Detecting dark matter from Supernovae

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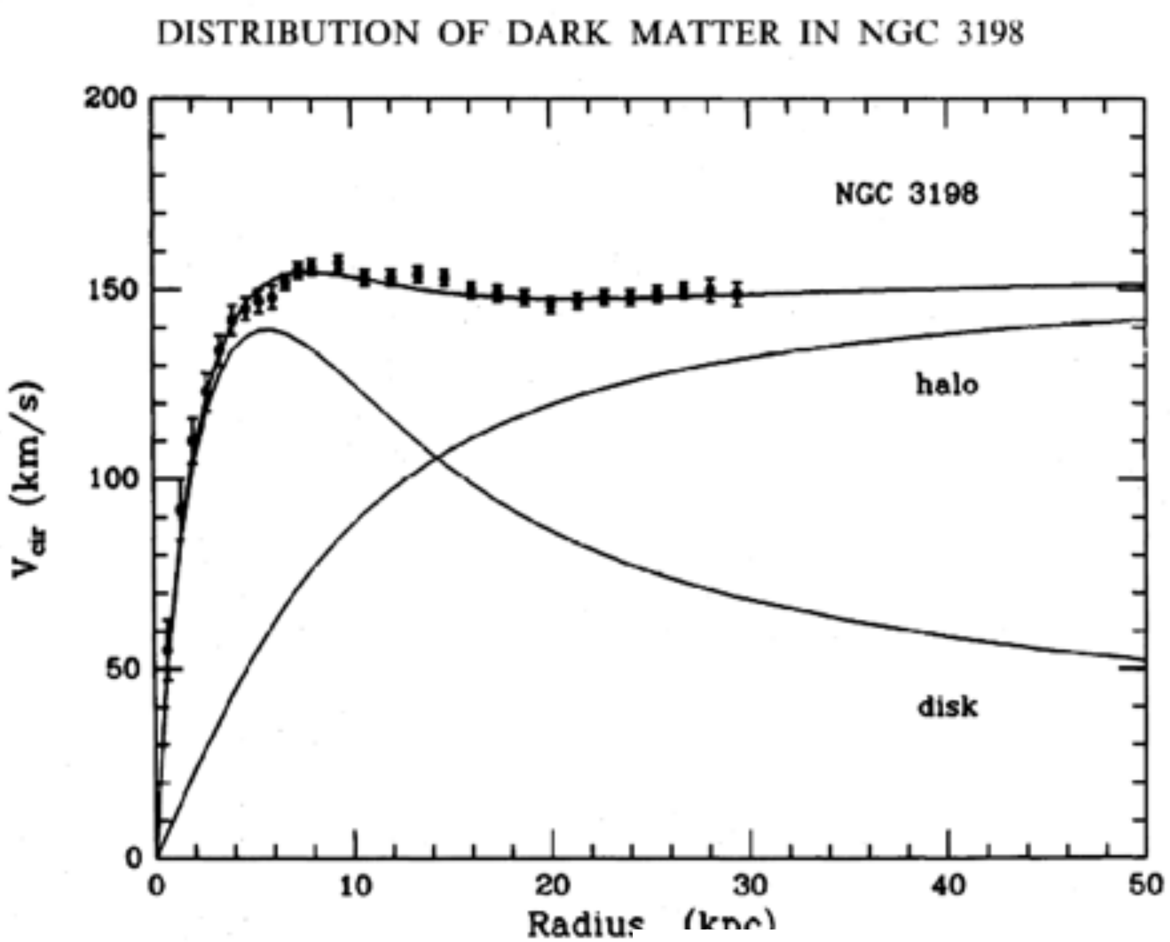
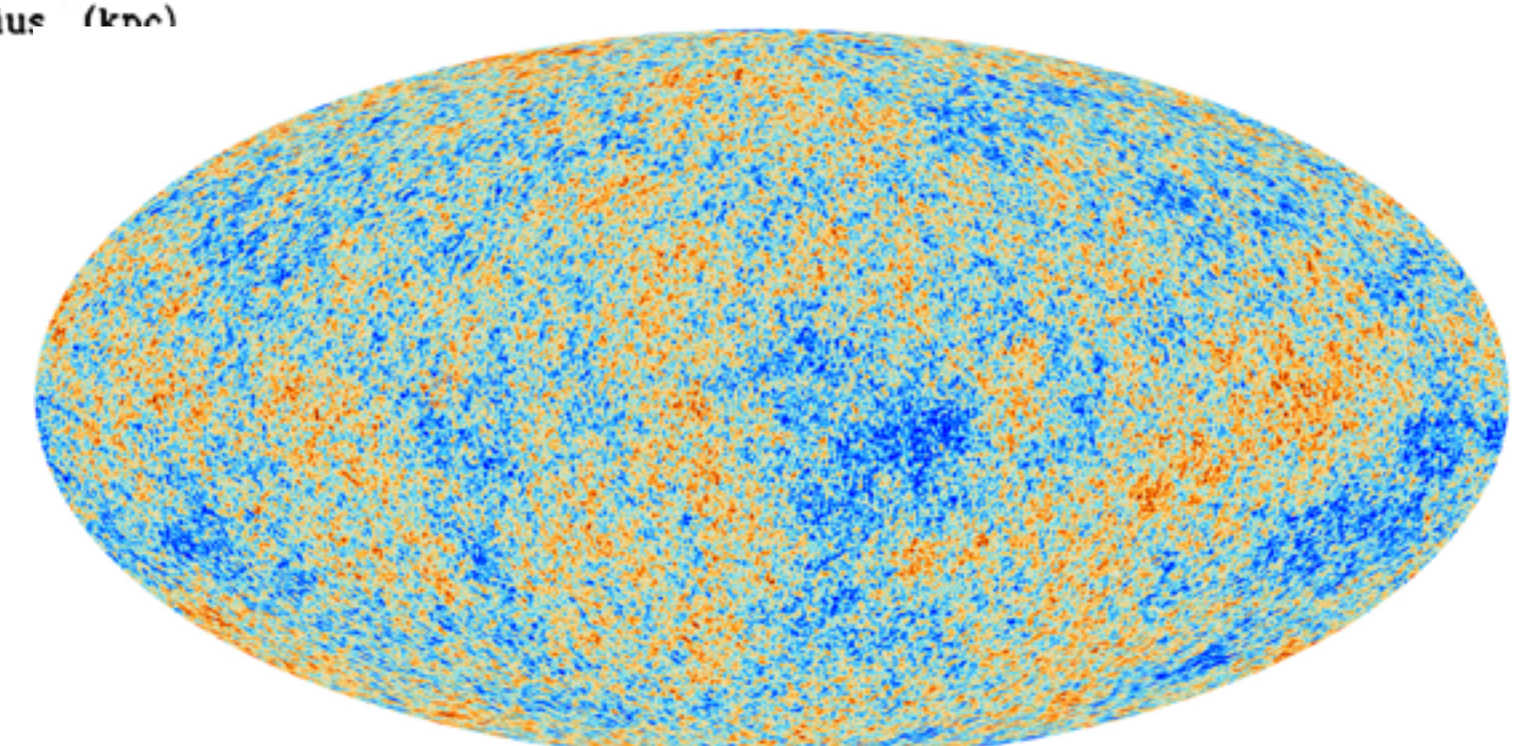
Dark matter


DISTRIBUTION OF DARK MATTER IN NGC 3198
NGC 3198
halo
disk
V_{cir} (km/s)
Radius (kpc)
0
50
100
150
200
0
10
20
30
40
50



WIMP searches

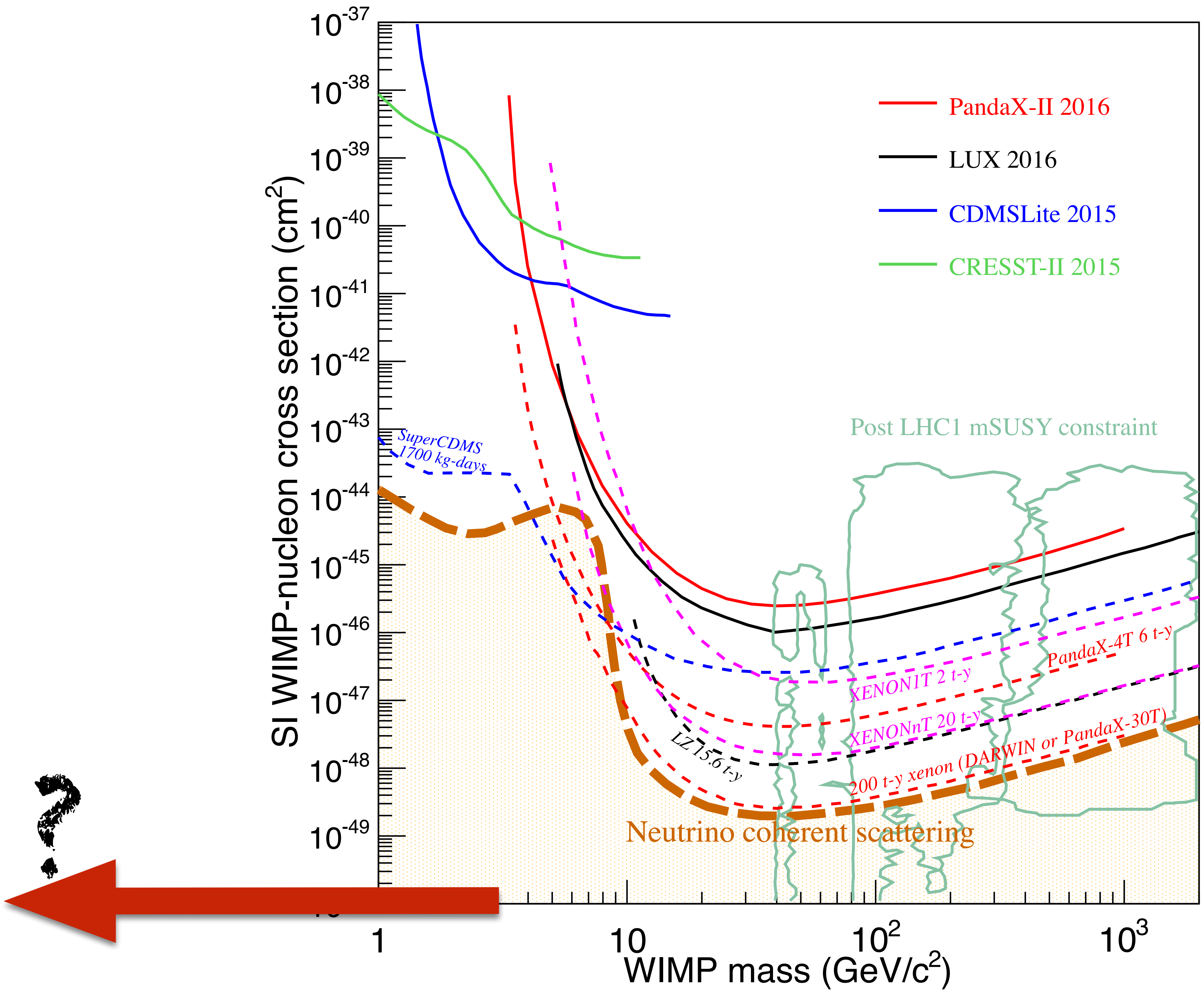


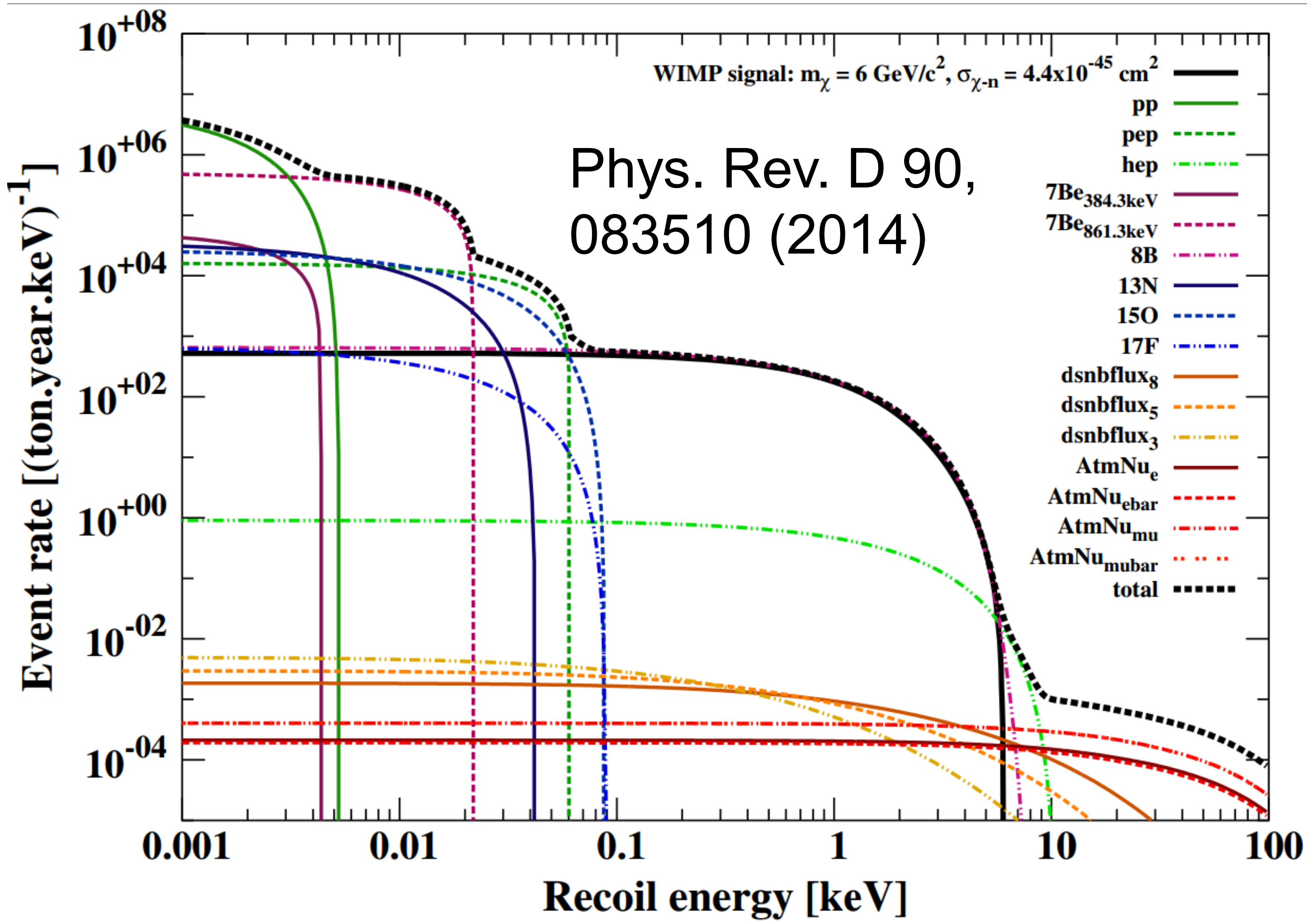
*Figure taken from arxiv:1709.00688

Challenges for sub-GeV DM

Low kinetic energy: $v \sim 10^{-3}$

$$K \sim 10^{-6} m_\chi < keV$$

Large background:

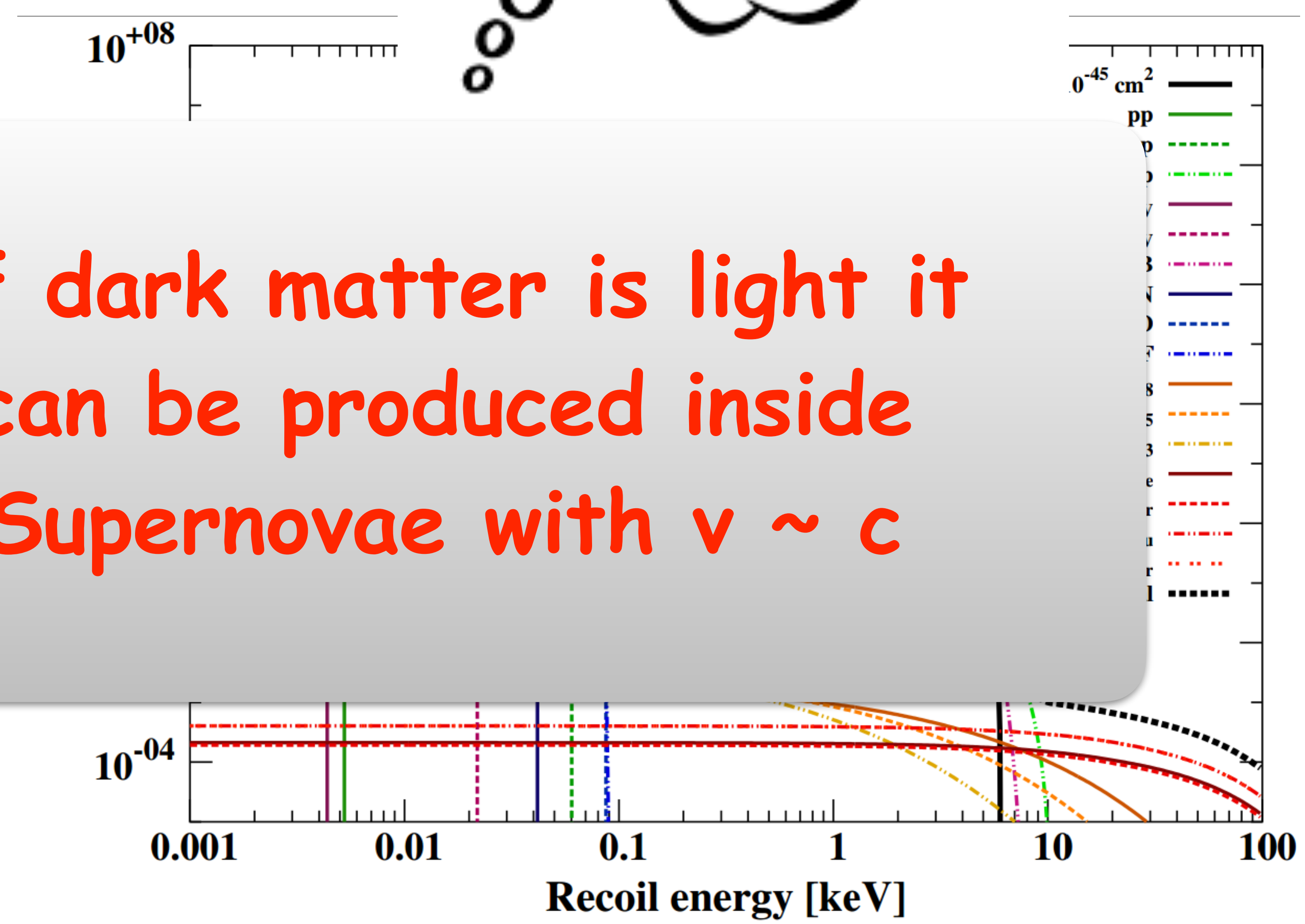


Challenges for sub-GeV DM

Low kinetic energy: $v \sim 10^{-3}$

$$K \sim 10^{-6} r$$

Large backg

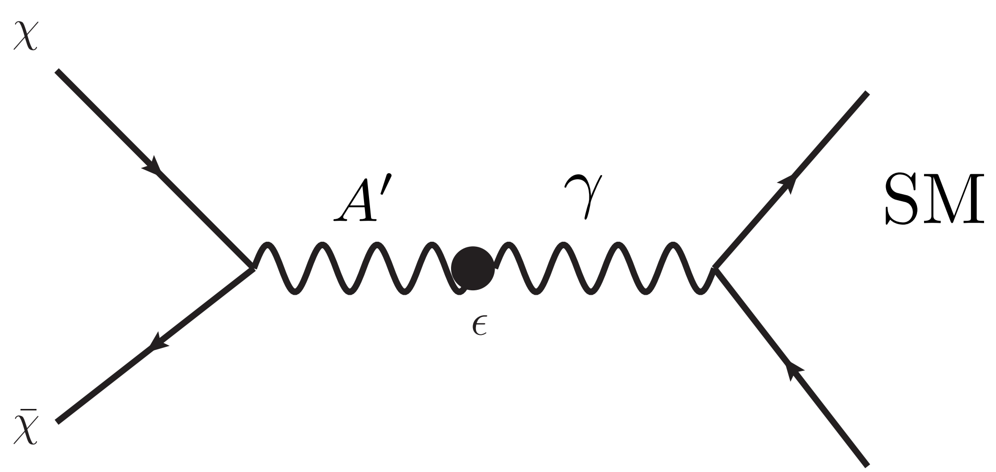


If dark matter is light it can be produced inside Supernovae with v ~ c

Dark photon portal

$$\mathcal{L} \supset A'_\mu \bar{\chi} \gamma^\mu \chi + \epsilon F'_{\mu\nu} F^{\mu\nu}$$

$$m_{A'} \gtrsim 200 \text{ MeV} > m_\chi$$

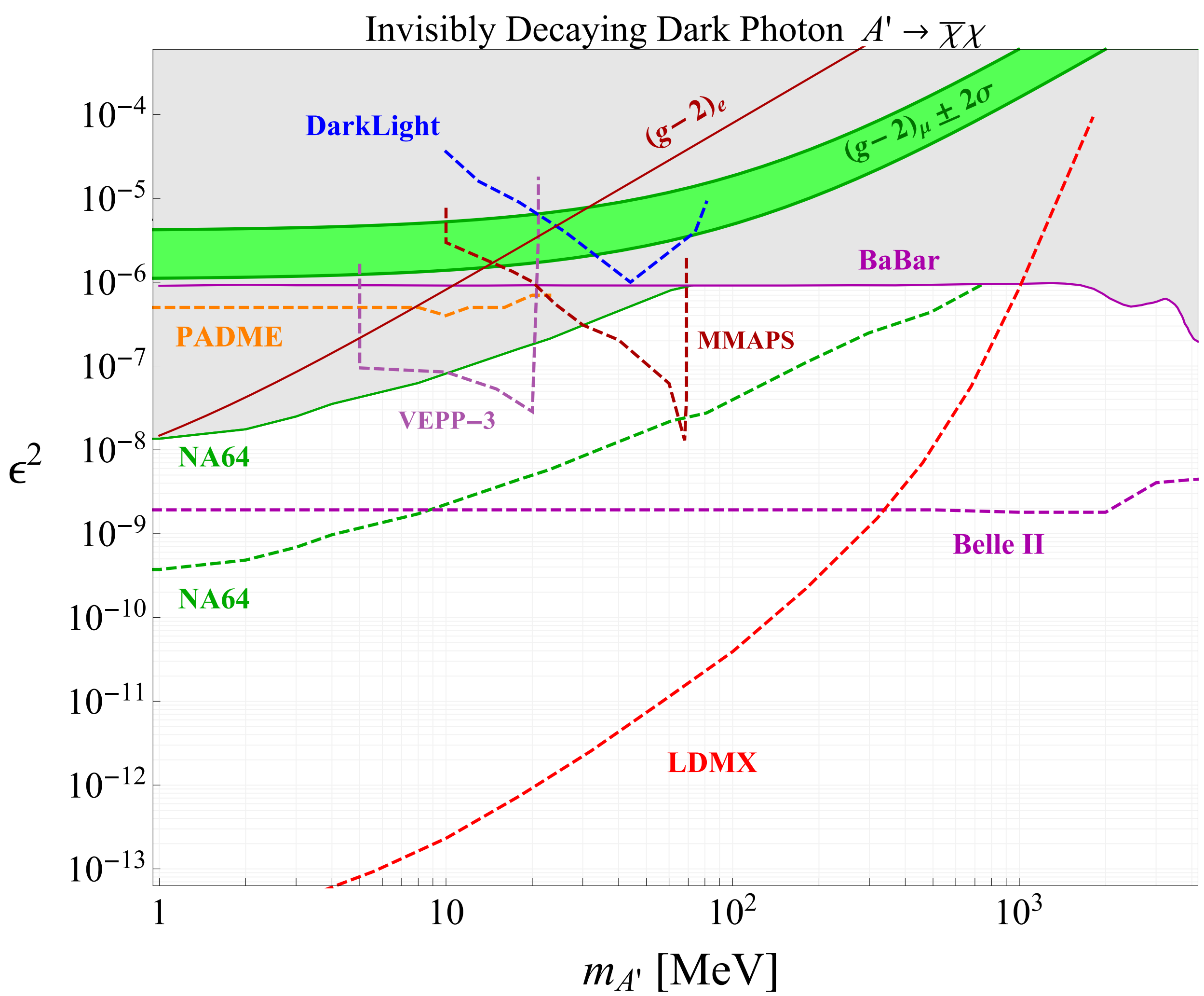


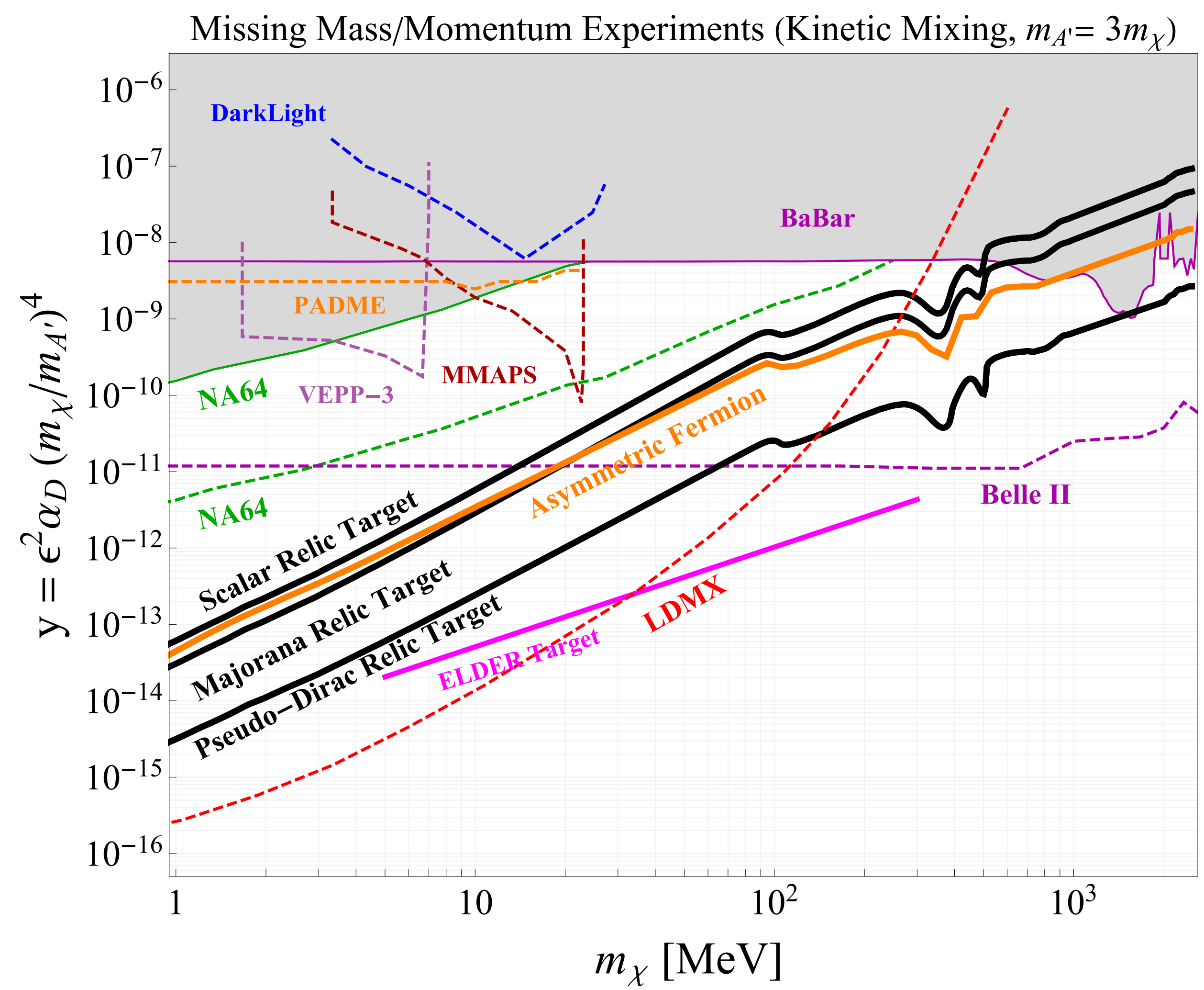
$$\mathcal{L} \supset \frac{g_d e \epsilon}{m_{A'}^2} \bar{\chi} \gamma_\mu \chi J^\mu_{\mathrm{EM}}$$

$$y = \alpha_d \epsilon^2 \left(\frac{m_\chi}{m_{A'}} \right)^4$$

Dark photon portal

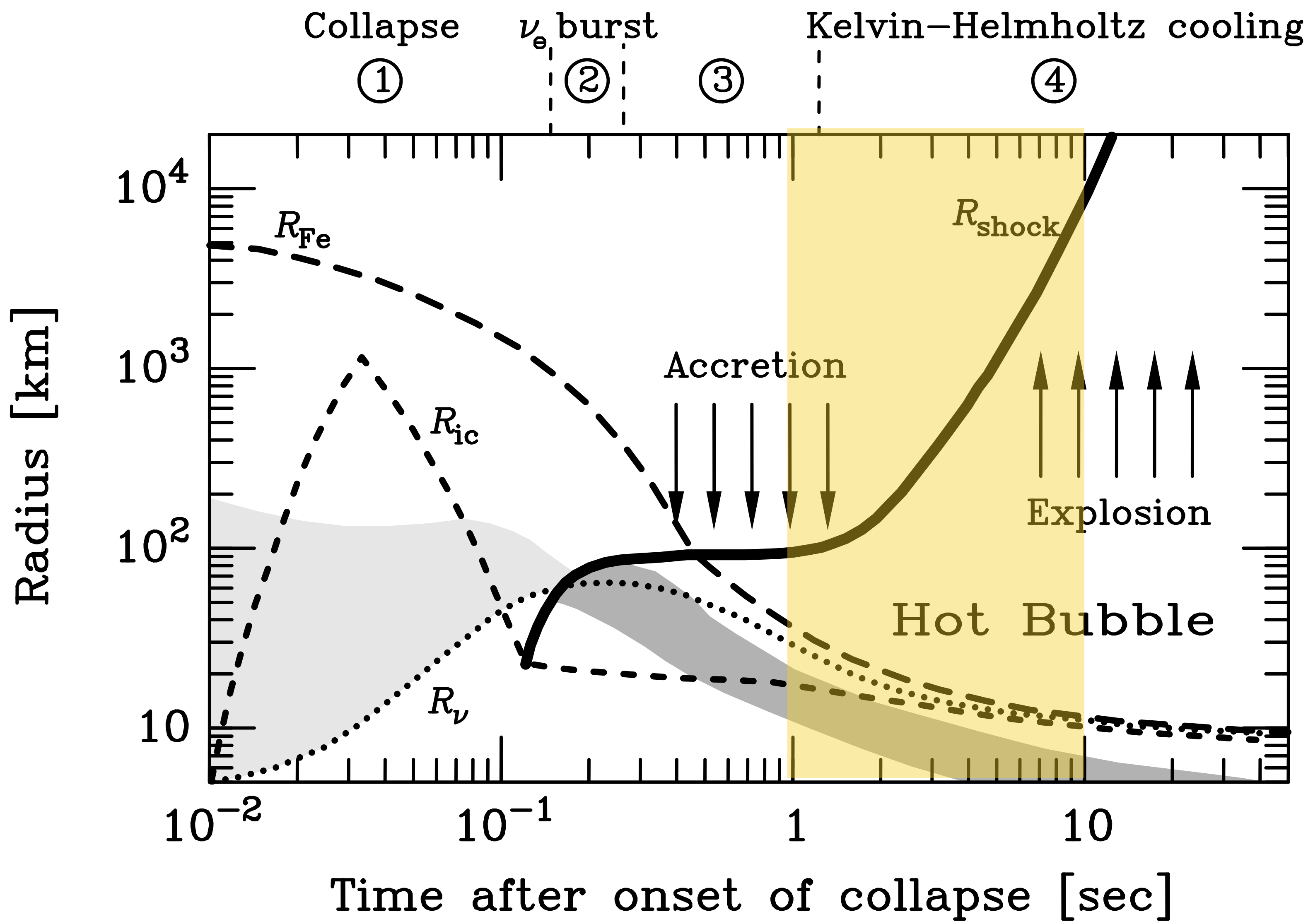
$$\mathcal{L} \supset \frac{g_d e \epsilon}{m_{A'}^2} \bar{\chi}\gamma_\mu \chi J^\mu_{\rm EM} \longrightarrow y = \alpha_d \epsilon^2 \left(\frac{m_\chi}{m_{A'}}\right)^4$$





* Figure from US Cosmic Visions Report

Core-Collapse Supernova



* Figure from: G. Raffelt, "Stars as Laboratories for Fundamental Physics" , 1996

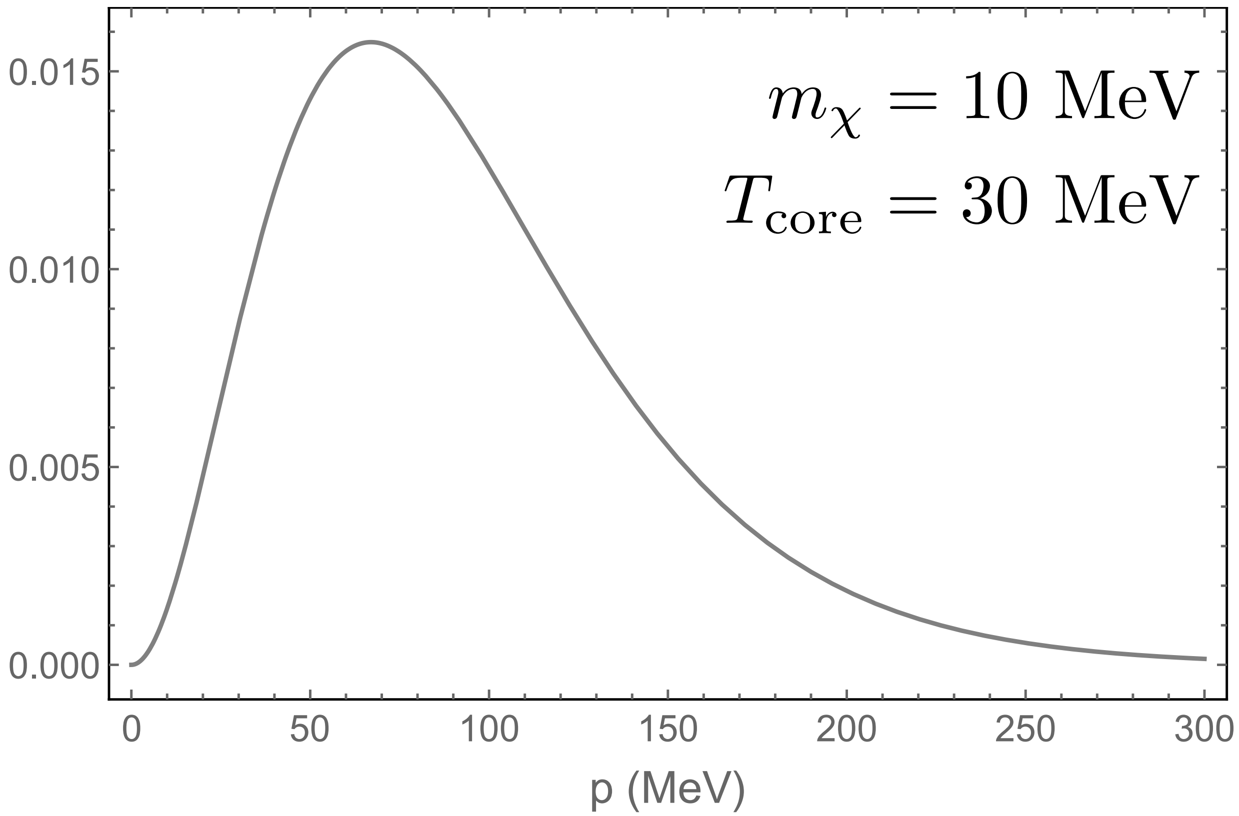
Important effects

Must take into account

- Interactions are large, so dark matter is trapped inside Supernova out to larger radii:
  - Emits as a black-body (surface vs volume)
  - Lower temperature

- Significant velocity spread $\rightarrow$ signal is significantly spread in time

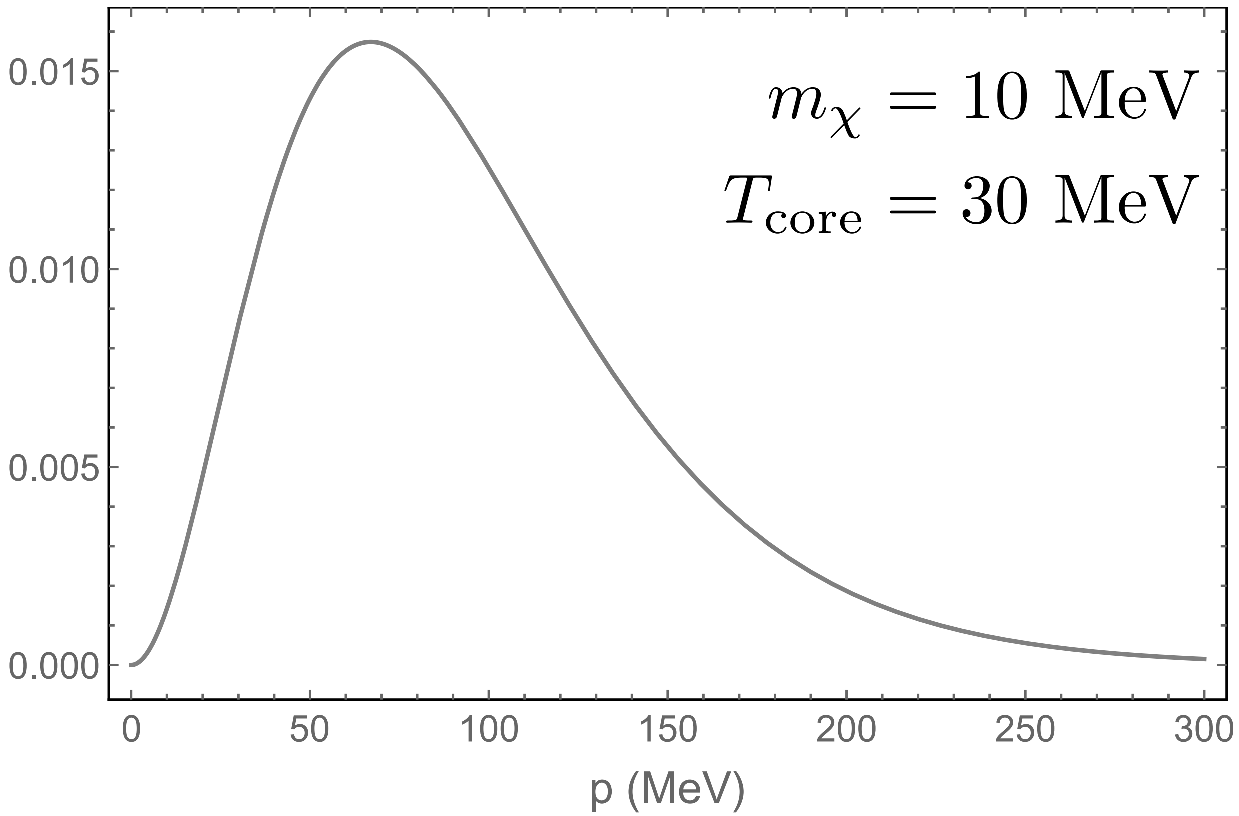
Velocity spread



$$\langle E_\chi \rangle \sim 60 \text{ MeV}$$

$$\langle v_\chi \rangle \sim 0.98$$

Velocity spread



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55 kpc ~ 180000 light years

- Dark matter from SN1987a: still some years to get here
- Signal spread:

$$\frac{\delta v}{v} \sim 1 \longrightarrow \frac{\delta t}{180000\text{yr}} \text{ dilution}$$

Semi-relativistic DM

- Dark matter from SN1987a: still some years to get here
- Signal spread: 10^{-13} dilution

- SN1987a not useful
- Sensitive to older SN (potentially much closer)
- Sensitive to diffuse background of older SN

Semi-relativistic DM

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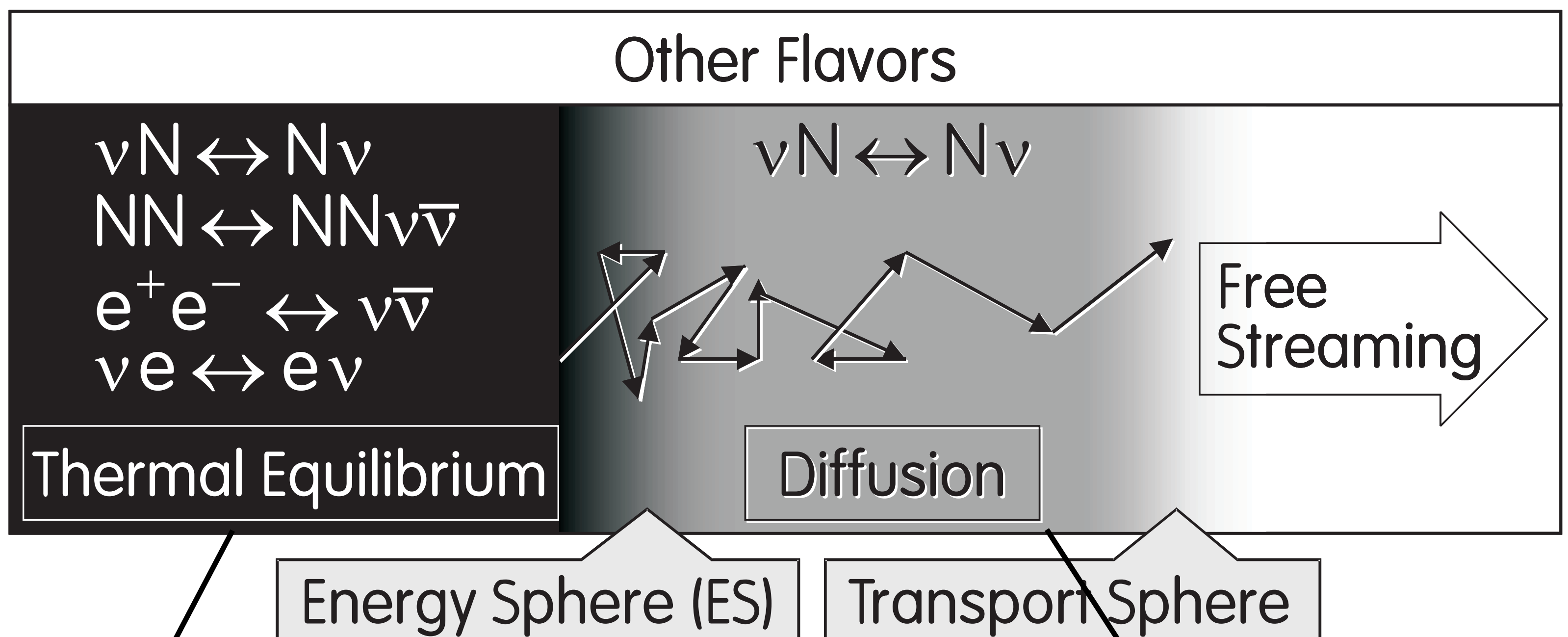
Focus on galactic diffuse background

Understanding Trapped Regime

Useful analogy with neutrino case



Interactions that change neutrino number and/or energy

Interactions that change direction without significant change in energy

Figure taken from: G. Raffelt astro-ph/0105250

Understanding Trapped Regime

- Ultimately described by a Boltzmann equation
- Reasonable results can be obtained using a "freeze-out" calculation.

<u>Freeze-out in time</u>

Rate ~ 1/timescale

e.g.

$$H \sim n\langle \sigma v \rangle$$

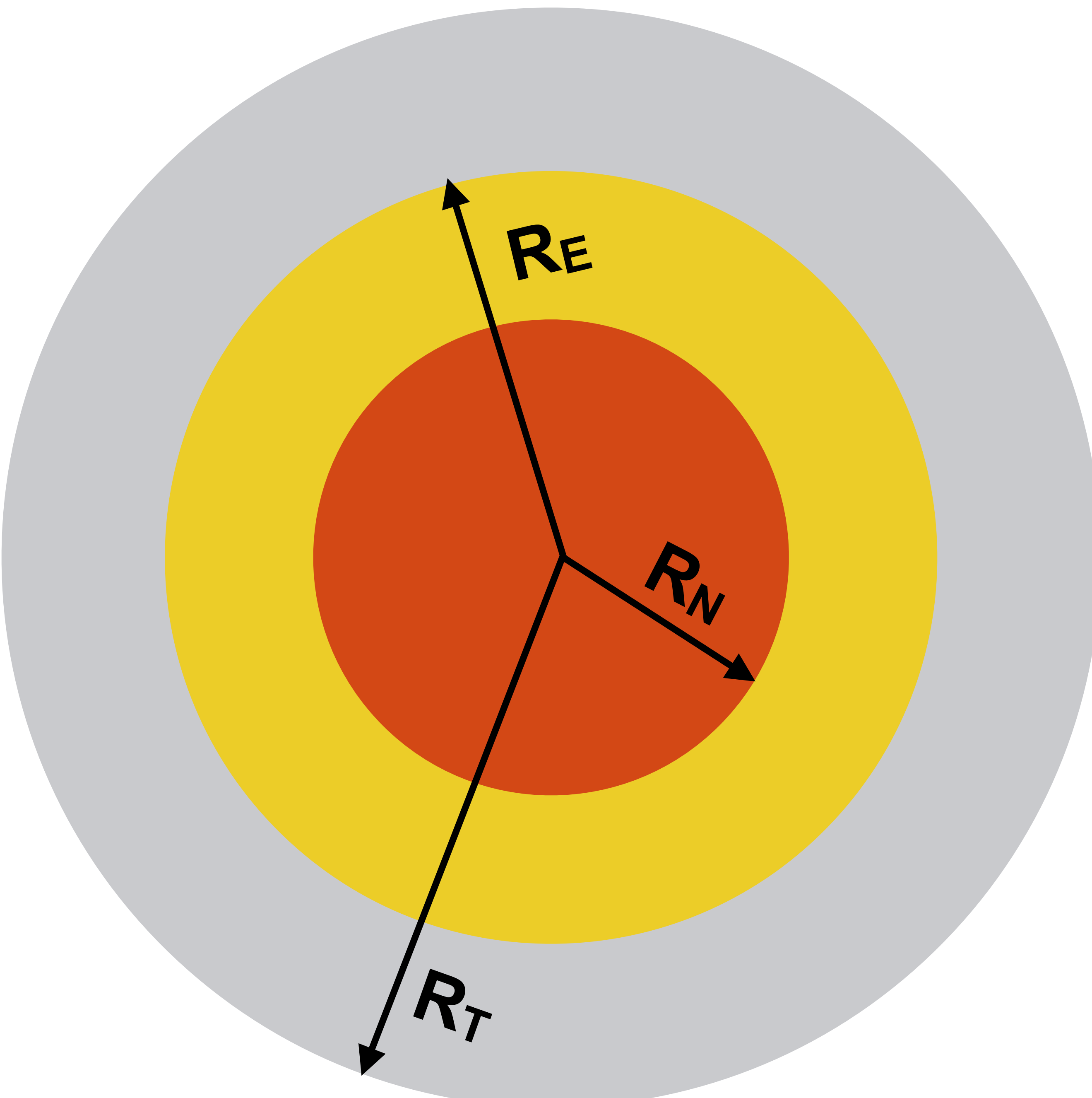
<u>Freeze-out in space</u>

Mean free path ~ typical distance

e.g.

$$\frac{1}{n(r)\langle \sigma \rangle} \sim r$$

Freeze-out Picture



- R_N : Number sphere

$$\bar{\chi}\chi \to e^+e^-$$

- R_E : Energy sphere

$$\chi e^\pm \to \chi e^\pm$$

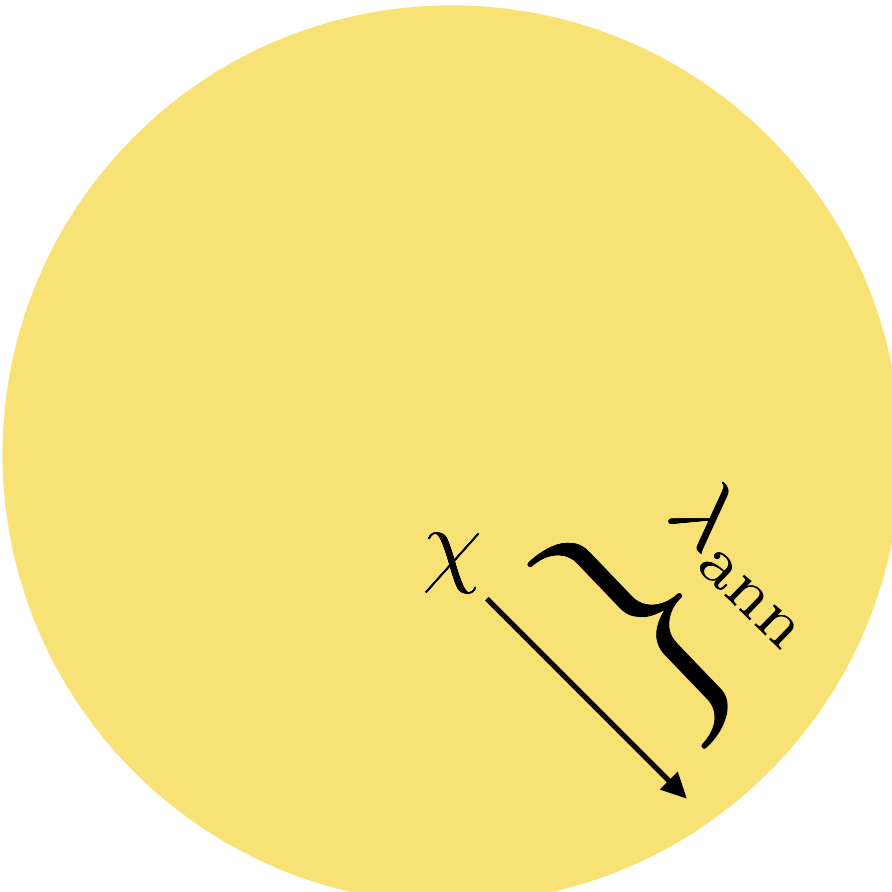
- R_T : Transport sphere

$$\chi p \to \chi p$$

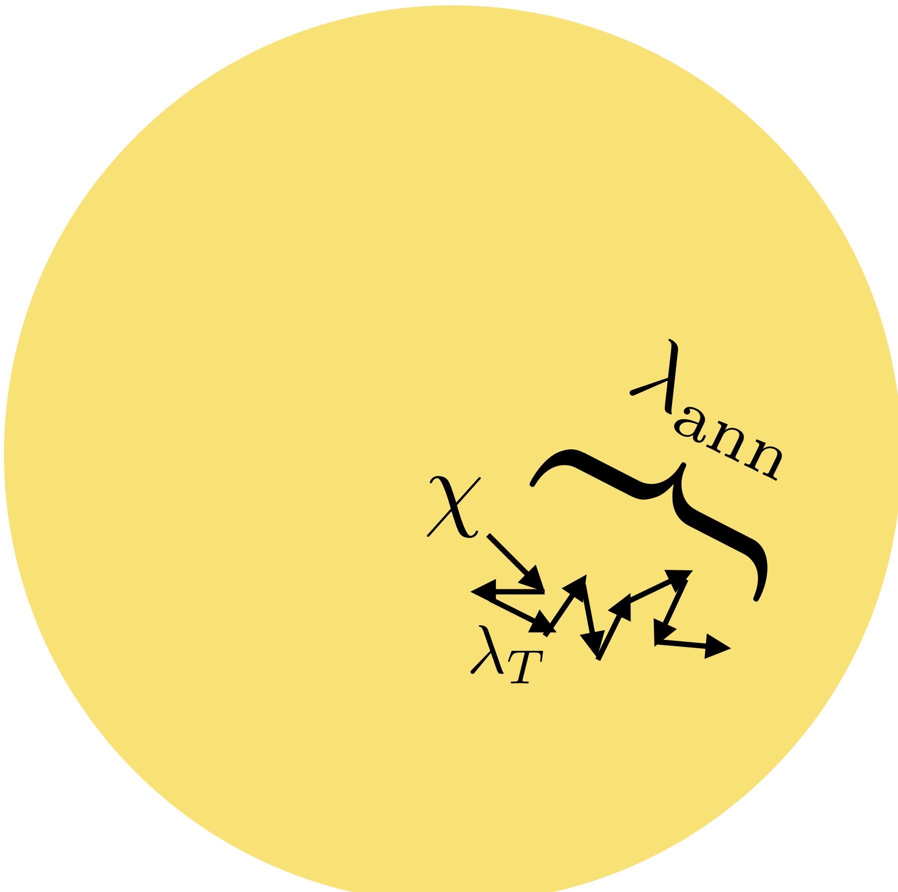
Radial freeze-out

<u>Freeze-out requirement:</u>

No other interactions



Diffusion

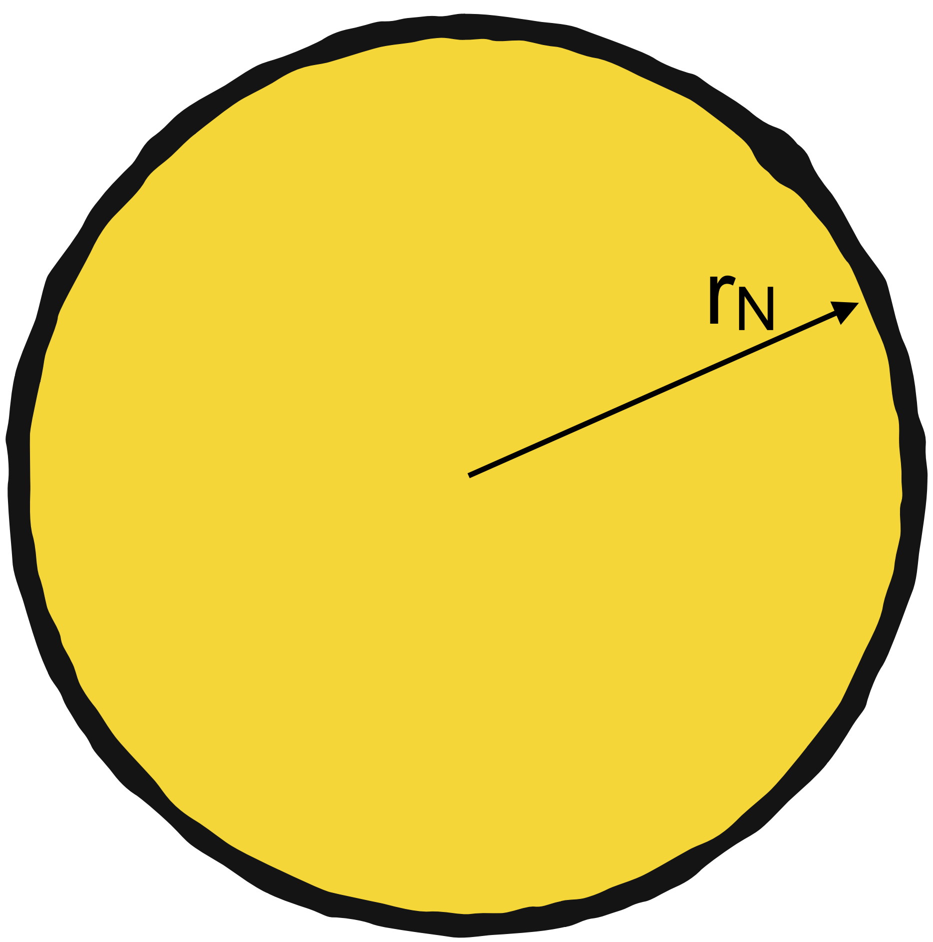


It takes $\left(\frac{\lambda_{\rm ann}}{\lambda_T}\right)$ longer to cover $\lambda_{\rm ann}$

Freeze-out calculation

Annihilation Sphere:

$$\tau_{\text{ann}} = \int_{r_N}^{\infty} \frac{dr}{\sqrt{\lambda_{\text{ann}}\,\lambda_T}} = 2/3$$



Treat as a perfect black-body

$$\Phi|_{r_N} = \frac{1}{4\pi^2} \int_{m_\chi}^{\infty} dE \, \frac{(E^2 - m_\chi^2)}{e^{E/T(r_N)} + 1}$$

$$\sim (MT)^{3/2} e^{-M/T}$$

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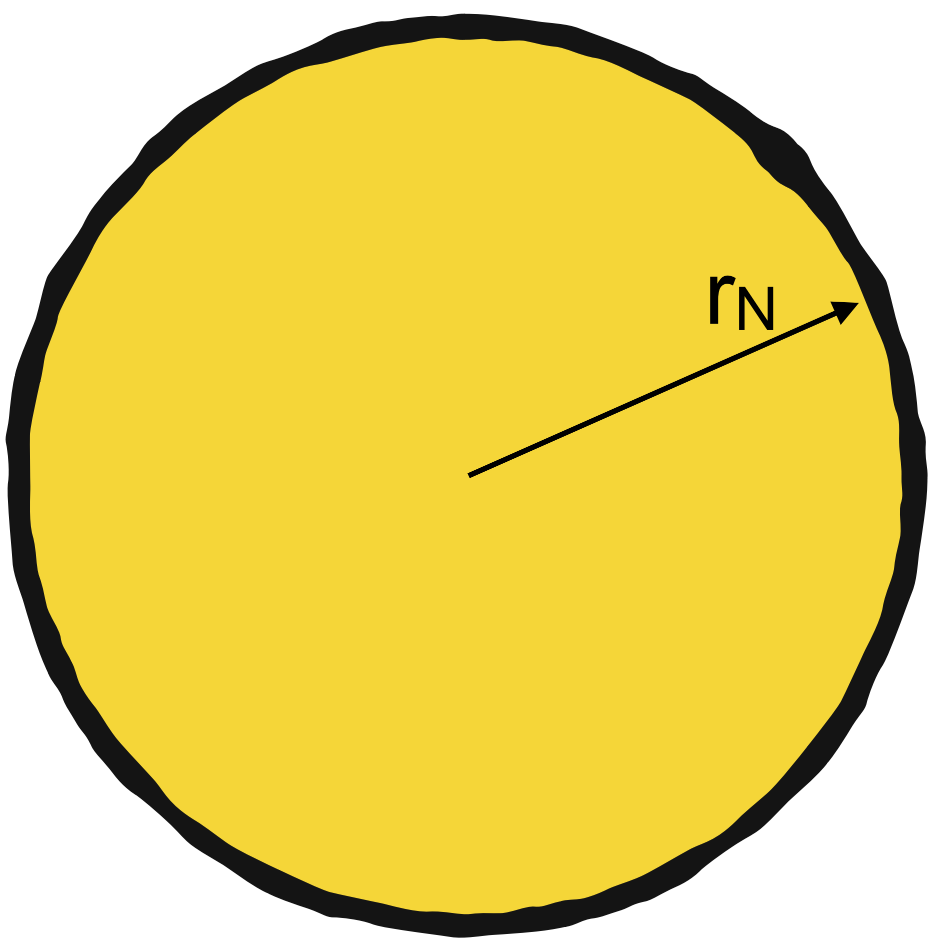

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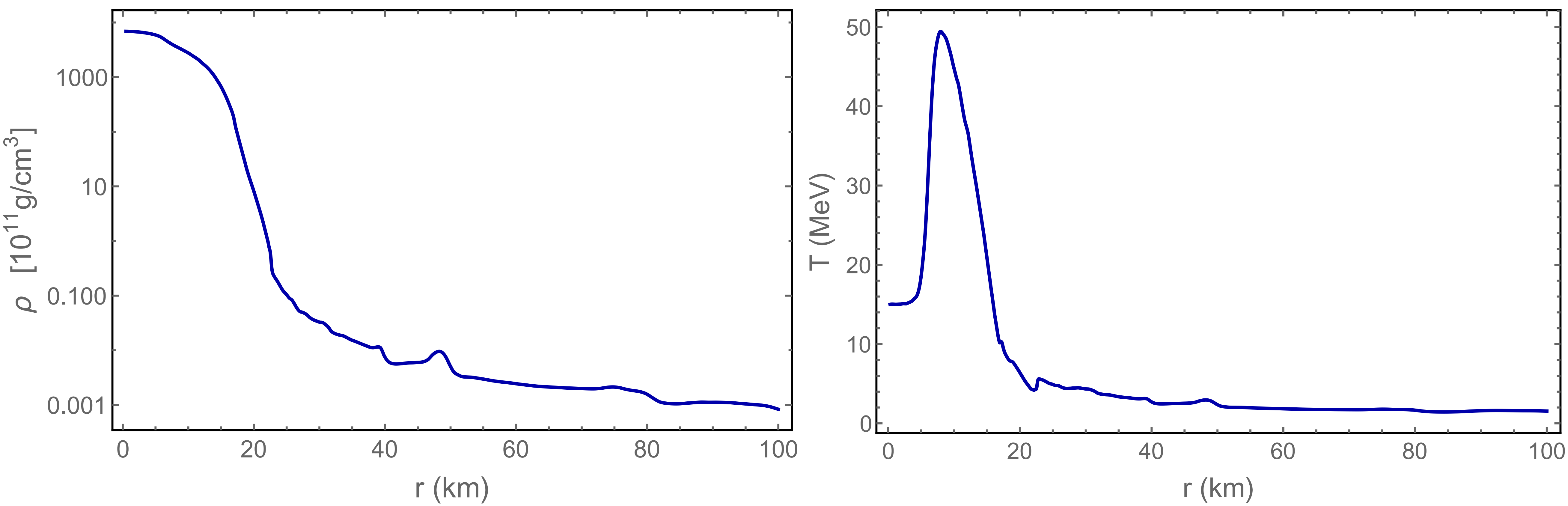
Include the effect of the energy sphere by assuming it doesn't change the total flux but redistributes momenta according to the temperature in r_E

Computing the flux

Snapshot at 1.5 seconds post bounce



Detecting DM flux

- Electron targets:

$$\Delta k_e \approx m_e \, v_{\rm DM}$$

$$\sigma_{\chi e} \propto \frac{m_e}{E_\chi}$$

- Nuclear targets

$$\Delta k_n \approx 2p_\chi$$

$$\sigma_{\chi n} \propto Z^2$$

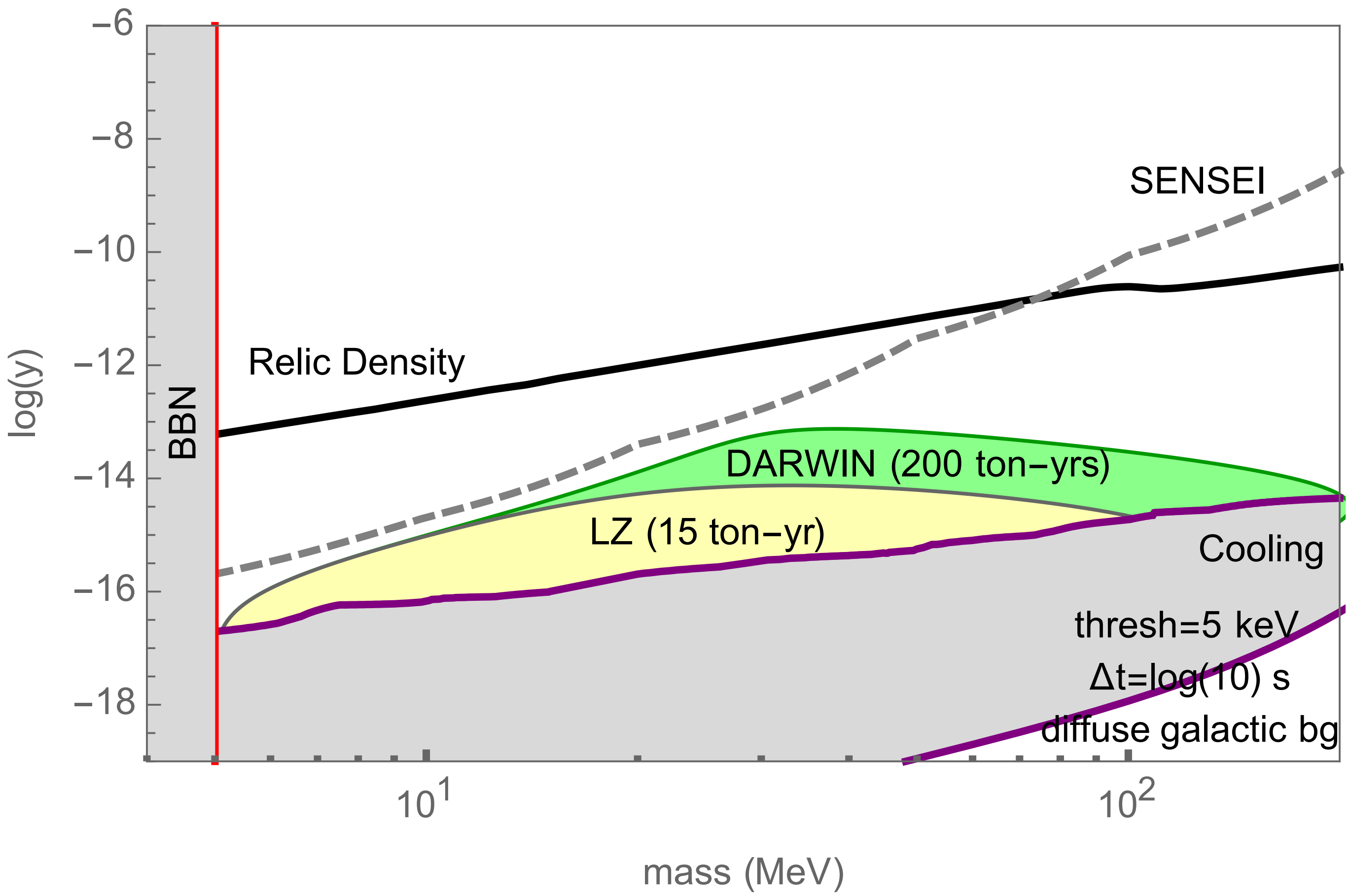
$$\longrightarrow$$

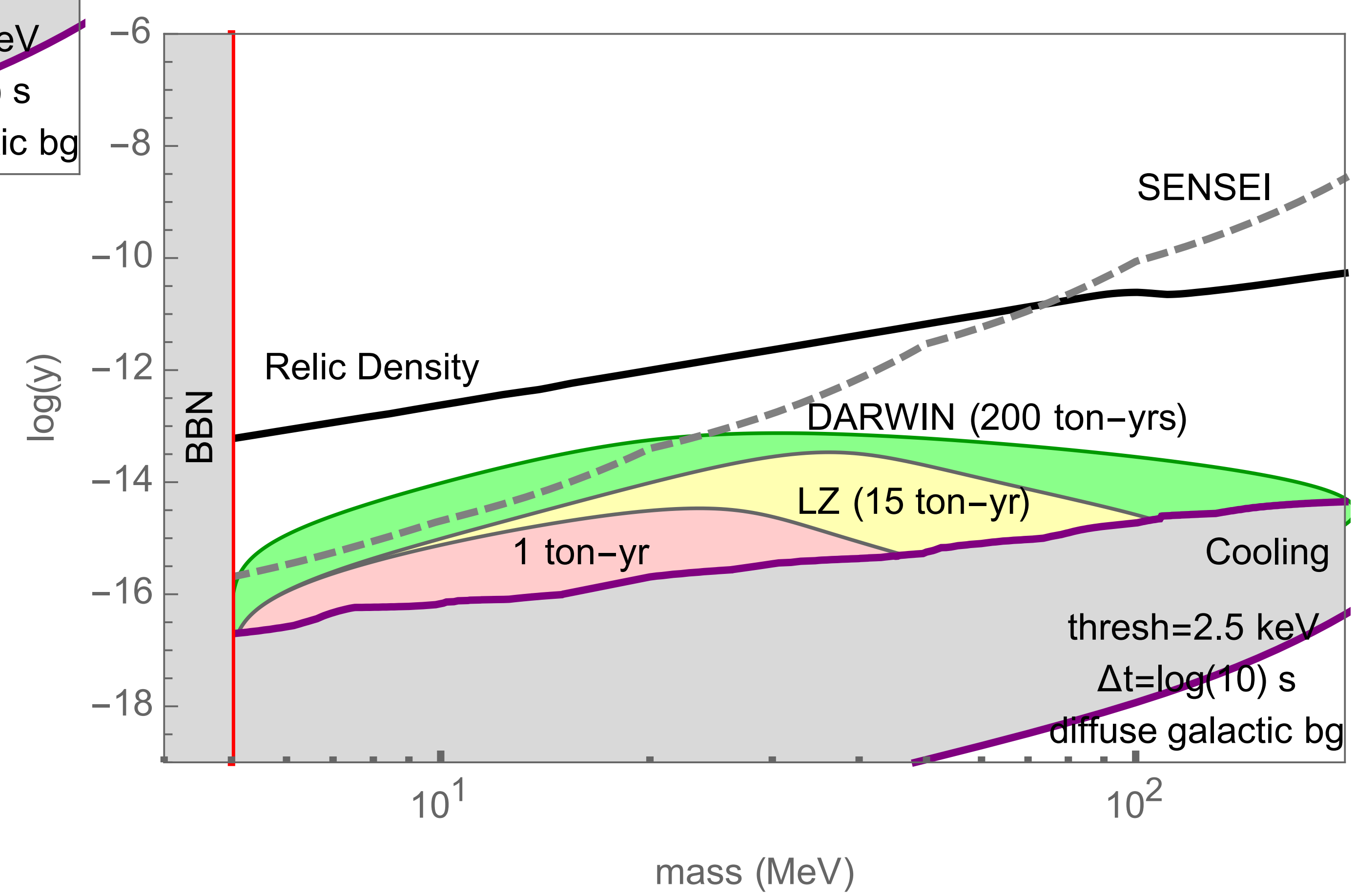
$$E_r \approx \frac{2p_\chi^2}{m_n}$$

$$p_{\rm min}^{\rm Xe} \approx 17 \text{ MeV}$$

Preliminary sensitivity

Galactic diffuse Supernovae flux





Conclusions

- Supernovae can be a source of boosted dark sector particles. Because of their large velocity, they are more easily detected than the local dark matter population.
- Some regions of parameter space might be probed by Xenon1T and a large region will be tested in future Xe experiments.
- Need to explore profile dependence.
- We explored a minimal heavy dark photon portal scenario. This analysis can be extended to a number of other dark sector scenarios.