15. May. 2019 @ Axion Cosmology in Kyoto

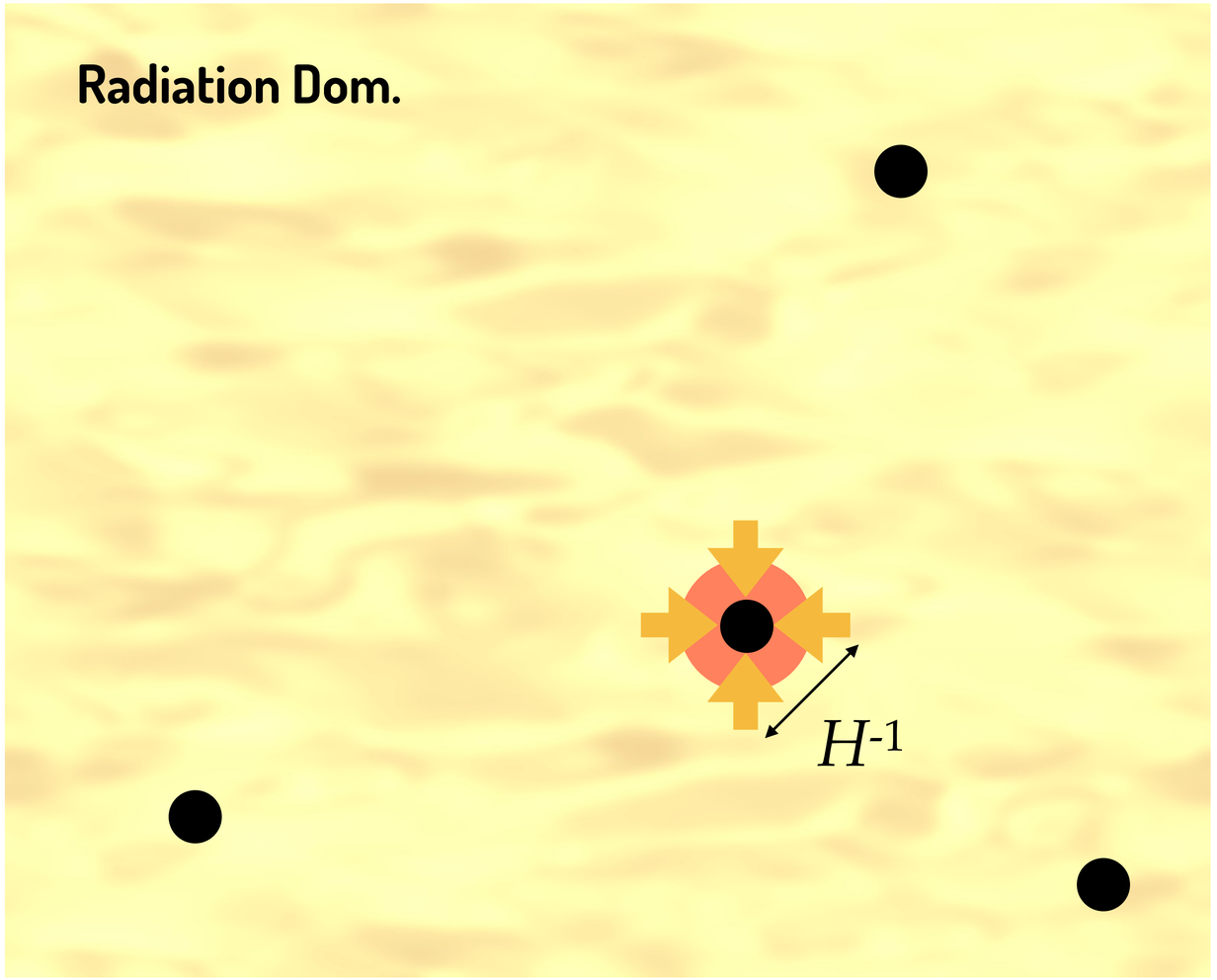
PBH tower in multi-phase inflation

Yuichiro TADA (Nagoya U.)

w/ S. Yokoyama 1904.10298

Primordial Black Hole

Carr & Hawking 1974



- **Overdensity**

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

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

- **Rarity**

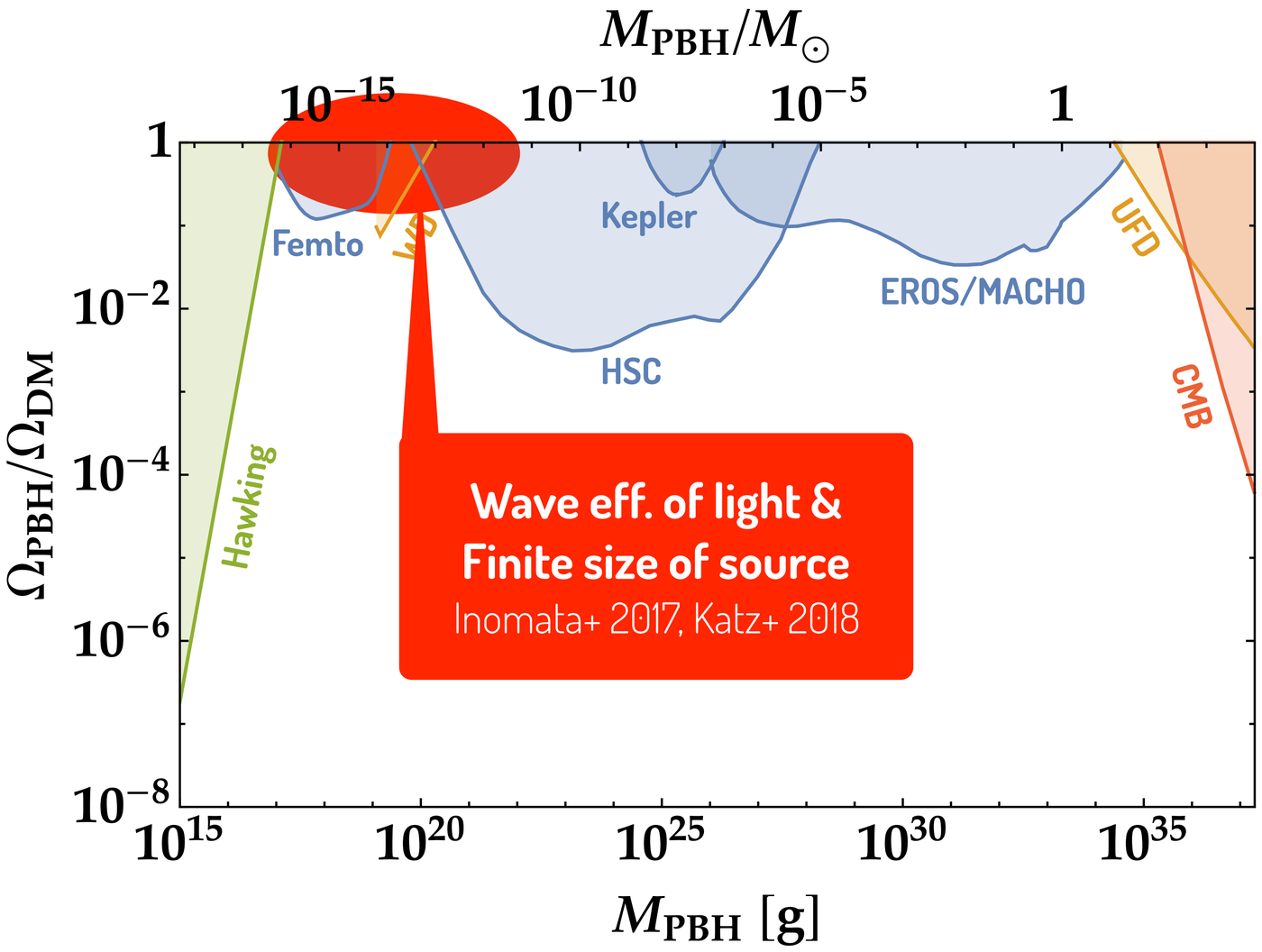
$$\frac{\Omega_{\rm PBH}}{\Omega_{\rm DM}} \sim \frac{\rho_{\rm PBH}/\rho_{\rm R}|_{\rm f}}{7\times 10^{-16}} \left(\frac{M_{\rm PBH}}{10^{20}\,{\rm g}} \right)^{-1/2}$$

$\sim 10\sigma$ rarity

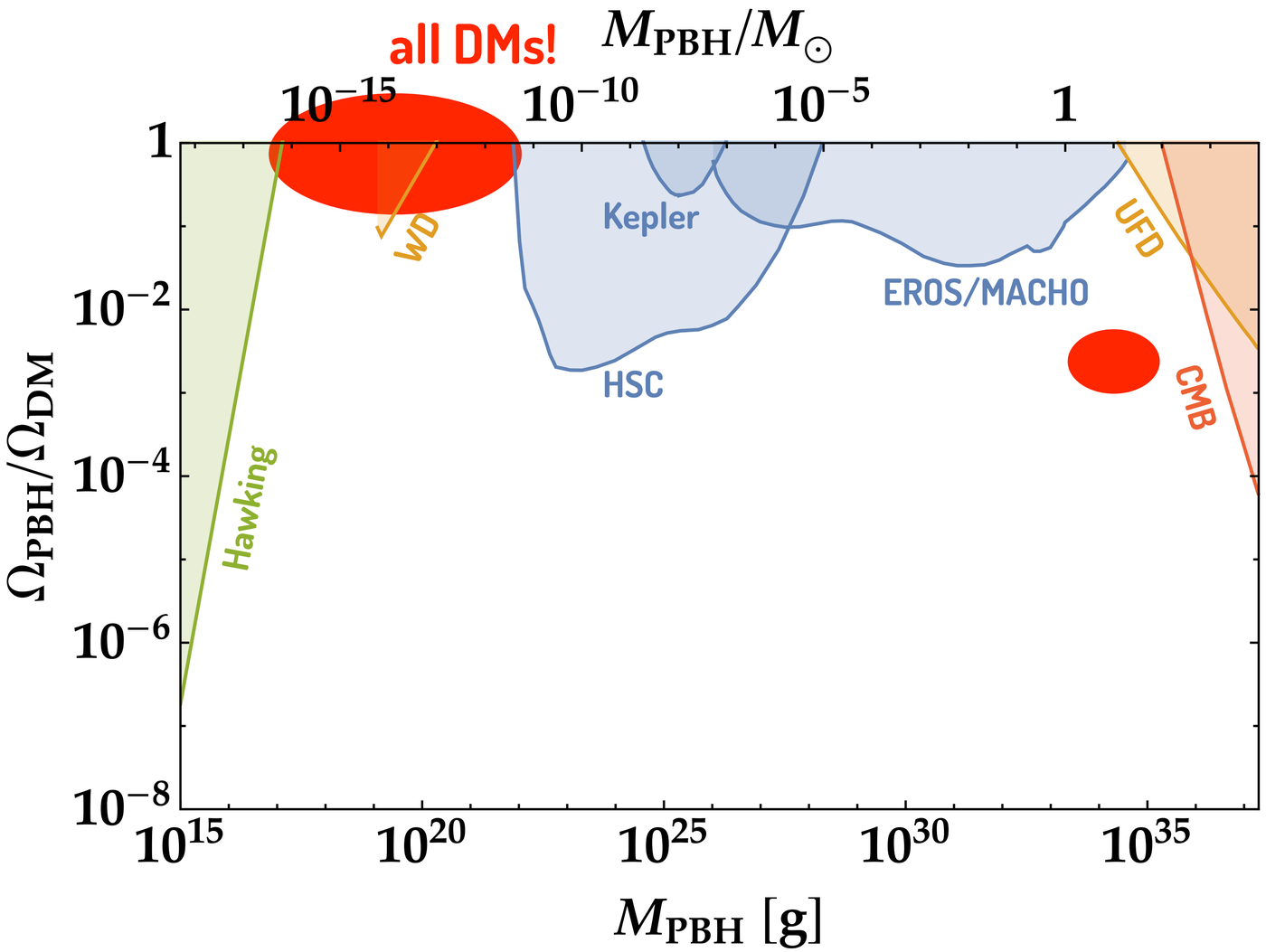
$$\Rightarrow \quad \mathscr{P}_{\mathscr{R}}(k_{\rm PBH}) \sim \left(\frac{\mathscr{R}_{\rm th}}{10} \right)^2 \simeq 10^{-2}$$

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

Obs. const. on PBH



Obs. const. on PBH



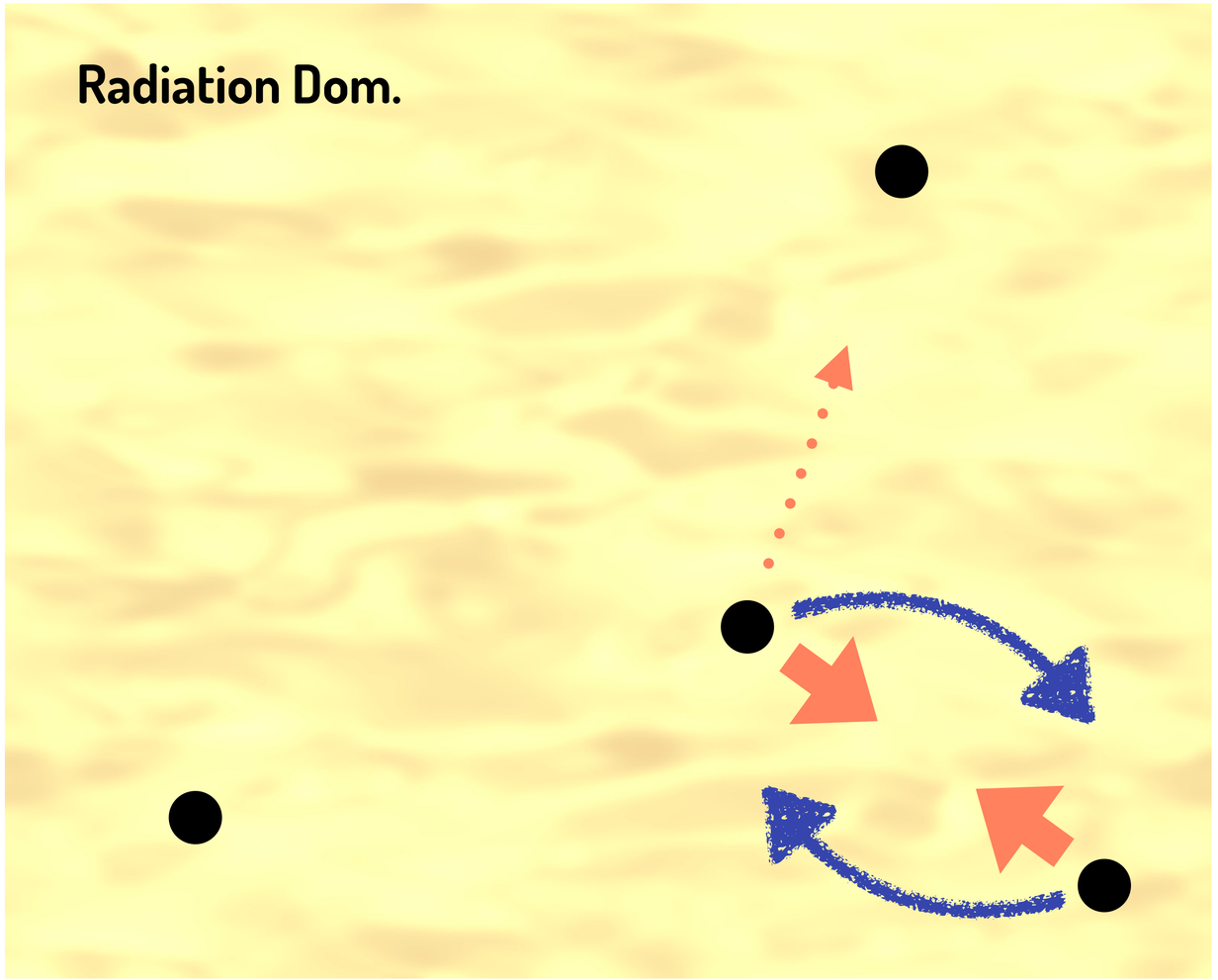
Massive than stellar BHs found

small spin

Event	$m_1/\mathrm{M}_\odot$	$m_2/\mathrm{M}_\odot$	$\mathcal{M}/\mathrm{M}_\odot$	$\chi_{\rm eff}$
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	$39.6^{+10.0}_{-6.6}$	$29.4^{+6.3}_{-7.1}$	$29.3^{+4.2}_{-3.2}$	$0.08^{+0.20}_{-0.22}$

LIGO/Virgo 2018

Binary PBH



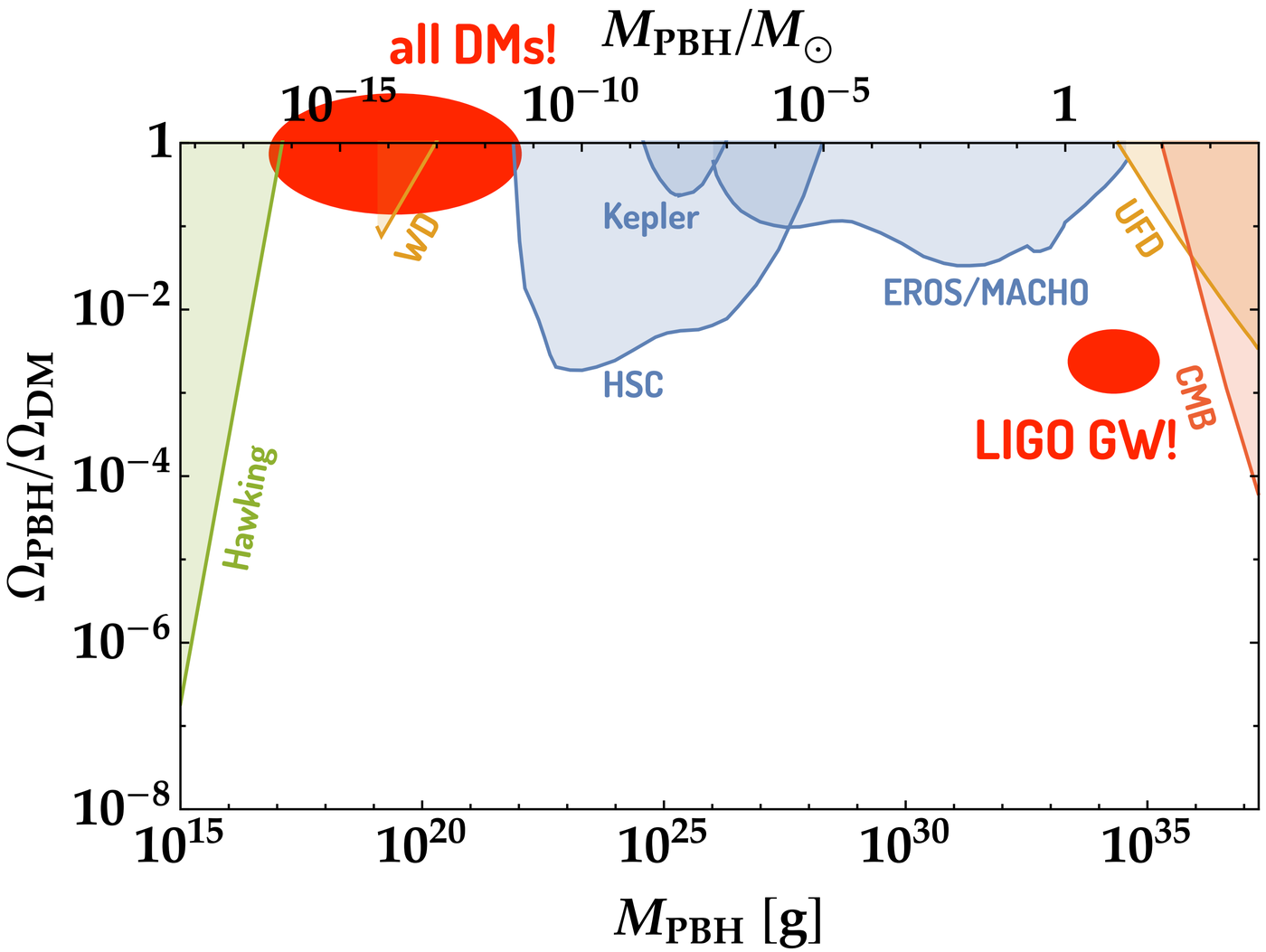
Sasaki+ 2016

$$\text{if} \quad \frac{\Omega_{\rm PBH}}{\Omega_{\rm DM}} \sim 10^{-3}\text{-}10^{-2}$$

$$\text{(merger rate)} \simeq 52.9^{+55.6}_{-27.0}\,{\rm Gpc}^{-3}\,{\rm yr}^{-1}$$

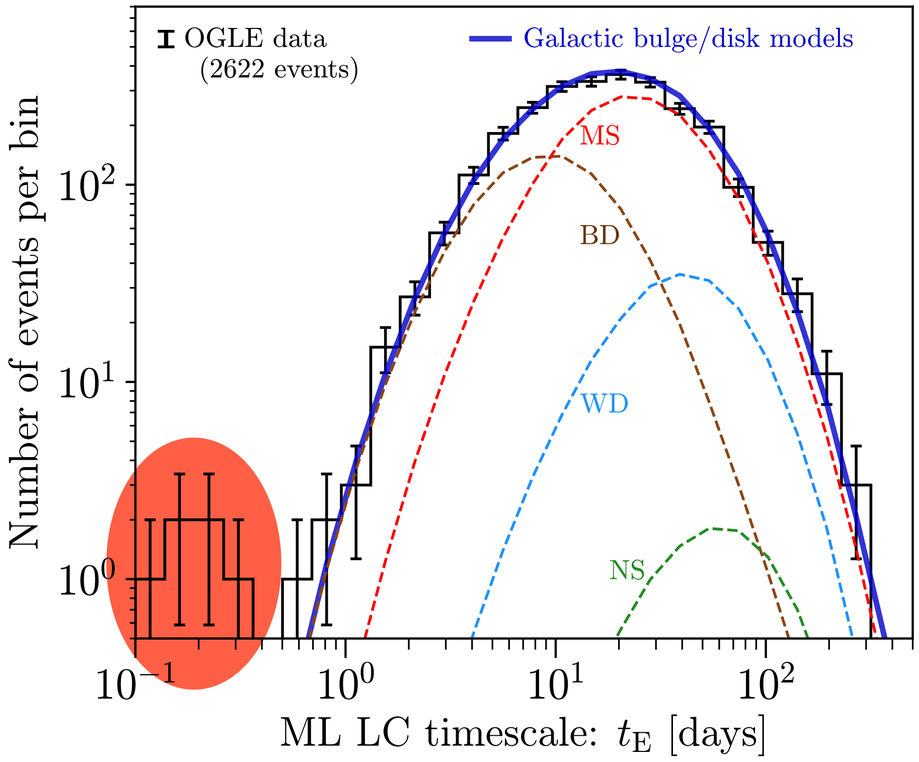
LIGO/Virgo 2018

Obs. const. on PBH

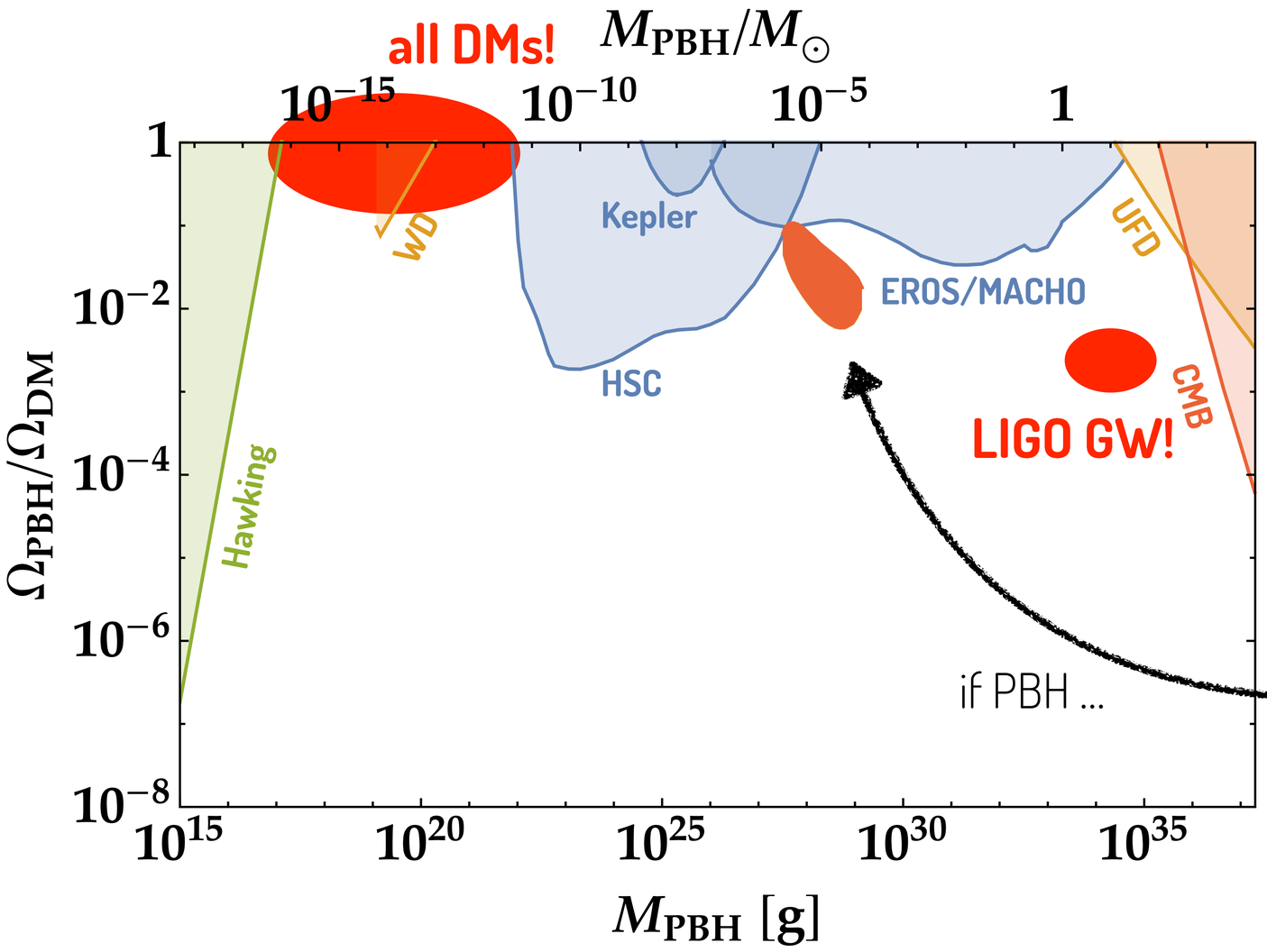


5-yr Optical Gravitational Lensing Experiment (OGLE)

Niikura+ 2019



Obs. const. on PBH



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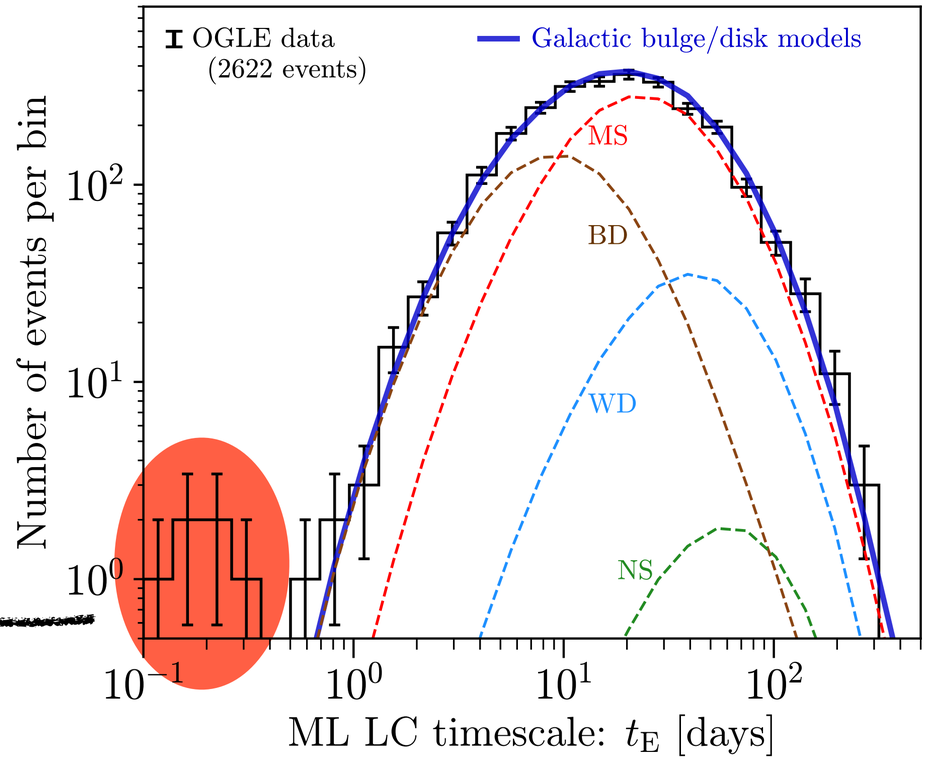
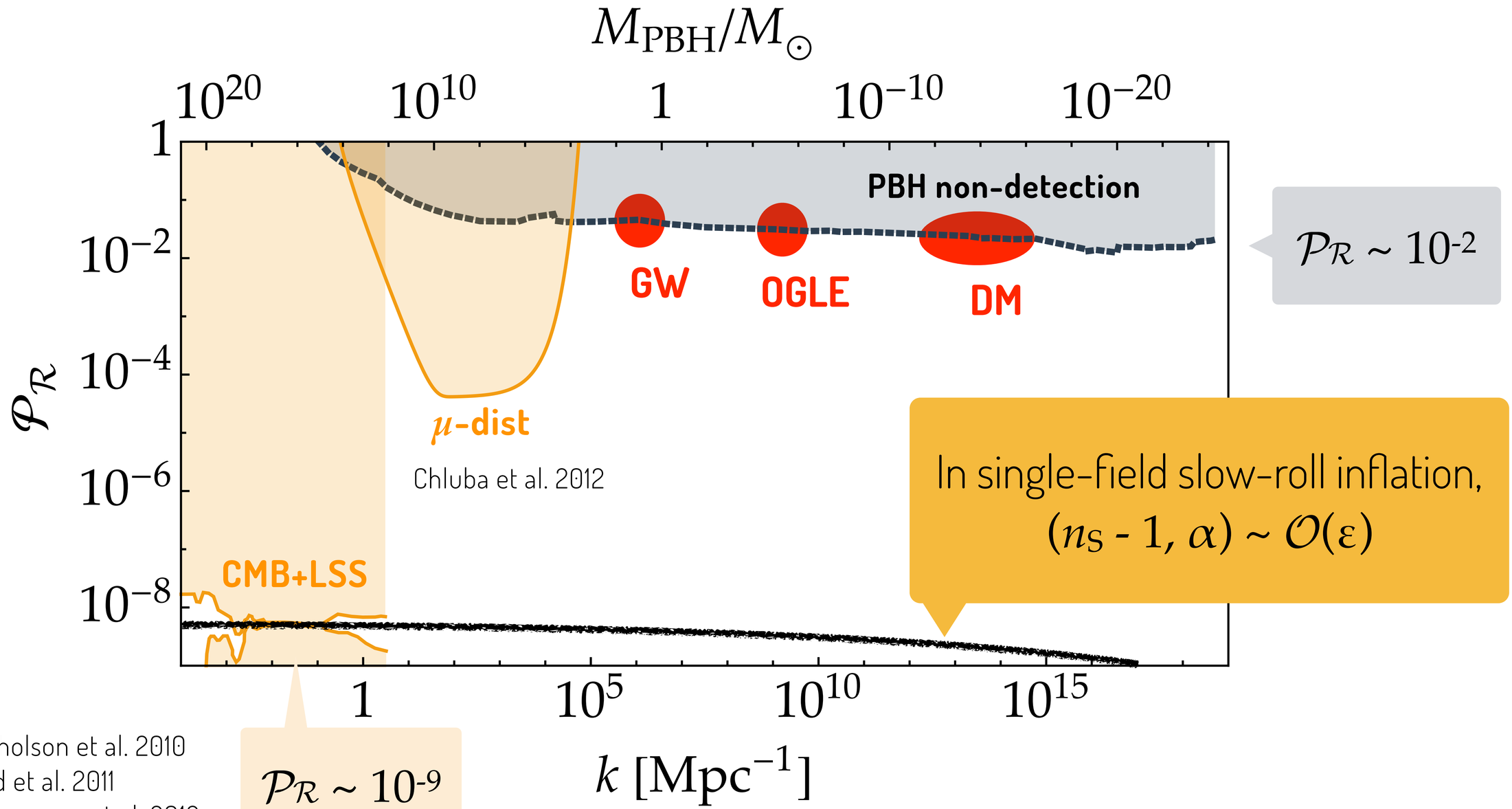


Inflationary sector ...

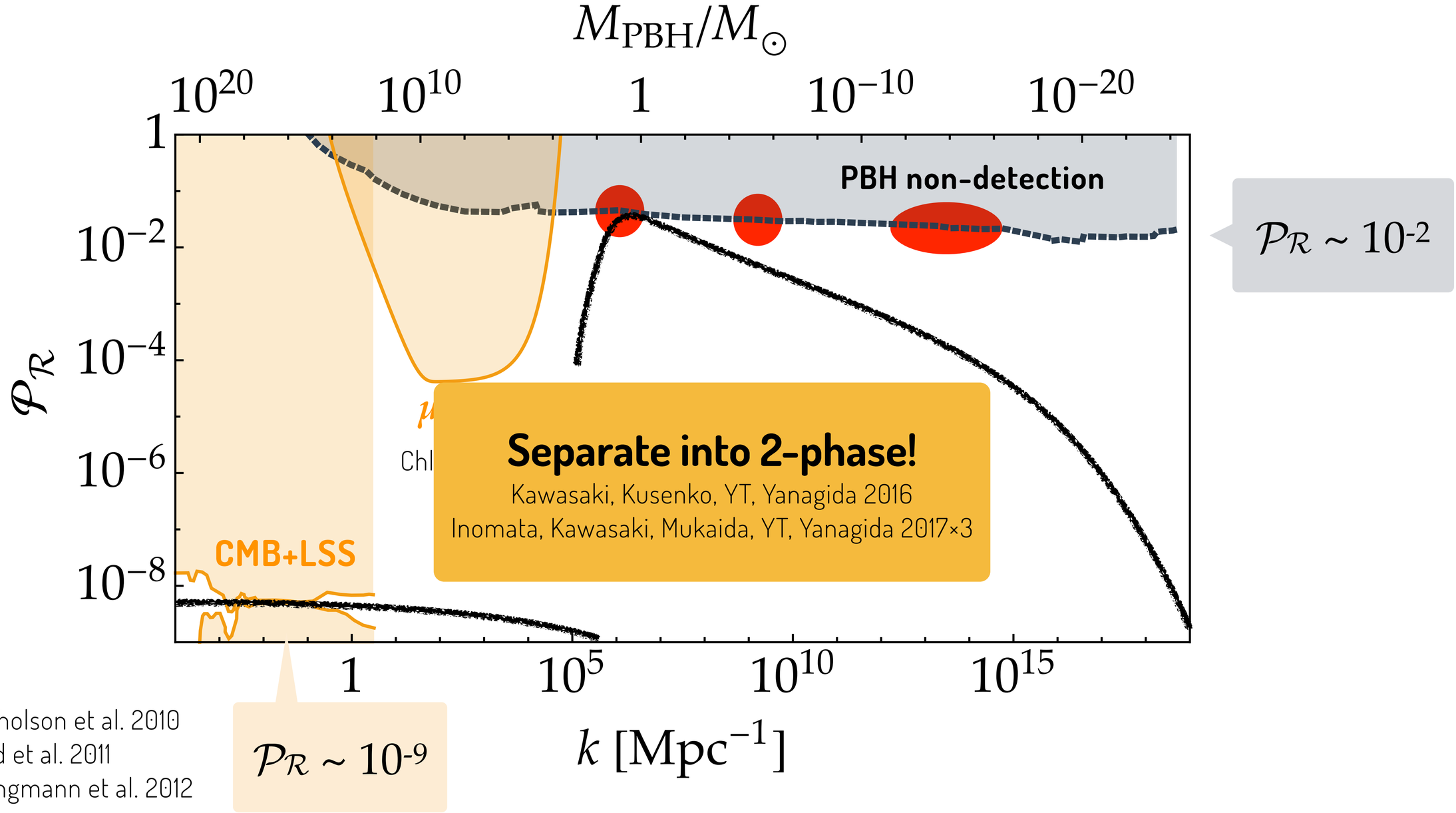


$\mathcal{P}_\mathcal{R} \sim 10^{-2}$

In single-field slow-roll inflation,
$(n_S - 1, \alpha) \sim \mathcal{O}(\varepsilon)$

$\mathcal{P}_\mathcal{R} \sim 10^{-9}$

Nicholson et al. 2010
Bird et al. 2011
Bringmann et al. 2012



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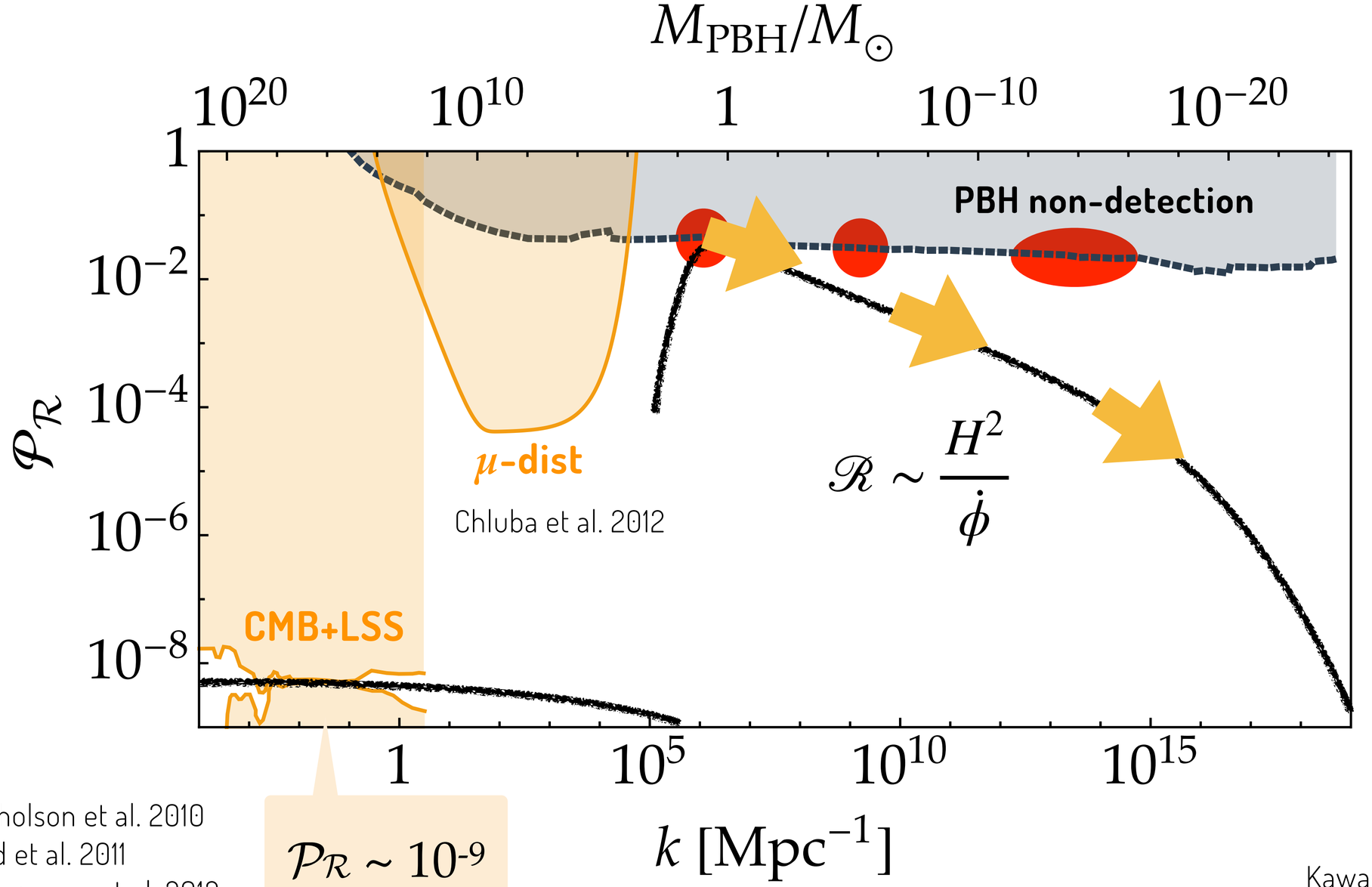

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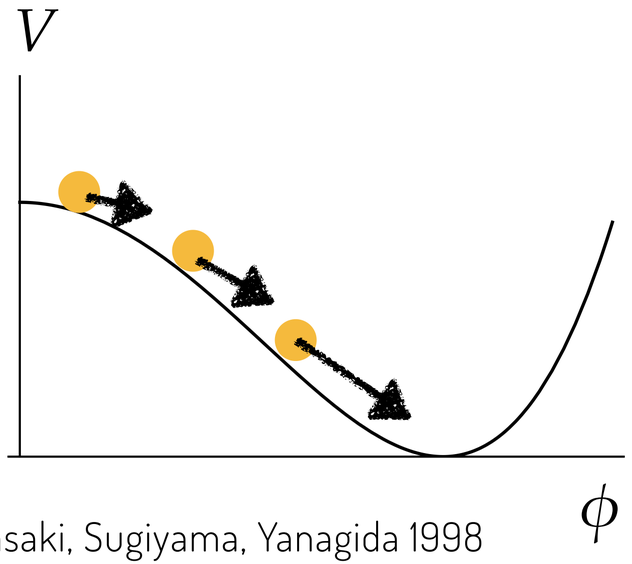

Kawasaki, Sugiyama, Yanagida 1998

Nicholson et al. 2010
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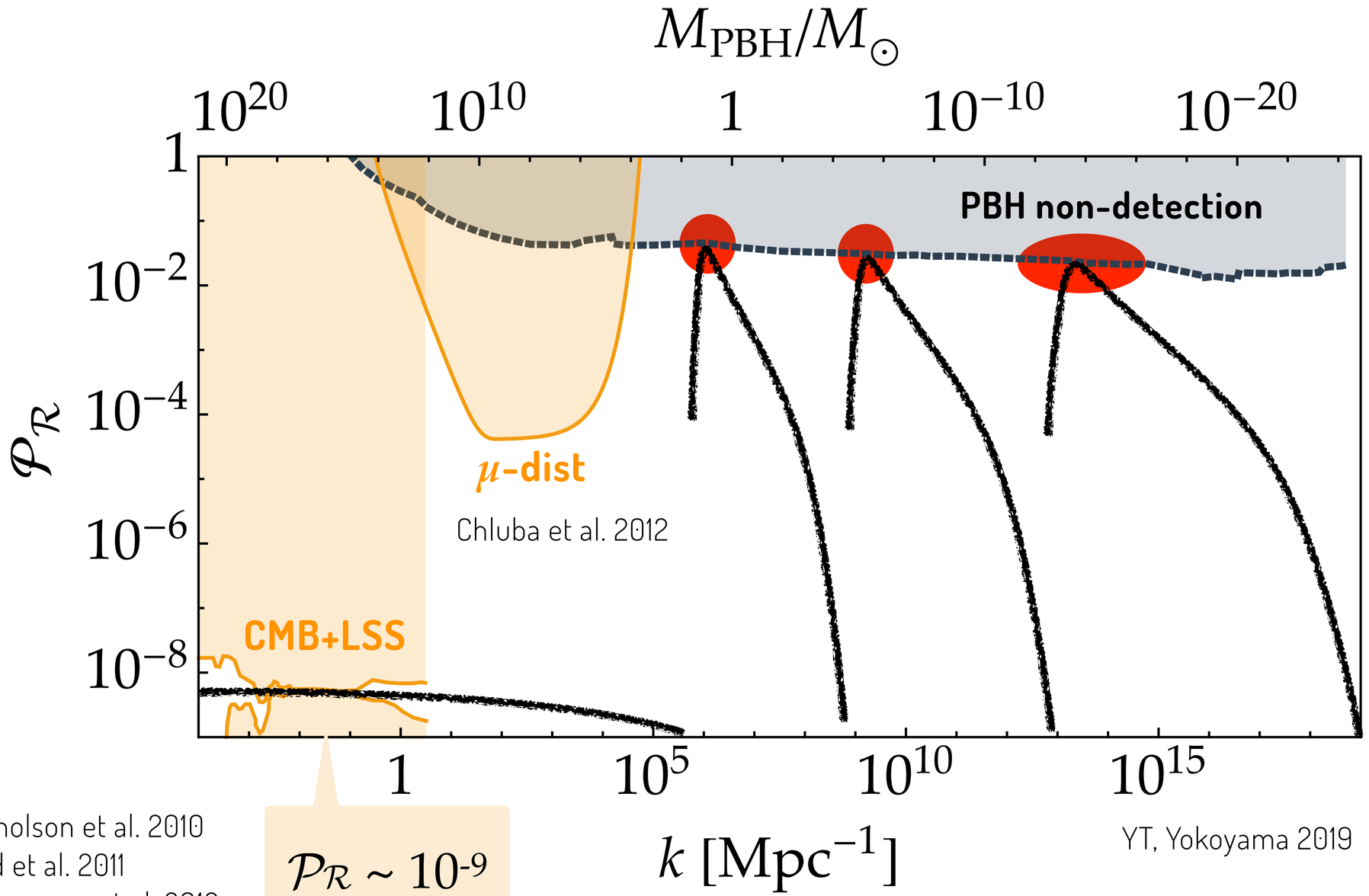
$\mathcal{P}_\mathcal{R} \sim 10^{-9}$



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$\mathcal{P}_\mathcal{R} \sim 10^{-9}$

YT, Yokoyama 2019

- **4-hilltop**

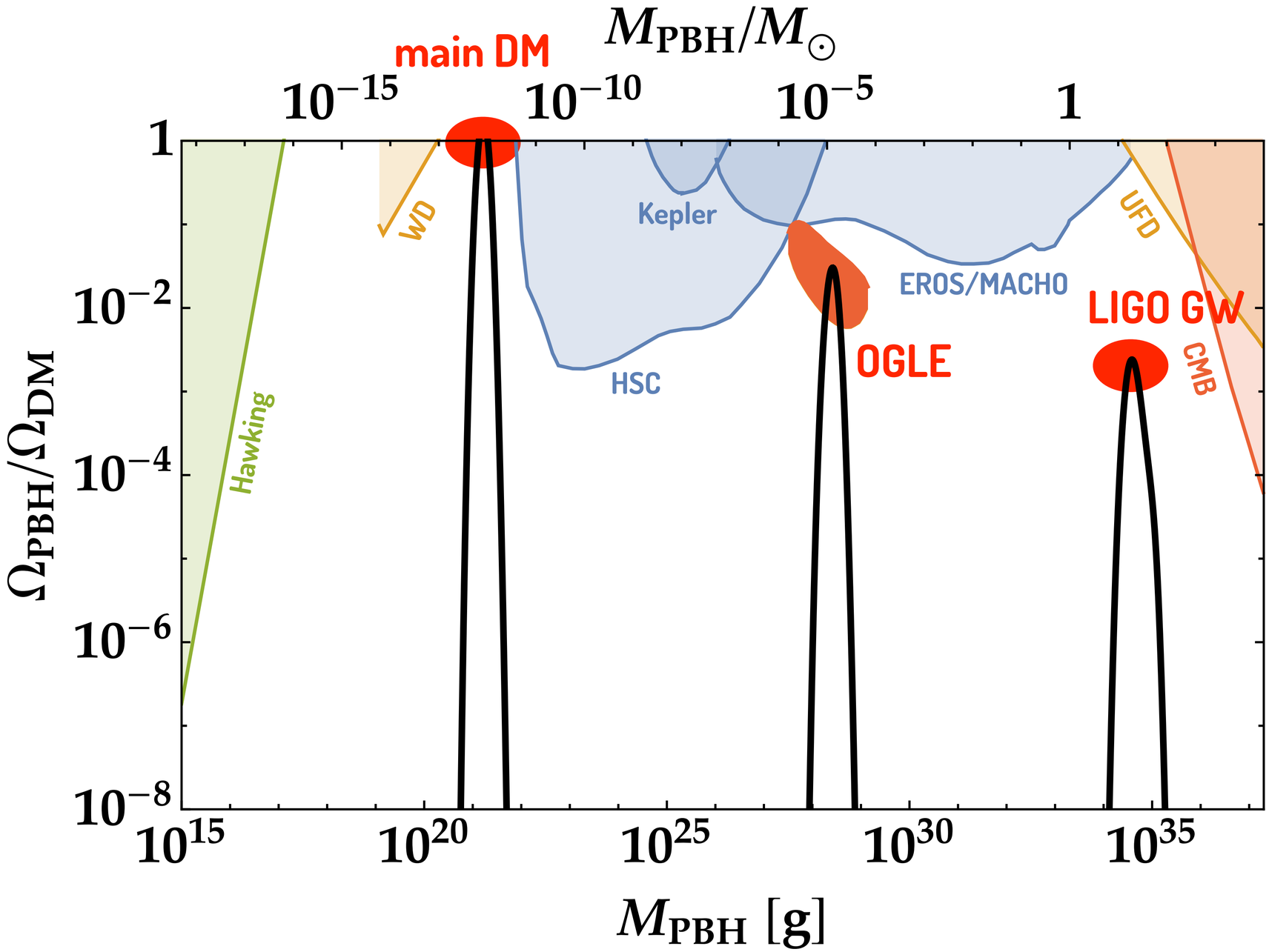
$$V_{\rm hill} = \sum_{i=1}^{4} V_{{\rm hill},i} \simeq \sum_i v_i^4 \left(1 - \frac{1}{2}\kappa_i \frac{\phi_i^2}{M_{\rm Pl}^2}\right)$$

$+$

- **Stabilization**

$$V_{\rm stab} = \sum_{i\neq j} \frac{c_{ij}}{2} V_{{\rm hill},i} \frac{\phi_j^2}{M_{\rm Pl}^2}$$

  - during phase-i: stabilize ϕ_{i+1}
  - after $V_{{\rm hill},i}$ decays: start phase-$(i+1)$


$M_{\rm PBH}/M_\odot$
main DM
10^{-15}
10^{-10}
10^{-5}
1
1
10^{-2}
10^{-4}
10^{-6}
10^{-8}
$\Omega_{\rm PBH}/\Omega_{\rm DM}$
Hawking
WD
Kepler
HSC
EROS/MACHO
OGLE
UFD
LIGO GW
CMB
10^{15}
10^{20}
10^{25}
10^{30}
10^{35}
$M_{\rm PBH}$ [g]

Testability

- LIGO/Virgo PBH

PBH tends to be spinless
Chiba & Yokoyama 2017

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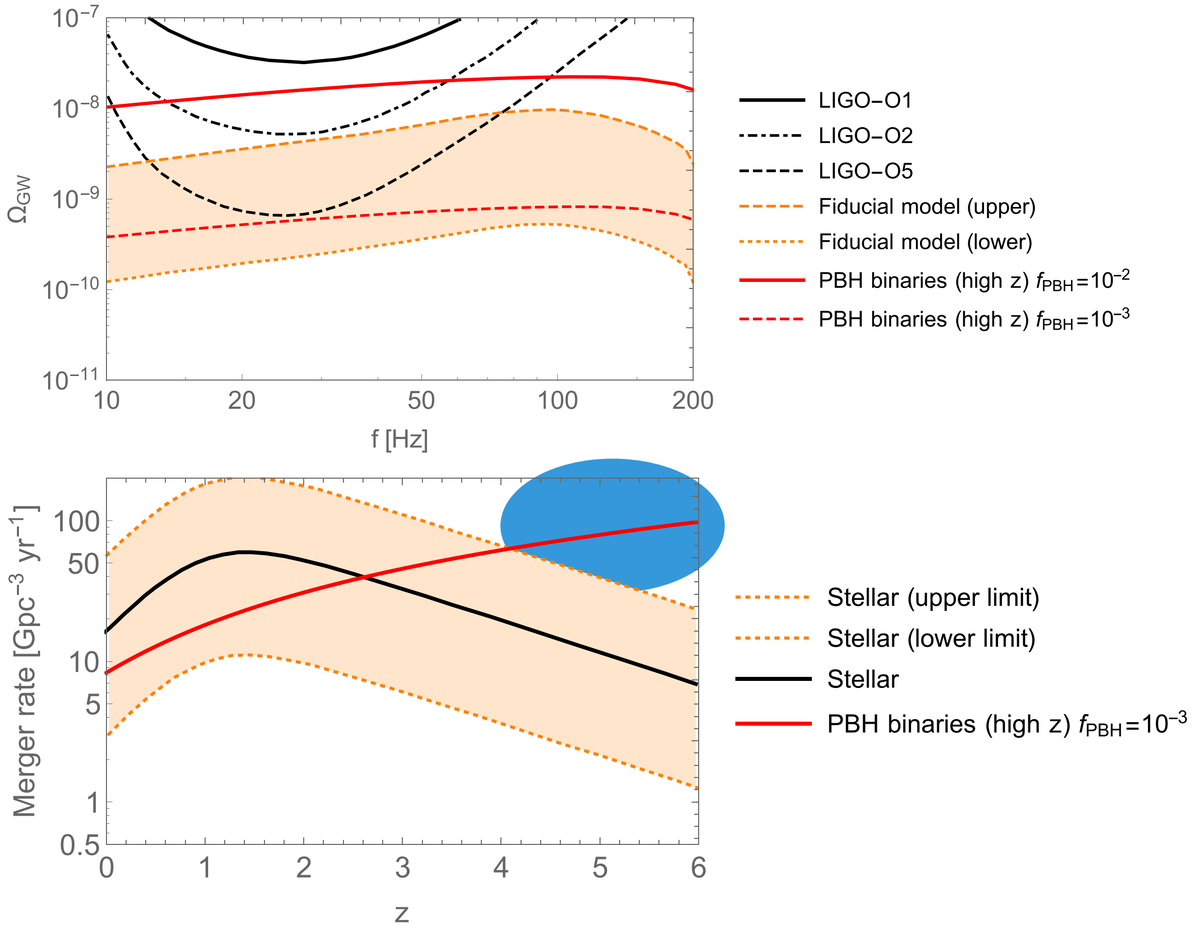
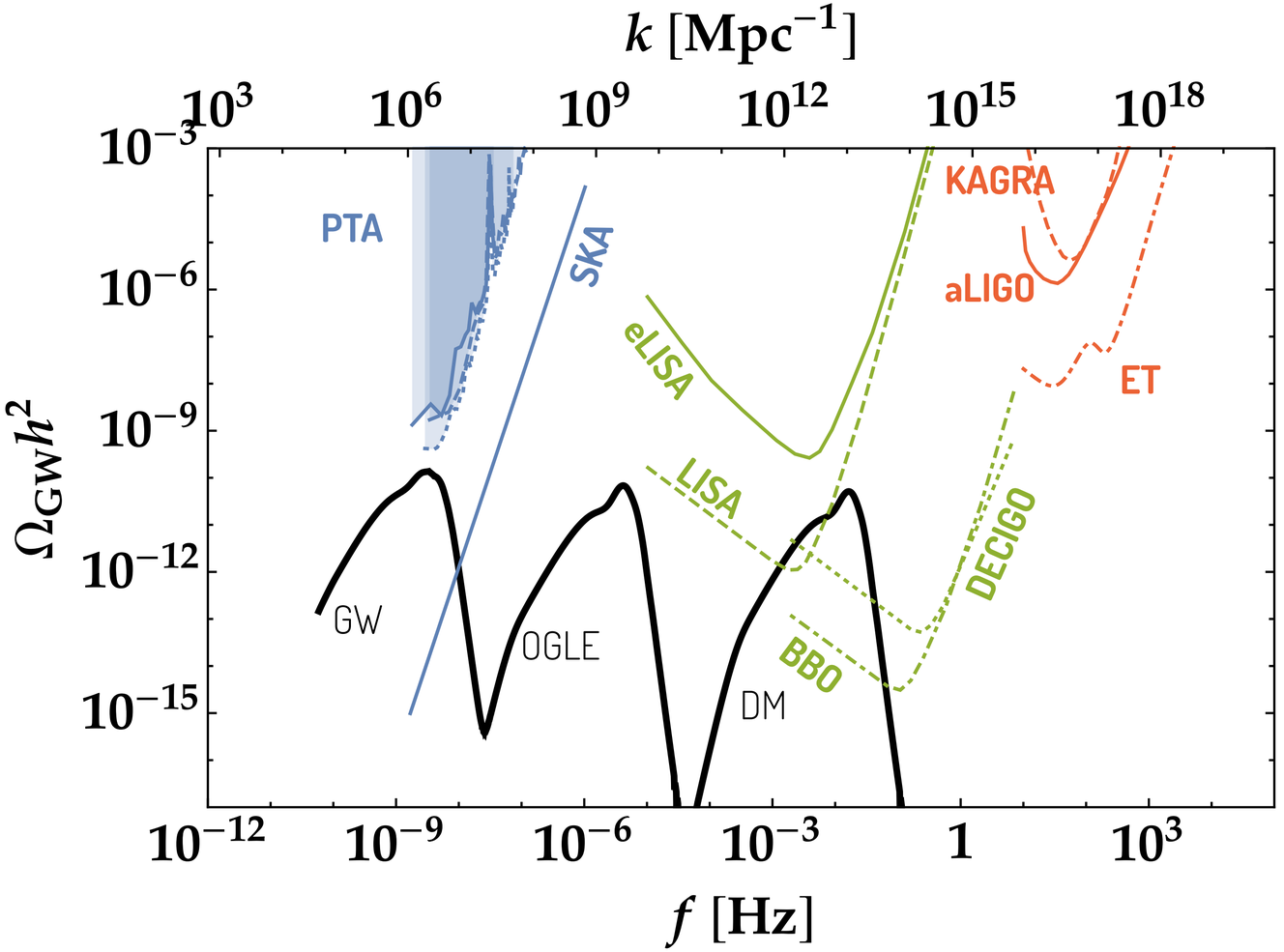
LIGO/Virgo 2018

Sasaki+ 2018



Testability

large scalar ptb. → secondary tensor ptb. (stochastic GW) : $\Omega_{\rm GW}h^2 \sim 10^{-9}\left(\frac{\mathscr{P}_{\mathscr{R}}}{10^{-2}}\right)^2$



Conclusions

- 3 interesting mass region for PBH

  $10\,M_\odot$: LIGO/Virgo GW

  $10^{-5}\,M_\odot$: OGLE lensing

  $10^{-12}\,M_\odot$: 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