

Warm inflection

Rafael Cerezo, João G. Rosa

Contents

- Inflation: basics
- Warm inflation
- Warm inflection

arXiv:1210.7975



ugr

Universidad
de **Granada**

IV CPAN Days
Granada, November 2012

Cosmological Puzzles

- **Horizon problem**

Why the Universe is homogeneous?

- **Flatness problem**

Why it is flat?

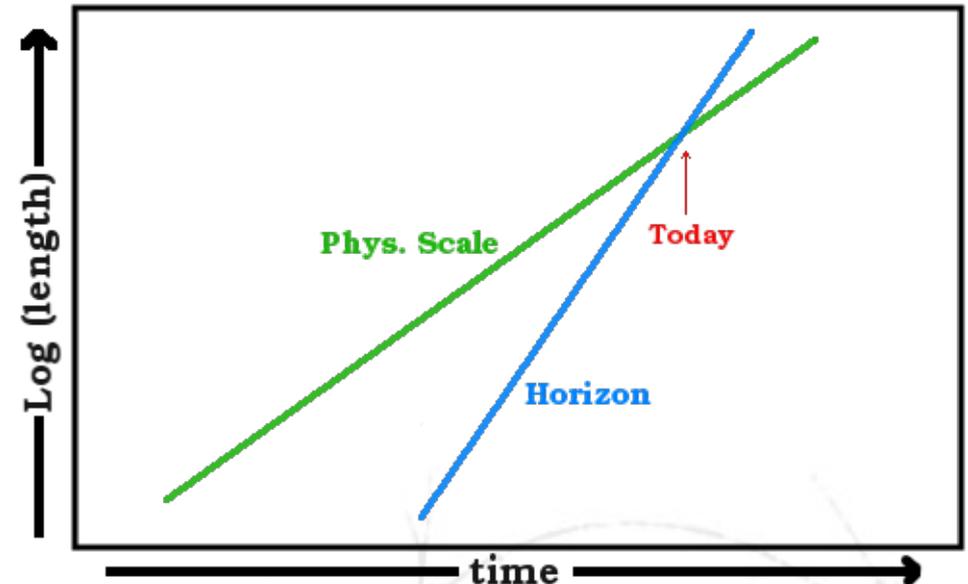
$$|\Omega(1s) - 1| < O(10^{-16})$$

- **Unwanted relics**

How to avoid them?

- **Primordial density perturbation**

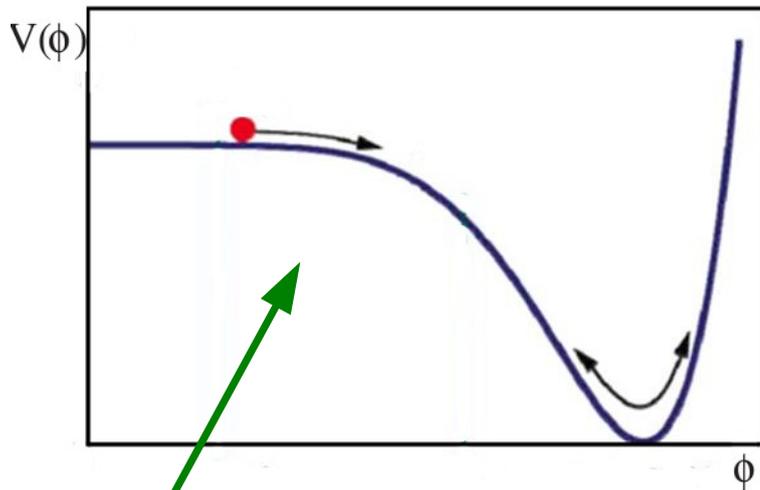
What's the origin of structure?



Inflation

$$\ddot{a} \sim -(\rho + 3p)$$

- Constant ✗
- Scalar field ✓



Inflation
interactions?

Reheating
interactions required!

$$V(\phi) \gg \dot{\phi}^2$$

$$\ddot{\phi} + \underbrace{3H\dot{\phi}}_{\text{friction}} + V_{\phi} = 0$$

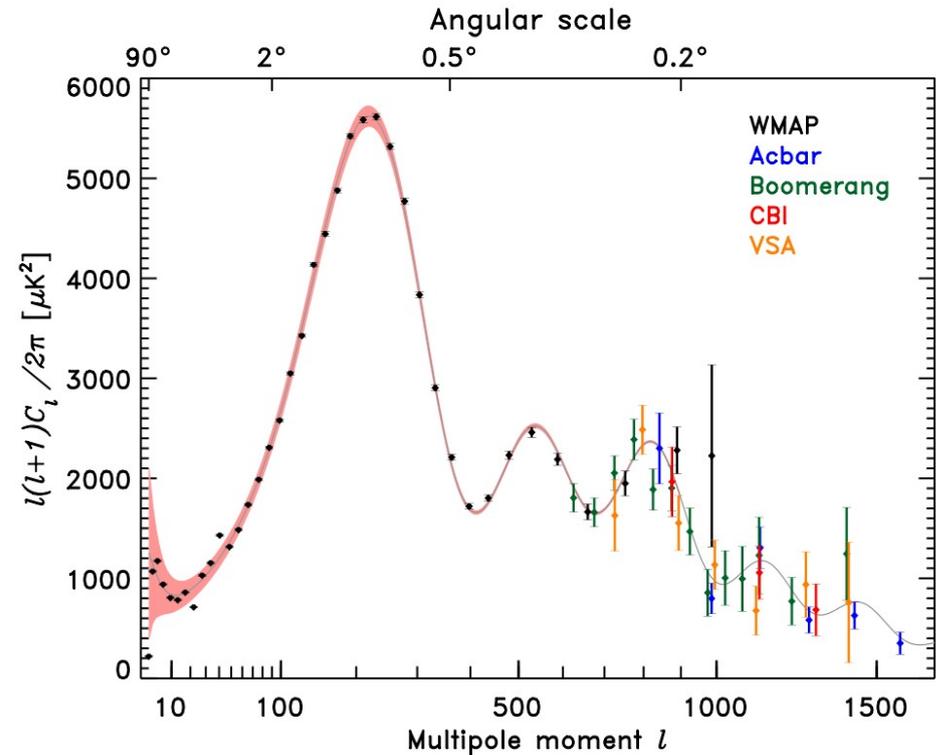
**Flat
potential**

Cosmic Microwave Background

$$P_k(t_*) = \Delta_s \left(\frac{k}{k_0} \right)^{n_s - 1}$$

- Adiabatic
 $|B_B < 0.34|$
- Scale invariant
 $n_s = 0,963 \pm 0,012$
- Gaussian?
 $-214 < f_{NL}^{equil} < 266$
- GW?
 $r < 0,24$

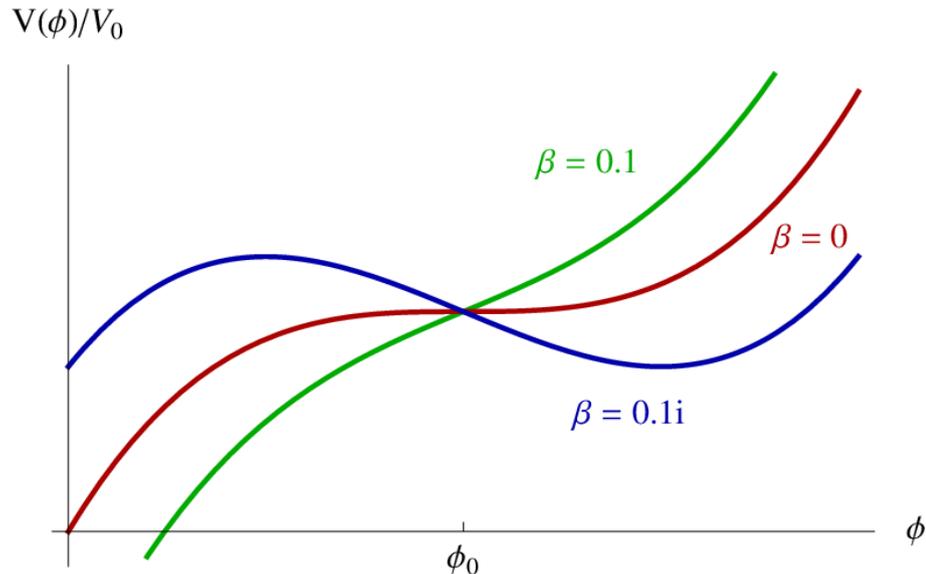
WMAP7 + BAO + H_0



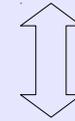
Jarosik et al'10 & Komatsu et al'10

Who's the scalar field?

Inflection point inflation



Inflection point



$$V''(\phi) = 0$$

Flat potential \implies saddle point \implies **fine tuning!**

$$V(\phi) = \frac{1}{2}m_\phi^2\phi^2 + \frac{h^2}{12}\phi^4 - \frac{Ah}{6\sqrt{3}}\phi^3 \quad \left\{ \begin{array}{l} A = 4m_\phi\sqrt{1-\beta^2} \\ \beta \approx O(10^{-3}) \end{array} \right.$$

Allahverdi et al'07

Interactions

—————> Energy transfer

$$\ddot{\phi} + 3H\dot{\phi} + V_{\phi} = -\Upsilon\dot{\phi}$$
$$\dot{\rho}_r + 4H\rho_r = +\Upsilon\dot{\phi}^2$$

$-\Upsilon\dot{\phi} =$ Extra friction

- Smaller scales
- No η -problem
- Steeper potential

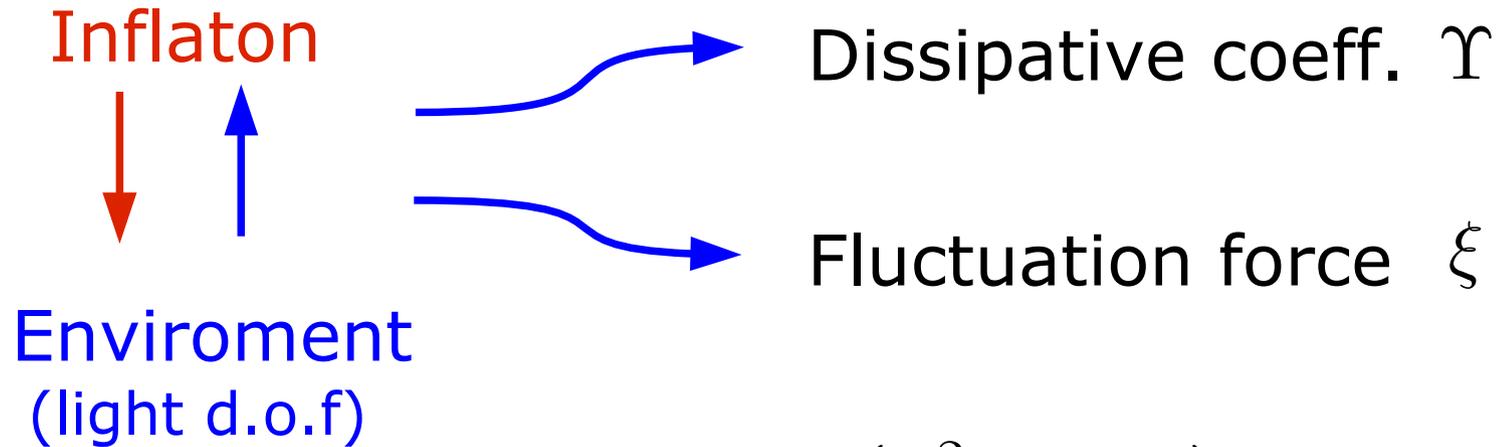
$+\Upsilon\dot{\phi}^2 =$ Source

- Reheating
- Baryogenesis

Conditions

- $V(\phi) \gg \dot{\phi}^2$
- $\rho_{\phi} > \rho_r$
- $T > H$

$$\rho_r = C_r T^4$$



$$\delta\ddot{\phi} + (3H + \Upsilon)\delta\dot{\phi} + \dot{\phi}\delta\Upsilon + \left(\frac{k^2}{a^2} + V_{\phi\phi}\right)\delta\phi = \xi_k$$

Thermal spectrum

- $P_{\mathcal{R}} \simeq \left(\frac{H}{2\pi}\right) \left(\frac{3H^2}{V_\phi}\right) (1 + Q)^{5/4} \left(\frac{T}{H}\right)^{1/2}$
- $r \lesssim 16\epsilon_\phi$
- $f_{NL}^{equil} \approx -15 \ln\left(1 + \frac{Q}{14}\right) - \frac{5}{2}$

$$Q = \frac{\Upsilon}{3H}$$

Dissipative coefficient

$$W = W(\Phi) + g\Phi S^2 \quad \times$$

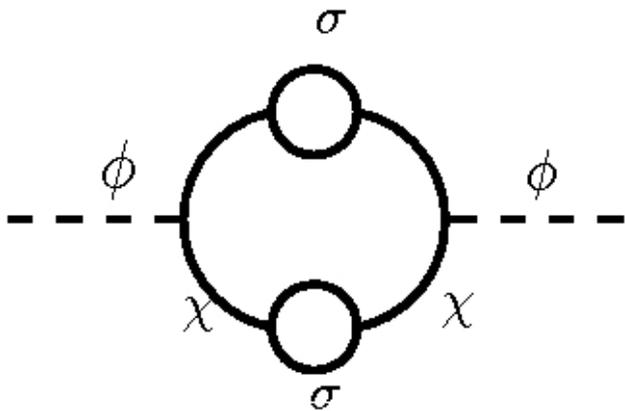
- $m_\sigma > T$ No dissipation
- $m_\sigma < T$ Thermal corrections

Yokoyama&Linde'98

$$W = W(\Phi) + g\Phi X^2 + hXS^2 \quad \checkmark$$

- $m_\chi > T$
- $m_\sigma < T$

Boltzmann & Dissipation



$$m_\chi \gg T$$

$$\Upsilon = C_\phi \frac{T^3}{\phi^2}$$

$$C_\phi = h^4 N_X N_{decay}^2$$

Warm inflection

$$V(\phi) \simeq V_0 \left[1 + 3\beta^2 \left(\frac{\phi - \phi_0}{\phi_0} \right) + \cancel{4} \left(\frac{\phi - \phi_0}{\phi_0} \right)^3 \right]$$

Model dependent

$\beta = 0 \longrightarrow$ Saddle point

Conditions

- $V(\phi) \gg \dot{\phi}^2$
- $\rho_\phi > \rho_r$
- $T > H$
- $m_\chi > T$

Free Parameters

- V_0
 - ϕ_*
 - β
 - ϕ_0
 - C_ϕ
 - C_r
- } CMB

$$\rho_r = C_r T^4$$

$$C_r = \frac{\pi^2}{30} g_*$$

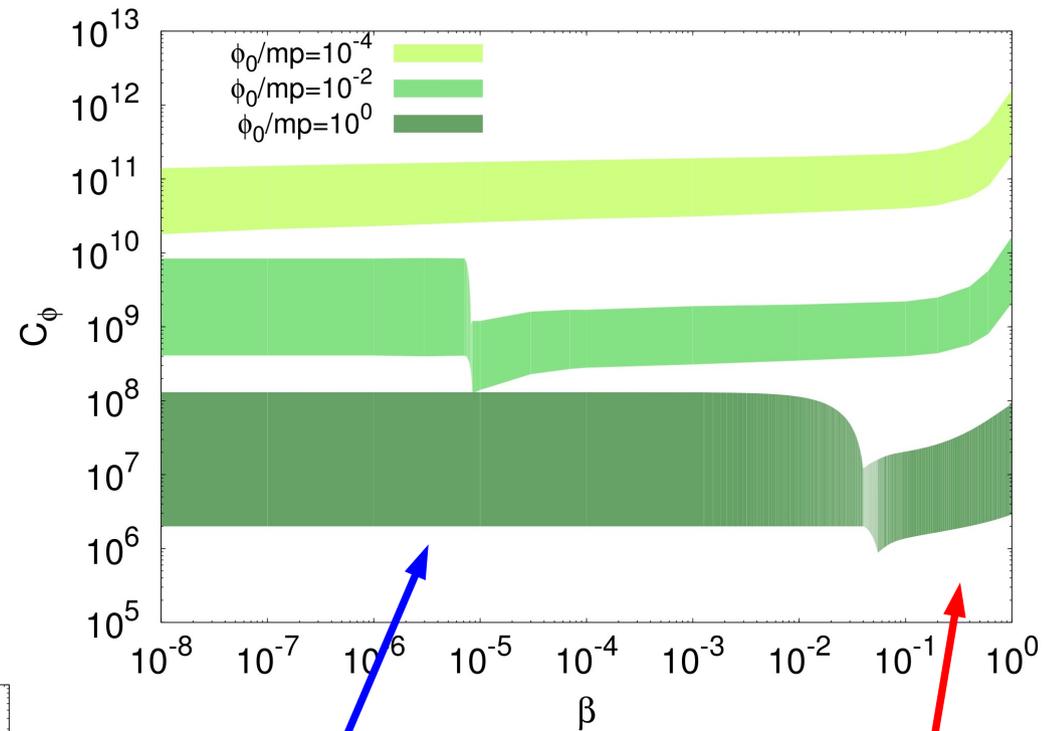
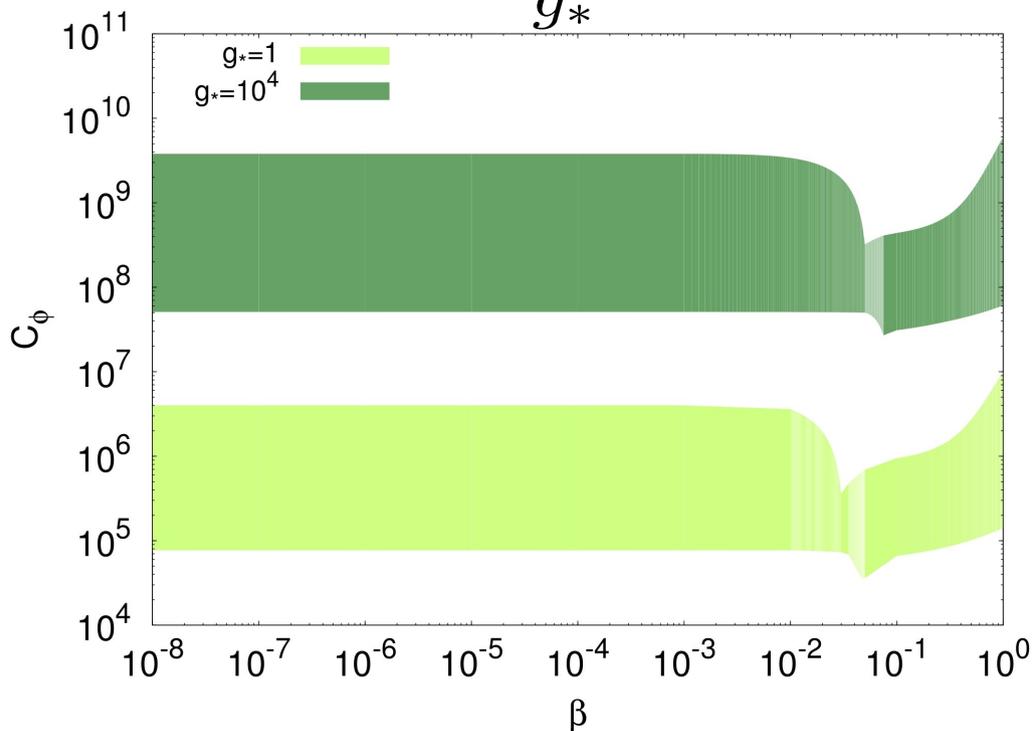
Results

No fine tuning!

$$N_\chi \sim O(100)$$

$$N_{decay} \sim O(100)$$

$$\Upsilon \sim \frac{C_\phi}{g_*^{3/4}}$$



$T > H$

$\rho_\phi > \rho_r$

$$+\Upsilon \dot{\phi}^2$$

$$C_\phi \sim O(10^6) \longrightarrow \text{General feature}$$

Lower multiplicities?

- $m_\chi \gtrsim T \quad \Upsilon = C_\phi (T\phi)^{1/2} e^{-\frac{m_\chi}{T}}$

$\frac{m_\chi}{T}$ nearly constant ☺

Bastero-Gil et al'12

- Non-equilibrium effects \longrightarrow bulk viscosity

beyond linear regime ?

Bastero-Gil et al'12

- $T \sim H$ warm & cold

Thermal QFT in de Sitter spaces ☹

- Inflation vs CMB
- Inflection point \rightarrow fine tuning
- Warm inflation \rightarrow interactions
- Warm inflection: tuning \leftrightarrow multiplicities
- Reduce multiplicities?

Thank you for your attention