Sub-parsec scale imaging of Centaurus A

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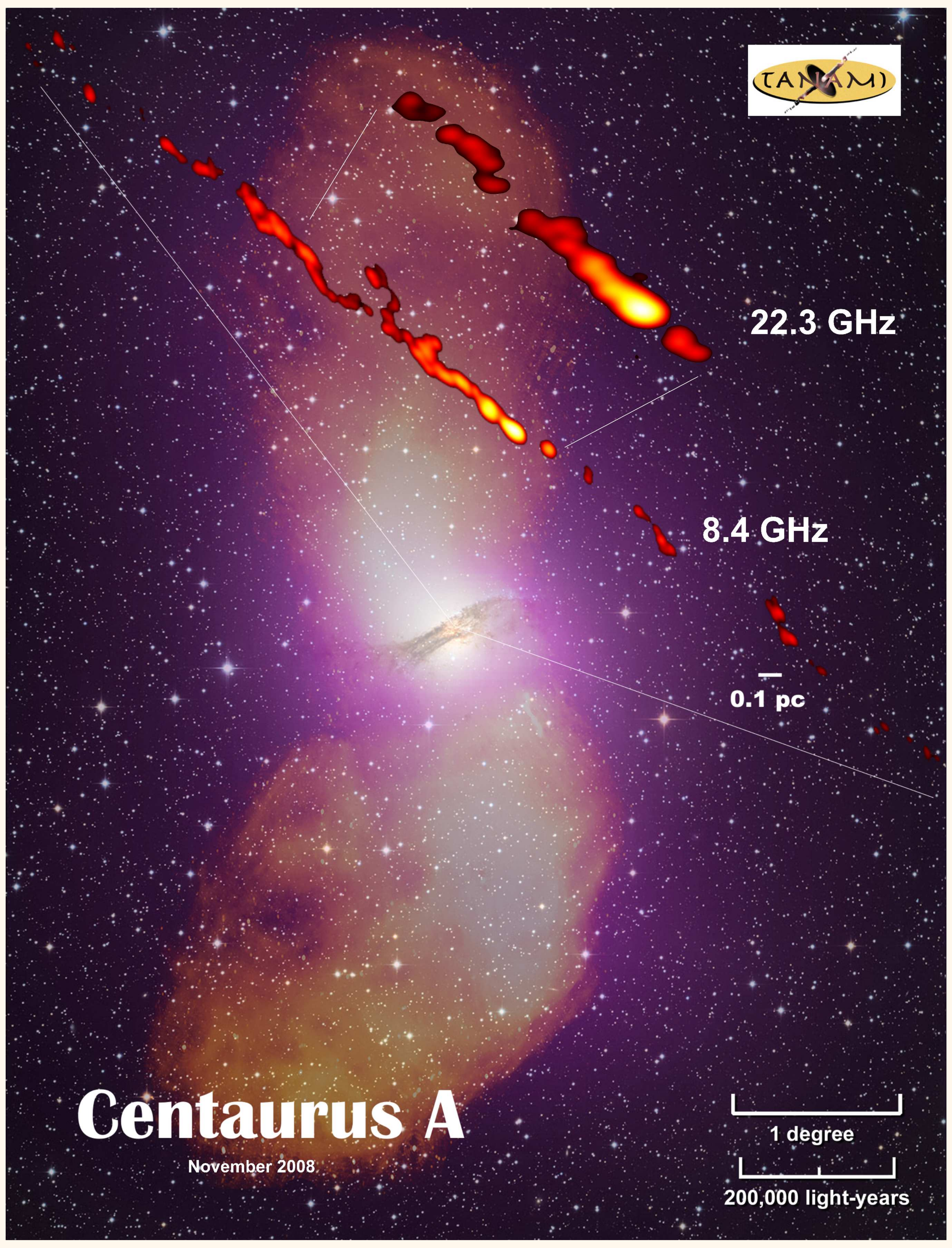
Abstract

At a distance of about 3.8 Mpc, the radio galaxy Centaurus A is the closest active galaxy. Therefore it is a key target for studying the innermost regions of active galactic nuclei (AGN). VLBI observations conducted within the framework of the TANAMI program enable us to study the central region of the Cen A jet with some of the highest linear resolutions ever achieved in an AGN. At 8.4 GHz, we resolve structures smaller than 18 milliparsec. This region is the likely origin of the nuclear γ-ray emission recently detected by the *Fermi* Large Area Telescope (LAT). We show images of the first three TANAMI 8.4 GHz observation epochs of the sub-parsec scale jet-counterjet system of Cen A. With a simultaneous 22.3 GHz observation in November 2008, we present a high resolution spectral index map of the inner few milliarcseconds of the jet probing the putative emission region of γ-ray-photons.



Background

On parsec scales, Centaurus A exhibits a bright jet and a fainter counter-jet at a viewing angle of 50° - 80° with a jet speed of 0.1 c [a]. The central region was highly resolved for the first time with the VLBI Space Observatory Program (VSOP) at 5 GHz[b]. Cen A can be seen over the whole range of the electromagnetic spectrum up to the highest energies. It is the closest known extragalactic γ-ray source seen by *Fermi*/LAT[c]: both, its giant radio lobes (see Fig. 1) and the nuclear region were detected. Recently, ground-based VLBI observations of sub-parsec scale jet-counterjet system of Cen A conducted within the framework of the **TANAMI** program (Tracking Active Galactic Nuclei with Austral Milliarcsecond Interferometry[d], see Poster by Kadler et al.) achieved **some of the highest linear resolutions ever for an AGN, 0.59 mas × 0.978 mas** at 8.4 GHz, corresponding to a linear scale of less than 3500 AU.

[a]Tingay et al. 1998, AJ, 115, 960
[b]Horiuchi, S., Meier, D. L., Preston, R. A., & Tingay, S. J. 2006, PASJ, 58, 211
[c]Abdo, A. A., et al. 2010, ApJS, 188, 405
[d]Ojha et al. 2010, in press (arXiv:1005.4432)

Table 1: The TANAMI-Array

Telescope	Diameter (meters)	Location
Parkes	64	Parkes, New South Wales
ATCA	5x22	Narrabri, New South Wales
Mopra	22	Coonabarabran, New South Wales
Hobart	26	Mt. Pleasant, Tasmania
Ceduna	30	Ceduna, South Australia
DSS43[a]	70	Tidbinbilla, ACT
DSS45[a]	34	Tidbinbilla, ACT
Hartebeesthoek[c]	26	Hartebeesthoek, South Africa
O'Higgins[b]	9	O'Higgins, Antarctica
TIGO[b]	6	Concepcion, Chile

[a]Operated by the Deep Space Network of the National Aeronautics and Space Administration
[b]Operated by Bundesamt für Kartographie und Geodäsie (BKG) [c]Not available since September 2008

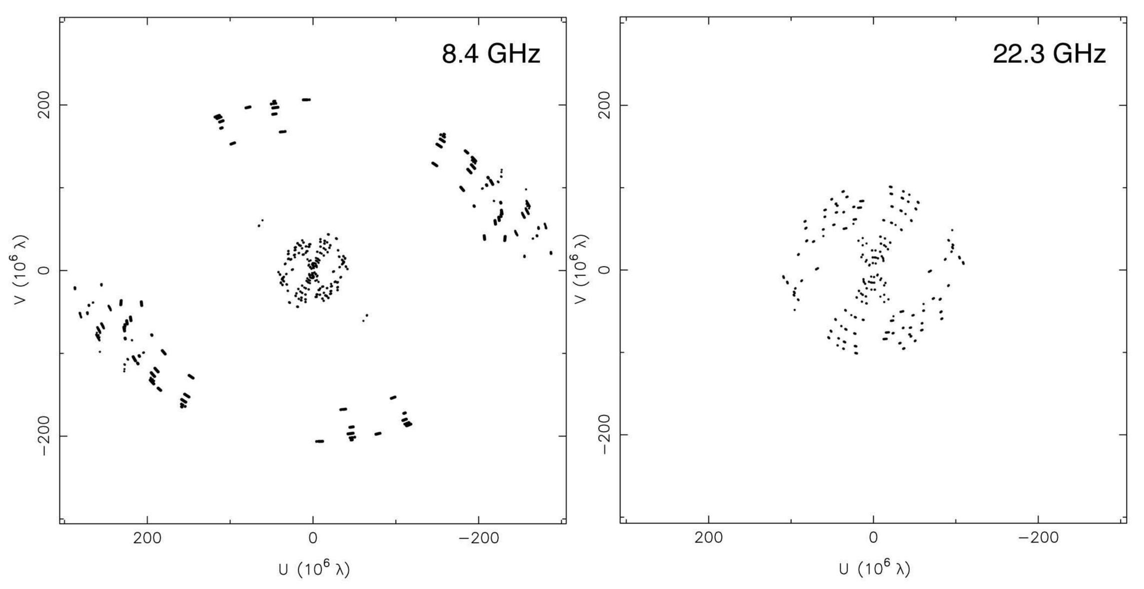
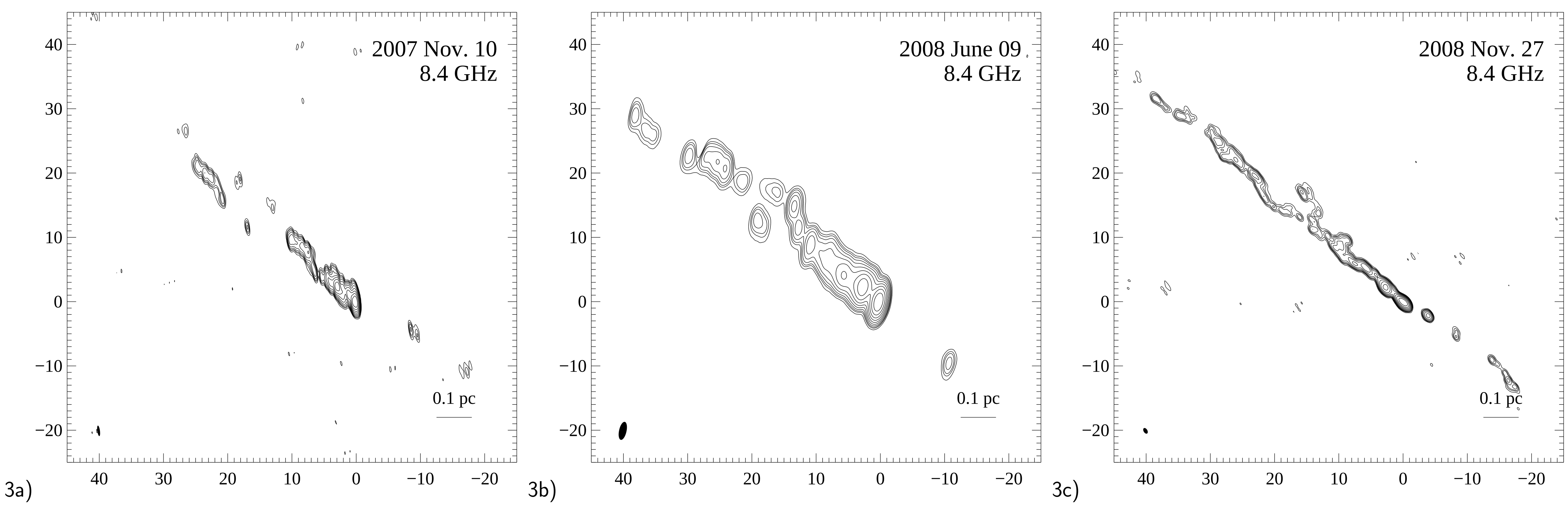


Figure 2: (u, v)-coverage for Cen A at 8.4 GHz (left) and 22.3 GHz (right) for the November 2008 TANAMI observation using the Australian Long Baseline Array (LBA) and associated telescopes, the 9 m O'Higgins antenna, Antarctica, and the 6 m TIGO antenna in Chile. Telescope characteristics can be seen in Table 1.

Figure 1: Collage of a 1.4 GHz-radio(ATCA,orange)/optical(Capella Observatory)/γ-ray(purple,*Fermi*/LAT) composite of the kpc-scale structure (Credit: CSIRO/ATNF,NASA/DOE,ESO,Fermi-LAT Collaboration) and a zoom-in of the central region of Cen A using the high resolution 8.4 GHz and 22.3 GHz TANAMI images of November 2008.



Until November 2008, TANAMI observed Cen A three times at 8.4 GHz and one time simultaneously at 22.3 GHz. Figure 3 a-c shows the 8.4 GHz images of Cen A of November 2007 (a), June 2008 (b) and of November 2008 (c). Image parameters and observation characteristics are listed in the table below. The 22.3 GHz image can be seen in Fig. 4b. Significant features, like a well collimated jet at a mean position angle (P.A.) of $\sim 50°$ and a fainter counter-jet (P.A.$\sim -130°$) with an emission gap in between, and a widening of the jet at about 25 mas (≈ 0.4 pc) downstream and a subsequent recollimation are seen at all epochs and at both frequencies.

Results

- We produced a spectral index map of the simultaneaous 8.4 GHz and 22.3 GHz observations of Nov. 2008 (see Fig. 4). The spectral index α (defined as $F_\nu \sim \nu^{+\alpha}$) was calculated for $S_{8.4\mathrm{GHz}} \geq 3\sigma_{8.4\mathrm{GHz}}$ and $S_{22.3\mathrm{GHz}} \geq 2\sigma_{22.3\mathrm{GHz}}$. The overlaid contours show the flux density distribution at 8.4 GHz folded with a common beam of 1.61×1.02 mas (P.A. $= 88°$).
- Flat spectrum regions in the sub-parsec scale radio jet are possible production regions of high energetic photons.
We identify the inner few milliarcseconds ($\sim$ 0.2 pc) of the Cen A radio jet as possible sources of γ-ray emission[a], with the strongest inverted-spectral emission coming from the jet core on scales of $\leq$0.1 pc.
- The 8.4 GHz flux variability is only moderate with a mean of $S_{\mathrm{peak}} \sim 0.71\,\mathrm{Jy\,beam^{-1}}$ and $S_{\mathrm{total}} \sim 3.5\,\mathrm{Jy}$.

Table 2: Image parameters and observation characteristics (natural weighting)

Frequency [GHz]	Epoch yyyy-mm-dd	RMS [b] $[\mathrm{mJy\,beam^{-1}}]$	S_{peak} $[\mathrm{Jy\,beam^{-1}}]$	S_{total} [Jy]	θ_{maj} [mas]	θ_{min} [mas]	P.A. [°]
8.4	2007-11-10	0.37 ± 0.04	0.60	2.6 ± 0.1	1.6	0.4	8
8.4	2008-06-09	0.58 ± 0.05	1.06	3.1 ± 0.1	2.9	1.2	−13
8.4	2008-11-27	0.39 ± 0.02	0.74	3.9 ± 0.1	0.9	0.6	31
22.3	2008-11-29	0.47 ± 0.03	1.77	3.4 ± 0.1	2.0	1.3	88

[a]Abdo, A. A., et al. 2010, submitted to ApJ, ArXiv:1005.2626
[b]RMS values are determined in a region of the final map without significant source flux.

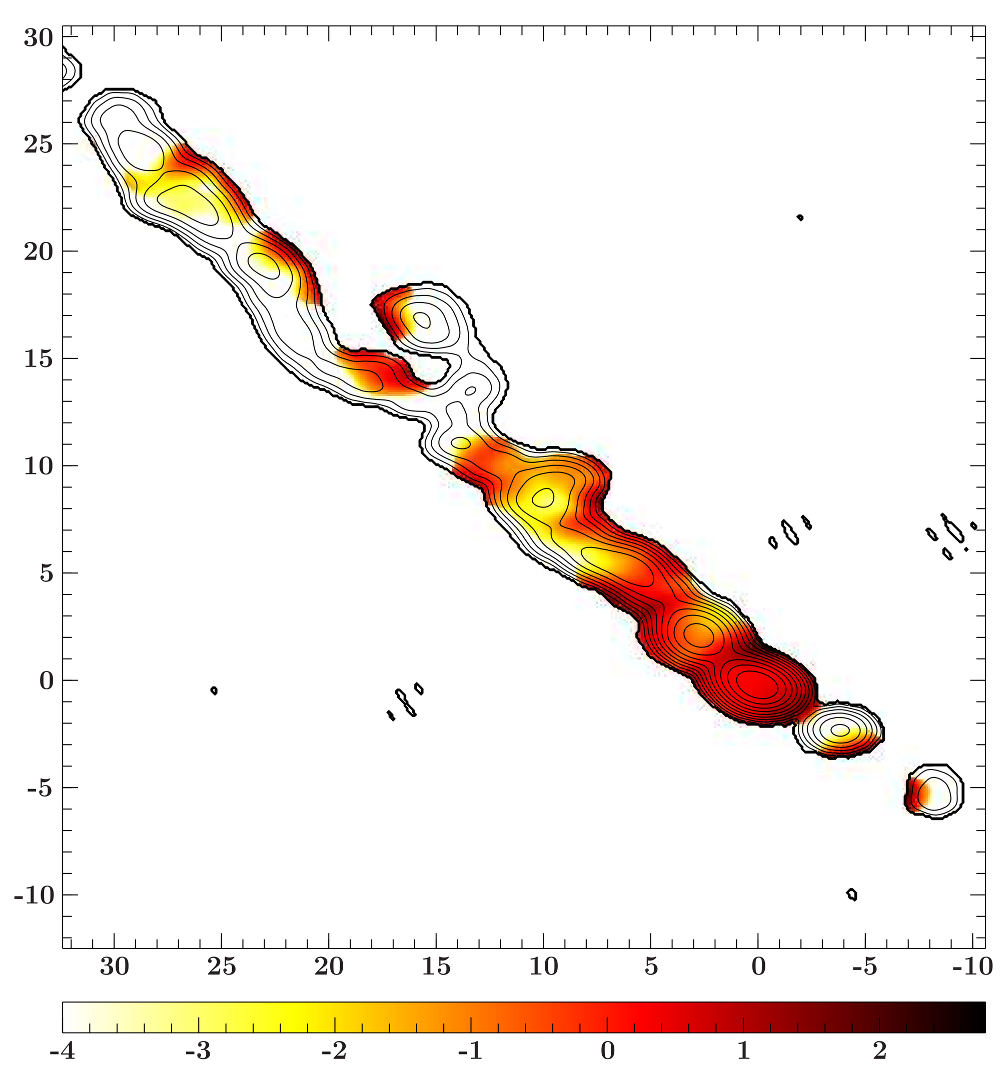


Figure 4: 8.4 GHz−22.3 GHz spectral index map

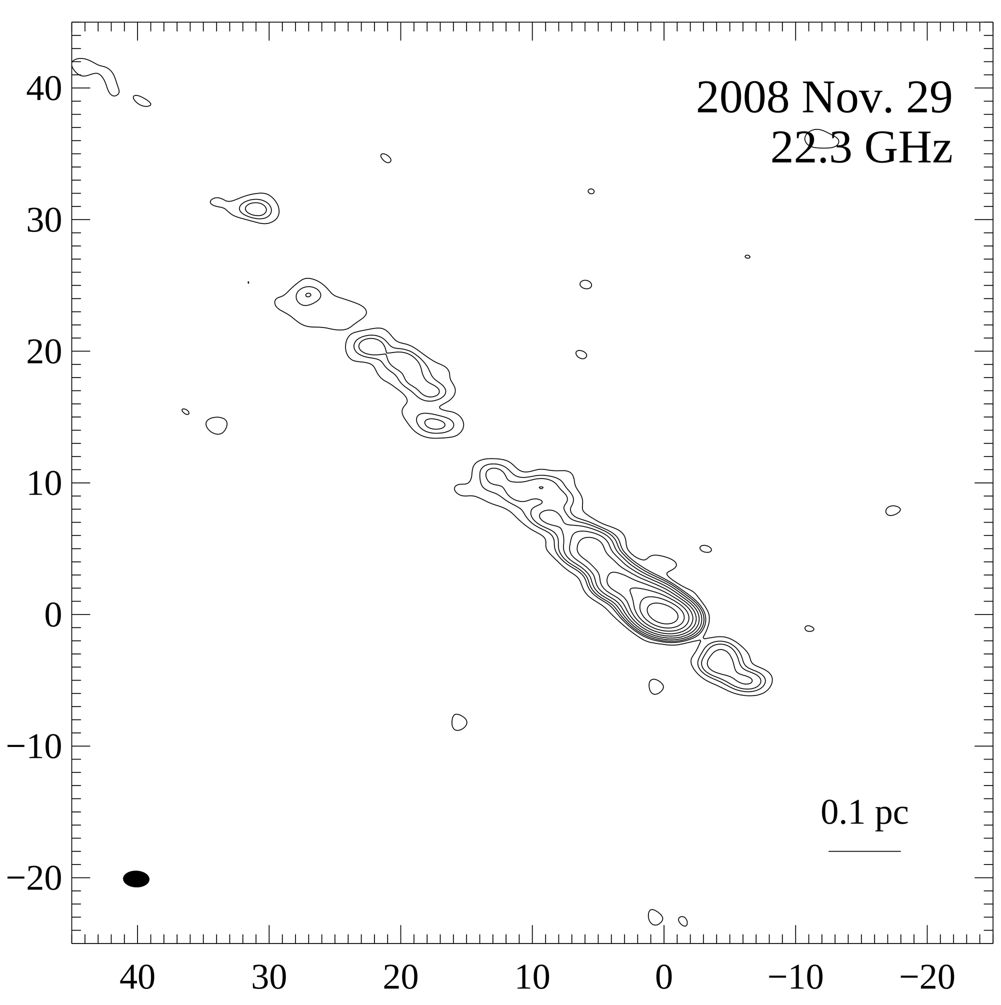


Figure 5: 22.3 GHz image of Cen A of November 2008 (simultaneous to the 8.4 GHz observation just above)

Outlook

Our three 8.4 GHz jet images (separated by about 0.5 years each) can be fitted with a self-consistent model of Gaussian components within the inner 25 mas. At least one more observation epoch is required to measure robust component velocities. Ongoing analysis will consider the time dependent evolution of the spectral distribution. Further details on the presented results can be found here: `http://arxiv.org/abs/1006.1486` and will be the main subject of a publication close to submission.

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