Blazars at Low Radio Frequencies

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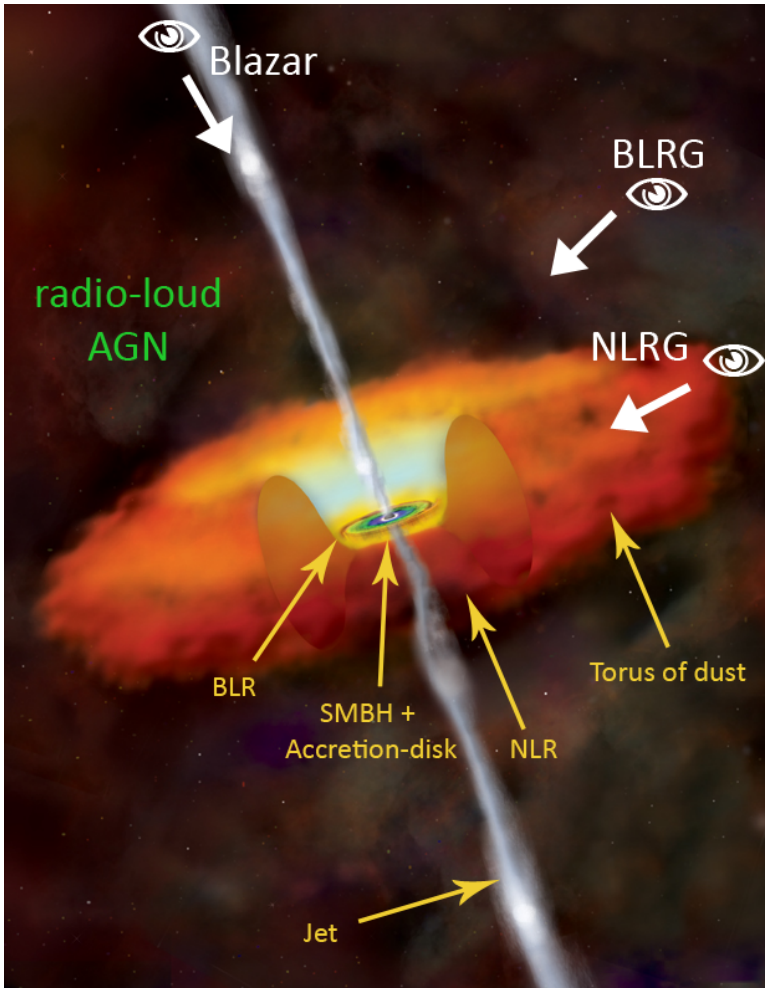
Testing the AGN Unification

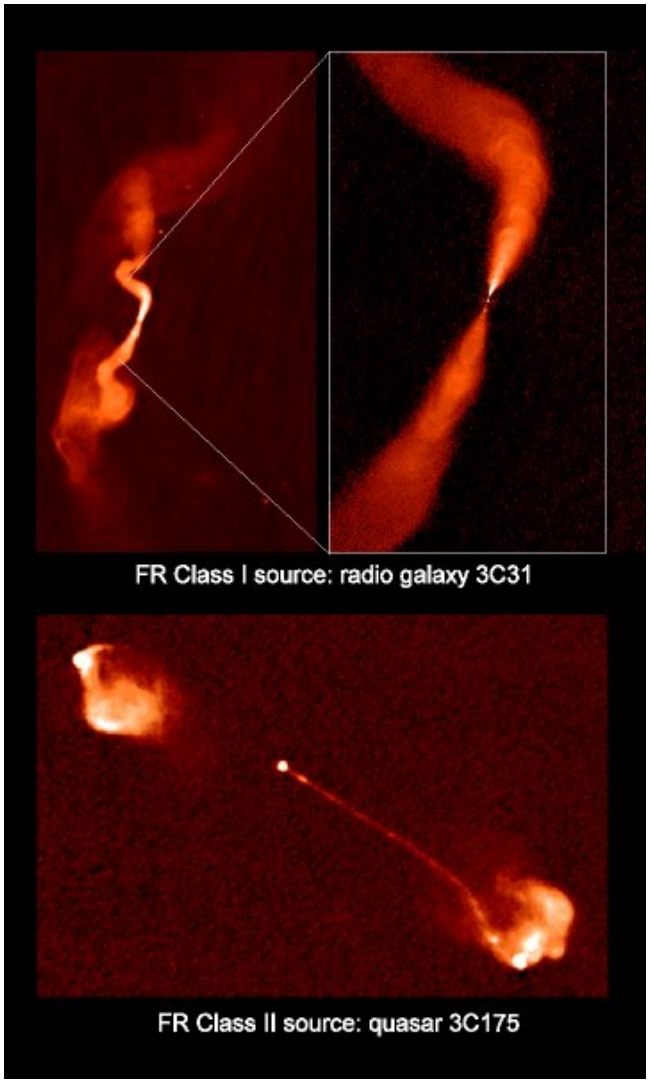
Unification model:

- angle-dependency
  - radio galaxies
  - blazars
- luminosity
  - FR I
  - FR II
- strong beaming for blazars

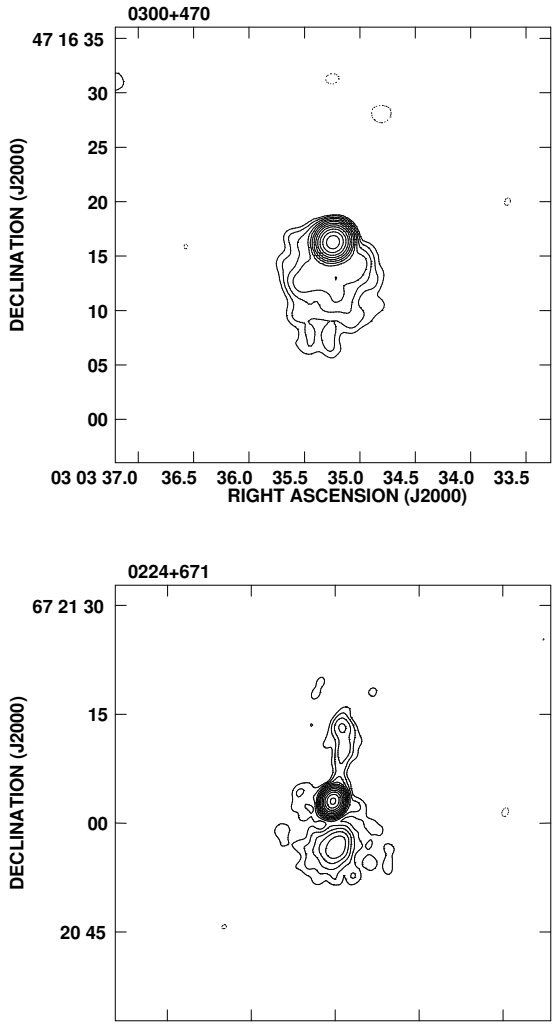


Scheme of unification model for radio-loud AGN.
Credit: NASA/CXC/M.Weiss (modified)

AGN Unification



VLA images of 3C31 at 1.4 GHz (left) and 8.4 GHz (right) and 3C175 at 4.9 GHz (bottom). Credit: Bridle



VLA-view at 1.4 GHz: BL Lac 0300+407 (top) and quasar 0224+671 (bottom). Taken from Cooper et al. (2007)

Aim of the Project

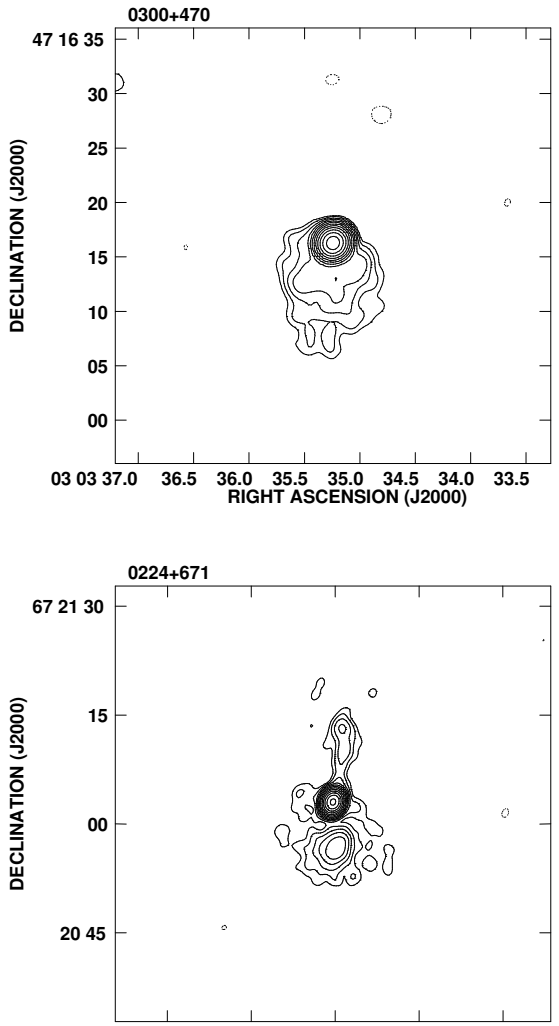
Aim:

→ imaging of blazars at low frequencies

→ test unification model:
FR I/FR II ⇒ BL Lac/Quasar

Challenge:

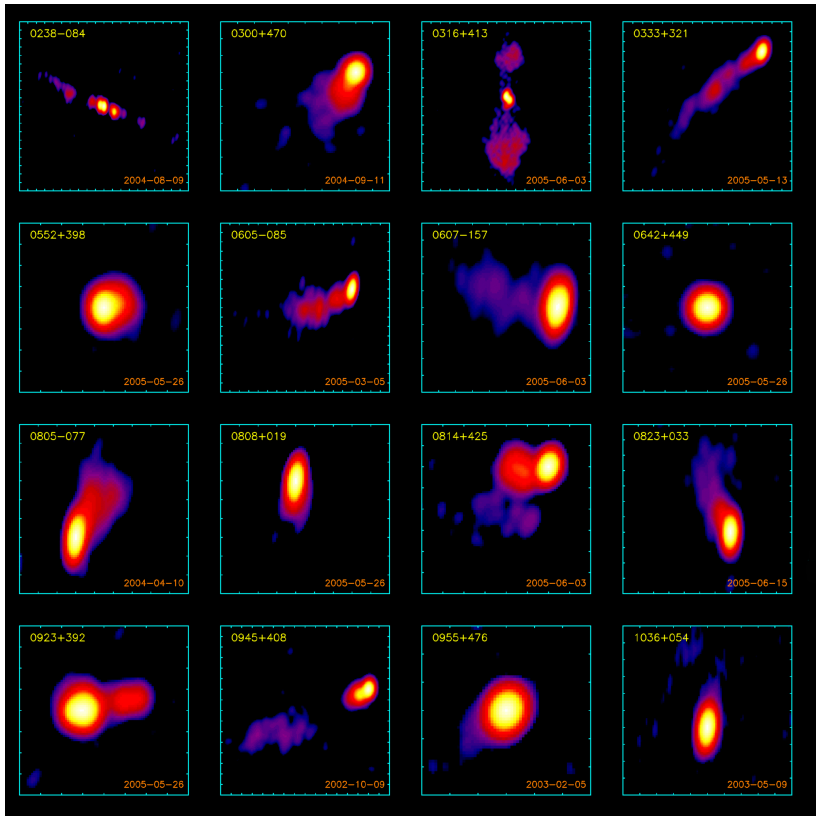
- emission of the jet and the core at GHz-Frequencies beamed
- dominated by core emission



VLA-view at 1.4 GHz: BL Lac 0300+407 (top) and quasar 0224+671 (bottom). Taken from Cooper et al. (2007)

MOJAVE

- MOJAVE*: Monitoring of Jets in Active galactic nuclei with VLBA Experiments
- largest ongoing monitoring survey in Northern Hemisphere
- MOJAVE 1 sample with 135 brightest core-dominated extragalactic jets (>1.5 Jy at 15 GHz)
- kinematics well studied at 15 GHz
- statistical complete sample



Example of VLBI radio images for MOJAVE sources. Credit: MOJAVE

*PI: Lister, http://www.physics.purdue.edu/astro/MOJAVE/

LOFAR

LOFAR (Low Frequency Array):

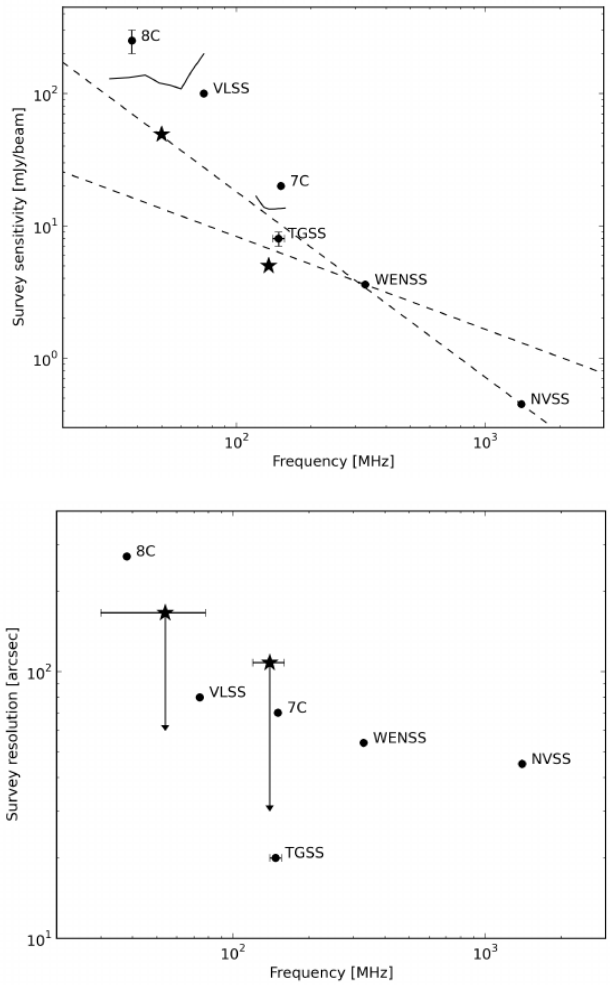
- Frequency ranges:
  - LBA (low band antennas): 10-90 MHz
  - HBA (high band antennas): 110-250 MHz
- stations:
  - 24 core stations (2 km baseline)
  - 14 remote stations (100 km baseline)
  - 8 international stations (1000 km baseline)

Location of European LOFAR stations. Credit: ASTRON

MSSS

MSSS - "Multifrequency Snapshot Sky Survey" with LOFAR:

- first northern-sky imaging survey with LOFAR
- covering frequencies 30-160 MHz (LBA + HBA)
- including polarization measurements
- many ongoing early science studies:
  Transients, pulsar-search, magnetism, galaxy clusters, star-forming galaxies, AGN, supernovae, unknown diffuse emission

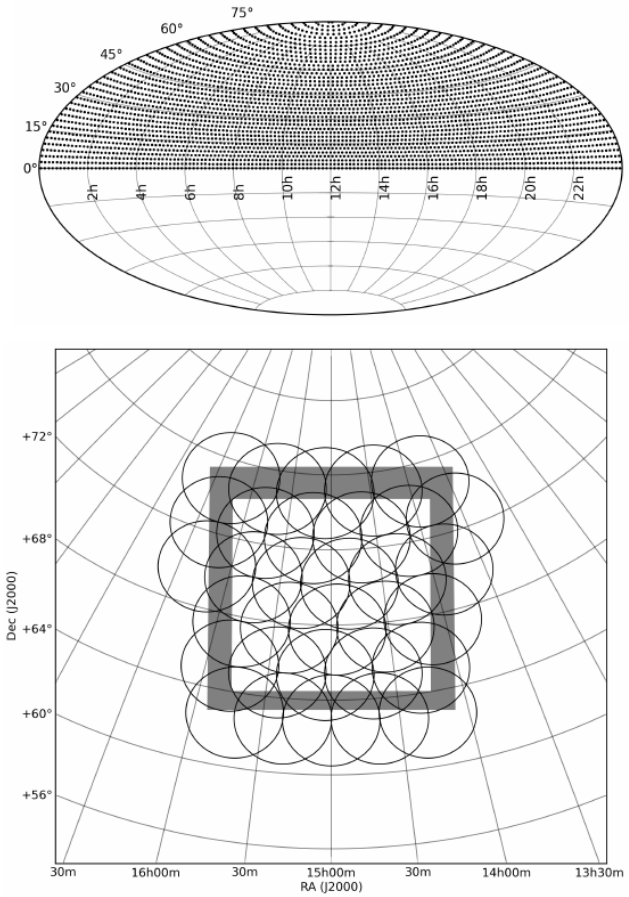


Taken from Heald et al., in prep

Possibilities with MSSS

Using preliminary HBA MSSS-data (120-160 MHz):

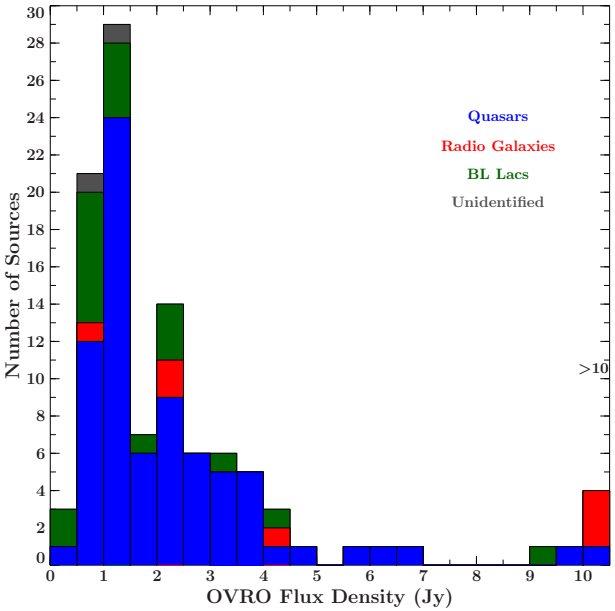
- Images with uv-limit: 2 kλ
  $\rightarrow$ $\sim$110 arcsec resolution
  $\rightarrow$ most sources unresolved
- 105 out of 135 sources overlap between MOJAVE1 and MSSS
- low-frequency properties of MOJAVE1 sources
- MSSS-flux densities compared to simultaneous OVRO observation (15 GHz single dish, 157 arcsec)

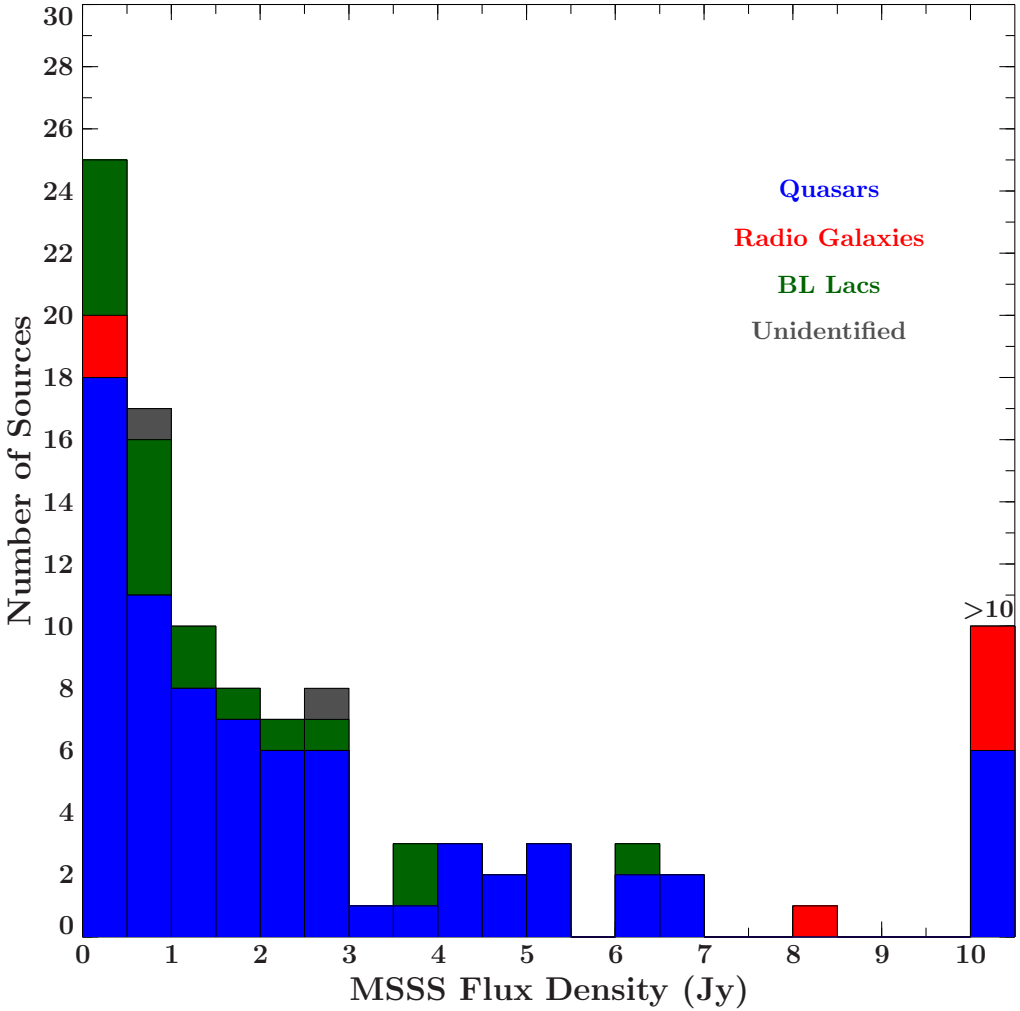


Taken from Heald et al., in prep

Flux-Density Distribution

- distribution similar to 15 GHz
- most sources unresolved
- brightest objects: nearby radio galaxies

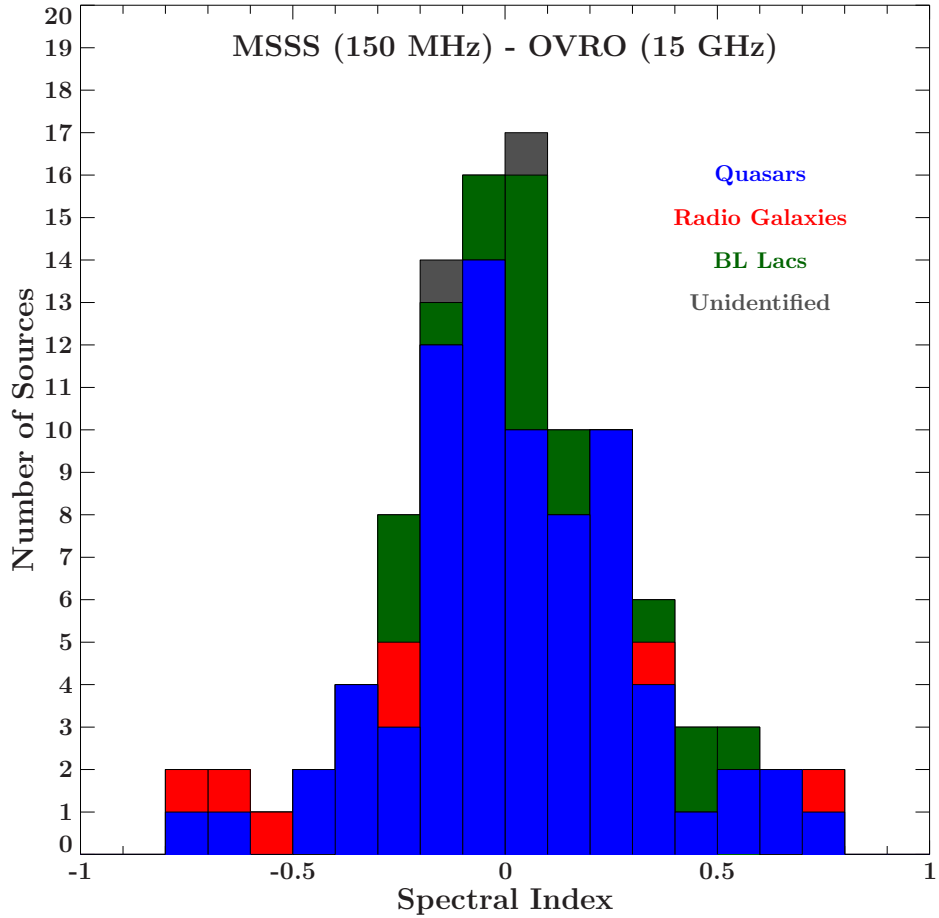




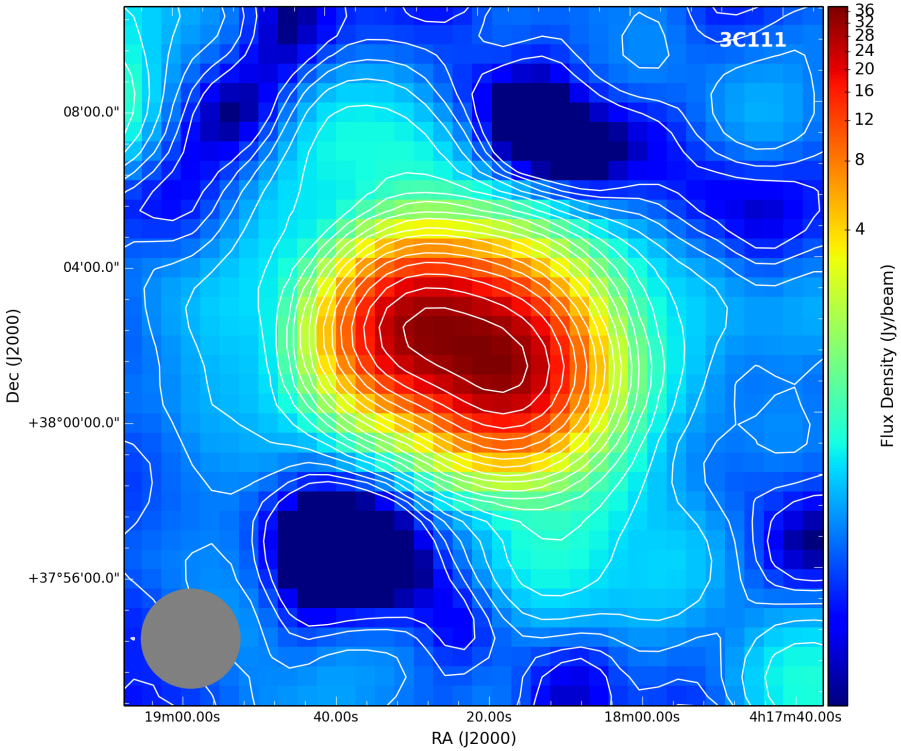
Spectral Indices

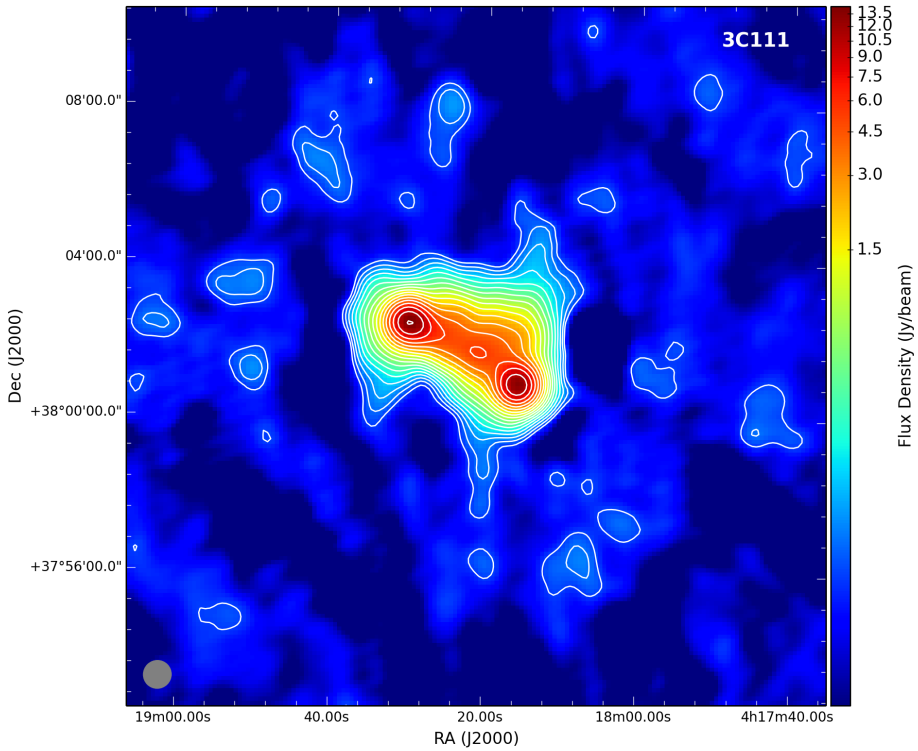
- unbeamed radio emission with spectral index
  -0.7 $< \alpha <$ -0.5
- beamed emission with flat spectrum $\alpha \sim 0$
  $\rightarrow$ most spectra flat
  $\rightarrow$ dominated by beamed core emission

$\rightarrow$ Flat blazar spectra extend down to LOFAR frequencies!



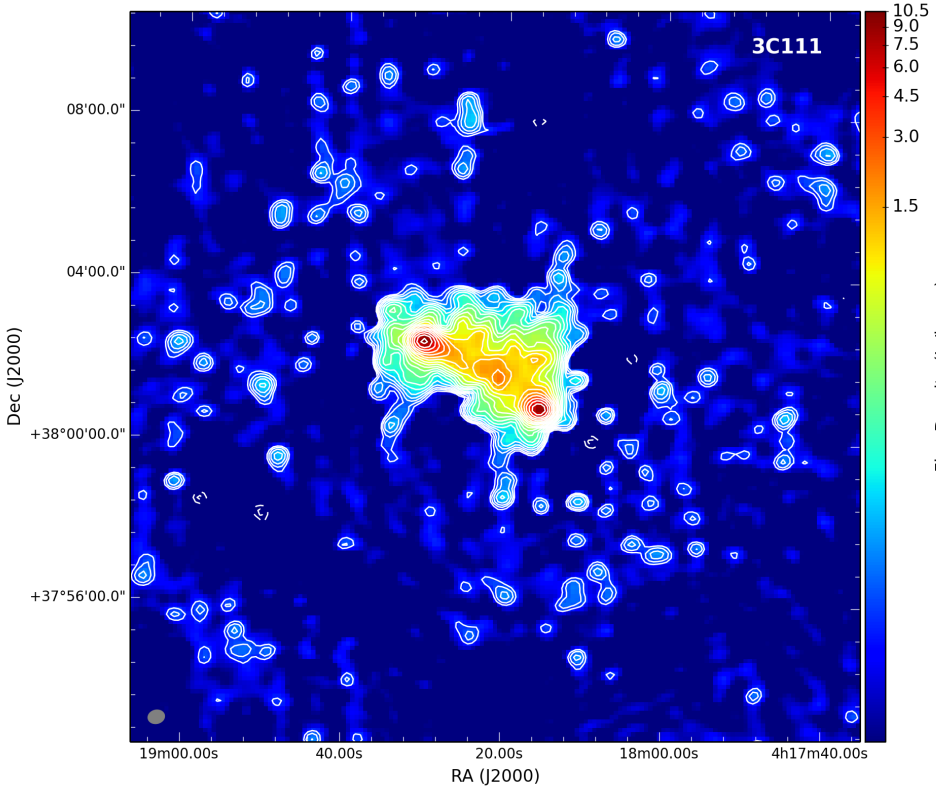
Reimaging

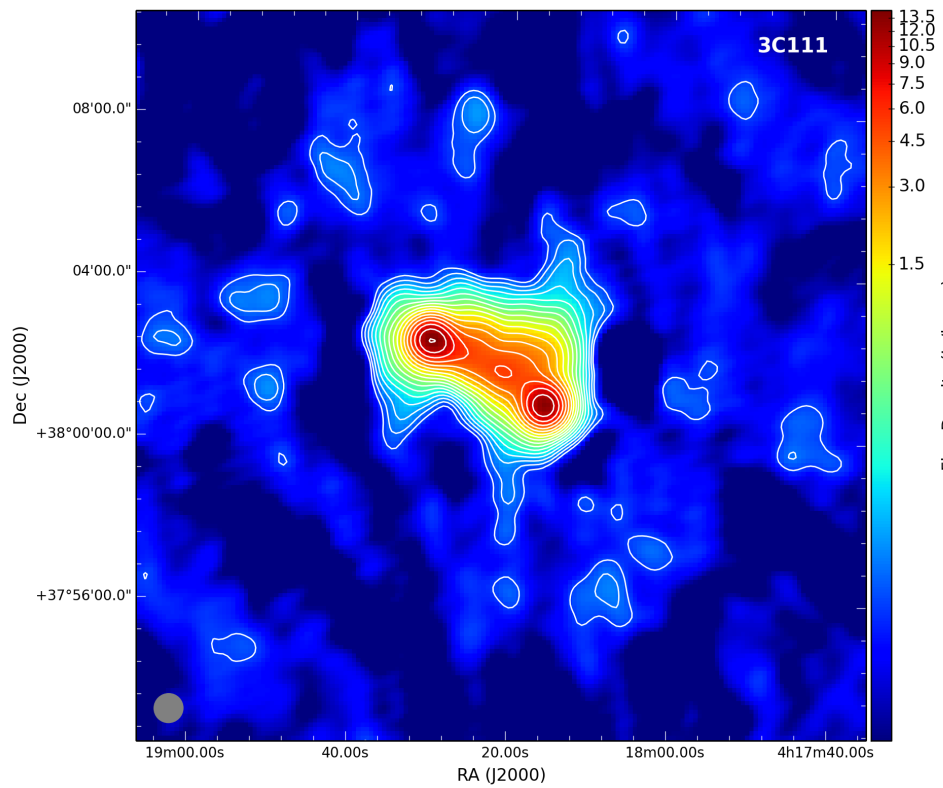




- MSSS default images are limited to uv-range of 2 kλ
- Reimaging with full uv-range can improve resolution to $\sim$20 arcsec

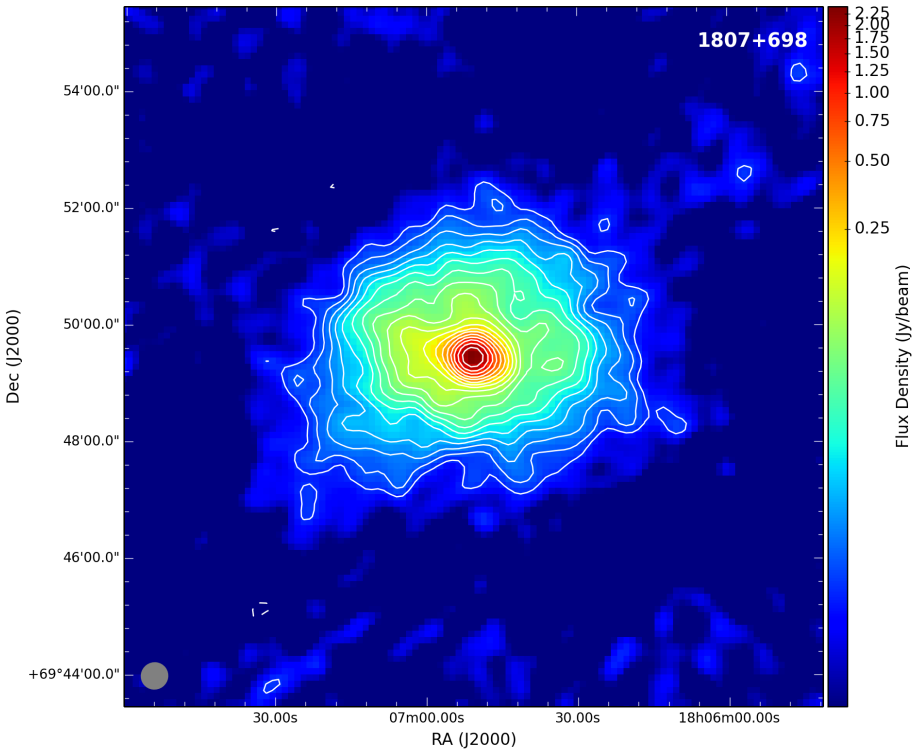
Reimaging

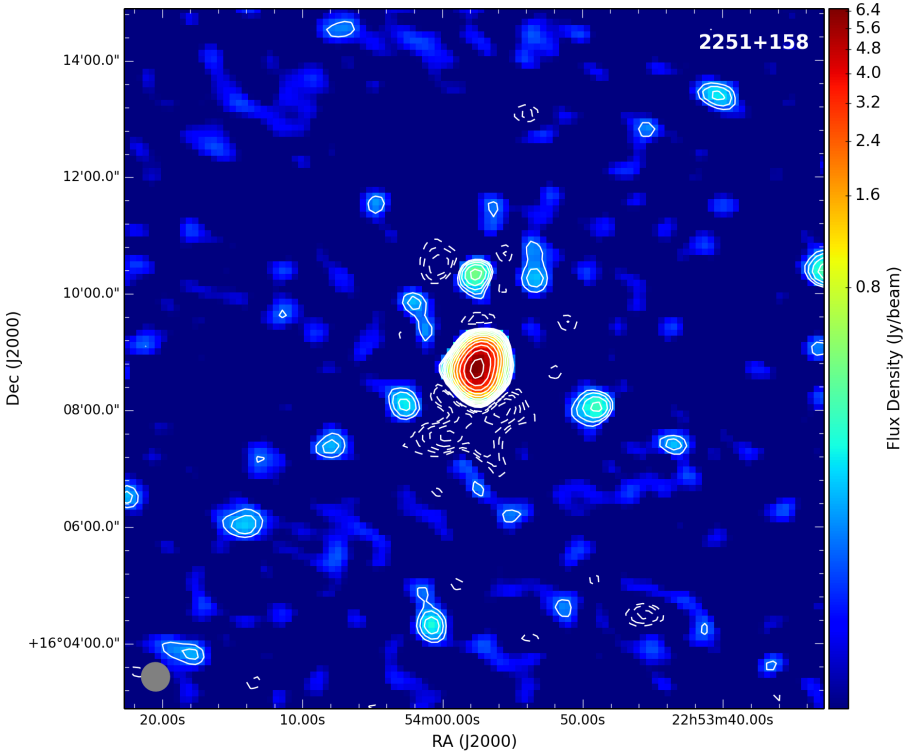




- reimaging of all 8 Bands $\rightarrow$ averaging to reduce noise-level

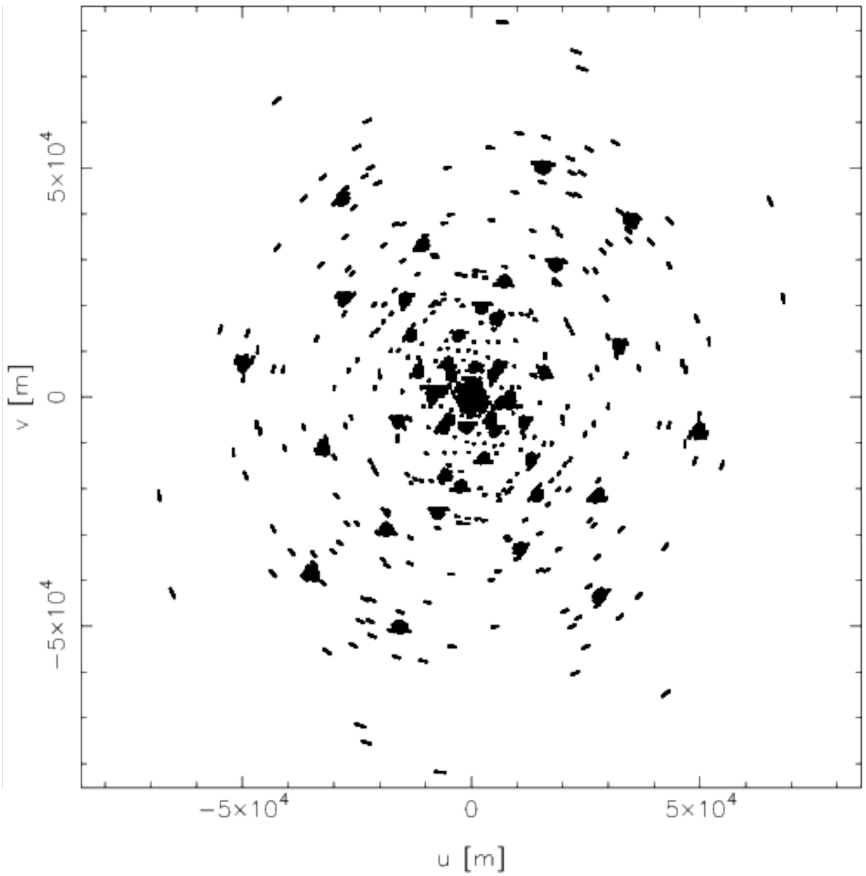
Reimaging

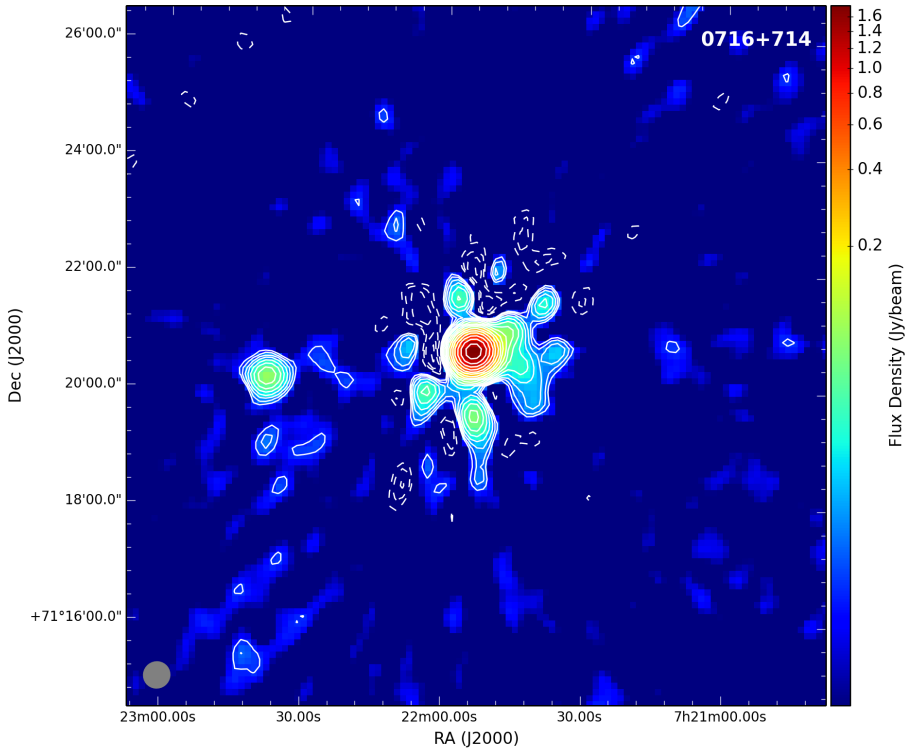




- Reimaging reveals extended emission for some sources
  $\rightarrow$ LOFAR sensitivity of snapshots sufficient for the lobe emission!

Reimaging





Taken from Heald et al., in prep

- uv-coverage not always sufficient to reconstruct the extended structure

Summary & Outlook

First results:

- spectral indices show mostly flat spectra
  $\rightarrow$ core emission still dominating and beamed
- reimaged MSSS data reveal extended emission for some sources
  $\rightarrow$ great sensitivity of LOFAR can detect the lobe emission at low frequencies even in snapshots

Outlook:

$\rightarrow$ deeper LOFAR observations with international baselines could allow to separate core and extended emission to estimate the intrinsic jet power