Perseus in Sicily: From Black Hole to Cluster Outskirts
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Flip of the jet head position of 3C 84 in 2015

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Abstract. By performing the multi-epoch monitoring observation with KaVA at 43 GHz, we investigate the kinematics of the notable newborn bright component C3 located at the tip of the recurrent jet of 3C 84. During 2015 August-September,we discover the positional flip of the C3 component about 0.4 milli-arcsecond in angular scale. The flux density of the C3 component coherently showed the monotonic increase after the flip during our monitoring period. These phenomena are in good agreement with characteristic behaviors of a jet propagation in clumpy ambient medium predicted in hydrodynamical simulations.

Keywords. galaxies: active, galaxies: jets, radio continuum: galaxies

1. KaVA Observation of 3C 84

Jets in active galaxies are generally thought to have a strong impact on interstellar medium especially when they are young. Hydrodynamical simulations actually indicate flips of the jet head caused by the interaction with the clumps (Wagner & Bicknell 2011), although such a phenomenon has not yet been observed so far. NGC 1275 (a.k.a. 3C 84) is a notable nearby giant elliptical galaxy at the center of the Perseus cluster. Nagai *et al.* (2010) discovered the emergence of newborn bright component so-called C3 in the radio jet 3C 84. Hence, 3C 84 is regarded as a unique laboratory to explore interactions between the jet and the circum-nuclear environment on parsec scale.

From 2015 August to 2016 June, we conducted full- track 12 epochs monitoring of 3C 84 at 43 GHz with KaVA, the combination of the Korean VLBI Network (KVN) and the Japanese VLBI Exploration of Radio Astrometry (VERA) radio arrays. The joint array, KaVA, has a total of seven antennas at frequencies of 22 and 43 GHz, resulting in angular resolutions of about 1.2 and 0.6 mas, respectively. Basic imaging capabilities of KaVA has been summarized in detail by Niinuma *et al.* (2014) and (Hada 2017). Left-hand circular polarization was received and sampled with a 2 bit quantization. All the data were recorded at 1 Gbps (256 MHz bandwidth, 16 MHz, 16 sub-bands) and correlated by the Daejeon correlator. As a technical note, we note that in the flux calibration of

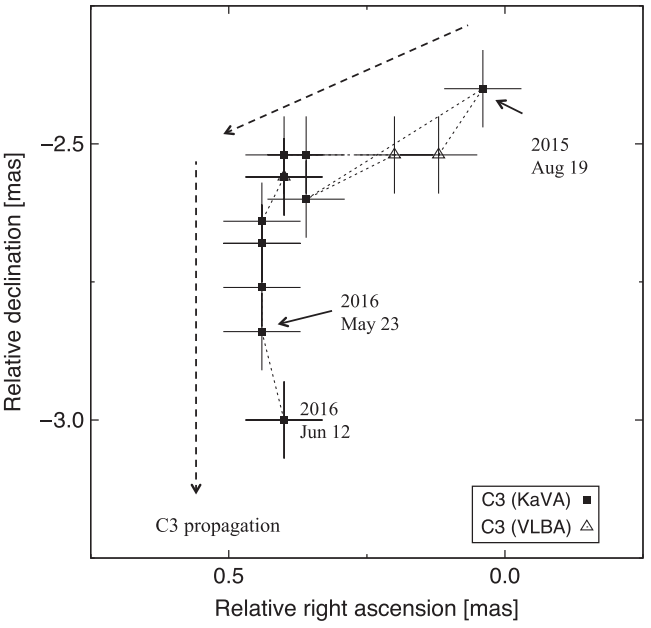

Figure 1. Relative peak intensity position of the component C3 with respect to C1 assuming as an origin (0, 0). The filled squares and open triangles represent the peak intensity position obtained with KaVA and VLBA observations, respectively.

KaVA one visibility amplitudes of KaVA correlated by the Daejeon hardware correlator (Lee *et al.* 2015a) should be corrected by multiplying the factor of 1.35 (Lee *et al.* 2015b).

2. Summary

Here we summarize our main findings following our recent work (Kino 2018).

• *Discovery of the position flip of C3*. We discover the significant flip of C3 with the angular scale of about 0.4 mas between Aug and Sep in 2015. As shown in Figure 1, the motion of the peak position of C3 was decelerated and C3 wobbled for a few months. After that, the peak position of C3 resume to propagate to the south direction.

• *Brightening of C3*. We find the clear monotonic increase of the peak intensity of the C3 component during the observation period. The peak intensity of C3 increased more than a factor 4 at the end of the observation period. The flip of C3 together with this monotonic enhancement of its flux density can be explained by a collision between the jet and a dense clump.

• *Estimate of the clump density*. We estimate the number density of the presumable clump based on the momentum balance between the jet thrust and the ram pressure from the clump and we find that the clump number density is estimated about 4×10^3 cm$^{-3} \lesssim n_{\rm cl} \lesssim 2 \times 10^5$ cm^{-3}. The clump's location and estimated number density are in good agreement with a cloud located deep side the NLR or a dense portion of an intergalactic molecular cloud.

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