Cosmic Magnetism

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Abstract

High–sensitivity, linear and circular polarization, large frequency range and good angular resolution are characteristics of the SKA which will allow a much deeper insight in all topics of Cosmic Magnetism. More specific goals will be: magnetism and cosmology, nearby galaxies, the so called fan region, the physics of AGN jets and cosmic ray anisotropies.

1 Introduction

Considering the possibilities of SKA, we have two types of objectives: general and particular. On one hand we are interested in participating in the general goals of the SKA Working Group *Cosmic Magnetism*. We would address general topics considered in the collaboration as are the 3D distribution of magnetic fields in the Milky Way as well as fields in SNR and HII regions. We aim to study the turbulent power spectrum, mainly in the small angular scales, which is largely unknown, and for which SKA will provide unprecedented high resolution. Existing data of the Faraday depth of extragalactic sources will be highly improved with the great capability of SKA. The Milky Way can be considered a foreground for observations of magnetic fields at the epochs of Recombination and Reionization, thus overlapping our interests with those of the cosmological working group. We do not comment on the general purposes as basically coincide with those outlined by the international SKA Collaboration. We take the presentations in AASKA14 and [1] as the basic information about the general objectives of SKA in the field of cosmic magnetism. In order to understand how the magnetic fields are built up, wide band polarization spectral imaging will be a major contributor. SKA will make fundamental contributions to the study of magnetic fields in galaxies and clusters, thanks to its superb sensitivity, high polarization purity, large frequency range, high frequency agility and the possibility to observe large bandwidths with high spectral resolution.

On the other hand, our particular interests are focused on more specific goals which are outlined here.

2 Magnetism and cosmology

A precise description of the Faraday rotation in our Galaxy would permit us to better identify the regions where the detection of the rotated angle of polarization could have measurable effects to assess magnetic fields at the Recombination epoch (z=1100) and at the Reionization epoch ($z \sim$10). An accurate separation of the different components is crucial for this task. An upper limit of the magnetic strength at Recombination of 4 nG (comoving field) has been established by Planck [2], but future polarization data can give more precise upper limits. We could in turn obtain better constraints with the large capability of SKA. With respect the Reionization epoch (z <10) the possibility of detecting a direct Faraday signal cannot be disregarded yet. In this case, a correlation with the angular distribution obtained by SKA and LOFAR would provide observational clues to study the role of magnetic fields in the formation of the patched structures of ionized regions. At least, interesting upper limits could be established about this influence. This search would be related to the possible influence of magnetic fields in the formation of the large-scale structure.

After decoupling, magnetic fields may influence the thermal and ionization history of the Universe in two ways [3]. First, they can dissipate energy via ambipolar diffusion, due to the existence of a residual ionized component in the almost neutral plasma after decoupling. In addition, and for small enough scales, they can generate decaying magnetohydrodynamic turbulence, due to non-linear effects. These processes may affect the ionization history of the Universe, producing potentially measurable effects in the redshift evolution of the measured 21 cm line, but also creating distortions of the black-body spectrum of the cosmic microwave background (CMB) [4], and generating additional "Thomson optical depth" to CMB photons, which affect the the temperature and polarization power spectra at high multipoles [5, 6].

3 Fan Region

The study of the magnetic field distribution in the Milky Way is one of the main objectives of SKA. The high angular resolution, the high sensitivity and the inclusion of polarization of this large sky area would clearly permit the study of many particular features of subsystems in the Milky Way. A puzzling area is the so called *fan* region, which is probably a complicated structure (see [7]). This region is especially interesting because it is near the anti-center region, it is affected by a spiral arm, it has a very strong synchrotron emission and the order of the polarization vectors is highly noticeable. It contains a SNR but its size is small compared with the dimensions of the fan. A 3D dissection carried out by SKA could permit a better description of this region and to assess the role of magnetic fields in its structure

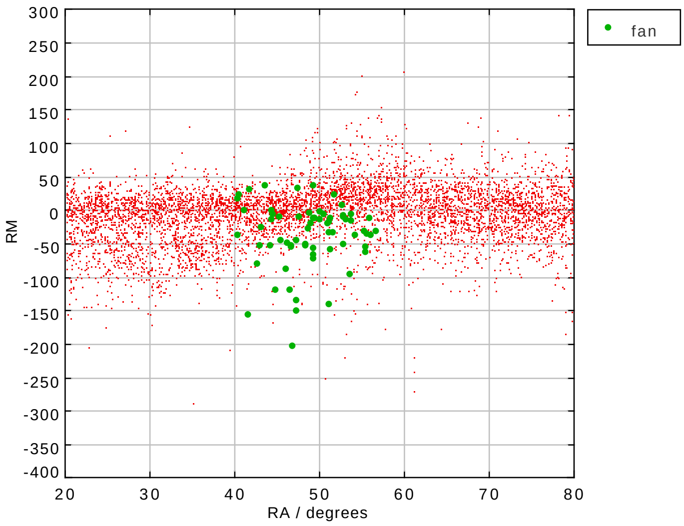

Figure 1: Faraday rotation measurement of pulsars in the Galaxy (red small points) and in the fan region (green large dots) showing that this region has peculiar magnetic properties. The data source was the ATNF Pulsar Catalog http://www.atnf.csiro.au/research/pulsar/psrcat/.

and dynamics. It cannot be disregarded that this region is enriched with extragalactic cosmic rays in the 10-100 TeV spectral region.

4 Other nearby galaxies

The objective of SKA covers about 30 nearby galaxies that could be observed in 3D, thanks to the different Faraday depths at different wavelengths. We would be particularly interested in assessing the magnetic field patterns in these galaxies, as they are clue to know the balance between pregalactic distributions (bisymmetric) or dynamo driven distributions (axisymmetric) [8]. Toroidal patterns could be explained by both mechanisms. The evolution of magnetic fields in galaxies is a controversial subject of which the observations of SKA could permit deeper understanding. Of particular interest is the role of magnetic fields in bars, because the strength is higher than in normal spirals, reaching values of about 40 μG [9]. The properties of the field in the upstream and the downstream regions divided by the bar shock are very different and the influence on star formation is far from being understood. Dynamical effects, including the feeding of the AGN are important but ignored.

5 Active Galactic Nuclei Jet Polarization Studies

As it has been described in detail by Agudo et al. (this book), and [10], SKA will allow to make a step forward in our understanding of extragalactic jet physics in general, and in particular of their magnetic fields: i) thanks to the high precision in the determination of the linear and circular polarization in AGN jets, it will be possible to characterize the relativistic-jet composition (electron-positron vs. electron-proton), particle acceleration and magnetic field configuration; ii) thanks to the determination of the magnetic field configuration, discriminate between different models for the relativistic jet formation, disk-launched jets or black hole launched jets; ii) thanks to the SKA multifrequency capabilities, it will be possible to estimate the plasma velocity, density and magnetic field for hundreds of relativistic jets; iii) thanks to the superb sensitivity of SKA, it will be possible to understand the physical differences between radio-loud and radio-quiet AGN populations; iv) thanks to multi-epoch polarimetric observations, it will also be possible to establish the location of the high energy bursts within the relativistic jets at a much wider range of radio luminosities than currently feasible.

6 Anisotropies in cosmic rays and magnetic fields

Regular toroidal fields in disky structures could constitute magnetic lenses, for charged Cosmic Ray (CR) particles [11]. The dimensions of the lens should depend on the field strengths and mainly on the energy of the incoming cosmic rays. The theoretical study of lenses and their properties compared with optical and gravitational lenses is simple but the identification of lenses in the real sky, with more or less degree of geometrical symmetry requires a more detailed description with a very large angular resolution. The interpretation of large and small scale anisotropies observed by CR telescopes such as Milagro or Hawk requires a precise knowledge of magnetic structures and their possible lensing effects [12].

7 Dynamical effects of magnetic fields at the rim of galaxies

Magnetic fields in the outer part of galaxies will be measured with unprecedent precision, because of the very large amount of foreground polarized extragalactic sources that can be measured. In principle, we could have a value of the strength for each extragalactic source, due to the Faraday Rotation. The outer part of spiral galaxies are expected to be more affected by the dynamic action of fields. One of the problems to be considered is the role of magnetic fields in the rotation curve. If ordered magnetic fields have strengths of the order of μG inside galaxies and of the order of μG outside, in the intergalactic medium, they must be of the order of μG in the most external galactic rim. Therefore, the Alfvén speed must increase exponentially, eventually reaching the order of the rotation velocity [13]. Other galactic features in the outer disk with a possible dynamical contribution of magnetic fields [14] (e.g., warps [15] and stellar truncations [16]) will be revisited with the high resolution of SKA.

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