Hunting Primordial Black Hole Dark Matter in the Lyman-α forest

https://arxiv.org/abs/2409.10617
(Submitted to PRD)

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This work is done in collaboration with:

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Dr. Priyank Parashari

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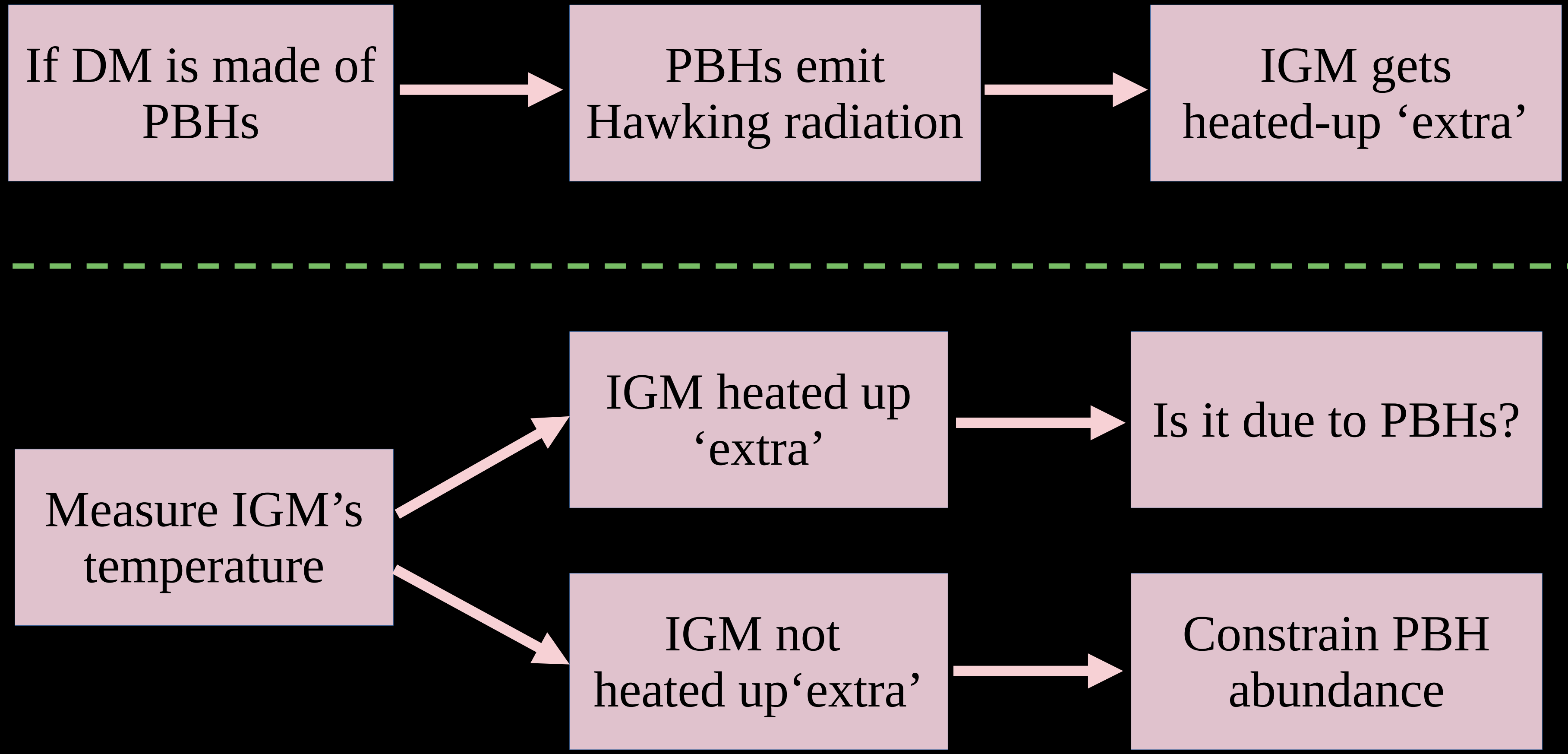
The bird's eye view



What is everything made of?

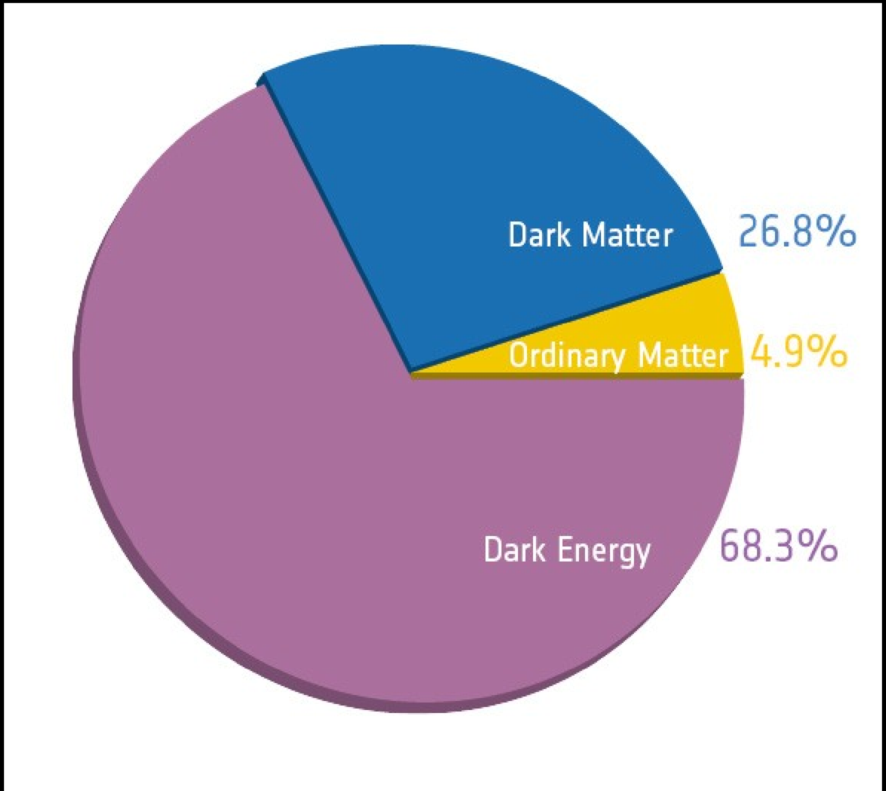


Image credit: Planck/ESA

Primordial Black Holes 101

- Black Holes formed in the early universe from the collapse of high matter-overdensities.

  - The same overdensities that form galaxies at larger scales, being not as high.

- Many mechanisms for their production exist in literature.

  - Including some that don’t rely on the canonical overdensities produced by inflation.

- They can be formed having a wide range of masses.

- They can be formed with non-zero spins also.

Primordial Black Holes 102

- PBHs would be non-relativistically moving today.
- They would hardly interact with baryons except through gravitation.
- They can be stable over cosmological timescales.
- Do not contribute to the baryonic matter density.

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Smells like Dark Matter?

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Smells like Dark Matter?

- Can form in the right abundance to constitute dark matter completely/significantly!

Observational constraints on PBHs

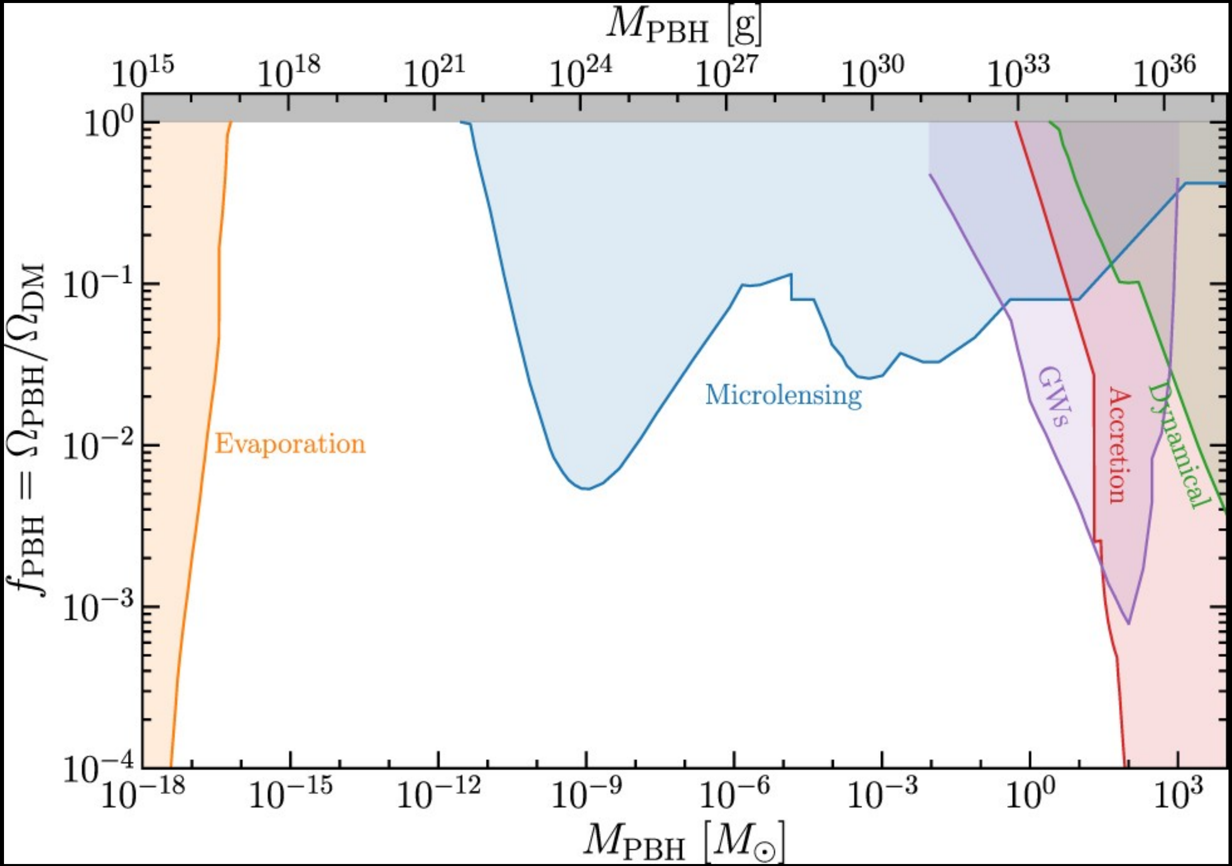

Image credit: https://arxiv.org/pdf/2402.15211

Hawking tell us that Black Holes have temperature

$$T = \frac{\hbar c^3}{8\pi G k_B M}$$

$$T \propto \frac{1}{M}$$

Hawking evaporation of Black Holes

BHs are near-blackbodies.

$\hbar = c = k_B = G = 1$

The spectrum of Hawking radiation by non-spinning black holes is given by:

$$\frac{d^2 N_{i,lm}}{dt dE} = \frac{1}{2\pi} \frac{\Gamma_{s_i lm}(E, M)}{e^{E/T} - (-1)^{2s_i}}$$

Graybody factors.

Encode deviation from blackbody spectrum.

Graybody factors have to be calculated numerically. We use the code `BlackHawk v2.0`.

The spectrum is different for spinning BHs, which is also computed using `BlackHawk v2.0`.

Hawking radiation spectra when black hole spins

For spinning Black Holes, it turns out that the temperature depends on the spin too.

$$T = \frac{1}{4\pi M}\left(\frac{\sqrt{1 - a^{*2}}}{1 + \sqrt{1 - a^{*2}}}\right)$$

where, $a^* = \frac{J}{M^2}$ is the dimensionless spin parameter.

See https://arxiv.org/pdf/1905.04268

Hawking radiation spectra when black hole spins

For spinning Black Holes, the Hawking radiation spectrum is given by:

$$\frac{d^2 N_{i,lm}}{dtdE} = \frac{1}{2\pi} \frac{\Gamma_{s_i lm}(E, M, \Omega)}{e^{(E-m\Omega)/T} - (-1)^{2s_i}}$$

where,

$$\Omega = 4\pi J/MA$$

$$A = 8\pi M \left(M + \sqrt{M^2 - \frac{J^2}{M^2}} \right)$$

See https://arxiv.org/pdf/1905.04268

What Hawking radiation does to IGM's temperature

- Exotic energy injection changes temperature and ionization history of the IGM.
- Only the photons and electrons/positrons injected in the IGM are important to consider.
- Primary as well as secondary electrons/positrons important.
- Injected particles don't deposit energy instantaneously, but cool over cosmological timescales.

What Hawking radiation does to IGM's temperature

The following differential equations have to be solved simultaneously:

$$\dot{T} = \dot{T}^{(0)} + \dot{T}^{\mathrm{inj}} + \dot{T}^{\mathrm{re}}$$

$$\dot{x} = \dot{x}^{(0)} + \dot{x}^{\mathrm{inj}} + \dot{x}^{\mathrm{re}}$$

where T is Temperature, and x is the ionization fraction of hydrogen n_{HII}/n_H.

We solve these equations using the code `DarkHistory`.

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We modify the code `DarkHistory` to and solve these equations for evaporating black holes .

We obtain $T(z)$

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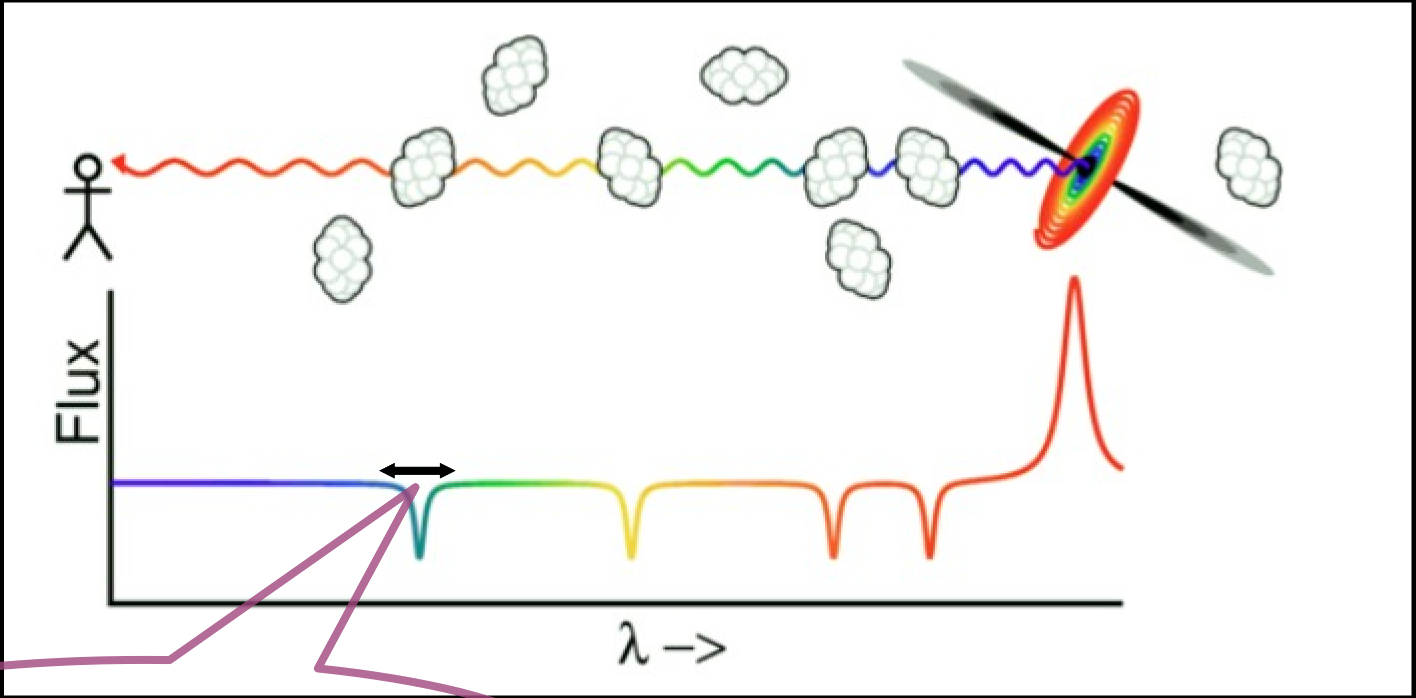
But how to measure the actual $T(z)$?

How to measure IGM's temperature: Lyman-α Forest



Width of the absorption features contains information of temperature

Image credit: https://astro.ucla.edu/~wright/Lyman-alpha-forest.html

Lyman-α Forest

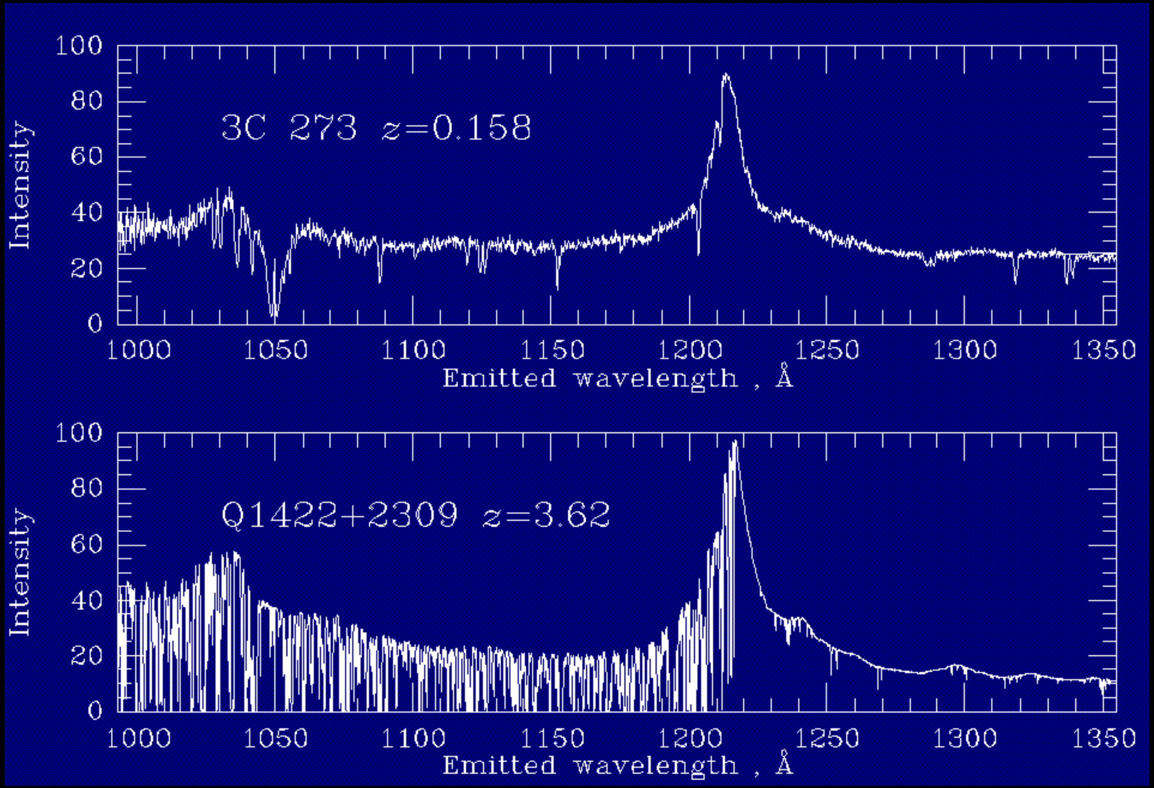
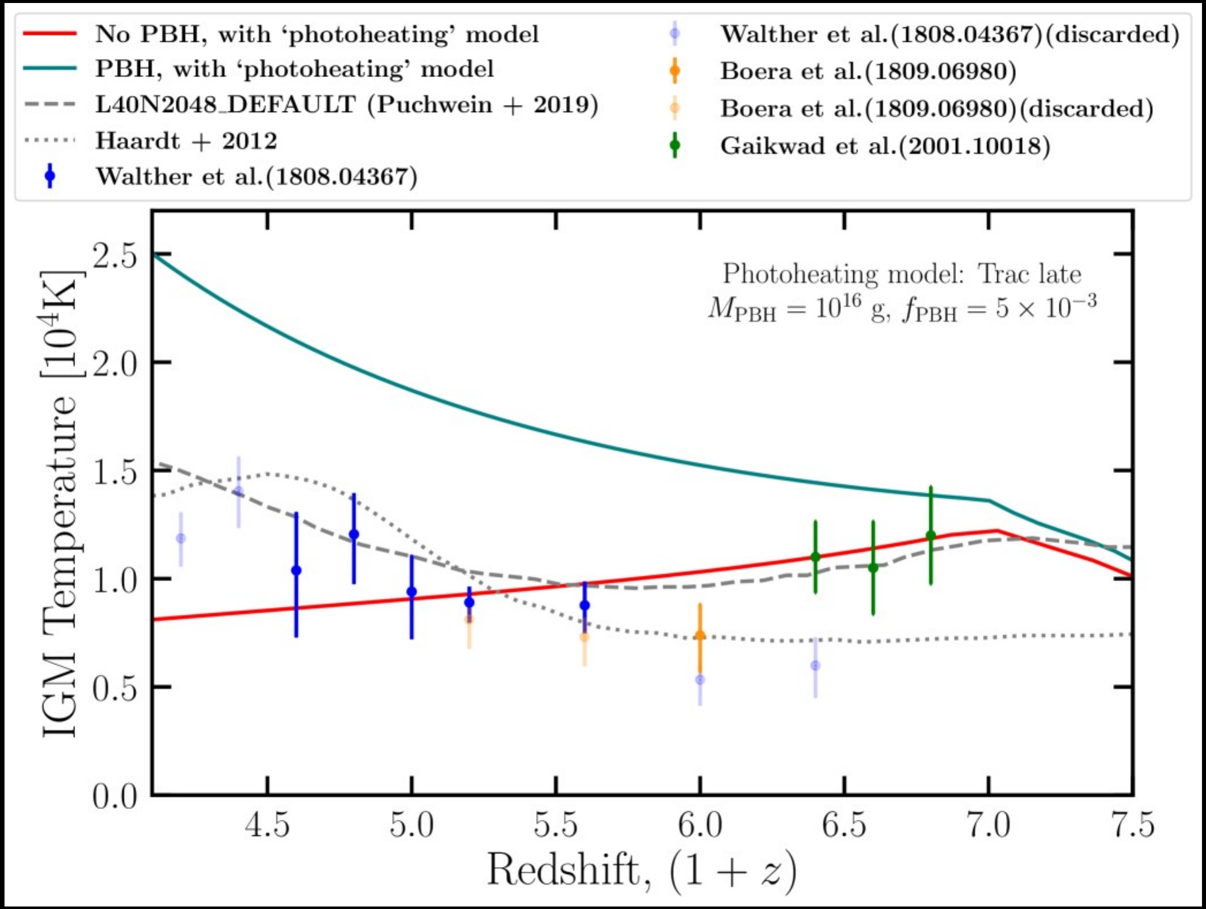


Image credit: https://pages.astronomy.ua.edu/keel/agn/forest.gif

Results



Saha, AS, Parashari, Laha

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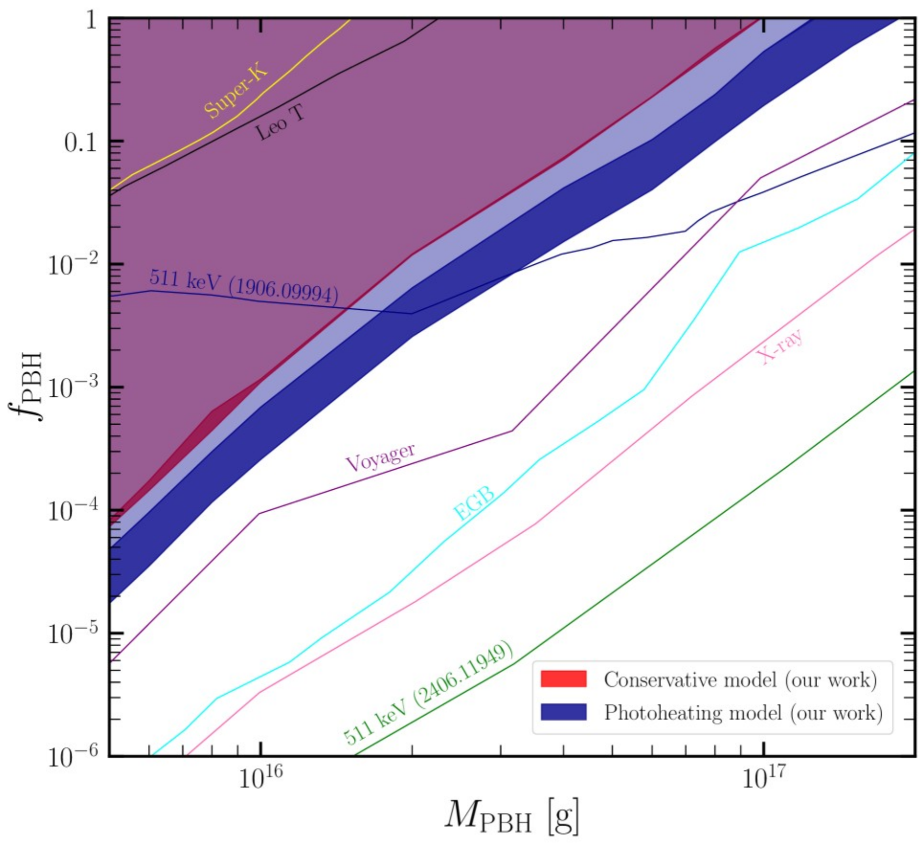

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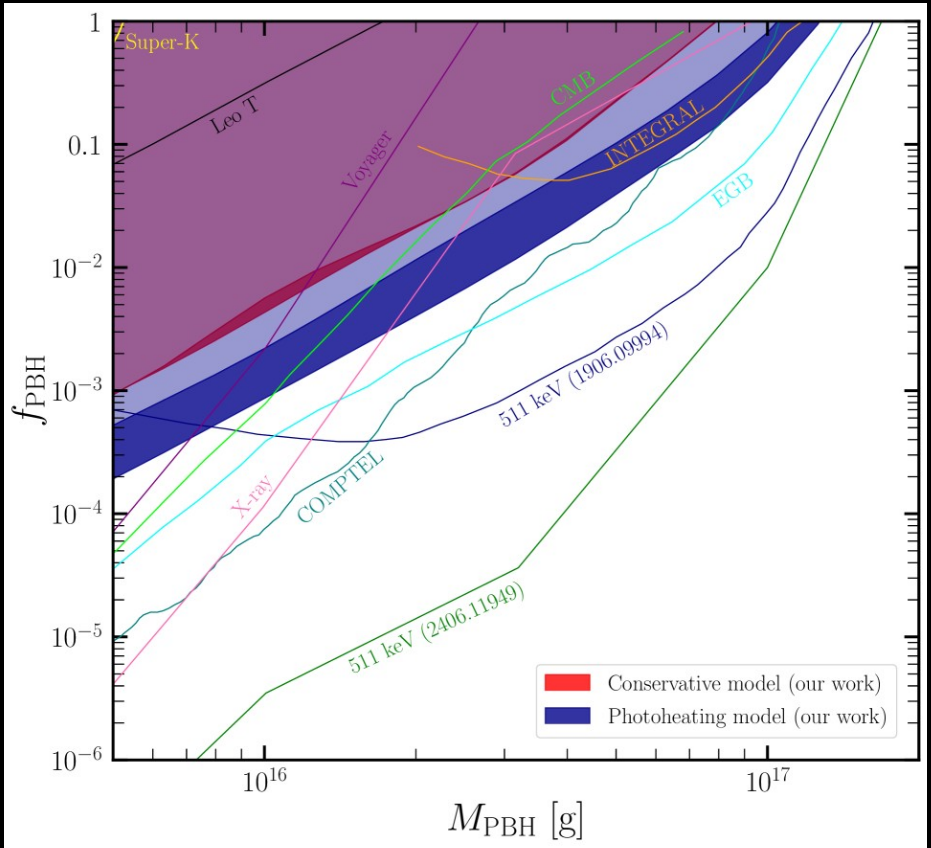

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Summary

- Black Holes formed early in the universe, a.k.a Primordial Black Holes can constitute all/part of Dark matter.
- Hawking evaporation of light PBHs can lead to direct and indirect observable consequences, providing a way to constrain these beasts.
- Hawking evaporation spectrum utilized to calculate its effect on the evolution of Inter-galactic medium's temperature.
- The temperature of the IGM has been measured at some redshifts using the Lyman-α spectroscopy.
- By comparing the calculated temperature evolution of IGM assuming evaporating PBHs' existence with the measured temperatue values leads to upper limits on fraction of Dark Matter in the form of PBHs.

See the paper

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