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Can we observe the poloidal magnetic field?

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Abstract

We present results of radio continuum observations of a few edge-on spiral galaxies. Observed polarization magnetic vectors follow the X-shaped pattern, sticking out of the galactic plane far into the halo. The picture seem to be common among galaxies seen edge-on. In the most cases the magnetic vectors are plane parallel close to the galactic disk and the whole pattern resembles poloidal component of the dynamo-produced magnetic field. The best studied case of NGC 5775 show that the picture is well free of the Faraday effects.

1 Introduction

Looking at nearly face-on spiral galaxies in continuum emission at radio feequencies we see more or less regular spiral structure of magnetic vectors of polarized emission (see e.g. Beck or Urbanik this volume). Such configuration can be attributed to magnetic field close to the galactic plane, being "illuminated" by relativistic electrons spiraling around field lines and emitting synchrotron radiation.

The magnetic field configuration itself can be explained by galactic dynamo mechanisms. Very simplified dynamo-made magetic field consists of thoroidal component with substantial radial component (inclined to the azimuthal direction) in the vicinity the galactic disk, but also a poloidal (with dipolar or quadrupolar symmetry) magnetic field component extending far into the galactic halo (see e.g. Widrow 2002).

If global galactic magnetic field is made due to some kind of dynamo mechanism, and if there are enough relativistic electrons away from the galactic plane we shall be able to detect synchrotron radiation in galactic halos while observing edge-on spiral galaxies.

2 Observations

2.1 NGC 5775

The most clear picture so far of polarized radio emission of edge-on galaxy NGC 5775 can be seen in Tüllmann et al (2000) and is reproduced here as Fig. 1.

Detectable radio continuum seen at 4.86 GHz extends far into the galactic halo (up to about 10 kpc from the galactic plane) having significant polarization degree reaching 50% in some places.

Polarization magnetic vectors, close to the galactic plane, form plane parallel configuration, and X-shaped structure in all four quadrants in the halo of the galaxy. It is better seen on the polarized intensity map (Fig. 1 right) where magnetic vectors follow ridges of polarized emission intensity.

The X-shaped polarized emission intensity distribution seem to follow the Hα filaments. This fact and the very high star formation rate of this object (Lee et al. 2001) can lead to the

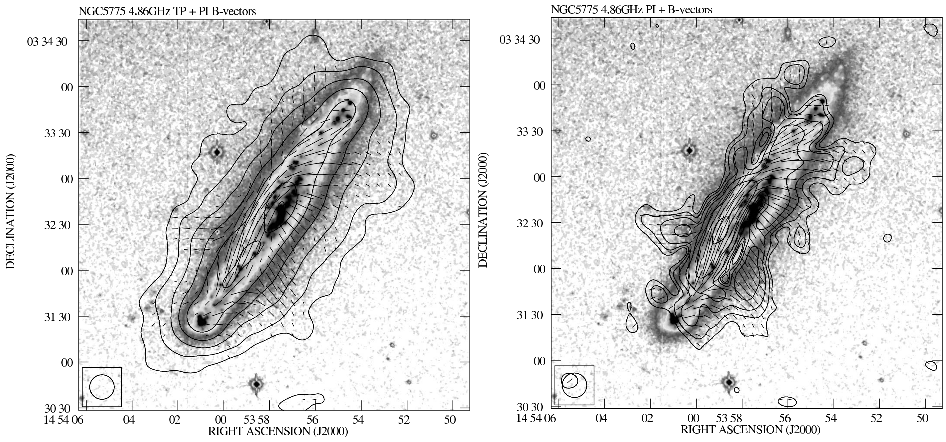

Figure 1: Radio continuum emission at 4.86 GHz of NGC 5775. Total intensity (left) and polarized intensity (right) contours with apparent polarization B-vectors proportional to the polarized intensity, both ovarlaid onto the Hα image (digitally processed to see faint extensions in the galactic halo)

concluson, that the observed magnetic field configuration is caused by galactic wind blowing out of the galaxy and pooling magnetic field lines out of the disk along the Hα filaments, and thus ordering it (seen as enhanced polarization degree).

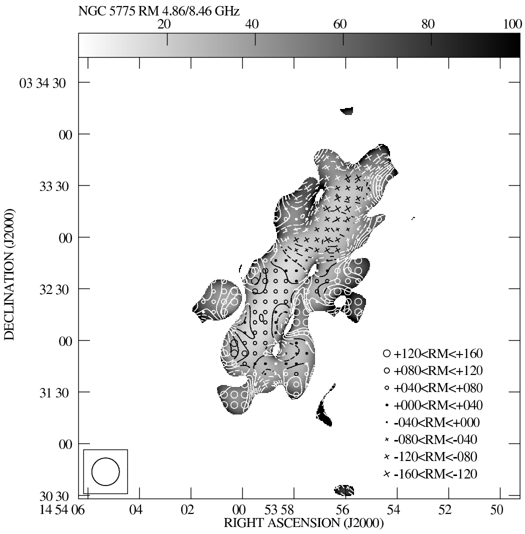

Figure 2: Faraday rotation measure distribution of NGC 5775 calculated between 8.46 and 4.86 GHz shown as symbols (and contours), overlaid onto the uncertainty of this quantity shown as gray-scale

An argument against the hypothesis described above comes from the Faraday rotation distribution. Using the VLA[1] we obtained deep polarized continuum map of NGC 5775 at

[1]Very Large Array of the National Radio Aastronomy Observatory is a facility of National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

8.46 GHz, and calculated the Faraday rotation measure distribution between this frequency and 4.86 GHz (Fig. 2).

The Faraday rotation measure is relatively small close to the galactic plane, with respect to the value one can expect taking into account long path-length through the entire galactic disk, and it shows some east-west asymmetry. However, in the most interesting areas, in the X-shaped extensionsn it is high, reaching $100\,\mathrm{rad/m^2}$. This situation is barely visible in the nothern part of the galaxy, but is clear in the southern part, in places where Hα filaments are more prominent.

It means, magnetic field in the extensions is highly *unidirectional*, and as such it is unlikely, that the field is simply stretched away by the galactic wind. Some other magnetic field ordering mechanism is needed. Galactic dynamo is the best candidate here.

2.2 NGC 4666

Very similar apparent magnetic field configuration shows another violently star-forming galaxy NGC 4666. Its radio continuum emission ontop of the optical image is presented on Fig. 3.

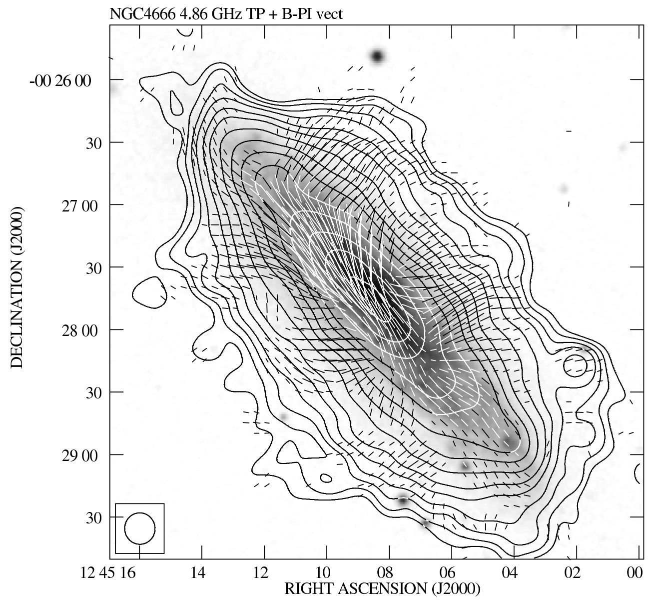

Figure 3: Contour total power intensity plot of NGC 4666 at 4.86 GHz with apparent polarization magnetic vectors proportional to the polarized intensity, overlaid onto the optical blue image from the DSS

Apparent (not corrected for Faraday rotation) polarization magnetic vertors form again plane parallel structure close to the disk and the forest of vectors sticking out of the galactic center, similar to the NGC 5775, X-shaped structure, extending far out of the visible optical image.

However, more solid discussion on that case needs again Faraday rotation information and could be done after deep poarization observing at another (higher) frequency. Existent VLA data at 1.49 GHz suffer high depolarization (probably mostly Faraday) efects.

2.3 NGC 4217

Another edge-on spiral galaxy NGC 4217 forms stars much less violently than previous examples. Its absolute inrfrared brightness is $\sim 2^m$ lower. Nevertheless, its poarization apparent magnetic vectors orientation forms again the same X-shaped configuration.

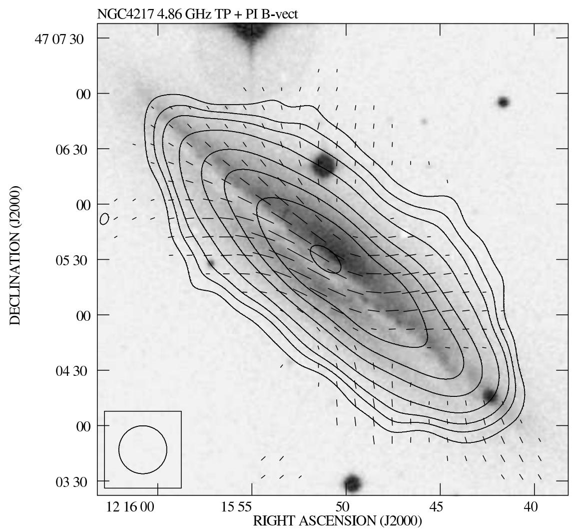

Figure 4: Contour total power intensity plot of NGC 4217 at 4.86 GHz with apparent polarization magnetic vectors proportional to the polarized intensity, overlaid onto the optical blue image from the DSS

The continuum total intensity together with apparent magnetic vectors and optical image of NGC 4217 is presented on Fig. 4. Again, analysis on other radio frequency would be very helpful. So far, data at 1.49 GHz are of limited sesitivity, and we can only state here, that Faraday effects seem to be much less important than in case of NGC 4666.

Immediate question rises up concerning this galaxy – what mechanism orders magnetic field far out of the galactic disk, and what is even more interesting what provides relativistic electrons good number of kiloparsecs away of the galactic disk in case of such low star formation rate.

Answer to the first question can be constructed with the help of some galactic dynamo action, though the second one remains open.

2.4 Other examples

Galaxies discussed so far present common picture of plane parallel magnetic vectors close to the galactic plane and X-shaped magnetic in some distance from it. Such configuration fits well into the quadrupoloidal dynamo-produced magnetic field structure. There are other similar cases like NGC 891 or NGC 3628 with star formation rates somewhere between the extreme cases NGC 4217 and NGC 4666. They also suggest quadrupoloidal magnetic field configuration (Fig. 5)

But there are exceptions as well. Fig. 6 presents total intensities contour plots with apparent magnetic vectors of polarized intensities of two of them. NGC 4631 (Fig. 6 left) is a starburst galaxy and it shows well known X-shaped magnetic field configuration, but with apparent magnetic vectors *crossing* the disk plane at almost right angle. This can be attributed to dipoloidal symmetry and thus still fits into the dynamo-produced magnetic field.

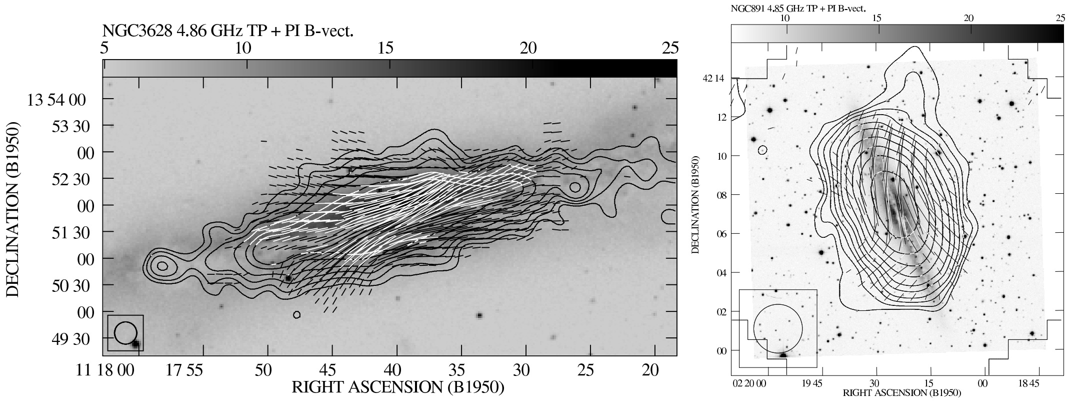

Figure 5: Total intensity contour plots of NGC 3628 (left) and NGC 891 (right) together with apparent magnetic vectors proportional to the polarized intensities and overlaid onto their respective optical images (from the DSS). Radio data of NGC 891 are from M.Krause (priv. comm.)

The other example (Fig. 6 right) is NGC 4565. Its infrared index (in LEDA database) is comarable with that for NGC 5775, but shows no radio emission at 4.86 GHz beyond the optical boundaries at all. Apparent magnetic vectors close to the galactic plane form a picture without any particular symmetry. Most probably significantly preprocessed by Faraday effects.

3 Summary

Polarized emission observations at radio frequencies shown here provide informations of magnetic field configuration far in the galactic halo.

- in most cases magnetic field lines form apparent structure of quadrupolar symmetry, being plane-parallel close to the galaxy plane and pointing diagonally in all four quadrants making X-shaped structure away from the plane
- Faraday rotation data suggest, that the apparent structure resembles well true magnetic field configuration, and only locally can be affected by rotation effects
- the magnetic field configuration of such symmetry can be attributed to poloidal component of dynamo-produced (amplified and/or ordered) magnetic field
- other than quadrupoloidal magnetic field symmetry (as in NGC 4631) seems to be an exception, but still its dipoloidal symmetry can be explained by dynamo-made field component

Main question raised in this contribution concerns the mechanism of supplying relativistic electrons at large distances away from the obvious sources in the galactic plane. The synchrotron radiation is well traced in extreme cases more than 10 kpc from the plane, and large radio halo seem to not depend on the overall star formation rate of the galaxy nor on the strong galactic wind activity.

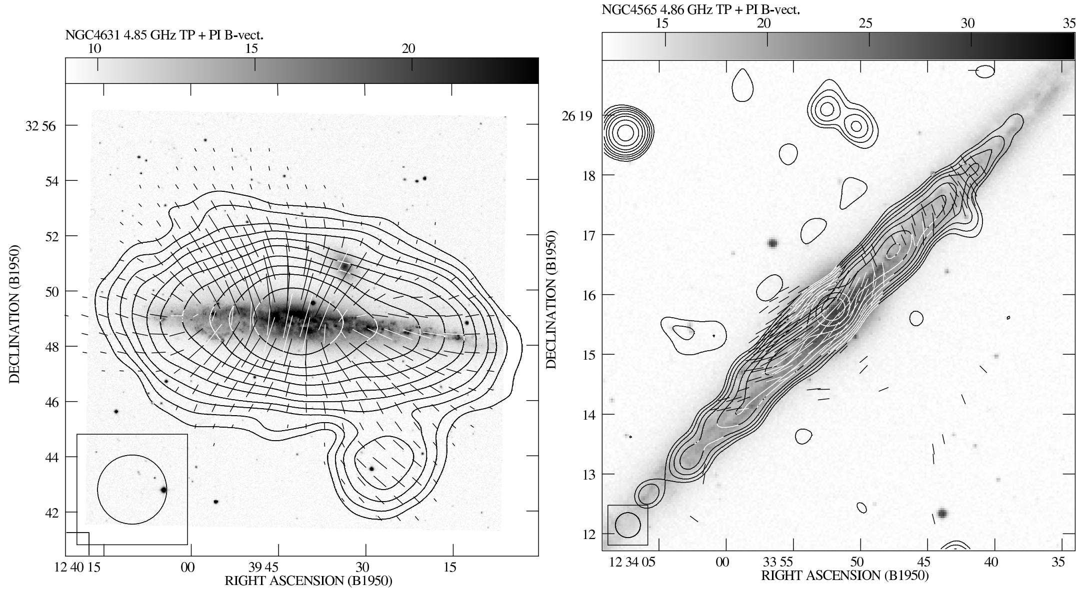

Figure 6: Total intensity contour plots of NGC 4631 (left) and NGC 4565 (right) together with apparent magnetic vectors proportional to the polarized intensities and overlaid onto their respective optical images (from the DSS). Radio data of NGC 4631 are from M.Krause (priv. comm.)

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