Observing the dark sector with supernovae

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(hep-ph: 1901.08596)

(hep-ph: 1905.09284)

Outline

- **Part I:** Supernova (SN) production of MeV-scale particles is large well below cooling bound.
- **Part II:** Decay products of SN-produced dark photons can be observed. (hep-ph: 1901.08596)
- **Part III:** SN-produced light dark matter is detectable in existing WIMP detectors. (hep-ph: 1905.09284)

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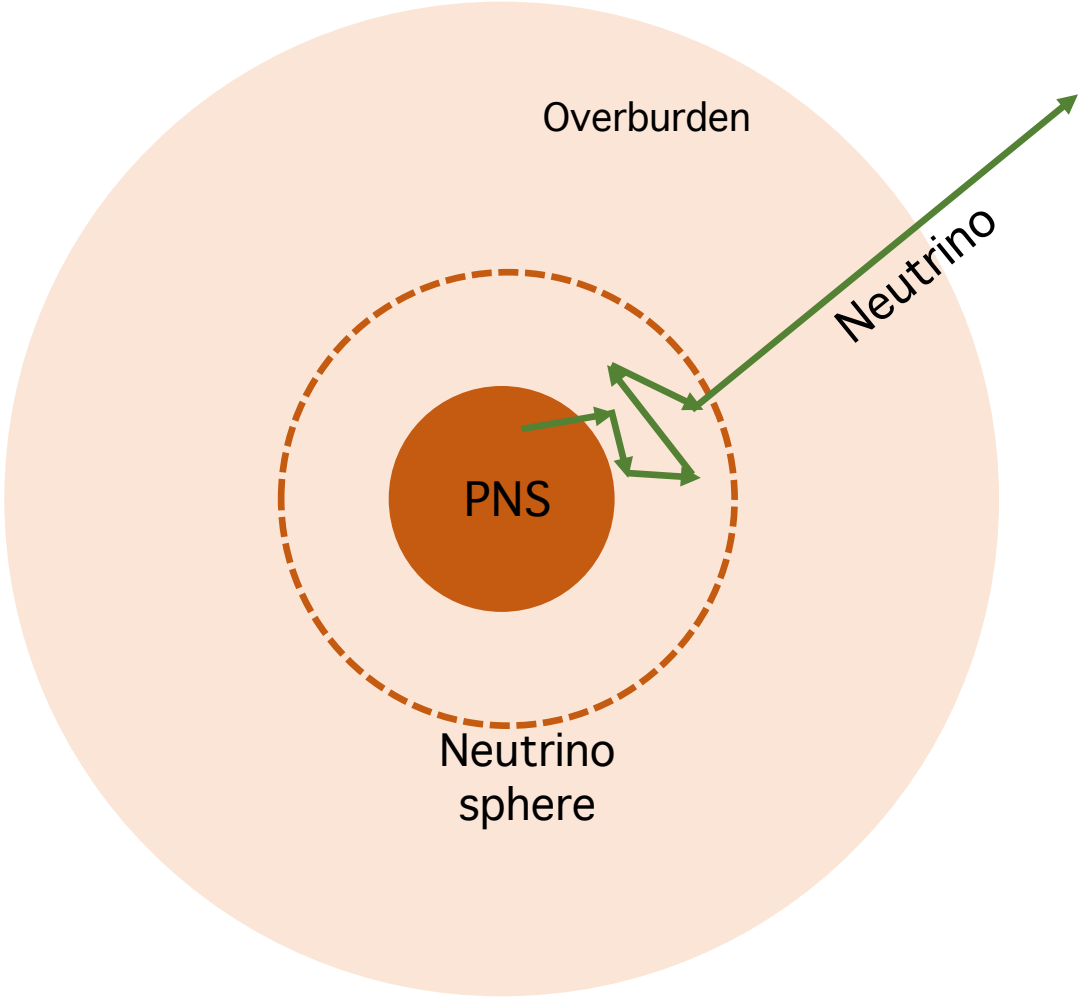
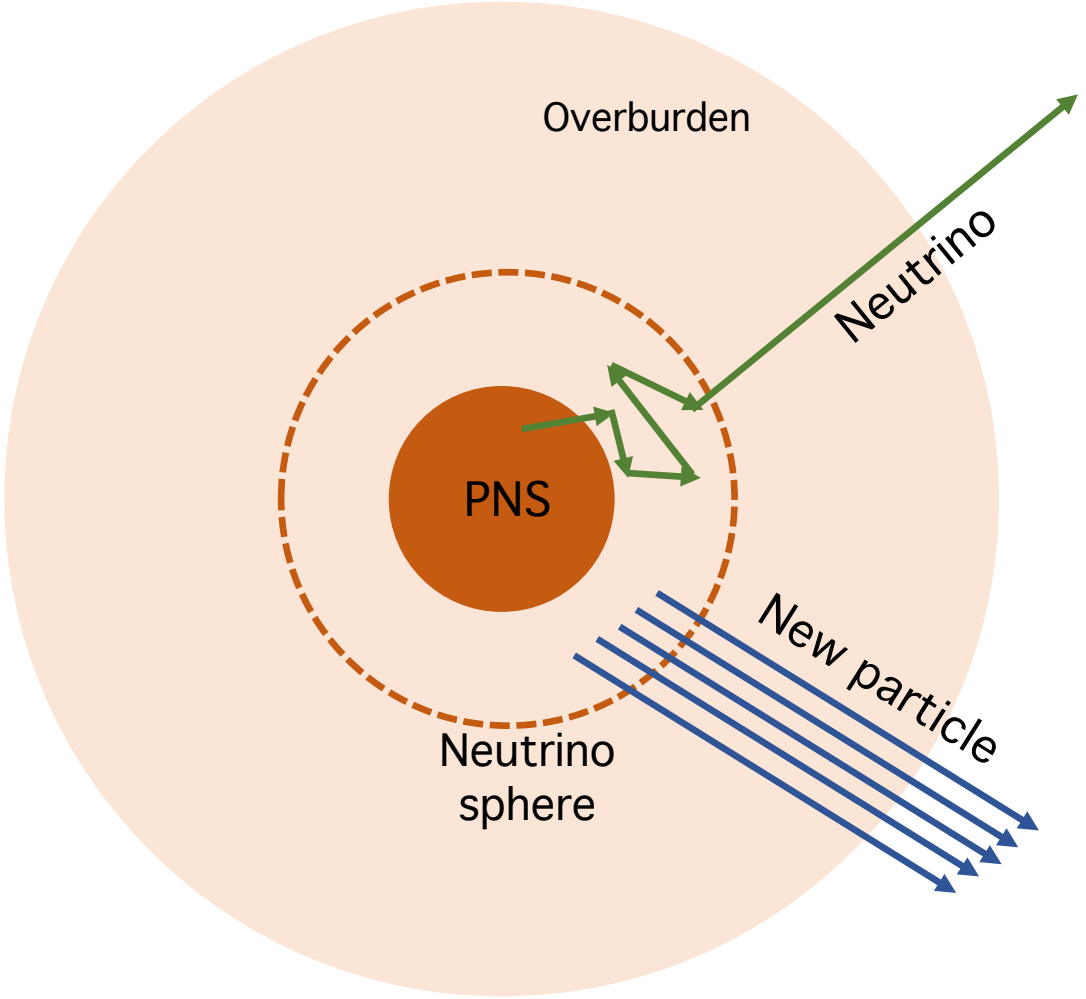
Supernovae

- 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



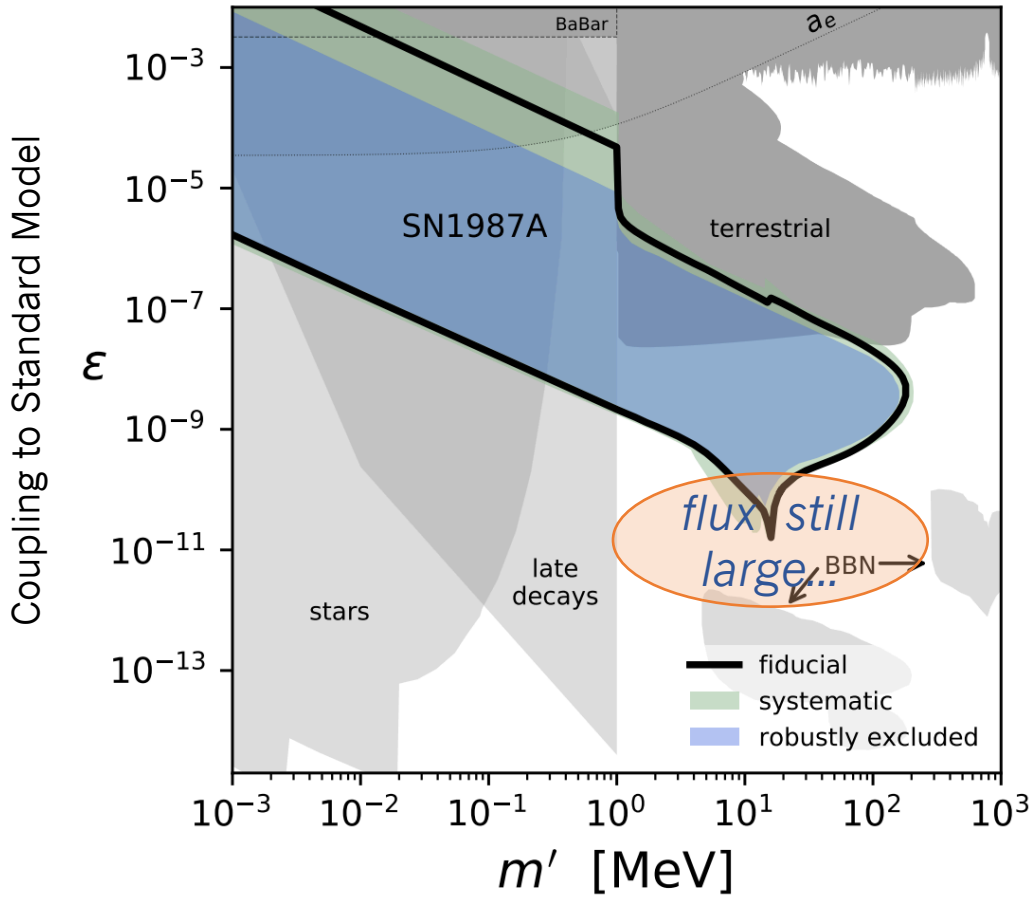
Supernova cooling constraint

- 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

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



Previous bounds on dark photon. *Chang, Essig, McDermott (2016)*

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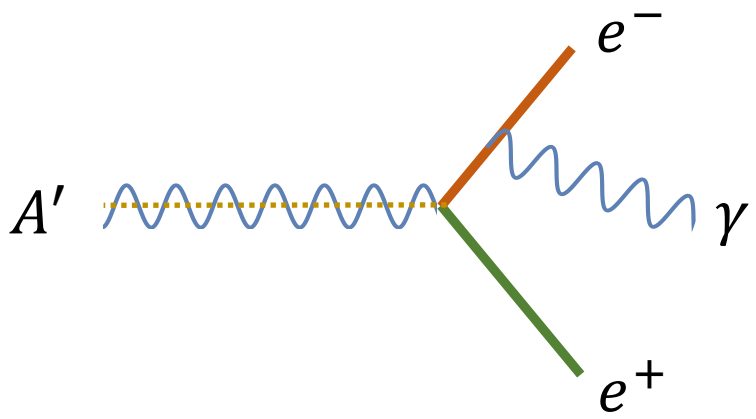
Dark photon

- Kinetic mixing ϵ with SM photon

$$\mathcal{L} \supset \frac{1}{2} m' A'_\mu A'^\mu - \frac{1}{4} F'_{\mu\nu} F'^{\mu\nu} - \frac{\epsilon}{2} F'_{\mu\nu} F^{\mu\nu}$$

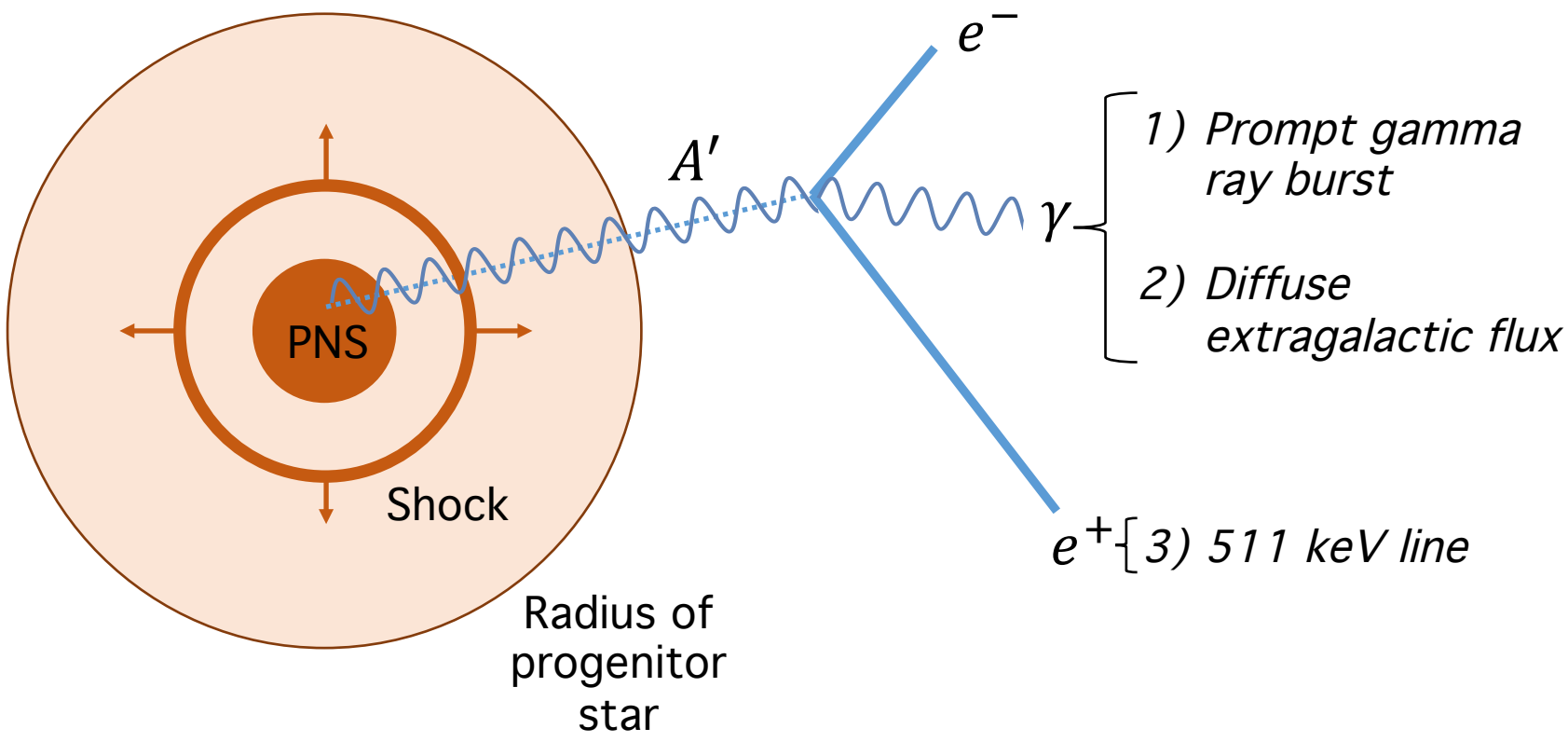
- Decay modes:
  - e^+e^-
  - $e^+e^-\gamma$ (~1%)

Decays



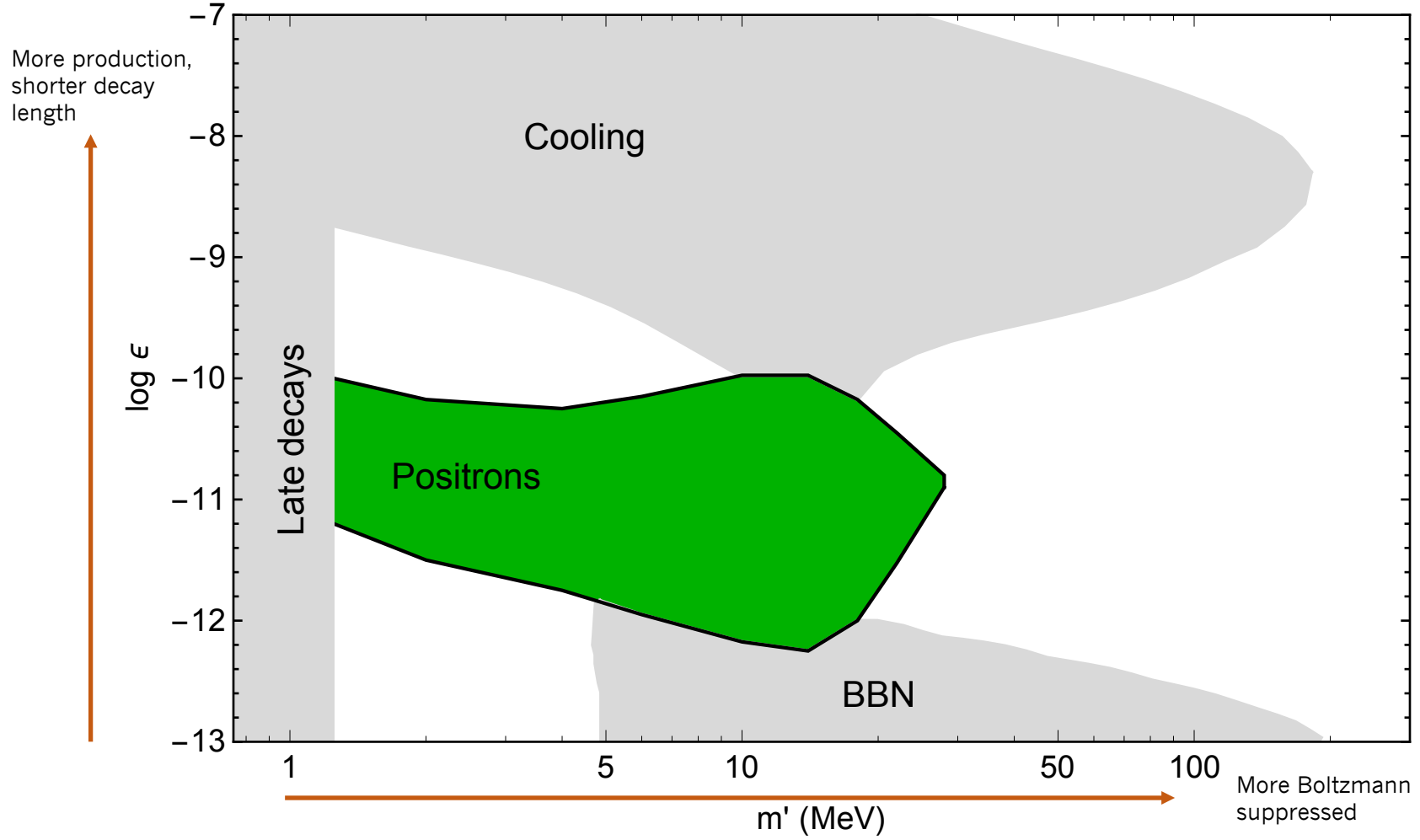
Observable signatures

- Below cooling bound, supernovae still produce many dark photons
- Dark photons escape from SN and decay
- Decay products leave observable signatures



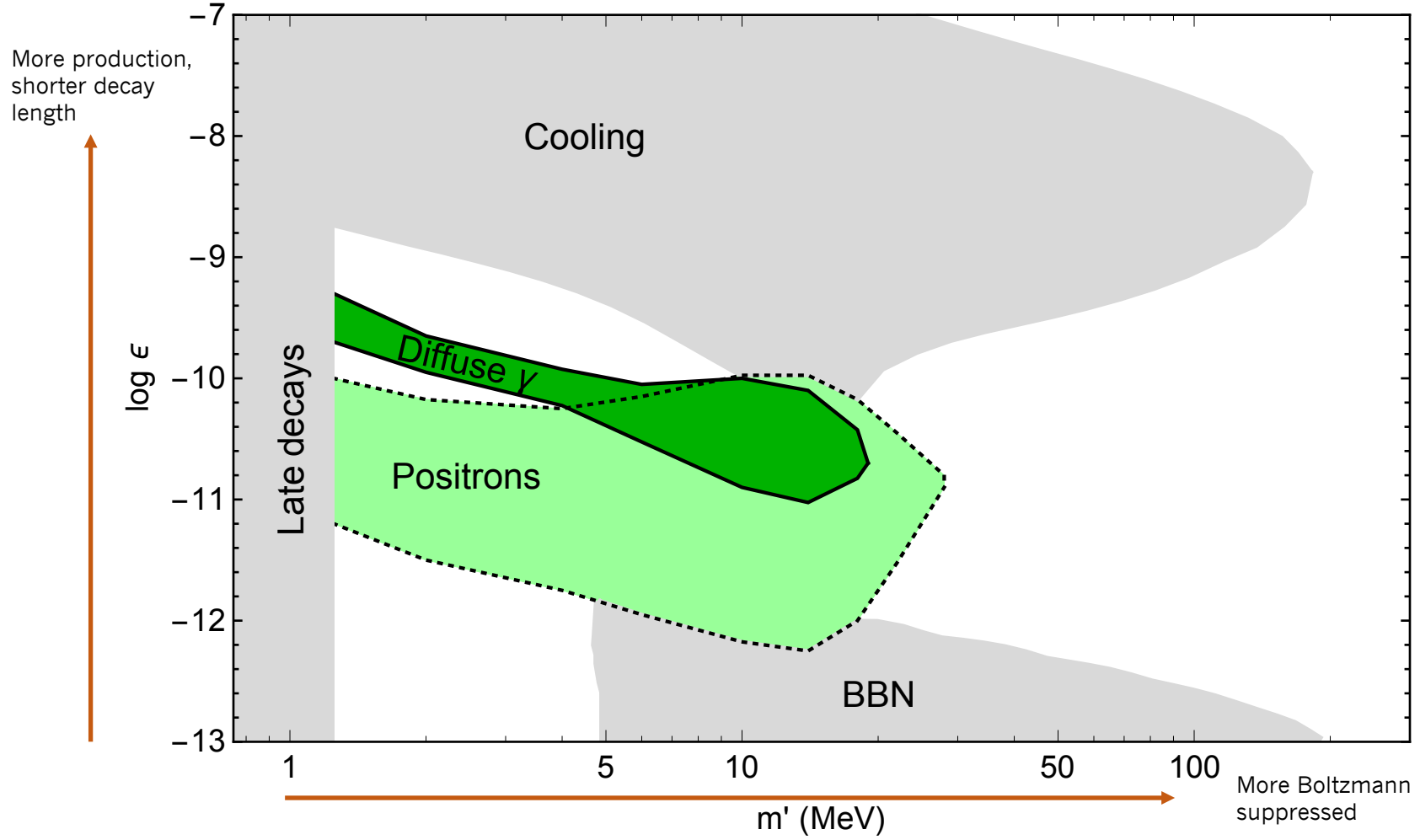
Signature #1: Positron annihilation

- Positrons slow and annihilate in galaxy
- Constrained by INTEGRAL measurement of 511 keV line



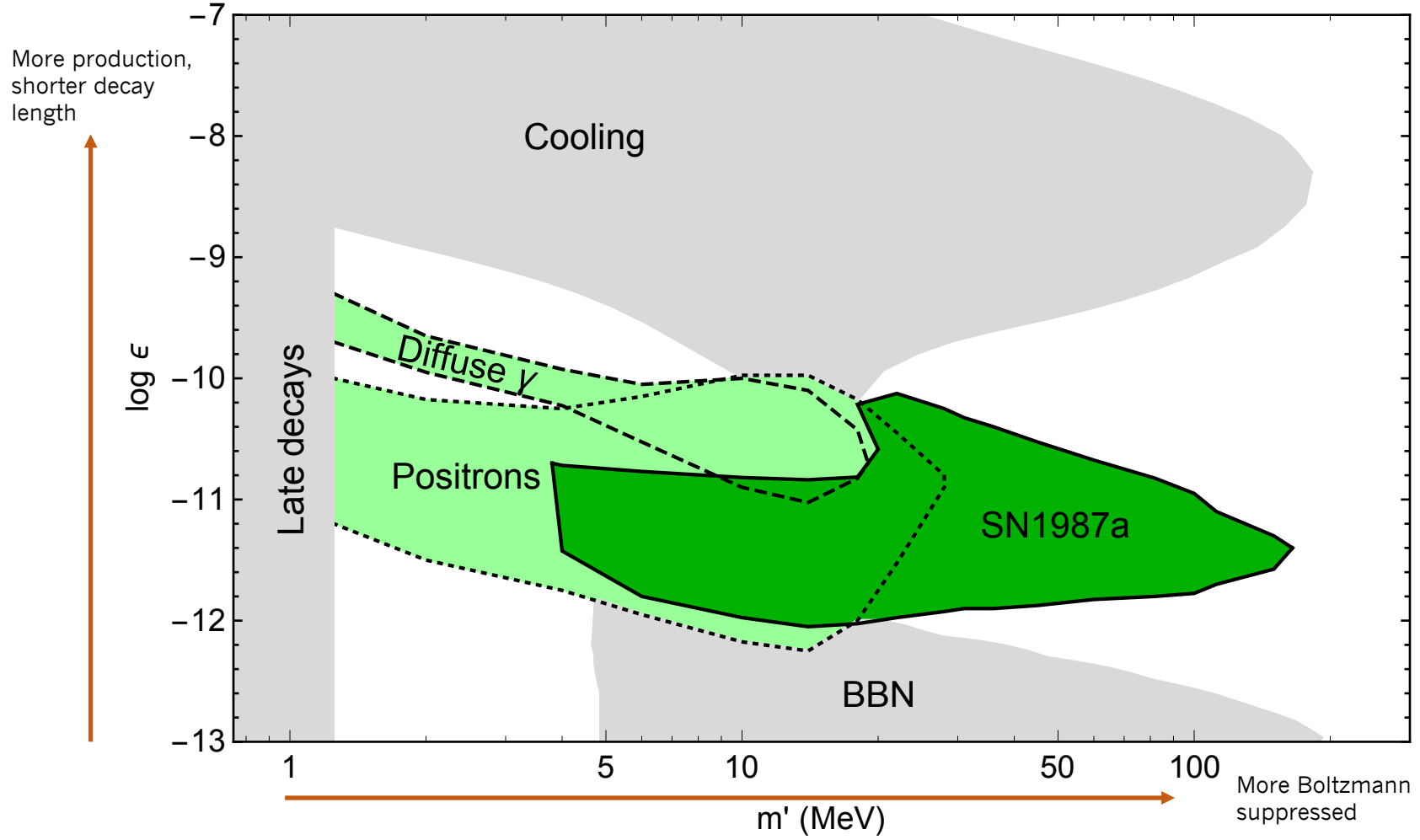
Signature #2: Diffuse extragalactic gamma rays

- Decay products can form e^+e^- plasma **("fireball")**
- Diffuse extragalactic flux of gamma rays measured by SMM



Signature #3: Prompt gamma rays

- SN1987a gamma ray emission constrained by GRS
- Discovery potential (next galactic supernova)



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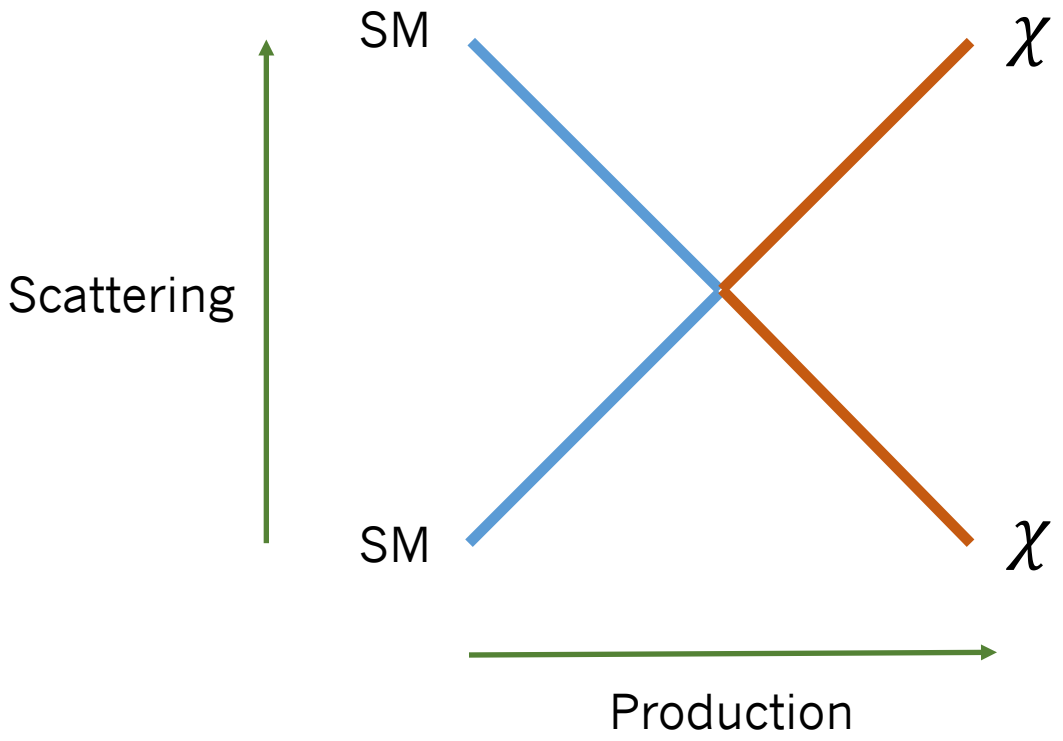
Dark fermion

- ** **Different model than previous section** **
- Dark sector with stable fermion (χ)
- DM-SM coupling through heavy dark photon (A')

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



Diffusive trapping

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

Production/annihilation

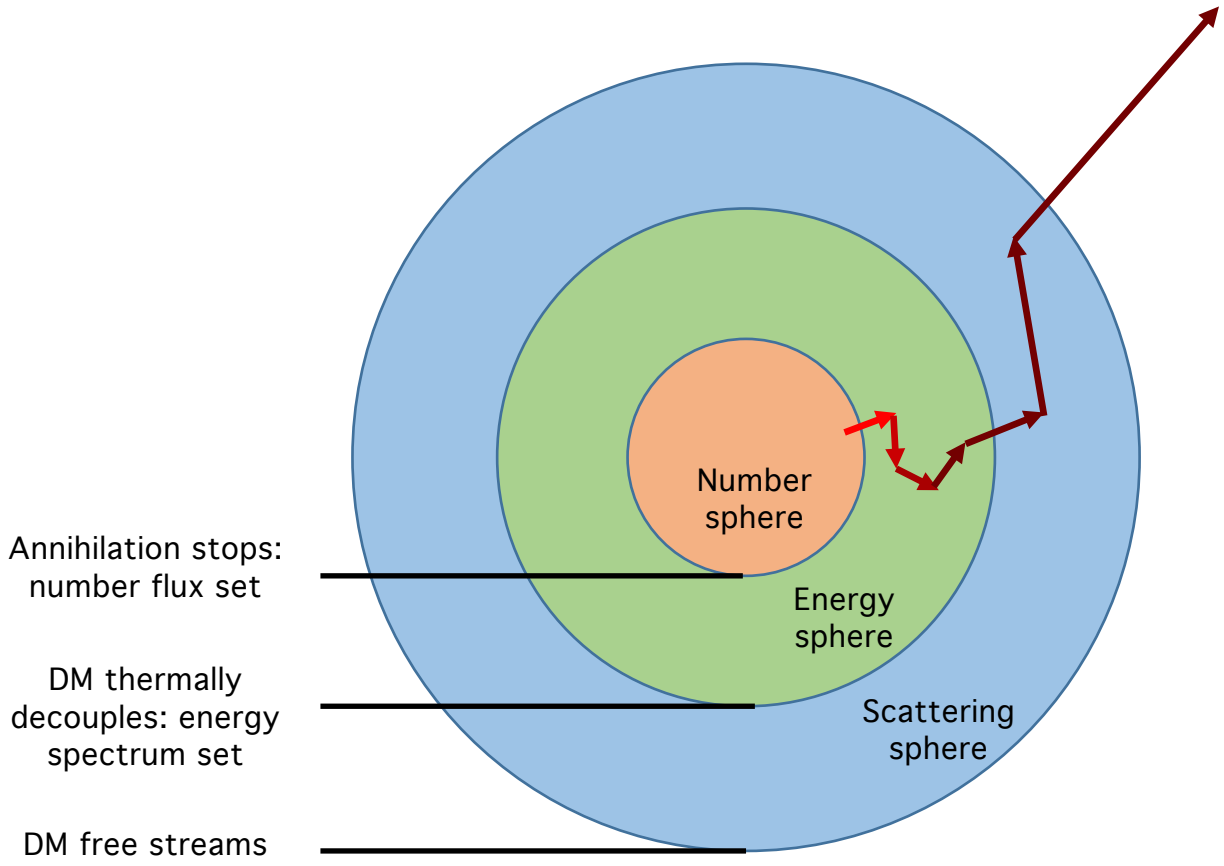
$$\chi\ \bar{\chi} \longleftrightarrow e^+\ e^-$$

Energy transfer

$$\chi\ e \longrightarrow \chi\ e$$

Diffusive scattering

$$\chi\ p \longrightarrow \chi\ p$$



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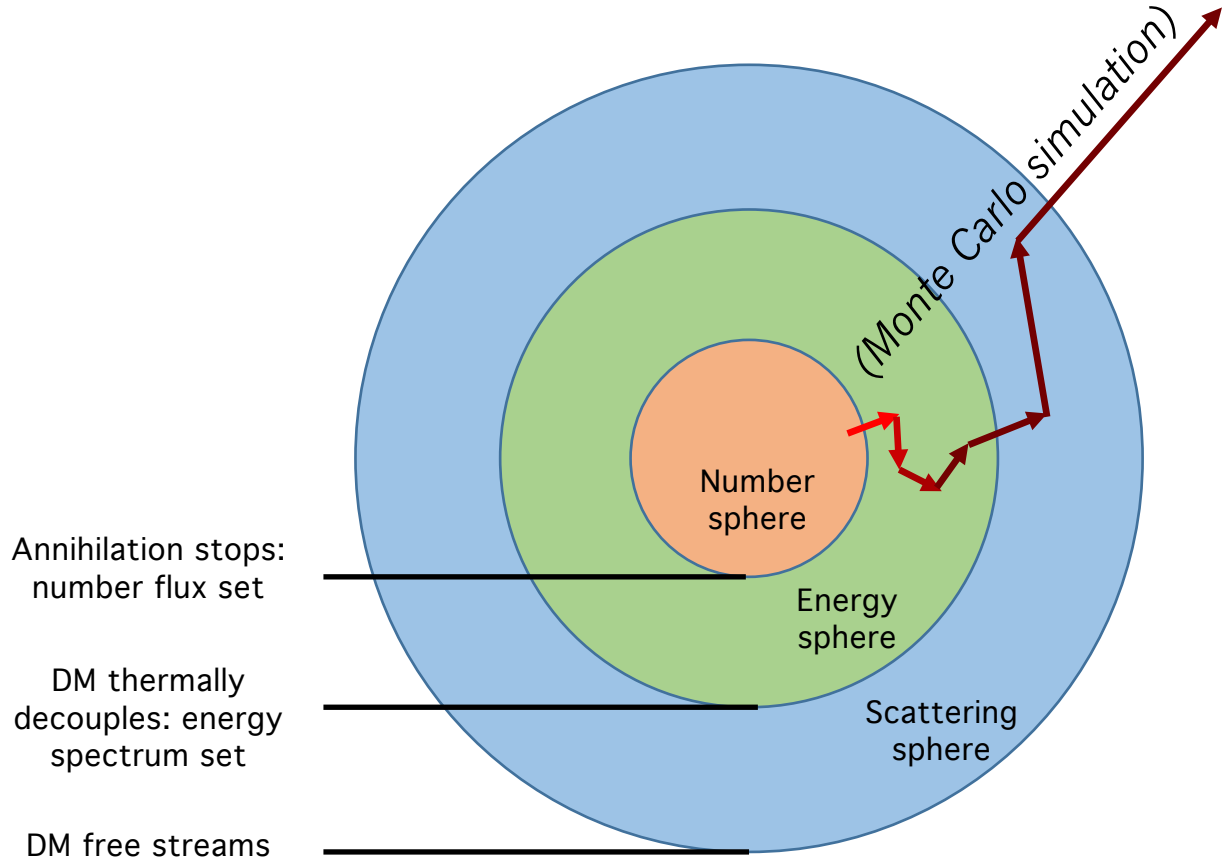
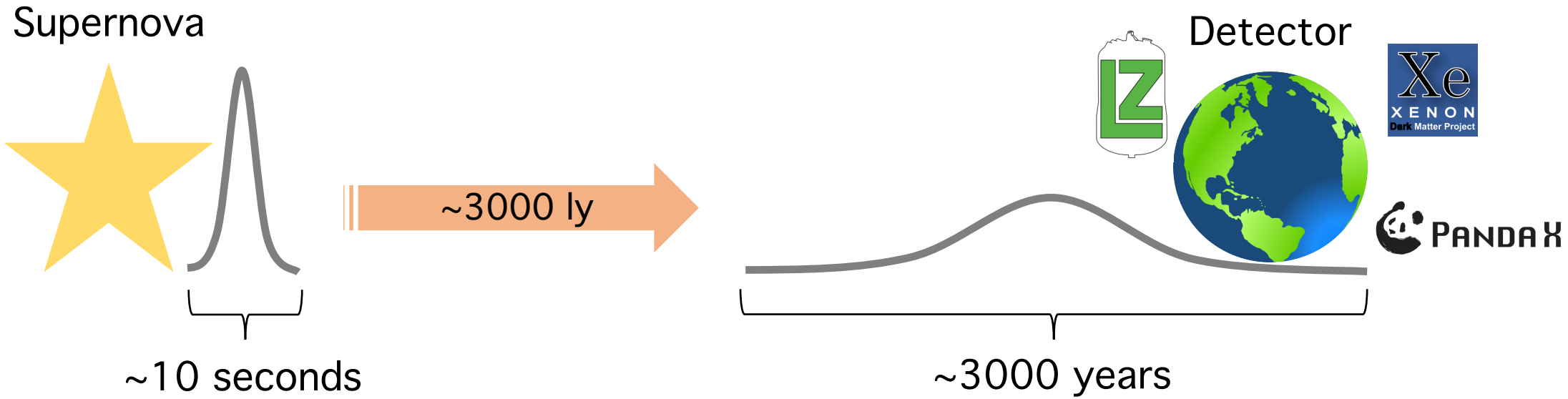


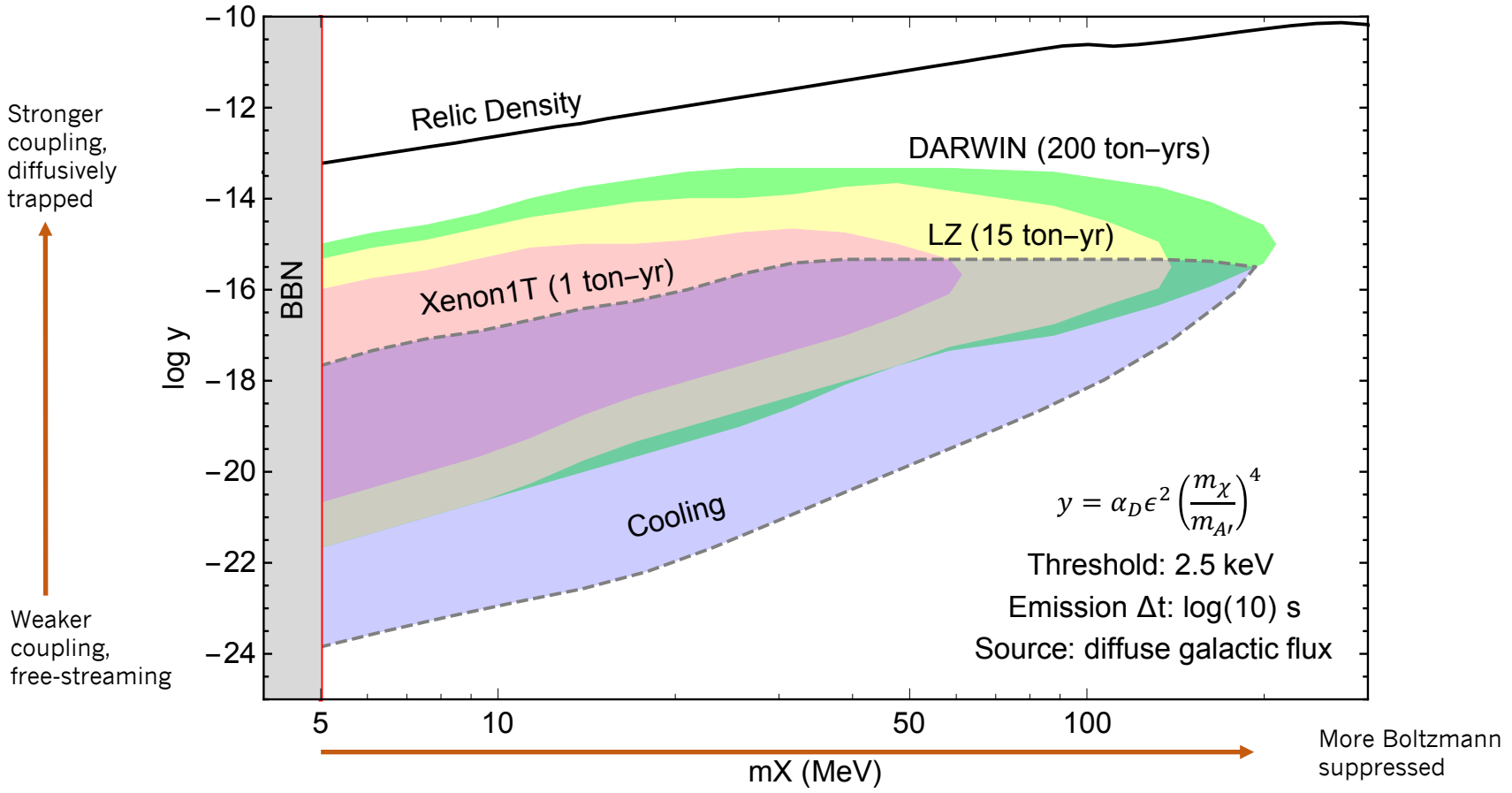
Diffuse galactic flux

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



Direct detection

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



Conclusions

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Thank you!