PROCEEDINGS OF SCIENCE

RadioAstron observations of 3C 345[*]

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Supermassive black holes (SMBHs) in the centres of radio-loud active galactic nuclei (AGN) produce collimated relativistic outflows (jets). Space-VLBI observations within the RadioAstron key science program on AGN polarization provide images at an unprecedented resolution, which enables us to study the magnetic field strength and morphology in the innermost regions of AGN jets. We present here images from 1.6 GHz RadioAstron observations of the sub-parsec scale jet in the powerful blazar 3C 345, revealing the complex jet structure at ∼200 microarcseconds (∼1.9 pc).

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1. The RadioAstron AGN Polarization Key Science Program

Supermassive black holes in the centres of radio-loud active galactic nuclei (AGN) produce collimated relativistic outflows (jets). Space-VLBI observations within the RadioAstron [5] key science program on AGN polarization [6, 7] provide images at an unprecedented resolution, which enables us to study the magnetic field strength and morphology in the innermost regions of AGN jets. In this way the existence of helical magnetic fields can be tested by searching for Faraday rotation gradients across the jet (e.g. [8]).
Ten of the brightest and highly polarized AGN were observed so far during observing periods AO-1, 2, 3, 4, and 5 since July 2013 to April 2018, with continuation approved for AO-6 [6, 7, 9, 10].

2. Observations and data reduction

The strong blazar 3C 345 (1641+399) is a flat-spectrum radio quasar and is situated at a redshift of $z = 0.59$ [11]. The source is core-dominated and shows a bending jet at low radio frequencies (e,g. [12, 13]).
The observations at $\lambda = 18\,\mathrm{cm}$ took place on March 30-31, 2016 during AO-3. A total of 18 antennas from a ground array were observing, including the VLBA (except Mauna Kea) and eight EVN antennas. These were complemented by the 10-m Spekt-R space telescope. We performed a standard data reduction in AIPS, while the imaging was done in difmap with a uniform weighting scheme. We detect ground-space fringes up to **9 Earth diameters**. The resulting *uv*-coverage of the observations is shown in Fig. 1.

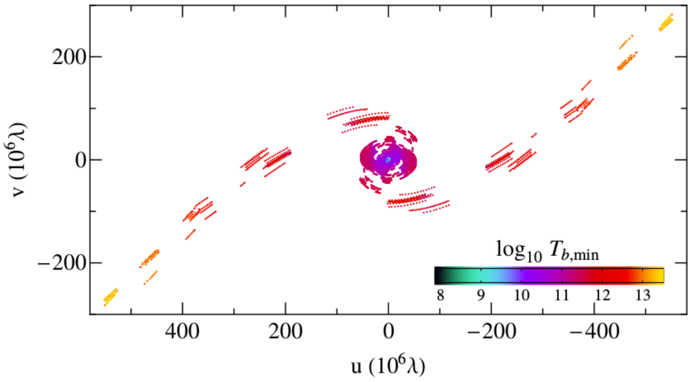

Figure 1: Interferometric coverage (*uv*-coverage) of RadioAstron observations of 3C 345 at 1.6 GHz, with the color scale indicating the minimum brightness temperature inferred from the visibility amplitudes [14]. These measurements imply a brightness temperature in excess of 3.4×10^{13} K in the most compact regions of the jet.

3. Results

We present the calibrated visibility data in Fig. 2 and preliminary images of the source in total intensity in Fig. 3. The polarization imaging results will be presented elsewhere.
The minimum brightness temperature of the most compact features can be conveniently estimated

using the visibilities only [14]. These estimates are shown in Fig. 1, where $T_{\rm b,min}$ is overplotted onto the UV coverage. The maximum $T_{\rm b,min}$ that we find is about 3.4×10^{13} K, showing at the largest *uv* distances.

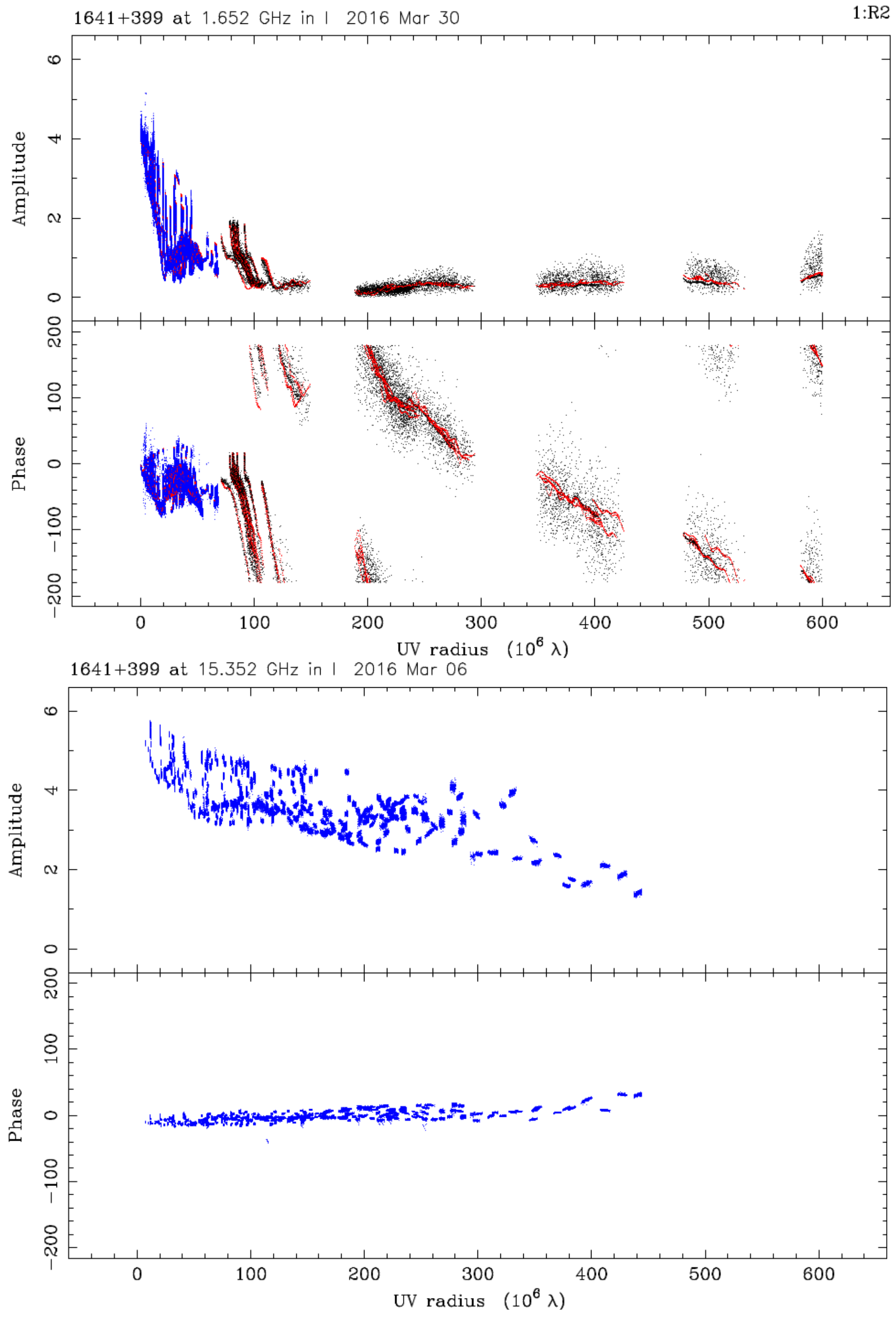

Figure 2: Amplitudes and phases obtained in the 1.6 GHz RadioAstron (top) and 15 GHz MOJAVE (bottom) observations of 3C 345. The black data points in the top panel correspond to the space baselines, red shows the source model (blue contours in Fig. 3). The RadioAstron data show a more complex compact structure on baselines of $> 100\,{\rm M}\lambda$.

3C 345 is monitored by the MOJAVE program and was observed on March 5th, 2016, nearly simultaneously to our RadioAstron observations. The resolution of the 15 GHz VLBA image (see the MOJAVE webpage) [1, 2] is comparable to the RadioAstron image. We recover the same basic structure of the inner jet, although the MOJAVE data suggest more compact emission (see Fig. 2), as the visibilities do not fall off as sharply at $< 100\,\mathrm{M}\lambda$.

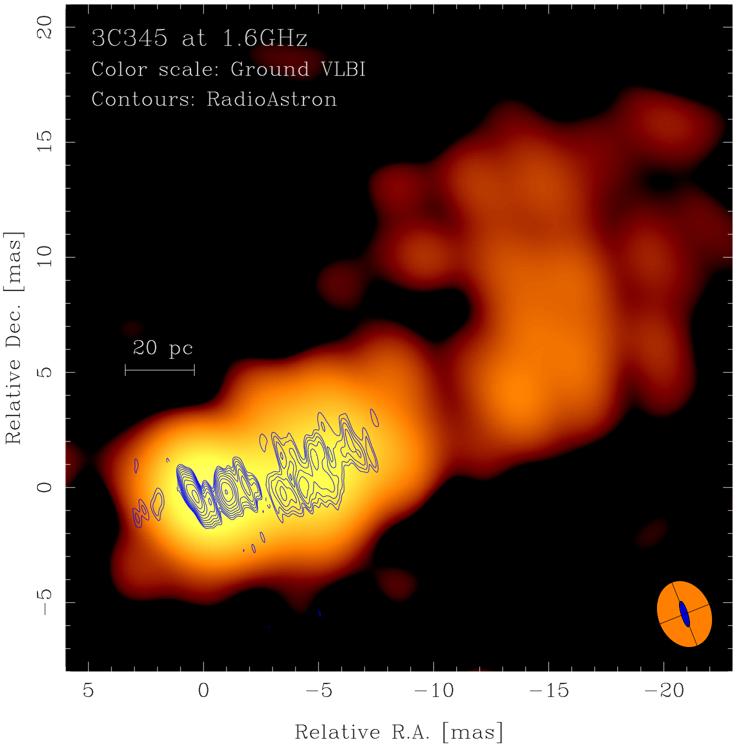

Figure 3: 3C 345 at 1.6 GHz with RadioAstron, overlaid as contours over the ground array image obtained from the same observation. The respective synthesized beams of the two images are shown in the lower right corner. The beam minor axis is 2.33 mas (15.6 pc) for the ground array, and 0.28 mas (1.9 pc) with RadioAstron. Images were obtained with a uniform data weighting.

4. Conclusions

The RadioAstron observation of 3C345 at 1.6 GHz have yielded fringe detections between ground antennas and the space radio telescope up to projected baseline distances of ∼9 Earth diameters. 3C 345 was successfully imaged with RadioAstron with sub-mas resolution, corresponding to a projected distance of 1.9 pc or ∼5000 gravitational radii for a black hole mass of $4 \times 10^{9}\,\mathrm{M}_{\odot}$ [15]. The visibility amplitudes imply the presence of emitting regions with observed brightness temperature in excess of 3.4×10^{13} K, well above the inverse Compton limit of $10^{11.5}$ K. Considering the redshift $z = 0.59$ and the Doppler factor $\delta = 9.1$ [16] of the source, the intrinsic brightness temperature $T_{\mathrm{b,min}} \sim 6 \times 10^{12}$ K, which is still above the theoretical limit. This suggests locally efficient injection or re-acceleration of particles in the jet to counter the inverse Compton cooling, or an unusual geometry of the jet.

These results suggest promising future findings also for the linear polarization, the imaging of which is under progress. Future modeling and comparison with radiative magneto-hydrodynamic simulations will give more insight into the fundamental jet properties and the jet formation processes.

References

[1] Lister, M. L. et al., 2009, *MOJAVE: Monitoring of Jets in Active Galactic Nuclei with VLBA Experiments. V. Multi-Epoch VLBA Images*, AJ 137, 3718 [arXiv:0812.3947]

[2] Lister, M. L. et al., 2018, *MOJAVE: XV. VLBA 15 GHz Total Intensity and Polarization Maps of 437 Parsec-scale AGN Jets from 1996 to 2017*, ApJS 234, 12 [arXiv:1711.07802]

[3] Bruni, G. et al., 2016, *The RadioAstron Dedicated DiFX Distribution*, Galaxies 4, 55

[4] Deller, A. T. et al., 2011, *DiFX-2: A More Flexible, Efficient, Robust, and Powerful Software Correlator*, PASP 123, 275 [arXiv:1101.0885]

[5] Kardashev, N. S. et al., 2013, *"RadioAstron"-A telescope with a size of 300 000 km: Main parameters and first observational results*, Astron. Rep. 57, 153 [arXiv:1303.5013]

[6] Lobanov, A. P. et al., 2015, *RadioAstron space VLBI imaging of polarized radio emission in the high-redshift quasar 0642+449 at 1.6 GHz*, A&A 583, A100 [arXiv:1504.04273]

[7] Pashchenko, I. N. et al., 2015, *First Estimate of the Value of the Instrumental Polarization of the RadioAstron Space Radio Telescope Using the Results of an Early Scientific Program for Observing Active Galactic Nuclei*, Cosmic Research 53, 199

[8] Gómez, J. L., et al., 2011, *On the Source of Faraday Rotation in the Jet of the Radio Galaxy 3C 120*, ApJ 733, 11 [arXiv:1102.1943]

[9] Gómez, J. L. et al., 2016, *Probing the innermost regions of AGN jets and their magnetic fields with RadioAstron. I. Imaging BL Lacertae at 21 μas resolution*, ApJ 817, 96 [arXiv:1512.04690]

[10] Bruni, G. et al., 2017, *Probing the innermost regions of AGN jets and their magnetic fields with RadioAstron II. Observations of 3C 273 at minimum activity*, A&A 604, A111 [arXiv:1707.01386]

[11] Marziani, P. et al., 1996, *Comparative Analysis of the High- and Low-Ionization Lines in the Broad-Line Region of Active Galactic Nuclei*, ApJS 104, 37

[12] Ros, E. et al., 2000, *Total intensity and polarized emission of the parsec-scale jet in 3C 345*, A&A 354, 55 [arXiv:astro-ph/9911454]

[13] Schinzel, F. et al., 2012, *Relativistic outflow drives γ-ray emission in 3C 345*, A&A, 537, 70 [arXiv:1111.2045]

[14] Lobanov, A. P., 2015, *Brightness temperature constraints from interferometric visibilities*, A&A 574, A84 [arXiv:1412.2121]

[15] Lobanov, A. P., 1998, *Ultracompact jets in active galactic nuclei*, A&A 330, 79 [arXiv:astro-ph/9712132]

[16] Liodakis, I. et al., 2017, *Reconciling inverse-Compton Doppler factors with variability Doppler factors in blazar jets*, A&A 602, A104 [arXiv:1503.04780]