THERMAL and MAGNETIC EFFECTS on the WARM INFLATION SCENARIO

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PRIMORDIAL MAGNETIC FIELDS

INFLATION

Can produce large-scale cosmological magnetic fields

- Quantum fluctuations excite Maxwell field modes on scales $\lambda \leq H^{-1}$

- The inflationary expansion stretches these wavelengths to scales $\geq H^{-1}$, and fluctuations freeze-out (as classical electromagnetic waves).

- These initially static electric and magnetic fields can lead to current supported magnetic fields once the modes reenter the horizon

PRIMORDIAL MAGNETIC FIELDS

Nevertheless, magnetic fluctuations that have survived a period of de Sitter expansion are typically very weak

Since magnetic fields are conformally coupled to gravity

$$\rho_B \propto a^{-4}$$

The conformal invariance of Maxwell equations is broken in models in which the electromagnetic field is gravitationally coupled (Turner and Widrow, 1988)

PRIMORDIAL MAGNETIC FIELDS

- Non-abelian gauge theories may have a ferromagnetic vacuum (Savvidy vacuum), with a non zero magnetic field, even at high temperarures (Savviddy, 1977; Enqvist and Olesen, 1994)

- On anoher hand, upper limits on inflation energy scale may be established from cosmic magnetic fields (Fujita and Mukohyama, 2012)

WARM INFLATION

A model for inflation where thermal equilibrium is maintained, with no need of a large scale reheating. It requires a dissipative component of sufficient size (Berera & Fang, 1995; Berera, 1995).

$$\ddot{\phi} + \left(3H + \Gamma\right)\dot{\phi} + V_{T,\phi} = 0$$

Starting from the finite temperature one-loop Coleman-Weinberg potential for SU(5), they find a slow-roll solution for “unexceptional values” of the coupling constant.

WARM INFLATION

Particle models with global SUSY, with dissipative effects of particle production (Hall and Moss, 2004)

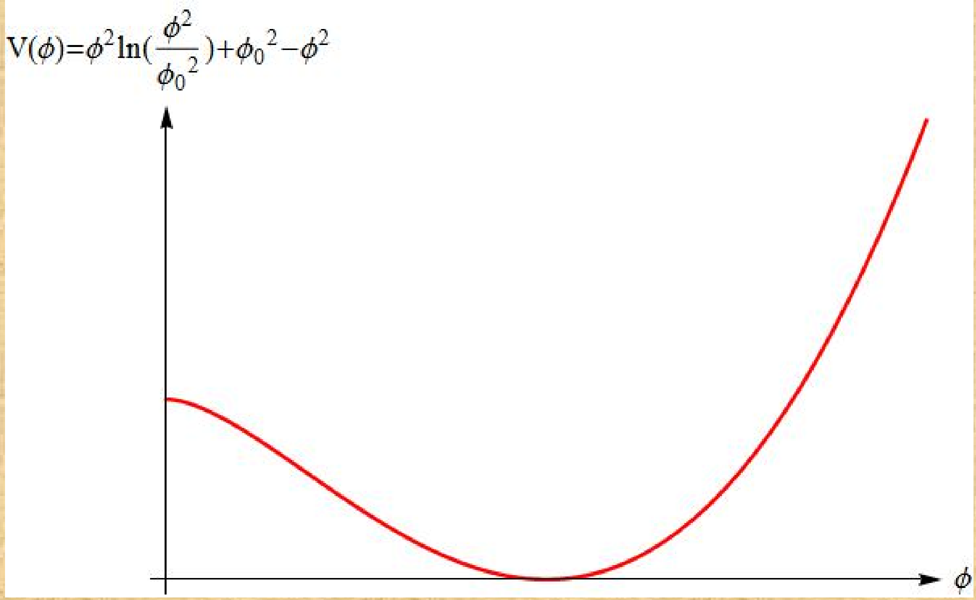
In a two stage reheating process, $\phi \rightarrow \chi \rightarrow \tilde{y}\ \tilde{y}$

the radiative corrections to the inflaton potential are small due to fermion-boson cancellation and thermal contribution to the inflaton mass from heavy sector loops are Boltzmann supressed

The flatness of the potential is not spoiled.

In fact, a lot of work has been done about constructing supersymmetric inflation without fine-tuning (e.g. Lyth and Riotto, 1999; Dvali, Shafi and Shaefer, 1994)

WARM INFLATION



They start from a new-inflation type potential, with quantum corrections at one loop

$$V(\phi) = \frac{1}{2} g^2 M_S^2 \left[\phi^2 \ln\left(\frac{\phi^2}{\phi_0^2} \right) + \phi_0^2 - \phi^2 \right]$$

and study thermal effects.

WARM INFLATION

Assumptions

- One superfield is coupled to the inflaton (becomes very heavy) and the other one has a vanishing coupling (light sector)
- Soft SUSY breaking in the heavy sector
- Light radiation thermalises

THERMAL CONTRIBUTION

$$\mathcal{L}_S = g^2\left|\Lambda^2 - |\chi|^2\right|^2 + 4g^2|\varphi|^2|\chi|^2 + 4h^2|y|^2|\chi|^2 + h^2|y|^4$$
$$+ 2gh\left(y^2\varphi^\dagger\chi^\dagger + y^{\dagger 2}\varphi\chi\right)$$

with $\phi = \sqrt{2}\,\mathrm{Re}\,\varphi$

$$\mathcal{L}_f = g\left(\varphi\,\overline{\psi}_\chi P_L \psi_\chi + \varphi^\dagger\,\overline{\psi}_\chi P_R \psi_\chi\right) + h\left(\chi\,\overline{\psi}_y P_L \psi_y + \chi^\dagger\,\overline{\psi}_y P_R \psi_y\right)$$
$$+ 2g\left(\chi\,\overline{\psi}_\chi P_L \psi_\varphi + \chi^\dagger\,\overline{\psi}_\chi P_R \psi_\varphi\right) + 2h\left(y\,\overline{\psi}_y P_L \psi_\chi + y^\dagger\,\overline{\psi}_y P_R \psi_\chi\right)$$

Feynman diagrams:

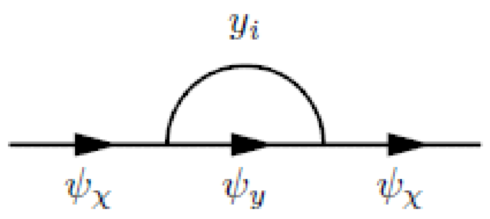
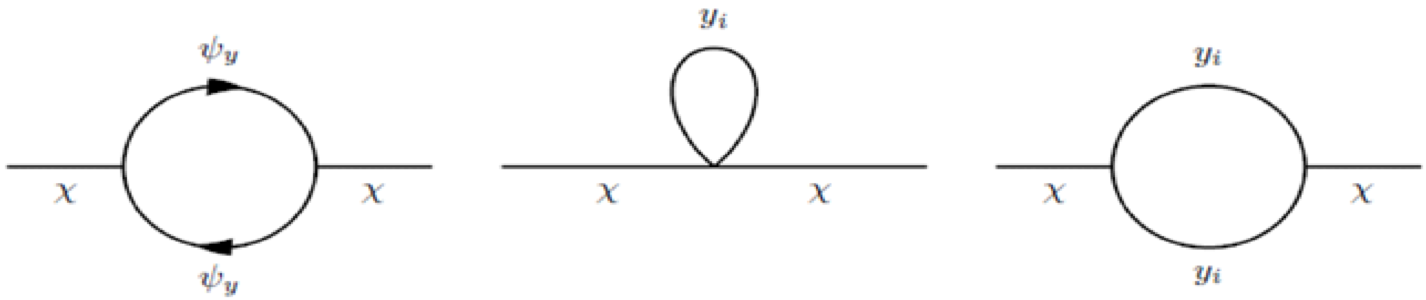


Diagram for the fermionic self energy



(a) (b) (c)

Diagrams for the bosonic self energy

THERMAL CONTRIBUTION

Self energies, in the HTL limit:

$$\Sigma(P) = -4h^2T\sum_n \int \frac{d^3k}{(2\pi)^3}(\not K - \not P)\Delta(K)\tilde{\Delta}(P-K)$$

where *Δ(K)*≈*K*$^{-2}$, $k^0=2n\pi T$ for bosons and $k^0=(2n+1)\pi T$ for fermions (denoted by a tilde)

$$m_f^2 \equiv \Sigma \approx \frac{h^2T^2}{2}$$

$$\Pi(P)_a = h^2T\sum_n \int \frac{d^3k}{(2\pi)^3} Tr[\not K(\not K - \not P)]\tilde{\Delta}(K)\tilde{\Delta}(K-P)$$

$$\Pi(P)_a = -4h^2T\sum_n \int \frac{d^3k}{(2\pi)^3} K^2\tilde{\Delta}(K)\tilde{\Delta}(K-P) \approx \frac{1}{6}h^2T^2$$

THERMAL CONTRIBUTION

$$\Pi(P)_b = 4h^2T\sum_n \int \frac{d^3k}{(2\pi)^3}\Delta(K) \approx \frac{1}{3}h^2T^2$$

$$\Pi(P)_c = 4g^2\phi^2T\sum_n \int \frac{d^3k}{(2\pi)^3}\Delta(K)\Delta(K-P) \approx \frac{1}{2\pi^2}g^2h^2\phi^2 \log\frac{T^2}{p^2}$$

$$m_b^2 \equiv \Pi_a + \Pi_b \approx \frac{h^2T^2}{2}$$

MAGNETIC CONTRIBUTION

Propagators with magnetic fields, with Shwinger proper time method:

$$iD_B(k) = \int_0^\infty \frac{ds}{\cos eBs} \times \exp\left\{ is\left(k_\parallel^2 - k_\perp^2 \frac{\tan eBs}{eBs} - m_b^2 + i\varepsilon \right) \right\}$$

$$iS_B(k) = \int_0^\infty \frac{ds}{\cos eBs} \times \exp\left\{ is\left(k_\parallel^2 - k_\perp^2 \frac{\tan eBs}{eBs} - m_f^2 + i\varepsilon \right) \right\}$$

$$\times \left[\left(m_f + \not{k}_\parallel \right) e^{ieBs\sigma_3} - \frac{\not{k}_\perp}{\cos eBs} \right]$$

MAGNETIC CONTRIBUTION

We work with a constant magnetic field along the z axis, so

$$k_{||}^2=k_0^2-k_3^2,\; k_{\perp}^2=k_1^2+k_2^2$$

and with the hierarchy of scales:

$$eB << m^2 << T^2$$

where *m* is the mass of the fields inside the loop.

MAGNETIC CONTRIBUTION

Landau levels:

$$iD_B(k) = 2i\sum_{l=0}^{\infty} \frac{(-1)^l L_l\left(\frac{2k_\perp^2}{eB}\right) e^{-\frac{k_\perp^2}{eB}}}{k_\parallel^2 - (2l+1)eB - m_b^2 + i\varepsilon}$$

$$iS_B(k) = i\sum_{l=0}^{\infty} \frac{d_l\left(\frac{k_\perp^2}{eB}\right) D + d_l'\left(\frac{k_\perp^2}{eB}\right) \bar{D}}{k_\parallel^2 - 2leB - m_f^2 + i\varepsilon} + \frac{\not{k}_\perp}{k_\perp^2}$$

$$D = (m_f + \not{k}_\parallel) + \not{k}_\perp \frac{m_f^2 - k_\parallel^2}{k_\perp^2}$$

$$\bar{D} = \gamma_5 \not{u}\not{b}(m_f + \not{k}_\parallel)$$

MAGNETIC CONTRIBUTION

$$m_b^2(T,B) \approx \frac{h^2T^2}{2}\left(1 - \frac{2m_y}{\pi T} - \frac{1}{12\pi}\frac{(eB)^2}{m_y^3 T}\right)$$

$$m_f^2(T,B) \approx \frac{h^2T^2}{2}\left(1 - \frac{1}{3\pi}\frac{r(eB)}{m_y T} + \frac{11}{12\pi}\frac{(eB)^2}{m_y^3 T}\right)$$

Where r = ± 1 represents the two possible orientations w/r to the magnetic field

EFFECTIVE POTENTIAL preliminary results

$$V_\chi = \int \frac{d^4P}{(2\pi)^4} \ln \det\left(G^{-1}\right) - \int \frac{d^4P}{(2\pi)^4} \ln \det\left(S^{-1} S^{*-1}\right)^{-1/2}$$

$$iS^{-1} = \not{P} - m^2_{\Psi_\chi} \qquad G^{-1} = P^2 + m^2_\chi$$

$$m^2_\chi = 2g^2\phi^2 + m_b^2(T,B) + M_S^2$$

$$m^2_{\Psi_\chi} = 2g^2\phi^2 + m_f^2(T,B)$$

EFFECTIVE POTENTIAL
preliminary results

$$V_\chi = \frac{1}{32\pi^2}\left[m_\chi^4 \ln\left(\frac{m_\chi^2}{\mu^2}\right) - m_{\Psi_\chi}^4 \ln\left(\frac{m_{\Psi_\chi}^2}{\mu^2}\right)\right] + const.$$

with μ the renormalization scale

$$V(\phi, T, B) = -\frac{\pi^2}{90} g_* T^4 + V_\chi(\phi, T, B)$$

FUTURE WORK

- Analyze if the effective potential fulfills the slow-roll conditions
- Study the effect on the density fluctuations spectrum
- Explore if inflation can impose some bounds on primordial magnetic fields and vice versa