# The nature of the low frequency emission in M51 & NGC891

**David Mulcahy (University of Southampton)**

Andreas Horneffer (MPIfR), Rainer Beck (MPIfR), George Heald (ASTRON), Andrew Fletcher (Uni of Newcastle), Anna Scaife (Uni of Southampton), Bjorn Adebahr (MPIfR) and the MKSP Team

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# The nature of the low frequency emission of M51

## First observations of a nearby galaxy with LOFAR

David D. Mulcahy[1,⋆], Andreas Horneffer[1], Rainer Beck[1], George Heald[2], Andrew Fletcher[3], Anna Scaife[4], Björn Adebahr[1], and Members of the MKSP

[1] Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, 53121 Bonn, Germany
[2] ASTRON, Postbus 2, 7990 AA, Dwingeloo, The Netherlands
[3] School of Mathematics and Statistics, Newcastle University, Newcastle-upon-Tyne NE1 7RU, UK
[4] School of Physics and Astronomy, University of Southampton, Highfield, SO17 1SJ, Southampton, UK

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**ABSTRACT**

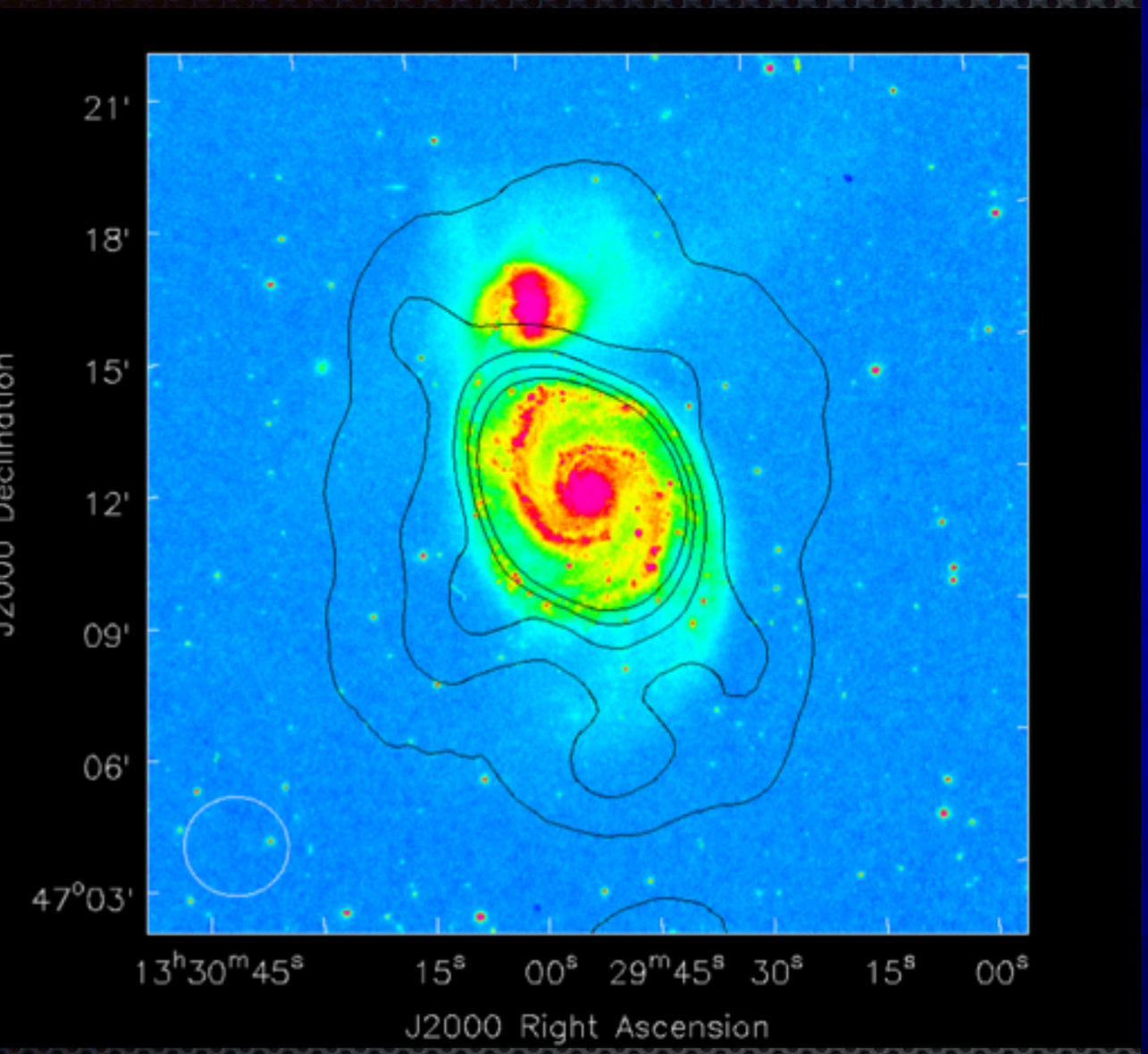
*Context.* Low-frequency radio continuum observations (< 300 MHz) can provide valuable information on the propagation of low-energy cosmic ray electrons. Nearby spiral galaxies have hardly been studied in this frequency range due to the technical challenges of low frequency radio interferometry. This is now changing with the start of operations of LOFAR.
*Aims.* We aim to study the propagation of low energy cosmic ray electrons in the interarm regions and the extended disk of the face-on spiral galaxy Messier 51. We also search for polarization in M51 and other extragalactic objects.
*Methods.* The grand-design spiral galaxy M51 was observed with the LOFAR High Frequency Antennas (HBA) and imaged in total intensity and polarization. This observation covered the bandwidth between 115 MHz and 175 MHz with 244 subbands and 8 channels each, resulting in 1952 channels. This allowed us to use RM Synthesis to search for polarization.
*Results.* We produced a map of total emission of M51 at the mean frequency of 151 MHz with 20″ resolution and 0.3 mJy rms noise, which is the most sensitive map of a galaxy at frequencies below 300 MHz so far. The spectrum of total radio emission is straight, while flat spectral indices in the central region indicates thermal absorption. We observe the disk to extend out to 16 kpc and a break in the radial profile near the edge of the optical disk. The radial scale lengths in the inner and outer disks are larger at 151 MHz, and the break is smoother at 151 MHz than that observed at 1.4 GHz. The arm–interarm contrast is smaller at 151 MHz than at 1400 MHz, indicating propagation of cosmic ray electrons (CRE) from spiral arms into interarm regions. The correlations between the maps of radio emission at 151 MHz and 1400 MHz and the far-infrared emission at 70 $\mu$m reveal breaks at scales of 1.4 and 0.7 kpc, respectively, consistent with CRE diffusion. The total (equipartition) magnetic field strength decreases from about 28 $\mu$G in the central region to about 5 $\mu$G at 10 kpc radius. – No significant polarization was detected for M51, due to severe Faraday depolarization. Six extragalactic sources are detected in polarization in the M51 field of 4.1° × 4.1° size. Two sources show a multiple structure.
*Conclusions.* Our main results, the scale lengths of the inner and outer disks at 151 MHz and 1.4 GHz, arm – interarm contrast and the break scales of the radio –far-infrared correlations, can consistently be explained by CRE diffusion, leading to a longer propagation length of CRE with lower energy. The distribution of CRE sources steepens at about 10 kpc radius, where the star formation rate also decreases sharply. We find evidence that thermal absorption is primarily caused by HII regions. The non-detection of polarization from M51 at 151 MHz is consistent with the estimates of Faraday depolarization. Future search for polarized emission in this frequency range should concentrate on regions with small density of thermal electrons and weak magnetic fields.

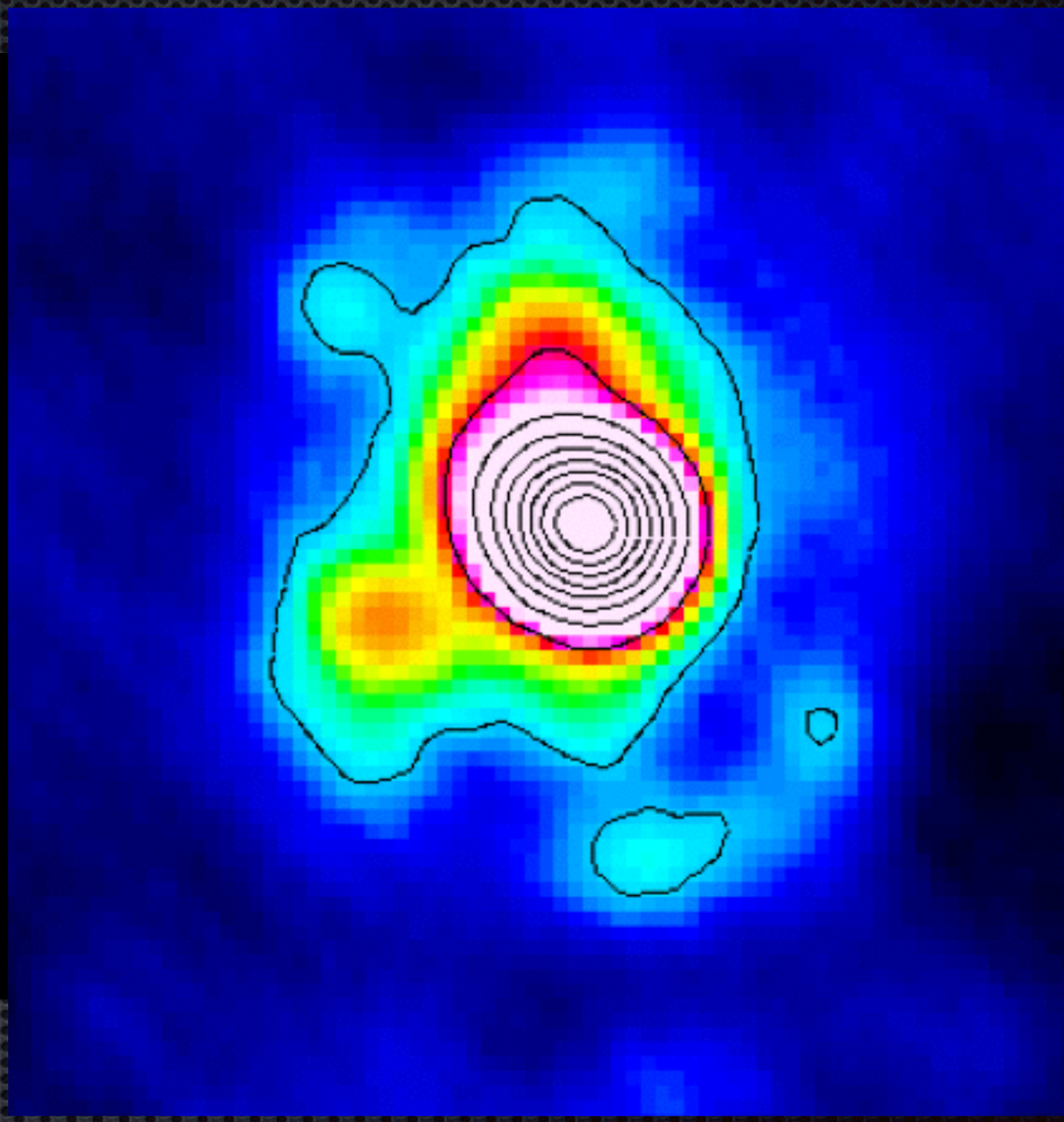
**Key words.** Polarization – ISM: cosmic rays – galaxies: individual: M51 – galaxies: ISM – galaxies: magnetic fields – radio continuum: galaxies

# Overview

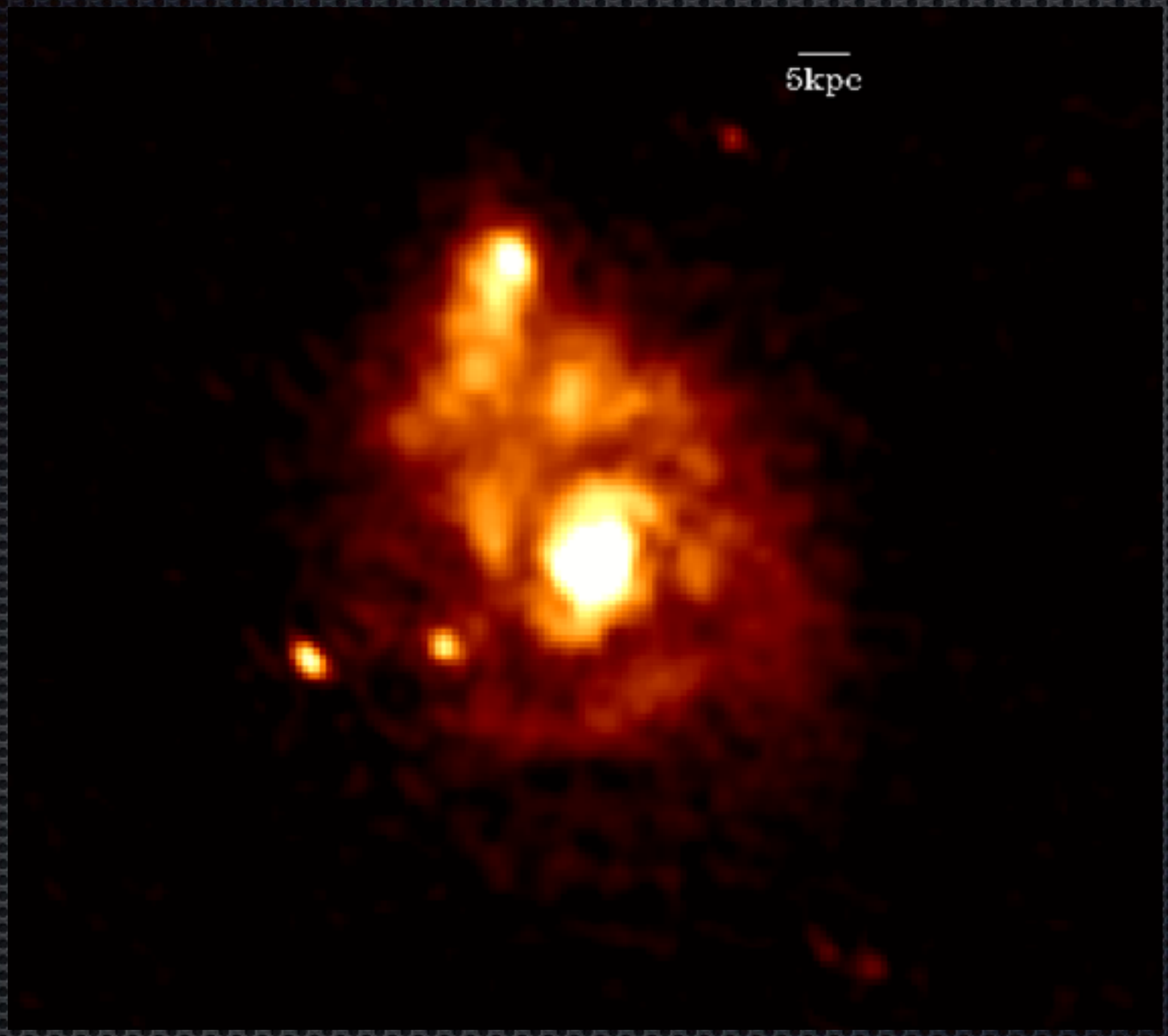
- Presenting M51 & NGC891 at 151 MHz
- CRE propagation in M51
- Thermal absorption
- Polarization in the M51 field

# M51 in 2011


21'
18'
15'
12'
09'
06'
47°03'
J2000 Declination
13h30m45s
15s
00s
29m45s
30s
15s
00s
J2000 Right Ascension

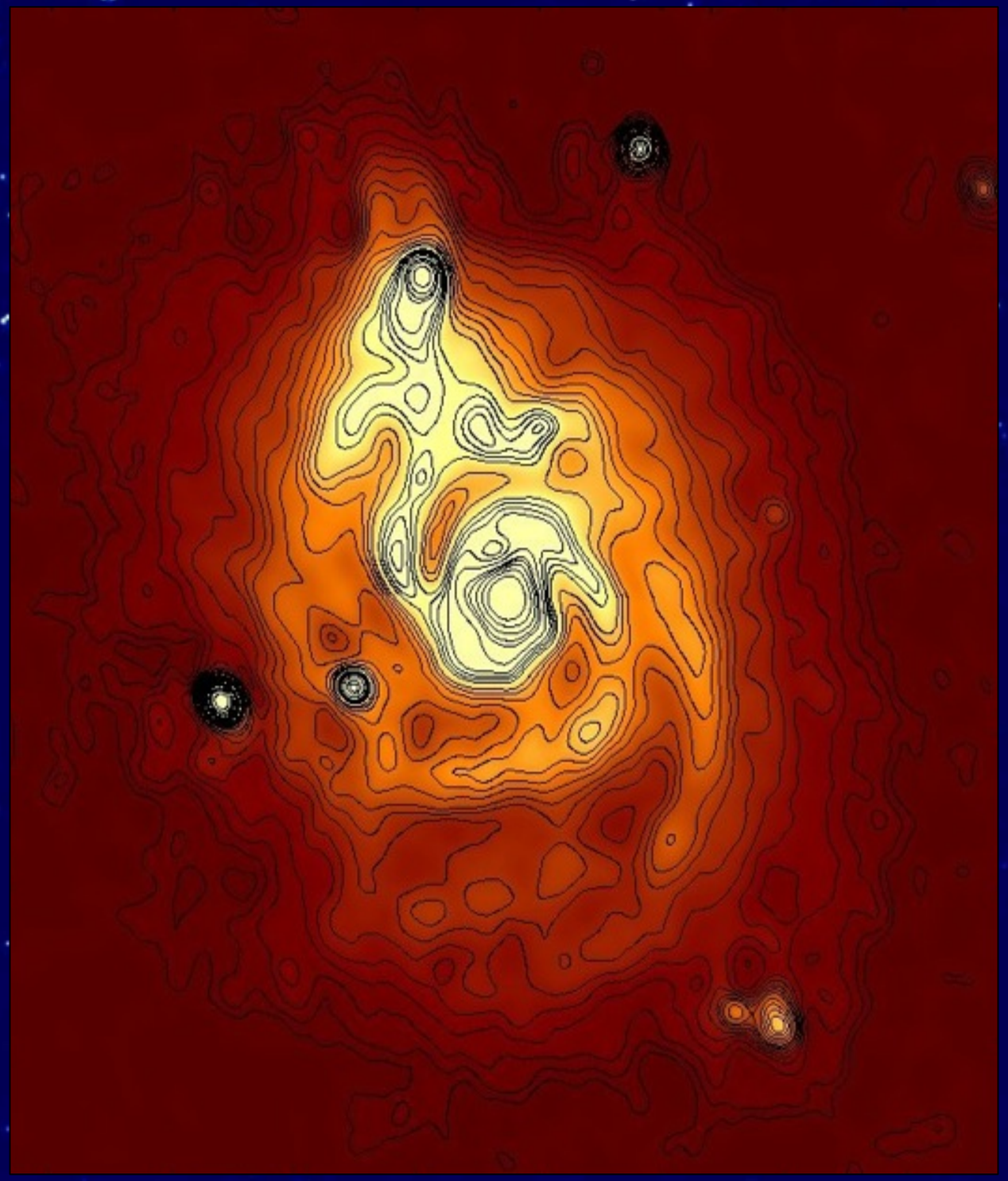


# M51 in 2012



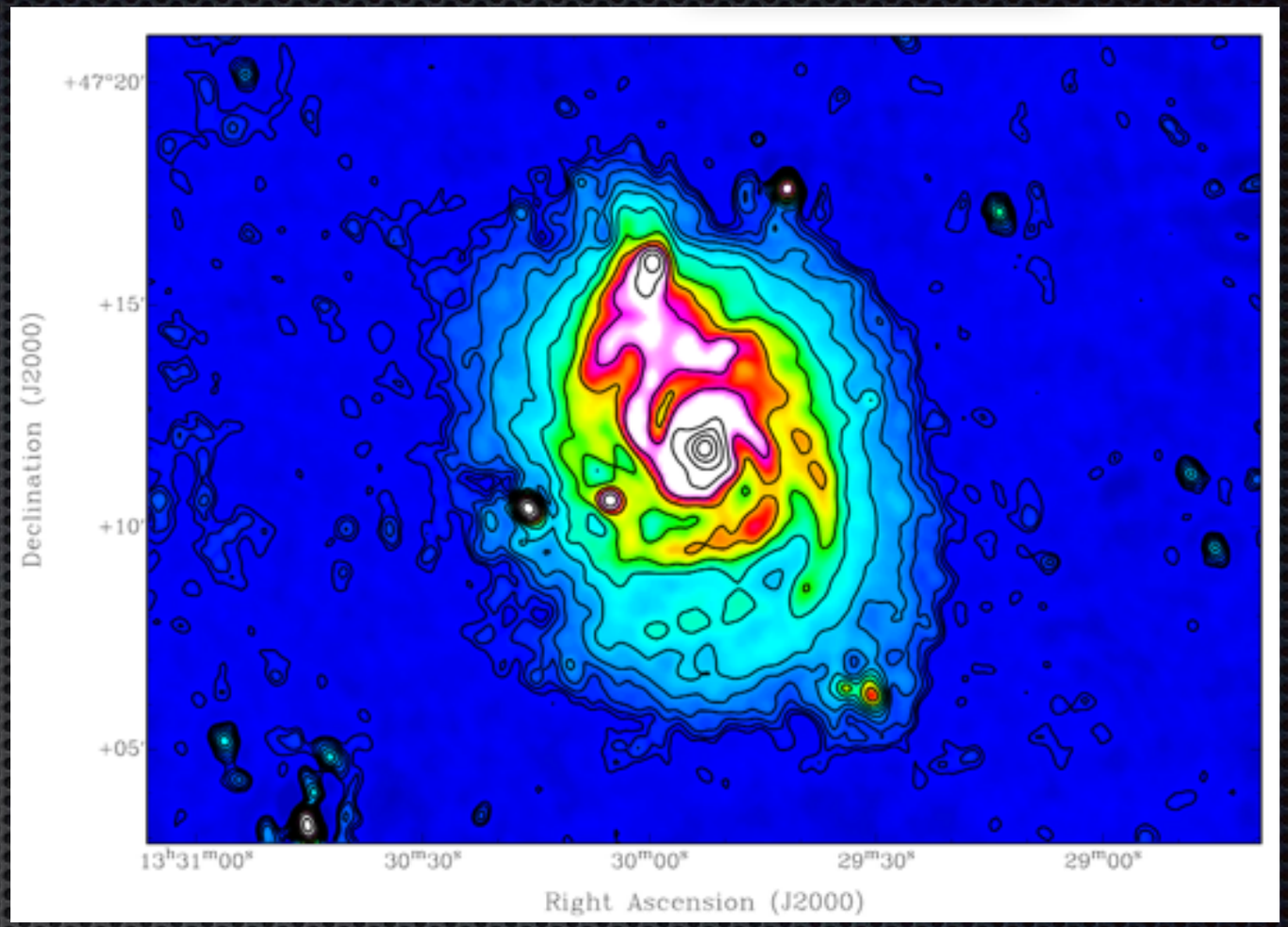

5kpc
Last Year

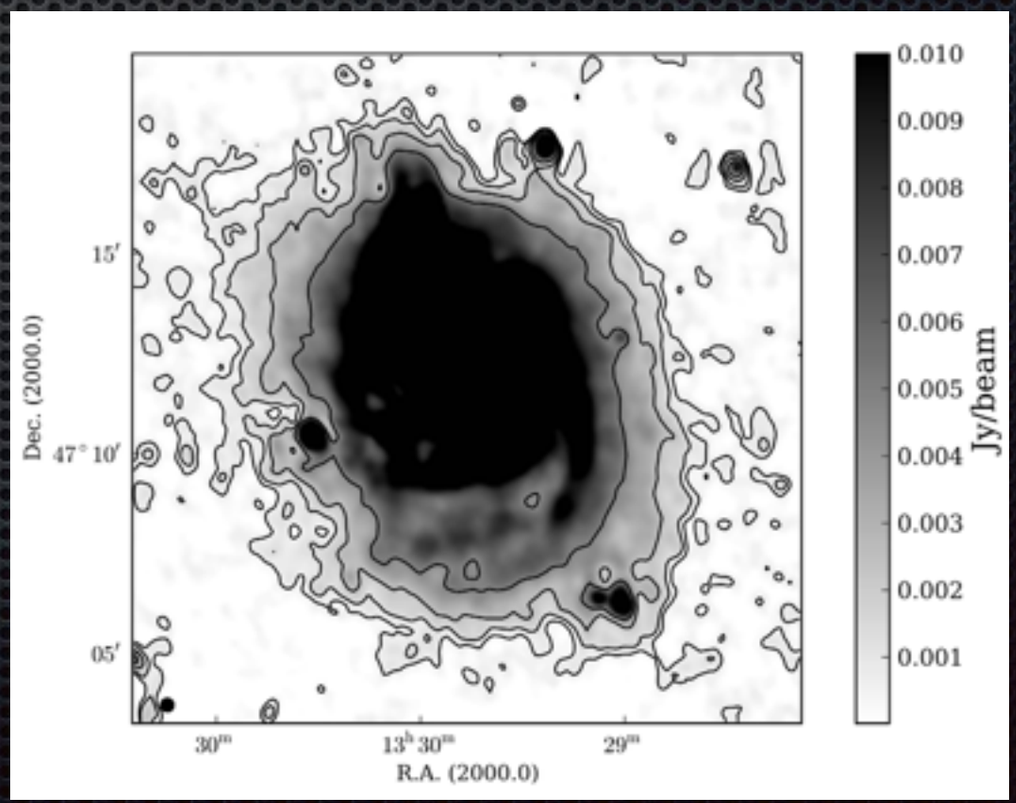
# M51 at 151 MHz



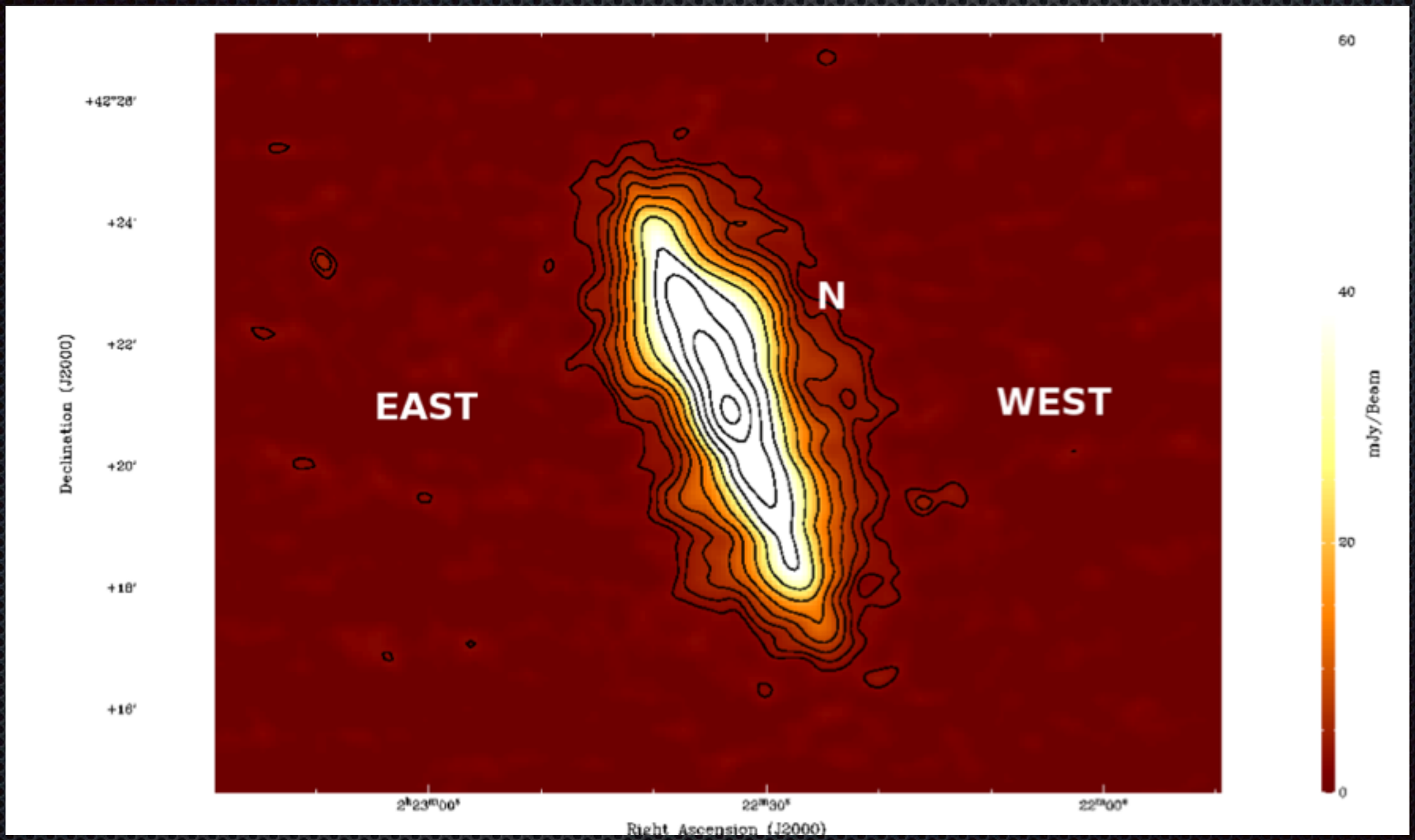
# M51 at 151 MHz

- Noise is found to be 300-400 microJy/beam near galaxy.
- Deepest image so far of any galaxy in low frequency regime.
- Able to detect the disk out to 16 kpc.
- Largest extent of M51 detected in radio continuum.



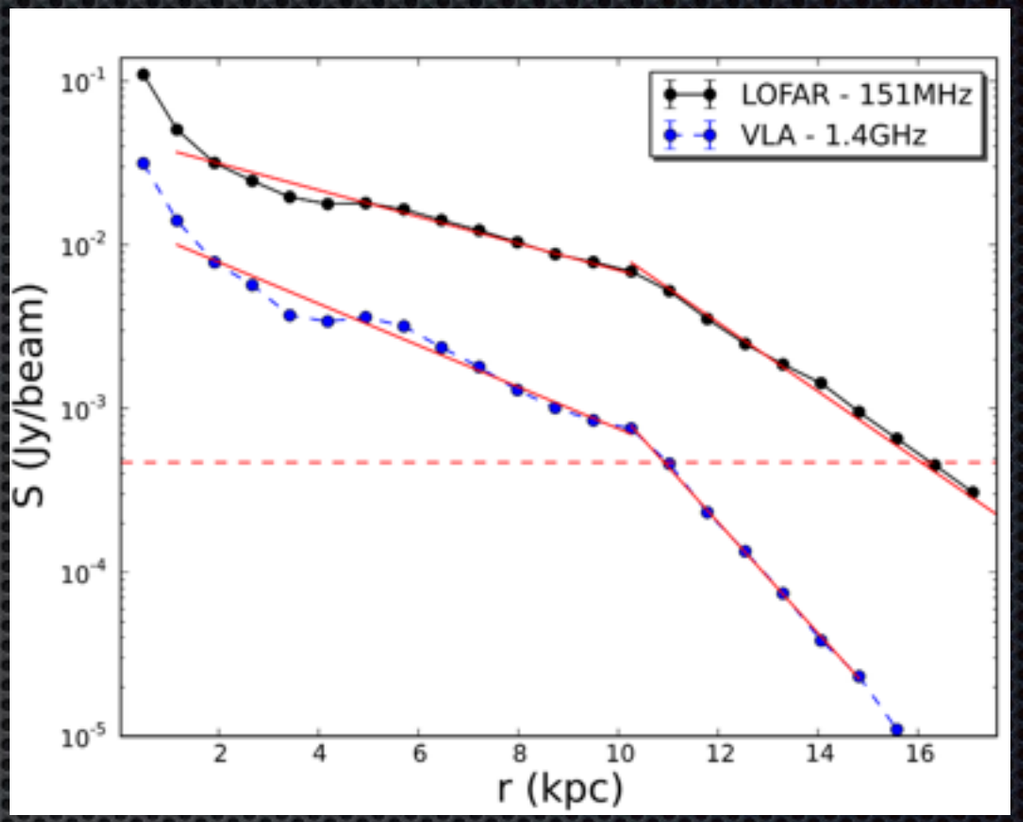



# NGC891 at 146 MHz

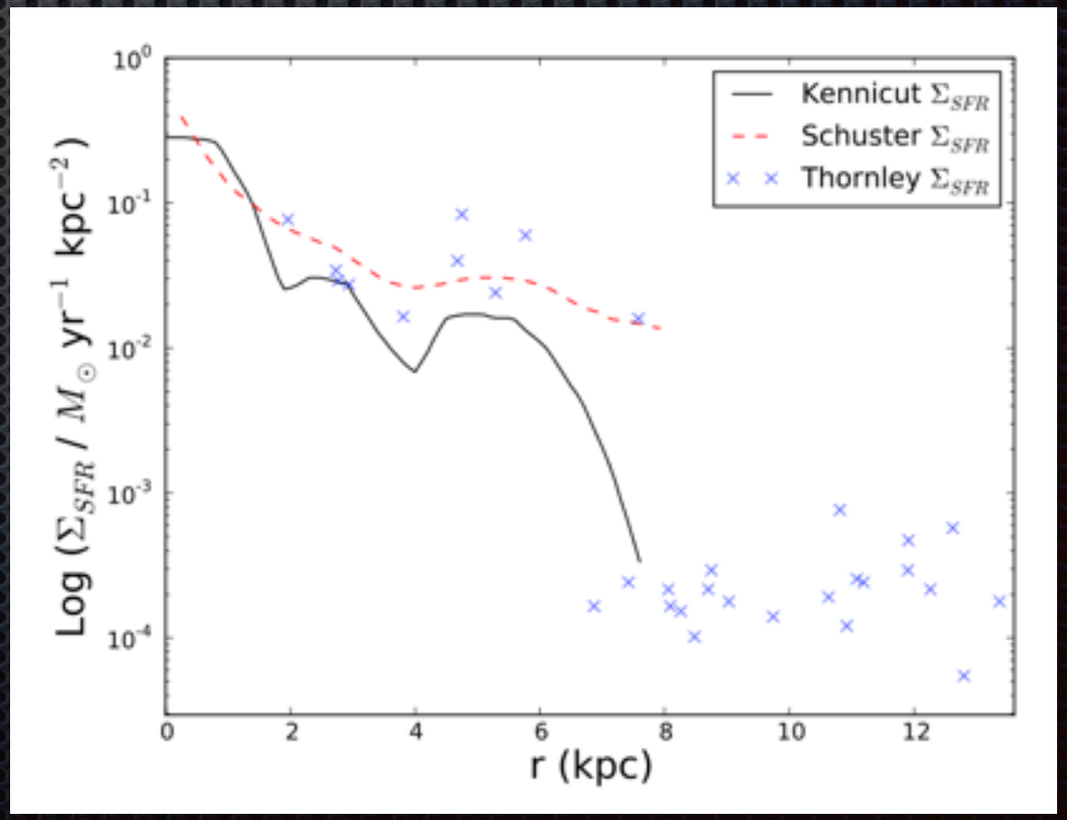


- In M51 we observe a break in the radial profile at approximately 10 kpc.
- The break becomes smoother with decreasing frequency.
- Therefore, detecting the extreme outer disk becomes more difficult than envisioned.

Radial profile of M51 at 1.4 GHz & 151 MHz




Radial profile of star formation rate



# Cosmic Ray Propagation in the star forming disk

Diffusion model

$$l_{\mathrm{dif}} \propto B_{\mathrm{tot}}^{-3/4}\, \nu^{-1/4}$$

Streaming instability model

$$l_{\mathrm{stream}} = v_{\mathrm{A}}\, t_{\mathrm{CRE}} \propto B_{\mathrm{tot}}^{-1/2}\, \nu^{-1/2}$$

- Diffusion model predicts a ratio of propagation length of 1/1.75 between 1.4 GHz and 151 MHz.
- Streaming model predicts a ratio of propagation length of 1/3.04

# Scale lengths used

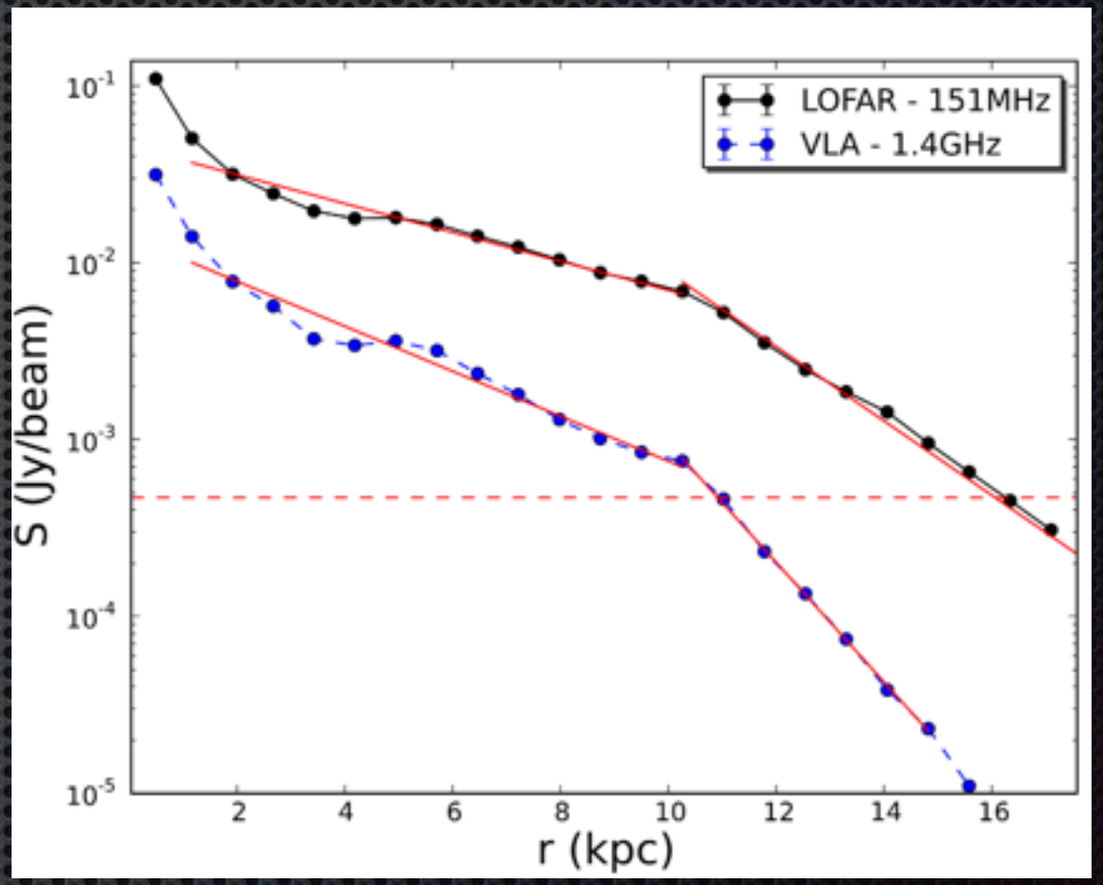
$$I(R) = \begin{cases} I_0\, exp(-r/l_{\text{inner}}) & \text{r} \leq 10\,\text{kpc} \\ I_{10}\, exp(-r/l_{\text{outer}}) & \text{r} \geq 10\,\text{kpc}\,. \end{cases}$$

# Scale lengths found

| $\nu$ (MHz) | $l_{\text{inner}}$ (kpc) | $l_{\text{outer}}$ (kpc) |
|---|---|---|
| 1400 | 3.4 ± 0.2 | 1.28 ± 0.02 |
| 151 | 5.32 ± 0.4 | 2.06 ± 0.06 |
| HI * | 5.5 | 2.1 |

* derived from Bigiel et al. (2010)

- Scale lengths in the inner and outer disks are larger at 151 MHz than at 1.4 GHz by a factor of 1.6+/- 0.1.
- Supports diffusion model.
- Other methods support this finding (eg. Radio-IR cross correlation).



# Modelling CRE propagation in M51

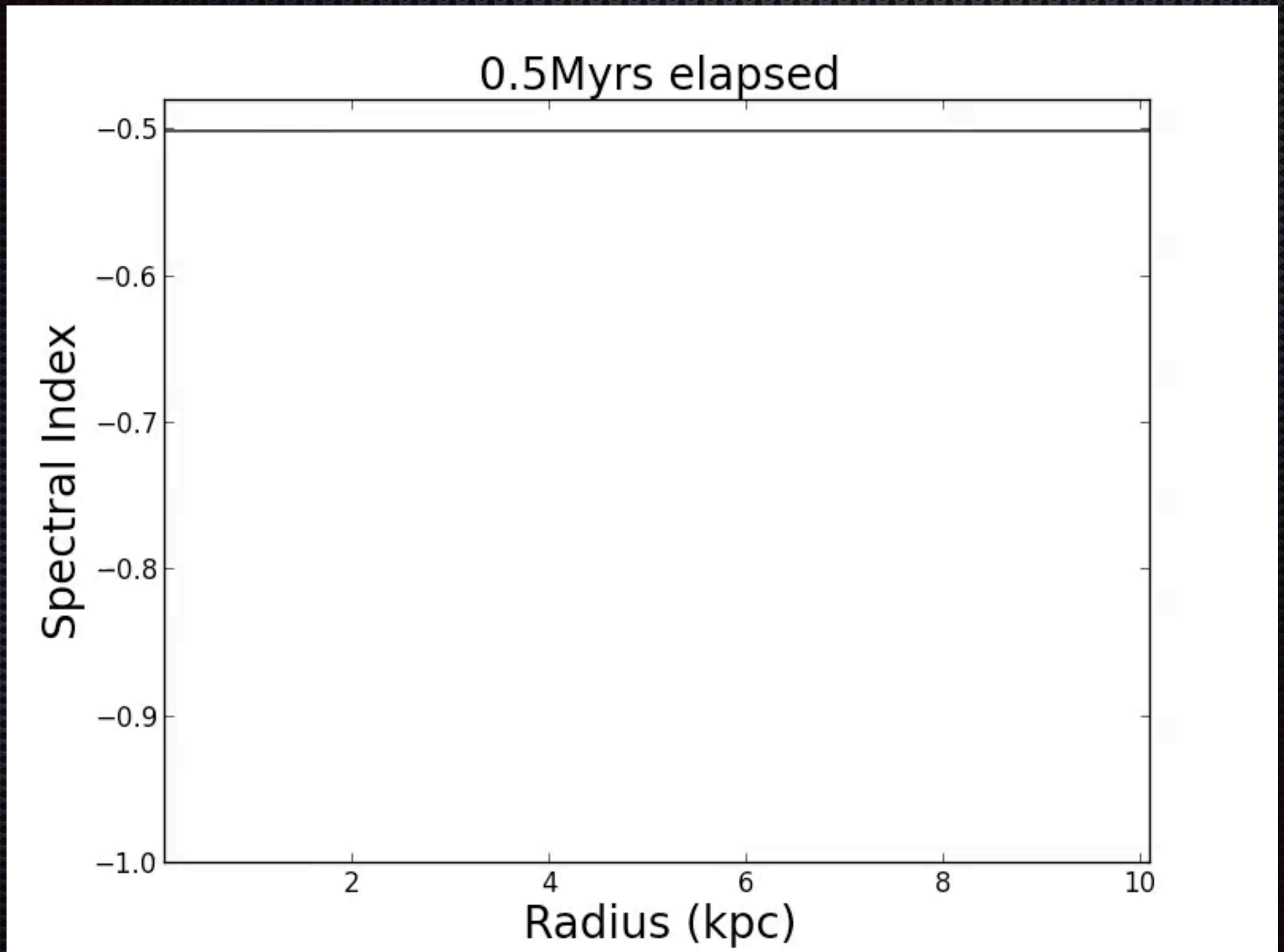
- Modelling the CRE propagation in M51in 1-D (radial) using the following equation:

$$\frac{\partial N}{\partial t} = \Theta \frac{1}{r'} \frac{\partial}{\partial r'} \left( r' \frac{\partial N}{\partial r'} \right) + \Phi \frac{\partial}{\partial E'} [E'^2 B'^2] + KQ(r') E'^{-p} - t_0 \frac{N(R,E)}{\tau_{esc}}$$

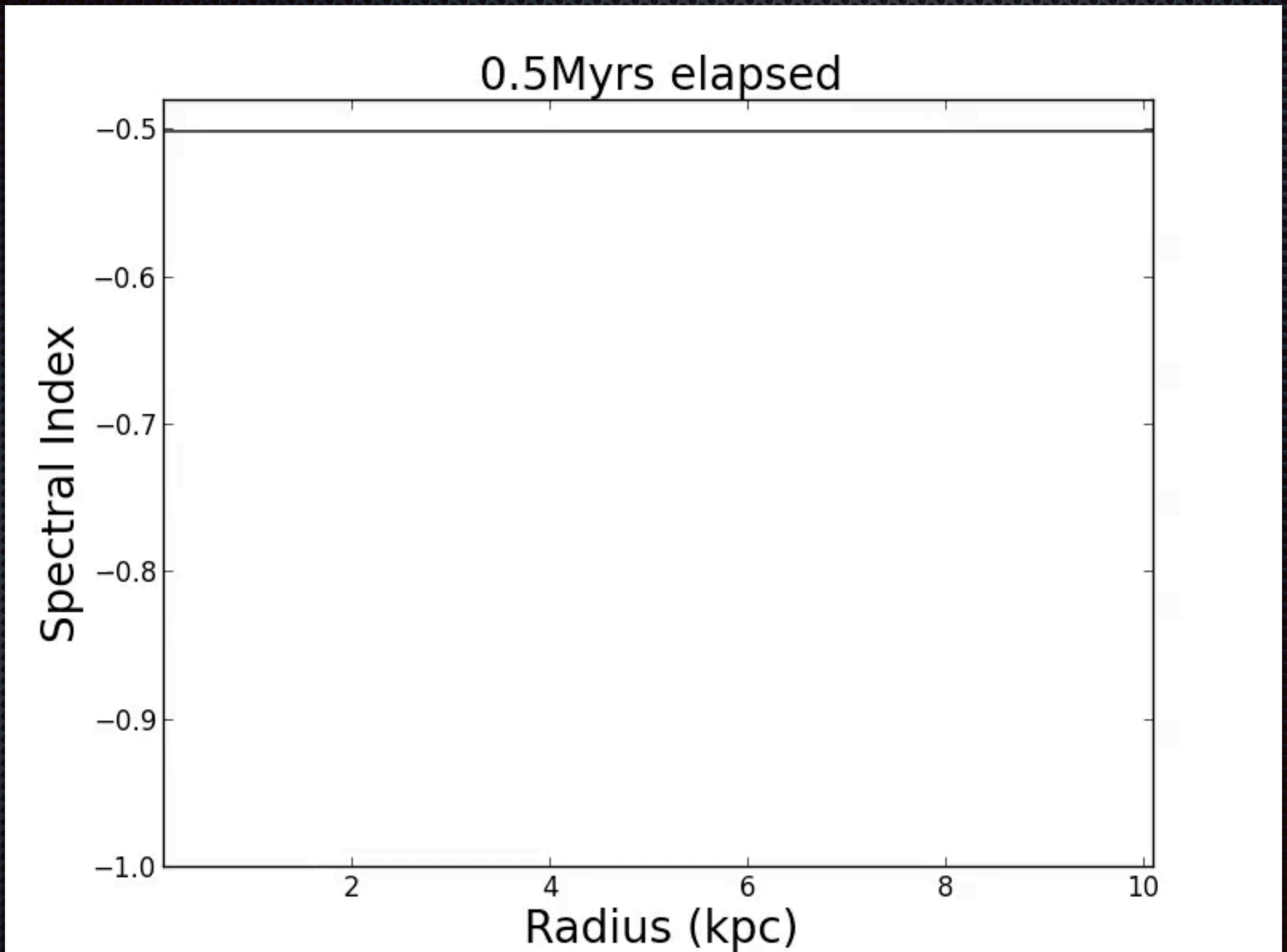
CRE Diffusion | Energy Losses | CRE Injection | Escape Term

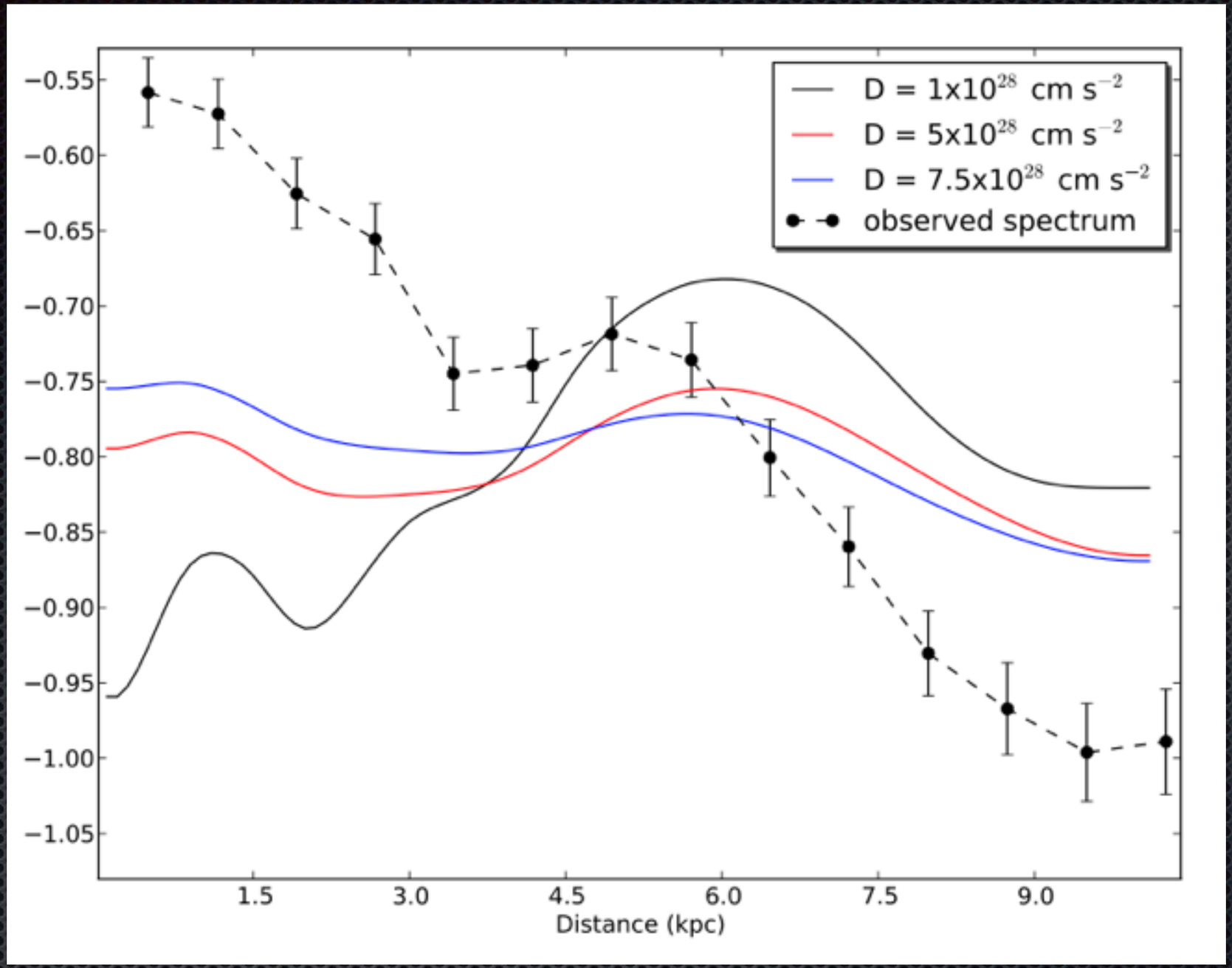
- Input required: radial profile of SFR and B field strength

# Diffusion Coefficient: 2.8*10^28



# Diffusion Coefficient: 7.5*10^28

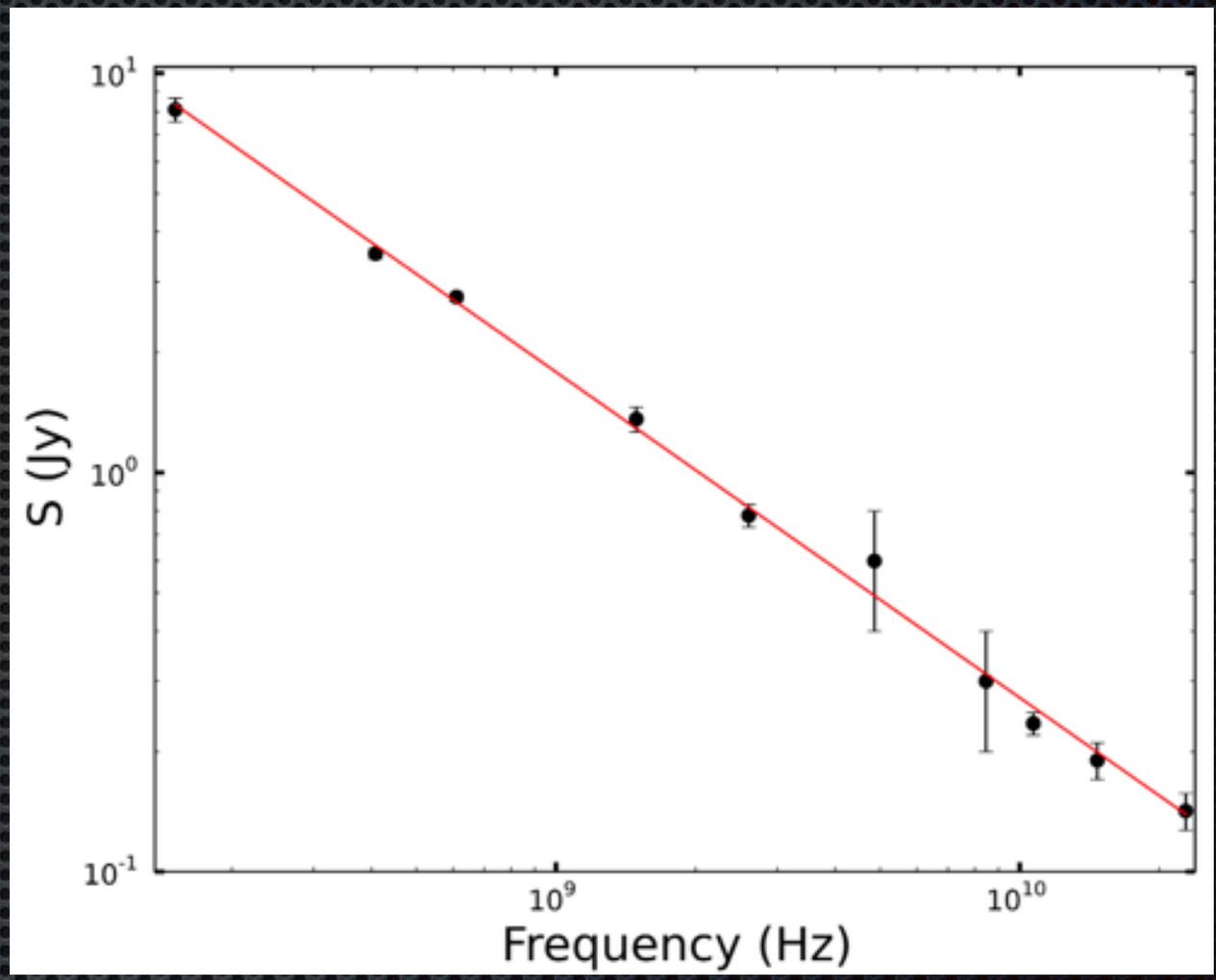





Future work include computing scale lengths, extending radius to 16kpc, investigating other galaxies etc

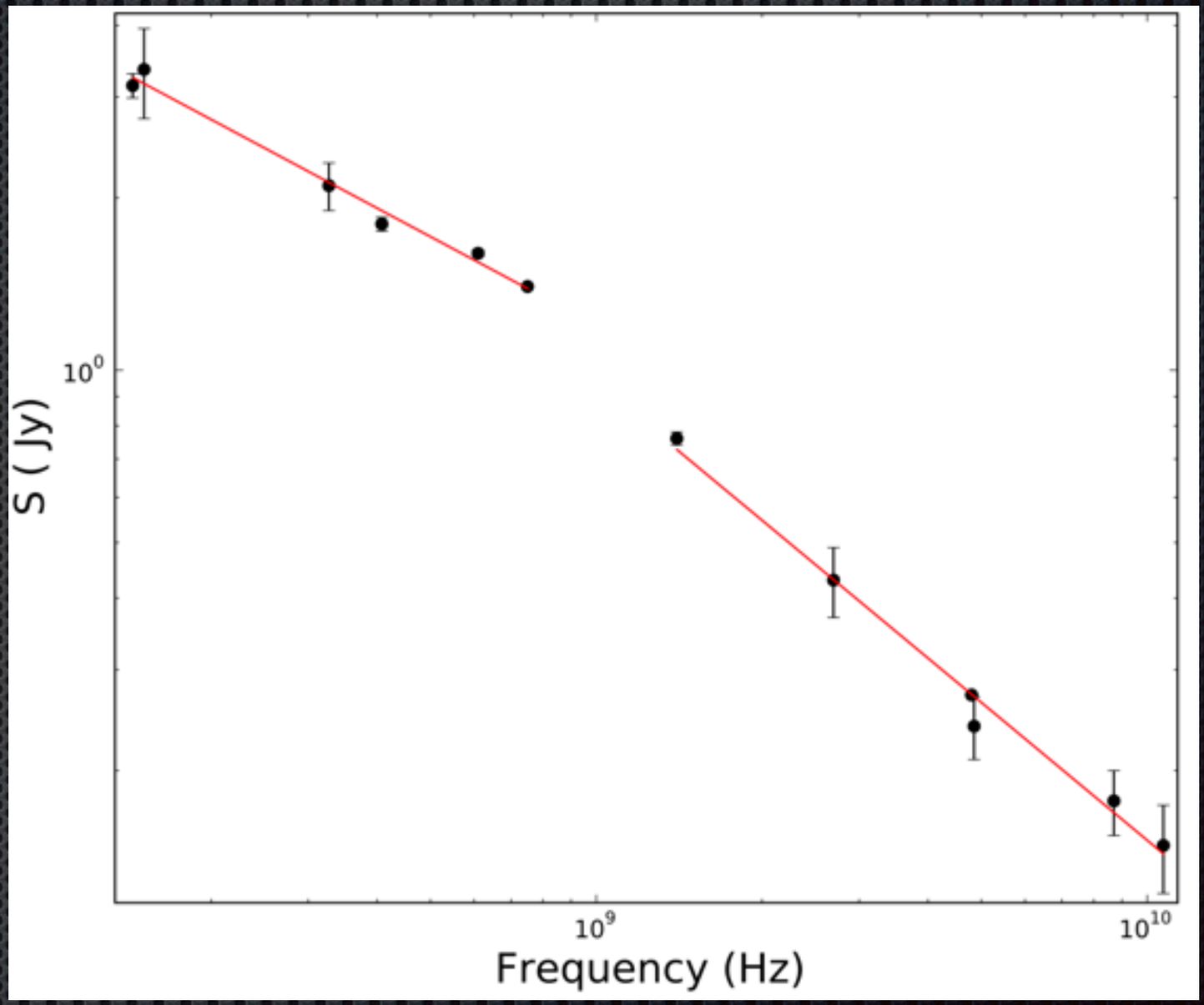
# Integrated spectrum of M51

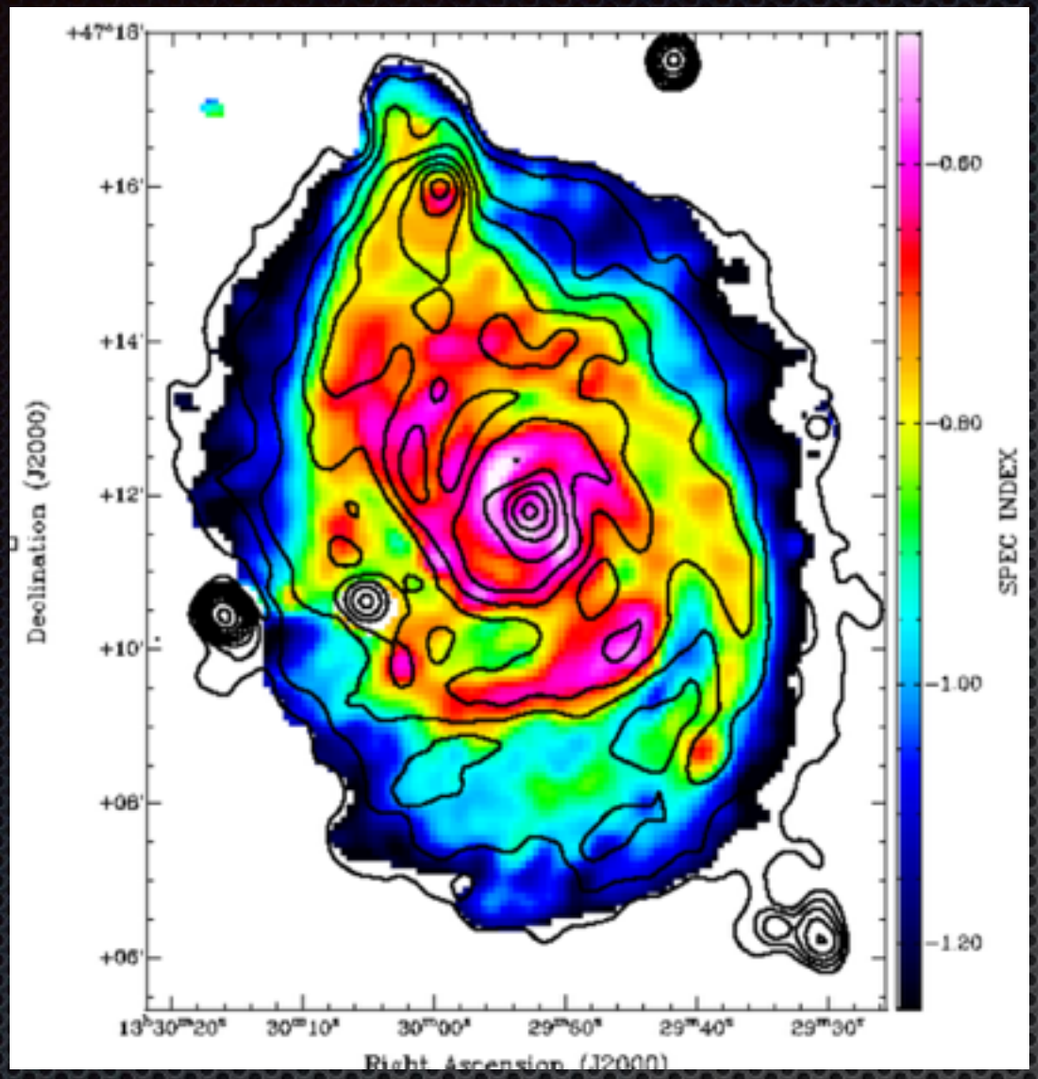
- Integrated spectral index is found to be -0.81+/-0.02.
- No sign of flattening down to 151 MHz.
- This disagrees with findings from Pohl et al (1991).

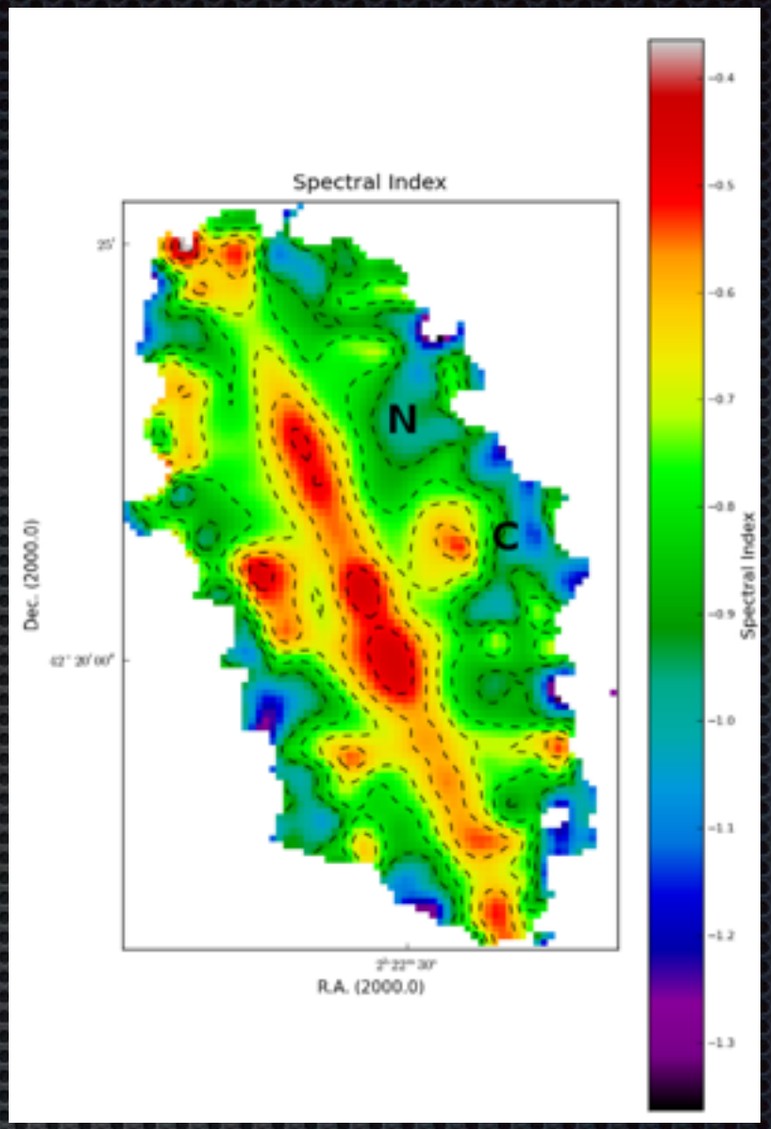


# Integrated Spectrum of NGC891

- Confirm spectral break for NGC891.
- High frequency spectral index found to be approx -0.78.
- Low frequency spectral index found to be approx -0.51.



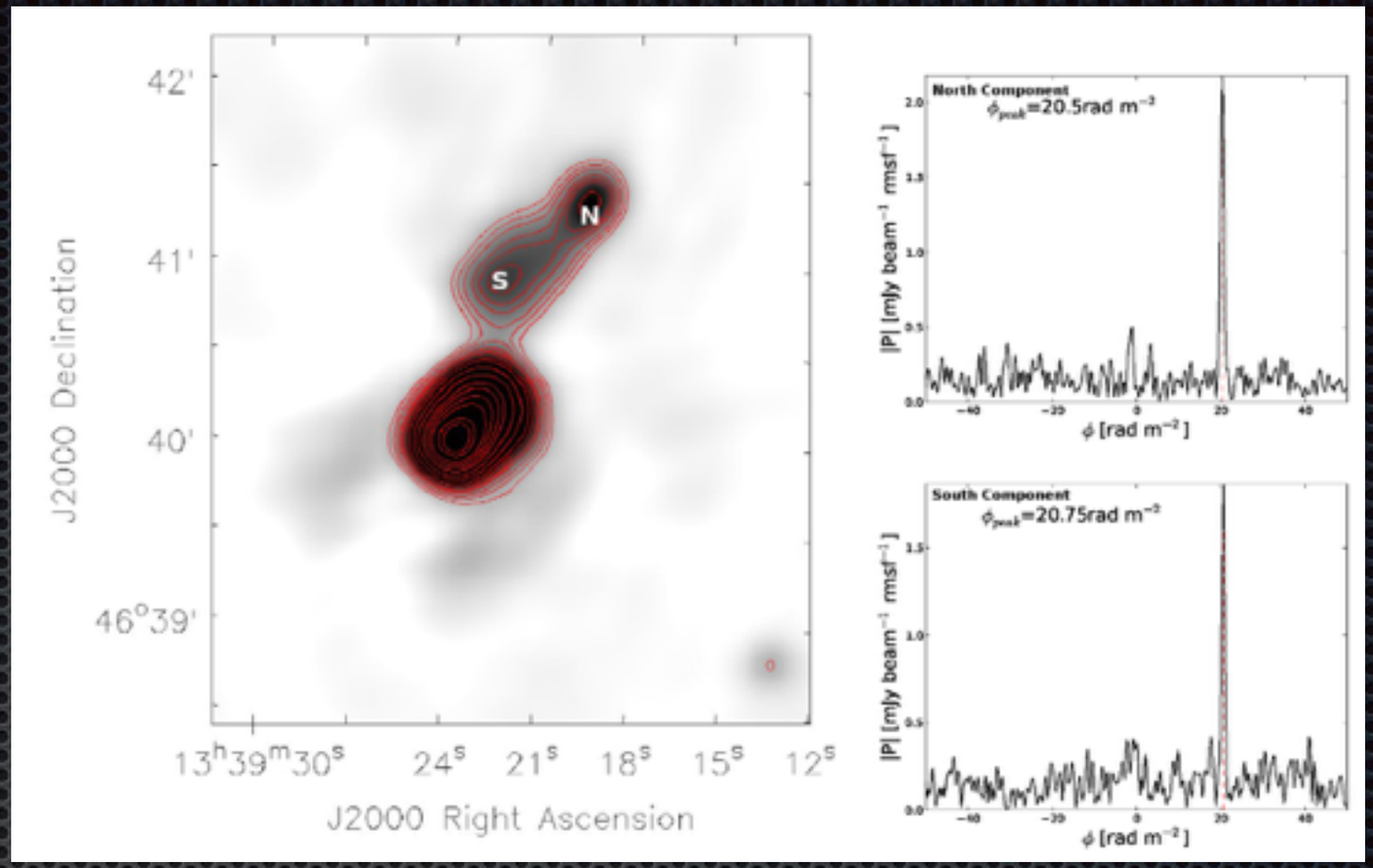


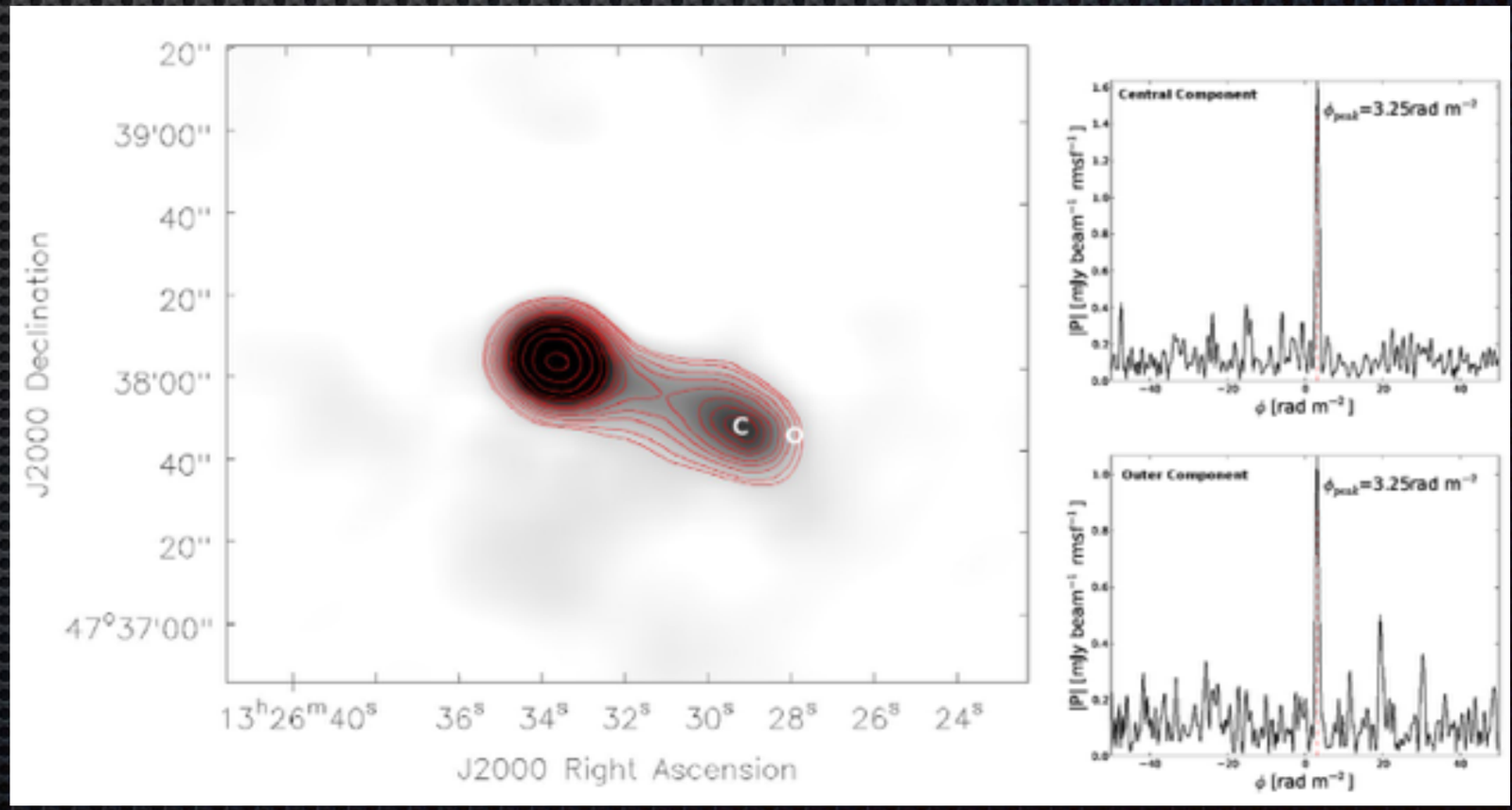

- HII regions are seen to have spectral index less than -0.5 indicating thermal absorption.
- NGC891 shows much more flatter spectra indicating that path length and therefore inclination of galaxy is important.
- Indicates thermal absorption but disagrees with findings with Israel & Mahoney (1991).

# Extragalactic polarized detections in M51 field

- 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 2.8 square degrees.



# Conclusions

- Diffusion is found to be the most dominant process of CRE propagation in the star forming disk of M51.
- Modelling of the CRE propagation indicates that the diffusion coefficient in M51 is approx 7.5*10^28 cm^2 s^-1.
- Thermal absorption is seen in M51 & NGC891 and is greatest in HII regions.
- Non detection of diffuse polarized emission from M51.
- RM grids of nearby galaxies will be extremely difficult at these low frequencies due to the sparsity of polarized sources.

# Future Work

- LBA observations have being proposed for cycle 2 to further constrain the parameters of thermal absorption and CRE diffusion.

- More galaxies at a range of inclinations and SFR rates need to being observed,reduced and analysed by the MKSP, in order to support these findings.

- Theoretical modelling of the diffusion loss equation are being performed and compared to observations.