

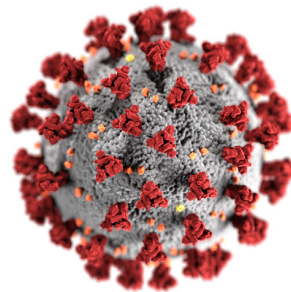
# Self-interacting Dark Matter from Primordial Black Holes

Based on:  
NB & Óscar Zapata  
arXiv:[2010.09725](https://arxiv.org/abs/2010.09725), 2011.02510, 2011.12306

**Nicolás BERNAL**



Beyond Standard Model: From Theory to Experiment (BSM- 2021)  
March 29 – April 2, 2021

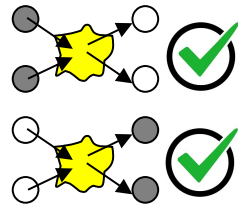
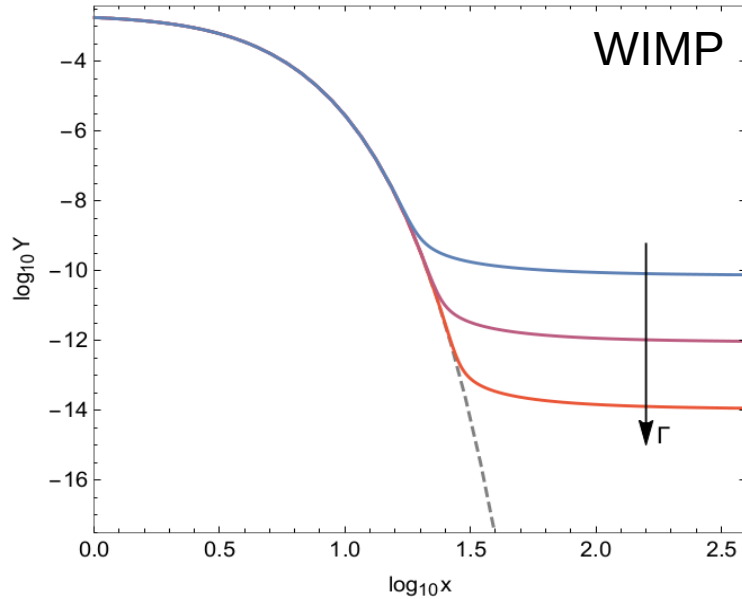


El conocimiento  
es de todos

Minciencias

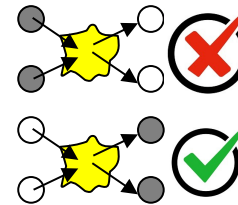
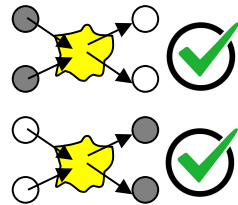
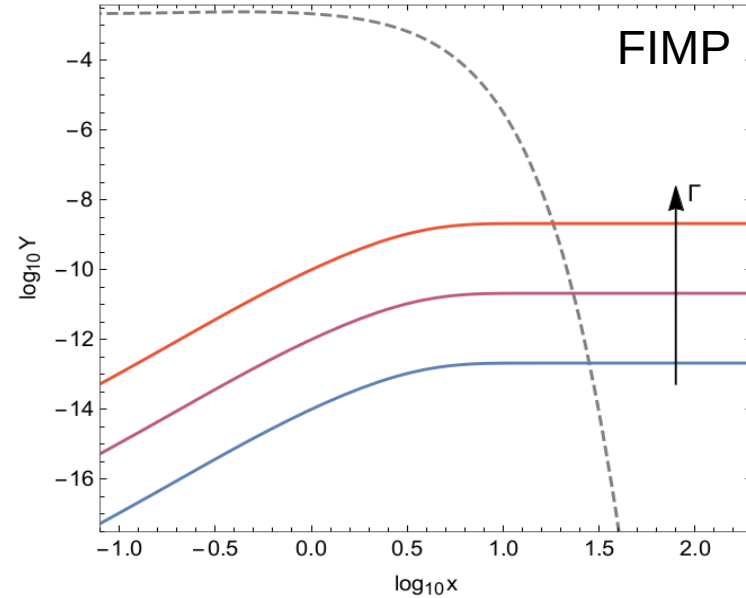
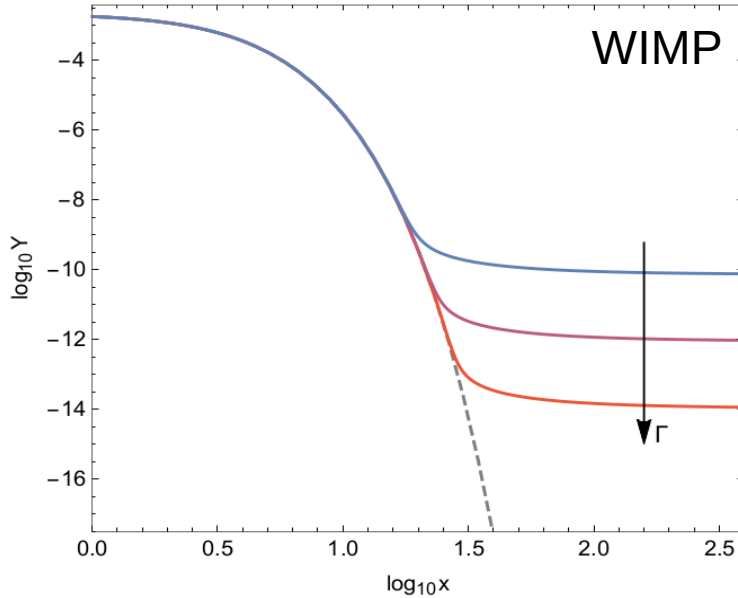
# Dark Matter: WIMP

$$\frac{dn_\chi}{dt} + 3H n_\chi = -\langle v\sigma_\chi \rangle [n_\chi^2 - (n_\chi^{\text{eq}})^2]$$



# Dark Matter: WIMP vs FIMP

$$\frac{dn_\chi}{dt} + 3H n_\chi = -\langle v\sigma_\chi \rangle [n_\chi^2 - (n_\chi^{\text{eq}})^2]$$





**What if DM *only* couples to the SM  
via *gravitational interactions*?**



**What if DM *only* couples to the SM  
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**DM is *unavoidably* produced  
by PBH Hawking evaporation!**



# Primordial Black Holes

- \* Density fluctuations can collapse into a PBH in the early universe
- \* Lose mass by emitting *all* particles via Hawking evaporation
  - PBH have a  $\sim$ black body spectrum, with temperature  $T_{\text{BH}} \sim 1/M_{\text{BH}}$
  - PBHs unavoidable radiate DM!
- \* If  $M_{\text{in}} < 10^9$  g, PBH completely evaporate before BBN
  - poorly constrained

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Effective theory: Two free parameters

- \* A single PBH characterized by its mass at formation  $M_{\text{in}}$   
(or equivalently, by the SM temperature  $T_{\text{in}}$  at formation)
- \* Initial PBH energy density  $\beta = \rho_{\text{BH}}/\rho_{\text{SM}}$

# DM from PBHs

**DM density = PBH density x # DM emitted per PBH**

Number of DM particles radiated per PBH

→ Only depends on initial PBH mass!

$$N_j = \frac{15 \zeta(3)}{\pi^4} \frac{g_j C_n}{g_*(T_{\text{BH}})} \begin{cases} \left(\frac{M_{\text{in}}}{M_P}\right)^2 & \text{for } m_j \leq T_{\text{BH}}^{\text{in}} \\ \left(\frac{M_P}{m_j}\right)^2 & \text{for } m_j \geq T_{\text{BH}}^{\text{in}} \end{cases}$$



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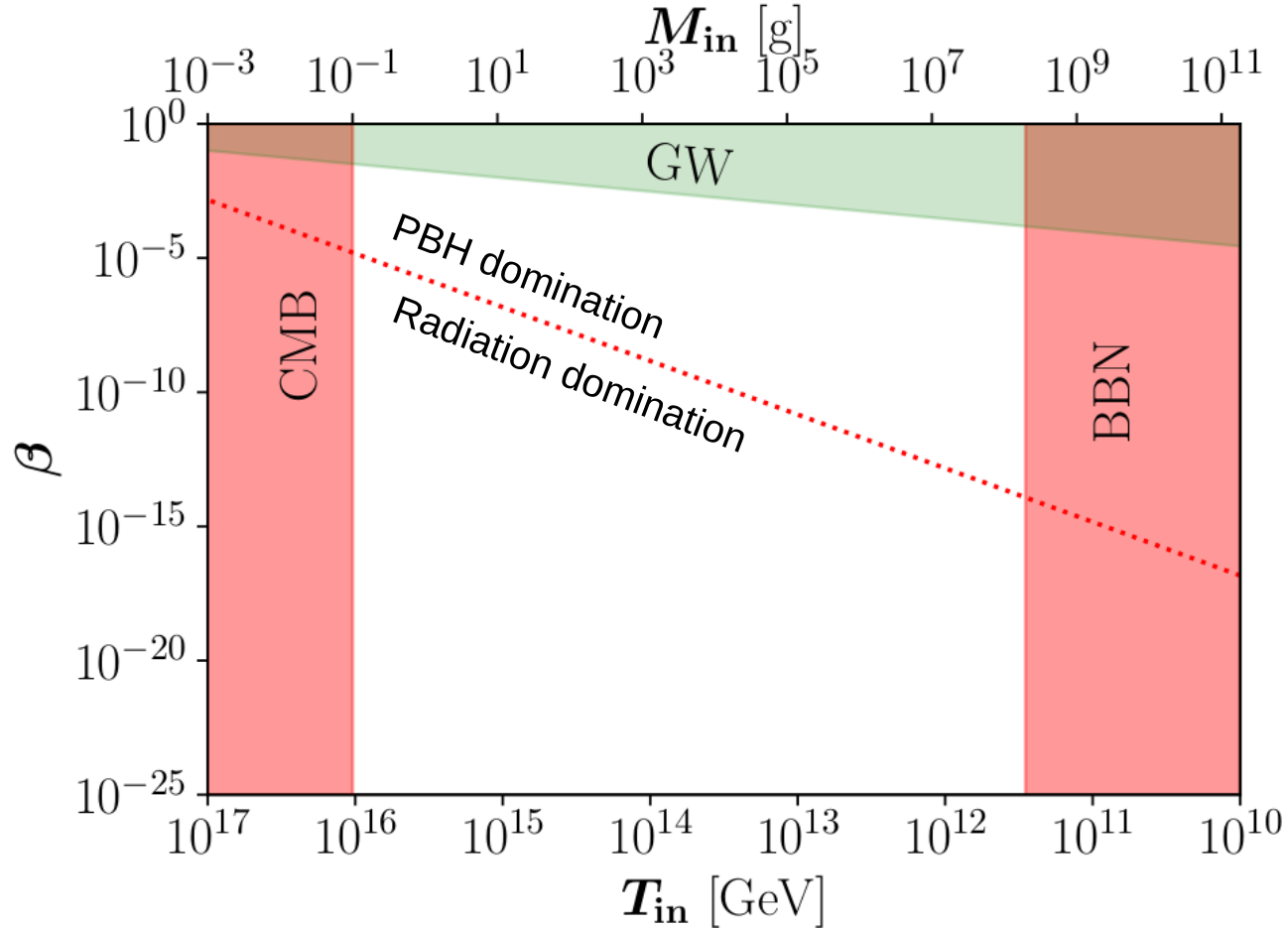
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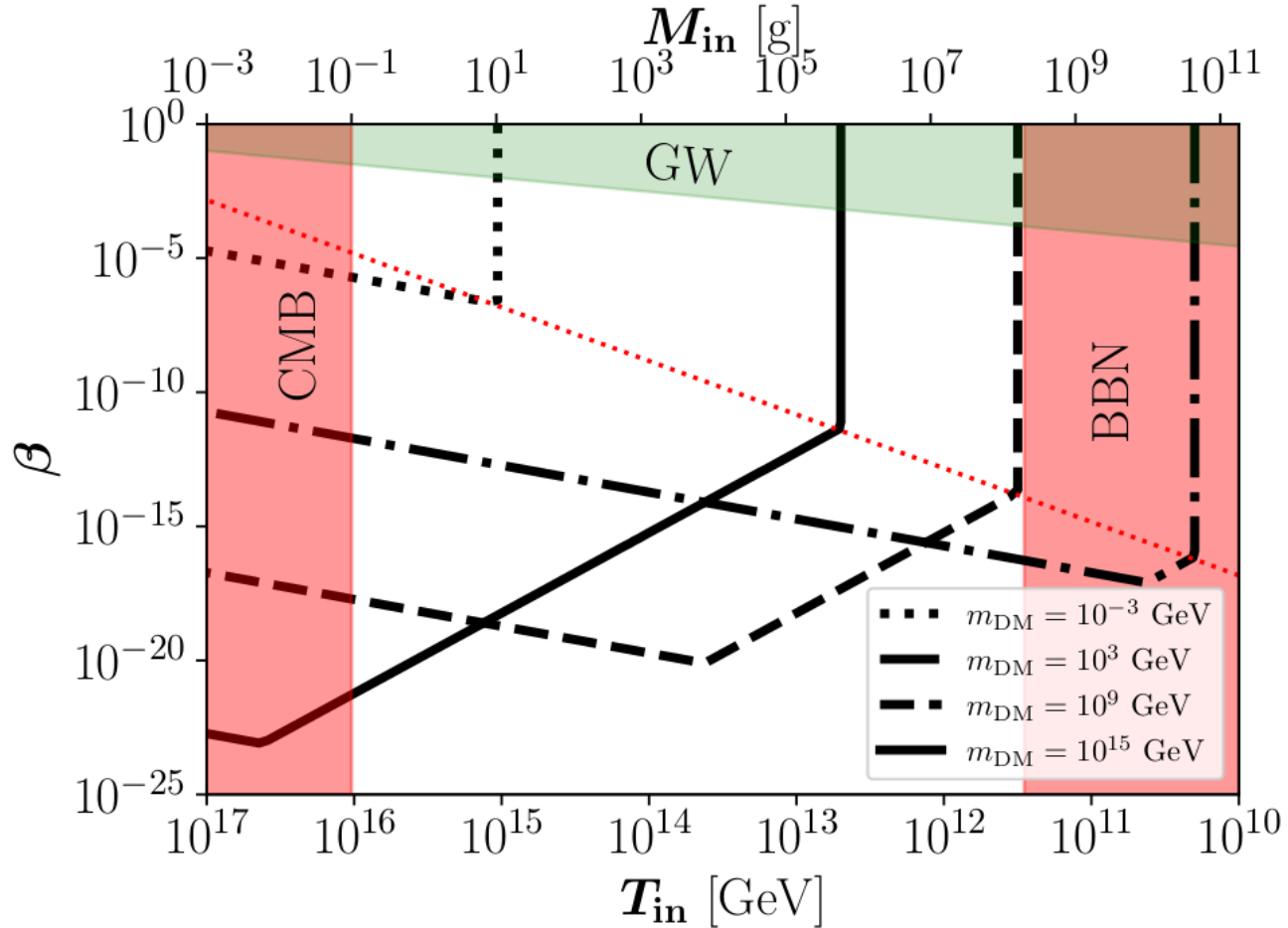
As PBH scale like non-relativistic matter,  
they can dominate the total energy density of the universe

→ Nonstandard expansion!

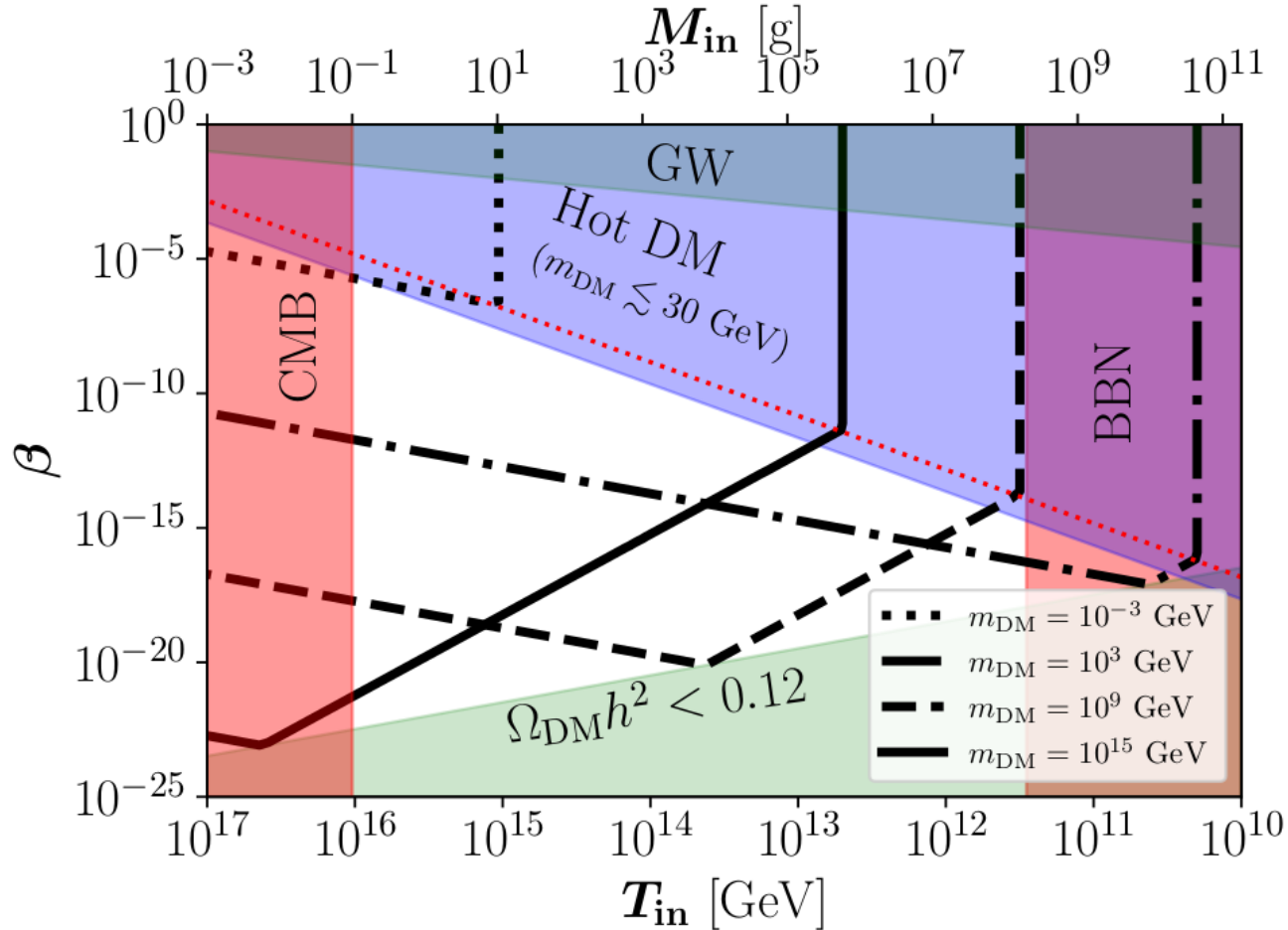
# DM from PBHs



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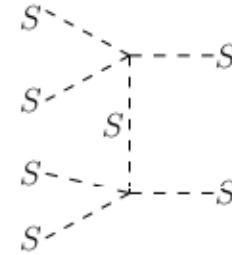
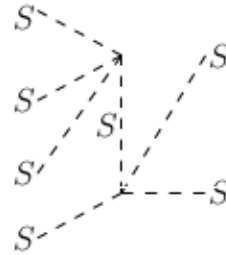
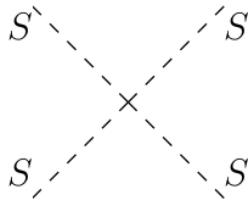
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# Self-interacting DM from PBHs

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  - DM thermalizes
  - Number-changing interactions: **2** ↔ **3**, **2** ↔ **4**...



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- \* What is DM equilibrium number density? (chemical equilibrium)

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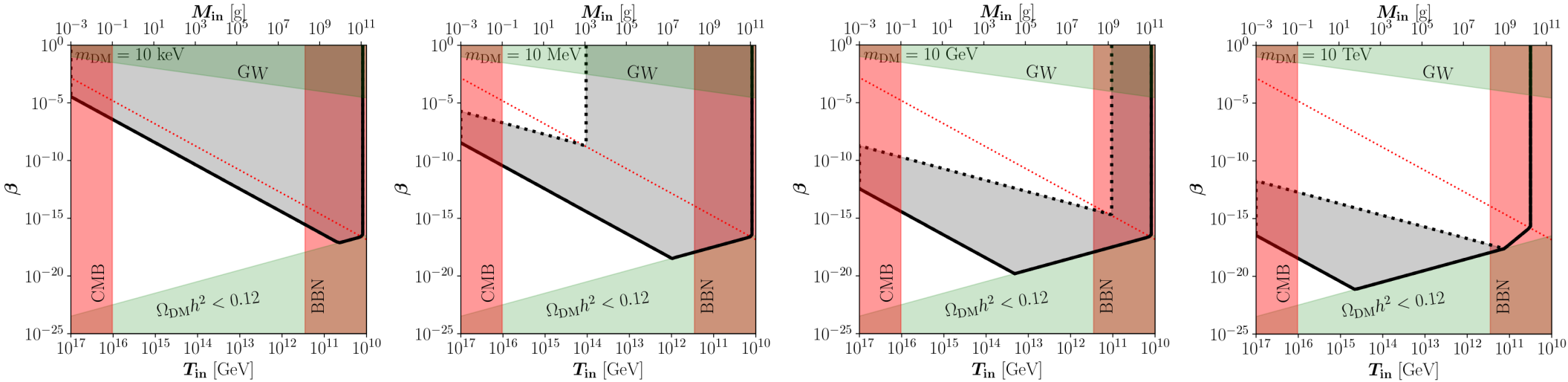
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## Self-interactions:

- Increase the DM density
- Decrease the mean DM kinetic energy



# Self-interacting DM from PBHs



\* DM production more efficient


→ smaller  $\beta$  could be explored

\* DM cools down

→ keV DM becomes viable

\* **Model independent result**

# Conclusions

- It's possible that DM *only* features *gravitational* interactions 
- PBHs formed in the early universe
- $0.1 \text{ g} < M_{\text{in}} < 10^9 \text{ g}$  evaporate before BBN
- PBHs could Hawking radiate the *whole* DM density
- DM masses:  $1 \text{ MeV} < m_{\text{DM}} < 10^{18} \text{ GeV}$
- DM self-interactions:
  - boost DM density  
Boost factors of several order of magnitude can be computed in a *model independent way!*
  - cools down DM: keV DM becomes viable
- Gravitational DM production is unavoidable!

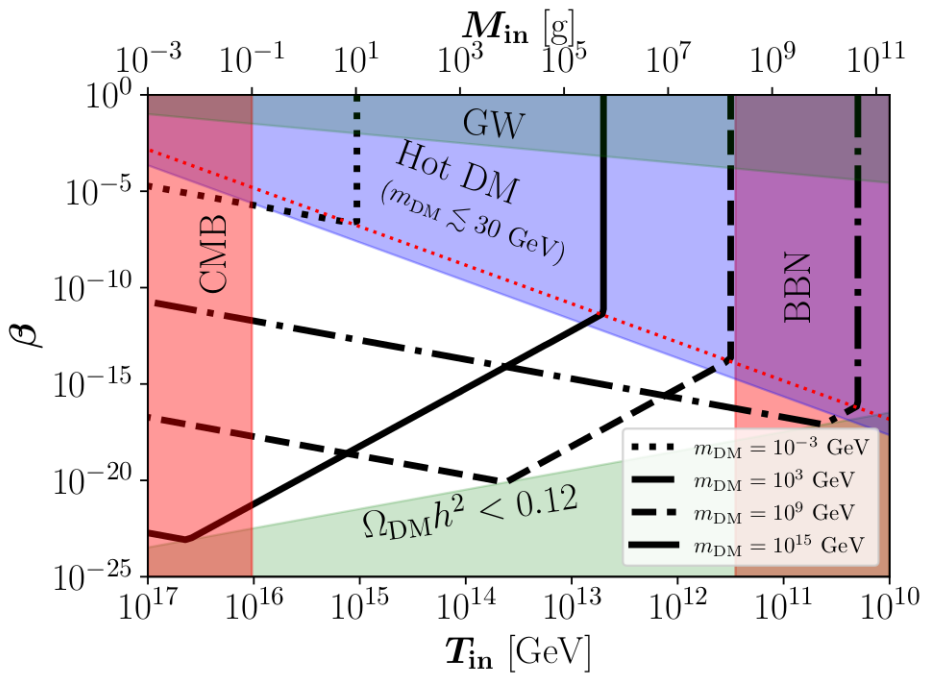


**¡Muchas  
gracias!**

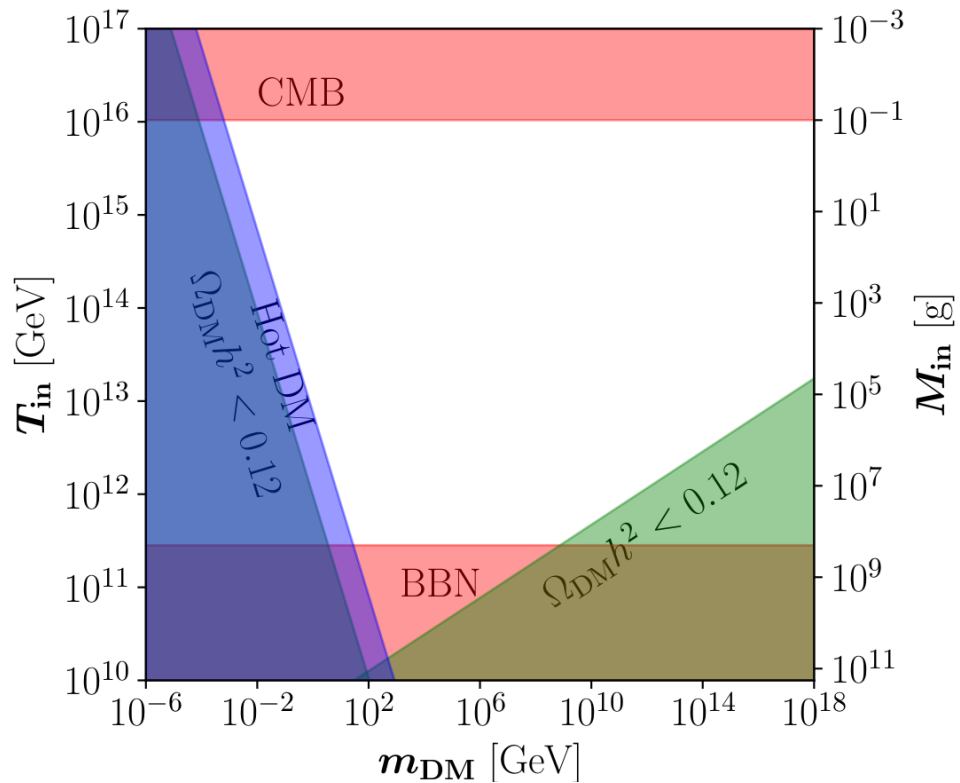


## 2. Gravitational UV freeze-in

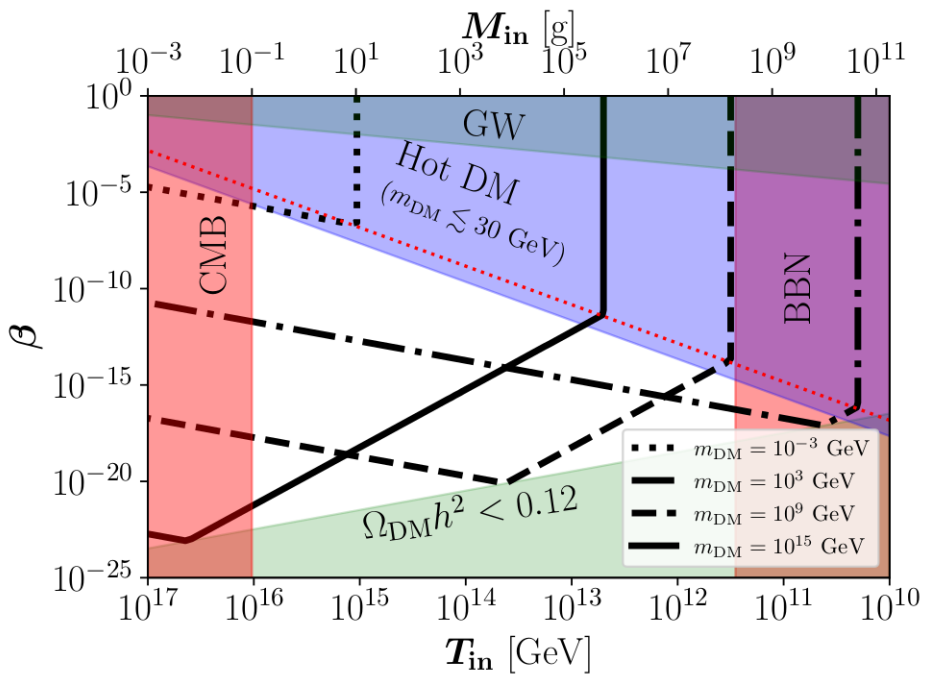
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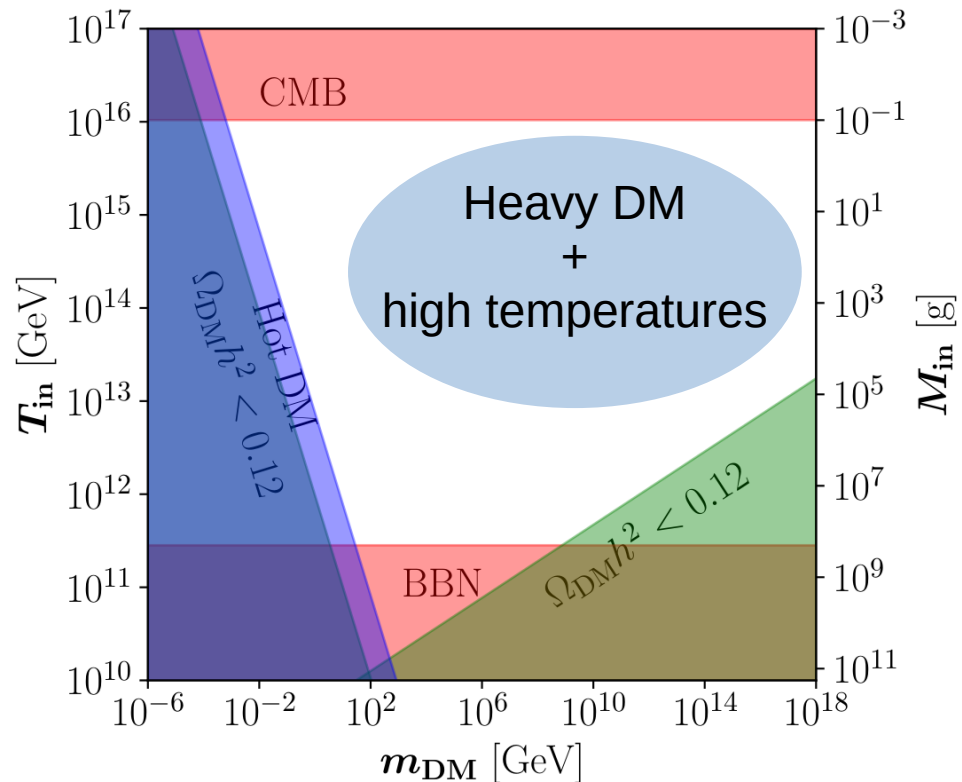
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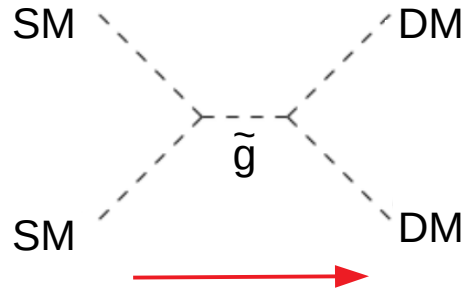


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# Gravitational UV Freeze-in

An example of UV FIMP, mediated by massless SM gravitons



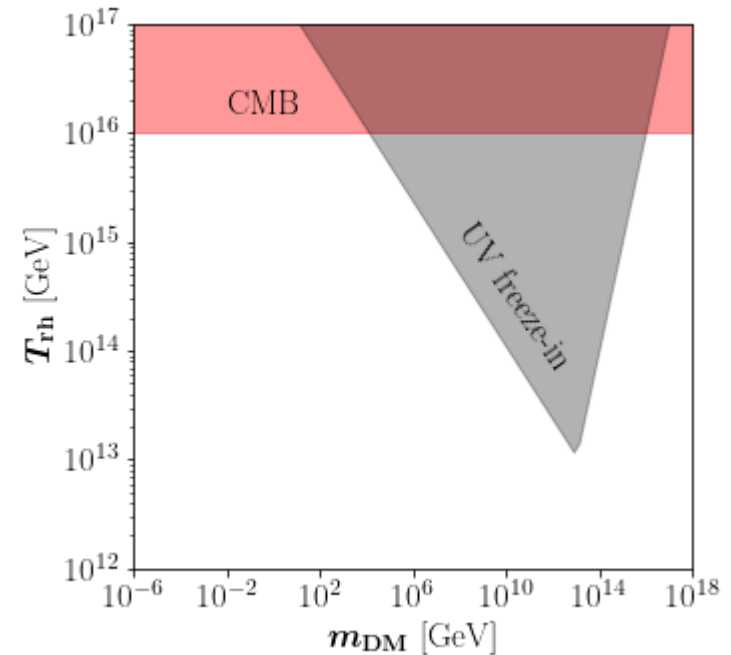
Depends on:

- \* DM mass and spin

- \* Reheating temperature  $T_{\text{rh}}$

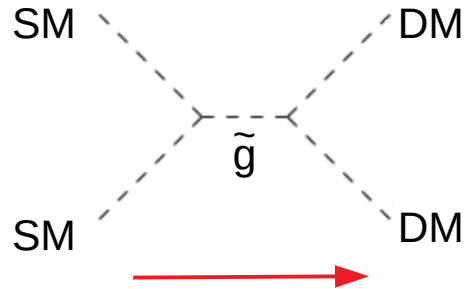
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$$\Omega h^2 \sim m * (T_{\text{rh}}/M_P)^3$$



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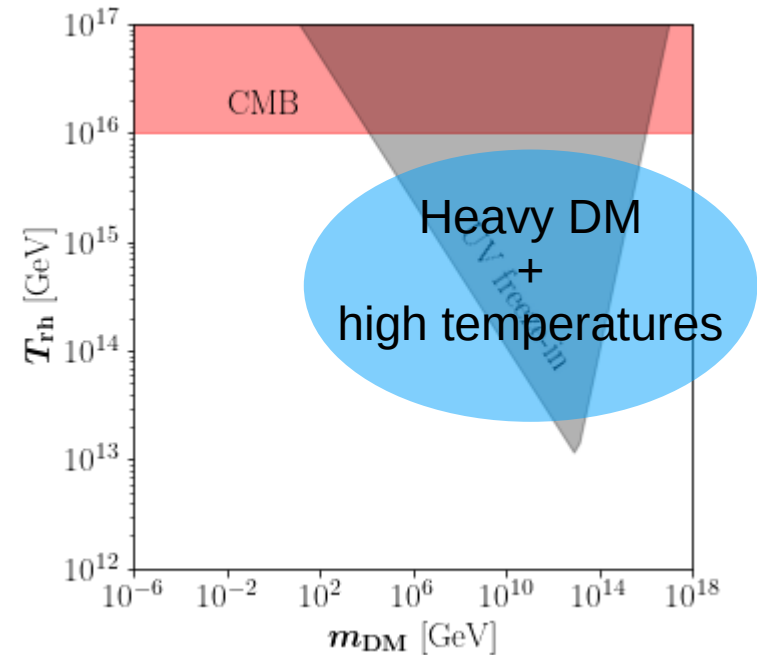
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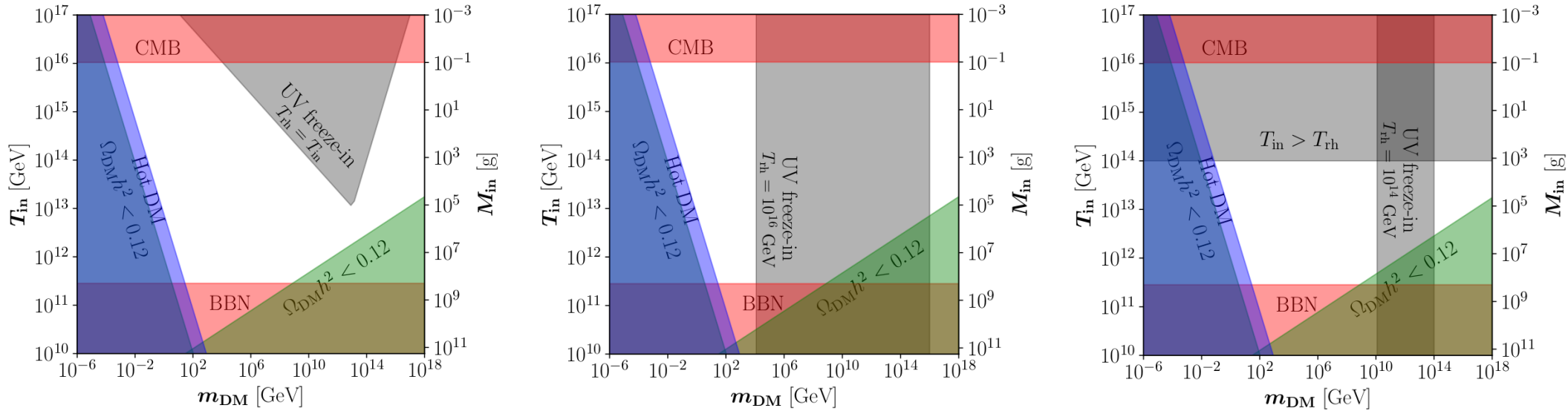
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# Gravitational DM: PBHs & UV Freeze-in



Gravitational UV freeze-in strongly constrains super heavy DM radiated by PBHs!