THE MAGNETIC FIELD IN EDGE-ON GALAXIES.

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ABSTRACT. We observed the linearly polarized emission of the edge-on galaxies NGC891 and NGC4631 in order to determine the magnetic field structure.

INTRODUCTION.

Edge-on spiral galaxies are obviously ideal objects to study the distribution of the radio continuum emission perpendicular to the plane (z-direction). Since the radio emission at ~1GHz is predominantly synchrotron emission we can study *i)* the propagation of the cosmic rays, in particular the electron component, out of the plane and *ii)* the strength and structure of the magnetic field (B-field) away from the plane. From an interpretational point of view these topics are related. The propagation and (non-) confinement of the relativistic electrons in the radio halo depend on the properties of the B-field. On the other hand, processes, like galactic winds, that influence the propagation of the the relativistic electrons, but also just the presence of cosmic rays, have an effect on the B-field. They can, in addition to large scale dynamo activity, give rise to a well structured B-field in the radio halo.

Since the first, unambigious, discovery of a large scale radio halo in NGC4631 (Ekers and Sancisi, 1977) it was clear that there *can* be significantly strong B-fields at z>5kpc. However, it is not clear yet how common this is. Of the ~10 relatively well studied edge-on galaxies *only* NGC891 and NGC4631 show clear evidence for radio emission at z>5kpc. This could be due to the finite sensitivity of the observations. Note that Beuermann *et al.* (1985) presented a two-disk model for the unresolved galactic radio emission in which the thick disk component (radio halo) has a full equivalent width of up to 6kpc. Since the Galaxy is a moderate radio emitter one could speculate that radio halos with B-field strengths $\geq 1\mu$G are quite common.

Because of their large z-extent, NGC891 and NGC4631 have been selected for observations of their linearly polarized emission in order to determine the B-field structure. In both galaxies significant linearly polarized emission at large distances from the plane has been detected. The total and polarized intensity maps of NGC4631 are shown in Hummel *et al.* (1988).

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OBSERVATIONS AND RESULTS.

The galaxies were observed with the VLA in its most compact configuration (D-array) and at 1.5GHz. The resulting resolution is 40″ and the rms noise is 0.025 and 0.015mJy/beam for NGC891 and NGC4631, respectively. The higher noise in case of NGC891 is due to the shorter observing time and the presence of 3C66 ~40′ north of NGC891.

NGC891 shows polarized emission on both sides of the optical major axis. The largest z-extent of ~3′ is found in the south-western part. Here the degree of polarization ($P_{\%}$) is 15→20%. In other areas of the radio halo (1′<z<2′) $P_{\%}$ ~5%. At the major axis $P_{\%}$ drops below 1%. The observed E-vectors show a regular structure on scales of 2′→3′.

In case of NGC4631 the polarized emission extends to z~4′ and the strongest polarized emission and highest degree of polarization ($P_{\%}$=20→25%) is found in the north-east. At other locations in the radio halo (1′.5<z<4′) $P_{\%}$=5→10% . Again, at the major axis $P_{\%}$ is <1% . The observed E-vectors show regular structures on scales of 2′→4′. The most regular structure is seen in the north-east.

There is as yet no information on the *internal* rotation measure (RM_g). From background sources within 10° of the galaxies we determined the *foreground* rotation measure (RM_{fg}). They are −72±5 and −9±3 rad/m^2 in the direction of NGC891 and NGC4631, respectively. With the *assumption* that RM_g is negligible at high z we can determine the B-field structure in the radio halo. To avoid regions where RM_g is high we did the correction for RM_{fg} only in those regions with $P_{\%}$ >5% . Figure 1 shows the deduced B-field vectors.

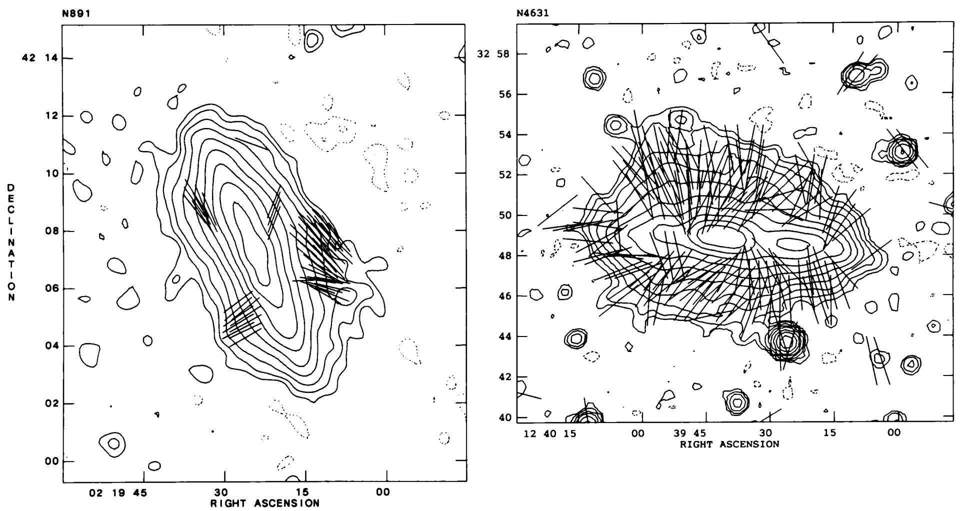

Figure 1: *The 1.49GHz total intensity maps of the galaxies NGC891 and NGC4631. The superposed vectors are the B-field vectors. Note that they have only been corrected for the foreground rotation measure, not for the internal rotation measure.*

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The main region in NGC891 where $P_{\%}$ >5% is in the south-west. There the B-vectors make an angle of ~30°→80° with the optical major axis. They are alligned in the direction of the extension seen in the total intensity maps. In this region we derive a total B-field strength (B_t) of ~4μG and the uniform component (B_u) has 1→3μG. We do not yet know the direction of the B-field.

A large fraction of the radio halo of NGC4631 shows $P_{\%}$ >5% . Correcting the observed E-vectors for the small RM_{fg} and converting them to B-vectors gives NGC4631 a real "edgehog" appearance. The B_u-field shows a regular structure, and there is a significant z-component almost everywhere in the radio halo. The best ordered field is found in the north-east where the B-vectors make an angle of ~70° with the optical major axis. At z=5kpc we derive B_t=5μG and B_u ~2μG.

CONCLUDING REMARKS.

NGC891 and NGC4631 are the *first* galaxies for which information on the B-field at high z has become available. So far the observations of the linearly polarized emission have been done mainly at 1.5GHz and this obviously limits the study of the B-field structures. However, investigations at other frequencies are being carried out. Further, there are some projects that try to extent this kind of study to other edge-on galaxies. A similar remark can be made concerning the studies of the propagation of relativistic electrons out of the plane, which also focus on NGC891 and NGC4631.

The latter studies (Hummel *et al.* , in preparation) show that the spectra of the integrated radio emission and the radio spectral index distributions of NGC891 and NGC4631 are at least *consistent* with galactic wind models. Hummel *et al.* (1988) suggested that the extraordinary bright and extended radio halo of NGC4631, and also its well structured B-field is due to strong streaming motions perpendicular to the plane. These could be due to the gravitational interaction between NGC4631 and NGC4656 (see Weliachew *et al.* , 1978). It should also be noted that possibly the star formation rate in NGC4631 is higher than in NGC891. Such a higher star formation rate could also result in a more effective galactic wind. Hence it seems that, at least in NGC4631, convection perpendicular to the plane has to be taken into account when explaining the B-field structure in the radio haloes.

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F. KRAUSE: Do you have information concerning the direction of the B-field vector: i.e. the same direction above and below the plane or opposite?

HUMMEL: Unfortunately we do not yet have such information. This requires multifrequency observations which are underway. This will hopefully enable us to determine the internal rotation measure and hence the direction of the B-field.

BELVEDERE: What is the physical mechanism for the onset of convection out of the plane of a galaxy?

HUMMEL: The onset for convection (galactic winds, galactic fountains) is presumably the heating of the interstellar matter by recent star formation and supernova explosions and the presence of the cosmic rays. This has been discussed in more detail by Völk on this symposium.

VÖLK: Naively speaking the increase of the degree of polarization with z would imply that the B-field becomes more regular with increasing z. Could you comment on that?

HUMMEL: Before trying to interprete the change of the observed degree of polarization with z one has to consider *i)* the observed distribution has to be corrected for the beam broadening, *ii)* close to the galaxy's plane one expects a lot of Faraday depolarization, which probably decreases with z and *iii)* if the B-field in the plane of the galaxy is mainly in the x-y plane but in the halo mainly in the z-direction then there is a range in z where beam depolarization affects the z-distribution of $P_{\%}$. Hence to study $P_{\%}(z)$ requires also multifrequency observations. By the way, *in principle* such observations could also be used to determine the z-distribution of the thermal radio emission and hence the distribution of the thermal electrons. This would of course be important for an evaluation of the Faraday depolarization.

KUNDT: A warning word concerning the hope to see cosmic-ray electrons escape into the galactic halo: to my knowledge, the best-studied galactic chimney is the one 'above' the HII-region S54, which is so far only seen by its *thermal* radio emission. If the relativistic electrons escape in a streaming mode rather than diffusive mode, their escape cannot be mapped directly (1987, Astrophys. Space Sci. **136**, 281).

HUMMEL: Note that the chimneys, possibly visible as dust streaks perpendicular to the major axis, of NGC 891 have not been mapped yet at radio frequencies because of lack of resolution and sensitivity. Further, I think that it is possible to map the escape, even if it is in a streaming mode. Provided there is a strong enough B-field the different modes of propagation can be studied by spectral index studies.