Primordial Magnetogenesis in a Bouncing Universe

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Abstract

Models of primordial magnetogenesis are in general investigated during phase transitions or inflation. Inflationary magnetogenesis is usually preferred as it naturally generates coherent magnetic fields on very large scales. We argue that magnetogenesis in bouncing models shares this property while alleviating various issues encountered in inflationary magnetogenesis. The focus is on a quantum bouncing model in a universe filled with dark matter featuring a coupling between curvature and electromagnetism. This model is able to generate magnetic fields compatible with current observations, and does not suffer from backreaction in the physically relevant parameter space [1].

Primordial Magnetogenesis

Magnetic fields are omnipresent in the Universe, with observations consistent with weak $\simeq 10^{-16}$ Gauss fields in the intergalactic medium, coherent on Mpc scales. Primordial seed fields are usually modeled during inflation. For a successful magnetogenesis, conformal invariance of electromagnetism (EM) must be broken, *e.g.* by adding a mass term, by coupling EM with another field or with gravity.

However, inflationary magnetogenesis suffers from some issues, such as an exponential sensitivity of the magnetic field's amplitude with the inflationary model's parameters, the strong coupling problem, and backreaction from electrogenesis. A non-singular cosmological model alleviates the sensitivity issue by construction, since expansion is slower than in inflation.

I present here the results of a bouncing model in which the background dynamics is obtained by canonically quantising general relativity. To correct the problem of time associated with this procedure, a pressureless scalar field (*i.e.* dark matter) is added in the Wheeler-deWitt (WdW) equation. Applying the de Broglie-Bohm theory to the wave function of the Universe, solving the WdW equation gives a scale factor in cosmic time [2]

$$a(t) = a_b \left[1 + \left(\frac{t}{t_b}\right)^2\right] , \qquad (1)$$

in which the subscript b means we evaluate at the bounce. The bounce timescale is constrained between $10^3 t_{\text{planck}} < t_b < 10^{40} t_{\text{planck}}$. The lower bound avoids spoiling an eventual spacetime discreteness, and the upper bound indicates the bounce must happen before the Big-Bang Nucleosynthesis.

The electromagnetic sector is modeled by a non-minimal coupling between Maxwell electromagnetism and gravity

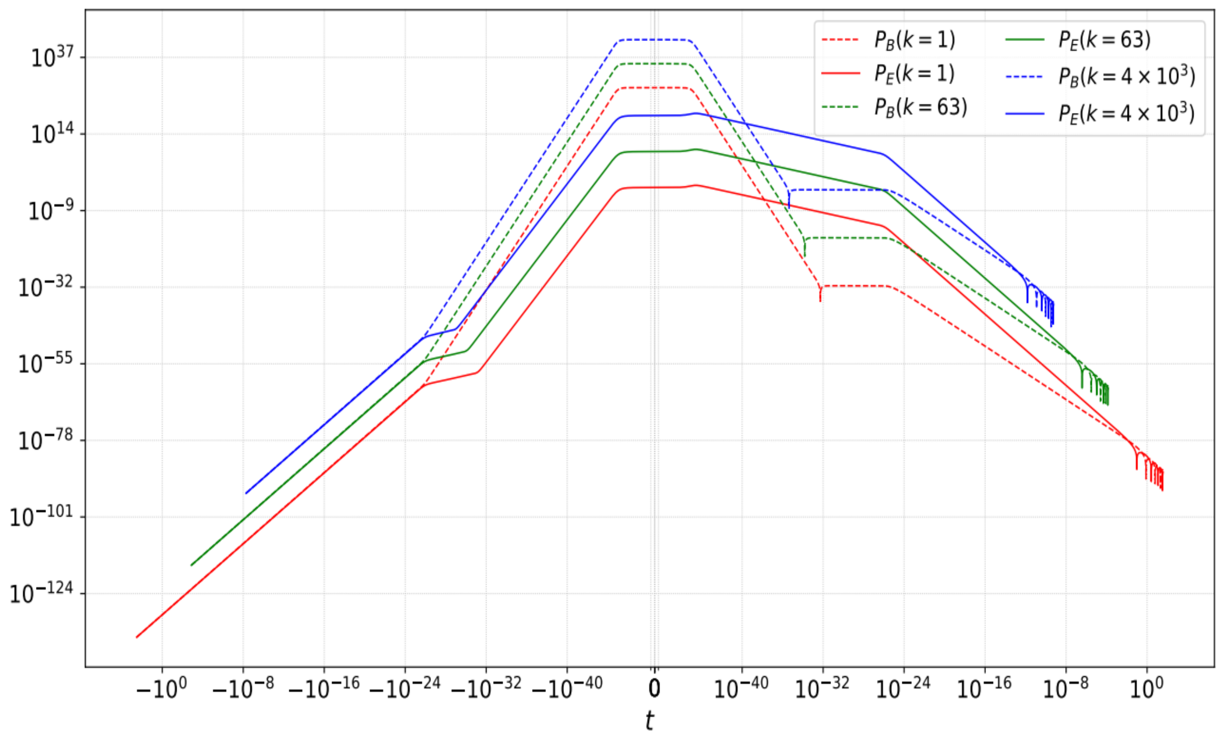
$$\mathcal{L}_{EM} = -\left(\frac{1}{4} + \frac{R}{m_\star^2}\right) F_{\mu\nu}F^{\mu\nu} , \qquad (2)$$

which is theoretically motivated by vacuum polarisation of quantum electrodynamics in a curved background.

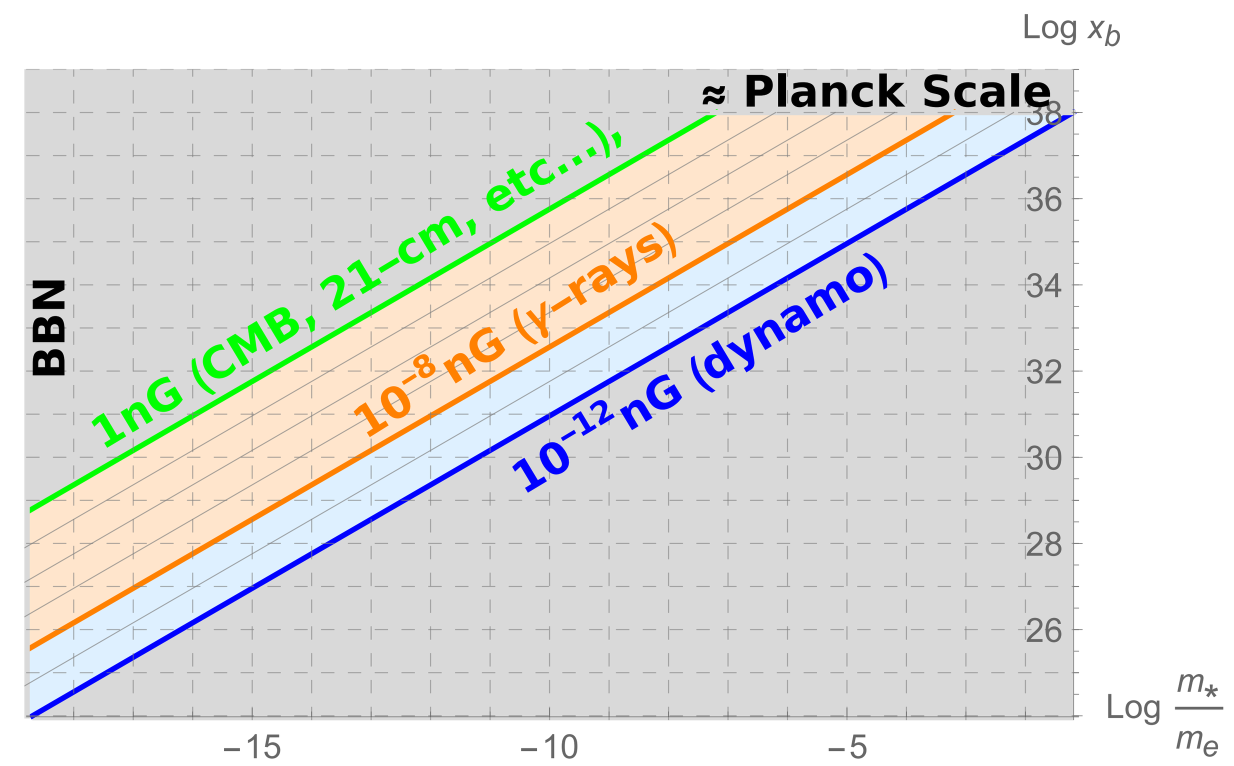
This model depends on three parameters: the normalised scale factor at the bounce, x_b, the dark matter density today Ω_m and a mass scale $m_\star$ to be fixed by observations. We adopted a dark matter density, constrained by observations, of about $\Omega_m \simeq 0.3$.

The evolution of the electric and magnetic energy densities (resp. P_E and P_B) are shown below for three scales ($k = 1, 63, 4.000$, in units of Hubble radius). At the beginning, the electromagnetic field is in an adiabatic vacuum. Only vacuum fluctuations are present, with a k^4 spectrum, increasing as a^{-4} due to contraction. When the coupling becomes relevant, the magnetic field power spectrum increases faster in the contracting phase, while the electric field power spectrum presents a slower increment. After the bounce, the situation is reversed.

We notice a window in time in which the electric density is bigger than the magnetic density, and backreaction could be a problem. However, in the parameter space of interest, we have $\rho_E < 10^{-4}\rho_m$, and the electric field does not spoil the background dynamics.



The magnetic fields generated in this model follow a powar-law k^6, which is expected in non-helical magnetogenesis model, though quite different from other models in the literature. We are ultimately interested in the parameter space of magnetic field amplitudes consistent with current limits at 1 Megaparsec. The blue region represents the allowed values to initiate the dynamo effect, with the blue line a theoretical lower limit. The orange region represents allowed values by observations at large scales in voids, with the orange line a lower limit derived by blazars observations and the green line an upper limit derived using Ultra-High-Energy Cosmic Rays, Ultra-Faint Dwarf galaxies, 21-cm hydrogen lines, among others. Note the orange and blue regions are overlapping. The grey shaded region represents excluded values of the magnetic field. Each oblique grey line gives an amplitude for the magnetic field a hundred times higher than the lower line. Note that we use the electron mass as reference.



Conclusion

Magnetogenesis in the quantum bounce model under scrutiny:

- naturally avoids the strong coupling problem,
- is free from backreaction up to galactic scale,
- has well-defined initial conditions (adiabatic vacuum),
- follows a power-law with magnetic (and electric) spectral index $n = 6$,
- is compatible with observations on scales from the Hubble radius up to 1 Megaparsec.

References

[1] E. Frion, N. Pinto-Neto, S. D. P. Vitenti, and S. E. Perez Bergliaffa. Primordial Magnetogenesis in a Bouncing Universe. *Phys. Rev. D*, 101(10):103503, 2020.

[2] P. Peter, E. J. C. Pinho, and N. Pinto-Neto. A Non inflationary model with scale invariant cosmological perturbations. *Phys. Rev. D*, 75:023516, 2007.

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