Searching for Magnetic Fields at Low Frequencies: Early Observations with LOFAR on M51 & NGC4631

David Mulcahy

On behalf of the Magnetism KSP

DFG Research Unit 1254

- Magnetization of Interstellar and Intergalactic Media – The Prospects of Low-Frequency Radio Observations
- Active since summer 2010
- 10 PhD students & 2 postdocs are currently active
- 1 dedicated project on LOFAR commissioning (see Andreas' talk)

MKSP galaxies & commissioning working groups

- Björn Adebahr – Ruhr-Universität Bochum, Germany
- Mike Bell – MPA Garching, Germany
- Krzysztof Chyzy - Jagiellonian University, Poland
- Robert Drzazga - Jagiellonian University, Poland
- René Giessübel –MPIfR, Germany
- George Heald – ASTRON, Netherlands
- Andreas Horneffer – MPIfR, Germany
- Wojciech Jurusik - Jagiellonian University, Poland
- David Mulcahy – MPIfR, Germany
- Blazej Nikiel-Wroczynski – Jagiellonian University, Poland
- Carlos Sotomayor - Ruhr-Universität Bochum, Germany

Current Work

- Determining the best & most efficient method of calibration.
- Most ideal imaging parameters for extended emission is being investigated.
- Searching for optimal polarized calibrators:
  →Pulsars with a non-zero Faraday depth
- Investigating the properties of the Ionosphere.

NGC4631 Details

- Edge-on spiral galaxy at a distance of approx 6.7 Mpc.
- Has the largest Radio Halo observed thus far, with a scale height of approximately 2.5kpc.
- The scale height of the total magnetic field is approx 10kpc.
- Radio Halo above the inner disk is composed of magnetic spurs connected to star-forming regions in the disk, likely dragged by a strong galactic wind.
- Ideal target for LOFAR observations

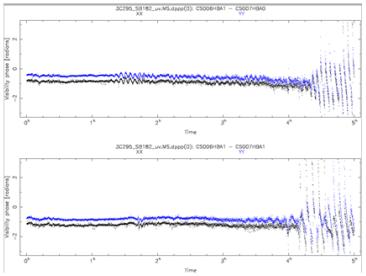
Marita Krause

NGC4631

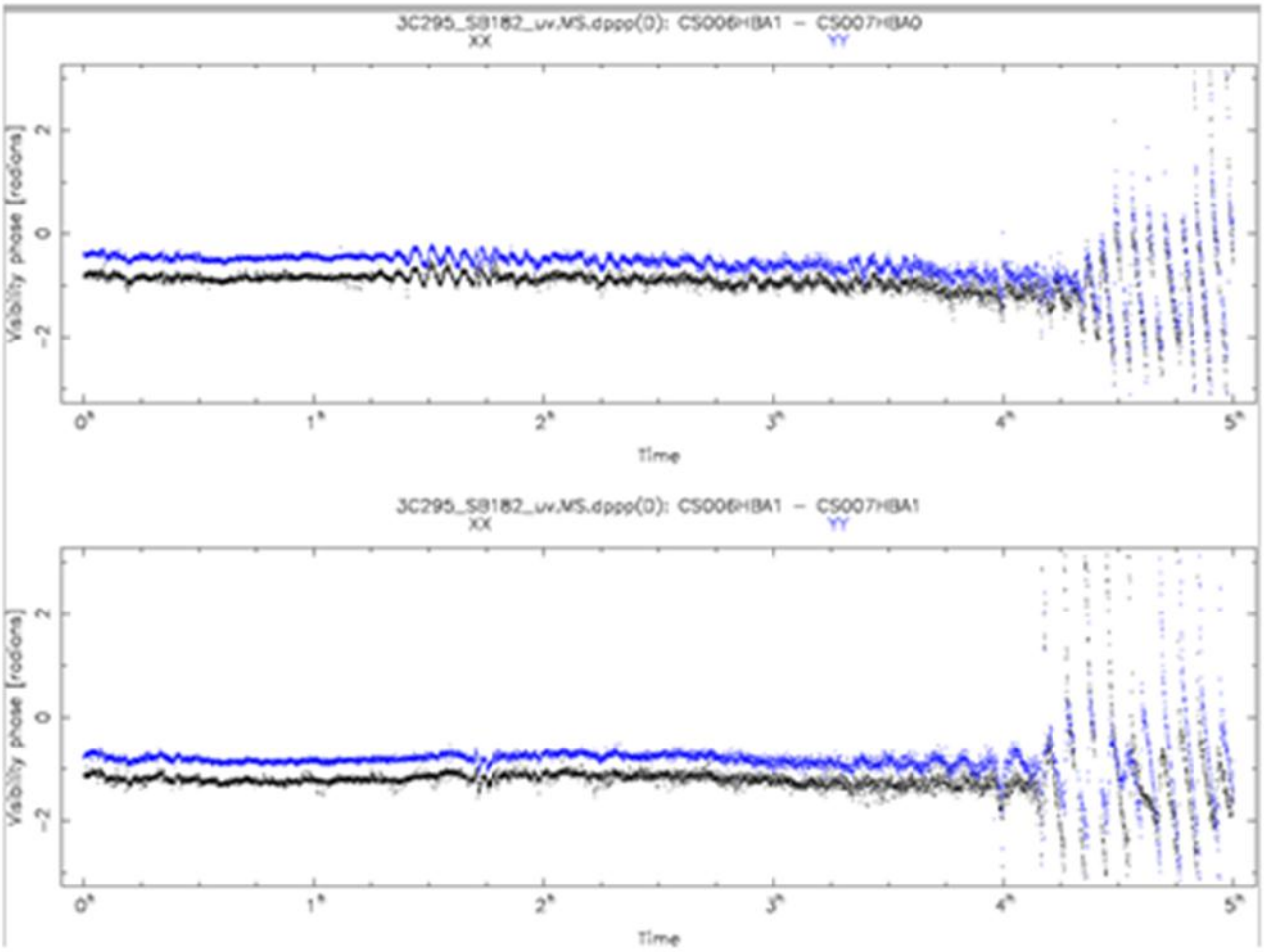
LOFAR Observation Details

- Observed with LOFAR HBA (110-240MHz)
- Observed for 7 hours
- Dual-beam observation, half of the beamlets pointed at one source hence only half of the subbands can be used.
- Observed calibrator 3C286 simultaneously
- Same frequency coverage on both source & calibrator
- 122 frequency channels of 210 KHz for source & calibrator.

Flagging Data



Flagging Data



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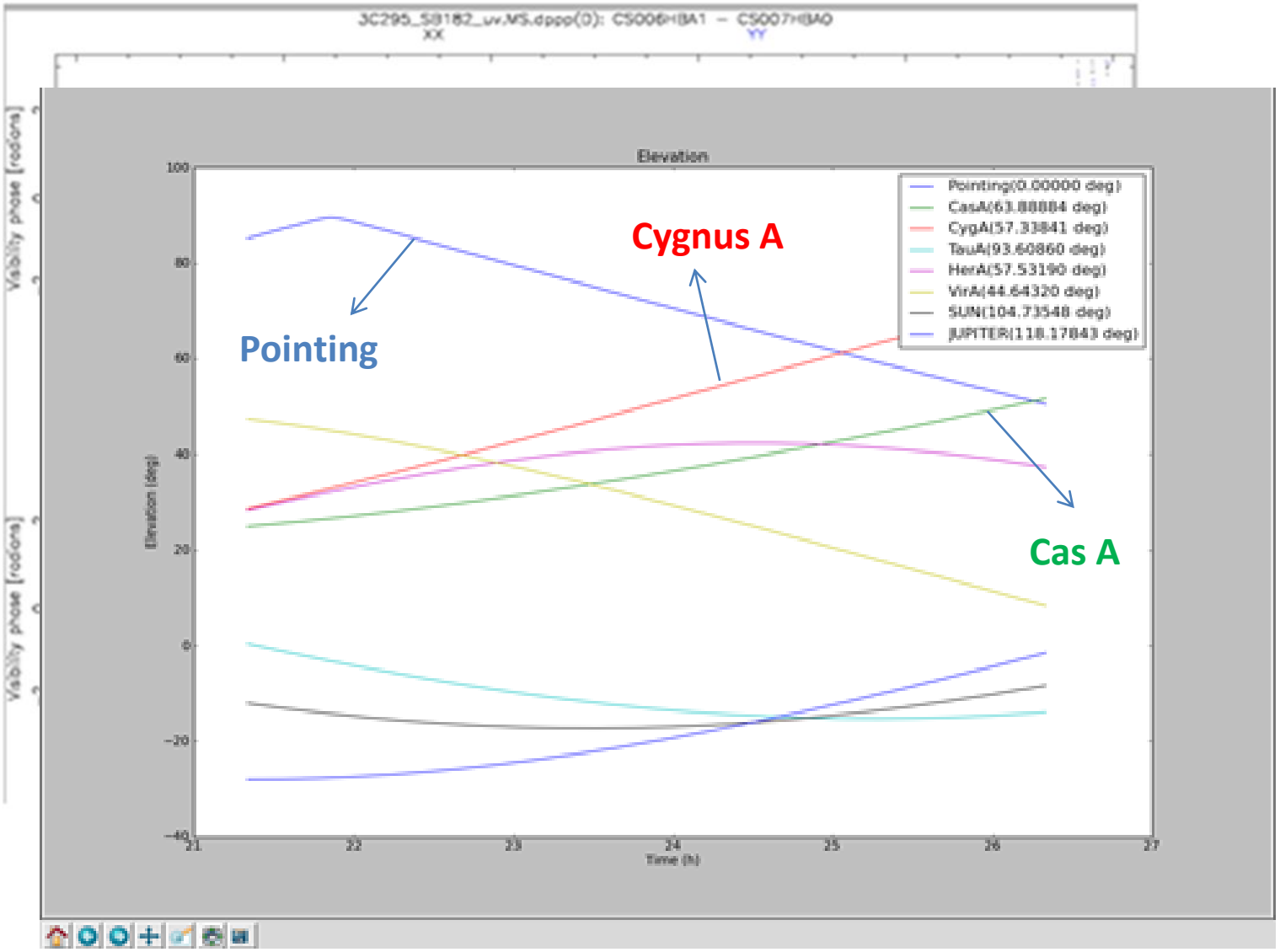
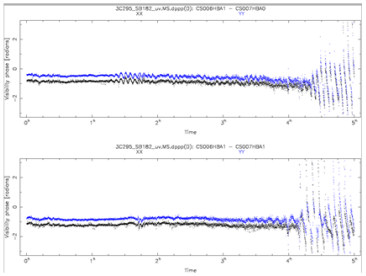
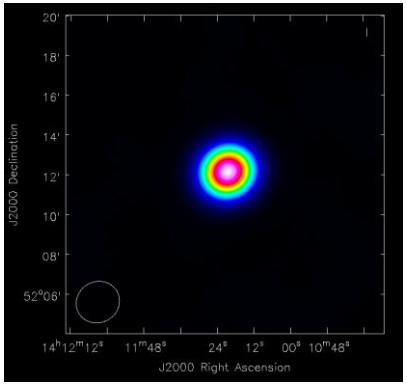


M51:
Final hour
Subtracted-
Due to A-
Team
sources

Flagged Data



Calibrate the Calibrator

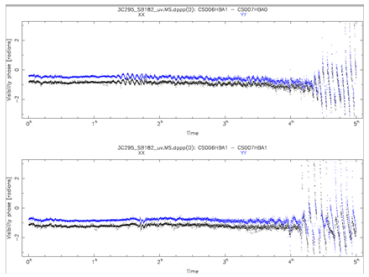


Calibrator: 3C295/3C286

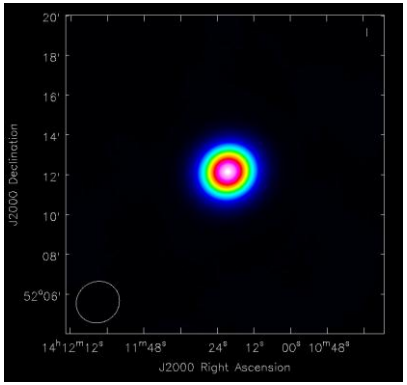
uv-plane-cal-transfer.parset
Model.Beam.Enable = T
Solves for all 4 elements in the gain Jones' matrix

3C295/3C286.skymodel
Specifies direction only for target

Flagging Data

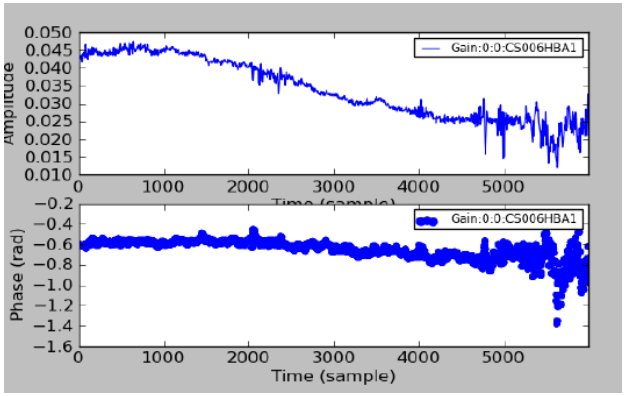


Calibrate the Calibrator



Calibrator: 3C295/3C286

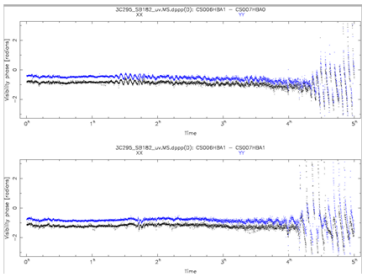
Analyse Gains



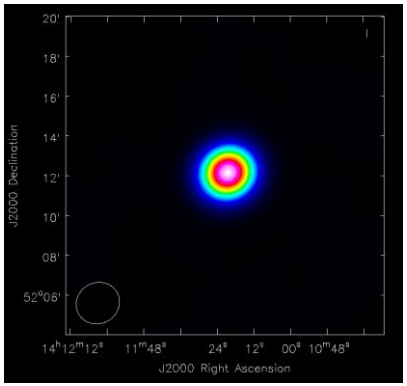
uv-plane-cal-transfer.parset
Model.Beam.Enable = T
Solves for all 4 elements in the gain Jones' matrix

3C295/3C286.skymodel
Specifies direction only for target

Flagging Data

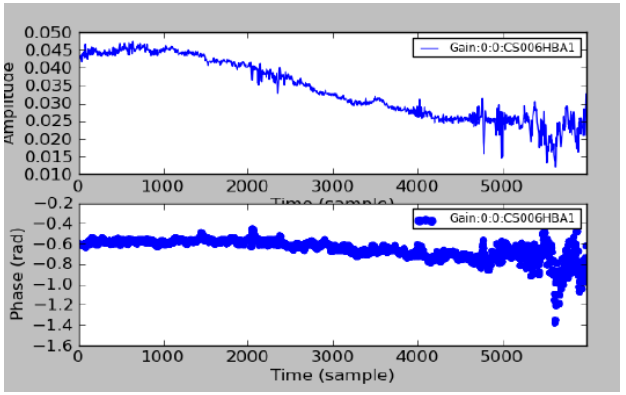


Calibrate the Calibrator



Calibrator: 3C295/3C286

Analyse Gains

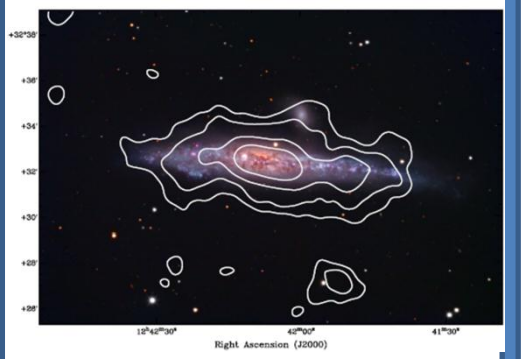


Apply Gains to the target field
--instrument-db
3C286/3C295.MS/instrument

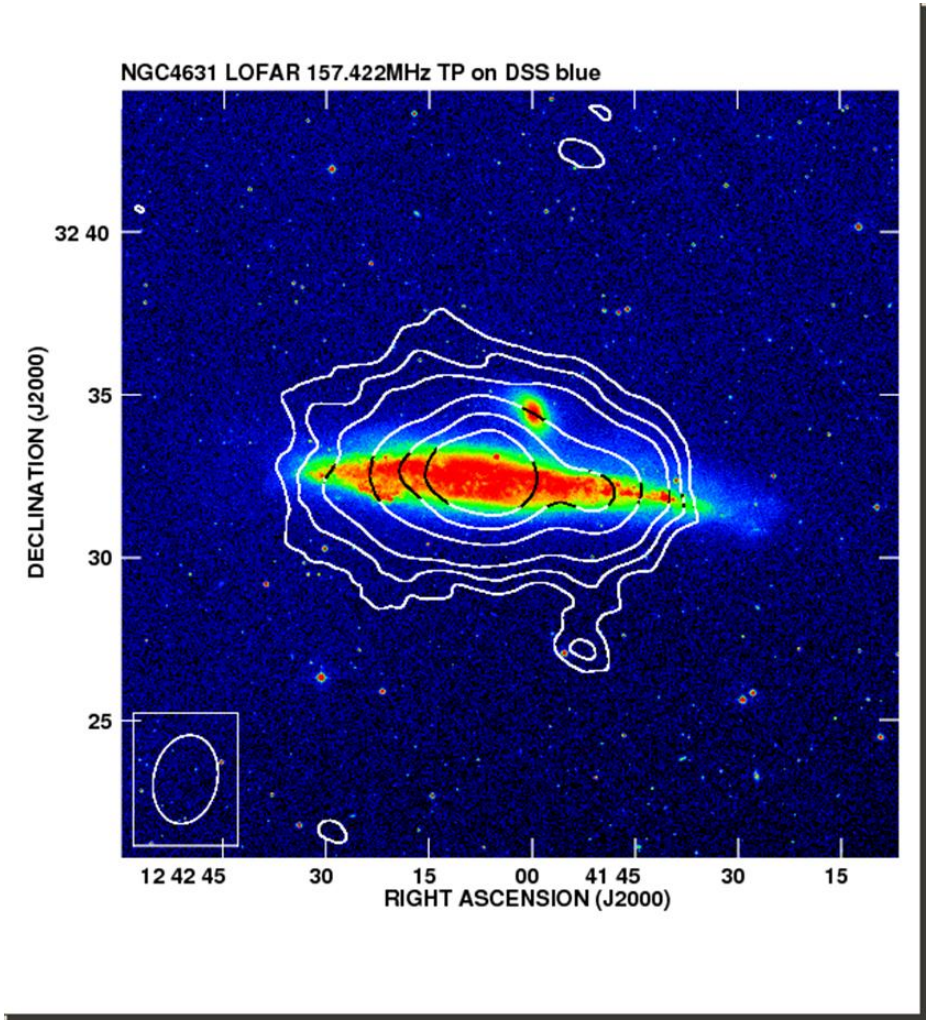
uv-plane-cal-transfer.parset
Model.Beam.Enable = T
Solves for all 4 elements in the gain Jones' matrix

3C295/3C286.skymodel
Specifies direction only for target

Correct.parset – only solve steps
Model.Beam.Enable = T



Image!!!

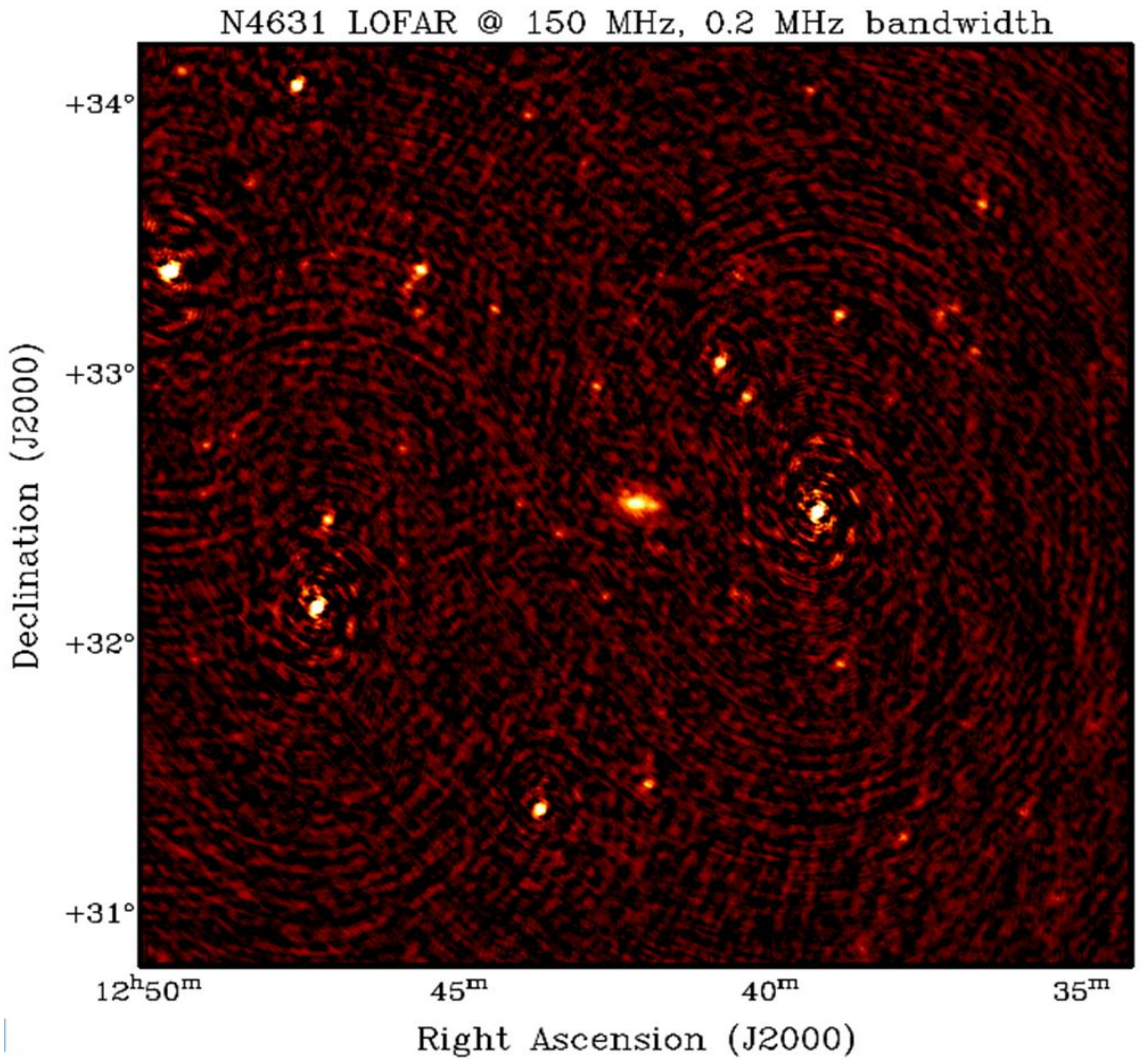


Robert Drzazga

NGC4631

LOFAR Observation –Classical SelfCal Calibration

Calibration in BBS on a single source 4C+32.40 with a total flux density of 3.2 Jy at 157MHz (Single Subband), followed by two cycles of self-calibration. Briggs weighting: robust = 1.0

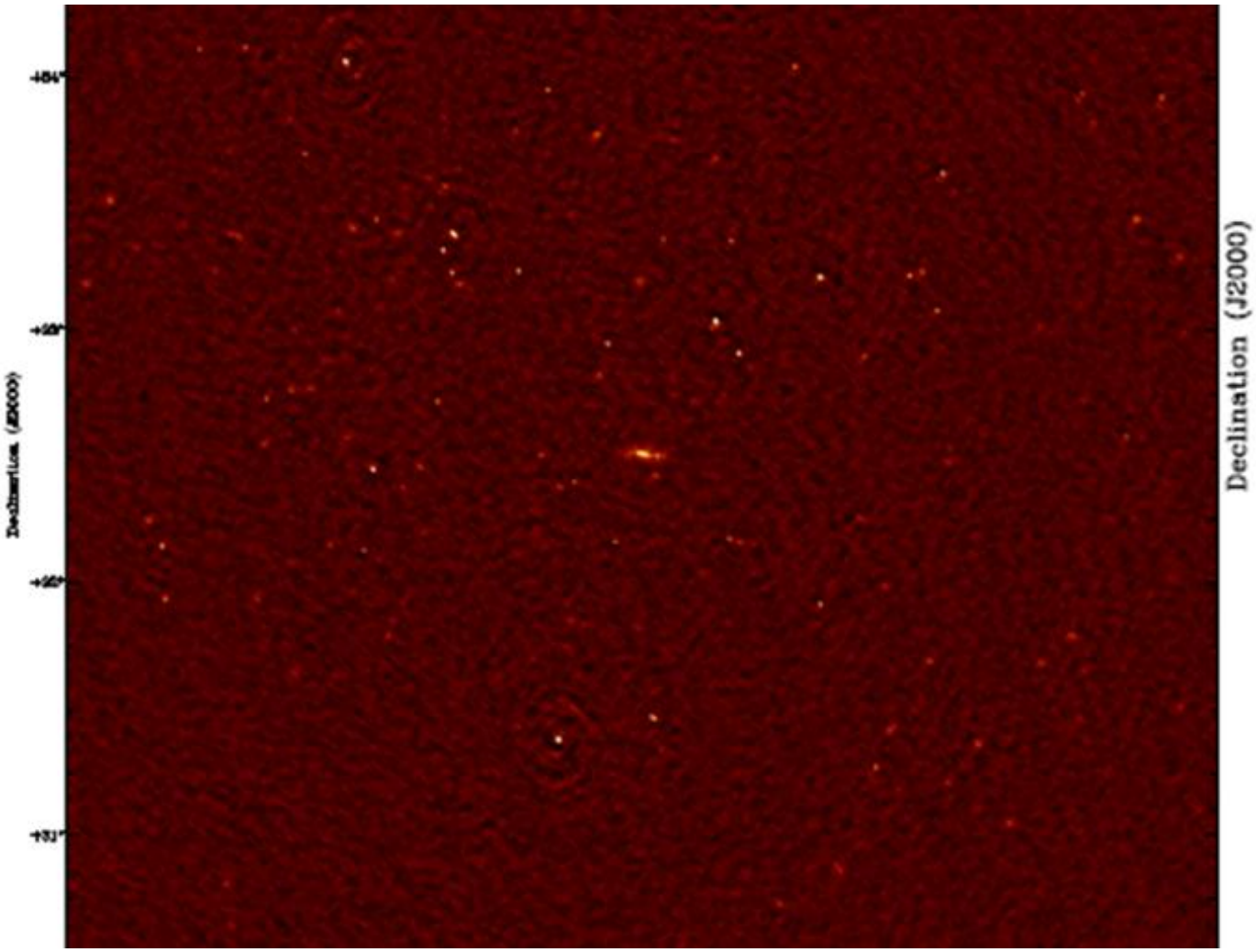


George Heald

NGC4631

LOFAR Observation – Transfer of Gain Solutions

Calibrated 3C286 first and then transferred the obtained Gain Solutions to NGC4631. Above image: robust = 0; 30’’ taper; no cleaning.



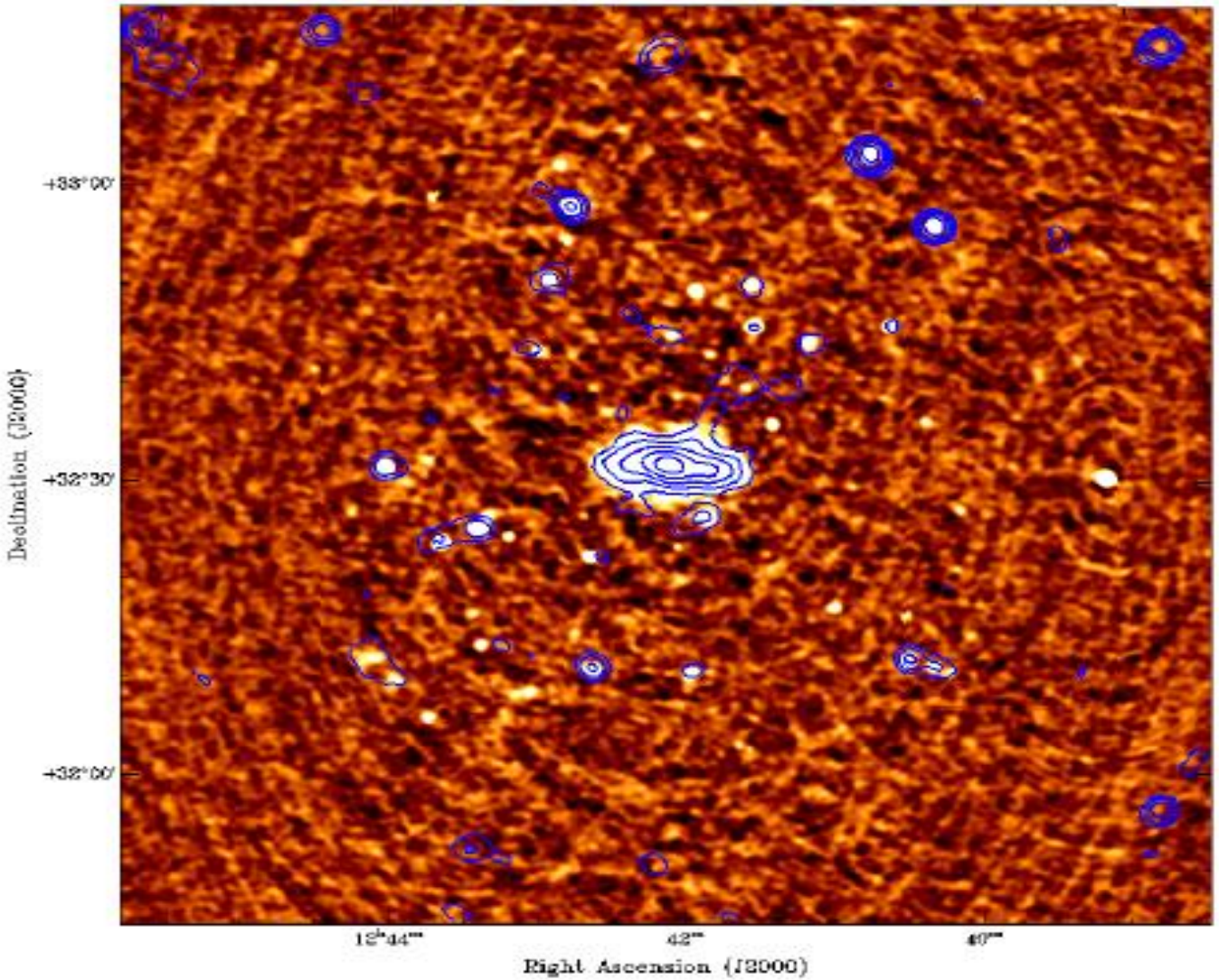
WIDEFIELD

George Heald

NGC4631

LOFAR Observation – Transfer of Gain Solutions

Images were produced after self cal and removing 3 brightest sources in the field using direction-dependent gains.



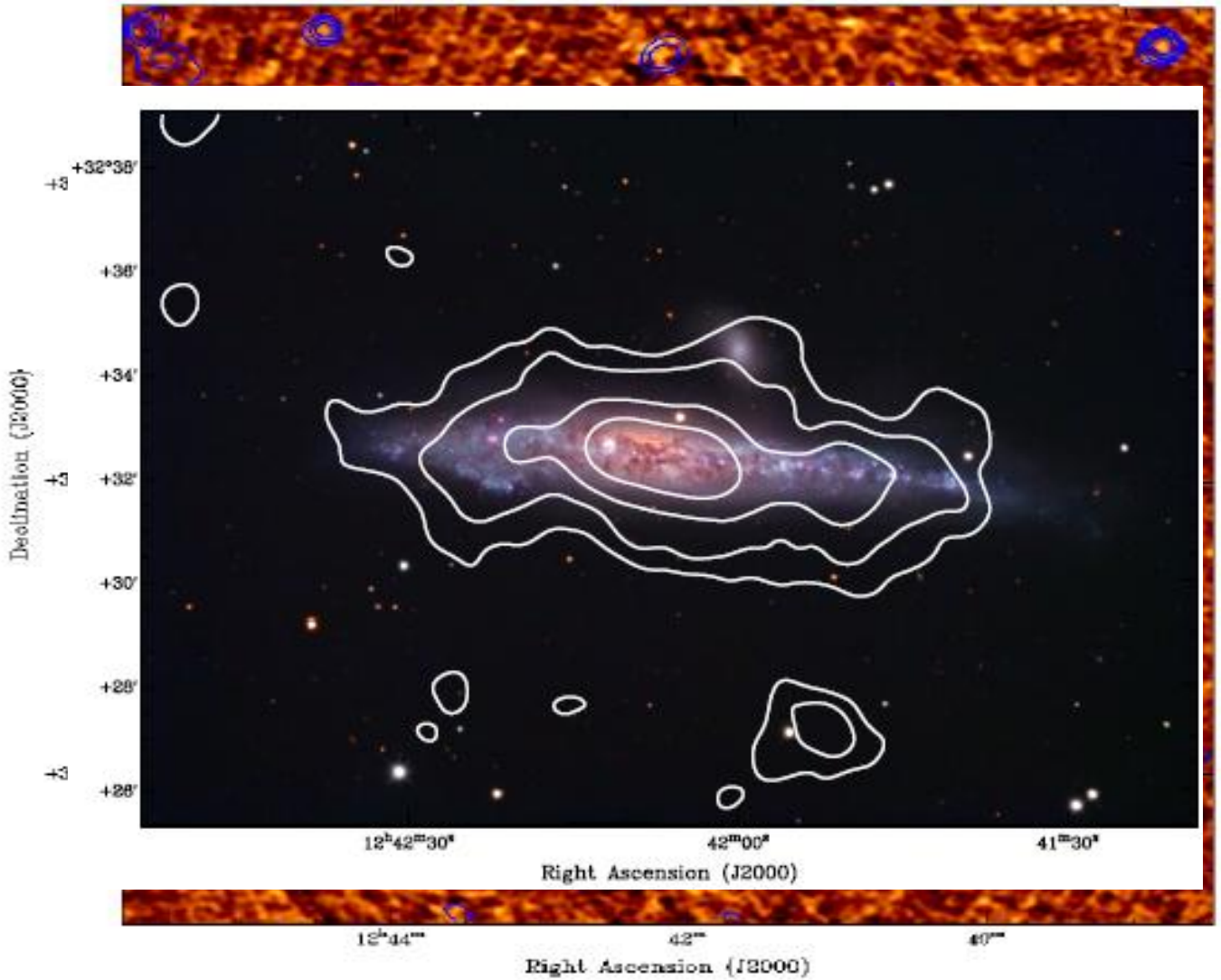
Overlaid onto HALOGAS Image

George Heald

LOFAR Observation – Transfer of Gain Solutions

Images were produced after self cal and removing 3 brightest sources in the field using direction-dependent gains.

LOFAR contours onto HALOGAS- 1.4GHz continuum survey with WSRT



Closeup:
Overlaid onto
Optical Image

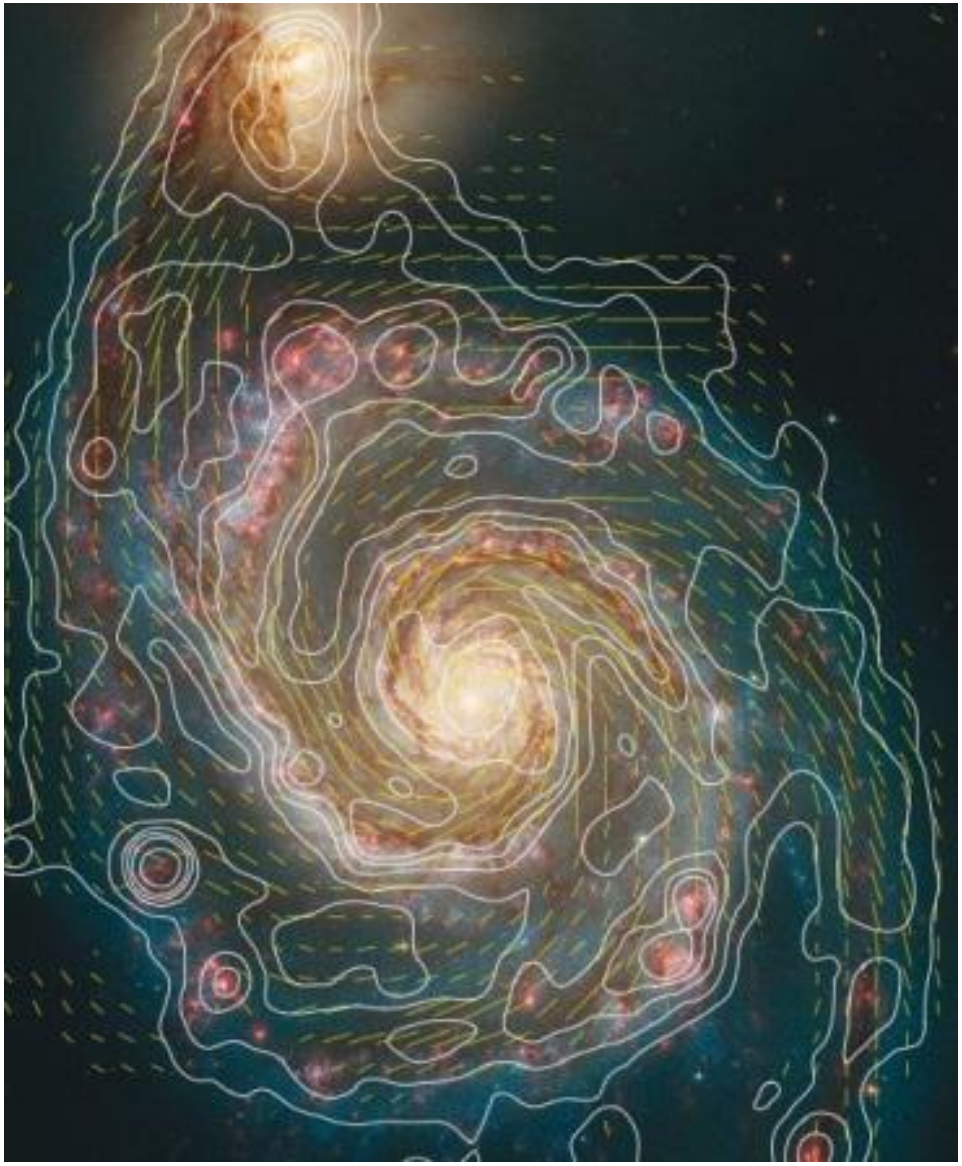
George
Heald

LOFAR Observation – Transfer of Gain Solutions

Images were produced after self cal and removing 3 brightest sources in the field using direction-dependent gains.

M51

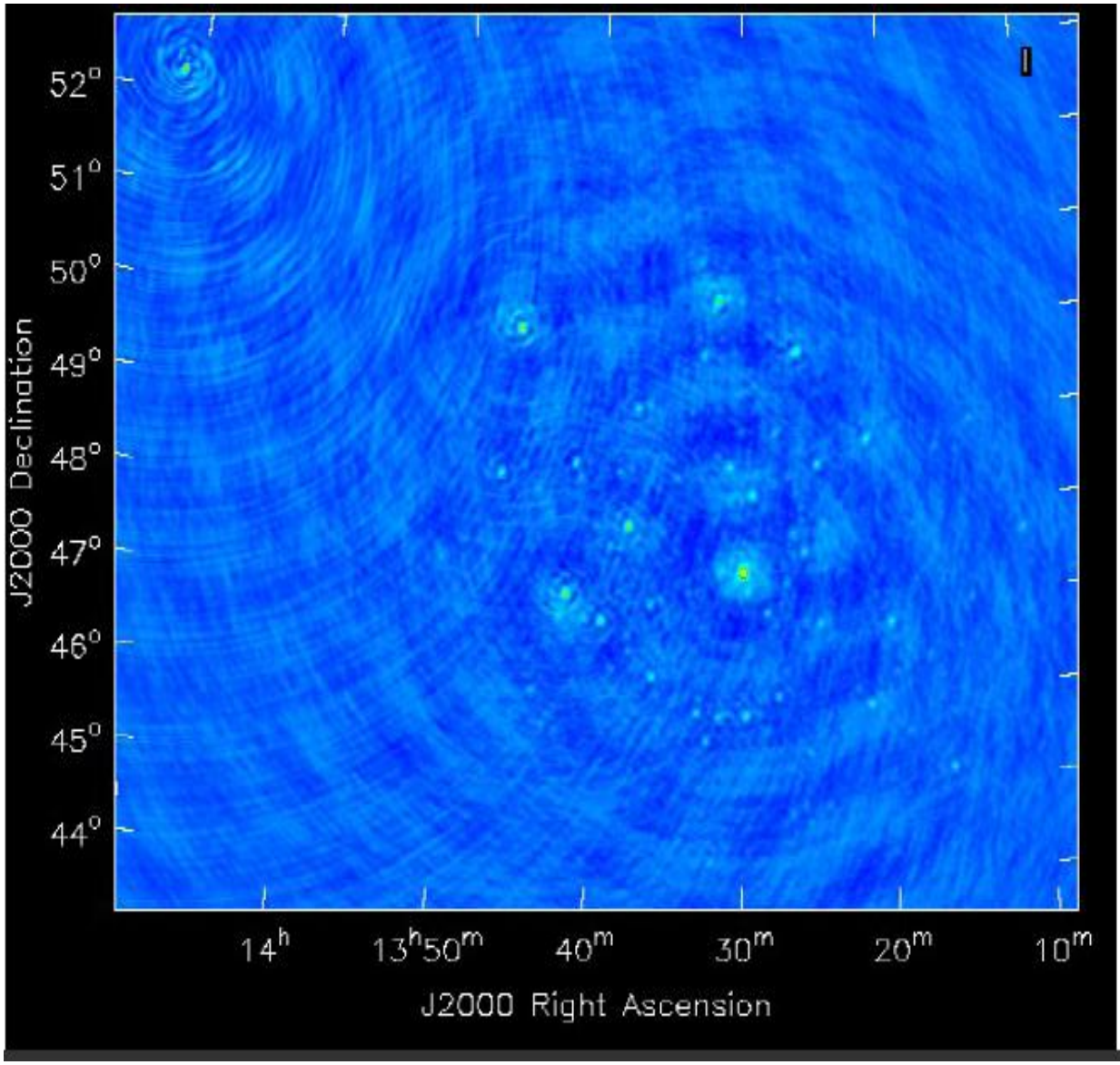
- M51 is a grand-design spiral galaxy with two very prominent spiral arms.
- Perturbed by its close companion NGC5195 which may have resulted in two systems of density waves.
- Orientation of the magnetic field lines follow very closely the spiral arms. (Berkhuijsen et al. 1996, Patrickeyev et al 2006, Fletcher et al. 2011)



Fletcher, Beck et al (2011)

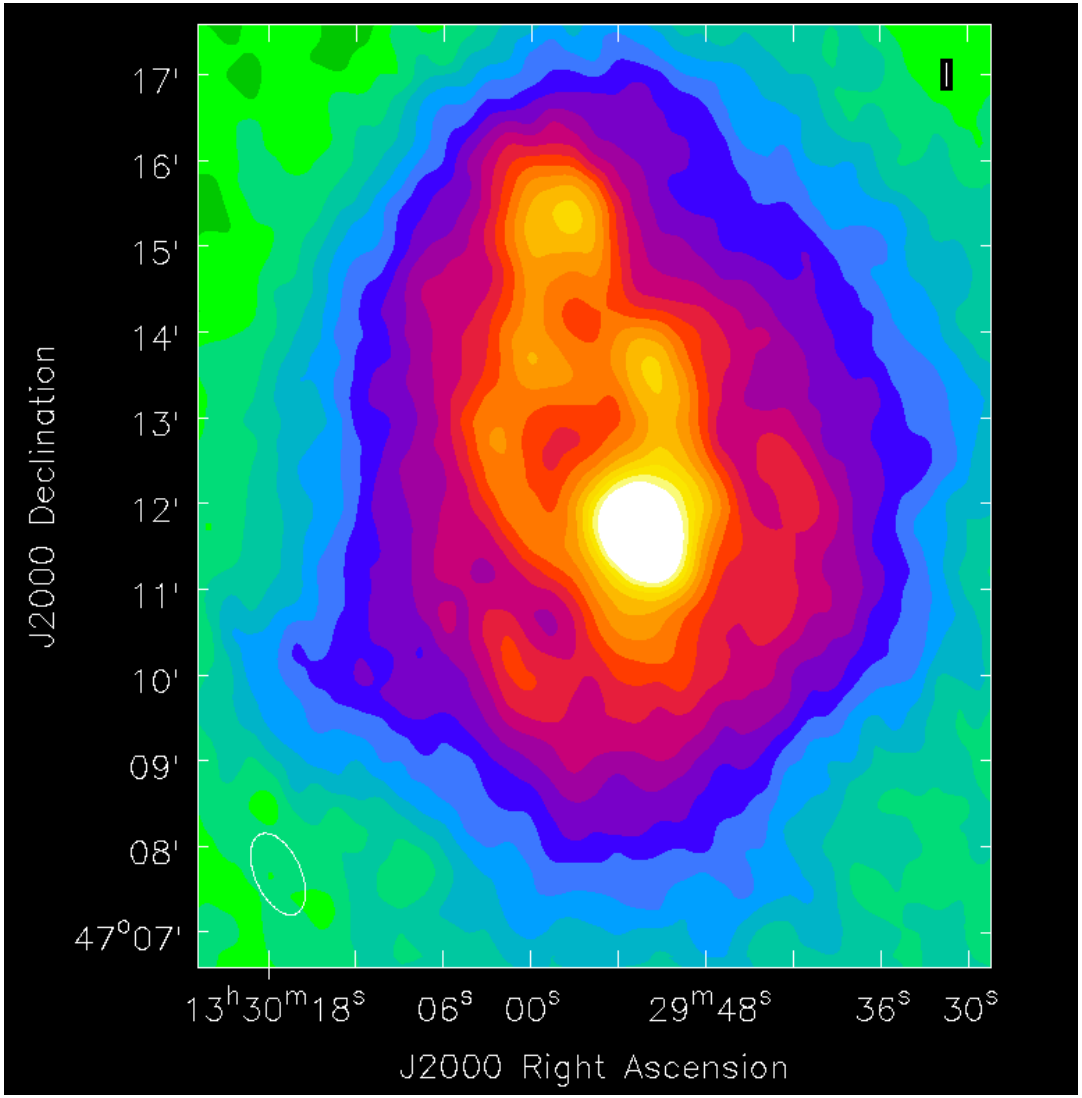
M51
LOFAR Observation Details – Transfer of Gain Solutions

- Observed calibrator 3C295 simultaneously.
- Same frequency coverage on both source & calibrator.
- 121 frequency channels of 210 kHz for source & calibrator.
- Calibrator 3C295 was calibrated and the Gain solutions were transferred to M51.
- Shown right is Subband 60 at 139.06MHz; widefield view
- Natural weighting used



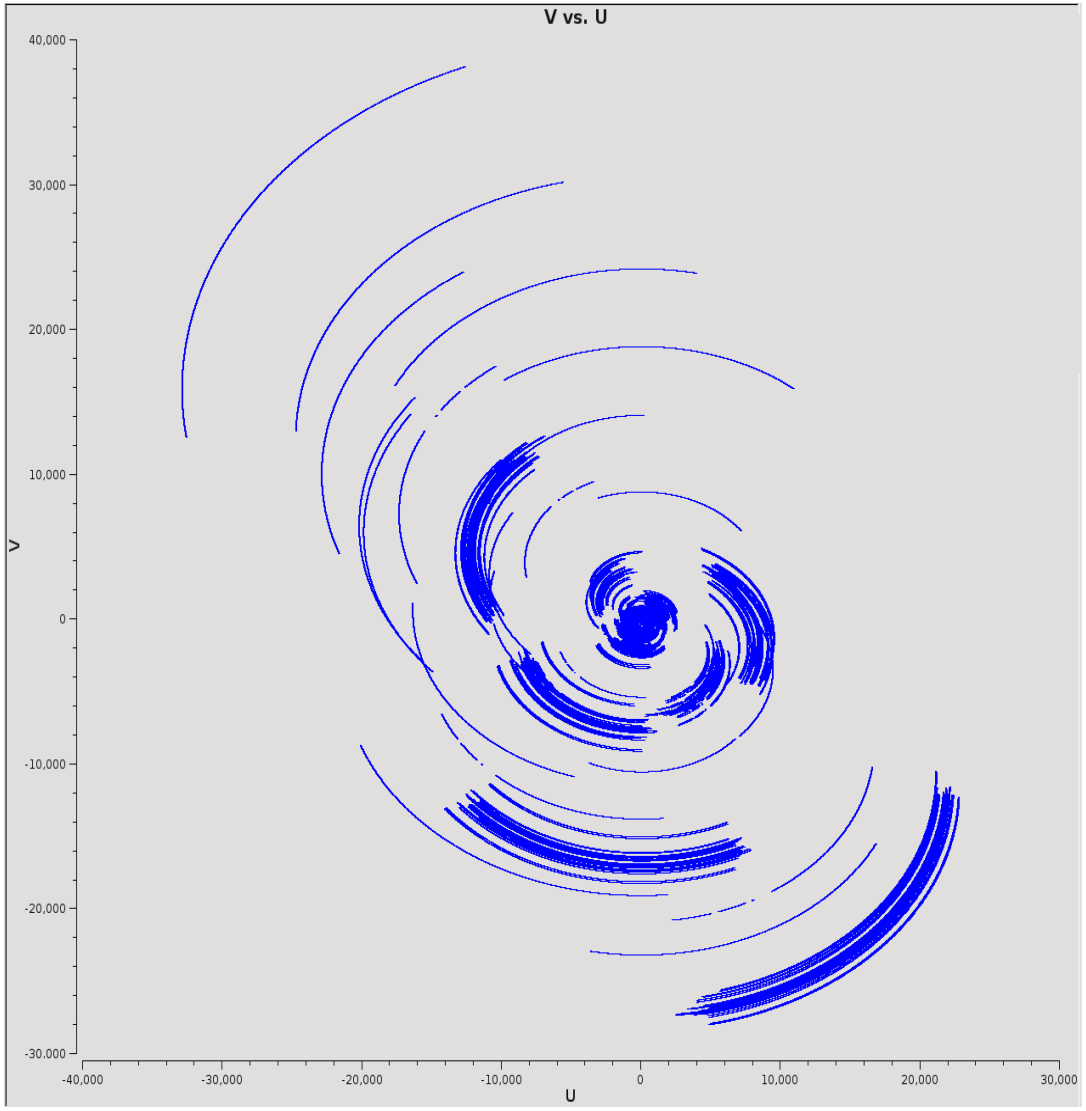
Higher Resolution map of M51

- Robust Weighting of 0.25 was used to produce image to the right.
- Single Subband at 145.7 MHz



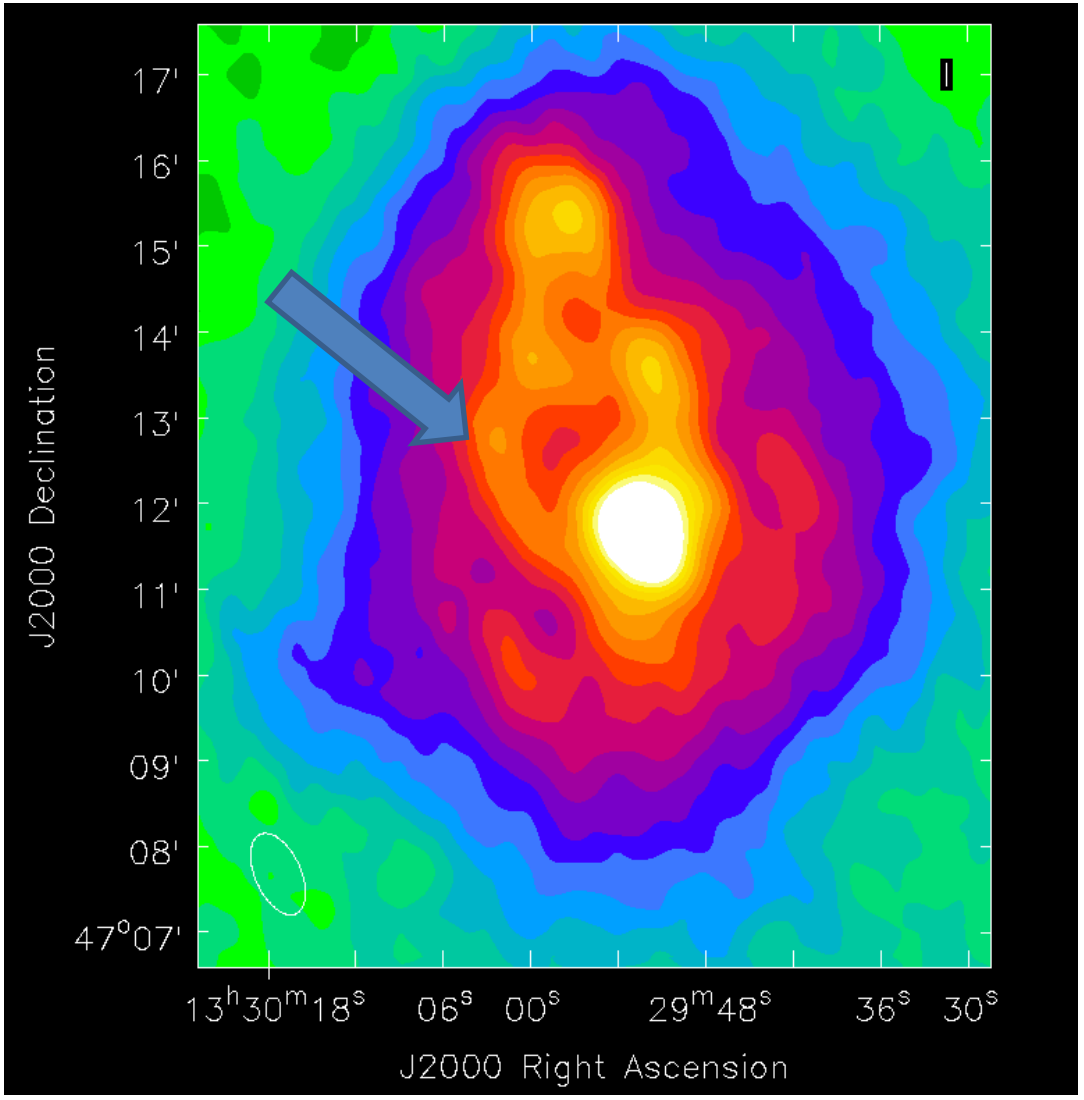
Higher Resolution map of M51

- Robust Weighting of 0.25 was used to produce image to the right.
- Single Subband at 145.7 MHz
- Due to uv-coverage, beam is quite elliptical



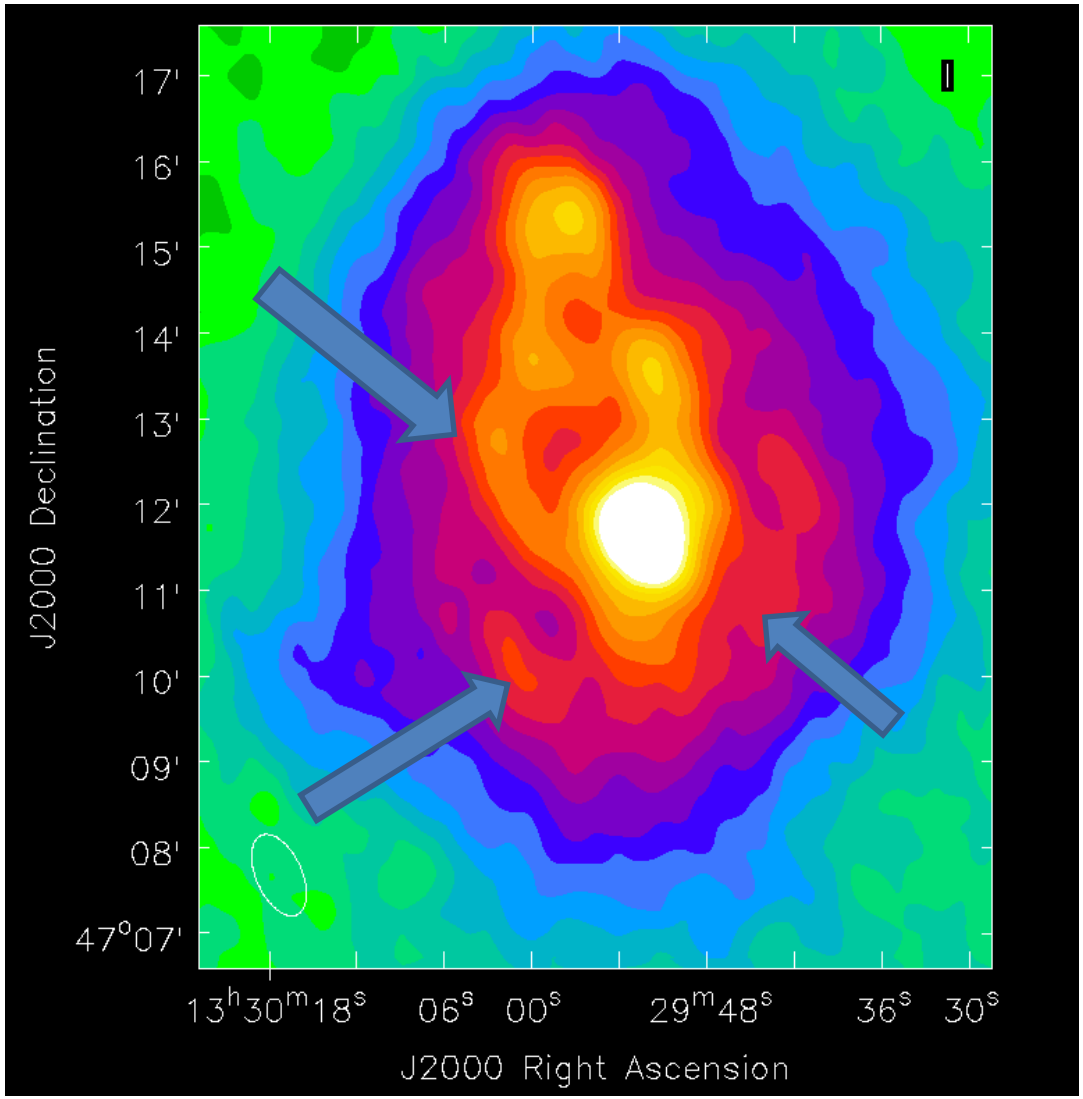
Higher Resolution map of M51

- Robust Weighting of 0.25 was used to produce image to the right.
- Single subband at 145.7 MHz
- Due to uv-coverage, beam is quite elliptical
- Left spiral arm can be seen.



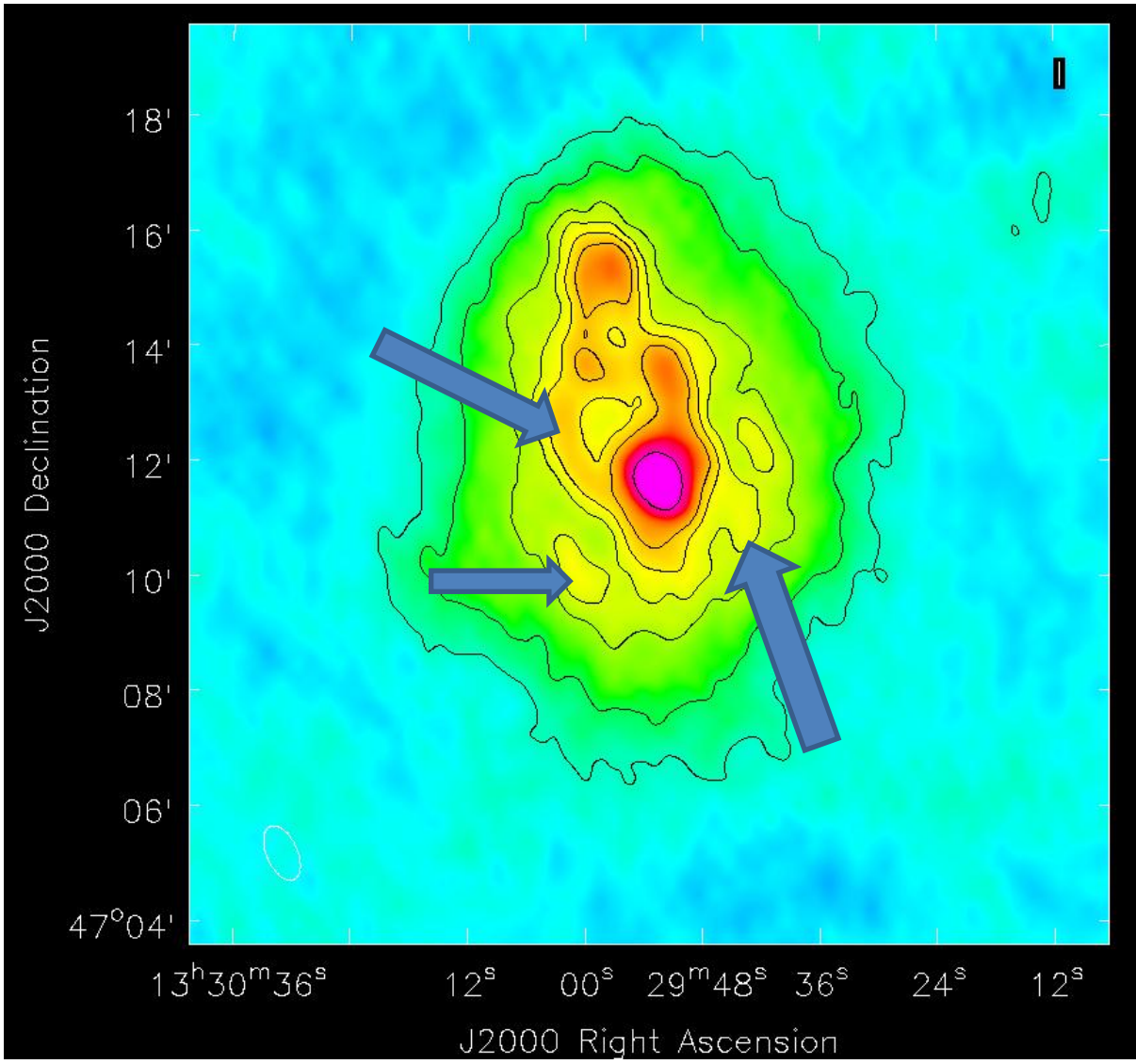
Higher Resolution map of M51

- Robust Weighting of 0.25 was used to produce image to the right.
- Single subband at 145.7 MHz
- Due to uv-coverage, beam is quite elliptical
- Left spiral arm can be seen.
- As well as sections of the right spiral arm.



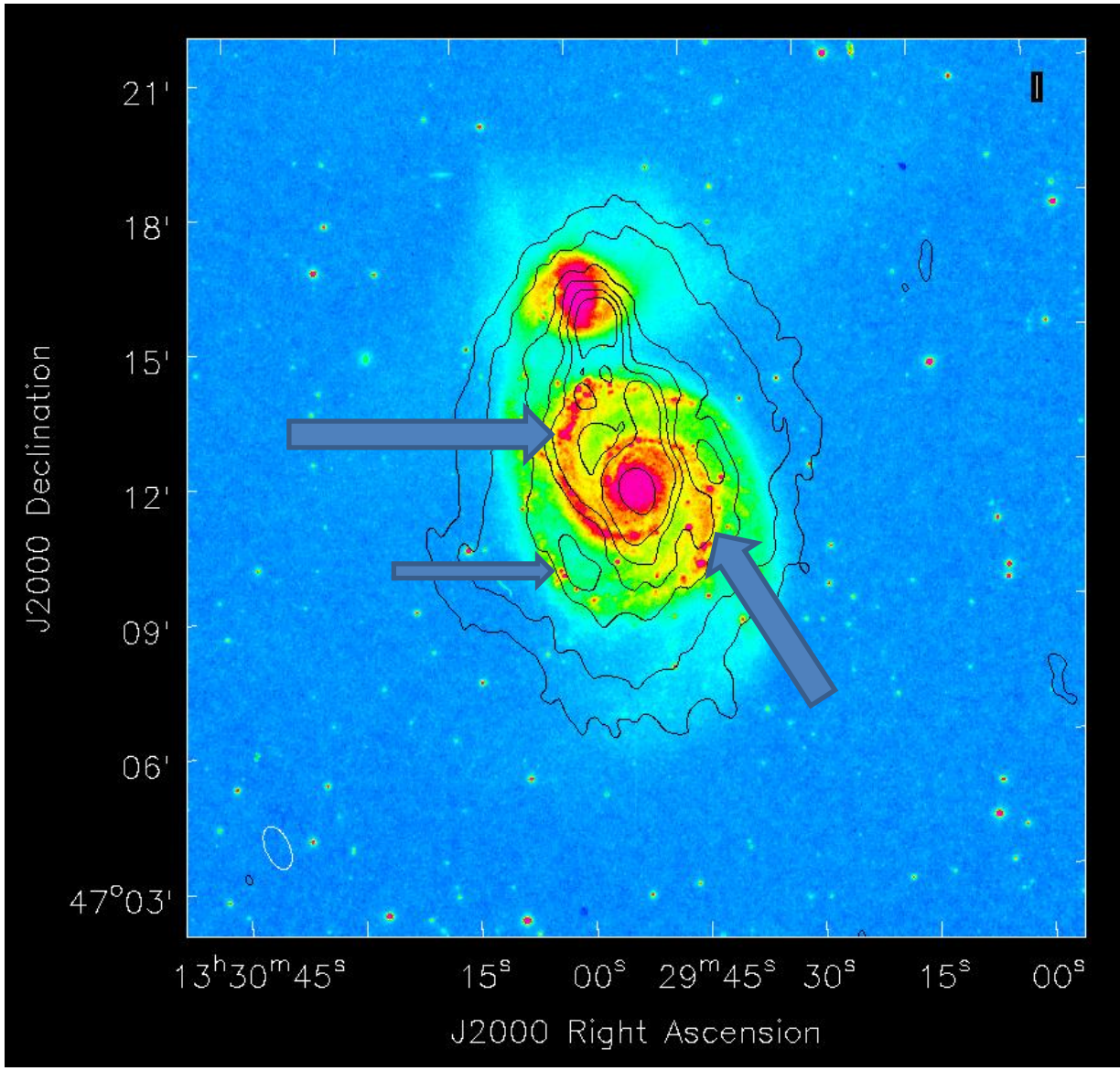
Higher Resolution map of M51

- Robust Weighting of 0.25 was used to produce image to the right.
- Single subband at 145.7 MHz
- Due to uv-coverage, beam is quite elliptical
- Left spiral arm can be seen.
- As well as sections of the right spiral arm.
- Base contour is at the 3 sigma level.



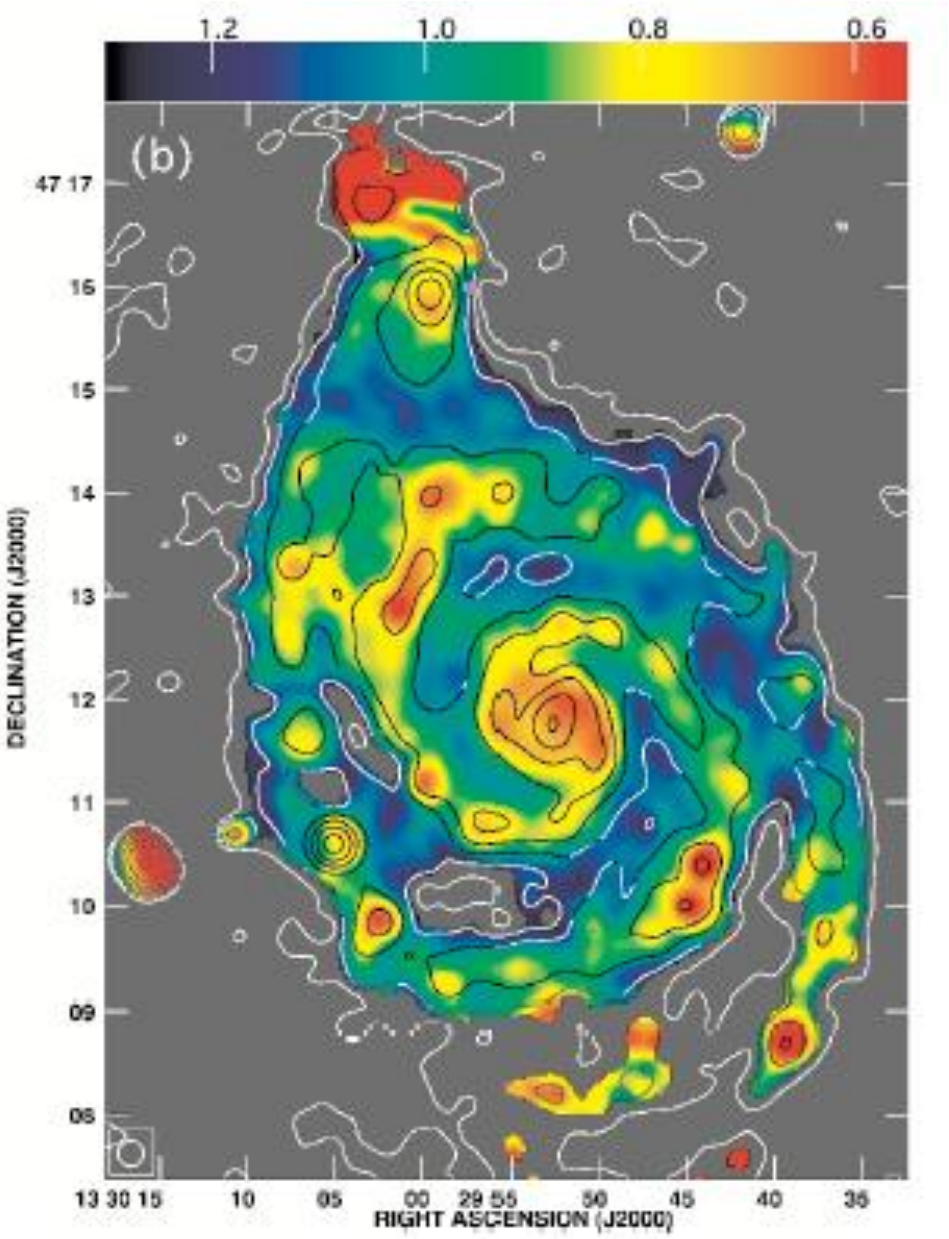
Higher Resolution map of M51

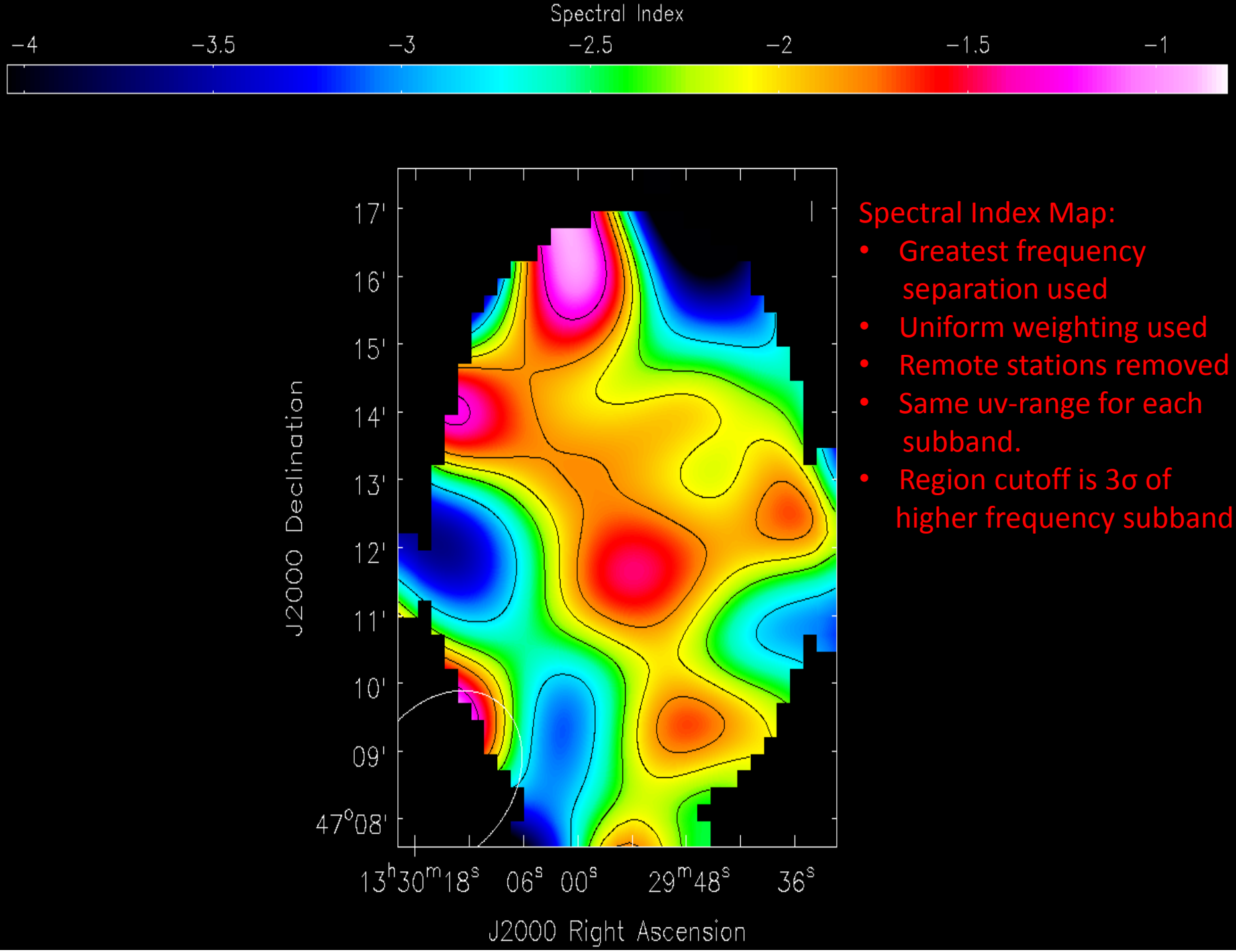
- Robust Weighting of 0.25 was used to produce image to the right.
- Single subband at 145.7 MHz
- Due to uv-coverage, beam is quite elliptical
- Left spiral arm can be seen.
- As well as sections of the right spiral arm.
- Base contour is at the 3 sigma level.
- Large Halo can also be seen!



Spectral Index Maps of M51

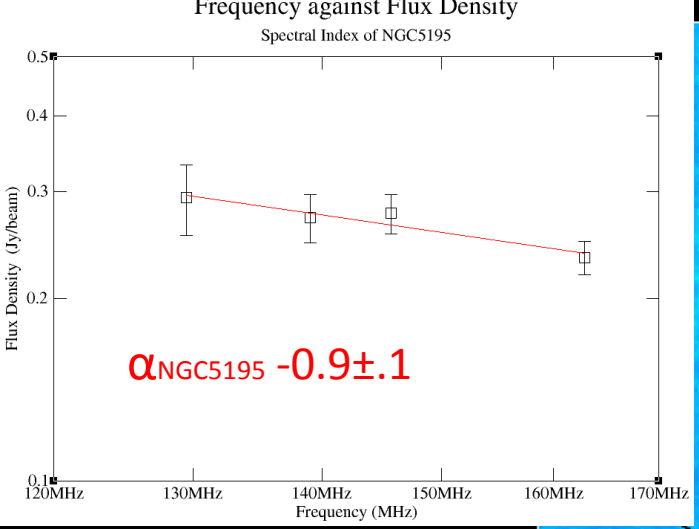
- At low frequencies, one expects a lower thermal fraction and older CR electrons; therefore a steeper spectral index.
- There should be spectral variations between arm & interarm regions and between disk & halo.
- Shown right is the spectral index between wavelengths 20-6cm from Fletcher et al (2011).

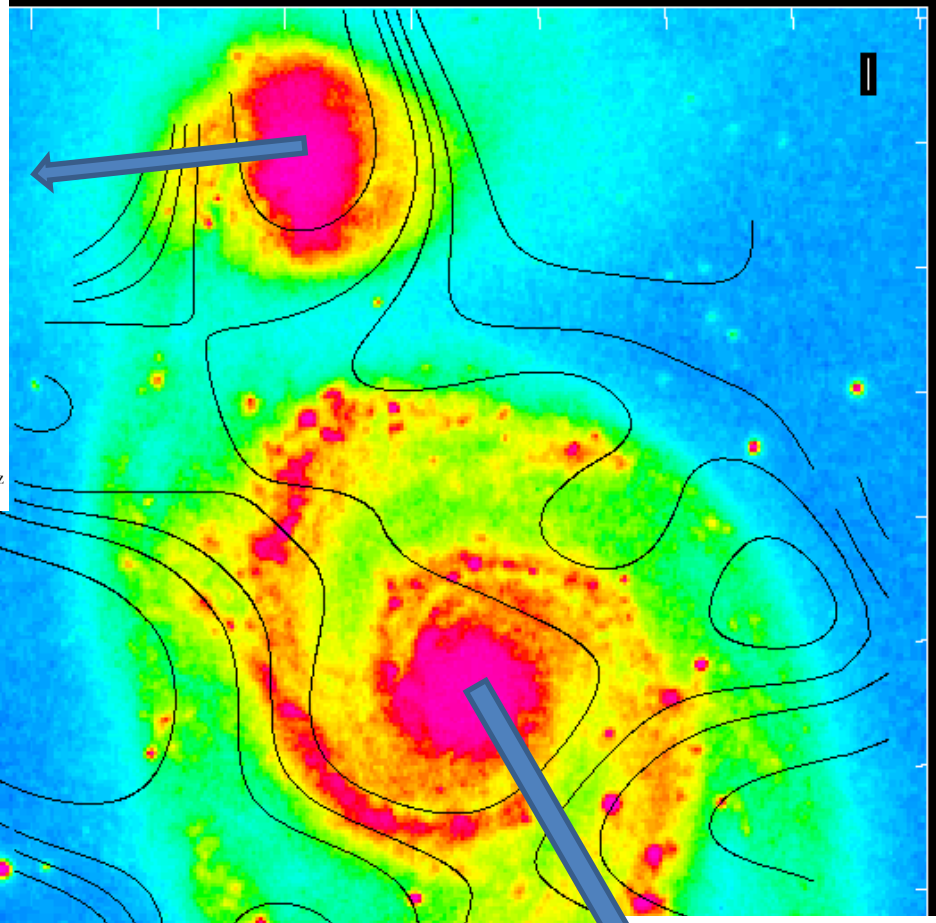


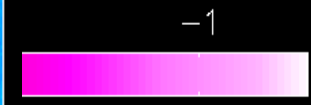


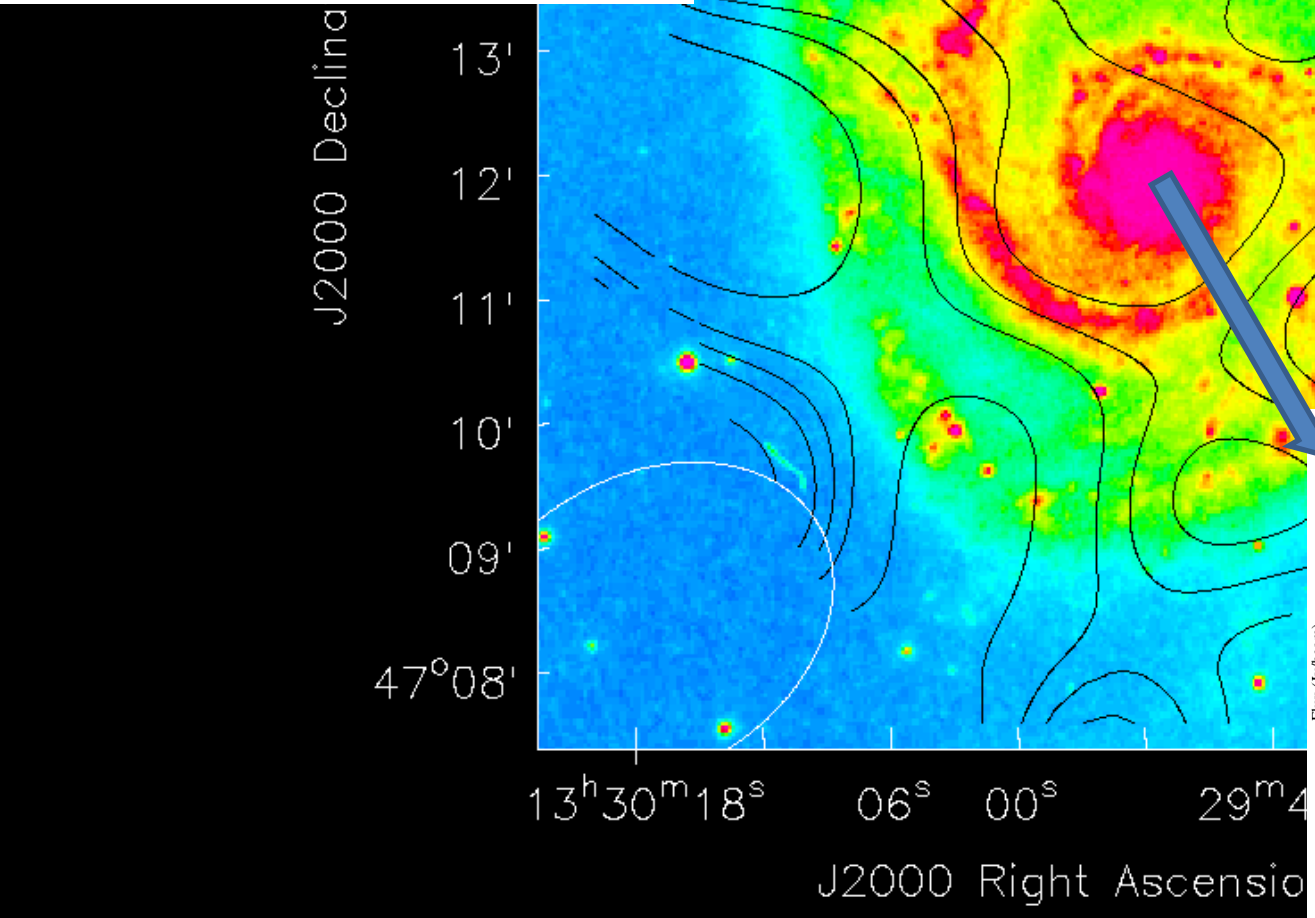
Spectral Index Map:

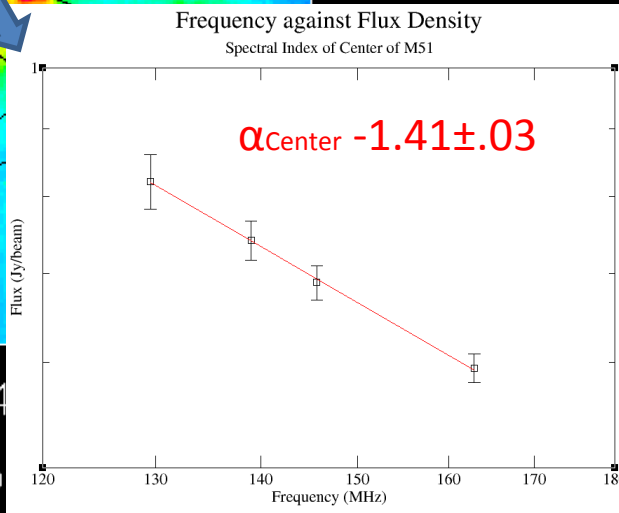
- Greatest frequency separation used
- Uniform weighting used
- Remote stations removed
- Same uv-range for each subband.
- Region cutoff is 3σ of higher frequency subband.

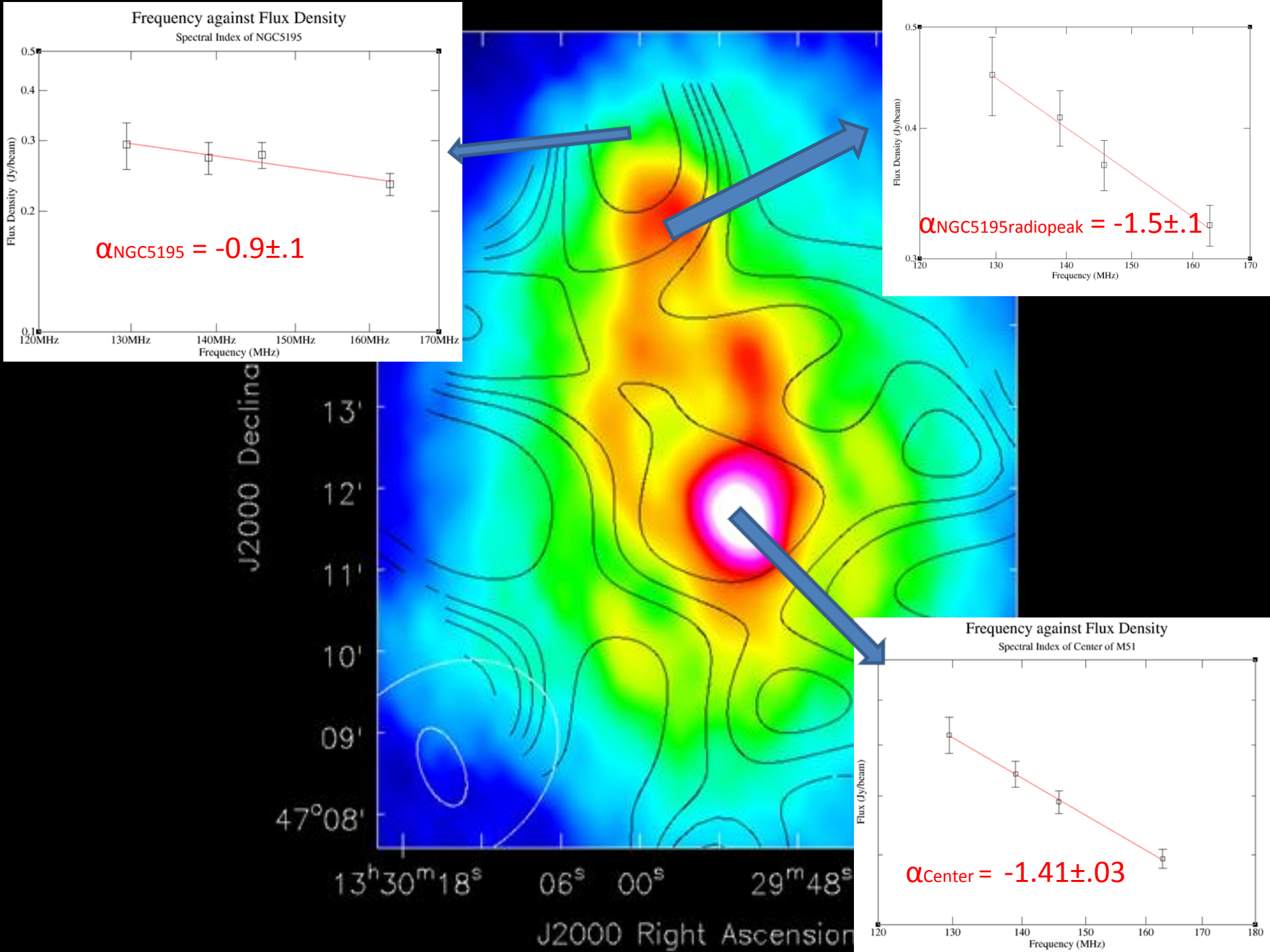

Frequency against Flux Density
Spectral Index of NGC5195
Flux Density (Jy/beam)
0.5
0.4
0.3
0.2
0.1
120MHz
130MHz
140MHz
150MHz
160MHz
170MHz
Frequency (MHz)
αNGC5195 -0.9±.1


I


−1

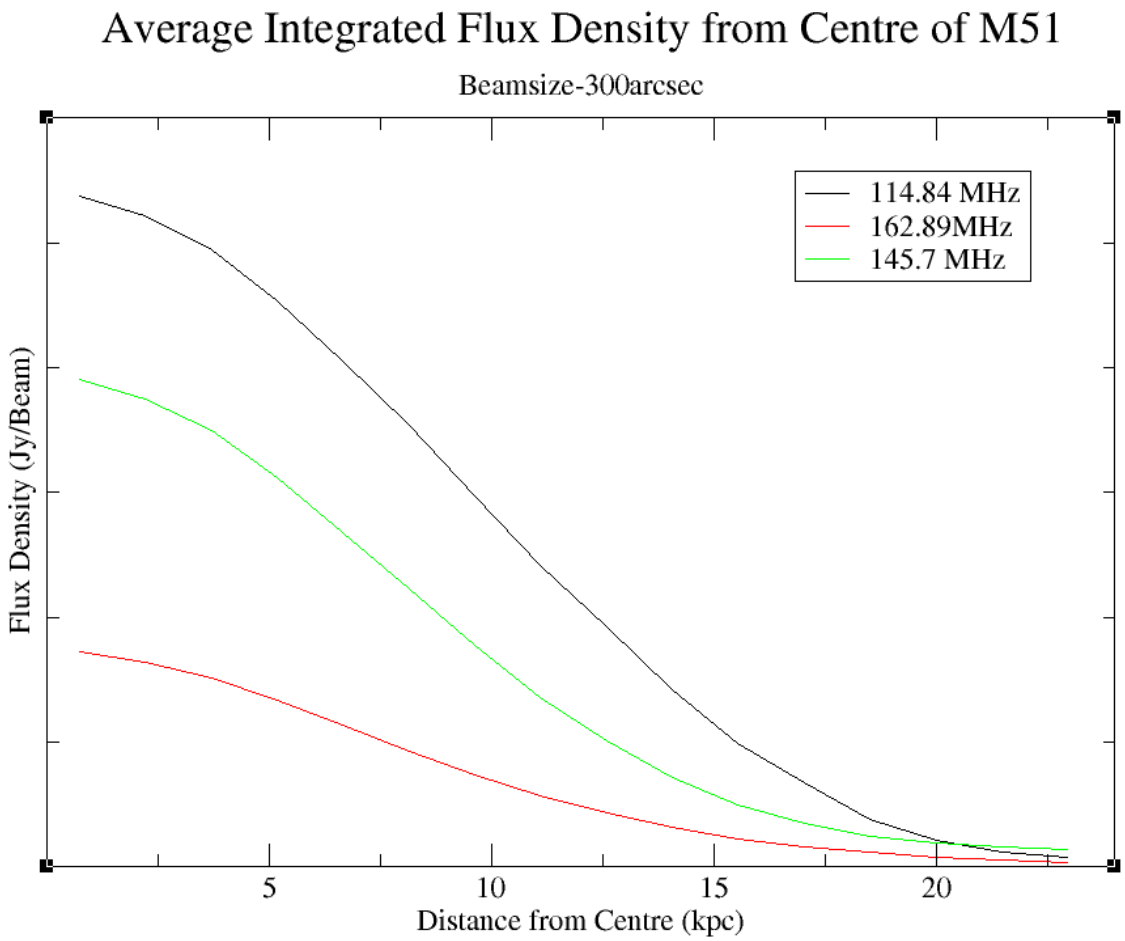

J2000 Declina
13'
12'
11'
10'
09'
47°08'
13h30m18s
06s
00s
29m4
J2000 Right Ascensio


Frequency against Flux Density
Spectral Index of Center of M51
αCenter -1.41±.03
Flux (Jy/beam)
120
130
140
150
160
170
Frequency (MHz)


Frequency against Flux Density
Spectral Index of NGC5195
Flux Density (Jy/beam)
0.5
0.4
0.3
0.2
0.1
120MHz
130MHz
140MHz
150MHz
160MHz
170MHz
Frequency (MHz)
αNGC5195 = -0.9±.1
Flux Density (Jy/beam)
0.5
0.4
0.3
120
130
140
150
160
170
Frequency (MHz)
αNGC5195radiopeak = -1.5±.1
J2000 Declina
13'
12'
11'
10'
09'
47°08'
13h30m18s
06s
00s
29m48s
J2000 Right Ascension
Frequency against Flux Density
Spectral Index of Center of M51
Flux (Jy/beam)
120
130
140
150
160
170
180
Frequency (MHz)
αCenter = -1.41±.03

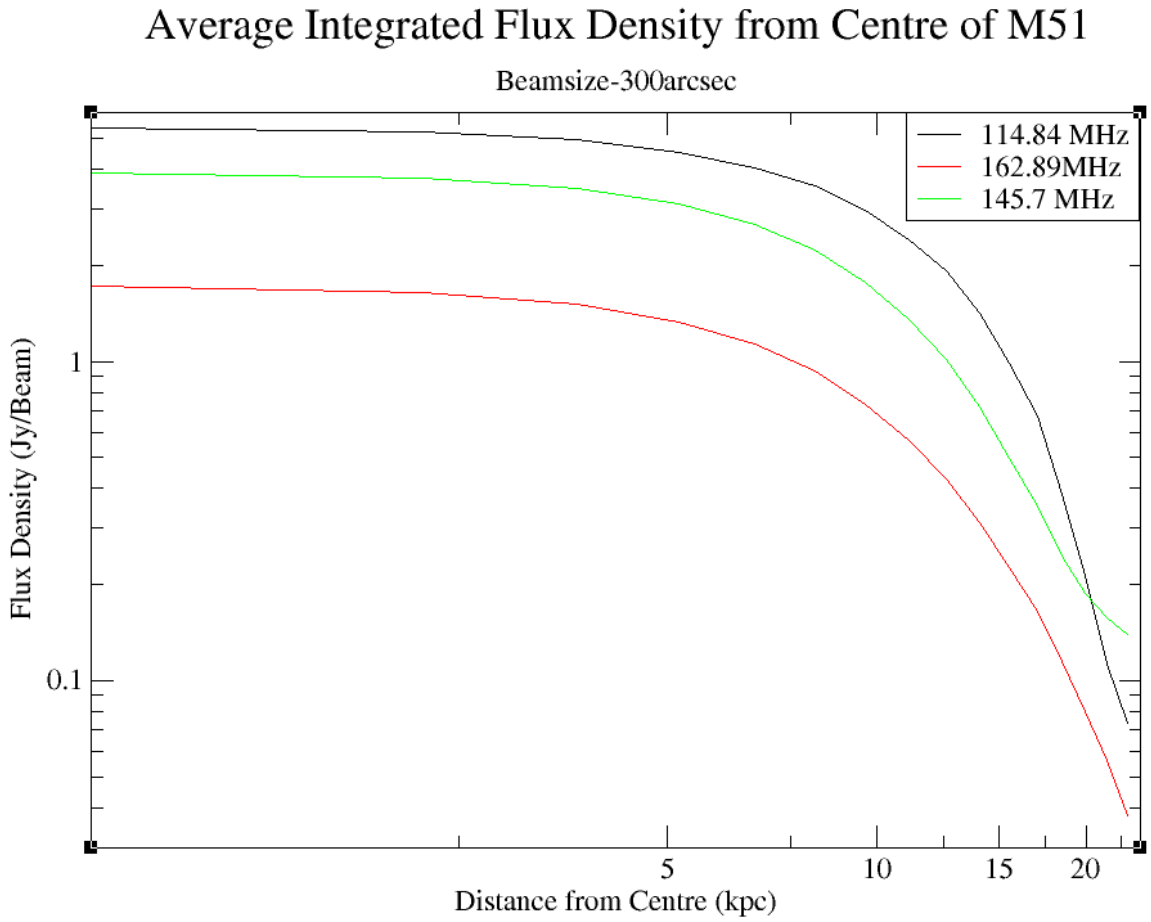
The Halo of M51

- LOFAR subbands were compared to a recent Effelsberg observation at 2.65GHz.
- Radial surface brightness profile was produced.



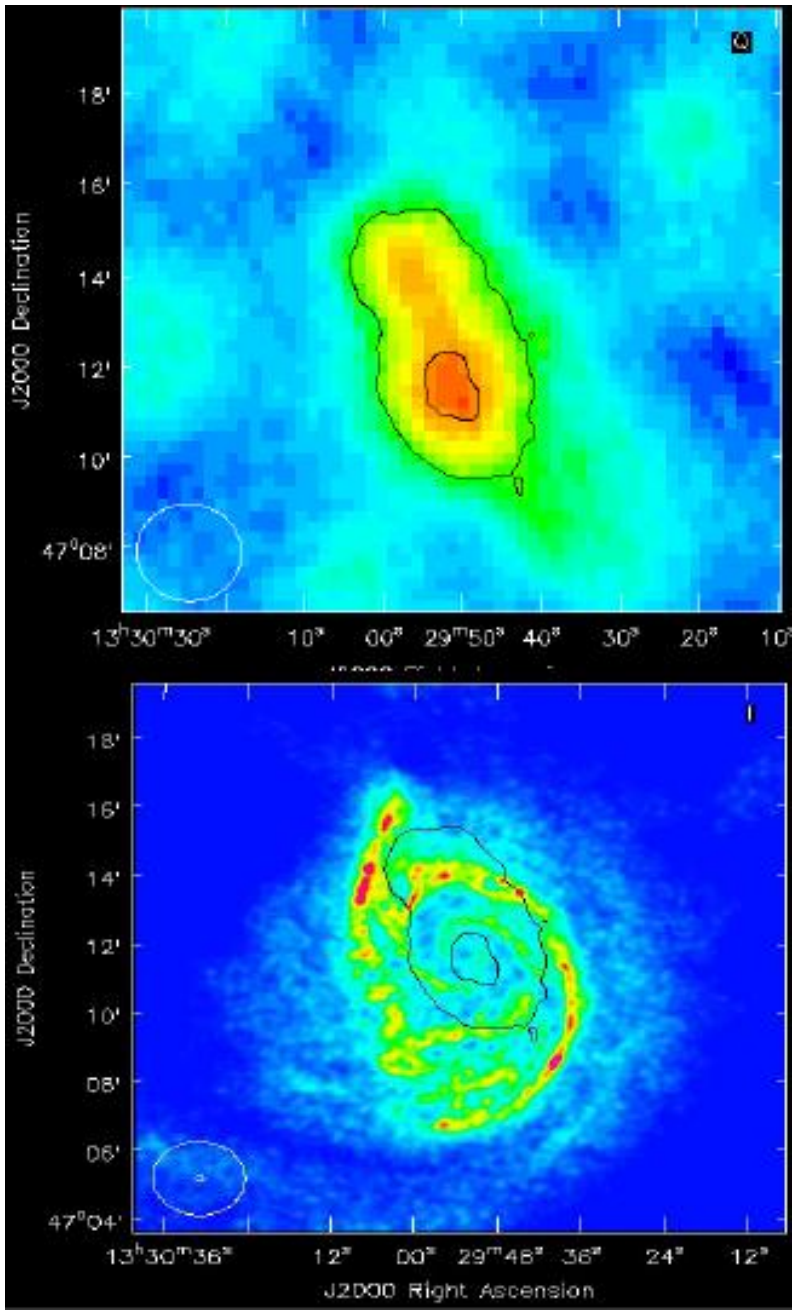
The Halo of M51

- LOFAR subbands were compared to a recent Effelsberg observation at 2.65GHz.
- Radial surface brightness profile was produced.
- Lower frequency subbands show an extended halo.



M51 LOFAR Observation – Instrumental Polarization

- Subband 60 (139MHz) shows polarization at the location of M51.
- Other Subbands show polarization only in Stokes Q.
- Unlikely to see real polarization in a single subband due to bandwidth depolarization. Instrumental polarization is too strong, signal to noise is too weak.
- Therefore, RM Synthesis is needed to separate instrumental and real polarization.



David Mulcahy

Conclusions

- The radio haloes of NGC4631 & M51 are clearly visible at LOFAR frequencies.
- A steep spectrum region is detected between M51 and its companion, perhaps a pool of old electrons or a shock at the interface region.
- The Spectral Index of the M51 center is very steep (-1.4).
- Images will be significantly improved when combining all subbands and removing 3C295 from the uv-data of the target observation.
- Much more work is needed especially with respect to calibration and detection of diffuse polarized emission.