Cosmic Magnetic Fields

Leonardo Campanelli
Università Degli Studi di Bari

X-mas Workshop
Bari 12/23/13

Summary

- Seeds & Generation
- Evolution & Constraints
- Creation at Inflation
- Conclusions

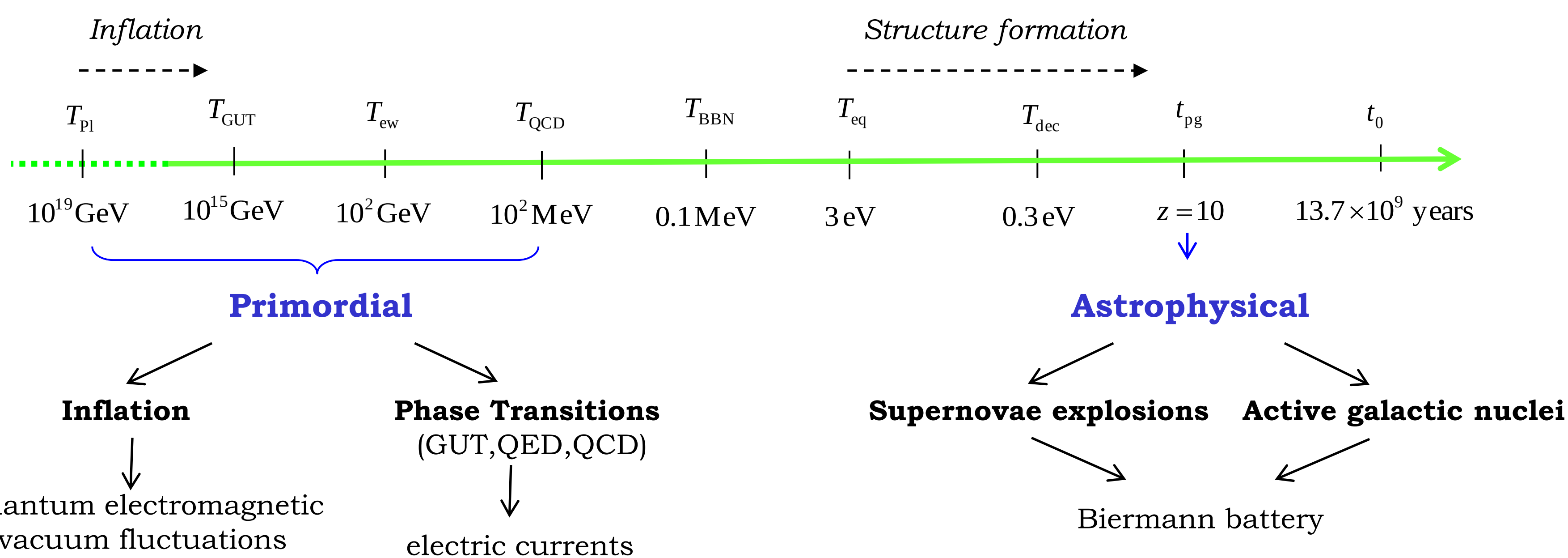
Seeds & Generation

- ***Astrophysical observations indicate the presence of large-scale (Mpc) magnetic fields in:***

Galaxies	**Galaxy Clusters**	**Cosmic Voids**
$B_{\rm galactic} \sim \mu{\rm G}$	$B_{\rm cluster} \sim \mu{\rm G}$	$B_{\rm void} \gtrsim 10^{-14}{\rm G}$

Alfven frozen flux effect + Kelvin-Helmholtz instability $\Longrightarrow$ $B_{\rm seed} \sim 10^{-12}{\rm G}, \;\; \xi \gtrsim {\rm Mpc}$

- ***Cosmic magnetic fields could have been generated either in the early universe or during the process of large–scale structure formation***



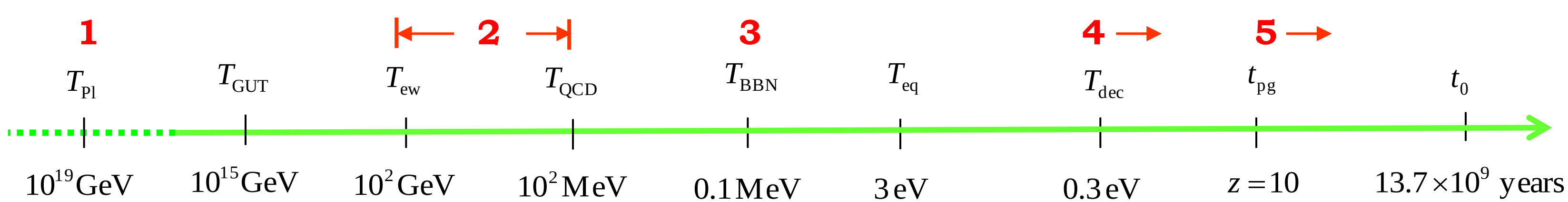
Evolution & Constraints

- ***If cosmic magnetic fields are primordial, it is then important to follow their evolution from the time of their generation until today***

Magnetohydrodynamics in expanding universe: turbulence and dissipation

Inflationary Fileds	**Phase-Transition-Generated Fields**
(L.C. et al. 2012)	(Jedamzik, Banerjee 2003; L.C. 2013)
stable on large scales	small-scale problem

- ***Cosmic magnetic fields must not spoil the cosmological standard model***



1 Inflation (Martin, Yokoyama 2008; L.C. work inprogress)

2 Axion (L.C., Giannotti, 2006)

3 Big Bang Nucleosyntesis (Greenstein 1969; L.C. 2011)

4 Cosmic Microwave Background (Zeldovich, Novikov 1983; L.C., et al. 2006)

5 Large-Scale Structure (Wasserman 1978)

Creation at Inflation

$$\mathcal{L}_{\rm em} = \mathcal{L}_{\rm Maxwell} + \mathcal{L}_{\rm nonstandard}$$

- $\mathcal{L}_{\rm Maxwell} \;\Rightarrow\; \langle 0, {\rm in}|\mathbf{B}^2|0, {\rm in}\rangle = \langle 0, {\rm out}|\mathbf{B}^2|0, {\rm out}\rangle \propto a^{-4}\int_0^\infty dk\, k^3 = \infty$

- $\mathcal{L}_{\rm nonstandard} \propto RF_{\mu\nu}F^{\mu\nu} + RA_\mu A^\mu + \theta F_{\mu\nu}\widetilde{F}^{\mu\nu}$ (Turner, Widrow 1988)
  $+\; e^\Phi F_{\mu\nu}F^{\mu\nu} + e^\varphi F_{\mu\nu}F^{\mu\nu}$ (Ratra 1992) (Gasperini et al. 1995)
  $+\; f^2(\Phi)F_{\mu\nu}F^{\mu\nu} + f^2(\theta)F_{\mu\nu}\widetilde{F}^{\mu\nu}$ (Martin, Yokoyama 2008) (L.C. 2009)
  $+\; \beta^2\left(1 - \sqrt{1 + 2F_{\mu\nu}F^{\mu\nu}/\beta^2}\right)$ (L.C., Cea 2008)
  $+\; (k_F)_{\mu\nu\tau\sigma}F^{\mu\nu}F^{\tau\sigma} + \ldots$ (L.C., et al. 2009)

$$\Rightarrow\; \langle 0, {\rm in}|\mathbf{B}^2|0, {\rm in}\rangle = \langle n_{\mathbf{k}}, n_{-\mathbf{k}}, {\rm out}|\mathbf{B}^2|n_{\mathbf{k}}, n_{-\mathbf{k}}, {\rm out}\rangle \propto a^{-4}\int_0^\infty dk\,(n_{\mathbf{k}} + n_{-\mathbf{k}} + 1)\,k^3$$

$\text{WKB approximation:}\quad n_{\mathbf{k}} = e^{2S_k}$ (L.C. work in progress)

Renormalization

$$G_{\mu\nu} + \Lambda_{\rm bare}g_{\mu\nu} = 8\pi G_{\rm bare}\,\langle T^{\rm em}_{\mu\nu}\rangle \;\Rightarrow\; G_{\mu\nu} + \Lambda g_{\mu\nu} + a\,H^{(1)}_{\mu\nu} + b\,H^{(2)}_{\mu\nu} = \langle T^{\rm em}_{\mu\nu}\rangle_{\rm ren}$$

$\mathcal{L}_{\rm Maxwell} \;\Rightarrow\; \langle 0, {\rm in}|\mathbf{B}^2|0, {\rm in}\rangle_{\rm ren} = \langle 0, {\rm out}|\mathbf{B}^2|0, {\rm out}\rangle_{\rm ren} \propto H^4$ (L.C. 2013)

this accounts for cosmic magnetic fields if the scale of inflation is around $10^{16}\,$GeV

Conclusions

- **The universe is magnetized**
- **Future experiments will establish if cosmic magnetic fields are or not primordial**
- **If primordial, cosmic magnetic fields could be a natural outcome of inflation**