بررسی مدل های تورمی با میدان های پیمانه ای آبلی و غیر آبلی

مسلم زارعی

دانشکده فیزیک – دانشگاه صنعتی اصفهان

Outline:

1- A short history of CMB

2- Review of Gauge-flation model

3- Review of Choromo-natural model

4- The parameter space of these models

5-Inflationary models with Abelian gauge fields

SICAL REVIEW VOLUME 73, NUMBER 7 APRIL 1, 1948

Letters to the Editor

UBLICATION of brief reports of important discoveries in physics may be secured by addressing them to this tment. The closing date for this department is five weeks to the date of issue. No proof will be sent to the authors. Board of Editors does not hold itself responsible for the ons expressed by the correspondents. Communications d not exceed 600 words in length.

The Origin of Chemical Elements

R. A. ALPHER*
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AND
H. BETHE
Cornell University, Ithaca, New York
AND
G. GAMOW
The George Washington University, Washington, D. C.
February 18, 1948

S pointed out by one of us,[1] various nuclear species must have originated not as the result of an equilib- corresponding to a certain temperature and density, ather as a consequence of a continuous building-up ss arrested by a rapid expansion and cooling of the ordial matter. According to this picture, we must ine the early stage of matter as a highly compressed ron gas (overheated neutral nuclear fluid) which ed decaying into protons and electrons when the gas ure fell down as the result of universal expansion. The tive capture of the still remaining neutrons by the y formed protons must have led first to the formation uterium nuclei, and the subsequent neutron captures ted in the building up of heavier and heavier nuclei. It be remembered that, due to the comparatively short allowed for this process,[1] the building up of heavier s must have proceeded just above the upper fringe of table elements (short-lived Fermi elements), and the nt frequency distribution of various atomic species attained only somewhat later as the result of adjust- of their electric charges by β-decay.

us the observed slope of the abundance curve must be related to the temperature of the original neutron but rather to the time period permitted by the expan- process. Also, the individual abundances of various ar species must depend not so much on their intrinsic lities (mass defects) as on the values of their neutron ure cross sections. The equations governing such a ling-up process apparently can be written in the form:

$$\frac{dn_i}{dt}=f(t)(\sigma_{i-1}n_{i-1}-\sigma_i n_i) \quad i=1,2,\cdots 238, \qquad (1)$$

e n_i and σ_i are the relative numbers and capture cross ons for the nuclei of atomic weight i, and where $f(t)$ is a r characterizing the decrease of the density with time.

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$$\int_{t_0}^{\infty}(10^8/t^2)dt \leq 5\times10^4, \qquad (2)$$

which gives us $t_0 \leq 20$ sec. and $\rho_0 \leq 2.5\times10^6$ g sec./cm^3. This result may have two meanings: (a) for the higher densities existing prior to that time the temperature of the neutron gas was so high that no aggregation was taking place, (b) the density of the universe never exceeded the value 2.5×10^6 g sec./cm^3 which can possibly be understood if we

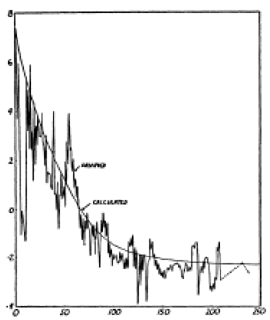
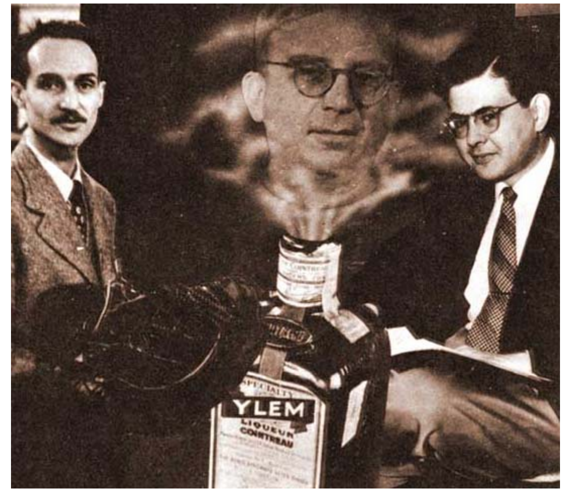


FIG. 1.
Log of relative abundance
Atomic weight



THE ORIGIN AND ABUNDANCE DISTRIBUTION OF THE ELEMENTS[1,2]

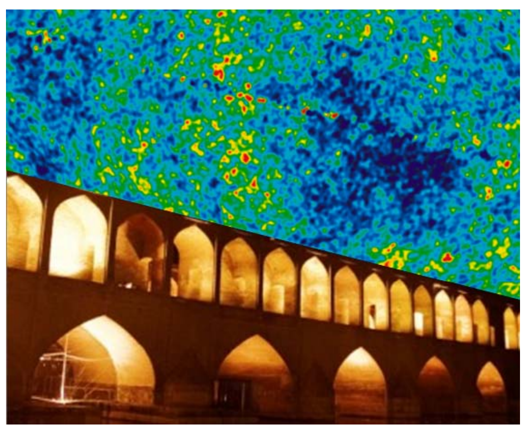
BY RALPH A. ALPHER AND ROBERT C. HERMAN[3]
Applied Physics Laboratory, The Johns Hopkins University, Silver Spring, Maryland

1953

INTRODUCTION

During the past two decades there has been a considerable effort made toward understanding the origin and relative abundance distribution of nuclear species. This has been made possible by advances in nuclear physics and astrophysics which indicate that the origin and the observed abundance distribution must be closely connected. On the one hand, nuclear physics suggests a generic relationship between nuclear species in that they are composed of the same constituents and exhibit significant correlations between their systematic properties and abundances. On the other hand, astrophysics suggests that our present universe has a definite age, that the observed relative abundances appear to be universal quantities, and that the physical conditions required for nuclear synthesis might be found in the early stages of the universe or in the interiors of special types of stars. √

The principal stimulus for theoretical speculation has been the recent analysis and compilation of adequate relative abundance data. Several very different theories have been developed to explain the origin and abundance distribution of the elements. One of the earliest of these describes the observed abundances as a "frozen-in" thermodynamic equilibrium distribution of an assembly of nuclei and elementary particles, where the fundamental parameters are nuclear binding energies, temperature and density. In a recent theory the abundances of the elements are considered as resulting from non-equilibrium processes, involving the formation of the lightest nuclei by thermonuclear processes with both neutrons and charged particles, and formation of the remaining nuclei principally by the successive radiative capture of neutrons, with intervening β-decay. In a third type of theory the formation of elements involves the fission of one or many supernuclei or polyneutron complexes. Finally, another attack on this problem which leads to a steady-state cosmology involves either the continuous and spontaneous creation of matter uniformly throughout the universe at a rate such as to maintain the mean density of the universe at a constant value, or the sudden appearance in the

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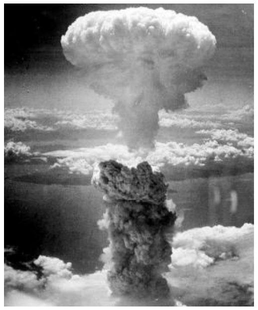     

high pressure, such as the zero-mass scalar, capable of speeding the universe through the period of helium formation. To have a closed space, an energy density of 2×10^{-29} gm/cm^3 is needed. Without a zero-mass scalar, or some other "hard" interaction, the energy could not be in the form of ordinary matter and may be presumed to be gravitational radiation (Wheeler 1958).

One other possibility for closing the universe, with matter providing the energy content of the universe, is the assumption that the universe contains a net electron-type neutrino abundance (in excess of antineutrinos) greatly larger than the nucleon abundance. In this case, if the neutrino abundance were so great that these neutrinos are degenerate, the degeneracy would have forced a negligible equilibrium neutron abundance in the early, highly contracted universe, thus removing the possibility of nuclear reactions leading to helium formation. However, the required ratio of lepton to baryon number must be $> 10^9$.

We deeply appreciate the helpfulness of Drs. Penzias and Wilson of the Bell Telephone Laboratories, Crawford Hill, Holmdel, New Jersey, in discussing with us the result of their measurements and in showing us their receiving system. We are also grateful for several helpful suggestions of Professor J. A. Wheeler.

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May 7, 1965
Palmer Physical Laboratory
Princeton, New Jersey

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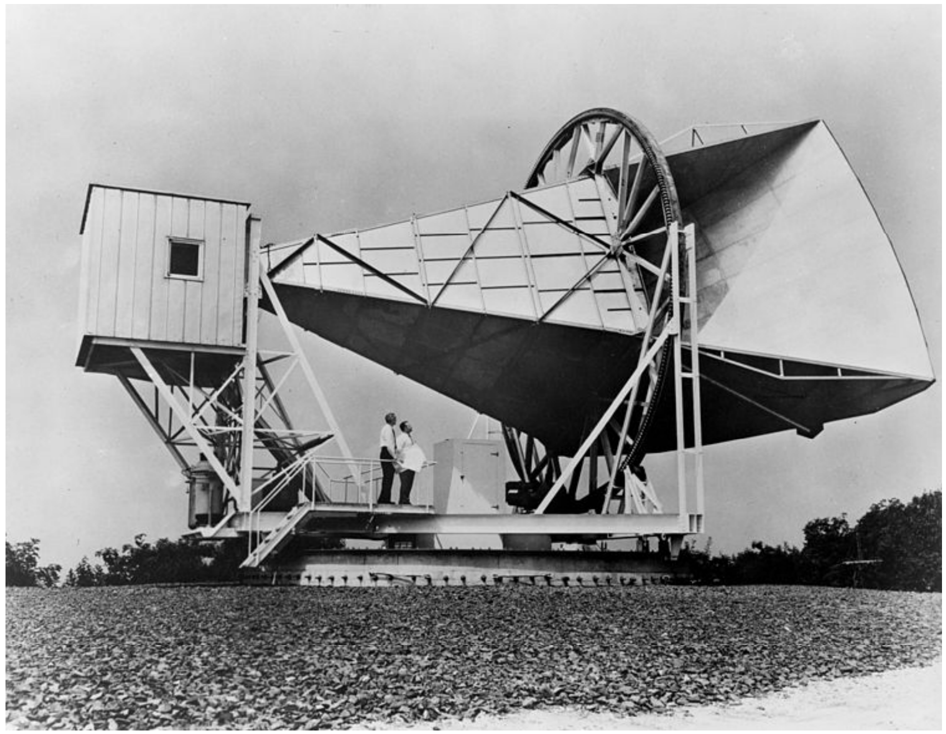
A MEASUREMENT OF EXCESS ANTENNA TEMPERATURE AT 4080 Mc/s

Measurements of the effective zenith noise temperature of the 20-foot horn-reflector antenna (Crawford, Hogg, and Hunt 1961) at the Crawford Hill Laboratory, Holmdel, New Jersey, at 4080 Mc/s have yielded a value about 3.5° K higher than expected. This excess temperature is, within the limits of our observations, isotropic, unpolarized, and



In 1978, Penzias and Wilson were awarded the Nobel Prize for Physics for their joint discovery.

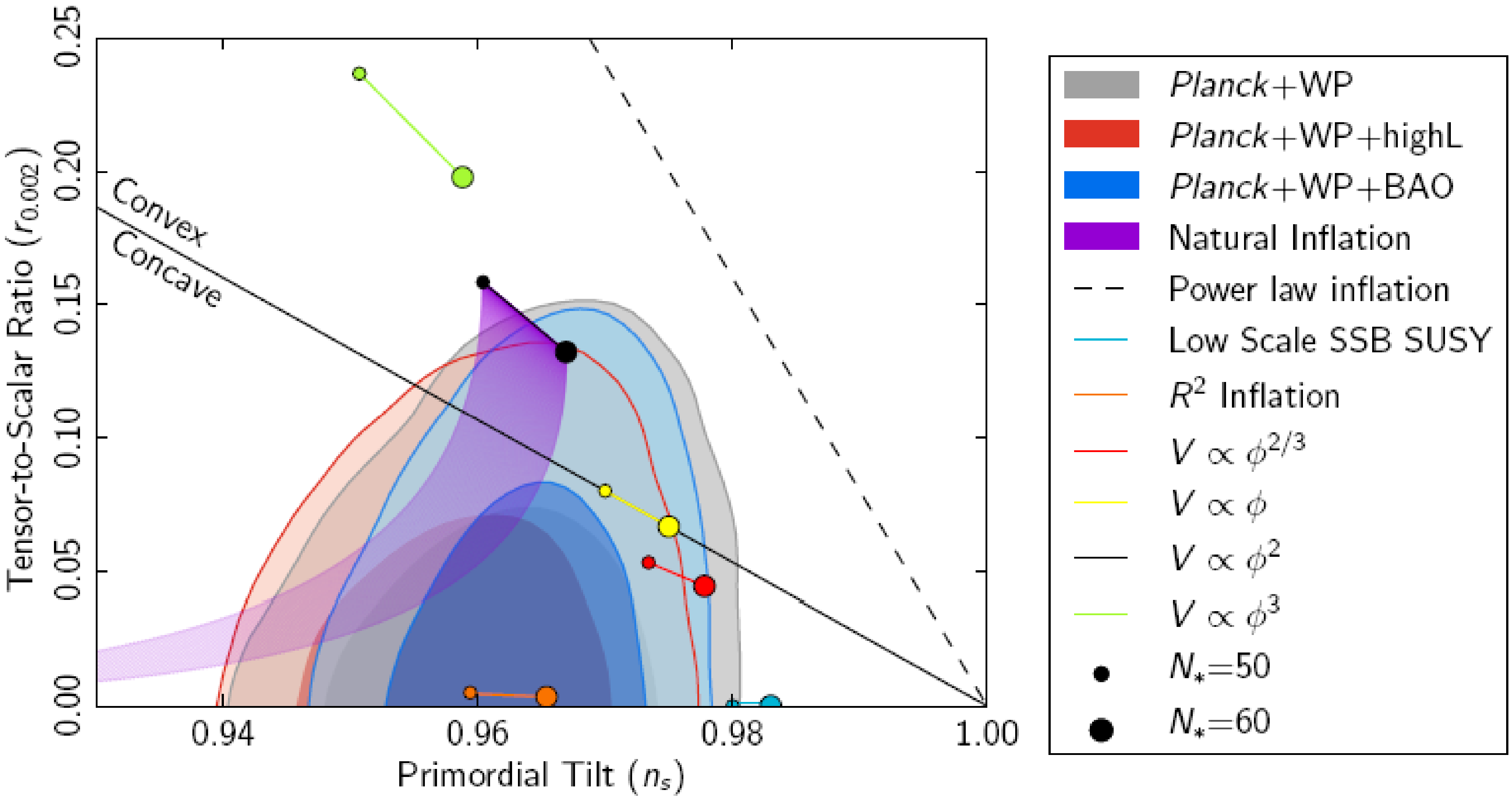


Fig. 1. Marginalized joint 68% and 95% CL regions for n_s and $r_{0.002}$ from *Planck* in combination with other data sets compared to the theoretical predictions of selected inflationary models.

$$V(\phi) = \Lambda^4 \left[1 + \cos\left(\frac{\phi}{f}\right)\right]$$

$$V_* = \frac{3\pi^2 A_s}{2}\, r\, M_{pl}^4 = (1.94 \times 10^{16}\ \mathrm{GeV})^4 \frac{r_*}{0.12}$$

$$f \gtrsim 5\ M_{pl}.$$

Gauge-flation*

$$S=\int d^4x\sqrt{-g}\left[-\frac{R}{2}-\frac{1}{4}F^a_{\ \mu\nu}F_a^{\ \mu\nu}+\frac{\kappa}{384}(\epsilon^{\mu\nu\lambda\sigma}F^a_{\ \mu\nu}F^a_{\ \lambda\sigma})^2\right]$$

$$F^a_{\ \mu\nu}=\partial_\mu A^a_{\ \nu}-\partial_\nu A^a_{\ \mu}-g\epsilon^a_{\ bc}A^b_{\ \mu}A^c_{\ \nu} \qquad A^a_{\ \mu}=\begin{cases}\phi(t)\delta^a_i\,, & \mu=i\\ 0\,, & \mu=0\end{cases}$$

$$F^a_{\ 0i}=\dot\phi\delta^a_i\,, \qquad F^a_{\ ij}=-g\phi^2\epsilon^a_{\ ij}$$

$$\mathcal{L}_{red}=\frac{3}{2}\left(\frac{\dot\phi^2}{a^2}-\frac{g^2\phi^4}{a^4}+\kappa\frac{g^2\phi^4\dot\phi^2}{a^6}\right)$$

$$\rho=\rho_{YM}+\rho_\kappa\,, \qquad P=\frac{1}{3}\rho_{YM}-\rho_\kappa$$

$$\rho_{YM}=\frac{3}{2}\left(\frac{\dot\phi^2}{a^2}+\frac{g^2\phi^4}{a^4}\right) \qquad \rho_\kappa=\frac{3}{2}\kappa\frac{g^2\phi^4\dot\phi^2}{a^6} \qquad \epsilon=-\frac{\dot H}{H^2}=\frac{2\rho_{YM}}{\rho_{YM}+\rho_\kappa}$$

*A. Maleknejad and M. M. Sheikh-Jabbari, Phys. Rev. D **84**, 043515 (2011) [arXiv:1102.1932 [hep-ph]].

Cosmic perturbation of gauge-flation

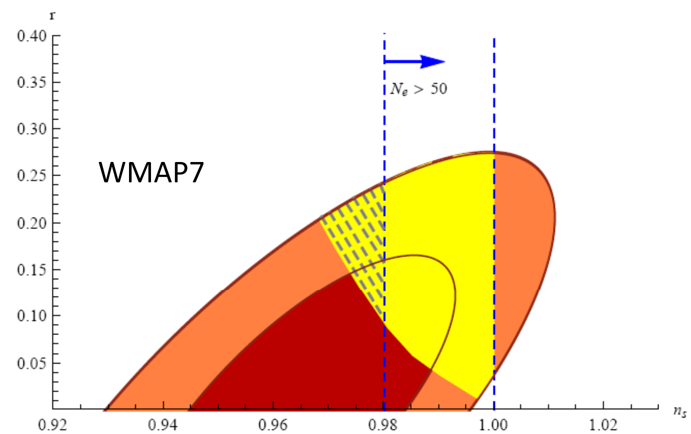
$$\delta A^a{}_0 = \delta^{ak}\partial_k \dot{Y} + \delta^a_j u^j ,$$
$$\delta A^a{}_i = \delta^a_i Q + \delta^{aj}\partial_{ij}(M + \partial_i v_j + t_{ij}) + \epsilon^a{}_i{}^j (g\phi \partial_j P + w_j)$$

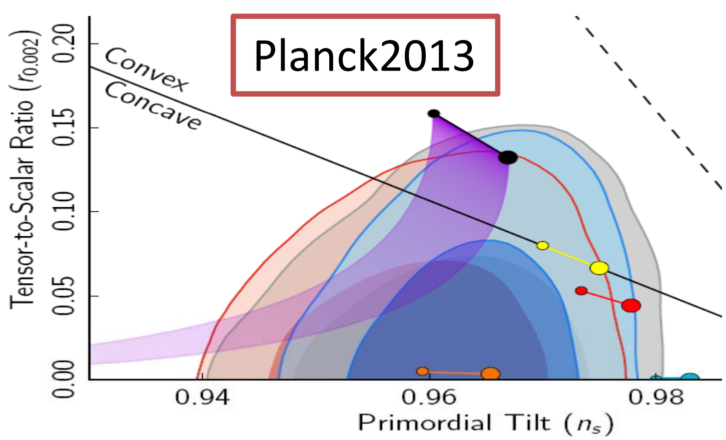
$$ds^2 = -(1+2A)dt^2 + 2a(\partial_i B - S_i)dx^i dt$$
$$+ a^2 \left((1-2C)\delta_{ij} + 2\partial_{ij}E + 2\partial_{(i}W_{j)} + h_{ij}\right) dx^i dx^j$$

Among 12 gauge field perturbations and 10 metric perturbations one scalar and one vector mode of the gauge field, and two scalars and one vector of the metric modes are gauge degrees of freedom.

Hence we find five gauge-invariant scalar, three mass-less vector and two mass-less tensor modes

Power spectrum of curvature perturbations	$\mathcal{P}_{\mathcal{R}}$	$\frac{1}{8\pi^2\epsilon}\left(\frac{H}{M_{\rm pl}}\right)^2$
Spectral Tilt	$n_s - 1$	$-2(\epsilon - \eta)$





Chromo-natural inflation*

Integrating out the scalar field → Gauge-flation

$$\mathcal{L} = \sqrt{-g}\left[-\frac{R}{2} - \frac{1}{4}F^a_{\mu\nu}F_a^{\mu\nu} - \frac{1}{2}(\partial\mathcal{X})^2 - \mu^4\left(1+\cos\left(\frac{\mathcal{X}}{f}\right)\right) - \frac{\lambda}{8f}\mathcal{X}F^a_{\mu\nu}\tilde{F}_a^{\mu\nu}\right]$$

$$A^a_0 = 0, \quad A^a_i = \psi(t)\,a(t)\,\delta^a_i$$

$$F_{0i} = \partial_t(\psi(t)\,a(t))\delta^a_i, \qquad F^a_{ij} = -\tilde{g}f^a_{ij}(\psi(t)\,a(t))^2$$

$$\mathcal{L}_m = a^3\left[\frac{3}{2}\frac{1}{a^2}\left(\frac{\partial(\psi a)}{\partial t}\right)^2 - \frac{3}{2}\tilde{g}^2\psi^4 + \frac{1}{2}\dot{\mathcal{X}}^2 - \mu^4\left(1+\cos\left(\frac{\mathcal{X}}{f}\right)\right) - 3\tilde{g}\frac{\lambda}{f}\mathcal{X}\frac{\psi^2}{a}\frac{\partial(\psi a)}{\partial t}\right]$$

$$\ddot{\mathcal{X}} + 3H\dot{\mathcal{X}} - \frac{\mu^4}{f}\sin\left(\frac{\mathcal{X}}{f}\right) = -3\tilde{g}\frac{\lambda}{f}\psi^2\left(\dot{\psi} + H\psi\right)$$

$$\ddot{\psi} + 3H\dot{\psi} + (\dot{H} + 2H^2)\psi + 2\tilde{g}^2\psi^3 = \tilde{g}\frac{\lambda}{f}\psi^2\dot{\mathcal{X}}$$

$$\dot{\psi} = -H\frac{\psi(2f^2H^2 + 2\tilde{g}^2f^2\psi^2 + \tilde{g}^2\lambda^2\psi^4)}{(3f^2H^2 + \tilde{g}^2\lambda^2\psi^4)} + \frac{\tilde{g}\lambda\mu^4\psi^2\sin(\mathcal{X}/f)}{3\,(3f^2H^2 + \tilde{g}^2\lambda^2\psi^4)}.$$

$$H\dot{\psi} \simeq -H^2\psi + \frac{\mu^4\sin(\mathcal{X}/f)}{3\tilde{g}\lambda}\frac{H}{\psi^2}$$

$$V_{\rm eff}(\psi) = H^2\frac{\psi^2}{2} + \frac{\mu^4\sin(\mathcal{X}/f)}{3\tilde{g}\lambda}\frac{H}{\psi}$$

$$\dot{\psi} \simeq 0$$

$$\psi_{\rm min} \approx \left(\frac{\mu^4\sin(\mathcal{X}/f)}{3\tilde{g}\lambda H}\right)^{1/3}$$

$f < M_{\rm pl}$ — **a flatter potential**

*P. Adshead and M. Wyman, Phys. Rev. Lett **108**, 261302 (2012) [arXiv:1202.2366 [hep-th]]

$$\mathcal{L} = \sqrt{-g}\left[-\frac{R}{2} - \frac{1}{4}F^a_{\mu\nu}F^{\mu\nu}_a - \frac{1}{2}(\partial\mathcal{X})^2 - \mu^4\left(1+\cos\left(\frac{\mathcal{X}}{f}\right)\right) - \frac{\lambda}{8f}\mathcal{X}F^a_{\mu\nu}\tilde{F}^{\mu\nu}_a\right]$$

↓ Integrating out the gauge field

$$S_\chi = S_{\mathrm{SRHS}} = \int \mathrm{d}^4x\sqrt{-g}\left[\frac{M_{\mathrm{Pl}}^2}{2}R - \frac{1}{2}(\partial\chi)^2 + \frac{1}{4\Lambda^4}(\partial\chi)^4 - \mu^4\left(1+\cos\left(\frac{\chi}{f}\right)\right)\right]$$

$$\Lambda^4 = 8f^4g^2/\lambda^4$$

$$\ddot{\chi}\left(1+\frac{3\dot{\chi}^2}{\Lambda^4}\right) + 3H\dot{\chi}\left(1+\frac{\dot{\chi}^2}{\Lambda^4}\right) - \frac{\mu^4}{f}\sin\left(\frac{\chi}{f}\right) = 0$$

$$3H\dot{\chi}\left(1+\frac{\dot{\chi}^2}{\Lambda^4}\right) - \frac{\mu^4}{f}\sin\left(\frac{\chi}{f}\right) = 0$$

E. Dimastrogiovanni, M. Fasiello and A. J. Tolley, JCAP **1302**, 046 (2013) [arXiv:1211.1396 [hep-th]]

*The parameter space of chromo-natural inflation

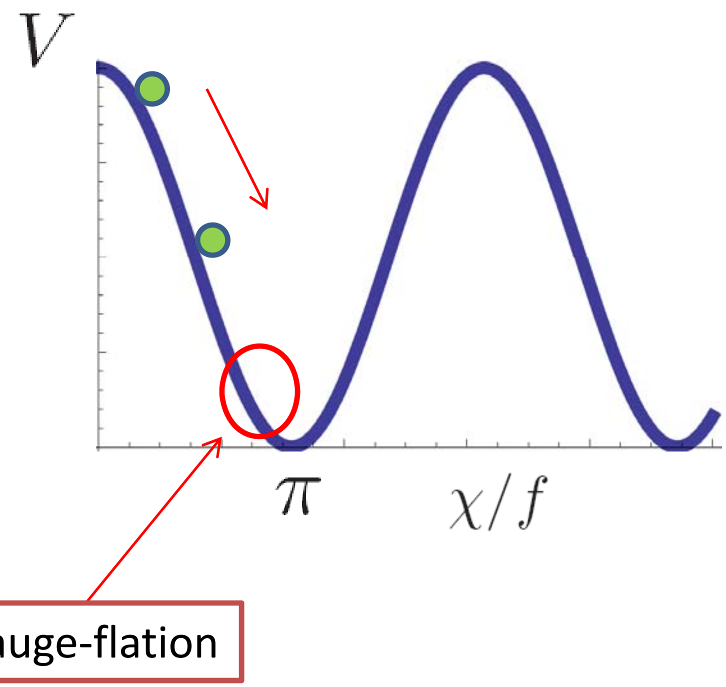
$$S = \int d^4x\sqrt{-\mathrm{g}}\left(-\frac{R}{2} - \frac{1}{4}F^a{}_{\mu\nu}F_a{}^{\mu\nu} - \frac{1}{2}(\partial_\mu\chi)^2 - \mu^4\left(1+\cos\left(\frac{\chi}{f}\right)\right) + \frac{\lambda}{8f}\chi(F\wedge F)\right),$$

$$F^a{}_{\mu\nu} = \partial_\mu A^a{}_\nu - \partial_\nu A^a{}_\mu - g\epsilon^a{}_{bc}A^a{}_\mu A^b{}_\nu$$

$$\Upsilon \equiv \left(\frac{2\lambda\mu^4}{3g^2}\right)^{\frac{1}{3}}$$

$$N_e \simeq \frac{3}{2}\Upsilon\lambda\int_{y_0}^{1}\frac{y}{\Upsilon^2(1-y^3)+y}dy$$

$$y_0 = \sin\left(\frac{\chi_0}{2f}\right)$$



*A. Maleknejad and M. Zarei, “Slow-roll trajectories in Chromo-Natural and Gauge-flation Models, an exhaustive analysis” accepted by PRD, arXiv:1212.6760 [hep-th]

$$S = \int d^4x\sqrt{-\mathrm{g}}\Big(-\frac{R}{2} - \frac{1}{4}F^a_{\ \mu\nu}F_a^{\ \mu\nu} - \frac{1}{2}(\partial_\mu\chi)^2 - \mu^4\big(1+\cos(\frac{\chi}{f})\big) + \frac{\lambda}{8f}\chi(F\wedge F)\Big),$$

$$\Upsilon \equiv \left(\frac{2\lambda\mu^4}{3g^2}\right)^{\frac{1}{3}}$$

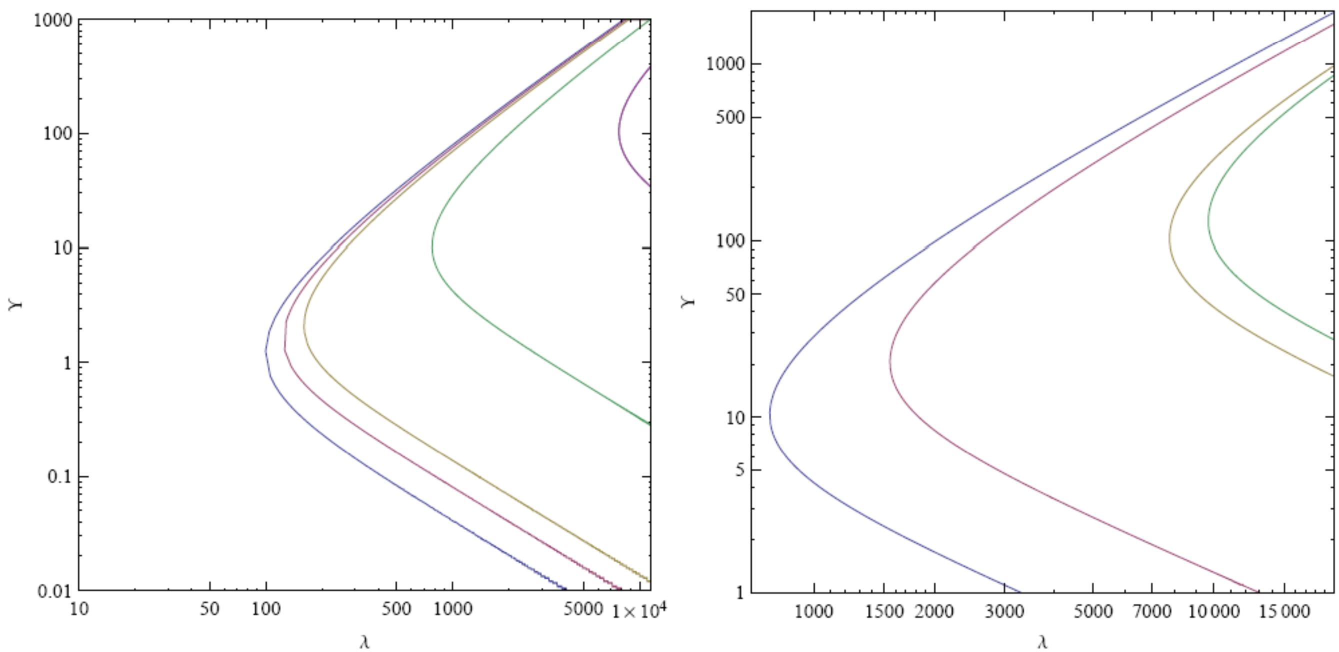
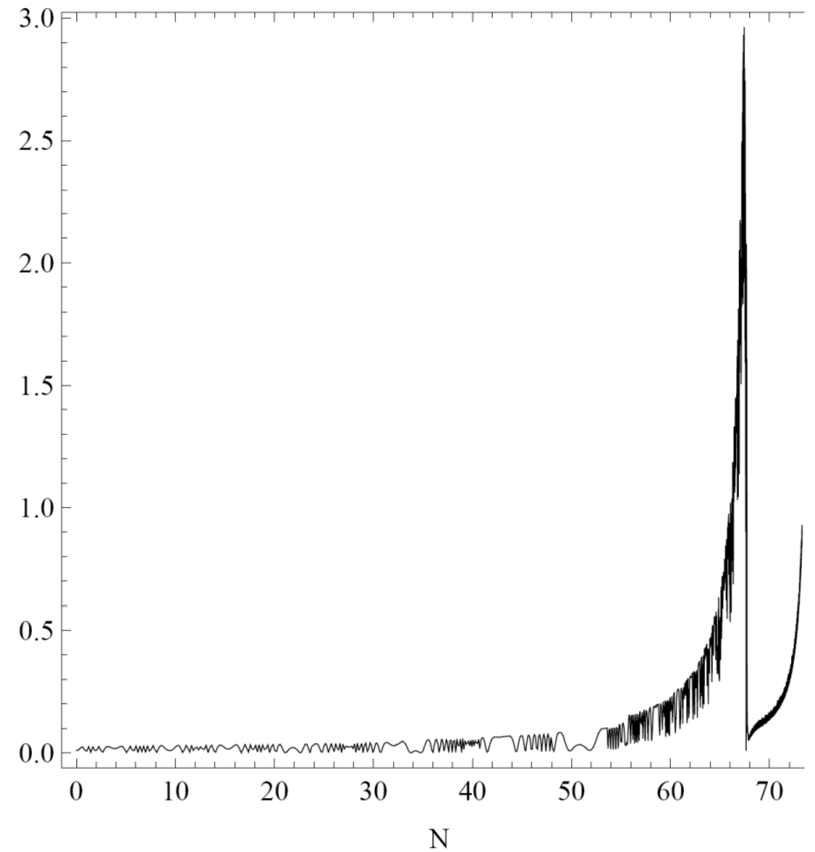
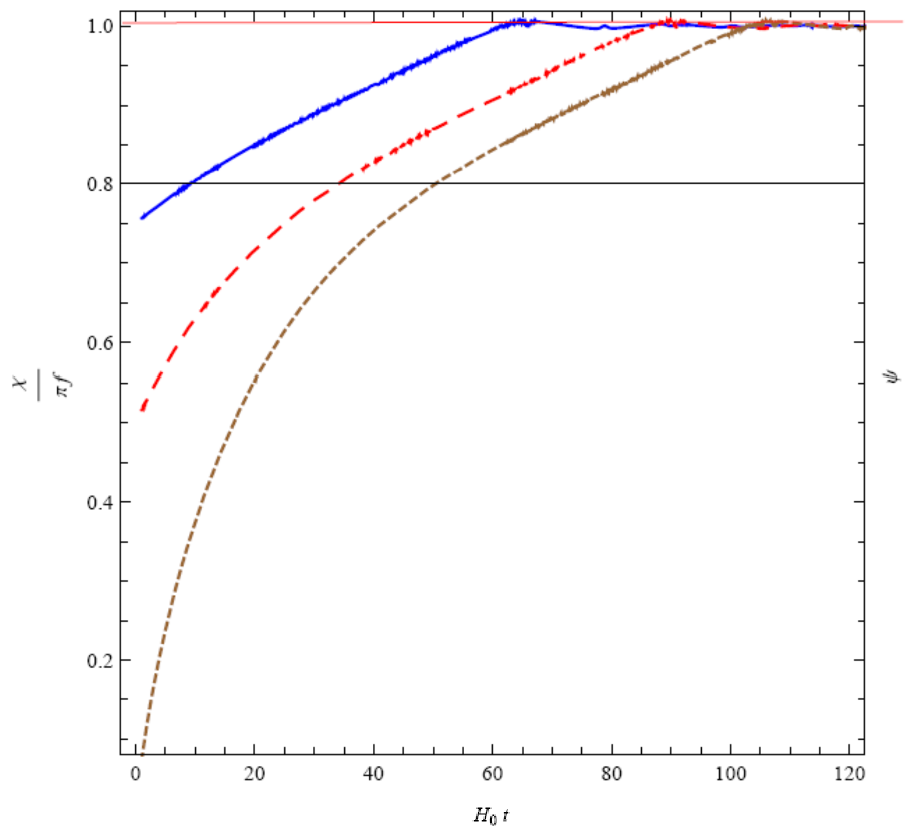


FIG. 2. These figures represent the allowed regions of parameter space in the $\lambda - \Upsilon$ plane for $N_e = 60$. The curves on the Left figure correspond to various initial values of axion field χ_0; from left to right they correspond to $\frac{\chi_0}{f} = 10^{-2}\pi,\ \pi/3,\ \pi/2,\ 0.9\pi$ and 0.99π. The Right plot shows the region on the parameter space which chromo-natural model is effectively equal to the gauge-flation, and the curves from left to right corresponds to $\frac{\chi_0}{f} = 0.9\pi,\ 0.95\pi\ ,0.99\pi$ and 0.992π. The "outer region of the curves correspond to $N_e < 60$ and are hence excluded. Note that λ is typically (e.g. the minimum value of λ) of order 10^2 for the "small axion values" (in the left figure), while it is of order 10^4 for the large axion values, in the right figure. The plots imply that $\log(\frac{\lambda}{\lambda_{min}}) \geq (\log(\frac{\Upsilon_{min}}{\Upsilon}))^2$, where $\lambda_{min} = \frac{4\times 60}{\pi - \chi_0/f}$ and $\Upsilon_{min}(\frac{\chi_0}{f}) \sim 10^{-2}\lambda_{min}(\frac{\chi_0}{f})$.

*A. Maleknejad and M. Zarei, "Slow-roll trajectories in Chromo-Natural and Gauge-flation Models, an exhaustive analysis" accepted by PRD, arXiv:1212.6760 [hep-th]

Two stage for inflation in chromo-natural model:





*A. Maleknejad and M. Zarei, "Slow-roll trajectories in Chromo-Natural and Gauge-flation Models, an exhaustive analysis" accepted by PRD, arXiv:1212.6760 [hep-th]

*Perturbations of chromo-natural inflation

$$S = \int d^4x\sqrt{-\mathrm{g}}(-\frac{R}{2} - \frac{1}{4}F^a{}_{\mu\nu}F_a{}^{\mu\nu} - \frac{1}{2}(\partial_\mu\chi)^2 -\mu^4(1+\cos(\frac{\chi}{f})) + \frac{\lambda}{8f}\chi(F\wedge F)),$$

$$A_0 = 0, \quad A_i = \phi\delta_i^a J_a = a\psi\delta_i^a J_a$$

$$F_{0i} = \partial_\tau\phi\delta^a{}_i J^a, \quad F_{ij} = g\phi^2 f_{ij}^a J^a$$

$$\delta A_\mu = \Psi_\mu$$

$$ds^2 = -N^2 d\tau^2 + \tilde{h}_{ij}(dx^i + N^i d\tau)(dx^j + N^j d\tau)$$

$$\delta^2\mathcal{L}_{\mathrm{YM}} = \mathrm{Tr}\left[(\partial_i\Psi_0 - ig\phi\,[J_i,\Psi_0])^2\right] - 4ig\partial_\tau\phi\mathrm{Tr}\left[\Psi_0\,[\Psi_i, J_i]\right] - 2\mathrm{Tr}\left[\Psi_0\partial_\tau(\partial_i\Psi_i - ig\phi\,[J_i,\Psi_i])\right]$$
$$+ \mathrm{Tr}\left[\partial_\tau\Psi_i\partial_\tau\Psi_i\right] - \mathrm{Tr}\left[\partial_j\Psi_i\partial_j\Psi_i - \partial_i\Psi_j\partial_j\Psi_i\right] + 2g\phi\epsilon_{ijk}\mathrm{Tr}\left[\partial_i\Psi_j\Omega_k\right]$$
$$- g^2\phi^2\mathrm{Tr}\left[(\Omega_k - \Psi_k)\Omega_k\right],$$

$$\Omega_i = i\epsilon_{ijk}\,[J_j,\Psi_k]$$

$$\delta^2\mathcal{L}_{\mathrm{CS}} = 2g\phi^2\frac{\lambda}{f}\delta\mathcal{X}\mathrm{Tr}\left[\partial_i\Psi_0 J_i\right] - \frac{\lambda}{f}\partial_\tau\mathcal{X}\mathrm{Tr}\left[g\phi\Psi_i\Omega_i - \epsilon_{ijk}\Psi_i\partial_j\Psi_k\right] + 2g\phi^2\frac{\lambda}{f}\partial_\tau\delta\mathcal{X}\mathrm{Tr}\left[\Psi_i J_i\right]$$
$$- 2\frac{\lambda}{f}\epsilon_{ijk}\partial_\tau\phi\delta\mathcal{X}\mathrm{Tr}\left[J_i\partial_j\Psi_k\right].$$

$$\delta^2\mathcal{L}_{\mathcal{X}} = \frac{1}{2}a^2(\partial_\tau\delta\mathcal{X})^2 - \frac{1}{2}a^2(\partial_i\delta\mathcal{X})^2 - a^4\frac{1}{2}\frac{d^2V}{d\mathcal{X}^2}\delta\mathcal{X}^2.$$

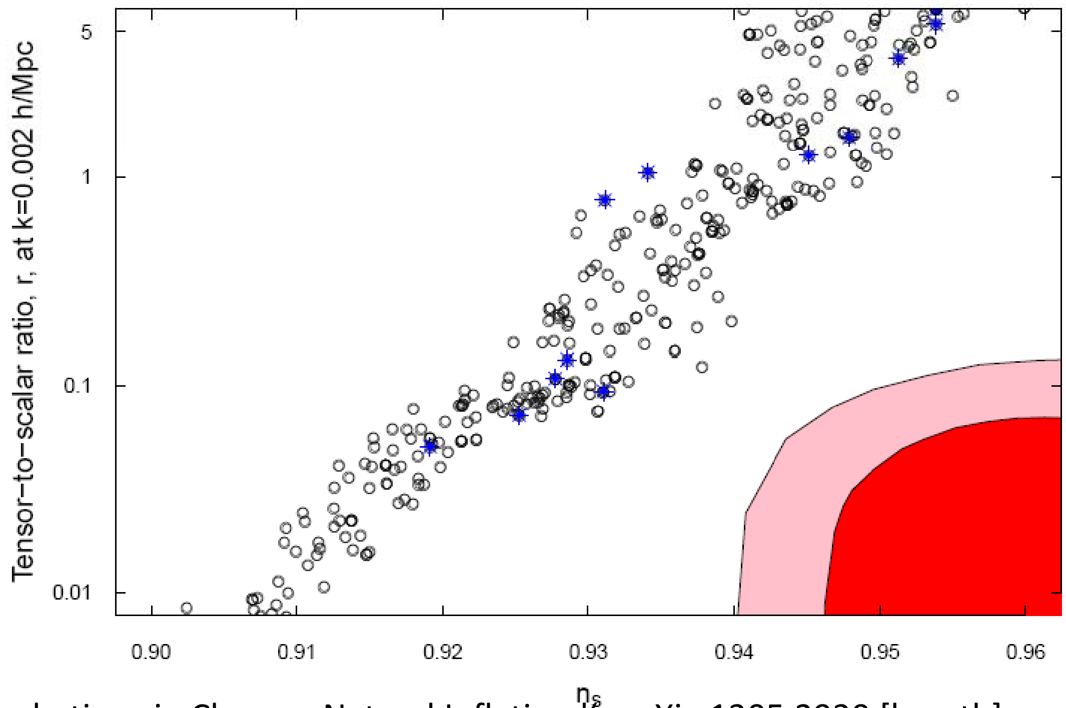
*P. Adshead, E. Martinec and M. Wyman, ``Perturbations in Chromo-Natural Inflation,'' arXiv:1305.2930 [hep-th]

$$\mathcal{R} \simeq \frac{1}{\sqrt{2k^3}} \cdot \frac{H}{\sqrt{2\epsilon_H}} \cdot \frac{m_\psi \boldsymbol{\varphi}(0)}{(1+m_\psi^2)^{1/2}}$$

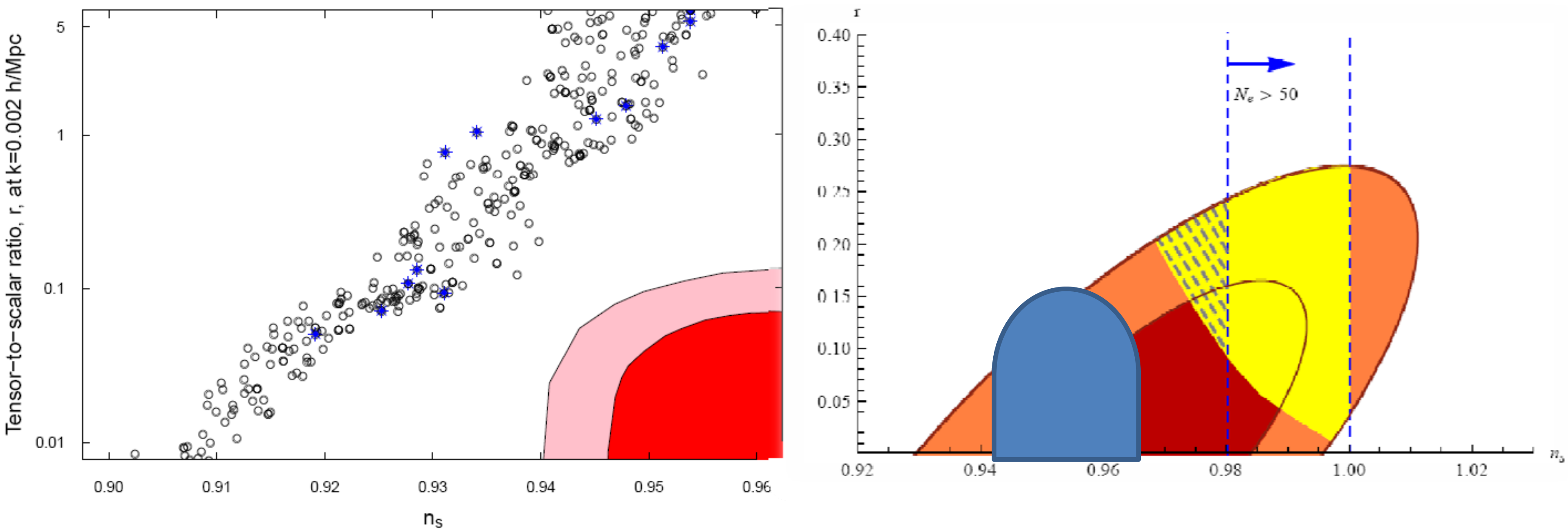
$$\langle \mathcal{R}_{\mathbf{k}} \mathcal{R}_{\mathbf{k}'} \rangle = (2\pi)^3 \delta^3(\mathbf{k}+\mathbf{k}') \frac{2\pi^2}{k^3} \Delta^2_{\mathcal{R}}(k)$$

$$n_s - 1 \simeq -2\epsilon_H + \eta_H + 2\frac{d \log \boldsymbol{\varphi}(0)}{dN}$$

$$r_- \simeq \frac{8(1+m_\psi^2)\epsilon_H}{m_\psi^2 \boldsymbol{\varphi}(0)^2}$$



*P. Adshead, E. Martinec and M. Wyman, ``Perturbations in Chromo-Natural Inflation,'' arXiv:1305.2930 [hep-th]



Tensor-to-scalar ratio, r, at k=0.002 h/Mpc
5
1
0.1
0.01
0.90
0.91
0.92
0.93
0.94
0.95
0.96
n_s
r
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
$N_e > 50$
0.92
0.94
0.96
0.98
1.00
1.02
n_s

Conclusion 1: Non-Abelian group does not work!

*Charge scalar inflation model

$$S = \int d^4x \sqrt{-g} \left[\frac{M_P^2}{2} R - \frac{1}{2} D_\mu \phi \, D^\mu \bar{\phi} - \frac{f^2(\phi)}{4} F_{\mu\nu} F^{\mu\nu} - V(\phi, \bar{\phi}) \right]$$

$$D_\mu \phi = \partial_\mu \phi + i \mathbf{e} \, \phi \, A_\mu \qquad F_{\mu\nu} = \nabla_\mu A_\nu - \nabla_\nu A_\mu = \partial_\mu A_\nu - \partial_\nu A_\mu$$

anomaly → $A_\mu = (0, A(t), 0, 0)$

$$ds^2 = -dt^2 + e^{2\alpha(t)} (e^{-4\sigma(t)} dx^2 + e^{2\sigma(t)} (dy^2 + dz^2))$$

$$V = \frac{\lambda}{4} \left(|\phi|^2 - \frac{M^2}{\lambda} \right)^2 \equiv \frac{\lambda \mu^4}{4} (\hat{\rho}^2 - 1)^2$$ → $$f(\rho) = \left(\frac{\mu}{\rho} \right)^p = \hat{\rho}^{-p}$$

$$P_\zeta(\vec{k}) = P_0(k) \left(1 + g_* \cos^2 \theta \right)$$

g_*: 0.07 ± 0.02

*R. Emami, H. Firouzjahi, S. M. Sadegh Movahed and M. Zarei, ``Anisotropic Inflation from Charged Scalar Fields,'' JCAP **1102**, 005 (2011)

*Gauge field curvaton **model

$$S = \int d^4x\sqrt{-g}\left[\frac{M_P^2}{2}R - \frac{1}{2}D_\mu\phi\, D^\mu\bar{\phi} - \frac{f^2(\phi)}{4}F_{\mu\nu}F^{\mu\nu} - V(\phi,\bar{\phi})\right]$$

$$\mathbf{W} = \frac{f}{a}\mathbf{A} \qquad V \simeq \frac{M^4}{4\lambda M_{Pl}^2} - \frac{M^2}{2}\rho$$

- During inflation gauge field is massless and inflation is given by scalar field.
- After inflation we find a massive gauge field with three degrees of freedom.
- The energy density of gauge field is dominated in this stage.

$$\mathbf{W}'' + \mathbf{W}' + m^2 e^{4N}\mathbf{W} = 0 \;\rightarrow\; \rho_W \sim a^{-3} \;\rightarrow\; \text{Isotropic expansion}$$

Quantum perturbations of gauge field after inflation →

$$\mathcal{P}_\zeta = N_W^2\left[\mathcal{P}_+ + (\mathcal{P}_{||} - \mathcal{P}_+)(\hat{\mathbf{N}}_W\cdot\hat{\boldsymbol{k}})^2\right]$$

$$g_* = 1 - \frac{\mathcal{P}_{||}}{\mathcal{P}_+}$$

*H. Firouzjahi, M. Zarei, Statistical Anisotropy from Gauge Field Curvaton, Work In Progress.

H. Firouzjahi, A. Green, K. Malik and M. Zarei, ``The Effect of Curvaton Decay on the Primordial Power Spectrum,'' Phys. Rev. D **87, 103502 (2013) arXiv:1209.2652 [astro-ph.CO].

Conclusion 2: Abelian group leads to scalar perturbation an preferred direction

$$P_\zeta(\vec{k}) = P_0(k)\left(1 + g_* \cos^2\theta\right)$$

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