EFFECTS of PRIMORDIAL MAGNETISM on the WARM INFLATION SCENARIO

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PRIMORDIAL MAGNETIC FIELDS

INFLATION

Can produce large-scale cosmological magnetic fields

- Quantum fluctuations excite light fields 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).

- During inflation the universe is not a good conductor → the magnetic flux is not conserved

PRIMORDIAL MAGNETIC FIELDS

After reheating, the universe becomes a good conductor and the magnetic flux is conserved $a^2 B \approx \text{const}$

Since magnetic fields are conformally coupled to gravity

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

So, magnetic fields are finally too weak.

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

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

heavy boson

light fermions

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 suppressed (Hall and Moss, 2004)

The flatness of the potential is not spoiled.

WARM INFLATION

$$L_S = -g^2|\chi|^4 - 2g^2\phi^2|\chi|^2$$

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:

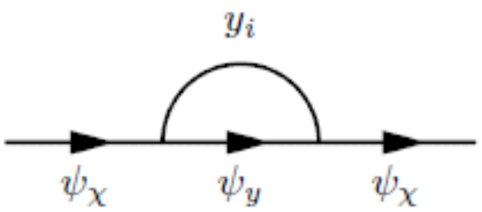
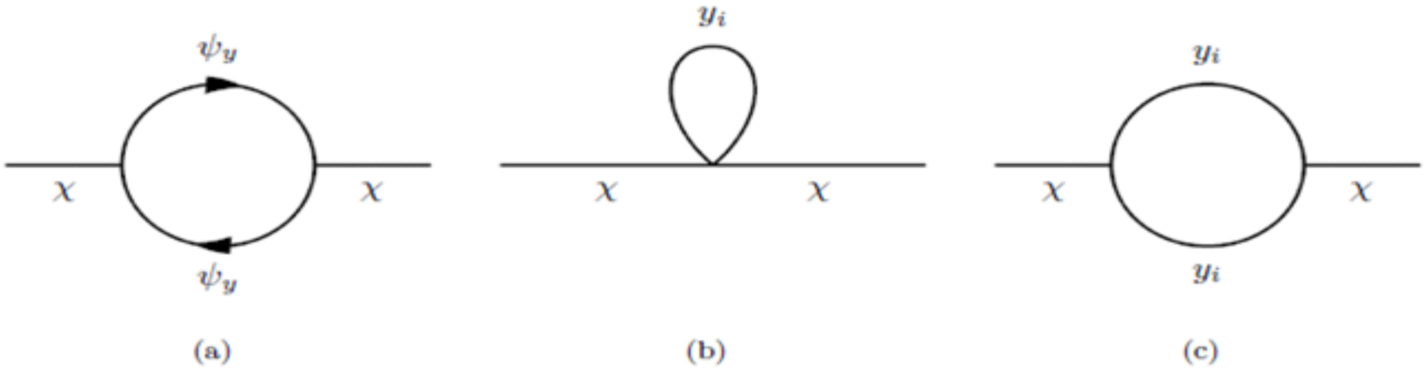


Diagram for the fermionic self energy



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

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

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

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

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's proper time method:

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

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

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

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:

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

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

$$D = \left(m_f + \not{\kappa}_\parallel\right) + \not{\kappa}_\perp \frac{m_f^2 - \kappa_\parallel^2}{\kappa_\perp^2} \qquad \overline{D} = \gamma_5 \not{u}\not{b}\left(m_f + \not{\kappa}_\parallel\right)$$

MAGNETIC CONTRIBUTION

$$m_b^2 = \frac{h^2T^2}{2}\left(1-\frac{2m_y}{T}-\frac{1}{2\pi^2T^2}\left(\ln\left(\frac{m_y^2}{(4\pi T)^2}\right)+2\gamma_E-1\right)-\frac{(eB)^2}{12\pi m_y^3T}\right)$$

$$m_f^2 = \frac{h^2T^2}{2}\left(1-\frac{2m_y}{T}-\frac{m_y^2}{2\pi^2T^2}\left(\ln\left(\frac{m_y^2}{(4\pi T)^2}\right)+2\gamma_E-1\right)-\frac{1}{3}\frac{r(eB)}{\pi m_yT}+\frac{11}{12\pi}\frac{(eB)^2}{m_y^3T}\right)$$

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

EFFECTIVE POTENTIAL preliminary results

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

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

$$m^2_\chi = 2g^2\phi^2 + m^2_b\left(T,B\right) + M^2_S$$

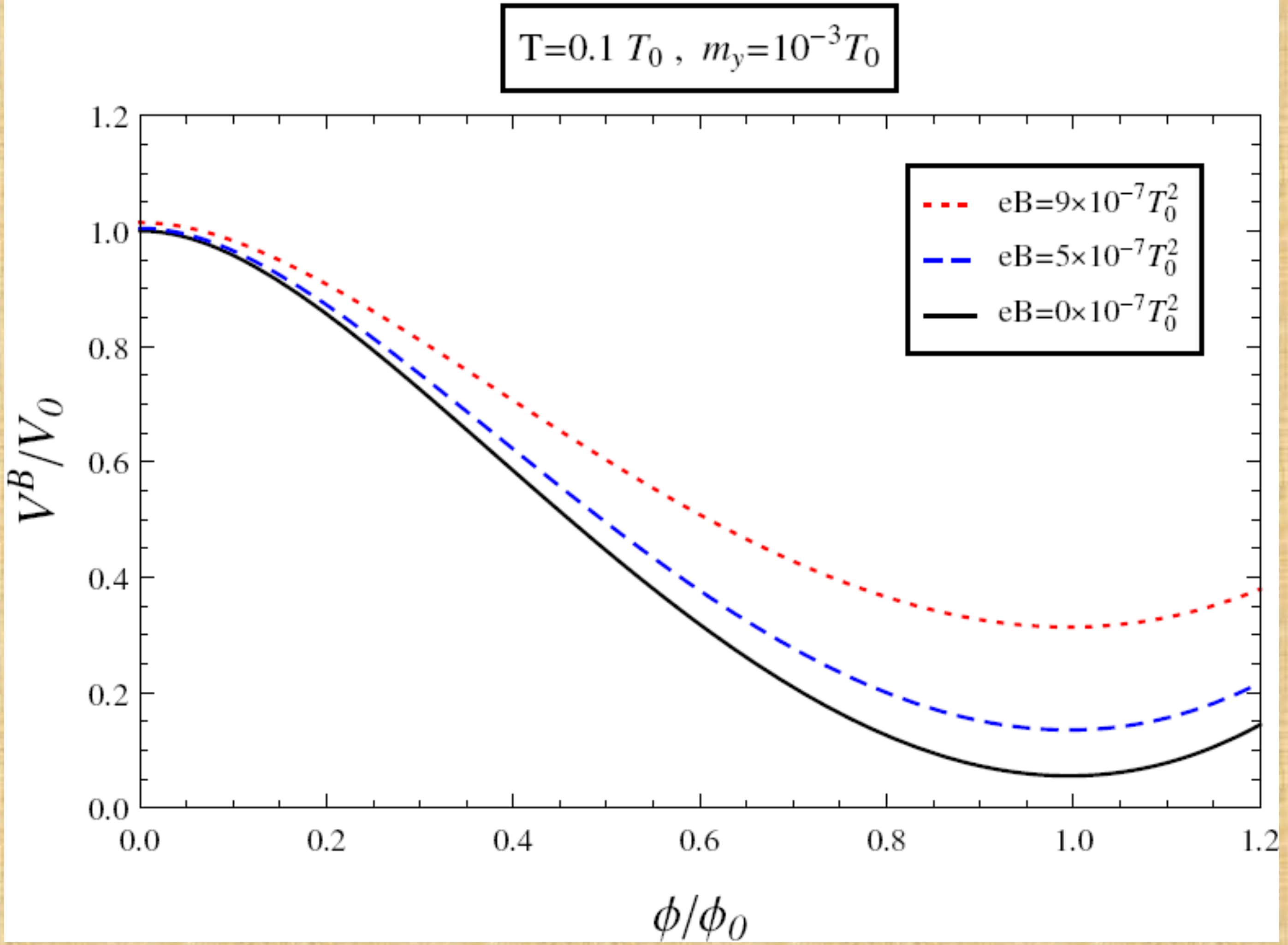
$$m^2_{\Psi_\chi} = 2g^2\phi^2 + m^2_f\left(T,B\right)$$

EFFECTIVE POTENTIAL

$$V_\chi = \frac{M_S^2}{16\pi^2}\left(2g^2\phi^2 + m_b^2(T,B)\right)\left[1 - \frac{m_f^2(T,B) - m_b^2(T,B)}{M_S^2}\right]$$
$$\left[\ln\left(\frac{2g^2\phi^2 + m_b^2(T,B)}{2g^2\phi_0^2}\right) - 1\right] + \frac{M_S^2 g^2 \phi_0^2}{8\pi^2}$$

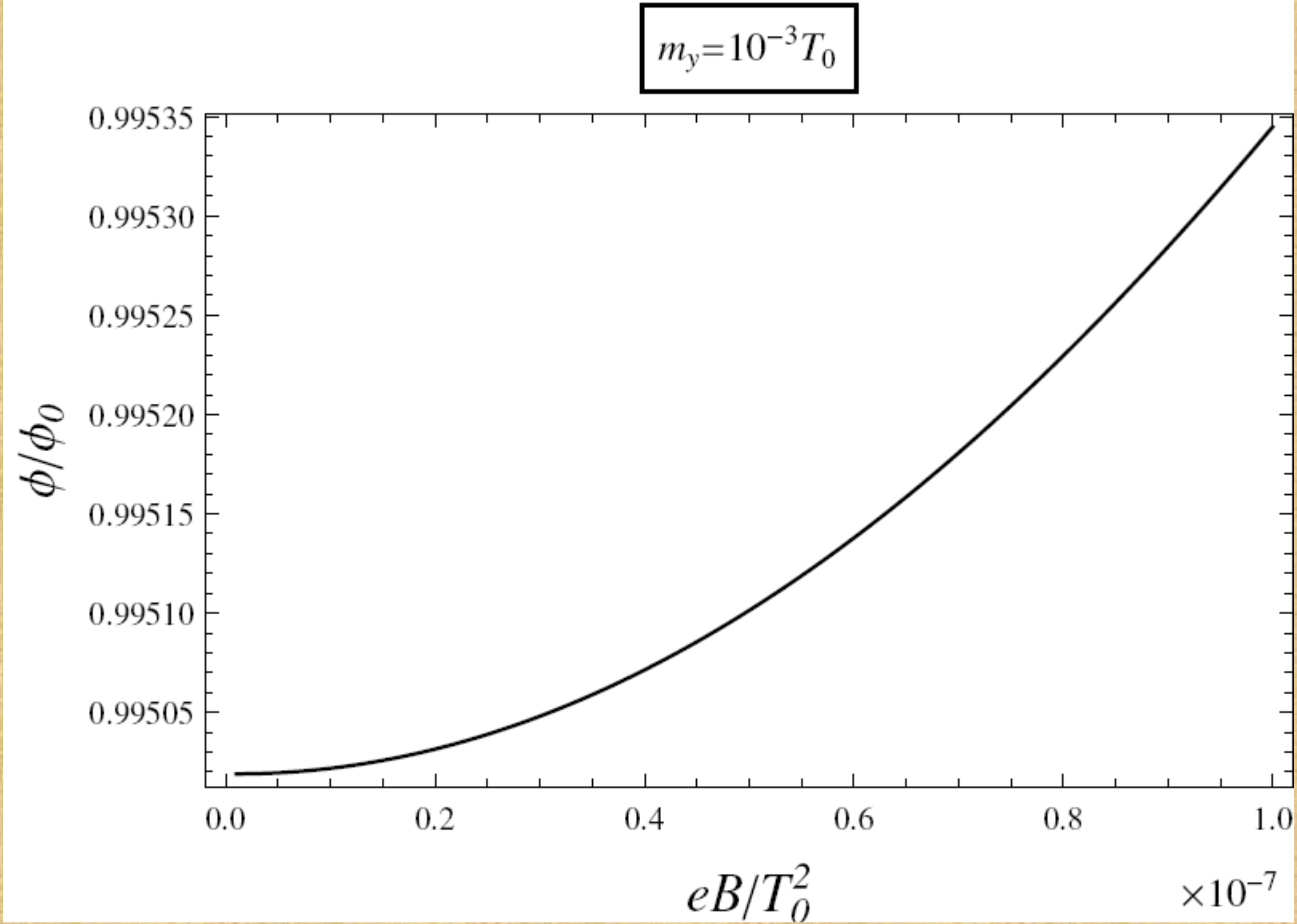
$$V(\phi,T,B) = -\frac{\pi^2}{90} g_* T^4 + V_\chi(\phi,T,B)$$

EFFECTIVE POTENTIAL



$$\frac{V^B}{V_0} = \frac{V(\phi,T,B) - V(0,T,0)}{V(0,0,0)} + 1$$

EFFECTIVE POTENTIAL



CONCLUSIONS

We have calculated magnetic contributions to the effective potential of a warm inflation model, based on global supersymmetry and a two-stage reheating process. For the employed hierarchy of scales, corrections are small and the flatness of the potential seems not to be spoiled.

In fact, magnetic terms work in the direction of making the potential less steep.

FUTURE WORK

- Develop the technique to work with stronger magnetic fields

- Analyze if the effective potential fulfills the slow-roll conditions

- Explore if inflation can impose some bounds on primordial magnetic fields and vice versa