Embedding primordial black holes in the early universe: theory and phenomenological applications of cosmological metrics to PBH dark matter binary abundance constraints and evaporation limits on asteroid-mass candidates

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Zachary S.C. Picker

Dunking PBHs in Cosmological Baths

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PBHs as dark matter

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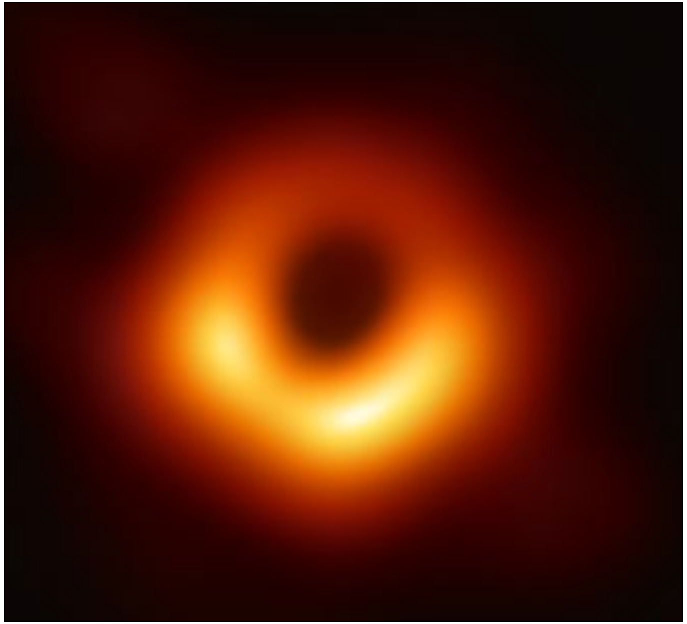
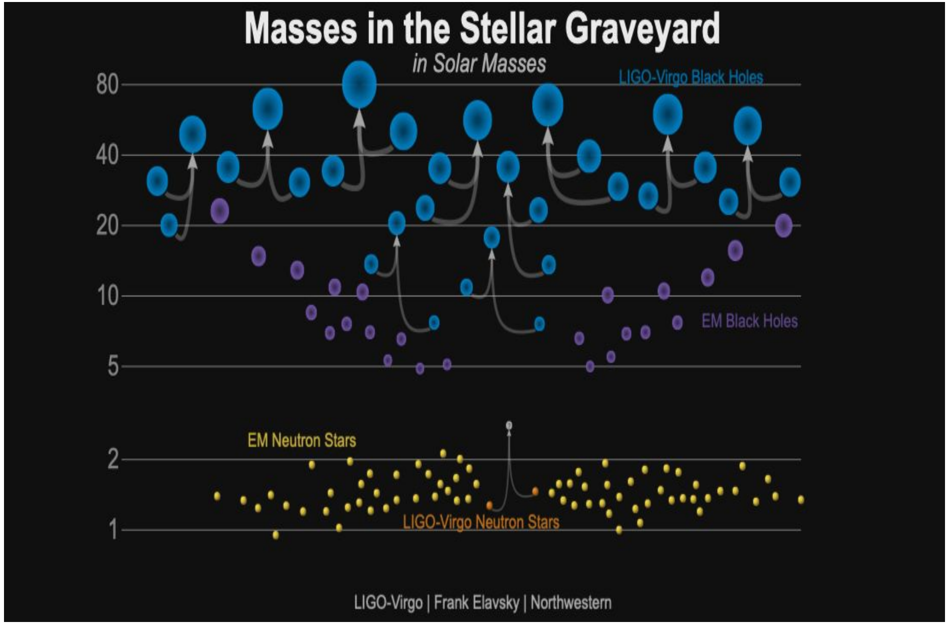
PBHs as dark matter





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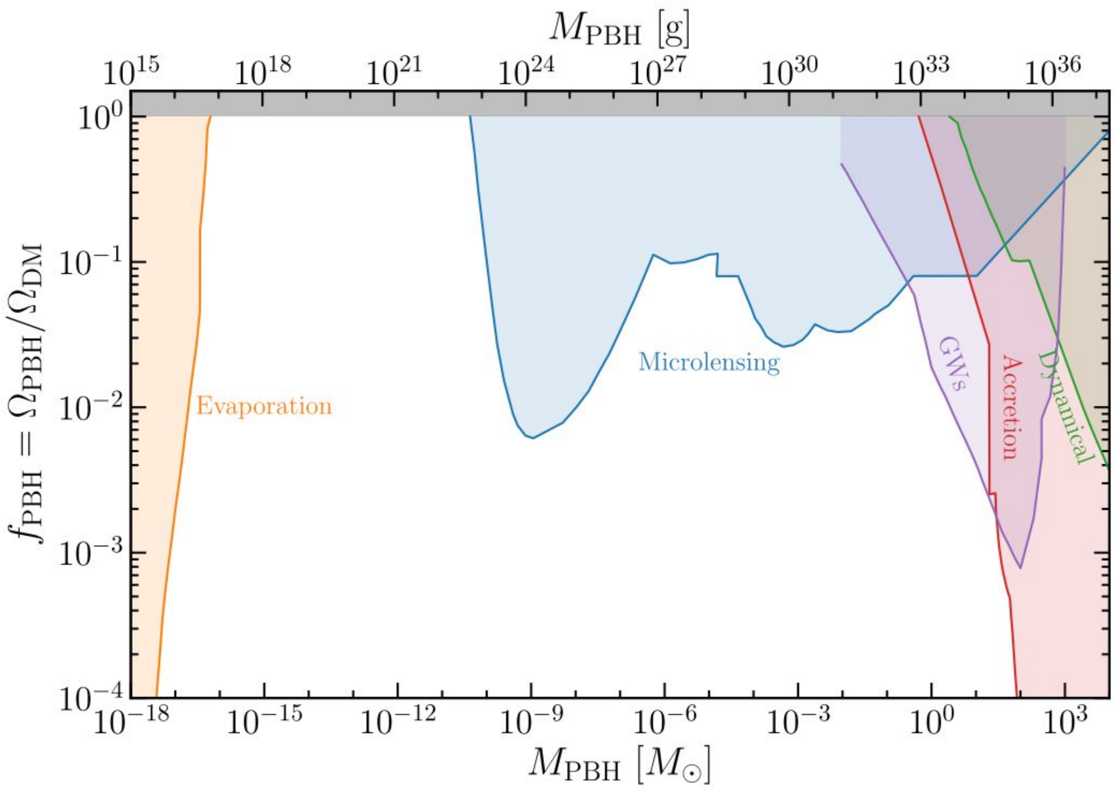
PBHs as dark matter



Green & Kavanaugh, 2020

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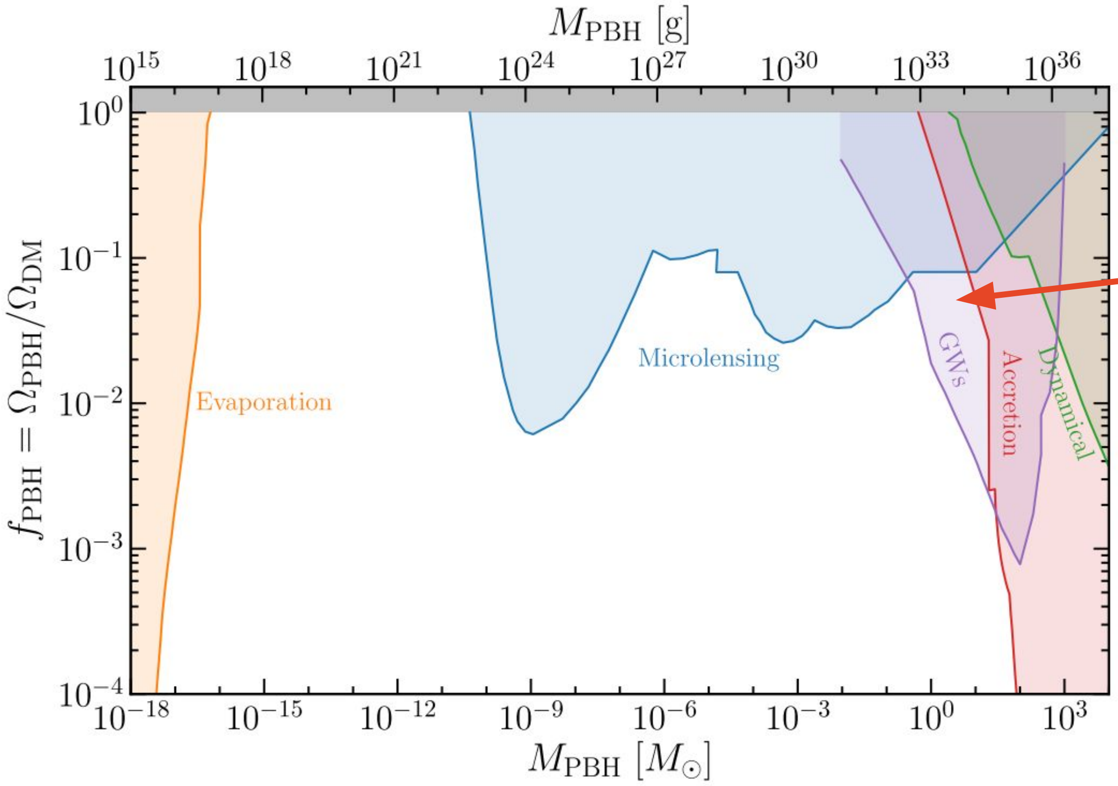

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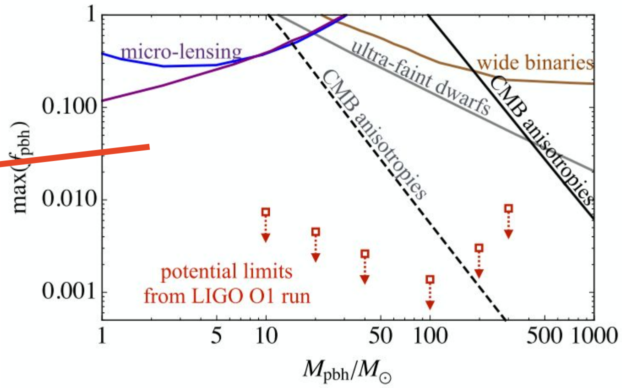

Y. Ali-Haïmoud, E. D. Kovetz, and M. Kamionkowski, Phys. Rev. D **96**, 123523 (2017), arXiv:1709.06576 [astro-ph.CO].

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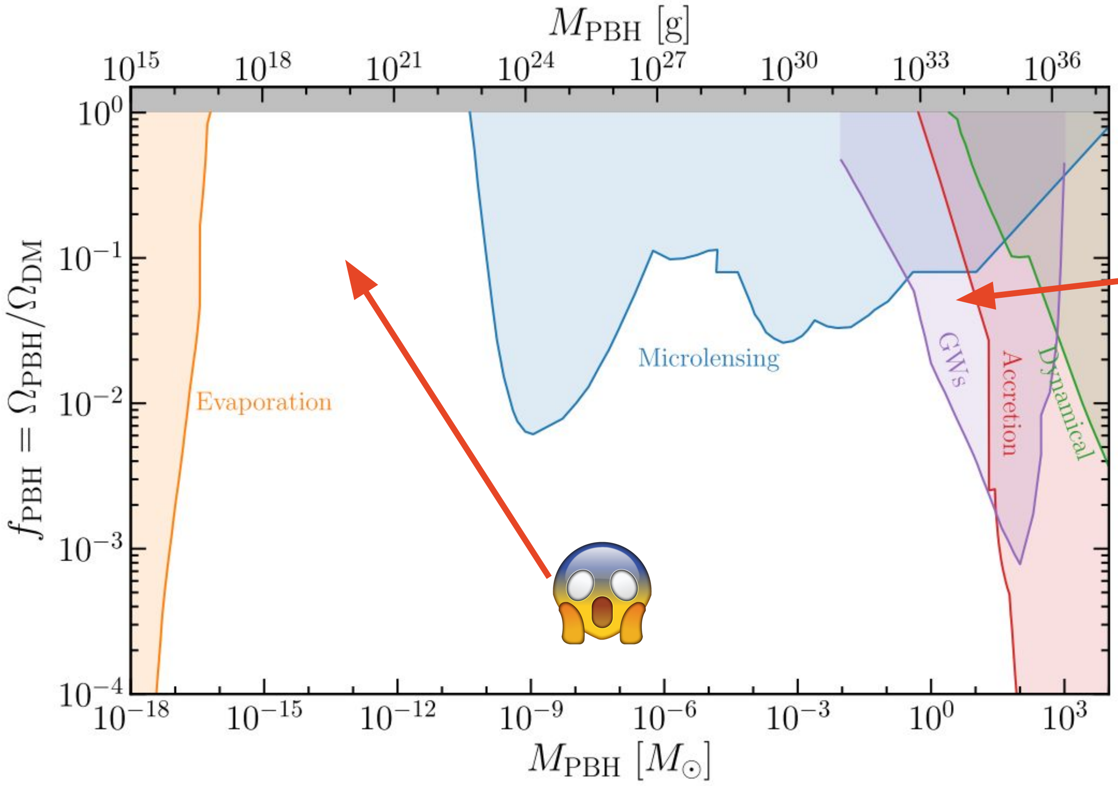

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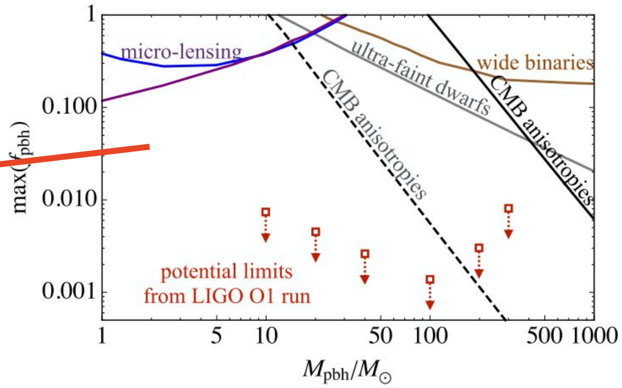

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Schwarzschild metric?

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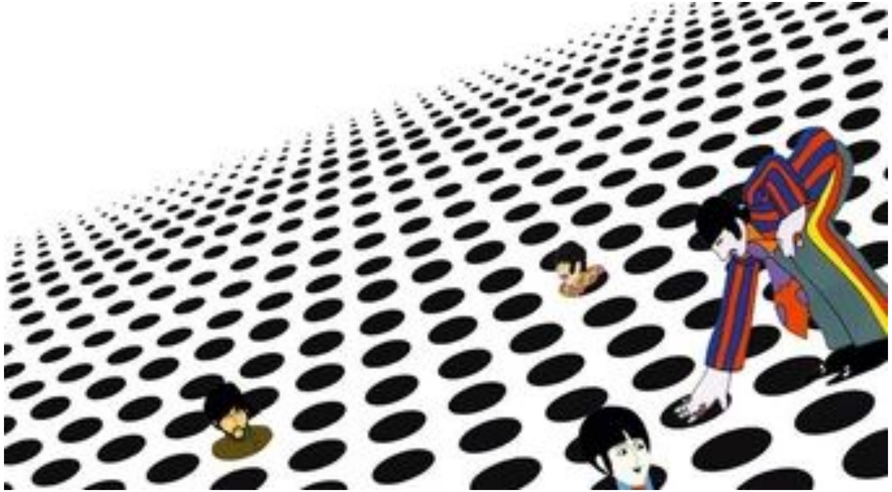

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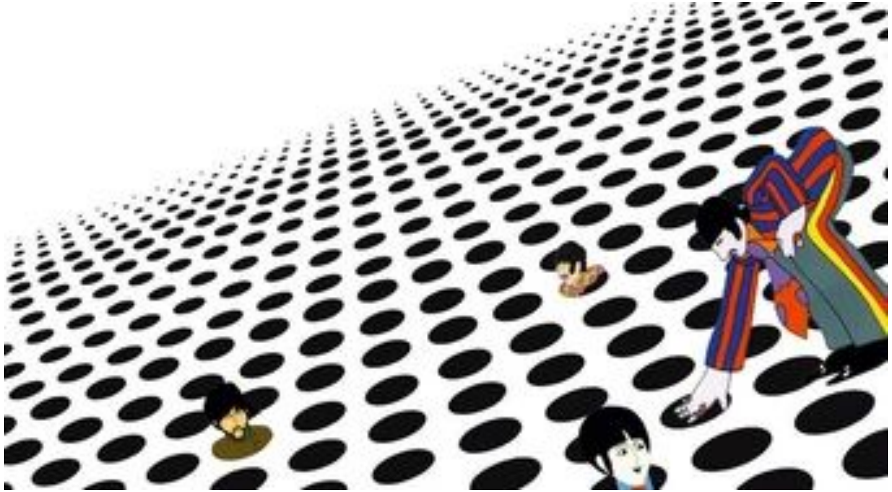

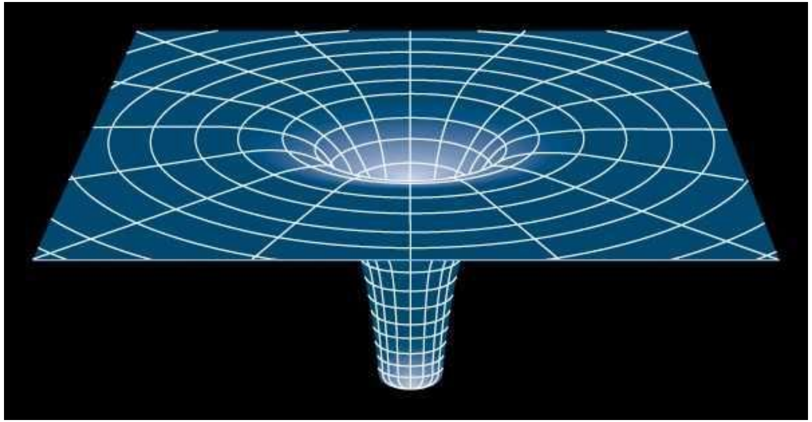

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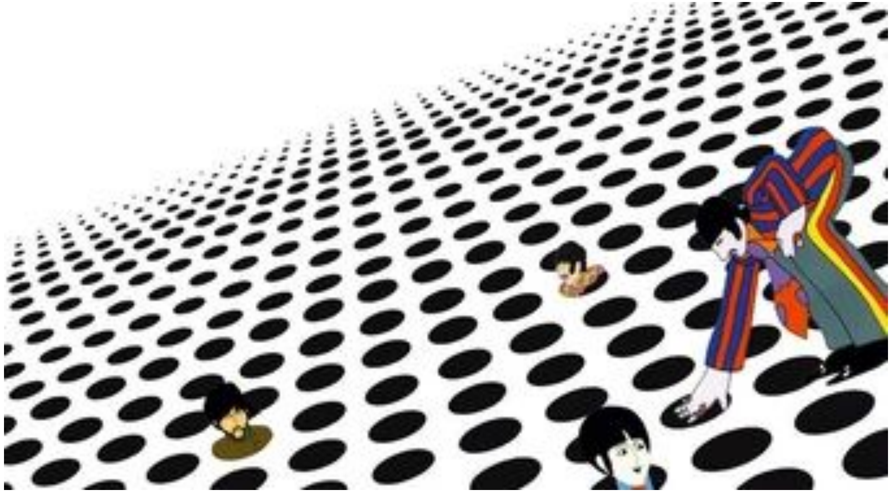

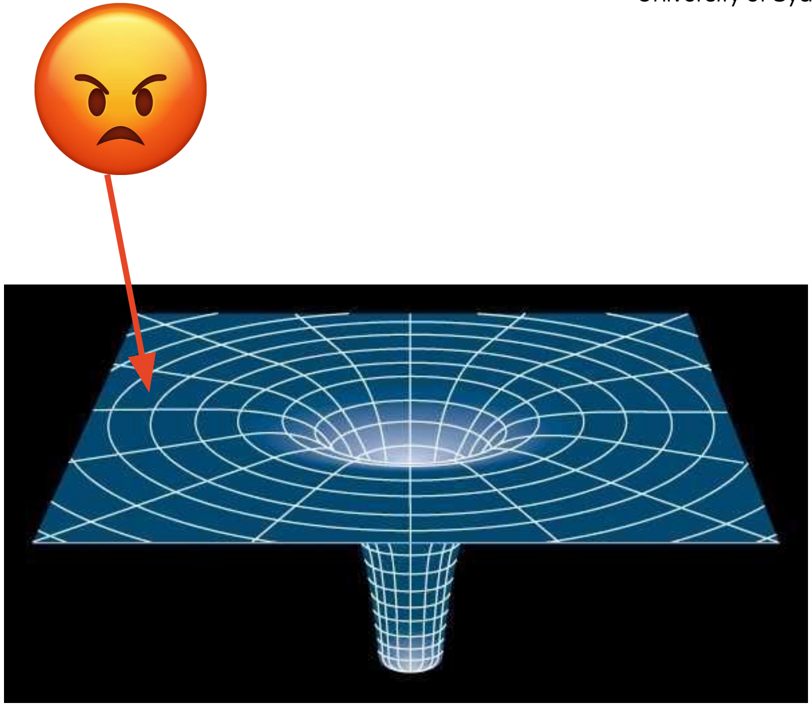

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Cosmological metrics

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Cosmological metrics

Einstein-Strauss ("Swiss Cheese Vacuole")

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Cosmological metrics

Einstein-Strauss (“Swiss Cheese Vacuole”)

McVittie metric

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Cosmological metrics

Einstein-Strauss (“Swiss Cheese Vacuole”)

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McVittie metric

Generalized McVittie metrics

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Thakurta metric

- Attractor solution

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Thakurta metric

- Attractor solution
- Simple + elegant:

$$ds^2 = a^2 ds^2_{schw.}$$

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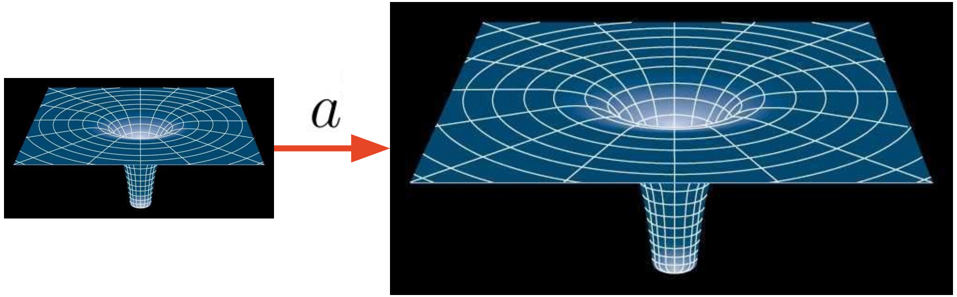
Thakurta metric

- Attractor solution
- Simple + elegant:

$$ds^2 = a^2 ds^2_{schw.}$$

- Local effective mass/ apparent horizon:



Binary abundance constraints

Prepared for submission to JCAP

CPPC-2020-05

Eliminating the LIGO bounds on primordial black hole dark matter

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Abstract. Primordial black holes (PBHs) in the mass range (30–100) $M_\odot$ are interesting candidates for dark matter but are tightly constrained by the LIGO merger rate. In deriving these constraints, PBHs were treated as *constant* Schwarzschild masses. A careful analysis of cosmological black holes however leads to a time-dependent effective mass. This implies stricter conditions for binary formation, so that the binaries formed merge well before LIGO's observations. The observed binaries are those coalescing within galactic halos, at a rate consistent with LIGO data. This reopens the possibility of LIGO mass PBH dark matter.

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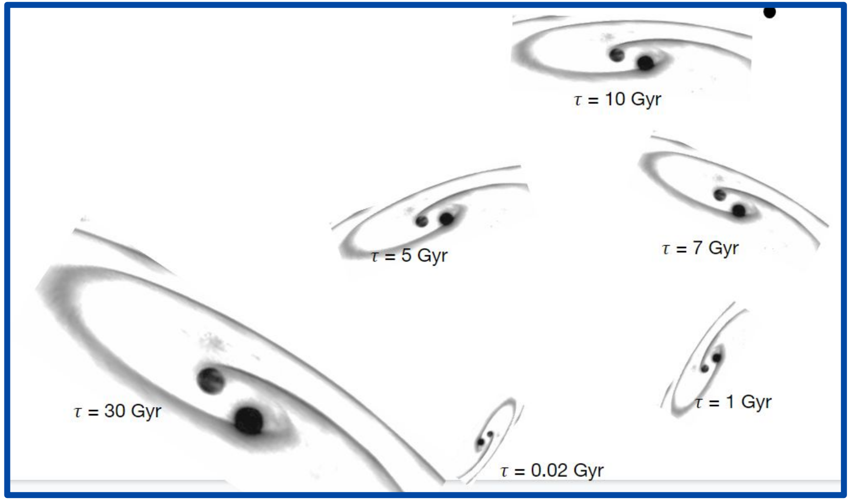
Binary abundance constraints

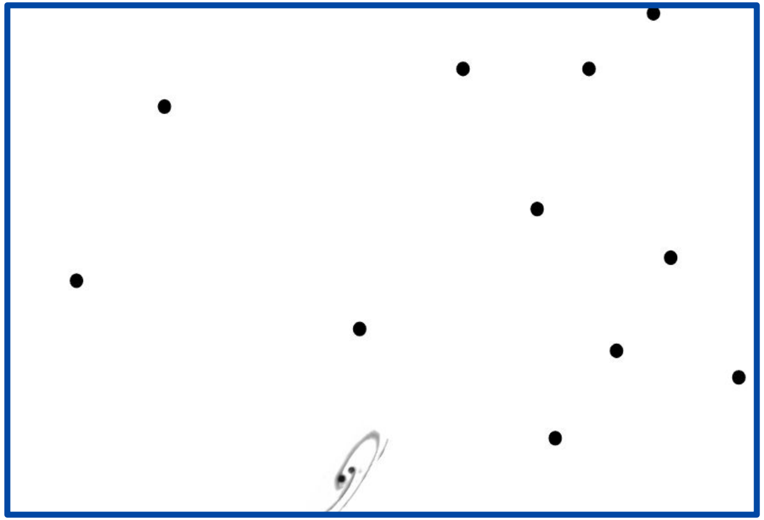
Previously

At matter-radiation equality:



Thakurta PBHs

At matter-radiation equality:



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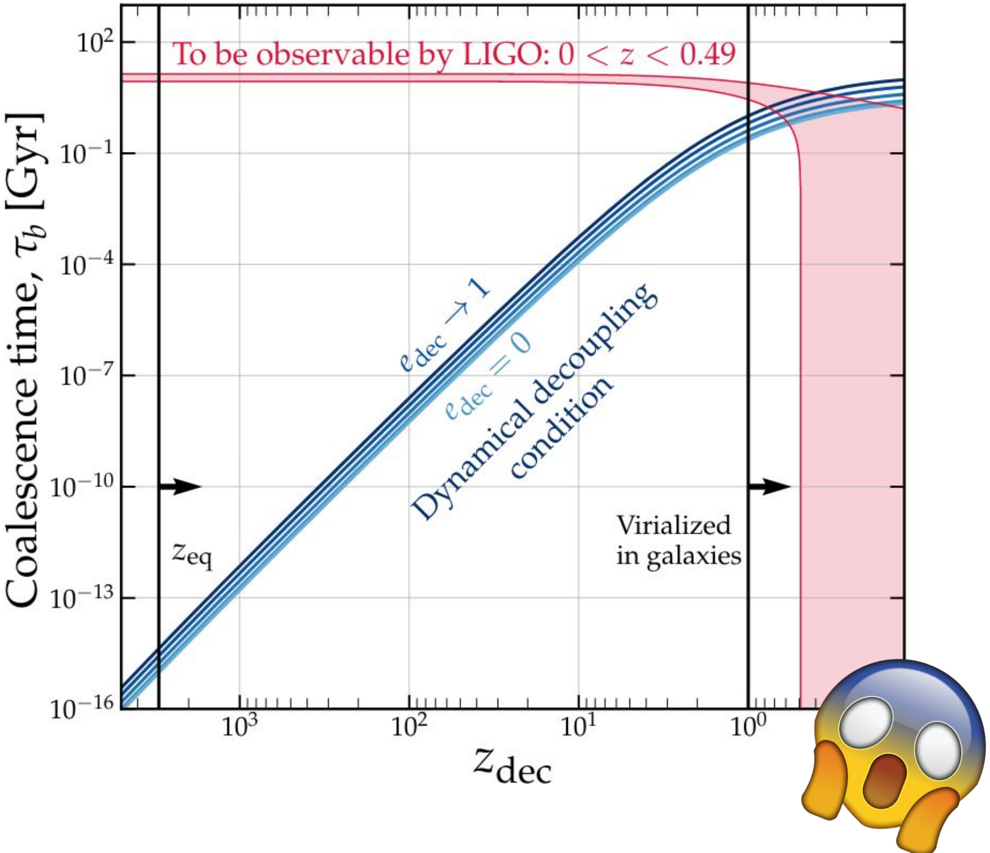
Binary abundance constraints



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Hawking radiation?

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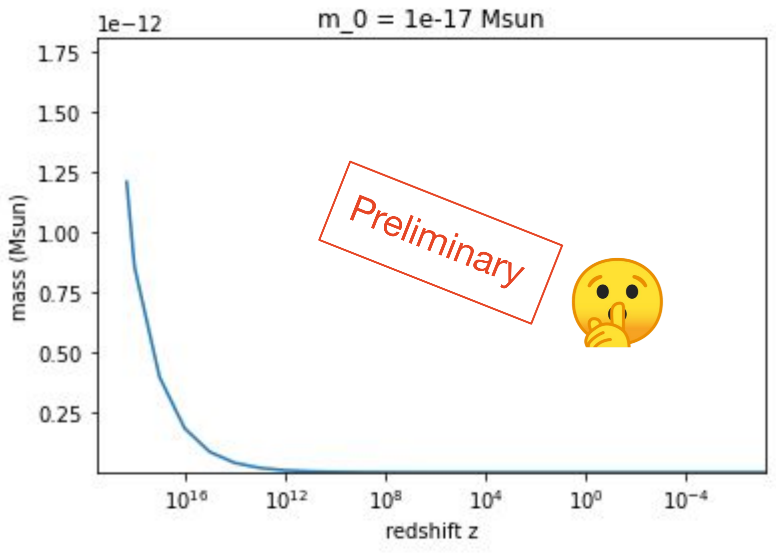

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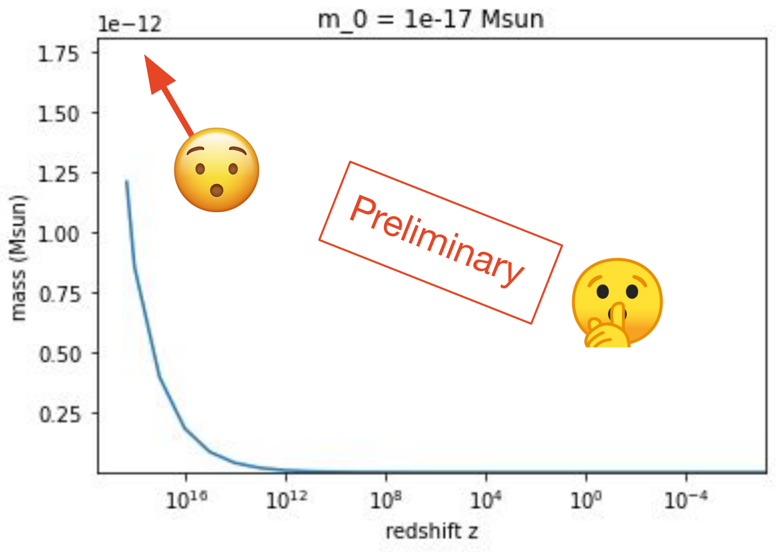

Carr et al, 2010

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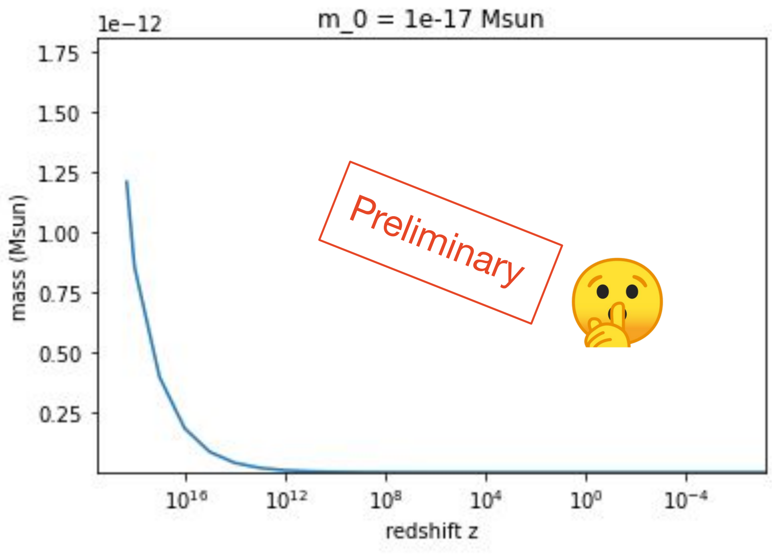

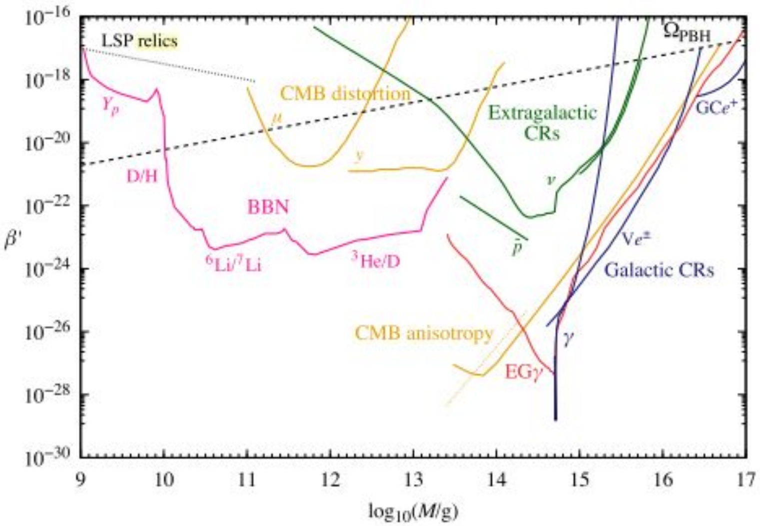

Carr et al, 2010

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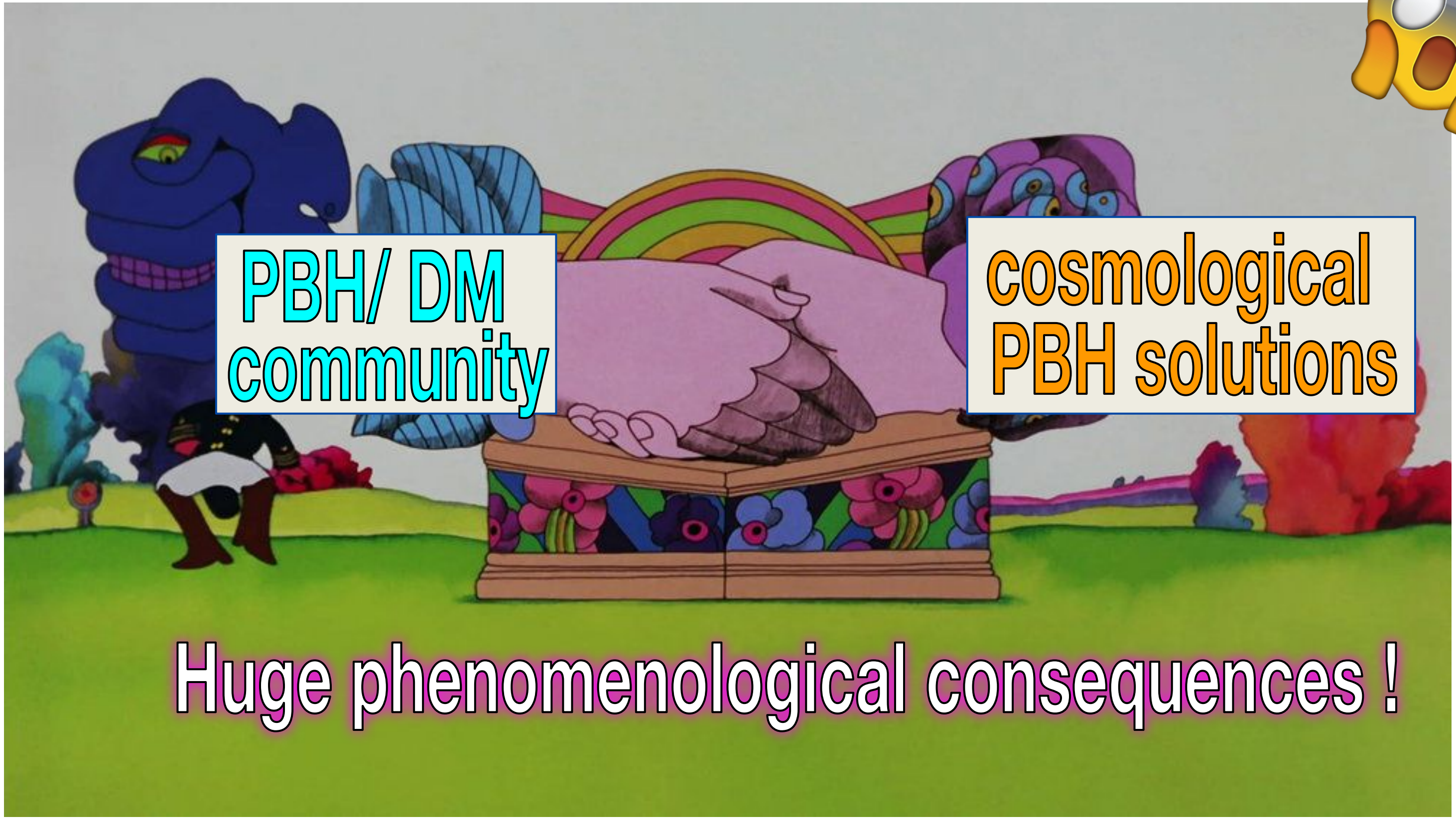
Morals and takeaways



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Morals and takeaways

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Actual physics: Thakurta metric

$$ds^2 = f(R)\left(1 - \frac{H^2 R^2}{f^2(R)}\right) dt^2 + \frac{2HR}{f(R)} dt\, dR - \frac{dR^2}{f(R)} - R^2\left(d\theta^2 + \sin^2\theta\, d\phi^2\right)$$

t -> new Kodama time t

$$ds^2 = \left(1 - \frac{2m(r,t)}{r}\right) dt^2 + \frac{dr^2}{1 - 2m(r,t)/r} + r^2 \left\{d\theta^2 + \sin^2\theta\, d\phi^2\right\}$$

Misner-Sharp mass: $m(r,t) = ma(t) + \frac{H^2 R^3}{2Gf(R)}$

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Actual physics: decoupling conditions

Previous:

$$\ddot{R} = \frac{\ddot{a}}{a}R - \frac{Gm}{R^2}$$

$$\frac{m}{V} \gtrsim \rho$$

Thakurta PBH:

$$\ddot{R} = -\frac{Gma}{R^2} + \frac{\ddot{a}}{a}R$$

$$\frac{ma(t)}{V} \gtrsim \rho$$

and

$$E = -GM\mu a^2/(2R)$$

$$\dot{R}/R = -\dot{E}/E + 2H$$

$$\dot{E}/E > 2H$$

$$(1+z_{\rm dec})^3 H(z_{\rm dec}) < \frac{1}{\tau_b}\frac{96}{425}\left(1 + \frac{73}{24}e_{\rm dec}^2 + \frac{37}{96}e_{\rm dec}^4\right)$$

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Actual physics: hawking radiation