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 :

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

- The content of our Universe is an isotropic fluid $(\rho_{\gamma}, \rho_{m} \text{ and } \rho_{\Lambda})$ and a homogeneous magnetic field $(\mathbf{B} = B\mathbf{e}_{\mathbf{z}})$ 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,

$$rac{a_{\perp}-a_{\parallel}}{a}\equiv\delta\ll1,\qquad a=\left(a_{\perp}^{2}a_{\parallel}
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ullet To first order in δ , the pressure difference of the free-streaming neutrinos is

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

ullet 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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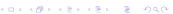
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- For $T > 1.4 \, \mathrm{Mev}$, neutrinos pressure is isotropic (high rate of collision). The only source of anisotropy is **B** leading to an anisotropic expansion of the Universe.
- At $T \simeq 1.4$ MeV, the neutrinos decouple and begin to free-stream. 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 $0.04 \mathrm{eV} < m_{\nu} < 1 \mathrm{eV}$.
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