LOFAR observations of the Leo Triplet:
searching for radio low frequency
evidence of interactions

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Outline

- Radio observations
- Nearby galaxies
- Interacting galaxies
- LOFAR
- & LOFAR data
Cosmic ray electrons with a power-law energy spectrum

\[ N(\epsilon) = N_0 \epsilon^{-\delta} \]

in a volume with a magnetic field \( B \)
lead to a power-law synchrotron spectrum

\[ I_{RC} \propto N_0 B^{(\delta+1)/2} \nu^{-\alpha} \]

with spectral index:

\[ \alpha = (\delta - 1)/2 \]
Minimizing the total energy content or assuming energy equipartition allows to estimate magnetic field:

\[ B_{eq} \propto \left( \frac{(k + 1) I_\nu}{L} \right)^{2/(5 + \delta)} \]

Beck & Krause (2005)

Linear polarization measures the intensity of the resolved ordered field in the plane of the sky can be derived.

A linearly polarized radio wave is rotated, by the Faraday effect in the passage through a magnetized medium, of an angle

\[ \phi = \text{RM} \lambda^2 \]

This effect gives us another method of studying magnetic fields – their regular component along the line of sight.
M51

Mulcahy et al. 2014

Fletcher et al. 2011

Spiral arms 10-20 $\mu$G  Interarm regions 8-11 $\mu$G

values consistent with models (Shneider et al. 2014)

LOFAR freq $\rightarrow$ small thermal component $\rightarrow$ small uncertainties
NGC 4736 (Chyzy & Buta, 2008)  
Polarized intensity @ 8.6 GHz  
contours overlaid on H\(\alpha\) image

NGC 1365 (Beck et al., 2005)  
Total intensity (contours)  
and B-vectors @ 4.8 GHz  
on optical image
Irregular and edge-on

M33 (Tabatabaei, 2013)  
Total radio intensity (colour) and B-vectors @ 8.4 GHz

NGC253 (Heesen, 2009)  
Total radio intensity (colour) and B-vectors @ 4.8 GHz

Antennae (NGC4038/39)

NGC4038 core

NGC4039 core

Relic spiral arms

Overlapping region

No star formation

Coherent magnetic field structure tracing the line of collision between the arms of the merging spirals.
Antennae simulations

Kotarba et al. (2010)
Virgo cluster's spiral galaxies

Pfrommer et al. 2010
Yellow arrows = projected orientation of the magnetic field
Virgo cluster's spiral galaxies

NGC4535 (Weżgowiec et al. 2007)
Polarized radio intensity (contours) and B-vectors @ 4.8 GHz

Indication for shear by tidal tails or ram pressure by the ICM

NGC4569 (Chyży et al. 2006)
Polarized radio intensity (contours) and B-vectors @ 4.8 GHz

Highly polarized radio lobes probably the result of past nuclear activity induced by interaction.
Leo Triplet

Distance ~ 10 Mpc

NGC3627 barred spiral
NGC3628 edge-on
NGC3623 highly inclined spiral

Large HI tidal tail
(Haynes et al 1979; Stierwalt et al., 2006)
Paladino et al. 2009
Spectral index distribution

Soida et al. 2001
Polarized intensity and B-vectors at 8.4 GHz

Wezgowiec et al. (2012) suggested that the unusual magnetic field observed could be the result of a past collision with a dwarf galaxy.
LOw Frequency ARray is an international telescope built by a consortium of Institutes in the Netherlands, Germany, UK, France and Sweeden.

- 46 Stations throughout Europe
- 38 LOFAR NL
- 24 Core Array
LOFAR antennas

- **Low Band Antennas**
  - LBA: 10—90 MHz
  - simple dipoles

- **High Band Antennas**
  - HBA: 110—240 MHz
  - tiled array
Low frequency challenges

Radio interferences

Bright sources

Ionosphere
The deepest image obtained so far for any galaxy in the low frequency regime

Mulchay et al., 2014
LOFAR image of Leo Triplet

Preliminary image @ 150 MHz
Bandwidth ~ 8 MHz
res ~ 50 arcsec
rms ~ 4 mJy/beam

rms is going to decrease using the full bandwidth (64 MHz) and the full time on source

Paladino et al.
Conclusions

Polarized radio emission is an excellent tracer of tidal effects between galaxies and of ram pressure in the ICM.

The decompression and diffusion timescales of the field are very long: it keeps memory of events in the past, up to the lifetime of the illuminating cosmic-ray electrons.

Tidal tails from interacting galaxies may also constitute a significant source of magnetic fields in the intracluster and intergalactic media.

High sensitivity and resolution observations are needed.

LOFAR and SKA are key instruments for these observations.