45.5 years of M31 observations with the Effelsberg telescope

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M31
HI
Westerbork
Braun et al. 2009
Why M31?

- Largest spiral galaxy on sky (2° – 6°)
- Good spatial resolution achievable with the Effelsberg 100-m telescope
- High declination allows long observation sessions
- Best-studied spiral galaxy
- Exceptionally regular magnetic field structure
- Prototype of a dynamo-generated magnetic field
- *M31 will determine the fate of the Milky Way*
First radio "image" of M31
158.5 MHz Jodrell Bank
(Hanbury Brown & Hazard 1951)

Fig. 4.—Contours of radio-frequency flux observed near the source in Andromeda with a 2-degree beam. (1 unit = $10^{-28}$ watts/square metre/c.p.s. $\lambda = 1.89$ metres.)
Most radio continuum surveys of M31 were made with the Effelsberg 100-m telescope.
First scan measurements in Effelsberg at 11.1 cm (Berkhuijsen & Wielebinski 1973)

The observations were made under good weather conditions in 1972, August 7 and 8.
First radio maps from Effelsberg at 11.1 cm and 6.2 cm
(Berkhuijsen et al. 1977 & 1983)

Background sources subtracted
STRUCTURE AND PROPERTIES OF NEARBY GALAXIES

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First detection of polarized radio emission in M31
Effelsberg 11.1 cm (4.5’ or 1.0 kpc resolution)
Rainer Beck, PhD Thesis 1979

Up to 45% polarized
First detection of polarized radio emission in M31
Effelsberg 11.1 cm
Beck et al. 1978, 1980

Detection of Polarised Radio Emission of M31

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Abstract
Polarised emission of more than 20% at λ11 cm has been detected in several places in the southern part of M31. Faraday rotation effects in our Galaxy and in M31 appear to be small; it is suggested that the magnetic field is aligned along the arm.

Key words: alignment of magnetic field — galaxies — M31 — polarised radio emission

Fig. 1 Observed field in M31

1. Introduction
Very little is known about the magnetic field in M31. The scarce observations of optical polarisation from globular clusters (Hiltner, 1958) show some evidence for a field parallel to the

Distribution of polarised radio emission in M31

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The ratio of main beam brightness temperature $T_b$(K) to the flux density $S$(Jy) was found to be $2.3 \pm 0.1$. 3C147 was used to determine the spurious instrumental polarisation, which was found to be highest at 2 arc min distance from the source with $\sim 0.5\%$ of the total emission.

Figure 1 shows the $\lambda$11.1 cm polarisation map of M31 superimposed on an optical picture. The map covers the area $-81 < \lambda_\alpha < +81$ arc min, $-45 < \beta_\alpha < +45$ arc min, where the
First painting M31 in colour at Landesmuseum Bonn
This Effelsberg radio map of M31 at a wavelength of 11 cm was prepared by R. Beck, E. Berkhuijsen, and R. Wielebinski. It covers an area of about 29.5 by 18.4 degrees. The strength of the radio emission is indicated by the color, ranging from blue (lowest intensity) to red (highest). A total of 84 unresolved radio sources not associated with M31, most of them radio galaxies or quasars, has been subtracted from the map. Note the radical difference between the appearance of this radio image and direct, long-exposure, photographs. All colored radio maps in this article were made at the computer center of the Rheinisches Landesmuseum in Bonn.
The whole galaxy in one run:
New broad-band receiver at 6.2 cm
Total intensity + B-vectors
(corrected for Faraday rotation in the Milky Way foreground)
Philip Hoernes, PhD 1996

Background sources subtracted
Astronomical magnetic fields

The subtleties of crystal close packing
agouti obesity syndrome explained
Darwinian selection on proteins
Circulation: 6.15 million!
Combined efforts:
VLA + Effelsberg 20.1 cm
(resolution 45" or 170 pc)
Beck et al. 1998

Background sources subtracted
VLA + Effelsberg 20.1 cm
Thermal + Nonthermal
(resolution 45" or 170 pc)
Tabatabaei et al. 2013

Nonthermal emission is much smoother
Synchrotron–FIR correlation is much flatter than thermal–FIR correlation

→ Cosmic rays diffuse over lengths of 1-2 kpc
Three recent Effelsberg surveys:

- 2645 MHz (11.1 cm)
- 4850 MHz (6.2 cm)
- 8350 MHz (3.6 cm)
Enlarged field:
Effelsberg 8-channel system at 11.1 cm
Total intensity + E+90° vectors
(5' or 1.1 kpc resolution)
David Mulcahy, Master Thesis 2011

Strong Faraday rotation
Background sources subtracted
Effelsberg broad-band receiver at 6.2 cm
Total intensity + E+90° vectors
(3' or 680 pc resolution)
Rene Gießübel, PhD Thesis 2012

Faraday rotation still significant
Polarized intensity at 6.2 cm
+ E+90° vectors
Effelsberg
Rene Gießübel, PhD Thesis 2012

Extent of the ordered field out to ≈20 kpc
High frequency: Effelsberg broad-band single-horn receiver at 3.6 cm
Total intensity + E+90° vectors
(1.5' or 340 pc resolution)
Rene Gießübel, PhD Thesis 2012

Small Faraday rotation
Radio emission components and scale lengths at 6.2 cm (3' resolution)
Berkhuijsen & Beck, in prep.

Large scale lengths: Evidence of cosmic-ray diffusion
Equipartition magnetic field strengths
Berkhuijsen & Beck, in prep.

- Total magnetic field strength: 4–8 μG
- Magnetic energy density similar to that of the kinetic turbulent motions, larger than the thermal energy density
- Ordered field has the largest scale length
Spectral index 20.1/3.6 cm
VLA/Effelsberg
(90" or 340 pc resolution)
Berkhuijsen & Beck, in prep.

Flat spectral index in star-forming "ring" due to thermal emission
Synchrotron spectral index 20.1/3.6 cm (90" resolution)
Berkhuijsen & Beck, in prep.

Cosmic-ray electrons in the "ring" are younger (flatter energy spectrum)
Old Faraday rotation measures 6.2/11.1 cm Effelsberg (5’ or 1.1 kpc resolution) Berkhuijsen et al. 2003, Fletcher et al. 2004

Axisymmetric spiral field generated by a mean-field dynamo
New Faraday rotation measures 6.2/11.1 cm Effelsberg (5' or 1.1 kpc resolution)
Berkhuijsen & Beck, in prep.

Axisymmetric spiral field confirmed
Polarized intensity 11.1 cm
+ B-vectors (corrected for Faraday rotation)
Effelsberg (5' or 1.1 kpc resolution)
Berkhuijsen & Beck, in prep.

Magnetic field NOT perfectly aligned along the "ring"
New Faraday rotation measures 3.6/6.2 cm
Effelsberg (2.6' or 590 pc resolution)
Berkhuijsen & Beck, in prep.

Similar RM pattern, but larger RM values
New Faraday rotation measures 3.6/6.2 cm along the "ring"
(Berkhuijsen & Beck, in prep.)
Polarized intensity 6.2 cm
+ B-vectors (corrected for Faraday rotation)
Effelsberg (2.6' or 590 pc resolution)
Berkhuijsen & Beck, in prep.

Magnetic field NOT perfectly aligned along the "ring"
M31 at 130 MHz
LOFAR HBA (200" or 760 pc resolution)
Horneffer & Beck, in prep.
INVESTIGATIONS BASED ON OUR DATA

1. Magnetic field studies
   - Magnetic field model for M31
     Beck (1982)
   - Bisymmetric magnetic field in M31
     Sofue, Beck (1987)
   - Magnetic field in the Andromeda nebula
     Ruzmaikin et al. (1990)
   - Helical magnetic field in M31
     Urbanik et al. (1994)
   - Nature of magnetic belt in M31
     Moss et al. (1998)
   - New clues to the magnetic field in M31
     Han et al. (1998)
   - Magnetic field in M31 from multi-wave polarization observations
     Fletcher et al. (2004)

2. Radio-FIR studies
   - Radio-FIR correlation in M31
     Hoernes et al. (1998)
   - How CR propagation influences radio-FIR correlations in M31 and M33
     Berkhuijsen et al. (2013)
   - Multi-scale Radio-FIR correlations in M31 and M33
     Tabatabei et al. (2013)

3. ISM studies
   - Faraday Ghosts
     Shukurov, Berkhuijsen (2003)
   - Volume filling factor in M31
     Berkhuijsen (2004)
The power of the Effelsberg 100-m telescope for continuum mapping

- Flexible scanning modes
- No missing large-scale structures
- Excellent sensitivity to detect weak diffuse emission
- Large objects can be mapped
- Excellent performance for linear polarization
- Best performance between 5 and 15 GHz
- Receiving systems have excellent stability
- Multi-horn systems reduce weather effects
- Advanced processing software (NOD3)
Wishlist

- Digital polarimeter for continuum mapping (in test phase) (for wide-band polarimetry and RM Synthesis)

- More horns for X band (8-9 GHz) and/or C/X-band (4-9 GHz) (to reduce weather effects)

- New multi-horn broadband system for Ku band (12-18 GHz) (to obtain high-resolution maps of galaxies with high surface brightness)
Crash in about 5 billion years