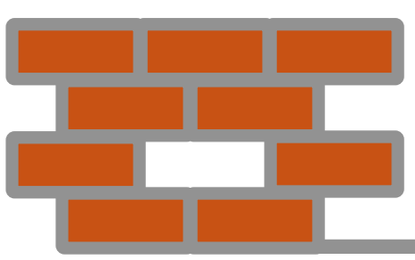


PONT - Avignon

11/12/2020

Hubble induced phase transitions: Defects are not forever

Dario Bettoni

Based on: **arXiv:1810.11117 (JCAP 1902 (2019) 034)** and **arXiv:1911.03484 (JCAP01 (2020) 002)**

J. Rubio (IST, Lisbon), G. Domenech (INFN, Padova), A. Lopez-Eigueren (Tufts University)

Introduction

Gravity-mediated inteplay between inflation and matter fields

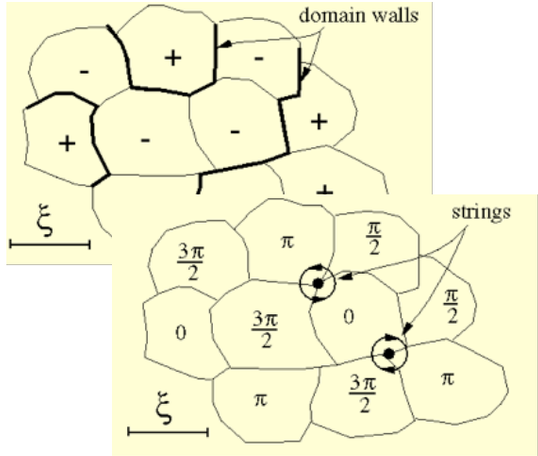
Rich phenomenology

¡Usually in terms of homogeneous field evolution!

- Baryogenesis [Bettoni, Rubio (2018)]
- Cosmic strings [Bettoni, Domenech, Rubio (2018)]
- Domain Walls [Bettoni, Rubio (2019)]
- Reheating [Dimopoulos et al. (2018), Opferkuch et al. (2019)]
- Dark Matter [Fairbairn et al. (2018) & Alonso-Álvarez (2018)]

Key concepts:

- *Spontaneous breaking of internal symmetries*
- Formation of *topological defects*
- The dynamics of defects leads to
  - *Gravitational waves* spectrum
  - Heating (radiation domination)



$$h''_{ij} + k^2 h_{ij} = 16\pi G a(\tau) T^{TT}_{ij}$$

Hubble building defects

Spectator field $\rho_\chi \ll \rho_{\rm inf}$

Non-minimal coupling

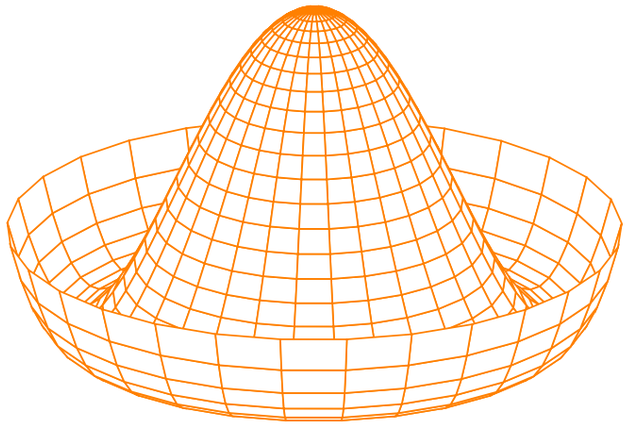
Internal symmetries

$$V_{\rm eff} = (m_\chi^2 + \xi R)|\chi|^2 + \frac{\lambda}{4}|\chi|^4$$

Stiff equation of state $R = 3(1-3w)H^2 < 0$

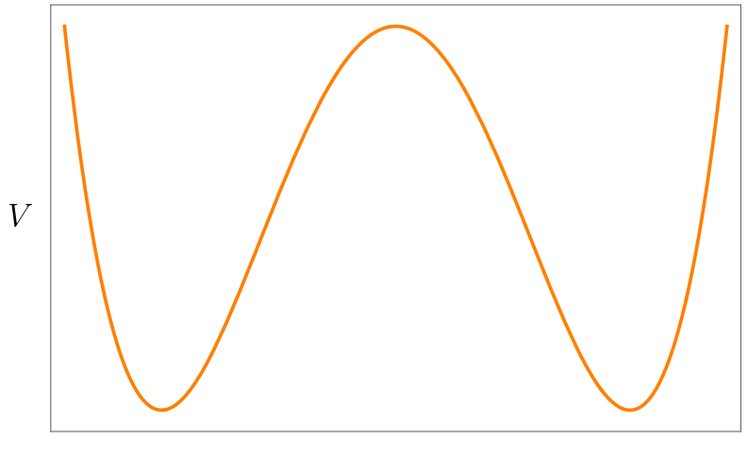
E.g., quintessential inflation

$U(1)$ symmetry



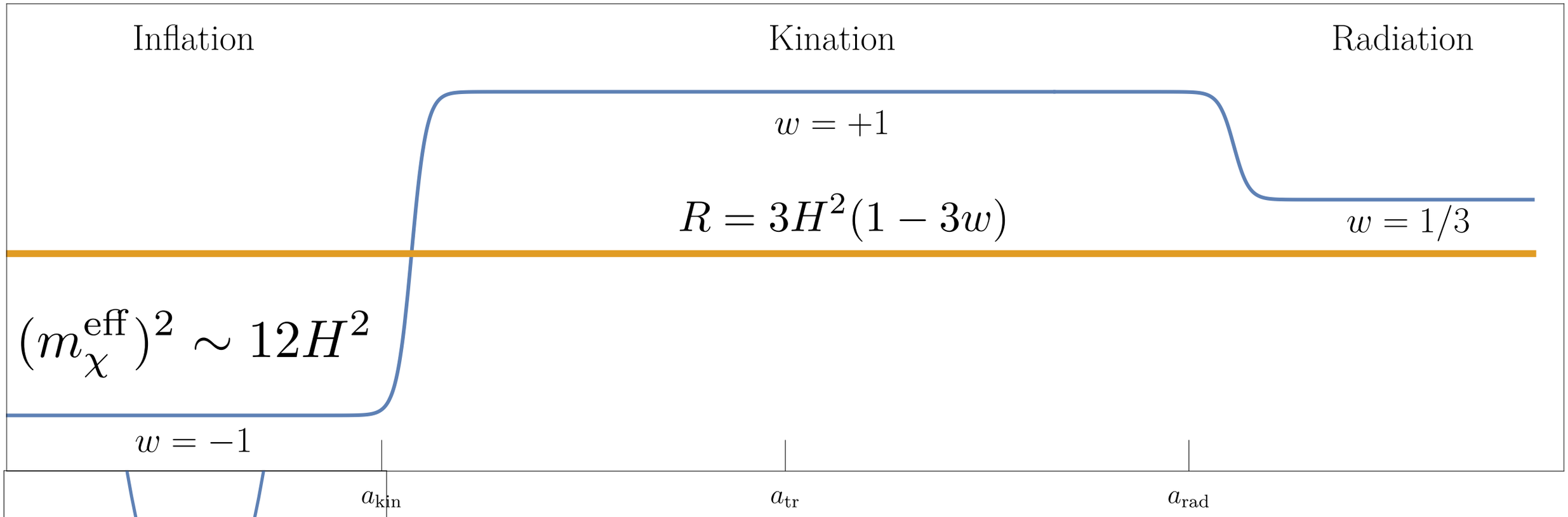
arXiv:1810.11117

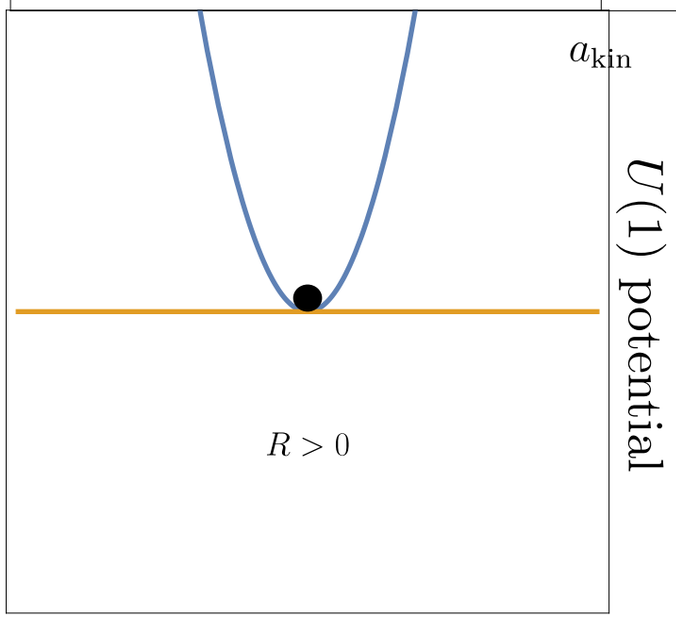
Z_2 symmetry



arXiv:1911.03484

Spectator field dynamics

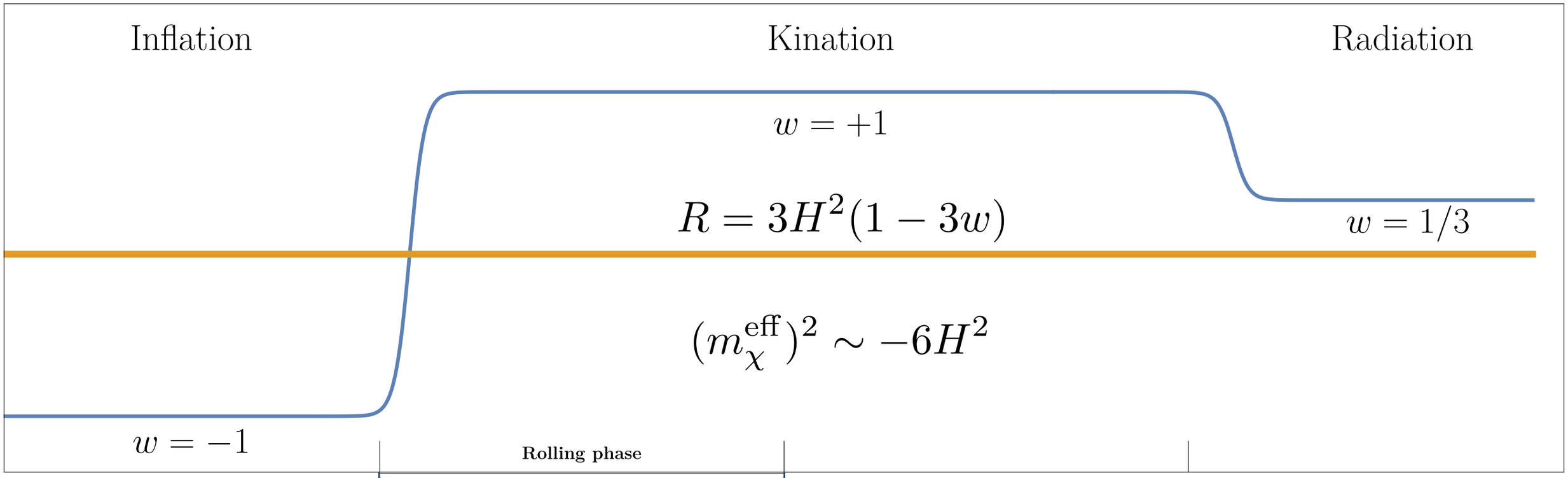


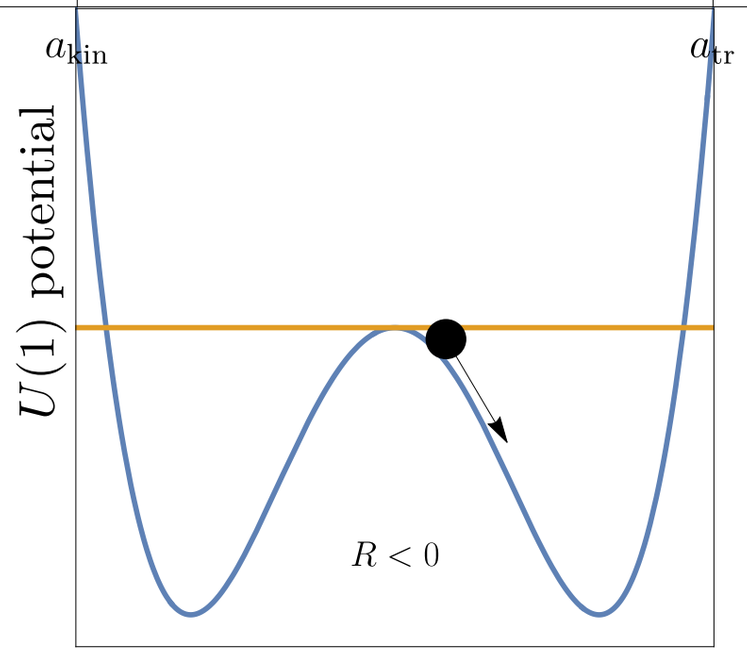


Inflation: Non-minimal coupling renders the field heavy

- U(1) symmetry is effectively preserved
- isocurvature perturbation are suppressed

Spectator field dynamics

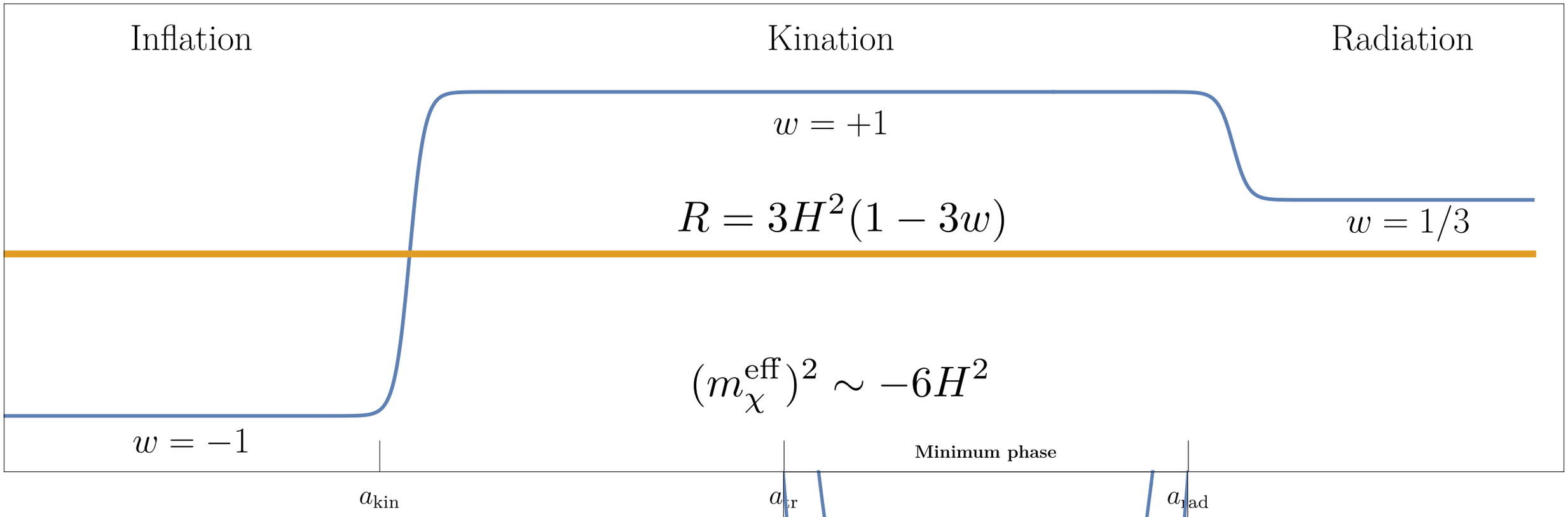




Rolling phase: The field starts to roll towards the new minimum at large values

Defects start to form!

Spectator field dynamics



Minimum phase: The field approaches the new time dependent minimum

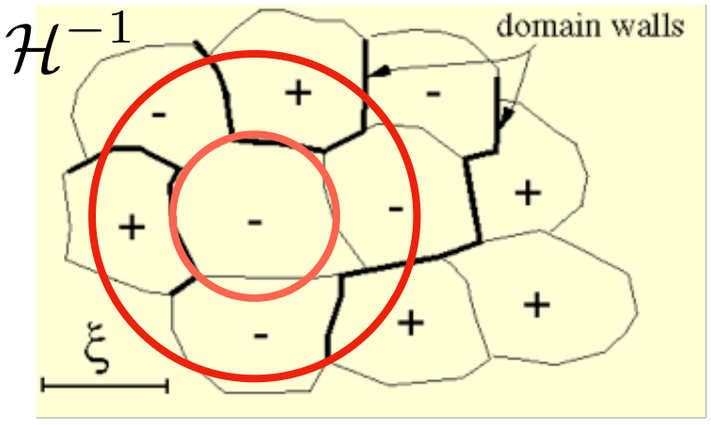
Trapping …

or Jumping?

Highly non-linear dynamics, simulations are needed!

Symmetry Breaking

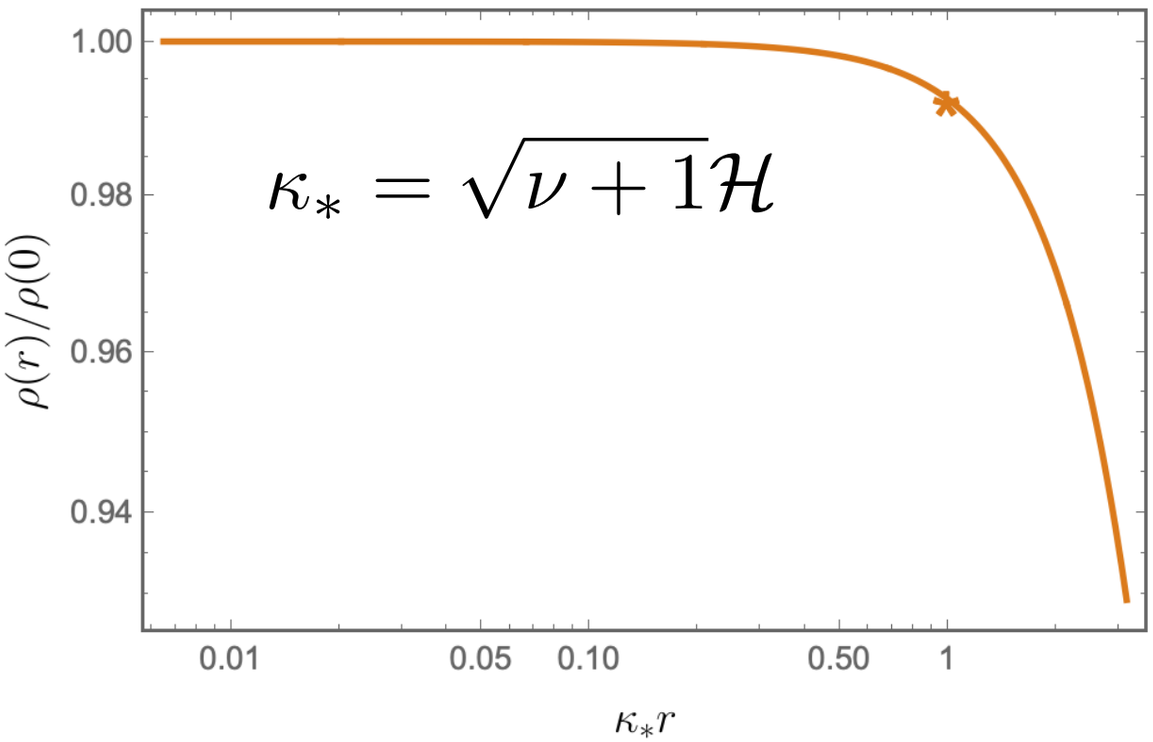
- $\chi(\vec{x})$ with $\langle\chi\rangle = 0$



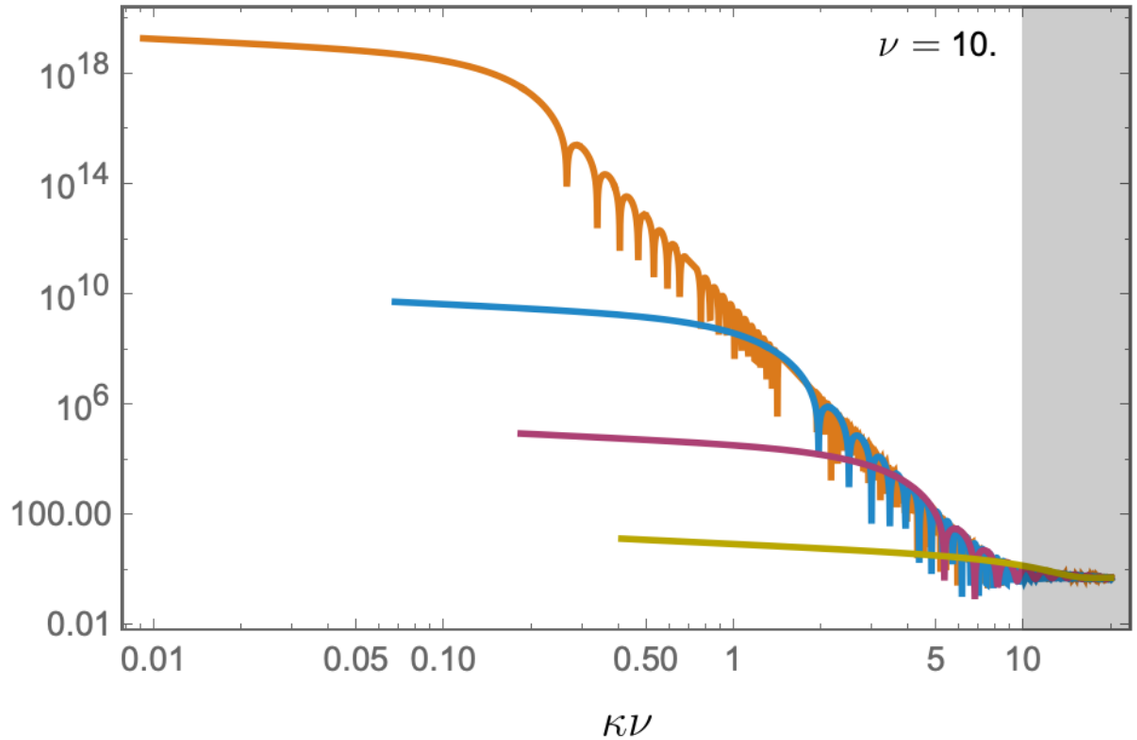
- Semi-classical process
- Spinodal/Tachyonic instability
- Classicalization (analytical)

$$\omega_\kappa^2(z) = \kappa^2 - \frac{\nu^2 - 1/4}{(z+\nu)^2}$$

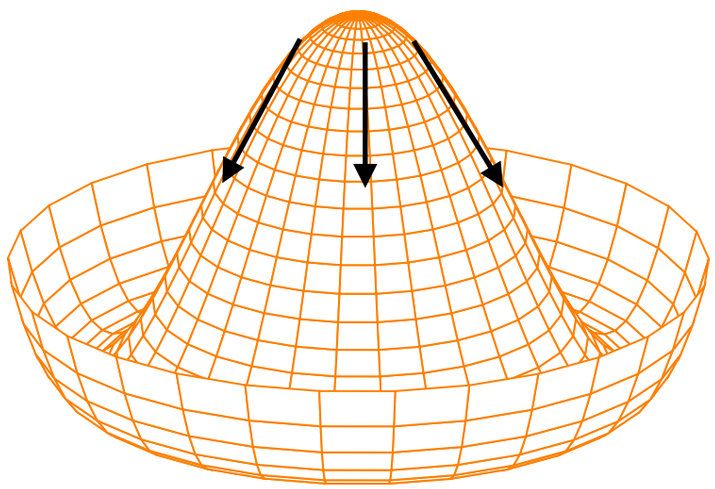
Following dynamics needs numerical simulations. However, ***statistical*** properties

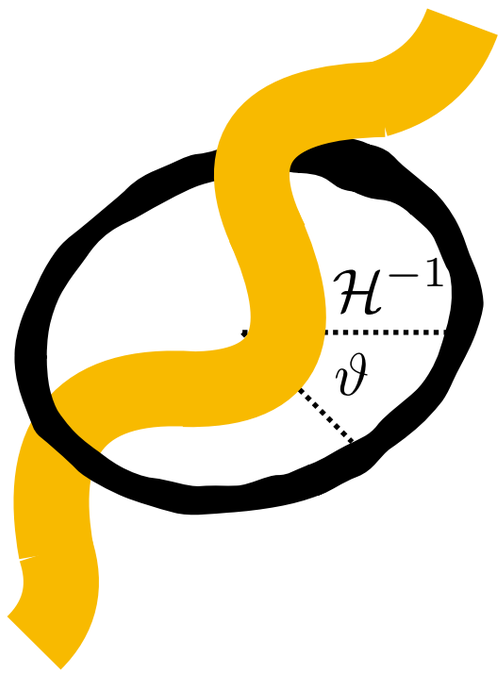


Treat field as classical Gaussian random field with quantum initial conditions



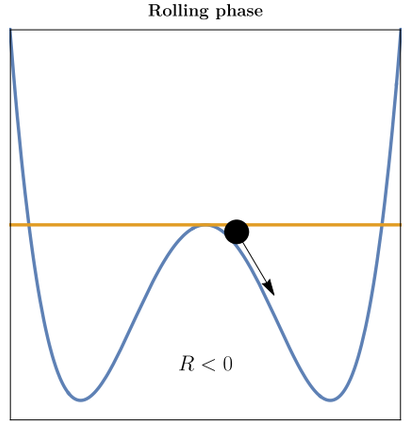
Cosmic string formation



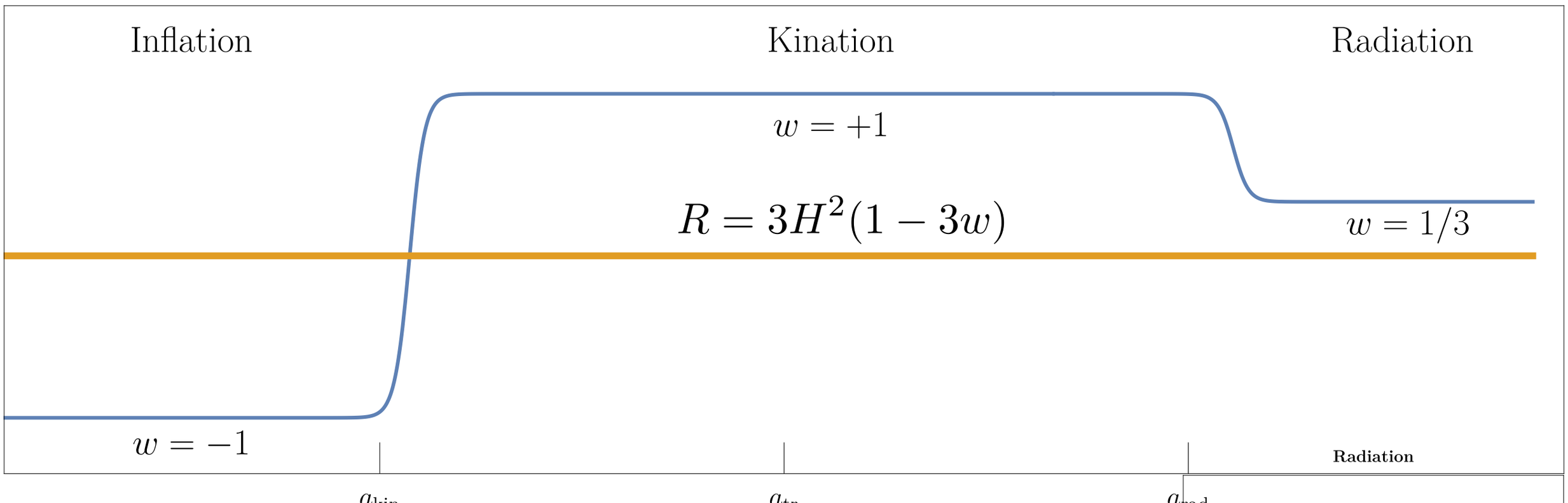


- Time dep. VEV
- *Short-lived*
- *fat* string
- Non scaling

$$\Omega_{\rm cs} \sim \frac{|\chi(t)|^2}{M_{\rm P}^2} \begin{cases} a^{\sqrt{6\xi}} \\ \\ a^{-\frac{6}{n-2}} \end{cases}$$

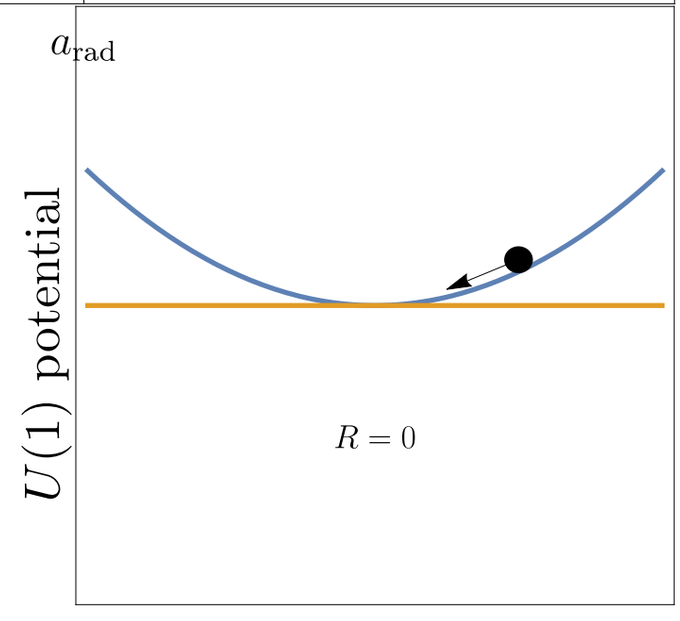


Spectator field dynamics



Symmetry restoration:

Exact	Effective
$R = 0$	$\omega_\kappa^2(z) = \kappa^2 - M^2(z) + 3\lambda Y_{\rm rms}^2(z)$



- The origin is again the minimum
- Field start to oscillate around the origin

} **Cosmic defects decay!**

GW spectrum

$$\Omega_{\rm GW}\left(\tau,k\right)=\int_{\tau_{\rm i}}^{\tau}d\log\tau'\,\frac{\Delta P_{\rm GW}(\tau',k)}{\Delta\log\tau'}\,\left(\frac{a(\tau')}{a(\tau)}\right)^{b}$$

- Instantaneous GW spectrum

$$\frac{\Delta P_{\rm GW}(t,k)}{\Delta N}\simeq\begin{cases}P_{\rm peak}(t)\left(\frac{k}{k_{\rm peak}(t)}\right)^{\alpha} & \text{for}\quad k\lesssim k_{\rm peak}\,,\\ P_{\rm peak}(t)\left(\frac{k}{k_{\rm peak}(t)}\right)^{-\bar{\alpha}} & \text{for}\quad k>k_{\rm peak}\,,\end{cases}$$

$$P_{\rm peak}(t)\sim\left(\frac{|\chi(t)|}{M_{\rm P}}\right)^{4}\qquad k_{\rm peak}(t)\sim aH$$

- Enhancement due to background

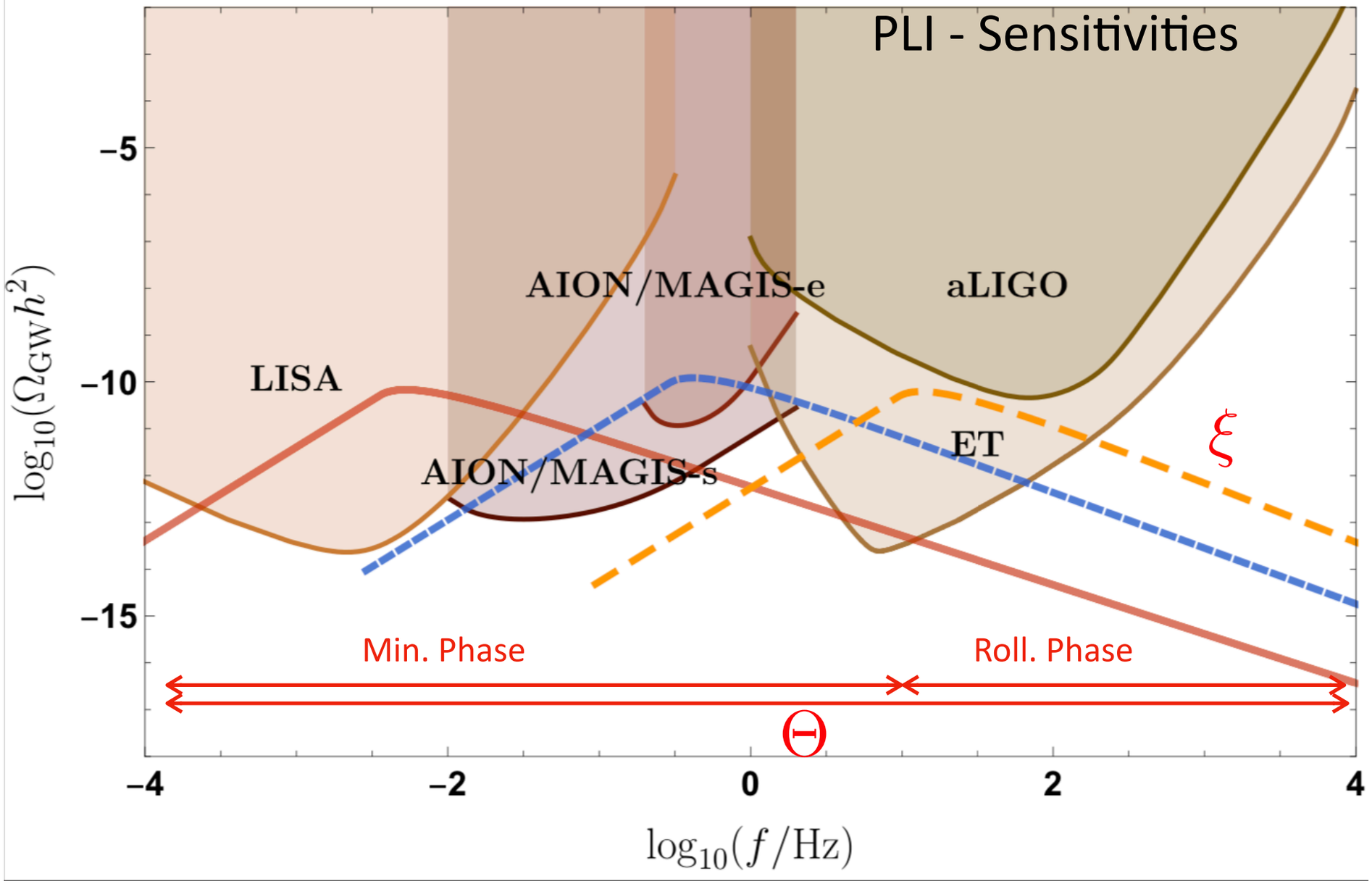
$$\rho_{\rm GW}\sim a^{-4}\qquad\rho_{\phi}\sim a^{-6}$$

GW spectrum

$$\Omega_{\rm GW}(\tau_0,k)h^2 = \Omega_{\rm R}h^2 \left(\frac{|\chi(\tau_{\rm kin}|}{M_{\rm P}}\right)^4 \Theta^{-1} F(k)$$

$$f_0^{\rm kin} \sim 3\times 10^{11}{\rm Hz}\left(\frac{H_{\rm kin}}{10^{11}{\rm GeV}}\right)^{1/2}\left(\frac{\Theta}{10^{-14}}\right)^{-1/4}$$

$$f_0^{\rm osc} \sim 3\times 10^{-3}{\rm Hz}\left(\frac{H_{\rm kin}}{10^{11}{\rm GeV}}\right)^{1/2}\left(\frac{\Theta}{10^{-14}}\right)^{3/4}\left(\frac{a_{\rm rad}}{a_{\rm osc}}\right)^2$$



Conclusions

NMC + Kinetic dominated epoch

Formation of topological defects and associated GW background

- Potentially detectable with forthcoming experiments
- Slopes related to the NMC and HO operators

- Peak position related to transition between *rolling* and *minimum* phases and Θ
- Amplitude of the peak related to $H_{\rm kin}$ and Θ

Conclusions

The process requires a quantum and local description

In order to draw phenomenological conclusions and parameter estimation need to take into account

- Backreaction
- Gradients
- Defects dynamics
- GW production

Numerical simulations needed to quantify are running…

… stay tuned!