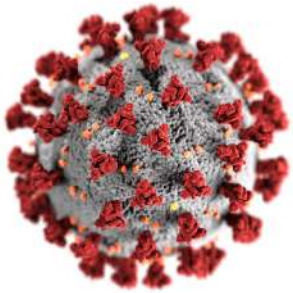
Gravitational Dark Matter: Primordial Black Holes and UV Freeze-in

Based on:
NB, Maíra Dutra, Yann Mambrini, Keith Olive, Marco Peloso & Mathias Pierre - arXiv:1803.01866
NB & Óscar Zapata - arXiv:2010.09725, 2011.02510, 2011.12306

Nicolás BERNAL

UAN UNIVERSIDAD ANTONIO NARIÑO



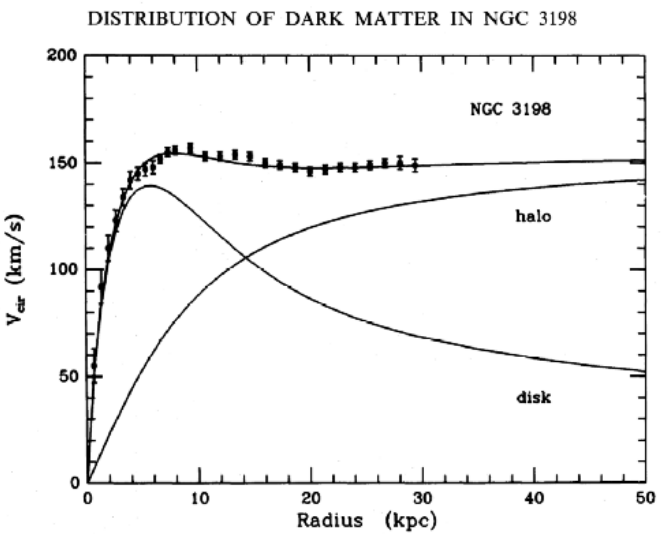
3rd South American Dark Matter Workshop
December 2-4, 2020

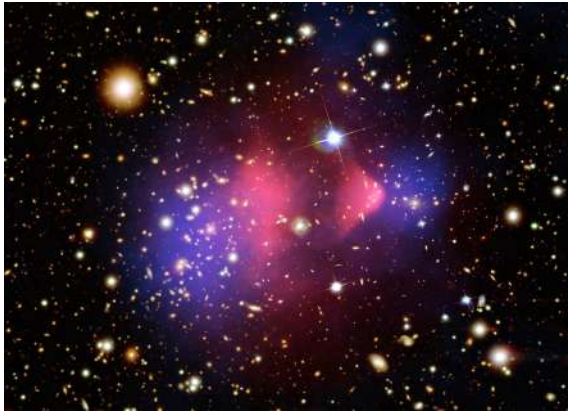
El conocimiento es de todos
Minciencias

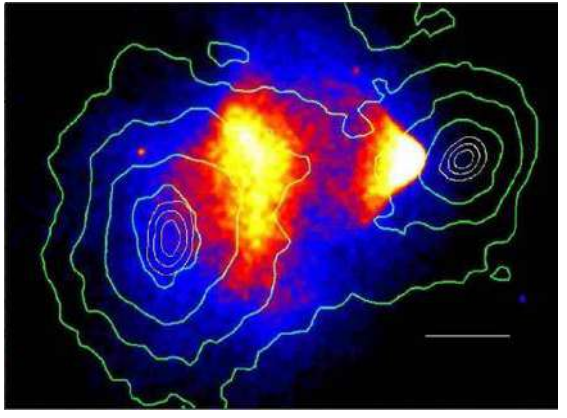
Evidences for Dark Matter

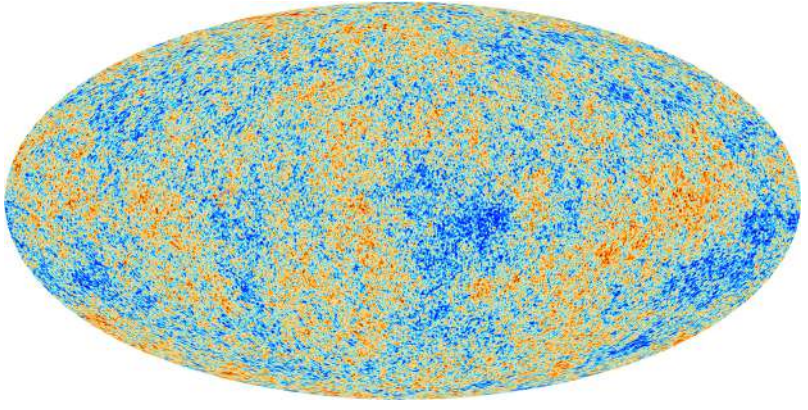
Several observations indicate the existence of non-luminous Dark Matter (missing *gravitational* force) at very different scales!

* Galactic rotation curves
* RC in Clusters of galaxies
* Clusters of galaxies
* CMB anisotropies









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

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

DM is *unavoidably* produced by PBH Hawking evaporation!

Primordial Black Holes

Talks by C. Unal B. Kavanagh

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

Primordial Black Holes

Talks by C. Unal B. Kavanagh

* Density fluctuations can collapse into a PBH in the early universe

* Lose mass by emitting *all* particles via Hawking evaporation
  → have a ~black body spectrum, with temperature $T_{BH} \sim 1/M_{BH}$
  → unavoidable radiate DM!

* If $M_{in} < 10^9$ g, PBHs completely evaporate before BBN
  → poorly constrain

Effective theory: <u>Two free parameters</u>

* A single PBH characterized by its mass at formation $\boldsymbol{M_{in}}$
  (or equivalently, by the SM temperature T_{in} at formation)

* Initial PBH energy density $\boldsymbol{\beta} = \rho_{BH}/\rho_{SM}$

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!

$$N_j = \frac{15\,\zeta(3)}{\pi^4}\frac{g_j\,\mathcal{C}_n}{g_\star(T_{\rm BH})}\begin{cases}\left(\frac{M_{\rm in}}{M_P}\right)^2 & \text{for} \quad m_j \leq T_{\rm BH}^{\rm in} \\ \left(\frac{M_P}{m_j}\right)^2 & \text{for} \quad m_j \geq T_{\rm BH}^{\rm in}\end{cases}$$

DM from PBHs

DM density = PBH density x # DM emitted per PBH

Number of DM particles radiated per PBH.

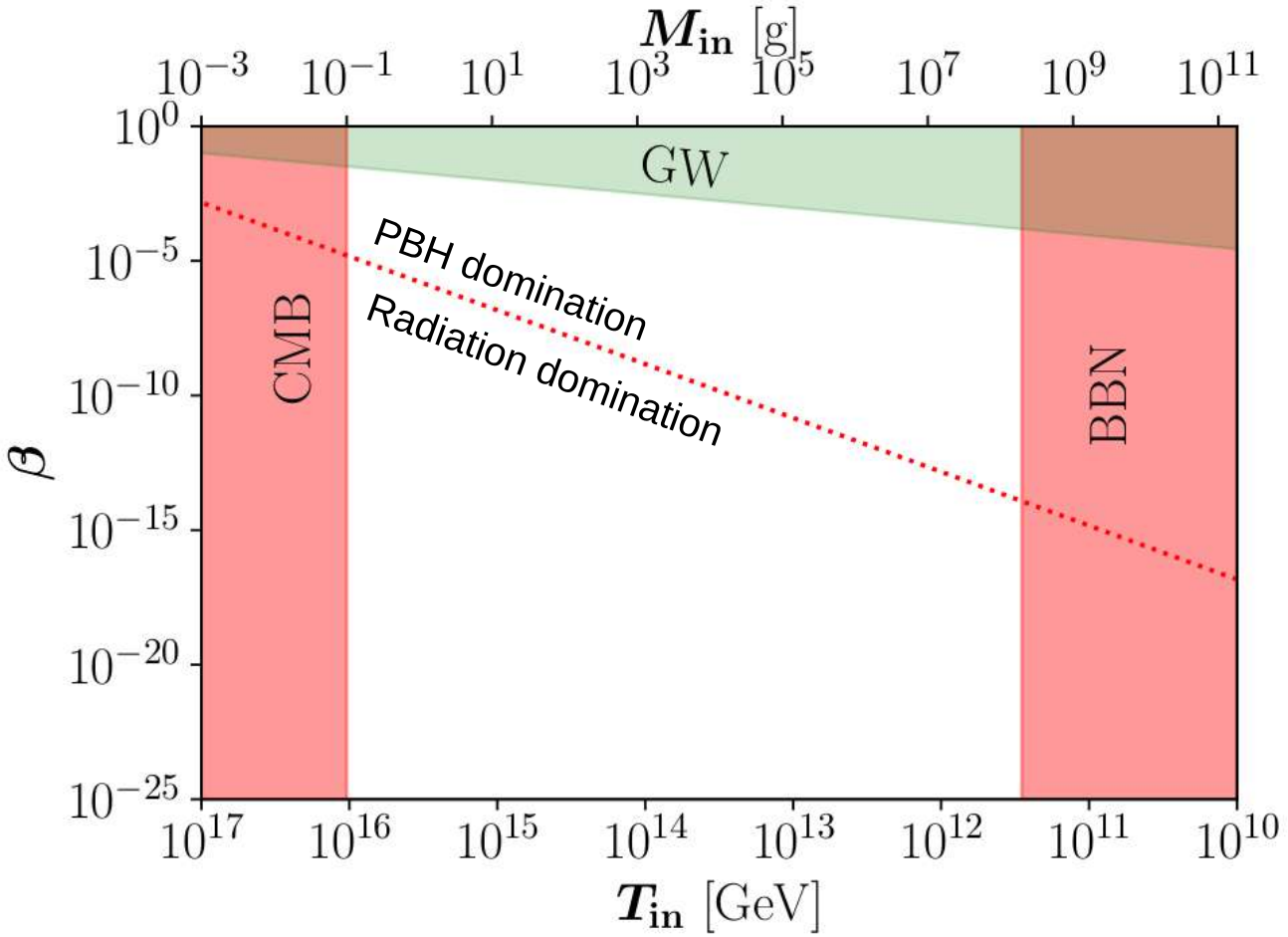
→ Only depends on initial PBH mass!

$$N_j = \frac{15\,\zeta(3)}{\pi^4}\frac{g_j\,\mathcal{C}_n}{g_\star(T_{\rm BH})}\begin{cases}\left(\frac{M_{\rm in}}{M_P}\right)^2 & \text{for} \quad m_j \leq T_{\rm BH}^{\rm in} \\ \left(\frac{M_P}{m_j}\right)^2 & \text{for} \quad m_j \geq T_{\rm BH}^{\rm in}\end{cases}$$

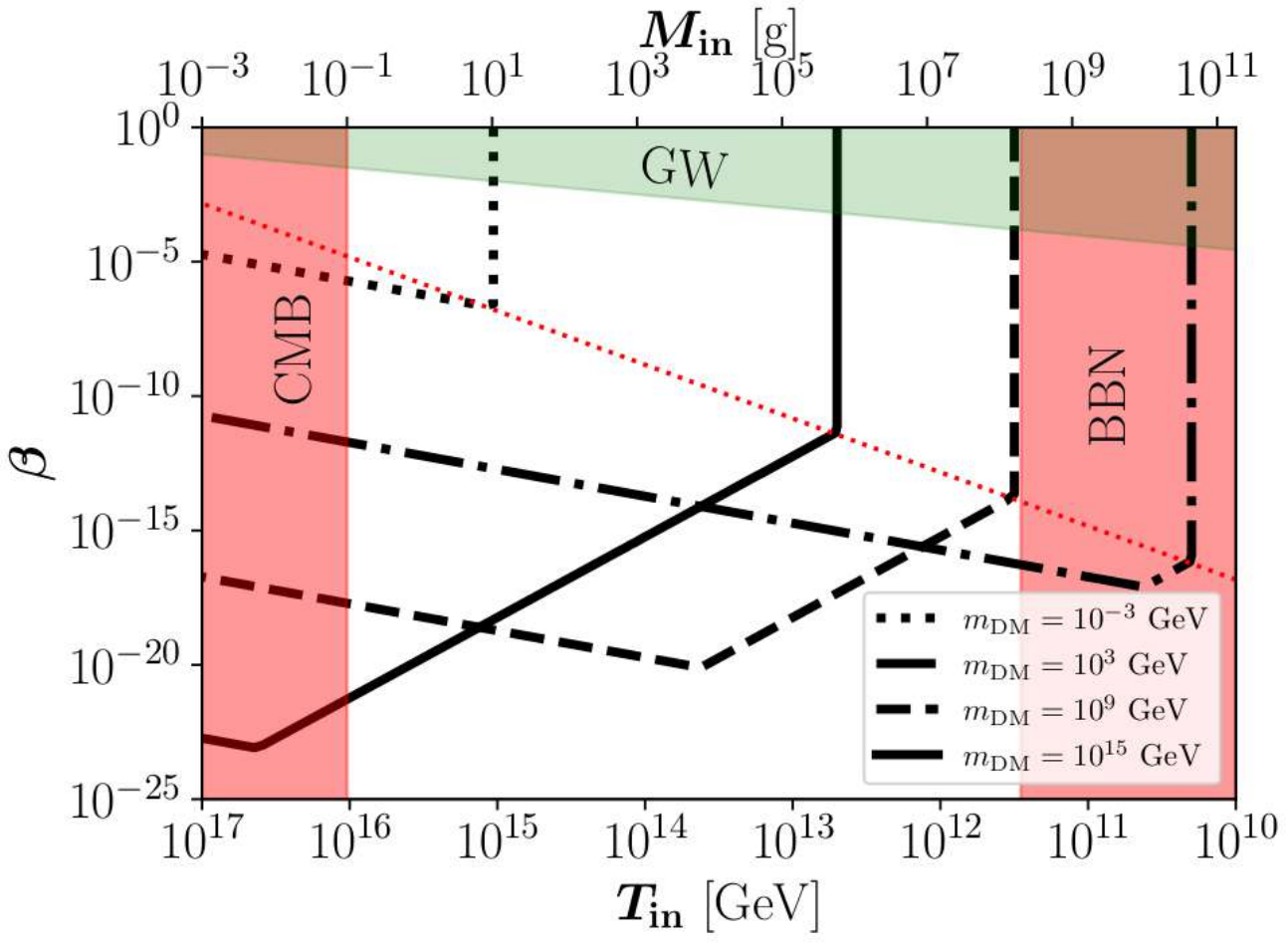
As PBH scale like non-relativistic matter,
they can dominate the total energy density of the universe

→ Nonstandard expansion!

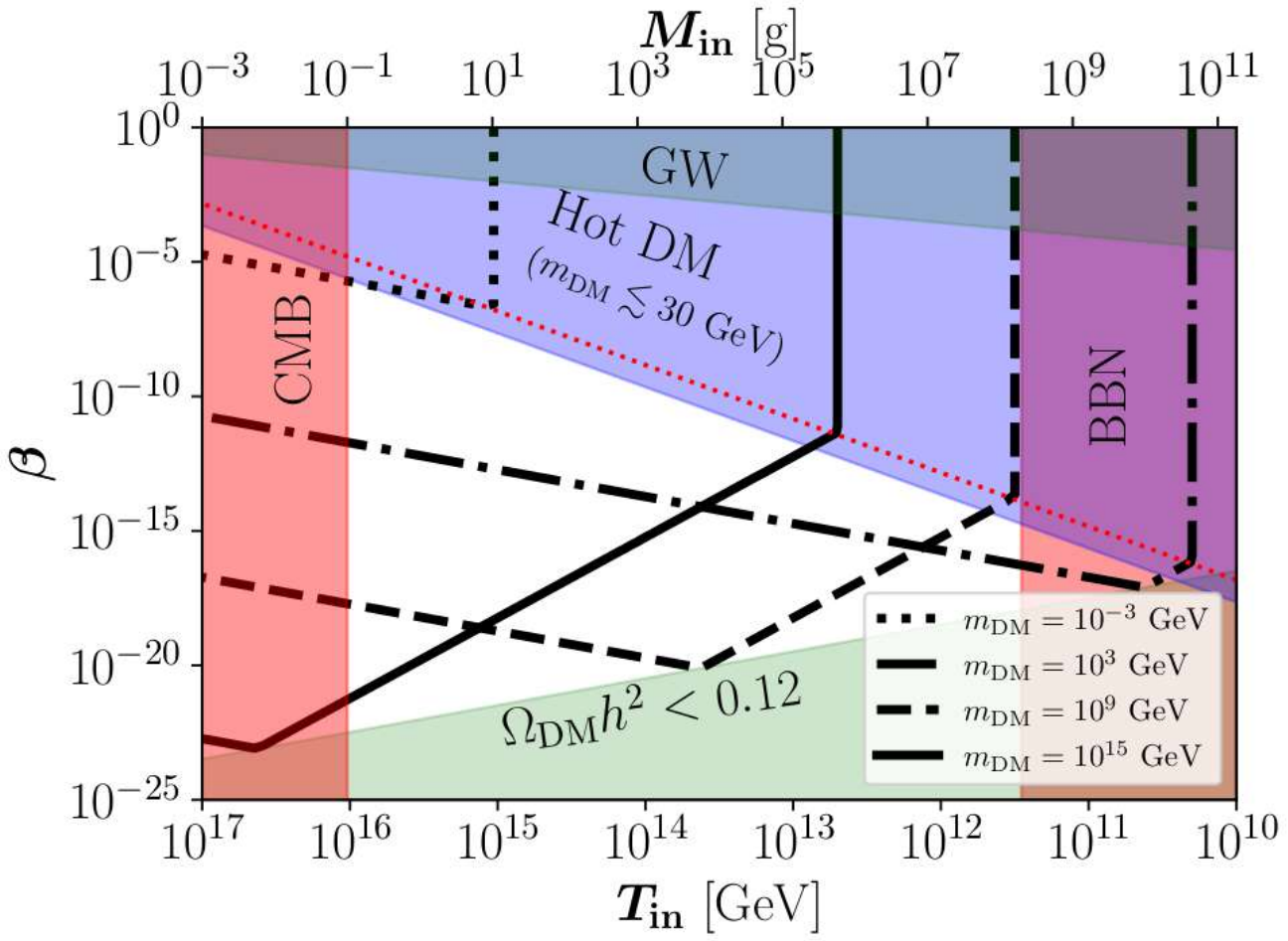
DM from PBHs


$M_{\rm in}$ [g]
10^{-3} 10^{-1} 10^{1} 10^{3} 10^{5} 10^{7} 10^{9} 10^{11}
10^{0}
10^{-5}
10^{-10}
10^{-15}
10^{-20}
10^{-25}
β
GW
CMB
BBN
PBH domination
Radiation domination
10^{17} 10^{16} 10^{15} 10^{14} 10^{13} 10^{12} 10^{11} 10^{10}
$T_{\rm in}$ [GeV]

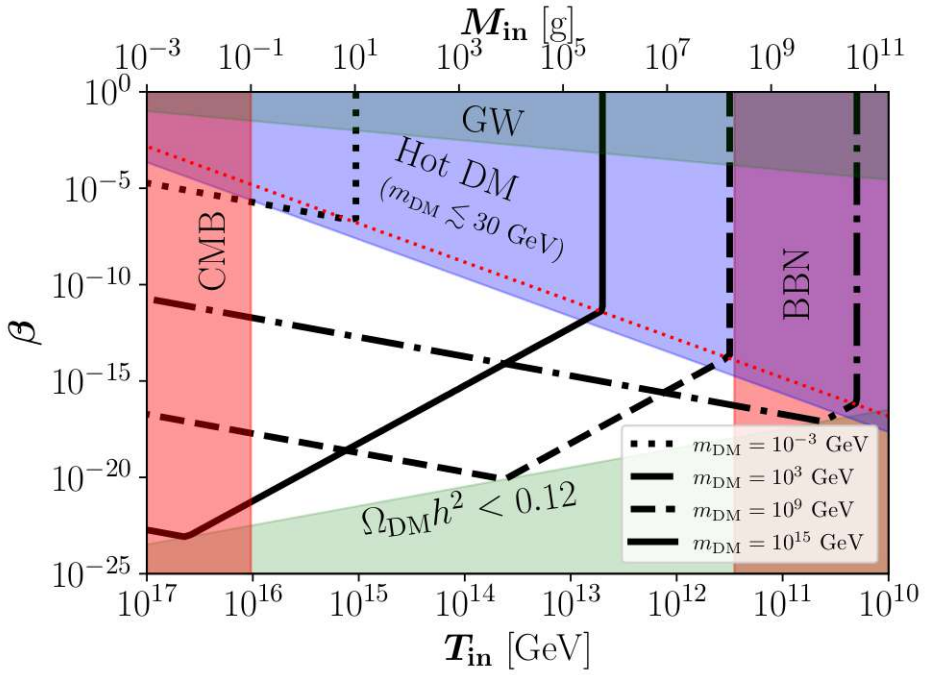
DM from PBHs


$M_{\rm in}$ [g]
10^{-3}
10^{-1}
10^{1}
10^{3}
10^{5}
10^{7}
10^{9}
10^{11}
10^{0}
10^{-5}
10^{-10}
10^{-15}
10^{-20}
10^{-25}
β
GW
CMB
BBN
$m_{\rm DM} = 10^{-3}$ GeV
$m_{\rm DM} = 10^{3}$ GeV
$m_{\rm DM} = 10^{9}$ GeV
$m_{\rm DM} = 10^{15}$ GeV
10^{17}
10^{16}
10^{15}
10^{14}
10^{13}
10^{12}
10^{11}
10^{10}
$T_{\rm in}$ [GeV]

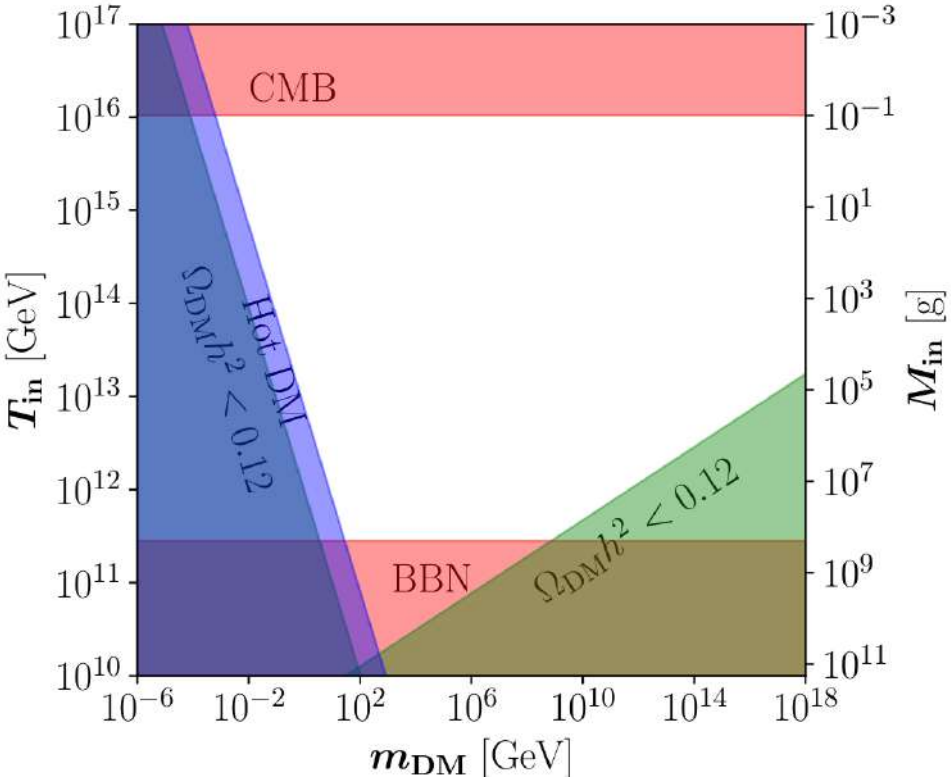
DM from PBHs


$M_{\rm in}$ [g]
10^{-3} 10^{-1} 10^{1} 10^{3} 10^{5} 10^{7} 10^{9} 10^{11}
10^{0} 10^{-5} 10^{-10} 10^{-15} 10^{-20} 10^{-25}
β
GW
Hot DM
($m_{\rm DM} \lesssim 30$ GeV)
CMB
BBN
$\Omega_{\rm DM}h^2 < 0.12$
$m_{\rm DM} = 10^{-3}$ GeV
$m_{\rm DM} = 10^{3}$ GeV
$m_{\rm DM} = 10^{9}$ GeV
$m_{\rm DM} = 10^{15}$ GeV
10^{17} 10^{16} 10^{15} 10^{14} 10^{13} 10^{12} 10^{11} 10^{10}
$T_{\rm in}$ [GeV]

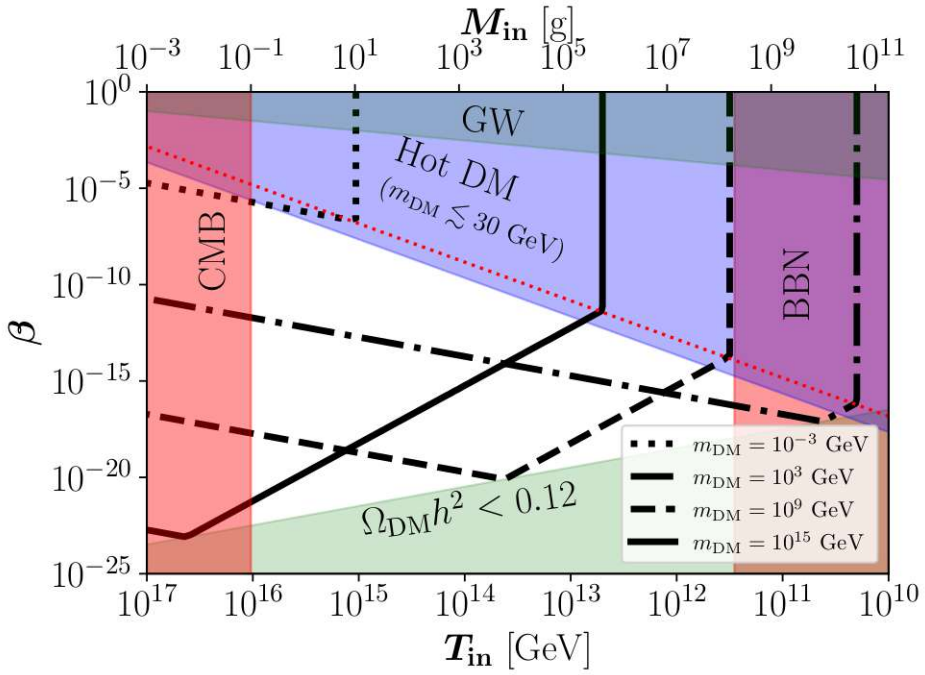
DM from PBHs


$M_{\rm in}$ [g]
10^{-3} 10^{-1} 10^{1} 10^{3} 10^{5} 10^{7} 10^{9} 10^{11}
10^{0} 10^{-5} 10^{-10} 10^{-15} 10^{-20} 10^{-25}
β
GW
Hot DM
($m_{\rm DM} \lesssim 30$ GeV)
CMB
BBN
$m_{\rm DM} = 10^{-3}$ GeV
$m_{\rm DM} = 10^{3}$ GeV
$m_{\rm DM} = 10^{9}$ GeV
$m_{\rm DM} = 10^{15}$ GeV
$\Omega_{\rm DM}h^2 < 0.12$
10^{17} 10^{16} 10^{15} 10^{14} 10^{13} 10^{12} 10^{11} 10^{10}
$T_{\rm in}$ [GeV]

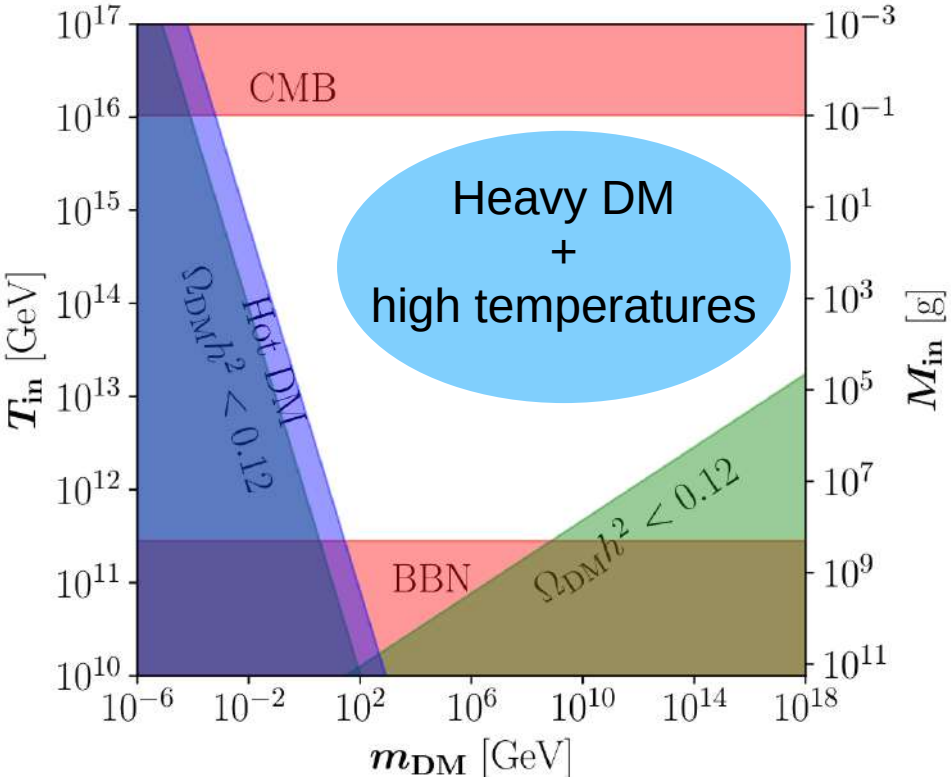
=


10^{17} 10^{16} 10^{15} 10^{14} 10^{13} 10^{12} 10^{11} 10^{10}
$T_{\rm in}$ [GeV]
10^{-3} 10^{-1} 10^{1} 10^{3} 10^{5} 10^{7} 10^{9} 10^{11}
$M_{\rm in}$ [g]
CMB
Hot DM
$\Omega_{\rm DM}h^2 < 0.12$
BBN
$\Omega_{\rm DM}h^2 < 0.12$
10^{-6} 10^{-2} 10^{2} 10^{6} 10^{10} 10^{14} 10^{18}
$m_{\rm DM}$ [GeV]

DM from PBHs


$M_{\rm in}$ [g]
10^{-3} 10^{-1} 10^{1} 10^{3} 10^{5} 10^{7} 10^{9} 10^{11}
10^{0} 10^{-5} 10^{-10} 10^{-15} 10^{-20} 10^{-25}
β
GW
Hot DM
($m_{\rm DM} \lesssim 30$ GeV)
CMB
BBN
$\Omega_{\rm DM}h^2 < 0.12$
$m_{\rm DM} = 10^{-3}$ GeV
$m_{\rm DM} = 10^{3}$ GeV
$m_{\rm DM} = 10^{9}$ GeV
$m_{\rm DM} = 10^{15}$ GeV
10^{17} 10^{16} 10^{15} 10^{14} 10^{13} 10^{12} 10^{11} 10^{10}
$T_{\rm in}$ [GeV]

=


10^{17} 10^{16} 10^{15} 10^{14} 10^{13} 10^{12} 10^{11} 10^{10}
$T_{\rm in}$ [GeV]
10^{-3} 10^{-1} 10^{1} 10^{3} 10^{5} 10^{7} 10^{9} 10^{11}
$M_{\rm in}$ [g]
CMB
Heavy DM
+
high temperatures
Hot DM
$\Omega_{\rm DM}h^2 < 0.12$
BBN
$\Omega_{\rm DM}h^2 < 0.12$
10^{-6} 10^{-2} 10^{2} 10^{6} 10^{10} 10^{14} 10^{18}
$m_{\rm DM}$ [GeV]

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

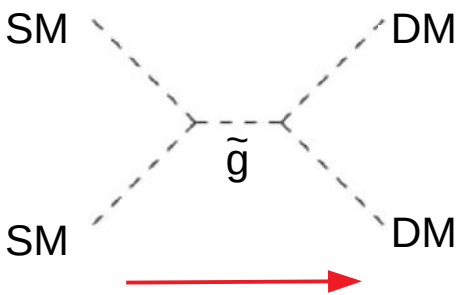
DM is *unavoidably* produced by PBH Hawking evaporation

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

DM is *unavoidably* produced by PBH Hawking evaporation and gravitational UV freeze-in!

Gravitational UV Freeze-in

An example of UV FIMP, mediated by massless SM gravitons

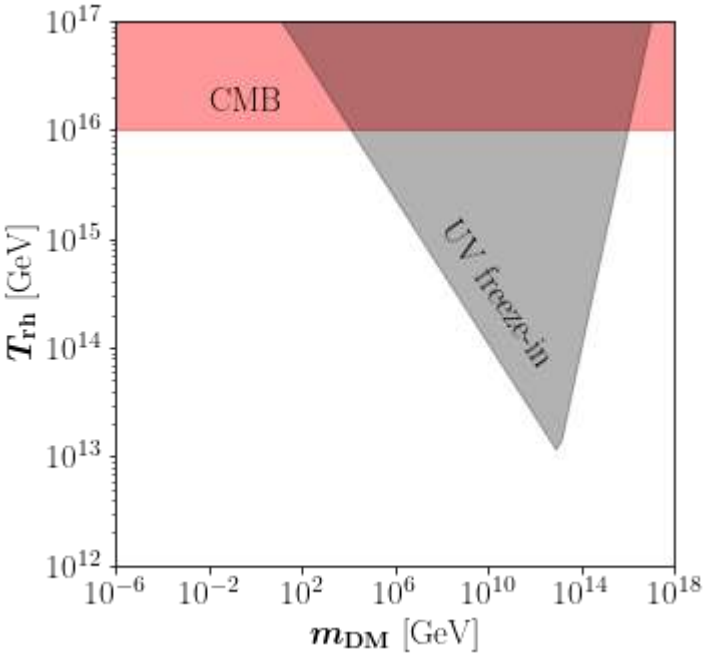


Depends on:

* DM mass and spin
* Reheating temperature T_{rh}

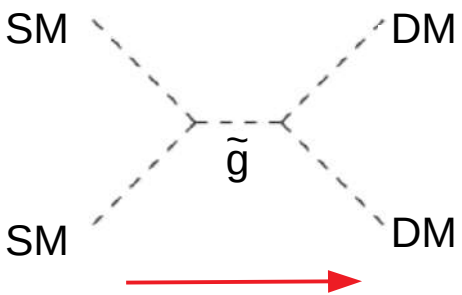
→ No free couplings: M_P

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



Gravitational UV Freeze-in

An example of UV FIMP, mediated by massless SM gravitons

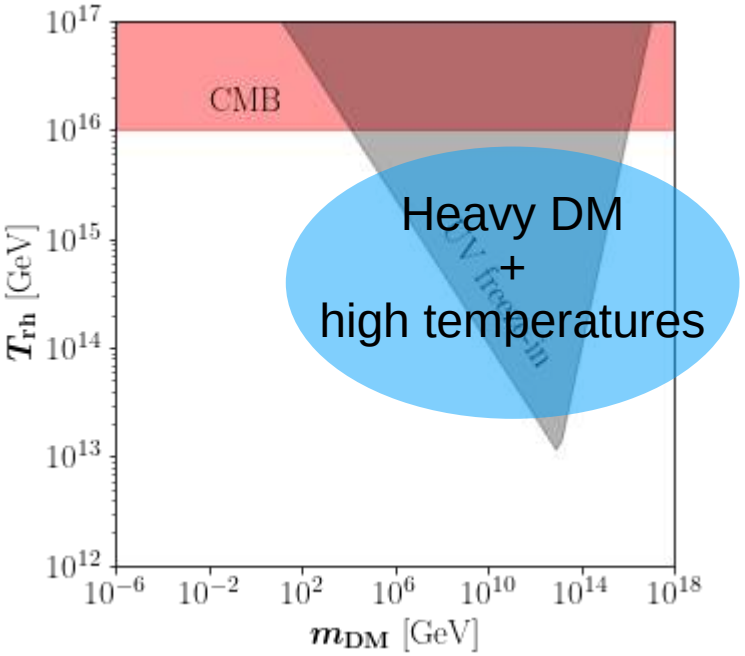


Depends on:

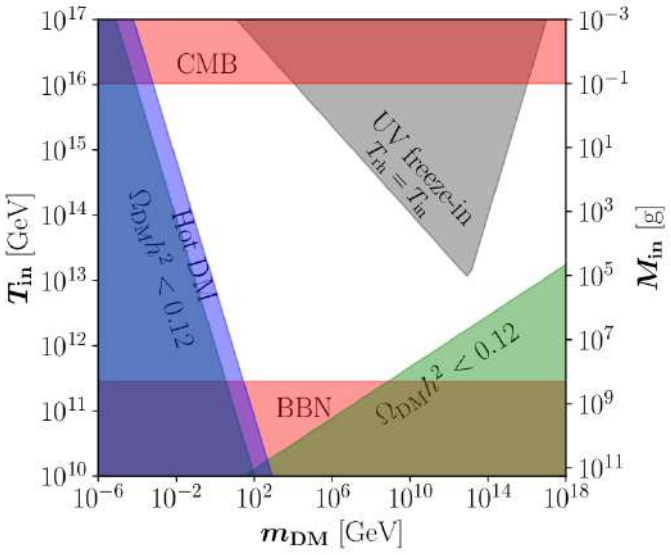
* DM mass and spin
* Reheating temperature T_{rh}

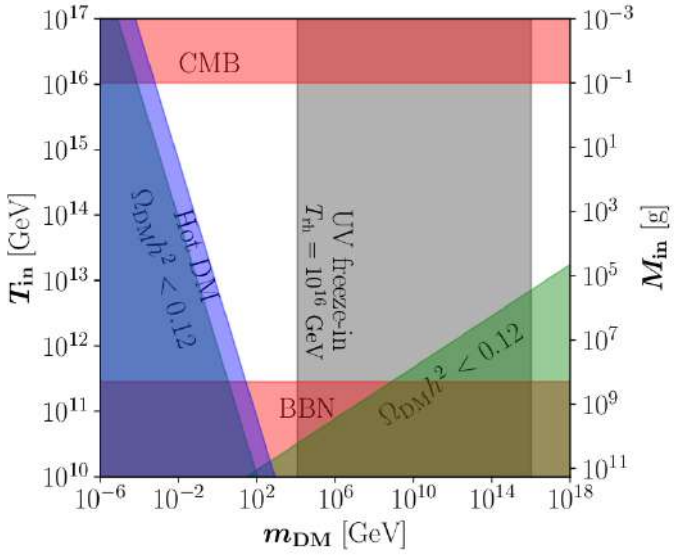
→ No free couplings: M_P

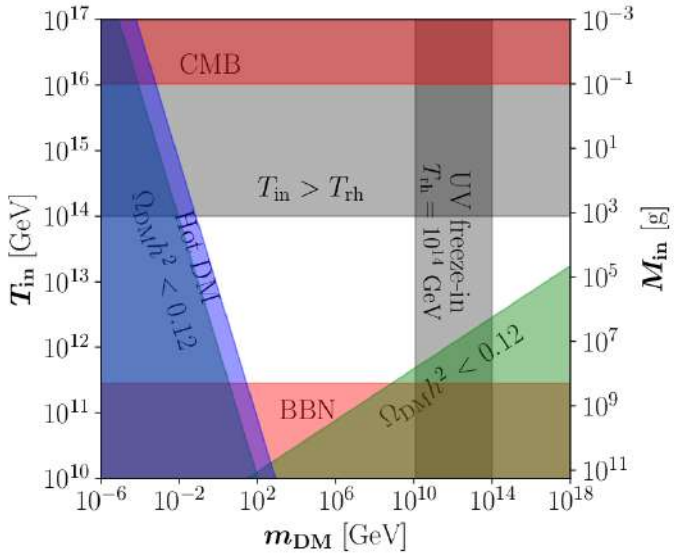
$\Omega h^2 \sim m\,(T_{rh}/M_P)^3$



Gravitational DM: PBHs & UV Freeze-in







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

Conclusions

- It’s possible that DM *only* features *gravitational* interactions
- PBH could Hawing radiate the *whole* DM density
- PBHs formed in the early universe
- 0.1 g < $M_{\rm in}$ < 10^9 g evaporate before BBN
- DM masses: 1 MeV < $m_{\rm DM}$ < 10^{18} GeV
  SM temperature at formation: 10^{12} GeV < $T_{\rm in}$ < 10^{16} GeV
- Gravitational UV freeze-in is effective in the same ballpark
- **Interplay between PBH and UV freeze-in production sets strong bounds to super heavy DM**
- **Gravitational DM production is unavoidable!**
- Test: baryogenesis, isocurvature, gravitational waves, non-Gaussianity...

Talks by: M. Fairbairn, C. Unal, B. Kavanagh

¡Muchas gracias!

Nicolás BERNAL @ UAN