The integrated polarization
of spiral galaxies

Jeroen M. Stil[1]**, Marita Krause**[2]**, Lydia Mitchell**[1]**, Rainer Beck**[2]
and A. Russell Taylor[1]

[1] Centre for Radio Astronomy, The University of Calgary, Calgary AB T2N 1N4, Canada
[2] Max Planck Institut für Radioastronomie, Auf dem Hügel 69, Bonn, Germany

Abstract. We present deep observations of polarized radio emission of distant spiral galaxies with the Effelsberg 100-m telescope† at 4.8 GHz. These cross scans with sensitivity of 50 μJy or better open the possibility of a statistical study of magnetic field properties and internal Faraday rotation as a function of inclination for a large sample of unresolved galaxies. The Square Kilometre Array (SKA) will be able to detect polarization of spiral galaxies to high redshift, probing the evolution of magnetic fields in disk galaxies over cosmic time.

Keywords. Galaxies: magnetic fields – galaxies: spiral – radio continuum: galaxies – polarization

1. Integrated polarization of spiral galaxies

The regular azimuthal magnetic field in spiral galaxy disks leads to polarized synchrotron emission, with locally observed values up to 40% polarized at 4.8 GHz. When an unresolved galaxy is observed at an angle with respect to the plane of the disk, the regular magnetic field projects into a net component in the plane of the sky, resulting in net polarized emission for the galaxy as a whole. Stil *et al.* (2008) presented observations and models of the polarization of the integrated radio emission of spiral galaxies at 4.8 GHz, with fractional polarization up to 17%. Figure 1 shows the sample of spiral galaxies without a bar (a) and with a bar (b) from Stil *et al.* (2008).

The curves in Figure 1 (a) and (b) represent axially symmetric models for the integrated polarization of spiral galaxies by Stil *et al.* (2008) that include depolarization by wavelength-independent depolarization, Faraday dispersion, and differential Faraday rotation (Sokoloff *et al.* 1998). Parameters in the model are the regular magnetic field B, the ratio of random to regular magnetic field strength $f_{\rm B}$, electron density n_e with filling factor f_i, thickness of the disk $2h$, and a turbulent scale length for rotation measure fluctuations $l_{\rm turb}$. A mean thermal fraction of 23% is assumed at 4.8 GHz (Condon & Yin 1990). From inclination $0°$ (face-on), to higher inclination, the degree of polarization initially increases as the regular magnetic field projects into a net component of the magnetic field in the plane of the sky. At inclinations higher than $\sim 60°$, Faraday depolarization dominates and the degree of polarization decreases with inclination.

The axially symmetric models successfully reproduce the observations in Figure 1a, but not in Figure 1b where large-scale magnetic fields along the bar add the orientation of the bar as an additional parameter that is currently not included in the models. An interesting feature of the models is the convergence of curves with the same value of $f_{\rm B}$ for inclinations less than $50°$. The uniformity of the magnetic field defines the polarized intensity almost everywhere in the disk, and thus the degree of polarization of

† The Effelsberg 100-m telescope is operated by the MPIfR on behalf of the Max-Planck-Gesellschaft
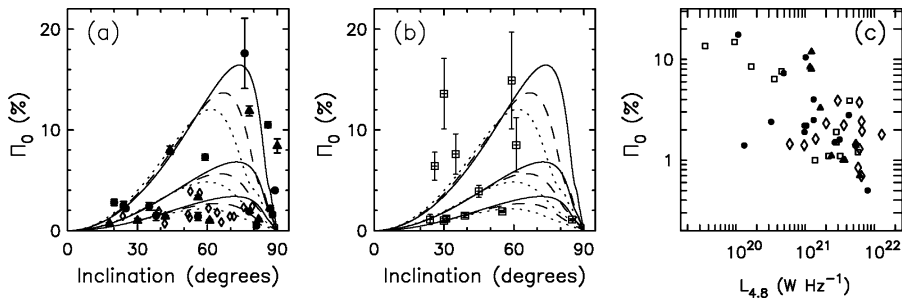
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Figure 1. (*a*) Integrated fractional polarization at 4.8 GHz of nearby spiral galaxies (dots), Virgo cluster spirals (triangles), and new Effelsberg observations of distant UGC spiral galaxies (diamonds). The curves represent axially symmetric models of the integrated polarization that include wavelength-independent depolarization Faraday dispersion and differential Faraday rotation. Upper solid curve: $B = 5$ μG, $f_B = 1.0$, $n_e = 0.03$ cm^{-3}, $f_i = 0.5$, $l_{turb} = 50$ pc, $(2h) = 1000$ pc, thermal fraction is 0.23. Dashed curve: double the magnetic field B. Dotted curve: triple the electron density n_e. (*b*) The same as (*a*) for barred galaxies (squares). The model curves in (*b*) are shown for comparison with (*a*) only. (*c*) Anti-correlation between fractional polarization and 4.8 GHz luminosity.

the integrated emission. This is a feature of models at frequencies more than a few GHz, where Faraday dispersion and differential Faraday rotation are relatively unimportant for low inclinations.

Figure 1c shows an anti-correlation of fractional polarization of the integrated emission with radio luminosity. This anti-correlation suggest that the magnetic field of luminous galaxies is less uniform, possibly because of a higher star formation rate.

Figure 1 also shows 14 galaxies observed in deep cross scans at 4.8 GHz with the Effelsberg telescope shown as diamonds. These galaxies are Milky Way size spiral galaxies at distances of several tens of Mpc selected from the Uppsala General Catalog (UGC) and detected in the NVSS with a 1.4 GHz flux density of 20 mJy or higher. The angular size of these galaxies is smaller than the 2.5′ beam of the Effelsberg telescope at 4.8 GHz. A sensitivity of 50 μJy beam^{-1} can be obtained with 1 hour total observing time per galaxy. This makes it possible to observe a large sample of galaxies for a statistical analysis of magnetic field uniformity and Faraday depolarization.

2. Evolution of Magnetic fields in disk galaxies

The Square Kilometre Array (SKA) will be able to detect polarization of radio sources fainter than 100 μJy, most of which are distant star forming galaxies. Although high-redshift galaxies will be mostly unresolved, polarization of their integrated emission provides information on the uniformity of their magnetic field and the amount of Faraday rotation. Our Effelsberg observations, when completed, will be part of a local comparison sample for galaxies at high redshift. Such observations will test large-scale dynamo models such as the turbulent dynamo at high redshift (Arshakian *et al.* 2008).

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