PARAMETER ESTIMATION FOR INFLATIONARY GRAVITATIONAL WAVE BACKGROUNDS WITH LISA

BASED ON PROJECT 15 OF THE COSWG

11TH LISA COSWG MEETING
JUN 17 2024

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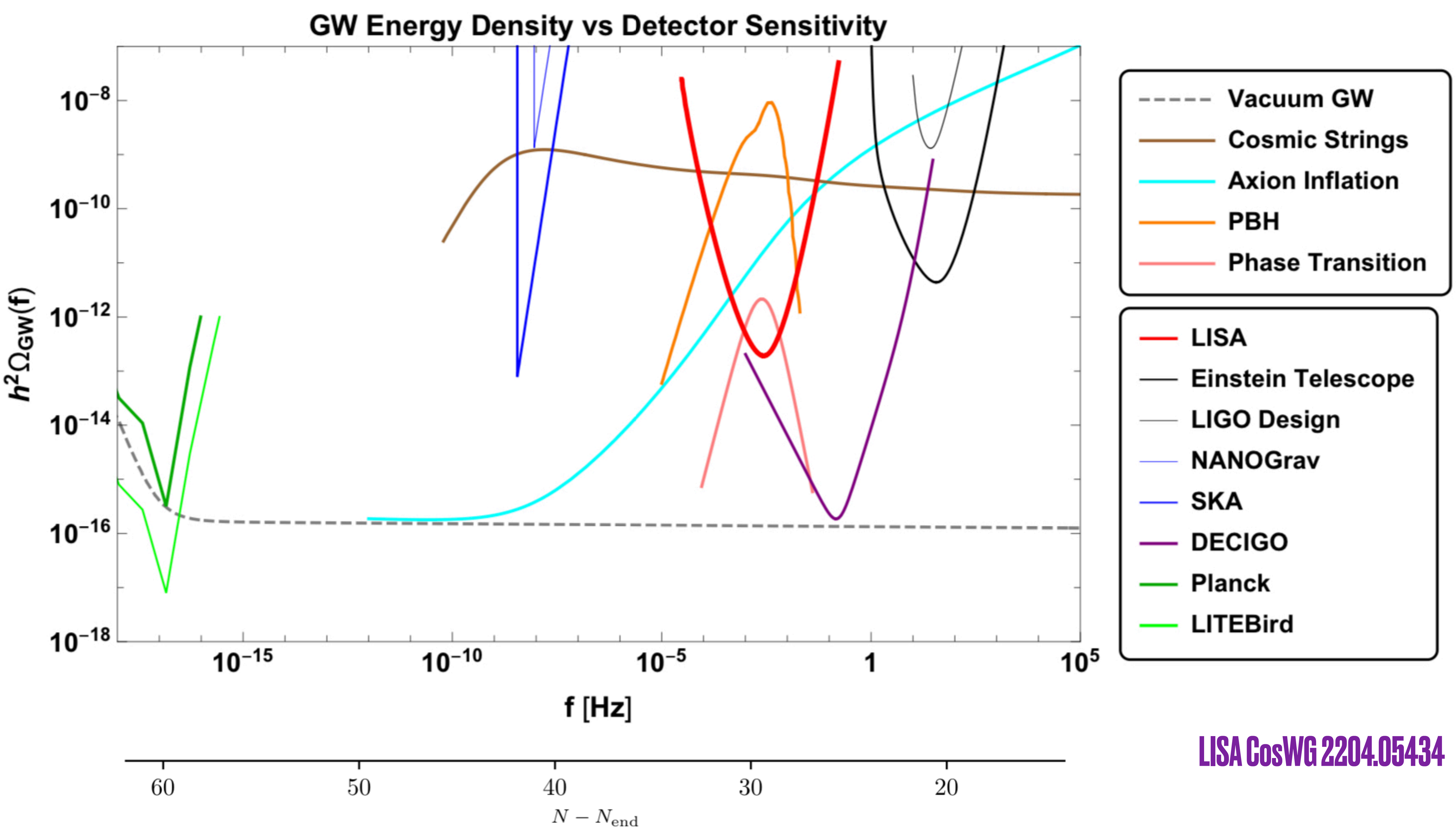
STOCHASTIC GRAVITATIONAL WAVE BACKGROUNDS



LISA CosWG 2204.05434

SURVEY INFLATIONARY MODELS

↓

GROUP THEM ACCORDING TO THE SPECTRAL SHAPE OF $\Omega_{\rm GW}(f)$

↓

BUILD A TEMPLATE BANK

↓

FORECAST CONSTRAINTS ON TEMPLATES

↓

DRAW CONCLUSIONS ABOUT EARLY UNIVERSE PHYSICS

DATA & ANALYSIS PIPELINE

MEASURING A BACKGROUND WITH LISA

Data:

$$\tilde{d}_i(f) = \int_{-T/2}^{T/2} d_i(t)\, \mathrm{e}^{-2\pi i f t}\, \mathrm{d}t$$

MEASURING A BACKGROUND WITH LISA

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$$\tilde{d}_i(f) = \int_{-T/2}^{T/2} d_i(t)\, \mathrm{e}^{-2\pi i f t}\, \mathrm{d}t$$

Channel *i*

MEASURING A BACKGROUND WITH LISA

Data:

$$\tilde{d}_i(f) = \int_{-T/2}^{T/2} d_i(t)\, \mathrm{e}^{-2\pi i f t}\, \mathrm{d}t$$

Observation time

MEASURING A BACKGROUND WITH LISA

Data:

$$\tilde{d}_i(f) = \int_{-T/2}^{T/2} d_i(t)\, \mathrm{e}^{-2\pi i f t}\, \mathrm{d}t$$

Time domain data stream

MEASURING A BACKGROUND WITH LISA

Data:

$$\tilde{d}_i(f) = \int_{-T/2}^{T/2} d_i(t)\, \mathrm{e}^{-2\pi i f t}\, \mathrm{d}t = \sum_{\nu} \tilde{n}_i^{\nu}(f) + \sum_{\sigma} \tilde{s}_i^{\sigma}(f)$$

Assumption 1: **only stochastic components.**

Transients, deterministic sources and glitches are removed

MEASURING A BACKGROUND WITH LISA

Data:

$$\tilde{d}_i(f) = \int_{-T/2}^{T/2} d_i(t)\, \mathrm{e}^{-2\pi i f t}\, \mathrm{d}t \;= \sum_{\nu} \tilde{n}_i^{\nu}(f) + \sum_{\sigma} \tilde{s}_i^{\sigma}(f)$$

Assumptions: only stochastic

MEASURING A BACKGROUND WITH LISA

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Instrumental noise **GW signal**

Assumptions: only stochastic

MEASURING A BACKGROUND WITH LISA

Data:

$$\tilde{d}_i(f) = \int_{-T/2}^{T/2} d_i(t)\, \mathrm{e}^{-2\pi i f t}\, \mathrm{d}t \;= \sum_{\nu} \tilde{n}_i^{\nu}(f) + \sum_{\sigma} \tilde{s}_i^{\sigma}(f)$$

$i = 1,2,3$ → X, Y, Z →

$$\mathrm{A} = \frac{\mathrm{Z} - \mathrm{X}}{\sqrt{2}}\,,$$

$$\mathrm{E} = \frac{\mathrm{X} - 2\mathrm{Y} + \mathrm{Z}}{\sqrt{6}}\,,$$

$$\mathrm{T} = \frac{\mathrm{X} + \mathrm{Y} + \mathrm{Z}}{\sqrt{3}}$$

TDI variables

Orthogonal channels

Assumptions: only stochastic

MEASURING A BACKGROUND WITH LISA

Data:

$$\tilde{d}_i(f) = \int_{-T/2}^{T/2} d_i(t)\, \mathrm{e}^{-2\pi i f t}\, \mathrm{d}t \;= \sum_{\nu} \tilde{n}_i^{\nu}(f) + \sum_{\sigma} \tilde{s}_i^{\sigma}(f)$$

(Implicit) assumption 2: equilateral geometry and equal noise in each spacecraft. (See Hartwig et al 2303.15929 for a paper relaxing these assumptions)

Assumptions: only stochastic

MEASURING A BACKGROUND WITH LISA

Data:

$$\tilde{d}_i(f) = \int_{-T/2}^{T/2} d_i(t)\, \mathrm{e}^{-2\pi i f t}\, \mathrm{d}t \;= \sum_{\nu} \tilde{n}_i^{\nu}(f) + \sum_{\sigma} \tilde{s}_i^{\sigma}(f)$$

Properties:

Assumption 3: noise and signals are

Gaussian and stationary.

The signal is also assumed to be isotropic

and non-chiral.

Assumptions: only stochastic, equilateral geometry

MEASURING A BACKGROUND WITH LISA

Data:

$$\tilde{d}_i(f) = \int_{-T/2}^{T/2} d_i(t)\, \mathrm{e}^{-2\pi i f t}\, \mathrm{d}t \; = \sum_{\nu} \tilde{n}_i^{\nu}(f) + \sum_{\sigma} \tilde{s}_i^{\sigma}(f)$$

Properties:

$$\langle \tilde{d}_i(f) \rangle = 0 \; ,$$

$$\langle \tilde{d}_i(f) \tilde{d}_j^*(f') \rangle = \frac{\delta(f - f')}{2} \left[\sum_{\nu} P_{N,ij}^{\nu}(f) + \sum_{\sigma} P_{S,ij}^{\sigma}(f) \right]$$

Assumptions: only stochastic, equilateral geometry, Gaussianity, stationarity, isotropy, no chirality.

INSTRUMENTAL NOISE

$$P_{N,ij}(f) \equiv \sum_{\nu} P^{\nu}_{N,ij}(f) = \left[T^{\rm TM}_{ij,lk}(f) S^{\rm TM}_{lk}(f) + T^{\rm OMS}_{ij,lk}(f) S^{\rm OMS}_{lk}(f)\right]$$

Assumptions: only stochastic, equilateral geometry, Gaussianity, stationarity, isotropy, no chirality.

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Transfer functions

Assumptions: only stochastic, equilateral geometry, Gaussianity, stationarity, isotropy, no chirality.

INSTRUMENTAL NOISE

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Test mass:

$$S^{\rm TM}_{lk}(f) = A^2_{lk} \left(1 + \left(\frac{0.4\mathrm{mHz}}{f}\right)^2\right)\left(1 + \left(\frac{f}{8\mathrm{mHz}}\right)^4\right)\left(\frac{1}{2\pi f c}\right)^2 \left(\frac{\mathrm{fm}^2}{\mathrm{s}^3}\right)$$

Optical metrology system:

$$S^{\rm OMS}_{lk}(f) = P^2_{lk} \left(1 + \left(\frac{2\times 10^{-3}\mathrm{Hz}}{f}\right)^4\right) \times \left(\frac{2\pi f}{c}\right)^2 \times \left(\frac{\mathrm{pm}^2}{\mathrm{Hz}}\right)$$

Assumptions: only stochastic, equilateral geometry, Gaussianity, stationarity, isotropy, no chirality.

INSTRUMENTAL NOISE

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<u>**Test mass**</u>:

$$S^{\rm TM}_{lk}(f) = A^2_{lk} \left(1 + \left(\frac{0.4\,{\rm mHz}}{f}\right)^2\right)\left(1 + \left(\frac{f}{8\,{\rm mHz}}\right)^4\right)\left(\frac{1}{2\pi f c}\right)^2 \left(\frac{{\rm fm}^2}{{\rm s}^3}\right)$$

<u>**Optical metrology system**</u>:

$$S^{\rm OMS}_{lk}(f) = P^2_{lk} \left(1 + \left(\frac{2\times 10^{-3}\,{\rm Hz}}{f}\right)^4\right) \times \left(\frac{2\pi f}{c}\right)^2 \times \left(\frac{{\rm pm}^2}{{\rm Hz}}\right)$$

<u>Assumptions</u>: only stochastic, equilateral geometry, Gaussianity, stationarity, isotropy, no chirality.

SIGNAL

$$h^2\Omega_{\rm GW}(f) \equiv \frac{4\pi^2 f^3}{3H_0^2} S_h(f)$$

$$P_{S,ij}(f) \equiv \sum_\sigma P^\sigma_{S,ij}(f) = \mathcal{R}_{ij}(f)\left[S_{\rm Gal}(f) + S_{\rm Ext}(f) + S_{\rm Cosmo}(f)\right]$$

Galactic:

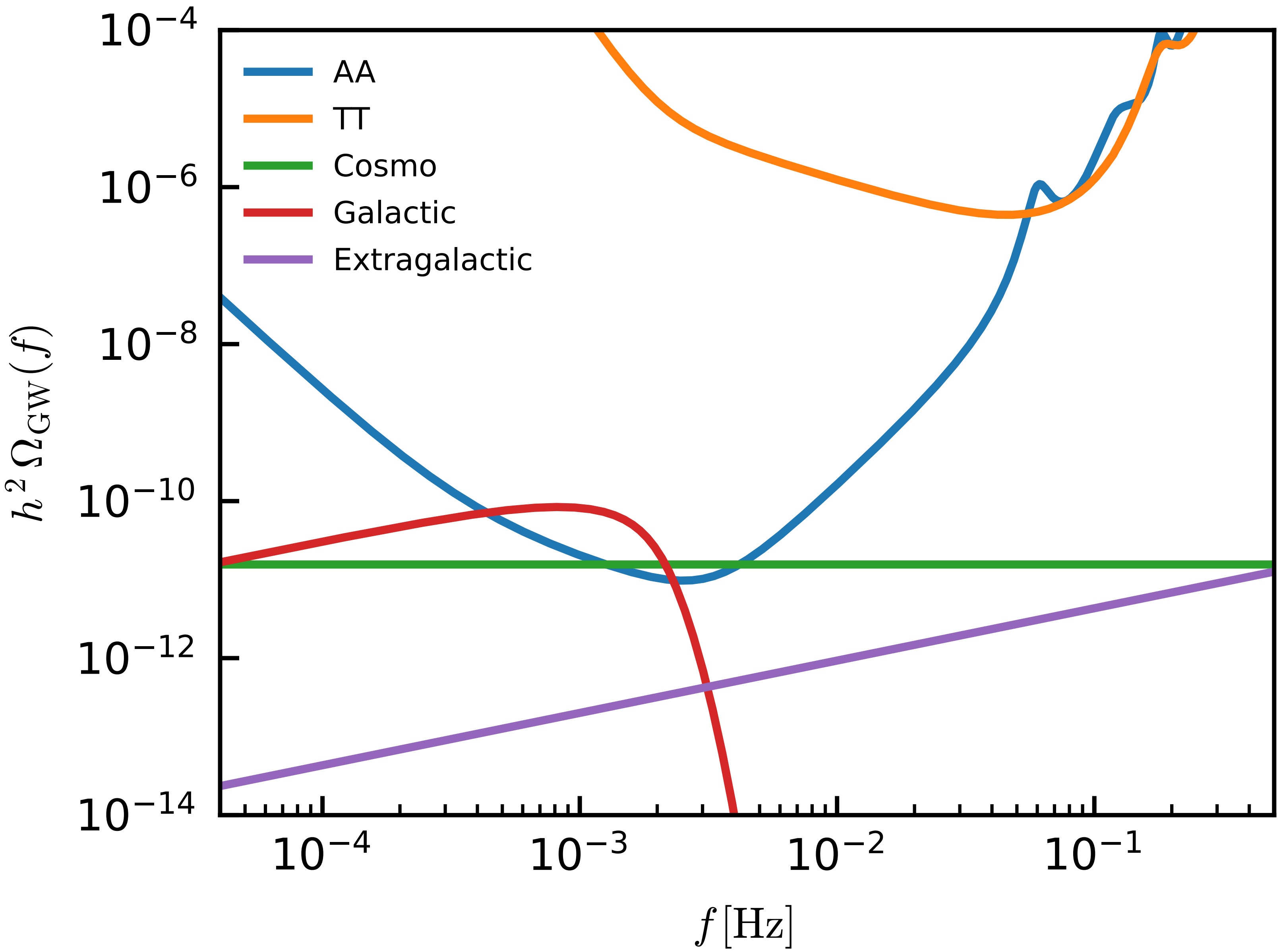
$$S_{\rm Gal}(f) = A_{\rm Gal}\left(\frac{f}{1\,{\rm Hz}}\right)^{-\frac{7}{3}} \times e^{-(f/f_1)^\alpha} \times \frac{1}{2}\left[1 + \tanh\frac{f_{\rm knee} - f}{f_2}\right]$$

Extragalactic :

$$h^2\Omega_{\rm Ext} = 10^{\log_{10}(h^2\Omega_{\rm Ext})}\left(\frac{f}{0.001{\rm H}z}\right)^{2/3}$$

Assumptions: only stochastic, equilateral geometry, Gaussianity, stationarity, isotropy, no chirality.

SIGNAL AND NOISE IN THE LISA BAND



Assumptions: only stochastic, equilateral geometry, Gaussianity, stationarity, isotropy, no chirality.

LIKELIHOOD

Divide full data stream into N_d segments, each lasting $T_{\rm obs}/N_d$.

$$T_{\rm obs}/N_d \sim 11.5\,\text{days} \mapsto \Delta f \sim 10^{-6}\,\text{Hz}$$

Assumption 4: $T_{\rm obs} = $ **4 years**

Assumptions: only stochastic, equilateral geometry, Gaussianity, stationarity, isotropy, no chirality.

LIKELIHOOD

Divide full data stream into N_d segments, each lasting $T_{\rm obs}/N_d$.

Generate N_d Gaussian realizations of noise and data.

Assumptions: only stochastic, equilateral geometry, Gaussianity, stationarity, isotropy, no chirality, 4 years data.

LIKELIHOOD

Divide full data stream into N_d segments, each lasting $T_{\rm obs}/N_d$.

Generate N_d Gaussian realizations of noise and data.

Average over realizations $\bar{D}^{\rm k}_{ij} \equiv \sum_{s=1}^{N_d} \tilde{d}_i^s(f_{\rm k})\tilde{d}_j^s(f_{\rm k})/N_d$

Assumptions: only stochastic, equilateral geometry, Gaussianity, stationarity, isotropy, no chirality, 4 years data.

LIKELIHOOD

Divide full data stream into N_d segments, each lasting $T_{\rm obs}/N_d$.

Generate N_d Gaussian realizations of noise and data.

Average over realizations $\bar{D}^{\rm k}_{ij} \equiv \sum_{s=1}^{N_d} \tilde{d}^s_i(f_{\rm k})\tilde{d}^s_j(f_{\rm k})/N_d$

Down sample data by coarse-graning $\bar{D}^k_{ij} \mapsto D^k_{ij}$

<u>Assumptions</u>: only stochastic, equilateral geometry, Gaussianity, stationarity, isotropy, no chirality, 4 years data.

LIKELIHOOD

$$\ln \mathcal{L}(\vec{\theta}) = \frac{1}{3} \ln \mathcal{L}_{\rm G}(\vec{\theta}|D^k_{ij}) + \frac{2}{3} \ln \mathcal{L}_{\rm LN}(\vec{\theta}|D^k_{ij})$$

$$\ln \mathcal{L}_{\rm G}(\vec{\theta}|D^k_{ij}) = -\frac{N_d}{2} \sum_k \sum_{i,j} w^k_{ij} \left[1 - D^k_{ij}/D^{\rm Th}_{ij}(f^k_{ij}, \vec{\theta})\right]^2$$

$$\ln \mathcal{L}_{{\rm L}N}(\vec{\theta}|D^k_{ij}) = -\frac{N_d}{2} \sum_k \sum_{i,j} w^k_{ij} \ln^2 \left[D^{\rm Th}_{ij}(f^k_{ij}, \vec{\theta})/D^k_{ij}\right]$$

Assumptions: only stochastic, equilateral geometry, Gaussianity, stationarity, isotropy, no chirality, 4 years data.

LIKELIHOOD

$$\ln \mathcal{L}(\vec{\theta}) = \frac{1}{3} \ln \mathcal{L}_{\mathrm{G}}(\vec{\theta}|D_{ij}^k) + \frac{2}{3} \ln \mathcal{L}_{\mathrm{LN}}(\vec{\theta}|D_{ij}^k)$$

$$\ln \mathcal{L}_{\mathrm{G}}(\vec{\theta}|D_{ij}^k) = -\frac{N_d}{2} \sum_k \sum_{i,j} w_{ij}^k \left[1 - D_{ij}^k / D_{ij}^{\mathrm{T}h}(f_{ij}^k, \vec{\theta})\right]^2$$

$$\ln \mathcal{L}_{\mathrm{L}N}(\vec{\theta}|D_{ij}^k) = -\frac{N_d}{2} \sum_k \sum_{i,j} w_{ij}^k \ln^2 \left[D_{ij}^{\mathrm{T}h}(f_{ij}^k, \vec{\theta}) / D_{ij}^k\right]$$

$$\vec{\theta} = \{A, P, \Omega_{\mathrm{gal}}, \Omega_{\mathrm{ext}}, \vec{\theta}_{\mathrm{Inf}}\}$$

Assumptions: only stochastic, equilateral geometry, Gaussianity, stationarity, isotropy, no chirality, 4 years data.

LIKELIHOOD

$$\ln \mathcal{L}(\vec{\theta}) = \frac{1}{3} \ln \mathcal{L}_{\mathrm{G}}(\vec{\theta}|D_{ij}^k) + \frac{2}{3} \ln \mathcal{L}_{\mathrm{LN}}(\vec{\theta}|D_{ij}^k)$$

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$$\vec{\theta} = \{A, P, \Omega_{\mathrm{gal}}, \Omega_{\mathrm{ext}}, \vec{\theta}_{\mathrm{Inf}}\}$$

Assumption 5: Gaussian priors on noise and foregrounds

Assumptions: only stochastic, equilateral geometry, Gaussianity, stationarity, isotropy, no chirality, 4 years data.

TEMPLATE BANK FOR INFLATIONARY MODELS & FORECASTS

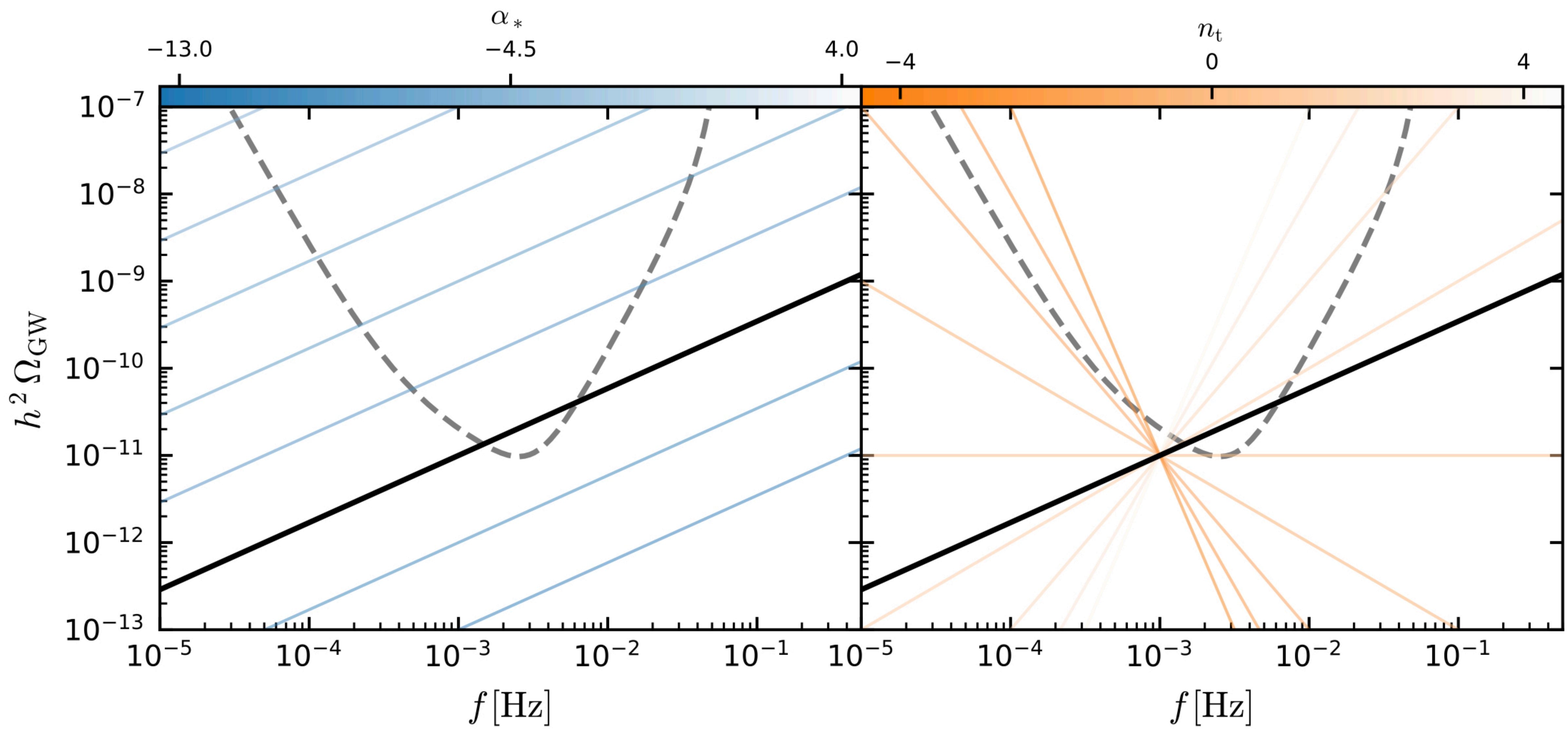
TEMPLATE BANK FOR INFLATIONARY MODELS & FORECASTS

1. POWER LAW
2. LOGNORMAL BUMP
3. BROKEN POWER LAW
4. DOUBLE PEAK
5. EXCITED STATES
6. LINEAR OSCILLATIONS
7. LOGARITHMIC OSCILLATIONS

POWER LAW

TEMPLATE DEFINITION

$$h^2\Omega_{\rm GW}^{\rm PL}(f,\vec{p}) = 10^{\alpha_*}\left(\frac{f}{f_*}\right)^{n_t} \qquad \vec{p} = \{\alpha_*, f_*, n_t\}$$



INFLATIONARY MODELS PRODUCING THE SIGNAL

Axion inflation:

Barnaby & Peloso 1011.1500, Sorbo 1101.1525

The inflaton is an axion coupled to a gauge field through an axial interaction. The rolling axion strongly amplifies the gauge field, which in turn produces a strong SGWB.

$$h^2\Omega_* \simeq 1.5 \times 10^{-13} \frac{H_*^4}{M_{\rm Pl}^4} \frac{e^{4\pi\xi_*}}{\xi_*^6}$$

$$n_t \simeq -4\epsilon_* + (4\pi\xi_* - 6)(\epsilon_* - \eta_*)$$

Broken space diffeomorphisms:

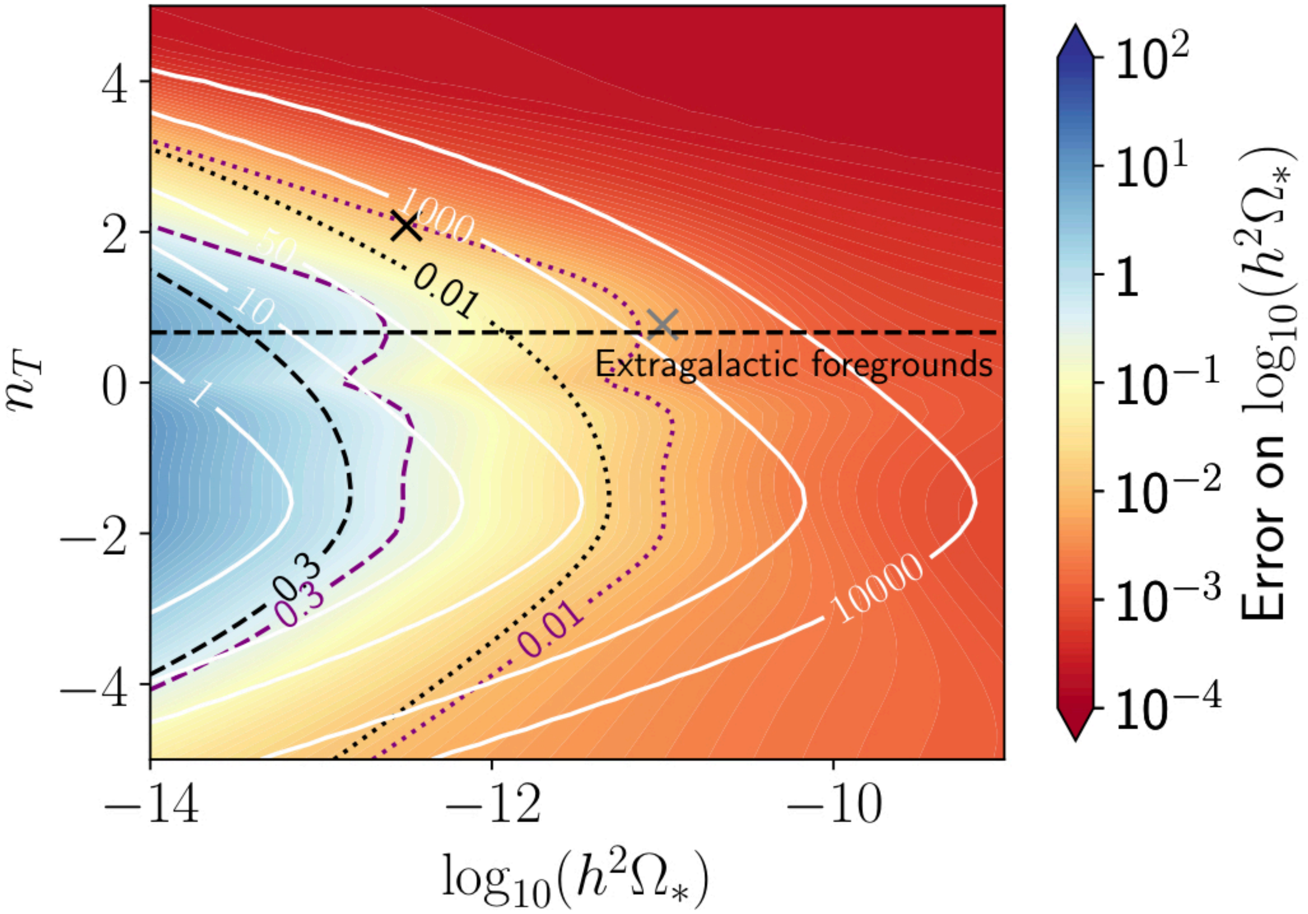
Ricciardone & Tasinato 1611.04516, 1711.02635, Fujita et al 1808.02381

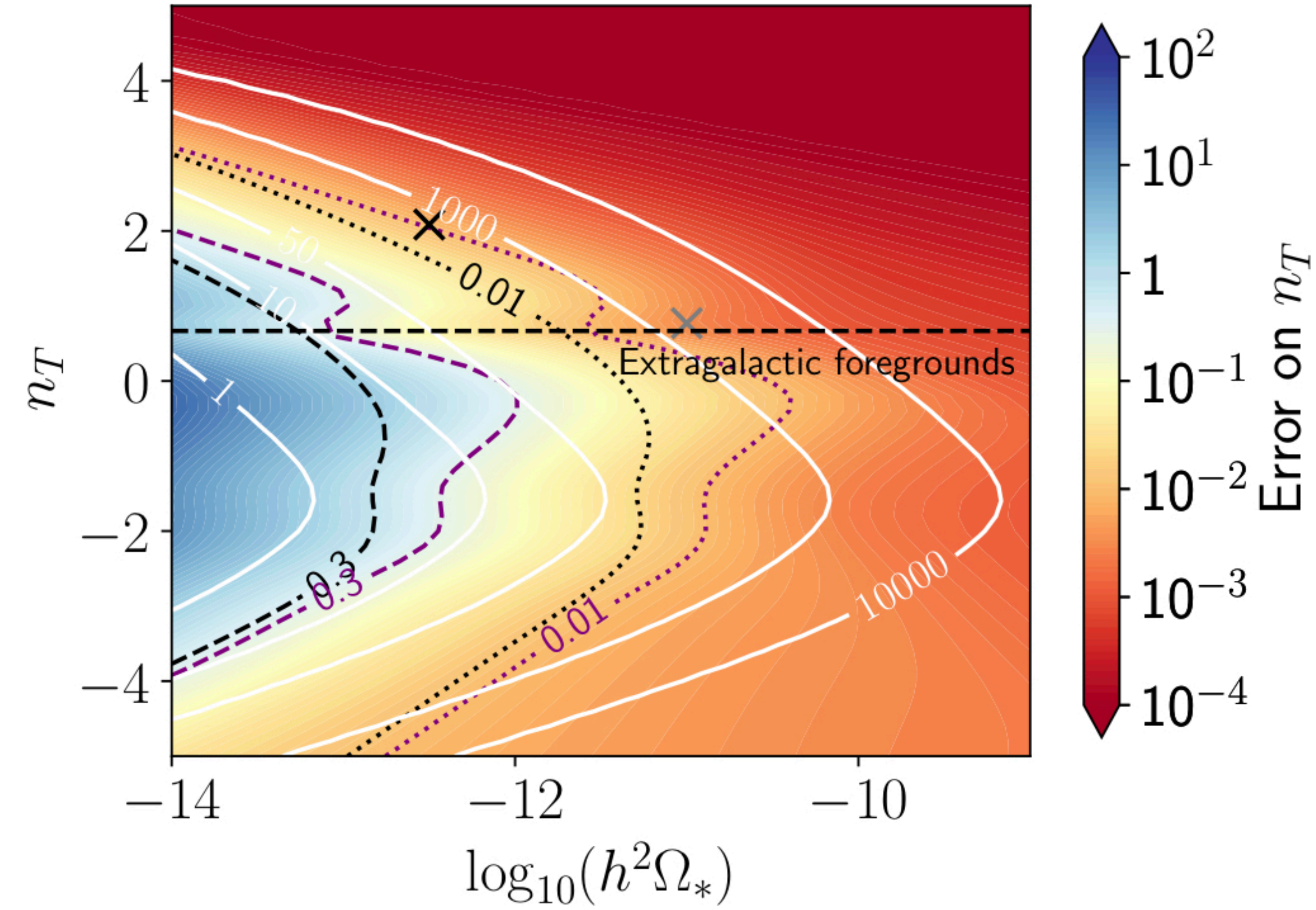
The breaking of space diffeomorphisms can give rise to a massive graviton during the inflationary epoch which tilts the SGWB spectrum towards the blue

$$h^2\Omega_* = \text{Model dependent}$$

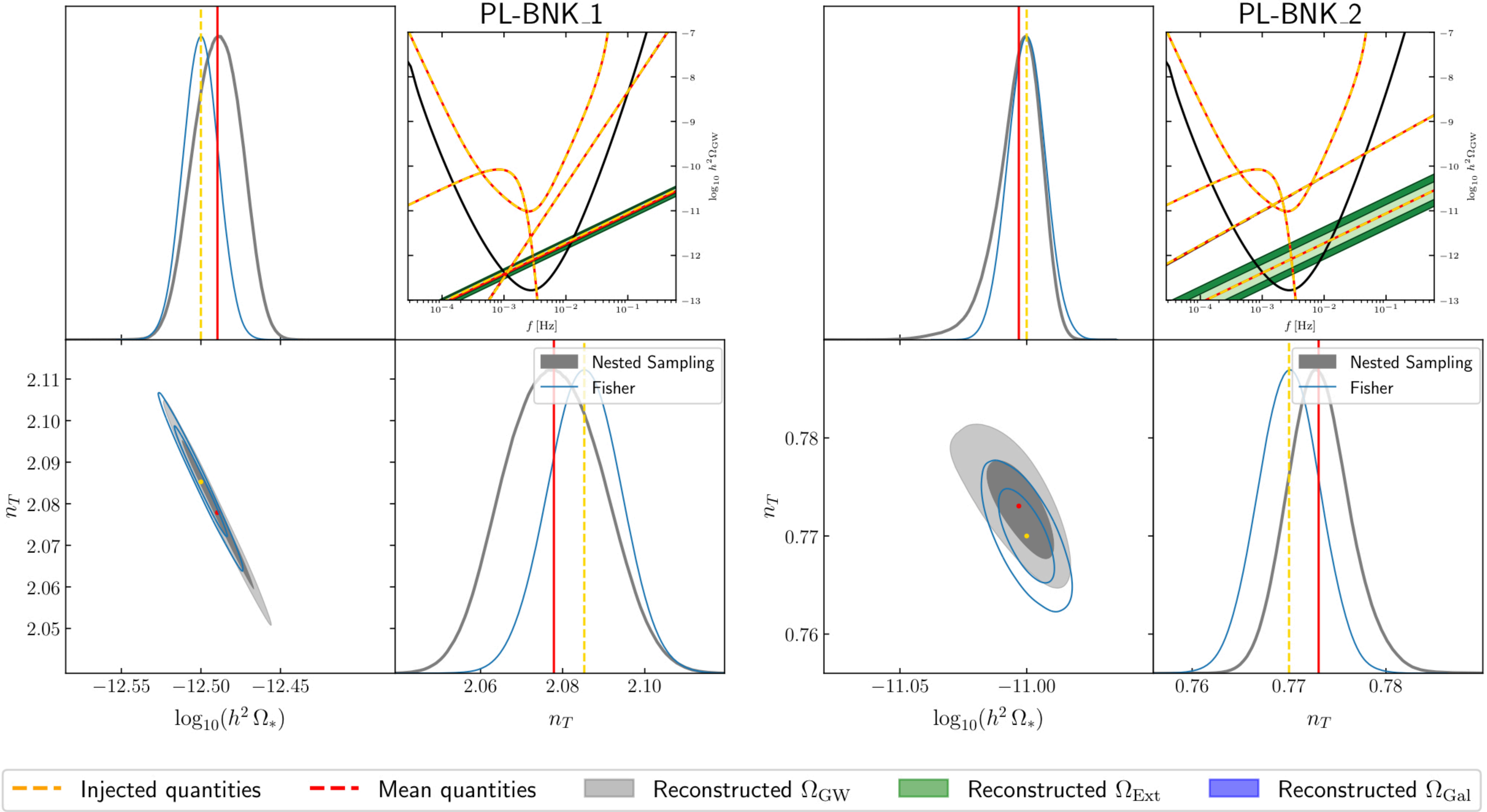
$$n_t \simeq \frac{2}{3}\frac{m_h^2}{H_*^2} > 0$$

FORECASTS (FISHER)

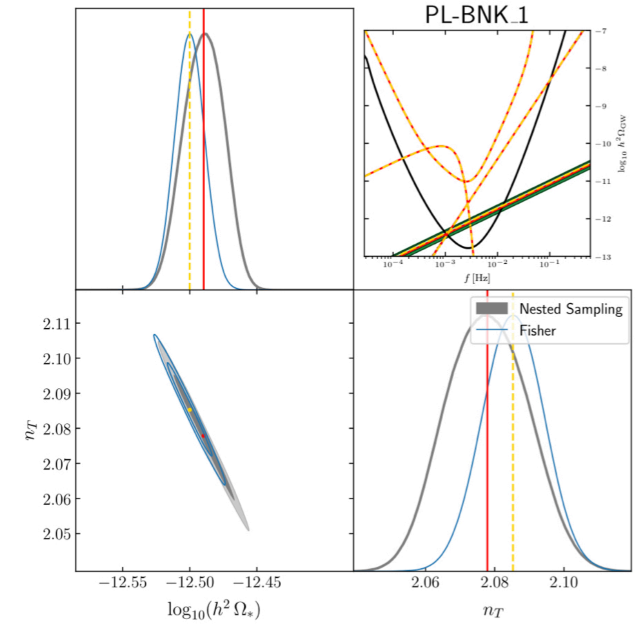




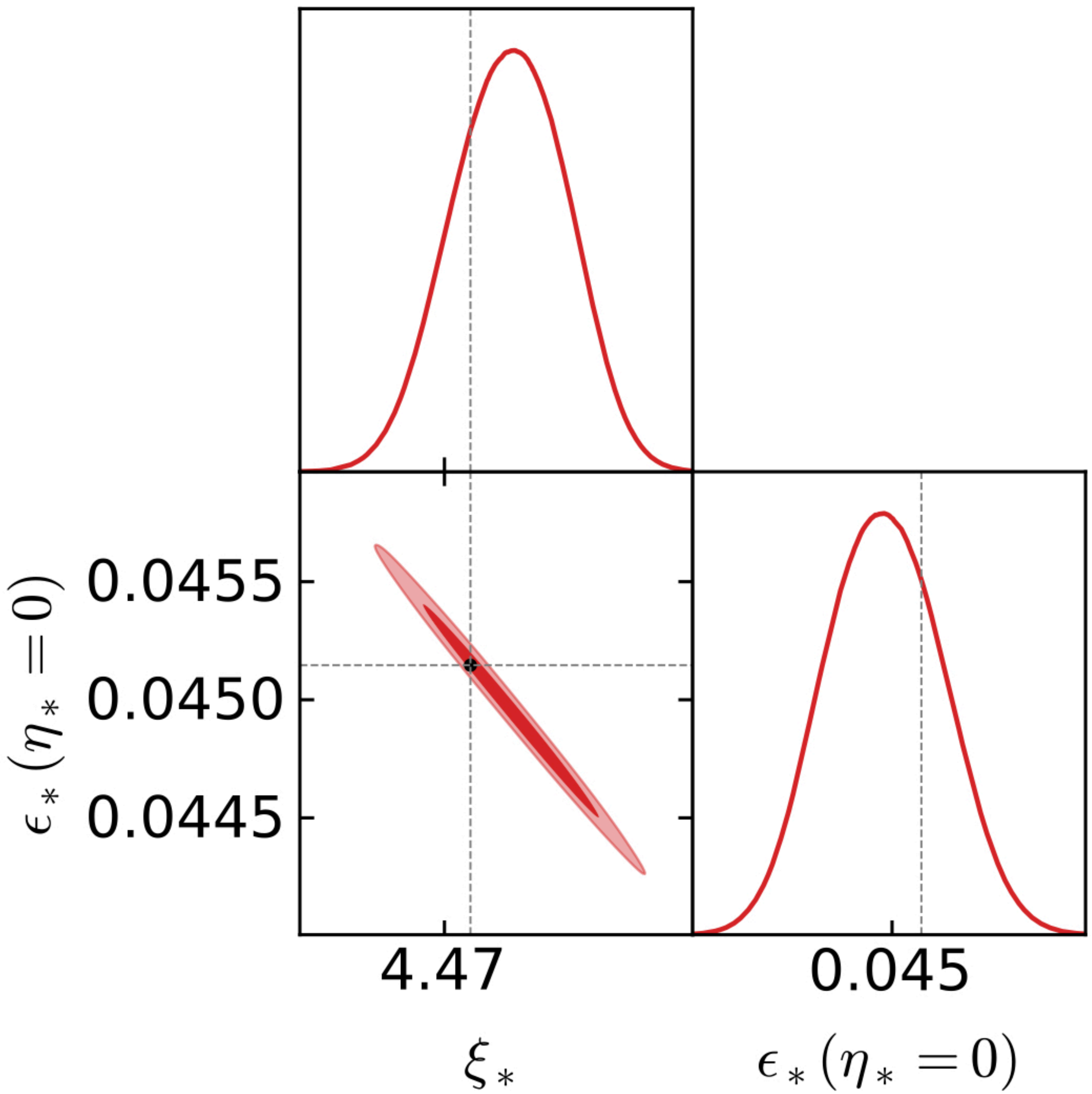
FORECASTS (NESTED SAMPLING)



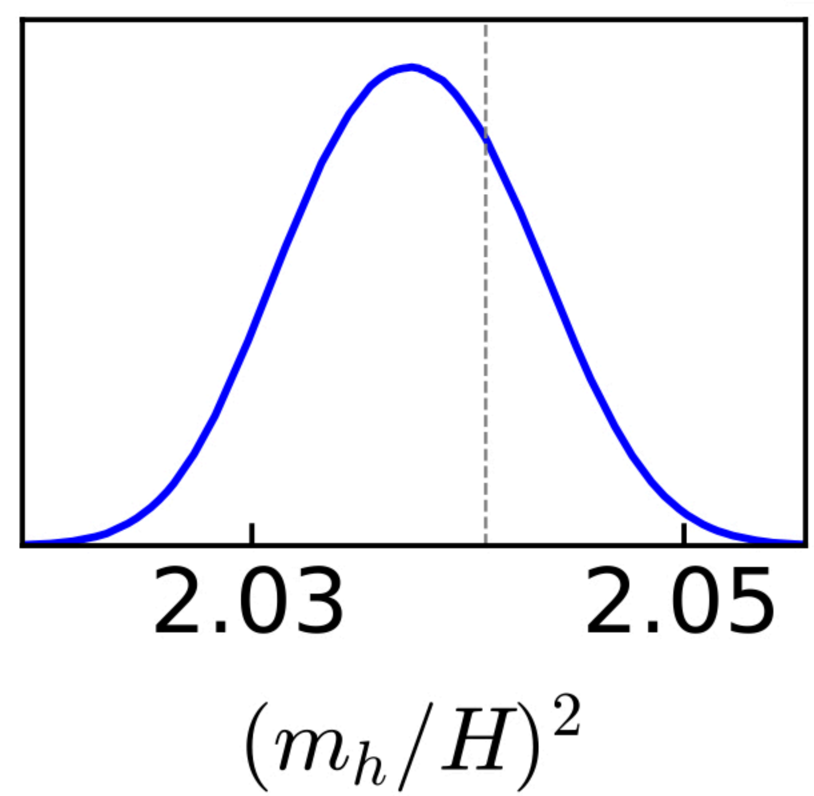
FORECASTS (BNK 1)



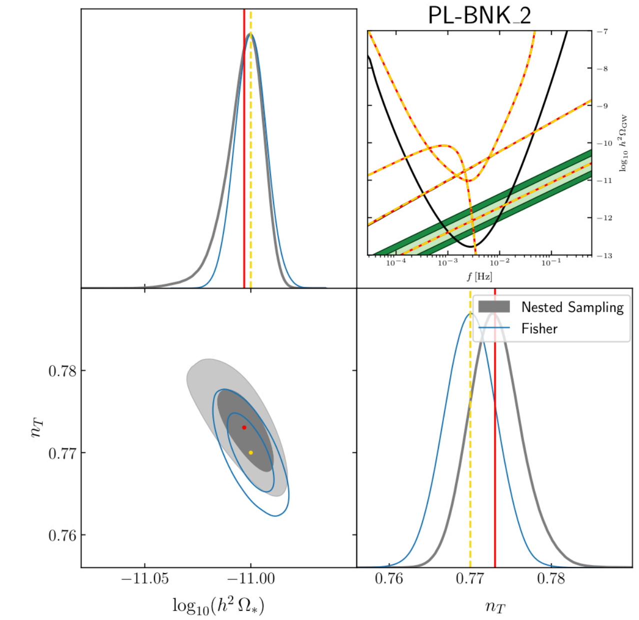
Ax Inf, PL-BNK_1

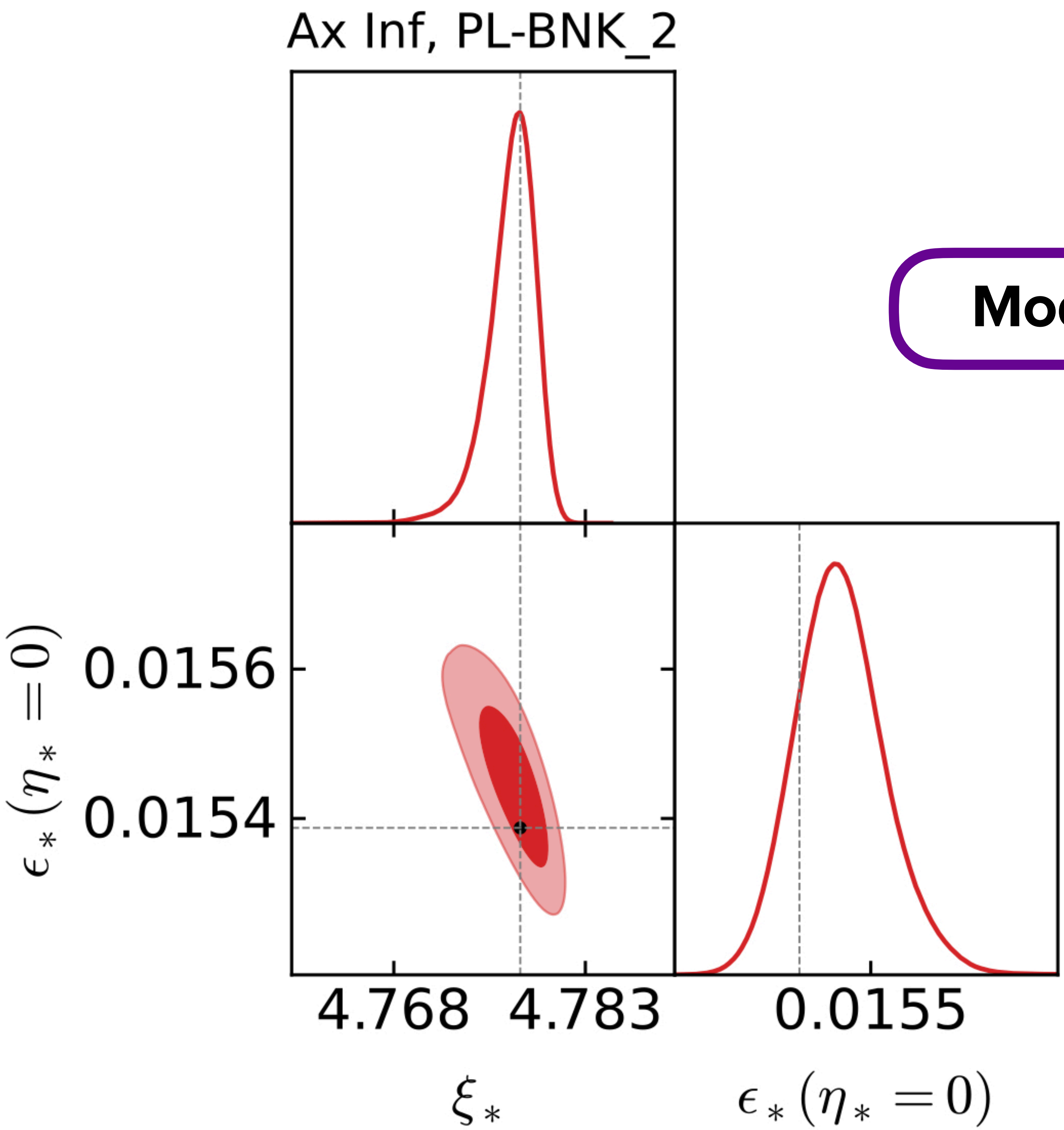


Massive Grav. PL-BNK_1

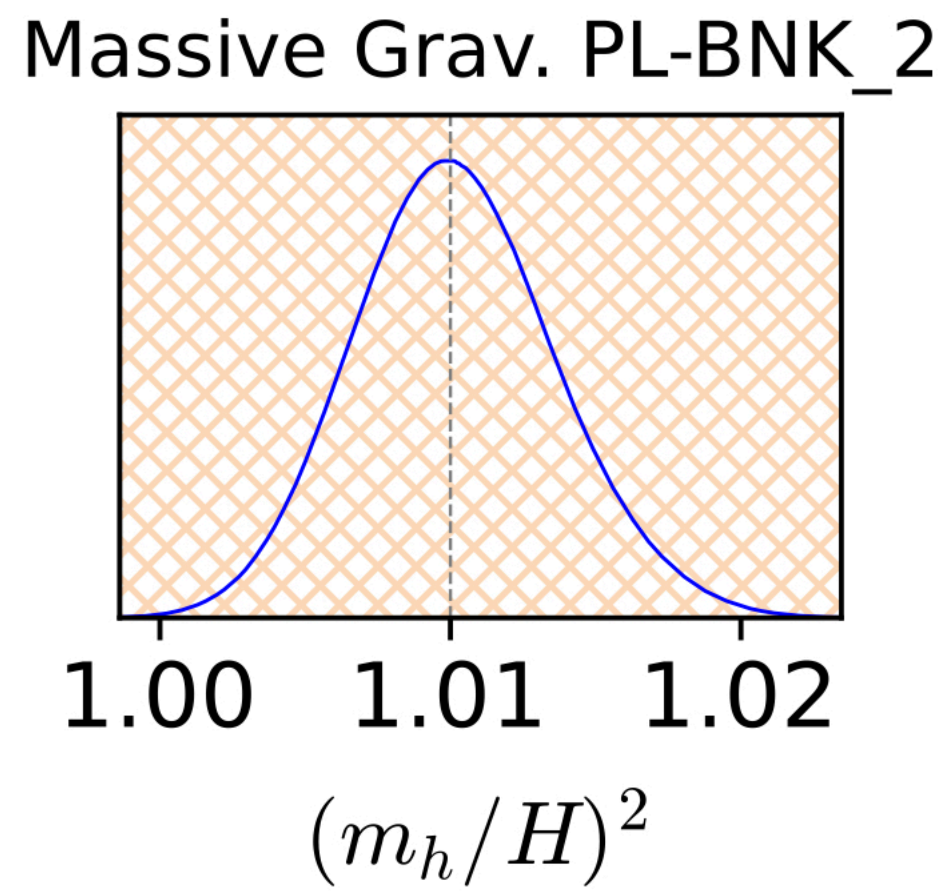


FORECASTS (BNK 2)





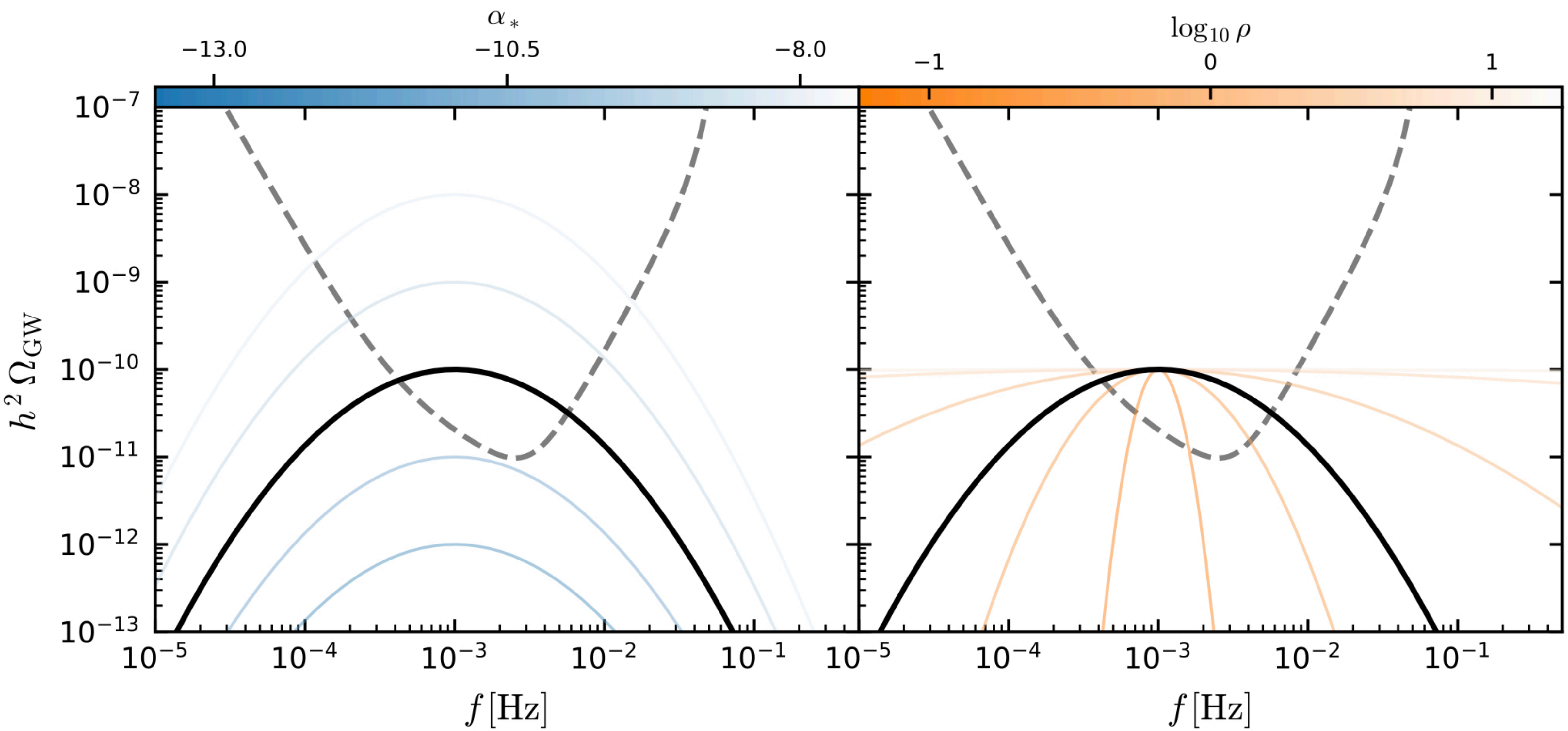
Model 2 is excluded



LOGNORMAL BUMP

TEMPLATE DEFINITION

$$h^2\Omega_{\rm GW}^{\rm LBp}(f,\vec{p}) = 10^{\alpha_*}\exp\left[-\frac{1}{2\rho^2}\,\log_{10}^2\left(\frac{f}{f_*}\right)\right] \qquad \vec{p} = \{\alpha_*, f_*, \rho\}$$



INFLATIONARY MODELS PRODUCING THE SIGNAL

Axion spectator:

Namba et al 1509.07521

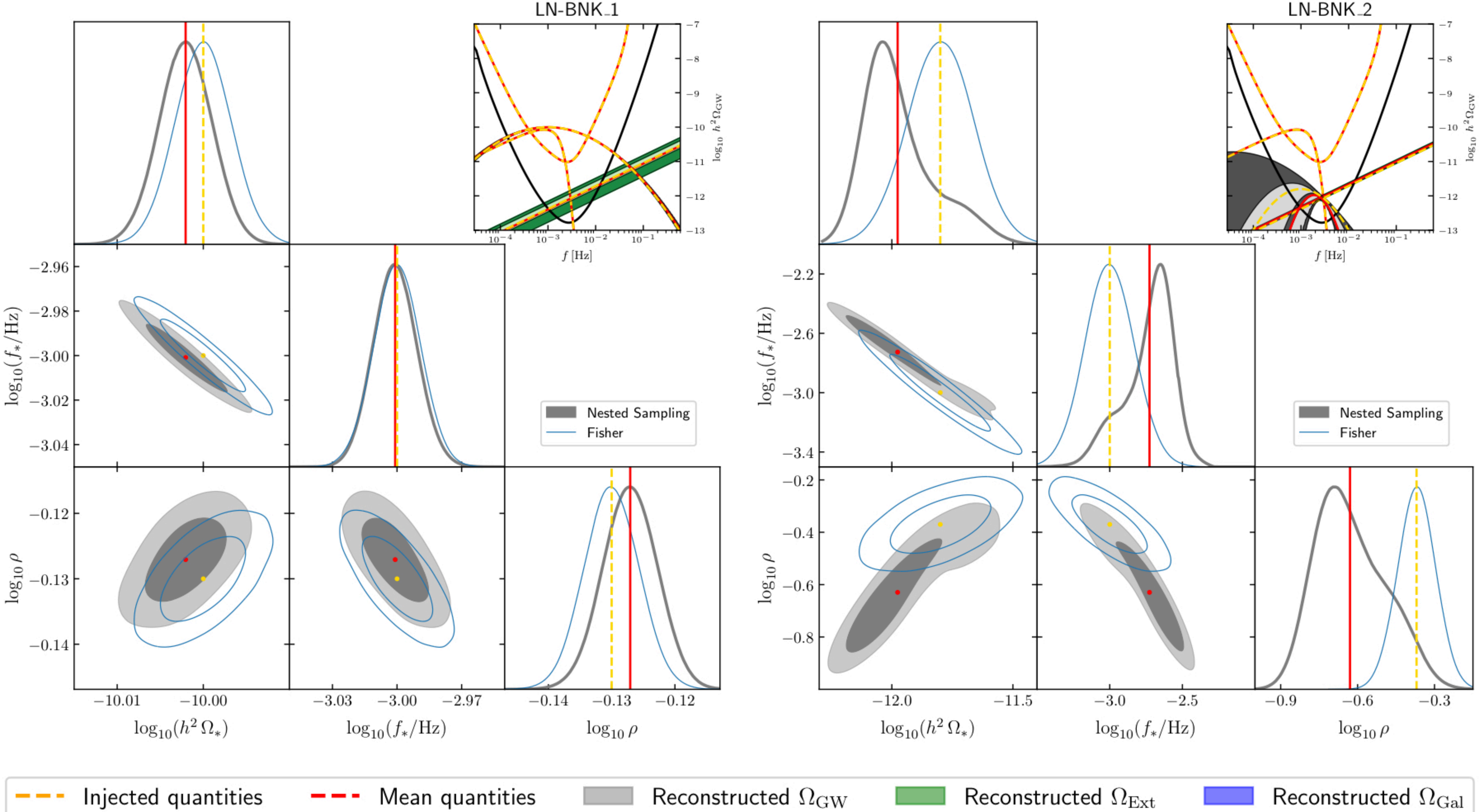
The axion coupled to a gauge field is now a spectator field rolling only for a short time ΔN.

$$h^2\Omega_* \simeq 1.5 \times 10^{-13} \, \frac{H_*^4}{M_{\rm Pl}^4} \, \frac{\mathrm{e}^{4\pi\xi_*}}{\xi_*^6}$$

$$\rho \propto \Delta N$$

$$f_* \propto a(N_*)H(N_*)$$

FORECASTS (NESTED SAMPLING)



INTERMEZZO: SCALAR-INDUCED GRAVITATIONAL WAVES

Large scalar perturbations source gravitational waves at 2nd order in perturbation theory when they re-enter the horizon during radiation era

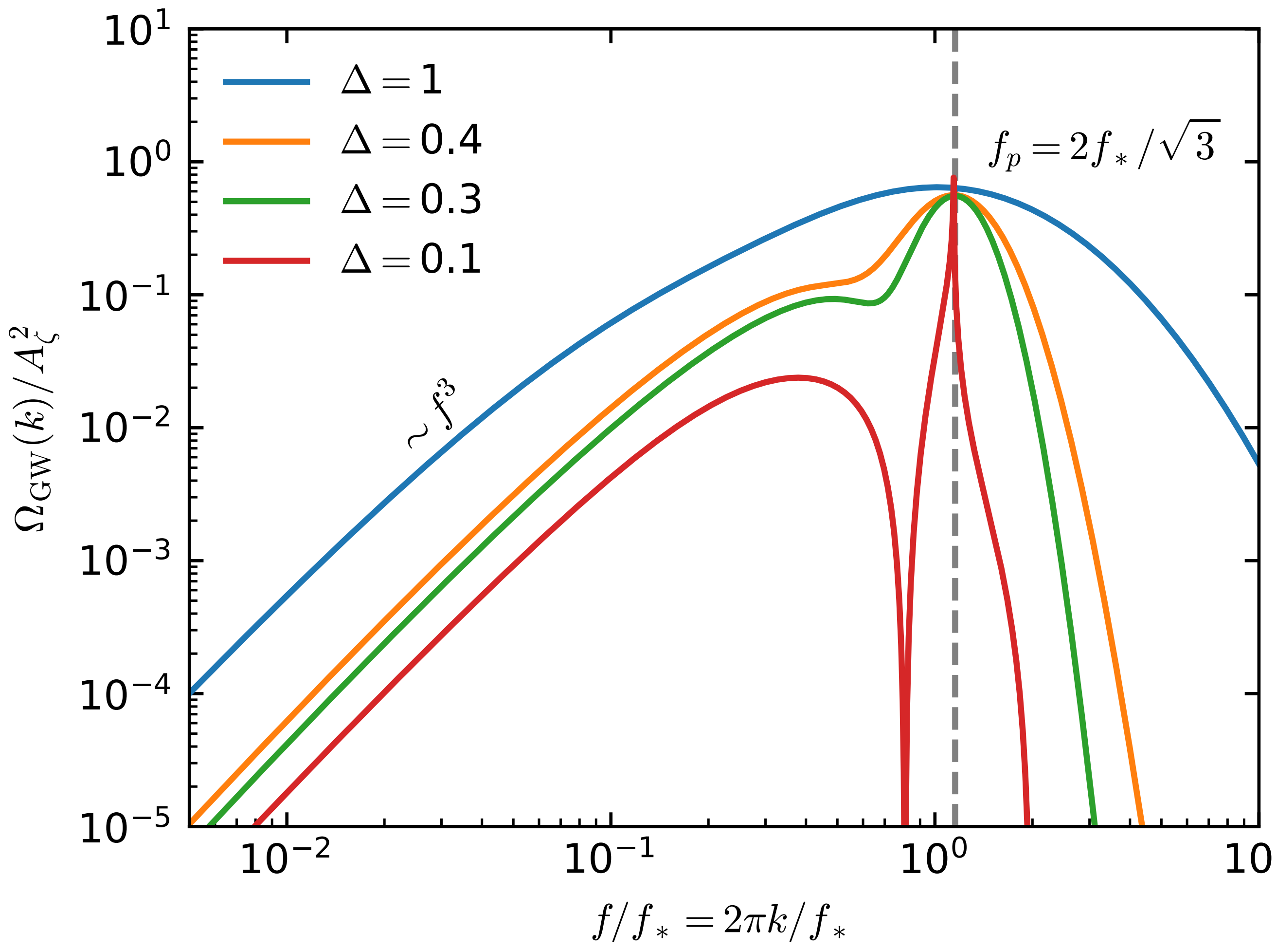
$$\Omega_{\rm ind}(k) = 0.387\,\Omega_{\rm R}\left(\frac{g_{*,s}^{4}g_{*}^{-3}}{106.75}\right)^{-\frac{1}{3}}\frac{1}{6}\int_{-1}^{1}dx\int_{1}^{\infty}dy\,\mathscr{P}\left(\frac{y-x}{2}k\right)\mathscr{P}\left(\frac{x+y}{2}k\right)F(x,y)$$

see Robert's talk and Domenech 2109.01398 for a review

SIGW FROM A LOGNORMAL $\mathscr{P}(k)$

Bumps in $\mathscr{P}(k)$ are often modeled using a Lognormal template

$$\mathscr{P}(k) = \frac{A_\zeta}{\sqrt{2\pi}\Delta} \exp\left[-\frac{\ln^2 k/k_*}{2\Delta^2}\right]$$

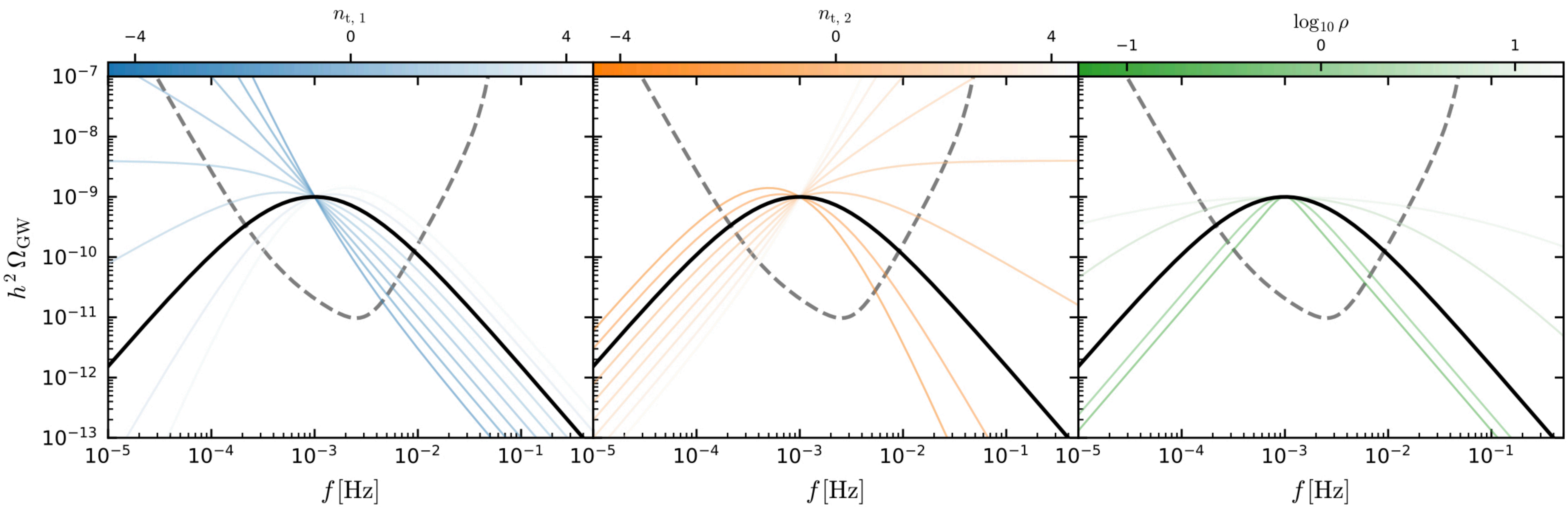


See Pi & Sasaki 2005.12306 for analytical solutions for $\Omega_{\rm GW}(f)$

BROKEN POWER LAW

TEMPLATE DEFINITION

$$h^2\Omega_{\rm GW}^{\rm BPL}(f,\vec{p}) = 10^{\alpha_*}\frac{\left(\frac{f}{f_*}\right)^{n_{t,1}}}{\left\{\frac{1}{2}\left[1+\left(\frac{f}{f_*}\right)^{1/\delta}\right]\right\}^{(n_{t,1}-n_{t,2})\delta}} \qquad \vec{p} = \{\alpha_*, f_*, n_{t,1}, n_{t,2}, \delta\}$$

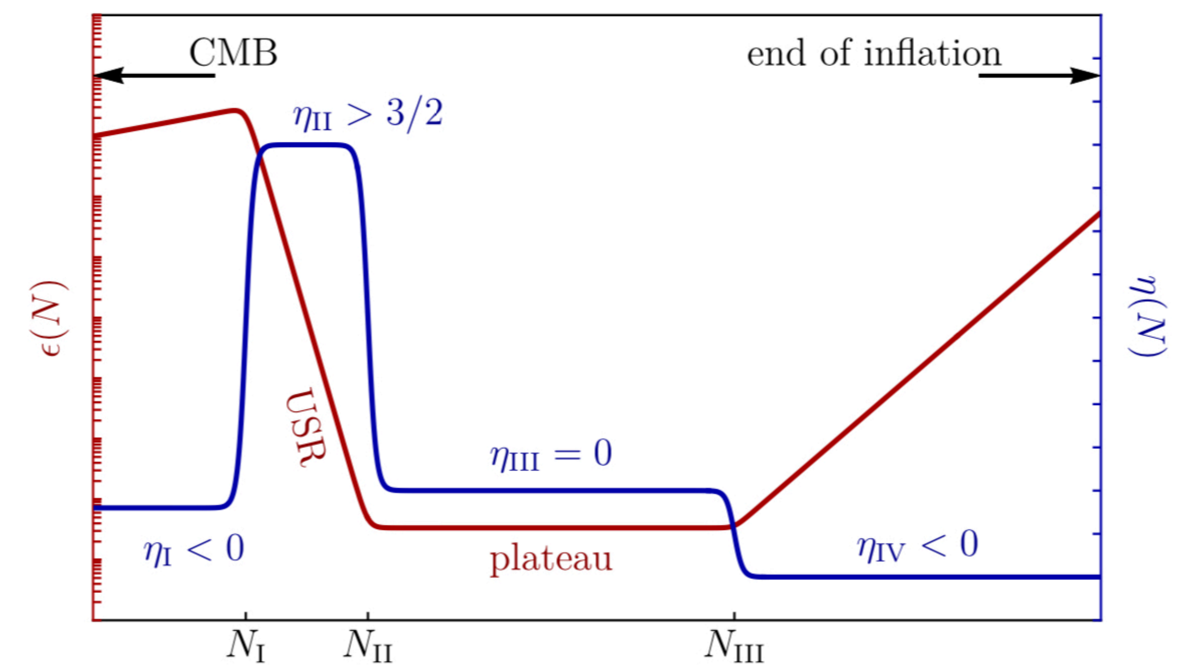


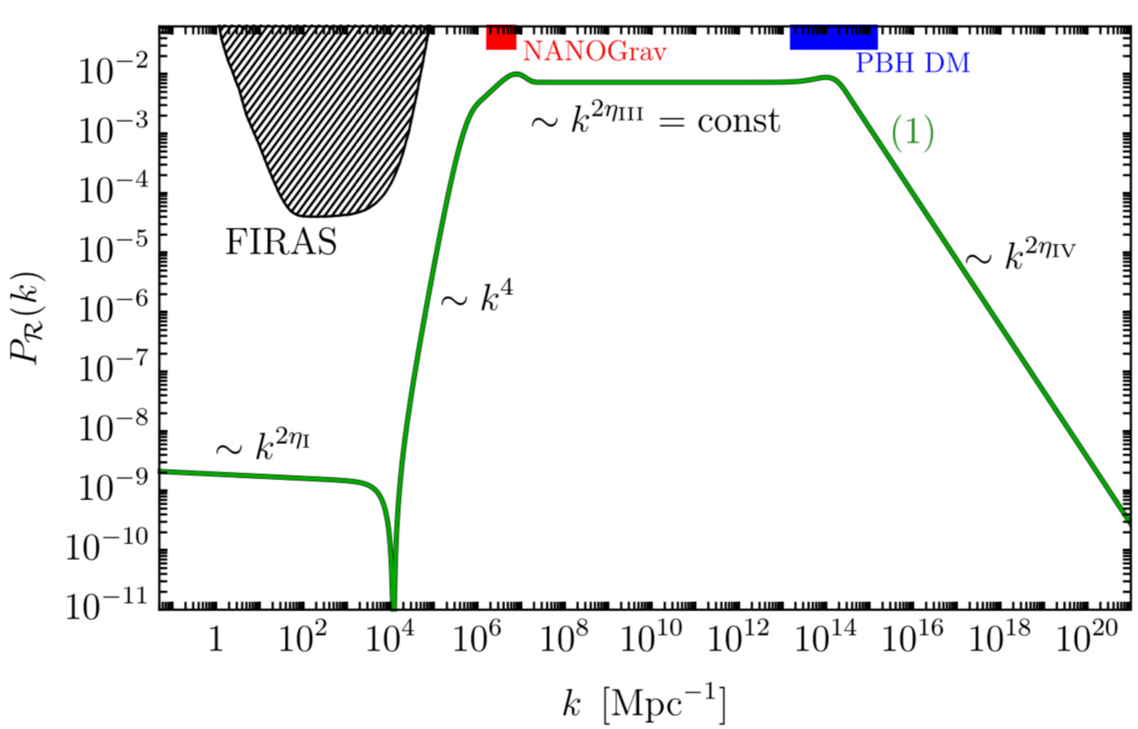
INFLATIONARY MODELS PRODUCING THE SIGNAL. MODEL 1

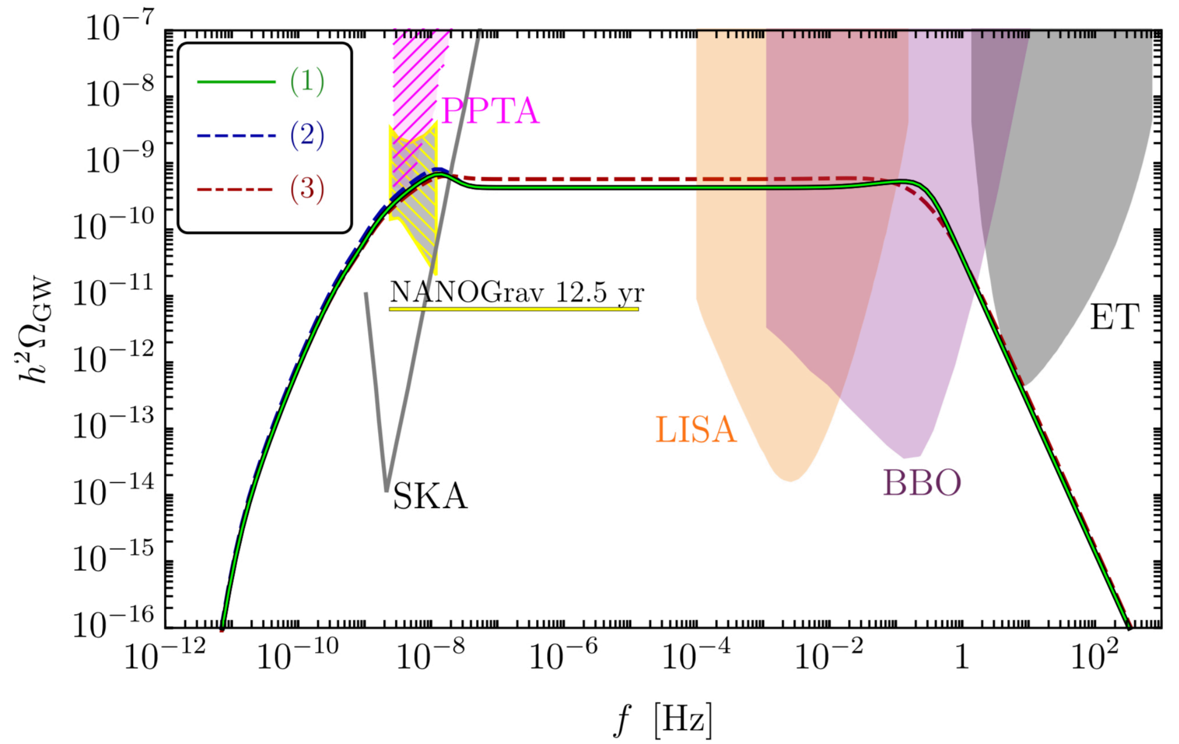
Second slow-roll stage:

Franciolini & Urbano 2207.10056

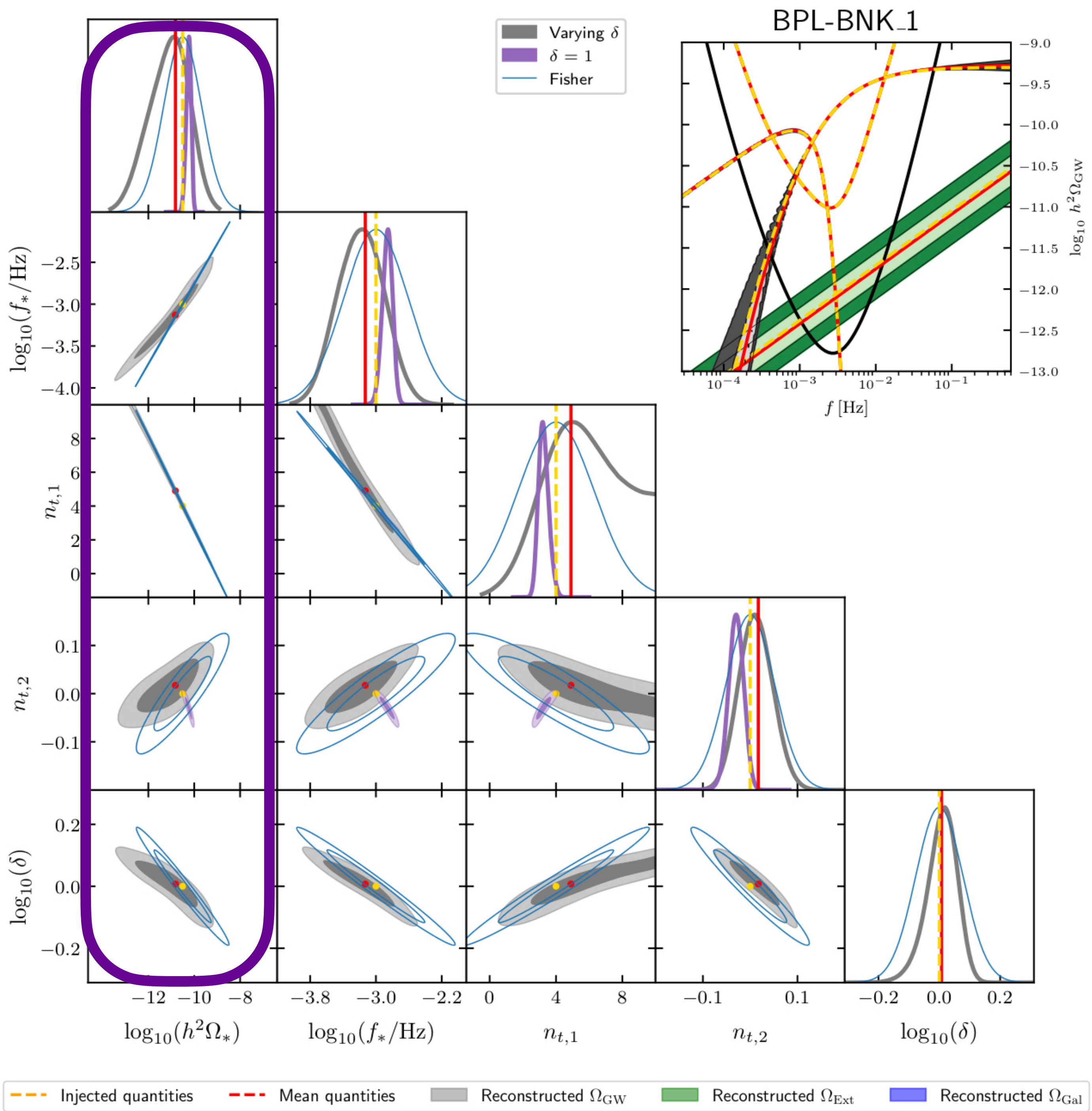
An ultra-slow-roll phase amplifies primordial scalar perturbations and is followed by a second slow-roll regime generating a plateau.





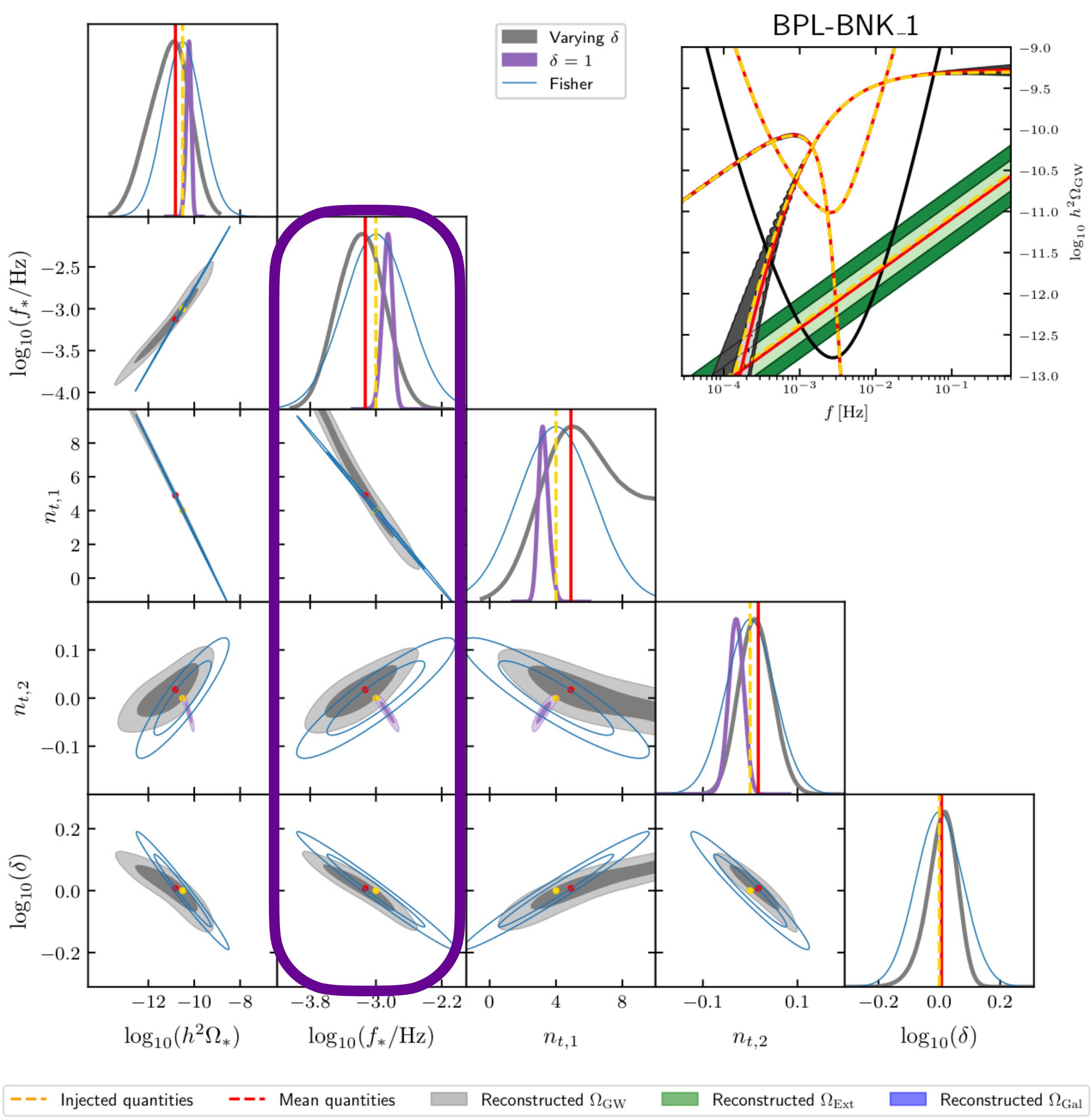


FORECAST. MODEL 1



Amplitude: ratio H^2/ϵ during the second SR stage, abundance of Primordial Black Holes $f_{\rm PBH}$.

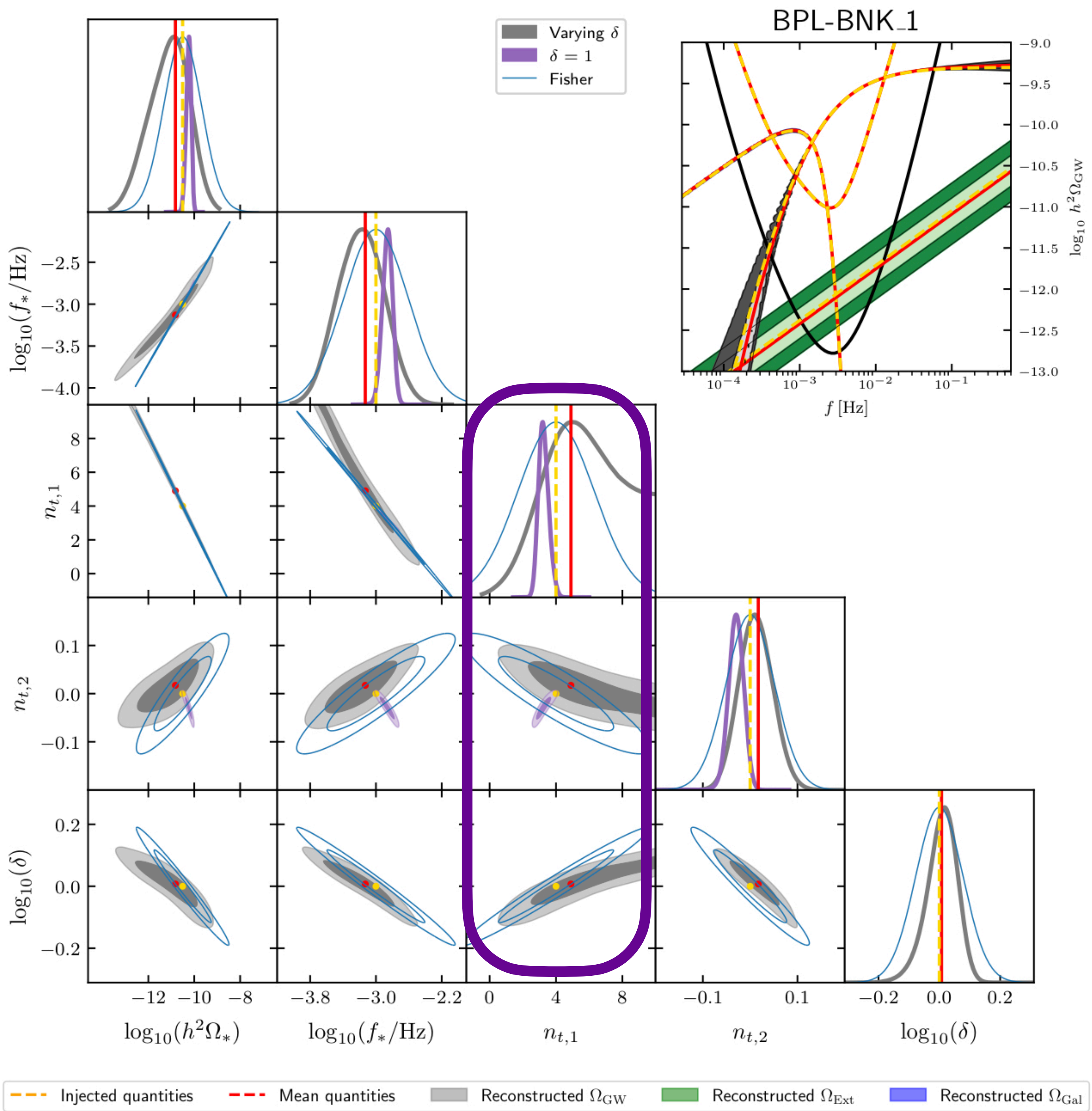
FORECAST. MODEL 1



Amplitude: ratio H^2/ϵ during the second SR stage, abundance of Primordial Black Holes $f_{\rm PBH}$.

Frequency of the turn: time of the onset of the second SR stage, mass of Primordial Black Holes $M/M_\odot$

FORECAST. MODEL 1

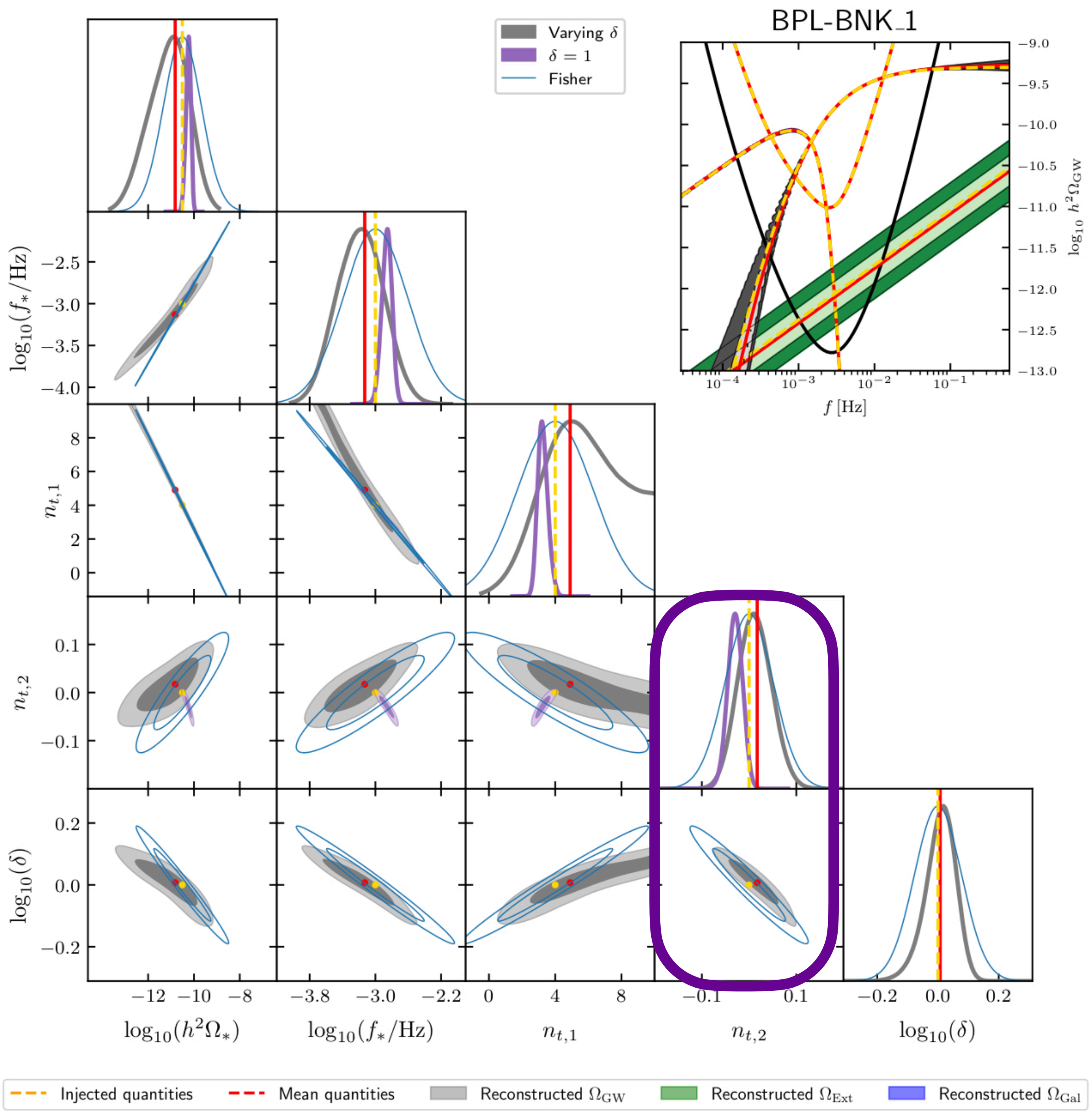


Amplitude: ratio H^2/ϵ during the second SR stage, abundance of Primordial Black Holes $f_{\rm PBH}$.

Frequency of the turn: time of the onset of the second SR stage, mass of Primordial Black Holes $M/M_\odot$.

IR spectral index: related to the scalar IR spectral index.

FORECAST. MODEL 1



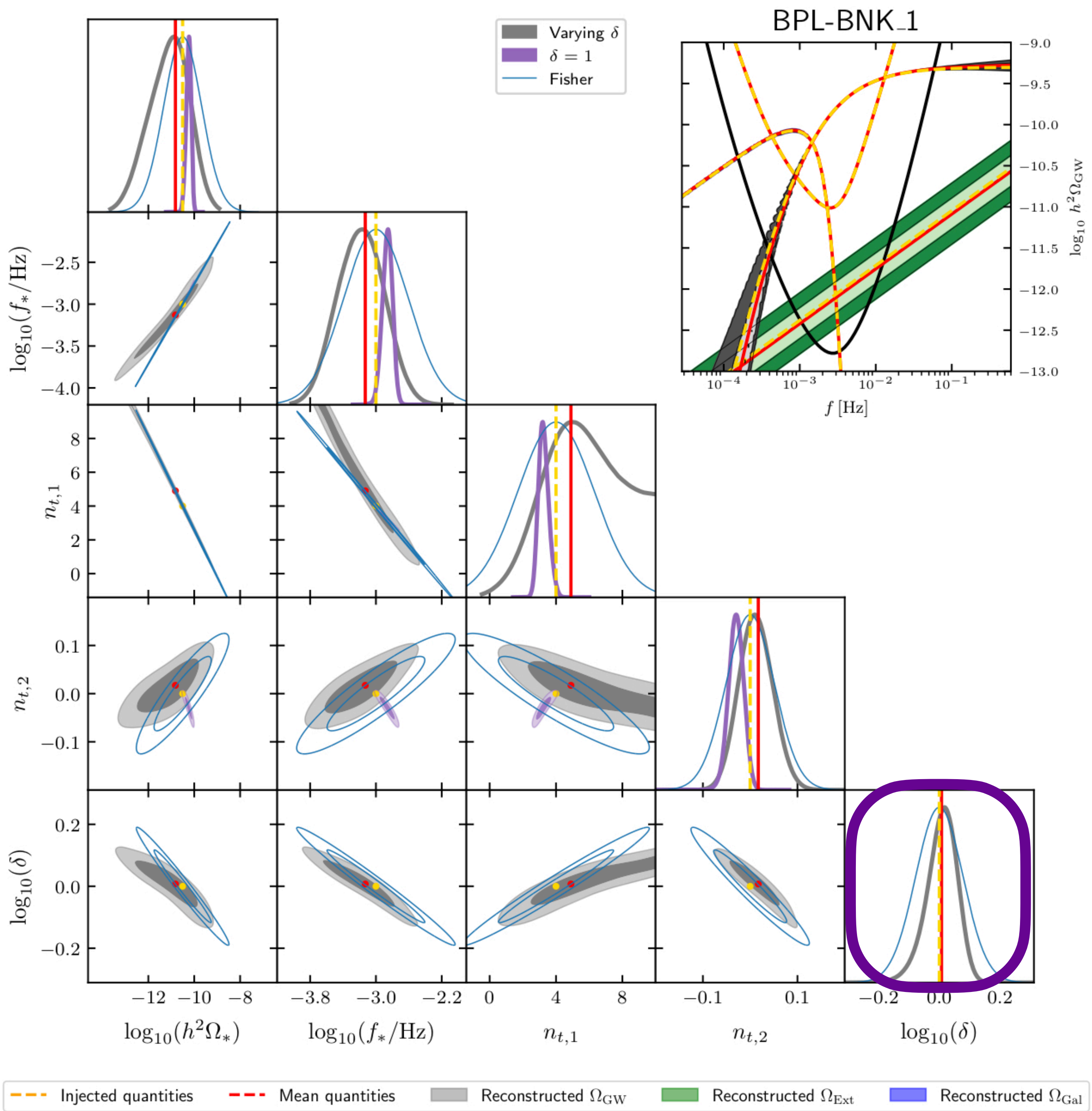
Amplitude: ratio H^2/ϵ during the second SR stage, abundance of Primordial Black Holes $f_{\rm PBH}$.

Frequency of the turn: time of the onset of the second SR stage, mass of Primordial Black Holes $M/M_\odot$.

IR spectral index: related to the scalar IR spectral index.

UV spectral index: predicted to be flat in this model

FORECAST. MODEL 1



Amplitude: ratio H^2/ϵ during the second SR stage, abundance of Primordial Black Holes $f_{\rm PBH}$.

Frequency of the turn: time of the onset of the second SR stage, mass of Primordial Black Holes $M/M_\odot$.

IR spectral index: related to the scalar IR spectral index.

UV spectral index: predicted to be flat in this model.

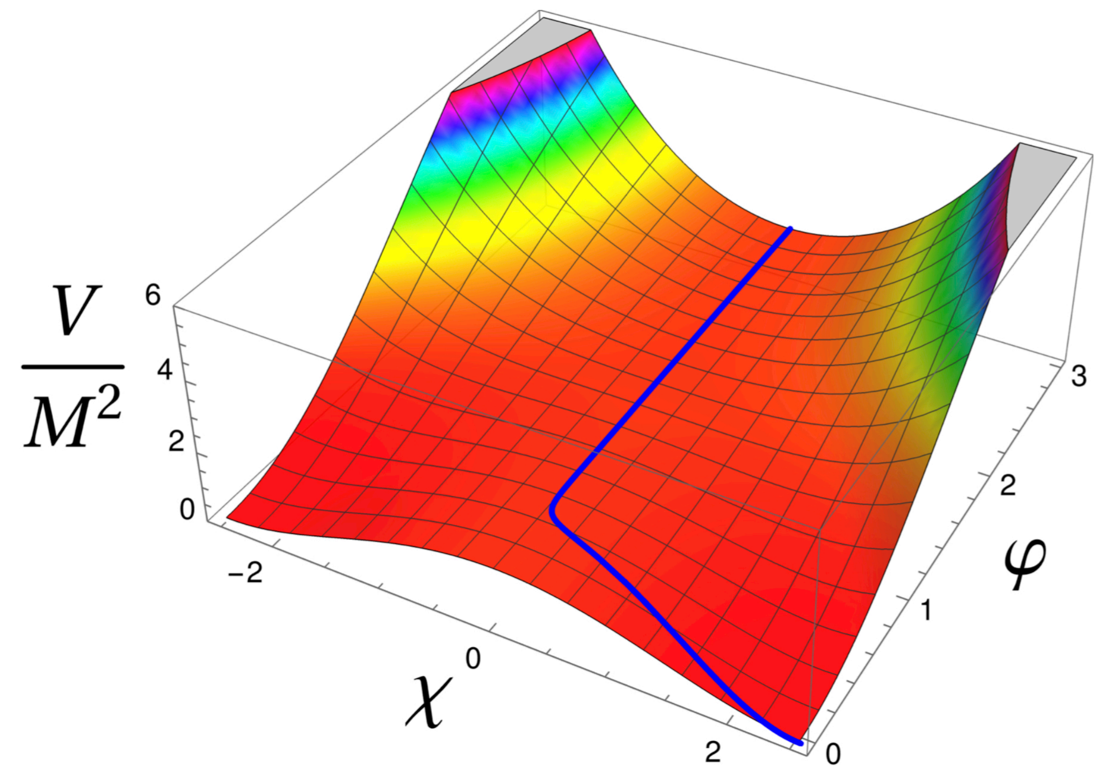
Smoothing parameter: related to the sharpness of the USR-SR transition.

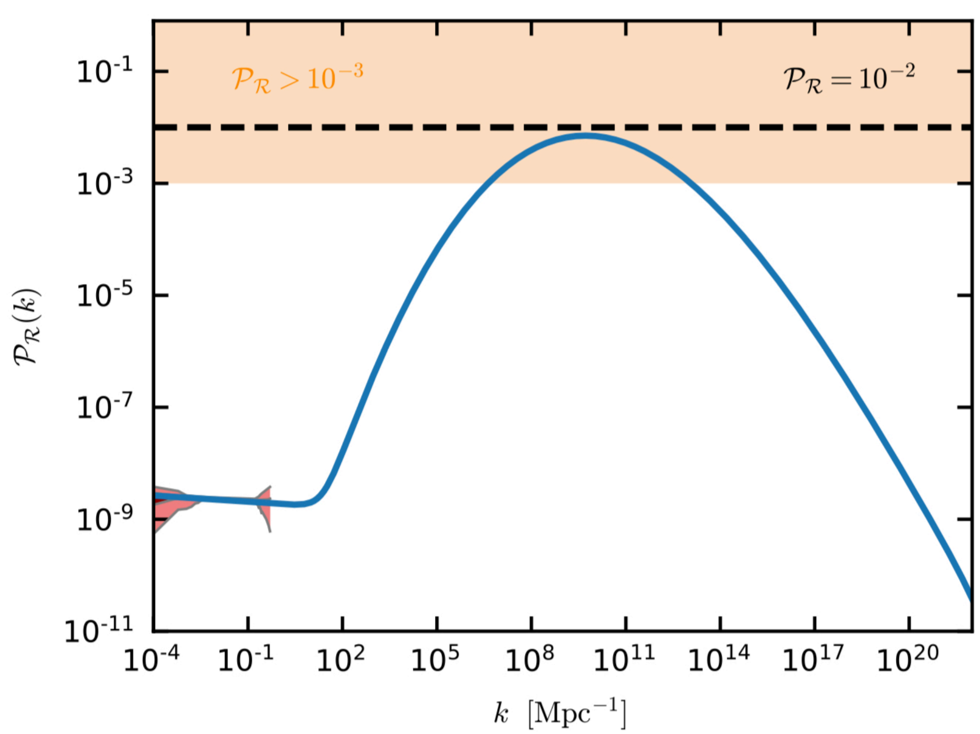
INFLATIONARY MODELS PRODUCING THE SIGNAL. MODEL 2

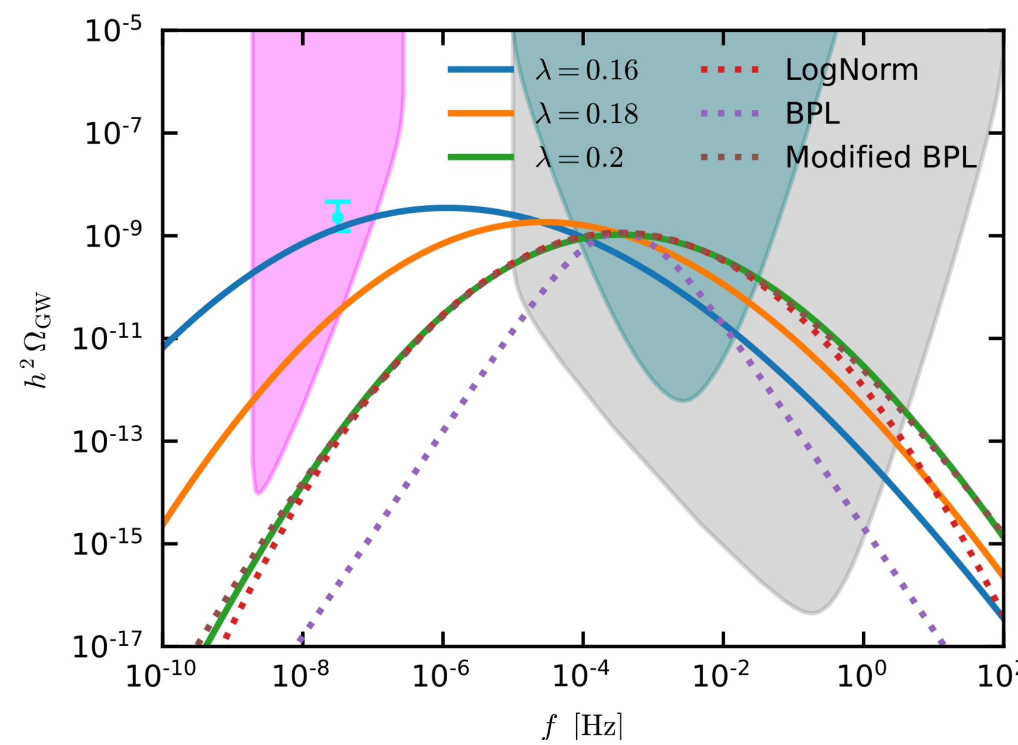
Hybrid inflation:

Braglia, Linde, Kallosh, Finelli 2211.14262

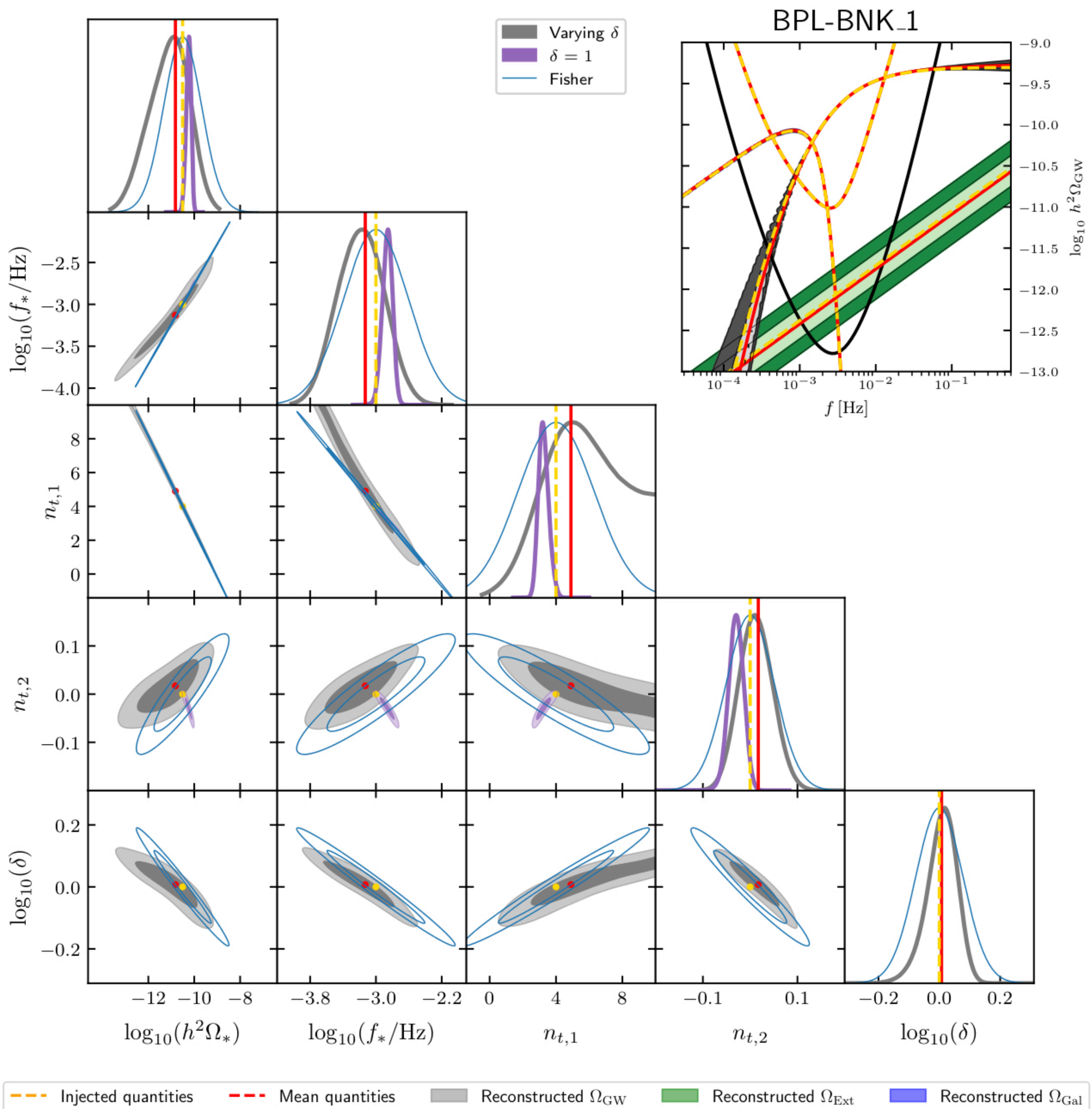
Primordial scalar perturbations are sourced by tachyonically amplified isocurvature perturbations during a waterfall phase producing a very broad bump.







FORECAST. MODEL 2



The signal is **well reconstructed,** but affected by **strong degeneracies**. The parameters are not well constrained.

Suboptimal parameterization.

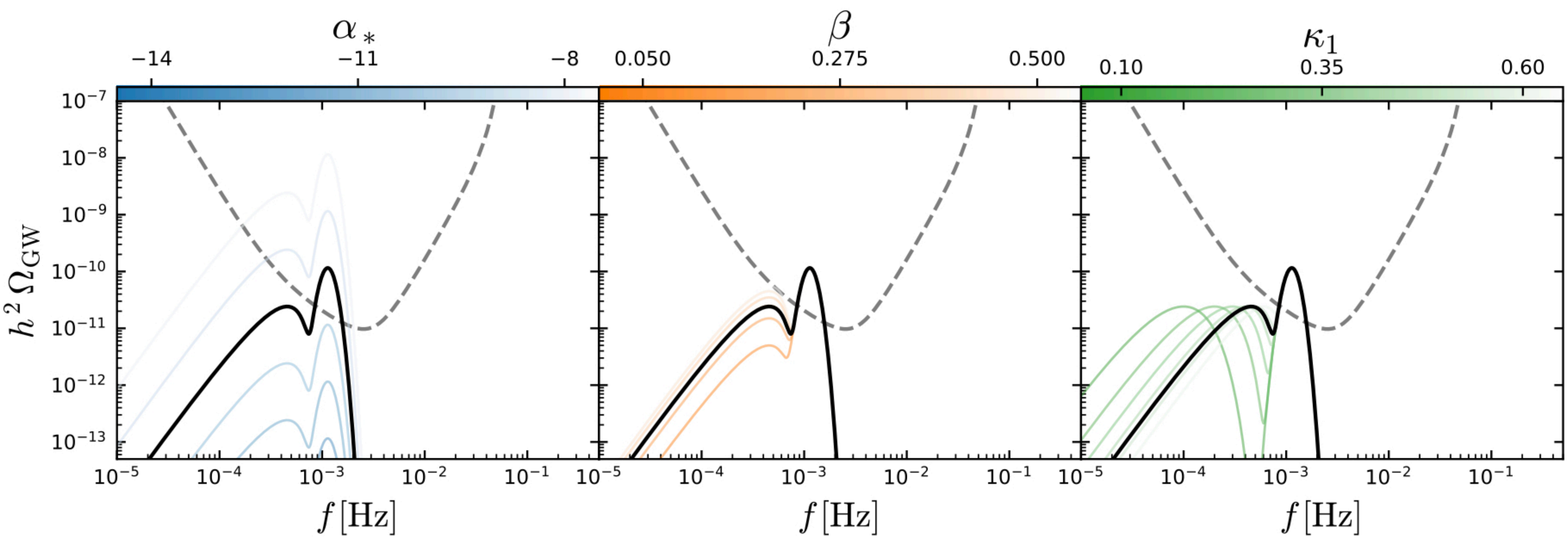
LISA **cannot measure** moderately **asymmetries** in very broad bumps, due to its limited bandwidth.

DOUBLE PEAK

TEMPLATE DEFINITION

$$\vec{p} = \{\alpha_*, f_*, \beta, \kappa_1, \kappa_2, \rho, \gamma\}$$

$$h^2\Omega_{\rm GW}^{\rm DP}(f,\vec{p}) = 10^{\alpha_*}\left[\beta\left(\frac{f}{\kappa_1 f_*}\right)^{n_p}\left[\frac{c_1 - f/f_*}{c_1-\kappa_1}\right]^{\frac{n_p}{\kappa_1}(c_1-\kappa_1)}\Theta\left(c_1 - \frac{f}{f_*}\right)\right.$$
$$\left. + \exp\left[-\frac{1}{2\rho^2}\log_{10}^2\left(\frac{f}{\kappa_2 f_*}\right)\right]\left\{1+\mathrm{erf}\left[-\gamma\log_{10}\left(\frac{f}{\kappa_2 f_*}\right)\right]\right\}\right]$$



TEMPLATE DEFINITION

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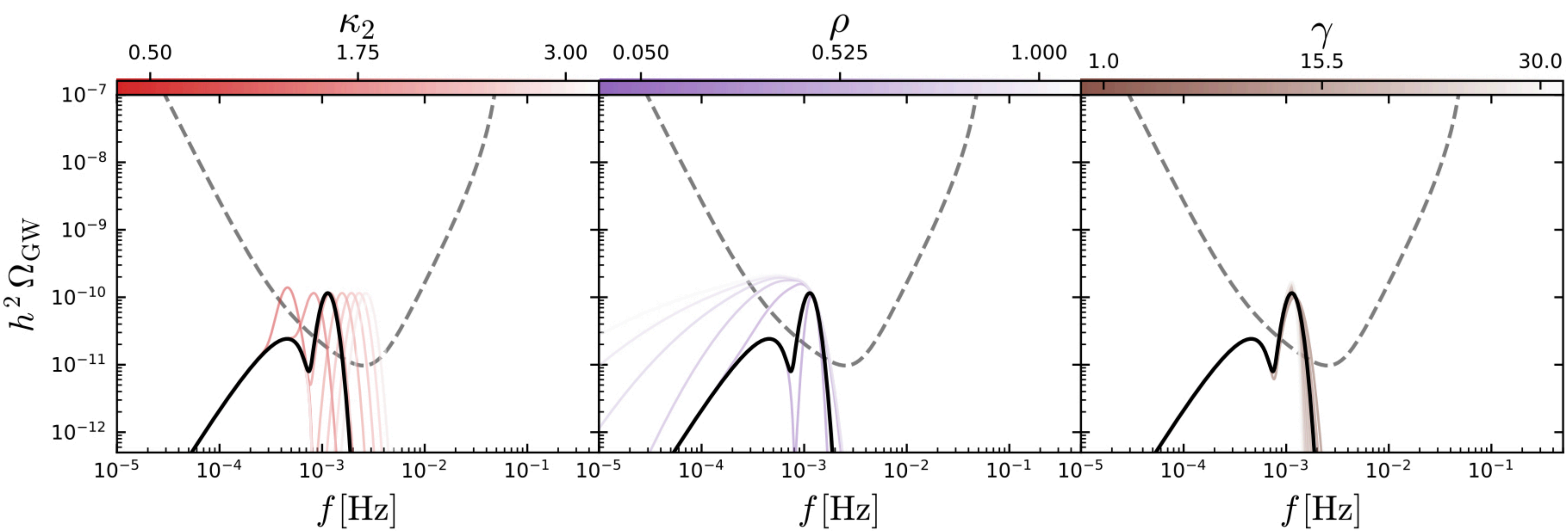


INFLATIONARY MODELS PRODUCING THE SIGNAL

Broken power law $\mathscr{P}_\zeta(k)$:

$$\mathcal{P}_\zeta^{\rm bpl}(k) = \frac{\mathcal{A}_s(p_1+p_2)}{\left[p_2\left(\frac{k}{k_*}\right)^{-p_1} + p_1\left(\frac{k}{k_*}\right)^{p_2}\right]}$$

Lognormal $\mathscr{P}_\zeta(k)$:

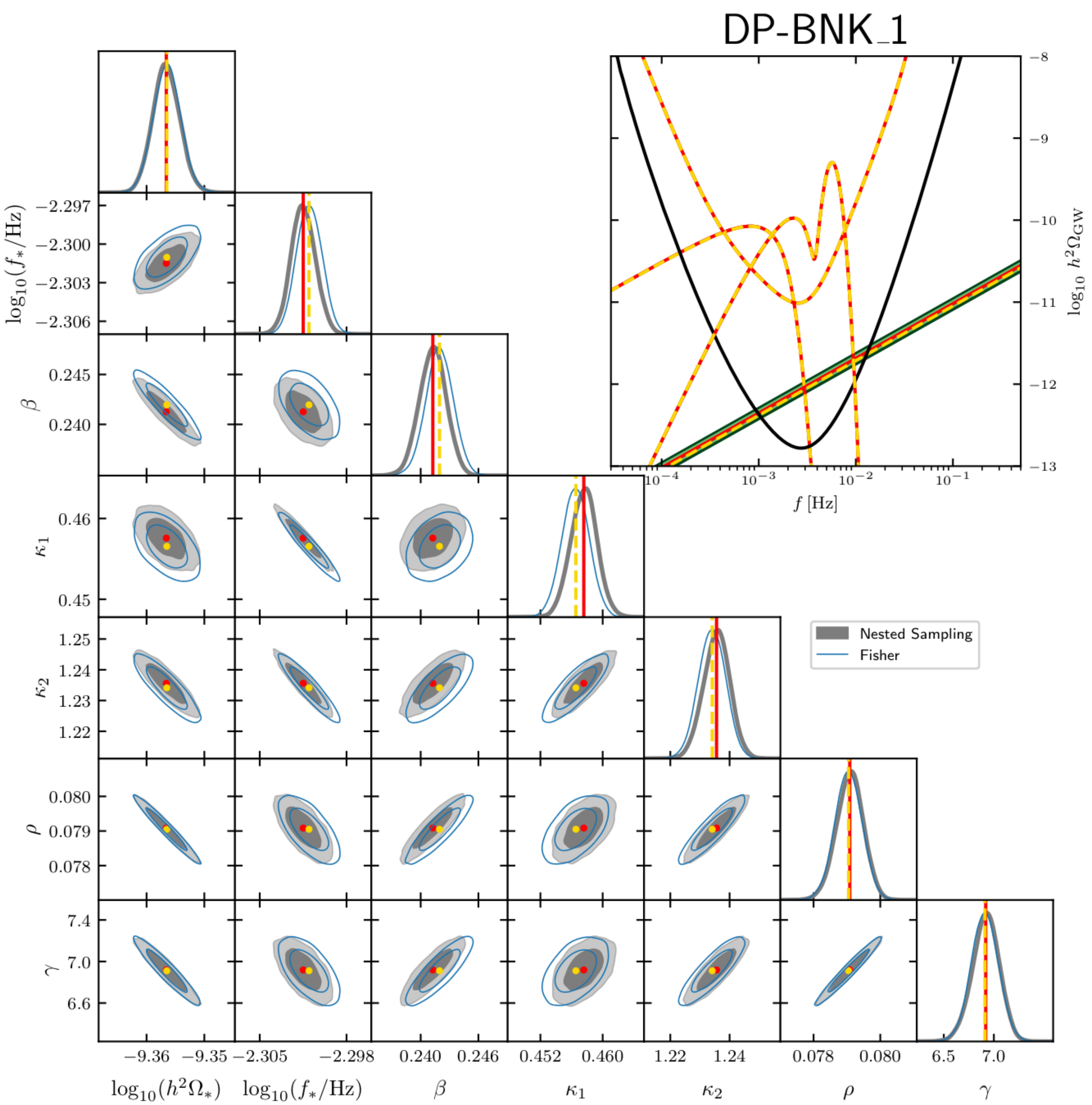
$$\mathcal{P}_\zeta^{\ln}(k) = \mathcal{A}_s \exp\left[-\frac{1}{2\Delta^2}\ln^2\left(\frac{k}{k_*}\right)\right]$$

See Ozsoy & Tasinato 2301.03600 for a review of models producing a peak in the scalar power spectrum

Prior on the 7 model parameters chosen so as to reproduce the GW background from these models.

More efficient approach: start from the parameters for $\mathscr{P}_\zeta(k)$ instead. See Robert's talk.

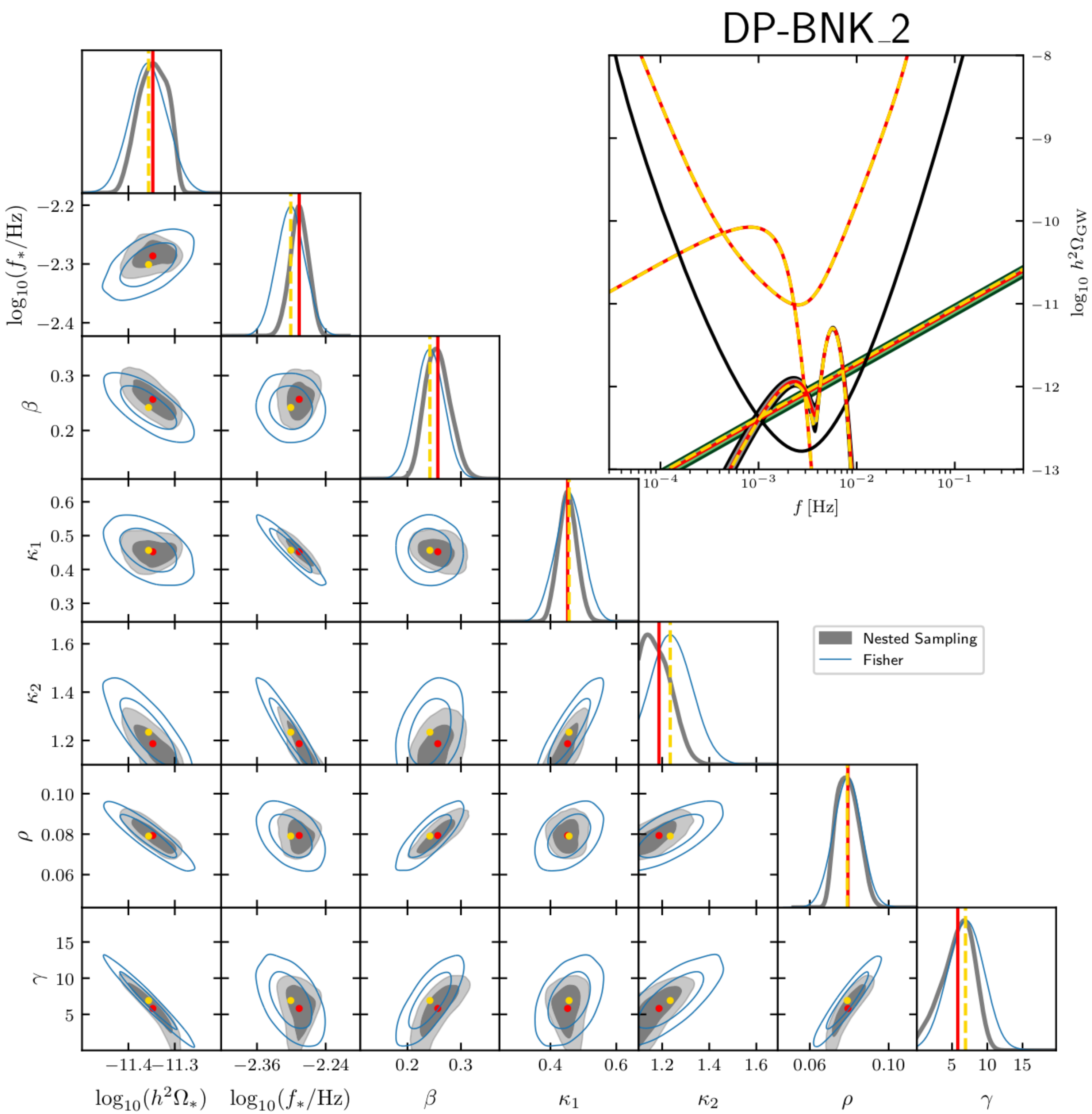
FORECAST. BNK 1



Very loud signal:

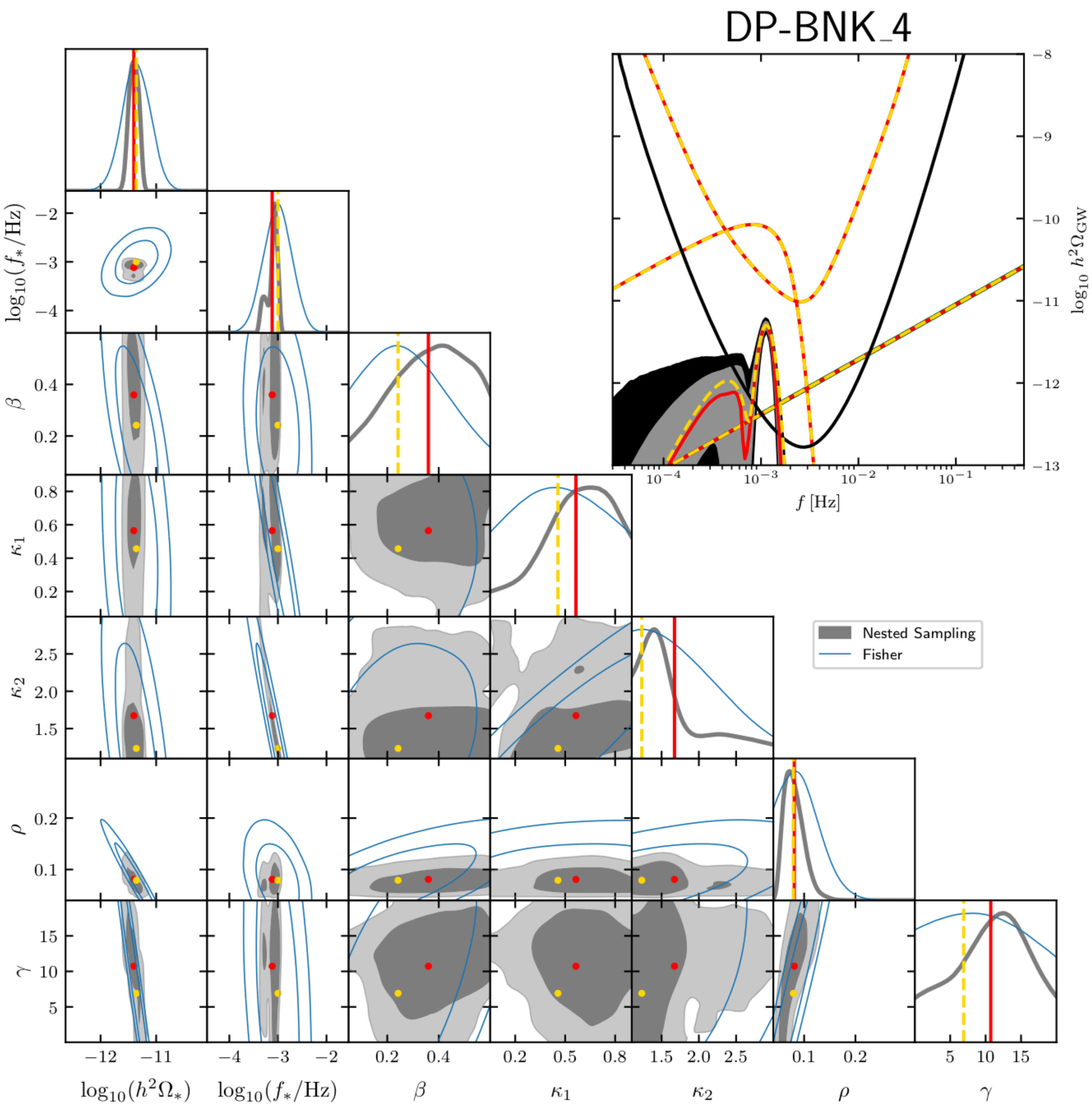
tight constraints on all parameters.

FORECAST. BNK 2



Moderately loud signal: some parameters are not constrained, but signal is reconstructed quite well.

FORECAST. BNK 3



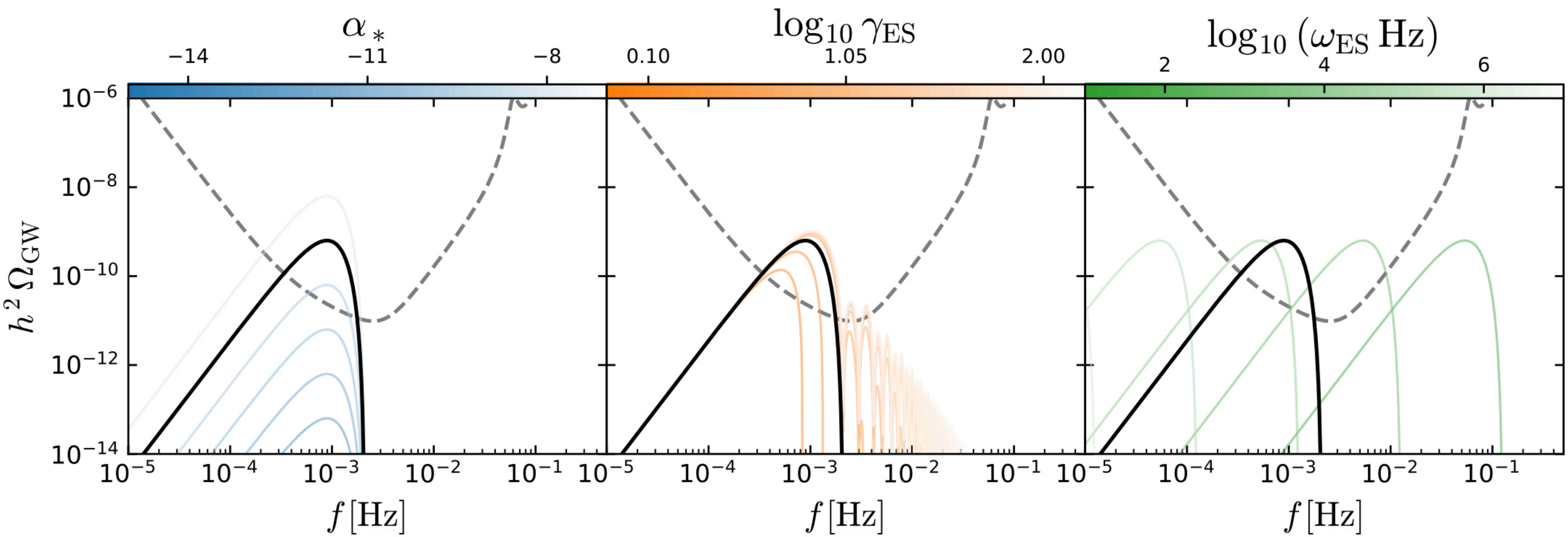
Faint signal: only certain features of the signal are constrained.

EXCITED STATES

TEMPLATE DEFINITION

$$h^2\Omega_{\rm GW}^{\rm ES}(f,\vec{p}) = \frac{10^{\alpha_*}}{0.052}\frac{1}{x^3}\left[1-\frac{x^2}{4\gamma_{\rm ES}^2}\right]^2\left[\sin(x)-2\frac{1-\cos(x)}{x}\right]^2\Theta(x_{\rm cut}-x)$$

$$x \equiv (f\,\omega_{\rm ES})/2 \qquad\qquad \vec{p} = \{\alpha_*, \gamma_{\rm ES}, \omega_{\rm ES}\}$$

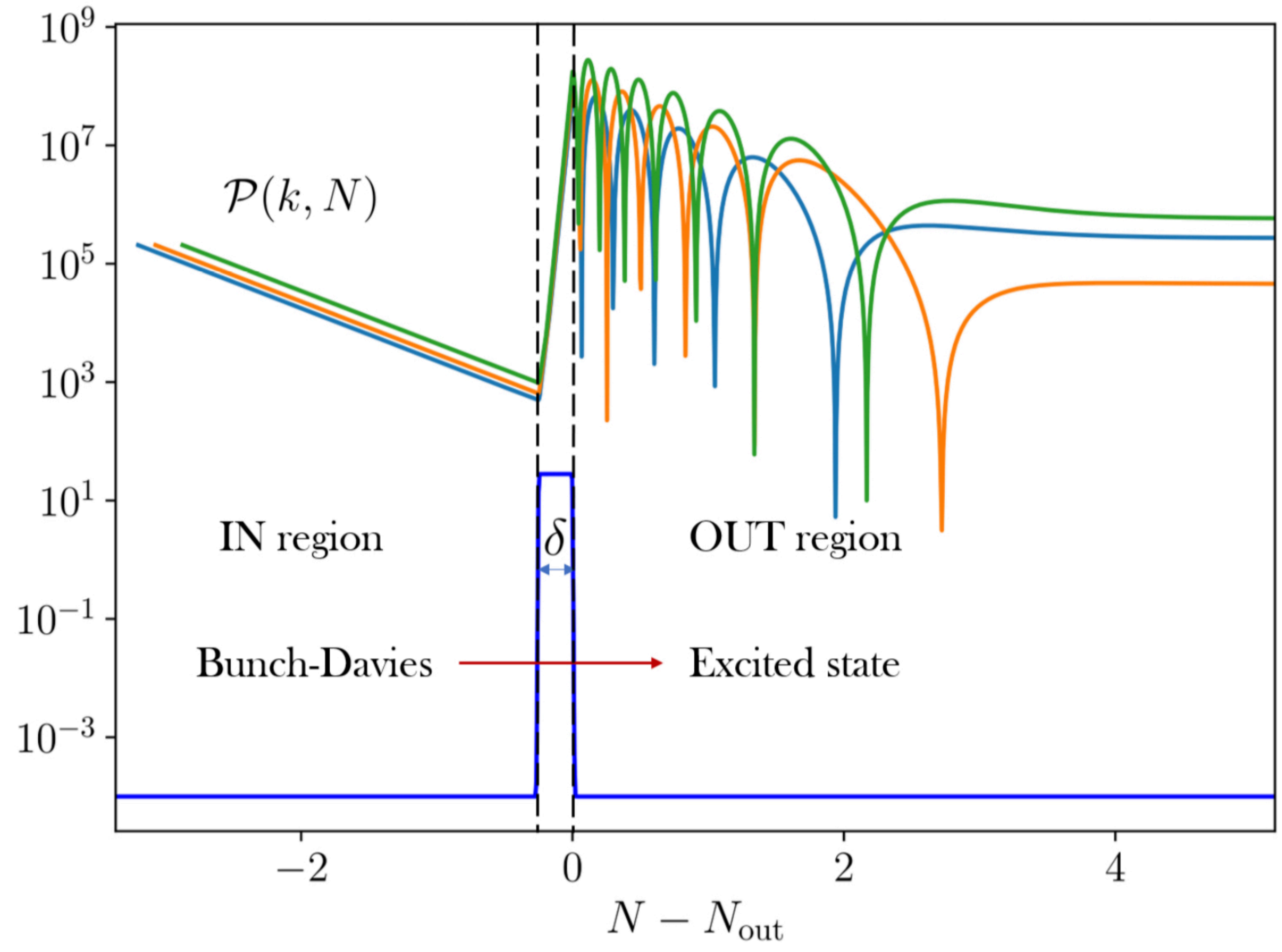


INFLATIONARY MODELS PRODUCING THE SIGNAL

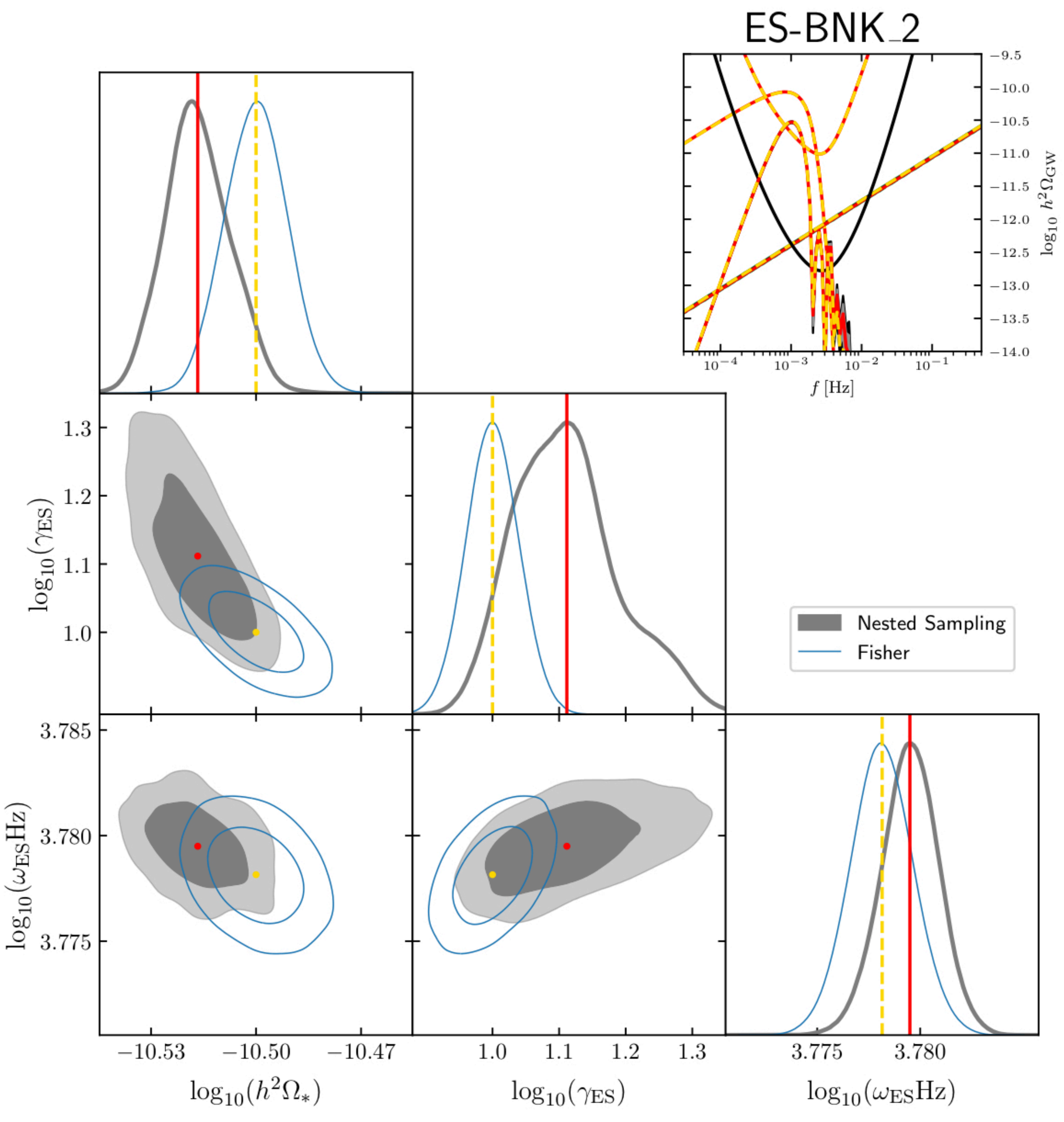
<u>Scalar- induced GWs during inflation:</u>

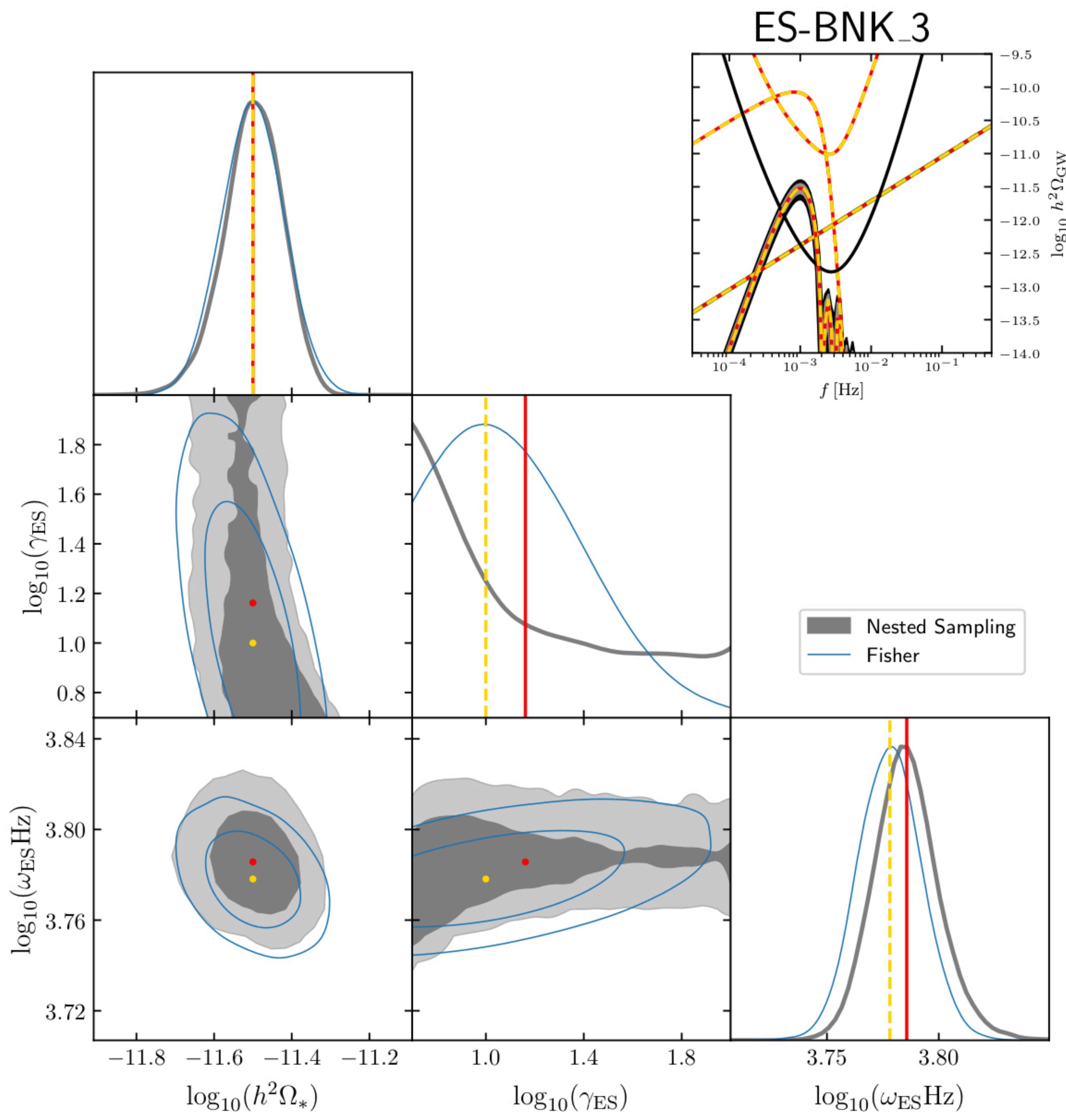
Inomata 2109.03972, Fumagalli et al 2111.14664

A sharp feature induces a temporary large amplification of sub horizon scalar modes. GWs are amplified by loop effects.



FORECASTS





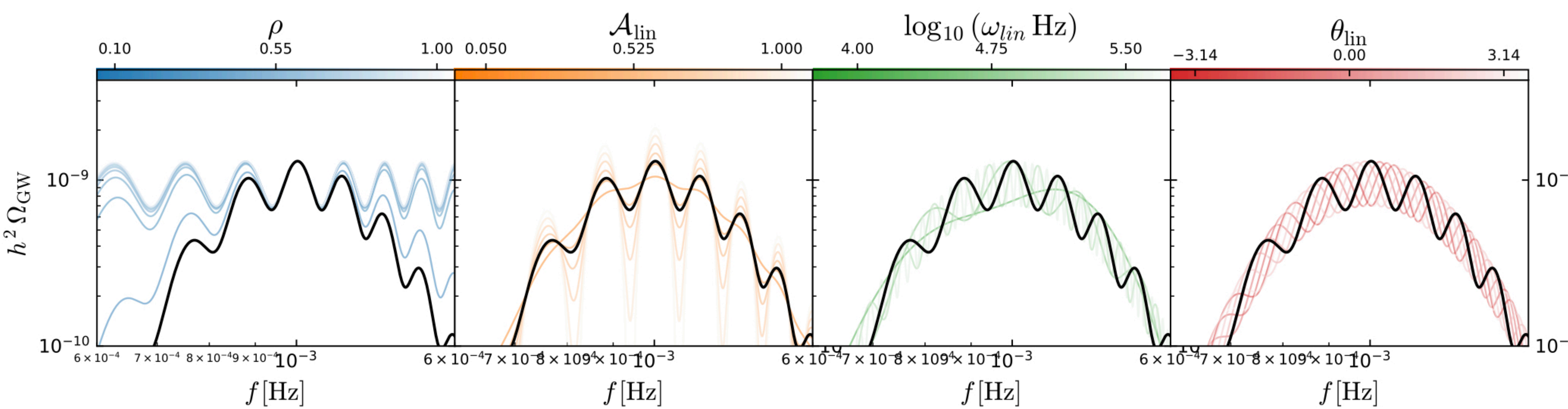
Only the amplitude and frequency can be constrained by LISA.

LINEAR OSCILLATIONS

TEMPLATE DEFINITION

$$h^2\Omega_{\rm GW}^{\rm LO}(f,\vec{p}) = \left[1 + \mathcal{A}_{\rm lin}\cos\left(\omega_{\rm lin} f + \theta_{\rm lin}\right)\right] h^2\Omega_{\rm GW}^{\rm env}(f,\vec{p}_{\rm env})$$

$$\vec{p} = \{\vec{p}_{\rm env}, \mathcal{A}_{\rm lin}, \omega_{\rm lin}, \theta_{\rm lin}\}$$

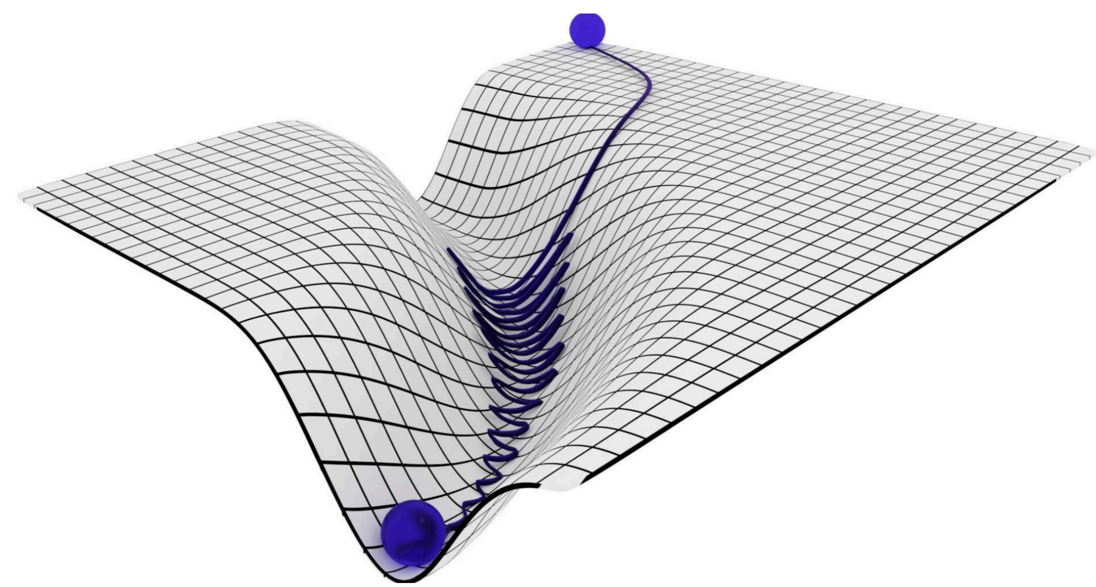


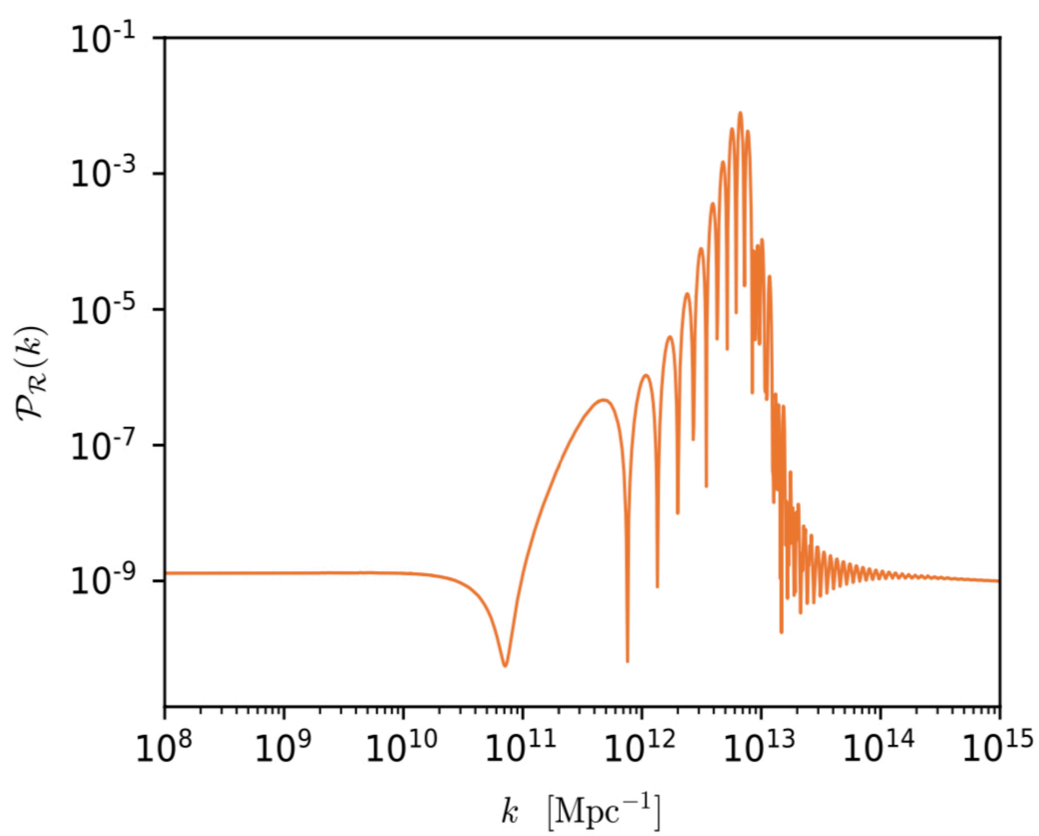
INFLATIONARY MODELS PRODUCING THE SIGNAL. MODEL 1

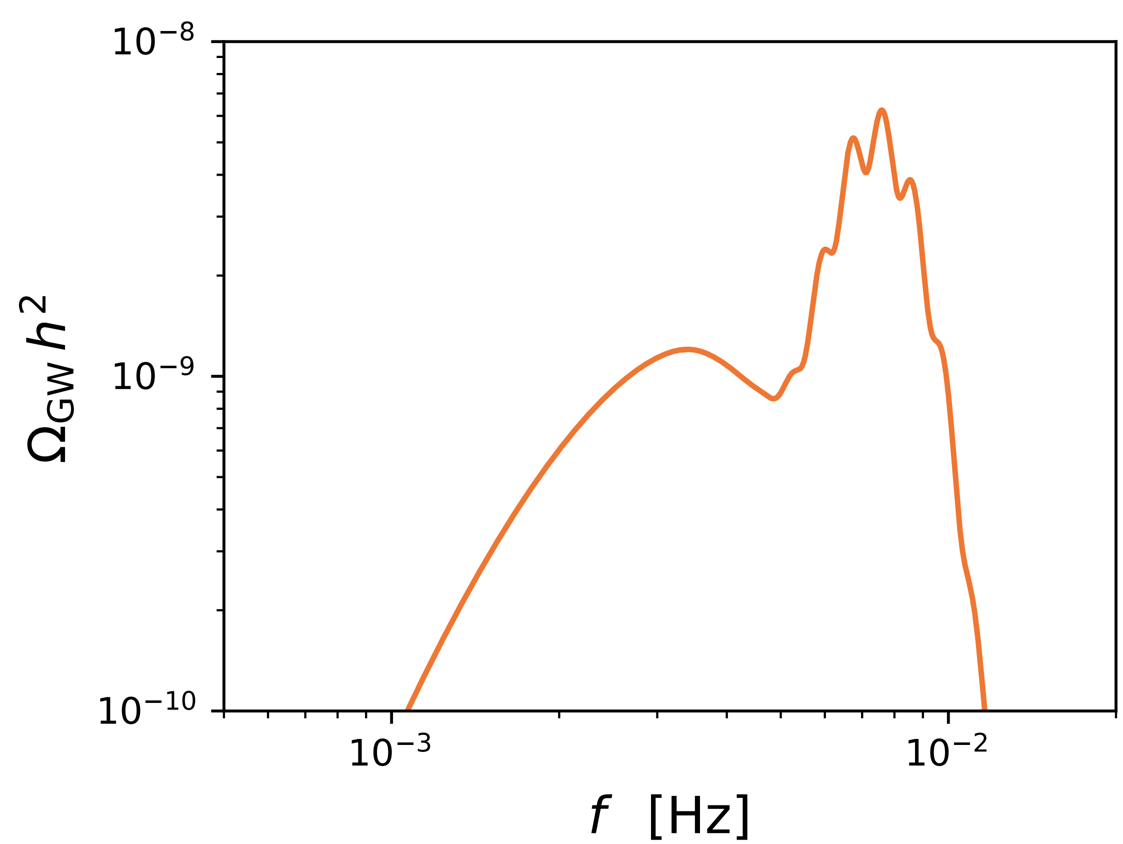
Sharp features during inflation:

Fumagalli et al 2012.02861, Braglia, Chen, Hazra 2012.05821

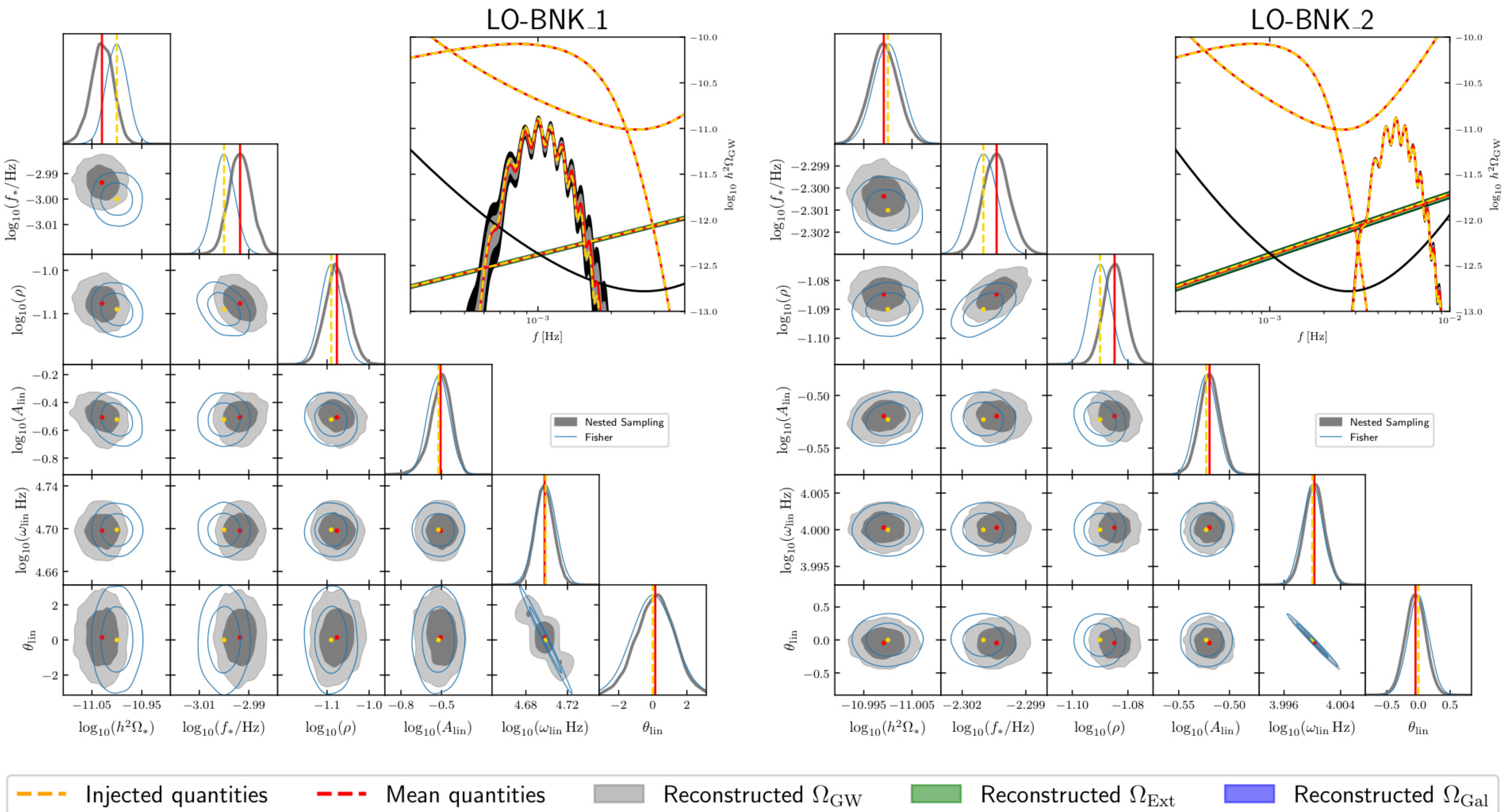
Scalar induced signal from sharp features during inflation produced at horizon re-entry.







FORECASTS



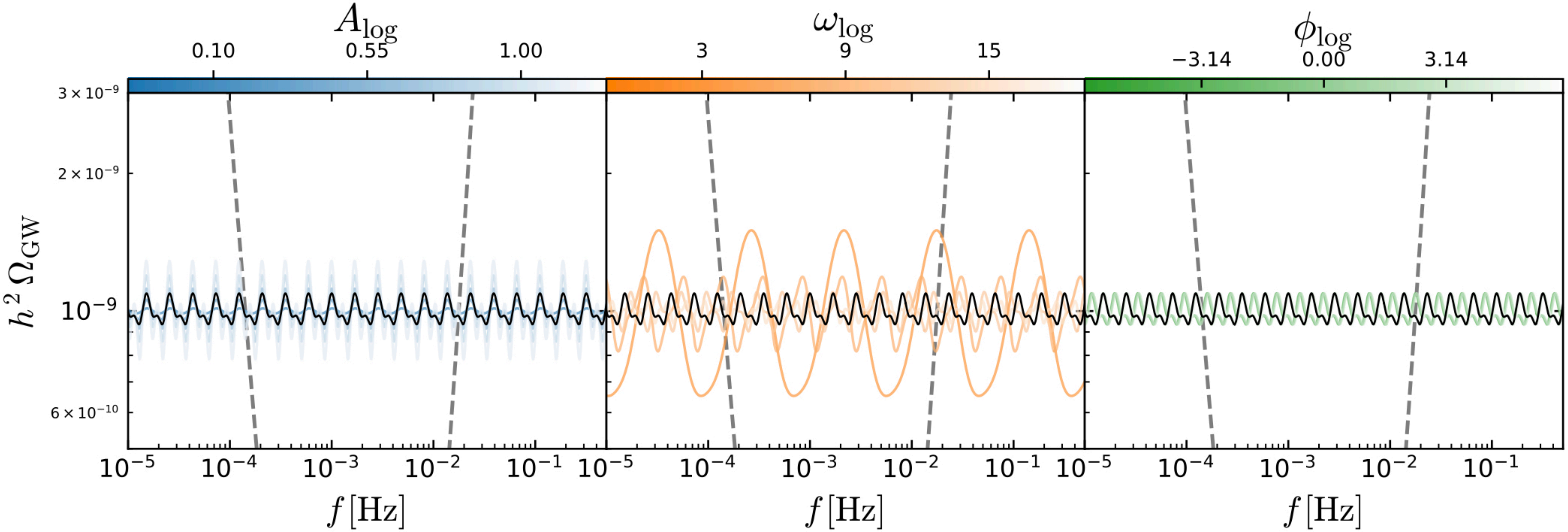
Because of their particular spectral shape oscillations can be <u>well constrained</u> by LISA.

RESONANT (LOGARITHMIC) OSCILLATIONS

TEMPLATE DEFINITION

$$h^2\Omega_{\rm GW}^{\rm RO}(f,\vec{p}) = \Big\{1 + \mathcal{A}_1(A_{\rm log},\omega_{\rm log})\cos\left[\omega_{\rm log}\ln(f/{\rm Hz}) + \theta_{\rm log,1}\right] + \mathcal{A}_2(A_{\rm log},\omega_{\rm log})\cos\left[2\omega_{\rm log}\ln(f/{\rm Hz}) + \theta_{\rm log,2}\right]\Big\} h^2\Omega_{\rm GW}^{\rm env}(f,\vec{p}_{\rm env})$$

$$\vec{p}_{\rm RO} = \{\alpha_*, A_{\rm log}, \omega_{\rm log}, \phi_{\rm log}\}$$



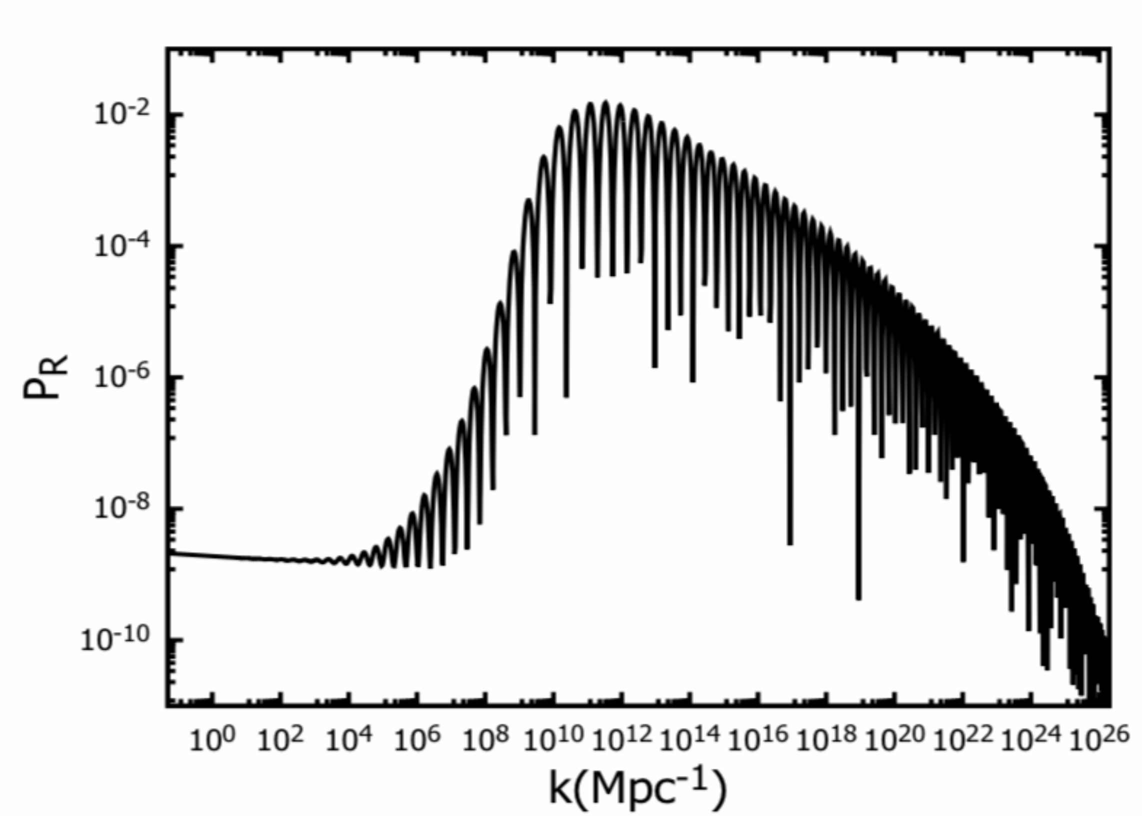
INFLATIONARY MODELS PRODUCING THE SIGNAL. MODEL 1

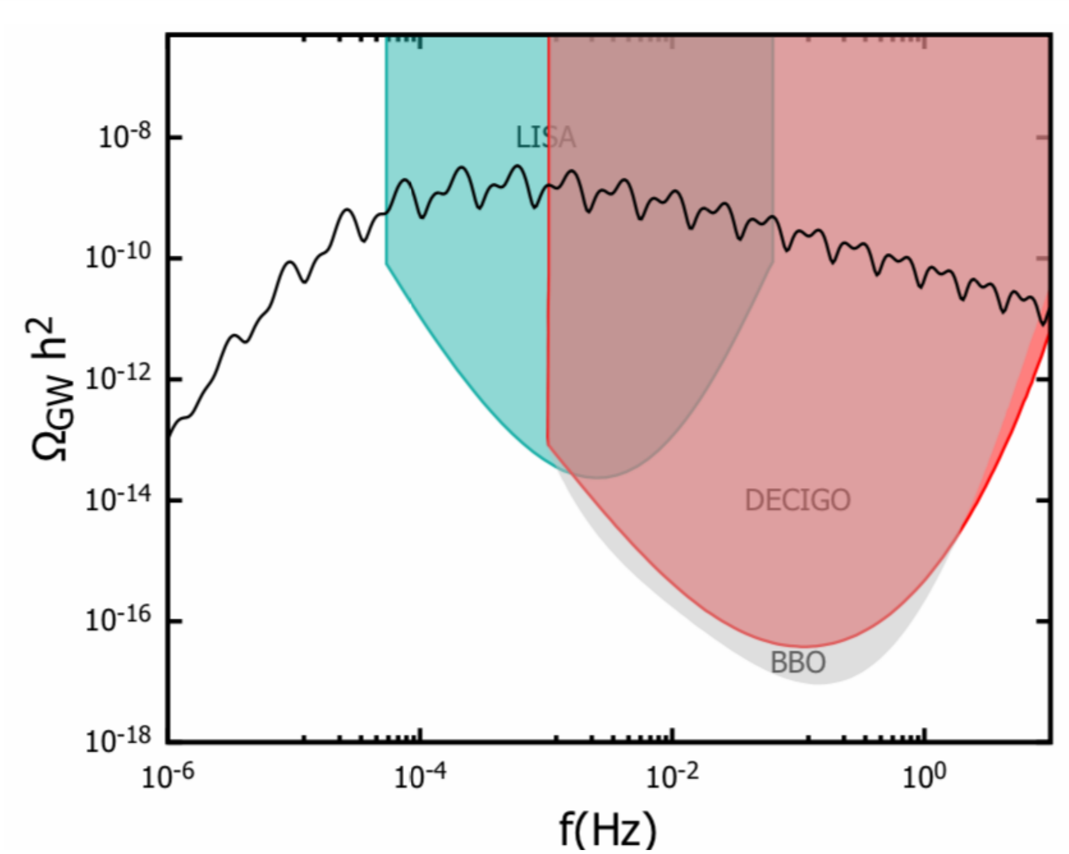
Resonant features during inflation:

Fumagalli et al 2105.06481

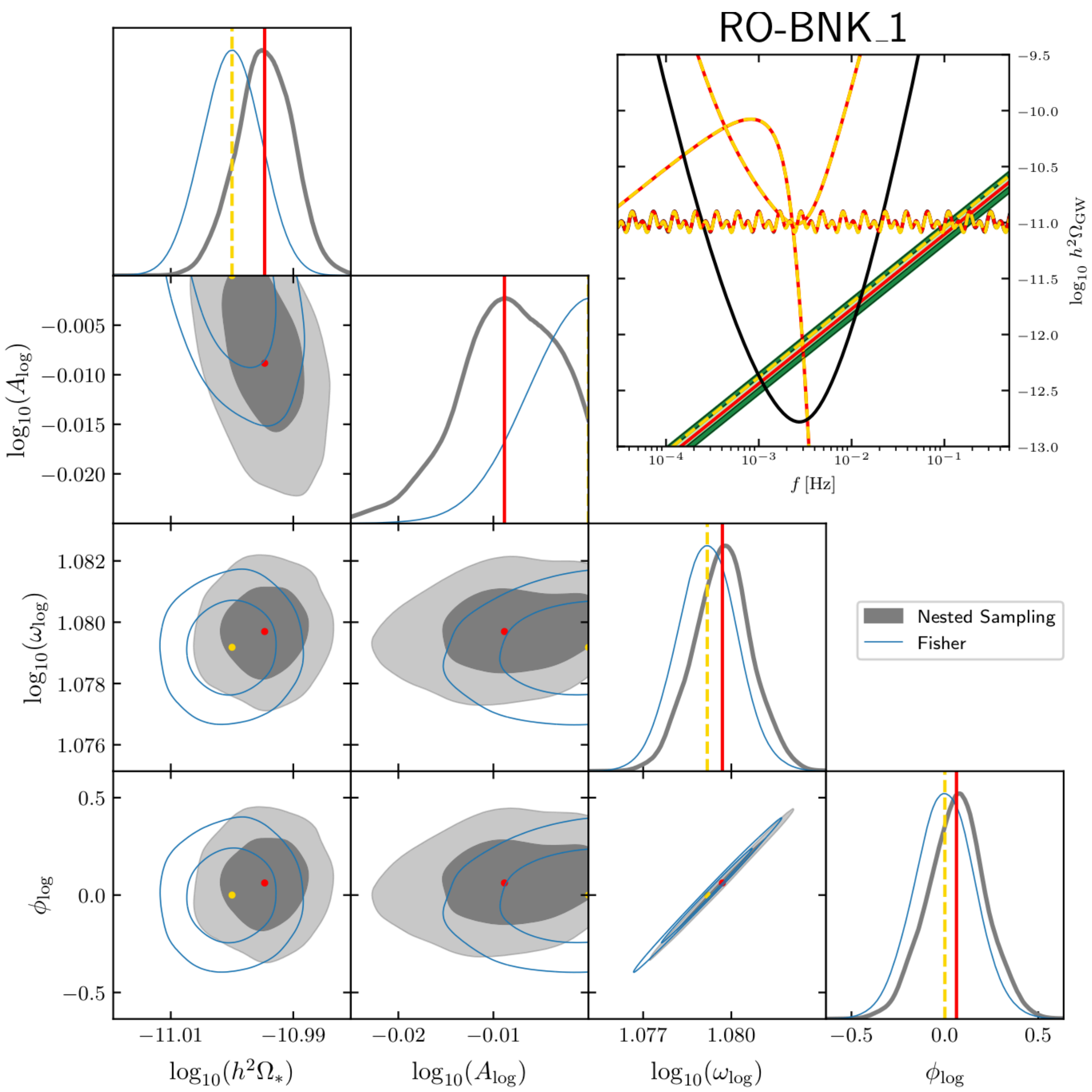
Currently a theoretical proposal based on analogies with resonant mechanisms in axion monodromy or primordial standard clock models. Models going in this direction include:

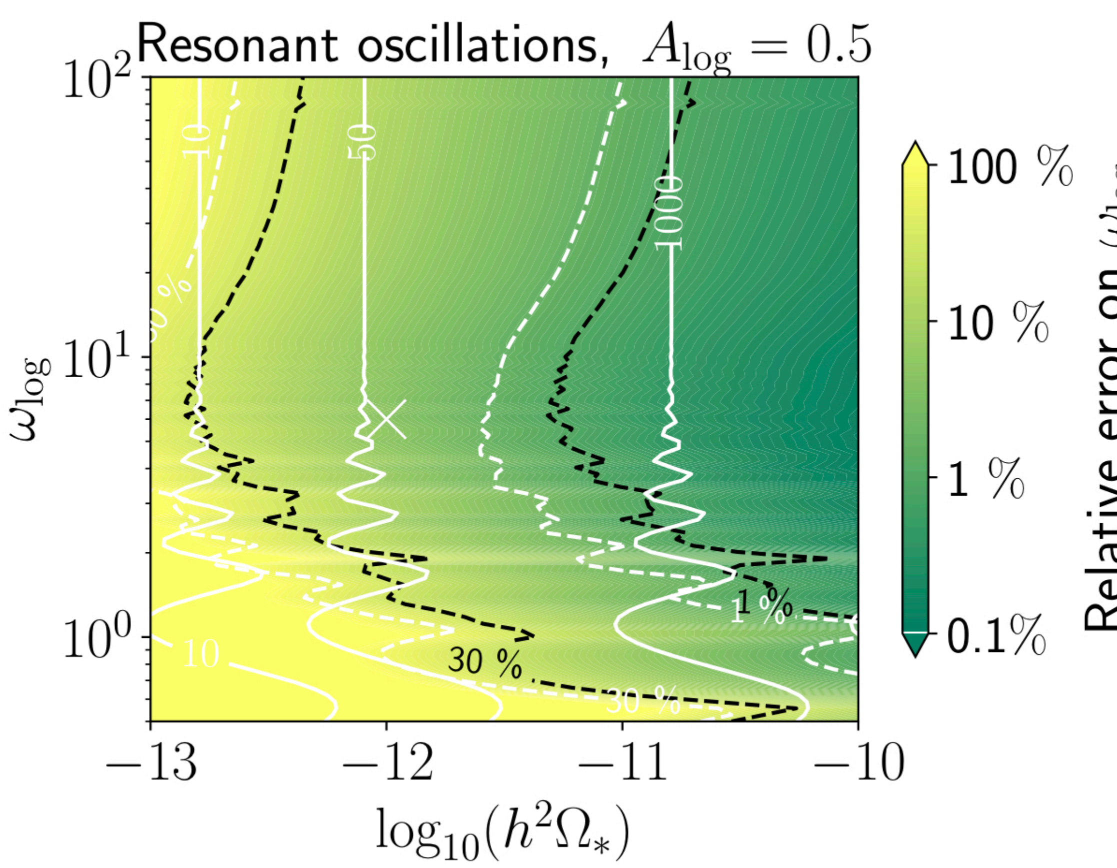
Battacharya & Zavala 2205.06065, Mavromatos et al 2206.07963, Calcagni & Kuroyanagi 2308.05904





FORECASTS





Constraints are dependent on the overall amplitude and the frequency of the signal.

SUMMARY

- We initiated the collection of a template bank for $\Omega_{\mathrm{GW}}(f)$ based on motivated inflationary scenarios.
- Within the LISA CosWG ongoing efforts for Cosmic strings and phase transitions
- Our results showcase the potential of LISA to constrain Inflation based on the reconstruction of the spectral shape of the GW background
- Other observables or correlation with other experiments may be needed to underpin the inflationary origin of the background if the spectral shape is degenerate with other models