

Constraints on Hubble Tension Alleviation Through Black Hole Superradiance

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1. The Hubble tension.
2. Black hole superradiance and its cosmological implications.
3. Results

Expansion and the Hubble Constant

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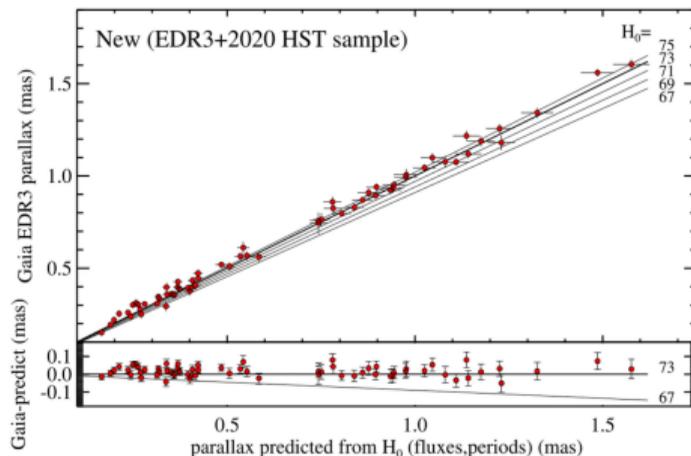
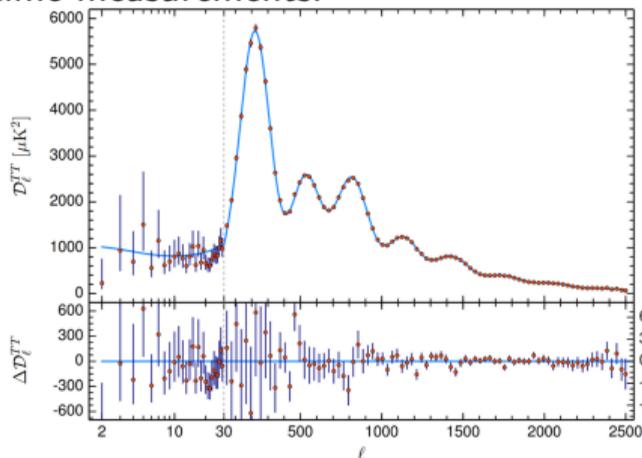
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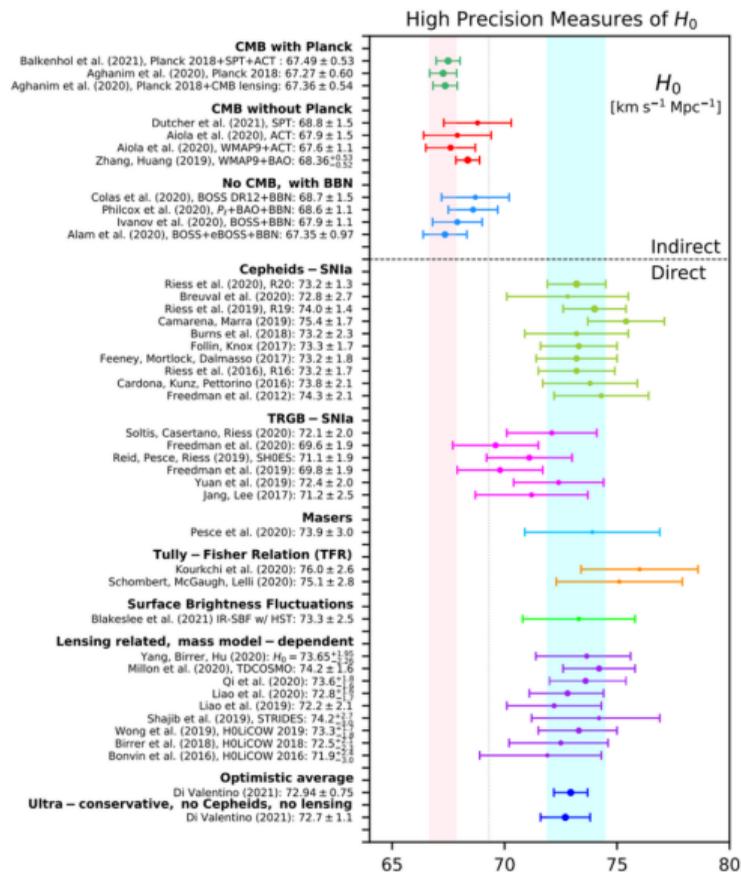
- One can infer the present-day expansion rate H_0 through a variety of early-time and late-time measurements.



The Hubble Tension

- Early-time and late-time inferences of H_0 have yielded different results, leading to a statistical tension of $4-6\sigma$.
- Early: $\sim 67 \pm 0.5 \frac{\text{km}}{\text{s Mpc}}$
- Late: $\sim 73 \pm 1 \frac{\text{km}}{\text{s Mpc}}$
- This has been particularly resistant to satisfactory theoretical explanation.

Figure: Valentino et. al. (arxiv:2103.01183)



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- Various constraints exist at present, but a window still exists at $\approx 10^{18}$ g.
- We use this window to take f_{PBH} to be 1.

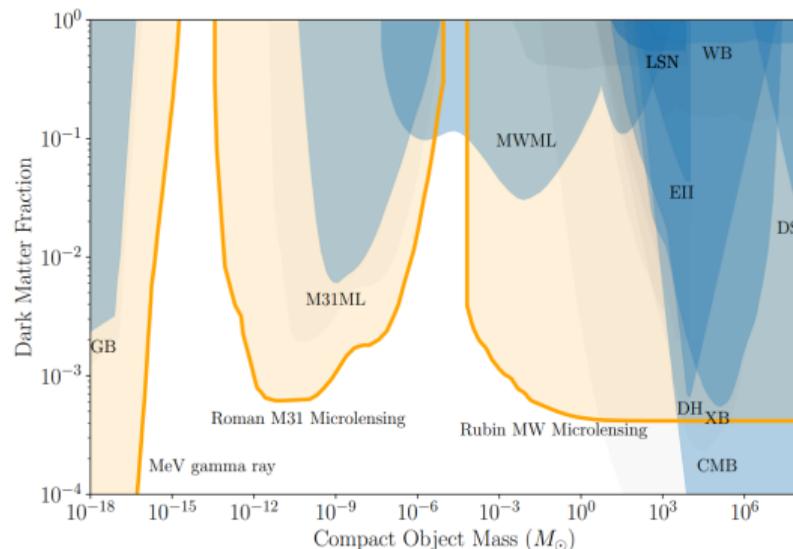


Figure: Snowmass 2021 (arxiv:2203.08967)

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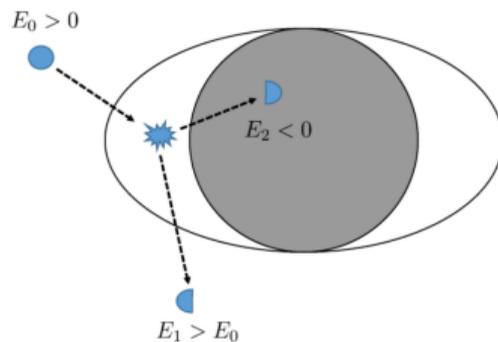


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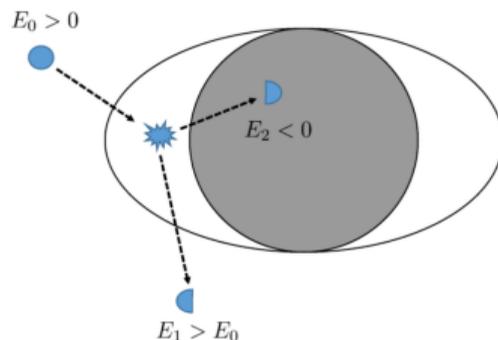


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- In this region, the timelike killing vector K^μ becomes spacelike, allowing $E = -K_\mu p^\mu < 0$.
- Extraction of the black hole's mass energy is then possible from angular momentum conversion.

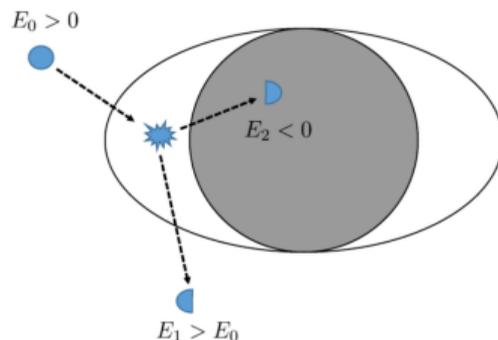


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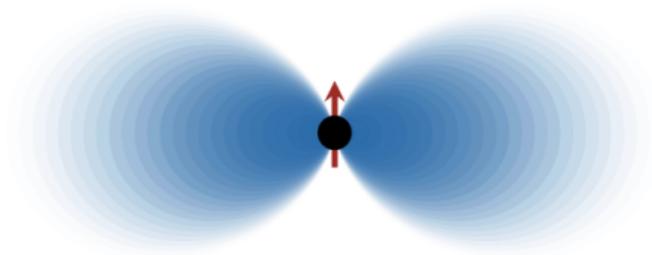


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- Superradiance: The field-theoretic equivalent to the Penrose process.
- A boson field (ϕ) with mass μ can take advantage of the available energy, occupying quasi-bound states in the ergosphere.
- States are defined by quantum numbers $|nlm\rangle$.

$$\omega_n \approx \mu \left(1 - \frac{(G\mu M_{\text{pbh}})^2}{2n^2} \right)$$

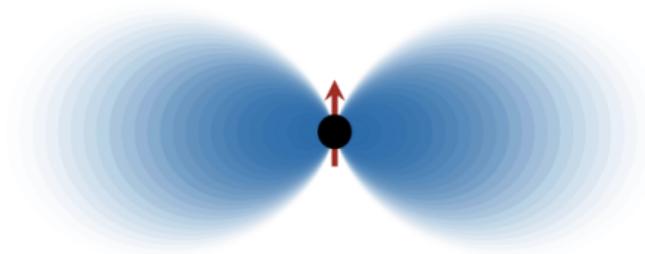


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Cosmological Background Effects

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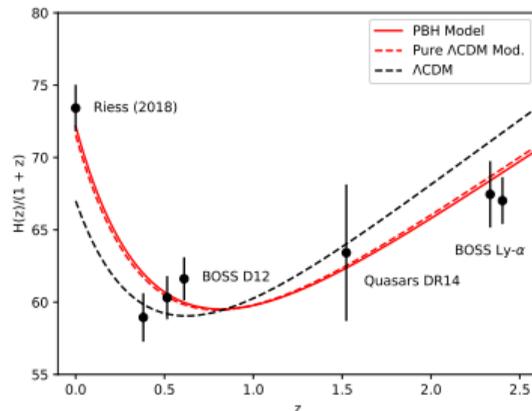
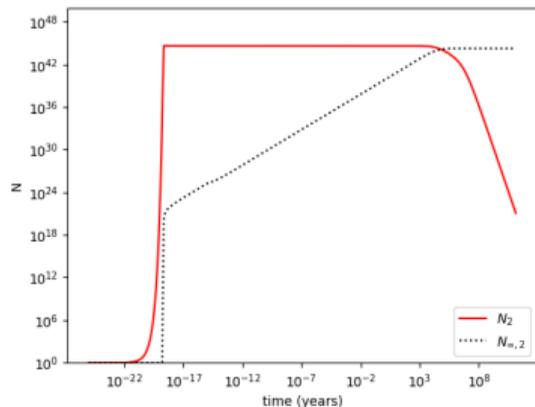
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- This yields a gradual conversion of CDM to warm dark matter (maximum $\sim 10\%$ of initial PBH energy), with the source being black hole angular momentum conversion.
- Together with modifications of base Λ CDM parameters, late-time increase of H can be achieved.



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Perturbative Effects

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- Exact calculation of perturbations is computationally expensive, so we use a fluid approximation.

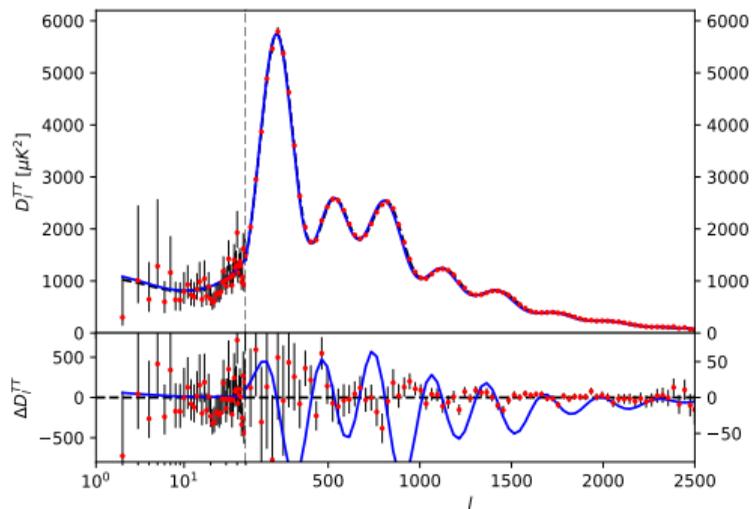
$$\dot{\delta} \simeq -(1+w) \left(\theta + \frac{\dot{h}}{2} \right) - 3H (c_{\text{eff}}^2 - w) \delta \quad (1)$$

$$\dot{\theta} \simeq -H (1 - c_{\text{eff}}^2) \theta + \frac{c_{\text{eff}}^2}{1+w} k^2 \delta \quad (2)$$

$$w(a) = \frac{1}{3} \langle v^2 \rangle = \frac{\int v^2(a, a') dn'}{3 \int dn'} \quad (3)$$

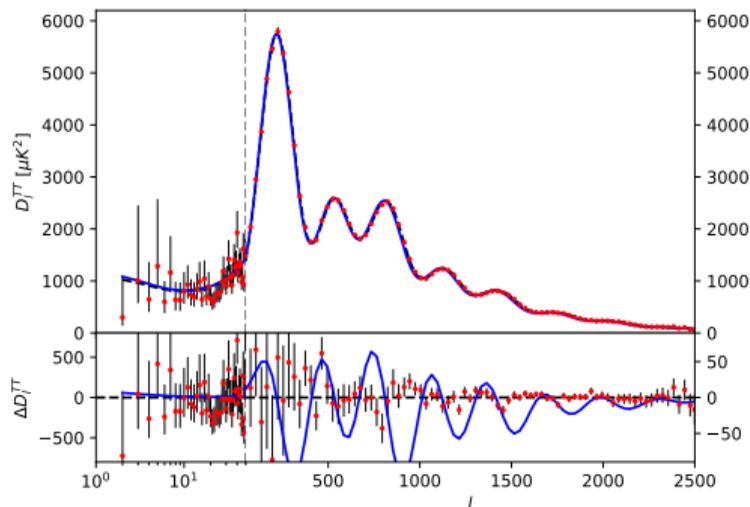
Qualitative CMB Effect

Naïvely taking $H_0 \rightarrow 73$ km/(s Mpc)

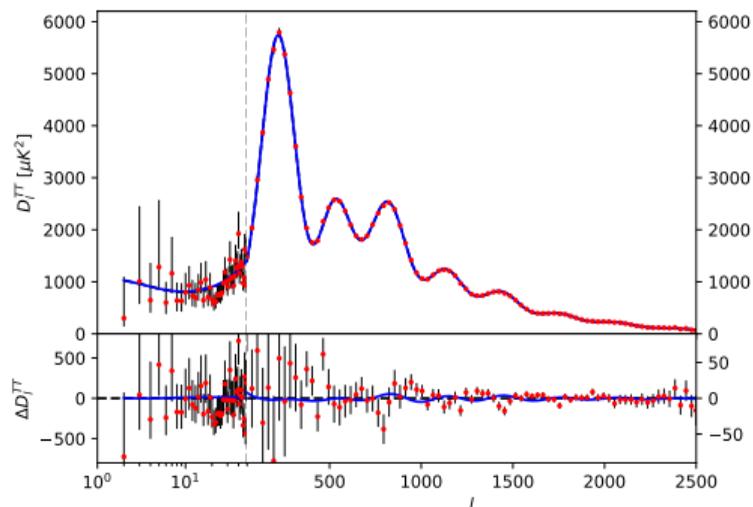


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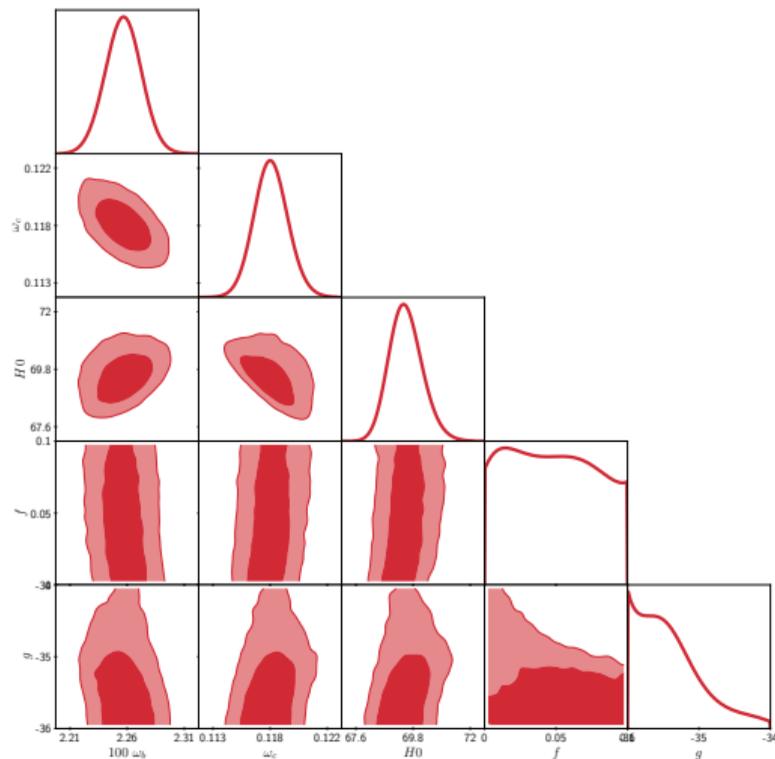


Adding superradiant PBHs



Simultaneous Early & Late Fit

- Simultaneous Fit to Planck data and a late-time value of $73 \pm 1 \frac{\text{km}}{\text{s Mpc}}$



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- Similar to models of exponentially decaying dark matter, a model of inverse decay is not preferred by the data.
- Some other/additional idea beyond conversion to warm/relativistic degrees of freedom may be needed, requiring further work.

Questions