Star formation and models of magnetic fields in spiral galaxies

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Introduction

Star formation is believed to be important for growth of magnetic fields in spiral galaxies.

The influence of star formation can be observed on such telescopes as LOFAR and SKA.

It is necessary to improve existing theoretical models of magnetic fields and describe this influence.

Star formation and kinematic parameters

Magnetic fields in spiral galaxies are described by equations of magnetohydrodynamics and the dynamo theory. But these equations do not include star formation parameters. They include only velocities of interstellar gas v, its density ρ and half-thickness of ionized gas disk h.

In the Milky Way $v_0 = 10$ km/s, $h_0 = 0.5$ kpc. We know, that in HII regions (which can be associated with star formation regions) $v = 35$ km/s, and $h = 1.0$ kpc. (Ruzmaikin et al., 1988) Next, we assume the gas density in HII regions to be a factor of 10 higher than the gas density.

In the Milky Way HII regions occupy 1.5 % of the disc, so we can normalize the star formation rate in the galaxy under consideration to that in the Milky Way and express it as a dimensionless quantity X and take in account that $1 < X < 70$.

Our parametrization

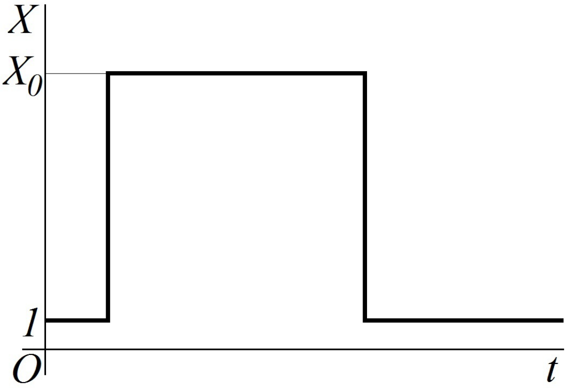
So, we can use such parametrization:

$$v = 10 + 0.35X \text{ (km/s)};$$

$$h = 500 + 7X \text{ (pc)};$$

$$\rho = \rho_0(1 + 0.12X).$$

Starburst model



no-z model

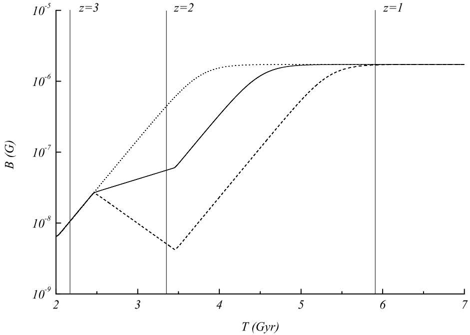
We used a model of magnetic field, called no-z model (Moss, 1995; Phillips, 2001):

$$\frac{\partial B_r}{\partial t} = -R_\alpha B_\varphi - \frac{\pi^2}{4} B_r + \lambda \{ \frac{\partial}{\partial r} (\frac{1}{r} \frac{\partial}{\partial r} (r B_r)) \},$$

$$\frac{\partial B_\varphi}{\partial t} = R_\omega r \frac{\partial \Omega}{\partial r} B_r - \frac{\pi^2}{4} B_\varphi + \lambda \{ \frac{\partial}{\partial r} (\frac{1}{r} \frac{\partial}{\partial r} (r B_\varphi)) \}.$$

We took: $R_\alpha = 0.9$, $R_\omega = 9$, $\frac{\partial \Omega}{\partial r} \sim \frac{1}{r}$.

Results, obtained in no-z model



Evolution of the magnetic field for various star formation rates during a starburst at the stage of an exponential magnetic field growth; the dashed, solid, and dotted lines correspond to $X = 1$, $X = 6$, and $X = 15$, respectively.

Problems of no-z model

The no-z model has some problems. For example, it does not take in account the helicity fluxes. Shukurov (2006) showed how to describe it in simple models of average field. We construct more careful model in partial equations, that takes in account difference of magnetic field in different parts of our galaxy.

More careful model

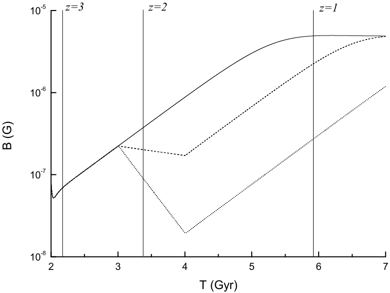
Here are the equations of our new model:

$$\frac{\partial B_r}{\partial t} = -\frac{2}{\pi} R_\alpha (1+\alpha) B_\varphi - (R_U + \frac{\pi^2}{4}) B_r + \lambda \{ \frac{\partial}{\partial r} (\frac{1}{r} \frac{\partial}{\partial r} (r B_r)) \},$$

$$\frac{\partial B_\varphi}{\partial t} = R_\omega r \frac{\partial \Omega}{\partial r} B_r - \frac{\pi^2}{4} B_\varphi + \lambda \{ \frac{\partial}{\partial r} (\frac{1}{r} \frac{\partial}{\partial r} (r B_\varphi)) \}.$$

$$\frac{\partial \alpha}{\partial t} = -R_U \alpha - C[(1+\alpha) B^2 + \frac{3 B_r B_\varphi}{8 R_\alpha} \sqrt{-\pi D (1+\alpha)} + \frac{\alpha}{R}] + \lambda \{ \frac{1}{r} \frac{\partial}{\partial r} (r \frac{\partial \alpha}{\partial r}) \}$$

Results, obtained in more careful model



Evolution of the magnetic field for various star formation rates during a starburst at the stage of an exponential magnetic field growth; the solid, dotted, and dashed lines correspond to $X = 1$, $X = 6$, and $X = 15$, respectively.

Summary

We showed that within the framework of the formulated ideas, the influence of the star formation rate on the galactic magnetic field evolution is a threshold one. This influence is small at moderate star formation rates ($X < 7$), while the large-scale magnetic field is destroyed when some (rather large) critical value is reached and it is restored only after completion of the starburst.

We have constructed new model of galaxy magnetic field. It takes in account helicity fluxes and heterogeneousness of the magnetic field.

Publication

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