

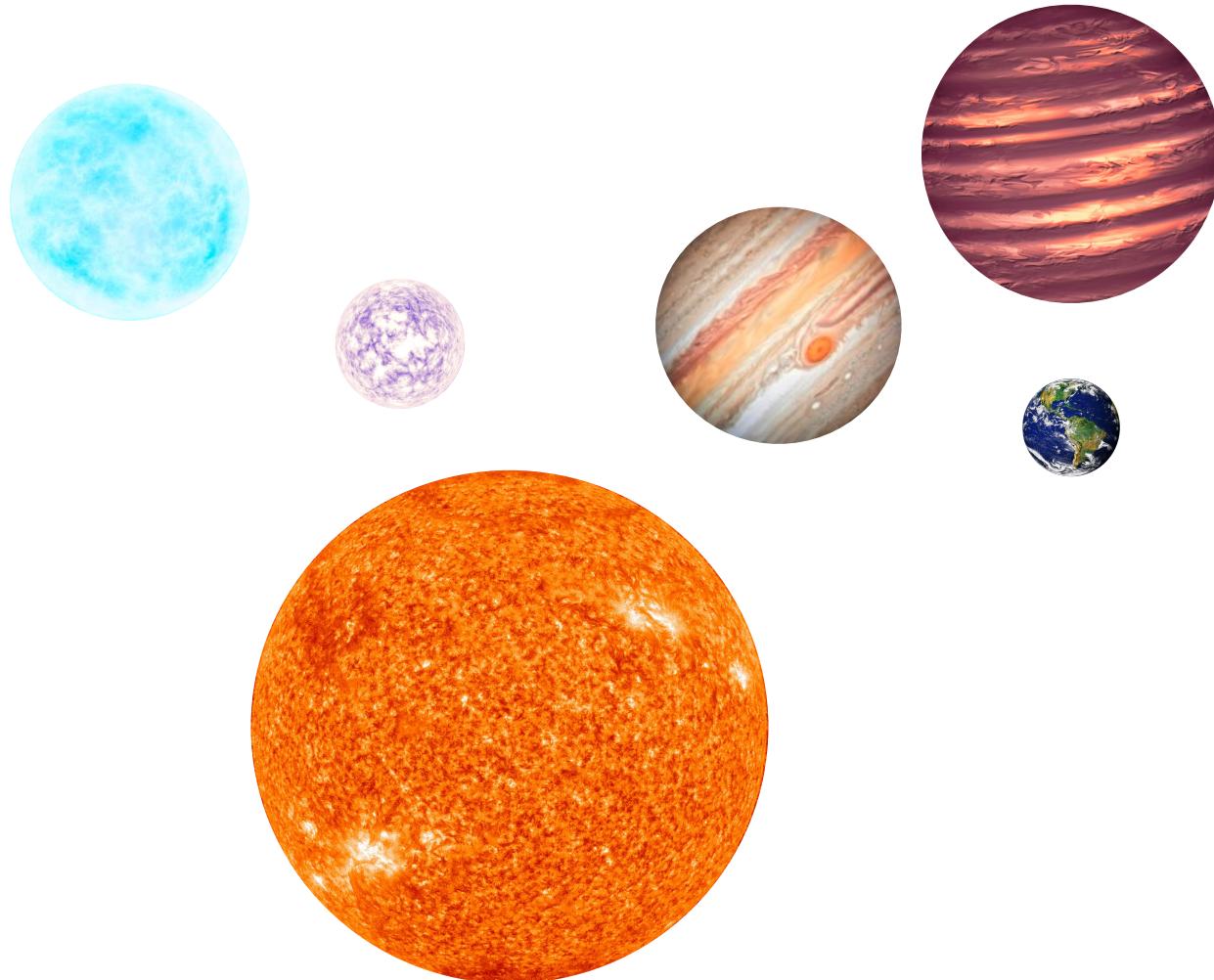
Evaporation Barrier for Dark Matter in Celestial Bodies

Javier F. Acevedo

May 9th 2023

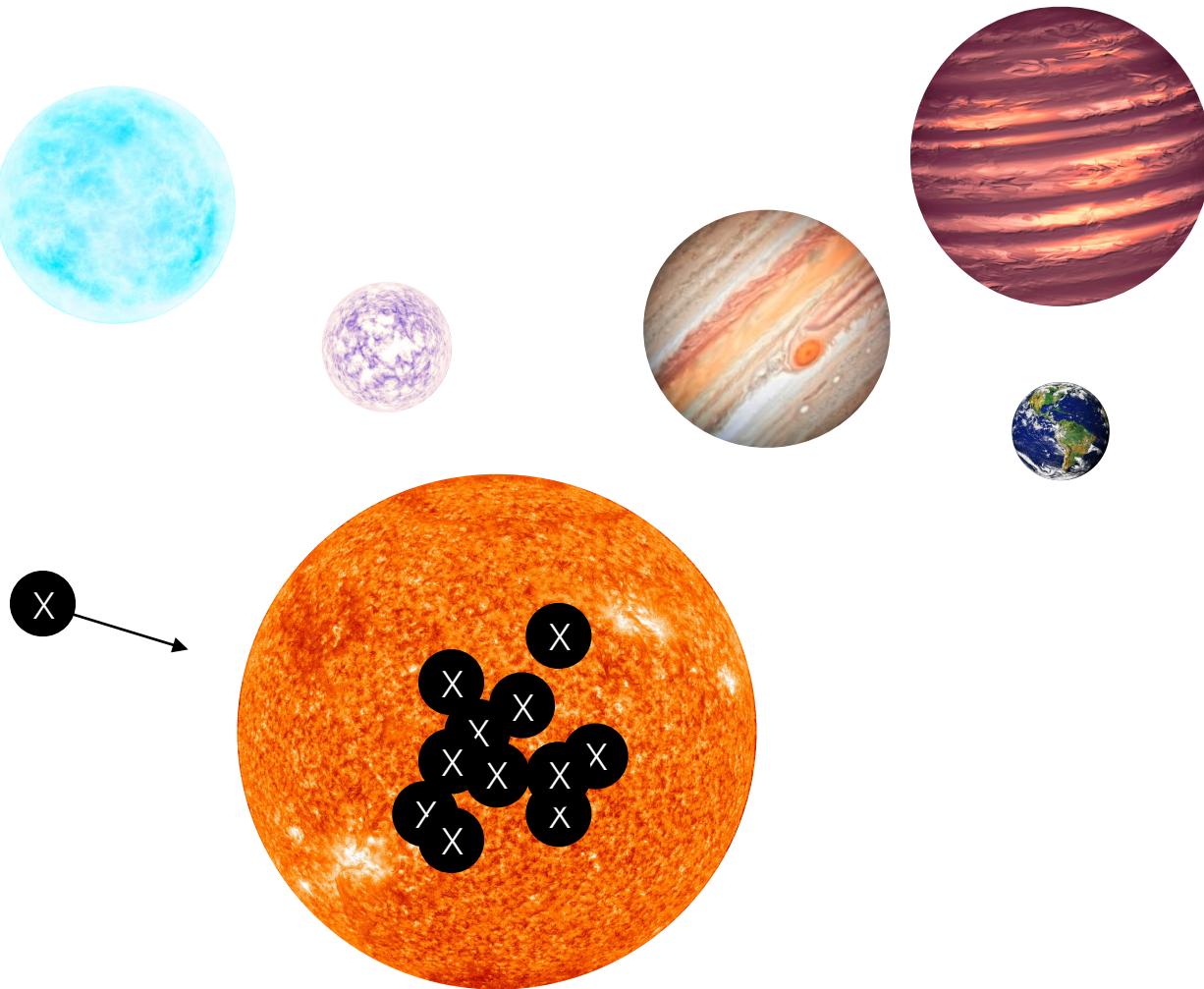
Based on: **2303.01516** w/ Rebecca Leane & Juri Smirnov

Celestial bodies as dark matter probes



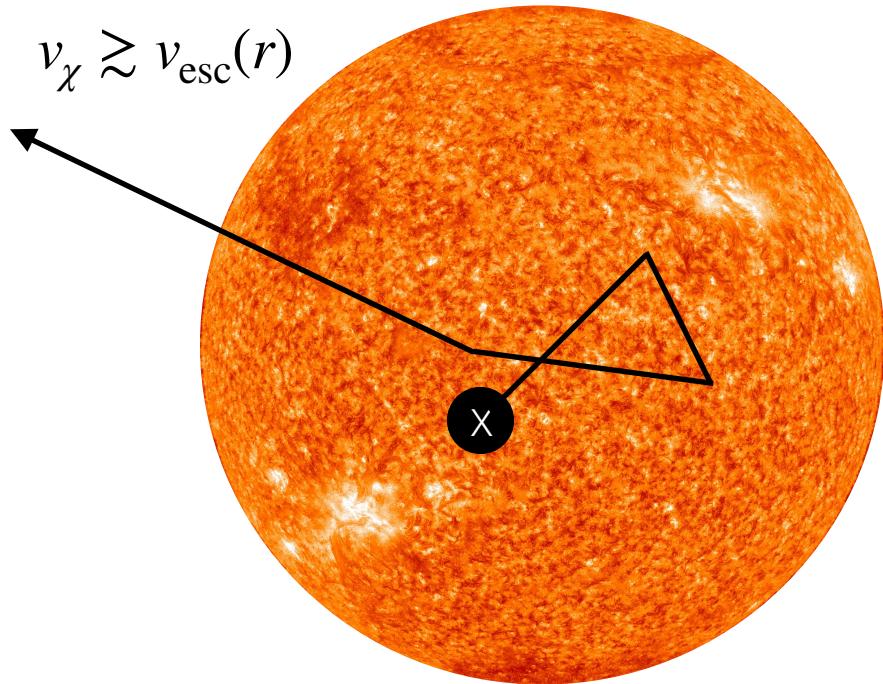
- Kinetic heating
- Stellar transients
- Annihilation to various states
- Transport processes
- Gravitational waves

Celestial bodies as dark matter probes



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

Dark matter evaporation

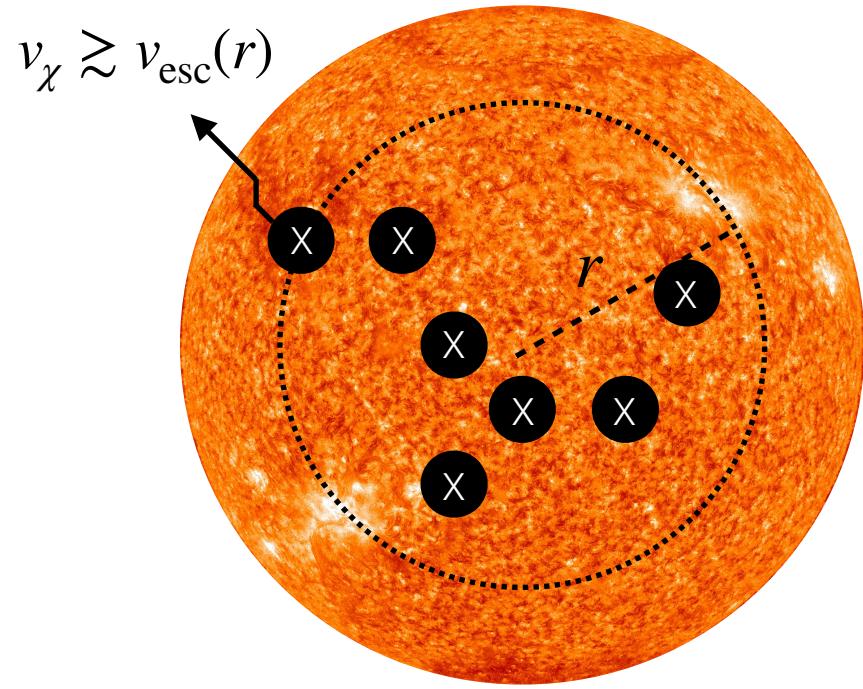


Evaporation: thermal upscattering
of the DM to the escape velocity

e.g. for the Sun:

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

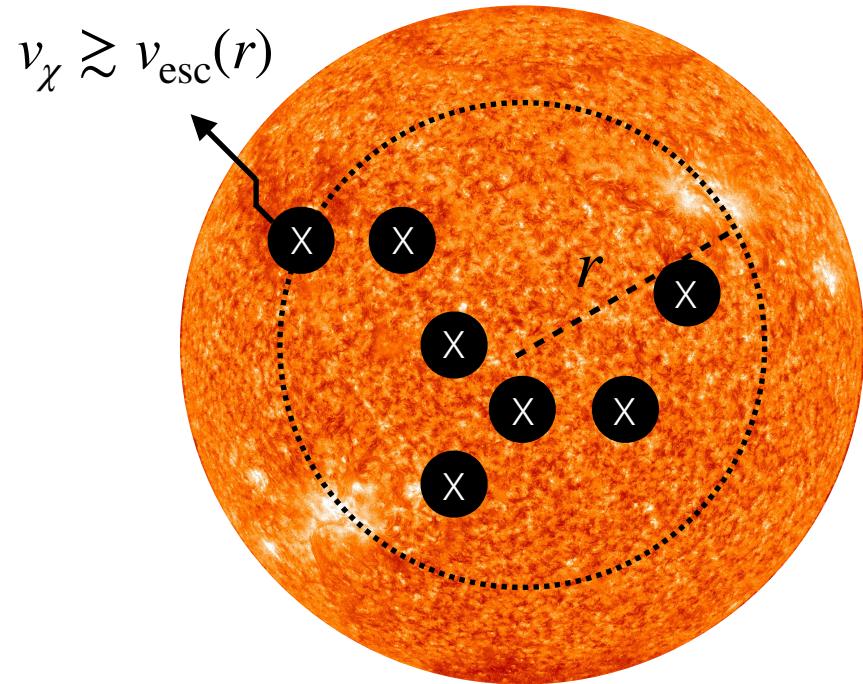
Dark matter evaporation



Accurate evaporation rate:

$$\Gamma_{\text{evap}} \propto \exp\left(-\frac{m_\chi \phi_{\text{grav}}(r)}{T_*(r)}\right) \exp(-\tau(r))$$

Dark matter evaporation

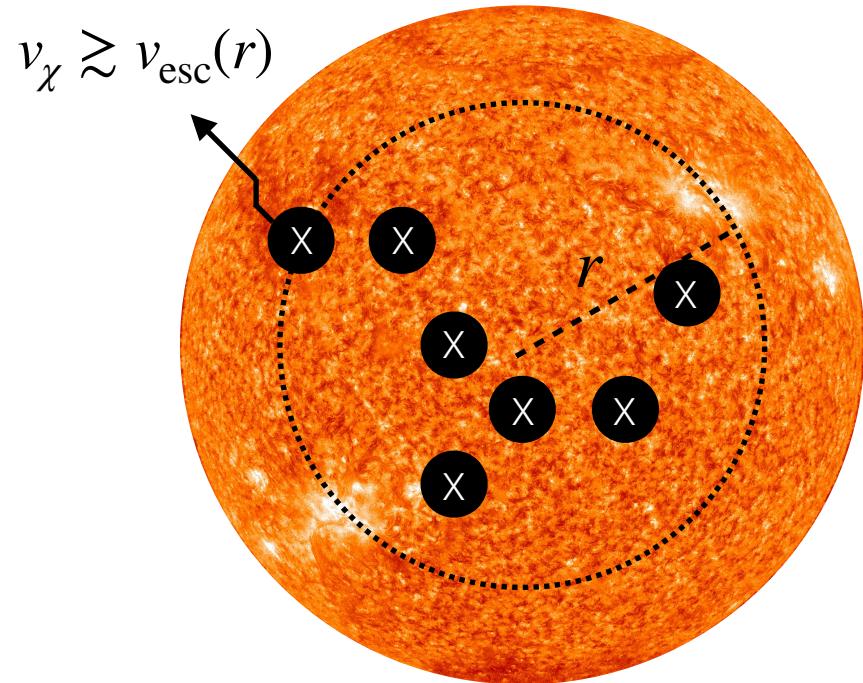


Accurate evaporation rate:

$$\Gamma_{\text{evap}} \propto \exp\left(-\frac{m_\chi \phi_{\text{grav}}(r)}{T_*(r)}\right) \exp(-\tau(r))$$

escape energy vs.
temperature

Dark matter evaporation



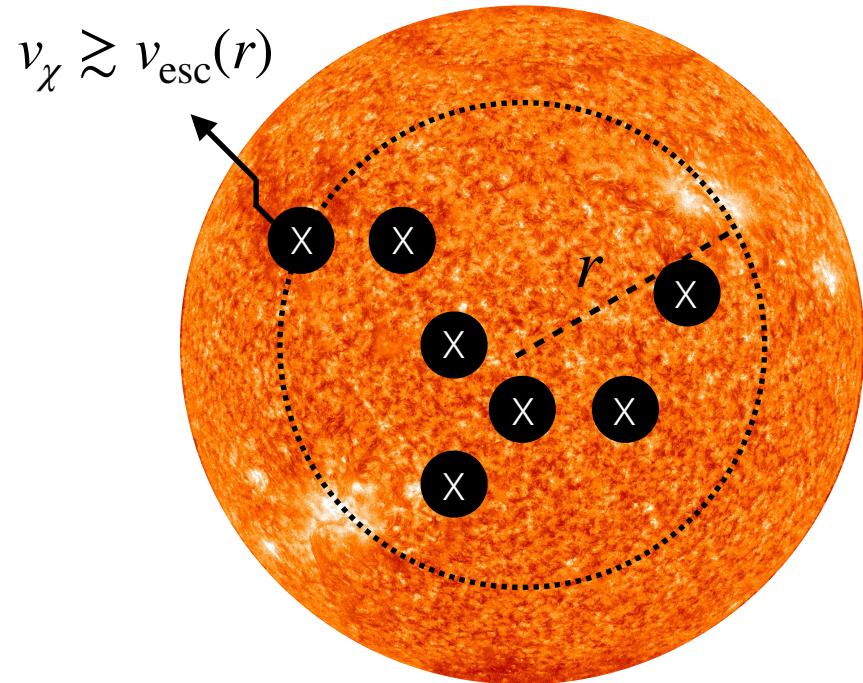
Accurate evaporation rate:

$$\Gamma_{\text{evap}} \propto \exp\left(-\frac{m_\chi \phi_{\text{grav}}(r)}{T_*(r)}\right) \exp(-\tau(r))$$

escape energy vs.
temperature

optical depth to
surface

Dark matter evaporation



Accurate evaporation rate:

$$\Gamma_{\text{evap}} \propto \exp\left(-\frac{m_\chi \phi_{\text{grav}}(r)}{T_*(r)}\right) \exp(-\tau(r))$$

escape energy vs.
temperature

optical depth to
surface

Usual assumptions:

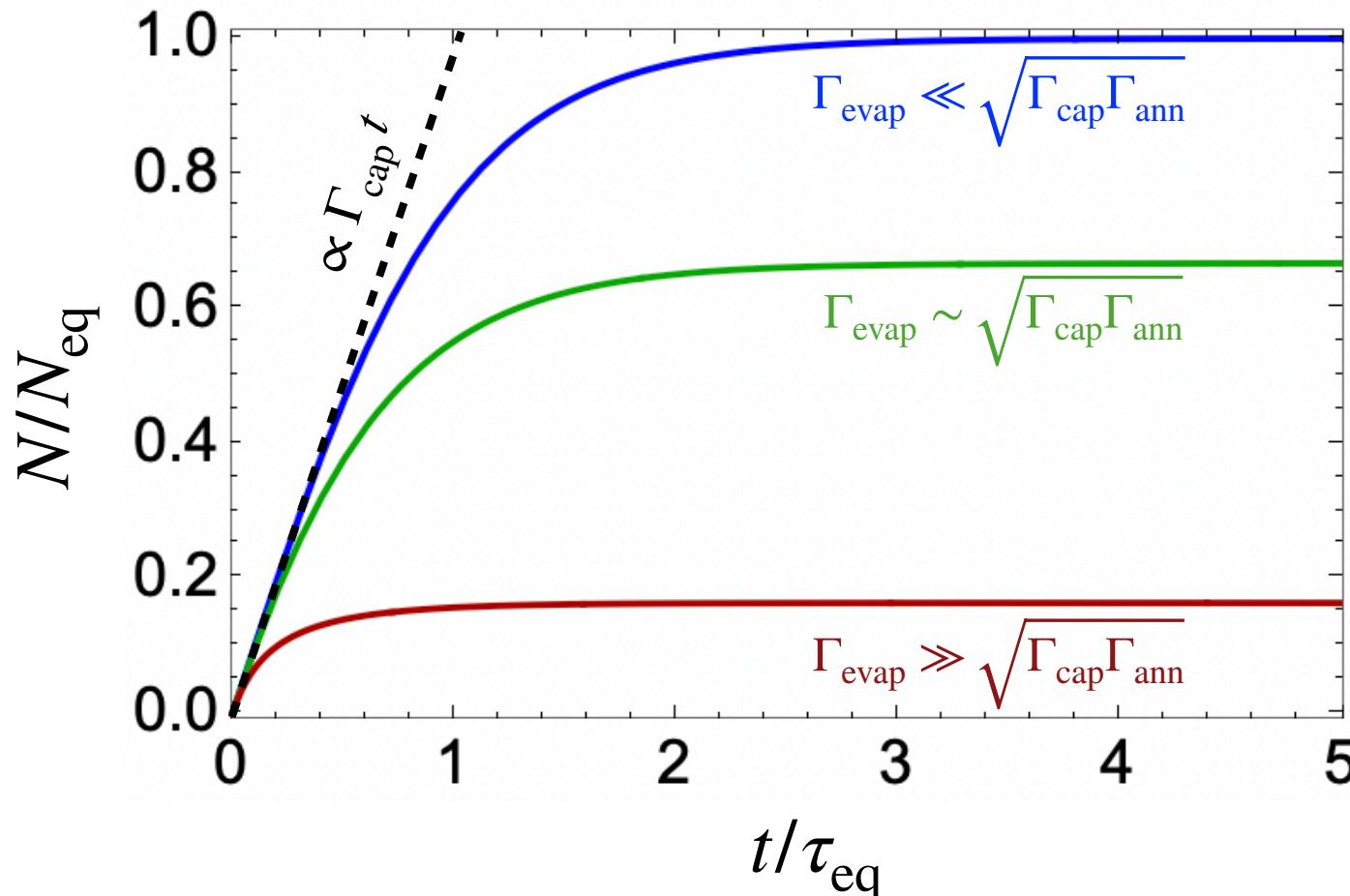
- DM-SM contact interactions
- Only gravity and temperature matters

Computing the evaporation mass

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

Computing the evaporation mass

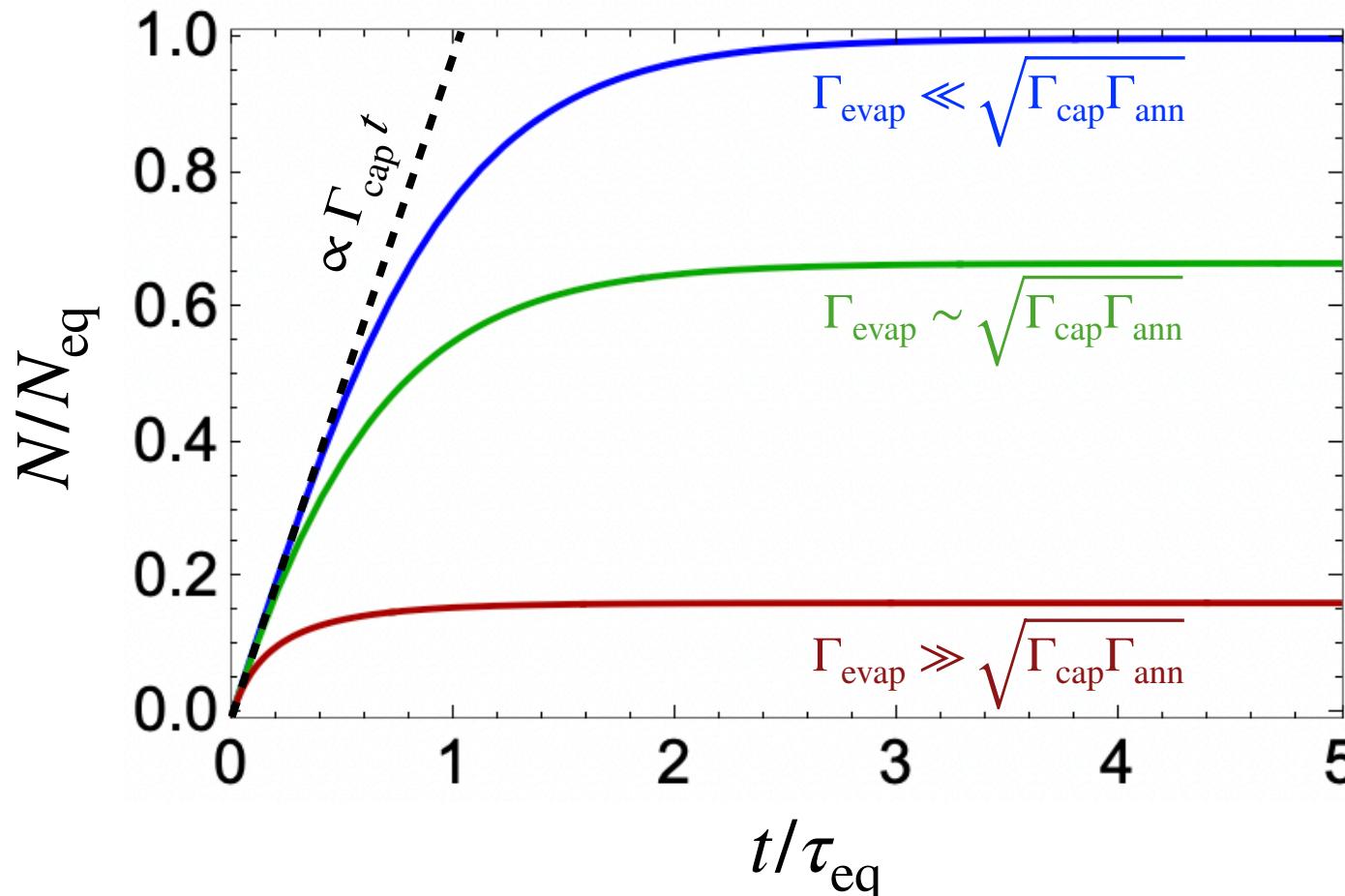
Evolution of net DM number given by: $\frac{dN_\chi}{dt} = \Gamma_{\text{cap}} - \Gamma_{\text{evap}}N_\chi - \Gamma_{\text{ann}}N_\chi^2$



Computing the evaporation mass

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

for the Sun:



$$m_\chi \simeq 3.21 \text{ GeV}$$

$$m_\chi \simeq 3.20 \text{ GeV}$$

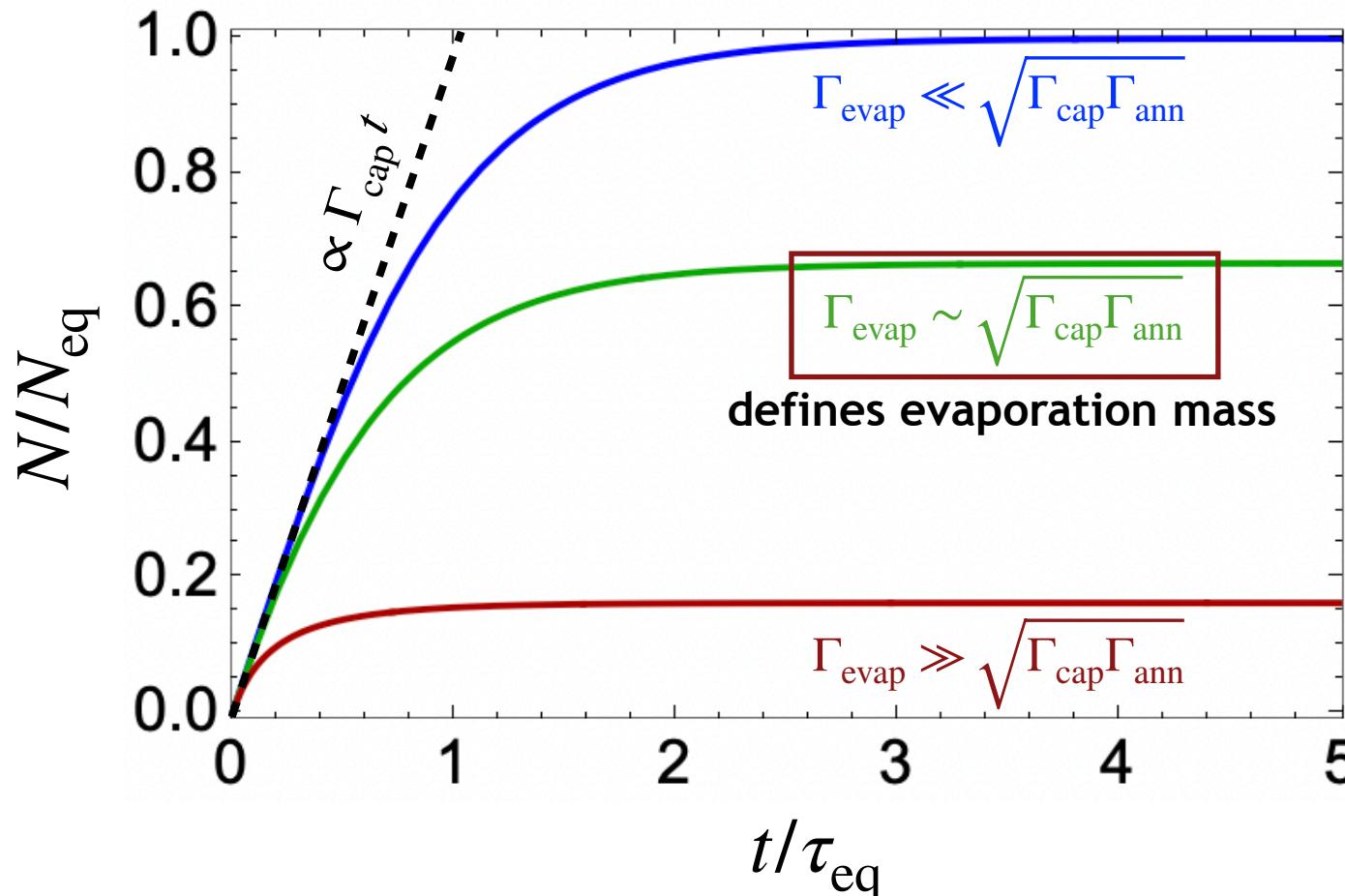
$$m_\chi \simeq 3.19 \text{ GeV}$$

(at cross-section $\sim 10^{-35} \text{ cm}^2$)

Computing the evaporation mass

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

for the Sun:



$$m_\chi \simeq 3.21 \text{ GeV}$$

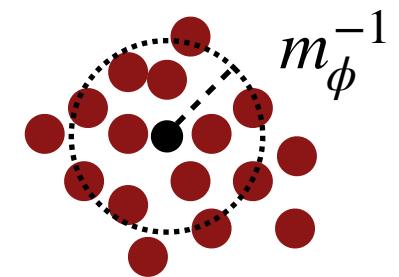
$$m_\chi \simeq 3.20 \text{ GeV}$$

$$m_\chi \simeq 3.19 \text{ GeV}$$

(at cross-section $\sim 10^{-35} \text{ cm}^2$)

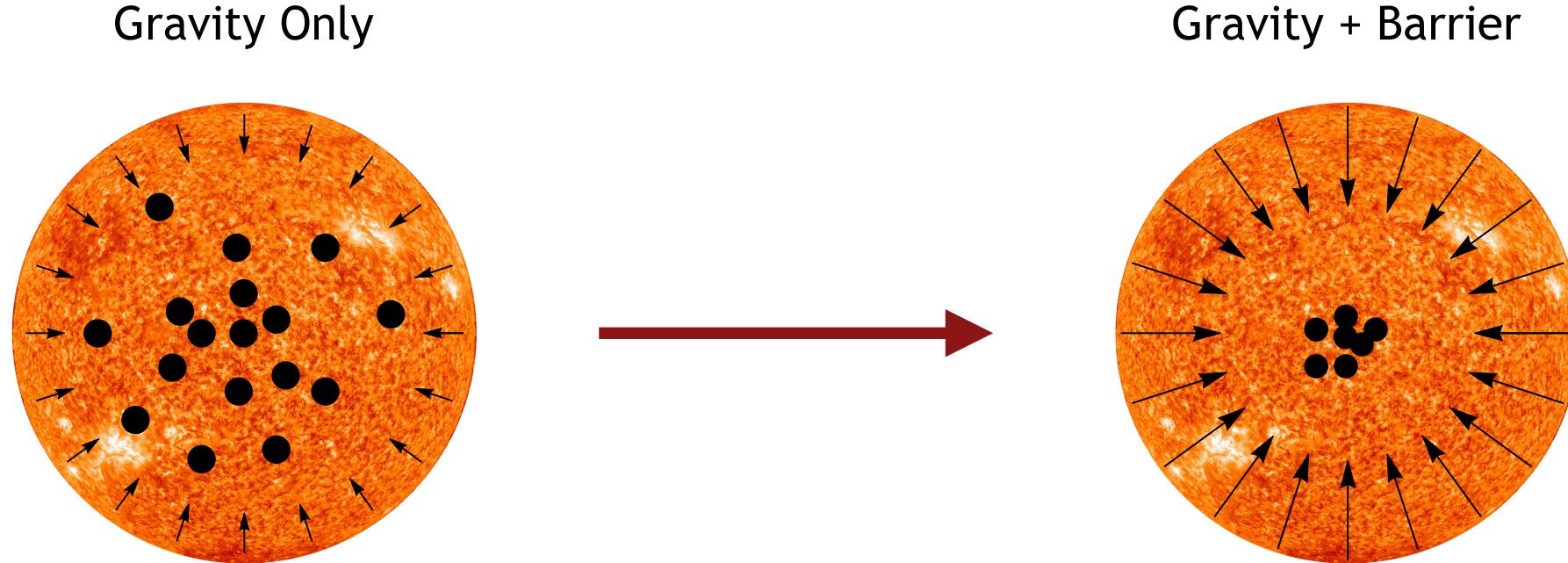
Evaporation Barrier

- Light scalars and vectors (w/ correct charge assignment) mediate long-range DM-SM attractive forces.
- DM particles “see” the large density of particles in celestial objects.
- Celestial objects source a potential for the DM:



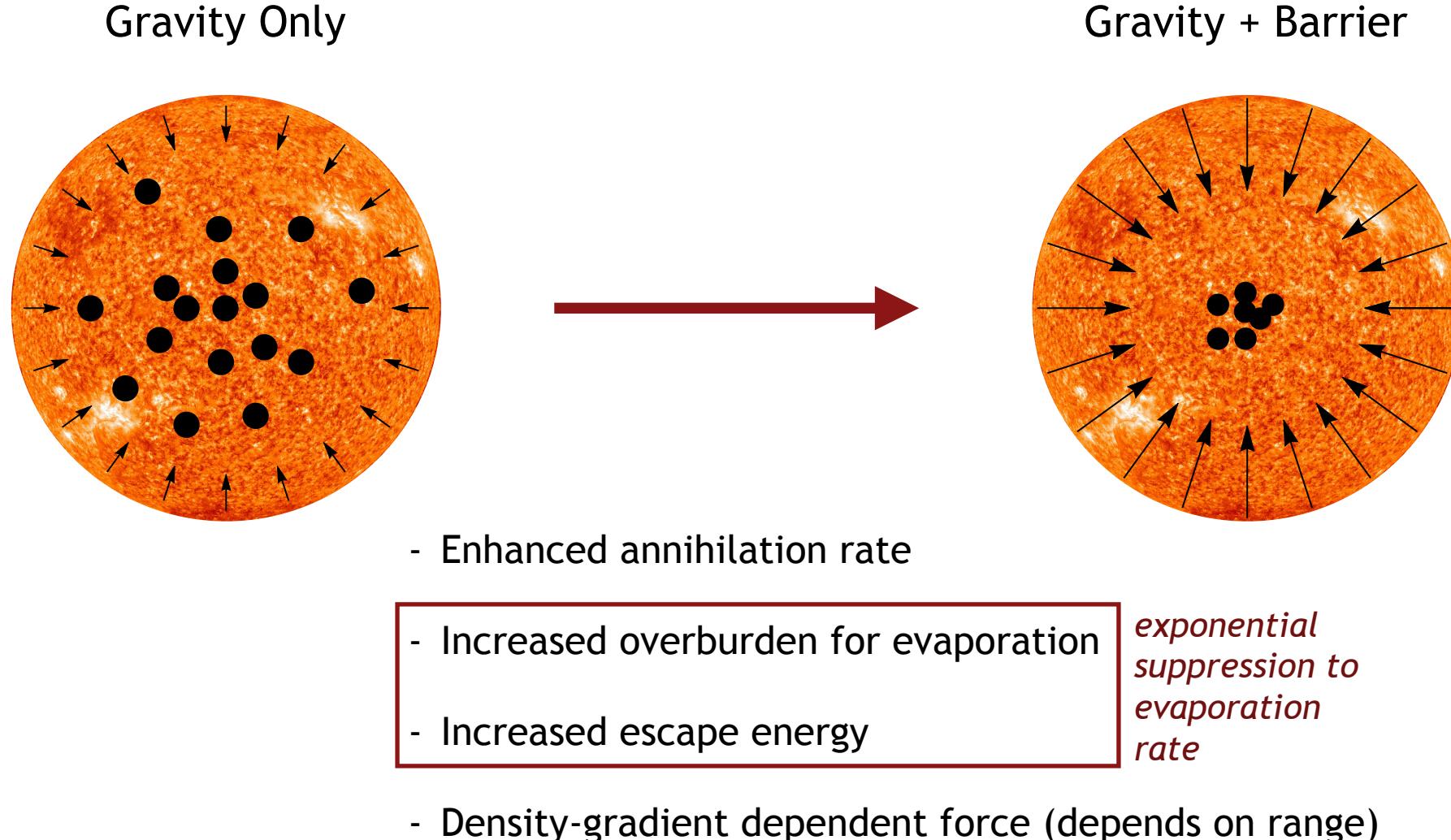
$$\phi_{\text{barrier}}(r) = \phi_{\text{barrier}}(0) \left[\frac{\sinh(m_\phi r)}{m_\phi r} \right] + g_{\text{SM}} g_\chi \int_0^r \left[\frac{\sinh(m_\phi(r-s))}{m_\phi r} \right] s n_{\text{SM}}(s) ds$$

Evaporation Barrier



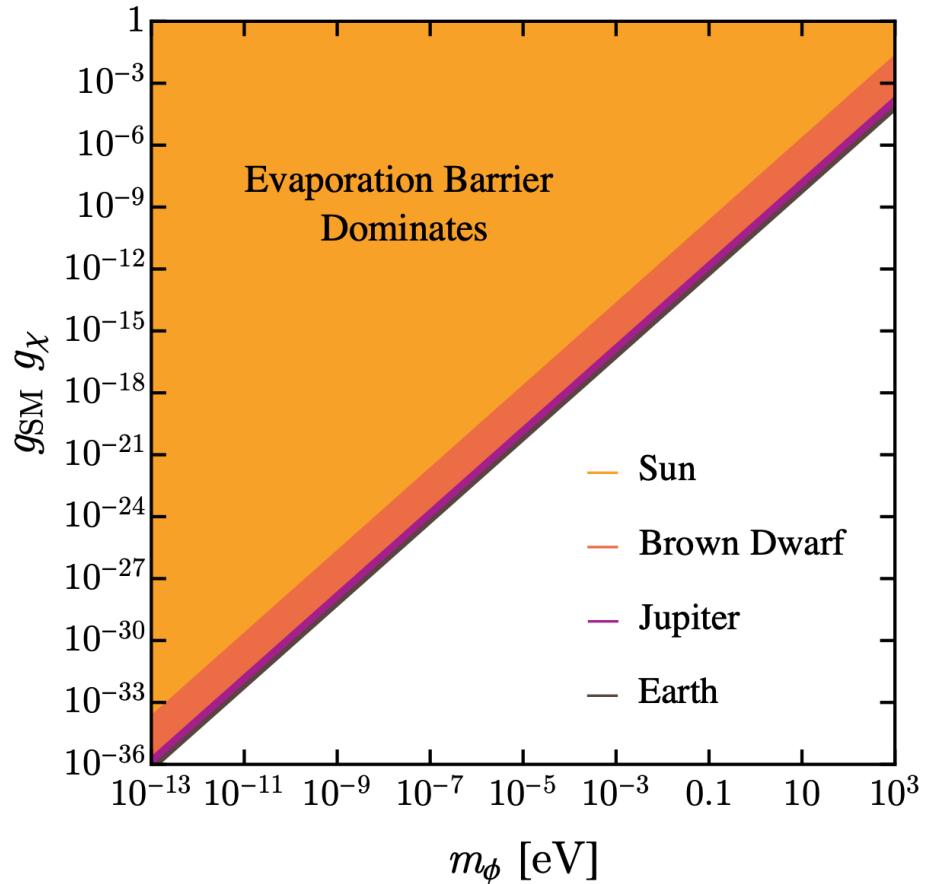
- Enhanced annihilation rate
- Increased overburden for evaporation
- Increased escape energy
- Density-gradient dependent force (depends on range)

Evaporation Barrier



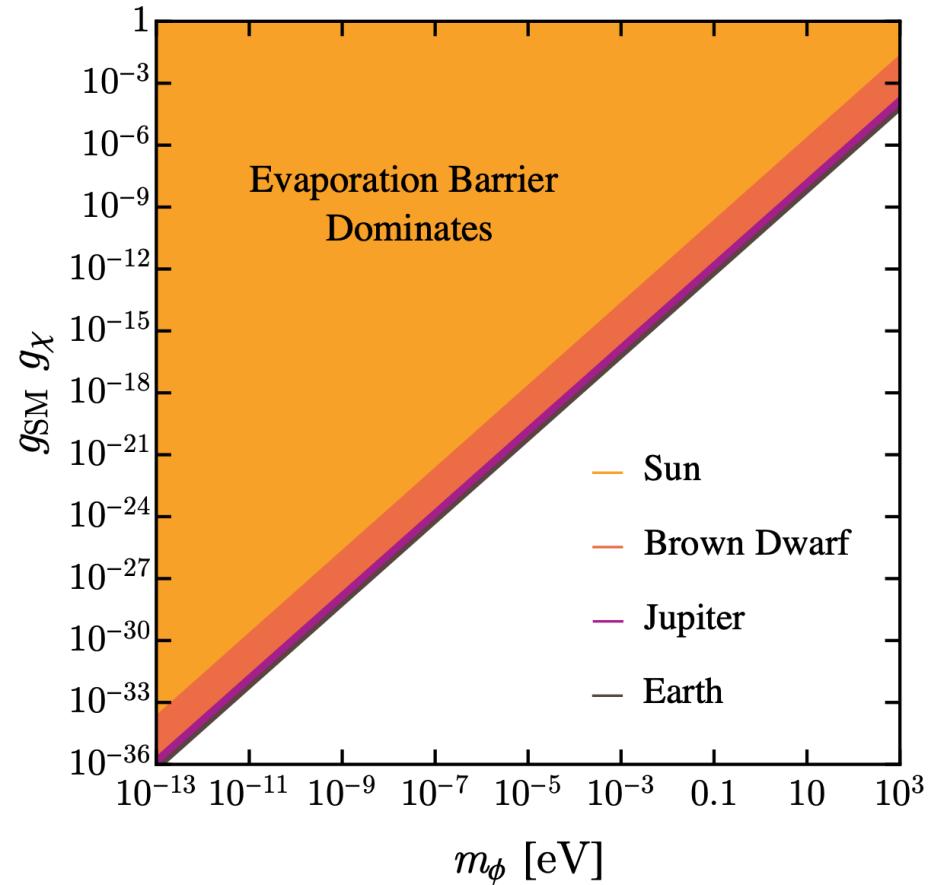
Evaporation Barrier

Evaporation mass changes when $\phi_{\text{barrier}}(r) \gtrsim m_\chi^{\text{evap}} \phi_{\text{grav}}(r)$



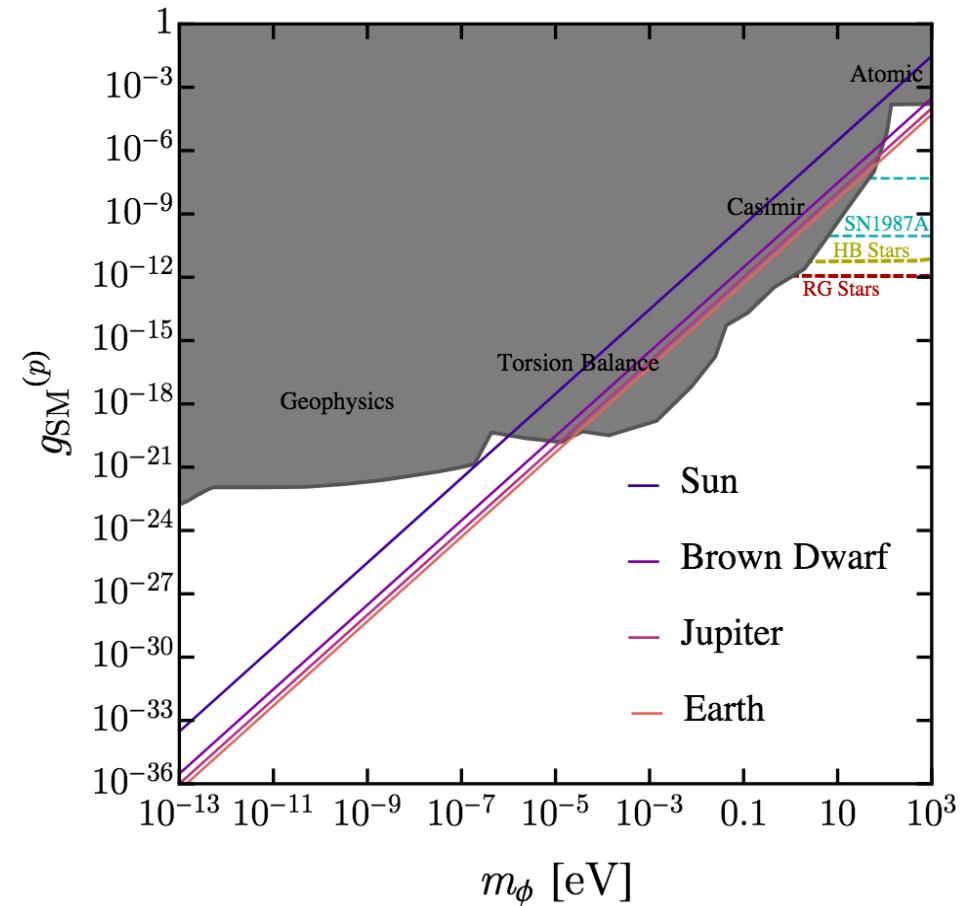
Evaporation Barrier

Evaporation mass changes when $\phi_{\text{barrier}}(r) \gtrsim m_\chi^{\text{evap}} \phi_{\text{grav}}(r)$



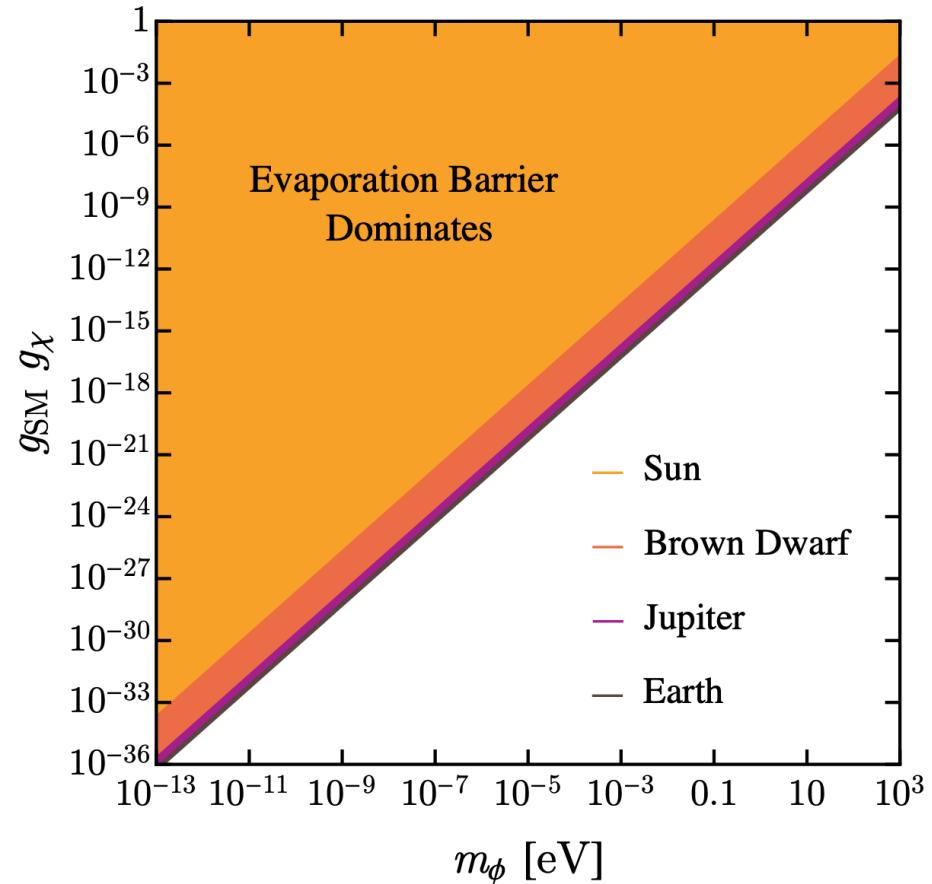
map to
specific model

proton coupling

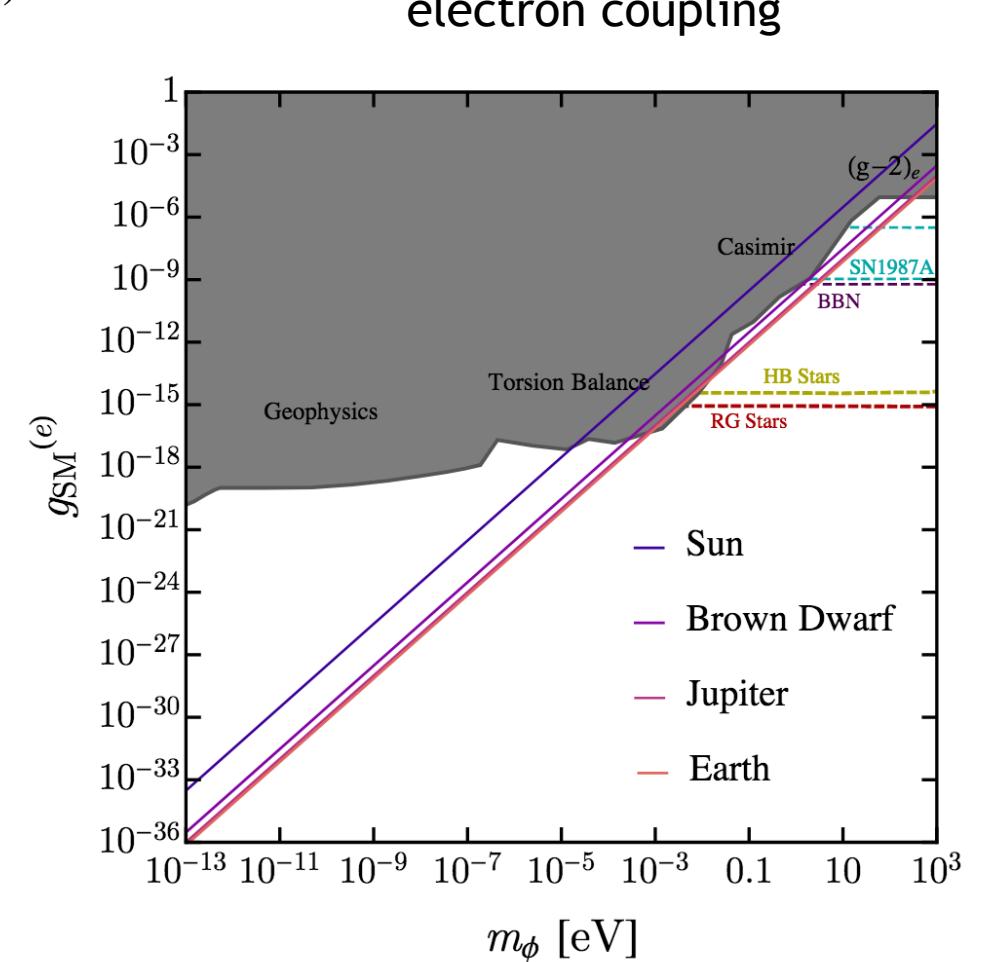


Evaporation Barrier

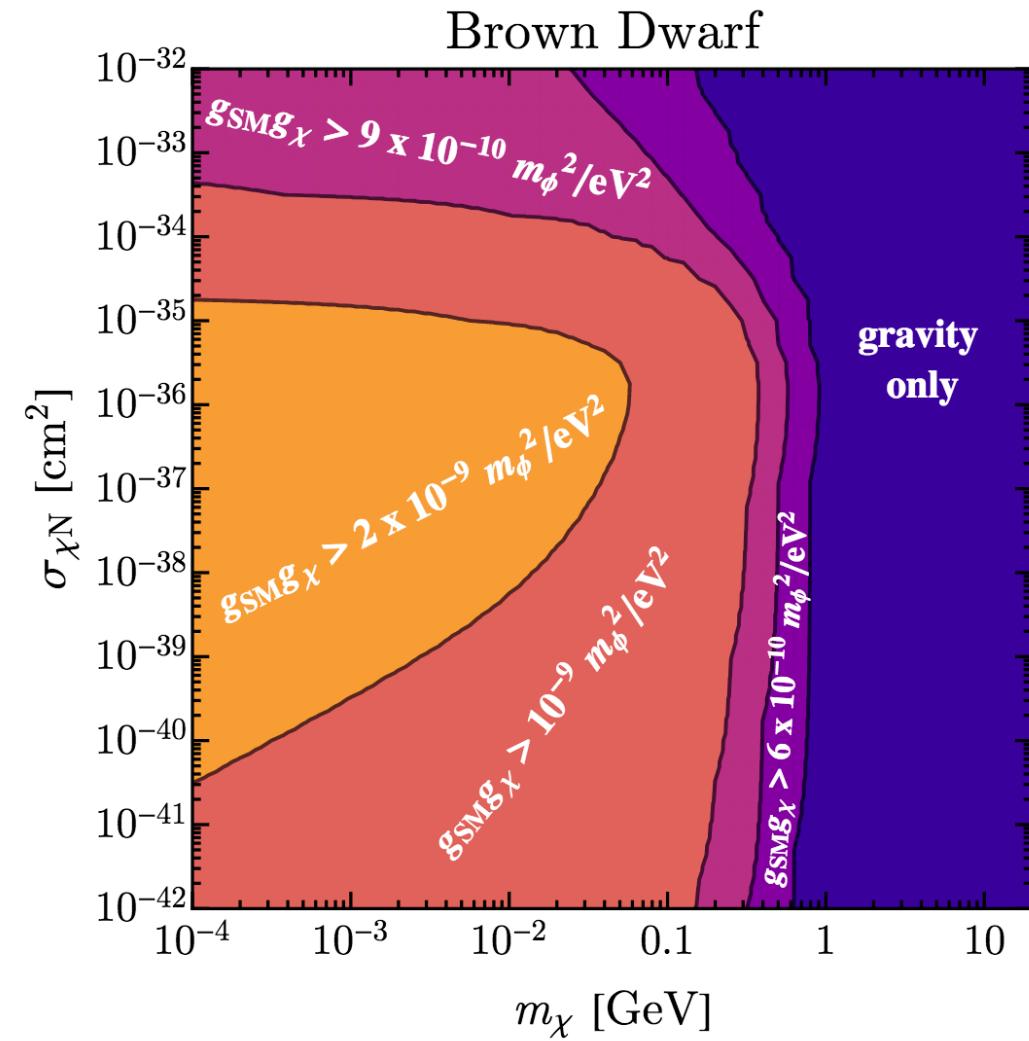
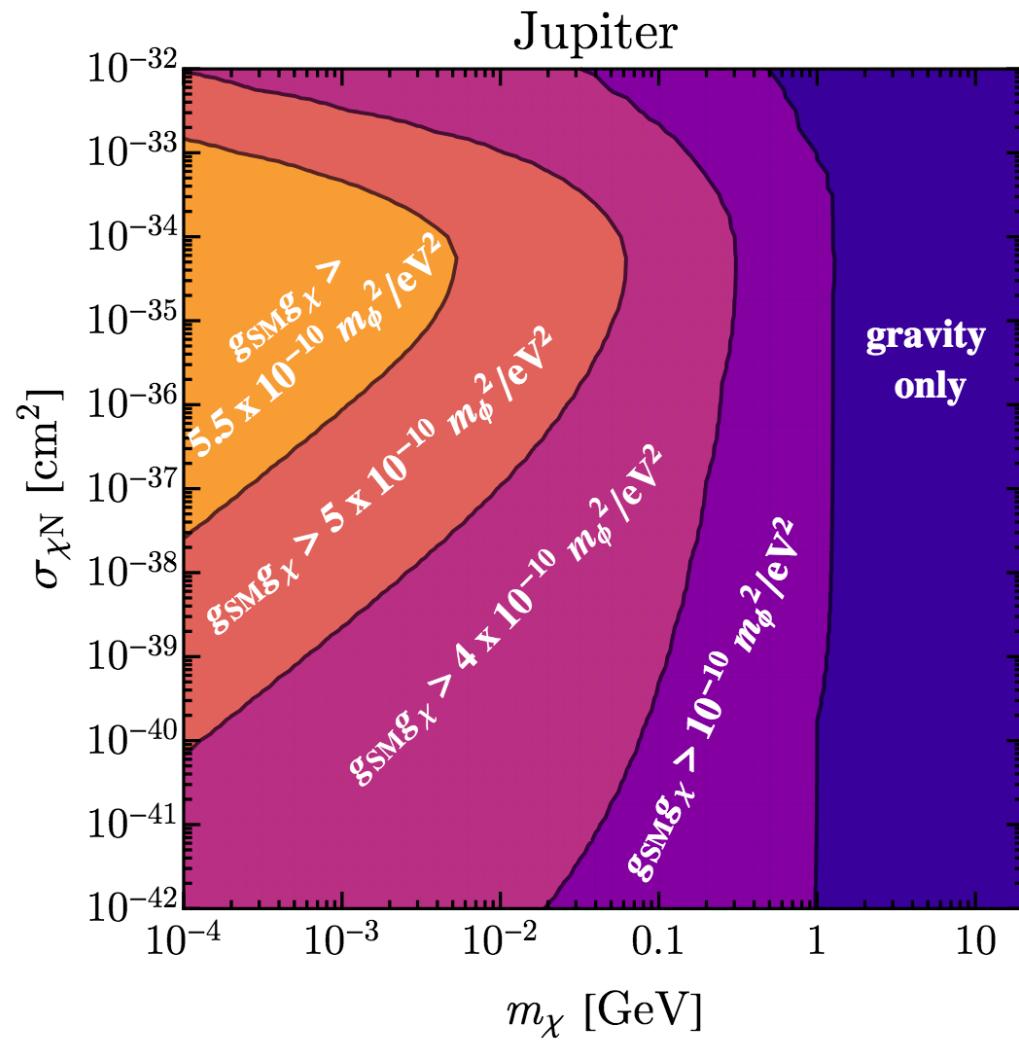
Evaporation mass changes when $\phi_{\text{barrier}}(r) \gtrsim m_\chi^{\text{evap}} \phi_{\text{grav}}(r)$



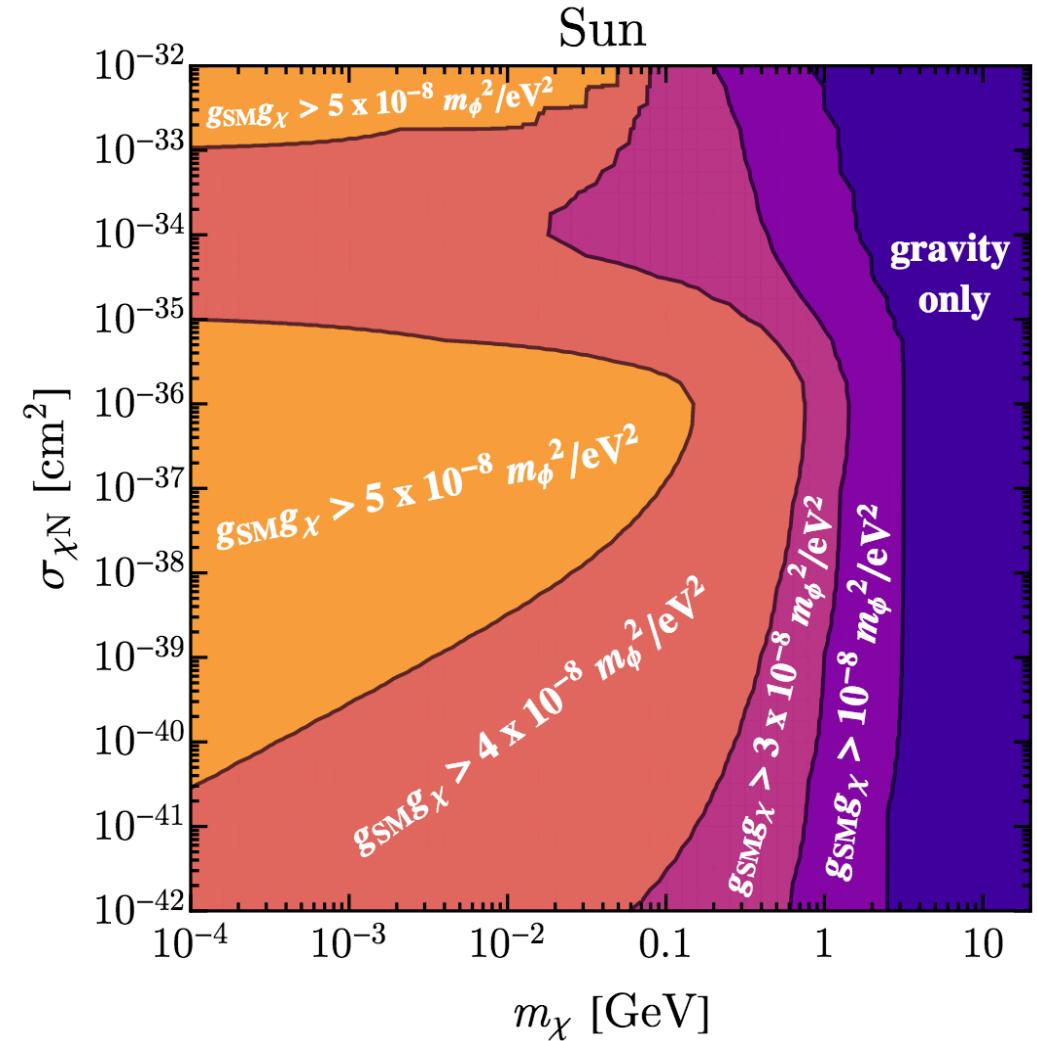
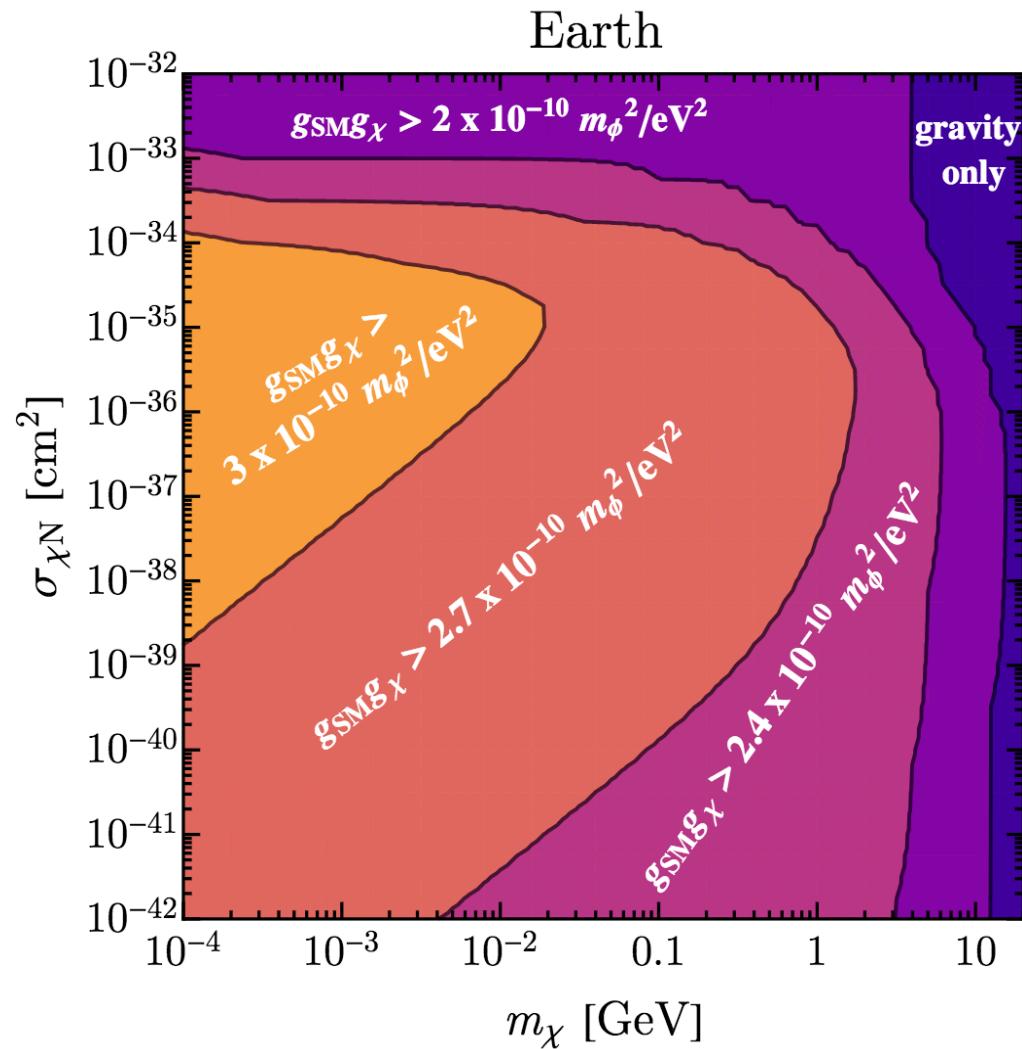
map to
specific model



New Parameter Space - Jupiter & Brown Dwarfs



New Parameter Space - Earth & Sun



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).