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Testing the cosmological evolution of magnetic fields in galaxies with the SKA

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Abstract. We investigate the cosmological evolution of large- and small-scale magnetic fields in galaxies at high redshifts. Results from simulations of hierarchical structure formation cosmology provide a tool to develop an evolutionary model of regular magnetic fields coupled to galaxy formation and evolution. Turbulence in protogalactic halos generated by thermal virialization can drive an efficient turbulent dynamo. The mean-field dynamo theory is used to derive the timescales of amplification and ordering of regular magnetic fields in disk and dwarf galaxies. For future observations with the SKA, we predict an anticorrelation at fixed redshift between galaxy size and the ratio between ordering scale and galaxy size. Undisturbed dwarf galaxies should host fully coherent fields at $z < 1$, spiral galaxies at $z < 0.5$.

Keywords. Techniques: polarimetric, galaxies: evolution, galaxies: magnetic fields, radio continuum: galaxies

1. Introduction: importance of magnetic evolution in galaxies

The observed polarized synchrotron emission and Faraday rotation showed the presence of regular large-scale magnetic fields with spiral patterns in the disks of nearby spiral galaxies (Beck 2005), which were successfully reproduced by mean-field dynamo theory (Beck et al 1996, Shukurov 2005). It is therefore natural to apply dynamo theory also in predicting the generation of magnetic fields in young galaxies at high redshifts.

We now have sufficient evidence that strong magnetic fields were present in the early Universe ($z < 3$; Bernet et al. 2008, Seymour et al. 2008) and that synchrotron emission from distant galaxies should be detected with future radio telescopes such as the Square Kilometre Array (SKA). The SKA will allow us to observe an enormous number of distant galaxies at similar resolution to that achievable for nearby galaxies today (van der Hulst et al. 2004). The formation and evolution of regular large-scale magnetic fields is intimately related to the formation and evolution of disks in galaxies in terms of geometrical and physical parameters. A more robust understanding of the history of magnetism in young galaxies may help to solve fundamental cosmological questions about the formation and evolution of galaxies (Gaensler et al. 2004).

2. Three-phase model for the evolution of magnetic fields in galaxies

We have used the dynamo theory to derive the timescales of amplification and ordering of magnetic fields in disk and quasi-spherical galaxies (Arshakian et al. 2008). This has provided a useful tool in developing a simple evolutionary model of regular magnetic fields, coupled with models describing the formation and evolution of galaxies. In the hierarchical structure formation scenario, we identified three main phases of magnetic-field evolution in galaxies. In the epoch of *dark matter halo formation*, seed magnetic fields of $\approx 10^{-18}$ G strength could have been generated in protogalaxies by the Biermann battery or Weibel instability (first phase). Turbulence in the protogalactic halo generated by *thermal virialization* could have driven the turbulent (small-scale) dynamo and amplify the seed field to the equipartition level of $\approx 20\ \mu$G within a few 10^8 yr (second phase). In the epoch of *disk formation*, the turbulent field served as a seed for the mean-field (large-scale) dynamo in the disk (third phase).

We defined three characteristic timescales for the evolution of galactic magnetic fields: one for the amplification of the seed field, a second for the amplification of the large-scale regular field, and a third for the field ordering on the galactic scale (Arshakian et al. 2008). Galaxies similar to the *Milky Way* formed their disk at $z \approx 10$. Regular fields of equipartition (several μG) strength and a few kpc coherence length were generated within 2 Gyr (until $z \approx 3$), but field ordering up to the coherence scale of the galaxy size took another 6 Gyr (until $z \approx 0.5$). *Giant galaxies* had already formed their disk at $z \approx 10$, allowing more efficient dynamo generation of equipartition regular fields (with a coherence length of about 1 kpc) until $z \approx 4$. However, the age of the Universe is too young for fully coherent fields to have already developed in giant galaxies larger than about 15 kpc. *Dwarf galaxies* formed even earlier and should have hosted fully coherent fields at $z \approx 1$. *Major mergers* excited starbursts with enhanced turbulence, which in turn amplified the turbulent field, whereas the regular field was disrupted and required several Gyr to recover. Measurement of regular fields can serve as a clock for measuring the time since the last starburst event. Starbursts due to major mergers enhance the turbulent field strength by a factor of a few and drive a fast wind outflow, which magnetizes the intergalactic medium. Observations of the radio emission from distant starburst galaxies can provide an estimate of the total magnetic-field strength in the IGM.

This evolutionary scenario can be tested by measurements of polarized synchrotron emission and Faraday rotation with the SKA. We *predict*: (i) an anticorrelation at fixed redshift between galaxy size and the ratio between ordering scale and galaxy size, (ii) undisturbed dwarf galaxies should host fully coherent large-scale fields at $z < 1$, spiral galaxies at $z < 0.5$, (iii) weak regular fields (small Faraday rotation) in spiral galaxies at $z < 3$, but possibly associated with strong anisotropic fields (strong polarized emission), would be signatures of major mergers.

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