A large scale coherent magnetic field: interactions with free streaming particles and limits from the CMB

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Constant magnetic field in an ideal fluid Universe

- We take a Bianchi I spacetime as model of our Universe :

$$ds^2 = -dt^2 + a_\perp^2(t)\left(dx^2 + dy^2\right) + a_\parallel^2(t)\,dz^2$$

- The content of our Universe is an isotropic fluid (ρ_γ, ρ_m and ρ_Λ) and a homogeneous magnetic field ($\mathbf{B} = B\mathbf{e_z}$) which sources the anisotropic expansion.
- All the constituents, except matter, contribute to the pressure components $P_\perp$ and $P_\parallel$. The contribution from the magnetic field is intrinsically anisotropic and given by

$$P_{B,\perp} = -P_{B,\parallel} = \rho_B.$$

Neutrino free-streaming and isotropisation

- Motivated by observations, we assume that the scale factor difference always remains small,

$$\frac{a_\perp - a_\parallel}{a} \equiv \delta \ll 1, \qquad a = \left(a_\perp^2 a_\parallel\right)^{1/3}$$

- To first order in δ, the pressure difference of the free-streaming neutrinos is

$$\begin{aligned} P_{\nu,\perp} - P_{\nu,\parallel} &\simeq -\frac{8}{15}\rho_\nu\left(\delta - \delta_\star\right) \\ &= -\left(P_{B,\perp} - P_{B,\parallel}\right) \end{aligned}$$

- From Einstein eq., we find to linear order in δ

$$\ddot{\delta} + 3H\dot{\delta} + \frac{8}{5}H^2\Omega_\nu\left(\delta - \delta_\star\right) = 6H^2\Omega_B$$

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Effects of neutrino free-streaming

- For $T > 1.4\,\mathrm{Mev}$, neutrinos pressure is isotropic (high rate of collision). The only source of anisotropy is **B** leading to an anisotropic expansion of the Universe.
- At $T \simeq 1.4\,\mathrm{Mev}$, the neutrinos decouple and begin to free-stream. This effect compensates the anistropic expansion of the magnetic field and δ tends to a constant.
- Once the temperature of the Universe drops below the neutrino mass scale, they become non-relativistic and δ grows again. 2 cases:
  1. $m_\nu > T_{dec}$: the isotropization effect will not be present and the CMB will be affected (quadrupole) by the anisotropic expansion sourced by **B**.
  2. $m_\nu < T_{dec}$: the anisotropic expansion will be reduced because the neutrinos maintain isotropic expansion until they become non-relativistic.
- $T_{dec} \simeq 0.3\mathrm{eV}$ and neutrino highest-mass eigenstate $0.04\mathrm{eV} < m_\nu < 1\mathrm{eV}$.
- More precise results will come from the simulation, work in progress.

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