Stochastic Gravitational Wave Background Detection through NANOGrav 15-year Data Set in the View of Massive Gravity

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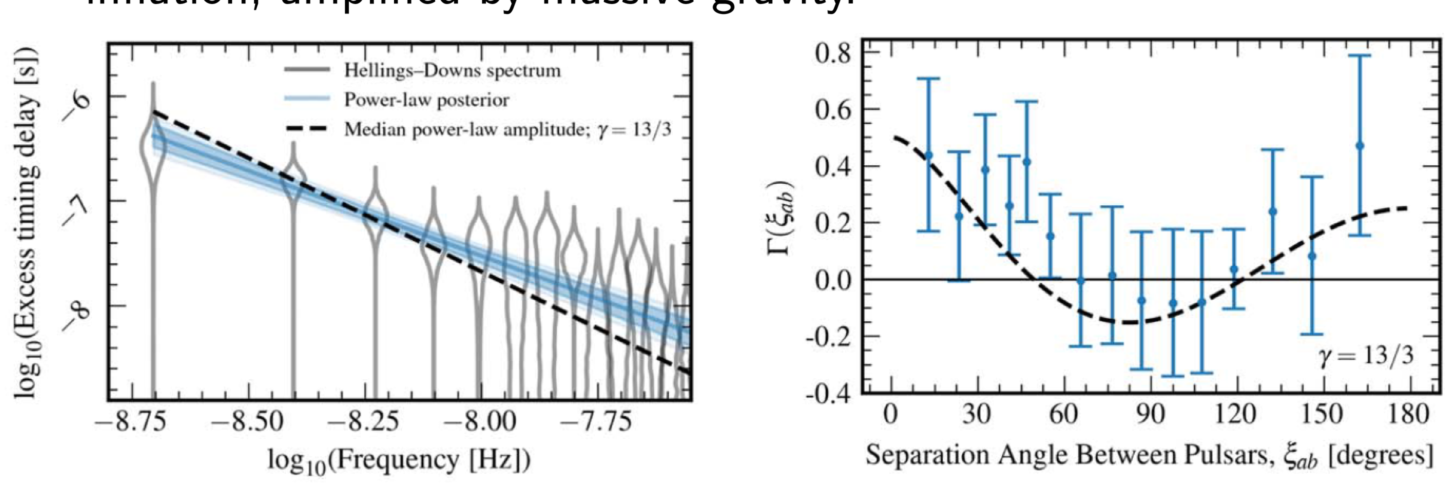
Abstract

- Convincing evidence of a stochastic gravitational wave background (SGWB) has been found by the NANOGrav 15-year data set (NG15).
- We evaluate the possibility of its source being from the early universe through massive tensor perturbations induced by parametric resonance.
- We find values of the graviton mass, mass cutoff time, and Hubble rate of inflation that amplify the energy spectra of primordial GWs to reproduce NG15 within 1-3σ.
- However, it is difficult to obey the BBN and CMB bound without introducing a suppression mechanism or making the graviton mass cutoff time too deep into the matter dominated era.

Background

- First detection of SGWB by NANOGrav collaboration in 2023 [1]
- Most popular explanation is astrophysical: inspiraling supermassive black hole binaries (SMBHBs) emitting low-frequency GWs [2].
- More exotic explanations lie in cosmological sources: cosmic strings, domain walls, first-order phase transitions, primordial magnetic fields, primordial GWs, scalar-induced GWs, etc [3].
- We explore the explanation of primordial GWs generated during inflation, amplified by massive gravity.



Massive Gravity

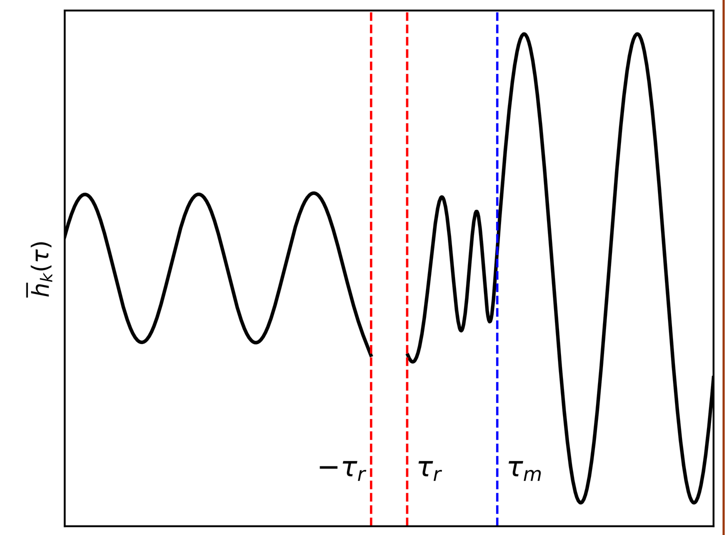
- We consider model of MTMG [4] where graviton mass $M_{\rm GW}$ is step-function of time [5]
- Equation of motion for the two tensor modes:

$$\bar{h}_k'' + \left(k^2 + a^2 M_{\rm GW}^2 - \frac{a''}{a}\right)\bar{h}_k = 0$$

- Scale factor a and graviton mass are defined as follows:

$$a(\tau) = \begin{cases} -1/(H_{\rm inf}\tau) & \tau < \tau_r \\ a_r\tau/\tau_r & \tau > \tau_r \end{cases}$$

$$M_{\rm GW}(\tau) = \begin{cases} m & \tau < \tau_m \\ 0 & \tau > \tau_m \end{cases}$$



Energy Density of GWs

- The present-day energy densities of GWs help us look at how primordial GWs are influenced by deviations from GR
- Energy density is defined as

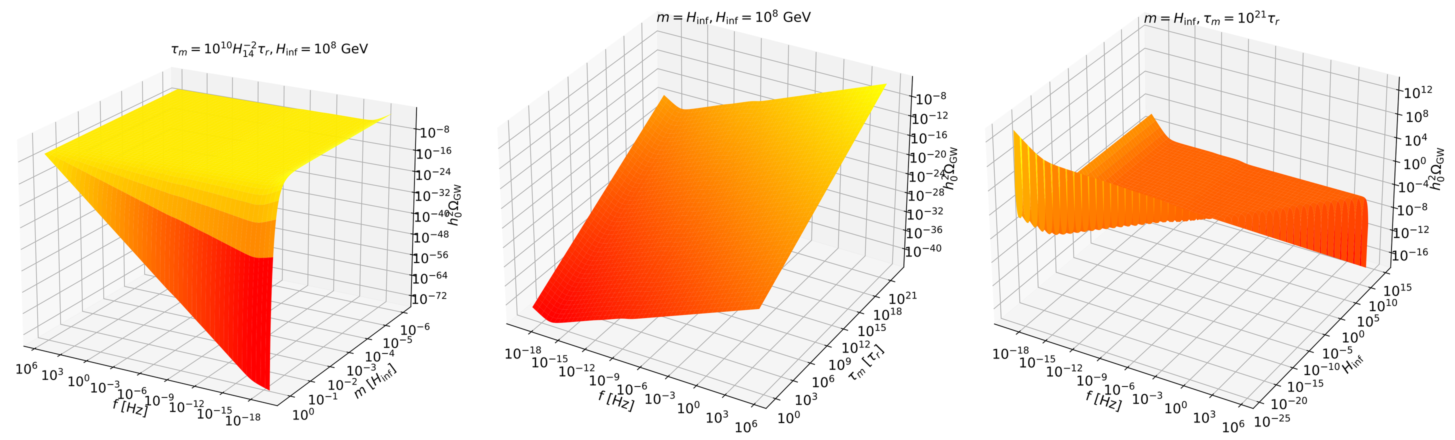
$$\Omega_{\rm GW} = \frac{1}{\rho_c}\frac{d\rho_{\rm GW}}{d\log k}$$

- In massive gravity, $\Omega_{\rm GW}$ is blue tilted / amplified:

$$\Omega_{{\rm GW},0}(f) = \frac{\pi^2 f^2}{3a_0^2H_0^2}\frac{\tau_m}{\tau_r}(k\tau_r)^{3-2\nu}\mathcal{P}_{\rm GR}(k)$$

- $\mathcal{P}_{\rm GR}(k)$ is defined in our paper [6] in Eq. 14.
- ν in the exponent is defined as

$$\nu = \sqrt{\frac{9}{4} - \frac{m^2}{H_{\rm inf}^2}}$$



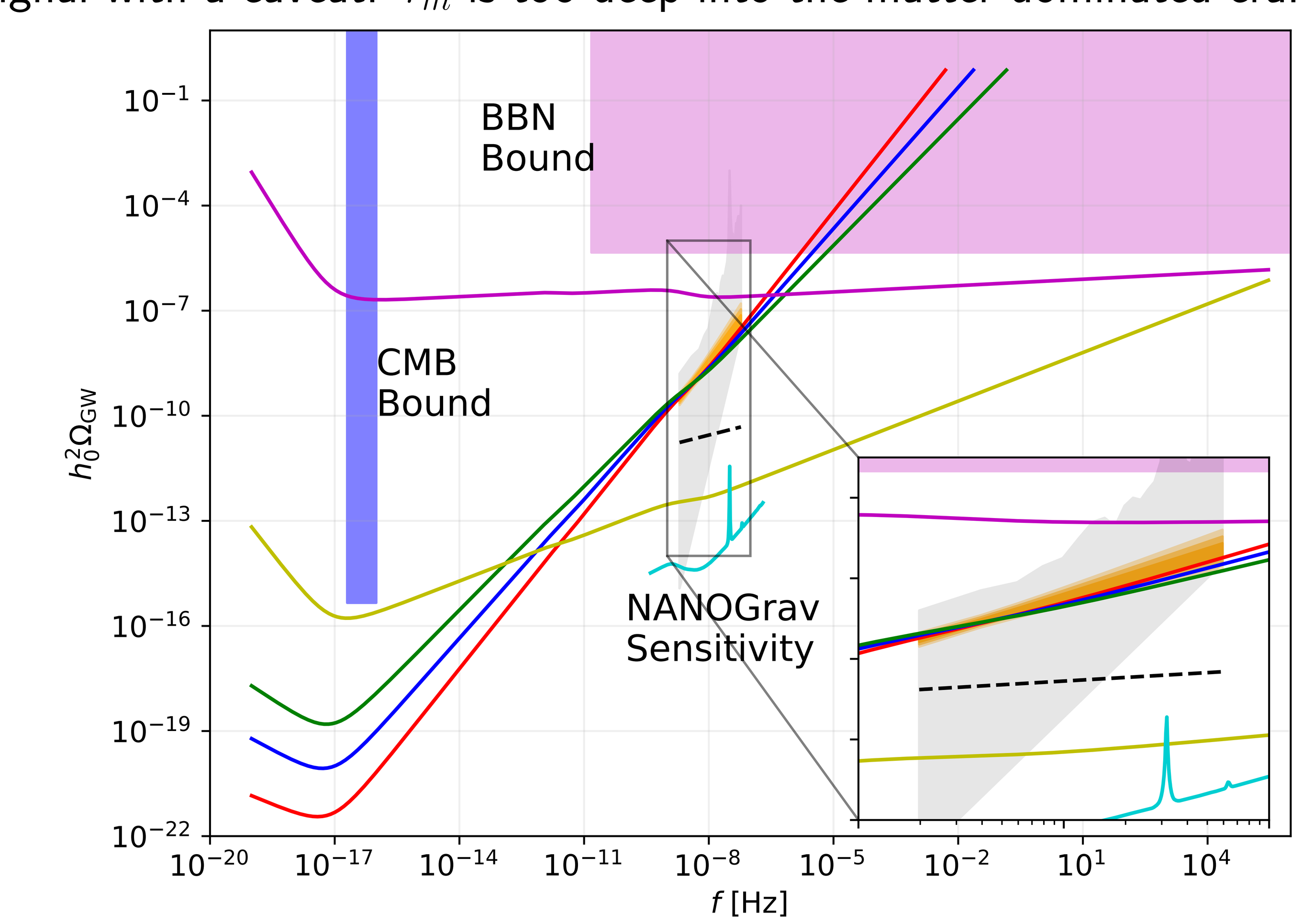
$h_0^2\Omega_{{\rm GW},0}$ as a function of f and $M_{\rm GW}$ (left), τ_m (middle), and $H_{\rm inf}$ (right).

Results

Our values for the parameters are

- $M_{\rm GW} = 1.298 H_{\rm inf}$, $H_{\rm inf} = 1.7\,{\rm GeV}$ to stay within 1σ (red curve)
- $M_{\rm GW} = 1.251 H_{\rm inf}$, $H_{\rm inf} = 8.0\,{\rm GeV}$ to stay within 2σ (blue curve)
- $M_{\rm GW} = 1.201 H_{\rm inf}$, $H_{\rm inf} = 50.\,{\rm GeV}$ to stay within 3σ (green curve)
- purple curve – partially produces the signal for large $\Omega_{\rm GW}$ and f
- golden curve – partially produces the signal for small $\Omega_{\rm GW}$ and f

Respecting CMB, BBN bounds and reproducing the signal are mutually exclusive. If we don't respect them, we achieve good agreement with signal with a caveat: τ_m is too deep into the matter dominated era.



Conclusions

- Time-dependent MTMG successfully reproduces NG15
- BBN bound is violated for $f \gtrsim 10^{-6}$ Hz.
- Suppression mechanism, analogous to the damping of the energy density from the free-streaming neutrinos [7], could be introduced
- More complicated functions for $M_{\rm GW}(t)$ are possible; future work can try to place constraints on the time evolution of the mass
- Further observations that place constraints on $H_{\rm inf}, a_r, \tau_r$ would be able to constrain the parameters of this theory

Source Code

The NANOGrav 15-Year data is available at nanograv.org/science/data, source code to reproduce all of the figures in our paper [6] is available at github.com/ChrisChoi314/constrain_mass_nanograv_15 and the TeX for this poster is at github.com/ChrisChoi314/mg_poster_aas243.

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