Minimal Inflation (arXiv:1001.0010; PLB 690, 68)

Raul Jimenez

ICREA

ICC University of Barcelona

icc.ub.edu/~jimenez

with

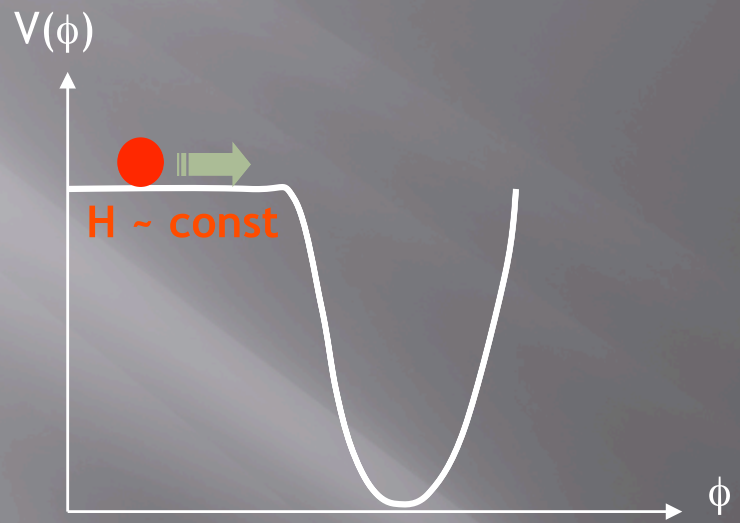
Luis Alvarez-Gaume (CERN)

Cesar Gomez (IFT/UAM)

Summary

1. Search for a physically motivated inflaton candidate
2. SUSY breaking as means to provide flat directions
3. Solution of the η problem
4. A novel mechanism to stop inflation

Inflation



$$\rho_Q = \frac{1}{2}\dot{q}^2 + V(q)$$

$$p_Q = \frac{1}{2}\dot{q}^2 - V(q)$$

Solves cosmological problems (Horizon, flatness).

Cosmological perturbations arise from quantum fluctuations, evolve classically.

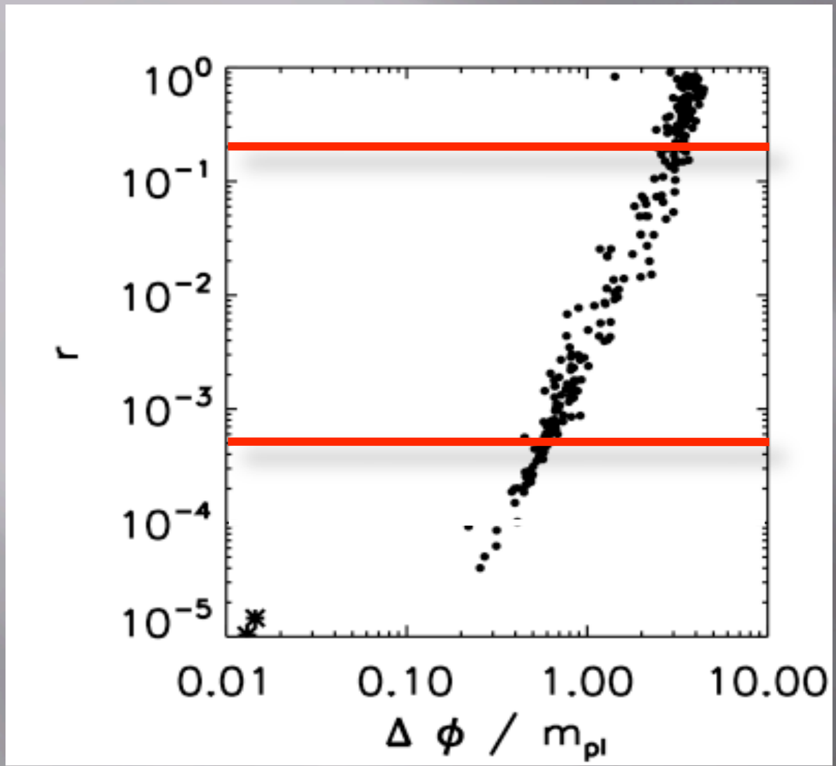
Guth (1981), Linde (1982), Albrecht & Steinhardt (1982), Sato (1981), Mukhanov & Chibisov (1981), Hawking (1982), Guth & Pi (1982), Starobinsky (1982), J. Bardeen, P.J. Steinhardt, M. Turner (1983), Mukhanov et al. 1992), Parker (1969), Birrell and Davies (1982)

HOW DO WE TEST IT and HOW DO WE BUILD PHYSICALLY MOTIVATED MODELS

Fine tuning

Implications of detection of primordial GW background

Verde, Peiris, Jimenez (2003) JCAP



Current obs. constraint

Best limit ever?

Inflation is probably small field class

Measuring fNL allows us to constraint inflationary models

Remember slow-roll parameters

$$\epsilon_* = \frac{m_{\rm Pl}^2}{16\pi}\left(\frac{V'}{V}\right)^2, \quad \text{and} \quad \eta_* = \frac{m_{\rm Pl}^2}{8\pi}\left[\frac{V''}{V} - \frac{1}{2}\left(\frac{V'}{V}\right)^2\right]$$

The skewness is

$$S_{3,\Phi} = \langle \Phi_{\rm B}^3 \rangle / \langle \Phi_{\rm B}^2 \rangle^2$$

$$S_{3,\Phi} = 2\epsilon_{\rm B} \times 3[1 + \gamma(n)]$$

Measuring fNL allows us to determine the shape of the inflaton potential

Relating the skewnness to the slow-roll parameters

fNL = $\epsilon_B = (5/2)\epsilon_* - (5/3)\eta_*$

But the primordial slope is

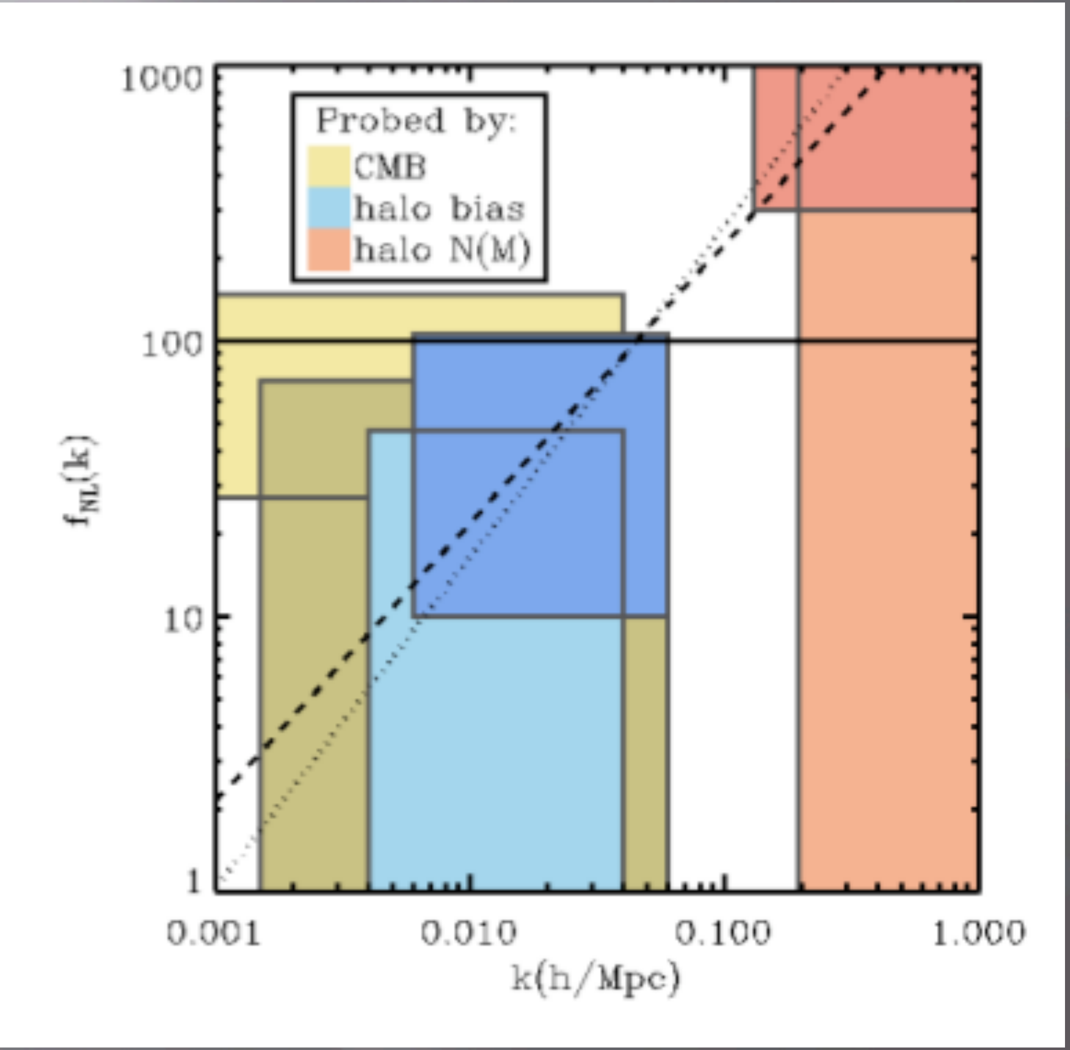
$$n = 2\epsilon_* - 6\eta_* + 1$$

So a measurement of fNL and n gives you a measurement of the slow-roll parameters

Verde, RJ, Kamionkowski, Matarrese MNRAS (2001)

Scale dependent f_{NL} ?

Hoyle, Jimenez, Verde 1009.3884



Problems with model building in inflation

1. Flat directions
2. SUGRA models suffer from the so-called eta problem.
3. Graceful exit. How do we stop inflation?
4. Initial conditions
5. Should provide a mechanism for re-heating (particle production)

TWO REASONS FOR SUSY

Natural flat directions

Vacuum energy: order parameter of SUSY breaking

Minimal Inflation

Flat directions

One reason to use SUSY in inflationary theories is the abundance of flat directions. Once SUSY breaks most flat directions are lifted, sometime by non-perturbative effects. However, the slopes in the potential can be maintained reasonably gentle without excessive fine-tuning.

Apart from flat directions in the original UV fields, in String-like theories one often encounters moduli fields with flat or nearly flat directions, where inflation can take place, and in some cases it is only instanton effects who do that. Recall the no-scale models...

There is a theorem (ma non troppo) which holds in many general circumstances which implies the existence of flat directions. If a SUSY theory is invariant under a given group, its potential is invariant under its complexification. This automatically implies the existence of flat directions, pseudo-goldstone bosons etc. Nice directions to inflate. The first paper on SUSY and inflation carried out the title: Inflations cries out for Supersymmetry.

$$G \to G^c$$

Most models of supersymmetric inflation are hybrid models (multi-field models, chaotic, waterfall...)

Our proposal for the inflaton

To identify the inflaton with the X field that is the order parameter of SUSY breaking.

In the language of the recent paper by Komargodski & Seiberg (0907.2441)

$$J_\mu = j_\mu + \theta^\alpha S_{\mu\alpha} + \bar\theta_{\dot\alpha} \bar S^{\dot\alpha}_\mu + (\theta\sigma^\nu\bar\theta)\, 2T_{\nu\mu} + \ldots$$

$$X = x(y) + \sqrt{2}\theta\psi(y) + \theta^2 F(y)$$

$$\bar D^{\dot\alpha} J_{\alpha\dot\alpha} = D_\alpha X$$

$$\psi_\alpha = \frac{\sqrt{2}}{3}\sigma^\mu_{\alpha\dot\alpha}\bar S^{\dot\alpha}_\mu, \qquad F = \frac{2}{3}T + i\partial_\mu j^\mu$$

X is the chiral superfield, microscopically it contains the conformal anomaly (the anomaly multiplet), hence it contains the order parameter for SUSY breaking as well as the goldstino field

Our proposal for the inflaton

In SUSY X provides an extremely flat direction so our proposal is to

1. Associate the x component of the superfield X with the inflaton.

2. Inflation takes place during the UV ➔ IR flow of the field X ➔ X_{NL}

3. In the IR it happens that $X^2_{NL} = 0$

However, the correct theory should include gravity, so we need to explore what happens in SUGRA models

$$K = \Phi\bar{\Phi} \qquad W = f\Phi$$

$$V = e^{K/M_p^2}\left(K^{-1}_{\Phi\bar{\Phi}} DW\bar{D}W - \frac{3}{M_p^2}W^2\right)$$

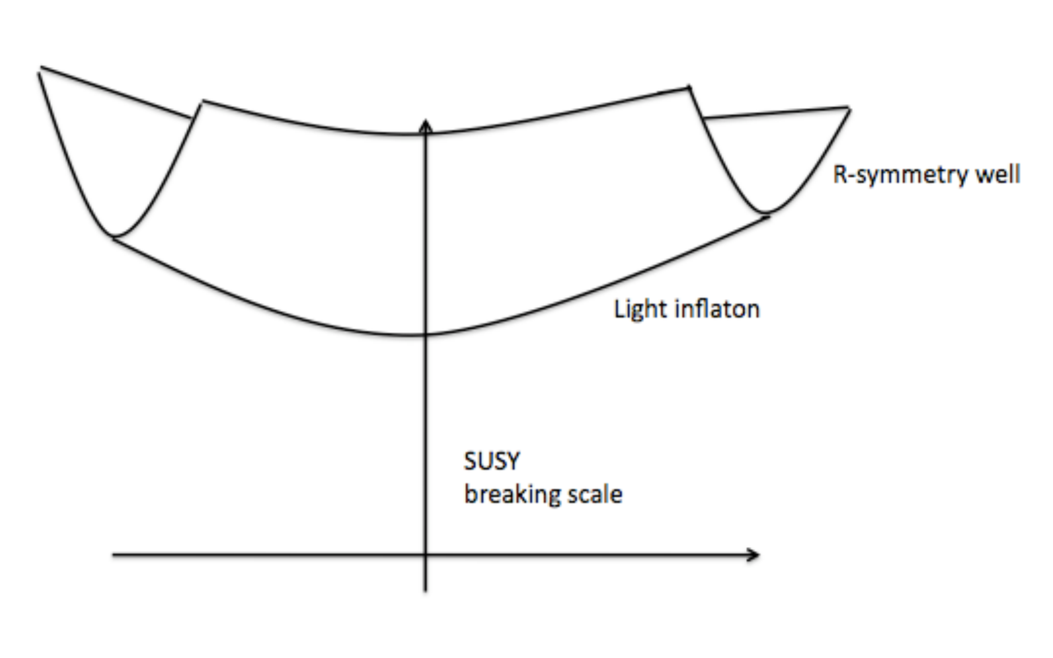
$$V = f^2(1 + \frac{A}{M_p^2}(\alpha^2 + \beta^2) + O(1/M_p^3)) \qquad m^2 \sim \frac{f^2}{M_p^2}$$

Solving the η problem

$$\eta = M_p^2 \frac{V''}{V} \sim O(1)$$

In order to solve this problem we introduce explicit breaking of R-symmetry

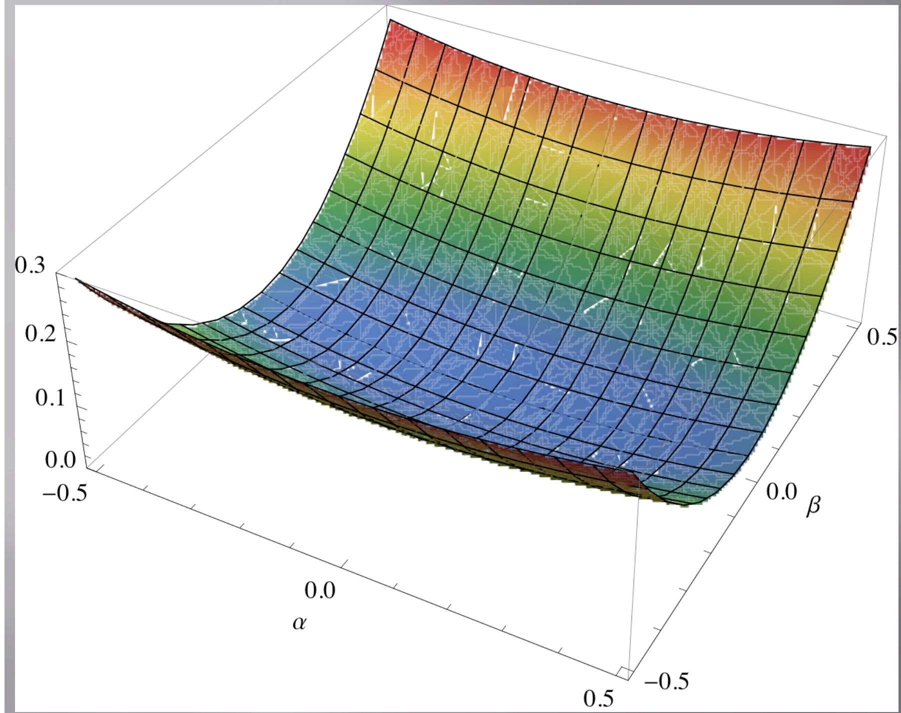
$$V = f^2 \left(1 + \frac{A}{M_p^2}(\alpha^2 + \beta^2) + \frac{B}{M_p^2}(\alpha^2 - \beta^2) + \ldots\right)$$



Explicit R-symmetric breaking

$$\eta = \frac{m^2_{inflaton}}{m^2_{gravitino}}$$

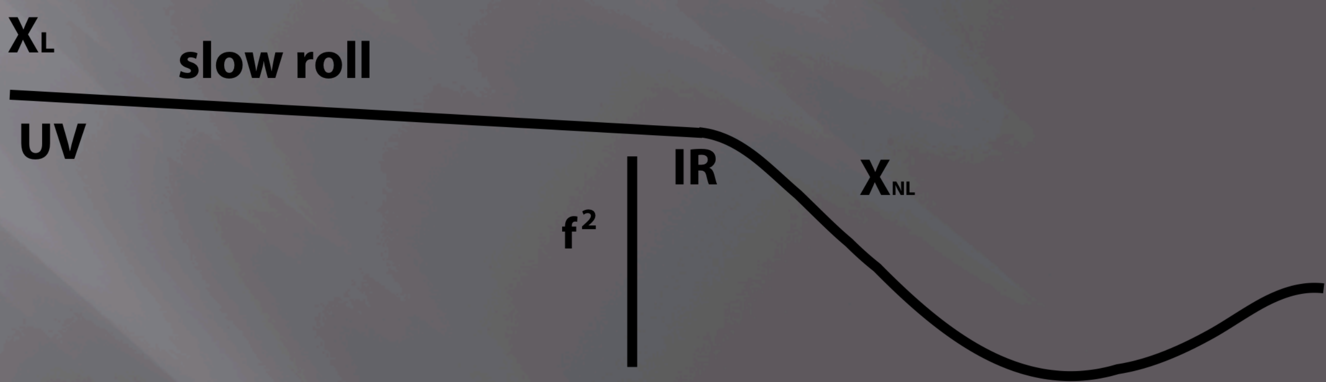
Minimal Inflation (THE POTENTIAL)



$$\Delta_R^2 = \frac{V/M_{pl}^4}{24\pi^2\epsilon}$$

$$2^{1/4}\,\frac{m_{3/2}}{m_\beta}\left(\frac{\sqrt{f}}{M}\right)^{1/2} = 0.027$$

$$\eta = \left(\frac{m_\beta}{m_{3/2}}\right)^2$$



A fermionic end to Inflation

In our model we obtain naturally that

N ~ O(100)

$$\eta \sim 0.1 - 0.01$$

$$\sqrt(f) \sim 10^{11} - 10^{13}\text{Gev}$$

The question is how we stop inflation? This is the most novel feature of our model as by identifying SUSY breaking scale and the scale of inflation we end the inflation when the scalar component of the universal X field reaches the vacuum with SUSY spontaneously broken. At this point the θ component becomes the SUSY Goldstone particle i.e the Goldstino and automatically the field playing until that moment the role of the inflaton becomes a two Goldstino composite field. The gracefull exit consist in distributing the energy density at the end of inflation for the Fermi liquid of Goldstinos

SUSY flow ⟷ Inflaton

$$X_{NL}^2 = 0,$$

$$X_{NL} = \frac{G^2}{2F} + \sqrt{2}\,\theta\, G + \theta^2 F.$$

1. The meaning of the flow

In the simplest model

$$\Box\Phi = -m^2\Phi + \frac{f}{M_p^2}\Psi\Psi$$

The flow $\Phi \rightarrow \frac{\Psi\Psi}{f}$ Goldstino

UV

IR

Note that at the end of the flow we have a fermionic field with fluctuations suppressed as $1/x^6$ naturally!

Summary

We have proposed that the Inflaton is the order parameter of SUSY breaking and that SUSY is broken at a relatively high scale 10^{11} GeV (note though that m_{SOFT} is still ~ 1 TeV)

We have shown that breaking R-symmetry cures the η problem and that we obtain enough number of e-foldings and a scale invariant spectrun of perturbations.

The main philosophical message of our inflationary scenario is that the inflaton was not born as a Goldstone boson but as the future companion of a Goldstone fermion and that is the reason its ultimate fate is to become composite after ending the job of infation.

Our model can be falsified if SUSY is found at LHC as we predict the scale of SUSY breaking from CMB perturbations

Further, the dark matter has to be the gravitino

The End

THANKS!