Gravitational wave background from binary supermassive black holes seeded by primordial black holes

SOKENDAI/KEK   D1

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Expected GW amplitude from simulations

NANOGrav 15-yr   Agazie, Anumarlapudi, et al. (2023)

$$A = 2.4^{+0.7}_{-0.6} \times 10^{-15} \quad \text{at} \quad f = 1 \, \text{yr}^{-1} \sim 3.17 \times 10^{-8} \, \text{Hz}$$

(median + 90% credible interval)

Predictions from the simulation based on
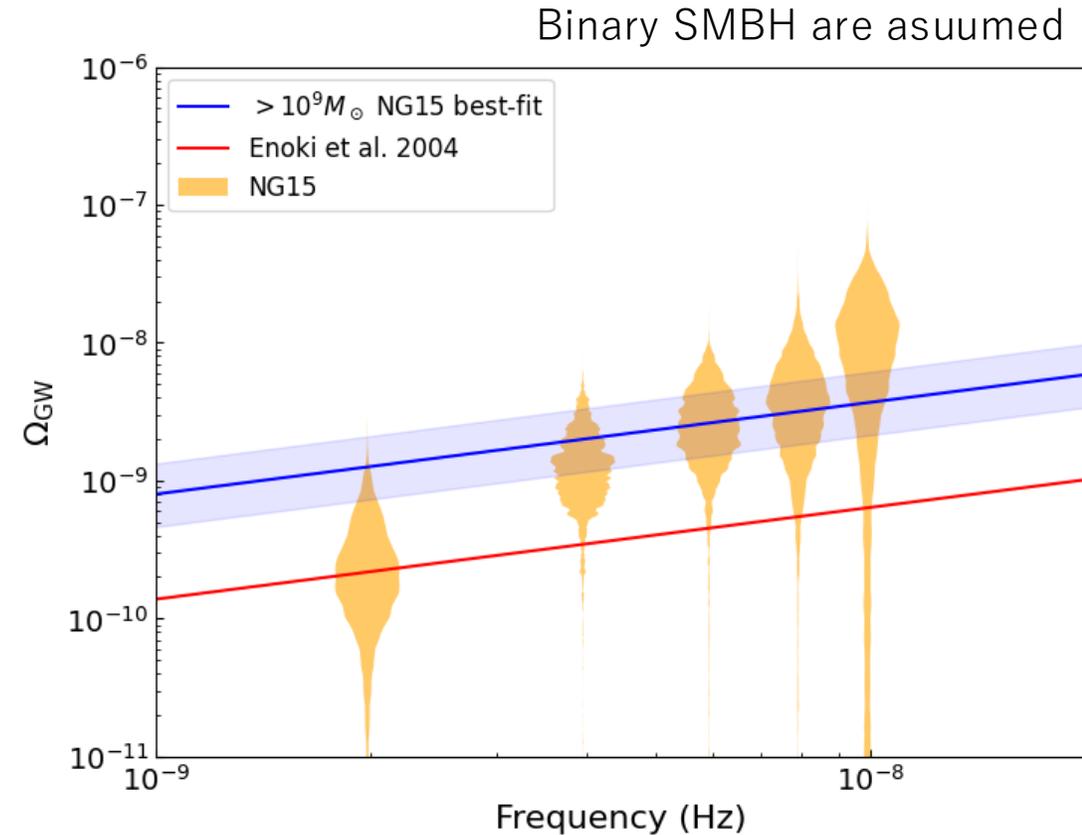semi-analytical model of galaxy formation & merger

Enoki, Nagashima et al. (2004)

$$h_c(f) \sim 10^{-16} \left(\frac{f}{10^{-6} \, \text{Hz}} \right)^{-\frac{2}{3}} \quad \text{for } f \lesssim 10^{-6} \, \text{Hz}$$

Binary SMBH are asuumed

Mikage U. Kobayashi, Kazunori Kohri arXiv:2511.04210

Simulations expected lower value
than NANOGrav 15-yr

Is an additional SMBH formation channel needed ?

Primordial black hole (PBH): BHs formed from the gravitational
collapse of large density fluctuations
in the early universe when they re-enter the horizon
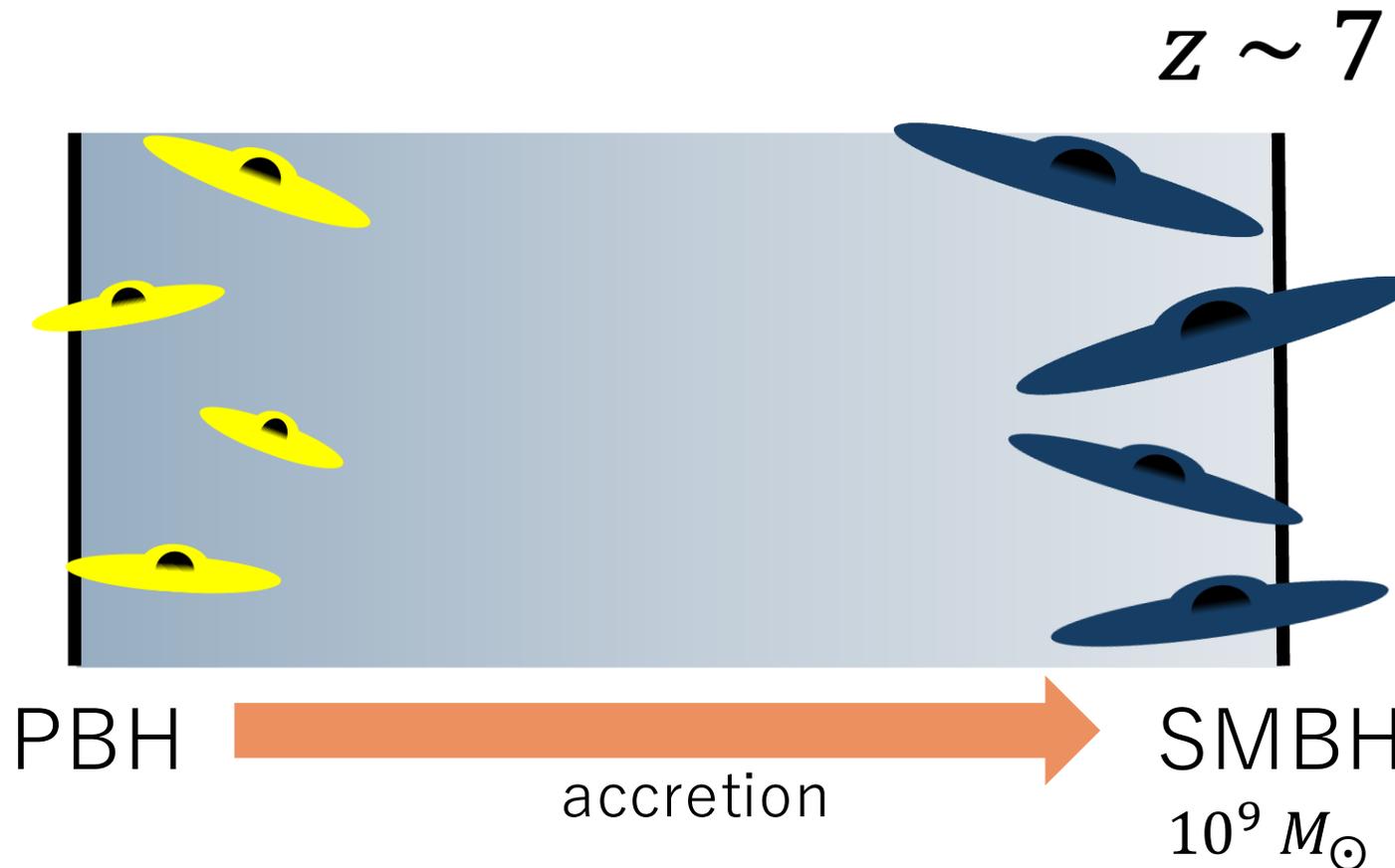
$$z \sim 7$$

PBH

accretion

SMBH
$10^9 \, M_\odot$
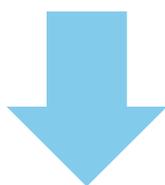
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PBH accretion is constrained by 21cm observations Kohri, Sekiguchi, Wang (2022)

Gas accretion onto PBHs

Intergalactic medium(IGM)
is heated

21cm emission line
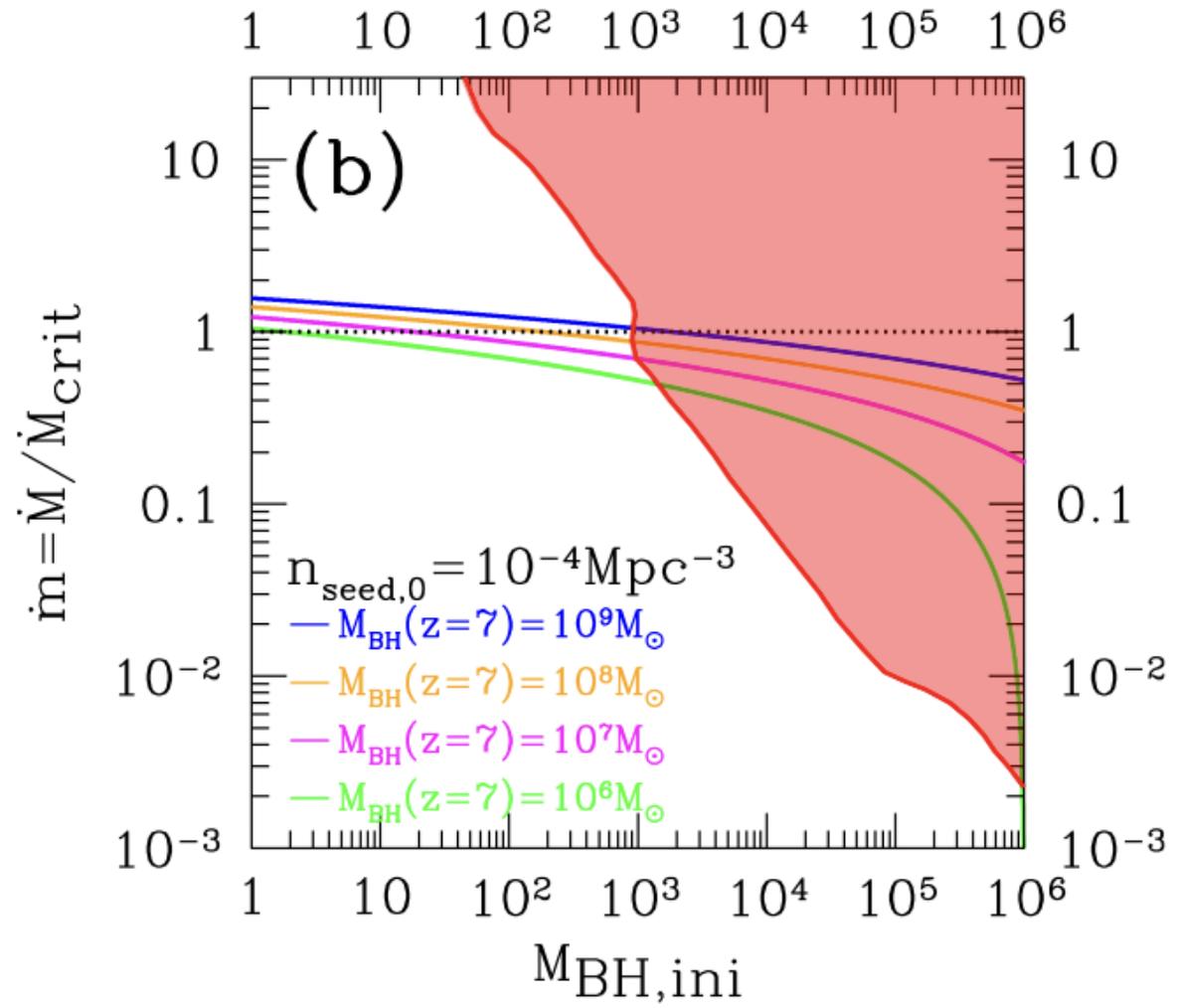
GW energy density spectrum

$$\Omega_{\mathrm{GW}}(f) \equiv \frac{1}{\rho_c}\frac{\mathrm{d}\rho_{\mathrm{GW}}}{\mathrm{d}\ln f} = \int \mathrm{d}m_1 \mathrm{d}m_2 \frac{\mathrm{d}z}{1+z}\frac{\mathrm{d}V_c}{\mathrm{d}z}\frac{\mathrm{d}R_{\mathrm{BH}}}{\mathrm{d}m_1 \mathrm{d}m_2}\frac{2\pi}{5}\frac{f^3\left|\tilde{h}(f)\right|^2}{\rho_c}$$

BH merger rate

Ellis, Fairbairn et al. (2023)

BH merger rate

$$\frac{\mathrm{d}R_{\mathrm{BH}}}{\mathrm{d}m_1 \mathrm{d}m_2} \approx C_{\mathrm{BH}}\frac{\mathrm{d}p(M_1, M_2, t)}{\mathrm{d}t\mathrm{d}M_2}\frac{\mathrm{d}M_2}{\mathrm{d}m_2}\frac{\mathrm{d}n(m_1, t)}{\mathrm{d}m_1}$$

PBH mass function

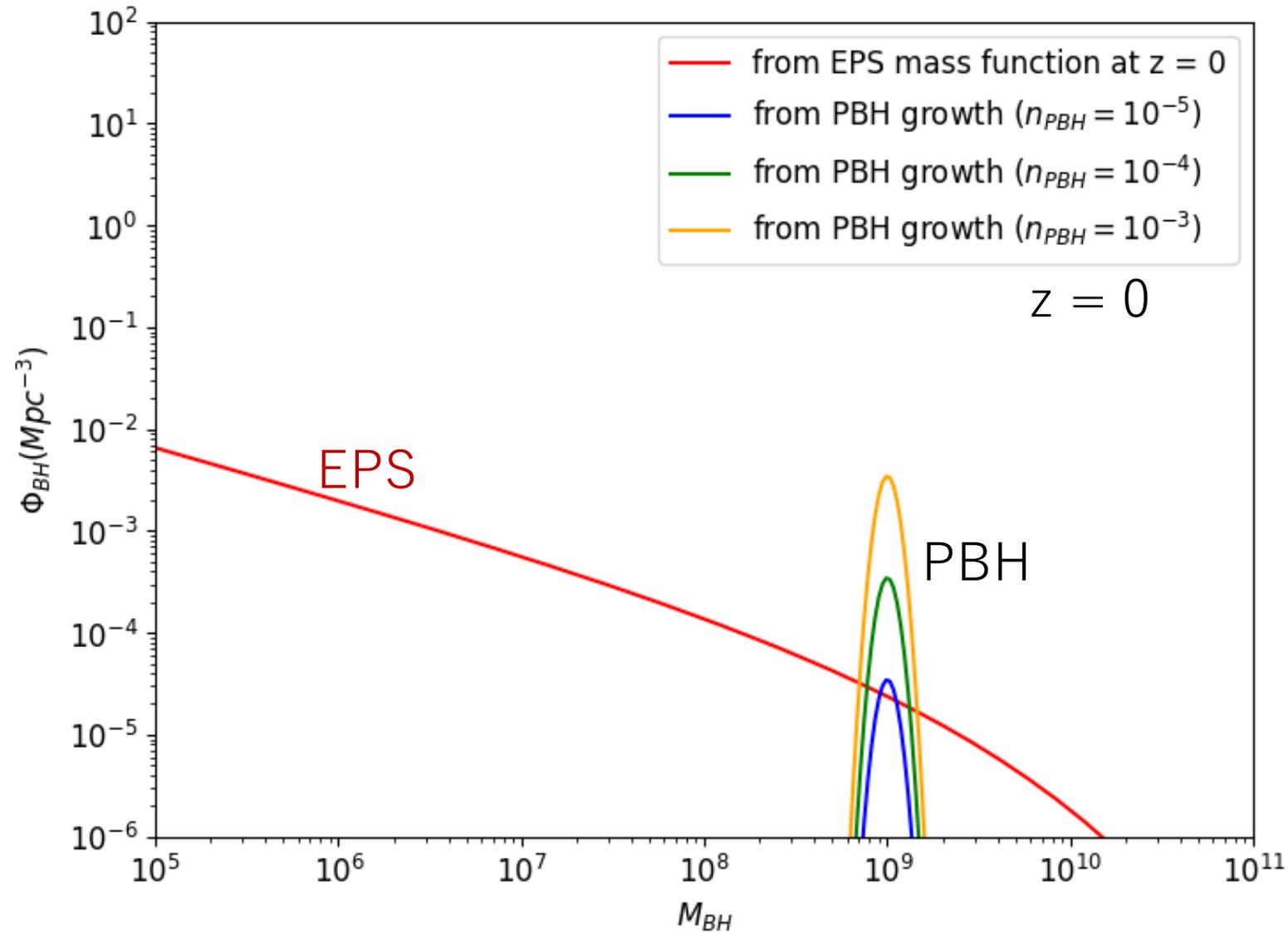$$\left.\frac{\mathrm{d}n}{\mathrm{d}m}\right|_{\mathrm{PBH}} \propto \frac{1}{\sqrt{2\pi}\sigma m}\exp\left(\frac{1}{2}\frac{(\log_{10}(m) - \mu)^2}{\sigma^2}\right)$$

$$\frac{\mathrm{d}n}{\mathrm{d}m} = \left.\frac{\mathrm{d}n}{\mathrm{d}m}\right|_{\mathrm{EPS}} + \left.\frac{\mathrm{d}n}{\mathrm{d}m}\right|_{\mathrm{PBH}}$$
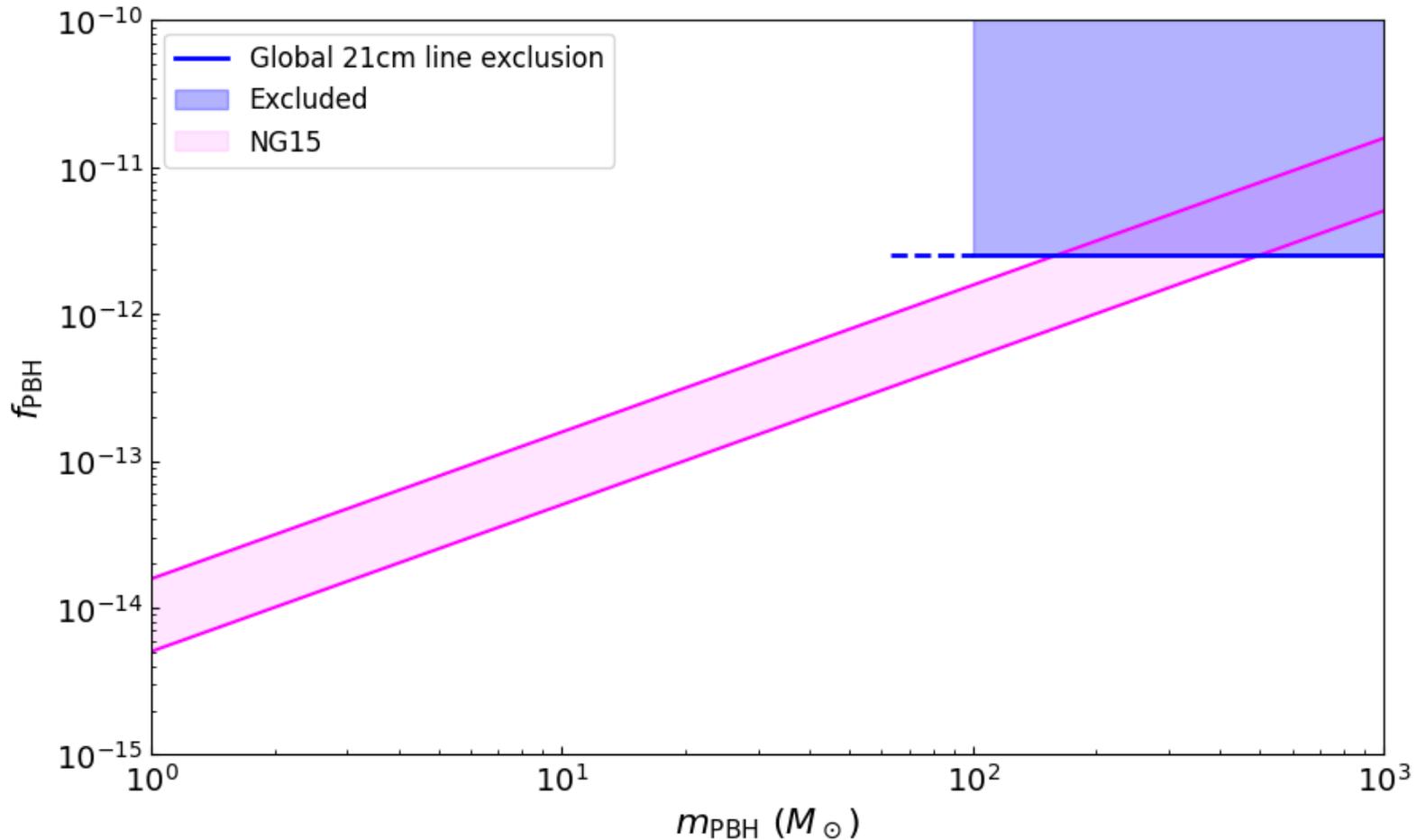
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BH mass function including PBH seed

Result

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arXiv:2511.04210

NANOGrav 15yr

$A = 2.4^{+0.7}_{-0.6} \times 10^{-15}$ at $f = 1\,\mathrm{yr}^{-1}$

(median + 90% credible interval)

$n_{\mathrm{seed,upper}} \sim 6.16 \times 10^{-4}\,\mathrm{Mpc}^{-3}$

$n_{\mathrm{seed,lower}} \sim 1.97 \times 10^{-4}\,\mathrm{Mpc}^{-3}$

$$f_{\mathrm{PBH}} = \frac{n_{\mathrm{seed,0}} m_{\mathrm{PBH}}}{\rho_{\mathrm{DM,0}}}$$

$n_{\mathrm{seed,0}}$: Comoving number density of PBH
m_{PBH} : PBH mass
$\rho_{\mathrm{DM,0}}$: DM mass density

Conclusion & Summary

・The GW amplitude observed by NANOGrav 15-yr is larger than predicted by simulations based on a semi-analytic galaxy formation model.

・We consider gas accretion onto PBHs as an additional SMBH formation channel.

・SMBHs with $10^9 M_\odot$ can form by z ~ 7 without violating global 21cm constraints.

・PBHs in the allowed parameter space can explain the NANOGrav 15-yr GW amplitude.