Gauged Inflaton

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Can we construct an Inflaton which carries the Standard Model charges ?

Collaborators

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Motivation

- Inflation dilutes everything :

  1) How to create Standard Model baryons &

  Cold dark matter

- Mass and couplings of the Inflaton should be

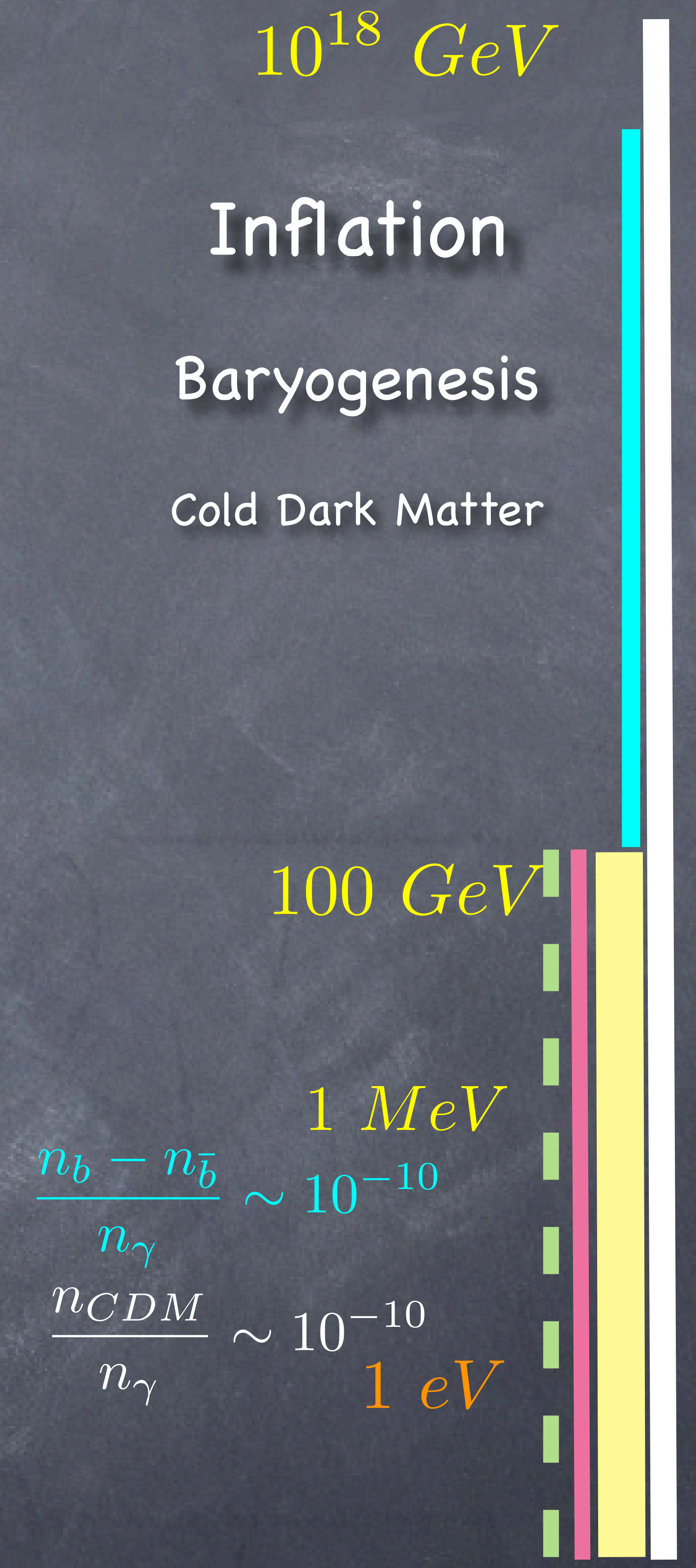
  known :

  1) Quantum stability, UV corrections

  2) Predictivity and reliability

  3) Testability

- Can we test the Inflaton in a laboratory ?



Existing models of inflation

- Particle physics motivated examples:

$$V(\phi,\chi) = \lambda^2\phi^2(\chi^2 - \chi_0^2)^2 + g^2\phi^2\chi^2 + m^2\phi^2$$

$$\phi,\ \chi \Rightarrow (Absolute\ Gauge\ Singlets)$$

$$\lambda,\ m,\ g\ \Rightarrow (Ad-hoc\ numbers\ just\ to\ match\ the\ CMB\ data)$$

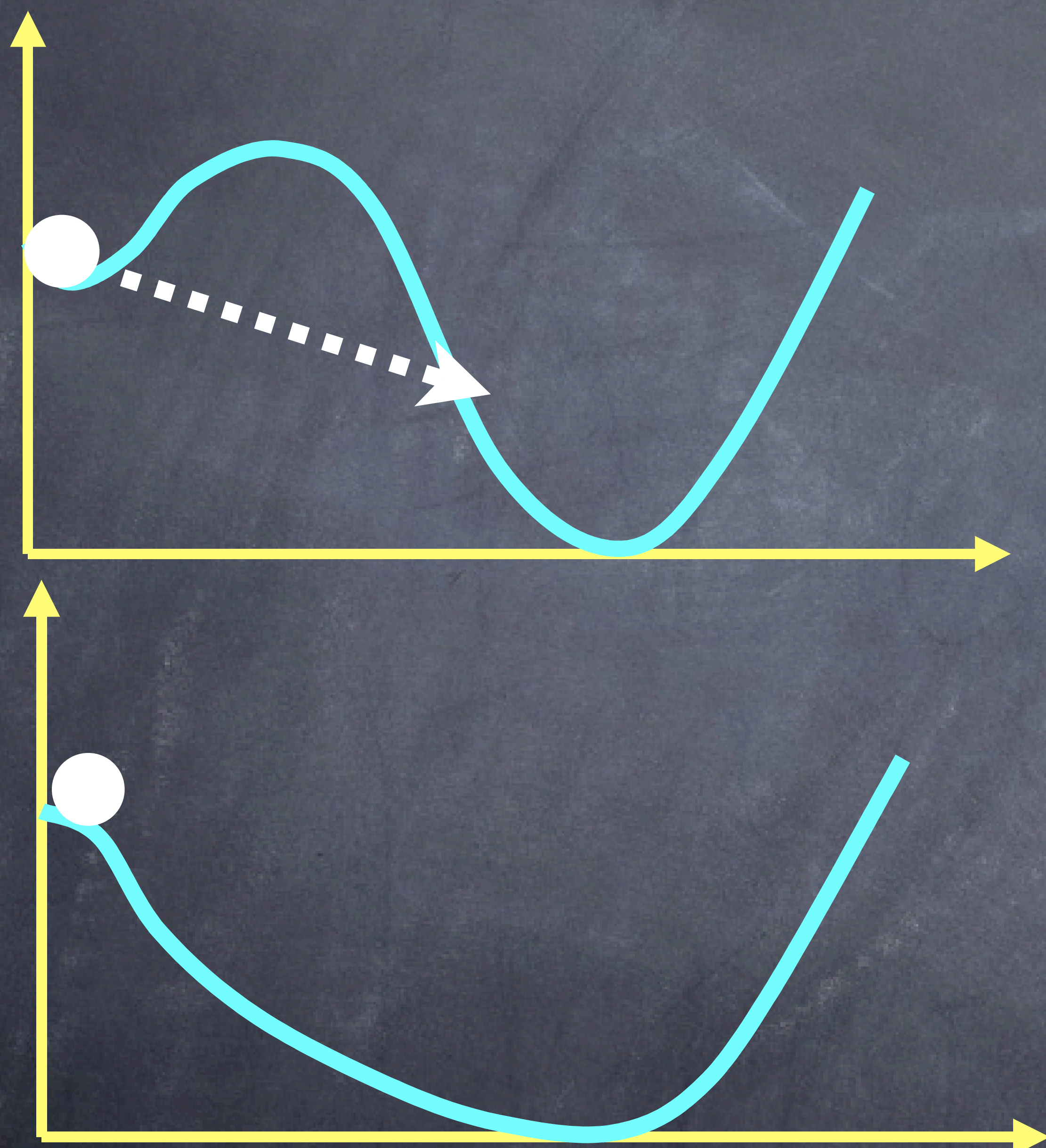
$$\phi$$

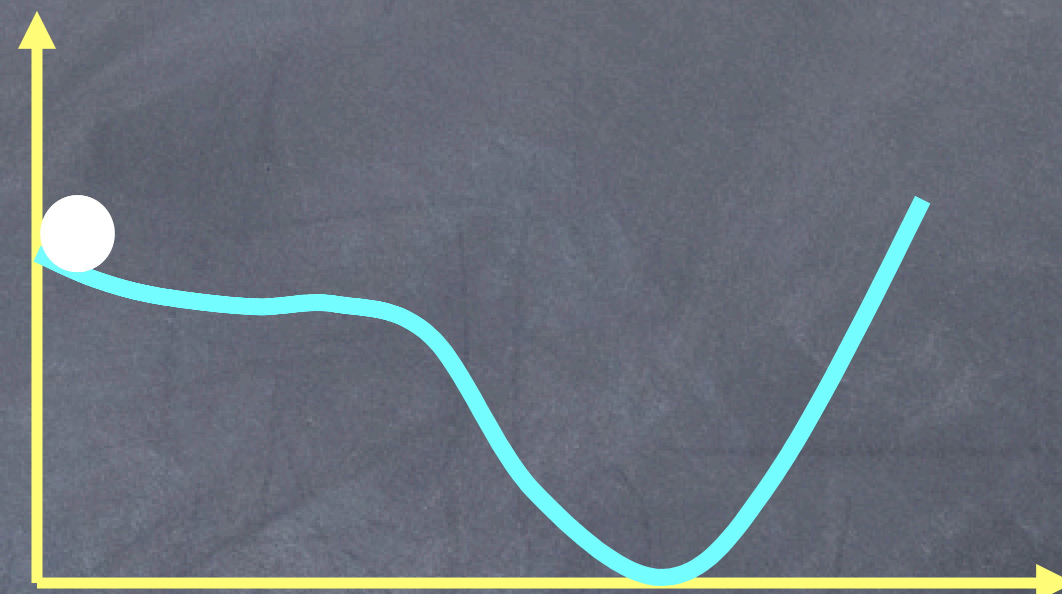
$$\phi^2(Higgs)^2 \qquad \phi^2(Hidden)^2$$

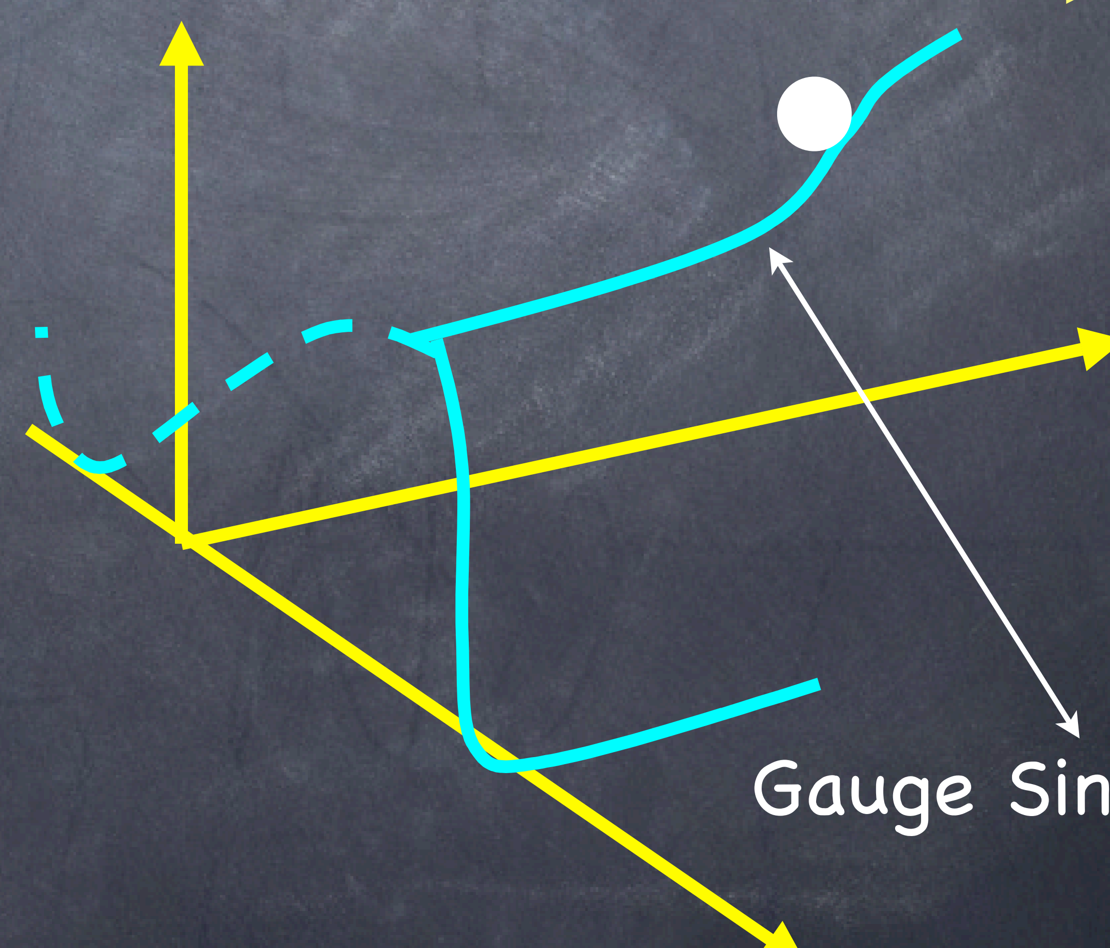
$SM\ degrees\ of\ freedom$ $\qquad$ $Hidden\ degrees\ of\ freedom$

Why the Inflaton predominantly decays into the SM baryons ?

Challenge is to get rid of the bump?







- In reality the potential is rather steep
- Radiative corrections spoil the shape

Existing models of inflation

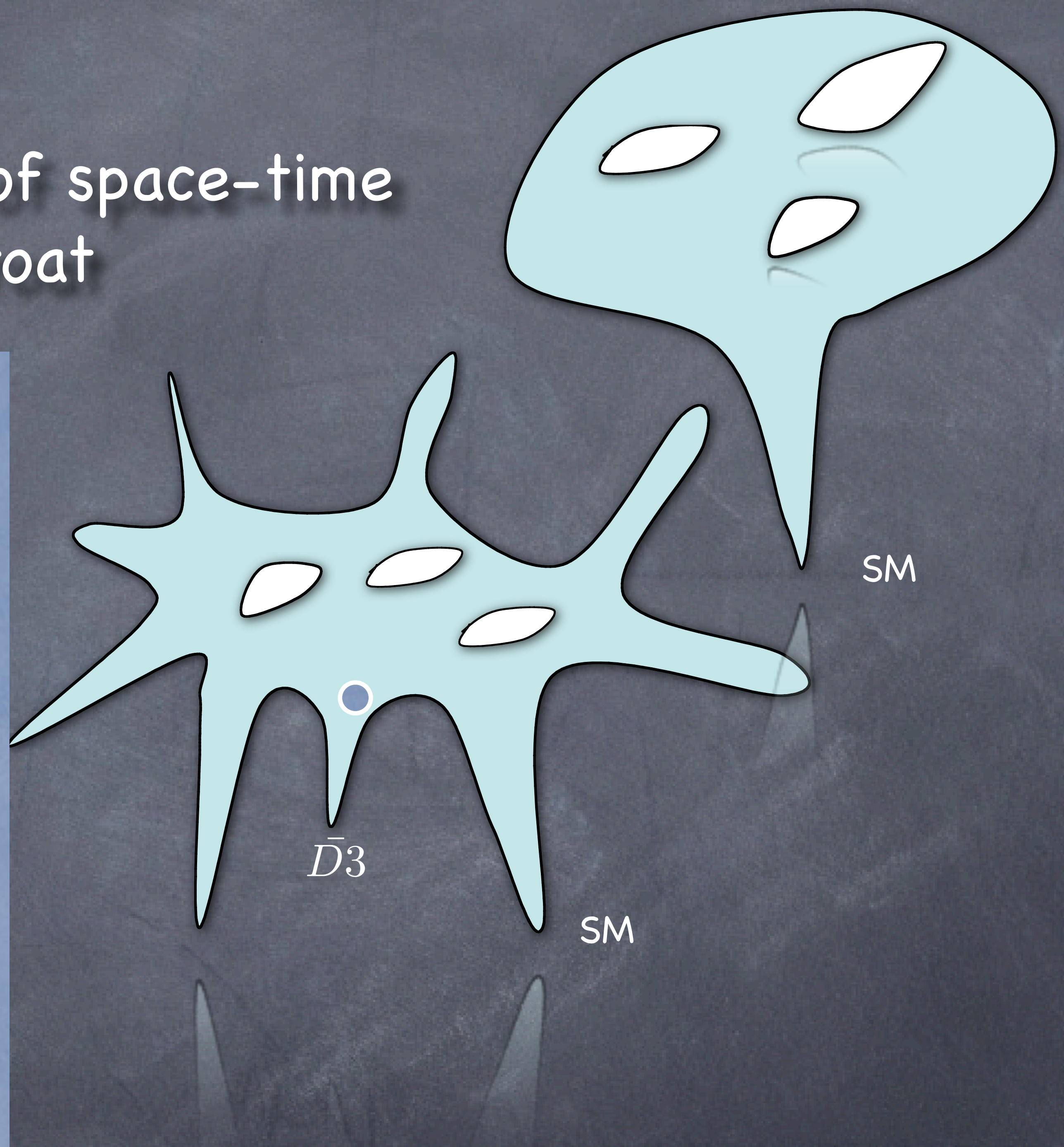
- String inspired models:
  1) Inflation happens in the bulk of space-time
  2) Inflation at the tip of the throat

How to transfer the energy from the bulk to the observable sector is not known

How to transfer the energy from one throat to another is still plagued by many issues

1) UV corrections
2) Boundary conditions

Q) Why the energy will be transferred only to the observable sector ?



A. Frey, A.M., R. Myers, 2005

Now imagine having a landscape of such shapes and throats

Q) Why can't we inflate the SM sector ?

SM Higgs

- SM Higgs with a Standard GR :

  1) Potential is too steep

  2) Energy density in the Higgs is not sufficient to generate observed density perturbations

- What if there exists: $\xi R H^2$

  1) Potential can be flattened and you can match the observations

  2) Who selects the coupling $\xi \sim 10^{-6}$

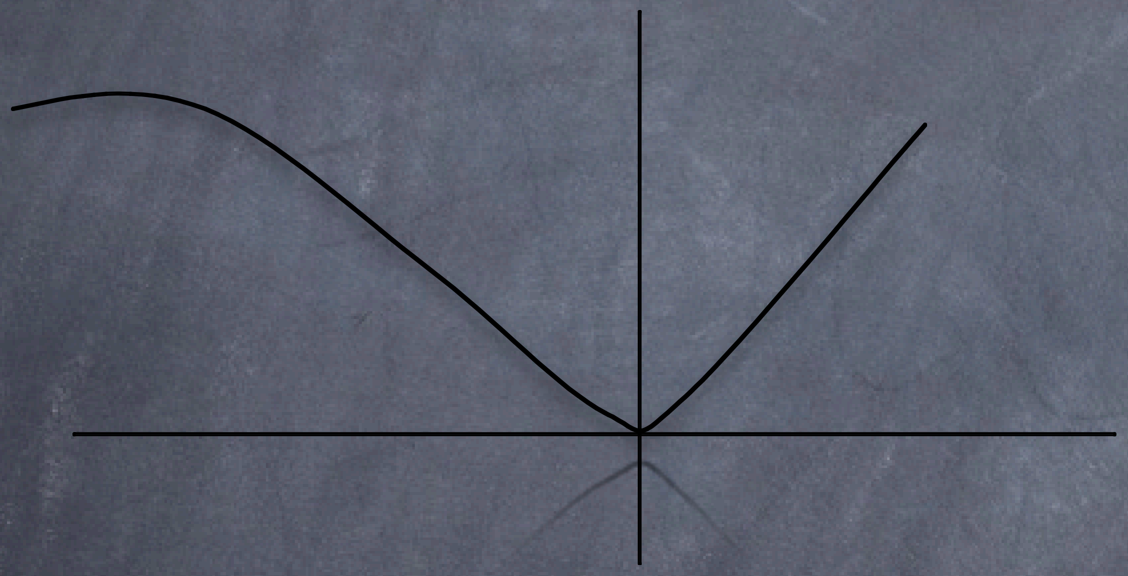
Shaposhnikov 2006

How would we test such non-conformal coupling ?

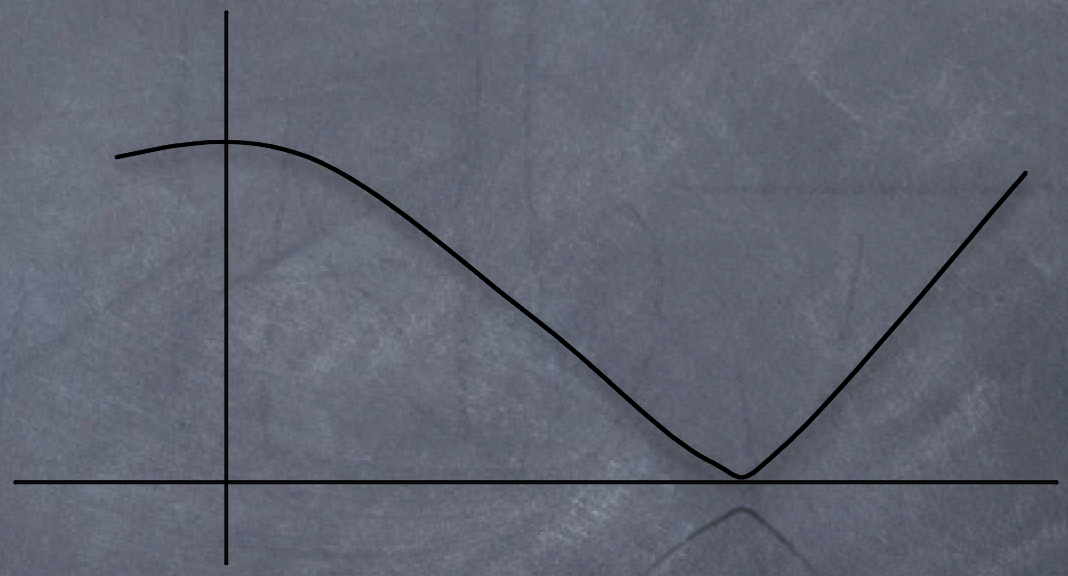
A gauged Inflaton

- Embed inflation within a SM gauge thory

Choice of Vacuum



Point of enhanced symmetry favored



Color & charge breaking minimum disfavored

Provided the order parameter carries SM charges

Note: The Higgs cannot be the inflaton without modifying GR

SUSY

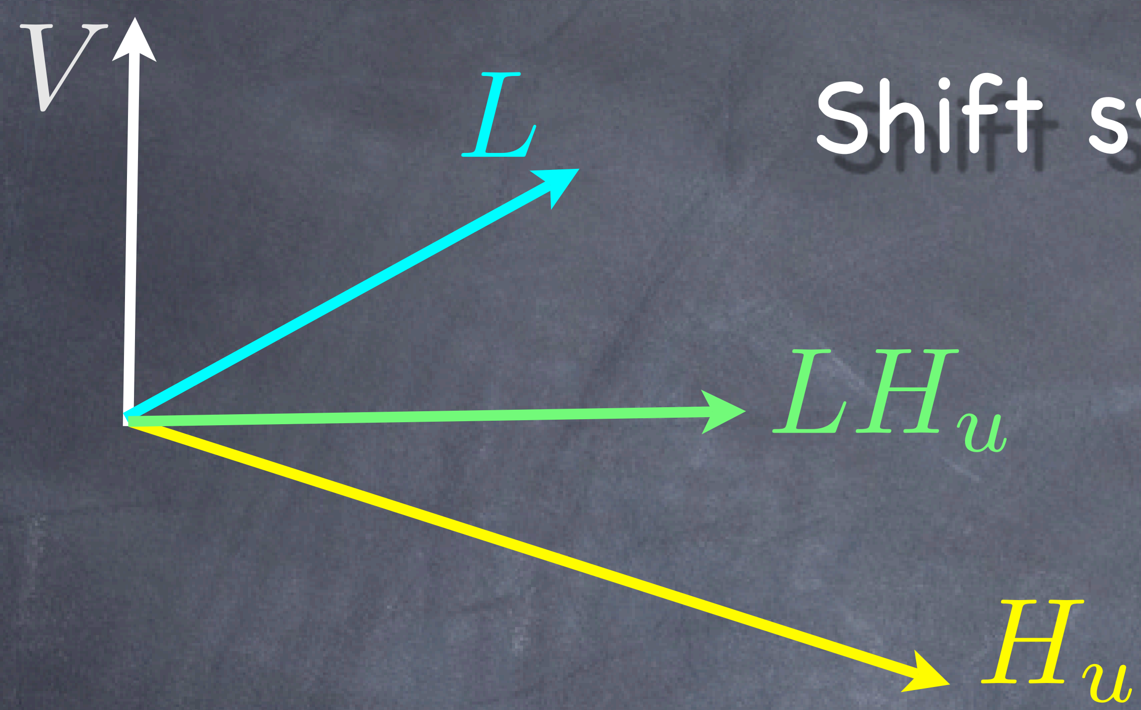
- SUSY address the hierarchy issue
- SUSY has scalars, i.e. squarks, sleptons, etc.
- SUSY has flat directions
  1) Gauge invariant combination of squarks and sleptons
  2) F-and D- flat directions

$$\tilde{u}\tilde{d}\tilde{d} \quad LL\tilde{e} \quad H_u H_d \quad LH_u \quad \tilde{u}\tilde{u}\tilde{d}\tilde{e} \quad QQQL$$

All carry SM charges

$$NH_uL \qquad SU(2)_L \times U(1)_Y \times U(1)_{B-L}$$

SUSY provides flat directions



Shift symmetry

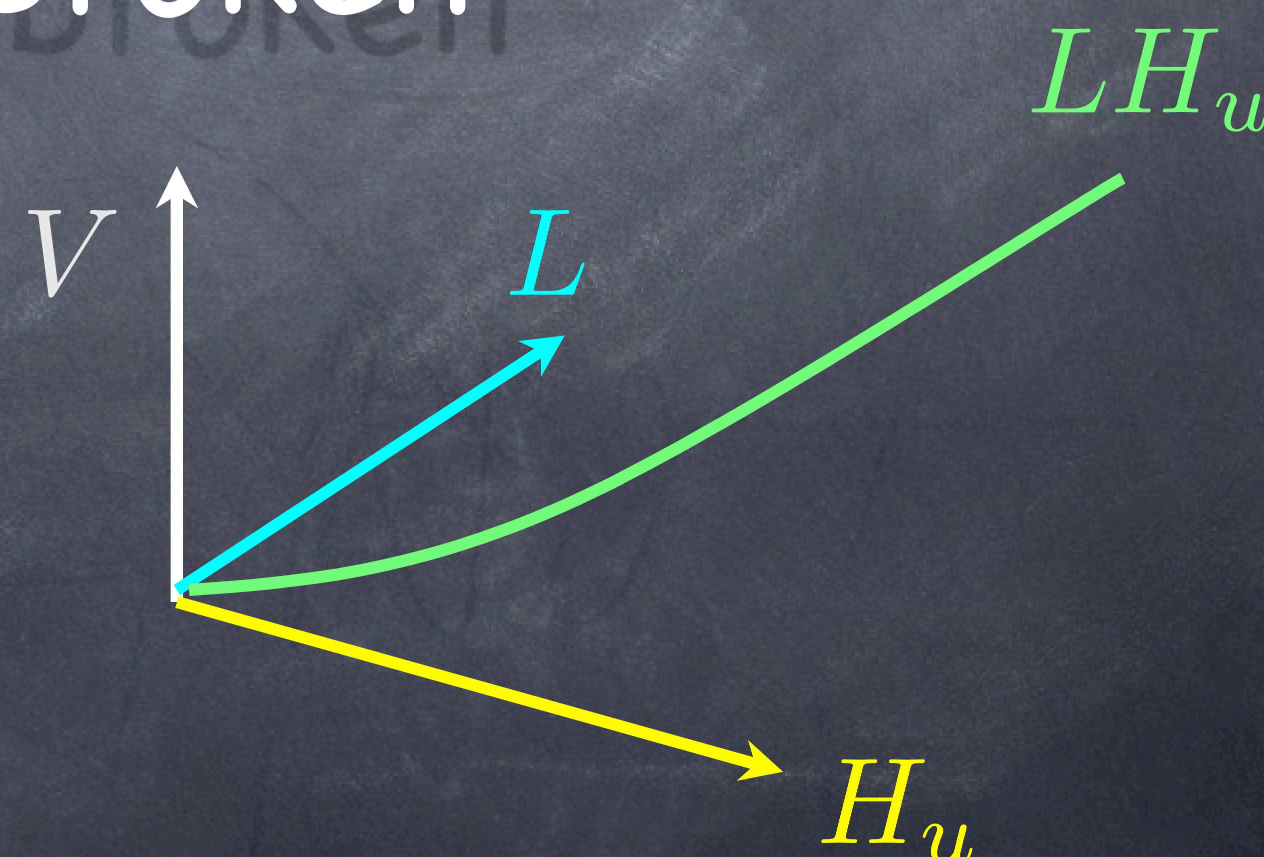
$$H_u = \frac{1}{\sqrt{2}}\begin{pmatrix}0\\ \phi\end{pmatrix}, \quad L = \frac{1}{\sqrt{2}}\begin{pmatrix}\phi\\ 0\end{pmatrix}$$

$$\Phi = LH_u \equiv c\phi^2$$

$$In\ \ general \quad \Phi = c\phi^m$$

SUSY is broken

Shift symmetry
is broken



Enqvist, Mazumdar Phys. Rept. (2004)

Dine, Kusenko, Rev. Mod. Phys. (2005)

Gauged Inflaton

$$\tilde{u}\tilde{d}\tilde{d} \quad LL\tilde{e} \quad NH_uL$$

Inflaton carries Standard Model Charges

Allahverdi, Enqvist, Jokinen, Garcia-Bellido, Mazumdar, PRL (2006)
Allahverdi, Kusenko, Mazumdar, JCAP (2006)

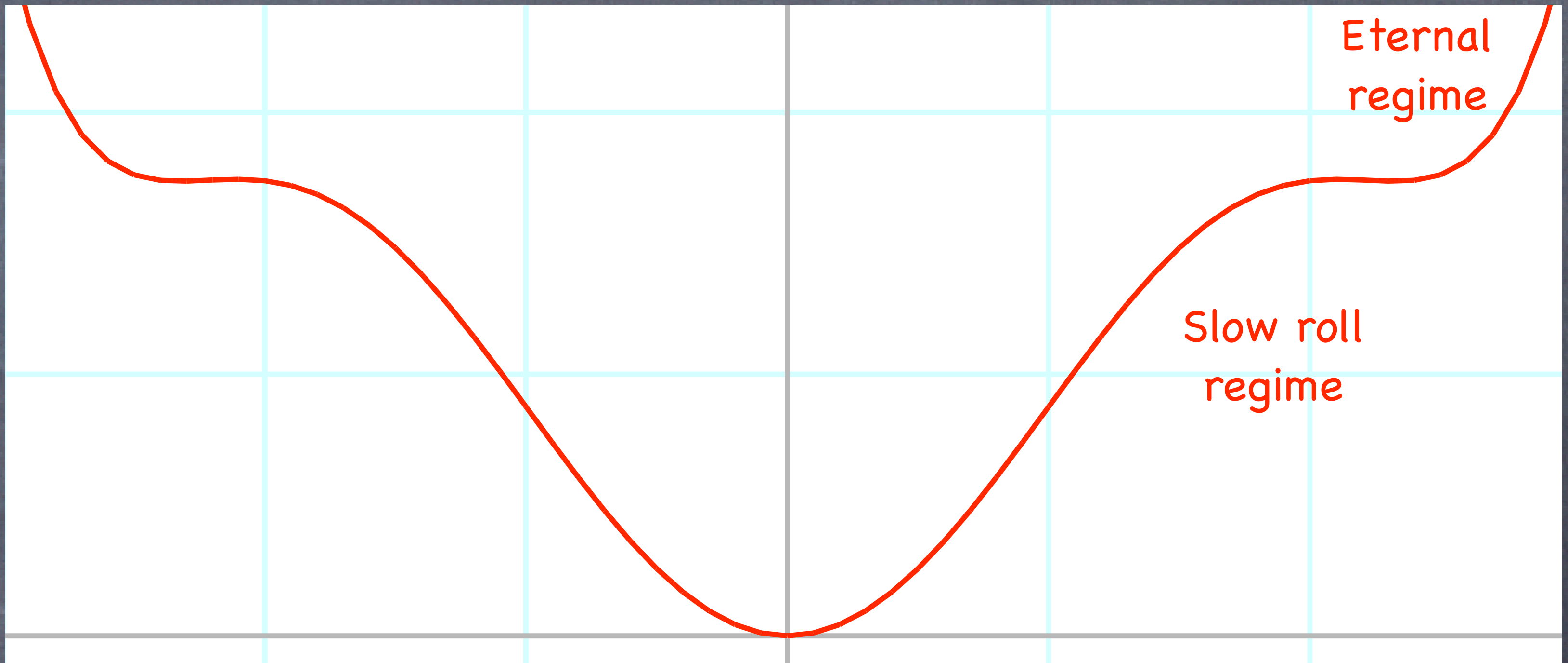
Gauged Inflaton

$$V = \frac{1}{2}m^2\phi^2 - A\frac{\lambda_6\phi^6}{M_*^3} + \lambda_6^2\frac{\phi^{10}}{M_*^6}$$

$$M_* \sim M_{GUT}, \quad \lambda_6 \sim 0.1 - 0.01, \quad m \sim m_{3/2} \sim 100\ \text{GeV}, \quad A^2 = 40 m_{3/2}$$

Allahverdi, Enqvist Garcia-Bellido & Mazumdar, Phys. Rev. Lett. (2006)

- A slow roll phase of inflation driven by third derivative of the potential, sufficiently large e-foldings of inflation
- No SUGRA eta problem
- UV / Trans-Planckin corrections are negligible
- No Moduli problem
- Low Reheat temperature but sufficient to excite thermal dark matter & baryogenesis



$$\Delta\phi << M_P, \quad \phi_0 << M_P$$

$$\dot{\phi}/H_{inf} > H_{inf}/2\pi \Rightarrow \frac{\phi_0 - \phi}{\phi_0} \geq \left(\frac{m_\phi \phi_0^2}{M_P^3}\right)^{1/2}$$

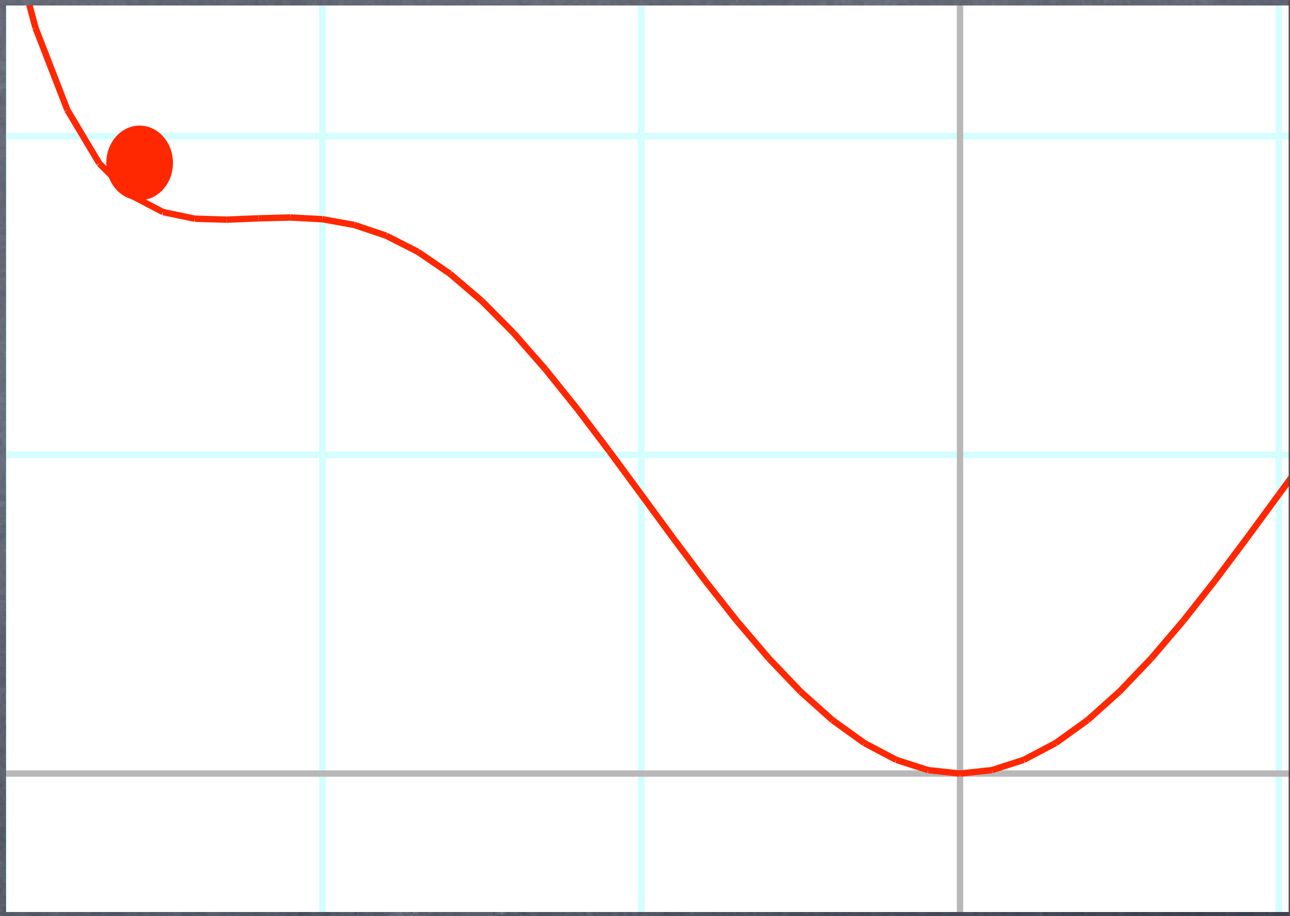
$$V'''(\phi_0) \neq 0 \quad V'(\phi_0) = 0, \quad V''(\phi_0) = 0$$

Inflation around Point of Inflection

Highlights of MSSM inflation

1) Sub-Planckian VeV: $\phi_0 = 3 \times 10^{14}\ GeV$

$$V = 10^{34} - 10^{38}\ GeV^4$$



2) Low scale inflation:

$$H_{inf} = (1 - 10)\ GeV$$

$$m_\phi \sim 1\ TeV \gg H_{inf} \sim 1\ GeV$$

(SUGRA corrections are negligible)

3) Enough e-foldings:

$$\mathcal{N}_e \sim \left(\frac{\phi_0^2}{m_\phi M_P} \right) \sim 10^6$$

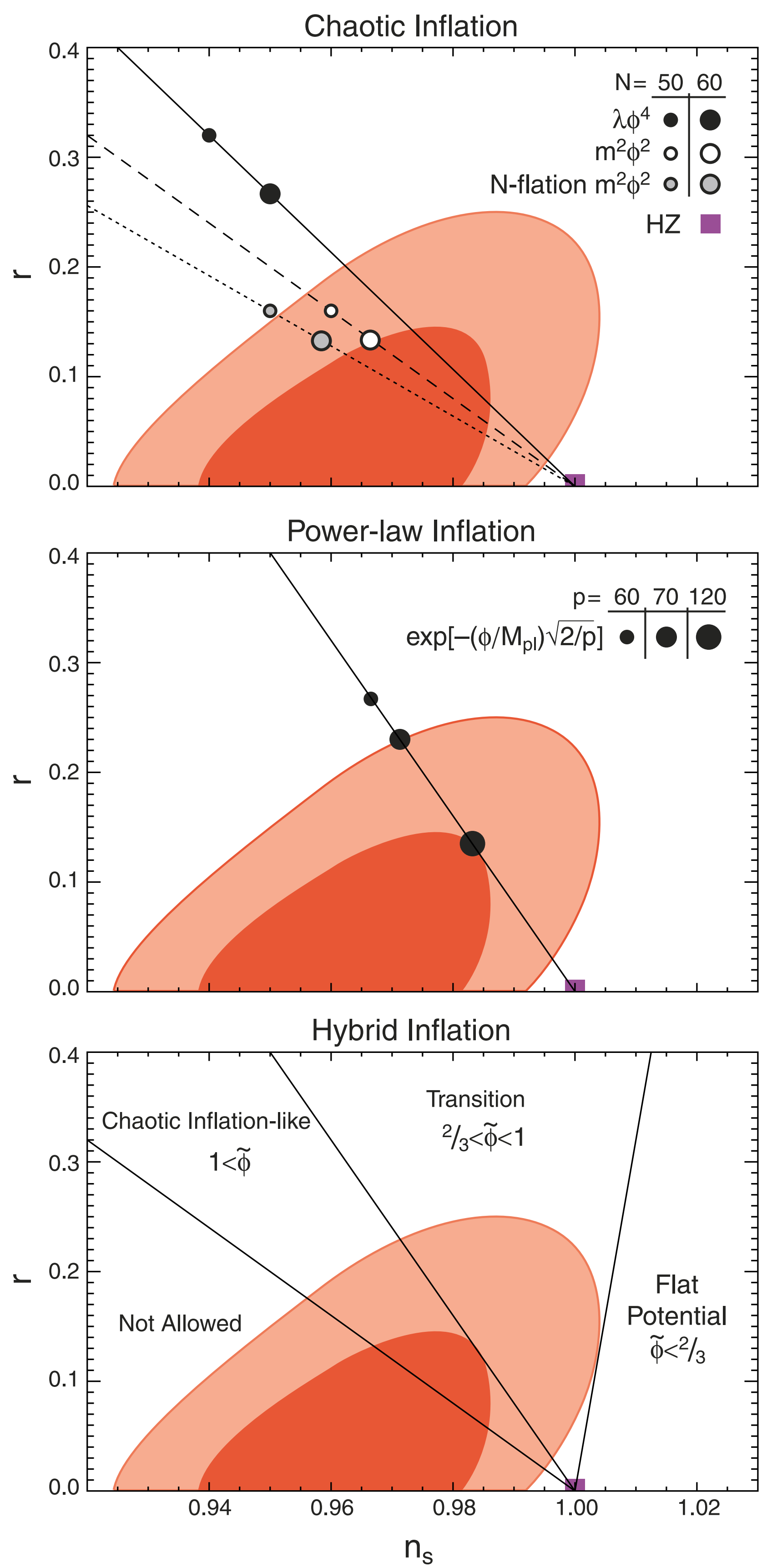
4) Maximum temperature:

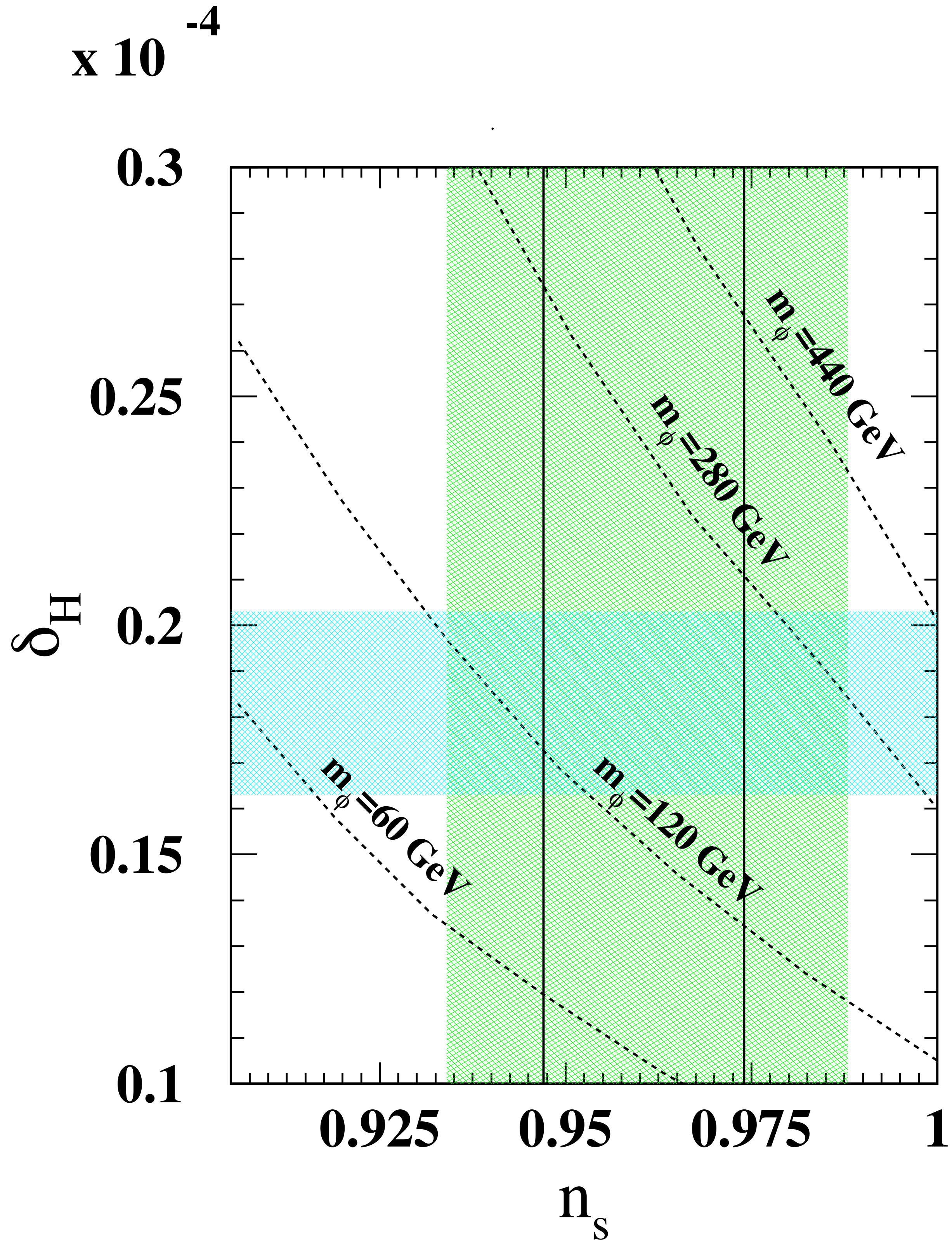
$$T_{max} \sim V(\phi)^{1/4} \sim 10^8\ GeV$$

5) Reheat temperature: $T_{rh} \sim 1 - 10\ TeV$

Allahverdi & Mazumdar
JCAP (2005), (2006)

CMB Predictions for the MSSM Inflaton

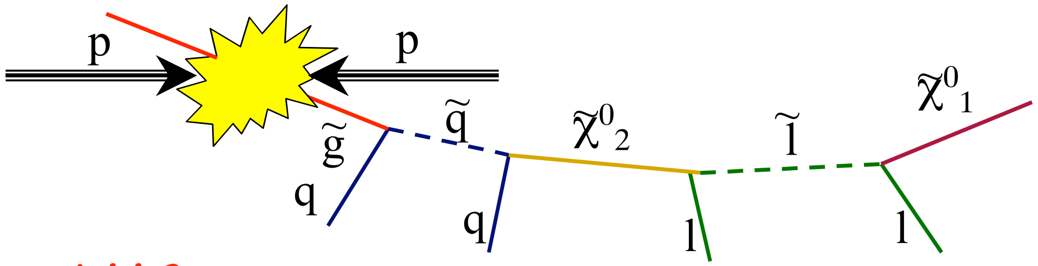




Allahverdi, Dutta, Mazumdar, Phy. Rev. D. (2007)
Allahverdi, Enqvist, Garcia-Bellido, Jokinen & Mazumdar, JCAP (2007)

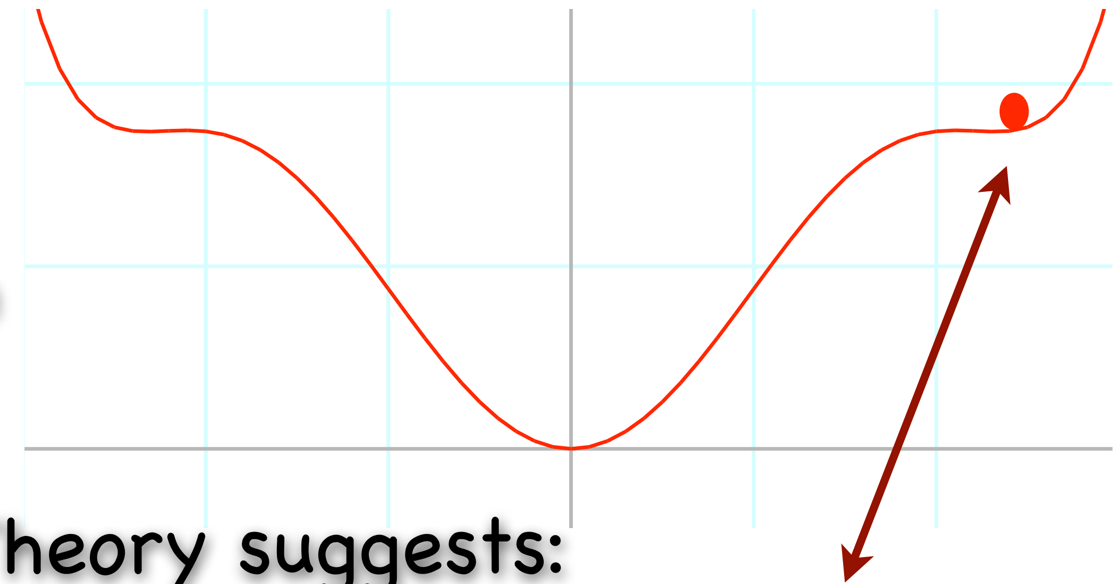
- Inflaton mass governs the spectral tilt & the amplitude of perturbations

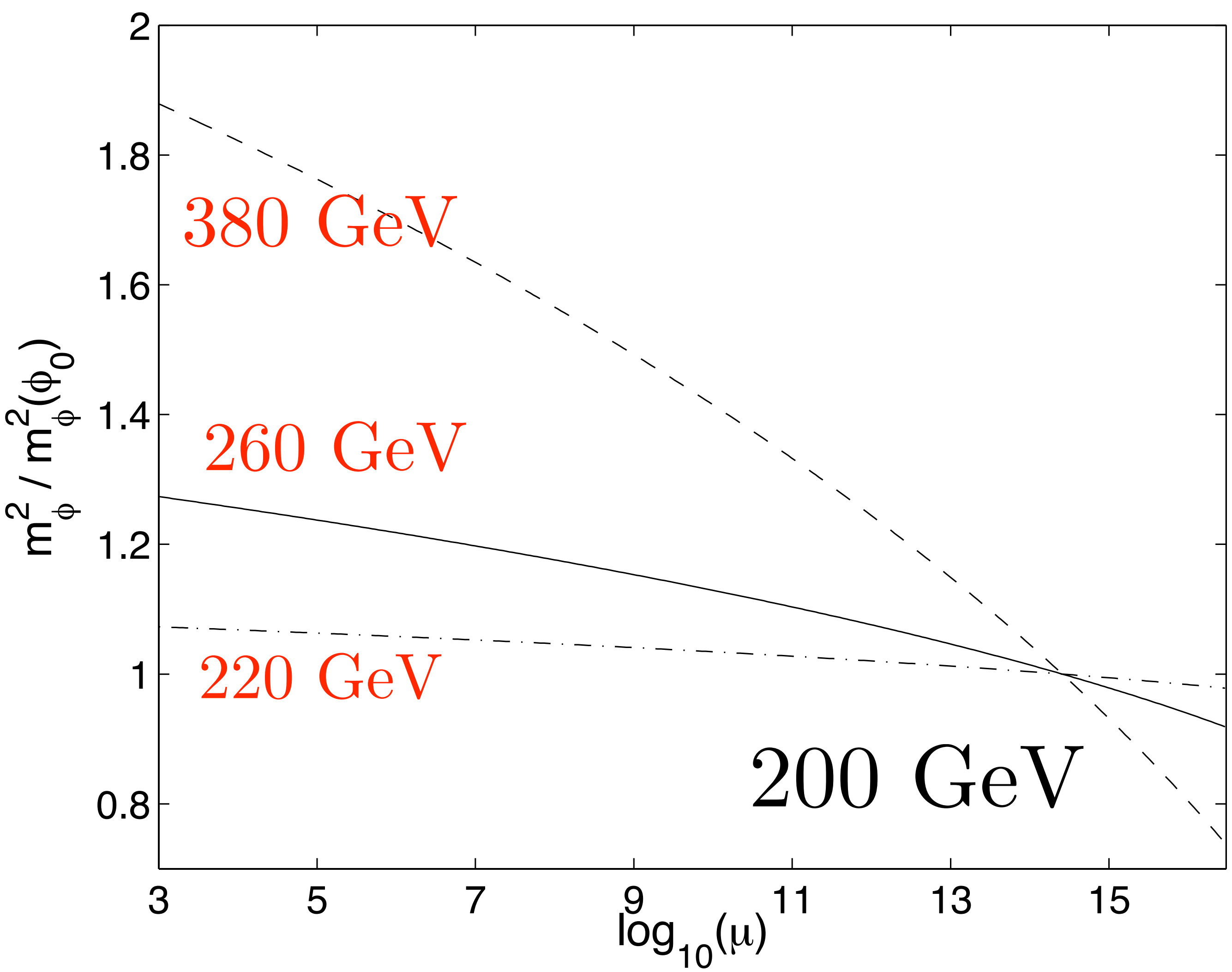
Probing the Inflaton @ LHC in conjunction with CMB observations



LHC

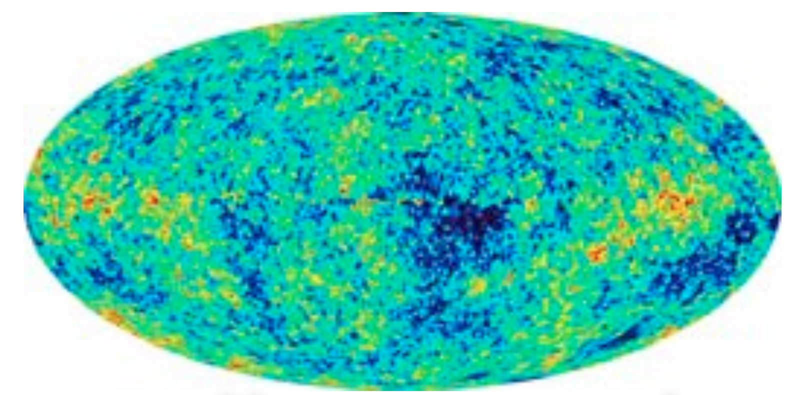
Inflation





Theory suggests:

$$\phi_0 \sim 10^{15}\ \mathrm{GeV}$$

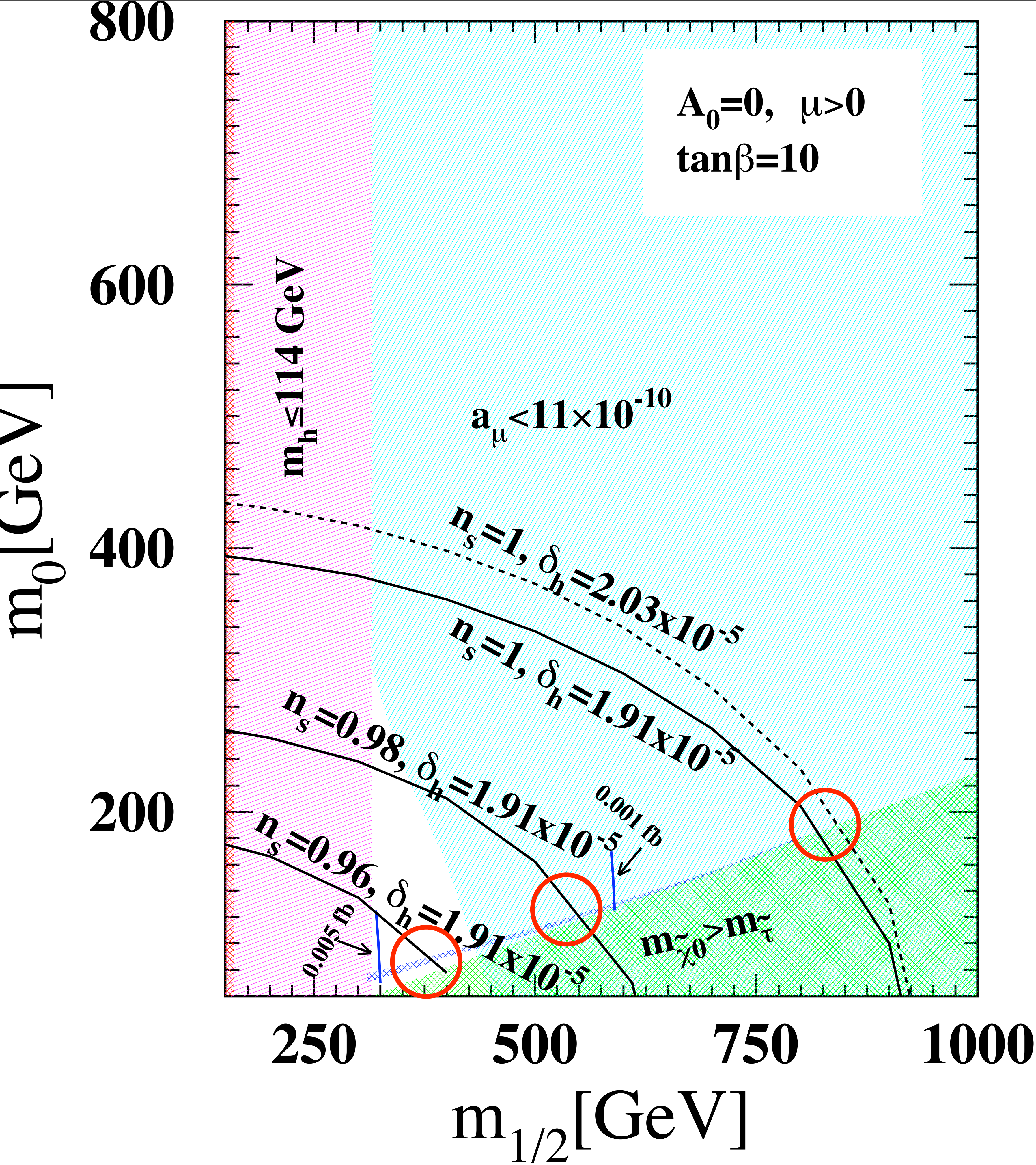


CMB observations suggest:

$$m_\phi(\phi_0) \sim 200\ \mathrm{GeV}$$

- LHC will constrain the masses for squarks, $\tilde{u}\tilde{d}\tilde{d}$

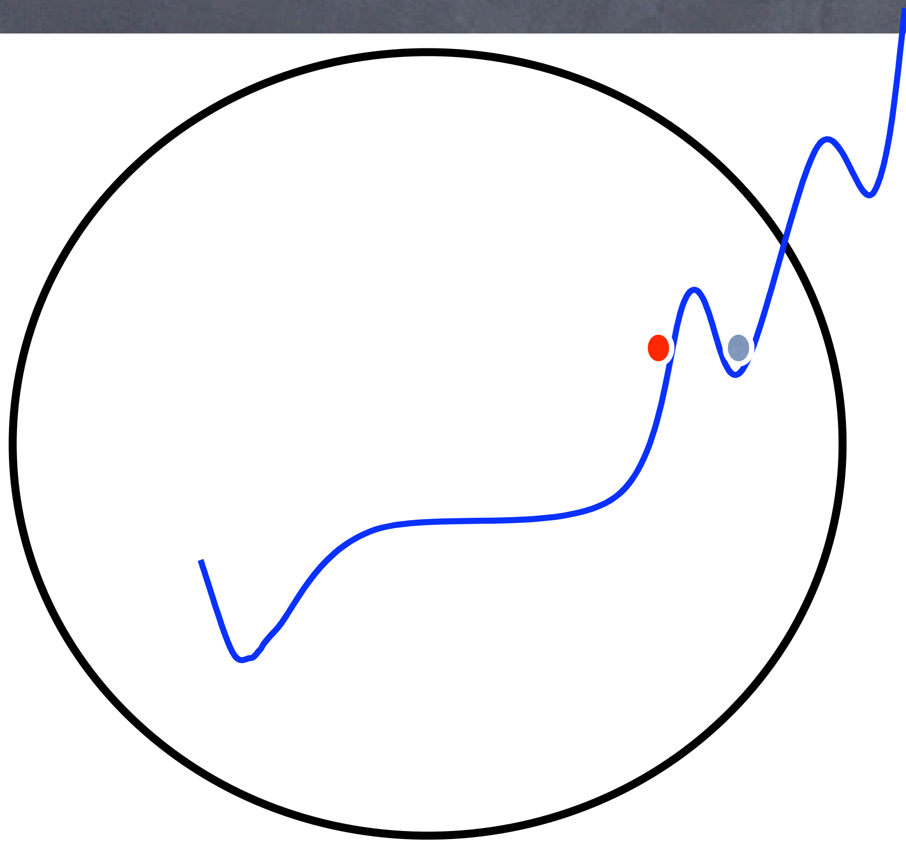
Allahverdi, Enqvist, Jokinen, Garcia-Bellido, Mazumdar JCAP (2006)



SUSY Dark Matter,
Inflation,
&
LHC

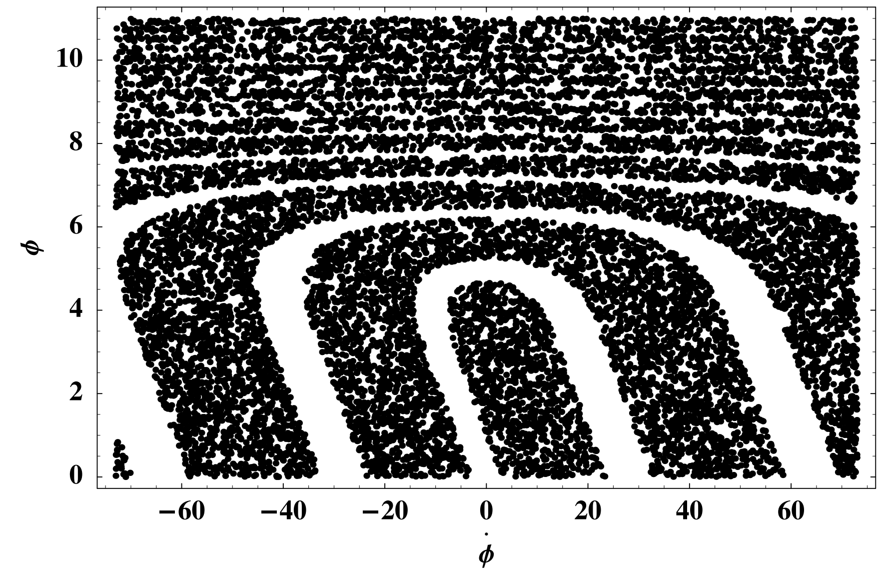
Allahverdi, Dutta, Mazumdar
Phys. Rev. D (2007)

MSSM Inflation happens in a large class of initial conditions



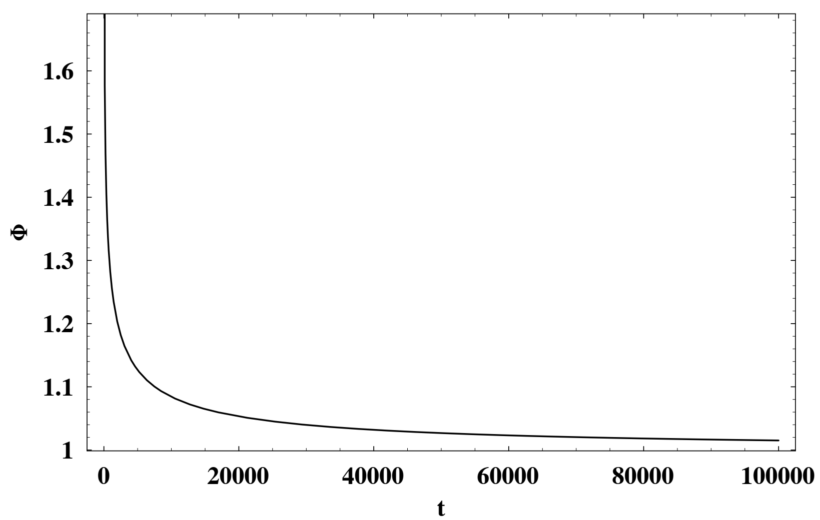
$$H^2 = \frac{V_{false} + V_{MSSM}}{3M_P^2}$$

$$V_{false} > V_{MSSM}$$

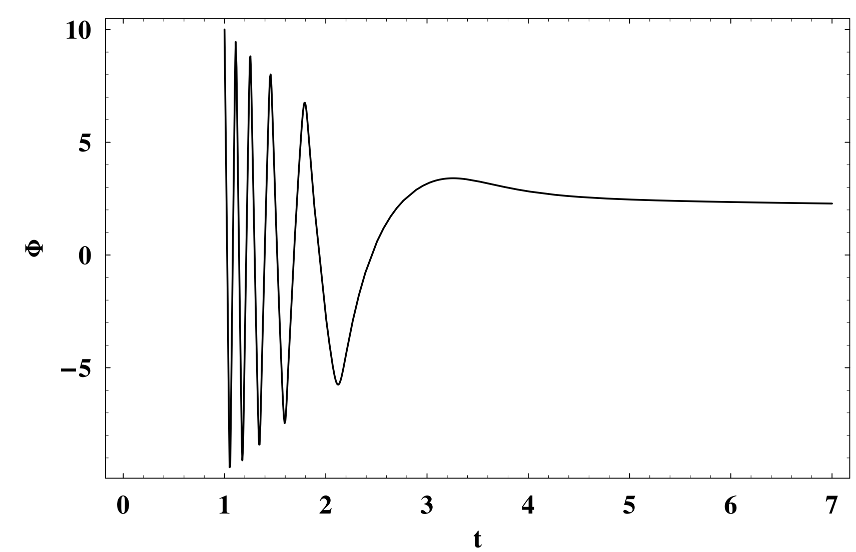


Allahverdi, Dutta, Mazumdar .....

MSSM Inflaton evolves during the false vacuum

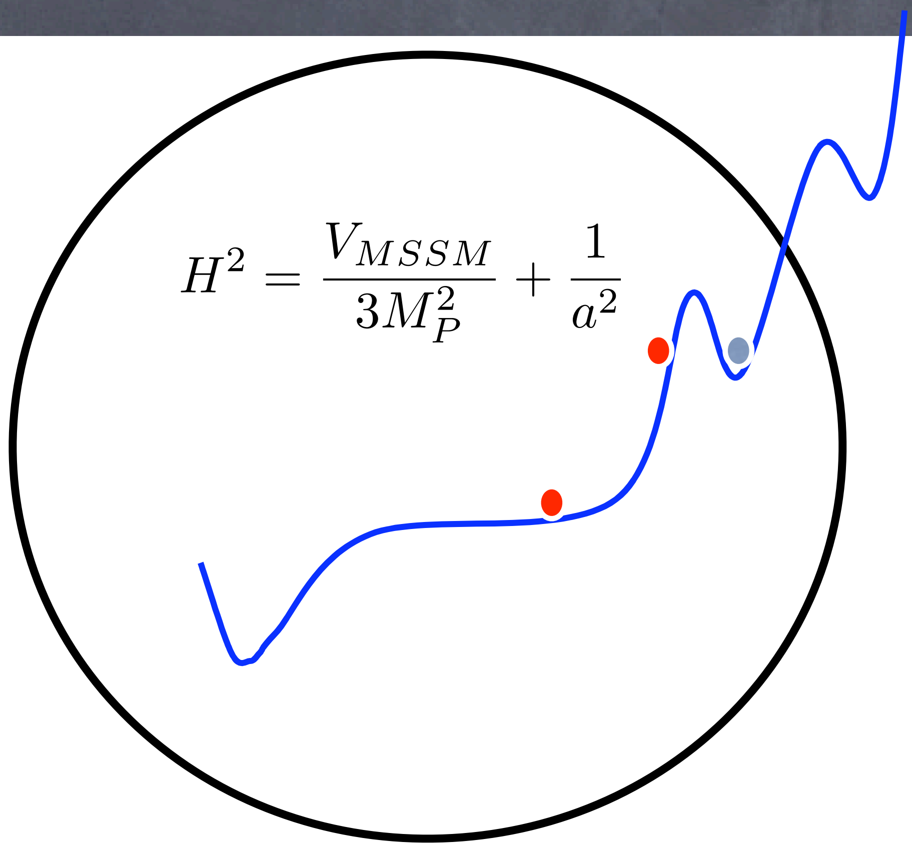


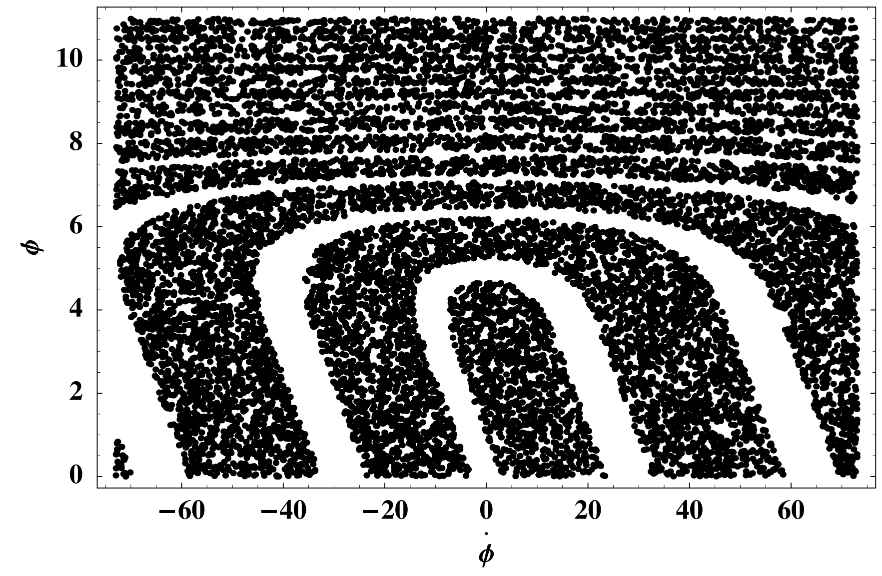
$$3H_{false}\dot{\phi} \approx -\frac{\phi^9}{M_P^6}$$



- Point of inflection is a dynamical attractor during false vacuum inflation

MSSM Inflation happens in a large class of initial conditions





Allahverdi, Dutta, Mazumdar .....

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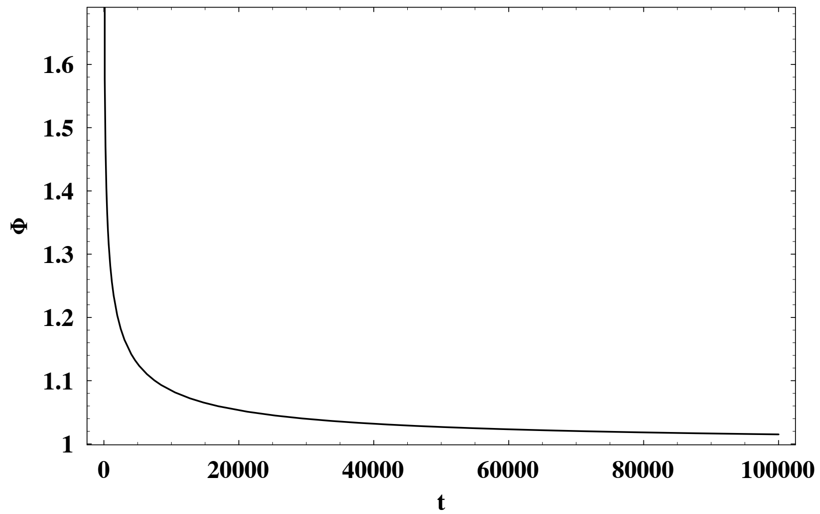

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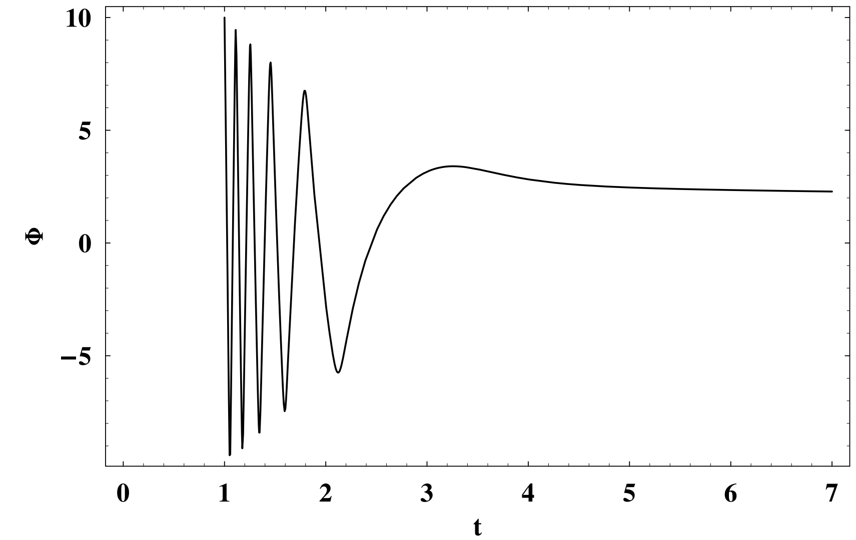

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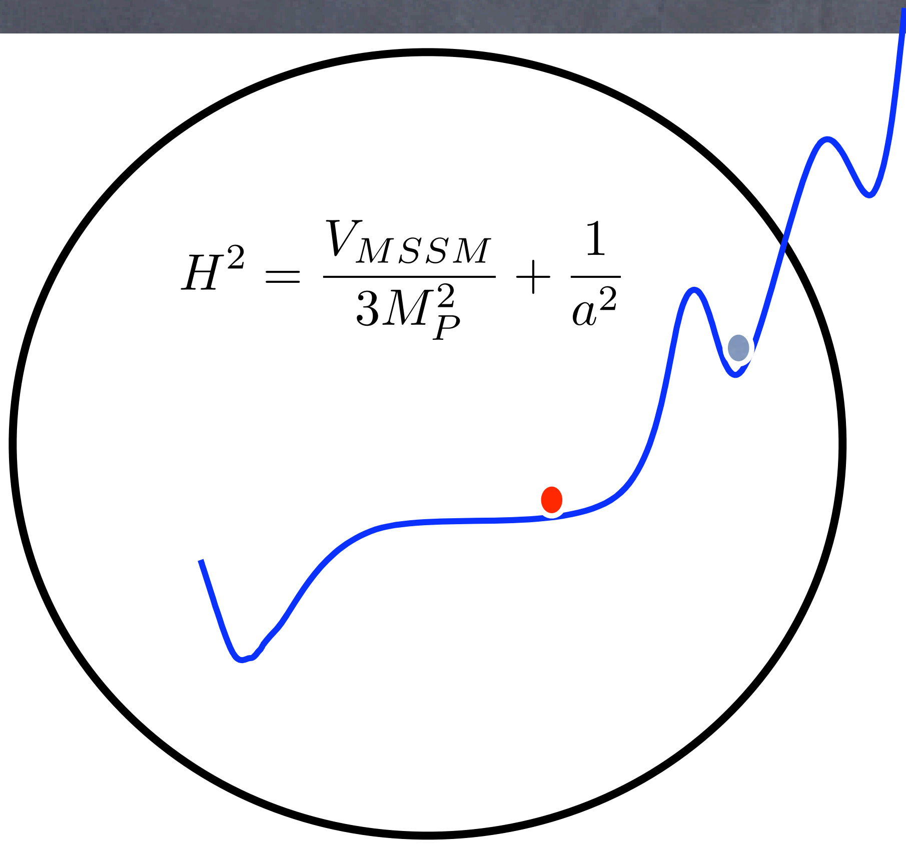
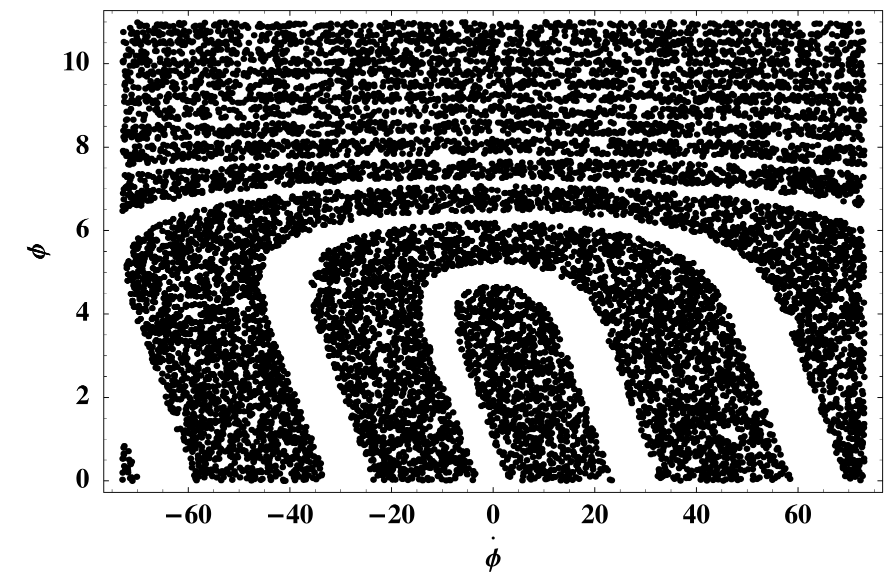
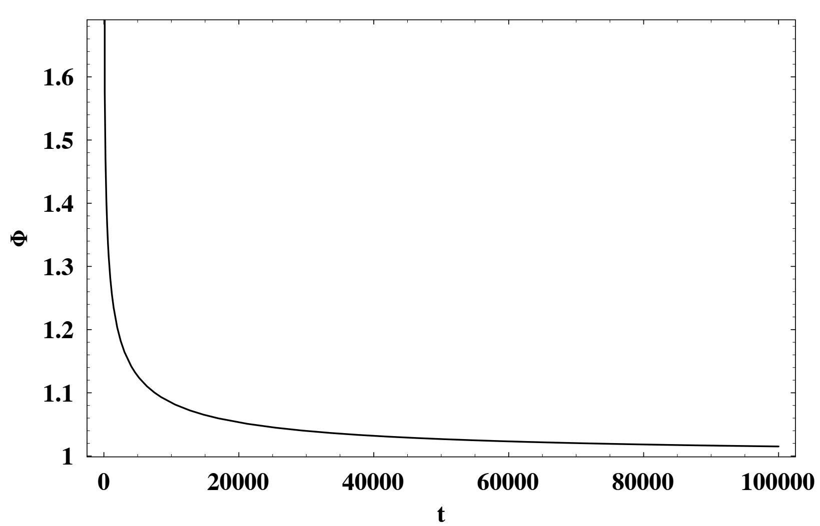




Allahverdi, Dutta, Mazumdar .....

MSSM Inflaton evolves during the false vacuum



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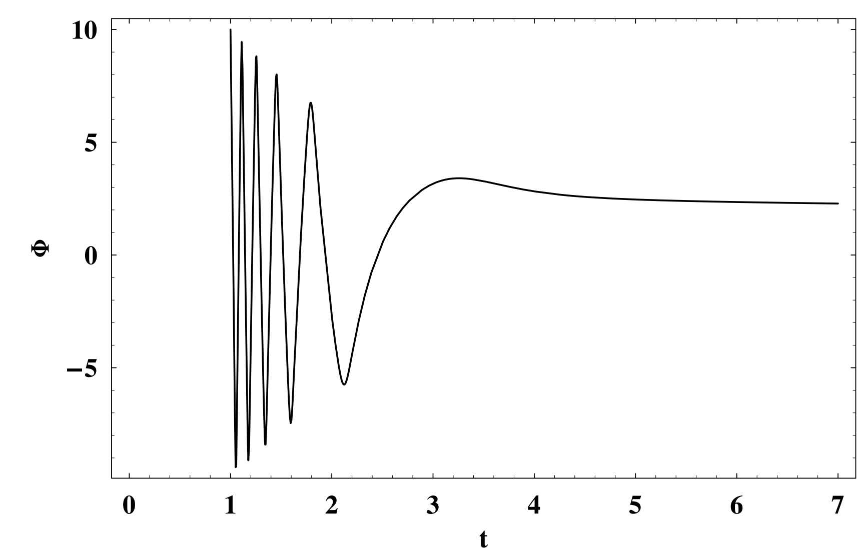
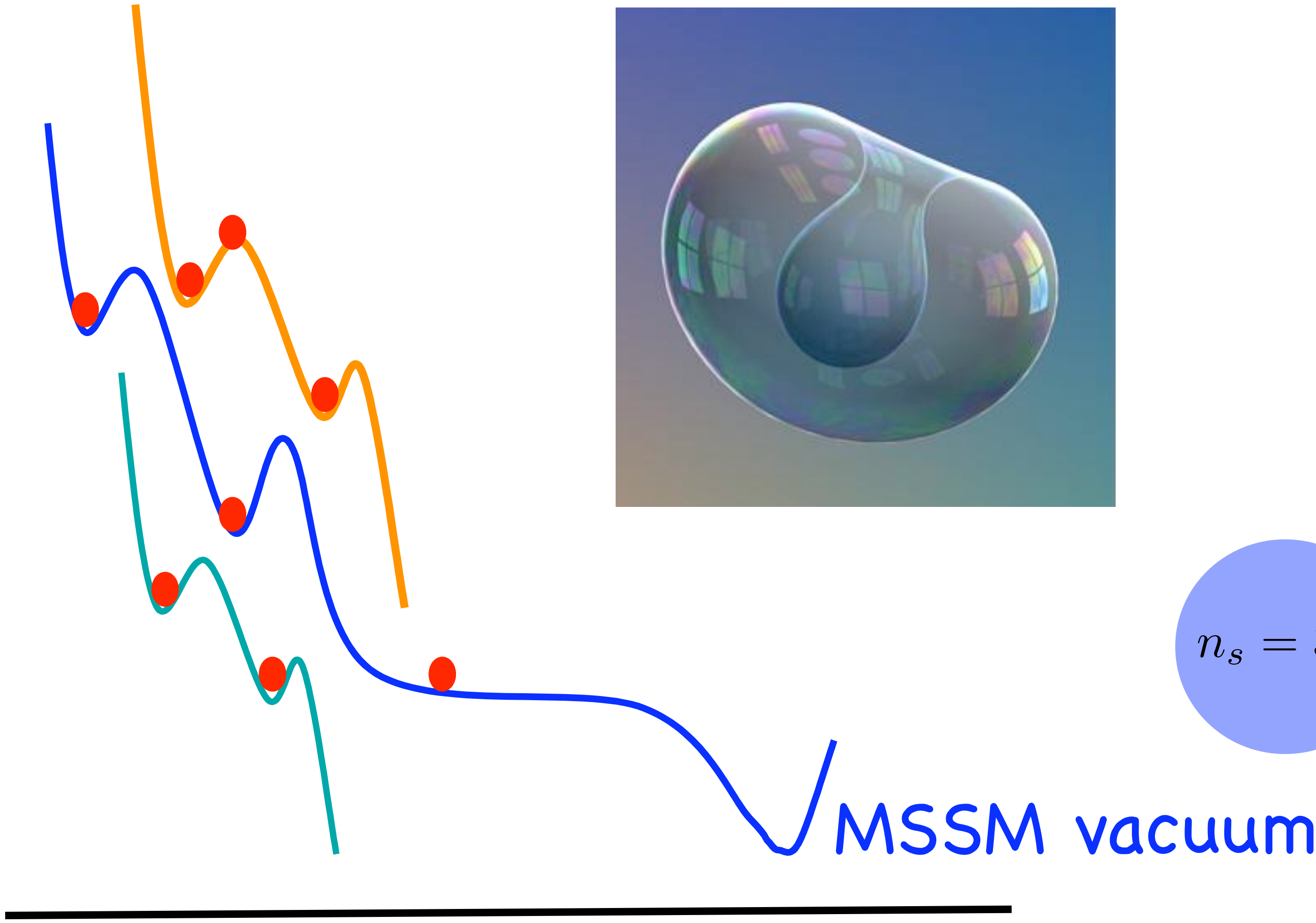
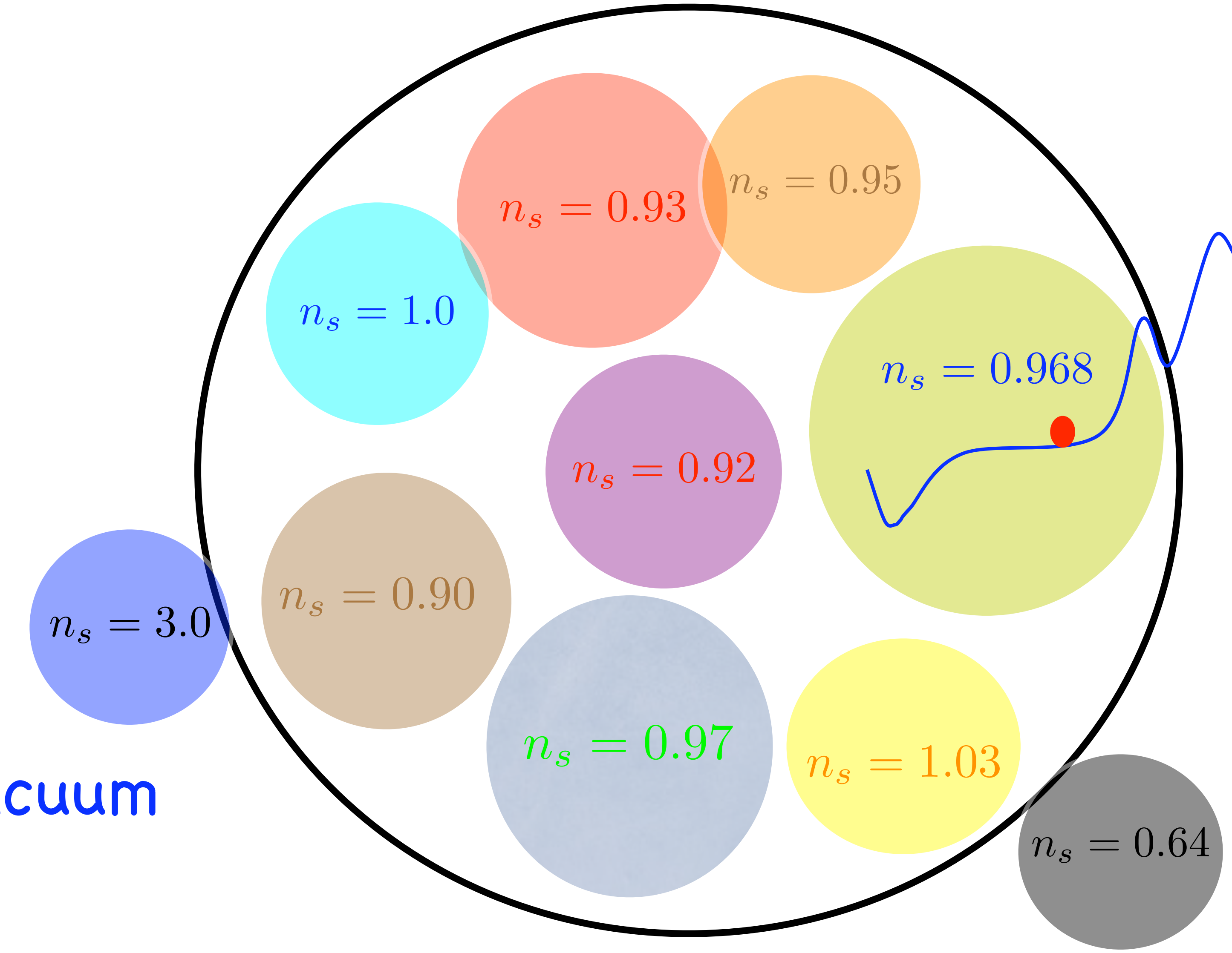


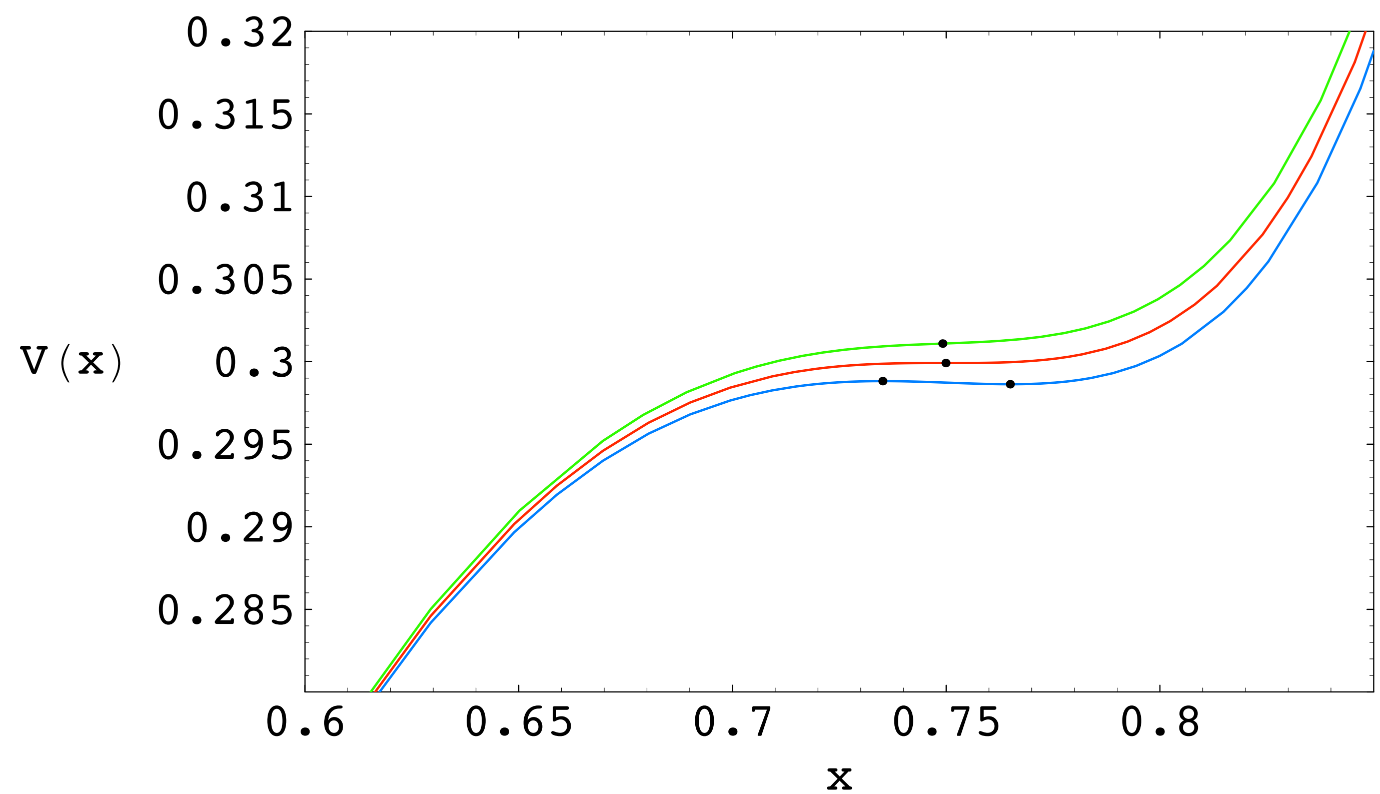
- Point of inflection is a dynamical attractor during false vacuum inflation

Naturalness issue



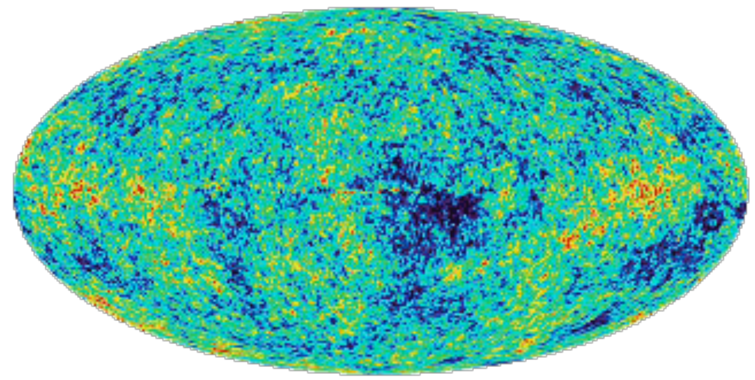


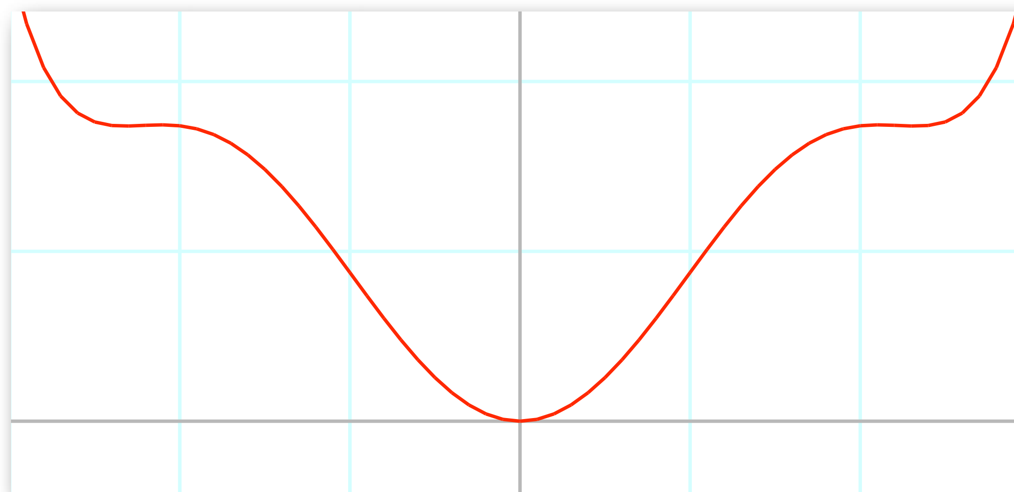
- The model address the naturalness issue : Why we see the observed amplitude and the spectral tilt

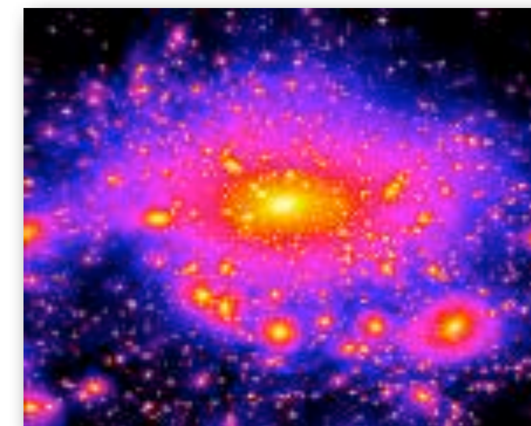


Allahverdi, Frey, Mazumdar   Phys. Rev. D (2007)

Conclusions : 3 unique examples







$\tilde{u}\tilde{d}\tilde{d}$ $\quad LL\tilde{e}$ $\quad \tilde{N}H_uL$

Inflation is the only link which connects CMB anisotropy, SM Baryons, and Dark Matter

MSSM

$$W_{\text{renorm}} = \mu H_u H_d + y_u^{ij} H_u Q_i u_j + y_d^{ij} H_d Q_i d_j + y_e^{ij} H_d L_i e_j$$

	B−L	Always lifted by W_{renorm}?
$\mathrm{LH_u}$	−1	
$\mathrm{H_uH_d}$	0	
udd	−1	
LLe	−1	
QdL	−1	
$\mathrm{QuH_u}$	0	√
$\mathrm{QdH_d}$	0	√
$\mathrm{LH_de}$	0	√
QQQL	0	
QuQd	0	
QuLe	0	
uude	0	
$\mathrm{QQQH_d}$	1	√
$\mathrm{QuH_de}$	1	√
dddLL	−3	
uuuee	1	
QuQue	1	
QQQQu	1	
$\mathrm{dddLH_d}$	−2	√
$\mathrm{uudQdH_u}$	−1	√
$\mathrm{(QQQ)_4LLH_u}$	−1	√
$\mathrm{(QQQ)_4LH_uH_d}$	0	√
$\mathrm{(QQQ)_4H_uH_dH_d}$	1	√
$\mathrm{(QQQ)_4LLLe}$	−1	
uudQdQd	−1	
$\mathrm{(QQQ)_4LLH_de}$	0	√
$\mathrm{(QQQ)_4LH_dH_de}$	1	√
$\mathrm{(QQQ)_4H_dH_dH_de}$	2	√

- Simplest extension of the SM

$$SU(3)_c \times SU(2)_L \times U(1)_Y$$

- Nearly 300 gauge invariant combinations you can construct

- Their potentials are flat in a SUSY limit

$$W = W_{\text{renorm}} + \sum_{n>3} \frac{\lambda}{M^{n-3}} \Phi^n .$$

$$3 < n \leq 9$$

Dine, Randall, Thomas, Nucl. Phys. B. (1995)
Gherghetta, Martin, Kolda Phys. Rev. D (1996)

MSSM Inflation & Neutralino Dark Matter

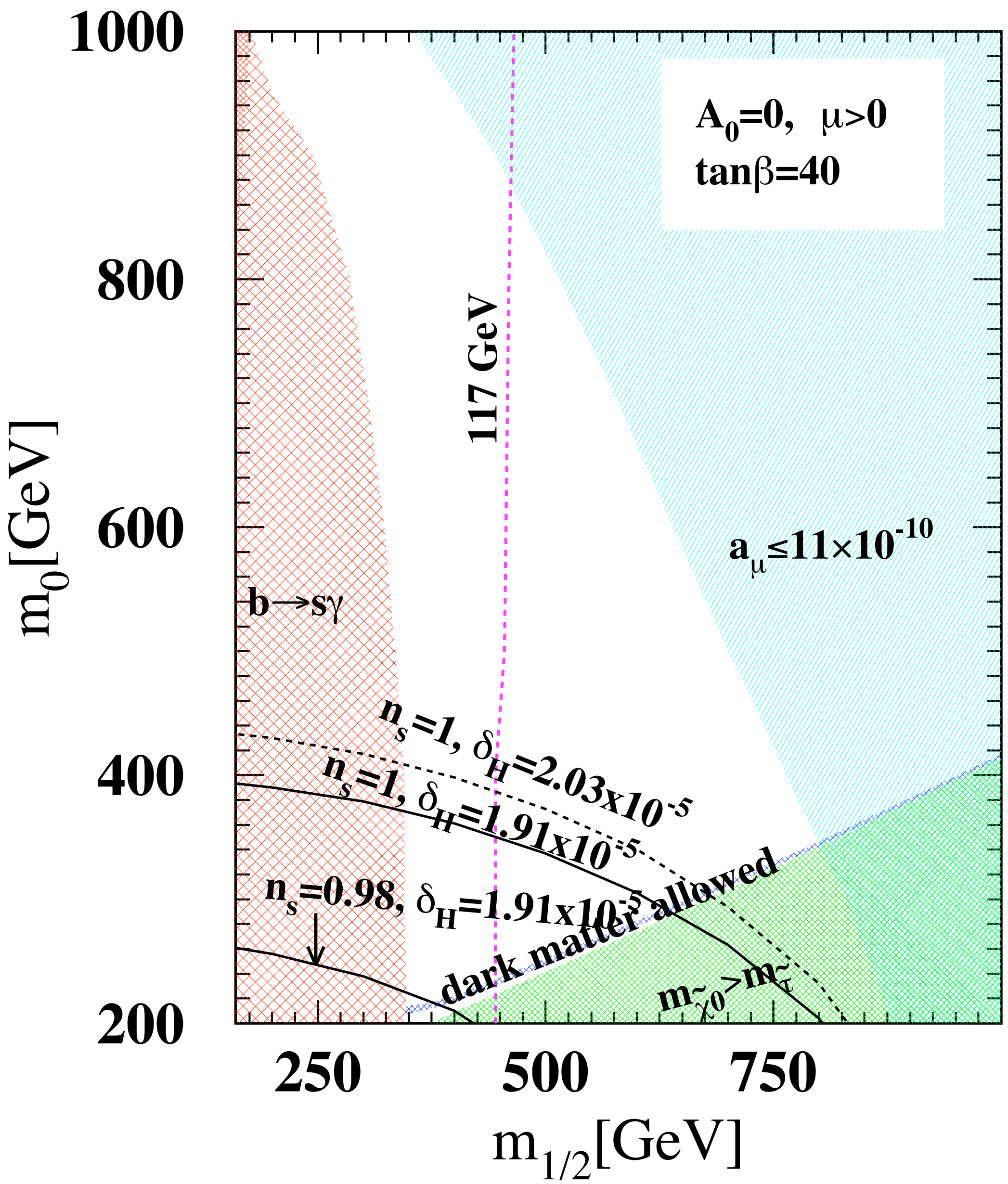


FIG. 4: The contours for different values of n_s and δ_H are shown in the $m_0 - m_{1/2}$ plane for $\tan\beta = 40$. We used $\lambda = 1$ for the contours. We show the dark matter allowed region narrow blue corridor, (g-2)$_\mu$ region (light blue) for $a_\mu \leq 11 \times 10^{-8}$, $b \to s\gamma$ allowed region (brick) and LEPII bounds on SUSY masses (red).

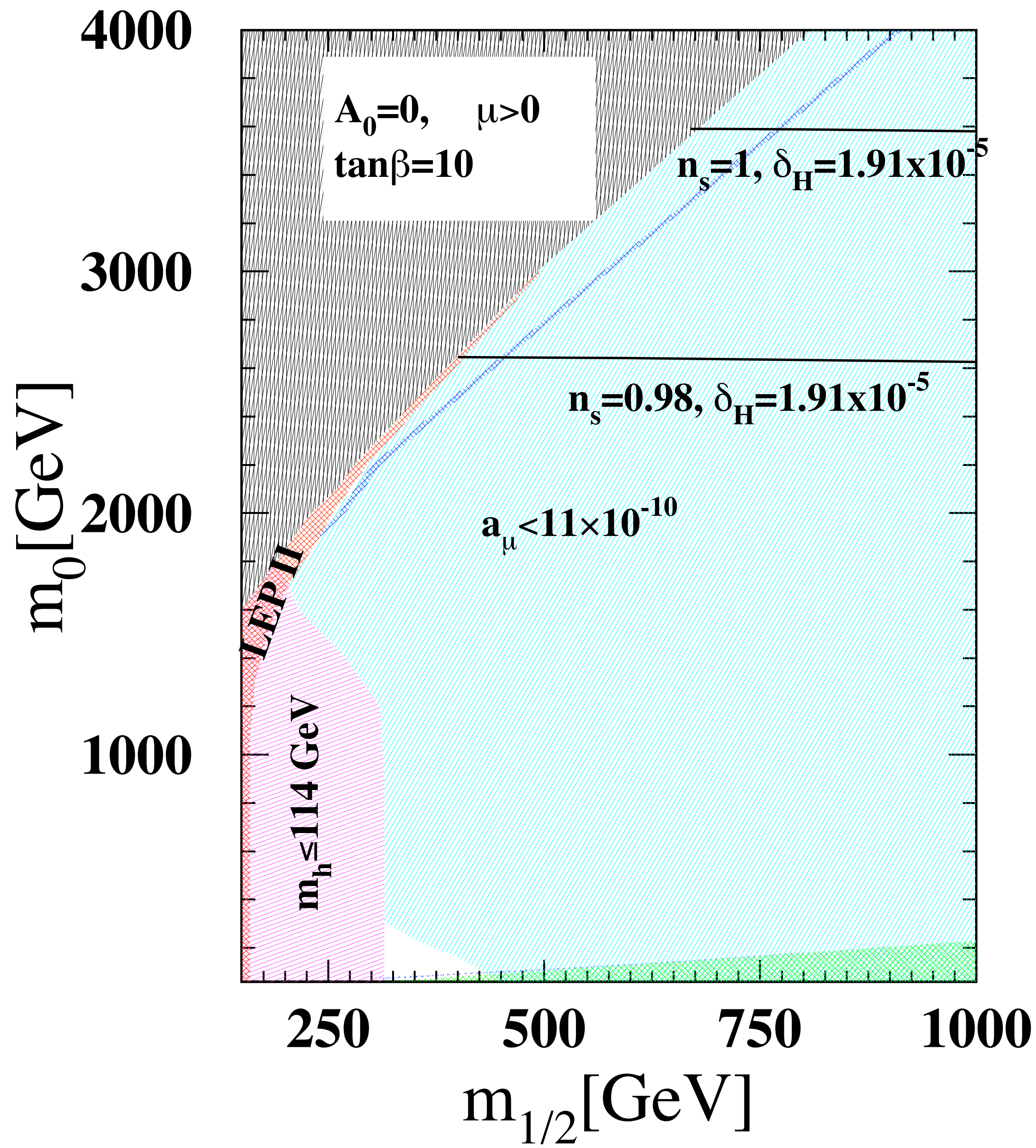
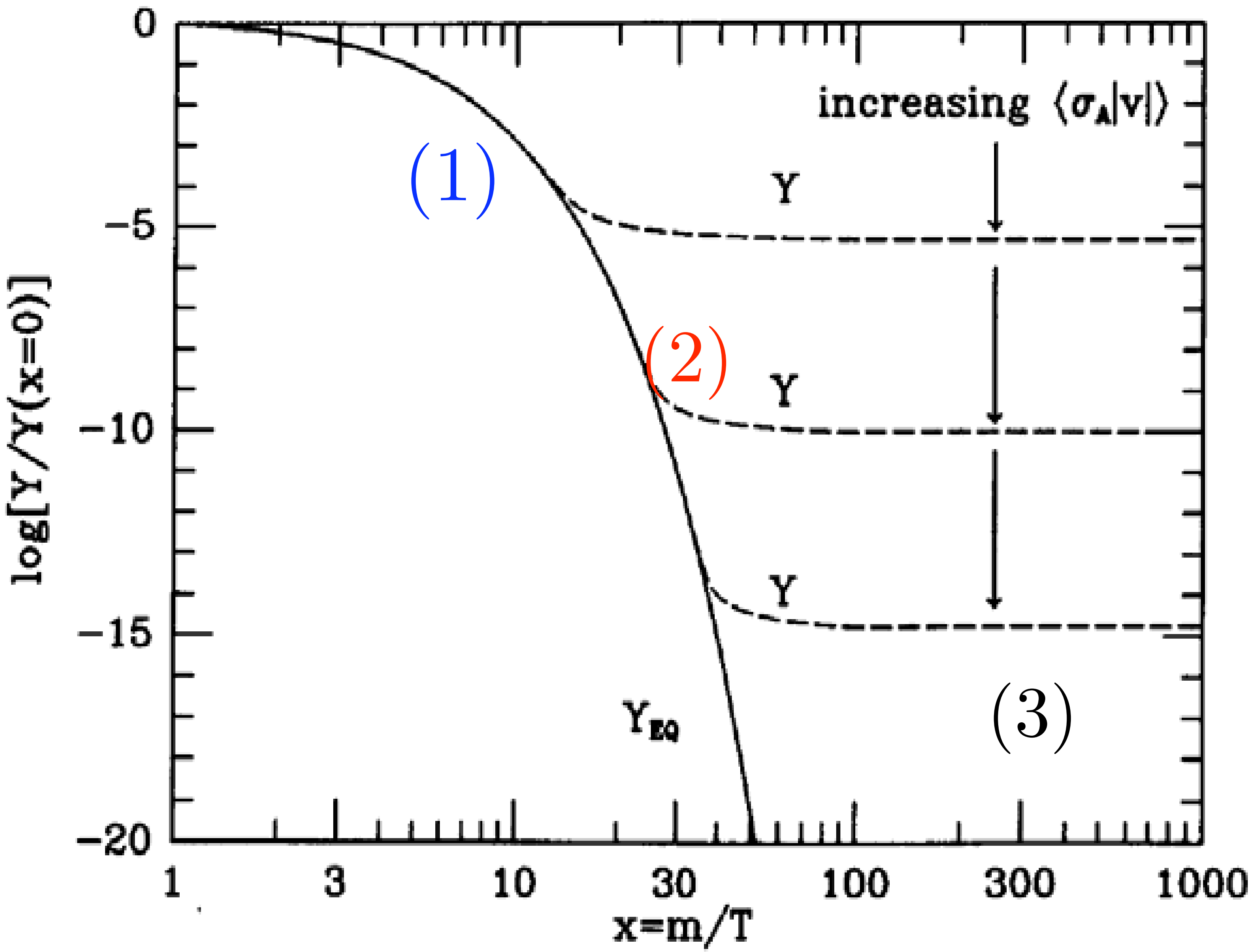


FIG. 5: The contours for different values of n_s and δ_H are shown in the $m_0 - m_{1/2}$ plane for $\tan\beta = 10$. We used $\lambda = 0.1$ for the contours. We show the dark matter allowed region narrow blue corridor, g-2 region (light blue) for $a_\mu \leq 11 \times 10^{-8}$, Higgs mass ≤ 114 GeV (pink region) and LEPII bounds on SUSY masses (red). The black region is not allowed by radiative electroweak symmetry breaking. We use $m_t = 172.7$ GeV for this graph.

Cold Dark Matter Synthesis

Heavy particles decouple from thermal bath

- CDM is in thermal eqbm.
- Universe cools
- Neutralinos freeze out



Mass of the Neutralino is around 100 GeV

DM testing Inflation & GUT

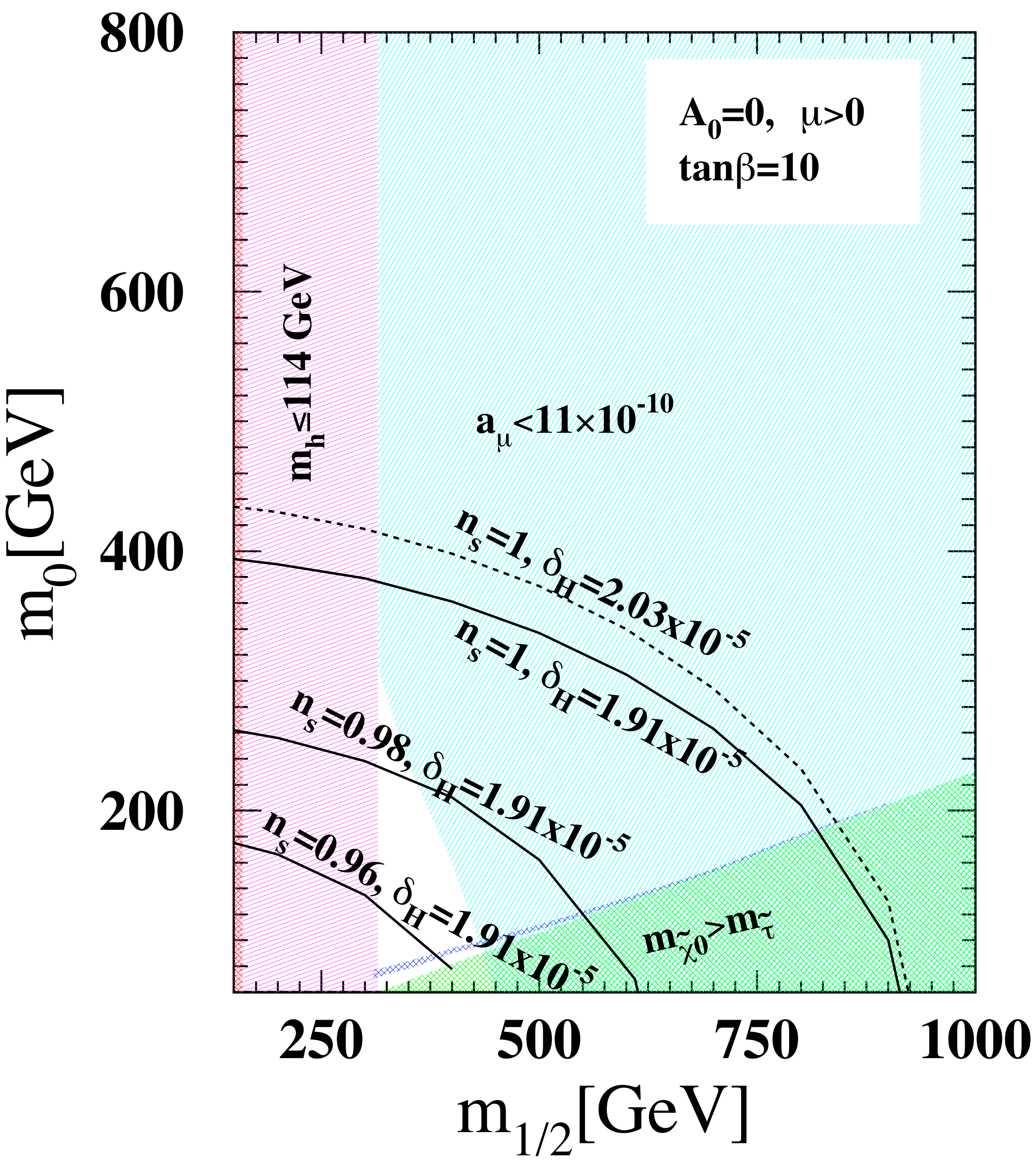


FIG. 3: The contours for different values of n_s and δ_H are shown in the $m_0 - m_{1/2}$ plane for $\tan\beta = 10$. We used $\lambda = 1$ for the contours. We show the dark matter allowed region narrow blue corridor, (g-2)$_\mu$ region (light blue) for $a_\mu \leq 11 \times 10^{-8}$, Higgs mass $\leq$ 114 GeV (pink region) and LEPII bounds on SUSY masses (red). We also show the the dark matter detection rate by vertical blue lines.

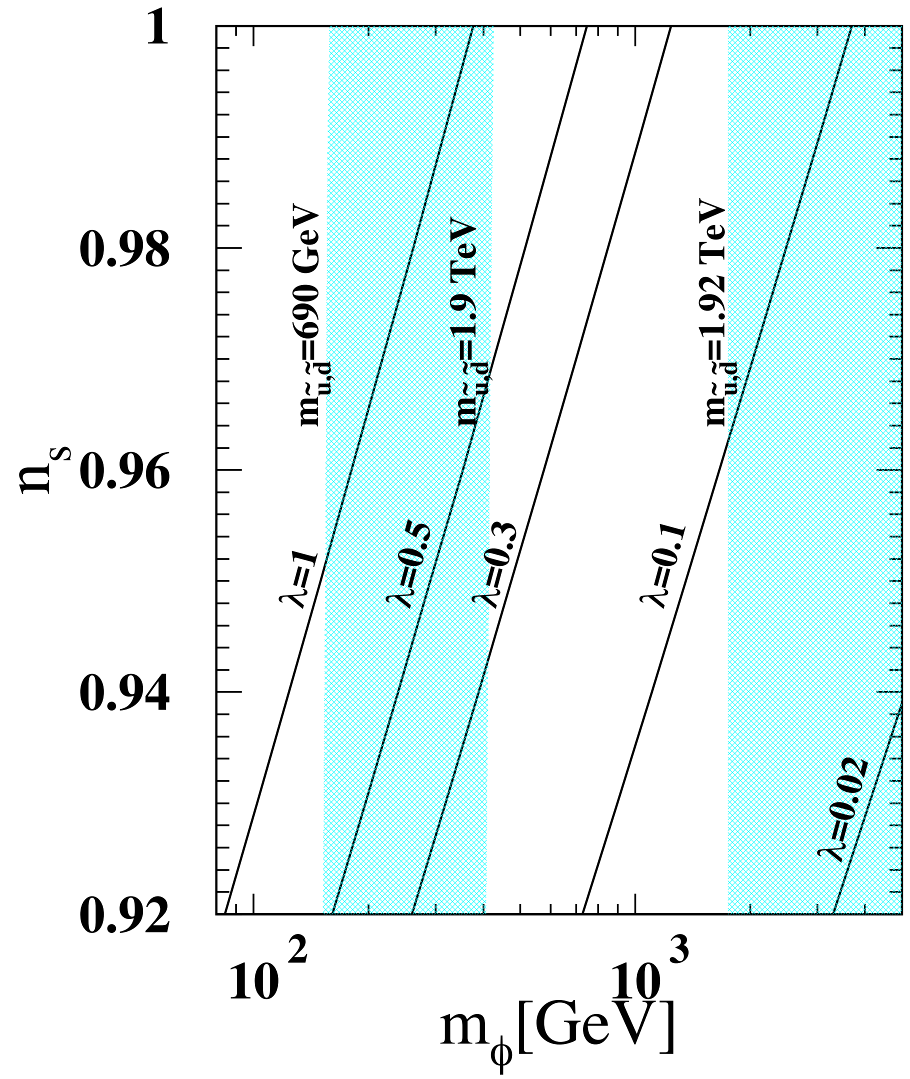


FIG. 6: Contours of λ for $\delta_H = 1.91 \times 10^{-5}$ in the n_s-m_ϕ plane. The blue band on the left is due to the stau-neutralino coannihilation region for $\tan\beta = 10$ and the blue band on the right (which continues beyond the plotting range) denotes the focus point region.

Allahverdi, Dutta, Mazumdar, Phy. Rev. D. (2007)

New Bench Mark Points: Inflation & Dark Matter