Primordial Black Holes as Dark Matter

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in collaboration with
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Talk based on arXiv:1705.05567, 1706.03746, 1804.08639

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Basics of Primordial Black Holes (PBHs)

Primordial Black Holes – Why are they interesting?

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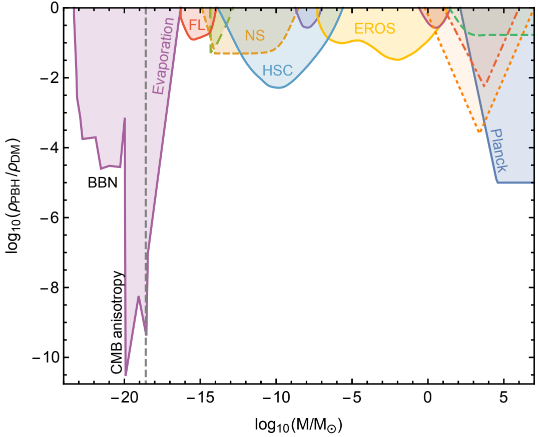
- Can they constitute all DM?



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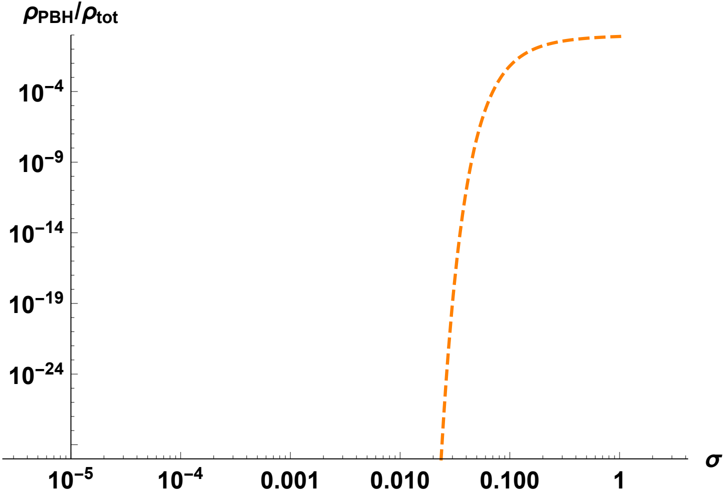
- In a matter-dominated Universe, perturbations grow as $\delta \propto a$ $\Rightarrow$ if there was enough time, even small perturbations can grow large, $\delta \sim 1$. Most importantly, in MD the Jeans pressure does not prevent PBHs from forming

PBHs – How many of them there are?



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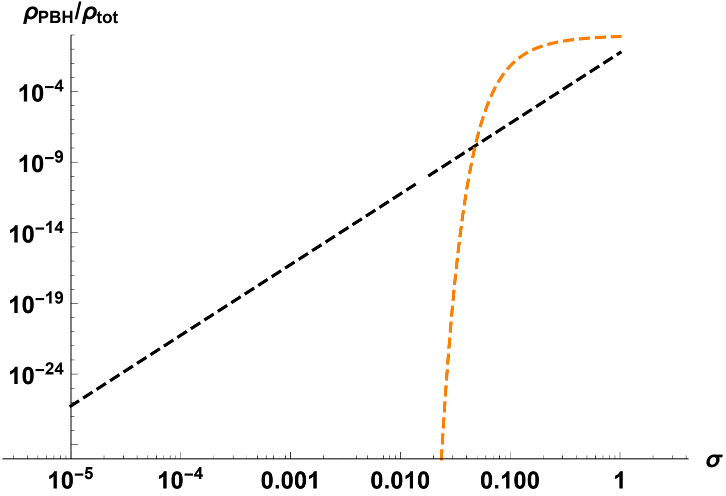

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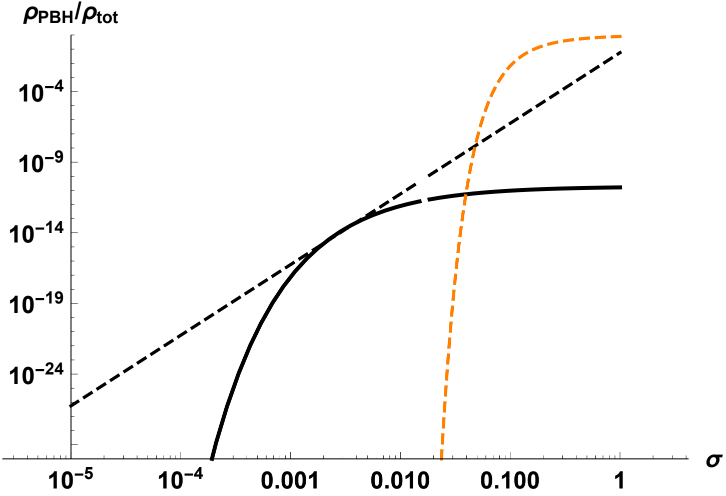

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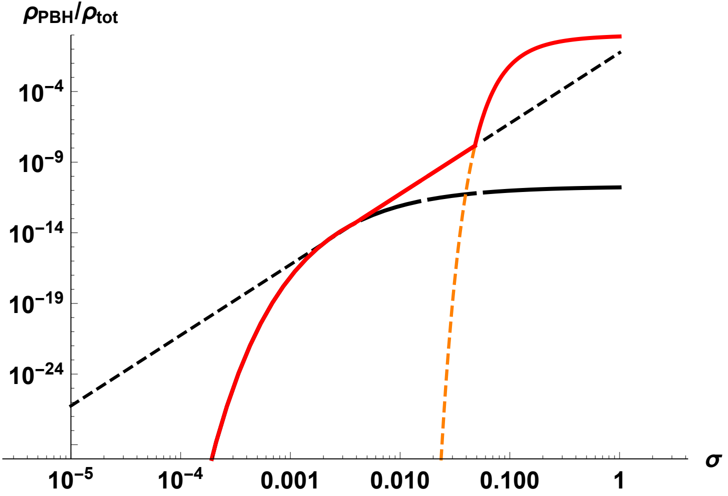

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  A: Initial asphericities and rotation will be amplified and this prevents PBH formation.

Primordial Black Holes – FAQ

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Primordial Black Holes – FAQ

- Q: Why do not all regions with large δ collapse?
  A: Initial asphericities and rotation will be amplified and this prevents PBH formation.
- Q: Why do not PBHs form in today's Universe?
  A: They could, but their fraction would be negligible.
- Q: What is the origin of these perturbations?
  A: That is THE question!

Examples of the origin of perturbations

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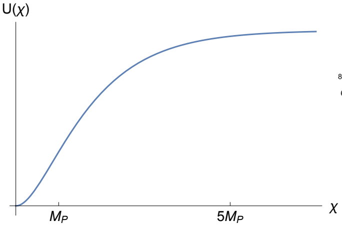

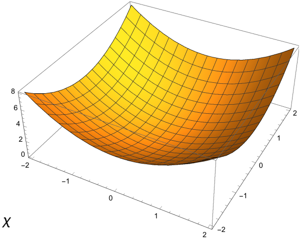

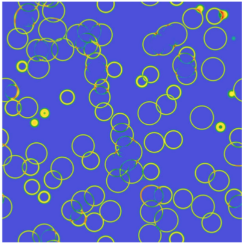

Rightmost image credit: David Weir / 1504.03291

PBHs as Dark Matter (1705.05567)

PBH mass function

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normalised so that the fraction of the DM in PBHs is

$$f_{\mathrm{PBH}} \equiv \frac{\Omega_{\mathrm{PBH}}}{\Omega_{\mathrm{DM}}} = \int \mathrm{d}M \, \psi(M)$$

Different mass functions

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- Monochromatic mass function: $\psi_{\rm mon}(M) = f_{\rm PBH}(M_c)\delta(M - M_c)$
- All mass functions that are not monochromatic are extended mass functions
- In most scenarios, one can expect the mass function to be extended rather than a monochromatic one

Examples of extended mass functions I

- A power-law mass function

$$\psi(M) \propto M^{\gamma-1} \quad (M_{\rm min} < M < M_{\rm max})$$

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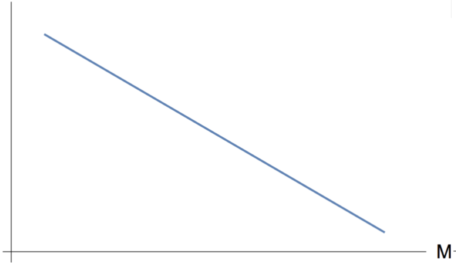
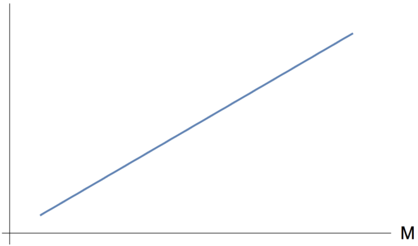


$M\psi(M)$ with $\gamma = -1$



$M\psi(M)$ with $\gamma = 1$

Examples of extended mass functions II

- A lognormal mass function

$$\psi(M) = \frac{f_{\rm PBH}}{\sqrt{2\pi}\sigma M} \exp\left(-\frac{\log^2(M/M_c)}{2\sigma^2}\right)$$

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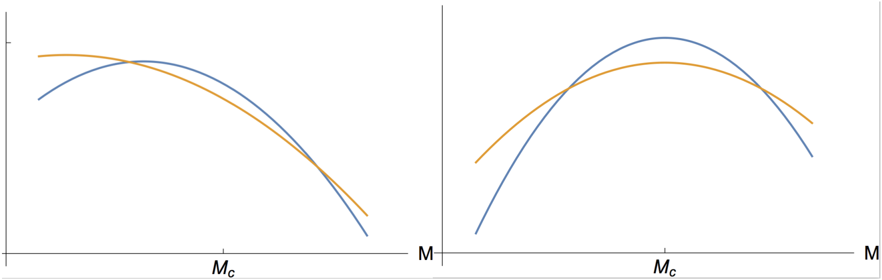
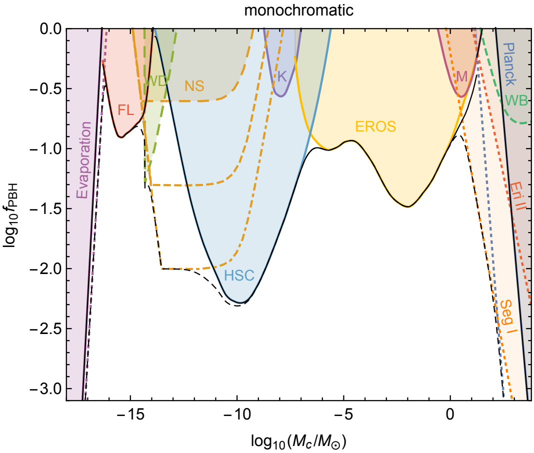


Left: $\psi(M)$ with $M_c = 1$, $\sigma = 1$ (blue) and $\sigma = 1.4$ (orange)
Right: $M\psi(M)$ with the same parameters as above

Constraints on PBHs



Constraints: evaporations; femtolensing of gamma-ray bursts (FL); neutron star capture (NS); white dwarf explosions (WD); the microlensing results from Subaru (HSC), Kepler (K), EROS and MACHO (M); Planck; survival of stars in Segue I (Seg I) and Eridanus II (Eri II); distribution of wide binaries (WB).

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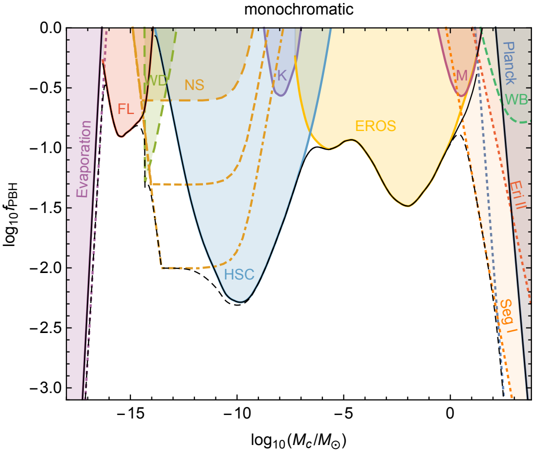

- Important: These constraints are for monochromatic mass functions only! ⇒ They have to be adopted for extended mass functions

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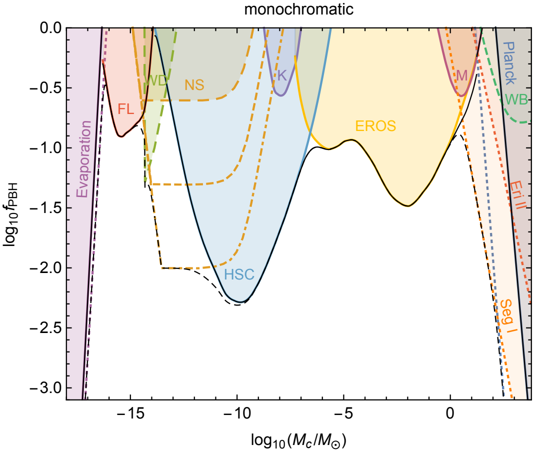

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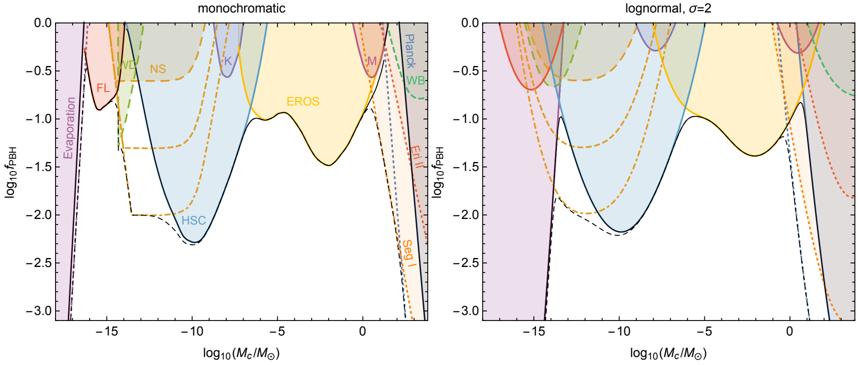
Constraints on PBHs with an extended mass function



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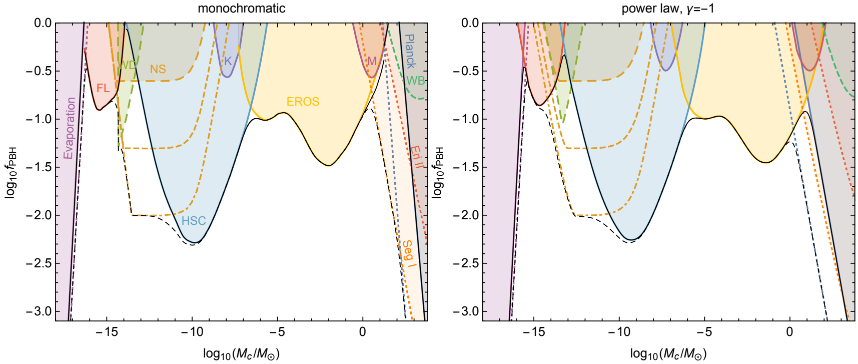

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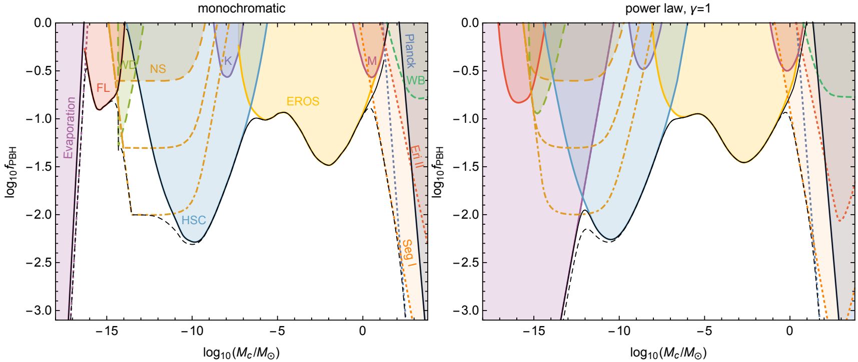
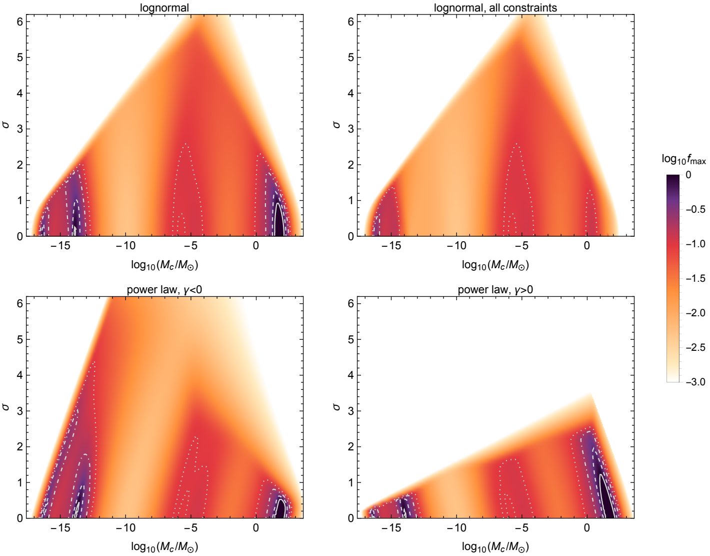


PBHs as Dark Matter



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- Detection of BH mergers with masses below the Chandrasekhar limit, $M < 1.4 M_\odot$
  $\Rightarrow$ Too faint to be detected by aLIGO–Virgo?

Can we learn something from the constraints on PBHs? (1706.03746)

Constraining Primordial Power Spectrum

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- 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,

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

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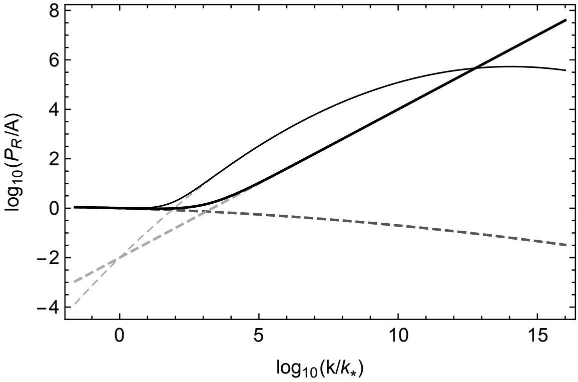
where k_* is a pivot scale, $A \simeq 10^{-9}$, and $n \simeq 0.968$.

- Perturbations in the s field dominate at large k

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

unless the running of the inflaton field's spectral index is considerable.

The total power spectrum



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

Black dashed line: inflaton. **Grey dashed lines**: spectator field for different choices of parameters.

Primordial Black Hole formation: theory

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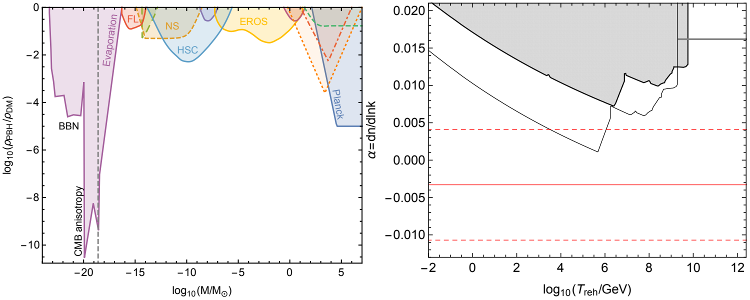
- PBH formation starts when δ grows large enough ($\delta \sim 1$) and ends when the MD ends

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.



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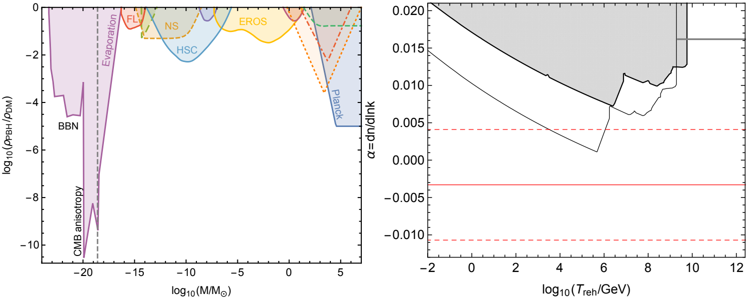

- For constraints on spectral features of the spectator field and PBH DM, see 1706.03746.

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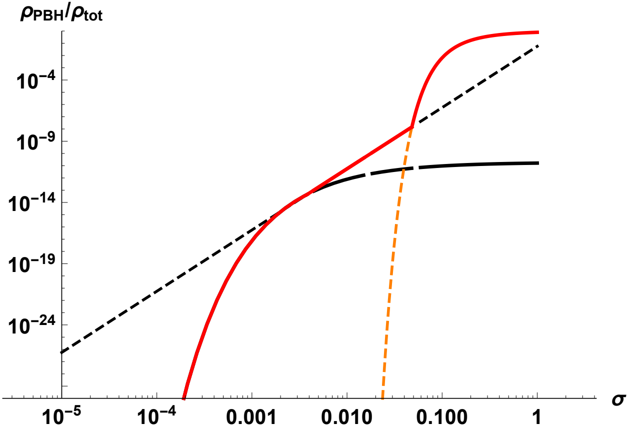

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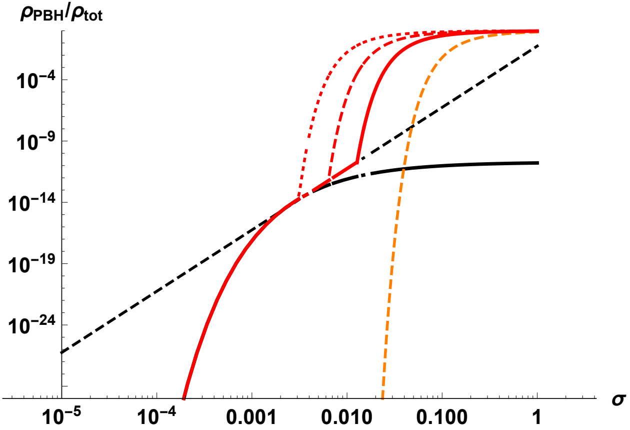
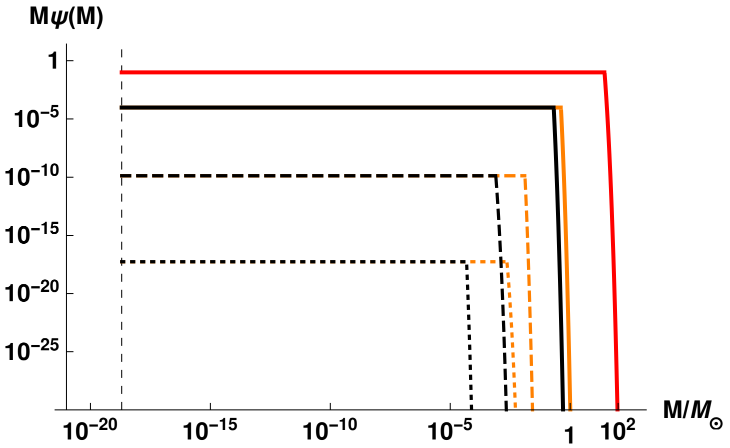
  $\Rightarrow$ 1804.08639



Cut-off in mass spectrum



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- Constraints on monochromatic PBH mass functions have to be carefully adopted for extended mass functions
- PBHs provide for an effective way to constrain curvature perturbations at small scales
- Subdominant radiation bath can have a larger effect on PBH formation than previously thought