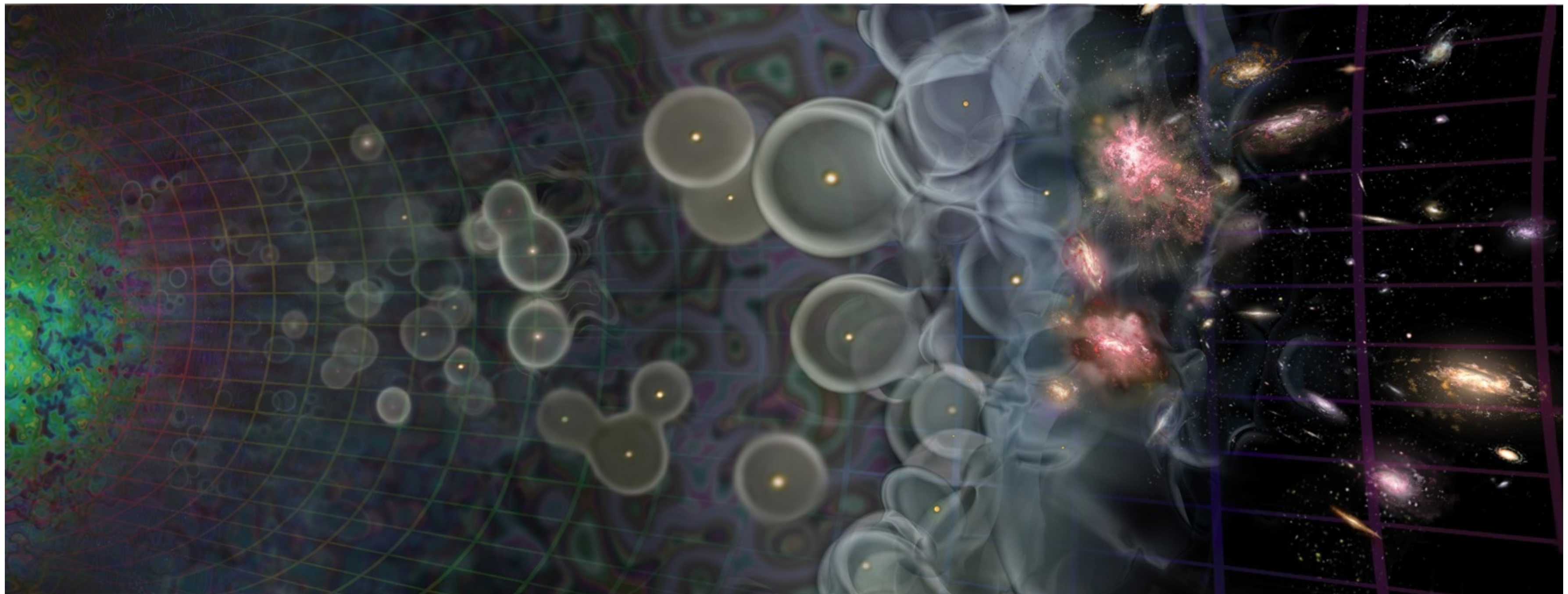

Inflacion

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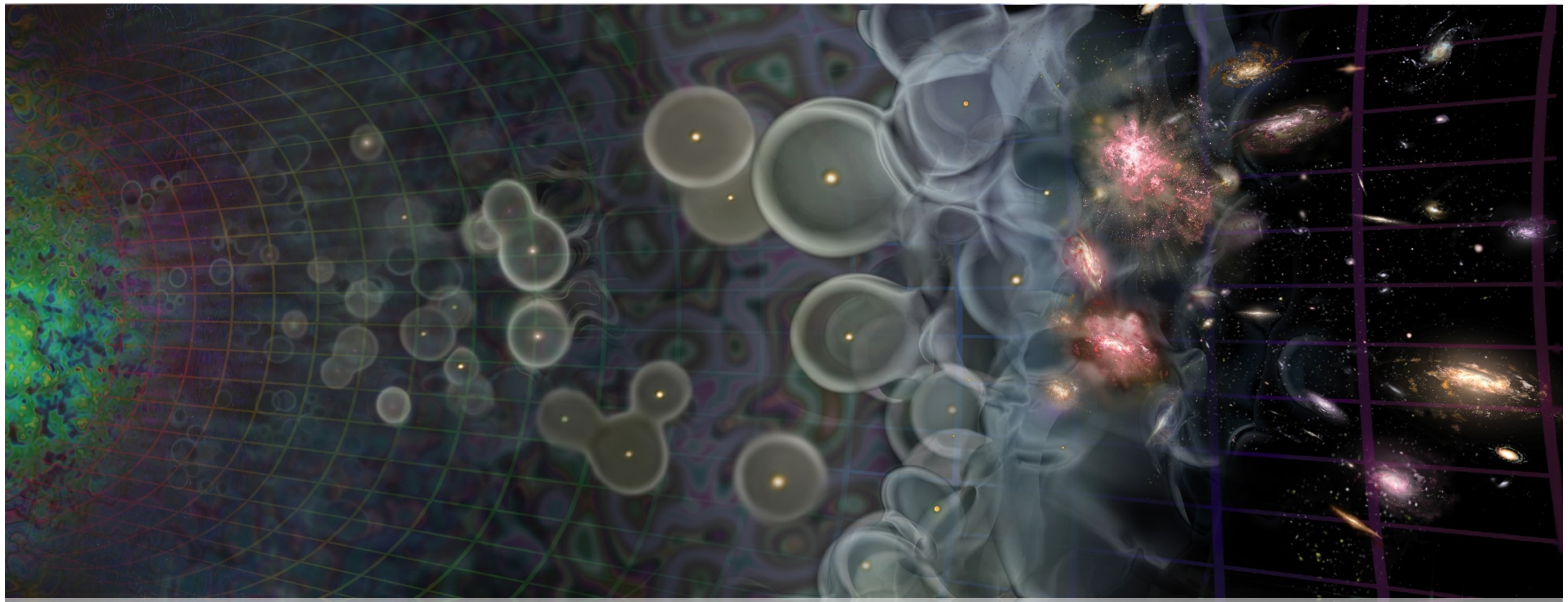
Jueves 27 Agosto

Summary

- Observational problems with the standard model
    - Homogeneity
    - Flatness
    - Non-causal perturbations
    - Topological Defects: Cosmic strings
- The solution: Inflation
    - Scalar field equations
    - The slow-roll model
    - Perturbations

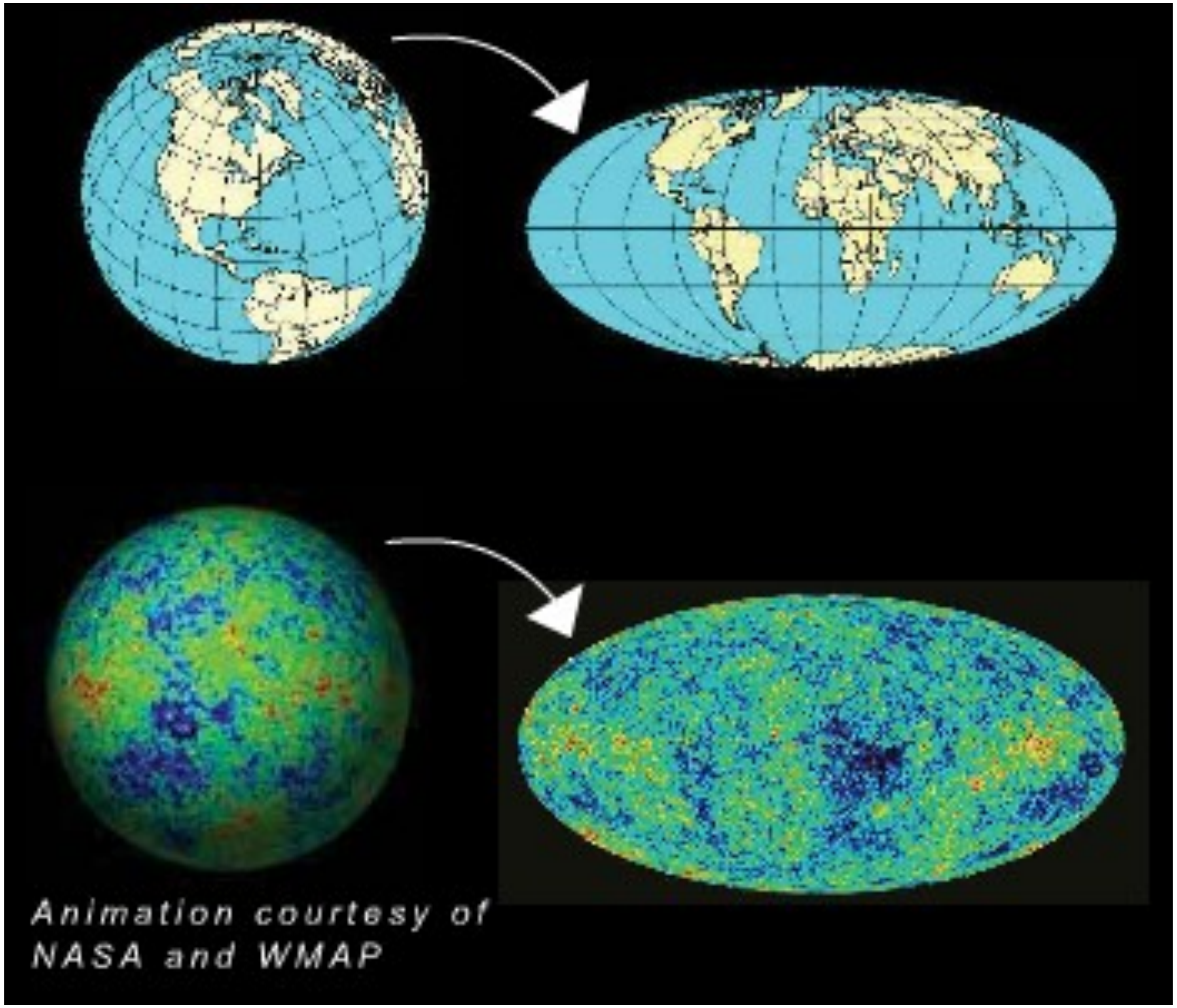


Shortcomings

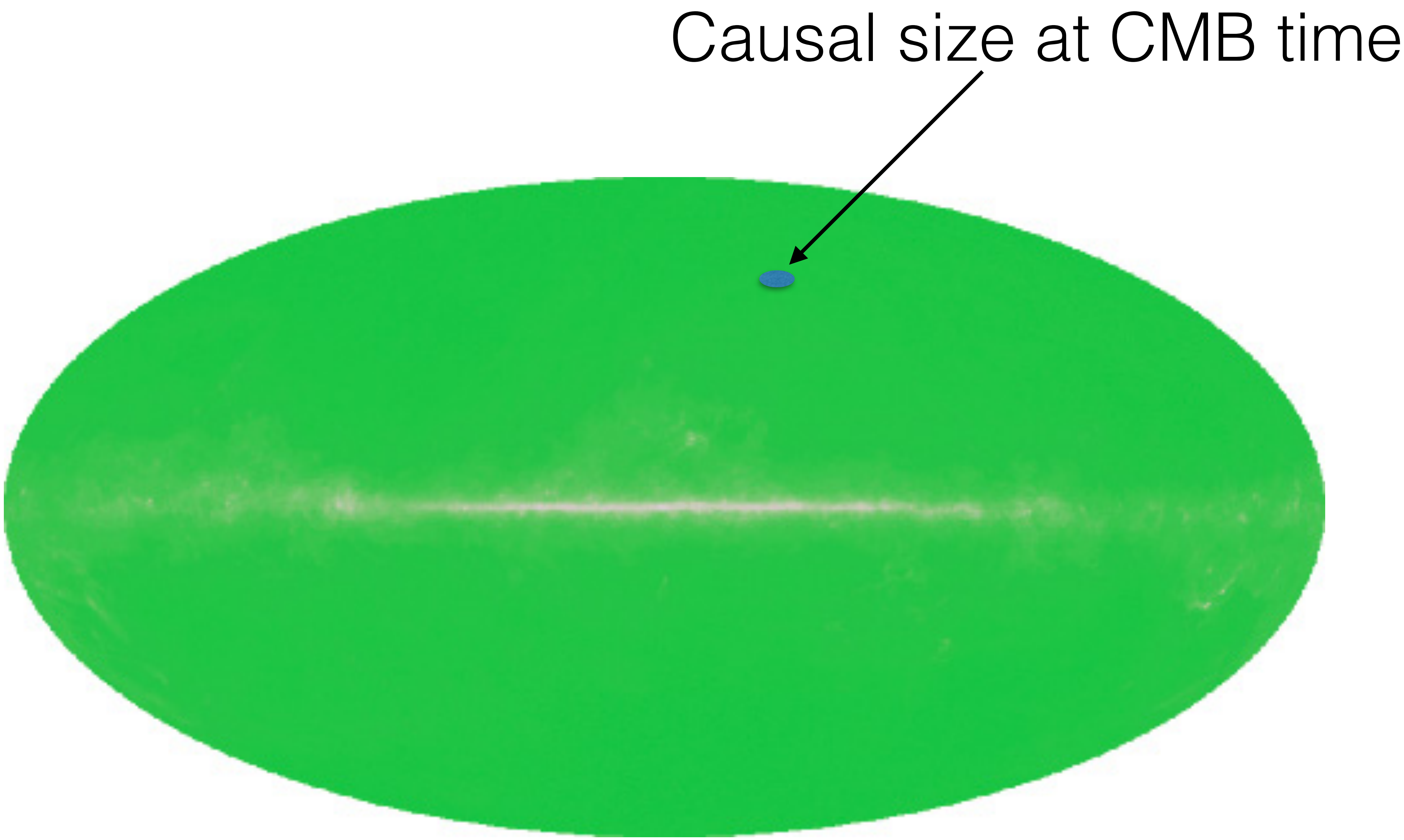
Shortcomings with the model

- Why the observable universe is so homogeneous?
- Why the observable universe is so flat?
- Why are non-causal perturbations in the CMB TT power-spectrum? (predicted before obs)
- Why are not more topological defects? (the first one)

Projection

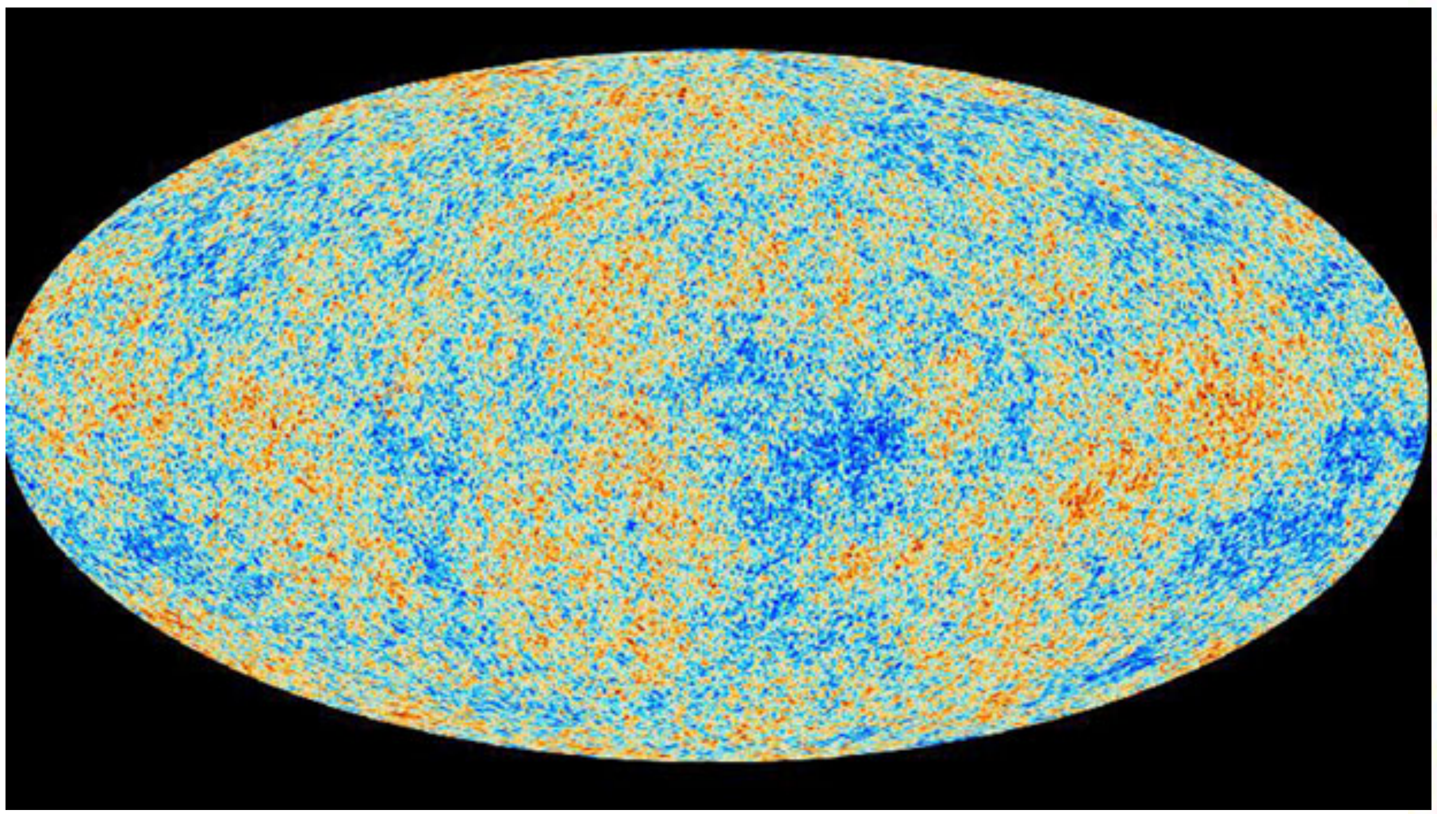


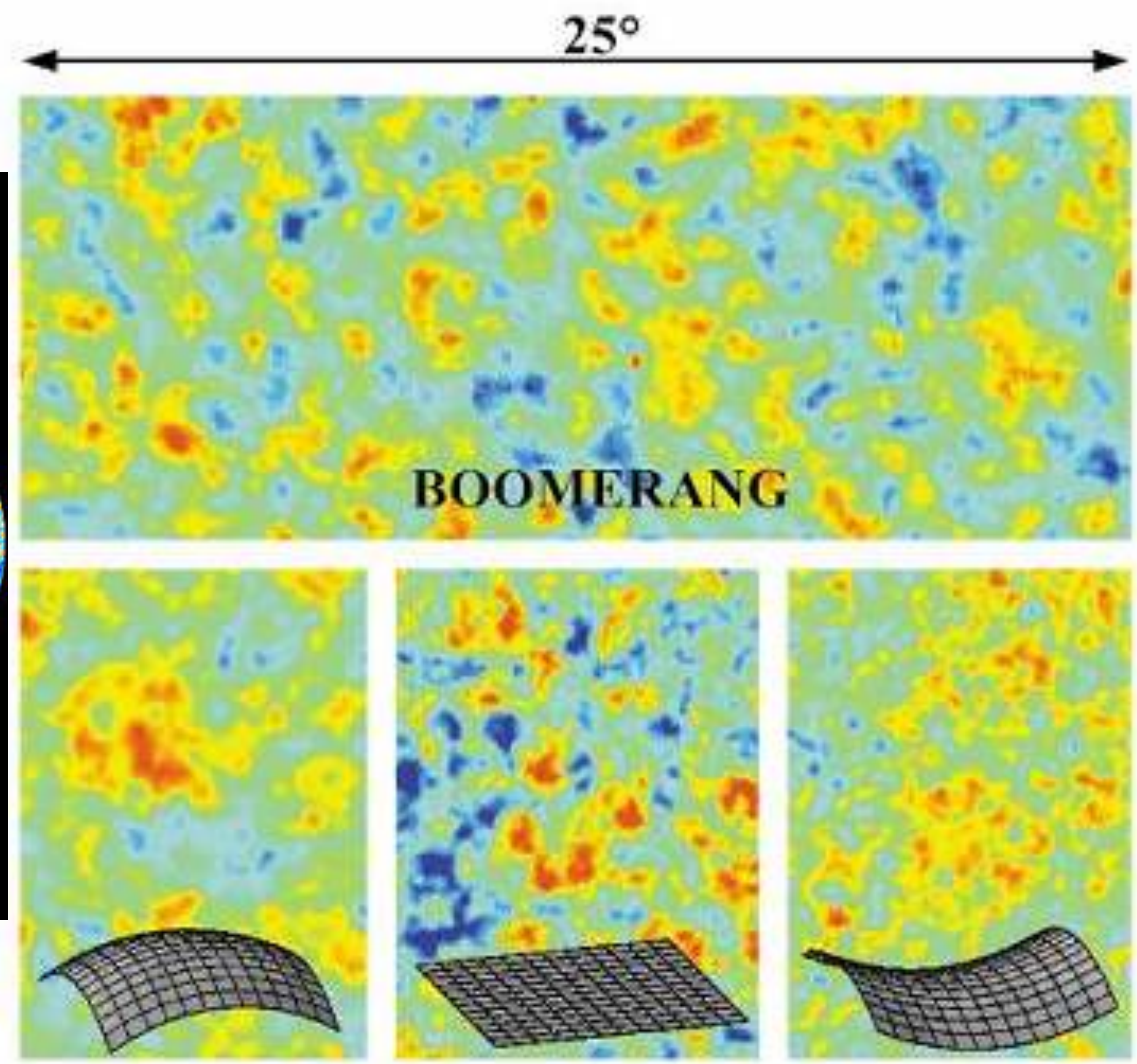
Homogeneous Universe



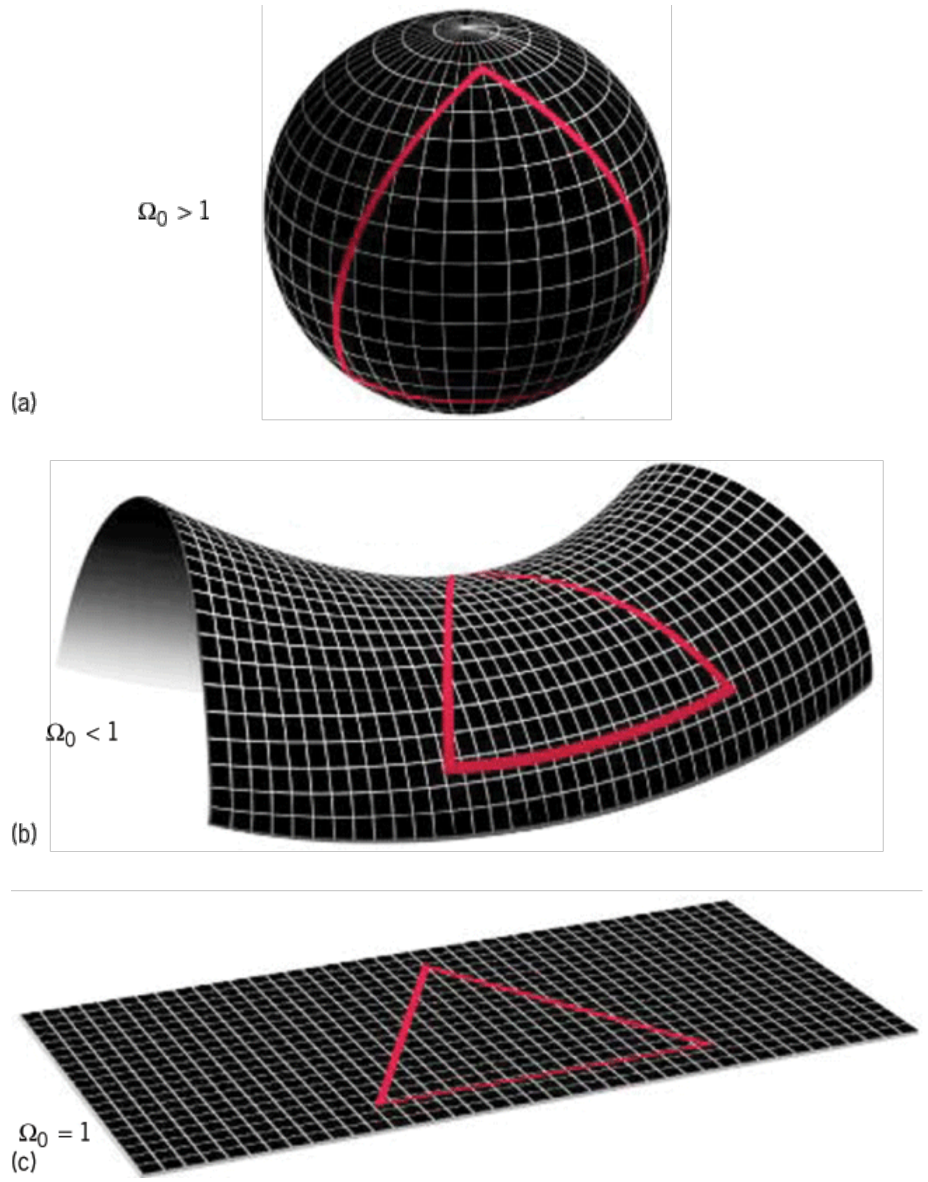
So, there is no physical process to thermalize the entire observable universe

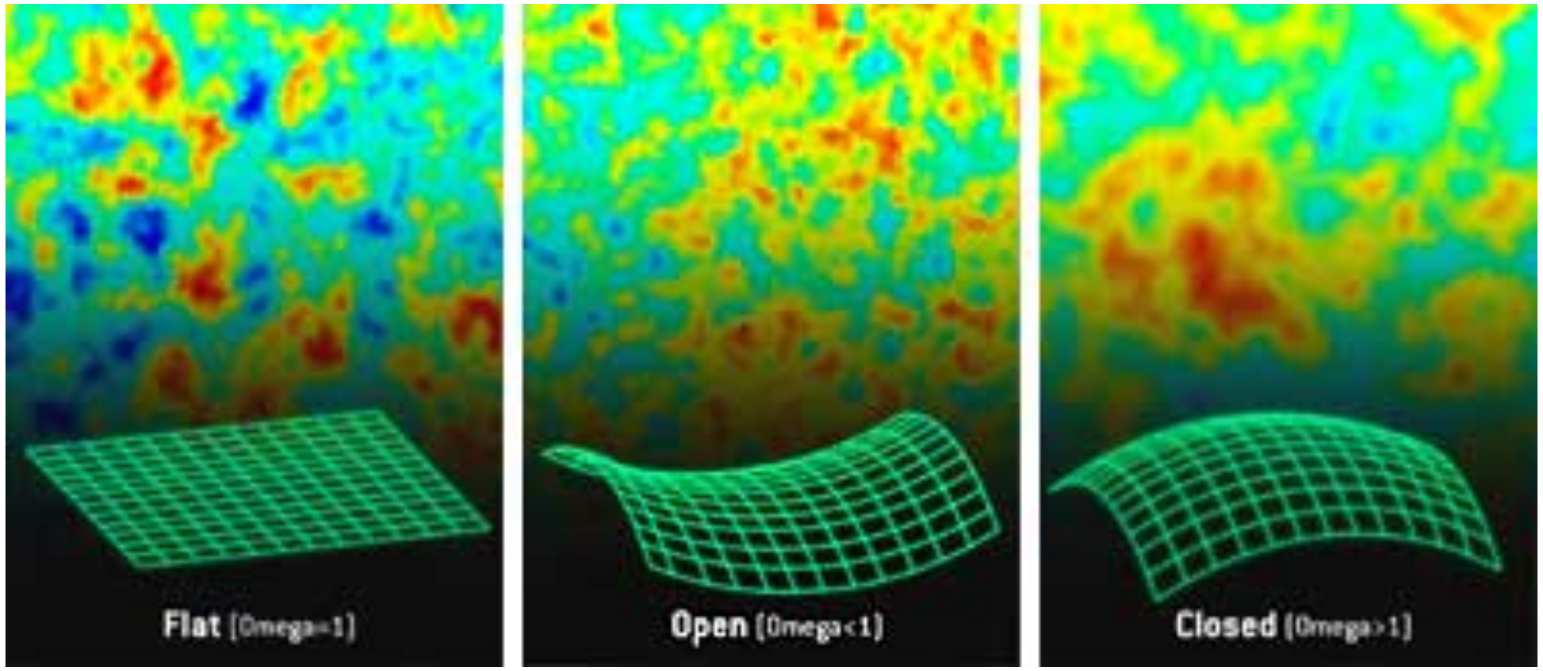
Flat Universe and CMB





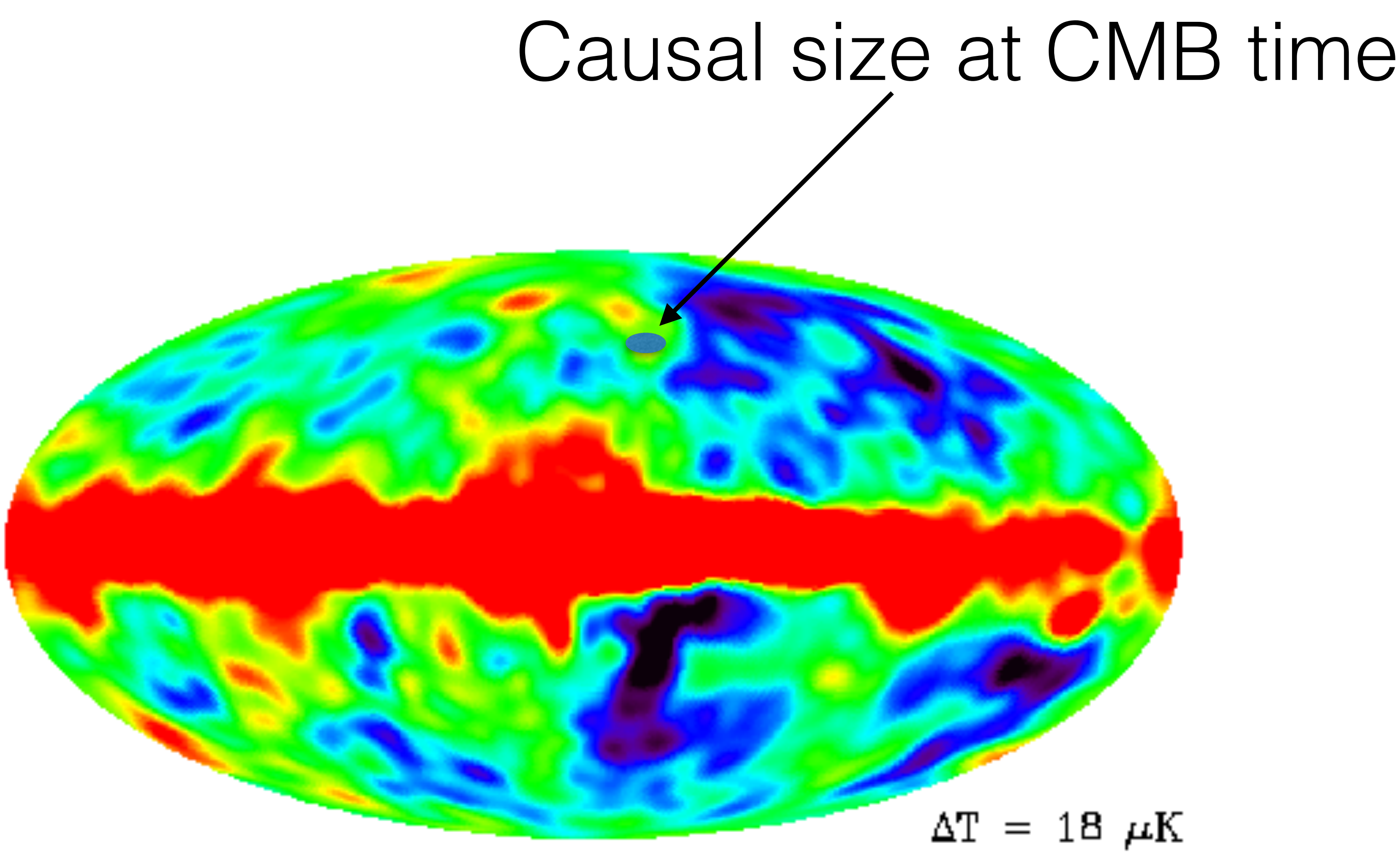
Flat Universe and CMB





$$|\Omega_k(hoy)| \lesssim 3.10^{-5} \quad \Rightarrow \quad |\Omega_k(planck)| \lesssim \mathcal{O}\left(10^{-61}\right)$$

Non-causal perturbations



Topological defects

Going back in time, the Universe was smaller and so the density-energy was greater and so the temperature too

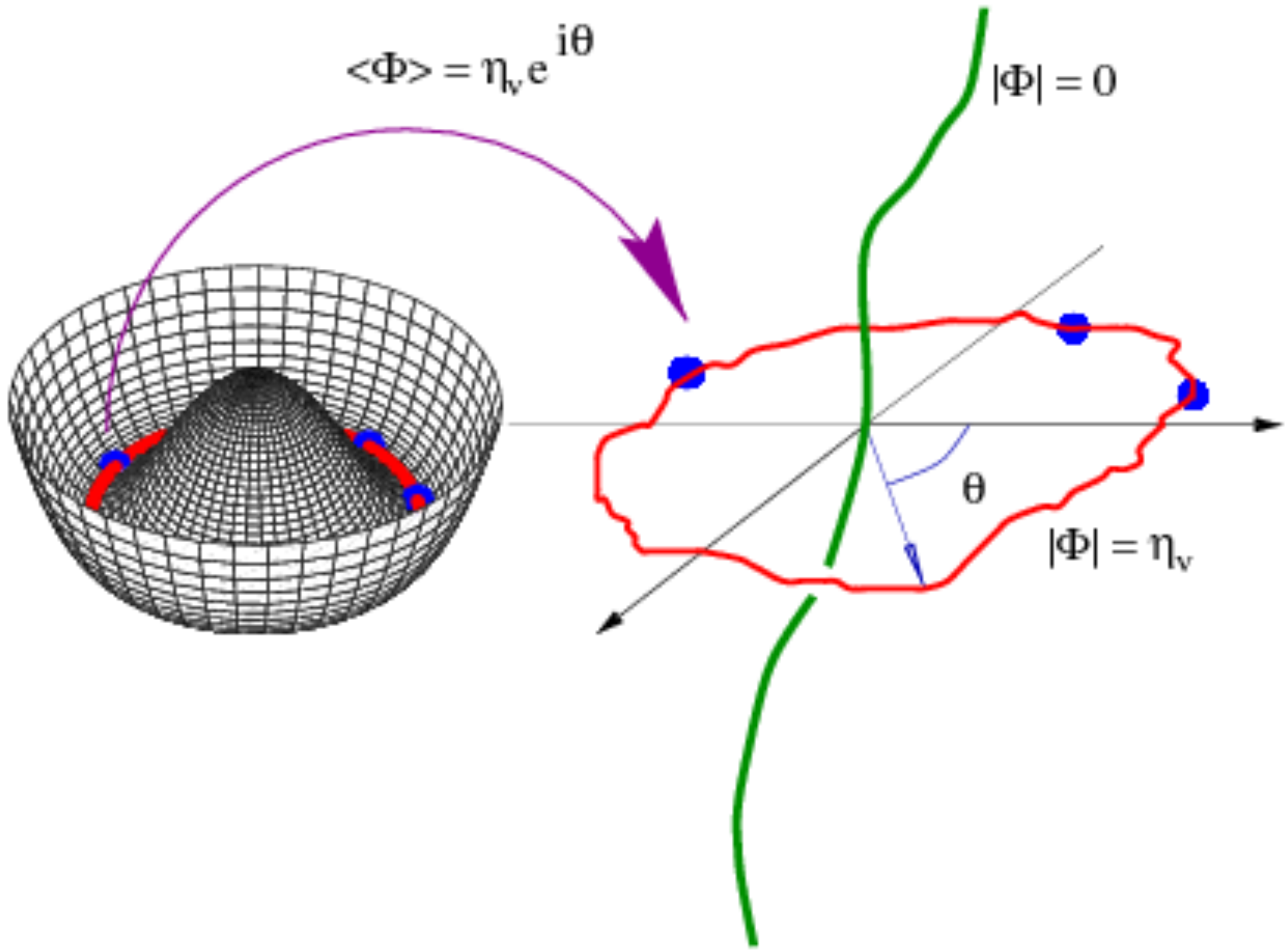
Entonces existe un tiempo en donde la temperatura fue mas grande que

$$T_{GUT} \sim 10^6 GeV$$

Moviendo el tiempo en sentido contrario, entonces existe un tiempo donde la temperatura se vuelve inferior de T_{GUT}

Topological defects

Spontaneous symmetry breaking

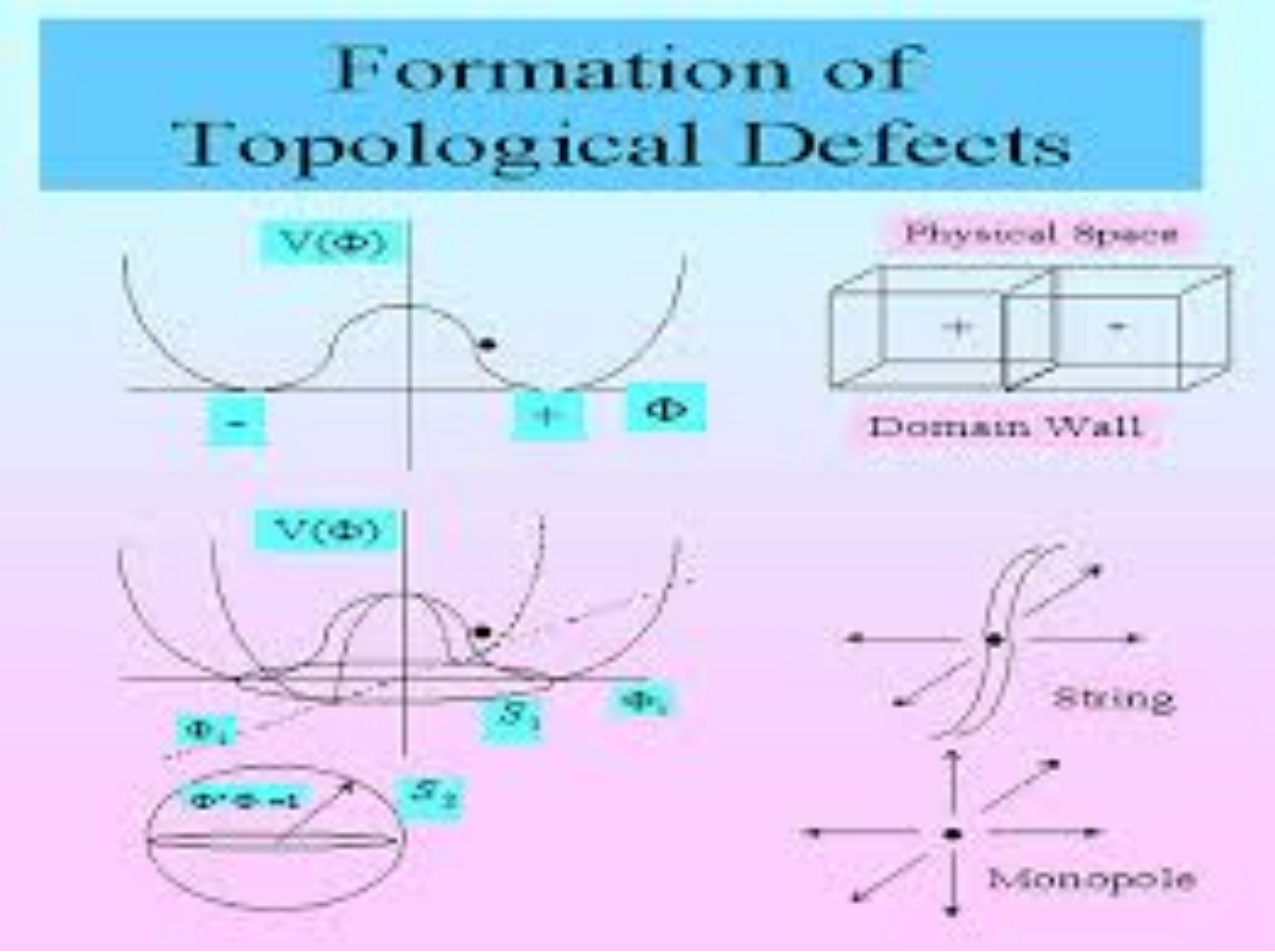


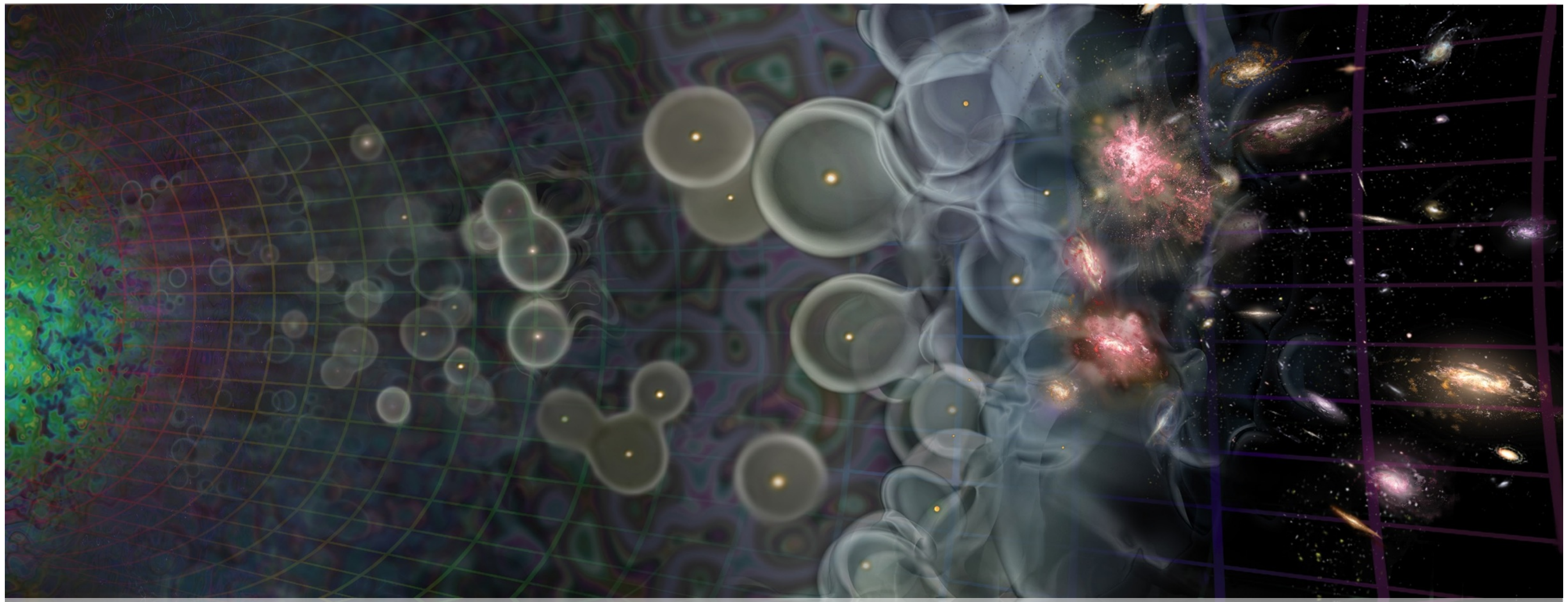
El valor de la energía fundamental de los campos se fijos a este tiempo de manera aleatoria.

Este valor es el mismo en toda las regiones causalmente vinculadas

Topological defects

Spontaneous symmetry breaking





Inflation

Scalar Field equations in FRW

Scalar field

Relatividad General

Accion :

$$S_{RG}[g] = \frac{c^4}{16\pi G}\int d^4x \boxed{R}\sqrt{-|g_{\mu\nu}|}$$

escalar de Ricci

Campo escalar acoplado a la metrica

Acoplado con la metrica

Auto-acoplado

Accion :

$$S_\phi[g] = \int d^4x\sqrt{-|g_{\mu\nu}|}\left(\frac{1}{2}\boxed{R} + \frac{1}{2}\boxed{g^{\mu\nu}\partial_\mu\phi\partial_\nu\phi} + \boxed{V(\phi)}\right)$$

Scalar field

$$S_\phi[g] = \int d^4x \sqrt{-|g_{\mu\nu}|} \left(\frac{1}{2}R + \frac{1}{2} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi + V(\phi) \right)$$

$$\boxed{T_{\mu\nu}}(\phi) \equiv \frac{1}{\sqrt{|g_{\mu\nu}|}} \frac{\delta S_\phi}{\delta g^{\mu\nu}} = \partial_\mu \phi \partial_\nu \phi - \boxed{g^{\mu\nu}} \left(\frac{1}{2} \partial^\alpha \phi \partial_\alpha \phi + V(\phi) \right)$$

$$\boxed{T_{\mu\nu}} = \begin{pmatrix} -\rho & 0 & 0 & 0 \\ 0 & p & 0 & 0 \\ 0 & 0 & p & 0 \\ 0 & 0 & 0 & p \end{pmatrix}$$

$$\boxed{g_{\mu\nu}} = \begin{pmatrix} -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Scalar field

$$\boxed{T_{\mu\nu}}(\phi) \equiv \frac{1}{\sqrt{|g_{\mu\nu}|}} \frac{\delta S_\phi}{\delta g^{\mu\nu}} = \partial_\mu \phi \partial_\nu \phi - \boxed{g^{\mu\nu}} \left(\frac{1}{2} \partial^\alpha \phi \partial_\alpha \phi + V(\phi) \right)$$

$$\boxed{T_{\mu\nu}} = \begin{pmatrix} -\rho & 0 & 0 & 0 \\ 0 & p & 0 & 0 \\ 0 & 0 & p & 0 \\ 0 & 0 & 0 & p \end{pmatrix} \qquad \boxed{g_{\mu\nu}} = \begin{pmatrix} -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Universo homogeno y isotropo: $\phi(\vec{x}, t) = \phi(t)$

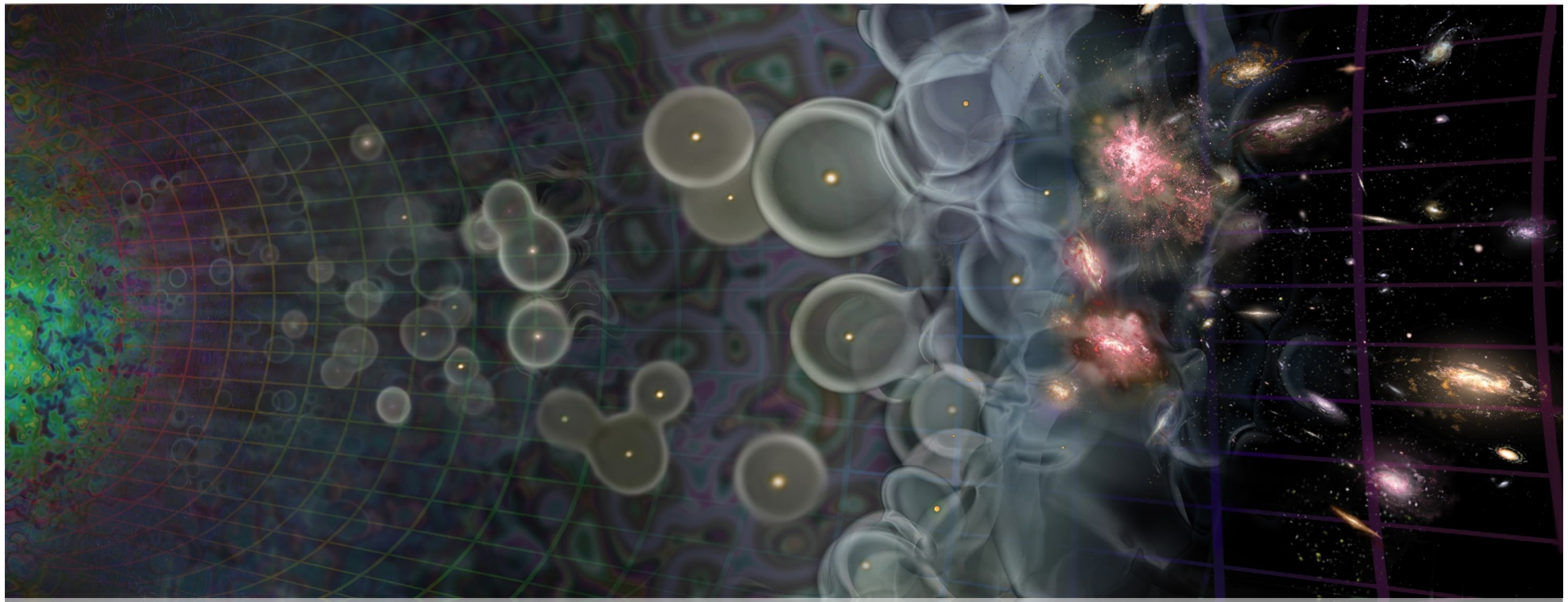
$$\{\partial_x \phi(t) = \partial_y \phi(t) = \partial_z \phi(t) = 0\} \Rightarrow \boxed{\partial_i \phi = 0}$$

$$\partial_t \phi = \frac{\partial \phi}{\partial t} = \boxed{\partial_0 \phi = \dot{\phi}}$$

Scalar field

$$T_{\mu\nu}(\phi) \equiv \frac{1}{\sqrt{|g_{\mu\nu}|}} \frac{\delta S_\phi}{\delta g^{\mu\nu}} = \partial_\mu \phi \partial_\nu \phi - g^{\mu\nu} \left(\frac{1}{2} \partial^\alpha \phi \partial_\alpha \phi + V(\phi) \right)$$

$$\boxed{\begin{array}{lcl} \underline{T_{00} = -\rho} & \rightarrow & \rho_\phi = \frac{1}{2}\dot{\phi}^2 + V(\phi) \\ \underline{T_{ii} = p} & \rightarrow & p_\phi = \frac{1}{2}\dot{\phi}^2 - V(\phi) \end{array}}$$



Inflation

Slow Roll Model

Scalar field

$$\rho_\phi = \frac{1}{2}\dot{\phi}^2 + V(\phi)$$

$$p_\phi = \frac{1}{2}\dot{\phi}^2 - V(\phi)$$

$$\omega_\phi = \frac{p_\phi}{\rho_\phi} = \frac{\frac{1}{2}\dot{\phi}^2 - V(\phi)}{\frac{1}{2}\dot{\phi}^2 + V(\phi)}$$

Slow Roll :

$$V(\phi) >> \dot{\phi}^2 \;\Rightarrow\; \omega_\phi \sim \frac{-V(\phi)}{V(\phi)} = -1$$

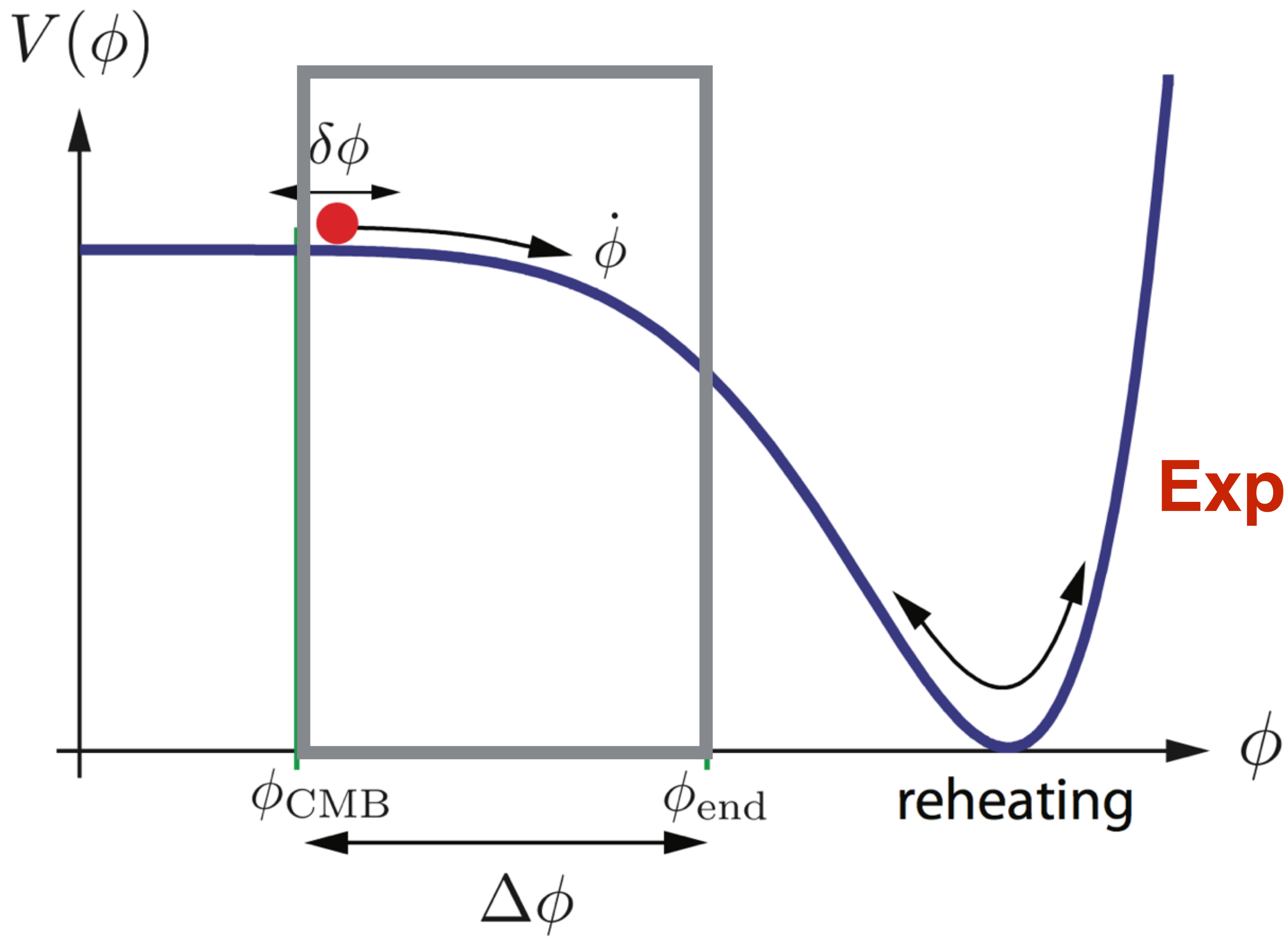
Reheating

$$\dot{\phi}^2 >> V(\phi) \;\Rightarrow\; \omega_\phi \sim \frac{\frac{1}{2}\dot{\phi}^2}{\frac{1}{2}\dot{\phi}^2} = 1$$

Slow Roll model

Slow Roll :

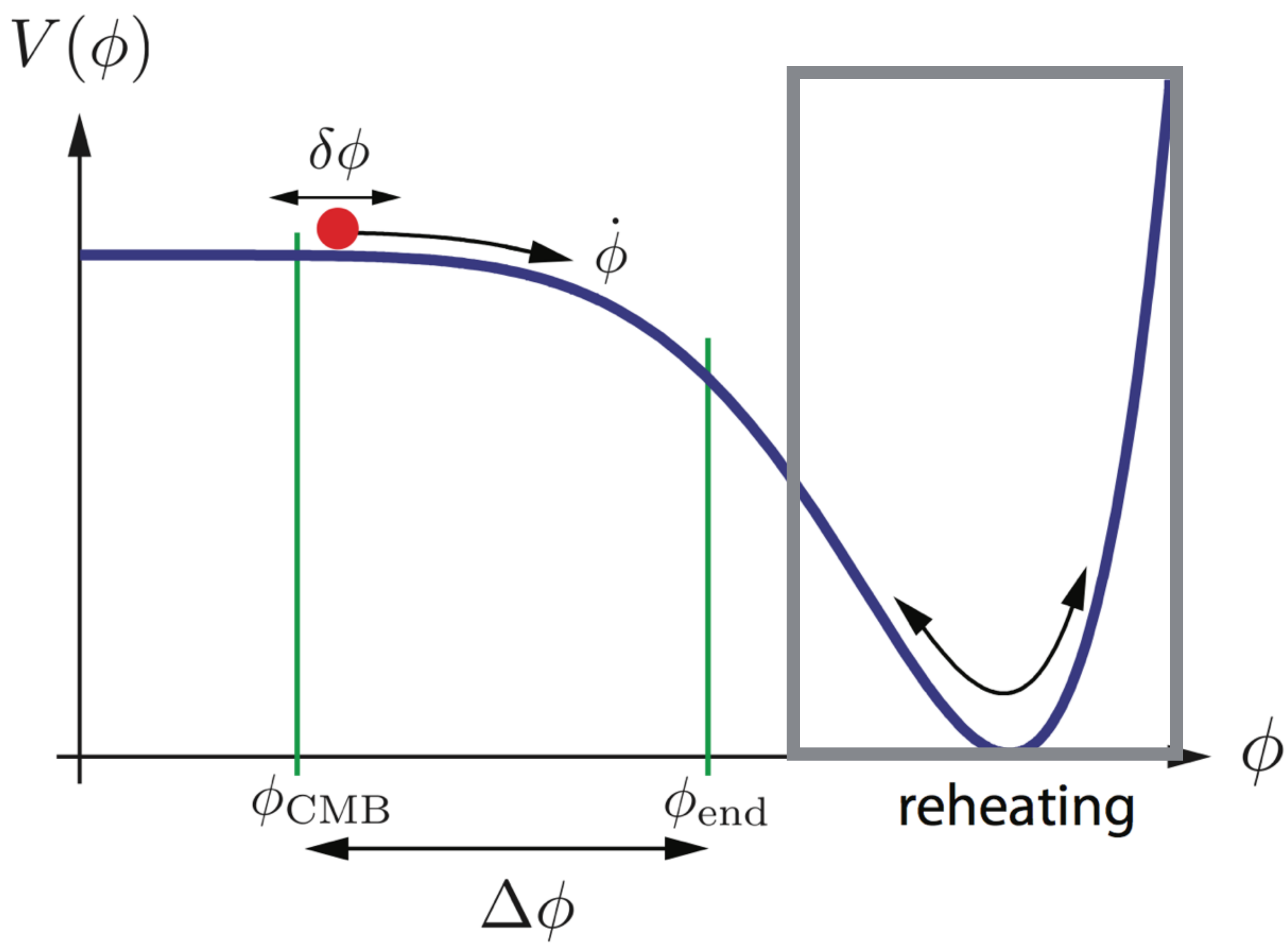
$$\omega_\phi = -1 \quad \Longleftrightarrow \quad \rho_\phi(a) = Cte \quad \Rightarrow \quad \boxed{a(t) \propto \exp\sqrt{\frac{8\pi G \rho_\phi}{3}}t}$$



Universe Expanding exponentially

Slow Roll model

Reheating : $\dot{\phi}^2 >> V(\phi) \Rightarrow \omega_\phi \sim \dfrac{\frac{1}{2}\dot{\phi}^2}{\frac{1}{2}\dot{\phi}^2} = 1$

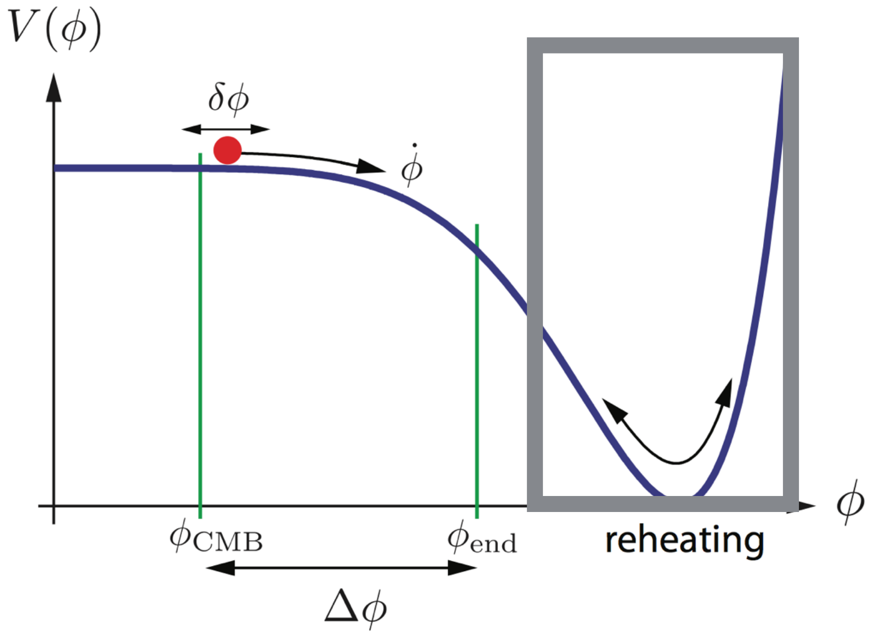


$a(t) \propto t^{\frac{2}{3(1+\omega)}}$

$$\boxed{a(t) \propto t^{\frac{1}{3}}}$$

Universe Expanding slow

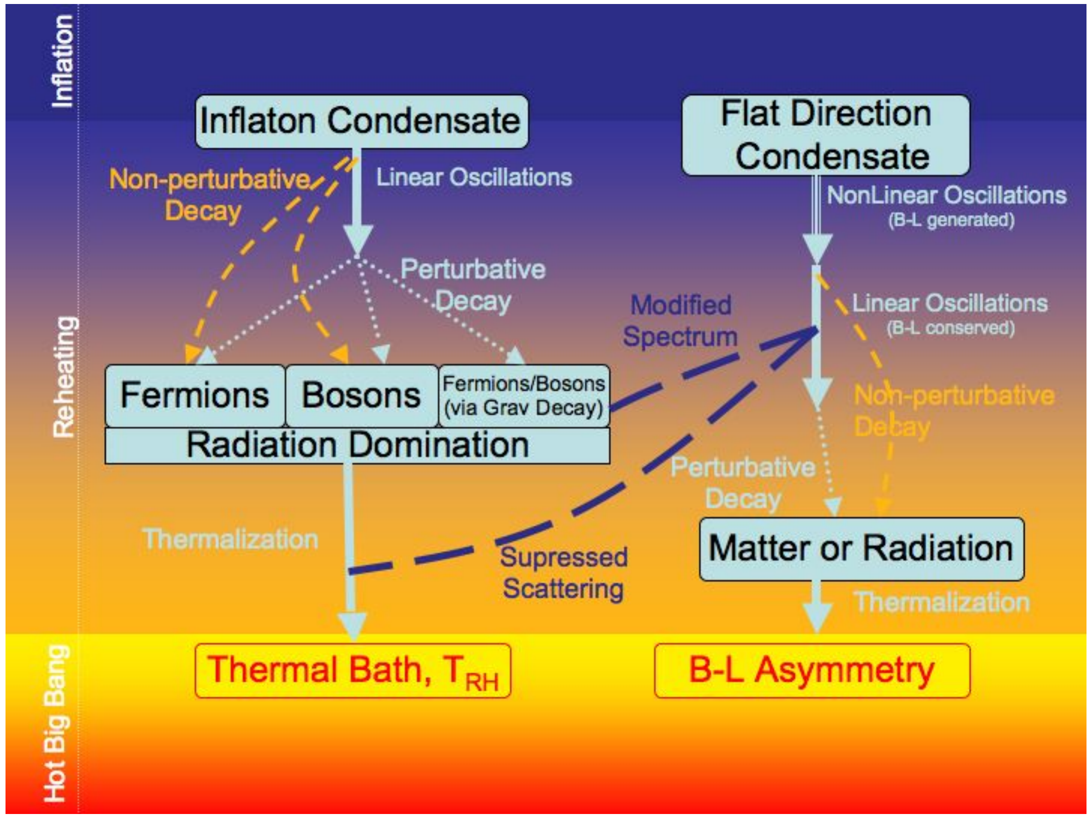
Reheating

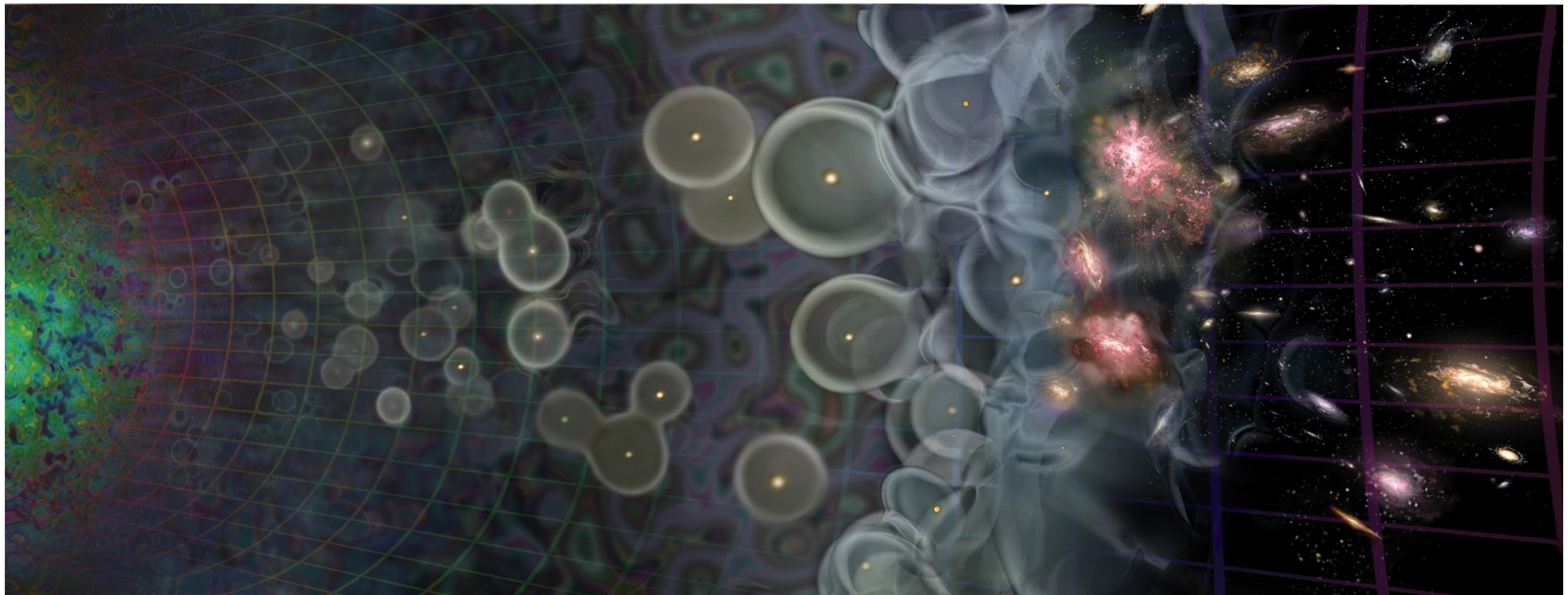


El campo de inflaton va a desintegrarse en las particulas del modelo estándar (y otros)

La temperatura baja mucho
Pero la desintegración
del campo de inflaton va recalentar
("reheating") el Universo

$$T_{GUT} \sim 10^6 GeV$$



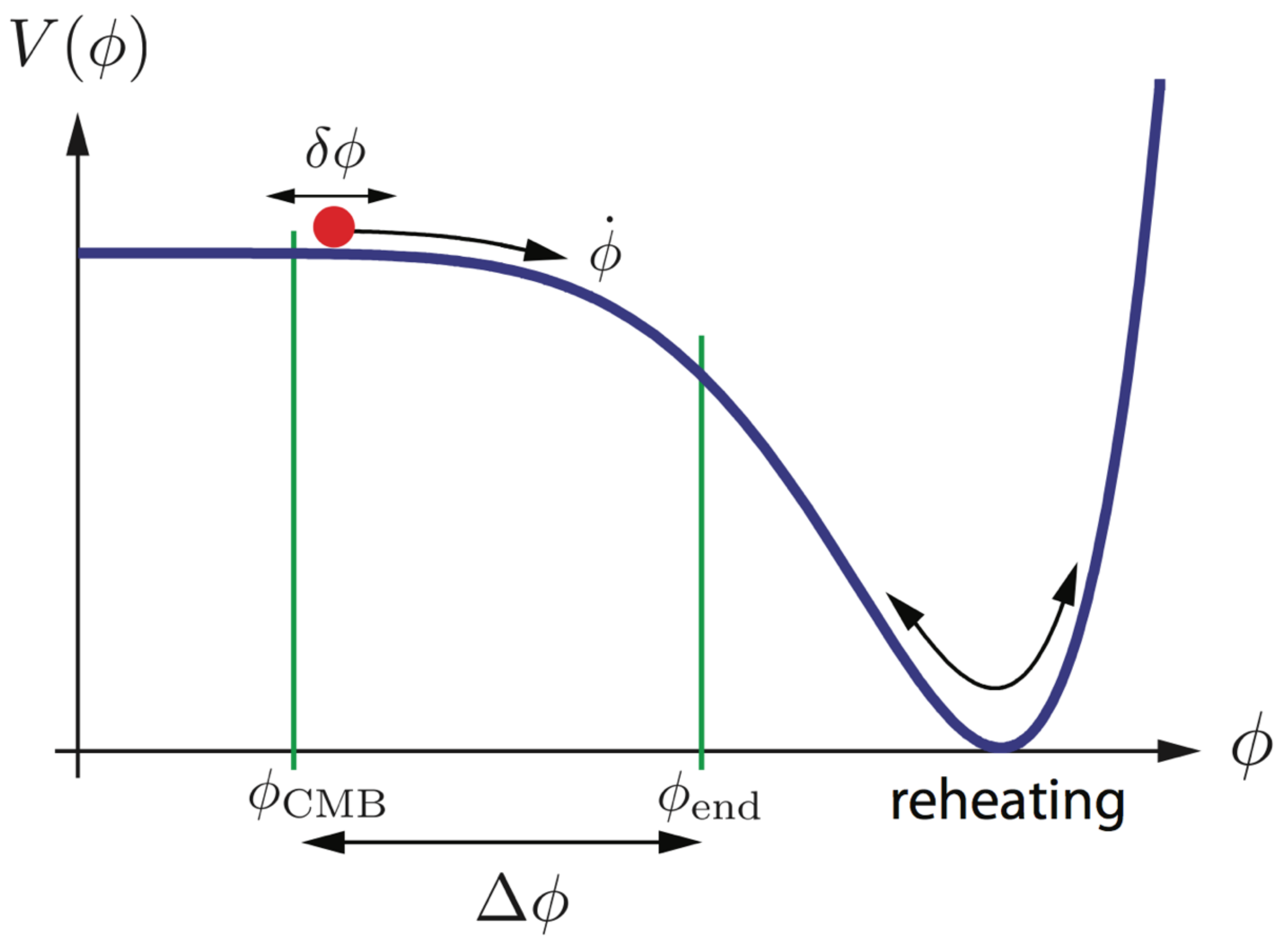


Inflation

Perturbations

Slow Roll model

Slow Roll : $$V(\phi) >> \dot{\phi}^2 \Rightarrow \omega_\phi \sim \frac{-V(\phi)}{V(\phi)} = -1$$



Perturbations

ϕ	ϕ	ϕ
ϕ	ϕ	ϕ
ϕ	ϕ	ϕ

Perturbation cuantica

$\phi+\delta_1$	$\phi+\delta_2$	$\phi+\delta_3$
$\phi+\delta_4$	$\phi+\delta_5$	$\phi+\delta_6$
$\phi+\delta_7$	$\phi+\delta_8$	$\phi+\delta_9$

Expansion exponential del universo

$\phi+\delta_1$	$\phi+\delta_2$	$\phi+\delta_3$
$\phi+\delta_4$	$\phi+\delta_5$	$\phi+\delta_6$
$\phi+\delta_7$	$\phi+\delta_8$	$\phi+\delta_9$

Perturbations

$\phi+\delta_1$	$\phi+\delta_2$	$\phi+\delta_3$
$\phi+\delta_4$	$\phi+\delta_5$	$\phi+\delta_6$
$\phi+\delta_7$	$\phi+\delta_8$	$\phi+\delta_9$

<table>
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<tr><td>$\phi+\delta_1+\delta_{1,3}$</td><td>$\phi+\delta_1+\delta_{1,4}$</td><td>$\phi+\delta_2+\delta_{2,3}$</td><td>$\phi+\delta_2+\delta_{2,4}$</td></tr>
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<tr><td colspan="2">$\phi+\delta_7$</td><td colspan="2">$\phi+\delta_8$</td><td colspan="2">$\phi+\delta_9$</td></tr>
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Perturbations