EFFECT of PRIMORDIAL MAGNETIC FIELDS on the INFLATON POTENTIAL

Essential Cosmology for the Next Generation

Cabo San Lucas, January 2014

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PRIMORDIAL MAGNETIC FIELDS

Magnetic fields are observed up to galaxy clusters [1]

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[2] E.J. Kim et al., Nature 341, 720-723 (1989).

PRIMORDIAL MAGNETIC FIELDS

Magnetic fields are observed up to galaxy clusters [1] and superclusters [2]
and there is indirect evidence, from gamma-ray observations of blazars [3], of a pervasive intergalactic magnetic field, with a lower bound of
10^{-16} – 10^{-15} Gauss (scaled to present value)

[1] Clarke et al., Astrophys. J. 547, L111-L114; Carilli &Taylor, Ann. Rev. Astron. Astrophys. 40, 319-348 (2002);Vogt & Enßlin, Astron. Astrophys. **434**, 67 (2005).
[2] E.J. Kim et al., Nature 341, 720-723 (1989).
[3] Neronov &Vovk, Science **328**, 73 (2010); Tavecchio et al., Mon. Not. R Astron. Soc., **406**, L70-L74 (2010); Dolag et al. Astrophys. J. Lett. **727**, L4(2011).

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The accumulating observational evidence for the presence of magnetic fields on all astrophysical scales, strengthens the idea of a primordial origin of cosmic magnetism

PRIMORDIAL MAGNETIC FIELDS

- Two related important consequences for the cosmological model: on one hand, the mechanisms for their generation and preservation have to be found.

  On the other, it is necessary to build a magnetized cosmological model.

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).

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

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

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

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The flatness of the potential is not spoiled.

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

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and study thermal effects.

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- 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

WARM INFLATION

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

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$$+ 2gh\left(y^2\varphi^\dagger\chi^\dagger + y^{\dagger 2}\varphi\chi\right)$$

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

Feynman diagrams..

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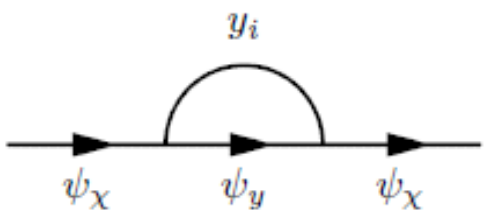
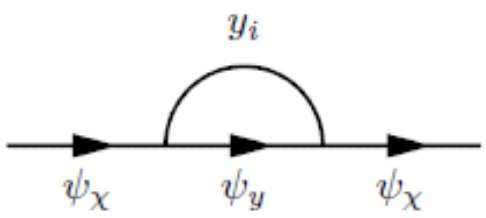


Diagram for the fermionic self energy

Feynman diagrams.



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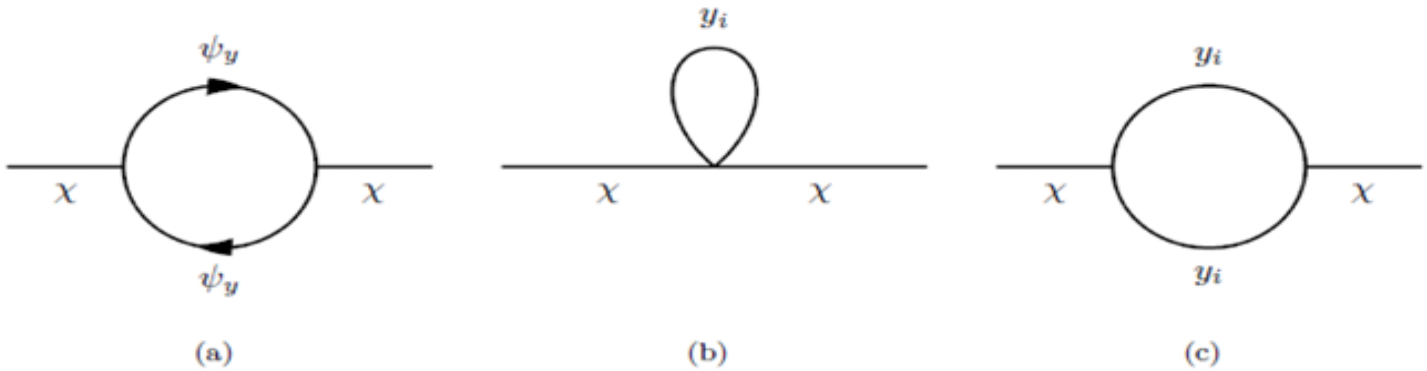


Diagrams for the bosonic self energy

EFFECTIVE POTENTIAL

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

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

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

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

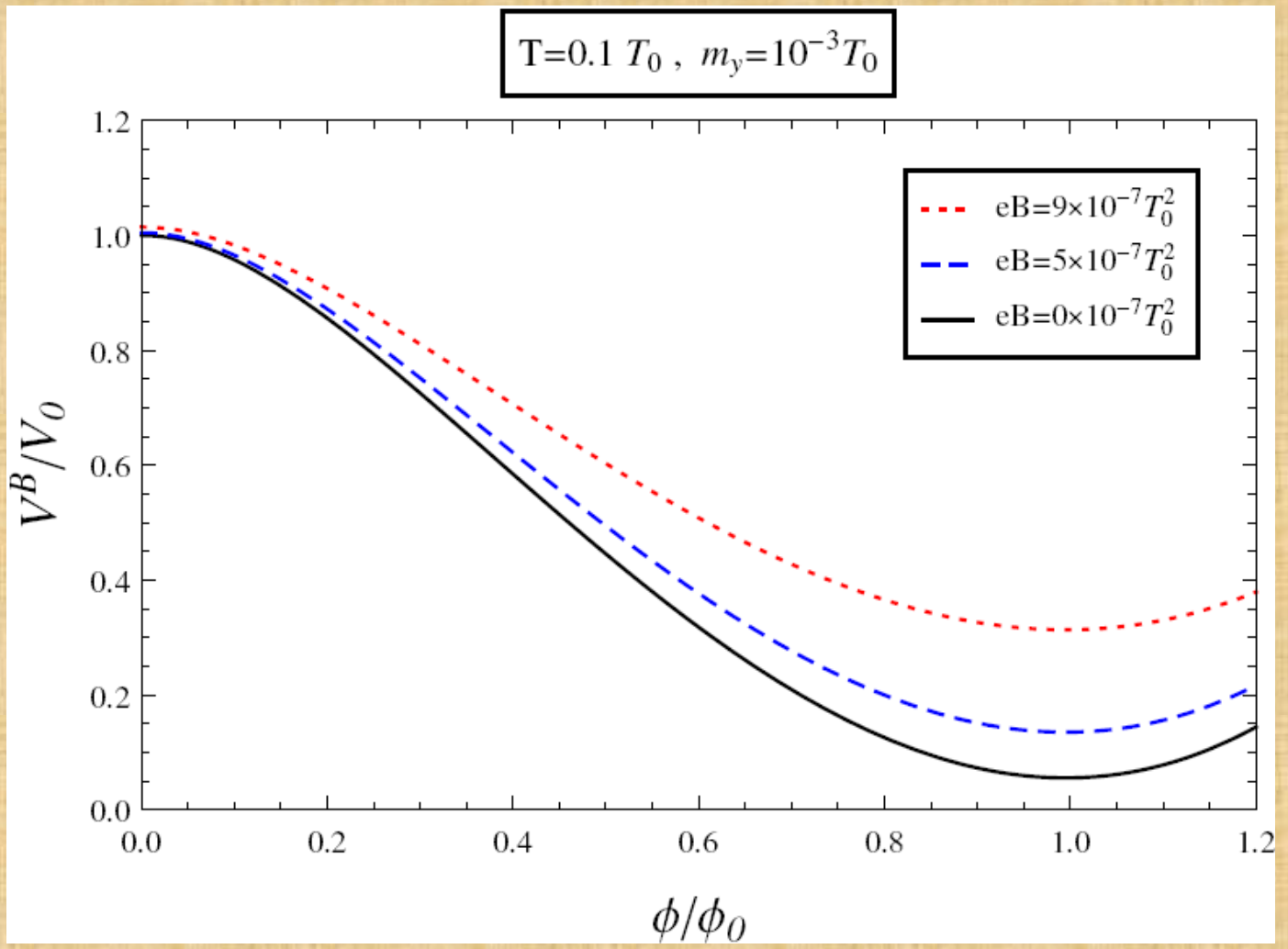
EFFECTIVE POTENTIAL

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

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

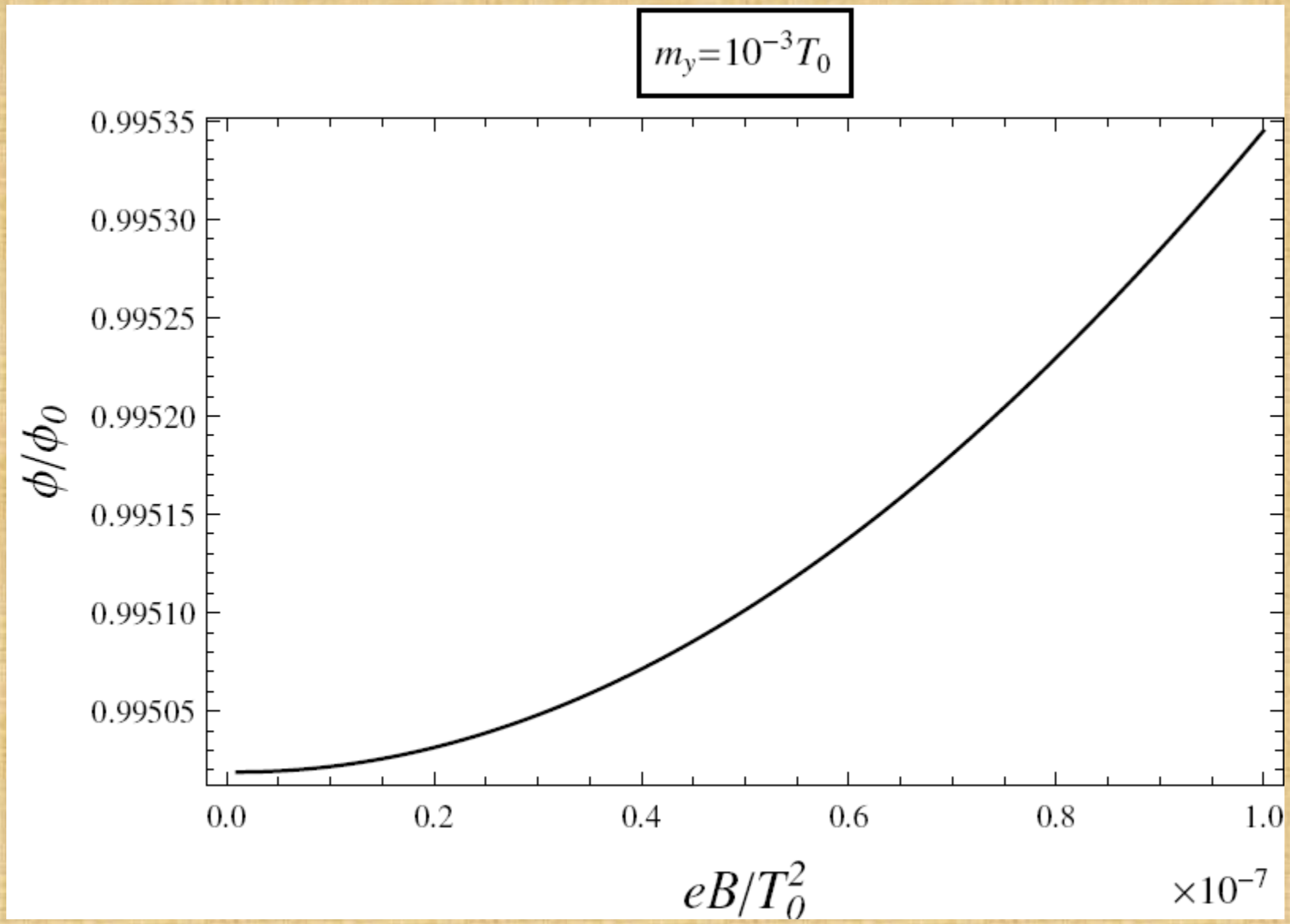
$$V(\phi,T,B) = -\frac{\pi^2}{90} g_* T^4 + V_\chi(\phi,T,B)$$

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 is not spoiled.

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

FUTURE WORK

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- Explore the consequences on density fluctuations

SELF-ENERGIES

In the HTL limit:

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

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)

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

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

SELF-ENERGIES

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

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

MAGNETIC CONTRIBUTION

Propagators with magnetic fields, with Shwinger's proper time method:

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

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

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:

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

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

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

THERMAL AND MAGNETIC CONTRIBUTIONS

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

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

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