URSI AP-RASC 2019, New Delhi, India, 09 - 15 March 2019

Global Millimeter VLBI Array Survey of Ultracompact Extragalactic Radio Sources at 86 GHz

Dhanya G. Nair*(1), Andrei P. Lobanov (1,2), Thomas P. Krichbaum(1), Eduardo Ros(1) and J. Anton Zensus(1)
(1) Max-Planck-Institut für Radioastronomie, Bonn, Germany ; e-mail: dhanya@mpifr-bonn.mpg.de
(2) Institut für Experimentalphysik, Universität Hamburg, Germany; e-mail: alobanov@mpifr-bonn.mpg.de

Very Long Baseline Interferometry (VLBI) observations at 86 GHz (~ 3 mm) reach a resolution of about 50 micro arcsec and sample the scales as small as 10^3-10^4 Schwarzschild radii of the central black hole in Active Galactic Nuclei (AGN), and uncover the jet regions where acceleration and collimation of the relativistic flow takes place. We present results from a large global 86 GHz VLBI survey of 162 ultra compact radio sources conducted in 2010-2011 using the Global Millimeter VLBI Array (GMVA). This survey has contributed an increase of ~ 2 on the total number of AGN ever imaged with VLBI at 86 GHz. For the first time, 3 mm VLBI maps of 138 sources are made. The survey data attained a baseline sensitivity of 0.1 Jy and a typical image sensitivity of 5 mJy/beam. Gaussian model fitting was used to represent the structure of the observed sources and to estimate the flux densities and sizes of the core and jet components. The model fitting yields estimates of the brightness temperature (T_b) of the VLBI bright core (base) of the jet and inner jet components of AGN, taking into account the resolution limits of the data at 3mm. The model fit based estimates of brightness temperatures were compared to the estimates of brightness temperature limits made directly from the visibility data, demonstrating a good agreement between the two methods.

The survey data are applied for studying jet physics down to smallest angular (~50 micro arcseconds). Brightness temperature measurements made from the survey data have been applied to estimate the intrinsic brightness temperature at the jet base (VLBI core) and in the nearest moving jet components. These measurements have been modeled by a basic population scenario with a constant Lorentz factor for the entire source sample. The investigation of the observed distribution of T_b by population modeling showed that the intrinsic brightness temperature, $T_0 = (3.77\pm0.14)\times10^{11}$ K for the jet cores, implying that the inverse Compton losses dominate the emission. In the nearest jet components, $T_0 = (1.42\pm0.19)\times10^{11}$ K is found, which is slightly higher than the equipartition limit of 5×10^{10} K expected for these jet regions [3]. For objects with sufficient structural detail detected, the adiabatic energy losses are shown to dominate the observed changes of brightness temperature along the jet, and the results are in agreement with theoretical predictions for adiabatically expanding jets [2]. Thus from this modeling, the core brightness is found to be limited by the inverse Compton losses, while equipartition and adiabatic expansion govern the observed evolution of the moving jet components. The peaking of brightness temperatures measured in the millimeter (mm) VLBI cores at ~ 10^{11} K could be best explained by assuming that plasma acceleration is still taking place in the region between the mm VLBI cores, a result which confirms the theoretical prediction that the acceleration zone extends on parsec scales.

Combining the survey estimates of brightness temperature with data obtained at lower frequencies, we have also studied jet acceleration on scales of ~100-10000 gravitational radii, showing that an MHD mechanism is most likely responsible for accelerating the jet plasma on these scales. The brightness temperature measurements of the 86 GHz VLBI survey are combined with that made from VLBI observations at lower frequencies of 2 GHz [4], 8 GHz [4] and 15 GHz [1] to study the evolution of intrinsic brightness temperature (T_0) with frequency and along the jet. The results show that the observed brightness temperature (T_b) at 86 GHz are systematically lower than observed brightness temperature (T_b) at 2, 8 and 15 GHz, which could be either due to resolved out flux at 86 GHz or due to the fact that the T_b at 86 GHz is intrinsically lower. Radio luminosity and jet parameters were used to convert frequency to linear coordinate along the investigate the evolution of T_b with the absolute distance of the VLBI core from the central engine, r. We modeled T_b at multiple frequencies from (2-86) GHz as a function of the absolute distance from the central engine and the best fit obtained for the maximum brightness temperature in the downstream of the jet was $T_m = (7.96\pm0.47)\times10^{11}$ K and initial brightness temperature near the jet base was 3.74×10^{10} K. This gives a clue that the brightness temperatures on sub-parsec scales are close to the equipartition temperature of 5×10^{10} K and start to increase on sub-parsec regions, reaching the inverse Compton limit of 10^{12} K on parsec scales. The trend on evolution of brightness temperature with the distance from the central engine we observed matches well with the magnetically driven, accelerating jet model suggested by [5] according to which, the mass flux is initially constant in the sub-parsec scale, and then increases, and then the mass flux gets constant again in the outer region.

1. Kovalev, Y.Y., Kellermann, K.I., Lister, M. L., et al. 2005, AJ, 130, 2473
2. Marscher,A.P. 1995, Proceedings of the National Academy of Science, 92, 11439
3. Nair, D.G., Lobanov, A.P., Krichbaum, T.P., et al. 2018, A&A, in press [arxiv:1808.09243]
4. Pushkarev, A.B & Kovalev Y. Y., 2012, A&A, 544, A34
5. Vlahakis, N. and Königl, A. 2004, ApJ, 605, 656