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Dynamo in the Early Universe

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DYNAMO IN THE EARLY UNIVERSE

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Magnetic fields in the Universe: As early as we can observe.

Galaxies, Cluster of galaxies, AGN, Quasars, Jets etc. $z \approx 1$. Cool Universe of low density and temperature. Celestial bodies, hot, partially ionized. Turbulence and convection.

Galaxies. Large-scale magnetic field. $B \sim 5\ \mu$G, $L \sim 10$ kpc. In the galactic plane. Equipartition with galactic turbulence and cosmic rays.

The Early Universe. Hot, dense. Very isotropic and homogeneous. No direct magnetic field observations however not excluded.

Is there any magnetic link between these stages?

Mirror asymmetry is crucial for cosmic magnetism in two ways.

Faraday rotation is the main source for our knowledge of galactic magnetic fields.

$$\psi = RM\lambda^2 + \psi_0$$

$$RM = 0.81 \int \mathbf{B} n_e \mathbf{dl}$$

$\mathbf{B}$ violates the mirror symmetry.

Structures in RM sky $- - -- >$ magnetic field of Milky Way

Polarization and RM in external galaxies $- - -- >$ magnetic fields

ψ_0, PI, ... contribute some features. Zeeman effect is important as a rare exception (no comparison with the solar case).

Turbulent magnetic fields. $l \sim 100$ pc. $b/B \sim 1 - -2$

Classical galaxies M31, M51, NGC6946, ...

Ring in Andromeda Nebula.

Magnetic field origin $---->$ Faraday electromagnetic induction. Larmor, 1919.

Lenz law! Two circuits are required.

Differential rotation. $B_r ---- > B_\phi$

Parker, 1955. Something like cyclonic motions. $B_r ---- > B_\phi$

Stehenbeck, Krause, Rädler, 1964. "Something" is a violation of the mirror symmetry in a rotating turbulence.

$$\alpha = \tau < \mathbf{v}\mathrm{rot}\,\mathbf{v} > /3$$

$$J = \alpha B$$

α-effect.
Coriolis force.

"Microscopic" explanation.

Magnetic field is frozen into the medium.

Lagrangian and Eulerian approach.

Zeldovich, Krakow, 1977.

Stretch-Twist-Fold scheme.

α gives twist.

Zeldovich, 1965. Homogeneous cosmological magnetic field can survive through the recombination epoch.

It can be weak enough not to destroy isotropy and still interesting for cosmic magnetism.

Most severe restrictions gives RM analysis.

B_c can be up to 10^{-9} G if completely homogeneous.

Two concepts of homogeneity.

$B_c \sim 10^{-15}$ G is still interesting.

Dynamo needs seed magnetic field.

Turbulent dynamo in protogalaxies can provide such field in principle.

This scenario is however quite restrictive however do not contradict to the available knowledge.

E.g. supernova are required very early to support the turbulence in protogalaxy.

Cosmological magnetic field is highly desirable.

Dynamo could operate in the Early Universe in principle.

High temperature $---->$ high conductivity.

But! (almost) no motions.

No general rotation.

No turbulence.

No α-effect based on Coriolis fotrce.
Weak interaction violates mirror symmetry.

P-asymmetry.

It provides α-effect without any turbulence/convection or motions at all.

Semikoz, Sokoloff, 2003 - large-scale magnetic field generation due to weak processes.

Galactic evolution begins in a magnetized medium.

Semikoz, Sokoloff, 2005 - production ofd magnetic helicity.

Cosmological magnetic field can be highly helical and almost homogeneous.

Magnetic helicity conservation and galactic dynamo suppression.

Primordial helicity can participate.