Impacts of Primordial Black Holes on IGM History

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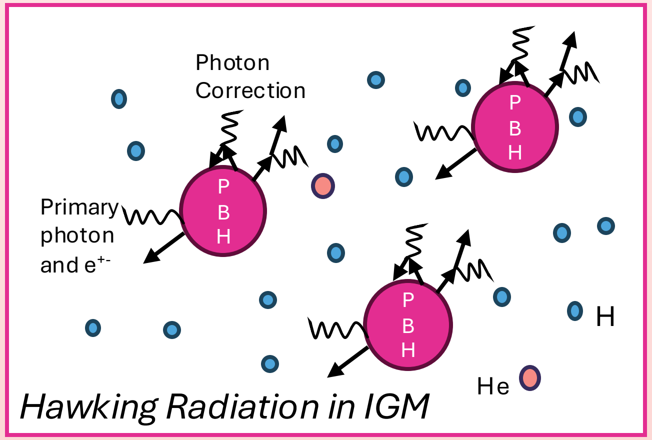
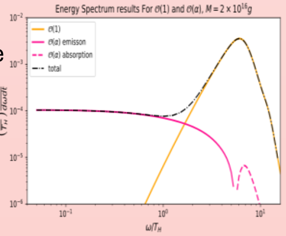


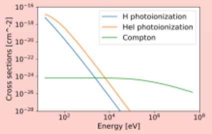
Background Info

Proposed DM Model: All DM is in the form of primordial black holes (PBHs) of mass 2.12 x 10^{16} g.



Hawking radiation (HR): First order interactions model comes from full perturbative QED first order calculation on Schwartzchild background **[1,2]**

Radiation energy range spans from ~10eV to ~10MeV.



Intergalactic medium (IGM) Information: Includes Hydrogen and Helium effects, and allows for low energy photoionization and higher energy Compton scattering.

References

[1]Silva, M., Vasquez, G., **Koivu, E.**, Das, A., & Hirata, C. M. 2023). PRD, 107(4), 045004.

[2] **Koivu, E.**, Kushan, J., Silva, M., Vasquez, G., Das, A. and Hirata, C.M. (2025). PRD, 111(4), 045011

Project Outline

Hawking Radiation from PBH encounters IGM

	Ionize	Heat	Excite
Ways of changing IGM history	Ionize	Heat	Excite (Still in progress)
Calculation Method	Calculate photons radiated by PBH (directly from HR and from secondary ionizations after other interactions)	Allow for Compton scattering and photoionization heating effects off gas in universe	Allow for Compton scattering and photoionizing excitation effects off Hydrogen which lead to Lyman alpha photons
Measurement Probe	Compare this number of photons to number of baryons in the universe	Calculate kinetic gas temperature history	Calculate 21cm spin temperature and differential brightness

Semi-analytic Calculations

Ionizing photons

$$\dot{N}_\gamma(z) = \int (1 - e^{-\tau(z)}) \frac{dN_\gamma}{d\omega dt}(1 + f_{\rm sec}(\omega))d\omega + \int \frac{dN_e}{dhdt} n_{\rm compt} p_{\rm compt} dh.$$

Photons radiated by PBH that interact with IGM in a Hubble radius boosted by secondary ionizations and e from HR which Compton scatter and generate tertiary electrons

Energy Injection:

$$\dot{E}_{i,j} = \int_0^\infty \frac{dN_\omega}{d\omega dt}(1 - e^{-\tau(z)})(E_i)[1 - f_{1,j}y_{1,heat} + f_{2,j}y_{2,heat}]p_{i,j}d\omega$$
$$i = \text{PI or Compt}$$
$$j = \text{H or He}$$

Sum over photons from HR that interact with IGM, including a correction factor that indicates fraction that goes into heating, and multiply by a branching ratio of species and processes and the associated energy

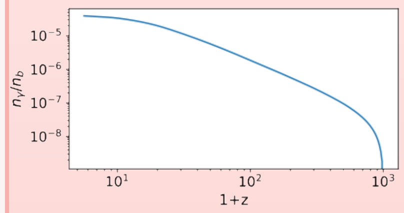
Kinetic gas temperature calculation:

$$\frac{dT_K}{dz} = \frac{-2T_k}{1+z} + \frac{x}{1+x}\frac{8\sigma_T a T_{CMB}^4}{3m_e c^2(1+z)H(z)}(T_{CMB} - T_K) + \frac{\dot{T}_{PBHs}}{(1+z)H(z)} + \frac{\dot{T}_{stellar}}{(1+z)H(z)}$$

Our modifications go here

Preliminary Results

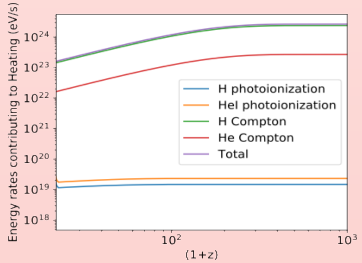
Ionization History

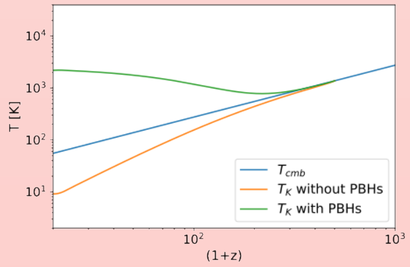


We find the total number of ionizations per baryon produced directly by HR or through secondary effects to peak at 10^{-5} per baryon. Therefore, we do not expect these PBHs to impact the ionizing history.

Thermal History

To characterize our results, we investigated which species and type of interaction contributed the most to heating over time. We find that the high energy Compton scattering is dominant until after reionization.





By propagating these energy rates into the kinetic gas temperature equation, we can calculate the temperature with and without the PBH heating. We find the early addition of PBH energy gives a boost to the temperature around the decoupling redshift (z~130). This boost allows the gas to efficiently heat and maintain much higher temperatures than the CMB even as the universe expands, unlike the scenario without PBHs.

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