INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
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SMR.762 - 20

SUMMER SCHOOL IN HIGH ENERGY PHYSICS AND COSMOLOGY

13 June - 29 July 1994

LECTURE ON SUSY GUTS AND INFLATION

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Please note: These are preliminary notes intended for internal distribution only.

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Inflation & Particle Physics

Inflationary Cosmology contains a large number of parameters. They include

$$H_0, \Omega_b, \Omega_{CDM}, \Omega_{HDM}, n_s, n_g, \Lambda, \ldots$$

Any 'sensible' theory hopefully predicts at least some of them, consistent with the observations.

Why should particle physics be relevant?

If we think that GUTS/SUSY GUTS are relevant, then have to worry about monopoles

<u>Plus</u> if we can do inflation with GUTS we can 'better trust' the calculation.

R-symmetric Superpotential

$$W = \kappa S \bar{\phi} \phi - \mu^2 S$$

gauge singlet

Gauge non-singlets

<u>Under R</u>:

$$\left.\begin{array}{l} S \to e^{i\gamma} S \\ \bar{\phi}\phi \to \text{invariant} \end{array}\right\} W \to e^{i\gamma} W$$

<u>Note</u>: S^2, S^3 excluded by R-sym.

From $W \longrightarrow V$ (potential)

$$V(S,\phi,\bar{\phi}) = \kappa^2 |S|^2 \left[|\phi|^2 + |\bar{\phi}|^2 \right] + \left| \kappa \phi\bar{\phi} - \mu^2 \right|^2 + D\text{-terms}$$

Look for supersymmetric minimum

Get

$$|\langle\phi\rangle| = |\langle\bar{\phi}\rangle| = \mu/\sqrt{\kappa} \quad (\kappa > 0) \quad (\equiv M_x)$$

$$\langle S \rangle = 0$$

Consider Early Universe With Chaotic Initial Conditions

In particular, for $S > S_c \, (\equiv M_x)$, it is favorable to have $\phi = \bar{\phi} = 0$

$(V = 2(\kappa^2|S|^2 - \kappa\mu^2)|\phi|^2 + \mu^4 + \kappa^2|\phi|^4$

Energy density $\sim \mu^4 \Rightarrow$ inflation

Q/ What 'drives' S to zero?

A/ Look at Radiative Corrections

(κ not small!)

<u>Note</u>: S non-vanishing $\Rightarrow$ SUSY broken

$F_S = \mu^2$

One Loop:

$$\Delta V(S) = \sum_i \frac{(-)^F}{64\pi^2} M_i^4(S) \ln\left(\frac{M_i^2(S)}{\Lambda^2}\right)$$

So

$$V_{eff}(S) = \mu^4 + \frac{\kappa^2}{32\pi^2}\Big[2\mu^4 \ln\left(\frac{\kappa^2 S^2}{\Lambda^2}\right)$$

$$+ (\kappa S^2 - \mu^2)^2 \ln\left(1 - \frac{\mu^2}{\kappa S^2}\right)$$

$$+ (\kappa S^2 + \mu^2)^2 \ln\left(1 + \frac{\mu^2}{\kappa^2 S^2}\right)\Big]$$

For $S \gg S_c$, it reduces to

$$V_{eff}(S) \sim \mu^4\Big[1 + \frac{\kappa^2}{32\pi^2}\Big(\ln \frac{\kappa^2 S^2}{\Lambda^2} + \frac{3}{2}\Big)$$

$S' > S_c$, μ^4 dominates $\to$ inflation

$S \approx S_c$, $\phi, \bar{\phi} \longrightarrow$ driven to their non-zero values

$\Rightarrow$ gauge symmetry broken

Below S_c , the term $\kappa^2 S^2 \phi^2$ is increasingly more effective in driving S to its supersymmetric value (of zero)

<u>Remark</u>:

Inflation ends before S reaches $S_c \Rightarrow \phi, \bar{\phi}$ cannot break the GUT symmetry but may have GUT vevs (e.g. $SO(10), (SU(3))^3$)

$$\ddot{\phi} + 3H\dot{\phi} \approx -\frac{\partial V}{\partial \phi}$$

'Slow roll' conditions

$$\epsilon \ll 1, \quad |\eta| \ll 1$$

$$\epsilon = \frac{M_P^2}{16\pi}\left(\frac{V'}{V}\right)^2, \quad \eta = \frac{M_P^2}{8\pi}\frac{V''}{V}$$

$$\eta = \left(\kappa M_P / 4\pi M_x\right)^2 \frac{1}{8\pi}\left[(3x^2-1)\ln\left(1-\frac{1}{x^2}\right) + (3x^2+1)\ln\left(1+\frac{1}{x^2}\right)\right.$$

blows up as $x \to 1$ $\quad (x \equiv S/S_c)$

<u>Note</u>: SUSY breaking effects are characterized by a TeV scale mass

$\Rightarrow$ small corrections to $V_{eff}(S)$

$\Rightarrow$ inflation does not depend on details of SUSY breaking

Let us look at $\delta\rho/\rho$ (or better still $(\Delta T/T)_Q$ ← measured by COBE) $\sim 7 \times 10^{-6}$

$$(\Delta T/T)_Q \approx \sqrt{\frac{32\pi}{45}} \, \frac{V^{3/2}}{M_P^3 V'}$$

$$\approx (8\pi N_Q)^{1/2} \underbrace{(M_X/M_P)^2}$$

Reminiscent of cosmic strings!!

$\therefore$ $\Delta T/T$ is small $\because$ M_{GUT} is about 3 orders of magnitude smaller than M_P

With $N_Q \sim 50$ say, $M_X \sim 10^{15.5}$ GeV

Spectral Index n of density fluctuations is readily estimated

$$n \approx 0.98 \quad (\text{close to H-Z})$$

What about κ?

$$\frac{\kappa}{x_Q} \sim \frac{8\pi}{\sqrt{N_Q}} \frac{M_x}{M_P}$$

With $x_Q \sim 10$ (so $S \sim 10 S_c \Rightarrow S \ll M_P$
$\Rightarrow$ planck scale corrections are small)

you get $\kappa \sim 10^{-2}$ ('tiny' coeffs. absent)

Does this work in realistic GUTS??

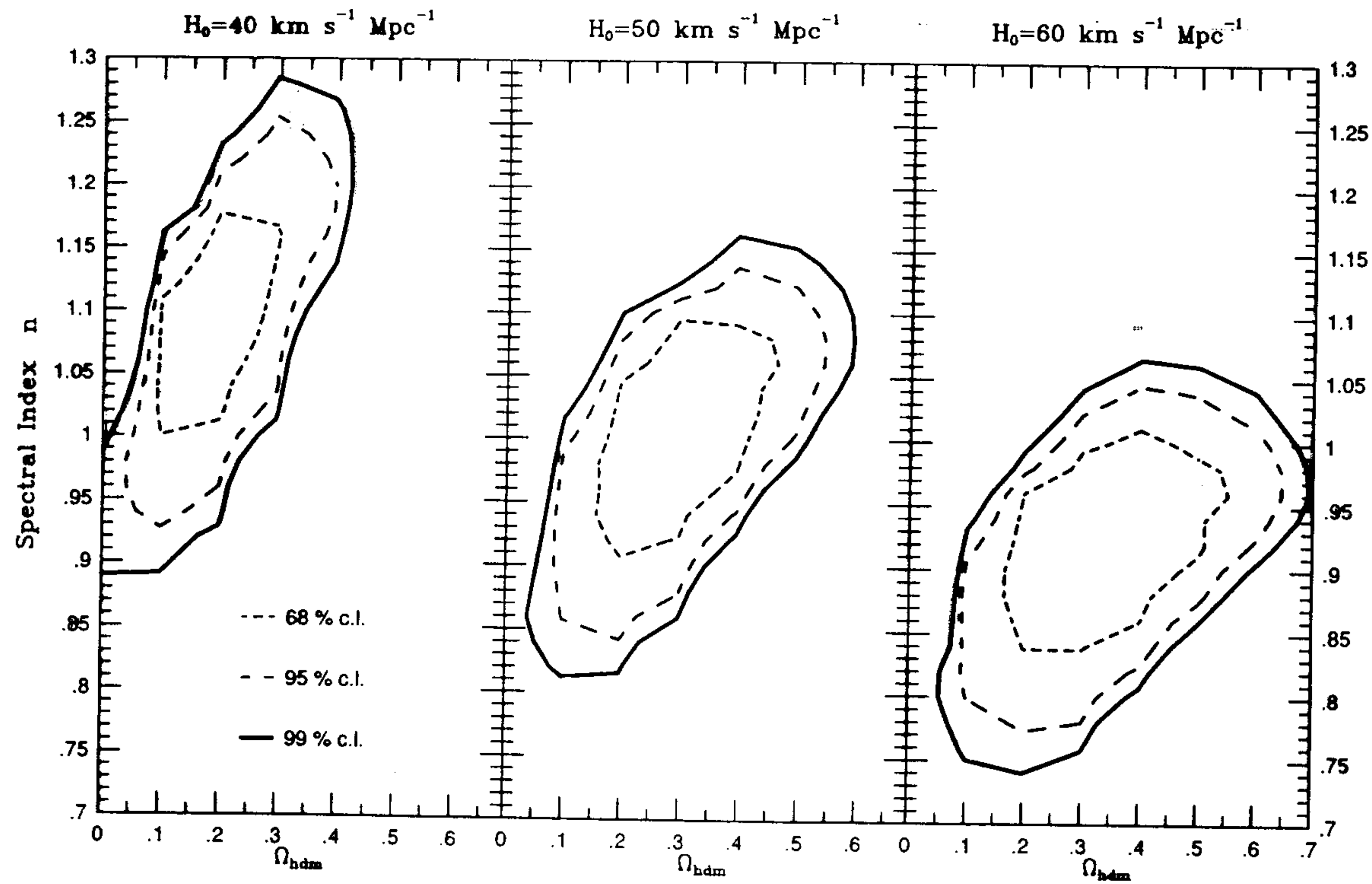
Need SO(10) or higher rank

Simplest example I know of

is based on $G \equiv SU(3)_c \times SU(3)_L \times SU(3)_R$

('trinification')

This model, at least in the 'higgs' sector, is far simpler than SO(10).



H0=40 km s-1 Mpc-1
H0=50 km s-1 Mpc-1
H0=60 km s-1 Mpc-1
Spectral Index n
Ωhdm
Ωhdm
Ωhdm
68 % c.l.
95 % c.l.
99 % c.l.