High-resolution wideband observations of 4C19.44 with International LOFAR

Javier Moldón

ASTRON Netherlands Institute for Radio Astronomy

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Collaborators

- Project collaborators:
  - Dan Harris (Smithsonian Astrophysical Observatory)
  - Adam Deller (Astron)
  - Raymond Oonk (Leiden University)
  - Raffaella Morganti (Astron)
  - Leith Godfrey (Astron)
  - Leah Morabito (Leiden University)

Introduction

- We aim to undertand the origin of the X-ray emission from quasar jets.
- Two main possibilities:
  - One-zone synchrotron radiation (like in FRI).
  - IC/CMB emission of a single population of electrons.

Introduction

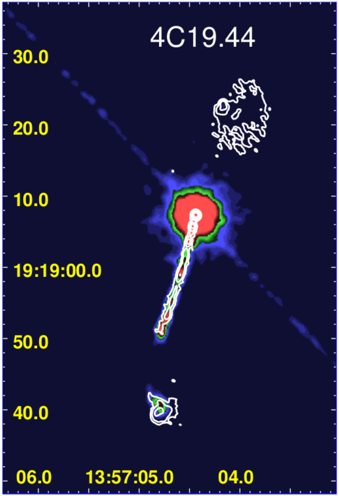
- In the IC/CMB model a single population of e^- produce:
  - radio/optical (synchrotron emission).
  - X-rays (IC with the CMB).
- We require:
  - Jet with bulk Lorentz factor $\Gamma \sim 10$.
  - Enough low-energy electrons with γ ~100.

Is there a population of e^- with γ ~100 present in the jet?

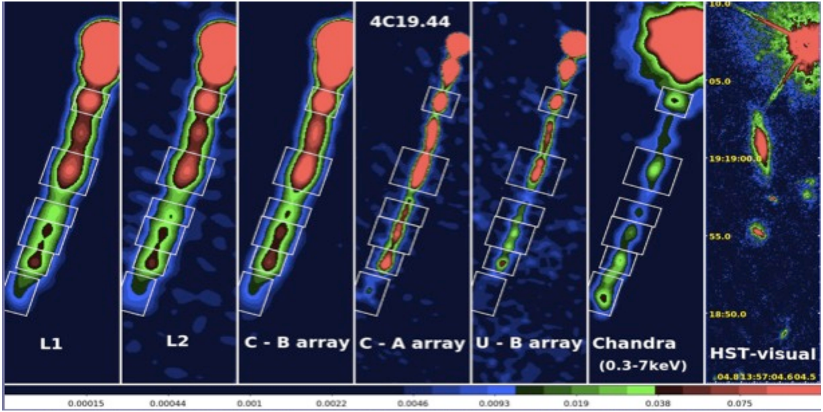
- If so, they will produce synchrotron emission at $\gamma \sim 1500(\frac{\nu}{1\ \mathrm{GHz}})^{1/2}$
- $\gamma \sim 100 \rightarrow$ synchrotron emission at 10–30 MHz.
- LOFAR HBA can explore the range $\gamma \sim 600 - 1000$.

Testing the IC/CMB model

- We can test the model with a source with clear radio and X-ray knots along the jet.
- 4C19.44 is a core dominated quasar at $z = 0.72$ (7.2 kpc/arcsec).



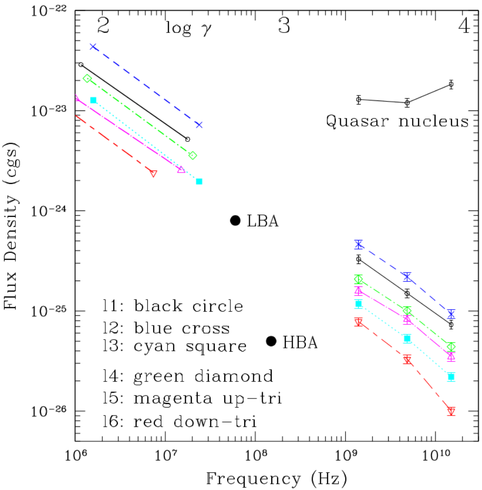
Jet acceleration in 4C19.44



- This source has a long jet providing many resolution elements with Chandra's arcsec resolution.
- VLA maps at L, C, and U bands, and 180 ks with *Chandra*.

Knot spectra

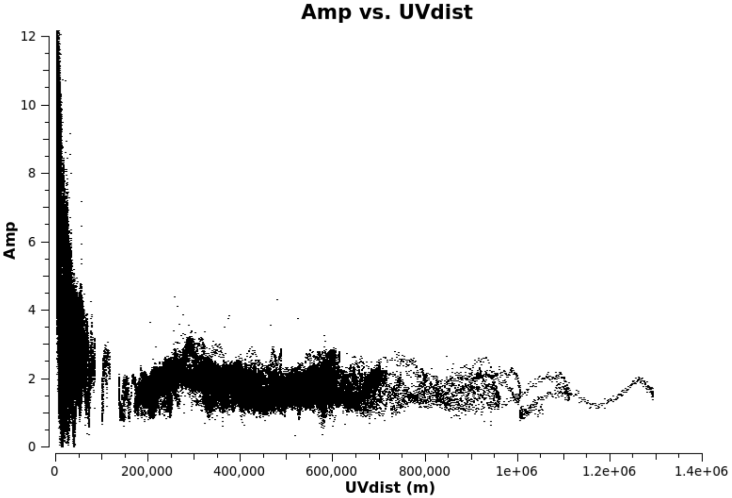
- For 6 regions down the jet, we extrapolate the spectrum of each knot to the low radio frequencies which would come from electrons responsible for the IC/CMB X-rays.
- Also shown are LOFAR sensitivities and the electron energy scale along the top axis.



Extreme summary of data and calibration

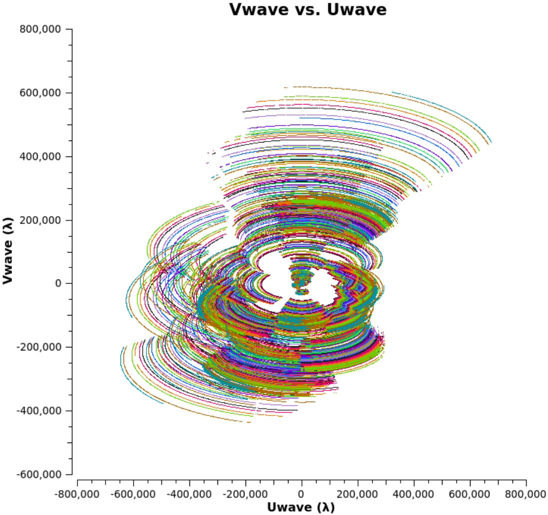
- Observation:
  - HBA observations conducted on May 14, 2014 for 7h.
  - 244 subbands between 115 and 190 MHz on the target.
  - 48 MHz on each 4C19.44 and 3C286.
  - RO pipeline to flag and averaging to 4ch/subband, 4 sec.
- Calibration guidelines:
  - 3C286 to calibrate amplitude and phase of CS and RS.
  - Convert to circular polarization.
  - Concatenate in blocks of 16 subbands (3 MHz).
  - Convert to UVFITS. Fring fitting in AIPS!
  - Self-calibration in CASA of long baselines.
  - Scale amplitudes to match CS, RS calibration.
  - Produce high-resolution and widefield low-resolution images.

UV plot of the source



- Significant structure up to ∼1300 km baselines.

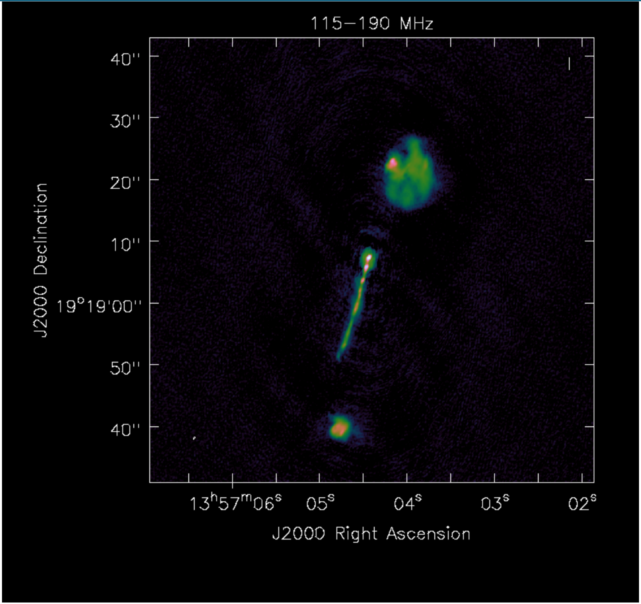
UV plot of the source



- Good uv-coverage thanks to bandwidth between 115 and 188 MHz.

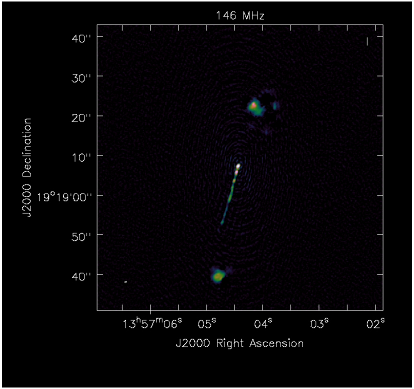
Results
High-resolution images

High resolution image of 4C19.44

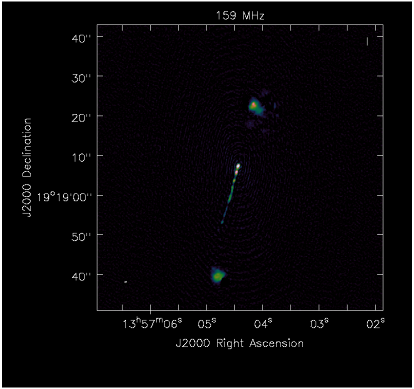


16 subbands high resolution imaging

146 MHz



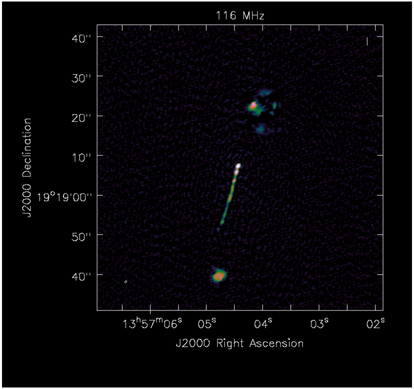
159 MHz



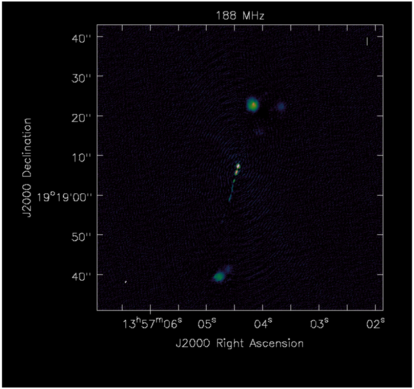
- Several knots along the jet and the two hotsposts are clearly detected at 150 MHz.

16 subbands high resolution imaging

116 MHz

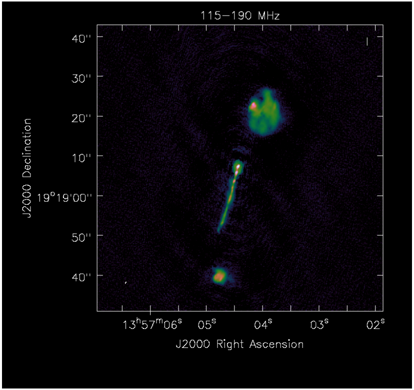


188 MHz

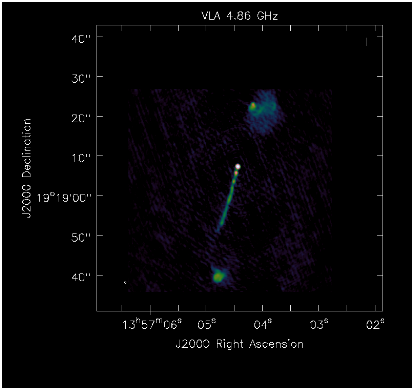


- Knots are detected also at extreme frequencies: 116 and 188 MHz bands.

Image fidelity (I)



LOFAR 150 MHz



VLA 4.87 GHz

Image fidelity (II)

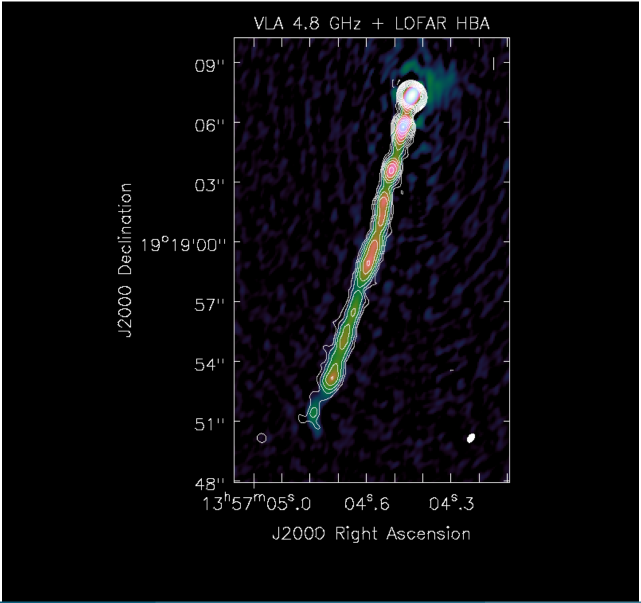
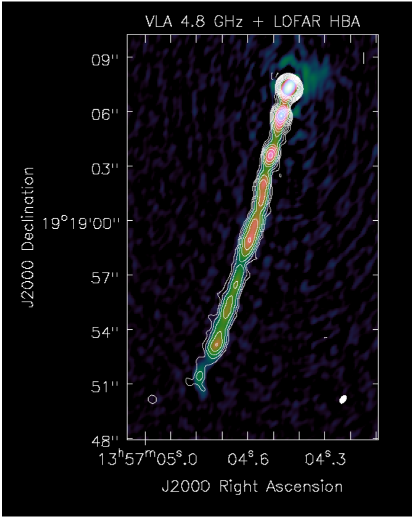


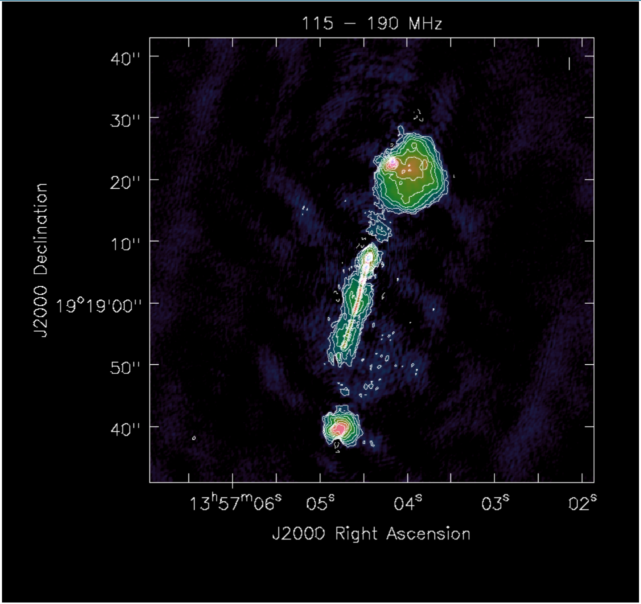
Image fidelity (II)

- Resolution is $0.5'' \times 0.3''$.
- Image rms is 85 μJy/beam (140 μJy/beam at the core).
- Dynamic range is 20 000:1 at 30 arcsec.
- Dynamic range is 10 000–15 000:1 at the core.

- Considering 20–30% flagged data, the expected thermal noise is ~ 55 μJy/beam.
- We obtain a noise $\sim 50\%$ higher than the thermal noise.



Still some diffuse emission



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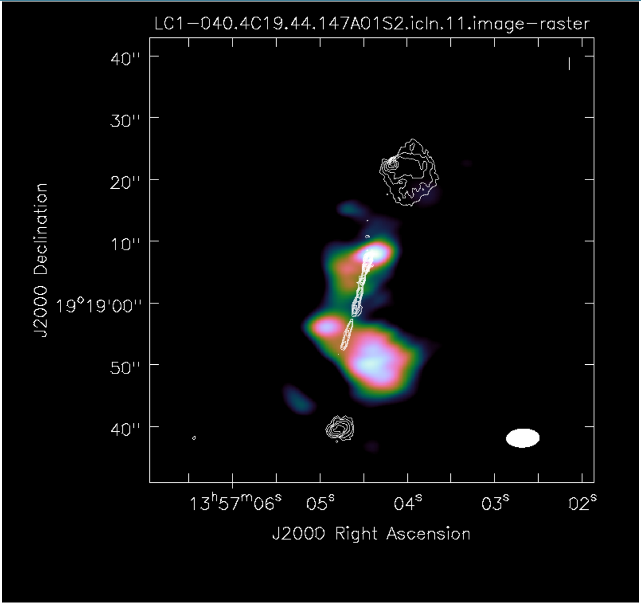
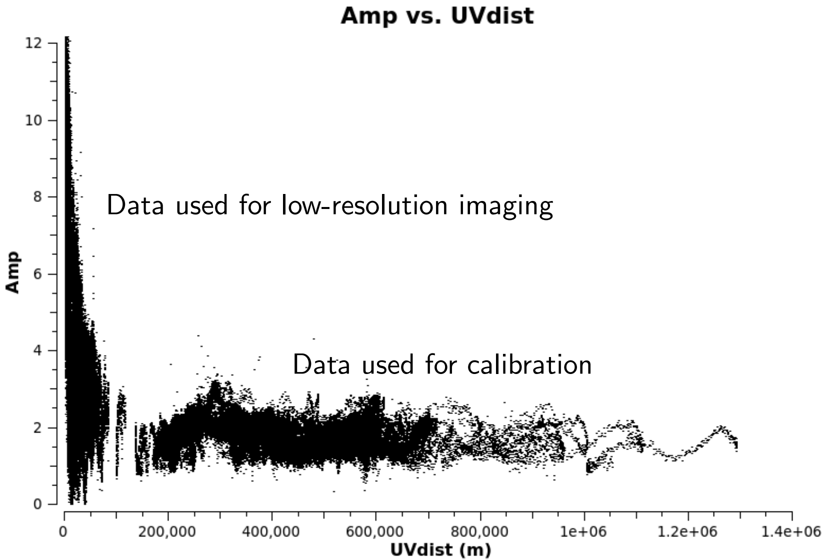
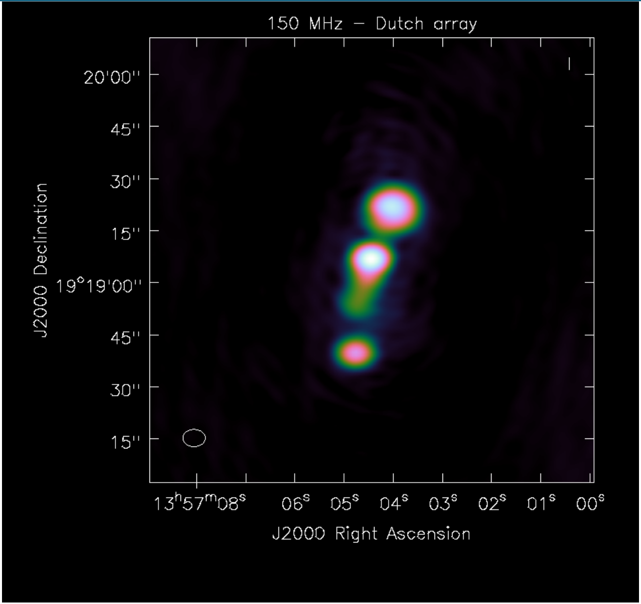


Low-resolution images

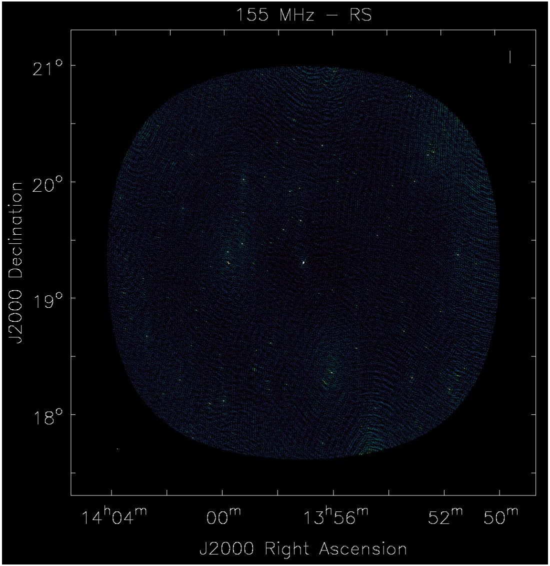
UV plot of the source



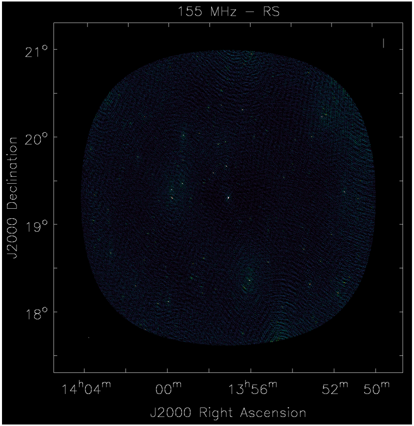
“Low”-resolution imaging

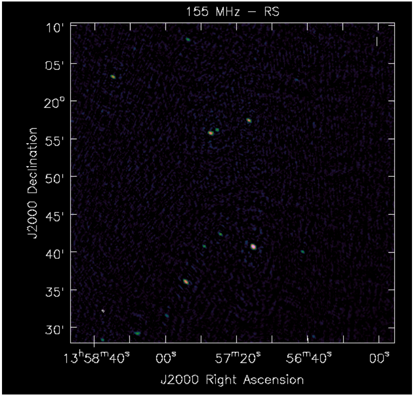


Widefield low-resolution imaging

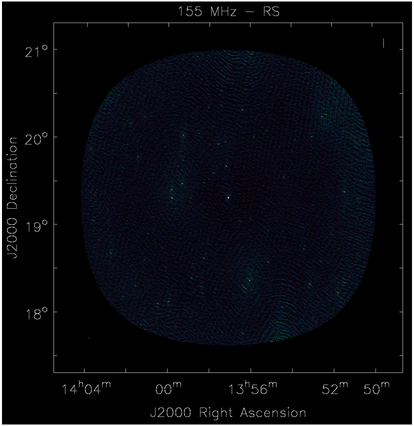


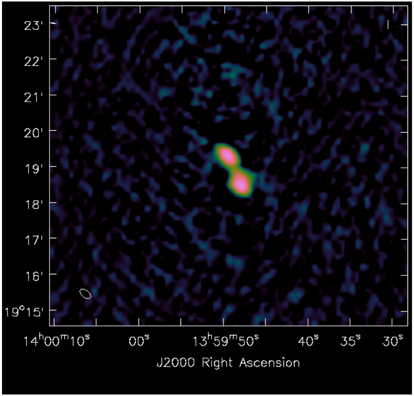
Widefield low-resolution imaging



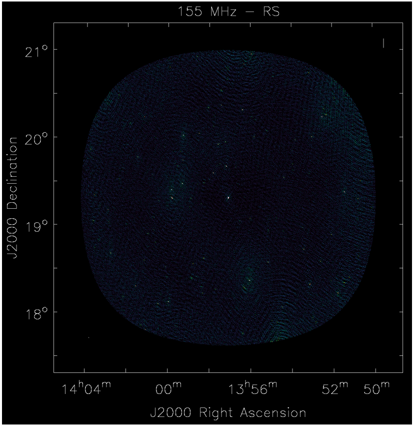


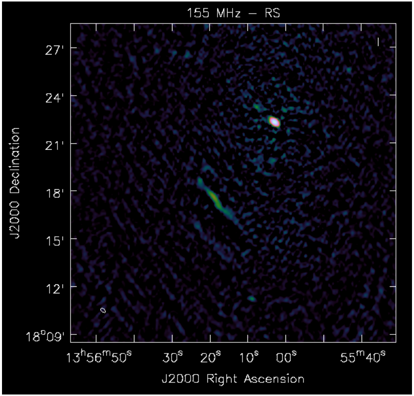
Wideband low-resolution imaging





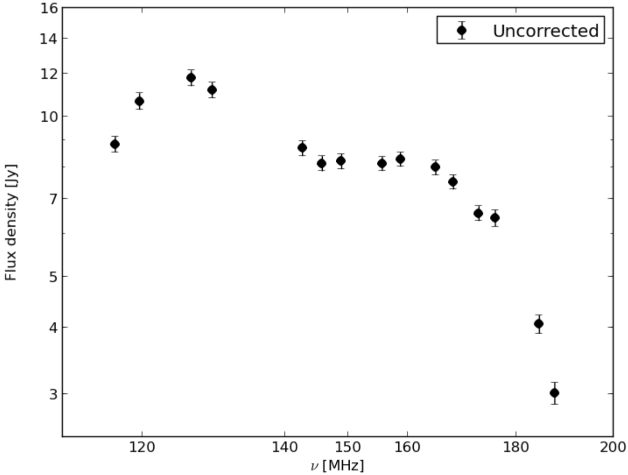
Wideband low-resolution imaging





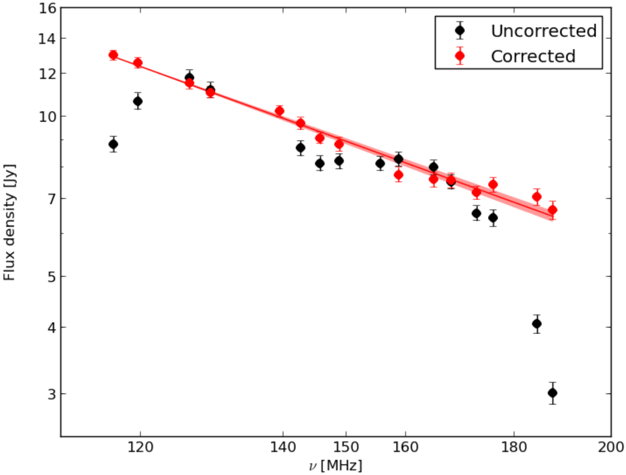
Spectral information

Low-resolution spectrum



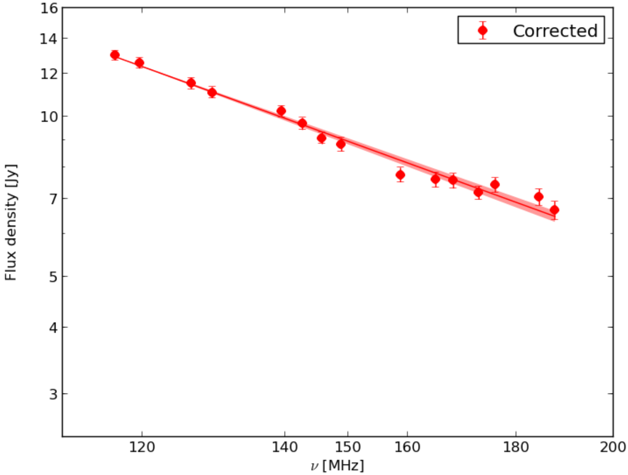
- The original spectrum has peculiar shape.

Low-resolution spectrum



- Power law without turn-over after correction of IS sensitivity.

Low-resolution spectrum



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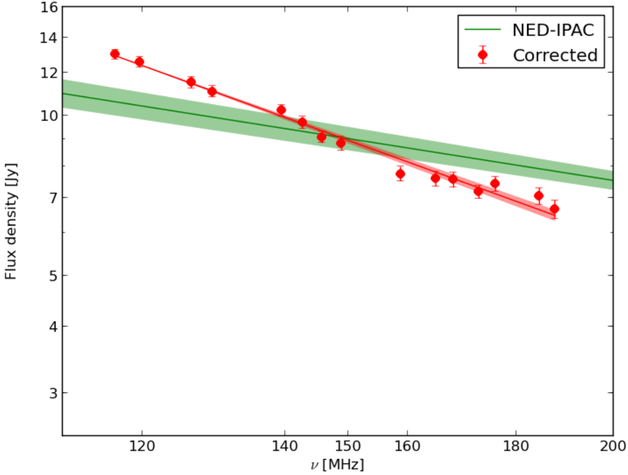
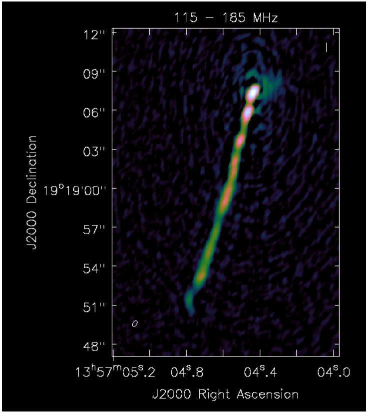
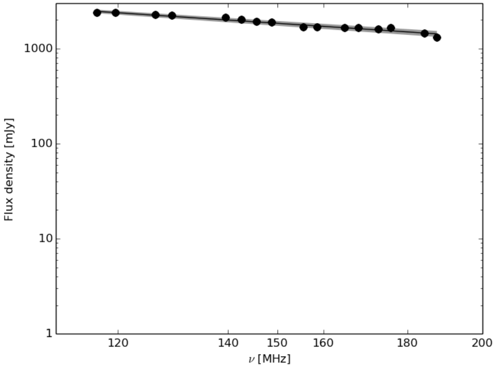
Low-resolution spectrum



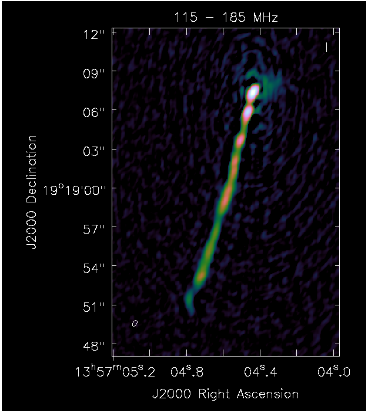
- Systematic (beam?) offset. Spectral index requires a $+0.8$ correction.

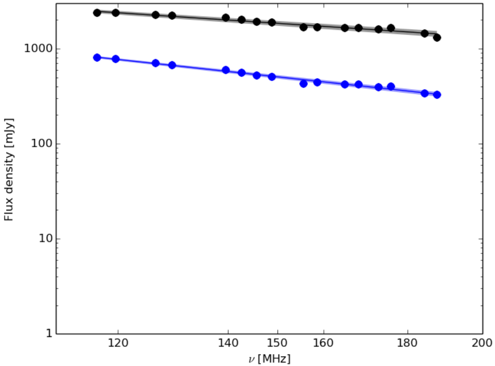
Knot spectra



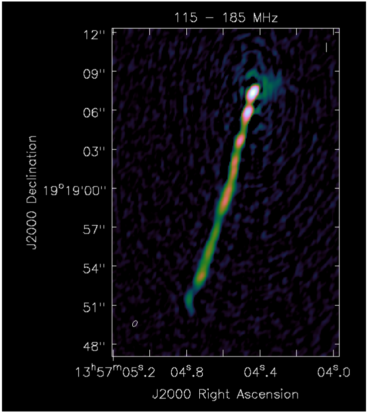


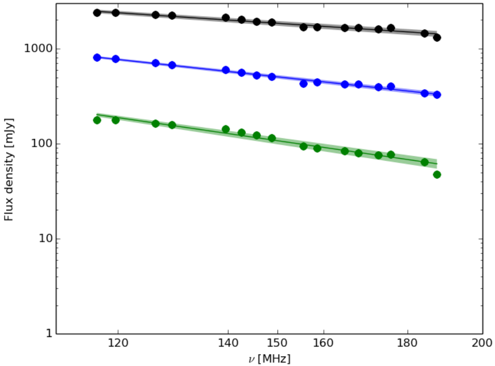
Knot spectra



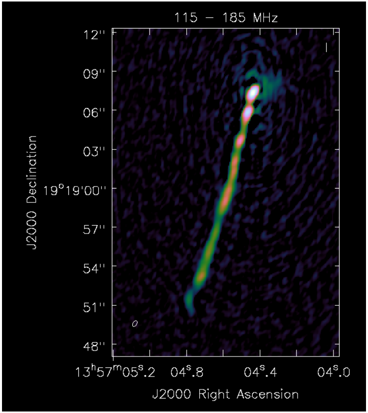


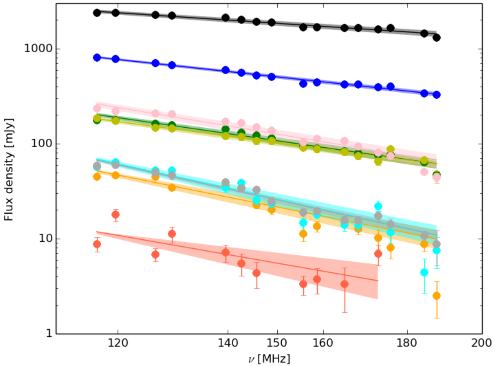
Knot spectra



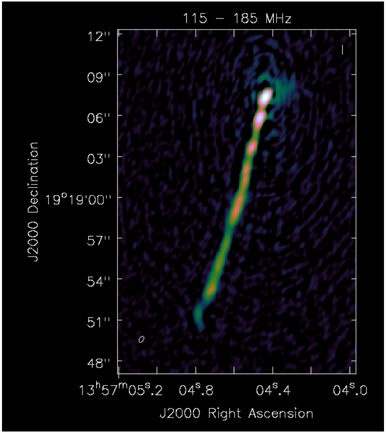


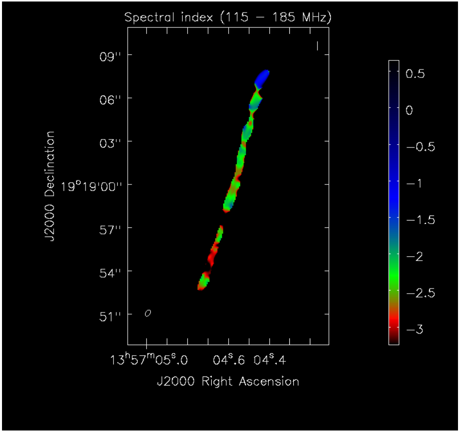
Knot spectra





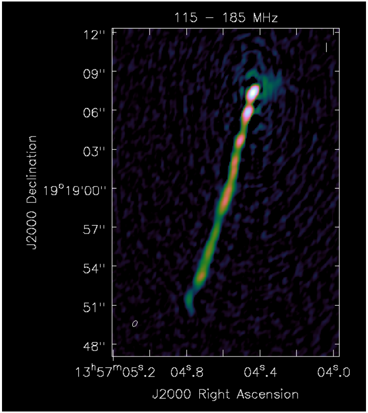
Knot spectra

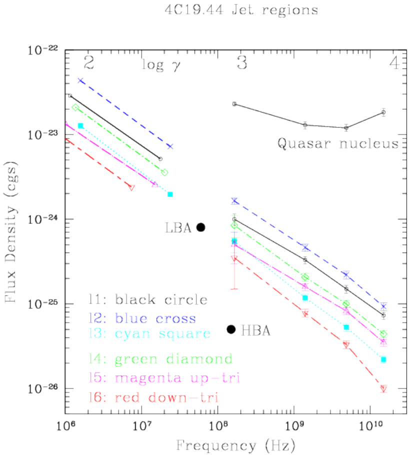




Conclusions & summary

Conclusions





- No spectral turnover at low frequencies.

Conclusions

- Preliminary conclusions:
  - Compatible with a low-energy population of electrons capable of producing the X-ray emission through IC/CMB.
  - Shock acceleration processes require a break in the electron population at $\gamma \sim 2000$. The steep spectrum pose a severe challenge to shock acceleration processes along the jet.
- More to do:
  - Study the radio spectral index along the kpc-scale jet and compare with X-ray spectral index.
  - Search for turnover on the hotspots, which can constrain lower γ.
  - Compare the morphology of the hotspots of the LOFAR and *Chandra* images.

Summary

- Long baseline HBA observations provide 0.5 arcsec resolution imaging.
- Down to a noise of $85\ \mu$Jy/beam, $\sim$50% higher than the estimated thermal noise.
- Dynamic ranges of 10 000–20 000:1.
- Coherent in-band calibration although...
- ...global spectral index offset to be fixed.
- The outside-inside (long to short baselines) calibration process works extremely well.