SEARCH FOR SCALAR INDUCED GRAVITATIONAL WAVES IN PTAS

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Based on: 2302.07901

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MOTIVATION

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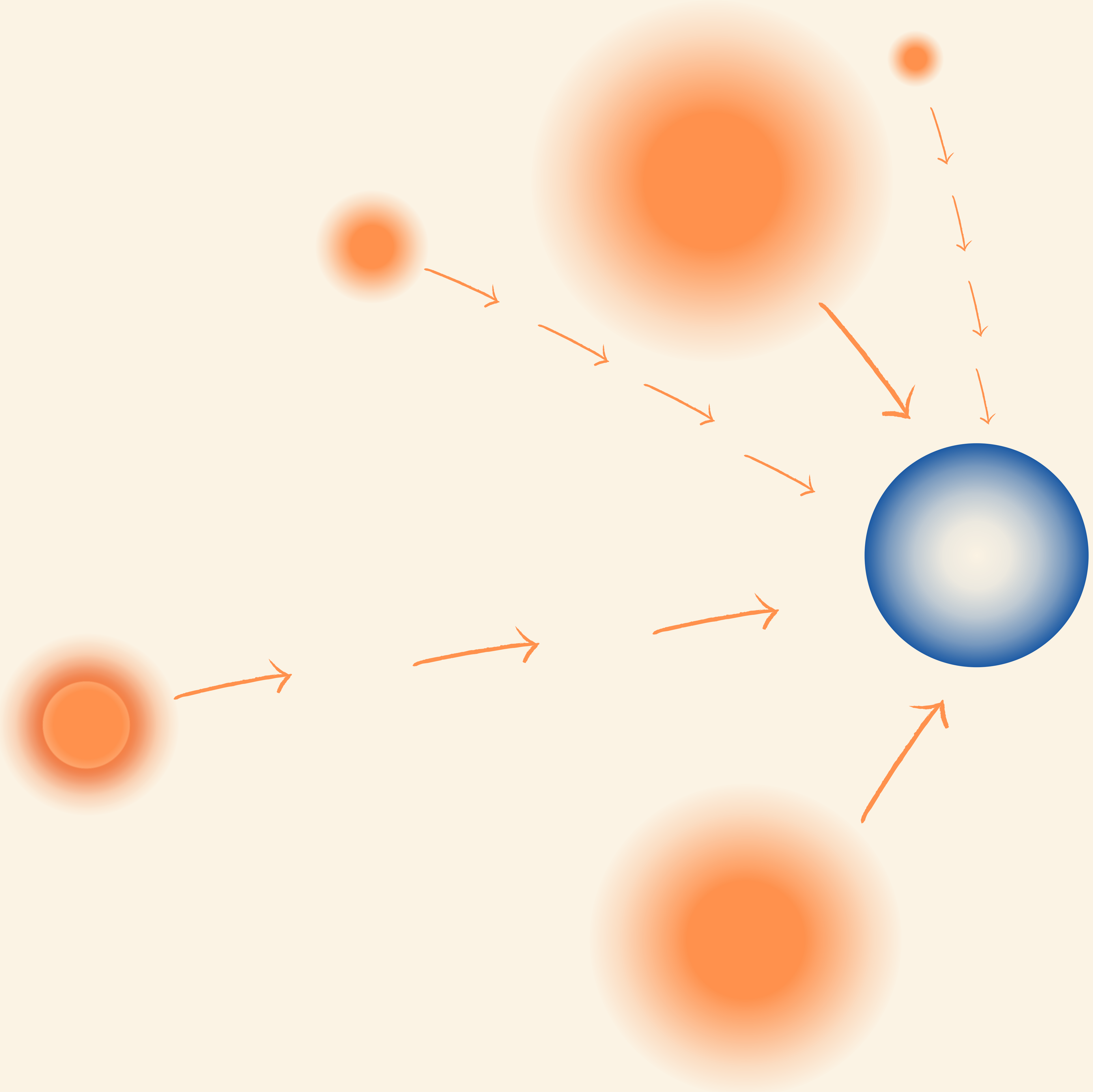
PULSAR TIMING ARRAYS



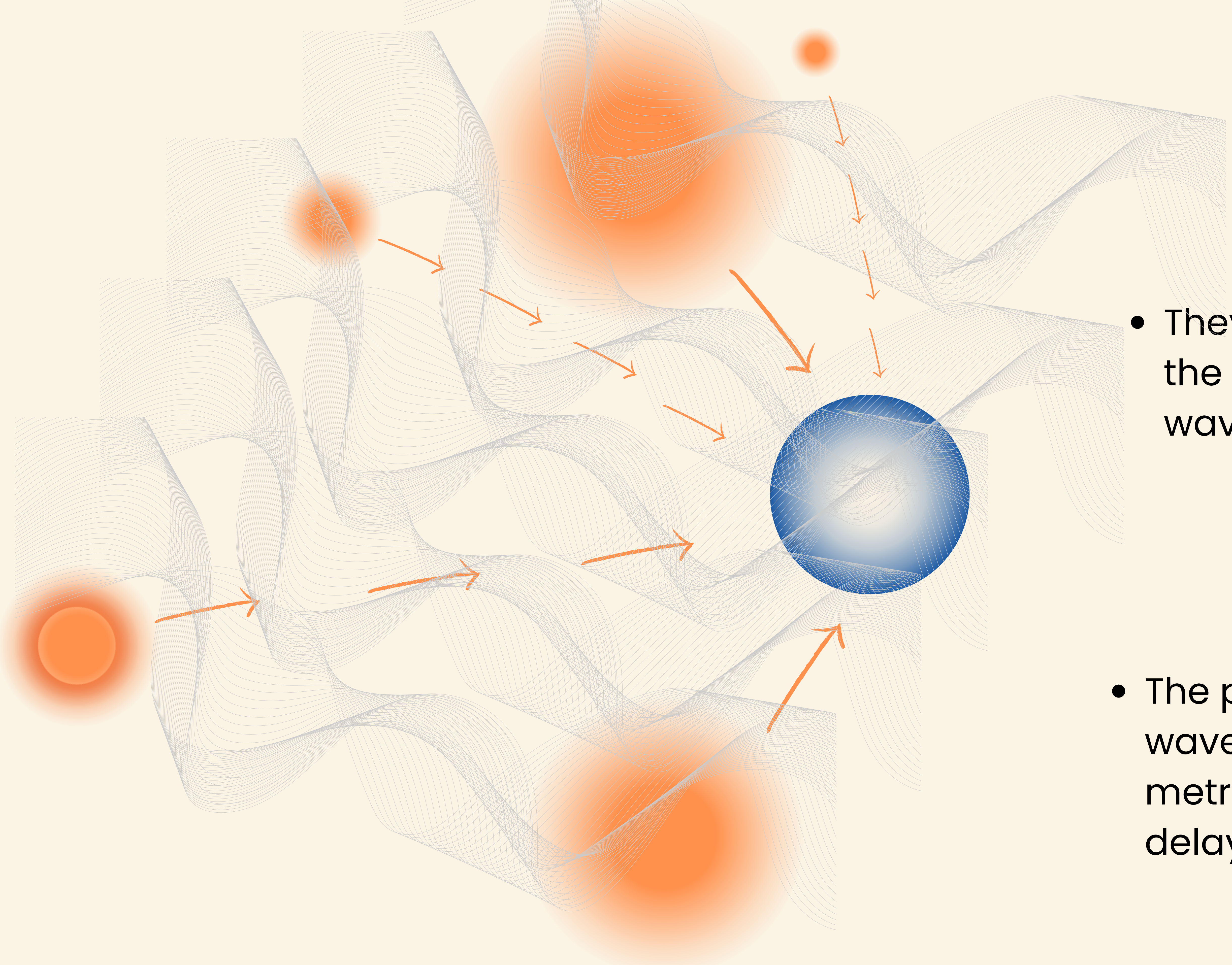
- Pulsar Timing Arrays record the time of arrival of the light pulses emitted by pulsars

- These pulses are extremely stable in time

- However, many external effects can alter the expected period of the pulsars

This is what PTAs are looking for

PULSAR TIMING ARRAYS



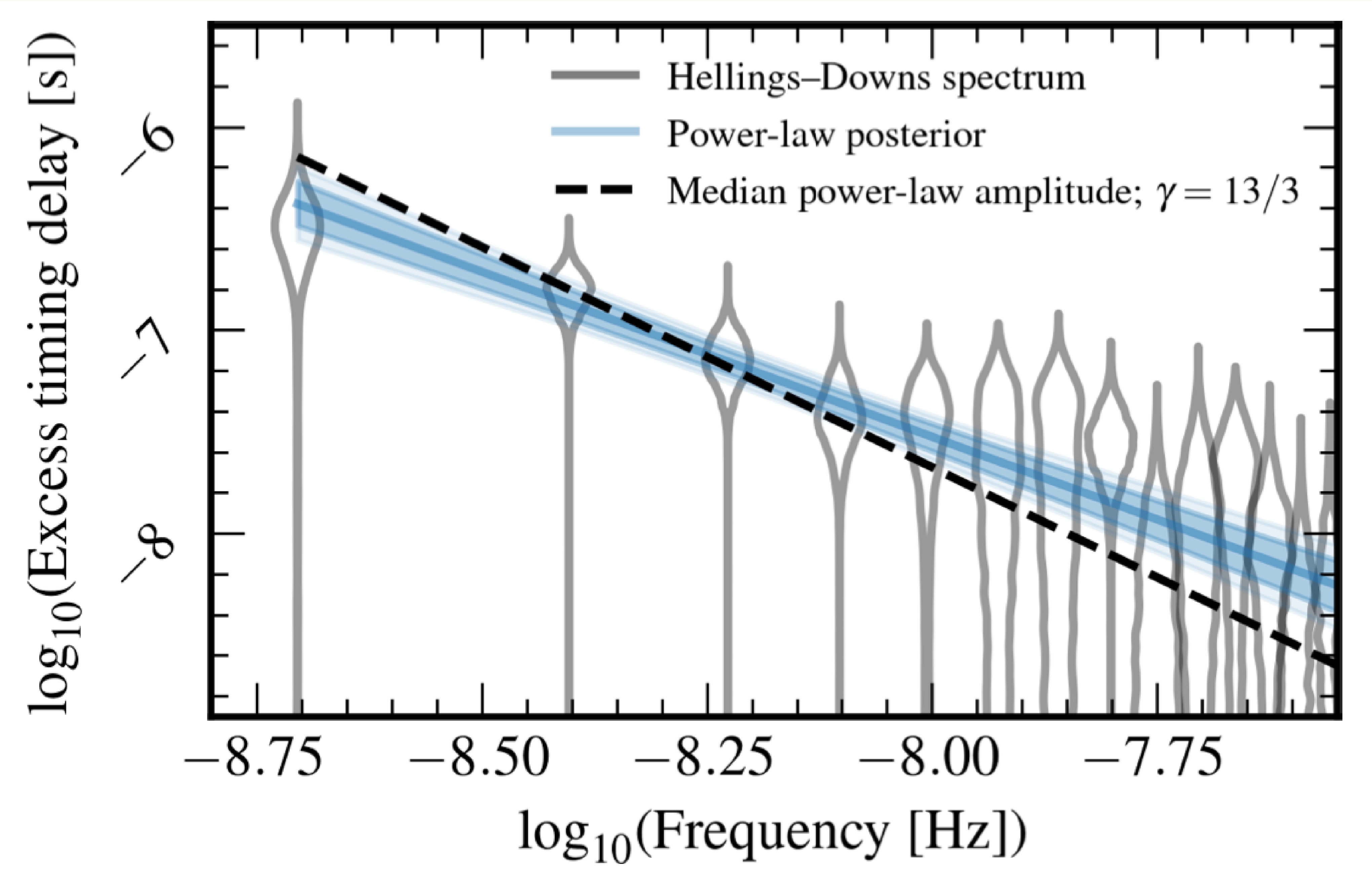
- They can be used to detect the presence of gravitational waves

Gravitational Wave Background

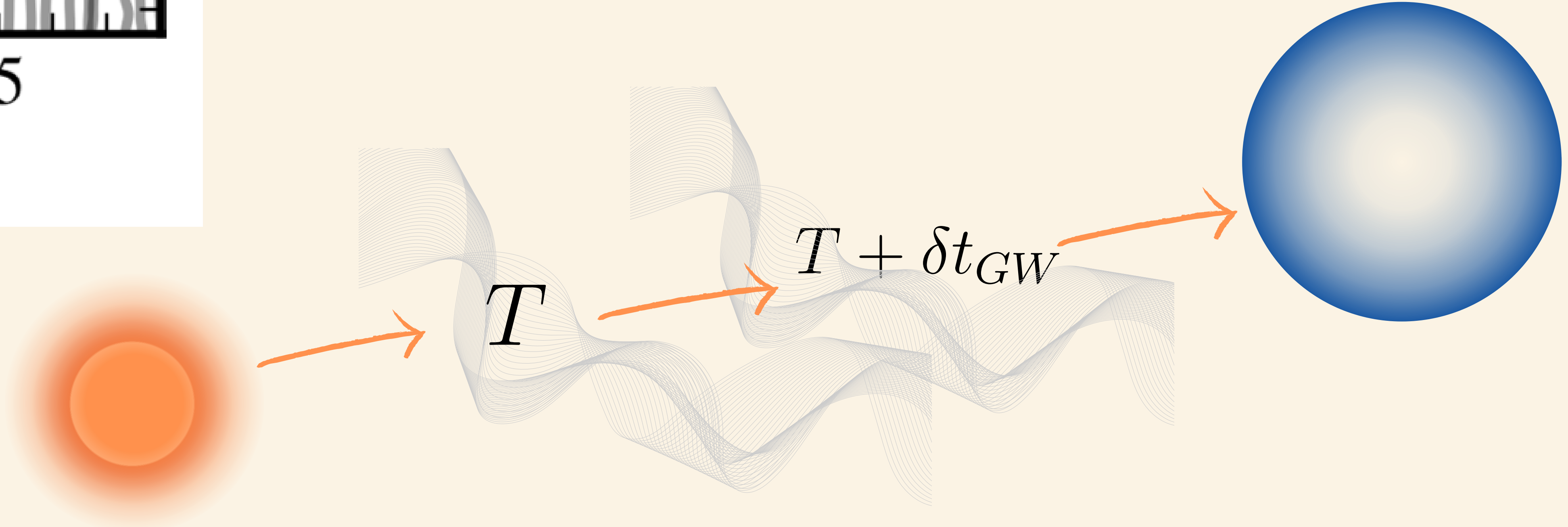
- The presence of a gravitational wave background disturb the metric and induce correlated time delays

POTENTIAL GW SIGNAL IN PTA

[2306.16213]



Potential signal from a nHZ frequency GW background observed in all PTAs

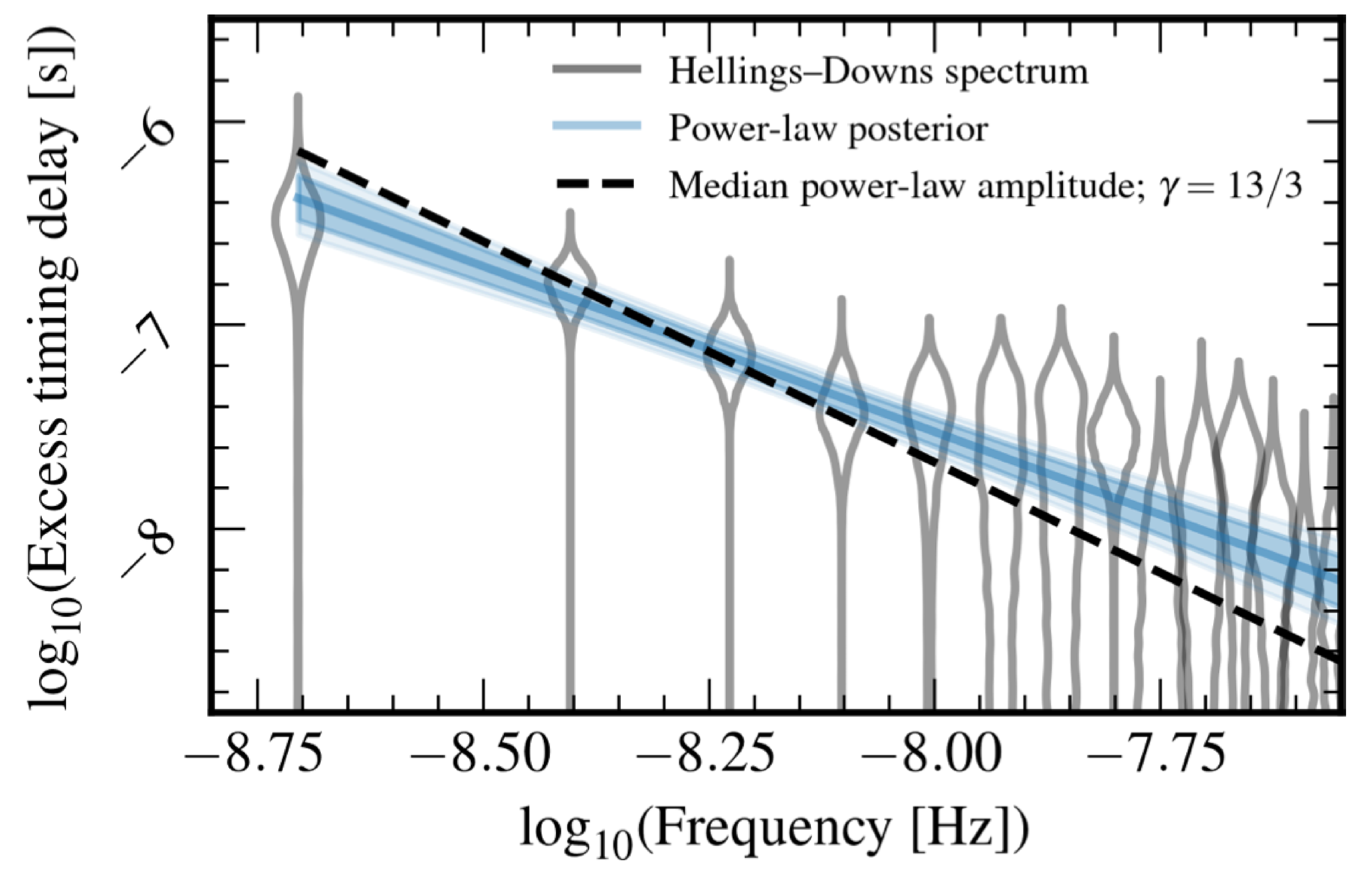


ORIGIN OF THE SIGNAL

Astrophysical source:

- Super massive black holes

[2306.16213]



Cosmological sources:

- Phase transition
- Inflation
- cosmic strings
- Scalar induced GWs

ORIGIN OF THE SIGNAL

Astrophysical source:

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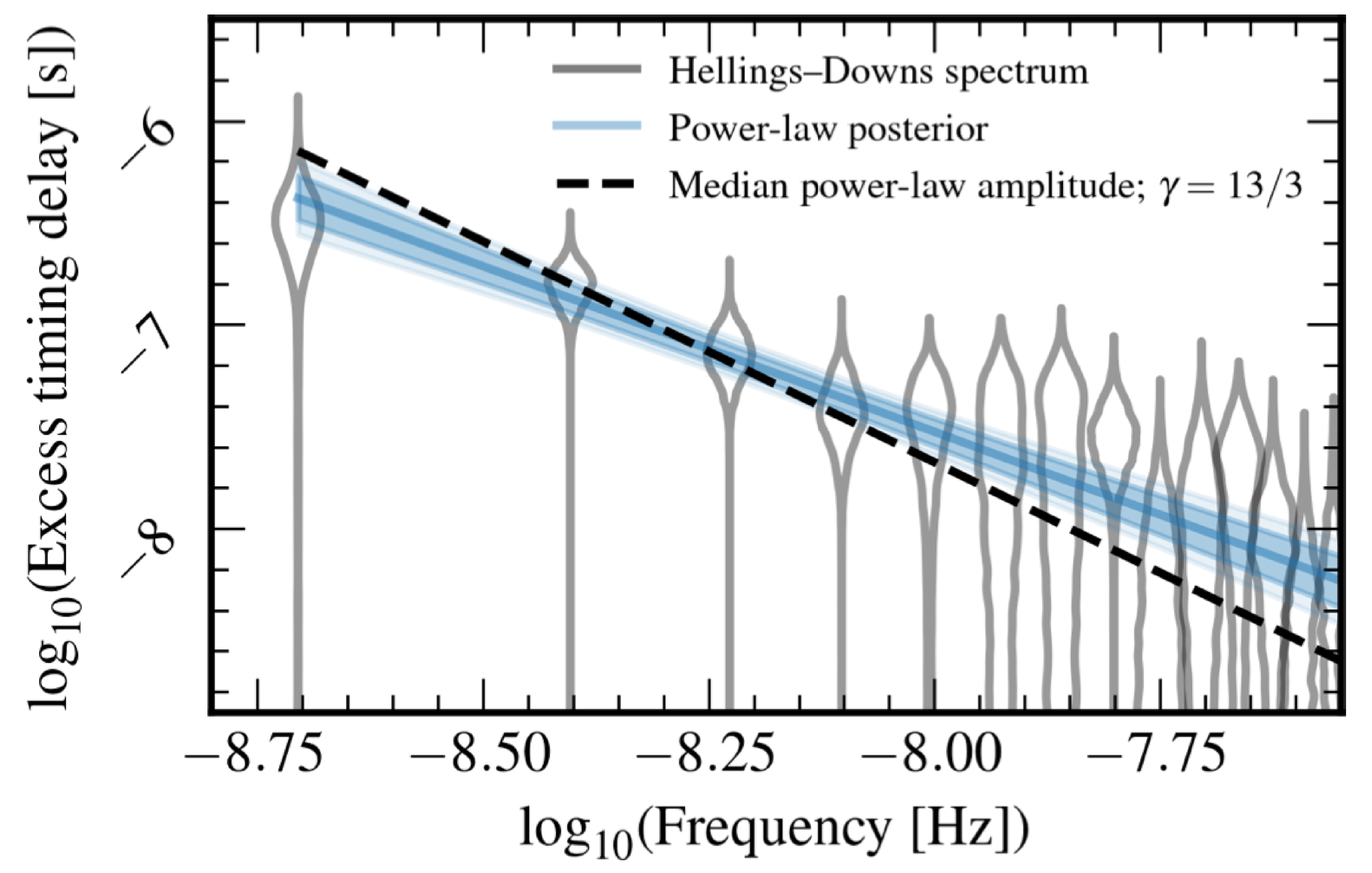

Cosmological sources:

- Phase transition
- Inflation
- cosmic strings
- Scalar induced GWs

Could they explain the signal ??

WHAT ARE THE SIGWS?

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SCALAR INDUCED GWS

- Primordial metric perturbations are decomposed into scalar and tensor perturbations

Scalar perturbations

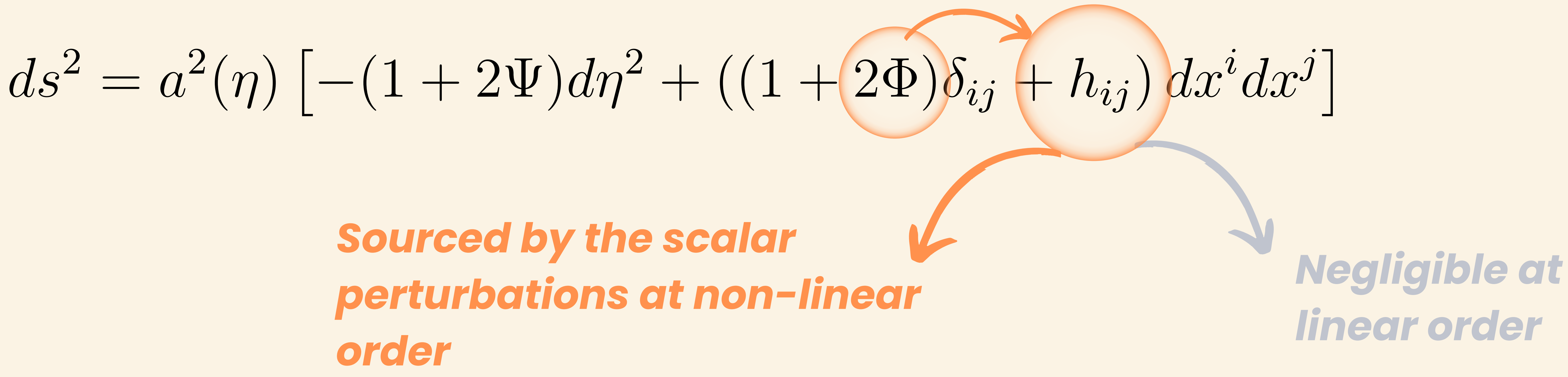
$$ds^2 = a^2(\eta)\left[-(1+2\Psi)d\eta^2 + ((1+2\Phi)\delta_{ij} + h_{ij})\,dx^i dx^j\right]$$

Negligible at linear order

→ No GWs produced at linear order in perturbation theory/for small perturbations

SCALAR INDUCED GWS

- Primordial metric perturbations are decomposed into scalar and tensor perturbations



$$ds^2 = a^2(\eta)\left[-(1+2\Psi)d\eta^2 + ((1+2\Phi)\delta_{ij} + h_{ij})\,dx^i dx^j\right]$$

Sourced by the scalar perturbations at non-linear order

Negligible at linear order

→ Gravitational waves produced if large primordial perturbations!

CAN THE SIGWS EXPLAIN THE PTA SIGNAL ?

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SCALAR INDUCED GWS

- CMB constrains the amplitude of the scalar perturbations at large scales

$P_\zeta \approx \mathcal{O}(10^{-9})$ at scales $k \approx \mathcal{O}(1\mathrm{Mpc}^{-1})$ [1807.06211]

Too small to induce any detectable GWs...

Almost no constraints on the perturbation amplitude at small scales !

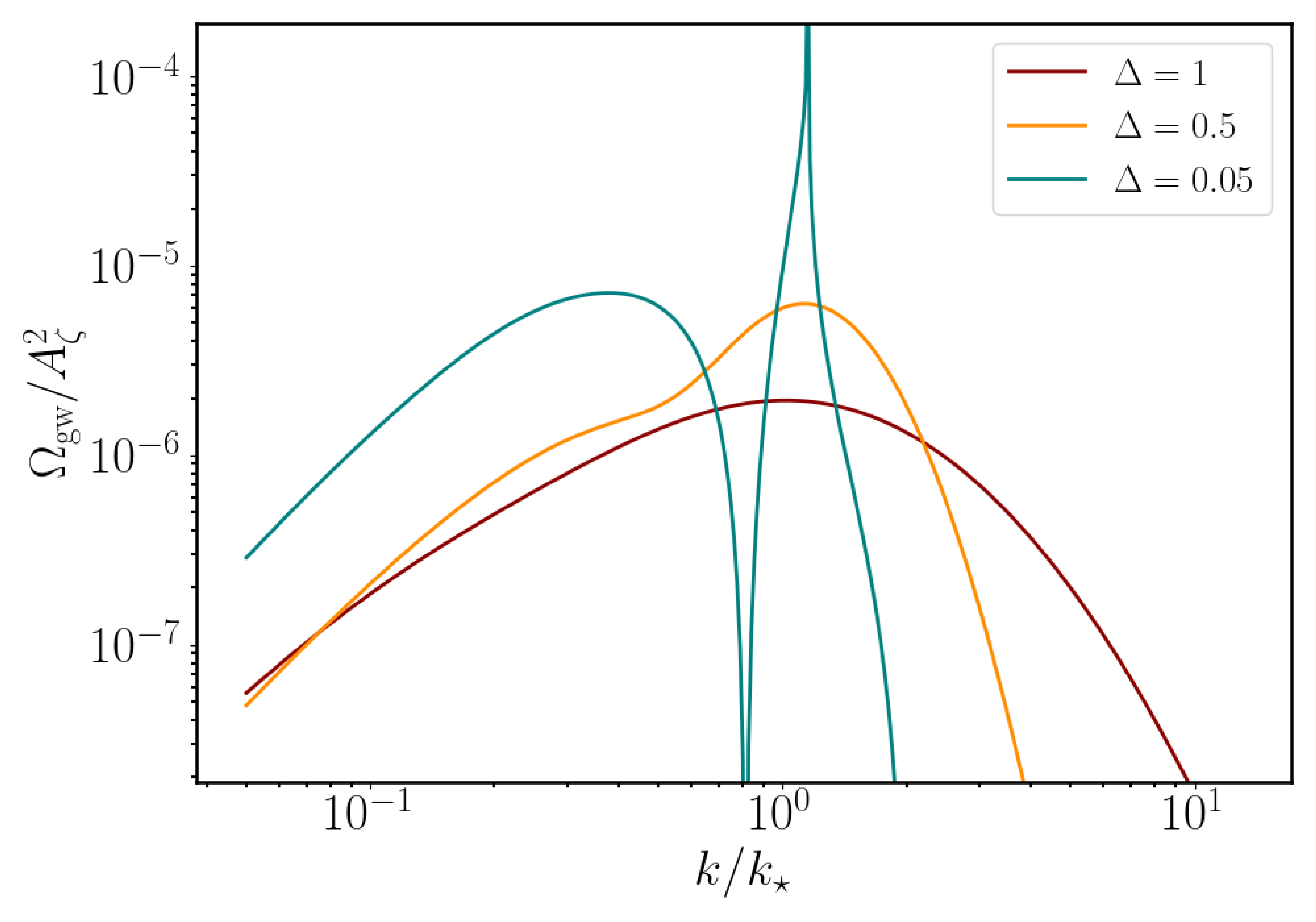
SCALAR INDUCED GWS

- CMB constrains the amplitude of the scalar perturbations at large scales

$P_\zeta \approx \mathcal{O}(10^{-9})$ at scales $k \approx \mathcal{O}(1\mathrm{Mpc}^{-1})$

- ***Parametrize the power spectrum at small scales with a log-normal shape***

$$P_\zeta(k) = \frac{A_\zeta}{\sqrt{2\pi}\Delta}\mathrm{Exp}\left(-\frac{\log^2(k/k_*)}{2\Delta^2}\right)$$



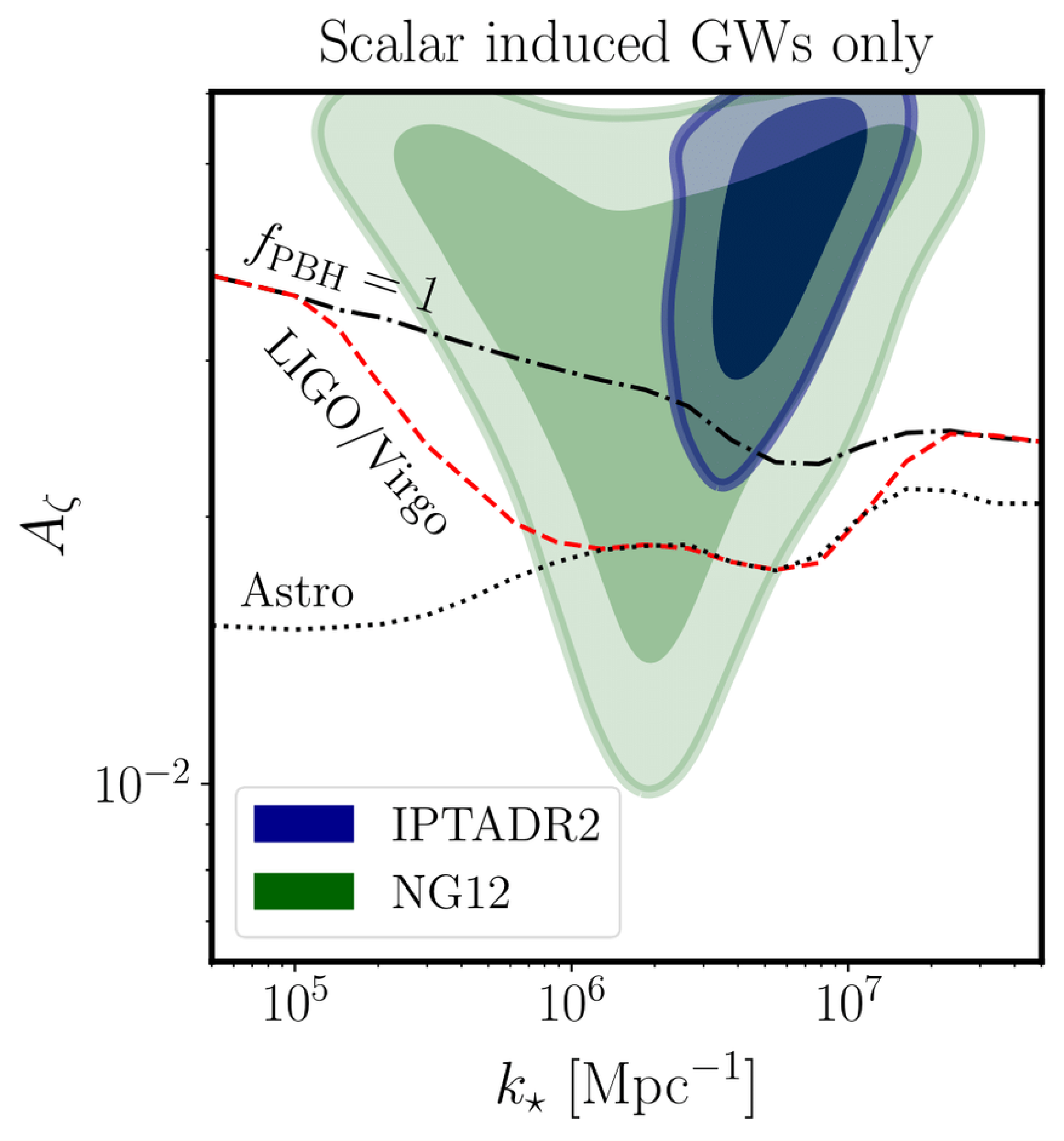
BAYESIAN SEARCH IN PTA DATA

- Parametrize the power spectrum at small scales with a log-normal function

$$P_\zeta(k) = \frac{A_\zeta}{\sqrt{2\pi}\Delta}\mathrm{Exp}\left(-\frac{\log^2(k/k_*)}{2\Delta^2}\right)$$

- Use IPTA and NANOGrav data to find what parameter space fits the signal

$$\boxed{\begin{array}{l} A_\zeta \sim 10^{-2} \\ k_\star \sim 10^6\,\mathrm{Mpc}^{-1} \end{array}}$$



PRIMORDIAL BLACK HOLES FROM CURVATURE PERTURBATIONS

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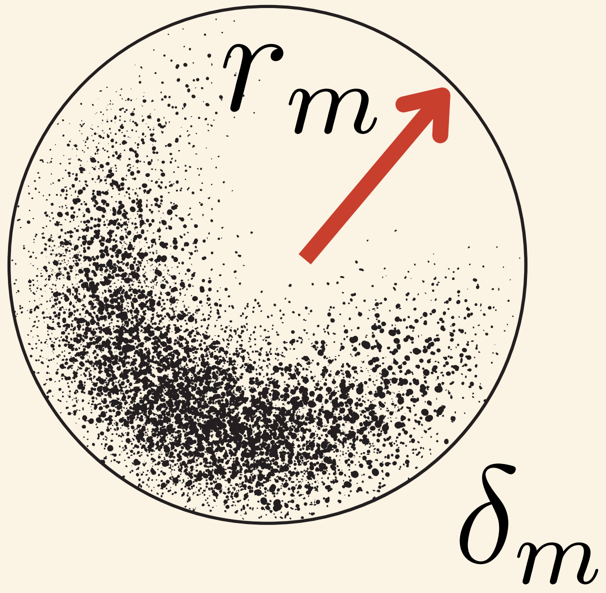
PBH FORMATION FROM LARGE CURVATURE FLUCTUATIONS

- Let's consider a perturbation δ_m with a given scale r_m

For big enough perturbation

$$\boxed{M = \kappa M_H(r_m)\left(\delta_m - \frac{3}{8}\delta_m^2 - \delta_c\right)^\gamma}$$



- What is the population of PBH today?

→ Depends on the curvature power spectrum

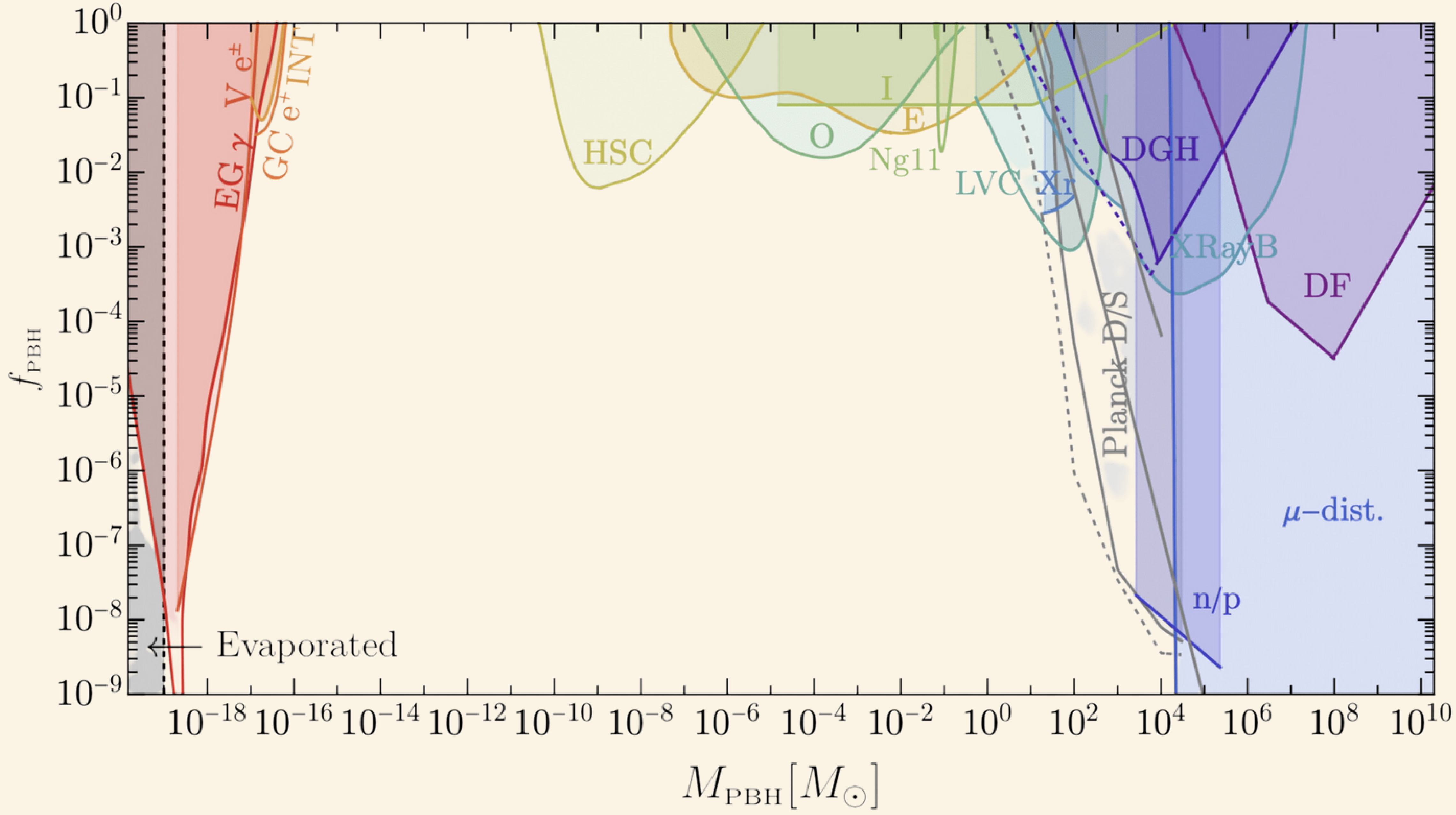
PBH FORMATION FROM LARGE CURVATURE FLUCTUATIONS

$$f_{\mathrm{PBH}} = F_f(P_\zeta)$$
$$\langle M_{\mathrm{PBH}} \rangle = F_M(P_\zeta)$$

- One could translate them into constraints on the amplitude A_ζ

- How do those upper limits show up in our bayesian search?

[2110.06815]



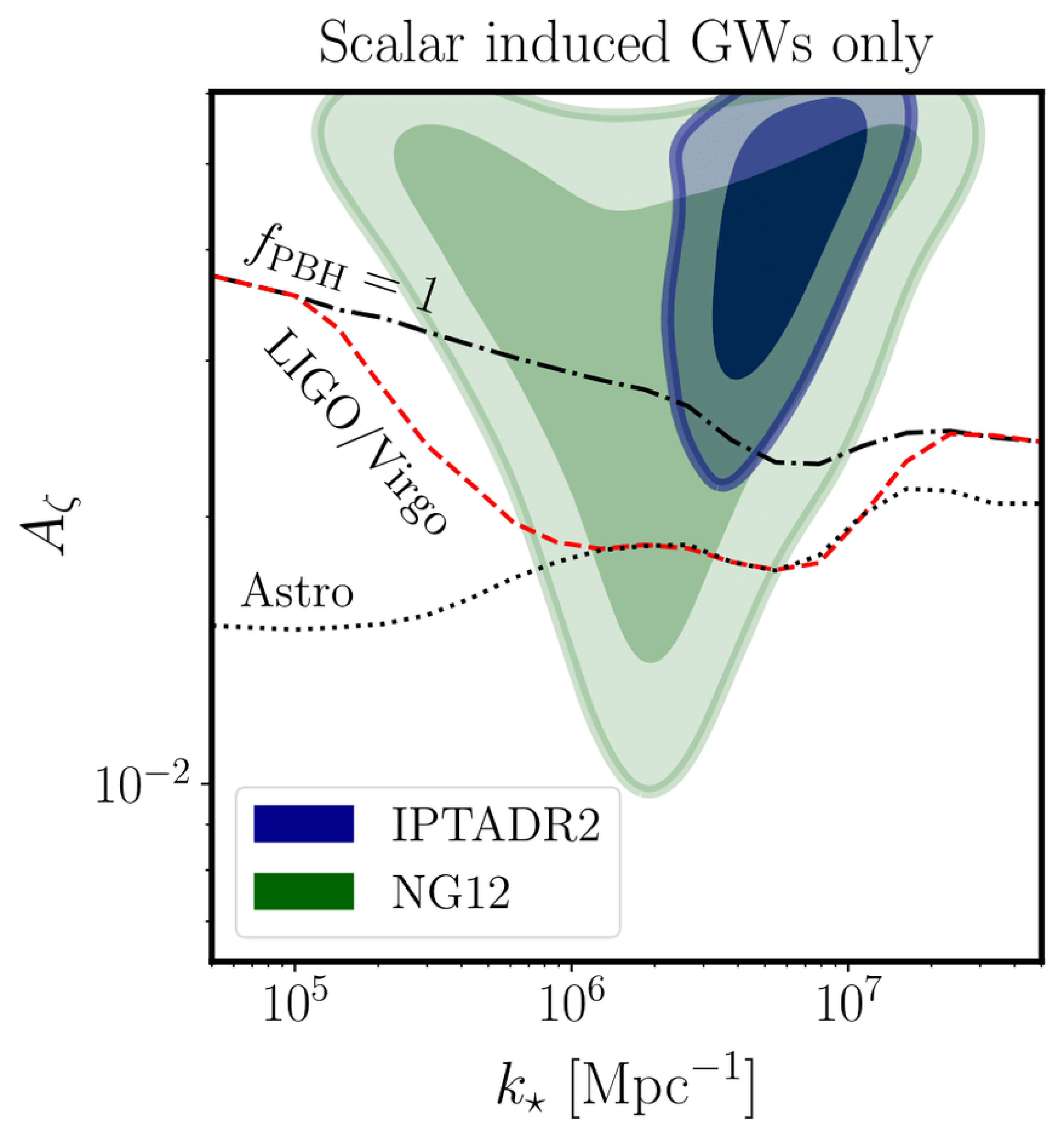
BAYESIAN SEARCH IN PTA DATA

$$\boxed{A_\zeta \sim 10^{-2}}$$

That large amplitudes of fluctuations also produce primordial black holes...

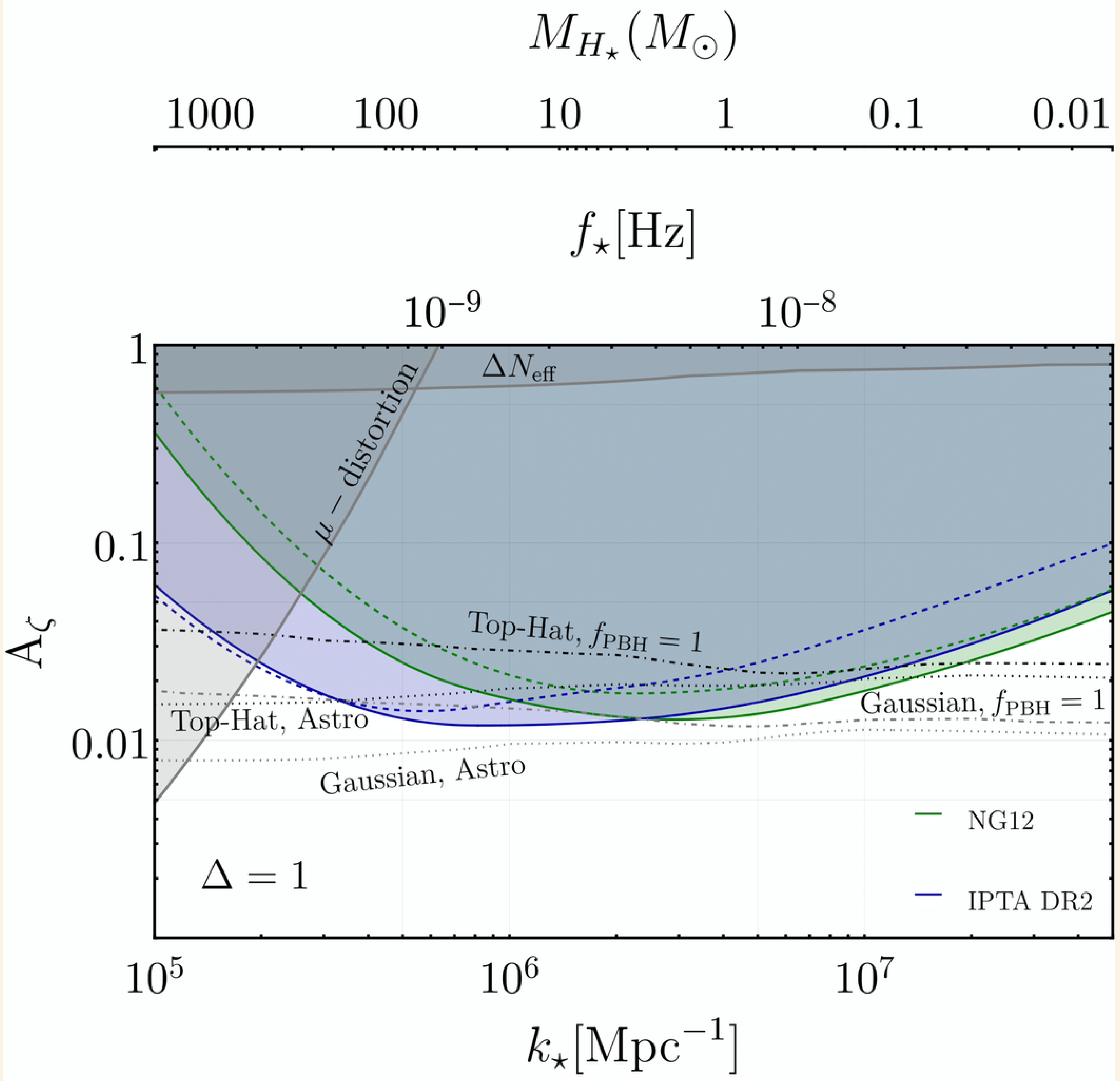
- The PBH abundance is a function of the parameters $(A_\zeta, k_\star, \Delta)$

The parameter space that can explain the signal is in conflict with PBH overproduction constraints

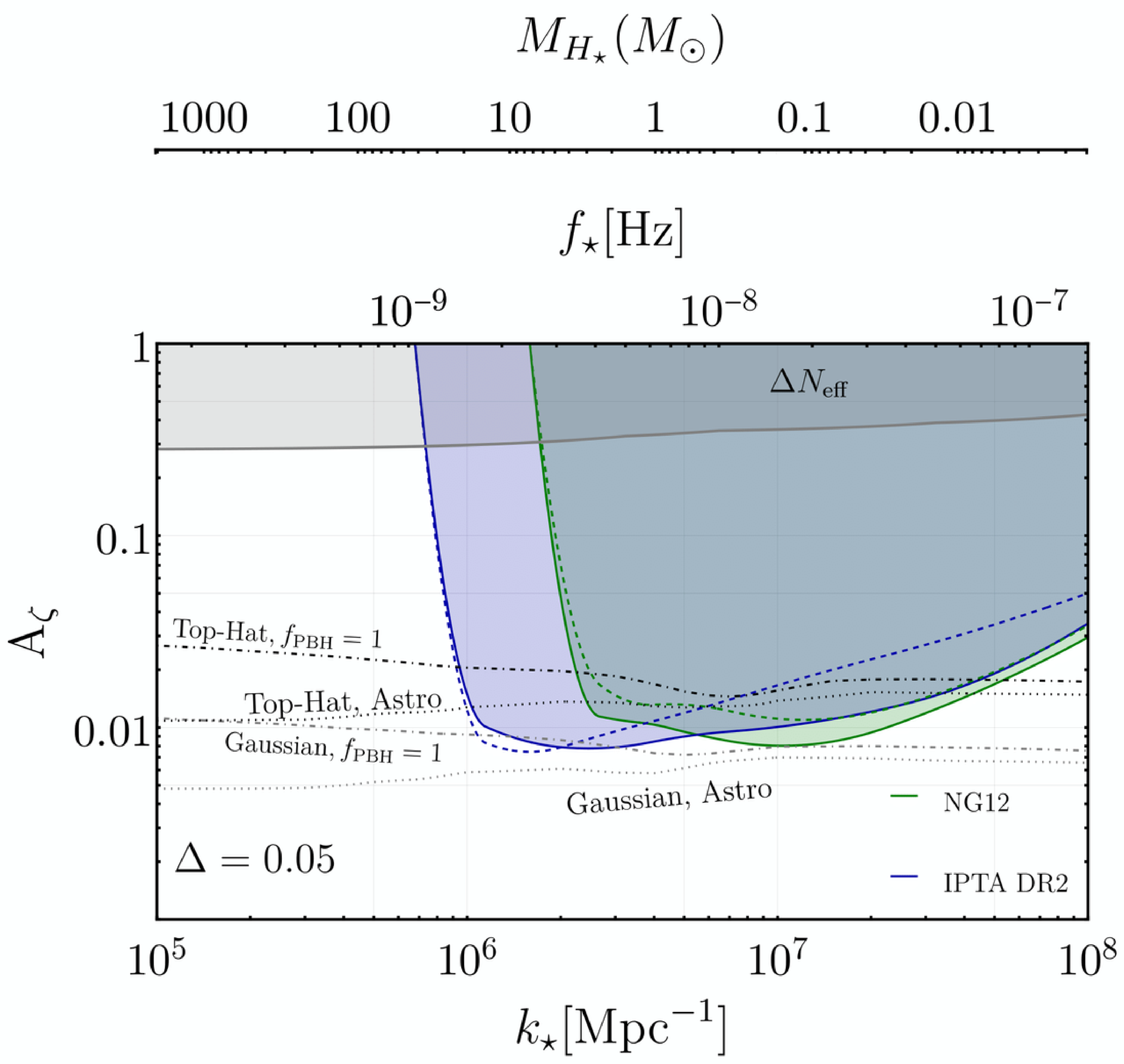


UPPER LIMITS ON THE CURVATURE POWER SPECTRUM

$\Delta = 1$



$\Delta = 0.05$



CONCLUSION

- Large amplitudes of the curvature power spectrum produce GW able to explain the signal observed in PTA
- Such large amplitudes would produce primordial black holes as well
- We have shown that the parameter space able to explain the signal would potentially produce too many PBHs compared to observational data
- The SMBH model is favored to explain to signal and we therefore derived upper limits on the amplitude of the curvature spectrum

THANK YOU!

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