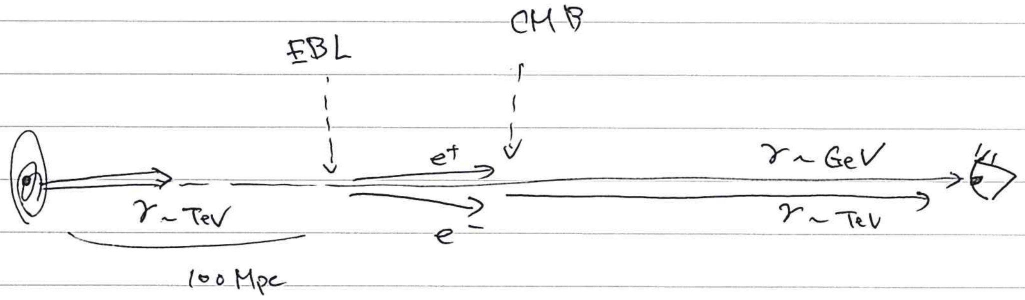
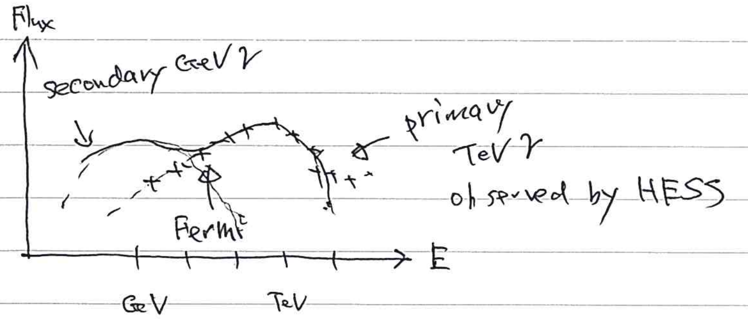
Baryon asymmetry from cosmological (hyper) magnetic fields

1. Intergalactic MFs
2. Baryogenesis from decaying hyper magnetic helicity
3. generation of helical (hyper) magnetic field

1. Intergalactic MFs

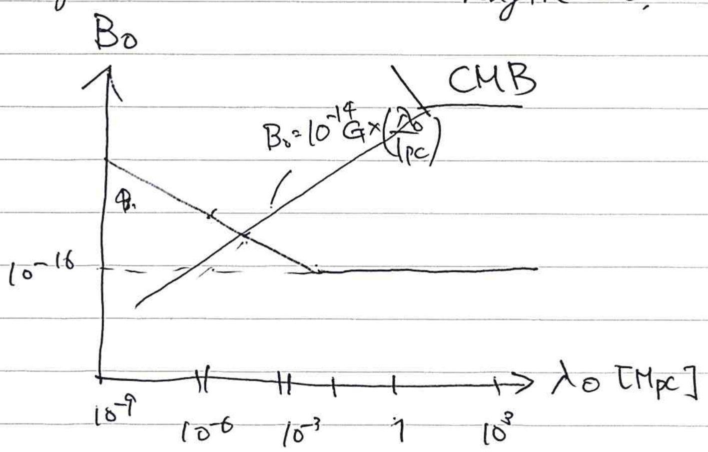
the reason why recently the interest in cosmological / primordial MFs is increasing is the indirect suggestions of existence of intergalactic MFs through the obs. of TeV blazars





$\longrightarrow$ If MFs exist in the intergalactic void, it explains the absence of secondary GeV cascade γ.

Parameterising IGMF with field strength B_0 & coherence length λ_0



$$B_0 > \begin{cases} 10^{-16}\,[G] & (\lambda > 10^{-2} Mpc) \\ 10^{-16} G \left(\frac{\lambda}{10^{-2} Mpc}\right)^{-1/2} & (\lambda < 10^{-2} Mpc) \end{cases}$$

$\Rightarrow$ intergalactic void $\longrightarrow$ primordial origin?

2. Baryogenesis from decaying magnetic helicity ('98 Giovannini & Shaposhnikov, '16 KK & Fujita / KK & Long)

What happens if MFs exist in the very early Universe?

→ If they exist before EWSB and carries helicity
Baryon asymmetry can be generated.

SM chiral anomaly

$$\Delta Q_B = \Delta Q_L = N_g \left(\Delta N_{CS} - \frac{g'^2}{16\pi^2}\Delta H_Y\right)$$

$$N_{CS} = \frac{g^2}{32\pi^2}\int d^3x\, \varepsilon^{ijk}\left(W^a_{ij}W^a_k - \frac{g}{3}\varepsilon_{abc}W^a_i W^b_j W^c_k\right)$$

$$H_Y = \int d^3x\, \varepsilon^{ijk} Y_i \partial_j Y_k = \int d^3x\, \vec{Y}\cdot\vec{B}$$

ΔN_{CS} ← "sphaleron" generated by thermal fluctuation
→ leptogenesis, EWBG

ΔH_Y ← often omitted since it is not generated much by thermal fluctuation.

BG helical hyper MFs

If exist, we can have easily ΔH_Y.

$$\frac{dn_B}{dt} \ni -\#\frac{d}{dt}H_Y \sim \mathbf{E}\cdot\mathbf{B}$$

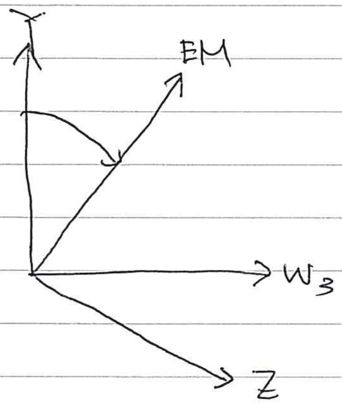
☆ in the rad. dom. Univ.

$$\nabla\times\mathbf{B} = \cancel{\dot{\mathbf{E}}} + \mathbf{J}$$

$\mathbf{J} = \sigma(\mathbf{E}+\mathbf{v}\times\mathbf{B})$ + (chiral magnetic effect)
Ohm's current

↳ $\mathbf{E} = -\mathbf{v}\times\mathbf{B} + \frac{1}{\sigma}(\nabla\times\mathbf{B})$

$$\rightarrow \frac{dn_B}{dt} \ni \frac{1}{\sigma}\mathbf{B}\cdot(\nabla\times\mathbf{B}) \sim \pm\frac{B^2}{\sigma\lambda}$$ ← maximally helical



* EWSB $\quad B_Y \longrightarrow B_{em}$

massless MF. $\quad B_A = \cos\theta_W(t) B_Y + \sin\theta_W(t) B_{W_3}$

$$A = \cos\theta_W(t)\, Y + \sin\theta_W(t)\, W_3$$

~~$(\to E \ni -\dot{A})$~~

Quasi-Adiabatic transition

$$H_Y \longrightarrow H_{em} = \cancel{\cos^2\theta_W H_Y + \sin\theta_W B_{W_3}}$$

$$H$$

$$\searrow \cos^2\theta_W H_Y \quad \to \Delta H_Y = -\sin^2\theta_W H_Y$$

$$N_{CS}^{W_3} : 0 \to \sin^2\theta_W H_Y \qquad \Delta N_{CS} = \sin^2\theta_W H_Y$$

$$\Delta Q_B = \# \Delta N_{CS} - \# \Delta H_Y = \# \sin^2\theta_W H_Y$$

or. $\quad E_A \ni -\dot{A} \ni \sin\theta_W \dot{\theta} Y$

$$\to E\cdot B = \sin\theta_W \dot{\theta}\, Y\cdot B = \sin 2\theta_W \dot{\theta} H_Y$$

$$\to \frac{d\eta_B}{dt} = \dot{\theta}_W \sin 2\theta_W h_Y \qquad \left(B = \nabla\times Y \sim \frac{Y}{\lambda}\right)$$

$$= \dot{\theta}_W \sin 2\theta_W \lambda B^2.$$

We worry about washout.

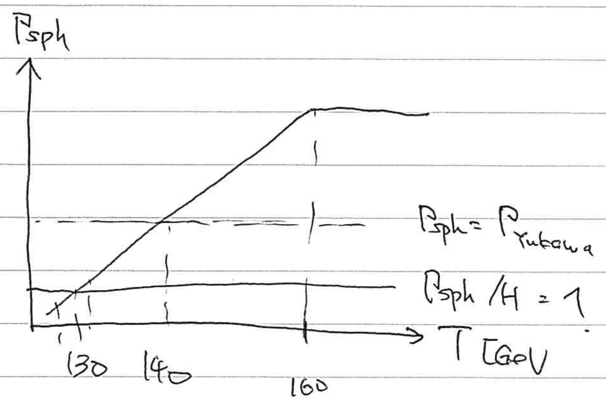
$$\frac{d\eta_B}{dt} = \left(\# \frac{B^2}{\sigma\lambda} + \dot{\theta}_W \sin 2\theta_W \lambda B^2\right) - \Gamma_{w.o.}\eta_B$$

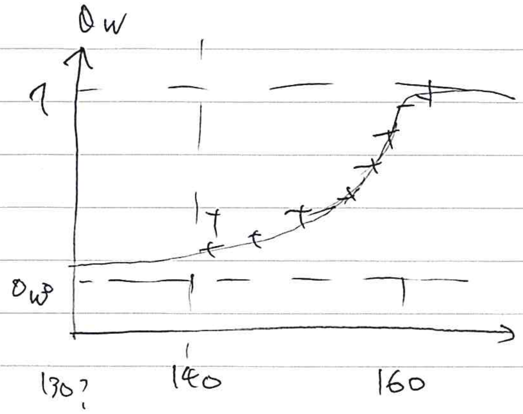
@ high temperature $\to \Gamma_{w.o} \sim \Gamma_{\text{electron yukawa}}$

@ low temperature $\to \Gamma_{w.o} \sim \Gamma_{\text{sphaleron}}$

$$\longrightarrow \eta_B = \frac{\# \frac{B^2}{\sigma\lambda} + \dot{\theta}_W \sin 2\theta_W \lambda B^3}{\Gamma_{w.o}}$$

Baryon Asymmetry remains!





(9) $T \sim 135\,\mathrm{GeV}$ when sph. decouples

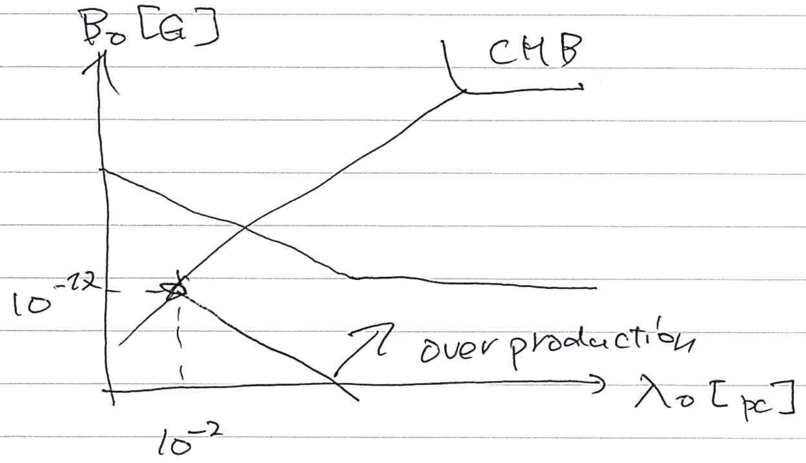
$\theta_W \neq \theta_W^0 \to \dot{\theta}_W \neq 0$

$$\eta_B \sim \left.\frac{\dot{\theta}_W \sin 2\theta_W \lambda B^2}{\Gamma_{sph}}\right|_{T\sim 135\,\mathrm{GeV}}$$

$$\to \eta_B \sim 10^{-10} \underbrace{f(\theta_W, T\sim 135\,\mathrm{GeV})}_{\parallel \; -\sin(2\theta_W) T \frac{d\theta_W}{dT}} \left(\frac{\lambda_{EW}}{10^6\,\mathrm{GeV}^{-1}}\right) \left(\frac{B_{EW}}{10^{-3}\,\mathrm{GeV}^2}\right)^2$$

N.T. $\rho_B = \frac{B^2}{2} \ll \rho_{tot} \sim T^4$!

Relation to ~~EW~~ IGMF (see Jennifer's talk)



3. Magnetogenesis

☆ axionic inflation $\frac{\phi}{f} F\tilde{F}$ coupling

↳ $\ddot{A}^{\pm}_k + [\cancel{k^2 \pm} k^2 (1 \mp \frac{\dot{\phi}}{k \tau H f})] A^{\pm}_k = 0$

→ instability in one helicity mode

☆ chiral plasma instability

How to take into account backreaction of baryogenesis

$$\frac{dn_5}{dt} = \# F\tilde{F}$$

$$\frac{dB}{dt} = ?? \, f(n_5)$$

Maxwell eqn.

$$\frac{dB}{dt} = -\nabla \times E \qquad \nabla \times B = J$$

$$= \sigma(E + v \times B) + \frac{2\alpha}{\pi} \mu_5 B$$

$$= -\frac{1}{\sigma} \nabla \times (\nabla \times B - \underbrace{\otimes}_{\substack{(n_5)\,? \\ \| \\ \frac{2\alpha}{\pi\sigma} \mu_5 \nabla \times B}})$$

$$+ \nabla \times (v \times B)$$

$$\frac{dB^{\pm}_k}{dt} = -\frac{k^2}{\sigma} B_k \pm \frac{2\alpha}{\pi\sigma} \mu_5 k B_k + (k v \cdot B)$$

instability @ $k < \alpha \mu_5$.

→ Jennifer's talk