Anomaly-Induced **Inflation**

Graceful Exit

and

Supersymmetry

Joan Solà

Dep. E.C.M.

Universitat de Barcelona (**UB**)& IFAE

References:

I.L. Shapiro, J.S., *Phys. Lett.* **B**530 (2002) 10

I.L. Shapiro, J.S. *JHEP.* **0202** (2002) 006
I.L. Shapiro, J.S. *Phys. Lett.* **B**475 (2000) 236

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GUIDELINES

- Introduction and motivation for inflation.
- Basic framework of Anomaly-Induced Inflation
- Conformal invariant SM and MSSM.
- The renormalization group scale in Cosmology
- The role of masses in tempering inflation: cosmological motivation for SUSY
- Graceful exit from anomaly-induced inflation: SUSYdecoupling
- Conclusions.

$\boxed{\text{Introduction and Motivation for Inflation}}$

Friedmann's equation reads

$$\boxed{\Omega_m + \Omega_\Lambda + \Omega_k = 1}$$

where

$$\Omega_m = \frac{\rho_m}{\rho_c}\,, \quad \Omega_\Lambda = \frac{\Lambda}{\rho_c} = \frac{\lambda}{3H^2}\,, \quad \Omega_k = -\frac{k}{a^2\, H^2}$$

Notice that, if there is a de Sitter phase,

$$a(t) \propto e^{H\,t} \Rightarrow \Omega_k \propto e^{-2H\,t} \to 0$$

and then

$$\boxed{\Omega \equiv \Omega_m + \Omega_\Lambda = 1}$$

$\Rightarrow$ Popular scenario: Inflationary Universe. It may automatically solve 5 of the 6 classical Cosmological Problems of the standard BB-model:

- 1) monopole problem ($\surd$),
- 2) horizon problem ($\surd$),
- 3) flatness-curvature-entropy problem ($\surd$),
- 4) rotation problem ($\surd$),
- 5) large-scale homogeneity versus small-scale inhomogeneity problem ($\surd$)
- 6) the cosmological constant problem (**unsolved!!**)

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$\boxed{\text{Need } \sim 65 \textbf{ e-folds} \text{ (factor } 10^{28}\text{) of inflation (at least)}}$

Λ in the SM and beyond

Source	**Effect** (GeV^4)	Λ/Λ_{exp}
electron 0-point	10^{-16}	10^{31}
QCD chiral	10^{-4}	10^{43}
QCD gluon	10^{-2}	10^{45}
Electroweak SM	10^{+9}	10^{55}
typical GUT	10^{+64}	10^{111}
Quantum Gravity	10^{+76}	10^{123} !!

◇ From the observed Ω_Λ (high-z supernovae) and the critical density

$$\rho_{c0} = 8.1\, h^2 \times 10^{-47}\, GeV^4$$
$$\simeq (2-5) \times 10^{-47}\, GeV^4 \quad (h \simeq 0.5 - 0.8)$$

we have

$$\boxed{\Lambda_{exp} \gtrsim +2 \times 10^{-47}\, GeV^4}$$

Λ: Alfa and Omega

tempo	passage	age	$\bar{\rho}$	$\bar{p}$	$\bar{\rho} + 3\,\bar{p}$
prestissimo	string?	$< 10^{-43}\,s$	?	?	?
presto	vacuum	$< 10^{-38}\,s$	Λ_e	$-\Lambda_e$	$-$
allegro	matter	$< 10^{-36}\,s$	ρ_ϕ	0	$+$
andante	radiation	$< 10^4\,yr$	T^4	T^4	$+$
largo	matter	$\lesssim 10^{10}\,yr$	$\rho + \Lambda$	$-\Lambda$	$\pm$
largissimo	vacuum	∞ !!	Λ	$-\Lambda$	$-$

• If we believe the recent high-z supernovae data the residual Cosmological Constant (being $\Lambda > 0$) will drive away (very slowly) the final fate of the Universe into a diluting inflationary phase

• An effective Λ could also have played a role immediately after the birth of the Universe, in the form of a huge Vacuum Energy $\Lambda_e > 0$ that could have triggered a very fast (superluminical) Inflationary Epoch.

• In the conventional approach mostly followed at present (since Guth 1981 and Linde 1982 seminal works), this effective Λ is usually obtained from the contrived properties of the potential of some *ad hoc* scalar field called inflaton. But there are other possibilities, within the extended theories of gravity, that emerged after the "pre-inflationary" attempt at solving the singularity problem (Starobinsky, 1980).

Inflation and Physics Beyond the SM

- Inflation solves so many problems of the Early Universe that there are not much doubts that it really took place. However, it is difficult, if not impossible, to understand inflation without resorting to Physics Beyond the SM.

- The MSSM, being a full Quantum Field Theory, is a most attractive framework for extending the theory of strong and EW interactions.

- Moreover, the MSSM offers a starting point for a successful GUT where a radiatively stable Higgs Sector can survive.

- We expect that the MSSM, and in general SUSY, should also play a relevant role in the very early universe, in particular in inflationary cosmology

- Inflation induced by the conformal anomaly can be stable (no fine-tuning) or unstable (Starobinsky 1980), and in the latter case it may end into the FLRW phase only if there is an initial deviation leading to an expansion lower than exponential (Vilenkin, 1985).

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A conformal invariant formulation of gravity and SUSY matter could perhaps provide a suitable mechanism for stable inflation at the beginning, and unstable inflation at the end.

This is possible thanks to the decoupling of the heavy degrees of freedom after soft SUSY-breaking.

If we could further introduce a natural mechanism (compatible with classical conformal symmetry!) that "tempers" the unstable phase of inflation, the final upshot could be the long sought-after graceful exit of inflation to the standard FLRW regime .

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Basic Framework of Anomaly-Induced Inflation

• Consider the vacuum quantum effects in the Early Universe, when the typical energy of quantum processes is very high but sub-Planckian ⇒ appropriate framework is not the string theory but some QFT. No quantum gravity effects relevant ⇒ metric is a classical, generally curved, background. For a renormalizable theory we need the minimal vacuum action

$$S_{vac} = \int d^4x\sqrt{-g}\,\left\{a_1C^2 + a_2E + a_3\Box R\right\}.$$

We may add it to the Hilbert-Einstein action without perturbing the cosmological solution.

• At this epoch particle masses are negligible ⇒ expect local conformal invariance for the quantum matter fields. So, at the classical level,

$$S_{cl} \,=\, -\,\frac{1}{16\pi G}\int d^4x\,\sqrt{-g}\,R \,+\, S_{conf-matt} \,+\, S_{vac}$$

where $S_{conf-matt}$ contains massless boson and fermion fields and conformally invariant kinetic terms :

$$S_0 = \int d^4x\sqrt{-g}\,\{\,\frac{1}{2}\,g^{\mu\nu}\partial_\mu\,\varphi\partial_\nu\varphi + \frac{1}{12}\,R\varphi^2\,\}\,,$$

$$S_{1/2} = \int d^4x\sqrt{-g}\,\{i\,\bar{\psi}\gamma^\mu\nabla_\mu\psi\}\,,\quad S_1 = \int d^4x\sqrt{-g}\,\{-\frac{1}{4}\,F_{\mu\nu}F^{\mu\nu}\}\,.$$

where $\nabla_\mu = \partial_\mu + (1/2)i\,\omega_{\mu ab}S^{ab} + ...$ contains the spin connection. In addition, there are renormalizable interactions $S_{\rm int}$ between gauge-matter fields, Yukawa couplings and scalar self-interactions, all of them automatically conformally invariant.

• Matter effects seen only at the quantum level through the vacuum conformal trace anomaly of our QFT:

$$< T_{\mu}^{\mu} >= -\frac{2}{\sqrt{-g}}\, g_{\mu\nu}\frac{\delta}{\delta g_{\mu\nu}}\Gamma = -\frac{1}{(4\pi)^2}\,(wC^2 + bE + c\Box R)\,,$$

whose coefficients (the β-functions for the parameters a_1, a_2, a_3) are fully determined by the matter content $(N_0, N_{1/2}, N_1)$ of our QFT:

$$w = \frac{N_0 + 6N_{1/2} + 12N_1}{120\cdot(4\pi)^2} > 0\;, \quad b = -\frac{N_0 + 11N_{1/2} + 62N_1}{360\cdot(4\pi)^2} < 0$$

The one controlling stability ($c > 0$) or instability ($c < 0$) of inflation

$$c = \frac{N_0 + 6N_{1/2} - 18N_1}{180\cdot(4\pi)^2}$$

crucially depends on the matter content.

• Instability can also be controled by introducing non-conformal higher derivative terms (like $\sqrt{-g}\,R^2$) in the classical action, but this possibility will not be considered (unnatural $\Leftrightarrow$ *ad hoc* inflatons) .

• A natural mechanism for inflation should be one that appears from a self-consistent solution of the functional anomaly equation above (or appropriate extensions thereof)

• A suitable extension appears when considering the effect from "conformal invariant mass terms". At lower energies, mass terms may become relevant $\Rightarrow$ Renormalize the Hilbert-Einstein term and temper the process of anomaly-induced inflation (see below!)

Conformal Invariant SM and MSSM

• To account for the particle mass effects at lower energy we wish to derive an effective action Γ for massive fields in such a way that they initially enter as "conformal invariant mass terms". We will follow the "Cosmon Model approach" *

• Dilatation symmetry and conformization is well-known as applied to both GR and Particle Physics **.

• The original action of the theory includes kinetic and interaction terms which are already conformal invariant. The only non-invariant terms in the SM and MSSM are the massive ones for the scalar (Higgs+sfermions) and spinor fields:

$$\frac{1}{2}\int d^4x\sqrt{-g}\; m_{\varphi_i}^2\,\varphi_i^2\,, \qquad \int d^4x\sqrt{-g}\; m_{\psi_j}\,\bar{\psi}_j\psi_j \qquad (\forall i,j).$$

• Furthermore, our model includes gravity and we have already admitted the non-invariant HE-term

$$S_{HE} = -\frac{1}{16\pi G}\int d^4x\sqrt{-g}\,R\,.$$

Can we make all these terms conformally invariant too? $\Rightarrow$ Need a new auxiliar scalar field, χ !! *

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* R.D.Peccei, J.Solà, C. Wetterich, Phys. Lett. B 195(1987)183

** S. Deser, Ann. Phys. **59** (1970) 248; S. Coleman, Erice Lectures (1971), Cf. *Aspects of Symmetry* (Cambridge Univ. Press, 1985)

• In both cases the conformal non-invariance is caused by the presence of dimensional parameters $m^2_{\varphi_i}$, m_{ψ_j} and ${M_P}^2 = G_N^{-1}$. The central idea of the Cosmon Model was to replace these parameters by functions of some new auxiliary scalar field χ. For instance, we replace

$$m^2_{\varphi_i} \to \frac{m^2_{\varphi_i}}{M^2}\,\chi^2\,, \qquad m_{\psi_j} \to \frac{m_{\psi_j}}{M}\,\chi\,, \qquad {M_P}^2 \to \frac{{M_P}^2}{M^2}\,\chi^2\,,$$

where M is some dimensional order parameter, e.g. related to a high scale of spontaneous breaking of dilatation symmetry. It is supposed that the new scalar field χ takes the values close to M, especially at low energies.

• In the matter field sector, the massive terms are replaced by the Yukawa and $(scalar)^4$ interaction terms between physical fields (spinors, Higgs and sfermions) and the new auxiliary scalar χ

The action of the new SM or MSSM becomes invariant under the local conformal transformation

$$\chi \to \chi\, e^{-\sigma} \qquad (\sigma = \sigma(x))$$

which is performed together with the usual relations

$$g_{\mu\nu} \to g_{\mu\nu}\, e^{2\sigma}\,, \quad \varphi \to \varphi\, e^{-\sigma}\,, \quad \psi \to \psi\, e^{-3/2\,\sigma}\,.$$

Also the HE-term can be "conformized" thanks to χ:

$$S^*_{HE} = -\frac{1}{16\pi G_N\, M^2}\int d^4x\sqrt{-g}\,\left[\,R\chi^2 + 6\,(\partial\chi)^2\,\right]\,,$$

where $(\partial\chi)^2 = g^{\mu\nu}\partial_\mu\chi\partial_\nu\chi\,$. After fixing $\chi \to M$ ("conformal unitary gauge"), these expressions become identical to the initial ones.

• At the quantum level the conformal frames are <u>not</u> equivalent due to the anomaly $\Rightarrow \exists$ New dynamical fields!

• The modified functional conformal anomaly equation for the effective action with the additional background field χ is

$$< T^\mu_\mu >= -\frac{2}{\sqrt{-g}} g_{\mu\nu} \frac{\delta}{\delta g_{\mu\nu}} \Gamma = -\frac{1}{(4\pi)^2} \{ w C^2 + b E + c \Box R) \,,$$

$$+ d F^2 + f \, [\, R \chi^2 + 6 \, (\partial \chi)^2 \,] \} \,,$$

where for completeness we have also added the contribution from a background gauge field with field strength $F_{\mu\nu}$.

• The (very) important parameter f is just the β-function for the dimensionless coupling $h = (16\pi G_N M^2)^{-1}$ in the conformized HE-term. A direct calculation using the Schwinger-DeWitt method gives

$$f = \sum_i \frac{N_i}{3\,(4\pi)^2} \frac{{m_i}^2}{M^2} \,,$$

where N_i are the number of Dirac spinors with masses m_i. We note that bosons do <u>*not*</u> contribute to f.

• The Reigert (1980) and Fradkin&Tseytlin (1980) solution to the functional anomaly equation for zero masses is well-known, and it can be easily extended in our case. We put

$$g_{\mu\nu} = \bar{g}_{\mu\nu} \cdot e^{2\sigma} \qquad \chi = \bar{\chi} \cdot e^{-\sigma}$$

where the (fiducial) metric $\bar{g}_{\mu\nu}$ has fixed determinant and the field $\bar{\chi}$ does not change under the conformal transformation. Then, the solution of the equation for the effective action Γ proceeds in the usual way $\Rightarrow$

$$\Gamma = \int d^4x\sqrt{-\bar{g}}\,\{w\bar{C}^2 + b(\bar{E} - \frac{2}{3}\overline{\nabla}^2\bar{R}) + 2b\,\sigma\,\bar{\Delta}_4 + d\bar{F}^2$$

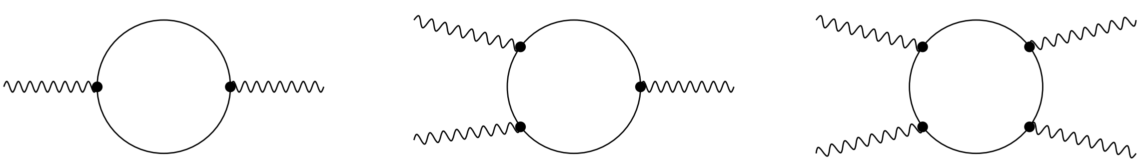
$$+f\,[\,\bar{R}\bar{\chi}^2 + 6\,(\partial\bar{\chi})^2\,]\,\}\sigma - \frac{3c+2b}{36}\int d^4x\sqrt{-g}\,R^2 + S_c[\bar{g}_{\mu\nu}]\,.$$

- The new dynamical scalar σ is just the conformal factor of the transformation, which does *not* cancel at the quantum level !!:

$$\boxed{g_{\mu\nu} = a^2(\eta)\,\bar{g}_{\mu\nu} = e^{2\sigma(\eta)}\;\bar{g}_{\mu\nu}}$$

where η is the conformal time: $dt = a(\eta)d\eta$. The presence of $\sigma = \ln a$ in Γ through linear coupling signals the breakdown of conformal invariance at the quantum level.

- The "Feynman diagrams" which contribute to Γ consist of quantum bubbles of matter (non-gravitational) fields with external tails of the σ field. According to the decoupling theorem (Appelquist&Carazzone) the loop of massive field decouples when the energy of external lines becomes much smaller than the mass of the quantum field in the loop.



$R = e^{-2\sigma}[\bar{R} - 6(\bar{\nabla}\sigma)^2 - 6\bar{\nabla}^2\sigma] \Rightarrow R^2$ gives only 2,3 or 4 external lines of the σ field

• Of course our goal is to derive the effective action *not* in terms of $\bar{\chi}$, but in terms of $\bar{g}_{\mu\nu}$ and $\chi \to M$.

• In contrast to σ, the Feynman diagram representation of the quantum interactions of matter with the new background field χ consists of bubbles of matter field with infinitely many external tails of χ fields, due to exponential interaction.

The role of masses in "tempering" inflation

• In order to understand the role of the particle masses* in the anomaly-induced inflation, let us consider the total quantum action

$$\boxed{S_t = S_{matter} + S^*_{EH} + S_{vac} + \Gamma}\,.$$

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$$S_t = \int d^4x\sqrt{-\bar{g}}\,\{\,(\,-\frac{{M_P}^2}{16\pi M^2}+f\sigma\,)\,[\,\bar{R}\bar{\chi}^2+6\,(\partial\bar{\chi})^2\,]$$

$$-(\,\frac{1}{4}-d\sigma\,)\,\bar{F}^2\,\}+S_{\text{conf}-\text{matt}}+\text{high. deriv. terms}\,.$$

• We know that there are 3 types of the homogeneous and isotropic metric: with $k = 0, 1, -1$. In the early universe the value of space curvature can not be important and hence we can safely take any of them. We take flat $k = 0$. But it can be checked that the results for $k = 1, -1$ are the same.

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* No need of quantum corrections in the matter sector
$\Rightarrow$ matter-radiation treated incoherently as a fluid

• In order to restore the HE term and get the inflationary solution, we fix the conformal unitary gauge and put $\chi = \bar{\chi}\, e^{\sigma} = M$.

• As we have just said, we can choose the conformally flat metric $\bar{g}_{\mu\nu} = \eta_{\mu\nu}$. Then the gravitational part of the action becomes

$$S_{grav} = \int d^4x \, \{ \, 2b \, (\partial^2 \sigma)^2 - (3c + 2b) \, [(\partial\sigma)^2 + \partial^2\sigma)]^2 -$$

$$- \, 6 {M_P}^2 \, e^{2\sigma} \, (\partial\sigma)^2 \, [\, 1 - \frac{16\pi M^2}{{M_P}^2} \, f \,] - (\, \frac{1}{4} - d\sigma \,) \, \bar{F}^2 \, \} \, .$$

• Computing the equation of motion in terms of the physical time t (where $dt = a(\eta) d\eta$) we find

$$a^2 a^{(4)} + 3 a \dot{a} a^{(3)} - \left(5 + \frac{4b}{c} \right) \dot{a}^2 \ddot{a} + a \ddot{a}^2 - \frac{{M_P}^2}{8\pi c} \left(a^2 \ddot{a} + a \dot{a}^2 \right) +$$

$$+ \underbrace{\frac{2 f M^2}{c} \ln a \left(a^2 \ddot{a} + a \dot{a}^2 \right) + \frac{2 f M^2}{c} \frac{\dot{a}^2}{a} - \frac{d \bar{F}^2}{6ca}}_{\text{this is the new contribution !!}} = 0.$$

• The full dif. eq. has been solved numerically. Analytically complicated, but it can be handled in the limit of small f. In this approximation:

$${M_P}^2 \longrightarrow {M_P}^2 \left[1 - \tilde{f} \ln a(t) \right] \, .$$

$$\tilde{f} \equiv \frac{16\pi f \, M^2}{{M_P}^2} = \sum_i \frac{N_i}{3\pi} \frac{m_i^2}{{M_P}^2}$$

Notice that $\tilde{f}$ does not depend on the scale M.

• Then the approximate solution is

$$a(t) = a_0\, e^{H_1\, t}\,, \qquad H_1 = const$$

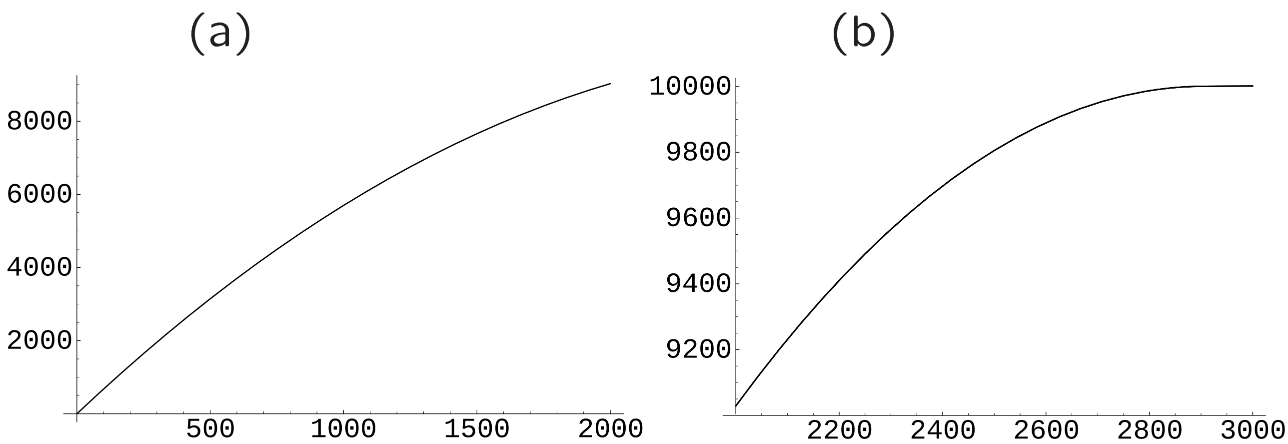
with

$$H_1 = \frac{M_P}{\sqrt{-16\pi b}} \longrightarrow \frac{M_P}{\sqrt{-16\pi b}}\left[1 - \tilde{f}\, \ln a(t)\right]^{1/2} = H(t)$$

• Solving numerically.

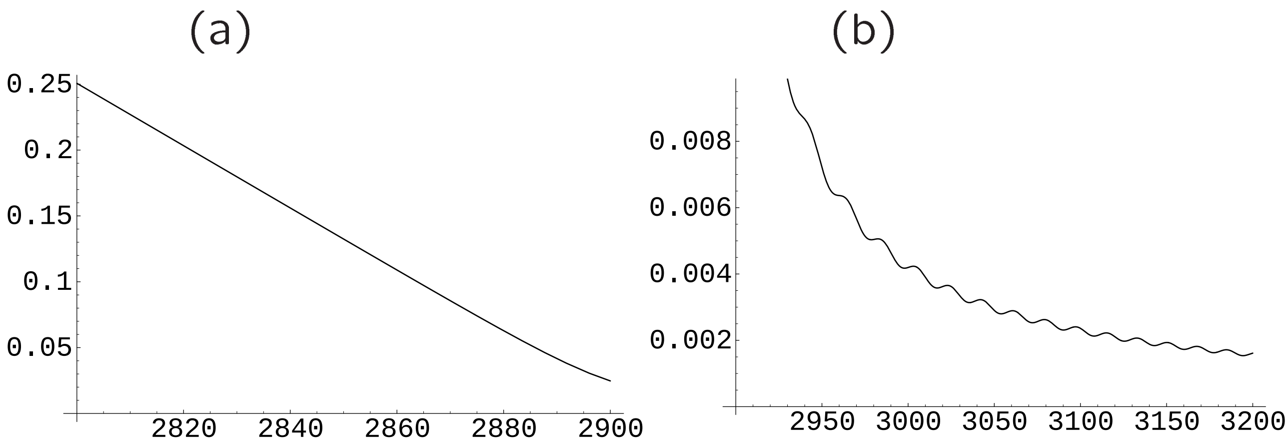
Confirms the analytical results in in the limit of small f. Since in the first period of inflation masses do not play much role and the stabilization of the exponential inflation proceeds very fast $\Rightarrow$ initial data as in the exponential inflation law:

$$a(0) = 1\,, \quad \dot{a}(0) = H_1\,, \quad \ddot{a}(0) = {H_1}^2\,, \quad a^{(3)}(0) = {H_1}^3\,.$$



(a) Plot of $\ln a(t)$ versus the physical time t; t is given in units of $16\,\pi/M_P$ and we fixed $\tilde{f} = 10^{-4}$. In this time interval, inflation does not stop, yet;
(b) As in (a), but extending the numerical analysis until reaching an approximate plateau marking the end of stable inflation.

• $\underline{H(t) \to 0}$ due to the massive fermions !!.



Plot of $\mathbf{H(t) = \dot{a}(t)/a(t)}$ versus $\mathbf{t}$;
(a) $\mathbf{H(t)}$ near the onset of the plateau;
(b) $\mathbf{H(t)}$ well over the plateau.

• We find that when we travel from the beginning of the plateau up to nearby points over it (namely about 10% increase of t after the onset of the plateau) $\Rightarrow$ $H(t)$ diminishes two orders of magnitude.

• This can roughly be compared (as in the original model by Guth, though of course in a different sense) to the situation in a supercooled phase transition in which energy decreases a lot before the transition really takes place.

• So in general $H(t)$ will decrease further below M_{SUSY}, and the difference between $H_f = M^*$ and M_{SUSY} at the moment of the transition can be significant, say one or two orders of magnitude $\Rightarrow$ does *not* create problems with CMBR.

• Let us also notice the oscillatory behaviour of $H(t)$ after reaching the plateau $\Rightarrow$ perhaps related to the reheating phenomenon, which is of course desirable before the universe stabilizes in the FLRW regime.

Γ versus the Renormalization Group

Let us compare Γ with the quantum correction from the RG.

- While the expansion of the homogeneous and isotropic universe means a conformal transformation of the metric $g_{\mu\nu}(t) \to a^2(\eta)\,\bar{g}_{\mu\nu}$ the RGE in curved space-time corresponds to the scale transformation of the metric $g_{\mu\nu} \to g_{\mu\nu} \cdot e^{-2t}$ simultaneous with the inverse transformation of all dimensional quantities $\mu \to \mu \cdot e^t$.

- The RGE for the effective action

$$\Gamma[e^{-2t} g_{\alpha\beta}, \Phi_i, P, \mu] = \Gamma[g_{\alpha\beta}, \Phi_i(t), P(t), \mu]\,,$$

  where Φ_i is the set of all fields and P the set of all parameters.

- In the leading-log approximation one can take the classical action and replace

$$P \to P_0 + \beta_P\, t\,.$$

- One can observe the complete equivalence of the two expressions in the terms which do not vanish for $\sigma = const$.

Graceful exit in anomaly-induced inflation

• $H(t)$ sets the scale of the renormalization group running for the gravitational part.

• Recall that the condition for stable inflation is $c > 0$. Then one can play with various models; e.g. from the previous equation it follows that the particle content of the SM $(N_0 = 4, N_{1/2} = 24, N_1 = 12)$ leads to $c < 0$ (unstable inflation) whereas for the MSSM $(N_0 = 104, N_{1/2} = 32, N_1 = 12)$ one has $c > 0$ (stable inflation) etc.

• The necessary and sufficient condition for the applicability of our approach is that $H(t)$ decreases from the initial value about $H_1 = M_P/\sqrt{-16\pi b} \sim 10^{18}\, GeV$, down to a scale $M^* \ll M_{SUSY}$, typically

$$\boxed{M^* \sim 10^{14}\, GeV \ll M_{SUSY} \sim 10^{16}\, GeV}$$

• For a really successful exit from the inflation phase we need to evaluate the dynamics of $H(t)$ during the last 65 e-folds of inflation. The amplitude of the gravitational waves is consistent with the observable range of anisotropy in the CMBR if, during the last 65 e-folds of the inflation, the Hubble constant H does not exceed $10^{-5} M_P$:

$$\boxed{\delta h/h = H/M_P = \delta T/T = \mathcal{O}(10^{-5})}$$

related to the fluctuations in the temperature of the relic radiation.

• The scale M^* signals the transition to the unstable phase $(c < 0)$ and with the help of the $\tilde{f} \neq 0$ coupling (halting inflation), the conditions develop for the Universe to tilt into the FLRW regime.

Some References on Anomaly-Induced Inflation

- M.V. Fischetti, J.B. Hartle and B.L. Hu, *Phys. Rev.* D20 (1979) 1757.

- A.A. Starobinsky, *Phys. Lett.* 91B (1980) 99.

- A. Vilenkin, *Phys. Rev.* D32 (1985) 2511.

- J.C. Fabris, A.M. Pelinson, I.L. Shapiro, Grav. *Grav. Cosmol.* 6 (2000) 59

- S.W. Hawking, T. Hertog and H.S. Real, *Trace Anomaly Driven Inflation* *Phys. Rev.* D63(2001)083504

- A.A. Starobinsky, JETP Lett. **34** (1981) 460

- J.C.Fabris, A.M.Pelinson and I.L.Shapiro, *Nucl. Phys.* B597 (2001) 539

I.L. Shapiro *The graceful exit from the anomaly-induced inflation: Supersymmetry as a key*, hep-ph/0103128.

- I. L. Shapiro and J. Solà, *Massive fields temper anomaly-induced inflation: the clue to graceful exit?* *Phys. Lett.* B530 (2002) 10

Conclusions

- We have assumed a framework of R^2-gravity at high (but sub-Plankian) energy where cosmological scales start to leave the horizon (inflation!) before Einstein GR is restored.
- Taking conformal symmetry as a guide, one obtains the anomaly-induced action in QFT.
- In the conventional approach one needs to add the non-conformal HE term by hand to recover Einstein gravity at lower energy.
- But, with the help of our χ field, the HE term (and all "mass terms") become natural conformal invariant parts of the whole classical action, and then Einstein gravity can be recovered at low energy by appropriate choice of conformal gauge.
- The resulting cosmological model develops an stable inflationary phase, which does not require special initial conditions.
- After decoupling of the SUSY particles inflation becomes unstable.
- Finally, due to the coupling of massive (fermion) matter fields to the HE term through the χ field, the exponential expansion is halted and the conditions become favorable for the onset of the standard FLRW regime.

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$\boxed{\text{In short:}}$

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$\boxed{\textbf{Full Conformal Symmetry} + \text{SUSY+QFT}}$

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$\boxed{\textbf{Graceful Self-Consistent Inflation without Inflaton}\text{?}}$