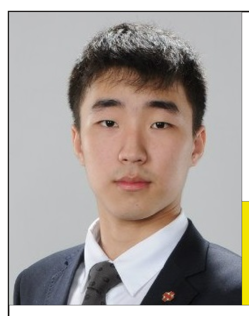

High-resolution study of the inner jet of M87 at 8 and 15 GHz

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Very high dynamic range of >20000:1 dual-frequency images and the spectral index map of the jet in M87 are obtained with a sub-parsec scale resolution. Edge-brightening due to stratification and the counter-jet are confirmed. Spines along the jet with an increased spectral index value are discovered.

Introduction

Virgo A or M87 is one of the brightest and closest radio source in the sky. The importance of studying it is significant. A lot of AGNs phenomena are still not clear, so Virgo A is the best candidate to study AGNs and their jets. Due to big angular size one can obtain high quality, high resolution, high dynamic range images that will help investigate AGNs and jets phenomena. The M87 inner jet image at 2 cm (Kovalev et al, 2007) have edge-brightened structure and low intensity region southeast to the core. According to the interpretations edge-brightened jet in the image is the result of stratification of the jet. And the region of low intensity to the southeast is counter-jet. To confirm this, dual-frequency observation is needed. Here the results of dual-frequency study of M87 inner jet are presented.

Observation and data reduction

The observation was carried out using VLBA, one of VLA (Y1) antennas in May 2009. There were tree observation days: 22, 23 and 24 May 2009. That include two frequency bands: 15.4 and 8.4 GHz. First, M87 in 15.4 GHz was observed in 22 May 2009. After that, in 8.4 GHz band 23 May 2009. And in 15.4 GHz band Virgo A was observed in 24 May 2009. All initial calibration of data was done in AIPS. Imaging was carried out in DIFMAP using phase, amplitude and phase self-calibration. Due to core shift caused by synchrotron self-absorption and image detail coordinate uncertainty, 2D cross-correlation was used to obtain core shifts between images with different frequencies. And to obtain spectral index distribution map, images were shifted and convolved with equal beams and pixel size in DIFMAP.

Dual-frequency M87 imaging results

In figure 1 the results of imaging are presented. Extremely high dynamic range more than 20000:1 was reached for all images. The noise out of source less than 50 microJy/beam. Almost 500 mas jet images with sub-milliarcsecond resolution was obtained. As expected, inner jet images show edge-brightened structure and the low intensity region in southeast. All images were masked at level of 5 sigma.

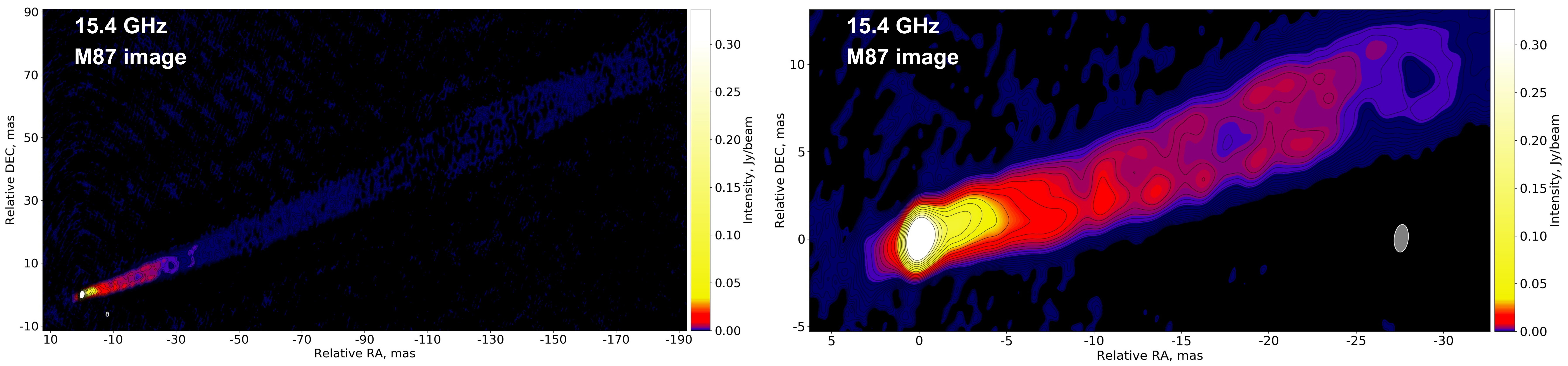

Fig. 1: M87 image in 15.4 GHz, VLBI + VLA (Y1). Beam FWHM: 1.6×0.8 mas, P.A. −6◦. Map peak: 1.22 Jy/beam. The contours are plotted in successive powers of 2 times the lowest contour of from 0.01% of U map peak.

Spectral index distribution

From the theory of synchrotron radiation, one knows that spectral index is dependent from the density of emitting electrons with specific energy. So, making spectral index distribution map allows rate energies of emitting electrons and so velocities. The higher the value of spectral indices, the greater energy of the emitting electrons. The figures below show spectral index distributions of the inner jet. On the figure 2 one can observe high spectral index values in the ridge of the jet, which indicates that inner jet regions have greater velocities. This conclusion confirms the interpretation of edge-brightened effect by stratification of the matter of the jet. The other interpretation is also confirmed by the spectral indices map. Spectral index is inverted in the optically thin jet. So, to confirm the interpretation, spectral indices of the region of low intensity must have inverted spectrum as well as optically thin jet. In the figures below this region have inverted spectrum as expected. So, one can conclude that the low intensity region southeast to the core is counter-jet. In addition to central ridge high values, spectral index distribution map show high values in the edges along the jet (Figure 3). It can be an either imaging effect, or physical. If it is an physical effect, this effect can be explained as increased plasma density and heating due to stratification and interaction with an external cocoon.

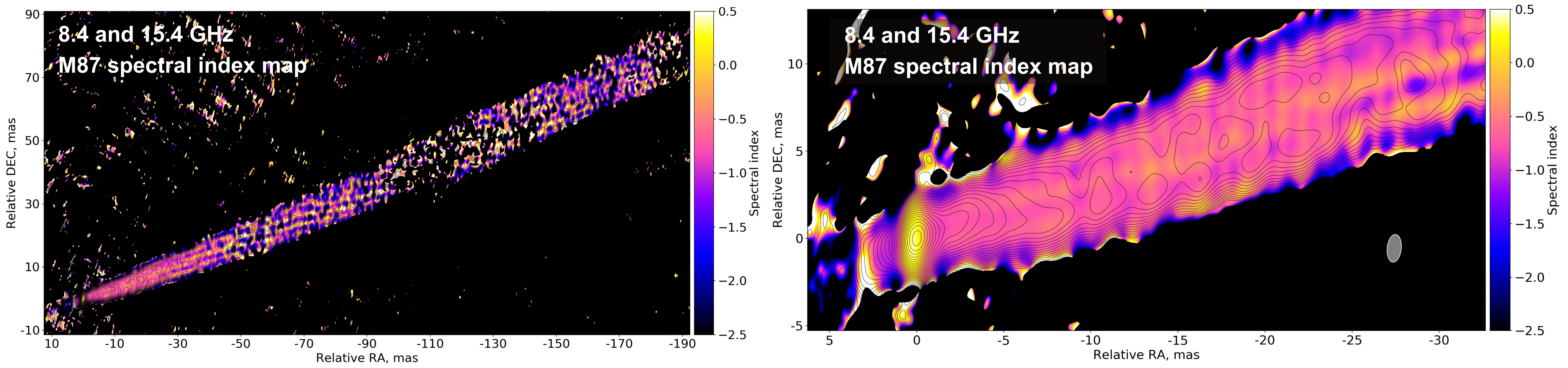

Fig. 2: Spectral index distribution maps made from 8.4 and 15.4 Ghz images with beam FWHM: 1.6×0.8 mas. The contours are plotted in successive powers of 2 times the lowest contour of from 0.01% of U map peak.

Plans

To test which effect made edge-brightening on spectral index map, the UV data will be synthesized from the model of hollow jet created from the original clean-model by deleting inner clean components of the jet. The data will be imaged, and the spectral index distribution will be obtained. If spectral index edge-brightening is imaging effect, the modeled spectral index distribution will be flat.

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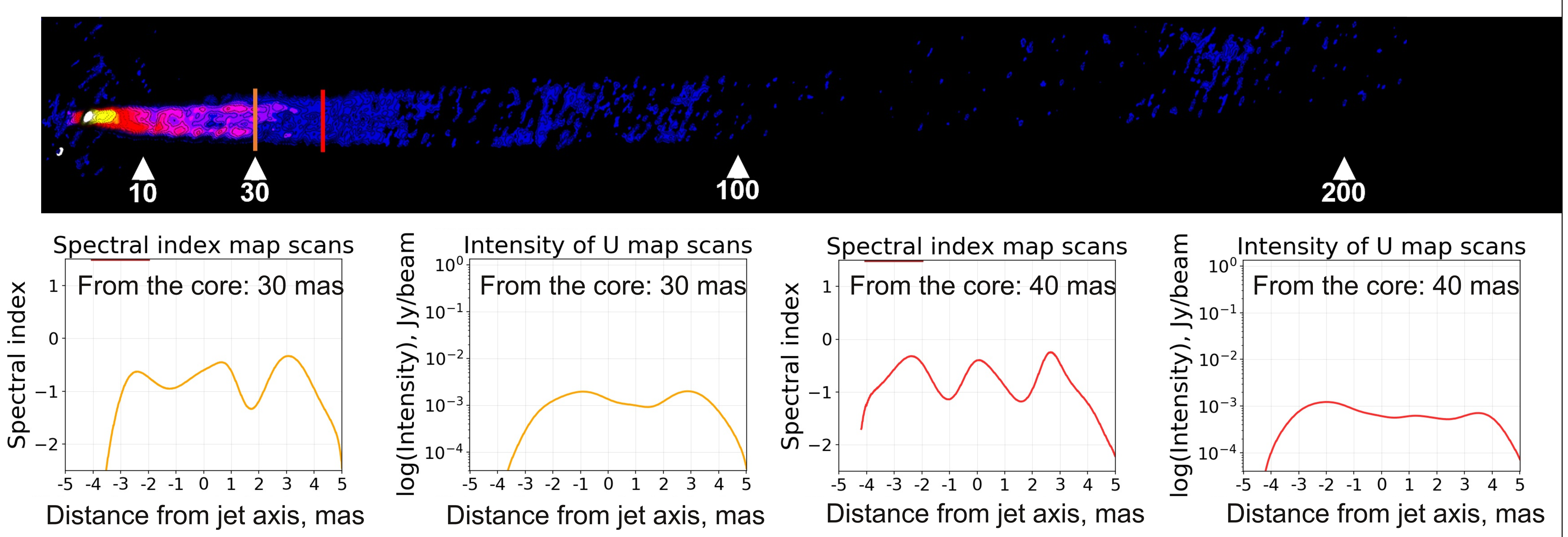

Fig. 3: Spectral index and intensity slices across the jet on distances 30 and 40 mas from the core. Beam FWHM: 1.6×0.8 mas, P.A. −6◦.