

Cosmological gravitational particle production and primordial black holes

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Objectives and motivations

- Dark matter that interacts only with gravity!
- Study the interplay among two different **gravitational** production mechanisms:

Primordial Black Holes (PBHs)

+

Cosmological Gravitational Particle Production (CGPP)

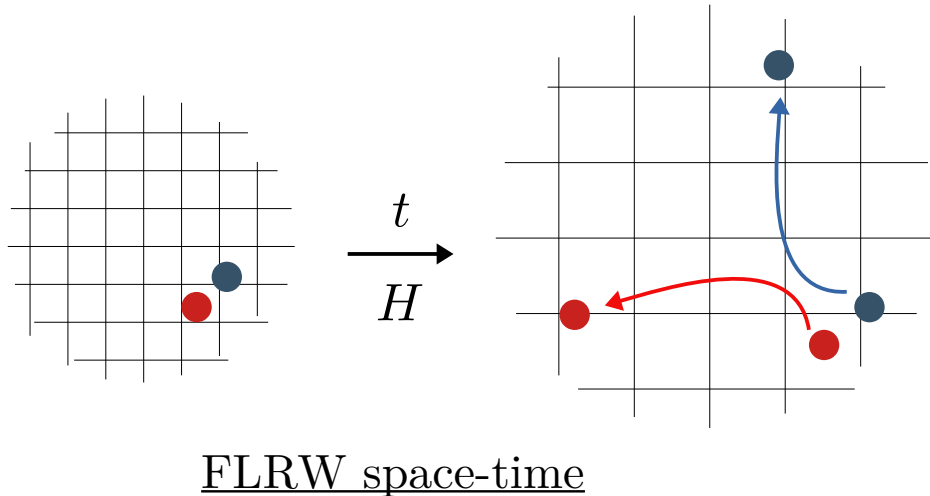
[Parker, 1968, 1969, 1971]

[Ford, 2021]

[Kolb, Long, 2023]

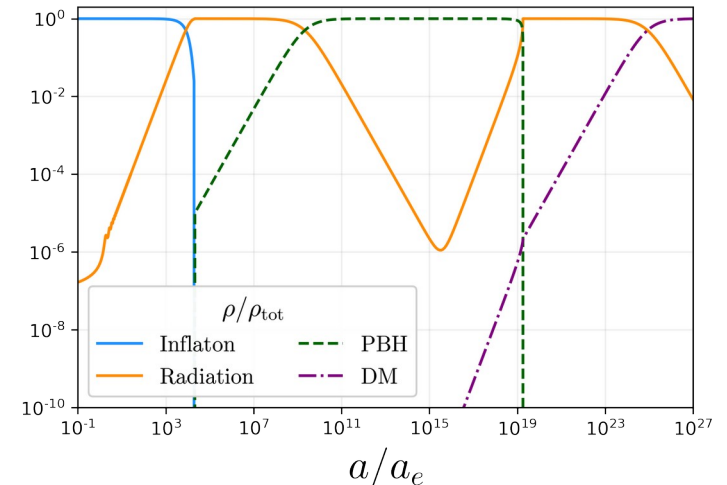
CGPP

- Particles that are produced by the expansion of the universe:



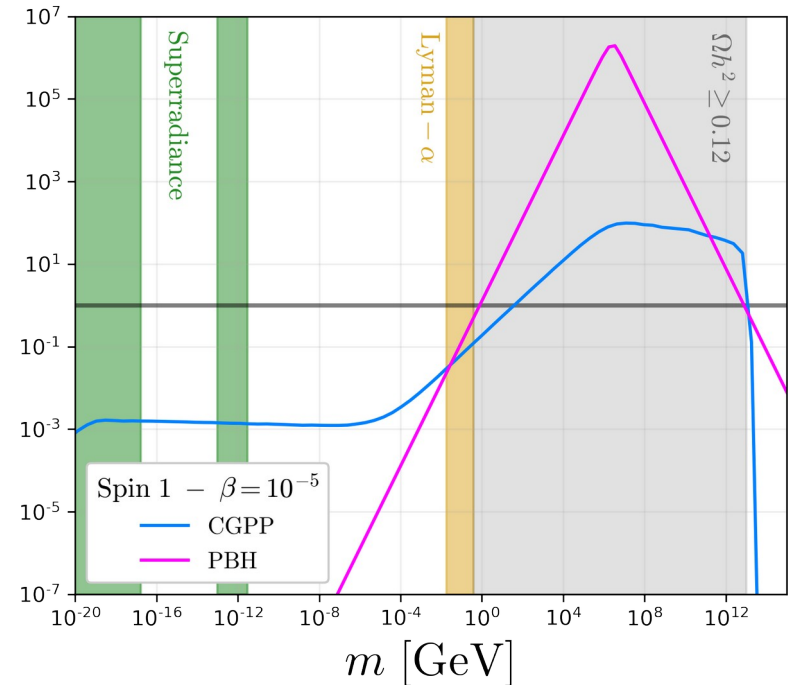
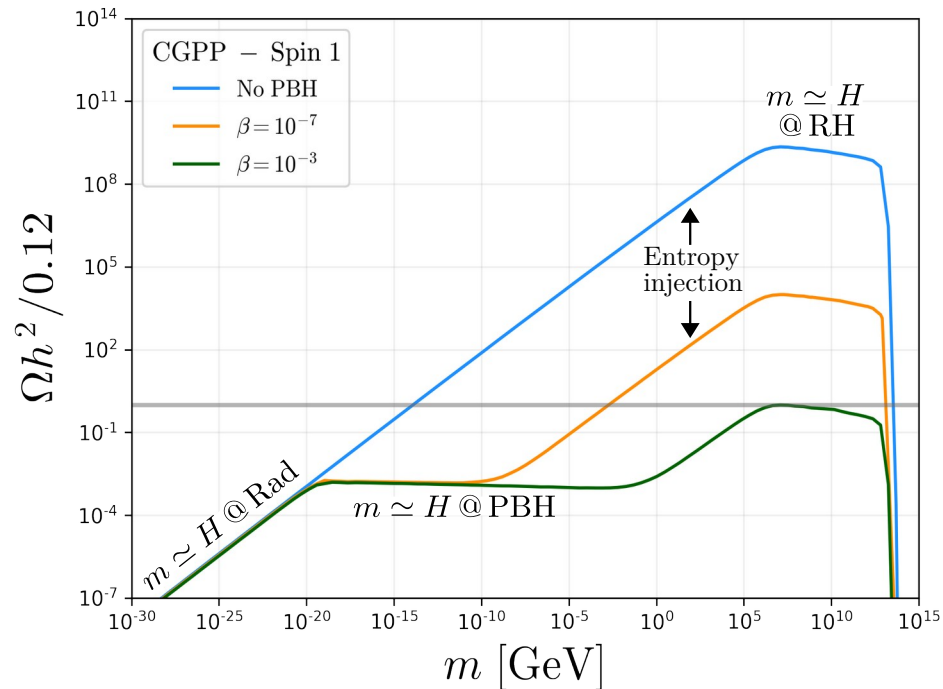
PBHs

- Black Holes from the early universe;
- Affect the cosmological evolution in many ways:



Results – Spin-1 DM

- CGPP and PBHs cannot be disentangled!



Conclusions

- PBHs can affect CGPP in an interesting and non-trivial way;
- This interplay deeply impacts the final DM abundance.

Thank you!
(and don't forget to check the poster!)

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Motivations

- Dark Matter can be purely gravitationally interacting;
- Two production mechanisms in this case are
 - 1) *Cosmological Gravitational Particle Production* (CGPP);
 - 2) Evaporation of *Primordial Black Holes* (PBHs);
- Understand qualitatively and quantitatively the interplay between both mechanisms.

PBHs

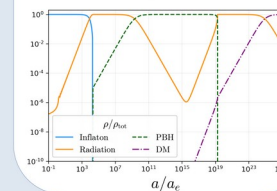
- Produced in the early universe by gravitational collapse of density perturbations;
- Characterised by mass and abundance:

$$M_{\text{PBH}} = \frac{4\pi\gamma}{3} \frac{\rho(T_i)}{H(T_i)^3}, \quad \beta = \frac{\rho_{\text{PBH}}(T_i)}{\rho(T_i)}$$
- Emit *all* particles via Hawking radiation → end up evaporating completely;
- Inject entropy in the plasma → dilution of Ωh^2 :

$$\frac{s(T \gtrsim T_{\text{ev}})}{s(T_{\text{ev}})} \simeq \left(1 + \beta \frac{T_i}{T_{\text{ev}}}\right)^{3/4}$$

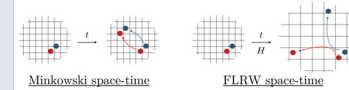
Cosmology

- Standard cosmological history:
Inflation → Reheating → Radiation
- PBHs can dominate the energy density for sufficiently large beta:



CGPP

- Particles produced from the expanding universe!
- Particle-antiparticle pairs from vacuum are drifted apart (efficient as long as $m \lesssim H$):



Minkowski space-time FLRW space-time

- We solve the EoM in FLRW background,

$$\chi_k''(\eta) + \omega_k^2(\eta)\chi_k(\eta) = 0, \quad d\eta = dt/a(t),$$
 for each comoving momentum mode k ;

- Time and spin dependent frequency:

$$\text{Spin 0: } \omega_k^2(\eta) = k^2 + a^2 m^2 + \left(\frac{1}{6} - \xi\right) a^2 R$$

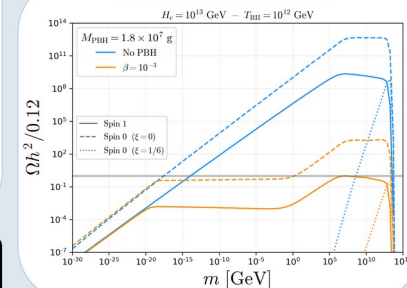
$$\text{Spin 1: } \omega_k^2(\eta) = k^2 + a^2 m^2 + \frac{k^2 a^2 R/6}{k^2 + a^2 m^2} + \frac{3k^2 a^4 m^2 H^2}{(k^2 + a^2 m^2)^2}$$

- We can solve for the comoving number density:

$$|\beta_k|^2 = \frac{\omega_k}{2} |\chi_k|^2 + \frac{|\chi_k'|^2}{2\omega_k} - \frac{1}{2} \quad (\text{Bogoliubov})$$

$$\Rightarrow n a^3 = \int_0^\infty \frac{dk}{k} \frac{k^3 |\beta_k|^2}{2\pi^2} \Big|_{\eta \rightarrow \infty}$$

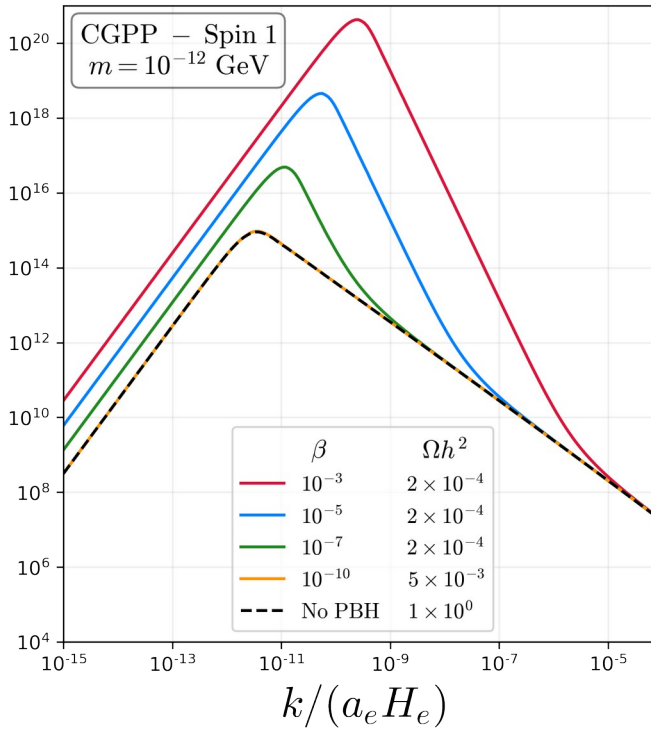
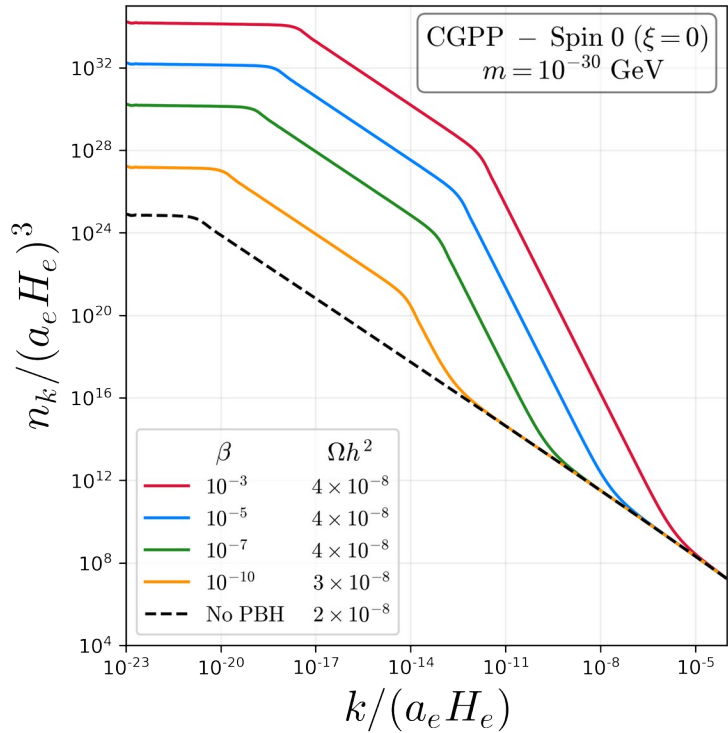
Results



Backup - CGPP

- Equations of motion: $\chi_k''(\eta) + \omega_k^2(\eta)\chi_k(\eta) = 0$
- Spin 0: $\omega_k^2(\eta) = k^2 + a^2m^2 + \left(\frac{1}{6} - \xi\right) a^2 R$
 - $\xi = 0$ is minimal coupling
 - $\xi = 1/6$ is conformal coupling
- Spin 1: $\omega_k^2(\eta) = k^2 + a^2m^2 + \frac{k^2 a^2 R/6}{k^2 + a^2m^2} + \frac{3k^2 a^4 m^2 H^2}{(k^2 + a^2m^2)^2}$

Backup - Results – Momentum spectrum

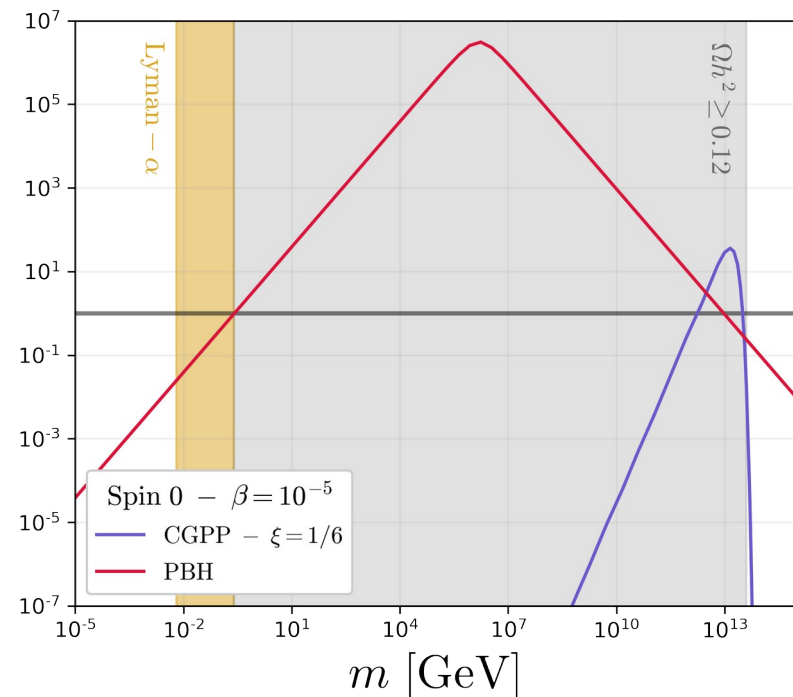
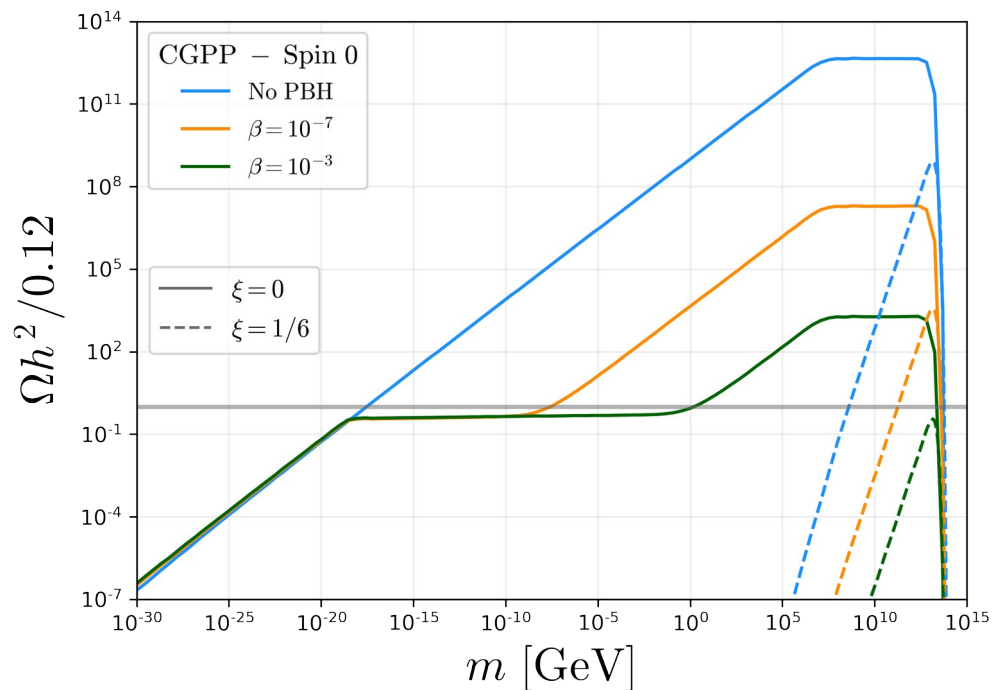


- Number per comoving momentum:

$$n_k = \frac{k^3}{2\pi^2} \times \left[\frac{\omega_k}{2} |\chi_k|^2 + \frac{|\chi'_k|^2}{2\omega_k} - \frac{1}{2} \right]$$

Backup - Results – Spin 0

- Minimally coupled strongly constrained by isocurvature



Backup - PBH production

- PBHs generated by ultra-slow roll of inflaton field:

$$V(\Phi) \rightarrow V(\Phi)(1 + \epsilon(\Phi)), \quad \epsilon(\Phi) = A \exp \left[-\frac{(\Phi - \Phi_0)^2}{\sigma^2} \right]$$

- Only mild effect in the reheating plateau:

