High-Resolution Observations of Centaurus A

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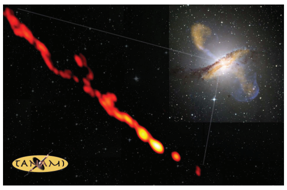


Credit: NASA/ESO/TANAMI/Müller et al. 2011

Abstract

The closest active galaxy Centaurus A is regularly observed at milliarcsecond resolution within the framework of the Southern Hemisphere AGN monitoring program TANAMI. Additional multiwavelength observations up to gamma-ray energies allow us to study the time evolution of the broad-band spectrum, providing crucial information on the emission mechanisms. We present recent TANAMI results on the jet properties at sub-parsec scales including 1.) a possible indication of a connection between hard X-ray and jet activity, 2.) a potential downstream acceleration at sub-parsec scales, and 3.) a suggested jet-star interaction. Our *XMM-Newton* and *Suzaku* monitoring campaign (2013-2014) will further help to shed light on the production sites of high-energy photons and allows us to disentangle emission components.

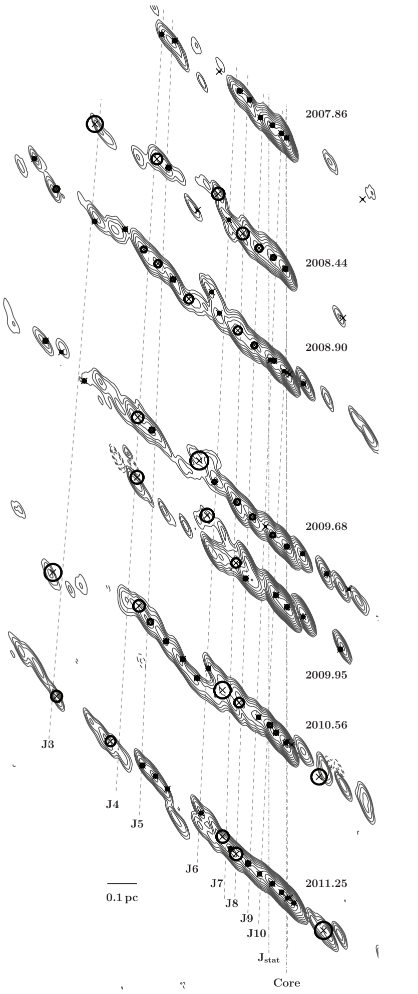


Figure 1: Time evolution (3.5 years of TANAMI monitoring) of the milliarcsecond-scale structure of Centaurus A at 8 GHz. The positions and FWHMs of the Gaussian `modelfit` components are overlaid as black circles. Outer components are faster than inner ones (see Fig. 4), one component is found stationary (J_{stat}).

RESULTS

The first seven epochs of high-resolution TANAMI VLBI observations at 8.4 GHz of Cen A resolve the jet on (sub-)milliarcsecond scales (Fig. 1). They show a differential motion of the sub-parsec scale jet with significantly higher component speeds further downstream. We determined apparent component speeds within a range of 0.1 *c* to 0.3 *c* (Fig. 4), as well as identified long-term stable features. In combination with the jet-to-counterjet ratio we can constrain the angle to the line of sight to $\theta \sim 12^\circ - 45^\circ$ (Fig. 5). The high resolution kinematics are best explained by a spine-sheath structure supported by the downstream acceleration occurring where the jet becomes optically thin. On top of the underlying, continuous flow, TANAMI observations clearly resolve individual jet features. The flow appears to be interrupted by an obstacle at a distance of ∼25 mas (0.4 pc) causing a local decrease in surface brightness and a circumferent jet behavior (Fig. 3). We propose a jet-star interaction scenario to explain this feature. The comparison of jet ejection times with high X-ray flux phases results in a possible indication for a connection between hard X-ray and jet activity (Fig. 2). (These results have been submitted to A&A, Müller et al. 2014.)

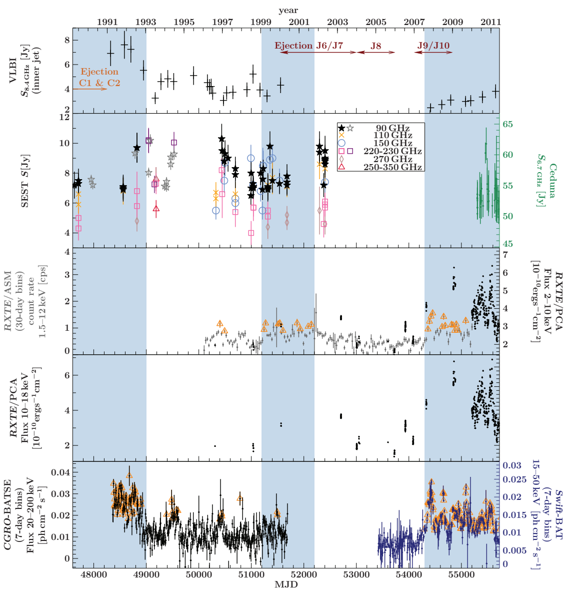


Figure 2: Radio and X-ray light curves of the Cen A core. *From top to bottom*: Archival (Tingay+1998,2001) and TANAMI 8.4 GHz flux density of inner jet, component ejection times including uncertainties indicated by arrows, SEST data (90 GHz – 350 GHz) from Israel+2008 and Tornikoski+1996, Ceduna monitoring at 6.7 GHz, *RXTE*/ASM and *RXTE*/PCA, *CGRO*/BATSE and *Swift*/BAT data after background subtraction. The blue shaded areas highlight the time periods of substantially prolonged higher X-ray activity, defined by an X-ray flux of 3σ above the mean (indicated by orange open triangles) in the continuous monitoring light curves by *RXTE*/ASM, *Swift*/BAT and *CGRO*/BATSE. It is striking that the continuous increase in the radio flux density of the inner jet (observed with TANAMI) follows the onset of activity in hard X-rays from end of 2007 onwards, supporting the results by Fukazawa+2011 who suggested a hardening of the X-ray emission could be due to enhanced jet emission. We can conclude that there is a possible indication for a connection between hard X-ray and jet activity in Cen A.

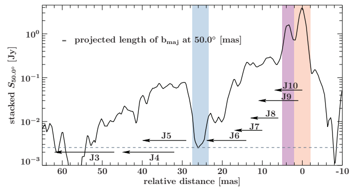


Figure 3: Flux density profile along the jet axis of stacked 8.4 GHz images. The gray dashed line indicates the noise level of the stacked image. The orange/purple shaded areas mark the core region and the stationary component, respectively. The blue shaded area at 25.5 ± 2.0 mas away from the phase center indicates the region of the jet where the widening and decrease in surface brightness at 8 GHz occurs. The black arrows indicate the traveled distances of the identified components causing a smoothing of the profile.

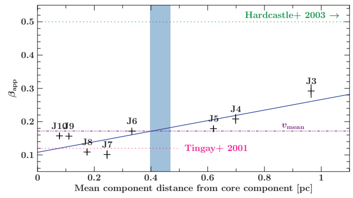


Figure 4: Evolution of individual component velocities as a function of mean component distance from the core component, which can be parameterized by a linear fit of $\beta_{app} = 0.16\,d + 0.11$ (blue line). The blue shaded area marks the position and extent of the jet widening at ∼ 25 mas (see Fig. 3), which can be interpreted as a jet-star-interaction. The mean component speed and archival measurements by Tingay+2001 and Hardcastle+2003 are indicated by straight lines. Components J4 and J3 show significantly higher speeds than components closer to the core, suggesting that the jet undergoes acceleration further out as seen in a statistically large sample of AGN jets by Lister+2013.

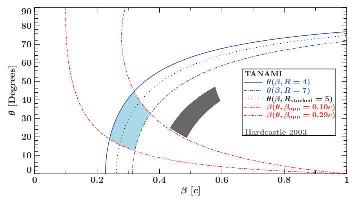
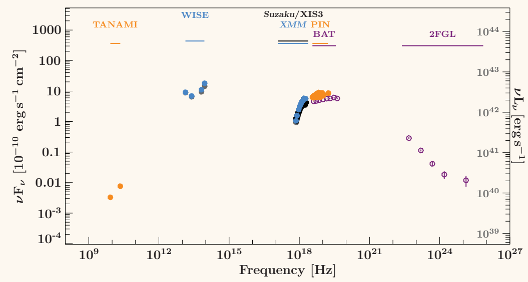


Figure 5: Constraints on the intrinsic jet speed β and the angle to the line of sight θ.
The blue-shaded intersection area marks the region of permitted parameter space for both values, constraining $\theta \sim 12^\circ - 45^\circ$ and $\beta \sim 0.24 - 0.37$. The gray-shaded region indicates the constraints according to measurements by Hardcastle+2003 at kpc-scales. We find that a larger angle to the line of sight cannot solely explain the faster apparent speed at kpc-scales, but requires in addition an increase in β from < 0.3 to > 0.45.

The TANAMI Program

The Southern Hemisphere VLBI project TANAMI (Tracking Active Galactic Nuclei with Austral Milliarcsecond Interferometry) aims to study the radio and γ-ray connection seen in many blazars by contemporaneous VLBI, *Fermi*/LAT and further multiwavelength observations. With the Australian Long Baseline Array (LBA) and additional telescopes in South Africa, Antarctica and Chile (see Fig. 4), we are monitoring a sample of currently 84 extragalactic jets south of −30° degrees approximately every 2 months at 8.4 GHz and 22.3 GHz with milli-arcsecond resolution. The TANAMI sample consists of a combined radio and γ-ray selected subsample, with new γ-ray bright sources being added upon detections by *Fermi*/LAT. For most of these sources, TANAMI provides the first VLBI images.

Figure 6: The TANAMI Array (Credit: J. Wilms/M. Kadler)
rightarrow`pulsar.sternwarte.uni-erlangen.de/tanami`



OUTLOOK Figure 7: Non-simultaneous SED of Cen A's core emission including recent *XMM* and *Suzaku* observations (August 2013). With simultaneous multiwavelength observations (VLBI, *XMM*, *Suzaku*, *NuSTAR* and *Fermi*/LAT) in the framework of the TANAMI program we will study the time evolution of the broadband emission.

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