Lowest mass limit of Primordial black holes from USR models and effects of reheating

(Based on JCAP01(2020)037 and arXiv:2009.10424)

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ICTS e-seminar

Less Travelled Path Of Dark Matter: Axions and Primordial Black Holes

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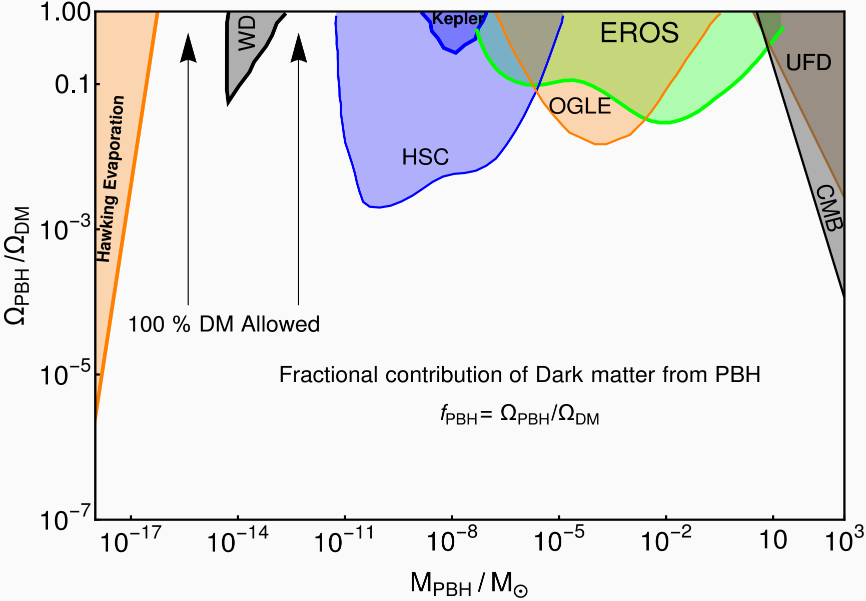
Overview

Primordial Black Holes from USR models as CDM

Primordial Black Holes as CDM and constraints



Inflection point model Potential

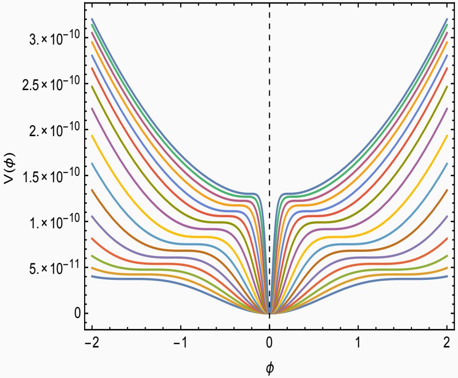
- $V'(x_0) = 0$
- $V''(x_0) = 0$
- $V'''(x_0) \neq 0$

Chosen Single field Potential of our Model

$$V(x) = V_0 \frac{ax^2+bx^4+cx^6}{(1+dx^2)^2}$$

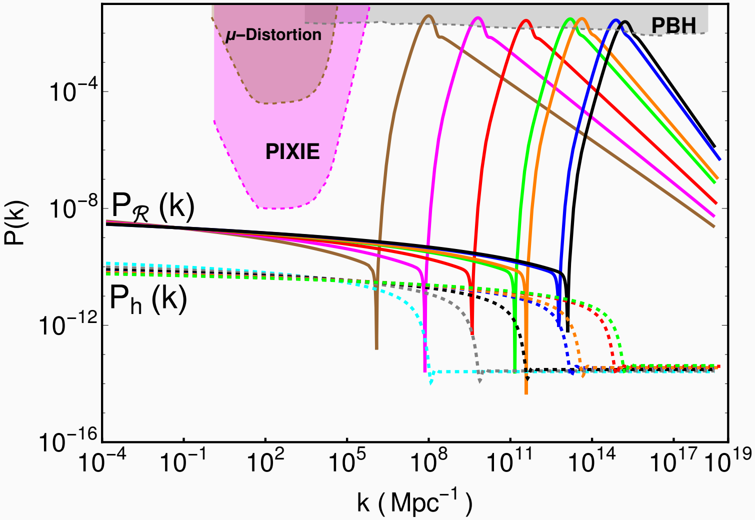
Behaviour in different regimes

- Large field limit : $V(x) \simeq \frac{V_0 c}{d^2} x^2$
- Small field limit : $V(x) \simeq V_0 a\, x^2$

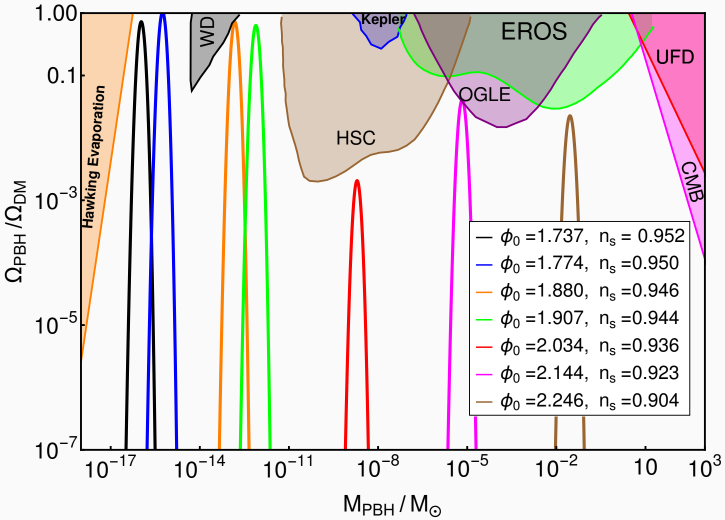


Bhaumik, Jain 2019

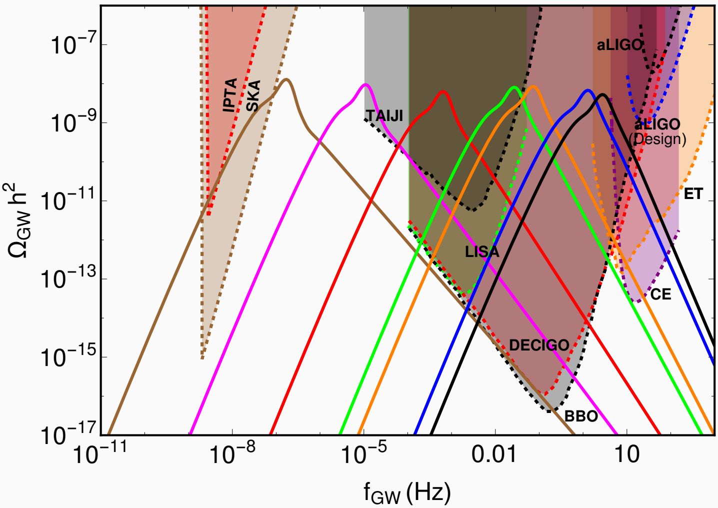
Scalar power spectra



PBH mass fraction

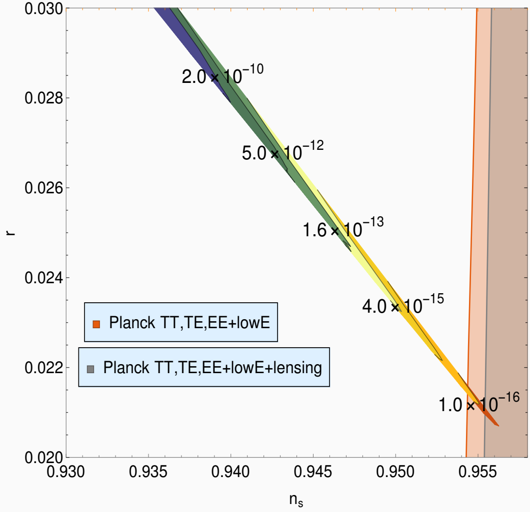


Secondary Stochastic GW Background (SGWB)



Bhaumik, Jain 2020

Scalar index and tensor to scalar ratio



Lowest Mass PBHs for USR models

Lowest Mass PBHs for USR models (with instantaneous transition to SR)

Limits on efold number

* Assuming $|\eta| \leq 1$ in SR:

$N_{end} - N_{peak} \geq 10.4$

* $N_{end} - N_{pivot} \leq 58.92 + \frac{ln(\epsilon)}{4}$

(agrees with Liddle,Leach 2003)

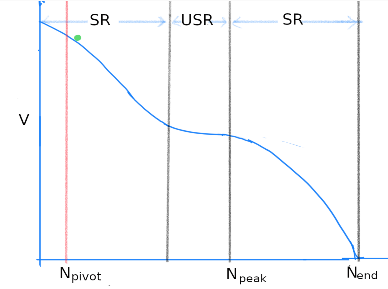
* $N_{peak} - N_{pivot} \geq 47.41$

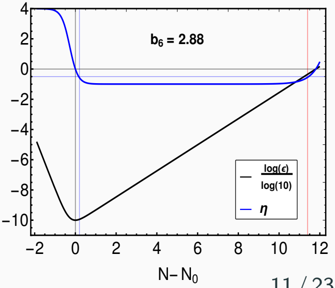
N→k→M$_{PBH}$,f$_{SGWB}$

$\mathbf{M}_{PBH} \geq 6.14 \times 10^{-23} M_{\odot}$

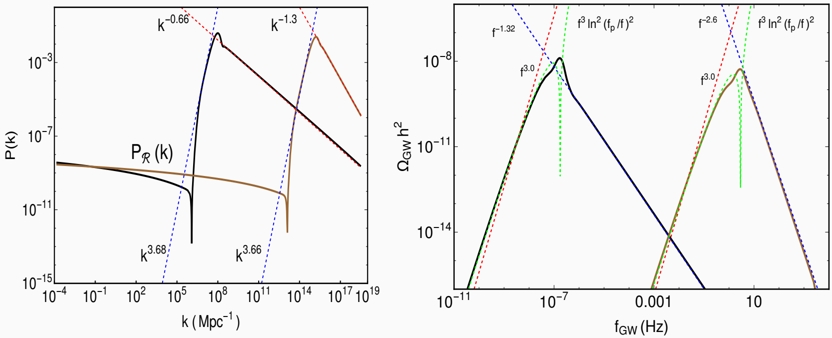
$\mathbf{f}_{SGWB} \leq 2.91 \times 10^{2} Hz$

[Bhaumik, Jain 2020]





Effects on the slope of SGWB peak

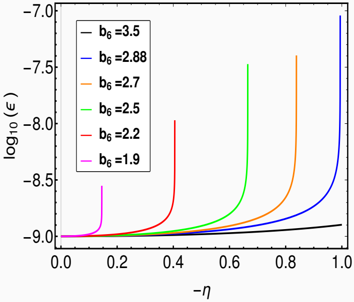


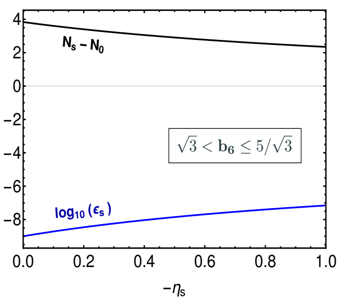
Slope in red tilted regimes

- $P_\zeta \sim k^{-\gamma} \rightarrow \Omega_{SGWB} \sim f^{-2\gamma}$ $(\gamma \leq 4.0)$ [Xu et al, Phys.Rev.D 2020]
- $N_{end} - N_{peak} \geq 10.4 \rightarrow \gamma \leq 2.0$
- Maximum slope of SGWB ≤ 4.0 .

Non-instantaneous transition to SR

Smooth transition to SR:
Potential: $V(x) = b_0 + b_1(\phi - \phi_0) + b_2(\phi - \phi_0)^2$
2nd Slow Roll parameter: $\eta = \epsilon - \phi_{NN}/\phi_N = \eta(N, b_6)$

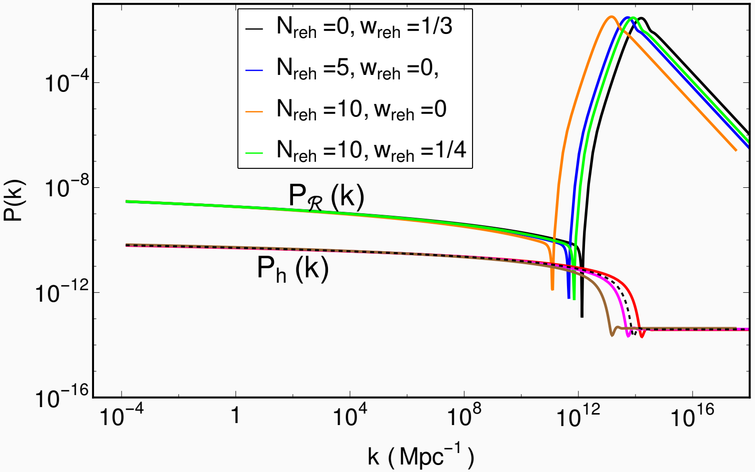




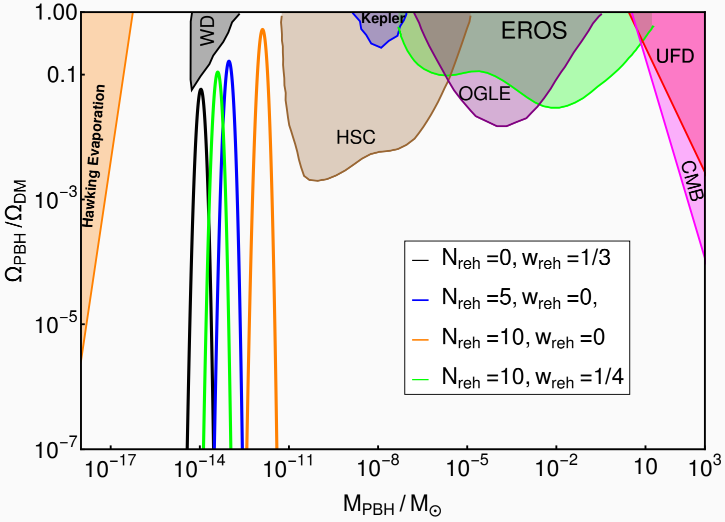
Minimum efold interval:
$N_{end} - N_{peak} = \Delta N_{transition} + \Delta N_{SR} \geq 10.58$

Effects of reheating

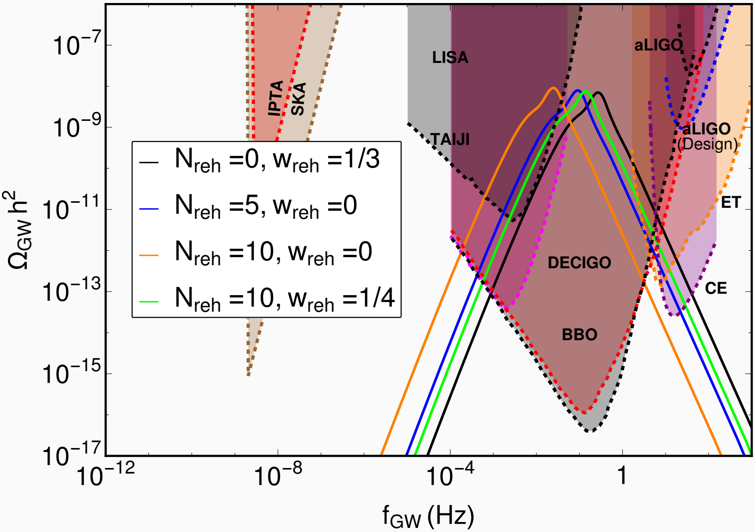
Power Spectra



Mass fraction

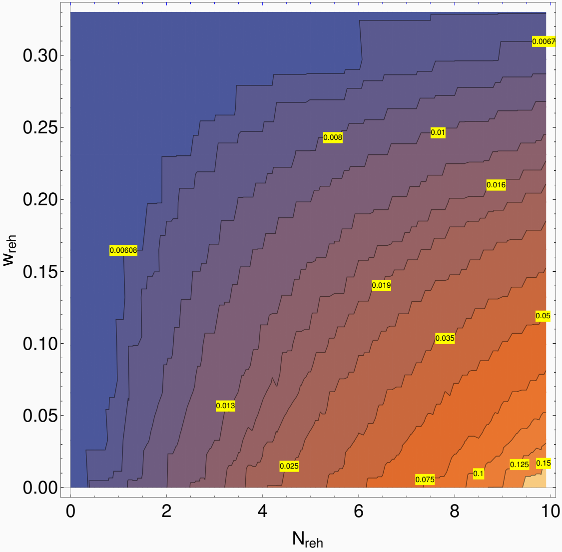


SGWB



$\Omega_{GW} h^2$
10^{-7}
10^{-9}
10^{-11}
10^{-13}
10^{-15}
10^{-17}
10^{-12}
10^{-8}
10^{-4}
1
f_{GW} (Hz)
IPTA
SKA
LISA
TAIJI
aLIGO
aLIGO (Design)
ET
CE
DECIGO
BBO
$N_{reh} = 0, w_{reh} = 1/3$
$N_{reh} = 5, w_{reh} = 0$
$N_{reh} = 10, w_{reh} = 0$
$N_{reh} = 10, w_{reh} = 1/4$

Contour plot for mass fraction



Effects of reheating on lowest mass limit

Non-instantaneous reheating history

- $N_{peak} - N_{pivot} \simeq 47.41 - \frac{1}{4} N_{reh}(1 - 3w_{reh})$
- $M_{PBH} \geq 6.14 \times 10^{-23} e^{\frac{1}{2} N_{reh}(1-3w_{reh})} \, M_{\odot}$
- $f_{SGWB} \leq 2.91 \times 10^{2} e^{-\frac{1}{4} N_{reh}(1-3w_{reh})} \, Hz.$

Matter dominated reheating
(w=0, $N_{reh} = 10$) :

- $M_{PBH} \geq 9.09 \times 10^{-21} M_{\odot}$
- $f_{SGWB} \leq 23.94 Hz.$

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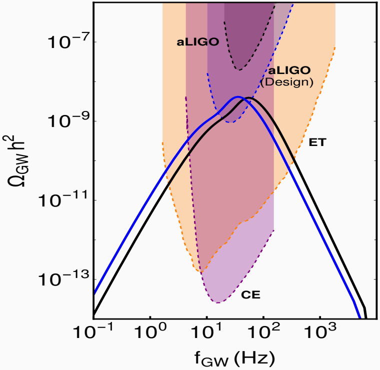

Summery

Summery of Results

- It is possible to produce PBHs in different mass ranges in these class of models.
- An upper mass limit comes from n_s problem.
- Also there is lower mass limit (and an upper limit on f_{SGWB}) for USR models which has no phase of fast roll ($\eta \geq -1.0$)
- Even for monochromatic case, a matter dominated reheating phase results in higher PBH mass range with more abundant PBH formation, and lower frequency range for SGWB peak.
- Different reheating history shows degeneracy with model parameters.
- For non-instantaneous reheating history, the lower mass bound gets even stronger.

arXix:1907.04125 and arXiv:2009.10424

End of Talk

Thank You