Nearby Spiral Galaxies at Low Frequencies: First observations of nearby galaxies with LOFAR

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LOFAR

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The nature of the low-frequency emission of M 51

First observations of a nearby galaxy with LOFAR⋆

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Overview of Presentation

- Low Frequency Science
- Overview of LOFAR
- Observations of M51 with LOFAR HBA
- Polarisation at low frequencies
- Observations of M51 with LOFAR LBA

Cosmic Ray Propagation at Low Frequencies

- At low frequencies we are observing synchrotron emission originating from low energy cosmic ray electrons.

- Low energy electrons suffer less from synchrotron and inverse Compton losses. Will travel further from their site of origin.

- Will enable the study of the extended disk and halo of galaxies.

- Able to estimate the magnetic field strength more accurately at low frequencies.

Thermal Free Free Absorption

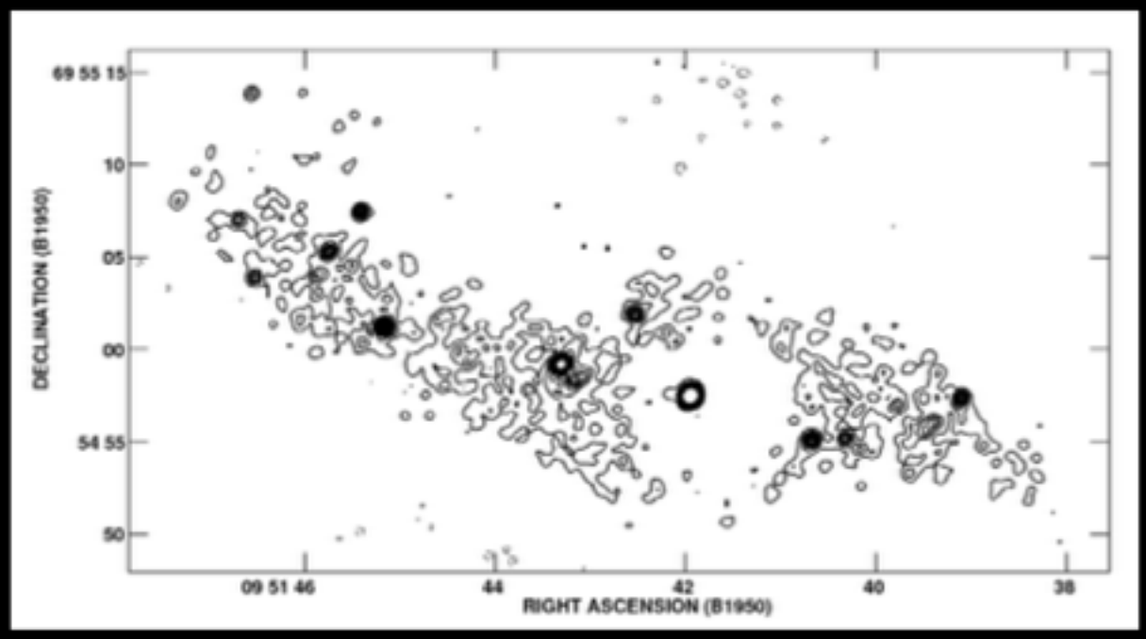
Free-free absorption in the case of an ionised foreground screen is given by:

$$I(\nu) = I_0(\frac{\nu}{\nu_0})^{\alpha} e^{-\tau(\nu)}$$

$$\tau = 3.01 \times 10^{-2} EM \nu^{-2} T_e^{-1.5} g_{ff}$$

$$EM = \int_0^{s_0} n_e^2 ds$$

Free free absorption seen in star burst galaxies (M82) but what about normal spiral galaxies?

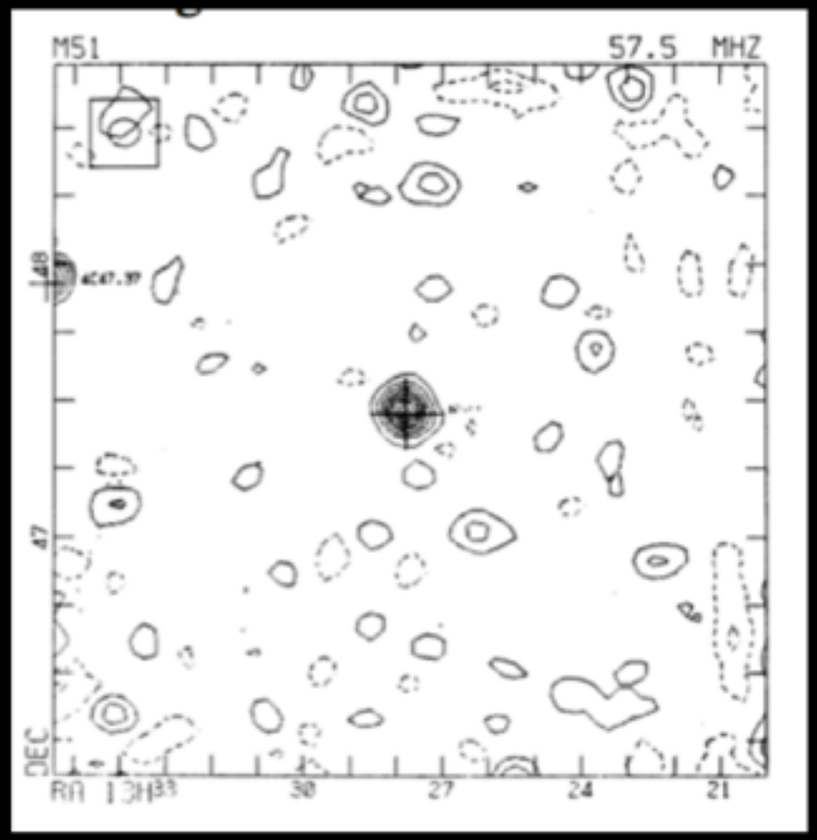


Willis et al (1997)

- Previous observations of nearby galaxies at low frequencies had poor resolution and sensitivity

- Observations of galaxies at 57.5 MHz with Clarke Lake (Israel & Mahoney 1990)

M51



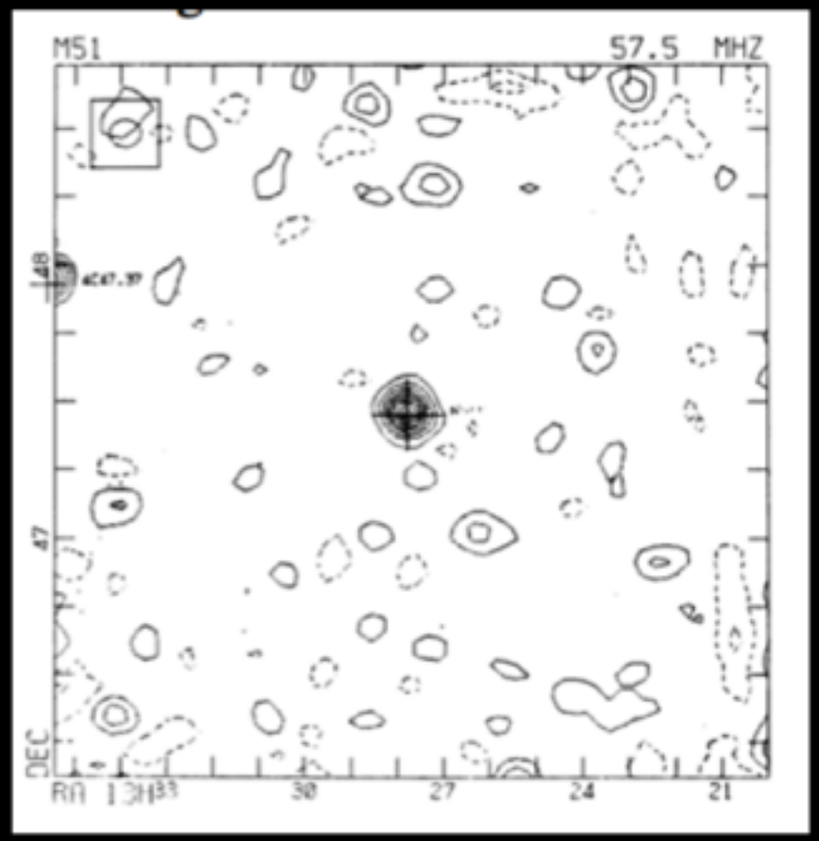
Israel & Mahoney 1990

- Integrated fluxes were systematically lower that the integrated fluxes extrapolated from 1.4 GHz.

- Greatest flattening seen in edge-on galaxies

- Proposed that it is caused by a smoothly distributed diffuse ionised gas component with a very low electron temperature T_e ~ 50K.

M51



Israel & Mahoney 1990

Main Aims of our Observations

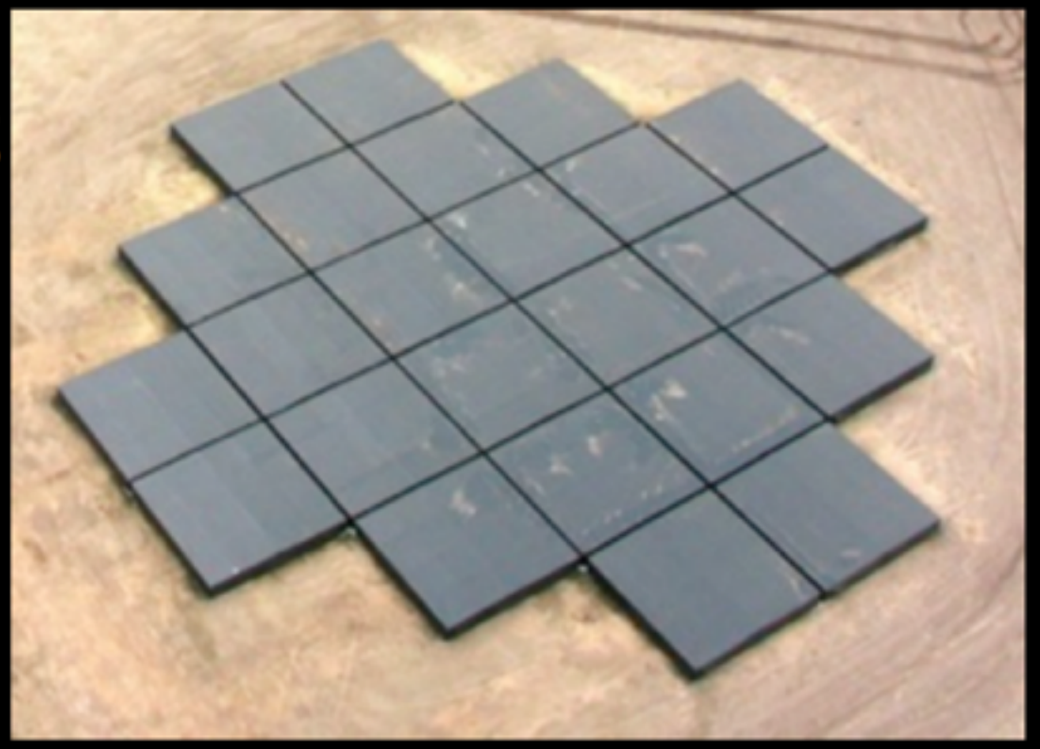
1. Observe the extended disks and haloes of nearby galaxies.
2. Increase our knowledge of cosmic ray propagation at low frequencies.
3. Investigate the nature of free free absorption.
4. Detect diffuse polarisation in nearby galaxies.
5. To determine if RM grids of galaxies using background polarised sources is possible with LOFAR.

LOFAR Specifications

- High Band Antenna (HBA)110-240 MHz
  -tiled array

- Low Band Antenna (LBA) 10-90 MHz
  -simple dipoles

- Linear Polarized feeds



- Arrays of dipoles provide flexibility in electronic beamforming

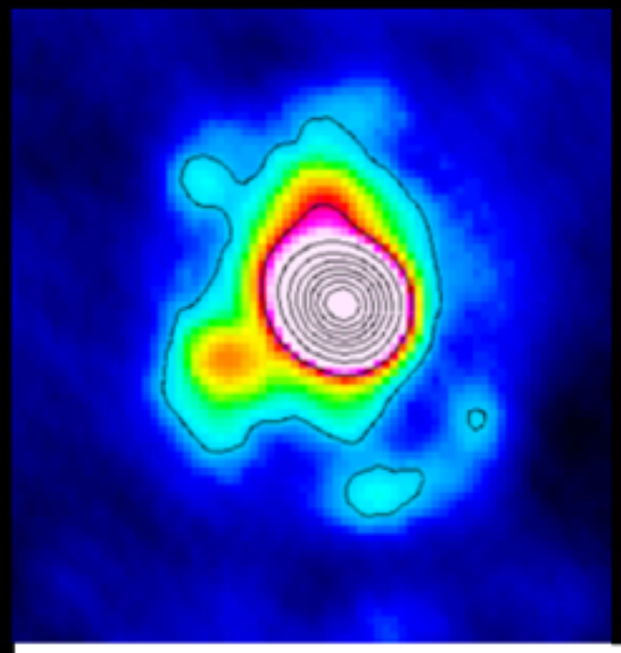
- 8 Bit sampling: 96 MHz bandwidth
  – 488 subbands; 64 channels

Observational Parameters

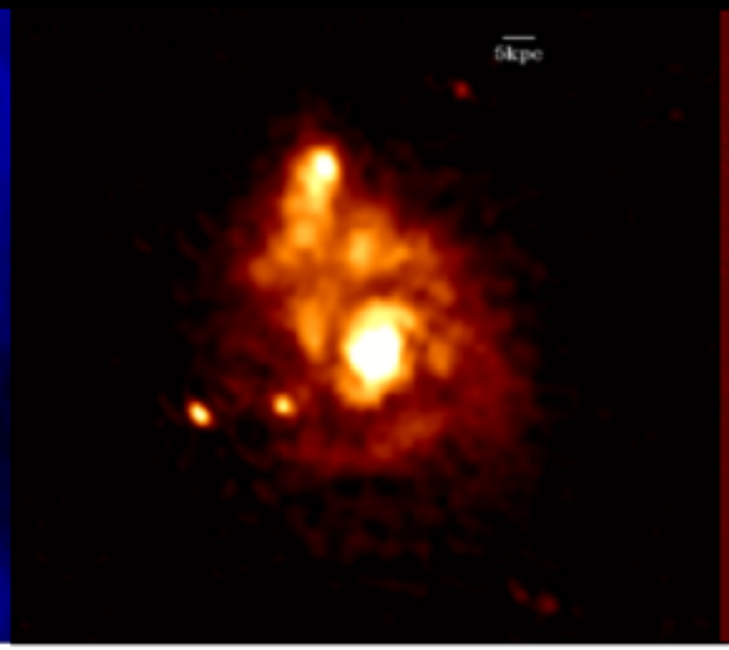
- 3C295 used as a calibrator
- Dual beam observation
- Frequency Range: 115.9 -175 MHz
- 48.8 MHz of bandwidth on both calibrator and target
- 8 hour observation

Evolution of LOFAR

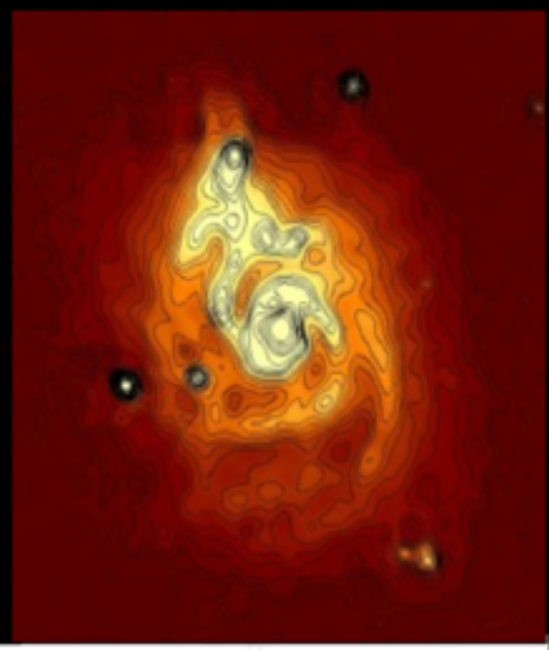
2011

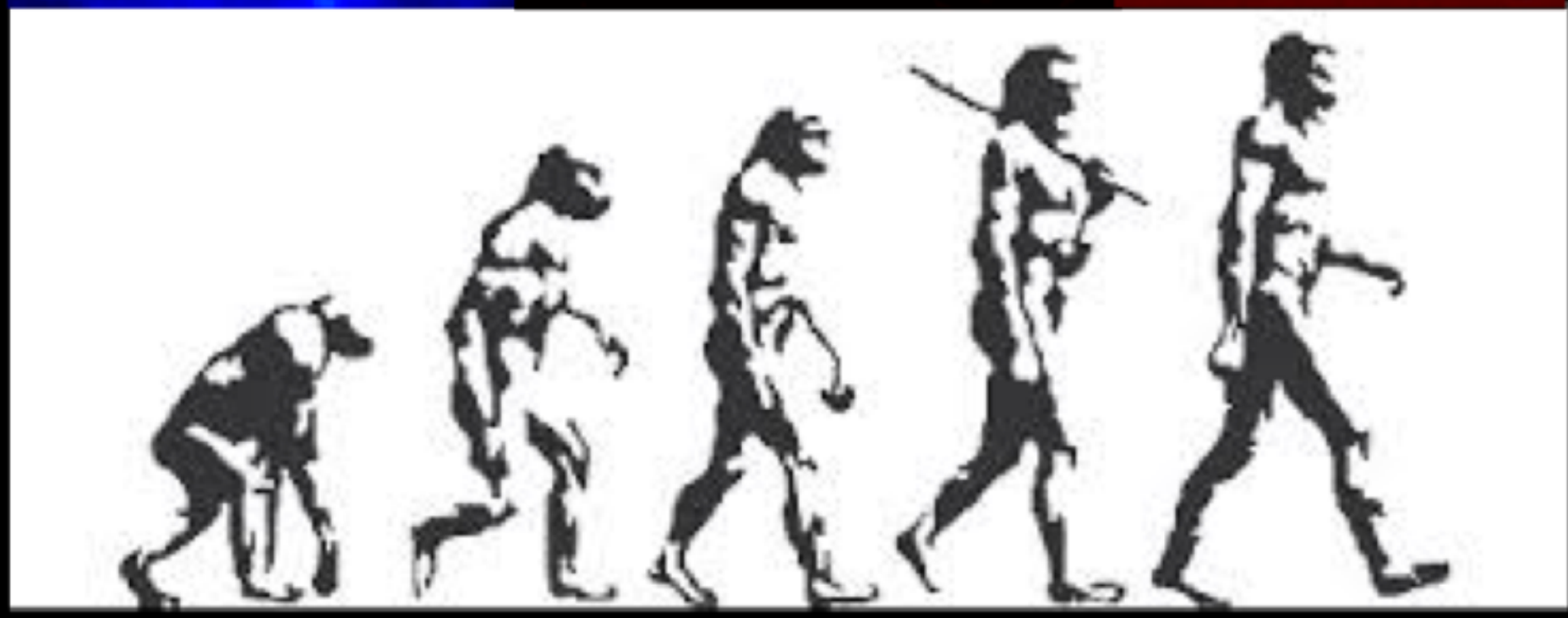


2012



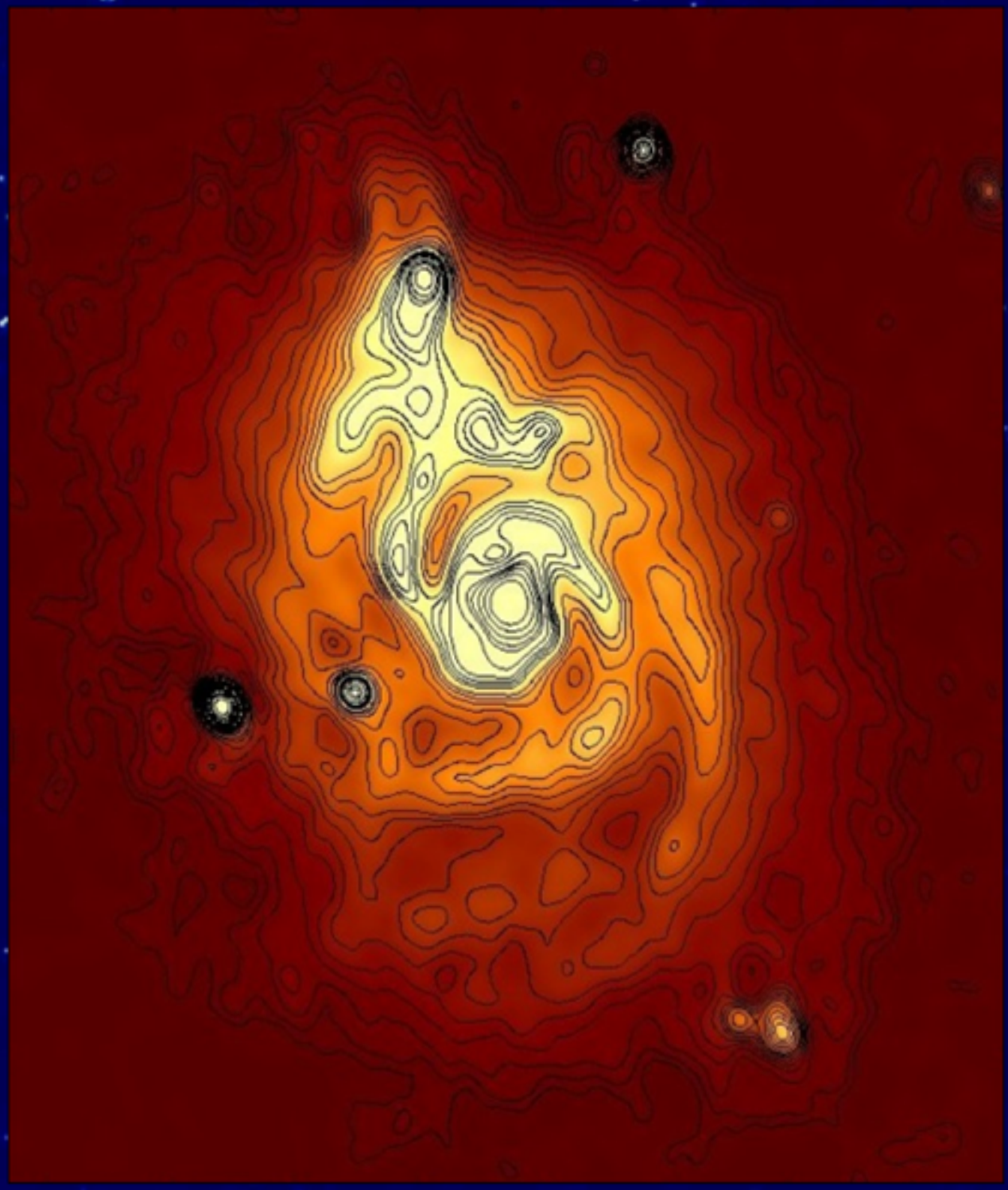
2013





M51 Field of View

M51 at 151 MHz

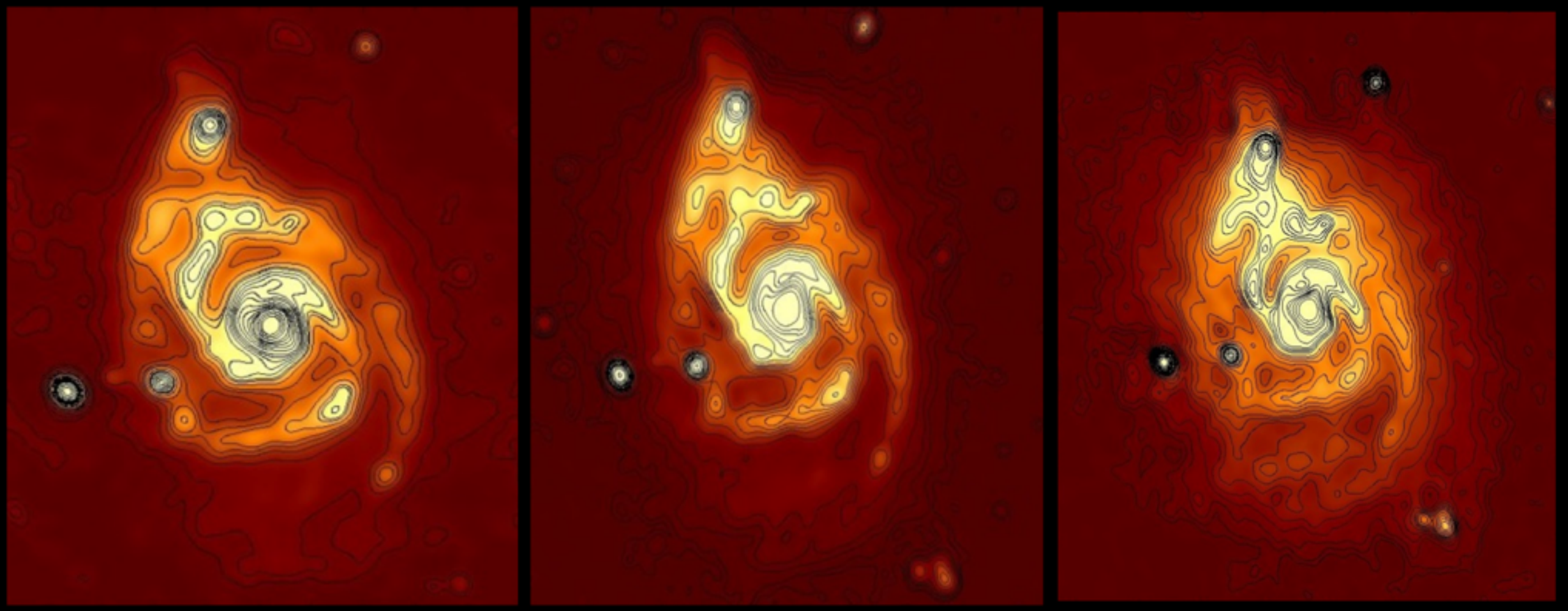


Comparison with Higher Frequencies

4.86 GHz

1.4 GHz

151 MHz



Fletcher et al. 2011

Most sensitive map of a galaxy below 300 MHz!

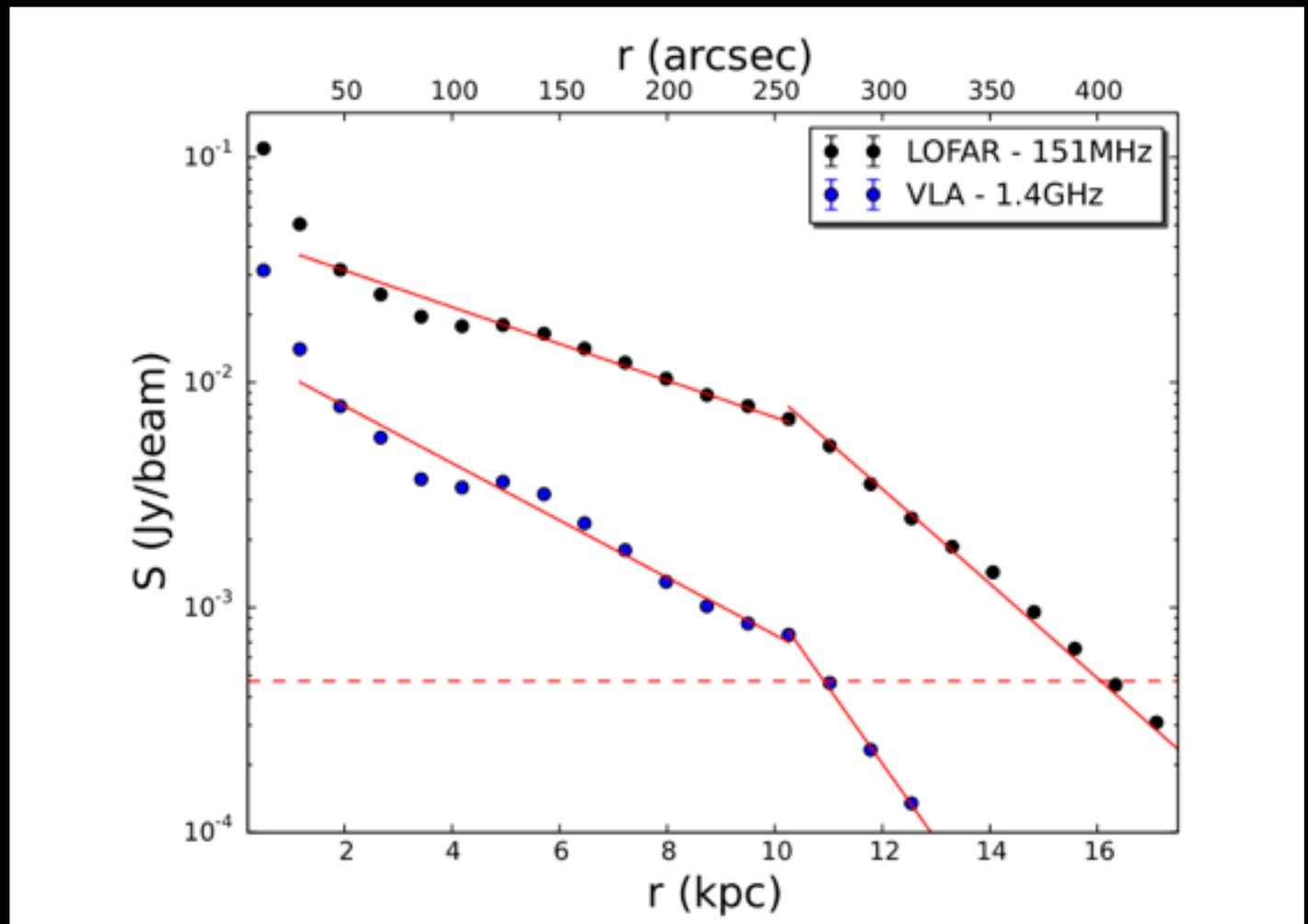
Propagation of Cosmic Ray Electrons

- Observe break in radio continuum profile

- Expect to see a ratio of scale lengths between 151 MHz and 1.4 GHz for diffusion to be 1/1.74.

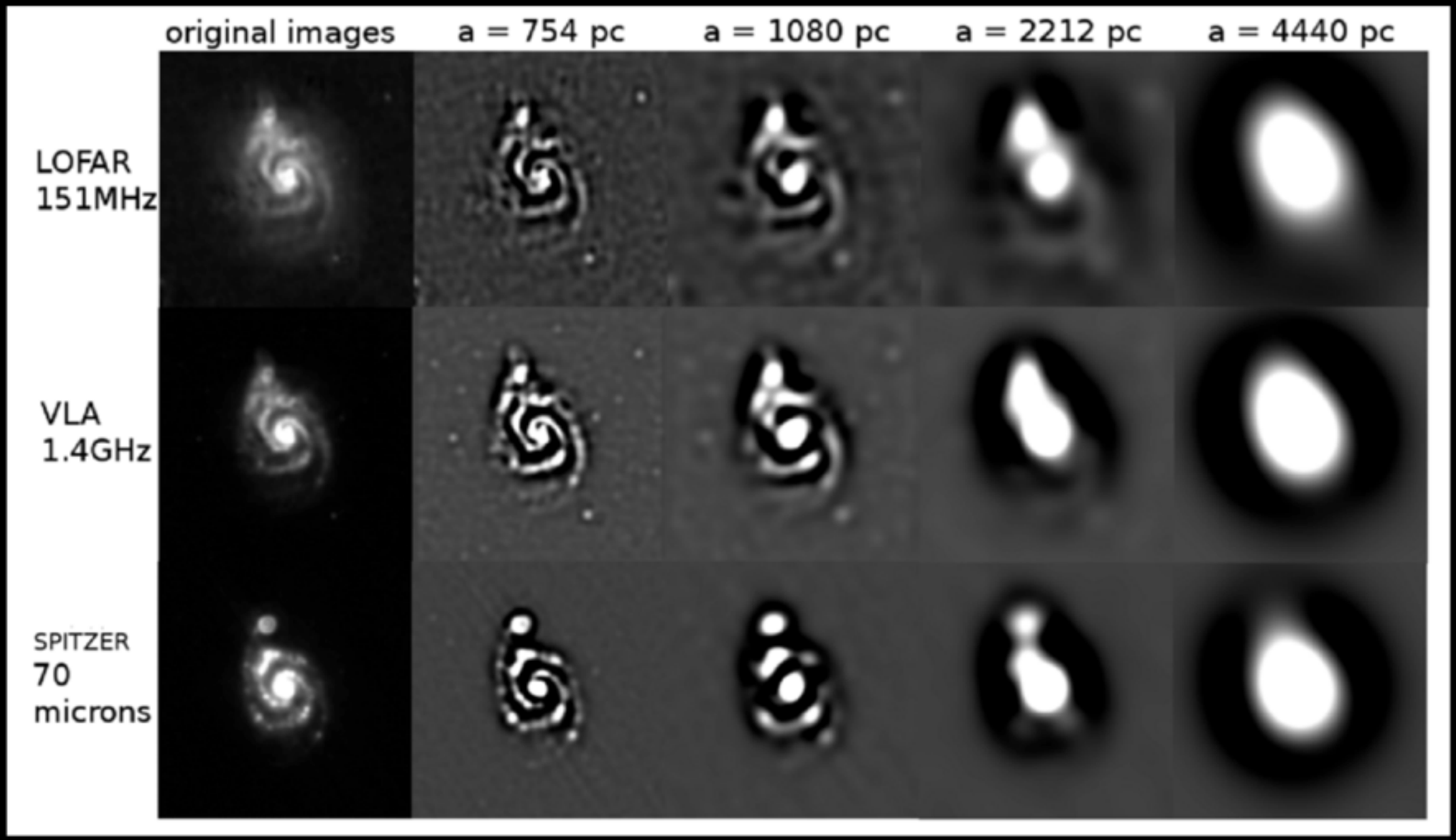
- Expect to see a ratio of scale lengths between 151 MHz and 1.4 GHz for streaming to be 1/3.04.

- Observe a of ratio 1/1.6, agrees with diffusion.



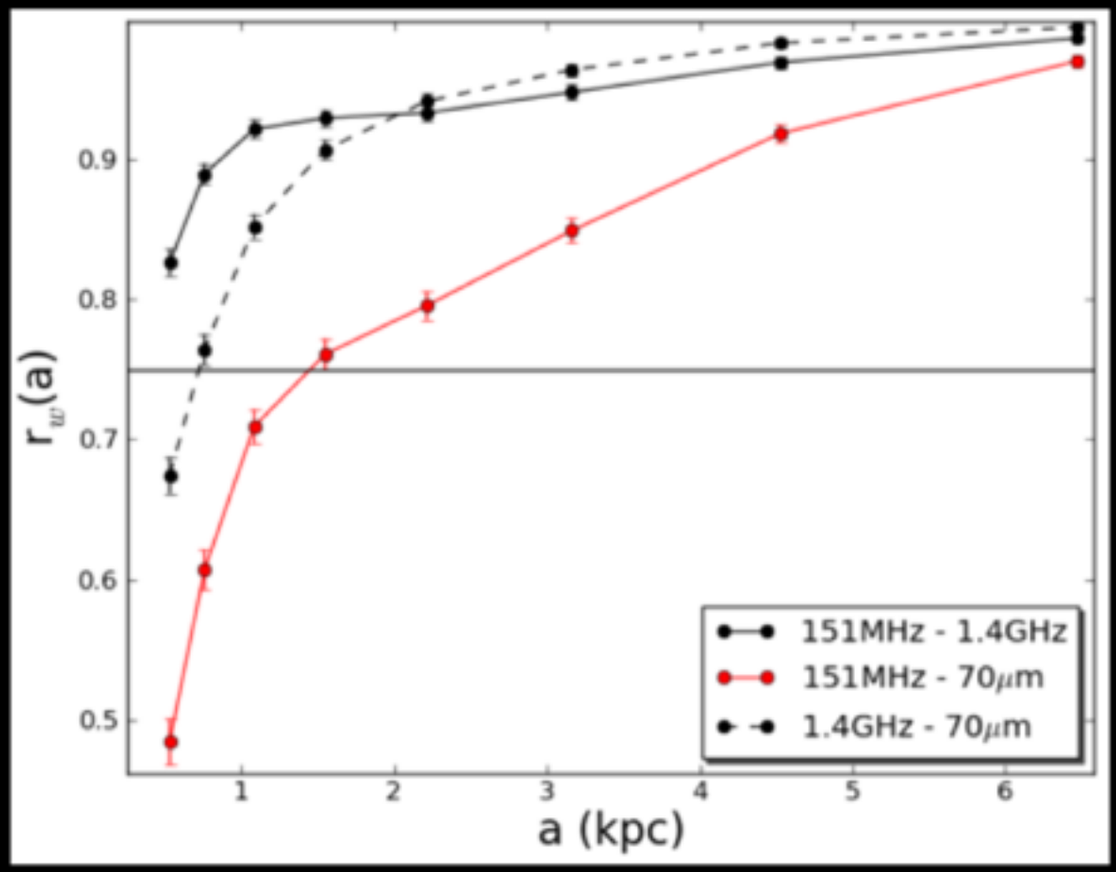
ν (MHz)	l_{inner} (kpc)	l_{outer} (kpc)
1400	3.4 ± 0.2	1.28 ± 0.02
151	5.32 ± 0.4	2.06 ± 0.06
H I*	5.5	2.1*

Wavelet Analysis of M51



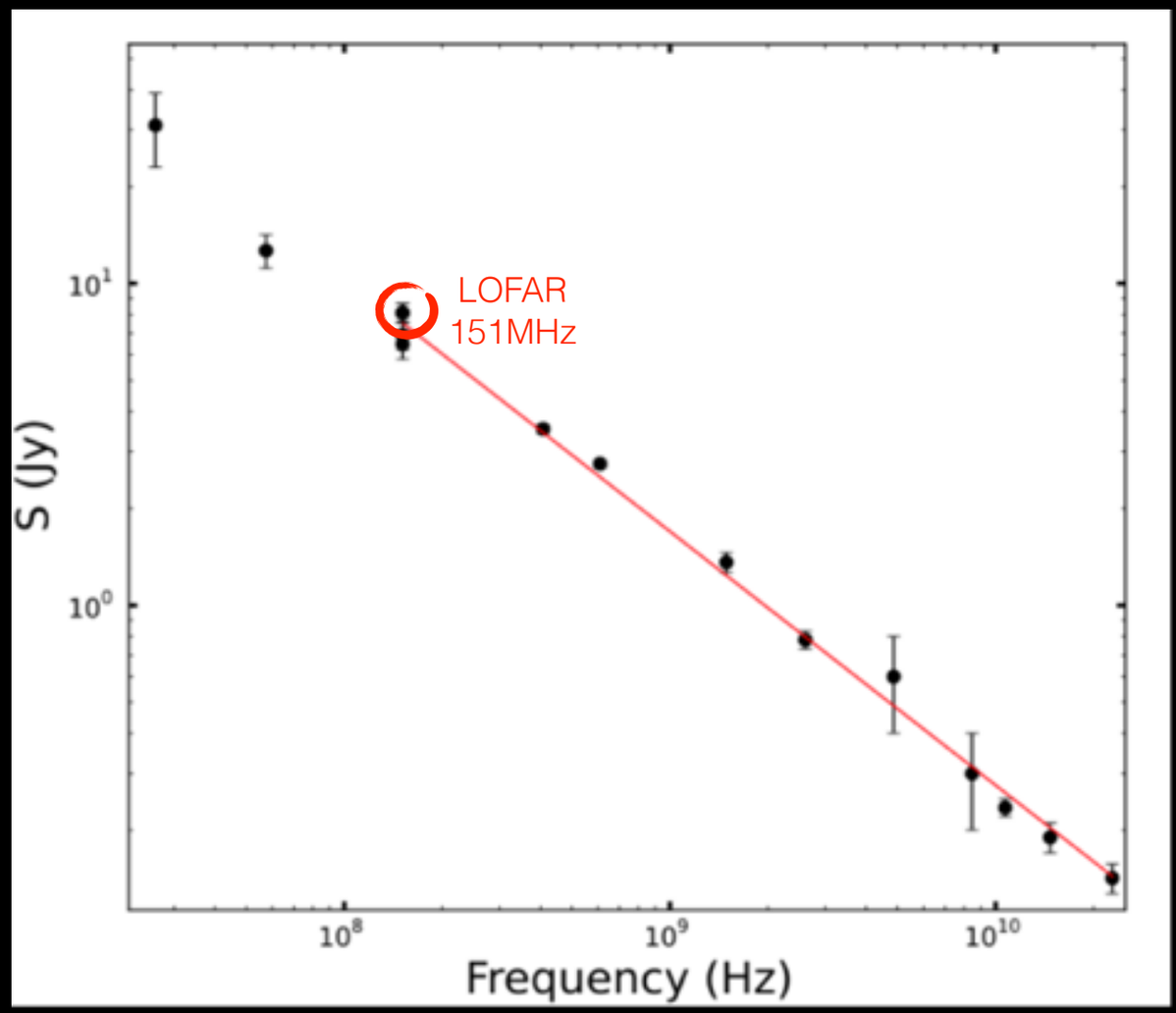
Wavelet Analysis of M51

- Define a significant correlation as 0.75, measure of diffusion length.
- Cross correlation between 151 MHz-70 microns found to be 1.45 kpc
- Cross correlation between 1.4 GHz -70 microns found to be 720 pcs
- Considerably lower than NGC6946 (1700 pc)

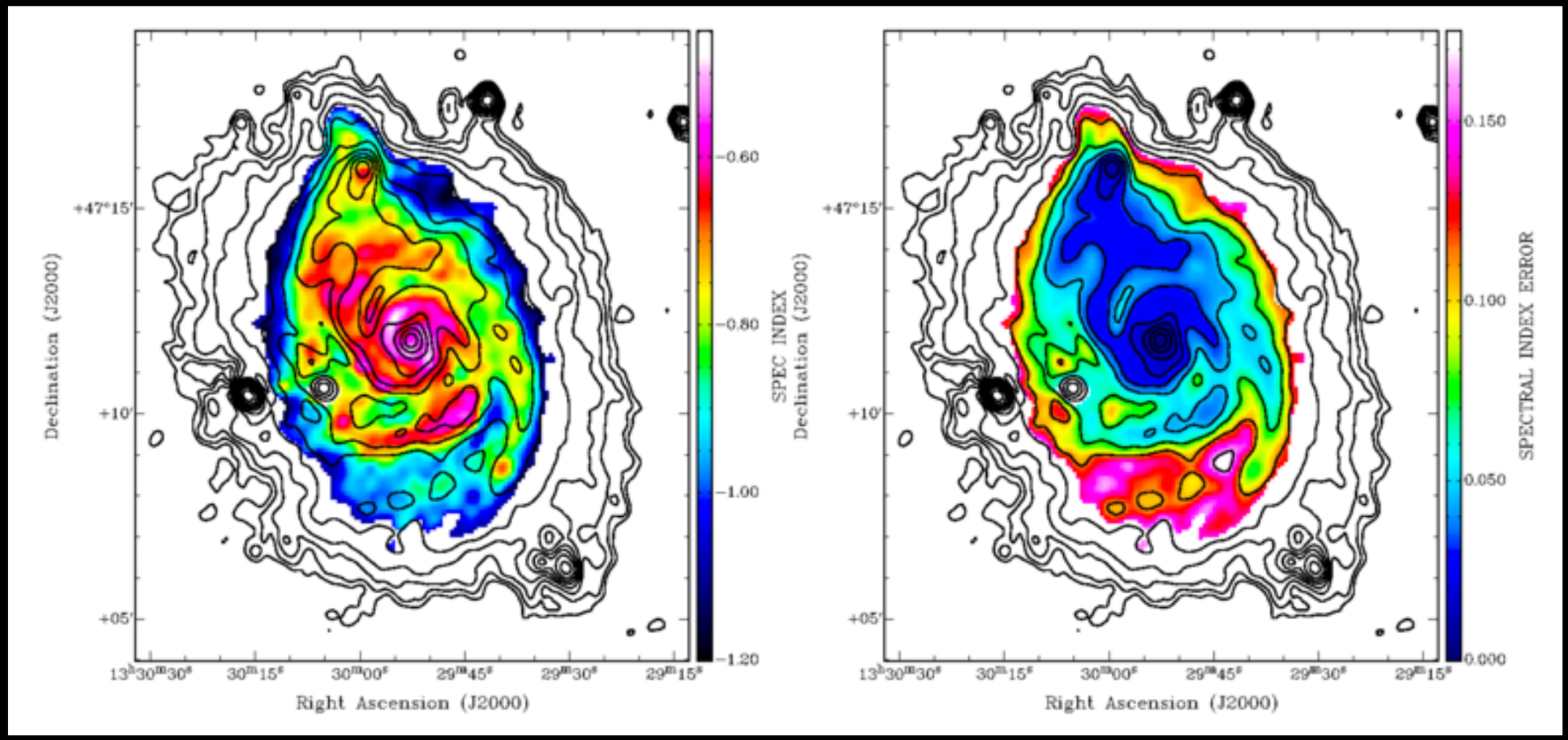


Integrated Spectrum of M51

- Integrated spectrum of M51 shows no signs of flatten down to 151 MHz.
- Able to fit a power law with a spectral index of -0.79.
- LBA data is needed to see if flatten of spectral index occurs at lower frequencies.

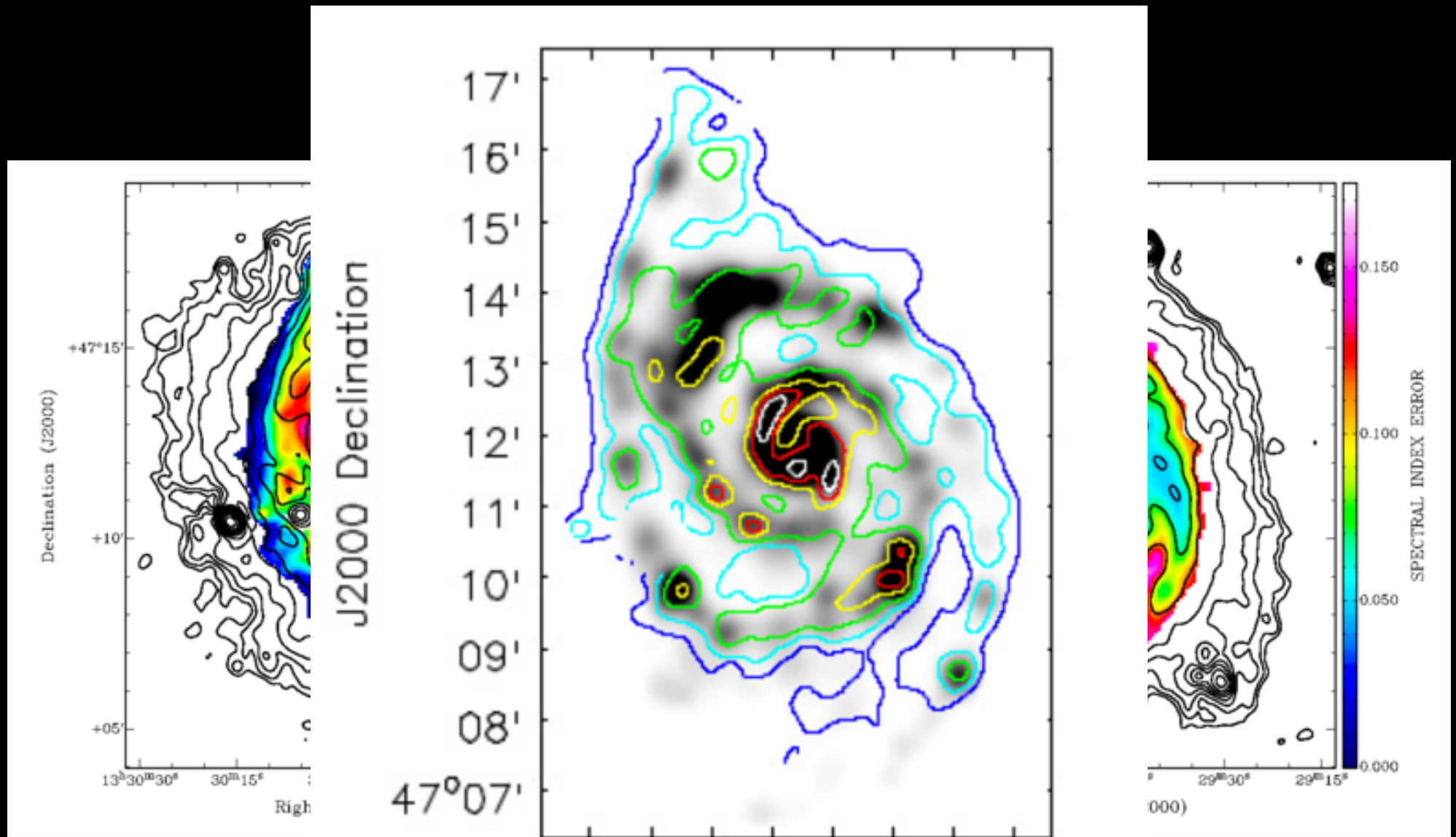


Spectral index map of M51 between 1.4 GHz and 151 MHz



Spectral Index Map Spectral Index Error Map

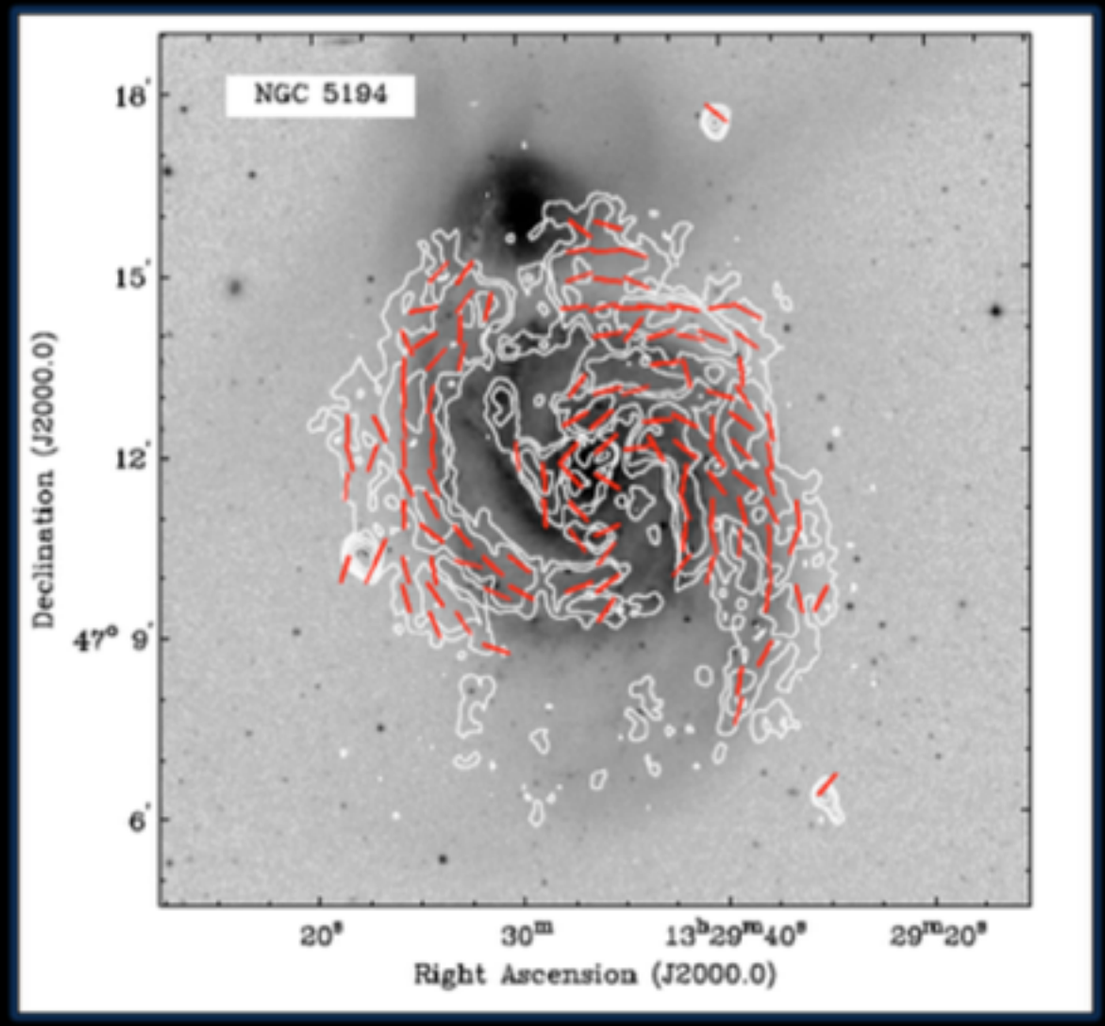
Spectral index map of M51 between 1.4 GHz and 151 MHz



Depolarization of M51

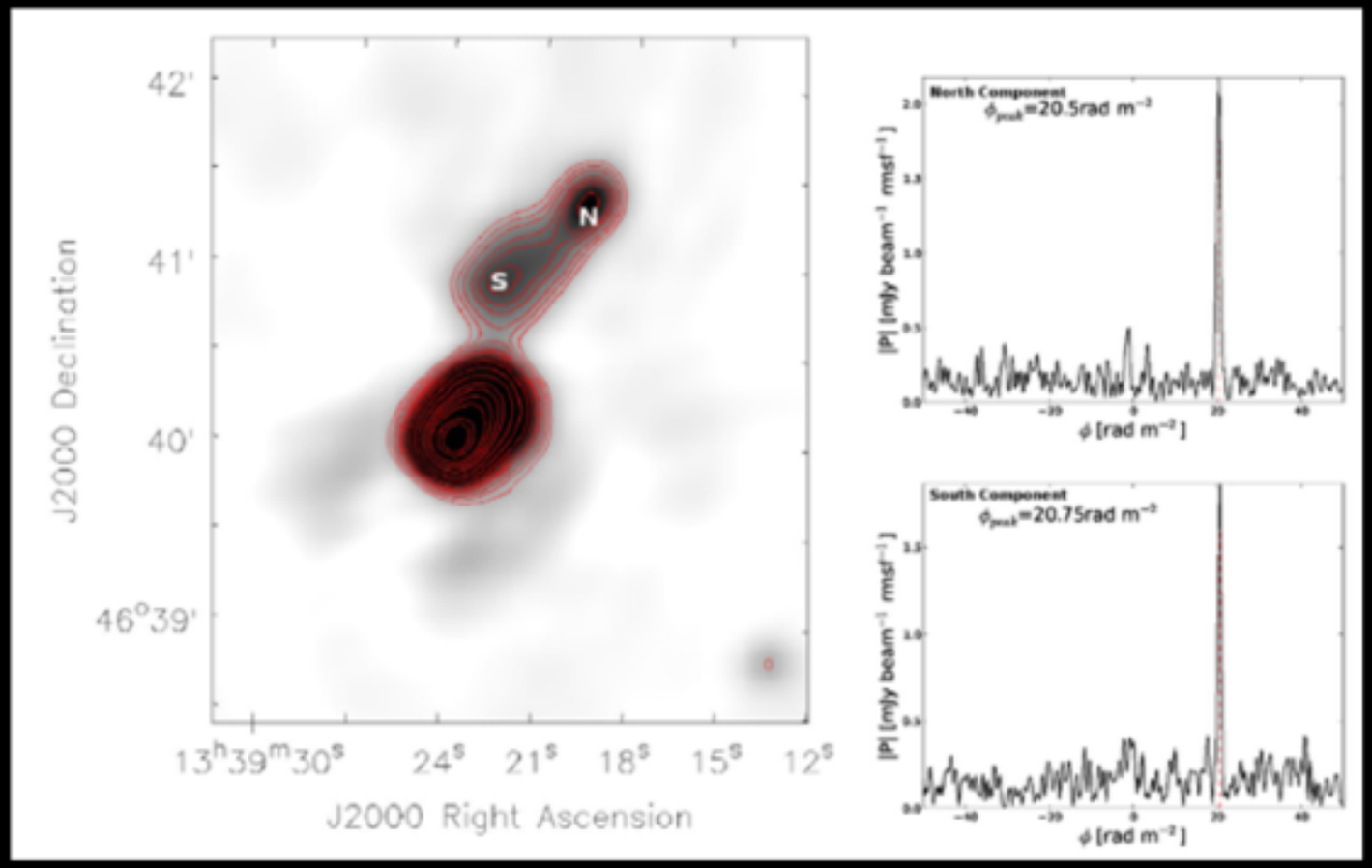
- M51' s inner disk becomes depolarized at 1.4 GHz
- But significant polarization can be seen in the outer disk of M51.
- Can see weak magnetic fields in the outer disk with LOFAR?

M51 at 1.4 GHz

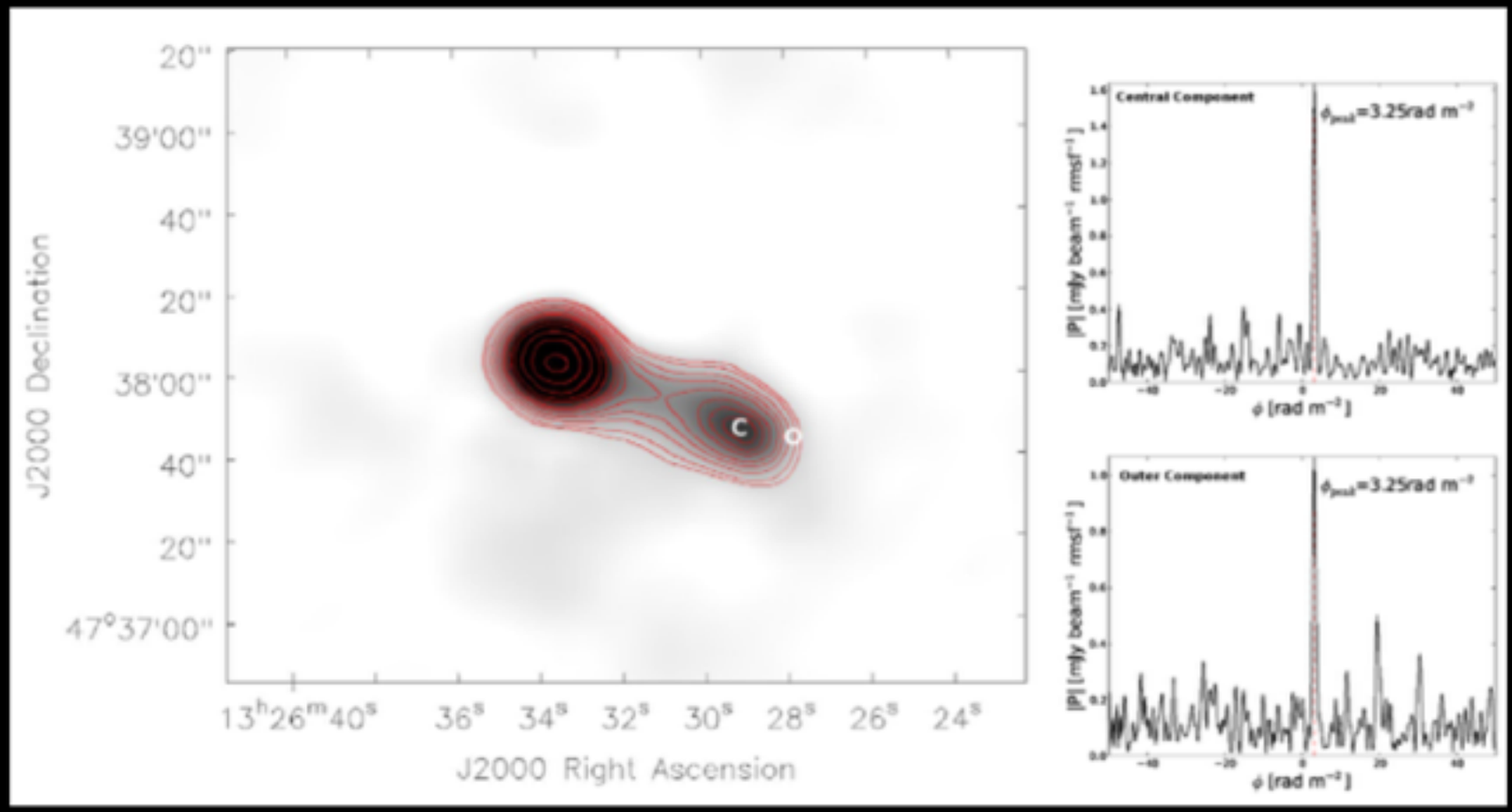


Heald et al. 2011

- M51 was not detected in polarisation due to strong depolarisation.
- Upper limit found to be 0.5 mJy/beam corresponding to polarisation degree of 0.006%.

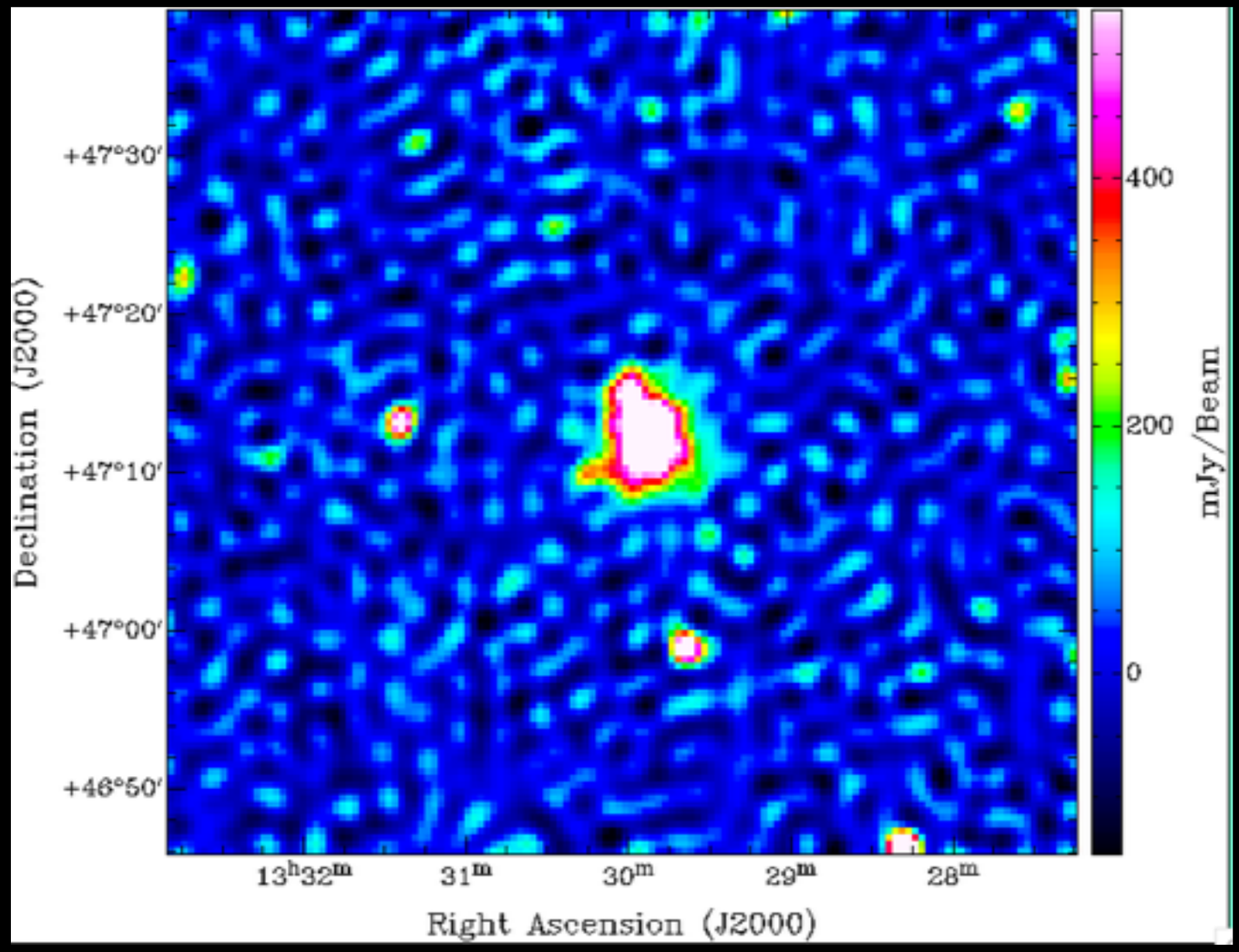


- We detected six extra galactic sources in a field of approximately 4.9 * 4.9 degrees.
- Number density is one polarized source per 1.7 square degrees.



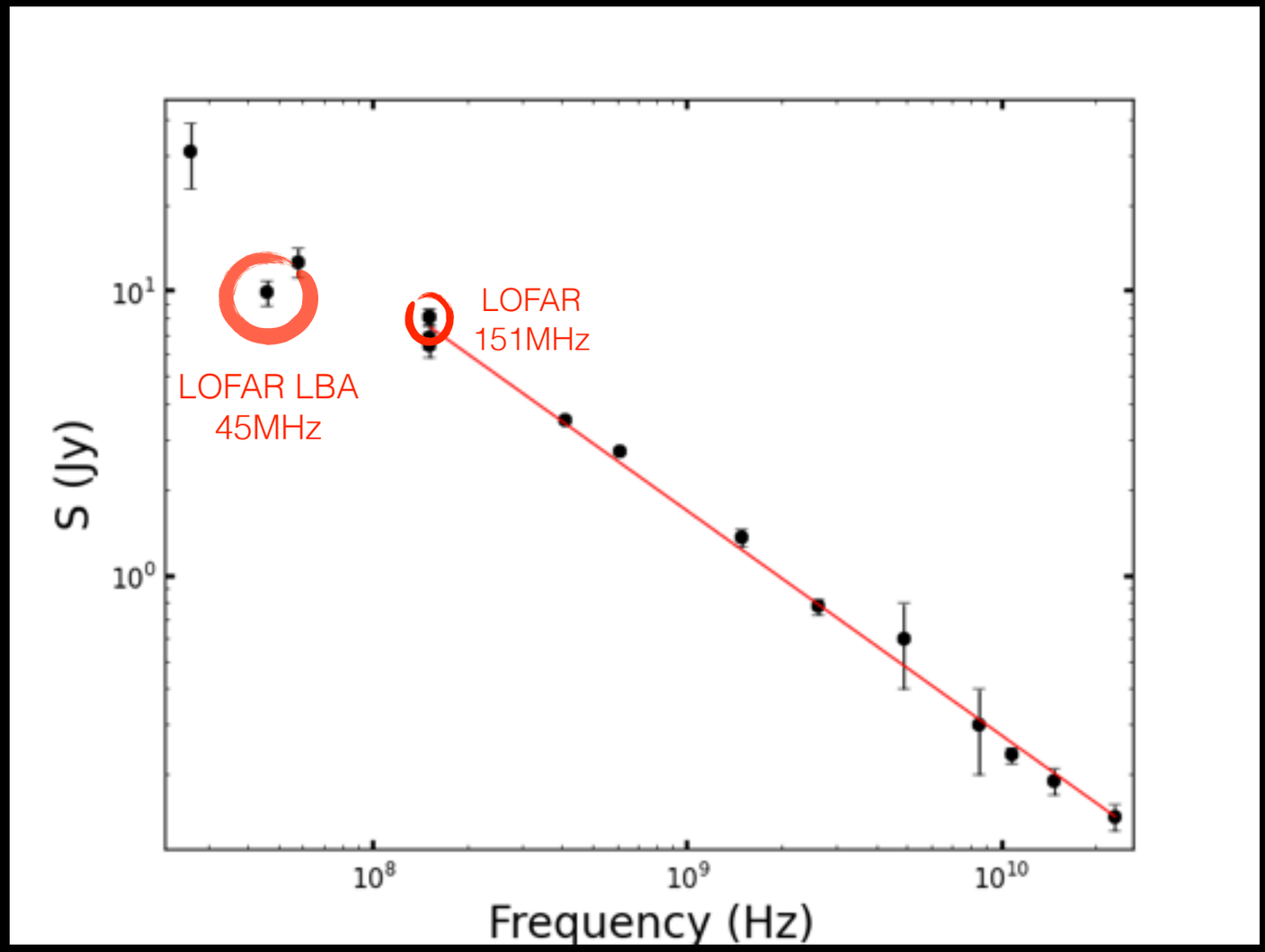
M51 LBA Observation

- Observations of M51 with LOFAR LBA have taken place.
- Preliminary image at 46 MHz (1 MHz Bandwidth out of 36 MHz)
- Noise is approx 43 mJy/ beam



Updated M51 Integrated Flux

- Integrated flux found to be approx 10 Jy.
- In agreement with Israel & Mahoney (1990)
- Flattening of the spectral index is becoming important below 100 MHz.



Conclusions

- M51 is the first galaxy to be observed with LOFAR and is the first time an external galaxy has been observed below 300 MHz at this sensitivity and resolution.

- Diffusion is seen to be the dominant process of CRE propagation in the star forming region of M51.

- We see evidence of free-free absorption in regions which correlate with HII regions.

- M51 was not detected in polarisation due to extreme depolarisation.

- Detected 6 extragalactic sources in the field, giving a number density of 1.7 per degree. This means using LOFAR to probe galaxies via RM grids will difficult.

- Preliminary images with LOFAR LBA show that flattening of the spectral index is becoming important below 100 MHz.