EuCAPT Workshop – Gravitational Wave Probes of Fundamental Physics

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arXiv 1811.11175

Dark, Cold, and Noisy: Constraining Secluded Hidden Sectors with Gravitational Waves

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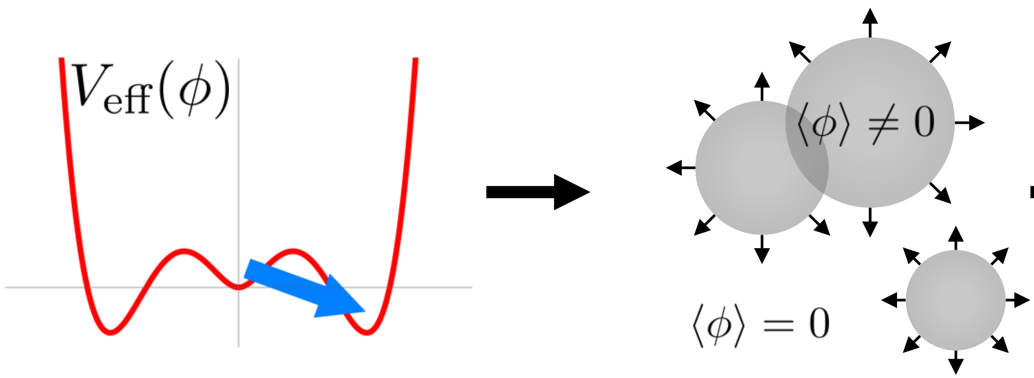
Motivation

First-order **phase transitions**



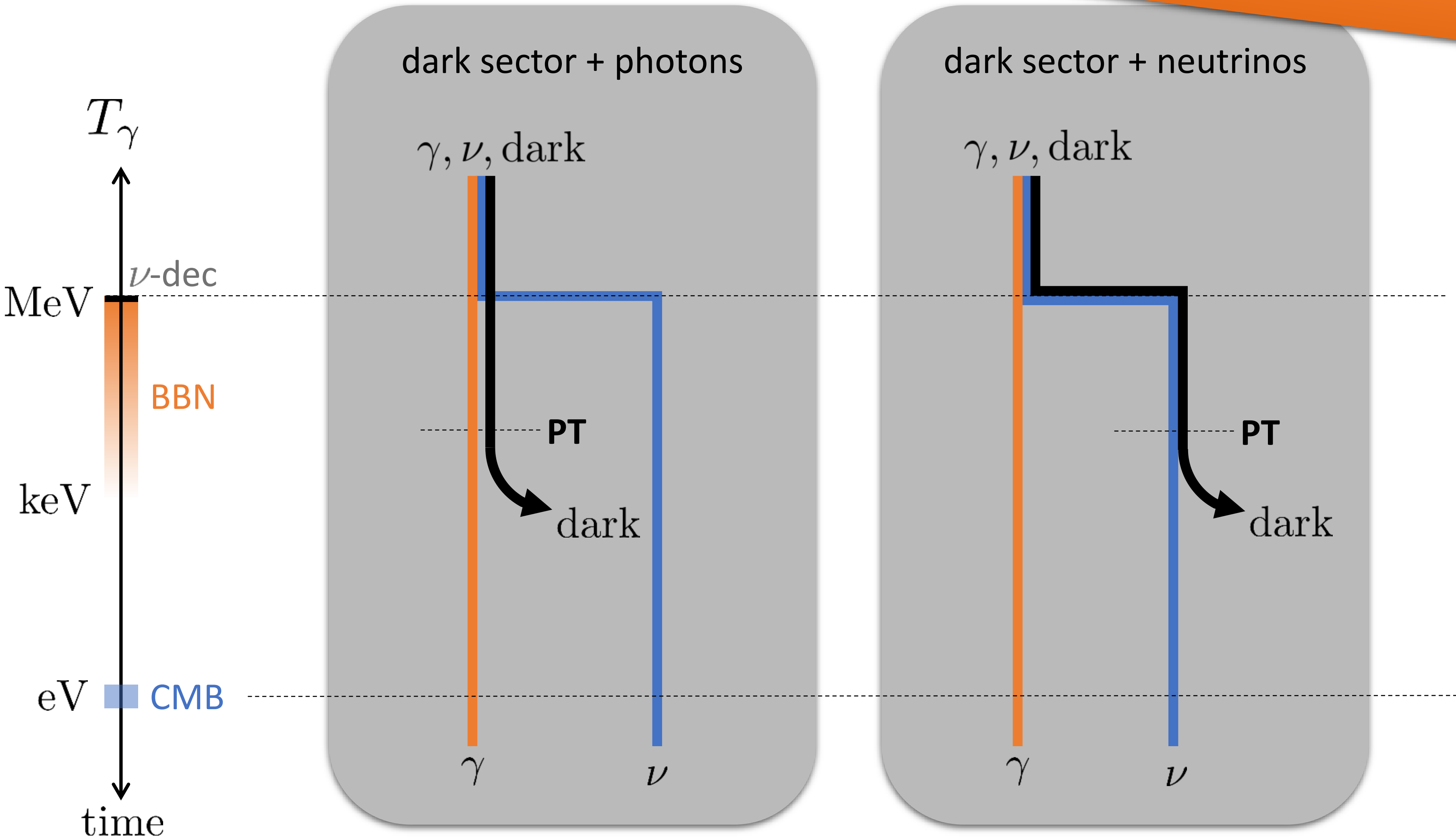
Stochastic
Gravitational Wave
Background

... in **sub-MeV** dark sectors?

- out of reach for direct detection
- fewer relativistic SM DOF → **stronger GWs**
- regime of **pulsar timing arrays** ($1 \sim 100\,\mathrm{nHz}$)
- interesting cosmology (constrained by **BBN/CMB**)

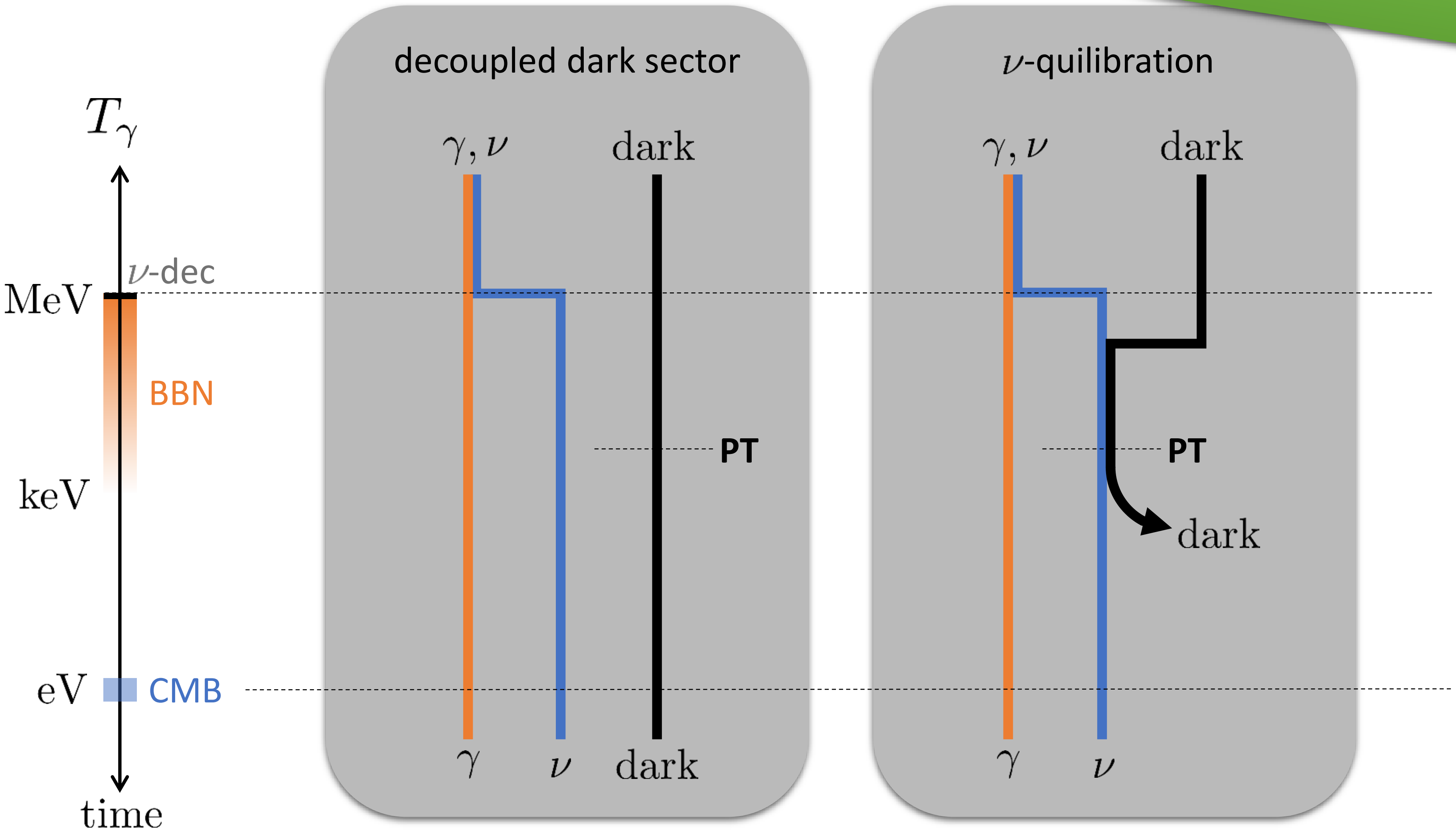
Conventional thermal scenarios

photons/neutrinos **too hot** → **ruled out**



Alternative thermal scenarios

compatible with **BBN/CMB**
BUT: dark sector must be **colder**



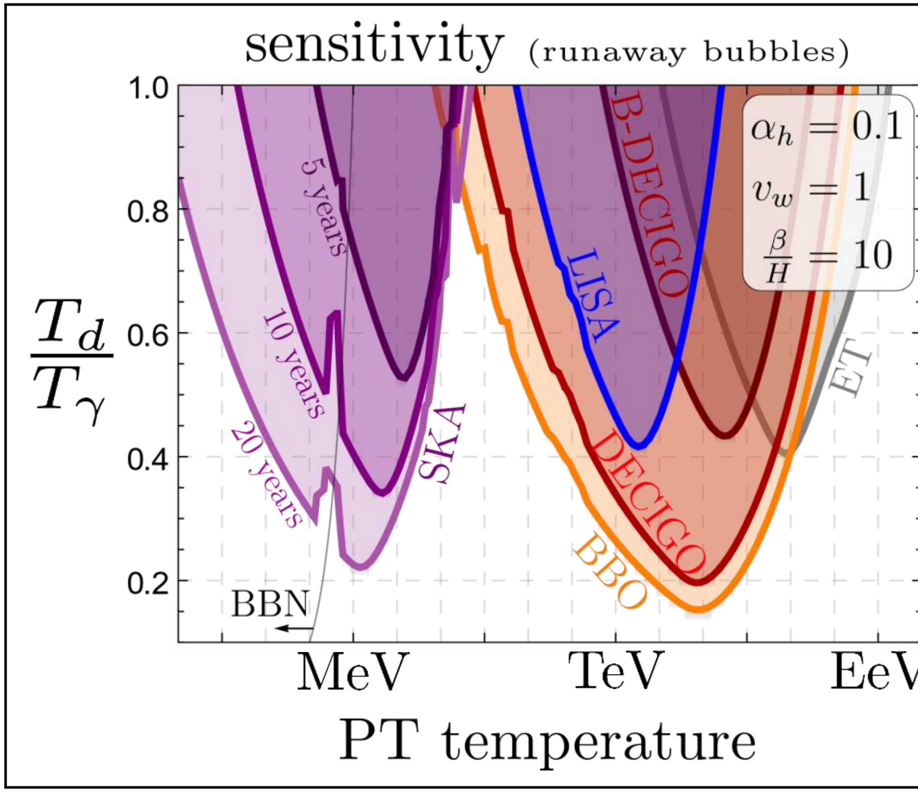
A **colder dark sector**...

$$T_d < T_\gamma$$

...**repairs cosmology**, but...

$$\frac{\text{PT energy}}{\varrho_{\text{rad}}} \propto \left(\frac{T_d}{T_\gamma}\right)^4$$

... **weakens GW signal**!

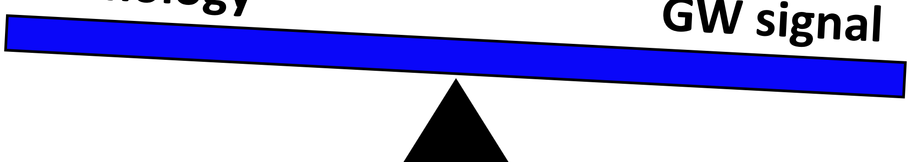


$T_d \ll T_\gamma$

consistent cosmology

$T_d \sim T_\gamma$

detectable GW signal



Benchmark models

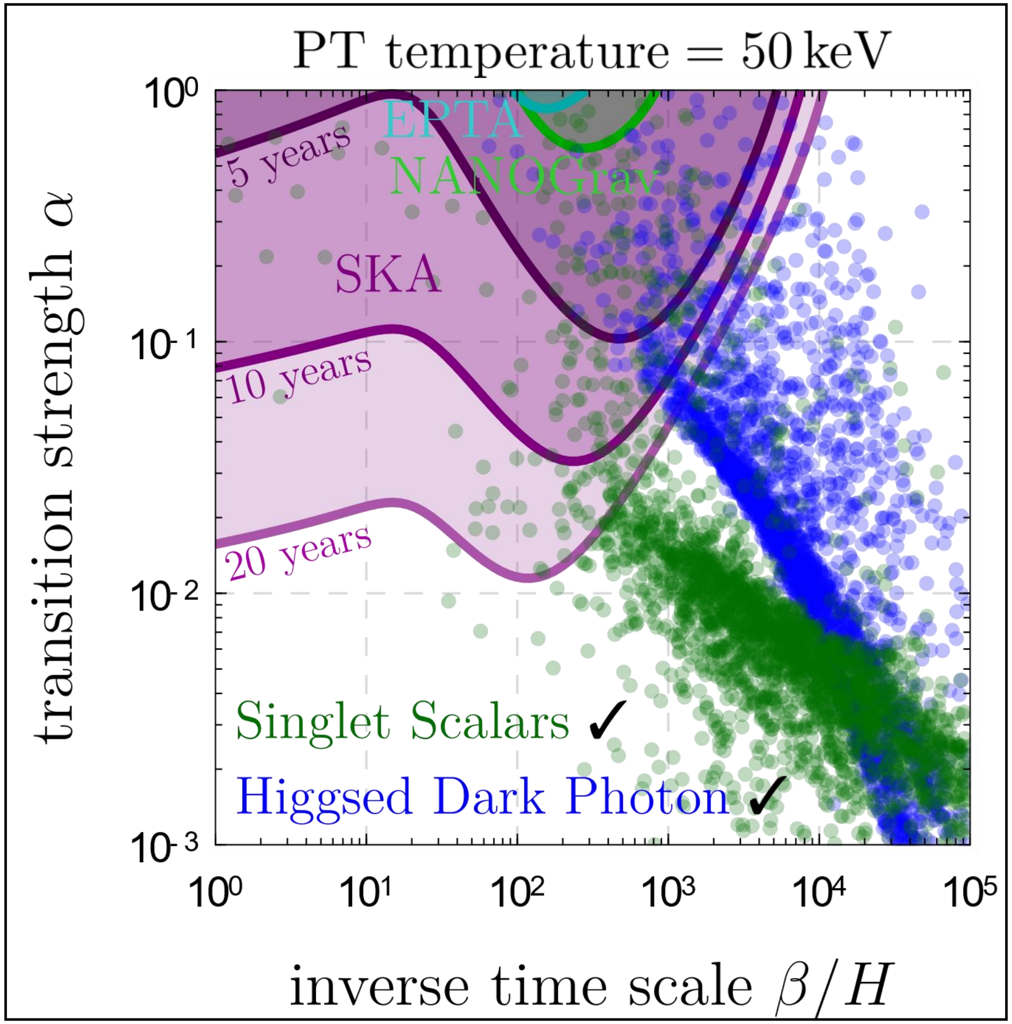
Singlet Scalars (2 DOF)

$$V \sim \mu_S^2 S^2 + \kappa S^3 + \lambda_S S^4$$

Higgsed Dark Photon (4 DOF)

$$V \sim -\mu_S^2 S^2 + \lambda_S S^4$$

$$\frac{T_d}{T_\gamma} \sim 0.5$$

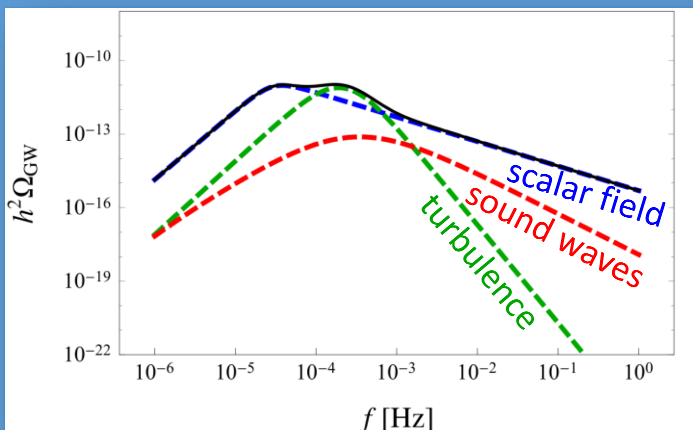


Sub-MeV dark sectors with **consistent cosmology** and **detectable gravitational waves** are possible!

Additional Material

Gravitational waves from first-order PTs

3 contributions



[Huber et al. - 0806.1828]
[Hindmarsh et al. - 1504.03291]
[Caprini et al. - 0909.0622]

4 parameters

- nucleation temperature T^{nuc}
- transition strength $\alpha \equiv \frac{\text{latent heat}}{\varrho_{\text{rad}}}$
- inverse timescale $\beta \equiv \frac{1}{\Gamma}\frac{d\Gamma}{dt}$
- bubble wall velocity v_w

2 main scenarios

- runaway bubble walls

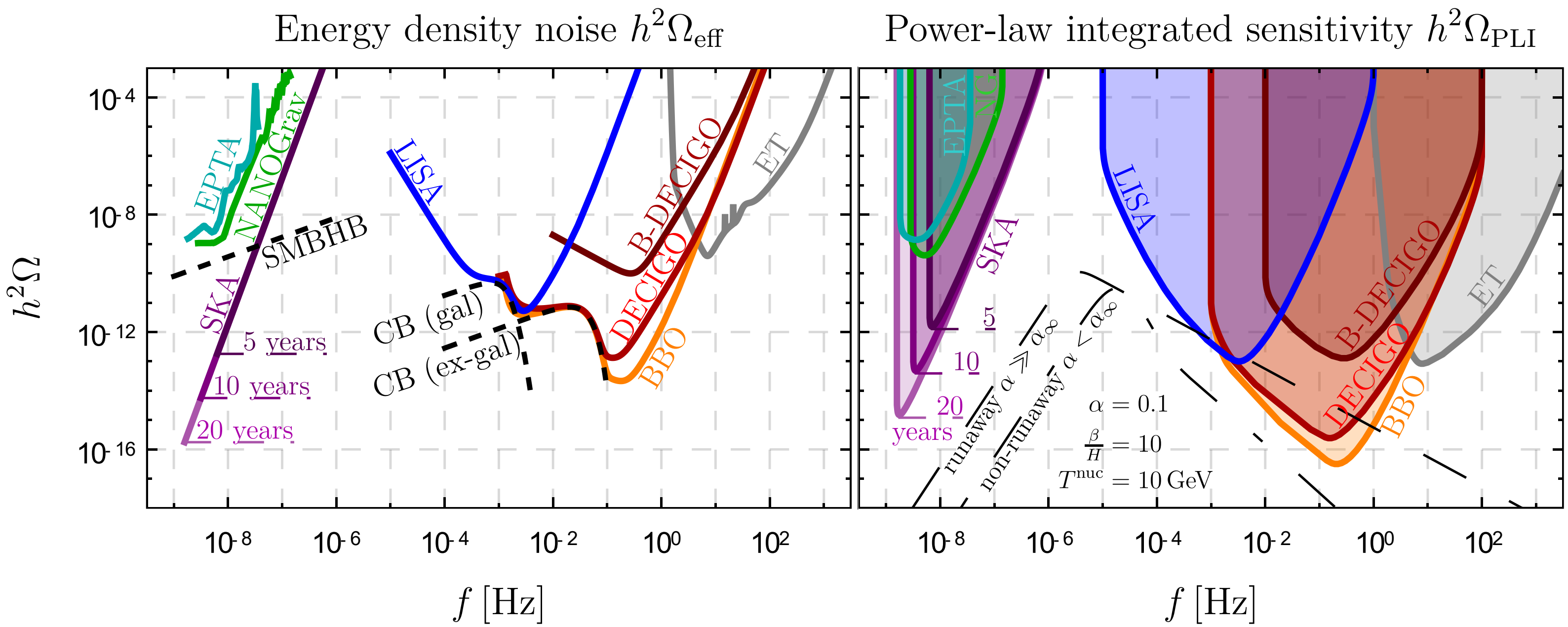
  (**scalar field contribution** dominates)

- non-runaway bubble walls

  (only **sound waves** & **turbulence** relevant)

[Espinosa et al. - 1004.4187]

Experimental sensitivity



Experiment	N_p	$T_{\rm obs}$	δt	σ	$\rho_{\rm thr}$
EPTA	6	8 – 18 years	10 days	0.1 – 1.7 µs	1.19
NANOGrav	34	4 – 11 years	7 – 30 days	0.1 – 3.7 µs	0.697
SKA (pessimistic)	50	20 years	7 days	100 ns	4
SKA (optimistic)	2000	10 years		50 ns	

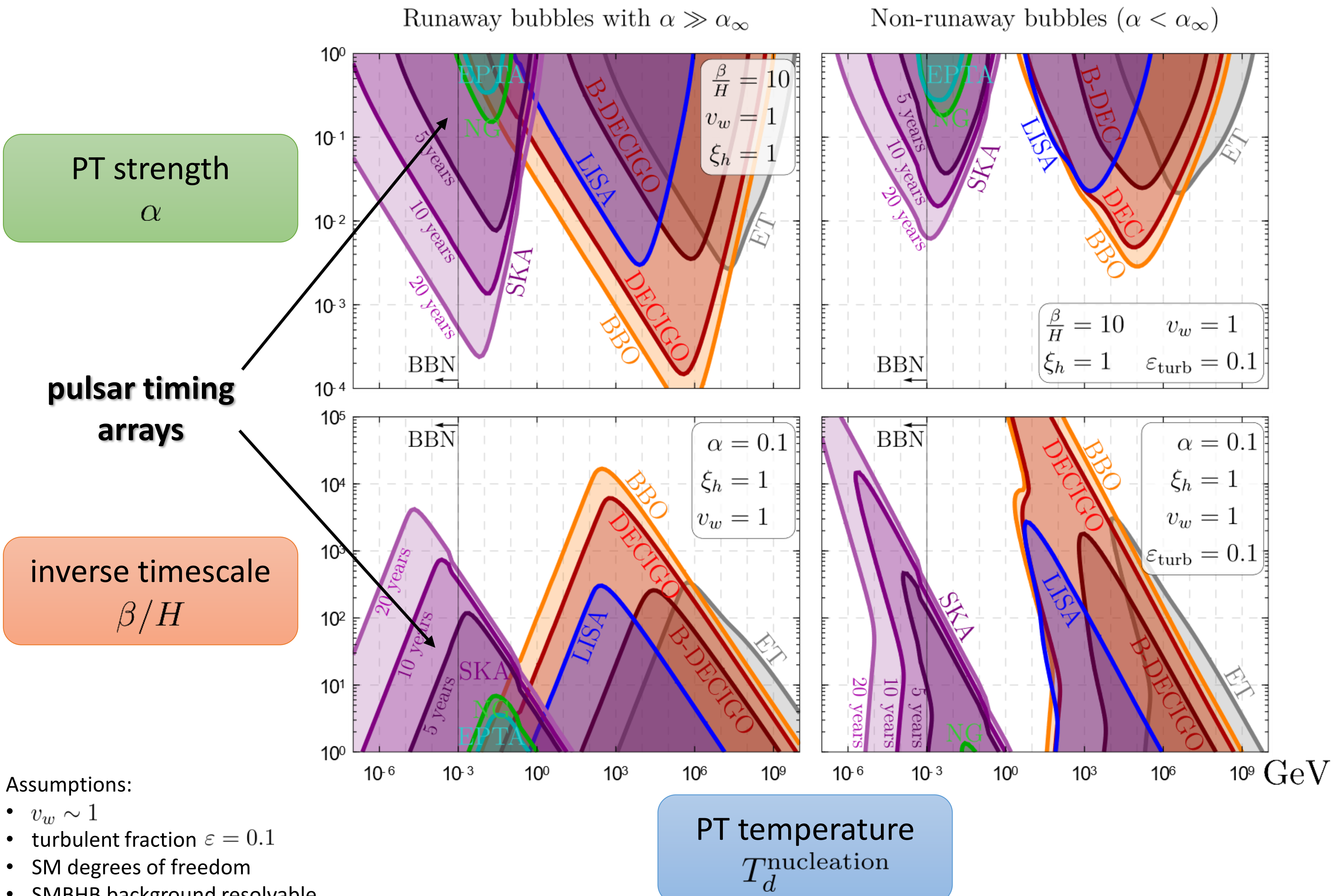
[Lentati et al. - 1504.03692, Desvignes et al. - 1602.08511]
[NANOGRAV Collaboration - 1801.02617]
[Janssen et al. - 1501.00127]

Experiment	$\rho_{\rm thr}$
LISA	10
B-DECIGO	8
DECIGO	10
BBO	10
ET	5

[Cornish et al. - 1803.01944, Caprini et al. - 1512.06239]
[Isoyama et al. - 1802.06977]
[Yagi et al. - 1302.2388]
[Yagi et al. - 1101.4997]
[Sathyaprakash et al. - 1206.0331]

$\rho_{\rm thr}$	SNR detection threshold
N_p	#pulsars
$T_{\rm obs}$	observation time
δt	timing interval
σ	timing uncertainty

Experimental sensitivity



Assumptions:

- $v_w \sim 1$
- turbulent fraction $\varepsilon = 0.1$
- SM degrees of freedom
- SMBHB background resolvable

Cosmological constraints

effective number of neutrino species

$$N_{\rm eff} \equiv \frac{8}{7}\frac{\varrho_{\rm rad}-\varrho_\gamma}{\varrho_{\rm rad}}\left(\frac{11}{4}\right)^{4/3}$$

Standard Model	$N_{\rm eff}^{\rm SM} = 3.046$	
BBN (light element abundances)	$N_{\rm eff} = 2.95^{+0.56}_{-0.52}$	$T \sim {\rm MeV} - 10\,{\rm keV}$
CMB (power spectrum)	$N_{\rm eff} = 2.99^{+0.34}_{-0.33}$	$T \sim {\rm eV}$
CMB+H0 (low redshift Hubble)	$N_{\rm eff} = 3.27 \pm 0.30$	$T \sim {\rm eV}$

[Mangano et. al. - hep-ph/0506164, Planck Collaboration - 1807.06209]

sub-MeV phase transition

→ typically **sub-MeV** particles

→ contribution to $\varrho_{\rm rad}$