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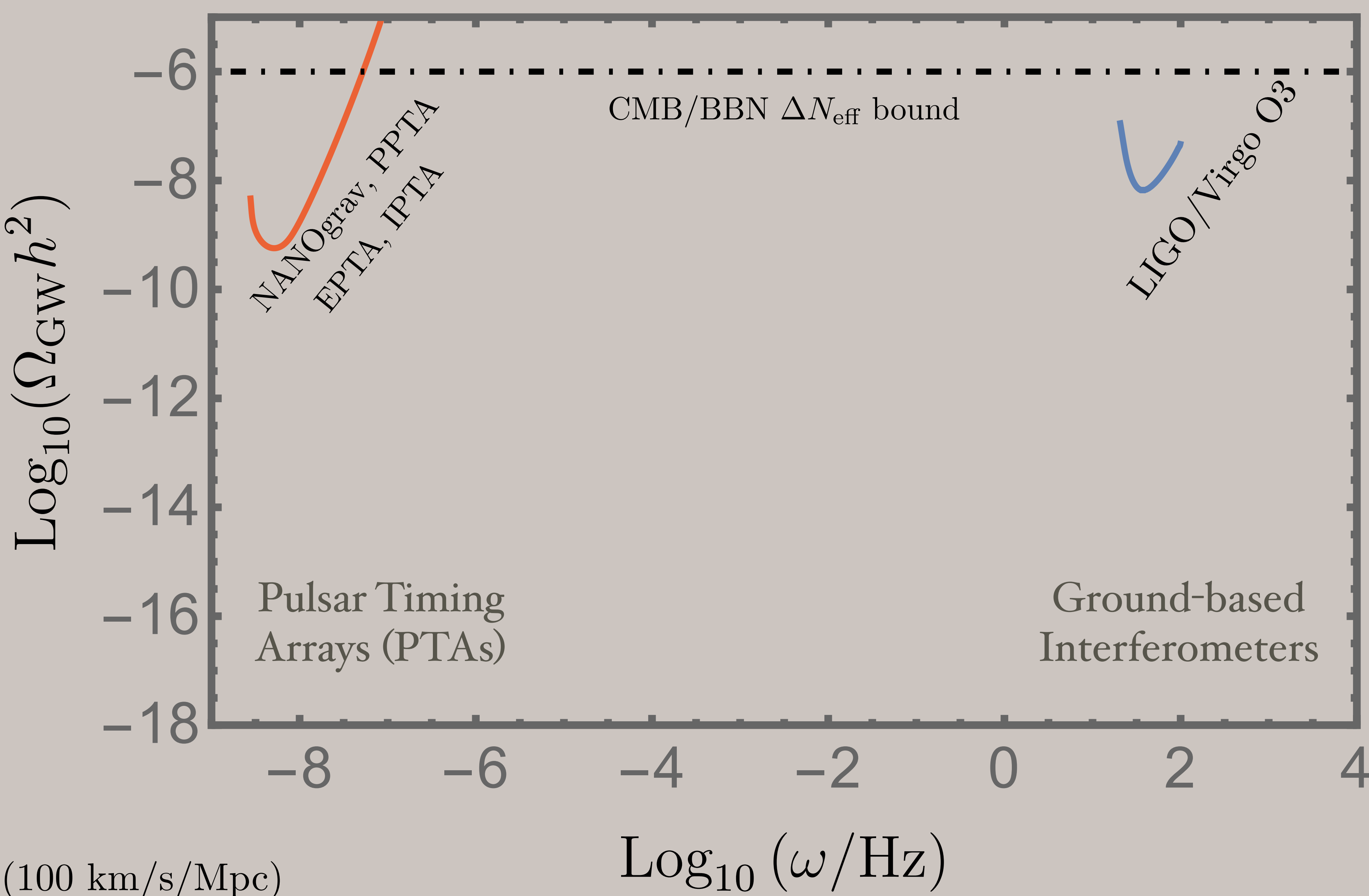

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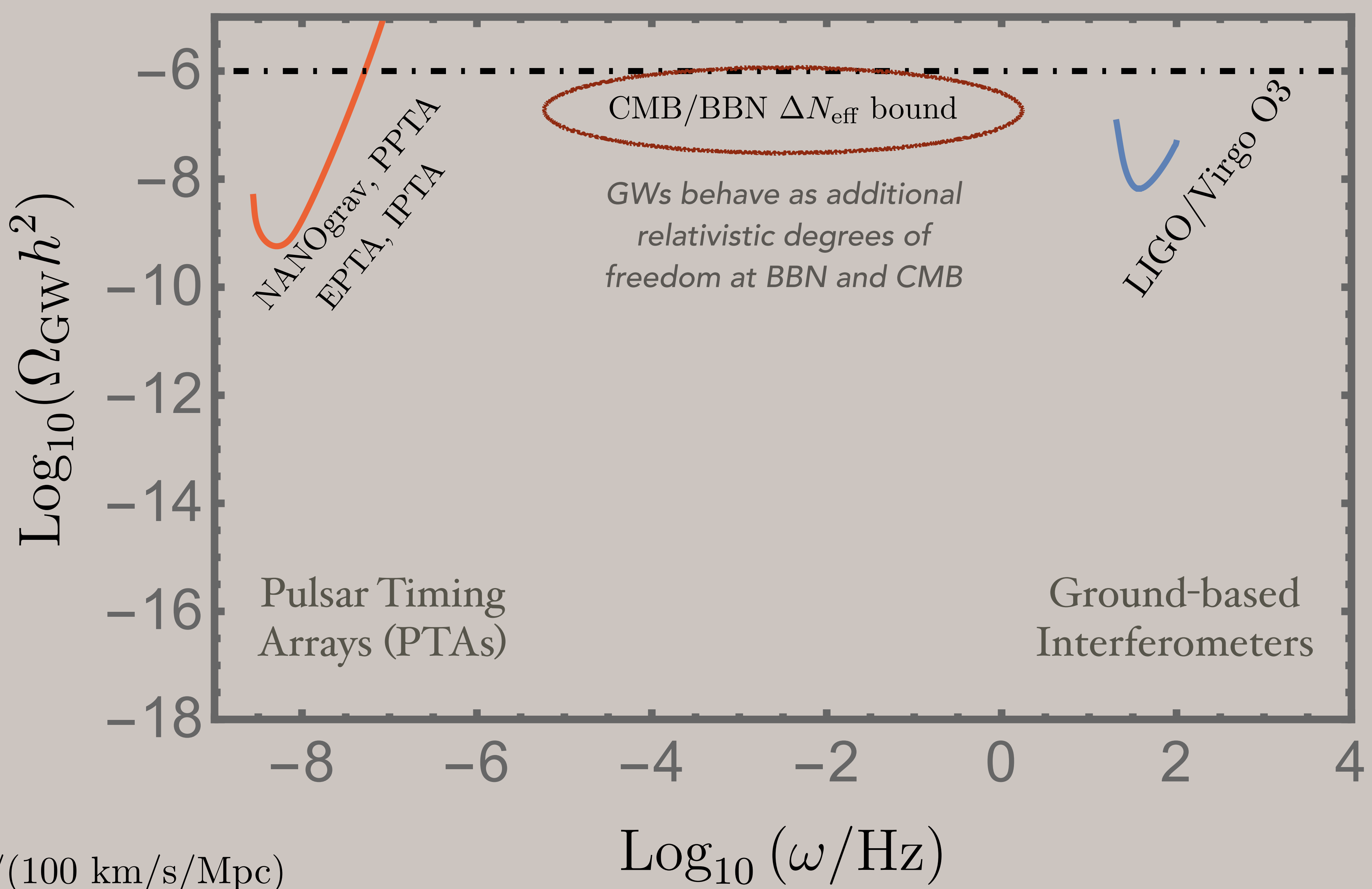

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SENSITIVITY OF FUTURE OBSERVATORIES

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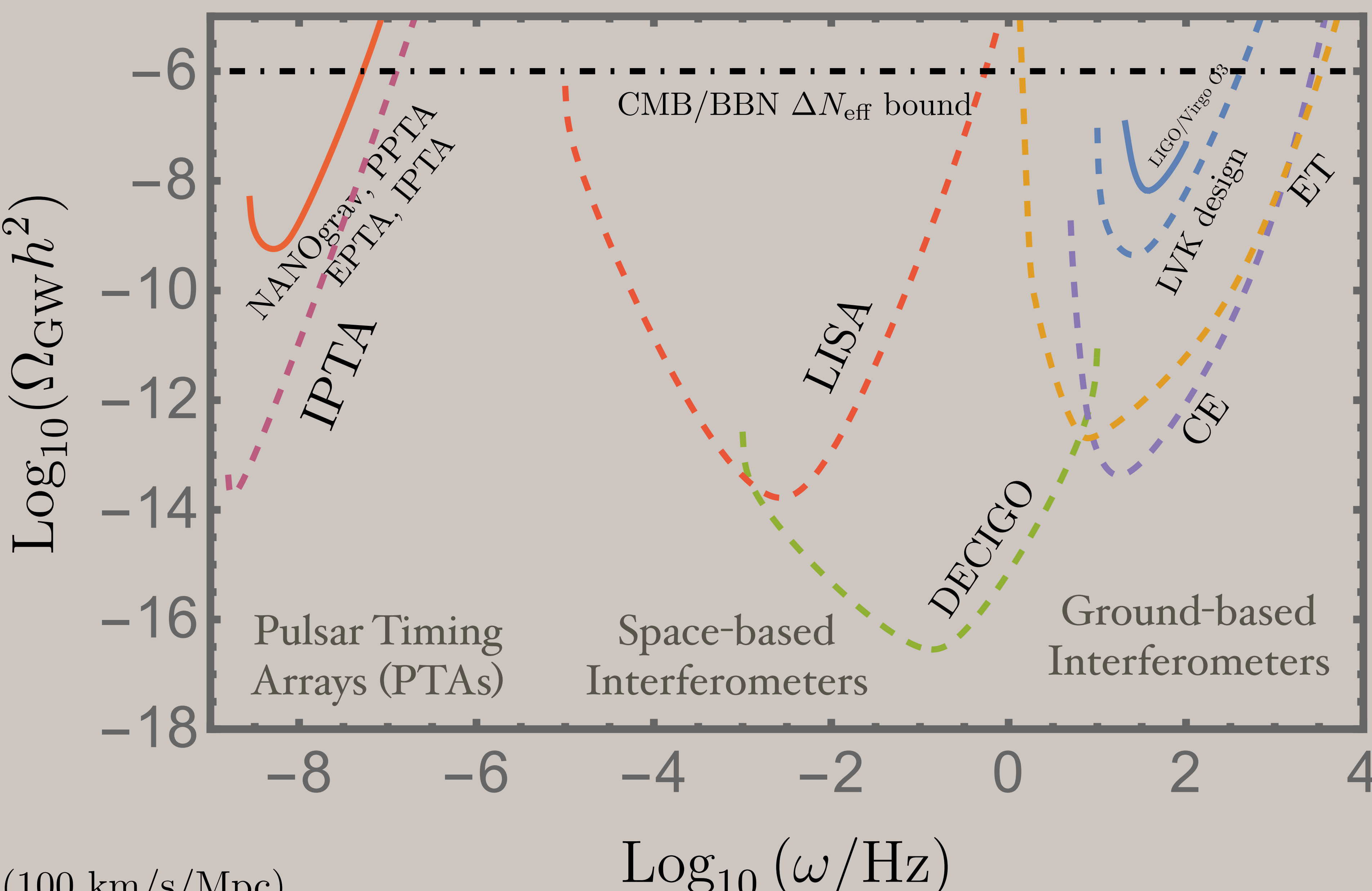

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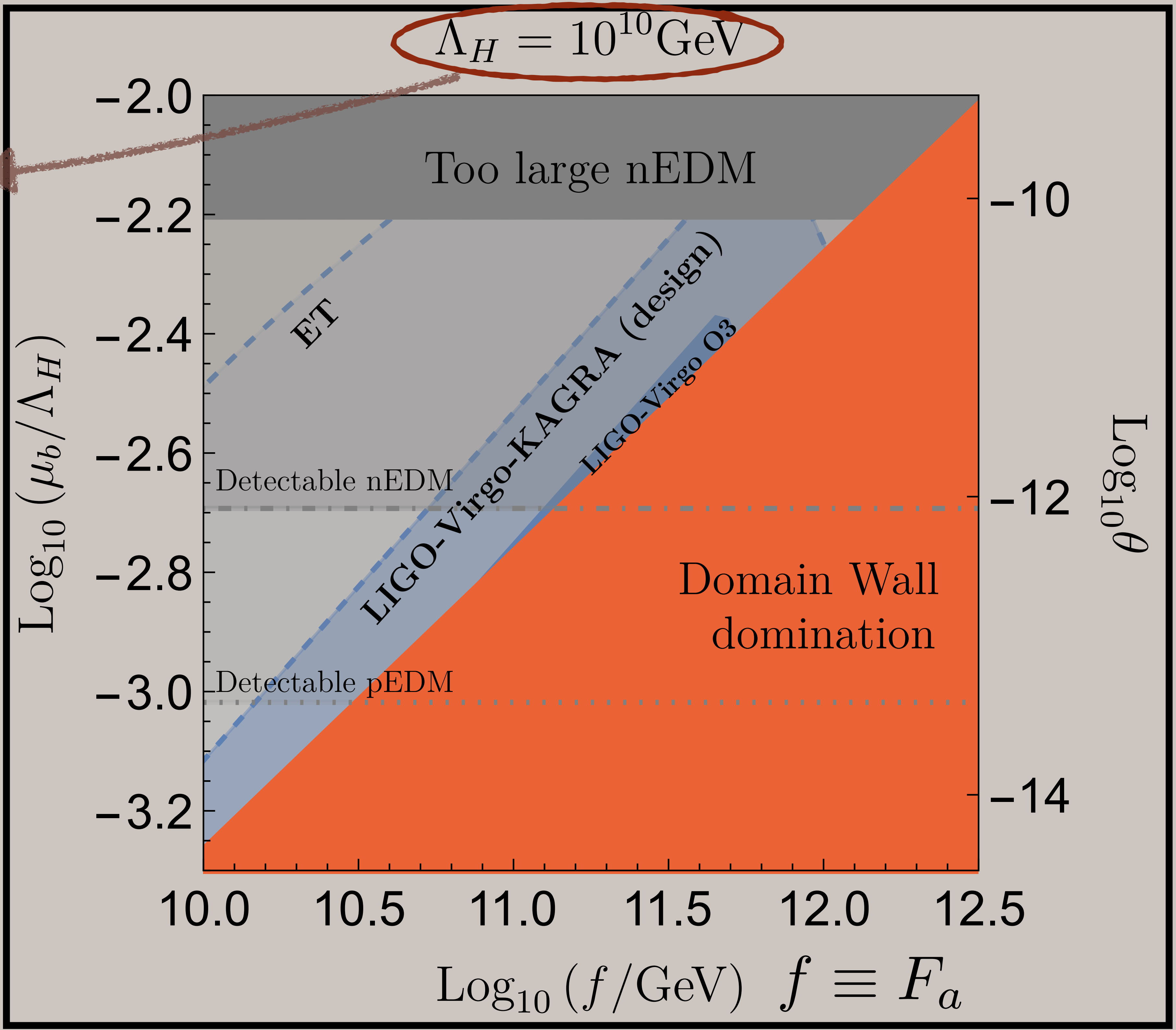
AXION QUALITY AT LIGO/VIRGO/KAGRA

Ferreira, Notari, Pujolàs, FR: 2107.07542, PRL

Scale of heavy QCD axion potential (replaces QCD scale)

2107.07542



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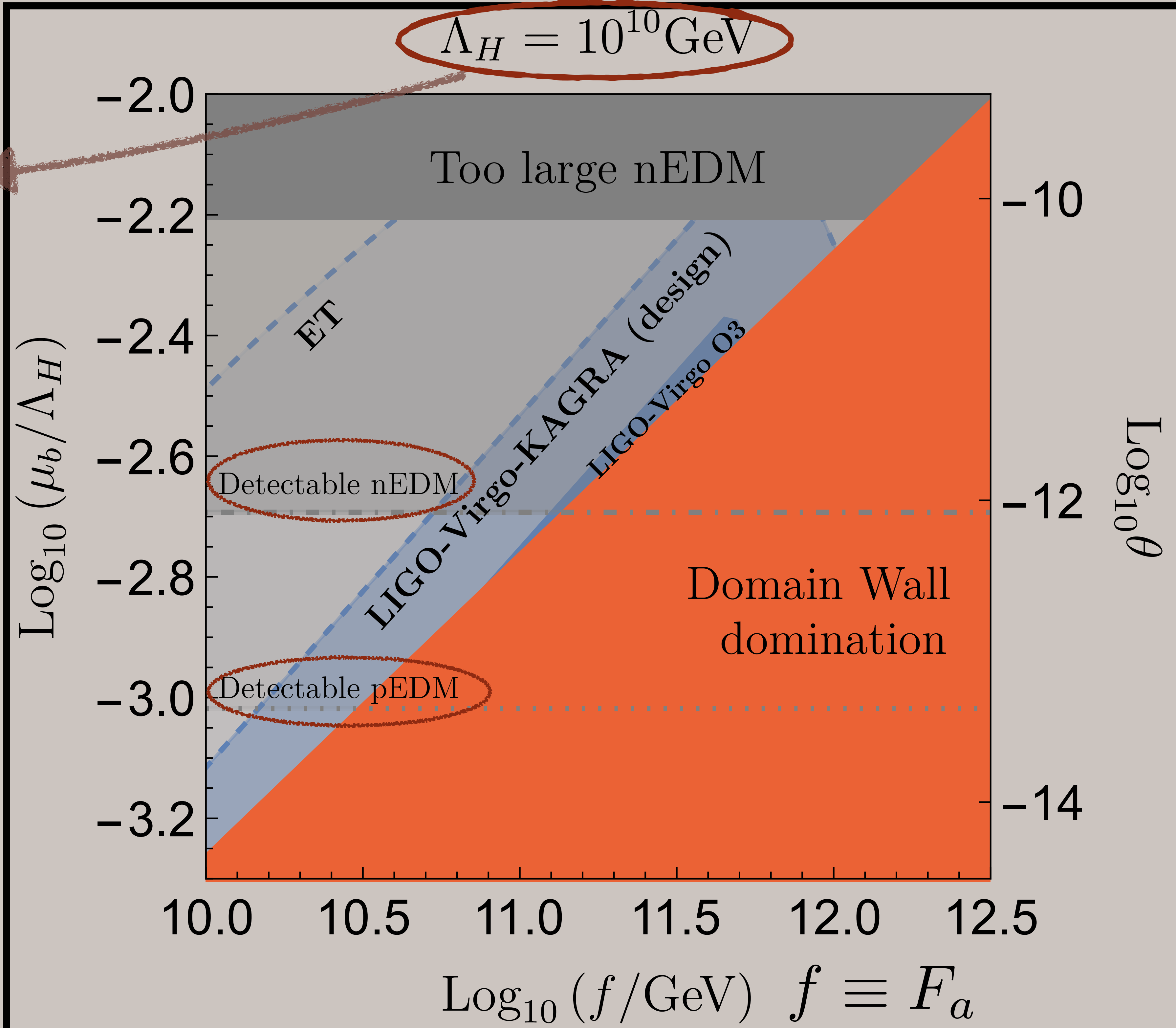
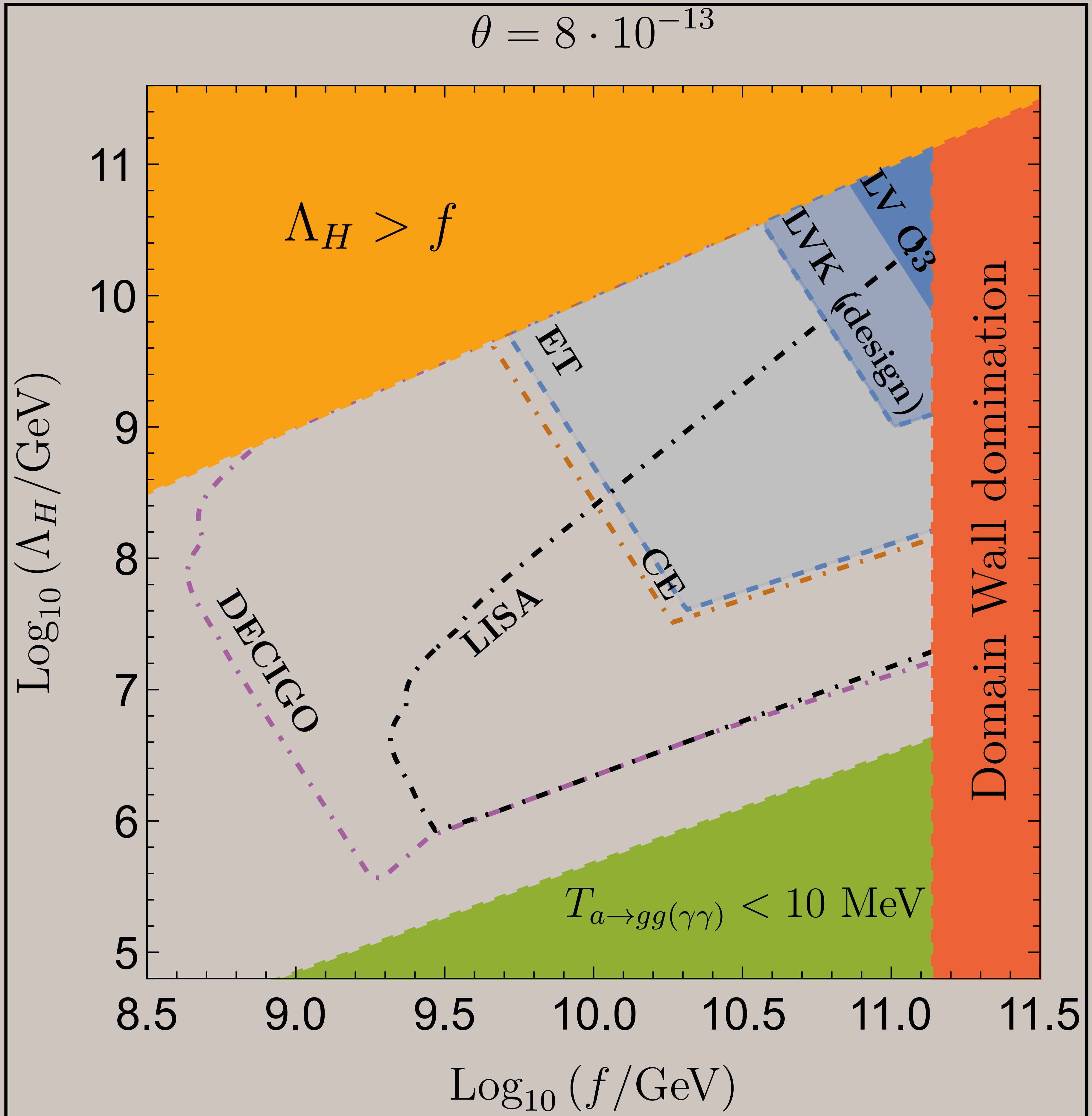
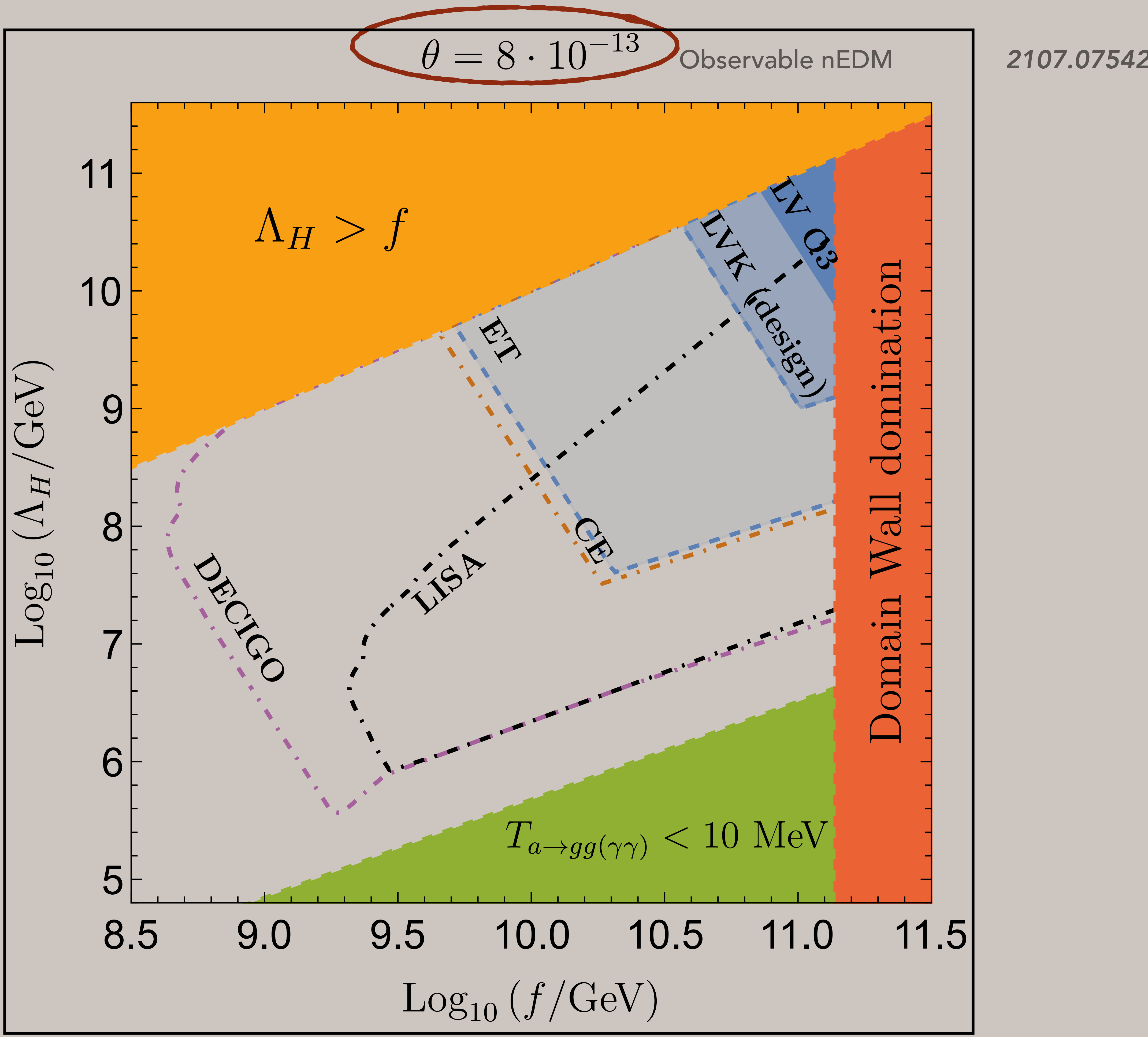


GW SIGNATURE IS CORRELATED WITH DETECTABLE NEUTRON (PROTON) ELECTRIC DIPOLE MOMENTS!



$\theta = 8 \cdot 10^{-13}$
2107.07542
$\Lambda_H > f$
LV O3
LVK (design)
ET
CE
LISA
DECIGO
Domain Wall domination
$T_{a\to gg(\gamma\gamma)} < 10$ MeV
$\mathrm{Log}_{10}(\Lambda_H/\mathrm{GeV})$
$\mathrm{Log}_{10}(f/\mathrm{GeV})$
11
10
9
8
7
6
5
8.5
9.0
9.5
10.0
10.5
11.0
11.5



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Observable nEDM
2107.07542
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SEARCH IN PULSAR TIMING ARRAY DATASETS

Ferreira, Notari, Pujolàs, FR: 2204.04228

PTA RESULTS

Current datasets show strong evidence for common-spectrum process

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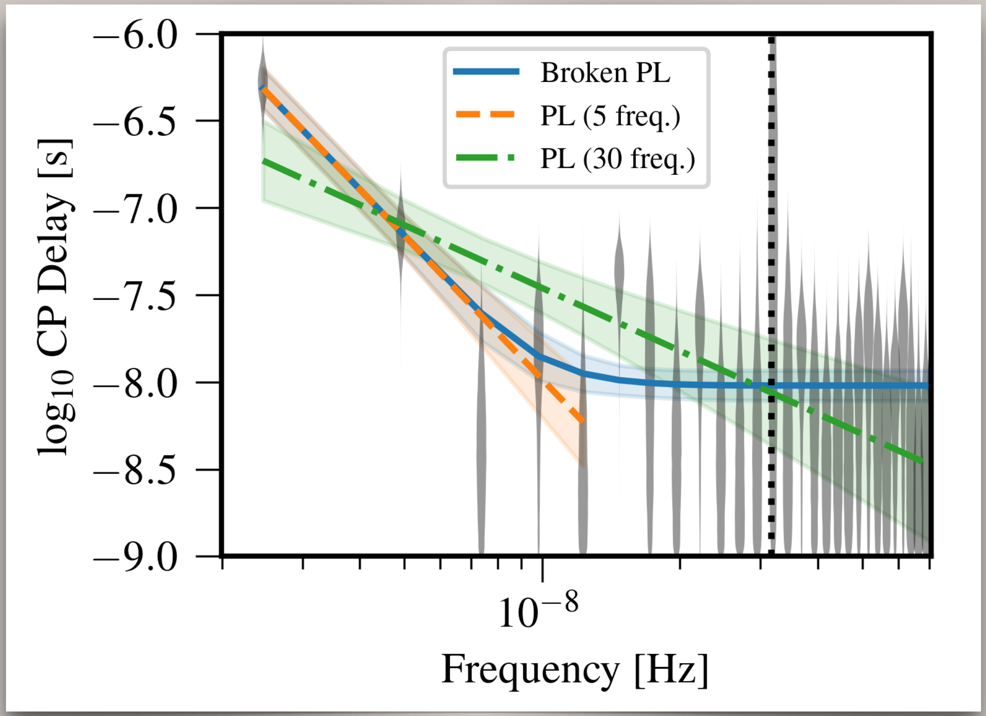

NG 12.5

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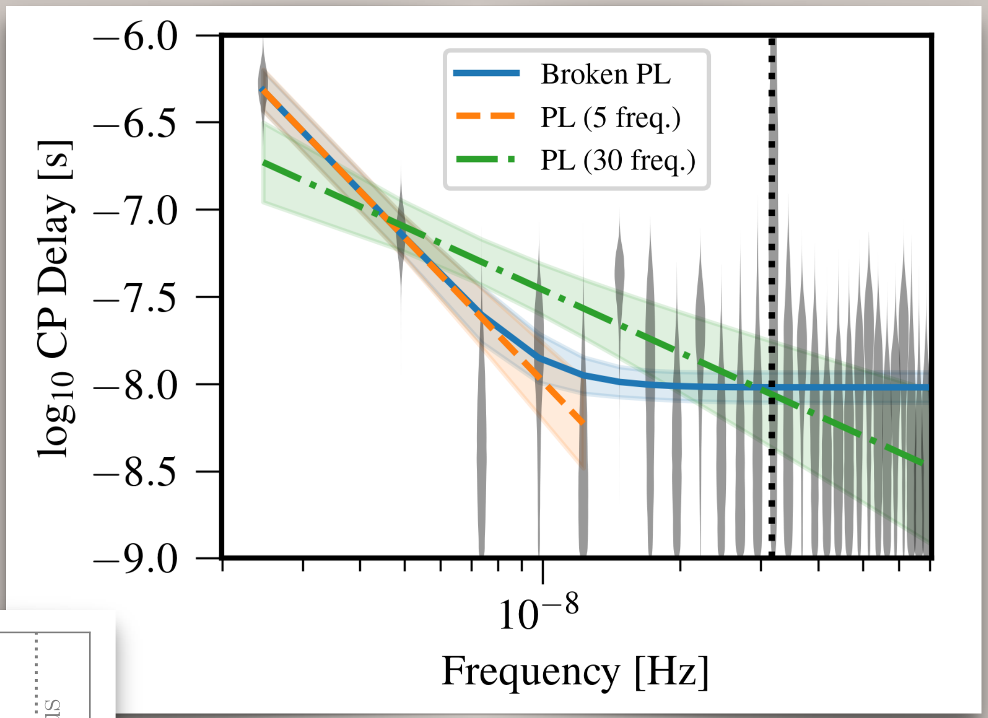
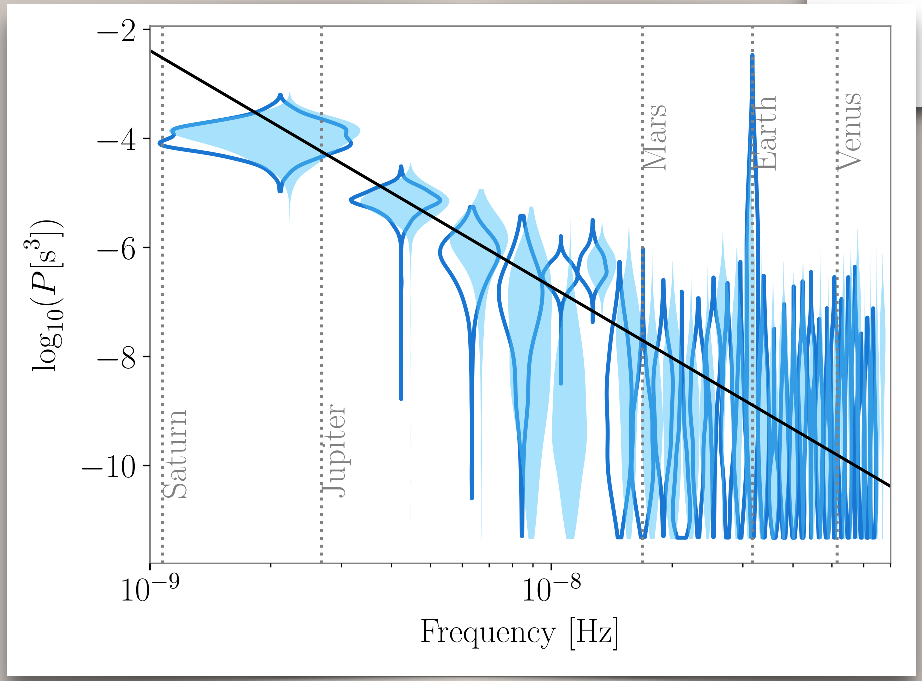


NG 12.5

PPTA DR2



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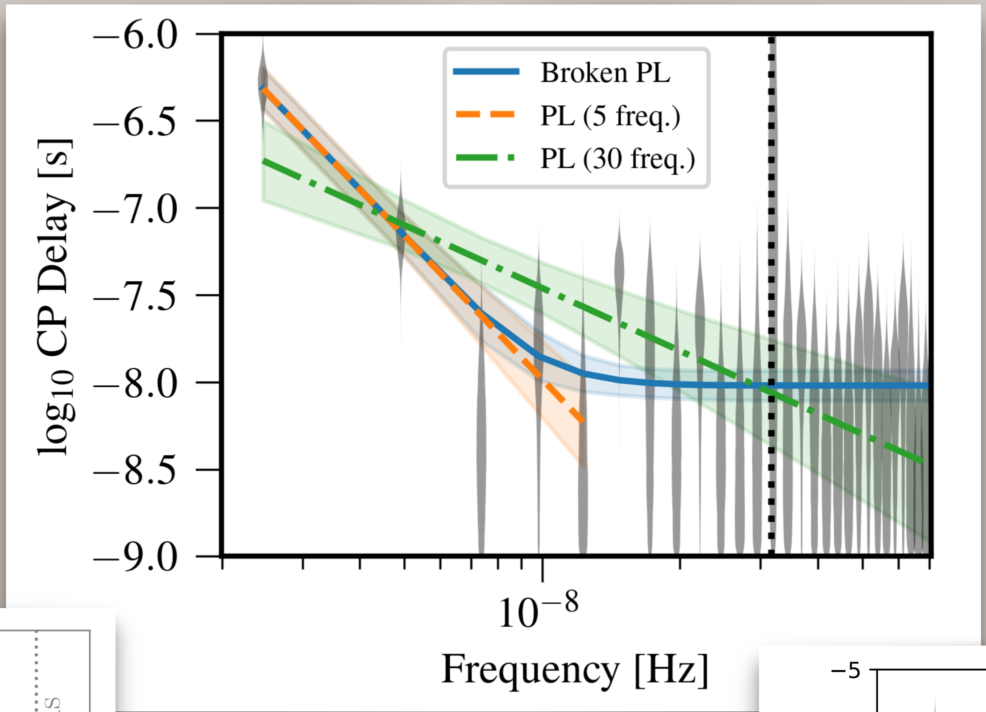

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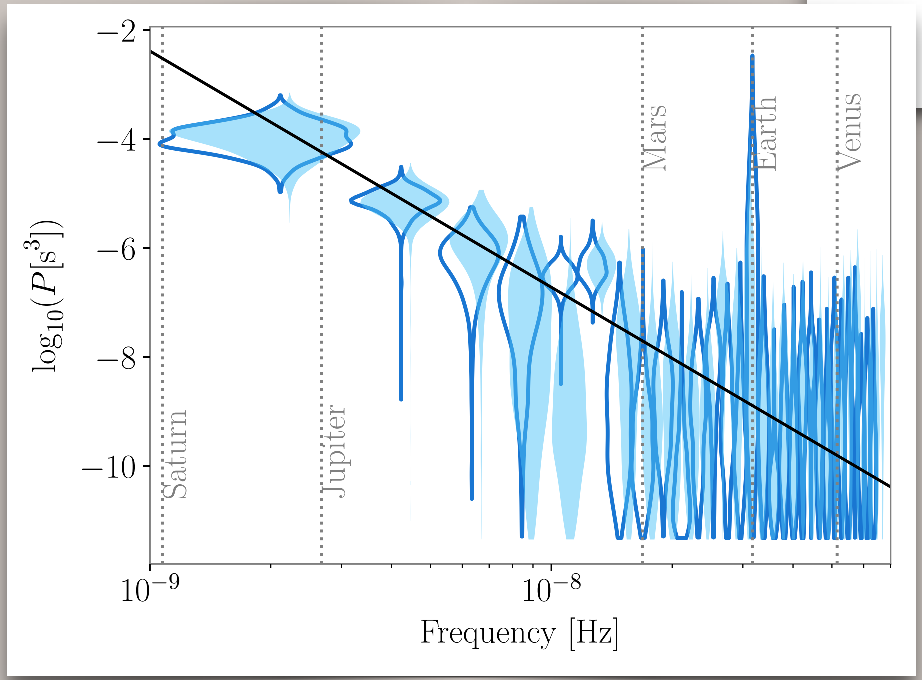
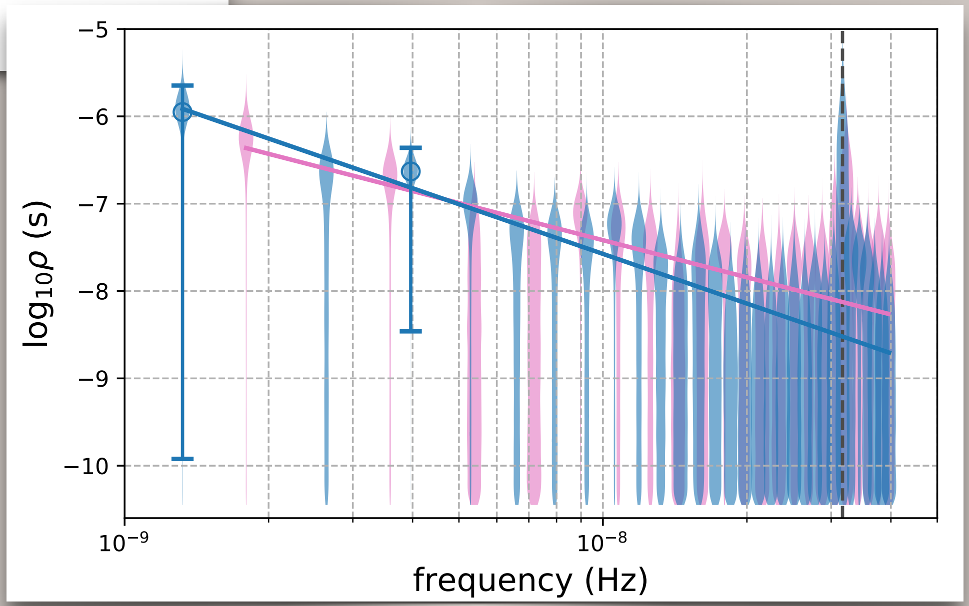


EPTA



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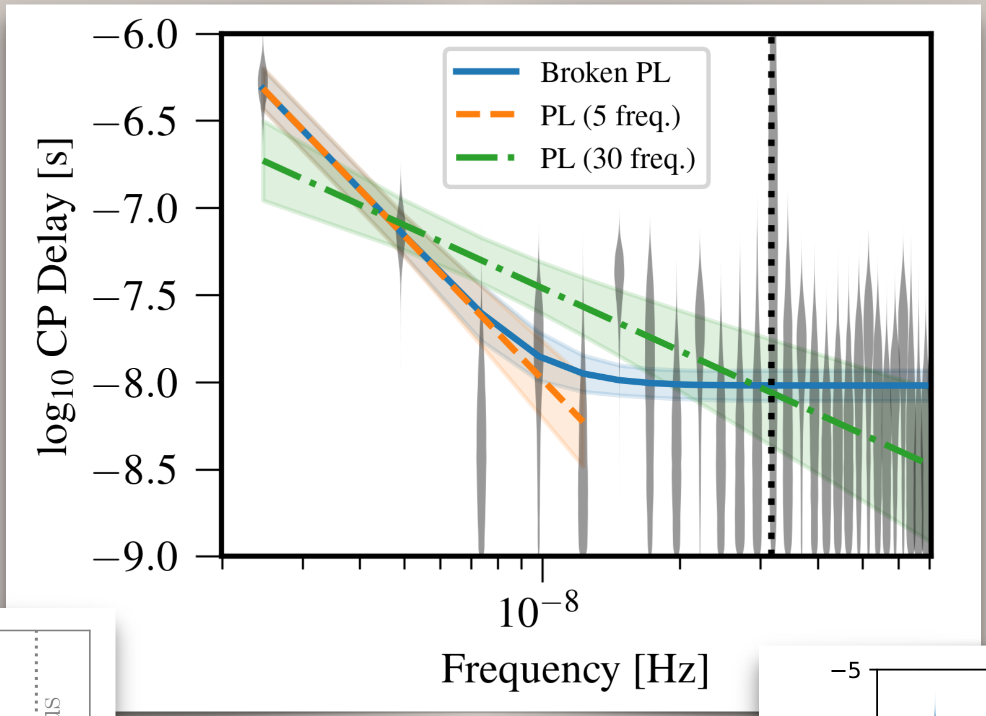

NG 12.5

International PTA DR2,
Based on previous releases
from NG, PPTA, EPTA

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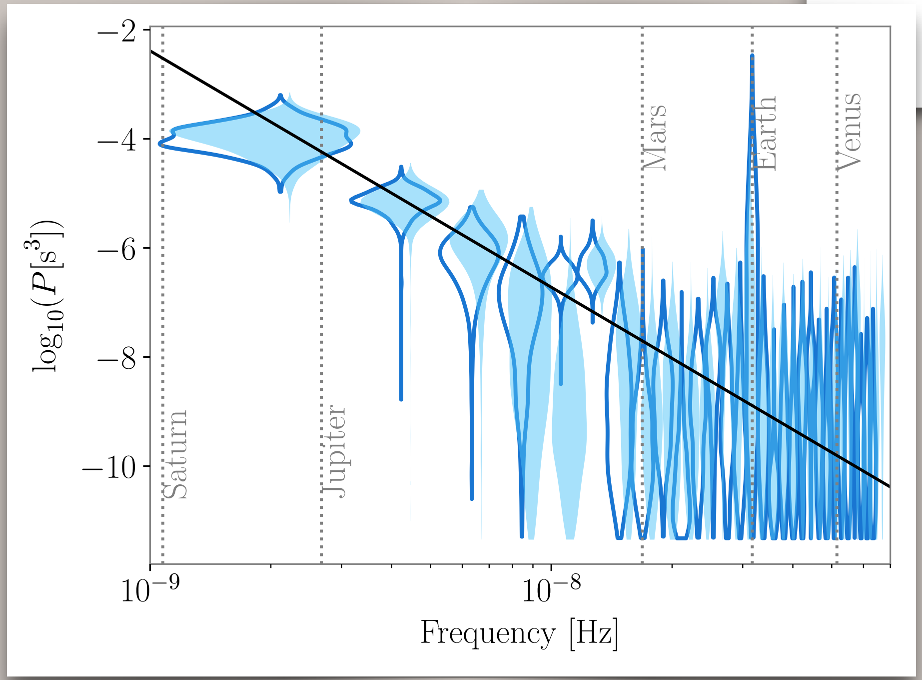

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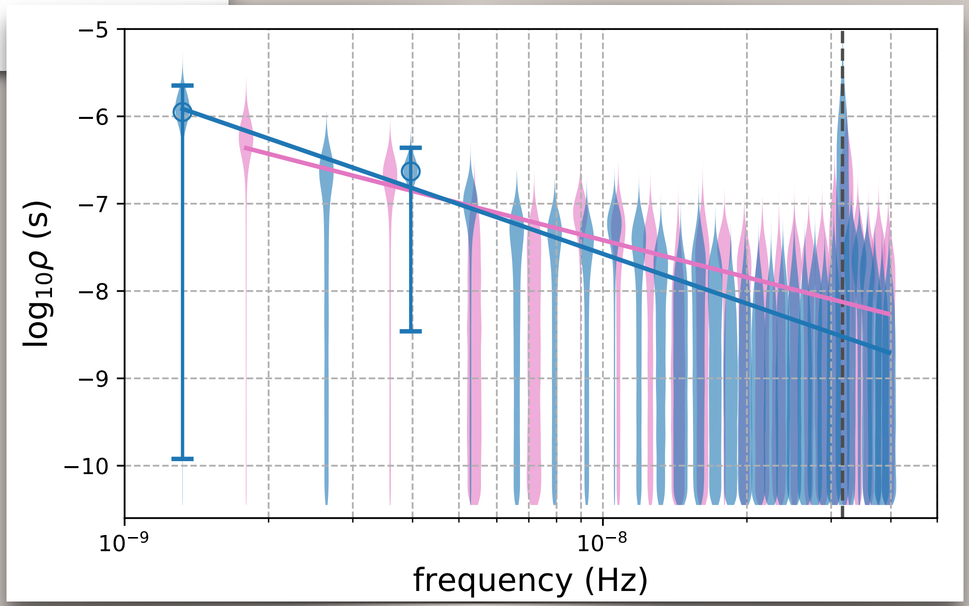

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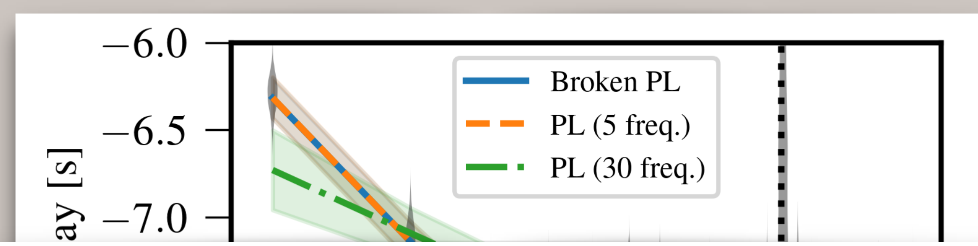

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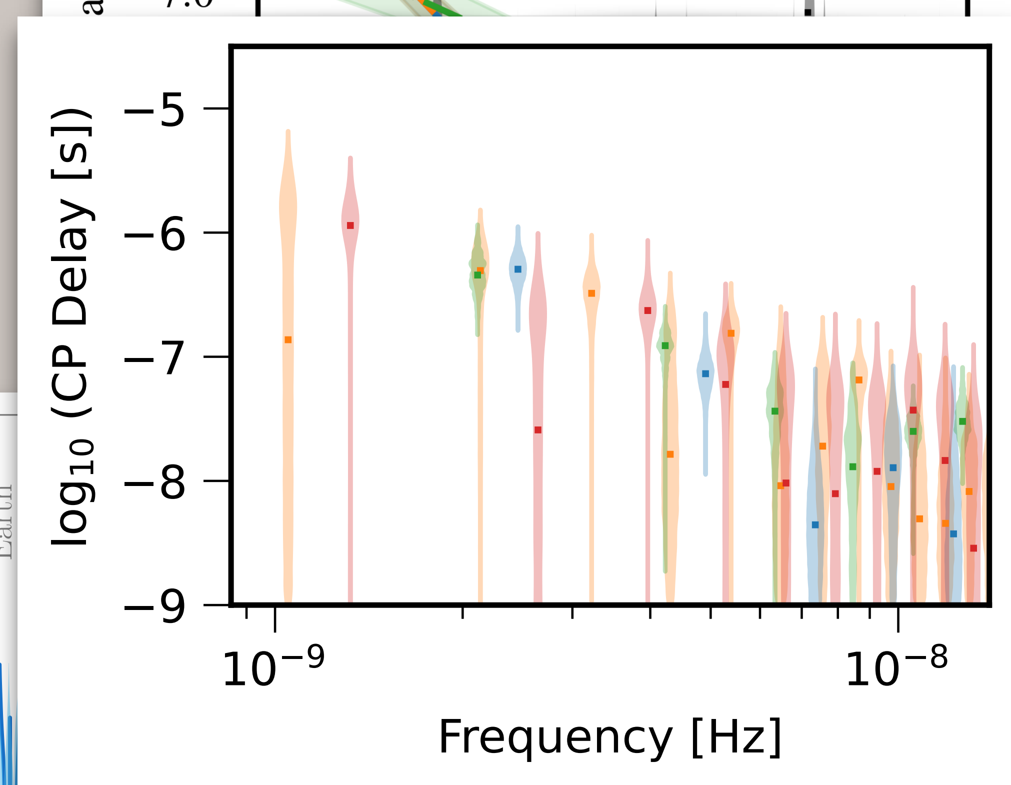

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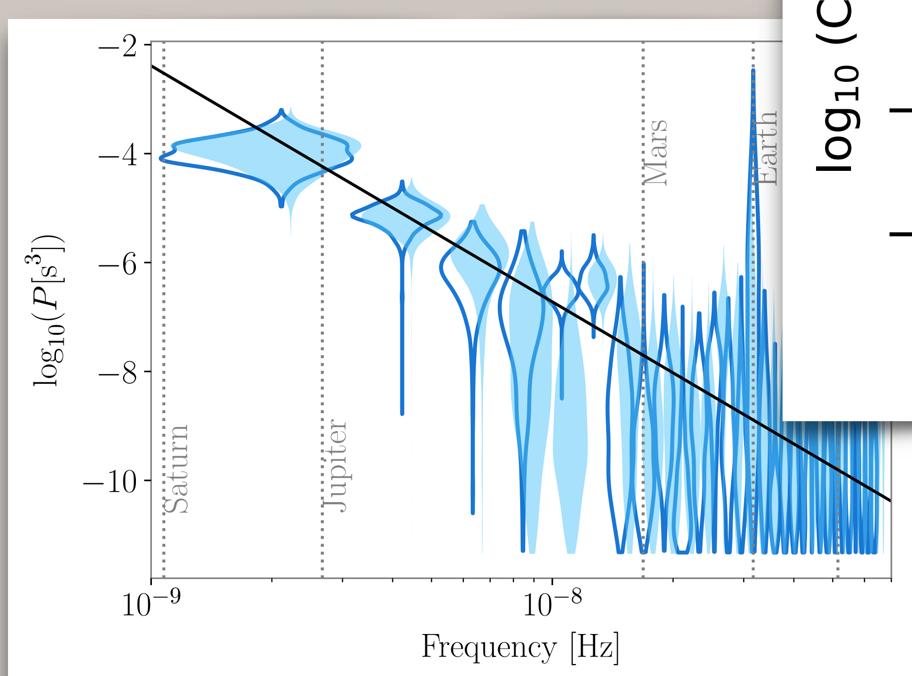

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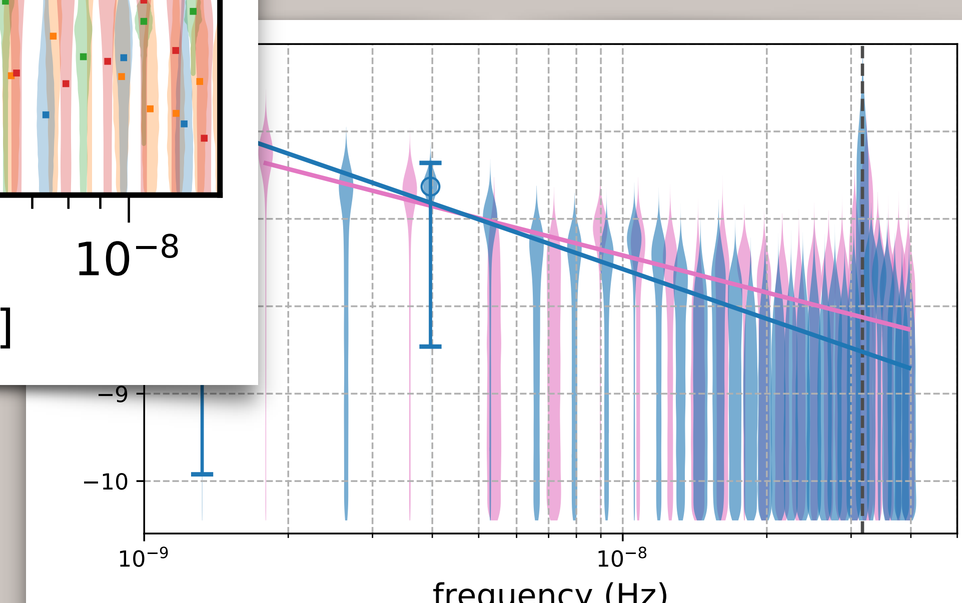
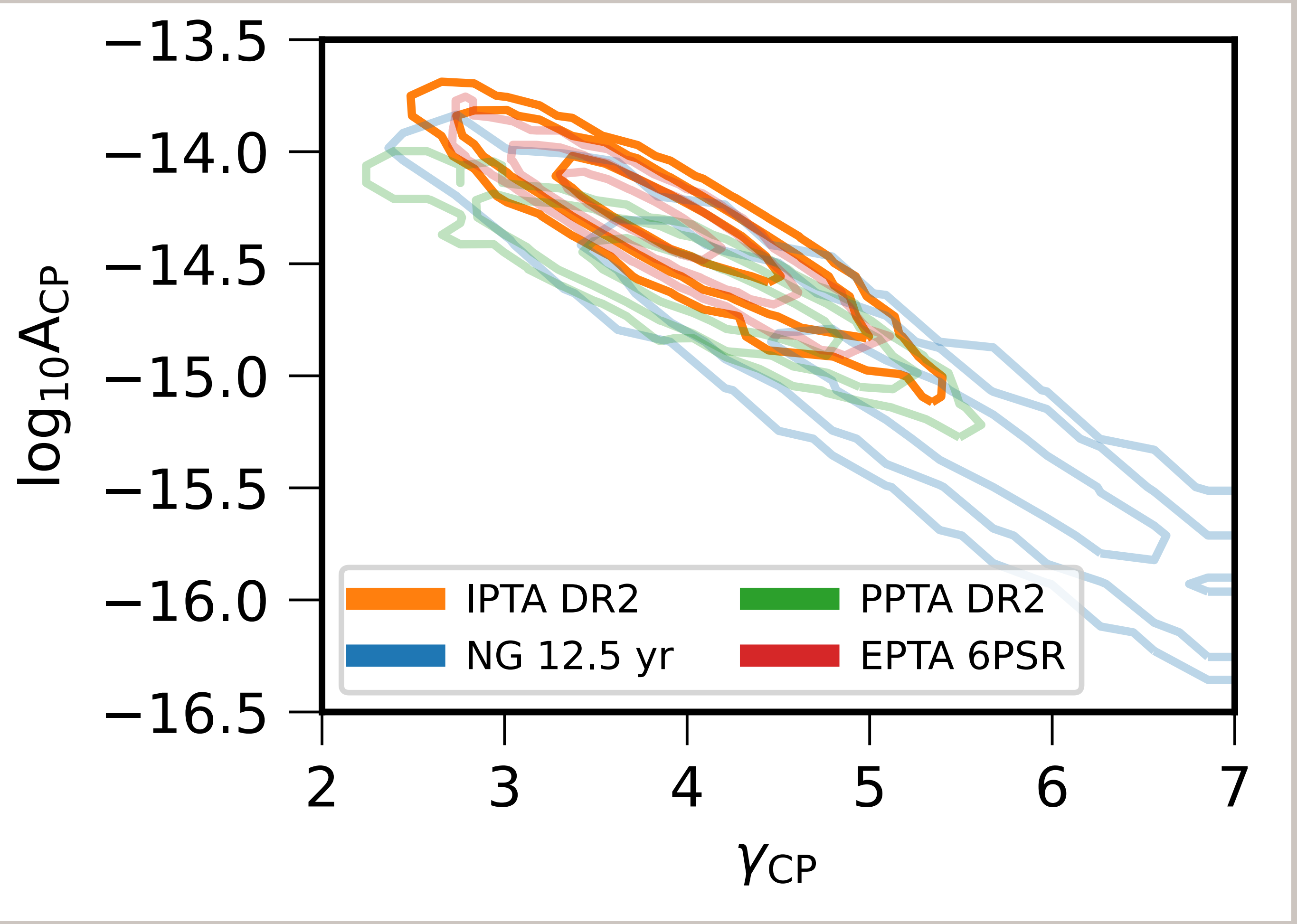


PTA RESULTS

*PTA collaborations model data in terms of **single power-law** signal*

$$S_{ab} = \Gamma_{ab} \frac{A^2_{\rm GWB}}{12\pi^2} \left(\frac{f}{\rm yr^{-1}}\right)^{-\gamma} {\rm yr}^3 \longrightarrow \Omega_{\rm GW} h^2 \sim f^{5-\gamma}$$



IPTA DR2, 2201.03980

***Caveat:** not yet complete evidence of GW, since Hellings-Downs correlation not detected yet*

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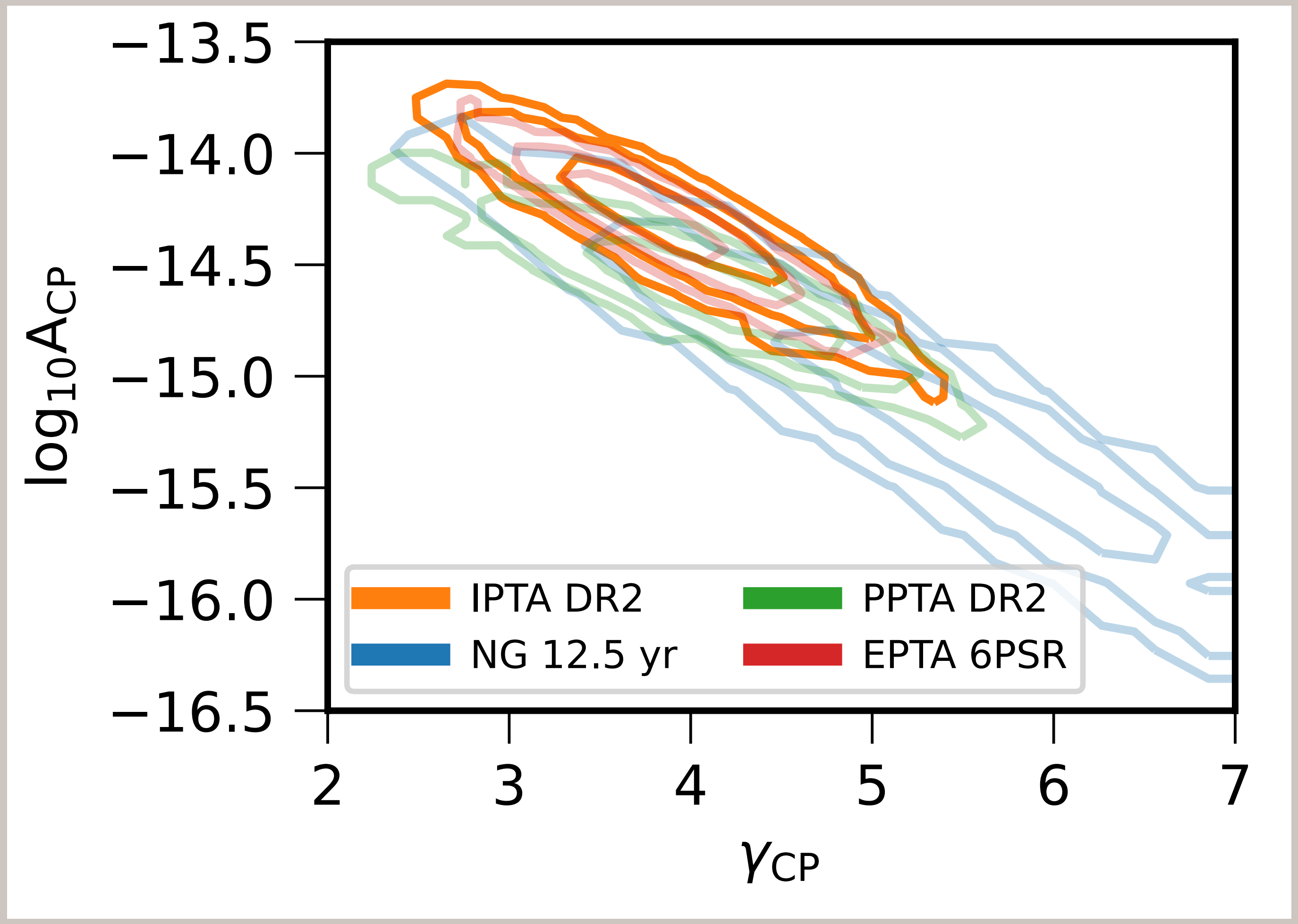
Broadly consistent results from all PTAs



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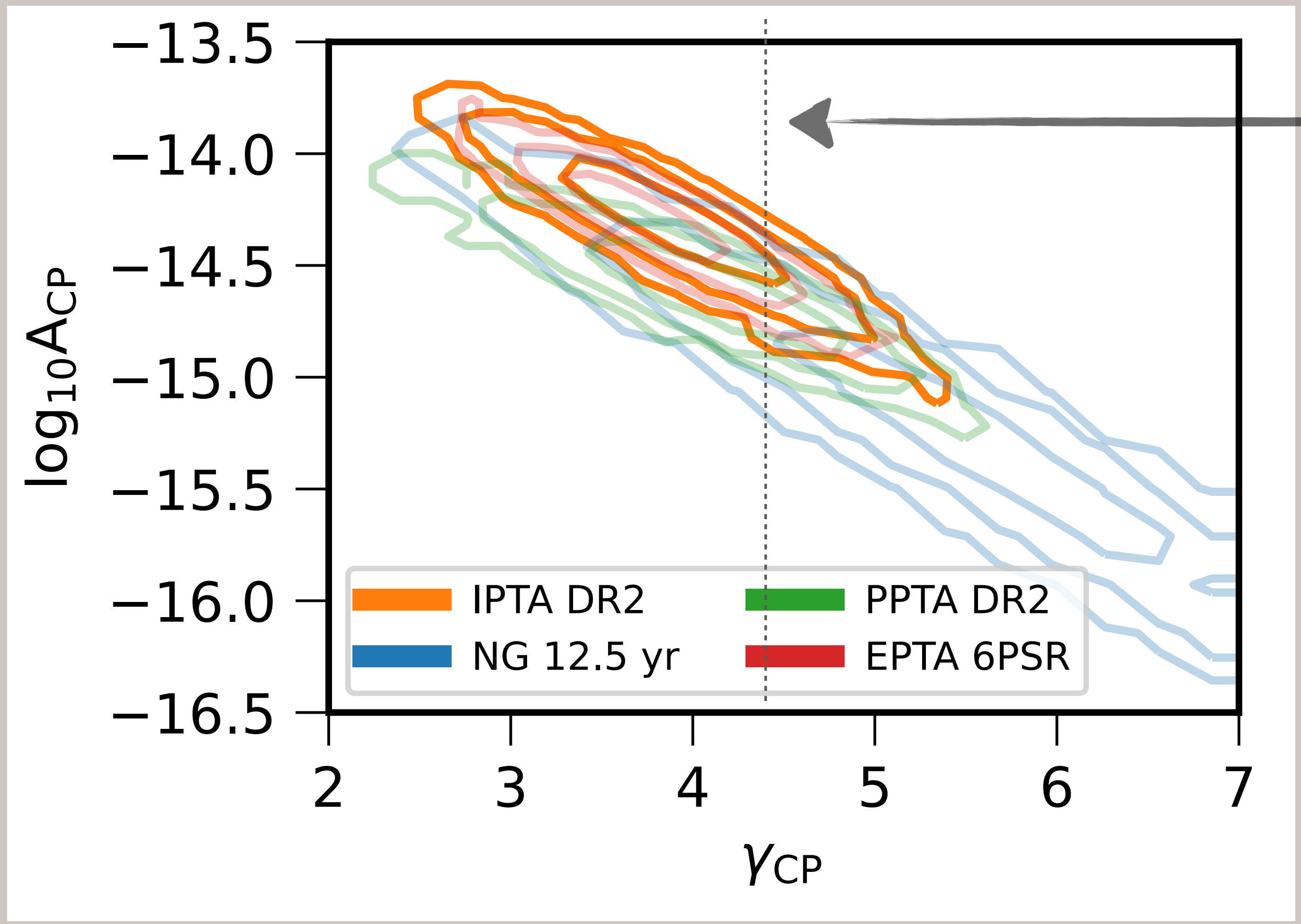

$\gamma = 13/3$

Expected slope from SMBH binaries (O(10⁶) solar masses), assuming circular orbits and evolution dominated by gravitational radiation

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SEARCH FOR GWS FROM DOMAIN WALLS

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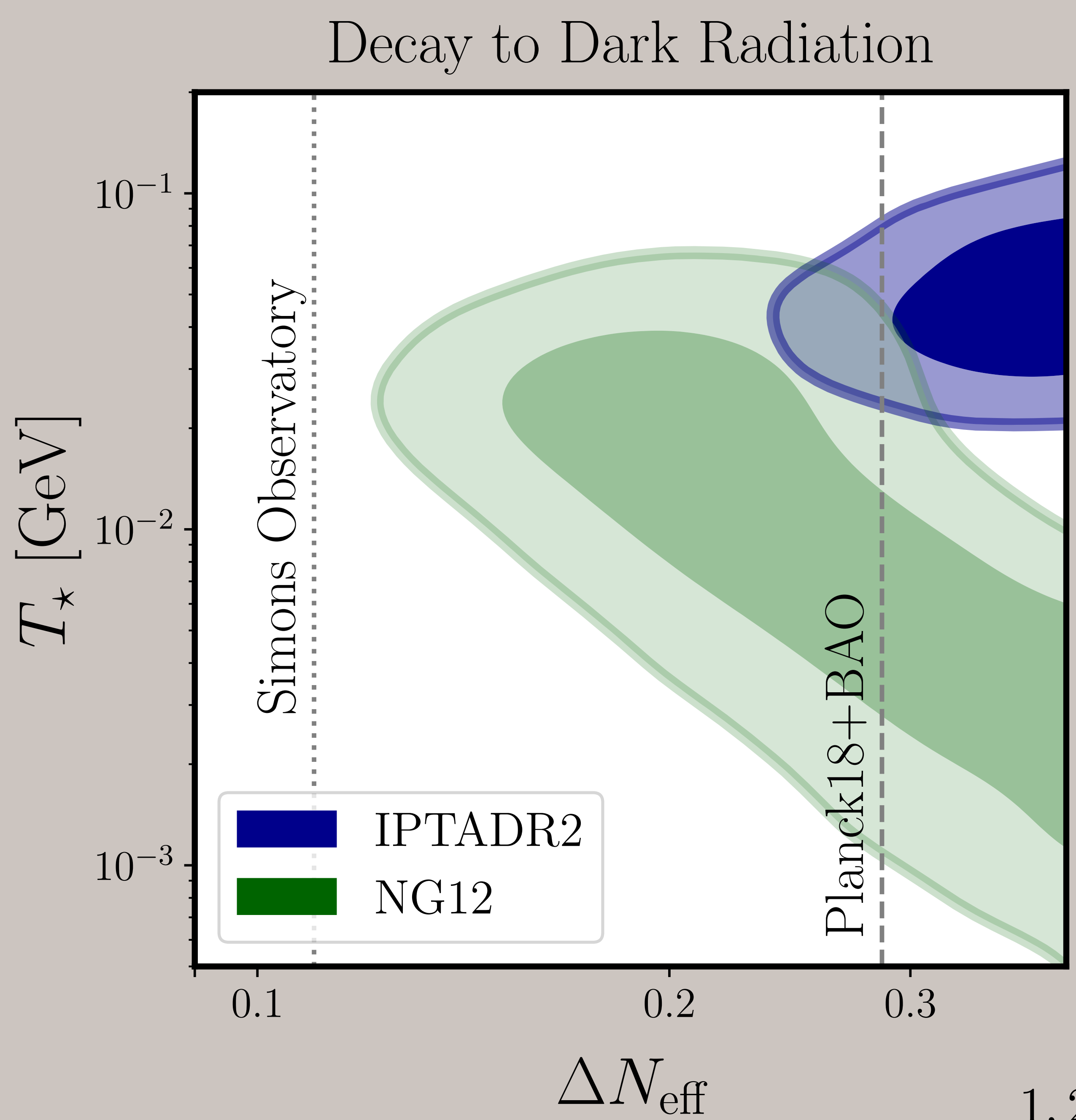

$1, 2\sigma$ contours

Signal correlated with detectable dark radiation (2sigma) at Simons Observatory

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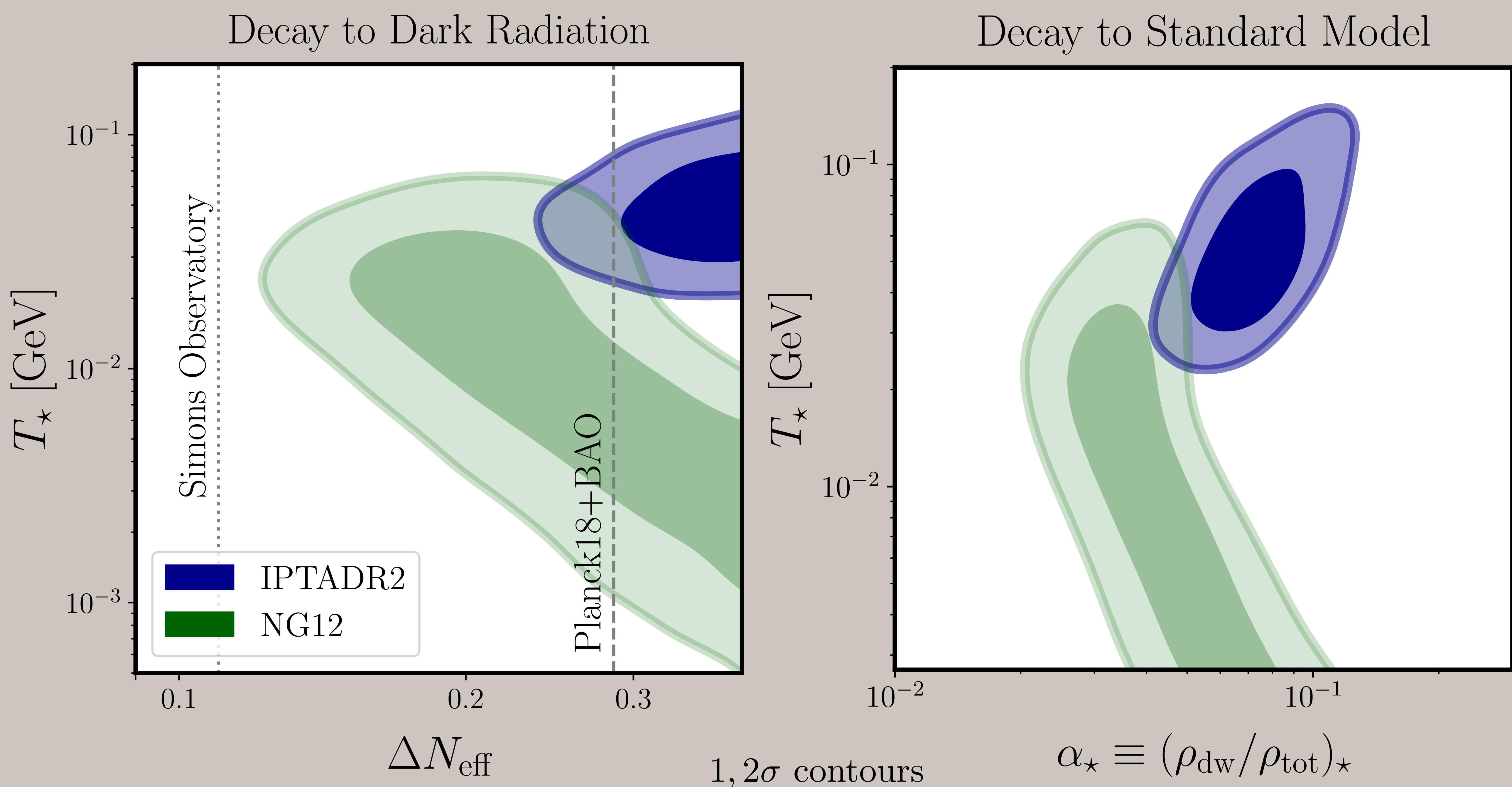

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DOMAIN WALLS IN PTA DATASETS

See also NANOgrav, PPTA searches for first order phase transitions, Bian 20, Wang 21,22 for other searches

We performed the first "early Universe" search in multiple datasets (NG 12.5 yrs and IPTA DR2)

$$\Omega_{\mathrm{GW,\ DW}}(f)h^2 \simeq 10^{-10}\tilde{\epsilon}\left(\frac{10.75}{g_*(T_\star)}\right)^{\frac{1}{3}}\left(\frac{\alpha_\star}{0.01}\right)^2 S(f/f_p^0)$$

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High frequency slope (β)

Width of peak (δ)

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High frequency slope

Width of peak

$$\delta, \beta \simeq 1$$

From simulations (Hiramatsu et al 13), Mild dependence on Ndw

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High frequency slope

Width of peak

Low frequency slope fixed by causality

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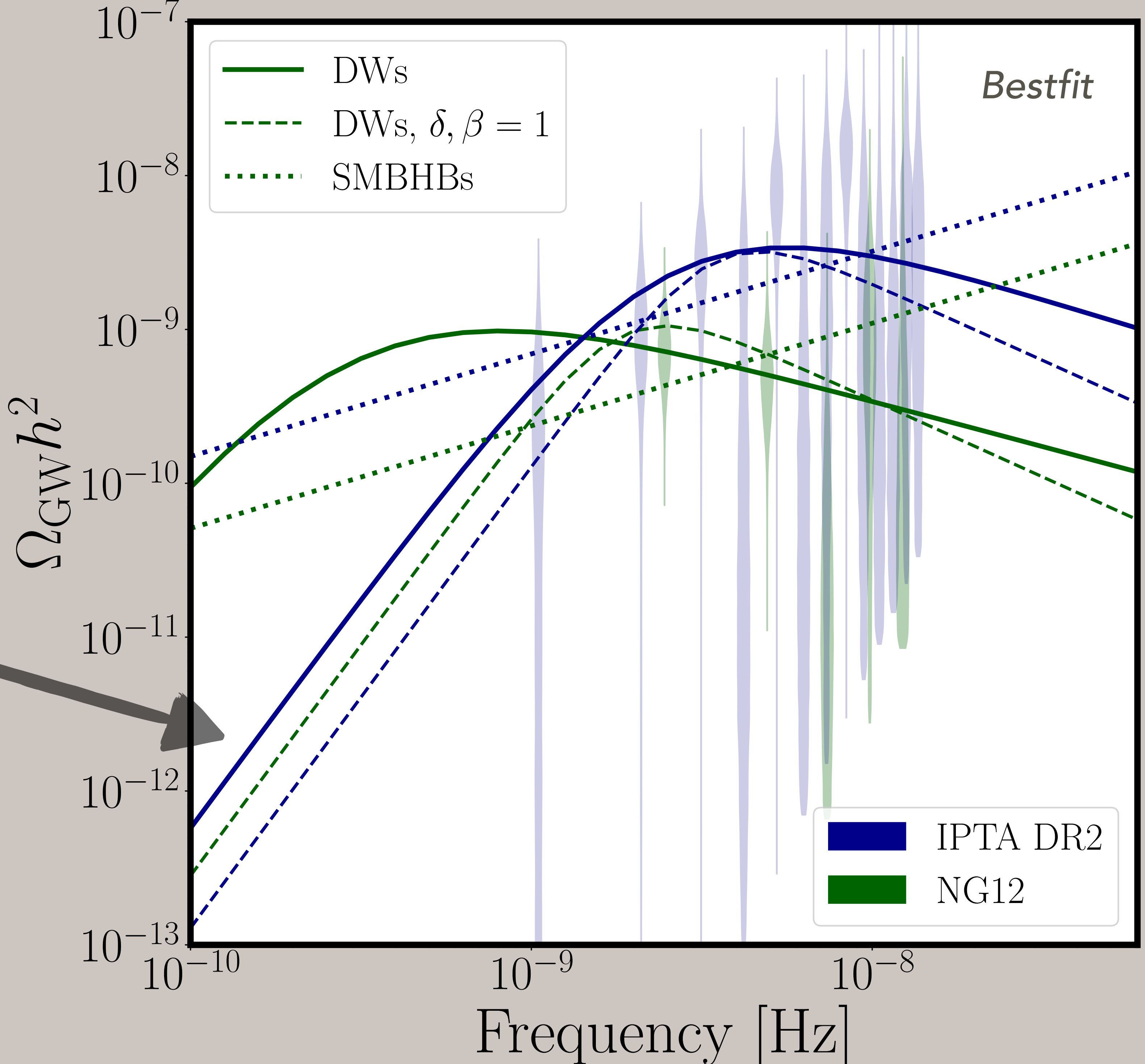
SEARCH FOR GWS FROM DOMAIN WALLS

$\sim f^3$

By causality



IPTA DR2 prefers region around peak,
NG 12.5 the large frequency tail

DOMAIN WALLS IN PTA DATASETS

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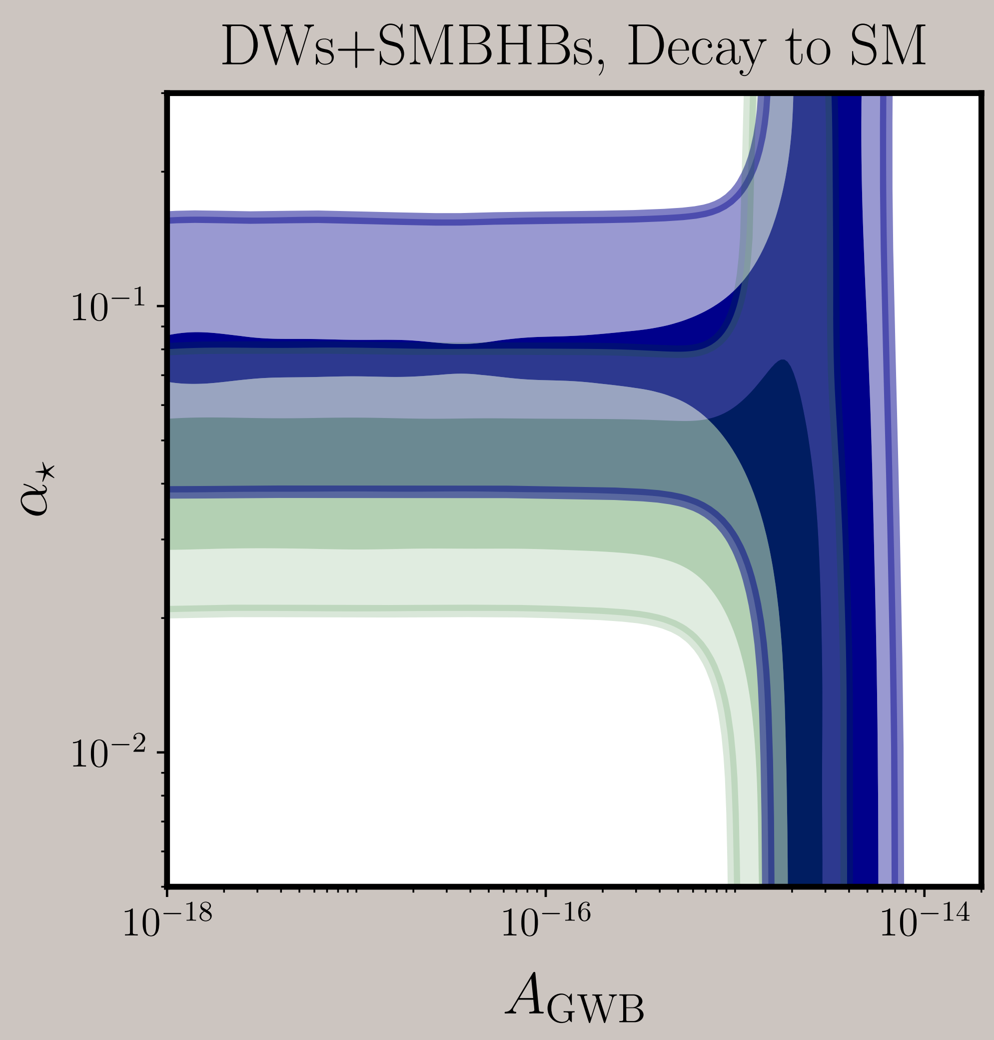

Including stochastic GWs from SMBH binaries, marginalising over other parameters

Both sources fit data equally well!

$1, 2\sigma$ contours

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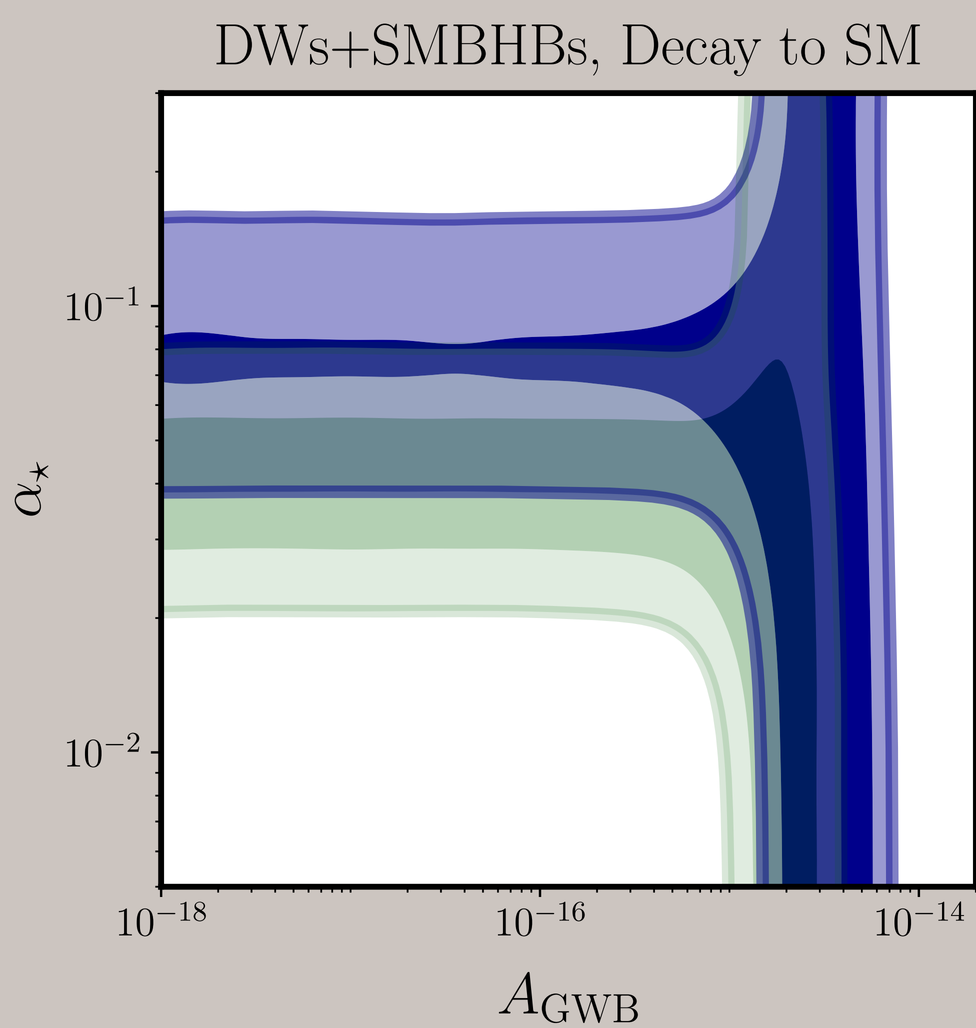

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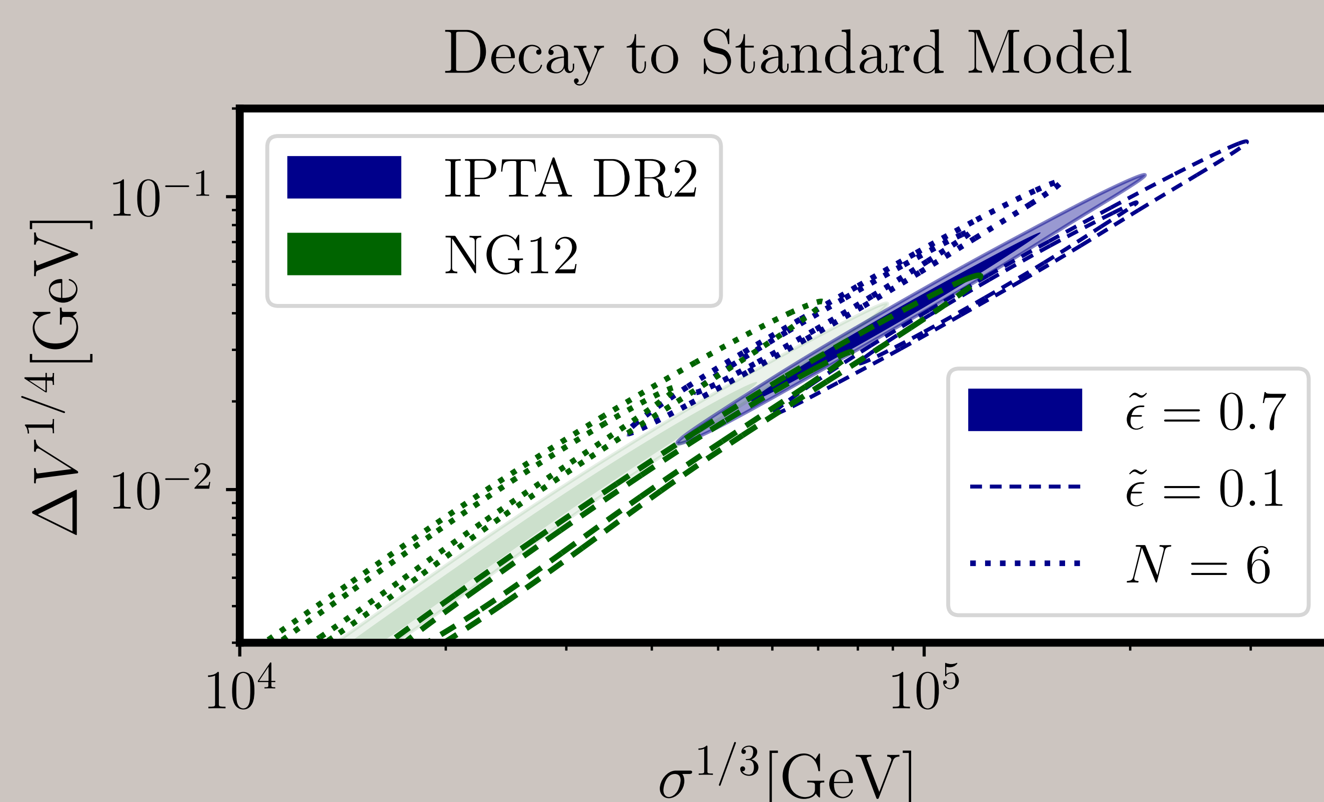

10-100 TeV scale is suggested for models with heavy scalars

Scale of explicit symmetry breaking around scale of QCD!

HEAVY AXION INTERPRETATION

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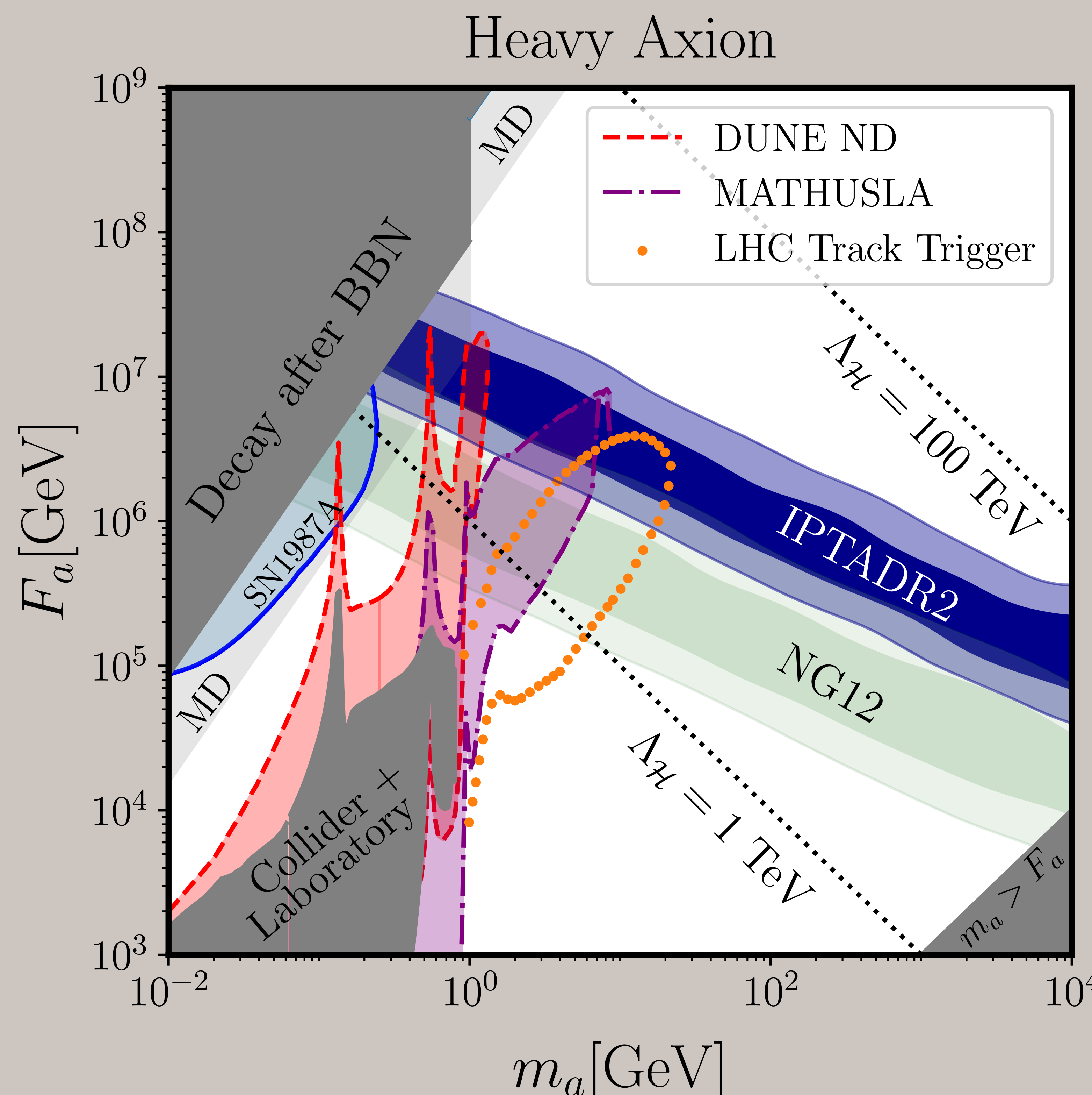
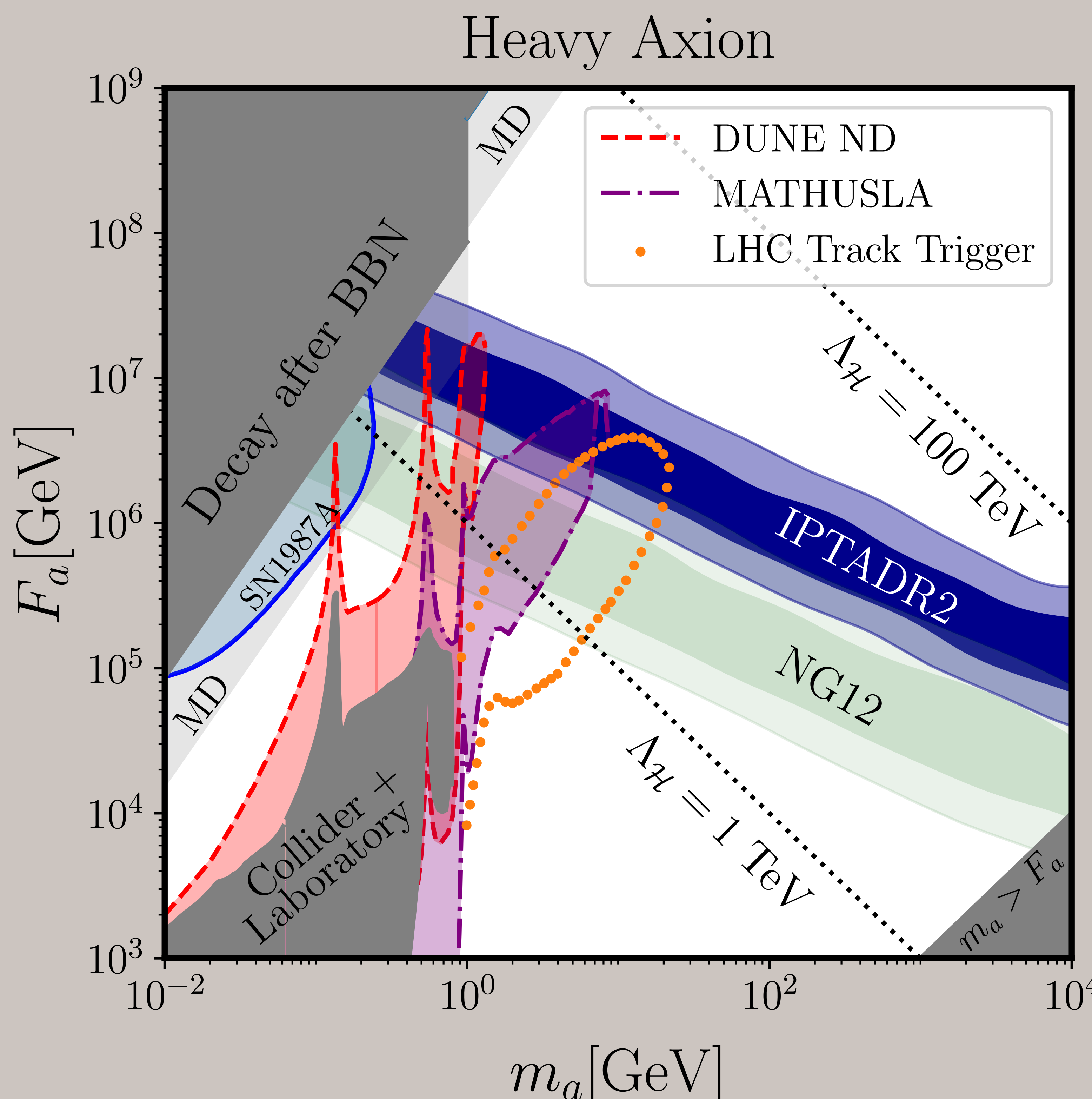
$$m_a \simeq \frac{\Lambda_{\mathcal{H}}^2}{F_a}$$



HEAVY AXION INTERPRETATION

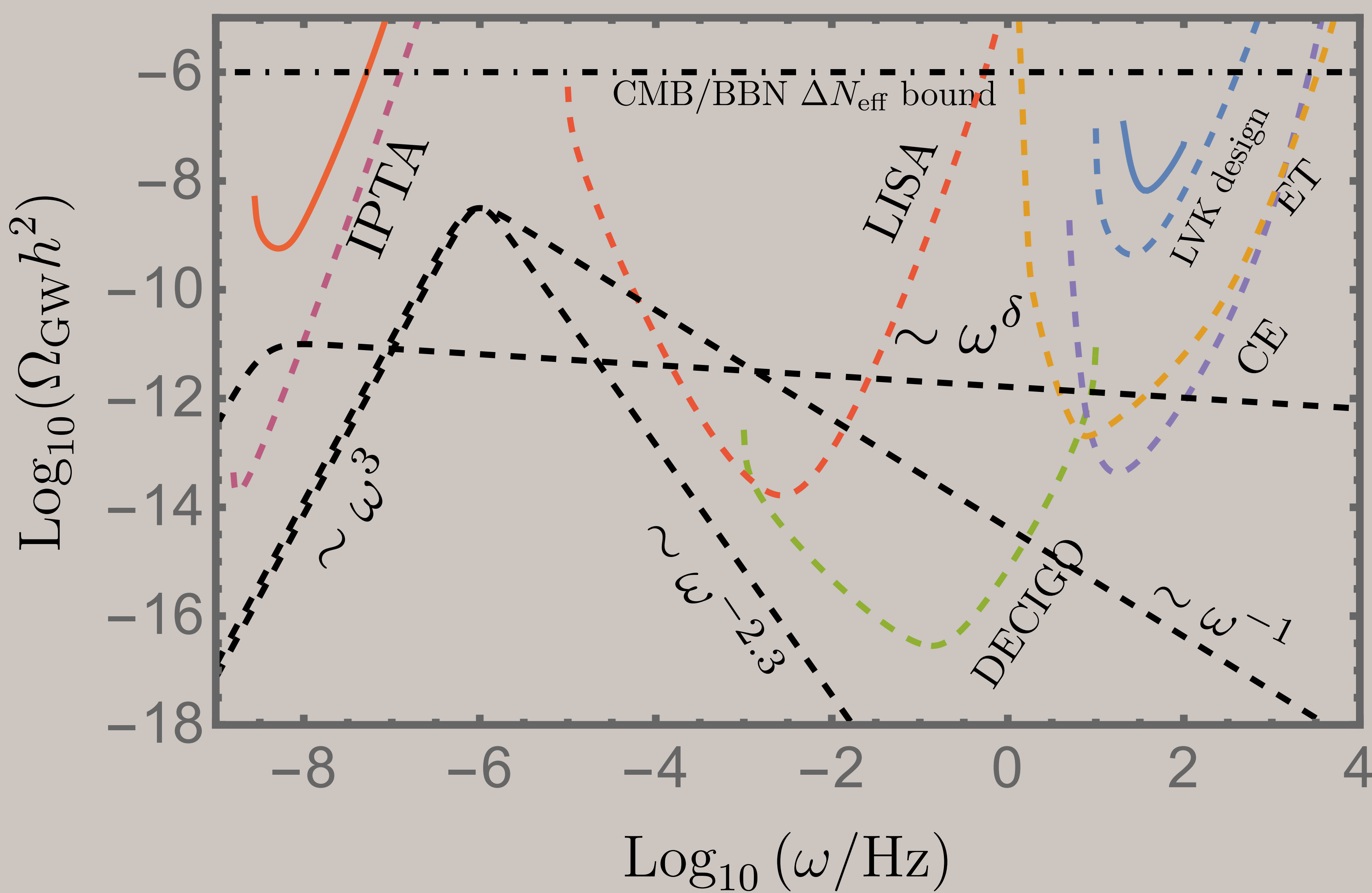
$$m_a \simeq \frac{\Lambda_{\mathcal{H}}^2}{F_a}$$

1-100 TeV scale suggested for Heavy confining dark sector which generate axion potential



BACKUP

GW SIGNALS


CMB/BBN ΔN_{eff} bound
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$\sim \omega^3$
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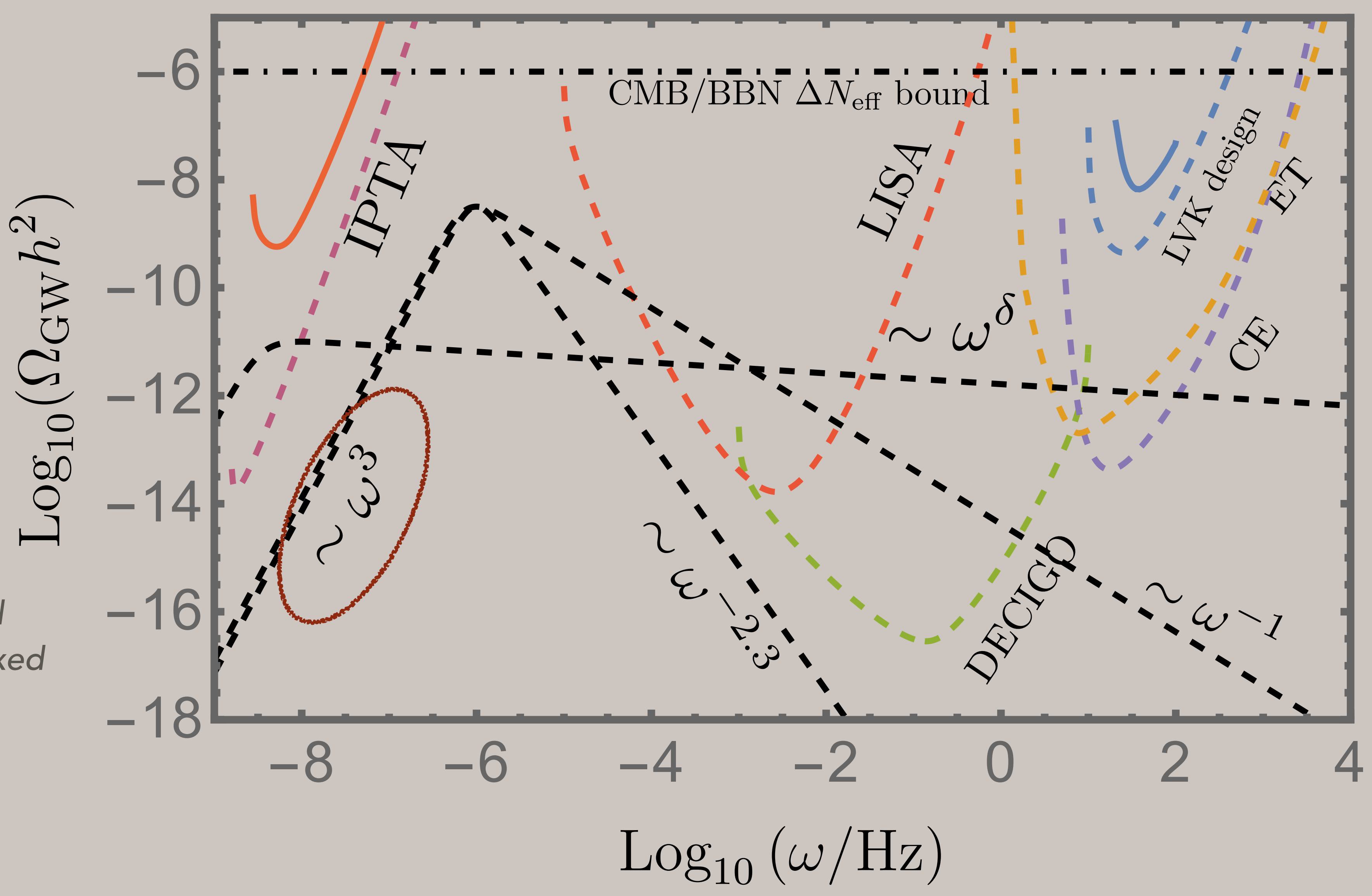
$\sim \omega^{\delta}$
$\sim \omega^{-1}$
$\mathrm{Log}_{10}(\Omega_{\mathrm{GW}}h^2)$
$\mathrm{Log}_{10}(\omega/\mathrm{Hz})$
−6
−8
−10
−12
−14
−16
−18
−8
−6
−4
−2
0
2
4

GW SIGNALS



Slope at small frequencies is fixed by causality

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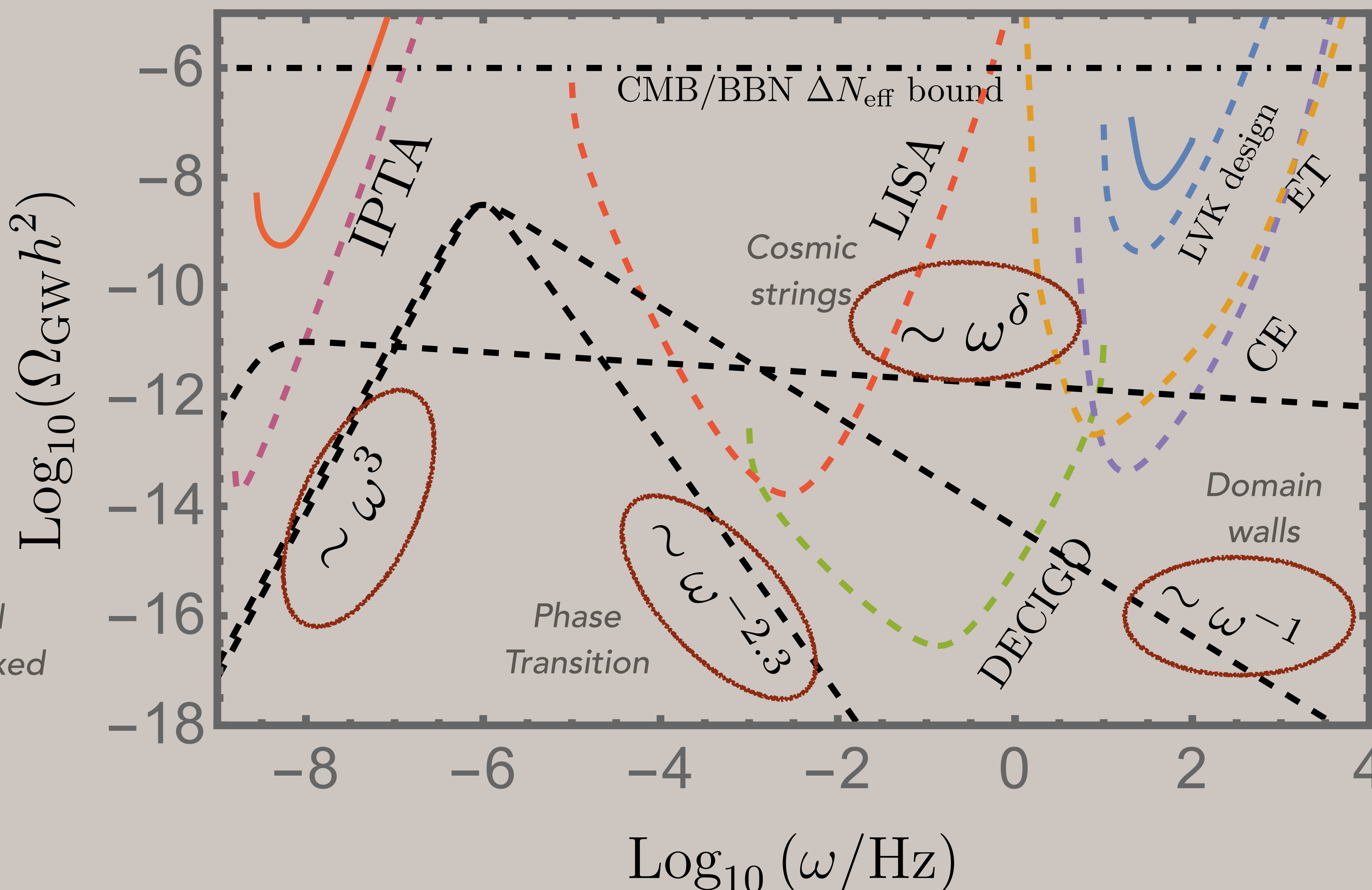

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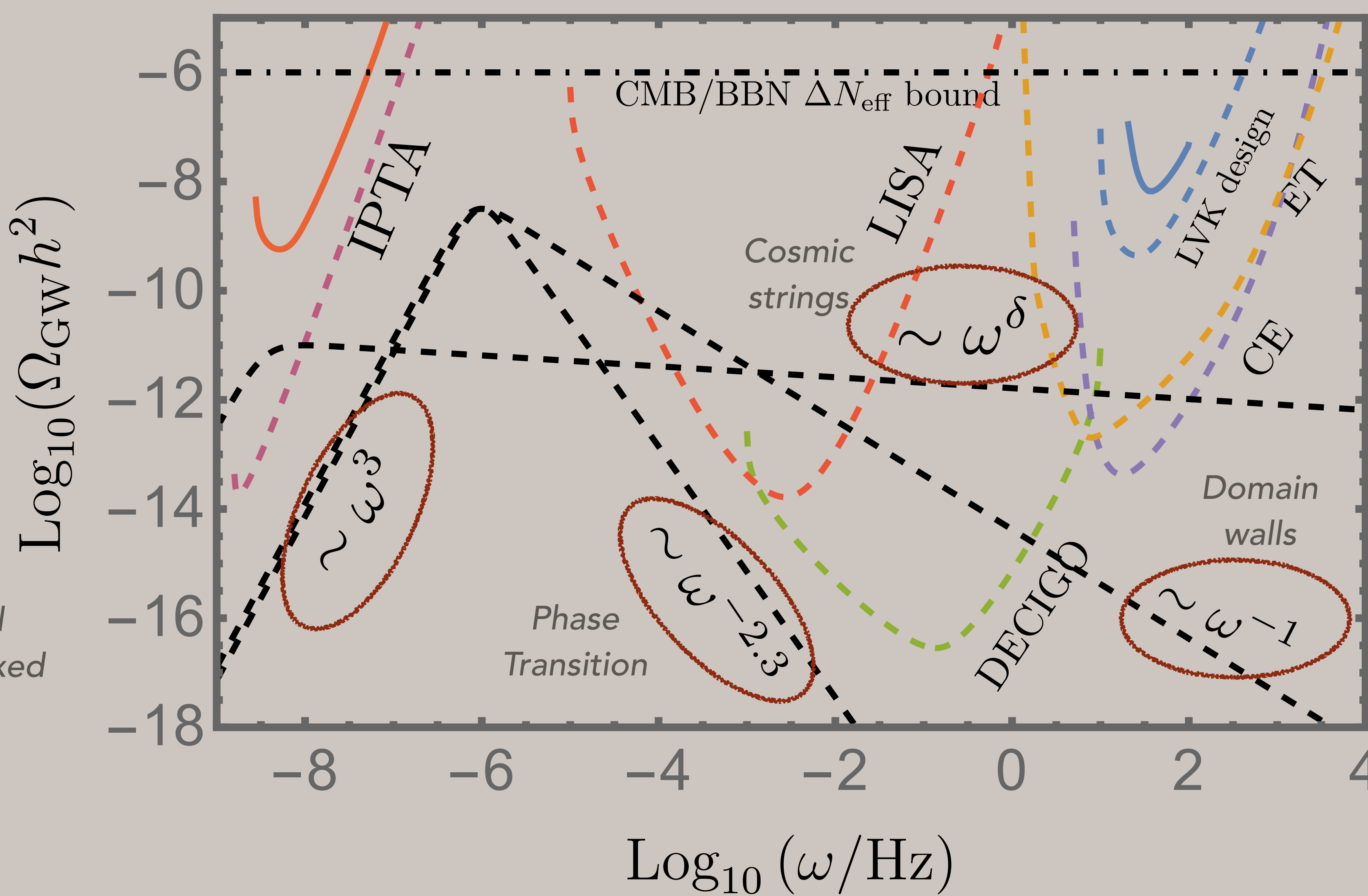

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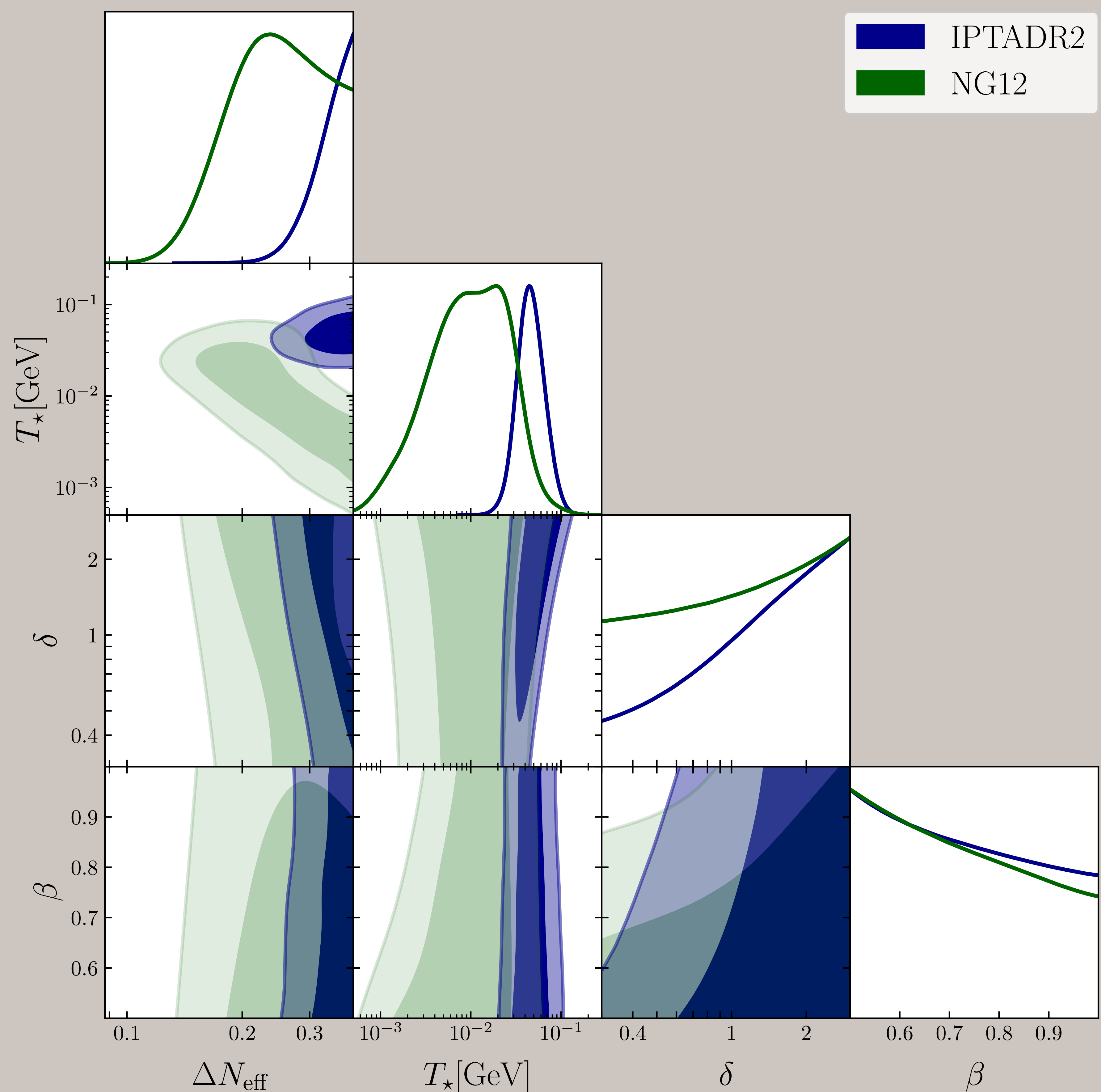
CURRENT (FUTURE) GW OBSERVATORIES **CAN DISCOVER** SOURCES THAT MAKE UP AT LEAST $\gtrsim 5\% (0.1\%)$ OF THE BACKGROUND ENERGY DENSITY!



IPTADR2
NG12
$T_\star$[GeV]
10^{-1}
10^{-2}
10^{-3}
δ
2
1
0.4
β
0.9
0.8
0.7
0.6
0.1
0.2
0.3
$\Delta N_{\rm eff}$
10^{-3}
10^{-2}
10^{-1}
$T_\star$[GeV]
0.4
1
2
δ
0.6
0.7
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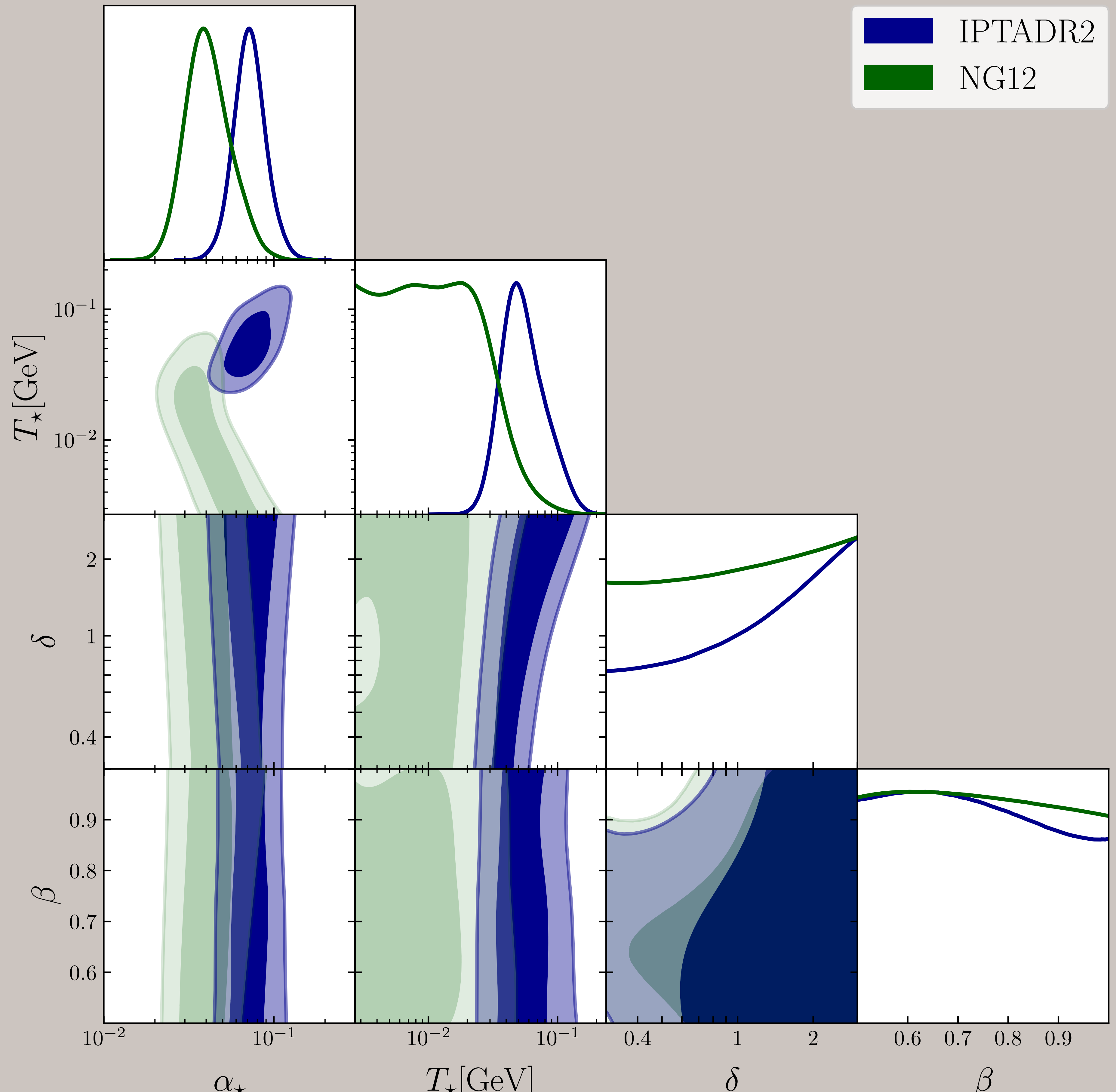
0.9
β



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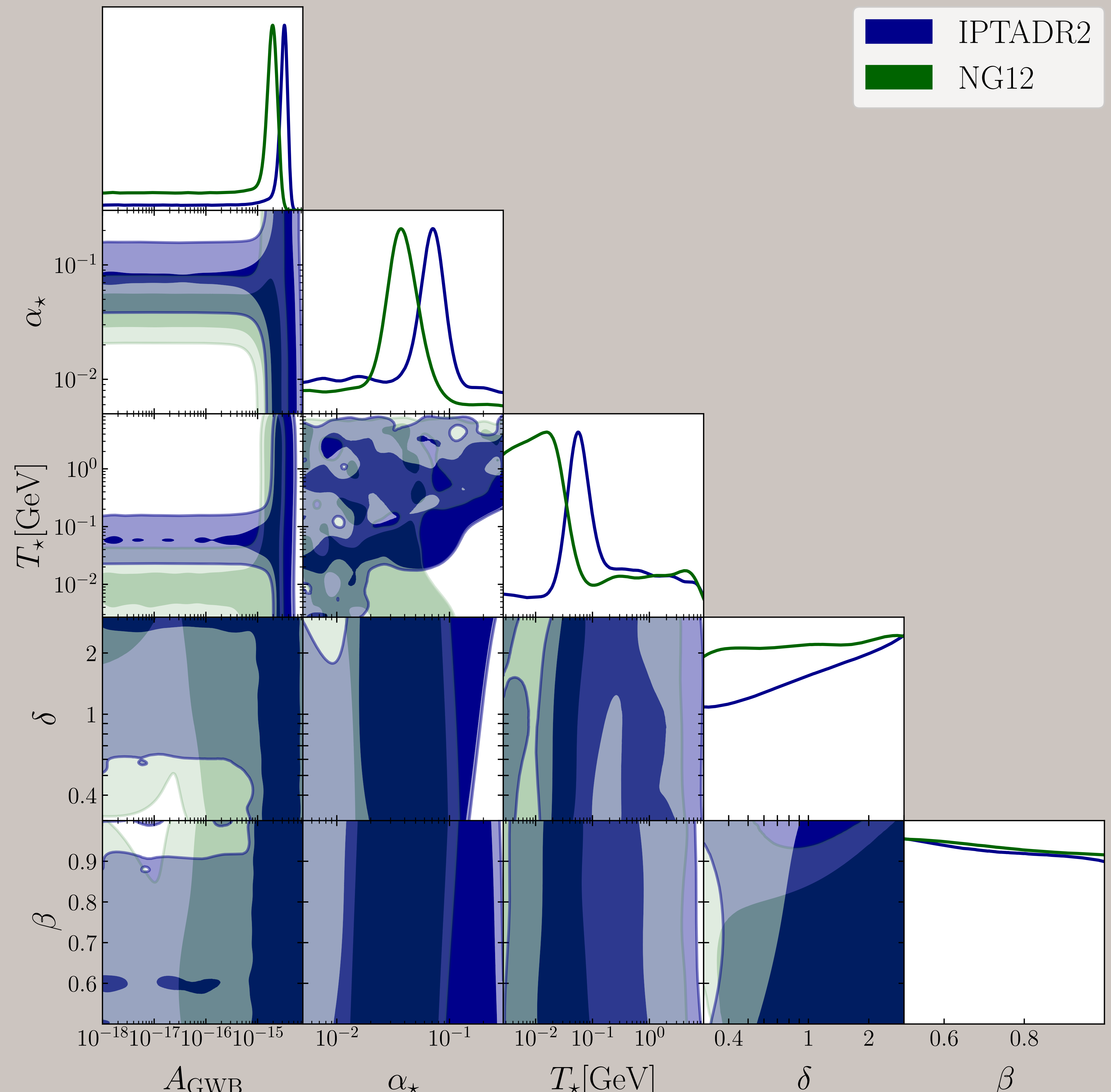
0.6
10^{-2}
10^{-1}
10^{-2}
10^{-1}
0.4
1
2
0.6
0.7
0.8
0.9
$\alpha_\star$
$T_\star$[GeV]
δ
β



IPTADR2
NG12
$\alpha_\star$
$T_\star$[GeV]
δ
β
$A_{\rm GWB}$

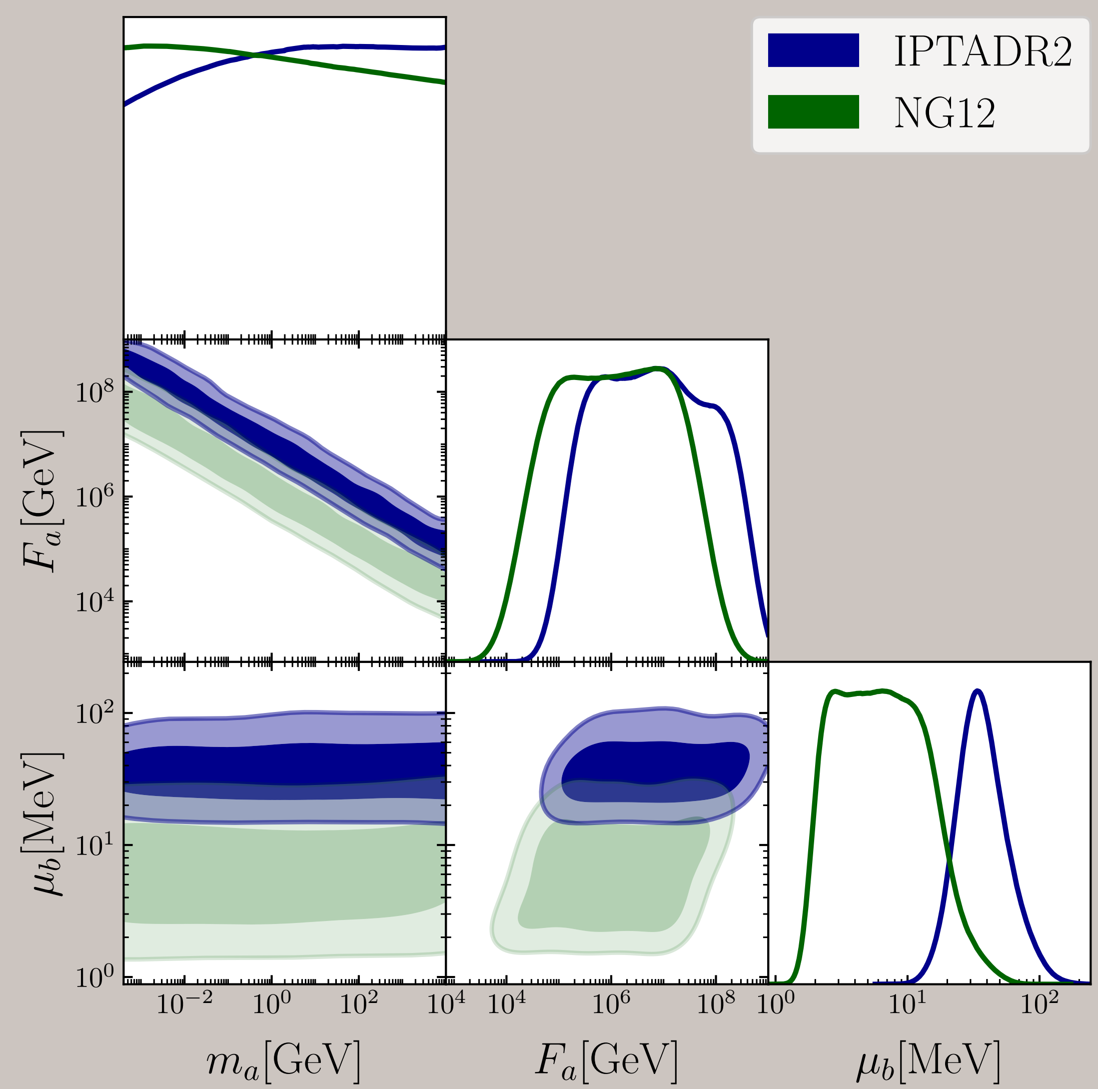
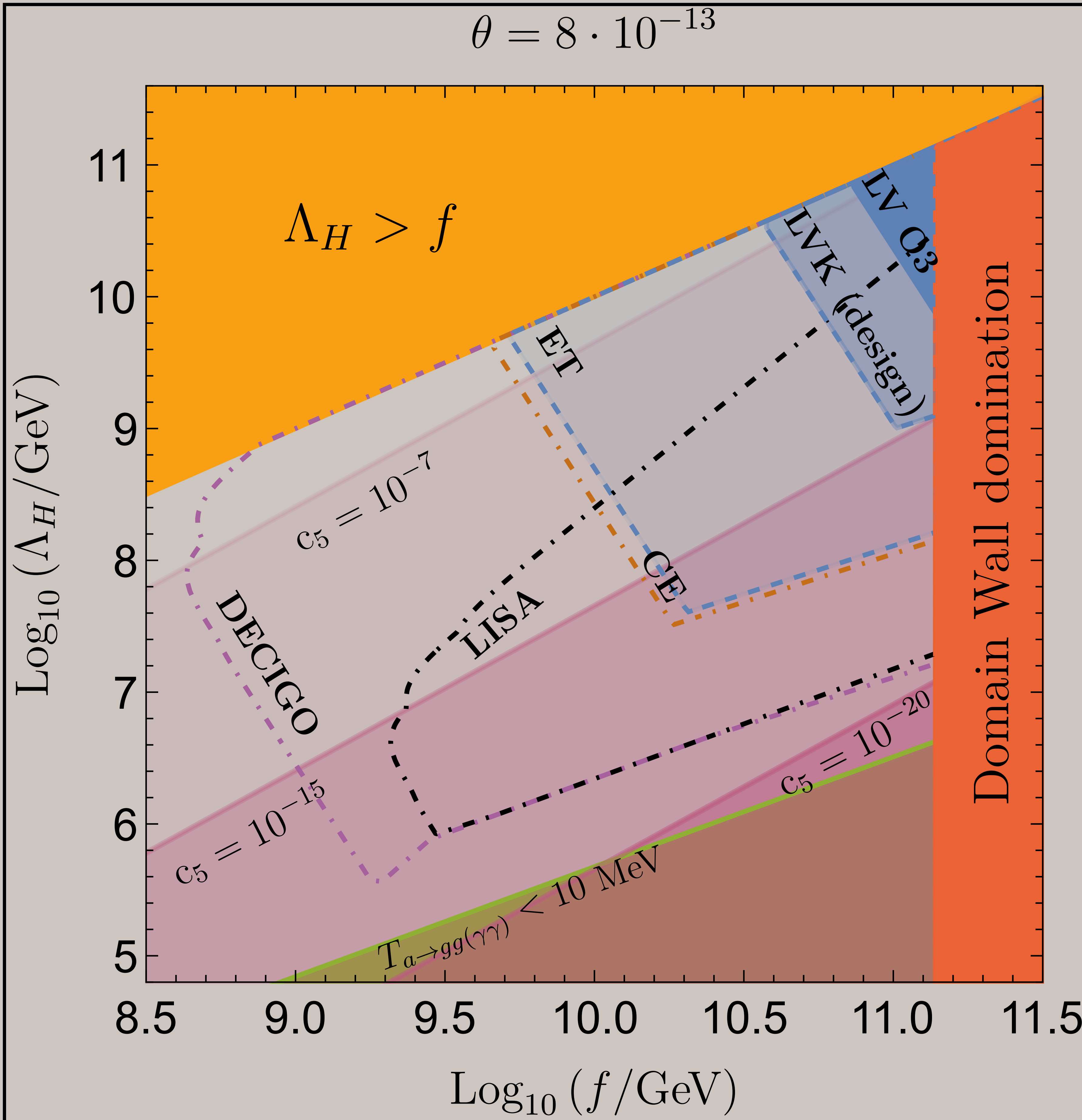


Figure 8. One and Two-dimensional posterior distributions, with 1σ and 2σ contours, of the parameters describing GWs from heavy axion DWs. The posteriors on the size of the gap energy $\mu_b^{1/4}$ are obtained using (6) and (B3).

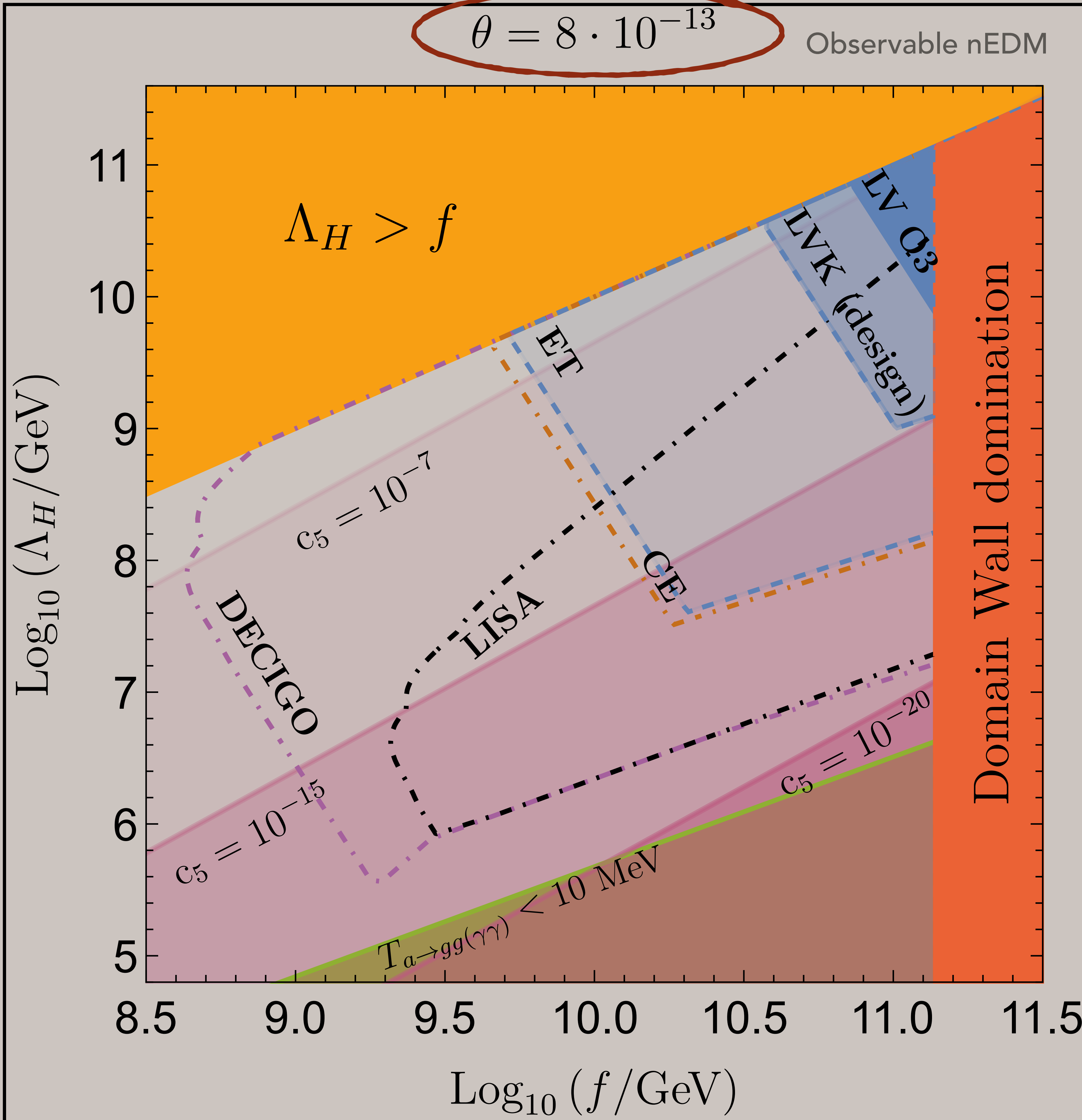


2107.07542

$$\Delta V \sim c_5 \frac{\mathcal{O}_5}{\Lambda_{\rm UV}}$$

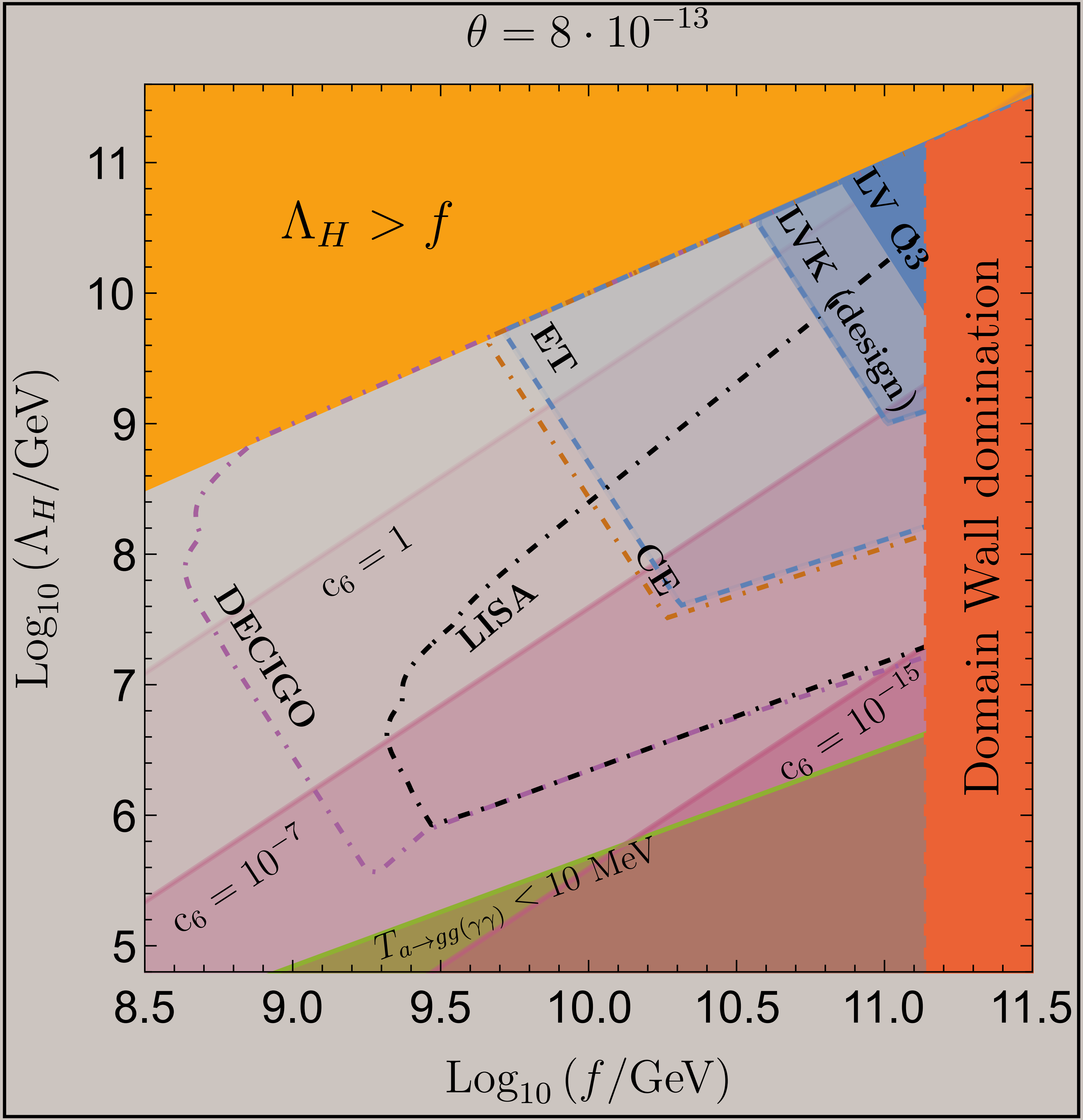
2107.07542

$\theta = 8 \cdot 10^{-13}$



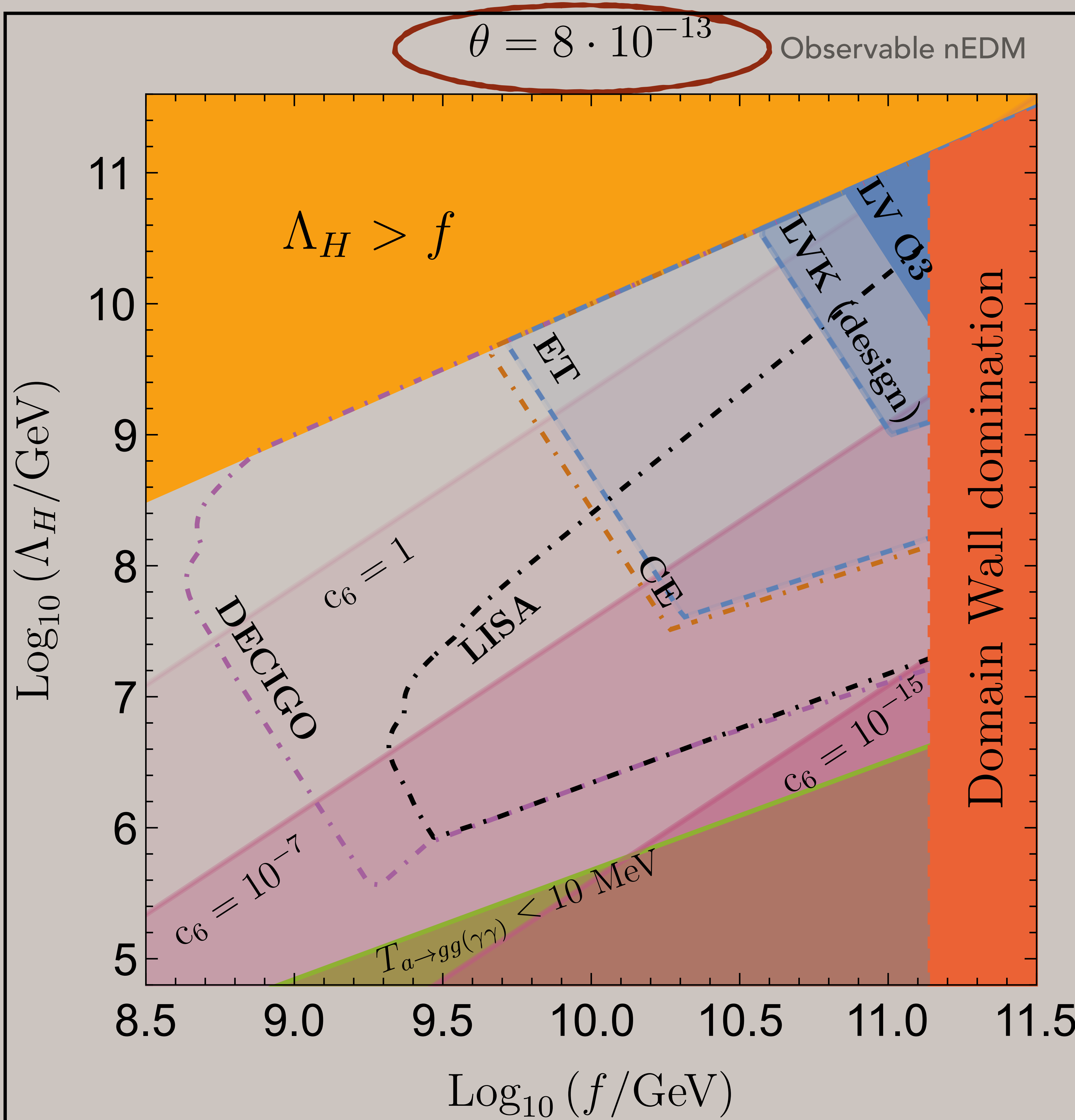
$$\Delta V \sim c_5 \frac{\mathcal{O}_5}{\Lambda_{\mathrm{UV}}}$$

2107.07542



$$\Delta V \sim c_6 \frac{\mathcal{O}_6}{\Lambda_{\rm UV}^2}$$

2107.07542



$$\Delta V \sim c_6 \frac{\mathcal{O}_6}{\Lambda_{\mathrm{UV}}^2}$$