CONSTRAINTS ON SCALAR PERTURBATIONS FROM PTA

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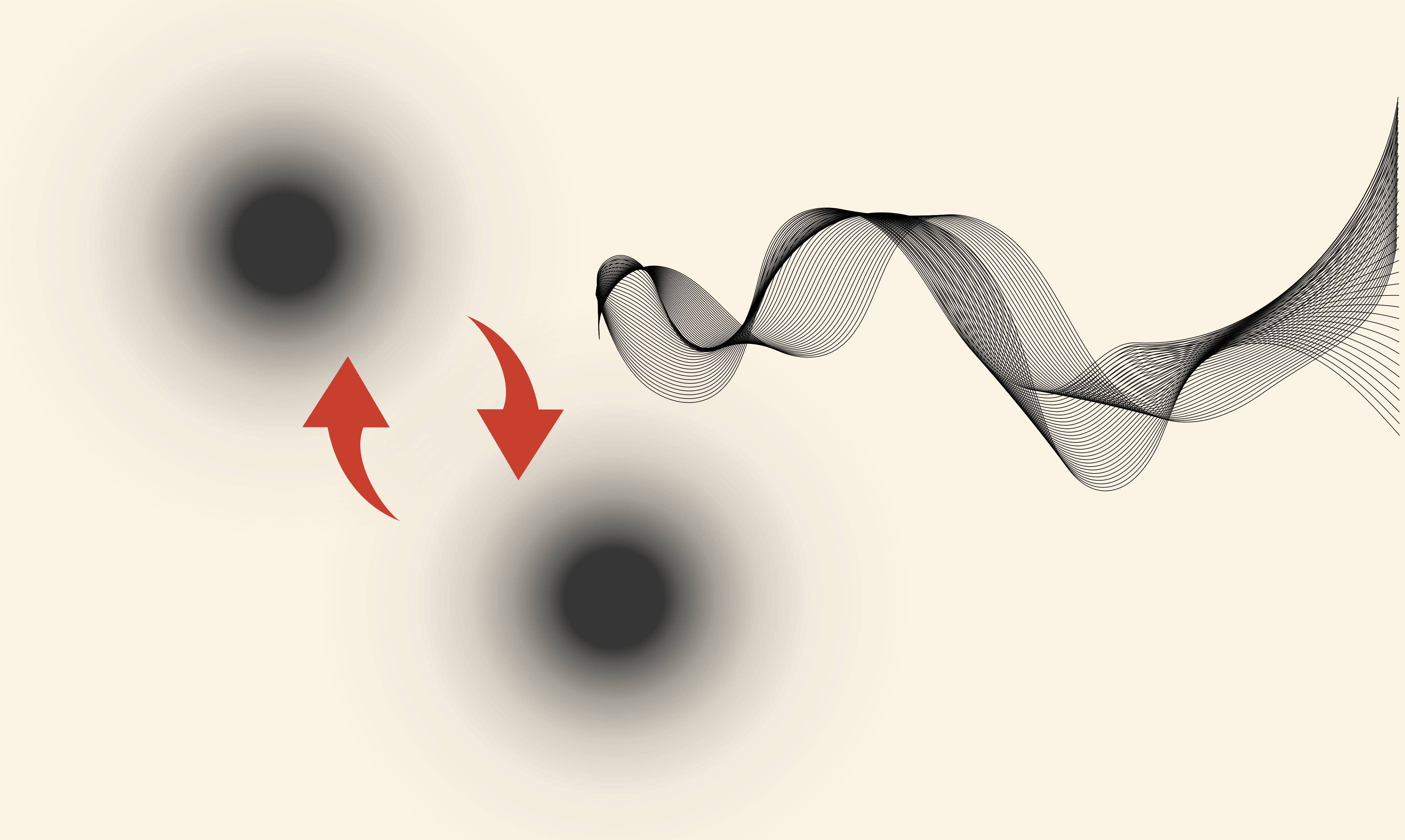
MOTIVATION

WHAT ARE THE SOURCES OF GW?

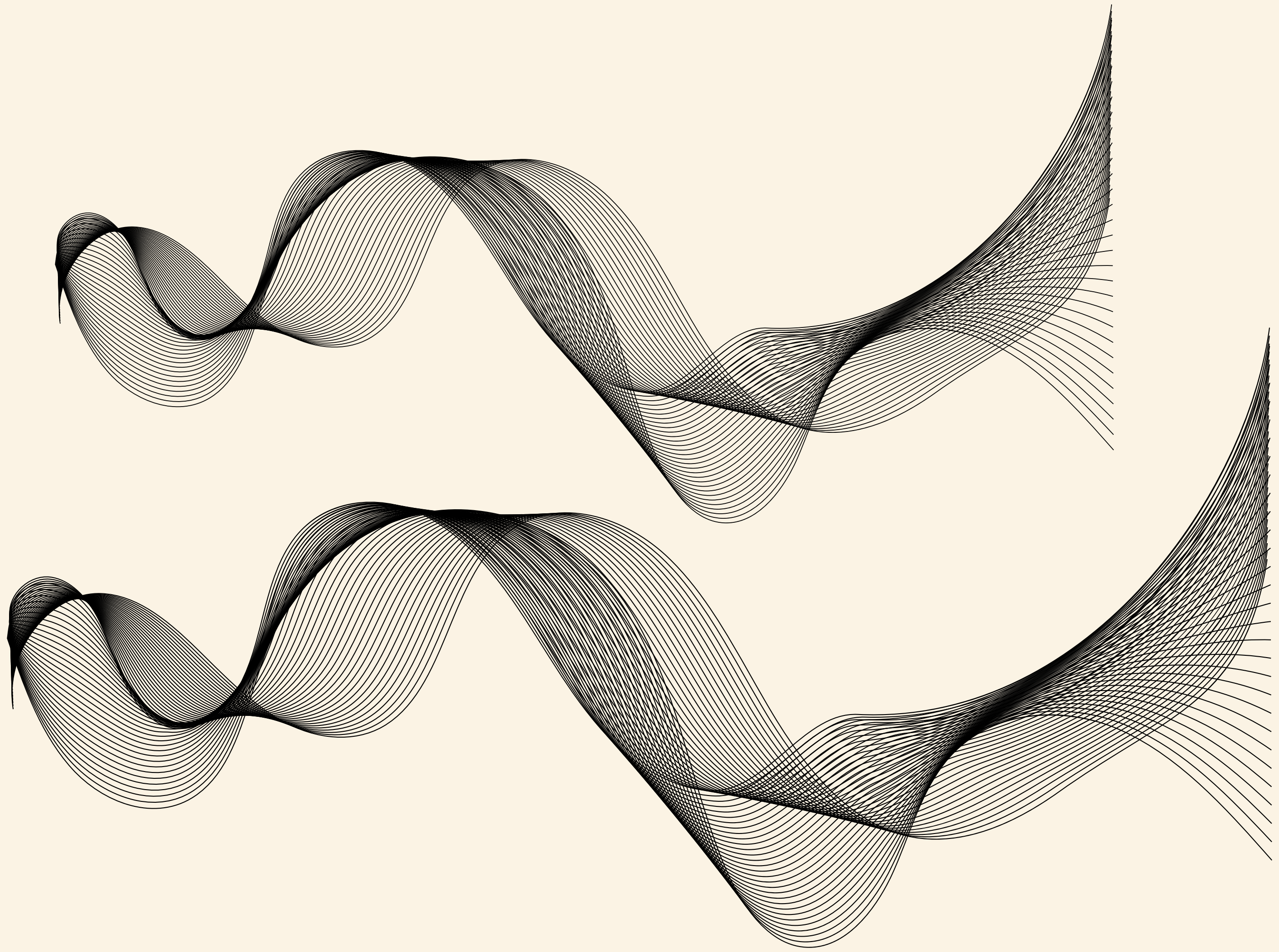
- All the GW events observed so far (LIGO-VIRGO) came from astrophysical objects



- Black hole + black hole merging
- Black hole + neutron star merging
- neutron star + neutron star merging

WHAT ARE THE SOURCES OF GW?

- But: Early universe phenomena could also trigger GW



So far never observed....

- Phase transitions in the early universe
- Domain walls (i.e. axion)
- Large perturbations in the early universe

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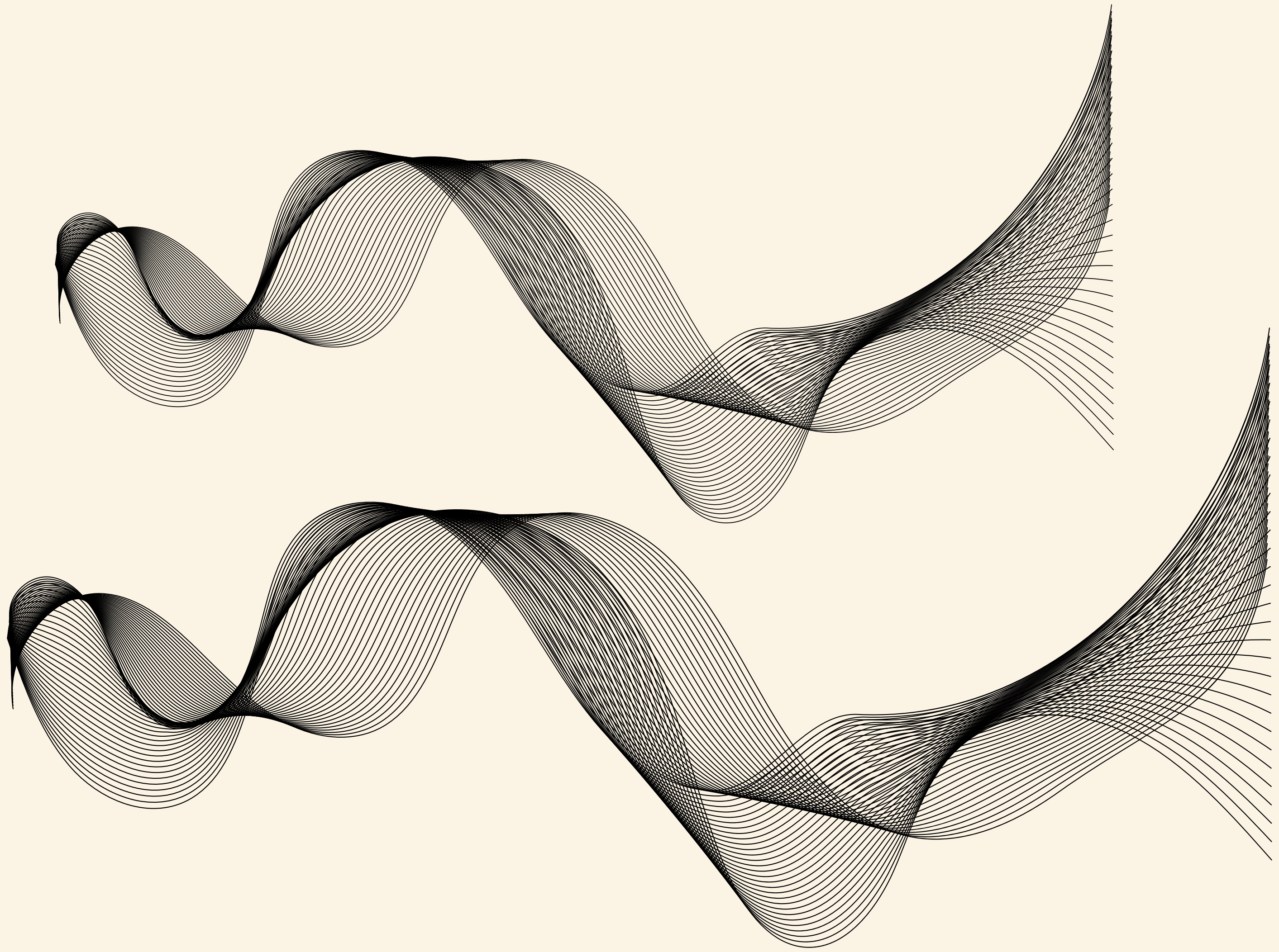

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this talk

SCALAR INDUCED GW

- Metric perturbations are decomposed into scalar and tensor perturbations

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

Negligible at linear order

SCALAR INDUCED GW

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

Sourced by the scalar perturbations at non-linear order

Negligible at linear order

- Gravitational wave spectrum is a function of the curvature power spectrum

$$\boxed{\Omega_{GW}(k) = F(P_\zeta(k))}$$

SCALAR INDUCED GW

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We know the curvature spectrum at large scales from CMB:

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

[1807.06211]

To small to produce any seizable GW...

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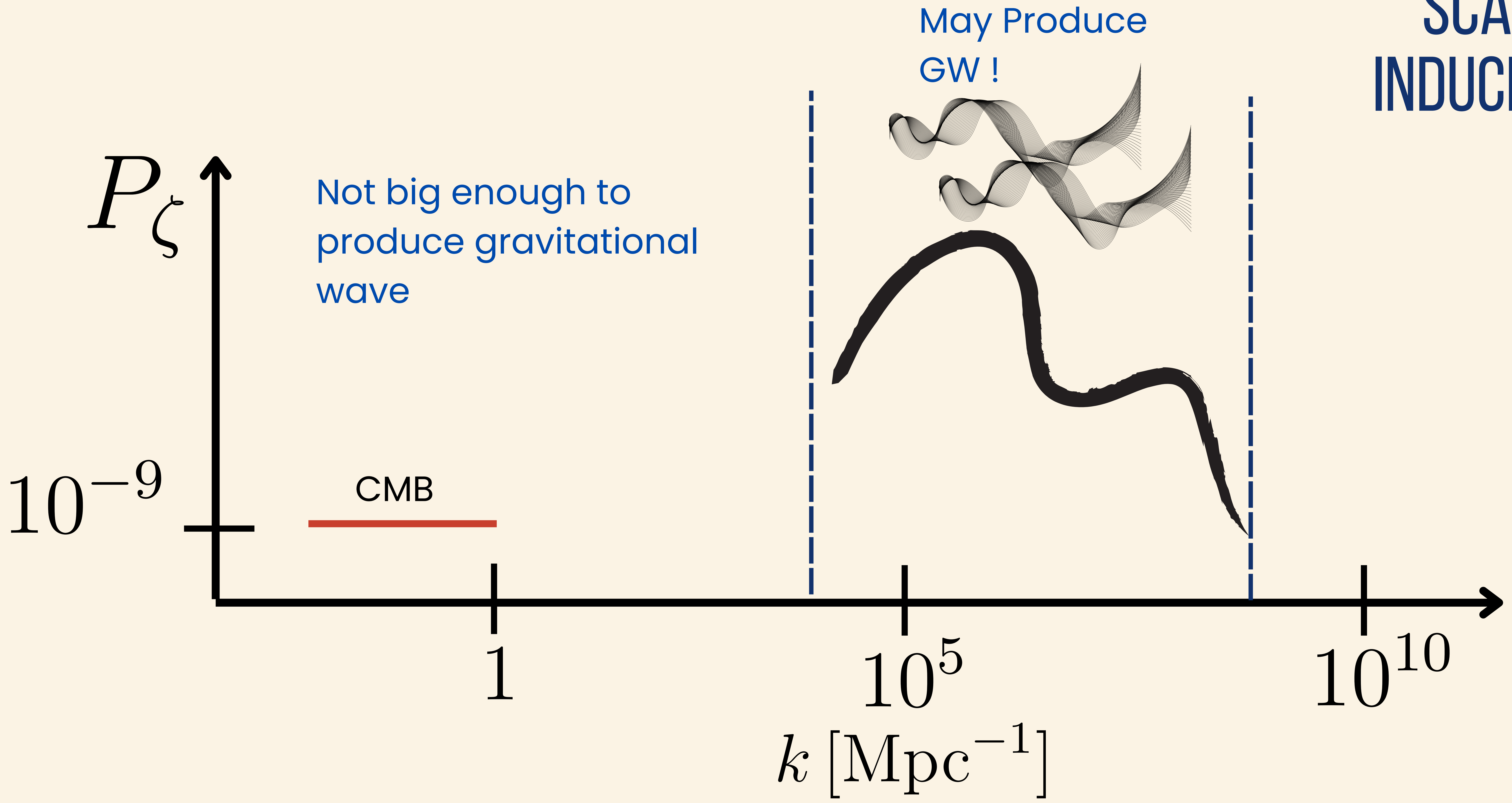
To small to produce any seizable GW...

Almost no constraints on the curvature power spectrum at small scales !

Could have big enough perturbations to produce GW

SCALAR INDUCED GW

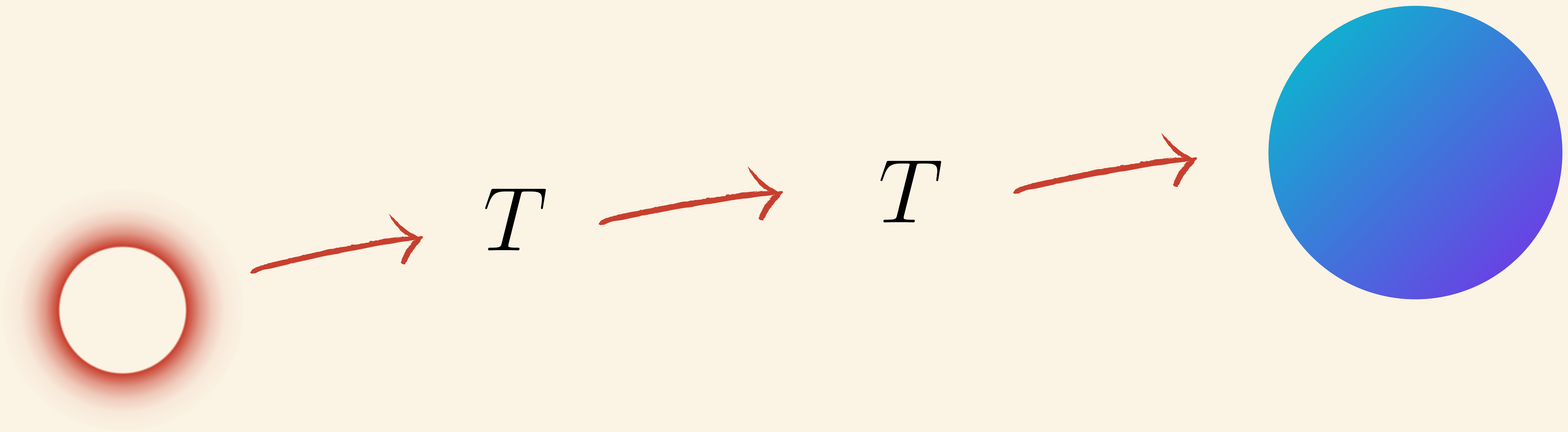


ANY SIGN OF THE SIGW ?

•••

POTENTIAL GW SIGNAL IN PTA

- Pulsars send light pulses with stable period



- PTA observe multiple pulsars with a well know period

POTENTIAL GW SIGNAL IN PTA

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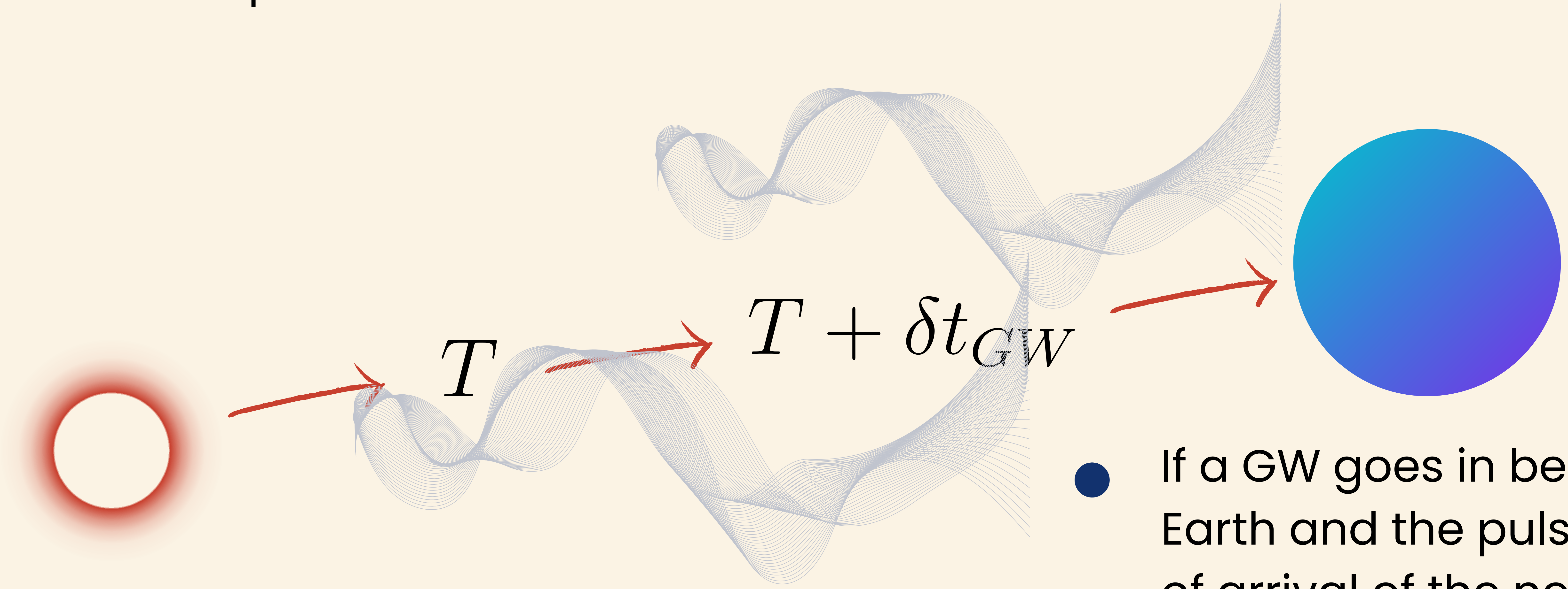

- If a GW goes in between the Earth and the pulsar, the time of arrival of the next pulse is delayed

POTENTIAL GW SIGNAL IN PTA

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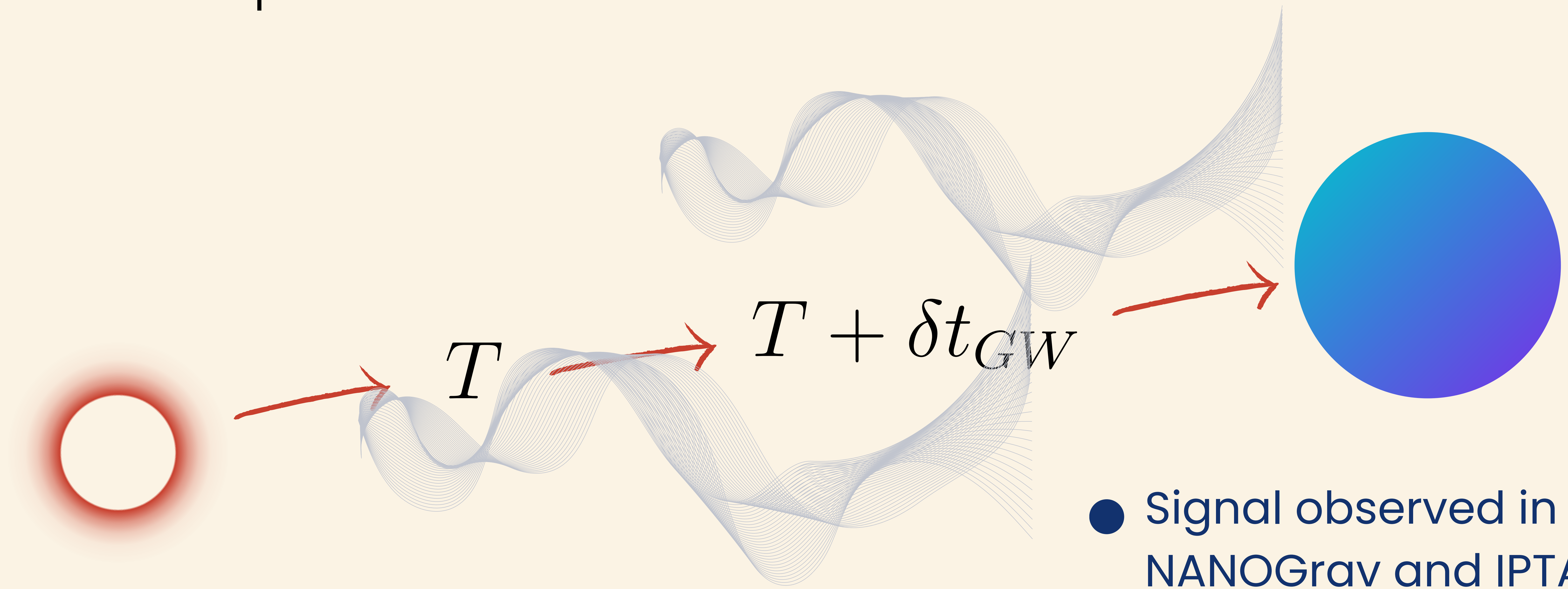


- Signal observed in NANOGrav and IPTA

WHAT IS THE ORIGIN OF THOSE GW?

- Coallescence of super massive black holes

Works well to explain the signal

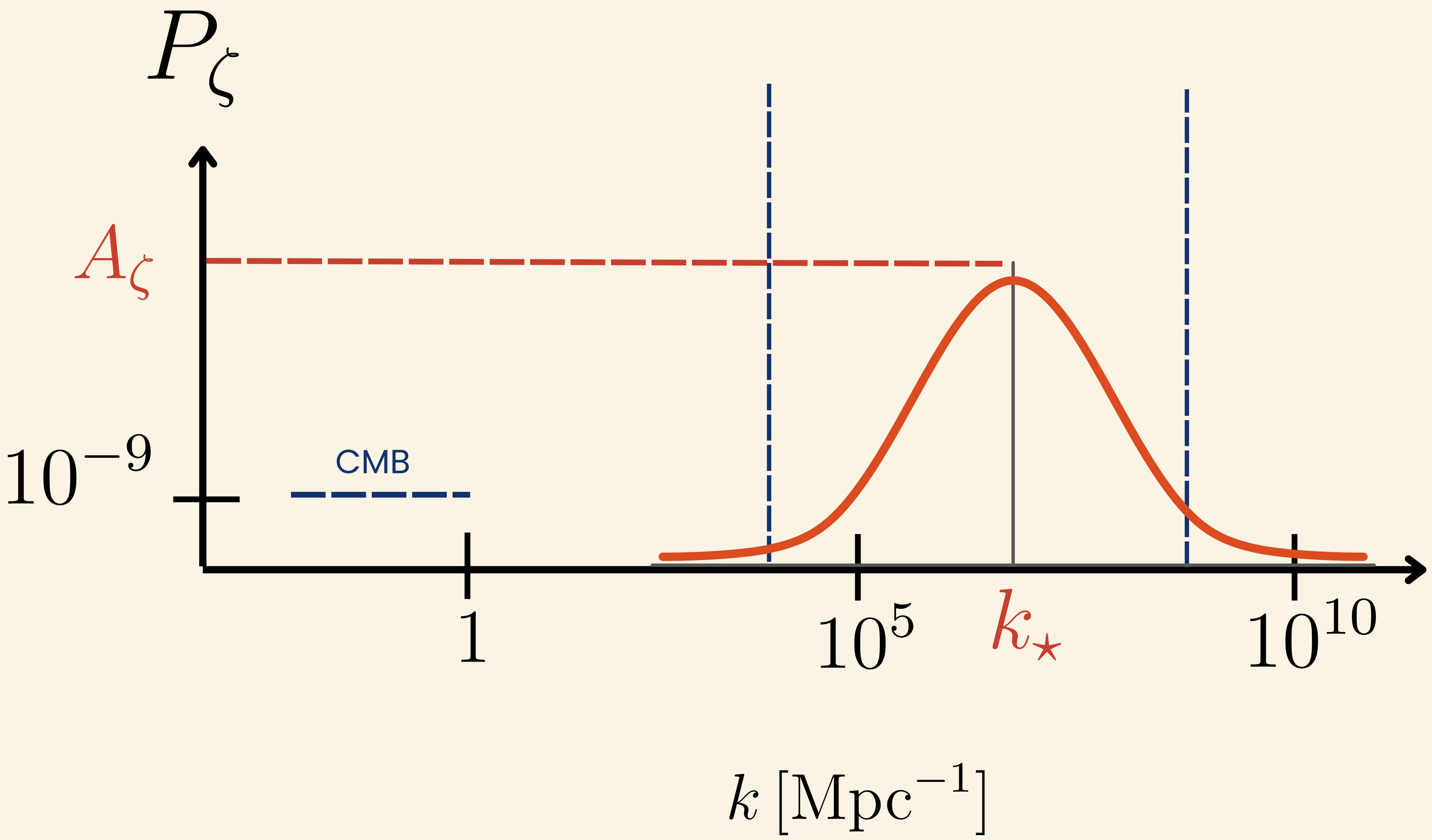
- Could those GW have been produced by large perturbations in the early universe?

Use bayesian search on the data to find what curvature power spectrum could explain the signal

PARAMETRIZATION OF THE POWER SPECTRUM

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

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



- Use data of IPTA and NANOgrav to find what values could explain the signal

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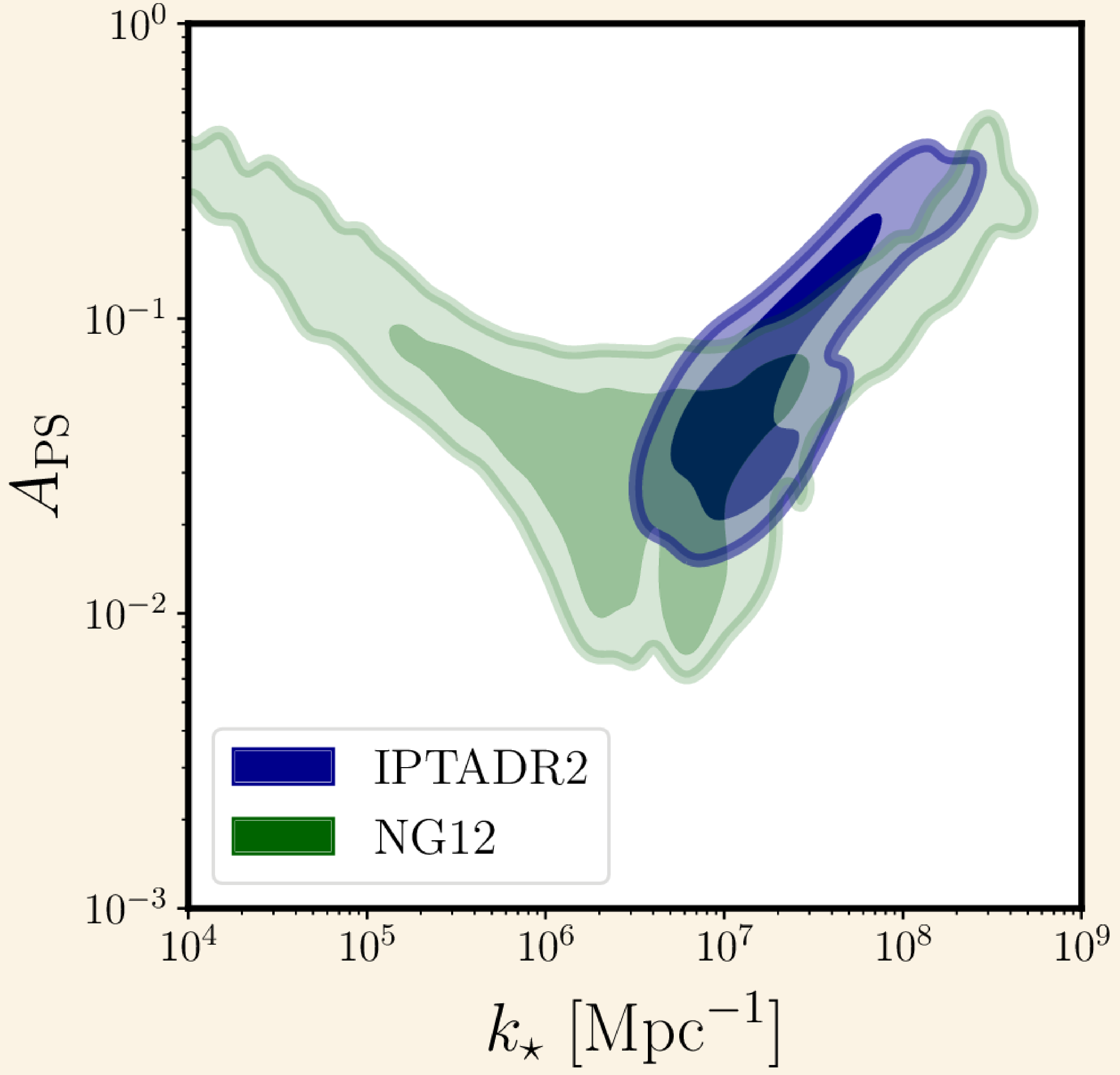


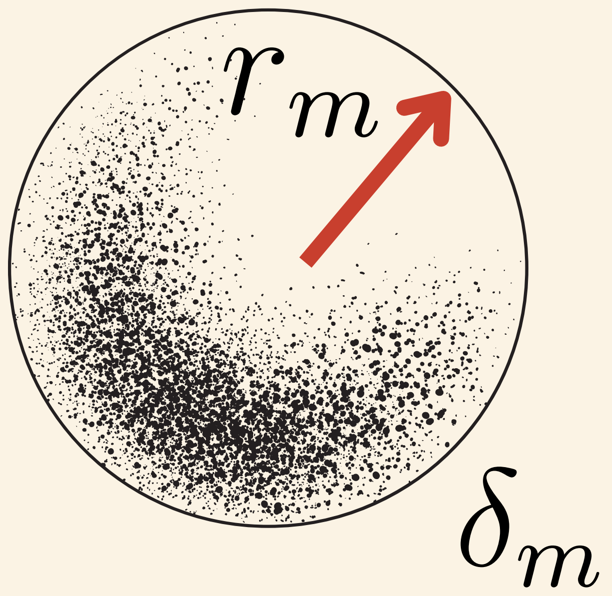
PRIMORDIAL BLACK HOLES FROM CURVATURE PERTURBATIONS

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

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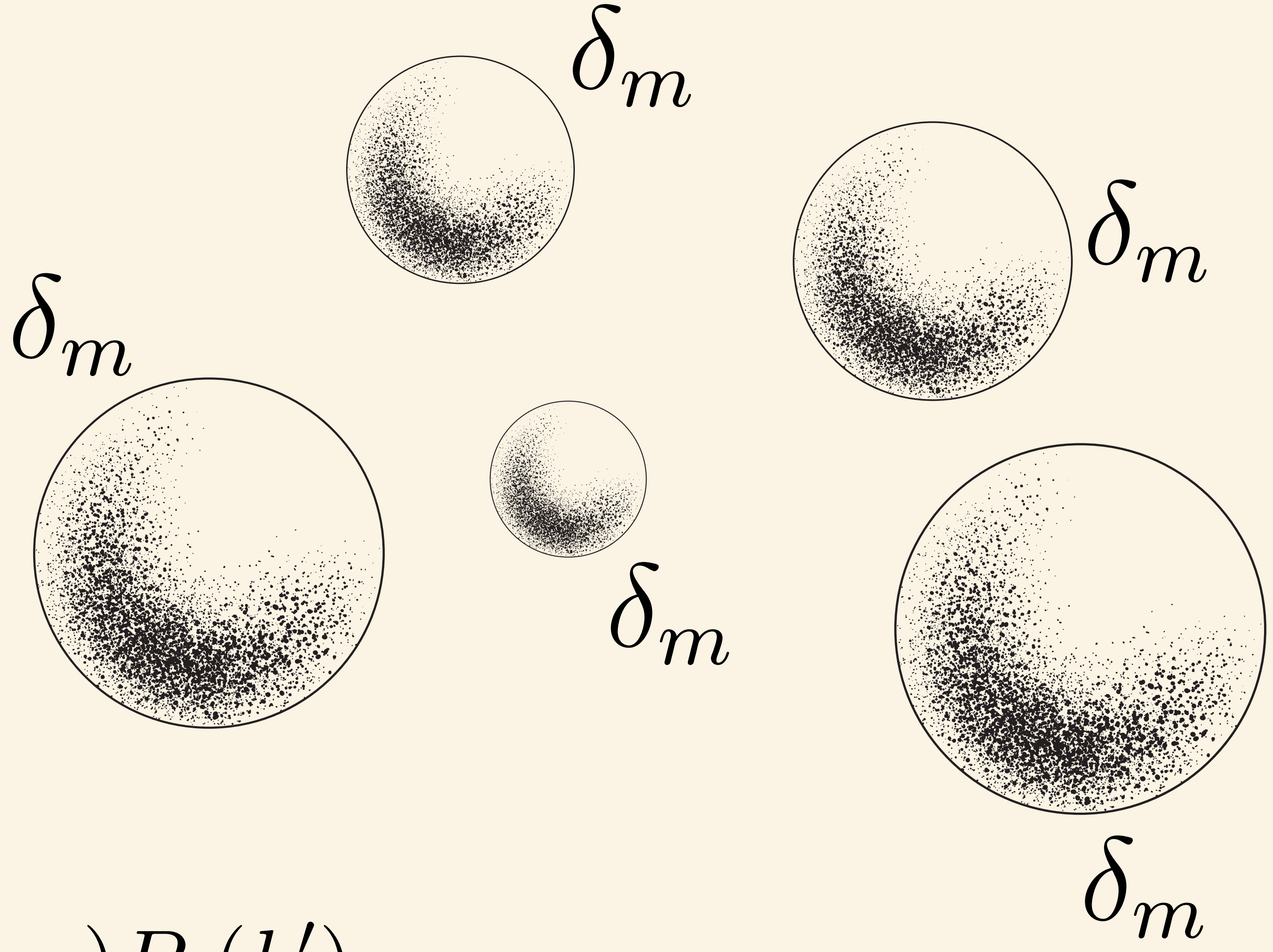


$$P_{r_m}(\delta_m) = \frac{1}{\sqrt{2\pi\sigma_{r_m}^2}} \exp\left(-\frac{\delta_m^2}{2\sigma_{r_m}^2}\right)$$

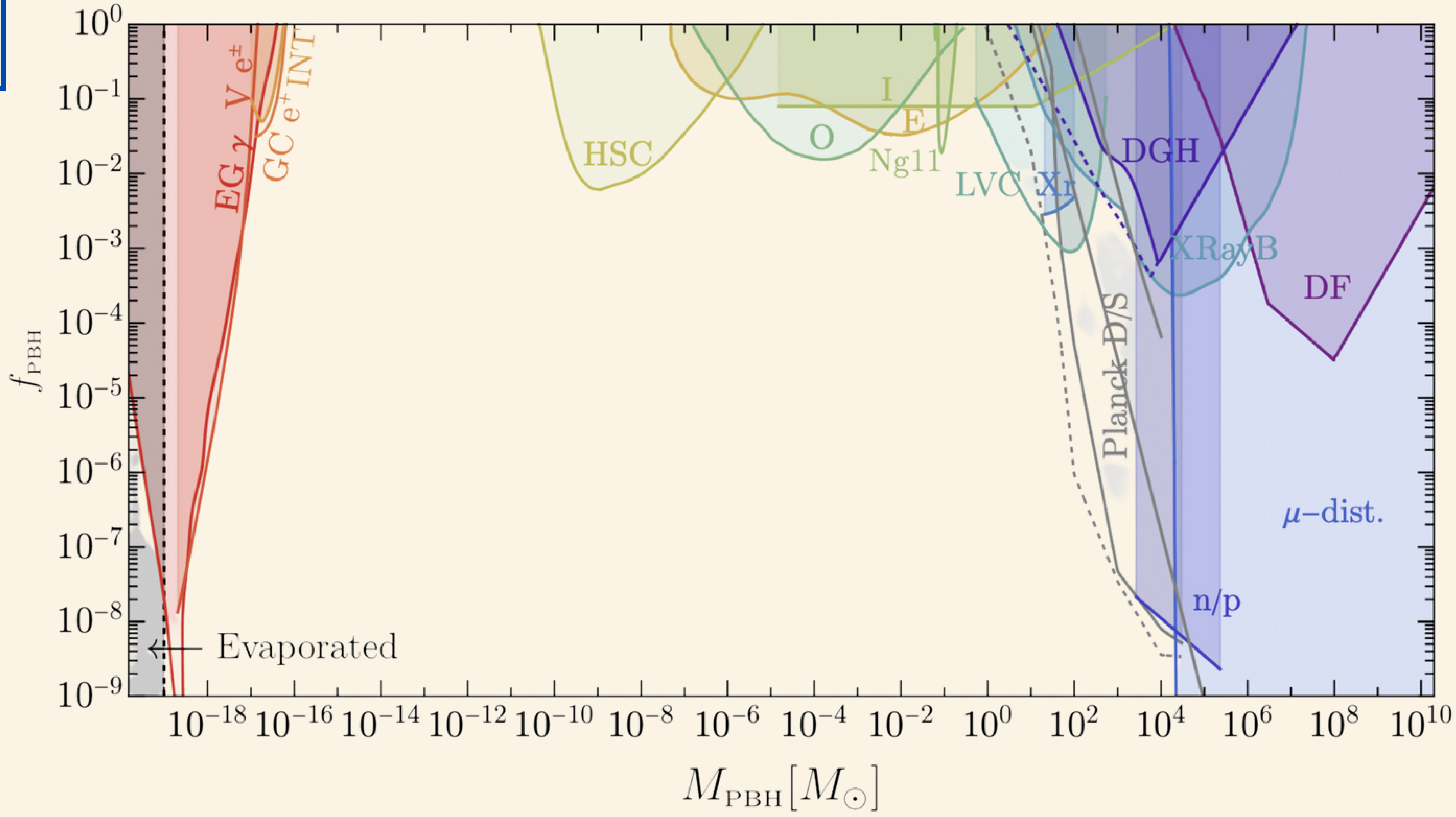
$$\sigma_{r_m}^2 = \frac{16}{81}\int_0^\infty \frac{\mathrm{d}k'}{k'}\,(k' r_m)^4 T^2(k', r_m) W^2(k'; r_m) P_\zeta(k').$$

PBH FORMATION FROM LARGE CURVATURE FLUCTUATIONS

- $$\boxed{\begin{aligned} f_{\rm PBH} &= F_f(P_\zeta) \\ \langle M_{\rm PBH}\rangle &= F_M(P_\zeta) \end{aligned}}$$

- One could translate them into constraints on the amplitude A_ζ

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



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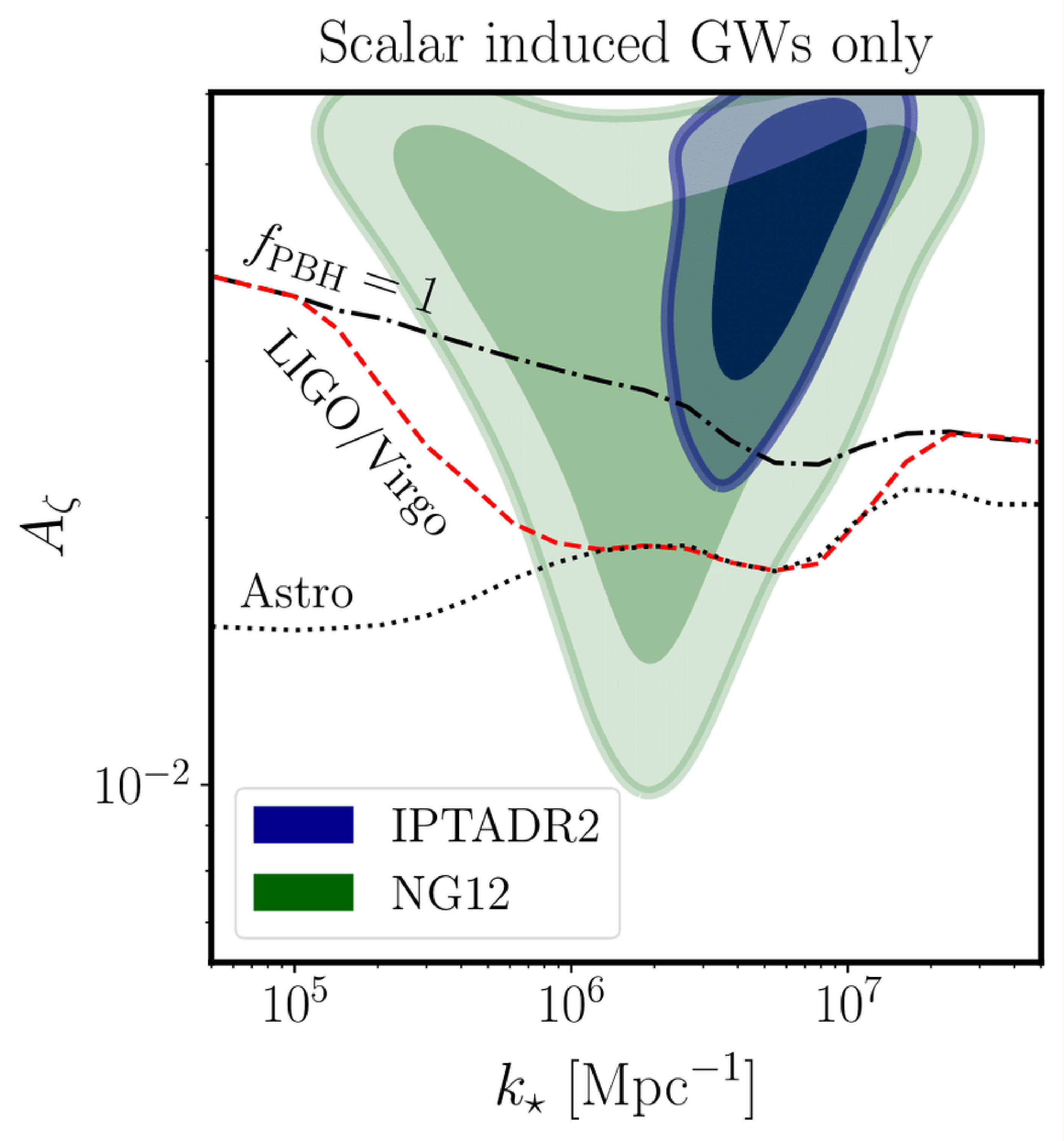

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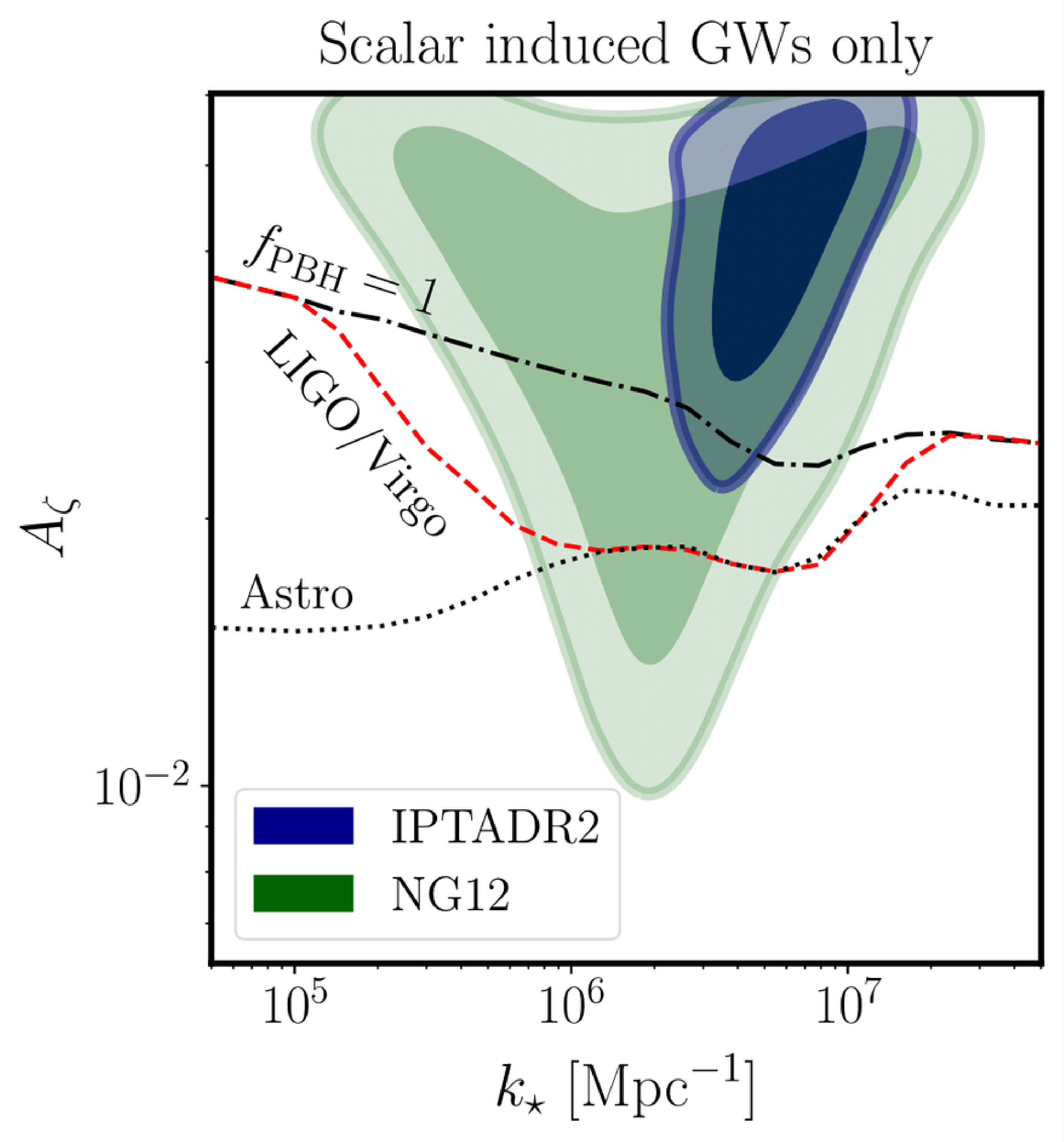
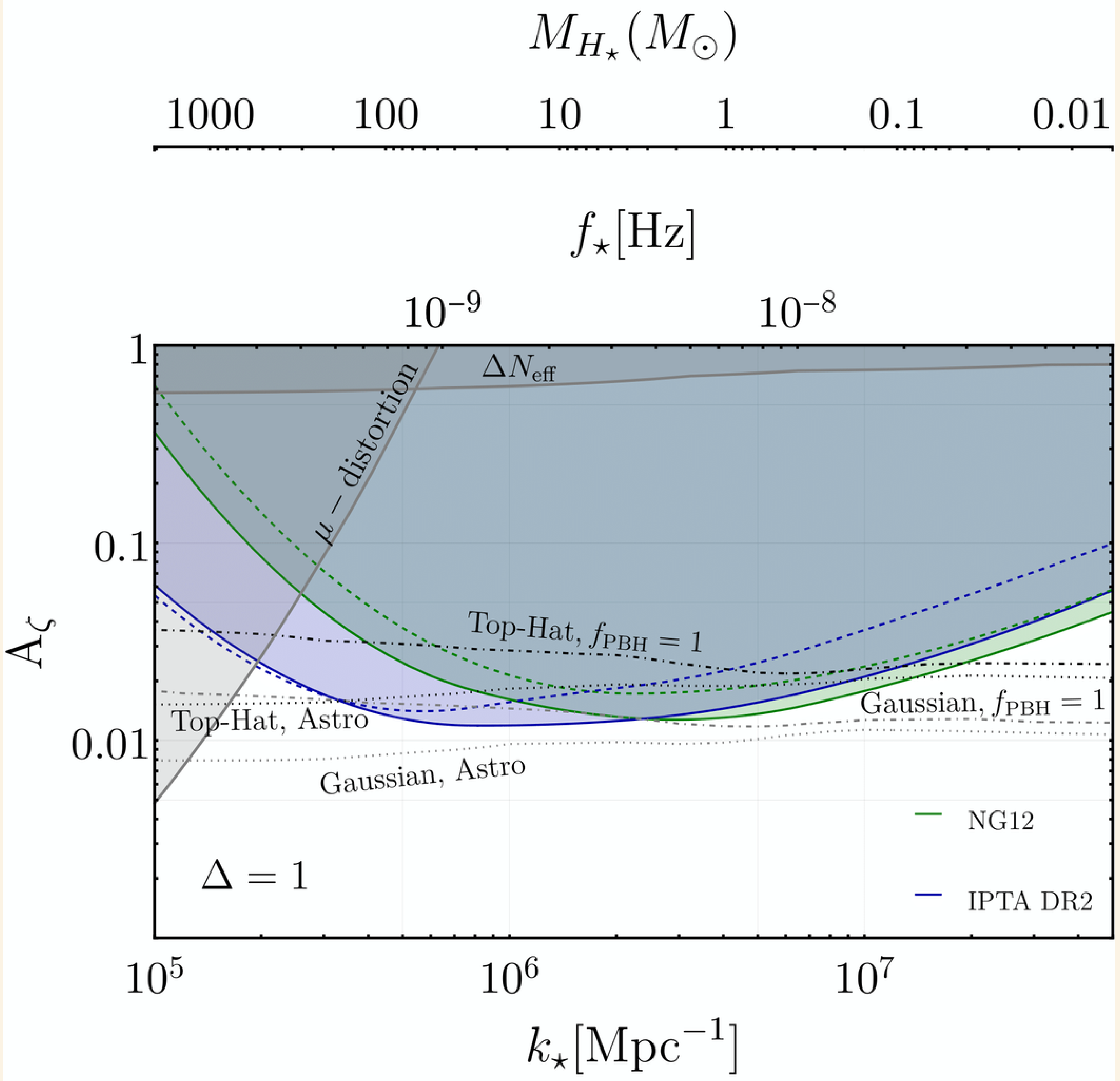
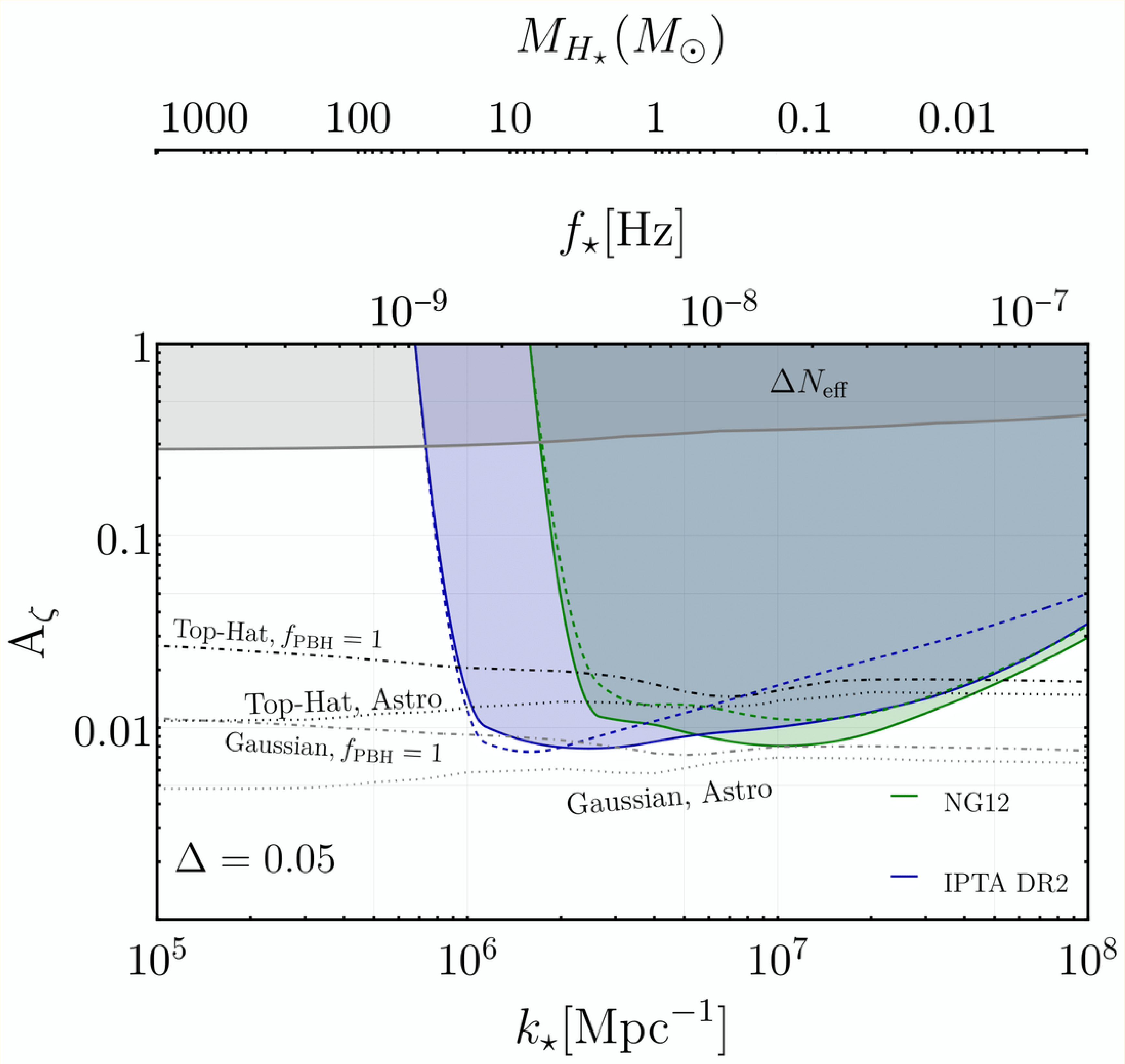
- The IPTA region able to explain the signal seems to produce to many PBH!!

$\Delta = 1$



$\Delta = 1$ $\Delta = 0.05$





CONCLUSION

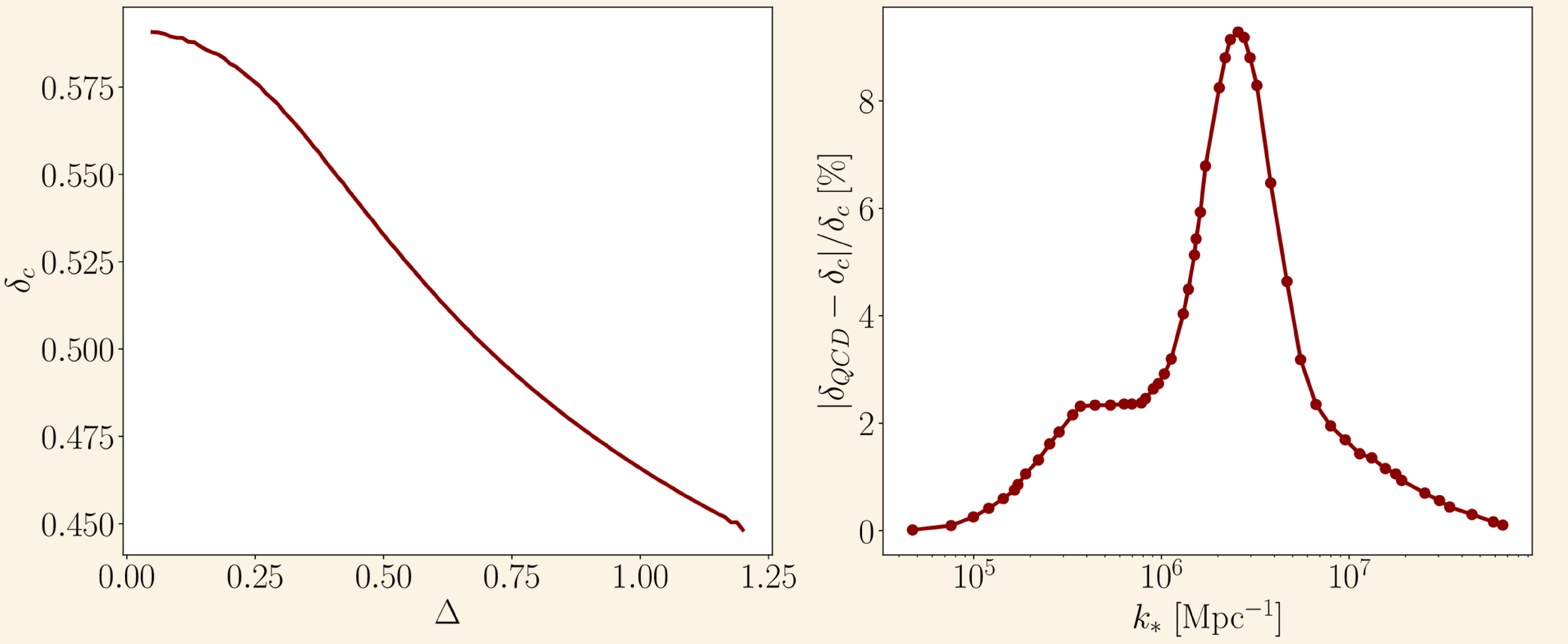
- Large amplitudes of the curvature power spectrum produce GW able to explain the signal observed in PTA

- 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

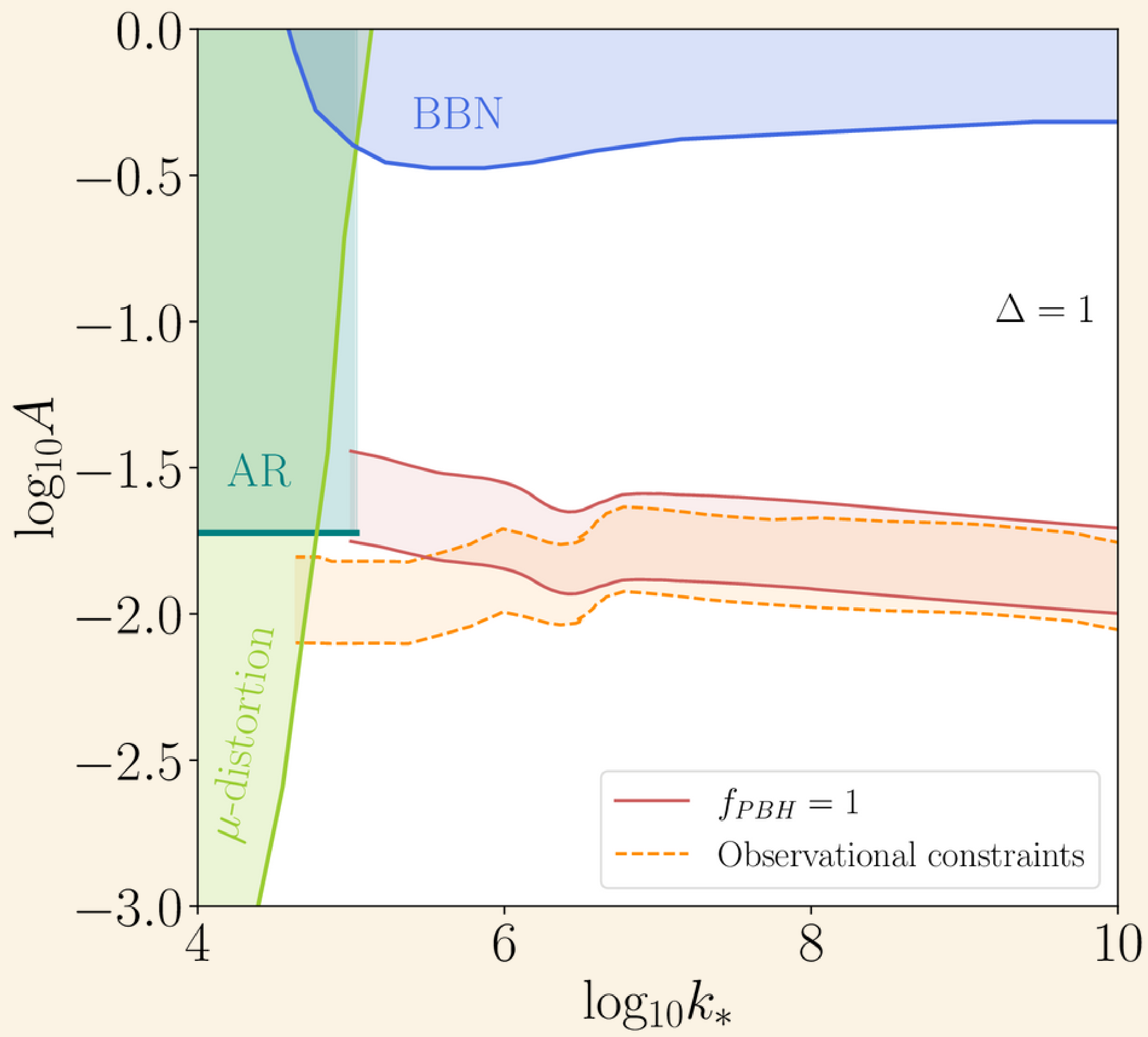
- The SMBH model is favored to explain to signal and we therefore derived upper limits on the amplitude of the curvature spectrum

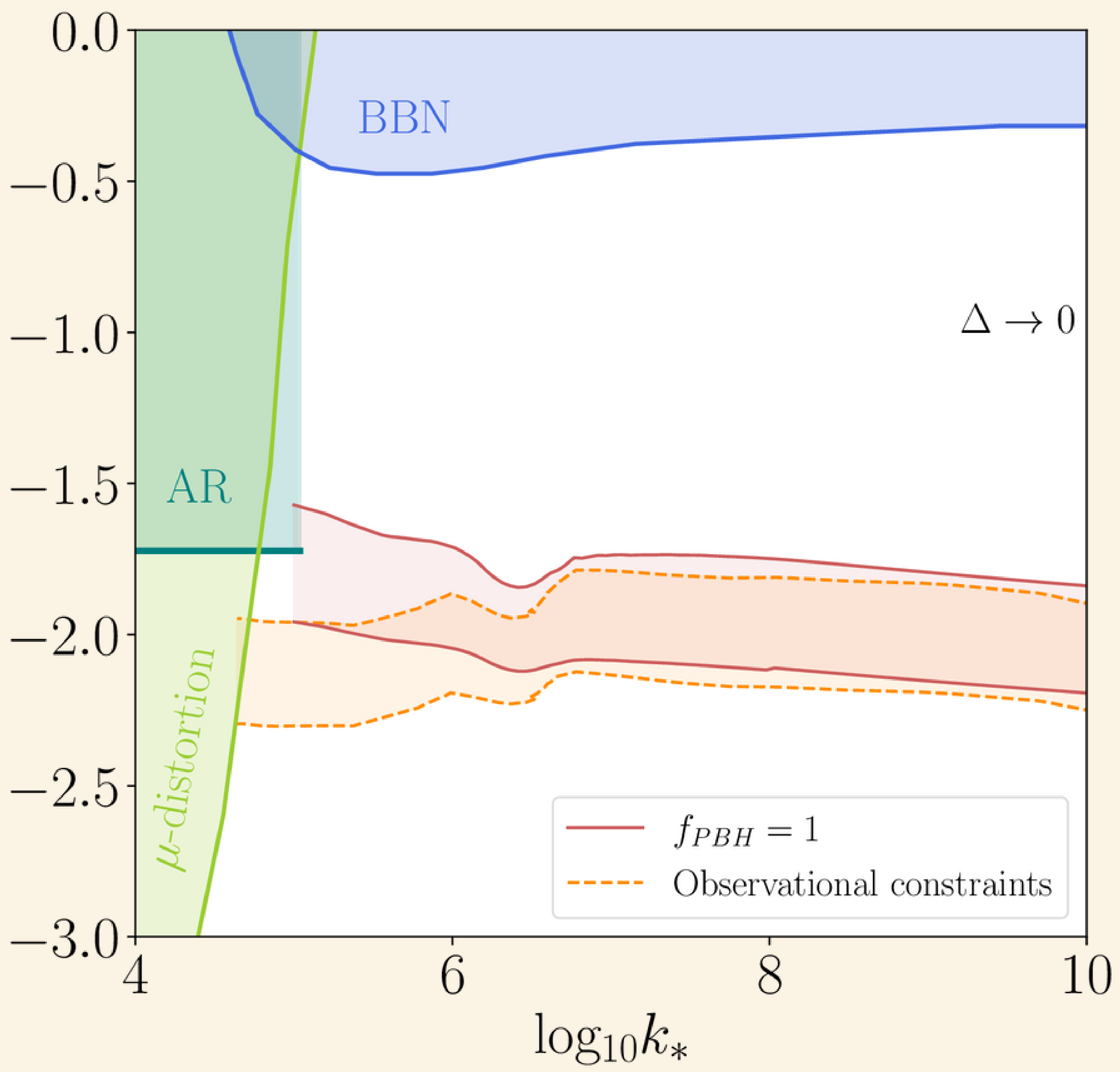
CRITICAL THRESHOLD



BACKUP

CONSTRAINTS PBH





HOW TO PROBE SMALL SCALE POWER SPECTRUM ?

- Parametrize the power spectrum with a log-normal shape

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

Perform bayesian search to determine the evidence regions