Hybrid inflation and baryogenesis

COSMO '07

Luis Ureña, David Delepine, Carlos Martínez

Instituto de Física
Universidad de Guanajuato

August 23, 2007

Outlook

1. Baryogenesis
   - Observational constraints
   - Sakharov's conditions
2. Complex hybrid inflation
   - Proposal
   - General dynamics
3. Asymmetrical charge
   - Quantum perturbations
4. Conclusions

Matter *vs* anti-Matter

- Protons *vs* anti-protons

$$\frac{n_{\bar{p}}}{n_p} \sim 10^{-4} \tag{1}$$

- Helium *vs* anti-Helium

$$\frac{n_{\bar{He}}}{n_{He}} \sim 10^{-4} \tag{2}$$

- Nucleosynthesis: baryon to photon ratio η

$$5.92 \times 10^{-10} < \eta \equiv \frac{n_b - n_{\bar{b}}}{n_\gamma} < 6.28 \times 10^{-10} \tag{3}$$

- Baryon number: B

$$8 \times 10^{-11} < B \equiv \frac{n_b - n_{\bar{b}}}{s} < 9 \times 10^{-11} \tag{4}$$

General conditions

- Baryon number violation: B is not a conserved quantity
- C and CP violation (separate matter from anti-matter)
  - C(harge conjugation):

$$\Gamma(q_i \rightarrow q_f) = \Gamma(\bar{q}_i \rightarrow \bar{q}_f) \tag{5}$$

  - C(harge conjugation)P(arity): No handedness asymmetry!
- Loss of thermal equilibrium: Stop reactions!

$$\Gamma < H \tag{6}$$

Ingredients and symmetries

- Inflaton field ϕ; Complex rainfall field a
- Symmetric potential

$$V(\phi, a) = \frac{M^4}{4\lambda^2}\left(1 - \frac{\lambda^2}{M^2}|a|^2\right)^2 + \left(\frac{m^2}{2} + \frac{g^2}{2}|a|^2\right)\phi^2 \tag{7}$$

  - C-invariant, $U(1)$-invariant, $(a \to -a)$-invariant
  - CP-preserving

Ingredients and symmetries

- Inflaton field ϕ; Complex rainfall field a
- Symmetric potential

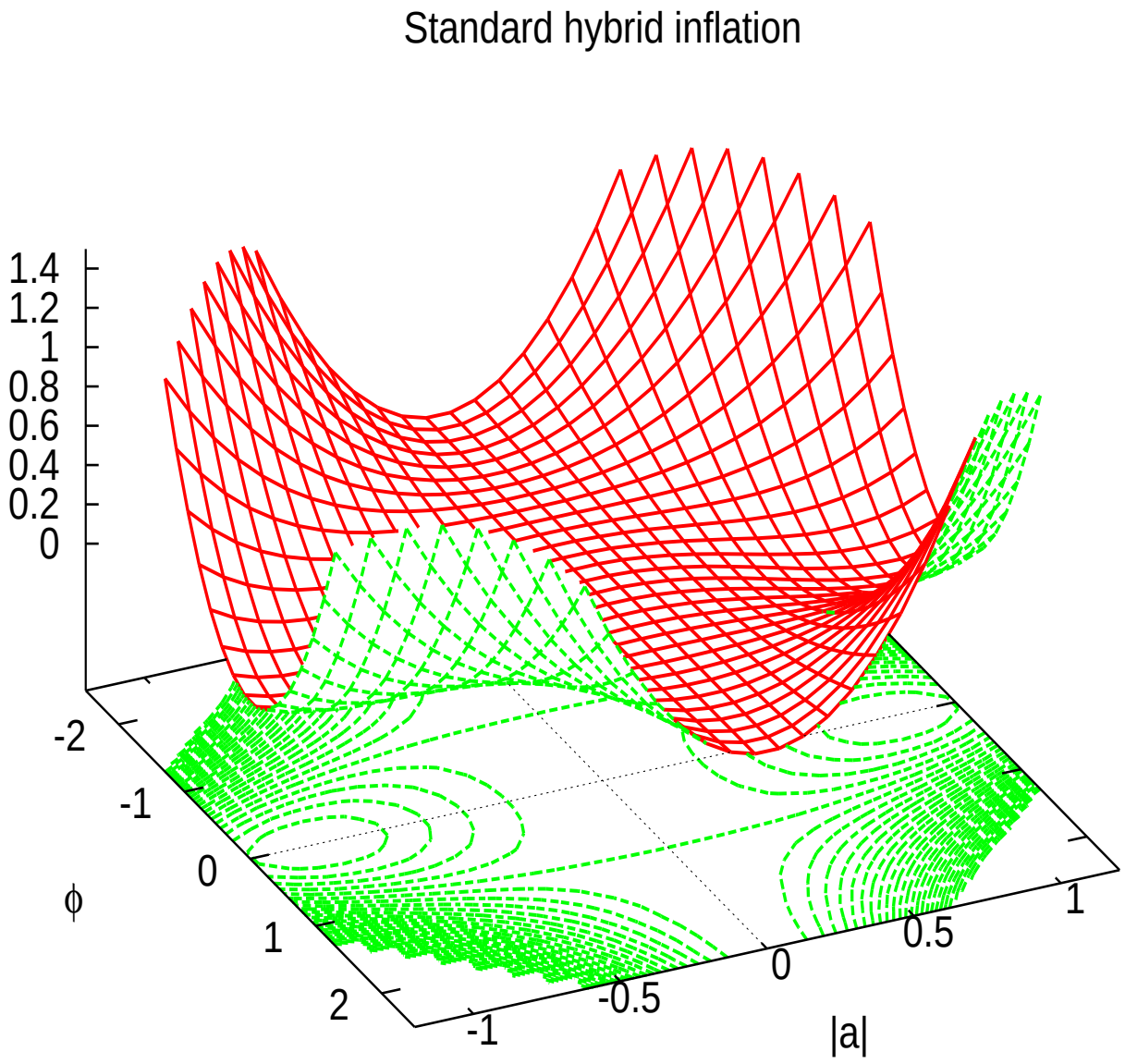
$$V(\phi, a) = \frac{M^4}{4\lambda^2}\left(1 - \frac{\lambda^2}{M^2}|a|^2\right)^2 + \left(\frac{m^2}{2} + \frac{g^2}{2}|a|^2\right)\phi^2 \tag{7}$$

  - C-invariant, $U(1)$-invariant, $(a \to -a)$-invariant
  - CP-preserving
- Asymmetric part

$$\ldots + \frac{\delta^2}{4}\left(a^2 + a^{\star 2}\right)\phi^2 \tag{8}$$

  - C-invariant, $U(1)$-broken, $(a \to -a)$-invariant
  - *Potentially CP* violating (!)

Inflationary dynamics (typical)



Inflationary dynamics (typical)

- Set conditions for vacuum (dominated) inflation

$$V(\phi, a) \simeq \frac{M^4}{4\lambda^2} \tag{9}$$

- Inflaton perturbations enhanced (effectively massless)
- Rainfall perturbations suppressed (massive)
- Boltzmann equation: $n_a = \mathrm{Im}(a^* \dot{a})$

$$\dot{n}_a + 3Hn_a = -\delta^2 |a|^2 \phi^2 \sin(2\theta_a) \to 0 \tag{10}$$

- No a-charge production, but a-charge dilution

End of inflation (double)

- *Instability* induced by the rainfall field

$$\phi_- = M/\sqrt{g^2-\delta^2} \tag{11}$$

$$\phi_+ = M/\sqrt{g^2+\delta^2} \tag{12}$$

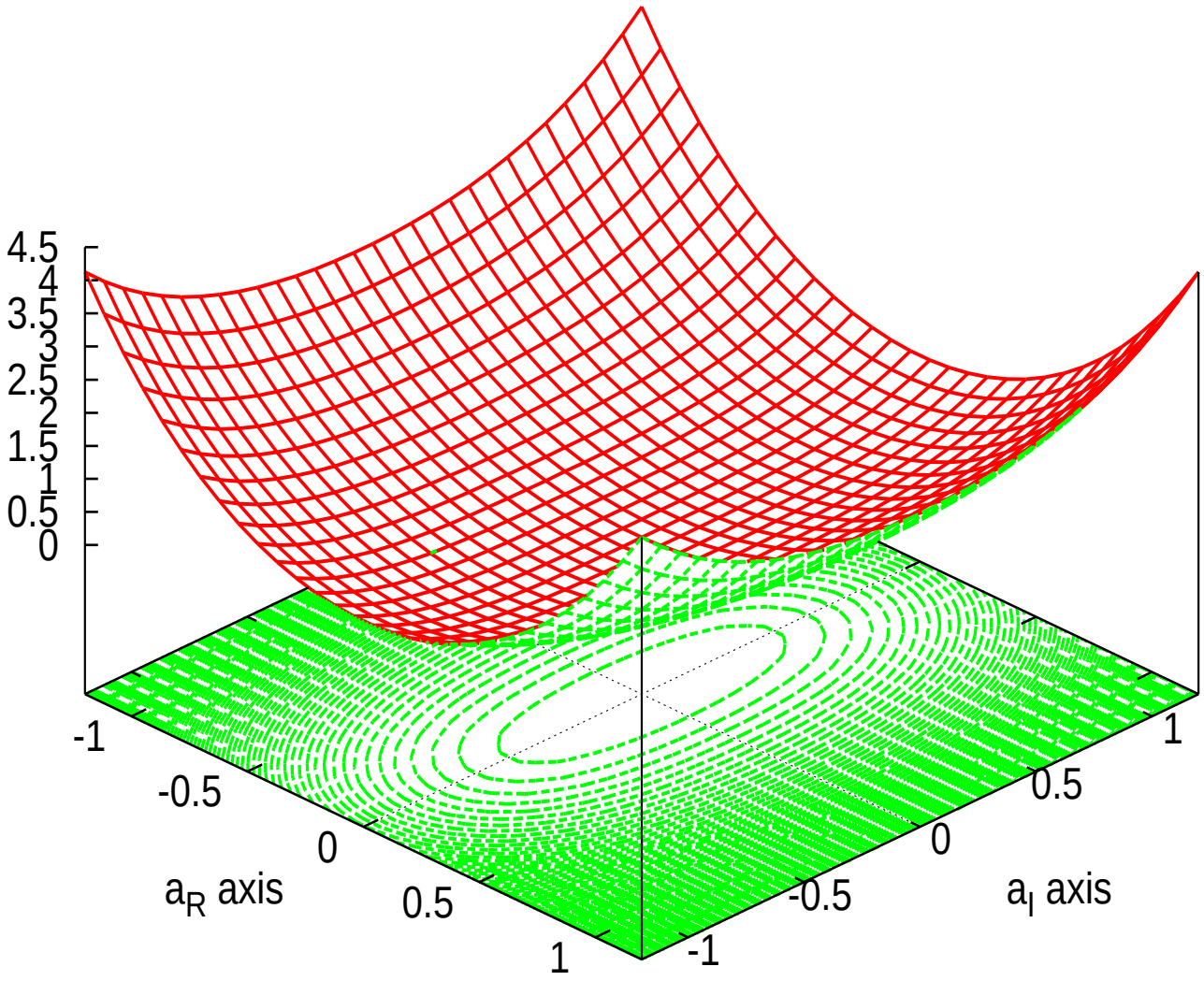
- Rainfall fields *become* massless

$$\delta a_I \simeq \left.\frac{H_0}{2\pi}\right|_{\phi=\phi_-}, \quad \delta a_R \simeq \left.\frac{H_0}{2\pi}\right|_{\phi=\phi_+} \tag{13}$$

  - Real and imaginary follow *different* evolutionary paths
  - Dynamical *charge* production
- End of inflation: $\phi_+ = \phi_{end}$

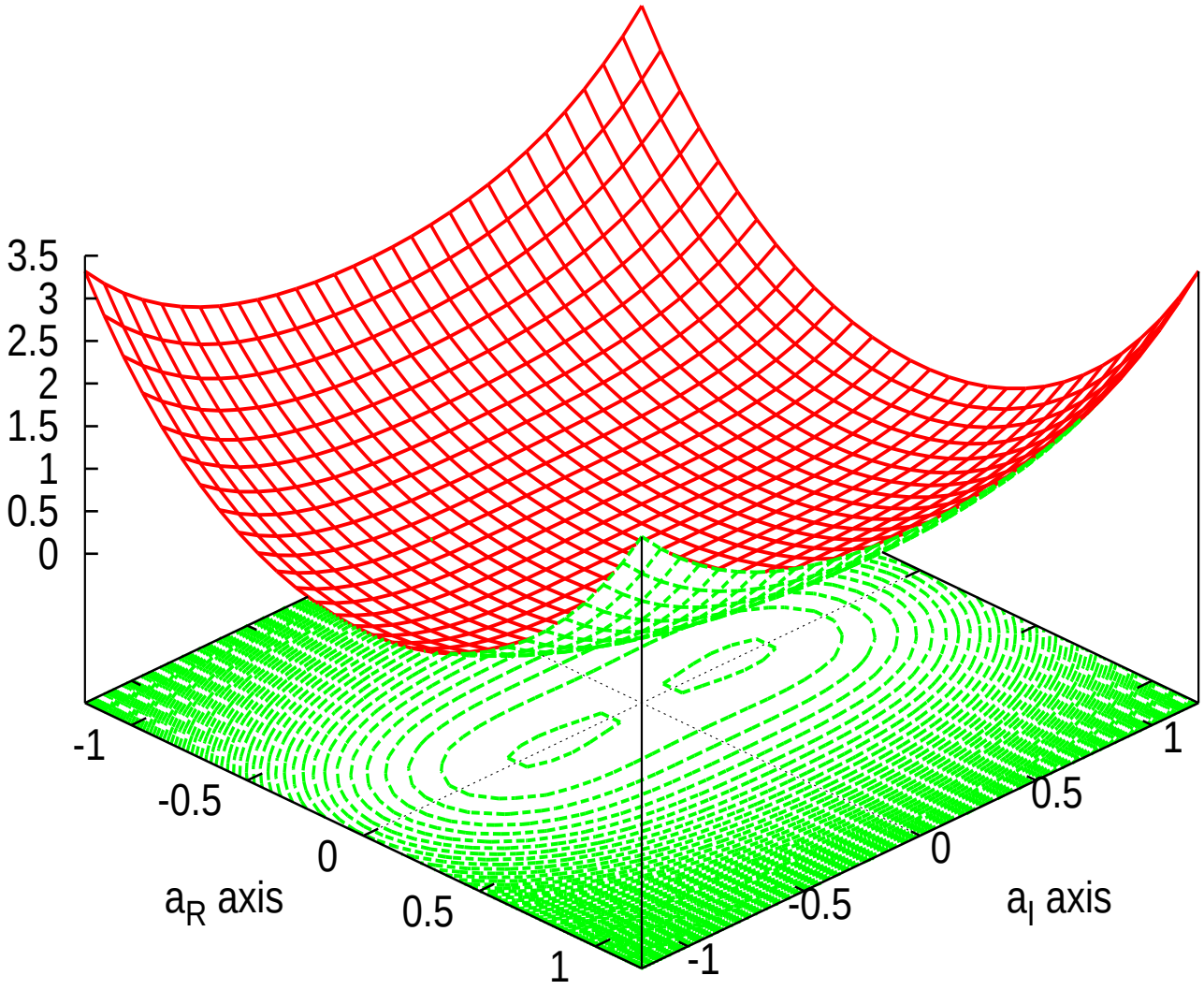
$$\ln\left(\frac{\phi_-}{\phi_{end}}\right) \simeq \ln\left(\frac{\sqrt{\pi}}{2}\frac{\phi_-}{m_{Pl}}\right) \simeq \frac{\delta^2}{g^2} \tag{14}$$

End of inflation (snapshots)

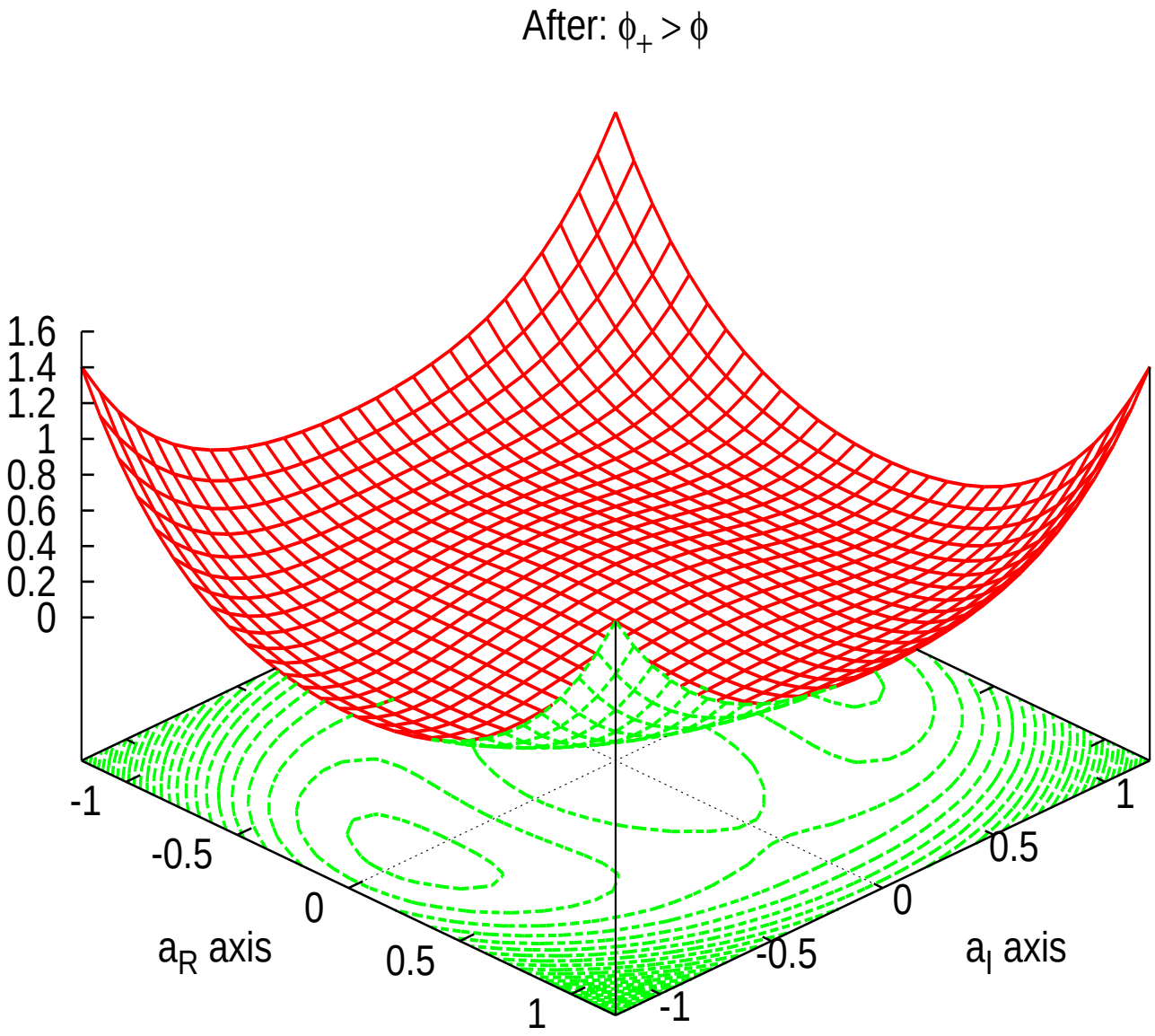


End of inflation (snapshots)

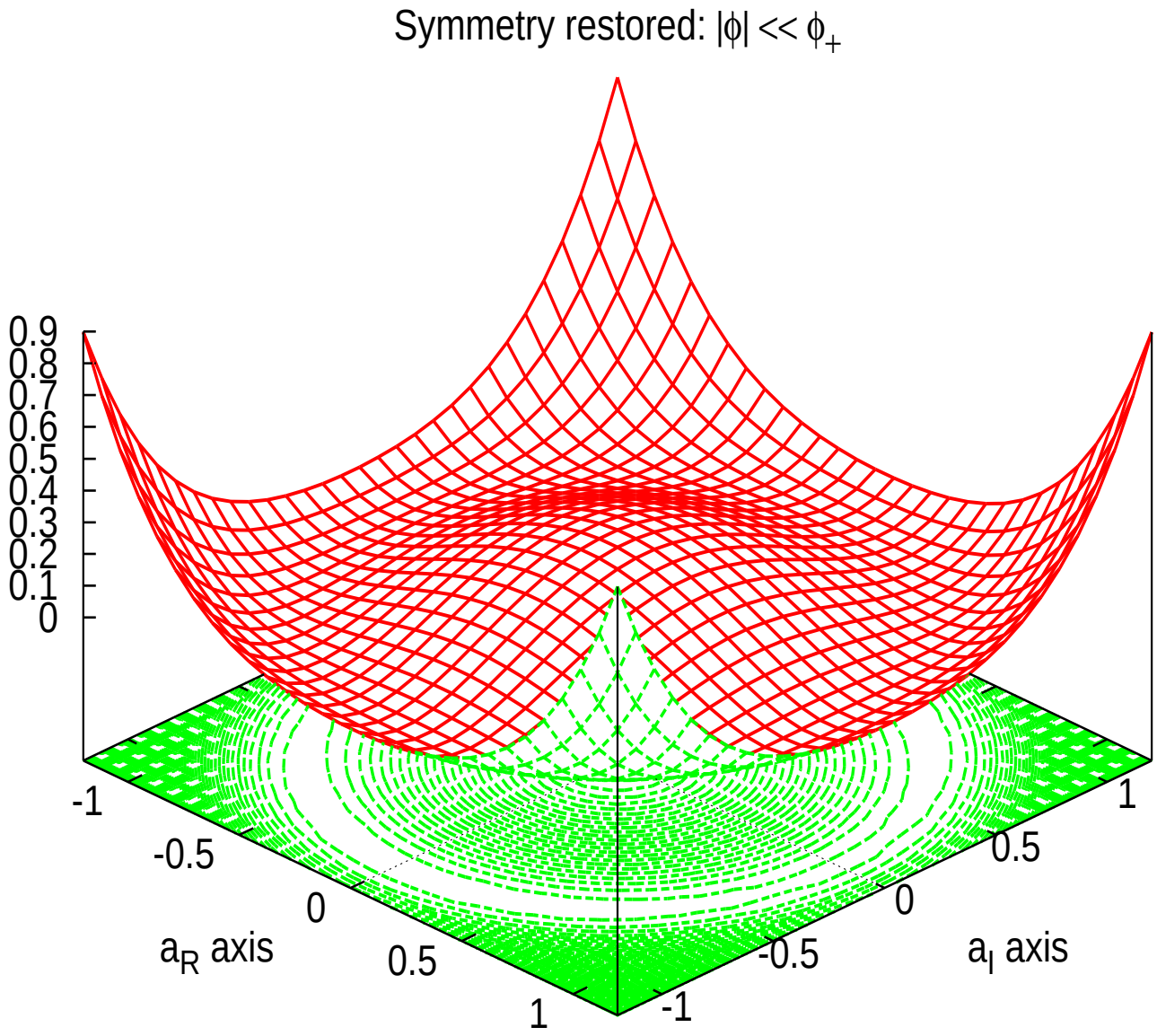
In between: $\phi_- > \phi > \phi_+$



End of inflation (snapshots)



End of inflation (snapshots)



Main results

- (Baryonic) Charge asymmetry (prompt reheating)

$$\left|\frac{n_a}{s}\right| \simeq \frac{g_*^{3/4}}{q_*}\frac{M^2}{m_{Pl}^2}\left(\frac{3H_0}{\sqrt{2}m}\frac{\delta}{g}\right)\exp\left(-\frac{9H_0^2}{2m^2}\frac{\delta^2}{g^2}\right) \qquad (15)$$

Main results

- (Baryonic) Charge asymmetry (prompt reheating)

$$\left|\frac{n_a}{s}\right| \simeq \frac{g_*^{3/4}}{q_*}\frac{M^2}{m_{Pl}^2}\left(\frac{3H_0}{\sqrt{2}m}\frac{\delta}{g}\right)\exp\left(-\frac{9H_0^2}{2m^2}\frac{\delta^2}{g^2}\right) \quad (15)$$

  - CMB primordial amplitude δ_H constraint

$$\frac{9H_0^2}{2m^2}\frac{\delta^2}{g^2} = \frac{3\pi^{3/2}}{2\lambda^2 g}\frac{(M/m_{Pl})^5}{(m/m_{Pl})^2} \simeq 3\times 10^{-4}\frac{\lambda}{g^2} \quad (16)$$

  - $+$ Spectral index n_s constraint

$$(M/\lambda m_{Pl}) < 5\times 10^{-5}/g \quad (17)$$

  - $+$ Cosmic strings

$$G\mu \simeq (M/\lambda m_{Pl})^2 < 10^{-6} \quad (18)$$

Conclusions

- CP symmetrical model
- CP dynamically broken
- Asymmetric charge generated from primordial quantum fluctuations

Conclusions

- CP symmetrical model
- CP dynamically broken
- Asymmetric charge generated from primordial quantum fluctuations
- Parameters allowed by all observations

$$10^{-5} < (M/\lambda m_{Pl}) < 10^{-4}, \quad 0.05 < g < 0.5 \qquad (19)$$

Conclusions

- CP symmetrical model
- CP dynamically broken
- Asymmetric charge generated from primordial quantum fluctuations
- Parameters allowed by all observations

$$10^{-5} < (M/\lambda m_{Pl}) < 10^{-4}\,, \quad 0.05 < g < 0.5 \tag{19}$$

- Reheating: Translation to baryonic asymmetry (!)

$$\left|\frac{n_B}{s}\right| \simeq \kappa_{inf}\, \Delta B\, \frac{\Gamma_{\Delta B}}{\Gamma_a} \left|\frac{n_a}{s}\right| \tag{20}$$

  - Inflaton channels are suppressed

$$\begin{cases} \Gamma(a \to 2\phi) & \sim & g^4/\lambda^2 \\ \Gamma(a + a \to \phi + \phi) & \sim & \delta^2 \end{cases} \tag{21}$$