

Gravitational Waves from colliding bubbles in cold hidden sectors

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collaboration with:

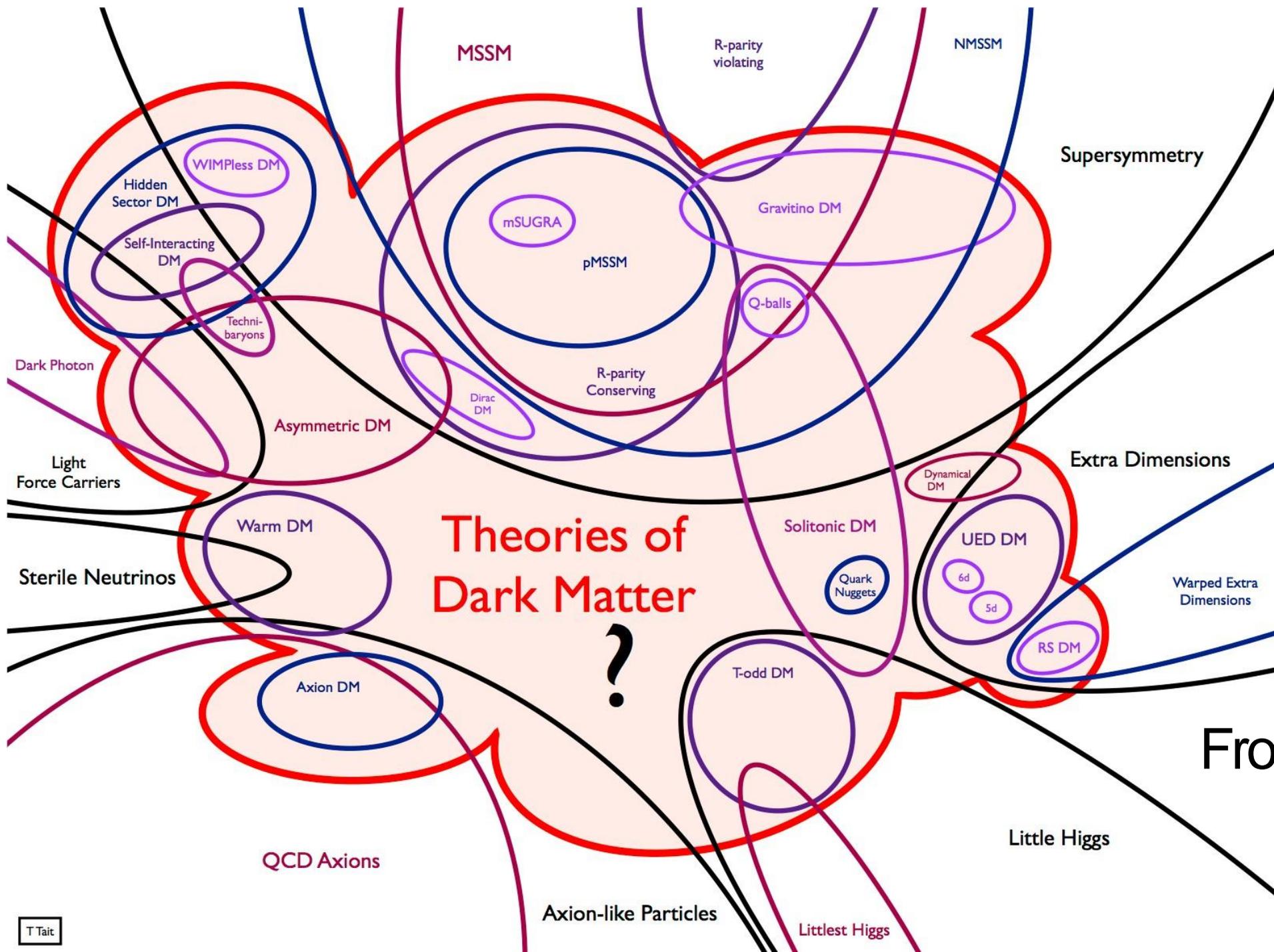
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Wickens** (KCL)

arXiv:1901.11038



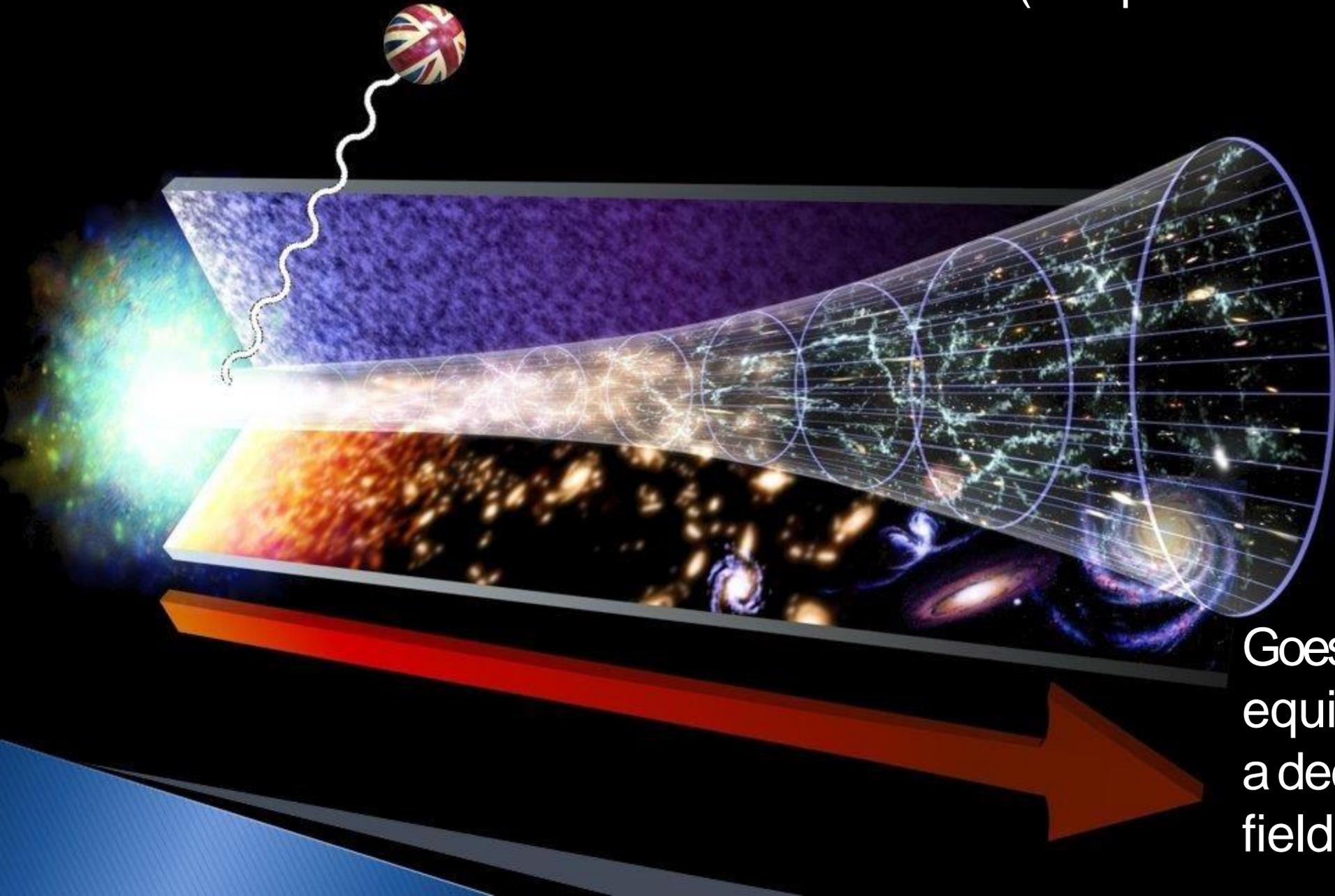
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From Tim Tait

The Brexiton (Enqvist 2017, Rajantie 2017)



Goes out of thermal equilibrium then acts as a decoupled spectator field while it decays

Everything couples to Gravity!

Q. If we observe phase transitions using gravitational waves, how will we know whether they come from our sector or some dark sector?

A. Like most things in Physics, it's a bit messy and complicated but today I will try to explain our investigations.

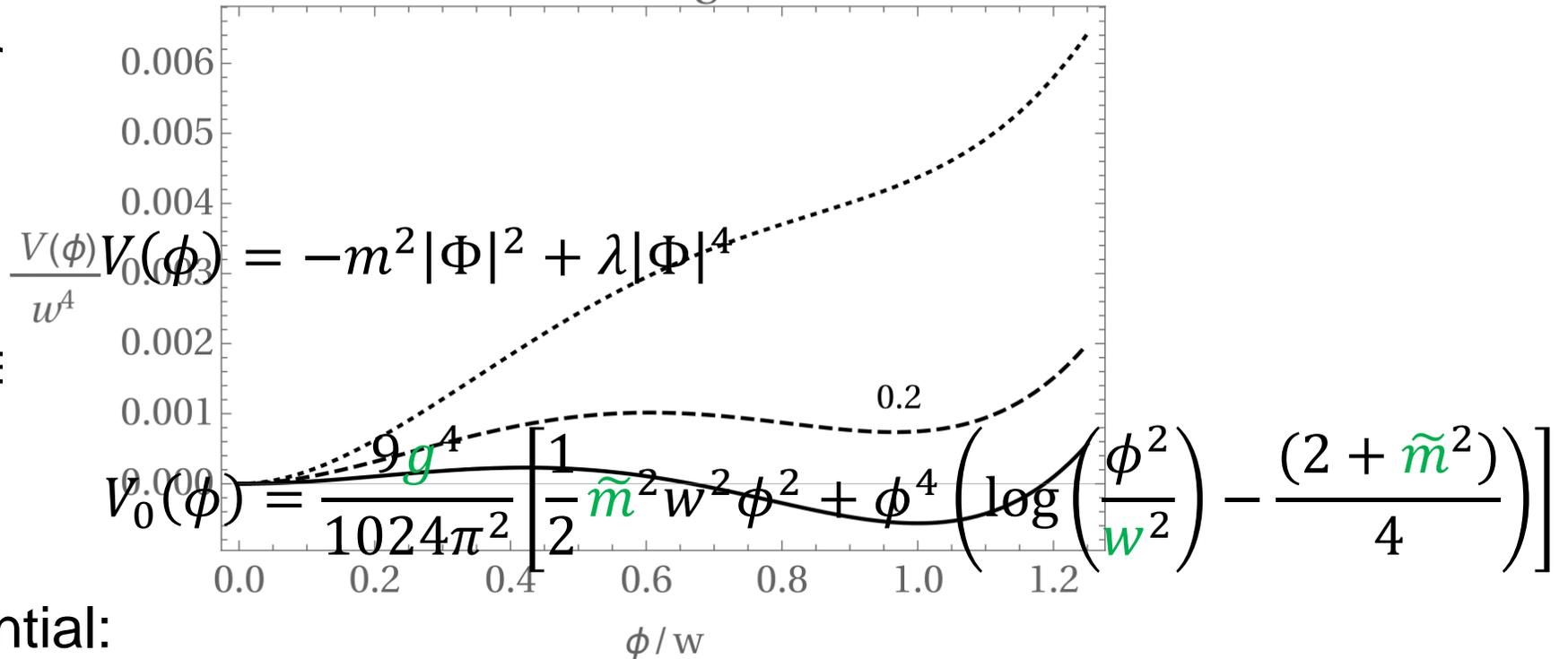
PLAN OF TALK

- Toy model
- Phase transitions
- Gravitational waves

Our toy cold hidden sector

An example hidden sector

$$\tilde{m}^2 = 1.5, g = 1.5$$



- SU(2) gauge group
- Tree level potential
- With 1-loop corrections
- Full thermal potential:

We consider parts of the parameter space where there is a barrier at zero temperature!

$$V(\phi, T_{hidden}) = V_0(\phi) + V_{T_{hidden}}(\phi, T_{hidden})$$

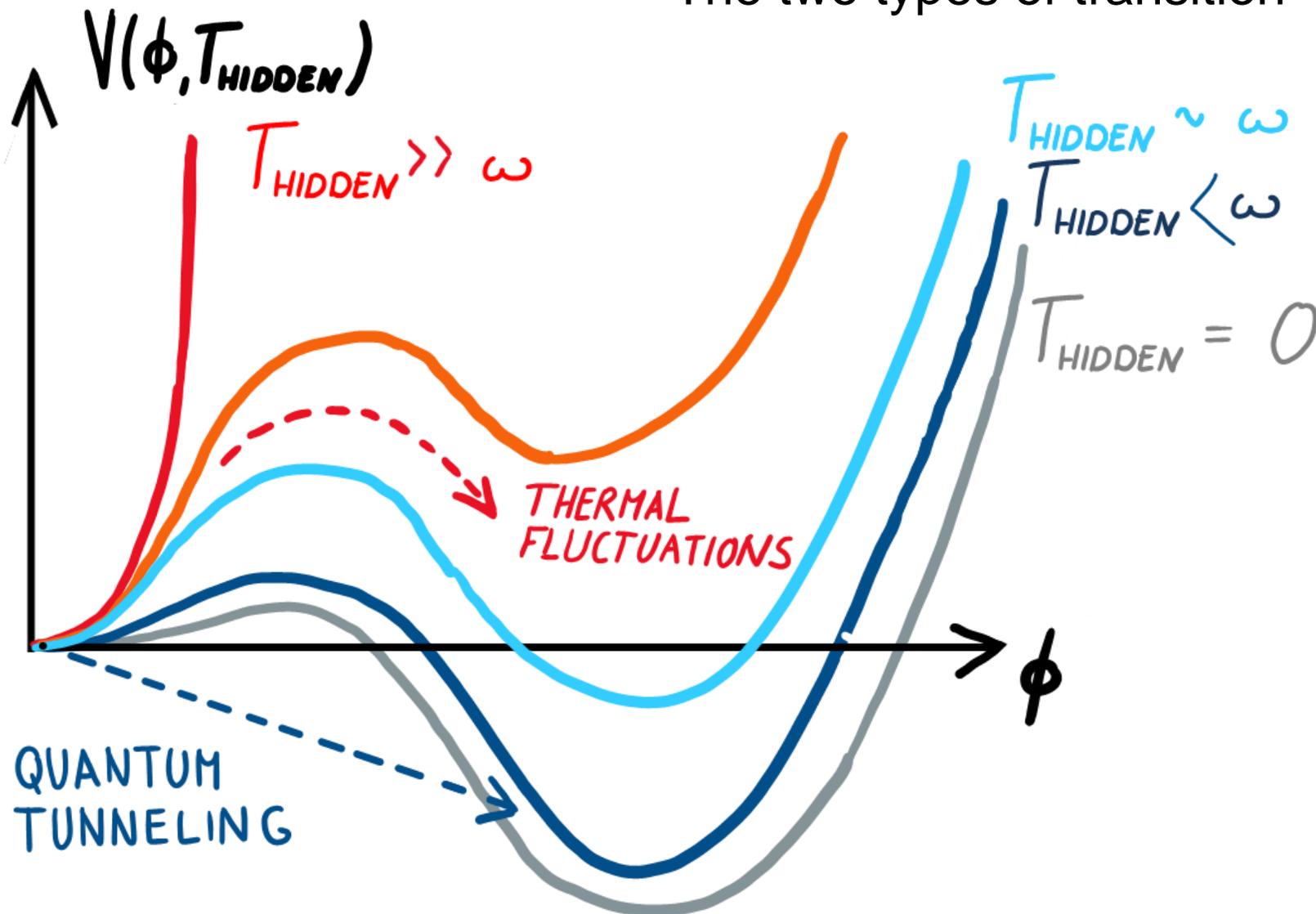
- Hidden sector vacuum energy relative to visible sector energy is given by parameter

$$\alpha = \frac{\rho_{\text{vac}}}{\rho_{\text{V}}}$$

- Decay of ϕ into hidden sector fermions is required if α is large or the hidden sector higgs or gauge bosons may create too much dark matter
- If there are too many hidden sector fermions, they will act as dark radiation which will create problems for BBN or CMB
- These constraints can all be applied in any given situation

Cold hidden sectors

The two types of transition



The realising transition

- Happens when $\Gamma_{\text{thermal}}(t) \frac{1}{t^4} \gg H(t)$

Cold hidden sectors

The two types of transition

Thermal phase transition

$$\Gamma_3 \simeq T_h^4 \left(\frac{S_3}{2\pi T_h} \right)^{3/2} e^{-S_3/T_h}$$

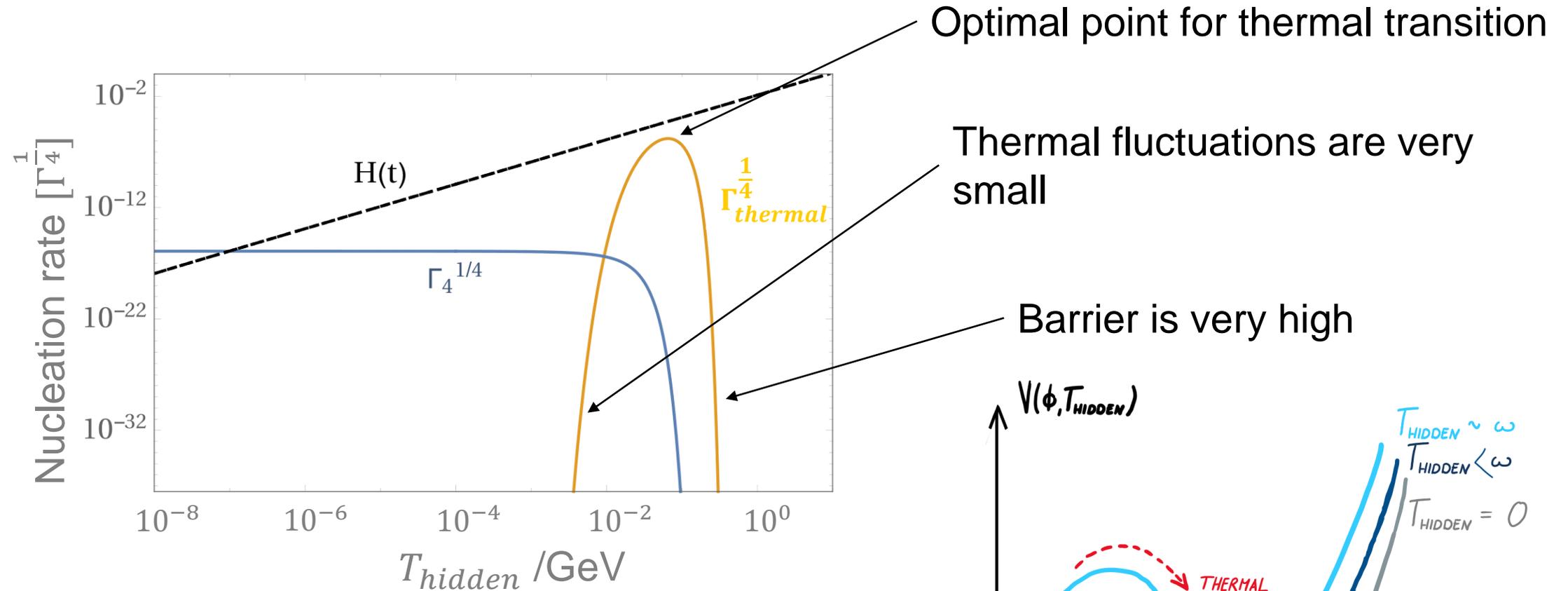
Tunneling Phase transition

$$\Gamma_4 \simeq w^4 \left(\frac{S_4}{2\pi} \right)^2 e^{-S_4}$$

Both temperature dependent

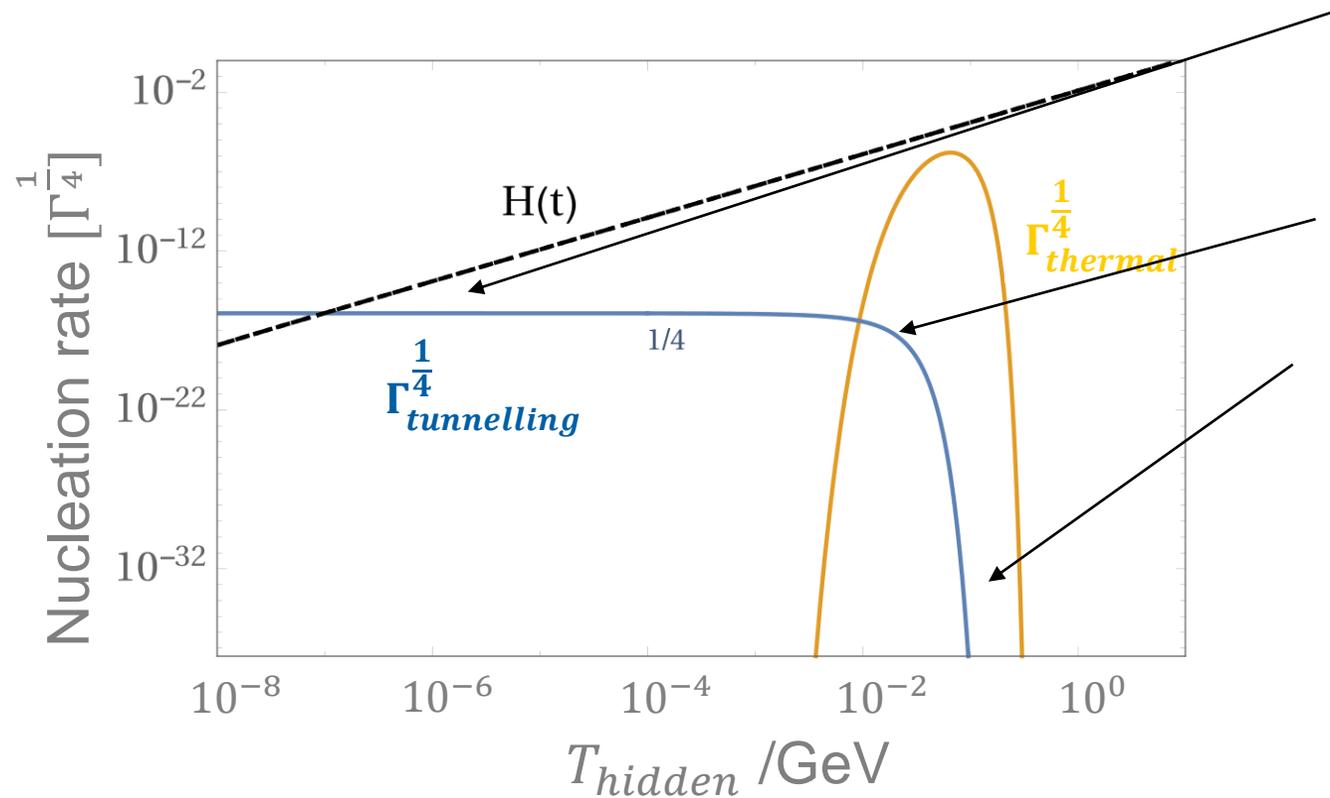
Thermal phase transition

The two types of transition: concrete example



Tunnelling phase transition

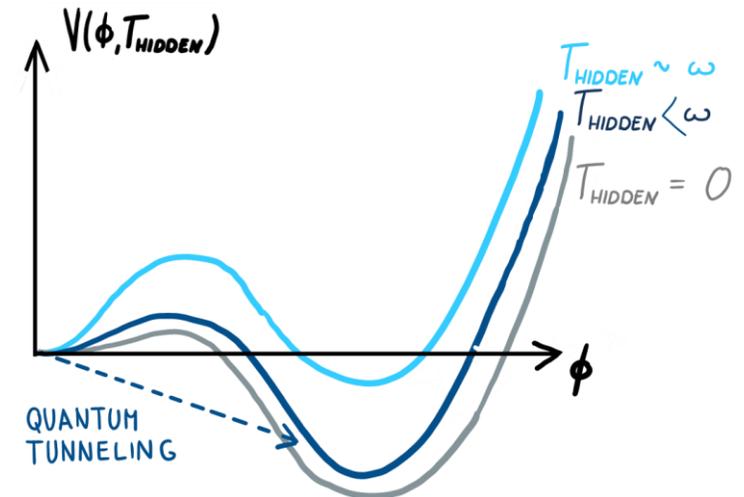
The two types of transition: concrete example



Tunnelling nucleation rate stays constant

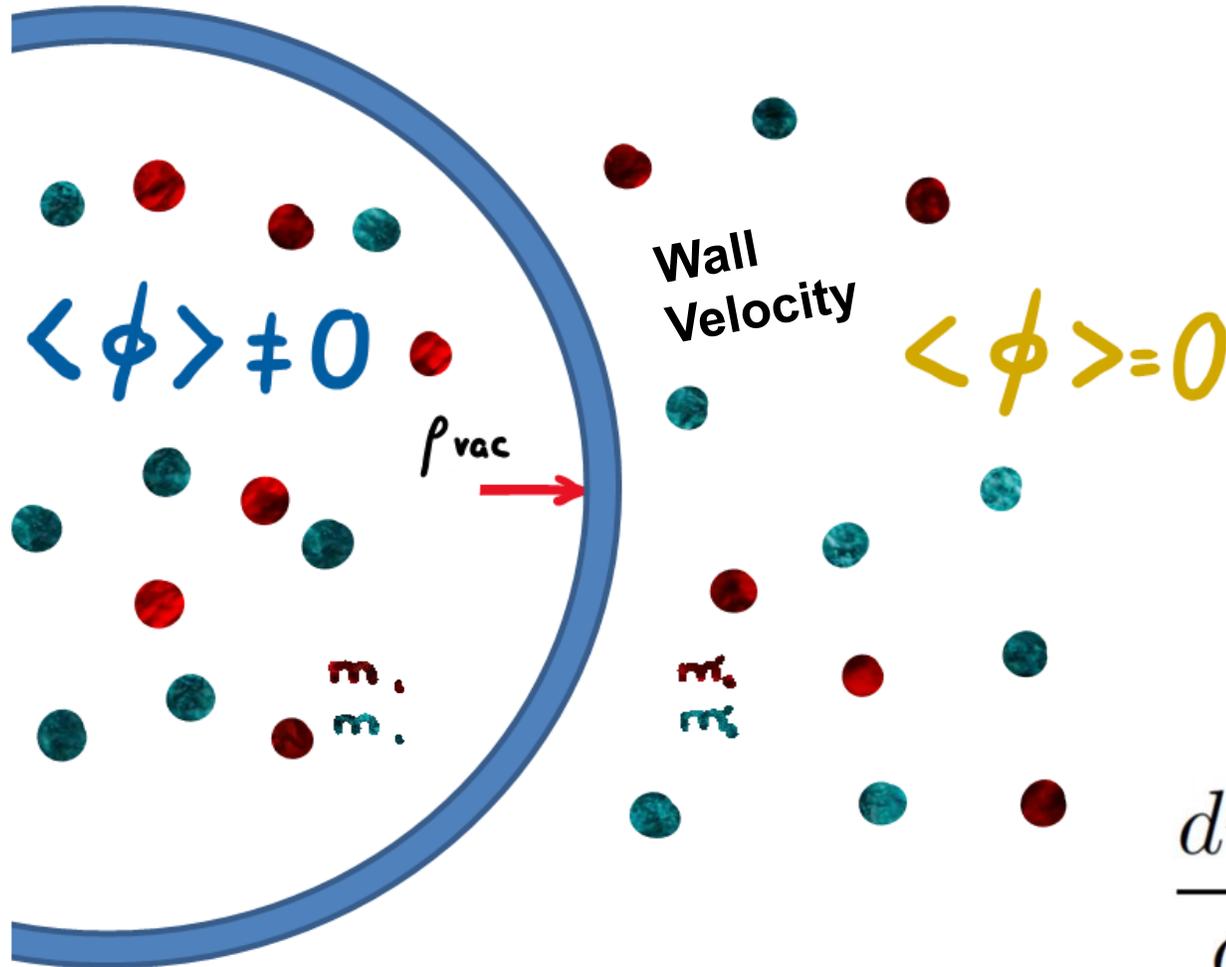
Barrier close to $T_{hidden} = 0$ form

Barrier height very high



Bubble wall dynamics

The wall velocity



- Friction set by T_{hidden}
- Friction determines wall velocity at collision
- Controls shape of GW spectrum (fraction in sound waves vs shock waves)

$$\frac{dv_w}{dt} = \frac{1}{\sigma \gamma_w^3} (\rho_{vac} - P_{fr})$$

Ratio of temperatures between dark and visible sector

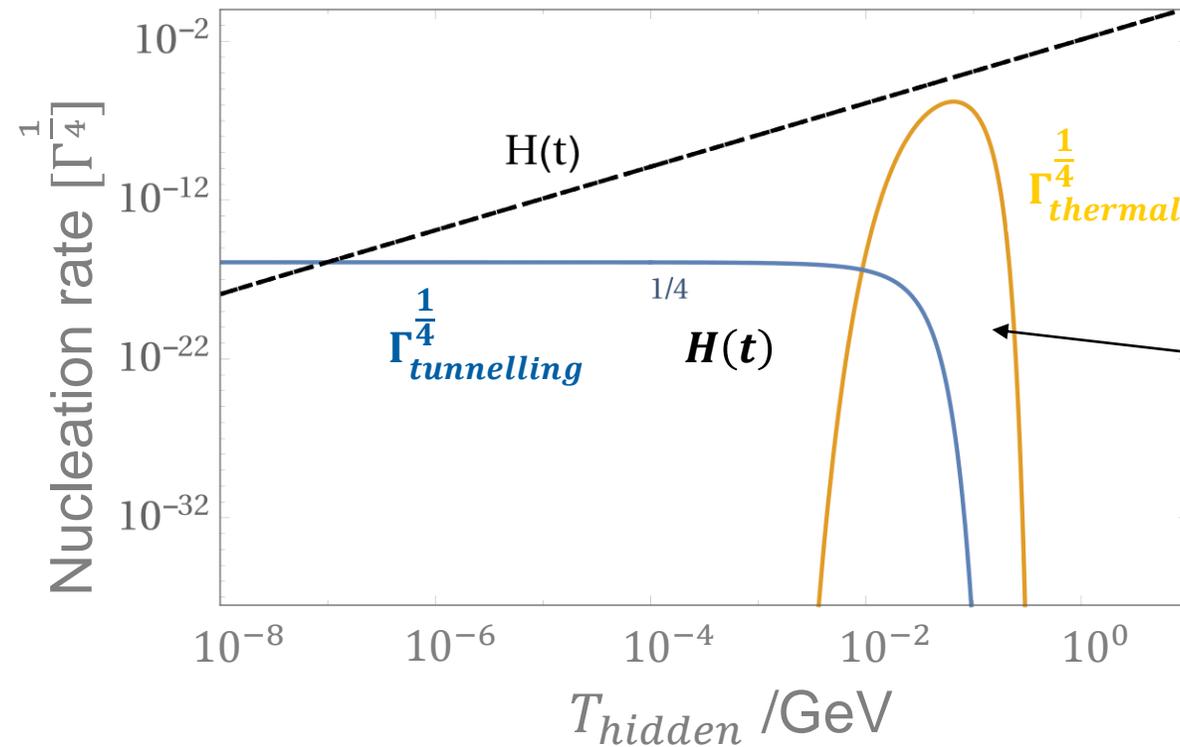
dark sector might have different temperature for a few reasons:-

- Large number of BSM degrees of freedom in visible sector
- Different reheating after inflation into visible and hidden sector
- String theory moduli decay preferentially into one sector rather than other

$$\epsilon \equiv \frac{T_h}{T_v}$$

Phase transitions

$$\text{Case 1: } \epsilon = \frac{T_{\text{hidden}}}{T_{\text{visible}}} \approx 1$$

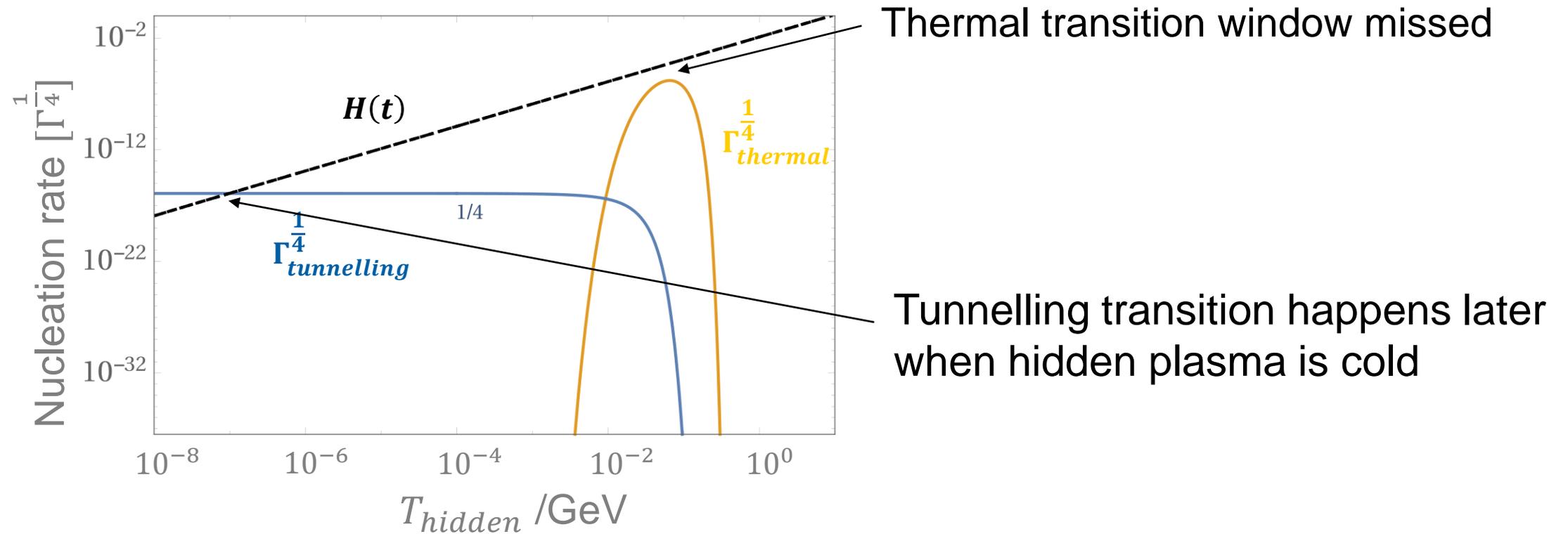


Thermal transition takes place when hidden plasma is hot

Hot plasma \rightarrow High friction \rightarrow Sound wave signal

Phase transitions

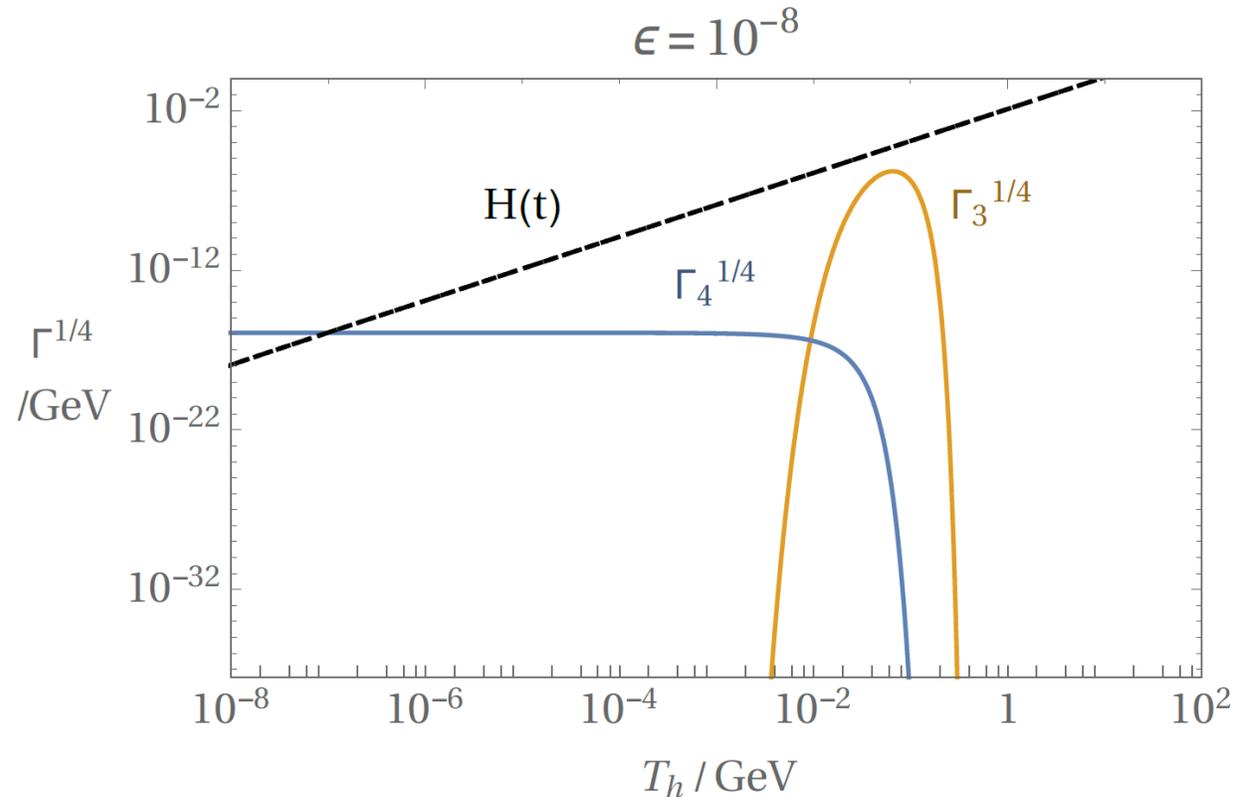
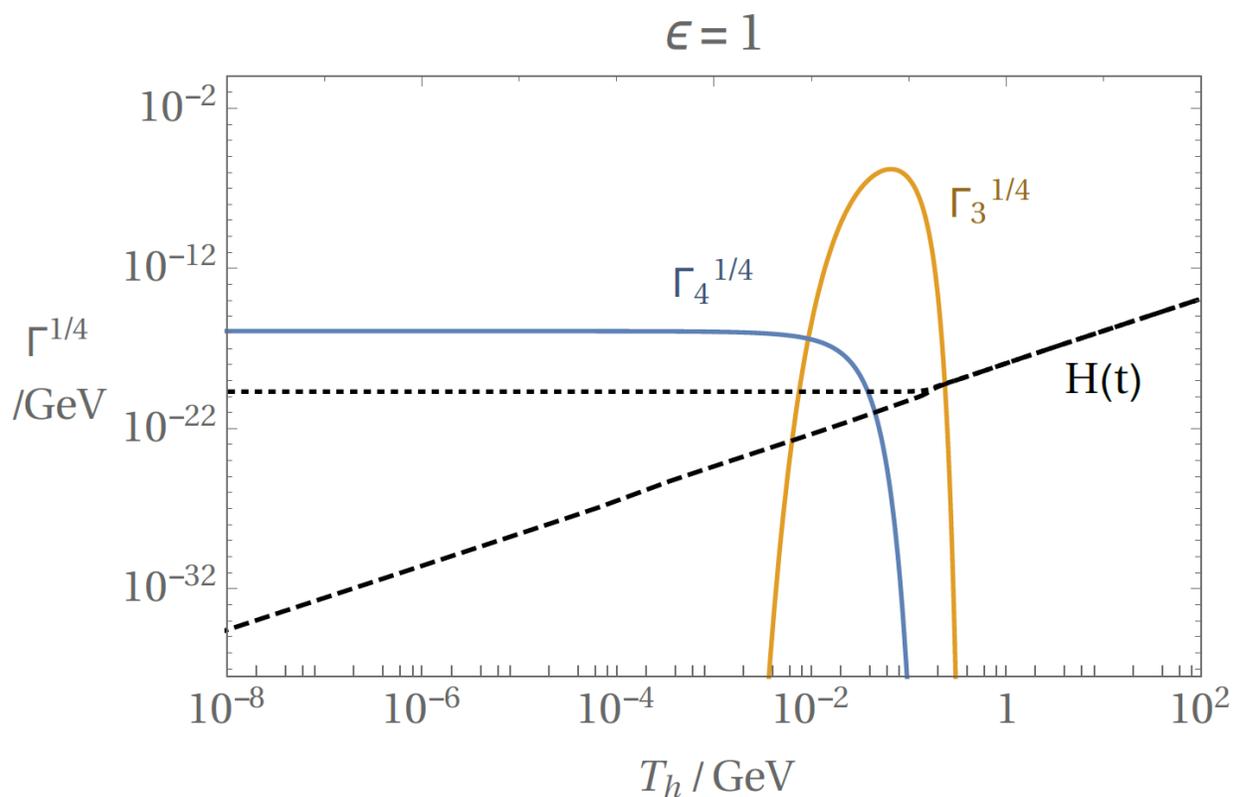
Case 2: $\epsilon = \frac{T_{hidden}}{T_{visible}} \ll 1$



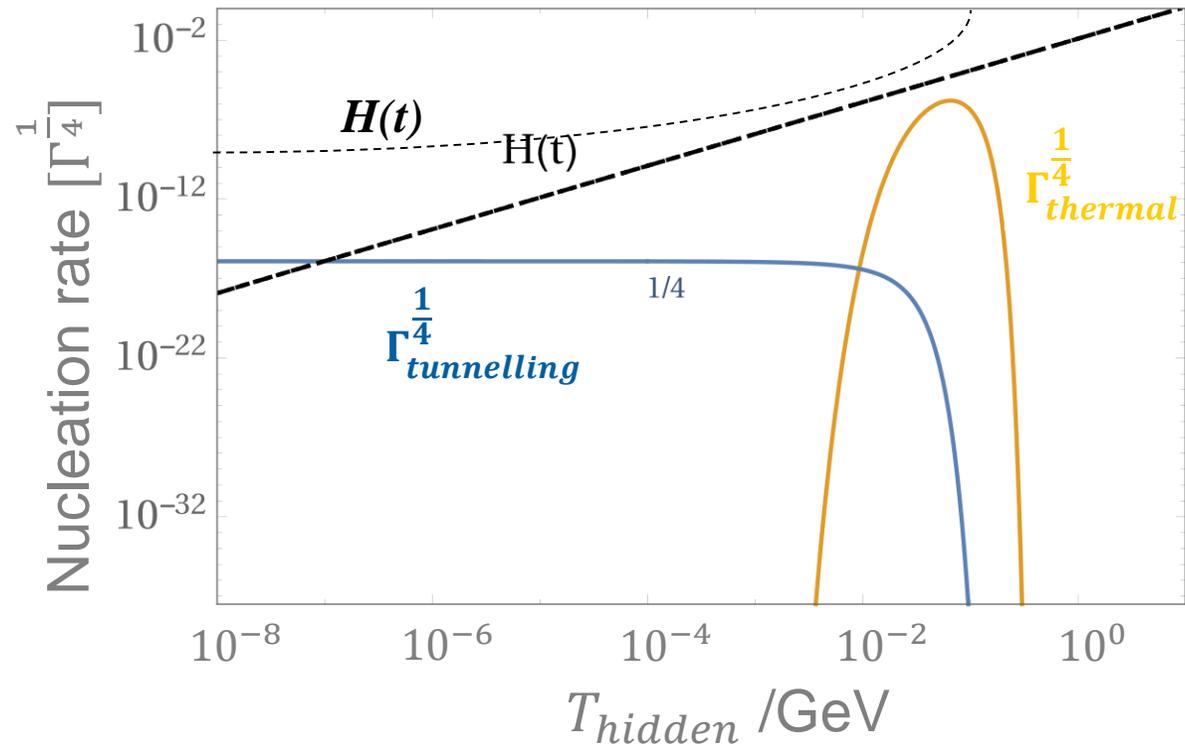
Cold plasma \rightarrow Low wall friction \rightarrow Bubble collision signal?

very different hidden sector temperatures, but visible sector temperature of phase transition can be the same (or bigger, or smaller)

$$\epsilon \equiv \frac{T_h}{T_v}$$



Incomplete Phase transitions

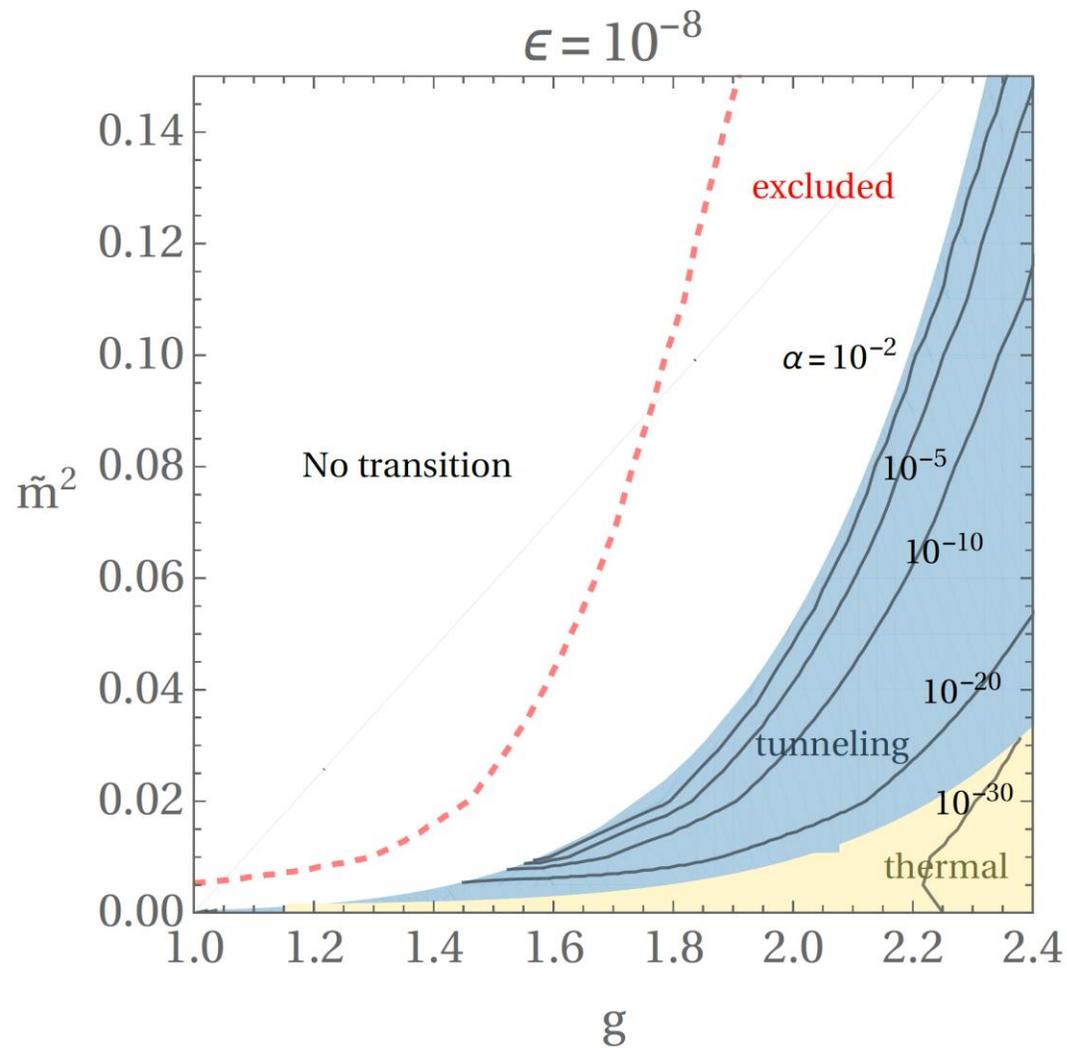
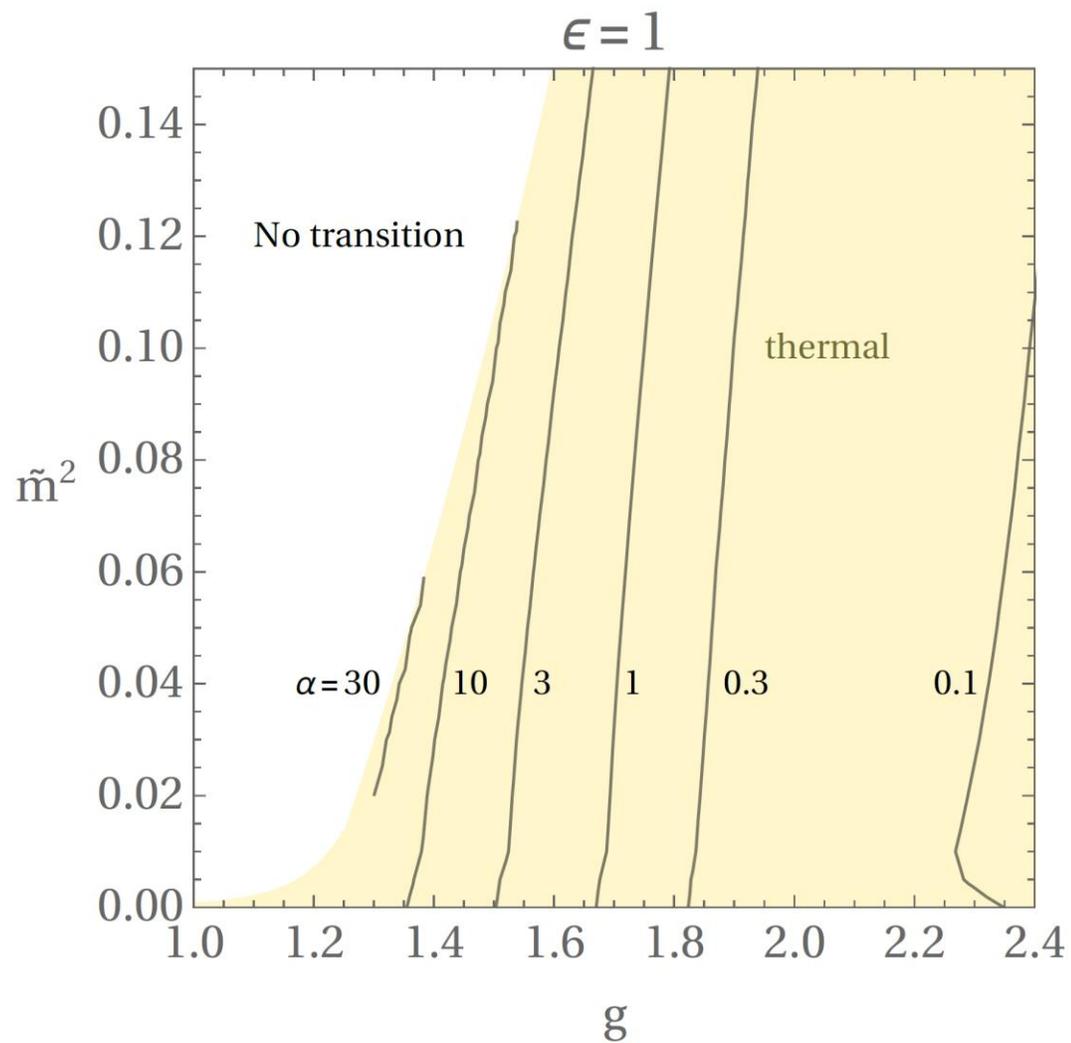


If vacuum energy density dominates expansion before phase transition, we are essentially stuck in old inflation scenario.

Phase transition never completes....

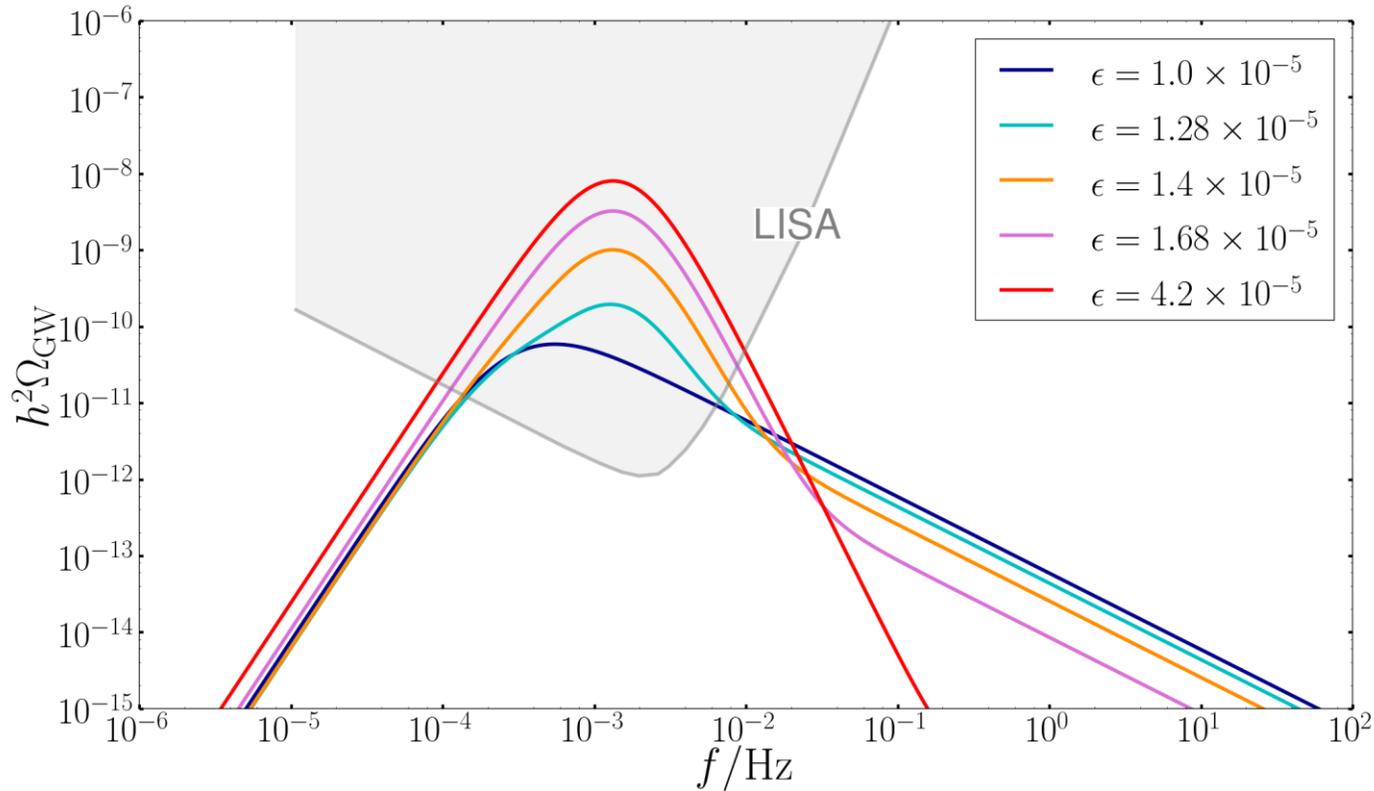
These phase transitions correspond to $w=1$ GeV

$$\alpha = \frac{\rho_{\text{vac}}}{\rho_{\text{V}}} \quad \epsilon \equiv \frac{T_{\text{h}}}{T_{\text{V}}}$$



Gravitational Waves : example 1

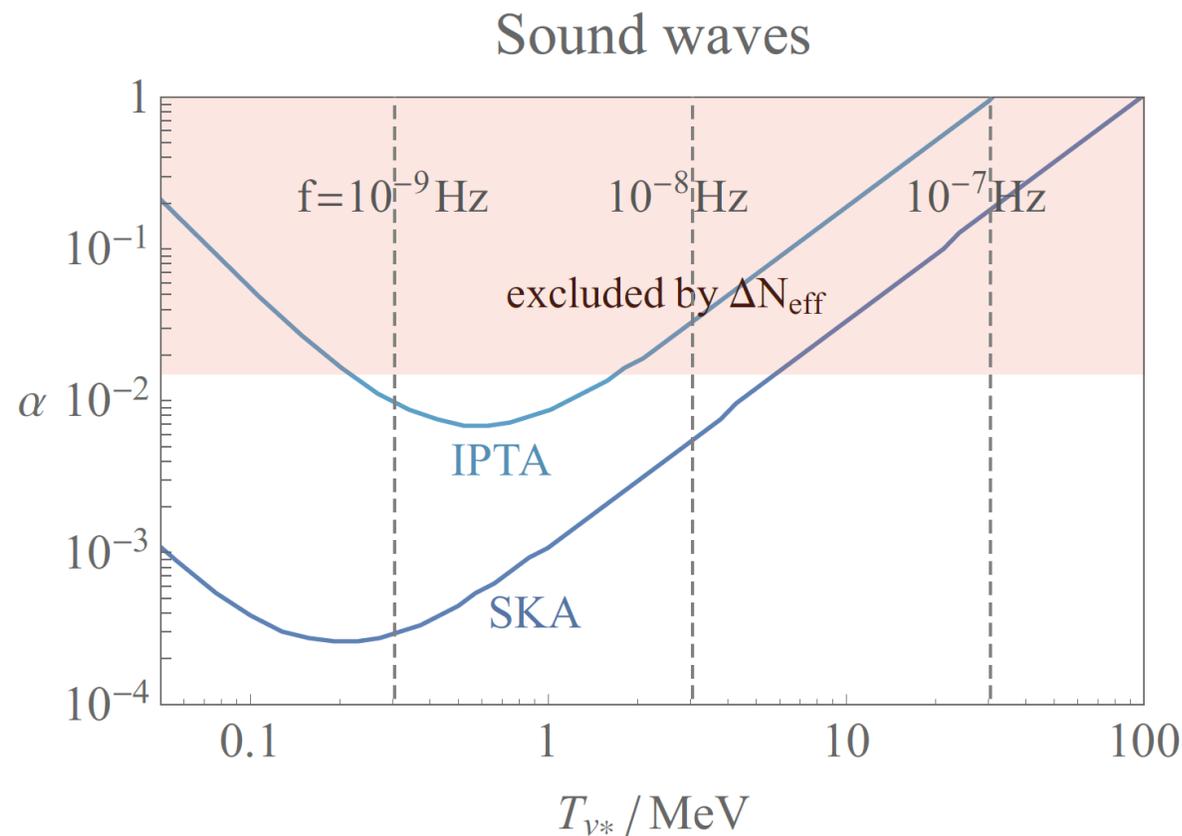
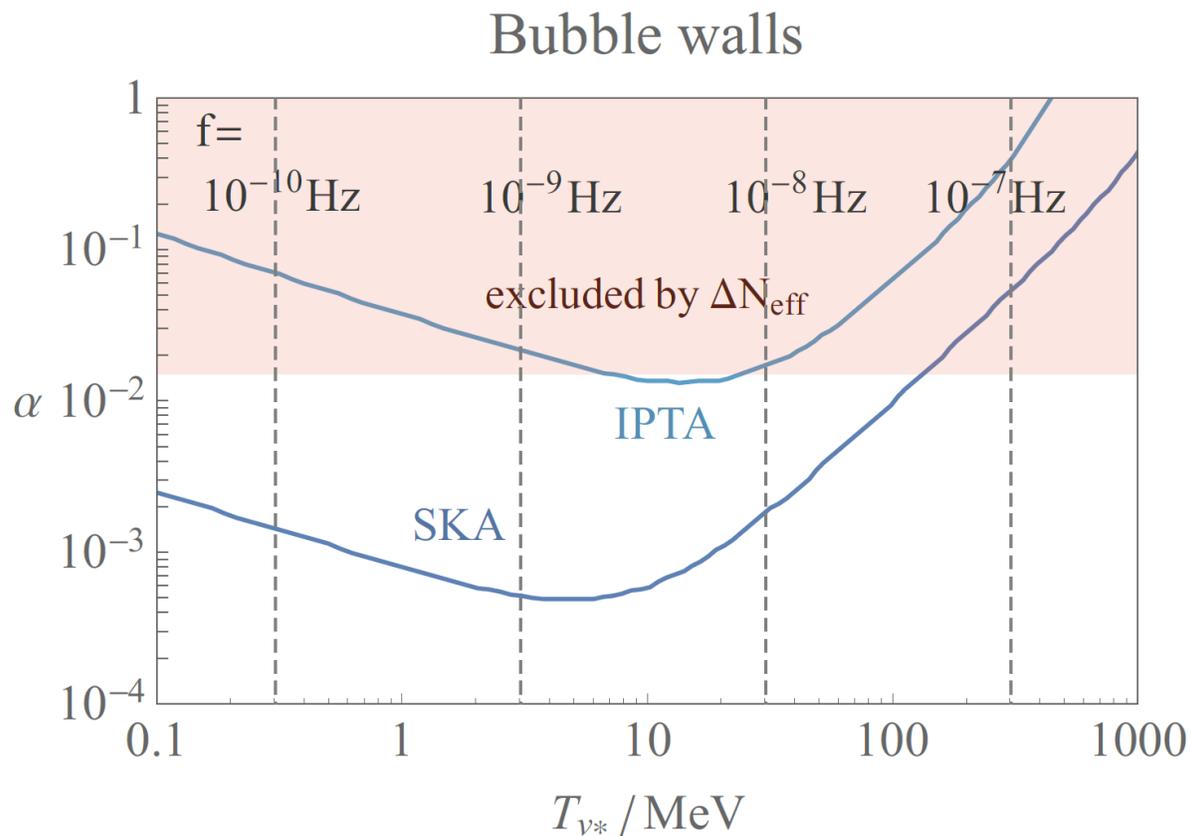
here **visible** temperature at transition is around TeV
Hidden sector temperature different



- Decreasing $\epsilon = \frac{T_{\text{hidden}}}{T_{\text{visible}}}$ decreases friction on bubble wall
- Sound wave \rightarrow bubble collision
- Changes the shape of the gravitational wave signal

A tunnelling transition where a sound wave is expected could be a signal of a hidden cold sector

Gravitational Waves : example 2



A phase transition with a frequency below 10^{-9} Hz would be strong evidence of a cold dark sector

Summary

- We investigated how to distinguish between hidden and visible sector phase transitions
- Cold hidden sector could give rise to the same peak frequency as hot visible sector but with different spectrum
- Strong phase transition at low frequency would be difficult to understand because of BBN



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