Probing Light Hidden Sectors with Pulsar Timing Arrays

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JG|U

PRISMA Cluster of Excellence
Precision Physics, Fundamental Interactions and Structure of Matter

In this talk:

Probing hidden sectors:

Gravitational waves from first-order phase transitions

Cosmological constraints

Experimental sensitivity to GW spectra

Example: Higgsed dark-photon model

Talking to the Hidden Sector

The fourth portal

The usual portal suspects:

- Vector: (kinetic mixing, weakly coupled gauge bosons, …)
- Scalar: (Higgs portals, …)
- Fermion: (neutrino portal, …)
- Any combination of the above

Talking to the Hidden Sector

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Typically we forget about gravity!

The upsides:

- Cannot be switched off
- Gravitational waves may provide brand new insights

Thermalised Hidden Sectors

Phase transition must occur in a thermalised sector to produce observable GW signal

Temperature in hidden sector typically deviates from temperature of the SM thermal bath:

$$\xi_h \equiv \frac{T_h}{T_\gamma} = \left(\frac{g_{*s,\gamma} g_{*s,h}^{\mathrm{dec}}}{g_{*s,\gamma}^{\mathrm{dec}} g_{*s,h}} \right)^{1/3}$$

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Temperature ratio strongly affects GW spectrum

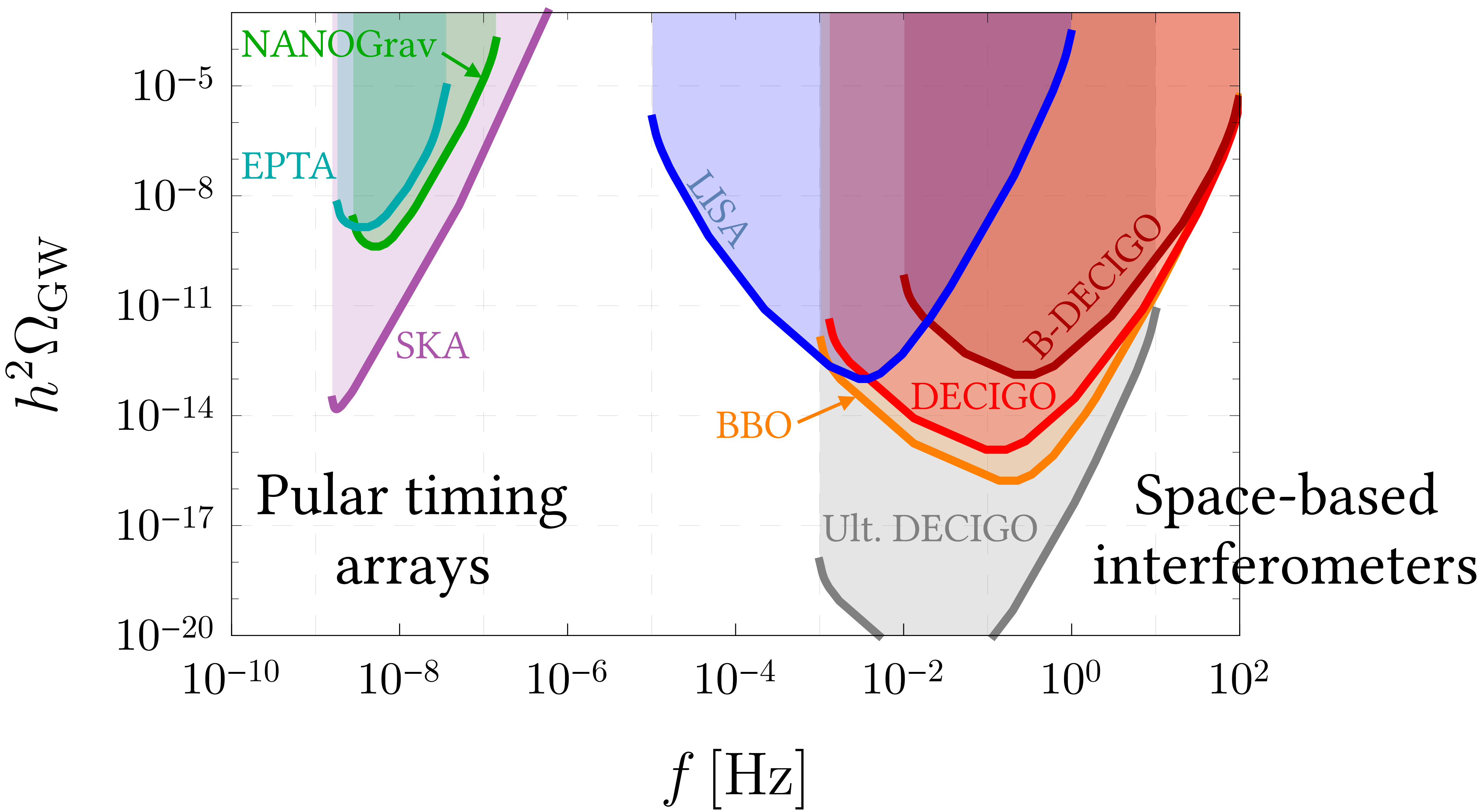
two effects ⟷

Stringent constraints on new thermalised keV/MeV relativistic degrees of freedom

Gravitational waves from first-order phase transitions

Gravitational Waves

Sensitivity curves

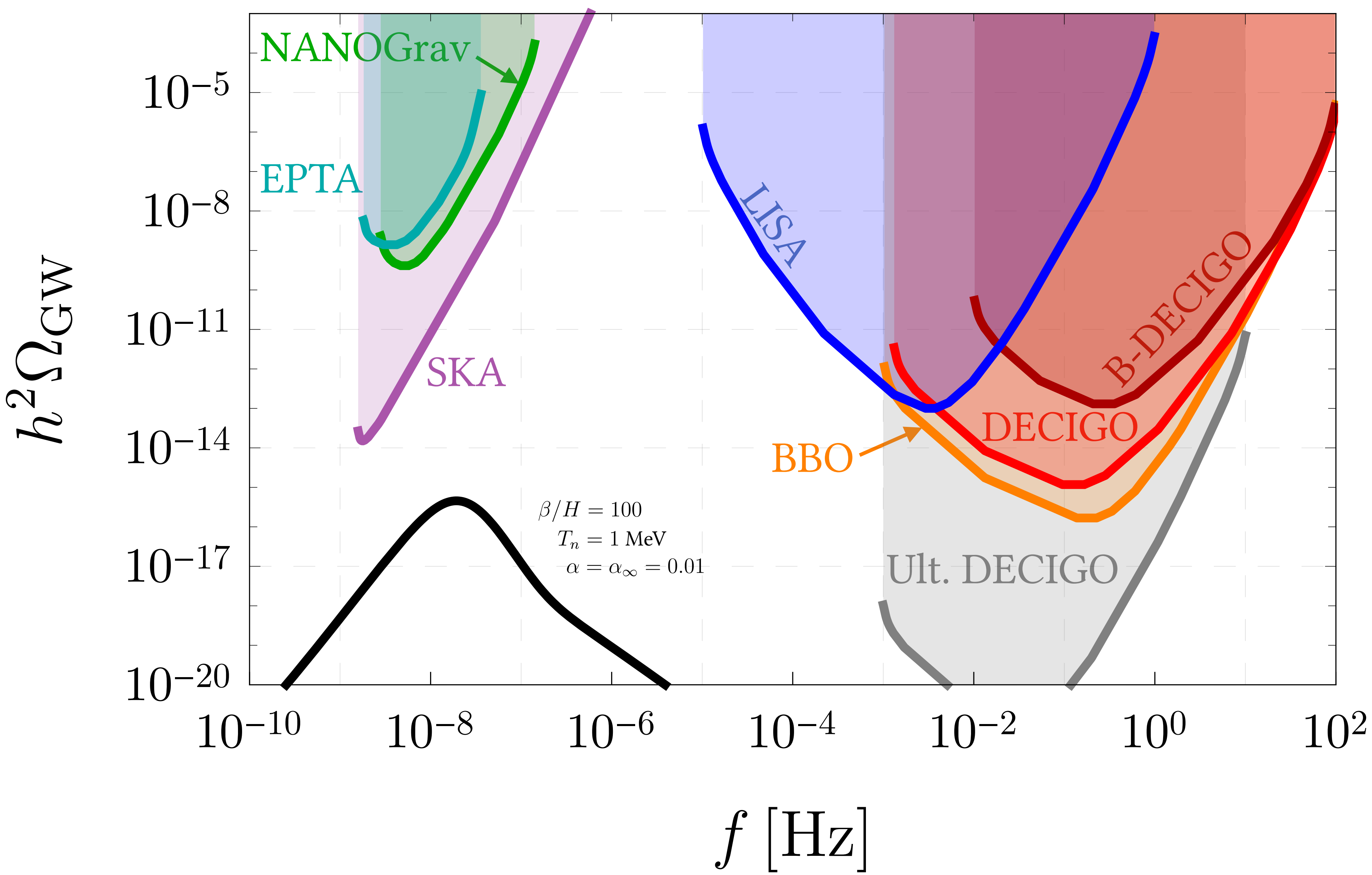


Power-law integrated sensitivity derived from experimental noise curves

[Thrane & Romano - 1310.5300]

Gravitational Waves

Sensitivity curves



Power-law integrated sensitivity derived from experimental noise curves

[Thrane & Romano - 1310.5300]

GW Stochastic Background

Parametrising the spectrum

Nucleation temperature: T_n

Strength: $\alpha \equiv \dfrac{\epsilon}{\rho_{\rm rel}}$

Inverse time-scale: $\dfrac{\beta}{H} \equiv -T_n \left.\dfrac{\mathrm{d}S}{\mathrm{d}T}\right|_{T_n}$

Bubble wall velocity: v_w

- Broken-power law spectra $\Omega_{\rm GW}(f)$ from fitting simulations [Huber et al. - 0806.1828, Hindmarsh et al. - 1504.03291, Caprini et al. - 0909.0622]
- Assuming $v_w \simeq 1$: valid for strong transitions

GW Stochastic Background

Parametrising the spectrum

		$\xi_h \neq 1$
Nucleation temperature:	T_n	$T_n = \xi_h^{-1}(T_n)_h$
Strength:	$\alpha \equiv \dfrac{\epsilon}{\rho_{\rm rel}}$	$\alpha = \xi_h^4 \alpha_h$
Inverse time-scale:	$\dfrac{\beta}{H} \equiv -T_n \left.\dfrac{\mathrm{d}S}{\mathrm{d}T}\right\vert_{T_n}$	$\dfrac{\beta}{H} = \xi_h^2 \left(\dfrac{\beta}{H}\right)_h$
Bubble wall velocity:	v_w	

- Broken-power law spectra $\Omega_{\rm GW}(f)$ from fitting simulations [Huber et al. - 0806.1828, Hindmarsh et al. - 1504.03291, Caprini et al. - 0909.0622]
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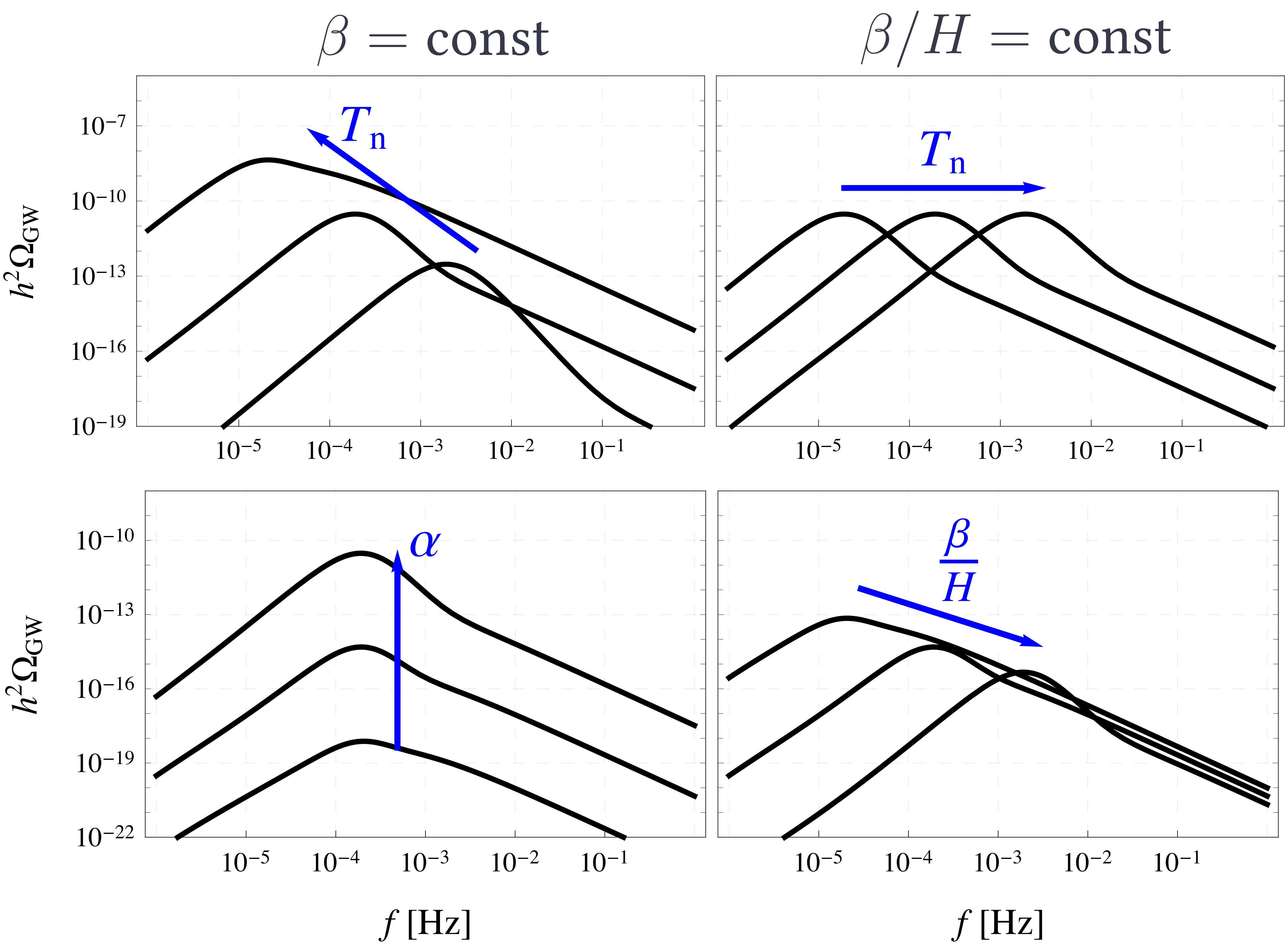
GW Stochastic Background

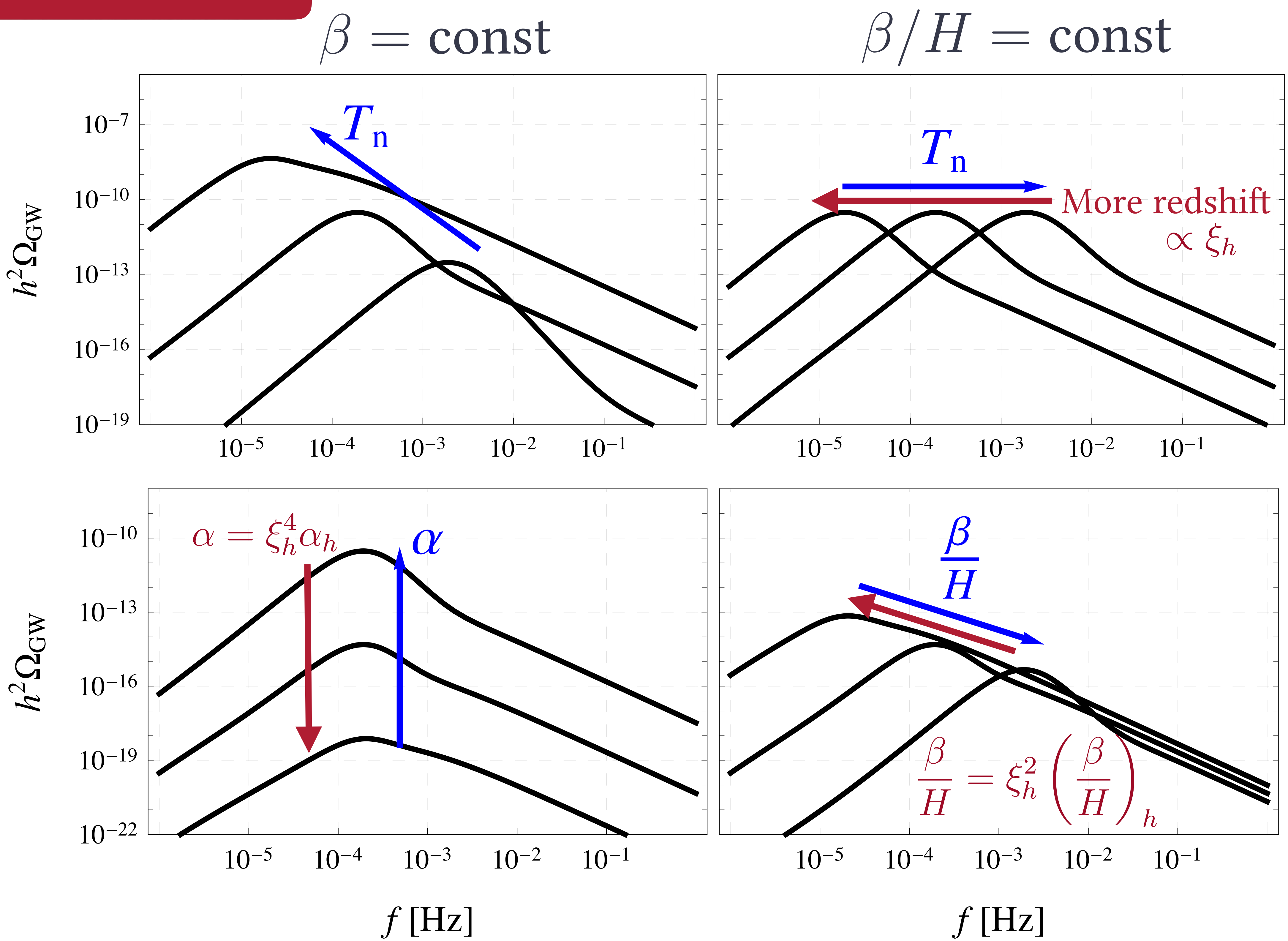
Scaling behaviour



GW Stochastic Background

ξ_h decreasing

Scaling behaviour



Cosmological Constraints

Cosmological Constraints

Thermal histories

Non-standard thermal history essential ingredient for MeV/keV scale phase transitions

$$N_{\text{eff}} = \frac{8}{7}\left(\frac{\rho_{\text{R}} - \rho_\gamma}{\rho_\gamma}\right)\left(\frac{T_\gamma^{\text{SM}}}{T_\nu^{\text{SM}}}\right)^4$$

Extra relativistic DOFs until after phase transition

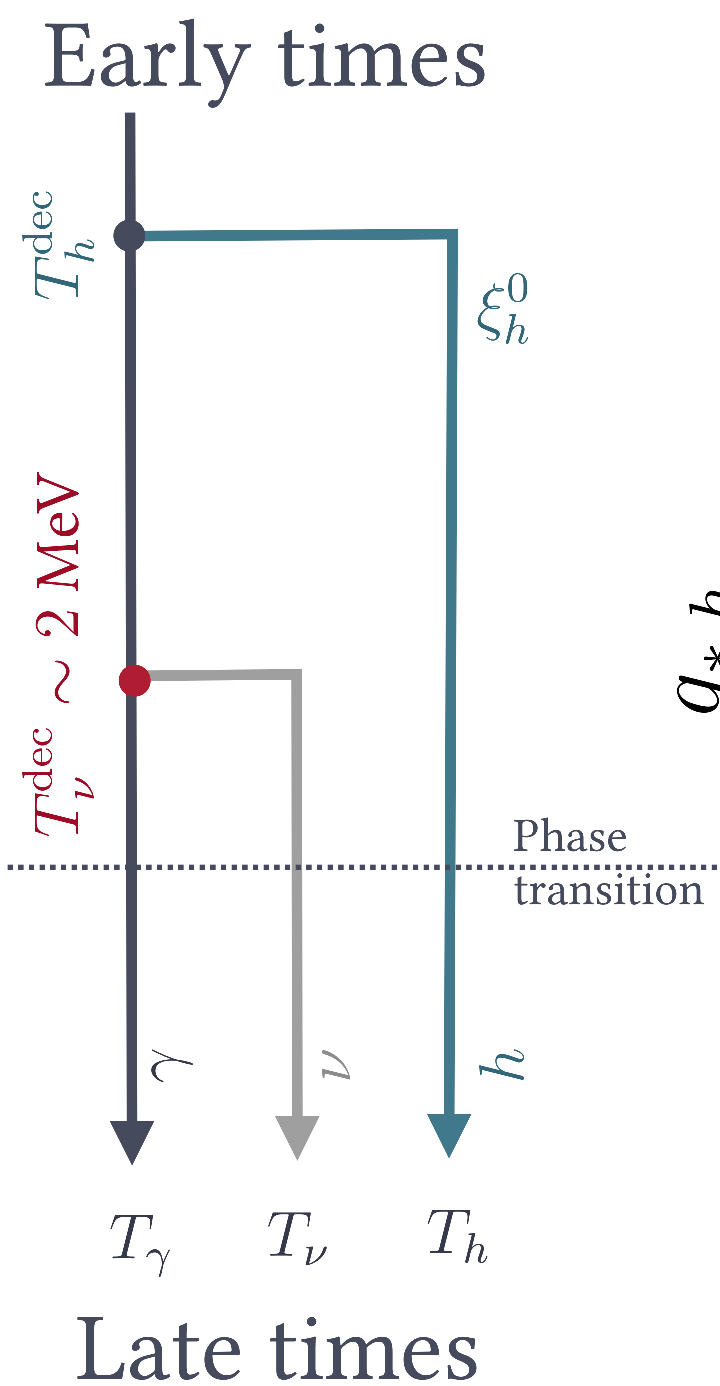
Three possibilities:

- Hidden sector remains coupled to photons or neutrinos
- Hidden sector decouples at early times
- Hidden sector decouples at early times but re-equilibrates with neutrinos below T_ν^{dec}

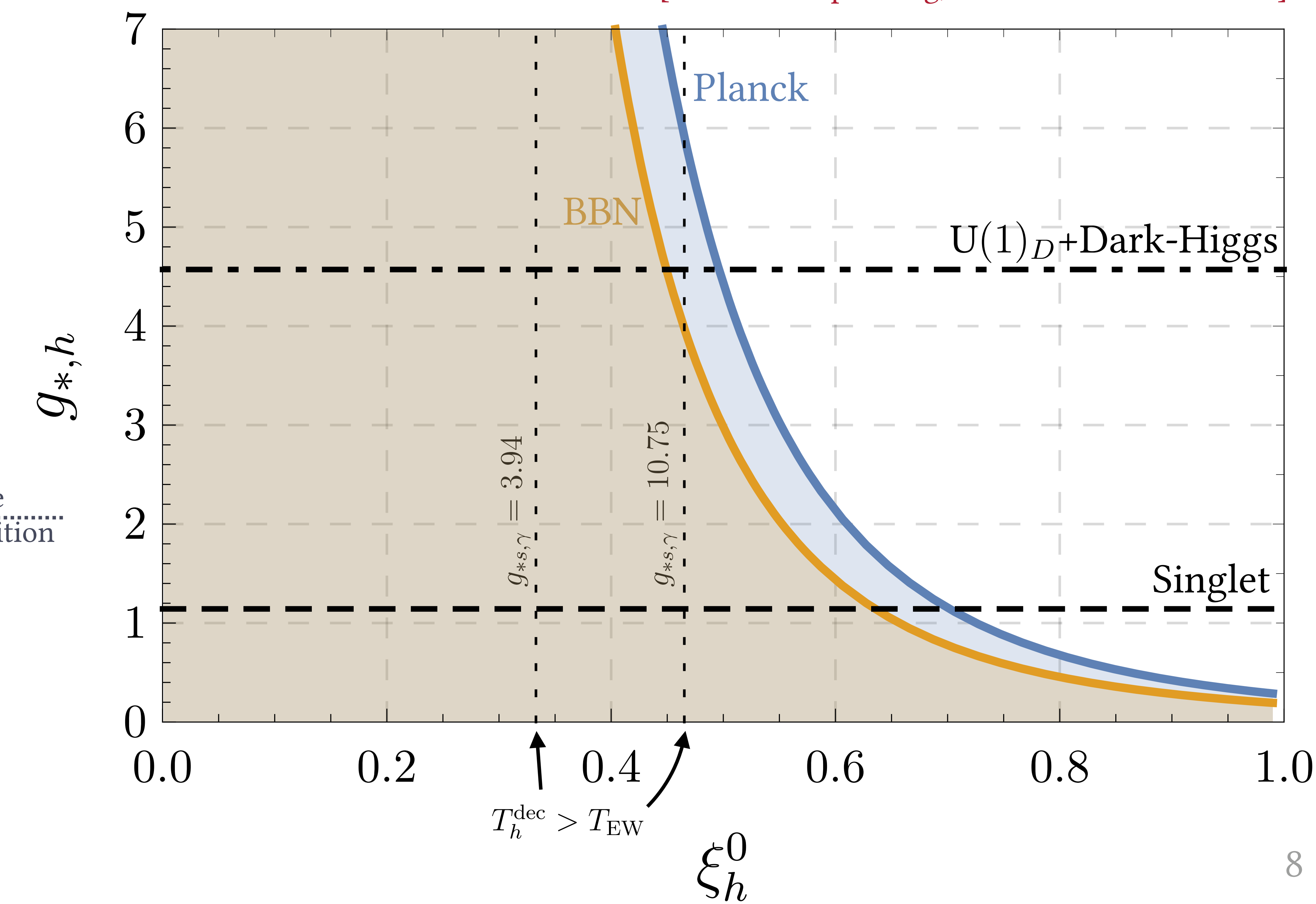
Cosmological Constraints

N_{eff} constraints

Decoupled hidden sector:



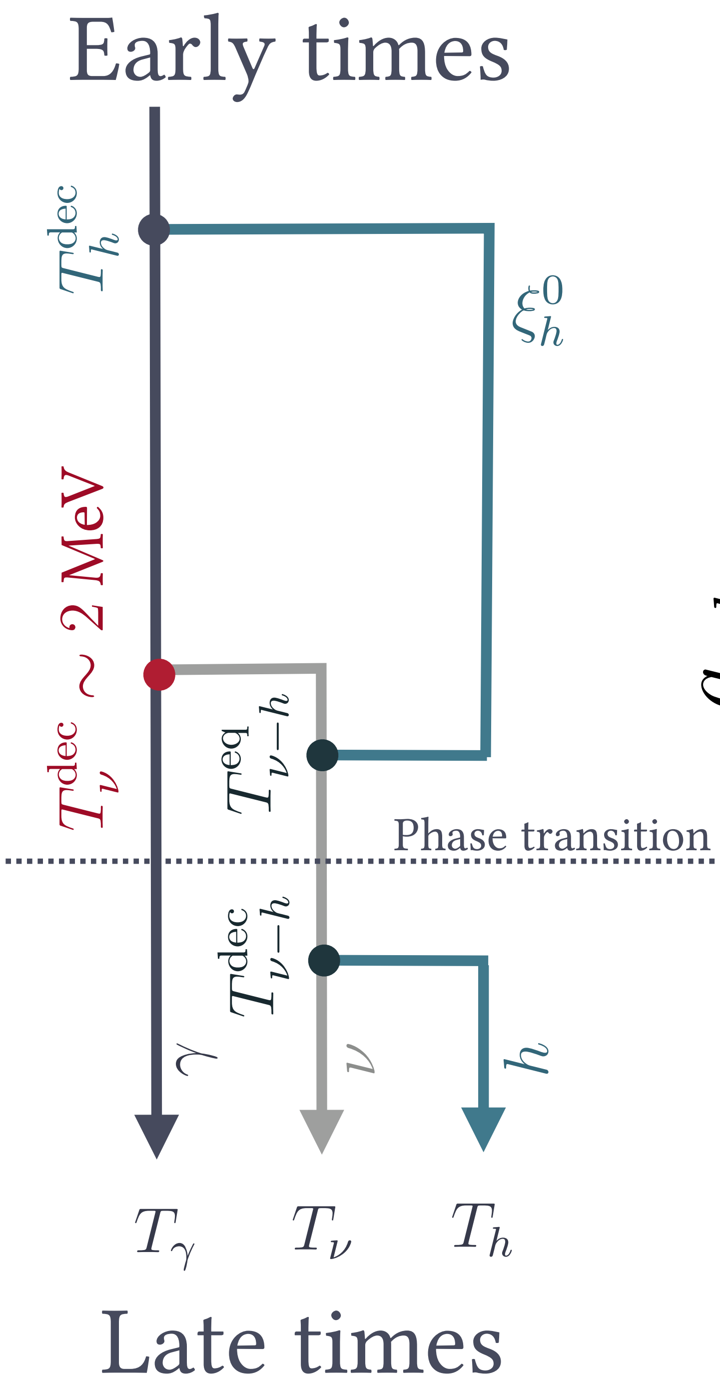
[see for example Feng, H. Tu & H. Yu -0808.2318]



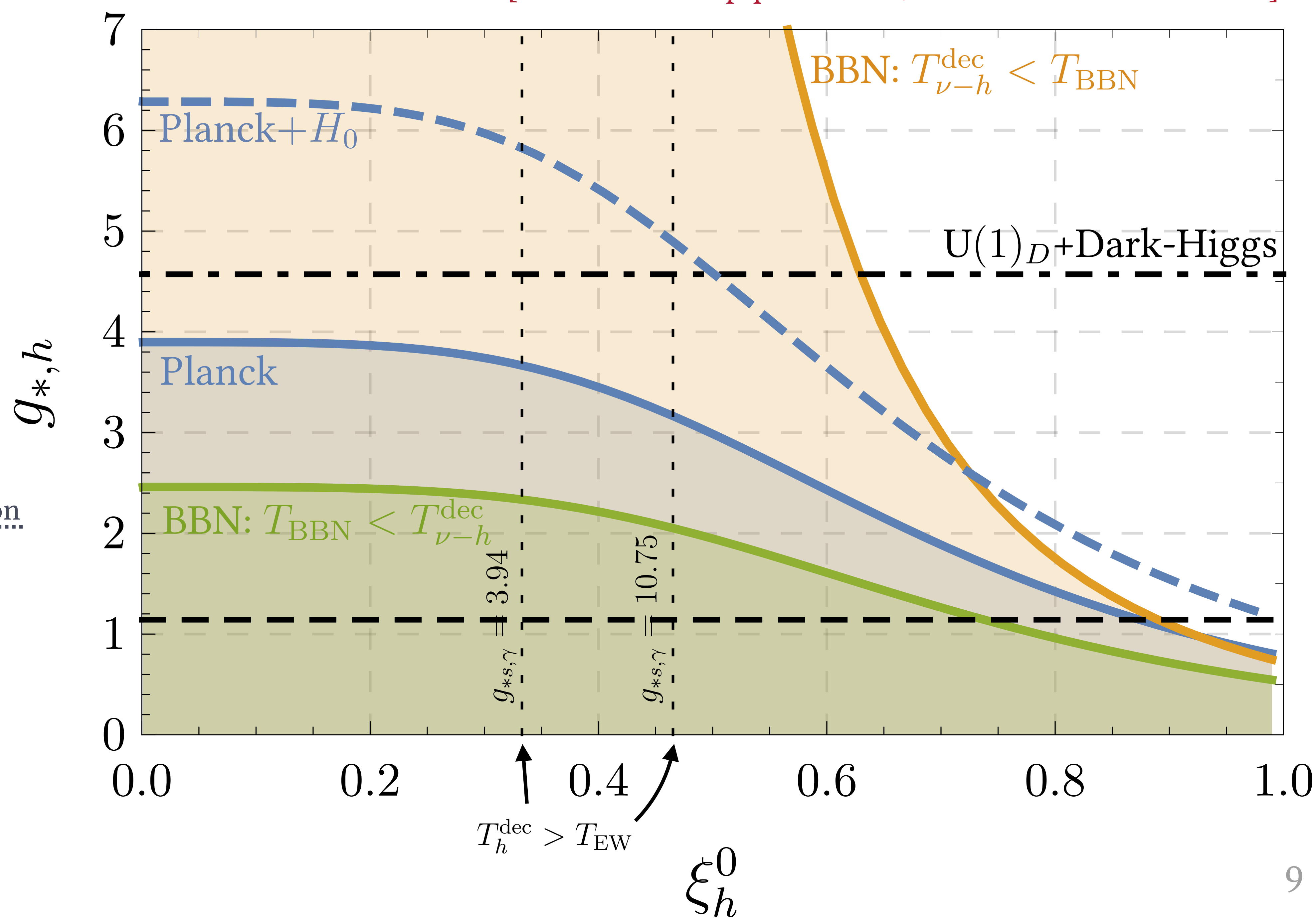
Cosmological Constraints

N_{eff} constraints

Re-equilibration with neutrinos:



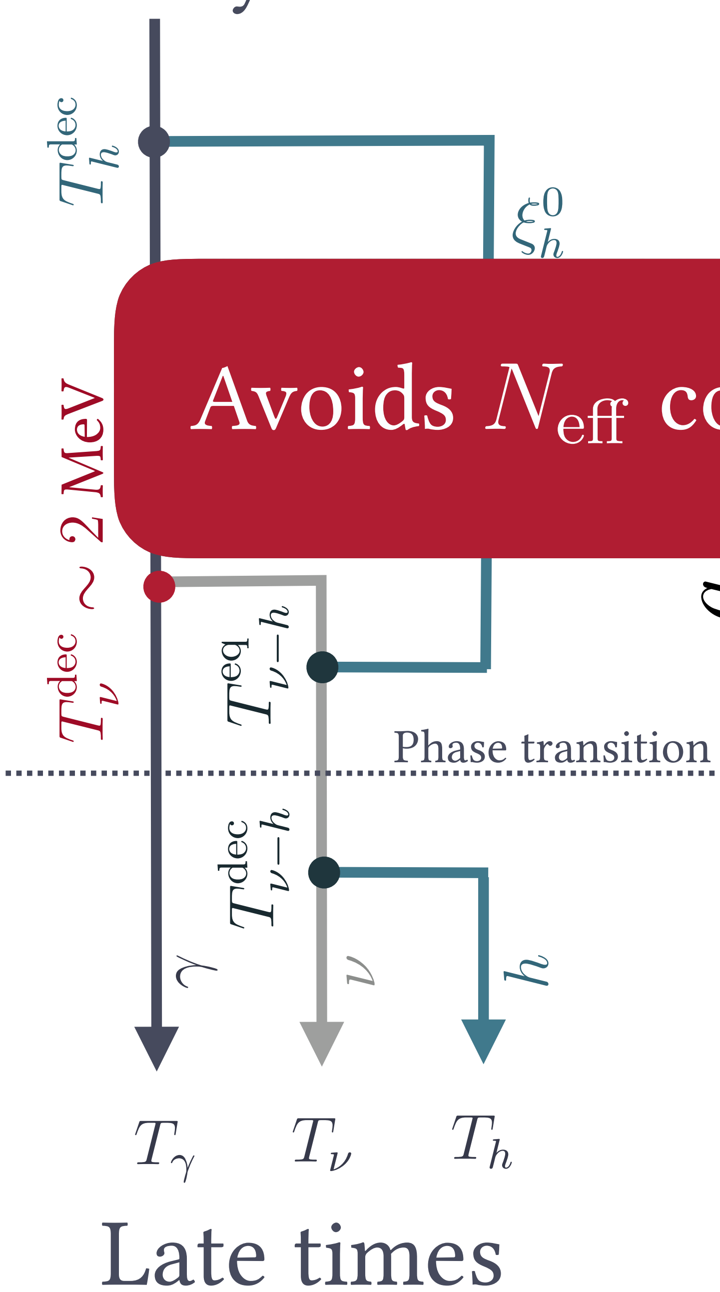
[Chacko et al. hep-ph/0312267; Berlin & Blinov 1706.07046]

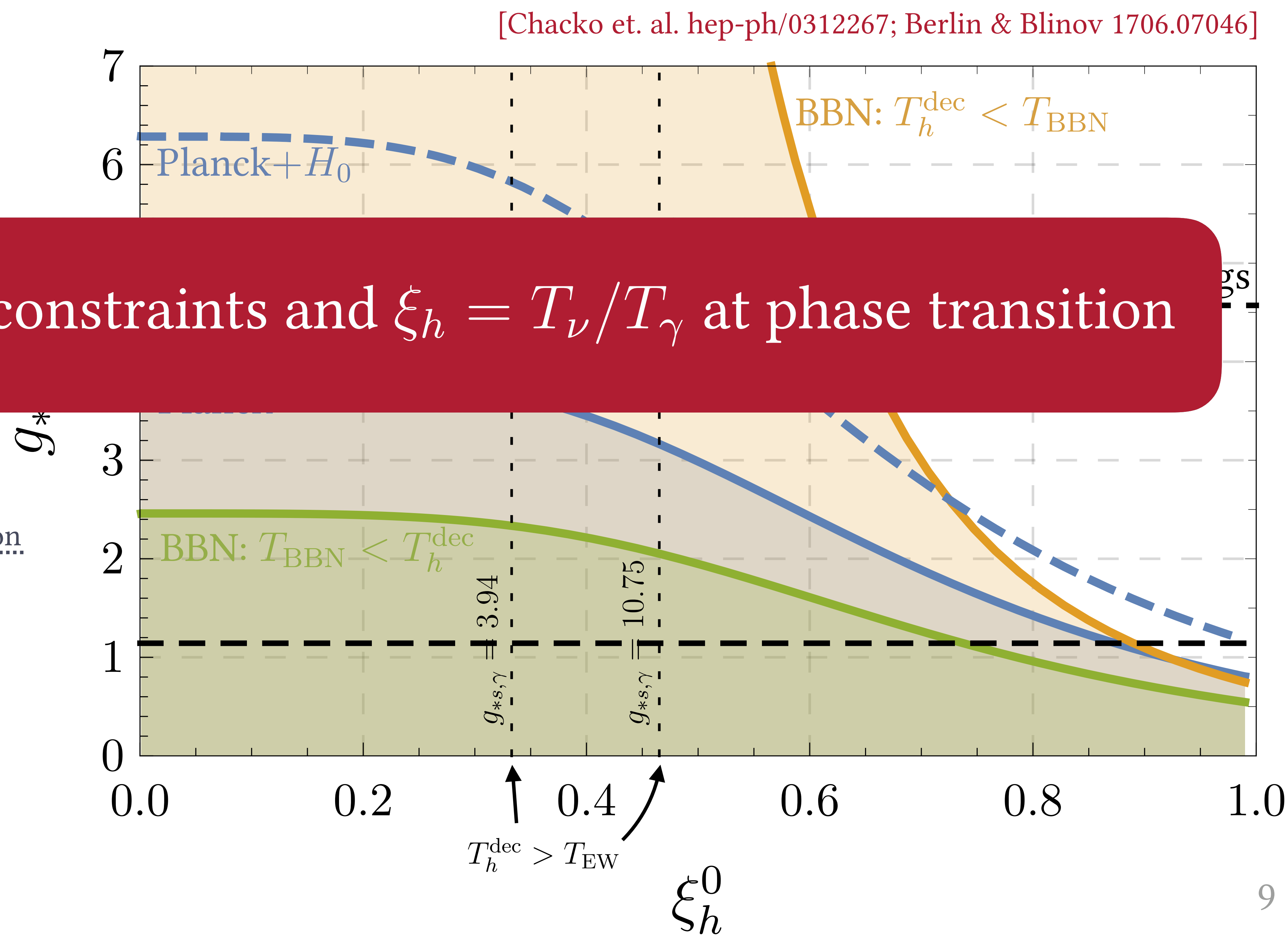


Cosmological Constraints

N_{eff} constraints

Re-equilibration with neutrinos:



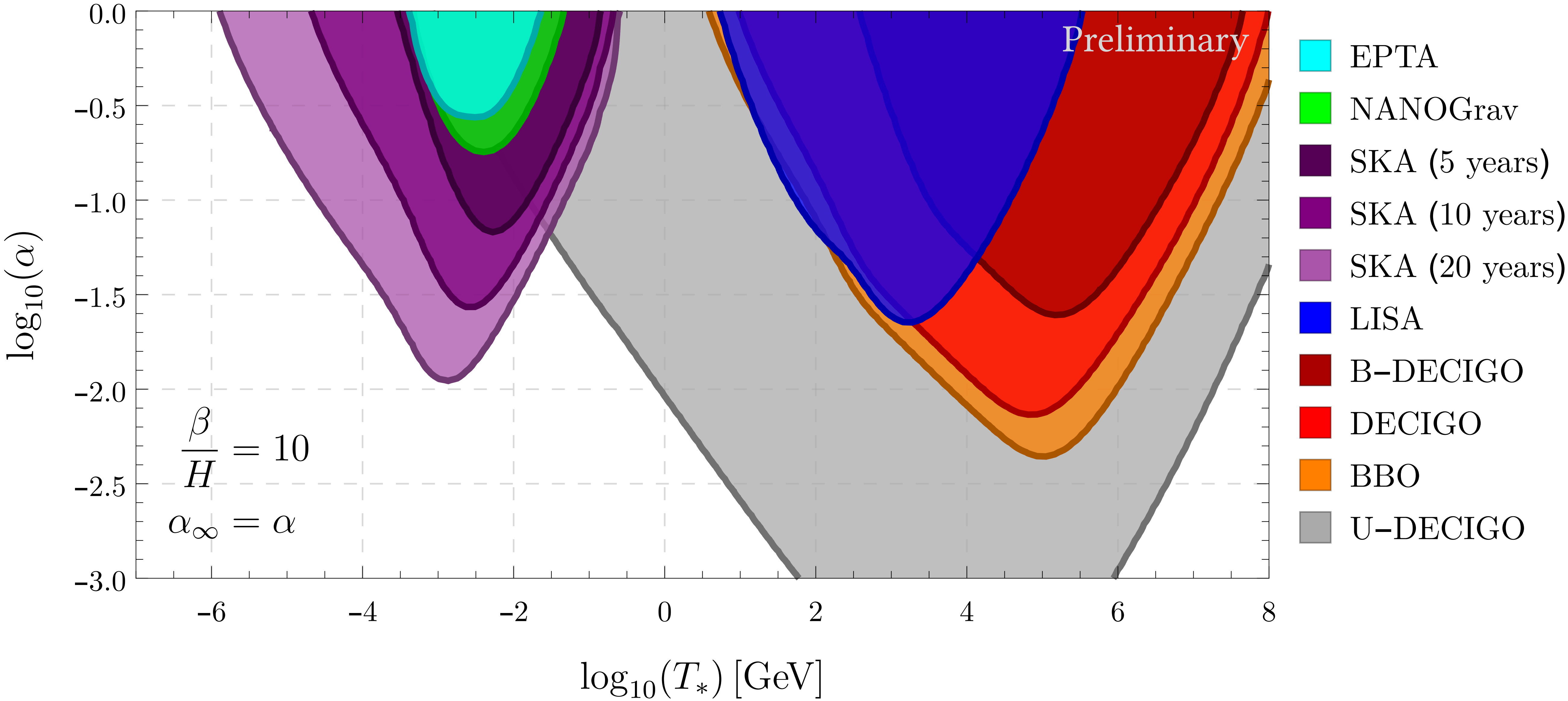


Avoids N_{eff} constraints and $\xi_h = T_\nu/T_\gamma$ at phase transition

Experimental Sensitivity to gravitational wave spectra

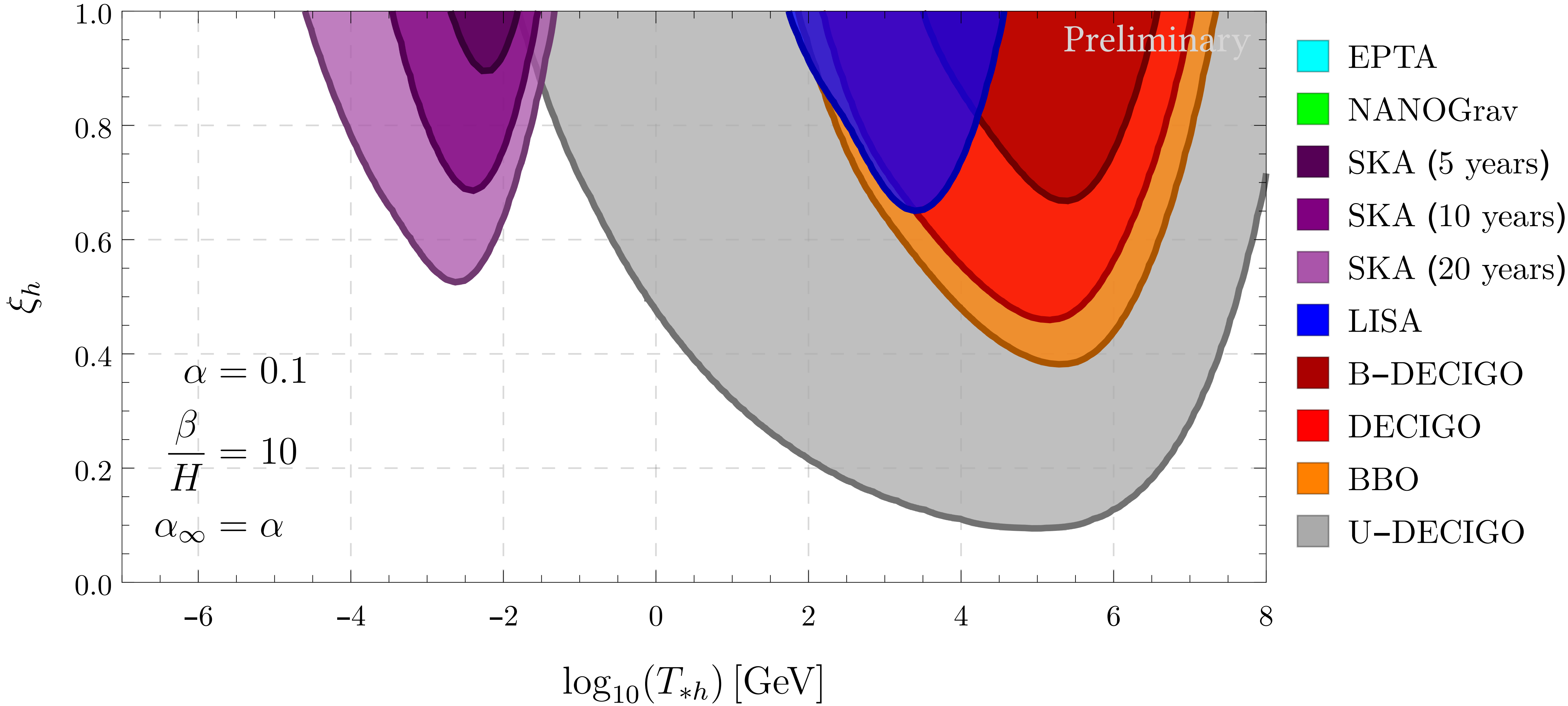
Detectability

Non-runaway bubbles



Detectability

Non-runaway bubbles



Detectability

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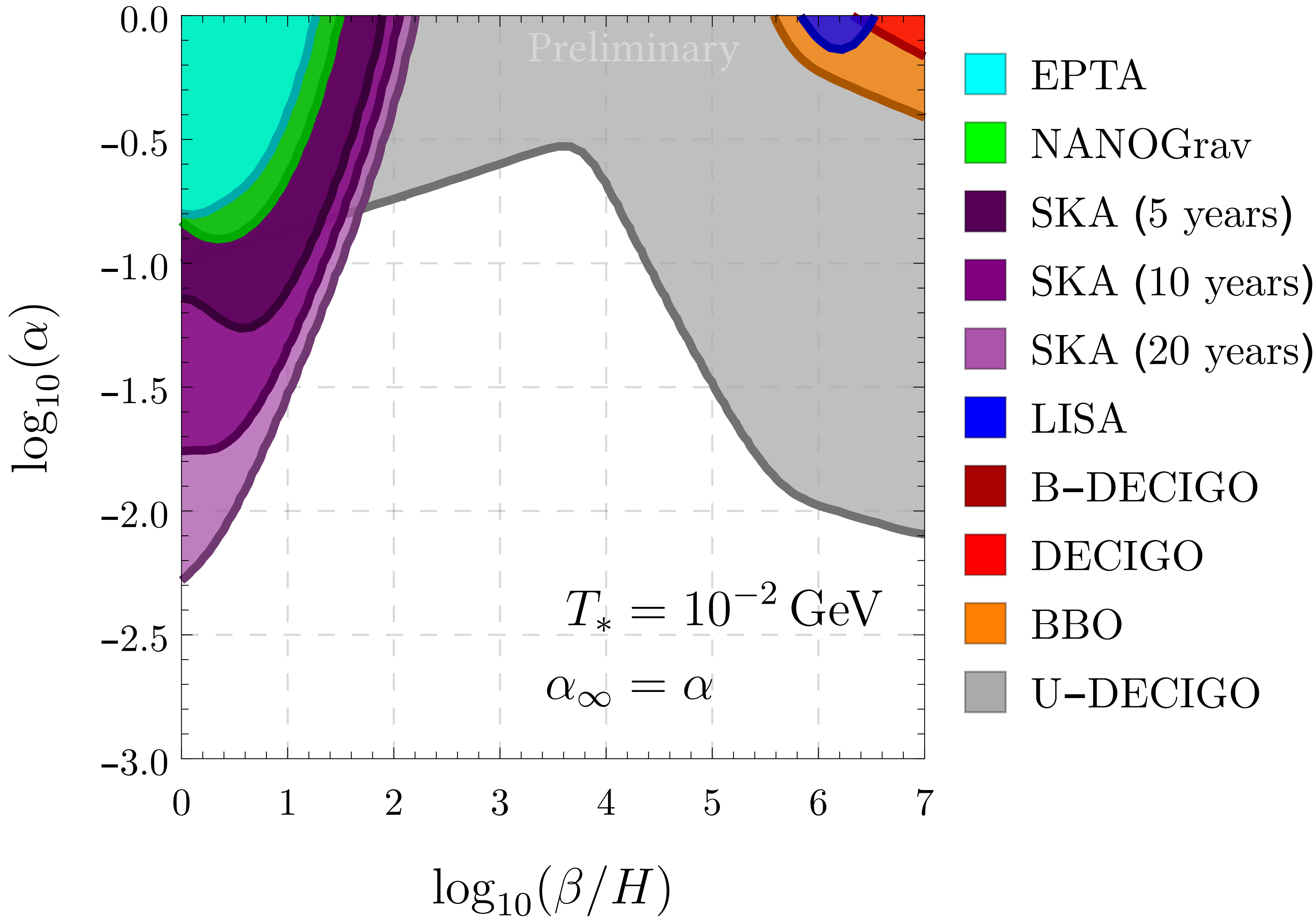

Detectability

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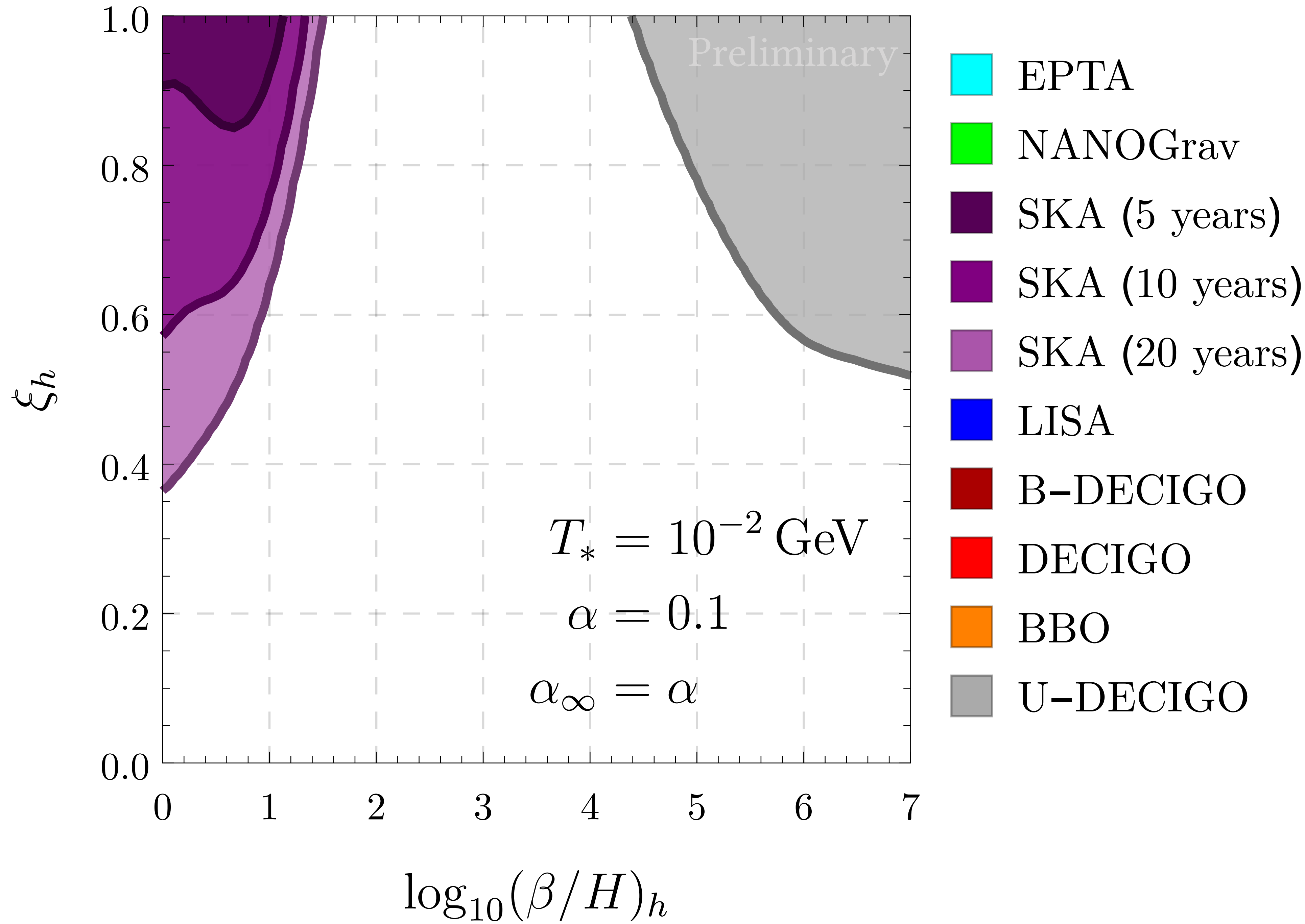
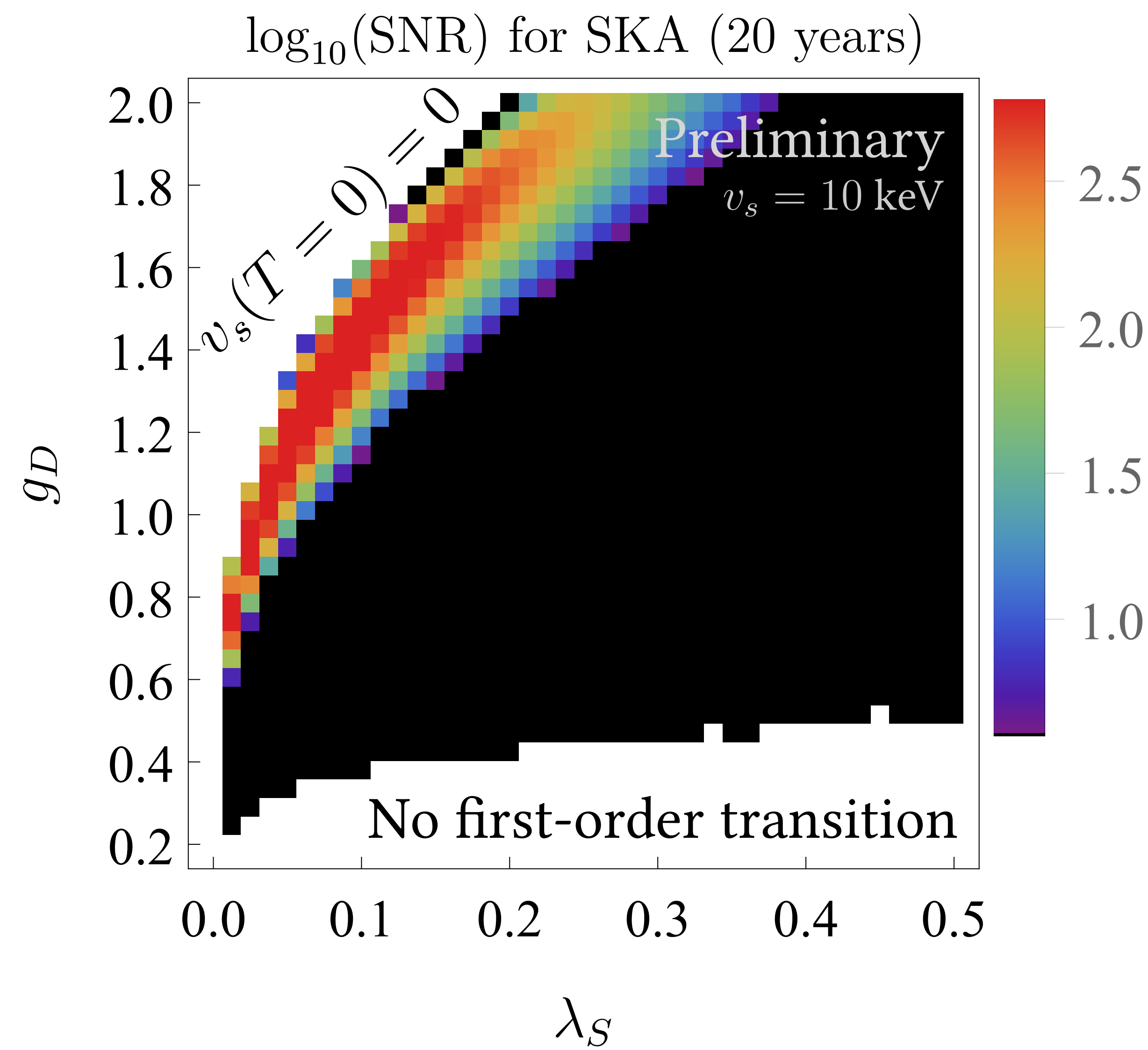


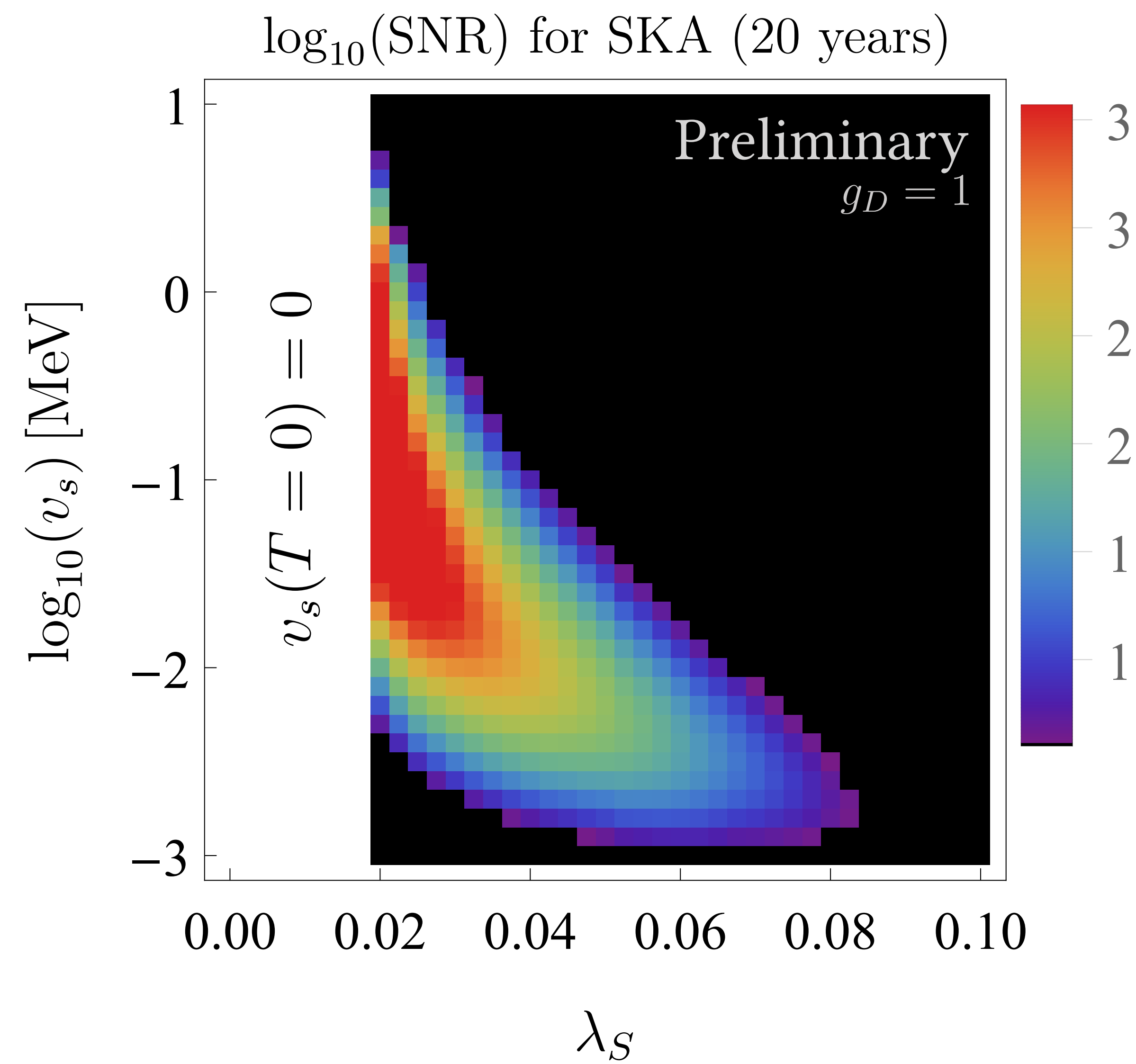
Higgsed Dark-Photon Model

Dark-Photon

First-order phase transition induced by $U(1)_D$ gauge boson

[for space-based experimental sensitivity see Addazi & Marcianò - 1703.03248, Hashino et. al - 1802.02947]

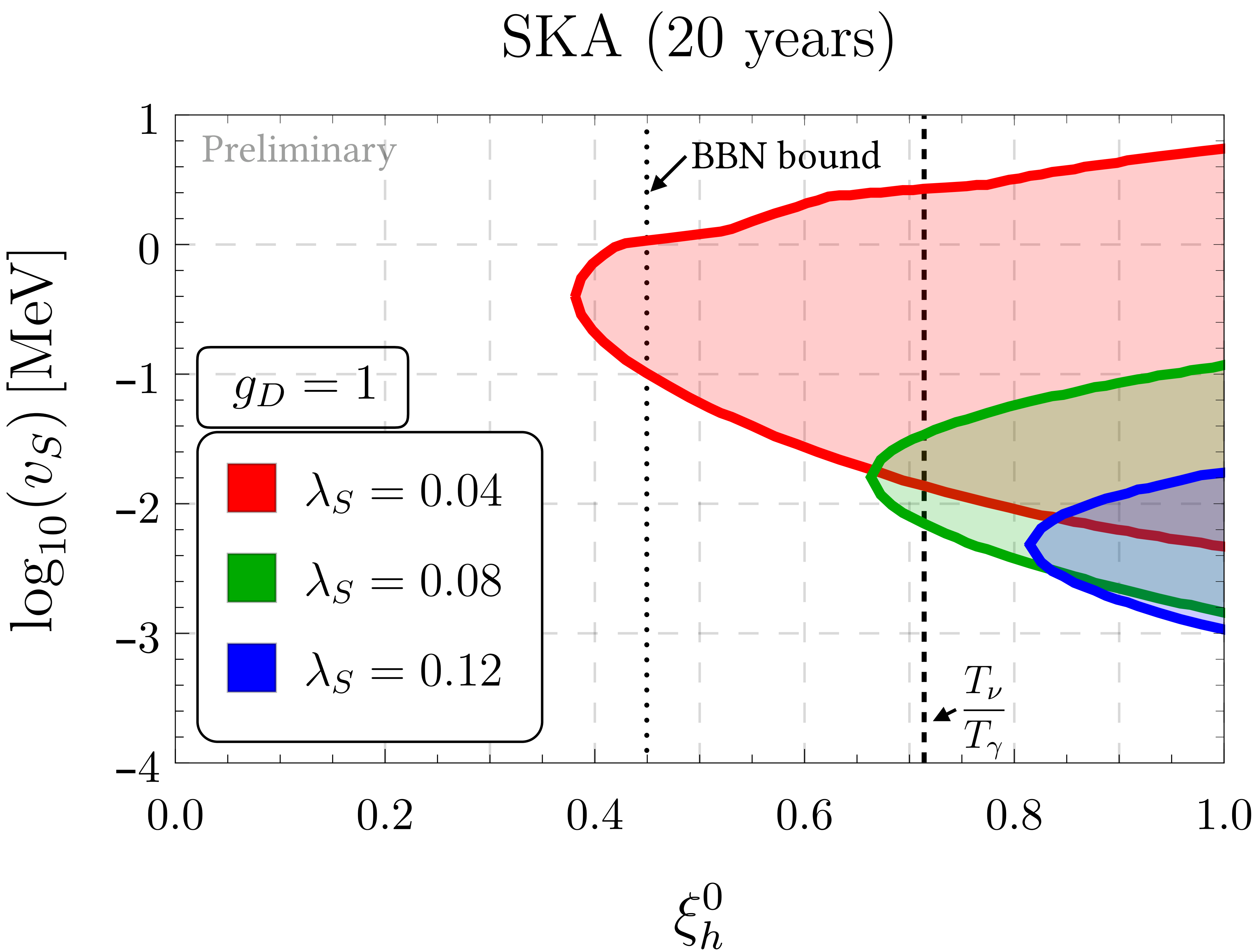




Sensitivity to scenarios where: $m_{A'} > m_{h_D}$

Dark-Photon

Sensitivity



Outlook

This talk

Temperature ratio and thermal history play important roles determining both cosmology constraints and GW signal

Sensitivity to models that are strongly constrained from cosmology

Work in progress

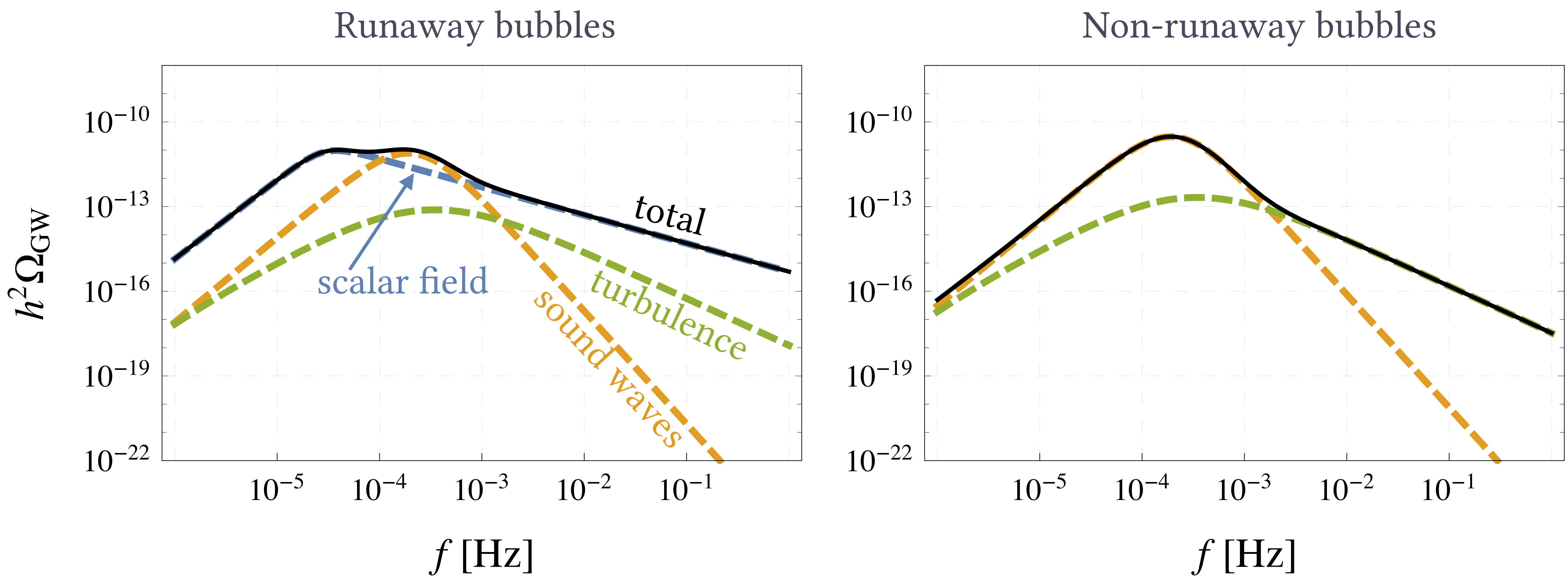
Additional models with fewer DOFs

Automation of GW spectrum calculation through extensions of existing tools

Additional Material

GW Stochastic Background

Contributions to the spectrum

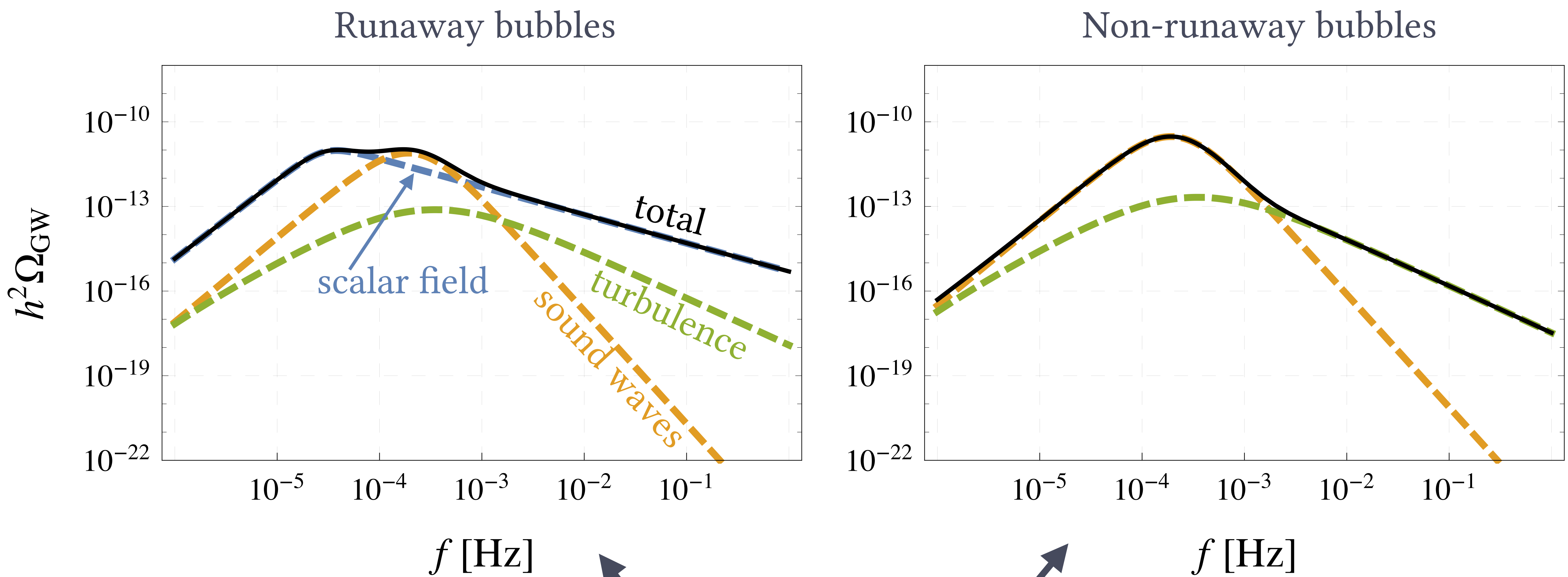


1. Ω_ϕ : Initial collision of bubble walls
2. $\Omega_{\rm sw}$: Collision of sound-waves in the plasma
3. $\Omega_{\rm turb}$: Plasma turbulence after sound wave collision

[Hindmarsh et al. - 1504.03291]

GW Stochastic Background

Contributions to the spectrum revisited



$\alpha > \alpha_\infty$

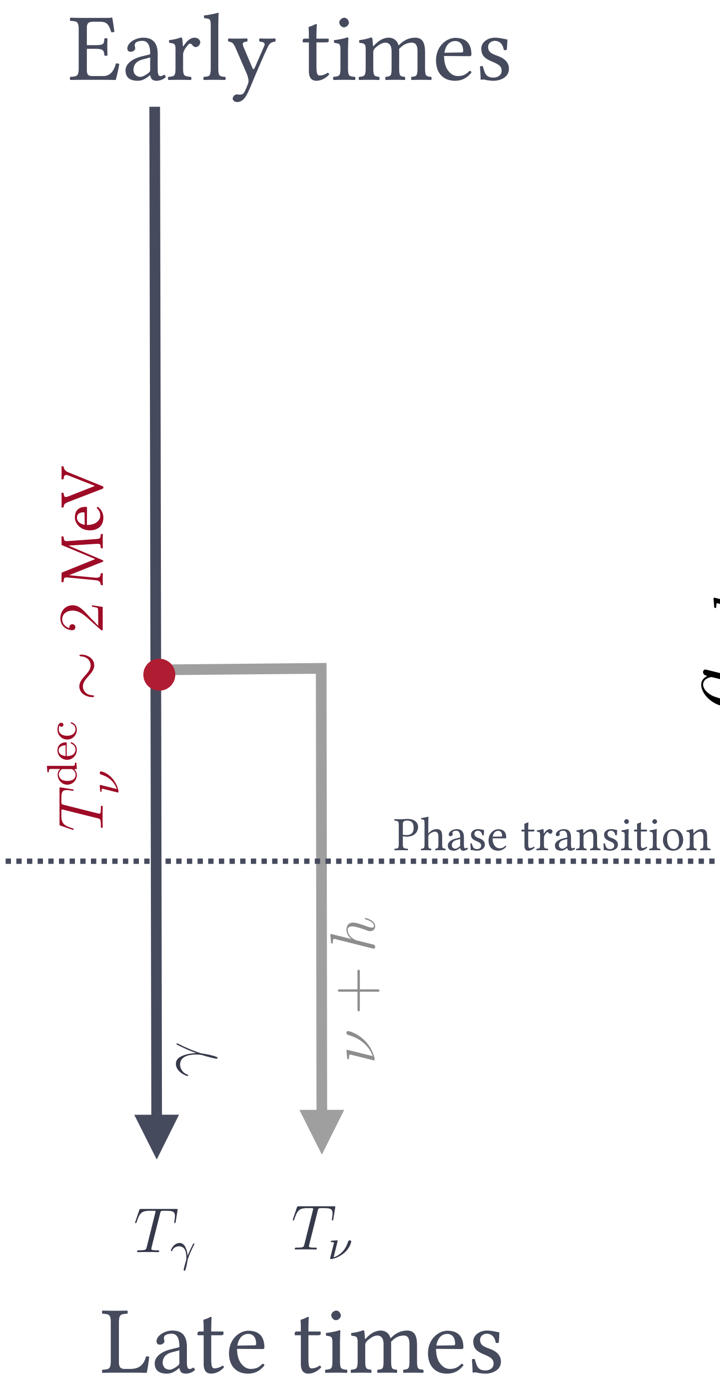
$\alpha \leq \alpha_\infty$

Bubble-wall friction: $\alpha_\infty \sim \sum_a \left[m_a(\phi_{\text{broken}}) - m_a(\phi_{\text{unbroken}})\right]$

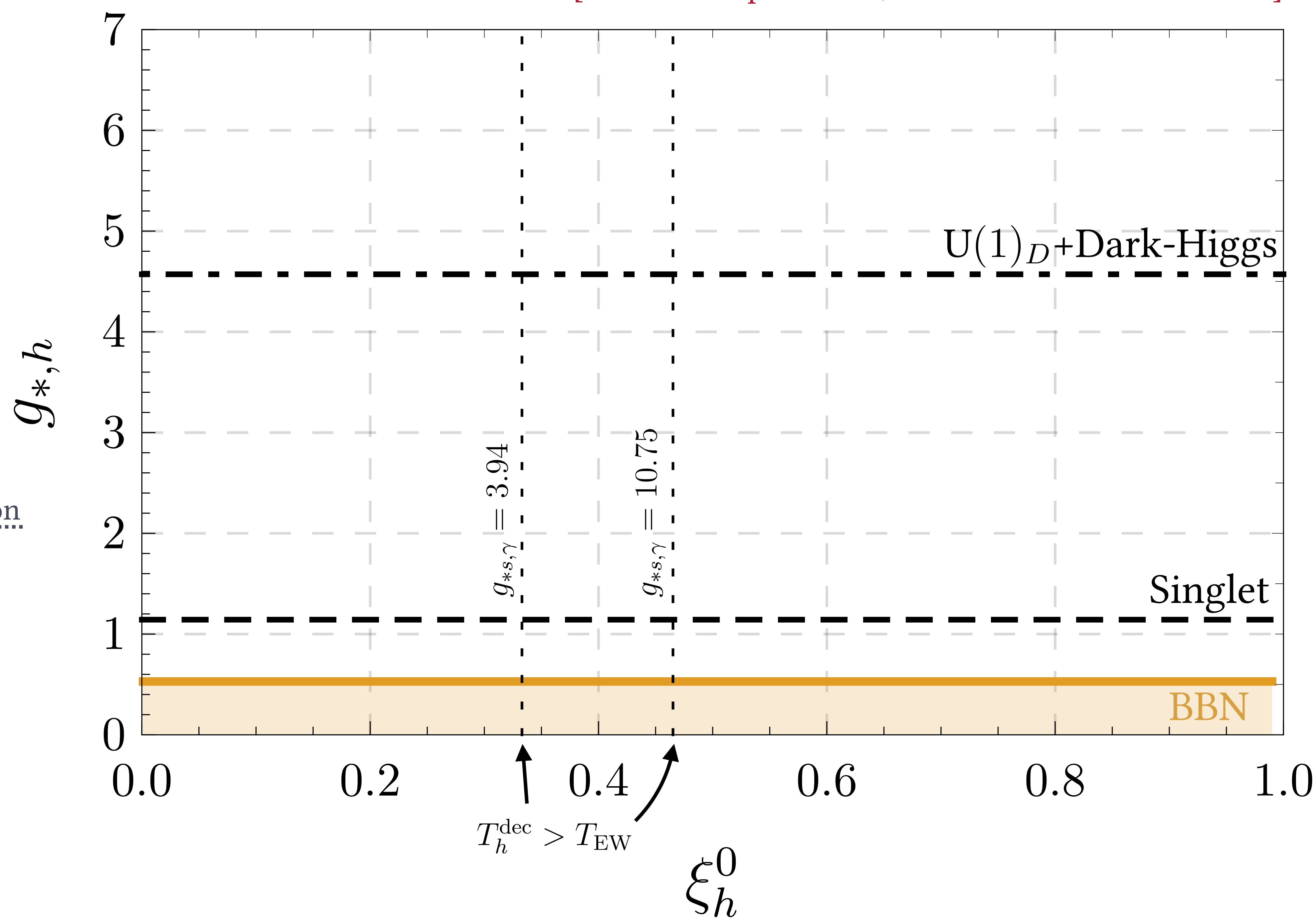
Cosmological Constraints

N_{eff} constraints

Hidden sector thermalised with neutrinos:

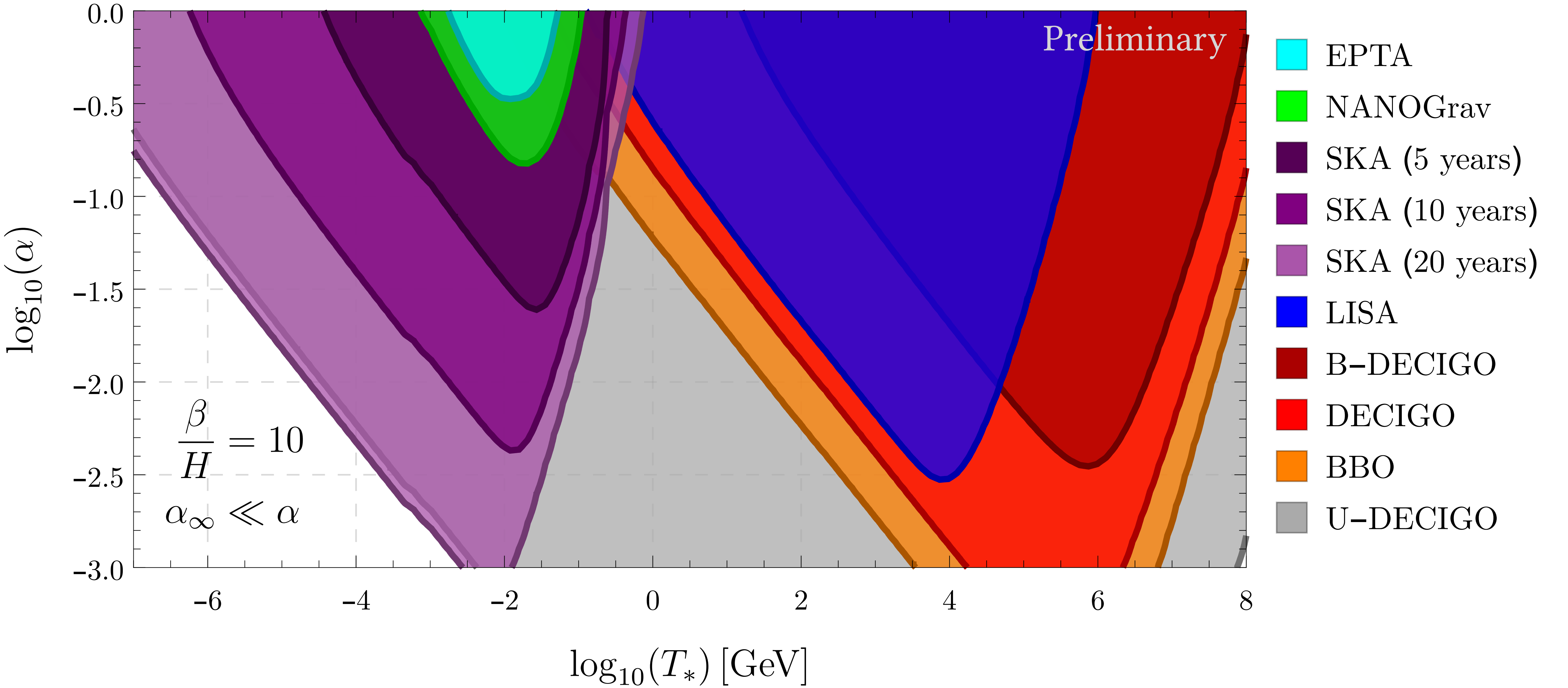


[see for example Bœhm, Dolan & McCabe - 1207.0497]



Detectability

Runaway bubbles



Detectability

Runaway bubbles