Magnetic Field Effect on the Effective Potential of a Heavy Charged Scalar Field

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Magnetic field

Magnetic fields are widespread in the universe[1]

- They have been observed up to galaxy clusters and super clusters.
- Indirect evidence, from gamma-ray observations of blazars, indicates the presence of an intergalactic magnetic field with a lower bound of $10^{-16} - 10^{-15}$ Gauss.
- Their origin is currently unknown, they can be either primordial or associated with structure formation.
- If they were present in the early universe then CMB should have some information about their effects over the phase transitions.

[1] A. Neronov and I. Vovk, Science **328**, 73 (2010),
K. Dolag, et al, Astrophys. J. Lett. **727**, L4 (2011).

Warm Inflation

In the warm inflation model[2] the inflaton is now assumed to interact with other fields, both during the inflationary expansion as well as at reheating, in a continues and more natural way.

- This is a model where (near) thermal equilibrium conditions are maintained during the inflationary expansion.
- The model does require a dissipative component Γ of sizable strength as compared to the expansion rate of the universe.
- This additional dissipation is responsible for producing radiation since during an exponential expansion, the dissipation is dissolved very quickly and a source of radiation is needed. In this way the equation of motion for the inflaton ϕ reads

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

where H is the Hubble parameter and V_T is the inflaton effective potential. Warm inflation requires $\Gamma > 3H$

[2] A. Berera and L. Z. Fang, Phys. Rev. Lett. **74**, 1912-1915 (1995), A. Berera, Phys. Rev. Lett. **75**, 3218-3221 (1995).

Warm Inflation

- Particle model with global SUSY, with dissipative effects of particle production[3]
- One superfield is coupled to the inflaton (becomes very heavy) and the other one has a vanishing coupling (light sector)
- We consider a two stage reheating process, $\phi \rightarrow \chi \rightarrow \tilde{y}\tilde{y}$. Note that 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
- Soft SUSY breaking in the heavy sector
- Light radiation thermalises

[3] L. M. Hall and I .G. Moss, Phys. Rev. D **71**, 023514 (2005).

Warm Inflation

The superpotential that involves all the interaction of the inflaton and the intermediate field χ reads[4]

$$W = g\Phi\Lambda^2 - g\Phi X^2 - hXY_1Y_2,$$

where Y are the light chiral superfield coupled to X the heavy sector. g and h are coupling constants and Λ is a mass scale. Some estimations have been done for the coupling constants g and h leading to consider it $\sim \mathcal{O}(0.1)$ and a mass scale of up to $\Lambda \sim 10^{11} GeV^4$.

Note that if the heavy field is charged then the following relation holds

$$q_X = q_{Y_1} + q_{Y_2}$$

with q_i the charge of each particle.

[4] L. M. Hall and I .G. Moss, Phys. Rev. D **71**, 023514 (2005).

Effective potential

In general, the contribution to the inflaton effective potential coming from the heavy charged particles up to one loop reads

$$V^1(\phi) = V^1_\chi + V^1_{\psi_\chi}.$$

In the presence of an external and uniform magnetic field B, which defines the z-direction, the above expressions become

$$V^1(\phi) = \frac{4}{2}\int \frac{d^4p}{(2\pi)^4}\left(\ln D_B^{-1}(p)\right) - \frac{1}{2}\int \frac{d^4p}{(2\pi)^4} \ln Det(S_B^{-1}(p)),$$

where D and S are the propagators of boson and fermion, respectively, and are given by:

$$D_B(p) = \int_0^\infty \frac{ds}{\cos q_\chi Bs} \exp\left\{ is(p_{||}^2 - p_\perp^2 \frac{\tan q_\chi Bs}{q_\chi Bs} - m_\chi^2 + i\epsilon)\right\},$$

$$S_B(p) = \int_0^\infty \frac{ds}{\cos q_\chi Bs} \exp\left\{ is(p_{||}^2 - p_\perp^2 \frac{\tan q_\chi Bs}{q_\chi Bs} - m_{\psi_\chi}^2 + i\epsilon)\right\} \times \left[(m_{\psi_\chi} + \not{p}_{||})e^{iq_\chi Bs\sigma_3} - \frac{\not{p}_\perp}{\cos q_\chi Bs}\right],$$

with s the Schwinger proper time parameter, $(a\cdot b)_{||} \equiv a_0b_0 - a_3b_3$, $(a\cdot b)_\perp \equiv a_1b_1 + a_2b_2$ and σ_3 the third Pauli matrix. q_χ denotes the charge associated to the heavy superfield fermion or boson components.

Effective potential

Once the integration over the momentum is carried out, and all divergent terms are isolated, the effective potential can be written as

$$V^1(\phi) \quad = \quad V_0^1 + V^1_{q_\chi B^2} + V^1_{df},$$

with

$$V_0^1 \quad = \quad \frac{1}{8\pi^2}\int_0^\infty \frac{ds}{s^3}\left\{e^{-sm_\chi^2} - e^{-sm_{\psi\chi}^2}\right\}$$

$$V^1_{q_\chi B^2} \quad = \quad -\frac{1}{8\pi^2}\int_0^\infty \frac{ds}{s}\left\{e^{-sm_\chi^2} + 2\ e^{-sm_{\psi\chi}^2}\right\}\frac{(q_\chi B)^2}{6}$$

$$V^1_{df} \quad = \quad \frac{1}{8\pi^2}\int_0^\infty \frac{ds}{s^3}\left\{e^{-sm_\chi^2}\left[\frac{q_\chi Bs}{\sinh(q_\chi Bs)} - 1 + \frac{1}{6}(q_\chi Bs)^2\right]\right.$$
$$\left. - e^{-sm_{\psi\chi}^2}\left[\frac{q_\chi Bs}{\coth(q_\chi Bs)} - 1 - \frac{1}{3}(q_\chi Bs)^2\right]\right\},$$

where the masses m_χ and m_{ψ_χ} keep track of the bosonic and fermionic sectors, respectively.

Thermal masses

Note that the main divergences cancel out and the remaining ones are due to the soft SUSY breaking term which we have defined as the slight difference between the fermion and boson masses, that is

$$\begin{aligned} m_{\chi}^2(T,B) &= 2g^2\phi^2 + m_b^2(T,B) + M_s^2, \\ m_{\Psi_\chi}^2(T,B;r) &= 2g^2\phi^2 + m_f^2(T,B;r), \end{aligned}$$

where $m_b^2(T,B)$ and $m_f^2(T,B,r)$ are the one loop self-energy corrections to the fermion and boson masses, respectively, that have to be calculated in a thermal magnetized bath.

By imposing that the effective potential lower value be zero at $\phi = \phi_0$, with ϕ_0 the inflaton vev, that is

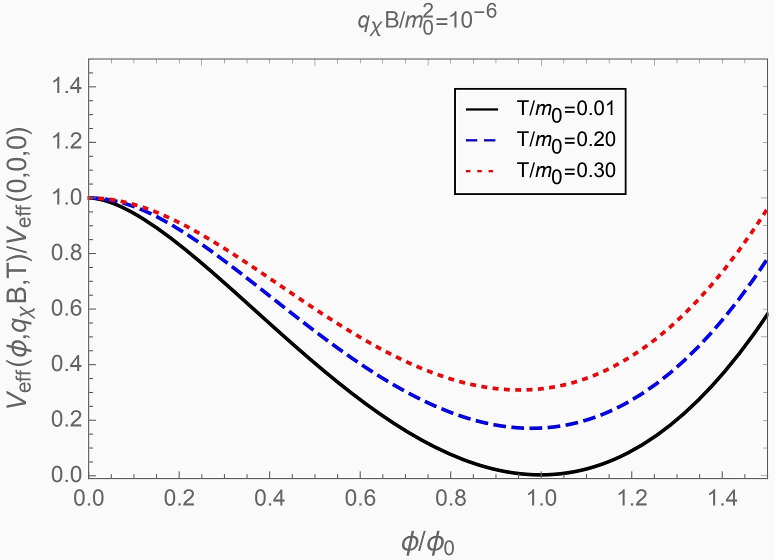
$$V_{\chi}^1(\phi,T,B)\big|_{\phi=\phi_0} = 0$$

and

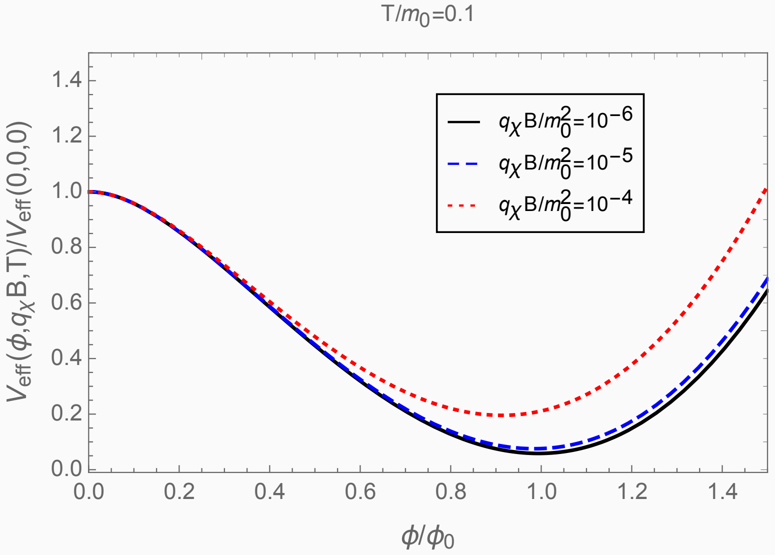
$$\frac{\partial}{\partial\phi} V_{\chi}^1(\phi,T,B)\bigg|_{\phi=\phi_0} = 0,$$

we carried out the renormalization.

Preliminary Results



Preliminary Results



Final remarks

- We have incorporated in the effective potential thermal masses as a first approximation, however a full magnetic field dependence on the light particle masses is needed for consistency.
- In this approach, the magnetic field effect on the effective potential seems modified the potential flatness making it less flat.
- The last observation could be more restrictive on the magnetic field strength.
- We shall include other aspects of the magnetic field like its effect on the decaying process of the heavy particles (see Gabriella's talk).

Thank you.

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