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COORDINATES AND MAGNIFICATIONS OF THE GRAVITATIONAL LENS CRITICAL IMAGES: SECOND ORDER CORRECTIONS NEAR SYMMETRIC CUSP

We found and analyzed corrections to the asymptotic formulae that describe coordinates and magnifications of the point source critical images near a cusp. We show that in the case when the lens mapping is symmetric with respect to the cusp axis, the first-order corrections equal to zero identically. For this case, expressions of the second order corrections are found. The Chang-Refsdal lens model is used as an illustration. It is shown that the account of the second order corrections can significantly extend ***the region near the cusp, where the asymptotic formulae have the prescribed accuracy.***

Key words: gravitational lens systems, Chang-Refsdal lens model.

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THE X-RAY STRUCTURE OF EXTRAGALACTIC JETS

The X-ray internal structure of extragalactic jets is analyzed. We have elaborated a method for recovering of the multi-component structure of a source on the basis of the observational data. The analysis was applied to the Chandra observations of core-dominated quasar 3C 273.

Key words: extragalactic jets, Chandra telescope.

1. Introduction. In spite of great progress in exploring active galactic nuclei (AGN) these objects remain one of the most enigmatic in modern astrophysics [1]. One of the manifestations of AGN activity is the existence of extragalactic jets that constitute the longest collimated structures in the Universe [2]. The detailed study of extragalactic jet structures in all wavelengths is important task for modeling the different astrophysical processes that take place in jets, for example the acceleration of cosmic rays up to the ultra high energies due to Fermi acceleration mechanisms [3-5].

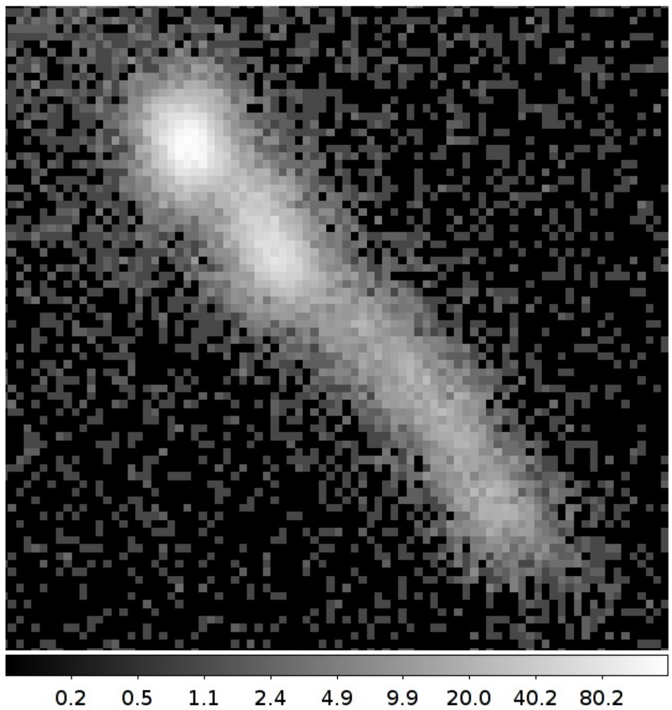

Figure 1. The merged Chandra image (counts) of the 3C 273 jet binned in 0.123" bins

2. Observational data. We have used four Chandra observations of core-dominated quasar 3C 273 and its jet (ObsIDs: 4876, 4877, 4878, 4879) with total exposure time of 160 ks [6]. The X-ray data analysis was processed with CIAO 4.4 – a software package for Chandra interactive analysis of the observations [7]. Before analysis we have reprocessed the data using reprocessing script that makes all recommended data processing steps presented in the CIAO analysis threads.

The pixel randomization was removed during reprocessing. We have not included energy-dependent sub-pixel event repositioning algorithm (EDSER) because the current version of SAOsac ray-trace simulator does not model the dither motion of the telescope, so currently it's not possible to use EDSER in a point spread function (PSF) model.

We have merged four observations for the further analysis (ObsIDs: 4876, 4877, 4878, 4879) and have binned them with the binning factor of 0.25 (it corresponds to the bin size 0.123"). The merged and binned image of the jet is presented on Figure 1.

3. Data analysis. Observing a multi-component source with spatial photon distribution $s_i(x,y)$ and using a telescope with PSF $P_i(x,y)$, one obtains a source image $N_i(x,y)$ that can be written as a convolution of the source $s_i(x,y)$ with PSF $P_i(x,y)$

$$N_i(x,y) = \sum\sum s_i(x',y')P_i(x-x',y-y') \quad (1)$$

where index i corresponds to the bin with coordinates (x,y).

As we do not know the exact source photon distribution $s_i(x,y)$, we can assume a source model S_i and build the model of source image that schematically can be written as

$$N_i^* = S_i \circ P_i \quad (2)$$

where the sign "$\circ$" means the convolution.

To find the best-fit parameters of the source model S_i we have used the forward-fitting algorithm employed by the Sherpa software package. The Nelder-Mead Simplex algorithm was used for optimization using Cash statistics.

In general case the source model S_i can be written as a sum of G_i components plus constant background C

$$S_i = \sum G_i + C \quad (3)$$

In order to estimate the number and positions of possible source components that will be used in fitting procedure we adaptively smoothed the jet image (see Figure 1) using CIAO tool *csmooth* with the minimal significance of the signal under the kernel equals to 3. It allowed us to identify statistically significant brightness enhancements over local background and visually estimate the correspondent source components. The smoothed image and preliminary source components are presented in Figure 2

Taking into account the source model (3), we can rewrite the equation of the image model (2) in the following form

$$N_i^* = \sum(G_i \circ P_i) + C \quad (4)$$

where P_i is the PSF for correspondent source model component G_i. As the PSF strongly depends on the position and energy one has to model PSF for the each source component separately.

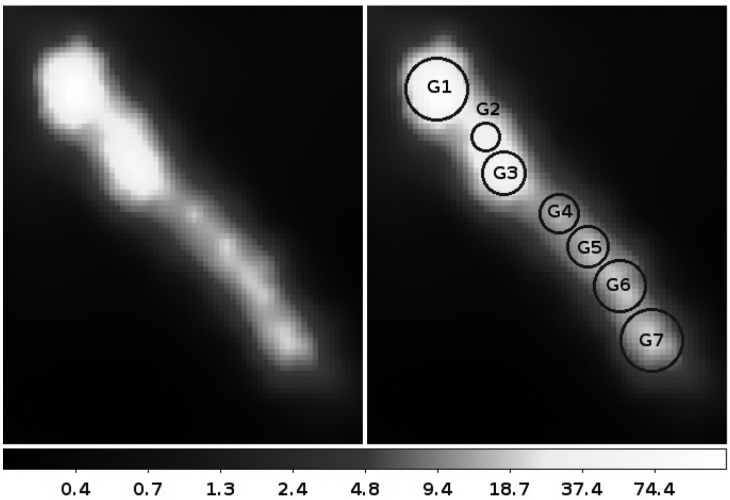

Figure 2. Adaptively smoothed image of jet (left) and source components (right)

4. Analysis of residuals. We take into account only statistical noise. We assume that the counts in each bin i have Poisson distribution with mean value equal to the total number of observed counts N_i in this bin, so the standard deviation in counts for bin i can be taken in form $\sqrt{N_i}$.

But if the number of the counts in each bin is small (<5), then we cannot assume that the Poisson distribution from which the counts are sampled has a nearly Gaussian shape. The standard deviation for this low-count case has been derived by [8]

$$\sigma_i = 1 + \sqrt{N_i + 0.75} \quad (5)$$

Higher-order terms of this equation have been dropped from the expression, so it is accurate to approximately one percent.

After fitting, we explore the residuals between observational data (see Figure 1) and the image model (4). One can analyze residuals between source counts N_i and modeled source counts N_i^* in terms of standard deviation of image count distribution given by equation (5). As a result we obtain the σ-map that shows the regions with statistically significant differences between observed data and the proposed model. The σ-map can be calculated by the following equation

$$R_i = \frac{N_i - N_i^*}{\sigma_i} \quad (6)$$

where N_i is the total counts in the image bin i, N_i^* is the modeled source counts in bin i, σ_i is the standard deviation defined by equation (5).

We have analyzed several source models and the results of the fitting for the best model are presented in Table 1 and in Figure 3. Model consists of eight symmetrical Gaussians.

Table 1. **Parameters of "8s" model**

Name	Type	FWHM (")	Amplitude, counts
G1a	Gaussian	0.29	510
G1b	Gaussian	0.27	1174
G2	Gaussian	0.28	418
G3	Gaussian	0.29	616
G4	Gaussian	068	35
G5	Gaussian	0.56	54
G6	Gaussian	0.3	178
G7	Gaussian	0.65	48
C	Constant	-	0.3

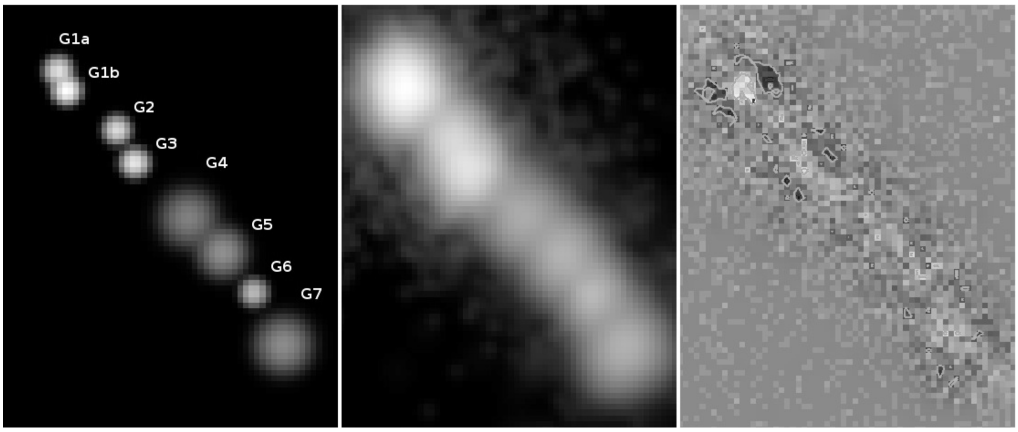

Figure 3. Source model "8s": the unconvolved (left) and convolved (middle) model components. The σ-map contours (right) are correspond to 1.6σ (light contours).

5. Conclusions. The X-ray jet of core-dominated quasar 3C273 was considered. The internal structure of jet was investigated. The multi-component model of jet was built to fit the observational data. The best-fit parameters of model were estimated. The sizes of model components have been analyzed.

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РЕНТГЕНІВСЬКІ СТРУКТУРИ ПОЗАГАЛАКТИЧНИХ ДЖЕТІВ

Проведено аналіз внутрішньої рентгенівської структури позагалактичних джетів. Розроблена методика відтворення багатокомпонентної структури джерела на основі спостережуваних даних. Аналіз застосовано до спостережень ядерно-домінантного квазара 3C 273 телескопом Чандра.

Ключові слова: позагалактичні джети, телескоп Чандра.

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РЕНТГЕНОВСКИЕ СТРУКТУРЫ ВНЕГАЛАКТИЧЕСКИХ ДЖЕТОВ

Проведен анализ внутренней рентгеновской структуры внегалактических джетов. Разработана методика воспроизведения многокомпонентной структуры источника на основе наблюдаемых данных. Анализ применен к наблюдениям ядерно-доминантного квазара 3C 273 телескопом Чандра.

Ключевые слова: внегалактические джеты, телескоп Чандра.