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

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Dark, Cold, and Noisy

Constraining Secluded Hidden Sectors with Gravitational Waves

arXiv:1811.11175

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in collaboration with

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COSMO19 – Aachen

Hidden Sectors

Open Problems

- dark matter
- baryon asymmetry
- ...

BSM searches

no BSM particles found so far ...

Hidden Sector

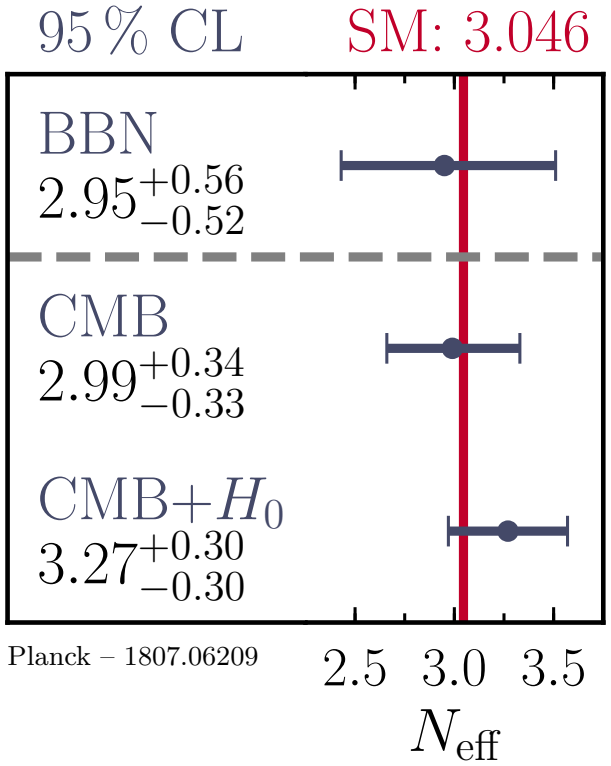
- no (or very weak) interactions with SM
- probably contains new symmetries
  $\Longrightarrow$ phase transition?

Sub-MeV Hidden Sectors

- sub-MeV hidden sectors contribute to the effective number of neutrino species $N_{\rm eff}$

$$\rho_{\rm rad} = \frac{\pi^2}{30}\sum_i g_i T_i^4 = \left[1 + \frac{7}{8}\left(\frac{4}{11}\right)^{\frac{4}{3}} N_{\rm eff}\right]\rho_\gamma$$

- at $T \lesssim$ MeV:
  additional rel. DOFs in thermal equilibrium with photons are excluded



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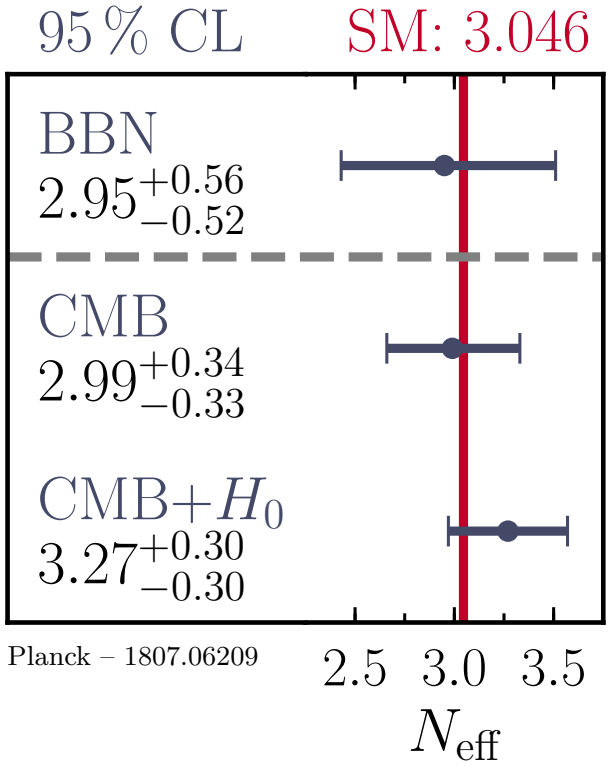
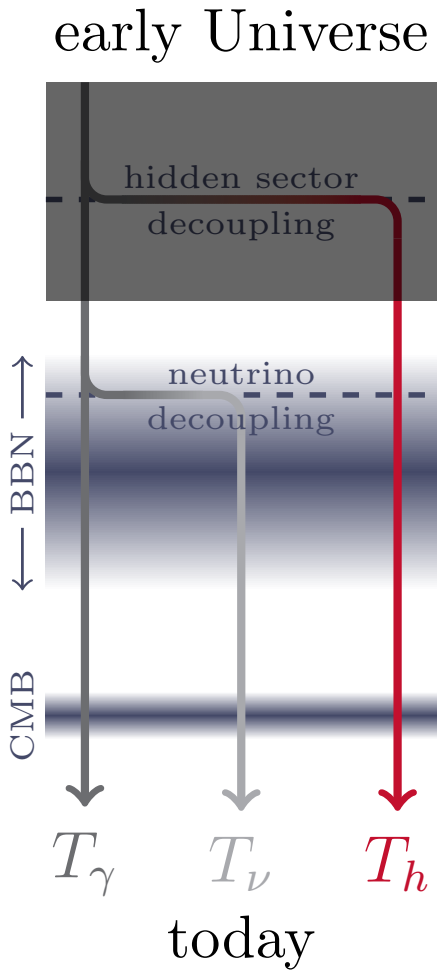


$\Longrightarrow$ sub-MeV hidden sector must be colder than SM

$\Longrightarrow$ impact on phase transition / GW spectrum ?

Completely Decoupled Hidden Sector



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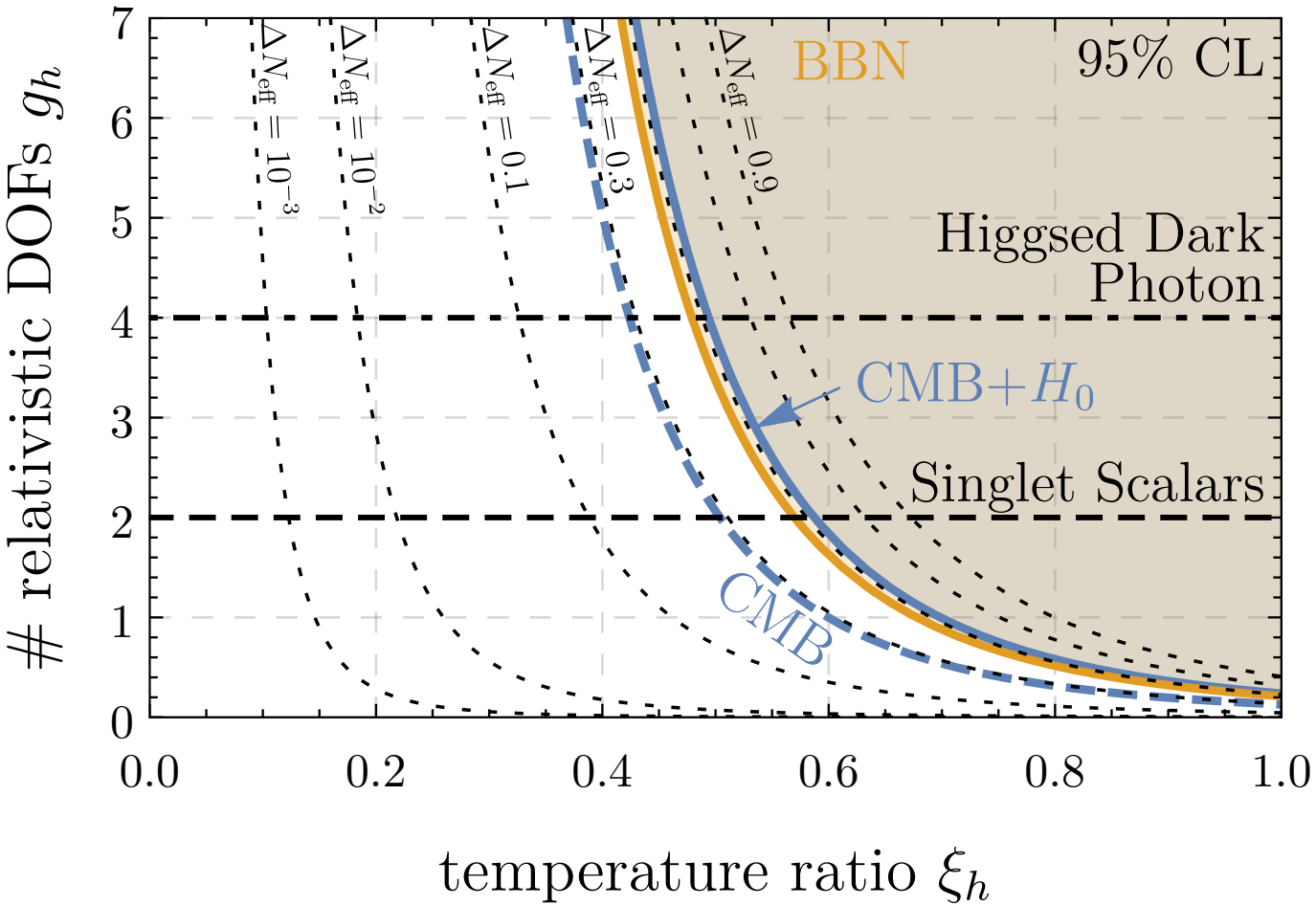
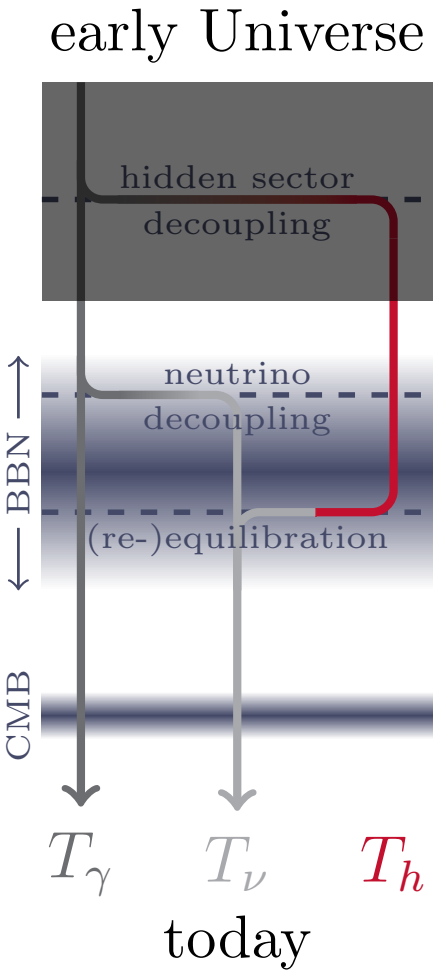


ν-quilibration



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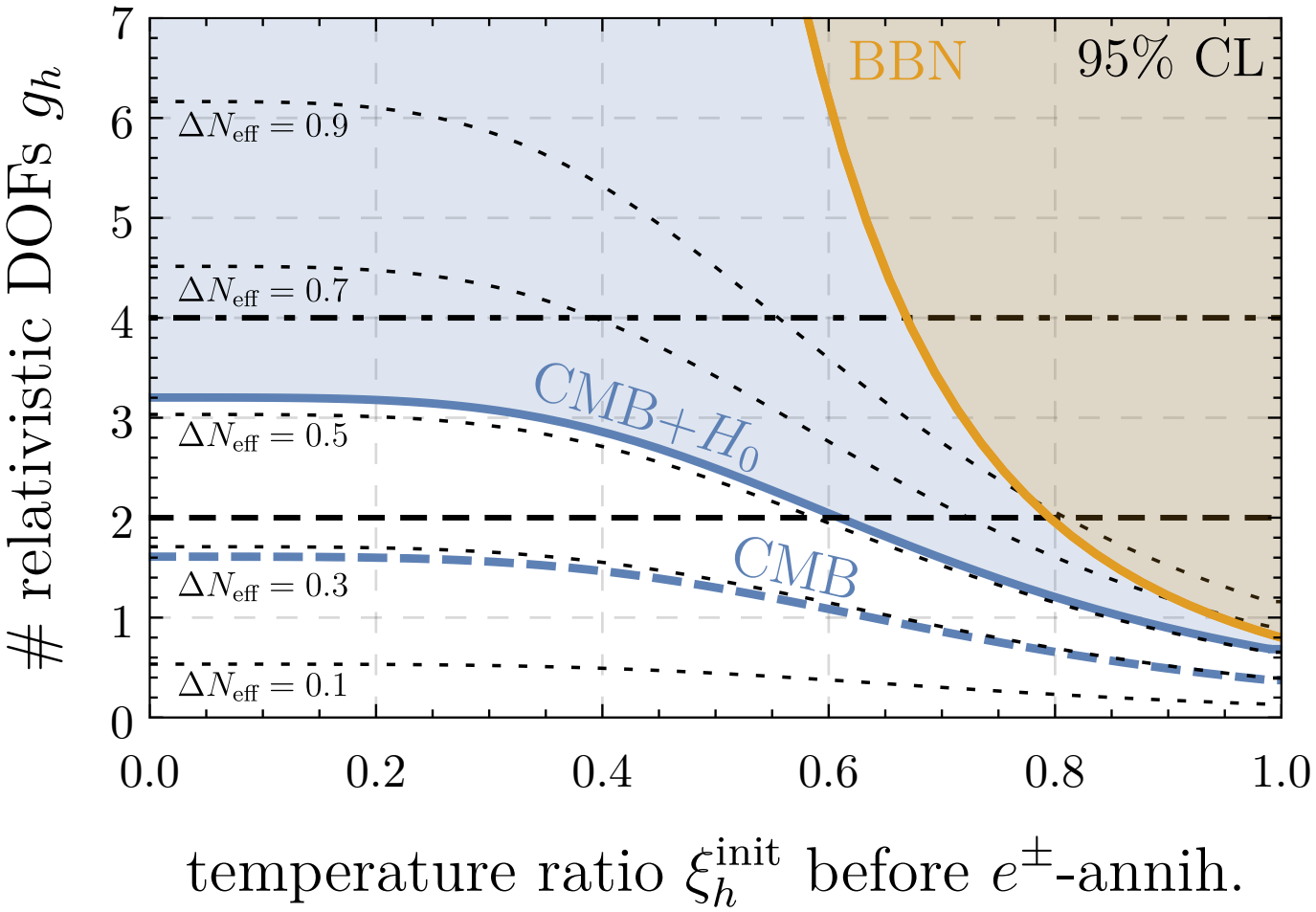
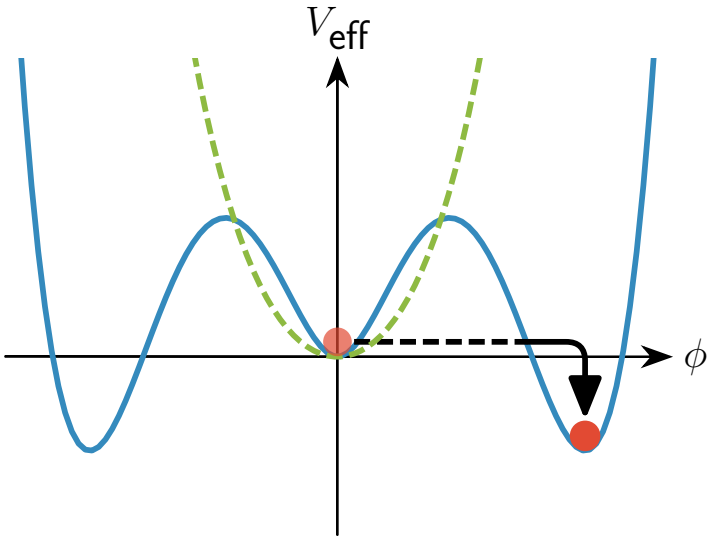


Cosmological Phase Transitions

finite-T corrections restore symmetry
$\Longrightarrow$ symmetry breaking phase transition



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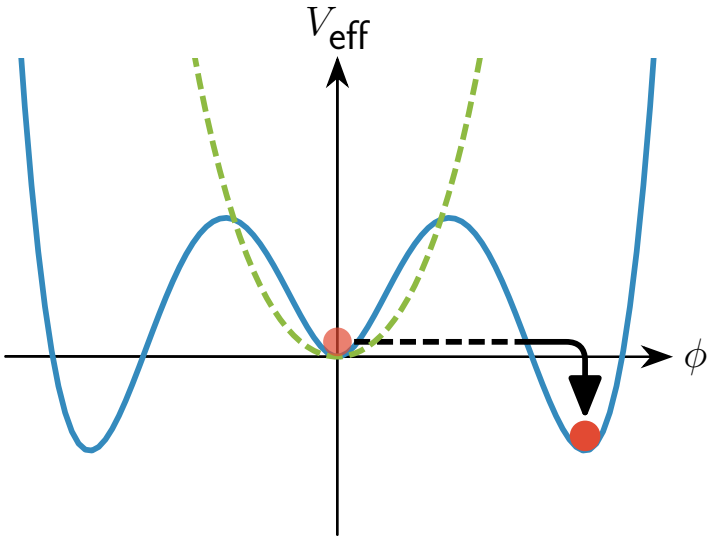
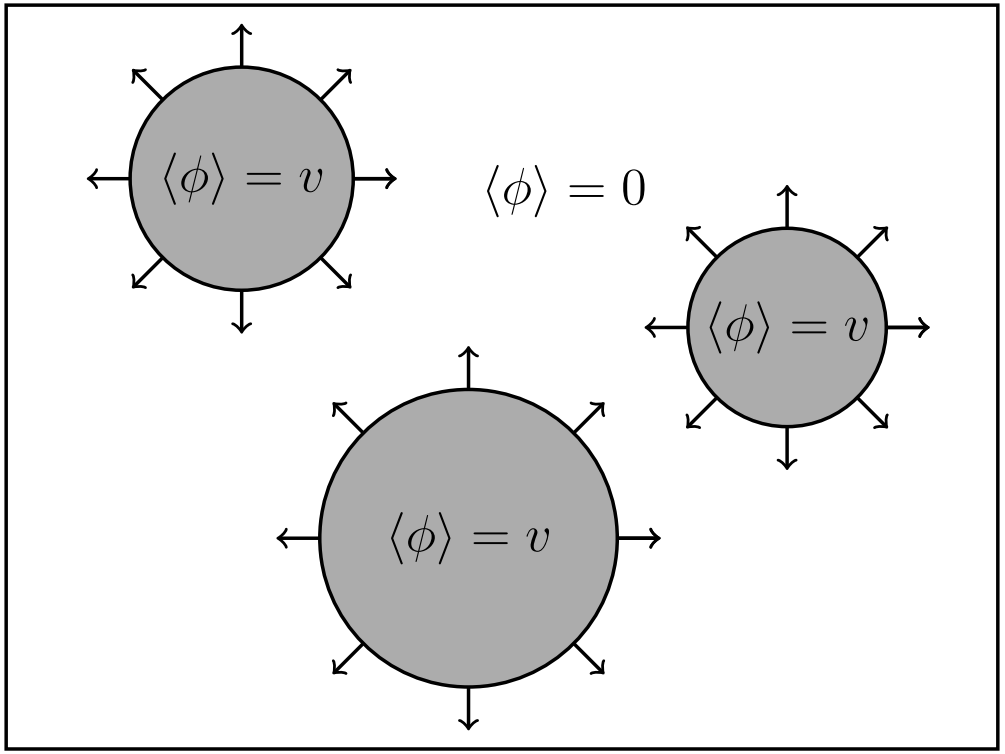




1st-order phase transition:

minima separated by potential barrier

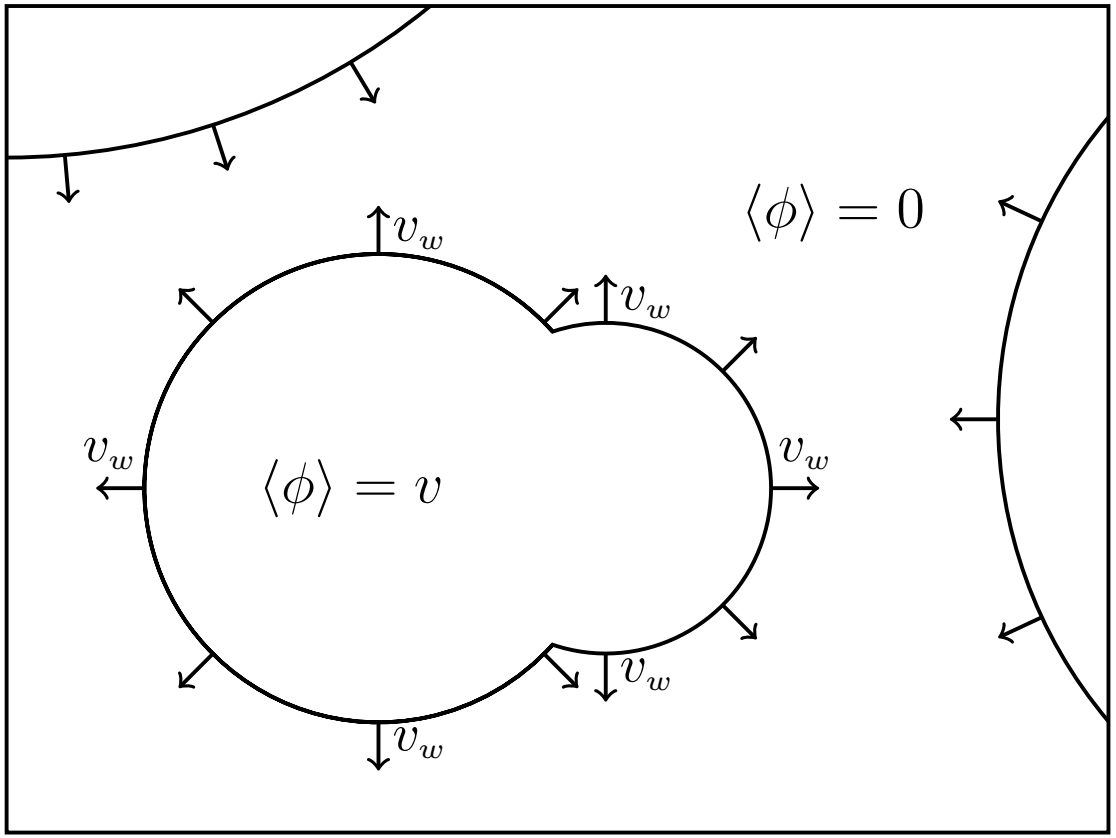
$\Longrightarrow$ transition via bubble nucleation

Gravitational Wave Spectrum

3 contributions:

$$\Omega_{\rm GW}(f) \equiv \frac{1}{\rho_c}\frac{{\rm d}\rho_{\rm GW}}{{\rm d}\log f} = \Omega_\phi(f) + \Omega_{\rm sw}(f) + \Omega_{\rm turb}(f)$$

collision of bubble walls



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sound waves in the plasma

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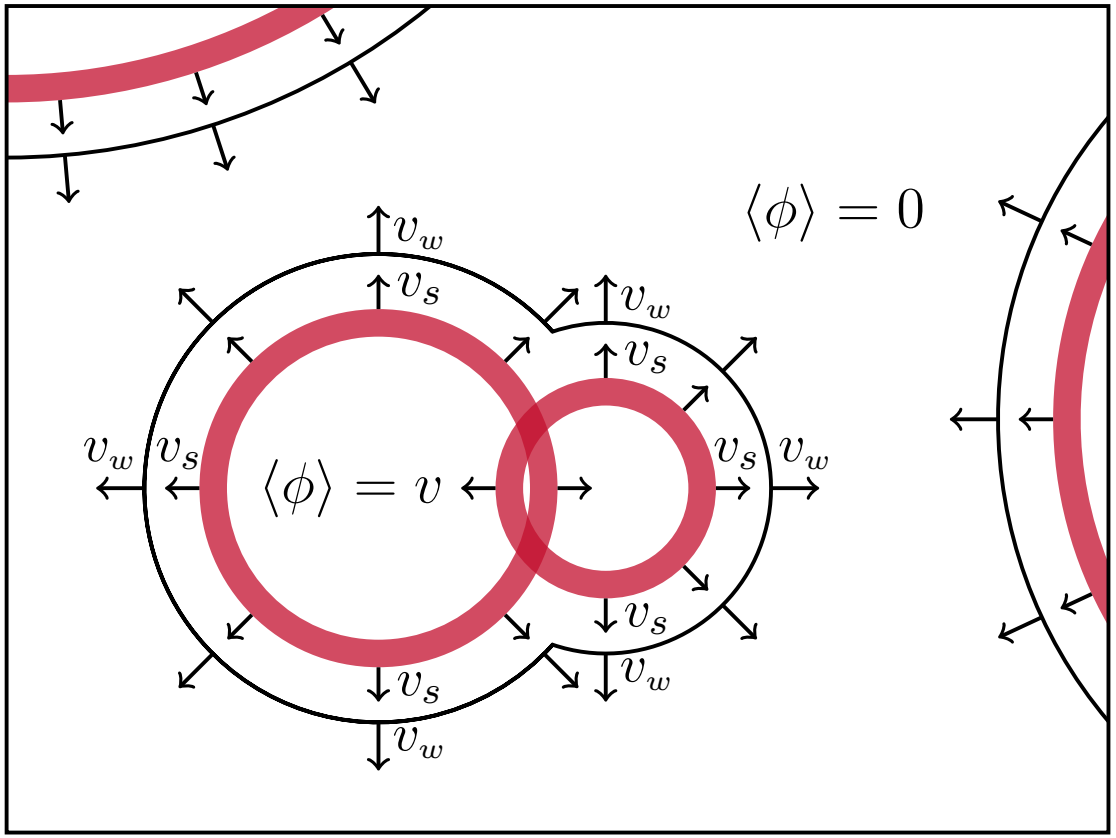

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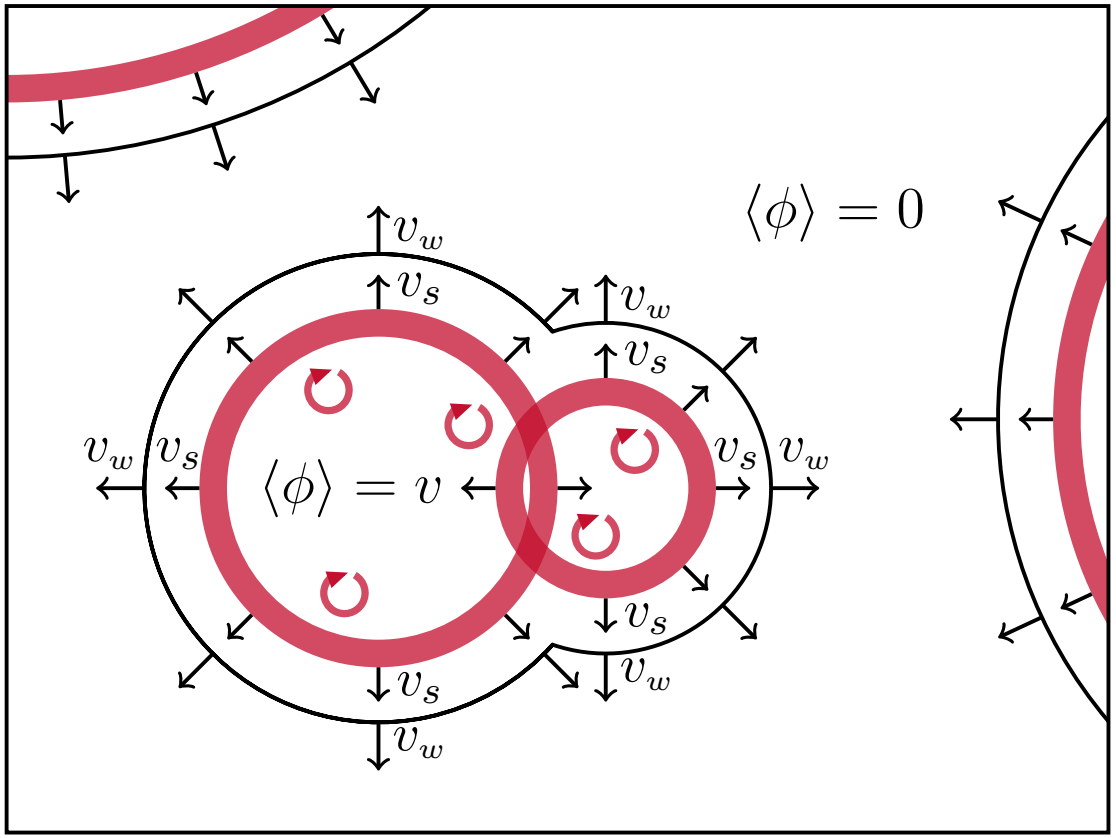
collision of bubble walls

turbulence, vortical fluid motion

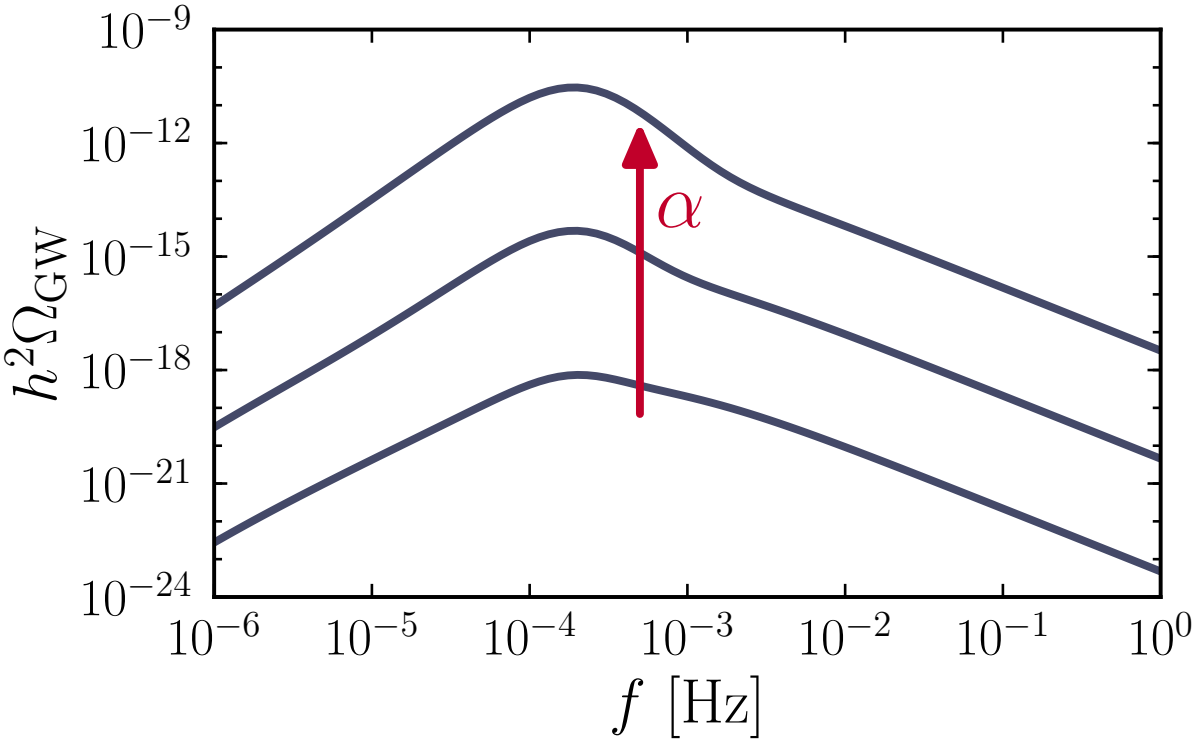


Phase Transition Parameters

1-st order phase transition characterized by 3 parameters:

strength:

$$\alpha \equiv \frac{\text{latent heat}}{\rho^*_{\text{rad}}}$$



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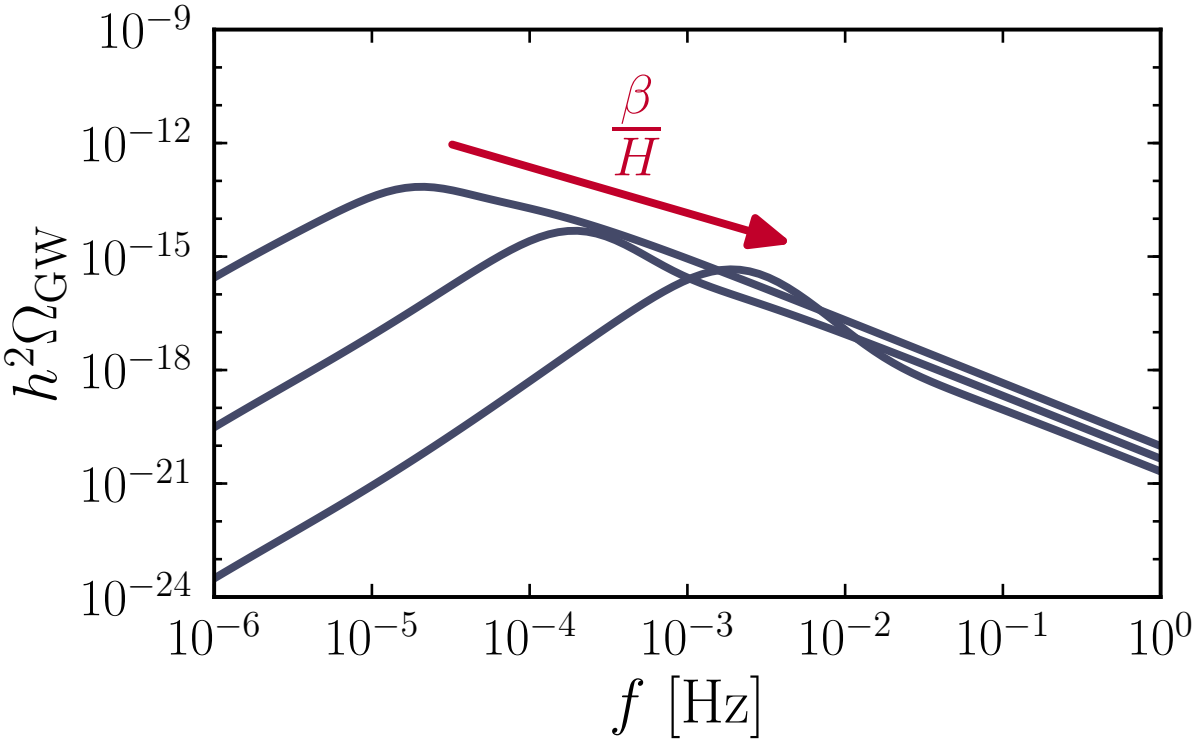

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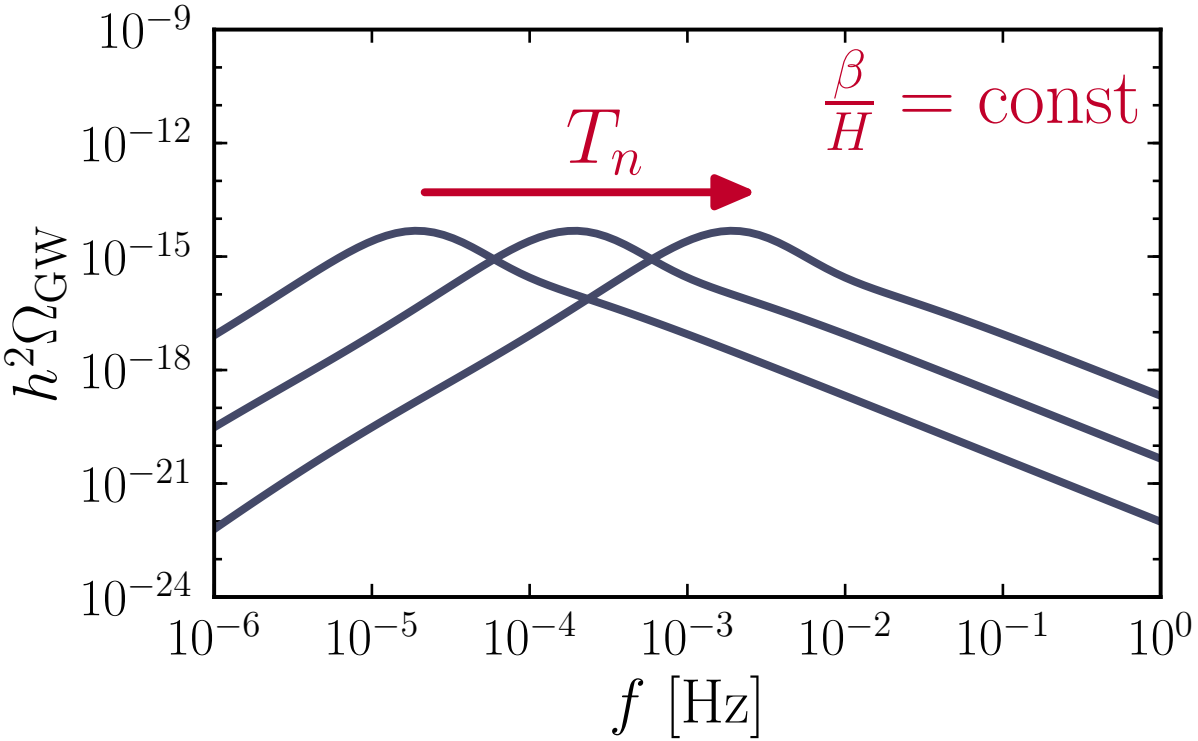
$$T_* \simeq T_{\rm nuc}$$



Phase Transitions in Secluded Hidden Sectors

temperature ratio: $\xi_h \equiv \frac{T_h}{T_\gamma}$

- $\alpha \simeq \alpha_h \xi_h^4$

  $\alpha_h \equiv [\alpha]_{\xi_h=1}$

- $f^0_{\rm peak} \sim T_\gamma^{\rm nuc} = \frac{T_h^{\rm nuc}}{\xi_h}$

- $\frac{\beta}{H}$ ξ_h-independent

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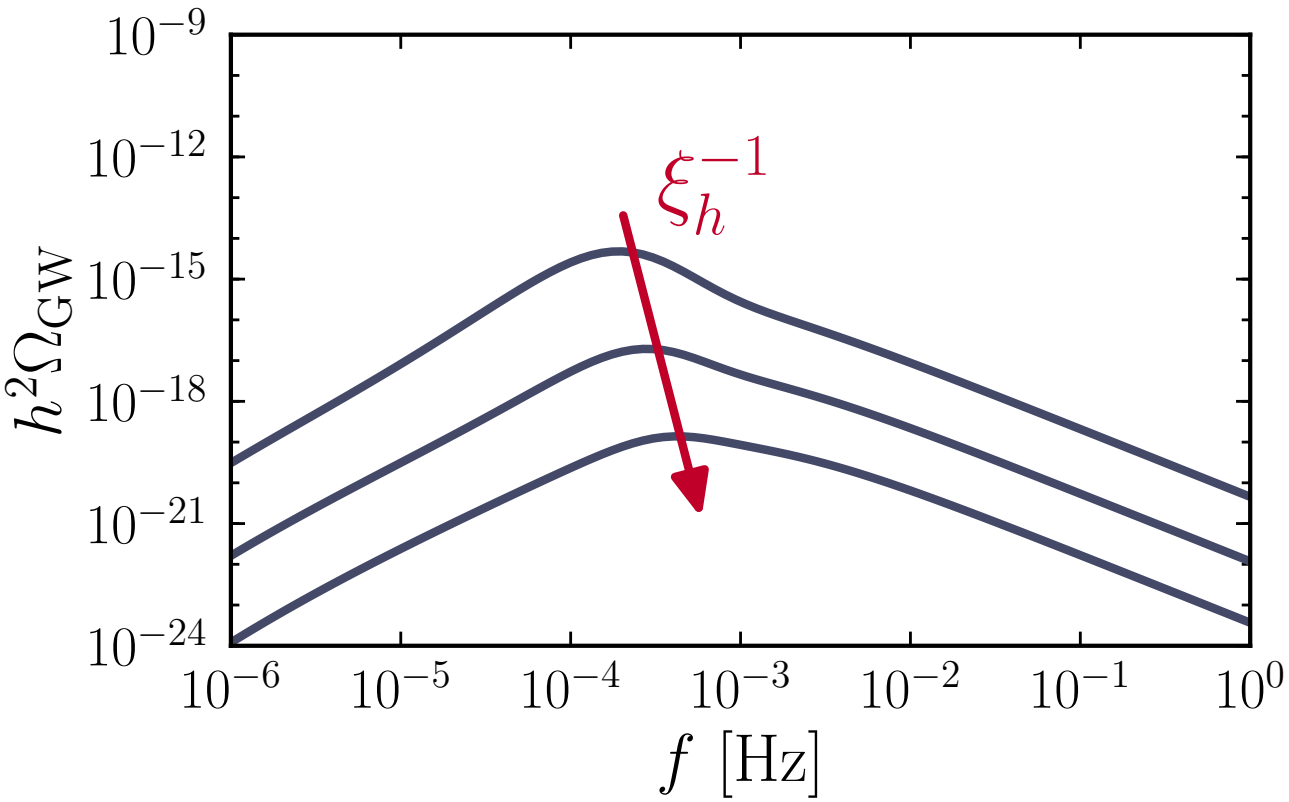
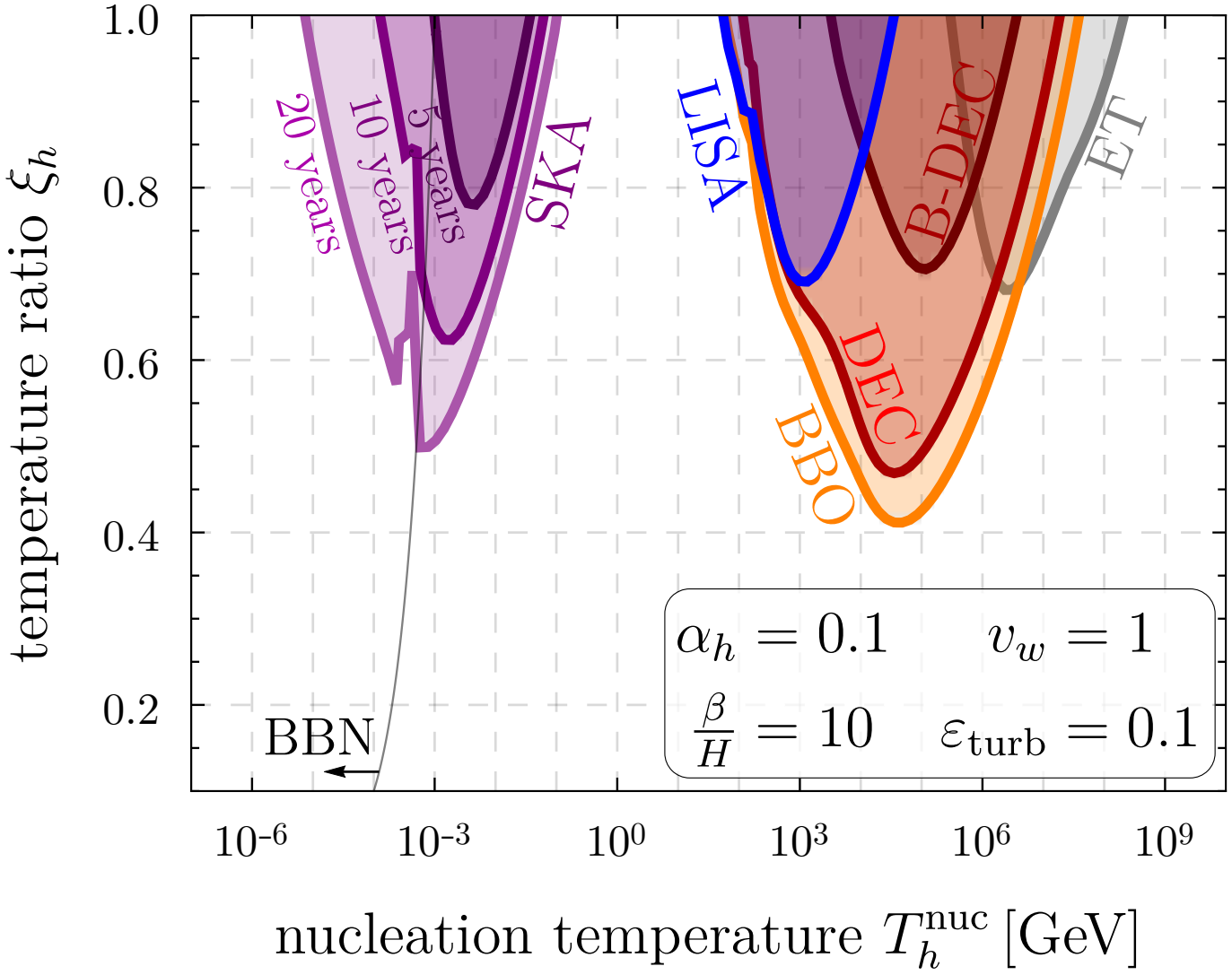


Sensitivity



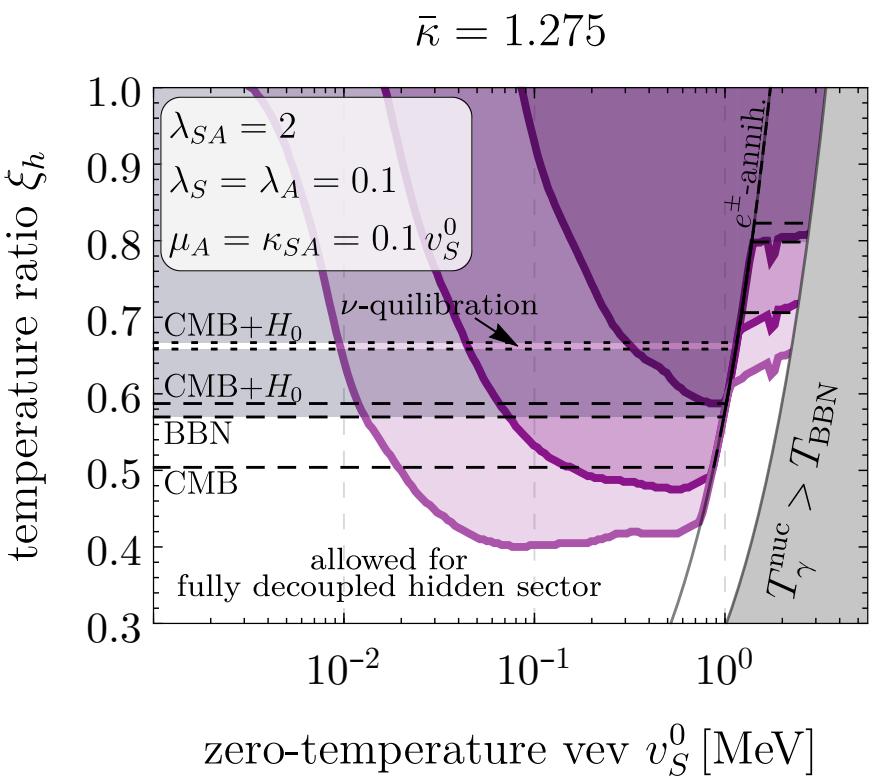
Hidden Sector Benchmark Models

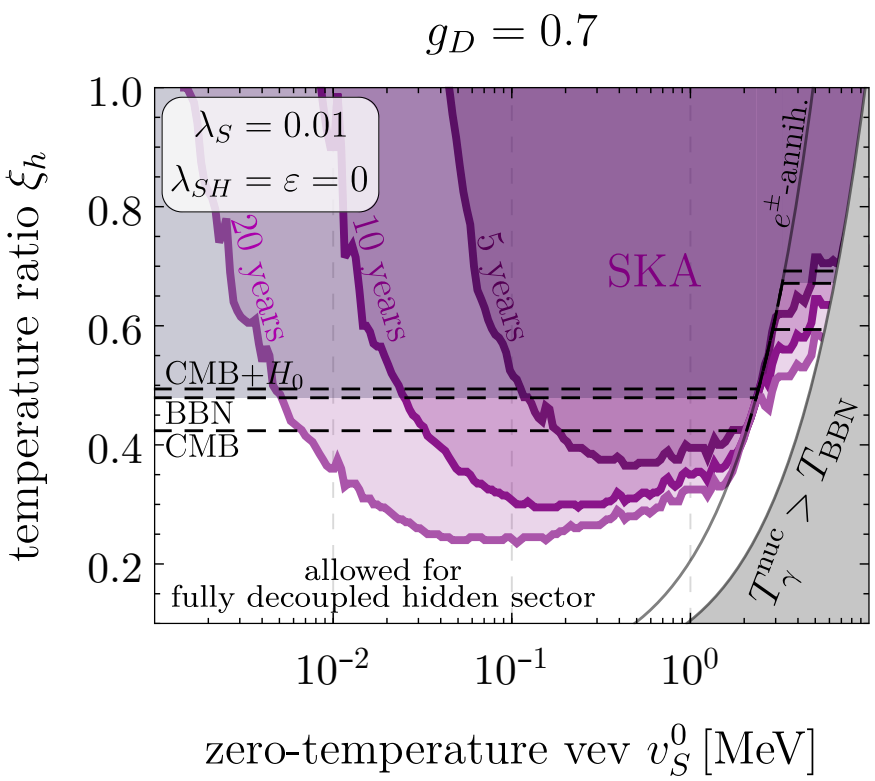
Singlet Scalars:

- 2 real scalars S and A
- $\langle S \rangle = v_S^0\,,\ \langle A \rangle = 0,\ A\ Z_2$-odd

Dark Photon:

- complex SM singlet scalar
- charged under dark $U(1)_D$





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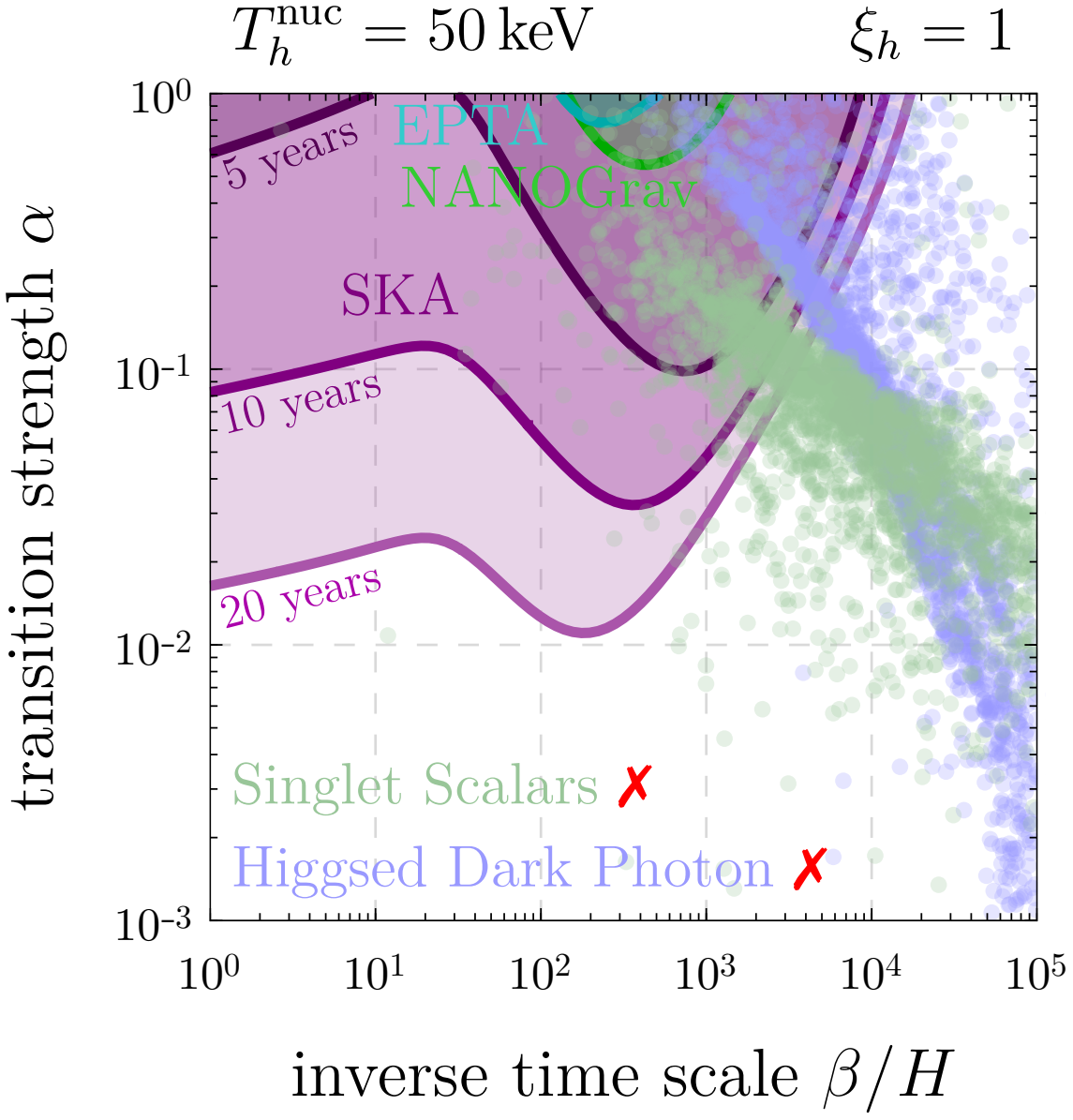

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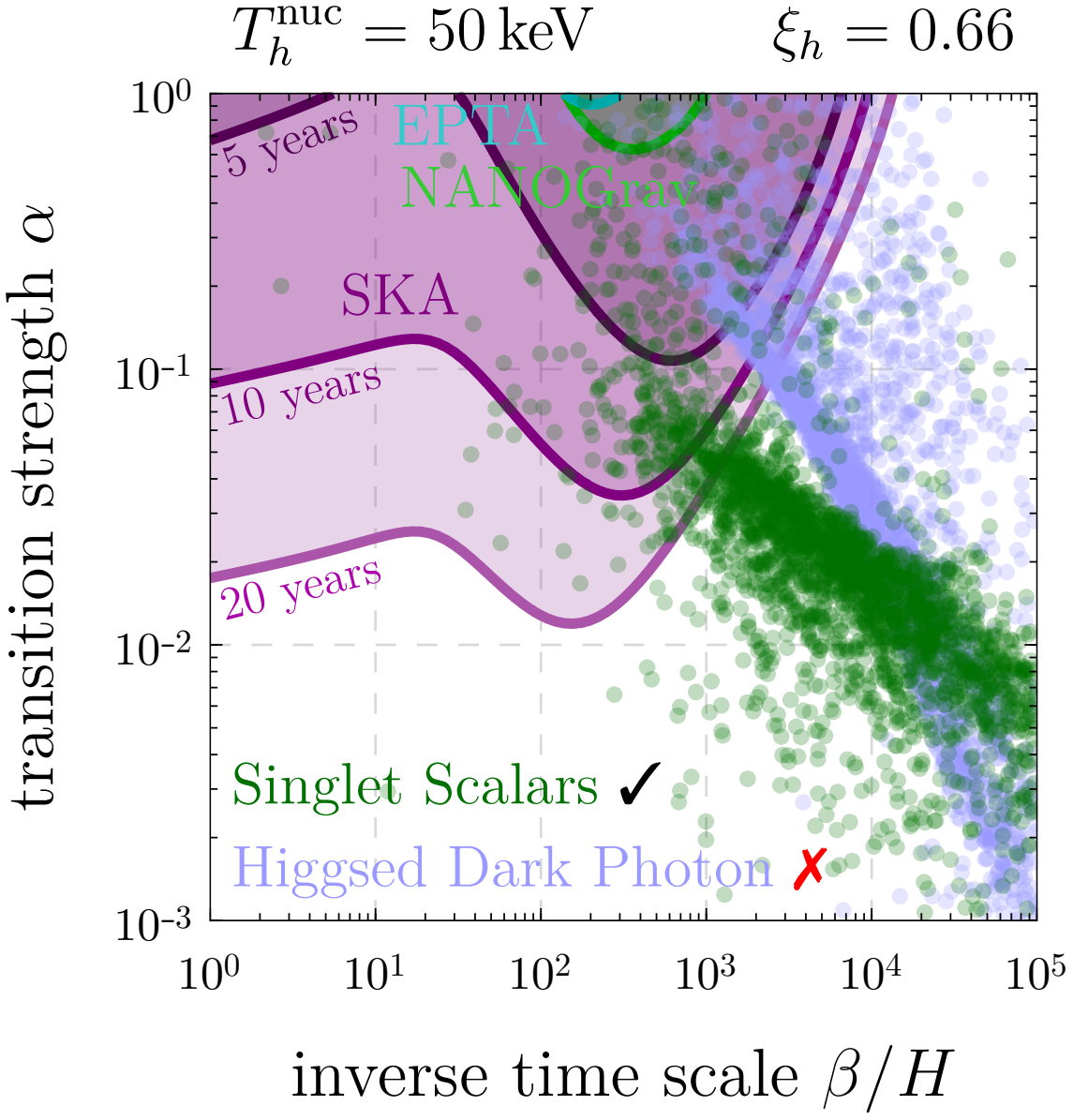

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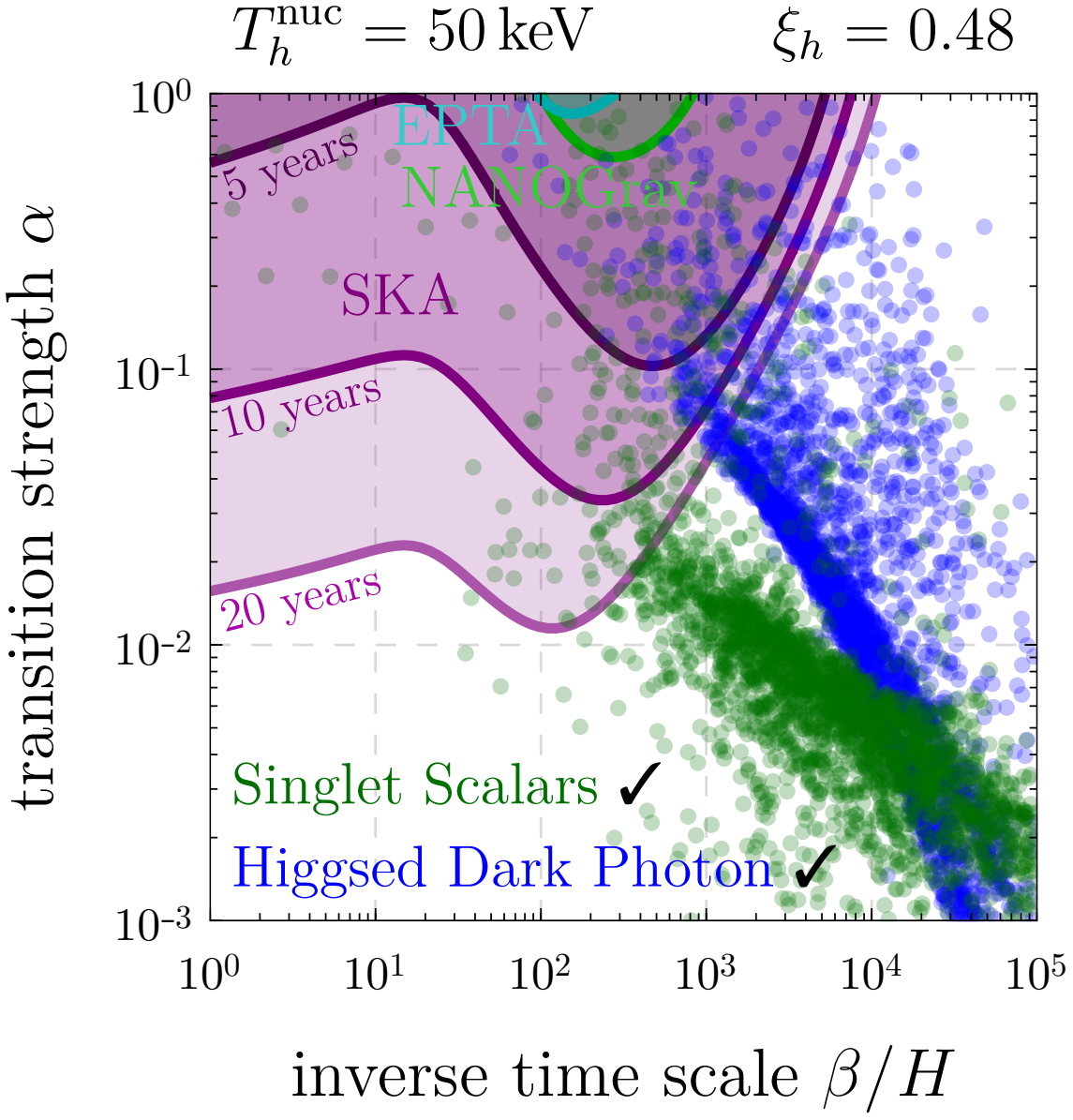

Conclusion

- sub-MeV hidden sector strongly constrained by $N_{\rm eff}$
  $\Longrightarrow$ requires colder hidden sector: $T_h < T_\gamma$
- GW power spectrum from hidden sector PT suppressed if
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Thank you for your attention!