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

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and

LOFAR MKSP Nearby Galaxies working group

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Outline

Radio observations

Nearby galaxies

Interacting galaxies

LOFAR

& LOFAR data

Synchrotron emission

Cosmic ray electrons with a power-law energy spectrum

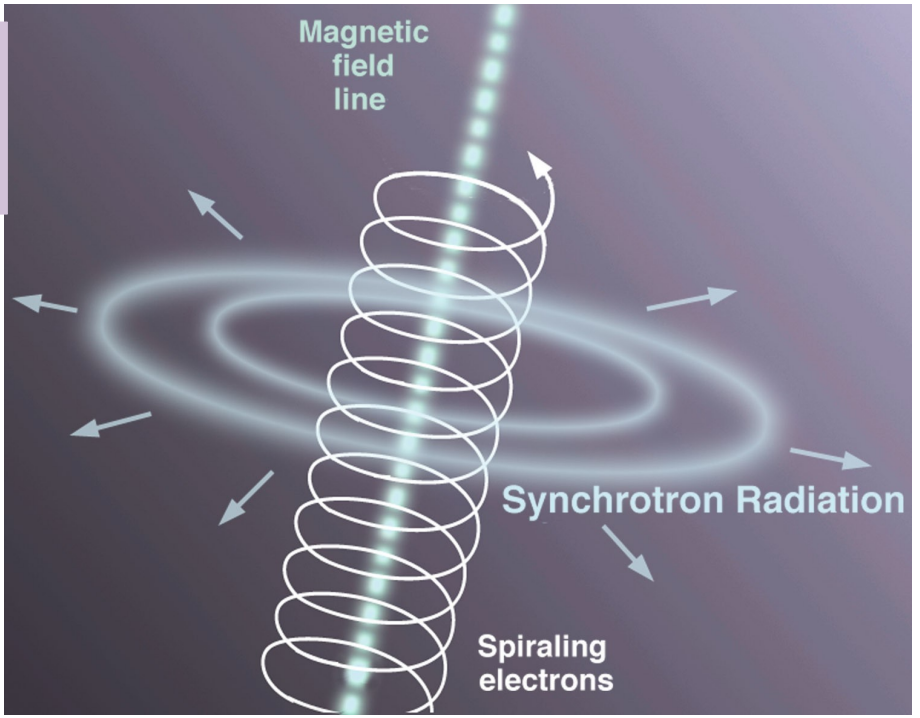
$$N(\epsilon) = N_0 \epsilon^{-\delta}$$

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:

$$\alpha = (\delta - 1)/2$$

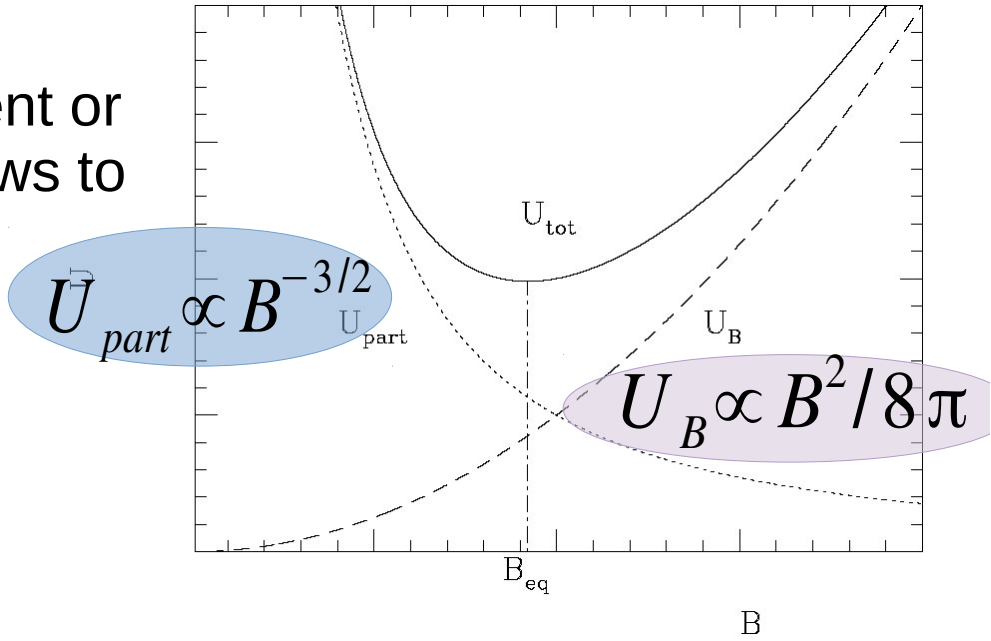


Magnetic field

- Minimizing the total energy content or assuming energy equipartition allows to estimate magnetic field:

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

Beck & Krause (2005)

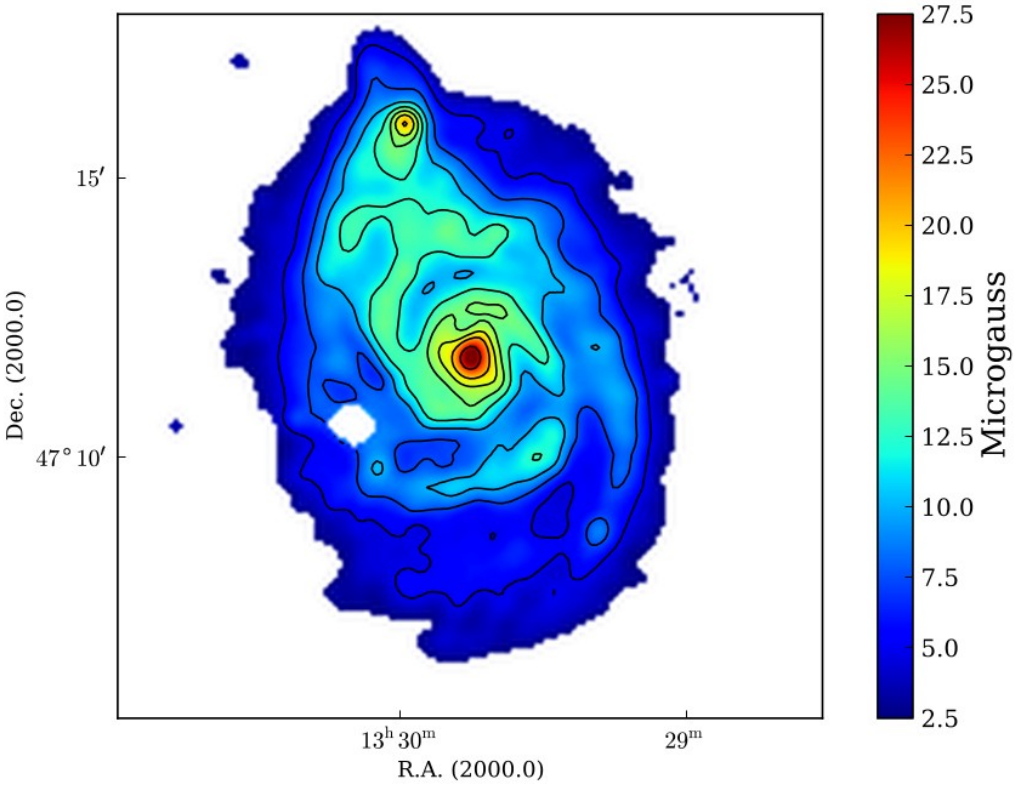


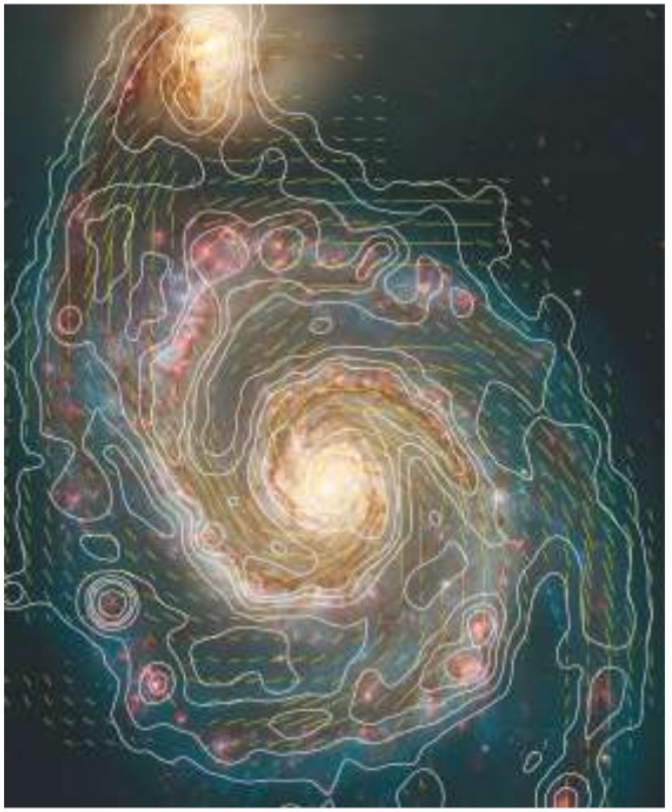
- Linear polarization measures the intensity of the resolved ordered field in the plane of the sky can be derived.

- A linearly polarized radio wave is rotated, by the Faraday effect in the passage through a magnetized medium, of an angle $\phi = \mathrm{RM}\ \lambda^2$

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

M51





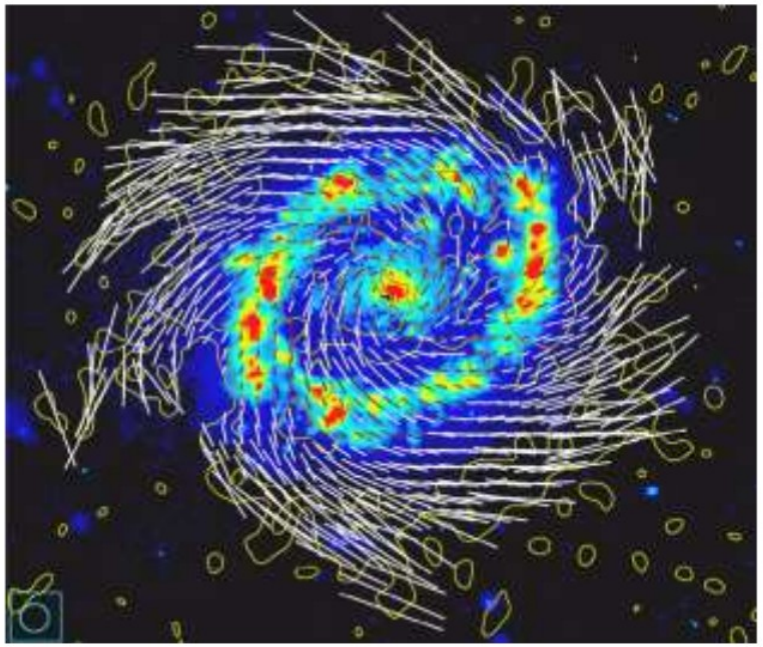
Mulcahy et al. 2014

Fletcher et al. 2011

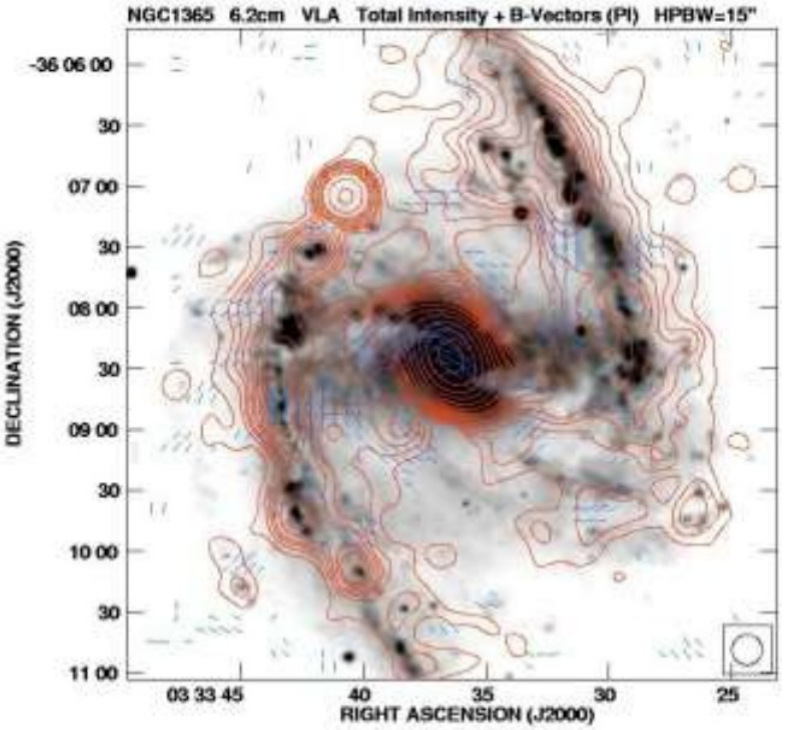
Spiral arms 10-20 μG Interarm regions 8-11 μG
values consistent with models (Shneider et al. 2014)

LOFAR freq → small thermal component → small uncertainties

Barred and non-barred

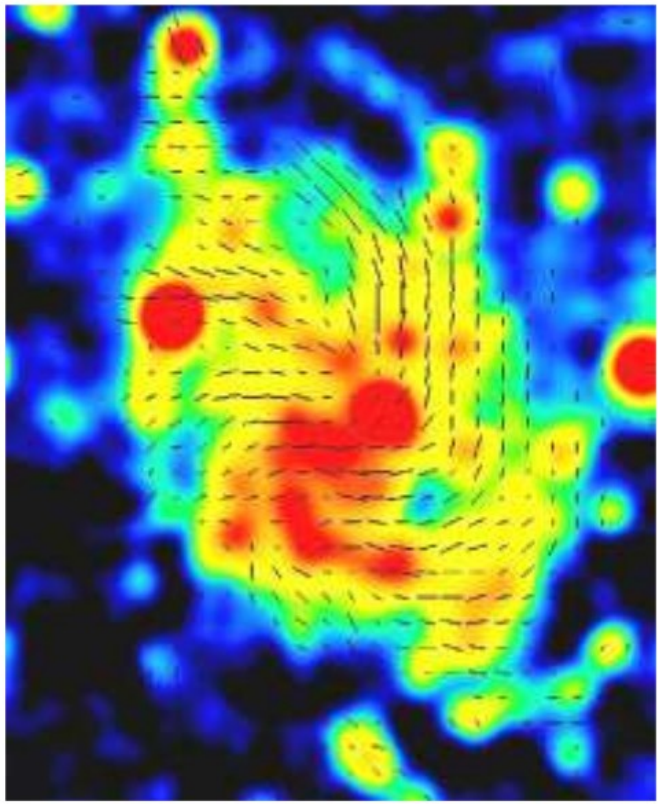


NGC 4736 (Chyzy & Buta, 2008)
Polarized intensity @ 8.6 GHz
contours overlaid on Hα image

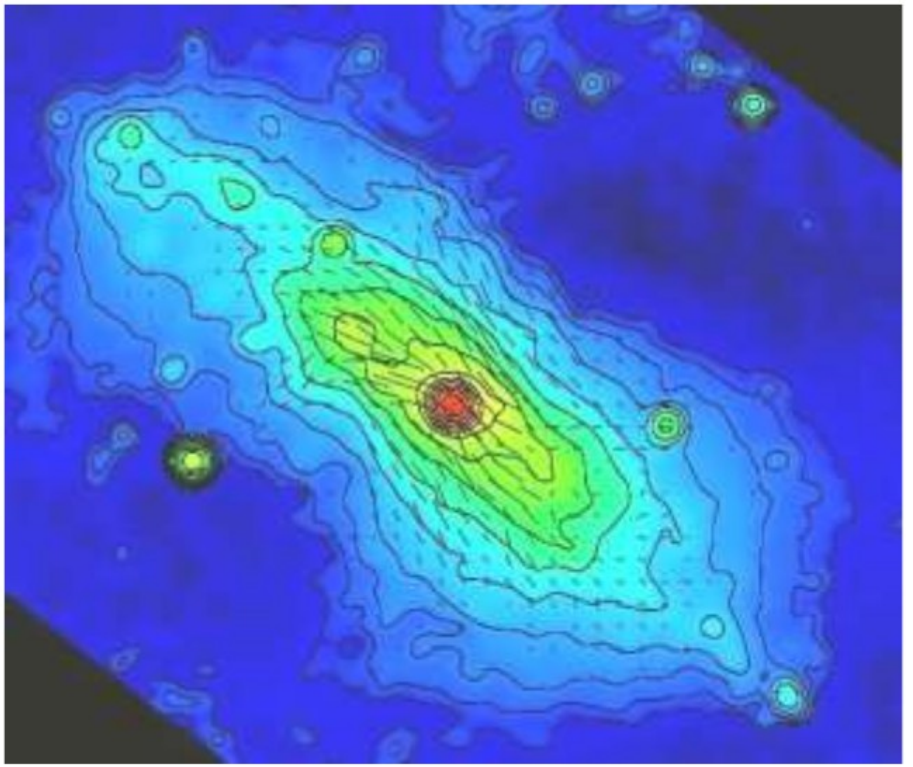


NGC 1365 (Beck et al., 2005)
Total intensity (contours)
and B-vectors @ 4.8 GHz
on optical image

Irregular and edge-on

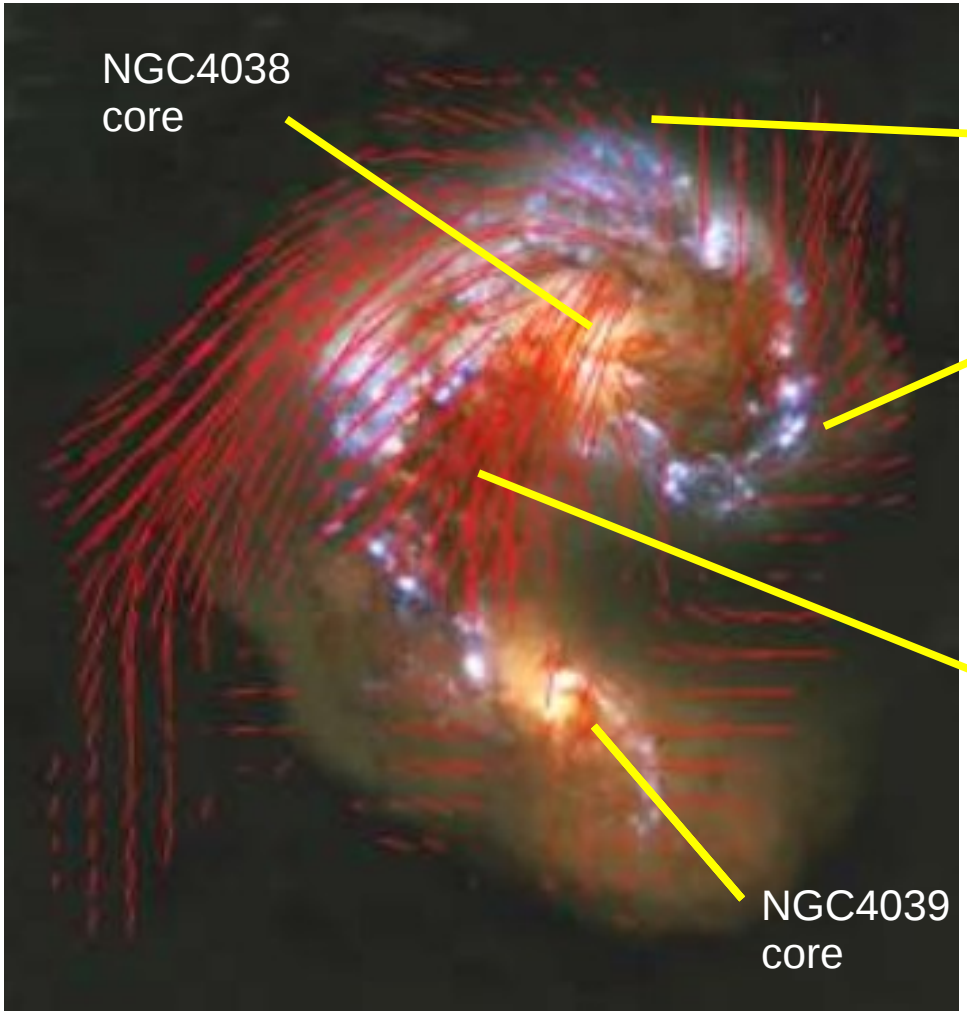


M33 (Tabatabaei, 2013)
Total radio intensity (colour) and
B-vectors @ 8.4 GHz



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

Antennae (NGC4038/39)



Relic spiral arms

Overlapping region

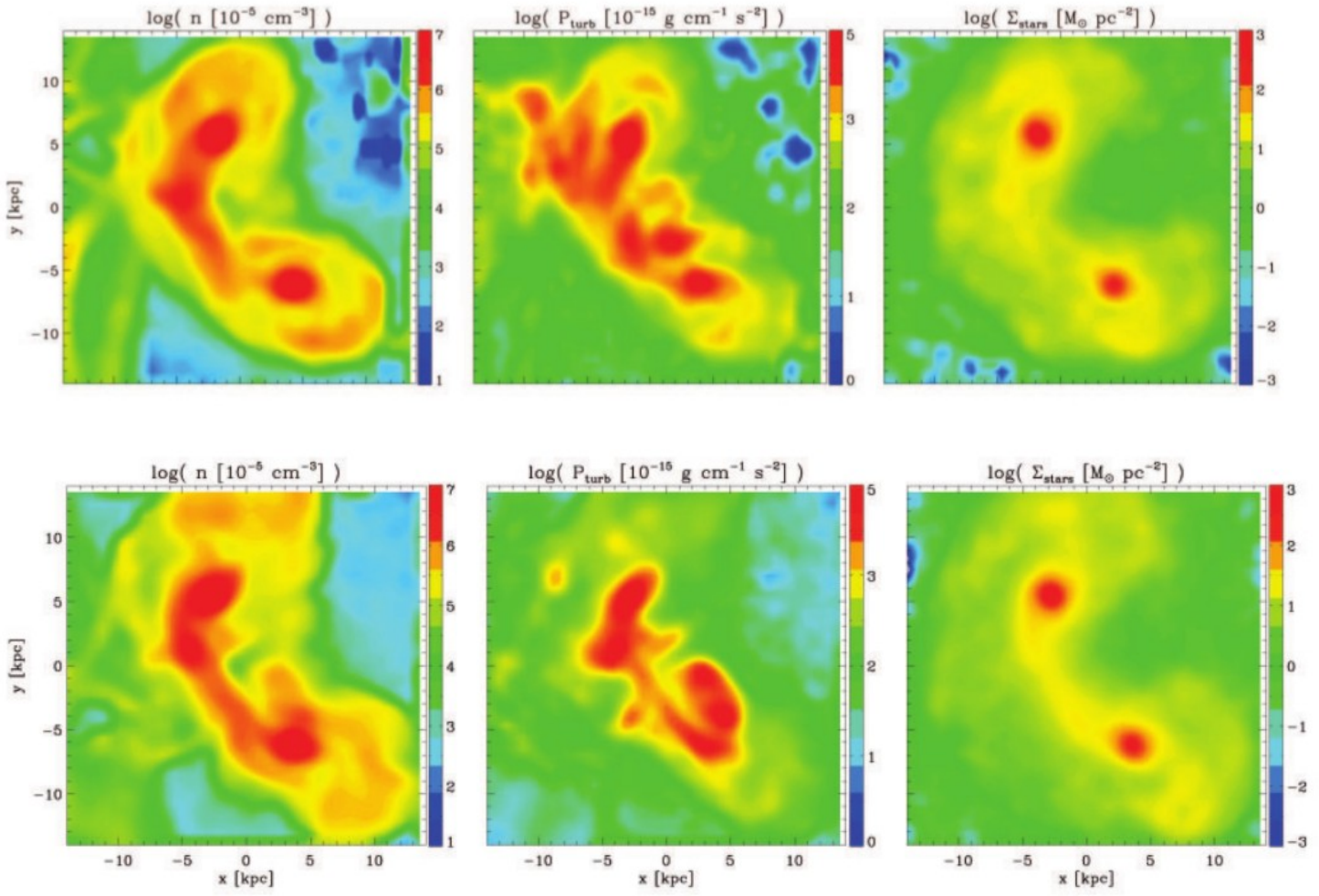
No star formation

Coherent magnetic field structure tracing the line of collision between t he arms of the merging spirals.

Chyży & Beck (2004)

Antennae simulations

n_e P_{turb} Σ_{star}

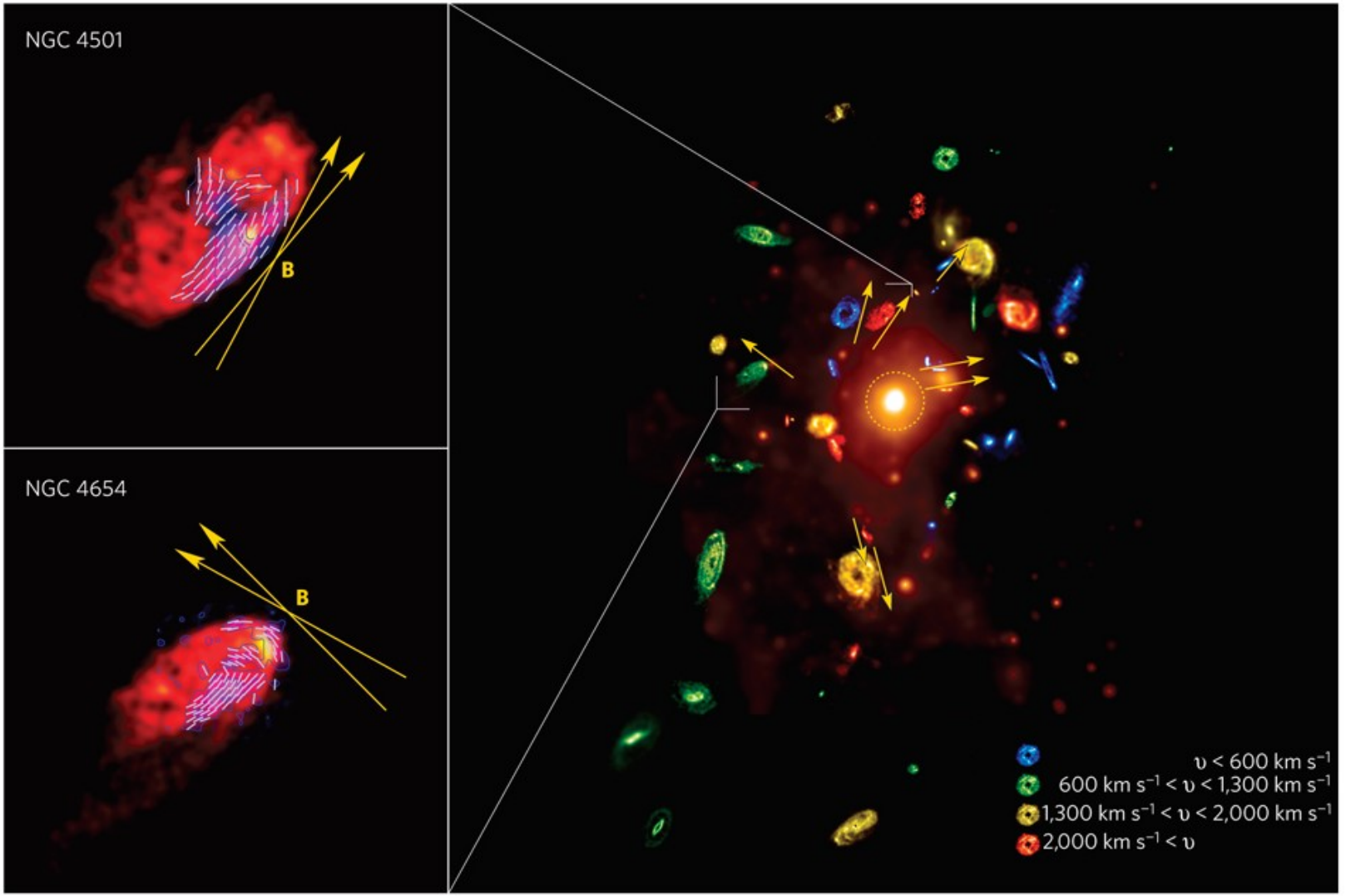


with magnetic field

without magnetic field

Kotarba et al. (2010)

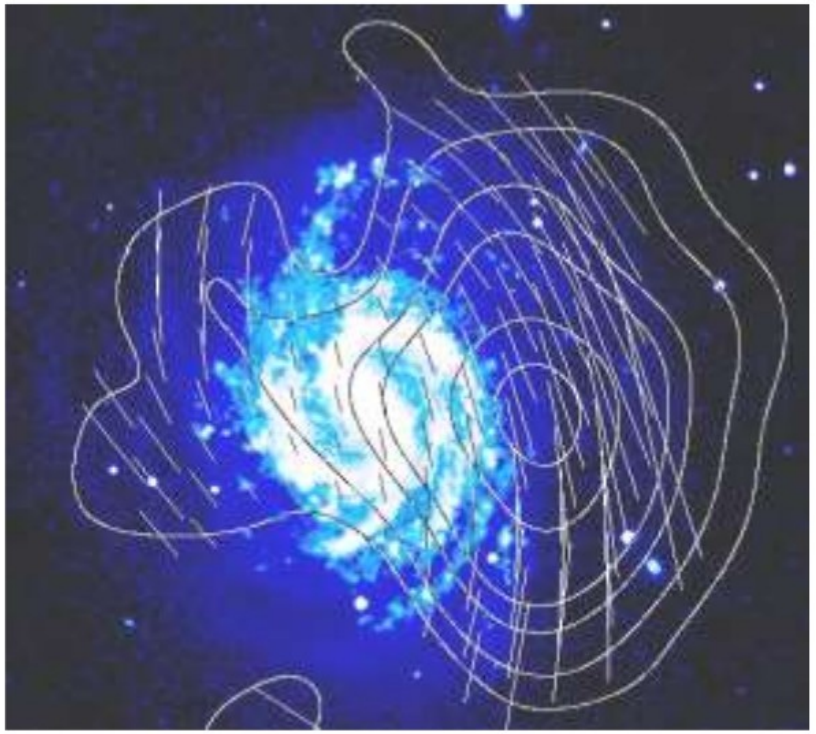
Virgo cluster's spiral galaxies



Pfrommer et al. 2010

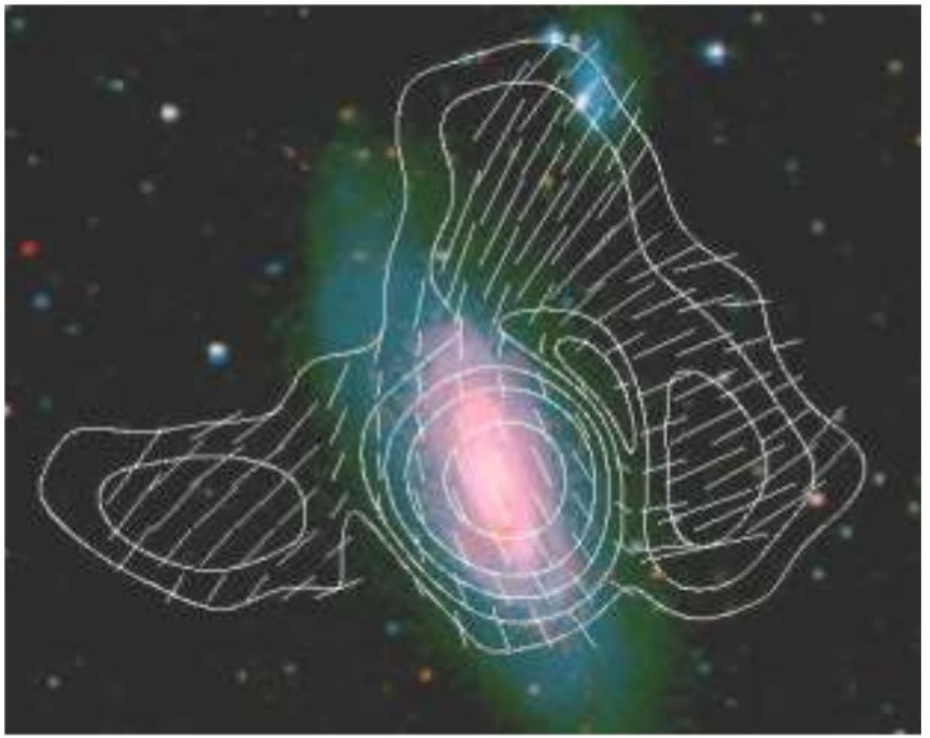
Yellow arrows = projected orientation of the magnetic field

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)

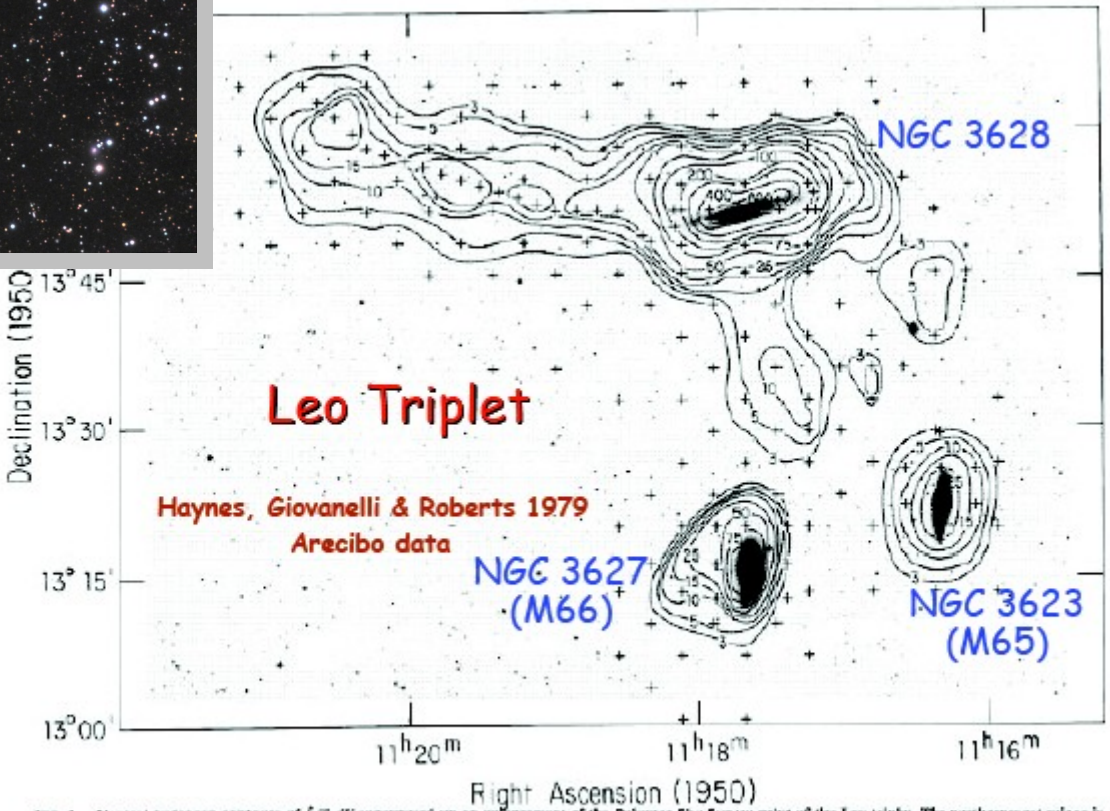
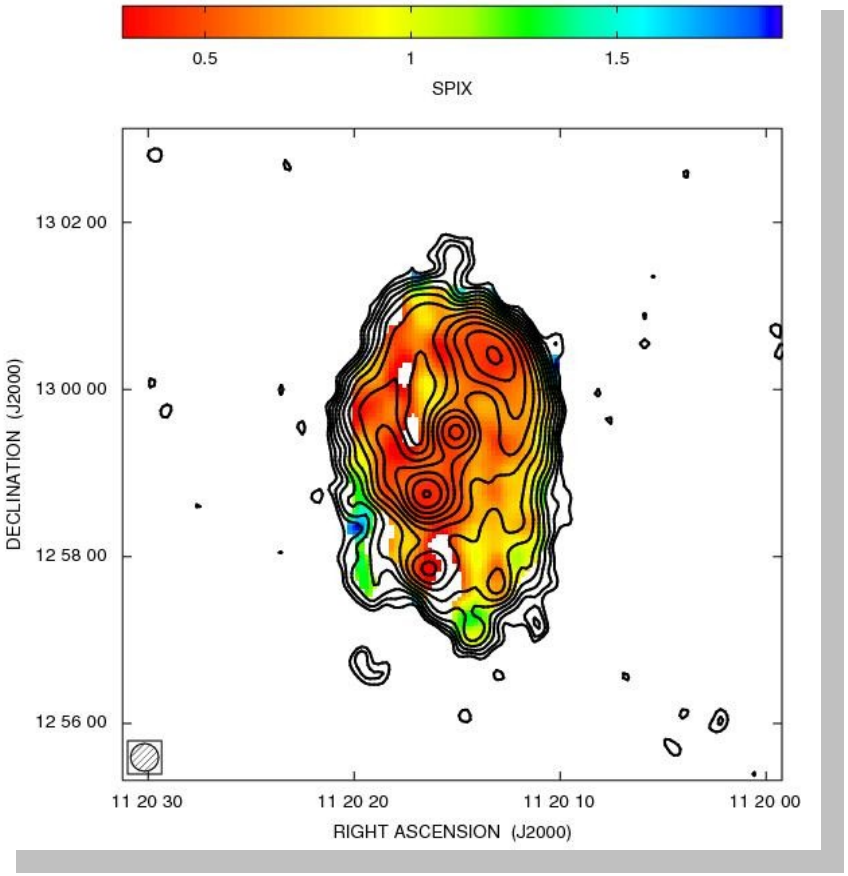


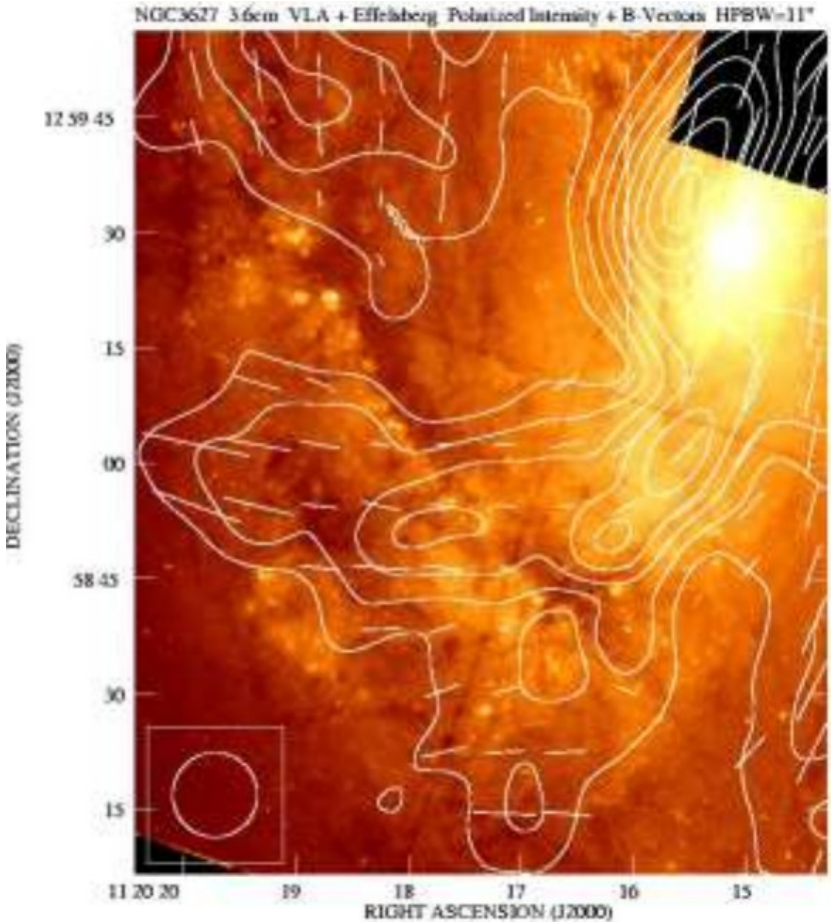
FIG. 1.—Neutral hydrogen contours of ∫ T_B dV superposed on an enlargement of the Palomar Sky Survey print of the Leo triplet. The northernmost galaxy is NGC 3628; the southernmost is NGC 3627; the westernmost is NGC 3623. Crosses mark the sampling points of the Arecibo observations. The long appendage extending eastward from NGC 3628 is referred to as the plume; the extension in the region between the three galaxies is the bridge.

HAYNES *et al.* (*see page 84*)

NGC3627



Paladino et al. 2009
Spectral index distribution



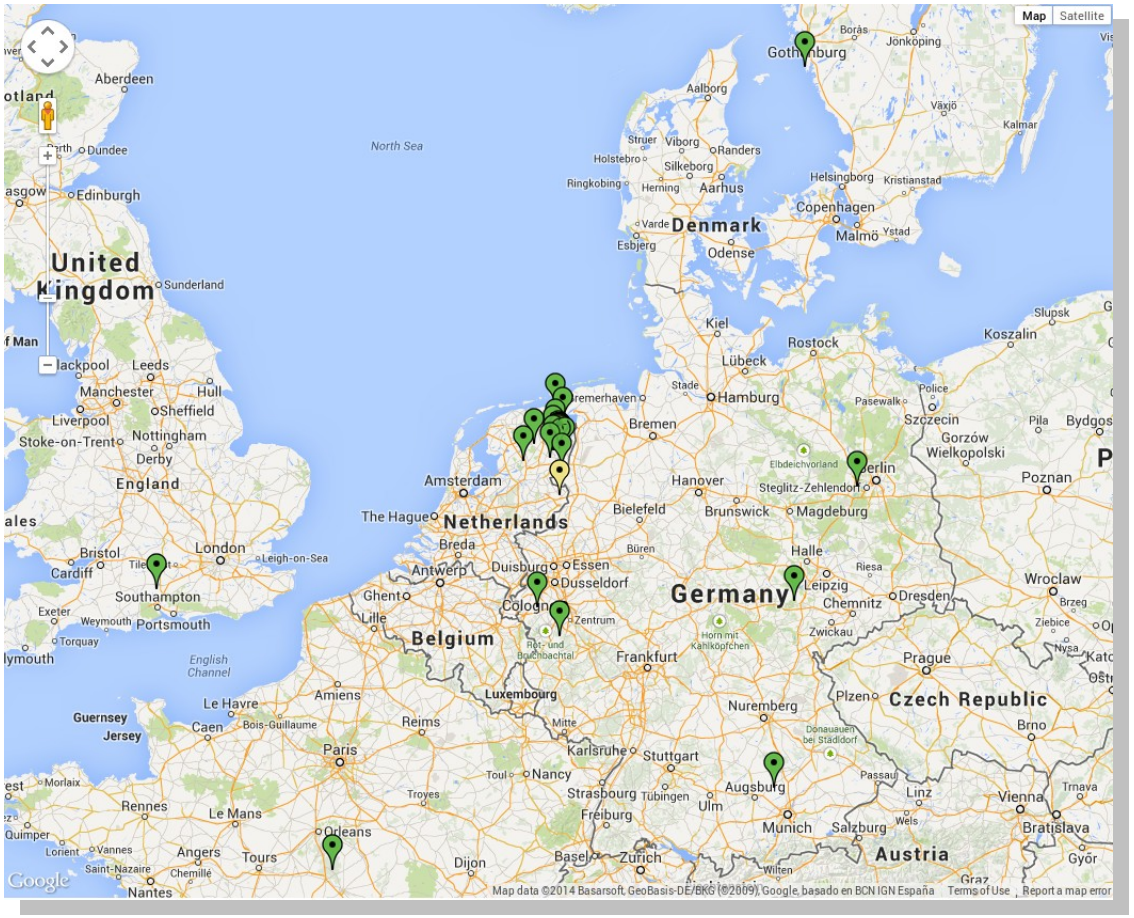
Soida et al. 2001
Polarized intensity and B-vectors at 8.4 GHz

Wezgowiec et al. (2012) suggested that the unusual magnetic field observed could be the result of a past collision with a dwarf galaxy.

LOFAR

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



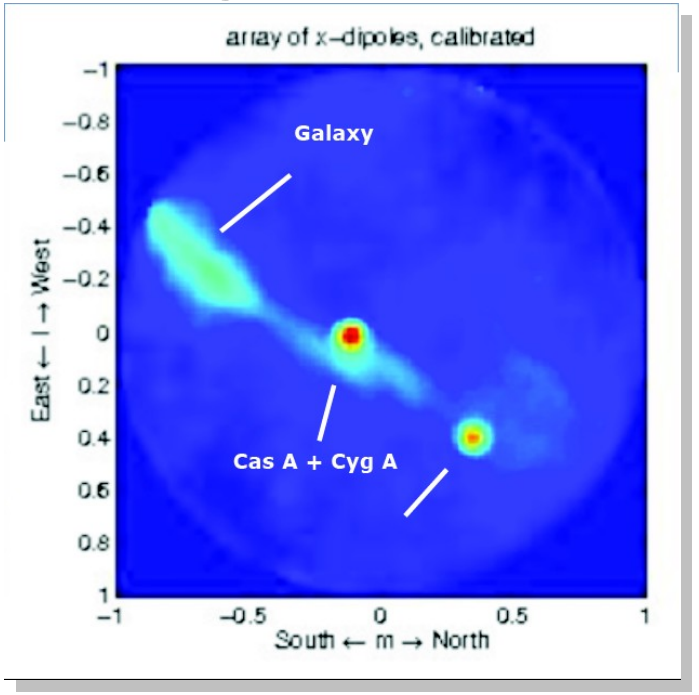
LOFAR antennas

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

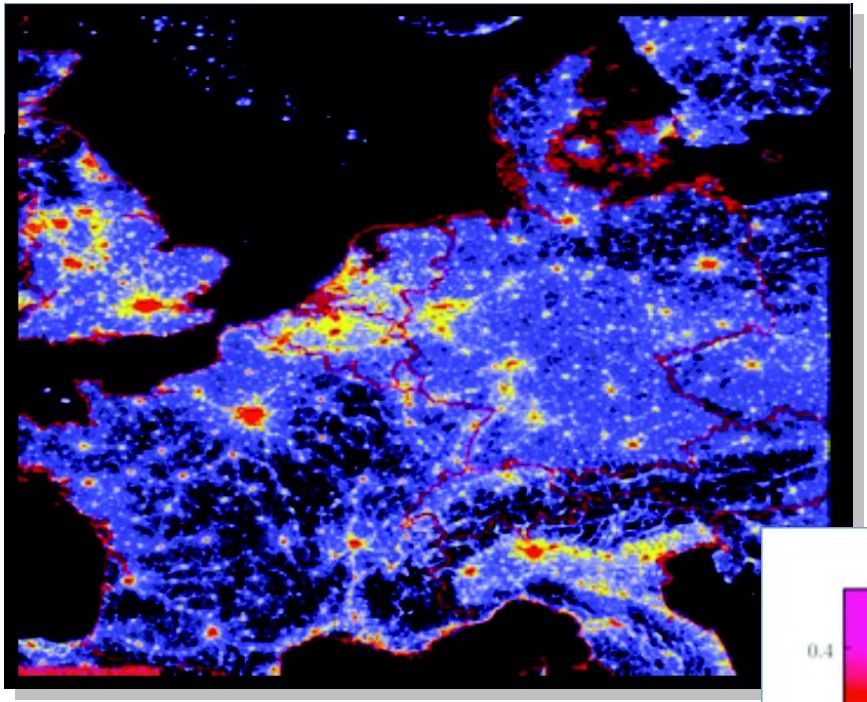
- High Band Antennas
  HBA : 110—240 MHz
  tiled array

Low frequency challenges

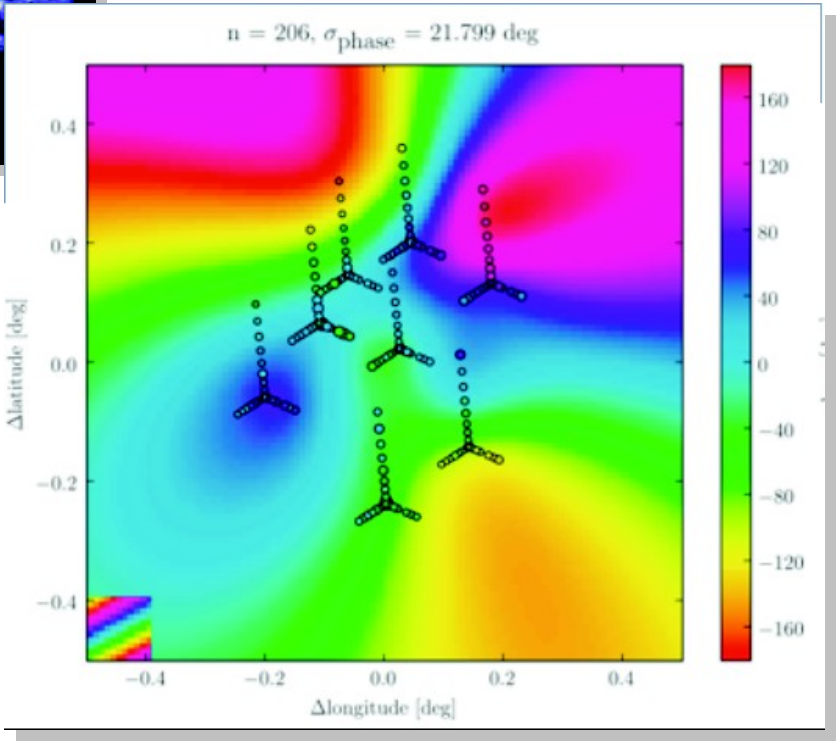
Bright sources



Radio interferences



Ionosphere

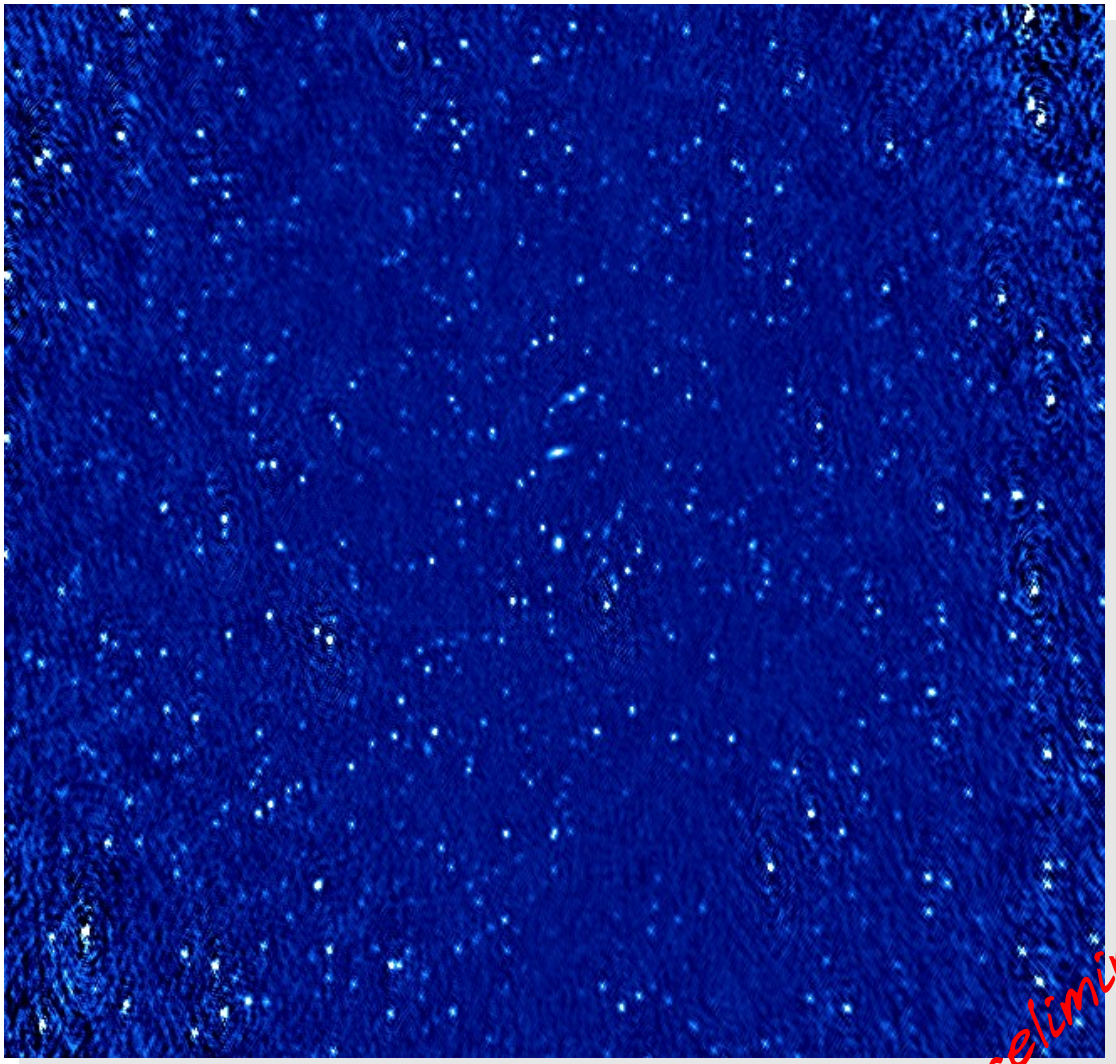


LOFAR image of M51

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

Mulchay et al., 2014

LOFAR image of Leo Triplet



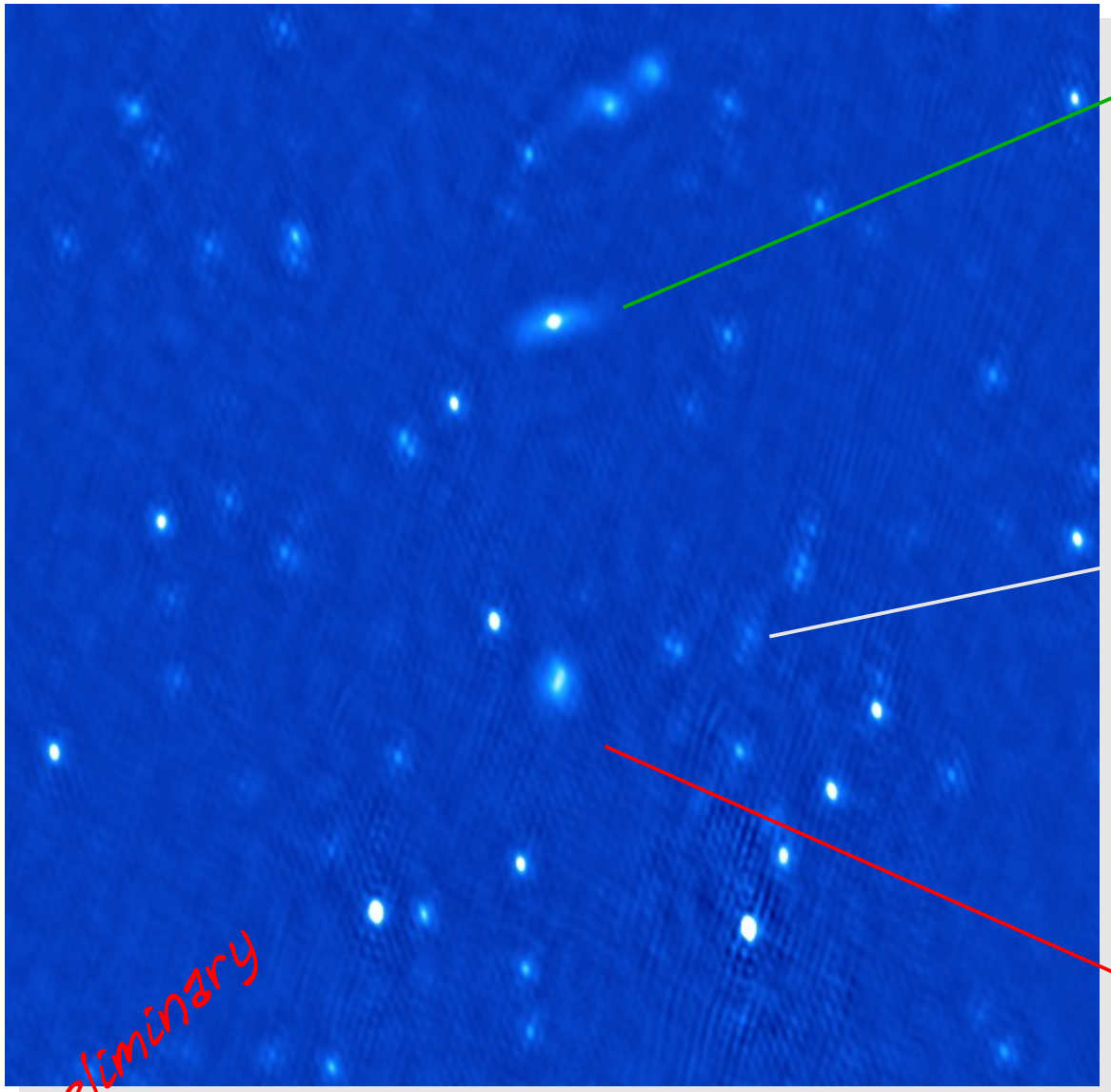
Preliminary image @ 150 MHz
Bandwidth ~ 8 MHz
res ~ 50 arcsec
rms ~ 4 mJy/beam

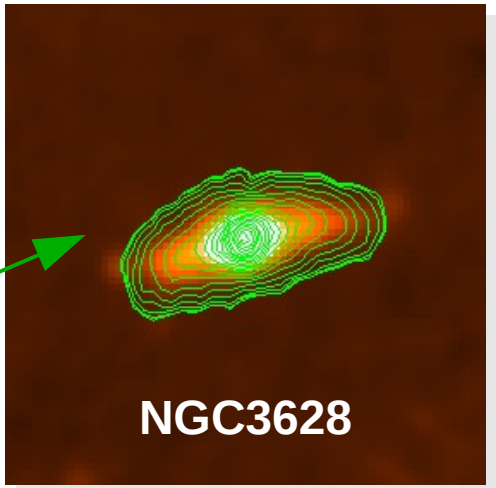
rms is going to decrease
using the full bandwidth (64 MHz)
and the full time on source

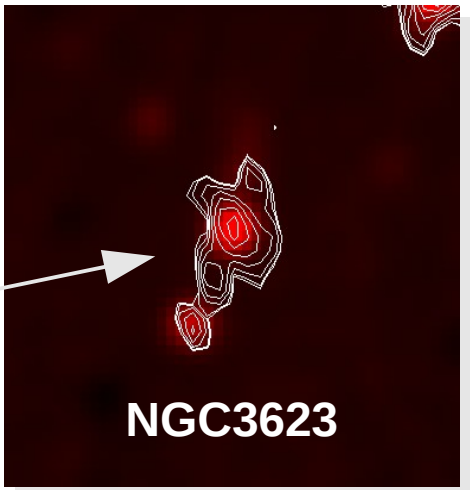
preliminary

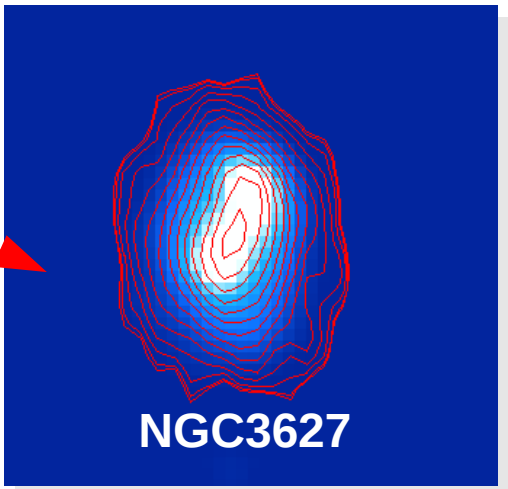
Paladino et al.

LOFAR image of Leo Triplet









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.

Grazie