LOFAR high-band observations of the microquasars SS433 and GRS 1915+105

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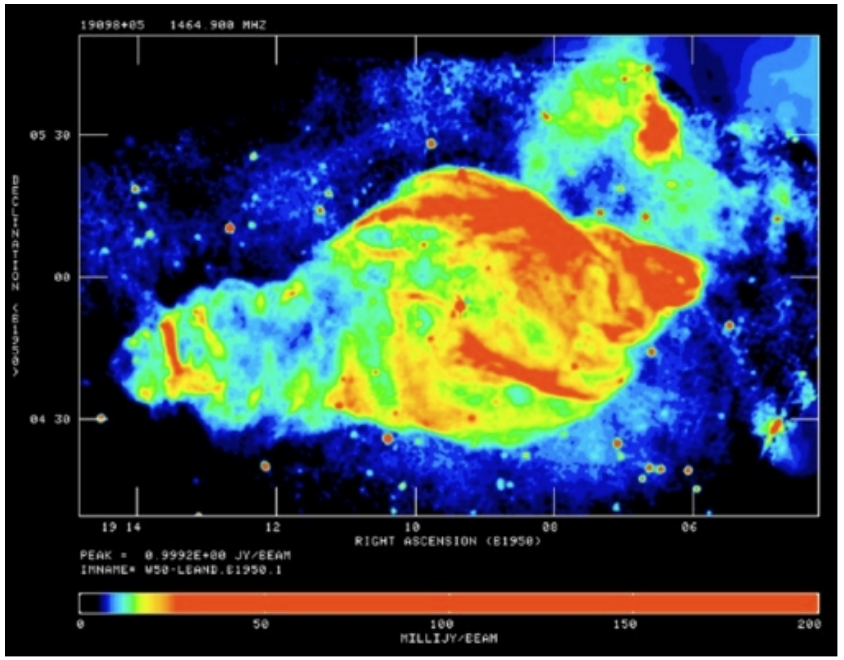
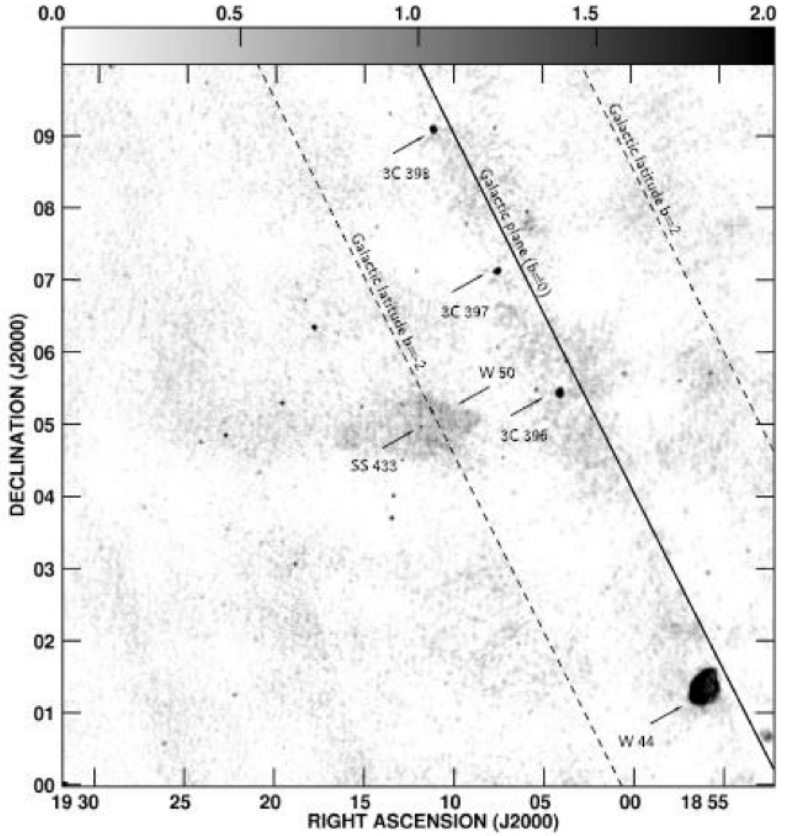
and the LOFAR Transients Key Science Project

SS433 / W50

* Famous microquasar at D = 5.5 kpc.
* Mildly-relativistic (0.26c), precessing jets (period 162.5 days).
* Evidence that jets have influenced W50 morphology.



* VLA 1465 MHz (Dubner et al. 1998)
* resolution 56 arcsec x 54 arcsec
* rms 0.5 mJy/beam



* VLA 74 MHz (Miller-Jones et al. 2007)
* resolution 108 arcsec x 93 arcsec
* rms 192 mJy/beam

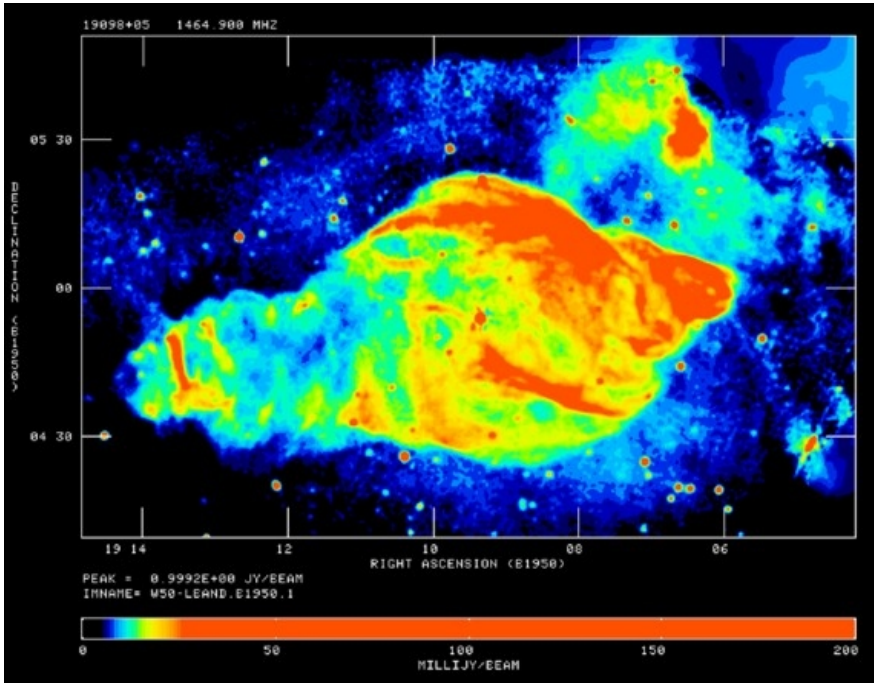
* Cycle 0 and 1 observations (LC0_039+LC1_023):

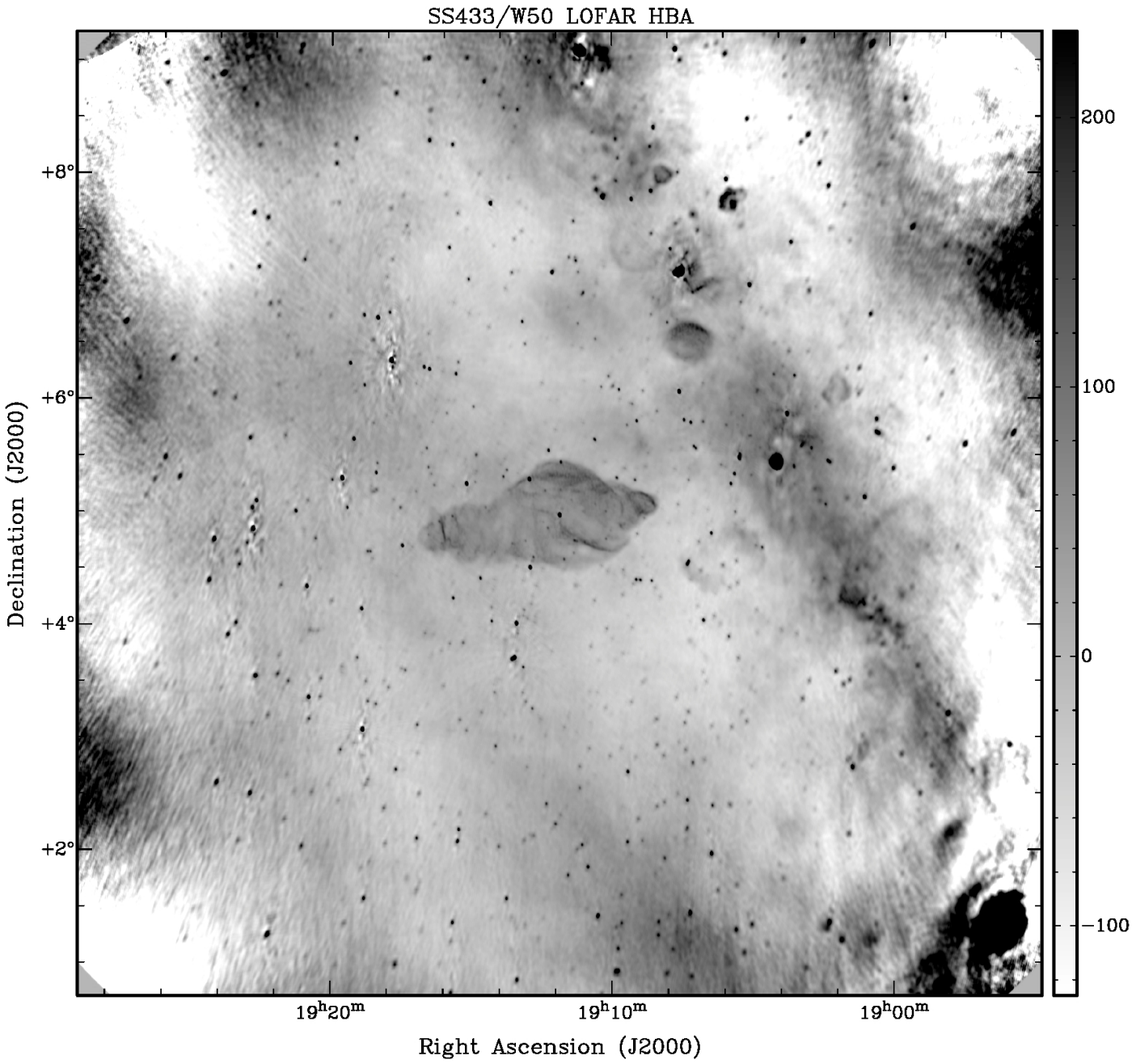
- 1 x 4h HBA, 1 x 3.5h LBA at start of Cycle 0 (16 bit mode)
- 1 x 4h HBA at start of Cycle 1 (8 bit mode)
- 12 x 30 min HBA (8 bit), 12 x 30 min LBA (16 bit) to monitor SS433 ~monthly

- Calibrators 3C380 (HBA) and 3C295 (LBA).
- No demixing of target field needed in high band.

- Data pre-processed by Observatory; calibration and imaging carried out on Southampton cluster.

- Reduction strategy similar to MSSS; imaging carried out with AWImager.





* HBA_DUAL map from Cycle 0

* 4h run on 2013 Feb. 18

* 48 MHz bandwidth; 115-163 MHz

* Observations of 3C380 every ~15 min

* Baselines < 4kλ (~8 km) for imaging

* Robust=0

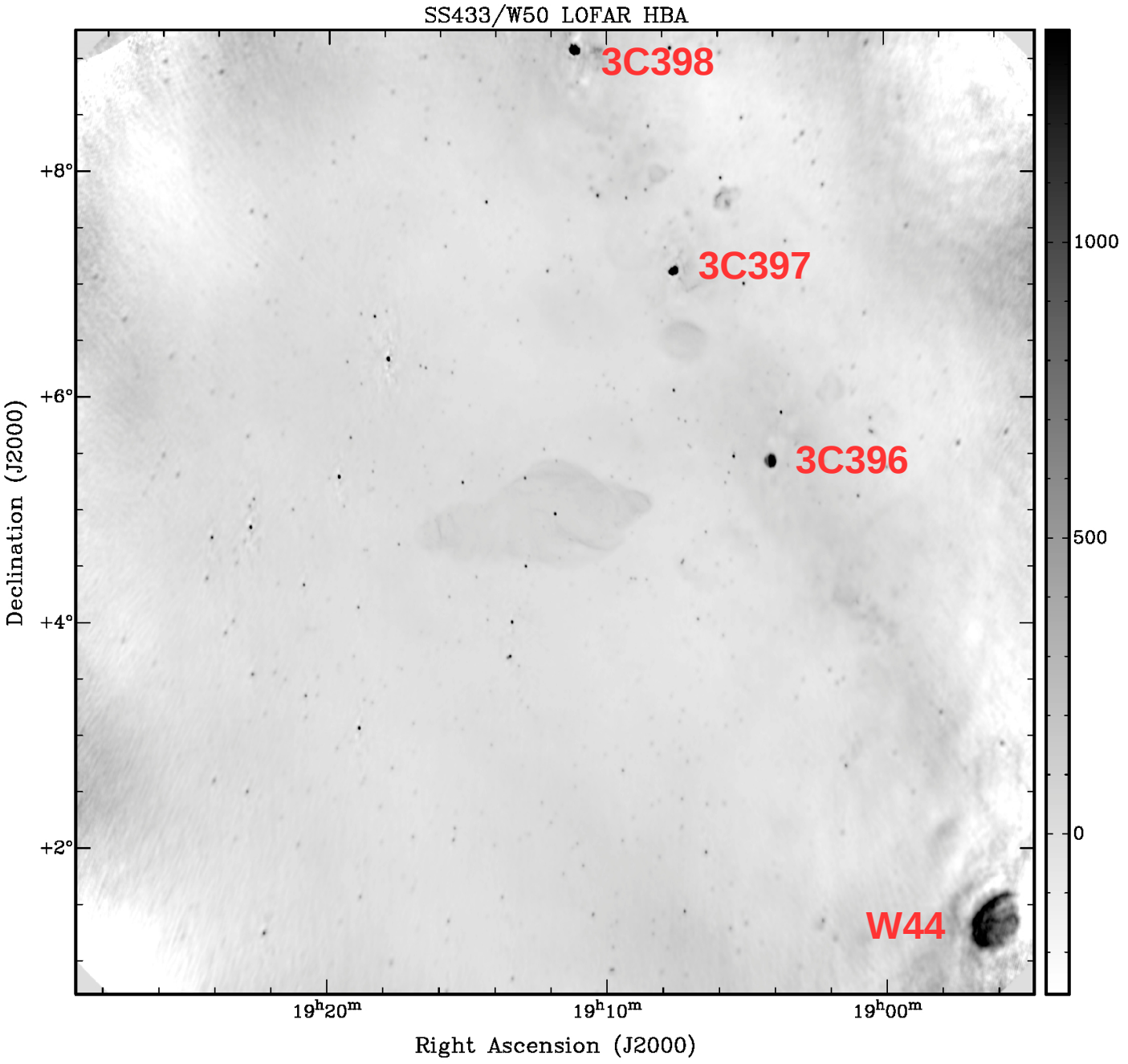
* Resolution 82 arcsec x 58 arcsec (beam PA 9 deg)

* Noise ~6-7 mJy/beam

* SS433 peak flux 2.1 Jy/beam

* SS433 integrated flux 2.4 Jy

Broderick et al., in prep.



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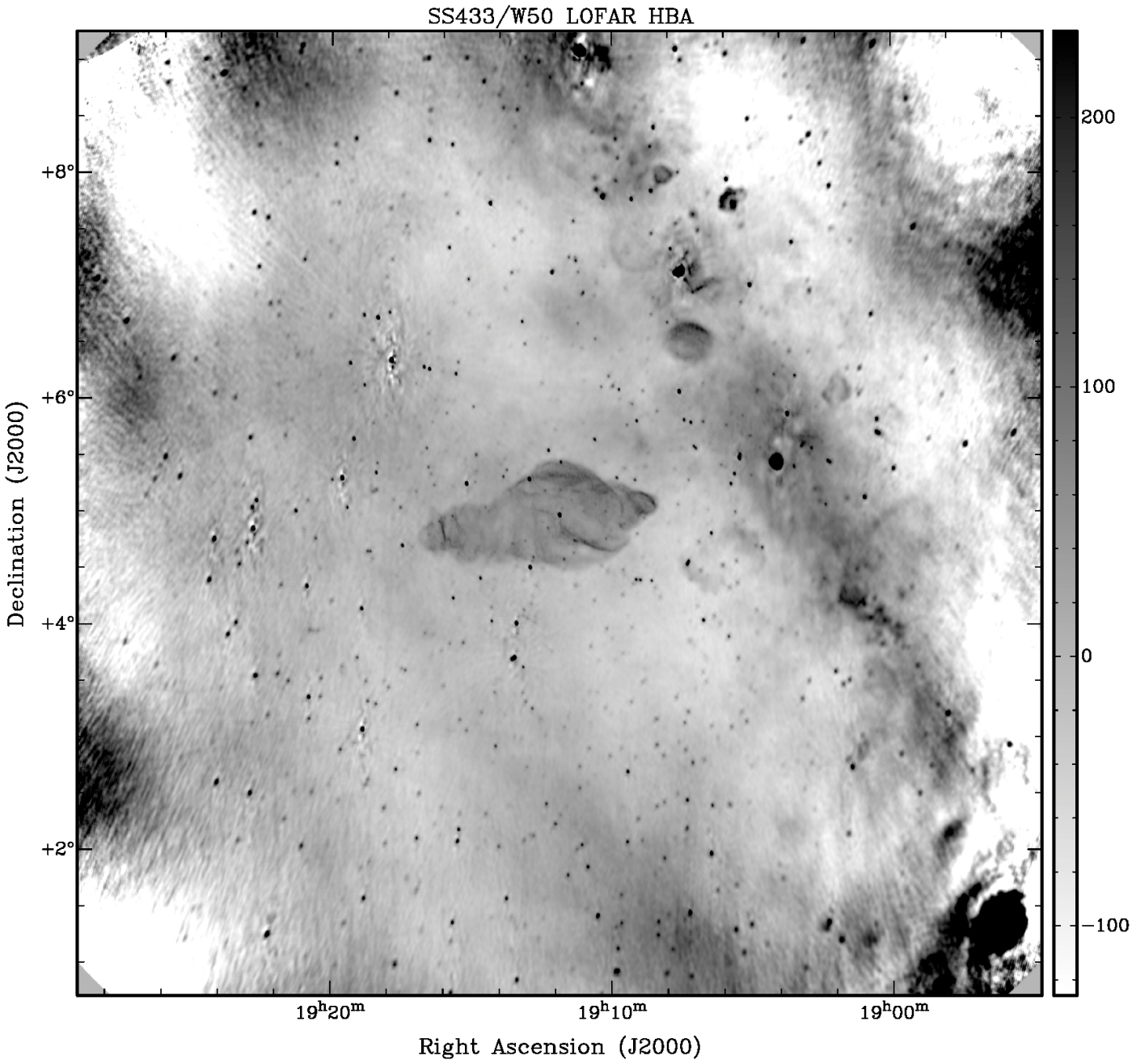

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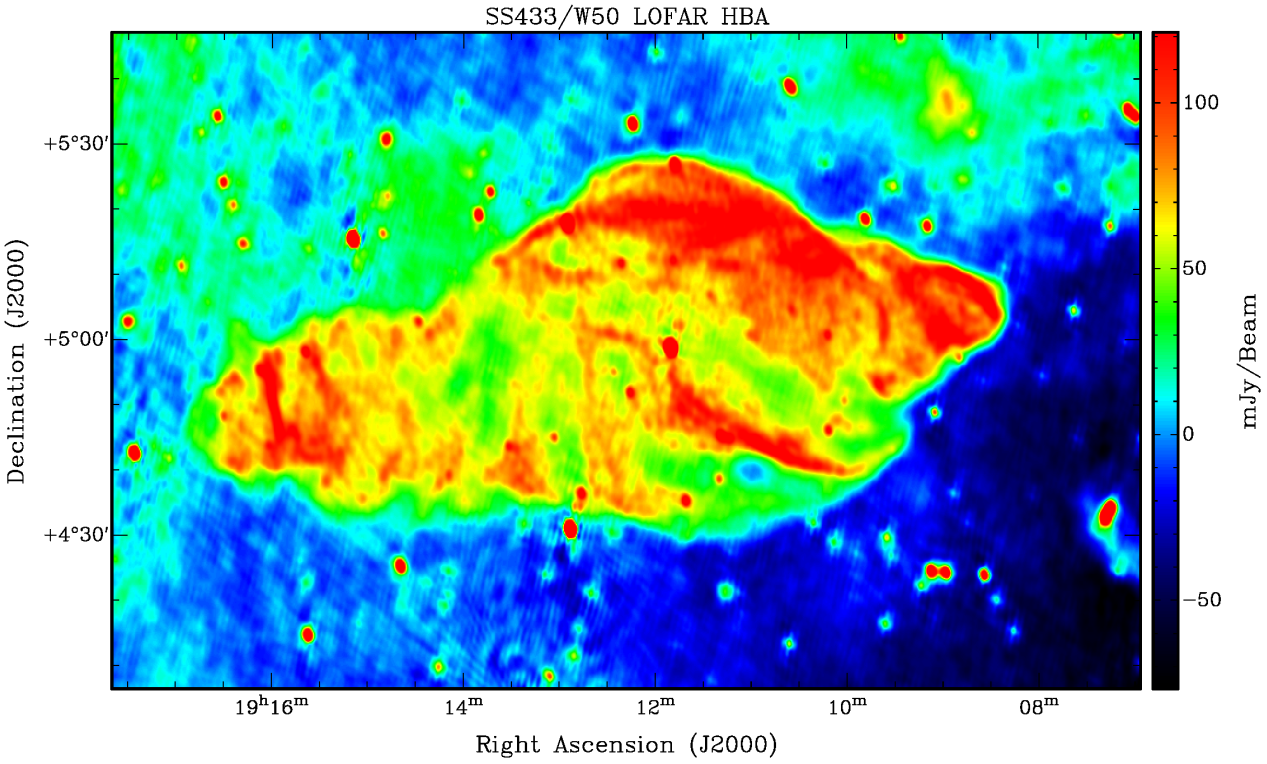
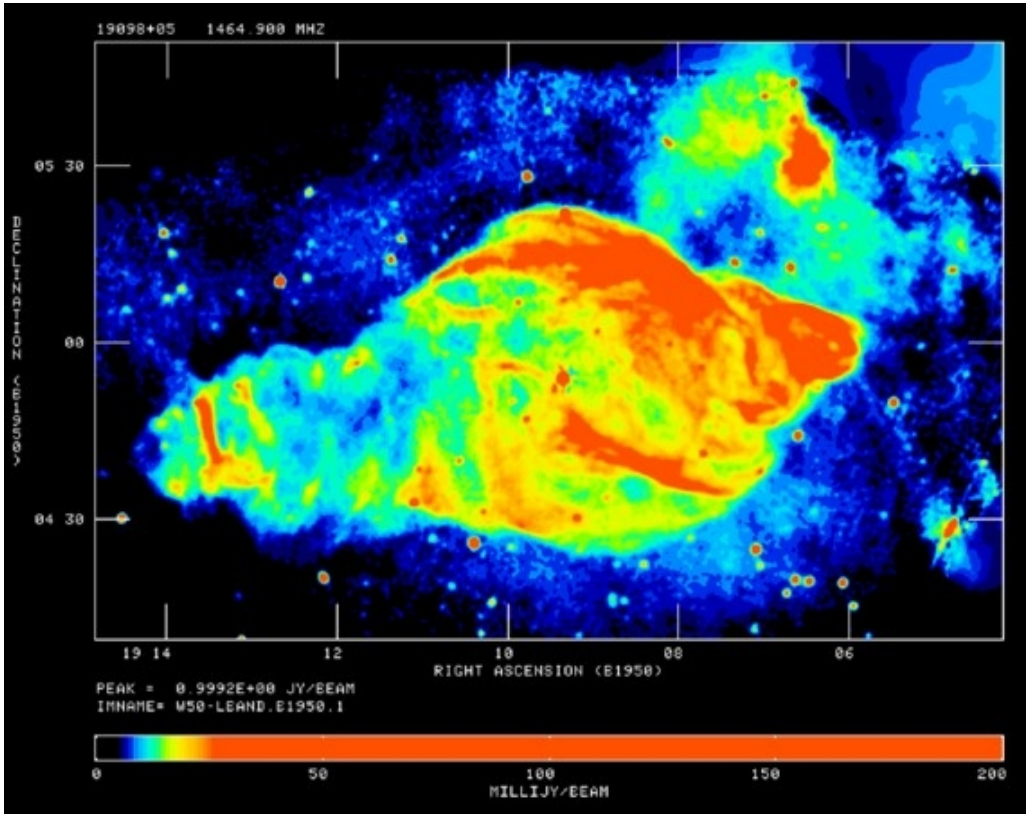


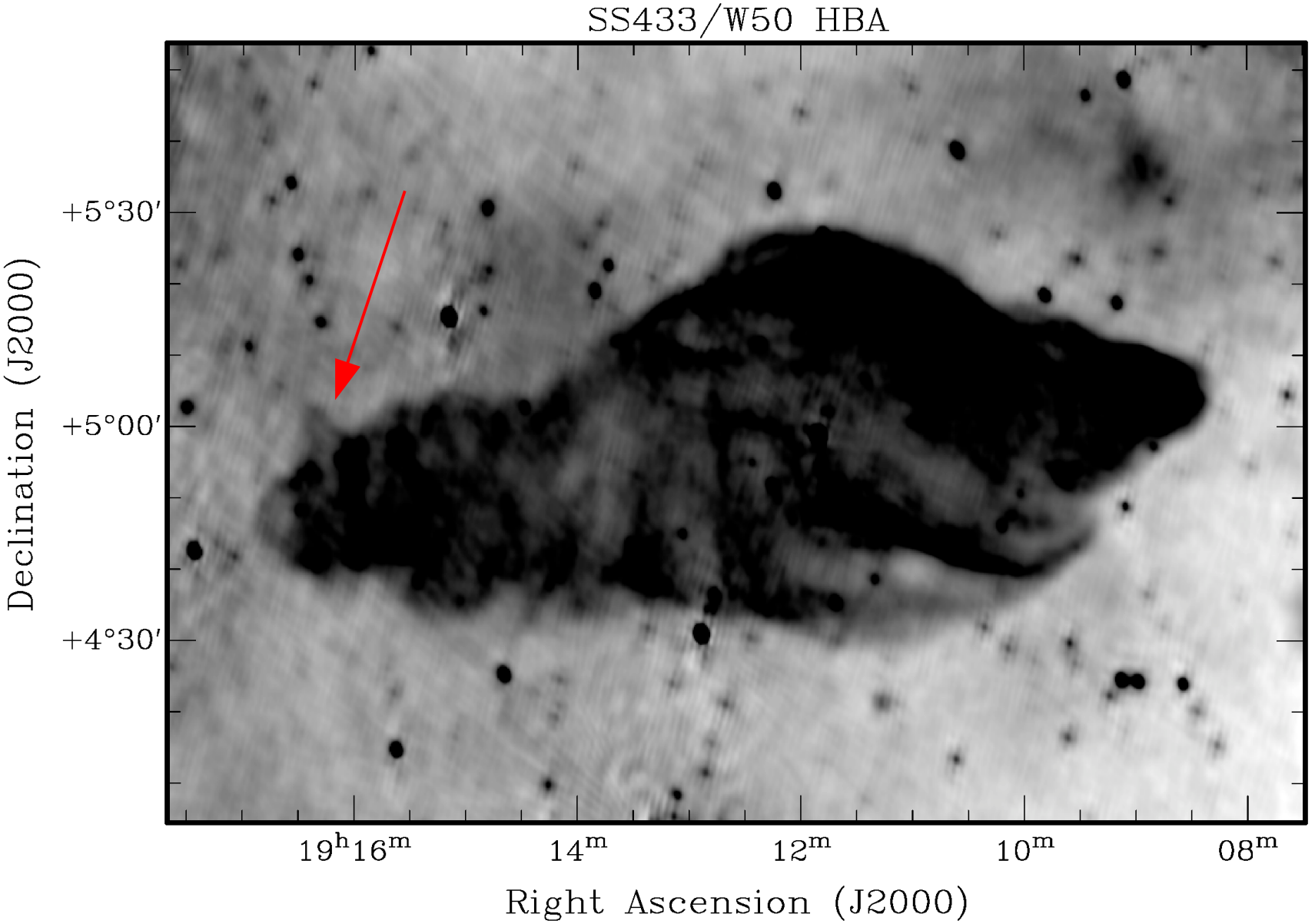
LOFAR HBA

* Resolution
  82 arcsec x
  58 arcsec

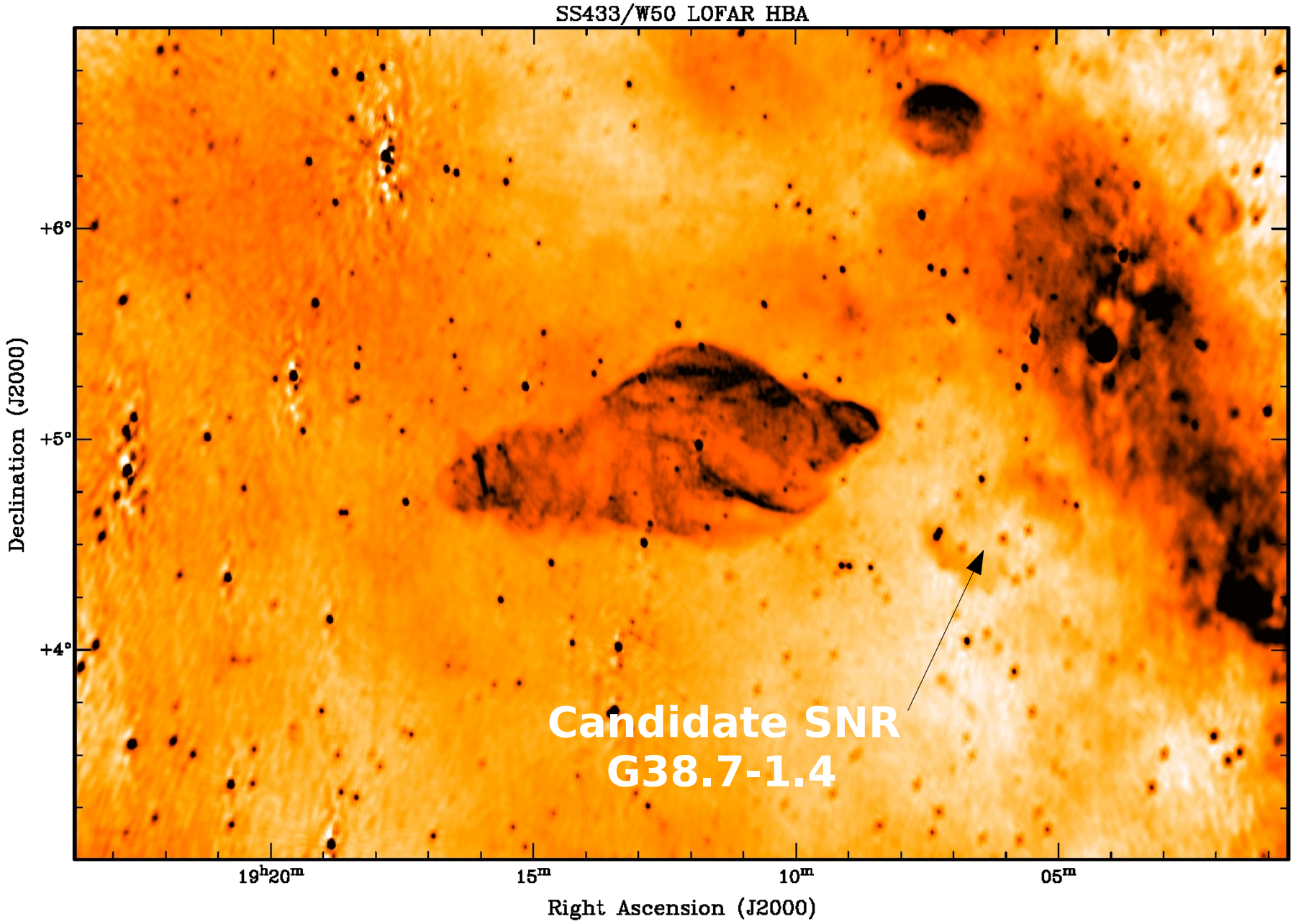


VLA 20 cm

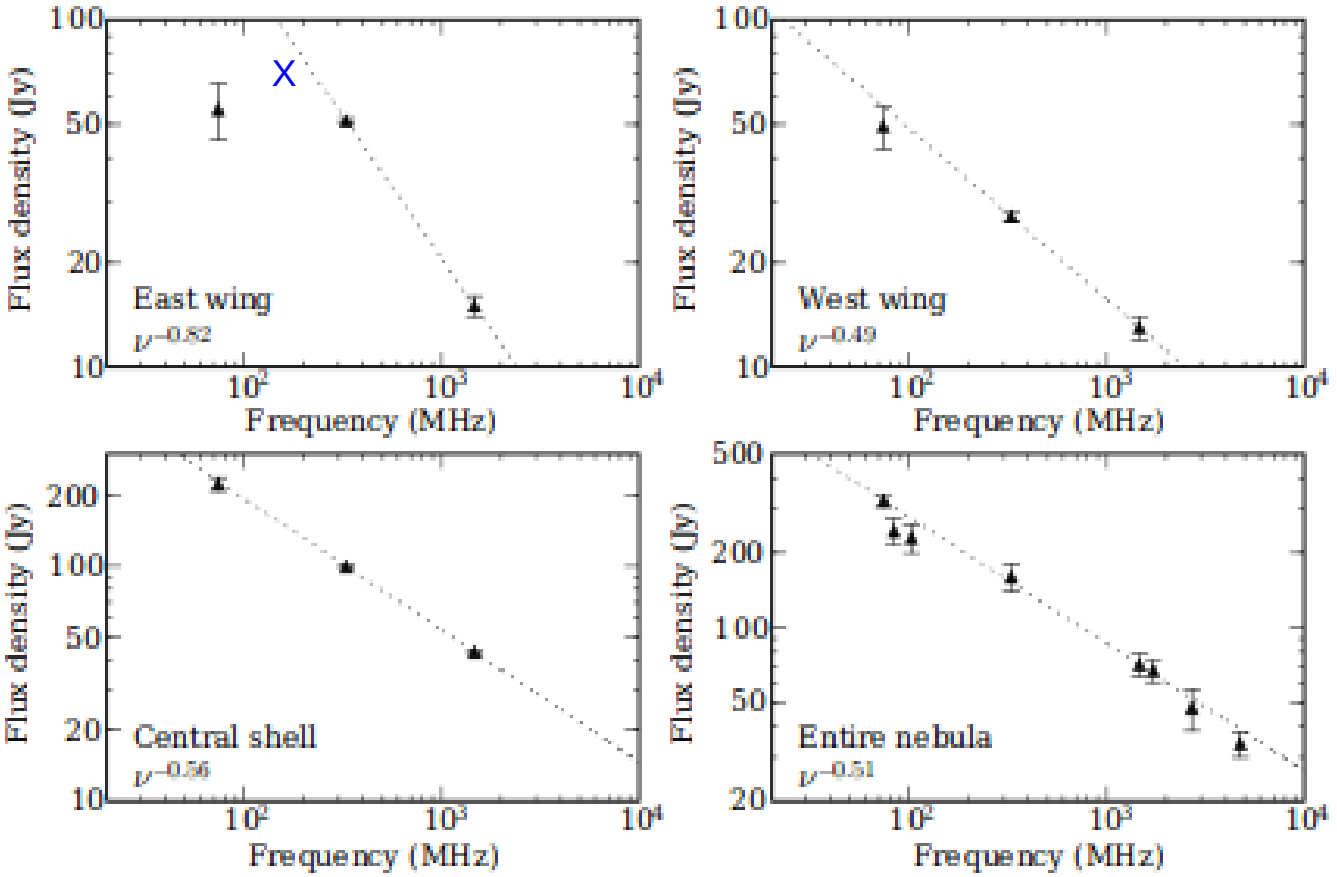
* Resolution
  56 arcsec x
  54 arcsec



*** 'Chimney' also seen at 1465 MHz (Dubner et al. 1998)**
*** Extension ~6 arcmin, width ~7 arcmin in base**
*** Two-point spectral index (145-1465 MHz) ~ -0.5**



Long-recognized incompleteness of Galactic SNR catalogues could be rectified with low-frequency studies (e.g. Brogan et al. 2004).

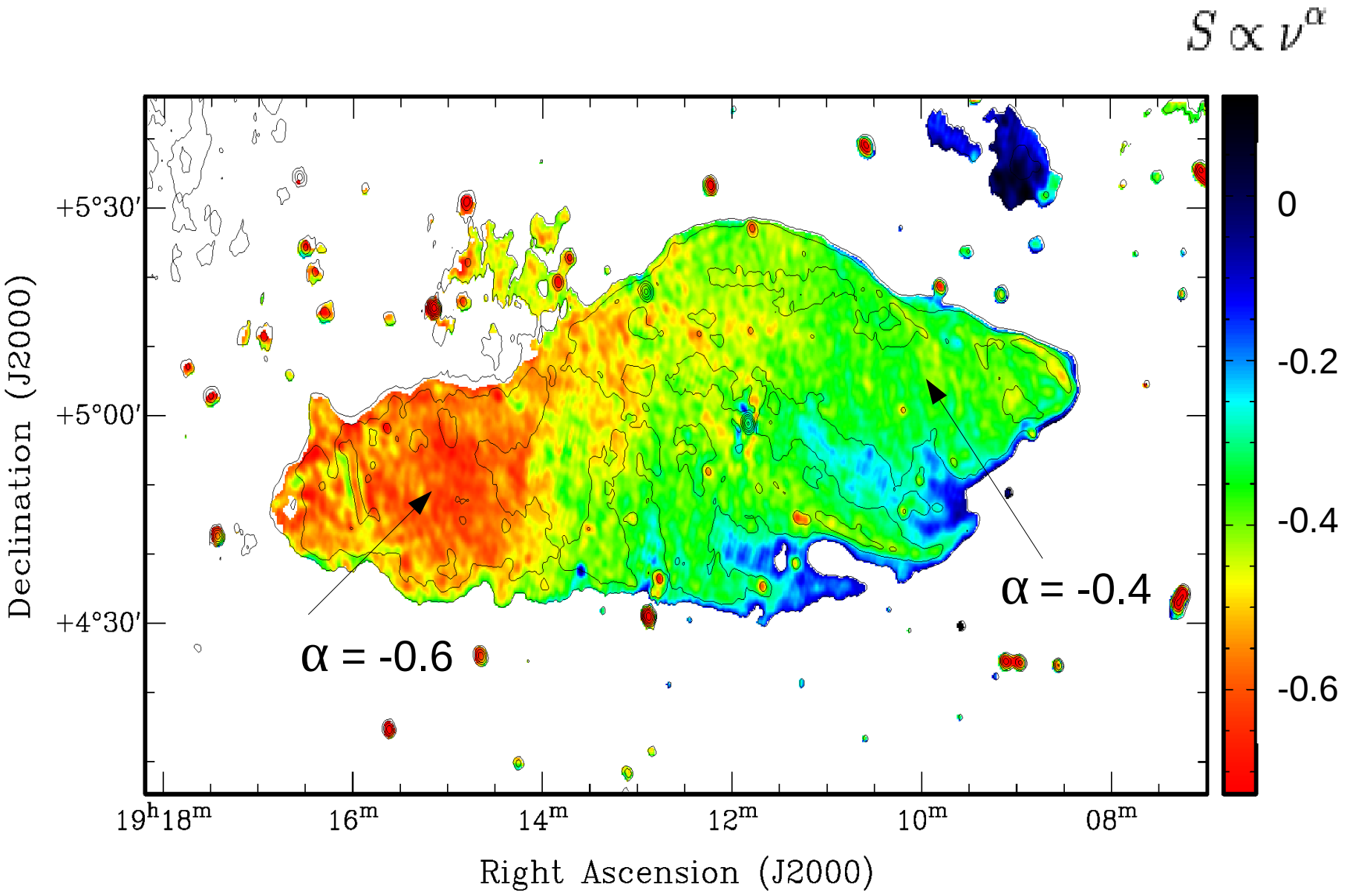


Miller-Jones et al. 2007

HBA flux densities:

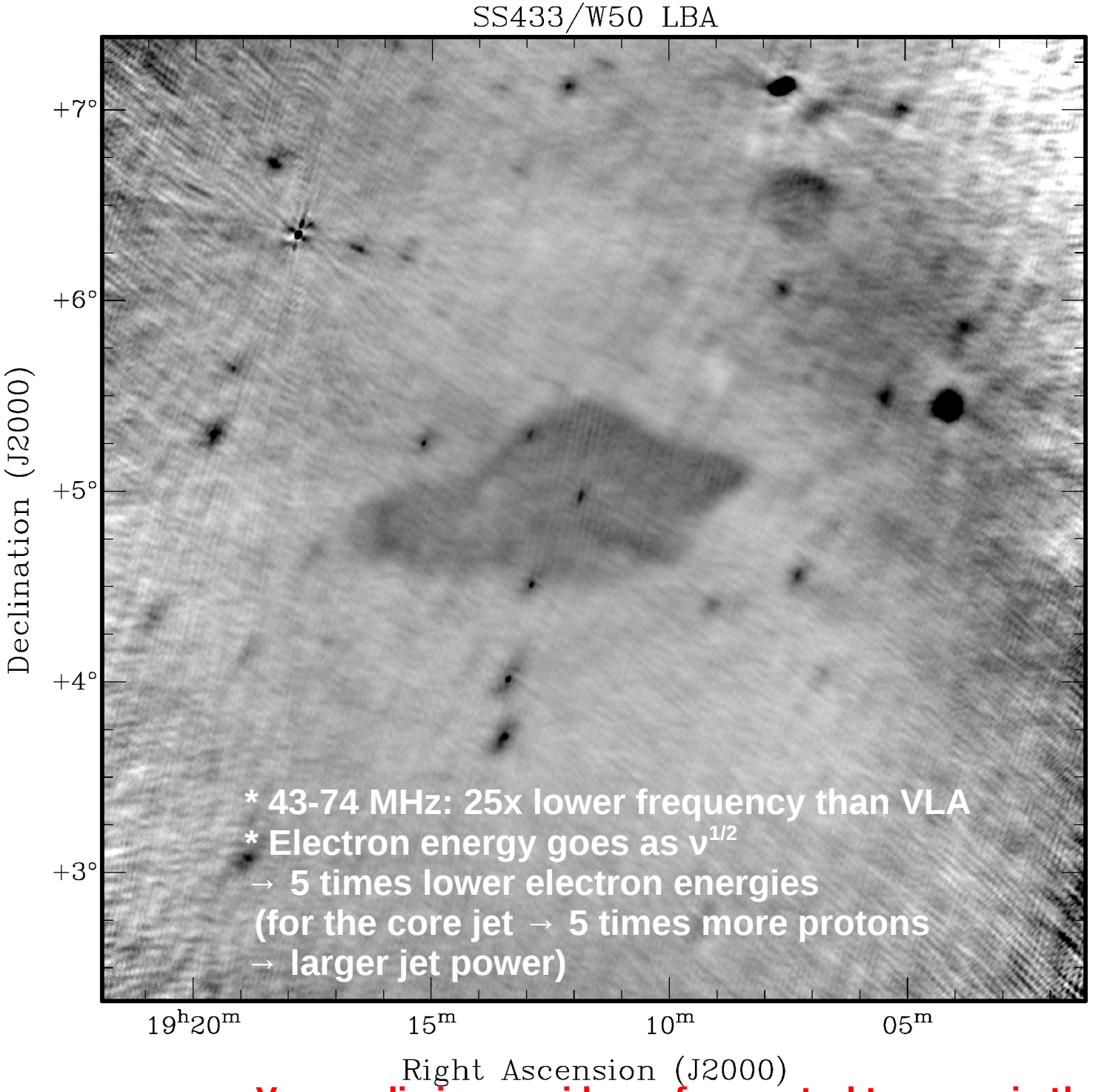
Central shell 152 ± 30 Jy (predicted 150 Jy)
Eastern wing 71 ± 14 Jy
Western wing 37 ± 7 Jy (predicted 40 Jy)
Entire nebula 260 ± 50 Jy (predicted 240 Jy)

Minimum energy ~10^{48} erg:
~0.1–1 per cent of the kinetic energy injected into surroundings by the jets.



*** Two-point spectral index map between 145 and 1465 MHz.**

*** Influence of fluctuating background levels still needs to be quantified properly.**



*** Preliminary 43-74 MHz averaged map from Cycle 0 (LBA_OUTER)**

*** 3.5h run 2013 February 13**

*** Simultaneous observations of target and calibrator**

*** Baselines < 12 km for imaging**

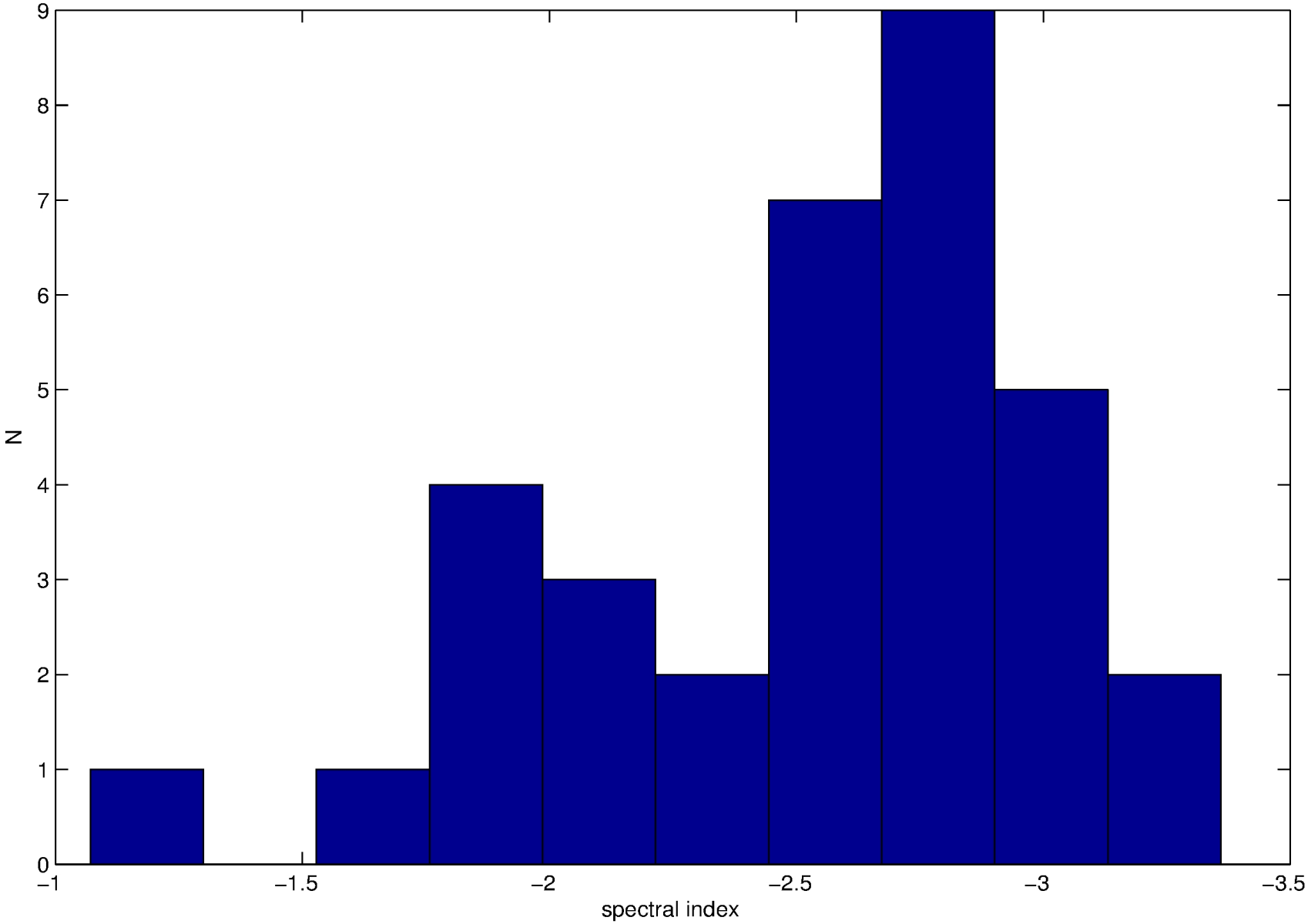
*** Robust=0**

*** Resolution 70 arcsec x 61 arcsec (PA 35 deg)**

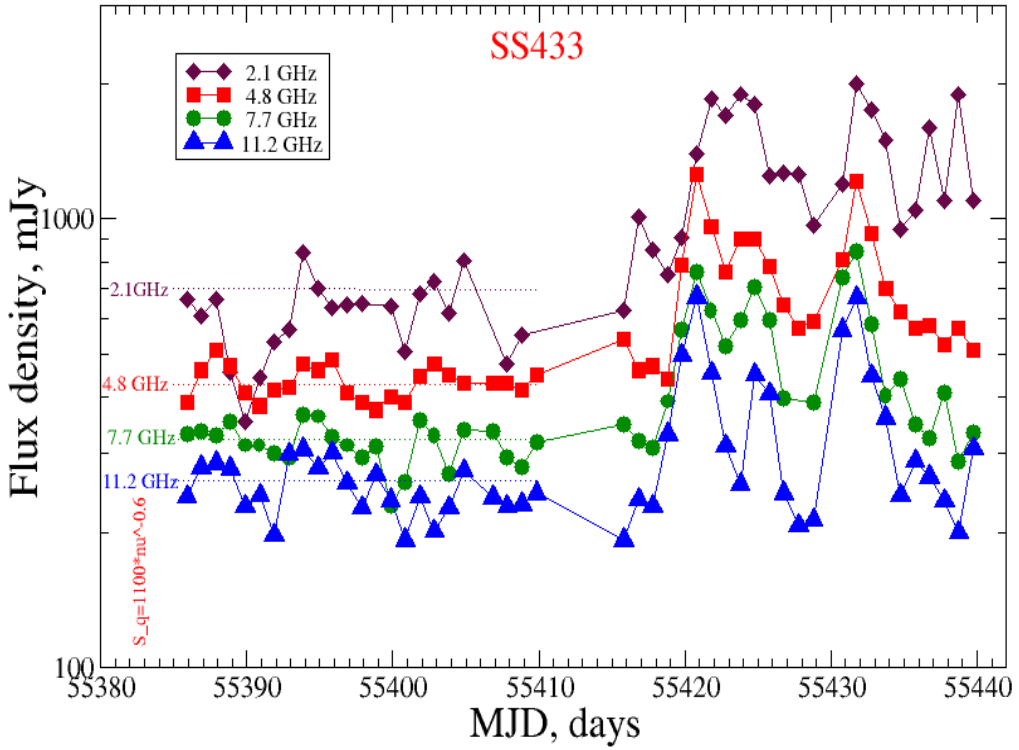
*** Noise 35 mJy/beam**

*** SS433 peak flux 0.7 Jy/beam**

Very preliminary evidence for spectral turnover in the LBA for SS433 and W50.



*** Spectral index for SS433 across LOFAR high band is far too steep (~ -2).**
*** Similar problem seen for other sources in field, and also in MSSS mosaic containing SS433. But average flux densities across band look fine....**

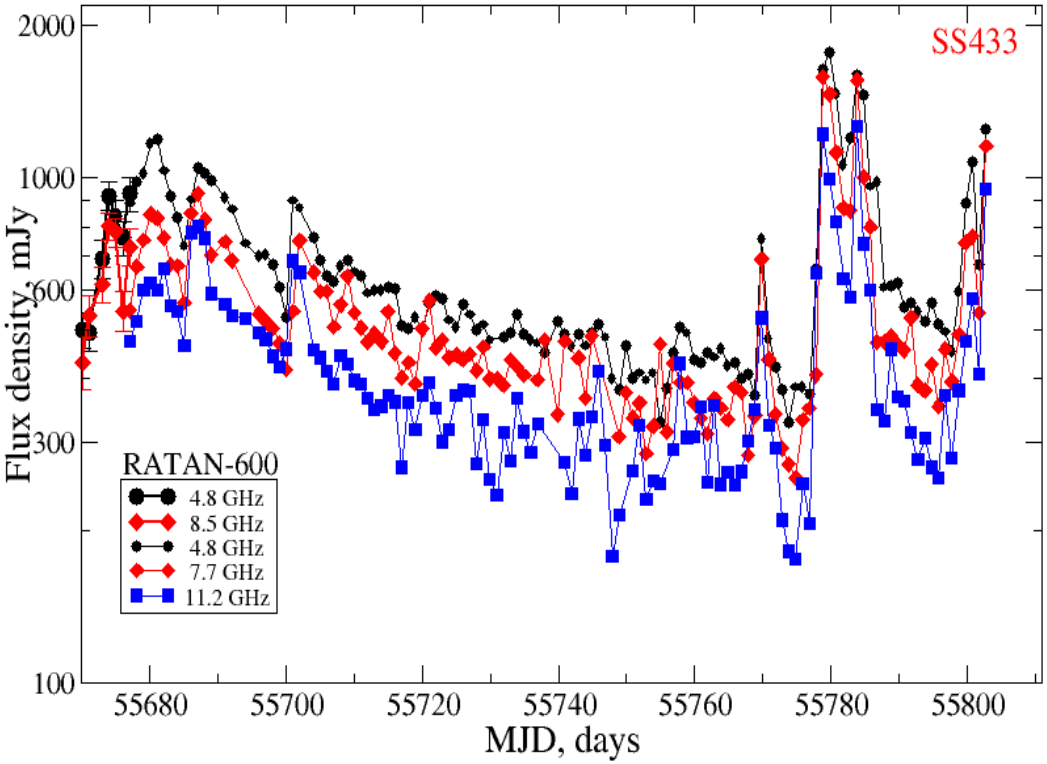


ATel #2812

(Trushkin & Nizhelskij; SAO RAS)

ATel #3547

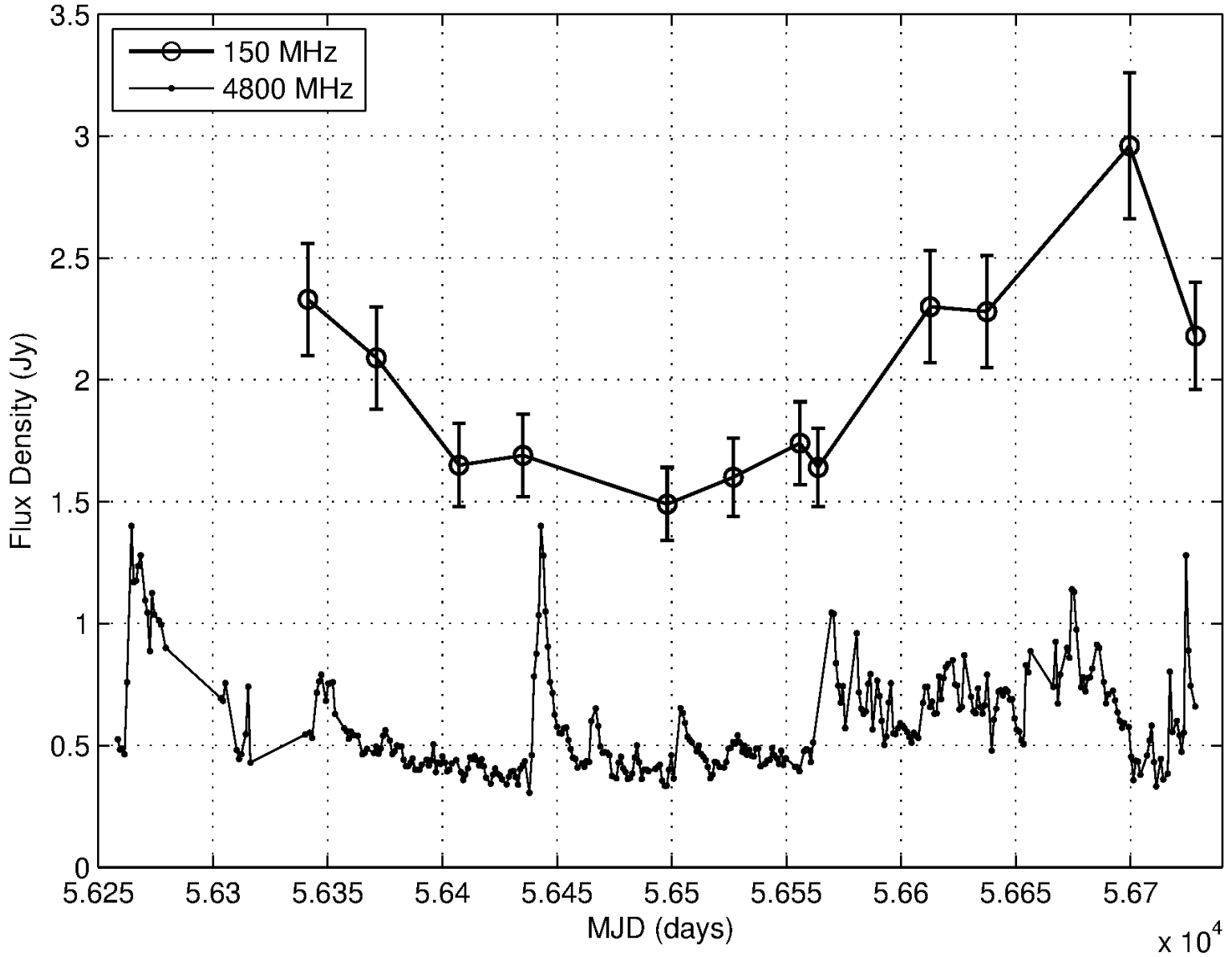
(Trushkin, Nizhelskij & Zhekanis; SAO RAS)



GHz-frequency variability

Broderick et al., in prep.

HBA monitoring Feb 2013 – Mar 2014



(RATAN-600 data; courtesy S. Trushkin)

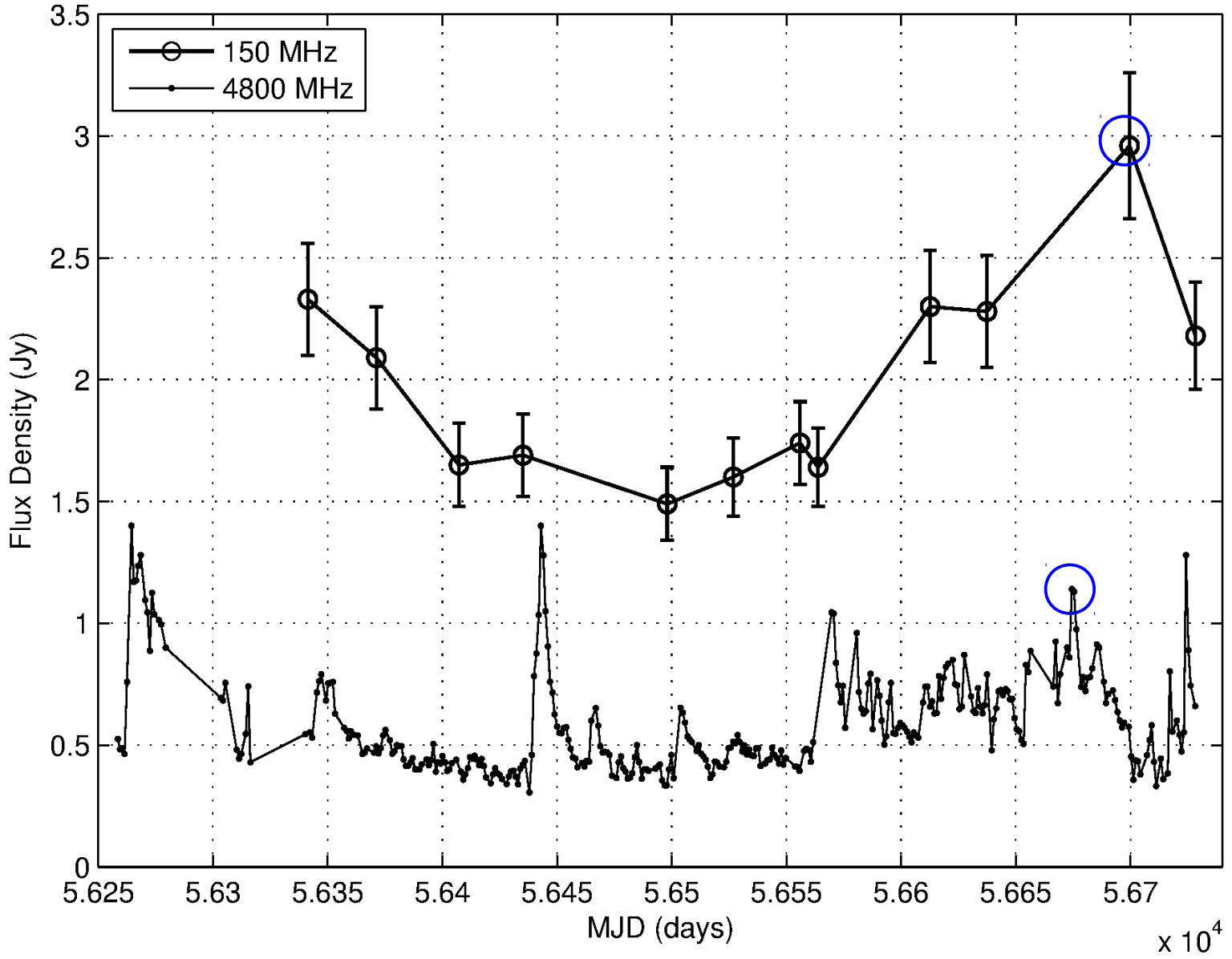
*** LOFAR calibration uncertainty ~10%.**

*** Resolution 150 MHz: 140 arcsec x 100 arcsec (baselines 0.1-3kλ)**

*** Indications of low-frequency variability → illustration of how LOFAR can become a key trigger for other facilities.**

Broderick et al., in prep.

HBA monitoring Feb 2013 – Mar 2014



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*** LOFAR calibration uncertainty ~10%.**

*** Resolution 150 MHz: 140 arcsec x 100 arcsec (baselines 0.1-3kλ)**

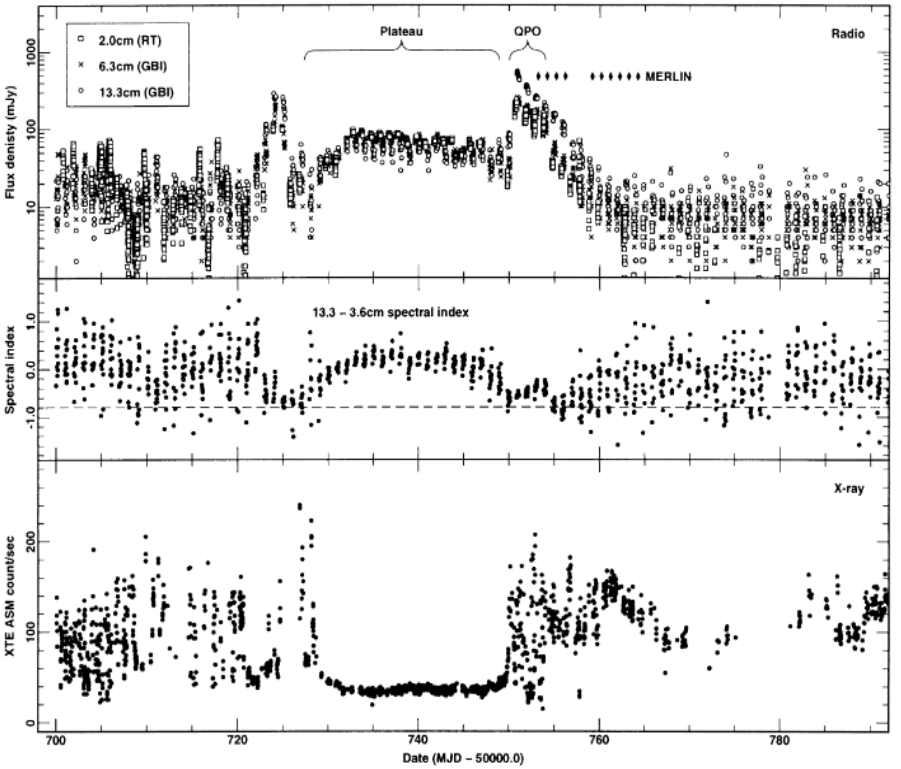
*** Indications of low-frequency variability → illustration of how LOFAR can become a key trigger for other facilities.**

GRS 1915+105

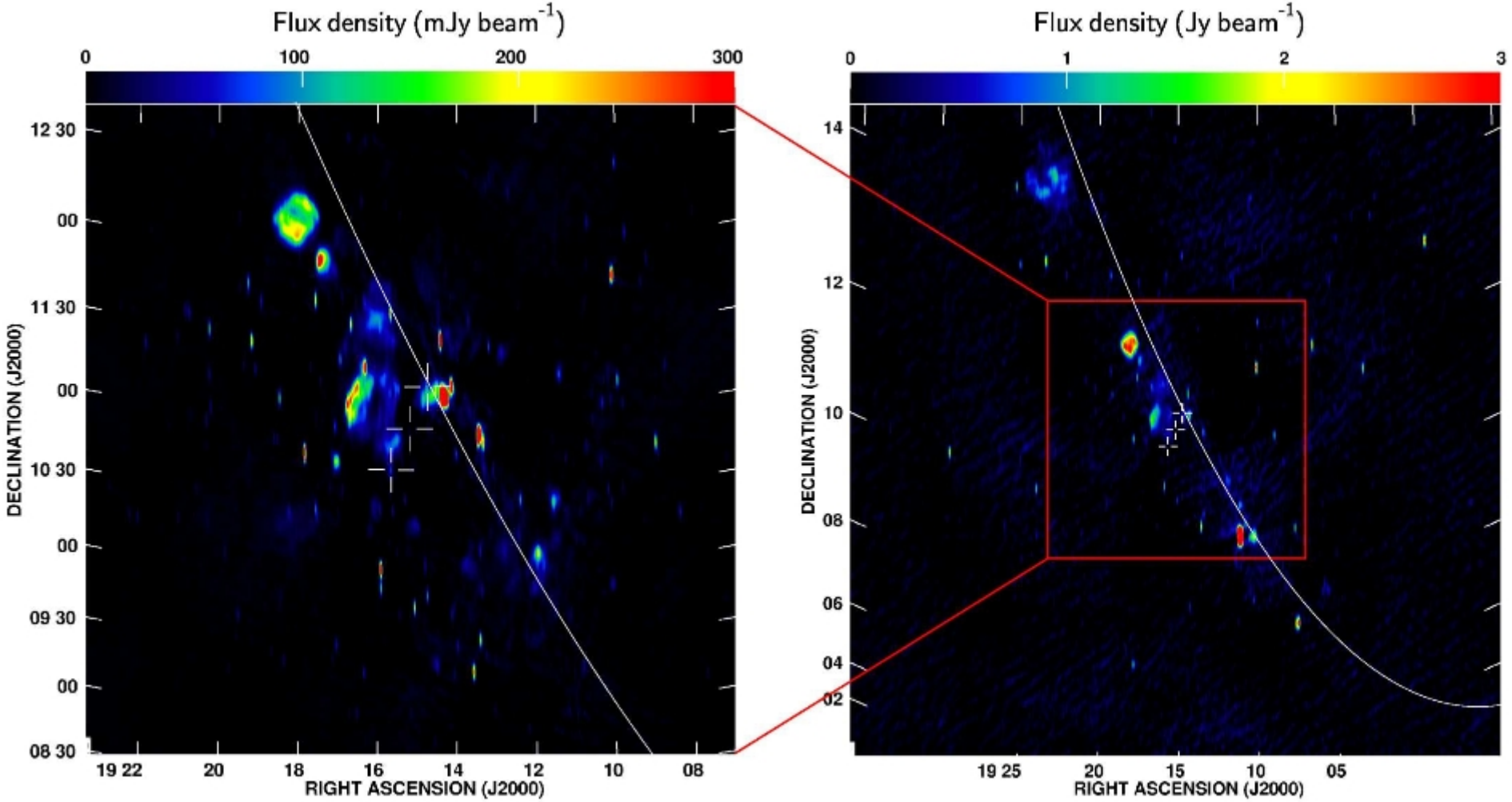
* Canonical microquasar system at D = 11 kpc.
* Jets with velocities > 0.9c (Mirabel & Rodriguez 1994, Fender et al. 1999).
* 244 MHz flux density reaches 750 mJy (Ishwara-Chandra et al. 2005).
* Existence of jet-inflated lobes around GRS 1915+105 has previously been suggested, although the evidence to date is inconclusive (e.g. Chaty et al. 2001).

LOFAR observations:

* 10.5 hours over 4 runs in 2013 November (LC1_023+DDT1_001).
* 108 'spare' sub-bands spanning 140-160 MHz.
* Similar reduction strategy as for SS433/W50.

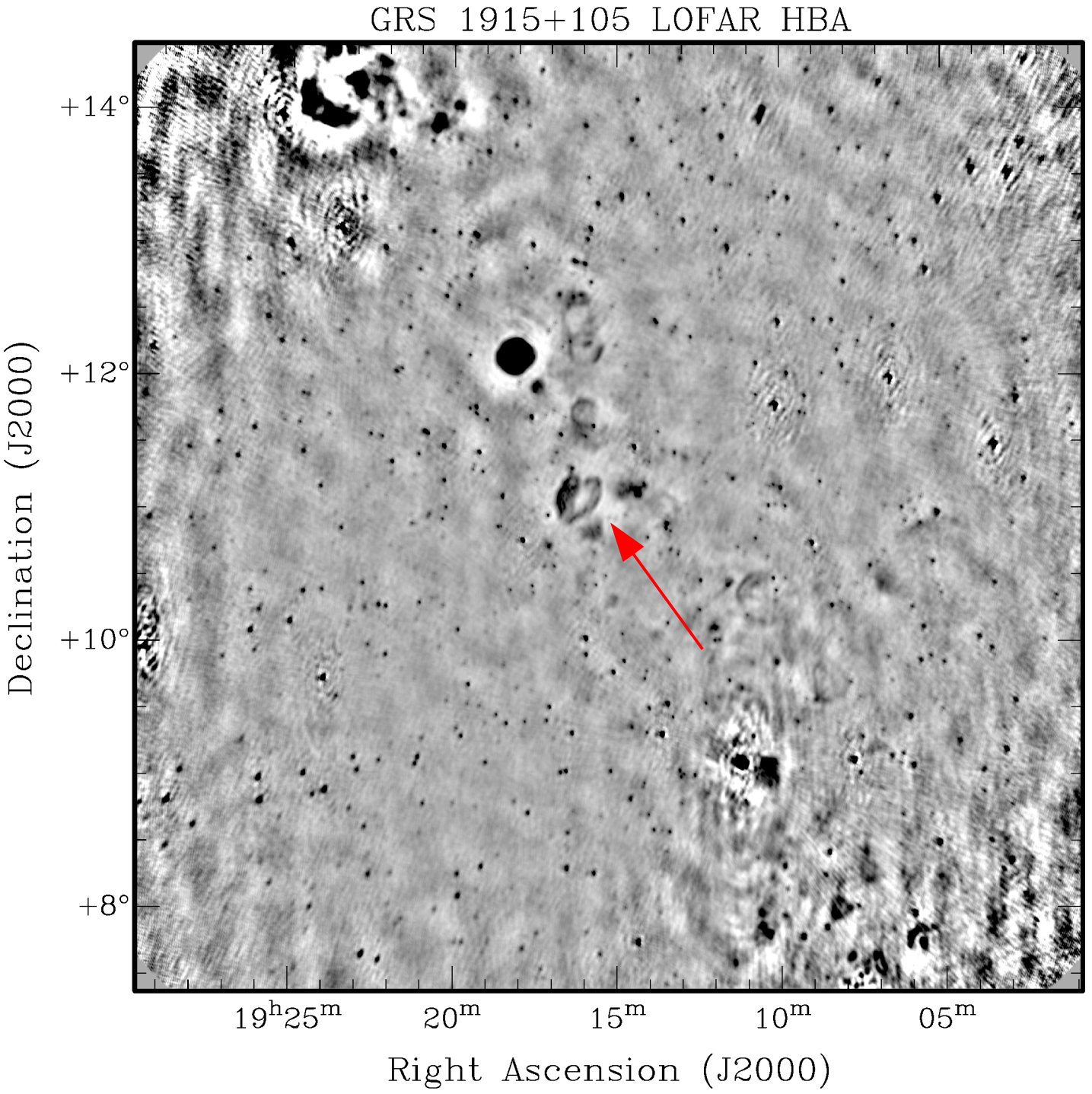


Fender et al. 1999



Miller-Jones et al. 2007

92 cm WSRT (left) and 2 m LFFE (right)



* HBA_DUAL_INNER map from Cycle 1

* 10.5h over 4 runs in 2013 November

* 20 MHz bandwidth; 140-160 MHz

* Observations of 3C380 every ~20 min

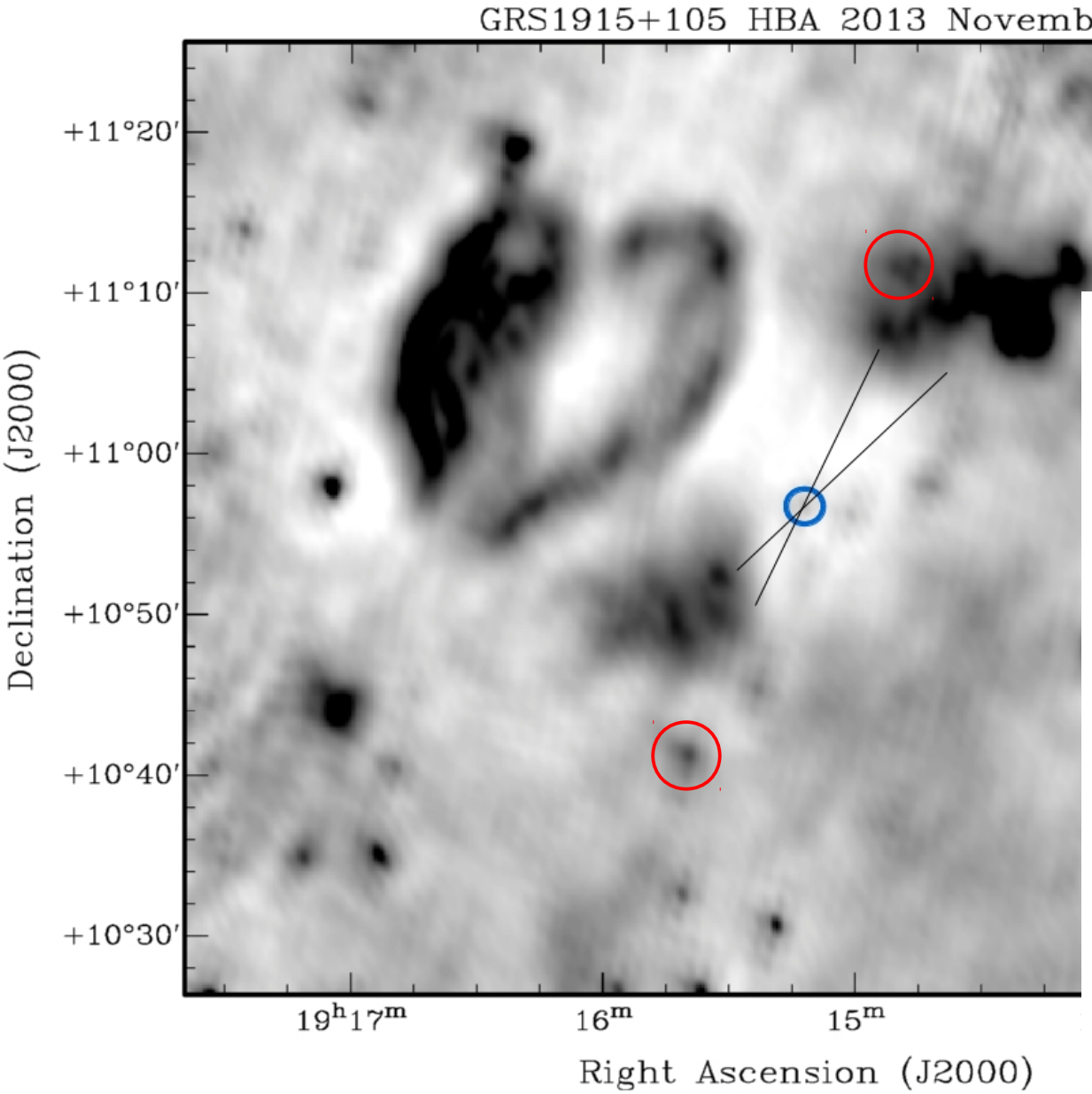
* Baselines 0.1-6kλ (~0.2-12 km) for imaging

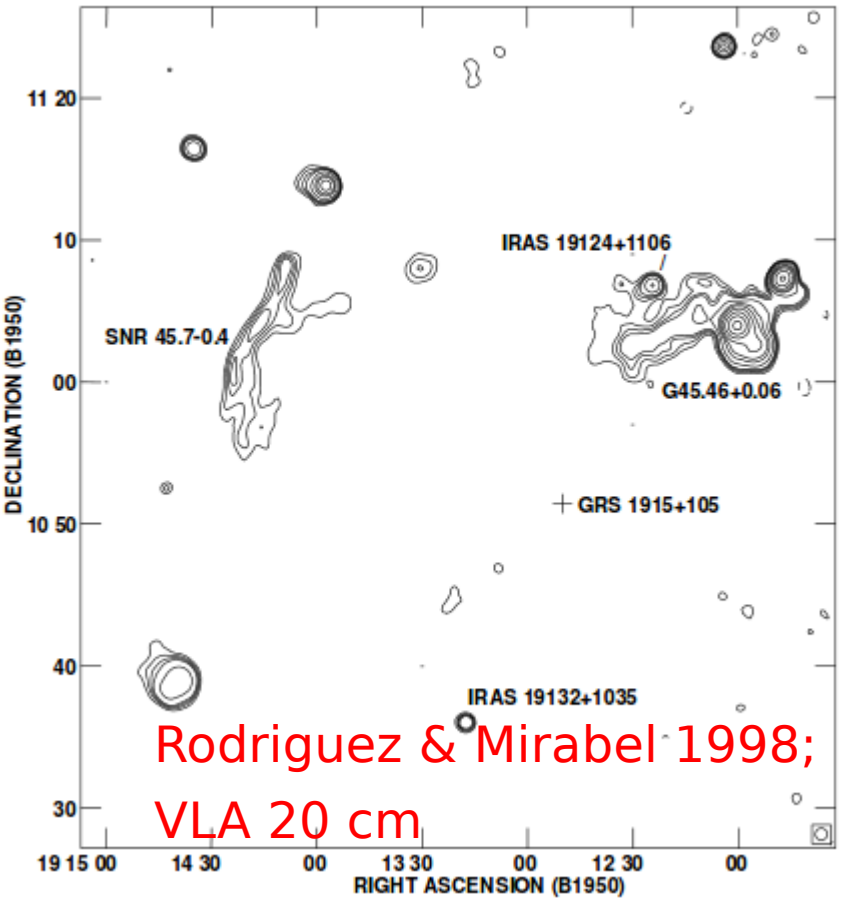
* Robust=0

* Resolution 60 arcsec x 40 arcsec (beam PA 14 deg)

* Noise ~10 mJy/beam

* GRS 1915 flux ~30 mJy

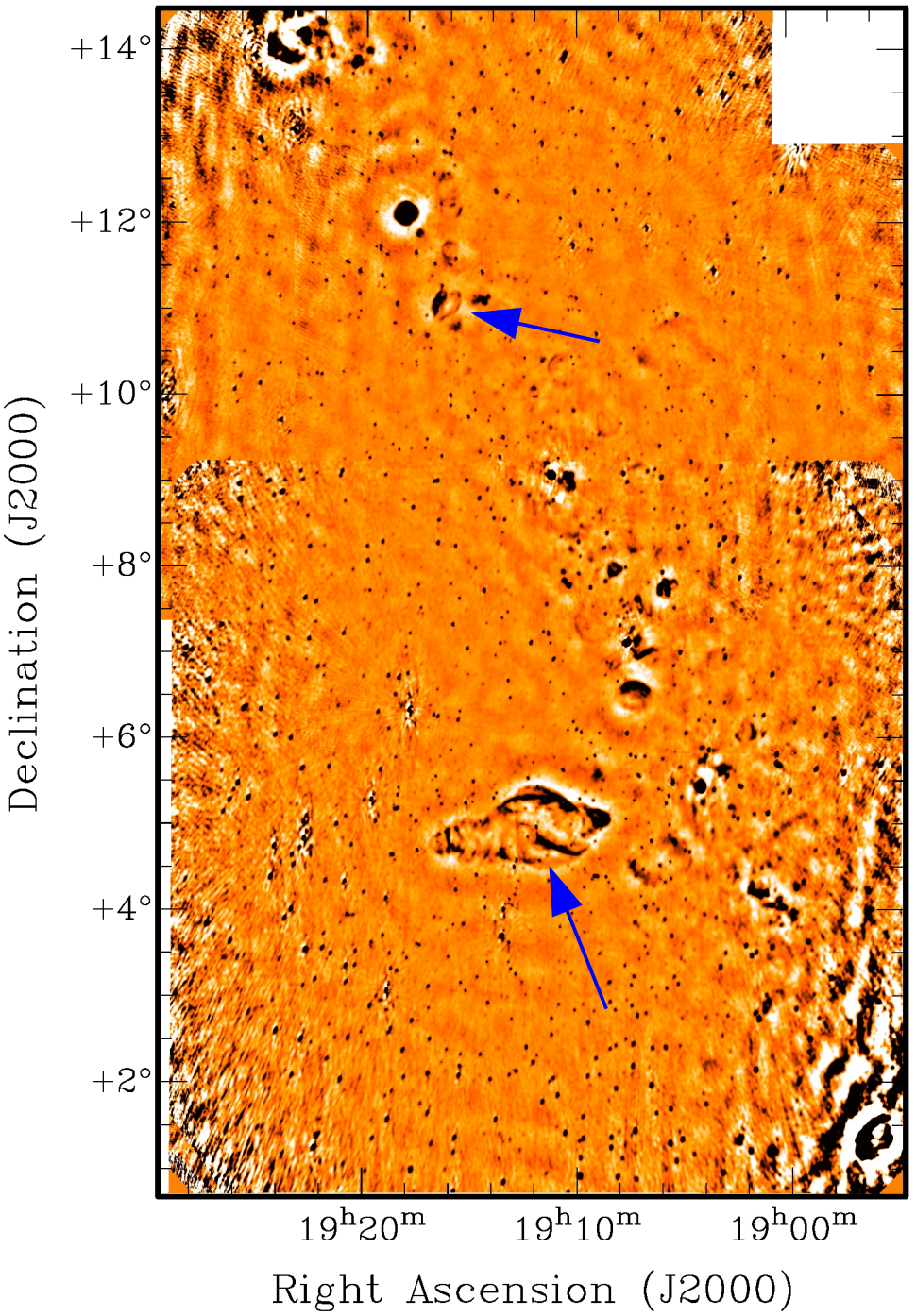




Rodriguez & Mirabel 1998;
VLA 20 cm

*** Measurement of the low-frequency morphology and spectra of the extended emission would help resolve debate. Should they be associated with the jets, could determine time-averaged jet power.**

Summary and future work



HBA mosaic of SS433/GRS1915 fields

* High-quality SS433/W50 data – paper in preparation.

* Variability detected for SS433 in high band.

* SS433 LBA observations to be fully reduced.

* Spectral index map between HBA and LBA.

* International station data for one HBA monitoring run.

* Multi-scale, wide-band deconvolution in updated AWImager.

* Higher-resolution HBA maps.

* GRS 1915+105 detection; jet-inflated lobes?

* Cycle 2 request: deep HBA observations of GRS 1915+105 and Cygnus X-1/X-3.

Thanks to Science Support and all of the LOFAR commissioners!