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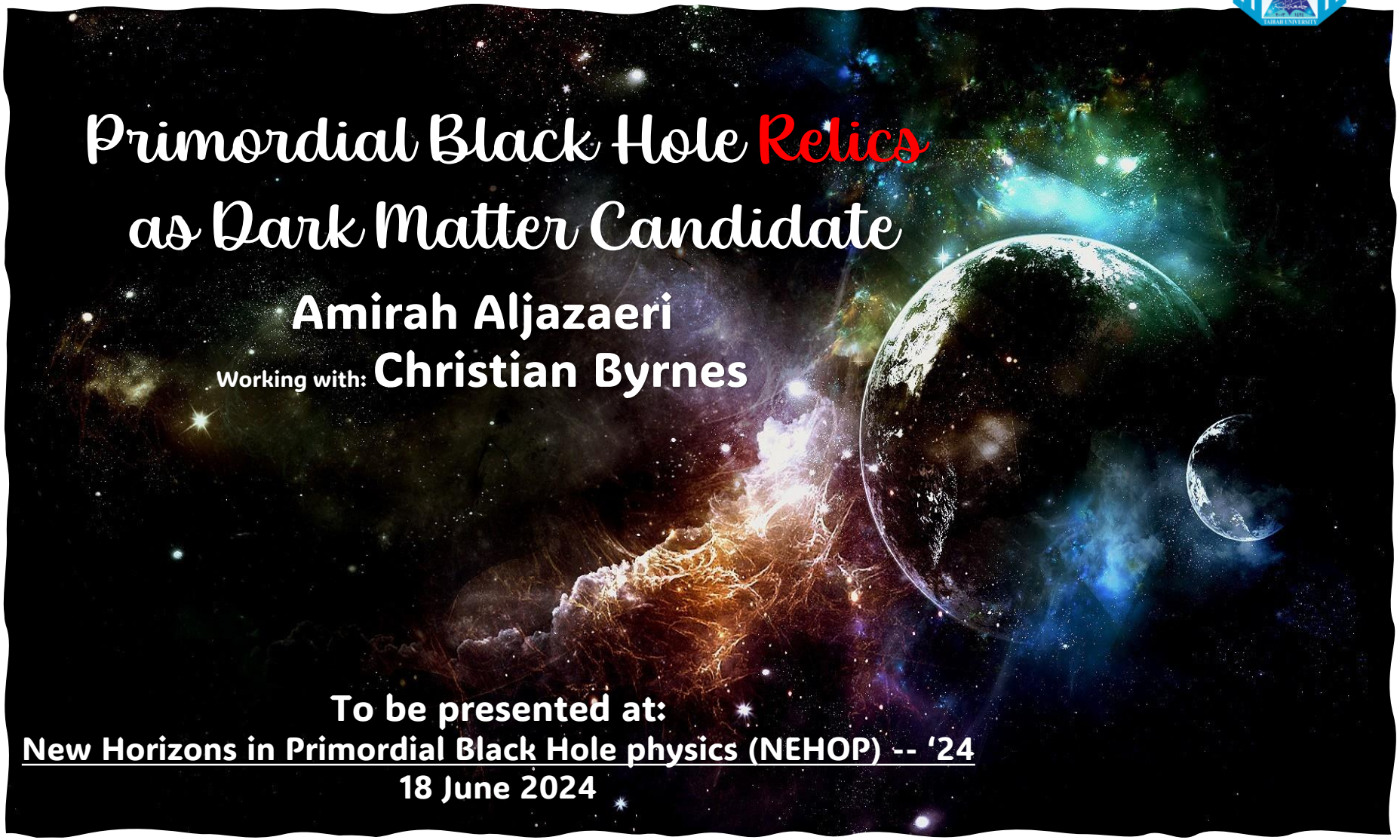

Primordial Black Hole Relics as Dark Matter Candidate

Amirah Aljazaeri

Working with: **Christian Byrnes**

To be presented at:

New Horizons in Primordial Black Hole physics (NEHOP) -- '24

18 June 2024

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PBH lifetime and evaporation

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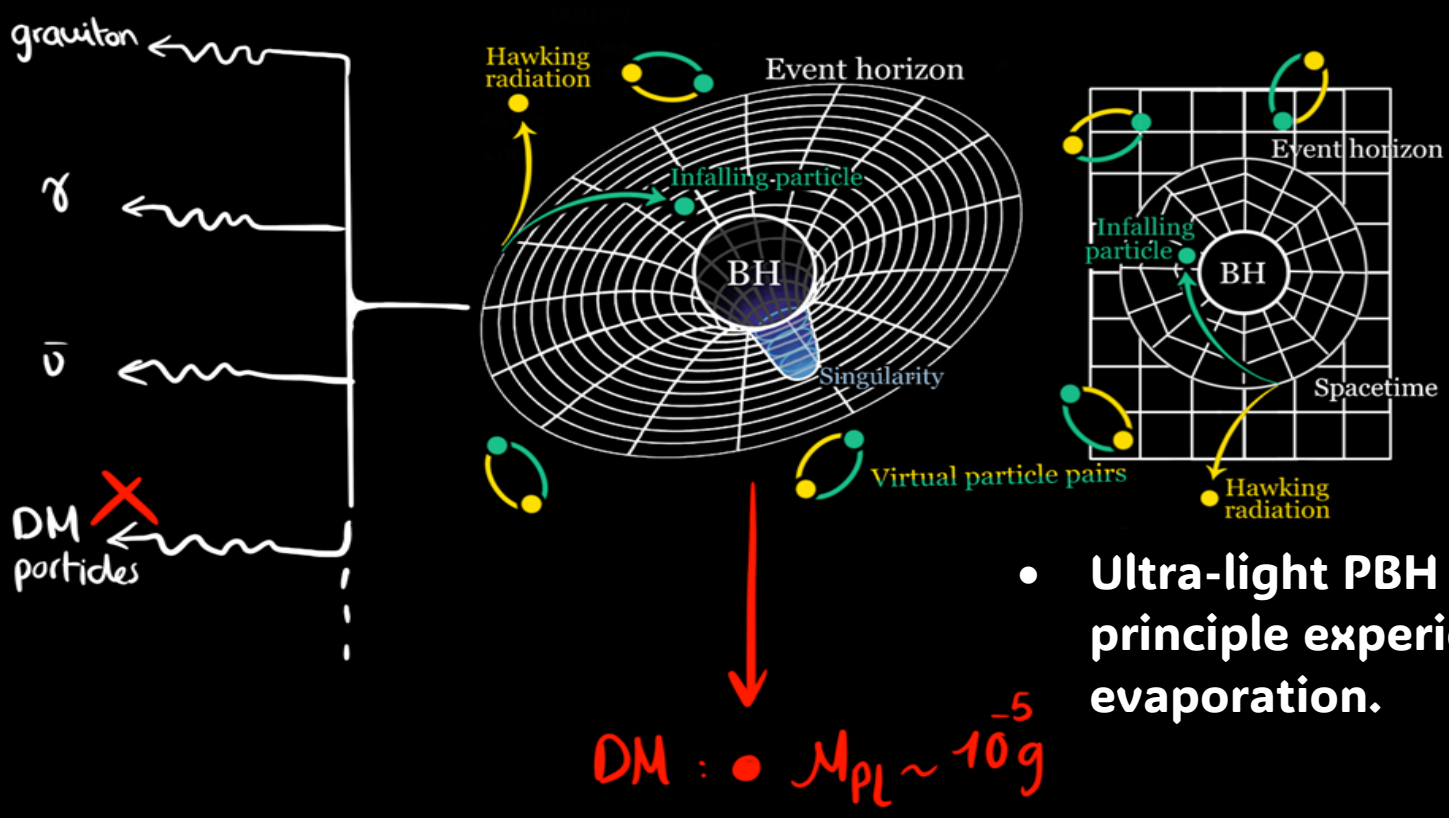

- **Ultra-light PBH could in principle experience Hawking evaporation.**
- **You could define DM in many way, but I'll be focusing on relics.**

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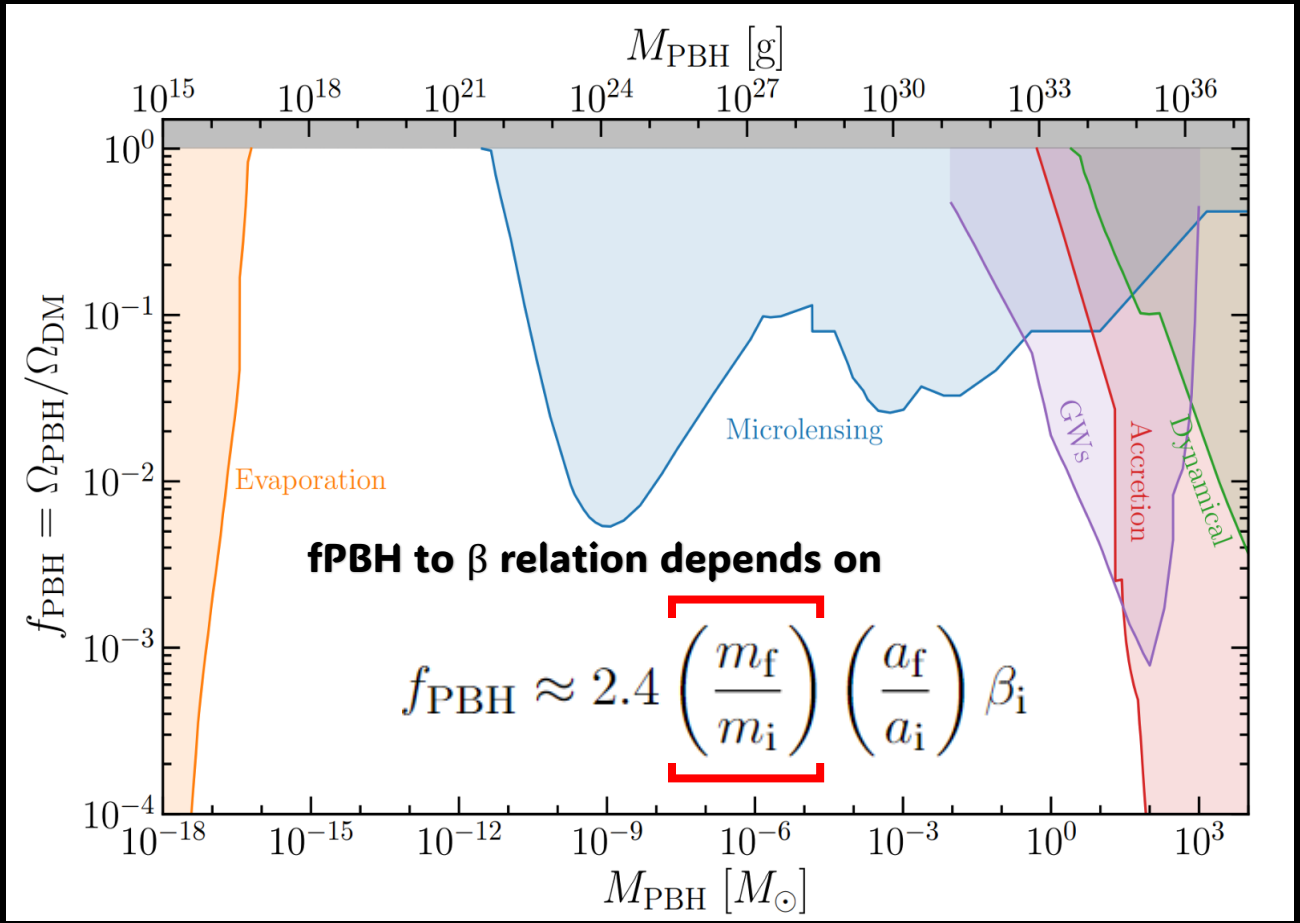
The fraction of DM as PBHs: f_{PBH}



- The attempt to have a better understanding of the meaning of fPBH
- If a PBH vanished (mf = 0).
- Motivate the need for relics.

Green, Anne M., and Bradley J. Kavanagh. Nuclear and Particle Physics 48.4 (2021): 043001.

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Introducing ePBH domination era

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PBH domination era.

- One can assume that universe formerly experienced an early matter-dominated epoch in which PBHs predominated after the standard RD.
- This is not a constraint on β but rather a limit.
- Why such an era is interesting?

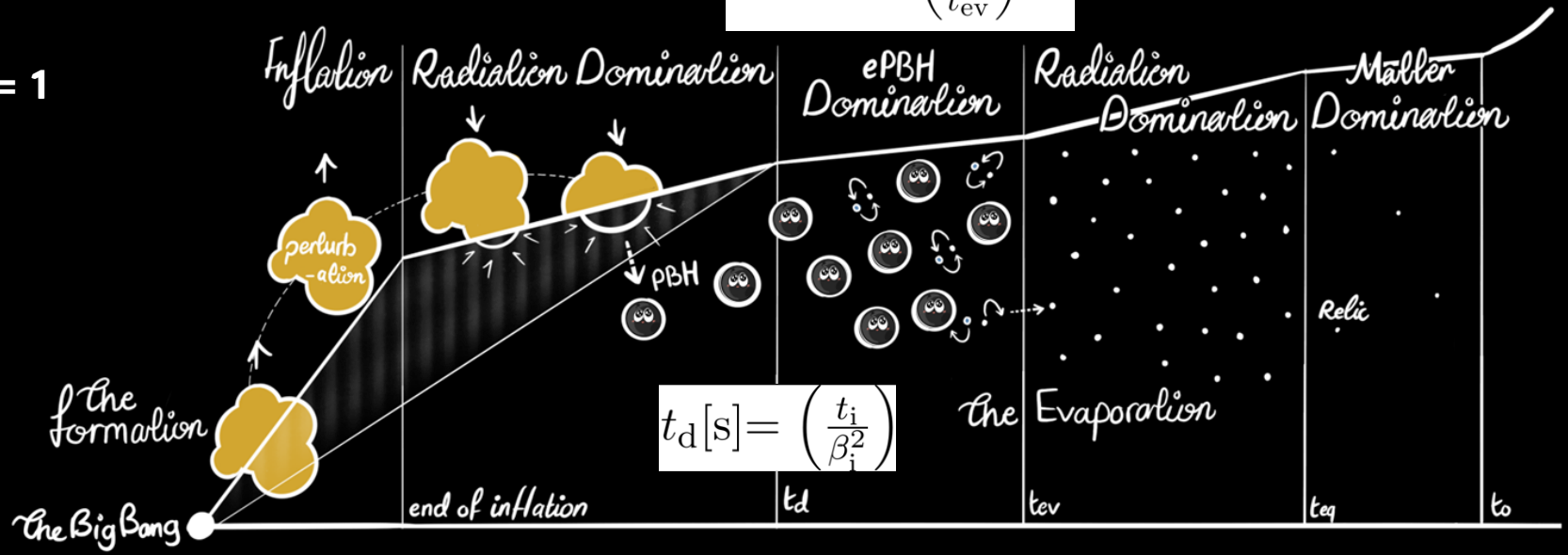
E.g.

Papanikolaou, T., Vennin, V., & Langlois, D. (2021). Gravitational waves from a universe filled with primordial black holes. 2021(03), 053

Dan Hooper's talk from yesterday

$$\beta_{\rm i} > \beta_{\rm cri} = \left(\frac{t_{\rm i}}{t_{\rm ev}}\right)^{1/2}$$

→ β = 1



$$t_{\rm d}[{\rm s}] = \left(\frac{t_{\rm i}}{\beta_{\rm i}^2}\right)$$

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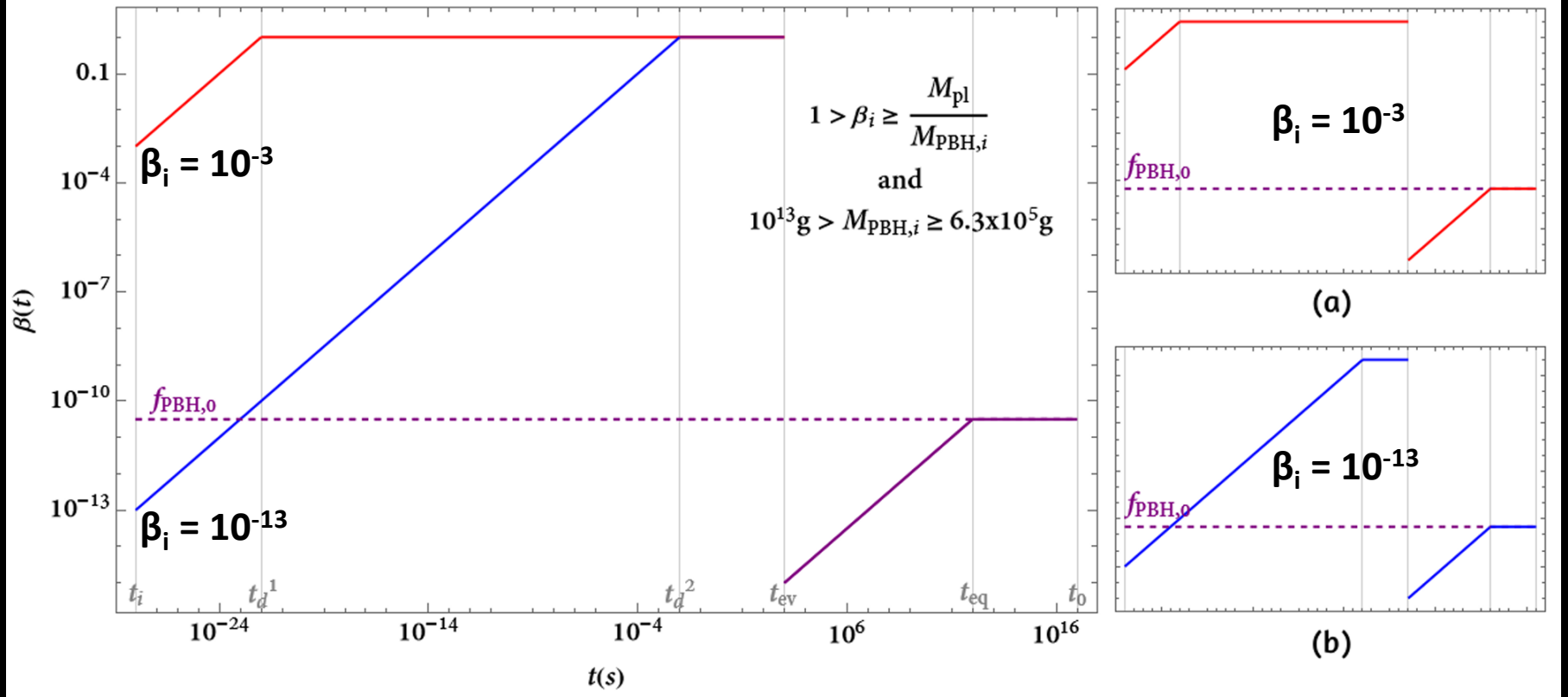
The abundance of PBHs as function of time for different β_i and same initial mass



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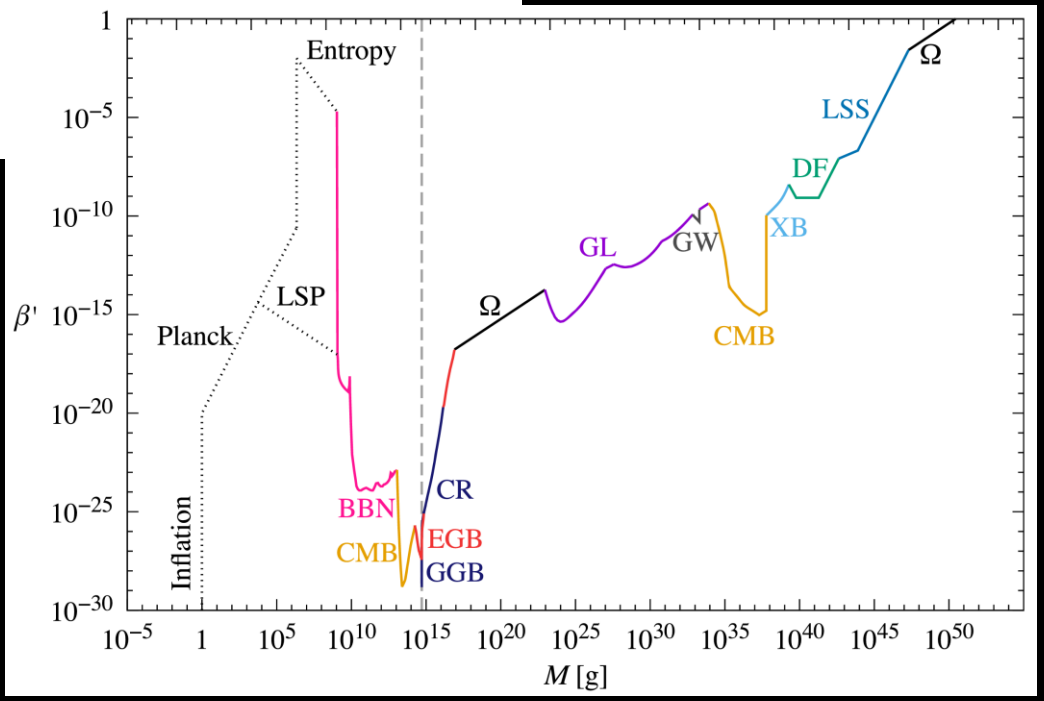
The abundance of PBHs : β

$$\beta = \left.\frac{\rho_{\rm PBH}}{\rho_{\rm tot}}\right|_{\rm form} = \frac{\rho^{\rm i}_{\rm PBH}}{\rho_r} = \frac{\rho^{\rm eq}_{\rm PBH}}{\rho^{\rm eq}_{\rm tot}}\left(\frac{a_{\rm i}}{a_{\rm eq}}\right) \approx f_{\rm PBH,0}\left(\frac{a_{\rm i}}{a_{\rm eq}}\right)$$

$$\approx 10^{-25}\left(\frac{M_{\rm PBH,i}}{\rm g}\right)^{1/2} f_{\rm PBH,0},$$



Carr, Bernard, et al. "Constraints on primordial black holes." Reports on Progress in Physics .116902 :(2021)84.11

Constraints on..

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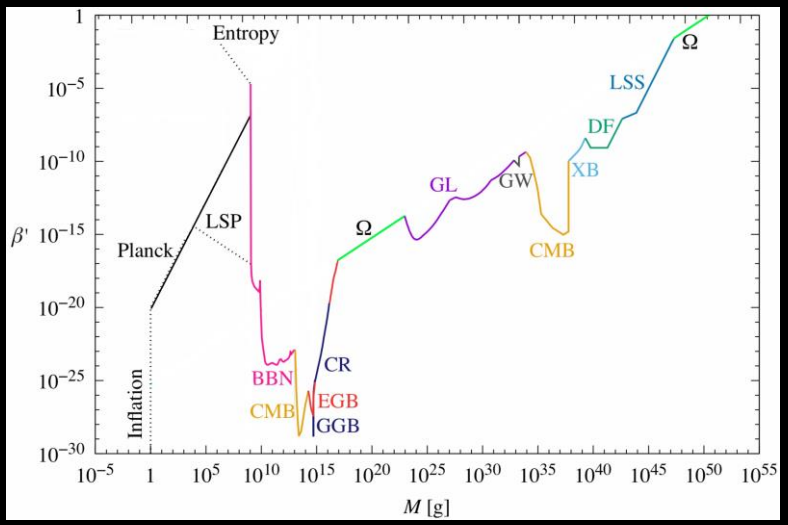
The fraction of DM as PBHs (f_{PBH}):

$$f_{\rm PBH} \approx 2.4 \left(\frac{m_{\rm f}}{m_{\rm i}}\right) \left(\frac{a_{\rm f}}{a_{\rm i}}\right) \beta_{\rm i}$$

Assuming Mpl relics:

$$f_{\rm PBH,0} \approx 2.4 \left(\frac{M_{\rm pl}}{M_{\rm PBH,i}}\right) \left(\frac{a_{\rm eq}}{a_{\rm i}}\right) \beta_{\rm i}$$

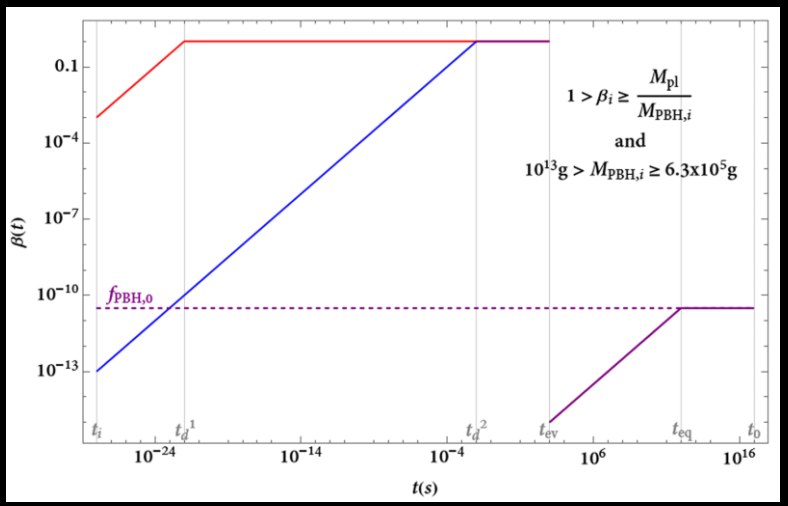


Assuming early PBH domination era:

$$f_{\rm PBH,0} = \left(\frac{M_{\rm pl}}{M_{\rm PBH,i}}\right) \left(\frac{a_{\rm d}}{a_{\rm i}}\right) \left(\frac{a_{\rm eq}}{a_{\rm ev}}\right) \beta_{\rm i}$$

$$= \left(\frac{M_{\rm pl}}{M_{\rm PBH,i}}\right) \left(\frac{a_{\rm eq}}{a_{\rm ev}}\right)$$

$$f_{\rm PBH,0} \approx 10^{14} \left(\frac{M_{\rm PBH,i}}{\rm g}\right)^{-5/2}$$



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Master Plot

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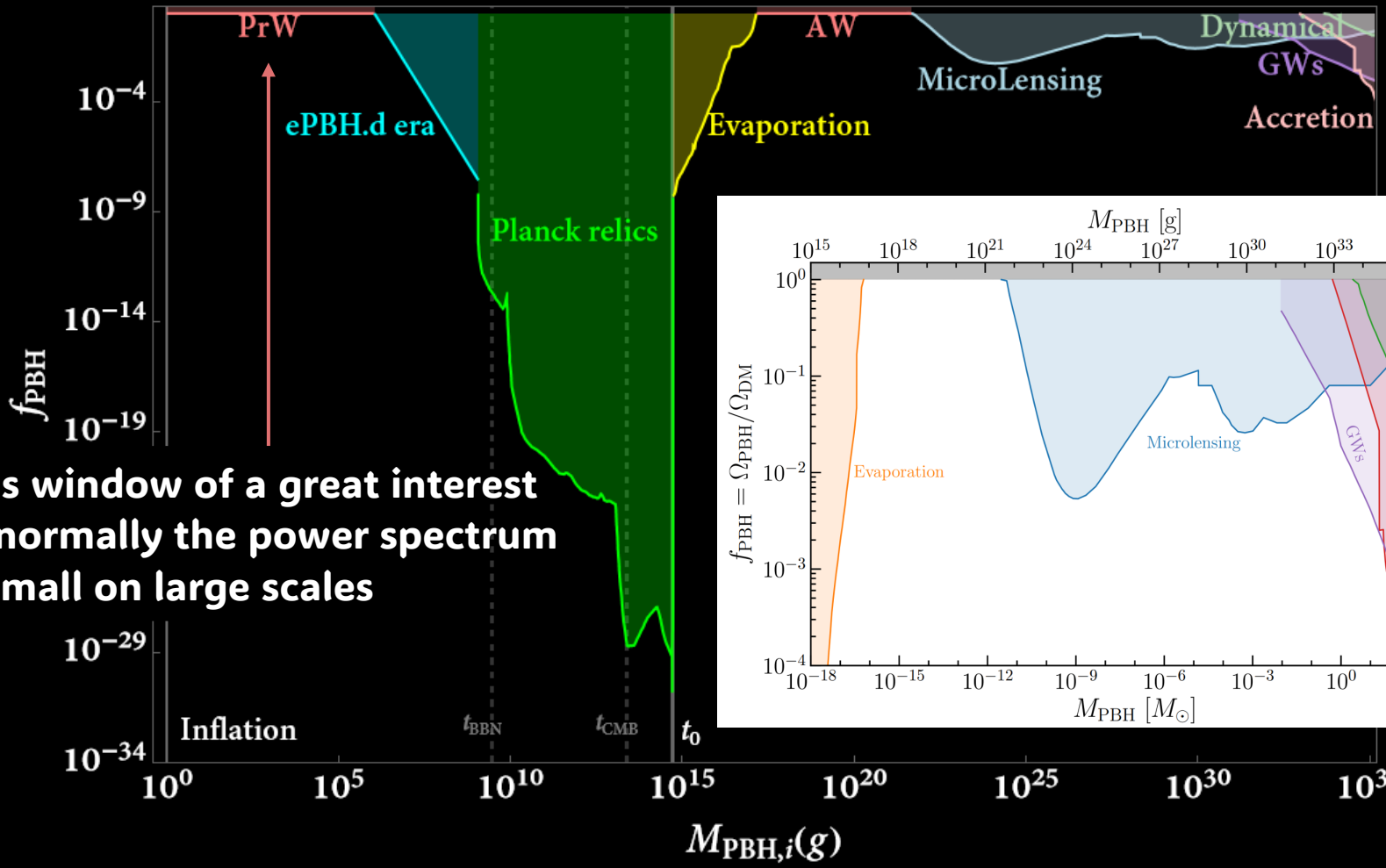
The fraction of DM as PBHs: f_{PBH}



This window of a great interest as normally the power spectrum is small on large scales

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We talked about..

- PBH evaporating into Planck mass relics:
  - Opens a unique window that explains all DM.
  - Tightens the observational constraints on β for light masses, which also applies to f_{PBH}.
  - most importantly: it provides a meaningful interpretation of fPBH at small scales.
- Although having an early PBH domination era wouldn't constrain β, it would set an additional constraint on f_{PBH} from accounting for all the DM today.
- Further discussion: Stochastic gravitational waves are the key probe when explaining how the PBH relics have formed.

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Thank you 

Diffuse emission from black hole remnants

Sina Kazemian,[1,*] Mateo Pascual,[1,†] Carlo Rovelli,[2,3,4,‡] and Francesca Vidotto[1,2,§]

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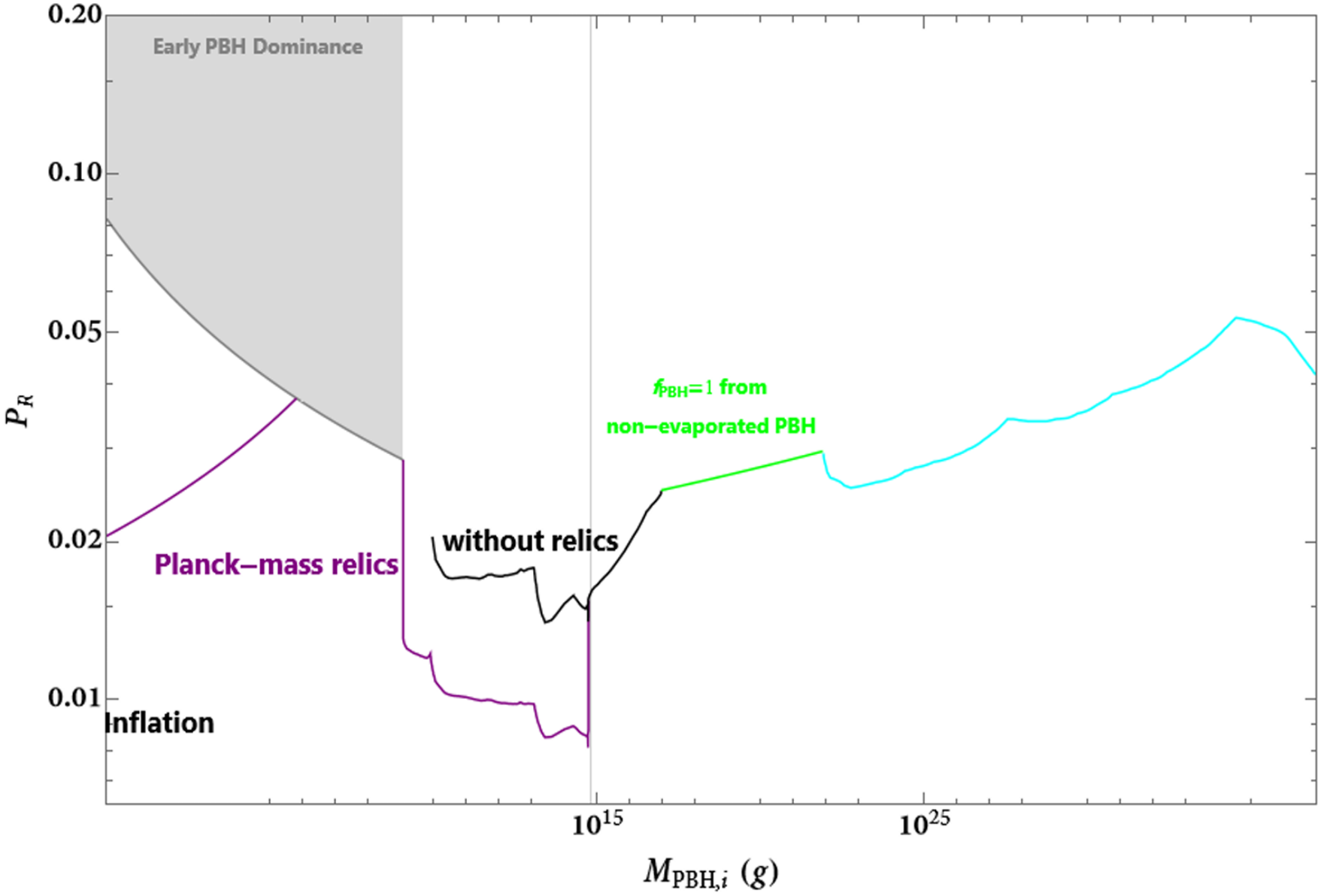
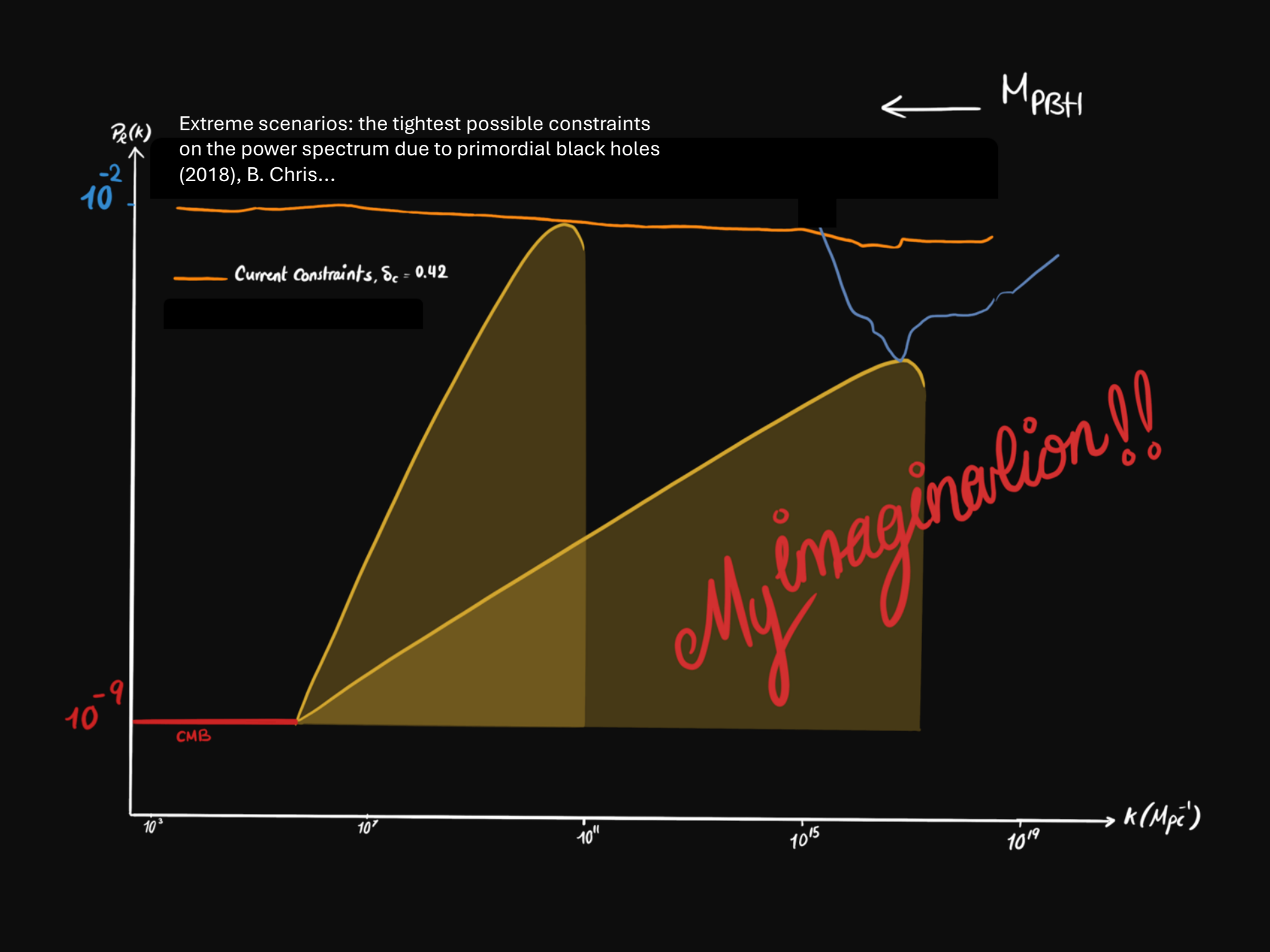
[2] *Dept. of Philosophy and Rotman Institute, Western University, N6A 3K7, London ON, Canada*
[3] *Aix Marseille University, Université de Toulon, CNRS, CPT, 13288 Marseille, France*
[4] *Perimeter Institute, 31 Caroline Street North, N2L 2Y5 Waterloo ON, Canada*

(Dated: May 5, 2023)

At the end of its evaporation, a black hole may leave a remnant where a large amount of information is stored. We argue that the existence of an area gap as predicted by Loop Quantum Gravity removes a main objection to this scenario. Remnants should radiate in the low-frequency spectrum. We model this emission and derive properties of the diffuse radiation emitted by a population of such objects. We show that the frequency and energy density of this radiation, which are measurable in principle, suffice to estimate the mass of the parent holes and the remnant density, if the age of the population is known.

Kazemian, S., Pascual, M., Rovelli, C., & Vidotto, F. (2023). Diffuse emission from black hole remnants. *Classical and Quantum Gravity*, *40*(8), 087001.


0.20
0.10
0.05
0.02
0.01
P_R
Early PBH Dominance
f_{PBH}=1 from
non−evaporated PBH
without relics
Planck−mass relics
Inflation
10^{15}
10^{25}
$M_{PBH,i}$ (g)


Extreme scenarios: the tightest possible constraints on the power spectrum due to primordial black holes (2018), B. Chris...
M_{PBH}
$P_R(k)$
10^{-2}
Current constraints, $\delta_c = 0.42$
10^{-9}
CMB
My imagination!!
10^3
10^7
10^{11}
10^{15}
10^{19}
$k\,(Mpc^{-1})$

The abundance of PBH at formation:

$$\beta = \frac{\rho_{PBH}}{\rho_{tot}}\Big|_{form}$$

until teq $\rho_{tot} \propto a^{-4}$, $\rho_{PBH} \propto a^{-3}$

$$\beta_{eq} = \frac{a_{eq}}{a_i}\beta_i = \left(\frac{M_{eq}}{M_i}\right)^{1/2}\beta_i$$

Then to relat $f_{PBH,0}$ with β_i, we need to find:

$$\beta_{eq} = \frac{\rho_{PBH}}{\rho_{tot}}\Big|_{eq} = \frac{\rho_{PBH}}{\rho_{dm}} \cdot \frac{\rho_{dm}}{\rho_{tot}}$$

$$= f_{PBH,0} \cdot \left(\frac{1}{2\left(1+\frac{\Omega_b}{\Omega_{DM}}\right)}\right)$$

$$\boxed{\frac{f_{PBH,0}}{2\left(1+\frac{\Omega_b}{\Omega_{DM}}\right)} = \left(\frac{a_{eq}}{a_i}\right)\beta_i \cdot \left(\frac{m_f}{m_i}\right)}$$

@ teq: $\frac{\rho_{dm}}{\rho_{tot}} + \frac{\rho_b}{\rho_{tot}} = \frac{1}{2}$

$$\frac{\rho_{dm}}{\rho_{tot}}\left(1+\frac{\Omega_b}{\Omega_{DM}}\right) = \frac{1}{2}$$