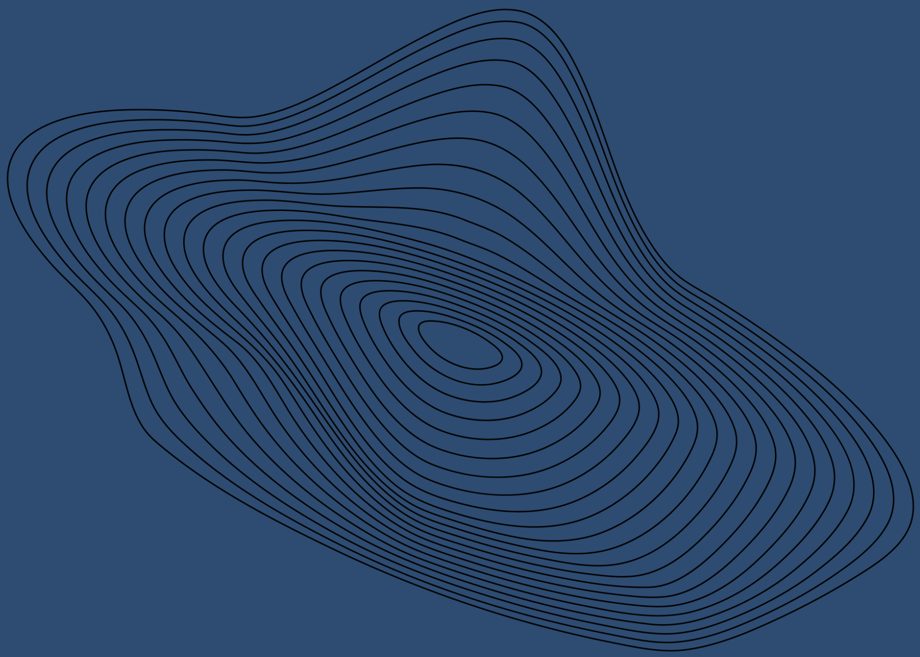

PHASE TRANSITION AND GRAVITATIONAL WAVES SIGNAL FROM CONFORMAL SYMMETRY BREAKING

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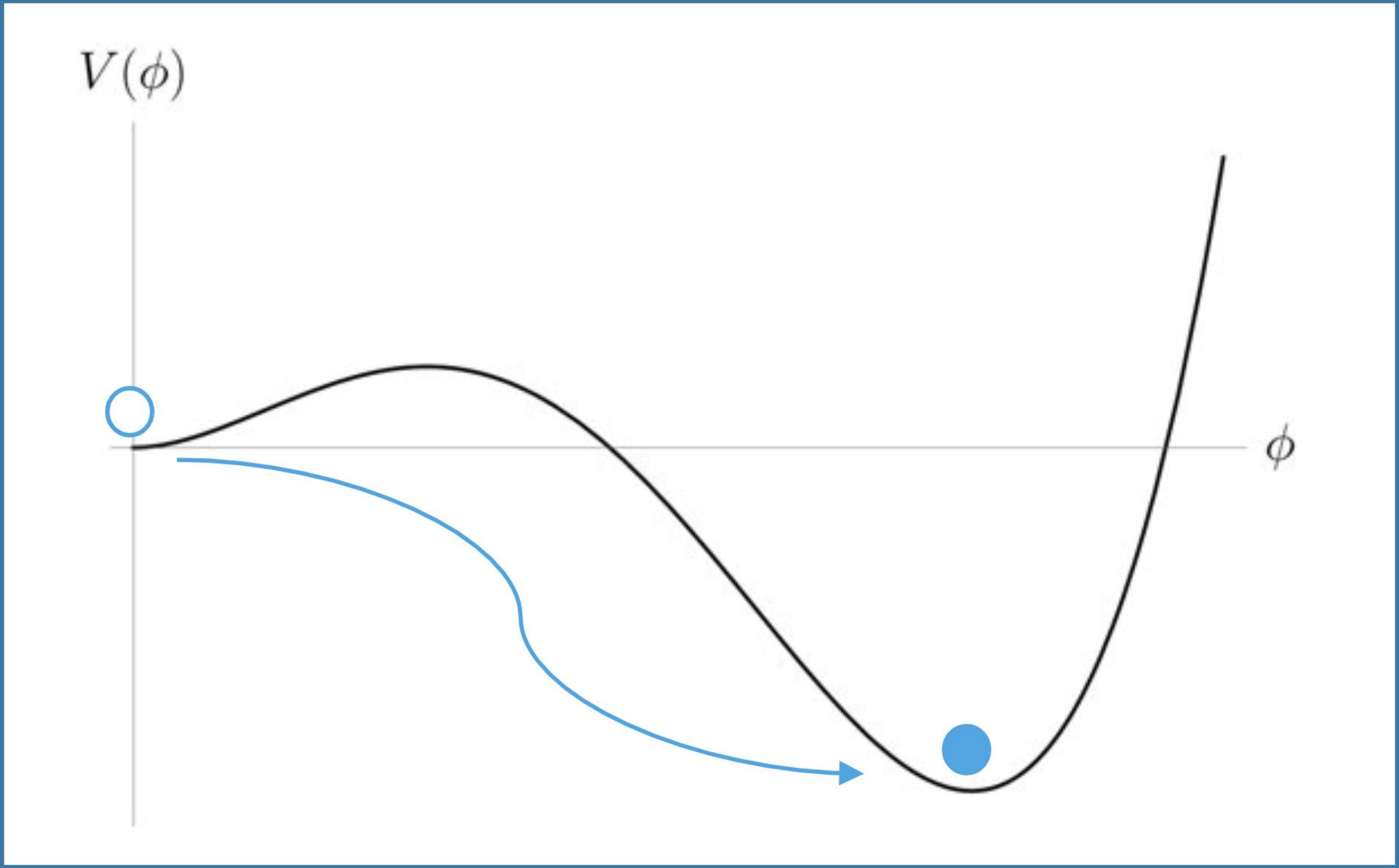
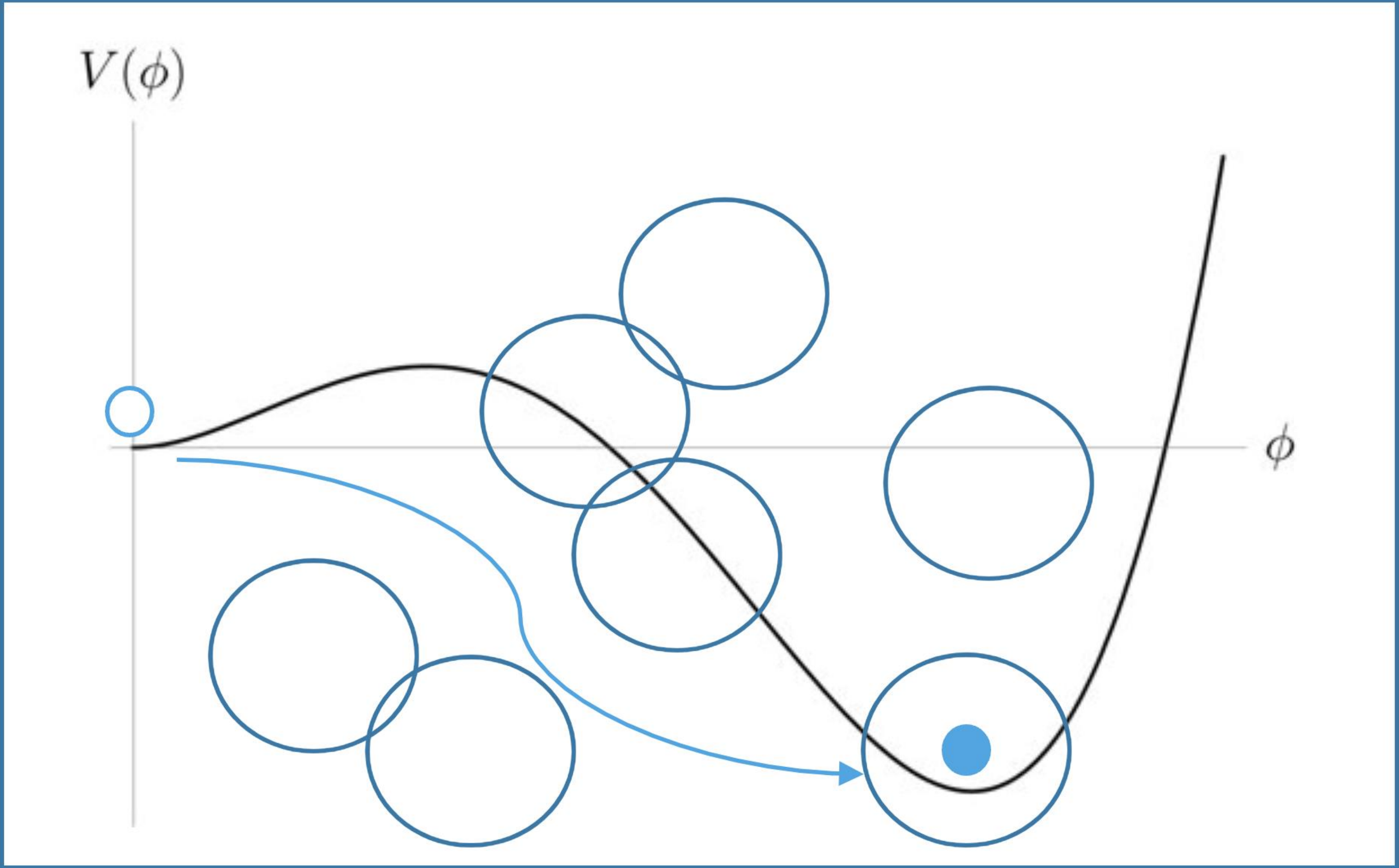
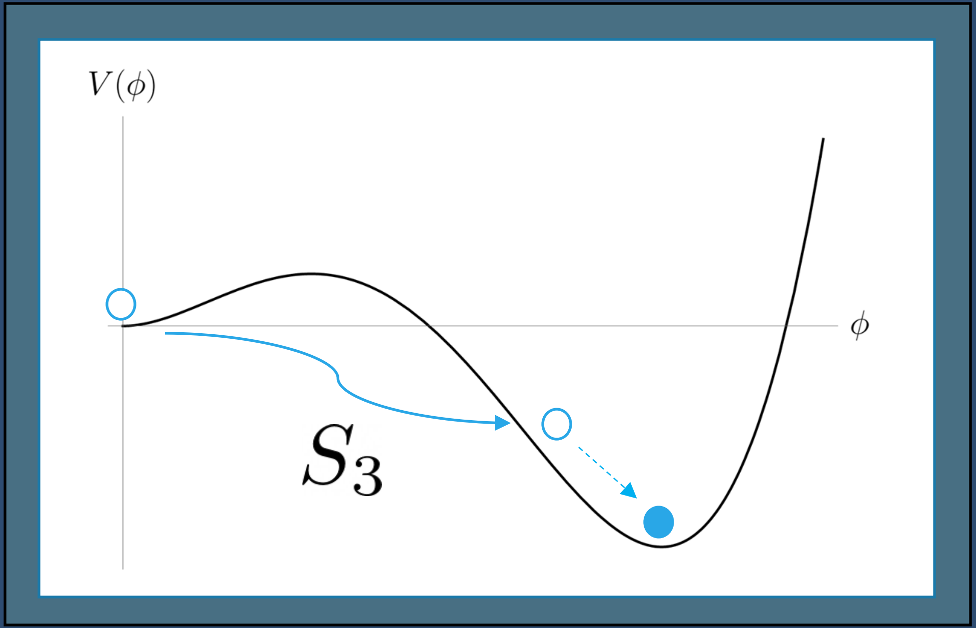
in collaboration with Alexandros Karam, Bogumiła Świeżewska.


$V(\phi)$
ϕ


$V(\phi)$
ϕ

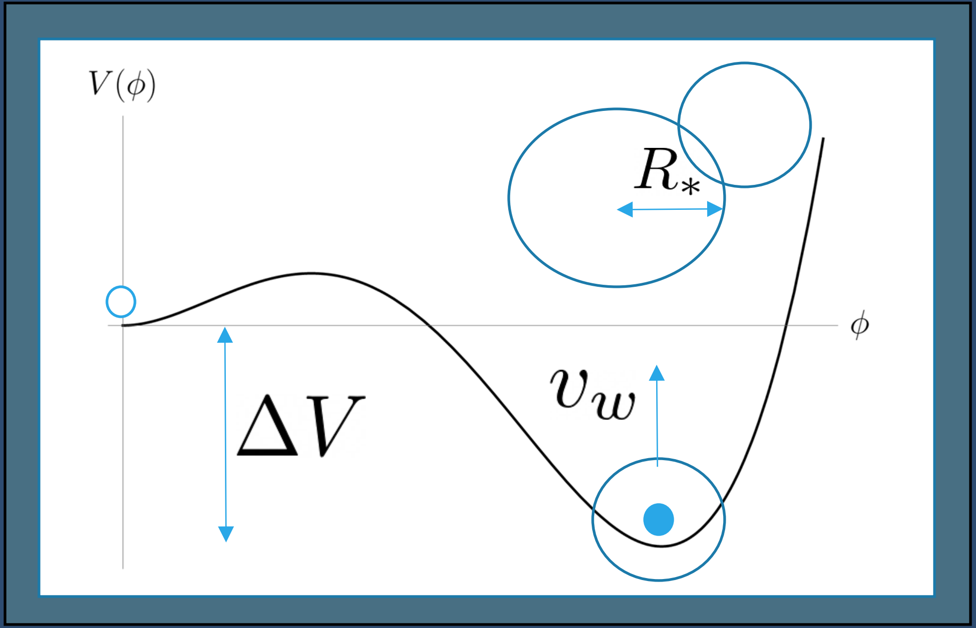
Thermal tunnelling

- Decay rate is given as: $$\Gamma(T) \simeq T^4 \left(\frac{S_3}{2\pi T}\right)^{\frac{3}{2}} e^{-S_3/T}$$
- Euclidean action along the bounce solution: $$S_3 = 4\pi \int r^2 \,\mathrm{d}r \left[\frac{1}{2}\left(\frac{\mathrm{d}\varphi}{\mathrm{d}r}\right)^2 + V_{\mathrm{eff}}(\varphi, T)\right]$$



Cosmological phase transitions

- "Strength" of the transition $\alpha \sim \frac{\Delta V}{\rho_{\text{rad}}(T_p)}$
- Average bubble radius R_* or inverse time scale $\beta \sim R_*^{-1}$
- Bubble wall velocity v_w
- Temperature T_p at which PT ends

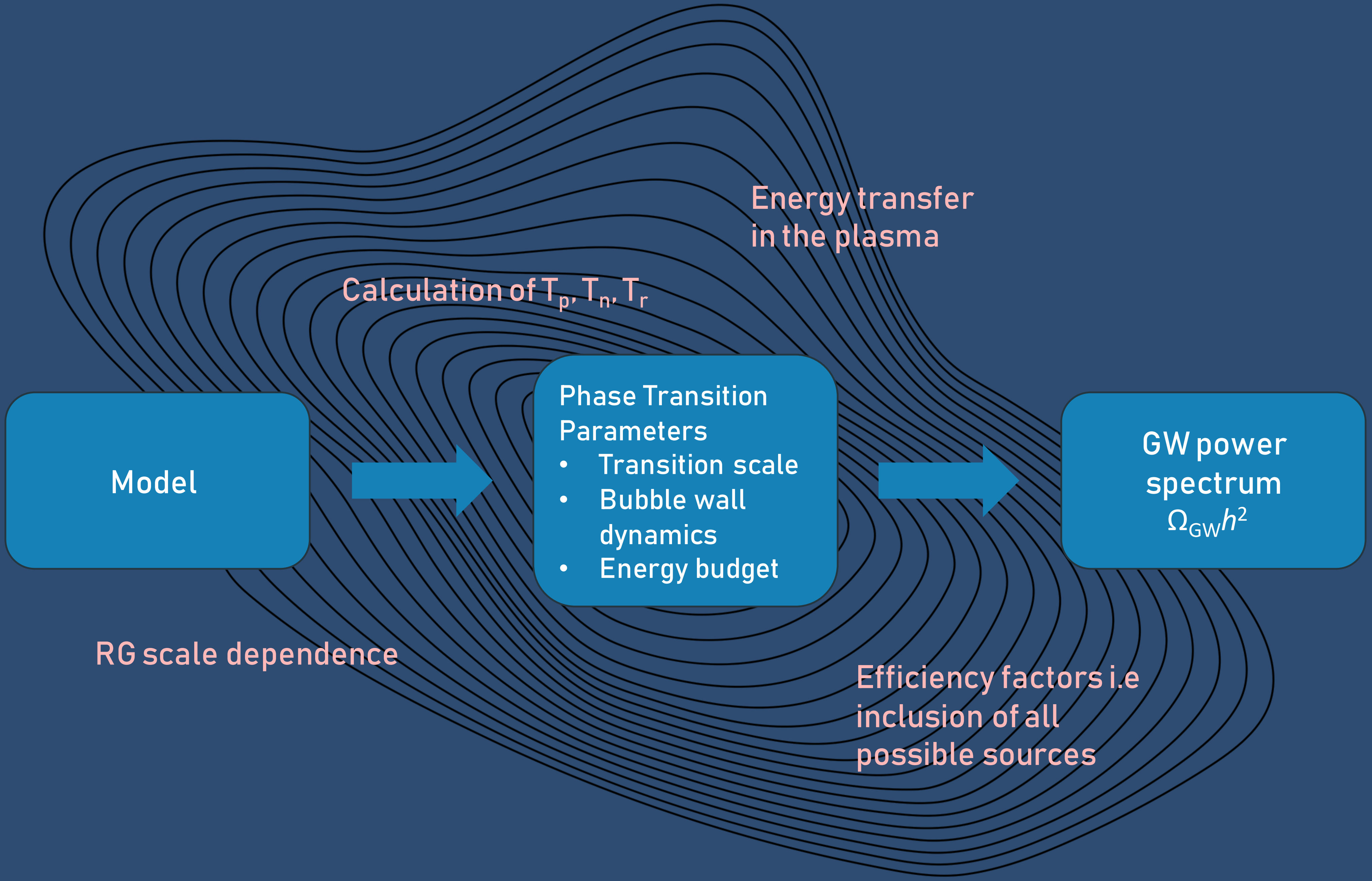


Caprini et al. arXiv:1910.13125

RG improved

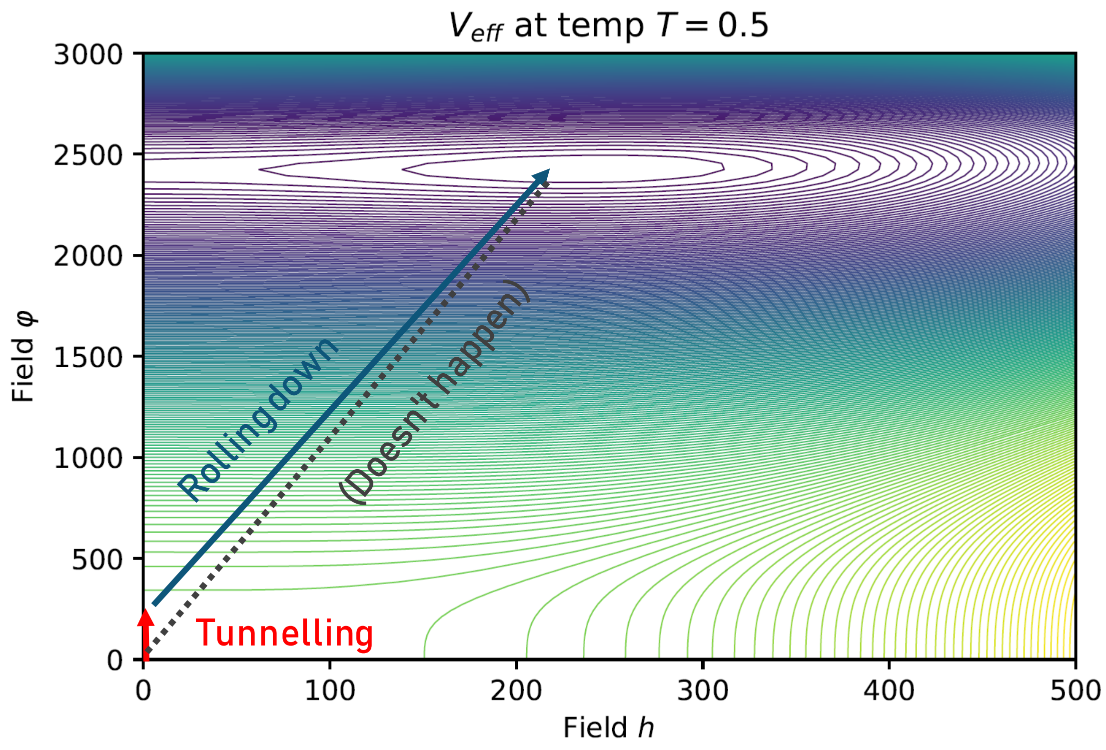
$$V_{\text{tree}} = \frac{1}{4}\left(\lambda_1 h^4 + \lambda_2 h^2 \phi^2 + \lambda_3 \phi^4\right)$$

C. D. Carone et al 1307.8428, T. Hambye et al 1306.2329, D. Marfatia et al 2006.07313, I. Baldes et al 1809.01198



J. Ellis, et al 2007.15586, D. Croon, et al 2009.10080, Lewicki et al 2111.02393

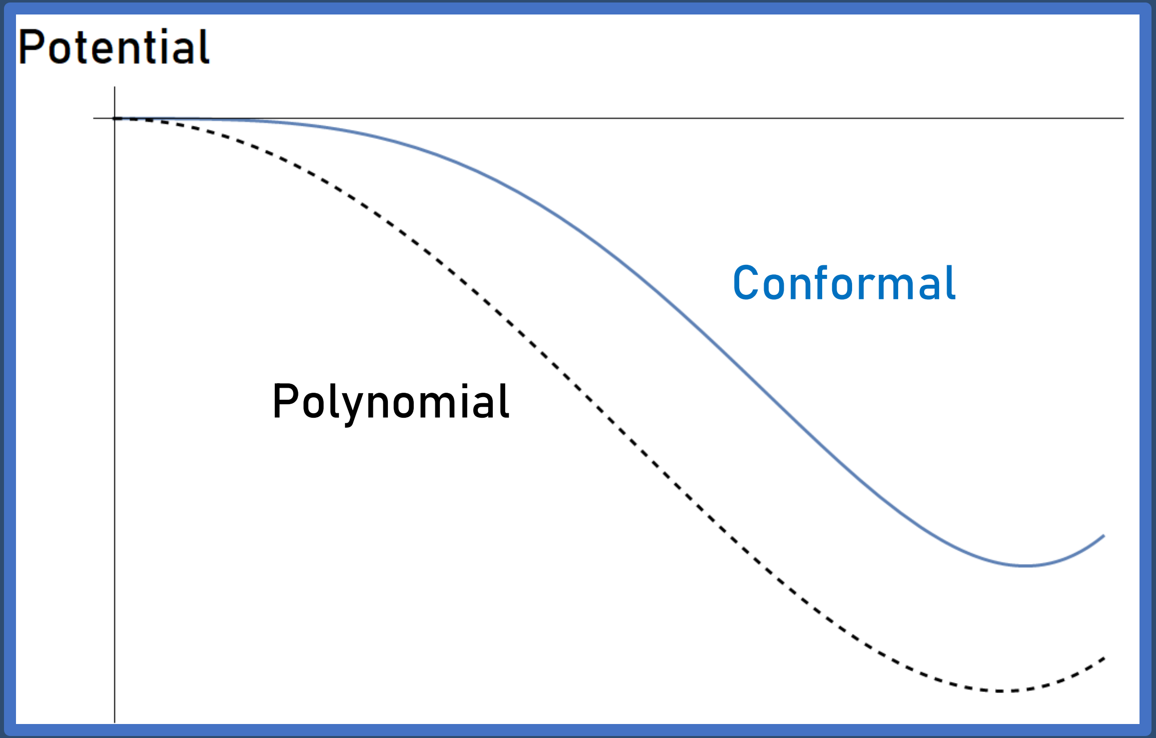
Tunneling scenario in SU(2)cSM



Tunnelling occurs only in the new scalar direction!

T.Prokopec et al 1809.11129

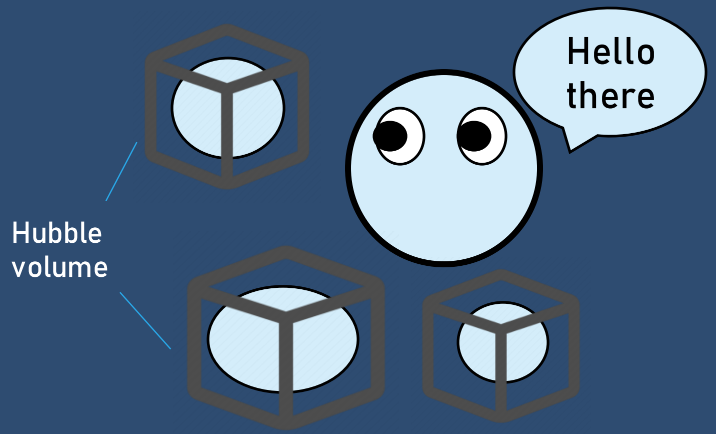
Introducing: supercooling



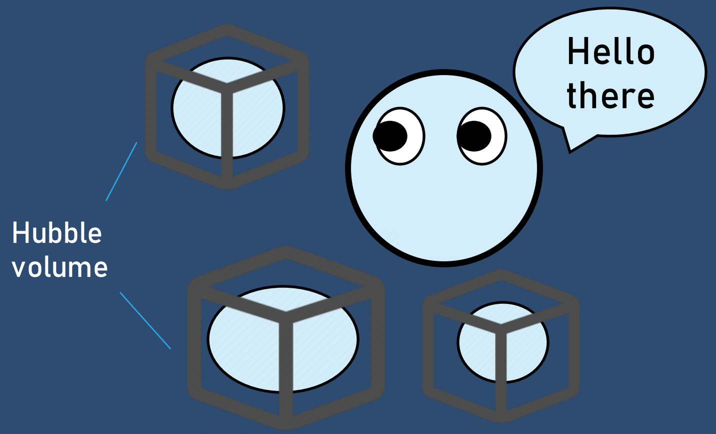
Features:

- phase transition happens at temperatures significantly below EW scale,
- thermally produced barrier lasts till $T = 0$,
- Induces strong Gravitational Wave signal.

- Nucleation temperature



- Nucleation temperature



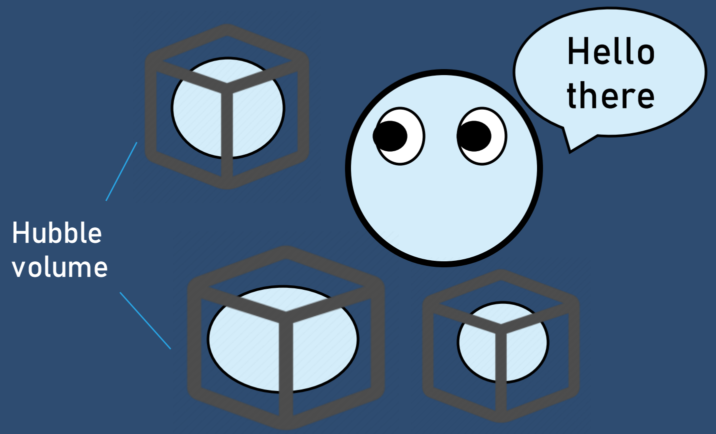
We calculate: $$N(T_n) = \int_{T_n}^{T_c} \frac{dT}{T} \frac{\Gamma(T)}{H(T)^4} = 1$$

One can also use an approximation:

But not this one $$\frac{S_3}{T} \simeq 140$$

$$\frac{\Gamma(T_n)}{H(T_n)^4} \simeq 1 \Rightarrow \frac{S_3}{T_n} = 4 \log\left(\frac{T_n}{H(T_n)}\right)$$

- Nucleation temperature



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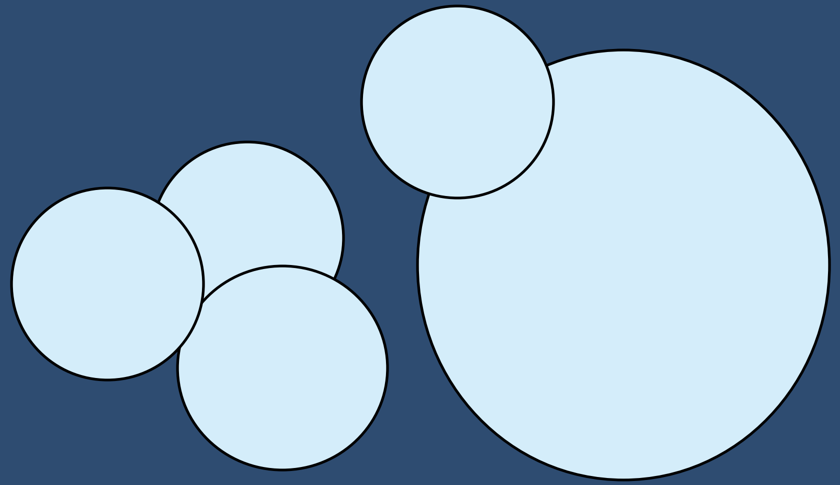
$$\frac{\Gamma(T_n)}{H(T_n)^4} \simeq 1 \Rightarrow \frac{S_3}{T_n} = 4 \log \left(\frac{T_n}{H(T_n)} \right)$$

- Percolation temperature



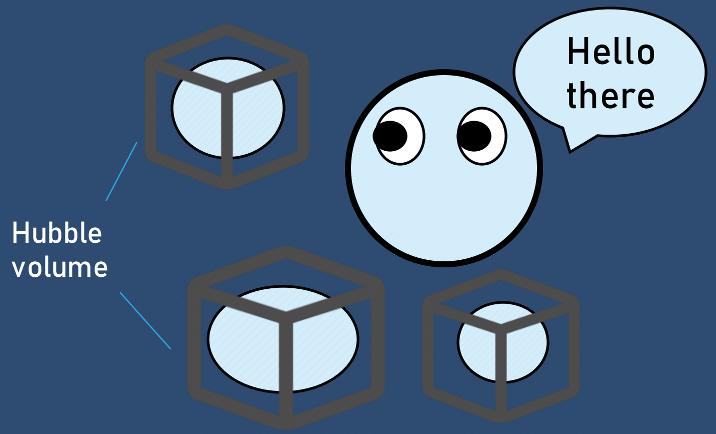
Probability of point still in false vacuum is $P = e^{-I(T)}$, where

$I(T)$ is the volume converted into true vacuum

Then we solve for condition:

$$I(T_p) \simeq 0.34$$

- Nucleation temperature



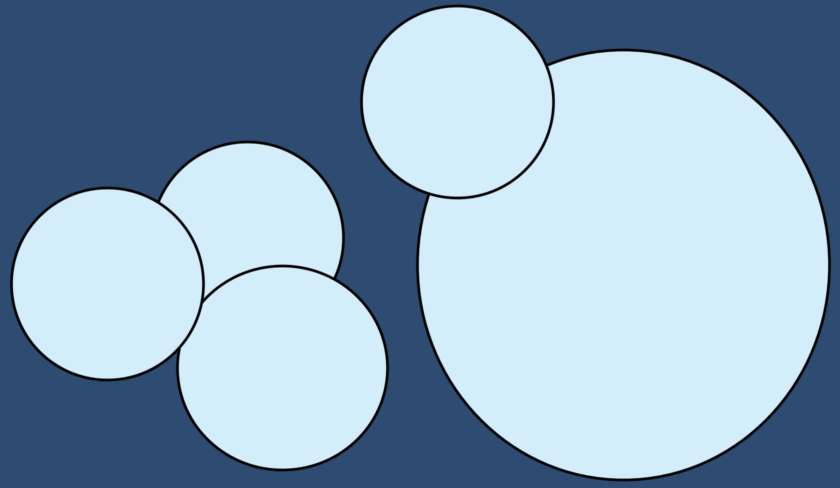
Are not equal in models with supercooling

We calculate: $N(T_n) = \int_{T_n}^{T_c} \frac{dT}{T} \frac{\Gamma(T)}{H(T)^4} = 1$

One can also use an approximation:

$$\frac{\Gamma(T_n)}{H(T_n)^4} \simeq 1 \Rightarrow \frac{S_3}{T_n} = 4 \log \left(\frac{T_n}{H(T_n)} \right)$$

- Percolation temperature



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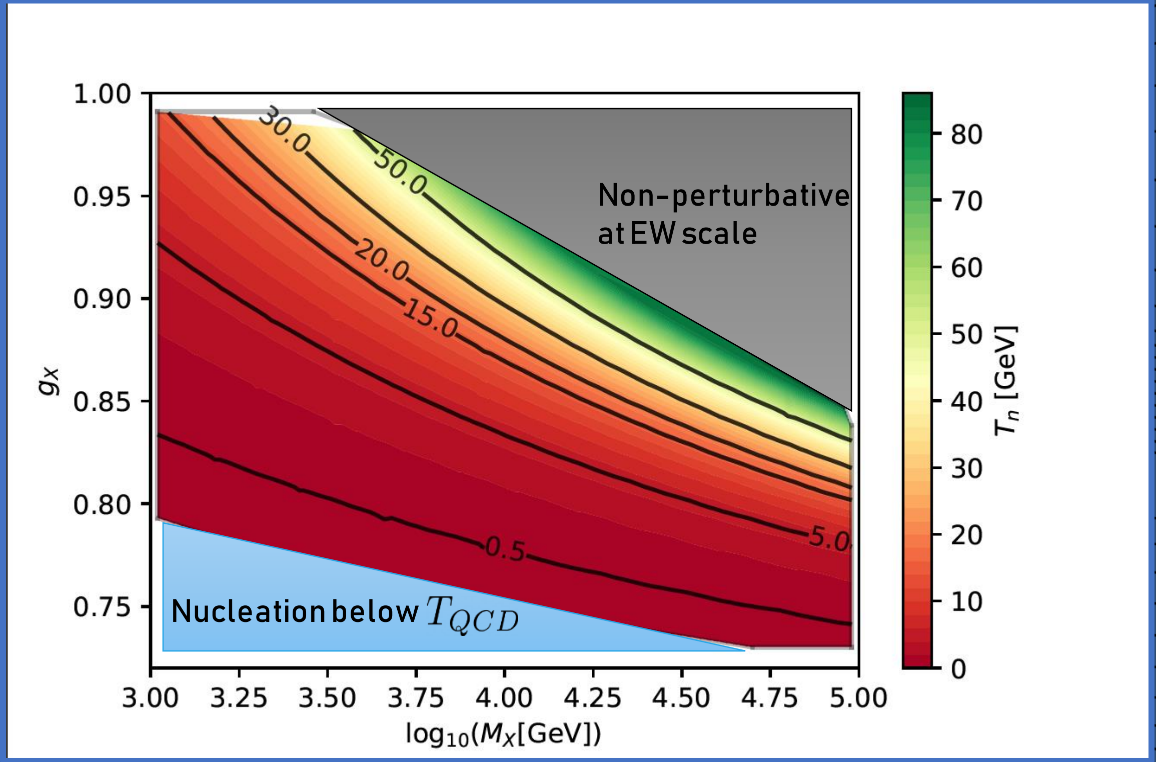
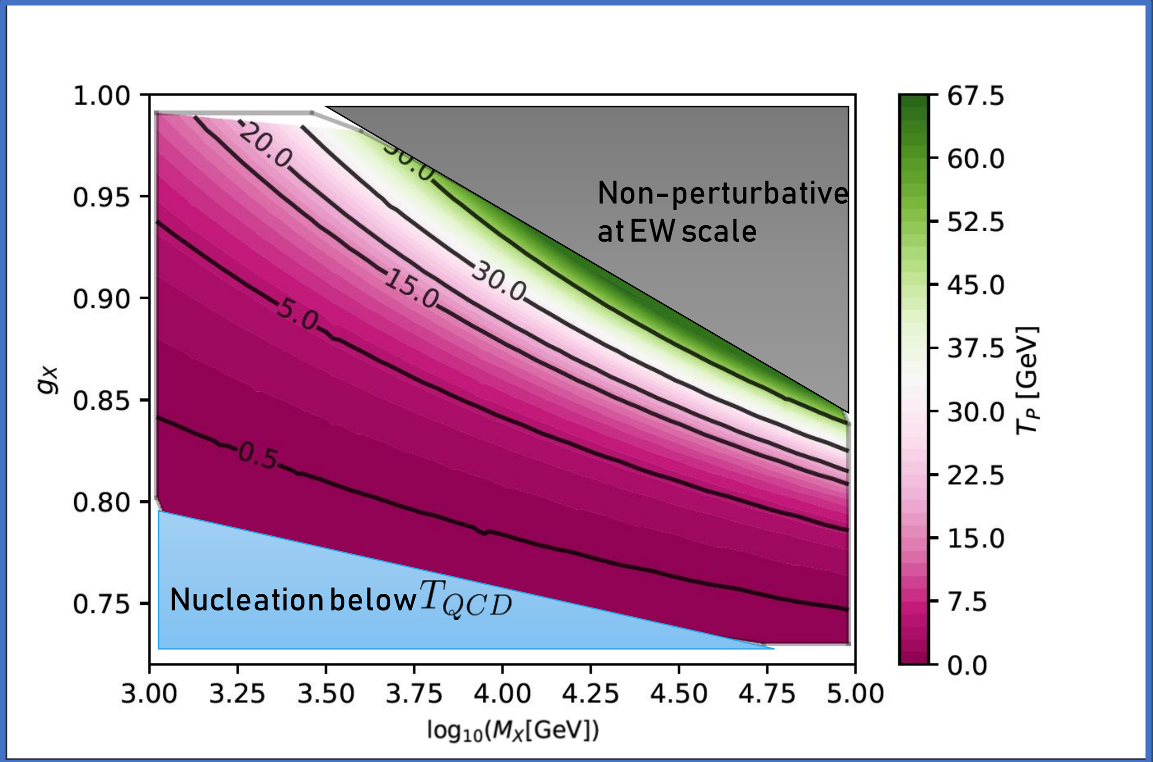
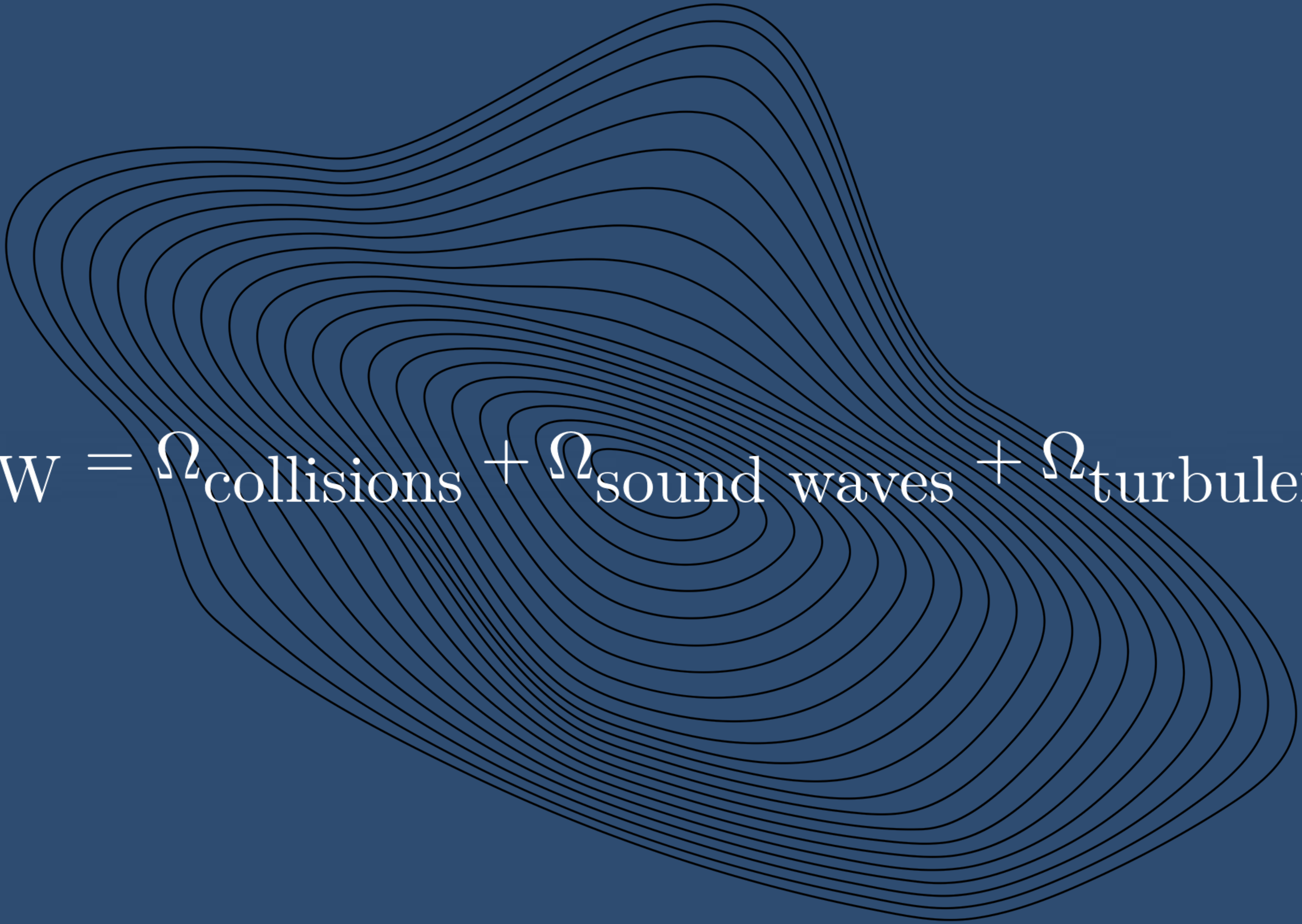
J.Ellis et al. arXiv:1809.08242

Nucleation vs Percolation







$$\Omega_{\mathrm{GW}} = \Omega_{\mathrm{collisions}} + \Omega_{\mathrm{sound\ waves}} + \Omega_{\mathrm{turbulence}}$$

How do we know which source dominates?

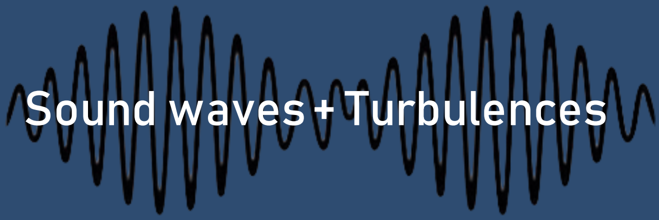
Efficiency factors:

$$\kappa_{col} = \frac{E_{\mathrm{wall}}}{E_V}$$

$$\kappa_{sw} \sim 1 - \kappa_{col}$$

Where the energy goes?

There is a lot of friction → Energy is dissipated in the surrounding plasma → Sound waves + Turbulences

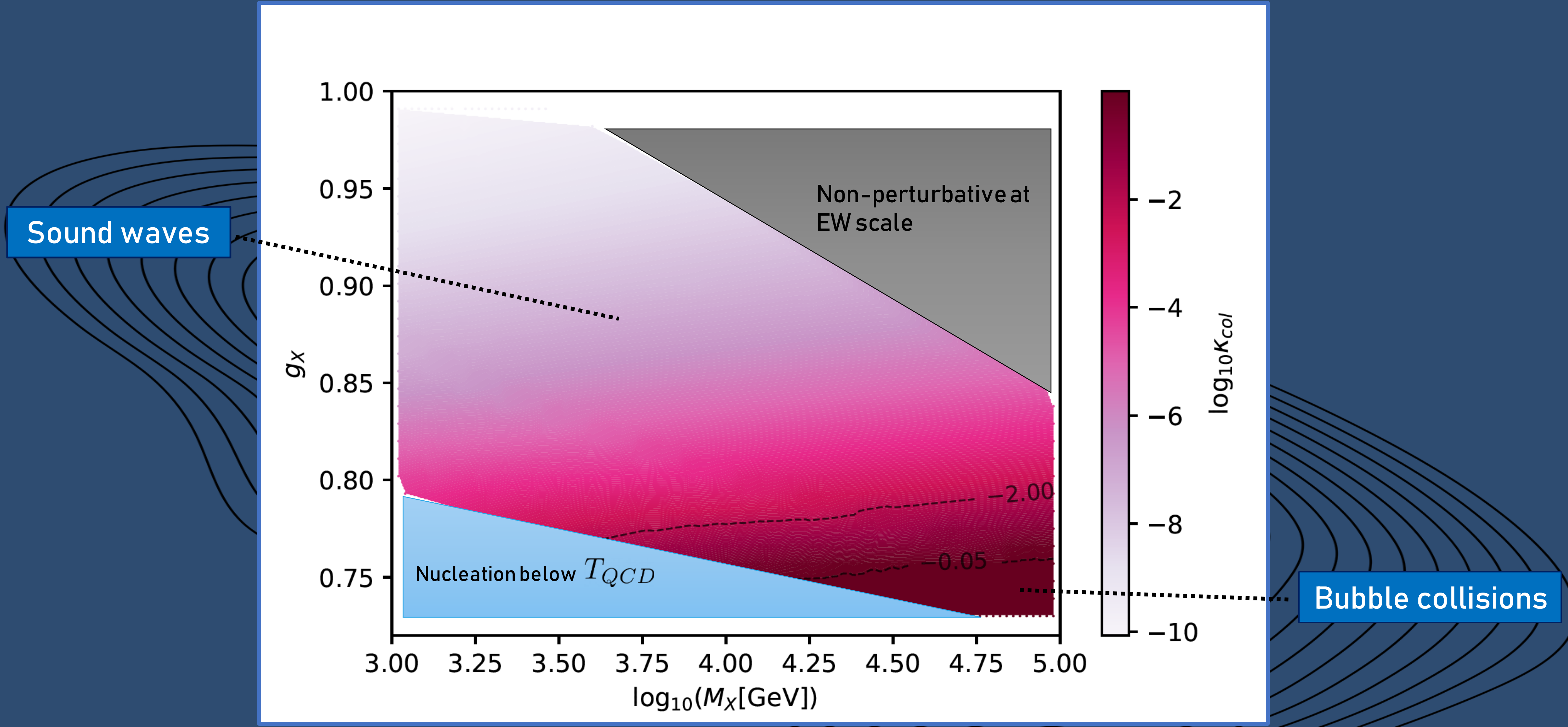


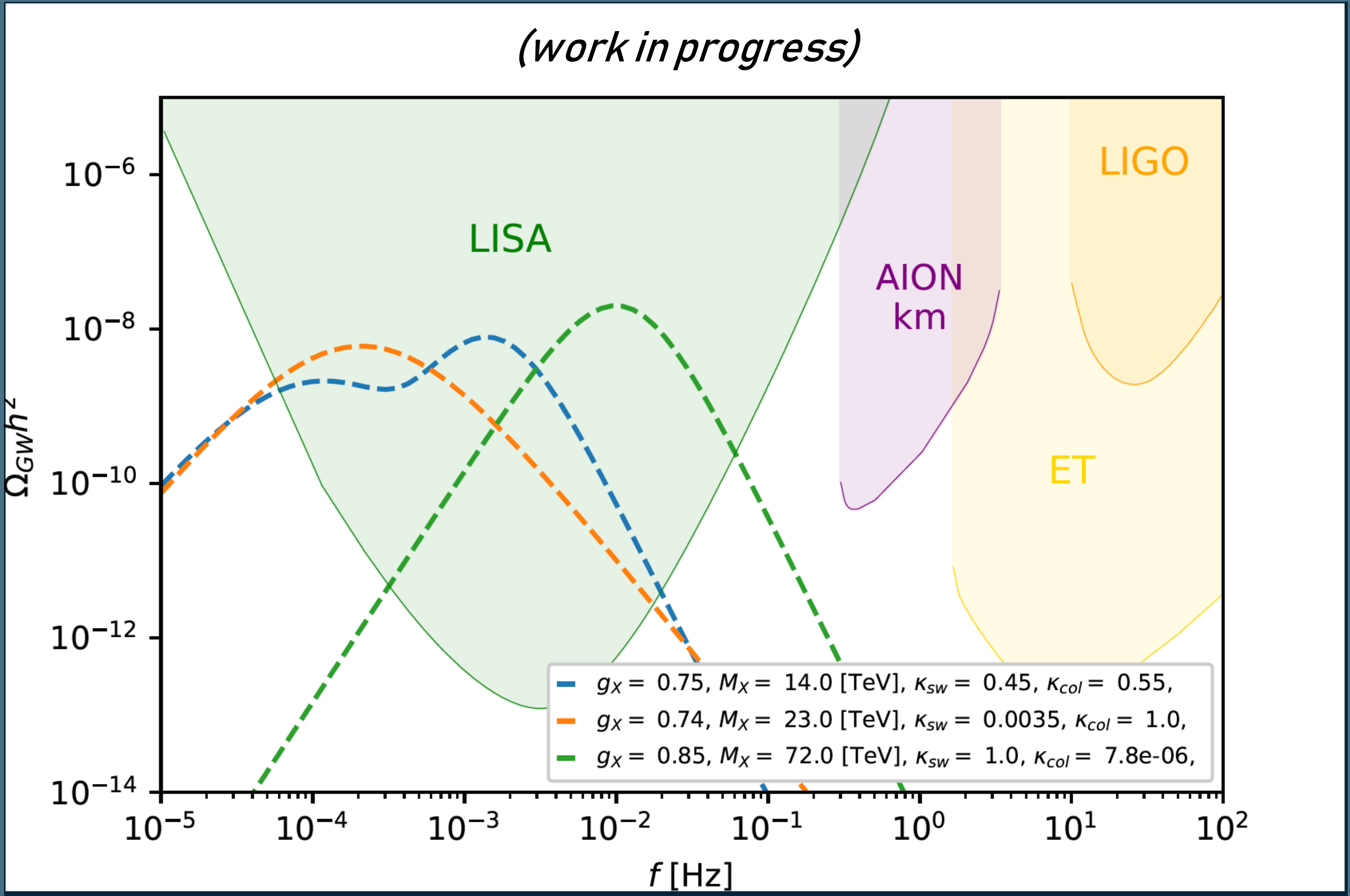
Bubble expansion accelerates → Energy goes to the bubble's wall → Bubble collisions

And the main GW source are...

J. Ellis, et al, arXiv:2007.15586

Energy transfer





Goal: provide accurate predictions for LISA.

Thank you

Reheating temperature

$\Gamma_\varphi > H_*$

- Reheating is instantaneous
- Released energy transforms into radiation
- Universe reheats up to the temperature T_V

but if....

$\Gamma_\varphi < H_*$

- Energy will be stored in the scalar field oscillating about the true vacuum
- Matter domination until temperature at which decay rate is equal to Hubble parameter
- This matter domination period changes the shape of GW spectrum

arXiv:2007.15586

Gravitational Wave signal in SU(2)cSM is generically strong and thus detectable

$$\alpha \sim \mathcal{O}(10^{10})$$

$$\Omega_{sw}h^2 \sim 4.13 \times 10^{-7} \, (R_* H_*) \left(\frac{\kappa_{sw}\alpha}{1+\alpha} \right)$$