20TH IAP COLLOQUIUM ON
CMB PHYSICS AND OBSERVATION
IAP - 28 JUNE - 2 JULY 2004

Constraining SUSY GUT models of inflation with the CMB

by

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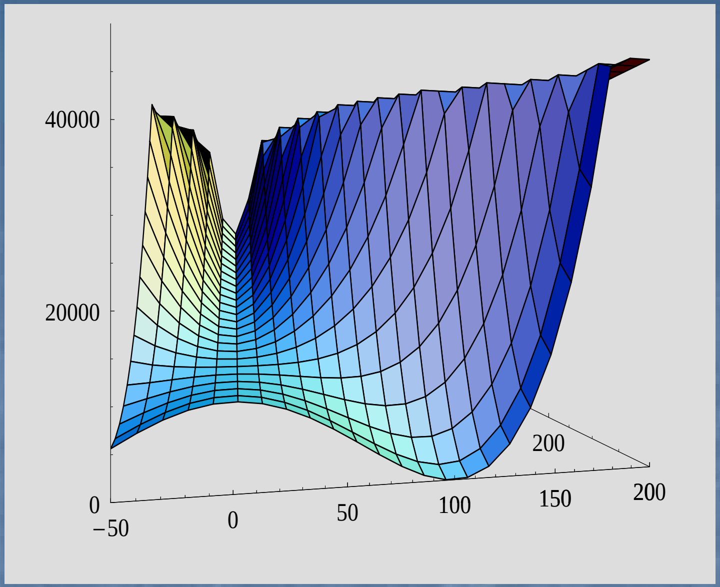
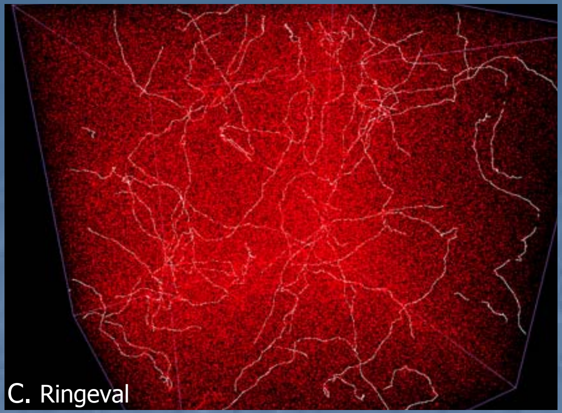
Collaboration : M. Sakellariadou

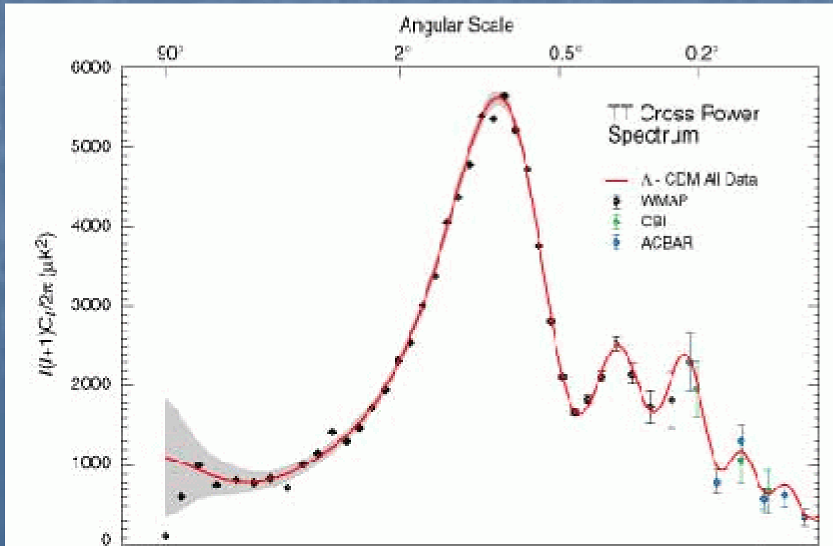
References : J. R., M. Sakellariadou (2004) [hep-ph/0405133, hep-ph/0406120]





Outline

- Framework and motivations
- Contributions to CMB anisotropies
  - F-term inflation
  - D-term inflation
- Constraints on inflationary models
- Conclusions



Framework and Motivations

[Jeannerot, J. R., Sakellariadou, PRD**68** (2003)]

Framework = Supersymmetric Grand Unified Theories

GUT ⟶ SSBs + phase transitions ⟶ Topological defects.

Selection of SSB patterns of GUT groups down to the SM in agreement with :

- Particle physics (neutrino oscillation, proton lifetime, SM)
- Cosmology (CMB observations, monopole problem, matter/antimatter asymmetry)

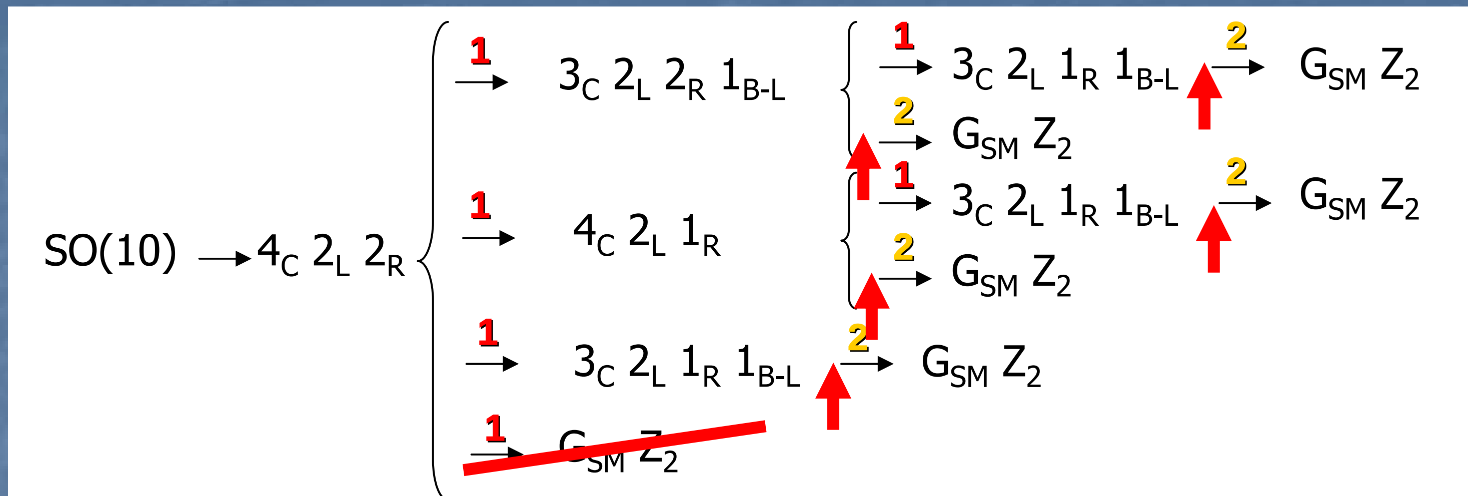
This necessitates a phase of inflation after the formation of monopoles :

Supersymmetric Hybrid Inflation.

It couples the inflaton with a pair of GUT Higgs fields. It ends with the SSB.

? GUT Inflation Standard Model

time



1: Monopoles **2**: Cosmic Strings ↑ INFLATION

Idem for SO(10), SU(5), SU(6), SU(7), E6, ...

Conclusions :

- In SUSY GUTs, formation of cosmic strings = GENERIC
- Formation at the end of inflation : $G\mu \sim M^2_{infl}$

ARE THEY CONSISTENT WTH CMB DATA ?

WHAT IS THEIR CONTRIBUTION TO THE CMB ANISOTROPIES ?

Contribution to CMB anisotropies
1. Inflationary part

$$\left(\frac{\delta T}{T}\right)^2_{Q-\text{infl}} = \left(\frac{\delta T}{T}\right)^2_{Q-\text{scal}} + \left(\frac{\delta T}{T}\right)^2_{Q-\text{tens}}$$

Sachs-Wolfe effect : ⇒

$$\left(\frac{\delta T}{T}\right)_{Q-\text{scal}} \propto \frac{V^{3/2}(\varphi_Q)}{M_{\mathrm{P}}{}^3 V'(\varphi_Q)}$$

$$\left(\frac{\delta T}{T}\right)_{Q-\text{tens}} \propto \frac{V^{1/2}(\varphi_Q)}{M_{\mathrm{P}}{}^2}$$

Number of e-foldings of inflation :

$$N_Q \equiv N(\varphi_Q \to \varphi_{end}) = -\frac{1}{M_{\mathrm{P}}{}^2} \int_{\varphi_Q}^{\varphi_{end}} \frac{V(\varphi)}{V'(\varphi)} \mathrm{d}\varphi$$

To solve the horizon problem, we need at least $N_Q \sim 60$.

The F term inflation

Superpotential : $W^F = \kappa S(\Phi_+\Phi_- - M^2)$

S
U
S
Y

$$V^F(\phi_+,\phi_-,S) = \kappa^2 \left|M^2 - \phi_+\phi_-\right|^2 + \kappa^2 |S|^2 \left(|\phi_-|^2 + |\phi_+|^2\right) + D - terms$$

[Dvali, Shafi, Schaefer PRL**73** (1994)]

A global minimum for $\langle\phi_+\rangle = \langle\phi_-\rangle = M$ and $\langle S\rangle = 0$ and a local minimum for $S \gg S_C$, $\langle\phi_+\rangle = \langle\phi_-\rangle = 0$, $V_0 = \kappa^2 M^4$.

⟶ Perfectly flat direction + F-term SUSY breaking => mass splitting of components of Φ.

1-loop radiative corrections [Coleman and Weinberg, PRD**7** (1973)]

$$V_{\mathrm{eff}}(S) = \kappa^2 M^4 \left\{ 1 + \frac{\kappa^2 N}{32\pi^2} \left[2\ln\frac{|S|^2 \kappa^2}{\Lambda^2} + (z+1)^2 \ln(1+z^{-1}) + (z-1)^2 \ln(1-z^{-1}) \right] \right\}$$

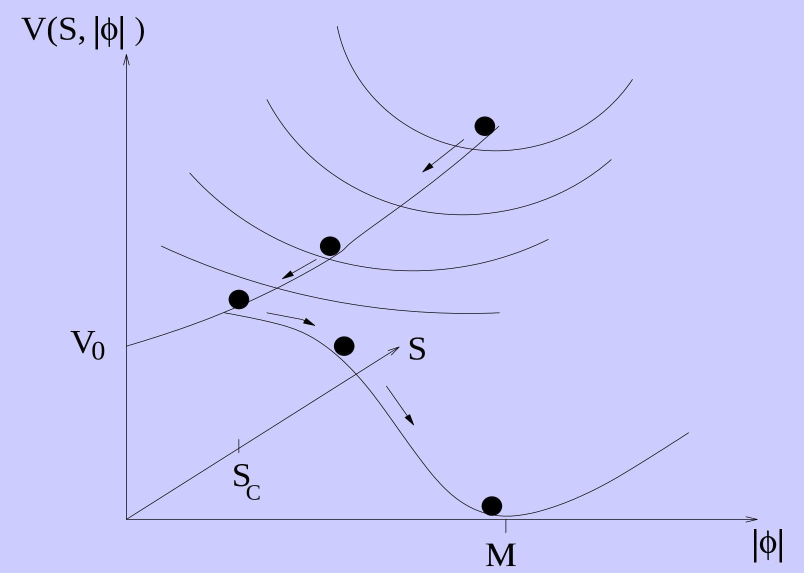
where $z = \frac{|S|^2}{M^2} \equiv x^2$

Assuming $\Delta V << V_0$, and using the complete effective potential for $V'(|S|)$,

$$\left(\frac{\delta T}{T}\right)_{Q-\text{scal}} \approx \frac{1}{\sqrt{45}}\sqrt{\frac{N_Q}{N}}\,\frac{M^2}{M_P^2}\left[x_Q y_Q f(x_Q^2)\right]^{-1}$$

[Senoguz and Shafi, PLB**567** (2003)]

$$\left(\frac{\delta T}{T}\right)_{Q-\text{tens}} \approx \frac{0.77}{8\pi}\kappa\frac{M^2}{M_P^2}$$



where $y_Q^2 = \int_1^{x_Q^2} \frac{\mathrm{dz}}{zf(z)}$ and

$$f(z) = (z+1)\ln(1+z^{-1}) + (z-1)\ln(1-z^{-1})$$

Calculating the number of e-fold N_Q, we obtain $\frac{M}{M_P} = \frac{\kappa\sqrt{NN_Q}}{2\pi} y_Q^{-1}$

Contribution to CMB anisotropies
2. Cosmic strings part

The cosmic strings contribution is proportionnal to the mass per unit lenght μ. For a network of Nambu-Goto strings,

$$\left(\frac{\delta T}{T}\right)_{Q-\text{strings}} \sim (9-10)G\mu \quad \text{where} \quad \mu = 2\pi\langle h\rangle^2$$

[Landriau and Shellard, astro-ph/0302166]

where, <h> is the VEV of the higgs field responsible of the strings formation. Here,

$$\langle h\rangle = \langle\phi_\pm\rangle = M \quad \text{and} \quad \left(\frac{\delta T}{T}\right)_{Q-\text{strings}} \approx \frac{9}{4}\frac{M^2}{{M_\text{P}}^2}$$

Contribution to CMB anisotropies
3. Total part

In conclusion, three sources contribute to the CMB quadrupole anisotropy :

$$\left(\frac{\delta T}{T}\right)^2_{Q-\mathrm{tot}} = \left(\frac{\delta T}{T}\right)^2_{Q-\mathrm{scal}} + \left(\frac{\delta T}{T}\right)^2_{Q-\mathrm{tens}} + \left(\frac{\delta T}{T}\right)^2_{Q-\mathrm{strings}}$$

where the r.h.s. must be normalised to COBE $(\delta T/T)_Q \sim 6\times10^{-6}$.

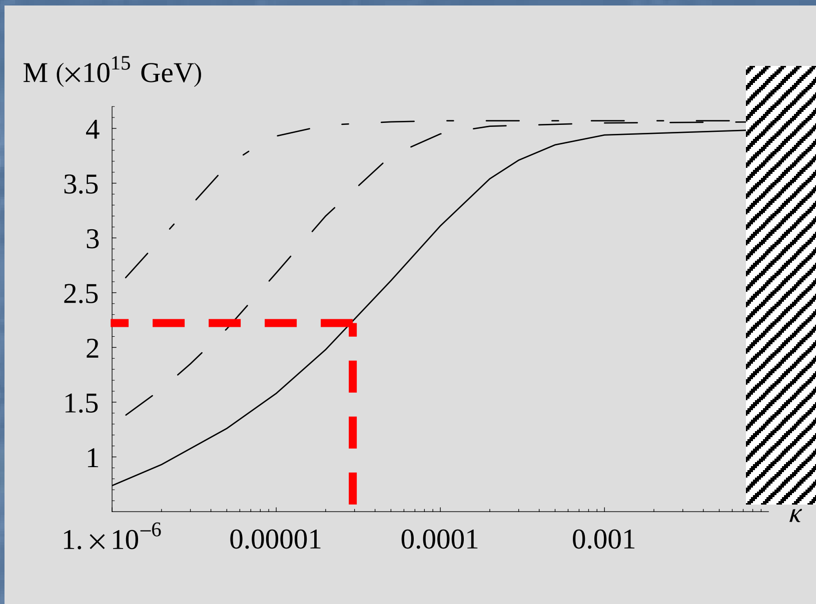
We obtain a single unknown equation in x_Q for a given κ, N=**3** and N_Q=60 :

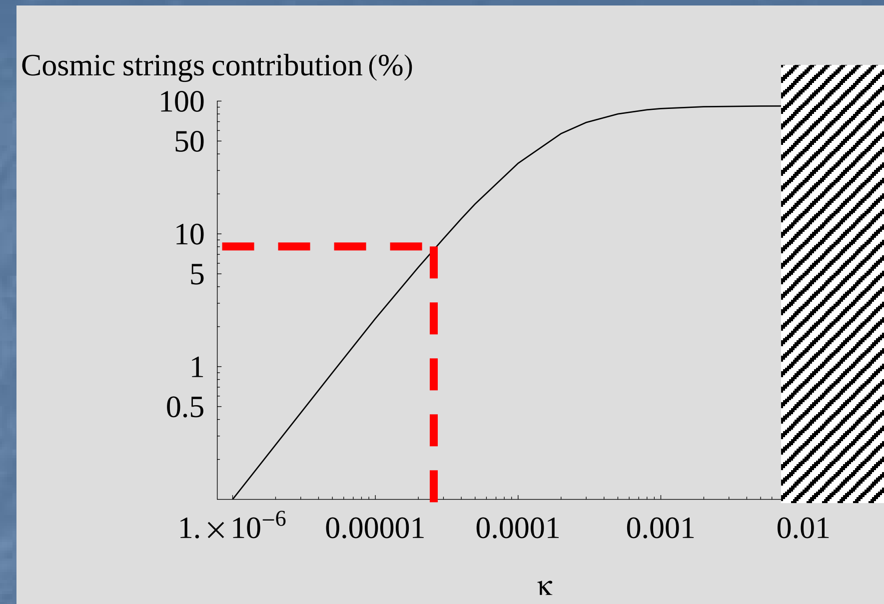
$$\left(\frac{\delta T}{T}\right)^2_{Q-\mathrm{COBE}} = y_Q^{-4}\left(\frac{\kappa^2 N N_Q}{32\pi^2}\right)^2\left[\frac{64 N_Q}{45 N} x_Q^{-2} y_Q^{-2} f^{-2}(x_Q^{\ 2}) + \left(\frac{0.77\kappa}{\pi}\right)^2 + 324\right]$$

Thus we obtain $x_Q(\kappa)$ and thus $M(\kappa)$. We can also calculate the strings contribution for a given κ defining

$$\mathrm{A}_{CS} = \left(\frac{\delta T}{T}\right)^2_{Q-\mathrm{strings}} \Big/ \left(\frac{\delta T}{T}\right)^2_{Q-\mathrm{tot}}$$

Constraints on F term inflation





- Gravitino constraint on the reheating temperature impose $\kappa < 8\times10^{-3}$
- In WMAP, the cosmic strings contribution to the CMB anisotropies is lower than 9% (99% CL). [Pogosian et al. astro-ph/0403268]

Consequences : $\kappa < 3\times10^{-5}$ ⟵ fine tuning of the coupling

$M < 2.2\times10^{15}$ GeV

The D term inflation

Introduction of an additionnal U(1) factor with a gauge coupling g and a non vanishing FI term ξ. [Charges under U(1) : $Q(\Phi_{\pm})=\pm 1$, $Q(S)=0$]

Superpotential :

$$W^D = \lambda S \Phi_+ \Phi_-$$

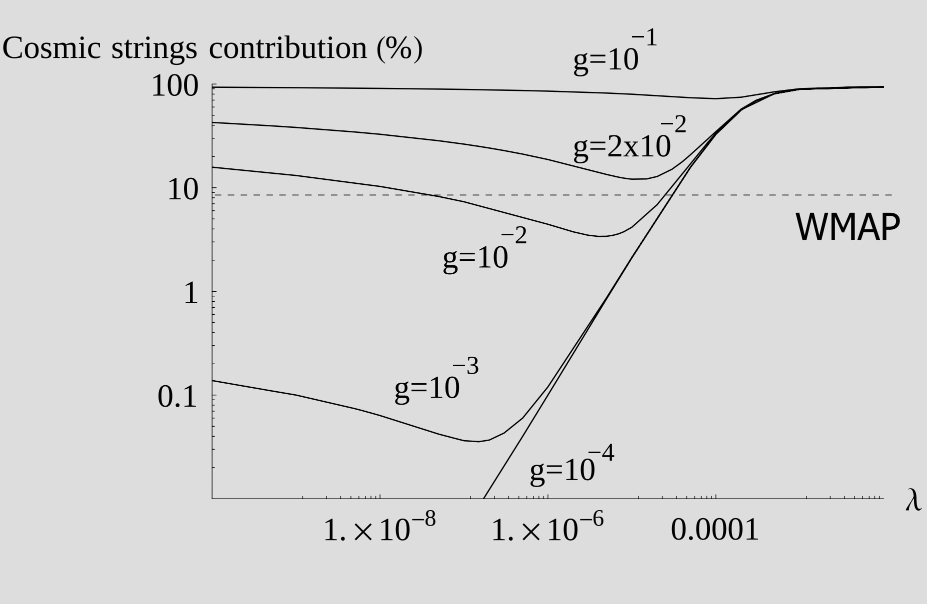
In the SUSY framework : the inflaton field reaches the PLANCK mass!!

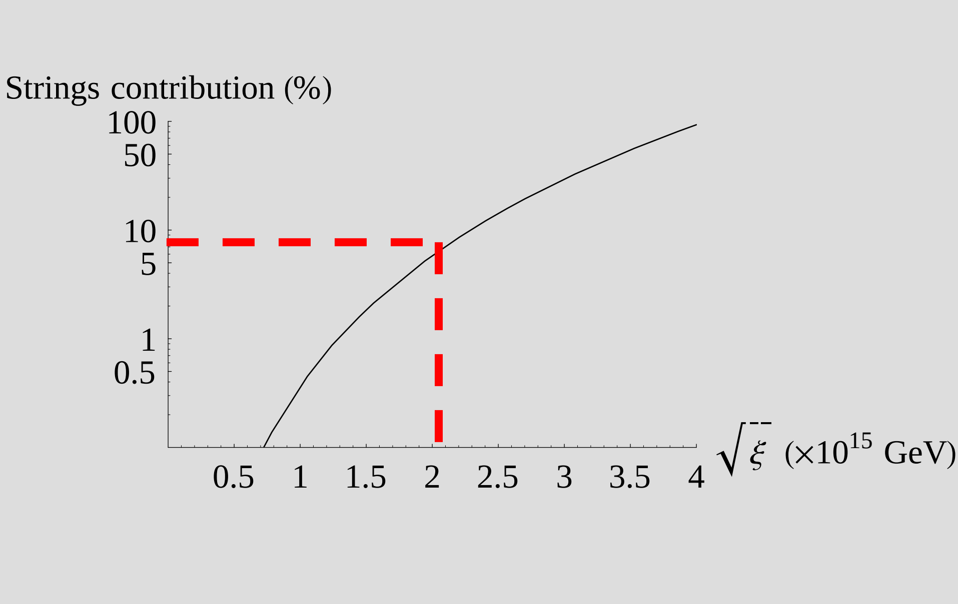
$\Rightarrow$ Supergravity is needed.

- $\longrightarrow$ Study in the minimal supergravity : $$K = |S|^2 + |\phi_+|^2 + |\phi_-|^2$$
- $\longrightarrow$ Completely numerical resolution.

We obtain the cosmic strings contribution as a function of the 3 parameters : g, λ, $\sqrt{\xi}$.

Constraints on D term inflation





- The WMAP constraint on cosmic string contribution to the CMB imposes

$$g < 2\times10^{-2}$$
$$\lambda < 3\times10^{-5}$$
$$\sqrt{\xi} < 2\times10^{15}\ \mathrm{GeV}$$

- The SUGRA corrections induce a lower limit on λ.

Conclusions

• The GUT cosmic strings are compatible with current CMB measurements.

• Their low influence on the power spectrum can be used to constrain inflationary models

• For F-term inflation, both the superpotential coupling κ and the mass scale M can be constrained.

• For D-term inflation, the gauge g and the superpotential λ coupling constant as well as the FI term ξ can be constrained.

The SUGRA framework is necessary. This is still an open possibility.

• For both, we obtain a mass scale (M or $\sqrt{\xi}$) smaller than 2×10^{15} GeV and a superpotential coupling (κ or λ) smaller than 3×10^{-5}.

These models suffer from some fine tuning...

J. R., M. Sakellariadou (2004) [hep-ph/0405133, hep-ph/0406120]