

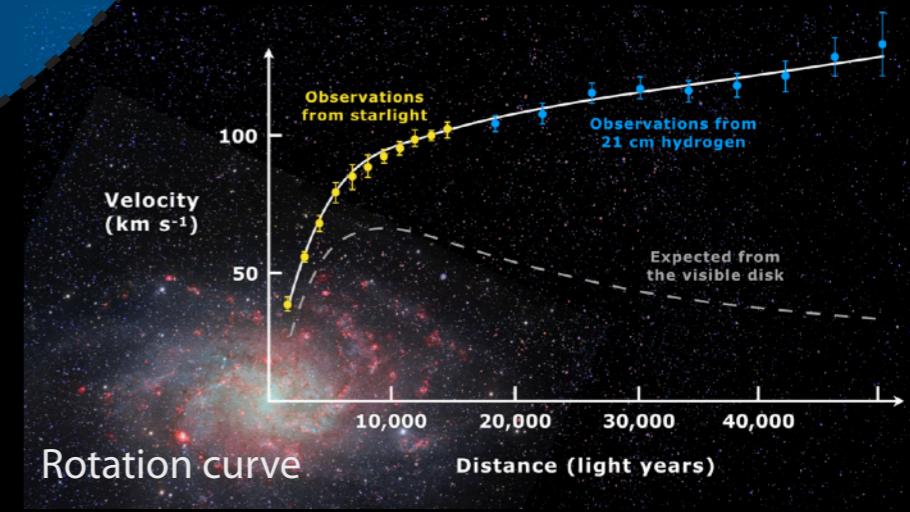
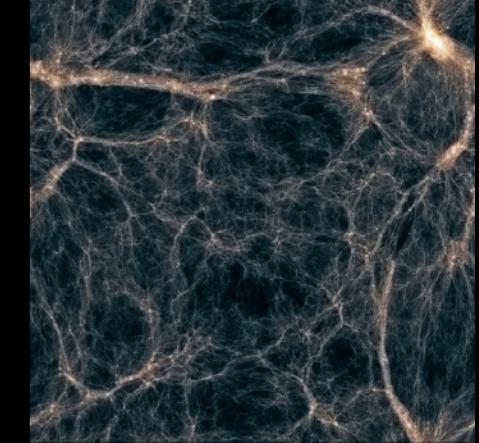
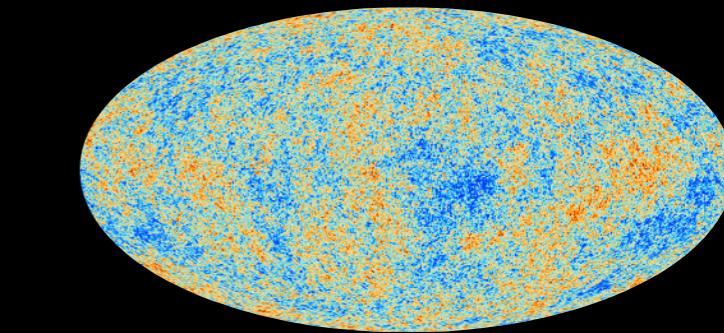
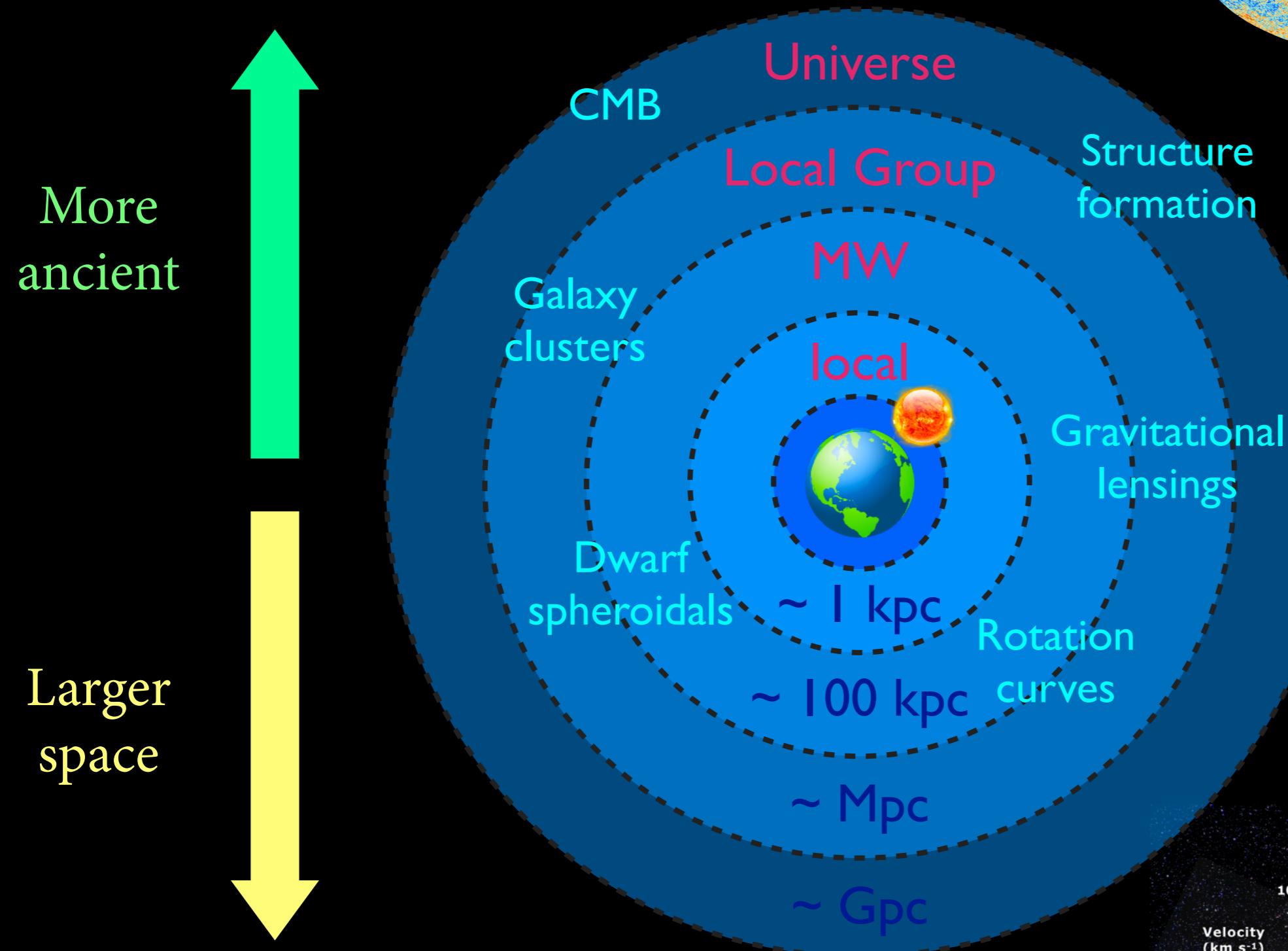
XVIII International Conference on Topics in Astroparticle and Underground Physics
Aug. 28 - Sep. 1, 2023, Vienna

Yen-Hsun Lin
Institute of Physics, Academia Sinica,
yenhsun@phys.ncku.edu.tw

in collaboration with
Guey-Lin Lin (NYCU), Tsung-Han Tsai (NTHU), Wen-Hua Wu (Rice U)
Meng-Ru Wu (AS) & Henry T.-K. Wong (AS)
PRL 130, 111002 (2023) [2206.06864] and 2307.03522

Searching light dark matter boosted by SN ν in Super-K, Hyper-K and DUNE

Dark matter is *ubiquitous* in the Universe!



The DM probes: m_χ & σ

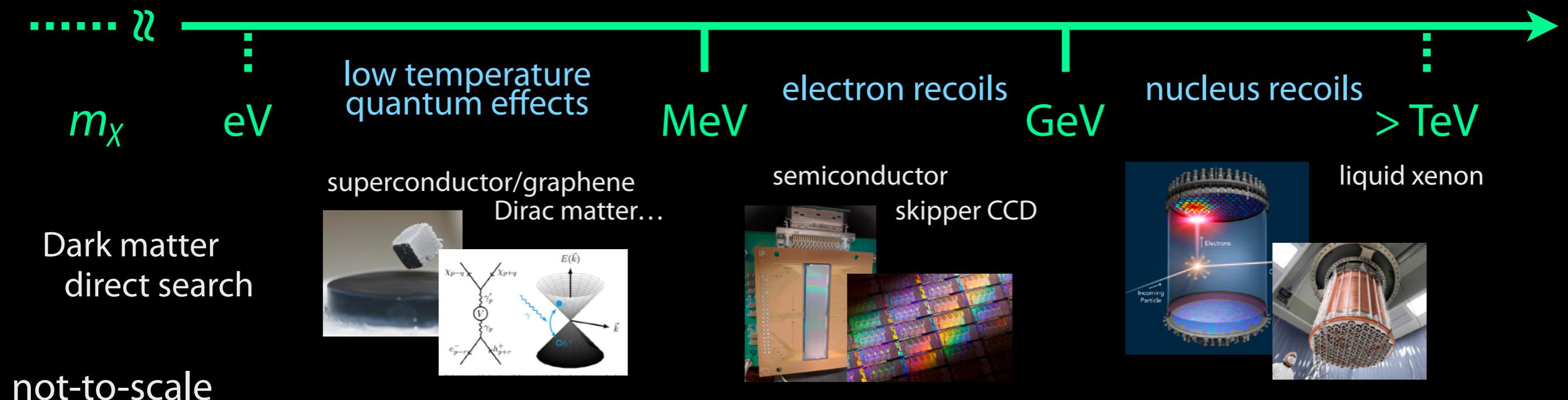
| | |
|------------------|-------------------|
| CDEX Collab. | Hochberg+ (2016) |
| LUX Collab. | Geilhufe+ (2019) |
| SENSEI Collab. | Kim+ (2020) |
| XENON Collab. | Kahn+ (2020) |
| Essig+ (2015) | Knapen+ (2020)... |
| Hochberg+ (2015) | |

A logarithmic scale diagram for mass m_χ . The x-axis is labeled with eV, MeV, GeV, and $>$ TeV. A vertical dashed line at $m_\chi = 1$ eV is labeled 'l'. Brackets indicate ranges: $[1 \text{ eV}, 1 \text{ MeV}]$, $[1 \text{ MeV}, 1 \text{ GeV}]$, and $[1 \text{ GeV}, > \text{TeV}]$.

not-to-scale

The DM probes: m_χ & σ

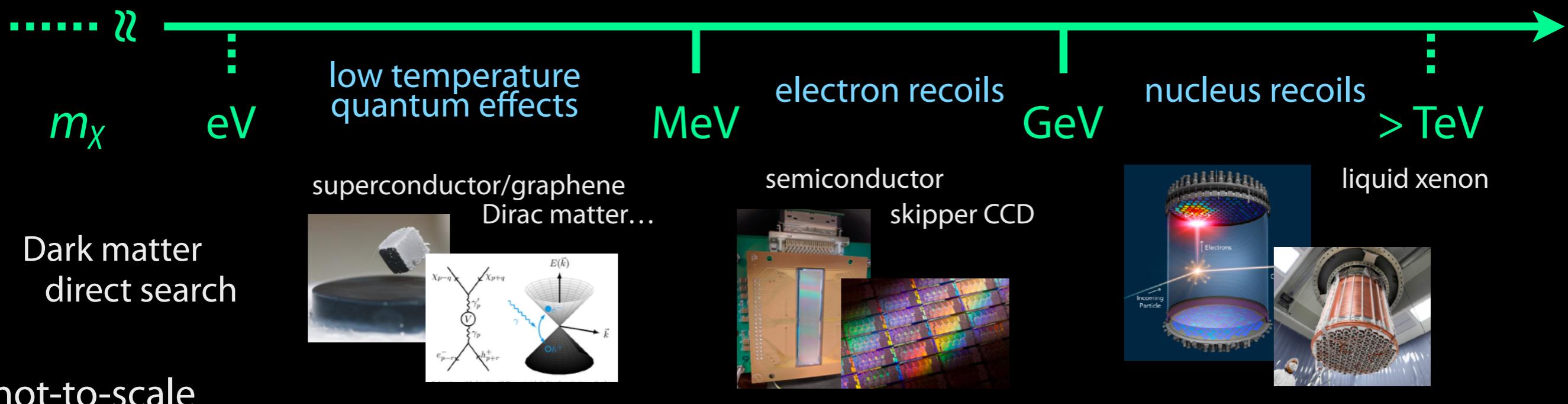
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The DM probes: m_χ & σ

Dark matter
indirect search

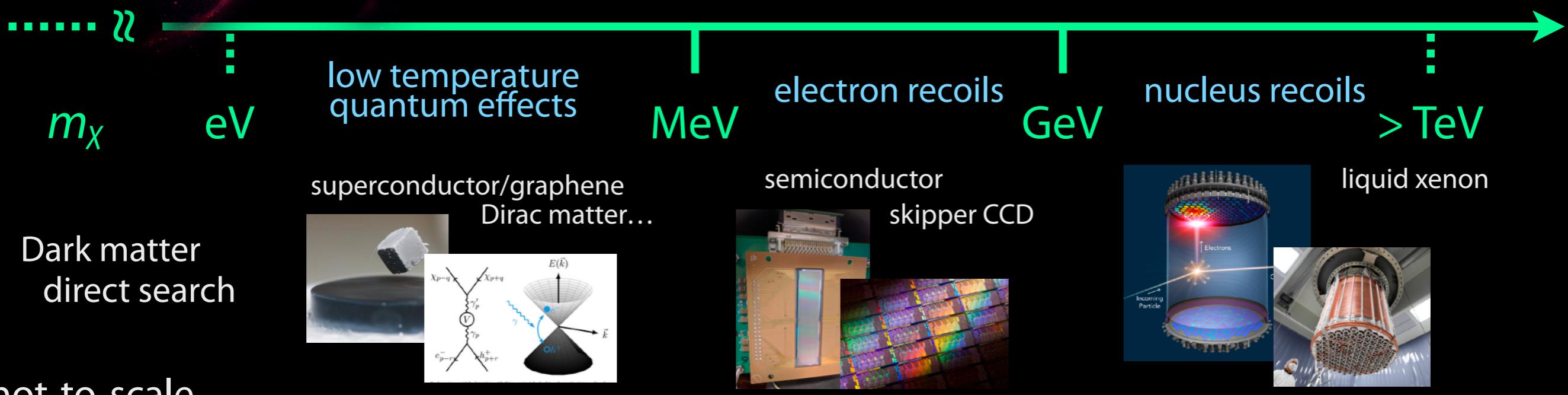
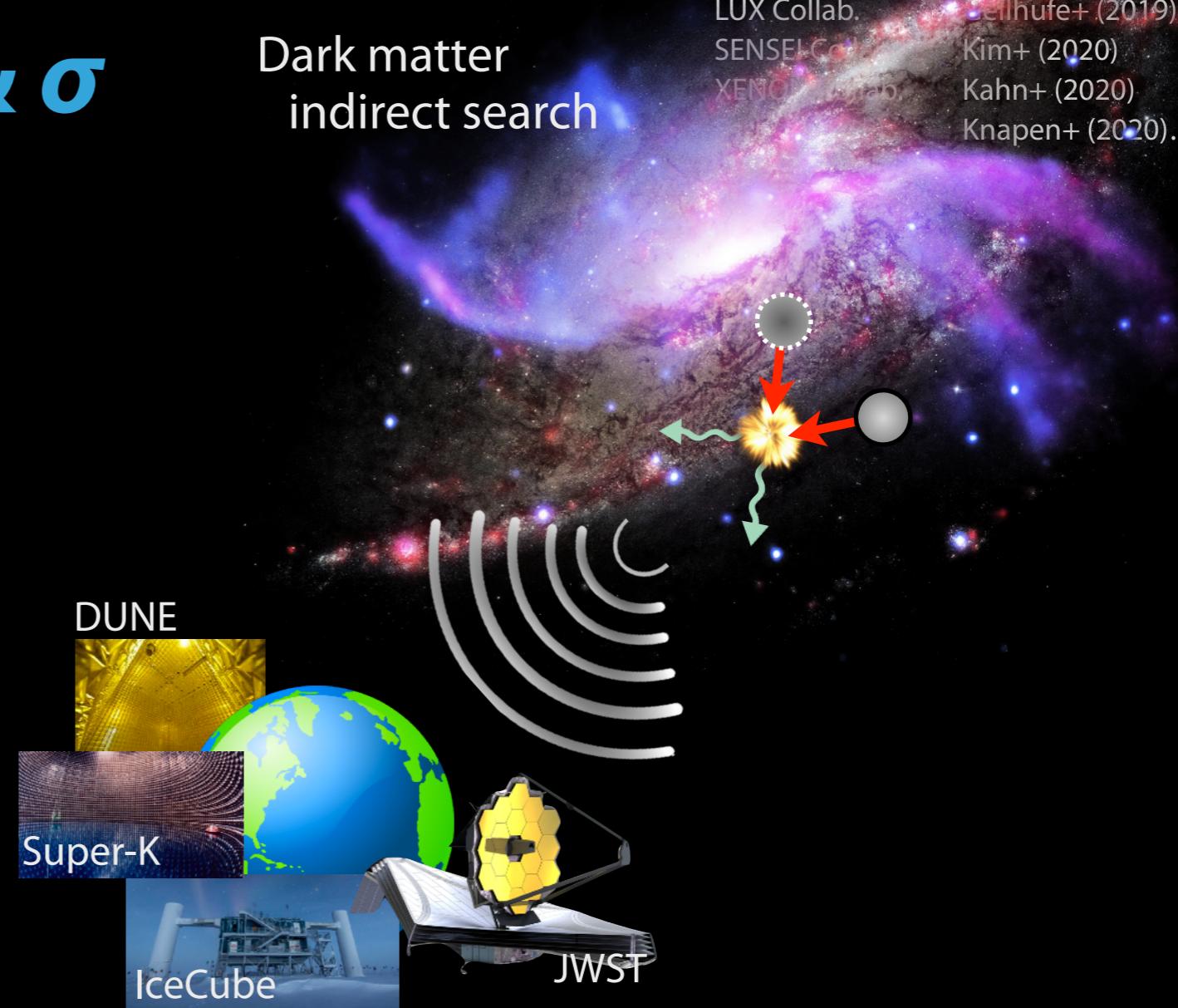
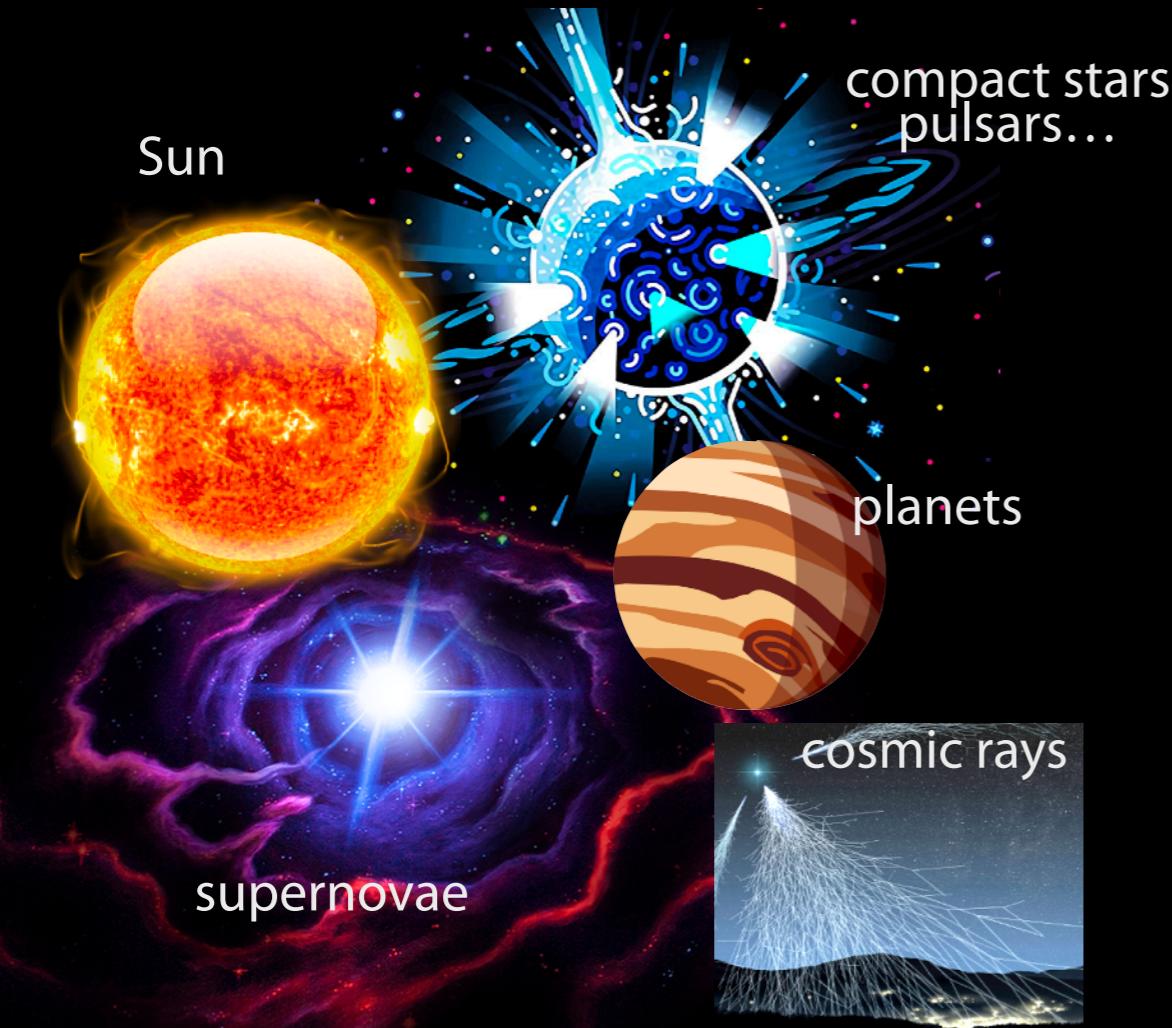
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The DM probes: m_χ & σ

Dark matter
indirect search

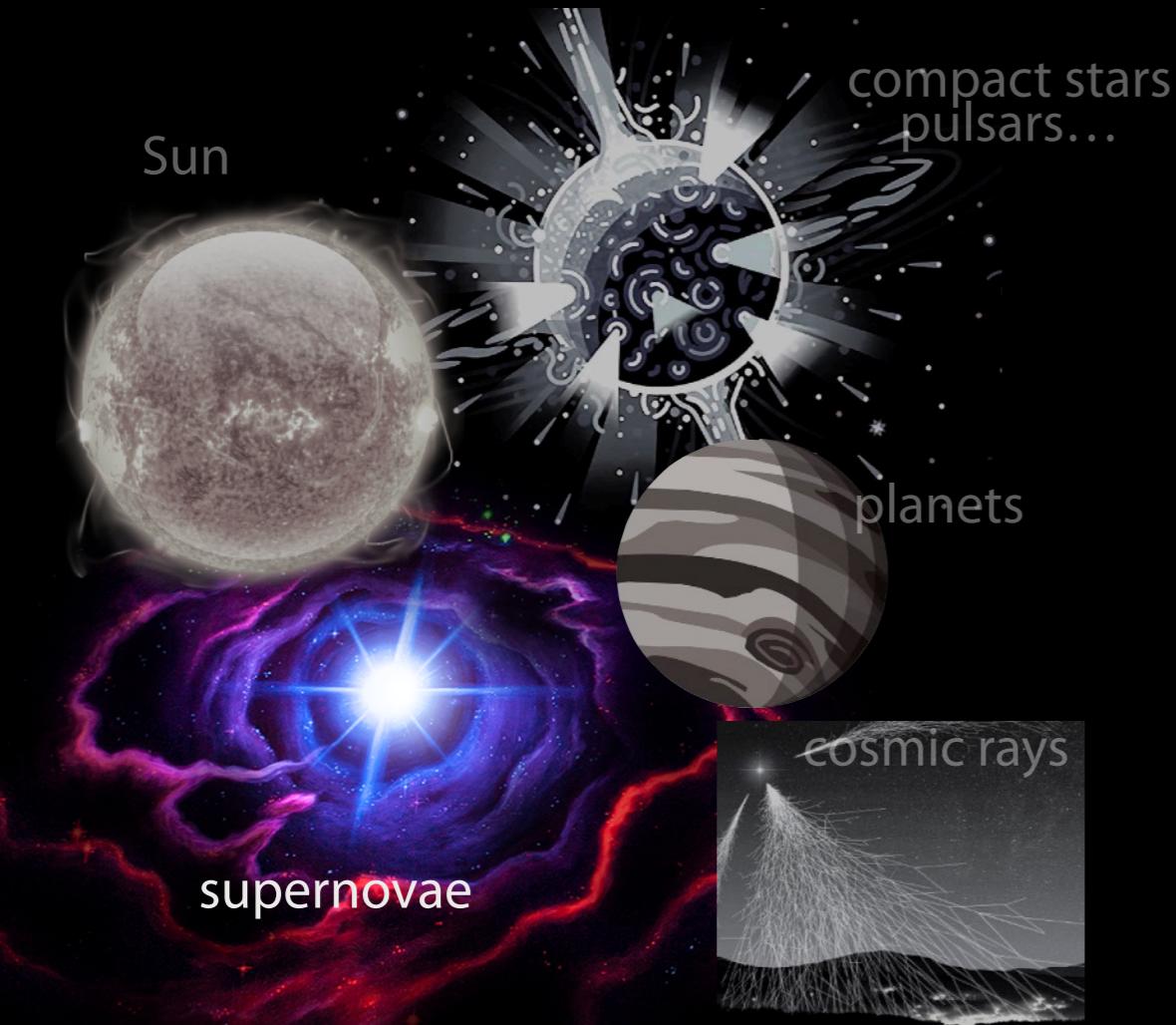
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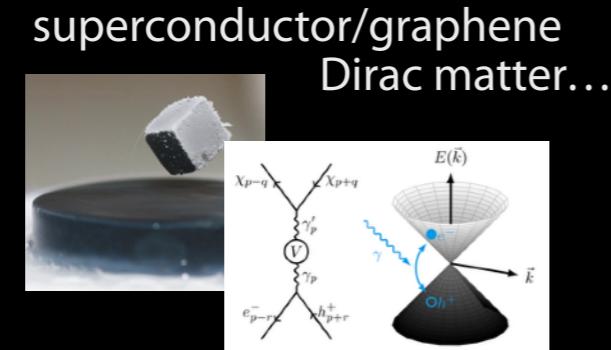
The DM probes: m_χ & σ

Dark matter
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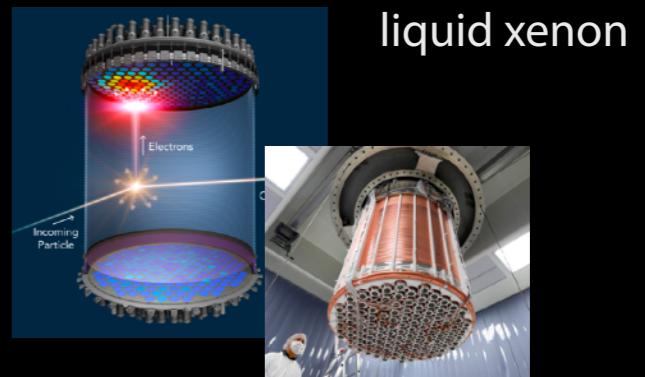
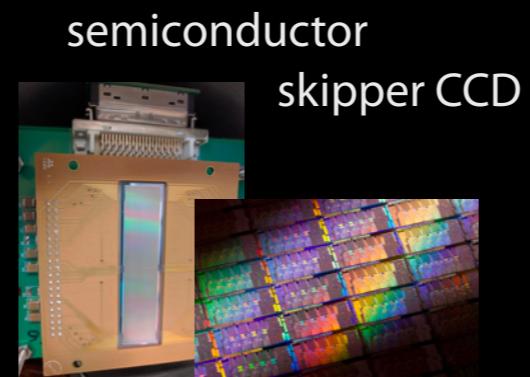
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Dark matter
direct search



not-to-scale

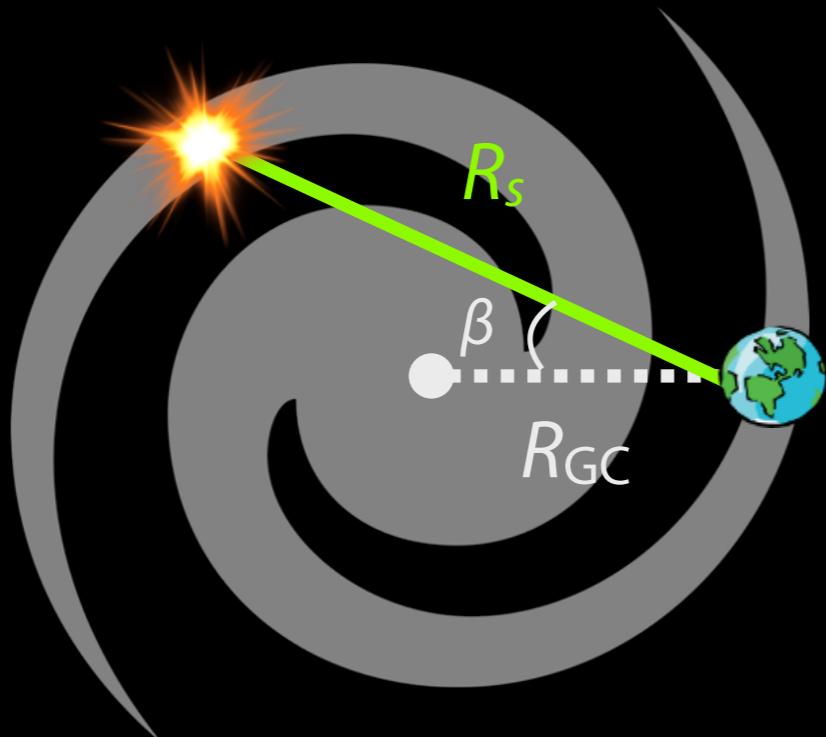


Galactic supernova

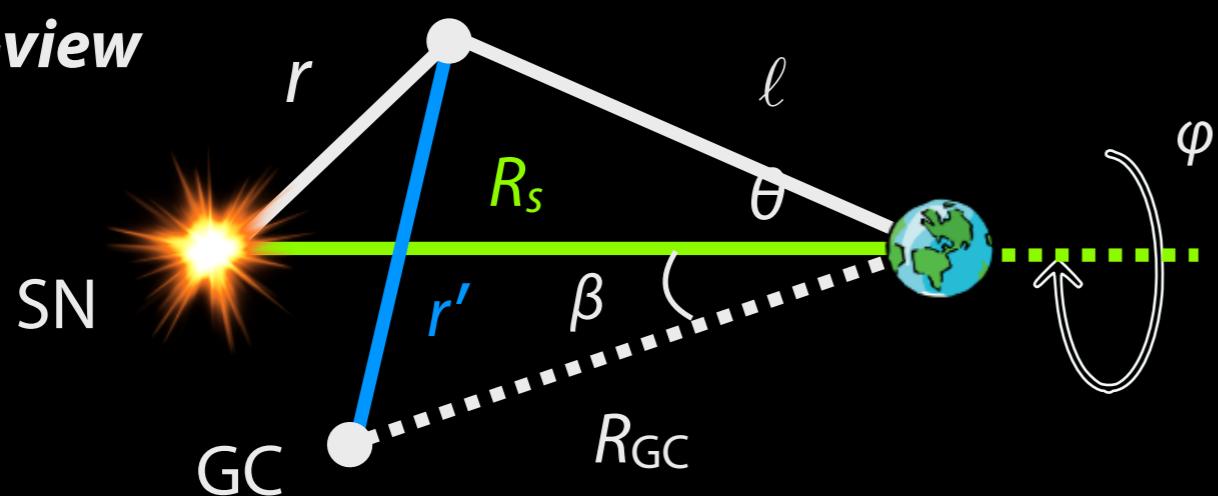
Galactic supernova

In practice

top-view



side-view

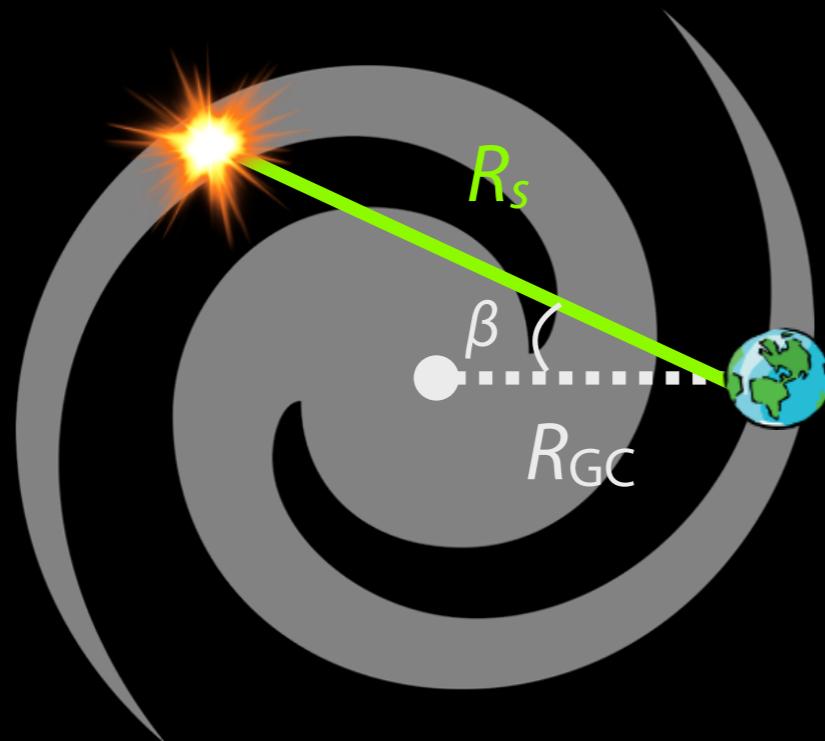


not-to-scale

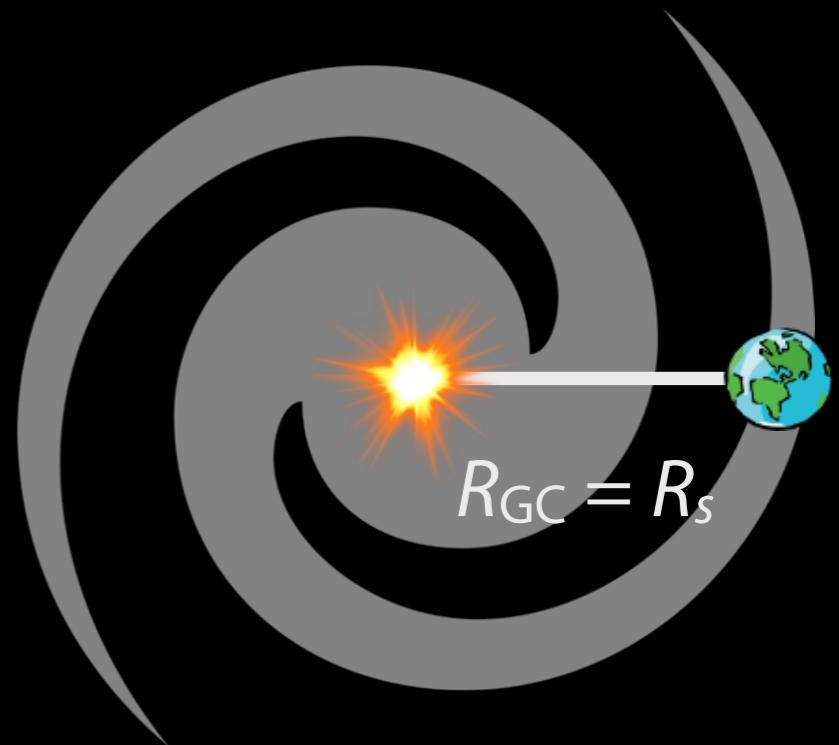
Galactic supernova

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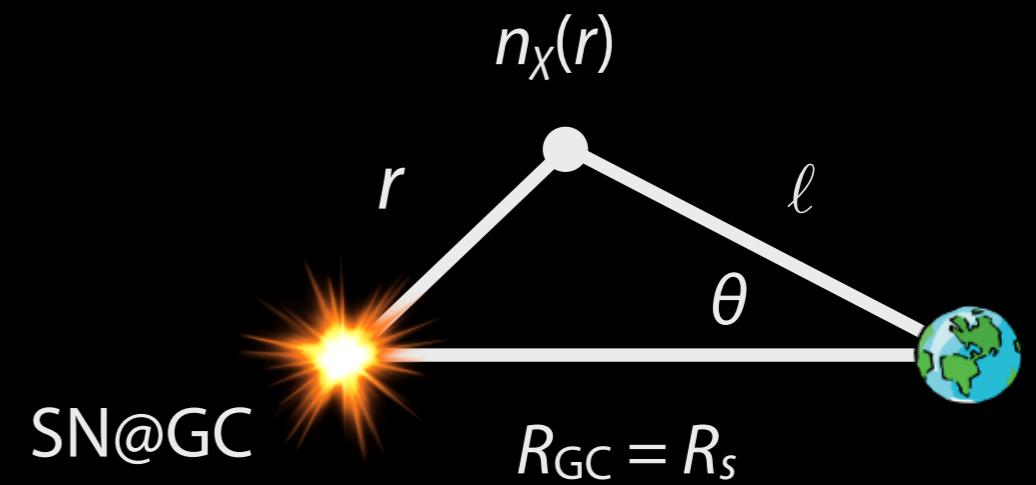
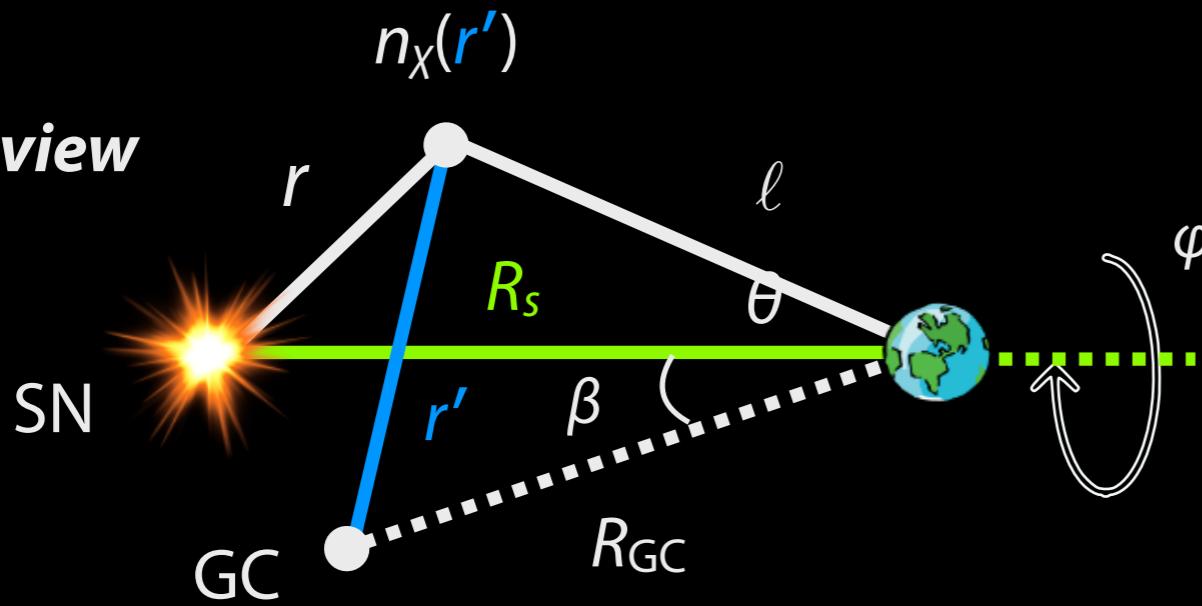
top-view



SN@GC



side-view



not-to-scale

Halo DM boosted by SNv

duration: ~ 10 s

$$N_\nu \approx 10^{58}$$

$$\bar{E}_\nu \approx 10 - 15 \text{ MeV}$$

$$\frac{dn_\nu}{dE_\nu} = \sum_i \frac{L_{\nu_i}}{4\pi r^2 \langle E_{\nu_i} \rangle} E_\nu^2 f_{\nu_i}(E_\nu)$$

Duan+ 2006

SN@GC

not-to-scale

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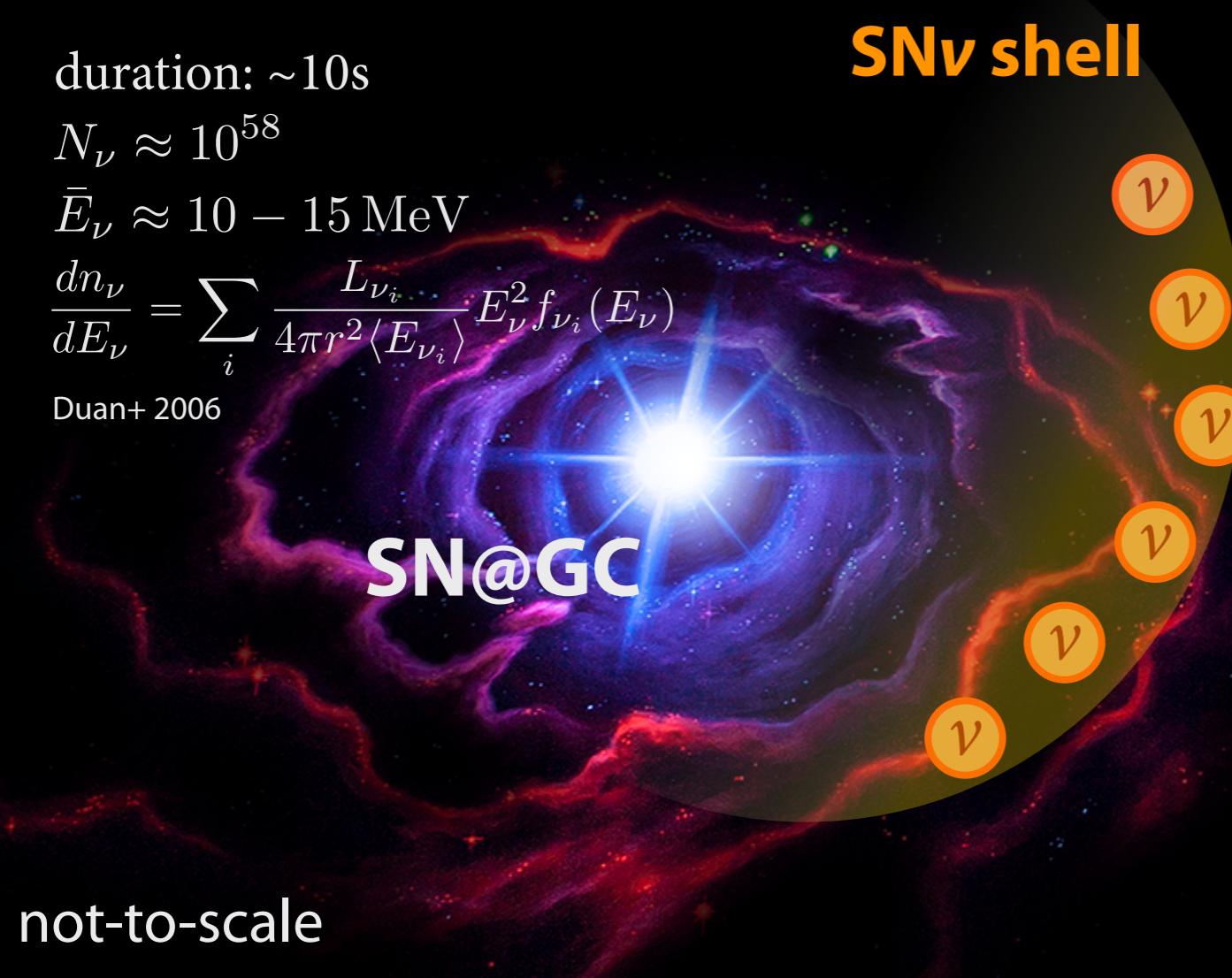
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SN ν shell

SN@GC

not-to-scale



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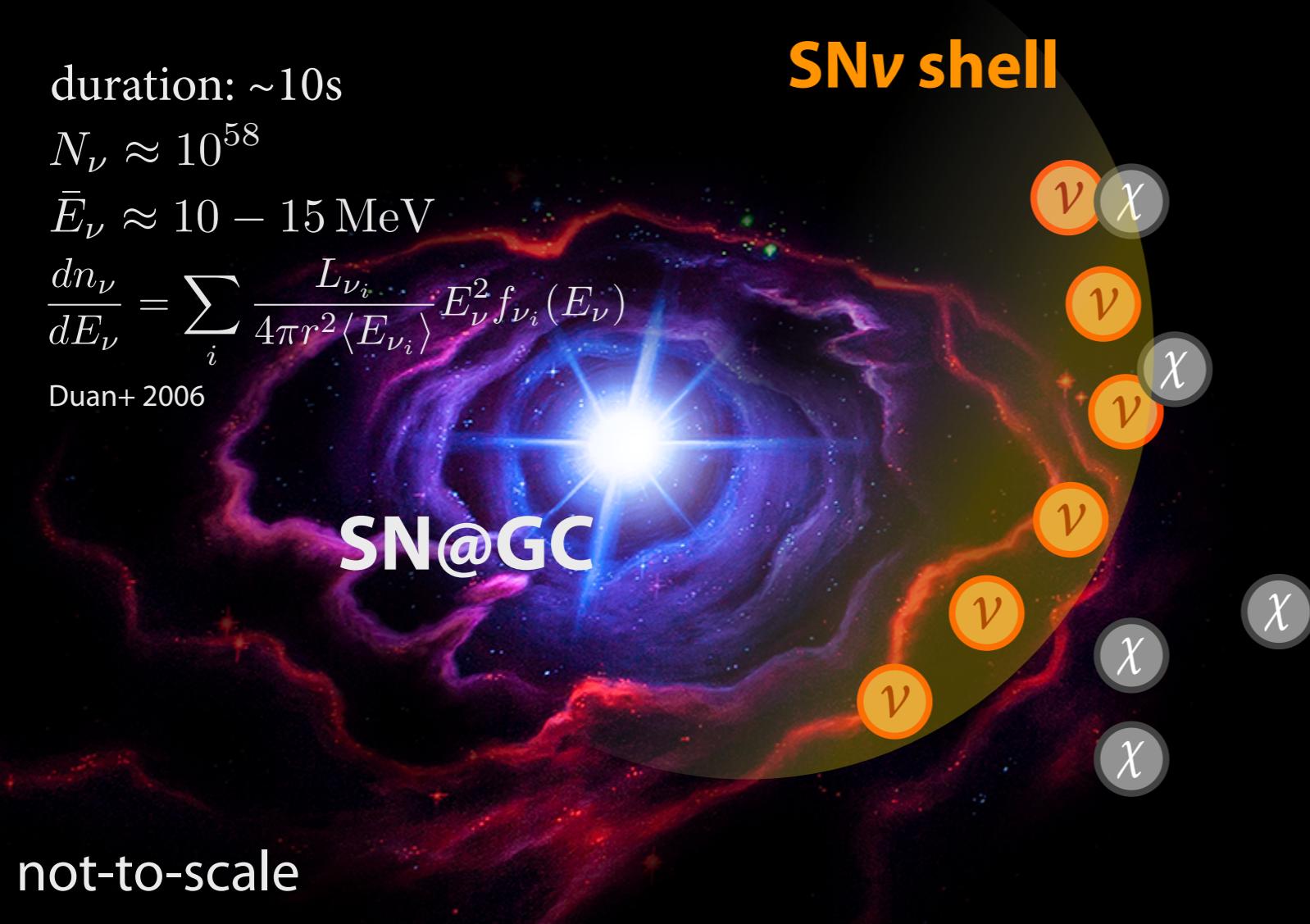
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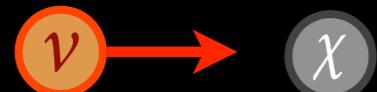
SN@GC

SN ν shell



Halo DM boosted by SN ν

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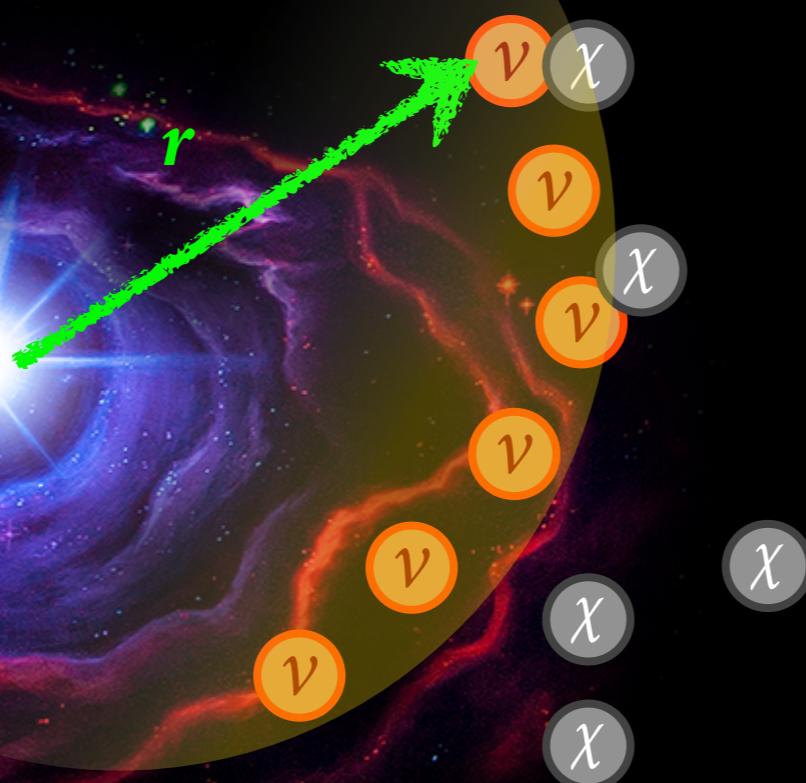
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Duan+ 2006

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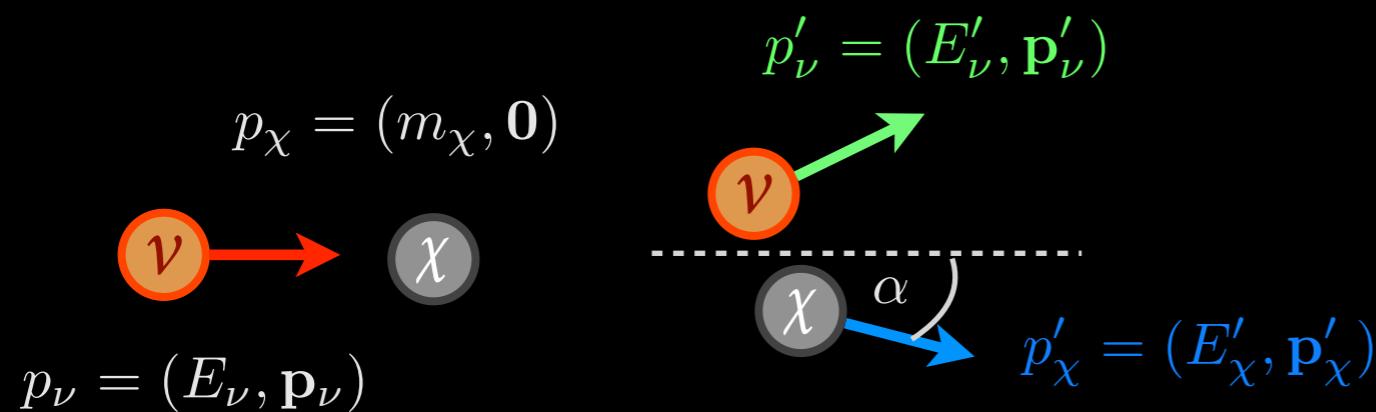
SN@GC



not-to-scale

Halo DM boosted by SN ν

- Non-zero DM- ν cross section $\sigma_{\chi\nu}$



- The BDM kinetic energy T_χ

$$T_\chi = E_\nu - E'_\nu(\cos \alpha) = \frac{E_\nu^2}{E_\nu + m_\chi/2} \left(\frac{1 + \cos \theta_c}{2} \right)$$

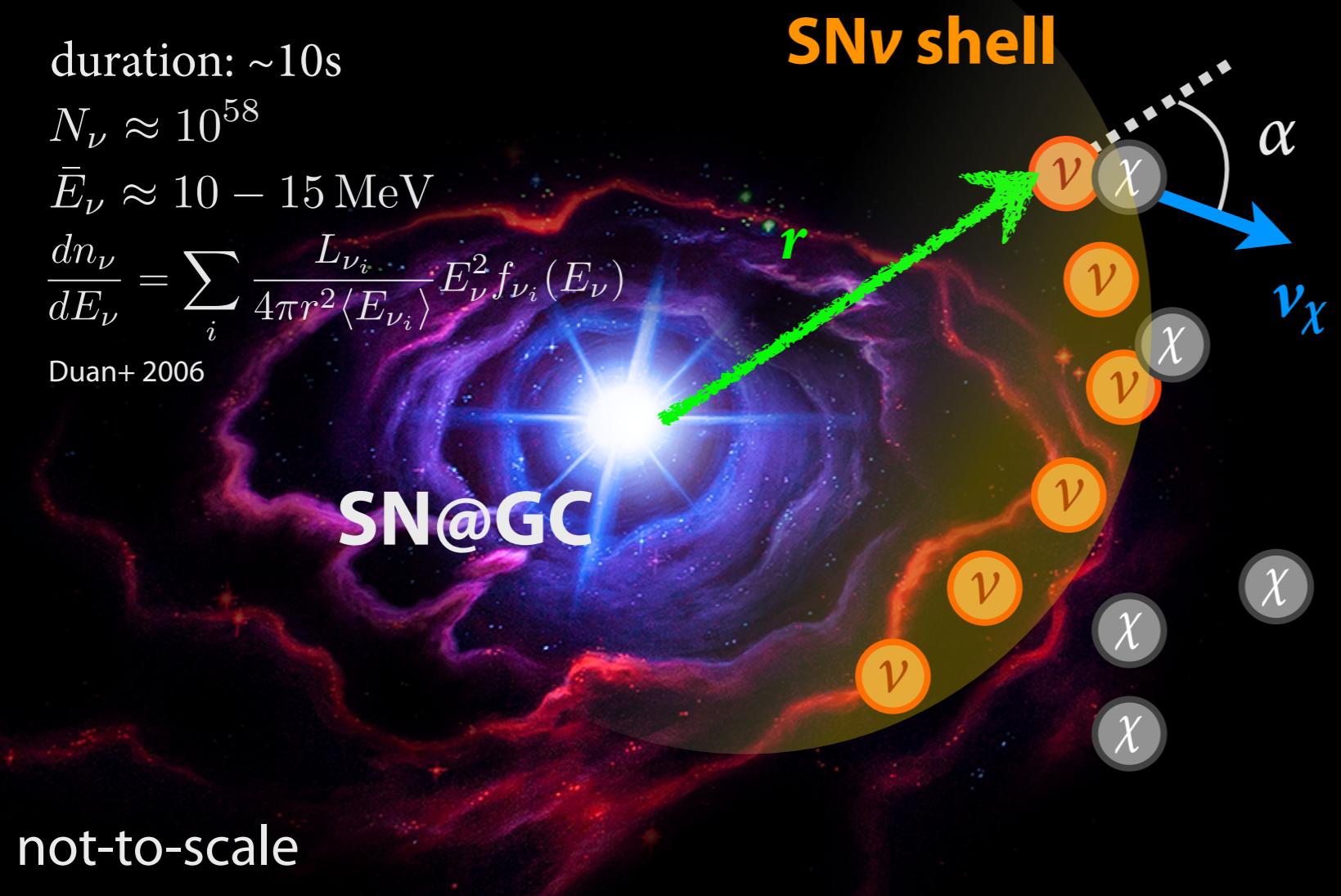
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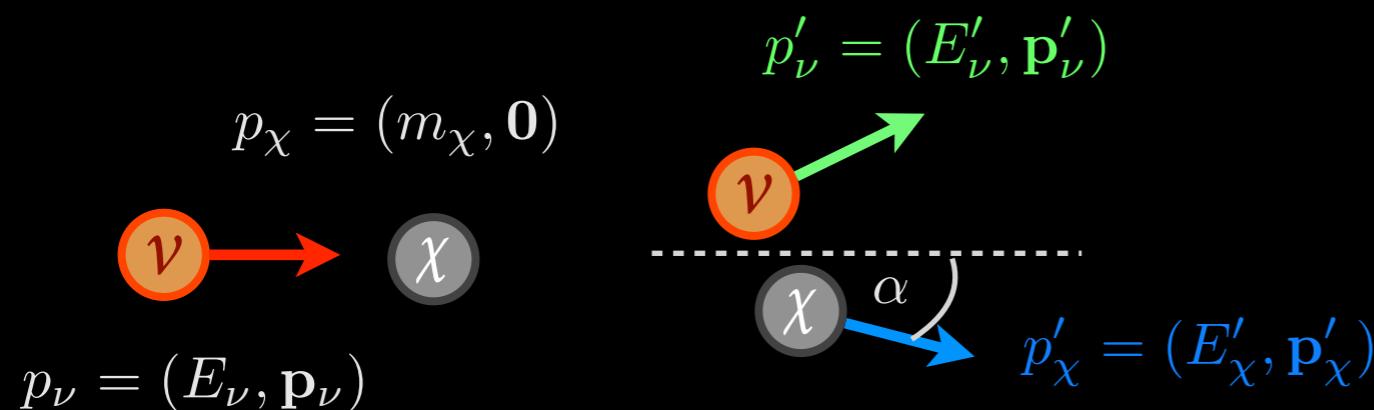
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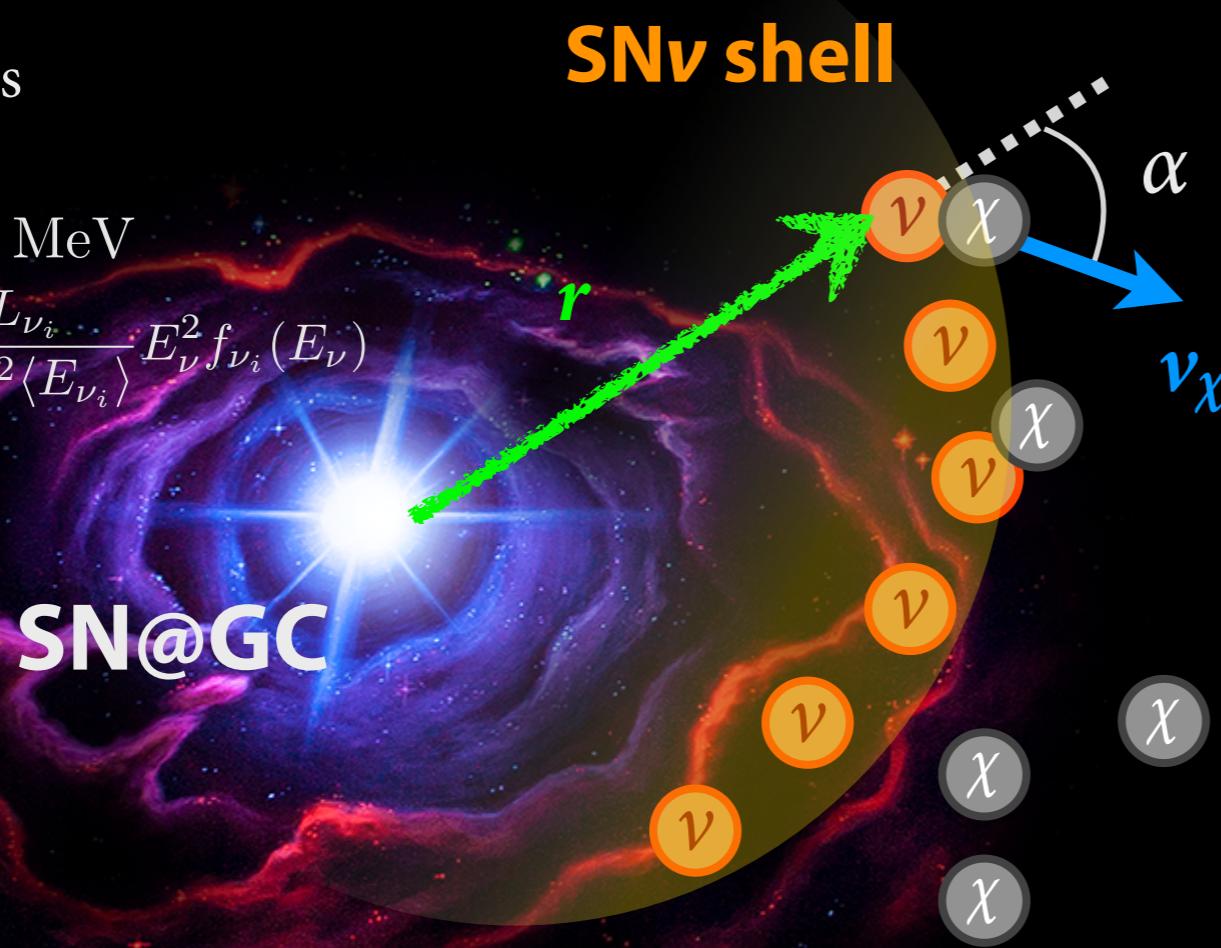
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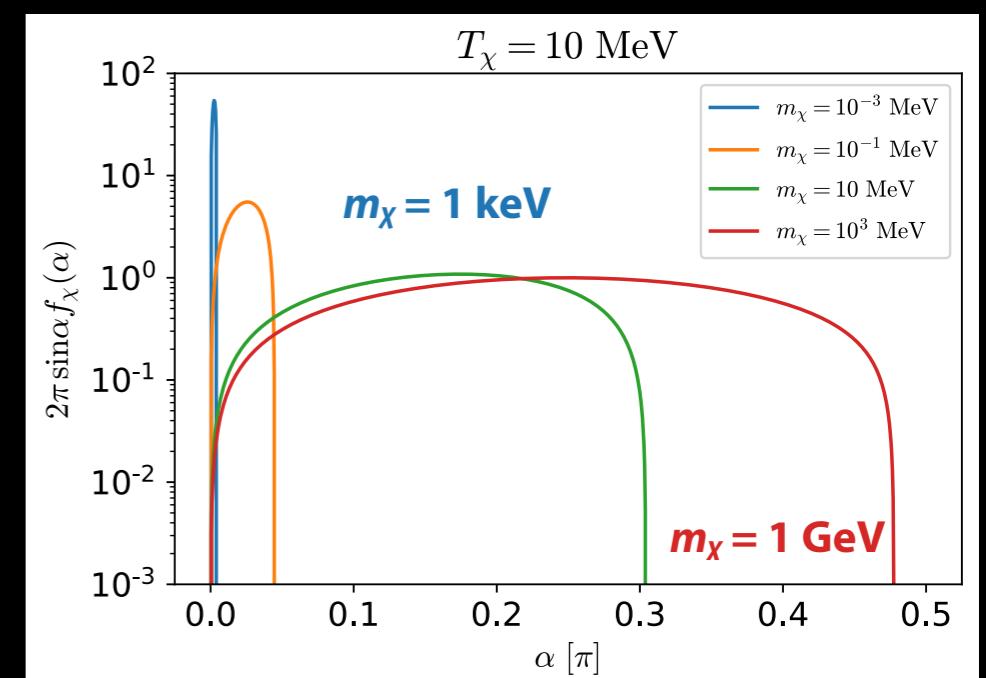
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Duan+ 2006



- The angular distribution

$$f_\chi(\alpha, E_\nu) = \frac{\gamma^2 \sec^3 \alpha}{\pi(1 + \gamma^2 \tan^2 \alpha)^2}$$



not-to-scale



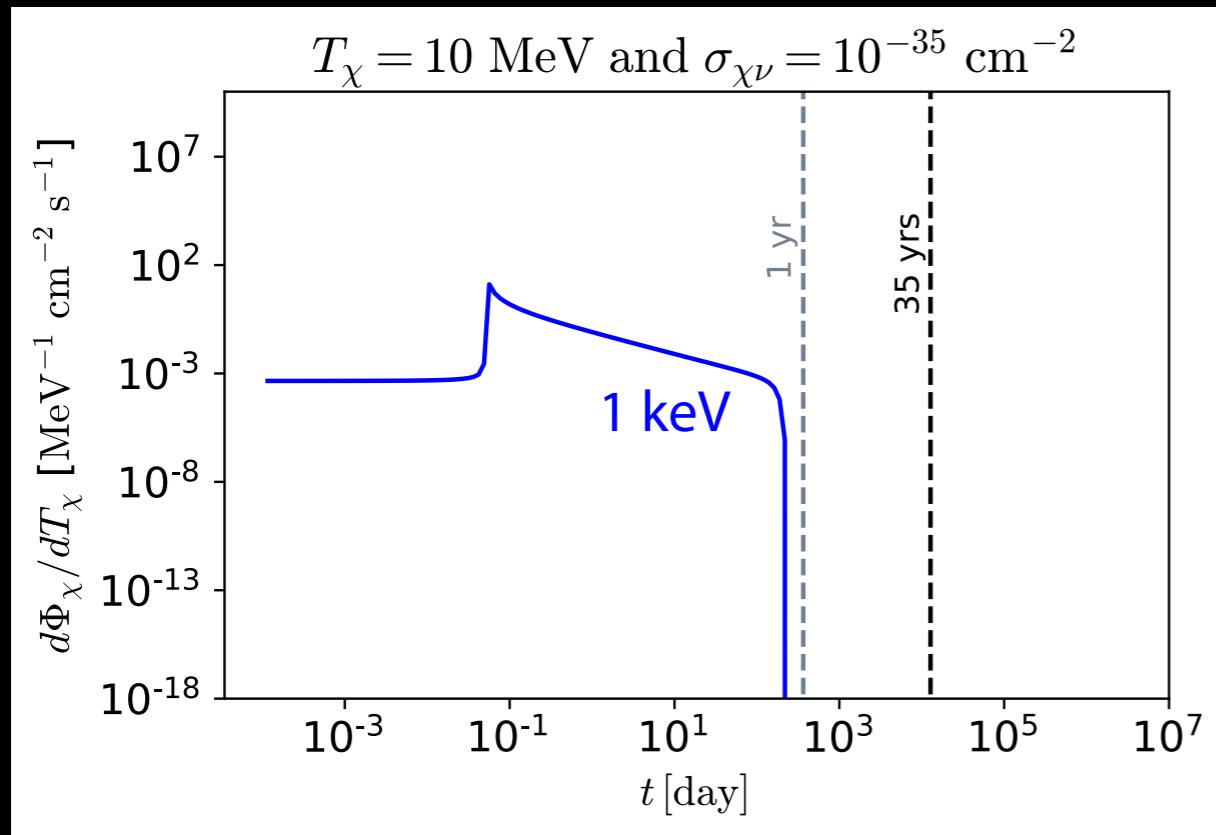
The BDM flux on the Earth

BDM flux from GC

BDM flux from GC

- BDM flux at Earth with $m_\chi = 1 \text{ keV}$ and $T_\chi = 10 \text{ MeV}$

$$\frac{d\Phi_\chi(T_\chi, t')}{dT_\chi} = 2\pi\tau \int_0^1 d\cos\theta \mathcal{J} j_\chi(r, T_\chi, \alpha) \Big|_{t'=\frac{r}{c} + \frac{\ell}{v_\chi}}$$

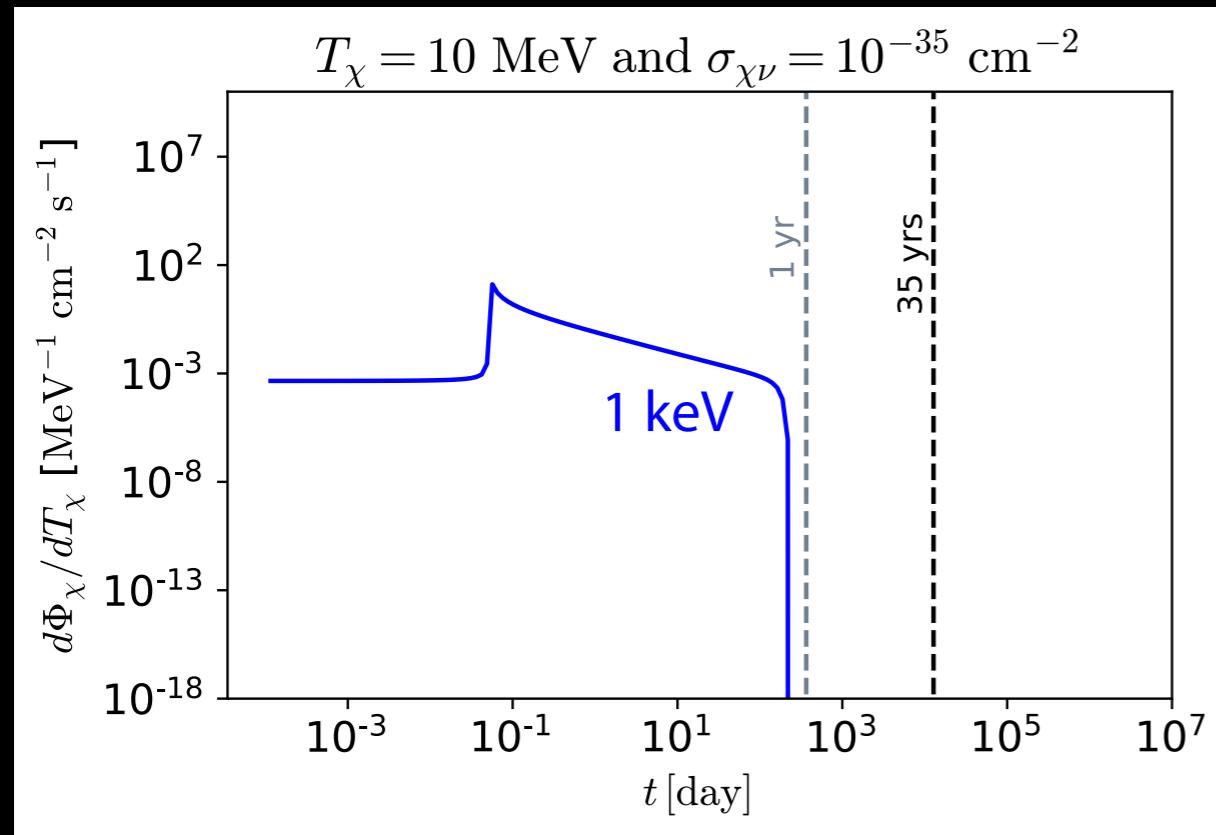


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- ▶ **Time-zero $t = 0$** indicates SN neutrinos arrived Earth

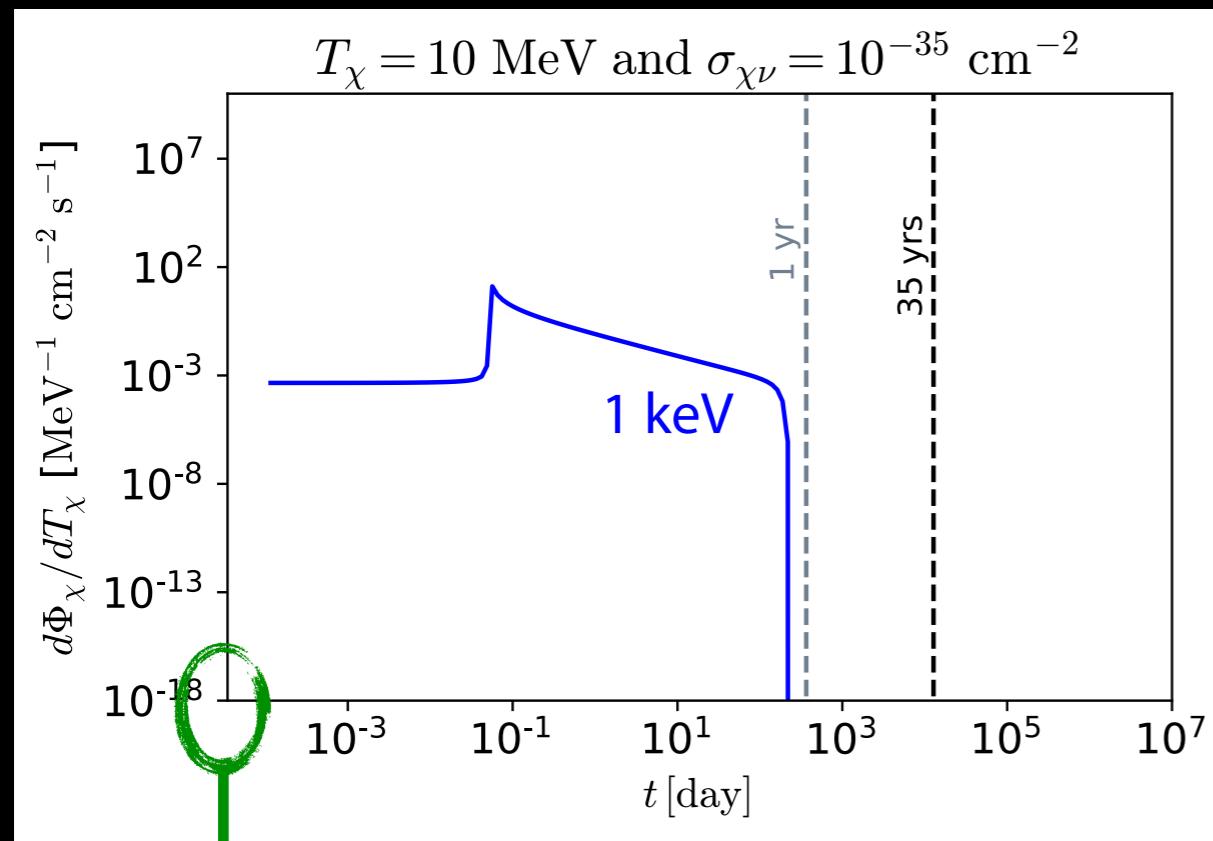


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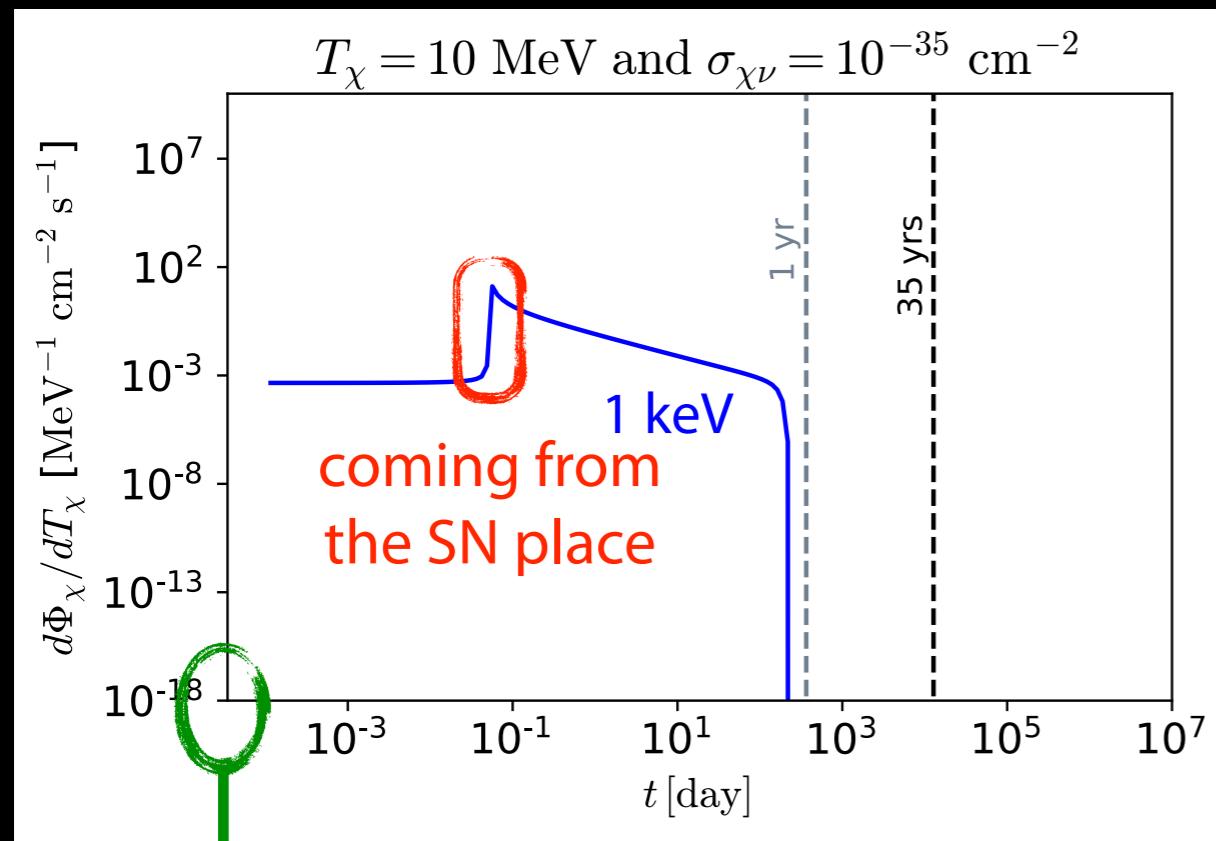
~10s after SNν
burst

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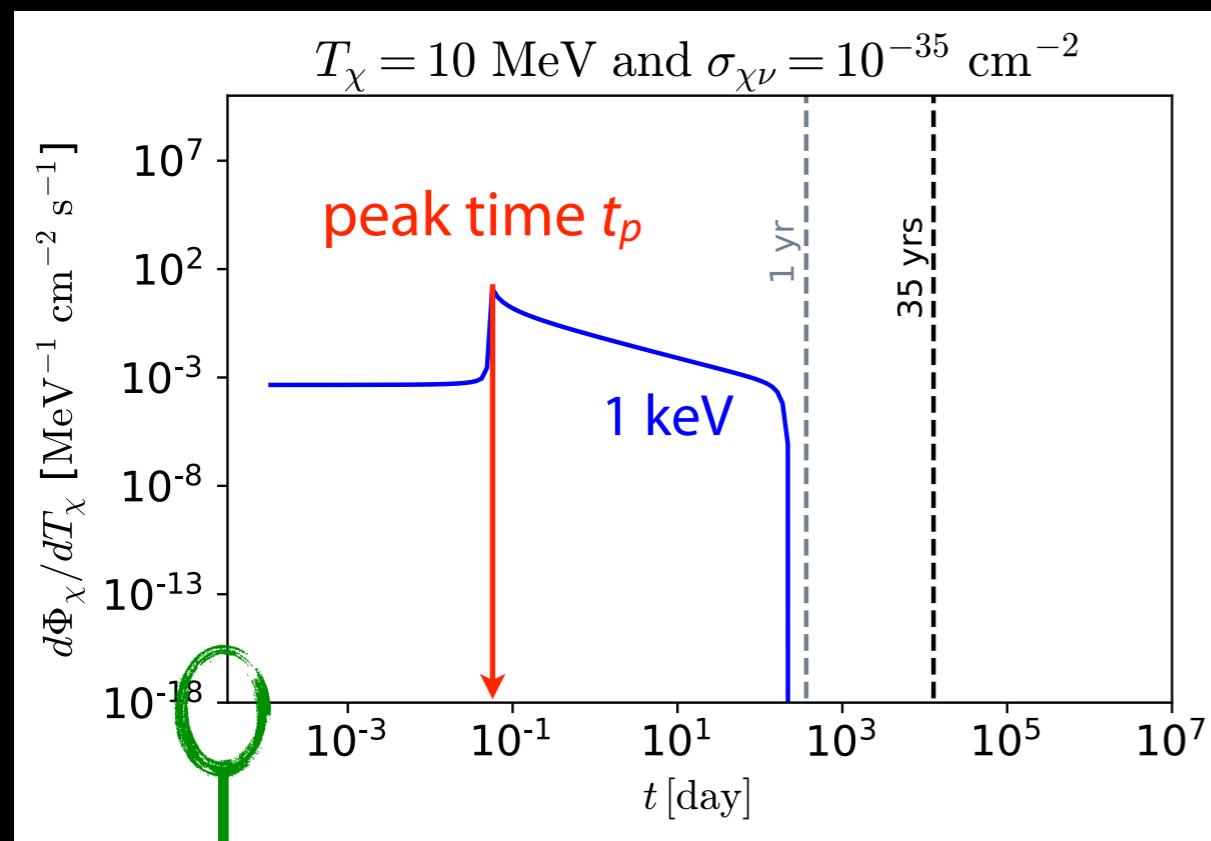
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- ▶ The **peak** is contributed by the BDM coming from the SN place



~10s after SN ν burst

$$t_p = R_s \left(\frac{1}{v_\chi} - \frac{1}{c} \right) \simeq \frac{m_\chi^2}{2T_\chi^2} \frac{R_s}{c}$$

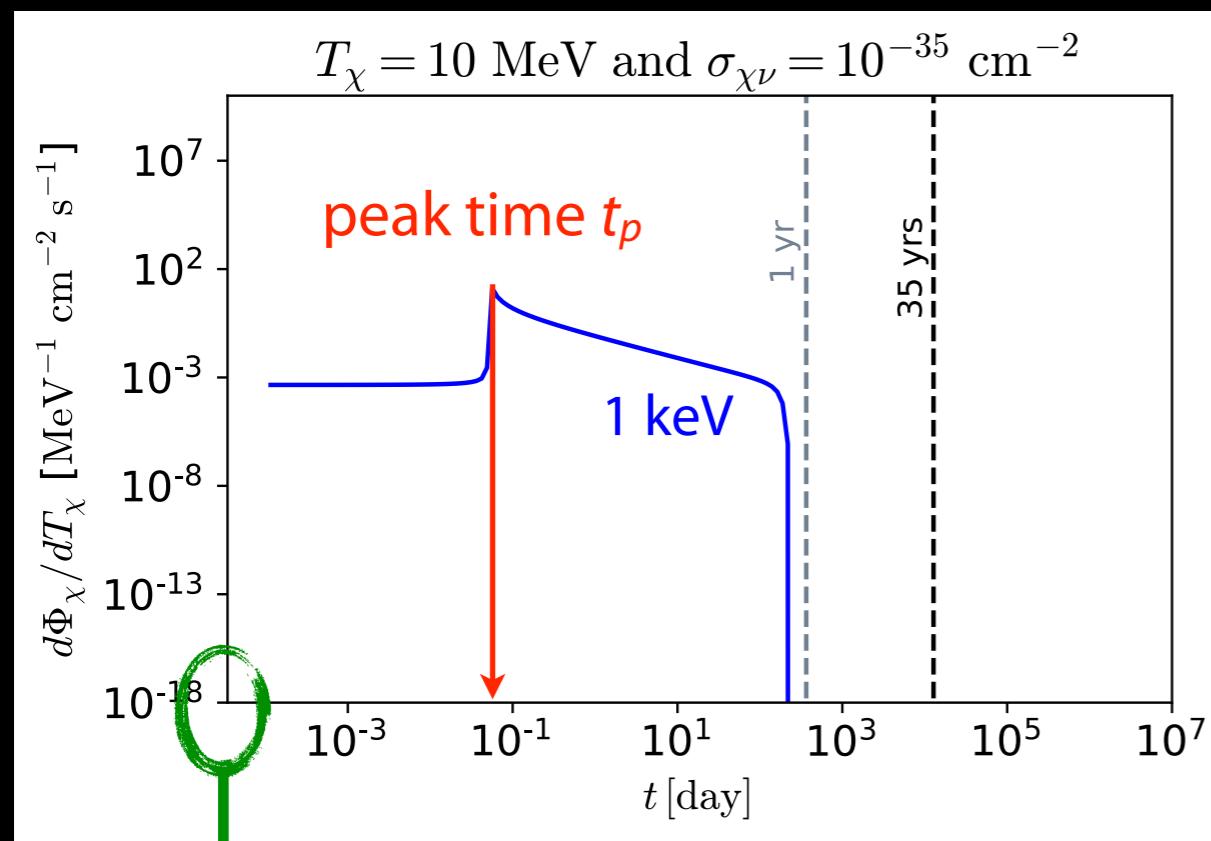
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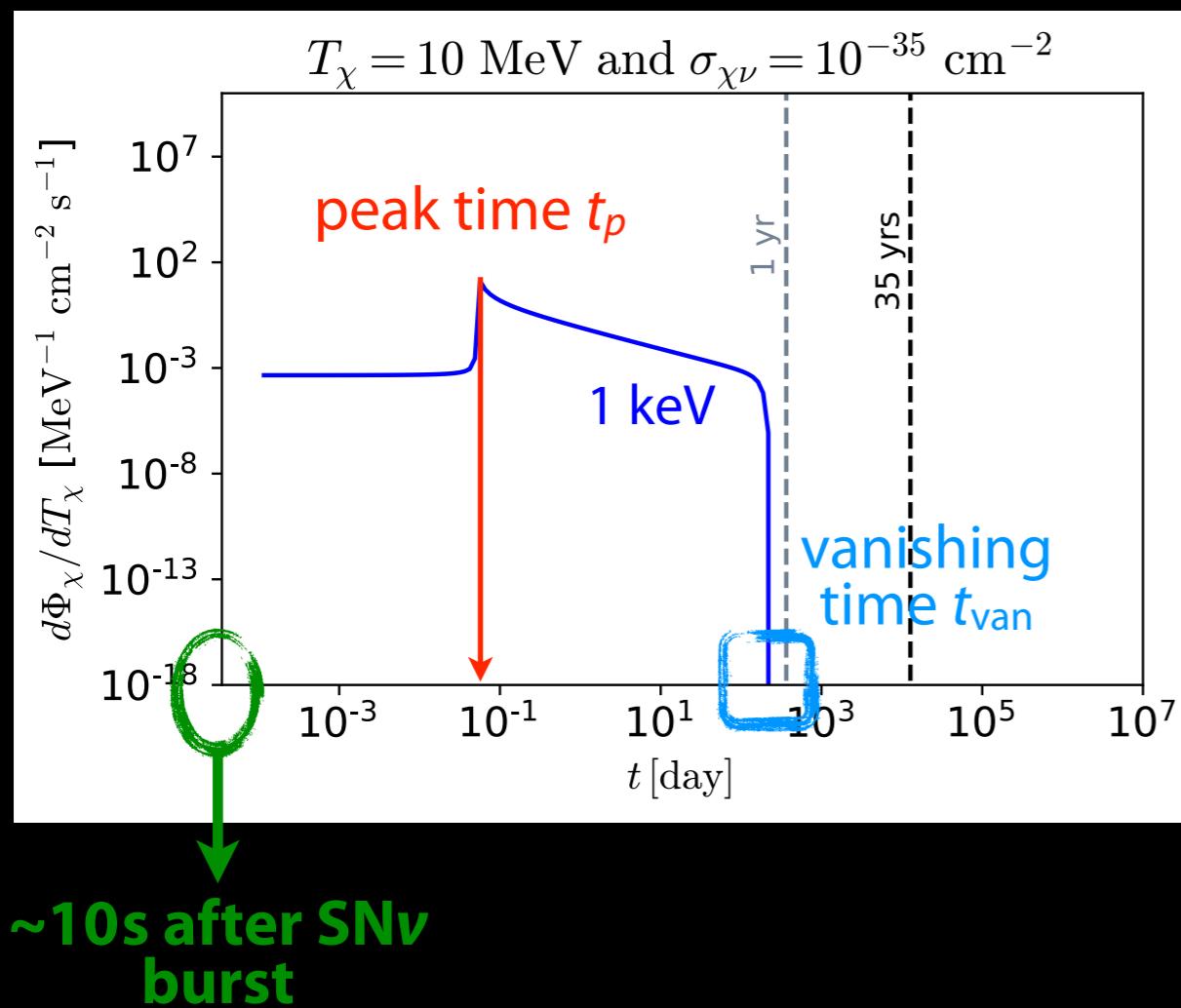
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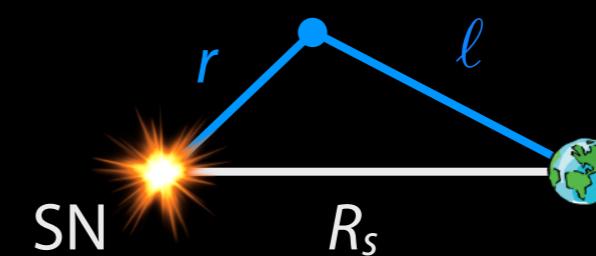
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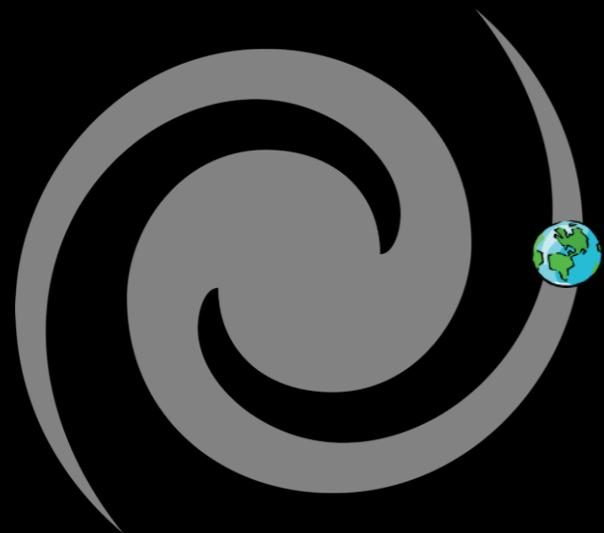
- ▶ m_χ can be directly measured!
- ▶ The **vanishing point** corresponds to the propagation length that *maximizes* the propagation time



$$t_{\text{van}} \simeq \frac{m_\chi}{4T_\chi} \frac{R_s}{c}$$

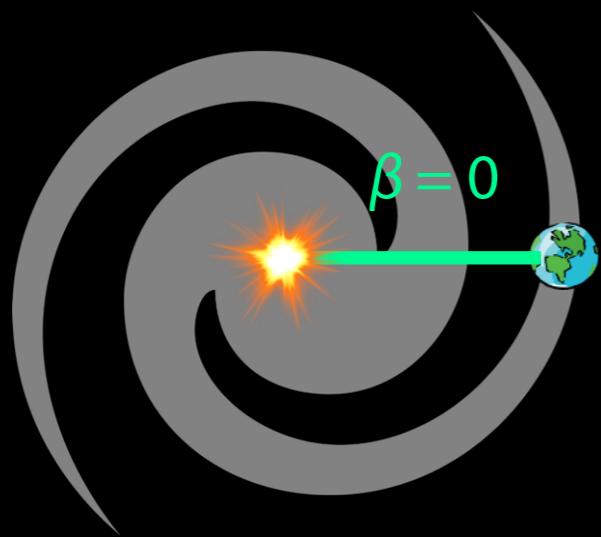
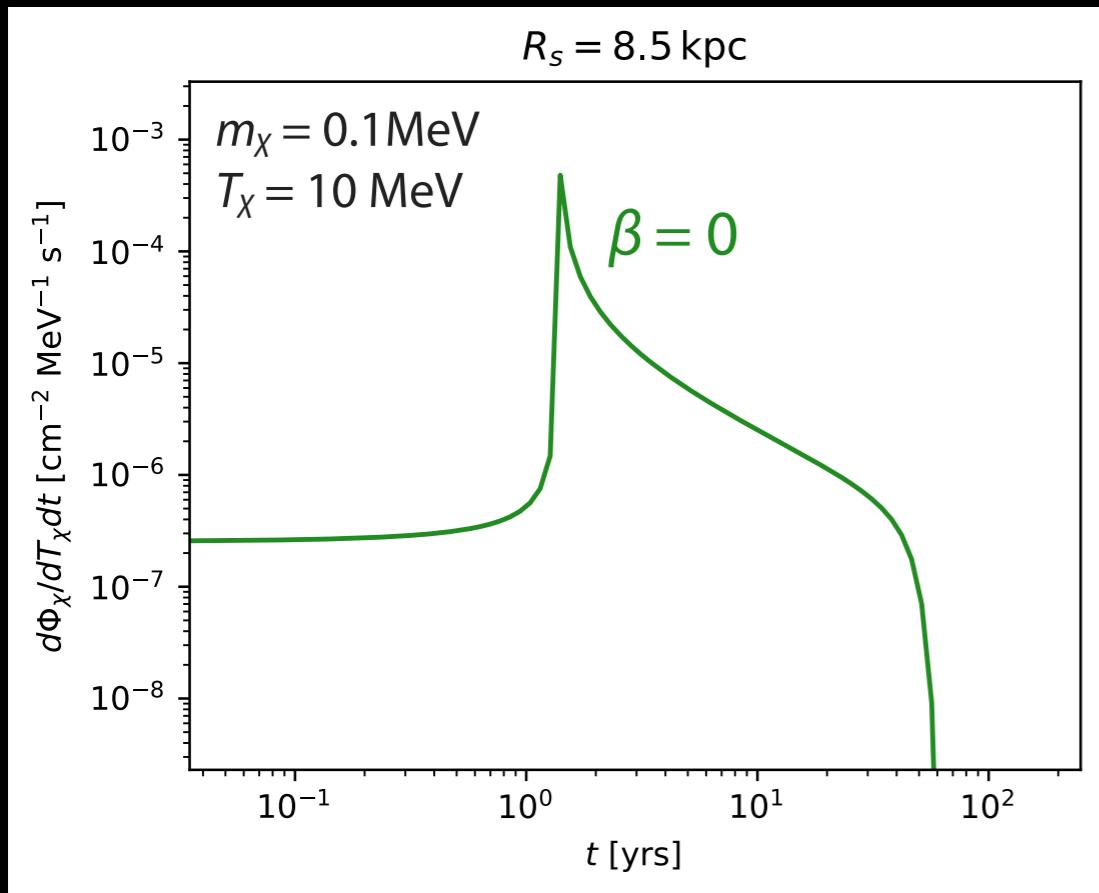
BDM from various places in MW

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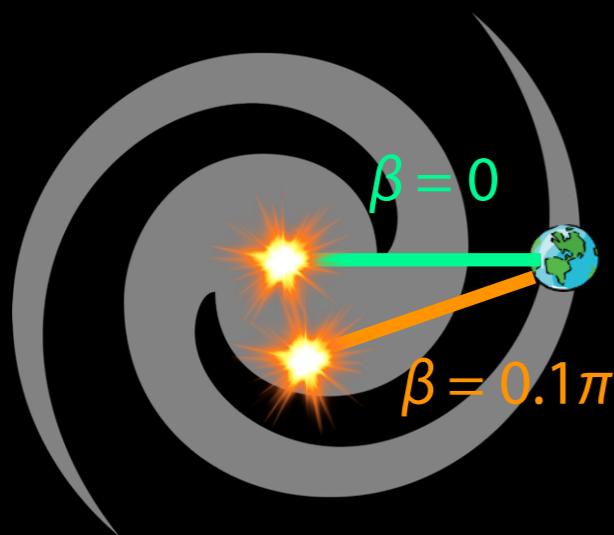
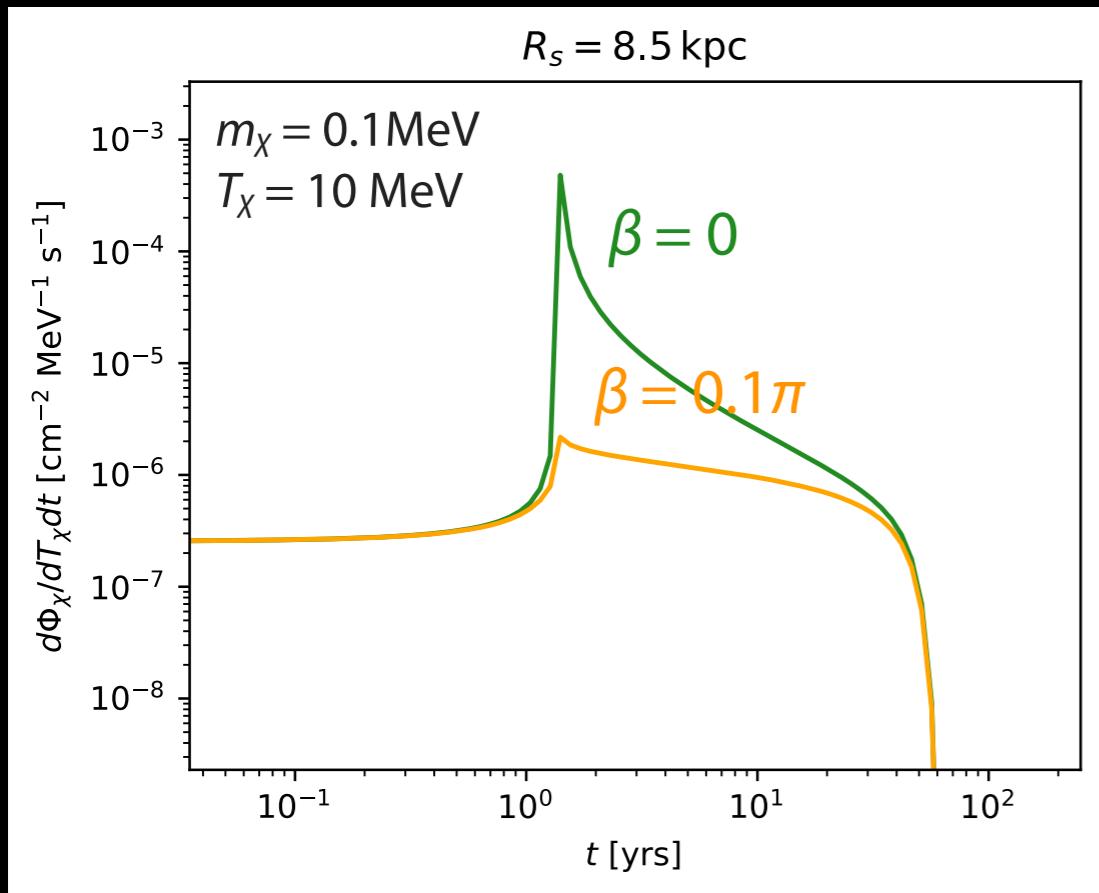
$R_s = 8.5 \text{ kpc}$ vs. β

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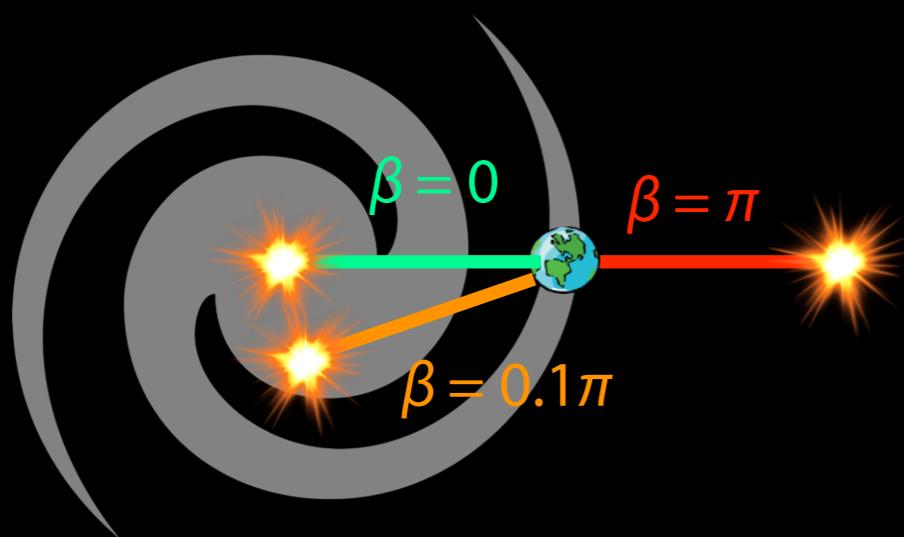
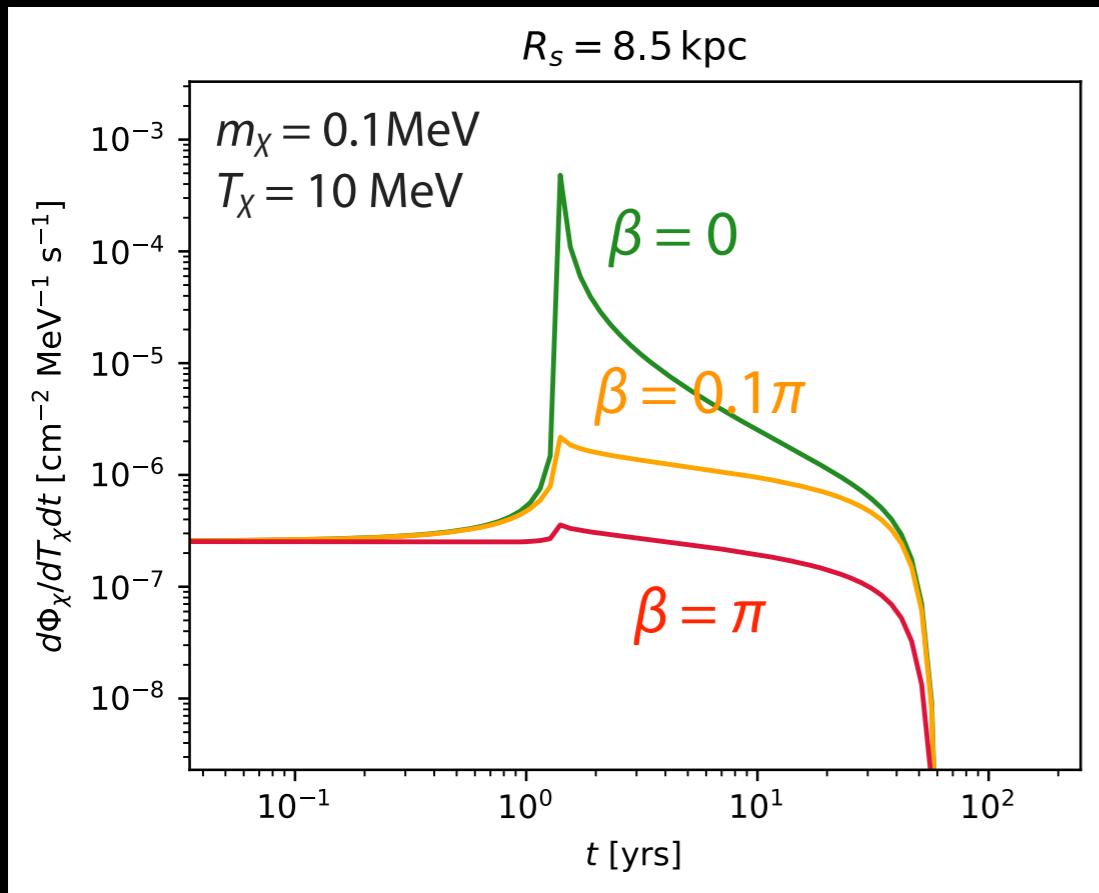
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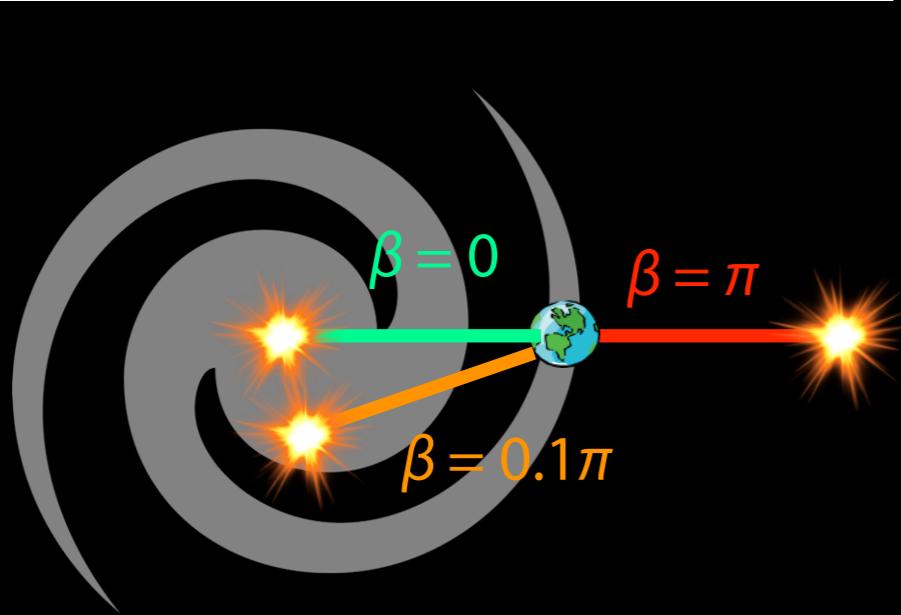
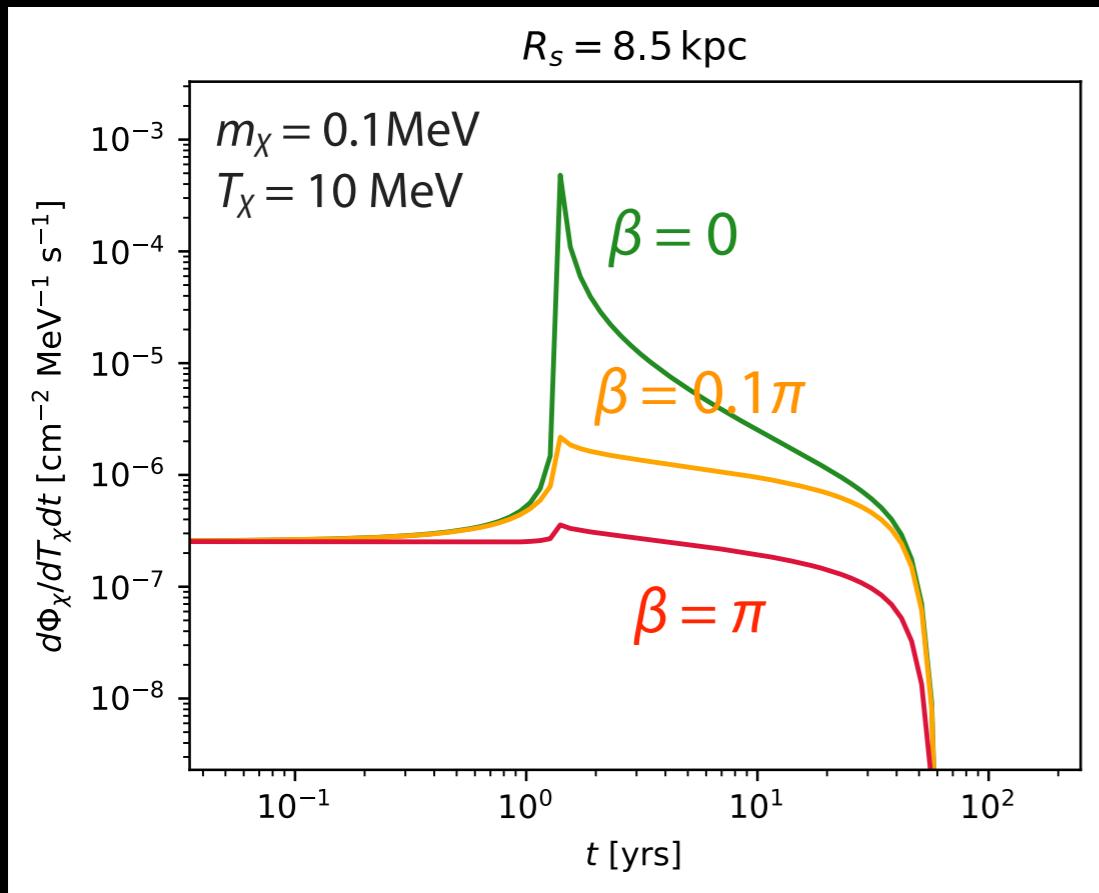
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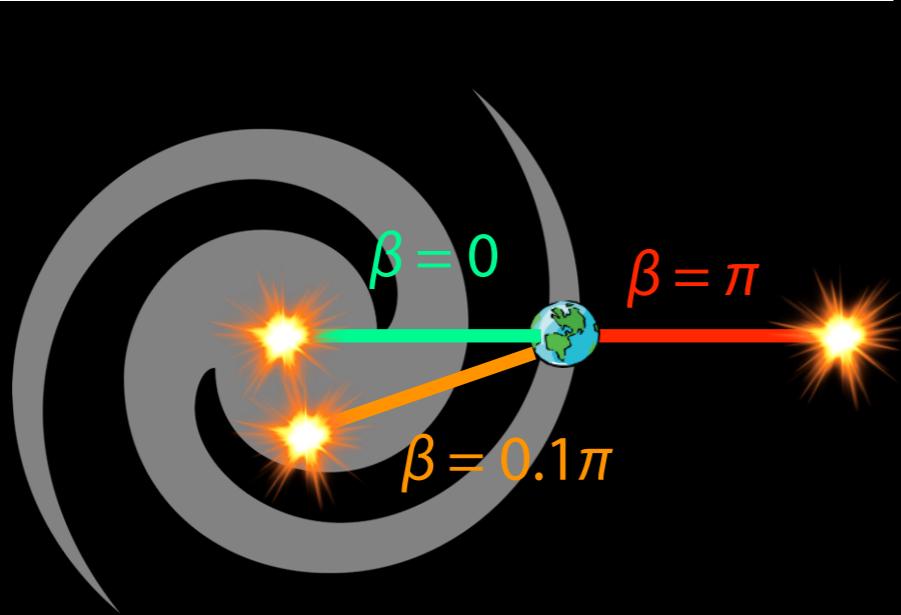
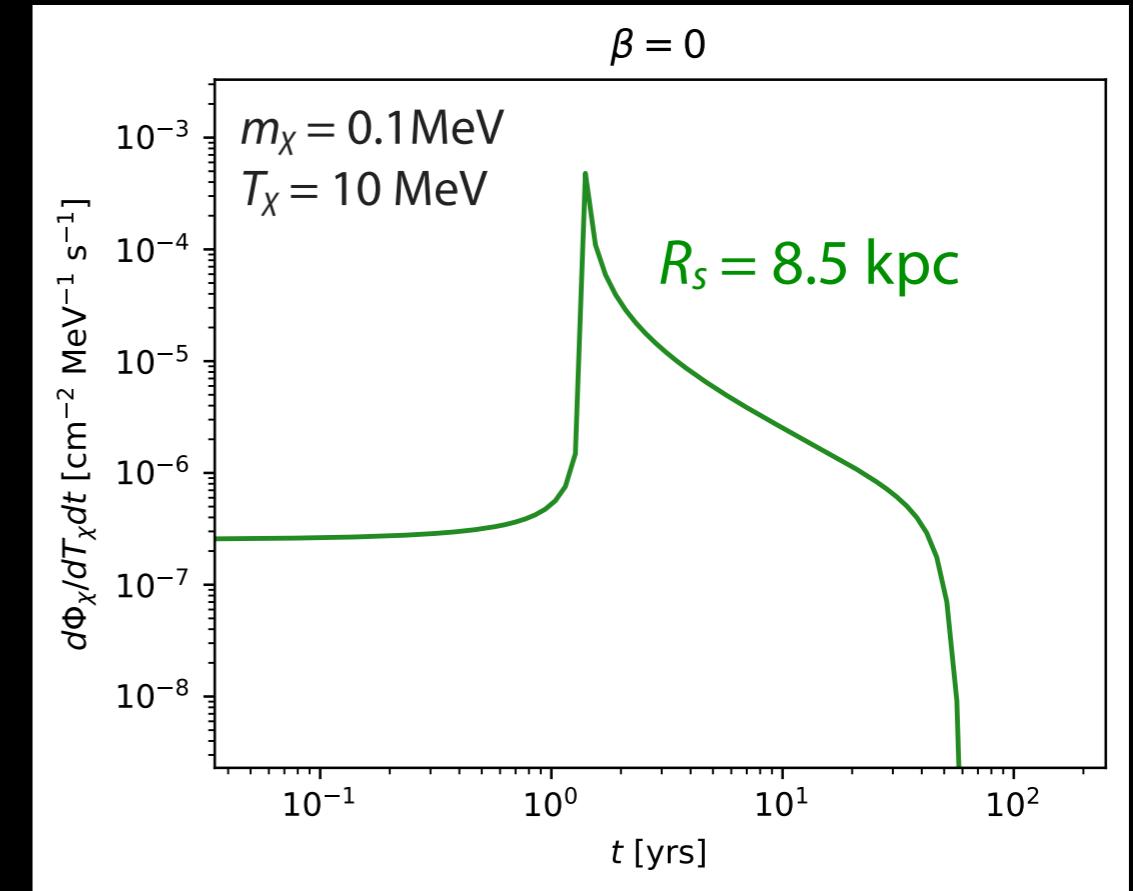
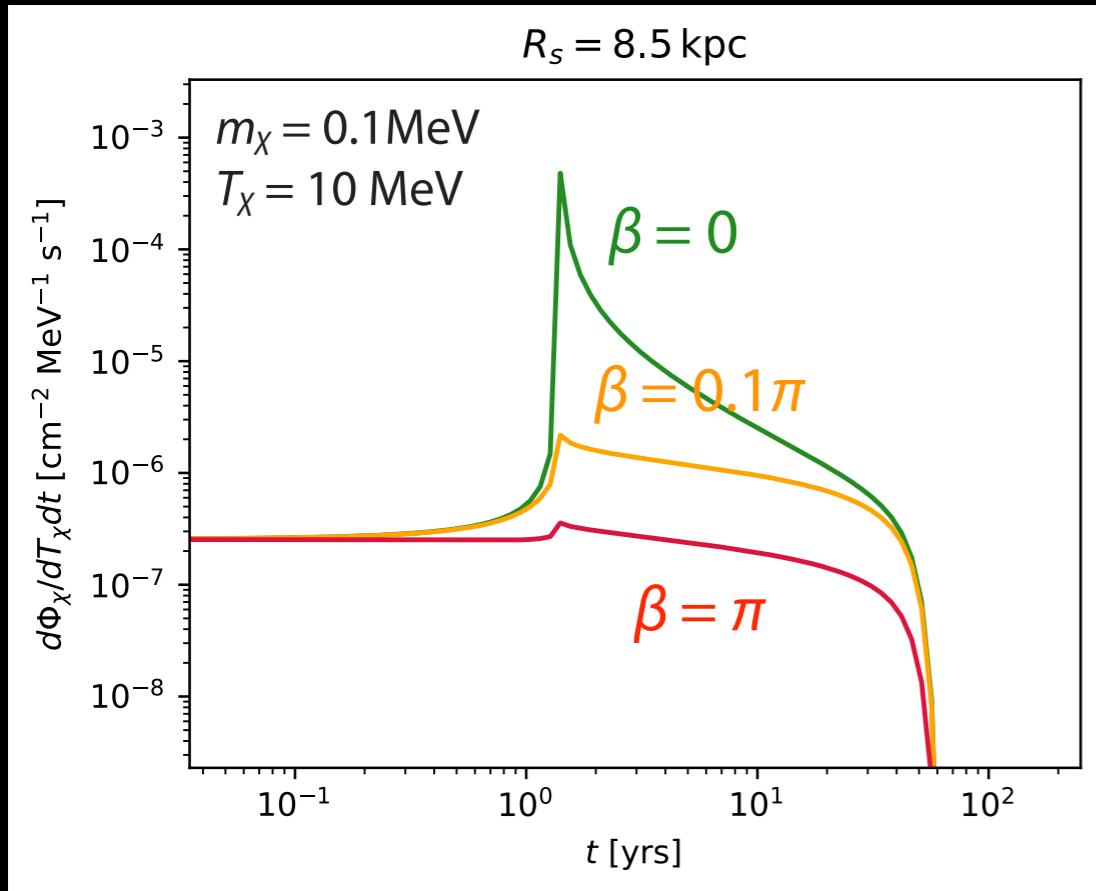


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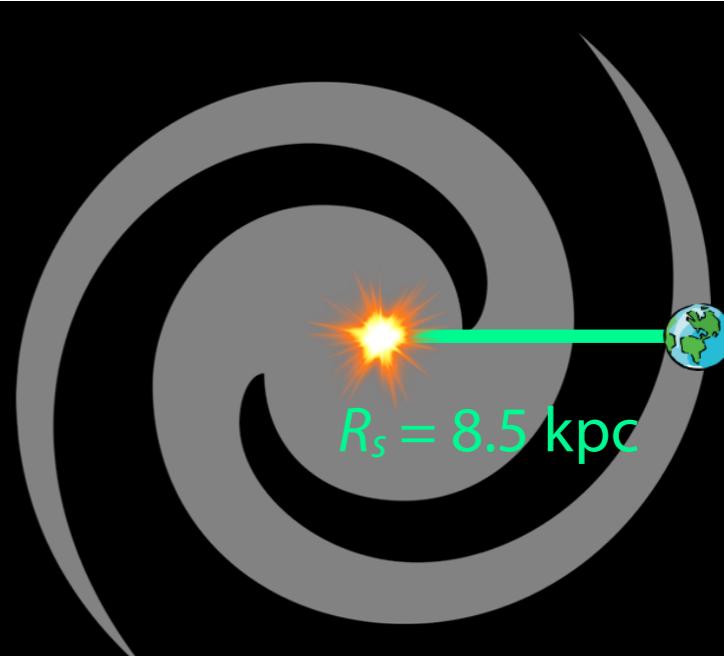


$\beta = 0$ vs. R_s

BDM from various places in MW

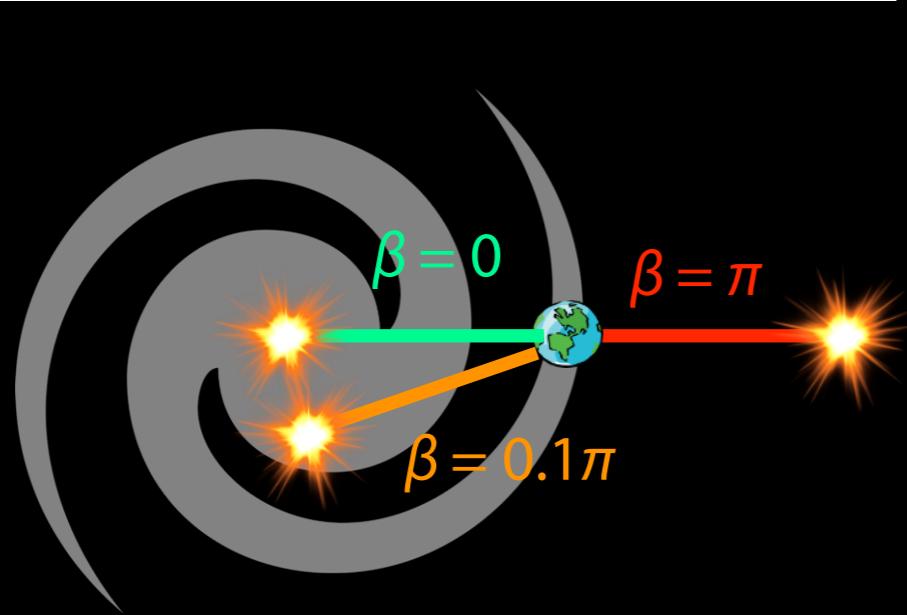
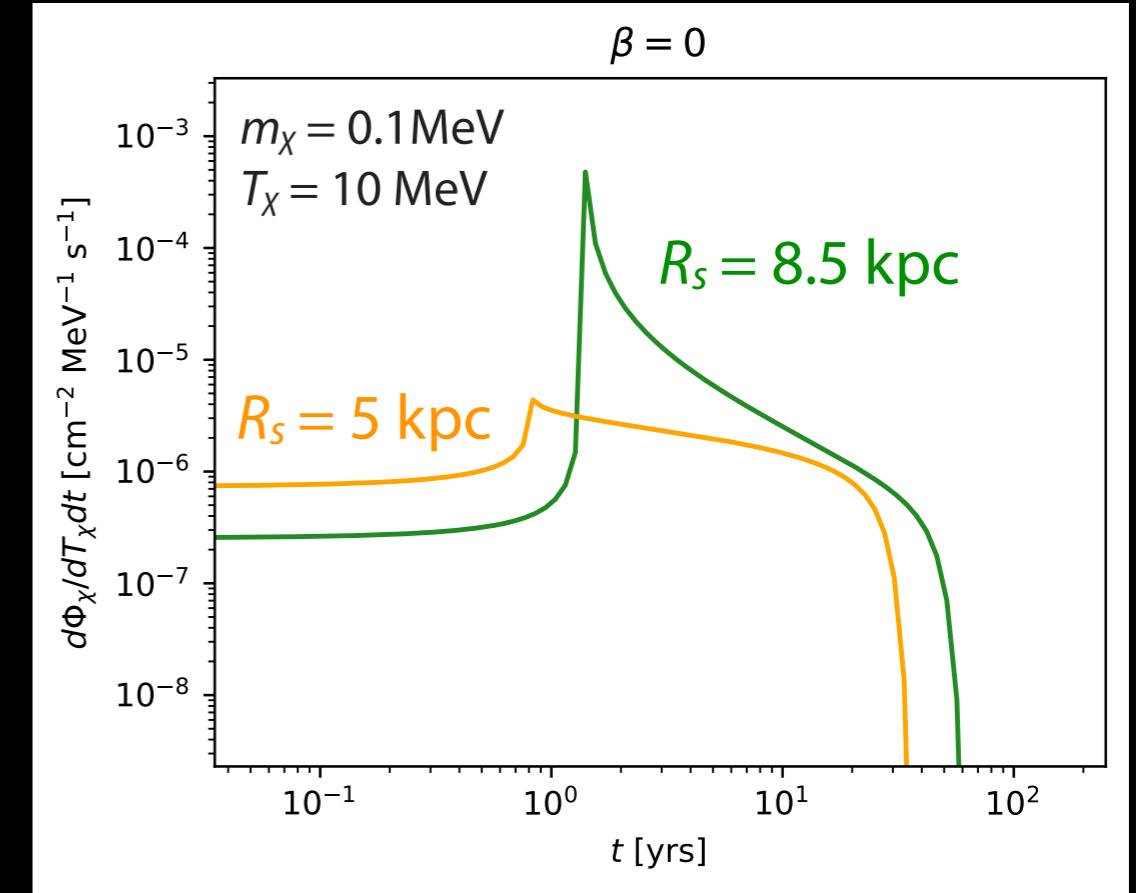
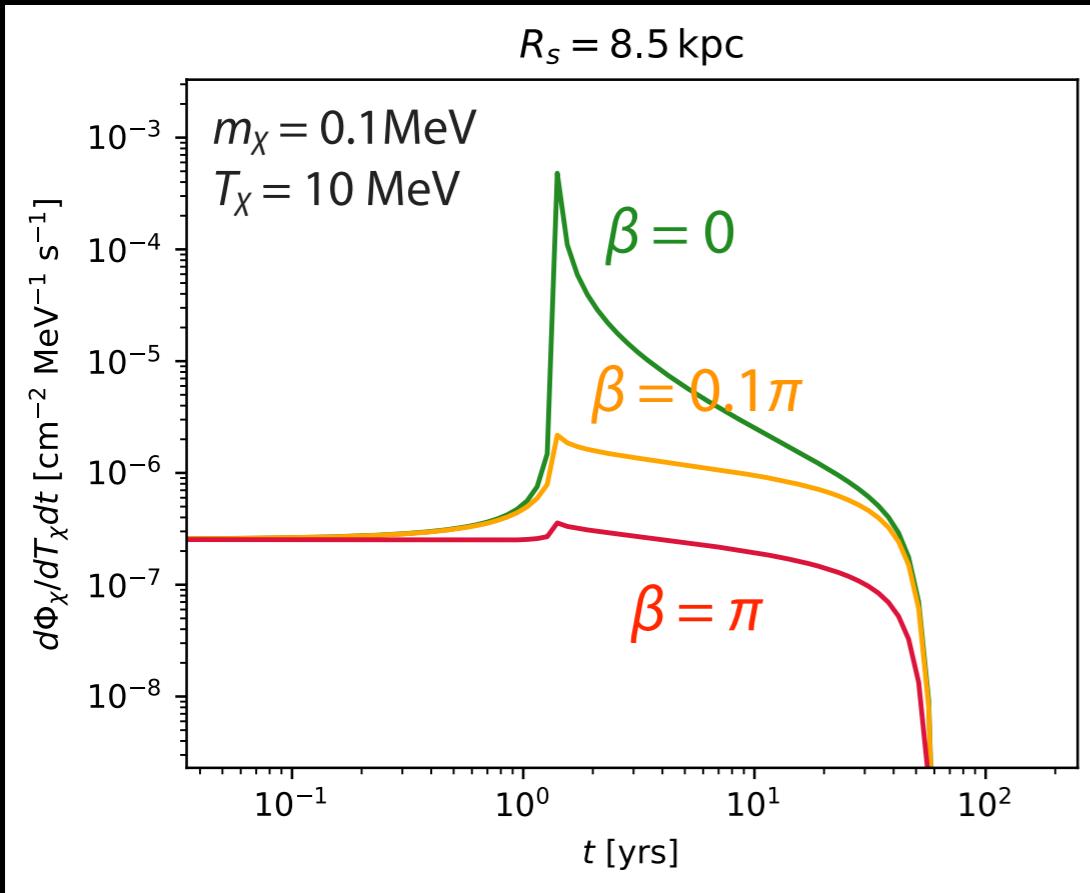


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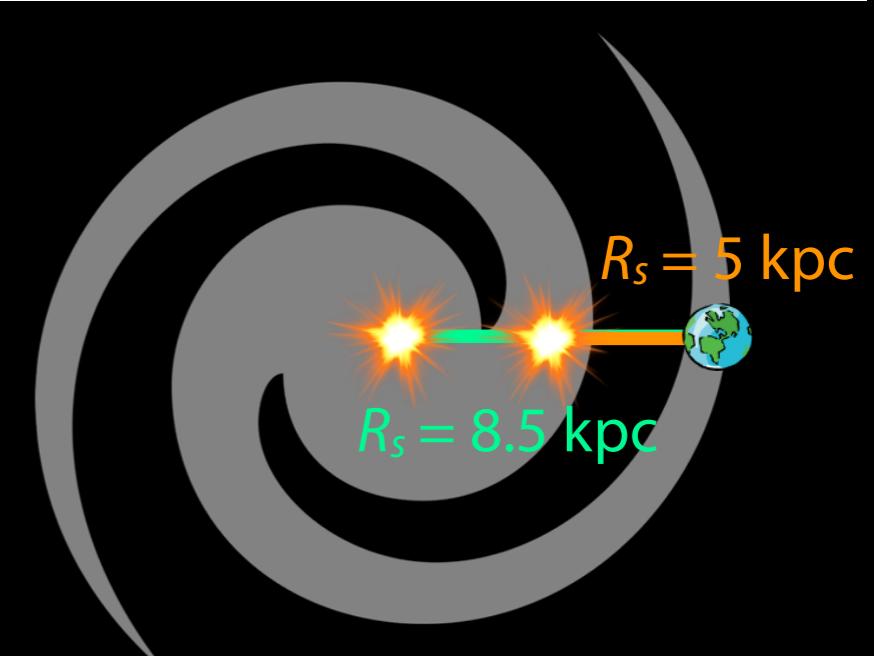


$\beta = 0$ vs. R_s

BDM from various places in MW

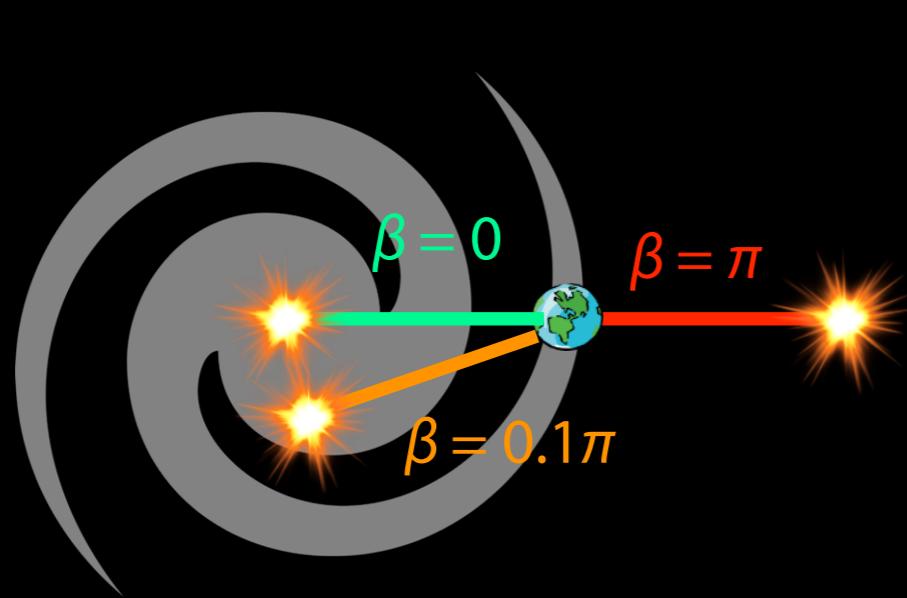
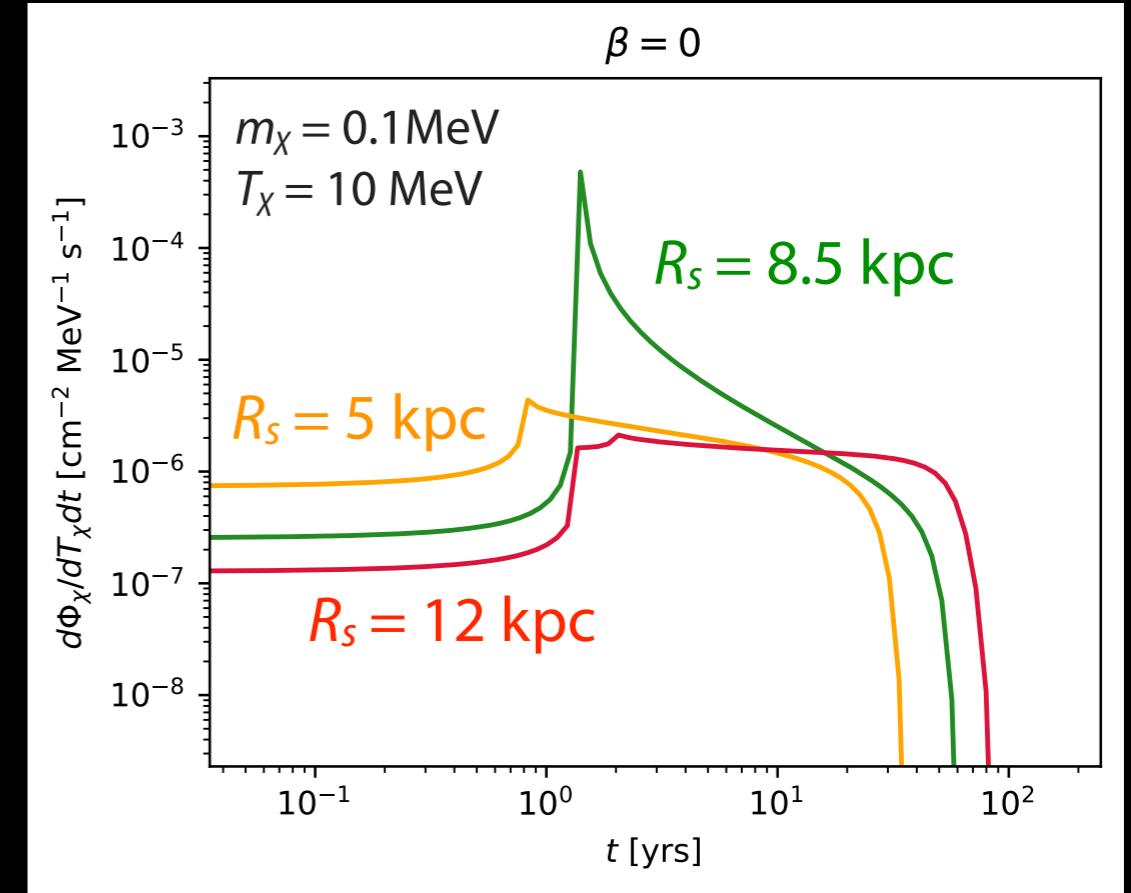
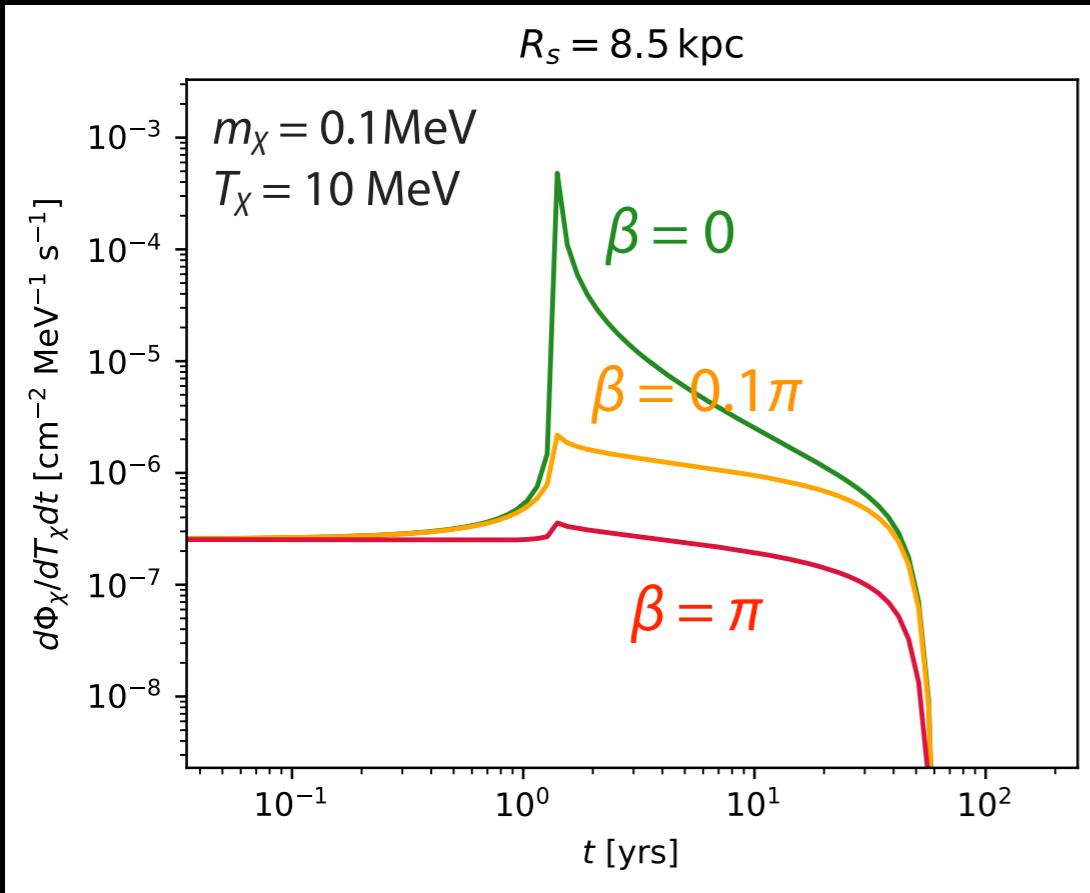


$R_s = 8.5 \text{ kpc}$ vs. β

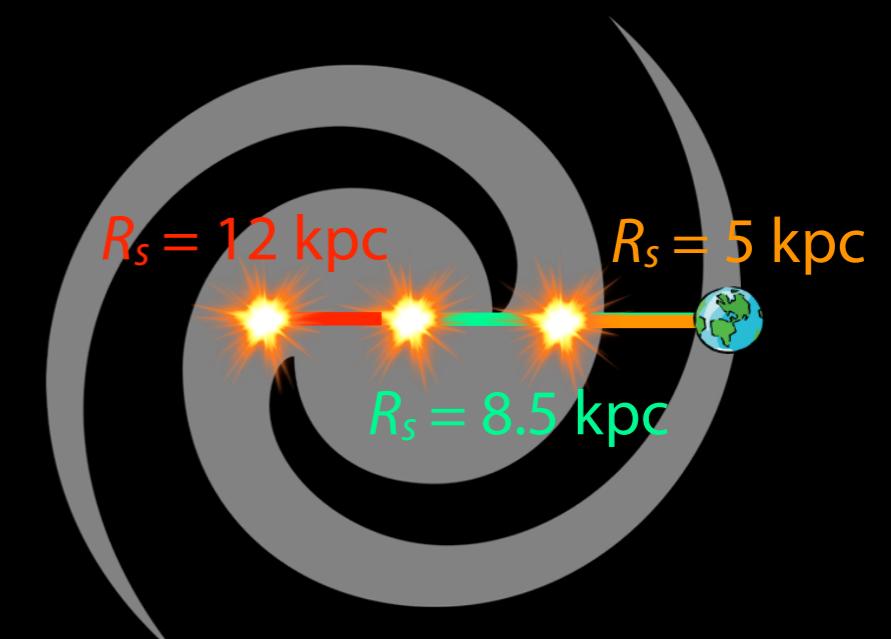


$\beta = 0$ vs. R_s

BDM from various places in MW



$R_s = 8.5 \text{ kpc}$ vs. β



$\beta = 0$ vs. R_s



Constraint and sensitivity

Sensitivity on model-agnostic parameters



- Constraint and sensitivity on $s = \sqrt{\sigma_{\chi\nu}\sigma_{\chi e}}$ by assuming $\sigma_{\chi\nu} = \sigma_{\chi e}$

$$\frac{N_\chi}{\sqrt{N_\chi + N_b}} = \begin{cases} 2.0, & \text{next GC SN} \\ 90\% \text{ CL}, & \text{SN1987a} \end{cases}$$

- The background $N_b \sim 526 \times M_T \times t_{\text{exp}}$ where M_T is the target mass

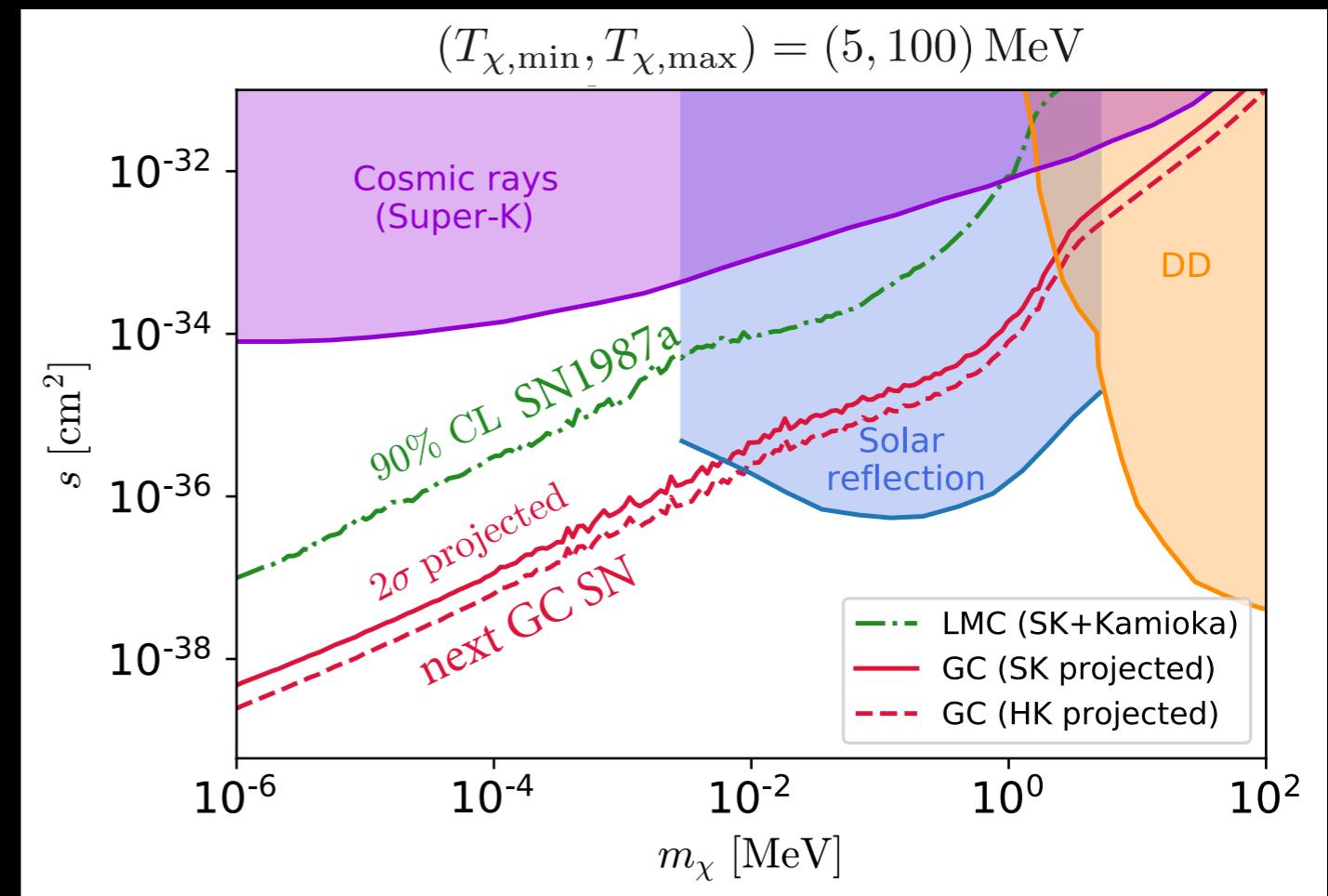
$$M_T = \begin{cases} 22 \text{ kton} : & \text{Super - K} \\ 220 \text{ kton} : & \text{Hyper - K} \end{cases}$$

- The exposure time

$$t_{\text{exp}} = \min(t_{\text{van}}, 35 \text{ yrs})$$

where

$$t_{\text{van}} \simeq \frac{m_\chi}{4T_\chi} \frac{R_s}{c}$$

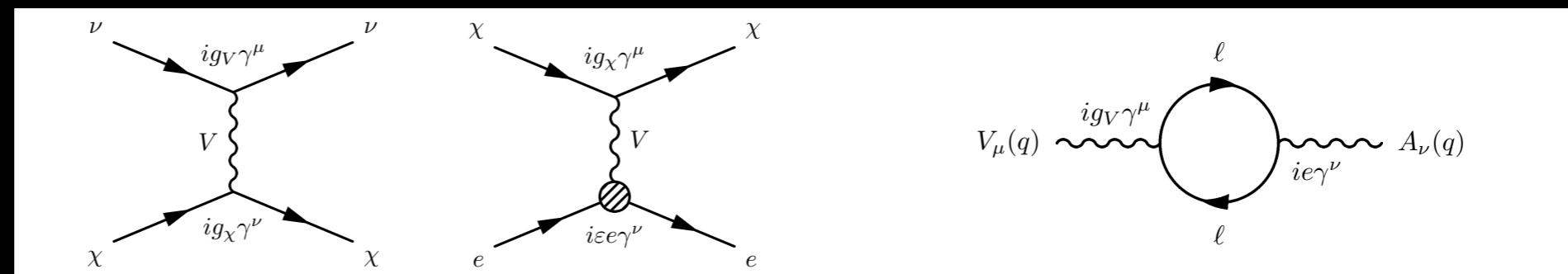
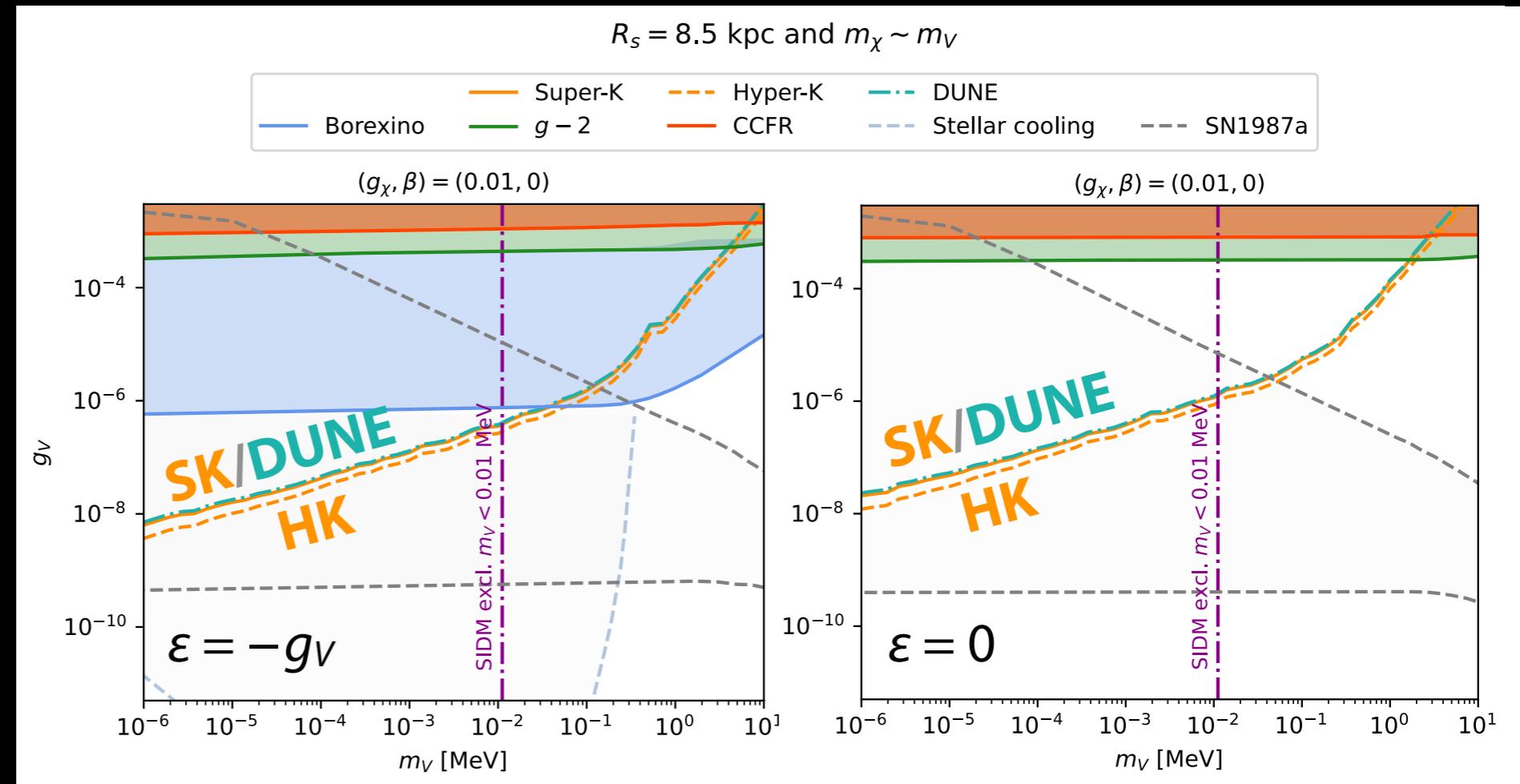


Sensitivity on L_μ - L_τ parameters

$$\mathcal{L}_{\chi, \text{int}} \supset \frac{\varepsilon}{2} F_{\mu\nu} V^{\mu\nu} + g_\chi V_\mu \bar{\chi} \gamma^\mu \chi + g_V V_\mu (\bar{\ell} \gamma^\mu \ell + \bar{\nu} \gamma^\mu P_L \nu)$$



$$M_T = \begin{cases} 17 \text{ kton} : \text{DUNE} \\ 22 \text{ kton} : \text{SK} \\ 220 \text{ kton} : \text{HK} \end{cases}$$





Summary

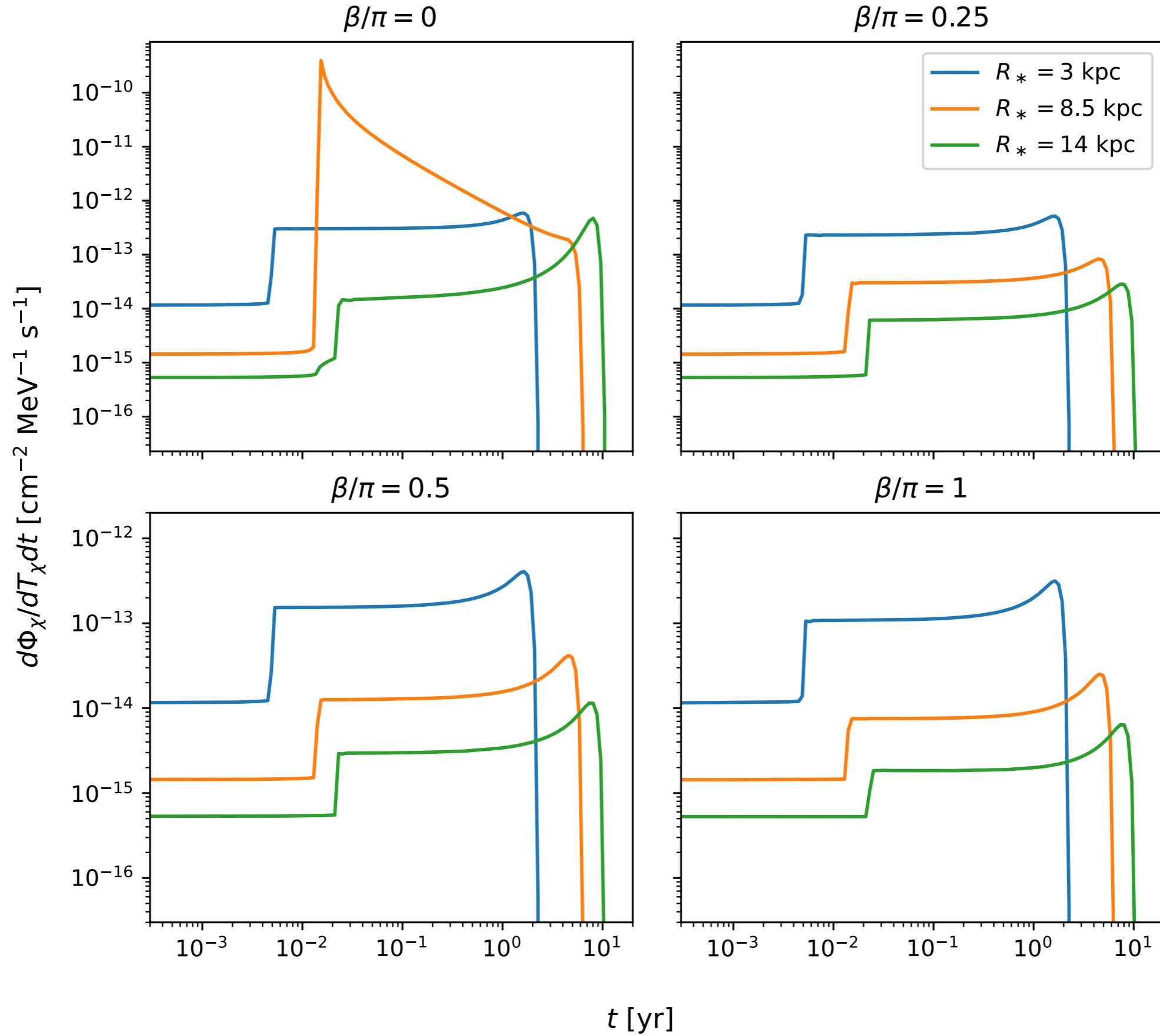
Summary

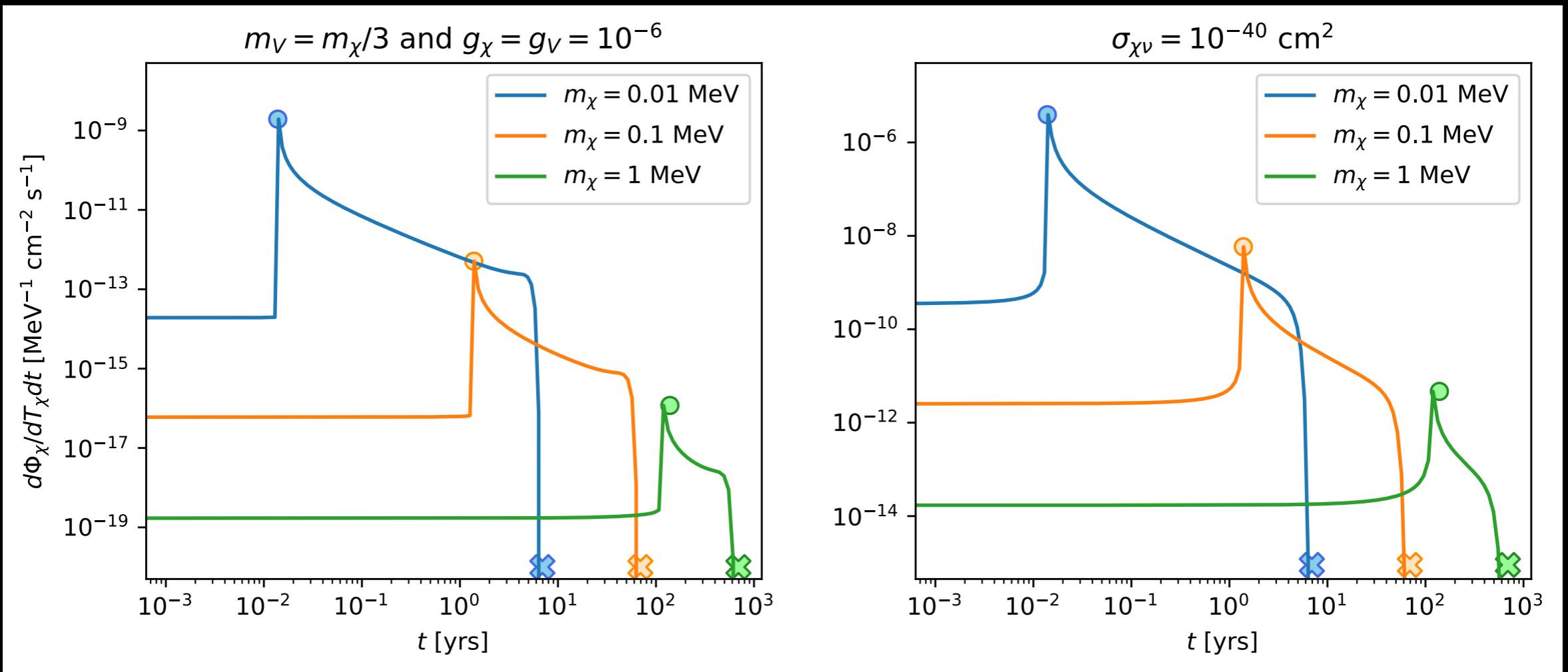
- ▶ We investigated a novel way of probing light DM in sub-MeV region with galactic SN ν
- ▶ Temporal profile measurement of the BDM flux can directly infer the DM mass, without any dependence on the phenomenological model
- ▶ Determination of t_{van} in advance leads to background reduction by controlling the detector exposure time $t_{\text{exp}} = \min(t_{\text{van}}, t_{\text{cut}} = 35 \text{ yrs})$
- ▶ SN ν BDM offers prominent sensitivity on interaction cross sections in sub-MeV DM



backups

$(m_\chi, T_\chi) = (0.01, 10) \text{ MeV}$, $m_V = m_\chi/3$ and $g_V = g_D = 10^{-6}$





$U(1)_{L_\mu - L_\tau}$ + Kinetic mixing

Model-agnostic

○ $t_p = R_s \left(\frac{1}{v_\chi} - \frac{1}{c} \right) \simeq \frac{m_\chi^2}{2T_\chi^2} \frac{R_s}{c}$

✗ $t_{\text{van}} \simeq \frac{m_\chi}{4T_\chi} \frac{R_s}{c}$