Proceedings of ICRC 2001: 2378 © Copernicus Gesellschaft 2001

ICRC 2001

Magnetic field structure in NGC 5775 from radiocontinuum polarization

R-J. Dettmar, M. Soida, R. Tüllmann, and M. Urbanik

Astronomisches Institut, Ruhr Universität Bochum, Germany

Astronomical Observatory, Jagiellonian University Krakow, Poland

Abstract. We present results of a recent radiocontinuum polarization study of the spiral galaxy NGC 5775 with regard to its large scale magnetic field structure and discuss the influence of the observed magnetic field on cosmic ray propagation.

Our analysis is based on Very Large Array data at 4.85 GHz and 1.49 GHz. We found that regular magnetic fields extend beyond 2 kpc from the mid-plane of the galaxy into the halo and possess a substantial component oriented perpendicular to the plane. In particular, the magnetic field forms X-shaped vertical extensions with a field direction parallel to Hα emitting spurs of ionized gas. The analysis of Faraday rotation between the mentioned frequencies suggests a dipolar magnetic field, in agreement with a rigid rotation curve of NGC 5775 which is implied by our Hα velocity field.

We suggest that vertical magnetic field components support the gas and cosmic ray transport along the magnetic lines from the disk into the halo. Magnetic reconnection may also contribute to the heating balance for halo gas.

1 Introduction

The discussion and validation of cosmic ray (CR) propagation models in galaxies requires a good knowledge of the magnetic field structure. Especially the study of cosmic ray streaming into the galactic halo depends on the information on vertical magnetic fields, as CR particles are most easily transported along magnetic field lines. So far only very few cases of a vertical magnetic field structure have been found in radiocontinuum polarization studies of edge-on spiral galaxies (Beck et al. 1996) with NGC 4631 being the best studied example (Golla & Hummel 1994). In this paper we present another case of a galaxy with well documented vertical magnetic field components extending beyond 2 kpc into the halo.

Correspondence to: R-J. Dettmar (dettmar@astro.ruhr-uni-bochum.de)

2 The radio data

The total power and polarization maps of NGC 5775 at 4.86 GHz and 1.49 GHz were made from archive data of the Very Large Array (VLA) of the National Radio Astronomy Observatory (NRAO)[1]. All data were recorded during the period 1989–1994. Data reduction has been performed using the standard AIPS package. We attained the noise levels of 16 μJy and 100 μJy in total power and 7 μJy and 20 μJy in polarization at 1.49 GHz and 4.86 GHz, respectively. NGC 5775 is found to possess a total power radio halo that can be traced considerably beyond 2 kpc (Fig. 1 left panel, see also Beck 1991). Its extent is roughly coincident with that of the Hα envelope. Some total power extensions are visible in the direction of spurs of ionized gas visible in our Hα map (Tüllmann et al 2000). They are also visible in our map at 1.49 GHz, thus they are of nonthermal origin.

The polarized emission makes four extensions into the halo, also coincident with Hα and total power spurs (Fig. 1 right panel), forming a characteristic X -like pattern. In this respect the halo of NGC 5775 resembles that of NGC 4631 (Golla & Hummel 1994, Beck 2000). The observed polarization B-vectors at 4.86 GHz are roughly parallel to the disk in the plane and highly inclined (45°–90°) at a projected distance z $\geq$ 20" from the plane. The B-vectors in the halo are parallel to the orientation of extensions and thus form a X -like structure, too. In the disk plane there is a depolarized "valley" along which the vectors meet at right angles.

At 1.49 GHz the degree of polarization in the disk plane is very low and frequent jumps in Faraday rotation measure (RM) indicate that the galaxy is Faraday thick at this frequency (vectors rotate by more than 90°). This makes the low frequency data useless to compute Faraday rotation measures close to the galactic midplane. A simple model estimate gives an electron density of $n_e \simeq 0.03\,\mathrm{cm}^{-1}$ and a uniform field strength of 2 μG in the edge-on position (large

[1]NRAO is a facility of National Science Foundation operated under cooperative agreement of Associated Universities Inc.

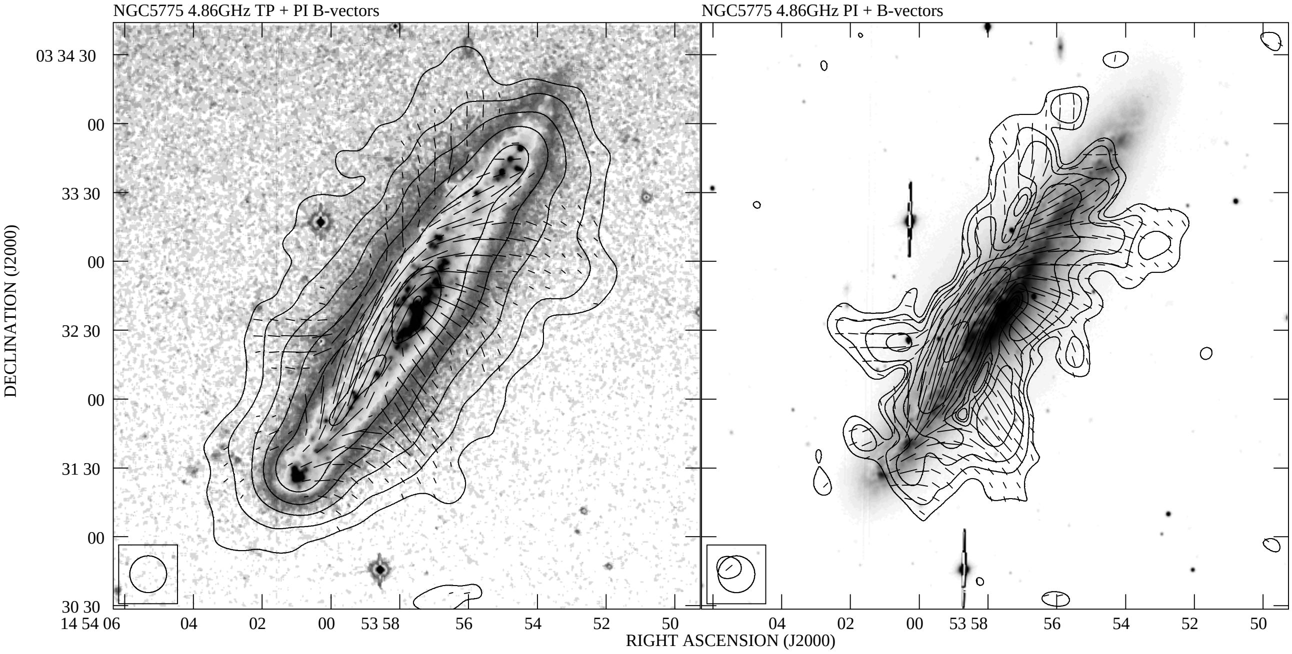

Fig. 1. VLA radio continuum at 4.86 GHz maps with total power contours (left) as well as contours of polarized intensity (right) and with observed B-vectors of polarized intensity overlaid onto the Hα image of NGC 5775. Contours are 3, 8, 21, 55, 144, 377 and 610 $\times$ 16 μJy for total power and 3, 5, 8, 13, 21 and 34×7 μJy for polarized intensity. The B-vectors of length of 1" correspond to 10 μJy. The beam size is 16"

pathlength!). NGC 5775 may become Faraday thick already at 4.86 GHz in agreement with the observed degree of polarization of $\leq$ 5% for the inner disk at this frequency.

A different situation exists in the halo for $z > 1$ kpc. Here we find a good agreement of the B-vector orientation at both frequencies with substantially higher degree of polarization even at the low frequency. This indicates a Faraday-thin regime already at 1.49 GHz and thus, even if the polarization position angle differs between 4.86 GHz and 1.49 GHz by several tens of degrees, this implies a Faraday rotation bias at 4.86 GHz of a few degrees only with the possibility to obtain reliable Faraday rotation measures.

3 Discussion

The existence of vertical magnetic field components in and/or above galactic disk is crucial for the problem of cosmic ray propagation from the disk to the halo. In particular, the cosmic ray electrons are expected to stream mostly along the magnetic filed lines. As beyond z of $\pm$ 1 kpc the Faraday rotation bias at 4.86 GHz does not exceed a few degrees we state that in the presented case of NGC 5775 the halo is dominated by vertical magnetic fields. This could be the reason for the X -shaped distribution of polarized intensity (Fig. 1 right panel). This seems to be supported by the existence of total power spurs, particularly visible after applying the digital filter to our total power maps (see Tüllmann et al 2000).

On larger scales the vertical magnetic field component can have two kinds of symmetry of different importance for the cosmic ray propagation. It can constitute either a part of global quadrupole-type or dipole-type poloidal field. In the first case the magnetic field lines make separate vertical loops above and below the disk plane being mostly disk-parallel below z of 1 kpc. In this case cosmic ray electrons – produced mostly in a thin disk of remnants of type II supernovae – need to be efficiently transported across a layer of disk-parallel field structures or some contribution from CR sources at larger heights is needed. In the second case the magnetic field lines cross the disk plane providing a direct link from the galactic midplane into the halo.

These models cannot be simply discriminated by the fact that the observed B-vectors are disk-parallel close to the galactic plane. As shown above, this region is Faraday-thick already at 6 cm and the B-vector directions cannot be trusted, especially as we see their sudden change of orientation across the unpolarized region. We tried to use the fact that for the quadrupole magnetic field the azimuthal (toroidal) field has the same direction above and below the galactic disk which yields the same sign of Faraday rotation above and below the disk plane in a given disk half. We averaged the Faraday rotation measures in four rectangular areas parallel to the disk plane placed symmetrically on both sides of the minor axis above and below the disk (excluding $|z| <1$ kpc). The values are presented in Fig. 2. We found positive RM above the SE and below the NW major semi-axes, as well as negative ones below the SE and above NW major semi-axes. This is typical for a large-scale azimuthal field with magnetic lines running around the disk but reversing across the plane, typically associated with a poloidal field of *dipolar* structure. We note that

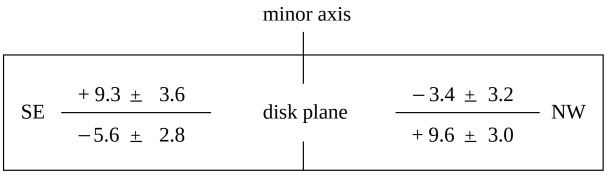

Fig. 2. Faraday rotation measures as determined in four rectangular areas parallel to the disk plane placed symmetrically on both sides of the minor axis above and below the disk

NGC 5775 rotates rigidly and has a large envelope of ionized gas (see Tüllmann et al. 2000) which makes the dipolar mode much easier to be excited than in differentially rotating systems where the quadrupolar field is preferred (Krause & Beck 1998 and references therein). We note that a dipolar field is postulated for the inner part of our Galaxy by Han et al. (1997) and for NGC 4631 (Beck 2000). Nevertheless, the deviations of the mean RM from zero is of order 2.5–3σ, as the toroidal field is usually weak above a z-height of 1 kpc. A definite proof that NGC 5775 possesses a dipolar magnetic field with magnetic lines crossing the disk plane, thus making the CR streaming from a thin disk of sources to the halo much easier, needs better data at higher frequencies where the effects of Faraday rotation are much smaller.

Acknowledgements. We express our gratitude to numerous colleagues from the Astronomical Observatory in Kraków for valuable discussions and to R. Beck for critical comments on the manuscript. This work was partly sponsored by the grant from Polish Research Committee (KBN), grant no. PB4264/P03/99/17. Our collaboration is supported by the academic exchange program between the Universities of Bochum and Kraków.

References

Beck R., 1991, in *The Interstellar Disk-Halo Connection in Galaxies*, ed. H. Bloemen, Kluver p. 267

Beck R., Brandenburg A., Moss D., Shukurov A., Sokoloff D., 1996, Ann. Rev. A&A 34, 155

Beck R., 2000, Phil. Trans. R. Soc. Lond. A 358, 777

Golla, G., Hummel, E., 1994, A&A 284, 777

Han J. L., Manchester R. N., Berkhuijsen E. M., Beck R., 1997, A&A 322, 98

Krause F., Beck R., 1998, A&A 335, 789

Tüllmann R., Dettmar R-J., Soida M., Urbanik M., Rossa J., 2000 A&A 364, L36