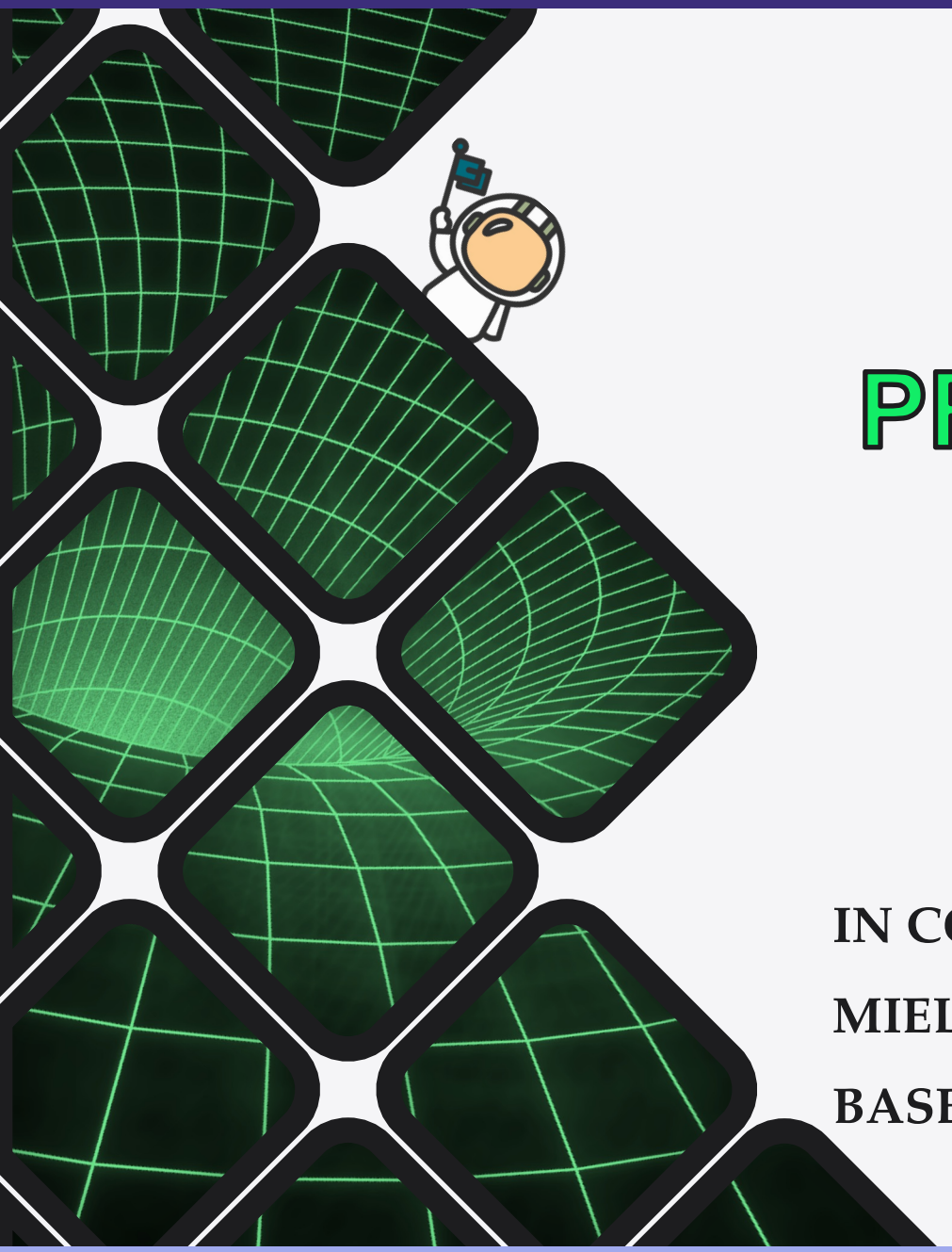


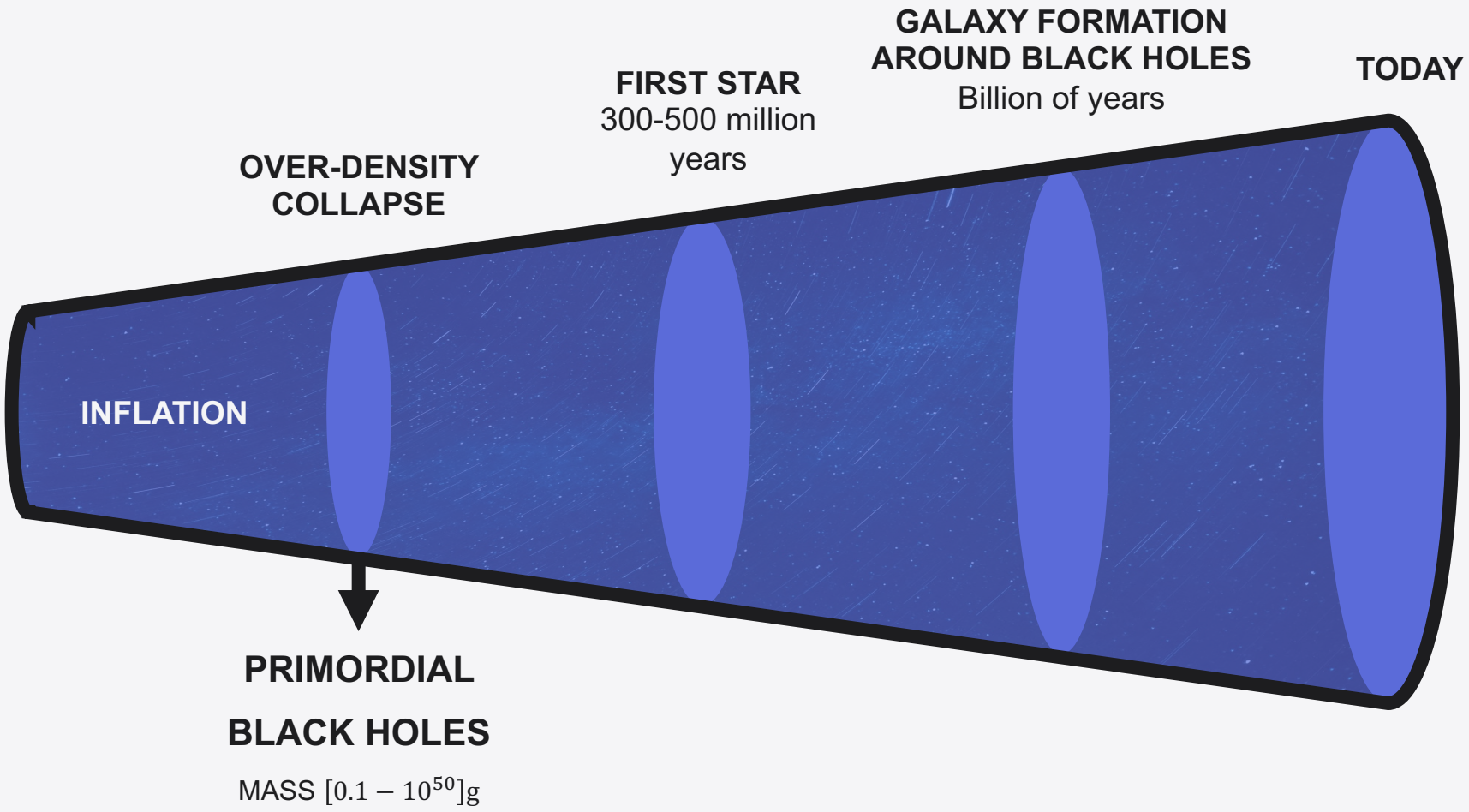
LIMITS ON LIGHT PRIMORDIAL BLACK HOLES FROM HIGH SCALE LEPTOGENESIS

IN COLLABORATION WITH: M. CHIANESE, J.W. GUNN, G. MIELE, S. MORISI, N. SAVIANO

BASED ON: PHYS. REV. D 107 (2023) 12, 123537

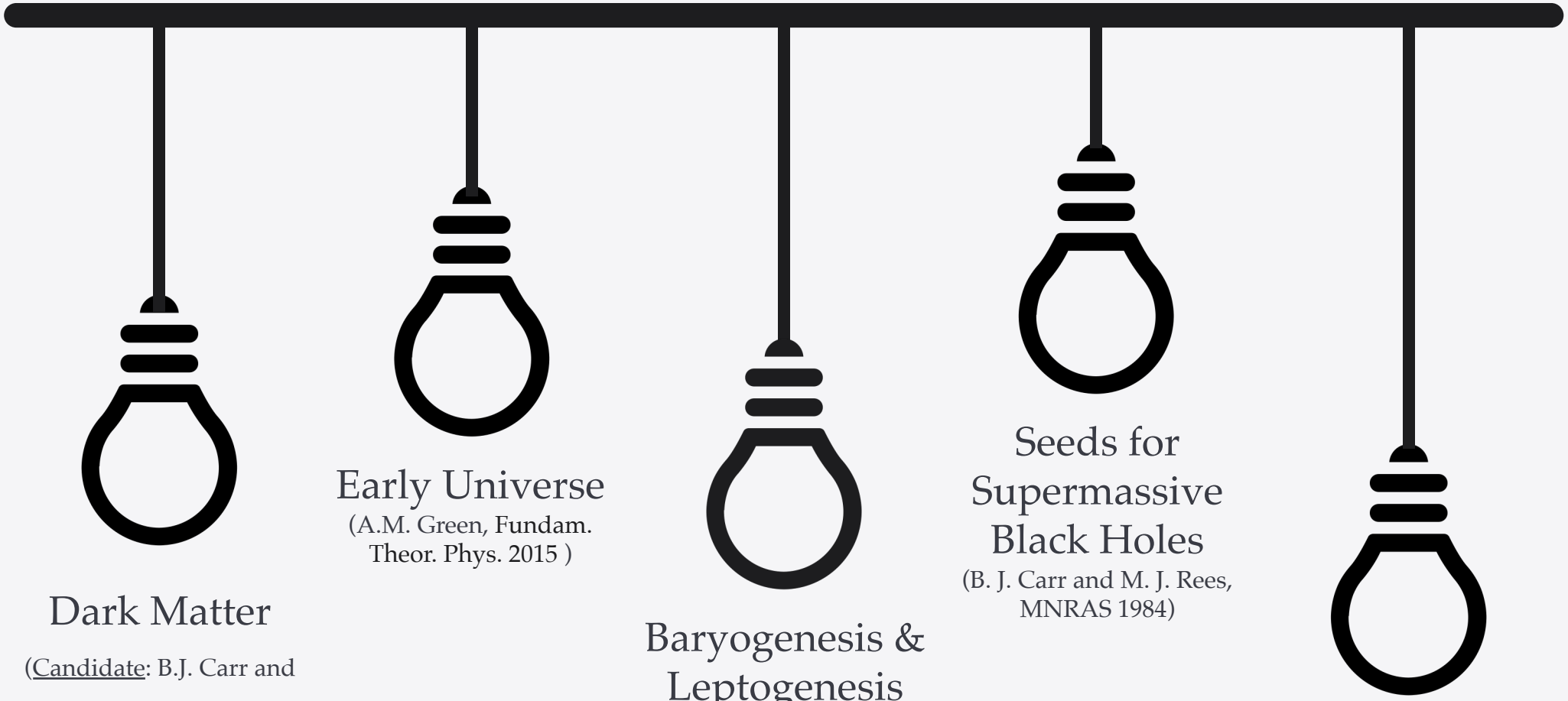
rcalabrese@na.infn.it

PRIMORDIAL BLACK HOLES



S. W. Hawking, *Commun.Math.Phys.* 1975
B. J. Carr, *Astrophys.J.* 1975
J. Auffinger, arXiv: 2206.02672

WHY PRIMORDIAL BLACK HOLES ?



Dark Matter

(Candidate: B.J. Carr and S.W. Hawking, MNRAS 1974. Source: L. Morrison et al, JCAP 2019)

Early Universe

(A.M. Green, Fundam. Theor. Phys. 2015)

Baryogenesis & Leptogenesis

(S. W. Hawking, Nature 1974; Y. B. Zeldovich, Pisma Zh. Eksp. Teor. Fiz. 1976)

Seeds for Supermassive Black Holes

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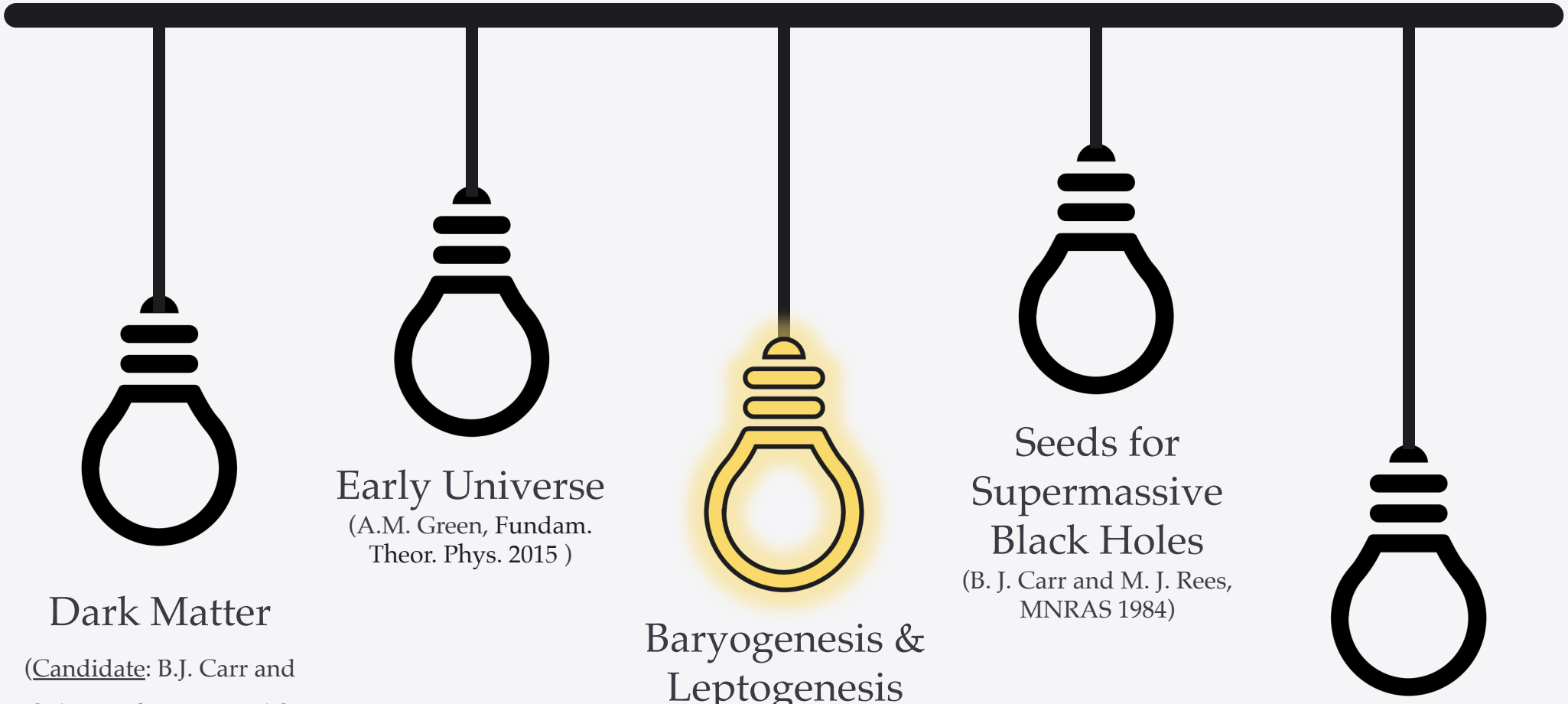

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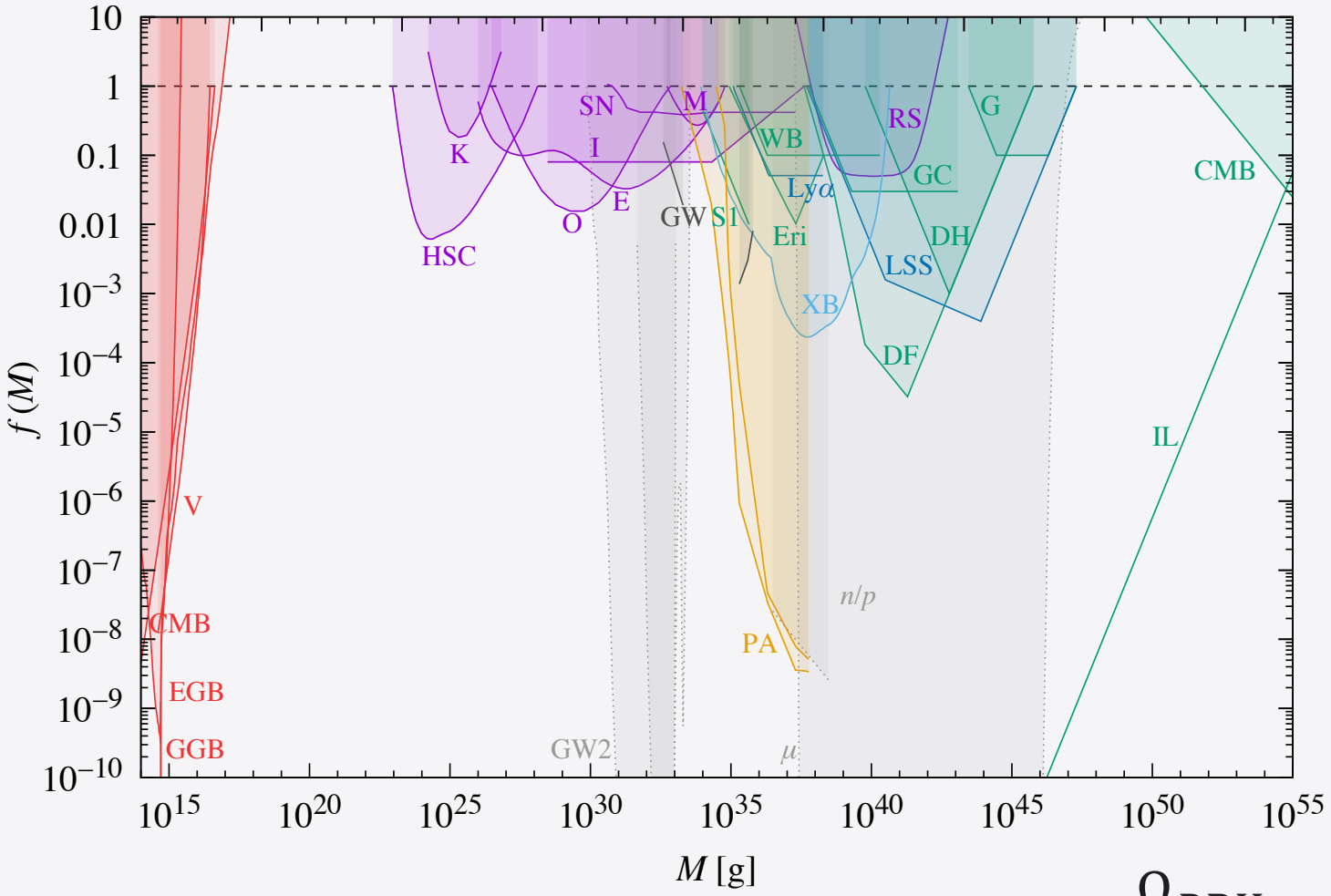
EXISTING CONSTRAINTS

B. Carr et al, Rept.Prog.Phys. 84 (2021) 11, 116902
G. Domènech et al, JCAP 04 (2021) 062
A.M. Green et al, J.Phys.G 48 (2021) 4, 043001



$$f(M) = \frac{\Omega_{PBH}}{\Omega_{DM}}$$

* dashed lines → not reliable
** dotted lines → rely on extra assumptions

- Lensing
- Evaporation
- CMB distortions
- Dynamical effects
- Accretion
- Large Scale Structure (LSS)
- Gravitational Waves (GWs)

EXISTING CONSTRAINTS

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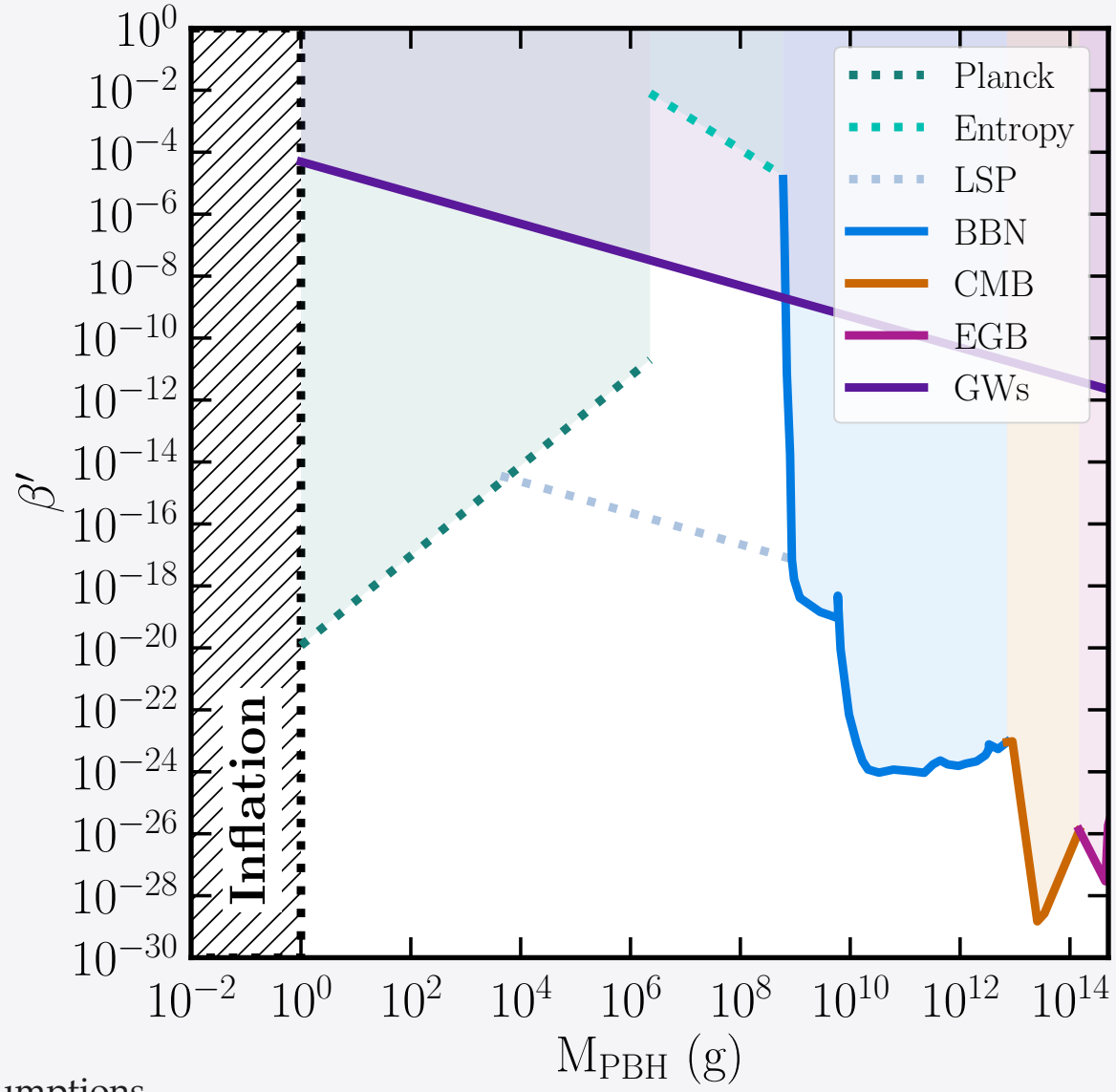


$$\beta' = \sqrt{\gamma_{PBH}} \frac{\rho_{PBH}}{\rho_{cr}}\bigg|_{form}$$

* dashed lines → not reliable
** dotted lines → rely on extra assumptions

BARYON ASYMMETRY

Our Universe is asymmetric in its matter/anti-matter content

$$Y_B = \frac{n_B - n_{\overline{B}}}{s_R} \simeq 8.73 \cdot 10^{-11}$$

In our quest to understand the origin of this asymmetry, we seek a mechanism that dynamically generates the baryon asymmetry, adhering to the **Sakharov Conditions**

1. Baryon number violation
2. C and CP violation
3. Departure from thermal equilibrium

V.A. Rubakov et al, Phys.Usp. 39 (1996) 461-502
Planck Collaboration, Astron.Astrophys. 641 (2020) A6
A.D. Sakharov, JETP Lett. 5 (1967) 24-27

LEPTOGENESIS

Leptogenesis provides an elegant explanation for the Baryon asymmetry and the **neutrino masses**

How does it work?

1. Right-handed neutrinos decay, violating the Lepton number conservation

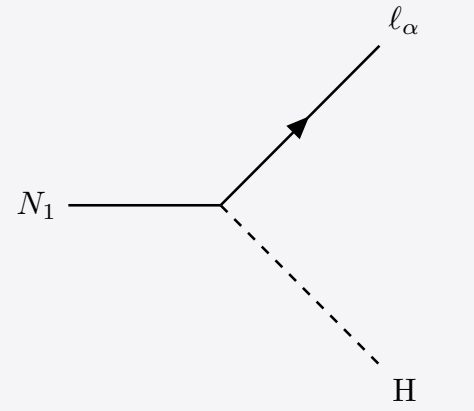
   Sphaleron transitions partially "transfer" the Lepton asymmetry in the Baryon sector
2. Right-handed neutrino interactions introduce new CP violation sources
3. Right-handed neutrinos decay out of equilibrium ($\Gamma_N < H$)

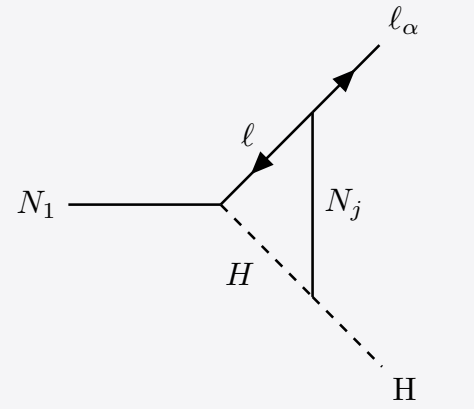
S. Davidson et al, Phys.Rept. 466 (2008) 105-177
W. Buchmuller et al, Annals Phys. 315 (2005) 305-351
G.F. Giudice et al, Nucl.Phys.B 685 (2004) 89-149

THERMAL LEPTOGENESIS

It is based on **type-I seesaw mechanism**:

$$\mathcal{L} \subset i\overline{N_i}\partial N_i - Y_{\alpha i}\overline{L_\alpha}N_i\,\tilde{\phi} - \frac{1}{2}\overline{N_i^c}\,\widehat{M_{ij}}N_j + h.c.$$

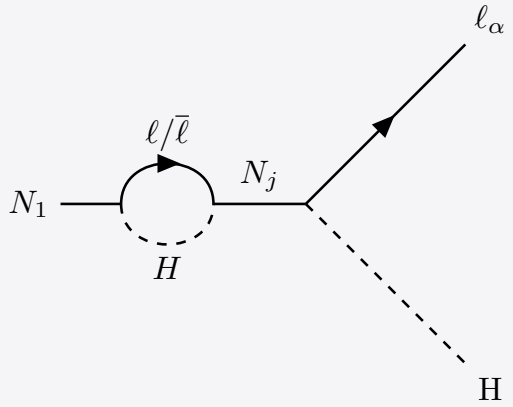




Main features:

- ★ $M_1 \in [10^{10} - 10^{16}]GeV$
- ★ $M_1 \ll M_2, M_3$ (we neglect the $N_{2,3}$ decays)
- ★ Normal ordering: $m_h = m_3 > m_2 \gtrsim m_1$

  Using the Casas-Ibarra parametrization there is only one relevant angle: $z_{13} = x + iy$



Hambye et al, Nuclear Physics B 695 (2004) 169–191

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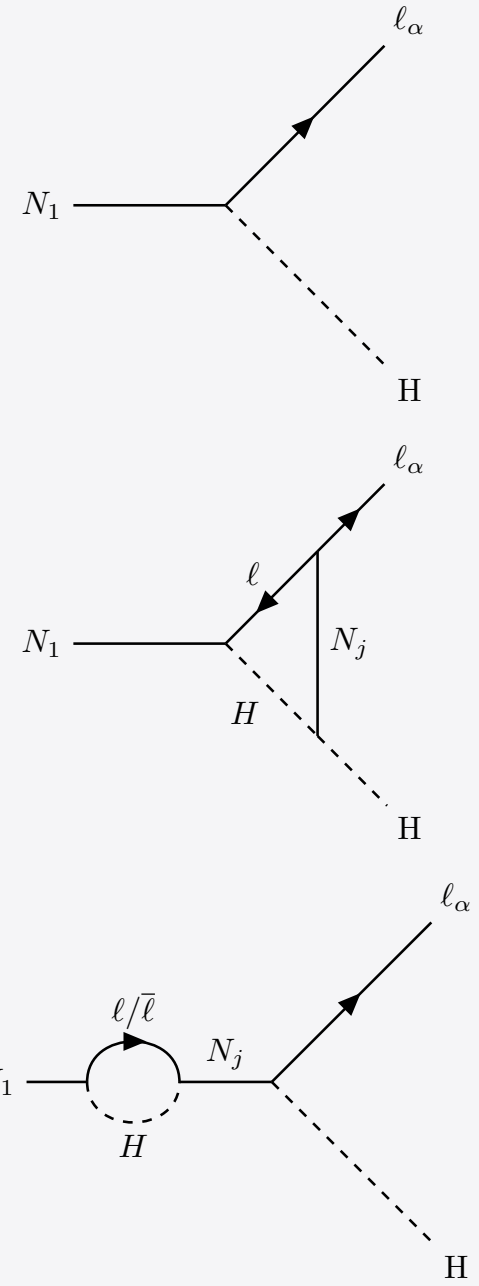

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Hambye et al, Nuclear Physics B 695 (2004) 169–191

PARAMETER SPACE

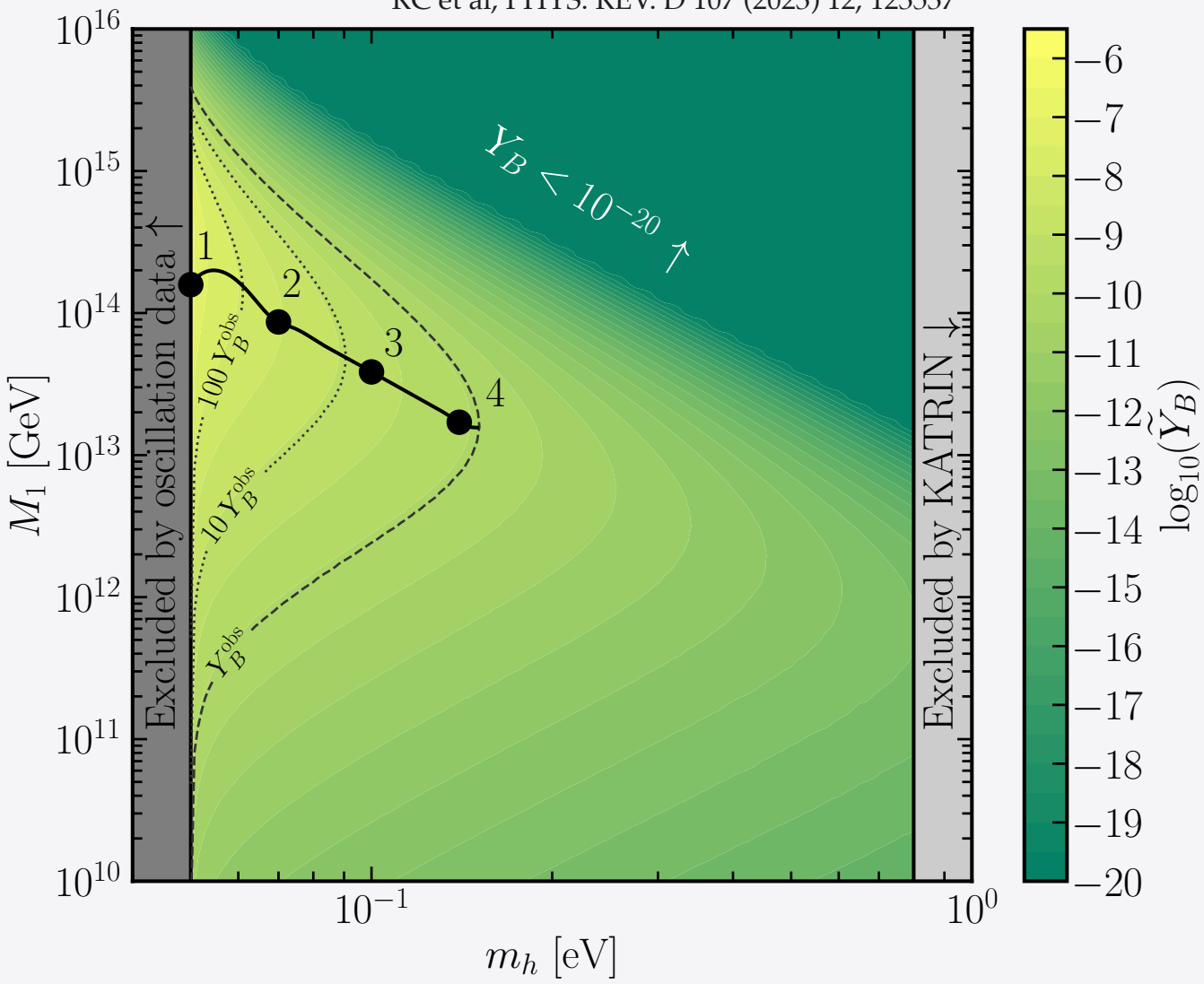
$$0 < x < \pi$$

$$0.14 < y < \pi$$

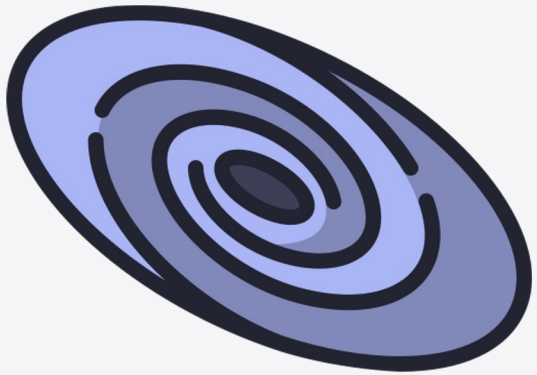
$$10^{10} GeV < M_1 < 10^{16} GeV$$

$$\sqrt{m_{atm}^2} < m_h < 0.8\ eV$$

RC et al, PHYS. REV. D 107 (2023) 12, 123537



EFFECT OF PRIMORDIAL BLACK HOLES



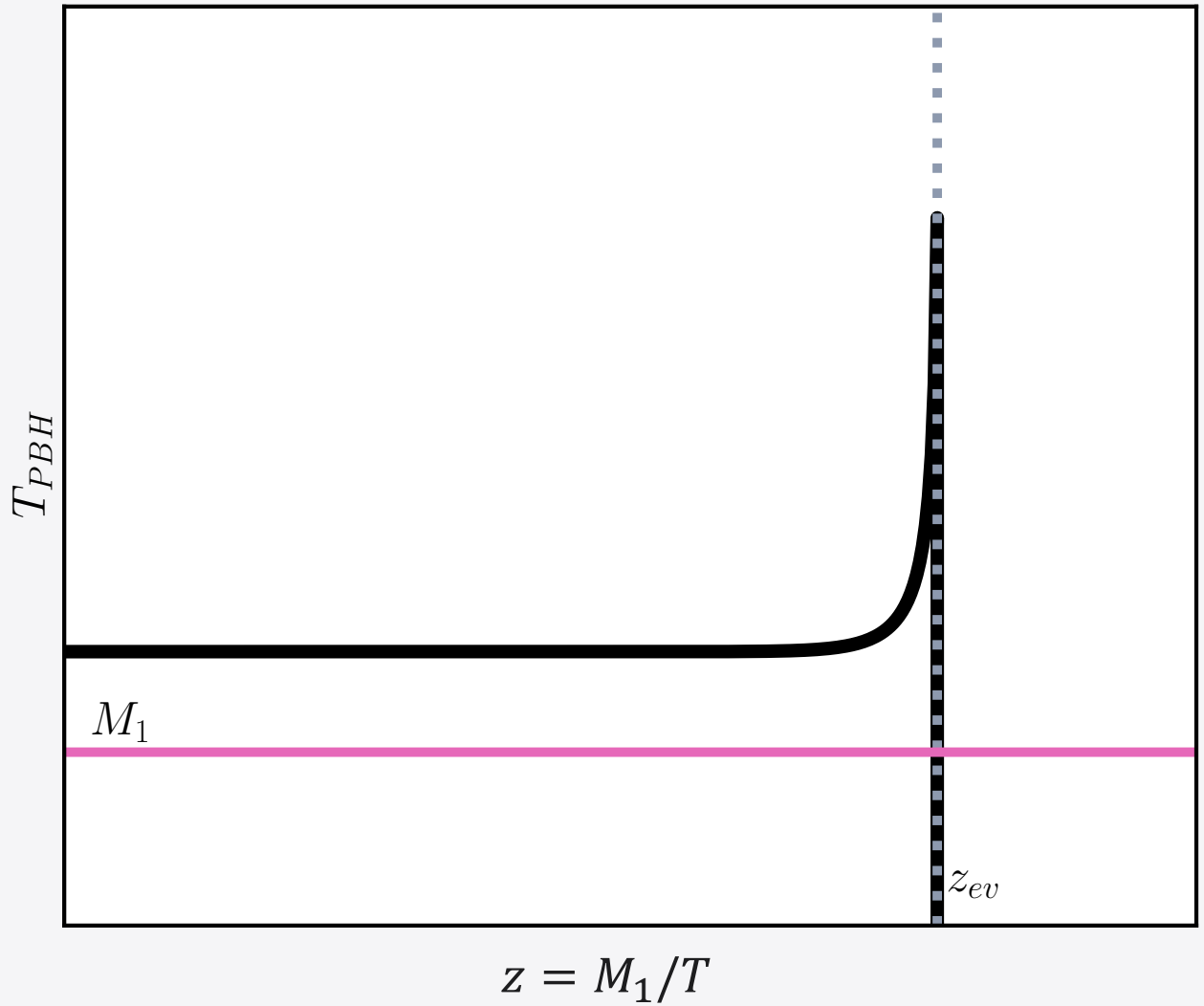
HAWKING RADIATION:

It provides an additional non-thermal source of right-handed neutrinos

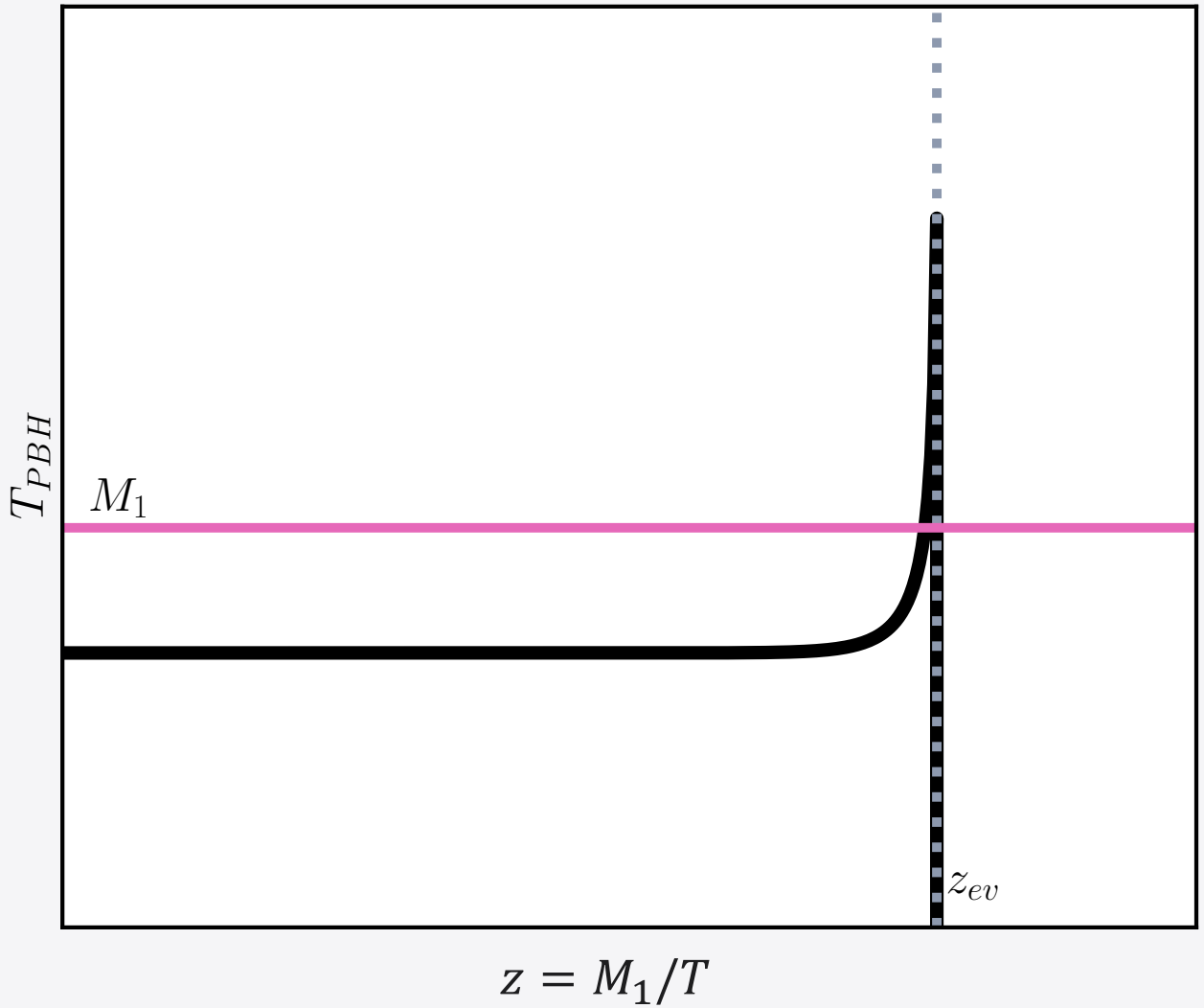
NON-STANDARD COSMOLOGY:

Primordial Black Holes can dominate for a short period

HAWKING RADIATION & RHNs



HAWKING RADIATION & RHNs



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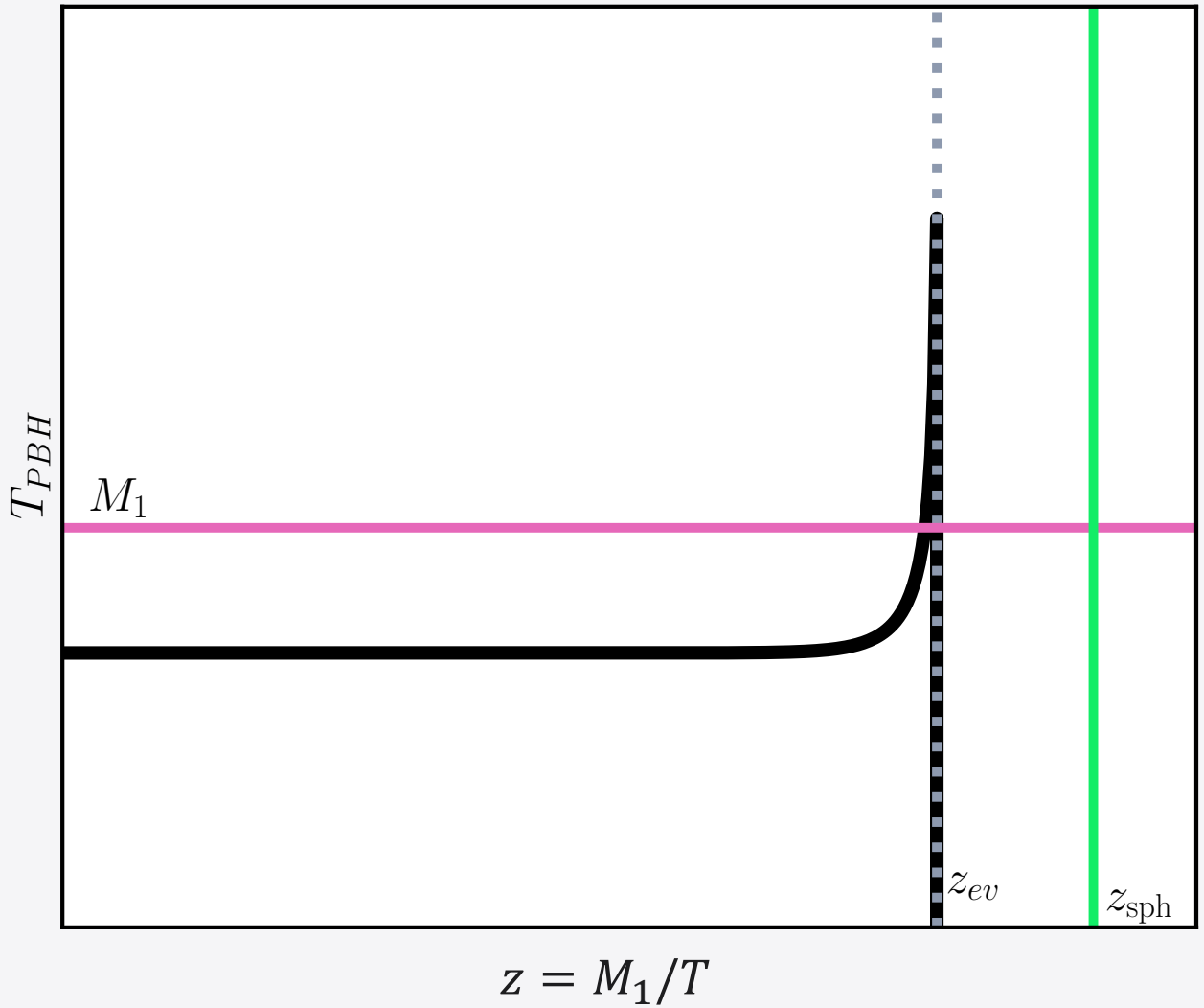

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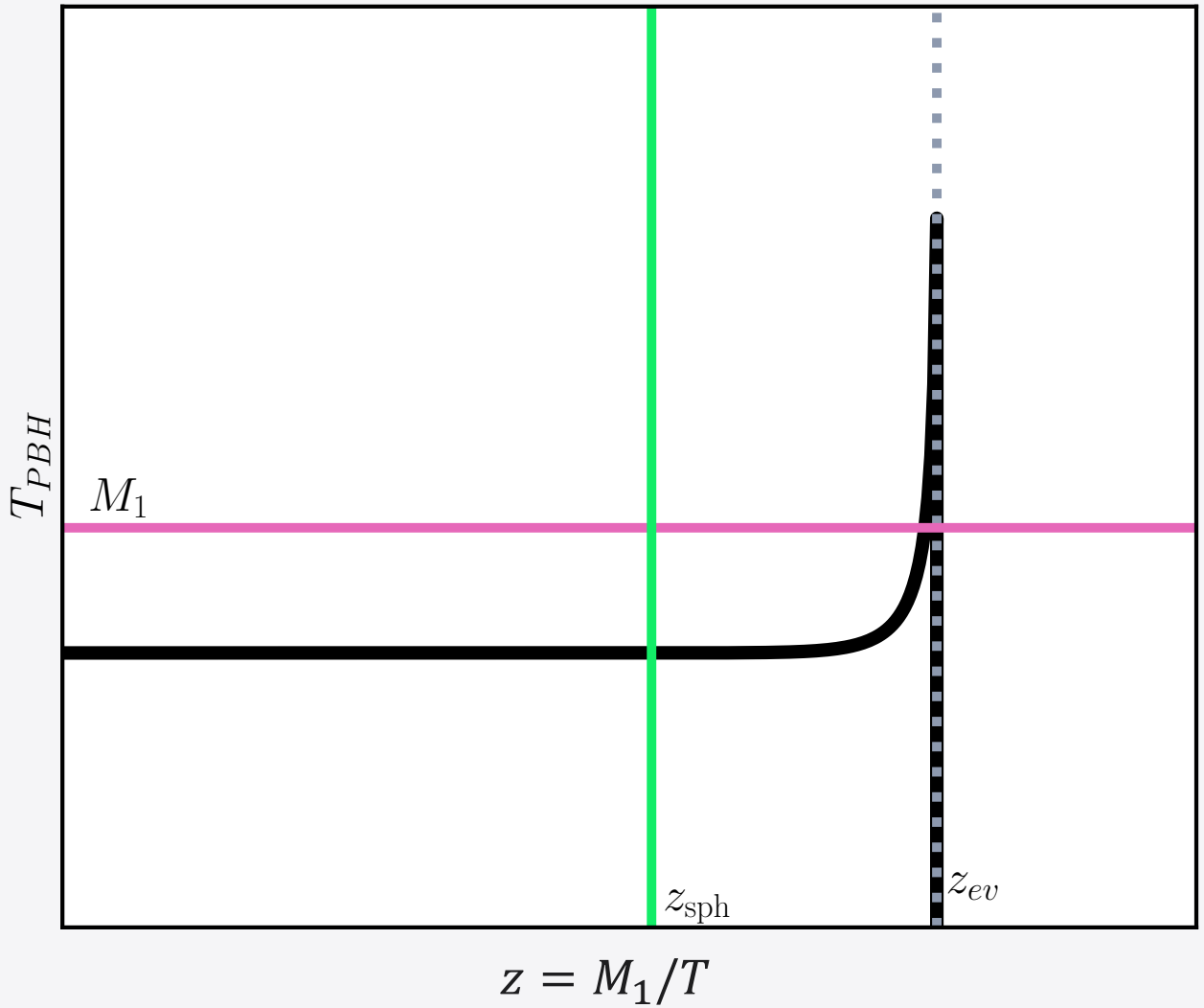

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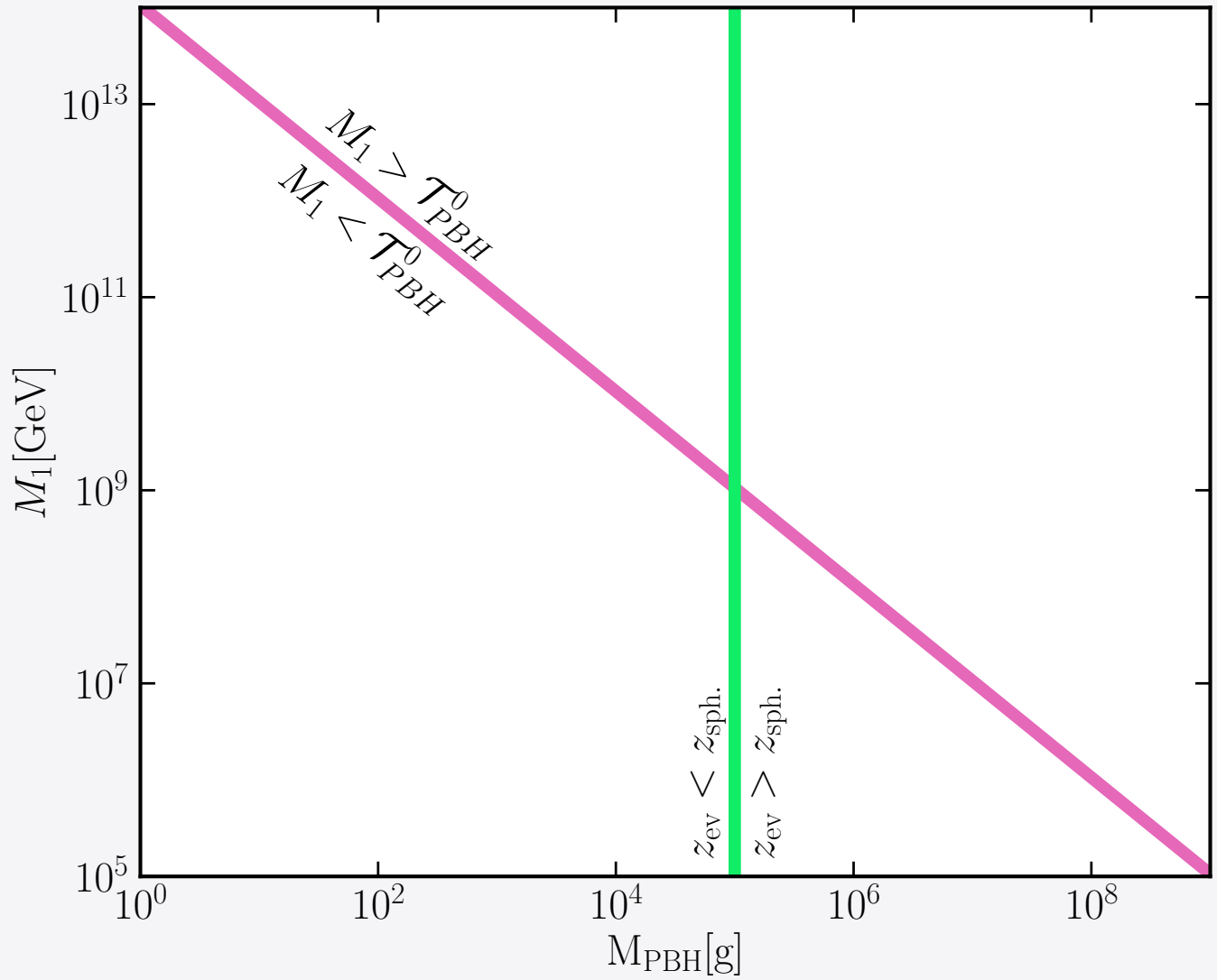

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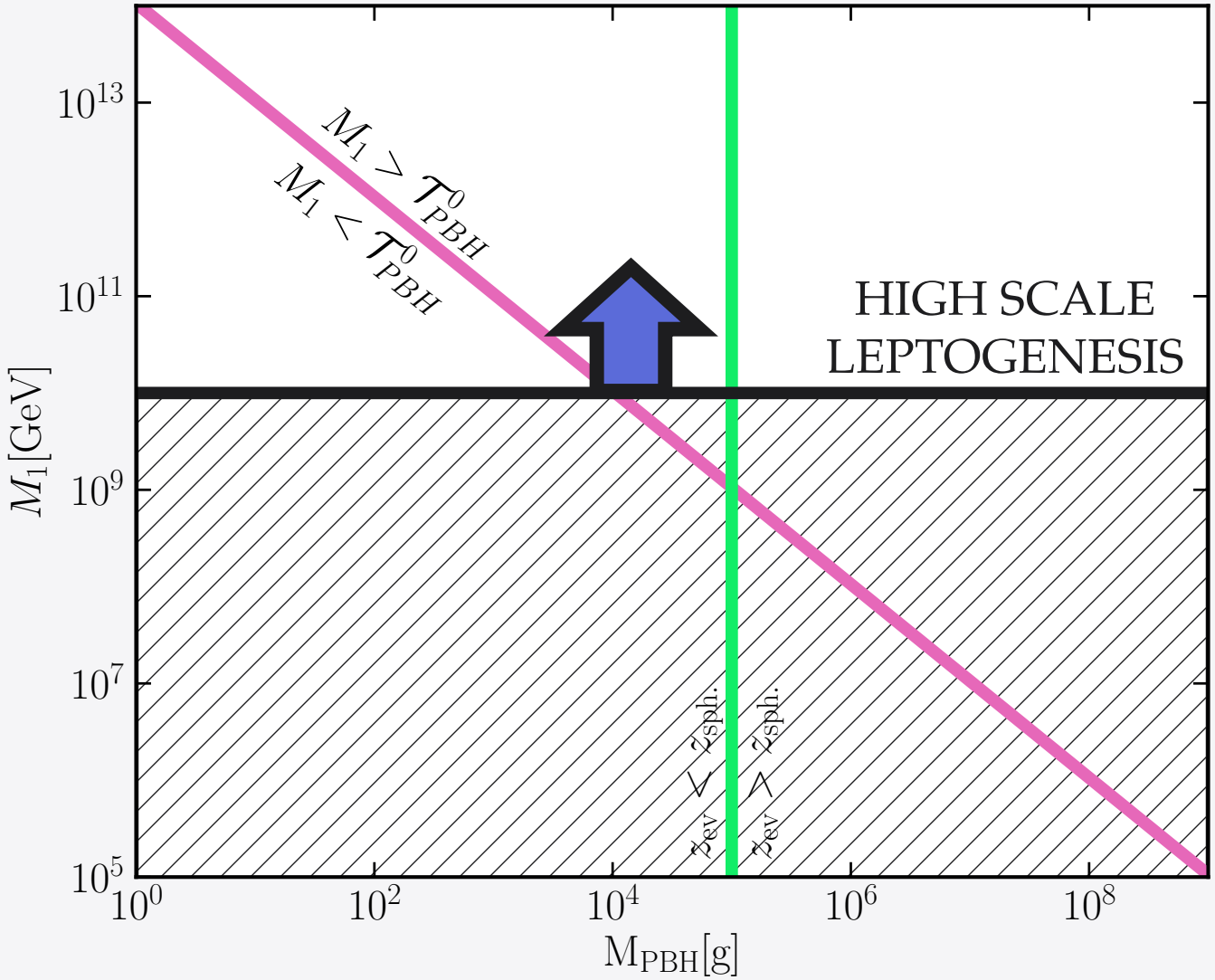

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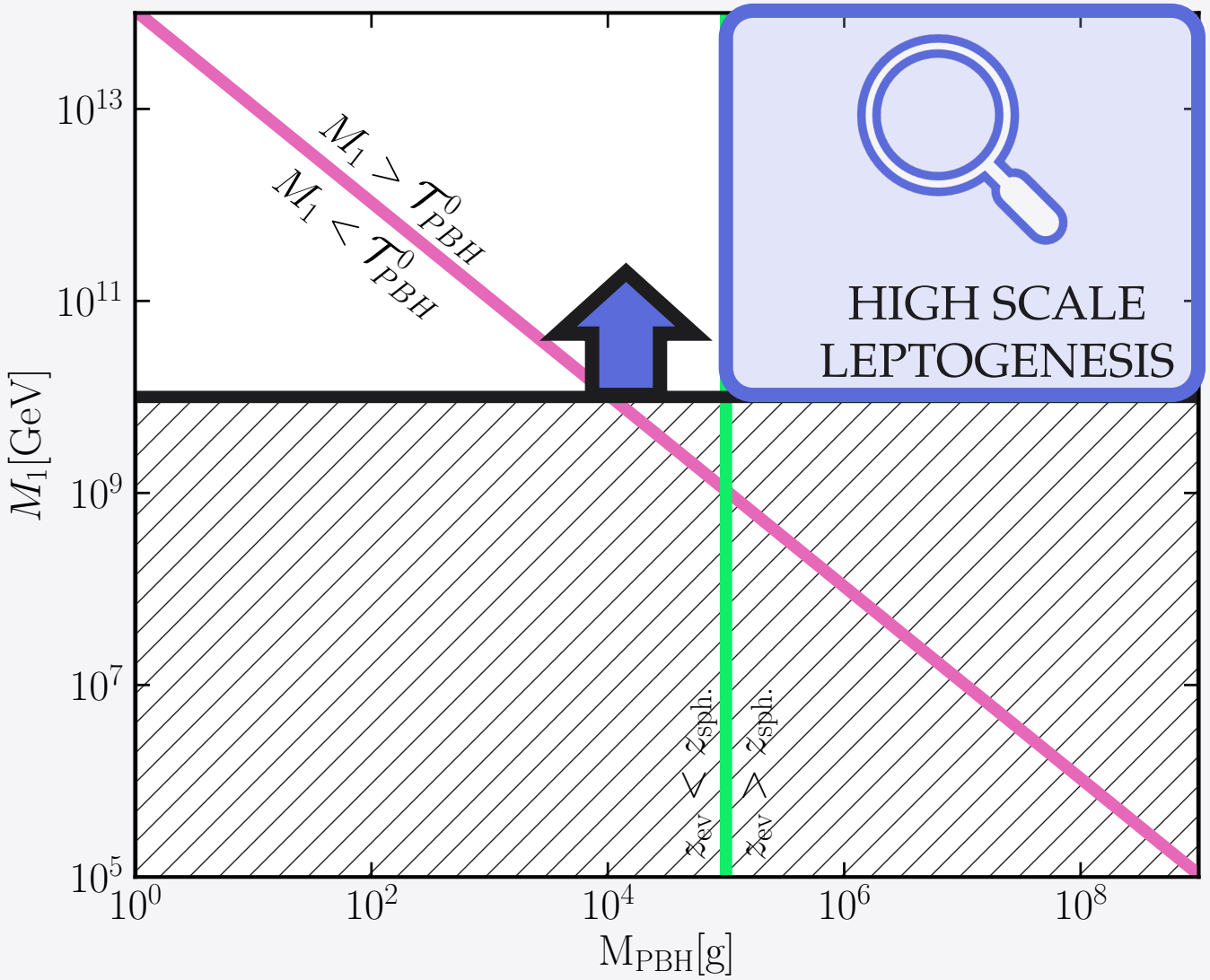
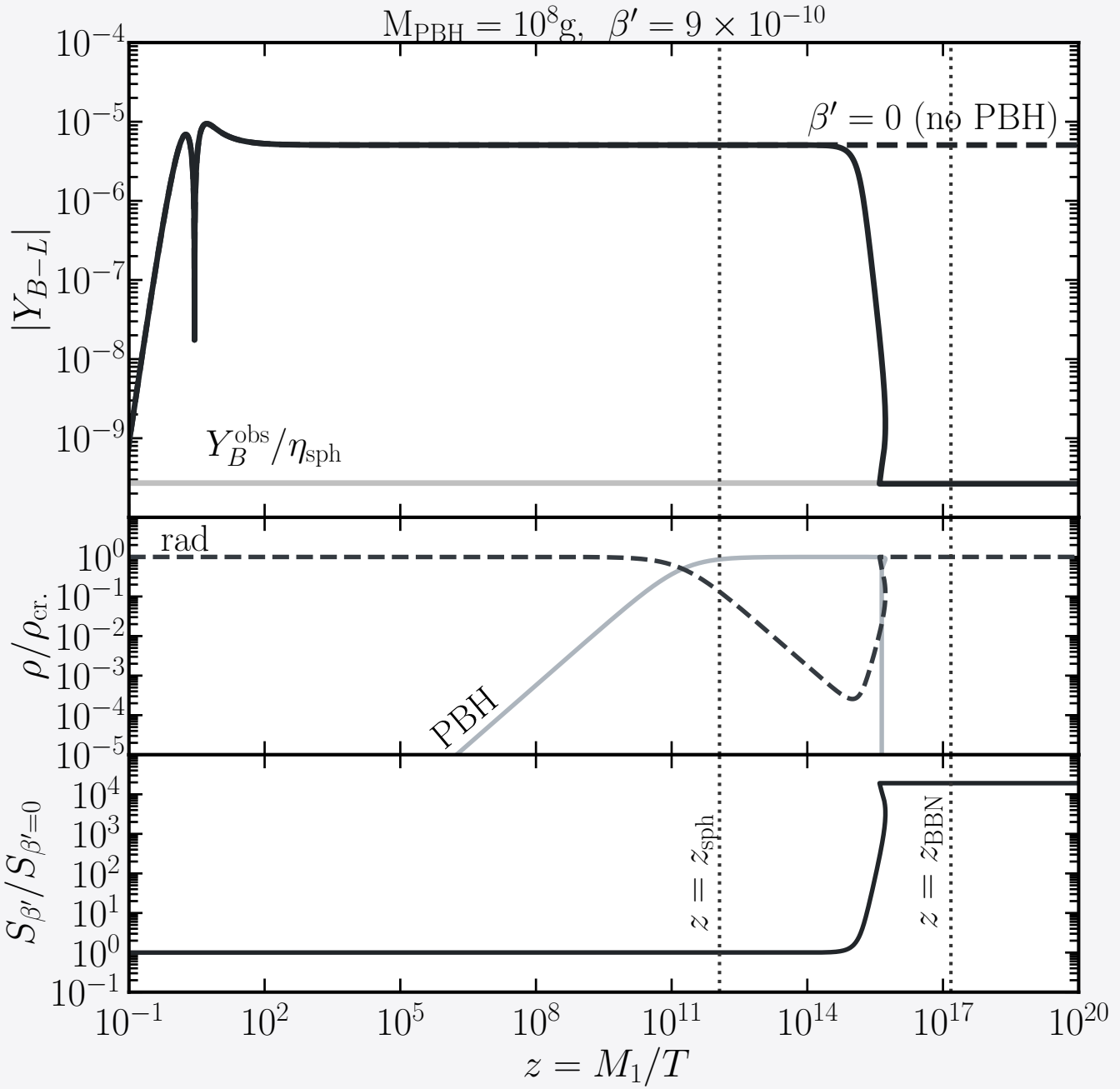


NON STANDARD COSMOLOGY

If Primordial Black Holes dominate the Universe for a short time, they alter the cosmological evolution



RC et al, PHYS. REV. D 107 (2023) 12, 123537

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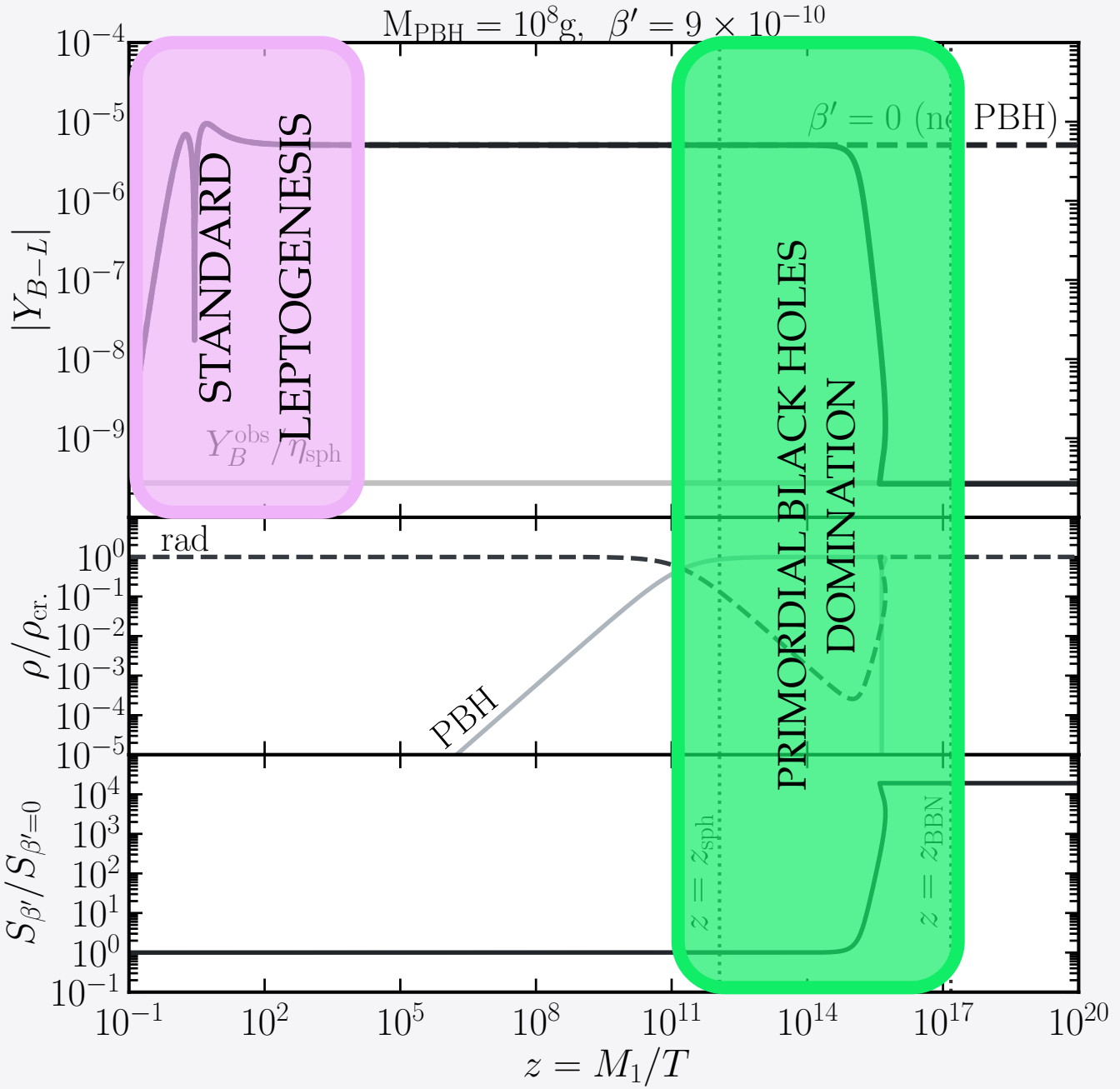
In our scenario, we focus on the entropy injection!



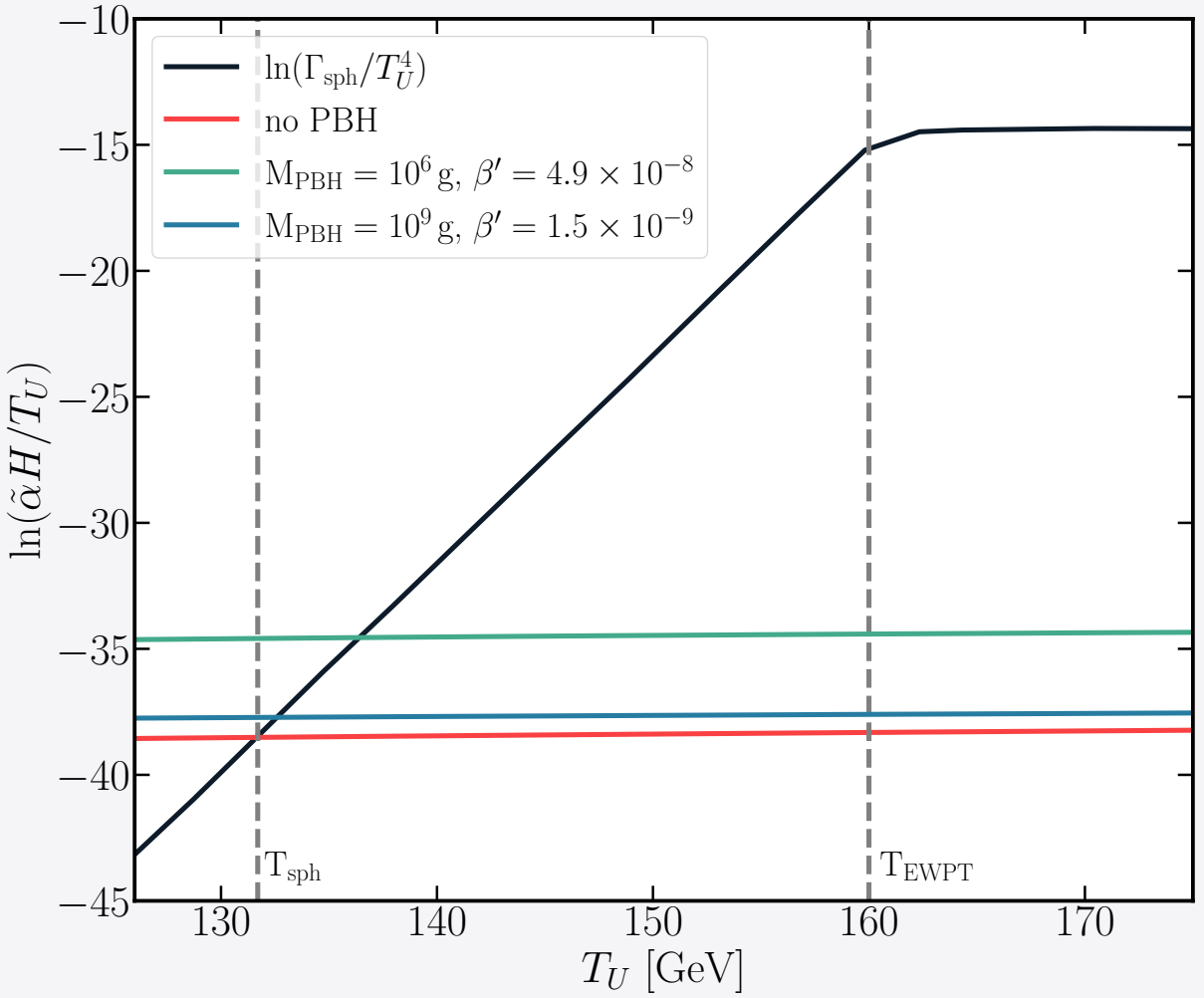
RC et al, PHYS. REV. D 107 (2023) 12, 123537

SPHALERON TRANSITION

Sphaleron transition can occur in a matter dominated Universe.

We verified that in our parameter space

$$T_{sph} < T_{EWPT}$$



RC et al, PHYS. REV. D 107 (2023) 12, 123537

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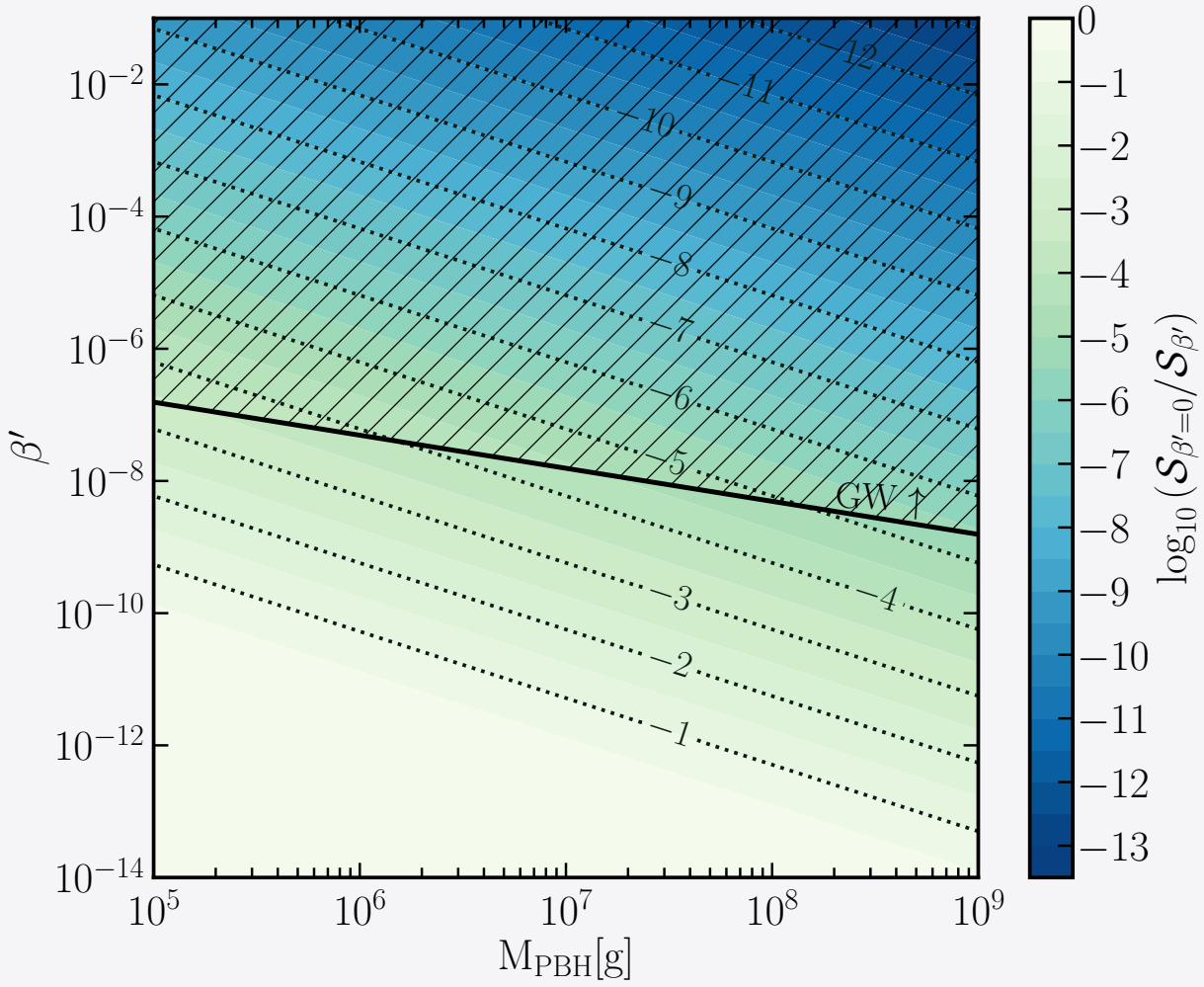

GW → G. Domènech et al, *JCAP* 04 (2021) 062

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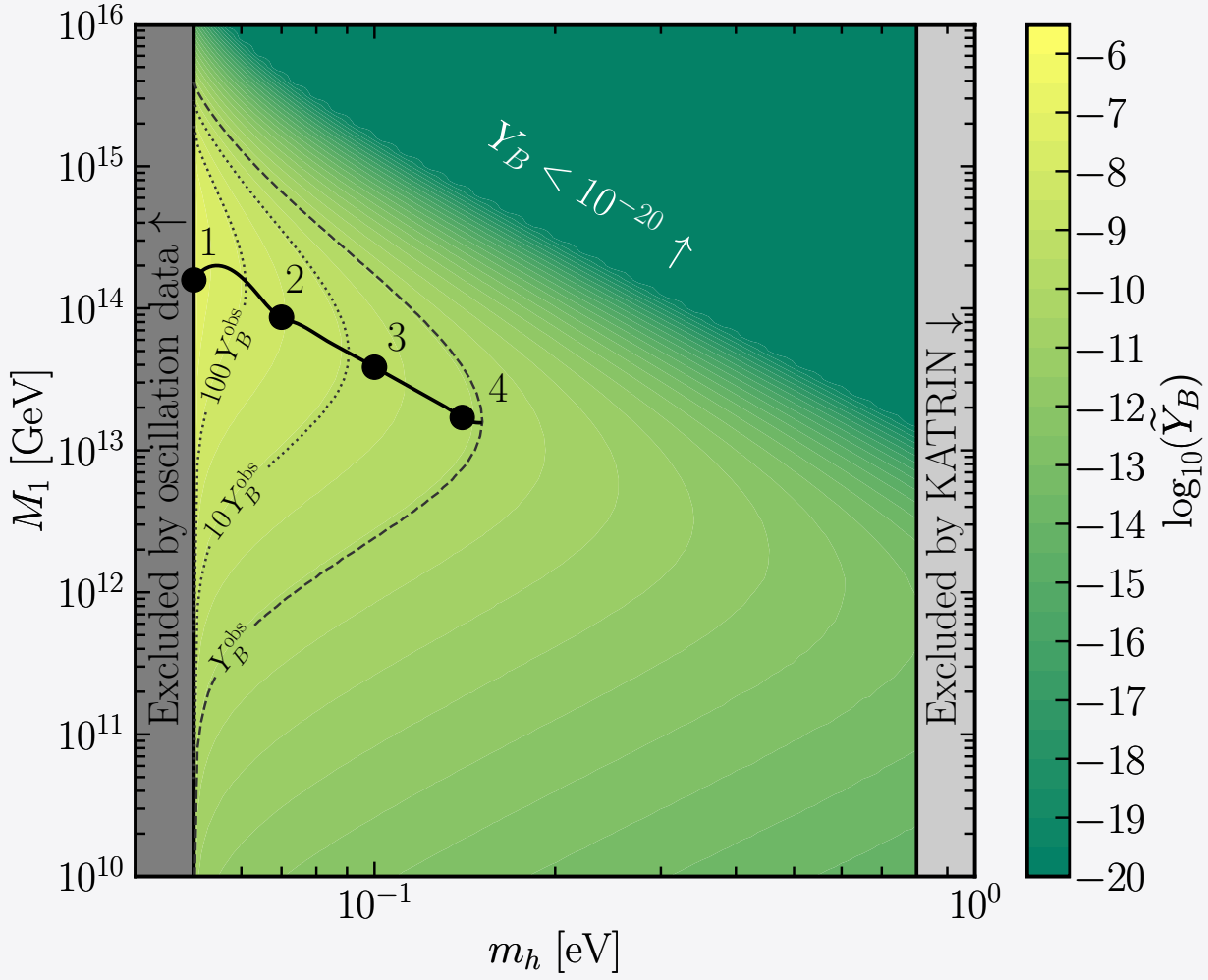

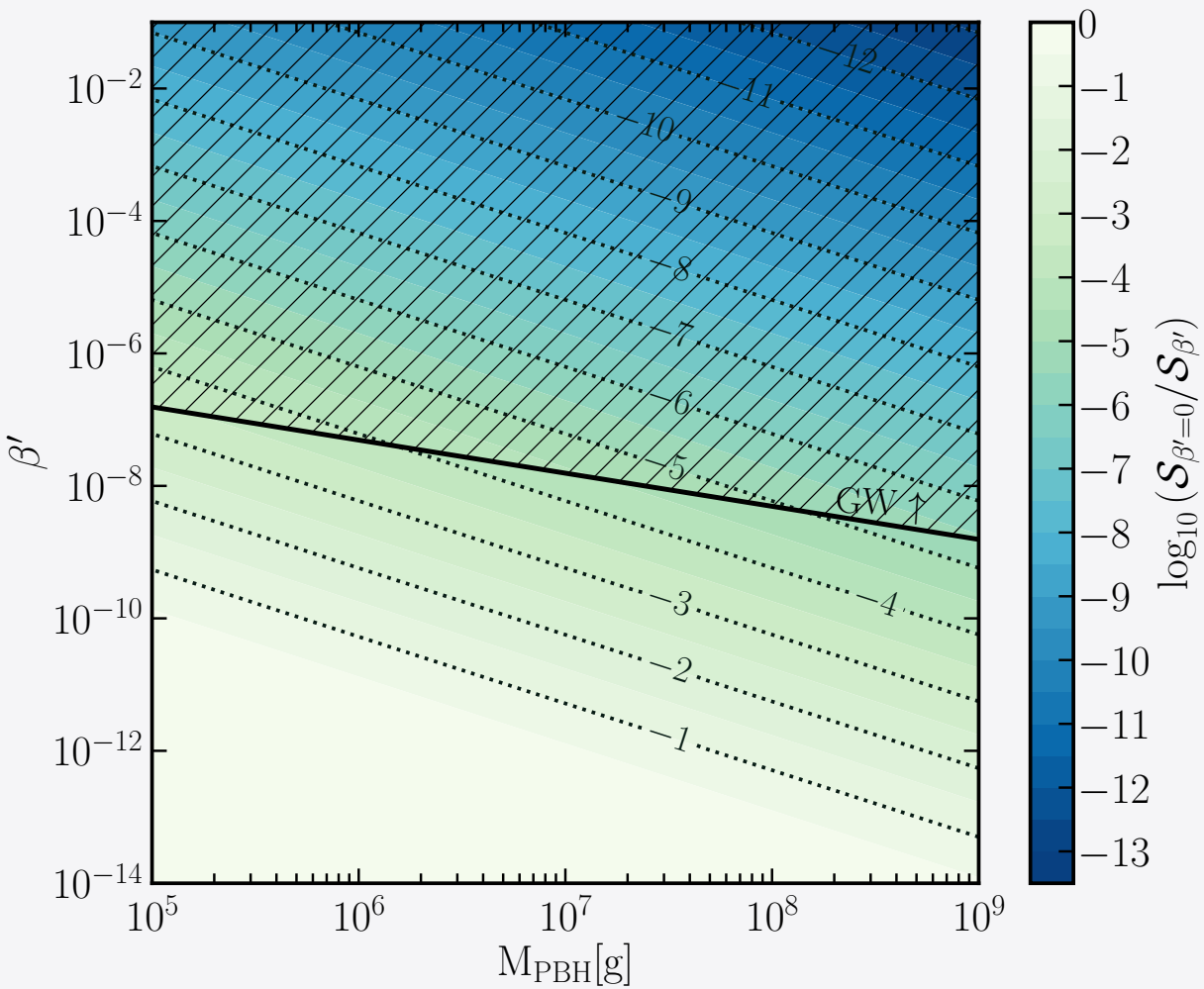

Entropy injection can partially or completely rule out the allowed parameter space in this plane!

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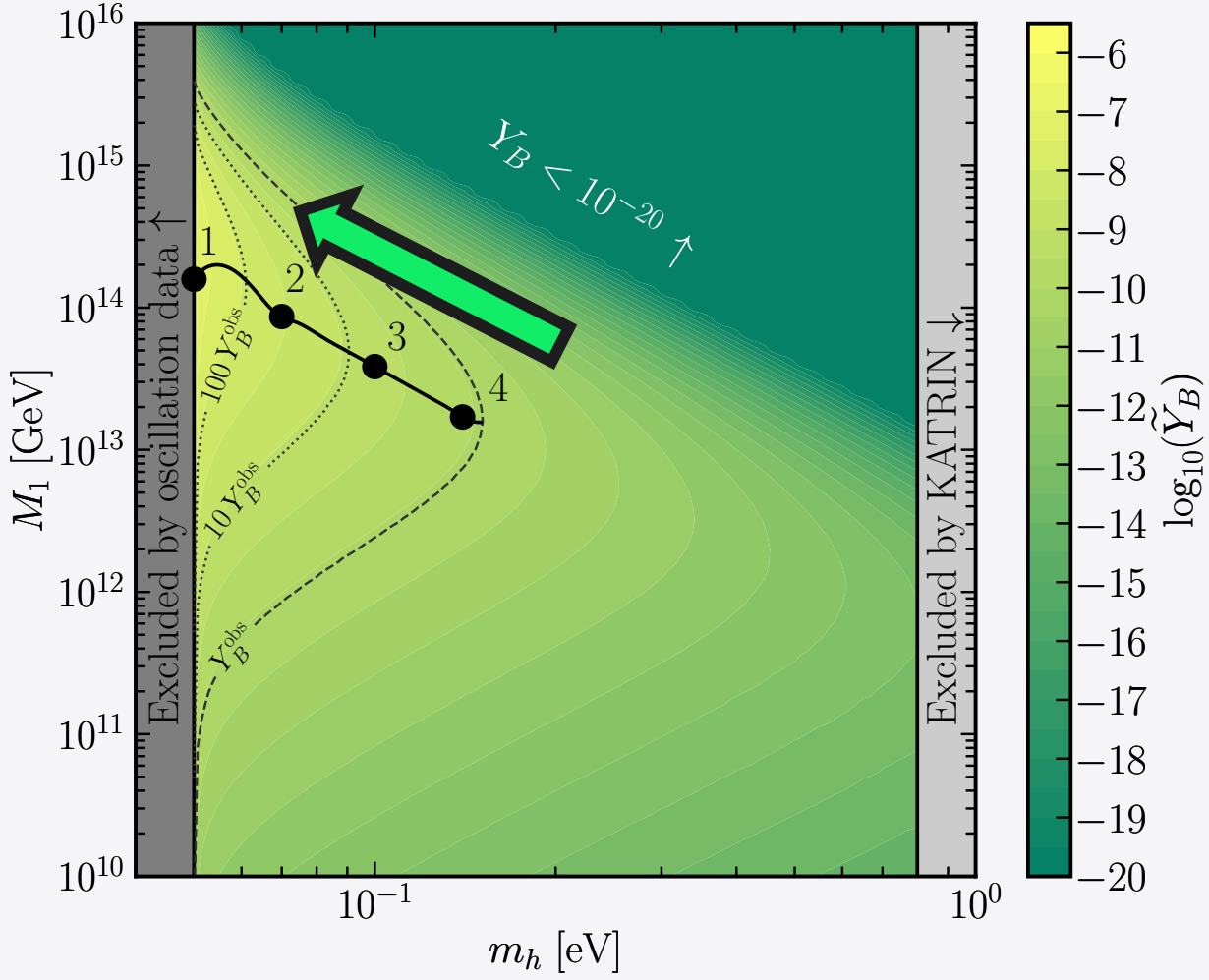

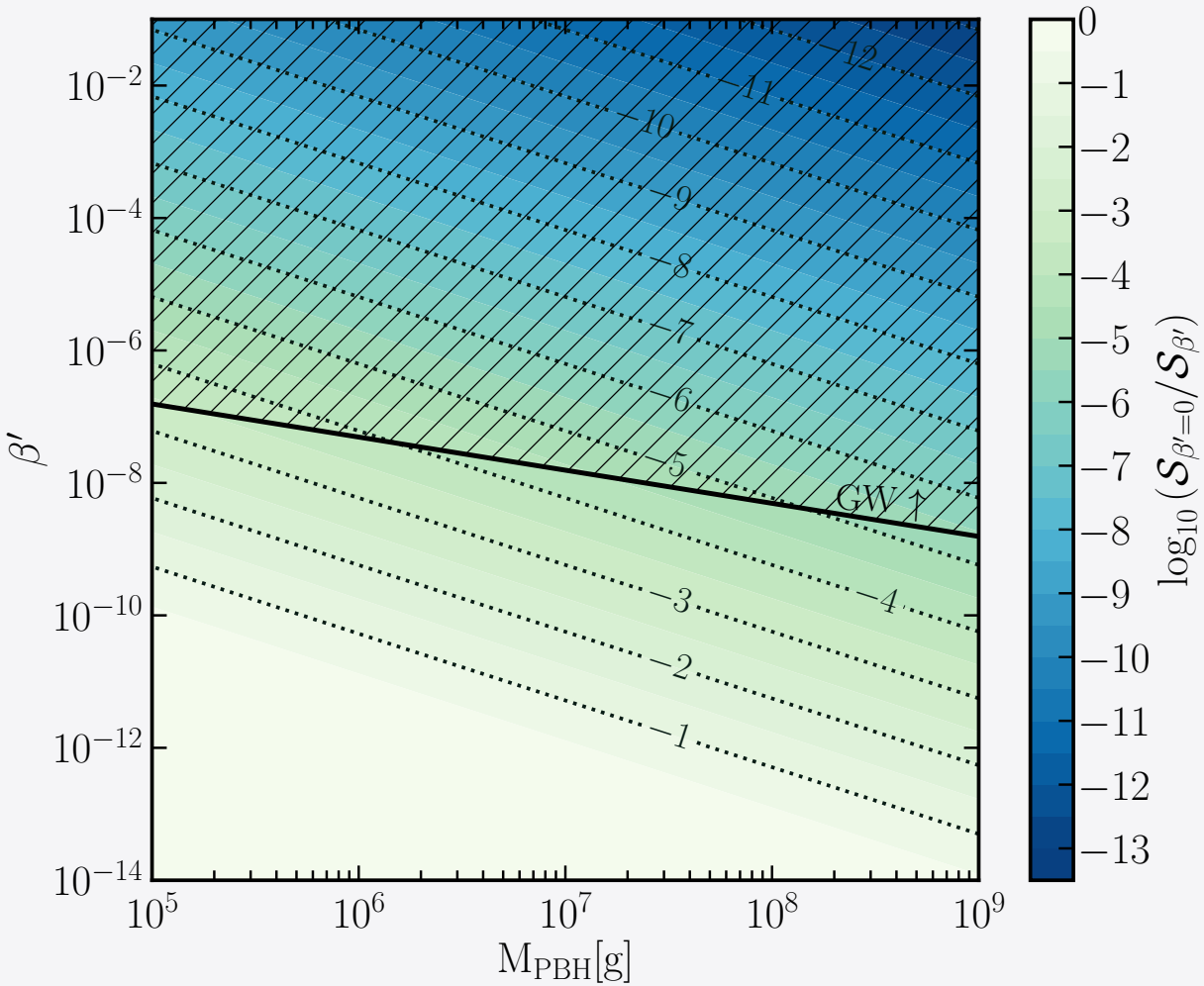

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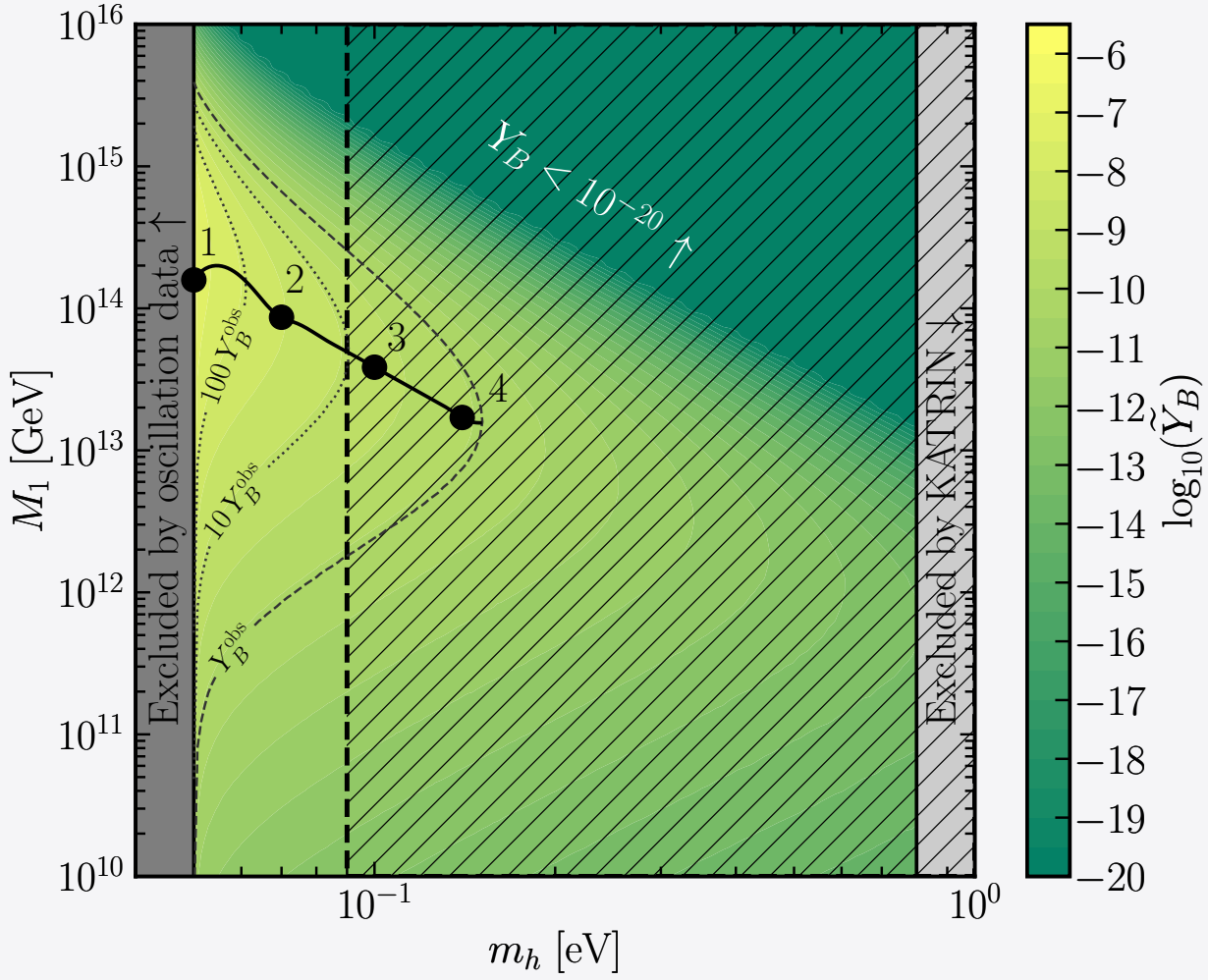

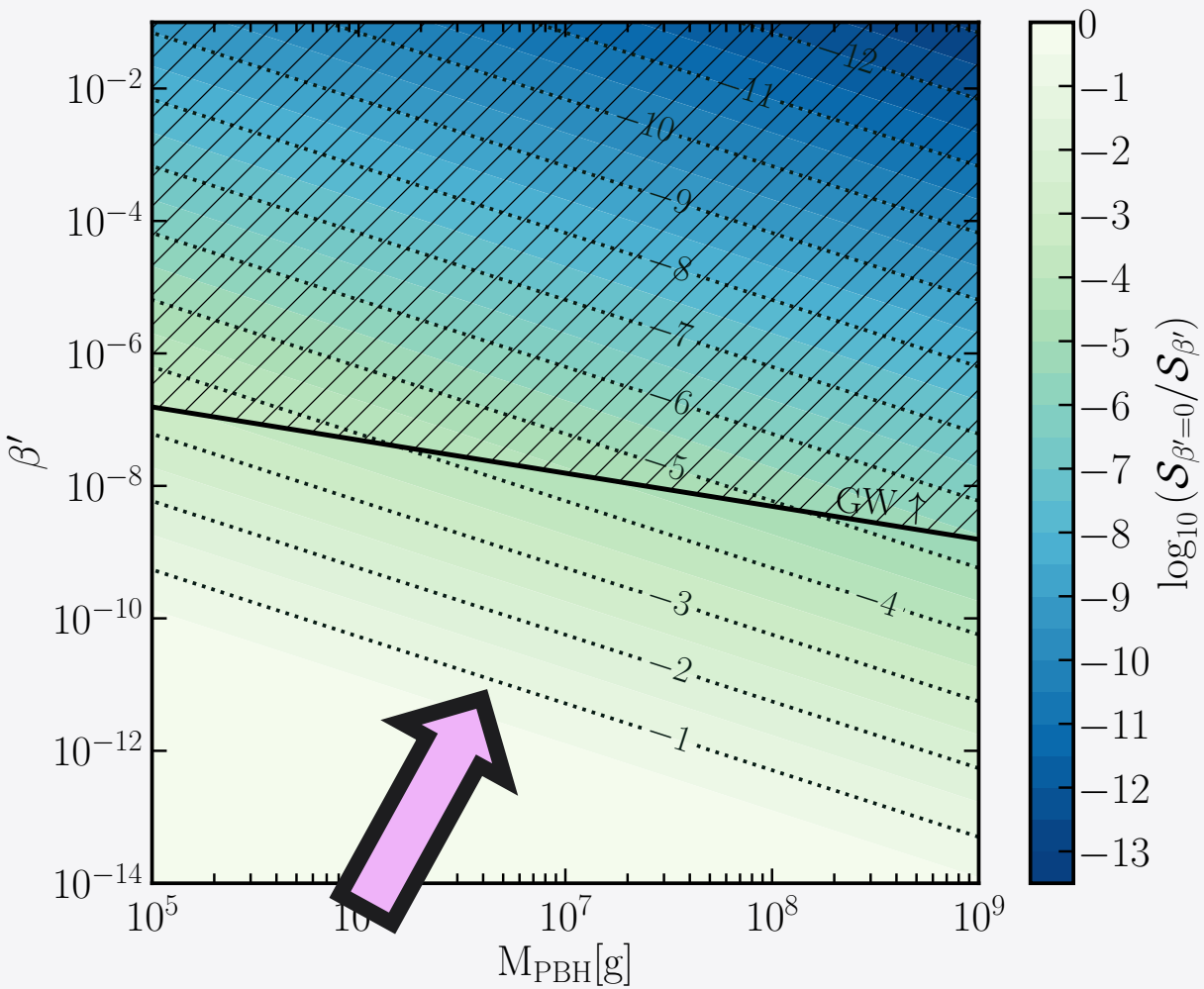

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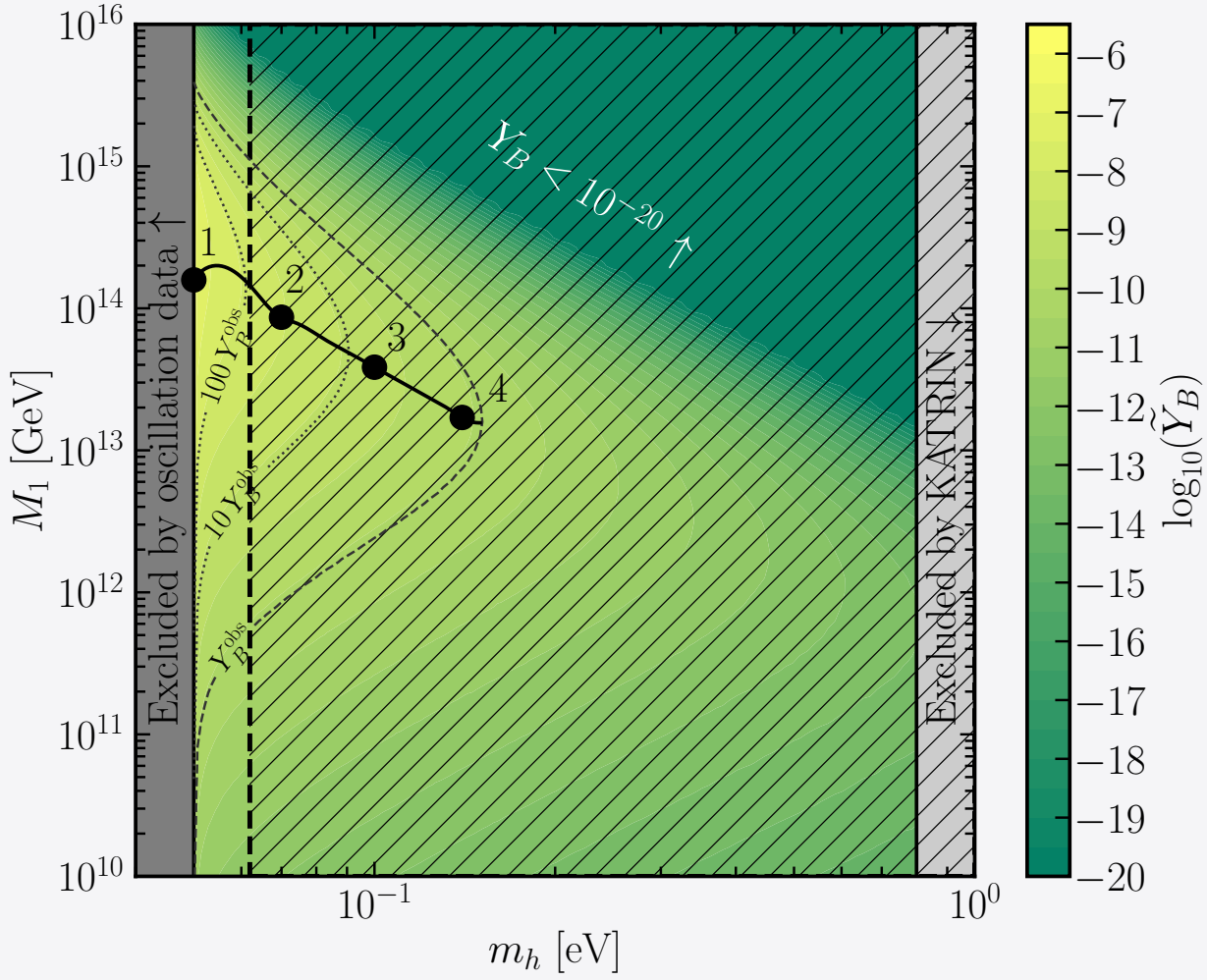

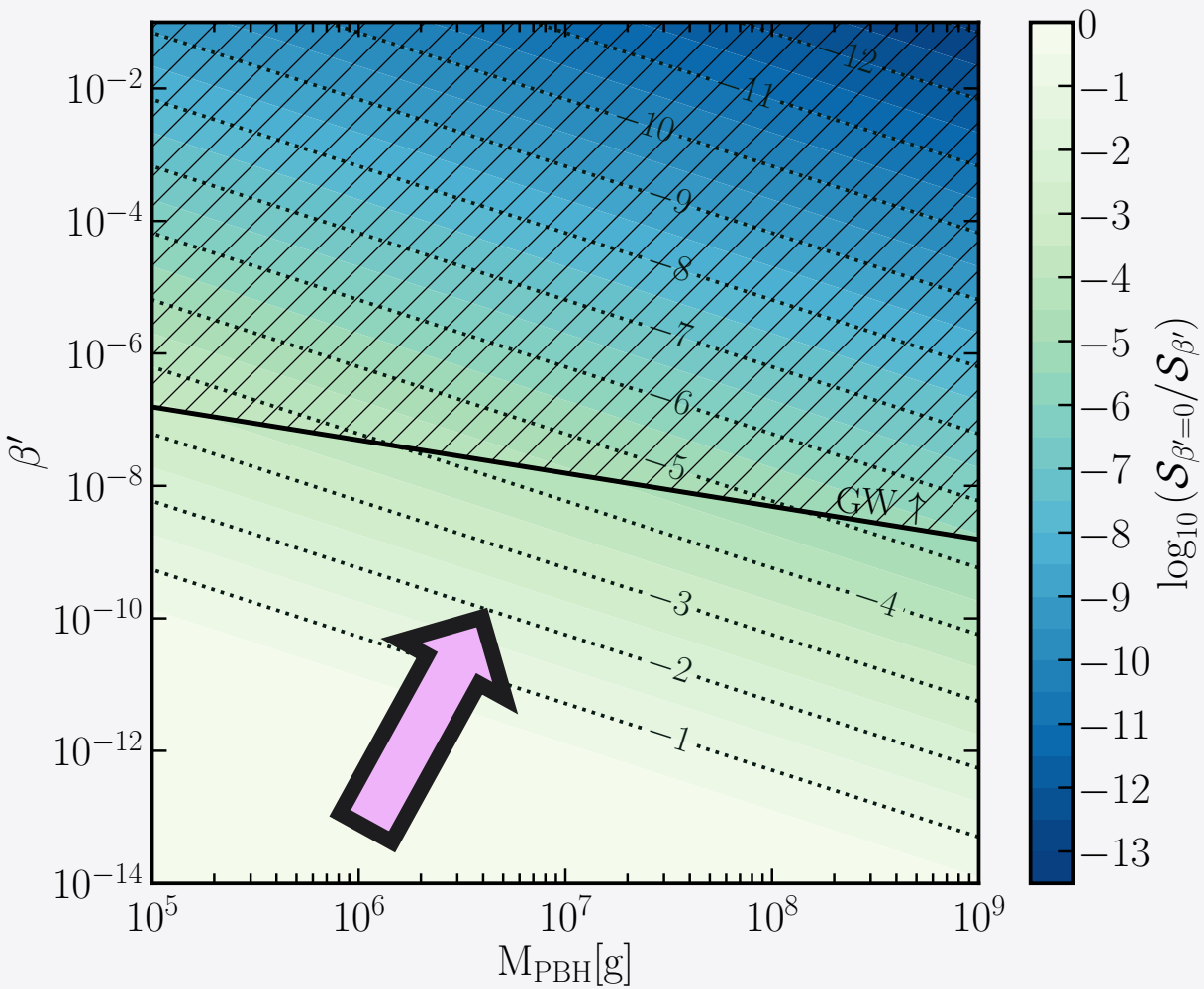

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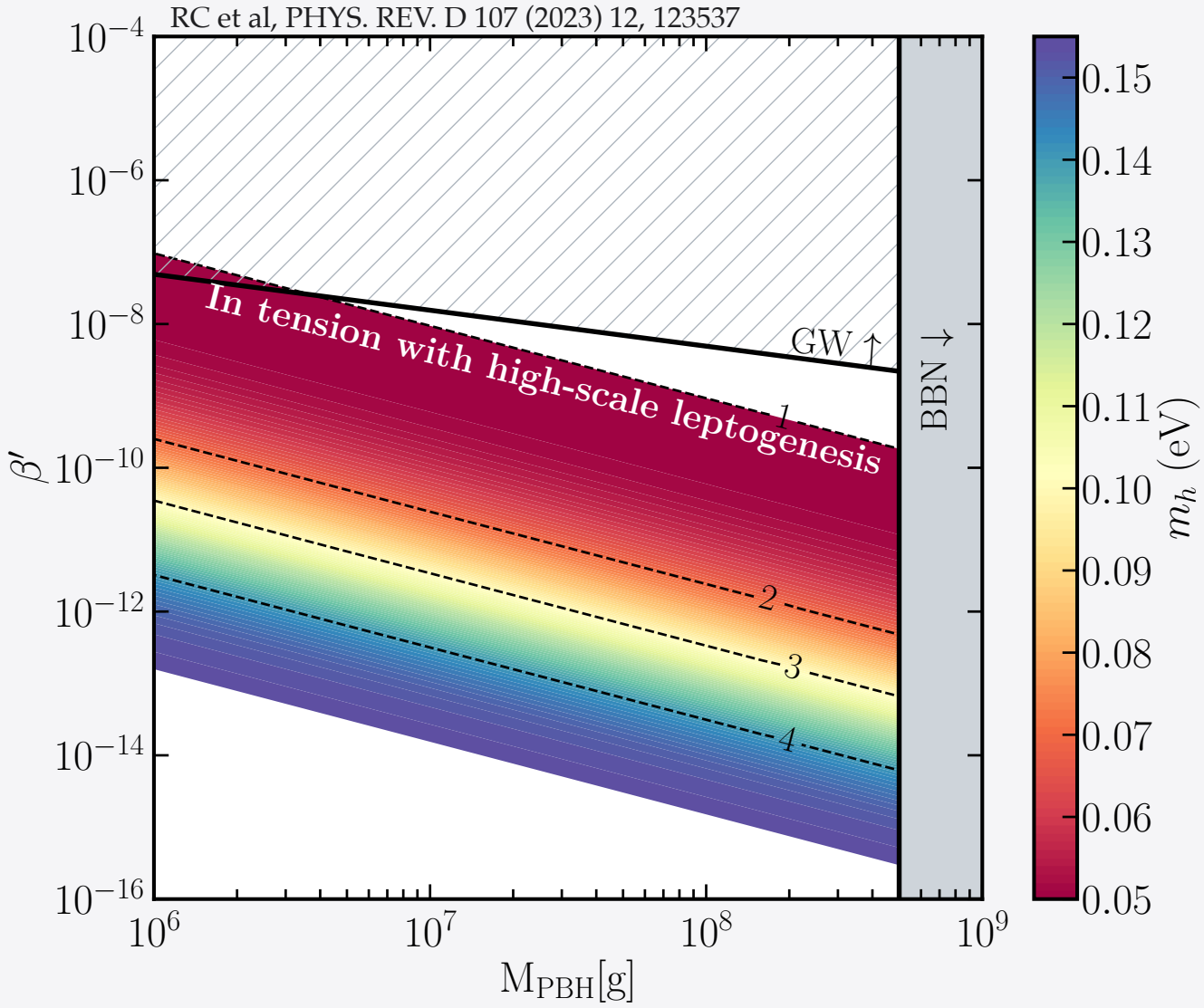
CONSTRAINTS



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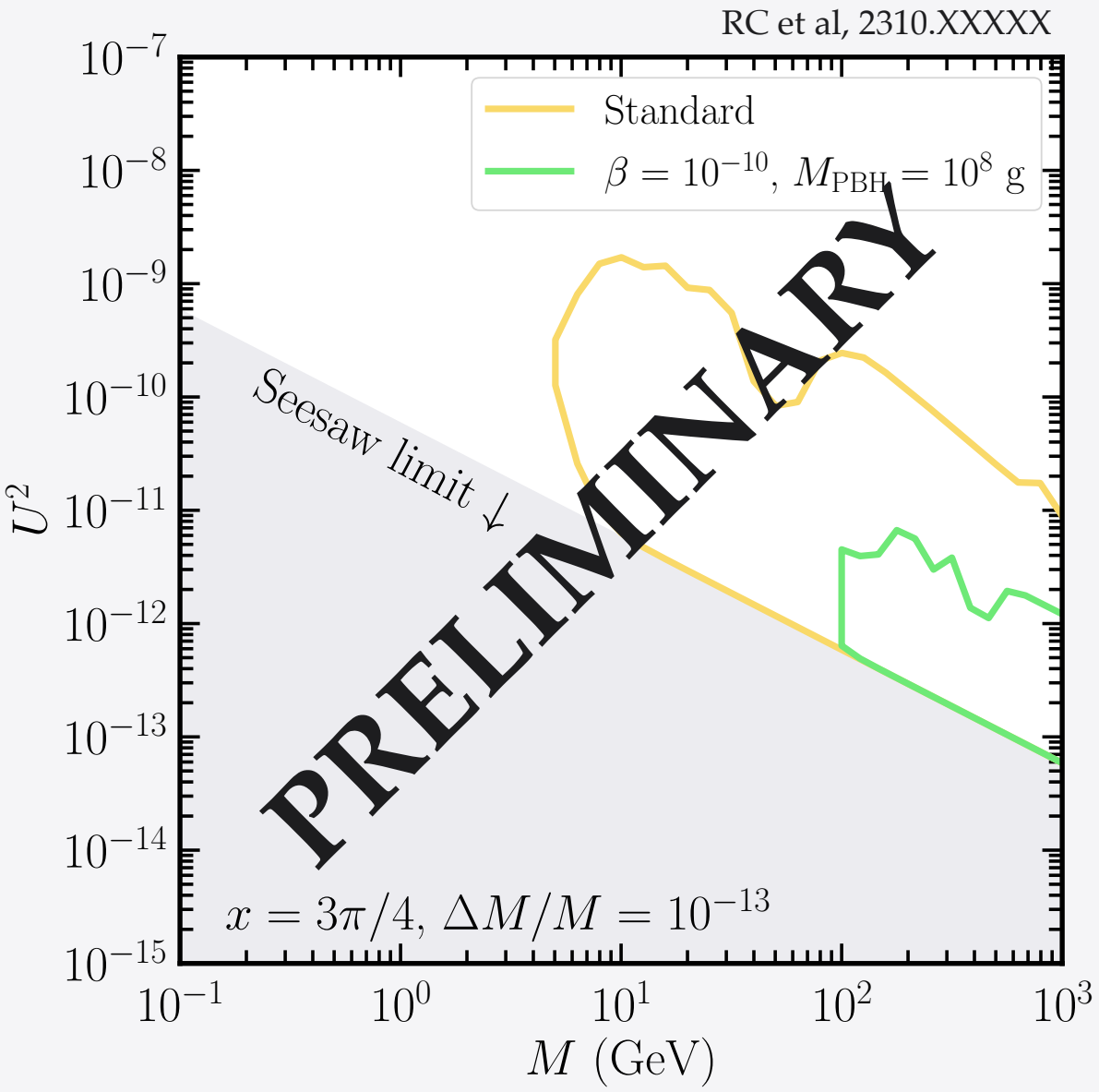
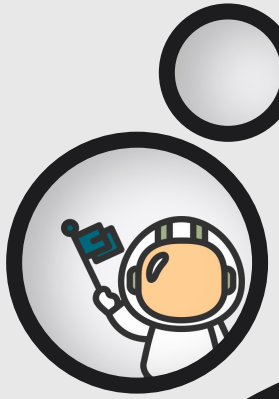
COMING SOON!

We are studying the interplay between **LOW SCALE LEPTOGENESIS ($M < 1\ TeV$)** and Primordial Black Holes!



CONCLUSIONS AND OUTLOOKS

- **We scan the parameter space of thermal leptogenesis to identify the maximum Y_B attainable**
- **We derive the entropy injection for each choice of M_{PBH} and β'**
  - We quantify the dilution of the baryon asymmetry
  - We show that the presence of Primordial Black Holes alters the evolution of the $B - L$ asymmetry
  - We derive **mutual exclusion limits** in the combined parameter spaces.



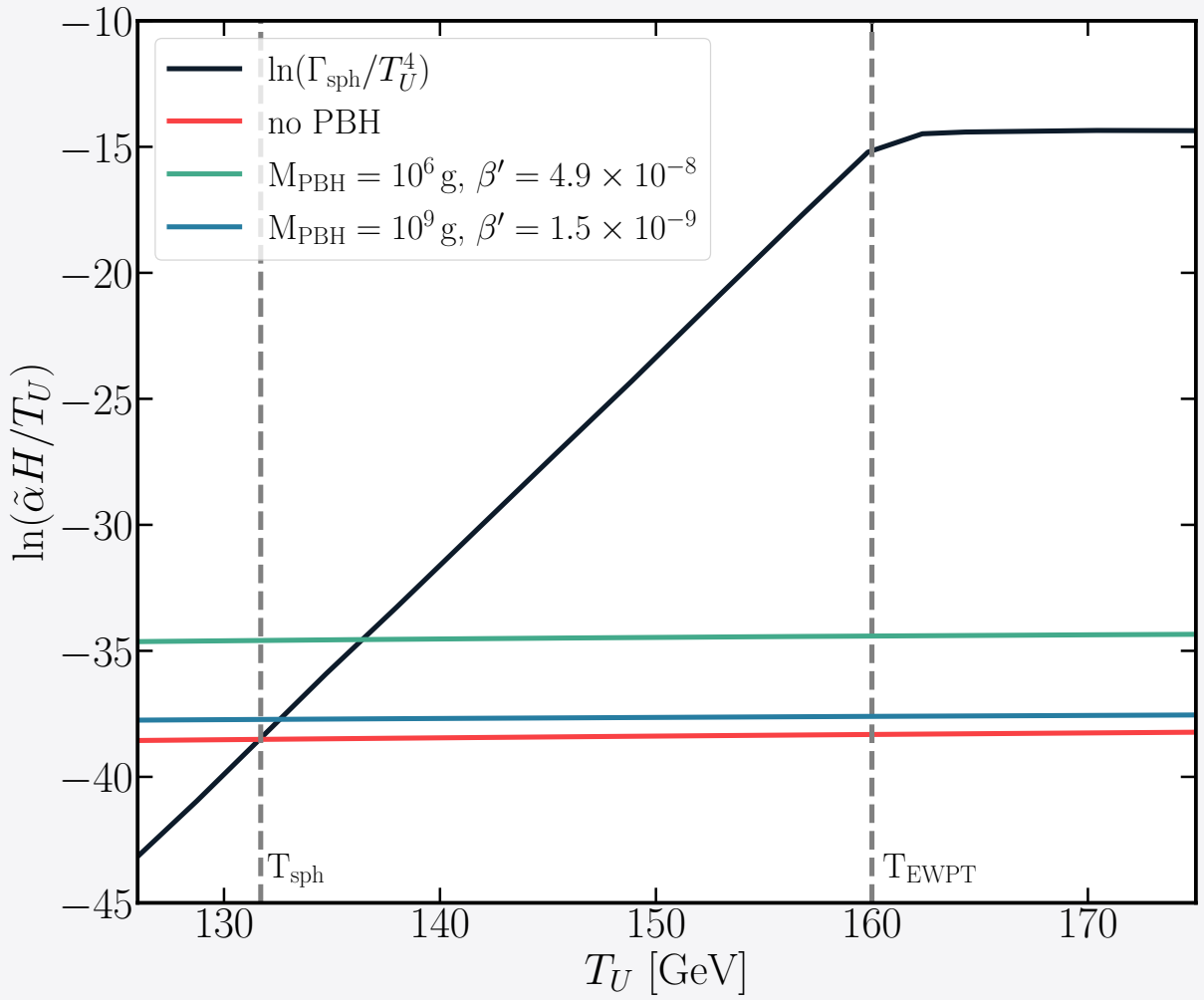
Thank you for your attention!

SPHALERON TRANSITION

The efficiency factor of sphaleron transitions depends on the temperature at which the processes freeze-out

$$Y_B = -\eta Y_{B-L}$$

$$\eta = \begin{cases} \frac{12}{37} & if\ T_{sph} < T_{EWPT} \\ \frac{28}{79} & otherwise \end{cases}$$



RC et al, PHYS. REV. D 107 (2023) 12, 123537