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KVN Source-Frequency Phase-Referencing Observation of 3C 66A & 3C 66B

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In this proceeding, we present some preliminary results of our KVN Source-Frequency Phase-Referencing (SFPR) observation of 3C 66A and 3C 66B. The motivation of this work is to measure the core-shift of these 2 sources and study the temporal evolution of the jet opacity. The KVN core-shift measurements are found to be affected by inner jet structure blending. We have conducted high resolution imaging observation with KaVA to overcome this issue. The measurement with structure correction is much smaller and thus more reasonable. No significant core-shift variation has been found over two months timescale while the core position at a single frequency has changed. This may be related to the inner jet structural change or real core motion.

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1. Introduction

The radio source 3C 66A (also known as B0219+428) is a well-known BL Lac object at a redshift of 0.33-0.44 [1]. 3C 66B (UGC 01841) is a nearby radio galaxy (D=86Mpc, z=0.0213). Both sources are bright at radio wavelengths and, under parsec-scale resolution, both sources show typical core-jet structures. The separation on the sky plane between these two sources is very small, $\sim$ 6 arcmin, which makes them an ideal pair for phase-referencing observations. Previous VLBA observation results have revealed a possible elliptical orbital motion of the jet core in 3C 66B based on the multi-epoch position measurements obtained by phase-referencing to the core of 3C 66A (See Figure 1& 2 in [2]). This result once led to the conclusion that a binary SMBH system was at the center of 3C 66B [2]. However, this explanation is under debate (e.g. [3]). Alternative explanations like single BH with jet precession cannot be ruled out because of the lack of central SMBH position information. Furthermore, there might be contributions from the reference source in the measurements because it is variable. Especially, follow-up studies have found apparent inward motions of the innermost components in the jet of 3C 66A which supports the later argument (See Figure 3 in [4]).

Non-stationarity of the core may exist in either or both of the two sources, and the reason is not clear. Detailed follow-up studies are necessary.

2. Method and Observation

Core-shift studies would be important to understand the non-stationarity of the cores. The core-shift effect represents the frequency dependence of the absolute position of the core, which is usually $r_c(\nu) \propto \nu^{-1/k_r}$ (e.g. [5]). k_r depends on the electron energy spectrum and on magnetic field and particle density distribution in the jet. Core-shift can provide information about the SMBH position (e.g. [6]). Multi-epoch measurements will enable us to trace the possible core motion in 3C 66A and SMBH positions in 3C 66B in order to check whether it is orbiting another SMBH.

There are several different ways of measuring the core-shift (e.g. See [7] for a summary). The one we use for this work is source-frequency phase-referencing (SFPR, [8]). The rationale is similar as measuring the relative position between sources with conventional phase-referencing. By doing phase-transfer at the frequency domain, the non-dispersive propagation effects like the tropospheric effects are calibrated and the residual phase will contain information of the relative position between frequencies, i.e. the core-shift. Then by referencing to another source to calibrate the dispersive items of the visibility phase, the residual phase will consist of the combined core-shift of the two sources, the target source structure and interpolation errors. This method works well for astrometry at mm wavelengths (e.g. [9]).

We used the Korean VLBI network (KVN) to carry out our SFPR observations toward 3C 66A and 3C 66B. The KVN is a dedicated mm-VLBI network. The quasi-optics (QO) system adopted by KVN make it very efficient in multi-frequency studies like SFPR.

Our observation has 6 epochs. Start from February 2014, we have observed 3C 66A and 3C 66B once every 2 months at 21.65 (K), 43.3 (Q) and 86.6 (W) GHz simultaneously. The observing frequencies are set to have integer ratios in order to avoid 2π ambiguities when doing frequency-phase-transfer (FPT). The total observation time for each epoch is $\sim$10 hours and the recording

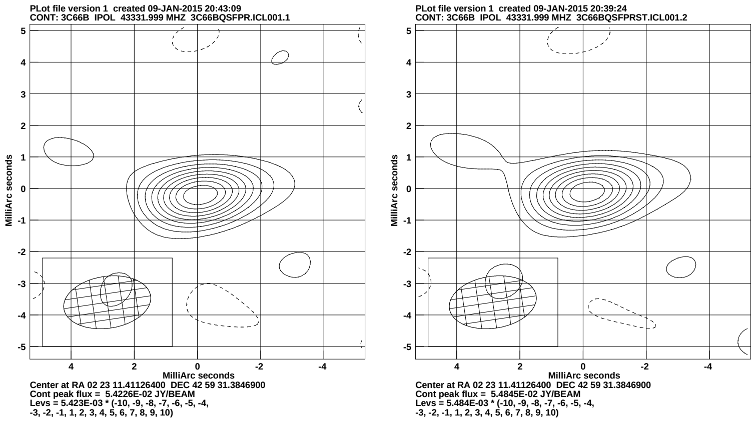

Figure 1: Left: SFPRed map of 3C 66B at 43GHz without correcting structural blending effect. Reference frequency is 22GHz and reference source is 3C 66A. Right: The Same as Left but with corrections of the source structure from KaVA high resolution maps.

bandwidth is 256 MHz (64, 64, and 128 MHz at K, Q, and W band, respectively). Typical duration for each scan is about 3 minutes for SFPR. We also have fast switching section ($\leq$ 1 minute per scan) to enable conventional Phase Referencing (PR) at the lowest frequency.

3. Preliminary Results and Discussion

In this section, we present the K-Q band preliminary results of the second epoch of observations which was carried out on April 15th, 2014. The preliminary results at the first epoch and details of the data analysis will appear in another conference proceedings [10]. The results show that FPT with simultaneous multi-frequency observation works quite well, the coherence time becomes much longer after FPT and then after reference to a nearby calibrator, high quality SFPRed maps can be obtained. However, the measurements are found to be affected by structural blending effect due to the large beam size of KVN.

Structural blending effect can be reduced by applying high resolution clean models obtained via imaging observation with other arrays like the VLBA [9]. For the second epoch observation, we have conducted imaging observation of 3C 66A with KaVA (KVN and VERA[1] array). KaVA has become a powerful array for imaging AGN jets at K and Q band [11]. The resolution of KaVA is >4 times better than KVN. Our KaVA observations were scheduled on the days right after the KVN SFPR observation.

Figure 1 shows the SFPRed maps of 3C 66B at Q band. The flux recovery of the maps are about 75% and the dynamic ranges are about 30. In each map, there is an offset from the center of the image to the peak. That is the astrometric measurement, i.e. the combined core-shift. The direction of the measured core-shift is roughly consistent with the combination of the predicted core-shift of each source, i.e. along the mean jet axis. The value measured by correcting the structural blending effect (0.16 ± 0.04 *mas*) is much smaller than the one without correction (0.23 ± 0.04 *mas*) and is more reasonable when comparing with the core-shift measured in other radio jets. The measured

[1] VLBI Exploration of Radio Astrometry

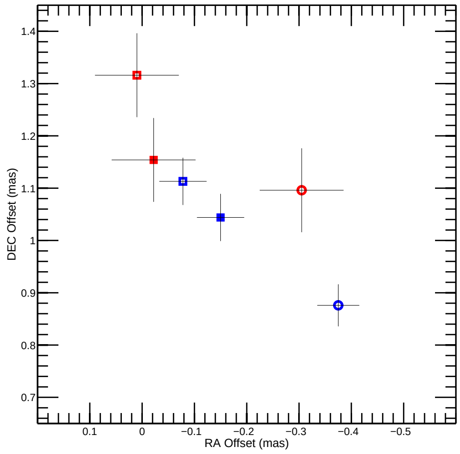

Figure 2: The measured core positions at the first 2 epochs. The circles and squares represents the 1st and 2nd epoch results, respectively. Red and blue symbols represents 22 and 43 GHz measurements respectively. The measurements with structural blending effect corrections appear as filled symbols while the ones without correction appear as open symbols.

core positions at the first 2 epochs are plotted in Figure 2. The red points represent the K band positions measured by conventional PR. The difference between blue and red points in each pair are the measured K-Q core-shift values, which represent the difference between core positions at the two different frequencies. The errors are calculated by half of the projected beamsize divided by the dynamic ranges of the corresponding map. Comparing the two epoch results, we found the core-shift does not change significantly (both 0.23 ± 0.04 *mas* without correcting the structural blending effect). However, the measured core position at K band has changed by 0.38 *mas*. The reason could be the motion of inner-jet components within the beamsize or real SMBH position change. Follow-up studies with more frequencies and the next few epochs may give the answer.

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