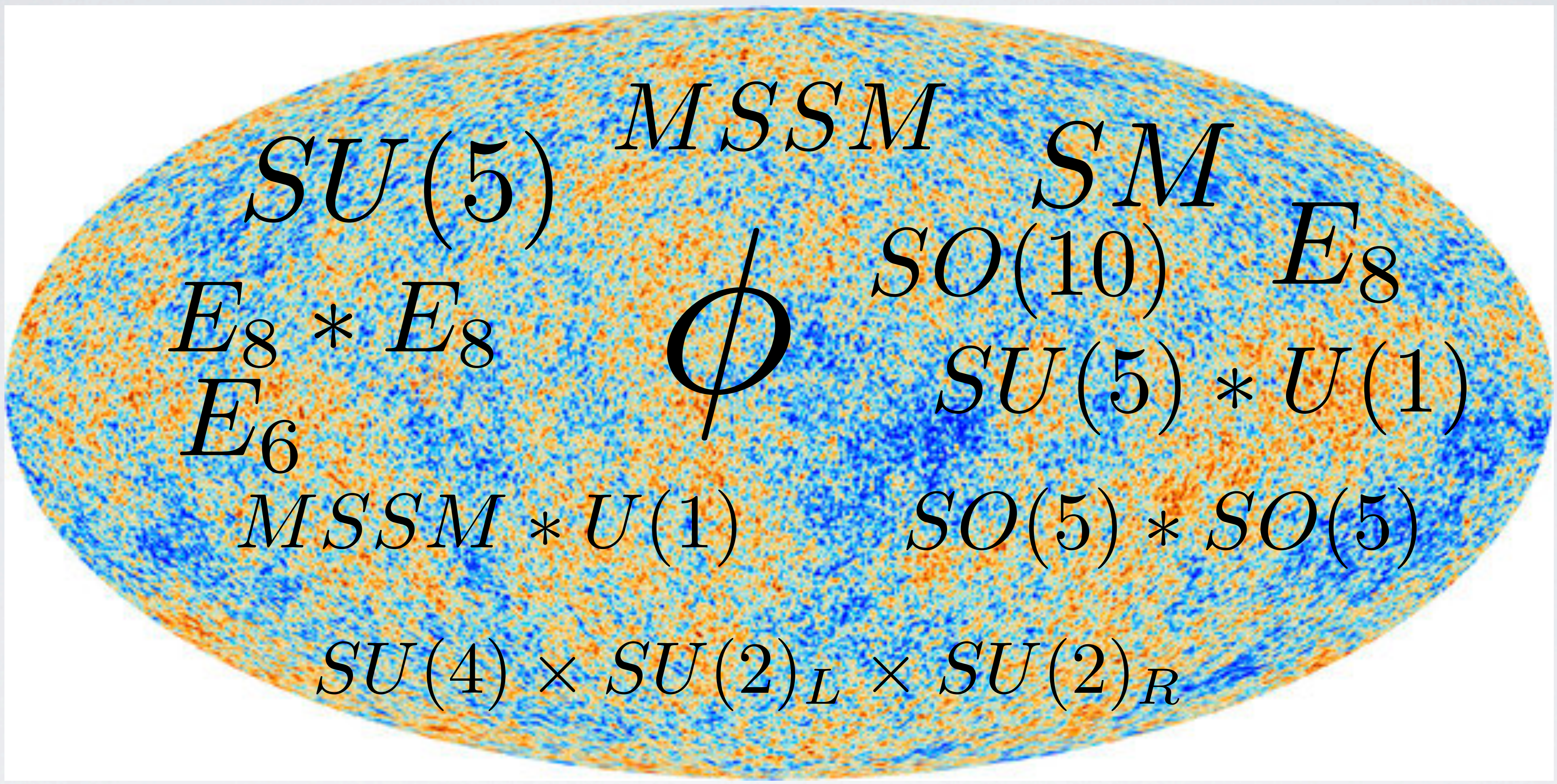
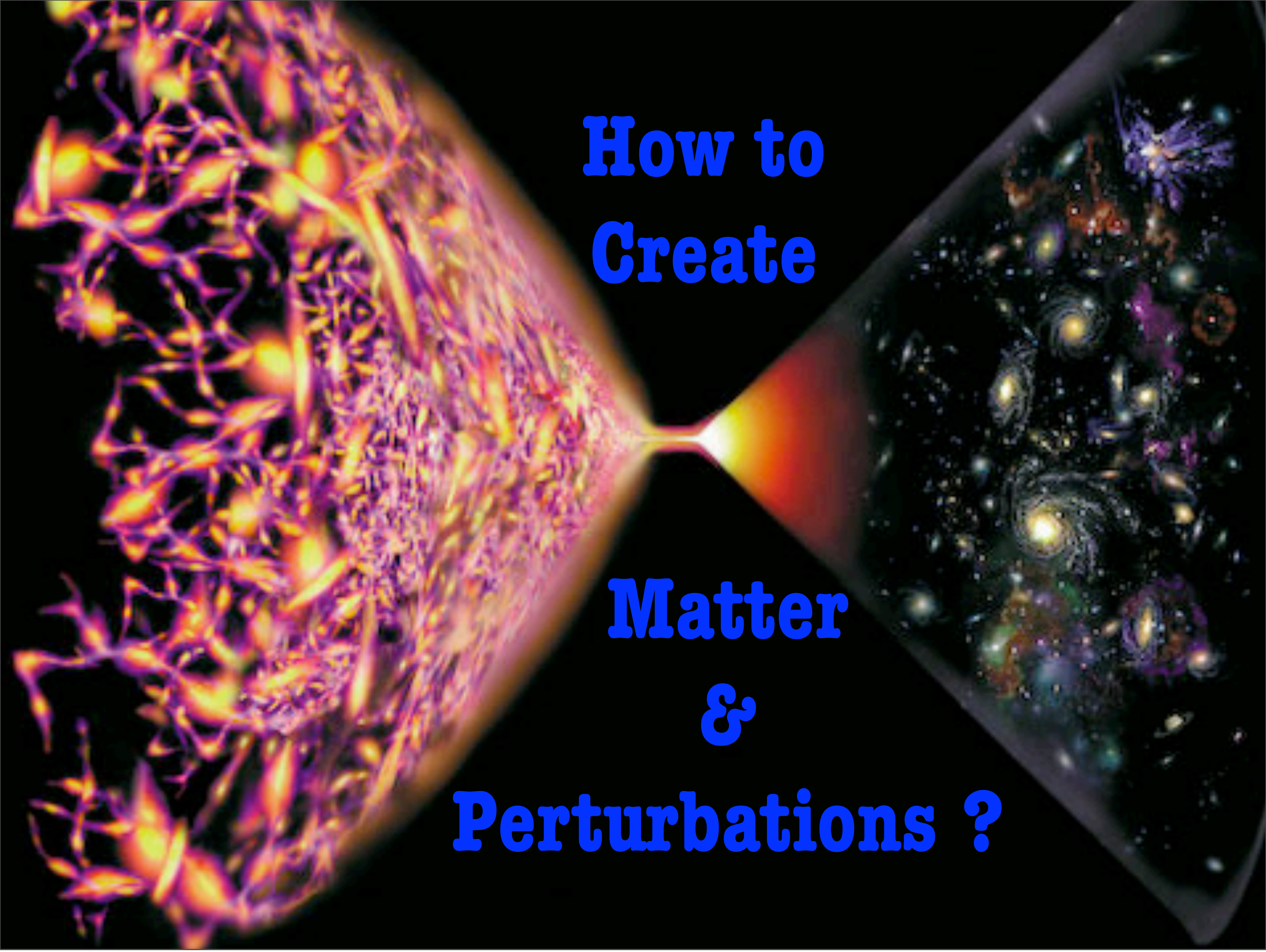
ORIGIN OF INFLATION FROM VISIBLE SECTOR MODELS OF PARTICLE PHYSICS

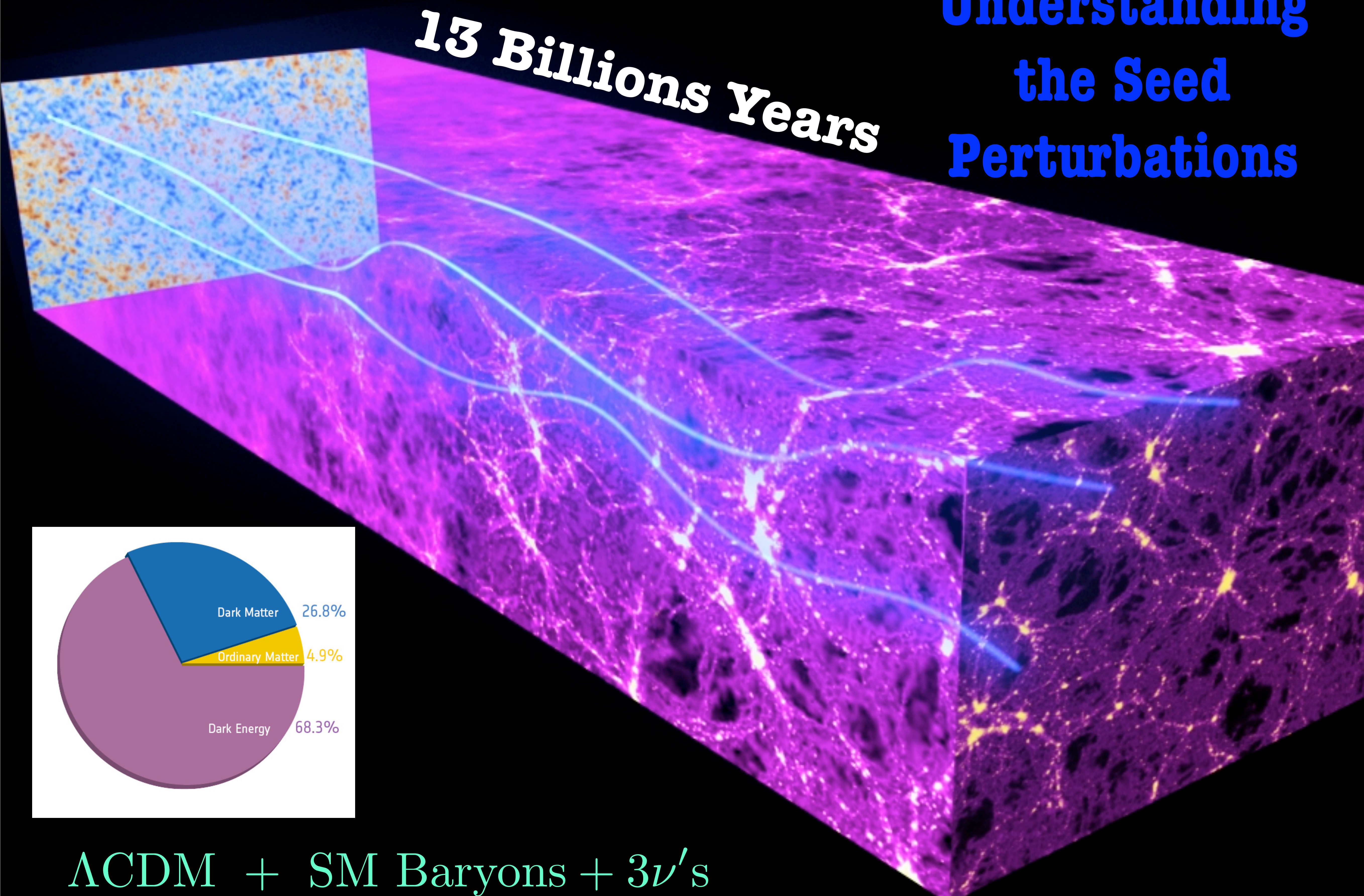


Anupam Mazumdar **Lancaster University**

Planck-2013: Bonn, 20-24 May

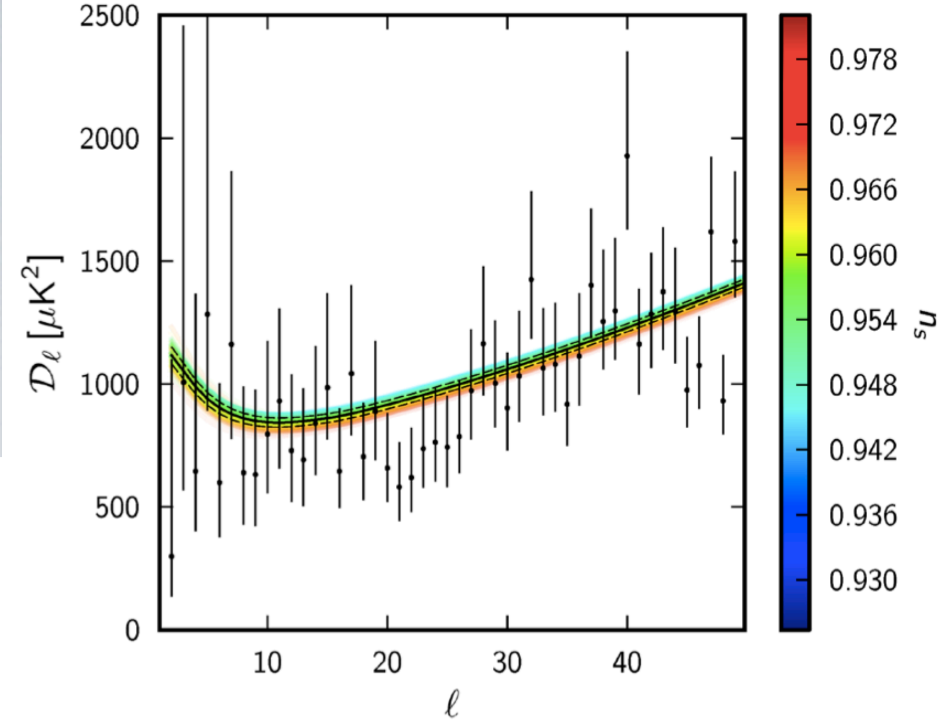

How to
Create
Matter
&
Perturbations ?

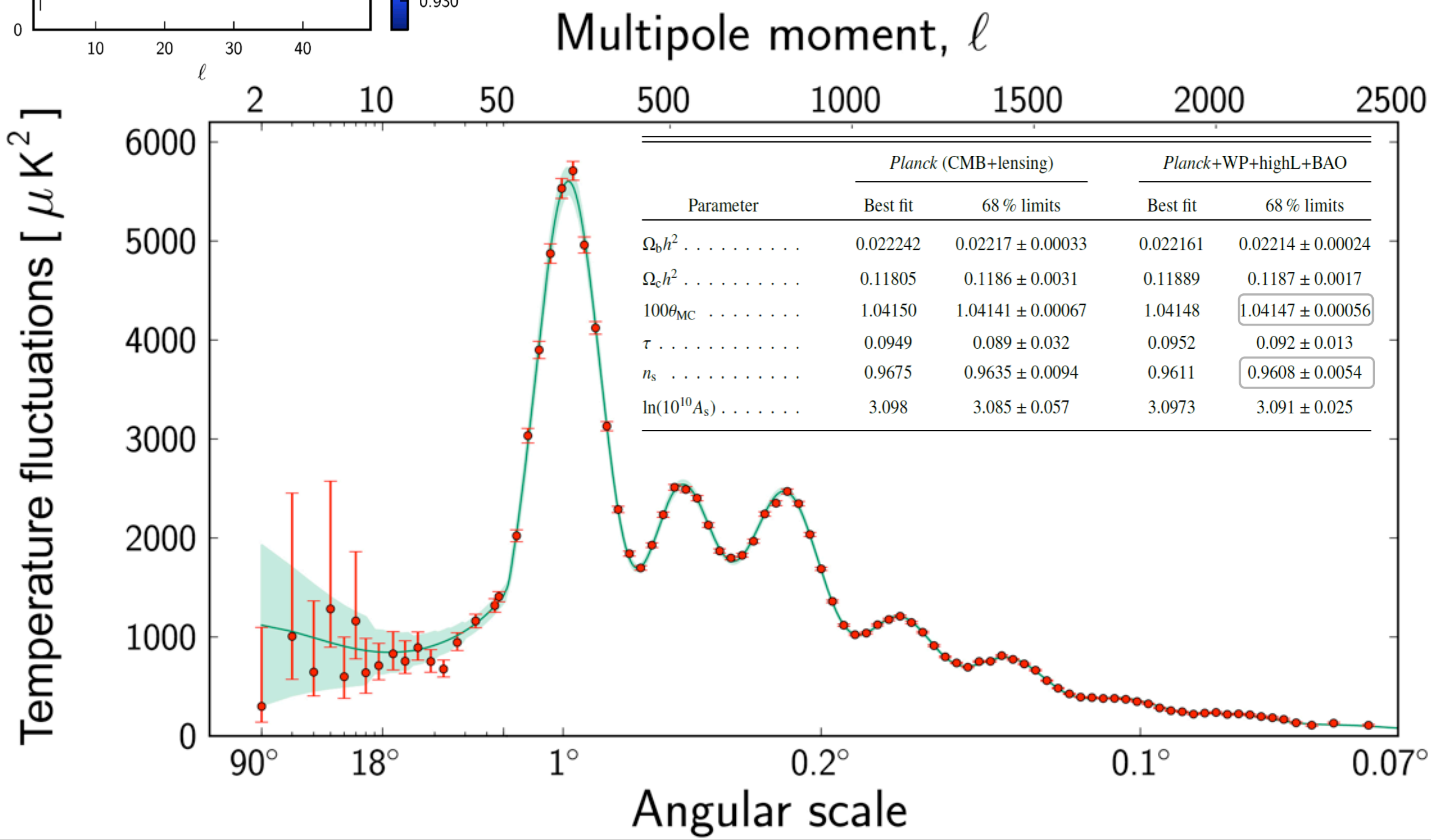
Understanding the Seed Perturbations



$$\Lambda\mathrm{CDM}\ +\ \mathrm{SM\ Baryons} + 3\nu'\mathrm{s}$$

Planck Multipoles





	Planck (CMB+lensing)		*Planck*+WP+highL+BAO	
Parameter	Best fit	68 % limits	Best fit	68 % limits
$\Omega_b h^2$	0.022242	0.02217 ± 0.00033	0.022161	0.02214 ± 0.00024
$\Omega_c h^2$	0.11805	0.1186 ± 0.0031	0.11889	0.1187 ± 0.0017
$100\theta_{MC}$	1.04150	1.04141 ± 0.00067	1.04148	1.04147 ± 0.00056
τ	0.0949	0.089 ± 0.032	0.0952	0.092 ± 0.013
n_s	0.9675	0.9635 ± 0.0094	0.9611	0.9608 ± 0.0054
$\ln(10^{10}A_s)$	3.098	3.085 ± 0.057	3.0973	3.091 ± 0.025

Generic Predictions for Inflation

Flatness $\Omega_0 = 1 \pm \mathcal{O}(10^{-5})$ — Confirmed

Adiabatic Perturbations for Baryons & CDM have a common origin, Iso-curvature perturbations less than 1% — Confirmed

Gaussian $\Phi = \Phi_g + f_{NL}\Phi_g^2$ $\quad f_{NL} \sim \mathcal{O}(1)$

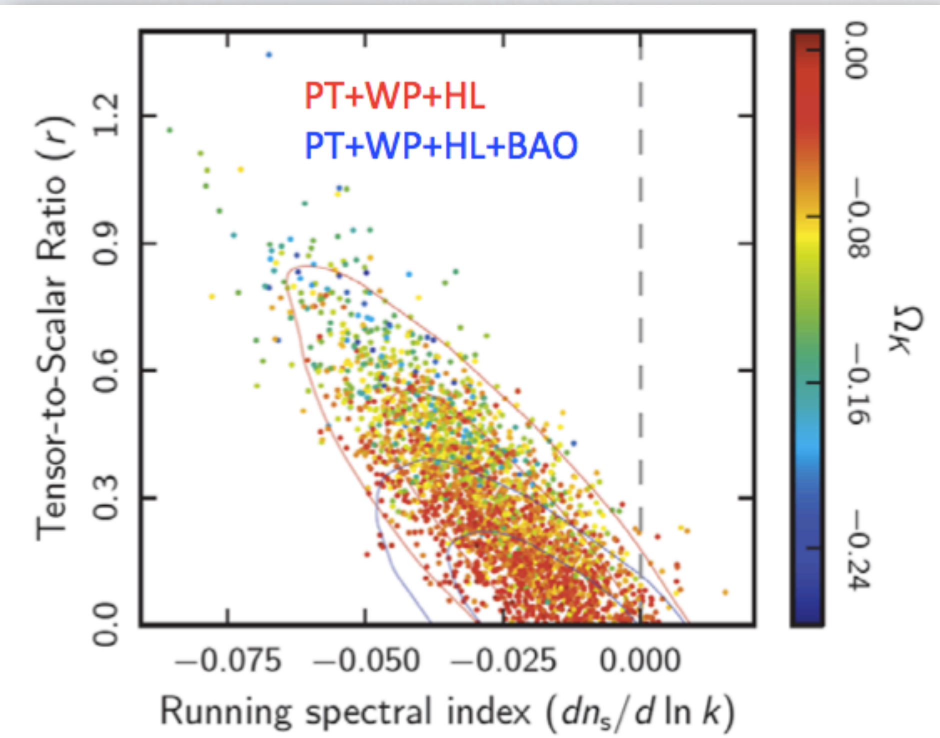
$$f_{NL}^{\rm Local} = 2.7 \pm 5.8$$
$$f_{NL}^{\rm Equi} = -42 \pm 75$$
$$f_{NL}^{\rm Ortho} = -25 \pm 39$$

Tilt $\Phi^2 \propto k^{1-n_s}$ $\quad n_s = 1 - 3\left(1+\frac{p}{\rho}\right) + \frac{d}{dN}\ln\left(1+\frac{p}{\rho}\right)$

$$n_s = 0.9608 \pm 0.0054$$

Tensor $r = \frac{T}{S} = 24\left(1+\frac{p}{\rho}\right)$

$$r < 0.12\left(\frac{V^{1/4}}{1.9\times 10^{16}\ {\rm GeV}}\right)^4$$



$$\langle G_{\mu\nu}\rangle = 8\pi G\langle T_{\mu\nu}\rangle$$

Both sides are treated quantum

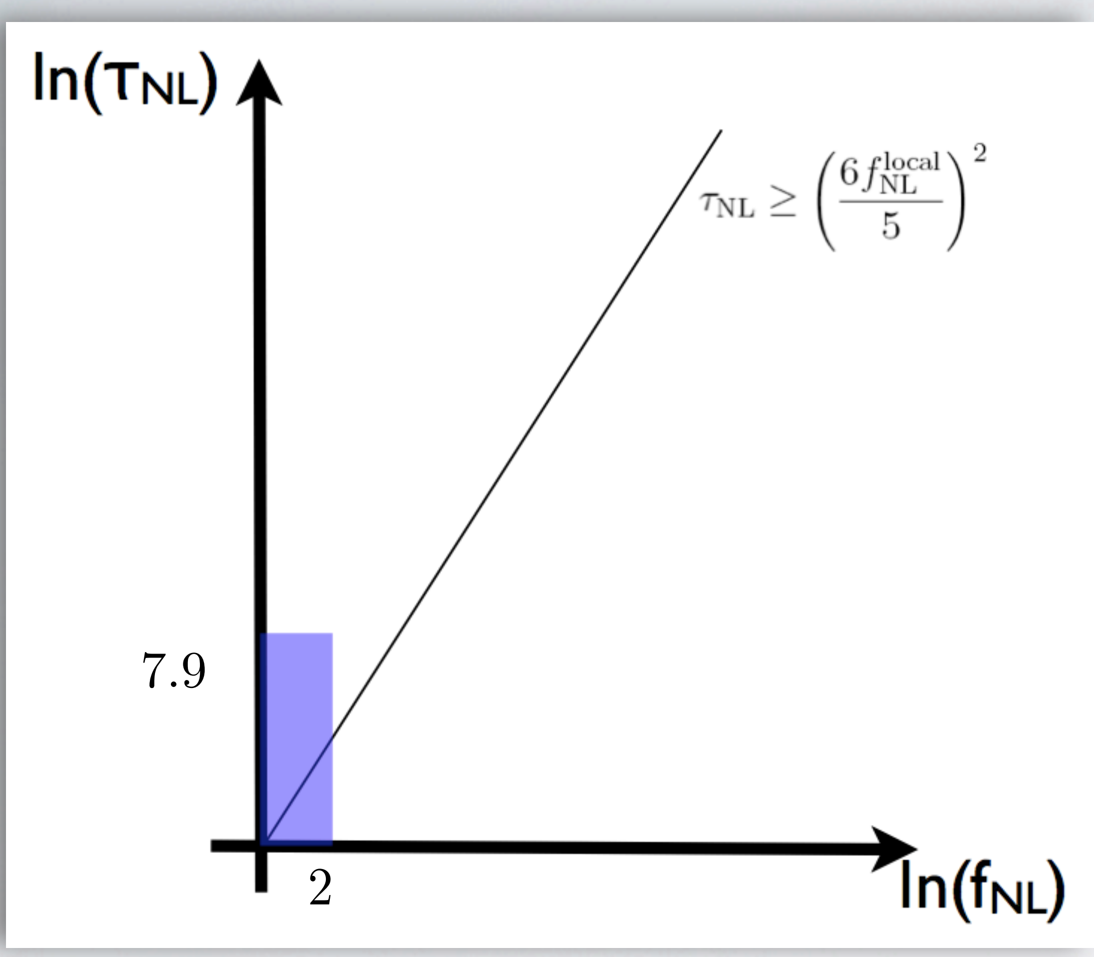
If Gravity is Classical, then $r = \frac{T}{S} = 0$

$$\because \quad \Box h_{\mu\nu} = 0$$

Ashoorioon, Dev, AM (2012)

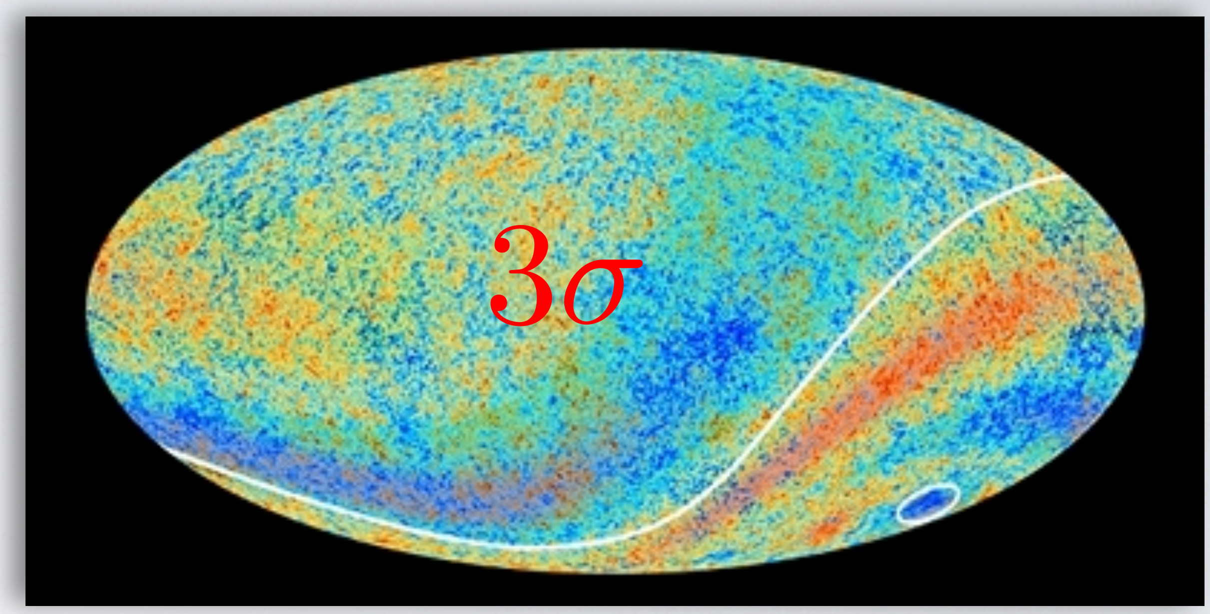
Chibisov, Mukhanov (1982)

Planck Data: Good Agreements



It is consistent with a SINGLE Inflaton

No need for exotic models, except



$$\mathcal{P}_\zeta(k,r) = \mathcal{P}_\zeta(k)[1 + 2A\vec{p}\cdot\vec{r}/r_{ls}] \qquad A = \frac{\Delta\mathcal{P}_\zeta}{\mathcal{P}_\zeta} = 0.072 \pm 0.022 \ (\ell < 64)$$

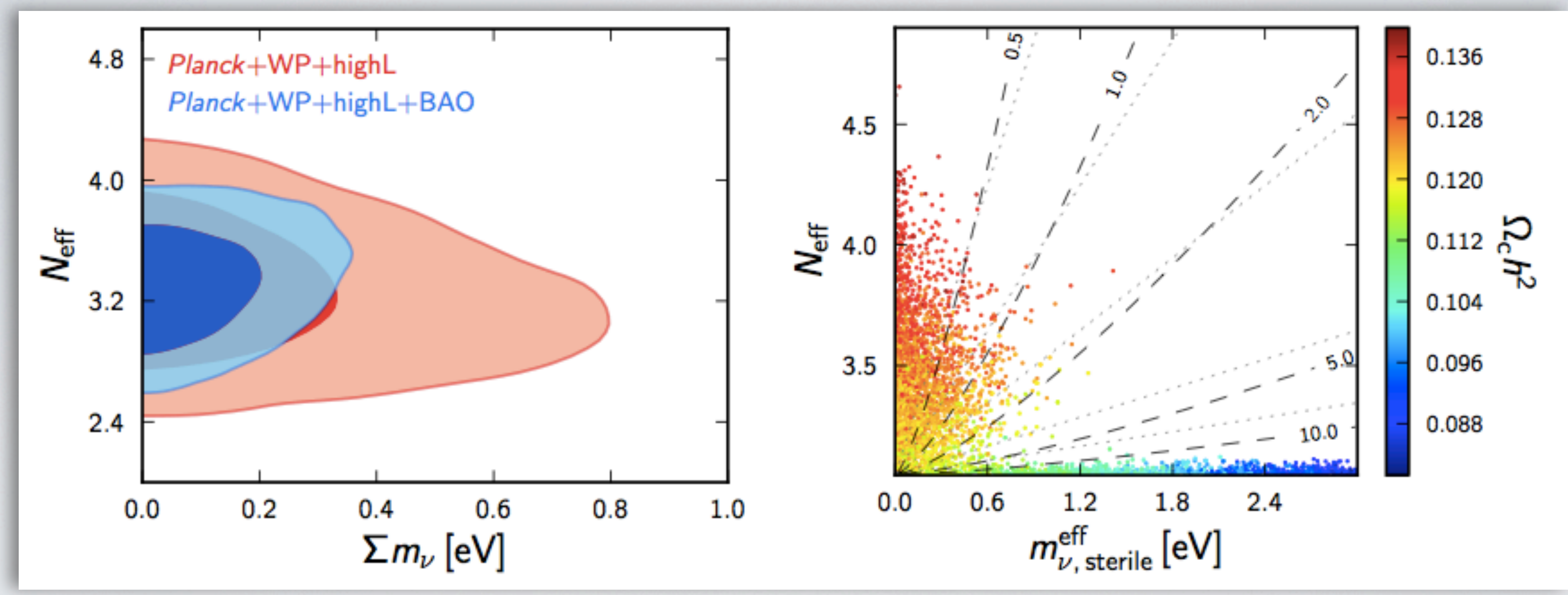
$$A \propto f_{NL} \qquad \Phi = \Phi_g + f_{NL}\Phi_g^2 + (\tau_{NL} + g_{NL})\Phi_g^3 + \cdots$$

More than one sources of Non-Gaussianity

$$+f_{NL} \quad \& \quad -f_{NL} \qquad |A| \leq \sqrt{\tau_{NL}} \qquad \tau_{NL} < 2800 \ (\ @ \ 95\%)$$

Wang, AM (2013), 1304.6399

NO Evidence for DARK/Hidden/Mirror Radiation



$$\rho_r = \rho_\gamma \left[1 + \frac{7}{8}\left(\frac{4}{11}\right)^{4/3} N_{eff}\right] \approx \rho_\gamma(1 + 0.2271 N_{eff})$$

Only SM relativistic d.o.f. + 3 thermalized light neutrinos

No need for light sterile states

Devil Hides in the Details

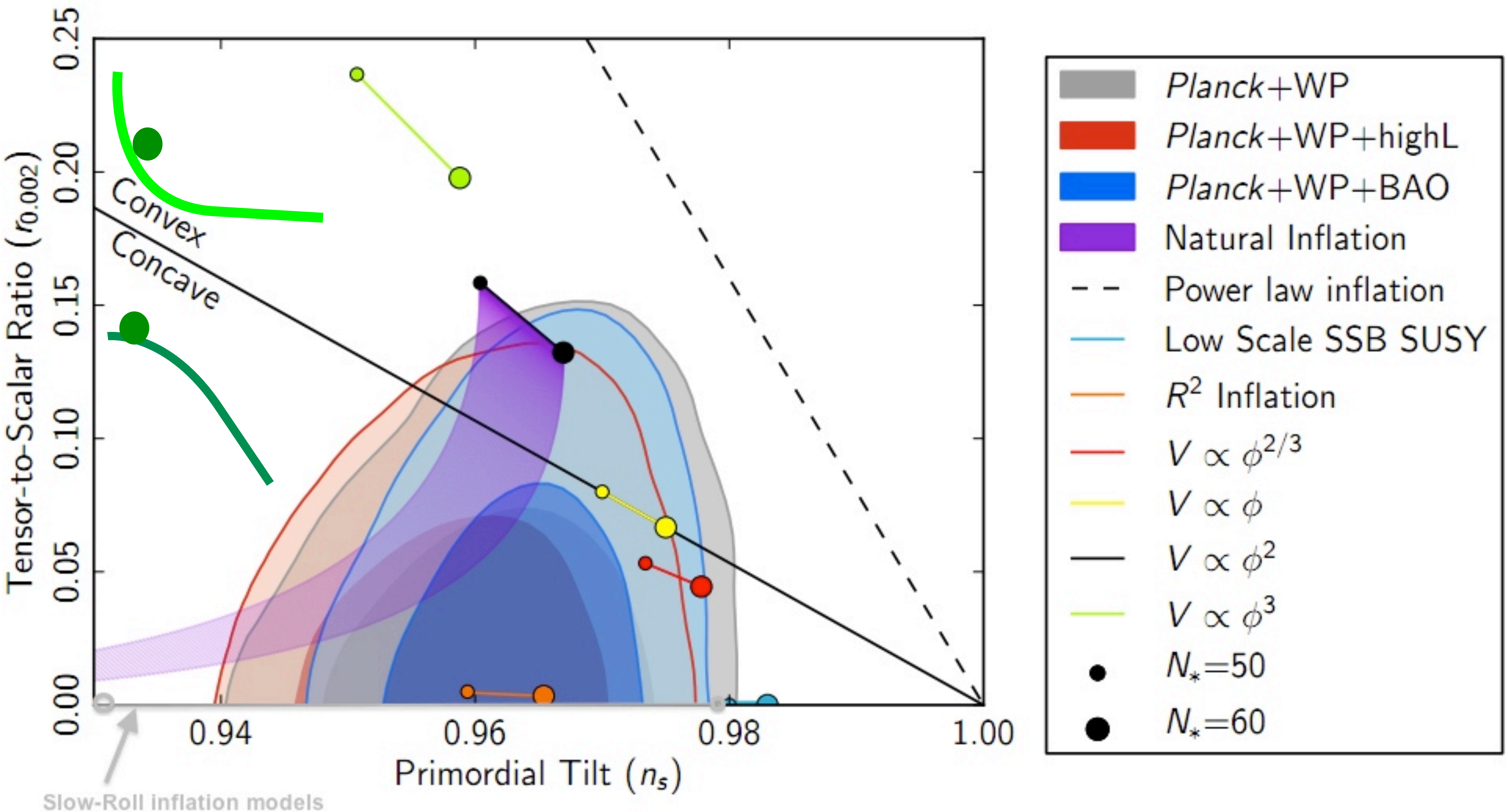


Fig. 1. Marginalized joint 68% and 95% CL regions for n_s and $r_{0.002}$ from *Planck* in combination with other data sets compared to the theoretical predictions of selected inflationary models.

Useful for Global Fitting but they shed NO light on our understanding of How to create Matter (US) & Perturbations ?

Challenges for $R+R^2$ It is utterly INCOMPLETE !

$$
\begin{aligned}
S_q \;=\; & \int d^4x\sqrt{-g}[RF_1(\Box)R + RF_2(\Box)\nabla_\mu\nabla_\nu R^{\mu\nu} + R_{\mu\nu}F_3(\Box)R^{\mu\nu} + R_\mu^\nu F_4(\Box)\nabla_\nu\nabla_\lambda R^{\mu\lambda} \\
+ \; & R^{\lambda\sigma}F_5(\Box)\nabla_\mu\nabla_\sigma\nabla_\nu\nabla_\lambda R^{\mu\nu} + RF_6(\Box)\nabla_\mu\nabla_\nu\nabla_\lambda\nabla_\sigma R^{\mu\nu\lambda\sigma} + R_{\mu\lambda}F_7(\Box)\nabla_\nu\nabla_\sigma R^{\mu\nu\lambda\sigma} \\
+ \; & R_\lambda^\rho F_8(\Box)\nabla_\mu\nabla_\sigma\nabla_\nu\nabla_\rho R^{\mu\nu\lambda\sigma} + R^{\mu_1\nu_1}F_9(\Box)\nabla_{\mu_1}\nabla_{\nu_1}\nabla_\mu\nabla_\nu\nabla_\lambda\nabla_\sigma R^{\mu\nu\lambda\sigma} \\
+ \; & R_{\mu\nu\lambda\sigma}F_{10}(\Box)R^{\mu\nu\lambda\sigma} + R^\rho_{\mu\nu\lambda}F_{11}(\Box)\nabla_\rho\nabla_\sigma R^{\mu\nu\lambda\sigma} + R_{\mu\rho_1\nu\sigma_1}F_{12}(\Box)\nabla^{\rho_1}\nabla^{\sigma_1}\nabla_\rho\nabla_\sigma R^{\mu\rho\nu\sigma} \\
+ \; & R_\mu^{\nu_1\rho_1\sigma_1}F_{13}(\Box)\nabla_{\rho_1}\nabla_{\sigma_1}\nabla_{\nu_1}\nabla_\nu\nabla_\rho\nabla_\sigma R^{\mu\nu\lambda\sigma} + R^{\mu_1\nu_1\rho_1\sigma_1}F_{14}(\Box)\nabla_{\rho_1}\nabla_{\sigma_1}\nabla_{\nu_1}\nabla_{\mu_1}\nabla_\mu\nabla_\nu\nabla_\rho\nabla_\sigma R^{\mu\nu\lambda\sigma}]
\end{aligned}
$$

Gravity Invokes ∞ Higher Order Corrections

$$S = \int d^4x\sqrt{-g}\left[R + R\mathcal{F}_1(\Box)R + R_{\mu\nu}\mathcal{F}_2(\Box)R^{\mu\nu} + R_{\mu\nu\alpha\beta}\mathcal{F}_3(\Box)R^{\mu\nu\alpha\beta}\right]$$

$$\mathcal{F}_i(\Box) = \sum_n^\infty a_n\Box^n \qquad \Delta\mathcal{L} = \sqrt{-g}\left(\alpha R^2 + \beta R^2_{\mu\nu} + \gamma R^2_{\alpha\beta\mu\nu}\right)$$

$$2\mathcal{F}_1(\Box) + \mathcal{F}_2(\Box) + 2\mathcal{F}_3(\Box) = 0$$

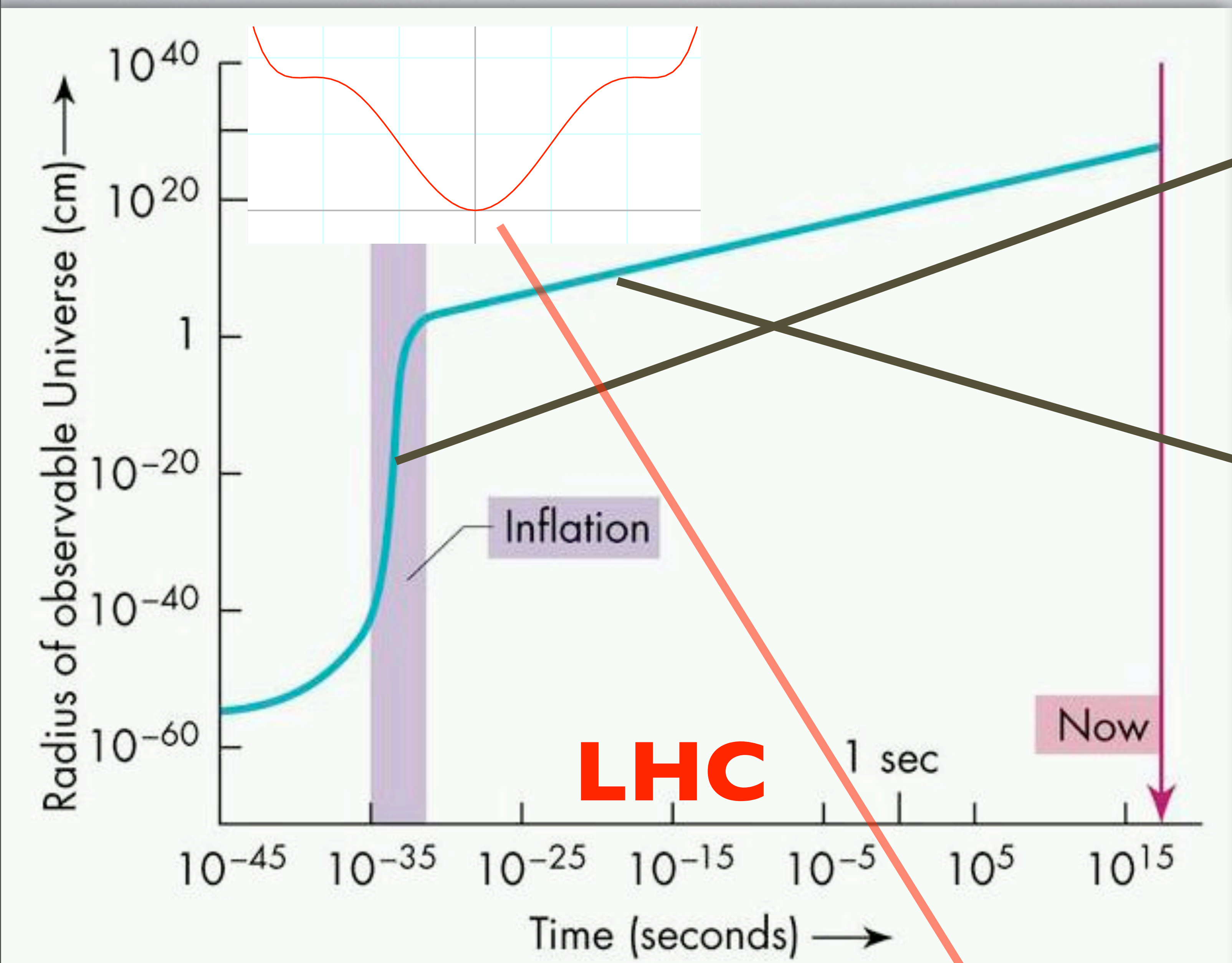
Classical Gravity becomes WEAK in the UV

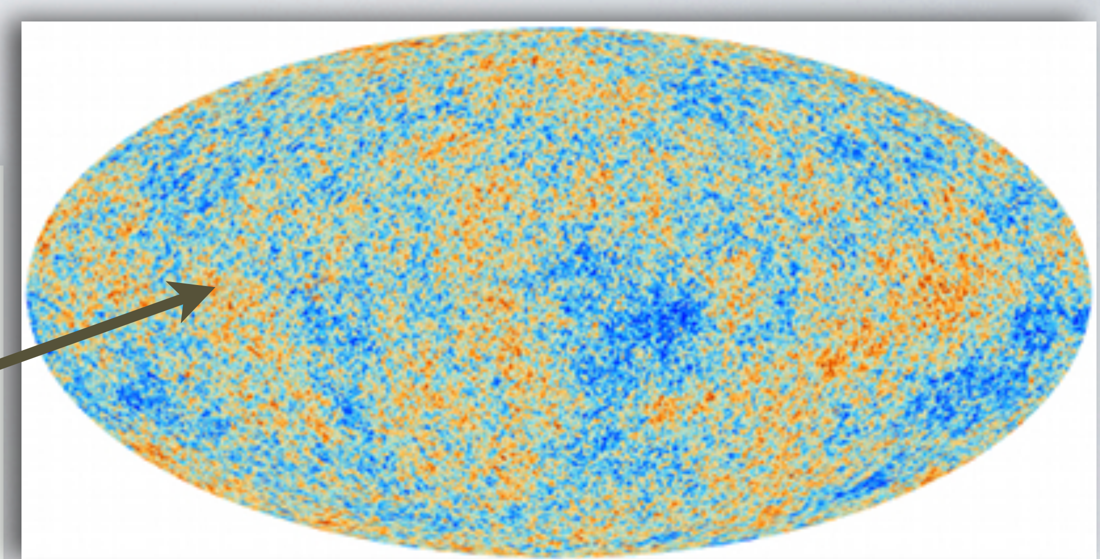
(Asymptotic Freedom)

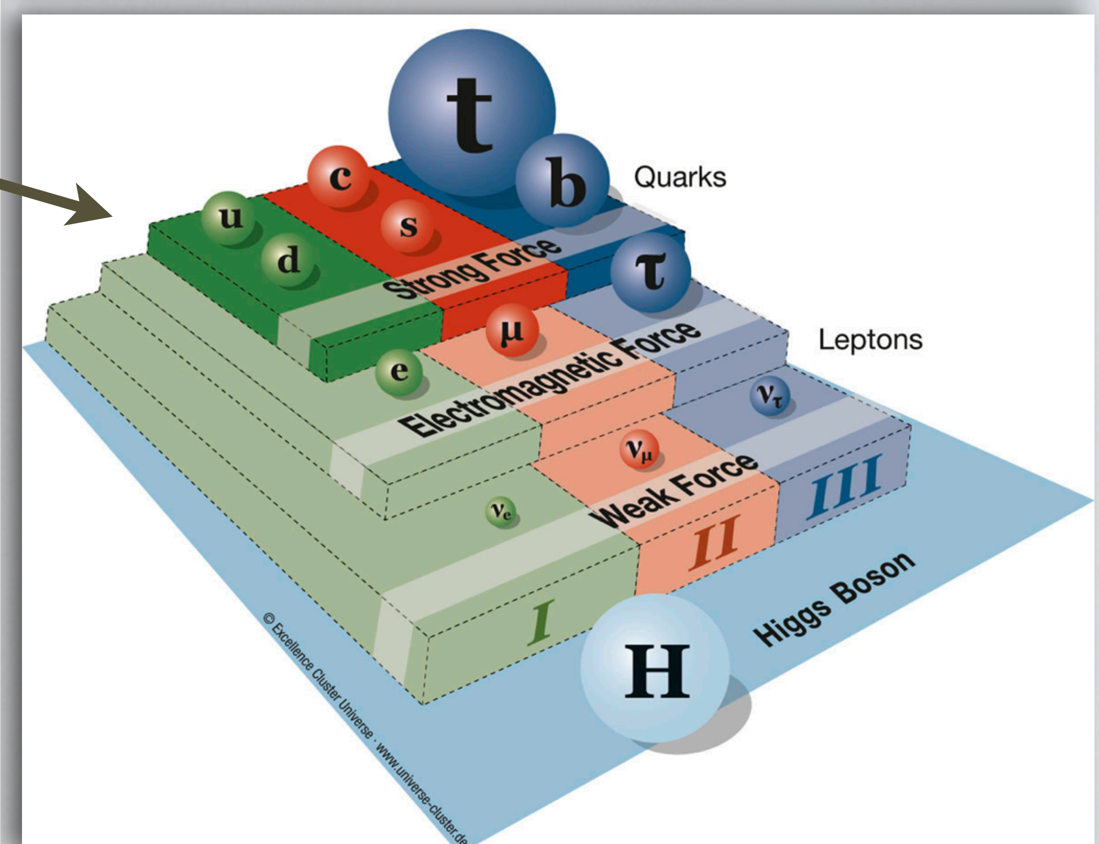
Biswas, Gerwick, Koivisto & AM, Phys. Rev. Lett. (2012)

Challenge: Inflation MUST create SM Radiation & Perturbations

NO Hidden Radiation







The Inflaton Vacuum cannot be arbitrary

A.M & Rocher, Phys. Rept. (2011), Particle Physics Models of Inflation & Curvaton

Last 50-60 e-folds of Inflation cannot be driven by an Arbitrary Field

Such as Gauge singlets, or String theory Moduli, or Dilaton, ...

You can always match the perturbations, exotic non-Gaussianity, wiggles, low multipoles, & perhaps what not,..., but creating the right form of matter remains the biggest challenge

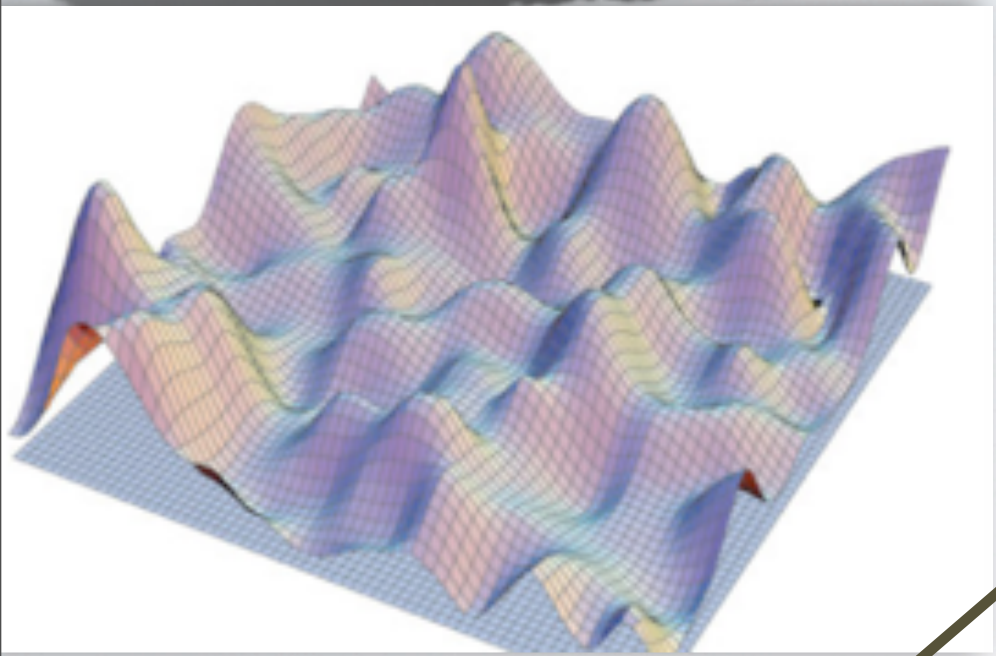
Last 50-60 e-folds of Inflation CANNOT be driven by Hidden Sector or a Gauge Singlet

$$W = \lambda\phi(\bar{\Psi}\Psi - v^2)$$

Hill-top, Hybrid inflation, Quartic, Quadratic, Axion, etc... are all driven by arbitrary gauge singlets

Hidden

Visible



NOTE: String theory has many hidden sectors but ONE Visible Sector only, i.e. SM or MSSM

- A Singlet can couple to Hidden Sector physics -- all the entropy can be dumped into the Hidden Sector dof.

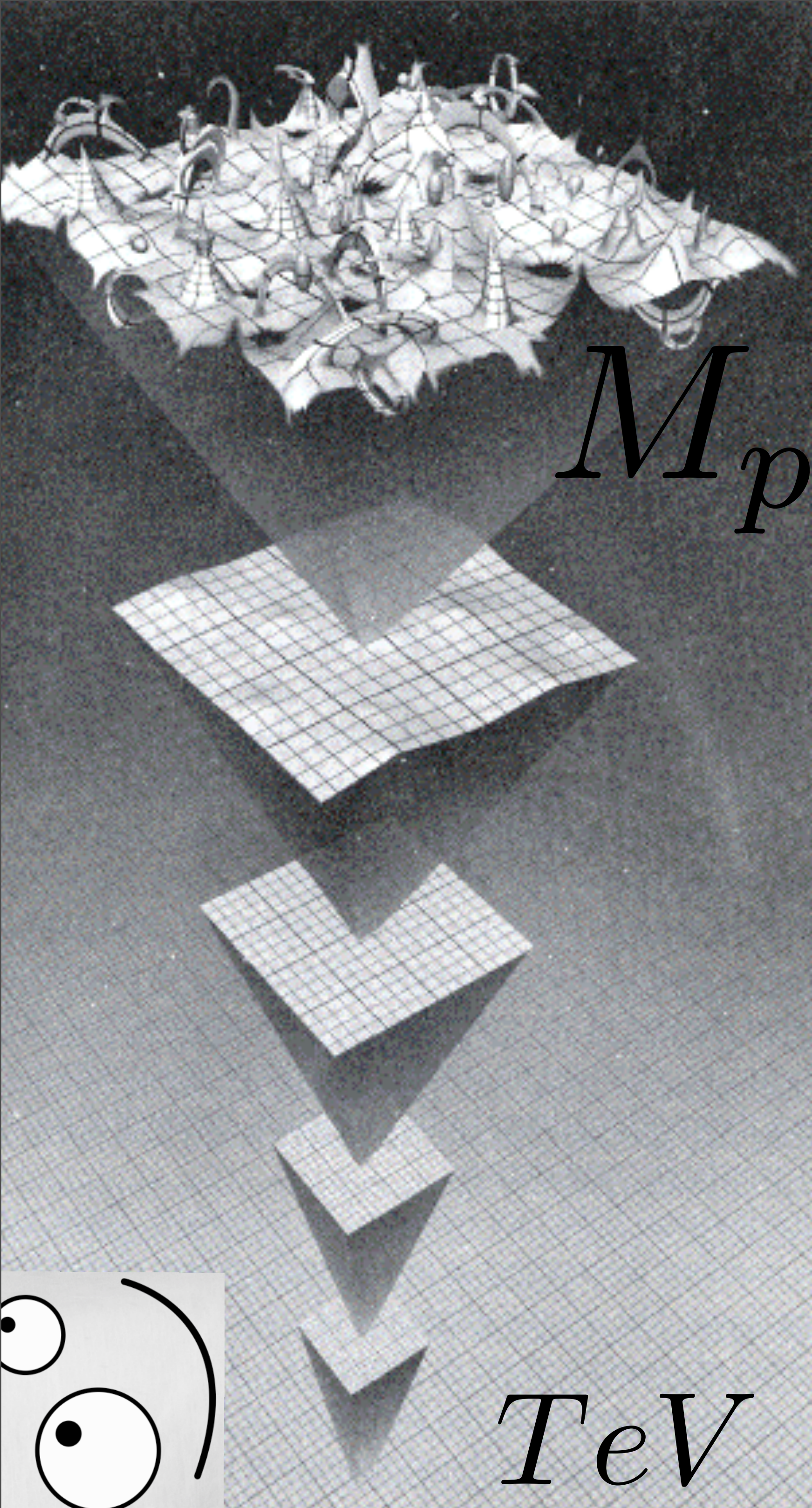
$$\Omega_X h^2 \approx 10^{17}\left(\frac{T_R}{10^9\ GeV}\right)\frac{\rho_X}{\rho_{inf}}$$

- Hidden Radiation, Excess Gravitino from every Hidden Gauge Sector !!!

- Over-Close the Universe prematurely by Hidden Sector Moduli domination

Cicoli & A.M, JCAP (2010)

Last 50-60 e-folds MUST happen within a Visible Sector



Inflation can happen in Many Many VACUA,

BUT the Lightest states are naturally responsible for the last phase of Inflation, i.e. MSSM Flat directions

Therefore Reheating the right thermal DOF & NO Iso-curvature perturbations

Constructing a Potential ...

$$V(\phi) = V_0 + a(\phi - \phi_0) + \frac{b}{2}(\phi - \phi_0)^2 + \frac{c}{6}(\phi - \phi_0)^3 + \cdots,$$
$$V_0 \equiv V(\phi_0)\ ,\ a \equiv V'(\phi_0)\ ,\ b \equiv V''(\phi_0)\ ,\ c \equiv V'''(\phi_0)\,,$$

$$\phi - \phi_0 \ll M_p$$

One requires shape & curvature smooth enough to appreciate the beauty

Constructing a Potential ...

$$V = \frac{1}{2}m^2|\phi|^2 - \frac{A\lambda}{nM_P^{n-3}}\phi^n + \frac{\lambda^2}{M_P^{2(n-3)}}|\phi|^{2(n-1)}$$

$$\frac{A}{m} = \sqrt{8(n-1)\left(1 - \frac{(n-2)^2}{4}\beta^2\right)}$$

$$\phi_0 = \left(\frac{M_P^{n-3}m}{\lambda\sqrt{2(n-1)}}\right)^{1/(n-2)}$$

$$V_0 = \frac{(n-2)^2}{2n(n-1)}m^2\phi_0^2\,,$$

$$a = \frac{(n-2)^2}{4}\beta^2 m^2\phi_0\,,$$

$$c = 2(n-2)^2\frac{m^2}{\phi_0}\,.$$

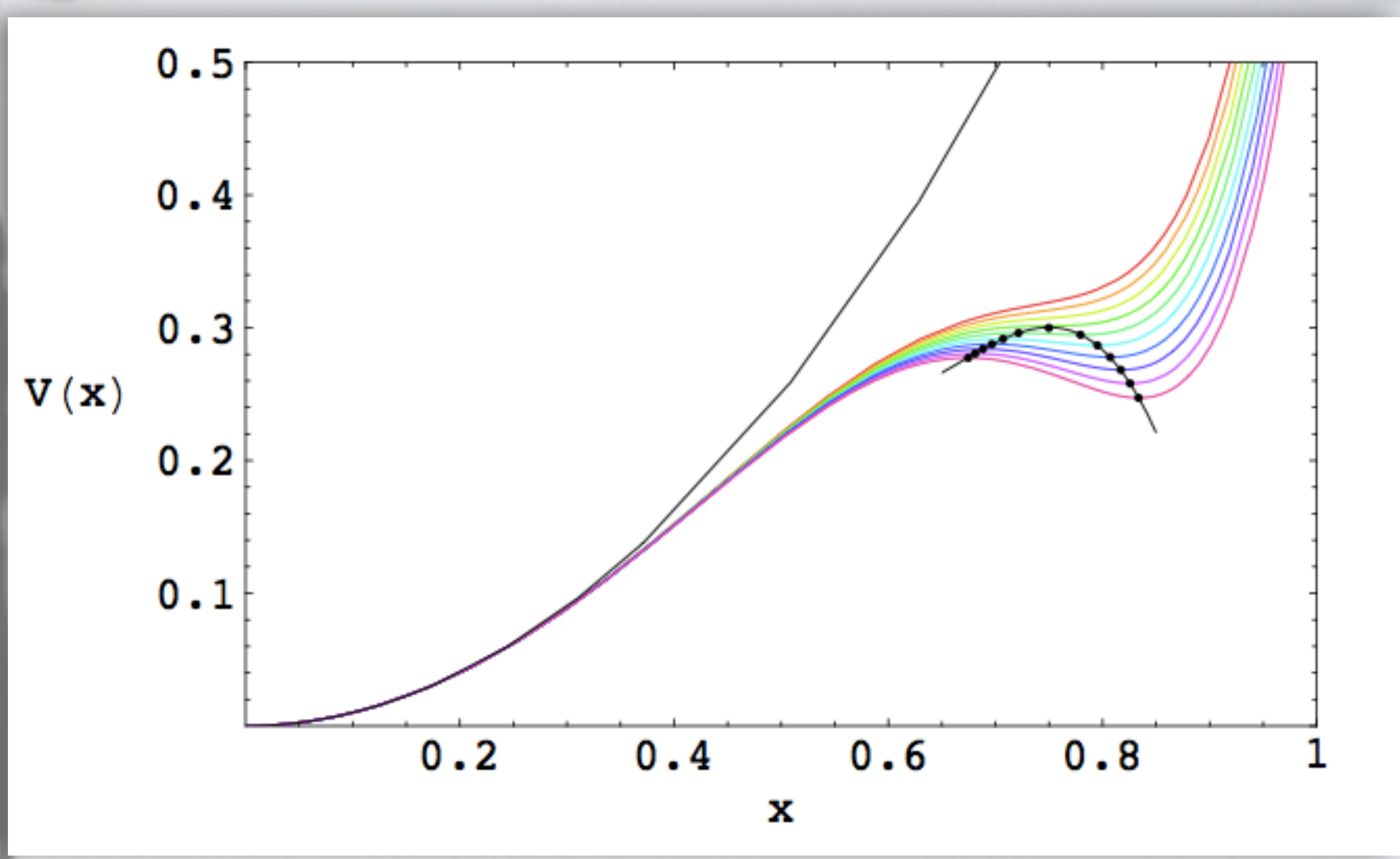
$$\mathcal{P}_R^{1/2} \equiv \frac{1}{\sqrt{24\pi^2}}\frac{V_0^{1/2}}{\epsilon^{1/2}M_P^2} = \frac{V_0^{1/2}}{2\pi\sqrt{6}M_P^2 X}\sin^2 Y$$

$$n_s \equiv 1 + 2\eta - 6\epsilon = 1 - \frac{4}{\mathcal{N}_{\rm COBE}}Y\cot Y\,,$$

$$\alpha = -\frac{4}{\mathcal{N}_{\rm COBE}^2}\left(\frac{Y}{\sin Y}\right)^2.$$

$$V(|\phi|) = \frac{1}{2}m^2|\phi|^2 - \frac{Ah}{3}\phi^3 + h^2|\phi|^4 \quad (n=3)$$

$$V(|\phi|) = \frac{1}{2}m^2|\phi|^2 - \frac{A\lambda}{6}\frac{\phi^6}{M_p^3} + \lambda^2\frac{|\phi|^{10}}{M_p^6} \quad (n=6)$$



Inflation takes place always Below Planck VeV

Allahverdi, Enqvist, Garcia-Bellido, AM, PRL (2006), JCAP (2006)

Bueno-Sanchez, Dimopoulos & Lyth, JCAP (2006)

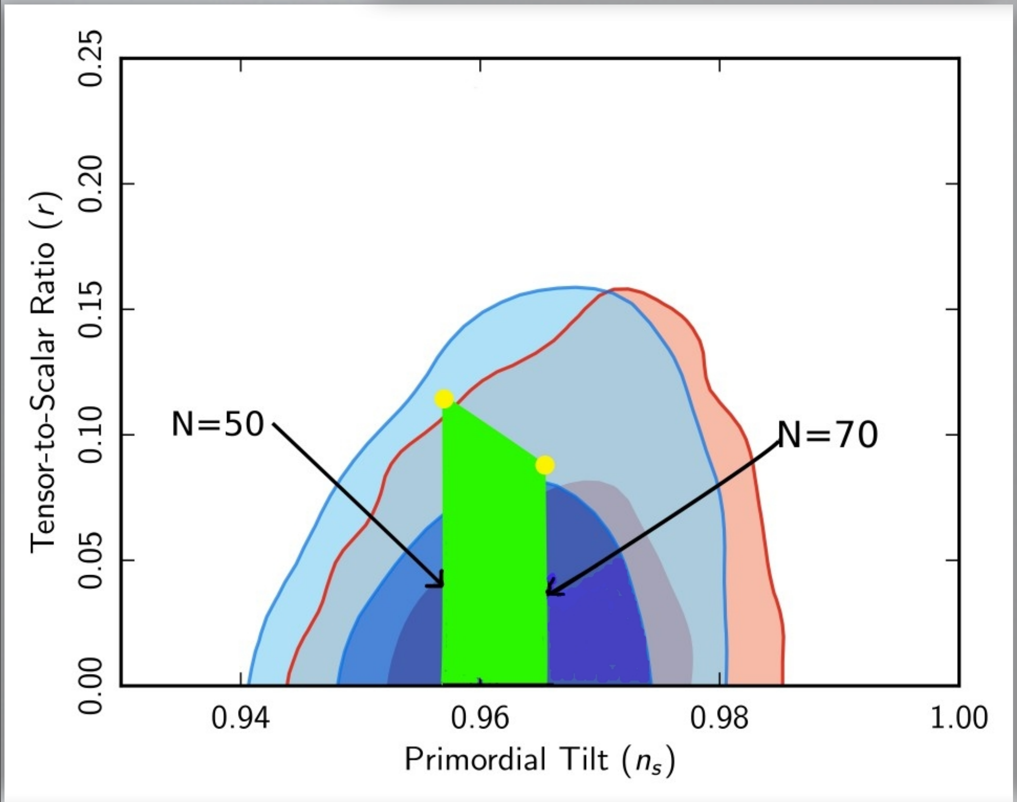
Allahverdi, Kusenko AM, JCAP (2006),

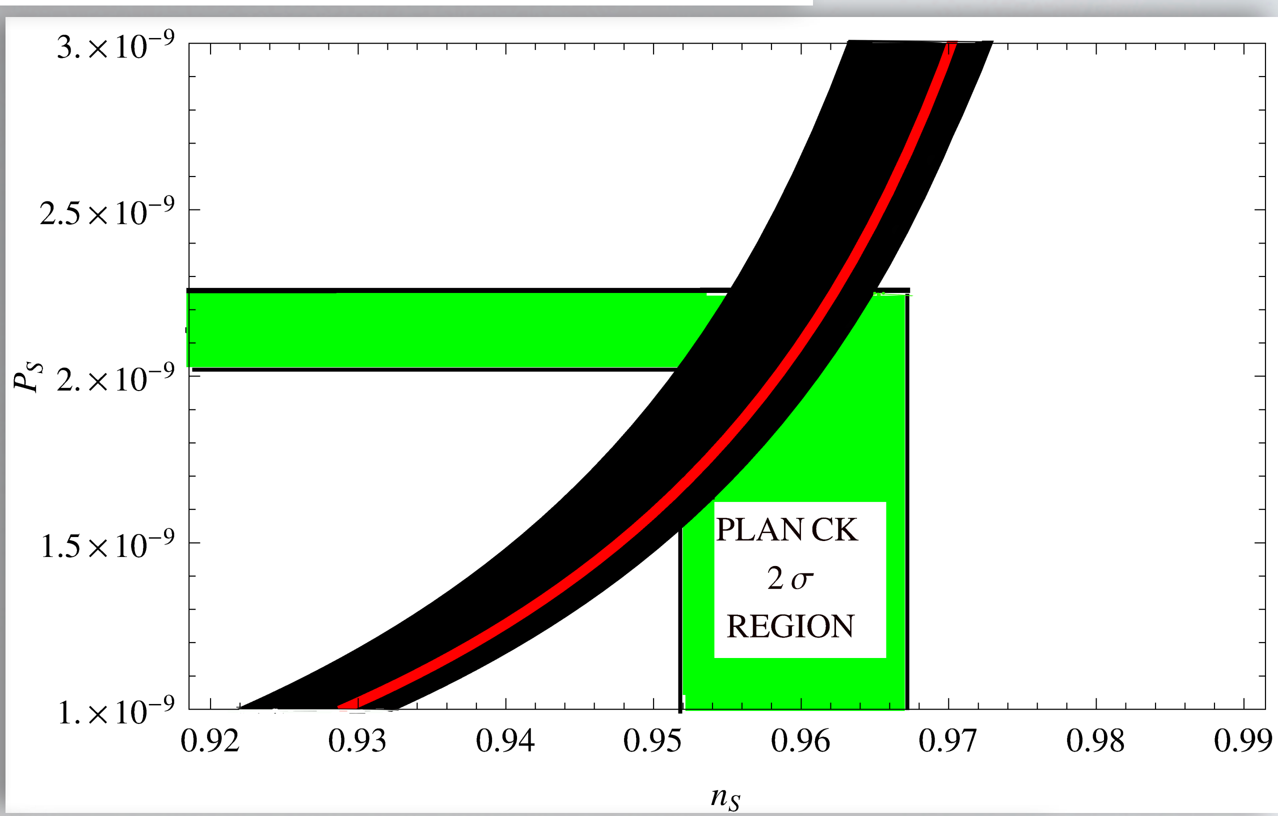
Allahverdi, Dutta & AM, PRL (2007)

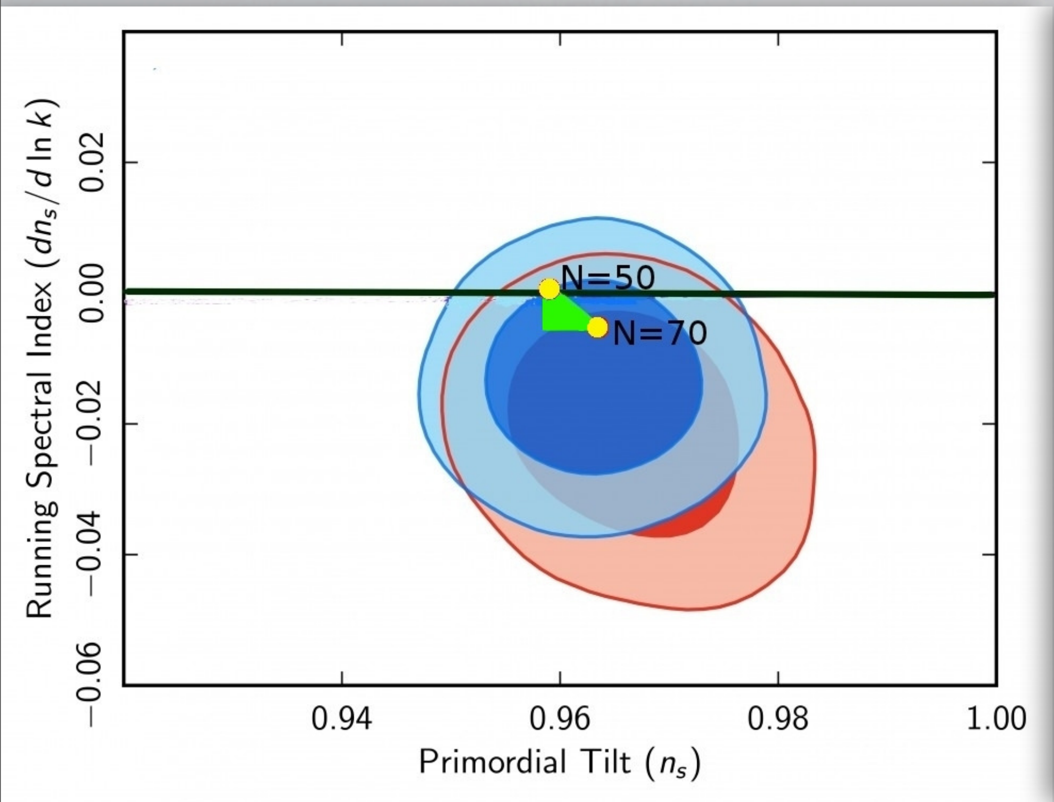
Inflection-point Inflation: Flexibility of the Potential

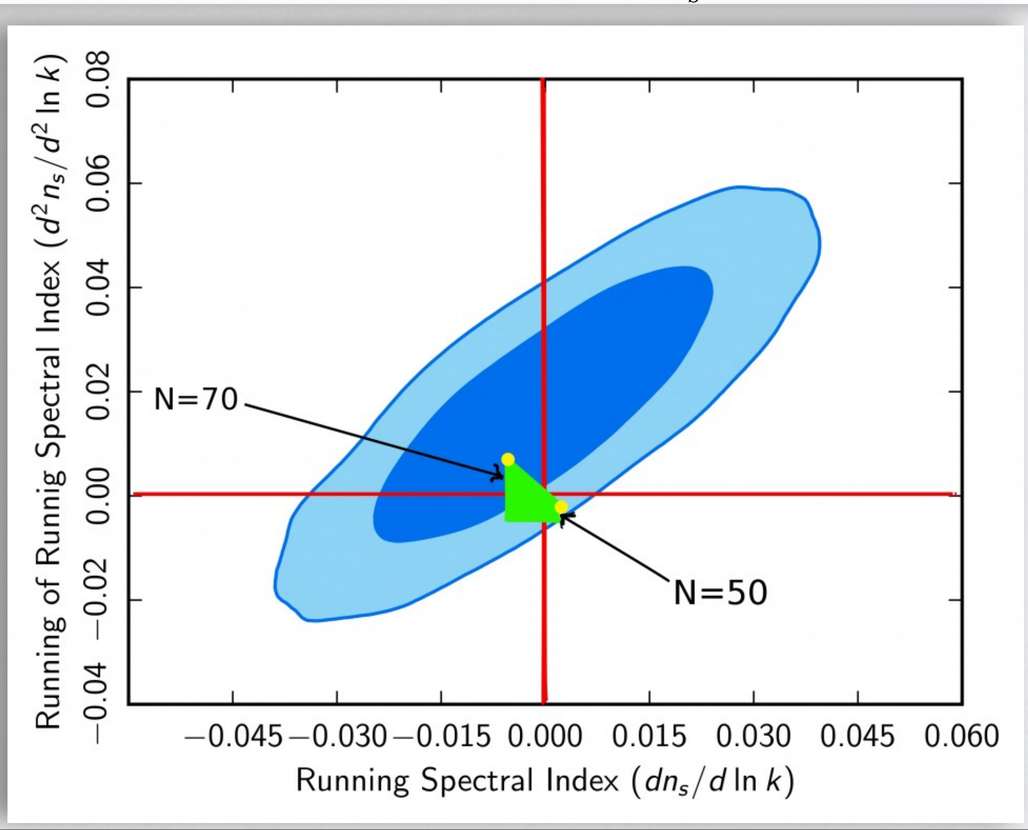
$$V(\phi) = V_c + \frac{c_H H^2}{2}|\phi|^2 - \frac{a_H H}{n M_P^{n-3}}\phi^n + \frac{|\phi|^{2(n-1)}}{M_P^{2(n-3)}}$$

SUGRA Corrections Included









Dine, Randall, Thomas PRL, (1996), NPB(1996)
Gherghetta, Martin, Kolda, PRD (1997)
Kasuya, Kawasaki, PRD (2006)
AM, Nadathur, Stephens, PRD (2011)
Hotchkiss, AM & Nadathur, JCAP (2012),
Choudhury, AM & Pal (Expected Soon)

Visible sector Inflatons

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

$SU(3)\times SU(2)_l \times U(1)_Y$

$$u_1 d_2 d_3 \qquad d_2^\beta = \frac{1}{\sqrt{3}}\phi \qquad u_1^\alpha = \frac{1}{\sqrt{3}}\phi \qquad d_3^\gamma = \frac{1}{\sqrt{3}}\phi$$

$$L_1 L_2 e_3 \qquad L_1^a = \frac{1}{\sqrt{3}}\begin{pmatrix}0\\ \phi\end{pmatrix} \qquad L_2^b = \frac{1}{\sqrt{3}}\begin{pmatrix}\phi\\ 0\end{pmatrix} \qquad e_3 = \frac{1}{\sqrt{3}}\phi$$

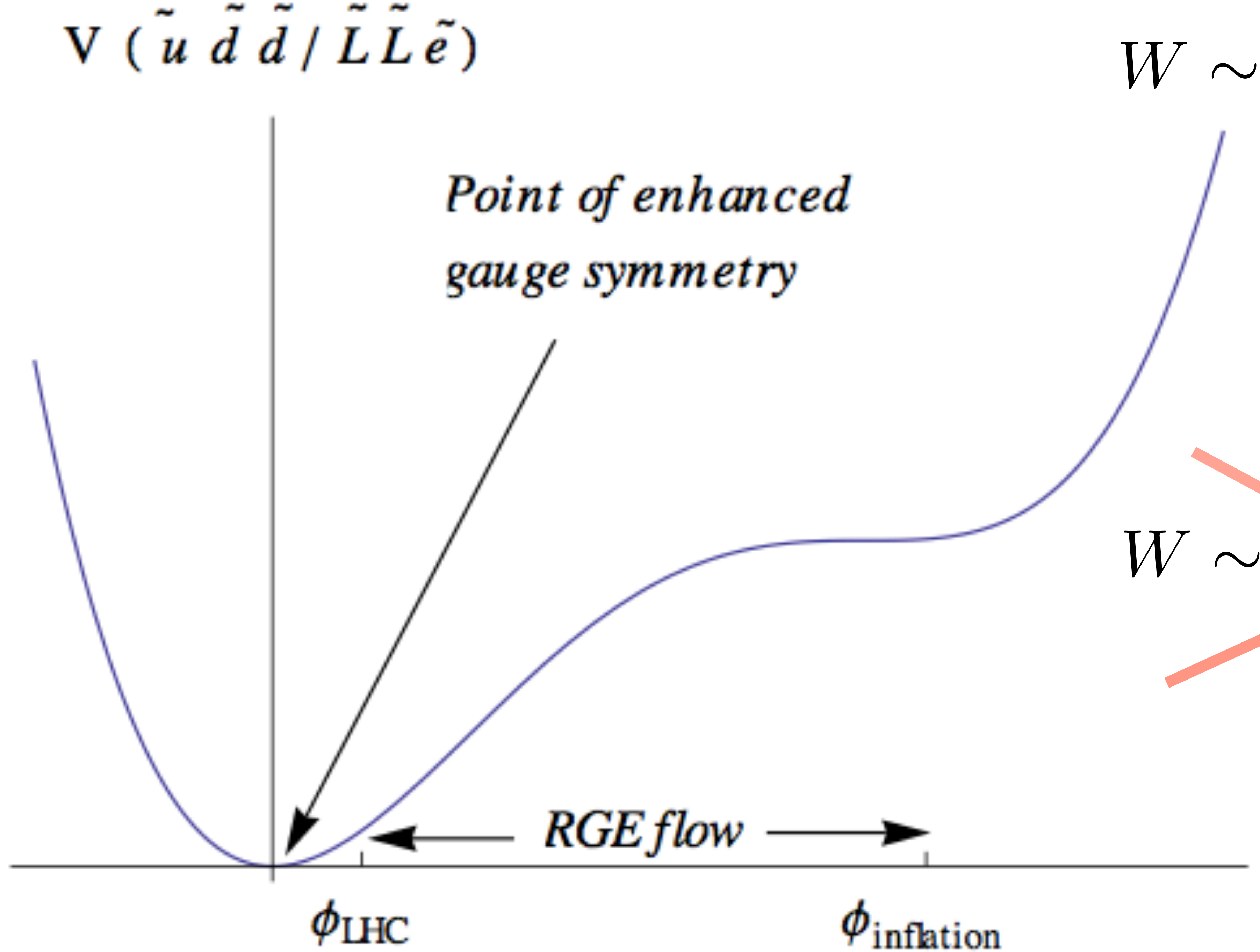
$$H_u H_d \qquad H_u = \frac{1}{\sqrt{2}}\begin{pmatrix}\phi\\ 0\end{pmatrix} \qquad H_d = \frac{1}{\sqrt{2}}\begin{pmatrix}0\\ \phi\end{pmatrix}$$

$SU(3)\times SU(2)_l \times U(1)_Y \times U(1)_{B-L}$

$$N H_u L \qquad N = \frac{1}{\sqrt{3}}\phi \qquad H_u = \frac{1}{\sqrt{3}}\begin{pmatrix}0\\ \phi\end{pmatrix} \qquad L = \frac{1}{\sqrt{3}}\begin{pmatrix}\phi\\ 0\end{pmatrix}$$

Allahverdi, Enqvist, Bellido, AM, (PRL, 2006), (JCAP, 2007), Allahverdi, Kusenko, AM, JCAP (2007),
Allahverdi, Dutta, AM (PRL 2007), Chatterjee, AM, JCAP (2011)

MSSM Inflaton Potentials



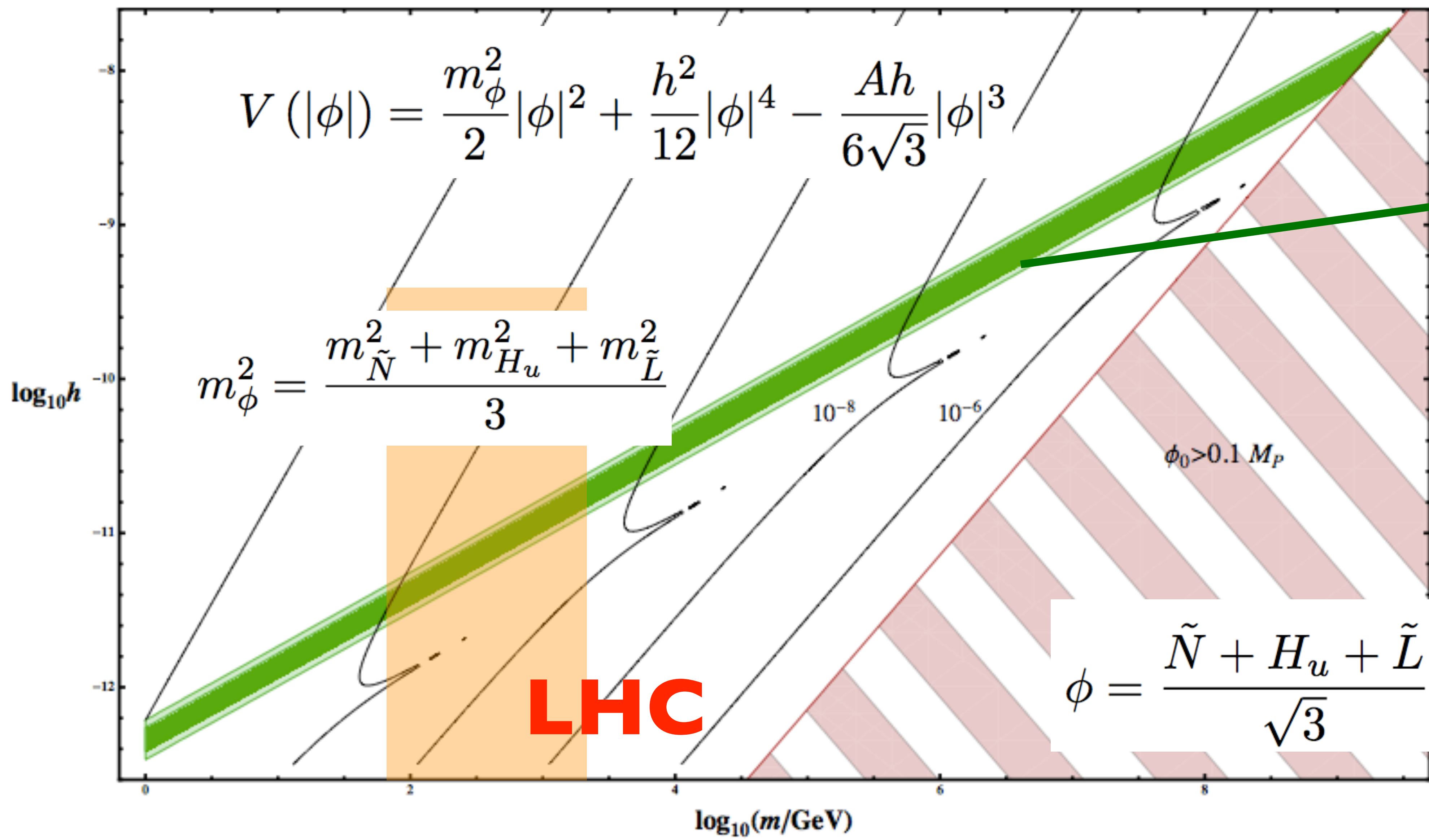
$$W \sim \lambda \sum_{n>3} \frac{\Phi^n}{M_p^{n-3}}$$

$$\cancel{W \sim \lambda \sum_{n>3} \frac{\Psi\Phi^{n-1}}{M_p^{n-3}}}$$

Potentials are constructed by small perturbations around the Enhanced Gauge Symmetry Point

Affleck, Dine, NPB (1985),
Dine, Randall, Thomas, NPB (1996)

Renormalizable Potential from a Visible Sector



$$\mathcal{P}_\zeta = 2.196^{+0.051}_{-0.060} \times 10^{-9}$$

$$n_s = 0.960 \pm 0.073$$

Allahverdi, Kusenko & AM, JCAP (2006)

Hotchkiss, AM & Nadathur, JCAP (2011)

Inflaton is a D-flat direction of MSSM*U(1), i.e. $SU(3) \times S(2)_L \times U(1)_Y \times U(1)_{B-L}$

$$W \supset h\mathbf{N}\mathbf{H}_u\mathbf{L}$$

$$m_\nu \sim h\langle H_u \rangle \sim 0.1 eV$$

Inflaton decays into MSSM dof + LSP (dark matter candidate)

Allahverdi, Dutta & AM, Phys.Rev.Lett. (2007)

Non-renormalizable Potential from MSSM

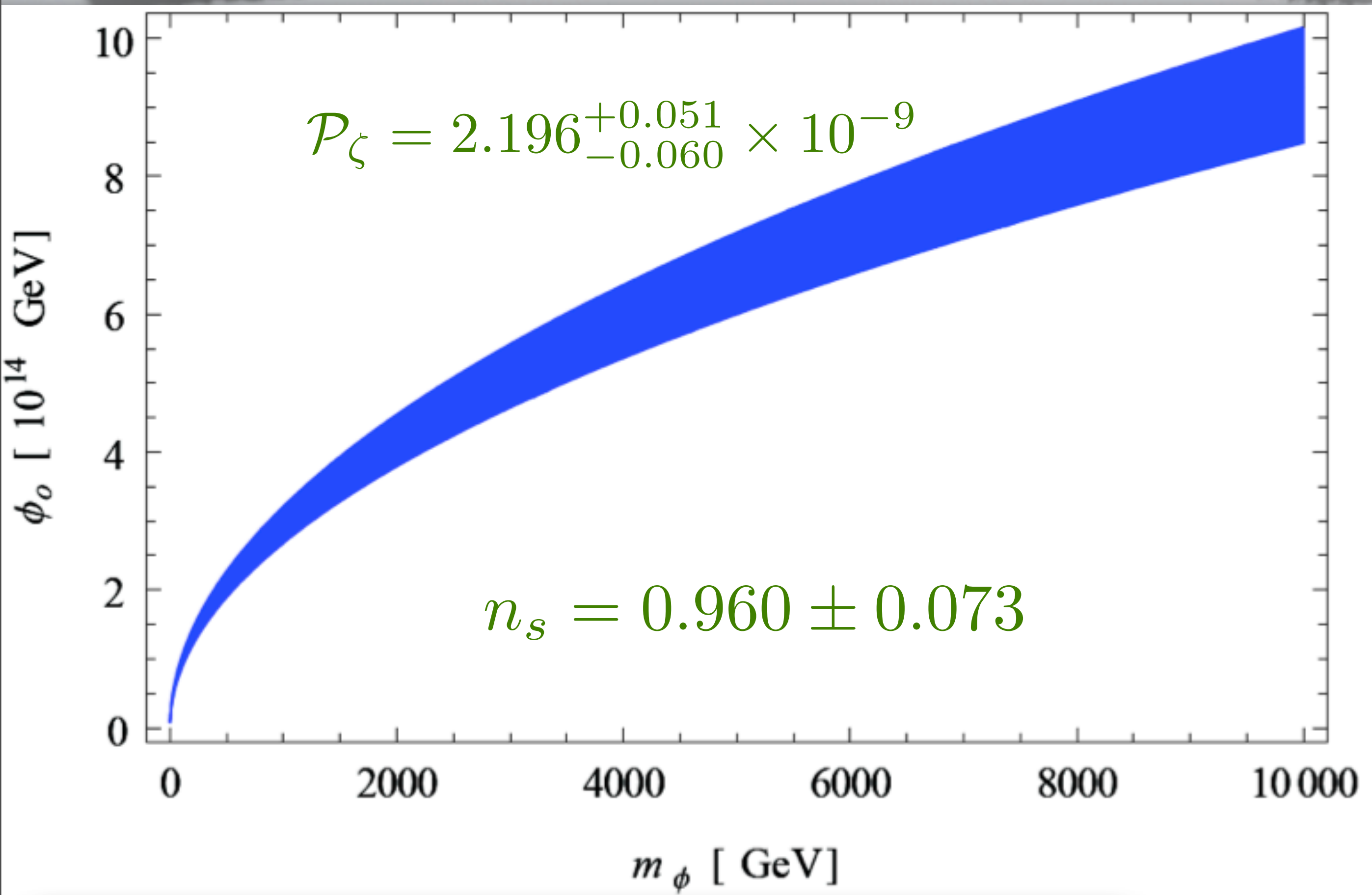
$$W = \lambda \frac{(LLe)(LLe)}{M_p^3} \quad \text{or} \quad \lambda \frac{(udd)(udd)}{M_p^3}$$

$$V(\phi) = \frac{1}{2} m_\phi^2 \phi^2 - A \frac{\lambda \phi^6}{6 M_p^6} + \lambda^2 \frac{\phi^{10}}{M_p^6}$$

$$m_\phi^2 = \frac{m_{\tilde{L}}^2 + m_{\tilde{L}}^2 + m_{\tilde{e}}^2}{3}$$

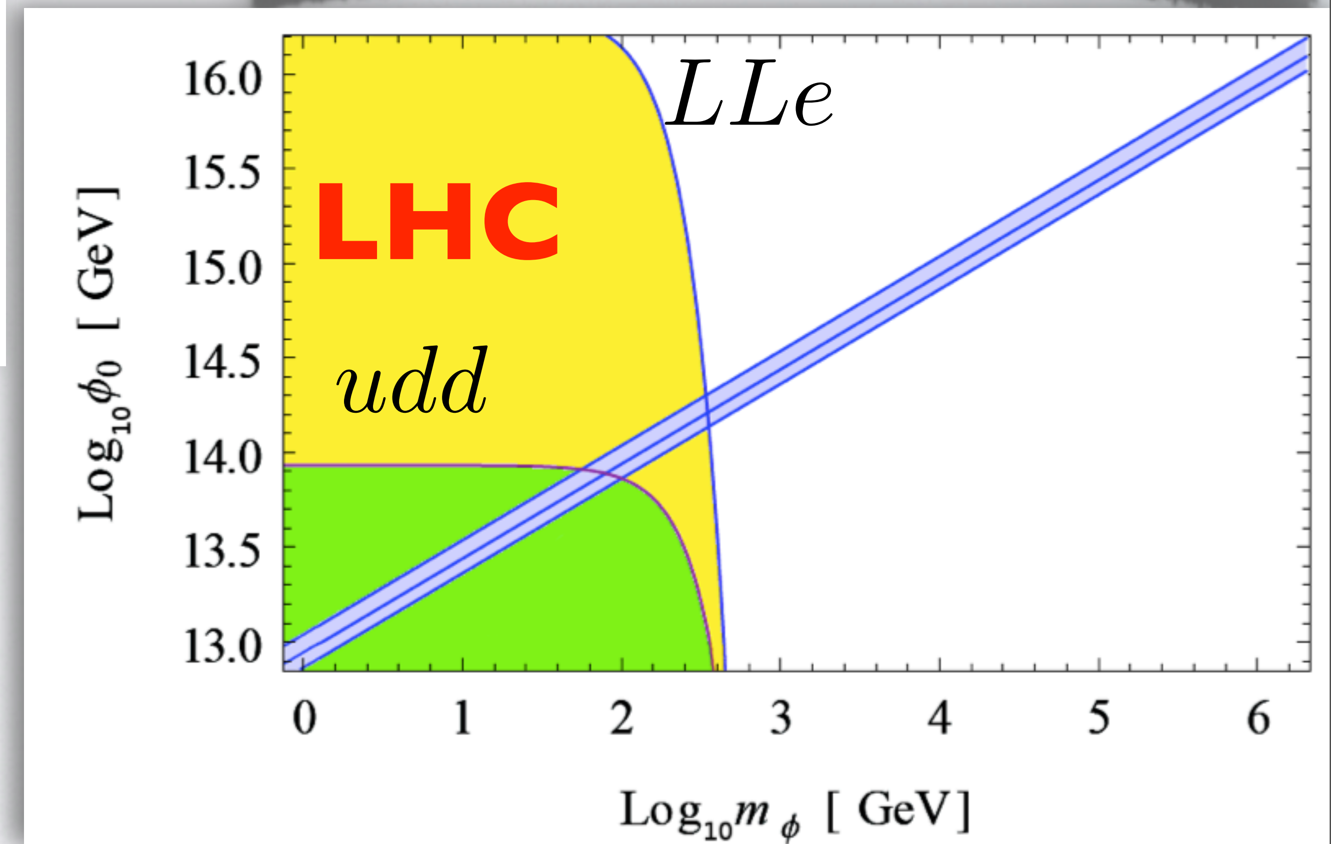
$$m_\phi^2 = \frac{m_{\tilde{u}}^2 + m_{\tilde{d}}^2 + m_{\tilde{d}}^2}{3}$$

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



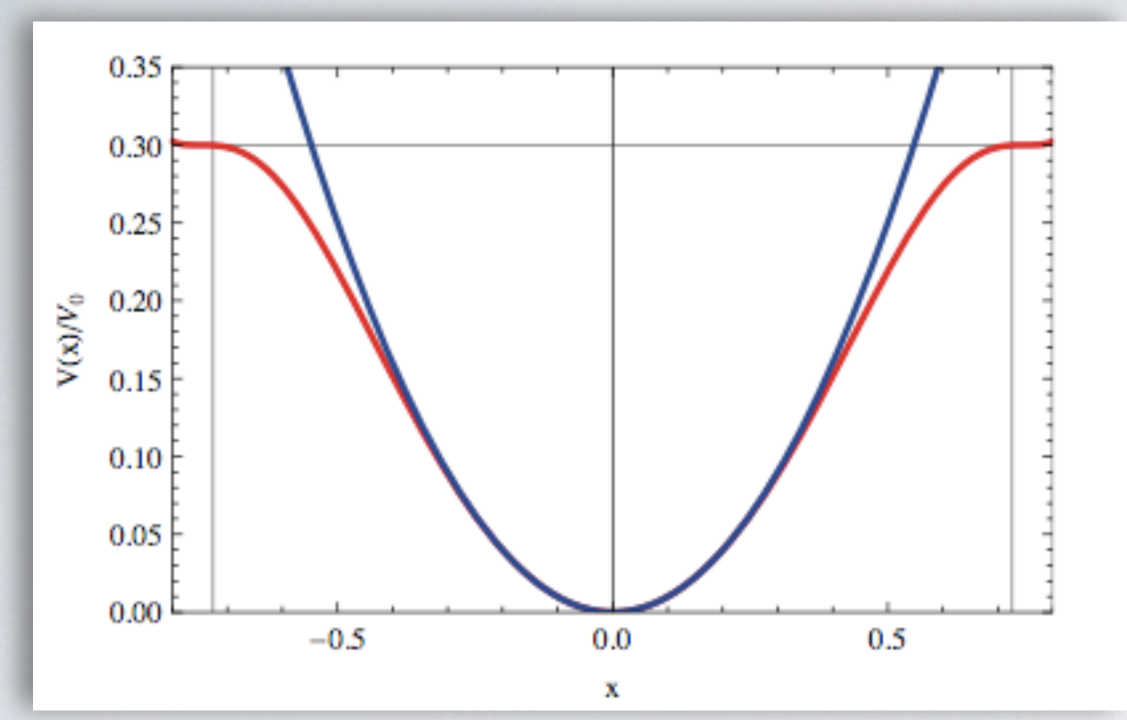
$$\hat{\mu} \frac{dm_\phi^2}{d\hat{\mu}} = -\frac{1}{6\pi^2} \left(4 M_3^2 g_3^2 + \frac{2}{5} M_1^2 g_1^2\right),$$

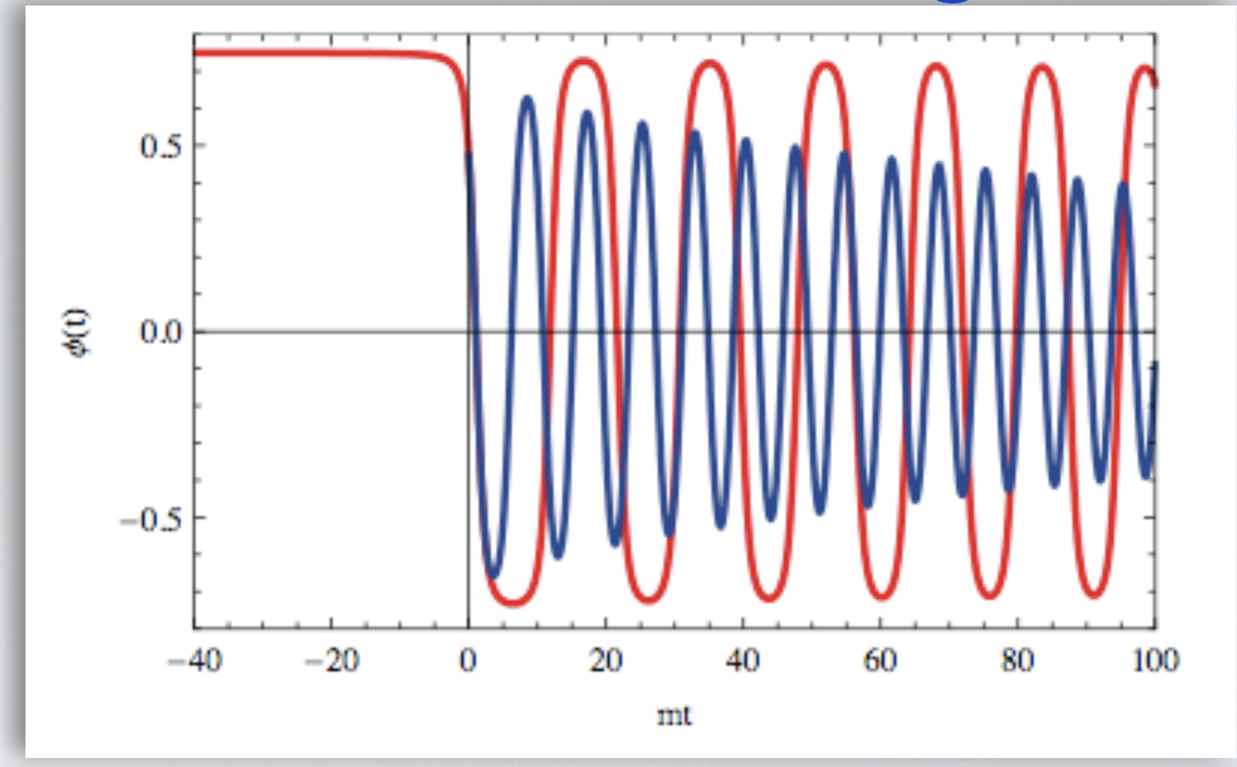
$$\hat{\mu} \frac{dA}{d\hat{\mu}} = -\frac{1}{4\pi^2} \left(\frac{16}{3} M_3 g_3^2 + \frac{8}{5} M_1 g_1^2\right).$$



Boehm, DaSilva, AM & Pukartas, PRD (2012), Wang, Pukartas & AM (hep-ph/1303.535)

MSSM dof Via Instant Preheating



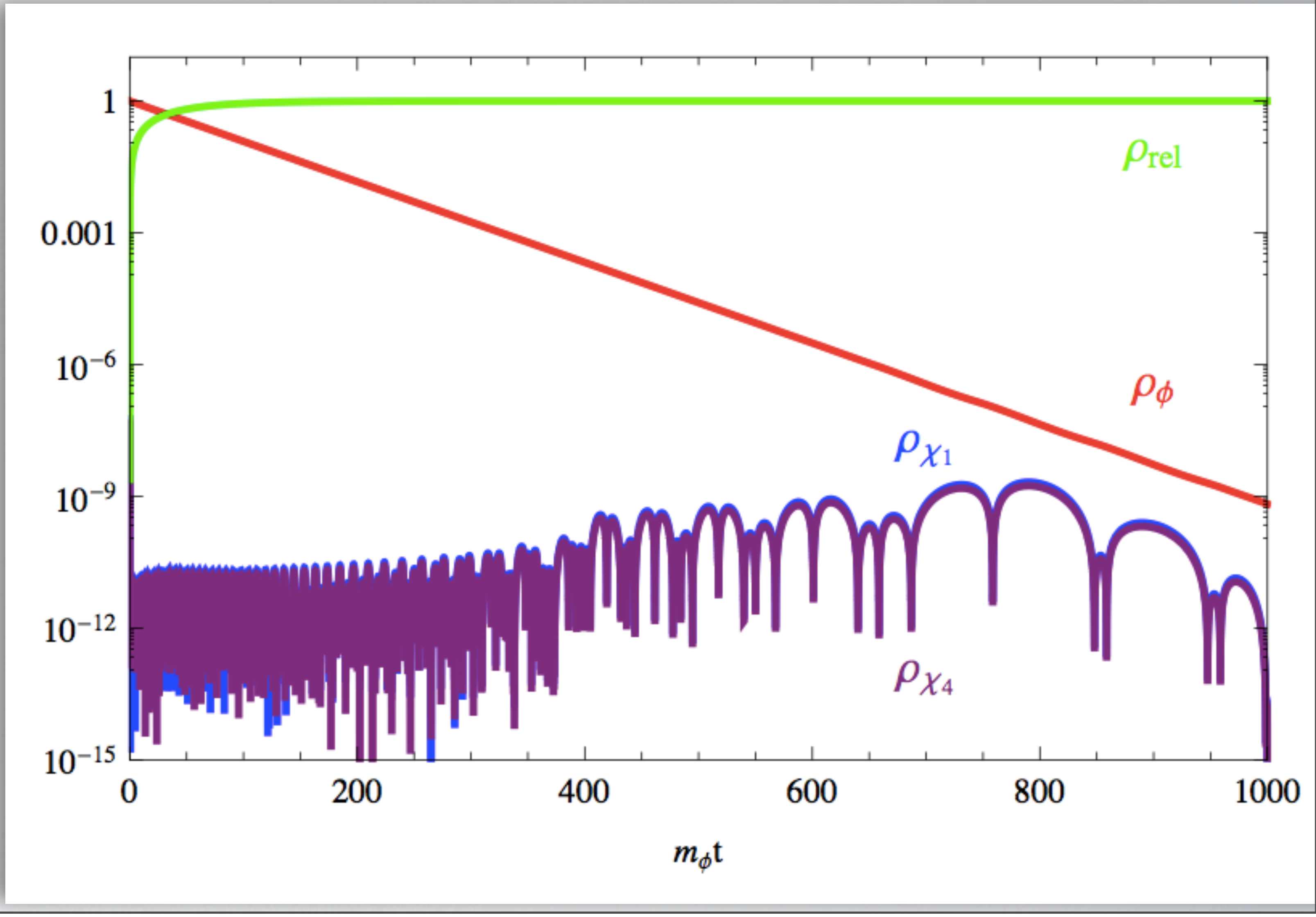


$$V = \frac{1}{2}m^2\phi^2 - A\frac{\phi^6}{M_P^3} + \frac{\phi^{10}}{M_P^4}$$

$$\frac{\rho_{rel}}{\rho_\phi} \sim 10\% \text{ (per crossing)}$$

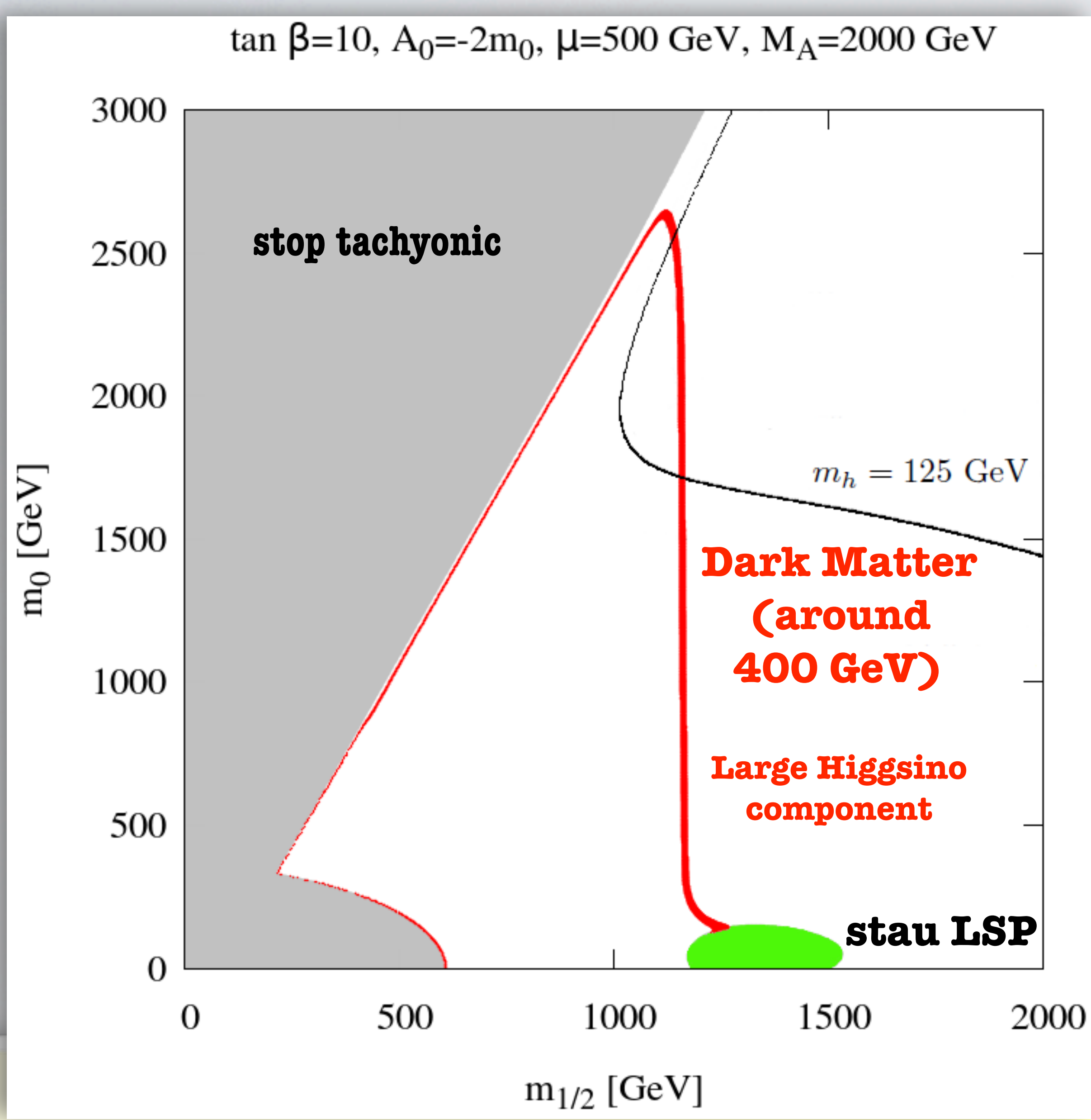
$$T_{rh} = \left(\frac{30}{\pi^2 g_*}\right)^{1/4} \rho_\phi^{1/4}$$

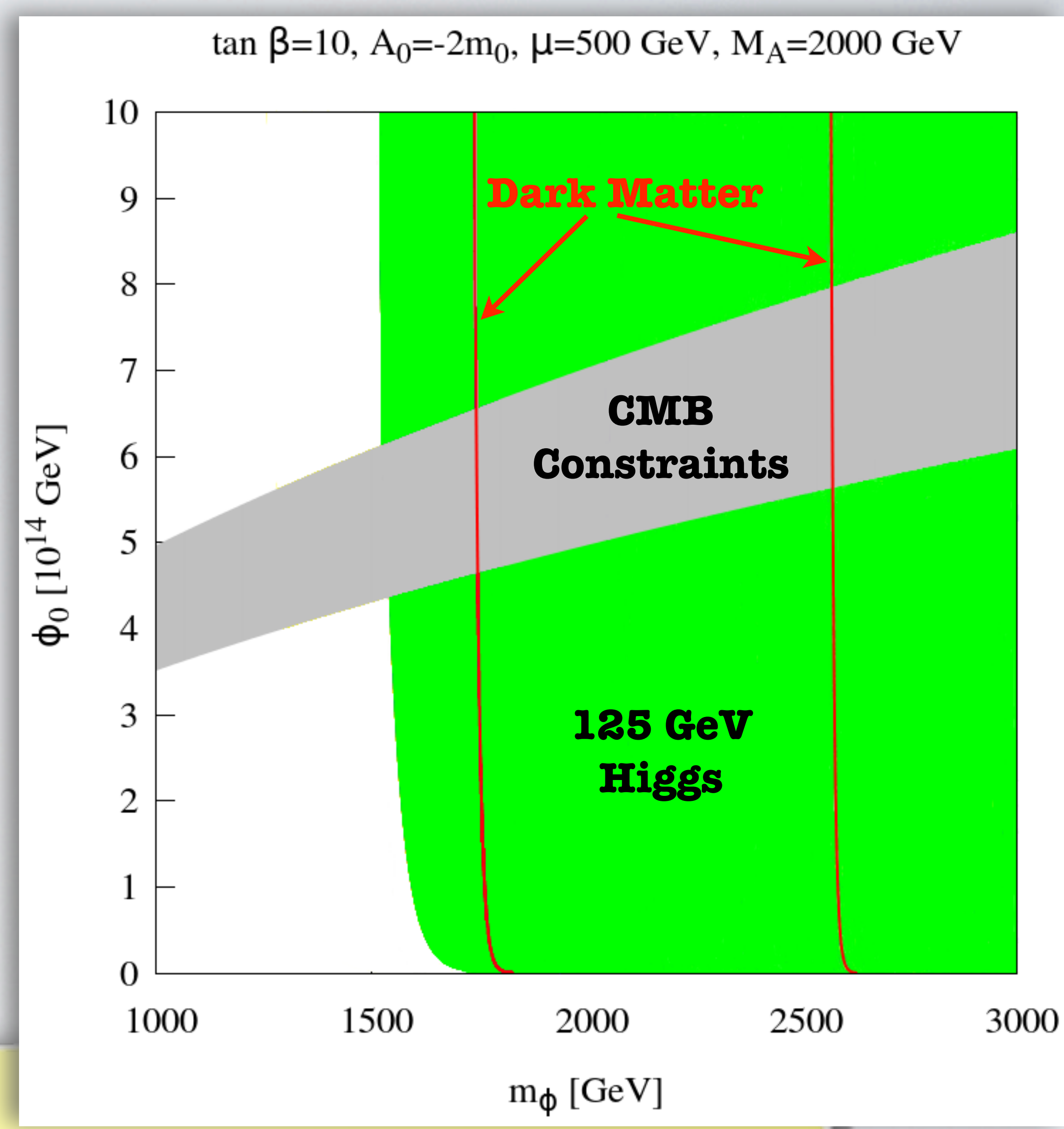
$$\sim 3 \times 10^8 \text{ GeV (for } m_\phi \sim 1 \text{ TeV)}$$



Allahverdi, Ferrantelli, Garcia-Bellido & AM PRD (2011)

Parameter space for Inflaton (udd) + DM within NUHM-2 scenario

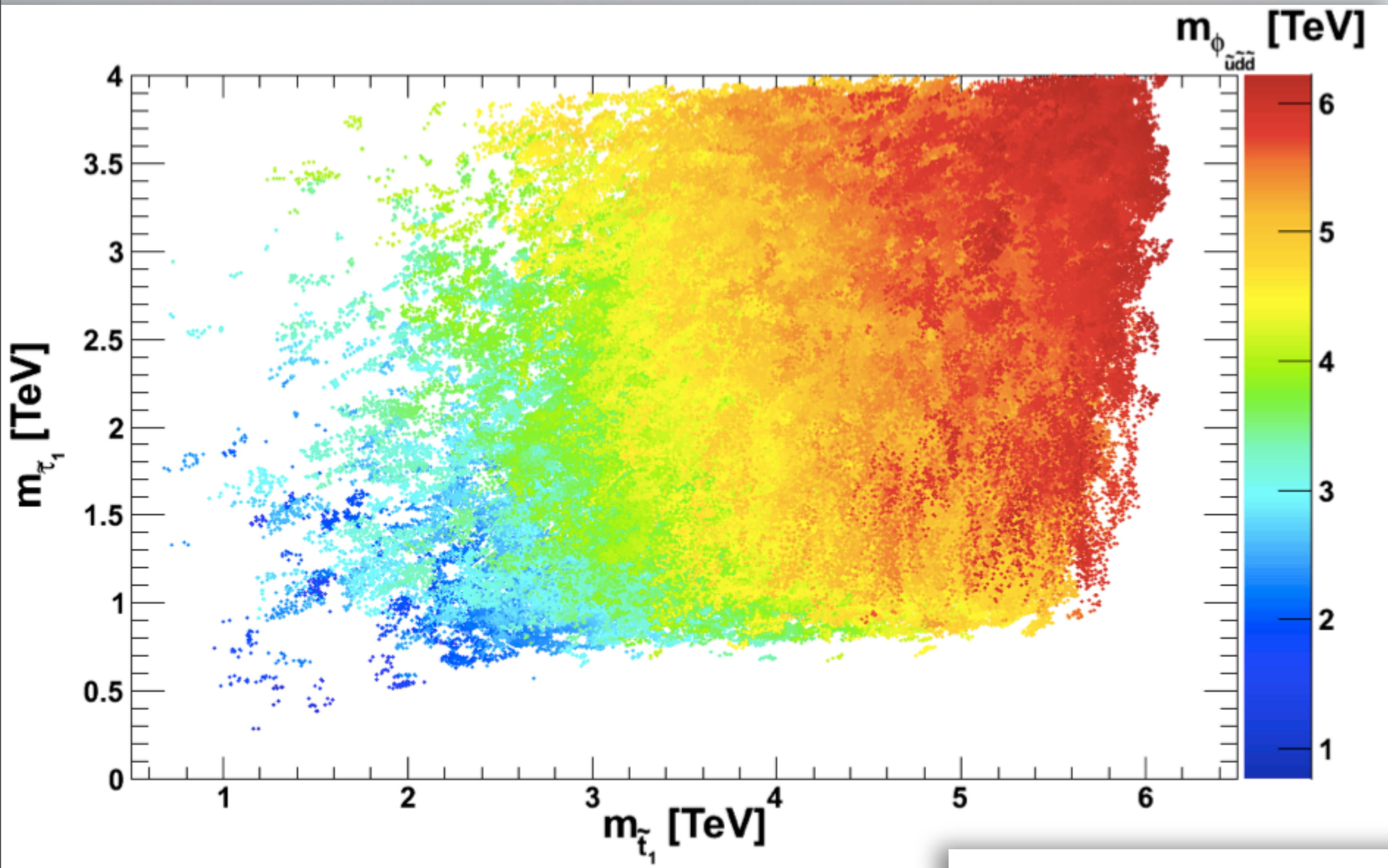




$$m_0,\ m_{1/2},\ A_0,\ \tan\beta,\ \mu,\ M_A$$

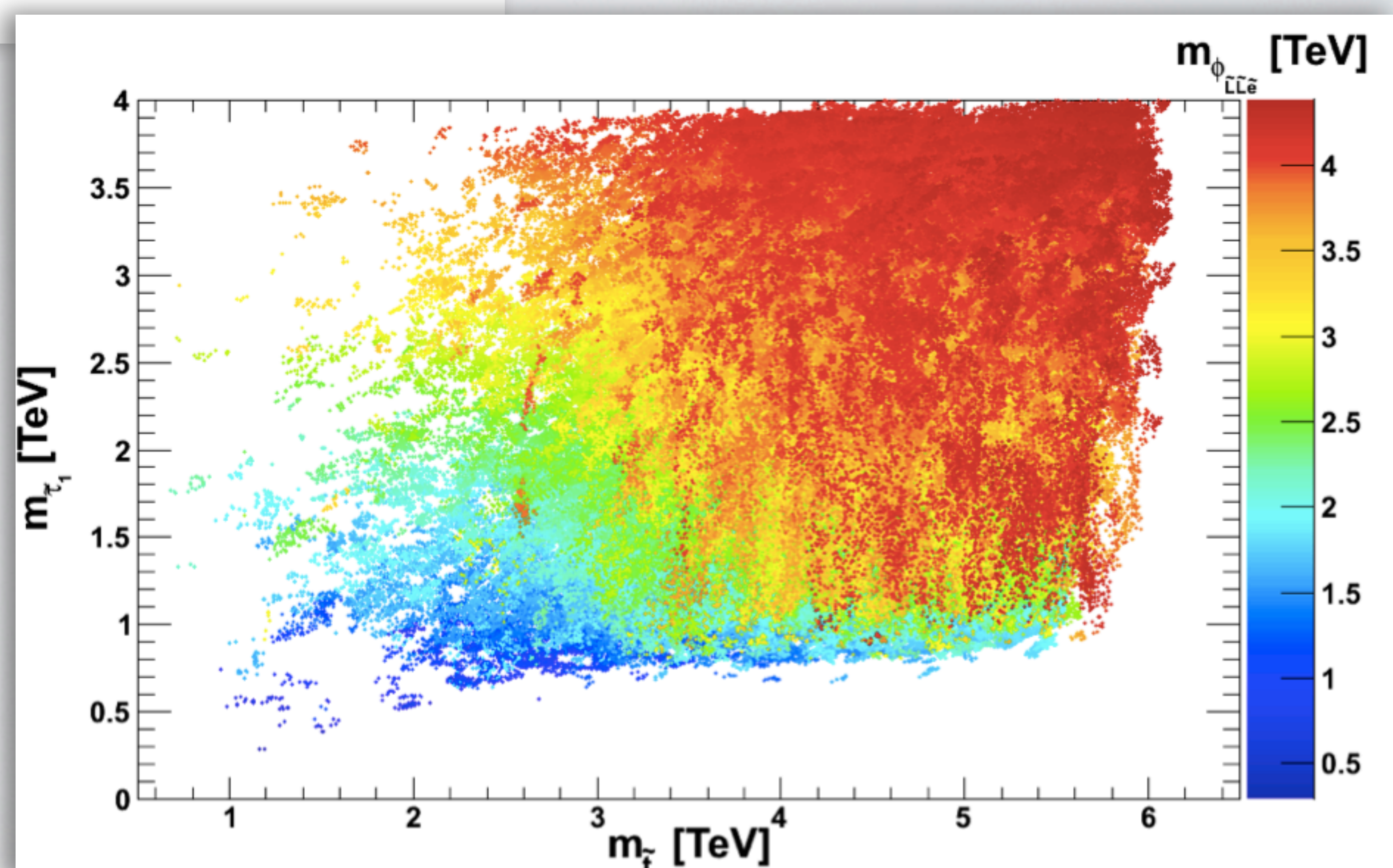
$$m^2_{H_u}(\mathrm{GUT}), m^2_{H_d}(\mathrm{GUT}) \neq m_0^2(\mathrm{GUT})$$
$$m^2_{H_u}(\mathrm{GUT}) \neq m^2_{H_d}(\mathrm{GUT})$$

Boehm, DaSilva, AM & Pukartas, PRD (2012), Wang, Pukartas & AM (hep-ph/1303.535)



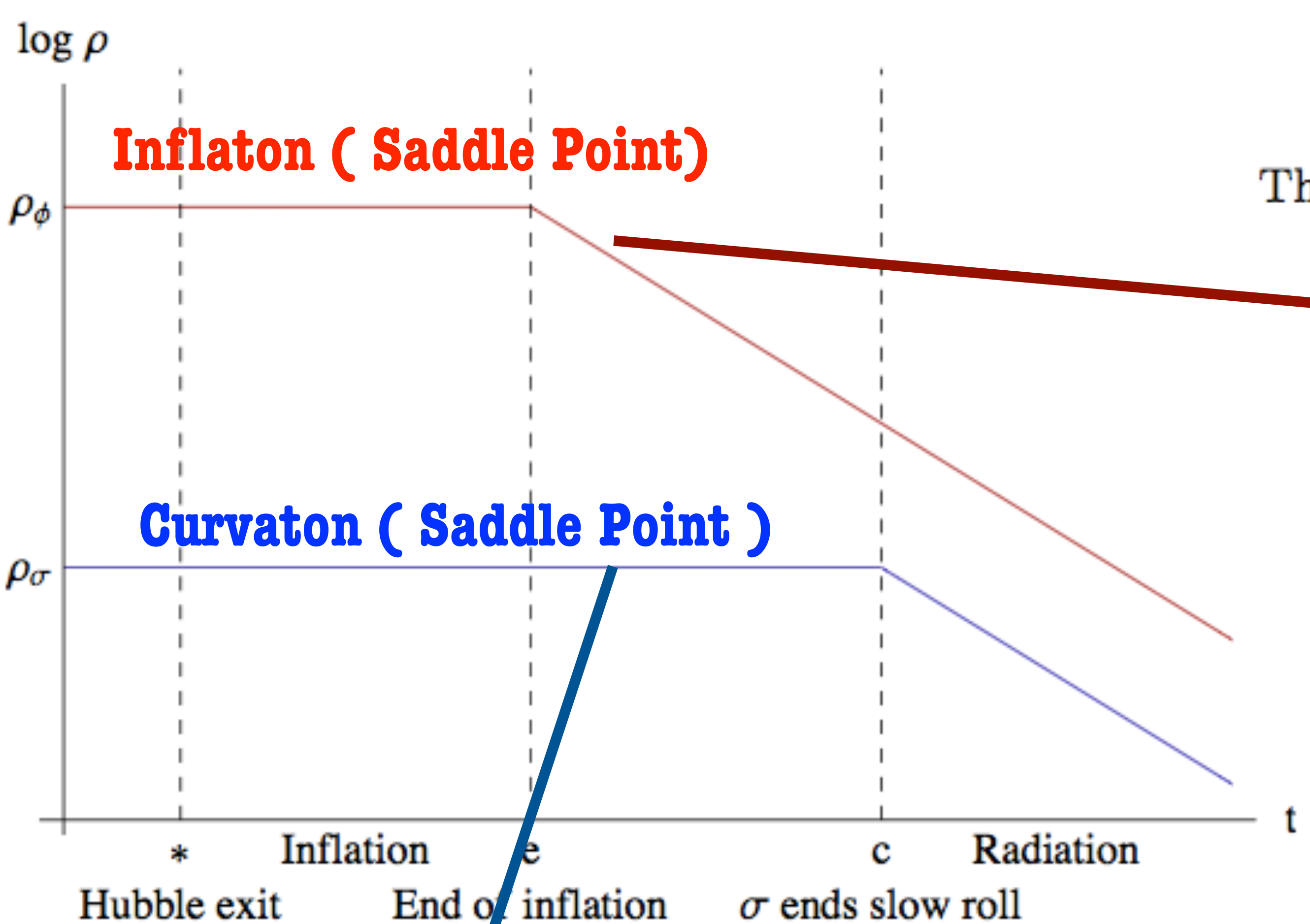
Scanning NUHM-2 scenario

Correlation between Inflaton, Stau & lightest Stop



Boehm, DaSilva, AM & Pukartas, PRD (2012),

Curvaton & Inflaton from MSSM



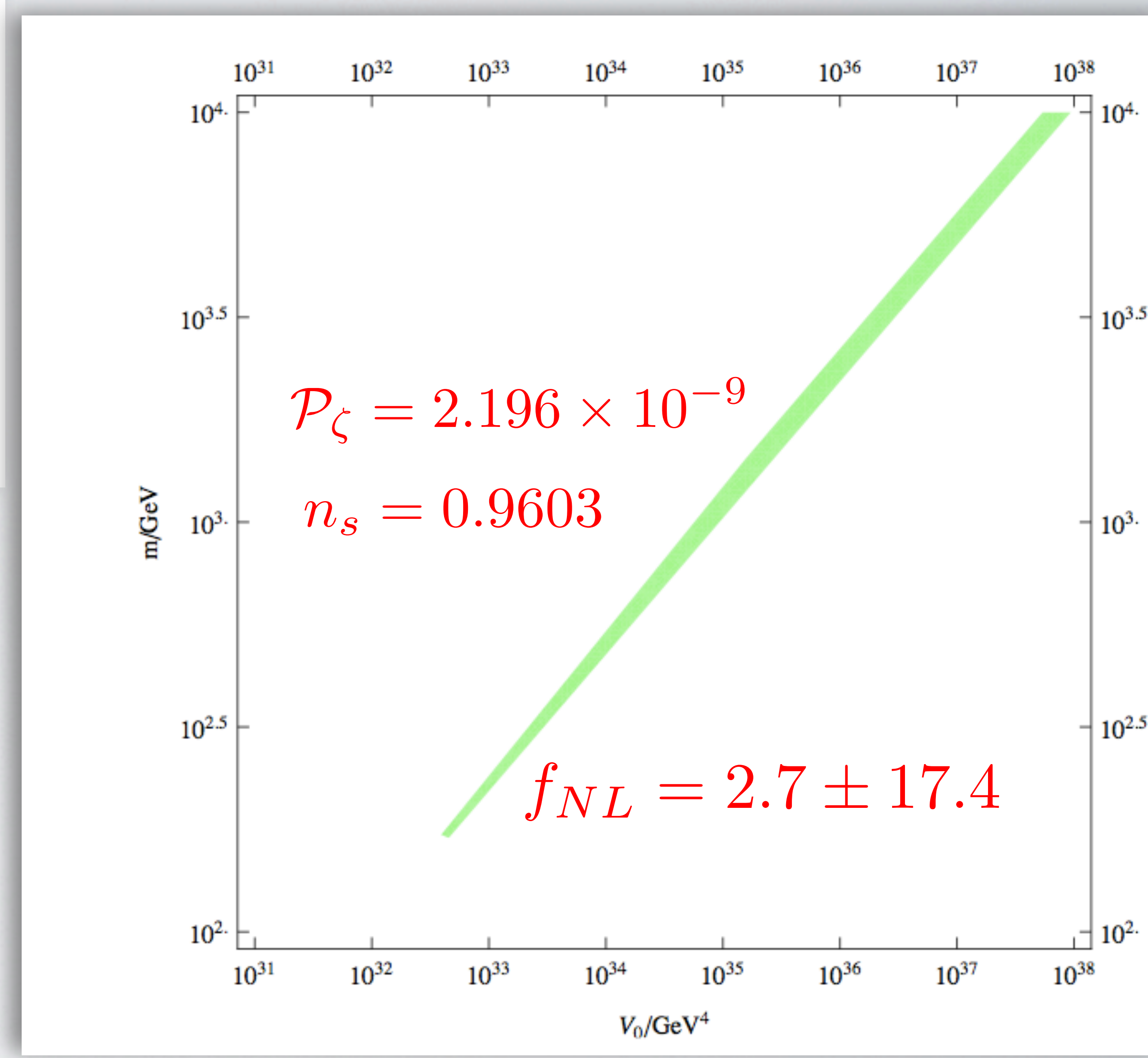
$$W = \sum_{m\geq 2} \frac{\lambda_m}{3m} \frac{\Phi^{3m}}{M_*^{3m-3}} \, .$$

The potential at lowest order would be:

$$\phi = \frac{\widetilde{u} + \widetilde{d} + \widetilde{d}}{\sqrt{3}} \qquad V(\phi) = \left| \lambda_2 \frac{\phi^5}{M_*^3} + \lambda_3 \frac{\phi^8}{M_*^6} + \lambda_4 \frac{\phi^{11}}{M_*^9} + \cdots \right|^2$$

$$\sigma = \frac{(\widetilde{L} + \widetilde{L} + \widetilde{e})}{\sqrt{3}} \, , \qquad m_\sigma^2 = \frac{m_{\widetilde{L}}^2 + m_{\widetilde{L}}^2 + m_{\widetilde{e}}^2}{3}$$

$$U(\sigma) = \frac{1}{2} m_\sigma^2 |\sigma|^2 - \frac{A\lambda}{6} \frac{\sigma^6}{M_*^3} + \lambda^2 \frac{|\sigma|^{10}}{M_*^6}$$



NO Iso-Curvature Perturbations

AM & Nadathur, Phys. Rev. Lett. (2012),

Wang, Pukartas & AM, (hep-ph/1303.535)

Bench-Mark Points for Visible Sector Models of Inflation & Curvaton

Planck Constraints (1σ)	MSSM inflation	MSSM Curvaton
Tensor-to-scalar ratio $r < 0.11$ (95% CL) [4]	★Negligible, ✓	Negligible, ✓
$10^9 P_\zeta = 2.196^{+0.051}_{-0.060}$ [2]	✓	✓
$n_s = 0.9603 \pm 0.073$ [2]	✓	✓
$dn_s/d\ln k = -0.0134 \pm 0.0090$ [4]	$\lesssim -0.002$, ✓	✓
$f_{\rm NL}^{local} = 2.7 \pm 5.8$ [3]	< 1, ✓	Constrained, ✓
$f_{\rm NL}^{equil} = -42 \pm 75$ [3]	< 1, ✓	Constrained, ✓
$f_{\rm NL}^{orth} = -25 \pm 39$ [3]	< 1, ✓	Constrained, ✓
Relativistic *dof* [2]	only SM	only SM

★ $r < 0.11$

With Hubble-Induced SUGRA Corrections

Inflection Point for Inflaton

Saddle Point for Both Inflaton & Curvaton

Conclusions

Last 50-60 e-folds of Inflation MUST be embedded within a VISIBLE sector

Discovery of B-modes will not only test the Inflationary paradigm but will also test the structure of Space-Time and perhaps the nature of Quantum Gravity itself

LHC data

Planck & Future

No TeV scale SUSY

Understand new d.o.f. of BSM physics

Construct inflationary vacuum within new BSM sector (without invoking hidden sectors)

(1) New Chapter

- Determine T_R
- Determine dark matter candidate
- Determine mechanism for baryogenesis

TeV scale SUSY

Constrain parameter space for TeV scale MSSM inflation from LHC

(2) Precision SUSY cosmology

- Constrain thermal history of the Universe precisely
- MSSM parameter space for inflation, baryogenesis, and dark matter

Small tensor perturbations

Large tensor perturbations

(3) TeV scale SUSY

- Construct high scale MSSM inflationary vacuum below M_p (without invoking hidden sectors)
- Connect inflation with LHC observables

(4) No TeV scale SUSY

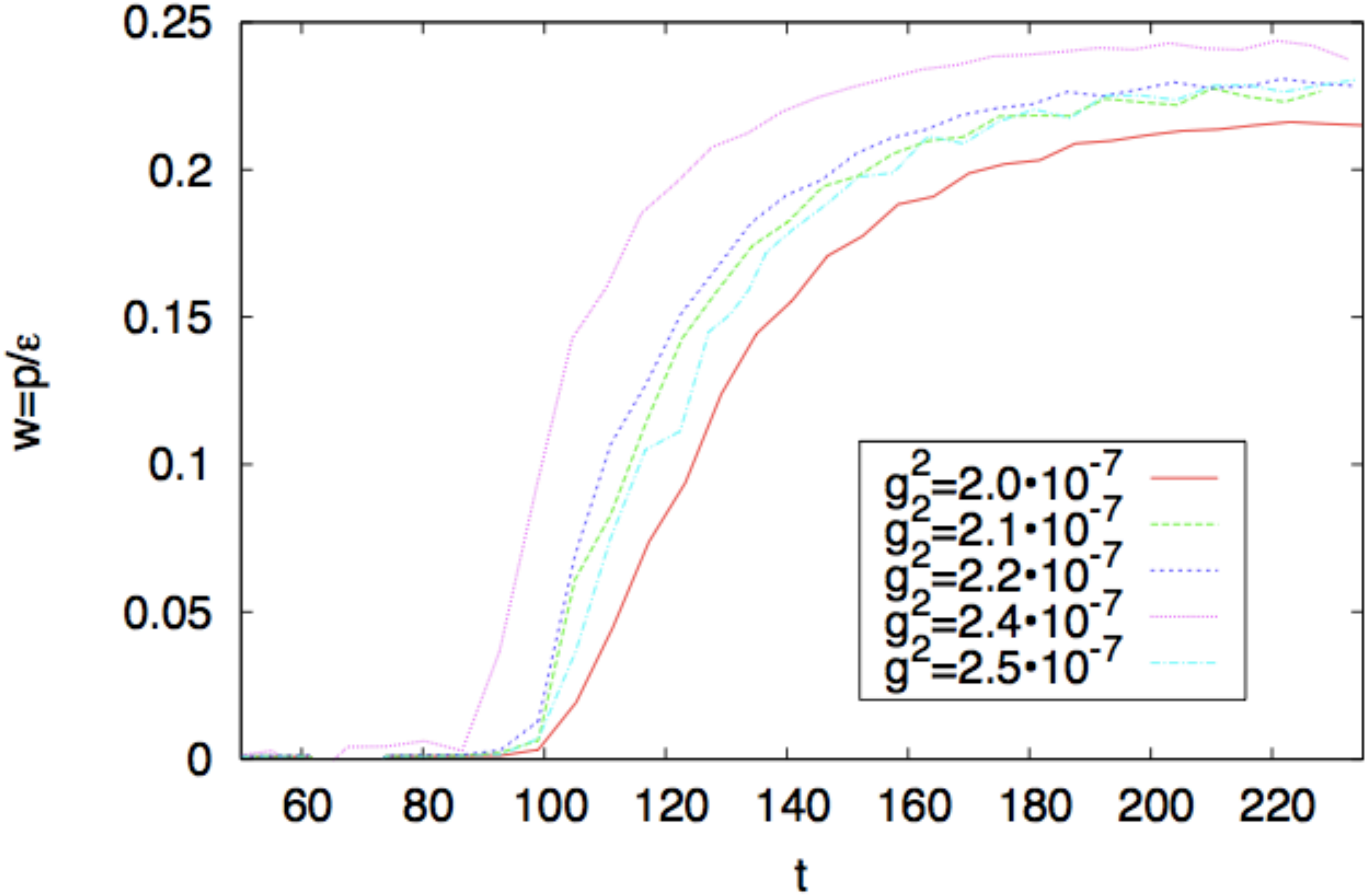
- Construct high scale inflationary vacuum based on new BSM physics (without invoking hidden sectors)
- Seek new LHC signatures

Revolutionary ROAD MAP

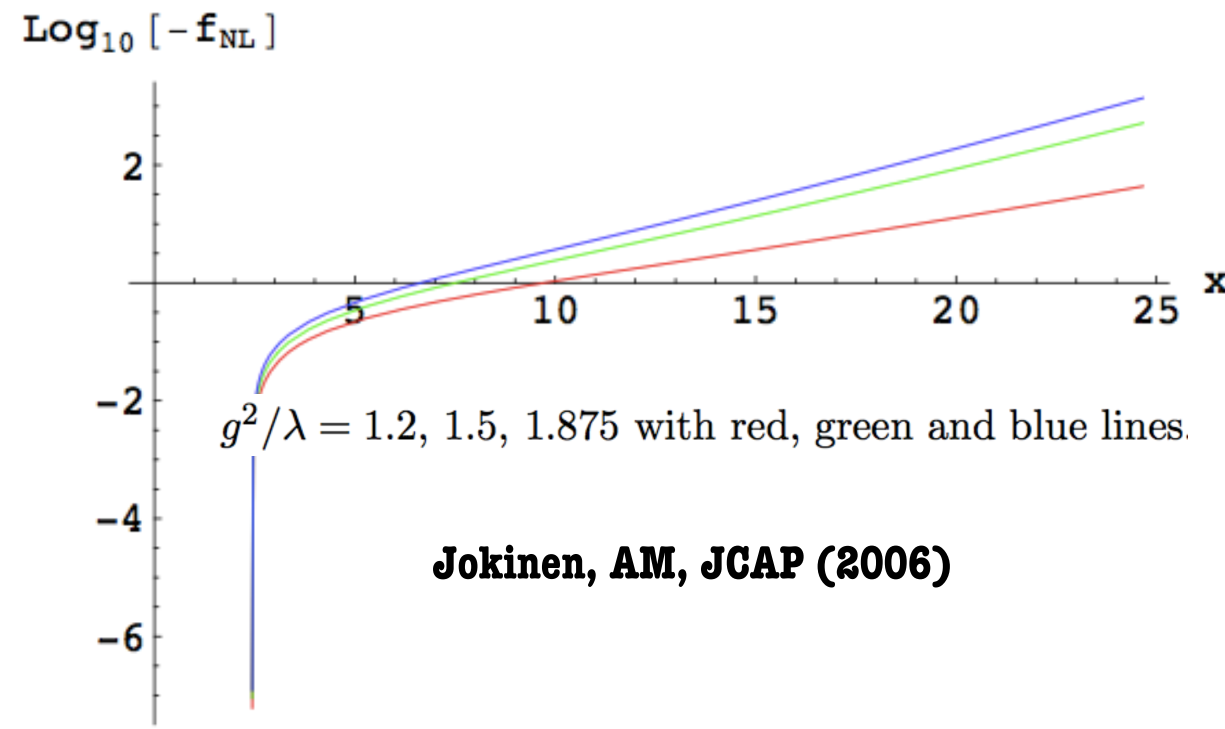
Extra Slides

ALARMINGLY LARGE NON-GAUSSINAITY DURING SINGLET PREHEATING

Podolsky, Felder, Kofman, Peloso, PRD (2005)



$$V(\varphi,\sigma) = \frac{1}{4}\lambda\varphi^4 + \frac{1}{2}g^2\varphi^2\sigma^2$$



Jokinen, AM, JCAP (2006)

Longer this time span of changing e.o.s ----> Larger will be Non-Gaussianity

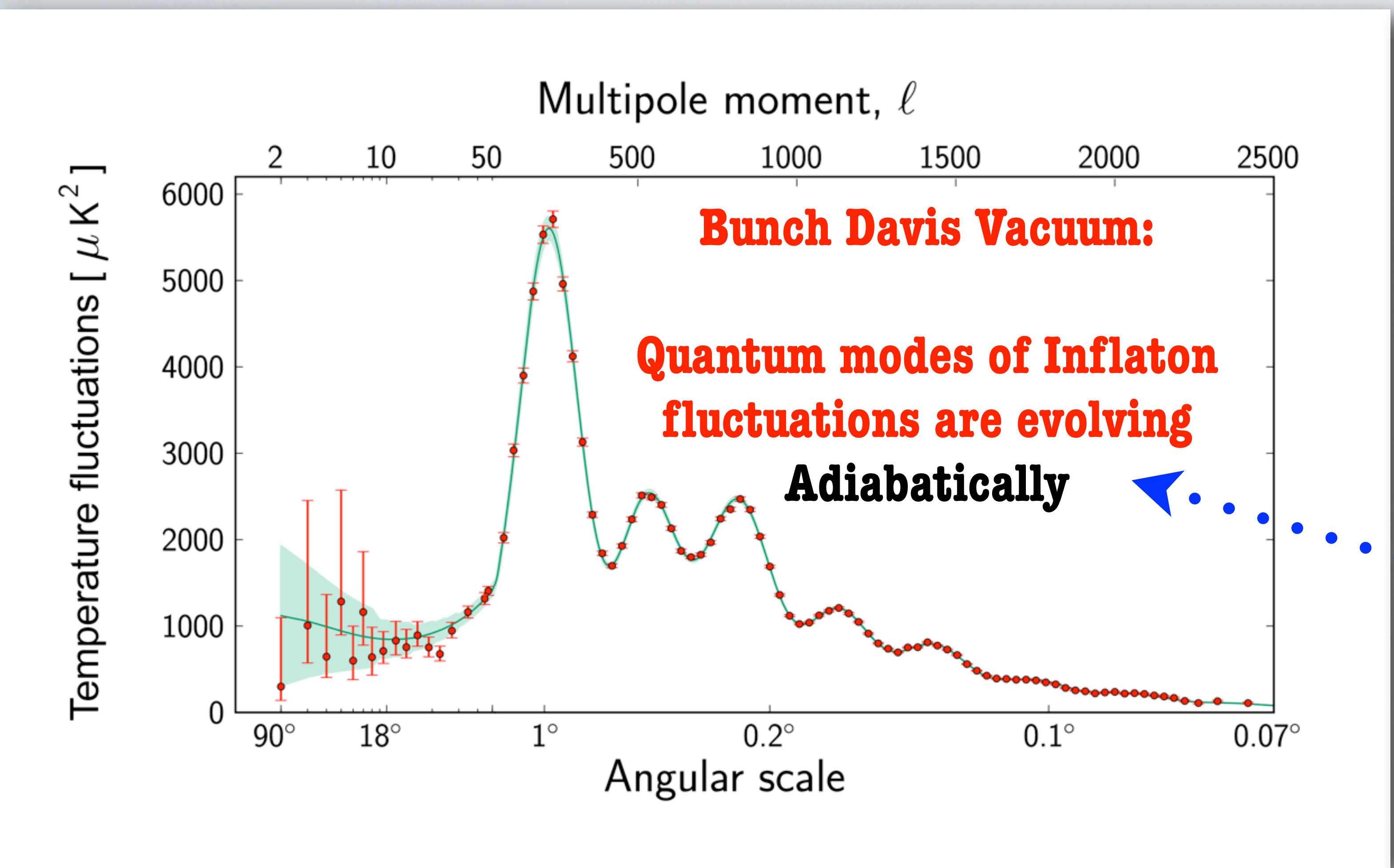
Enqvist, Jokinen, AM, Multamaki, Vaihkonen, Phys.Rev. Lett. (2005)

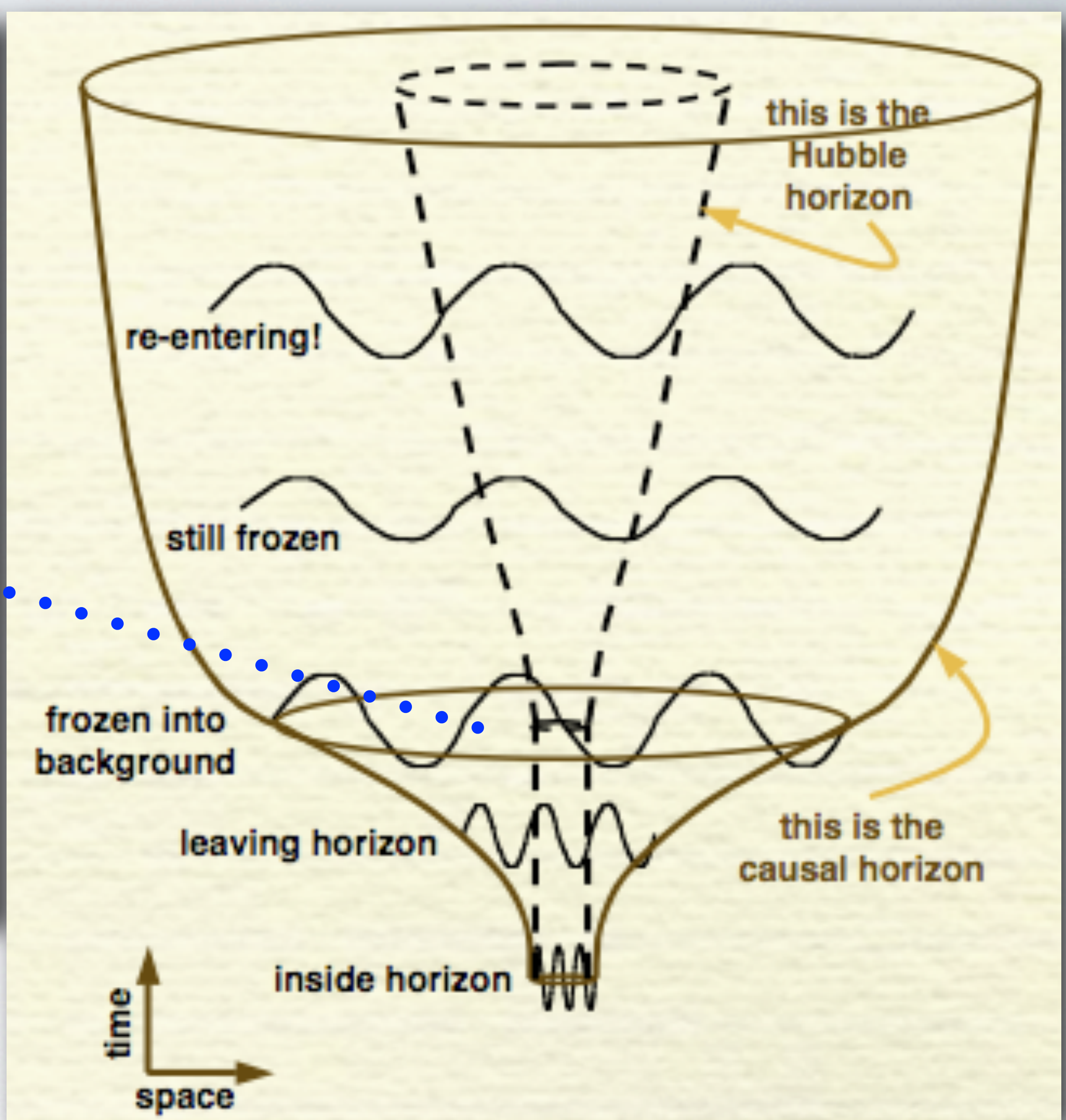
Instant Preheating Does NOT generate Non-Gaussianity $f_{NL} \ll 1$

Felder, Kofman, Linde, Phys.Rev.D (1998)

Enqvist, Jokinen, AM, Multamaki, Vaihkonen, JCAP (2005)

Inflation + Adiabatic Vacuum





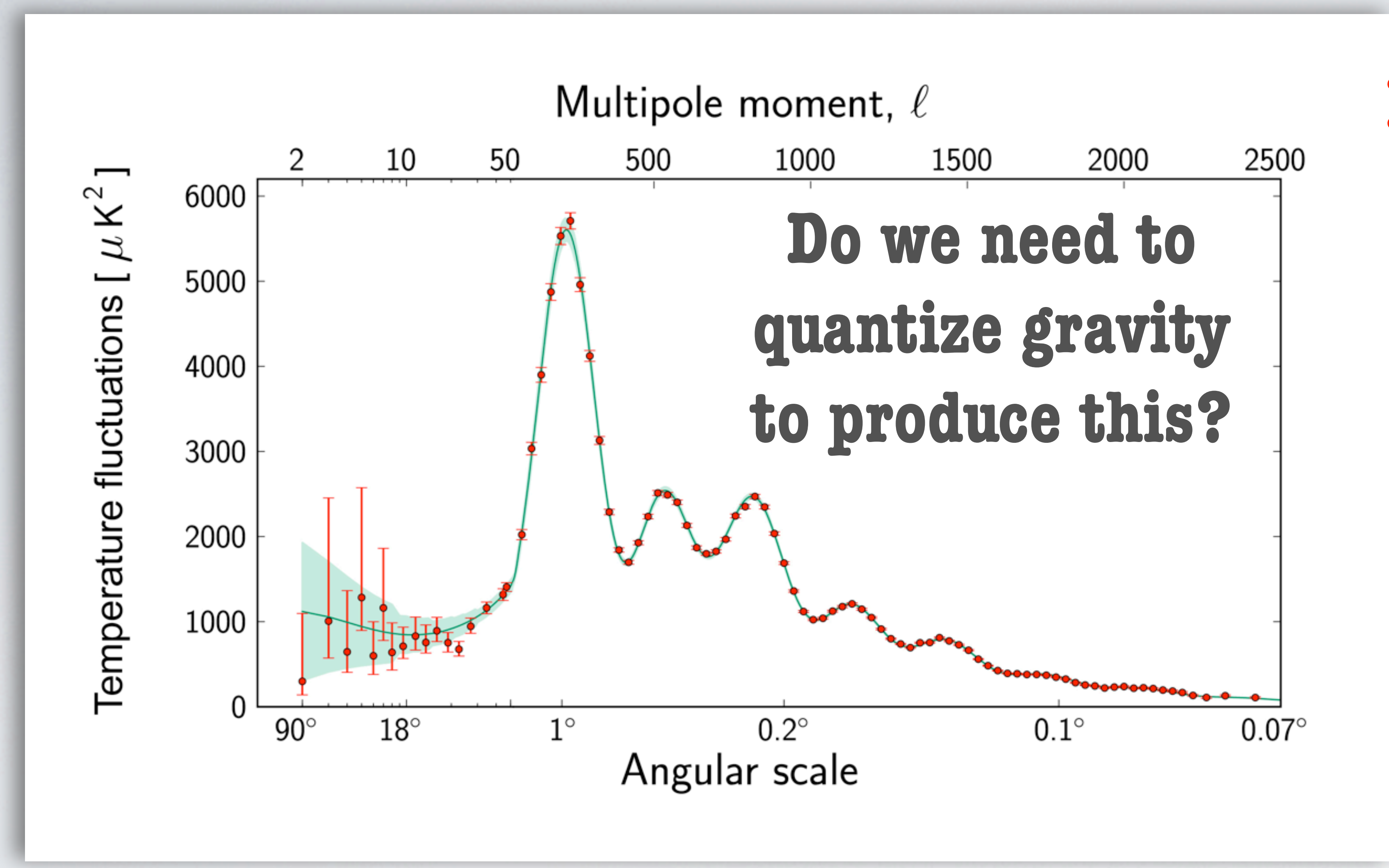
17 e-foldings

Why is Quantum Gravity so kind towards us?

What is the CMB telling us about the Nature of Gravity in UV?

Some Issues about Inflation

Quantization of Space Time



May be gravity remains classical forever

or

Gravity becomes Asymptotically Free in the UV

Biswas, Gerwick, Koivisto & AM, Phys. Rev. Lett. (2012)

Would we ever see B-mode of Polarization ?

Never: If Gravity is treated Classically

Ashoorioon, Dev & AM (1211.4678)

Note: B-modes do not require super-Planckian Inflaton VEVs such as Chaotic Inflation

Inflection Point Inflation can do so with VeVs below the cut-off

Hotchkiss, AM & Nadathur, JCAP (2012)

Beyond the SM: Where to Embed the Last Phase of Inflation ?

Visible sector inflation

(e.g. MSSM inflaton)

(P)Reheating

Visible sector *d.o.f.*

e.g. MSSM $\longrightarrow$ Precise determination of T_R

Direct decay

Thermal / non-thermal
leptogenesis,
EW baryogenesis, ...

Thermal relics

Affleck-Dine baryogenesis

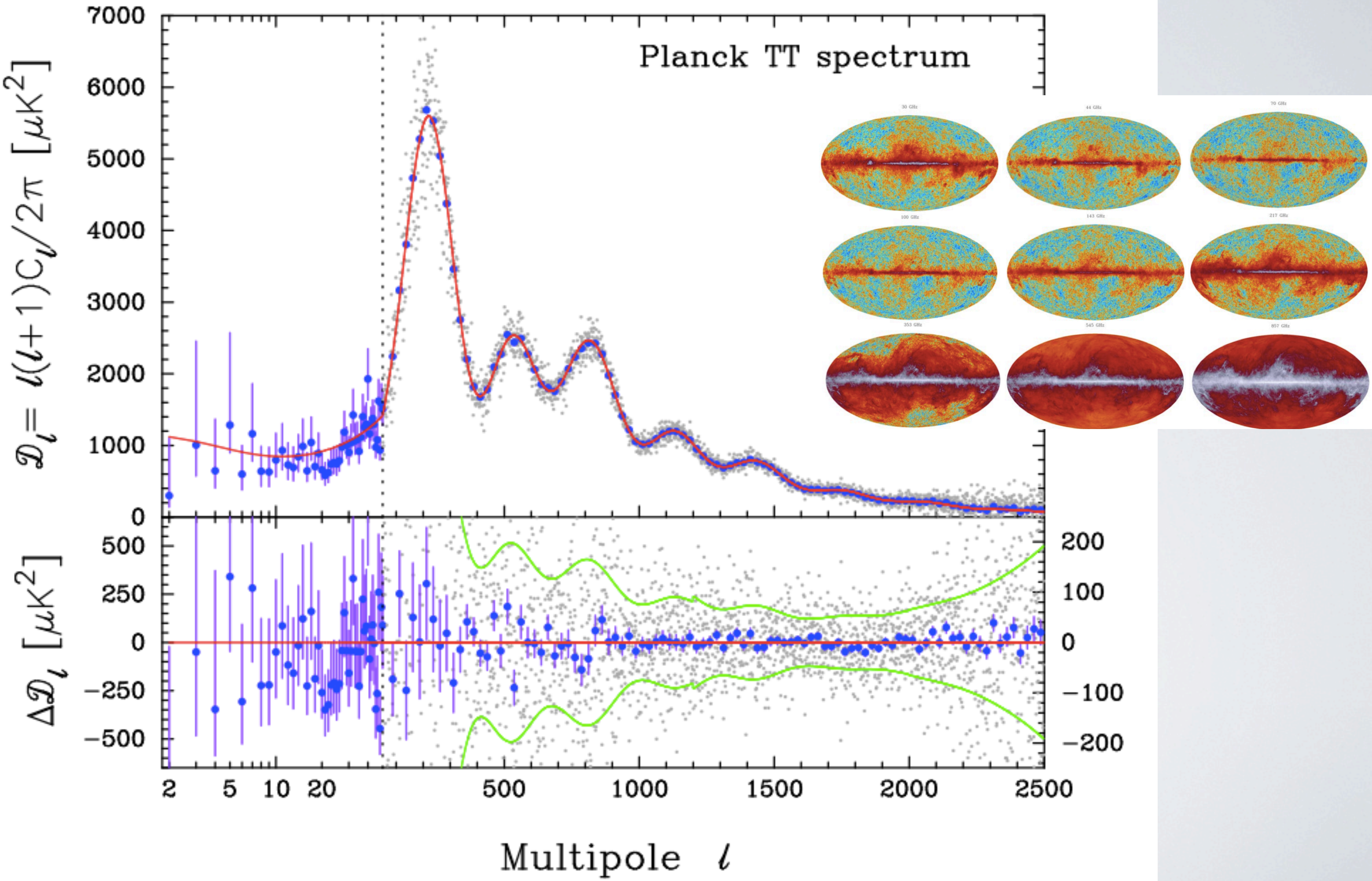
Q-ball decay

Visible sector dark matter

(e.g. LSP)

Inspite of the fact that SUSY
@ LHC is still Hiding !!

Planck


Planck TT spectrum
$\mathcal{D}_\ell = \ell(\ell+1)C_\ell/2\pi\ [\mu K^2]$
$\Delta\mathcal{D}_\ell\ [\mu K^2]$
Multipole ℓ
7000
6000
5000
4000
3000
2000
1000
0
500
250
0
−250
−500
200
100
0
−100
−200
2
5
10
20
500
1000
1500
2000
2500

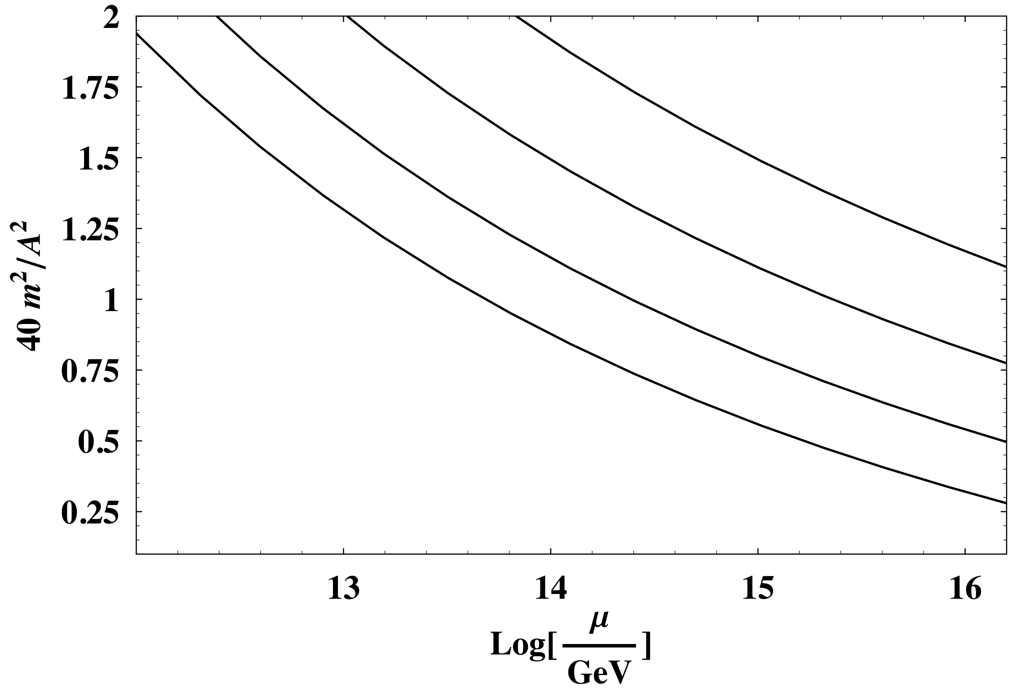


FIG. 2: The ratio $(40m_\phi^2/A^2)$ as a function of $\mathrm{Log}[\frac{\mu}{\mathrm{GeV}}]$ in the case of *udd* flat direction. The curves are for M_{GUT} boundary values m_ϕ= 150, 200, 250, 300 GeV (respectively from left to right), and $A = 1.6$ TeV.

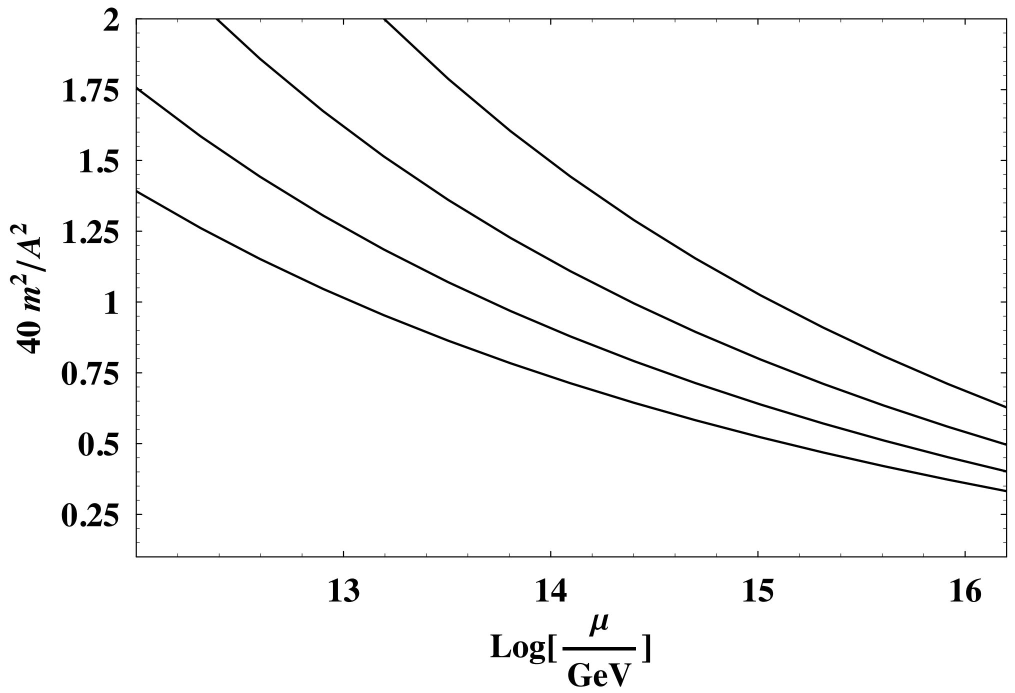


FIG. 3: The ratio $(40m_\phi^2/A^2)$ as a function of $\mathrm{Log}[\frac{\mu}{\mathrm{GeV}}]$ in the case of *udd* flat direction. The curves are for M_{GUT} boundary values A_{udd}=1.6, 1.8, 2.0, 2.2 TeV (respectively from top to bottom), and $m_\phi = 400$ GeV.

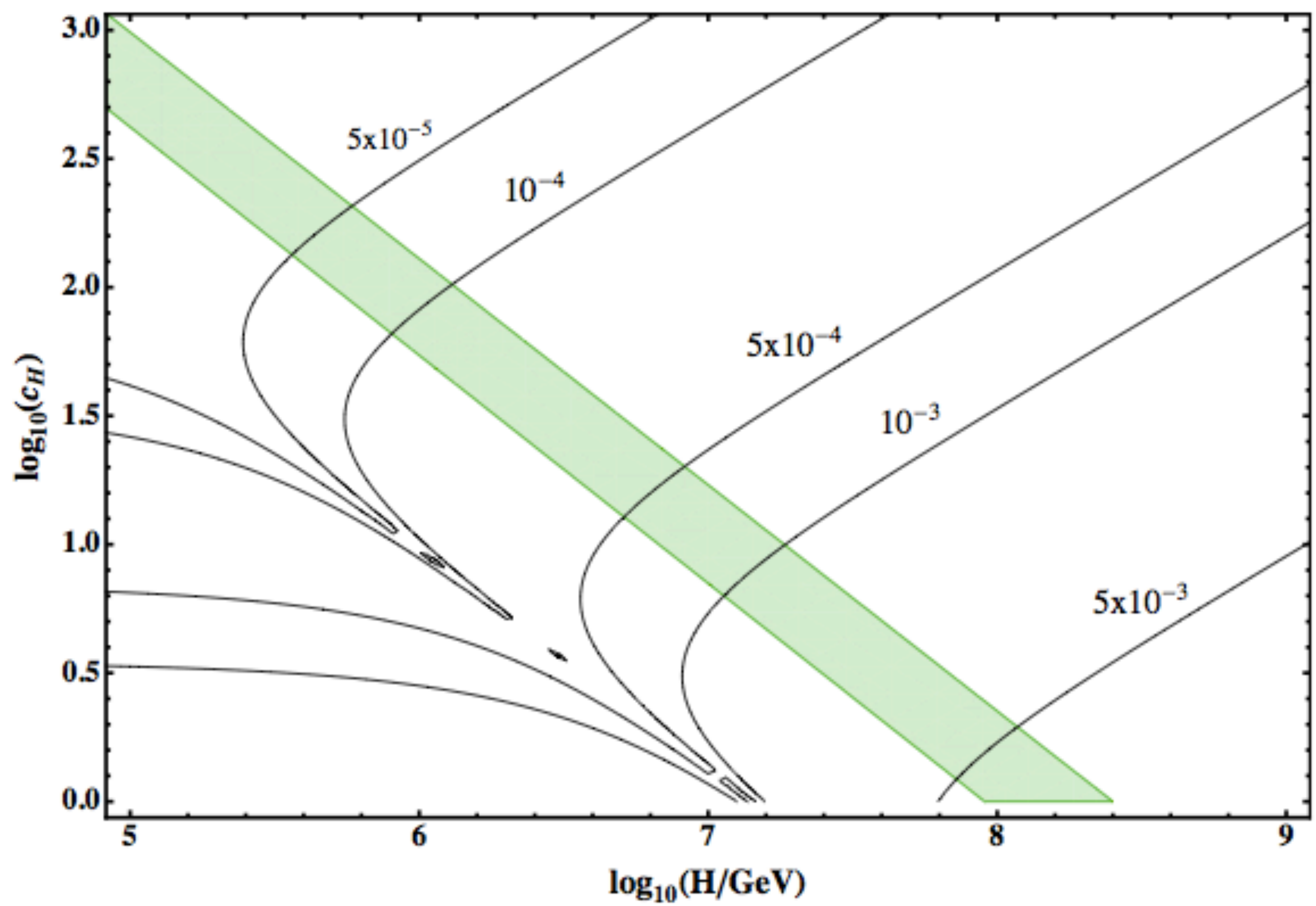
Is there a Fine - Tuning ?

$$m_\phi(\phi_0),\ A(\phi_0)$$

RG - Equations

$$m_\phi(100\ \mathrm{GeV}),\ A(100\ \mathrm{GeV})$$

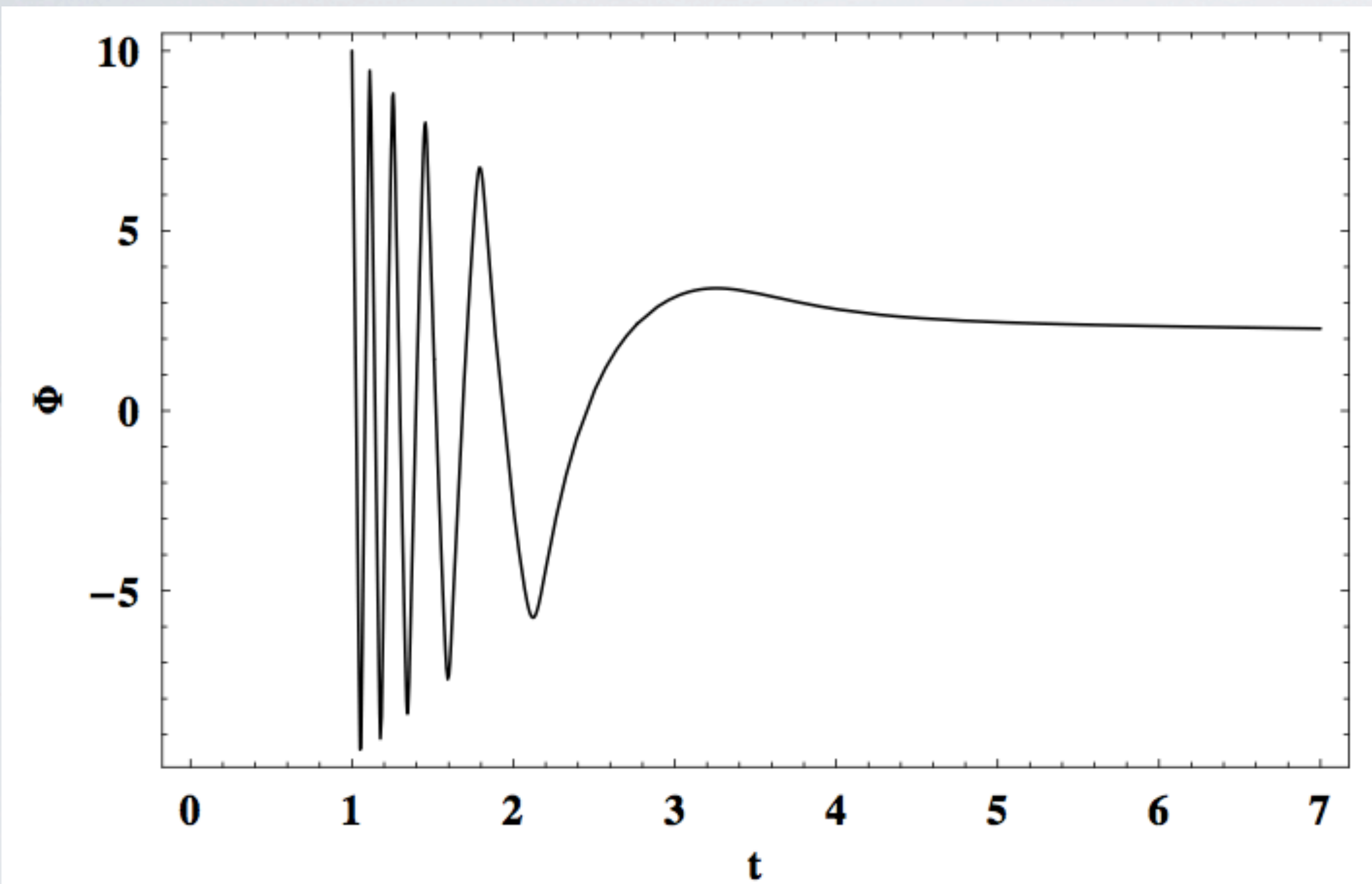
Supergravity Induced Potential



AM & Nadathur
Phys. Rev. D (2011)

$$V(\phi) = V_c + \frac{c_H H^2}{2}|\phi|^2 - \frac{a_H H}{n M_P^{n-3}}\phi^n + \frac{|\phi|^{2(n-1)}}{M_P^{2(n-3)}}$$

Attraction Towards Inflection Point



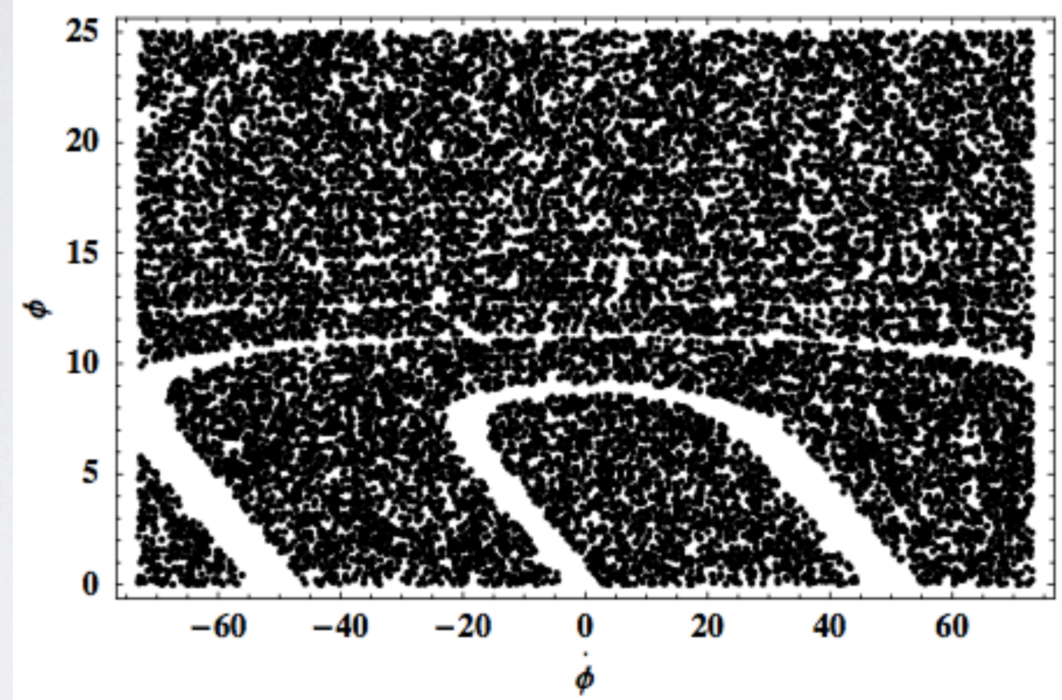


FIG. 5: Same as in Fig. (4) for $H_{\rm false} = 10^3 m_\phi$.

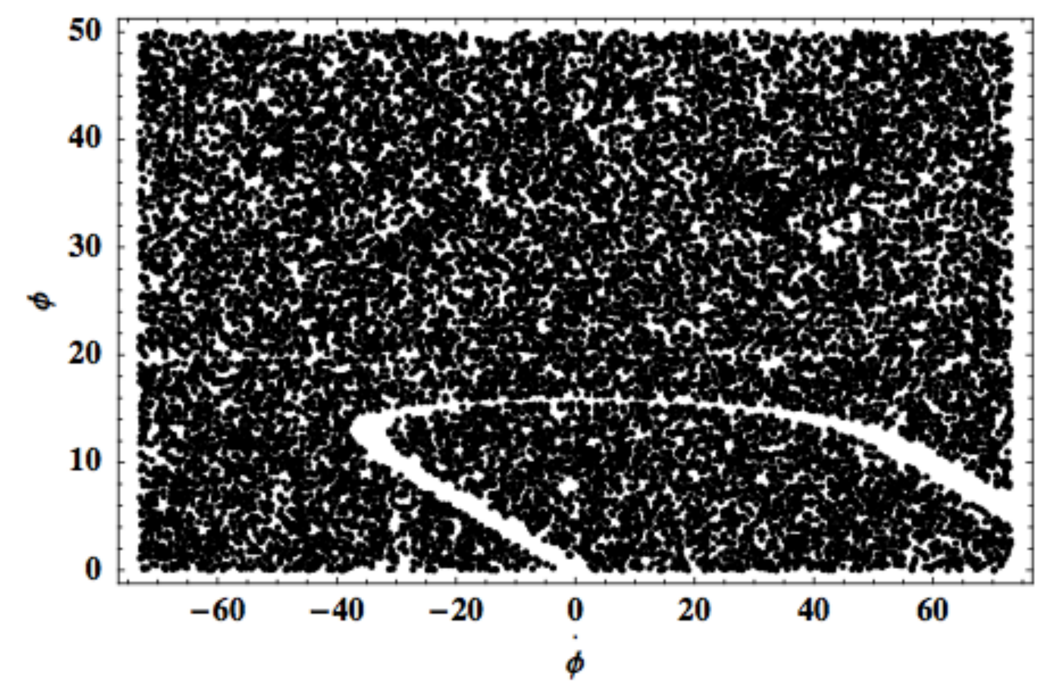


FIG. 6: Same as in Fig. (4) for $H_{\rm false} = 10^4 m_\phi$.

Allahverdi, Dutta & AM, Phys. Rev. D (2008)

Ever Changing models of Inflation

1980 R*R, OLD, NEW, CHAOTIC, EXTENDED, SOFT, BRANS-DICKE, SUSY, SUGRA, THERMAL, EXPONENTIAL, DOUBLE, ...

1990 HYBRID, MUTATED HYBRID, INVERTED HYBRID, F-TERM, D-TERM, K-TERM, TOPOLOGICAL, ASSISTED, ...

2000 N-FLATION, BRANE, BRANE-CHAOTIC/ HYBRID, TACHYONIC, DBI, RACE-TRACK, HILL-TOP, FAST-ROLL, P-TERM, F+D-TERM, EXTENDED-HIGGS, CYCLIC, Kahler, Non-Kahler, Sweese Cheese, D3/D7, ...

None of these models can actually work !!