

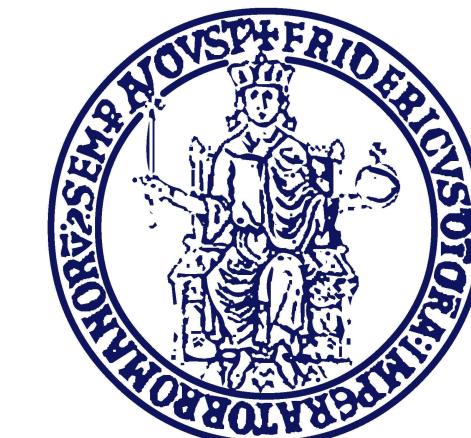
Direct detection of light dark matter from evaporating primordial black holes

Marco Chianese

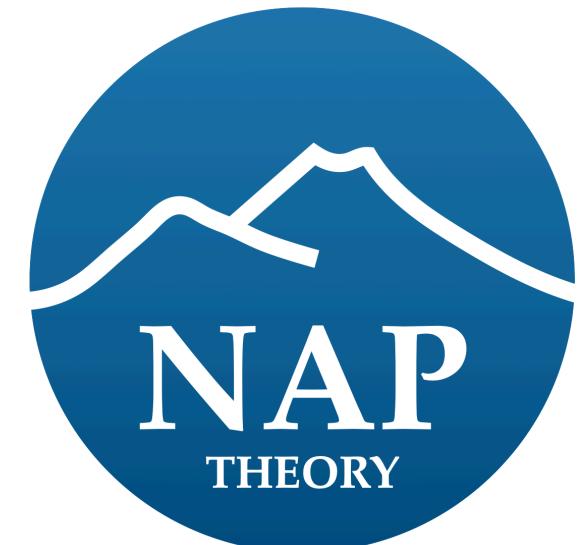
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22 September 2021, Bright ideas for a dark universe, DESY Hamburg

BASED ON CALABRESE, MC, FIORILLO,
SAVIANO, ARXIV:2107.13001



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FEDERICO II



Dark matter direct-detection experiments

They search for the nuclear recoil energy E_r caused by the possible scatterings with DM particles.

Very low sensitivity to light DM

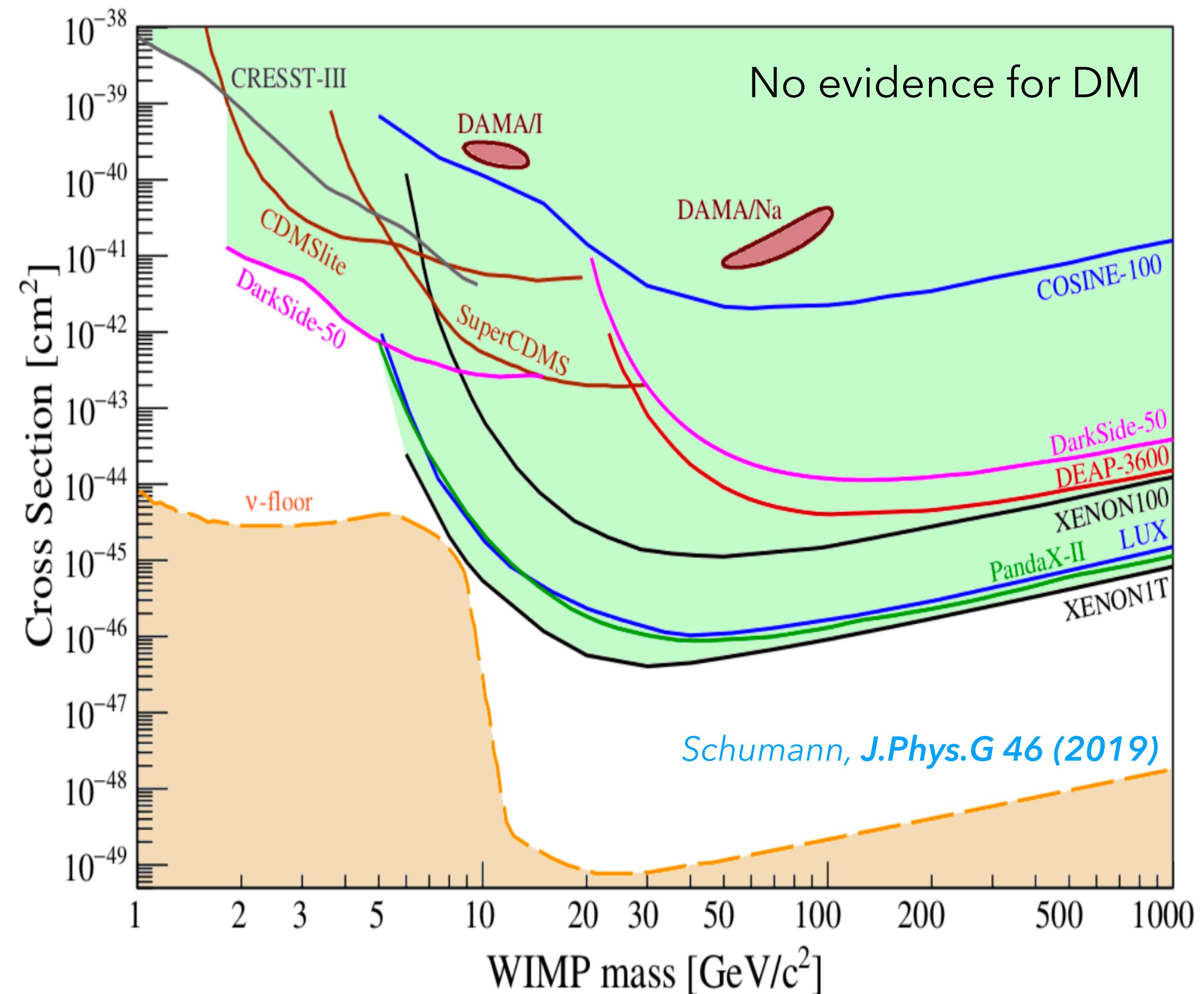
$$\frac{E_r}{50 \text{ keV}} \simeq \left(\frac{m_\chi}{100 \text{ GeV}} \right)^2 \left(\frac{v}{10^{-3}c} \right)^2 \left(\frac{100 \text{ GeV}}{m_N} \right)$$

Undetectable energies for $m_\chi \leq 1 \text{ GeV}$

Possible ways out

- ▶ Lighter nuclei (e.g. Argon instead of Xenon)
- ▶ Migdal effect
- ▶ **Boosted dark matter** $v \sim c$

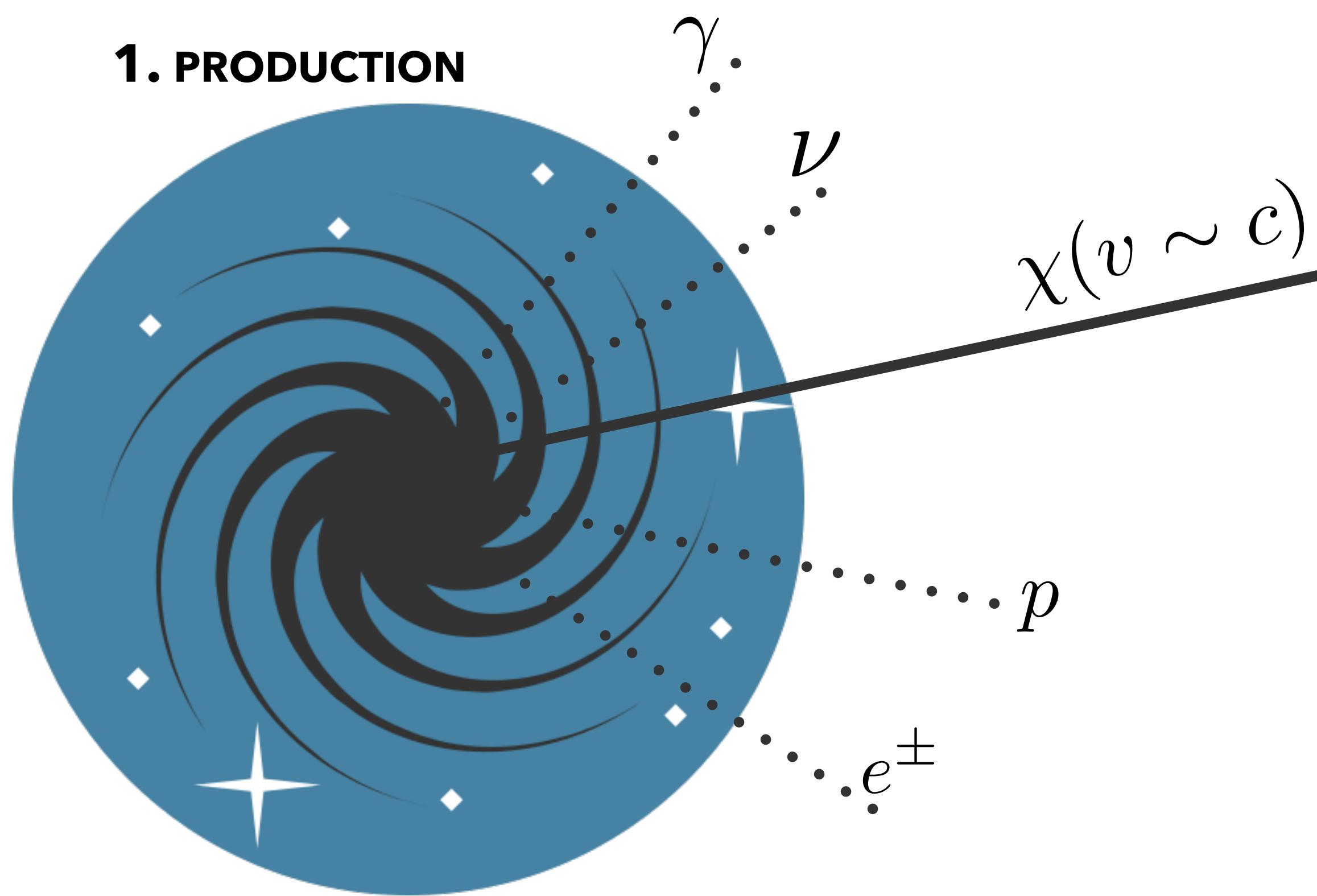
Agashe+, *JCAP* 1410; Giudice+, *PLB* 780 (2018); Fornal+, *PRL* 125 (2020); Kannike+, *PRD* 102 (2020); Cappiello+, *PRD* 99 (2019); Bringmann+, *PRL* 122 (2019); Ema+, *PRL* 122 (2019); Cappiello+, *PRD* 100 (2019); Ema+, *SciPost Phys.* 10 (2021)



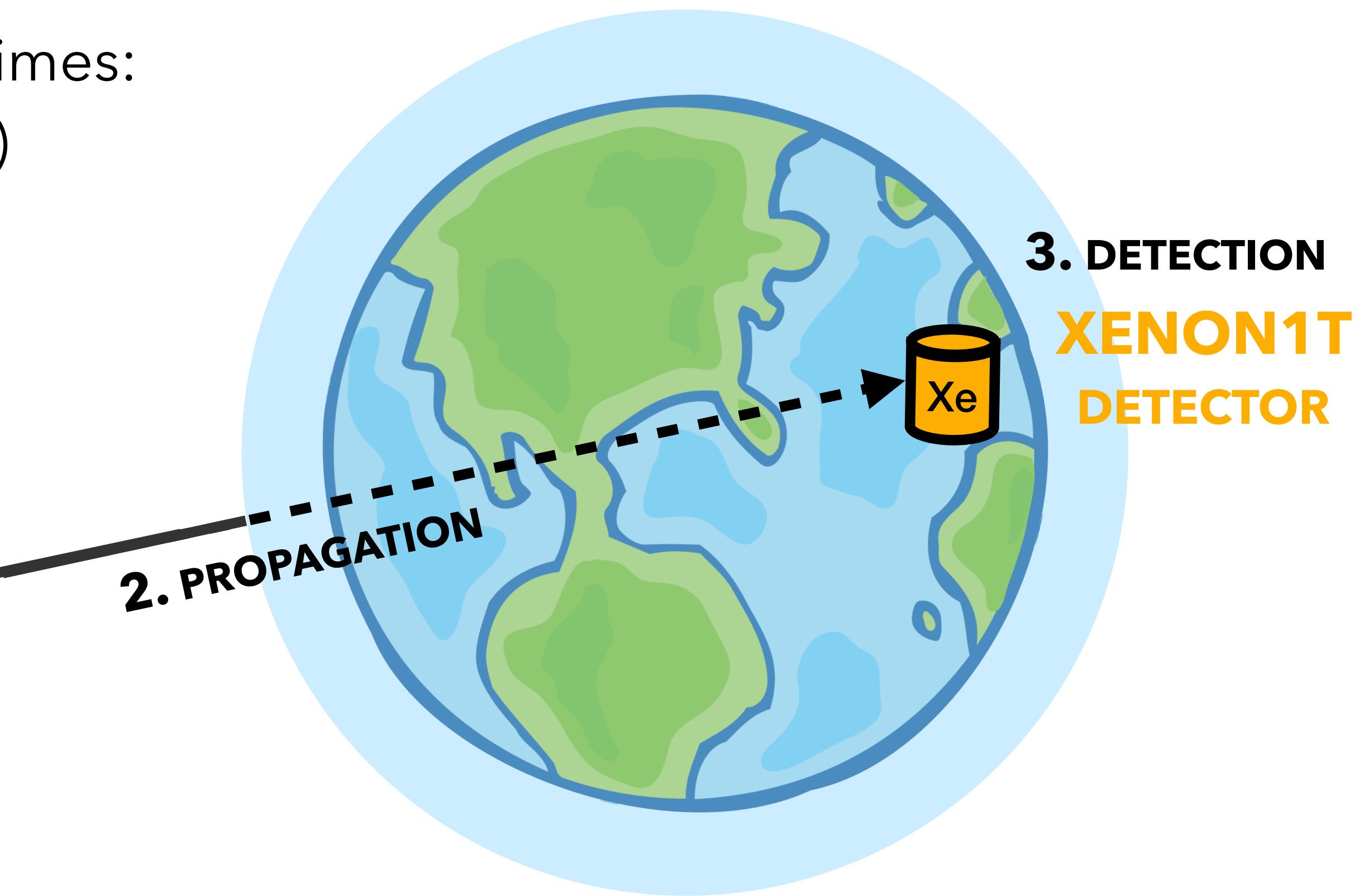
The ePBH-DM scenario

A novel mechanism for boosted DM at present times:
evaporating Primordial Black Holes (**ePBHs**)

Calabrese, MC, Fiorillo, Saviano, arXiv:2107.13001

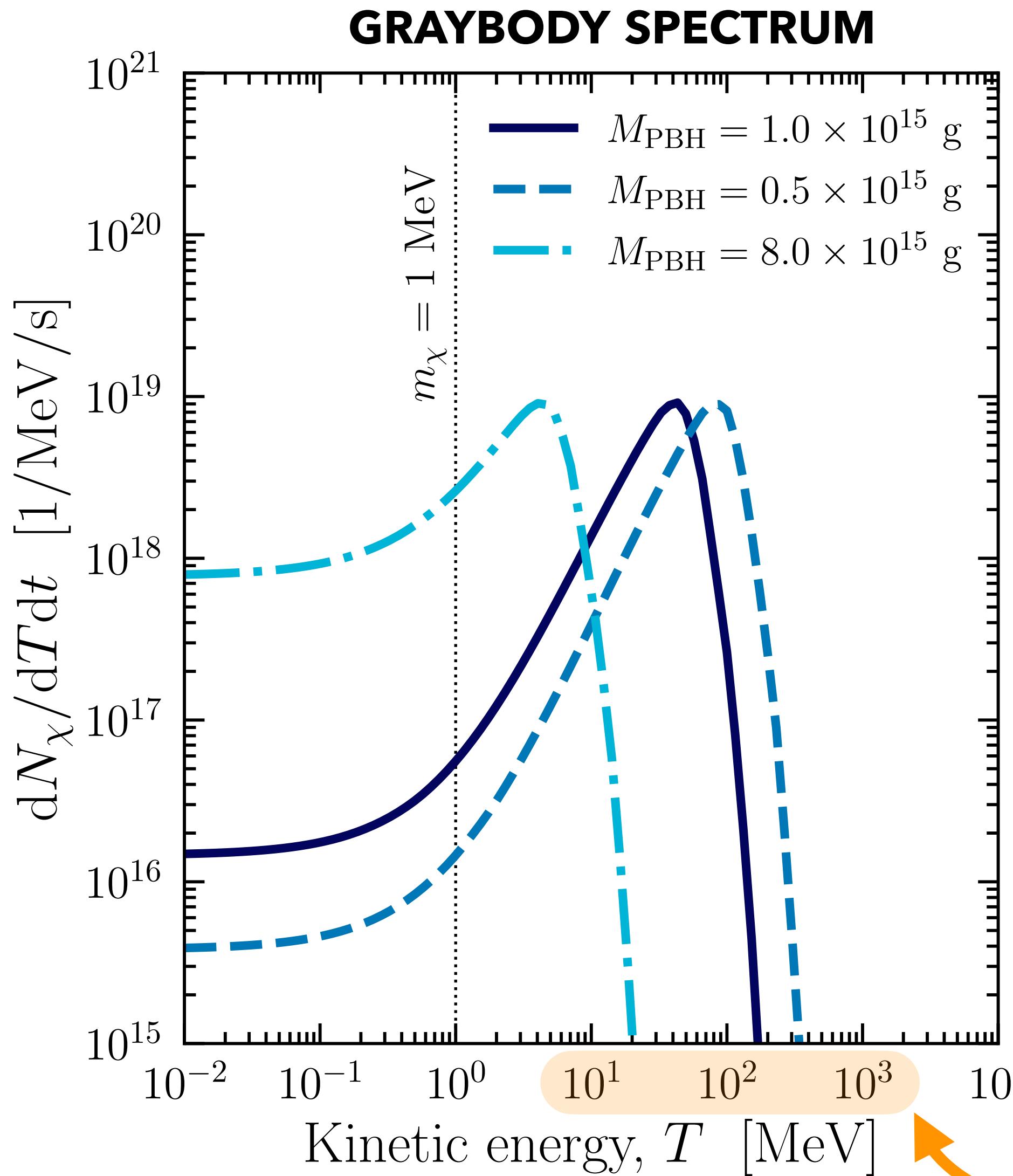


PBHs possibly exist in our Galaxy
and in the whole Universe



- ▶ DM production previously studied in the early Universe only
Carr, ApJ 206 (1976); Morrison+, JCAP 1905; Baldes+, JCAP 2008; Gondolo+, PRD 102 (2020); Bernal+, JCAP 2103 & PLB 815 (2021); Auffinger+, EPJP 136 (2021); Masina, arXiv:2103.13825; Cheek+, arXiv:2107.00013 & arXiv:2107.00016
- ▶ See Calabrese's talk for ePBHs into neutrinos!
Calabrese, Fiorillo, Miele, Morisi, Palazzo, arXiv:2106.02492

Evaporating Primordial Black Holes



- PBHs emit thermal Hawking radiation at a temperature:

$$T_{\text{PBH}} = 10.6 \left(\frac{10^{15} \text{ g}}{M_{\text{PBH}}} \right) \text{ MeV}$$

Hawking, *Comm. Math. Phys.* 43 (1976); Page, *PRD* 13 (1976)

- DM particles are efficiently produced if $m_\chi \leq T_{\text{PBH}}$

Calculation details

- Graybody factor computed with **BlackHawk** code
- Spinless and chargeless PBHs (conservative scenario)
- Fermionic Dirac DM particles (4 degrees of freedom)

Arbey, Auffinger,
EPJC 79 (2019)

Relativistic DM particles

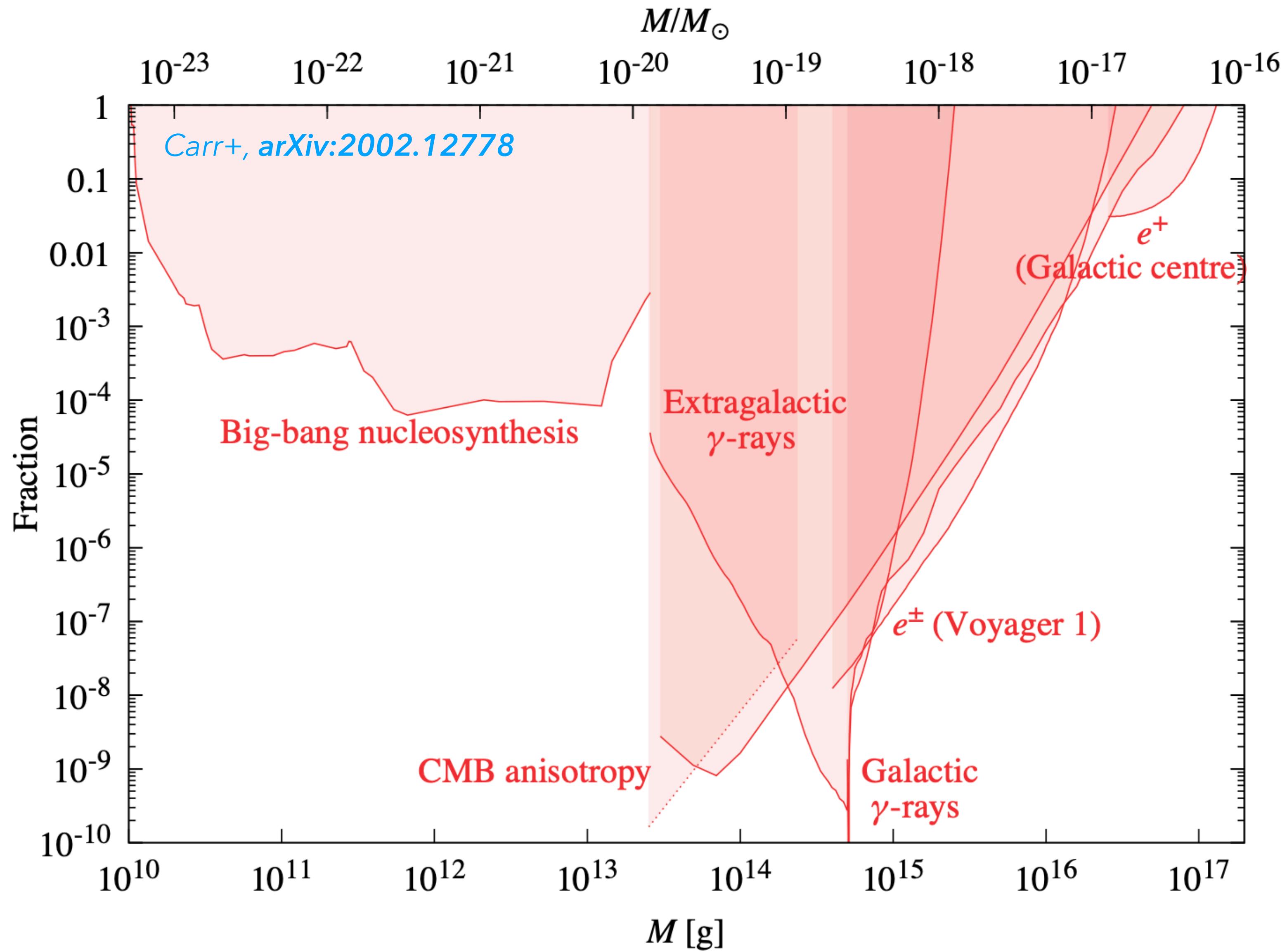
Constraints on PBH abundance

- Several observations strongly constrain the PBH abundance:

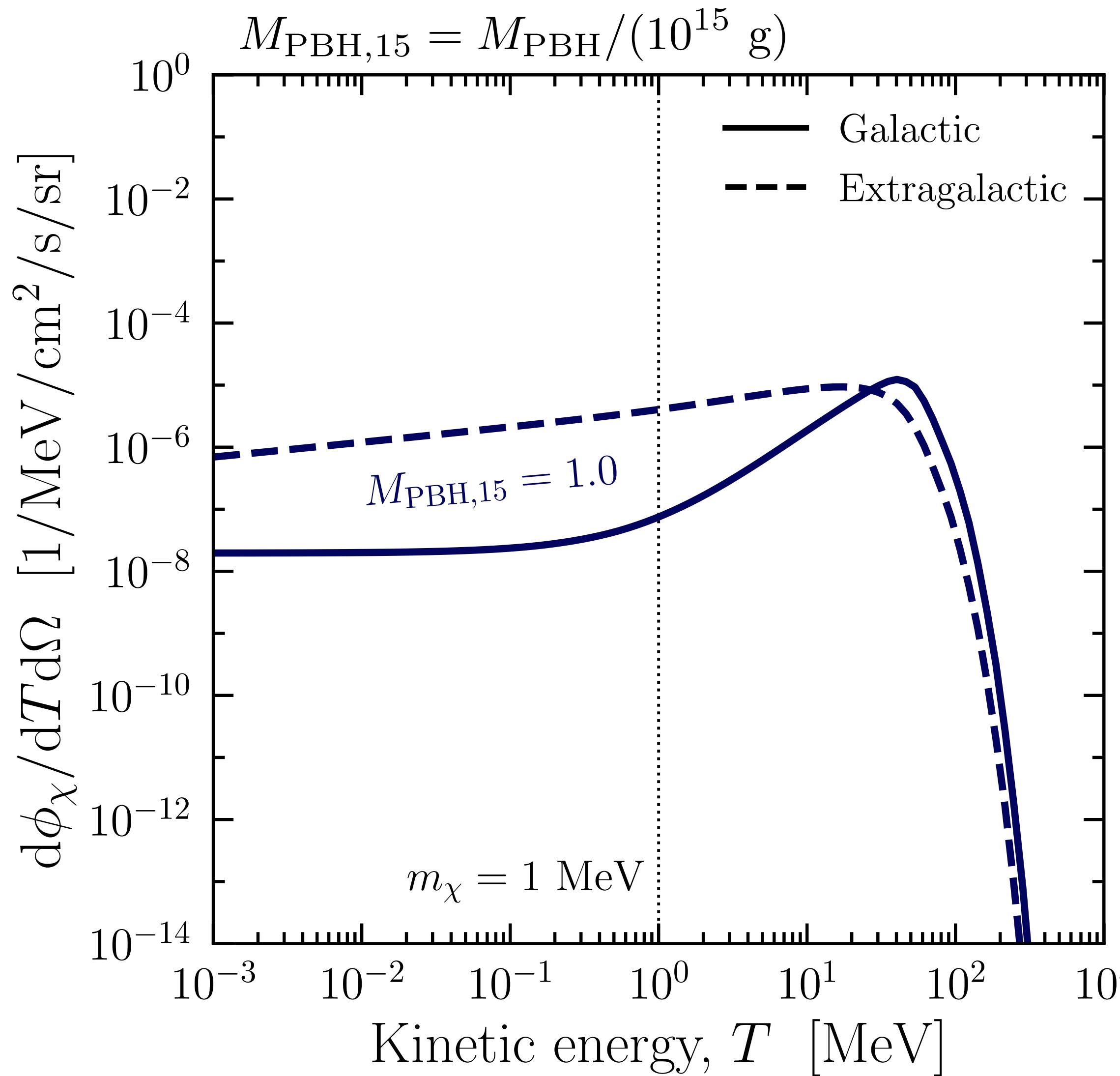
$$f_{\text{PBH}} = \frac{\Omega_{\text{PBH}}}{\Omega_{\text{DM}}} \ll 1$$

- Active searches for neutrino and gamma-ray bursts from ePBHs!

*VERITAS, J. Phys. Conf. Ser. 375 (2012);
H.E.S.S., ICRC (2013); HAWC, Astropart.
Phys. 64 (2015); VERITAS, PoS ICRC2017
691 (2018); Fermi-LAT, ApJ 857 (2018);
HAWC, JCAP 2004; IceCube, PoS ICRC2019
863 (2021); SWGO, arXiv:2103.16895*



Diffuse DM flux from ePBHs



Galactic component

- Navarro-Frenk-White distribution
- Dependent on galactic coordinates

Extragalactic component

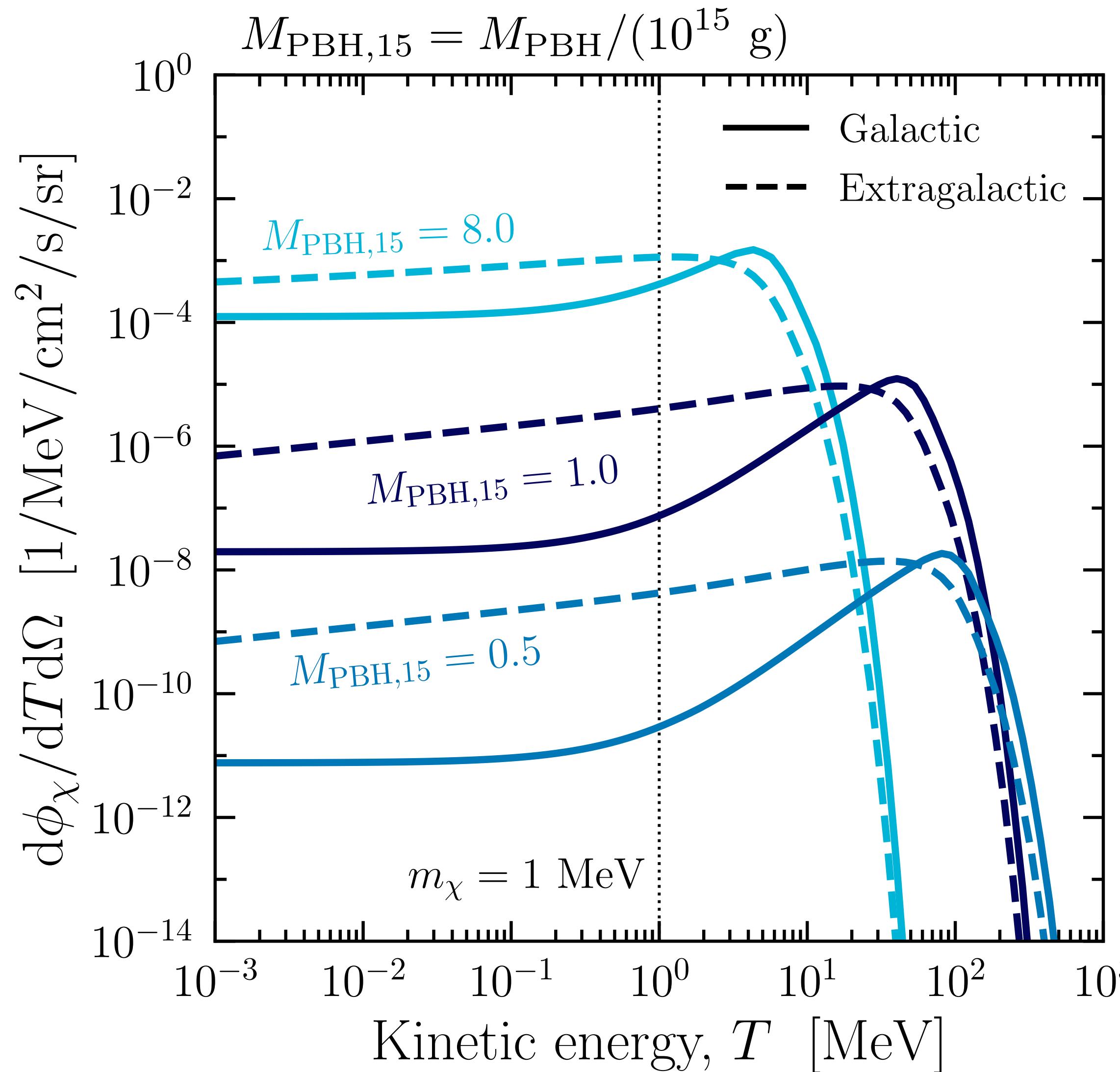
- Cosmological DM distribution with redshift
- Independent from galactic coordinates (isotropic)

$$\frac{d\phi_\chi}{dT d\Omega} \propto f_{\text{PBH}} \cdot \rho_\chi$$

Maximum allowed value

e.g. in this case $f_{\text{PBH}} = 3.9 \times 10^{-7}$

Diffuse DM flux from ePBHs



Larger PBH mass

- ▶ Smaller Hawking temperature, thus lower energies ↓
- ▶ Slower evaporation rate ↓
- ▶ Weaker constraints on f_{PBH} ↑

Smaller PBH mass

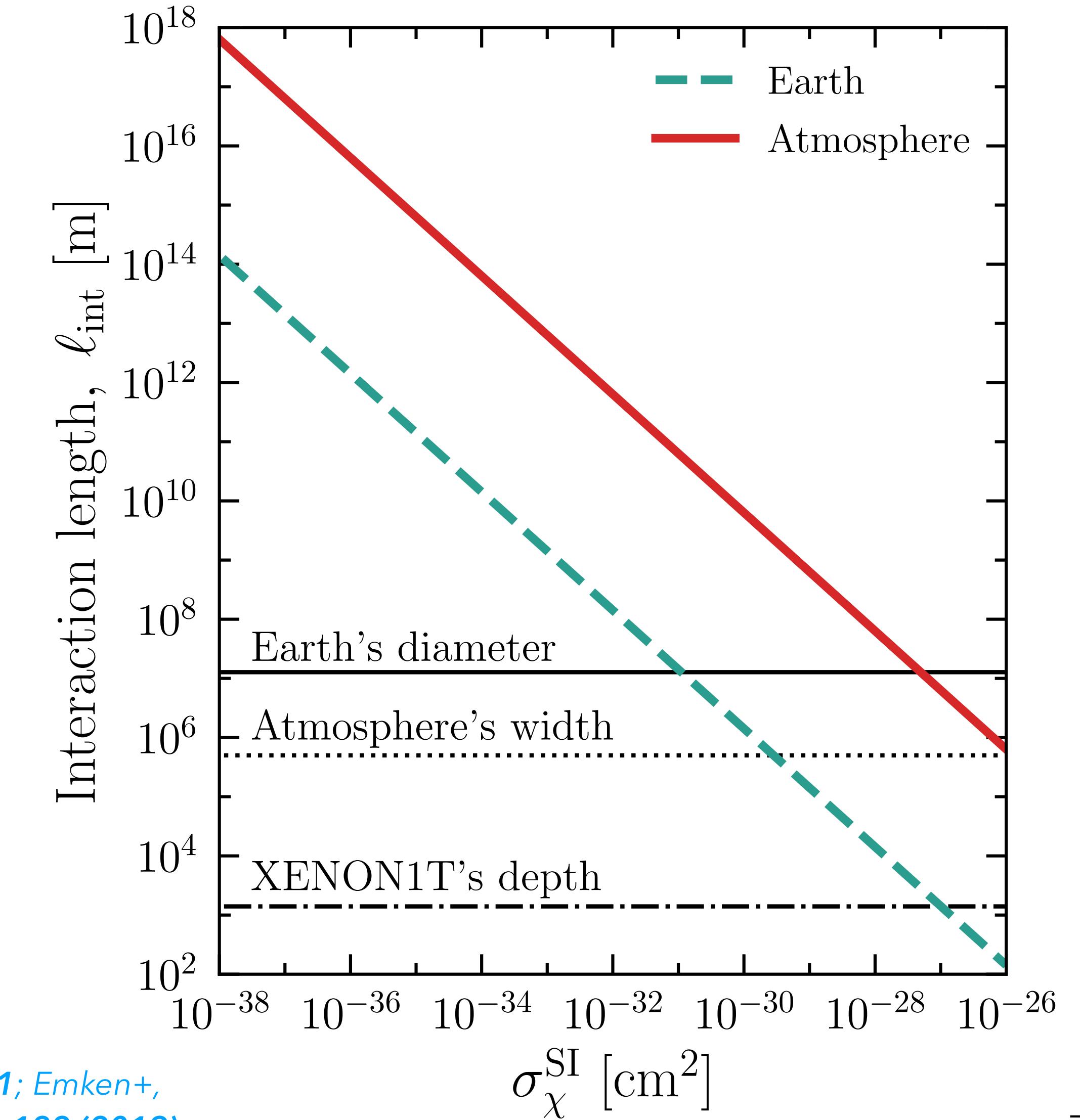
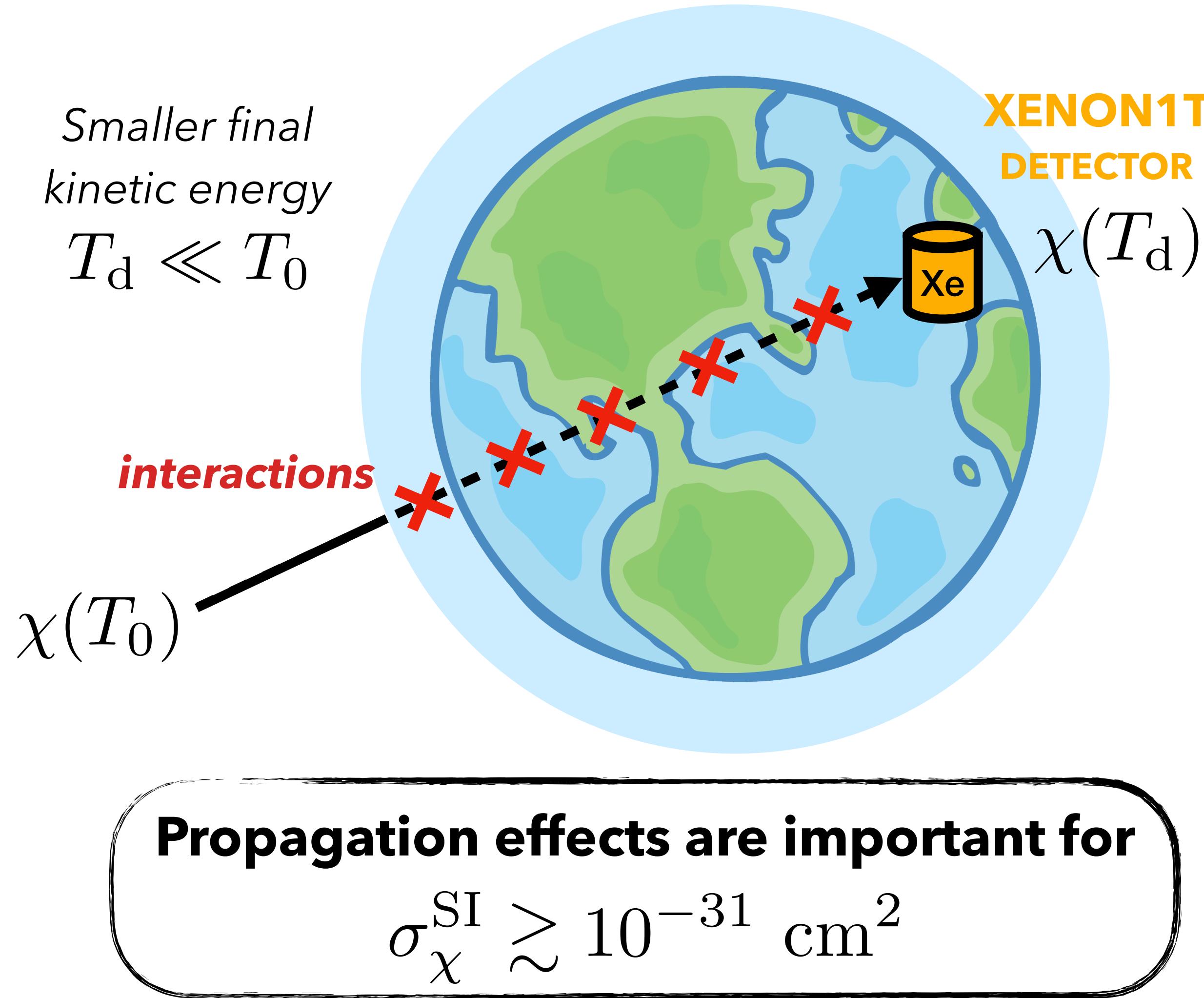
- ▶ Larger Hawking temperature, thus higher energies ↑
- ▶ Faster evaporation rate ↑
- ▶ Stronger constraints on f_{PBH} ↓

PBH mass window

$0.5 \lesssim M_{\text{PBH},15} \lesssim 8.0$

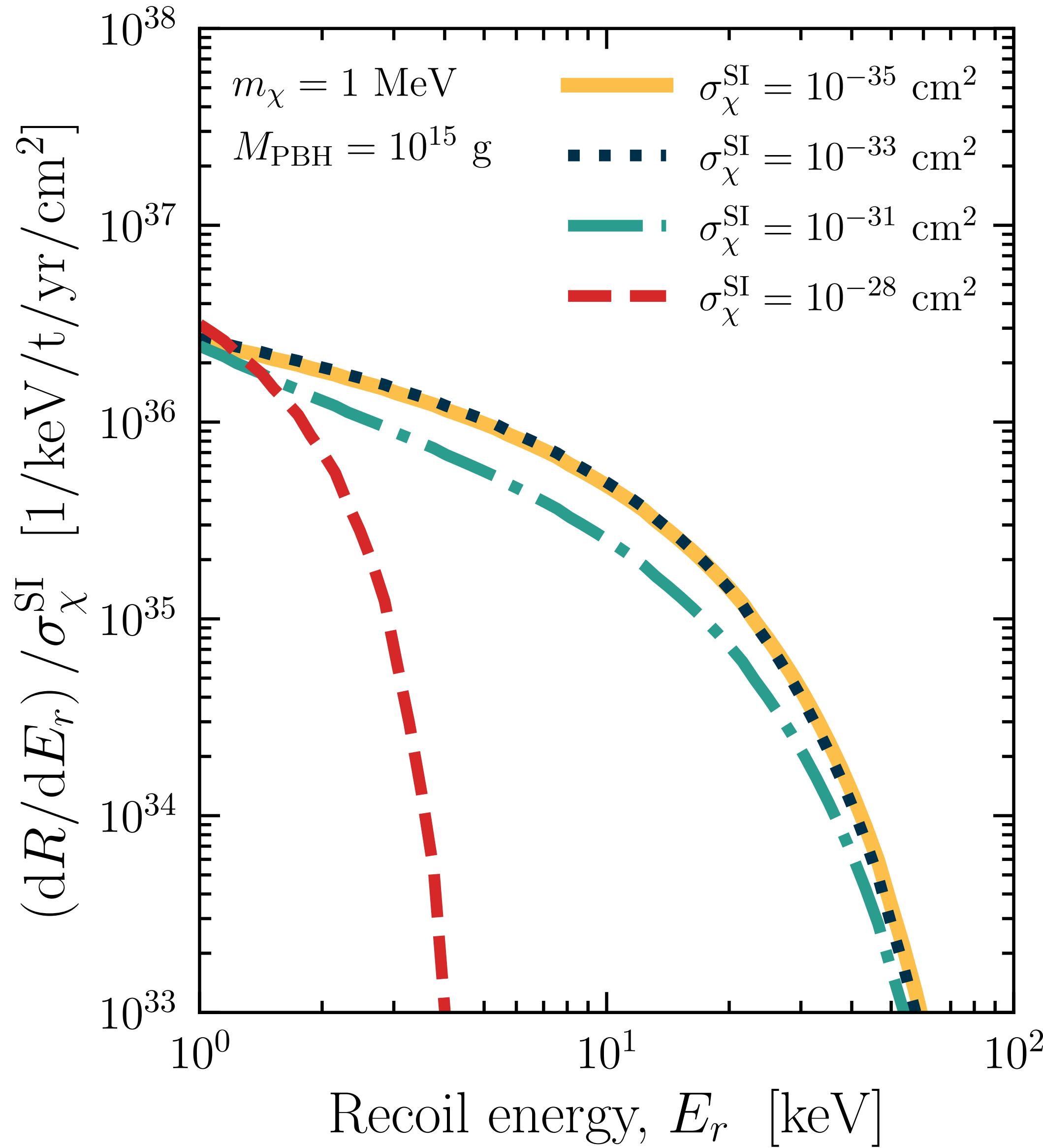
Propagation through Earth and atmosphere

We analytically account for the energy loss of DM particles in the ballistic-trajectory approximation.



See also: Kavanagh+, JCAP 1701; Emken+, PRD 97 (2018); Bringmann+, PRL 122 (2019)

Event rate in XENON1T detector



$$\frac{dR}{dE_r} = \sigma_{\chi X_e} \mathcal{N}_{X_e} \int dT_d d\Omega \frac{d\phi_\chi^d}{dT_d d\Omega} \frac{\Theta(E_r^{\max} - E_r)}{E_r^{\max}}$$

\downarrow

Total number of Xenon nuclei
(exposure of one ton year)

\downarrow

Flat distribution for the
maximum allowed recoil energy

- For small DM-nucleon cross-section, the event rate scale as

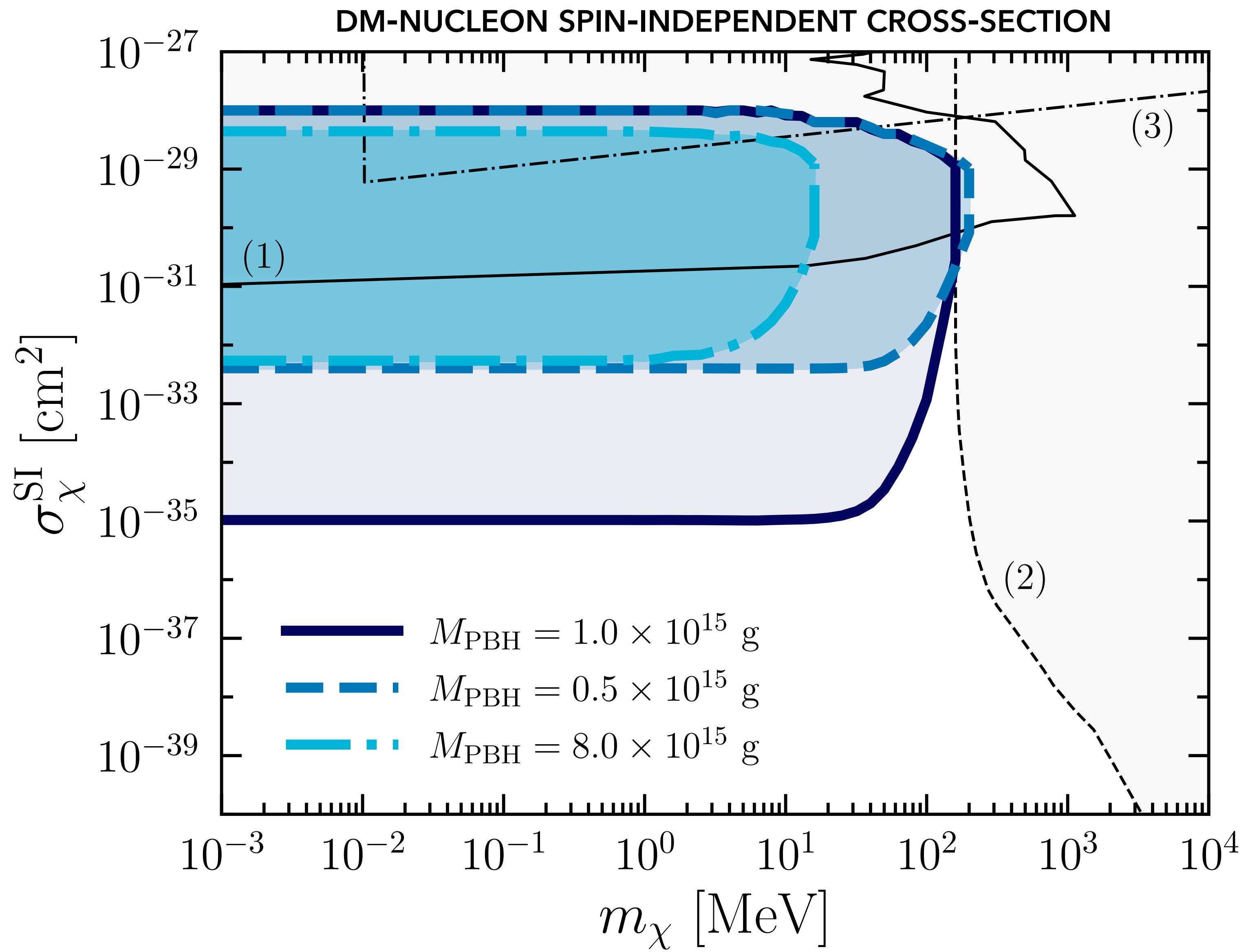
$$\frac{dR}{dE_r} \propto f_{\text{PBH}} \cdot \sigma_\chi^{\text{SI}}$$

Strong degeneracy!

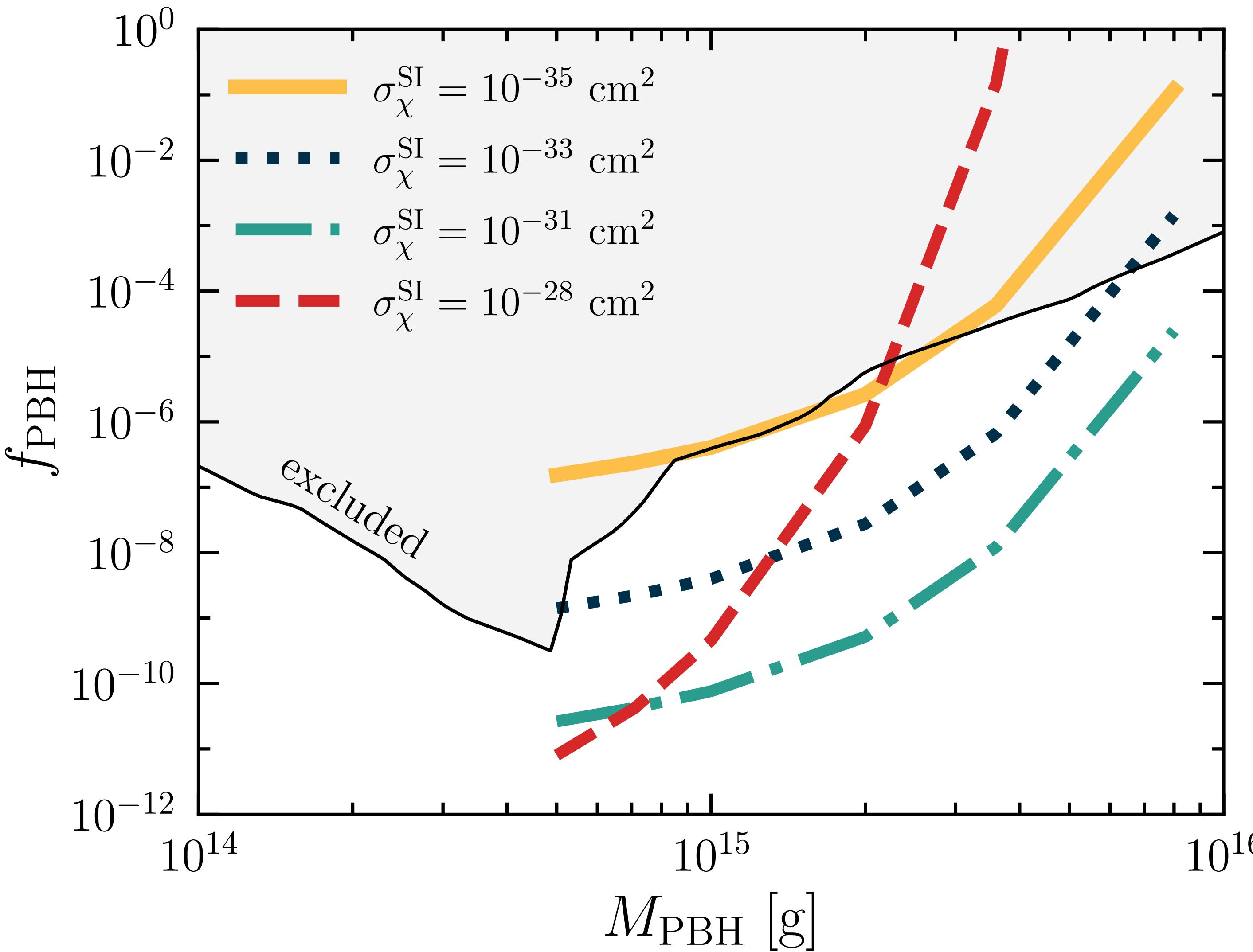
- For $\sigma_\chi^{\text{SI}} \gtrsim 10^{-31} \text{ cm}^2$, the propagation pushes the events to lower recoil energies (see red dashed line).

Our constraints on light Dark Matter

- ▶ No excess of events in XENON1T from 4.9 to 40.9 keV.
Aprile+ (XENON), PRL 121 (2018)
- ▶ **Significant improvement with respect to previous constraints:**
 - (1) CRs up-scatterings
 - (2) CRESST experiment
 - (3) Cosmology
- ▶ Our limits extend to lower DM masses though $m_\chi < 1$ keV highly disfavored.



Our constraints on PBHs



- ▶ Valid in any model of light DM particles.
- ▶ Dependence on the strength of DM-nucleon interactions.
- ▶ Almost independent from DM mass.
- ▶ For large cross-section, propagation effects are important (see red dashed line).

Conclusions

- ▶ Evaporating Primordial Black Holes with a mass from 10^{14} to 10^{16} g are an efficient source of boosted light Dark Matter particles!
- ▶ For the first time we have explored the phenomenological implications of the ePBH-DM scenario in direct detection experiments such as XENON1T.
- ▶ Strong constraints on the combined parameter space of DM and PBHs.
- ▶ **Stay tuned!** The ePBH-DM scenario has a very rich phenomenology.

Thanks for listening