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Primordial Black Holes from Inflaton and Spectator Field Perturbations

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Evidence for Dark Matter

- Great deal of evidence for the existence of dark matter: rotational velocity curves of galaxies, Bullet Cluster, acoustic peaks in the Cosmic Microwave Background (CMB) radiation spectrum...
- Still the nature of dark matter is unknown

What is Dark Matter?

- What is the correct explanation for the invisible matter content observed in the universe? Does the dark matter particle exist? Or are there many dark matter particles?
- Are they WIMP's, FIMP's, SIMP's, GIMP's, PIDM's, WISP's, ALP's, Wimpzillas, or sterile neutrinos? Or should gravity be modified?
- But... what if DM does not consist of new particles but primordial black holes (PBHs)?

Primordial Black Holes (PBH) - How do they form?

- PBHs can easily form in the early Universe from sufficiently large density perturbations - already within the GR
- In a radiation-dominated Universe, they can form when large enough perturbations ($\delta \gtrsim 0.5$) enter the horizon (tails of the Gaussian $\delta_{\mathbf{k}}$'s).
- In a matter-dominated Universe, perturbations grow as $\delta \propto a$ $\Rightarrow$ if there was enough time, even small perturbations can grow large, $\delta \sim 1$.

Primordial Black Holes – FAQ

- Q: Do you believe in PBHs?
  A: Well, it is not a matter of belief.

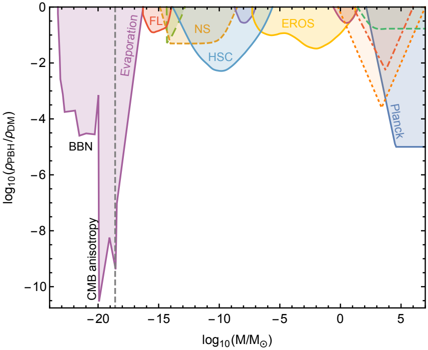
- Q: Why do not they form in today's Universe?
  A: They could, but the formation probability is negligible.

- Q: Why do not pressure effects etc. prevent them from forming?
  A: They do, not all regions collapse.

Primordial Black Holes – Why are they interesting?

- Especially the LIGO observation of $\mathcal{O}(10)M_{\odot}$ BH mergers is interesting for PBHs

- PBHs might constitute all DM, although this possibility is very constrained (see 1705.05567 and the next talk!)



Constraining Primordial Power Spectrum

- In any case, PBHs provide for an effective way to constrain curvature perturbations at small scales
- Let us assume that the are two components that contribute to the curvature power spectrum: the inflaton φ and a spectator field s

$$\mathcal{P}_{\mathcal{R}}(k) = \mathcal{P}_{\mathcal{R},\varphi}(k) + \mathcal{P}_{\mathcal{R},s}(k)$$

Primordial Power Spectrum with two components

- The inflaton perturbations produce a nearly flat spectrum at small k,

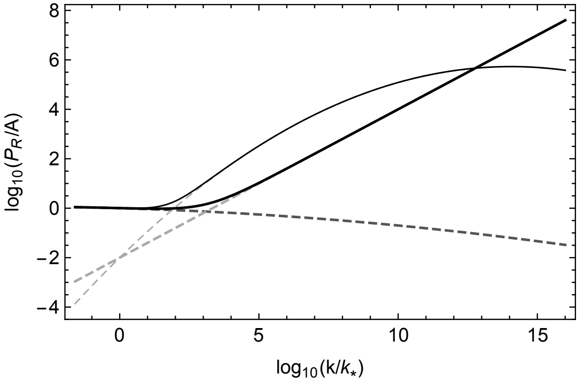
$$\mathcal{P}_{\mathcal{R},\varphi}(k) = A\left(\frac{k}{k_*}\right)^{n-1+\frac{1}{2}\mathrm{d}n/\mathrm{d}\ln k\,\ln\left(\frac{k}{k_*}\right)},$$

where k_* is a pivot scale, $A \simeq 10^{-9}$, and $n \simeq 0.968$.

- Perturbations in the s field dominate at large k

$$\mathcal{P}_{\mathcal{R},s}(k) = A_s\left(\frac{k}{k_*}\right)^{n_s-1+\frac{1}{2}\mathrm{d}n_s/\mathrm{d}\ln k\,\ln\left(\frac{k}{k_*}\right)}$$

The total power spectrum



The total curvature power spectrum (**black solid line**).

Black dashed line: inflaton. **Grey dashed lines**: spectator field.

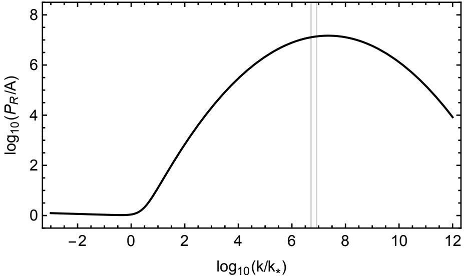
Primordial Black Hole formation: theory

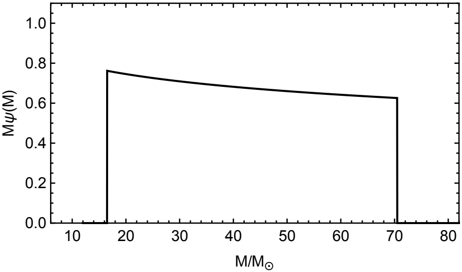
- Assume there was an early matter-dominated phase (MD) at $T > T_{\mathrm{BBN}} \simeq \mathcal{O}(1)$ MeV.
- Possible cause: reheating, massive metastable particles...
- PBH formation starts when δ grows large enough[1] ($\delta \sim 1$) and ends when the MD ends
- In MD, PBHs form with an energy $\rho_{\mathrm{PBH}}(M)/\rho_{\mathrm{tot}} \simeq 0.01\delta(M)^5$

[1] Recall that in MD $\delta \propto a$.

Primordial Black Hole formation: results

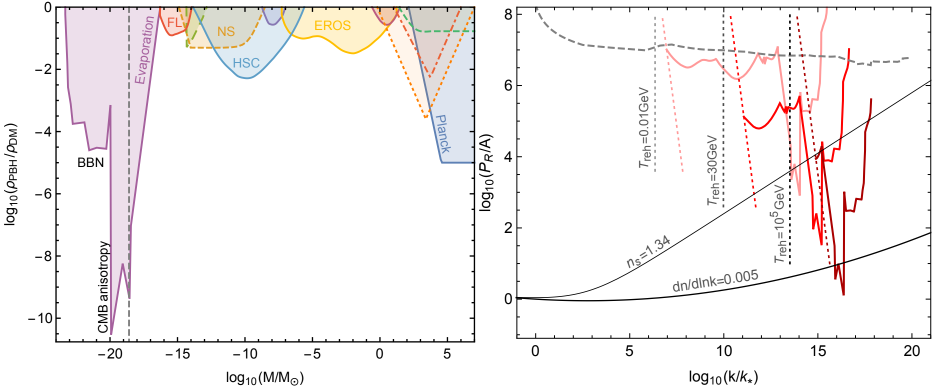
- **Five parameters**: A_s, n_s, $\mathrm{d}n_s/\mathrm{dln}k$, T_{MD}, T_{reh} (+ $\mathrm{d}n/\mathrm{dln}k$)





An example of the **total curvature power spectrum** (left) and the corresponding **PBH mass function** (right).

Constraints on primordial perturbations



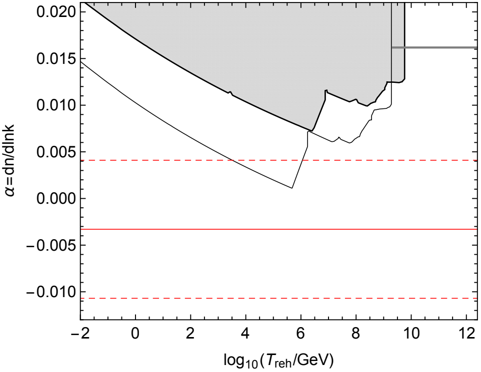
Left panel: Constraints on monochromatic PBH mass function.

Right panel: constraints on the amplitude of power spectrum. **Gray dashed line**: RD case. **Red lines**: MD case.

Thin black line: blue-tilted spectator field. **Thick black line**: inflaton with positive running.

Constraints on running of the spectral tilt

- We derive new constraints on the running of the inflaton field's spectral tilt. Red lines: Planck results.



- For constraints on spectral features of the spectator field and PBH DM, see 1706.03746.

Conclusions

- Primordial black holes are a compelling alternative to particle DM and may constitute all DM
- Cosmological and astrophysical observations provide a valuable resource on testing different dark matter models
- PBHs provide for an effective way to constrain curvature perturbations at small scales
  $\Rightarrow$ we placed new constraints on the running of the spectral tilt, $\mathrm{d}n/\mathrm{dln}k \lesssim 0.001$.