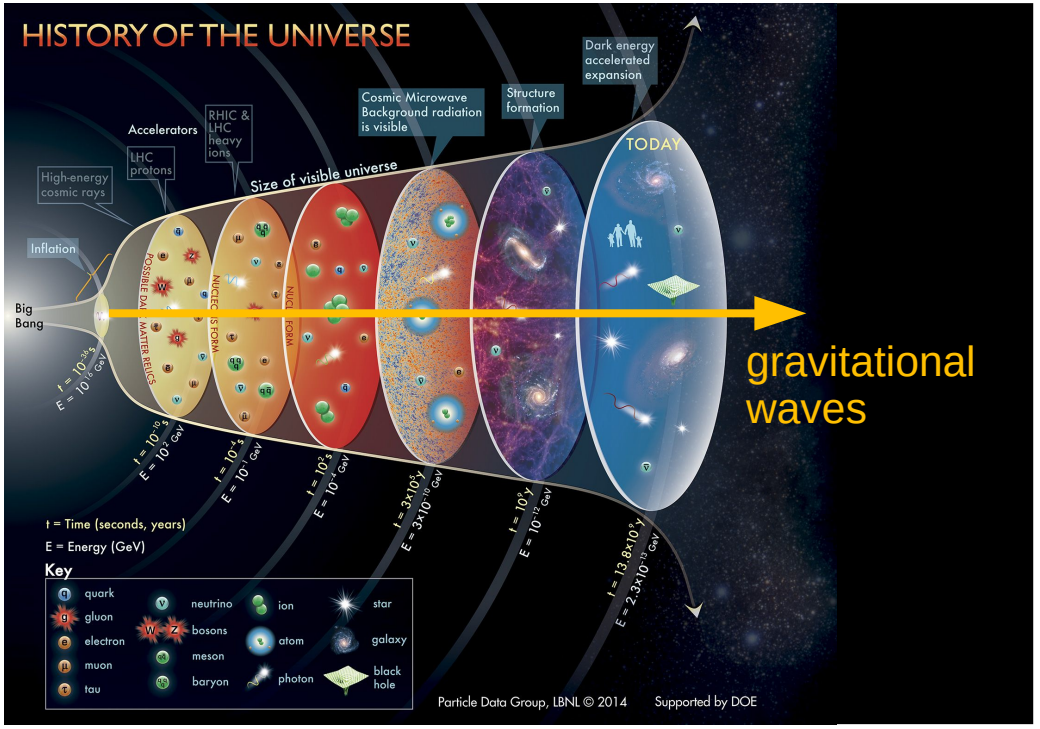
Probing the scale of grand unification with gravitational waves



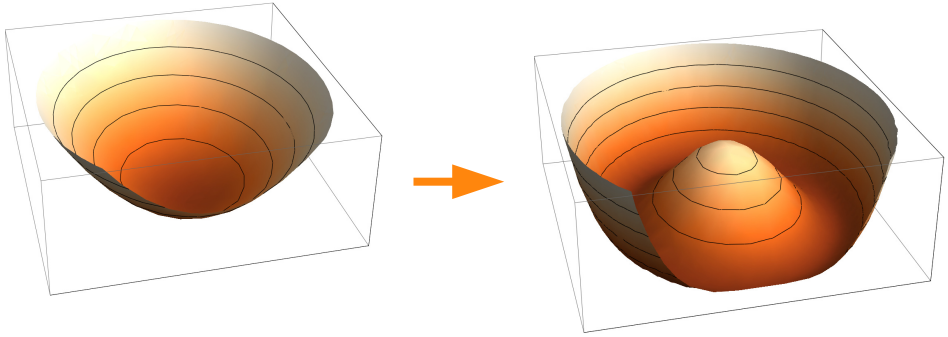
Valerie Domcke
CERN/EPFL

@ Lomonosov conference
23.08.2021

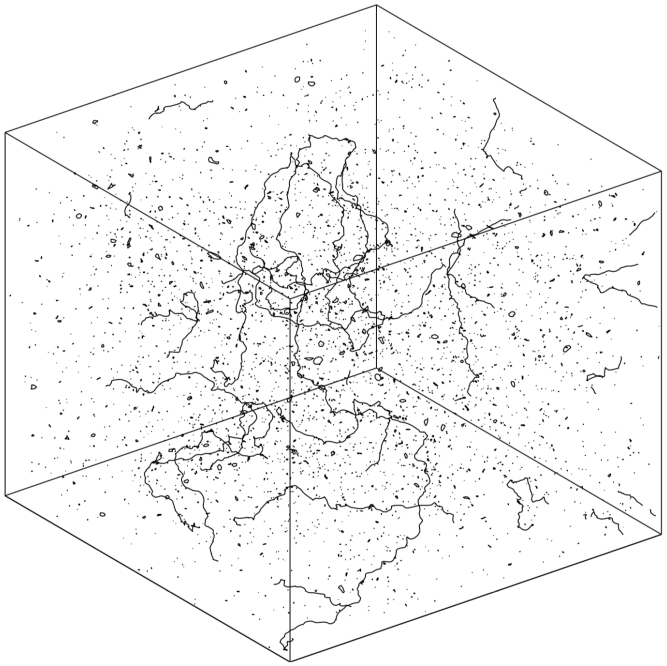
based on
1912.03695, 2009.10649, 2107.04578
w. W. Buchmüller, H. Murayama
and K. Schmitz

cosmic strings in a nutshell

- one-dimensional topological defects formed in an early Universe phase transition
- symmetry breaking pattern $G \to H$ produces cosmic strings iff $\Pi_1(G/H) \neq \mathbb{1}$



- form cosmic string network, evolves through
  - string (self-)intersection & loop formation
  - emission of particles and gravitational waves



Allen & Shellard `90

metastable cosmic strings

consider $SO(10) \to G_{SM} \times U(1)_{B-L} \to G_{SM}$

Vilenkin `82; Leblond, Shlaer, Siemens `09; Monin, Voloshin `08/09; Dror et al `19

$\Pi_1(G_{\rm SM} \times U(1)/G_{\rm SM}) = \Pi_1(U(1)) \neq \mathbb{1}$ → cosmic strings

$\Pi_1(SO(10)/G_{SM}) = \mathbb{1}$ → no cosmic strings

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resolution: no topologically stable cosmic strings

$SO(10) \to G_{SM} \times U(1)_{B-L}$ generates monopoles

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metastable string & monopole network

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cosmic inflation dilutes monopoles

metastable string & monopole network

$G_{SM} \times U(1)_{B-L} \to G_{SM}$ generates cosmic strings,

decay via Schwinger production of monopoles

$$\Gamma_d \sim \mu \exp(-\pi\kappa^2), \quad \kappa^2 = m^2/\mu$$

$\mu \sim v_{B-L}^2$ string tension

$m \sim v_{GUT}$ monopole mass

gravitational wave signal - SGWB

see eg. Auclair, Blanco-Pillado, Figuera et al `19

gravitational wave emission from integration over loop distribution function:

$$\Omega_{\rm GW}(f) = \frac{8\pi f (G\mu)^2}{3H_0^2} \sum_{n=1}^{\infty} C_n(f) P_n$$

$$C_n(f) = \frac{2n}{f^2} \int_0^{z_{\rm max}} dz \frac{\mathcal{N}(\ell(z), t(z))}{H(z)(1+z)^6}$$

GW power spectrum of a single loop

# of loops emitting GWs observed at frequency *f* today

# of loops with length ℓ at time *t*

with $\ell = 2n/((1+z)f)$

cosmological history

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$$\mathcal{N}(\ell, z) = \mathcal{N}(\ell, z)_{\kappa\to\infty} \times e^{-\Gamma_d[\ell(t-t_s)+1/2\Gamma G\mu(t-t_s)^2]} \times \Theta(\alpha t_s - \ell(t_s))$$

finte CS life time

number density for stable strings

$N_r(\ell, t) = 0.18\, t^{-3/2}(\ell + 50 G\mu t)^{-5/2}$

Blanco-Pillado, Olum, Shlaer '14

decay due to monopole production and GW emission

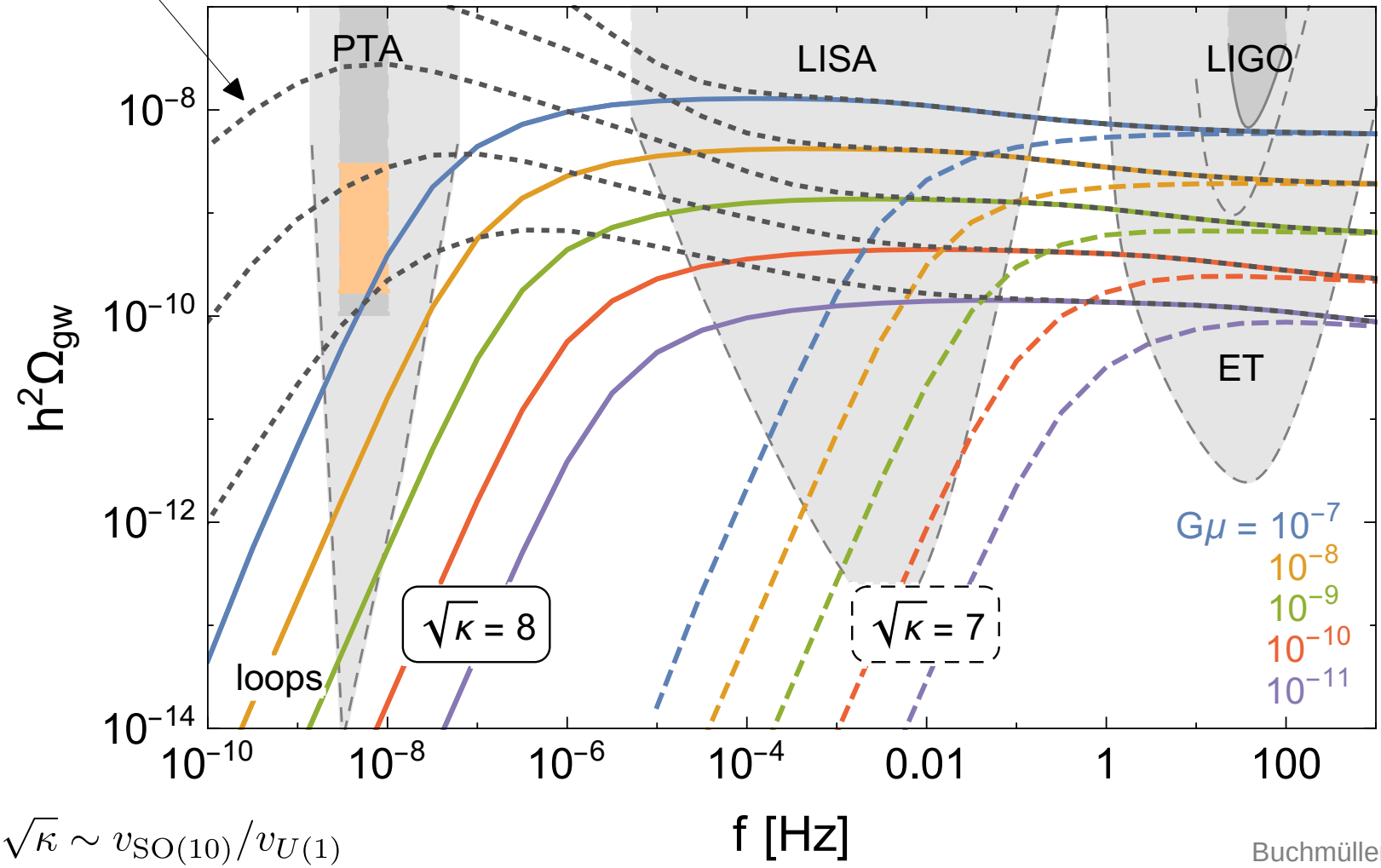
loop production only in scaling regime

Buchmüller, VD, Schmitz `21

gravitational wave spectrum

stable cosmic strings
(highly constrained by PTA)

metastable cosmic strings
discovery space for LISA, LIGO & beyond



$\sqrt{\kappa} \sim v_{\mathrm{SO}(10)}/v_{U(1)}$

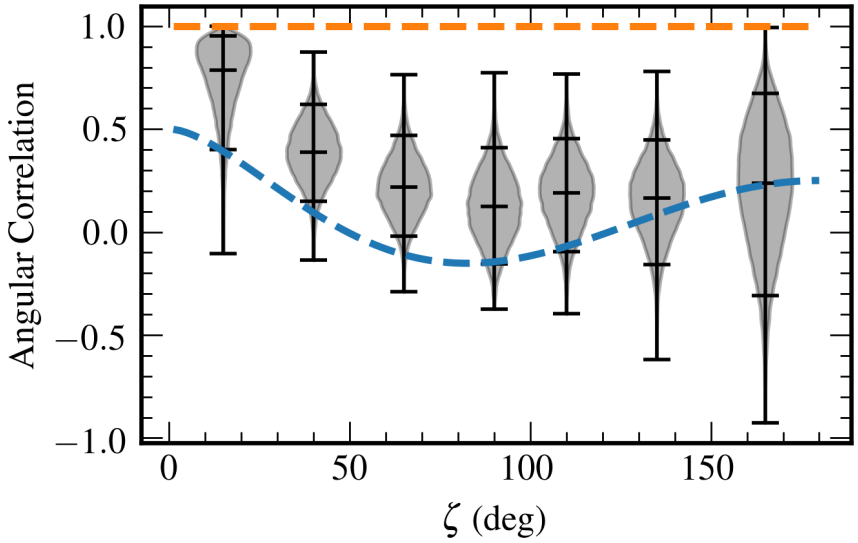
Buchmüller, VD, Schmitz `21

$SO(10) \to G_{\mathrm{SM}} \times U(1)_{B-L} \to G_{\mathrm{SM}}$ with $v_{B-L} \lesssim v_{GUT}$ can be tested with GWs!

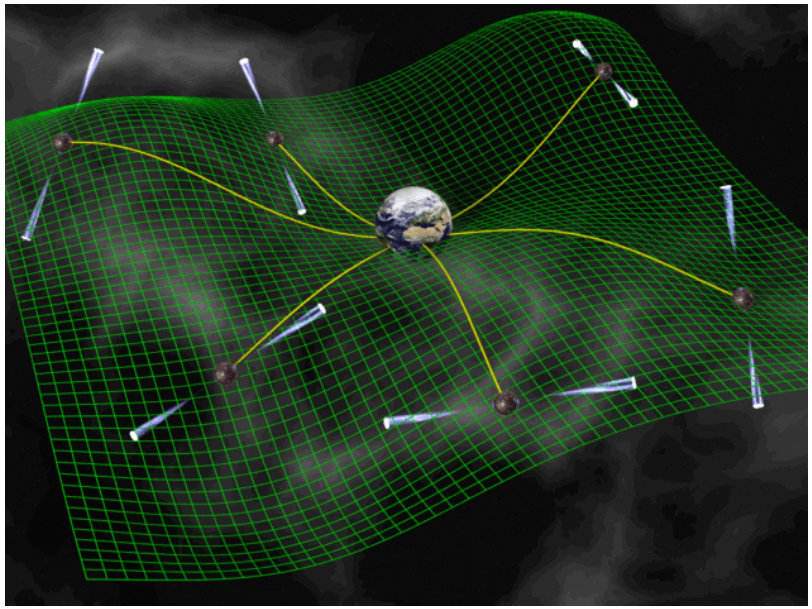
NANOGrav: A first glimpse of the SGWB?

Pulsar timing array NANOGrav, Sept 2020:

"Our analysis finds strong evidence of a stochastic process, modeled as a power-law, with common amplitude and spectral slope across pulsars."



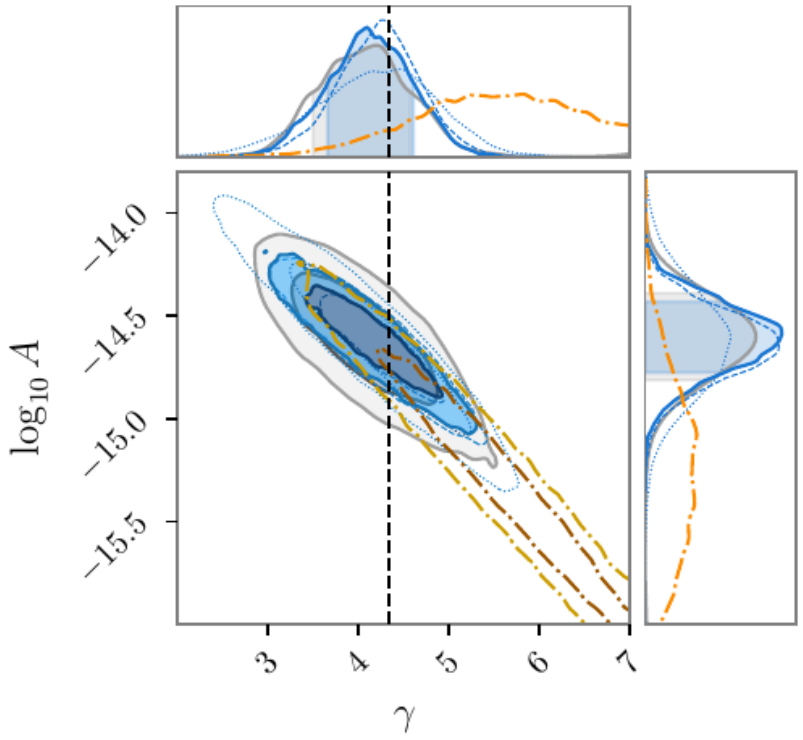
NANOGrav collaboration `20



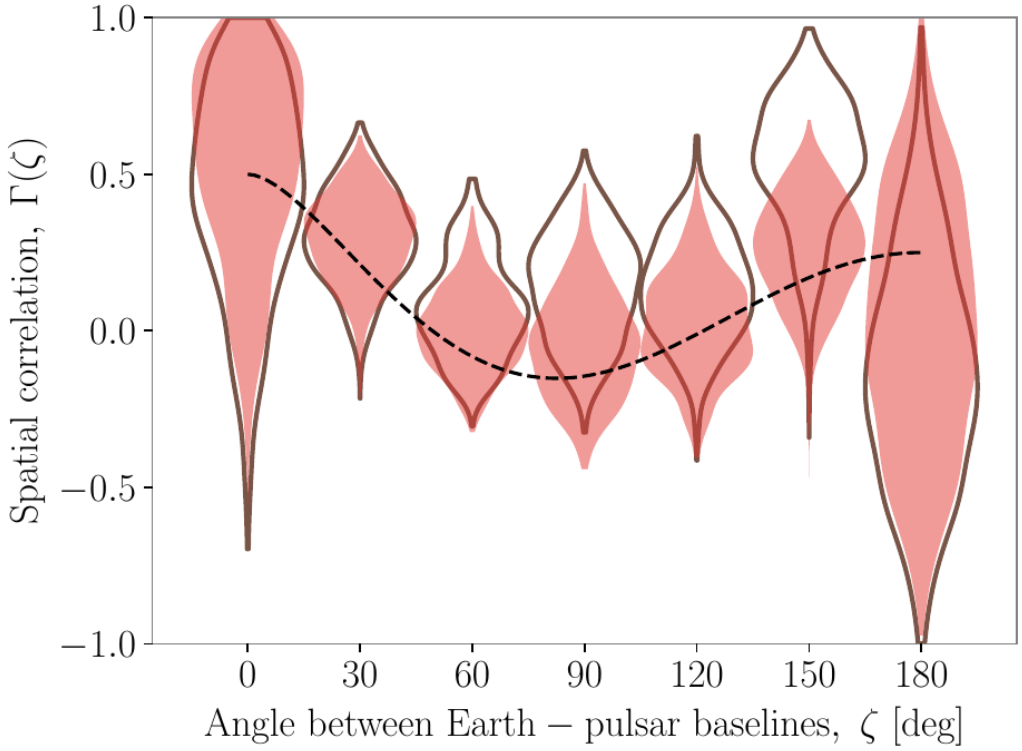
„However, we find no statistically significant evidence that this process has quadrupolar spatial correlations, which we would consider necessary to claim a GWB detection consistent with General Relativity."

Parkes Pulsar timing array

PPTA `21, 2107.12112



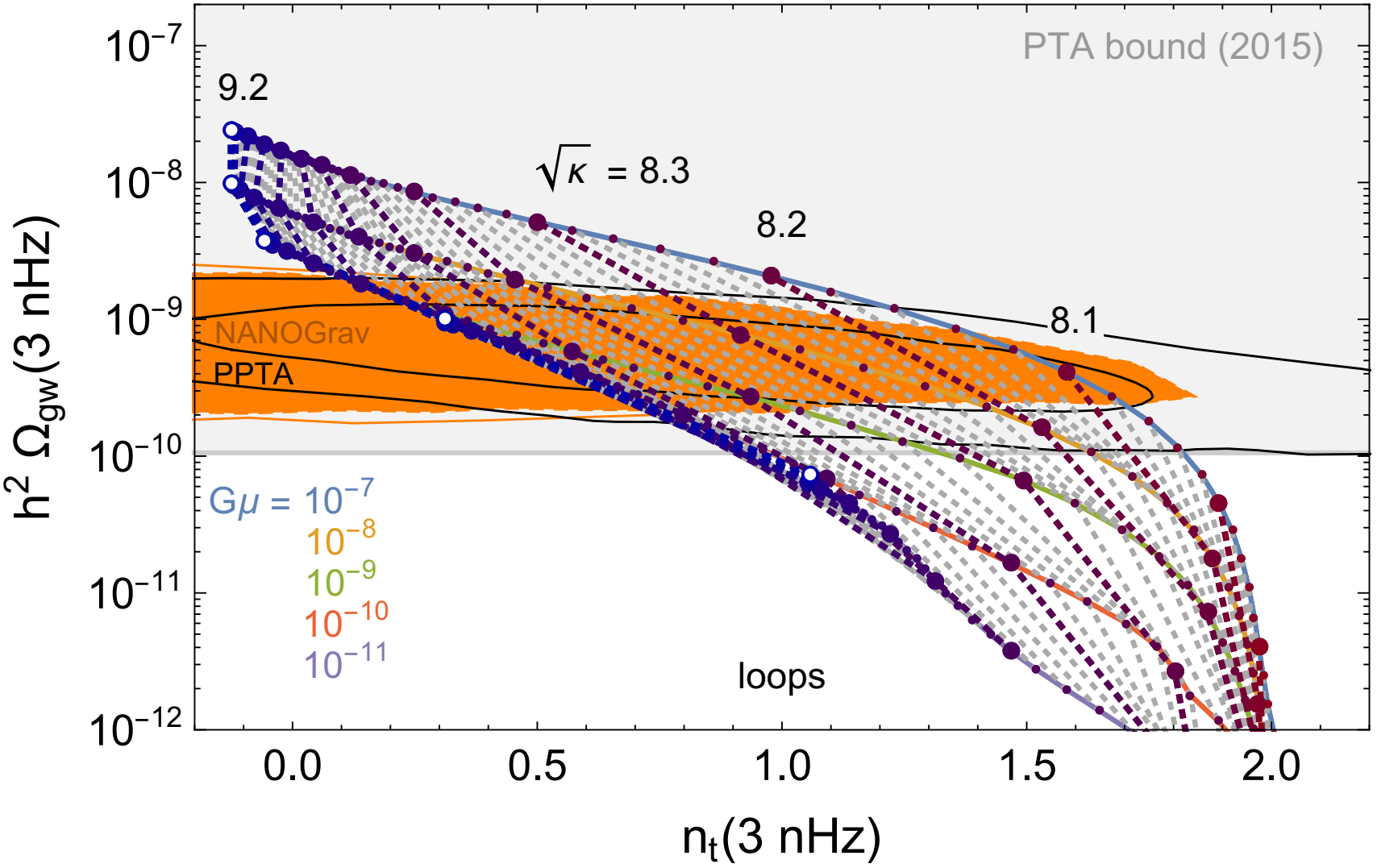
amplitude and spectral tilt
compatitive with NANOGrav



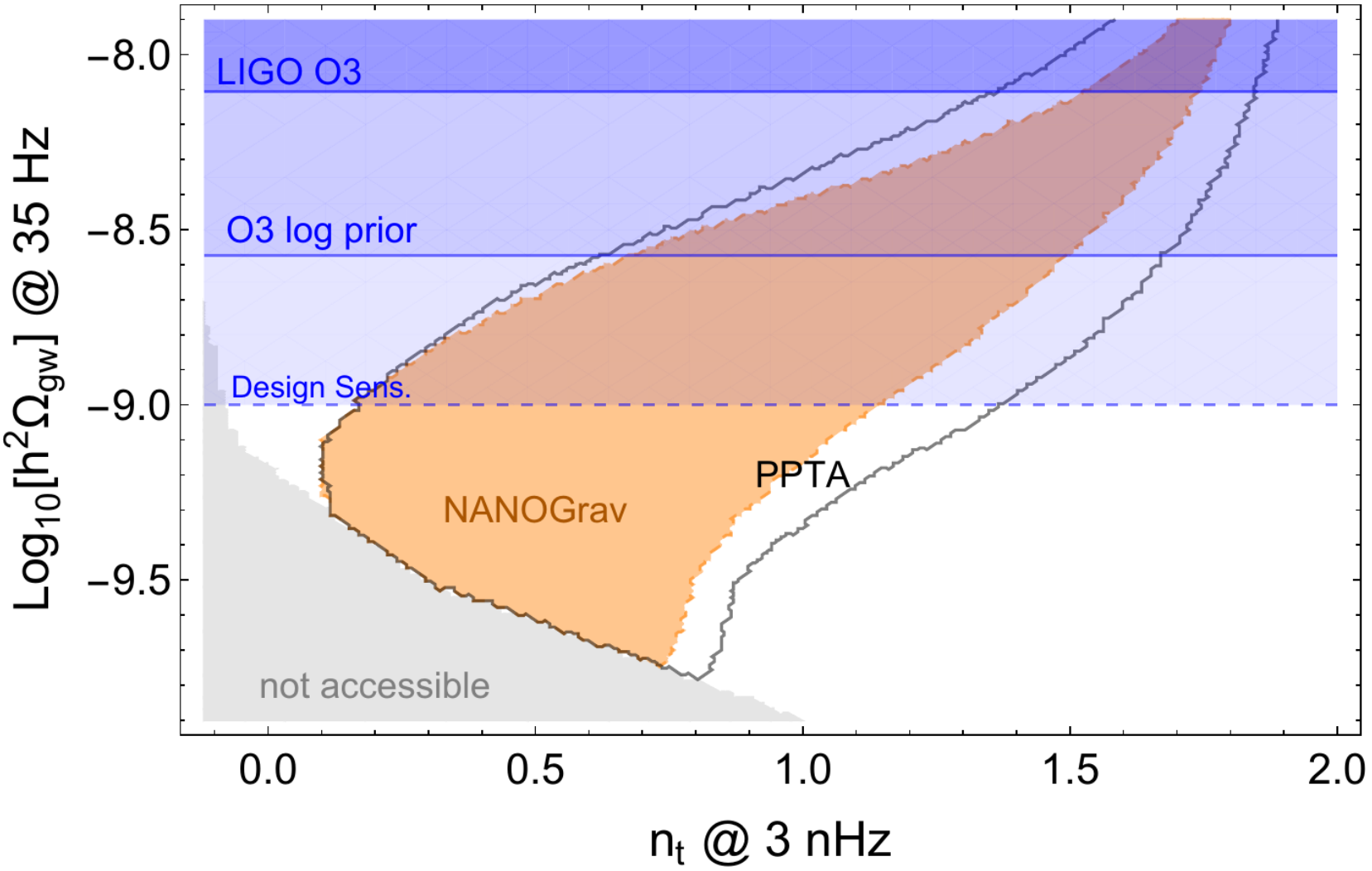
no significant detection of
quandropolar spatial correlation

Maybe. Stay tuned for more data!

cosmic strings at PTAs ?

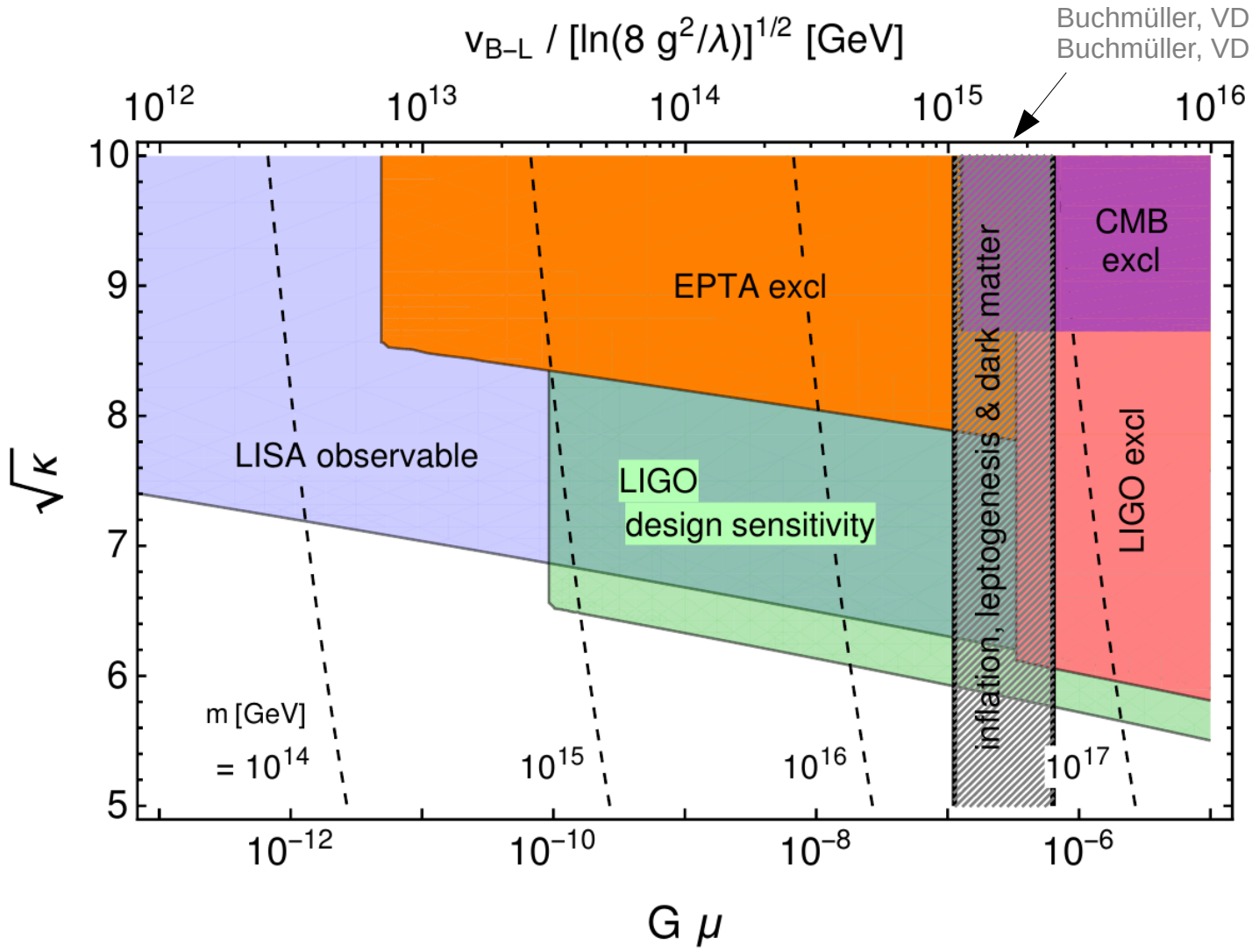


Prospects for GW searches



PTA hint will be probed with interferometers

parameter space of metastable strings



metastable GUT- scale strings are testable

Conclusions & Outlook

- Metastable cosmic strings are a fairly generic byproduct of GUTs with large stochastic GW signals possible at PTAs, LIGO or LISA

  ⟶ testable with upcoming GW detectors

- Excess noise observed in NANOGrav and PPTA data may be the first glimpse at a SGWB

  - amplitude & tilt compatible with metastable cosmic strings

  - also compatible with super-massive BH mergers

  - no detection of quadrupolar signature (yet). More careful scrutiny of data & data analysis needed

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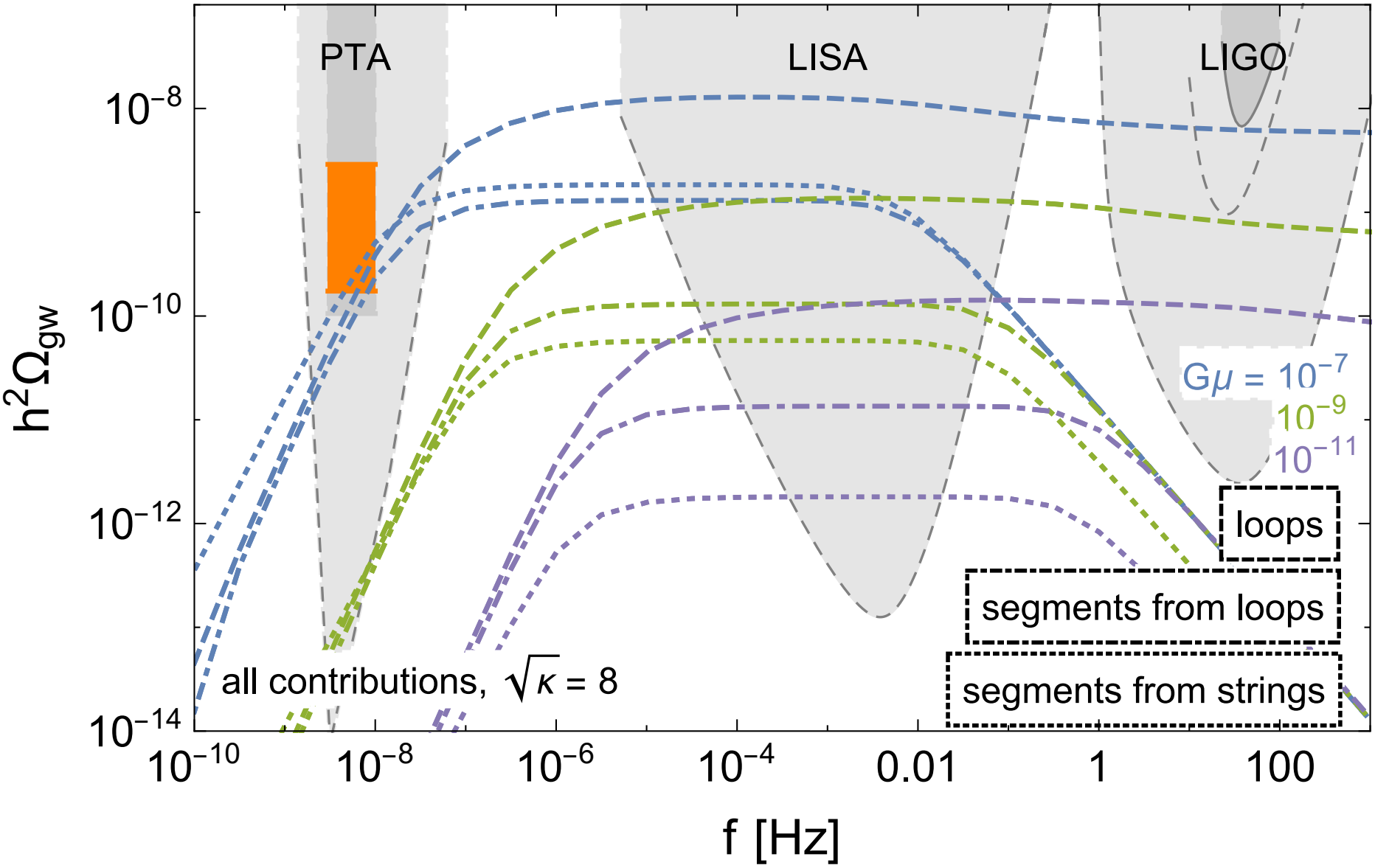
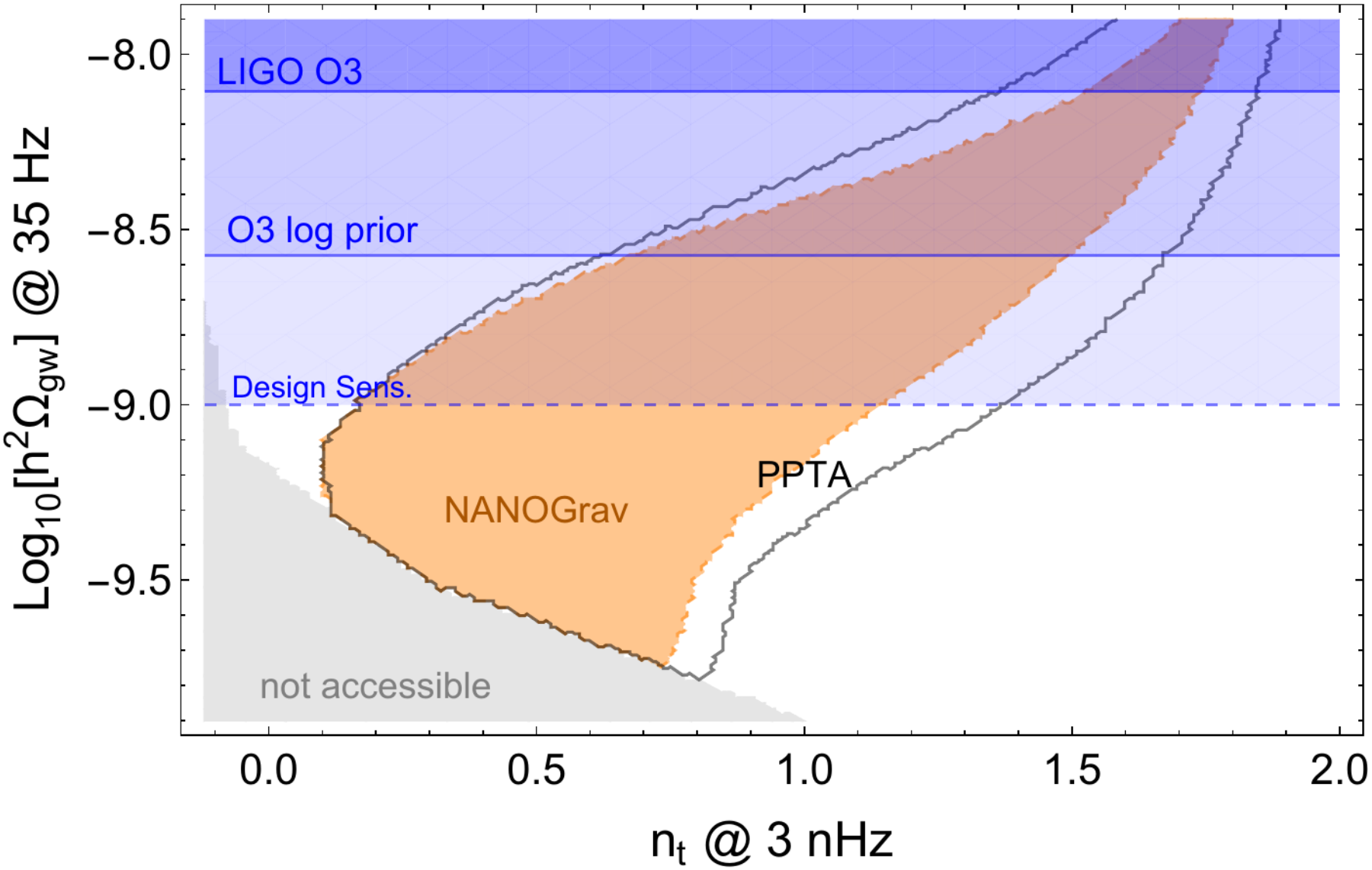
Questions ?

backup slides

GWs from segments



Prospects


LIGO O3
O3 log prior
Design Sens.
NANOGrav
PPTA
not accessible
−8.0
−8.5
−9.0
−9.5
0.0
0.5
1.0
1.5
2.0
Log10[h2Ωgw] @ 35 Hz
nt @ 3 nHz