Supernova signals of light dark matter in directional detectors

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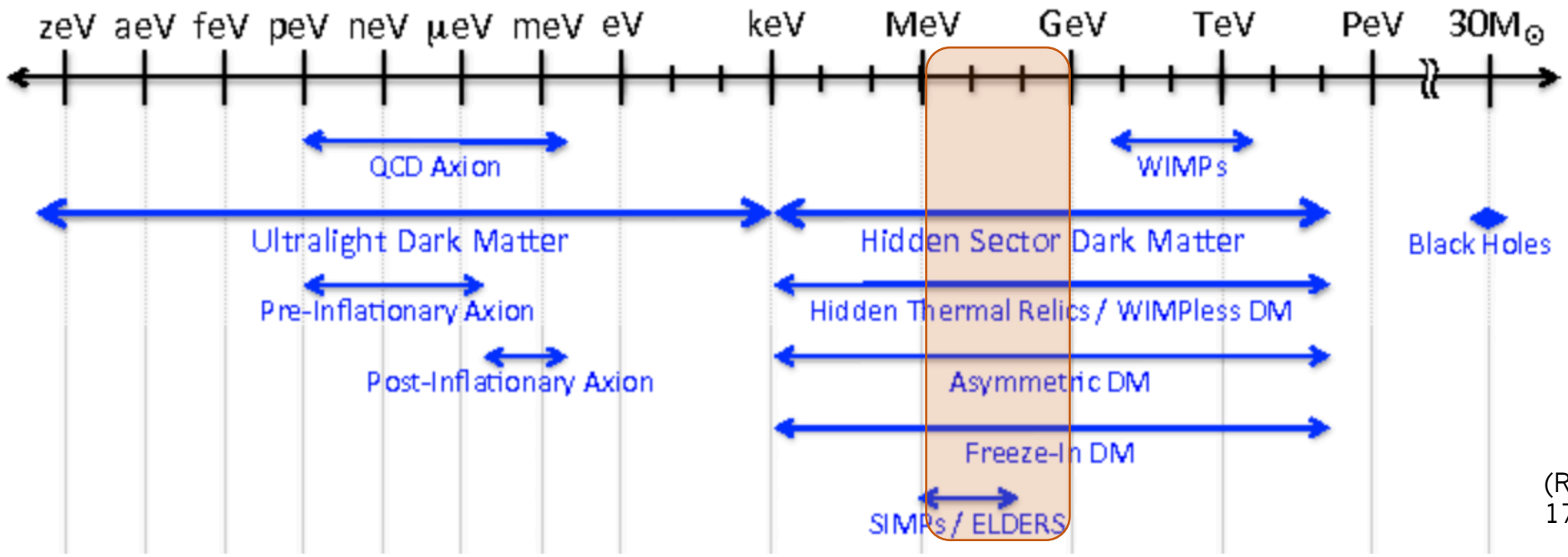
(hep-ph: 1905.09284)

Introduction

- Lack of WIMP signal motivates searches for other models
- *Light Dark Matter* = sub-GeV dark matter
- Dark photons, SIMPs, ELDERs, inelastic DM, hidden sectors…



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Outline

- **Part I:** Supernova (SN) production of MeV-scale particles is large well outside cooling bound.
- **Part II:** SN-produced light dark matter is detectable in WIMP detectors. (hep-ph: 1905.09284)
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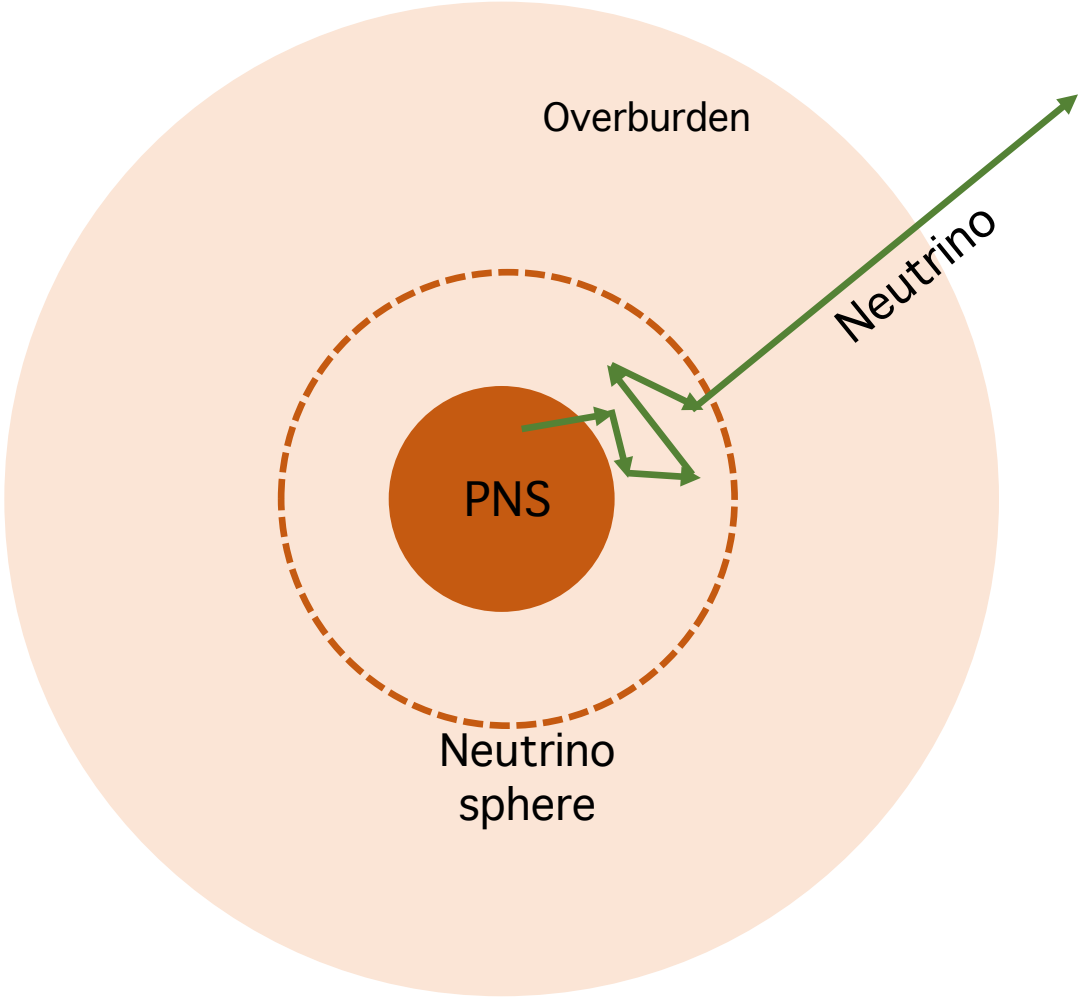
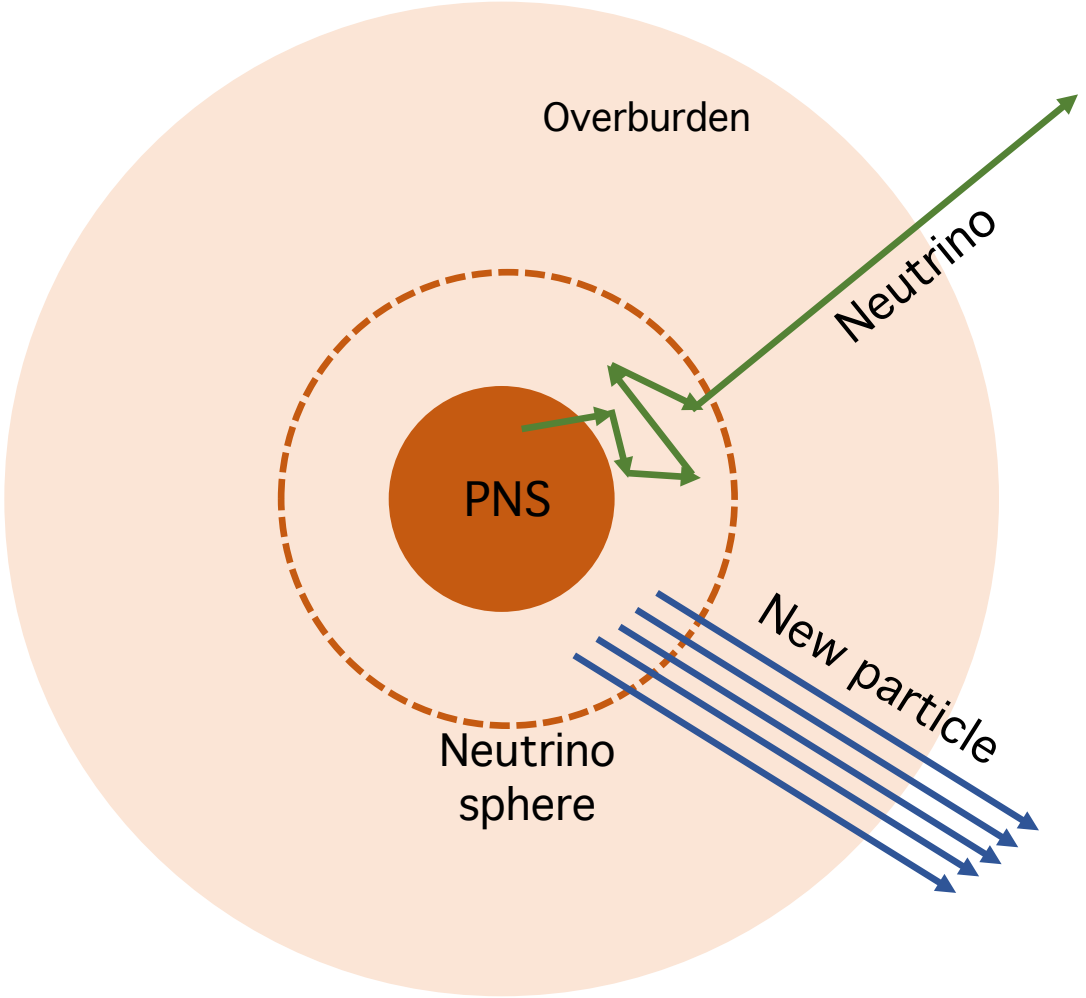
Supernovae

- Core-collapse of massive star releases **>10^{53} erg**
- Protoneutron star (PNS) has temperature ~**30 MeV**
- Neutrinos diffuse inside "neutrino sphere" then free-stream, cooling PNS



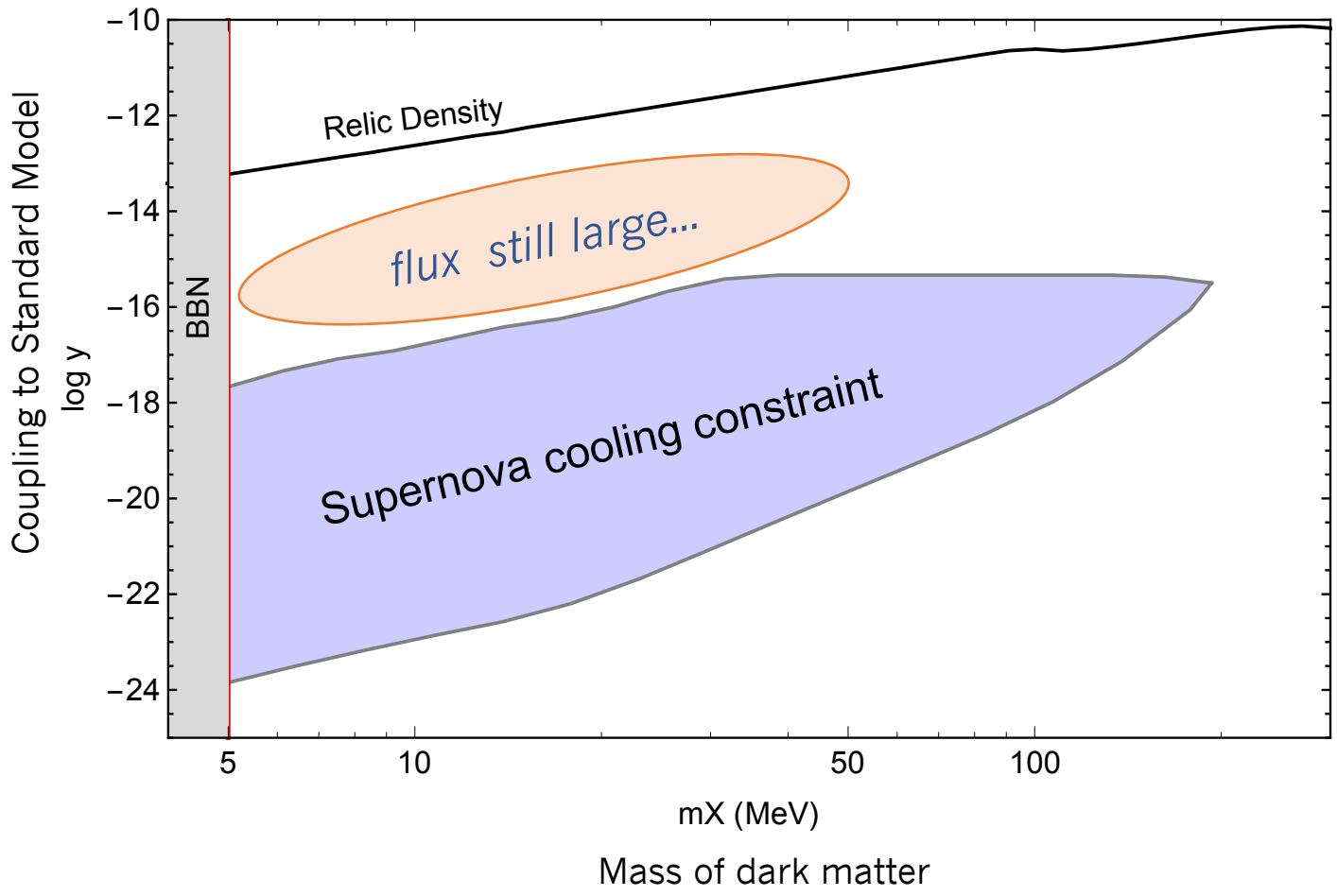
Supernova cooling constraint

- Core-collapse of massive star releases **$>10^{53}$ erg**
- Protoneutron star (PNS) has temperature ~**30 MeV**
- Neutrinos diffuse inside "neutrino sphere" then free-stream, cooling PNS
- 10-second cooling timescale observed during SN1987a
- **Cooling constraint:** new particle cannot transfer more energy than neutrinos



Motivation for our work

- Near cooling limit, flux of MeV-scale particles can still be very large
- **Direct observation can constrain where cooling bound fails!**



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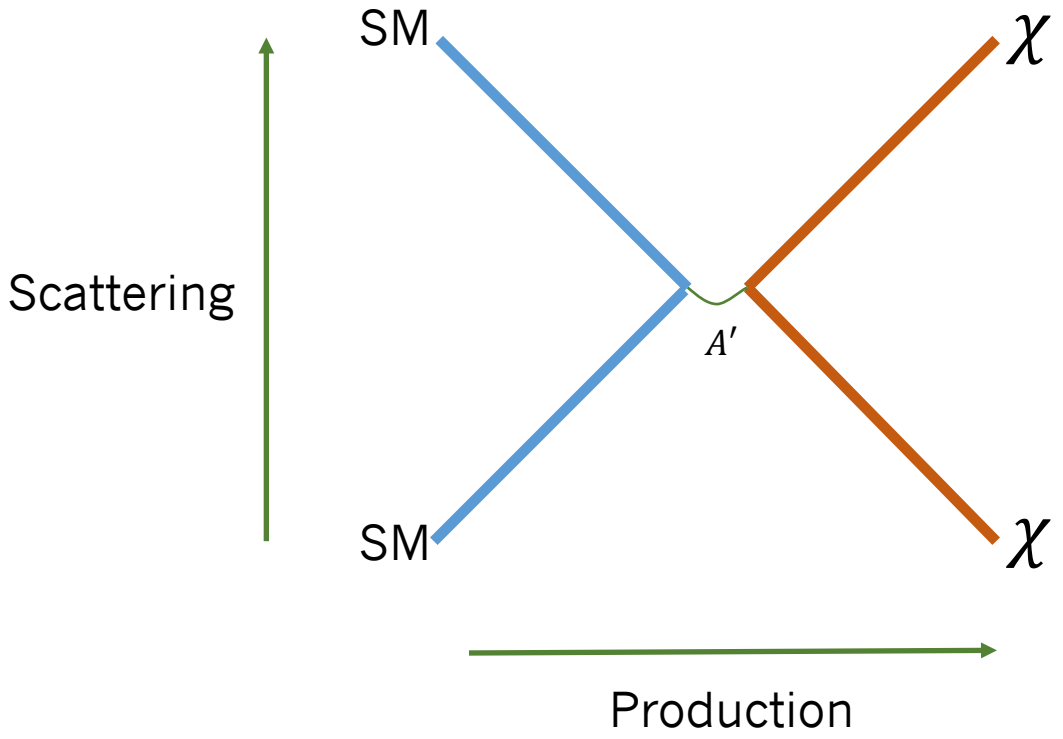
Dark fermion

- Dark sector with stable fermion (χ)
- DM-SM coupling through heavy dark photon (A')

$$\mathcal{L}_{\text{dark}} = -\frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} + \frac{\epsilon_Y}{2}F'_{\mu\nu}B_{\mu\nu} + \frac{m^2_{A'}}{2}A'_\mu A'^\mu + \bar{\chi}(i\not{\partial} - m_\chi)\chi$$

- **Results apply to large class of models**



Diffusive trapping

- **Above cooling bound, particles diffusively trapped by SM scattering**
- Spectrum set by radii at which interactions decouple

Production/annihilation

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

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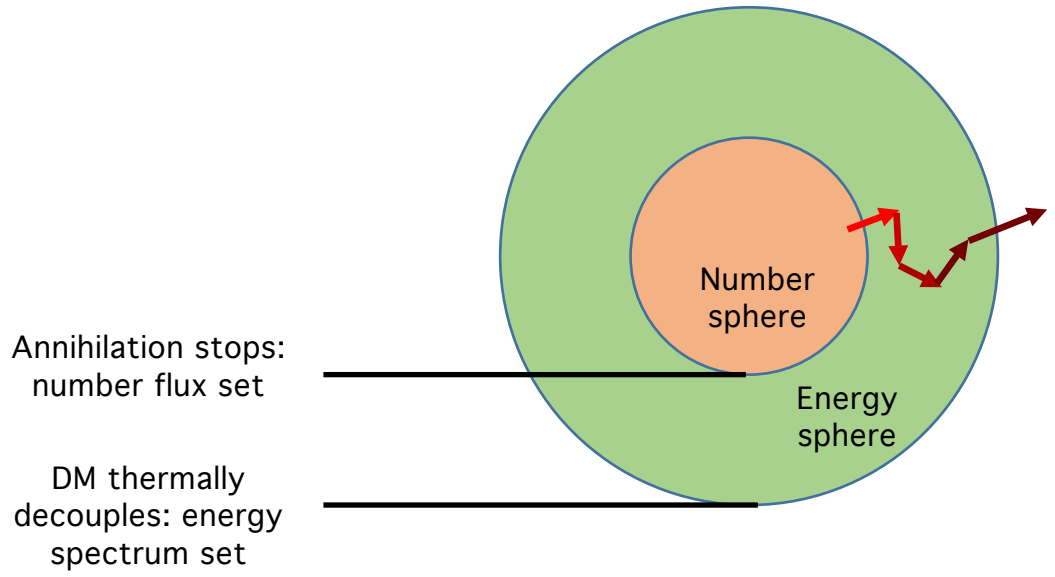

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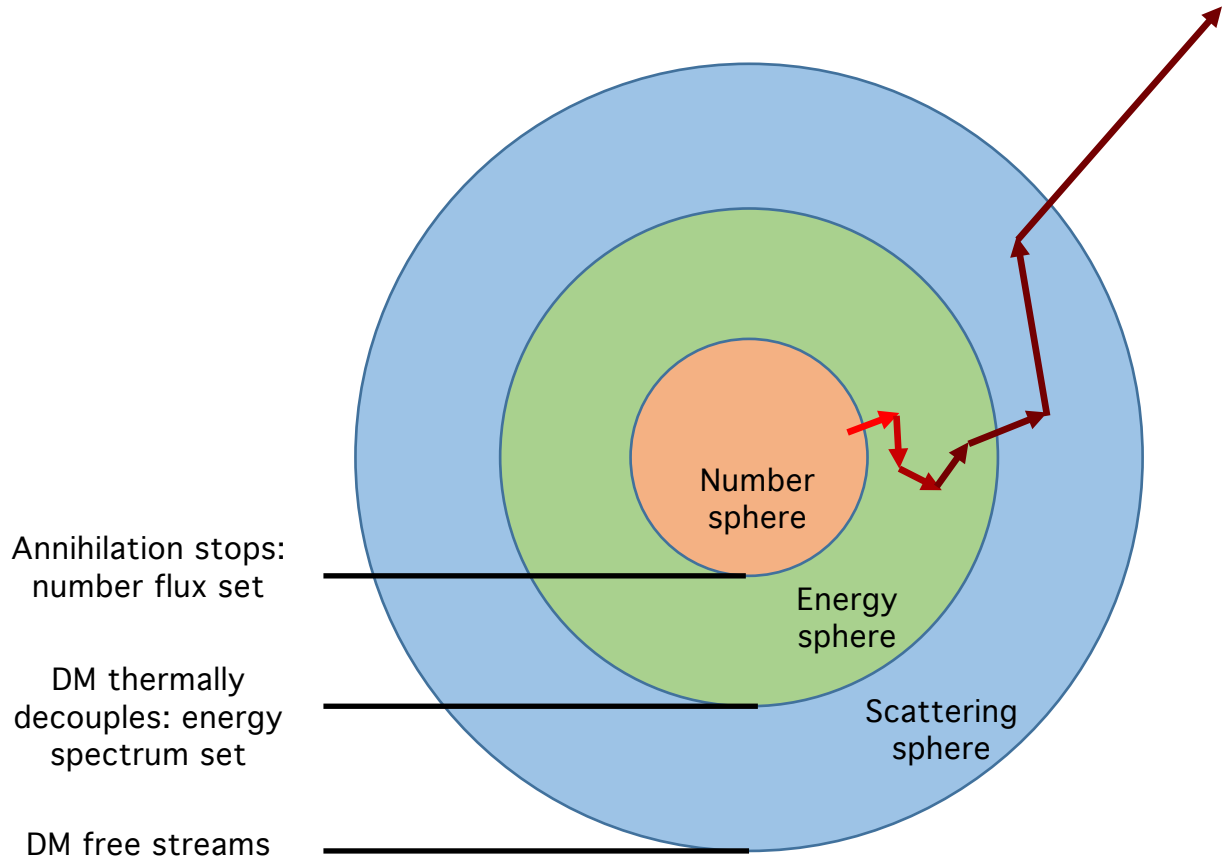

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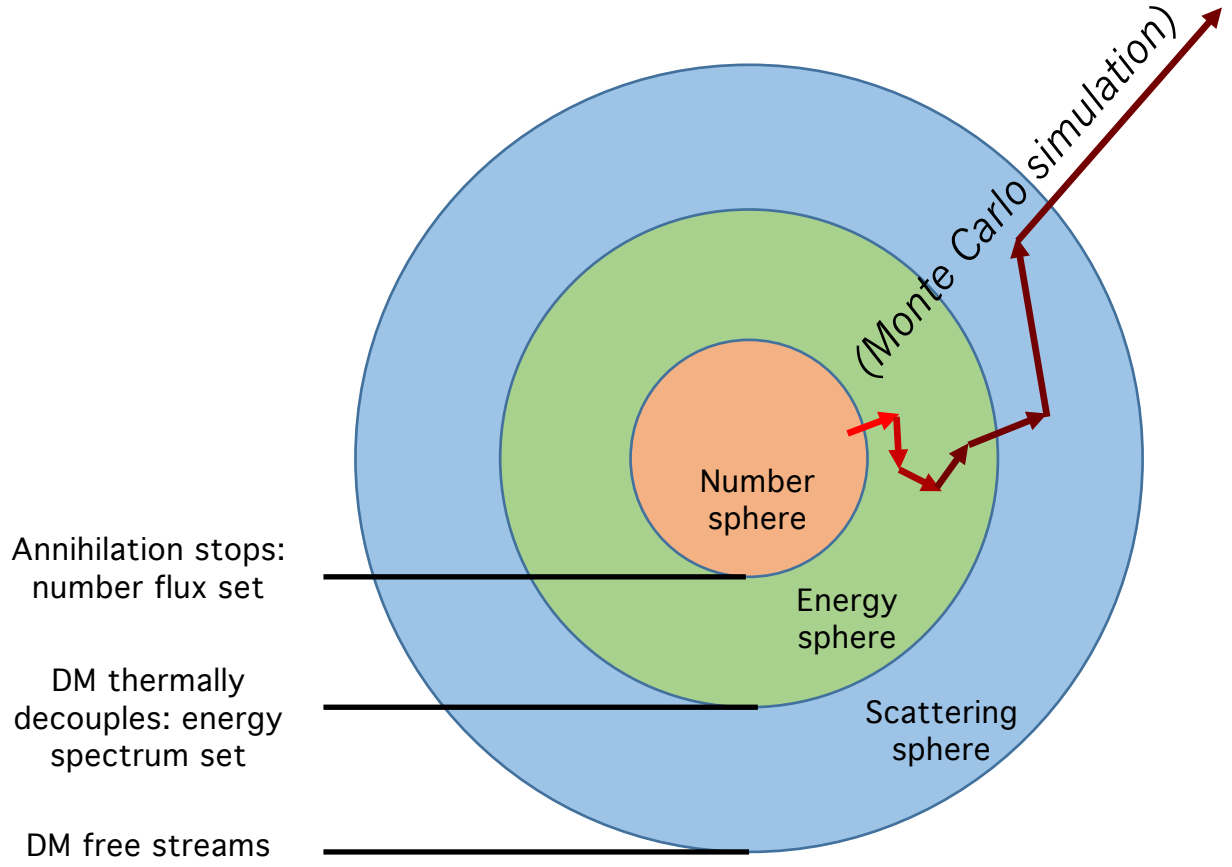
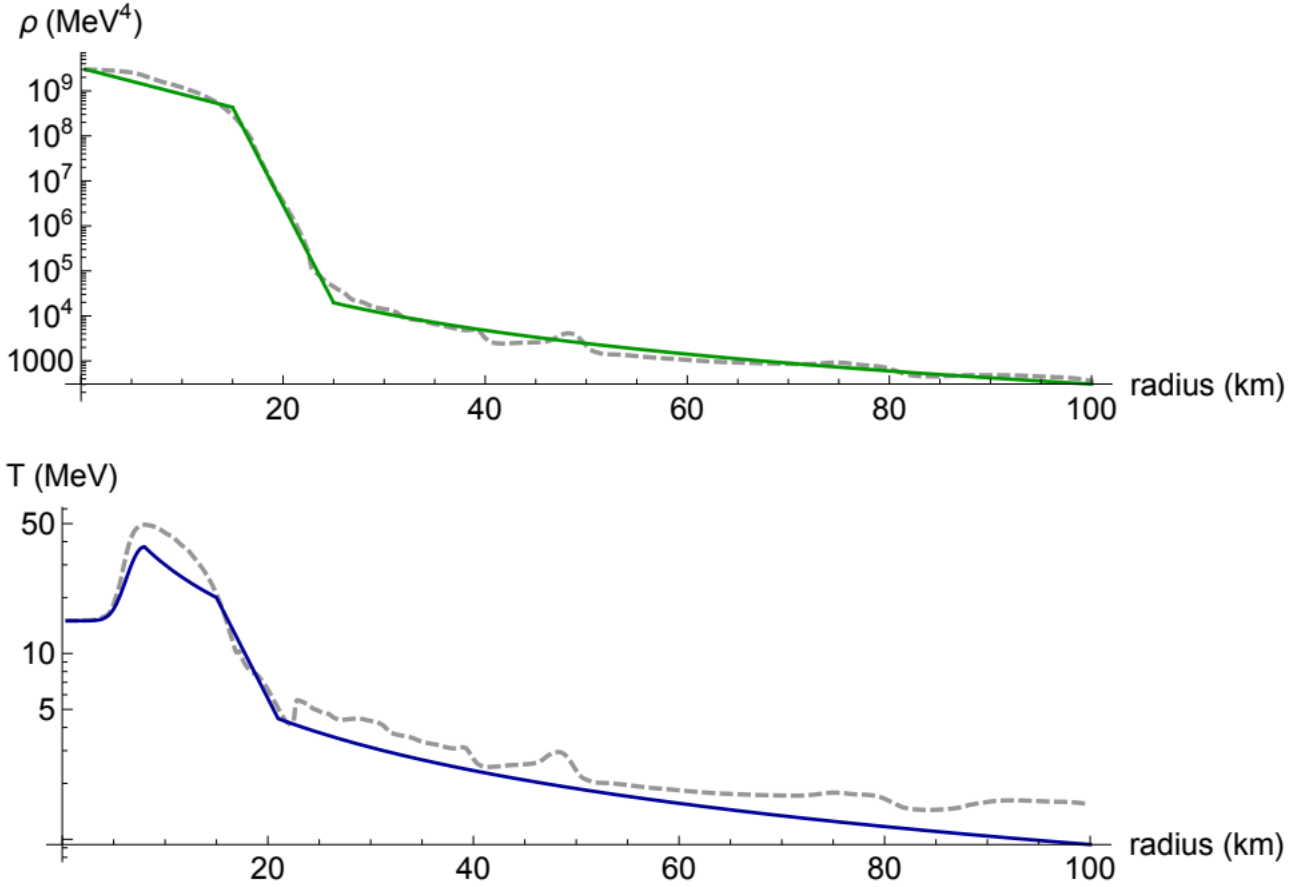


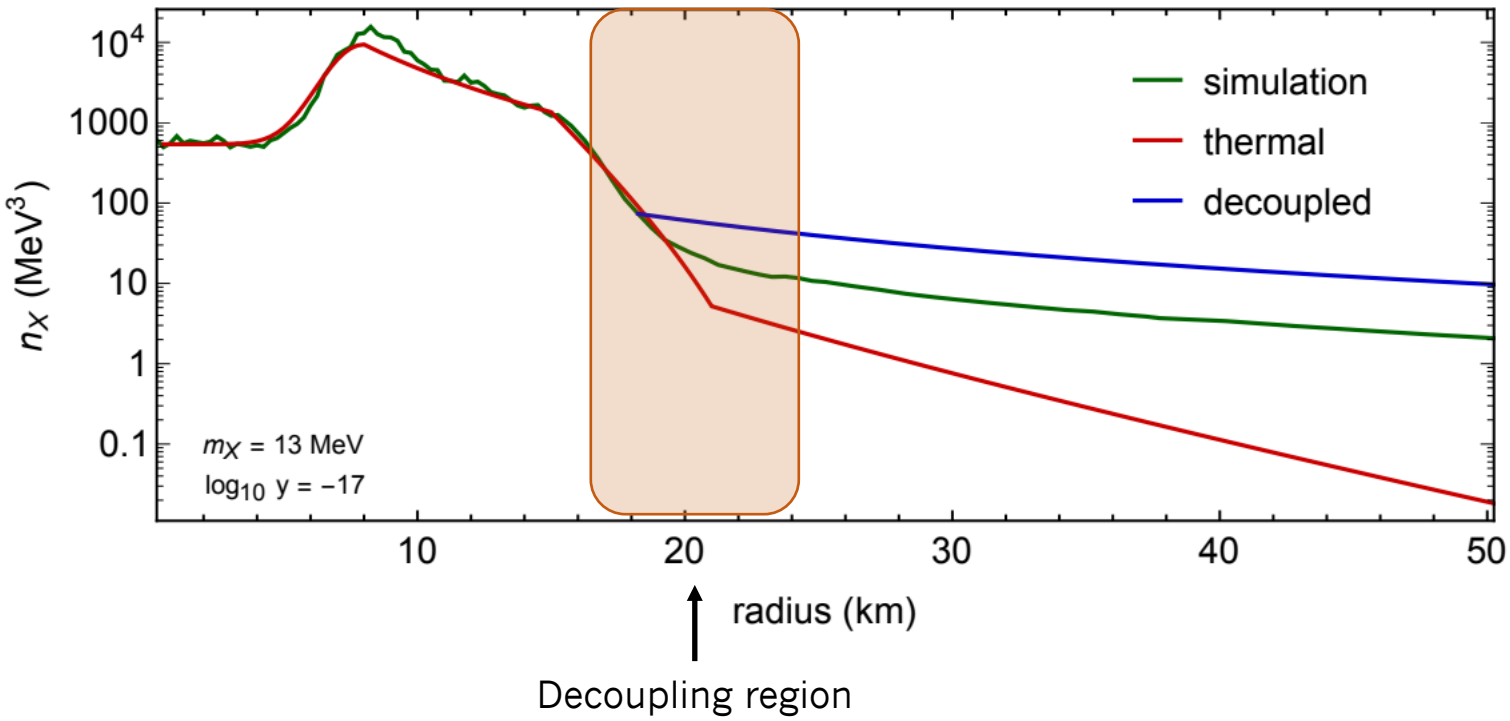
Initial profiles

- Analytic fit to supernova simulation
- Convenient for estimating SN profile uncertainty
- Sets rate of DM production



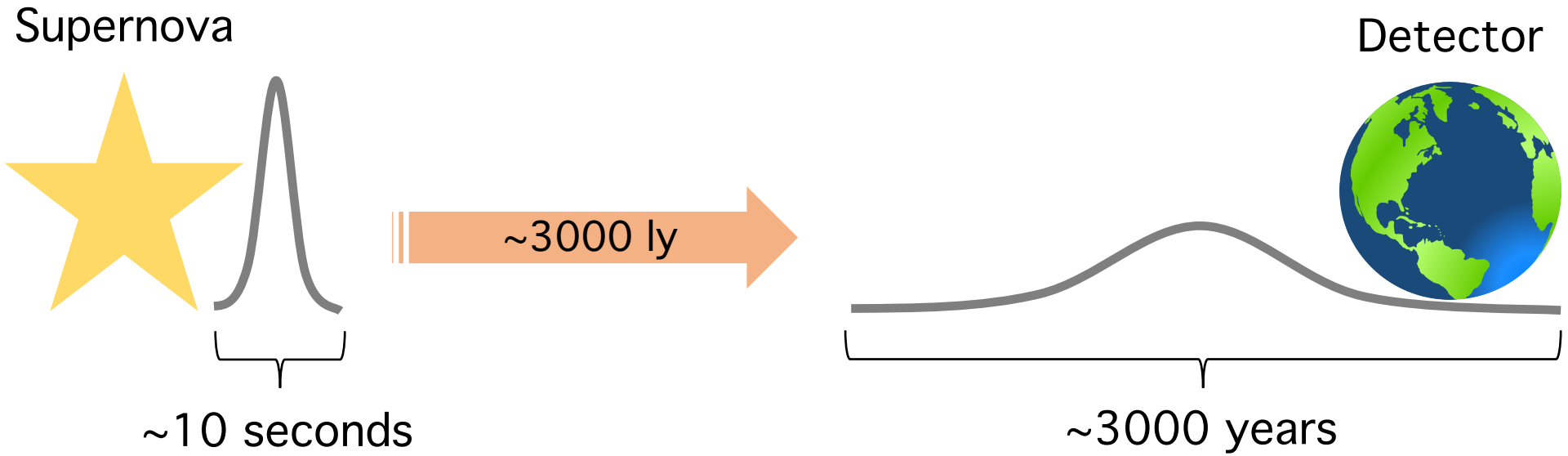
Monte Carlo simulation

- **Goal: find self-consistent n_X**
- Iteratively reweight DM profile until steady-state achieved
- Advantage: decoupling over extended region



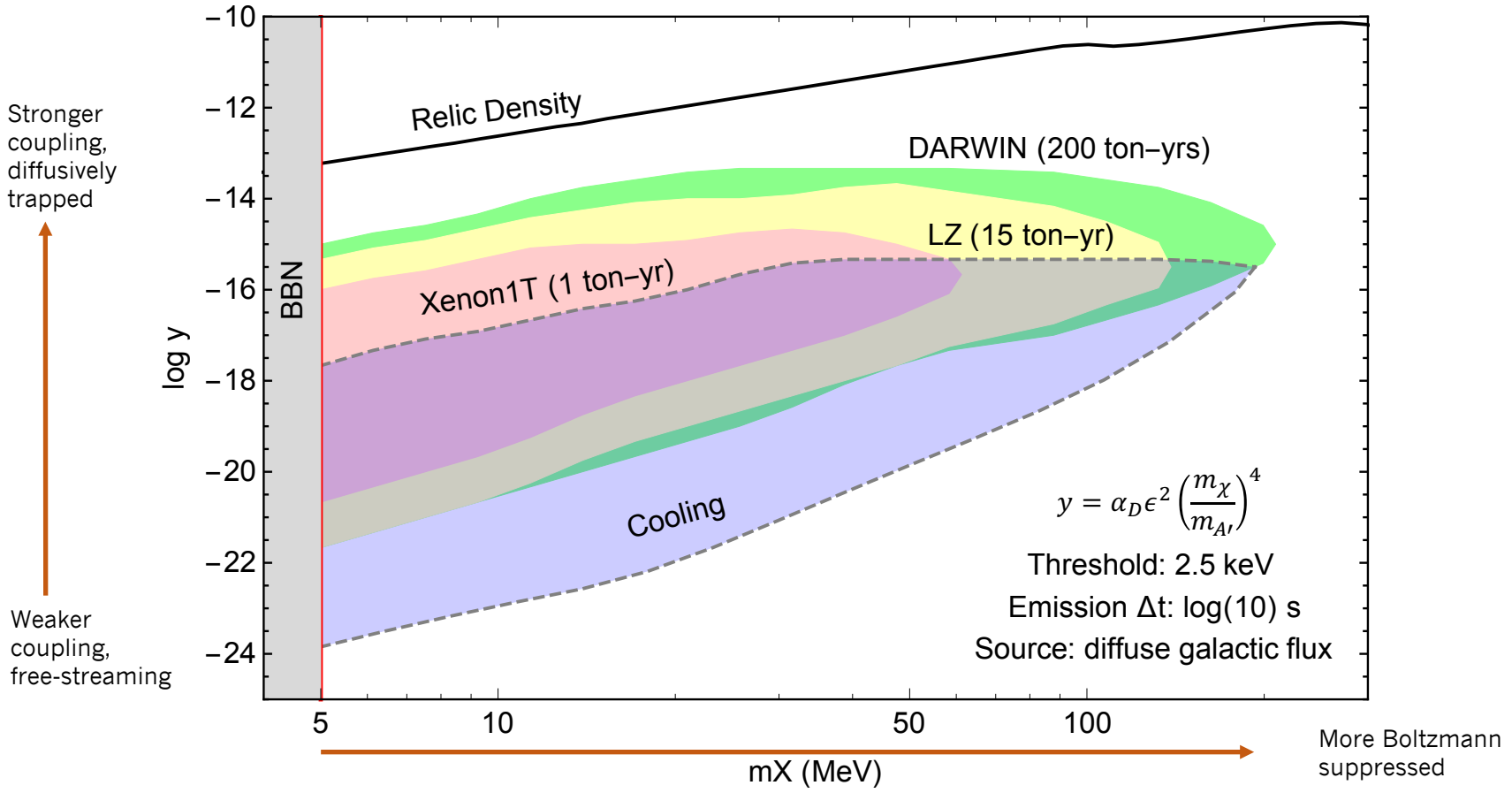
Diffuse galactic flux

- Dark fermions are produced at semirelativistic velocities
- **Emissions from several SN overlap to form diffuse flux**
- High-momentum population detectable in WIMP detector



Direct detection

- Diffuse flux has high momentum
- **WIMP detectors sensitive to diffuse flux of MeV-scale dark sector**



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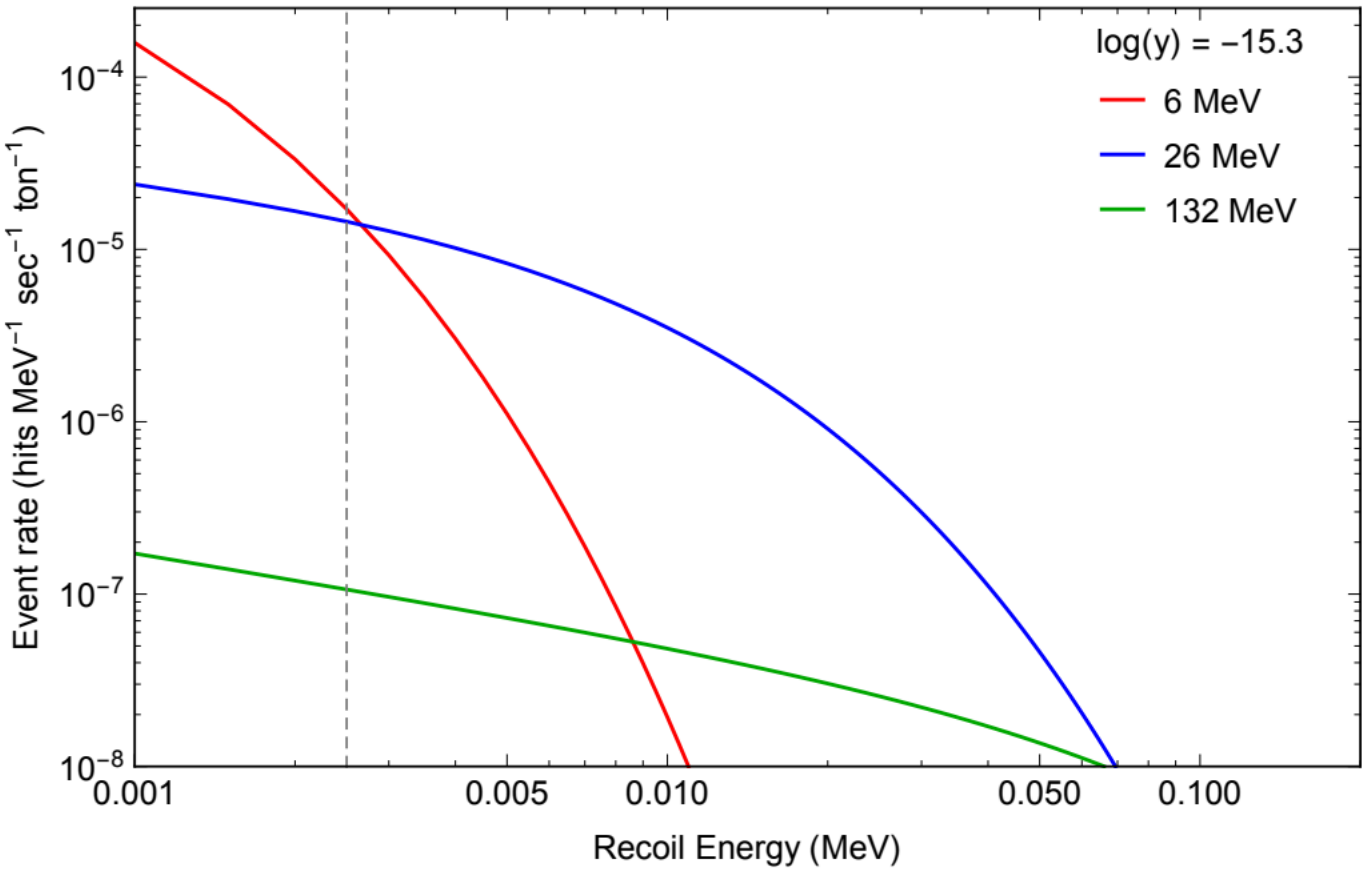
Discrimination

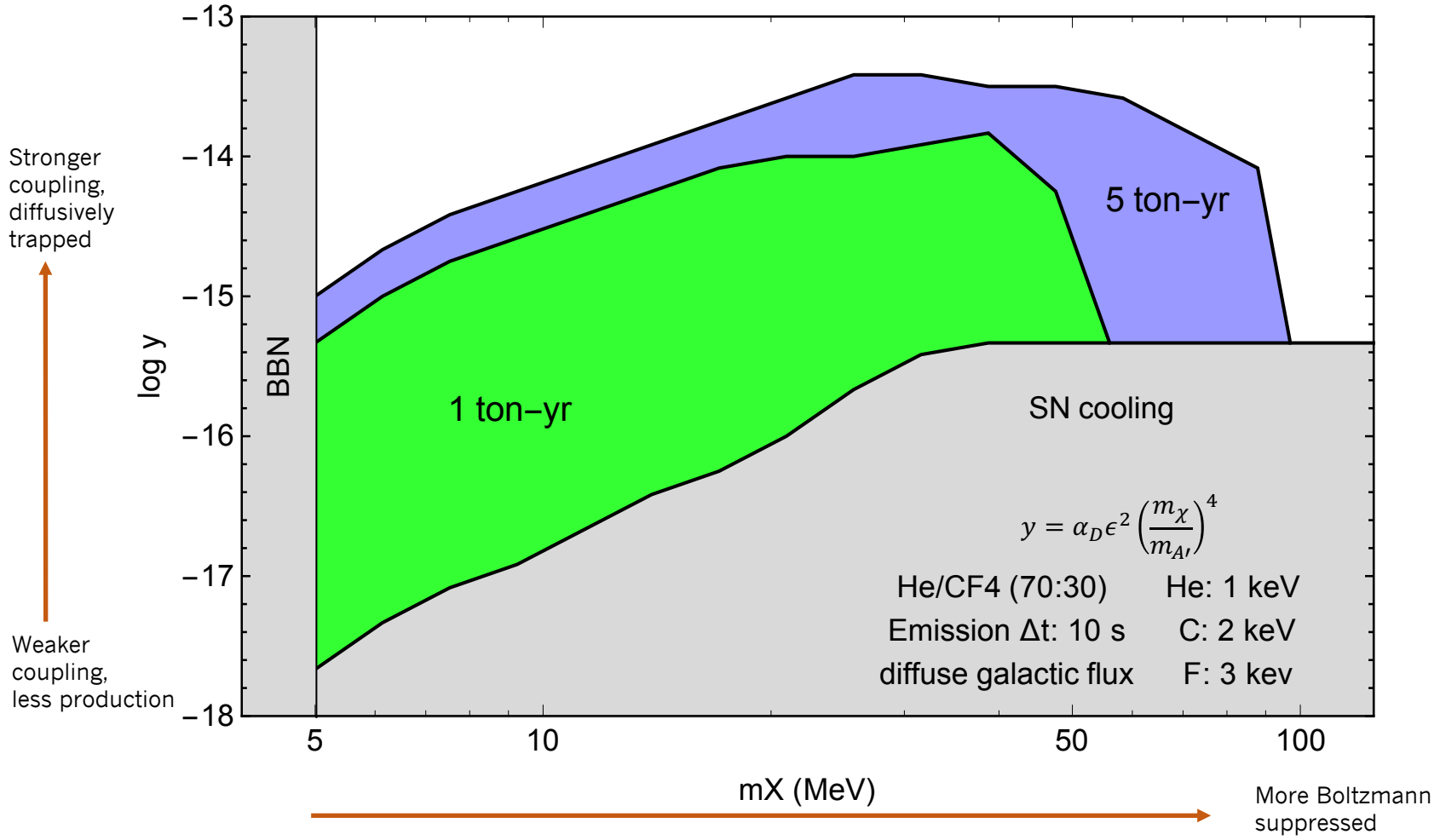
- Recoil spectra of cold WIMPs and hot MeV-scale DM very similar
- **How can we discriminate these two populations?**

Recoil spectra in liquid xenon for different DM mass



Direct detection

- Low-threshold directional detectors (e.g. CYGNUS) sensitive to diffuse flux



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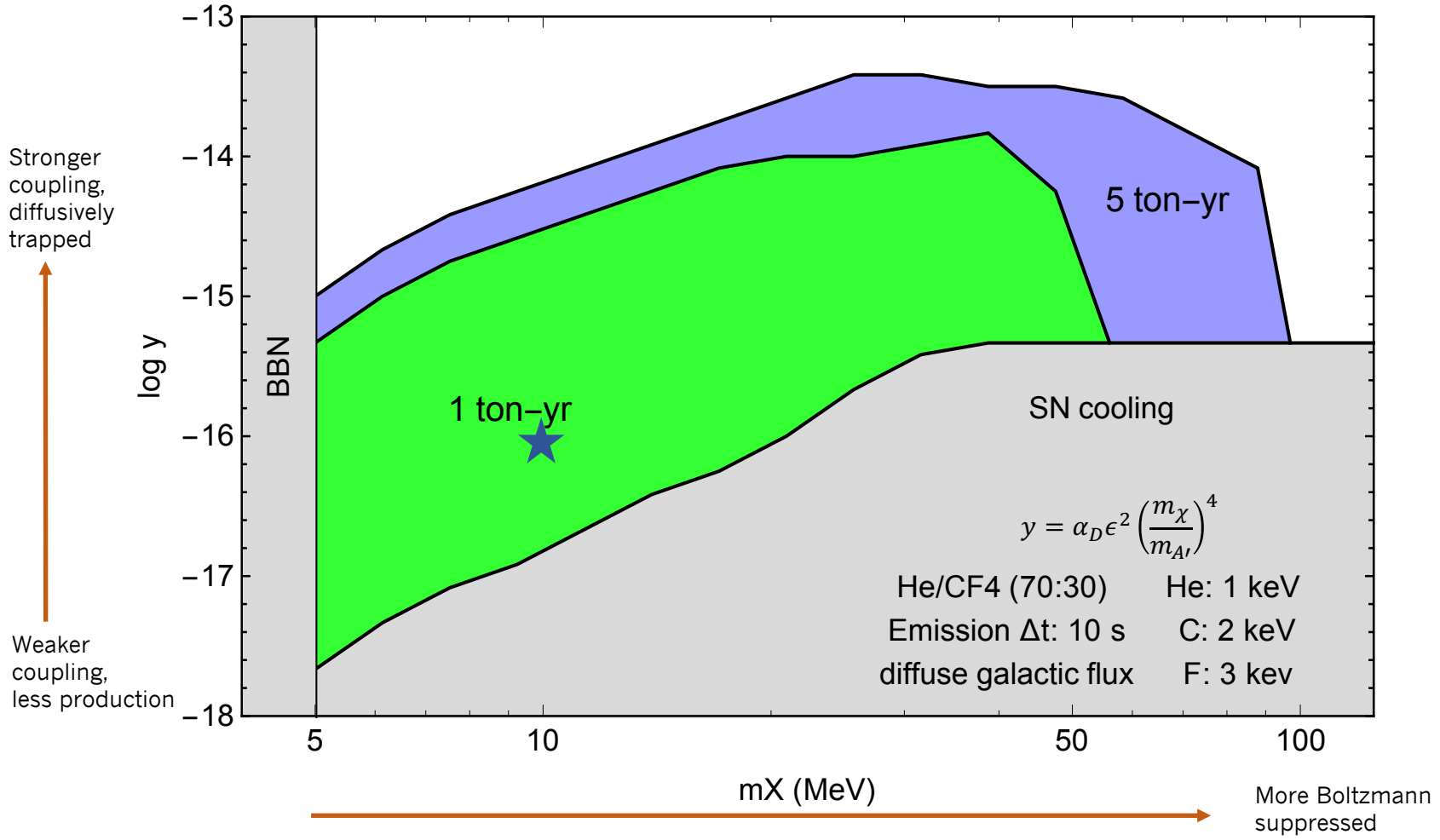
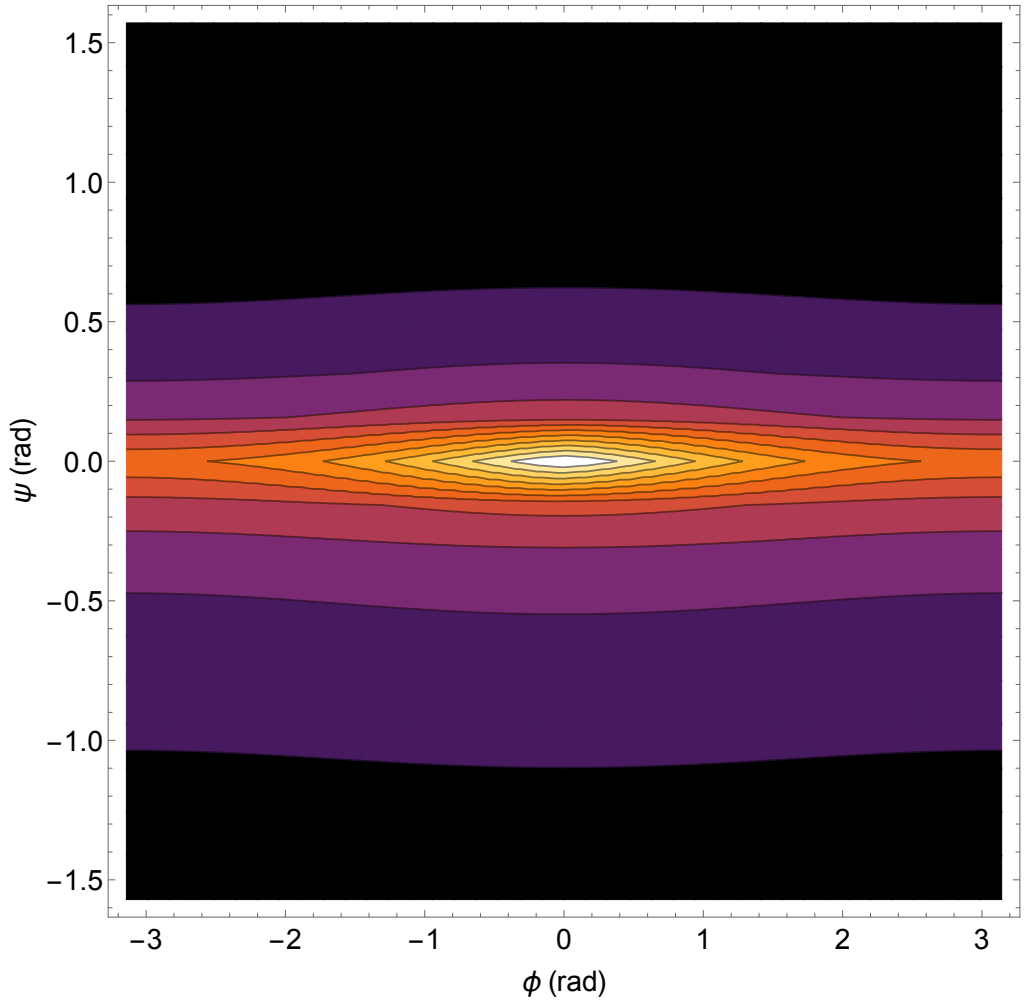


SN production

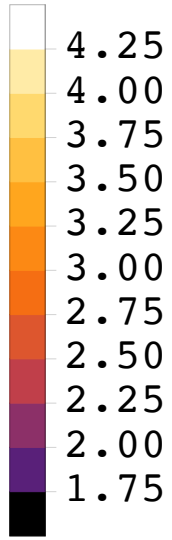
- **Diffuse flux strongly peaked towards Galactic center**
- Isotropic intergalactic contribution highly subdominant



m_X = 11 MeV
y = 1e-16

All-sky flux:
~10^4 cm^{-2} s^{-1}

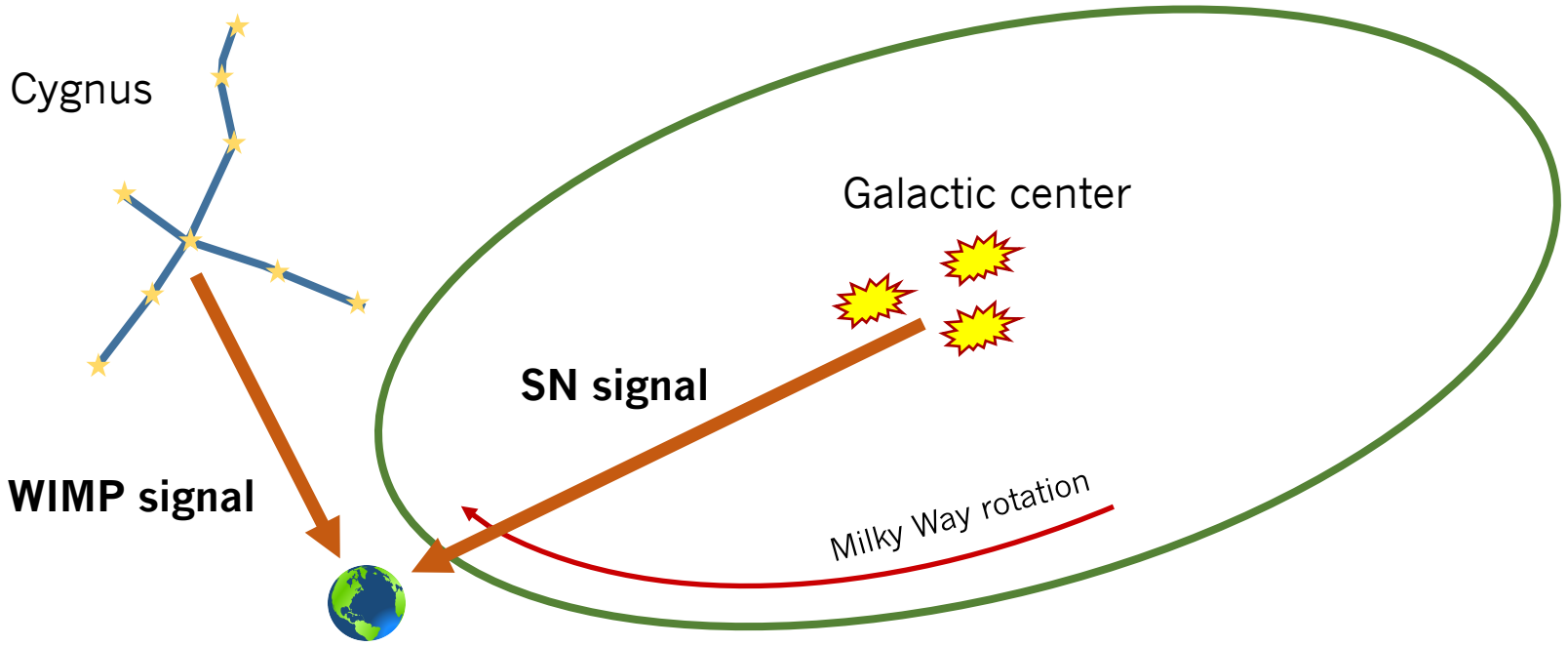
$\log_{10} \Phi$ (cm^{-2} s^{-1} sr^{-1})



Note: 100 GeV WIMP
~ 10^5 cm^{-2} s^{-1}

Discrimination

- Diffuse flux strongly peaked towards Galactic center
- **SN signal is perpendicular to WIMPs!**
- Directional detectors are necessary for discrimination of any future signal



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Thank you!