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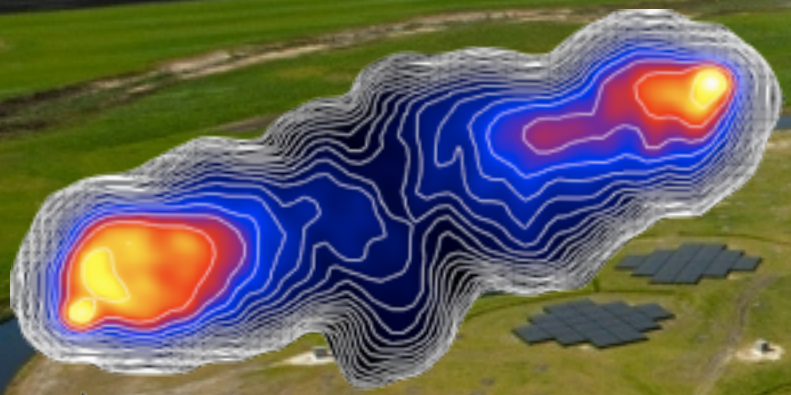
Netherlands Institute for Radio Astronomy

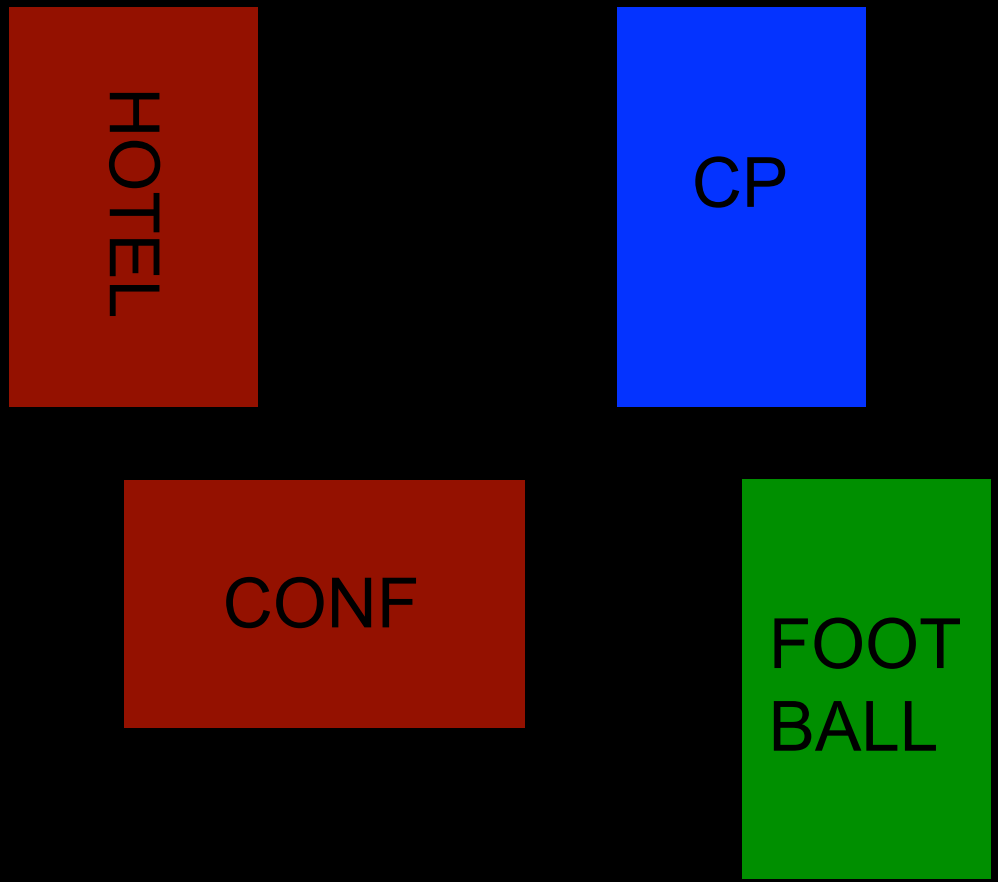


Multi-frequency imaging of Cygnus A with LOFAR

John McKean (ASTRON)
and all the imaging busy week team!

Football

- Football this early-evening 18:00 to 19:00.
- 9 players have signed up.



Overview

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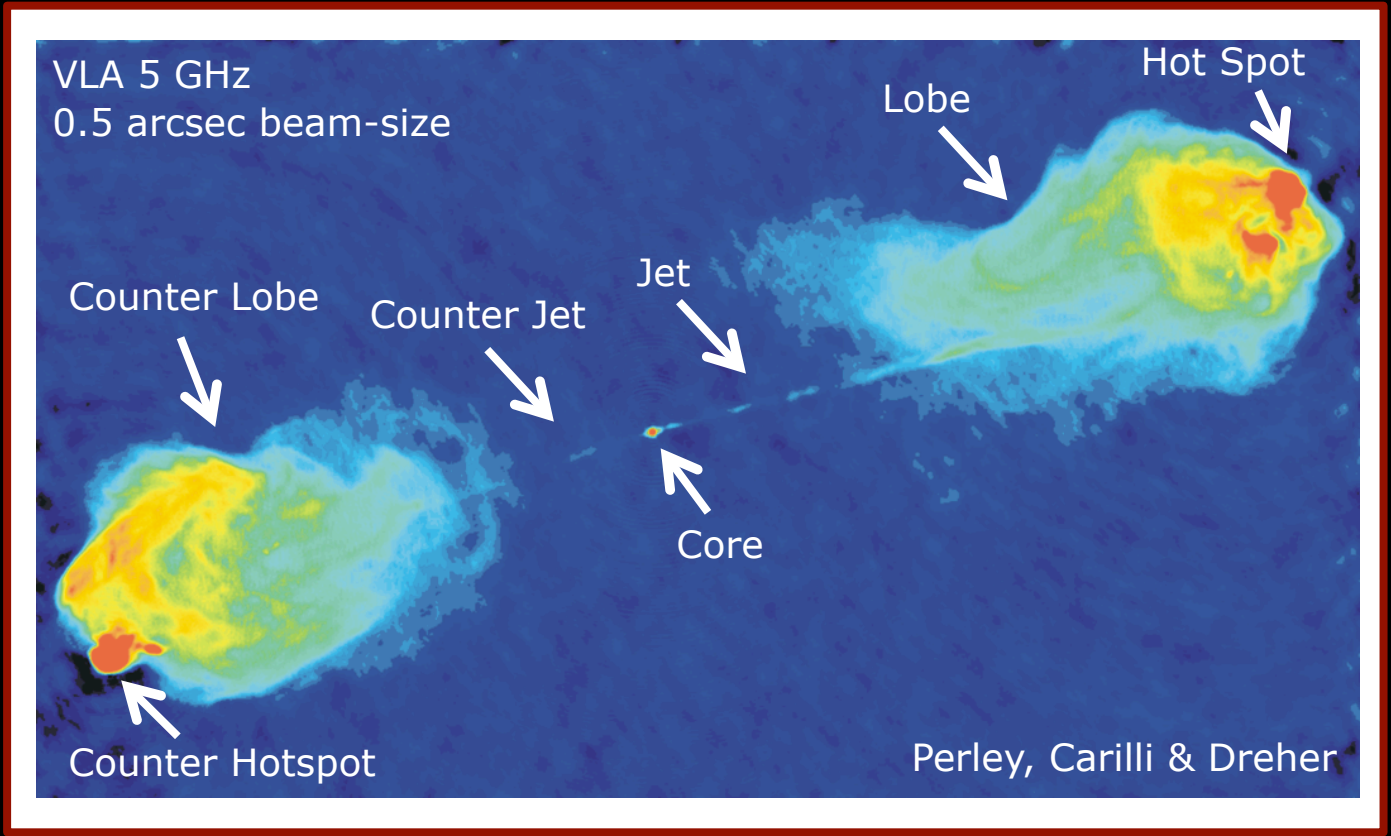
- Cygnus A: Commissioning and early science target
- LOFAR Imaging from ~30 to 240 MHz
- Low frequency spectral index maps
- From commissioning to science
- Summary

Cygnus A (3C 405)

- An FR-II classical double.
- z = 0.0561 (1 kpc / arcsec).
- 120 kpc in size.
- Falling into the Cygnus cluster?

- Strong core, jet, hot spot and lobe emission at cm-wavelengths
- Bright enough to test jet models for radio sources (~10^2 to 10^4 Jy).



Previous low-frequency imaging

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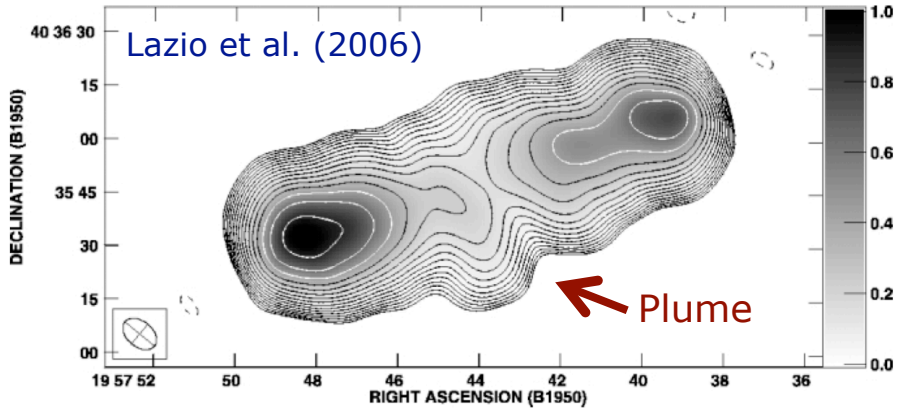
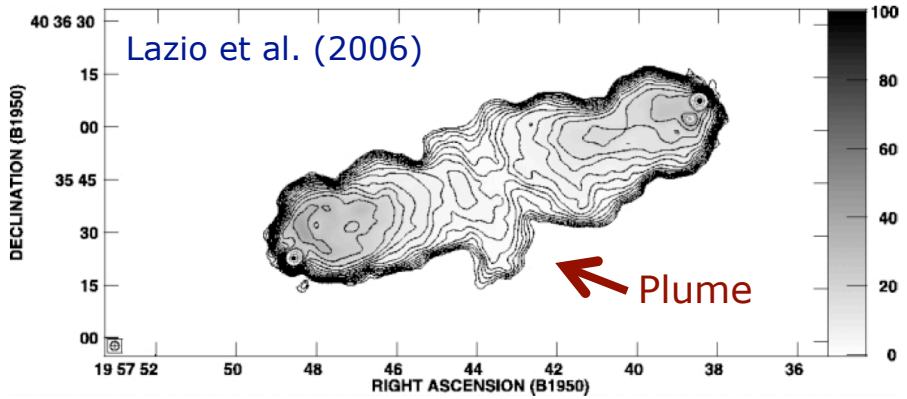
- Imaging at 74 MHz and 330 MHz with the VLA+ Pie Town (C), at 151 MHz with MERLIN.
- Low frequency plume emission.
- 151 MHz to 22 GHz data used to determine spectra age,

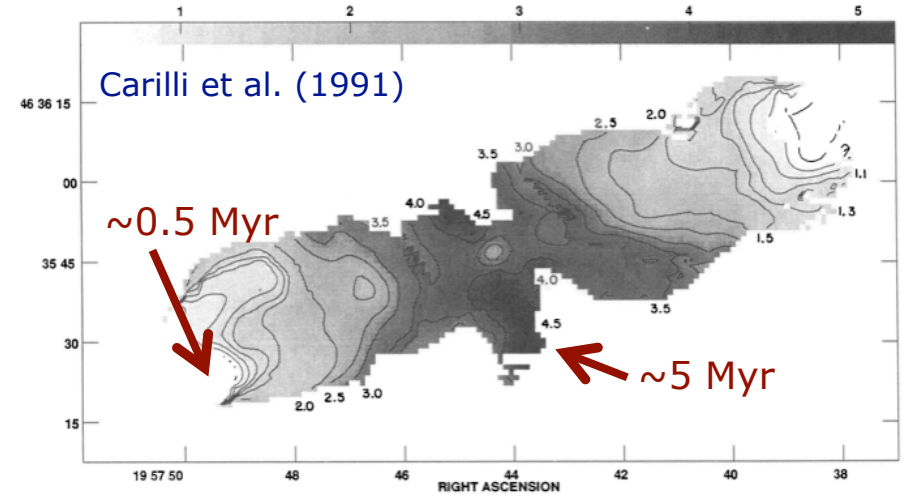
$$t_s = 1610\, B^{-3/2}\, \nu_B^{-1/2}\ \mathrm{Myr}$$

- Spectral aging analysis (Carilli et al. 1991) consistent with jet-model of Blandford & Rees (1974):

Particle acceleration at the hotspots with outflow into the lobes, energy loss due to synchrotron radiation.







Commissioning target

- Cygnus A has been observed during commissioning:

i) Brightest radio galaxy in the LOFAR sky.

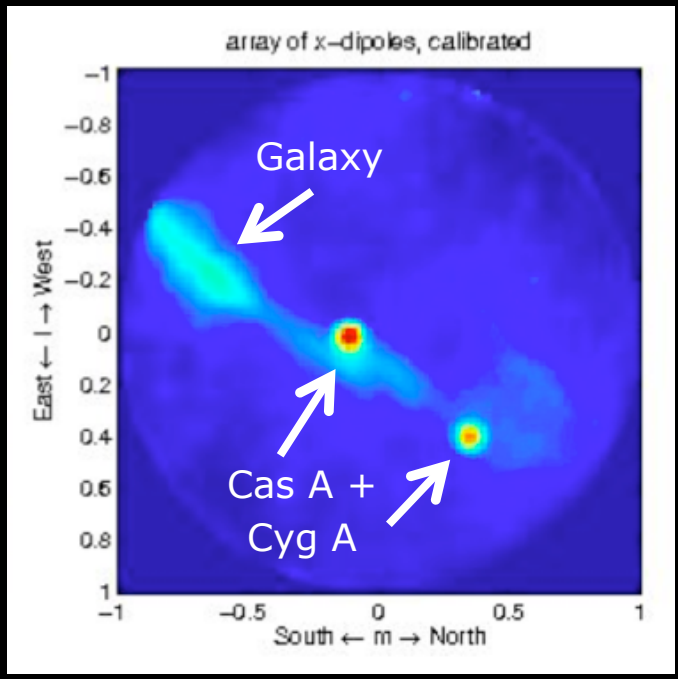
ii) no need for beam models.

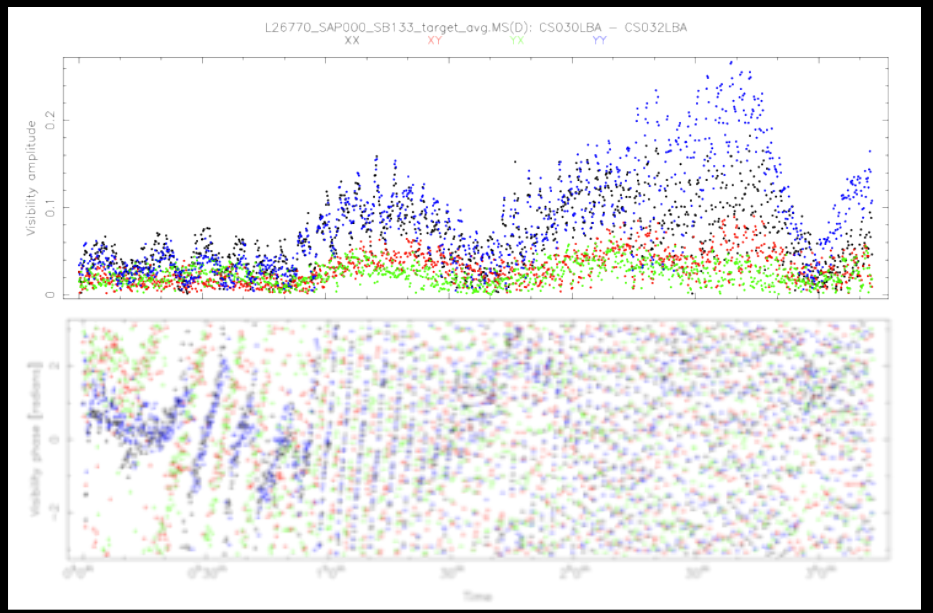
iii) emission on several angular scales.

iv) Good source model needed for the de-mixing.

v) Opportunity to carry out first science.

- Unlike 3C196, pulsars, the source model is quite complicated (emission on several angular scales.)





Observations & Data analysis

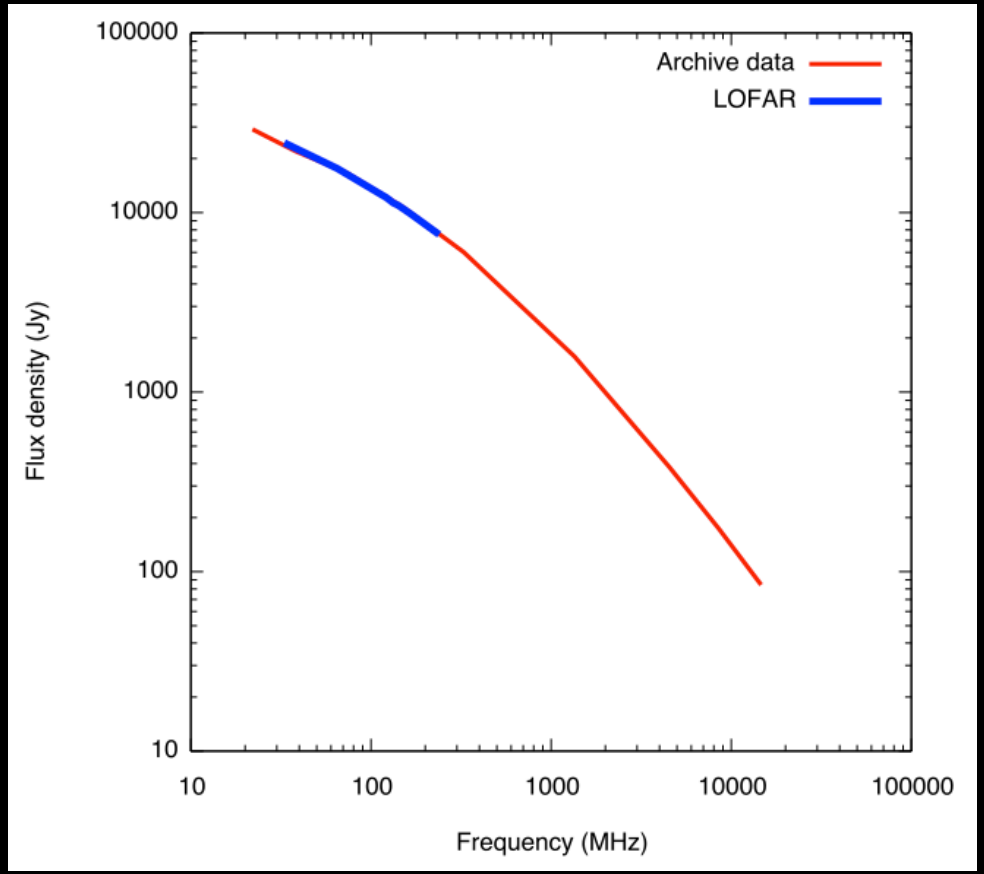
- Three datasets:

i) 30-78 MHz (5 x 1.5 h snapshots).

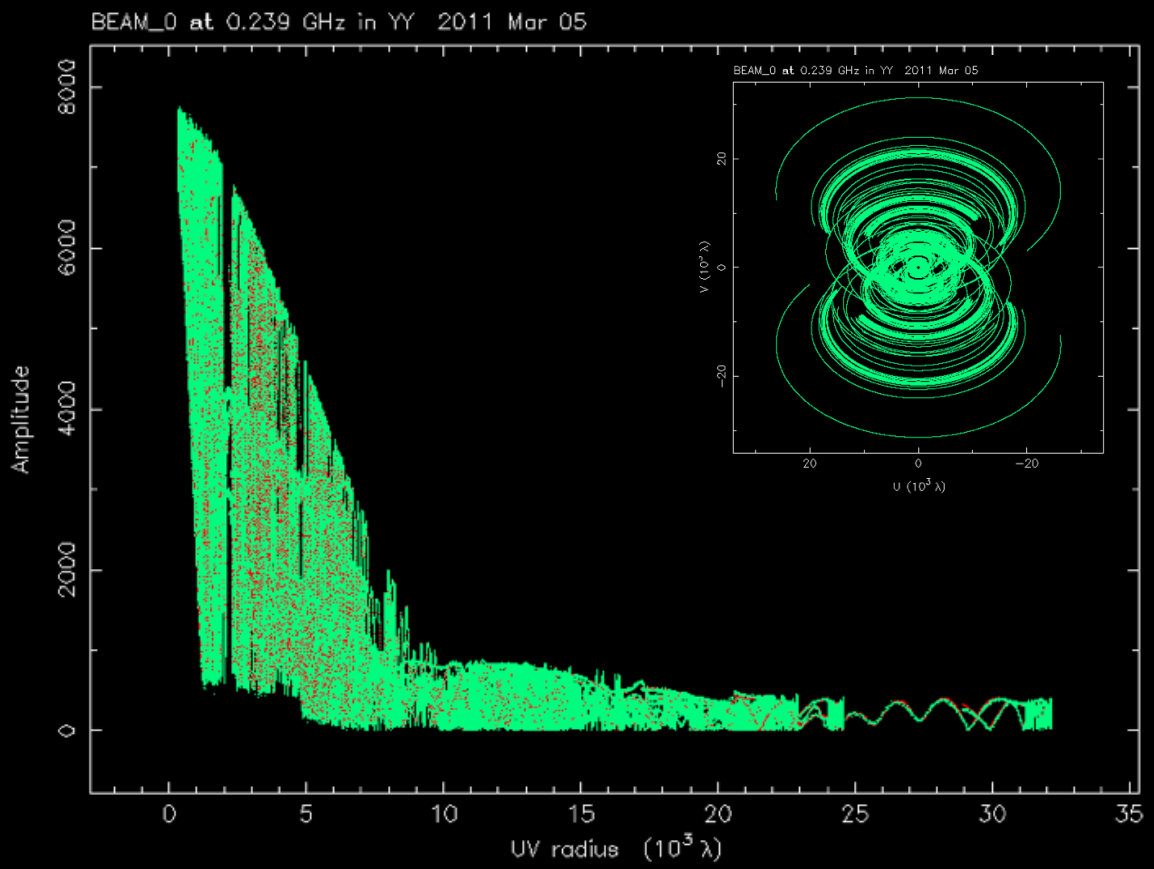
ii) 115-175 MHz (11 h long-track).

iii) 240 MHz (15 h long-track).

- Standard NDPPP+BBS run for initial calibration, using image at higher frequency.
- DDE's calculated for 30-78 MHz data.
- Flux-scale set by bootstrapping previous interferometric and single dish data.
- Imaging and self-calibration carried out with DIFMAP, using uniform weighting.
- Gaussian *uv*-taper to match the resolutions of different datasets for spectral index maps.

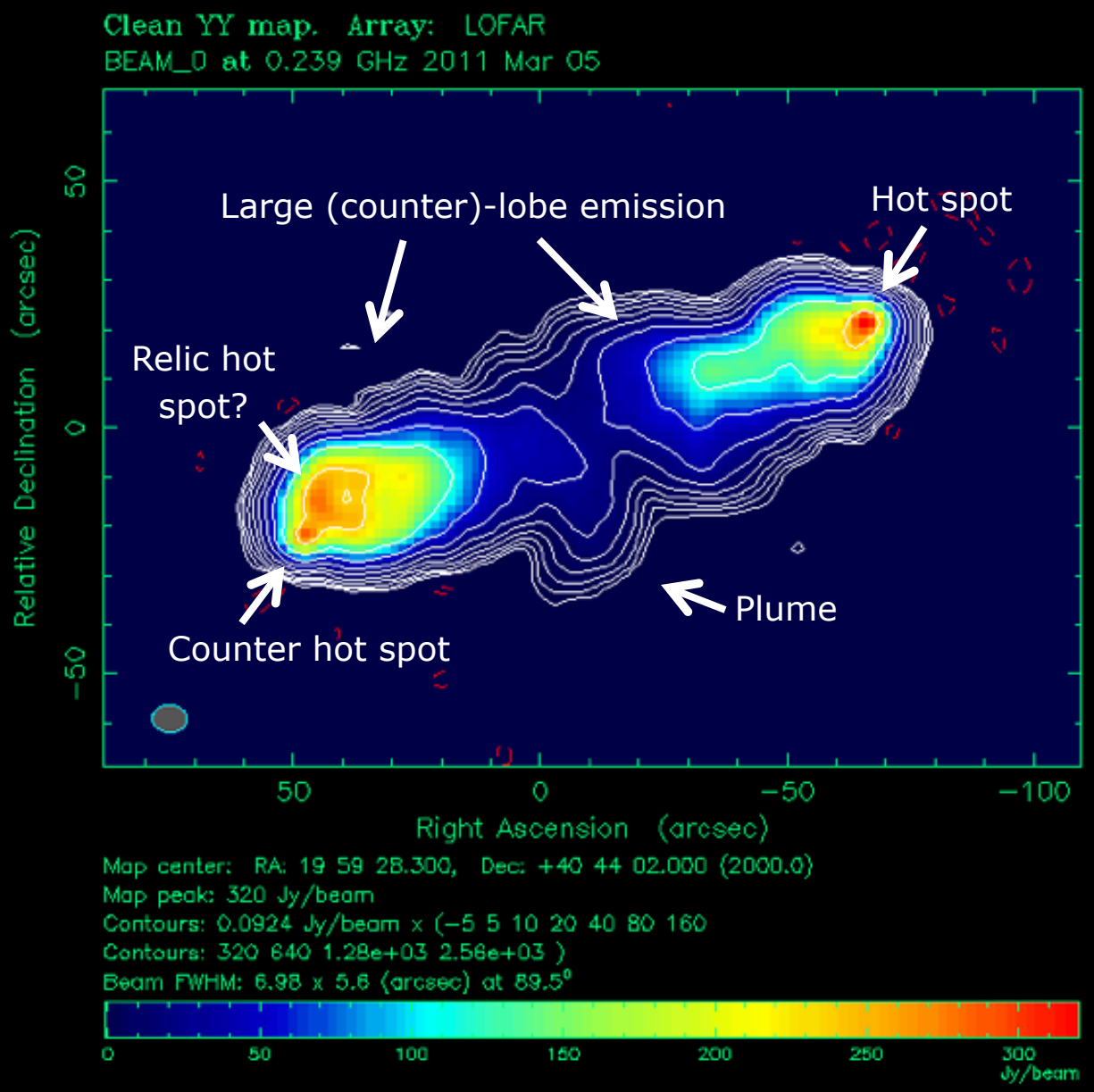


HBA imaging at 239 MHz

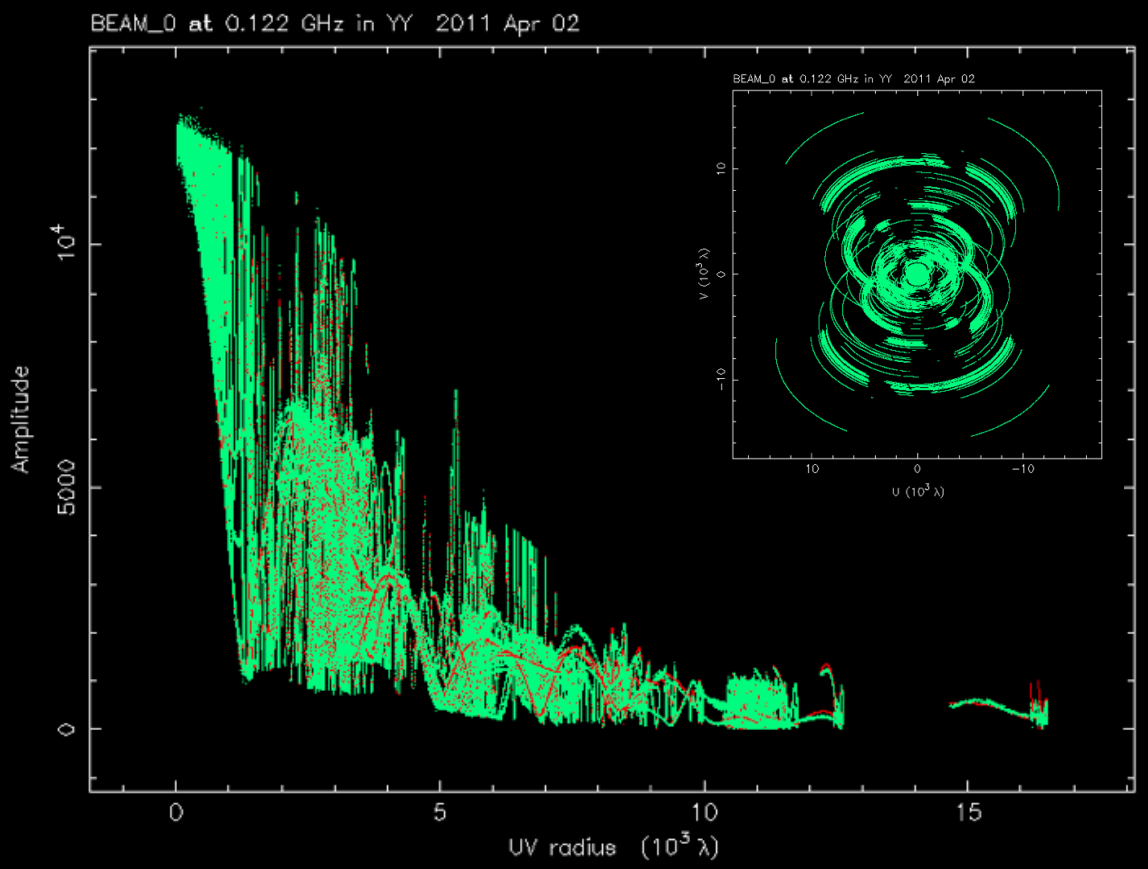


- 15 h observation.
- 19 core stations (2 failed) and 7 remote stations (RS106, RS205, RS208, RS306, RS307, RS406, RS503)
- Baselines from 0.3--30 km.
- UV coverage good in the centre (single sub-band).
- RS baseline data difficult to calibrate.
- Final calibrated data look good.

HBA imaging at 239 MHz

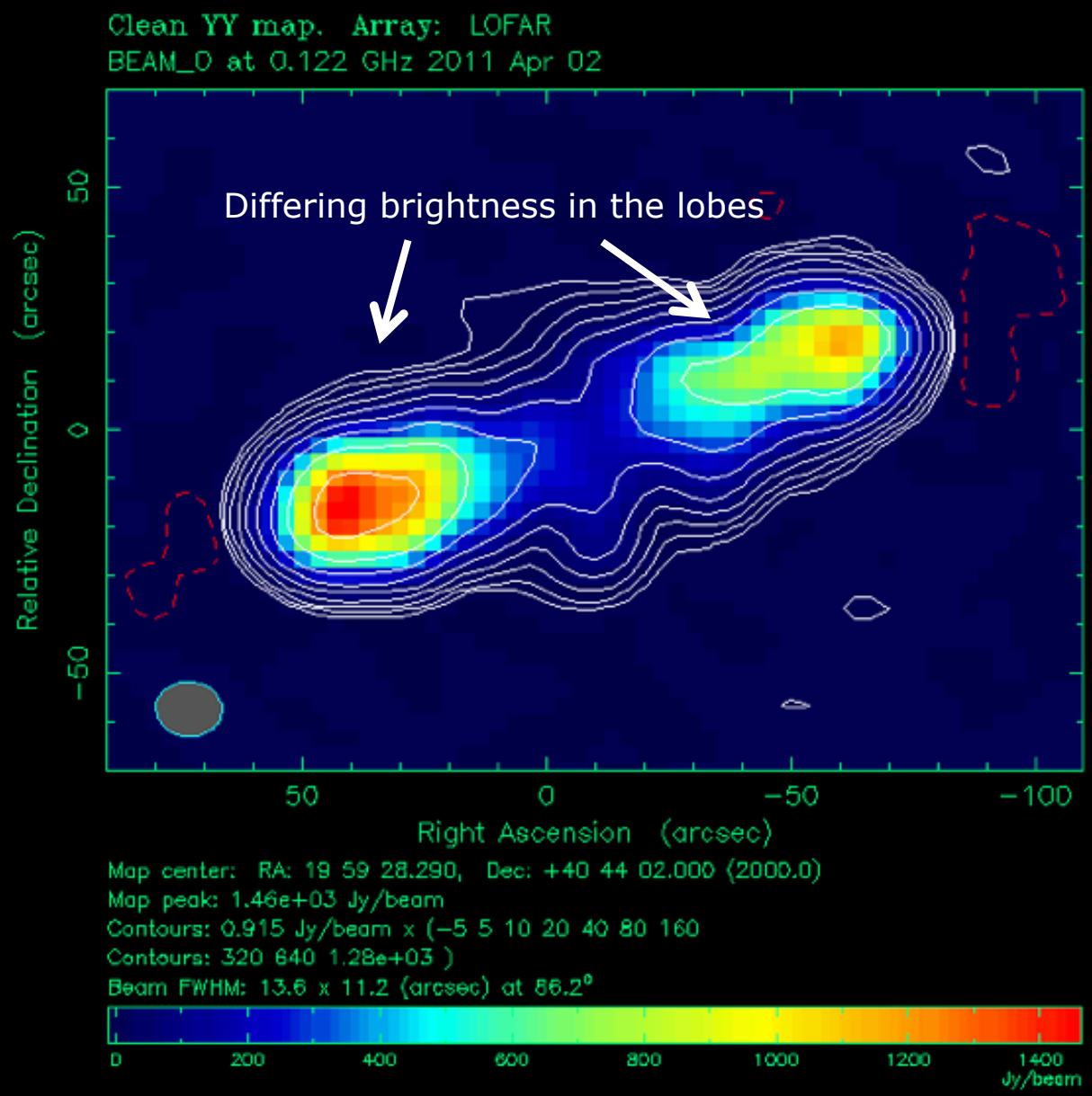


HBA imaging at 115MHz to 175 MHz

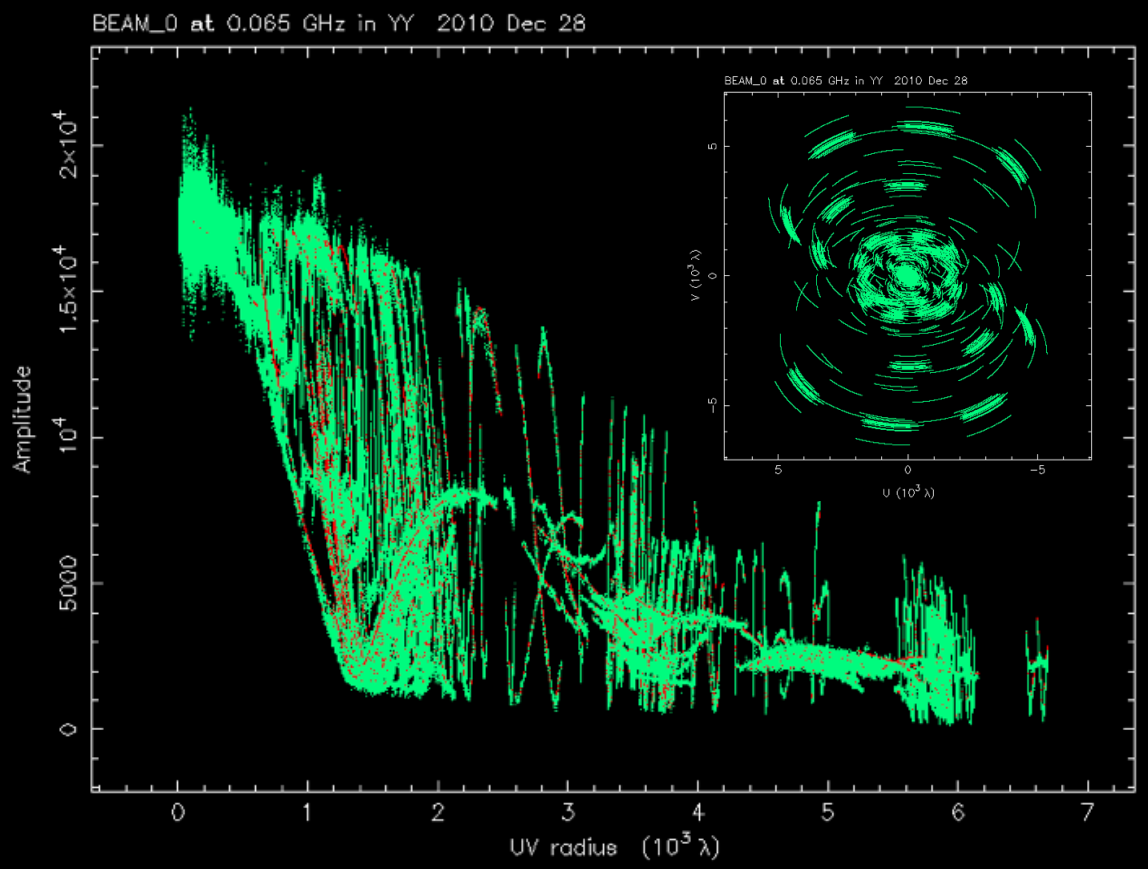


- 11 h observation.
- 20 core stations and 7 remote stations (RS106, RS205, RS208, RS306, RS307, RS406, RS503)
- Baselines from 0.3--30 km.
- UV coverage good, but with large gaps - flagging by the correlator?
- RS baseline data difficult to calibrate.
- Final calibrated data look good.

HBA imaging at 115MHz to 175 MHz

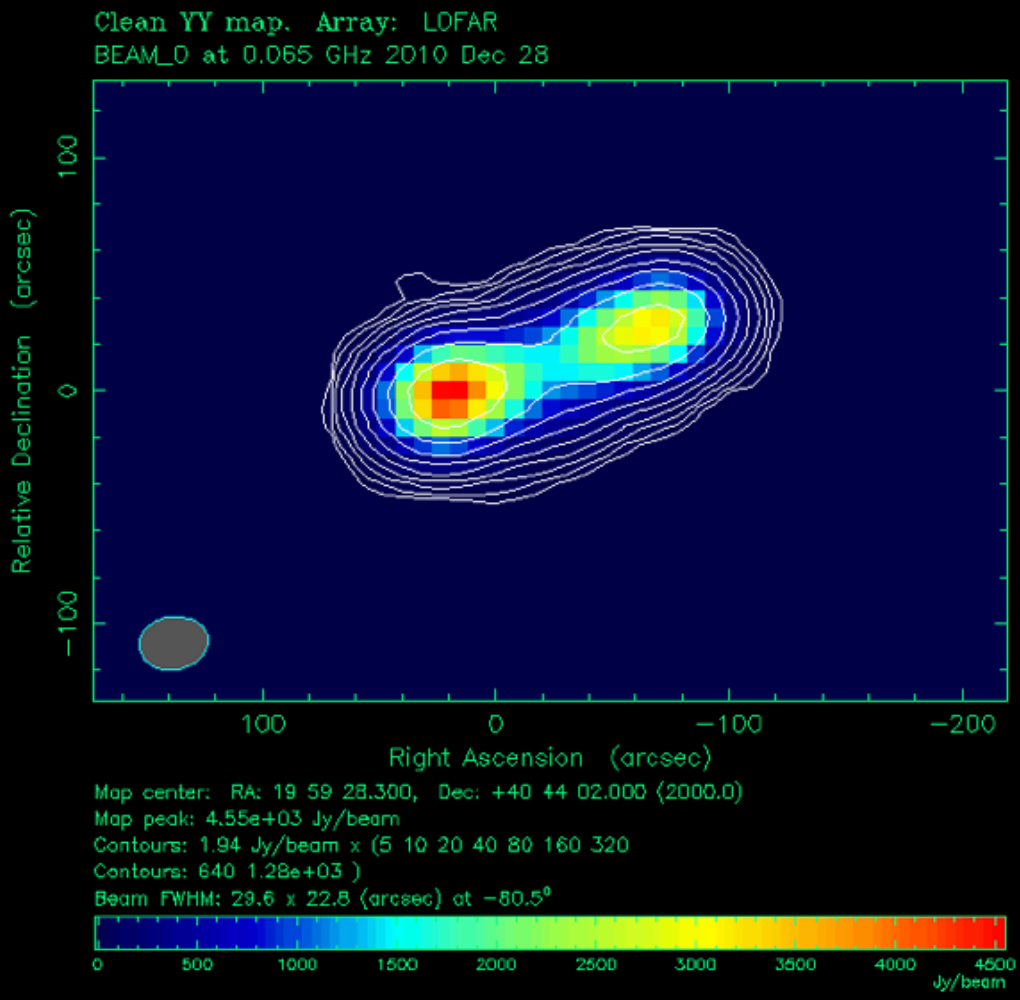


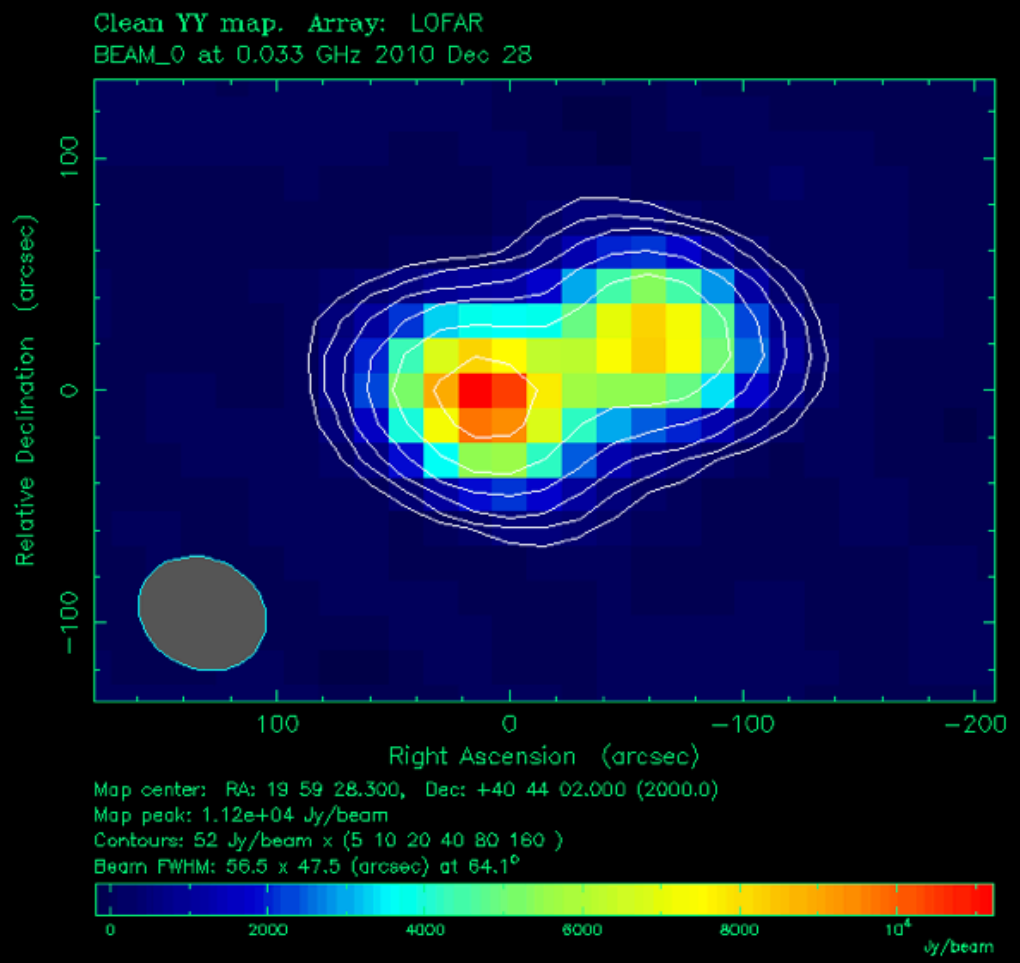
LBA imaging at 33 MHz and 65 MHz



- 5 x 1.5 h observation.
- 19 core stations and 6 remote stations (RS106, RS205, RS208, RS306, RS307, RS503)
- Baselines from 0.3--30 km.
- UV coverage patchy due to snapshot mode, not good for mapping extended emission.
- Cas A removed using direction dependent solutions in BBS - need a better model?

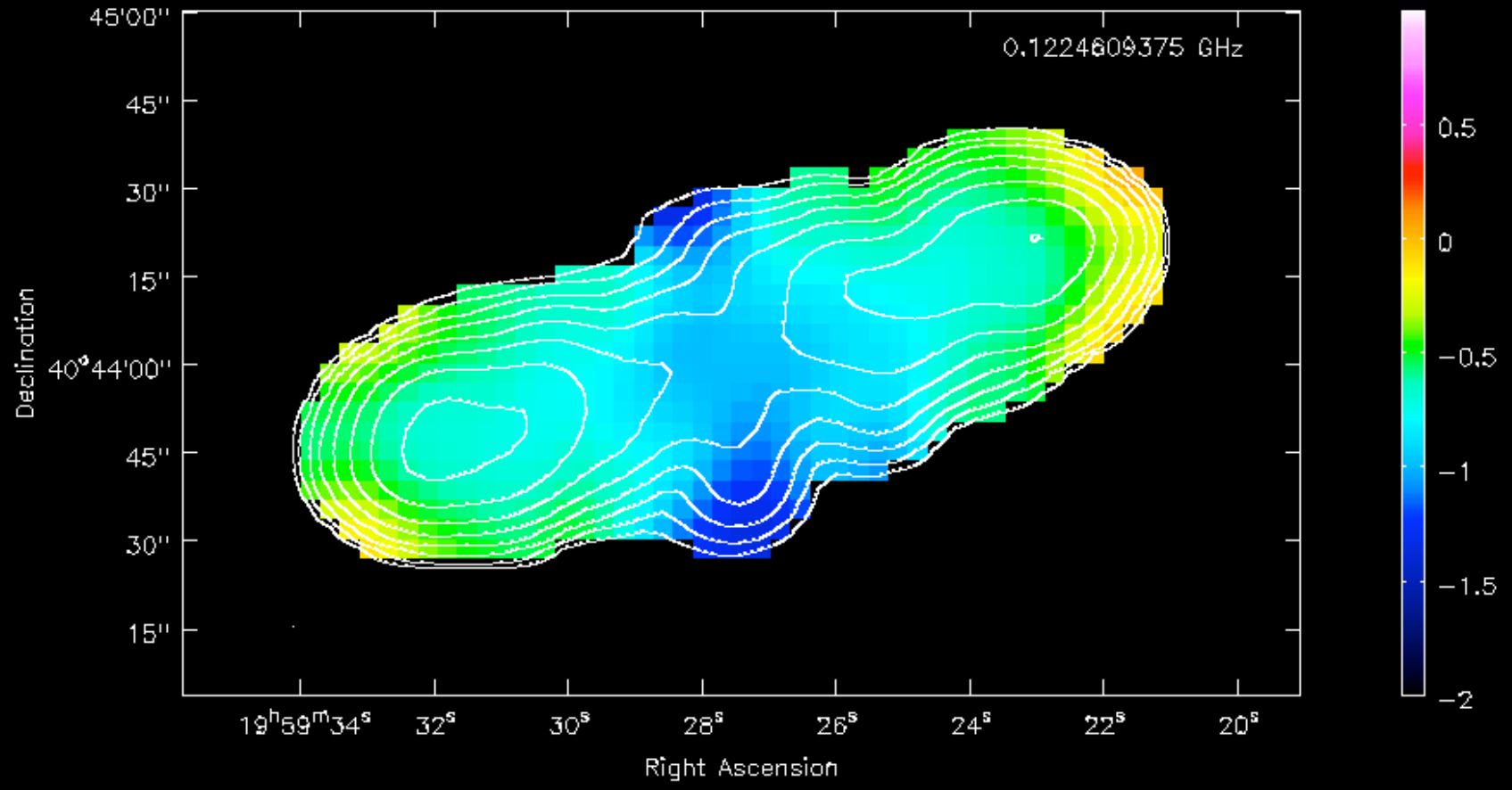
LBA imaging at 33 MHz and 65 MHz





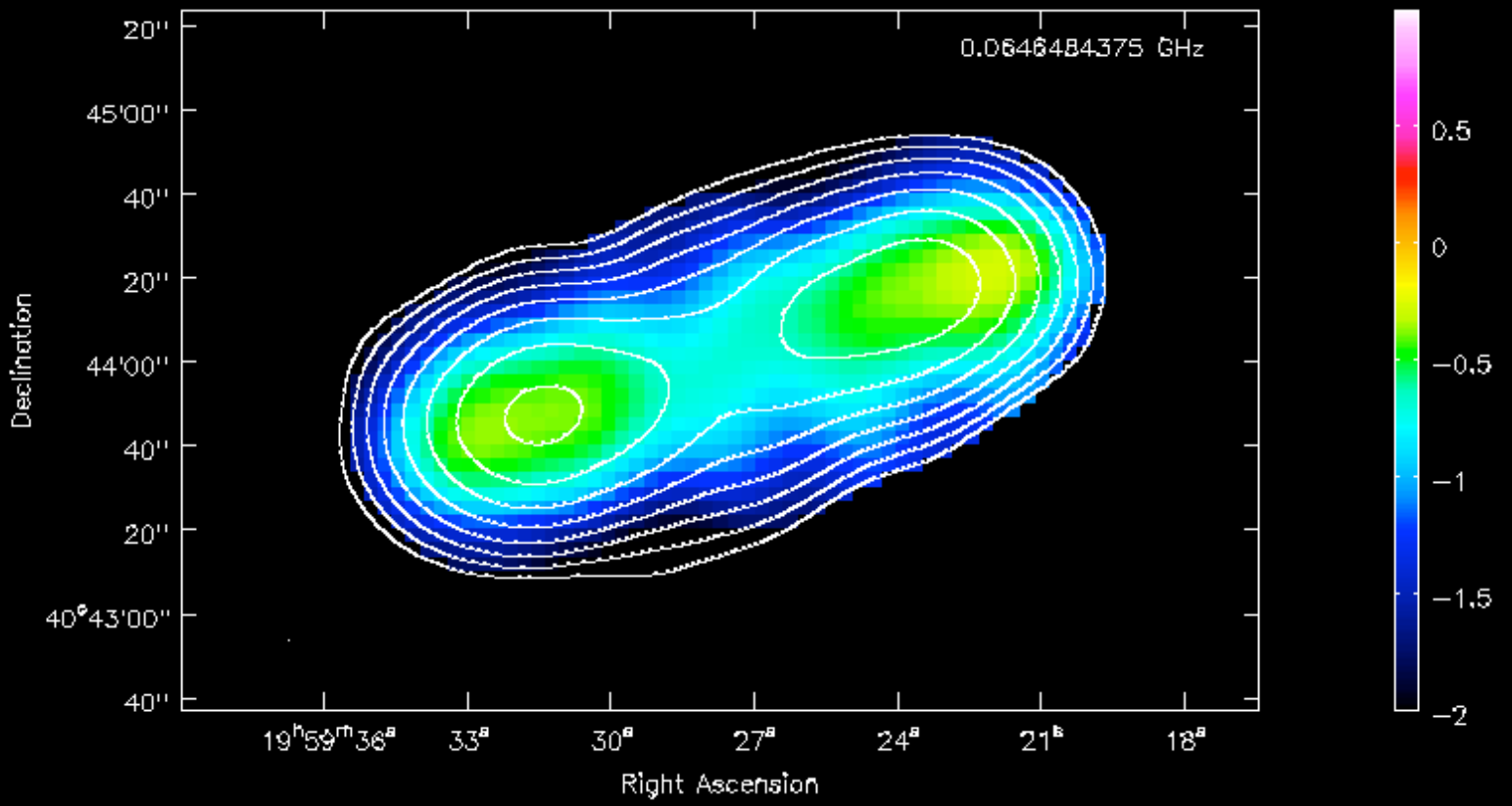
Differing brightness in the lobes down to 33 MHz

Preliminary spectral index maps



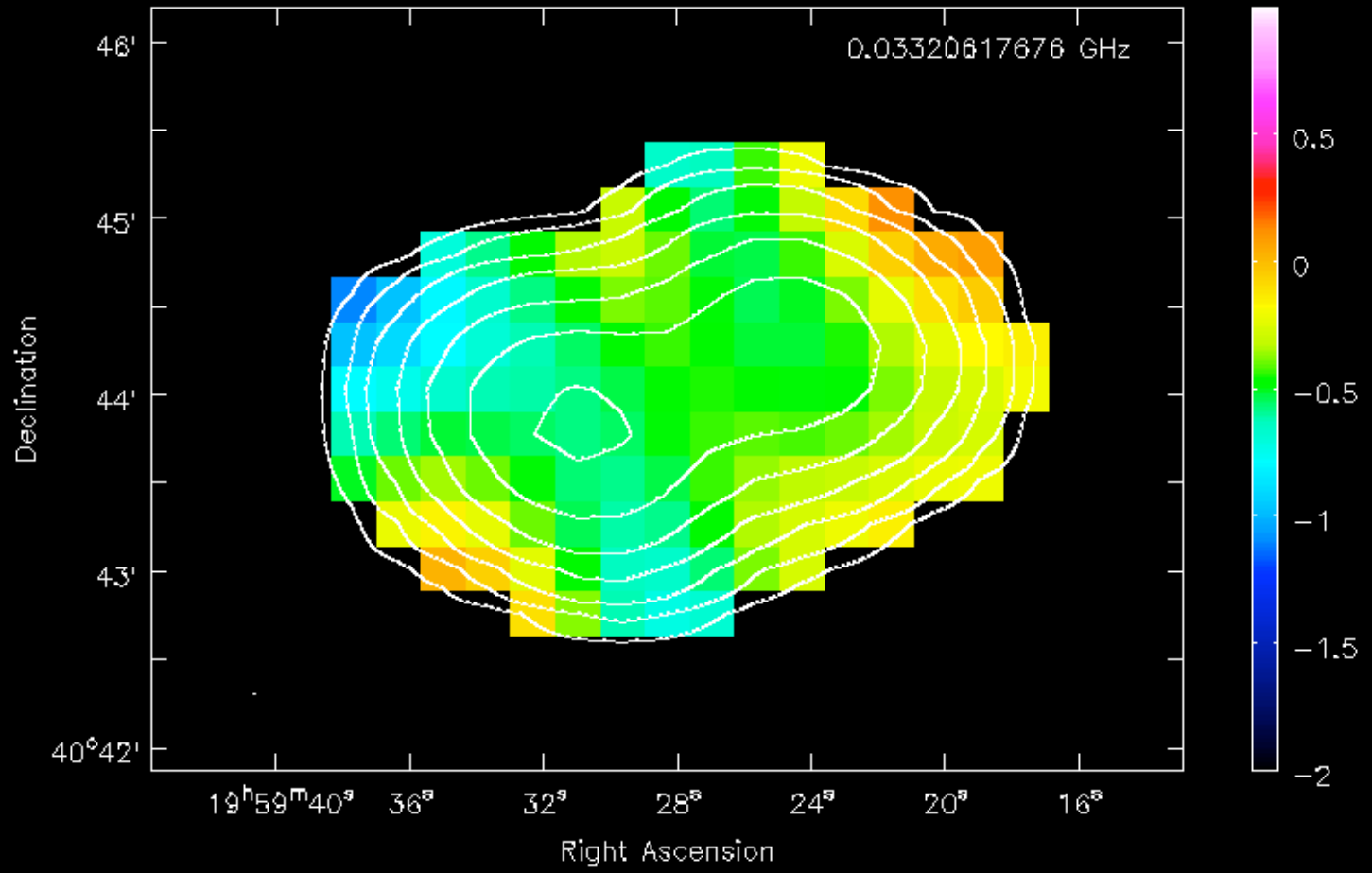
- LOFAR spectral index map between 122 and 239 MHz (Gaussian smoothed).
- Edge effects due to beam mis-matches (to be fixed).
- Spectral index of the lobe and counter-lobe are similar.
- Spectral index becomes steeper further away from the hot spots, as expected.

Preliminary spectral index maps



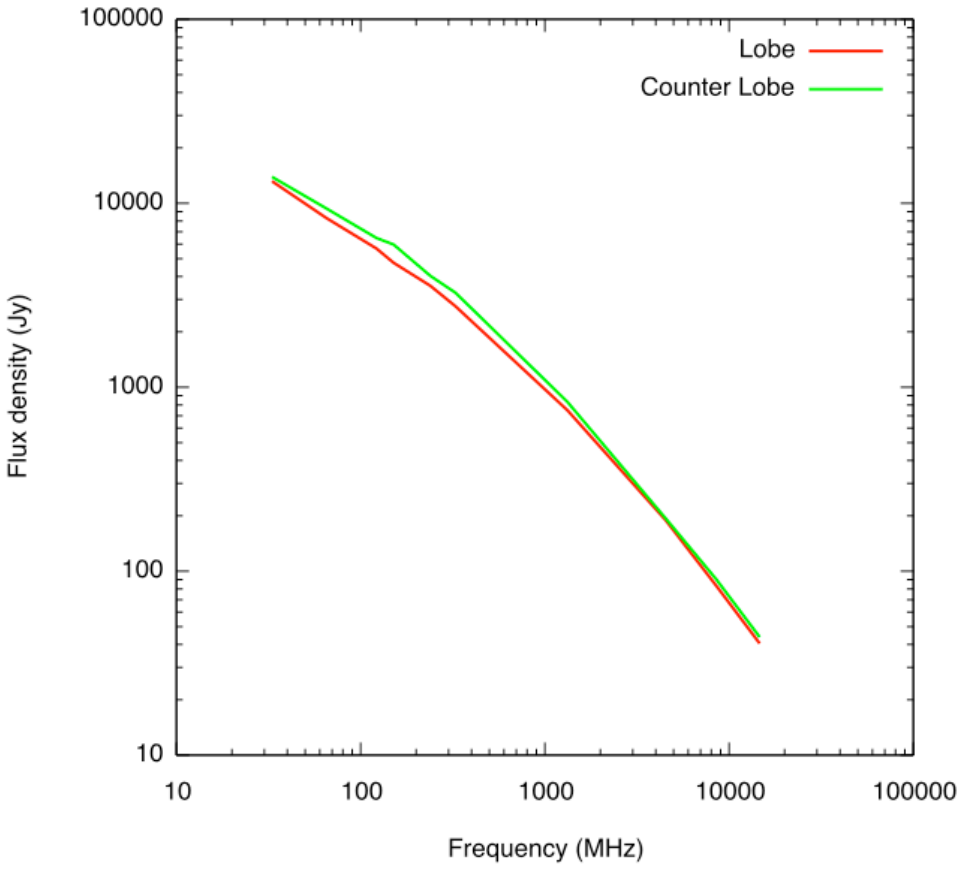
- LOFAR spectral index map between 65 and 122 MHz (Gaussian smoothed).
- Possible steep spectrum outer region (edge/beam effects?).
- There is a flattening of the lobe/counter-lobe spectral index, again similar, consistent with Lazio et al. (2006) who estimate -0.5.
- Possible different spectral index feature, south of the lobe.

Preliminary spectral index maps



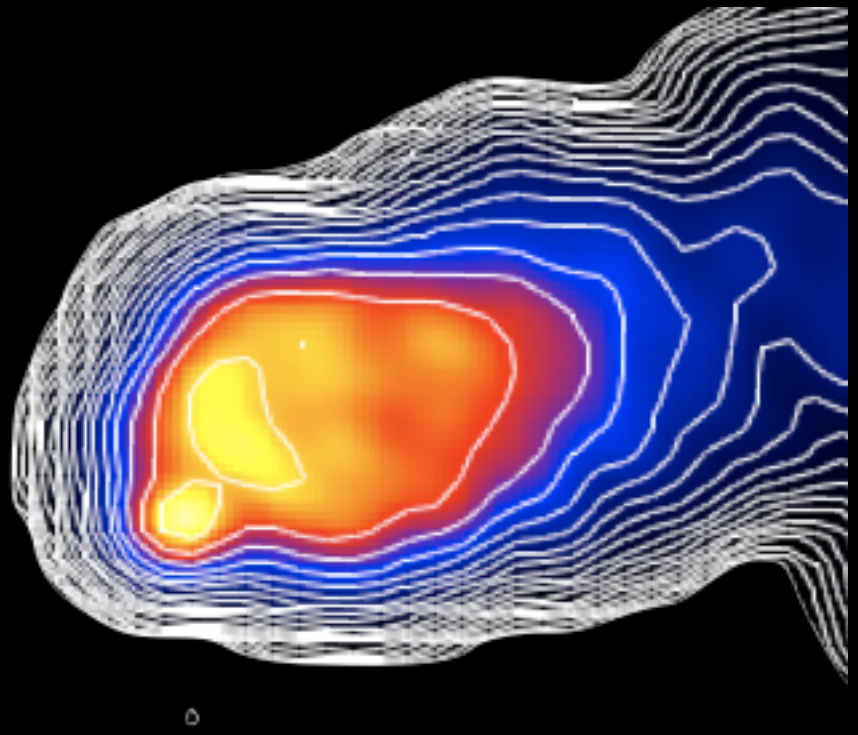
- LOFAR spectral index map between 33 and 65 MHz (Gaussian smoothed).
- The spectral index of the lobes are slightly different (-0.57 and -0.52).

Differences in the lobe/counter-lobe



- LOFAR extends the radio spectrum of the lobes down to 30 MHz.

- Classical double is expected to have similar lobe brightnesses.
- Counter lobe is brighter.
- Absorption? or adiabatic expansion?
- Relic hot-spot? (Steenbrugge et al. 2010)



The hot spots

- Lazio et al. (2006) calculate the hot-spot flux-densities, by removing an estimate of the lobe contributions and accounting for dilution due to the VLA ~10 arcsec beam.

- Spectra of hotspots are different.

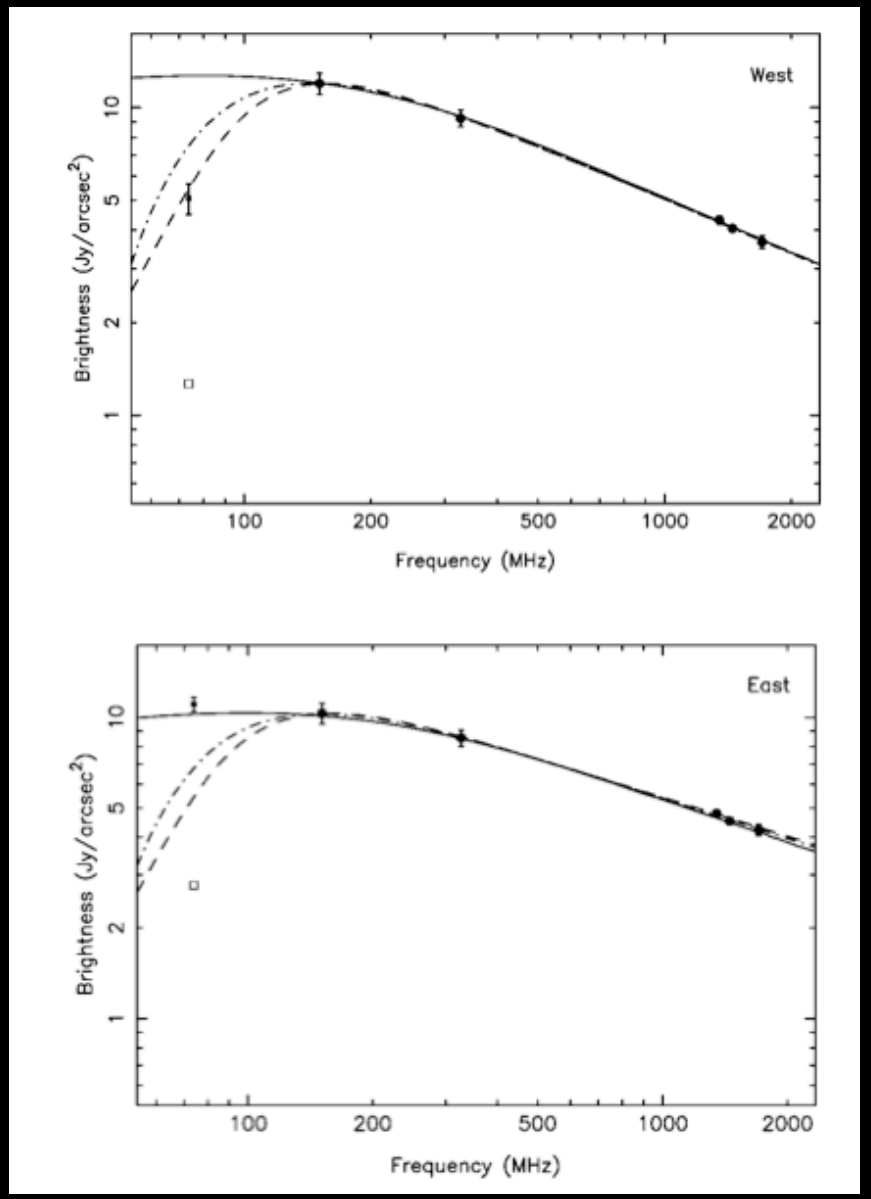
- Fitted models:

Low energy cut-off (solid).

Synchrotron self-absorbed (dashed).

Free-free absorption (dot-dashed).

- LOFAR will resolve this issue.



Summary

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- New LOFAR imaging has found:

i) Extended lobe and counter lobe emission, consistent with previous observations with the VLA and MERLIN (e.g. Lazio et al. 2006).

ii) A steepening of the spectral index towards the centre, as expected for the synchrotron aging model of Carilli et al. (1991).

iii) There is a difference in the brightness of the two lobes, but their spectral indices are similar - rules our free-free absorption (adiabatic expansion or a relic lobe from a previous burst of activity? e.g. Steenbrugge et al. 2010).

- New science results on the nature of the hot-spots will come with new data taken with the full array - including all remote stations (<4 arcsec to 120 MHz) and maybe international stations (<3 arcsec to 30 MHz).