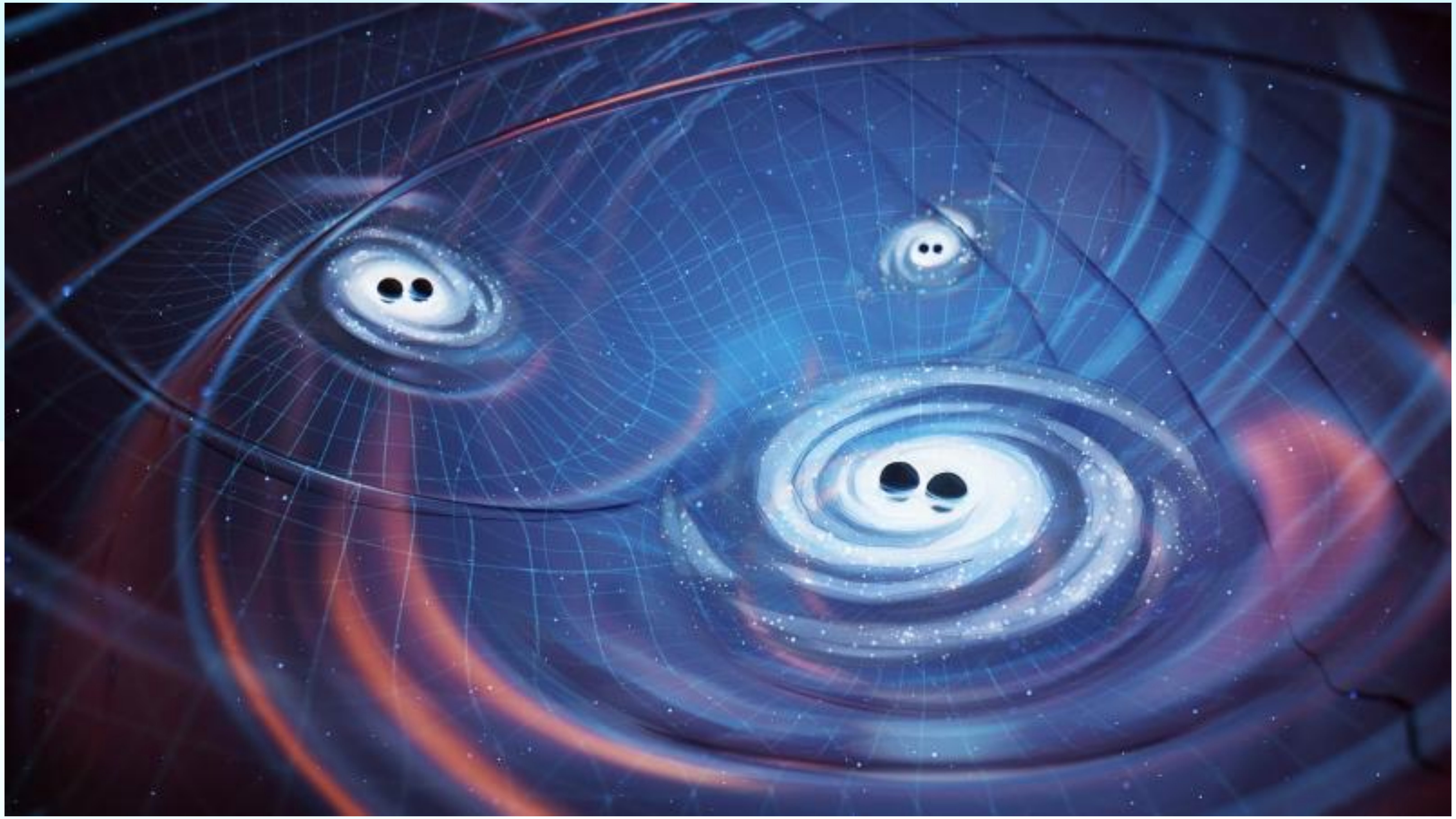
Universiteit Leiden

Instituut-Lorentz

Spacetime Oscillation and the Gravitational Wave Background

arXiv:2307.05455,
Gen Ye and Alessandra Silvestri

Gravitational Wave Background (GWB)



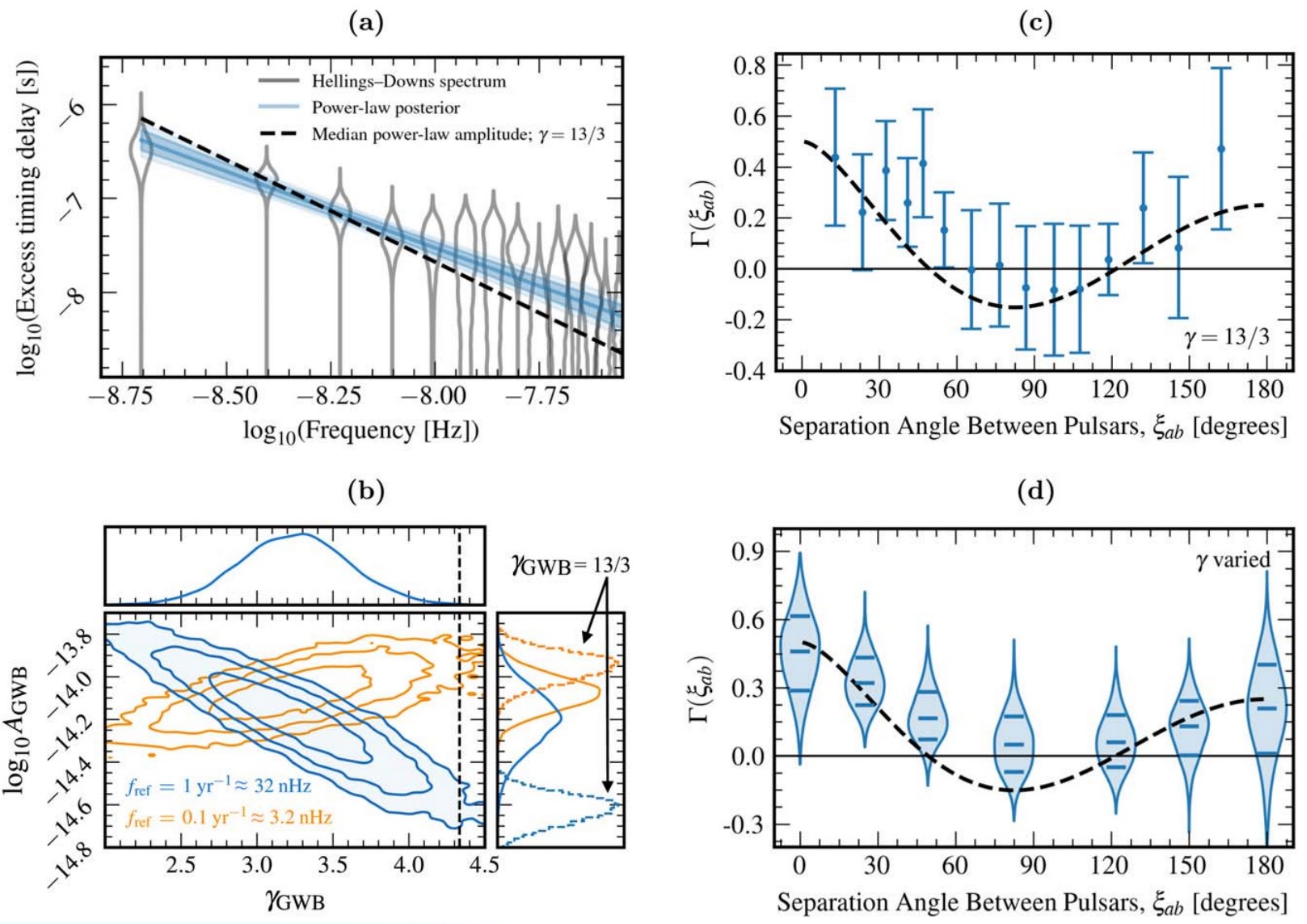
Low-Frequency Gravitational Waves | NANOGrav

"Chorus" of
Gravitational Waves

Individual Singer (Sources):

- Supermassive black hole binaries
- Remainings of cosmological phase transitions:
  - Bubbles
  - Cosmic strings
  - Domain walls
- "Echos" from the primordial Universe:
  - Scalar-induced GW
  - Primordial tensor modes

Evidence of GWB



Astrophys.J.Lett. 951 (2023) 1, L8

NANOGrav *Astrophys.J.Lett.* 951 (2023) 1, L8

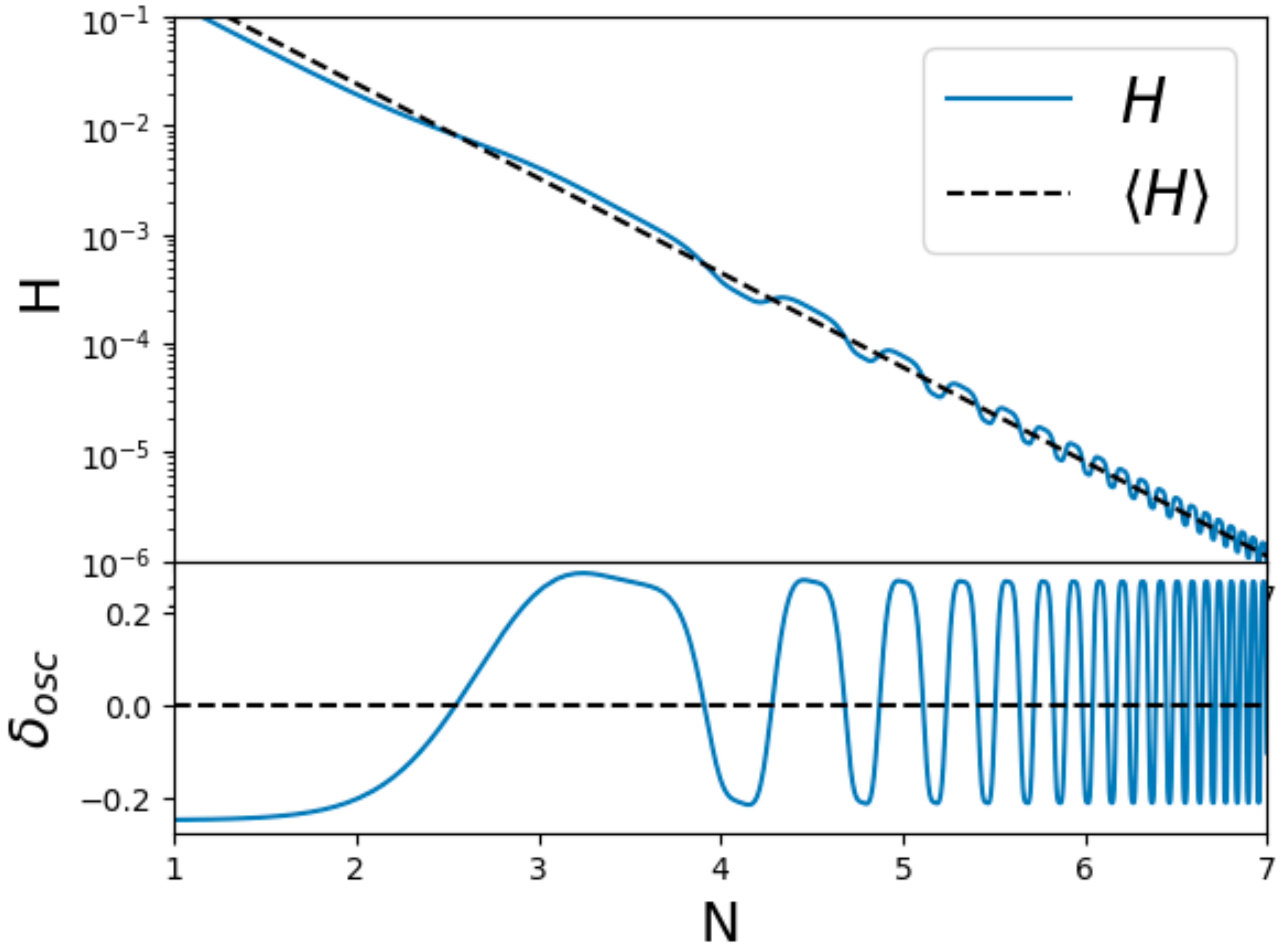
EPTA arXiv:2306.16214

PPTA *Astrophys.J.Lett.* 951 (2023) 1, L6

CPTA *Res.Astron.Astrophys.* 23 (2023) 7, 075024

- Hellings-Downs spatial correlation
- Continuous spectrum $\Omega_{GW} \propto f^2$
- $3 \sim 4\,\sigma$

Spacetime Wiggle and GW Resonance



$$\mathcal{S} = \int dx^4 \sqrt{-g}\left[\frac{M_p^2}{2} G_4(\phi) R - \frac{1}{2}(\partial\phi)^2 - \lambda\phi^4\right] + \mathcal{S}_m \qquad G_4(\phi) = 1 + \alpha\left(\frac{\phi}{M_p}\right)$$

$$\ddot{\gamma} + 2\Gamma\dot{\gamma} + k^2\gamma = 0$$

$$\mathcal{H} = \langle\mathcal{H}\rangle + \mathcal{H}_{\rm osc} \equiv \bar{\mathcal{H}}(1 + \delta_{\rm osc}), \qquad \delta_{\rm osc} < 1$$

- Generality:
  - $\Gamma \supset$ modified gravity
  - $c_T = 1$
- Source of δ_{osc}:
  - Oscillating field $O(H^2/k^2)$
  - Nonminimal coupling
  - …

Spacetime Wiggle and GW Resonance

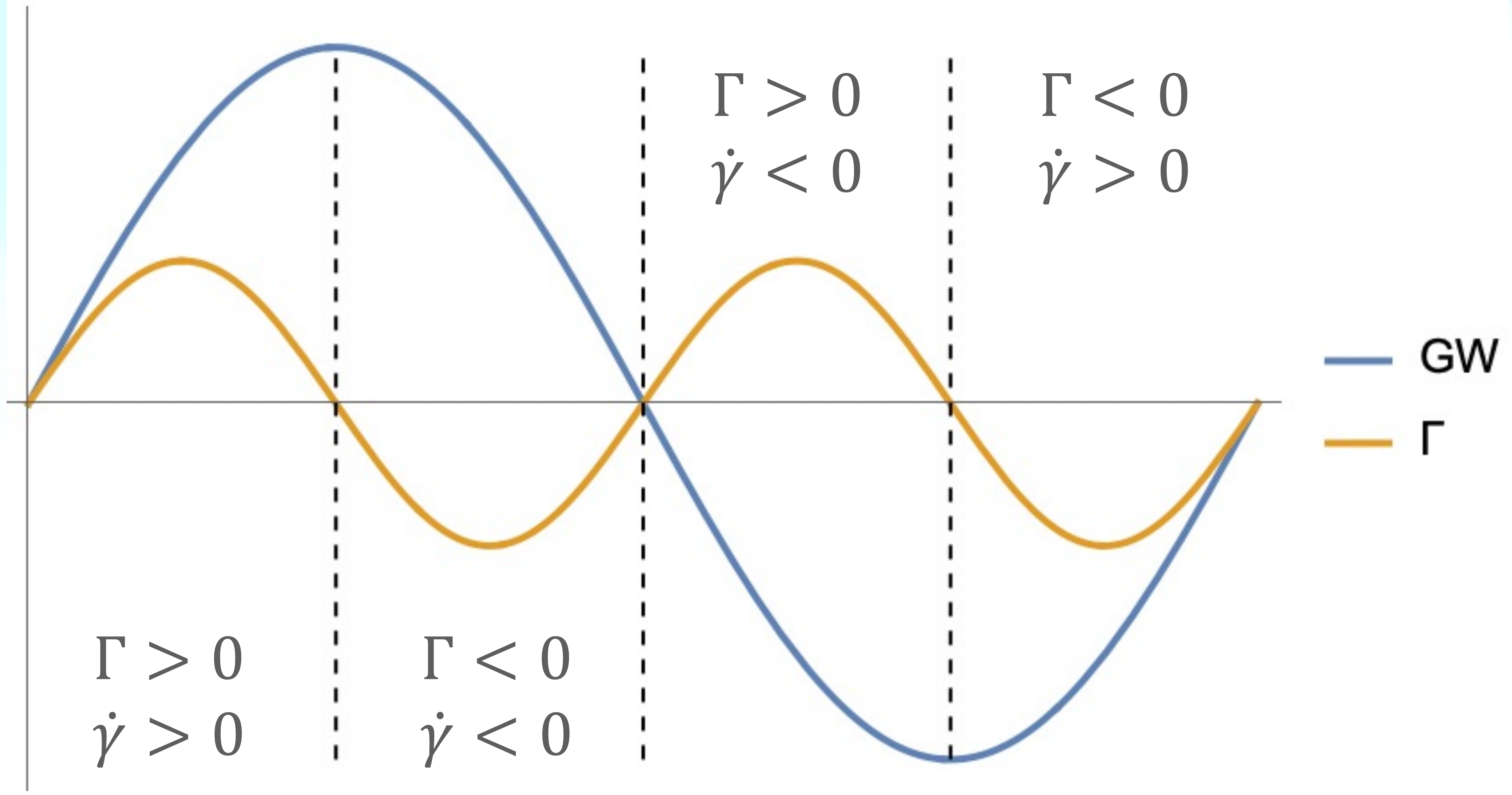
$$\ddot{\gamma} + 2\Gamma\dot{\gamma} + k^2\gamma = 0$$

Broad Spectrum Shape

$$\Gamma = \langle \mathcal{H} \rangle \simeq \frac{1}{\tau}$$

$$\gamma \sim \frac{\sin k\tau}{k\tau}$$

Local Spectrum Feature (Resonance)



$\Gamma\dot{\gamma} > 0$ ⬆ | $\Gamma\dot{\gamma} < 0$ ⬇

Resonance:

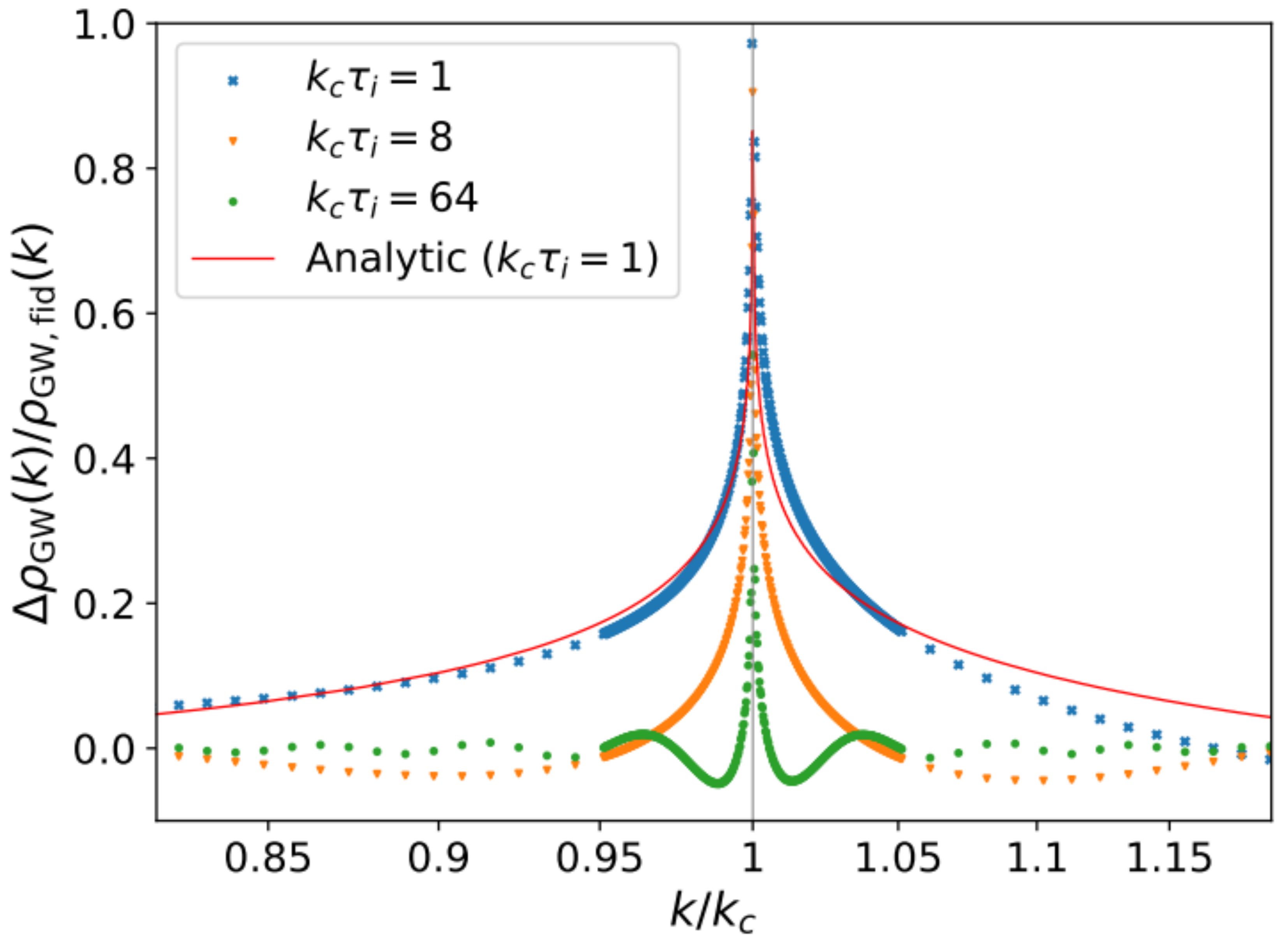
$f_c = f_{osc}/2$

Spacetime Wiggle and GW Resonance

$$\rho_{GW}(k) \simeq \left[1 + 2f(\Delta k)\psi_0 \sin(2\beta - \alpha) + f^2(\Delta k)\psi_0^2\right] \frac{M_p^2}{8\pi^2}\frac{k^3}{a^2\tau^2}$$

Assuming scale-invariant $P_{T,ini}$

Shape Function
$\Delta k \equiv k - k_{GW}$



Analytic approximation:

$$f(\Delta k) \sim \frac{1}{1+3w}\left[\mathrm{Ci}(2|\Delta \mathrm{k}|\tau) - \mathrm{Ci}(2|\Delta \mathrm{k}|\tau_\mathrm{i})\right]$$

Signal Strength

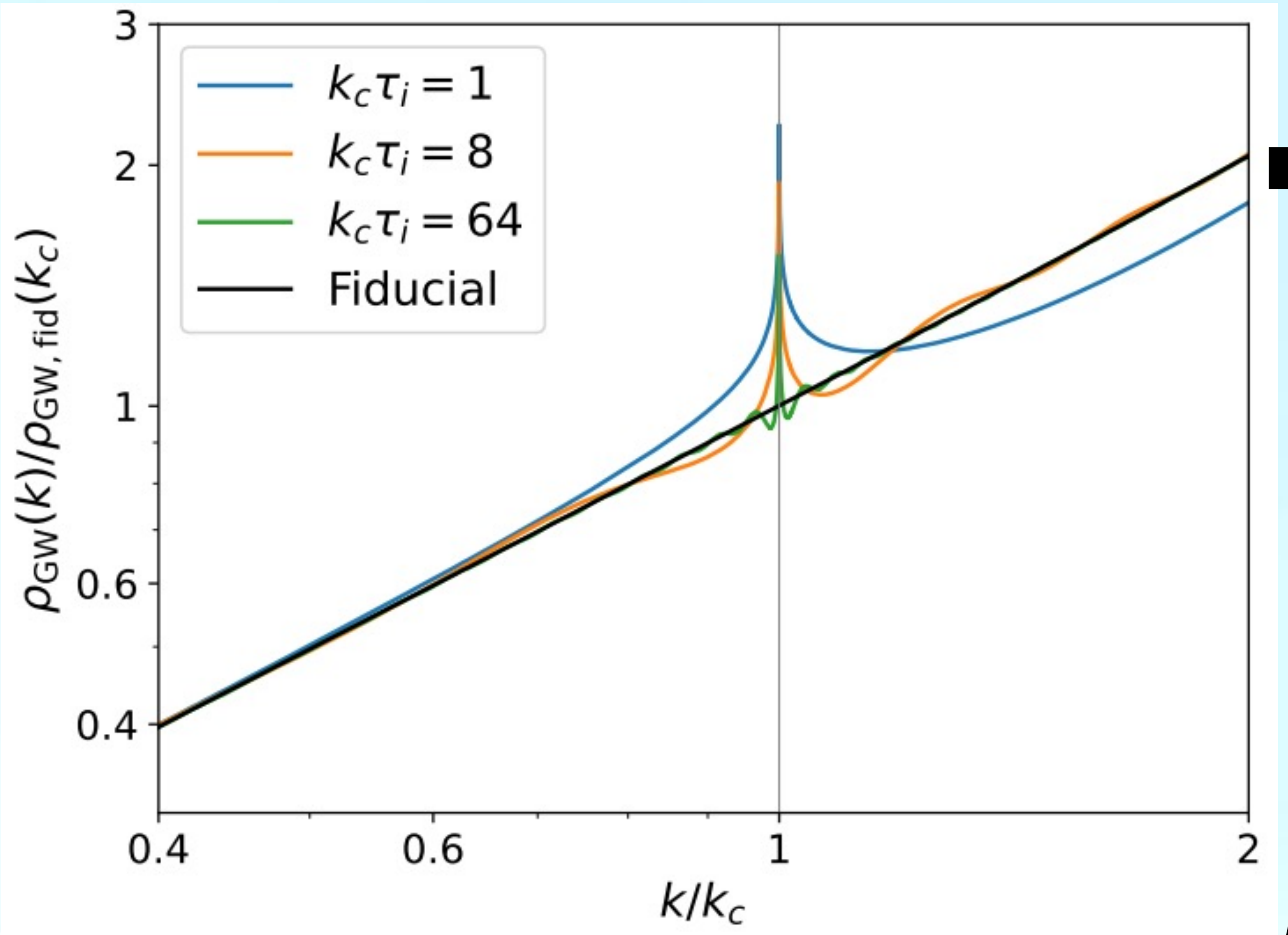
$$\psi_0 \simeq |\delta_{osc}|$$

E.g: CMB cos waves

Phase Factor α – phase of δ_{osc}. β – phase of GW

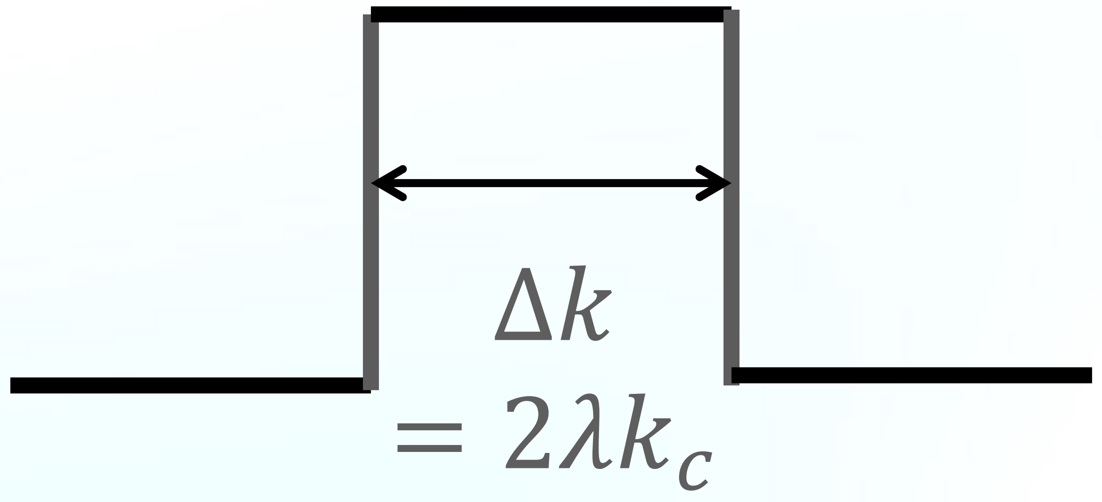
- GWB of ***primordial*** origin:
  - Superhorizon $h = h_0, \dot{h} = 0 \Rightarrow \beta$ is the same for all GW
  - **Signal strength** $\sim |\delta_{osc}|$
  - **Peak and Trough** (Example)
- GWB of ***subhorizon*** origin:
  - β is usually stochastic. E.g: uniform random β
  - **Signal strength** $\sim |\delta_{osc}|^2$
  - **Only Peak**

Prospects of observation

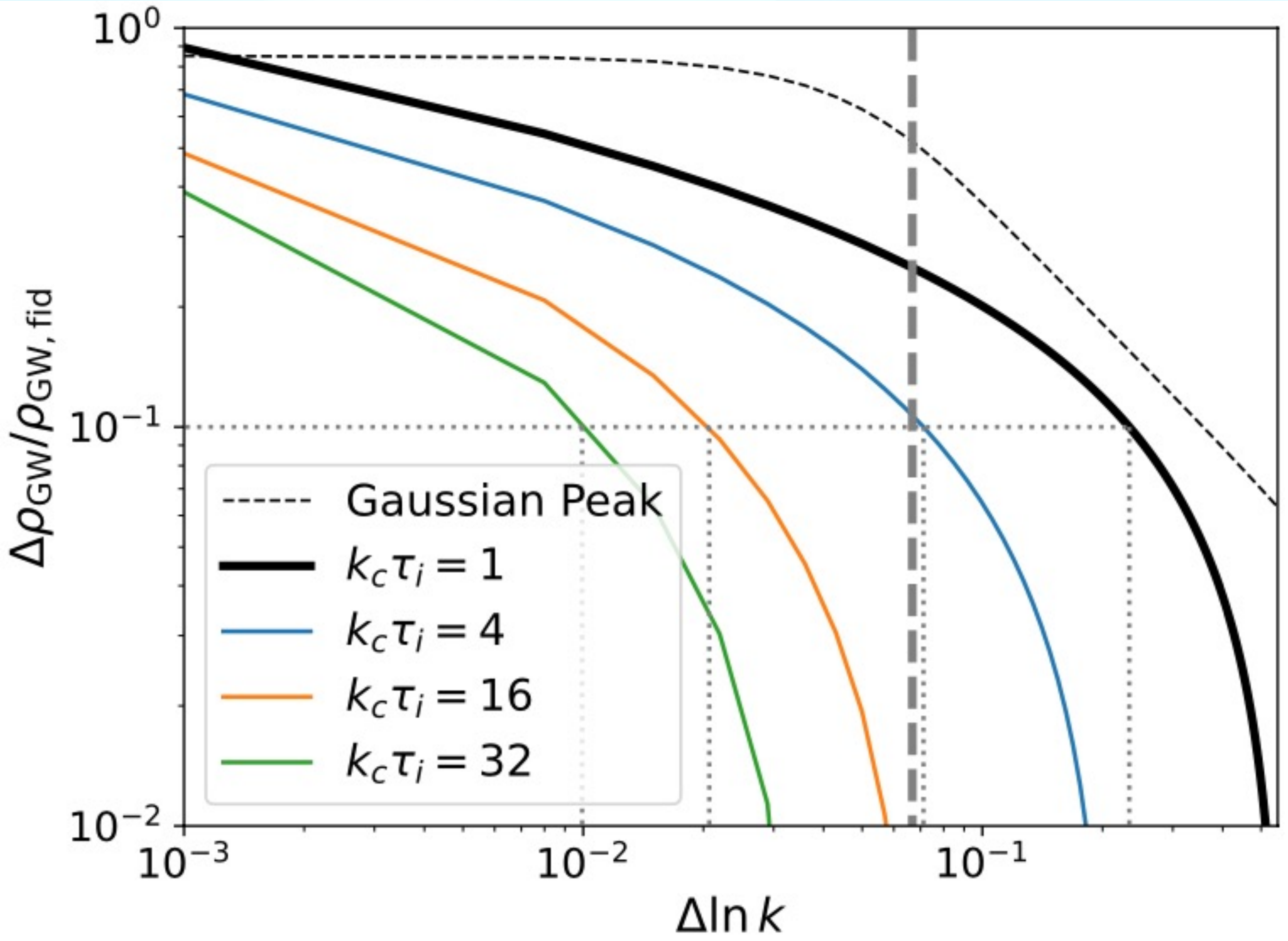


$$\Omega_{GW}(k) \to [1 + \psi_0 F_{\Delta k}(k, k_c)]\Omega_{GW}(k)$$

convolve



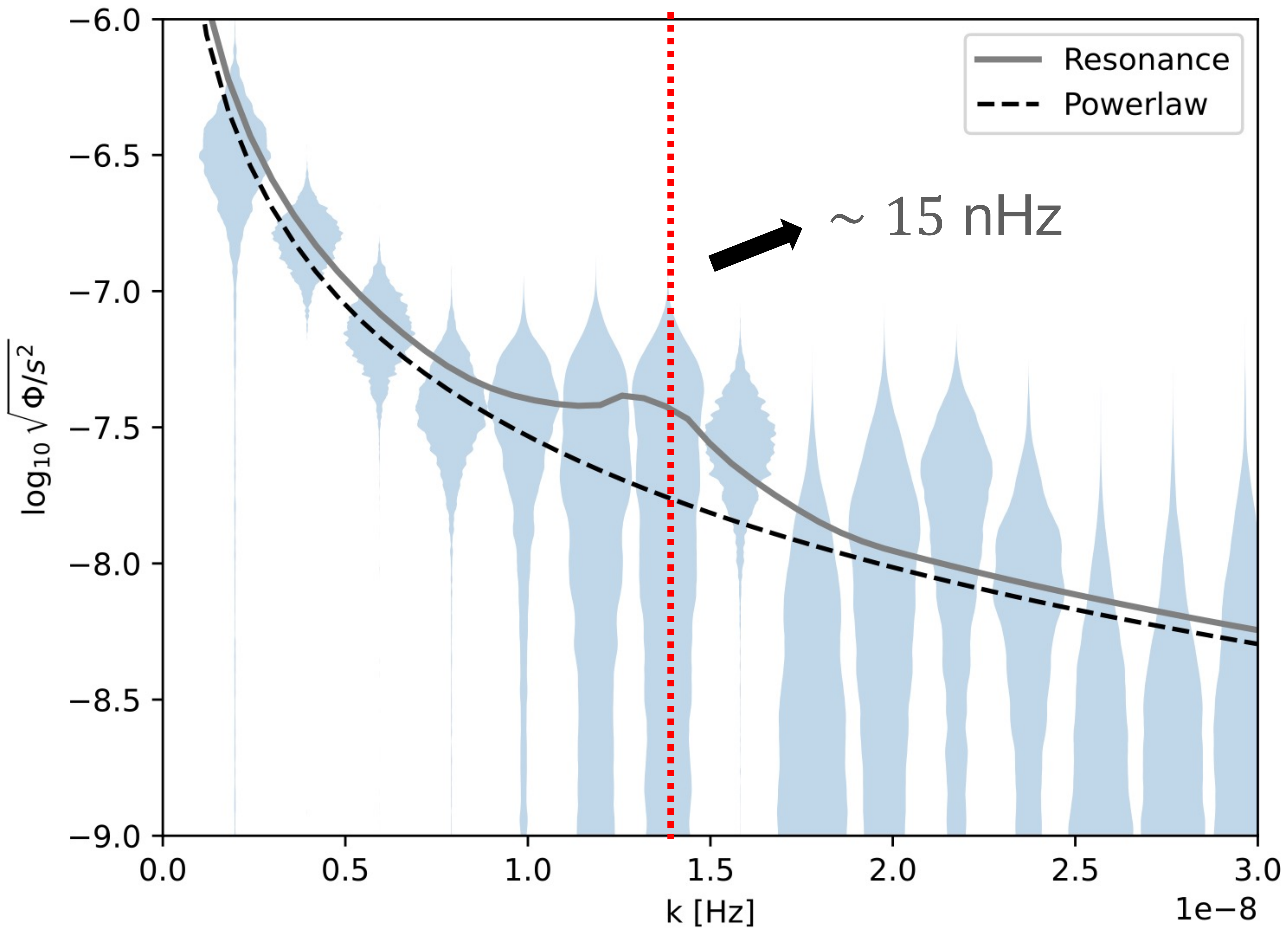
- ψ_0 - Signal Amplitude
- k_c - Peak/Trough Position
- Δk – Frequency Resolution?

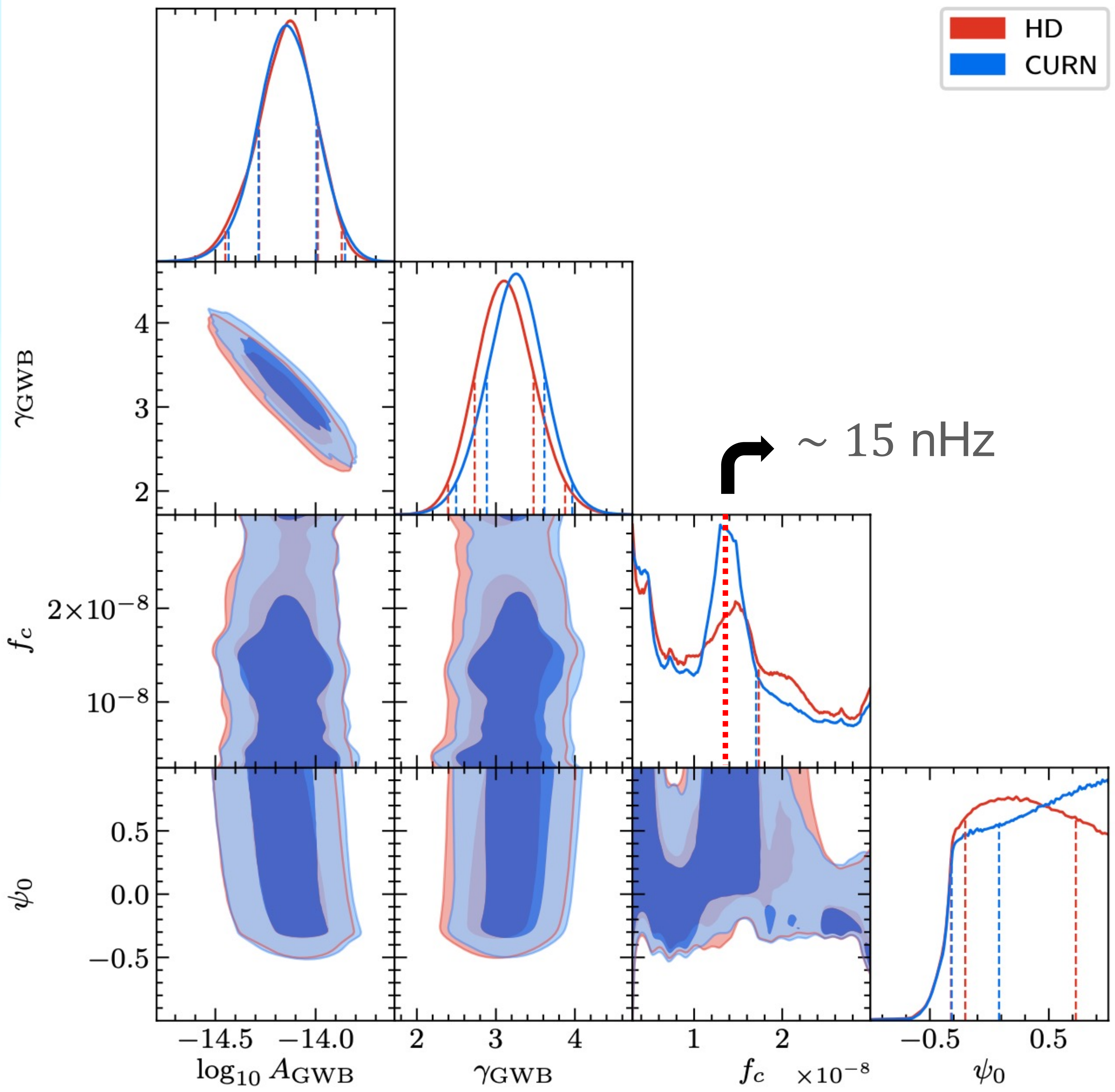


Prospects of observation

$$\Delta f = \frac{1}{15yr}$$

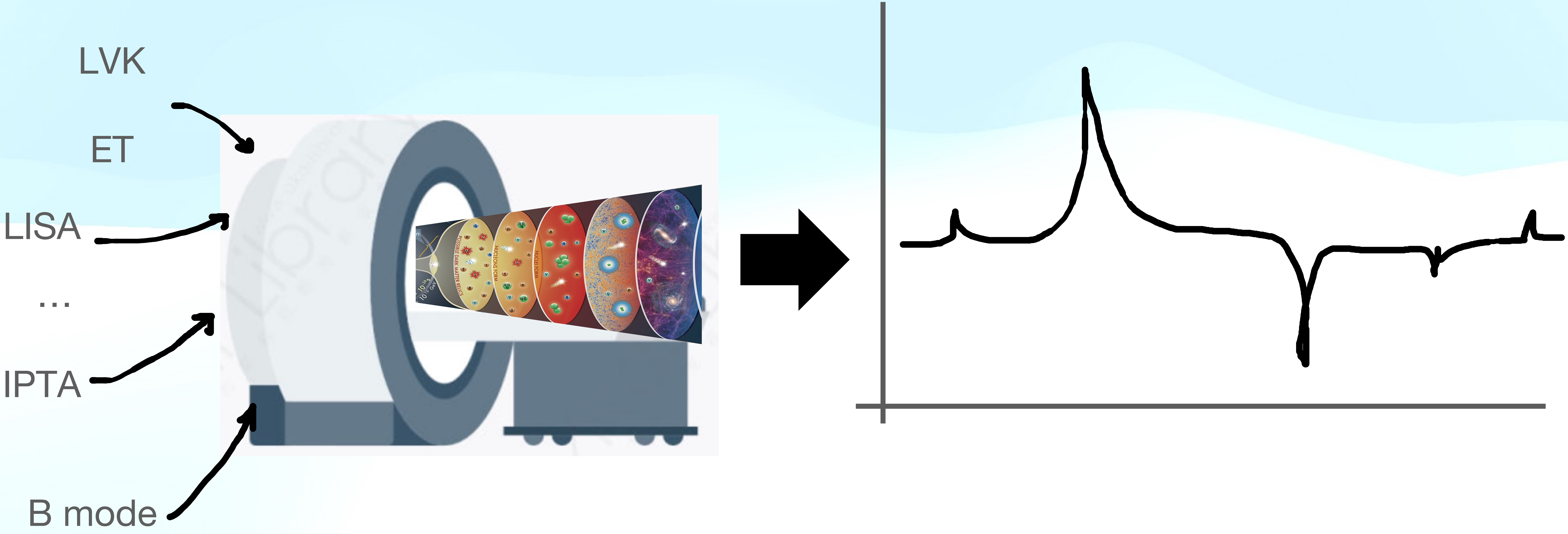
NANOGrav 15yr data





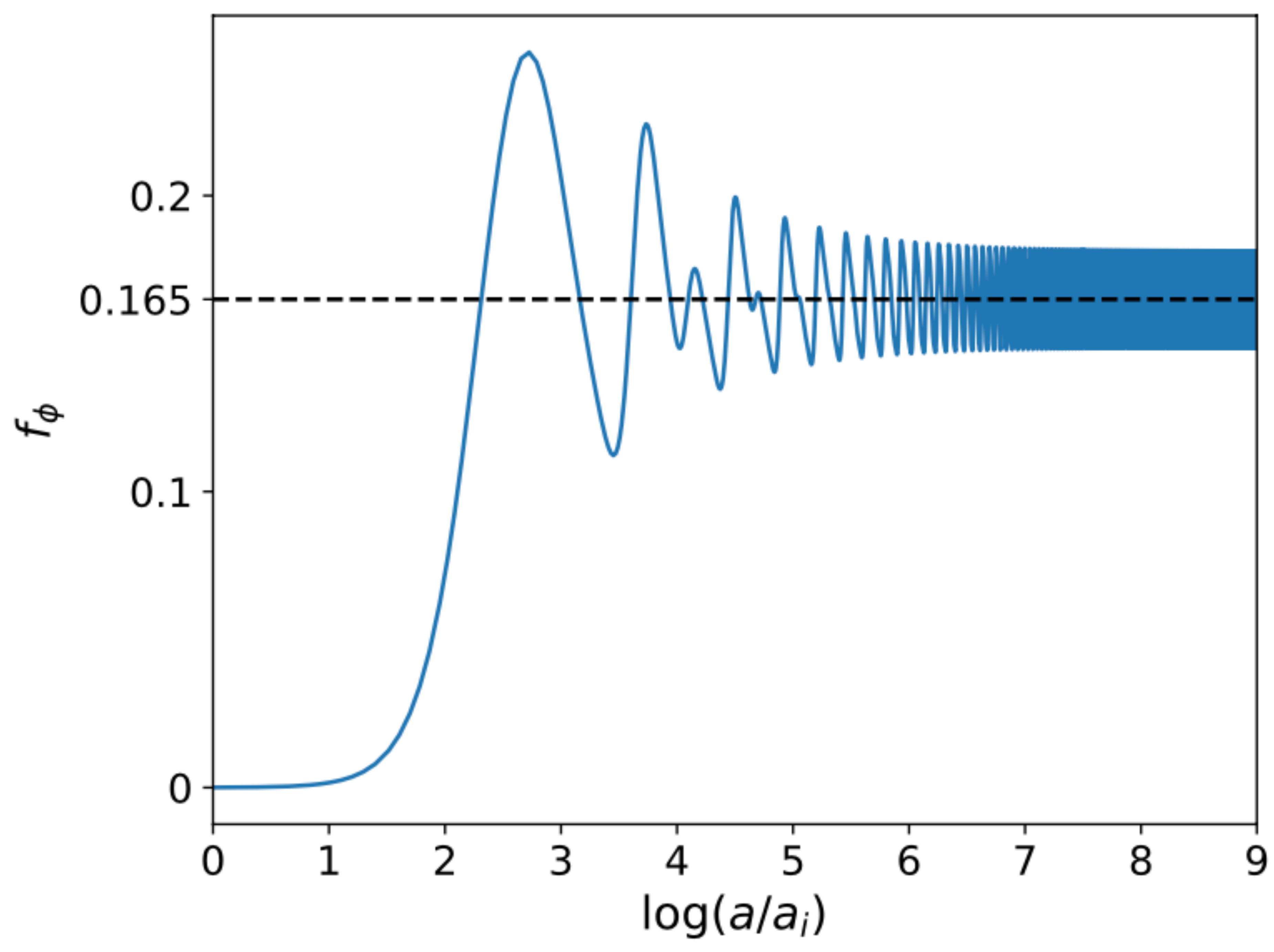
Gravitational Spectropy

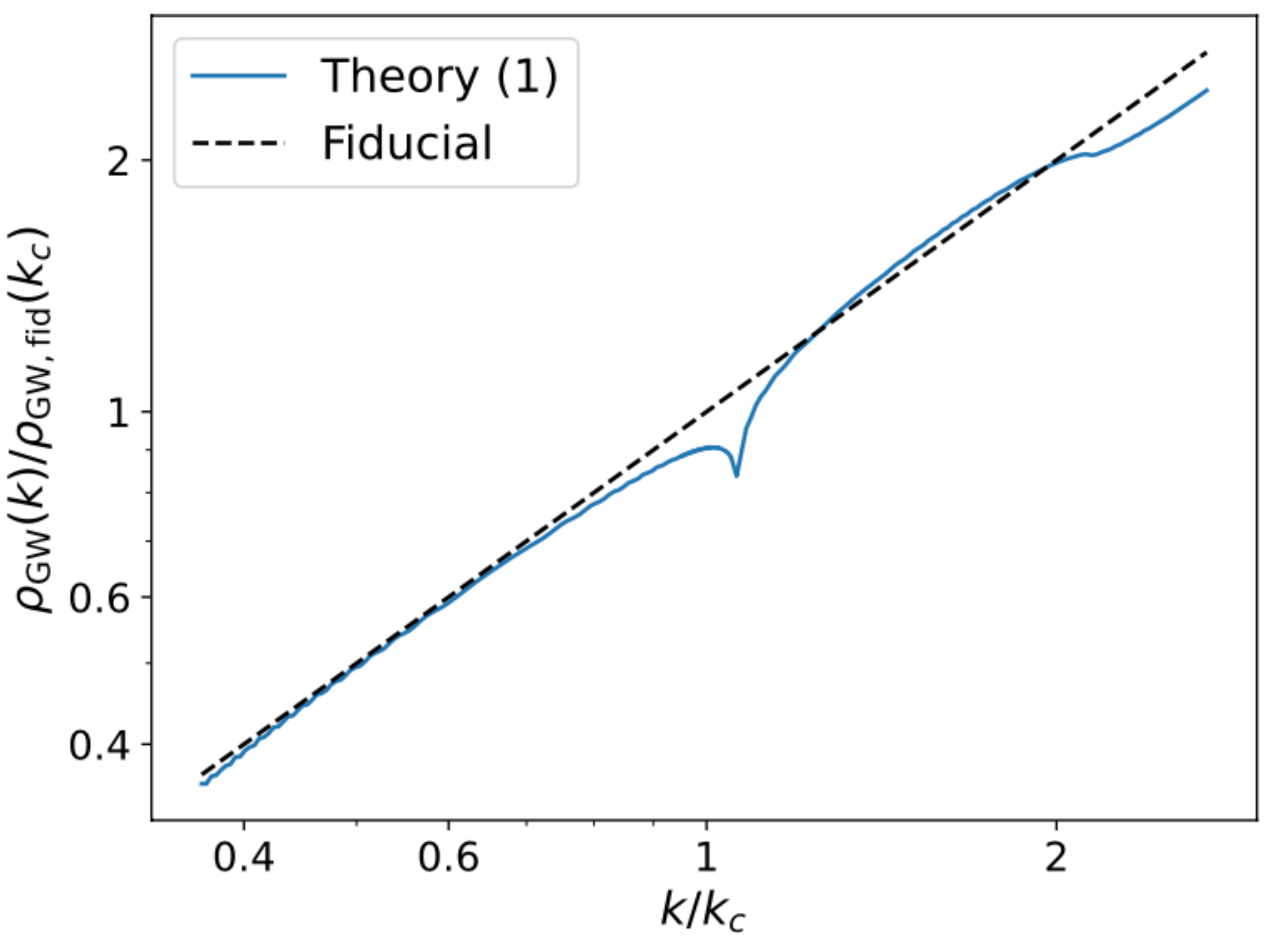
of the Early Universe



$$\mathcal{S} = \int dx^4 \sqrt{-g} \left[\frac{M_p^2}{2} G_4(\phi) R - \frac{1}{2}(\partial\phi)^2 - \lambda\phi^4 \right] + \mathcal{S}_m$$

$$G_4(\phi) = 1 + \alpha \left(\frac{\phi}{M_p} \right)$$





$$\frac{k_\phi}{\mathcal{H}_i} \simeq 2.2(\lambda f_\phi)^{1/4}$$

$$k_c = k_\phi/2$$