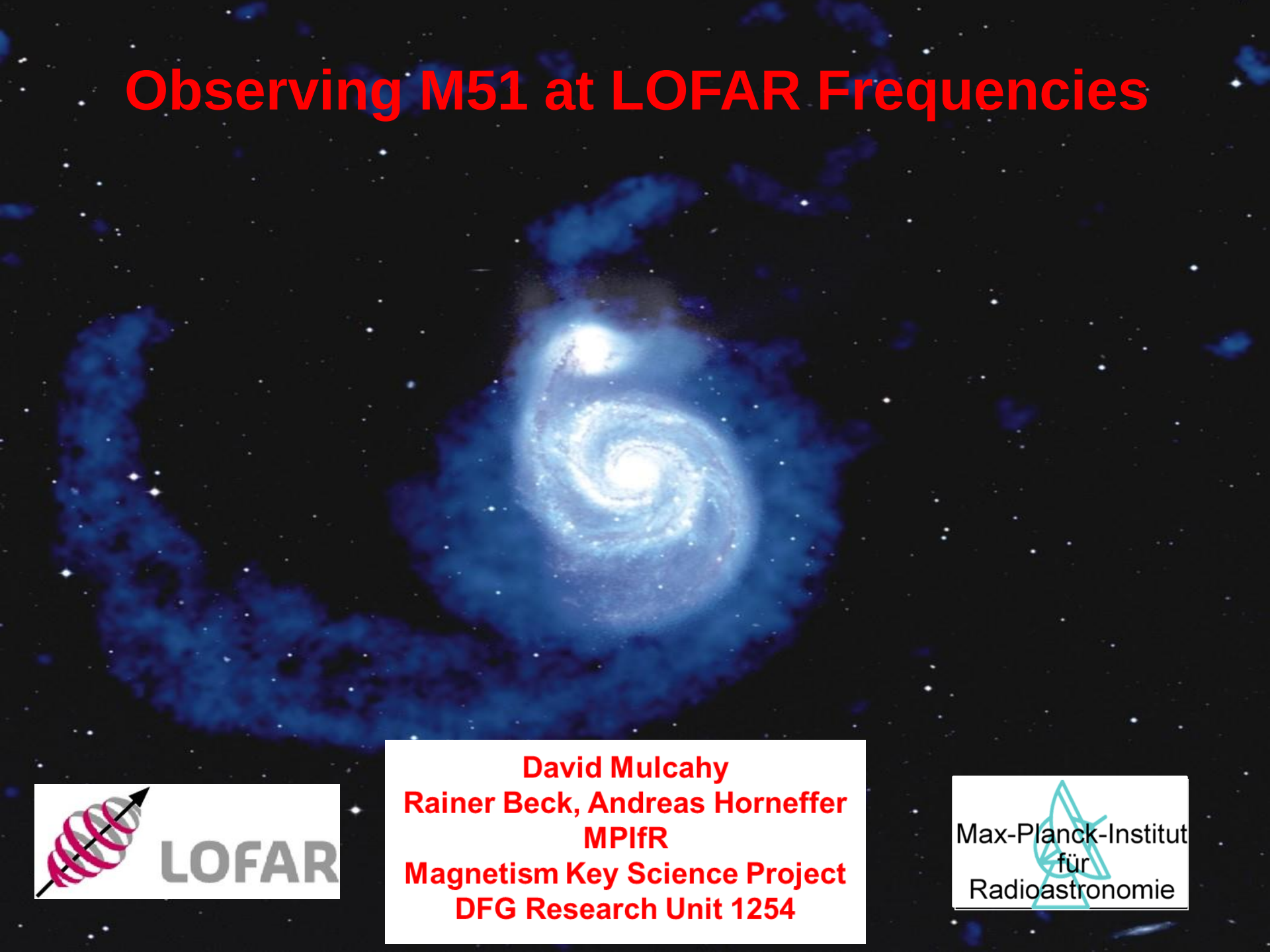
Observing M51 at LOFAR Frequencies



David Mulcahy
Rainer Beck, Andreas Horneffer
MPIfR
Magnetism Key Science Project
DFG Research Unit 1254

LOFAR

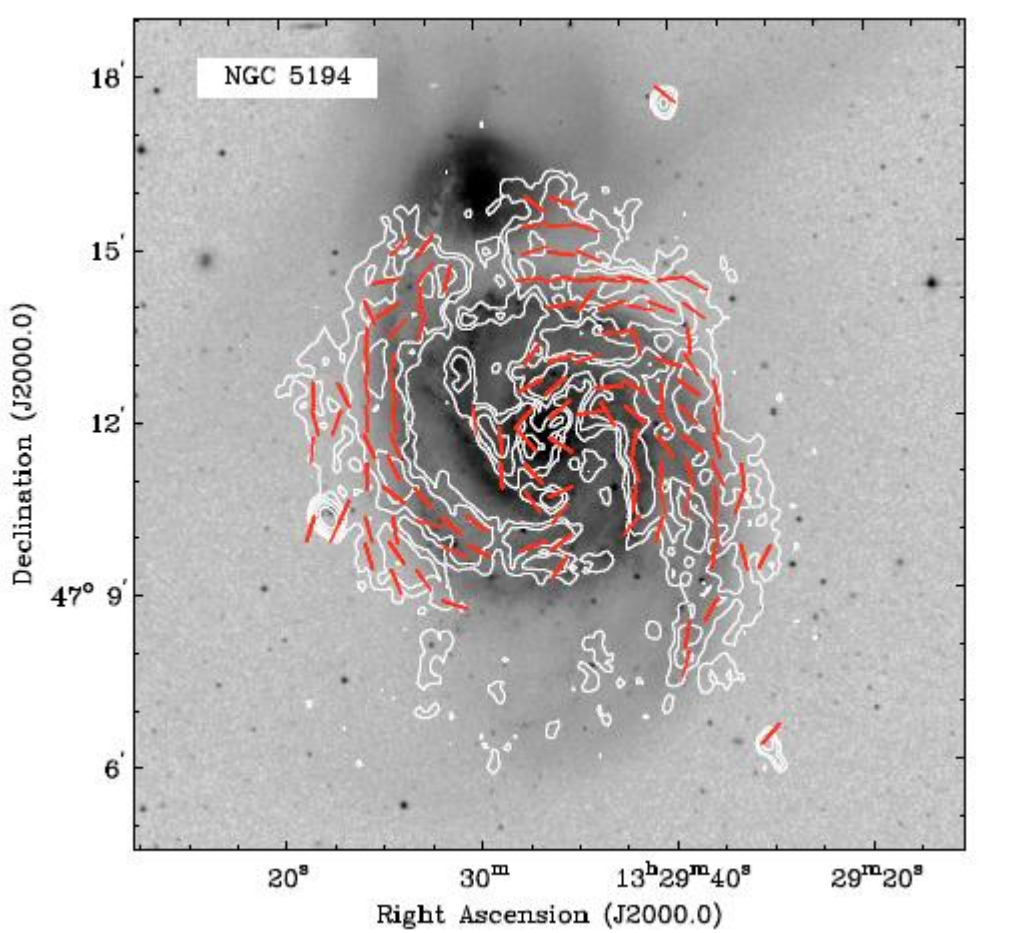
Max-Planck-Institut für Radioastronomie

Outline of Talk

- Why observe M51 at low frequencies ?
- Using Transfer of Gains from different beams to achieve calibration
- Interpolation of Gain Solutions in Frequency
- Resulting Images from 1st LOFAR Observation
- Issues with the old LOFAR observation
- Commissioning Progress with New LOFAR Observation
- Future Work

Why Observe M51 at low frequencies?

- M51 has a large extended disk in total power and polarized intensity

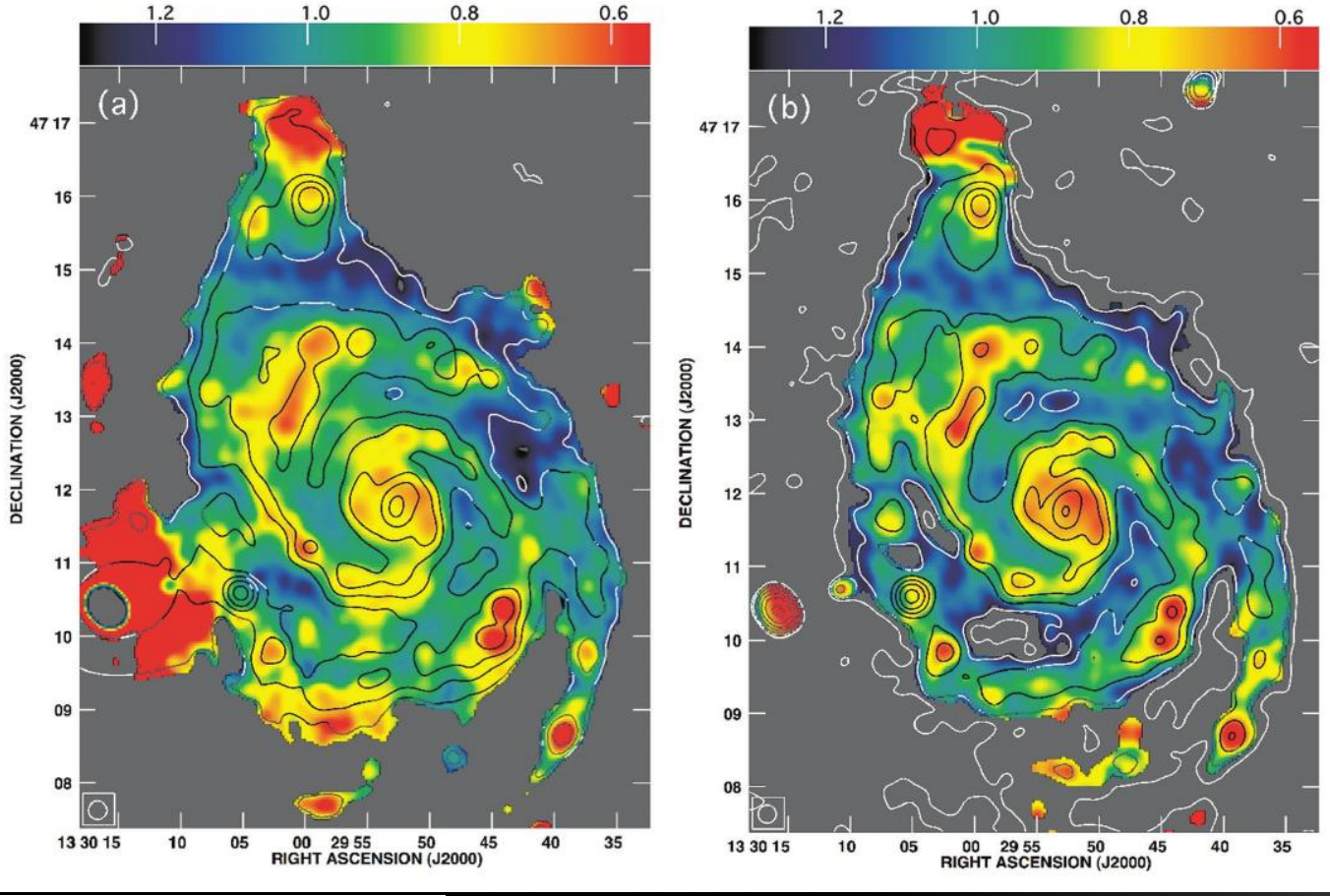


Heald et al (2009)

Heald et al (2009) found that the fractional polarization at 22cm was variable, 5% in the inner optical disk and increasing to 25-30% at larger radii, beyond the outer arms.

Why Observe M51 at low frequencies?

- M51 has a large extended disk in total power and polarized intensity
- Arm and Inter-Arm contrasts in spectral index



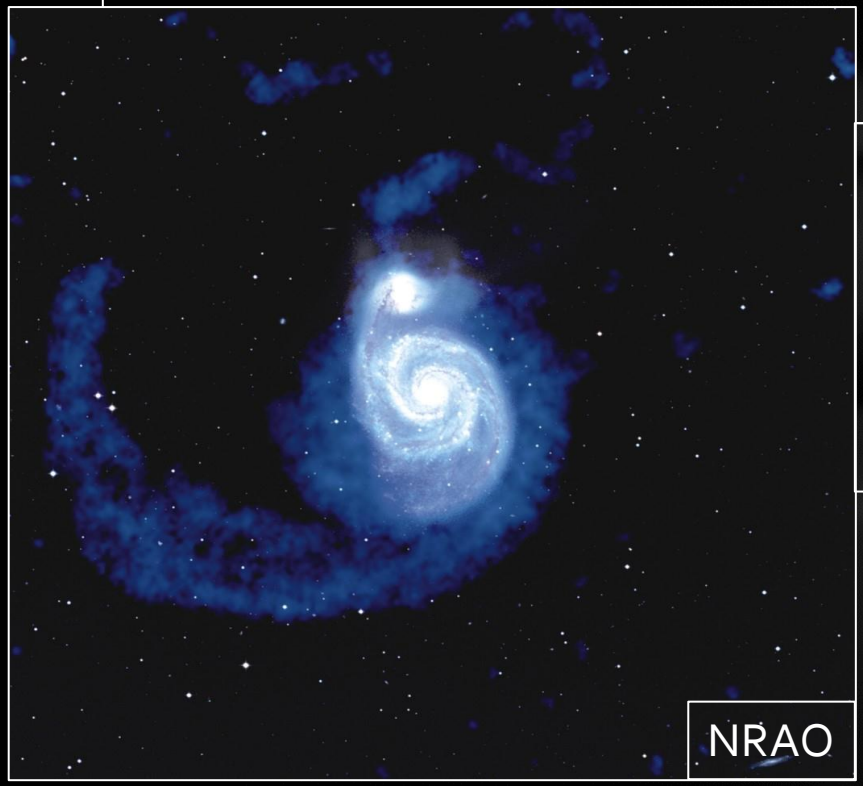
Left: spectral index map between 20 and 3cm
Right: spectral index map between 20 and 6cm

Wider frequency span will produce more accurate results

Fletcher et al. (2011)

Why Observe M51 at low frequencies?

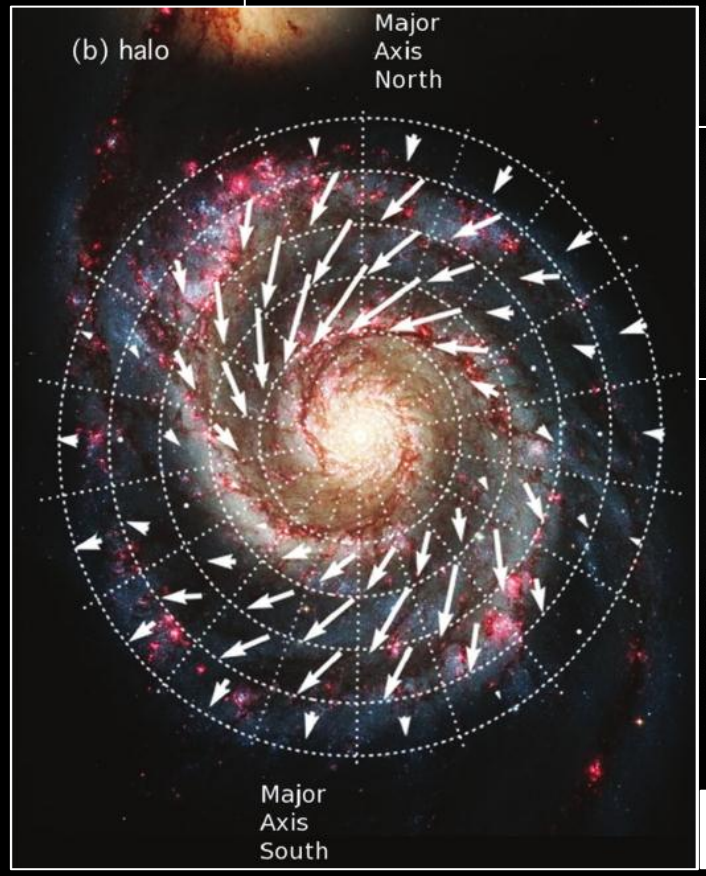
- M51 has a large extended disk in total power and polarized intensity
- Arm and Inter-arm contrasts in spectral index
- Interaction between companion Galaxy NGC5195 may have caused in two systems of density waves and outflows.



HI tail could be visible in radio continuum as HI is partially ionized and possible magnetized. Indications of this tail has been seen in recent GMRT data at 325MHz obtained by Andrew Fletcher.

Why Observe M51 at low frequencies?

- Multi frequency observations of M51 suggests a strong halo polarization and a bisymmetric horizontal azimuthal mode in the halo which we hope to observe with LOFAR using RM Synthesis.
- With LOFAR, polarization is not expected to be seen from the disk but only from the halo. This would be a strong test for this hypothesis.

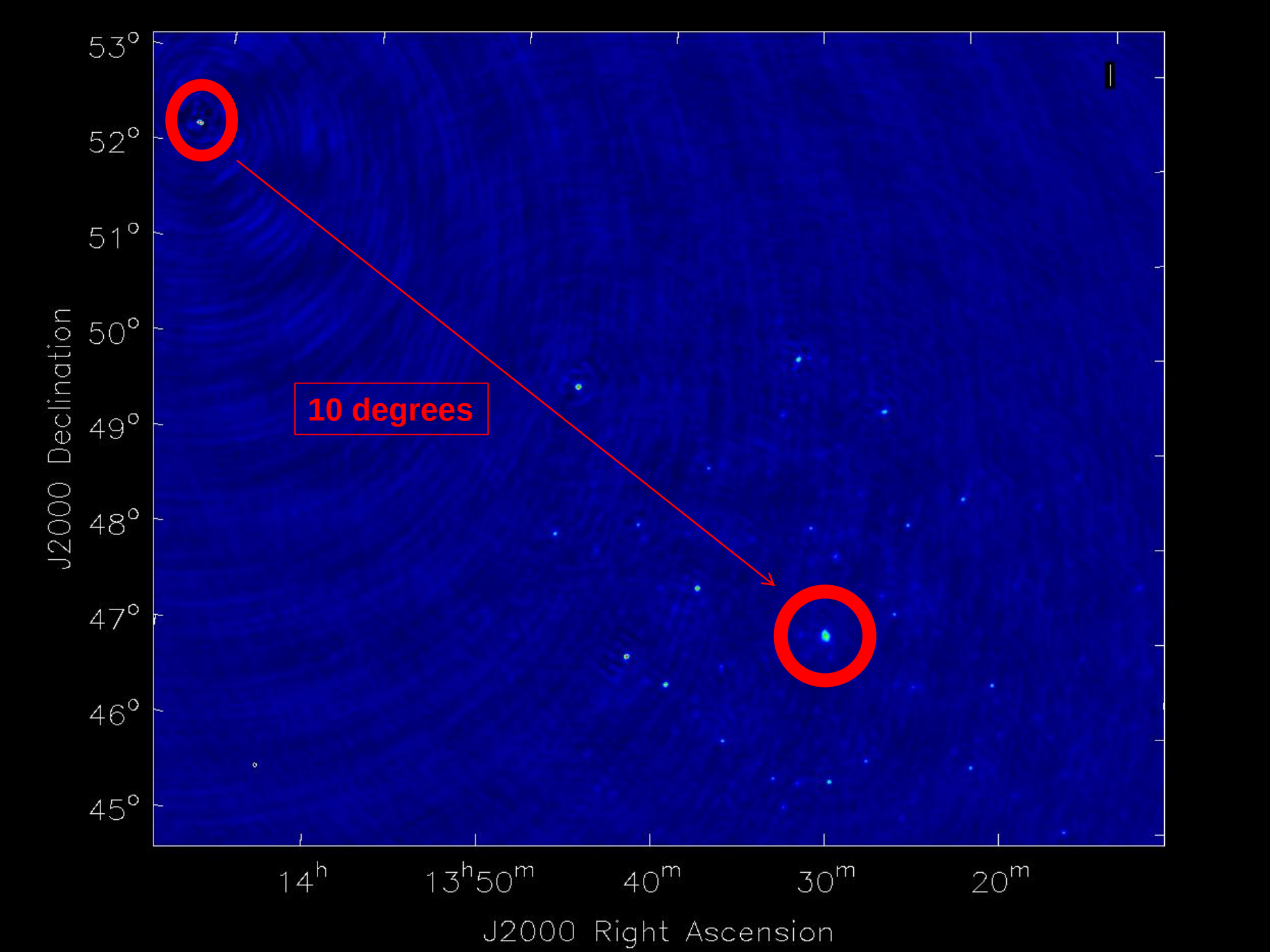


Heald et al. (2009) has used RM Synthesis on 22cm WSRT data which qualitatively showed the pattern expected from a bisymmetric magnetic field.

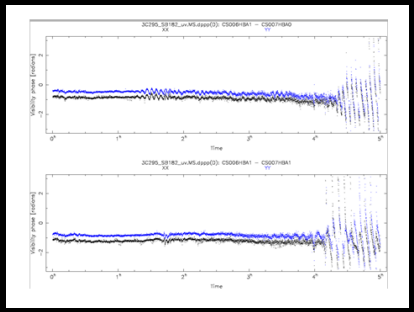
Fletcher et al (2011)

1st Observation of M51 and 3C295 with LOFAR- HBA

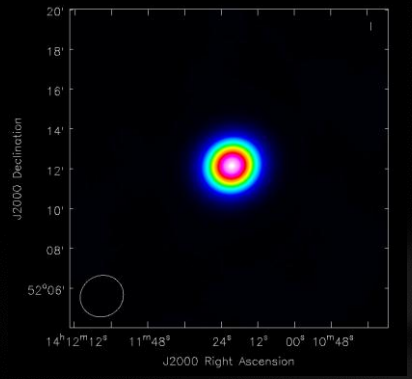
- Observed M51 and 3C295 dual beam mode in May 2011.
- 122 subbands of 200KHz on each target.
- Observation suffered from many broken tiles.
- Sidereal Time interval was not optimal.
- Many stations were not used in the observation.


53°
52°
51°
50°
49°
48°
47°
46°
45°
J2000 Declination
10 degrees
14h
13h50m
40m
30m
20m
J2000 Right Ascension

Preprocessing



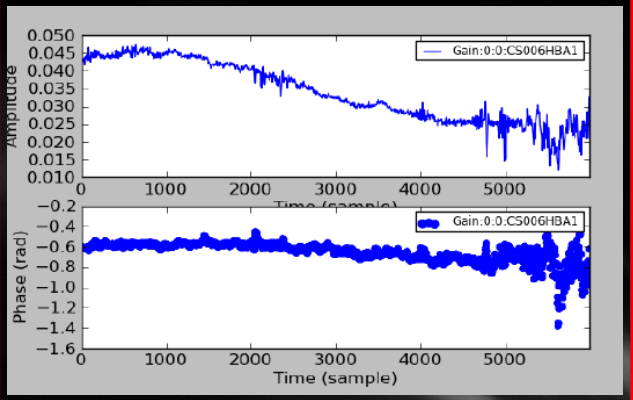
Calibrate the Calibrator



Calibrator: 3C295

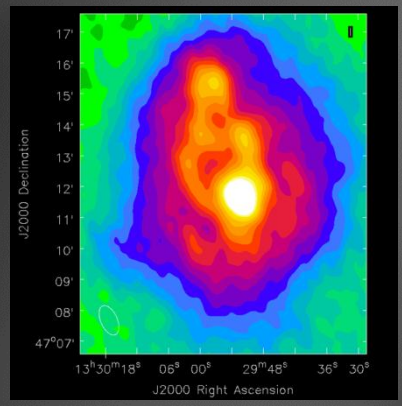
Solves for all 4 elements in the gain Jones' matrix

Analyze Gains



Apply Gains to the target field

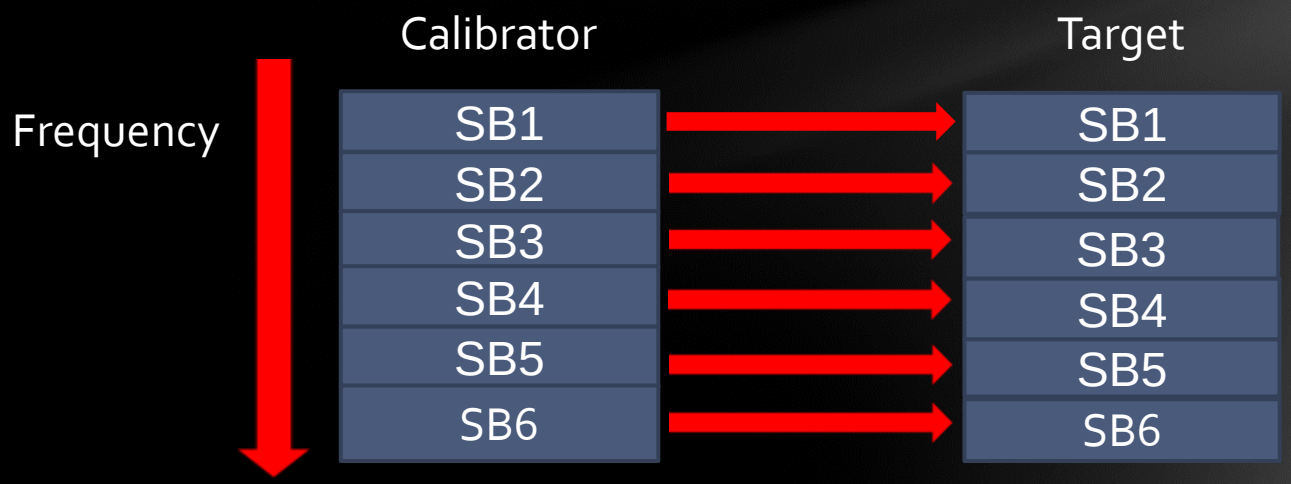
Scaife & Heald skymodel
Specifies direction only for target



Image!!!

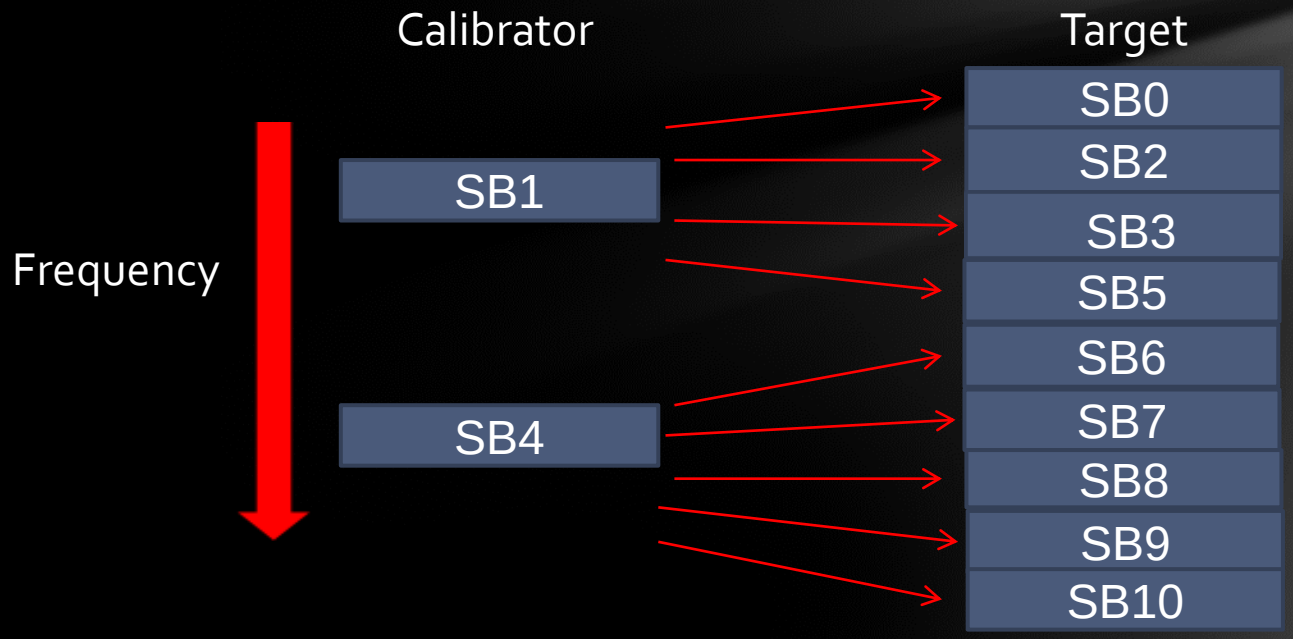
Disadvantage of Direct Gain Transfer
Motivation for Gain Interpolation

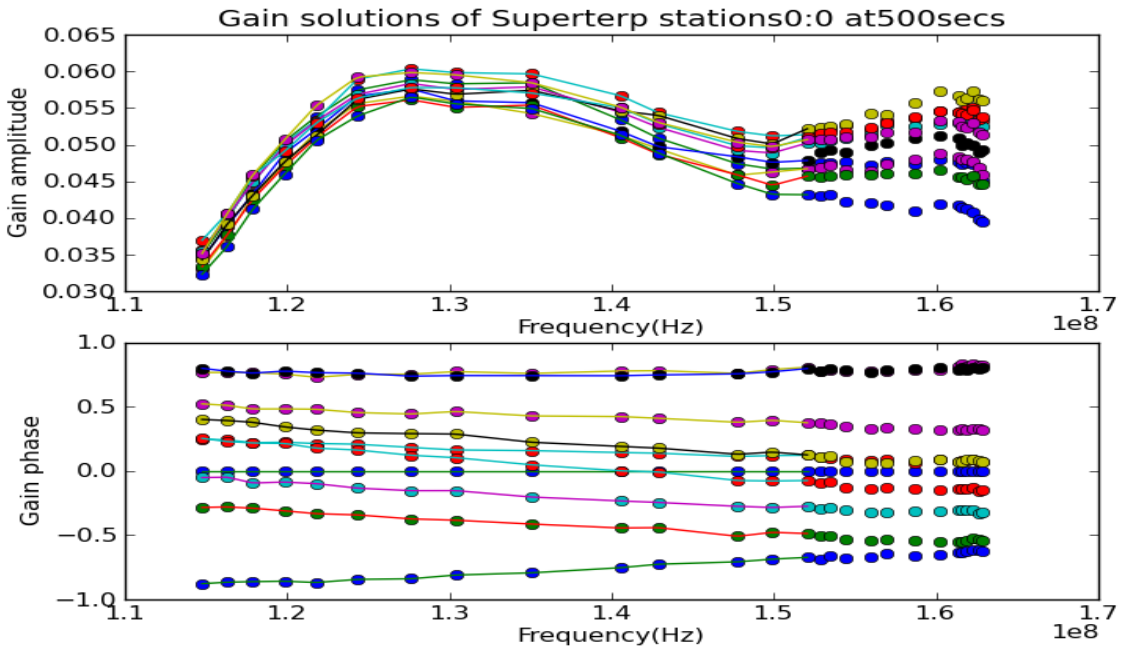
- At present, an equal amount of subbands must be used on both the calibrator and the target source.
- Therefore, observing bandwidth on the target source is halved.
- Decreasing the number of subbands used for calibration is very desirable.

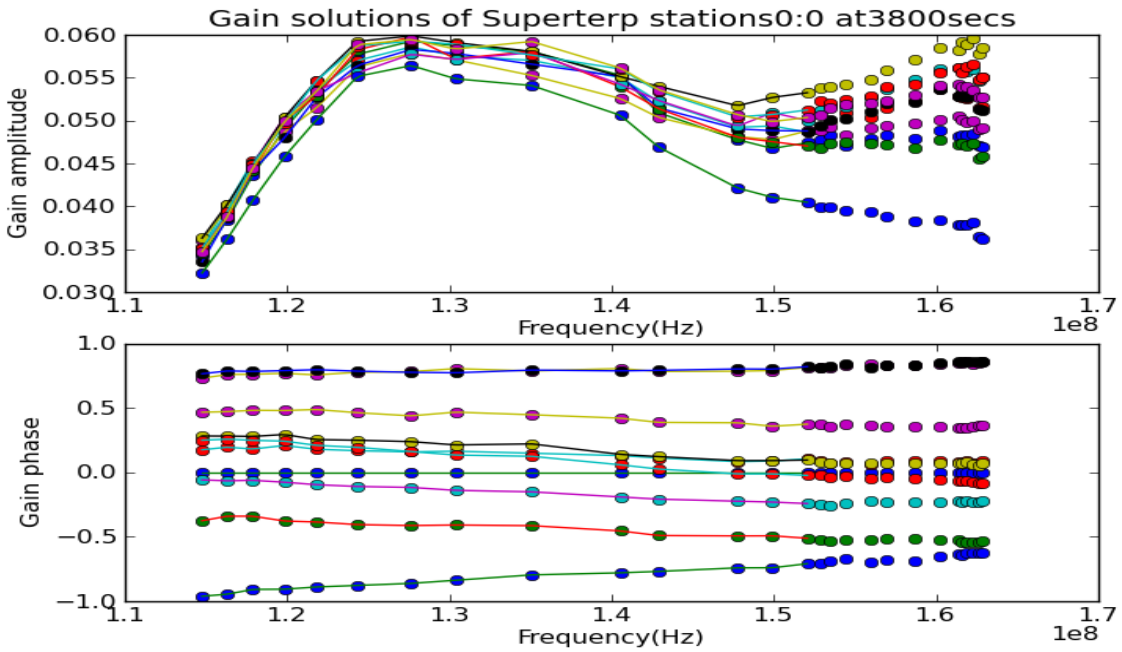


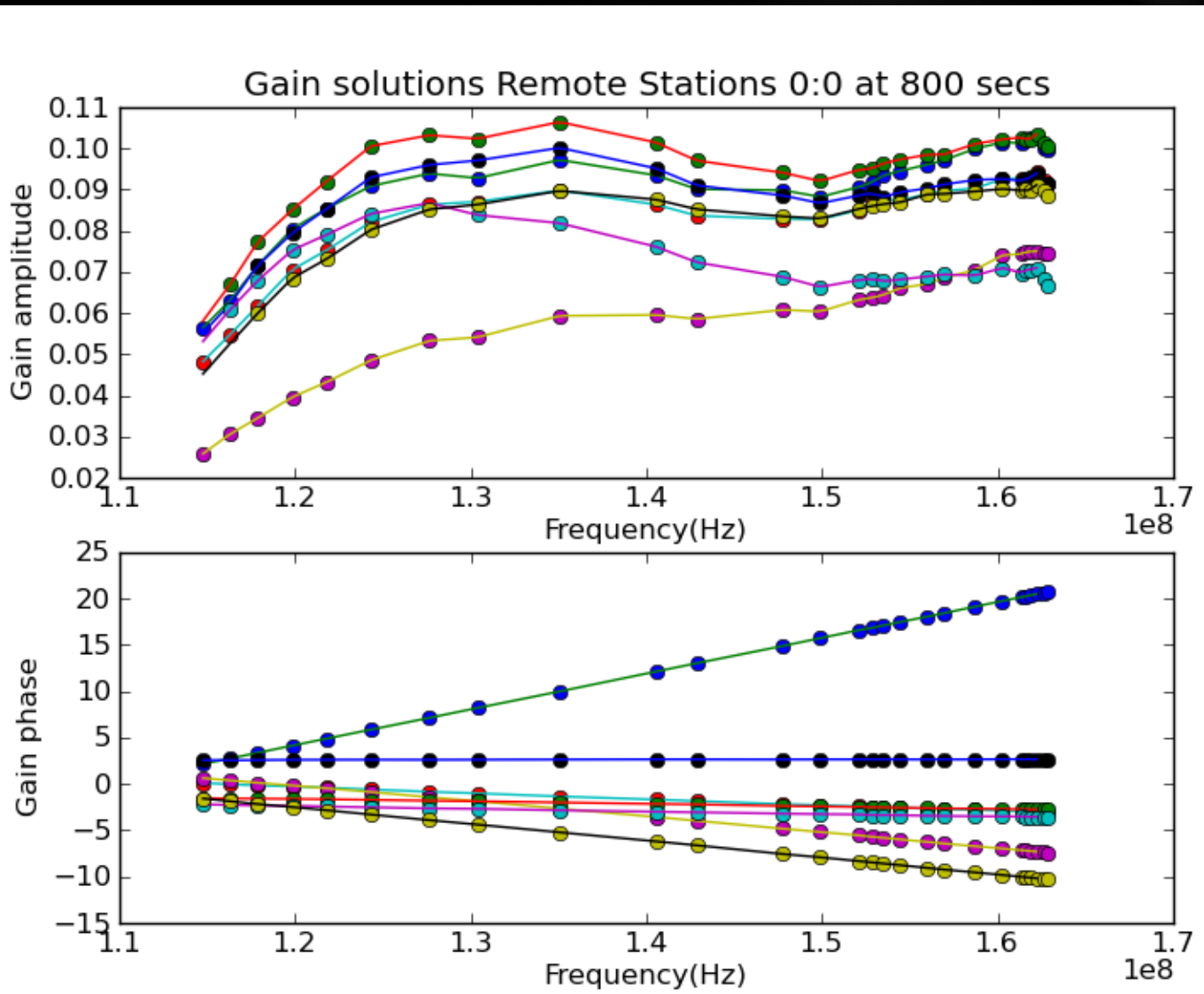
Disadvantage of Direct Gain Transfer
Motivation for Gain Interpolation

- At present, an equal amount of subbands must be used on both the calibrator and the target source.
- Therefore, observing bandwidth on the target source is halved.
- Decreasing the number of subbands used for calibration is very desirable.

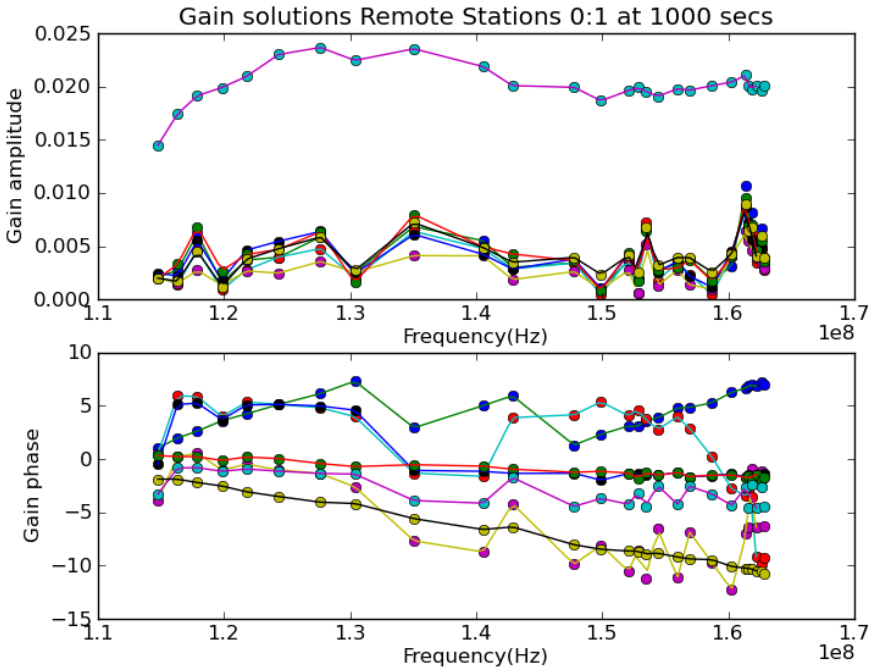


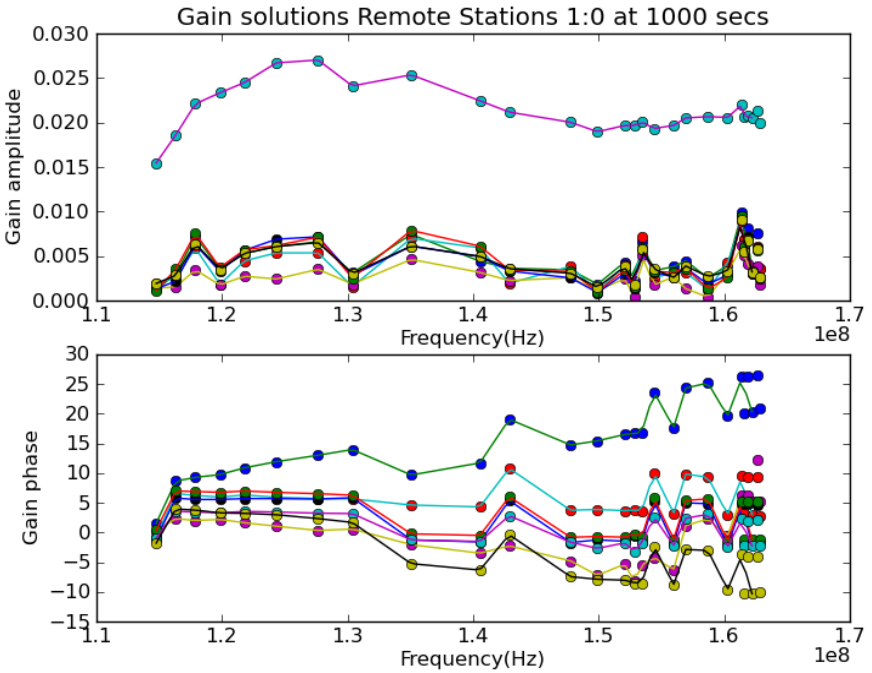

Gain solutions of Superterp stations0:0 at500secs
Gain amplitude
0.065
0.060
0.055
0.050
0.045
0.040
0.035
0.030
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1e8
Frequency(Hz)
Gain phase
1.0
0.5
0.0
−0.5
−1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1e8
Frequency(Hz)


Gain solutions of Superterp stations0:0 at3800secs
Gain amplitude
0.060
0.055
0.050
0.045
0.040
0.035
0.030
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1e8
Frequency(Hz)
Gain phase
1.0
0.5
0.0
−0.5
−1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1e8
Frequency(Hz)


Gain solutions Remote Stations 0:0 at 800 secs
Gain amplitude
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1e8
Frequency(Hz)
Gain phase
25
20
15
10
5
0
−5
−10
−15
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1e8
Frequency(Hz)

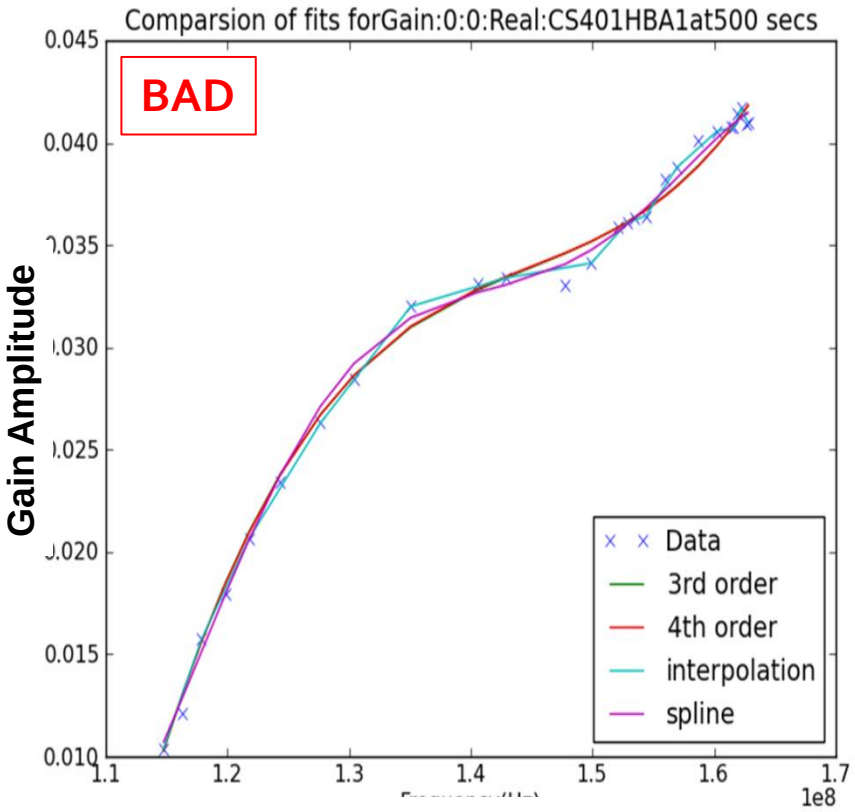
XY Gains solutions in Frequency

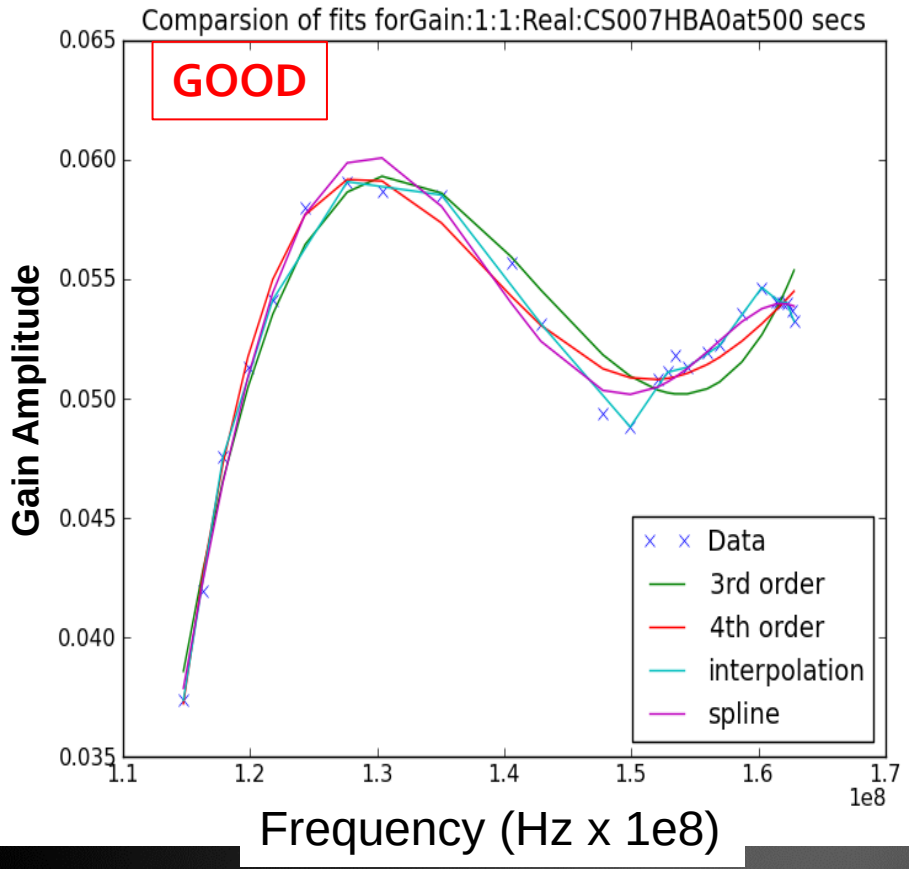




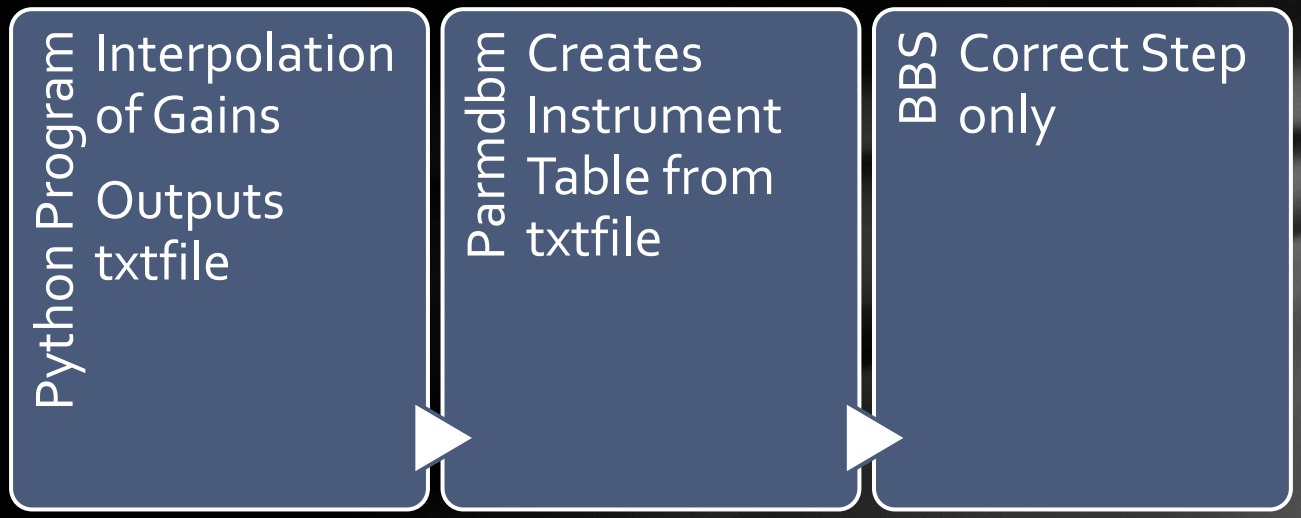
Identifying Problem Stations

- Shape of Gain Bandpass can indicate problematic stations





Entire Gain Interpolation Process

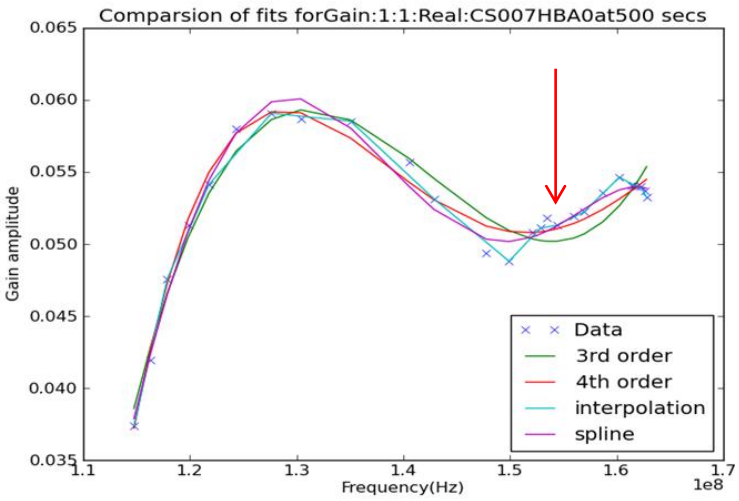


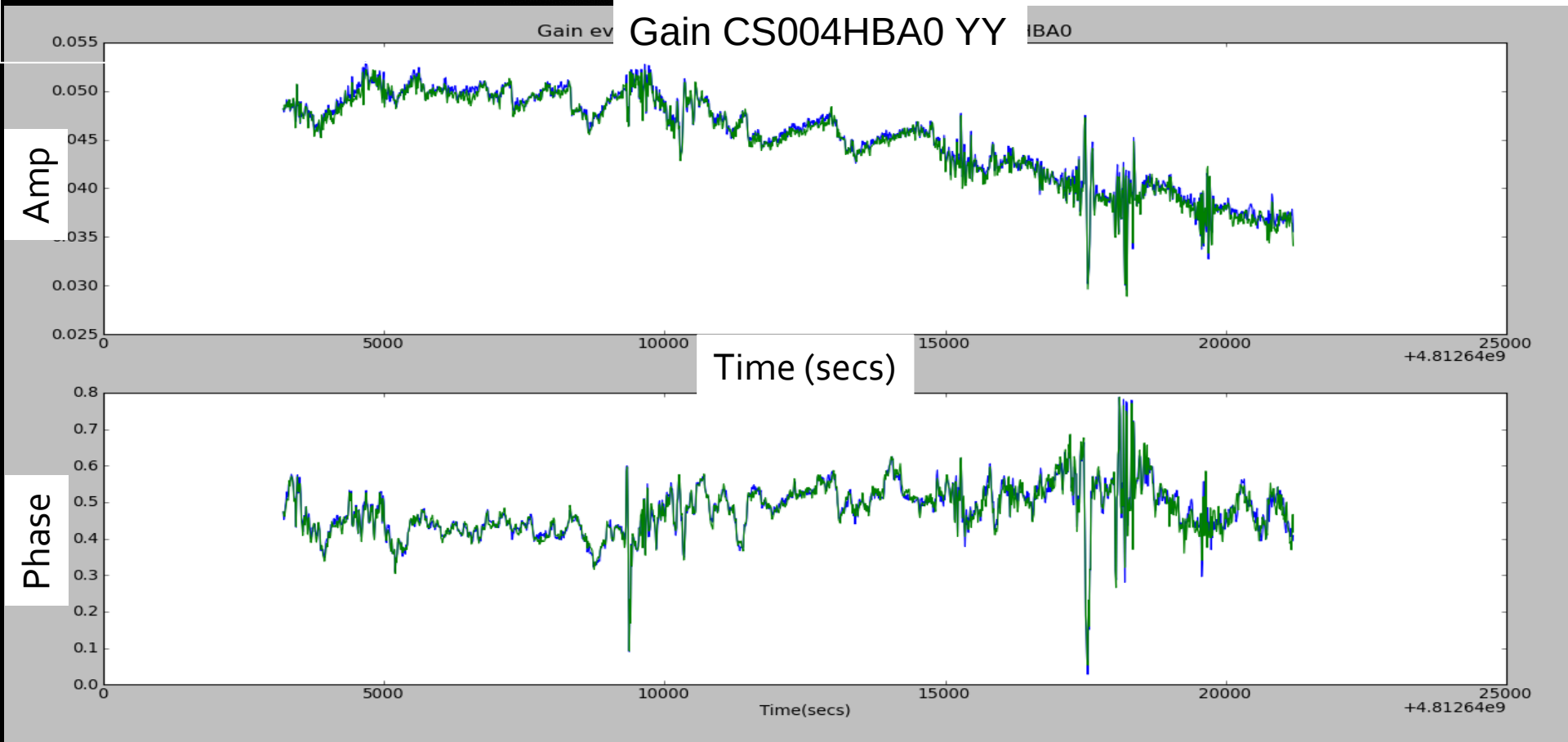
Detailed Description of Software can be found at:

http://www.lofar.org/wiki/doku.php?id=commissioning:pol_commissioning

Testing the model

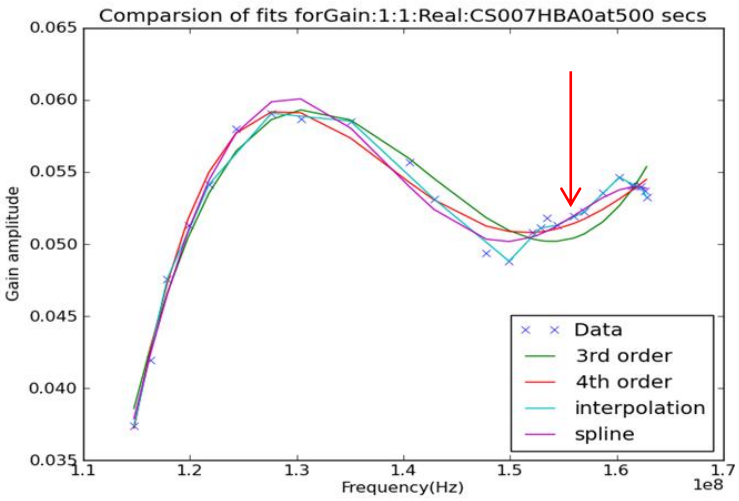
- Used program to predict and compare with subband (156MHz) not used in creating model.
- Blue is created model, Green are values obtained directly from the subband.

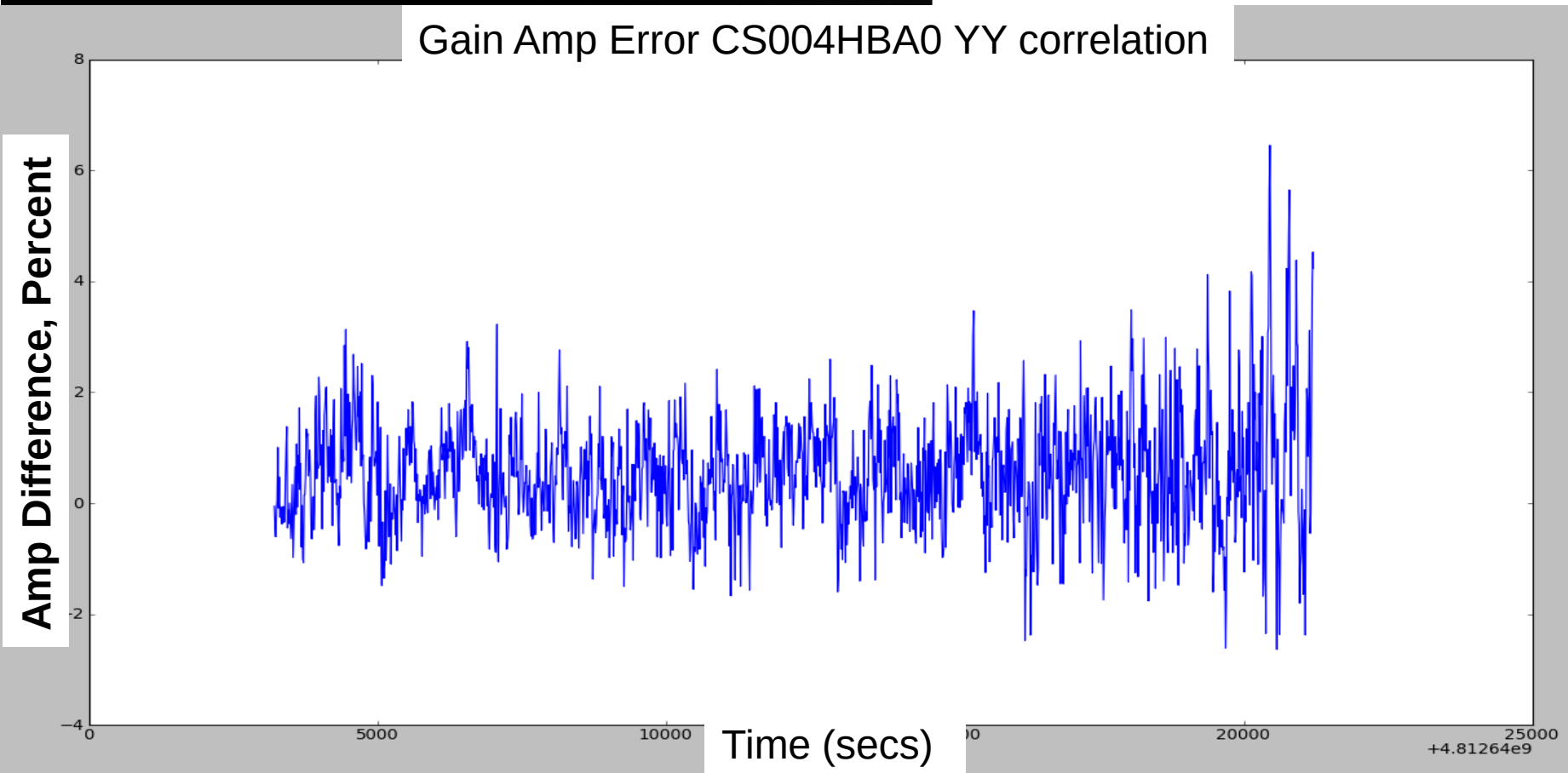




Testing the model

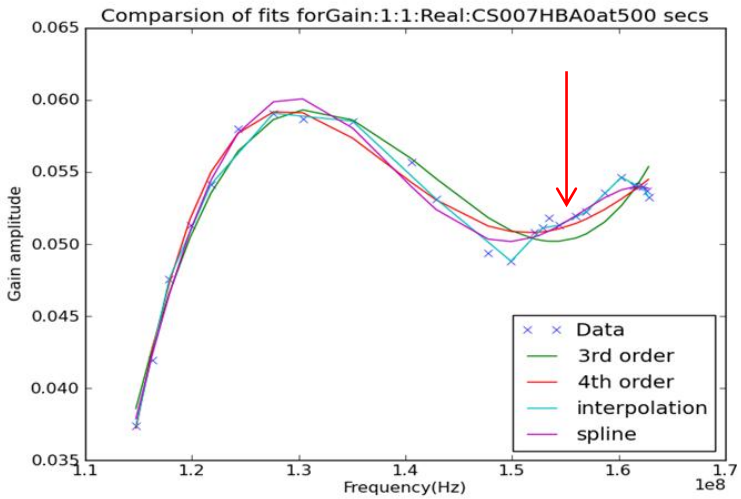
- Used program to predict and compare with subband (156MHz) not used in creating model.
- The difference in amplitude between real and model shows a difference of about 1% until the very end of the observation.

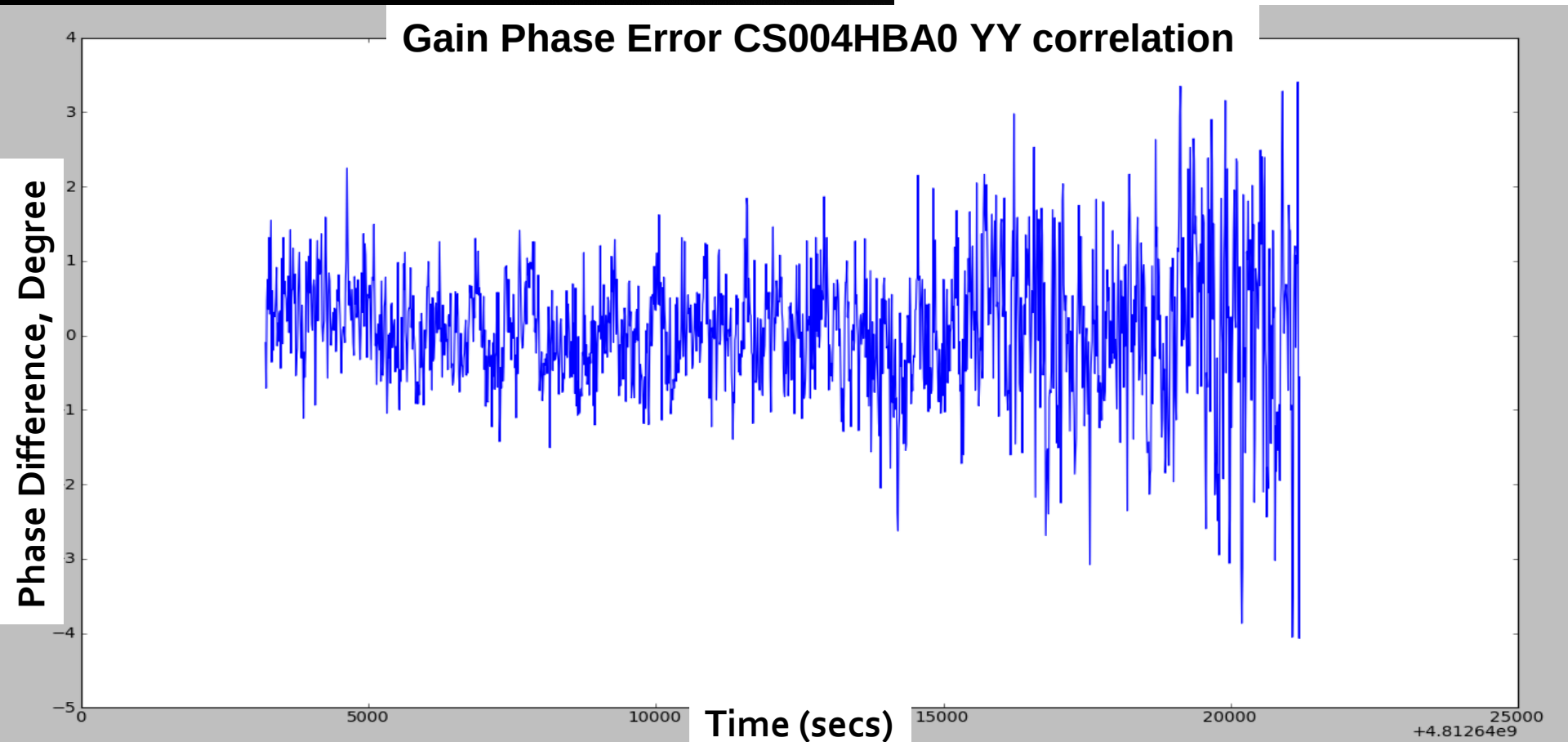




Testing the model

- Used program to predict and compare with subband (156MHz) not used in creating model.
- The difference in amplitude between real and model shows a difference of about 1% until the very end of the observation.
- Difference in phase shows an error of about 1 degree which increases at the end of the observation.

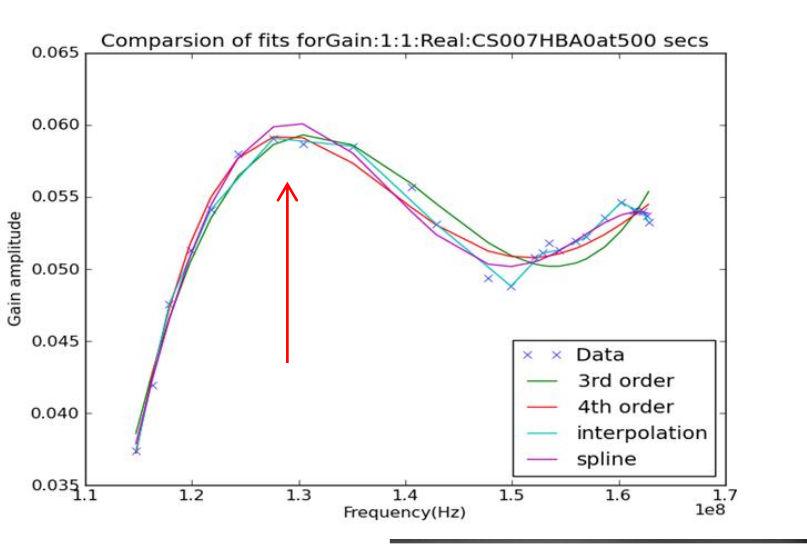


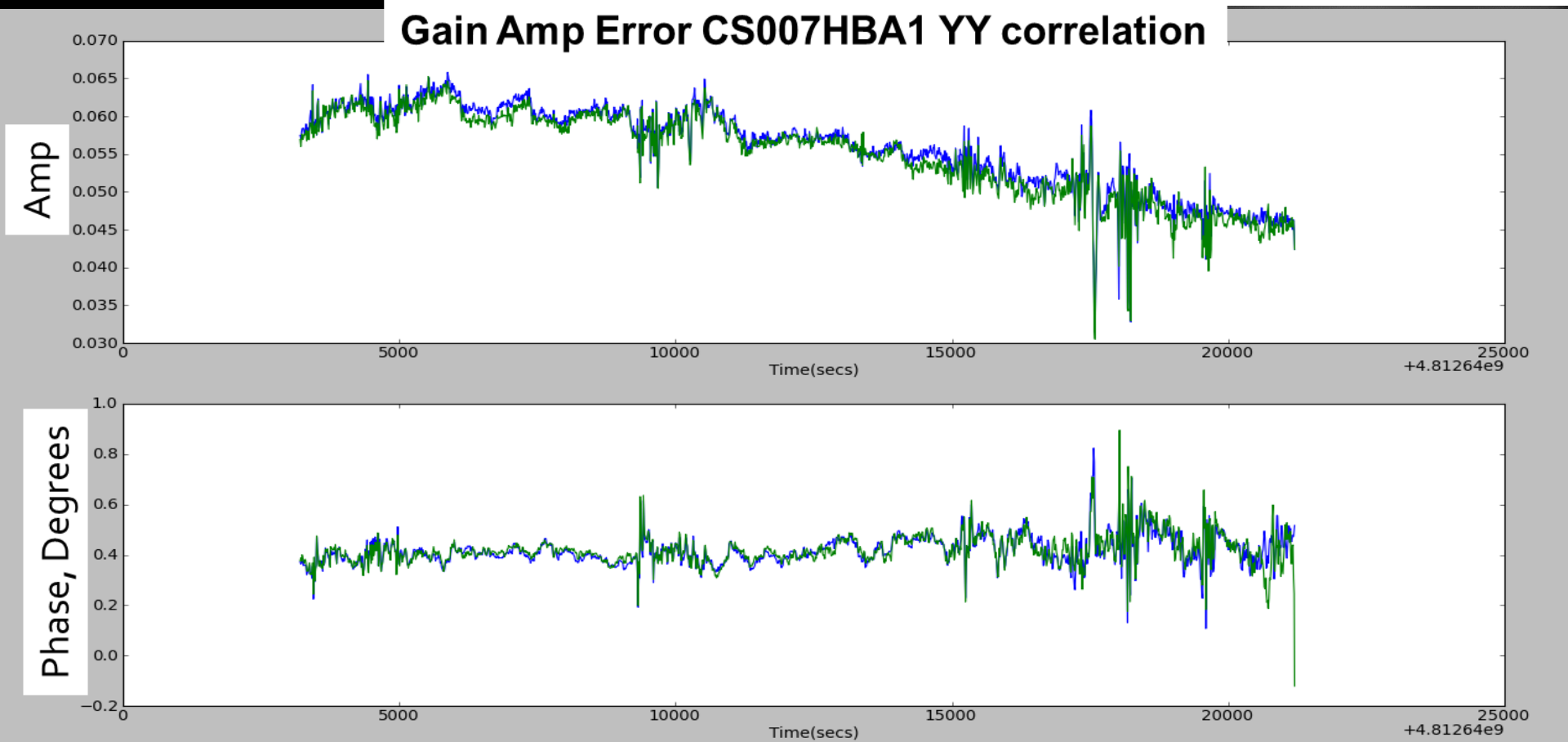


Testing the model

- Used program to predict and compare with subband (approx 130MHz) not used in creating model.

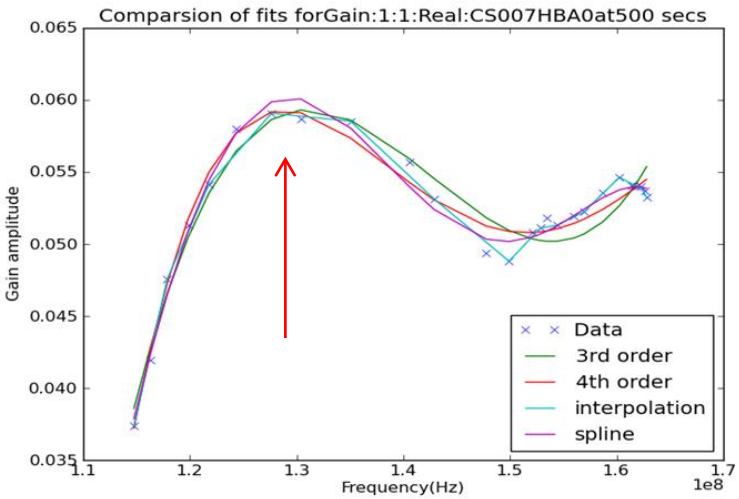
- Model is slightly overestimating gain.
- More subbands needed gain inflexion points at130 and 150 MHz

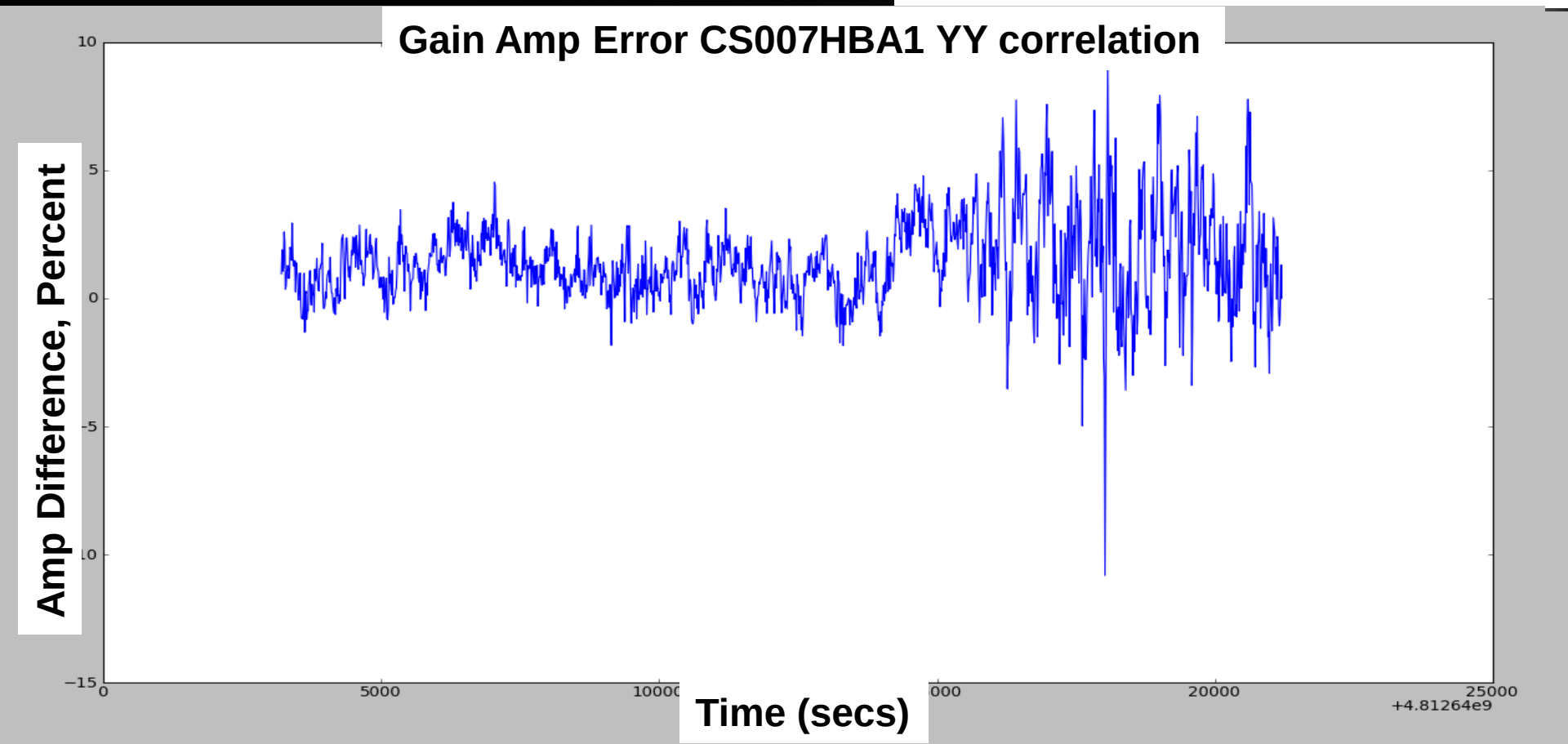




Testing the model

- Used program to predict and compare with subband (approx 130MHz) not used in creating model.
- Model is slightly overestimating gain.





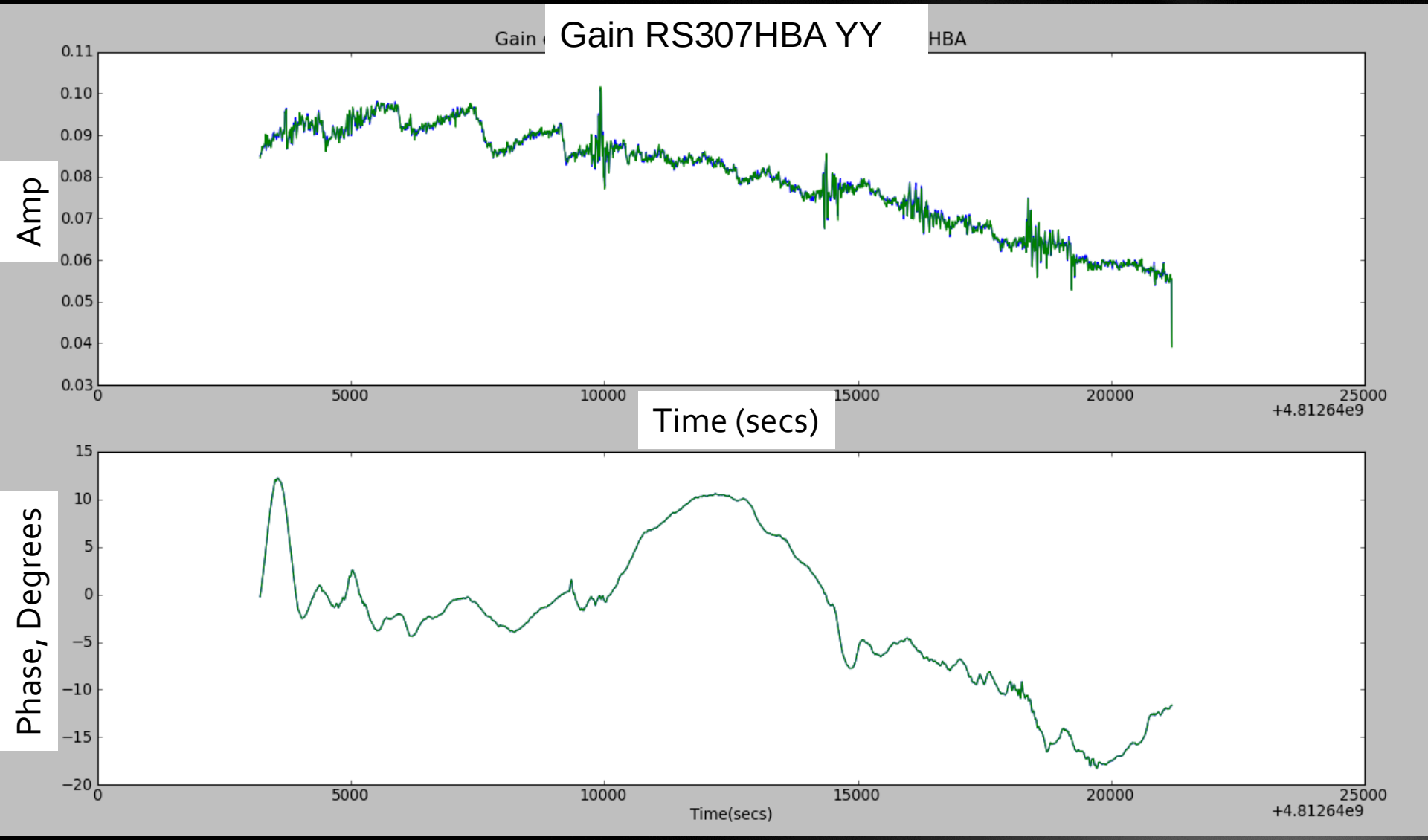
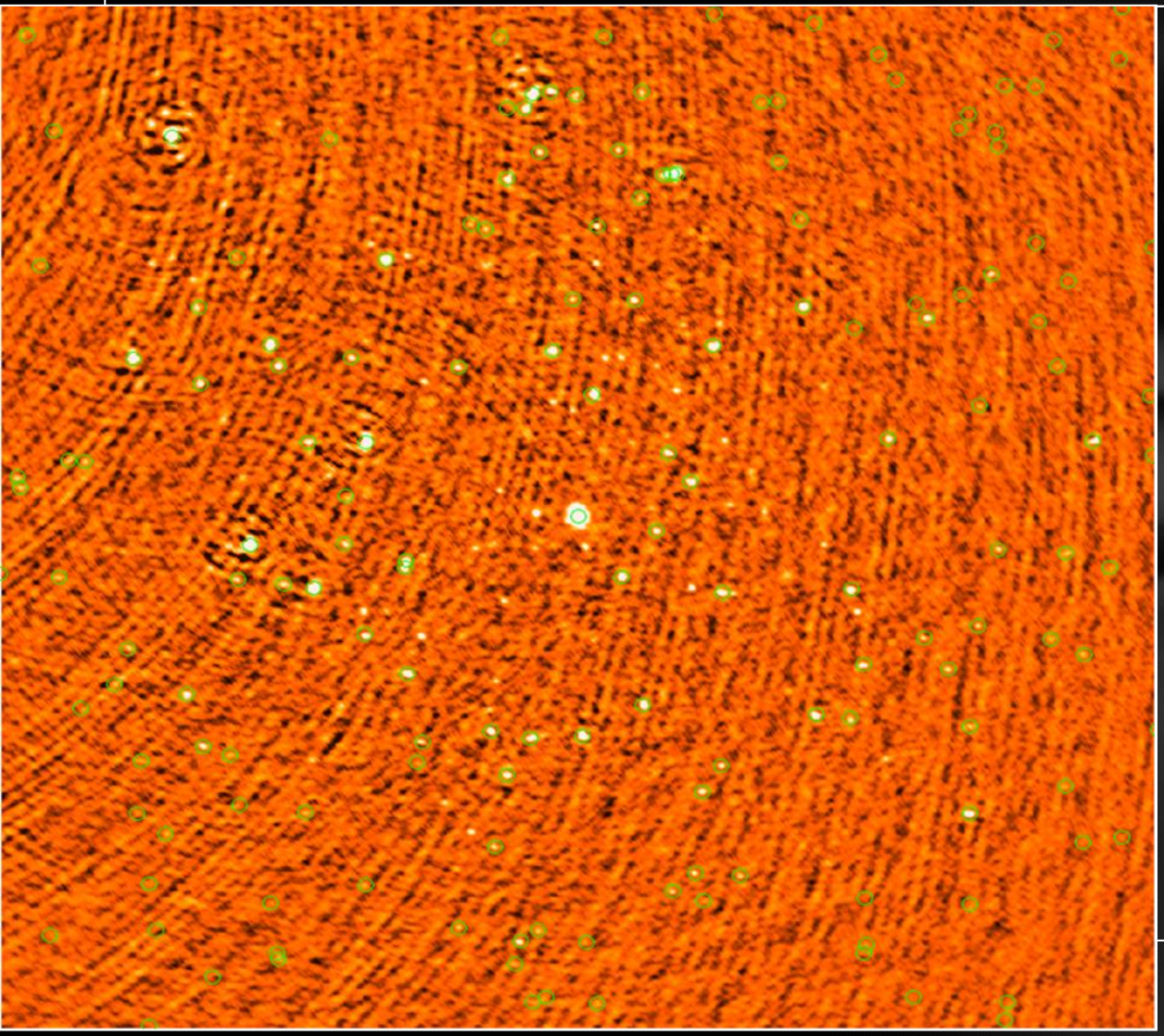

Gain RS307HBA YY
Amp
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0
5000
10000
15000
20000
25000
+4.81264e9
Time (secs)
Phase, Degrees
15
10
5
0
−5
−10
−15
−20
0
5000
10000
15000
20000
25000
Time(secs)
+4.81264e9

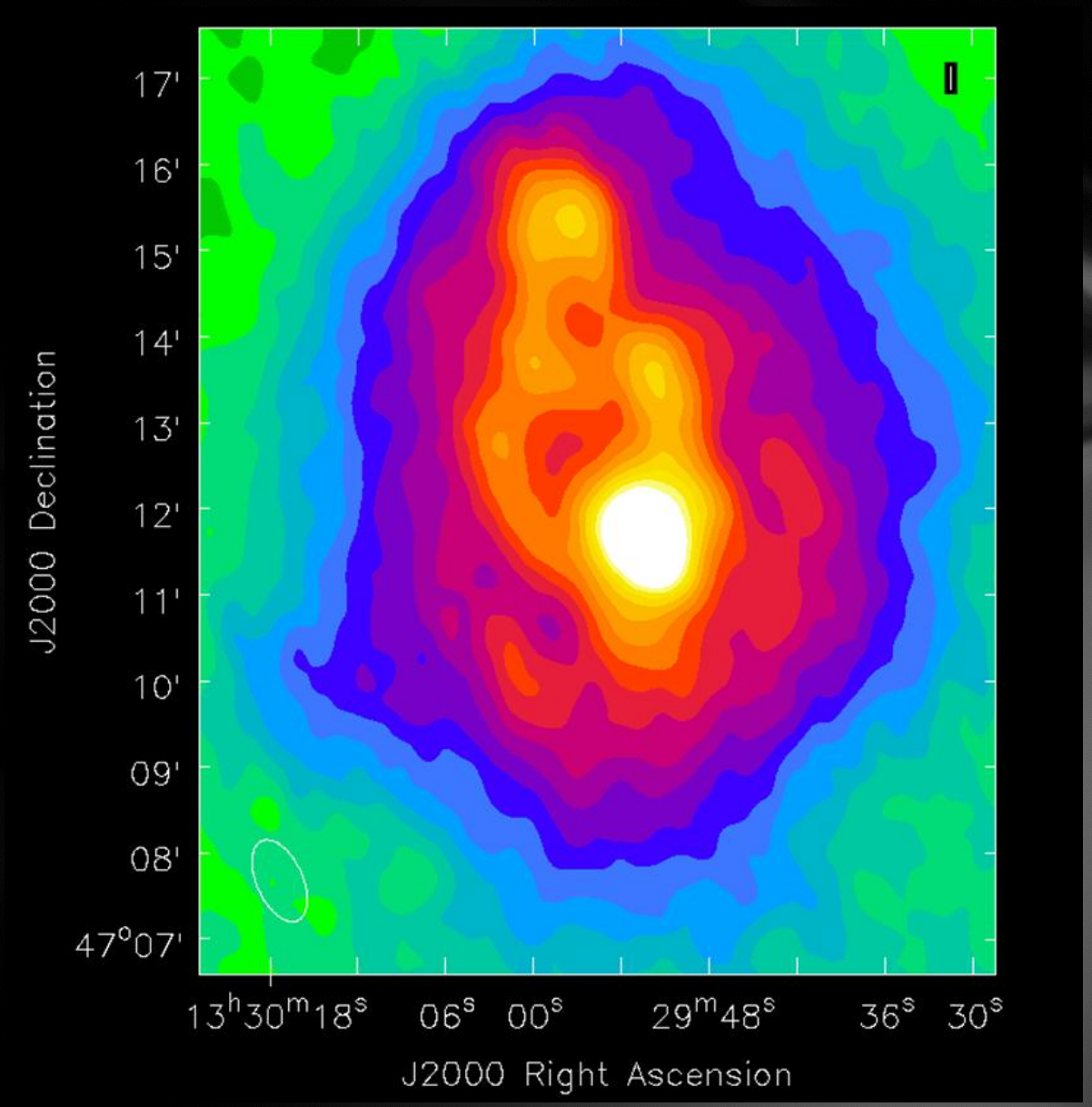
Image of a target Subband (145.12MHz) with Gain solutions transferred (Interpolation of 2.73MHz)

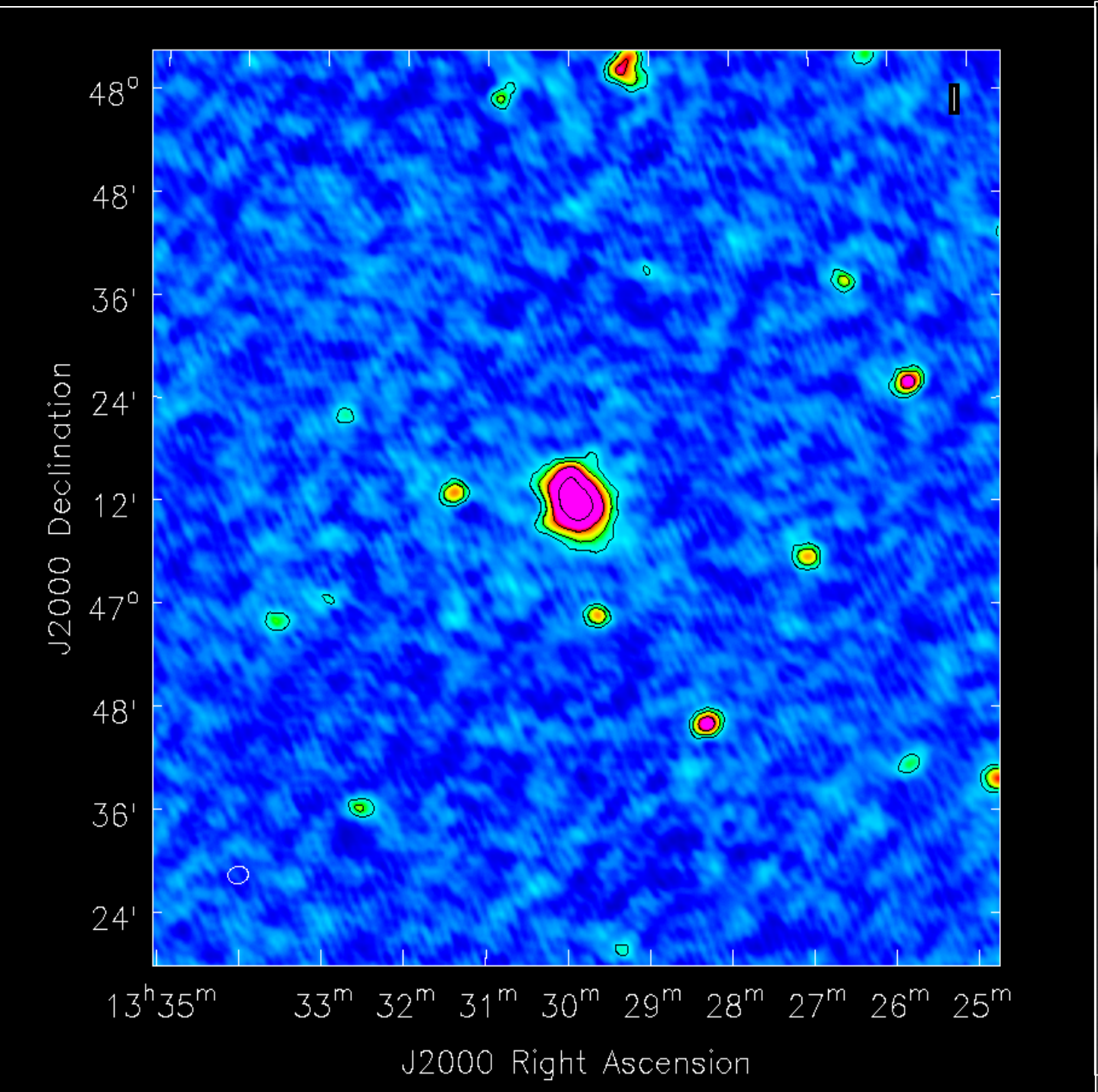


- Image of a target Subband (145.12MHz) with Gain solutions transferred (Interpolation of 2.73MHz)
- Visibilities less than 6km uvrange are imaged.
- Green circles indicate sources in the VLSS catalogue.
- As one can see, 3C295 is located outside the image in the north east producing many ripples.

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.





Close up of M51

145.12 MHz

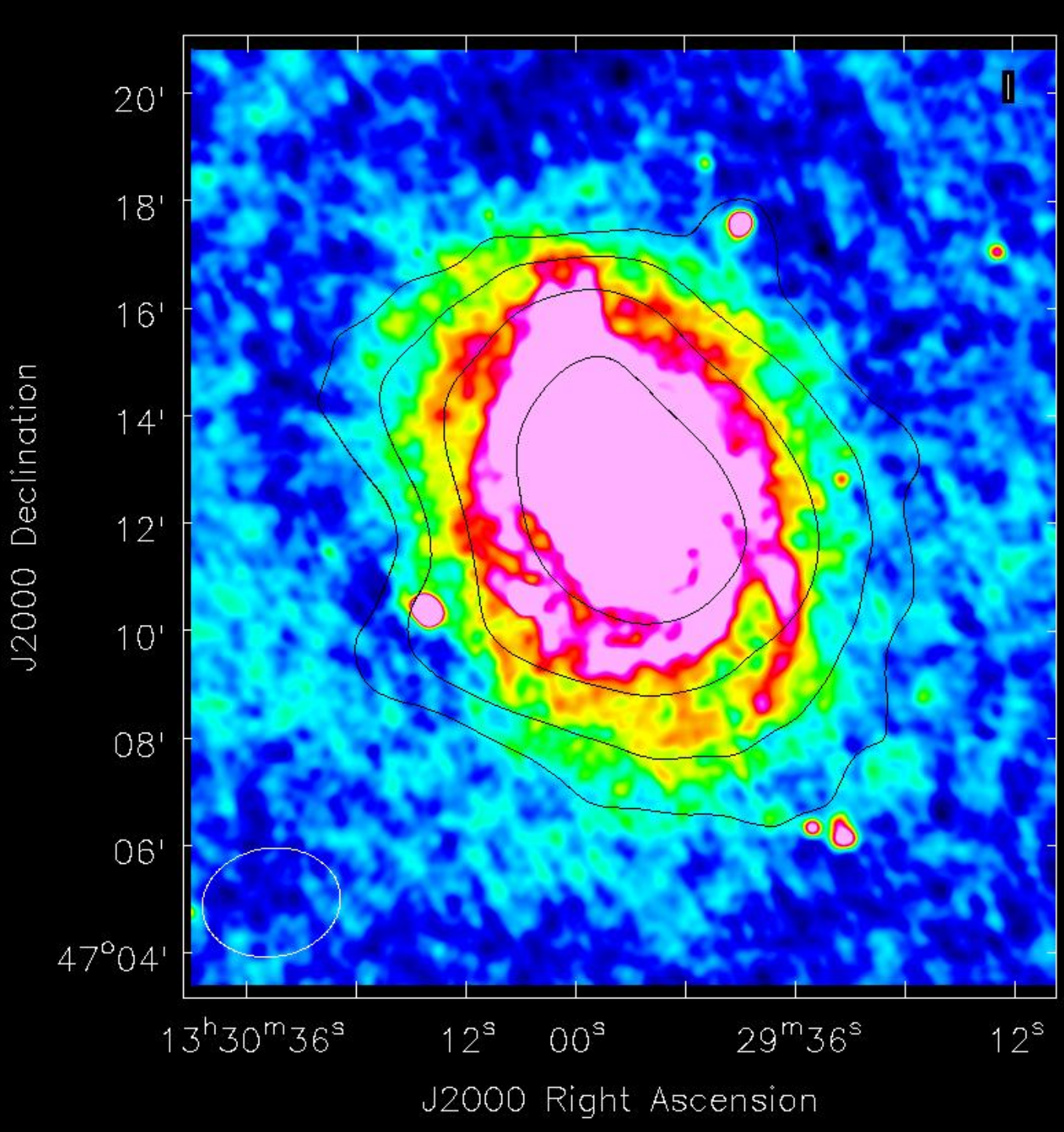
1 subband
Of 200 kHz

Baselines up to 6km

2 rounds of phase calibration and subtraction of 3C295

Noise is around 7.5mJy
15 times the thermal noise

Lowest contour is 5 sigma level



Previous LOFAR (contour) image overlayed onto 325MHz GMRT image

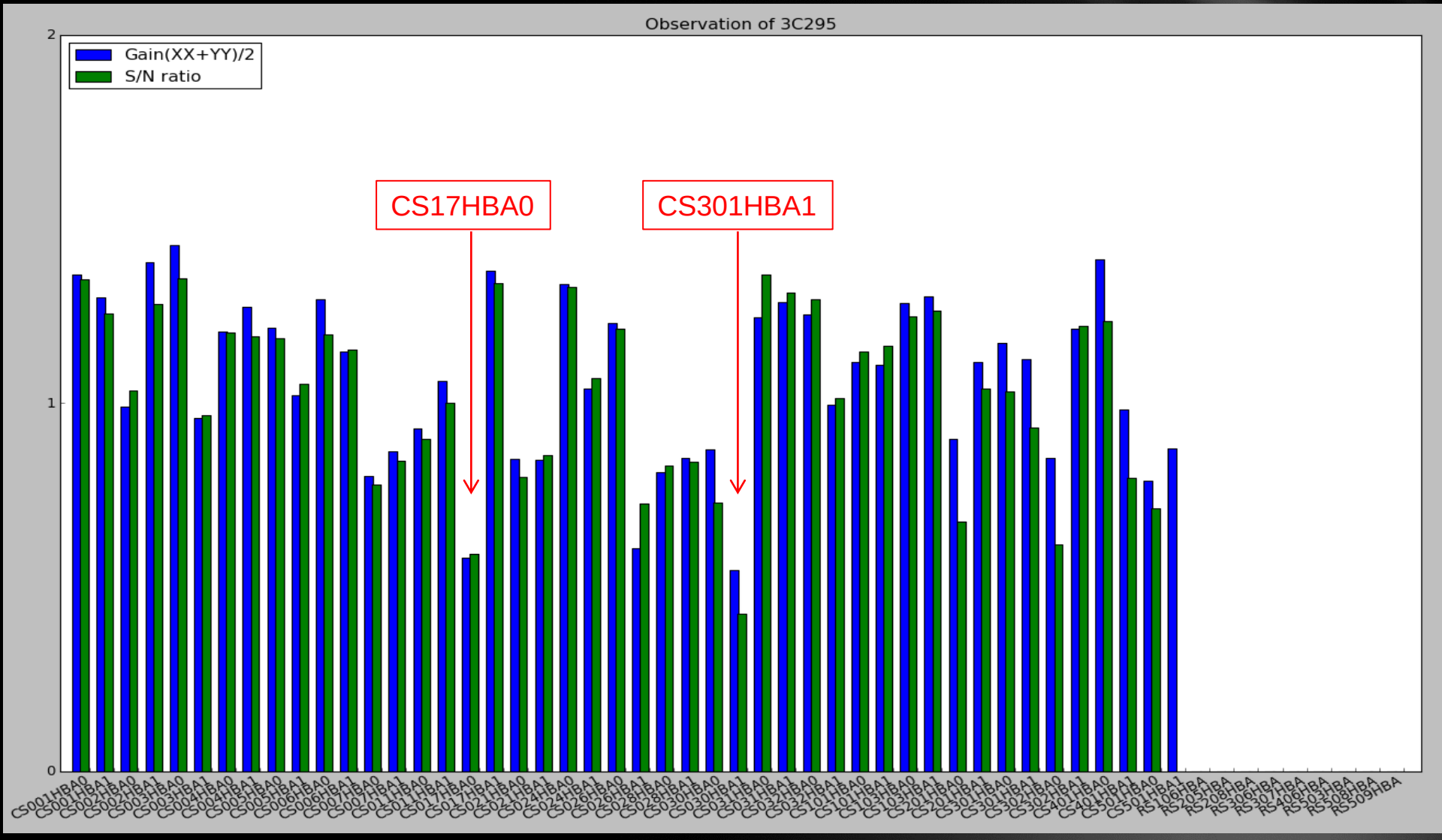
New Observation of 3C295 & M51 with LOFAR-HBA

- Main motivation: To further develop Gain Interpolation and learn to calibrate Total Flux properly
- Polarization work is secondary but will be attempted
- 6 hour nighttime observation was taken when M51 was at high elevation.
- 9 chunks of 20 subands (of 200KHz) spread evenly from 120 to 181MHz; 10 subbands placed near HBA-low filters; 54 subbands on calibrator.

Over **50%** increase of Subbands on the target!

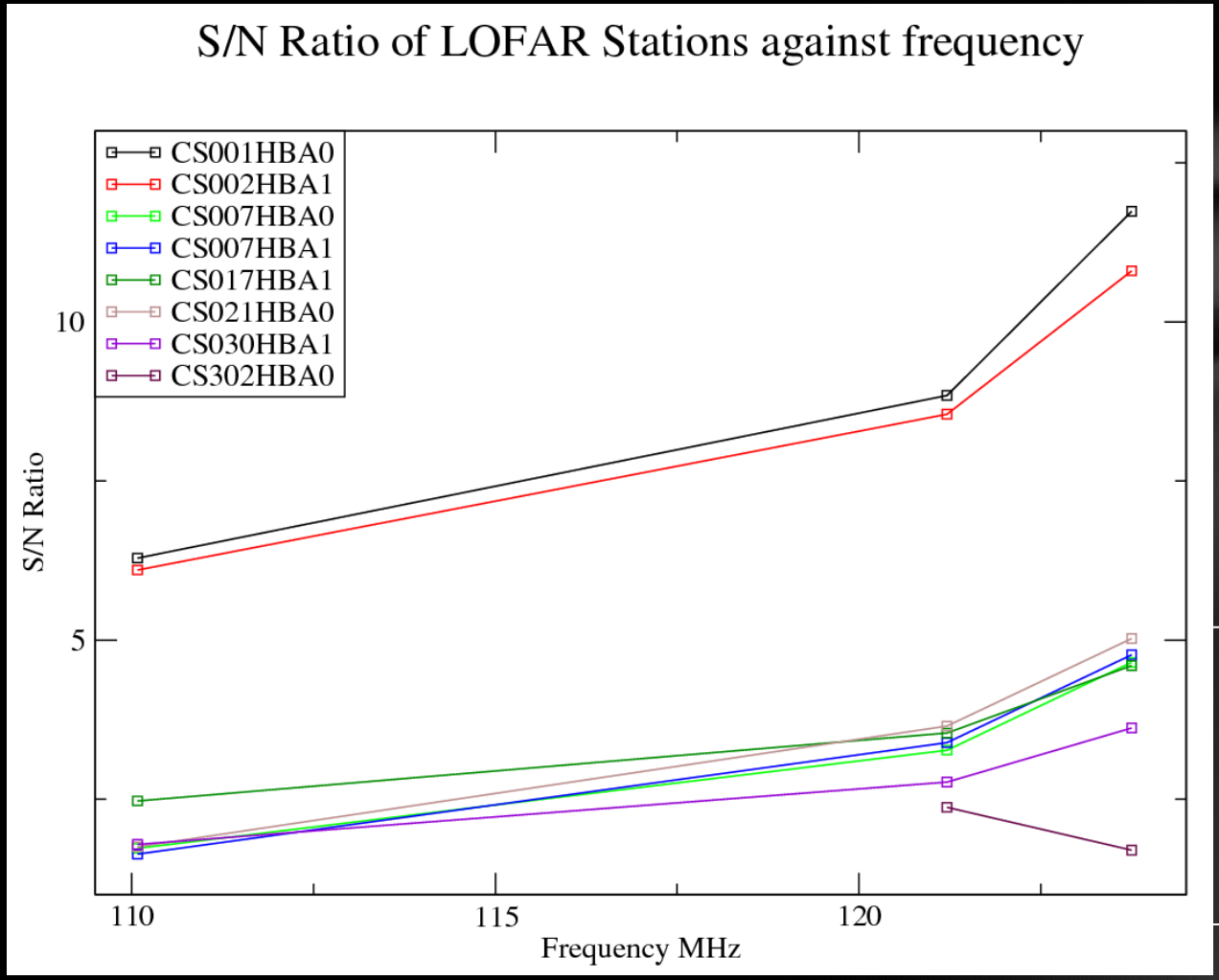
Preprocessing the Data

5ns offset in RSP boards is a very serious problem, stations need to be identified and flagged.

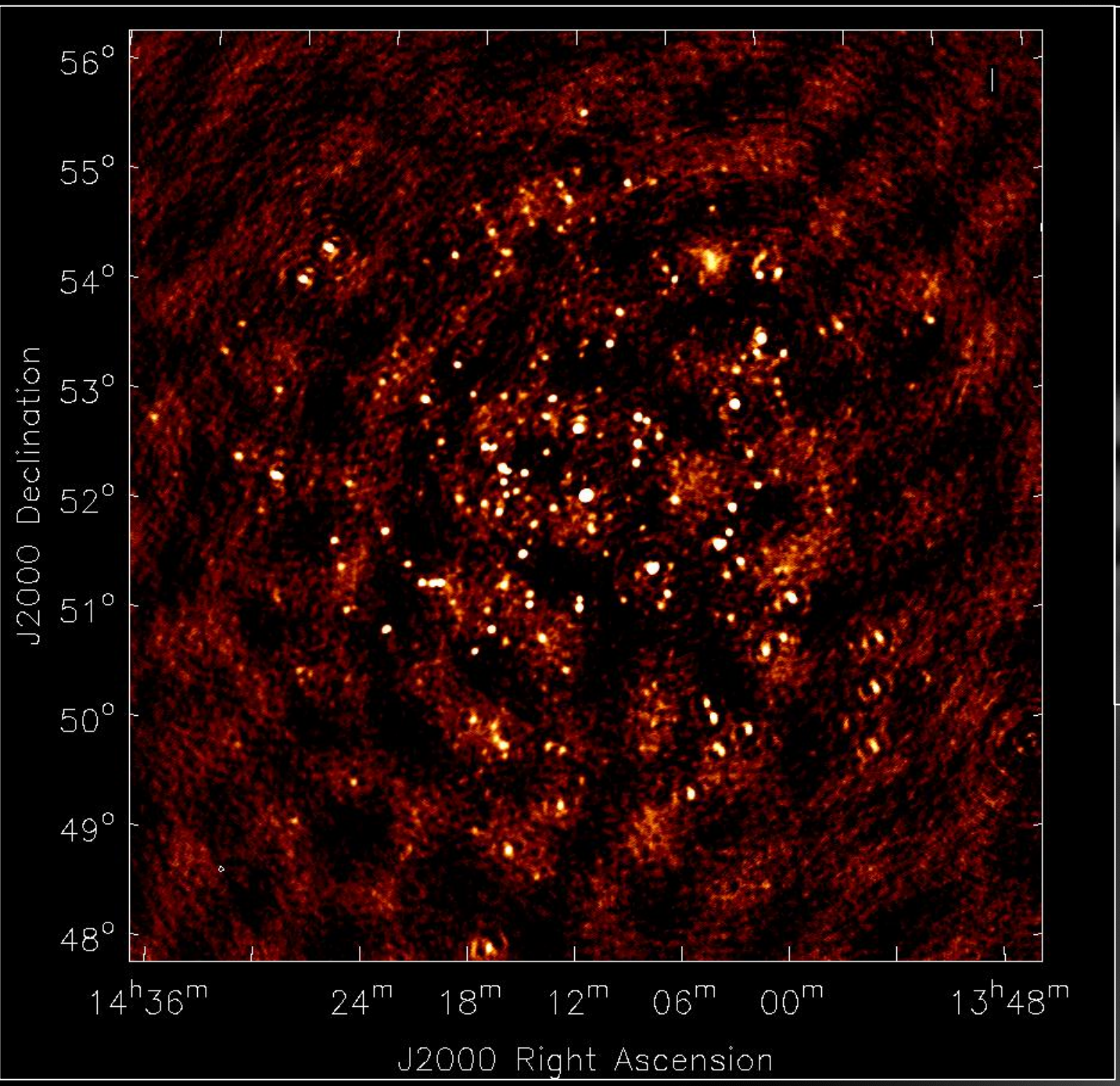


Preprocessing the Data

5ns offset in RSP boards is a very serious problem, stations need to be identified and flagged.



7 stations in total were found to suffer from this problem due to their low S/N and low gains compared to the median.



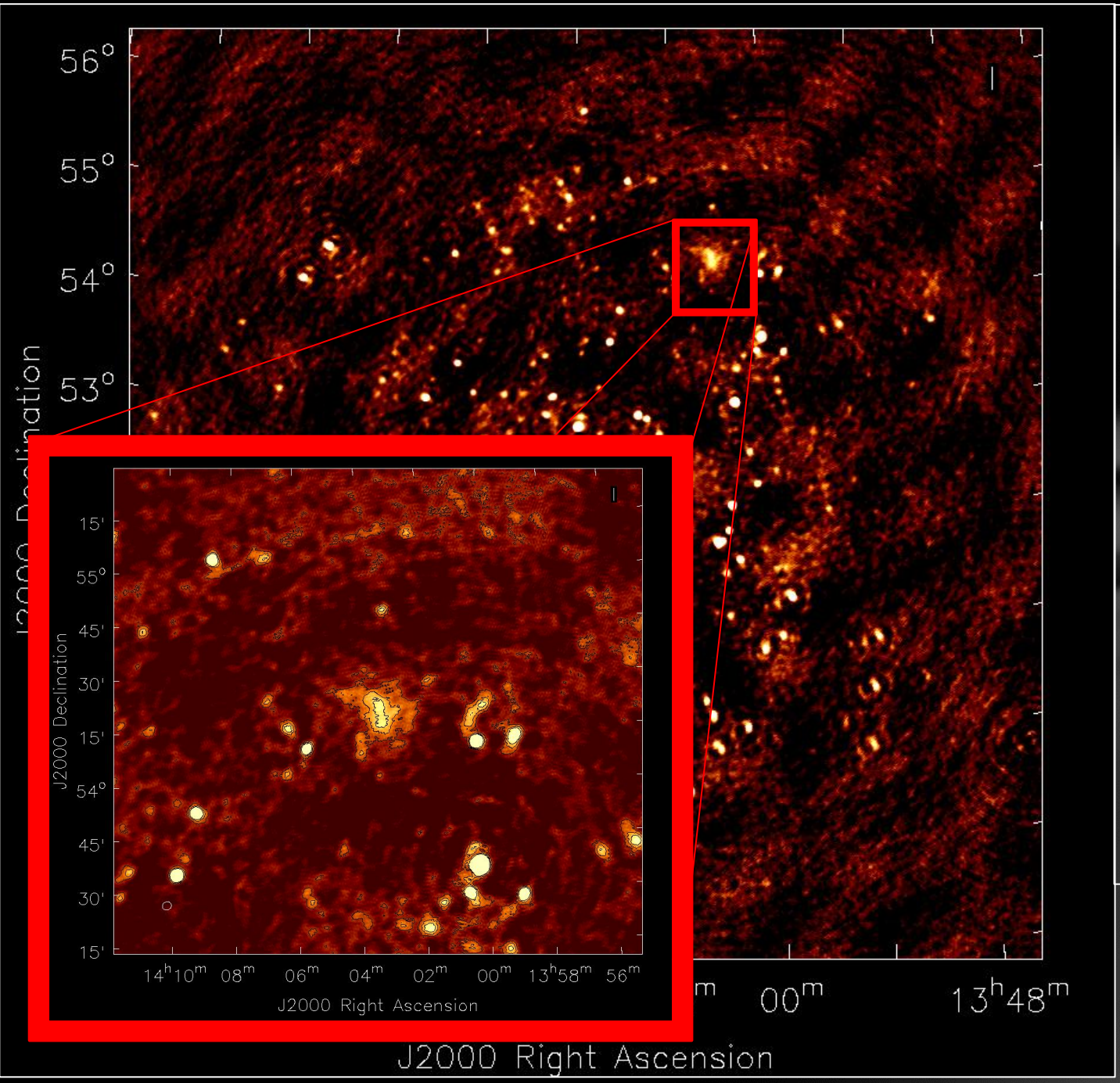
First Images

3C295 field

200kHz subband at 142MHz

Natural weighting

Many more point sources detected



First Images

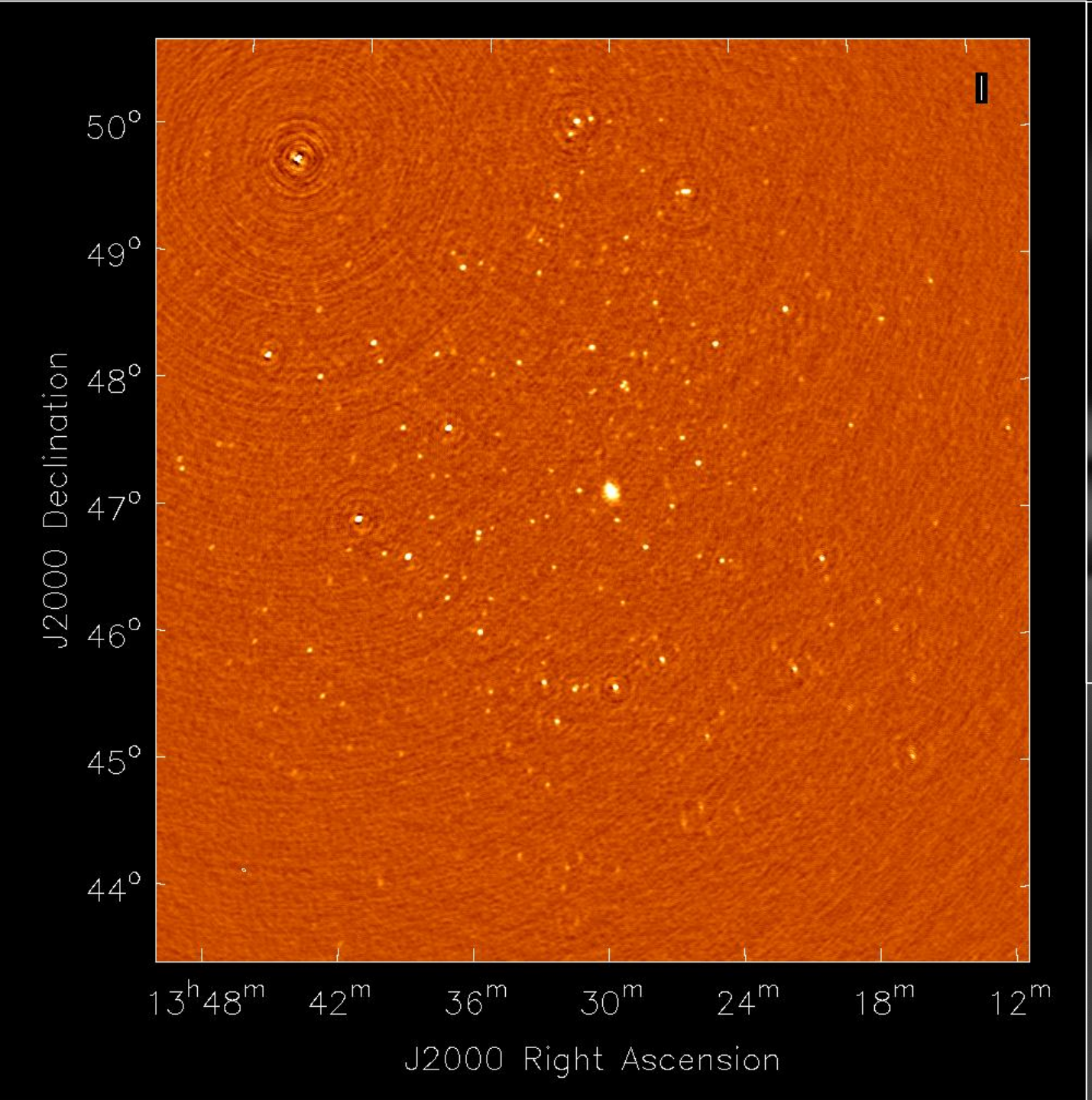
3C295 field

200 kHz subband at 142MHz

Natural weighting

Lot more point sources detected

M101 can be detected with only 1 subband.



First Images

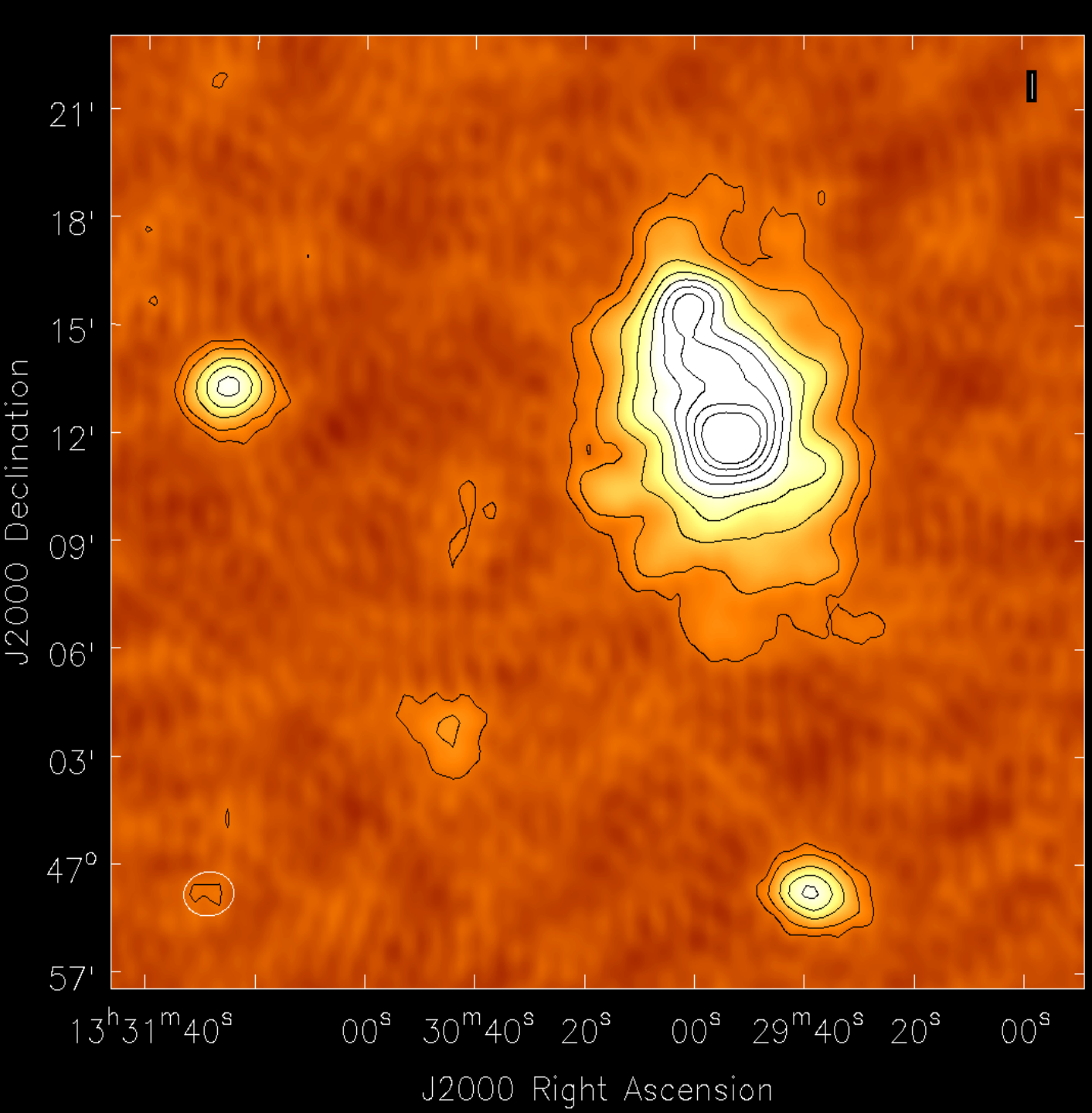
M51 field

1 subband of 200KHz at 142.7MHz

Robust weighting

UV taper of 6km used

3C295 is not a problem anymore



First Images

M51 field

1 subband of 200KHz at 142.7MHz

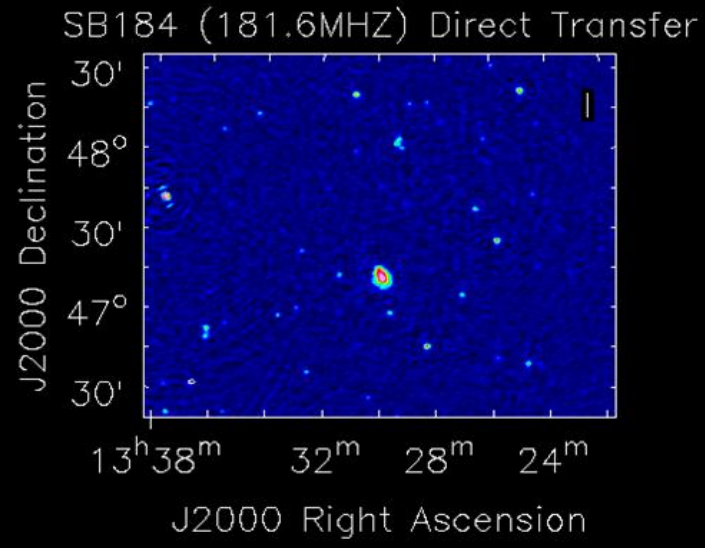
Robust weighting

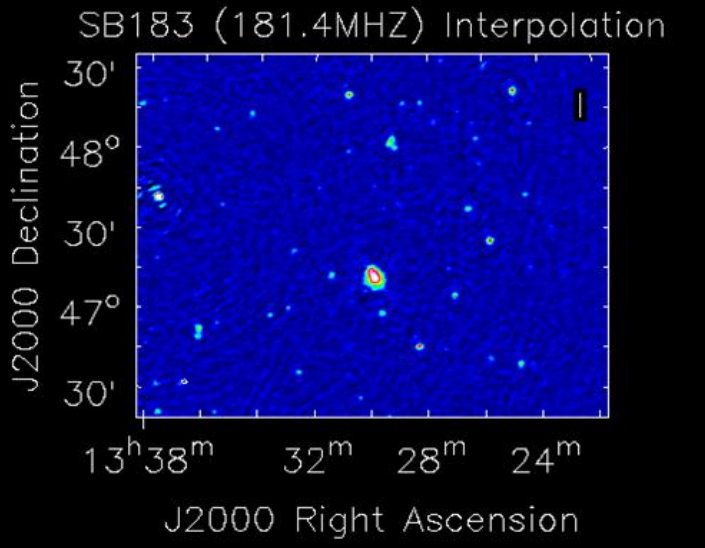
UV taper of 6km used

3C295 is not a problem anymore

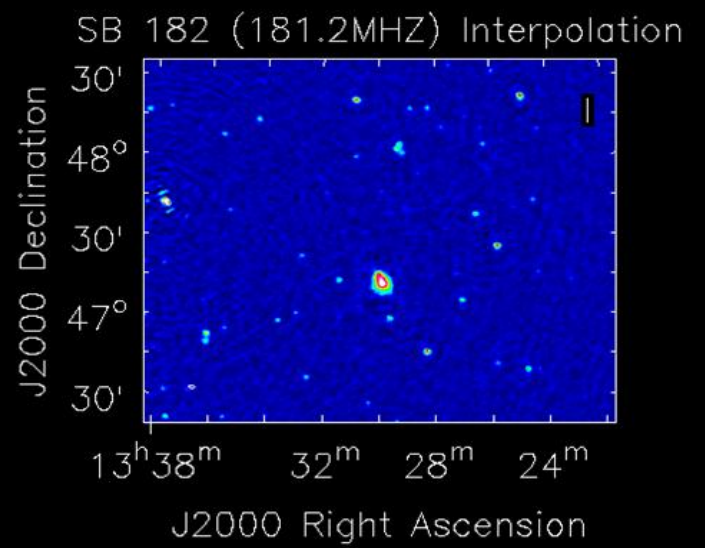
Preliminary work done on interpolation in new observation

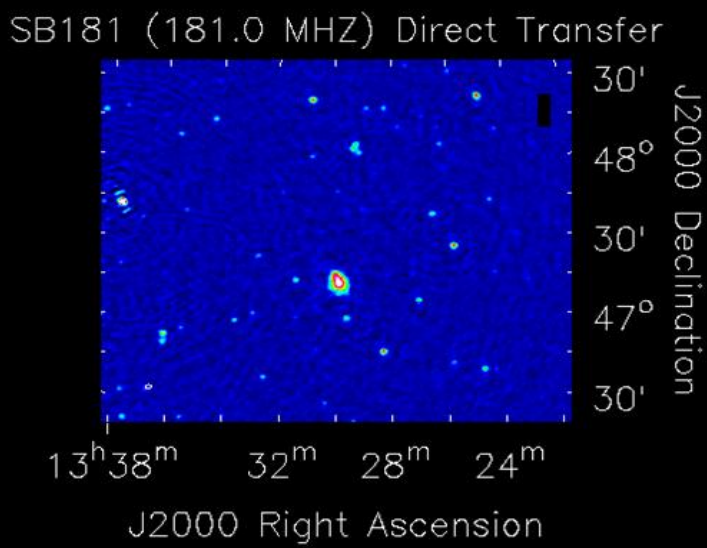
Stokes I images look good compared to direct transfer, noise is more or less the same





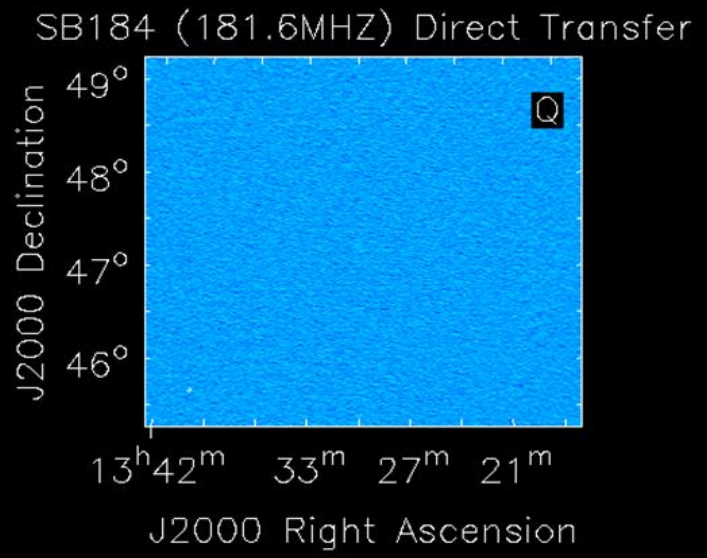
STOKES I

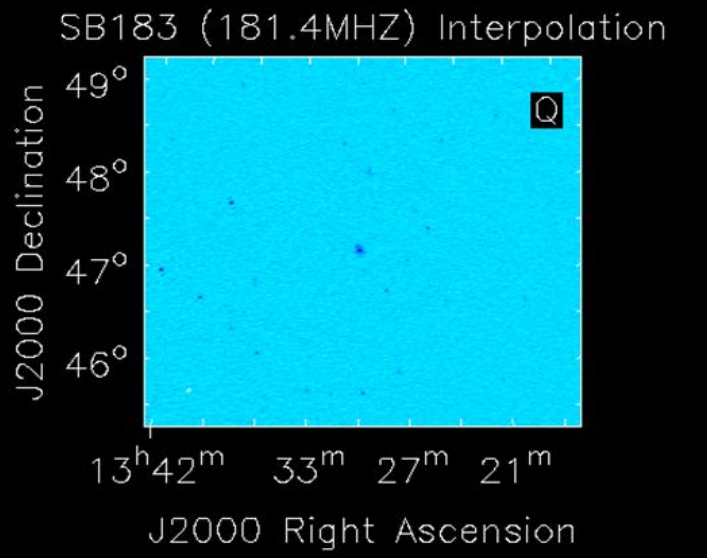




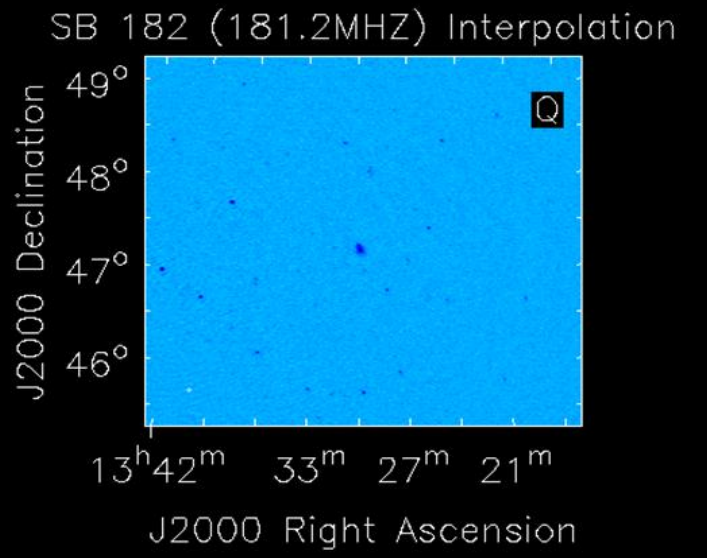
Preliminary work done on interpolation in new observation

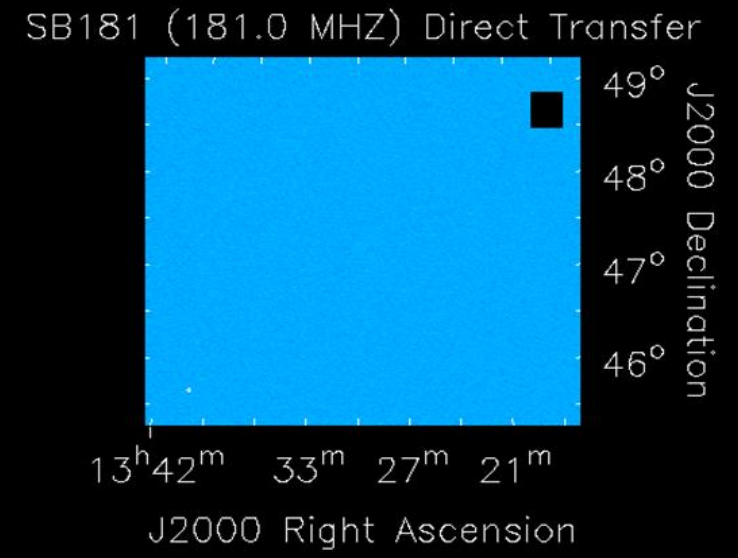
- However, high instrumental polarization is seen in Q and U!





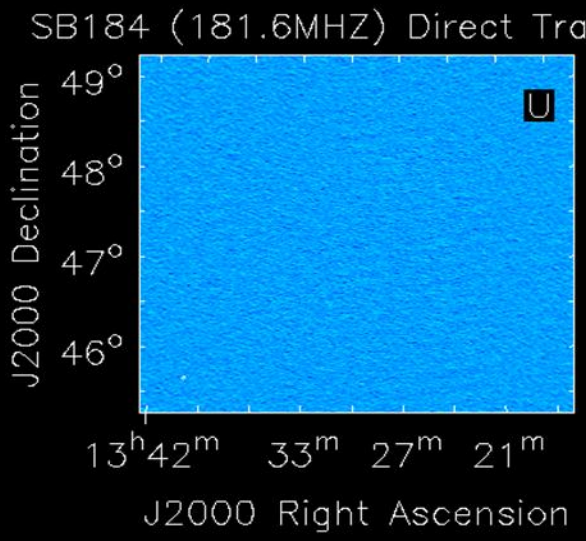
STOKES Q

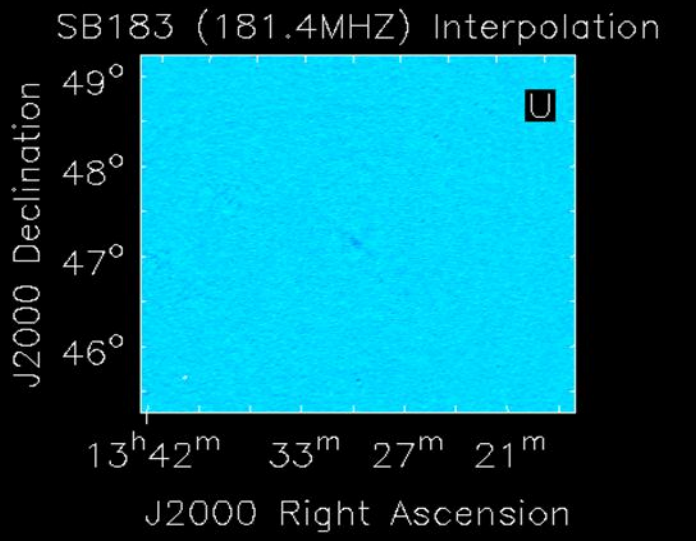




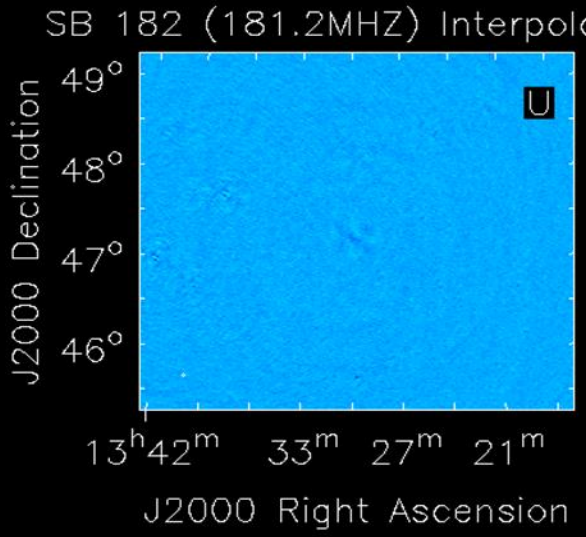
Preliminary work done on interpolation in new observation

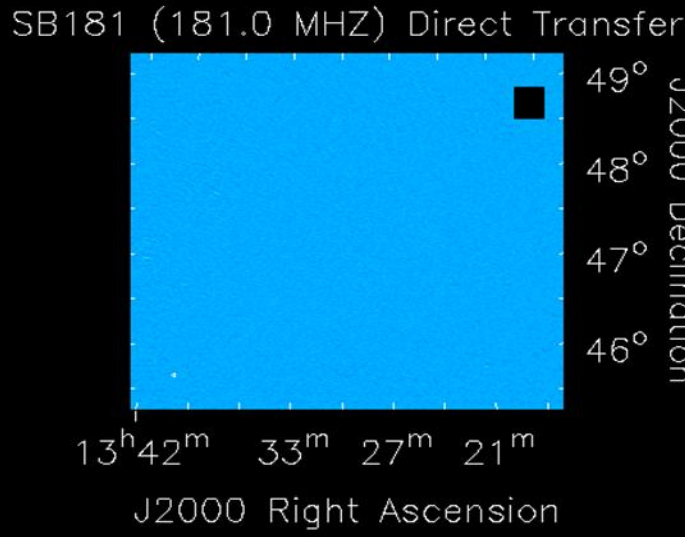
- However, high instrumental polarization is seen in Q and U!
- XY &YX gain interpolation fails

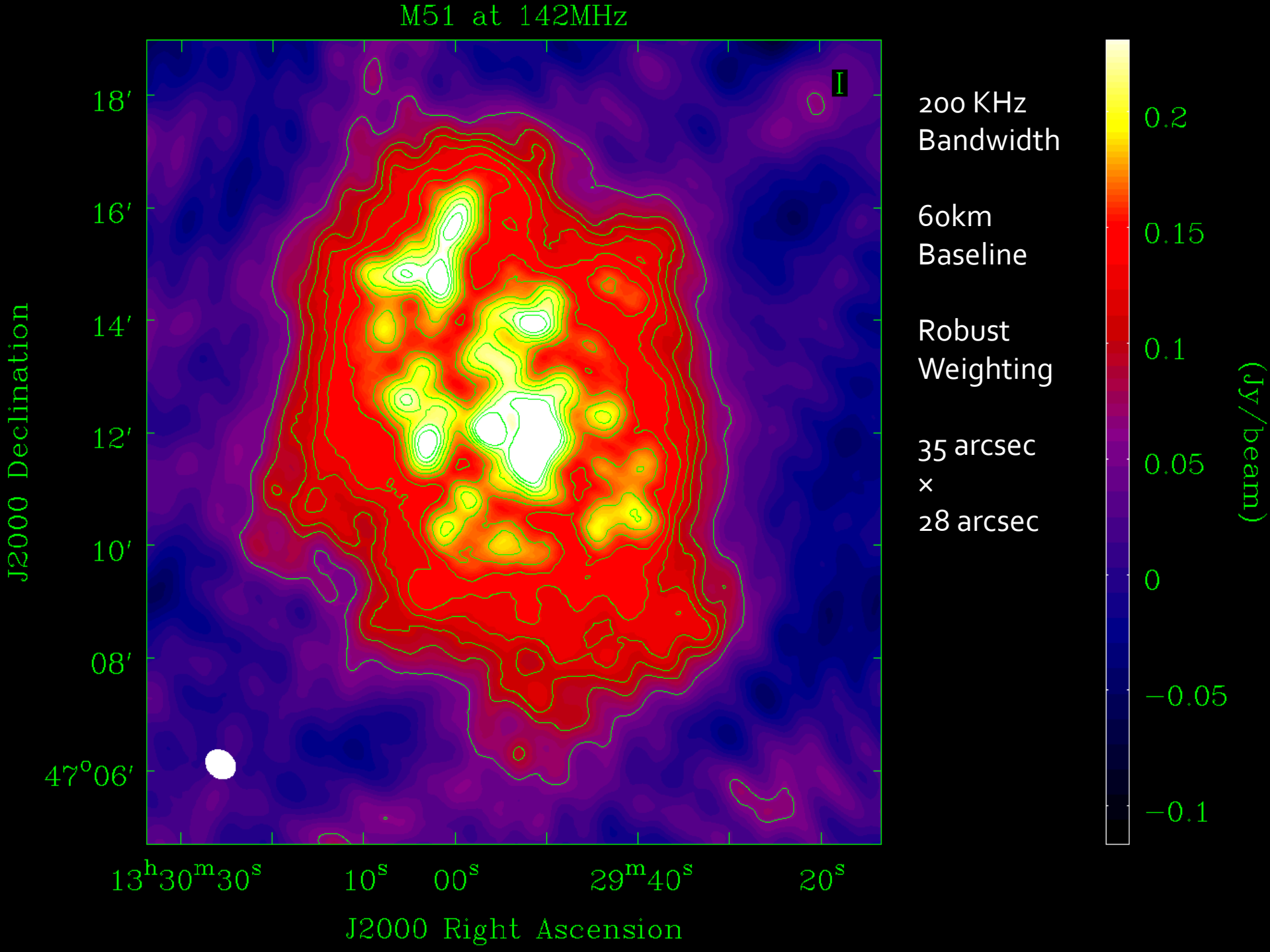




STOKES U






M51 at 142MHz
I
200 KHz
Bandwidth
60km
Baseline
Robust
Weighting
35 arcsec
×
28 arcsec
0.2
0.15
0.1
0.05
0
−0.05
−0.1
(Jy/beam)
18′
16′
14′
12′
10′
08′
47°06′
J2000 Declination
13h30m30s
10s
00s
29m40s
20s
J2000 Right Ascension

Present Issues with observing galaxies with LOFAR

- 5 ns delay in RSP boards, reducing number of useable stations
- Need for better calibration tables for Remote Stations
- Badly need new remote stations being constructed to achieve 10-15 arcsec resolution needed for studying nearby galaxies in detail and especially in polarization in order to avoid beam depolarization
- Removing sources on BBS can be very time consuming…
- Detecting Polarization is challenging and much more commissioning is needed

1. Polarized calibrators are needed
2. Beams are too large
3. Correction of Ionosphere

Next Steps for the LOFAR M51

- Getting a correctly calibrated Stokes I image is first priority to extract science.
- Spectral Index variations are hoped to be seen as well as the extended disk.
- Apply RM Synthesis and try to detect polarization in the extended disk and halo
- After long delays, data is now finally processed (flagged, bad stations removed, demixed, compressed and calibrator subbands calibrated).

Conclusions

- Transfer of Gains Solutions from calibrator to target source can be interpolated in frequency to give well calibrated results in HBA data.

- More tests being done on this especially with regards to flux scale critical for studies on spectral Index.

- The M51 disk is seen to extend further out than other low frequency observations for only one 200KHz subband. (There are 180 subbands)

Improvements are being made!

For updates, please check LOFAR Wiki!