LOFAR observations of 3C 31

Volker Heesen & Judith Croston
(U Southampton)

Image: *VLA 360 MHz* + *Chandra X-ray* + *DSS*

Some technical details

HBA

Observations and intial calibration

–10 hr, 8hr on-source, interleaved 10 min scans
–324 subbands, 18x18 sets
–No demixing
–RSMPP pipeline (A. Stewart, Oxford)
–Solves gains on primary (3C48)
–Gain transfer
–Phase cal on set with VLSS skymodel

Self-cal and imaging

–Create mask with PYBDSM
–Image FOV with awimager (18 subbands)
–Determine SKYMODEL with PYBDSM
–60pixel sliding window
–Self-calibration in phase with BBS
–Imaging with CASA MS-CLEAN
–Robust=0 or 0.5
–Pixel size 5 arcsec
–MS-scales of 0,3,6,10,20,40

LBA

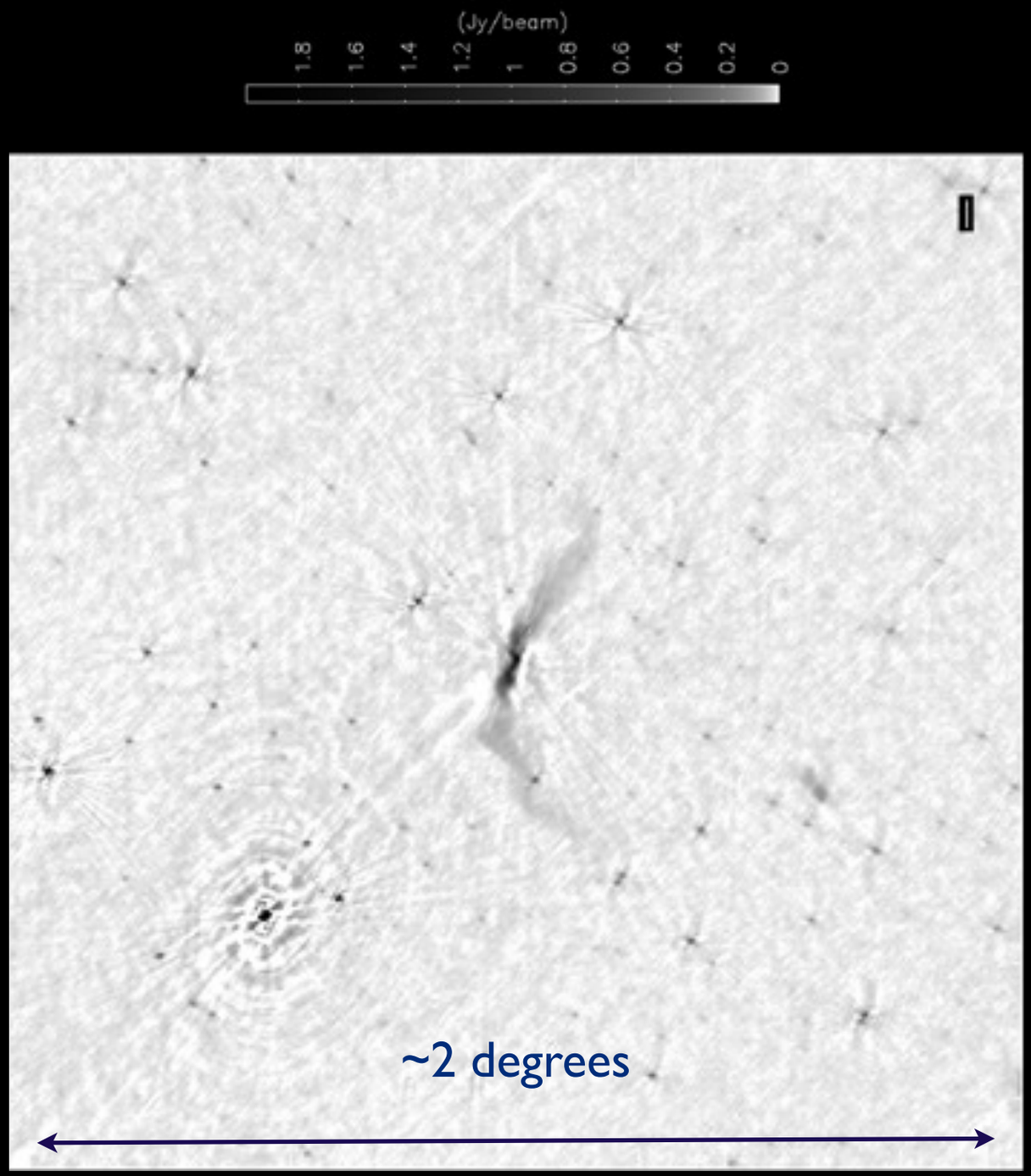
Observations and intial calibration

–10 hr, 8hr on-source, simultaneous on 3C48
–245 subbands, 12 subbands combined
–Demixing of Cyg A and Cas A
–ASTRON pipeline for amplitude gains
–RSMPP pipeline for phase-calib on VLSS

Self-cal and imaging

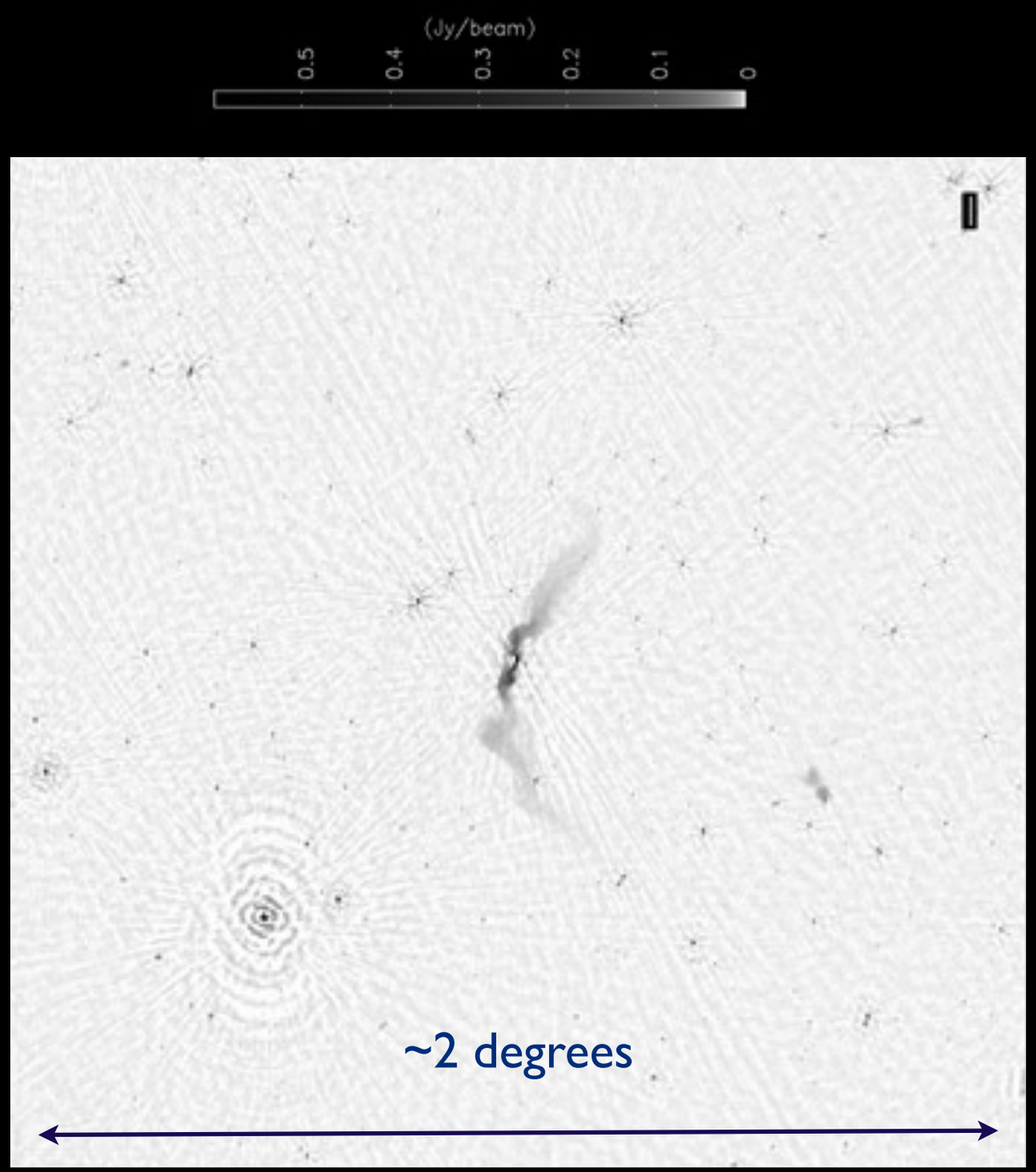
–Use HBA mask
–Image FOV with awimager (12 subbands)
–Determine SKYMODEL with PYBDSM
–60pixel sliding window
–Self-calibration in phase with BBS
–Imaging with CASA MS-CLEAN
–Robust=0
–Pixel size 5 arcsec
–MS-scales of 0,3,6,10,20,40

LBA – 55 MHz



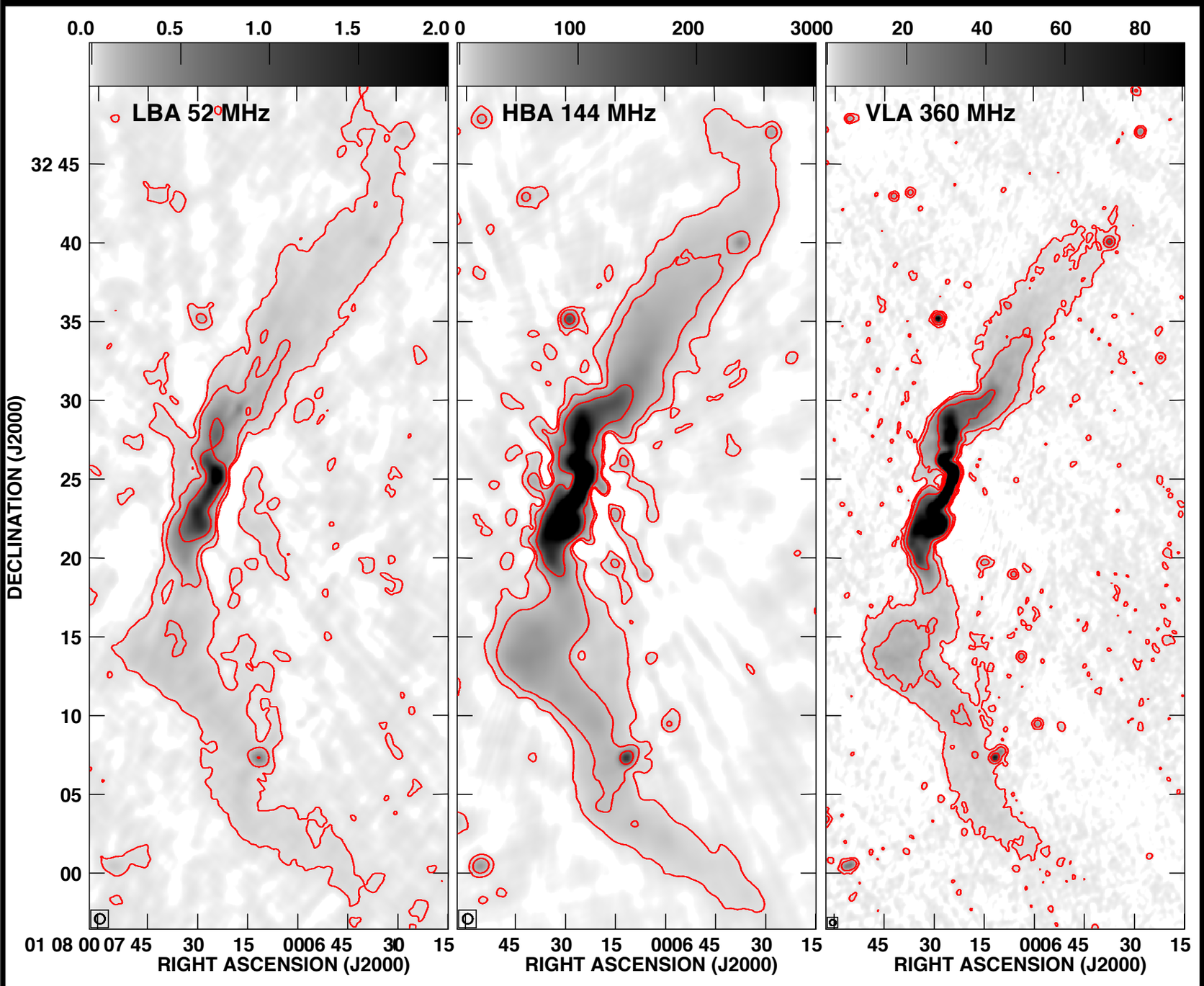
Some details:
- CLEANed with nterms=2
- rms noise = 5mJy/beam
- Resolution = 38x23 arcs

HBA – 144 MHz



Some details:
- CLEANed with nterms=1
- rms noise = 0.5–0.7 mJy/beam
- Resolution = 16x12 arcs

New LOFAR and VLA observations



rms = 5 mJy/beam
res = 55”

rms = 1 mJy/beam
res = 37”

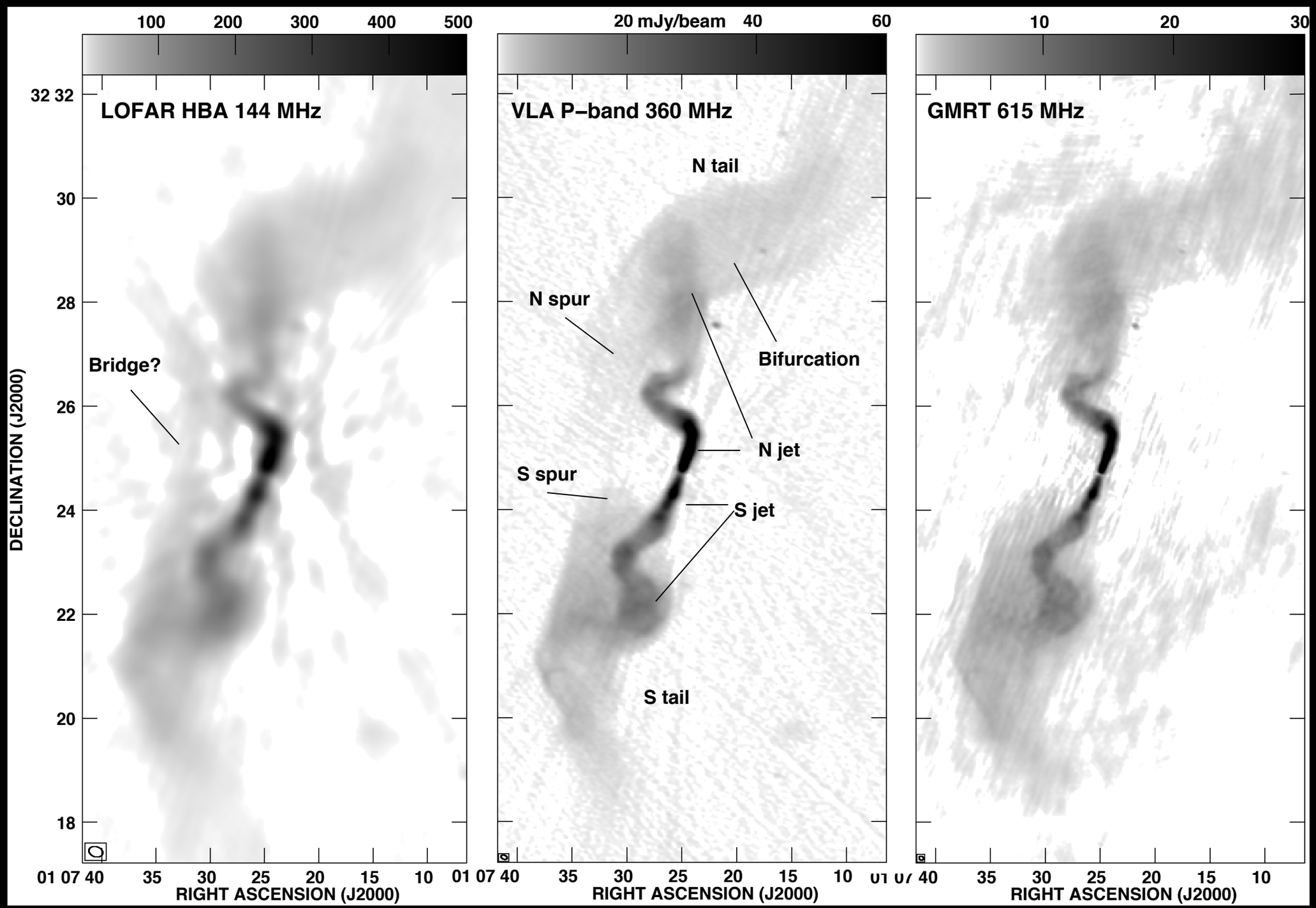
rms = 0.2 mJy/beam
res = 23”

—LOFAR LBA—	
Observations ID	L96535
Array configuration	LBA_OUTER
Integration time	1 s
Observation date	2013 Feb. 03
Total on-source time	8 h
Correlations	*XX*, *XY*, *YX*, *YY*
Frequency setup	30–87 MHz full coverage
Bandwidth	58 MHz
Bandwidth per sub-band	195.3125 kHz
Channels per sub-band	128

—LOFAR HBA—	
Observations ID	L86562–L86647
Array configuration	HBA_OUTER
Integration time	1 s
Observation date	2013 Feb. 17
Total on-source time	8 h
Correlations	*XX*, *XY*, *YX*, *YY*
Frequency setup	115–178 MHz full coverage
Bandwidth	95 MHz
Bandwidth per sub-band	195.3125 kHz
Channels per sub-band	128

—VLA *P*-band—	
Observations ID	13B-129
Array configuration	A-array / B-array
Integration time	1 s
Observation date	2014 Apr. 07 / 2013 Dec. 14
Total on-source time	4 h (each)
Correlations	*XX*, *XY*, *YX*, *YY*
Frequency setup	224–480 MHz full coverage
Bandwidth	256 MHz
Bandwidth per sub-band	16000 kHz
Channels per sub-band	128

Inner bright jet region



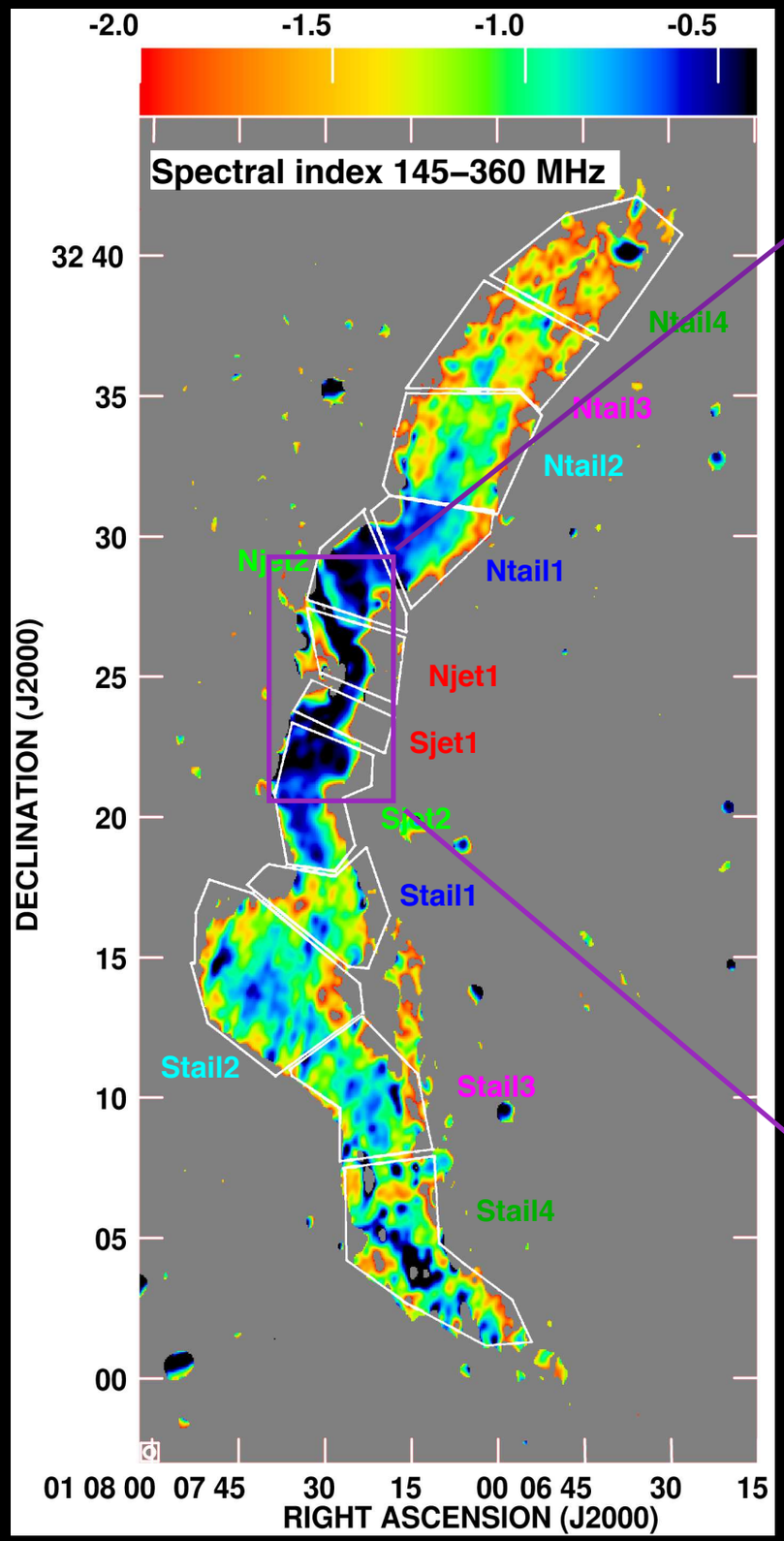
rms = 1–2 mJy/beam
res = 16”

rms = 0.15 mJy/beam
res = 8”

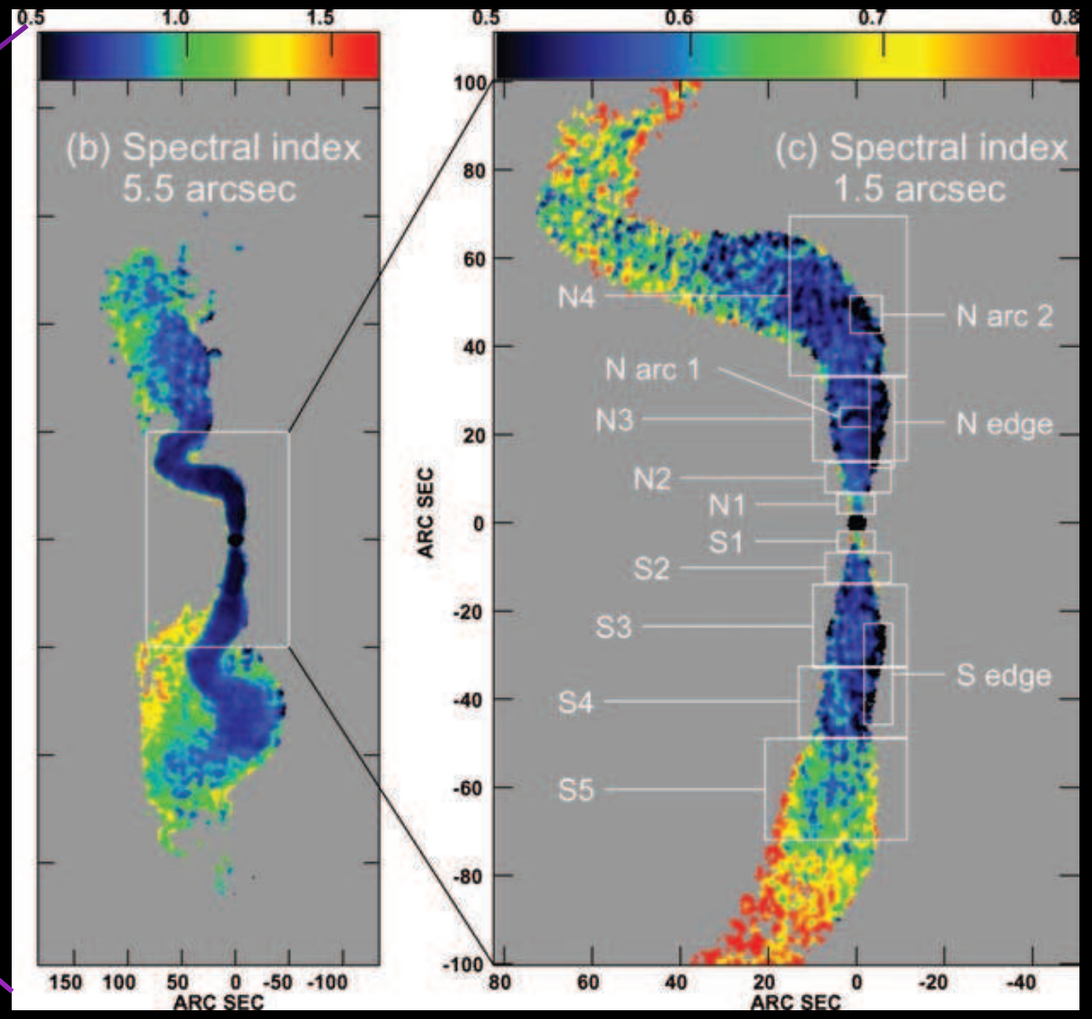
rms = 0.3 mJy/beam
res = 6”

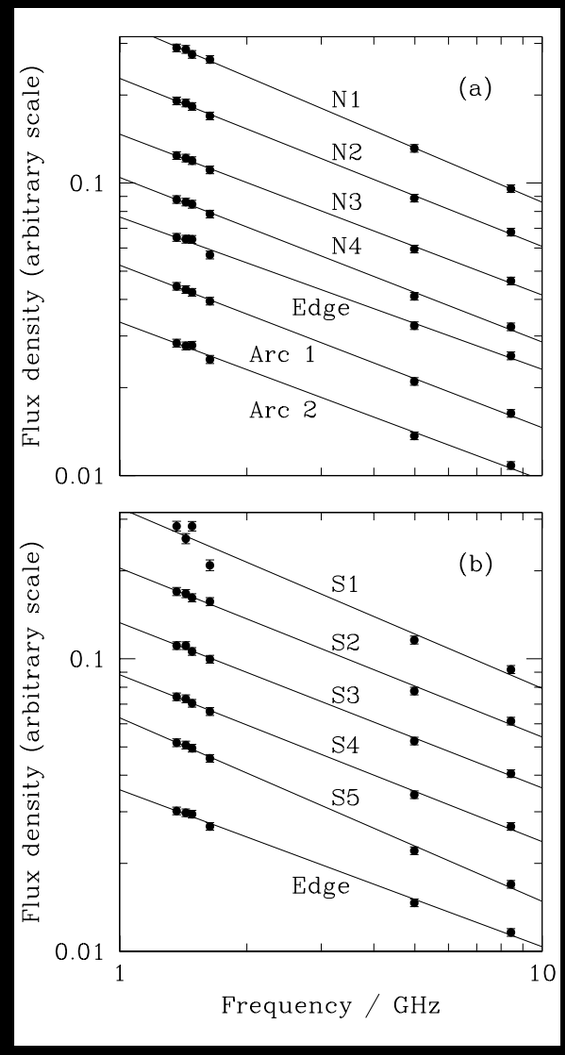
Radio spectral index

Spectral index 145–360 MHz



Spectral index 1.4–5 GHz

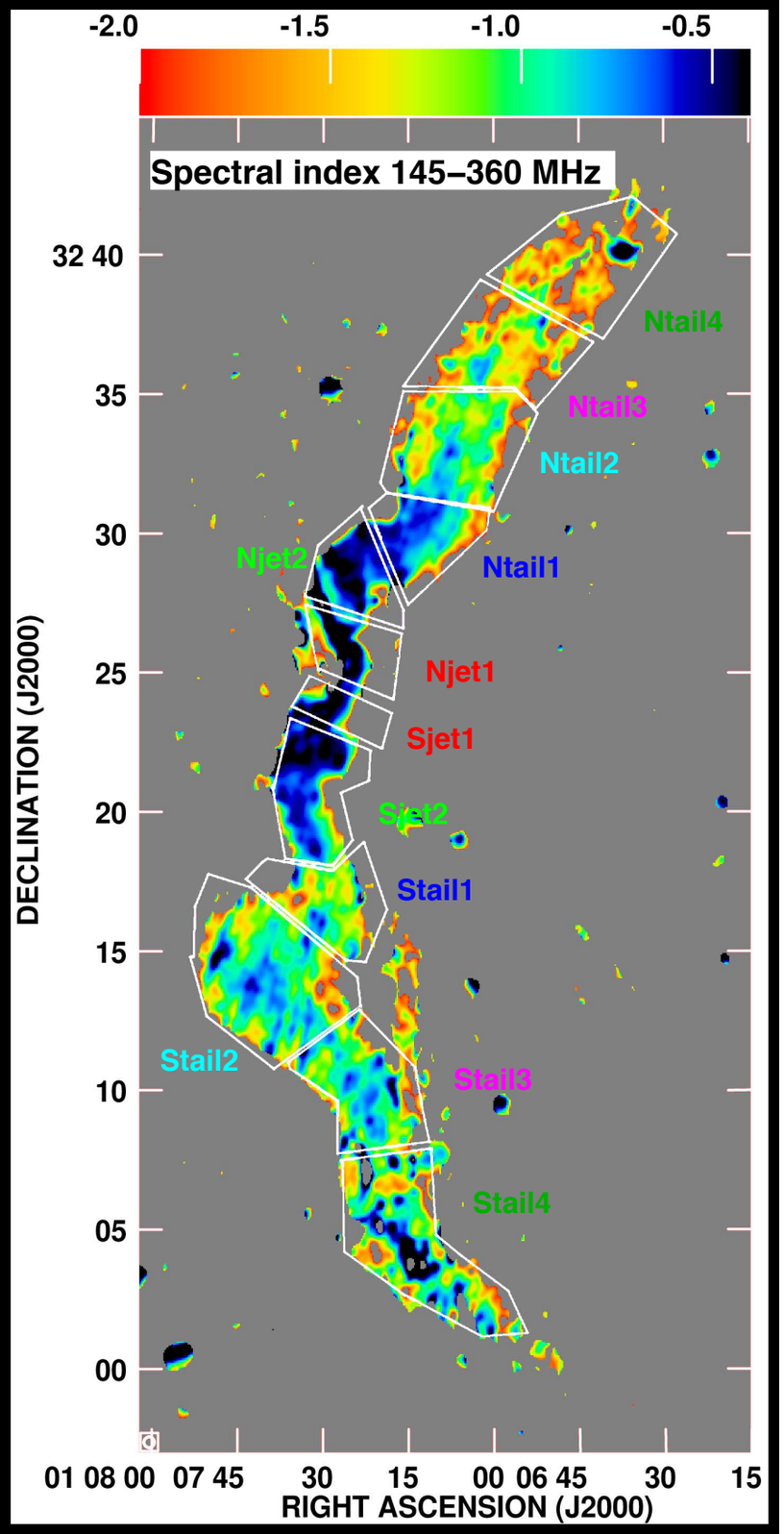




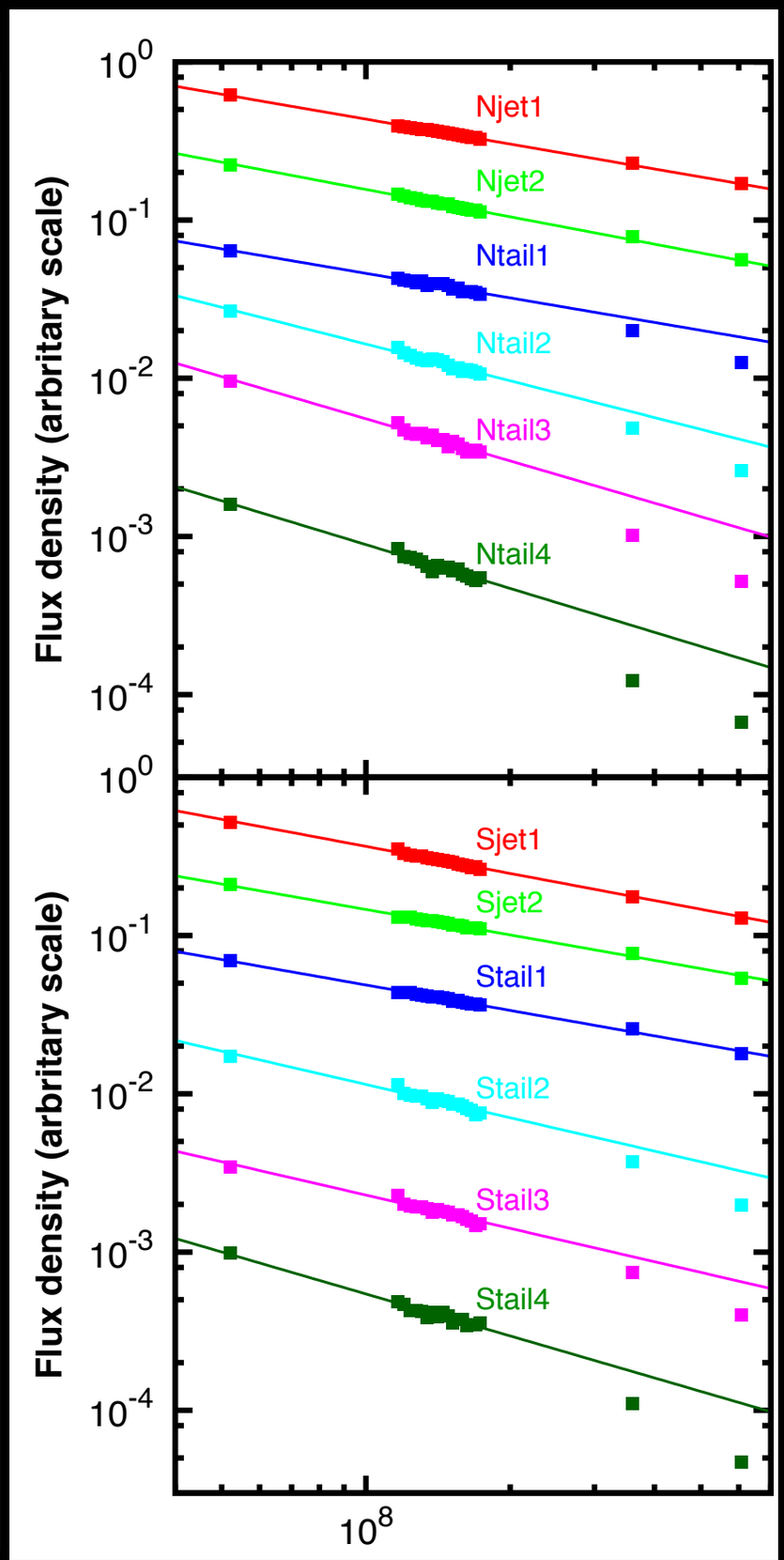
Laing+08

No spectral curvature

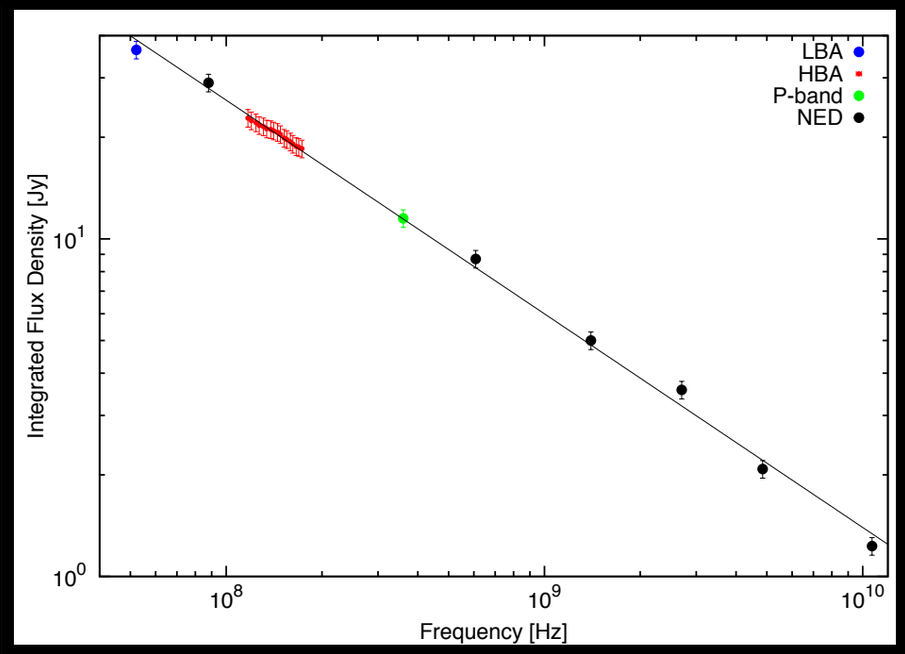
Spectral index 145–360 MHz



Radio spectra – power laws



Integrated flux density



Normalized to same area

Spectral curvature

1–D Modelling of CR–Transport

Convection: $$\frac{\partial N(E,z)}{\partial z} = \frac{1}{V}\left[\frac{\partial}{\partial E}\left(b(E)N(E,z)\right)\right]$$

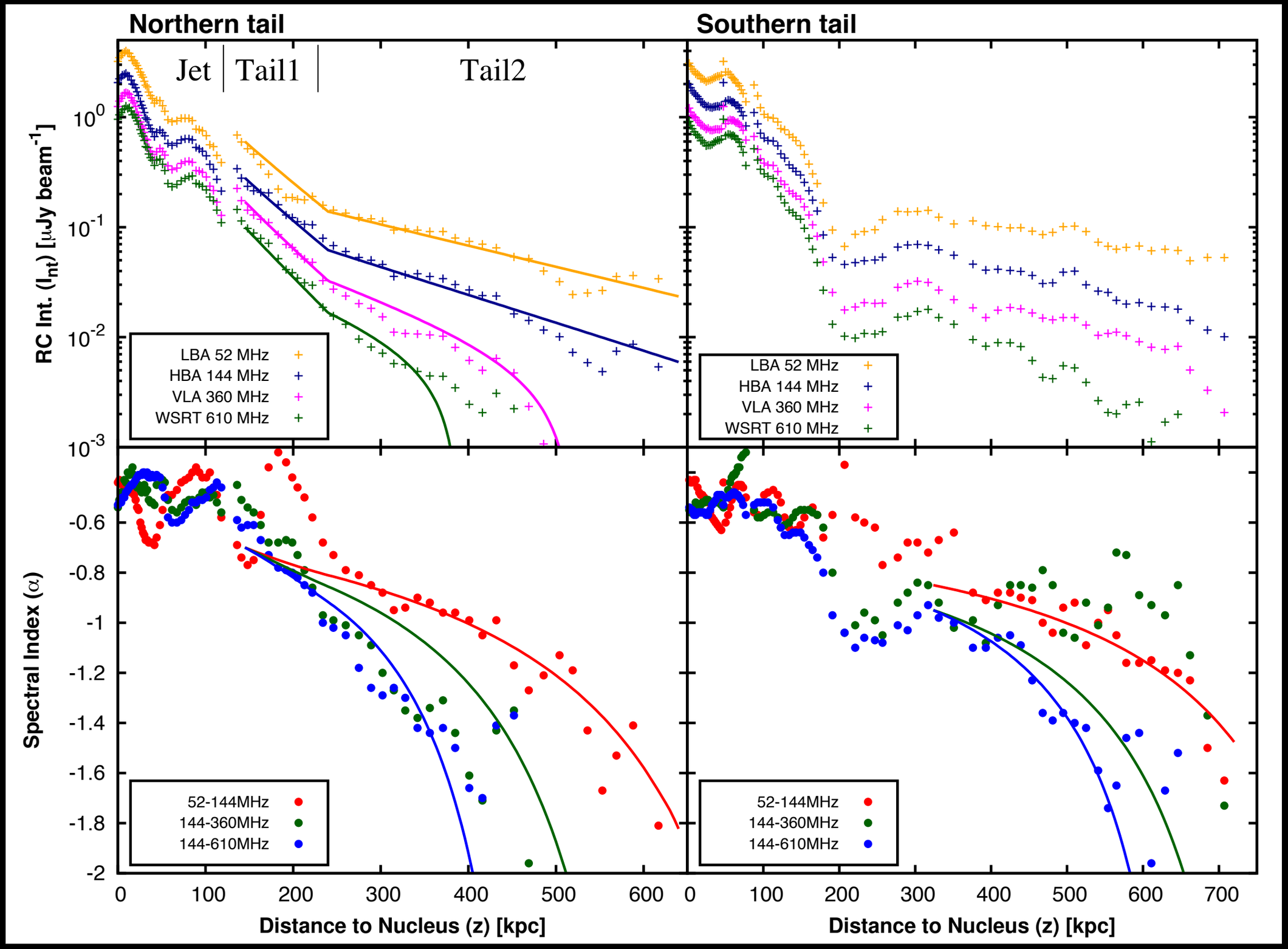
CRe number density

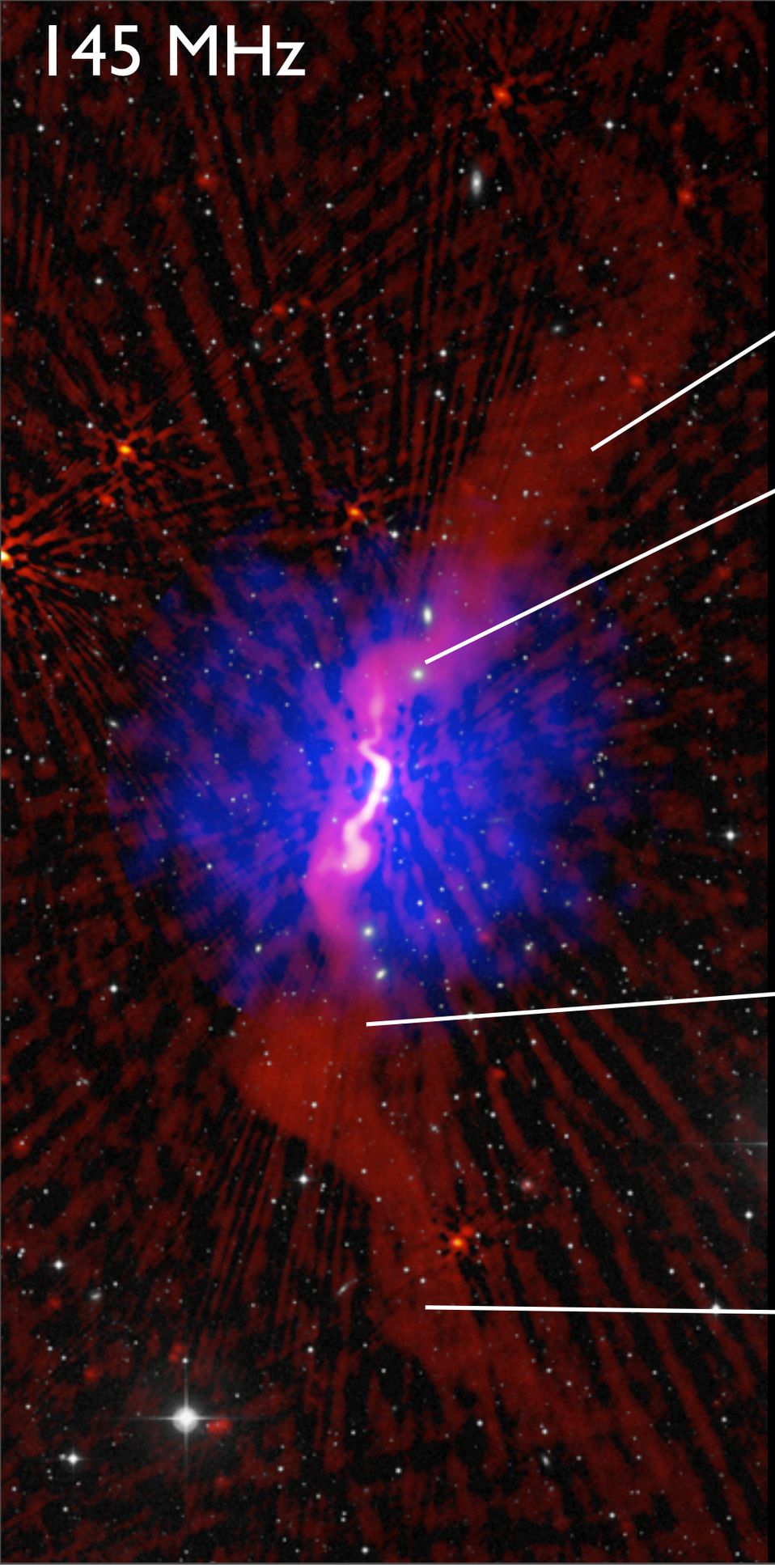
convection speed

b(E) = synchrotron + IC losses

Inner boundary condition: 10μG (Croston & Hardcastle 2014)

Convective cosmic ray transport





Northern radio tail
h_B = 350–450 kpc
V = 1800–2400 km s^{-1}

Transition region
h_B = 120 kpc
V ~ 2000 km s^{-1}

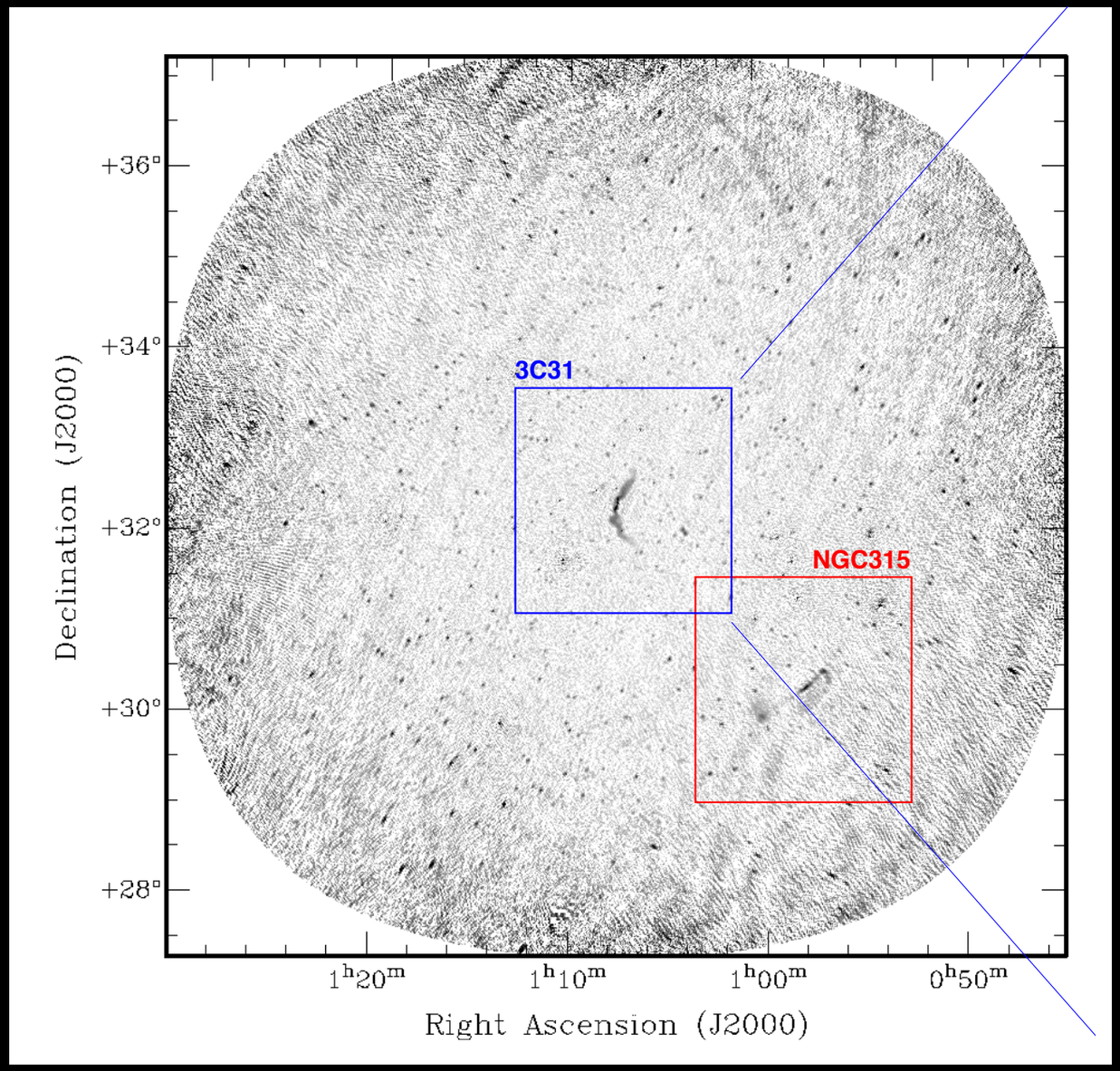
Transition region
h_B ~ 120 kpc
V ~ 2000 km s^{-1}

Southern radio tail
h_B = 1400–1500 kpc
V = 2300–2800 km s^{-1}

Conclusions

- Largest ever detected angular extent
- Total source extent: ~1.2 Mpc
- Spectral ageing in the radio tails
- Convections speeds ~2000 km s^{-1}
- Magnetic field: 3–10 μG in the tails
- Dynamical age: ~250 Myr

Outlook: image NGC 315



Strategy:

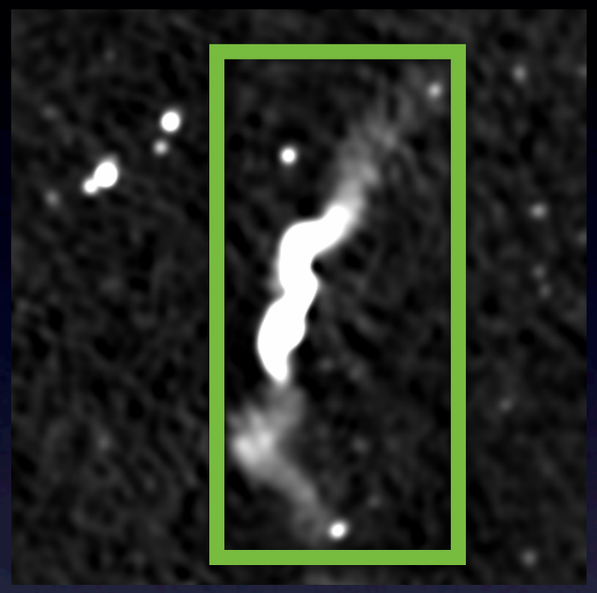
– Image with CASA

–Combine 18 subbands

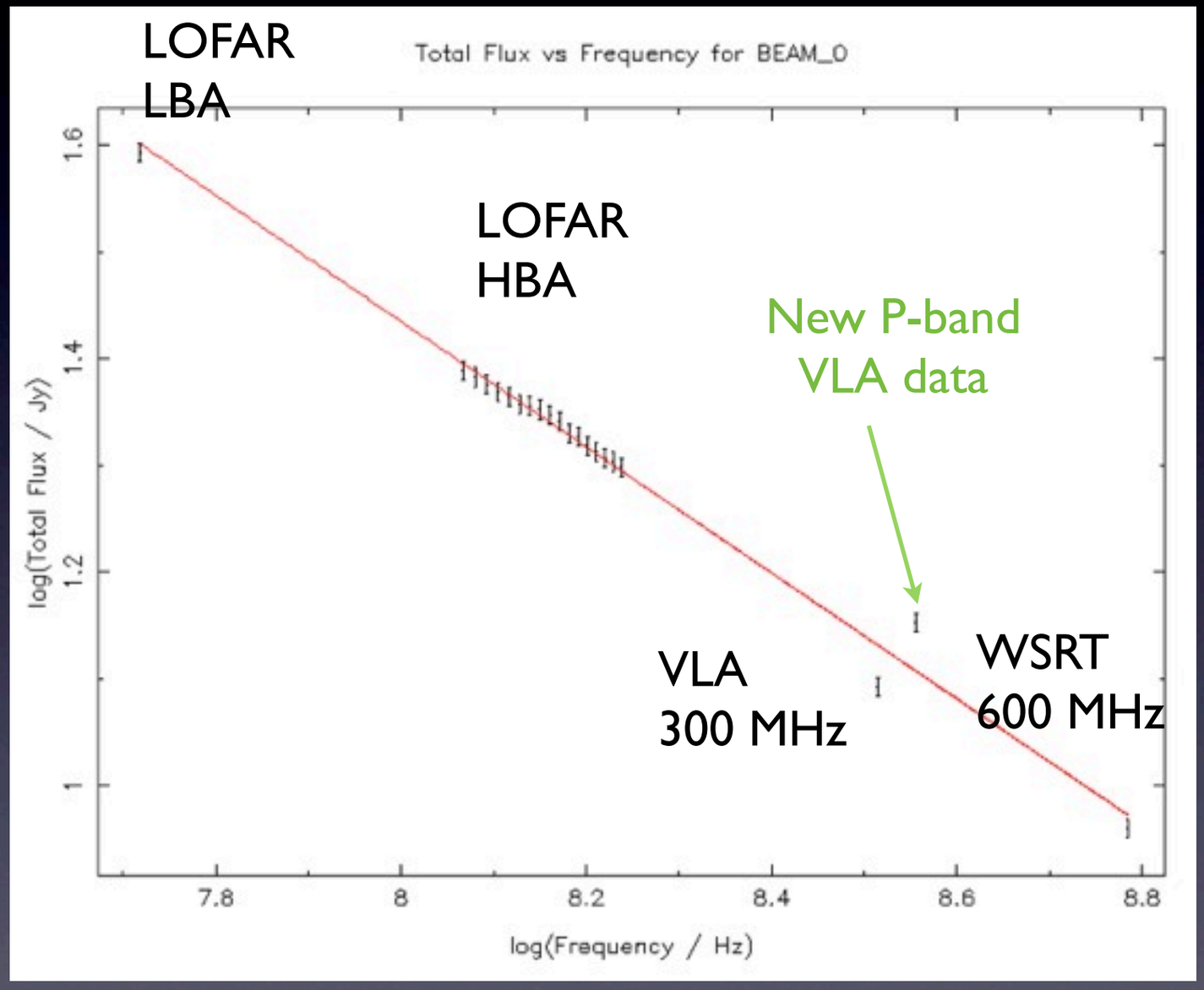
–Correct for PB

–Combine images

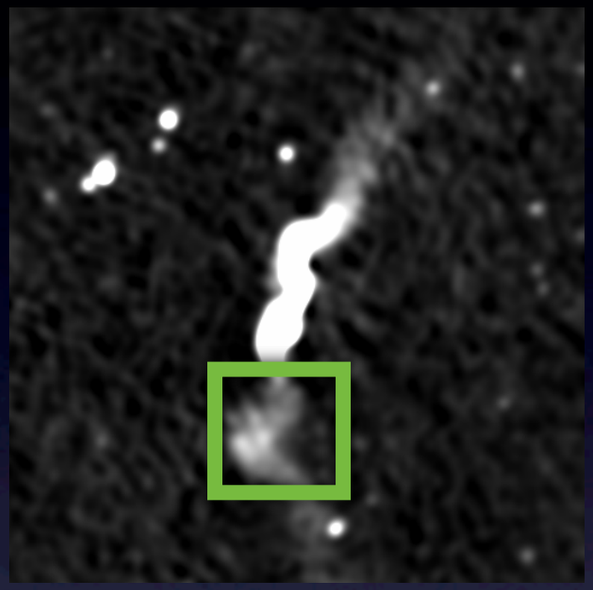
Spectrum integrated



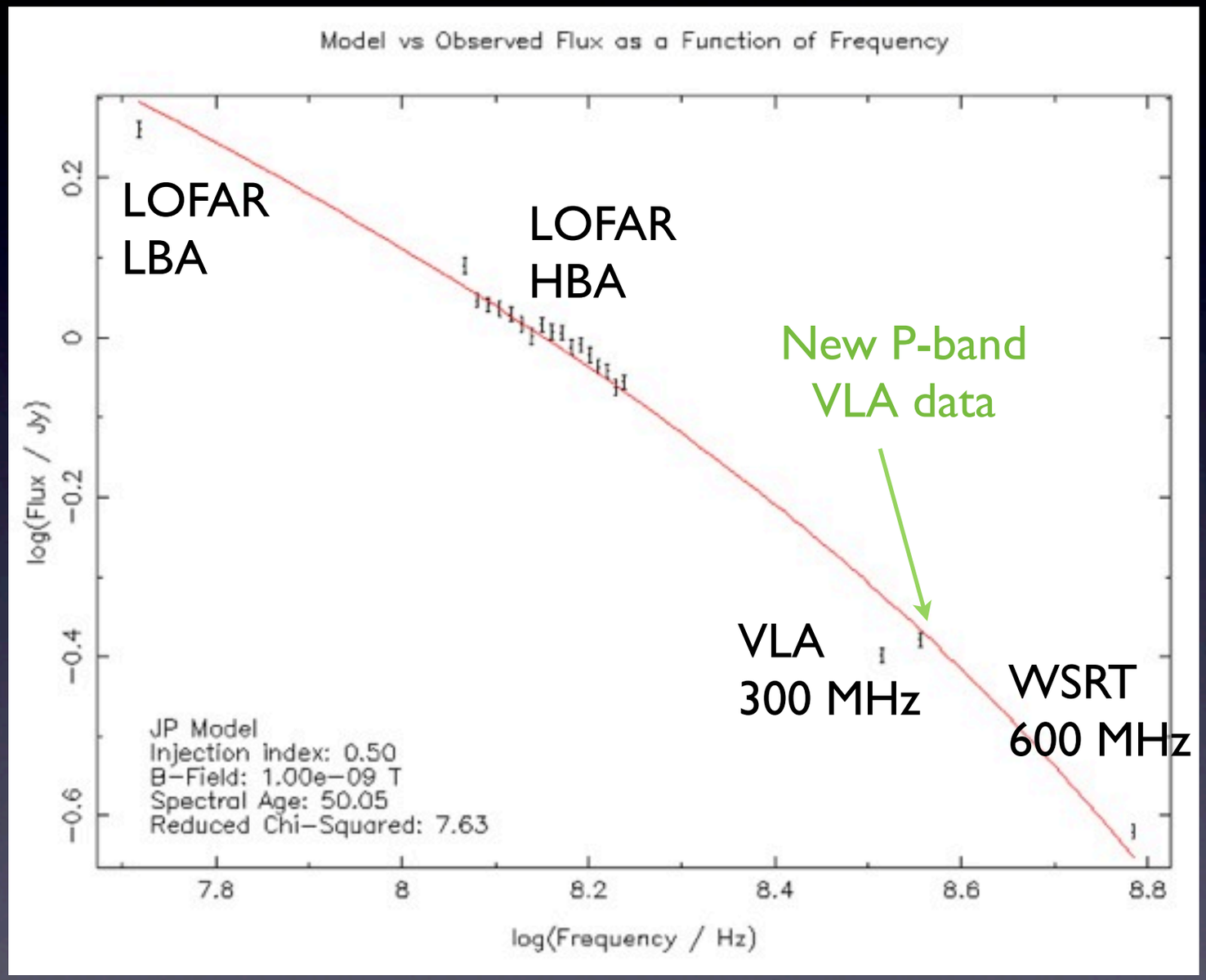
Res.=55 arcsec
Using BRATS (Harwood et al. 2013)



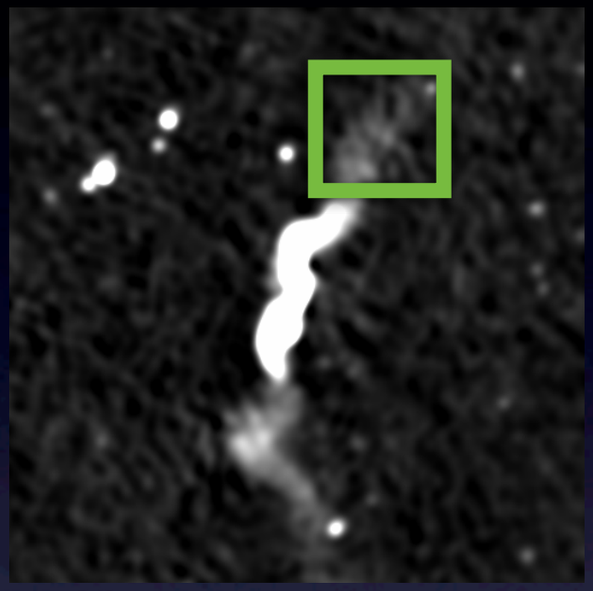
Spectrum southern lobe



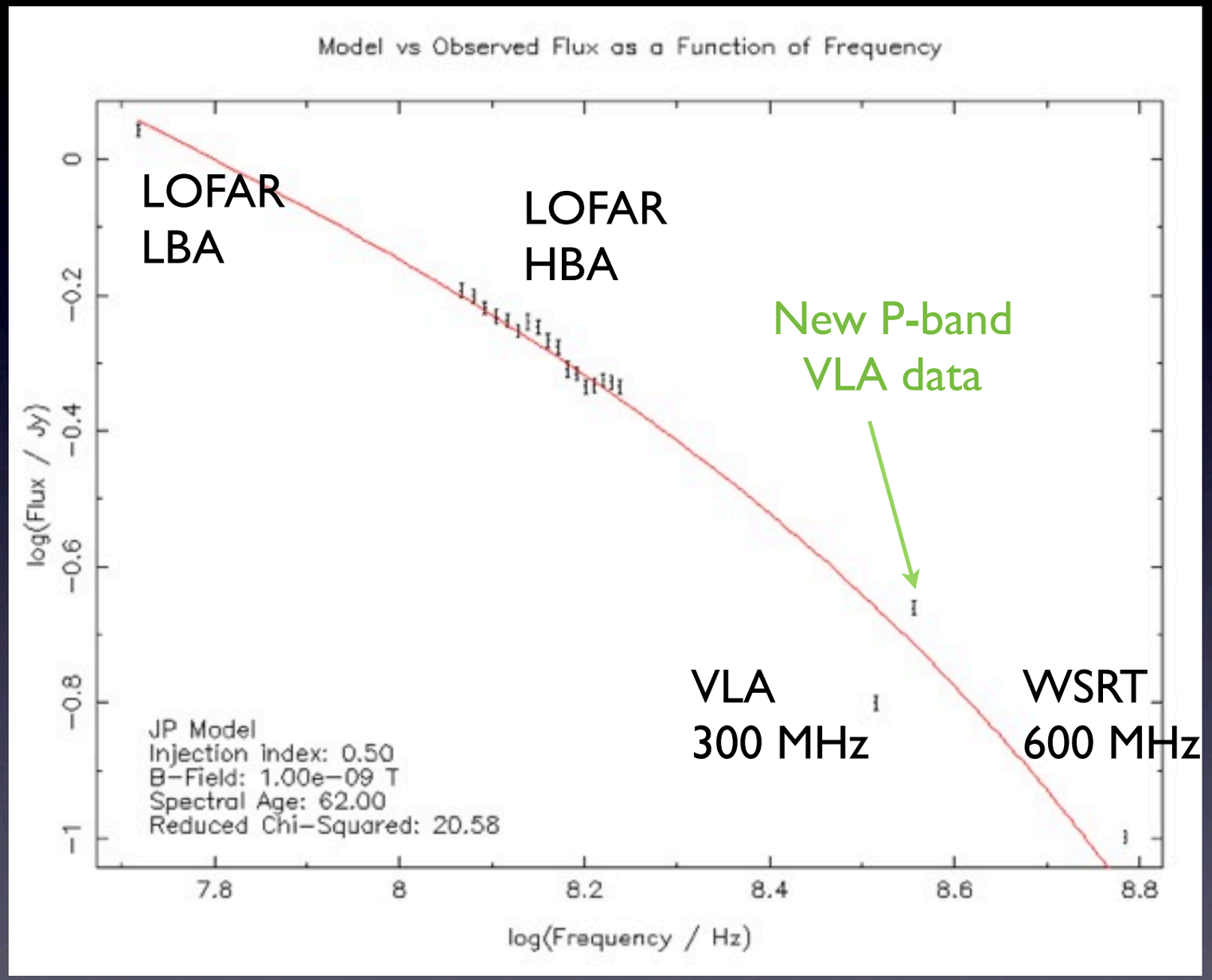
Fit JP-model
inj. index = 0.5
B = 10μG



Spectrum northern lobe

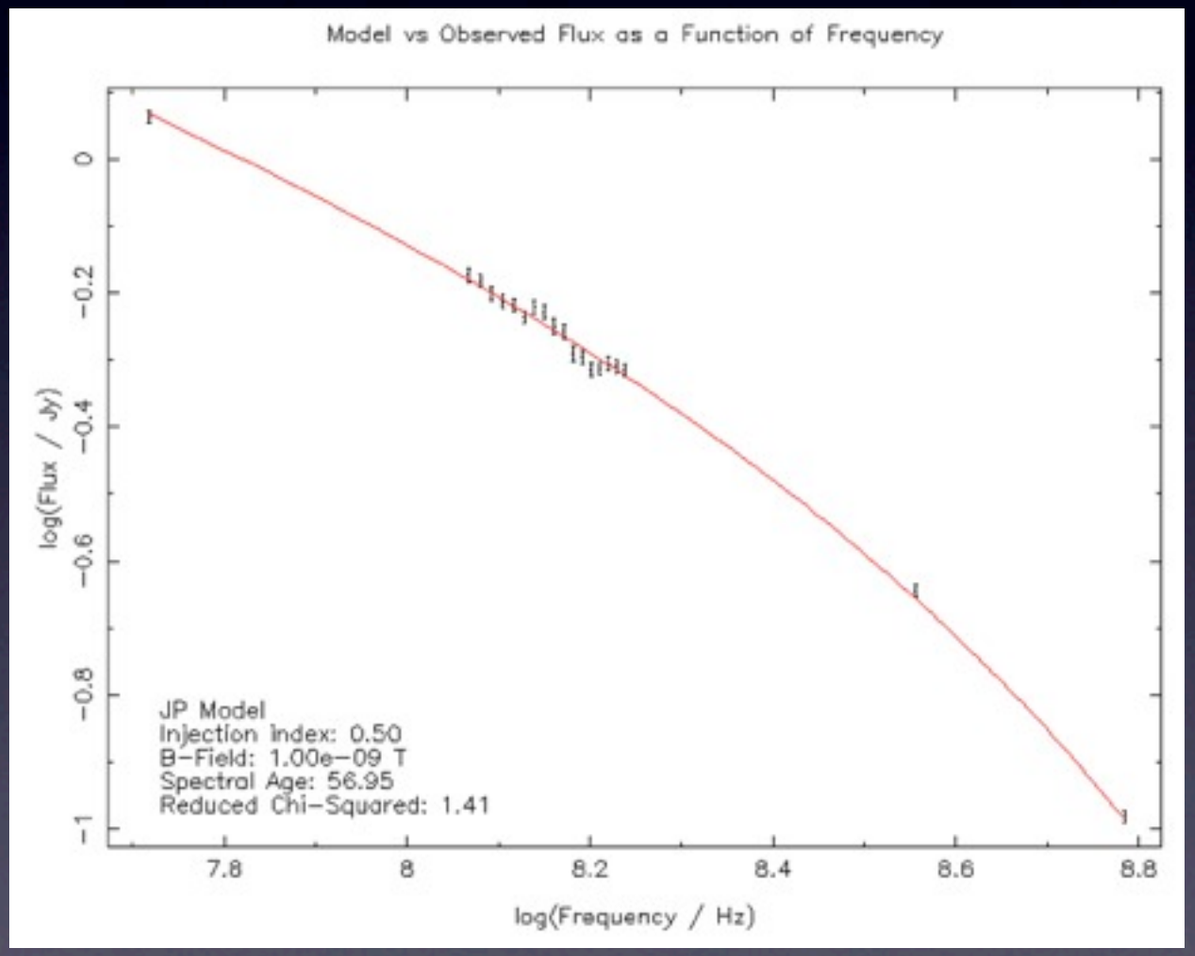


Fit JP-model
inj. index = 0.7
B = 10μG

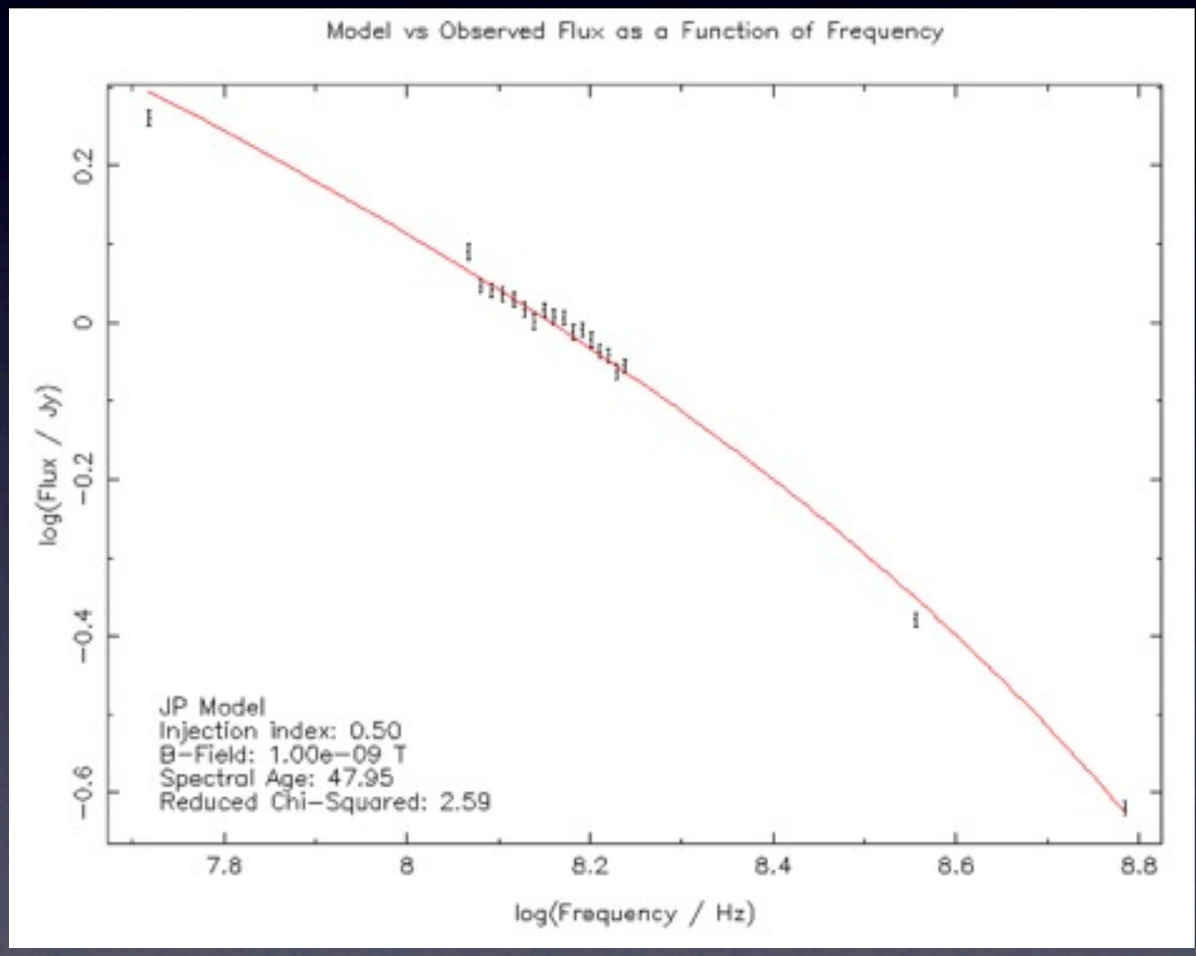


New spectral models

Northern lobe

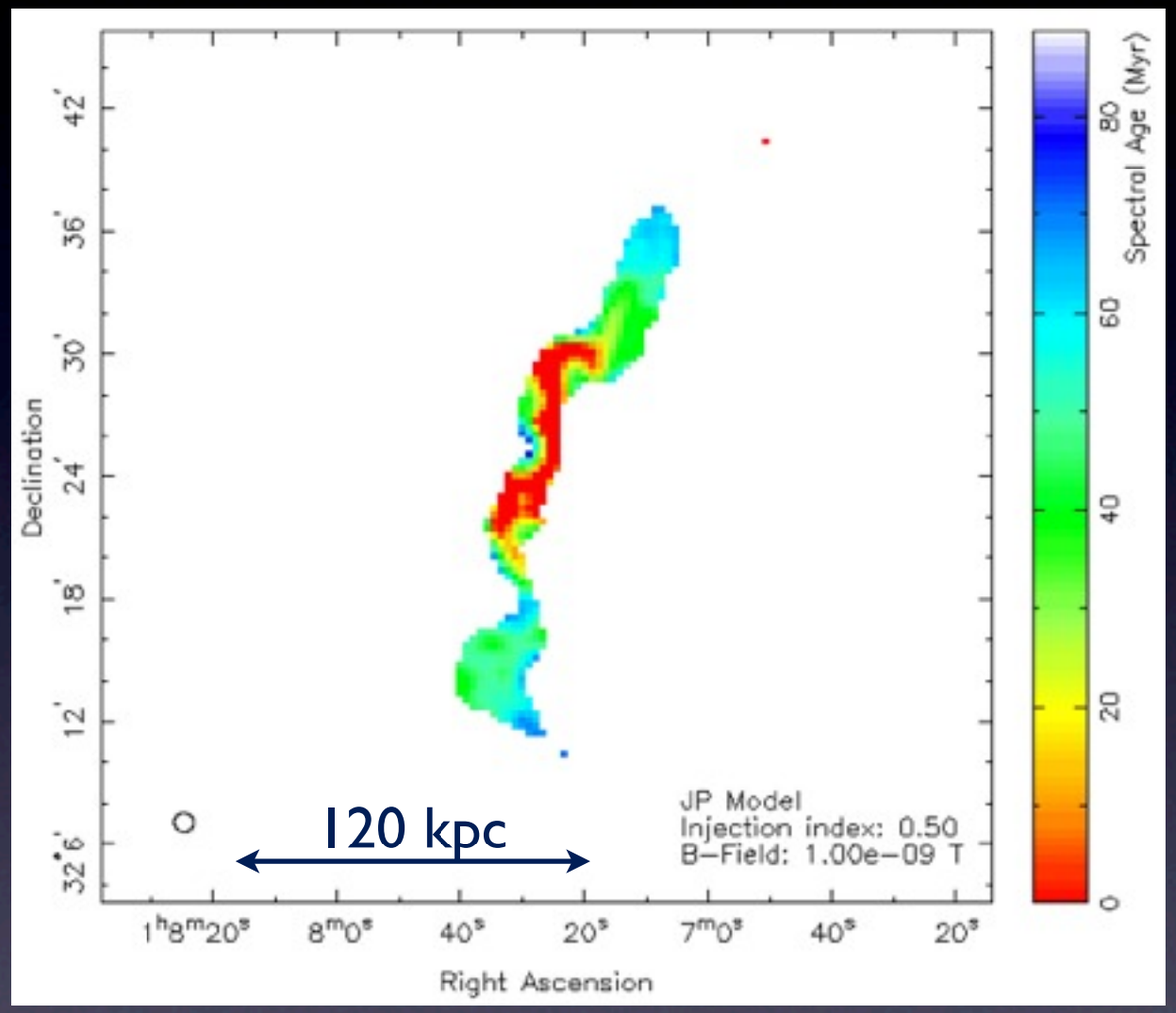


Southern lobe

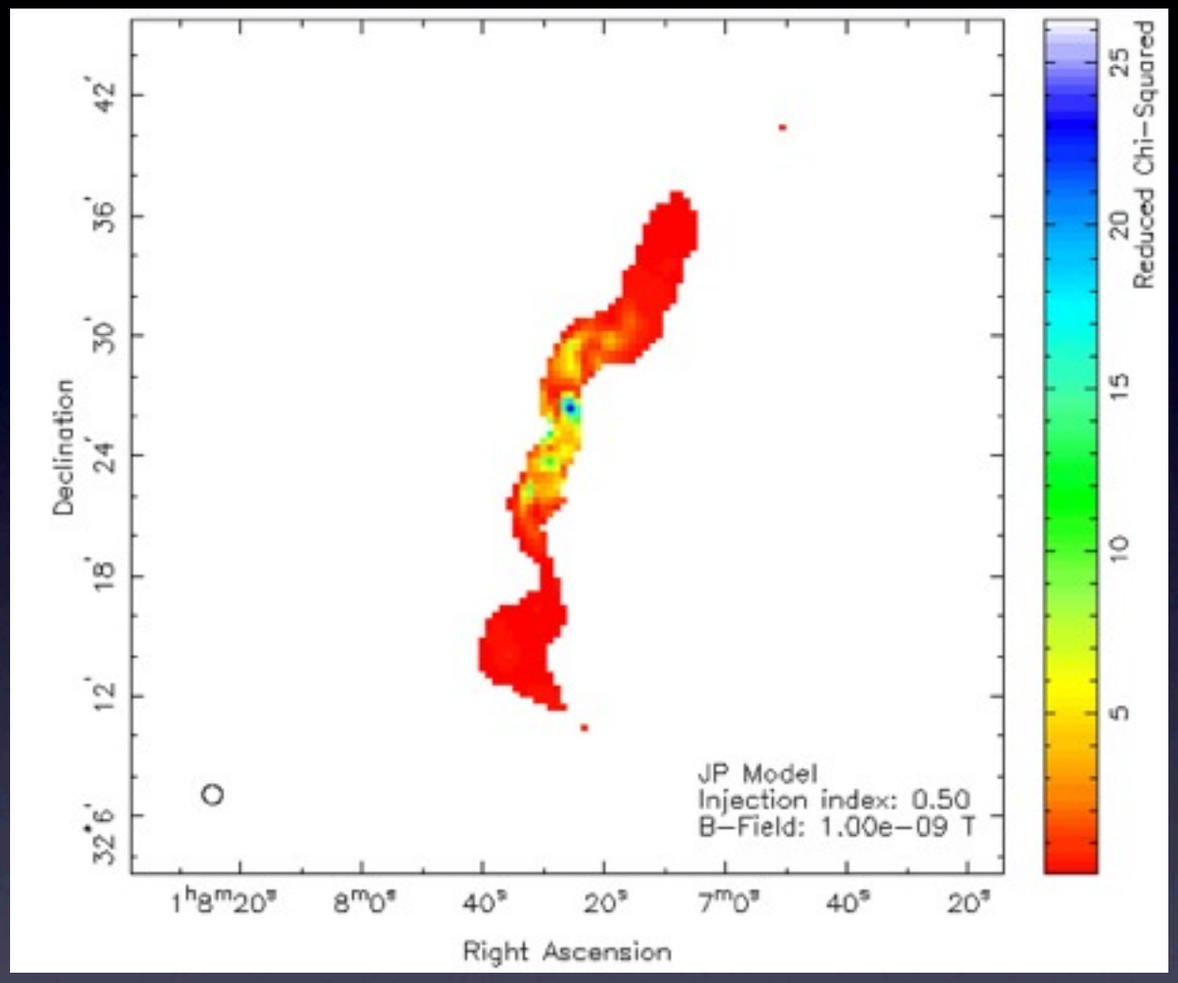


JP–model fits (BRATS, Harwood et al. 2013)

Spectral age



Reduced chi^2



Radio continuum data:

- LOFAR Low–band Antennae (LBA), 30–85 MHz
- LOFAR High–band Antennae (HBA), 115–178 MHz
- VLA P–band, 230–380 MHz, A– and B–configuration
- Spatial resolution = 19 kpc (FWHM=55", D = 73 Mpc)

Model input:

- Injection spectral index = 0.5
- Magnetic field strength = 10 μG(Crostron & Hardcastle 2014)