ΔN_{eff} from SGWB: PTA & CMB

Amresh Verma

Ph.D. Student, Ariel University

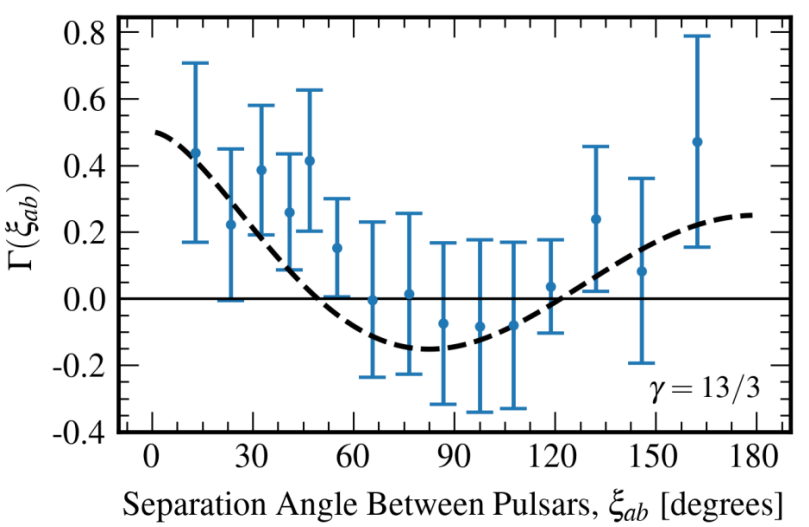
w/ Ido Ben-Dayan and Utkarsh Kumar

DESY Theory Workshop, 2025

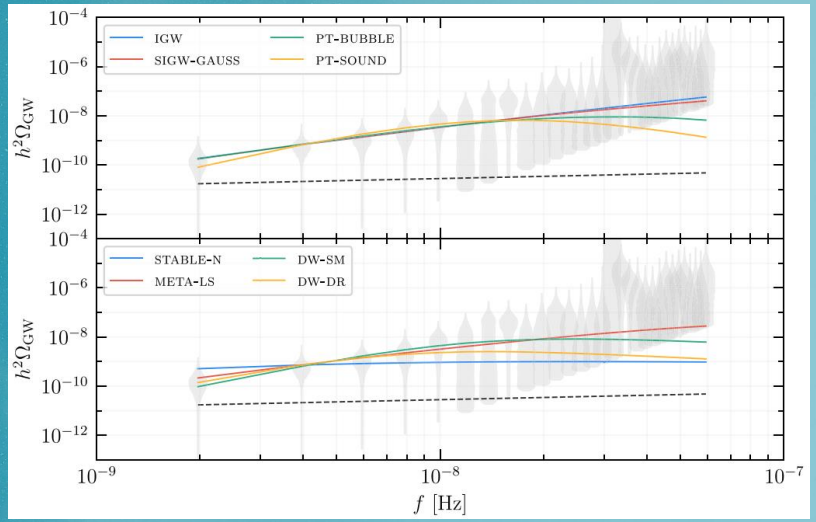
NANOGrav Result

⇒ The NANOGrav 15-year data set has provided **statistically significant** evidence for a **gravitational-wave background**.

⇒ The data set has revealed evidence for **Hellings-Downs** spatial correlations in the **timing residuals** for an ensemble of **67 pulsars**.



Gabriella Agazie et al, 2023 ApJL 951 L8



Adeela Afzal et al, 2023 ApJL 951 L11

Sources?

- **Astrophysical**

  1. **SMBHB?**

     - **Inspiralling phase can explain the observed signal**

     - **NANOGrav measures 10 time higher amplitude than the existing BH population models predict (**Sato-Polito et al.**)**

- **Cosmological**

  1. **Inflationary**
  2. **Phase Transitions**
  3. **Non-Standard Reheating**
  4. **More.....**

Models

⇒ **Blue tilted Inflation**

⇒ **Non-Standard Reheating, w_{rh}**

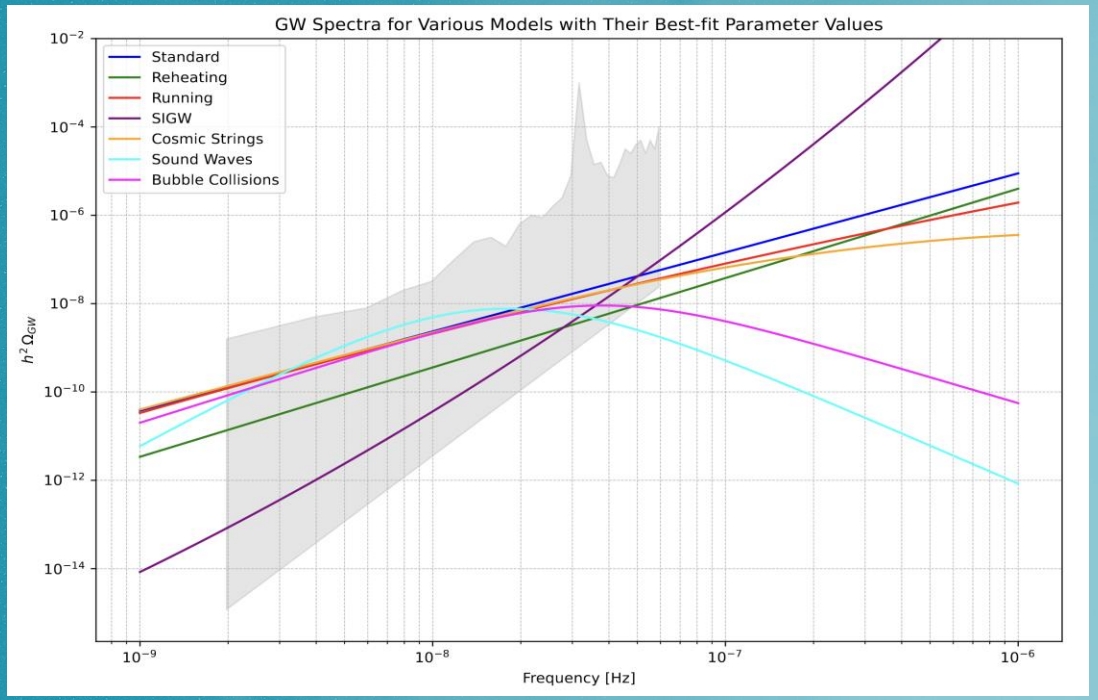
⇒ **Running tensor tilt,** $n_t(f) = n_t(f_{yr}) + \frac{\alpha_t}{2} \log\left(\frac{f}{f_{yr}}\right)$

⇒ **Scalar Induced Gravitational Waves**

$$\mathcal{P}_{\mathcal{R}}(k) = A_s \left(\frac{k}{k_0}\right)^{n_s(k_0)-1+\frac{\alpha(k_0)}{2}\ln\frac{k}{k_0}+\frac{\beta(k_0)}{6}\ln^2\frac{k}{k_0}}$$

⇒ **Phase Transition – Bubble & Sound**

⇒ **Metastable Cosmic Strings**



Tools Used:

1. **PTArcade (Mitridate, Andrea, et al.)**
2. **GetDist**

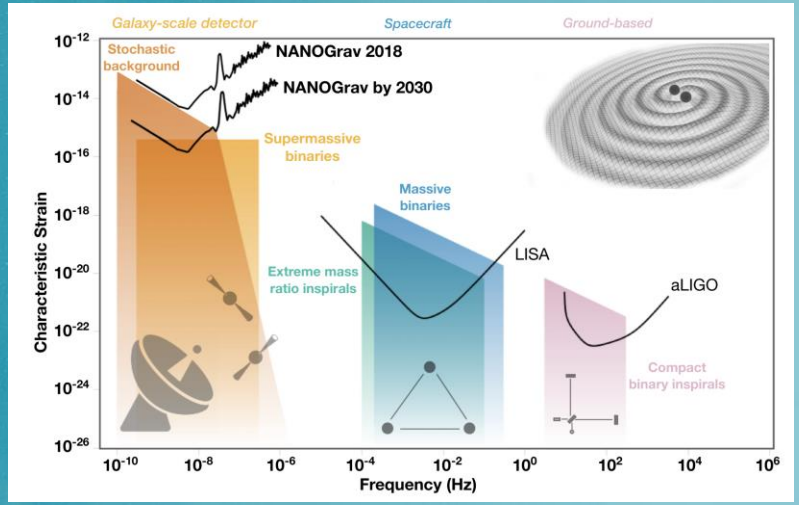
Neff

$$\Delta N_{eff} \approx 1.8 \times 10^5 \int_{f_{min}}^{f_{max}} df \frac{\Omega_{GW}(f)\, h^2}{f}$$

⇒ **Present: f_{max} = 60 nHz**

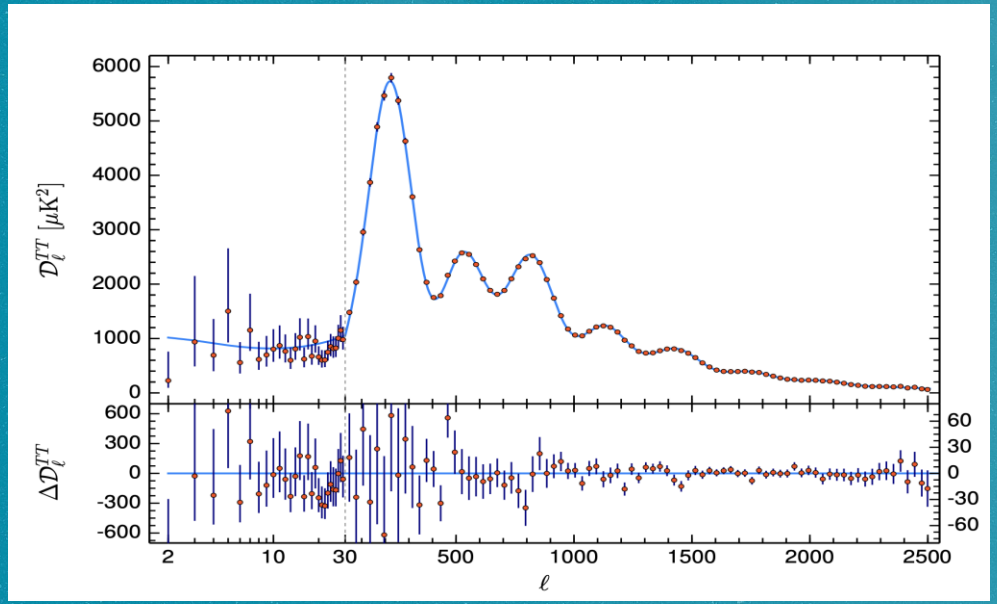
⇒ **Potential to reach: f_{max} ~ µHz**

⇒ If PTA is **cosmological**,
we have a **measurement** =>Strong constraints.



See: A. Brazier et al.

CMB



$$\mathrm{N_{eff}} = 2.89 \pm 0.19$$

Planck18 : (TT + TE + EE + lowE + Lensing)

$$\mathrm{P18}: \ \sigma(\mathrm{N_{eff}}) = 0.19$$

$$\mathrm{SO}: \ \sigma(\mathrm{N_{eff}}) = 0.045$$

$$\mathrm{S4}: \ \sigma(\mathrm{N_{eff}}) = 0.027$$

Example

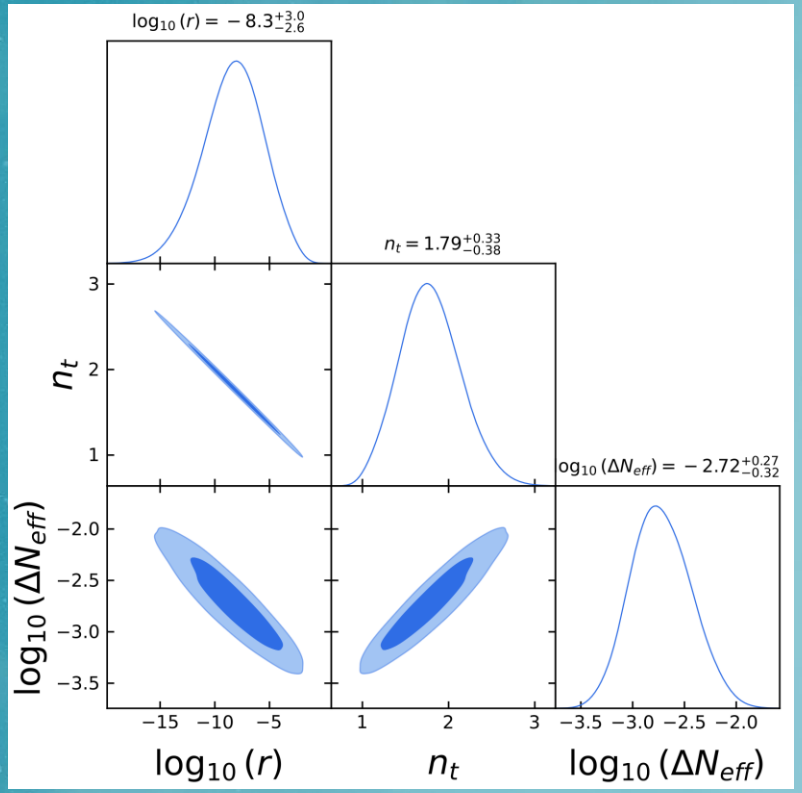
Inflationary:

$$\Omega_{\rm GW}^{\rm prim,i}(f) = \frac{r\, A_s\, \tilde{\gamma}}{24} \left(\frac{k}{k_*}\right)^{n_t}$$

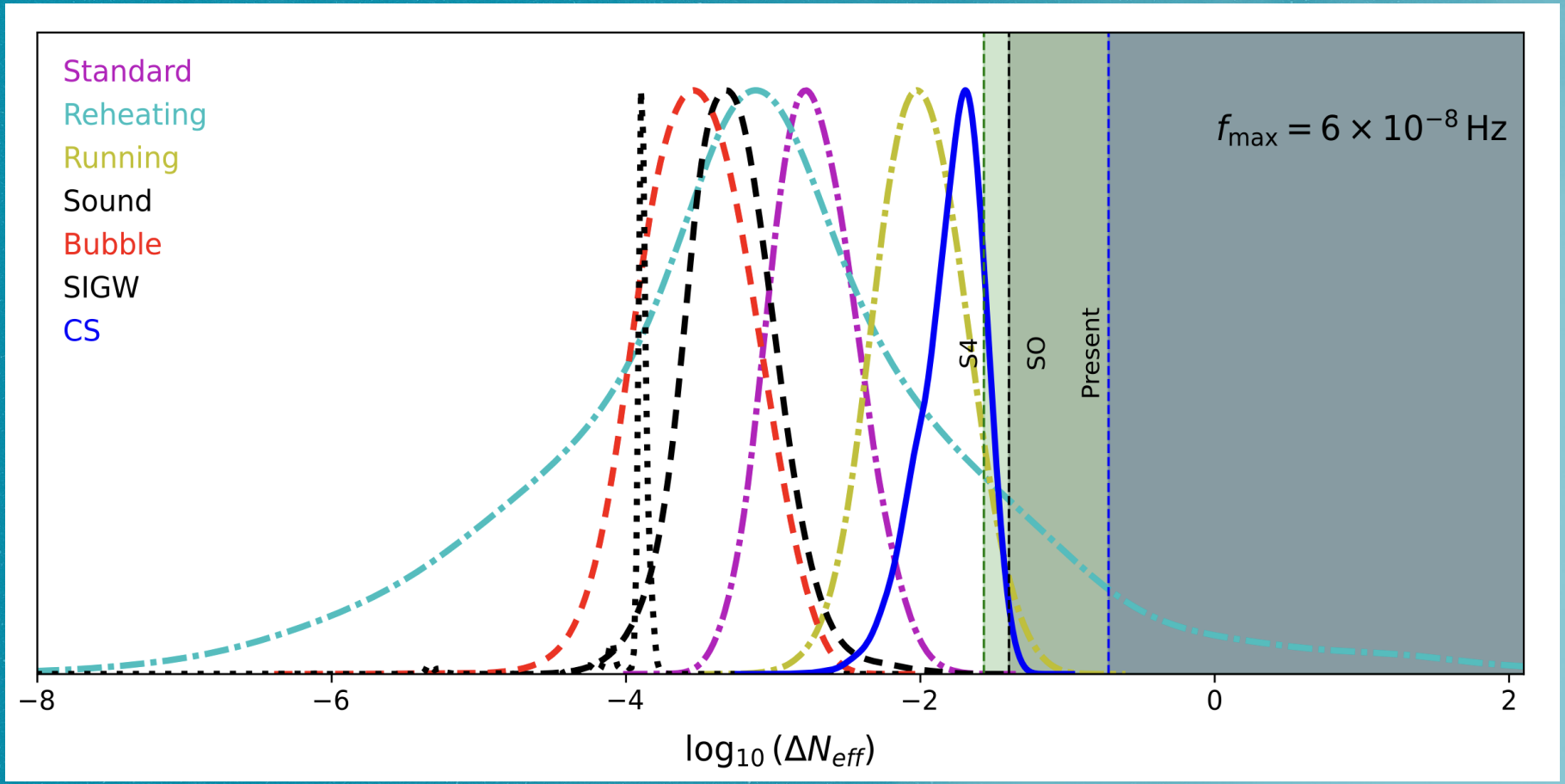
$$\Delta N_{eff} \approx 1.8 \times 10^5 \int_{f_{min}}^{f_{max}} df \frac{\Omega_{GW}(f)\, h^2}{f}$$

⇒ **Present: f_{max} = 60 nHz**

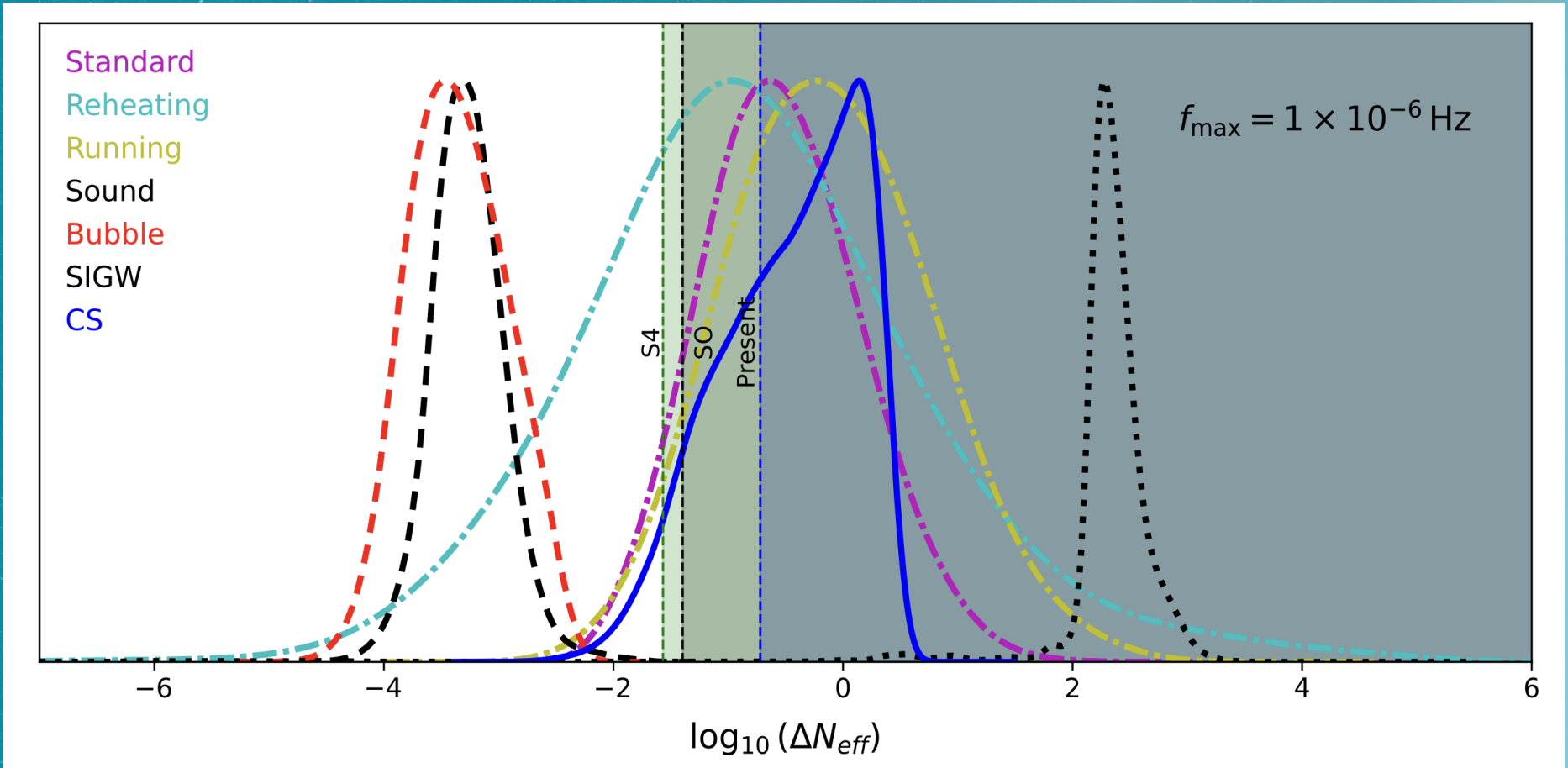
⇒ **Potential to reach: f_{max} ~ µHz**



Current Measurement



Future Prediction



3 Sigma Detection

Model	$\log_{10}\Delta N_{\rm eff}$				
	$f_{\rm max} = 6\times10^{-8}$ Hz	$f_{\rm max} = 1\times10^{-6}$ Hz	$\#\sigma_{\rm present}$	$\#\sigma_{\rm SO}$	$f_{3\sigma_{\rm SO}}$ (Hz)
Standard	$-2.72^{+0.27}_{-0.32}$	$-0.54^{+0.66}_{-0.76}$	1.52	6.41	6.65×10^{-7}
Reheating	-3.1 ± 1.5	$-0.80^{+1.3}_{-1.5}$	0.83	3.52	9.40×10^{-7}
Running	-2.00 ± 0.31	$-0.13^{+0.86}_{-0.97}$	3.90	16.4	3.15×10^{-7}
Sound	$-3.28^{+0.28}_{-0.32}$	$-3.26^{+0.28}_{-0.33}$	–	–	–
Bubble	-3.53 ± 0.38	$-3.35^{+0.41}_{-0.49}$	–	–	–
SIGW	$-3.894^{+0.031}_{-0.035}$	$2.336^{+0.231}_{-0.153}$	>1000	>1000	2.60×10^{-7}
Cosmic String	$-1.78^{+0.098}_{-0.210}$	$-0.53^{+0.93}_{-0.33}$	1.55	6.54	3.50×10^{-7}

⇒ PT do not generate an observable Neff contribution.

⇒ Every other models are expected to be detected or ruled out by CMB.

⇒ f_{max} ~ O(10^-7) Hz seems sufficient

Summary

⇒ If the PTA signal is of cosmological origin, it is a significant deviation from standard Cosmology, and implies New Physics.

⇒ All models except Phase Transition are expected to be detected or ruled out by CMB.

⇒ Combination of CMB, PTA (and LIGO) is highly beneficial for model selection. We expect definite results within 5-10 years.

Thank you