Split SUSY and Flat Directions

Kin-Wang Ng (吳建宏)

Institute of Physics (中央研究院物理所)
& Institute of Astronomy
and Astrophysics(中央研究院天文所)

Academia Sinica, Taiwan, ROC

SUSY 2015, Lake Tahoe
Aug 25, 2015

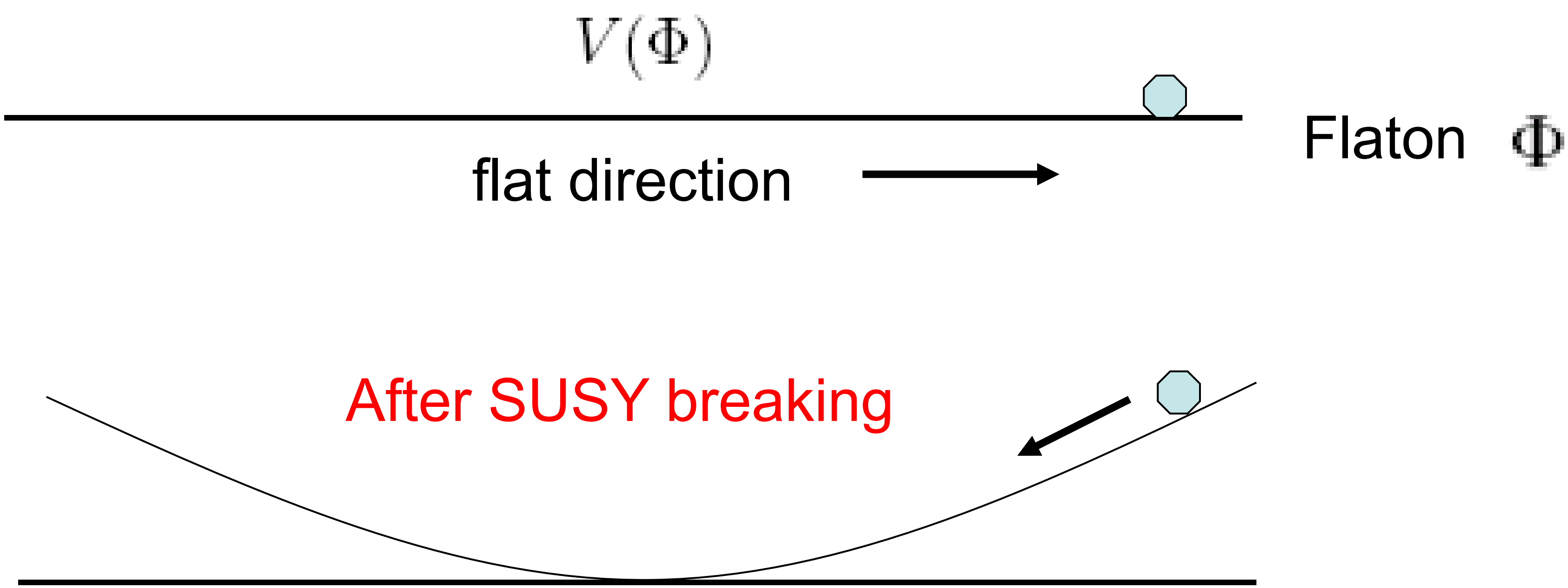
Collaborators: YY Charng, DS Lee, CN Leung

Flat Directions in Scalar Potential of MSSM

Non-zero vevs for squarks and sleptons

$$\langle \tilde{u}_3^c \rangle = a, \quad \langle \tilde{u}_1 \rangle = v; \quad \langle \tilde{s}_2^c \rangle = a,$$

$$\langle \tilde{\mu} \rangle = v; \quad \langle \tilde{b}_1^c \rangle = e^{i\xi}\sqrt{|v|^2 + |a|^2},$$



Affleck-Dine Baryogenesis

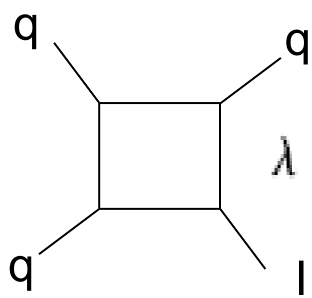
$$\mathcal{L} = \left(\partial_\mu \Phi^\dagger\right)\left(\partial^\mu \Phi\right) - V(\Phi),$$
$$V(\Phi) = m_\Phi^2 \Phi^\dagger \Phi + i\lambda\left(\Phi^4 - \Phi^{\dagger\,4}\right),$$

SUSY breaking scale

$m_\Phi^2 = M_S^2$

CP violating

with baryon or lepton number



$\lambda \sim \epsilon M_S^2 / M_G^2$

approximately conserved current

$$j_\mu = i(\Phi^\dagger \partial_\mu \Phi - (\partial_\mu \Phi^\dagger)\Phi)$$

$j_0 = n_B$

Classically, in an expanding universe, Φ obeys the equation of motion

$$\frac{d^2\Phi}{dt^2} + 3H\frac{d\Phi}{dt} + m_\Phi^2\Phi = 4i\lambda\Phi^{\dagger 3}, \tag{4}$$

where H is the Hubble parameter. With the initial conditions at $t = t_0$:

$$\Phi|_{t=t_0} = i\Phi_0 \quad \text{and} \quad \dot{\Phi}|_{t=t_0} = 0, \tag{5}$$

where Φ_0 is real and $\dot{\Phi} = d\Phi/dt$, it was found that the baryon number per particle at large times ($t \gg m_\Phi^{-1}$) in either a matter-dominated or a radiation-dominated universe is given by

$$r \simeq \lambda\Phi_0^2/m_\Phi^2. \tag{6}$$

$r \equiv n_B / n_\Phi >>$ observed $n_B/s \approx 10^{-10}$

Affleck-Dine Baryogenesis

$$\mathcal{L} = \left(\partial_\mu \Phi^\dagger\right)\left(\partial^\mu \Phi\right) - V(\Phi),$$

$$V(\Phi) = m_\Phi^2 \Phi^\dagger \Phi + i\lambda\left(\Phi^4 - \Phi^{\dagger\,4}\right),$$

SUSY

$$m_\Phi^2 = M_S^2 \text{ and } \lambda = \epsilon M_S^2/M_G^2$$

$$\epsilon = 10^{-3},\ M_S = 10^{-16} M_P,\ M_G = 10^{-2} M_P,$$

SPLIT SUSY

$$m_\Phi^2 = \tilde{m}^2 \text{ and } \lambda = \epsilon\, A / M_p$$

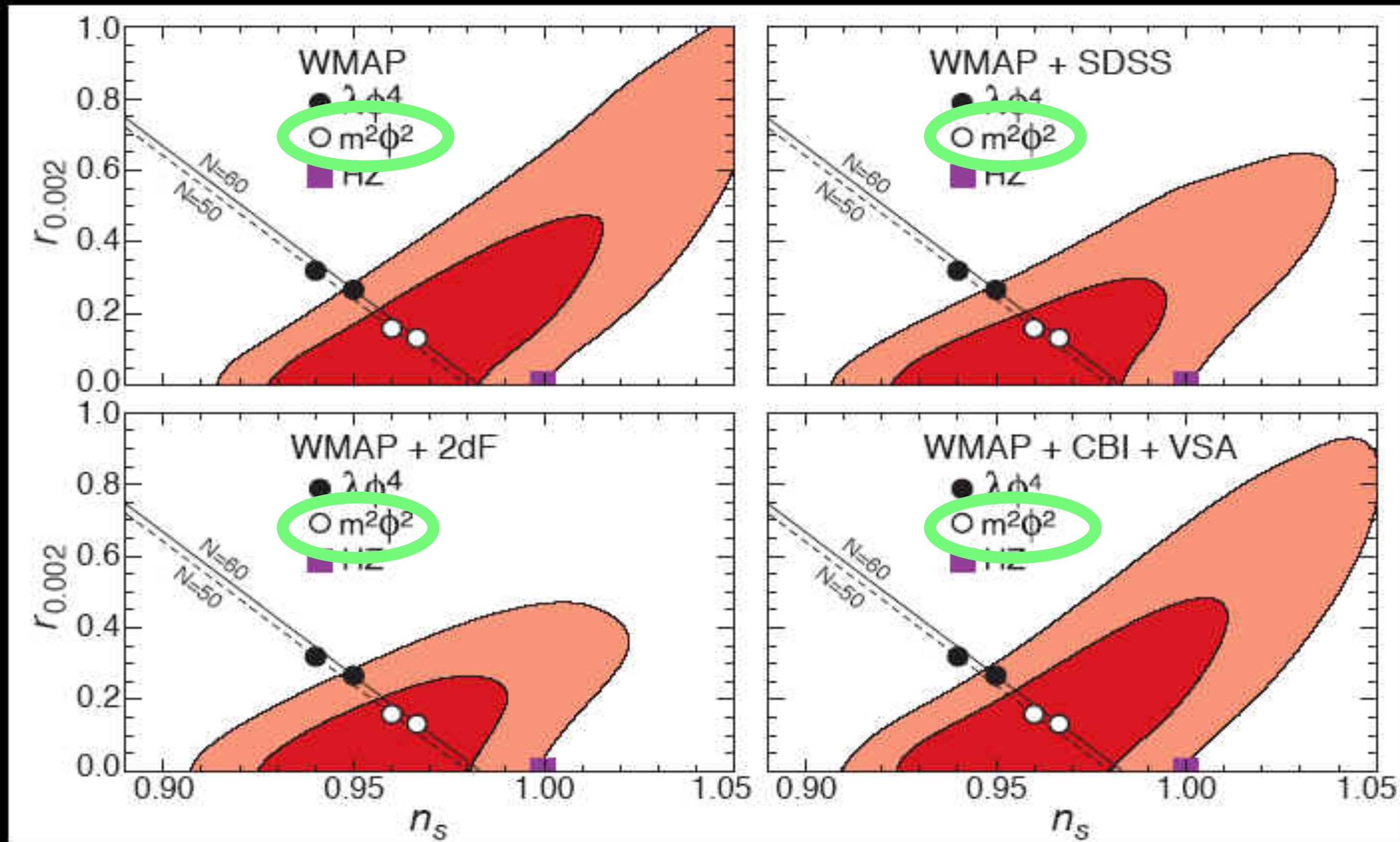
$$\epsilon = 10^{-1},\ \tilde{m} \lesssim 10^{13} \text{ GeV},\ A \sim \text{TeV}.$$

A-term
$\lambda\Phi^4$

M_P is the Planck mass **10^{19} GeV**

WMAP and chaotic inflation

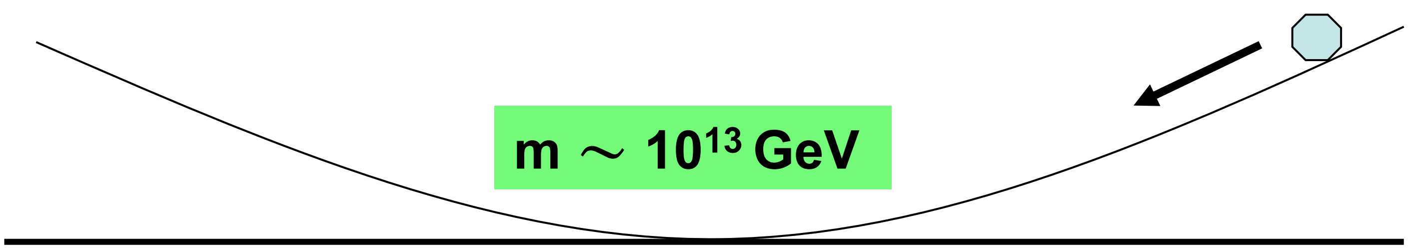
r : tenor/scalar



Spectral index

$$n(k) - 1 \equiv \frac{d \ln \mathcal{P}_{\mathcal{R}}}{d \ln k}$$

Spergel et al (2006)

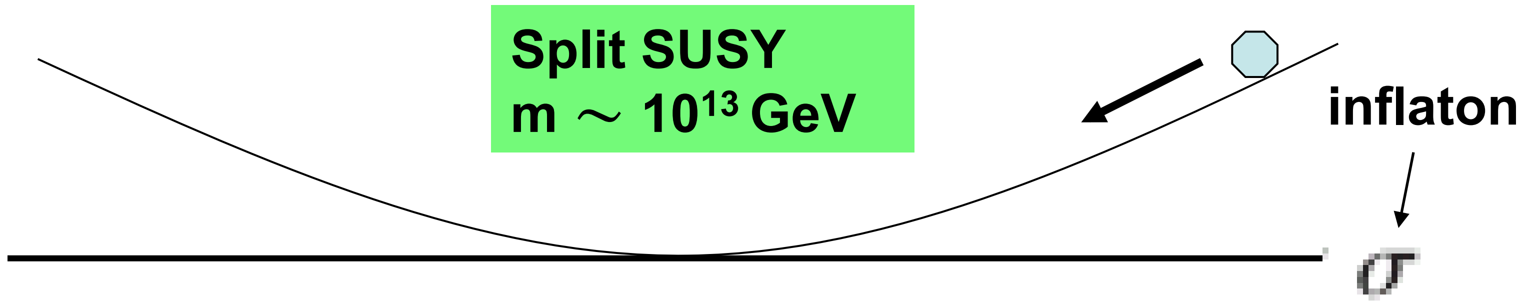


m ∼ 10^{13} GeV

There has been a scenario in which both baryogenesis and inflation are combined in one setting – one stone two birds

- Affleck-Dine Supersymmetric Baryogenesis 1985
- Chaotic inflation 1983
- Charng et al 2009, Hertzberg & Karouby 2014

Affleck-Dine Baryogenesis and chaotic inflation



$$m \simeq 1.1 \times 10^{-6} M_P, \ \lambda \simeq 1.8 \times 10^{-21},$$

$$\frac{1}{\sqrt{2}}(\sigma + i\chi) = e^{-i\bar{\theta}_0}\Phi.$$

initial conditions, $\bar{\sigma} = 4M_p$ and $\bar{\chi} = \dot{\bar{\sigma}} = \dot{\bar{\chi}} = 0$

Supergravity effects and η problem

$$V = e^{(8\pi/M_P^2)K}\left[\left(\frac{\partial^2 K}{\partial\Psi\partial\Psi^*}\right)^{-1} D_\Psi W D_{\Psi^*} W^* - 3\frac{8\pi}{M_P^2}|W|^2\right],$$

Here K is the Kähler potential, W is the superpotential, ; Ψ represents all relevant scalar fields in the model.

$$D_\Psi W = \frac{\partial W}{\partial\Psi} + \frac{8\pi}{M_P^2}\frac{\partial K}{\partial\Psi}W.$$

If K=AA*, then we have η Problem

Slow-roll parameters

$$\epsilon = \frac{M_P^2}{16\pi}\left(\frac{1}{V}\frac{\partial V}{\partial\bar\sigma}\right)^2, \qquad \eta = \frac{M_P^2}{8\pi}\left(\frac{1}{V}\frac{\partial^2 V}{\partial\bar\sigma^2}\right),$$

$$K(A, B) = \frac{1}{2}(A + A^*)^2 + BB^*, \quad W = mAB,$$

$$\begin{aligned} V(\rho, \sigma, \chi) = {} & m^2 e^{(8\pi/M_P^2)(\rho^2+\chi^2/2)} \\ & \times\left\{\frac{1}{2}(\rho^2 + \sigma^2)\left[1 + \left(\frac{8\pi}{M_P^2}\right)^2\frac{1}{4}\chi^4\right]\right. \\ & + \frac{1}{2}\chi^2\left[1 - \frac{8\pi}{M_P^2}\frac{1}{2}(\rho^2 + \sigma^2)\right. \\ & \left.\left. + \frac{8\pi}{M_P^2}2\rho^2\left(1 + \frac{8\pi}{M_P^2}\frac{1}{2}(\rho^2 + \sigma^2)\right)\right]\right\}. \end{aligned}$$

$$\langle\tilde u_3^c\rangle = A, \qquad \langle\tilde u_1\rangle = B; \qquad \langle\tilde s_2^c\rangle = A,$$

$$\langle\tilde\mu\rangle = B; \qquad \langle\tilde b_1^c\rangle = e^{i\xi}\sqrt{|A|^2 + |B|^2},$$

$$A = \frac{1}{\sqrt{2}}(\rho + i\sigma), \qquad |B| = \frac{1}{\sqrt{2}}\chi,$$

inflaton field (σ)

Shift Symmetry

$$K(A, B) = \frac{1}{2}(A + A^*)^2 + BB^*, \tag{17}$$

which is invariant under the shift of A: $A \to A + icM_P$, where c is a real parameter. As a consequence, the exponential factor in Eq. (15) no longer prevents the imaginary part of A from having a larger value than M_P, which we identify with the inflaton field σ in the potential (14). As

the AD mechanism, the scalar quark and lepton fields get vacuum expectation values which break the standard-model gauge symmetries. As such, during inflation there may exist effective operators, for example, $\bar{u}^*\langle Q\rangle\langle L\rangle\langle\bar{d}^*\rangle$ and $\bar{u}^* L\langle Q\rangle\langle\bar{d}^*\rangle$, which do not respect the standard-model gauge symmetries. This particular feature of the AD mechanism indeed opens a possibility for imposing a shift symmetry on the AD flat direction even though the flat direction is not a gauge singlet. For instance, assuming that all of the vacuum expectation values are real numbers, the Lagrangian may contain terms like $\bar{u} + \bar{u}^*$ which carries the shift symmetry. Interestingly, these operators are not

Summary

- ”Complex Chaotic Inflation” to accommodate inflation as well as baryogenesis
- Realized in Split SUSY models with $m \sim 10^{13}$ GeV, A-term coupling $\lambda \sim 10^{-21}$
- Shift symmetry may exist to solve **η** problem in supergravity effects