7. Mar. 2019 @ Accelerating Universe in the Dark in Kyoto





Primordial Black Hole



PBH tower in multi-phase inflation

Carr & Hawking 1974

- Overdensity

 $\delta > \delta_{\rm th} \simeq 0.4 \quad {\rm M}_{\rm Ha}$ $\left({\rm cf.} \ \mathscr{R}_{\rm th} \simeq \frac{9}{4} \delta_{\rm th} \simeq 1 \right)$

Musco, Miller, Rezolla 2005, ... Harada, Yoo, Kohri 2013

- Rarity $\frac{\Omega_{\text{PBH}}}{\Omega_{\text{DM}}} \sim \frac{\rho_{\text{PBH}}/\rho_{\text{R}}|_{\text{f}}}{7 \times 10^{-16}} \left(\frac{M_{\text{PBH}}}{10^{20} \,\text{g}}\right)^{-1/2}$ $\sim 10\sigma$ rarity $\mathcal{P}_{\mathcal{R}}(k_{\rm PBH}) \sim \left(\frac{\mathcal{R}_{\rm th}}{10}\right)^2 \simeq 10^{-2}$

 $\left(\text{cf.} \mathscr{P}_{\mathscr{R}}(k_{\text{CMB}}) \simeq 2 \times 10^{-9}\right)$

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Massive than stellar BHs found

small spin

Event	m_1/M_{\odot}	$m_2/{ m M}_{\odot}$	${\cal M}/{ m M}_{\odot}$	χ eff
GW150914	$35.6^{+4.8}_{-3.0}$	$30.6^{+3.0}_{-4.4}$	$28.6^{+1.6}_{-1.5}$	-0.01
GW151012	$23.3^{+14.0}_{-5.5}$	$13.6^{+4.1}_{-4.8}$	$15.2^{+2.0}_{-1.1}$	0.04^{+}_{-}
GW151226	$13.7^{+8.8}_{-3.2}$	$7.7^{+2.2}_{-2.6}$	$8.9^{+0.3}_{-0.3}$	0.18^{+}_{-}
GW170104	$31.0^{+7.2}_{-5.6}$	$20.1^{+4.9}_{-4.5}$	$21.5^{+2.1}_{-1.7}$	-0.04
GW170608	$10.9^{+5.3}_{-1.7}$	$7.6^{+1.3}_{-2.1}$	$7.9^{+0.2}_{-0.2}$	0.03_
GW170729	$50.6^{+16.6}_{-10.2}$	$34.3^{+9.1}_{-10.1}$	$35.7^{+6.5}_{-4.7}$	0.36_
GW170809	$35.2^{+8.3}_{-6.0}$	$23.8^{+5.2}_{-5.1}$	$25.0^{+2.1}_{-1.6}$	0.07^{+}_{-}
GW170814	$30.7^{+5.7}_{-3.0}$	$25.3\substack{+2.9\\-4.1}$	$24.2^{+1.4}_{-1.1}$	0.07^{+}_{-}
GW170817	$1.46^{+0.12}_{-0.10}$	$1.27\substack{+0.09 \\ -0.09}$	$1.186^{+0.001}_{-0.001}$	0.00^{+}_{-}
GW170818	$35.5_{-4.7}^{+7.5}$	$26.8^{+4.3}_{-5.2}$	$26.7^{+2.1}_{-1.7}$	-0.09
GW170823	$39.6^{+10.0}_{-6.6}$	$29.4_{-7.1}^{+6.3}$	$29.3^{+4.2}_{-3.2}$	0.08^{+}_{-}



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+0.12 -0.13 -0.28 -0.19 -0.20 -0.12 +0.17-0.20-0.19 -0.07 -0.21 -0.25 -0.16 -0.16 -0.12 -0.11 -0.02 -0.01 +0.18-0.21-0.20 -0.22



Binary PBH



PBH tower in multi-phase inflation







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1. PBH

7



Inflationary sector ...



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 $\mathcal{P}_{\mathcal{R}} \sim 10^{-2}$

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- Stabilization 1

$$V_{\rm stab} = \frac{1}{2} V_{\rm pre} \frac{\psi}{M}$$

- during pre-phase: stabilize ϕ
- after V_{pre} decays: start next phase

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Testability

– LIGO/Virgo PBH

PBH tends to be spinless Chiba & Yokoyama 2017

Event	$m_1/{ m M}_{\odot}$	$m_2/{ m M}_{\odot}$	${\cal M}/{ m M}_{\odot}$	$\chi_{ ext{eff}}$
GW150914	$35.6^{+4.8}_{-3.0}$	$30.6^{+3.0}_{-4.4}$	$28.6^{+1.6}_{-1.5}$	$-0.01^{+0.12}_{-0.13}$
GW151012	$23.3^{+14.0}_{-5.5}$	$13.6^{+4.1}_{-4.8}$	$15.2^{+2.0}_{-1.1}$	$0.04^{+0.28}_{-0.19}$
GW151226	$13.7^{+8.8}_{-3.2}$	$7.7^{+2.2}_{-2.6}$	$8.9^{+0.3}_{-0.3}$	$0.18^{+0.20}_{-0.12}$
GW170104	$31.0^{+7.2}_{-5.6}$	$20.1^{+4.9}_{-4.5}$	$21.5^{+2.1}_{-1.7}$	$-0.04^{+0.17}_{-0.20}$
GW170608	$10.9^{+5.3}_{-1.7}$	$7.6^{+1.3}_{-2.1}$	$7.9^{+0.2}_{-0.2}$	$0.03^{+0.19}_{-0.07}$
GW170729	$50.6^{+16.6}_{-10.2}$	$34.3^{+9.1}_{-10.1}$	$35.7^{+6.5}_{-4.7}$	$0.36^{+0.21}_{-0.25}$
GW170809	$35.2^{+8.3}_{-6.0}$	$23.8^{+5.2}_{-5.1}$	$25.0^{+2.1}_{-1.6}$	$0.07^{+0.16}_{-0.16}$
GW170814	$30.7^{+5.7}_{-3.0}$	$25.3^{+2.9}_{-4.1}$	$24.2^{+1.4}_{-1.1}$	$0.07^{+0.12}_{-0.11}$
GW170817	$1.46^{+0.12}_{-0.10}$	$1.27^{+0.09}_{-0.09}$	$1.186^{+0.001}_{-0.001}$	$0.00^{+0.02}_{-0.01}$
GW170818	$35.5^{+7.5}_{-4.7}$	$26.8^{+4.3}_{-5.2}$	$26.7^{+2.1}_{-1.7}$	$-0.09^{+0.18}_{-0.21}$
GW170823	$39.6^{+10.0}_{-6.6}$	$29.4_{-7.1}^{+6.3}$	$29.3^{+4.2}_{-3.2}$	$0.08^{+0.20}_{-0.22}$

LIGO/Virgo 2018

PBH tower in multi-phase inflation



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3. Testability



Testability



PBH tower in multi-phase inflation

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3. Testability



Conclusions

- 3 interesting mass region for PBH
 - $10 M_{\odot}$: LIGO/Virgo GW
 - 10-5 M ∘ : OGLE lensing
 - 10⁻¹² M ∘ : main component of DMs
- multi-phase inflation can realize them simultaneously cf. string swampland conjecture Ooguri & Vafa+ 2018 "dS vacua will be unstable in UV-complete theories"

testable by GW

PBH tower in multi-phase inflation



