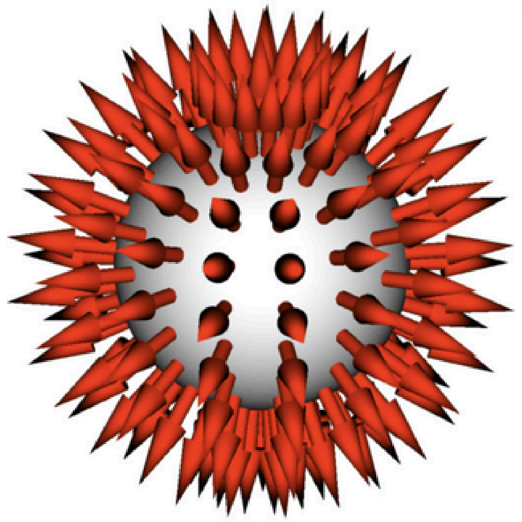
In collaboration with F. Brümmer (LUPM), G. Ferrante (U. Brussels), M. Frigerio (LPTHE)

No room for monopole dark matter

Théodore Fischer
LUPM, Montpellier



based on arXiv:2509.21924

Table of content

I Context and motivation

II The ‘t Hooft-Polyakov model

III Monopole production

IV Conclusion and outlooks

Context and motivation

Why monopole dark matter ?

- Analogy with the visible sector: ordinary matter is made out of electrically charged relics → could dark matter also be made of (dark) electric charged relics ? Why not magnetic relic ?
- Lightest charged particles are stable → monopoles stable because of their magnetic charge.
- Electrically-charged candidates are very well studied but few studies on dark magnetic monopoles → parameter space scan often incomplete or even poor estimation of relic densities in some cases.

Murayama, Shu, 2009
Baek, Ko, Park, 2013
Khoze, Ro, 2014
...

The ‘t Hooft Polyakov model

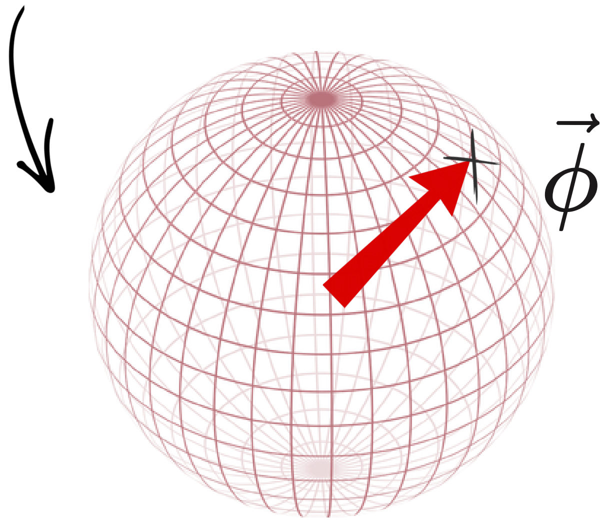
‘t Hooft 1974
Polyakov 1974

$$G = \mathrm{SO}(3)_D \to H = \mathrm{SO}(2)_D, \quad \phi \sim \mathbf{3}$$

$$\langle|\vec{\phi}|^2\rangle = \eta^2, \quad V(\phi) = \frac{\lambda}{4}\left(\phi_a\phi_a - \eta^2\right)^2$$

Vacuum manifold
is a 2-sphere of radius η

$$\mathcal{M} \simeq \mathbb{S}^2$$



The ‘t Hooft Polyakov model

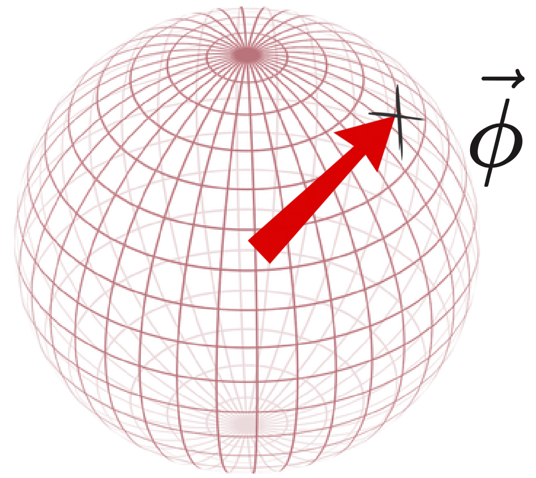
‘t Hooft 1974
Polyakov 1974

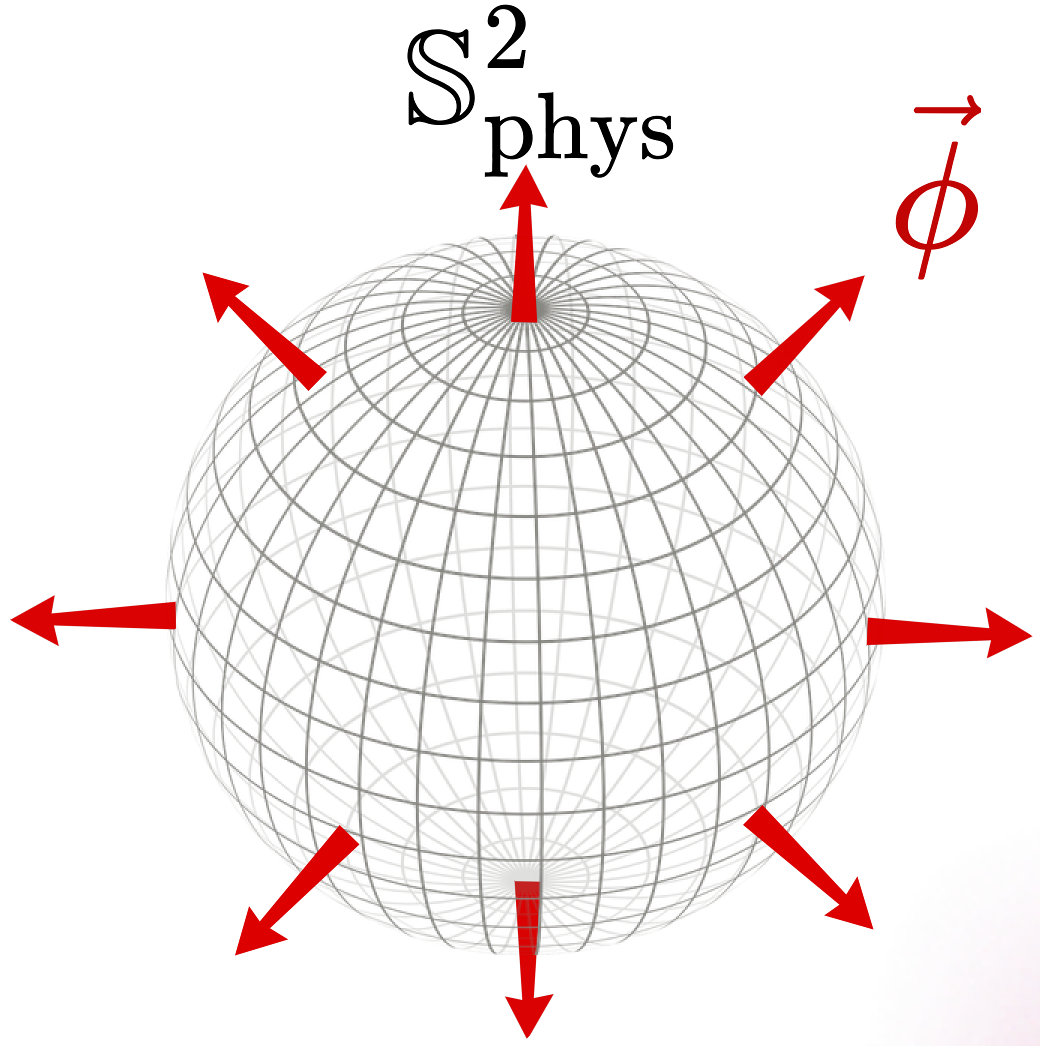
$$G = \mathrm{SO}(3)_D \to H = \mathrm{SO}(2)_D, \quad \phi \sim \mathbf{3}$$

$$\langle |\vec{\phi}|^2 \rangle = \eta^2, \quad V(\phi) = \frac{\lambda}{4}\left(\phi_a \phi_a - \eta^2\right)^2$$

Vacuum manifold
is a 2-sphere of radius η

$$\mathcal{M} \simeq \mathbb{S}^2$$





The ‘t Hooft Polyakov model

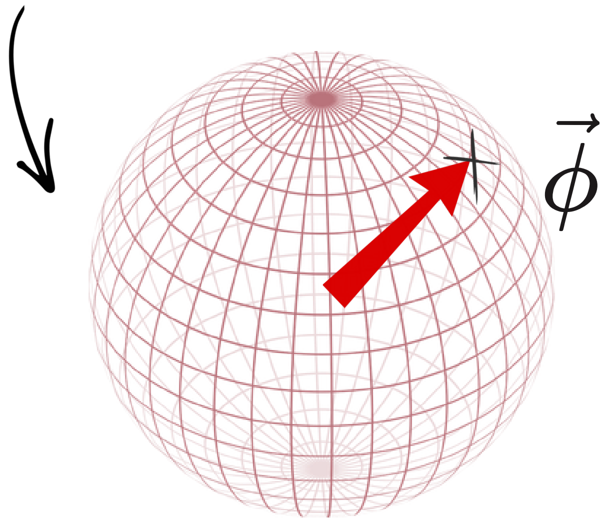
‘t Hooft 1974
Polyakov 1974

$$G = \mathrm{SO}(3)_D \to H = \mathrm{SO}(2)_D, \quad \phi \sim \mathbf{3}$$

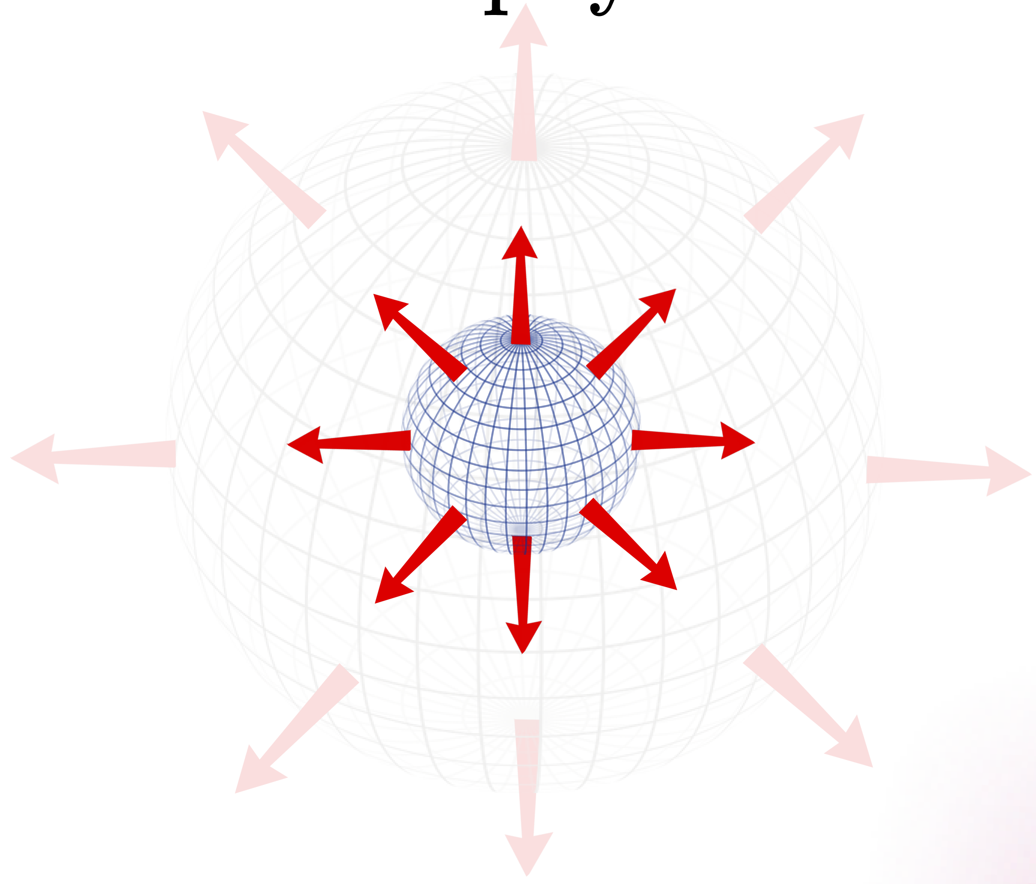
$$\langle|\vec{\phi}|^2\rangle = \eta^2, \quad V(\phi) = \frac{\lambda}{4}\left(\phi_a\phi_a - \eta^2\right)^2$$

Vacuum manifold
is a 2-sphere of radius η

$$\mathcal{M} \simeq \mathbb{S}^2$$



$\mathbb{S}^2_{\text{phys}}$



The ‘t Hooft Polyakov model

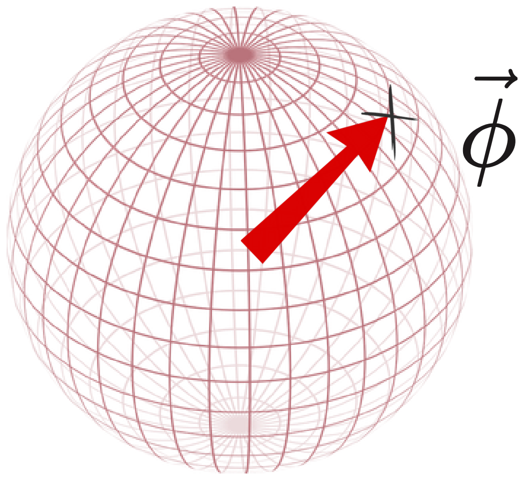
‘t Hooft 1974
Polyakov 1974

$$G = \mathrm{SO}(3)_D \to H = \mathrm{SO}(2)_D, \quad \phi \sim \mathbf{3}$$

$$\langle |\vec{\phi}|^2 \rangle = \eta^2, \quad V(\phi) = \frac{\lambda}{4}\left(\phi_a \phi_a - \eta^2\right)^2$$

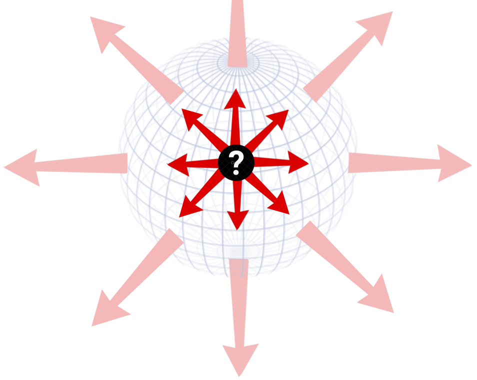
Vacuum manifold
is a 2-sphere of radius η

$$\mathcal{M} \simeq \mathbb{S}^2$$



$\vec{\phi}$

$\mathbb{S}^2_{\mathrm{phys}}$



The ‘t Hooft Polyakov model

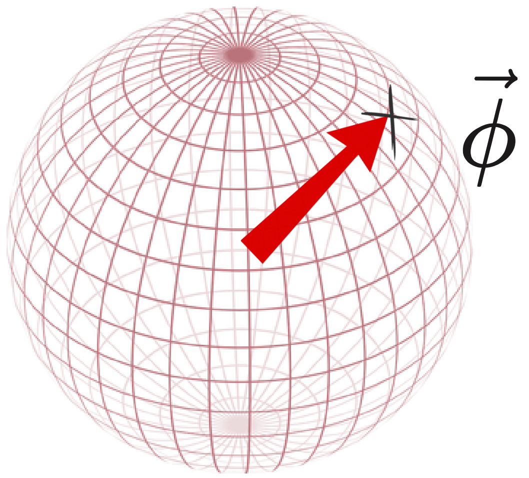
‘t Hooft 1974
Polyakov 1974

$$G = \mathrm{SO}(3)_D \to H = \mathrm{SO}(2)_D, \quad \phi \sim \mathbf{3}$$

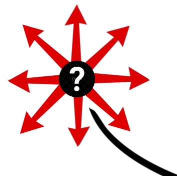
$$\langle |\vec{\phi}|^2 \rangle = \eta^2, \quad V(\phi) = \frac{\lambda}{4}\left(\phi_a \phi_a - \eta^2\right)^2$$

Vacuum manifold
is a 2-sphere of radius η

$$\mathcal{M} \simeq \mathbb{S}^2$$



$\mathbb{S}^2_{\text{phys}}$



$\vec{\phi} = \vec{0} \notin \mathcal{M}$

The 't Hooft Polyakov model

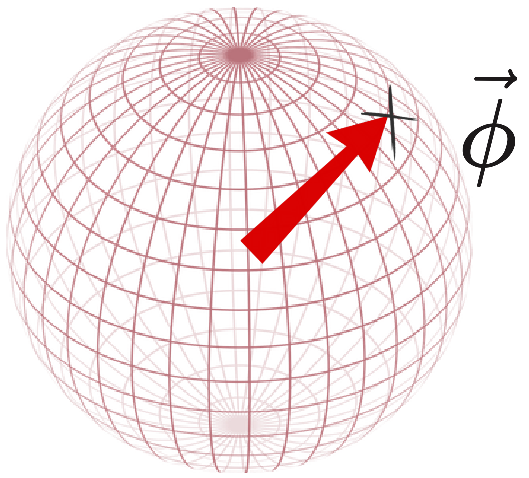
't Hooft 1974
Polyakov 1974

$$G = \mathrm{SO}(3)_D \to H = \mathrm{SO}(2)_D, \quad \phi \sim \mathbf{3}$$

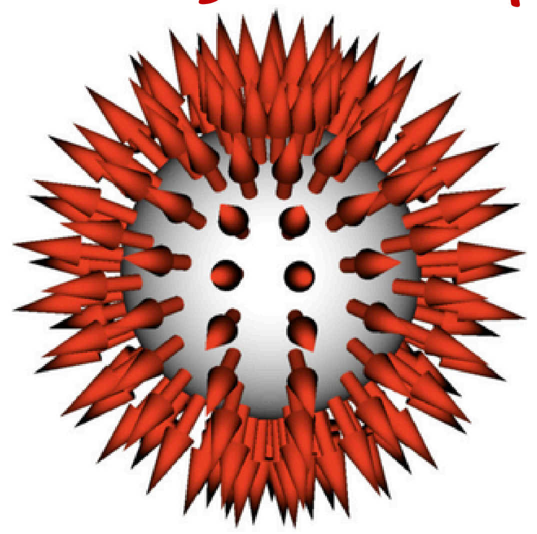
$$\langle |\vec{\phi}|^2 \rangle = \eta^2, \quad V(\phi) = \frac{\lambda}{4}\left(\phi_a \phi_a - \eta^2\right)^2$$

Vacuum manifold
is a 2-sphere of radius η

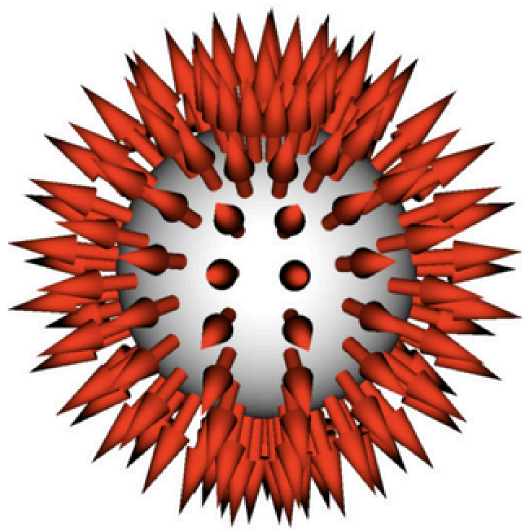
$$\mathcal{M} \simeq \mathbb{S}^2$$



't Hooft-Polyakov monopole !



The ‘t Hooft Polyakov monopole



- Unavoidable
- Stable (topology)
- Has a mass: $m_M \sim \frac{4\pi}{g}\eta$, with g the gauge coupling

Two stable relics

Monopoles $M^{\pm_m}$

Massive $W'^{\pm_e}$

Fixed by phase transition

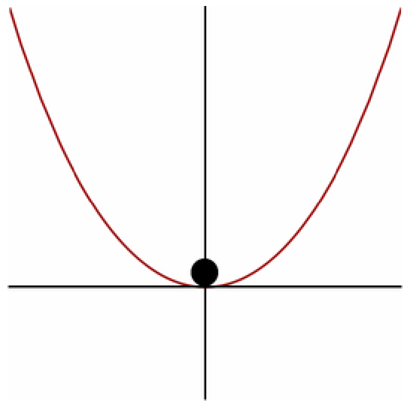
???

$$\Omega_M h^2 \sim 0.12 \gg \Omega_{W'} h^2$$

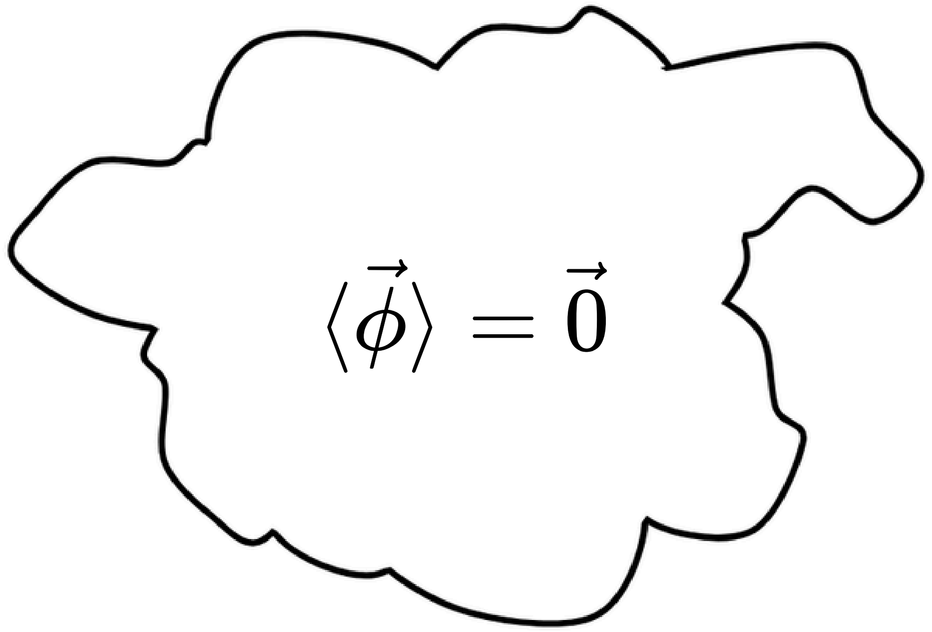
Fixed by freeze out

Monopole production

- At high temperature $T \gg T_c$

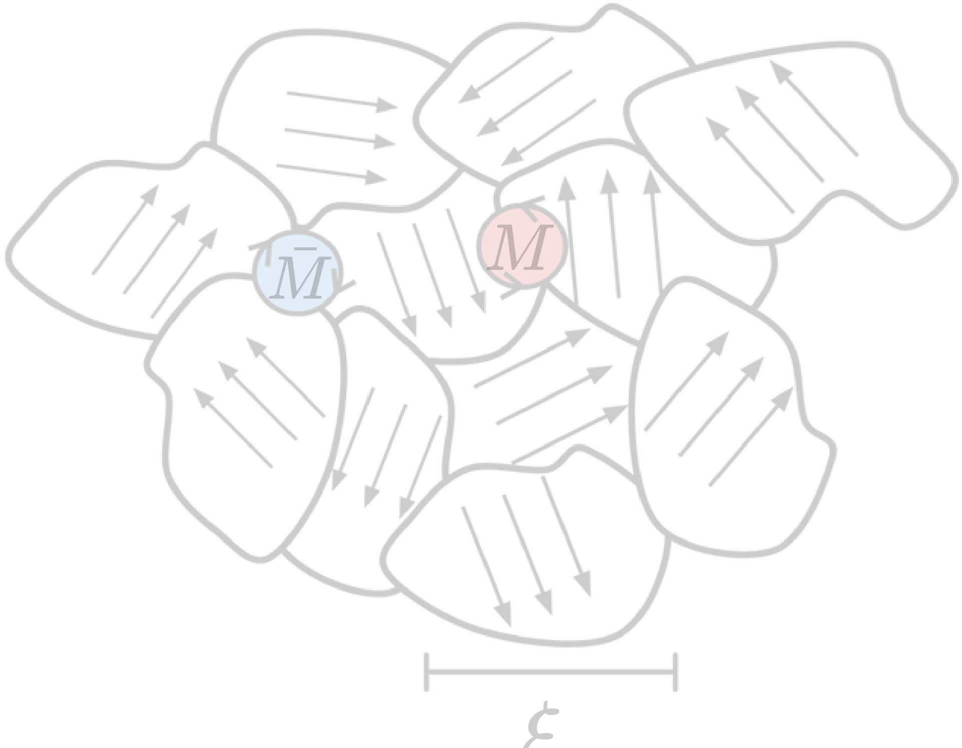


The universe is in the symmetric phase



- At low temperature $T \ll T_c$

The universe is in the broken phase

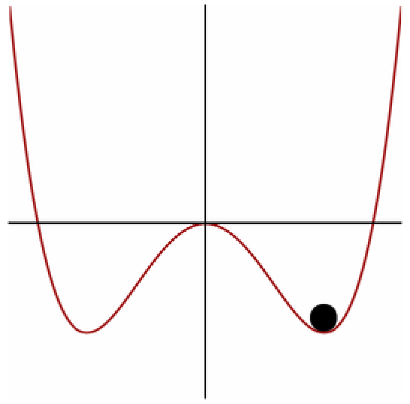


Monopole production

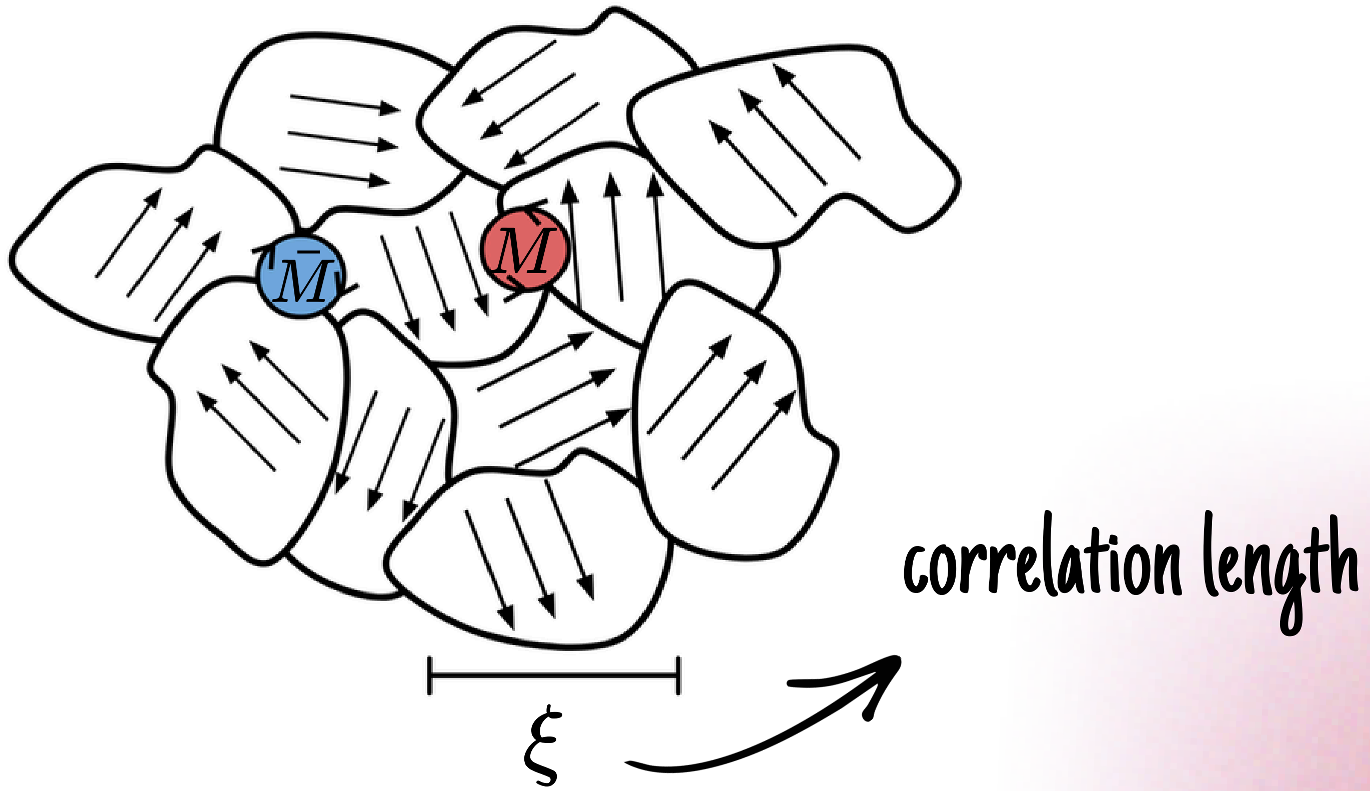
- At high temperature $T \gg T_c$

The universe is in the symmetric phase

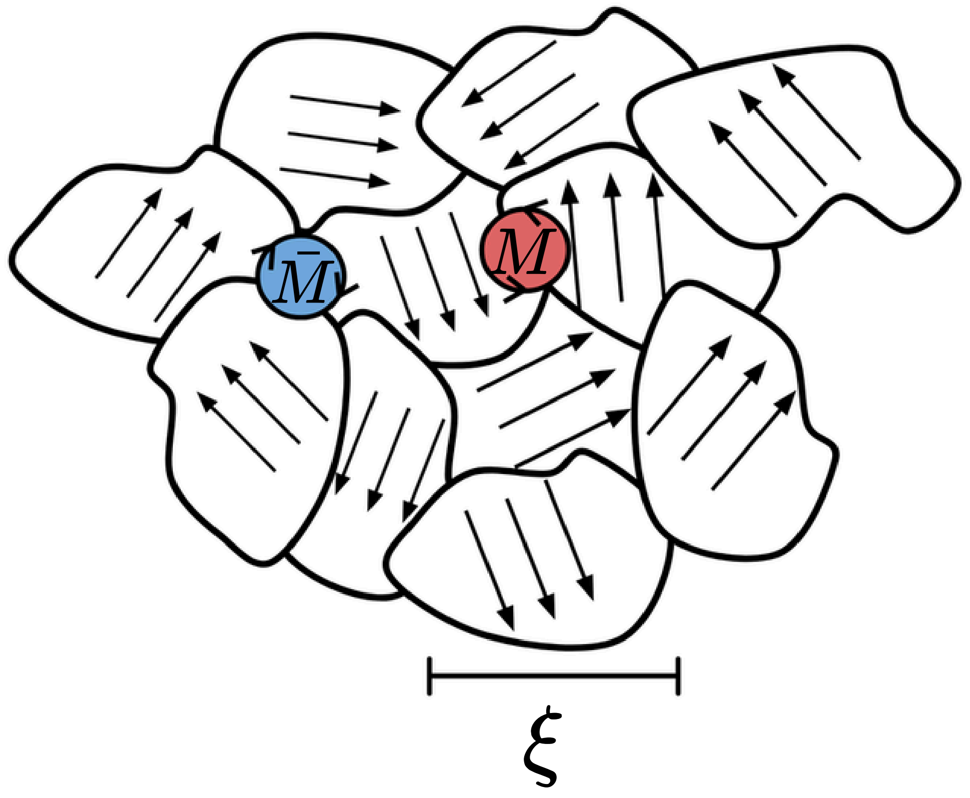
- At low temperature $T \ll T_c$



The universe is in the broken phase



Monopole production



At each intersection, there is a probability of ⅛ to produce a monopole configuration.

→ The number density of monopoles produced can be estimated by

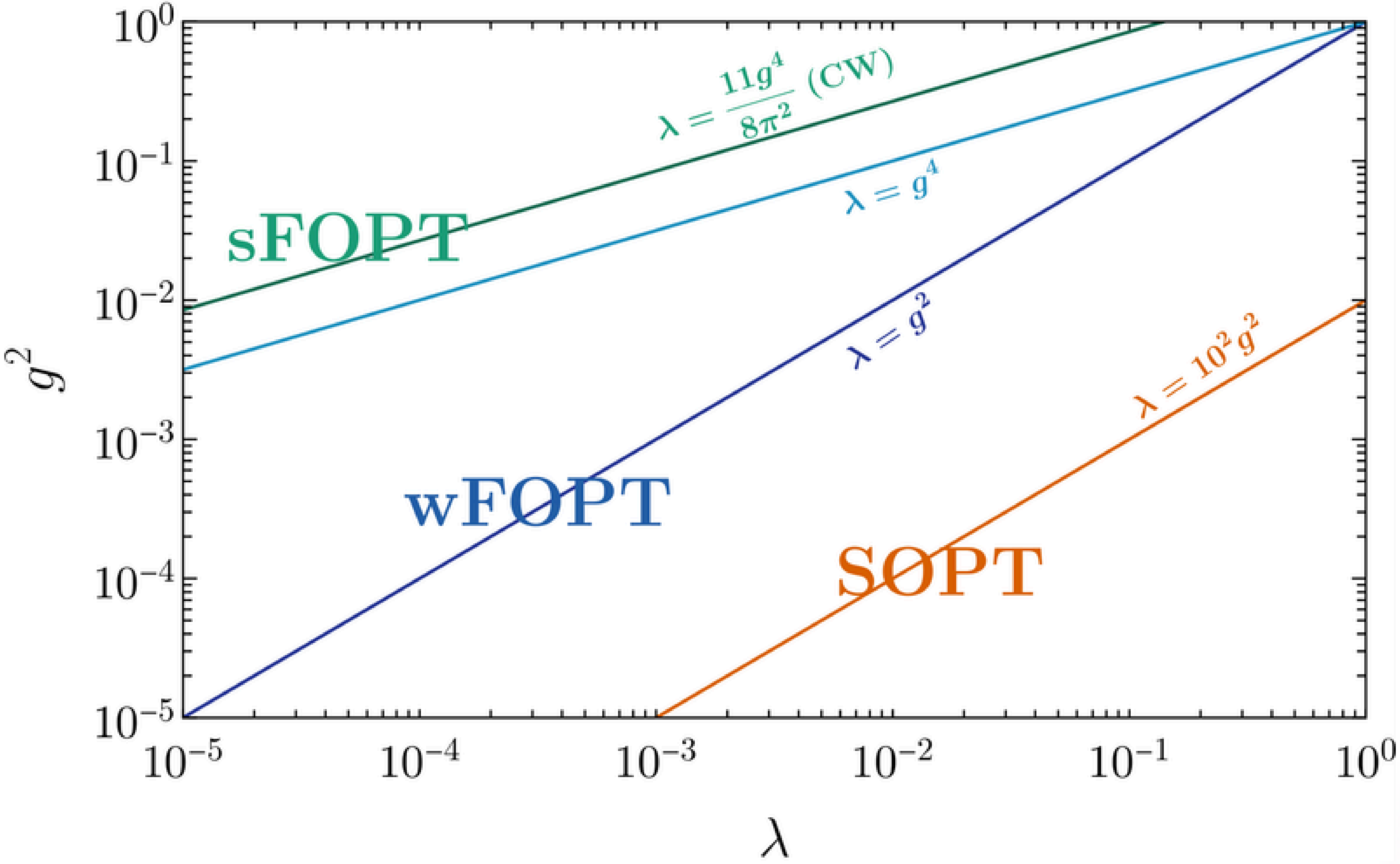
Kibble 1976

$$n_M \simeq \frac{1}{8}\xi^{-3}$$

Depends strongly on the nature of the phase transition !

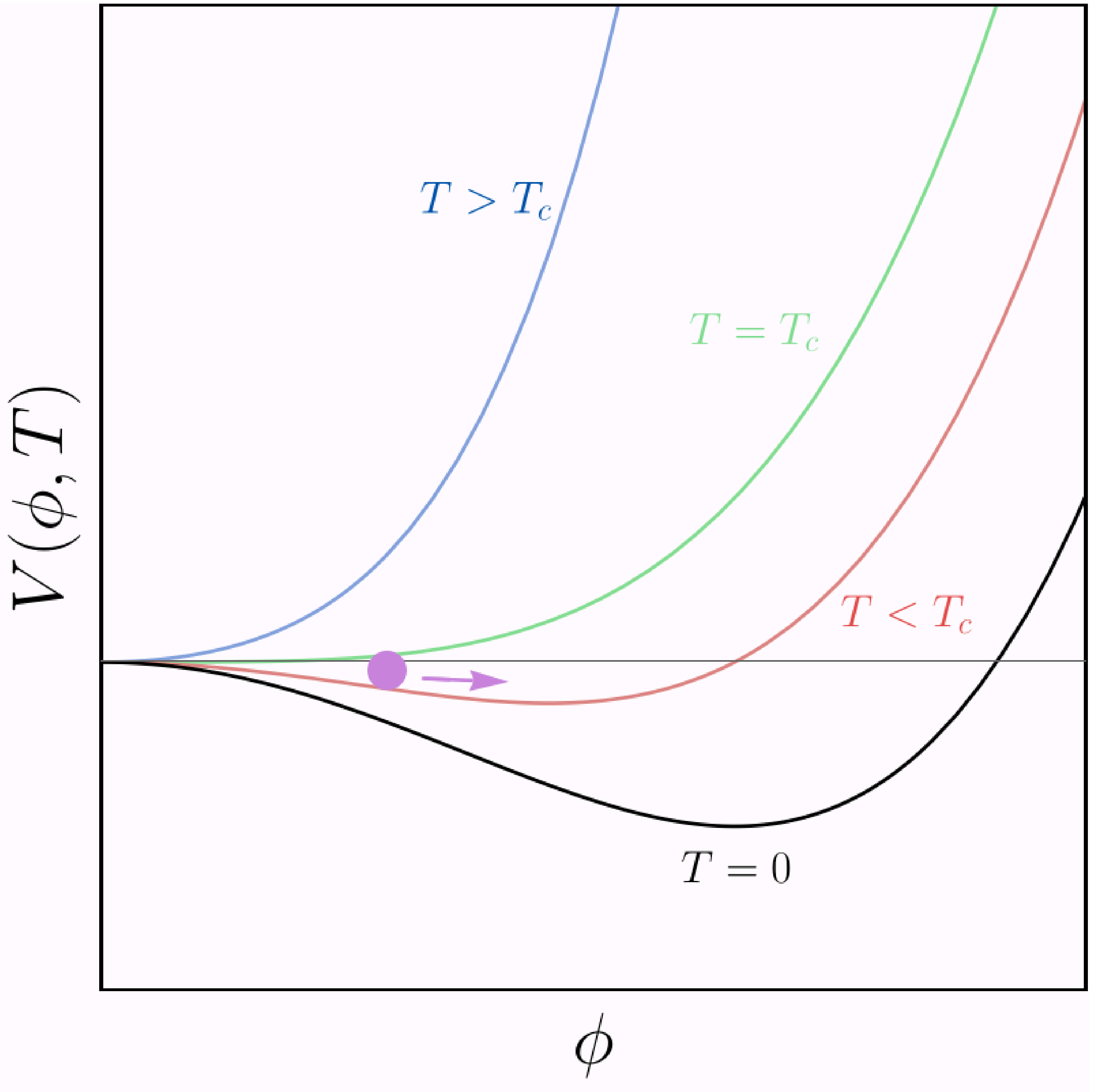
After production, density can decrease by $M - \bar{M}$ annihilation

Phase diagram of the model



Second order phase transitions

Second order phase transitions happens smoothly and are well understood.



In principle, the correlation length diverges near the critical temperature.
But, also the relaxation time diverges
→ Fluctuations freeze at a spatial scale given by

Kibble 1976
Zurek 1985
Murayama, Shu, 2009

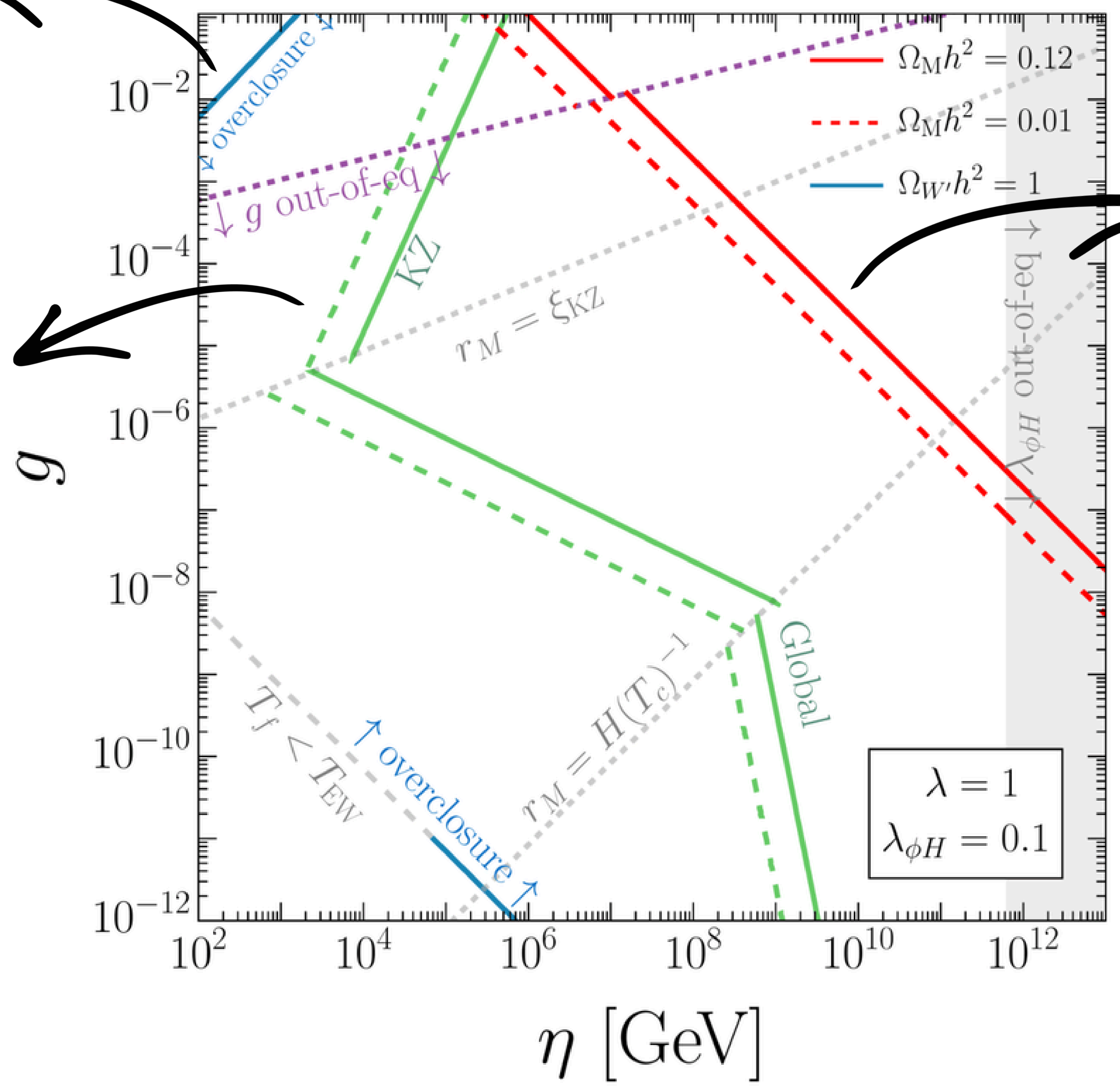
$$\xi_{\rm KZ} \simeq H^{-1}(T_c)\left[\frac{H(T_c)^2}{2\lambda\eta^2}\right]^{0.3}$$

Second order phase transitions

Fixed by freeze-out

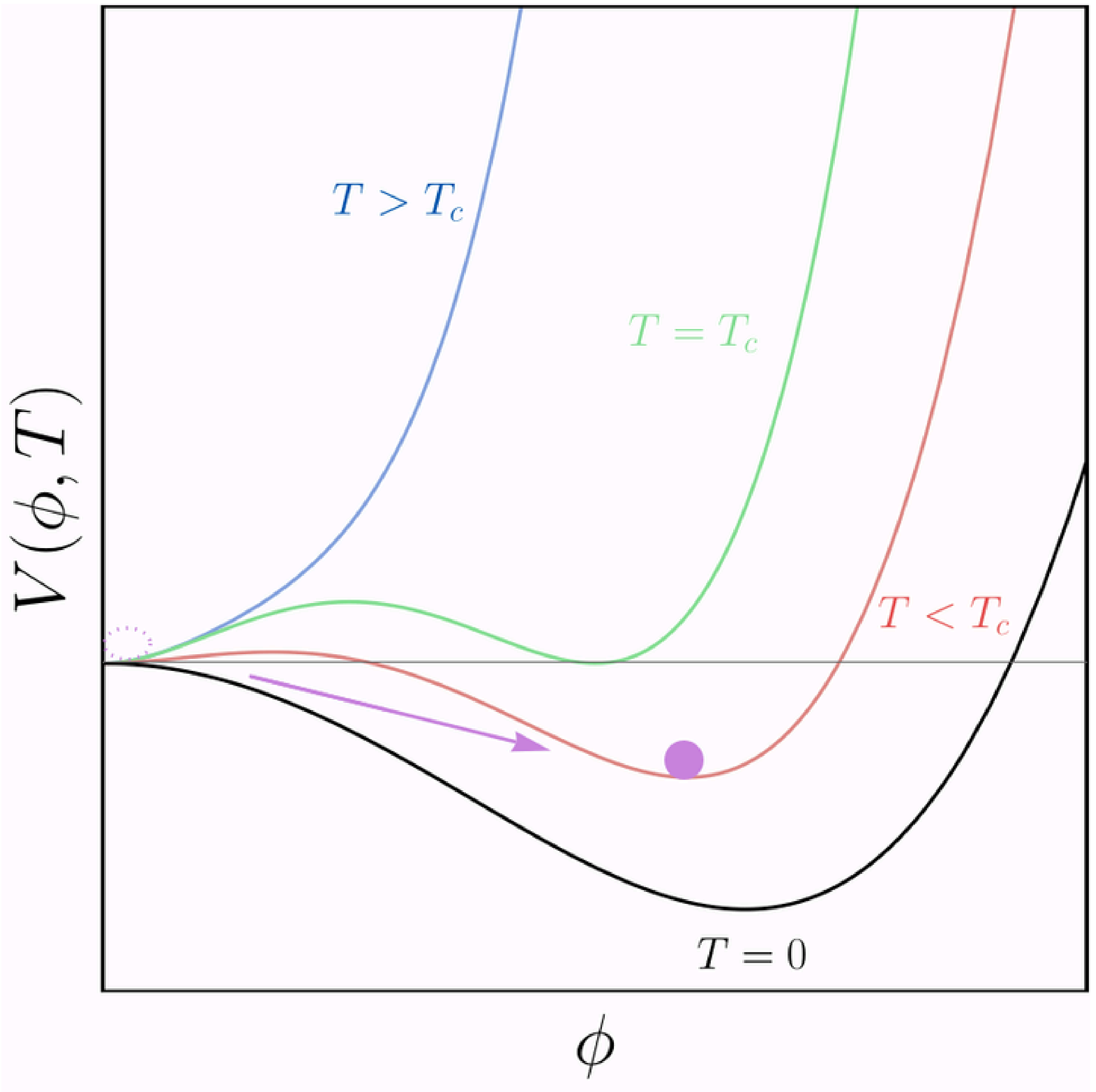
After annihilations

ξ_{KZ}



First order phase transitions

First order phase transitions proceed via bubble nucleation by thermal fluctuations.



Bubbles of true vacuum expand and percolate at some point. → Correlation length is fixed by the radius of bubbles at this time.

Linde, 1980

Nucleation rate per unit volume: $\Gamma \simeq T^4 e^{-S_3/T}$

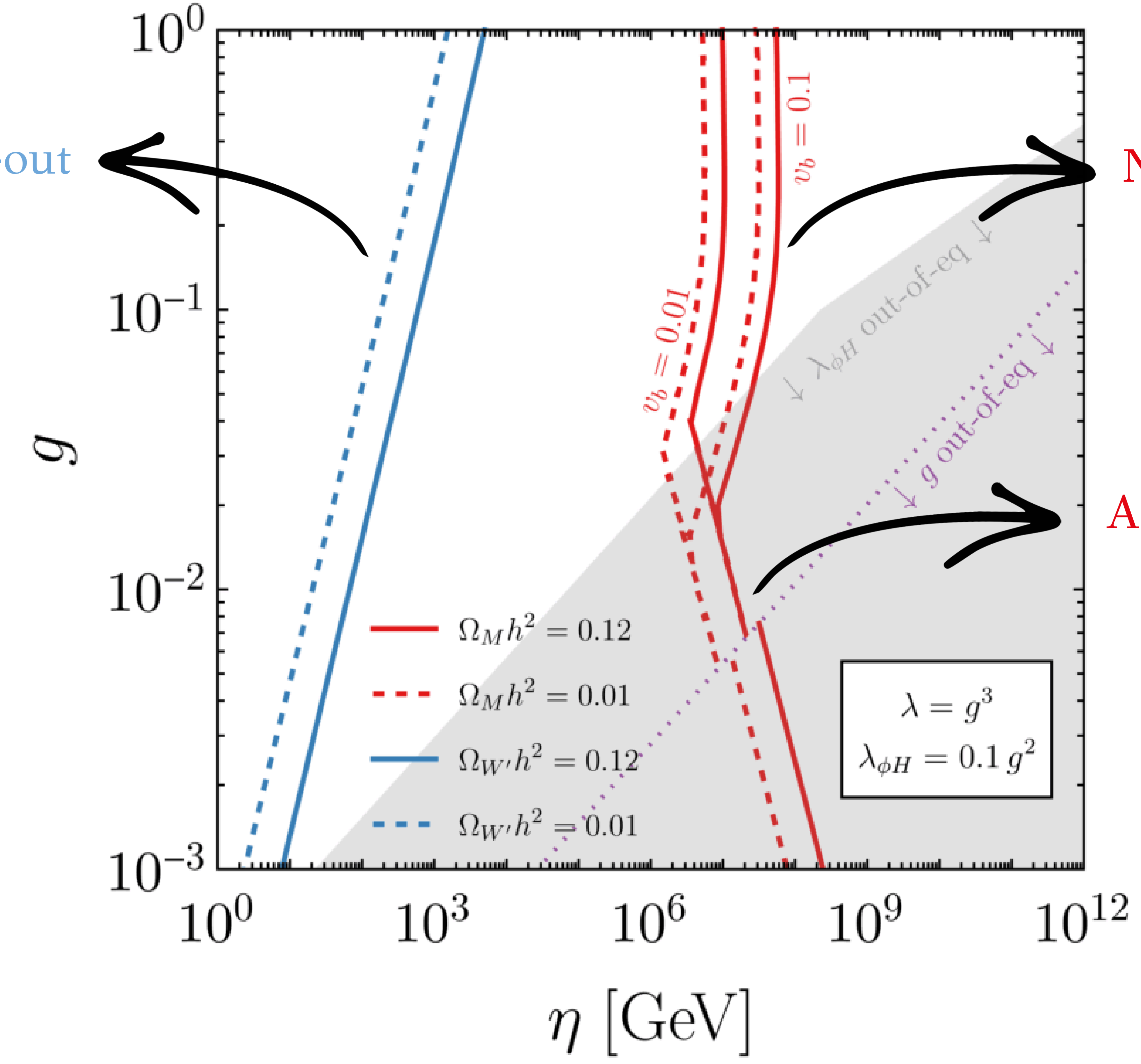
Bubbles start nucleating when $\Gamma(T_n) \simeq H(T_n)^4$ and percolate when ~29% of the universe is in the true vacuum. The correlation length is then estimated with

$$\xi = R(T_p) \sim v_b \left(\frac{d \log \Gamma}{dt} \Big|_{t_p} \right)^{-1}$$

Weakly first order

$$T_p \simeq T_c$$

Fixed by freeze-out

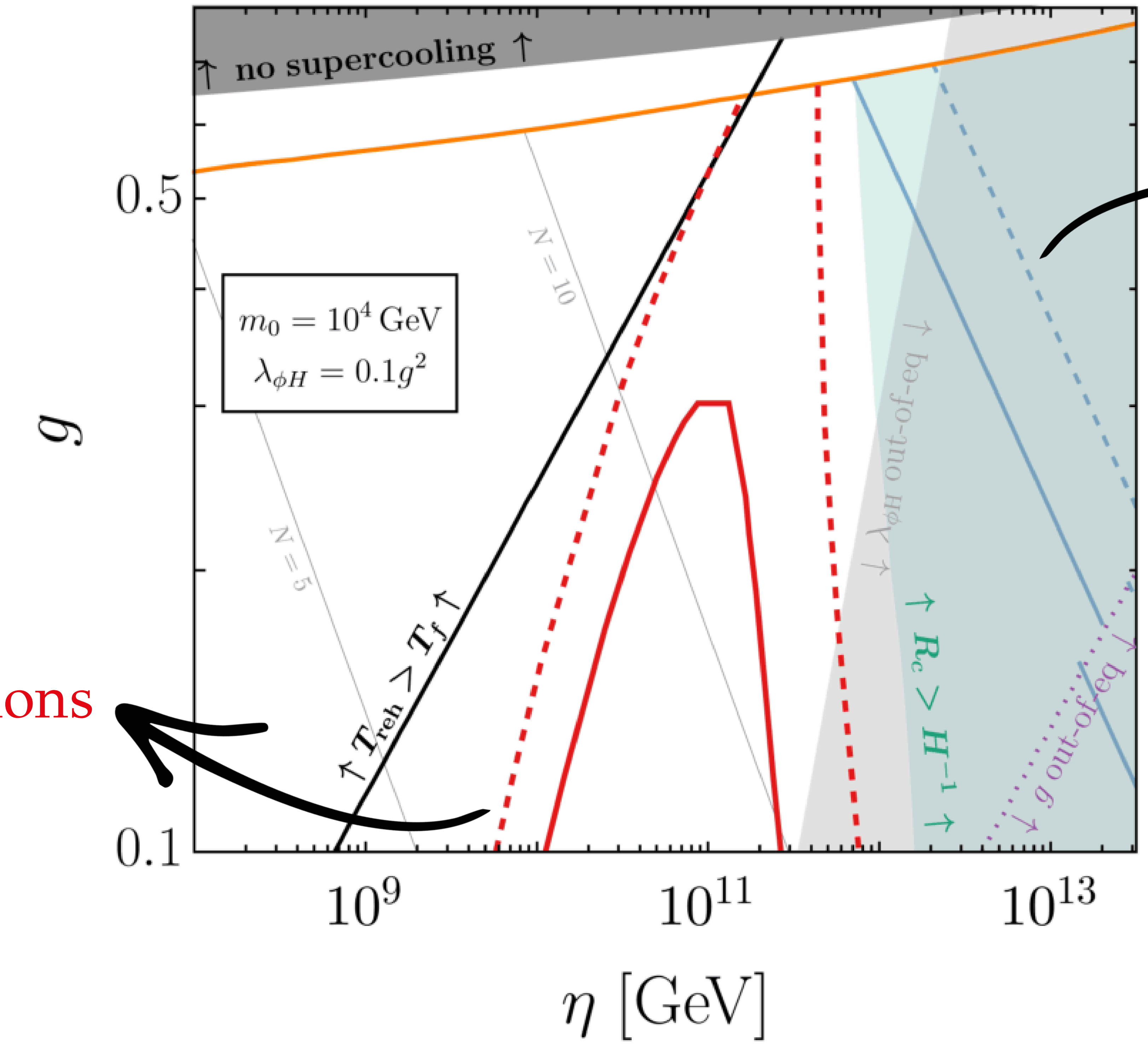


No annihilation

Annihilation dominates

Strongly first order

$T_p \ll T_c$: Phase transition ends after a period of inflation



W' diluted by thermal inflation

No annihilations

Conclusion and outlooks

For all pertubative values of the couplings, and for any vev, monopoles only make out a negligibly small fraction of DM:

$$\Omega_M \ll \Omega_{W'}$$

There is no room for (minimal) monopole DM !

Potential ways out:

Brummer, G. Ferrante, T. Fischer, M.Frigerio
"The price for monopole dark matter", coming soon !

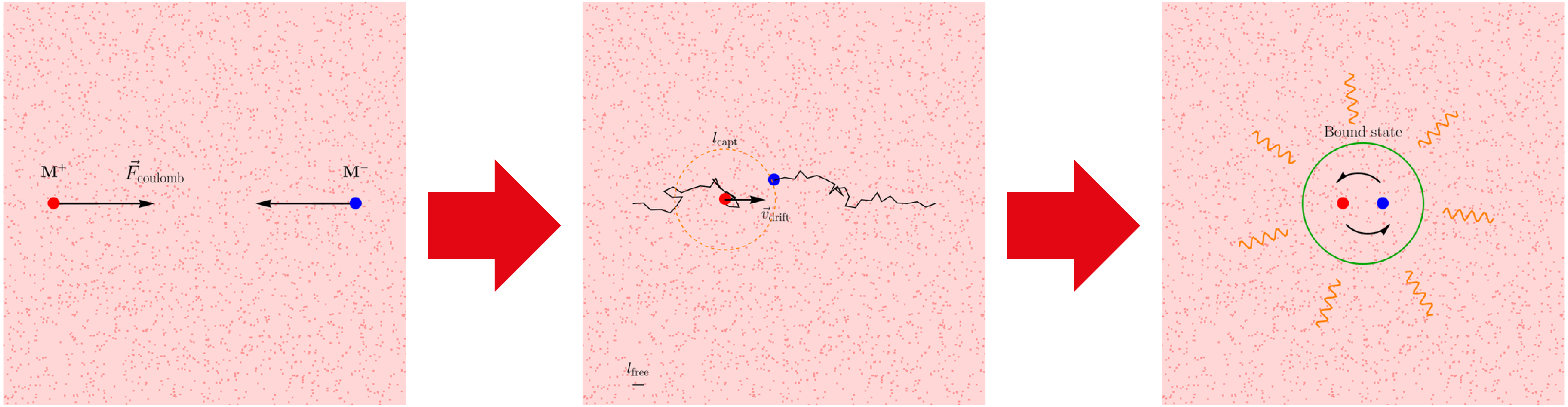
→ Make the W' disappear by adding lighter particles (to mimick GUT theories): introduce a doublet of charged fermions (strong constraints from ΔN_{eff} !)

→ Make the W' disappear in the SM with a large higgs portal. Also affects the monopole abundance !

→ Beyond 't Hooft-Polyakov monopoles: non-trivial topologies lead to more exotic topological defects with very different cosmologies.

Backup slides

Annihilations



$$\Gamma_a = \frac{v_{drift}}{d} \rightarrow \text{Solve Boltzmann equation}$$

Bounce action