Magnetic Fields in Late-type Dwarf Galaxies

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Dwarf galaxies:

- dynamically simple, e.g. possess no strong density waves (Hunter et al. 1998, ApJ, 493, 595)
- the classical mean-field dynamo process meets difficulties as dwarfs often show slow or chaotic global rotation
- the turbulent dynamo may work if only star formation is present (Beck et al. 1994, A&A, 289, 94) but magnetic fields and star formation are related nonlinearily (Chyży 2008, A&A, 482, 755)
- their low masses may lead to a rapid magnetic field escape
- they constitute good laboratories to investigate magnetic field amplification processes. The question arises:

Is their ISM virtually unmagnetized?

Previous studies:

NGC 4449 (rather large - some 9 kpc in size, high SF):
- strong total (15 μG) and regular (8 μG) magnetic fields
- a spiral-like magnetic structure resembling that in spiral galaxies (Chyży et al. 2000, A&A, 355, 128).

IC 10 (small - ca. 1.5 kpc, high SF):
- no regular pattern of the magnetic field
- the total magnetic field strength reaches 15 μG (Chyży et al. 2003, A&A, 405, 513).

Large and Small Magellanic Clouds (Gaensler et al. 2005, Science, 307, 1610, recent studies - Mao et al. 2008, arXiv:0807.1532v1 [astro-ph]):
- weak total magnetic fields (1 - 5 μG).

Thus, we state:
- wide range of magnetic field strengths in dwarf galaxies
- lack of clarity: what really influences magnetic field generation processes?
- further radio observations are necessary!

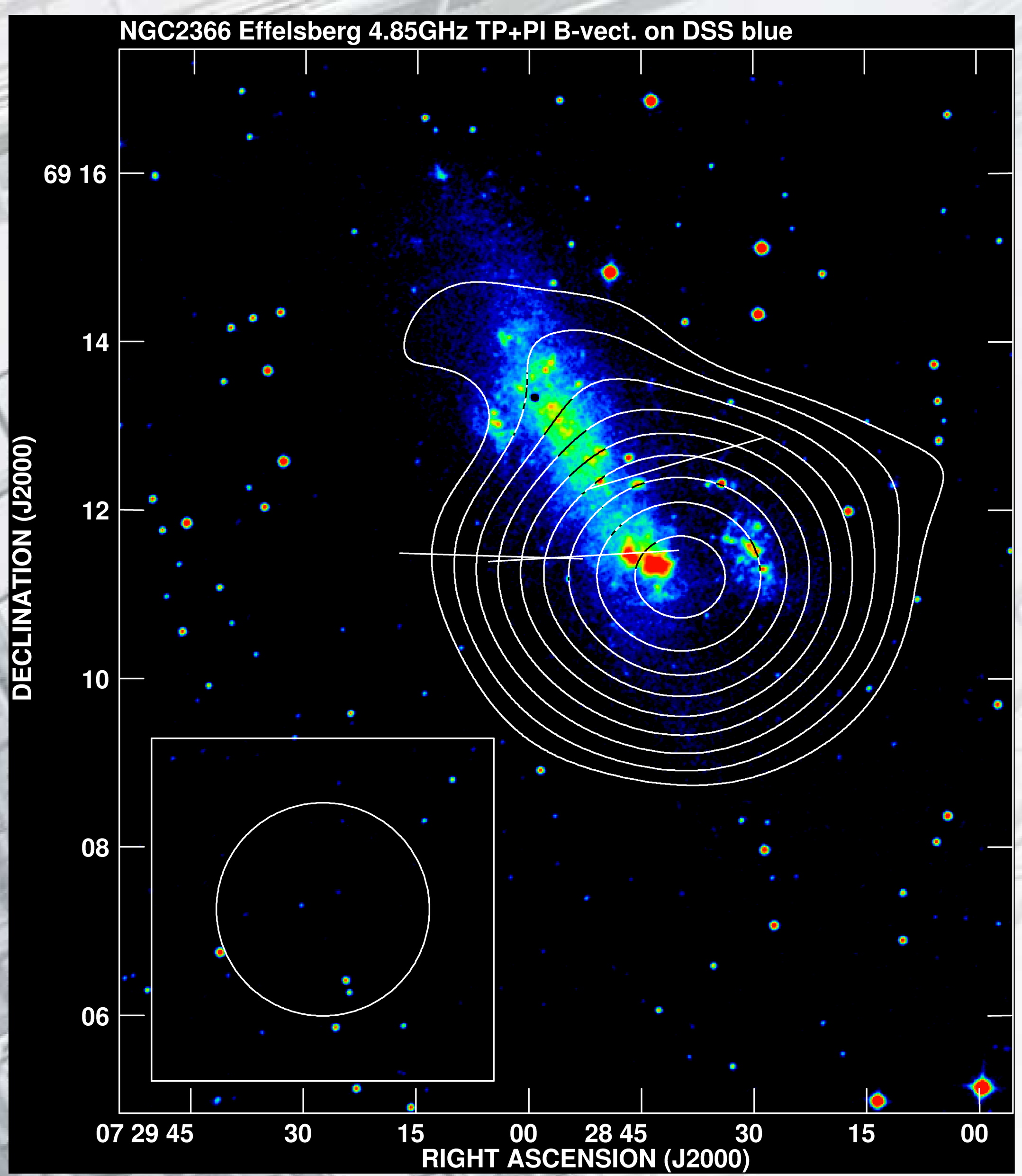

FIG. 1: Total power contours and B-vectors of polarized intensity of NGC 2366 at 4.85 GHz superimposed onto DSS blue image. The contour levels are (3, 5, 8, 12, 17, 23, 30, 38, 47) × 0.30 mJy/beam. A vector of 1′ length corresponds to a polarized intensity of 0.075 mJy/beam. The map resolution is 2′.5 HPBW.

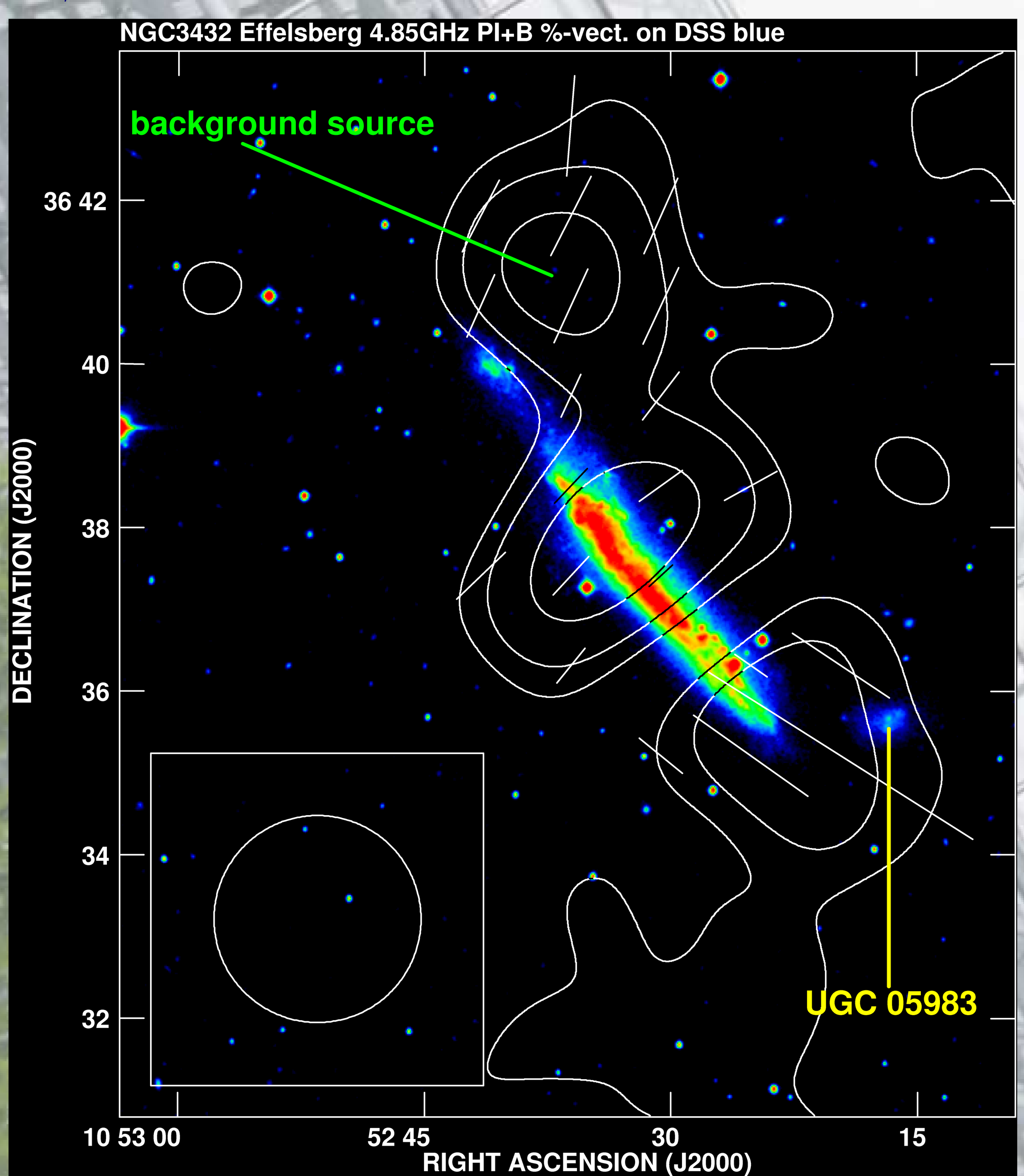

FIG. 2: Contours of polarized intensity and B-vectors of polarization degree of NGC 3432 at 4.85 GHz superimposed onto DSS blue image. The contour levels are (3, 5, 8) × 0.053 mJy/beam. A vector of 1′ length corresponds to a polarization degree of 3.8%. The map resolution is 2′.5 HPBW.

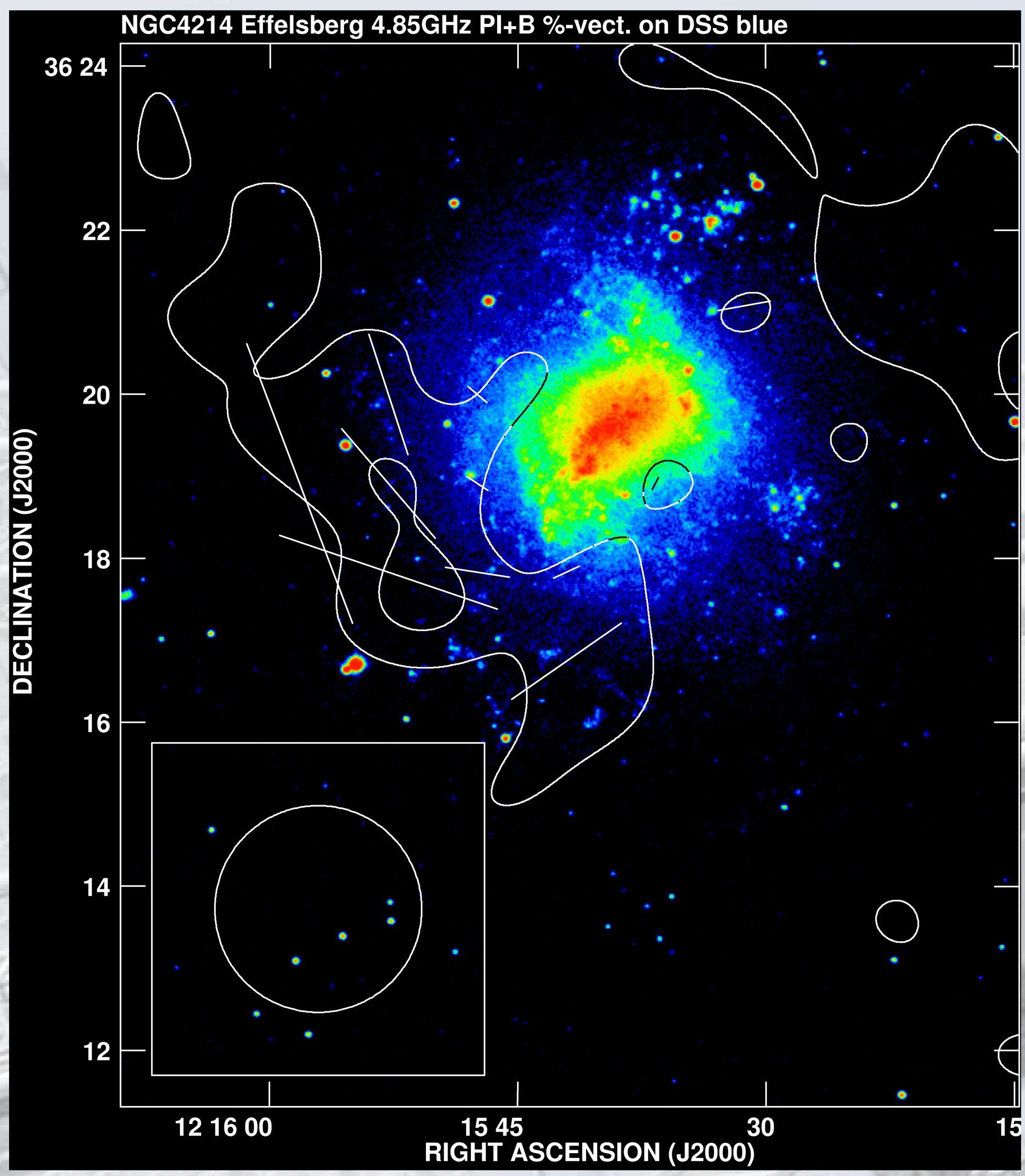

FIG. 3: Contours of polarized intensity and B-vectors of polarization degree of NGC 4214 at 4.85 GHz superimposed onto DSS blue image. The contour levels are (3, 5) × 0.045 mJy/beam. A vector of 1′ length corresponds to a polarization degree of 3.8%. The map resolution is 2′.5 HPBW.

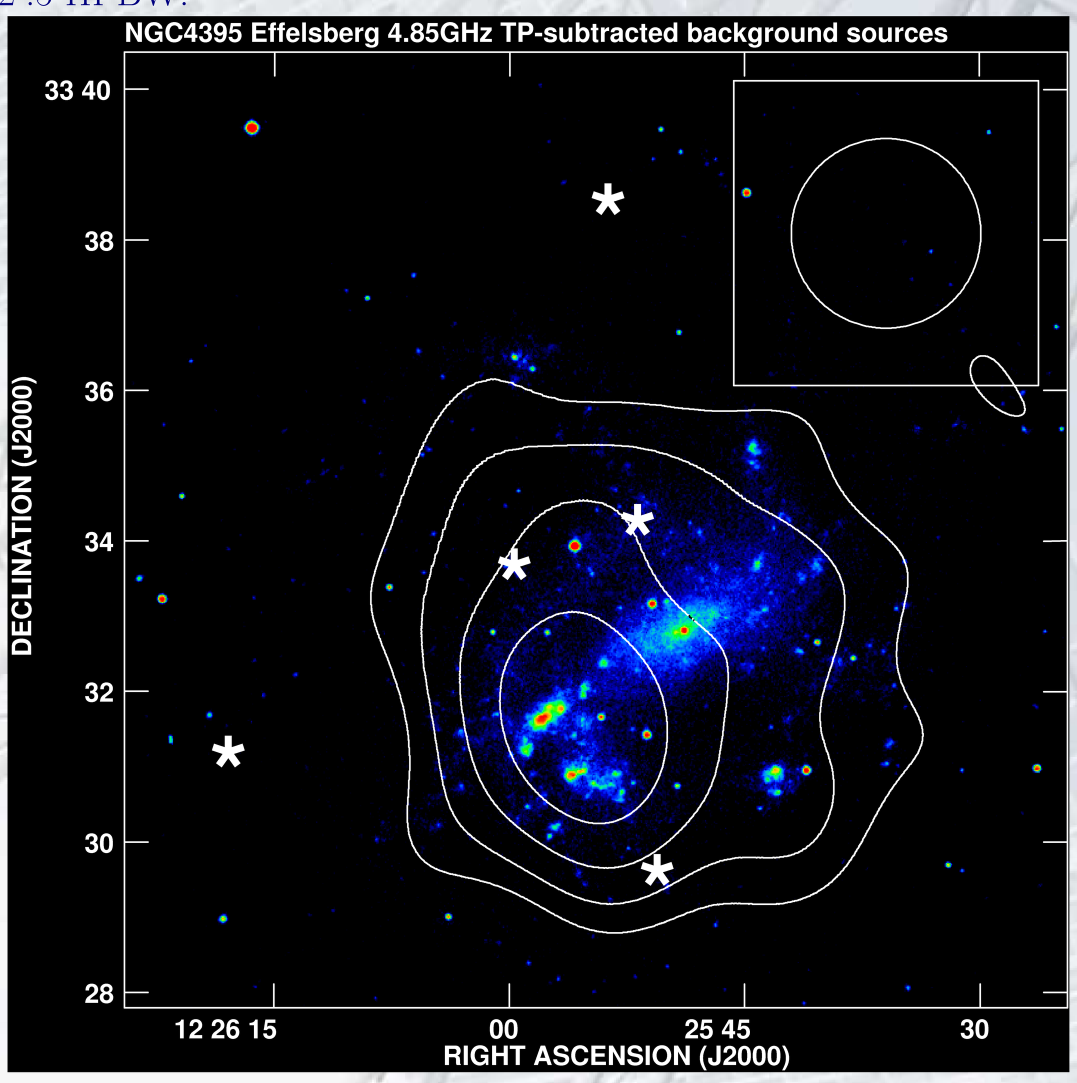

FIG. 4: Total power contours of NGC 4395 at 4.85 GHz with subtracted background sources. The map is superimposed onto DSS blue image. The contour levels are (3, 5, 8, 12) × 0.41 mJy/beam. The map resolution is 2′.5 HPBW. Stars indicate the positions of subtracted sources.

New observations:

Methods: Sensitive total power and polarimetric observations

Total power mapping => total (regular+random) magnetic fields

Polarization maps => regular magnetic fields and their orientation in the sky plane

Observing at high frequencies => Faraday effects negligible.

The sample: eight late-type dwarf galaxies (linear sizes in range of 3.5 to 16.1 kpc).

Radio telescope: 100m Effelsberg

Frequencies: 4.85, 2.64, and 1.40 GHz, for the two brightest objects also 8.35 GHz

New results:

Total power

Diffuse radio emission associated with galaxies (corrected for background sources) is visible in four objects (NGC 2366, NGC 3432, NGC 4214, NGC 4395). For the remaining galaxies (DDO 125, DDO 126, UGC 07698, IC 4182) only upper limits of their radio emission could be obtained. The detected radio emission in our dwarfs is coming mainly from star-forming regions (see e.g. Fig.1 and Fig.4). The global spectral indices are between 0.41 and 0.67, thus, the spectra seem to be flatter that for typical spiral galaxies.

Thermal fraction

Two different methods were used: 1) available Hα fluxes, 2) radio spectra computed by us using the radio data at different frequencies.

Result: Both methods give thermal fractions up to about 60% at 4.85 GHz - higher than in normal spirals (3 out of 4 objects for which radio emission is detected). For the 4 other galaxies estimated lower limits are in the range of 11 to 86%.

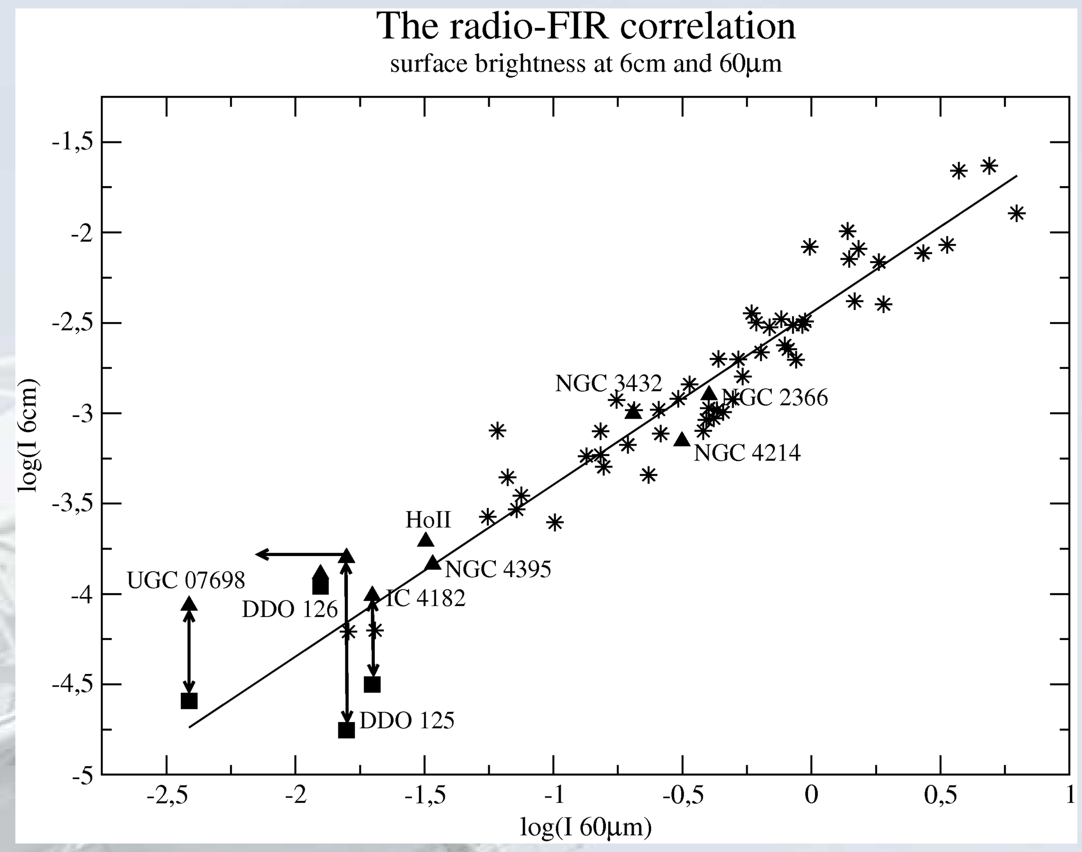

FIG. 5: The radio-FIR correlation between the face-on corrected surface brightness at 6 cm and 60 μm (in Jy/arcmin^2). Stars show galaxies from the sample by Gioia et al. (1982, A&A, 116, 164) and Chyży et al. (2007, A&A, 462, 933). Our objects are indicated by triangles. In case of galaxies for which we do not detect radio emission triangles mark the detection limits. For these objects we also estimated the *lower* limit of radio emission assuming it to be thermal and using the Hα fluxes. The solid line shows the orthogonal fit (slope 0.95) to the objects shown as stars.

Polarization

Detection of only two objects:

- NGC 3432 (almost edge-on) is detected in polarization at 4.85 GHz and 8.35 GHz. The B-vectors of polarized intensity in NGC 3432 (Fig. 2) reveal a dipole-like structure of the regular magnetic field (strength of 0.8 ± 0.2 μG).
- NGC 4214 (an almost face-on galaxy with little ordered structures , Fig. 3) shows a fragment of a spiral-like structure of the regular magnetic field (strength of 1.8 ± 0.5 μG) extending up to about 6 kpc. This magnetic field geometry resembles that generated by the global-scale mean-field dynamo process undisturbed by strong spiral density waves, like that in the ringed galaxy NGC 4736, (Chyży & Buta 2008, ApJ, 677, L17).

Magnetic field strength

The estimated mean total field strengths for all galaxies do not exceed 4–7 μG - significantly lower than for typical spiral galaxies. Nevertheless, magnetic fields are present, despite their rotation which is too slow for the classical mean-field dynamo. A likely process is the "fast dynamo" process based on the Parker instability (Hanasz et al. 2004, ApJ, 605, L33) or the turbulent dynamo.

Radio - FIR correlation

This relation is a powerful tool to search for magnetic field deficiencies for a given SFR. Results:

- Our observations extend the radio-FIR correlation towards the lowest values measured so far.
- Dwarf galaxies still follow the correlation between the total (thermal+nonthermal) radio surface brightness and that at 60 μm determined for larger objects (Fig. 5). The weak magnetic fields and the possible deficit of nonthermal radiation are compensated by higher thermal fractions.
- NGC 3432 belongs to galaxies with a modest SF level (like NGC 2366 and NGC 4214), however, it has a thermal fraction lower by a factor of several than these objects. It also has a HI mass several times higher than other objects in our sample, as well as the highest rotation speed.

Conclusions: Small, low mass galaxies tend to be deficient in synchrotron emission compared to the thermal emission from the ionized gas, caused by a weak magnetic field. The radio emission from the most massive (also rotating at the fastest rate) object in our sample shows a several times higher nonthermal fraction. The galaxy's mass (hence rotation speed) seems to be a key factor in generating strong magnetic fields.

LOFAR

LOFAR will allow us to extend the spectra of such galaxies to very low frequencies thereby enabling:

- a precise determination of nonthermal fractions and their comparison to large galaxies
- the construction of radio-FIR correlation at frequencies so low that the thermal emission will be negligible
- as the low mass may lead to intense magnetic field escape, LOFAR will enable a search for possible large halos/tails of a very steep spectrum (ageing CR electron population) which are best observable at low frequencies
- weak magnetic fields in galaxy halos can be detected by LOFAR measurements of Faraday rotation (Beck 2008, Rev.Mex.A&A, arXiv:0804.4594).

This will provide the answer to the question: are the dwarf galaxies really magnetic field–deficient?