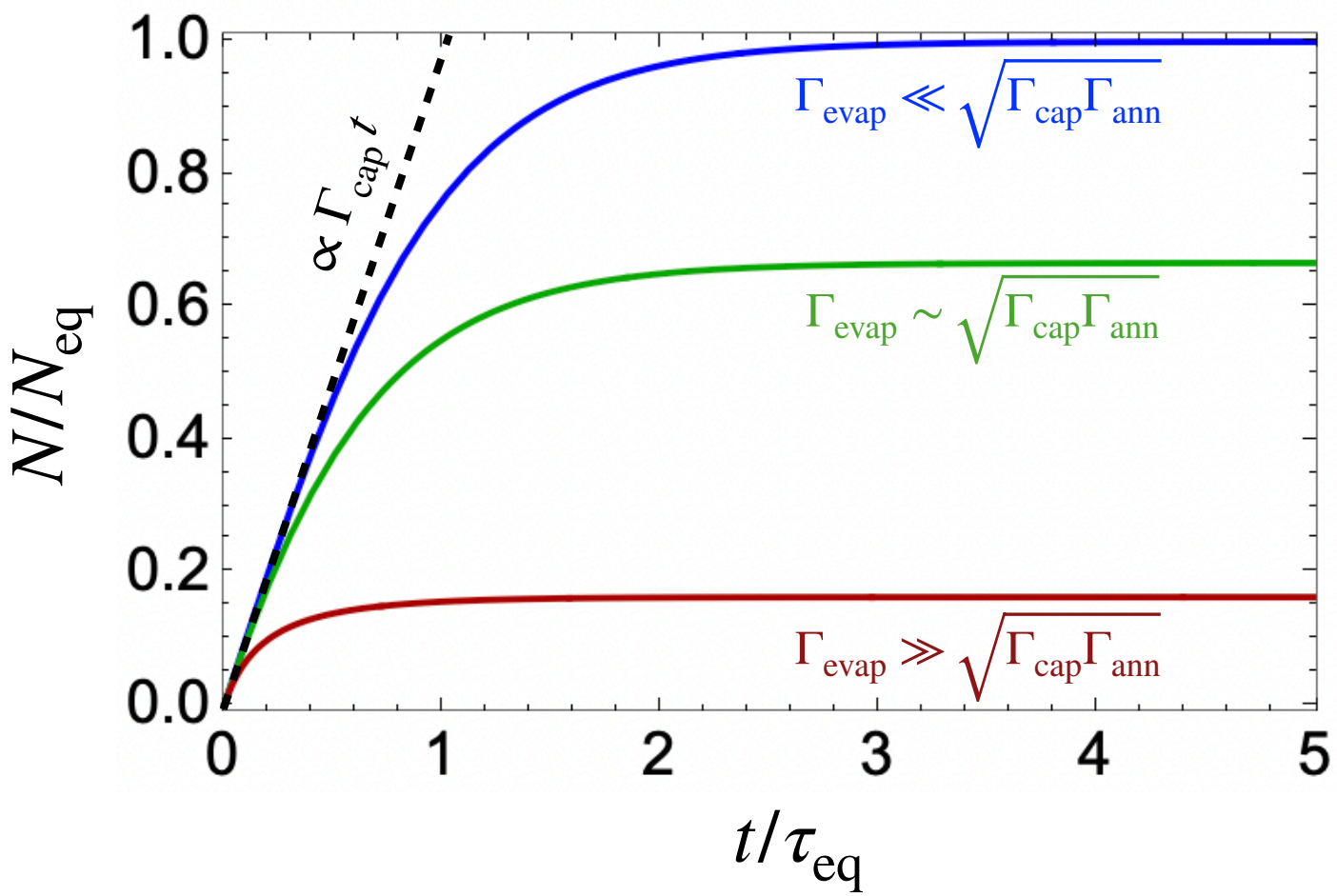


for the Sun:

$m_\chi \simeq 3.21$ GeV

$m_\chi \simeq 3.20$ GeV

$m_\chi \simeq 3.19$ GeV

(at cross-section ~$10^{-35}$ cm$^2$)

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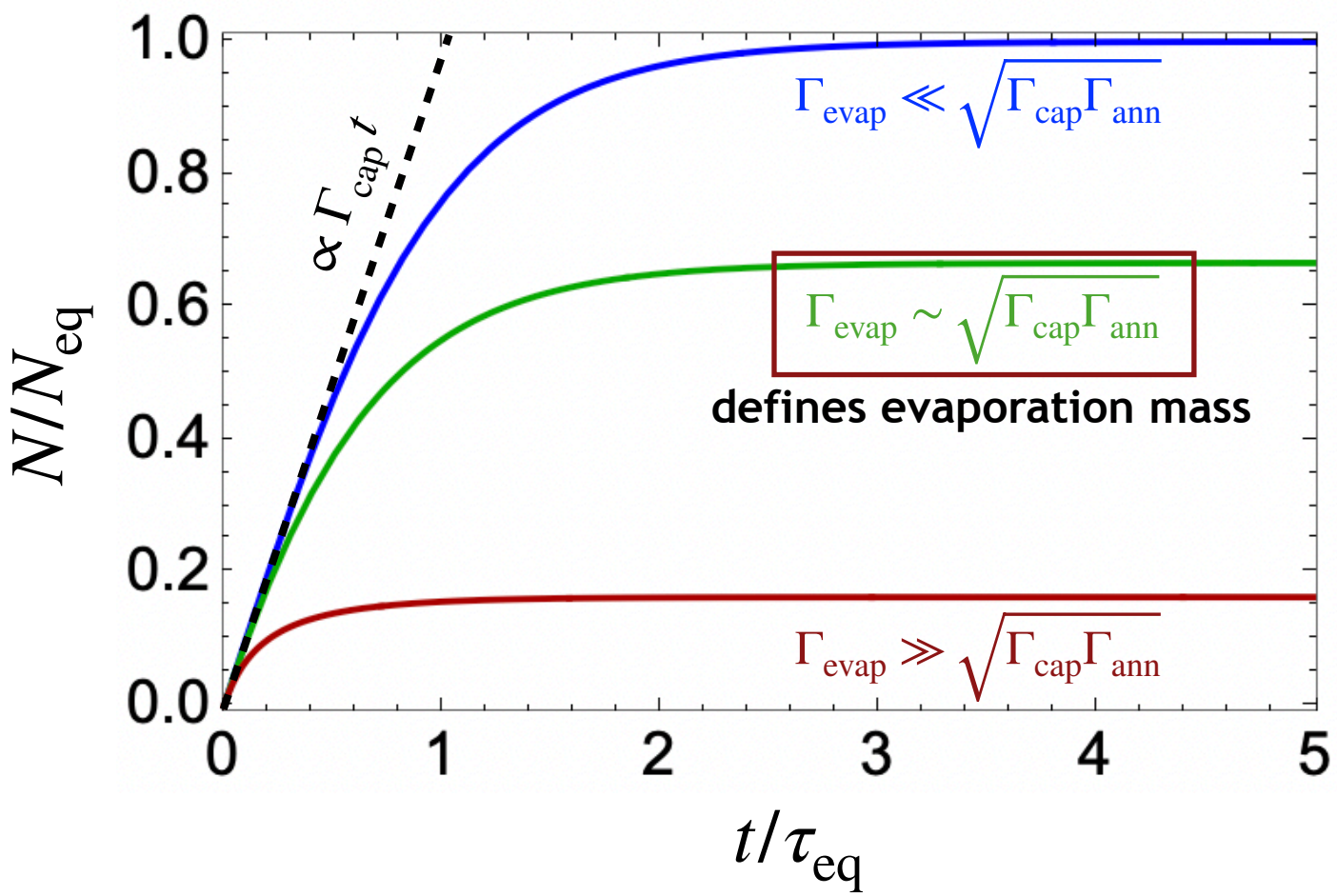


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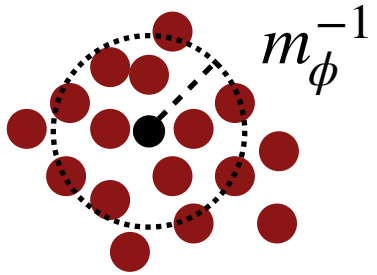

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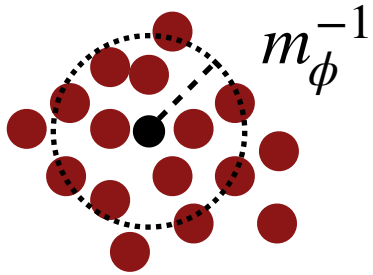


- Celestial objects source a potential for the DM:

$$\phi_{\rm barrier}(r) = \phi_{\rm barrier}(0)\left[\frac{\sinh(m_\phi r)}{m_\phi r}\right] + g_{\rm SM} g_\chi \int_0^r \left[\frac{\sinh(m_\phi (r-s))}{m_\phi r}\right] s\, n_{\rm SM}(s)\, ds$$

$$\xrightarrow[m_\phi \ll n'_{\rm SM}/n_{\rm SM}]{} \phi_{\rm barrier}(r) \sim \frac{n_{\rm SM}(r)}{m_\phi^2}$$

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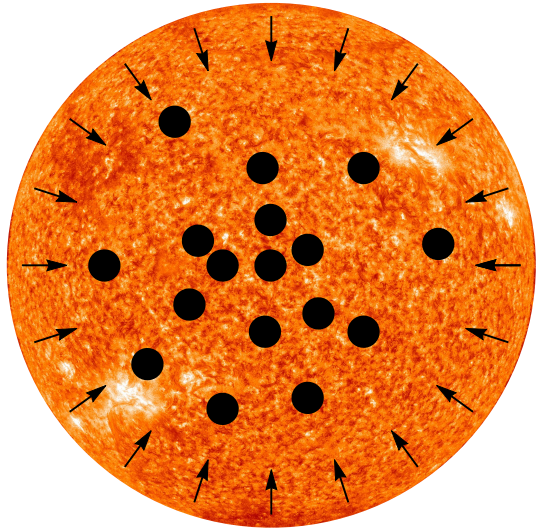
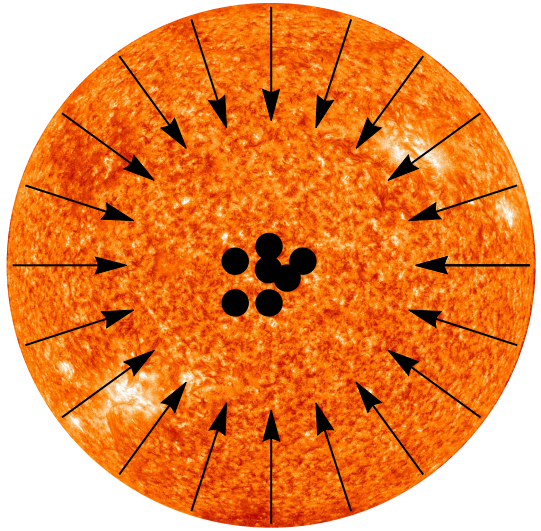
# Evaporation Barrier

Gravity Only



Gravity + Barrier



- Enhanced annihilation rate
- Increased overburden for evaporation
- Increased escape energy
- Density-gradient dependent force (depends on range)

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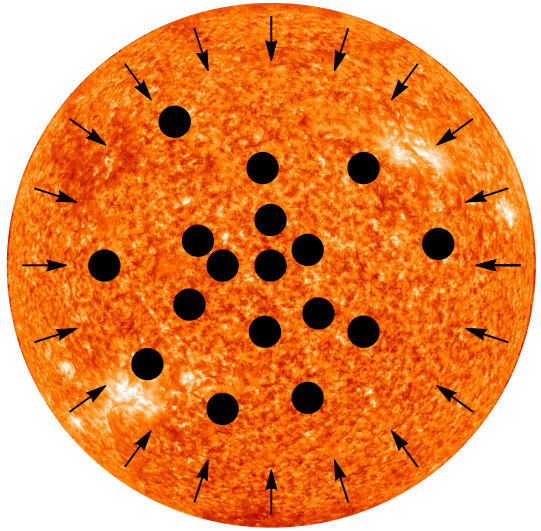

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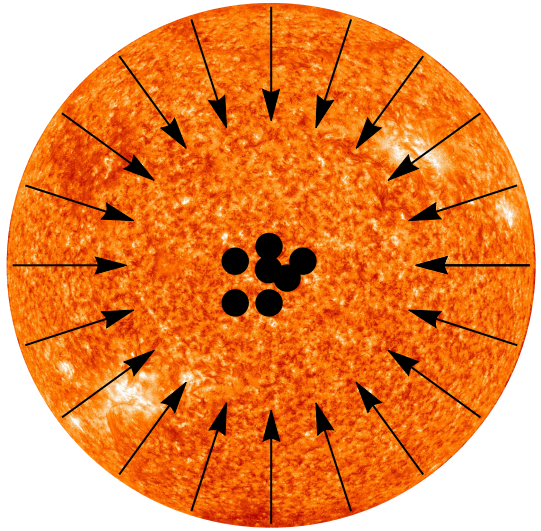

- Enhanced annihilation rate

- Increased overburden for evaporation

- Increased escape energy

*exponential suppression to evaporation rate*

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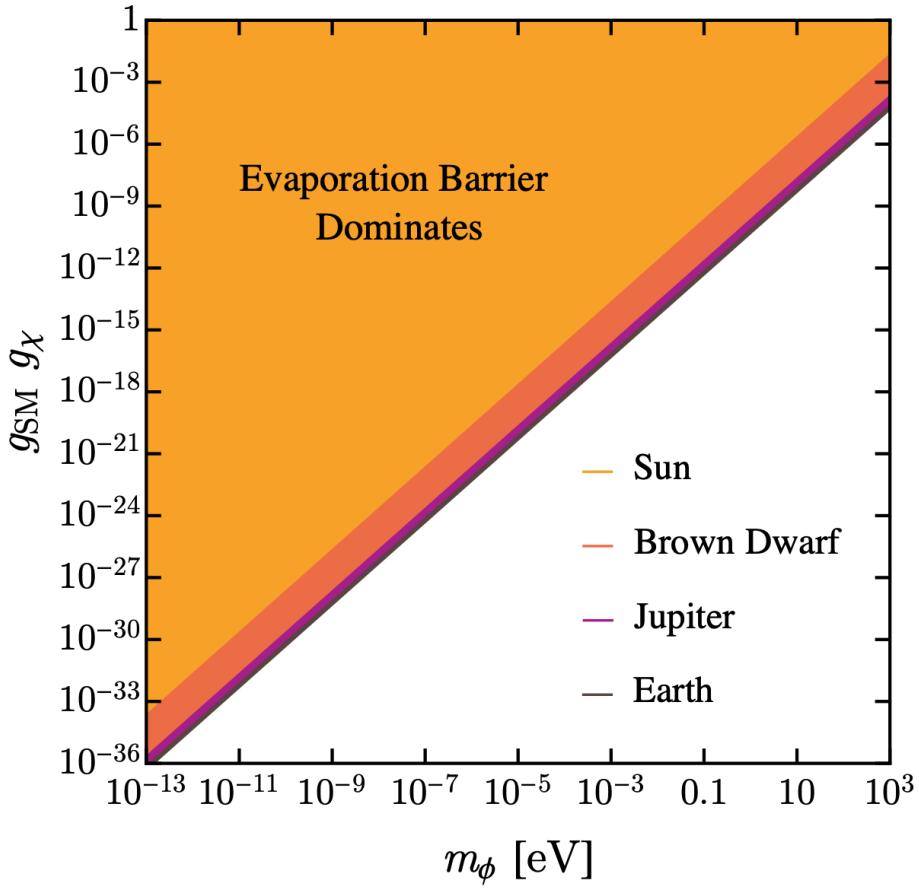
# Evaporation Barrier

Evaporation mass changes when: $\phi_{\rm barrier}(r) \gtrsim \phi_{\rm grav}(r)\Big|_{m_\chi^{\rm evap}}$

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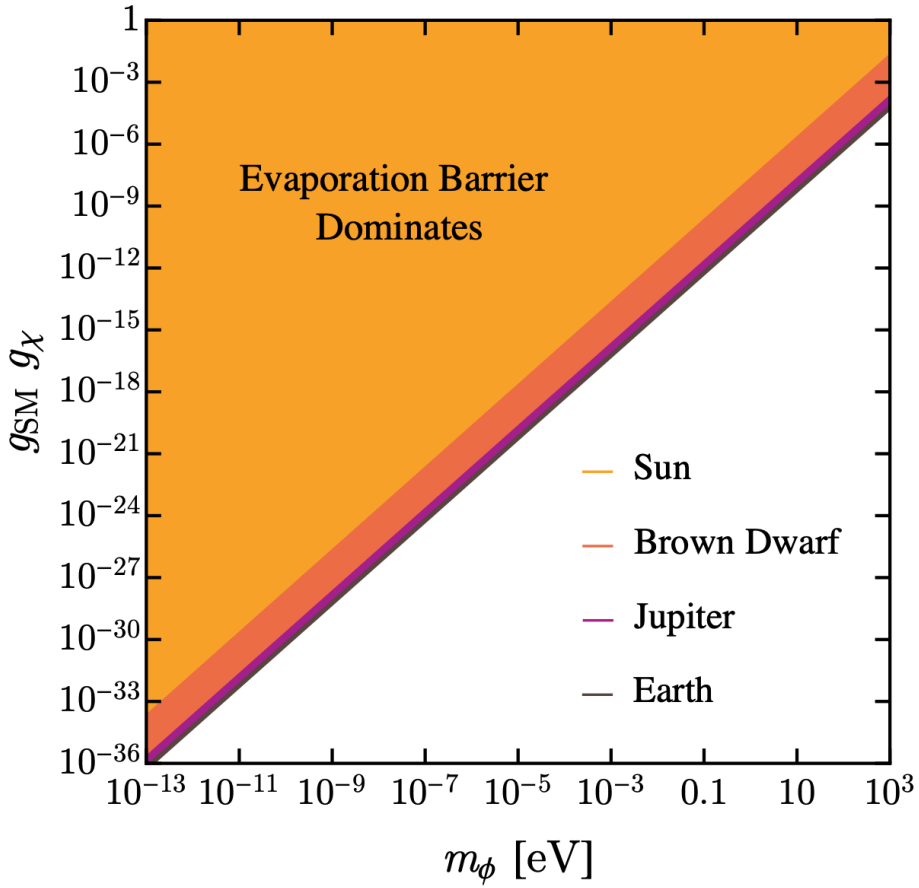
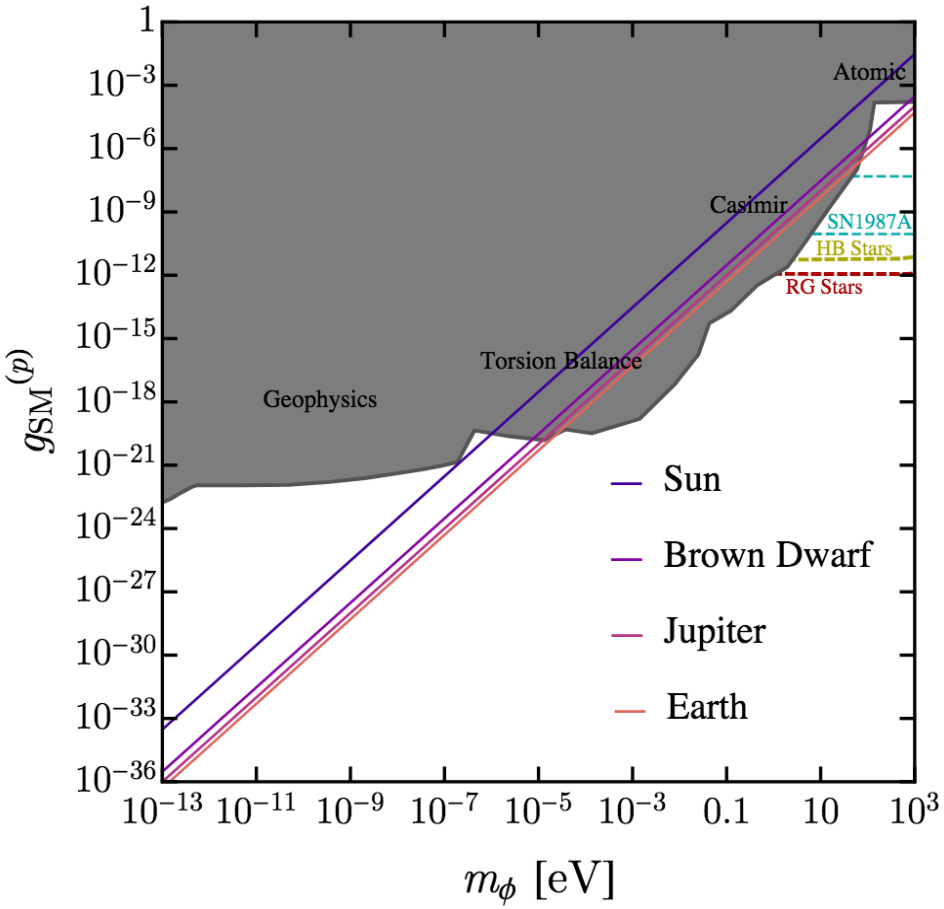



map to specific model

proton coupling



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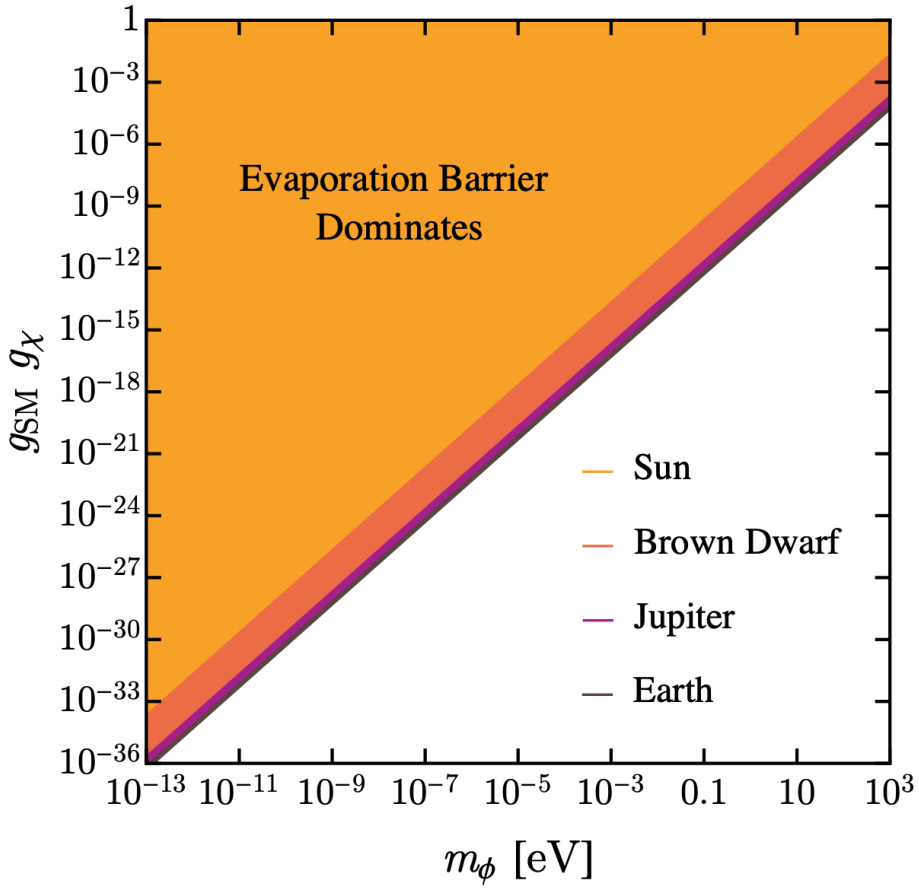


map to
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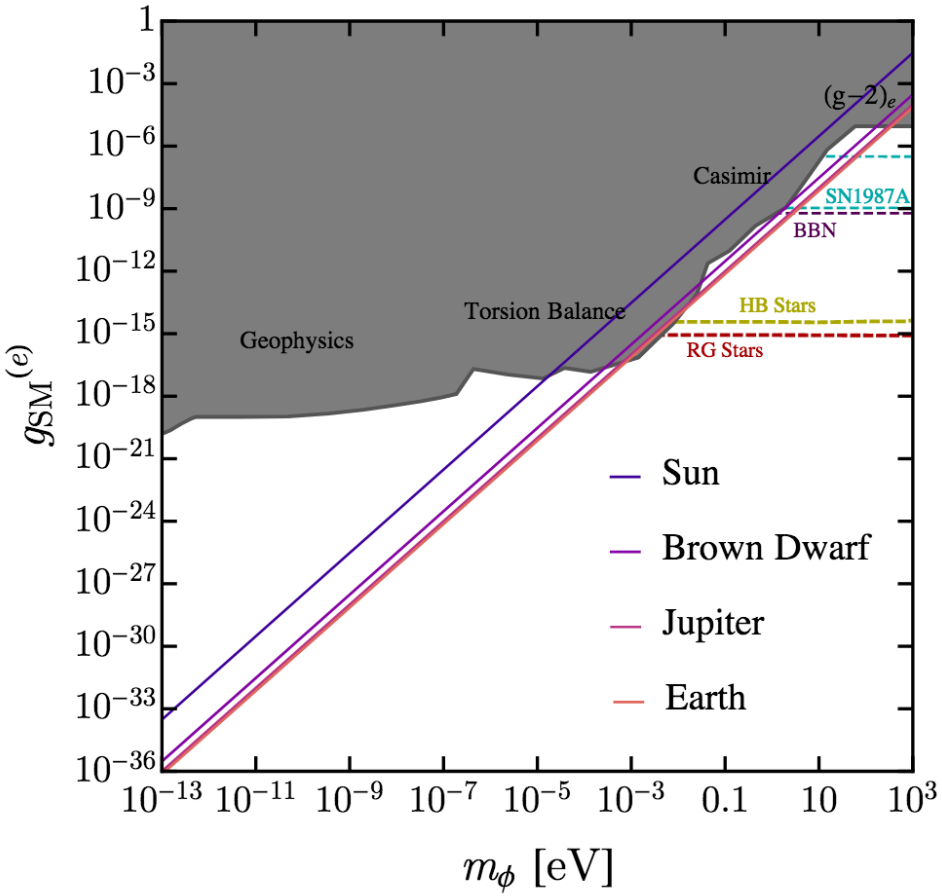
electron coupling

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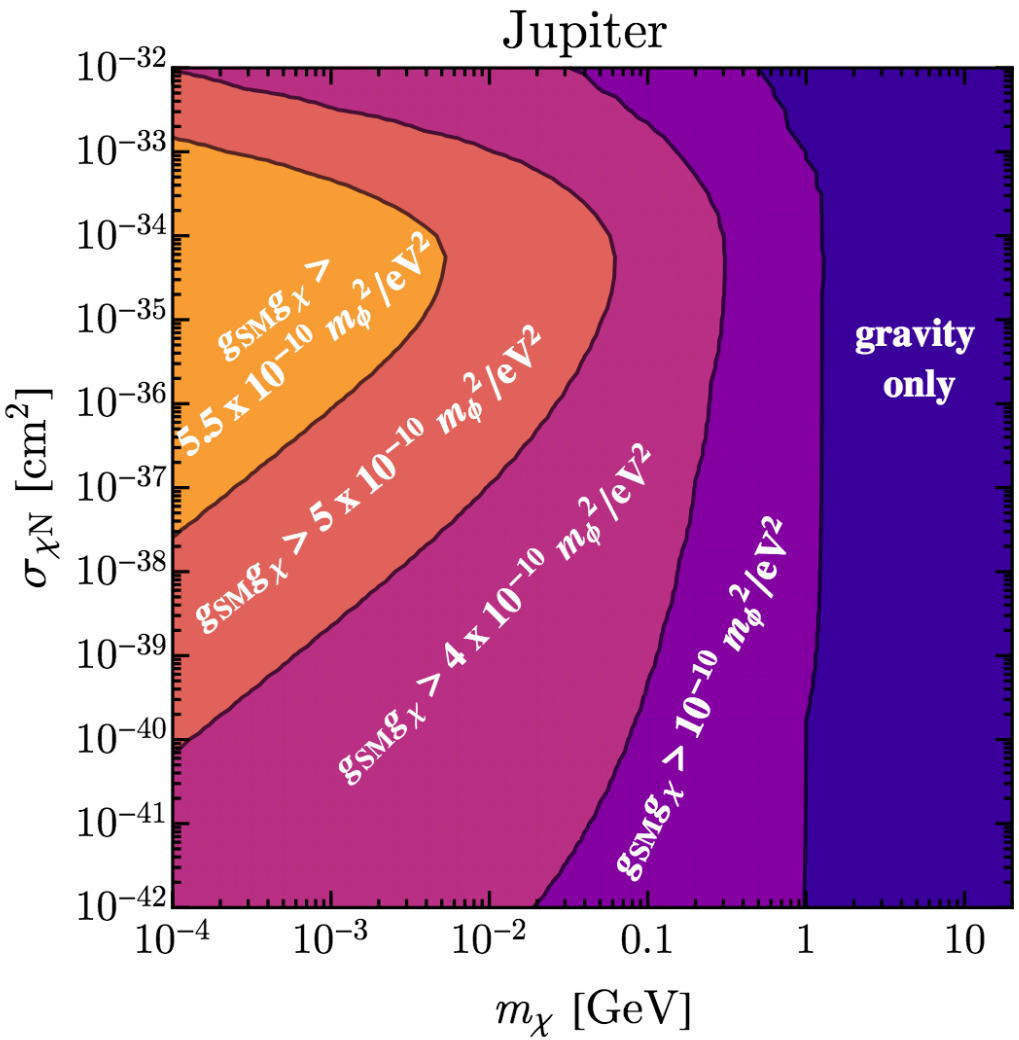
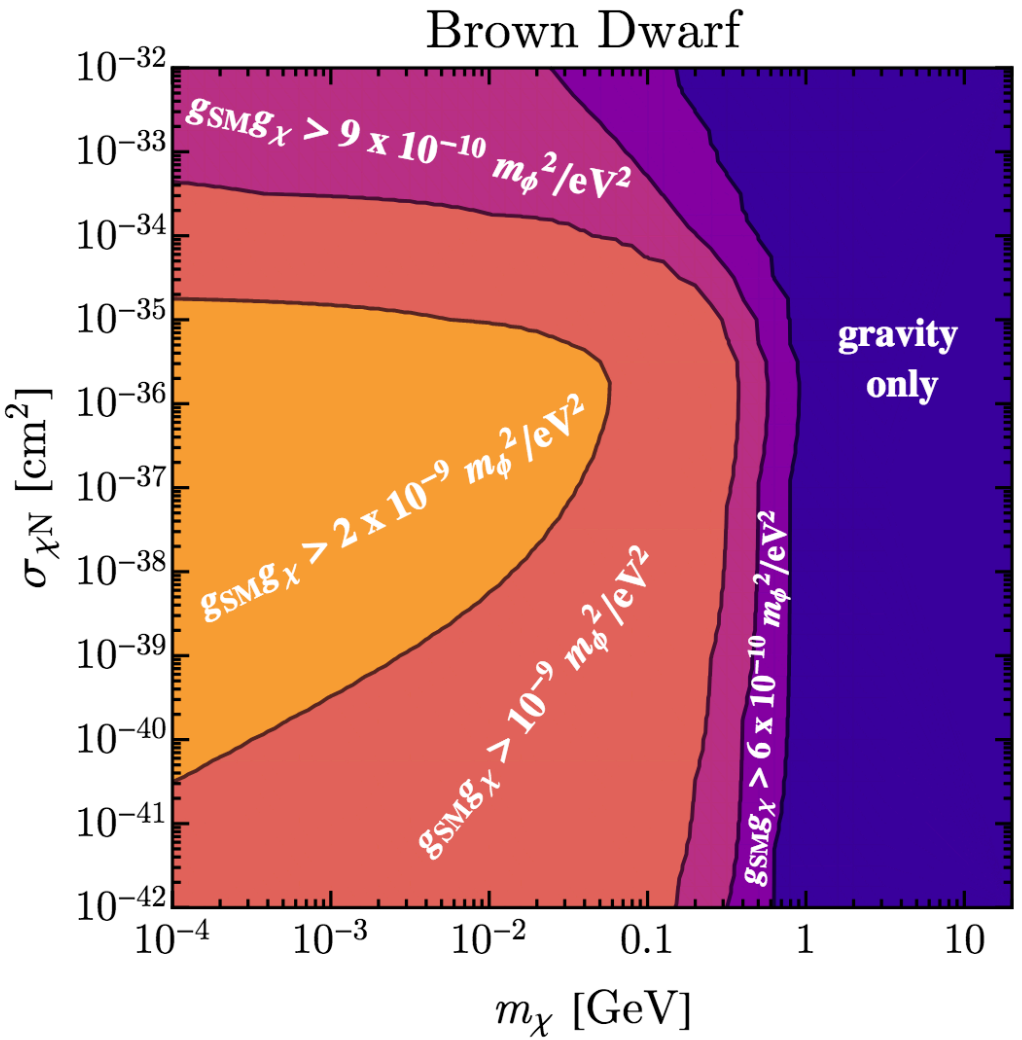
# New Parameter Space - Jupiter & Brown Dwarfs

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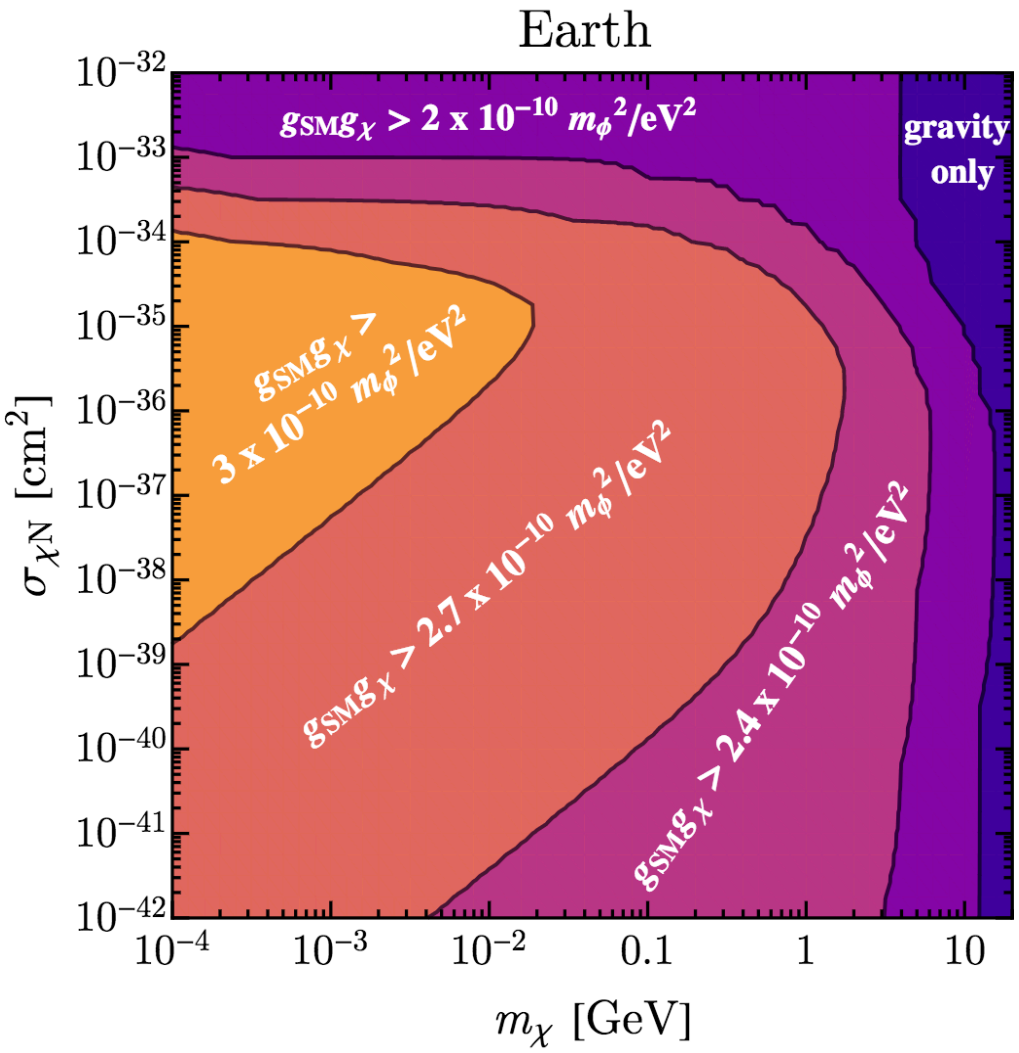
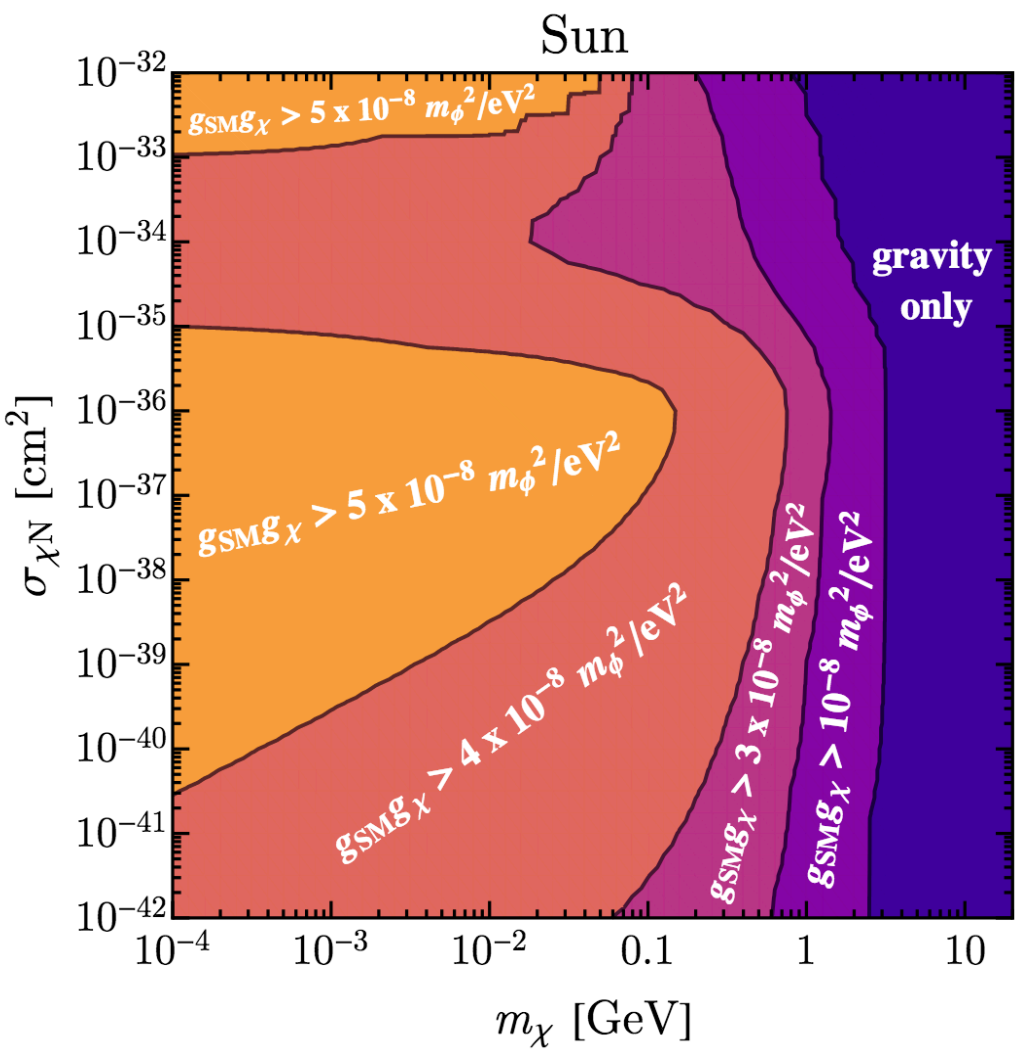
# New Parameter Space - Earth & Sun

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# Final Remarks

- We have shown for the first time that the evaporation mass is highly model-dependent.

- Barrier effect from light mediators opens up several orders of magnitude for DM searches in celestial objects.

- Data from celestial objects should be analyzed to the fullest extent that experimental thresholds allow (i.e. no cutoffs at the usually quoted evaporation mass).