Searching for New Physics in the Sky --
the case for Inflaton

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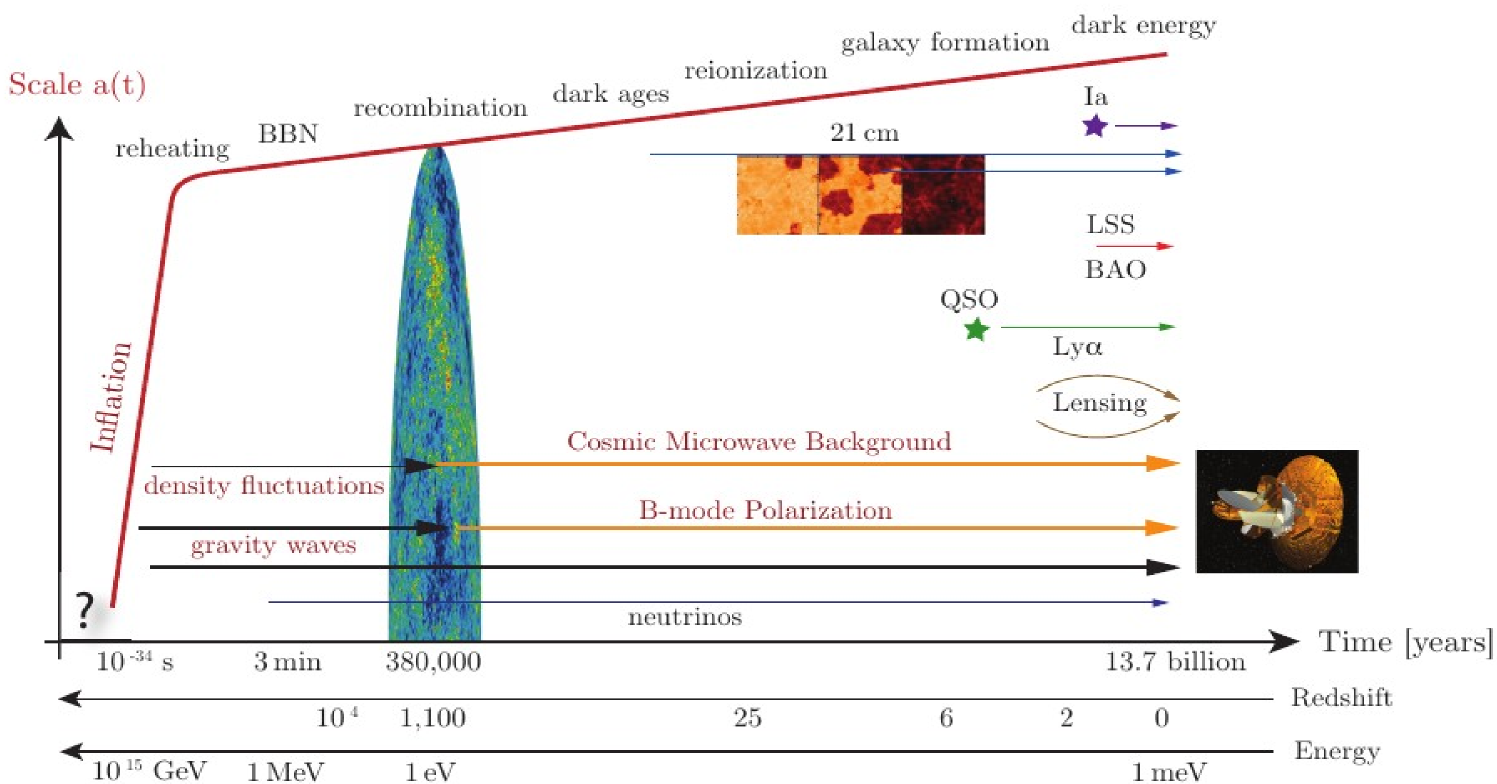
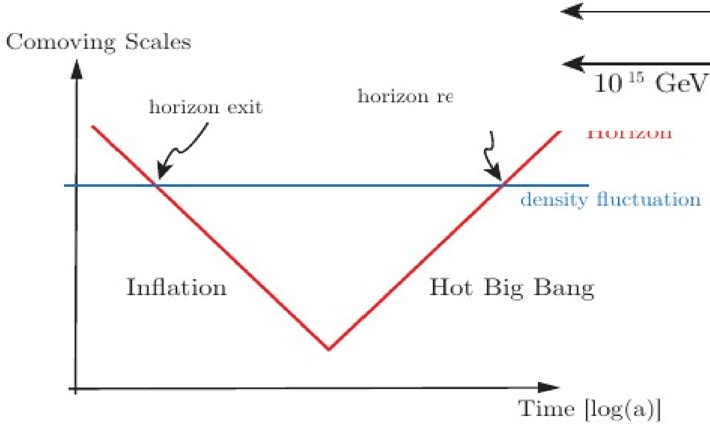
(Based on arXiv:1103.5758, 1409.4442, 1708.07293,
with Anupam Mazumdar)

Outline

- Motivation for Inflation
- Inflation within SUSY models : the case for Higgs Inflation
- Probing small scale power spectrum with gravity waves (and PBH)
- Conclusion and Outlook

History of the Universe

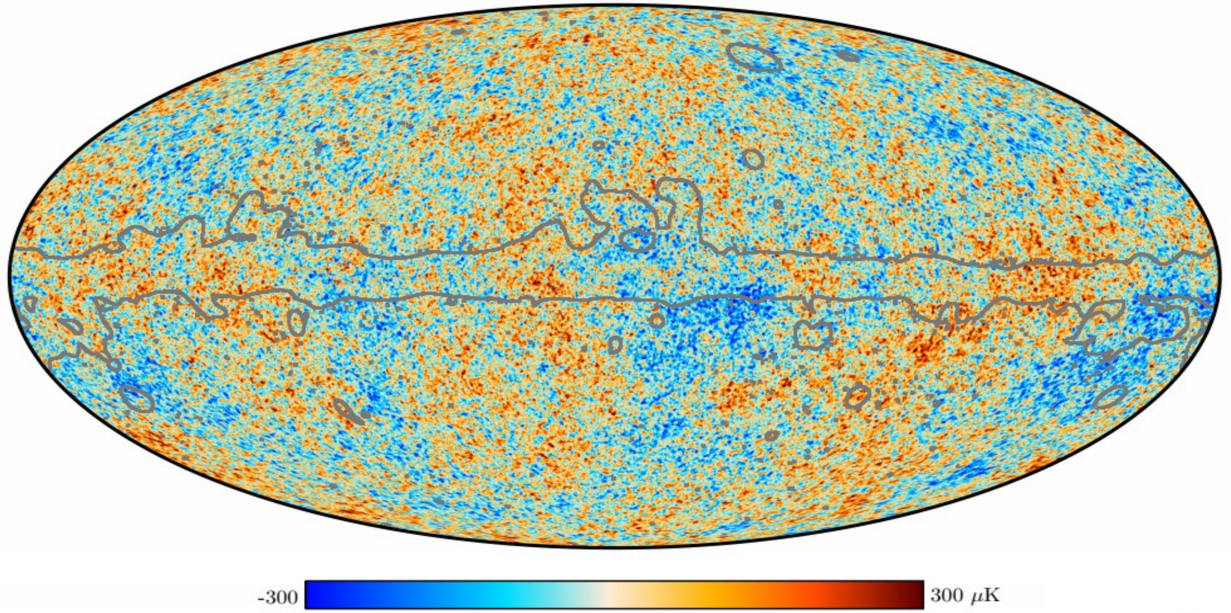




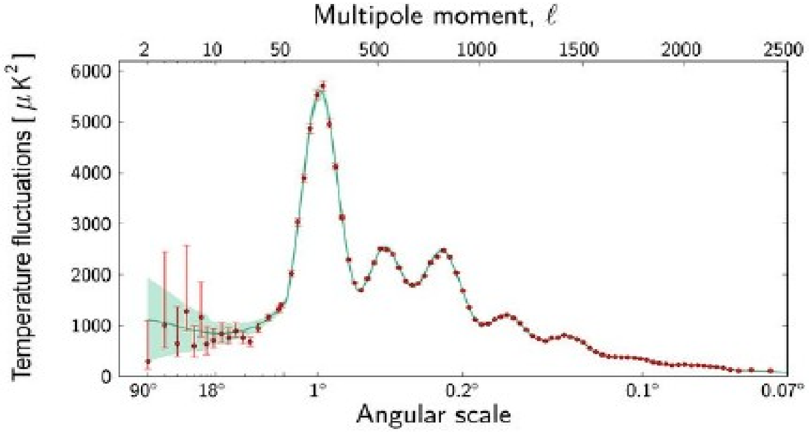
[Lecture notes by Baumann]

Introduction

Inflation : Addresses Horizon and flatness problems (also resolves monopole problems, generates entropy in the visible sector ...)



[Planck]



Inflation: Generalities

- "New" inflation scenarios

  Driven by a scalar field with uniform *ev* across Hubble patch [Linde;Albrecht,Steinhardt]

- Energy density dominated by the potential. Needs to be sufficiently *flat*

- Exponential expansion of about 45-60 efoldings

- Within SM, only scalar field is Higgs doublet, requires large non-minimal coupling with gravity! Unitarity issue.. [Shaposnikov,Bezrukov,2008; Burgess et.al., 2010]

- To generate visible sector particles inflaton must couple to these *dof.* The potential can be sensistive to radiative corrections. No protection for the *flatness*!

- Mass of a scalar field is not protected, mass term has "quadratic" dependence on cut-off scale!

The case for SUSY

- A hypothetical symmetry relating Bosons and Fermions, has “fermionic” generators
- Solves Hierarchy problem, cencels quadratic divergencies
- Unifies gauge couplings at a high energy scale
- Haag-Lopuzansky-Sohnius theorem
- Offers protection against rad.corr. “non-renormalization” theorem valid in ALL orders of perturbation theory
- Local SUSY > SUGRA (Special Breakthrough Prize: Freedman, Nieuwenhuizen, Ferrara)

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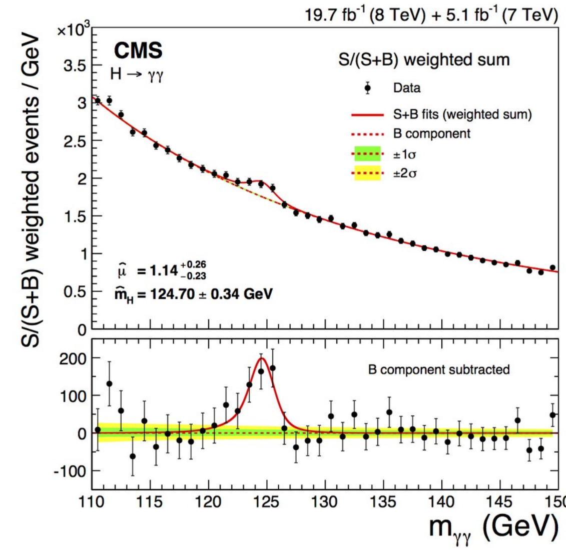
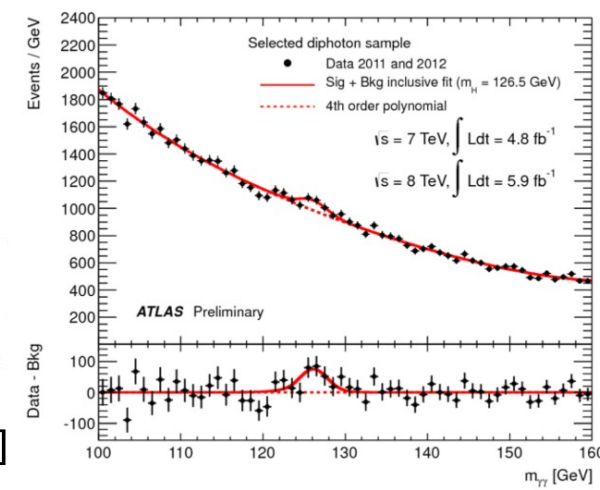
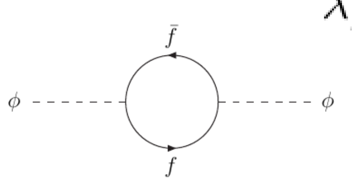
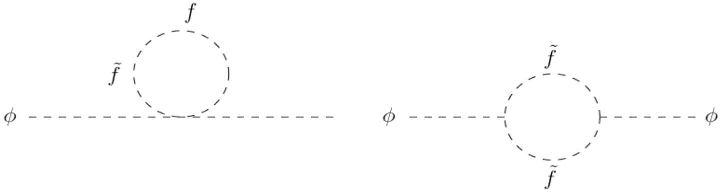




$$\tilde{\lambda}_f = -\lambda_f^2 \qquad -2N(f)\lambda_f^2 \int \frac{d^4k}{(2\pi)^4} \left[\frac{1}{k^2 - m_f^2} + \frac{2m_f^2}{\left(k^2 - m_f^2\right)^2} \right]$$



[Witten; Kaul, Majumdar’82]

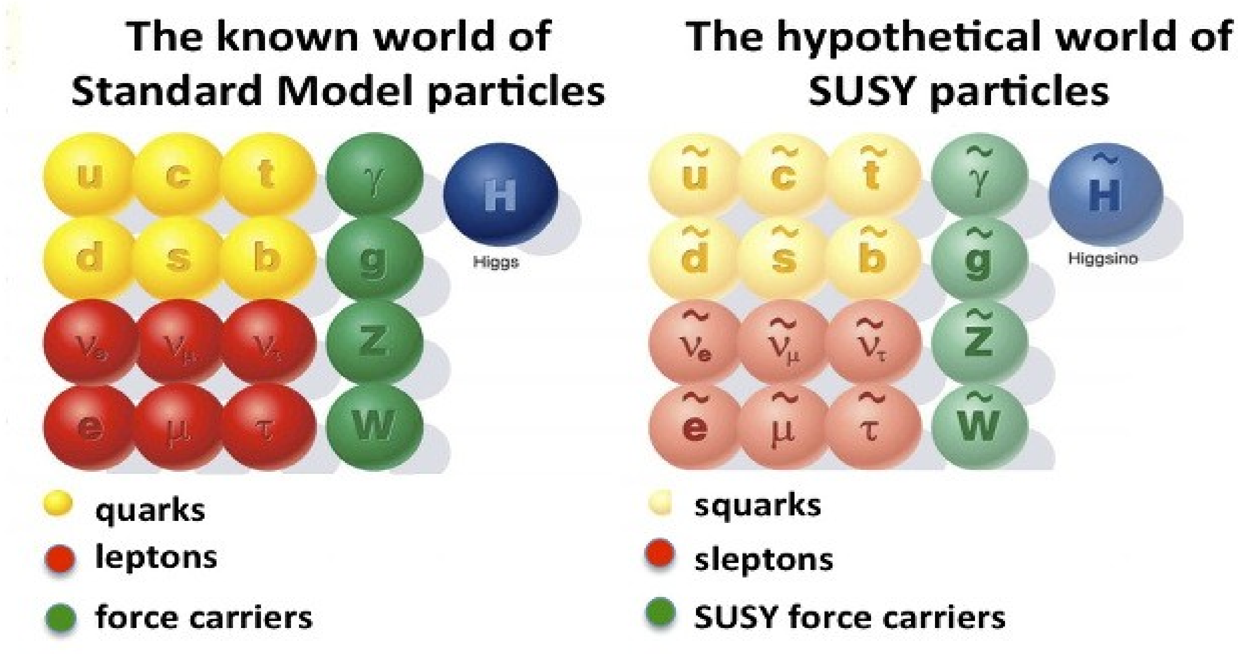


$$\epsilon = \frac{3\,\bar{m}_t^4}{2\pi^2 v^2 \sin^2\beta} \left[\log \frac{M_S^2}{\bar{m}_t^2} + \frac{X_t^2}{2\,M_S^2}\left(1 - \frac{X_t^2}{6\,M_S^2}\right)\right]$$

$$M_h \overset{M_A \gg M_Z}{\rightarrow} \sqrt{M_Z^2 \cos^2 2\beta + \epsilon \sin^2\beta} \left[1 + \frac{\epsilon M_Z^2 \cos^2\beta}{2M_A^2(M_Z^2 + \epsilon \sin^2\beta)} - \frac{M_Z^2 \sin^2\beta + \epsilon \cos^2\beta}{2M_A^2} \right]$$

[Review : Djouadi’05]

The case for SUSY ...



The Minimal SUSY (extension of the) Standard Model (MSSM)

- Has the same gauge group as SM : $SU(3)_c xSU(2)_L xU(1)_Y$
- Particle content follow from SM + extra Higgs doublet
- A discrete symmetry R-parity is assumed to presvent p decay via renormalizable terms, provides with a Dark Matter candidate
- Soft-SUSY breaking is assumed
- Neutrino mass generation mechanism requires extension

Inflation within SUSY

- For high scale inflation SUGRA needs to be invoked

- Inevitable correction from SUGRA, eta problem, need protection : Shift symmetry, Heisenberg symmetry ...

  [Dine,Fischler,Nemeschansky,1984;Coughlan,Holman,Ramond,Ross, 1984; Binetruy,Gaillard 1987, Gillard,Murayama,Olive,1995...]

- Supergravity potential : $V_F = e^K \left[D_{\Phi_i} W K^{-1}_{ij^*} D_{\Phi^*_j} W^* - 3|W|^2 \right]$

$$D_{\Phi_i} W = \frac{\partial W}{\partial \Phi_i} + \frac{\partial K}{\partial \Phi_i} W$$

[Review Yamaguchi 2011]

- Low scale inflations do not necessarily suffer

$$V(\phi) = H^2 M_P^2 f\left(\frac{\phi}{M_P}\right) \qquad H_{\rm inf}^2 M_P^2 \left(\frac{\phi}{M_P}\right)^p \ll m_\phi^2 \phi_0^2$$

Inflation within SUSY: The case for Higgs

- For low scale inflation : SUGRA corrections negligible
- Within MSSM, can accommodate inflaton

  [Allahverdi,Enqvist,Mazumdar,Garcia-Bellido,2006..]
- Several flat directions : UDD, LLE ...
- How about the Higgs Bosons : $\mathbf{H_1}$ $\mathbf{H_2}$
- D-flat direction, F-flatness lifted by mu term,
  also any number of Planck suppressed terms may be present

$$\mathcal{W} = \mu \mathbf{H_1}.\mathbf{H_2} + \frac{\lambda_k}{k}\frac{(\mathbf{H_1}.\mathbf{H_2})^k}{M_P^{2k-3}}$$

- Mu term is >O(100) GeV [LHC constraints!]

[ATLAS, CMS electroweak-ino searches]

Inflation within SUSY: The case for Higgs...

- The soft-SUSY breaking terms :

$$V_{H,Soft} = m_1^2|H_1|^2 + m_2^2|H_2|^2 + (B\mu H_1.H_2 + h.c.)$$

- The scalar potential :

$$\tilde{V}(\varphi,\theta) = \frac{1}{2}m^2(\theta)\varphi^2 + (-1)^{(k-1)}2\lambda_k^{'}\mu\cos((2k-2)\theta)\varphi^{2k} + 2\lambda_k^{'2}\varphi^{2(2k-1)}$$

$$\phi = |\phi|e^{i\theta},\ \varphi = \sqrt{2}|\phi|$$

- Some details :

$$H_1 = \frac{1}{\sqrt{2}}(\phi,0)^T,$$

$$H_2 = \frac{1}{\sqrt{2}}(0,\phi)^T,$$

$$m^2(\theta) = \frac{1}{2}(m_1^2 + m_2^2 + 2\mu^2 - 2B\mu\cos 2\theta)$$

$$\lambda_k^{'} = \frac{\lambda_k}{2^{(2k-1)}M_P^{2k-3}}.$$

- Assume B and mu to be real, experimental constraint on complex phases, 0 phase is well-motivated

[Pospelov, Ritz]

Inflation within SUSY: The case for Higgs...

- The scalar potential can have a local minima in the angular direction for
- And a suitable inflection point for :

$$m_0^2 = \frac{k^2\mu^2}{(2k-1)} + \tilde{\lambda}^2$$

$$\varphi_0 = \left(\frac{k|\mu||\lambda_k'|^{-1}}{2(2k-1)} \right)^{1/(2k-2)} (1-\lambda^2) \qquad \lambda^2 = \frac{\tilde{\lambda}^2 m_0^{-2}}{8(k-1)^2}$$

- The potential is :

$$V_0 = \frac{(k-1)^2 m_0^2}{k(2k-1)} \varphi_0^2 + \mathcal{O}(\lambda^2)$$

- Sub-Planckian *ev,* scale of inflation *low, no eta problem*
- Inflation ends when $|\eta| \simeq 1$

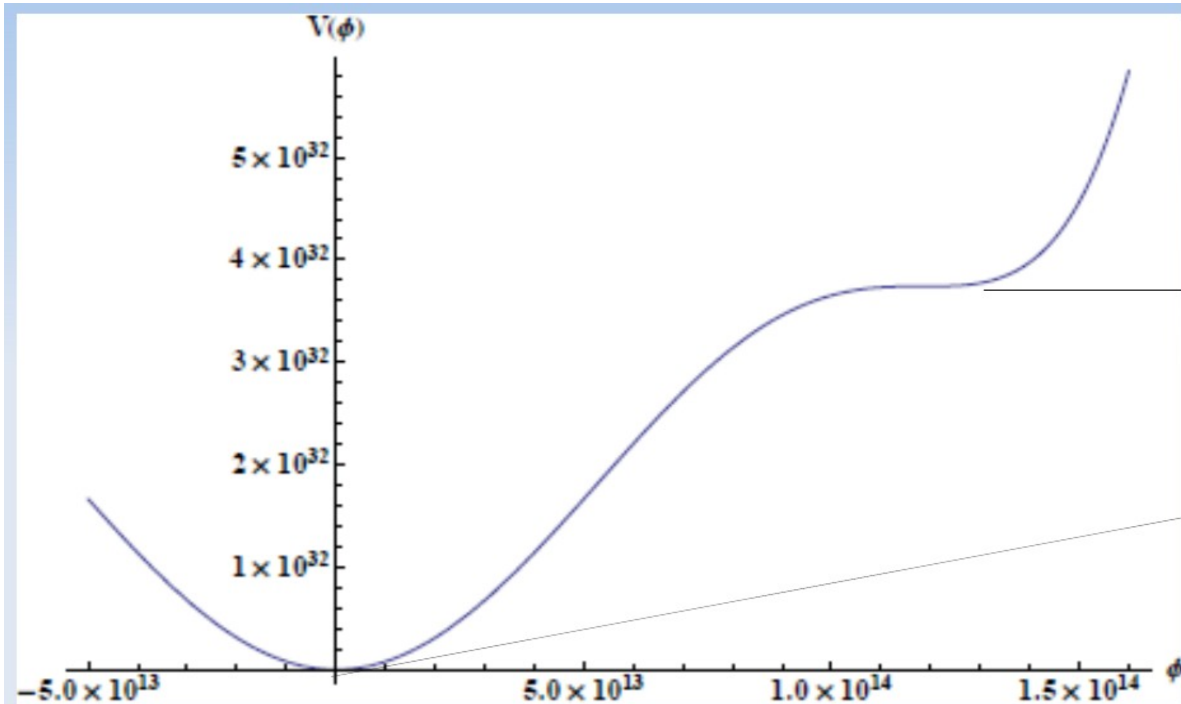
$$\frac{|\varphi_0 - \varphi|}{\varphi_0} \sim \left(\frac{\varphi_0}{8k(2k-1)M_P} \right)^2 \sim 10^{-8}$$

- Can get sufficient *e-foldings*

[Liddle,Leach,2003;Burgess et.al 2005]

$$N_{\rm COBE} \simeq 66.9 + (1/4)\ln(V(\varphi_0)/M_P^4) \sim 45$$

Inflation within SUSY: The case for Higgs...



Slow-roll regime

- EW symmetry restored.
- (P)reheating

moduli problem avoided

$\varphi_0 \sim 10^{14}\ \text{GeV}$ $\quad V(\varphi_0) = V_0 \simeq 10^{32}\ \ \text{GeV}^4$

$$H_{\text{inf}} \simeq \sqrt{\frac{V_0}{3M_P^2}} = \frac{k-1}{\sqrt{3k(2k-1)}}\frac{m_0\varphi_0}{M_P} \quad \sim 10^{-1}\ \text{GeV}$$

Inflation within SUSY : The case for Higgs...

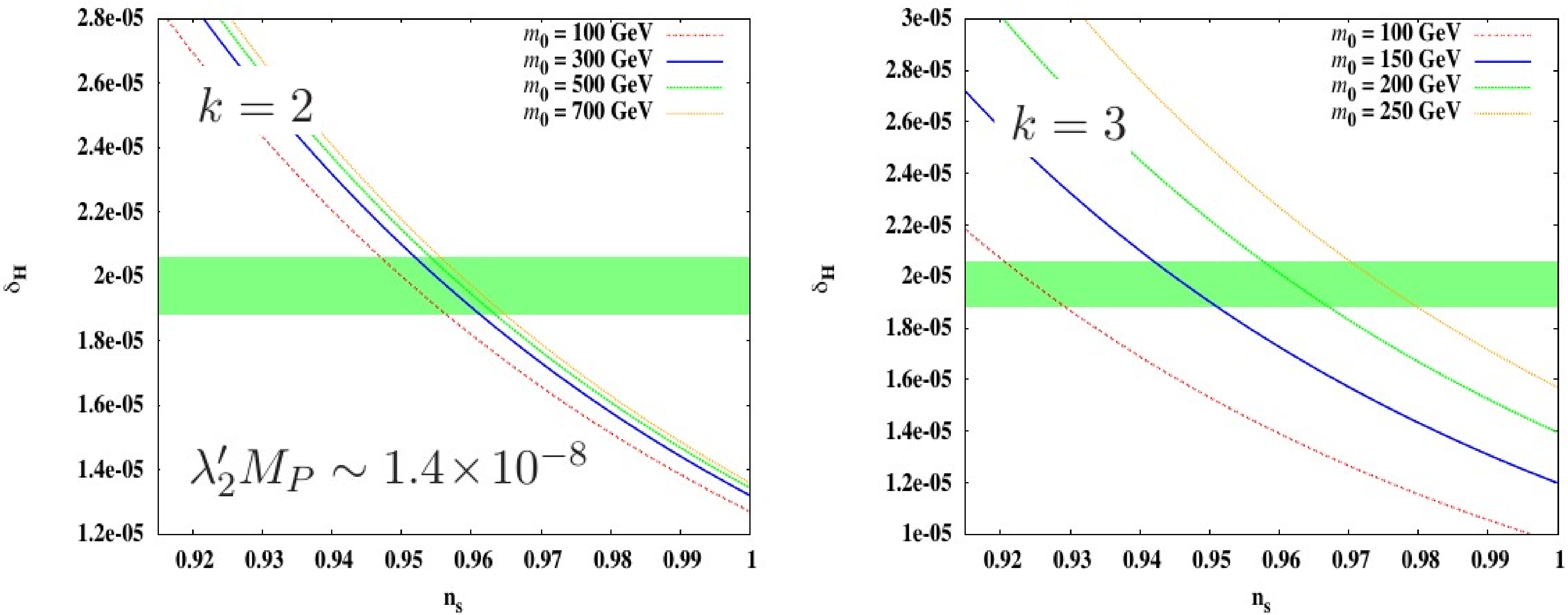
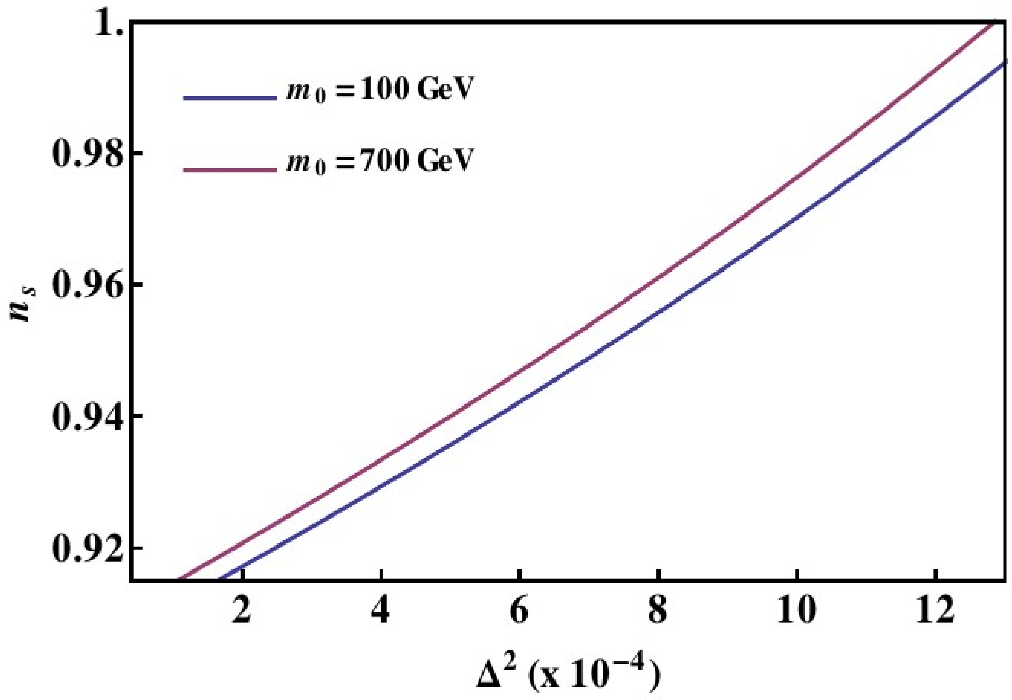


Figure 1. δ_H and n_s have been plotted for different values of m_0 and at the inflection point VEV, $\varphi_0 \sim 3 \times 10^{14}$ GeV. In frame (a) we have used $k = 2$ in the superpotential, we have taken $\lambda_2' M_P = 1.4 \times 10^{-8}$, see eq. (2.6). Although the splitting between these curves are not so sensitive to the inflaton mass, varying λ_2' it is possible to span the complete range in the n_s-δ_H plane. In frame (b) we have used $k = 3$ in the superpotential, and have used $\lambda_3' M_P^3 = -0.71$. The green bands denote 2σ allowed region of δ_H [1].

Inflation within SUSY : The case for Higgs...

- Fine tuning required : $$n_s = 1 - 4\sqrt{\Delta^2}\cot[\mathcal{N}_{\rm COBE}\sqrt{\Delta^2}]$$

$$\delta_H \simeq \frac{1}{5\pi}\sqrt{\frac{2}{3}2k(2k-1)}(2k-2)\left(\frac{m_0 M_P}{\varphi_0^2}\right)\frac{1}{\Delta^2}\sin^2[\mathcal{N}_{\rm COBE}\sqrt{\Delta^2}]$$

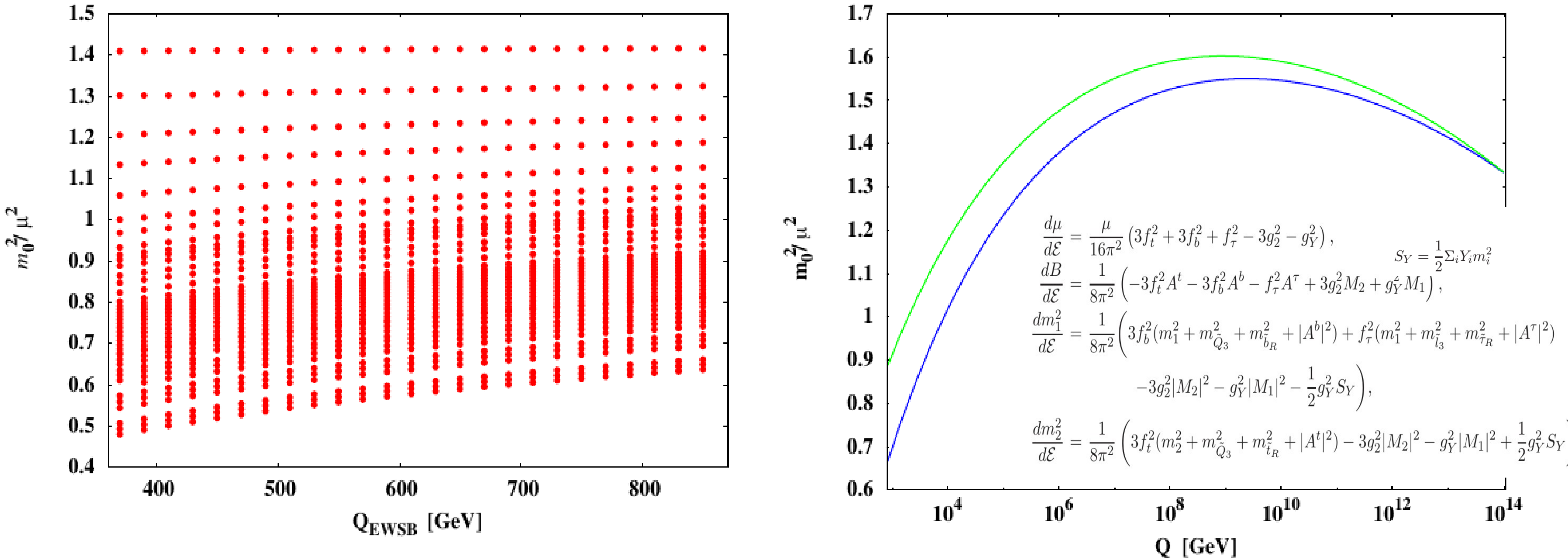


$$\Delta^2 \sim 10^{-3} \quad \Longrightarrow \quad \lambda \sim 10^{-11}$$

$$m_0^2 = \frac{k^2\mu^2}{(2k-1)} + \tilde{\lambda}^2$$

Figure 2. n_s has been plotted against vs Δ^2 for different values of m_0 for $k=2$ case with $\lambda_2' M_P = 1.4 \times 10^{-8}$.

Inflation within SUSY : EWSB ...



$$\frac{d\mu}{d\mathcal{E}} = \frac{\mu}{16\pi^2}\left(3f_t^2 + 3f_b^2 + f_\tau^2 - 3g_2^2 - g_Y^2\right),$$

$$S_Y = \frac{1}{2}\Sigma_i Y_i m_i^2$$

$$\frac{dB}{d\mathcal{E}} = \frac{1}{8\pi^2}\left(-3f_t^2 A^t - 3f_b^2 A^b - f_\tau^2 A^\tau + 3g_2^2 M_2 + g_Y^2 M_1\right),$$

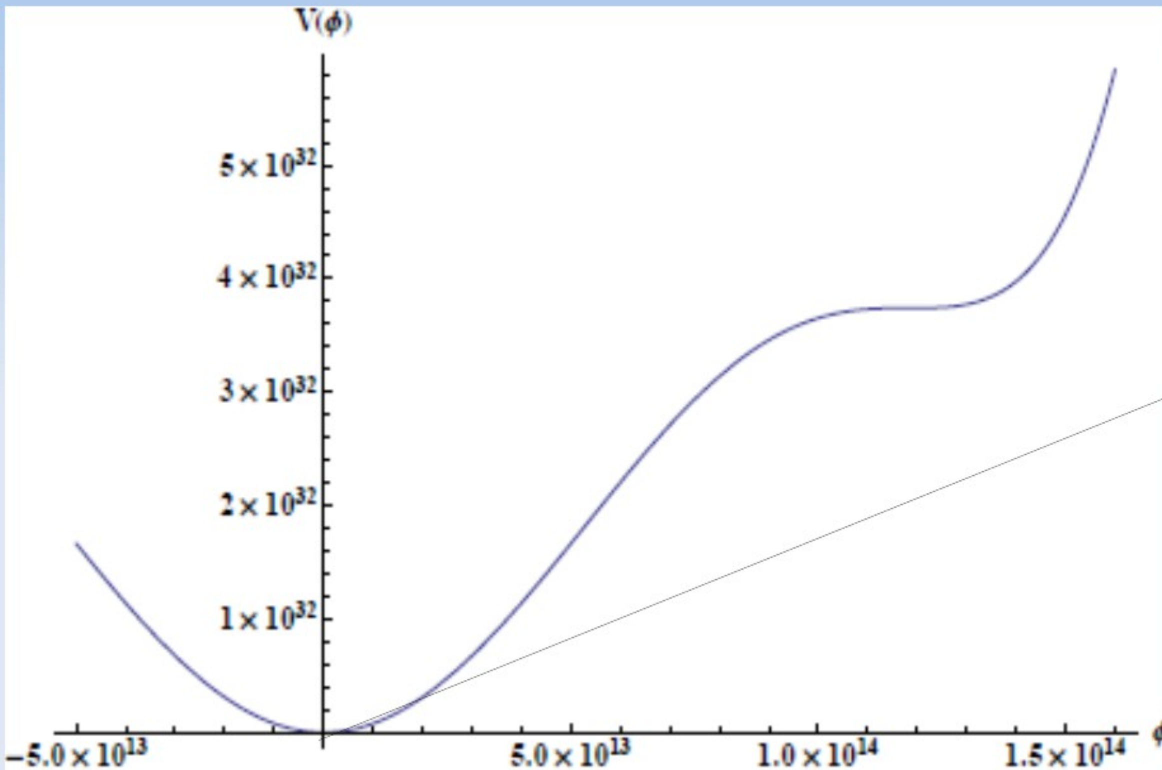
$$\frac{dm_1^2}{d\mathcal{E}} = \frac{1}{8\pi^2}\Big(3f_b^2(m_1^2 + m_{\tilde{Q}_3}^2 + m_{\tilde{b}_R}^2 + |A^b|^2) + f_\tau^2(m_1^2 + m_{\tilde{l}_3}^2 + m_{\tilde{\tau}_R}^2 + |A^\tau|^2)$$
$$-3g_2^2|M_2|^2 - g_Y^2|M_1|^2 - \frac{1}{2}g_Y^2 S_Y\Big),$$

$$\frac{dm_2^2}{d\mathcal{E}} = \frac{1}{8\pi^2}\left(3f_t^2(m_2^2 + m_{\tilde{Q}_3}^2 + m_{\tilde{t}_R}^2 + |A^t|^2) - 3g_2^2|M_2|^2 - g_Y^2|M_1|^2 + \frac{1}{2}g_Y^2 S_Y\right)$$

Figure 3. Frame (a): A sample plot where the ratio m_0^2/μ^2, see eq. (3.1), for $k = 2$, has been evaluated at the EWSB scale. The corresponding value at a high scale, $\varphi_0 \sim 10^{14}$ GeV, is set to 4/3, see eq. (3.1), with an accuracy of 0.1%. Frame (b): The ratio m_0^2/μ^2 for $k = 2$, has been evolved from 10^{14} GeV to the EWSB scale (chosen to be 850 GeV). The green line and the blue line correspond to $m_0 = 323.4$ GeV and $m_0 = 354$ GeV at 10^{14} GeV respectively. The ratio at the high scale (10^{14} GeV) is set to 4/3, see eq. (3.1), with an accuracy of 0.1%. The RGE accuracy in *SuSpect* [27] is about 0.01%.

- No UV fixed point. Parameter space consistent with Higgs mass of 125 GeV

Inflation within SUSY : (P)reheating ...



- Point of enhanced symmetry.
- Efficient (P)reheating, within 1 Hubble time, rapid thermalization expected.
- No relic topological defect

[for LLE inflaton: Allahverdi, Ferrantelli, Garcia-Bellido, Mazumdar; hep-ph/1103.2123]

- The final reheat temperature :

$$g_* = 228.75$$

$$\rho_0 = (4/15) m_0^2 \phi_0^2$$

$$T_{\rm rh} \simeq \left(\frac{30}{\pi^2 g_*} \right)^{1/4} \rho_0^{1/4} \simeq 2 \times 10^8 \ {\rm GeV}$$

Questions

- Can we generate sizable r with sub-Planckian excursion?

  Lyth Bound assumes constant (or monotonic variation) in slow-roll parameter

$$\frac{\Delta\phi}{M_{\rm Pl}} = \mathcal{O}(1)\sqrt{\frac{r}{0.01}}$$

[Lyth,1996;Lyth,Boubekeur,2006]

- How to probe the full inflationary potential in such cases? Any possibility to produce adequate PBH DM?

A “Phenomenological” Potential for Inflation

- Motivated by SUSY/SUGRA

$$V(\phi) = V_0 + A\phi^2 - B\phi^3 + C\phi^4$$

- The scalar potential :

  With sizable SUGRA contribution :

$$V_0 + c_H H^2 \phi^2 - a_H H \lambda_n \phi^n + \lambda_n^2 \phi^{2n-2}$$

- N=3,4,6

$$\phi = \frac{\widetilde{N} + H_u + \widetilde{L}}{\sqrt{3}} \qquad \phi = \frac{H_u + H_d}{\sqrt{2}}$$

$$\phi = \frac{\widetilde{u} + \widetilde{d} + \widetilde{d}}{\sqrt{3}} \qquad \phi = \frac{\widetilde{L} + \widetilde{L} + \widetilde{e}}{\sqrt{3}}$$

[See e.g. review Mazumdar,Rocher, 2010...]

- Ways to generate V0 : String theory “Landscape”, Hidden sector with a heavy superfield, hybrid scenarios ....

[Allahverdi,Frey,Mazumdar; Enqvist, Mether,Nurmi; Lalak,Turzynski]

Reconstructing the Parameters

- Some relevant "observables":

$$\mathcal{P}_s(k) = \frac{1}{8\pi^2}\frac{H^2}{\varepsilon_V}\Big|_{k=aH} = A_\mathrm{s}\left(\frac{k}{k_*}\right)^{n_\mathrm{s}-1+\frac{1}{2}\,\mathrm{d}n_\mathrm{s}/\mathrm{d}\ln k\,\ln(k/k_*)+\frac{1}{6}\,\mathrm{d}^2n_\mathrm{s}/\mathrm{d}\ln k^2(\ln(k/k_*))^2+\ldots}$$

$$\mathcal{P}_\mathrm{t}(k) = \frac{2H^2}{\pi^2}\Big|_{k=aH} = A_\mathrm{t}\left(\frac{k}{k_*}\right)^{n_\mathrm{t}+\frac{1}{2}\,\mathrm{d}n_\mathrm{t}/\mathrm{d}\ln k\,\ln(k/k_*)+\ldots},$$

$$\begin{aligned}
A_\mathrm{s} &\approx \frac{V}{24\pi^2 M_\mathrm{pl}^4\varepsilon_V},\\
n_\mathrm{s}-1 &\approx 2\eta_V - 6\varepsilon_V,\\
\mathrm{d}n_\mathrm{s}/\mathrm{d}\ln k &\approx 16\varepsilon_V\eta_V - 24\varepsilon_V^2 - 2\xi_V^2,\\
\mathrm{d}^2n_\mathrm{s}/\mathrm{d}\ln k^2 &\approx -192\varepsilon_V^3 + 192\varepsilon_V^2\eta_V - 32\varepsilon_V\eta_V^2\\
&\quad - 24\varepsilon_V\xi_V^2 + 2\eta_V\xi_V^2 + 2\sigma_V^3,\\
A_\mathrm{t} &\approx \frac{2V}{3\pi^2 M_\mathrm{pl}^4},\\
n_\mathrm{t} &\approx -2\varepsilon_V,\\
\mathrm{d}n_\mathrm{t}/\mathrm{d}\ln k &\approx 4\varepsilon_V\eta_V - 8\varepsilon_V^2\,.
\end{aligned}$$

- Reconstructing the potential at pivot scale $\phi_\mathrm{CMB} = 1\ M_P$

$$\begin{pmatrix} \phi_\mathrm{CMB}^2 & -\phi_\mathrm{CMB}^n & \phi_\mathrm{CMB}^{2(n-1)} \\ 2\phi_\mathrm{CMB} & -n\phi_\mathrm{CMB}^{(n-1)} & 2(n-1)\phi_\mathrm{CMB}^{2n-3} \\ 2 & -n(n-1)\phi_\mathrm{CMB}^{(n-2)} & 2(n-1)(2n-3)\phi_\mathrm{CMB}^{2(n-2)} \end{pmatrix}\begin{pmatrix} A \\ B \\ C \end{pmatrix} = \begin{pmatrix} V(\phi_\mathrm{CMB}) - V_0 \\ V'(\phi_\mathrm{CMB}) \\ V''(\phi_\mathrm{CMB}) \end{pmatrix}$$

[Hotchkiss,Mazumdar, Nadathur'11]

- Using :

$$V(\phi_\mathrm{CMB}) = \frac{3}{2}A_s r\pi^2,$$

$$V'(\phi_\mathrm{CMB}) = \frac{3}{2}\sqrt{\frac{r}{8}}\left(A_s r\pi^2\right),$$

$$V''(\phi_\mathrm{CMB}) = \frac{3}{4}\left(\frac{3r}{8} + n_s - 1\right)\left(A_s r\pi^2\right)$$

$$A_\mathrm{s} \approx \frac{V}{24\pi^2 M_\mathrm{pl}^4\varepsilon_V} \approx 2.2\times10^{-9}$$

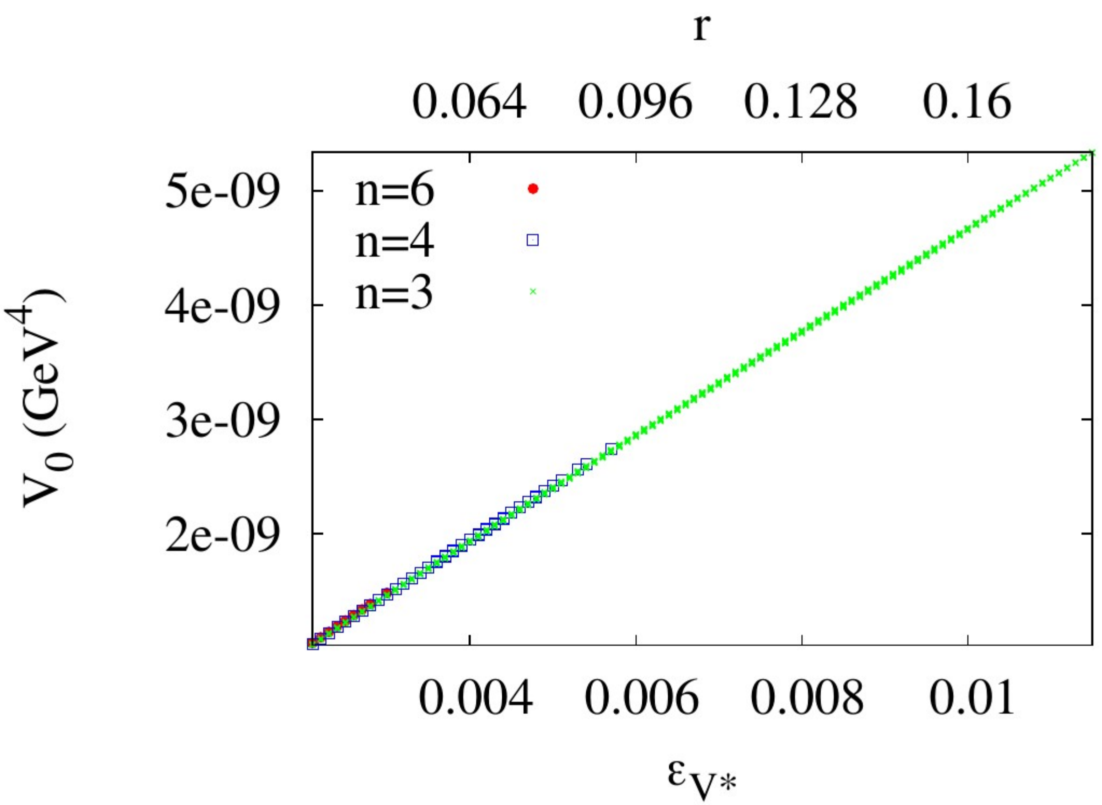
$$n_\mathrm{s} \approx 1 + 2\eta_V - 6\varepsilon_V \approx 0.96$$

Reconstructing the Parameters

- Some constraints from Planck:

Model	Parameter	*Planck*+WP+lensing	*Planck*+WP+high-ℓ
ΛCDM + $\mathrm{d}n_s/\mathrm{d}\ln k$ + $\mathrm{d}^2n_s/\mathrm{d}\ln k^2$	n_s	$0.9573^{+0.077}_{-0.079}$	$0.9476^{+0.086}_{-0.088}$
	$\mathrm{d}n_s/\mathrm{d}\ln k$	$0.006^{+0.015}_{-0.014}$	$0.001^{+0.013}_{-0.014}$
	$\mathrm{d}^2n_s/\mathrm{d}\ln k^2$	$0.019^{+0.018}_{-0.014}$	$0.022^{+0.016}_{-0.013}$
ΛCDM + r + $\mathrm{d}n_s/\mathrm{d}\ln k$	n_s	0.9633 ± 0.0072	0.9570 ± 0.0075
	r	< 0.26	< 0.23
	$\mathrm{d}n_s/\mathrm{d}\ln k$	-0.017 ± 0.012	$-0.022^{+0.011}_{-0.010}$

- Constrained from BICEP2 & KEK+Planck r(0.05) < 0.06 PRL'18 :



Results : Benchmarks

TABLE I. We have used $n_s = 0.96, A_s = 2.2 \times 10^{-9}, \phi_{\rm CMB} = 1$ in the Planck units for all the benchmarks evaluated at $k_* = 0.05$ Mpc^{-1}. The three benchmark points match the current CMBR data, i.e. the central values used in Eqs. (2), (3).

Benchmark Points (BP)	n	$V_0(k_*)$	$A(k_*)$	$B(k_*)$	$C(k_*)$	$\frac{dn_s}{d\ln k}(k_*)$	$\frac{d^2 n_s}{d\ln k^2}(k_*)$	$r(k_*)$
1	3	7.44×10^{-10}	0.868×10^{-10}	0.689×10^{-10}	0.190×10^{-10}	-0.006	0.003	0.024
2	3	1.506×10^{-10}	0.2046×10^{-10}	0.2246×10^{-10}	0.0757×10^{-10}	-0.0148	0.001	0.005
3	4	14.245×10^{-10}	1.240×10^{-10}	0.500×10^{-10}	0.112×10^{-10}	-0.0148	0.021	0.046

- The slow-roll parameters (non-monotonic) :

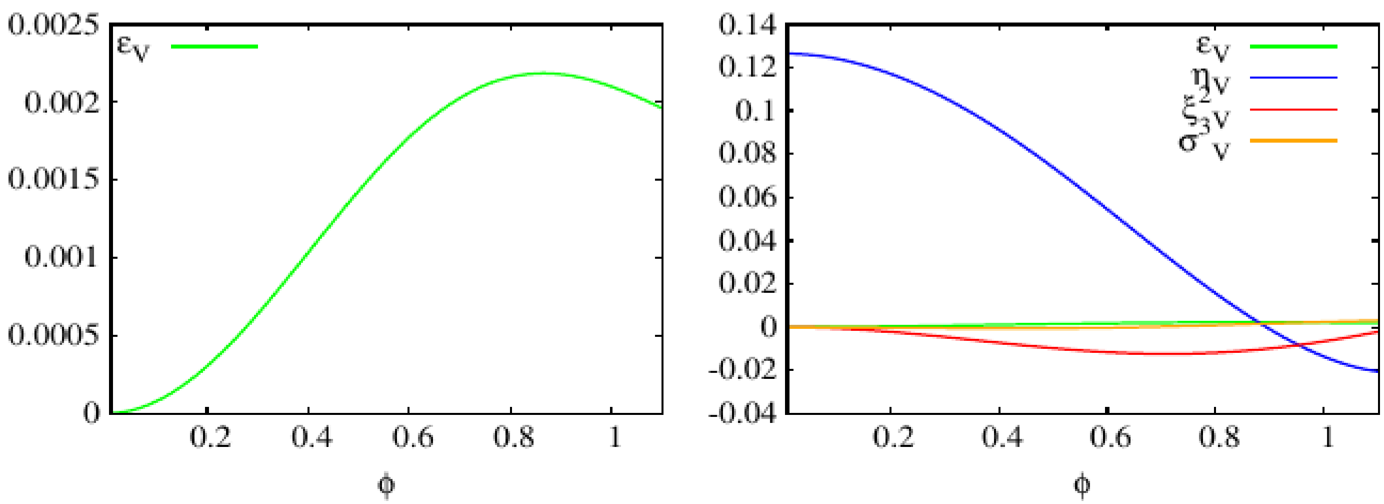
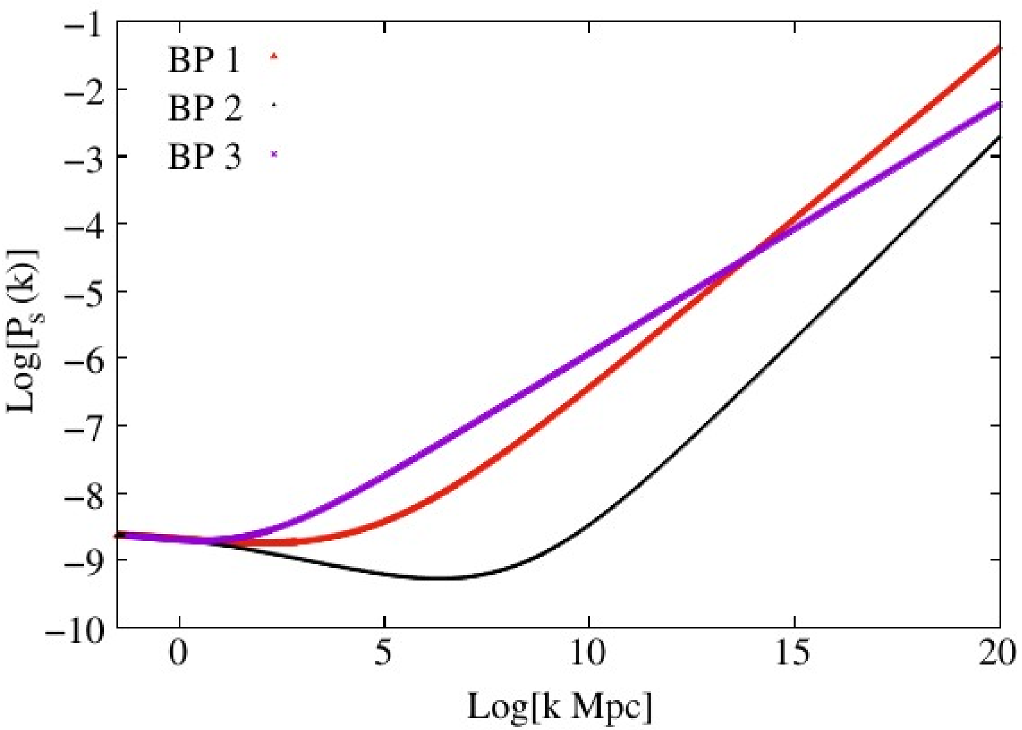


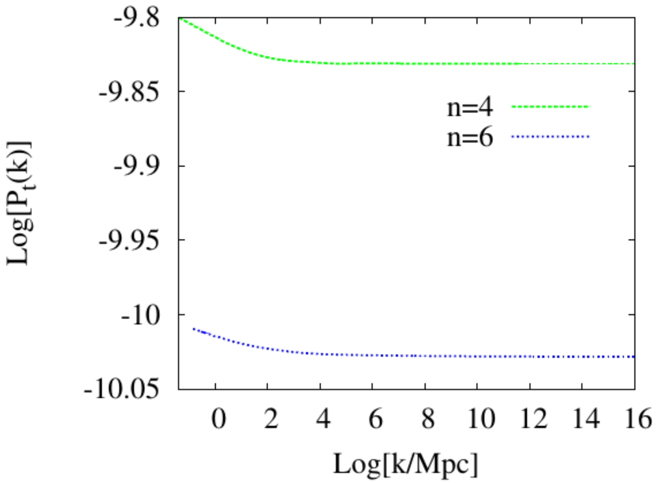
FIG. 2. The slow-roll parameters have been shown for the benchmark scenario BP-3 in Table I.

Results : Power Spectra

- The scalar power spectrum :
  (Solving full Mukhanov-Sasaki equation)

- Large power at small scales, slope dictated by A/V0





Results : Gravitational Wave at Small Scales

- The metric

$$ds^2 = -a(\eta)^2 \left[(1+2\Phi)d\eta^2 + \left\{ (1-2\Phi)\delta_{ij} + \frac{1}{2}h_{ij} \right\} dx^i dx^j \right]$$

- The transverse and traceless tensor perturbation

$$h_{ij}(\mathbf{x},\eta) = \frac{1}{(2\pi)^{3/2}} \int d^3\mathbf{k}\, e^{i\mathbf{k}.\mathbf{x}} [h_{\mathbf{k}}(\eta) e_{ij}(\mathbf{k}) + \bar{h}_{\mathbf{k}}(\eta) \tilde{e}_{ij}(\mathbf{k})] \qquad e^{ij}e_{ij} = 1 = \tilde{e}^{ij}\tilde{e}_{ij}, e^{ij}\tilde{e}_{ij} = 0$$

- The equation in the Fourier space (for + polarization):

$$h''_{\mathbf{k}} + 2\mathcal{H}h'_{\mathbf{k}} + k^2 h_{\mathbf{k}} = \mathcal{S}(\mathbf{k},\eta)$$

- Note that second order scalar perturbation can source tensor perturbation

[Ananda,Clarkson,Wands;
Baumann,Steinhardt,Takahashi,Ichiki,2007]

Results : Gravitational Wave at Small Scales

- The source term :

$$\mathcal{S}(\mathbf{k},\eta) = -4e^{lm}(\mathbf{k})\mathcal{S}_{lm}(\mathbf{k}) = \int \frac{d^3\mathbf{q}}{(2\pi)^{3/2}} e^{lm}(\mathbf{k}) q_l q_m \mathcal{F}(\mathbf{k},\mathbf{q},\eta)$$

$$\mathcal{F}(\mathbf{k},\mathbf{q},\eta) = 12\Phi(q,\eta)\Phi(|\mathbf{k}-\mathbf{q}|,\eta) + \frac{8}{\mathcal{H}}\Phi'(q,\eta)\Phi(|\mathbf{k}-\mathbf{q}|,\eta) + \frac{4}{\mathcal{H}^2}\Phi'(q,\eta)\Phi'(|\mathbf{k}-\mathbf{q}|,\eta).$$

- The second order source term is significant for

$$k \gg k_{\rm eq} \sim 0.01\ \mathrm{Mpc}^{-1}$$

- The corresponding modes enter during radiation domination

- Bardeen potential satisfies : $\Phi'' + \frac{6(1+w)}{(1+3w)\eta}\Phi' + wk^2\Phi = 0,\quad w = 1/3$

- Primordial and transfer fn

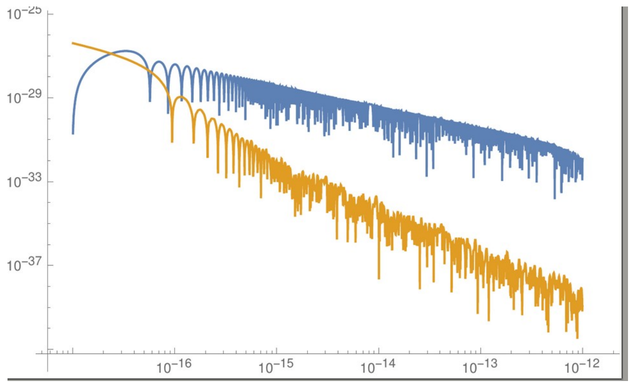
$$\Phi(k,\eta) = \frac{c(k)}{(k\eta)^3}\left[\frac{k\eta}{\sqrt{3}}\cos\left(\frac{k\eta}{\sqrt{3}}\right) - \sin\left(\frac{k\eta}{\sqrt{3}}\right)\right]$$

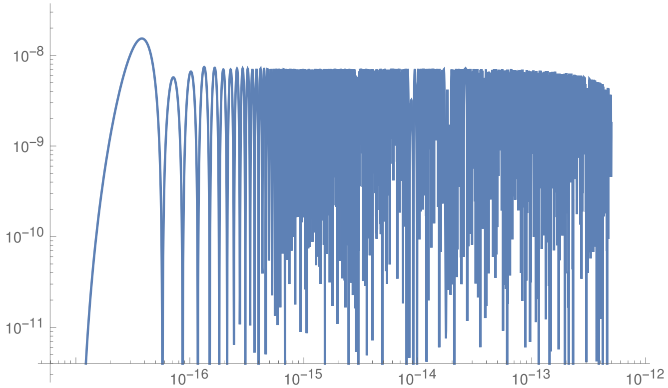
$$\Phi(k,\eta) = \Phi(k\eta)\phi_{\mathbf{k}} \qquad c(k)^2 \simeq (9\sqrt{3})^2 \frac{4}{9}\frac{2\pi^2}{k^3}P_s(k) = \frac{216\pi^2}{k^3}P_s(k)$$

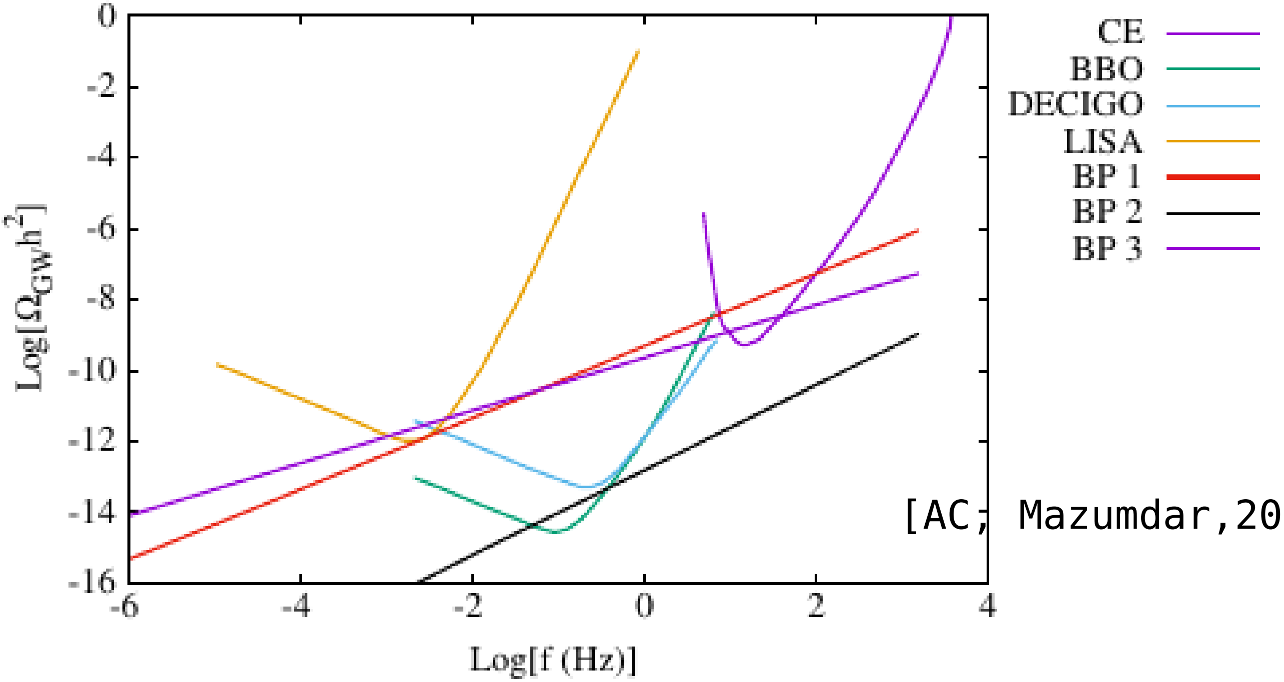
- PBH constraints respected, BBN+CMB constraints respected

$$\Omega_{\rm GW} \lesssim 10^{-5}$$

Primordial Gravitational Wave at Small Scales







[AC, Mazumdar,2017]

$$\mathcal{P}_h(k,\eta) = \frac{k^3}{2\pi^2}\left(|h_{\mathbf{k}}(\eta)|^2 + |\bar{h}_{\mathbf{k}}(\eta)|^2\right)$$

[Maggiore, 2000]

$$\rho_{\rm GW}(k,\eta) = \frac{\langle \dot{h}_{ij}\dot{h}^{ij}\rangle}{32\pi G} = \frac{1}{32\pi G}\frac{k^2}{a(\eta)^2}\mathcal{P}_h(k,\eta)$$

$$\Omega^0_{\rm GW}(k)h^2 = \frac{\Omega^0_{\rm rad}h^2}{2\Omega^{\rm eq}_{\rm rad}}\left(\frac{g_{*\rm eq}}{g_{*i}}\right)^{1/3}\frac{k^2\mathcal{P}_h(k,\eta_i)}{12a(\eta_i)^2H(\eta_i)^2}$$

Conclusion and Outlook

- Inflation can be embedded within MSSM, with fine-tuning

  Low-scale inflation, negligible SUGRA corrections, no moduli problem

- Large V0 can reduce the fine-tuning. Can obtain large r in presence of V0, with sub-Planckian excursion of the inflaton. Possible to obtain such potentials from SUGRA.

- PBHs (as DM) are difficult to produce in such simple (polynomial) inflationary models.

- Possible to probe (such large) scalar power at small scales with gravitational wave.

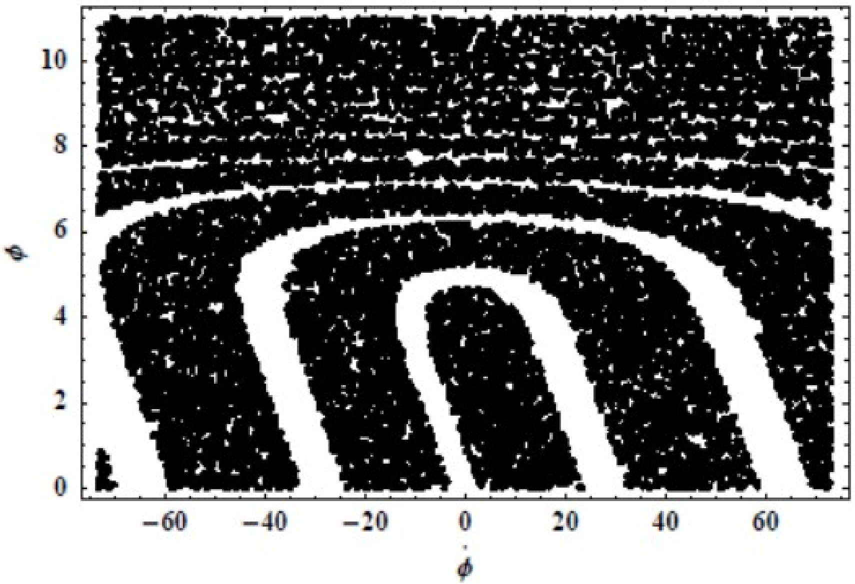


FIG. 4: We plot initial values of ϕ versus $\dot{\phi}$ for $H_{\rm false} = 10^2 m_\phi$. The dots show the initial values for which ϕ settles to $\pm\phi_0$ and the white bands ∩ show the critically damped regions where ϕ settles to zero.

Attraction towards the inflection Point :

- MSSM has metastable vacua
- Need inflation in the flase vacua
- If $m < H_{false}$, scalar fields can get displaced
- If started at a small VEV, MSSM inflaton can obtain quantum jumps of the order H_{false} /2 pi
- Need the rms value greater than the VEV at the inflection point : need ~10^{16} efoldings of false vacuum inflation.

[Allahverdi, Dutta, Mazumdar, hep-ph/08064557]

- In the string landscape favorable conditions exist
[Allahverdi, Frey, Mazumdar;hep-th/0701233]