NICPB Tallinn

Primordial black hole constraints for extended mass functions

B. Carr, M. Raidal, T. Tenkanen, VV and H. Veermäe, arXiv:1705.05567.
M. Raidal, VV and H. Veermäe, arXiv:1707.01480.

by

Ville Vaskonen

September 28, 2017

Outline

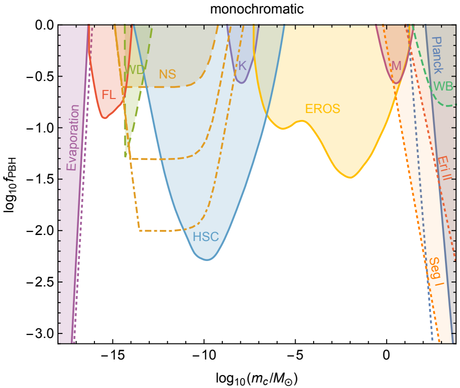
1. Extracting constraints for extended PBH mass functions
2. Constraint on PBH abundance from non-observation of the GW background by LIGO

1

Extracting constraints for extended PBH mass functions

Introduction

- Monochromatic PBH mass function: $\psi(m) = f_{\rm PBH}\delta(m - m_c)$, $f_{\rm PBH} \equiv \Omega_{\rm PBH}/\Omega_{\rm DM}$.



Extended PBH mass function

- Typically PBHs are produced at various masses
  $\implies$ extended mass function, $f_{\rm PBH} = \int {\rm d}m\, \psi(m)$.
- Lognormal mass function:

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

  $\log m_c$ and σ^2 are the mean and variance of the $\log m$ distribution.

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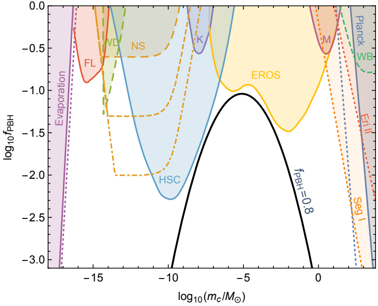

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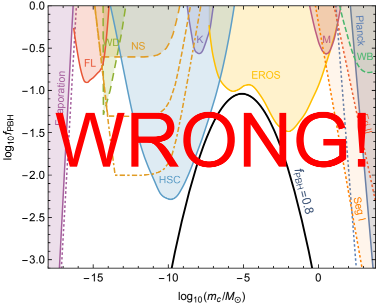

Constraints for arbitrary ψ

- PBHs of different mass contribute independently to all observables A for which the constraints were shown in the first plot:

$$A = A_0 + \int \mathrm{d}m\,\psi(m) K(m)\,.$$

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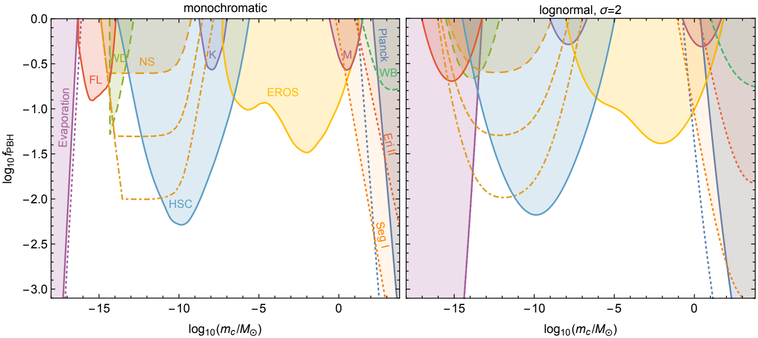
so for any mass function $A \leq A_{\rm exp}$ implies

$$\int \mathrm{d}m \frac{\psi(m)}{f_{\rm max}(m)} \leq 1 \, .$$

Constraints for lognormal ψ



- The wider the mass function is, the smaller is the maximal allowed PBH abundance.

2

Constraint on PBH abundance from non-observation of the GW background by LIGO

GW background

- The GWs from the unobservable events combine to create a stochastic GW background.
- Non-observation of the GW background constrains the PBH abundance.

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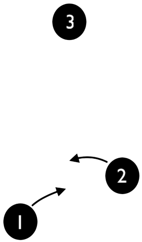
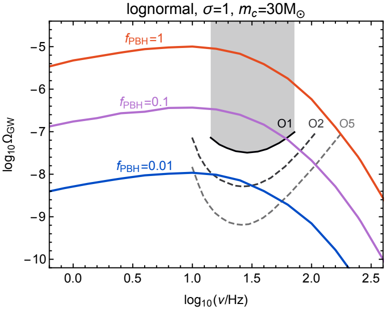
- Non-observation of the GW background constrains the PBH abundance.
- PBH binaries are formed in the early Universe dominantly by three-body interactions.

Nakamura, Sasaki, Tanaka, Thorne, astro-ph/9708060.
Ali-Haïmoud, Kovetz, Kamionkowski, 1709.06576.





Constraints from LIGO

- The observable is of the form

$$A = \int \mathrm{d}m_1 \mathrm{d}m_2 \mathrm{d}m_3 \psi(m_1)\psi(m_2)\psi(m_3) K(m_1, m_2, m_3) + \dots$$

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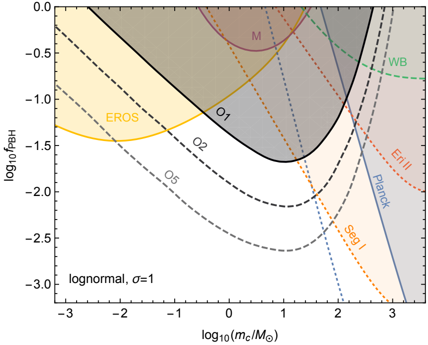
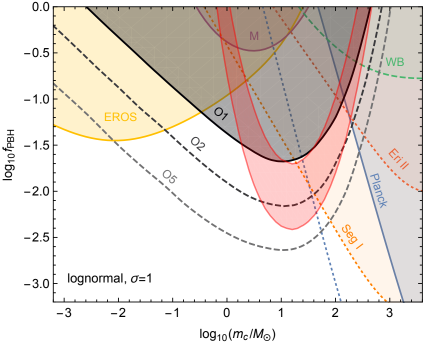
$\implies$ the constraint must be calculated separately for each mass function.

- LIGO gives the strongest constraint for $m_c \sim 1 - 10 M_\odot$:



LIGO observations

- PBH mergers are a viable explanation for the BH merger events observed by LIGO if the mass function is sufficiently narrow and peaked roughly around $30M_\odot$.



Summary

1. Each constraint on PBH abundance can be expressed in the form

$$\int \mathrm{d}m \frac{\psi(m)}{f_{\max}(m)} \leq 1\,,$$

where $f_{\max}(m)$ is the constraint for monochromatic mass function.

2. The wider the mass function is, the smaller is the maximal allowed PBH abundance.

3. The non-observation on the GW background from PBH mergers by LIGO gives the dominant constraint for $m_c \sim 1 - 10 M_\odot$.

4. The fraction of DM in PBHs needed to explain the observed BH merger events is $f_{\rm PBH} \sim 1\%$.

Lognormal mass function

For the lognormal mass function

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

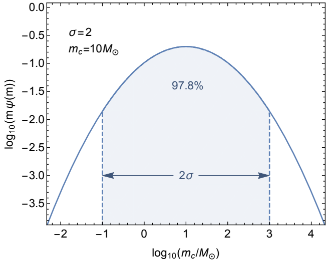
$\log m_c$ and σ^2 are the mean and variance of the $\log m$ distribution:

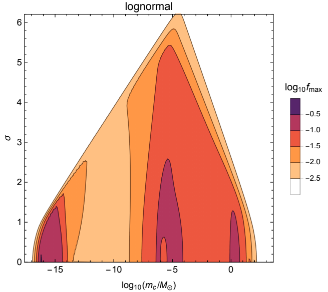
$$\log m_c \equiv \langle \log m \rangle_\psi , \quad \sigma^2 \equiv \langle \log^2 m \rangle_\psi - \langle \log m \rangle_\psi^2 \, ,$$

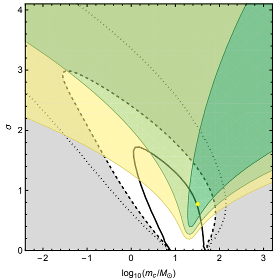
where

$$\langle X \rangle_\psi \equiv \frac{1}{f_{\rm PBH}} \int {\rm d}m \, \psi(m) X(m) \, .$$

More figures



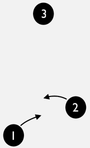




PBH binary formation

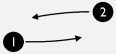
Early Universe

$$\frac{R_3(t_0)}{\mathrm{Gpc}^{-3}\mathrm{yr}^{-1}} \approx 5.1 \times 10^4 \delta_{\rm dc}^{\frac{16}{37}} f_{\rm PBH}^{\frac{53}{37}} \left(\frac{m_c}{30 M_\odot}\right)^{-\frac{32}{37}}$$



Late Universe

$$\frac{R_2(t_0)}{\mathrm{Gpc}^{-3}\mathrm{yr}^{-1}} \approx 3.7 \times 10^{-7} \delta_0 f_{\rm PBH}^2 \left(\frac{v_{\rm PBH}}{10\,\mathrm{km/s}}\right)^{-\frac{11}{7}}$$



$\Longrightarrow$ R_3 dominates over R_2 unless $\delta_0 \gtrsim 10^{11}$.