Do Pulsar Timing Datasets Favor Massive Gravity?

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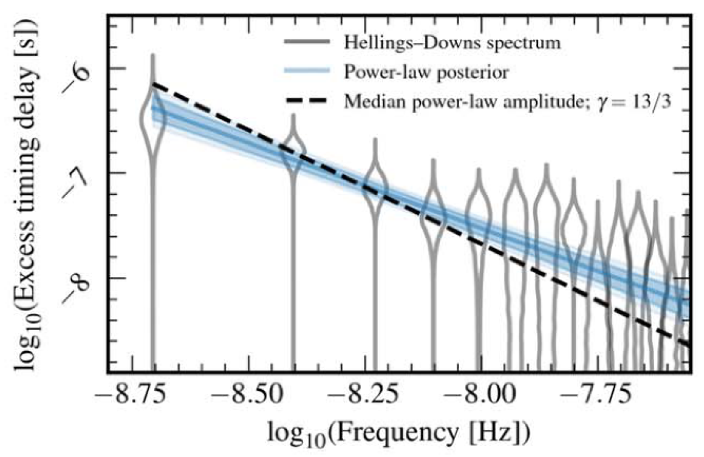
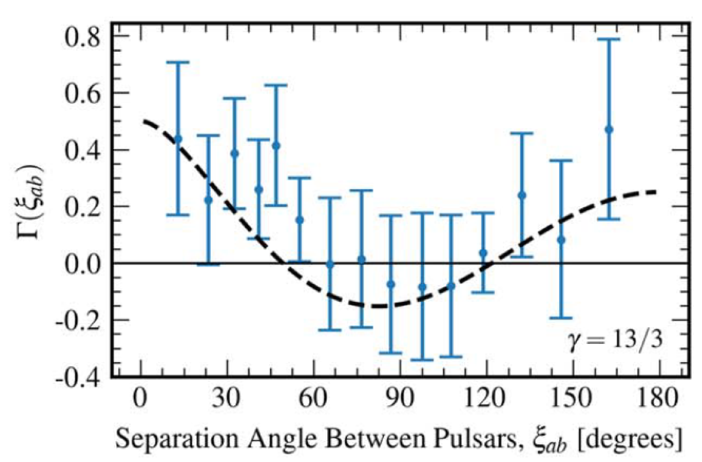
Abstract

- Massive gravity (MG) predicts a modified dispersion relation for gravitational waves (GWs), introducing new polarization modes.
- These changes imprint themselves on the Hellings-Downs (HD) angular correlation measured by pulsar timing arrays (PTAs) via the **effective overlap reduction function** (ORF).
- We derive the ORF with exponential factors, and compare it with the NANOGrav 15-year and Chinese PTA (CPTA) DR1 datasets.
- A one-parameter MG fit outperforms the HD curve for *both* datasets, lowering χ^2/d.o.f. from $1.71 \to 0.55$ for NANOGrav15 and $(3.00 \to 1.35)$ for CPTA.

Background

- Puzzles such as the tiny cosmological constant, the gauge hierarchy problem and the lack of a quantum gravity theory hint that General Relativity (GR) may be incomplete on cosmological scales.
- A widely explored extension is **massive gravity** (MG), where the graviton carries a small mass m_g
- Modern ghost-free frameworks (dRGT, bigravity) avoid the Boulware-Deser instability and predict MG effects only at distances $\gtrsim \lambda_g = 1/m_g$.
- PTAs have recently detected a nanohertz stochastic GW background (SGWB), characterised by the Hellings-Downs (HD) angular correlation expected in GR.





Massive Gravity Effects on GWs

(i) **Yukawa suppression**: potential is exponentially suppressed
(ii) **Dispersion**: $\omega^2 = k^2 + m_g^2 \quad \Rightarrow$, cut-off frequency $\omega \geq m_g$.
(iii) **Extra polarizations**: tensor (± 2), vector (± 1) and scalar (0)

- We focus on effects (ii) and (iii).
- PTAs are sensitive to frequencies

$$\frac{1}{T_{\text{obs}}} < f < \frac{1}{\delta t}$$

- Best-case scenario of PTA observation: a century: $f_{\min} \sim 3.17 \times 10^{-10}$ Hz $\Rightarrow m_g \sim 1.31 \times 10^{-24}$ eV.

Overlap Reduction Function

- We connect observables of the PTAs, the residuals, directly to the energy density and ORF through a 2-point correlation of the total redshift $\tilde{z}(f)$:

$$\langle \tilde{z}(f)\tilde{z}(f')\rangle = \frac{3H_0^2\,\delta^2(\hat{\Omega},\hat{\Omega}')\,\delta_{ii'}\,\delta(f-f')}{32\,\beta\,\pi^3|f|^3}\,\Omega_{\text{gw}}(|f|)\,\Gamma(|f|)$$

- We define the ORF, for modes $I = \{T, V, S\}$ as

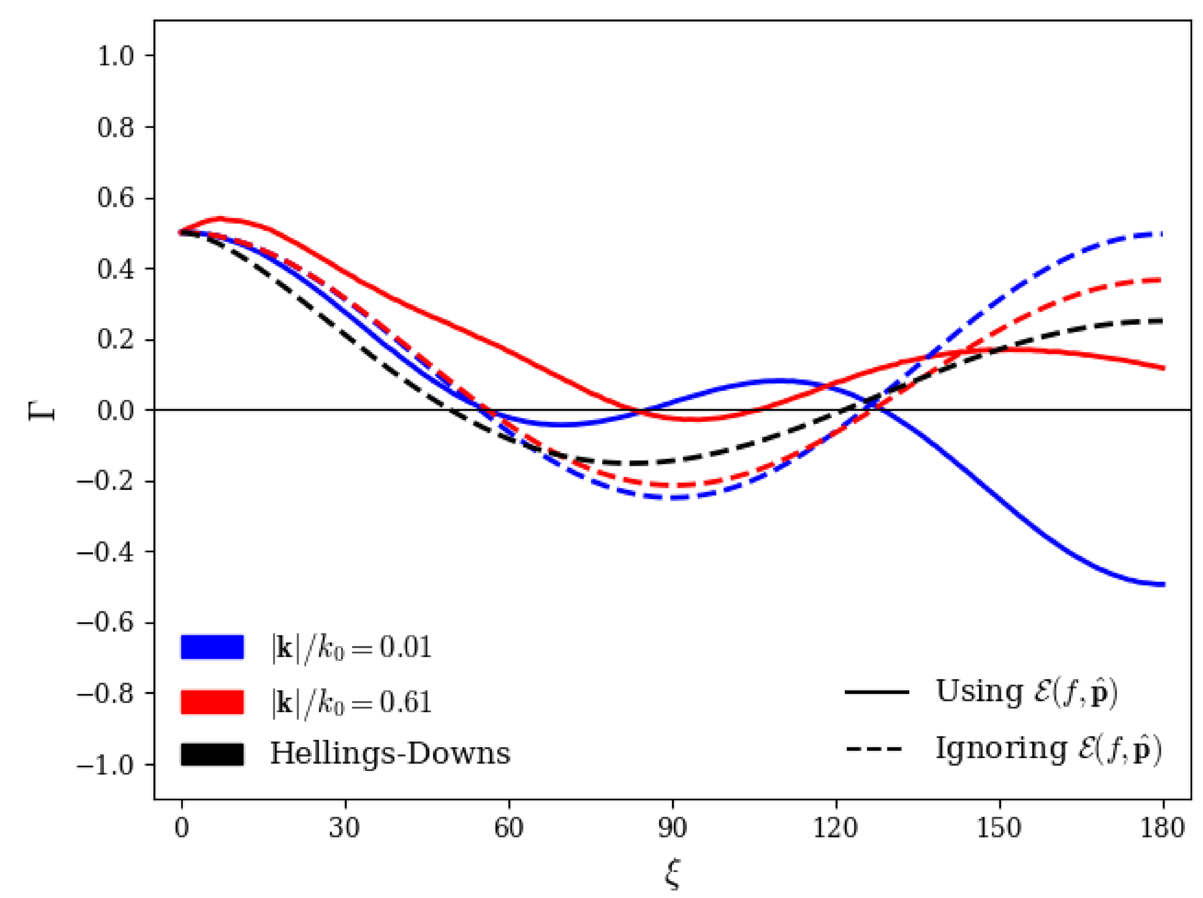
$$\Gamma_I(|f|) = \sum_{i\in I}\int_{S^2} d^2\hat{\mathbf{\Omega}}\,\mathcal{E}_1(-f,\hat{\Omega})\mathcal{E}_2(f,\hat{\Omega})F_1^{(i)}(\hat{\mathbf{\Omega}})F_2^{(i)}(\hat{\mathbf{\Omega}})$$

where we have the receiving function $F_j^{(i)}(\hat{\mathbf{\Omega}})$ and the exponential factor $\mathcal{E}_j(f,\hat{\Omega})$ for the j-th pulsar as

$$F_j^{(i)} = \frac{\hat{p}_j^{\mu}}{2}\left(-\frac{\hat{p}_j^{\nu}}{1+\frac{|\boldsymbol{k}|}{k_0}\hat{\mathbf{\Omega}}\cdot\hat{\boldsymbol{p}}_j}\epsilon_{\mu\nu}^{(i)} + \epsilon_{0\mu}^{(i)}\right), \mathcal{E}_j = e^{-i2\pi f L_j\left(1+\frac{|\boldsymbol{k}|}{k_0}\hat{\mathbf{\Omega}}\cdot\hat{\boldsymbol{p}}_j\right)} - 1$$

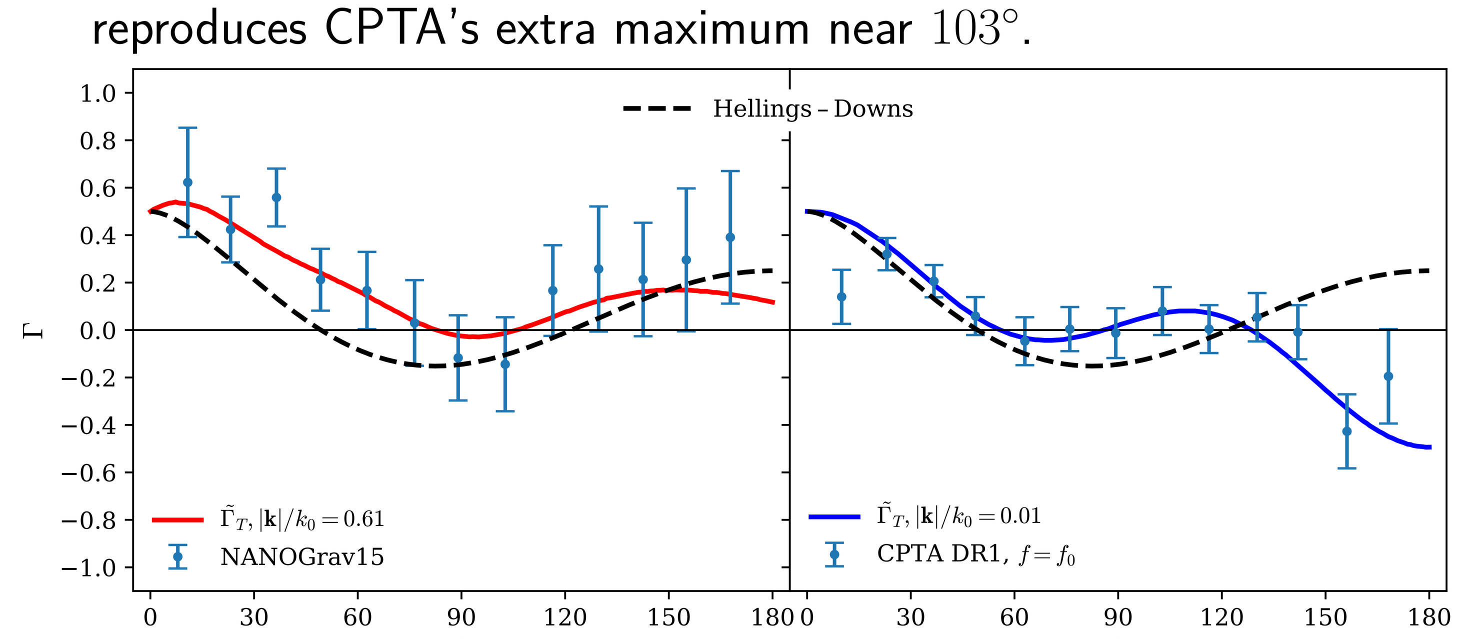
- Finally we have the effective ORF

$$\tilde{\Gamma}_T = \beta\left(\Gamma_T + \Gamma_V\frac{\Omega_V}{\Omega_T} + \Gamma_S\frac{\Omega_S}{\Omega_T}\right)$$



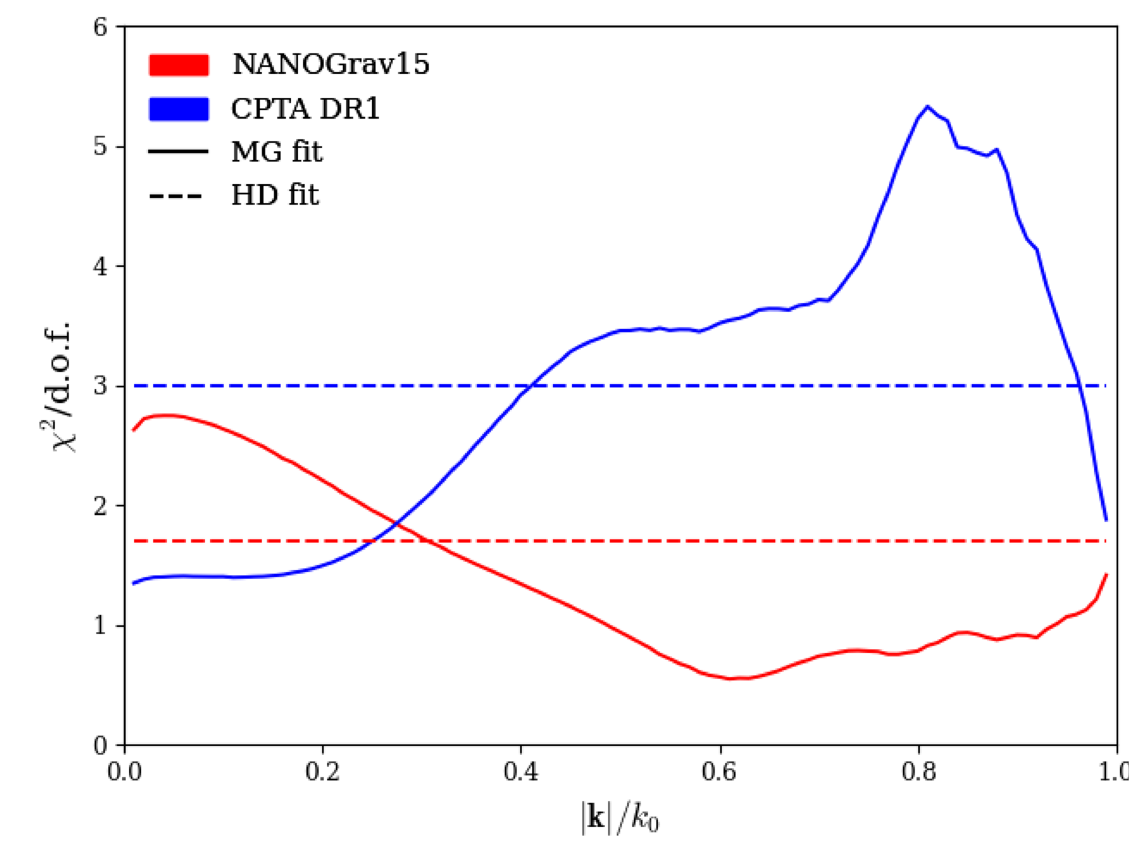
Data & Methodology

- Datasets: NANOGrav15 (67 pulsars) and CPTA DR1 (57).
- Fit single parameter $|k|/k_0$ via χ^2 minimisation.
- MG shifts $\zeta_{\min}$ from $\sim 97^\circ$ to $\sim 110^\circ$ in NANOGrav15 and reproduces CPTA's extra maximum near 103°.



Results cont

Data	Fit type	Best fit $\frac{k}{k_0}$	χ^2	χ^2/d.o.f.
NANOGrav15	HD	–	22.20	1.71
	MG	0.61	6.59	0.55
CPTA DR1	HD	–	38.95	3.00
	MG	0.01	16.58	1.35



Conclusions

- A one-parameter massive-gravity ORF out-fits the Hellings–Downs template for both NANOGrav15 and CPTA datasets.
- Best-fit ratios differ, reflecting distinct frequency windows and pulsar baselines.
- Hints at frequency-dependent angular correlation that other PTAs should look into.
- The method is source-agnostic: whether the SGWB is astrophysical or cosmological, the ORF carries the graviton-mass signature.

Source Code

- Code for all plots: zenodo.org/records/15793318
- NANOGrav15 dataset: nanograv.org/science/data

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