Analysis of the Multiwavelength Structure of the Large-Scale Jet in Quasar 3C 273 Jet

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Abstract

Here we present a detailed analysis of the best-quality multi-wavelength data gathered for the large-scale jet in the core-dominated quasar 3C 273. In our study we focus on investigating the morphology of the outflow at different frequencies in transverse and longitudinal directions and therefore we apply various techniques for the image deconvolution, paying particular attention to a precise modeling of the *Chandra* and *Hubble* point spread functions.

Introduction

Large-scale jets produced in active galactic nuclei (AGN) are spectacular manifestations of an efficient extraction of energy and momentum from supermassive black holes and their accretion disks. For many years since their discovery, these structures have been studied almost exclusively at radio frequencies, and only recently the new generation of sensitive, high-resolution optical and X-ray instruments, in particular the *Hubble* Space Telescope and the *Chandra* X-ray Observatory, enabled a truly multiwavelength investigation [1].

In this work we analyze all the available best-quality radio, far-ultraviolet, and X-ray data for a particularly prominent jet in the core-dominated quasar 3C 273. The jet has been studied in the past at various frequencies by a number of authors. The novelty of the investigation presented here lies in a careful image analysis involving combined, high-photon statistics datasets, including image deconvolution and forward-fitting of a multi-component image models. These allowed us for an original insight into the multiwavelength morphology of the target, and hence into the energy dissipation processes and structure of large-scale quasar jets in general.

Multiwavelength data

We have used all the archival observations of the target with the *Chandra* Advanced CCD Imaging Spectrometer (ACIS), the far-ultraviolet data obtained using the Advanced Camera for Surveys/Solar Blind Channel onboard the *Hubble* Space Telescope at $\simeq 150$ nm [2], and the 8.4 GHz maps obtained with the *Very Large Array*.

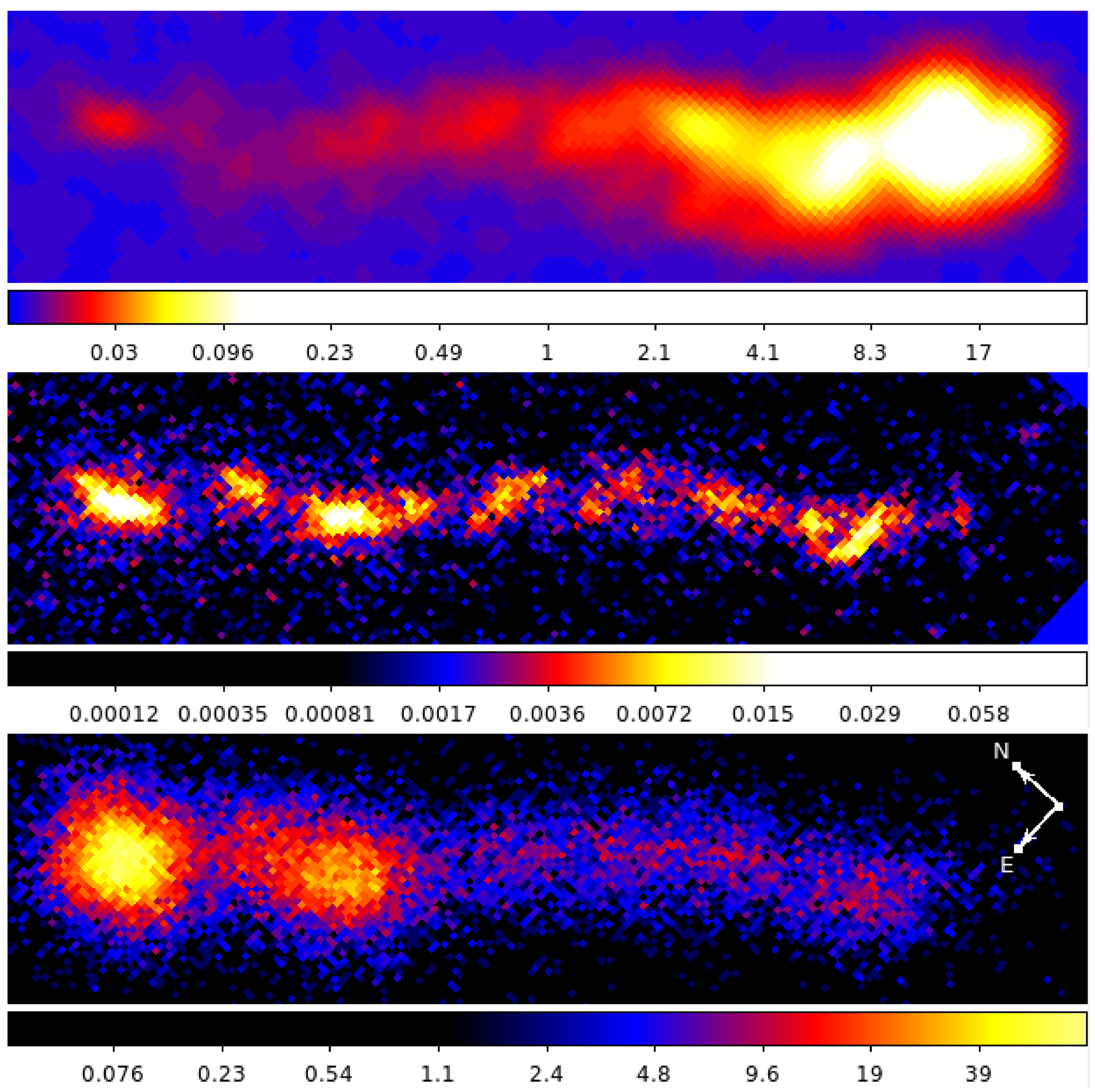

Figure 1: The *Chandra* ACIS X-ray, *Hubble* ACS/SBC ultraviolet, and *VLA* 8.4 GHz radio images of the 3C 273 jet (top, middle, and bottom panels, respectively).

Chandra ACIS PSF:
ChaRT+MARX for detailed ray-tracing.
Hubble ACS/SBC PSF: An image of a point-like star [2] and reproduced PSF using the encircled energy fraction for the ACS/SBC from servicing mission orbital verification.

Data analysis

Transverse Jet Profiles. To restore the jet internal structure several techniques were used for different frequencies, namely for X-ray data we used forward-fitting (FF) and Lucy-Richardson deconvolution algorithm (LRDA), for ultraviolet data – LRDA and for radio data we used AIPS fitting procedure. The transverse profiles were calculated through the minor axis of each knot.

Band	Knot A ["]	Knot B2 ["]
X-ray	0.18	0.18
UV	0.13	0.17
Radio	0.37	0.75

Table 1: The estimated sizes (FWHM) of first two knots in different wavelengths. The transverse profiles were calculated through the minor axis of each knot.

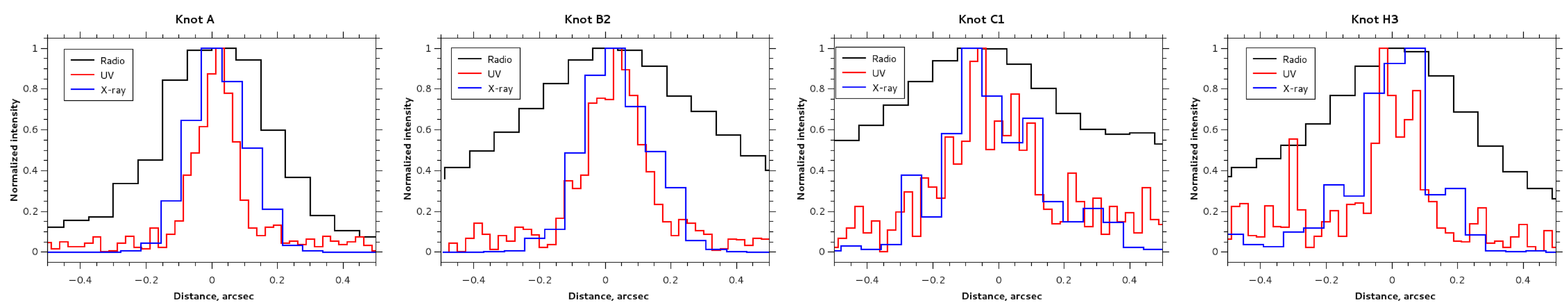

Figure 2: Transverse profiles of the brightest segments of the 3C 273 jet (knots A, B2, C1, and H3) at different frequencies, obtained from the original *VLA* and the deconvolved *Hubble* and *Chandra* images.

Longitudinal Jet Profiles. Since the knots are not located along a straight line, we estimated the X-ray/radio positional offsets as $\Delta_{\rm X/R} = \sqrt{(x_{\rm X} - x_{\rm R})^2 + (y_{\rm X} - y_{\rm R})^2}$, where $(x_{\rm X}, y_{\rm X})$ and $(x_{\rm R}, y_{\rm R})$ are the coordinates of the intensity peaks of X-ray and radio knots, respectively, calculated using coordinates of the corresponding centroids on the deconvolved maps.

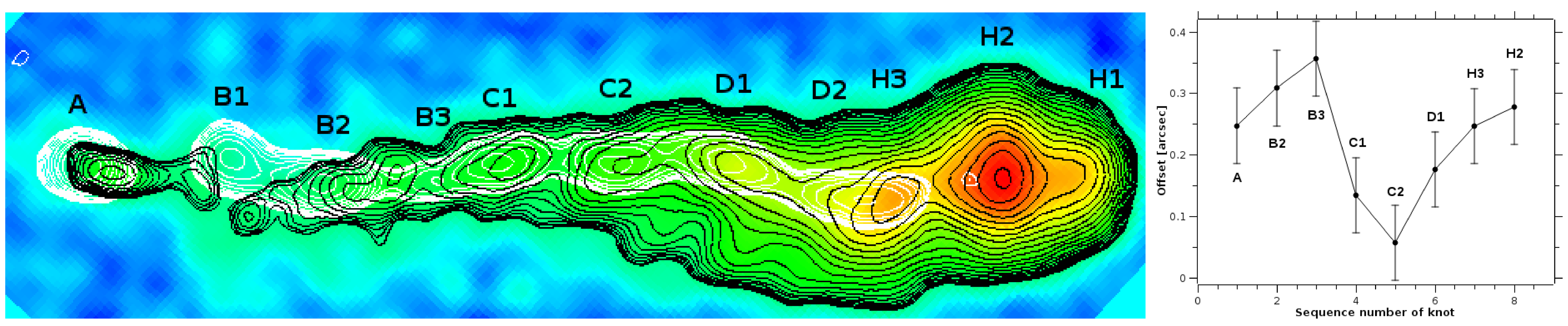

Figure 3: *Left panel:* The restored radio image with radio (black) and the deconvolved X-ray (white) contours superimposed. The radio contour levels increase from 0.005 to 0.2 Jy/beam by a factor of ~ 1.4. The X-ray contour levels increase from 4 to 270 "restored" counts by a factor of ~ 1.6. The knots labeling following [3]. The wiggling appearance of the outflow is clearly visible in the image. *Right panel:* Spatial offsets between radio and X-ray intensity peaks in the 3C 273 jet.

Conclusions

We find X-ray and far-ultraviolet jet knots of 3C 273 are not point-like, and can be resolved transversely as extended features with sizes of about $\simeq 0.5$ kpc. Also, the radio outflow seems to be wider than the deconvolved X-ray/ultraviolet jet. Finally, the intensity peaks of the X-ray knots are located systematically upstream of the corresponding radio intensity peaks; the distribution of the projected spatial offsets along the jet, ranging from $\lesssim 0.2$ kpc up to $\simeq 1$ kpc, seems to reflect to some extent a wiggling/curved appearance of the outflow.

Ref. & Acknowledgments

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