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Two-temperature magnetohydrodynamic simulation of jets in galaxy cluster: The X-ray property of the forward shocks

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Powerful radio jets are launched from radio-loud active galactic nuclei. Some radio jets drive external forward shocks into the intracluster medium (ICM), and these shocks are observed as X-ray surface brightness discontinuity. [1] The property of forward shocks gives an important clue to understanding the energetics of the jet-ICM system and the physical nature of the tenuous plasma. The forward shocks would also be expected to possible particle acceleration site. Some hydrodynamic models for powerful jets successfully reproduce observed structures. However, there is the discrepancy that the Mach number of the forward shock for the models is much higher than that for observation. [2]

A forward shock of AGN jet would be an ideal celestial laboratory to examine electron heating mechanism of collisionless shock. In collisonless system, it is not trivial that electrons can be heated up efficiently. Naively heavier protons have most of the bulk kinetic energy, and hence retain most of the thermal energy at the shock downstream. And, a timescale of proton-electron temperature equilibrium is comparable to the shock propagation time scale because the ICM is hot and low density. It is, therefore, expected to be the temperature equilibrium in the far downstream of the forward shock. [3] In addition to temperature non-equilibrium, projection effects, including the dependence of viewing angles, should also affect the measured Mach number. However, for the forward shock of AGN jets, no quantitative discussion of projection effects has been presented so far.

In this work, we performed a mock X-ray observation of powerful radio jets in a galaxy cluster (figure 1a), using the data of two-temperature magnetohydrodynamic simulations [4], to investigate projection and temperature non-equilibrium effects in a measurement of Mach number. We find that the measured Mach numbers from X-ray surface brightness strongly depend on inclination angle. At a high inclination angle, we can estimate the Mach number of 6, which is consistent with our simulation model. In contrary to this, the measured Mach number is lower than 2 at a low inclination angle (figure 1b). We also show post and pre-shock spectroscopic-like temperature. The projection effect significantly reduces the temperature jump for any inclination angle, even if thermal electrons are in instant equilibrium. As one of the examples, we compare our results with the results of Cygnus A. The observed temperature jump of our two-temperature model is consistent with that of Cygnus A. In addition to this, our models suggest that the viewing angle should be less than 50 degrees.

References

[1] Davide, A. Smith, et al. APJ, 565, 1, 195-207 (2002)
[2]M.J. Hardcastel & J.H. Croston, New Astronomy Reviews, 88, 101539, (2020)
[3] M. Takizawa, APJ, 520, 2, 514-528 (1999)
[4] T. Ohmura, doctoral thesis, “Two-temperature Magnetohydrodynamic Simulations of Extra-Galactic Jets” (2021)

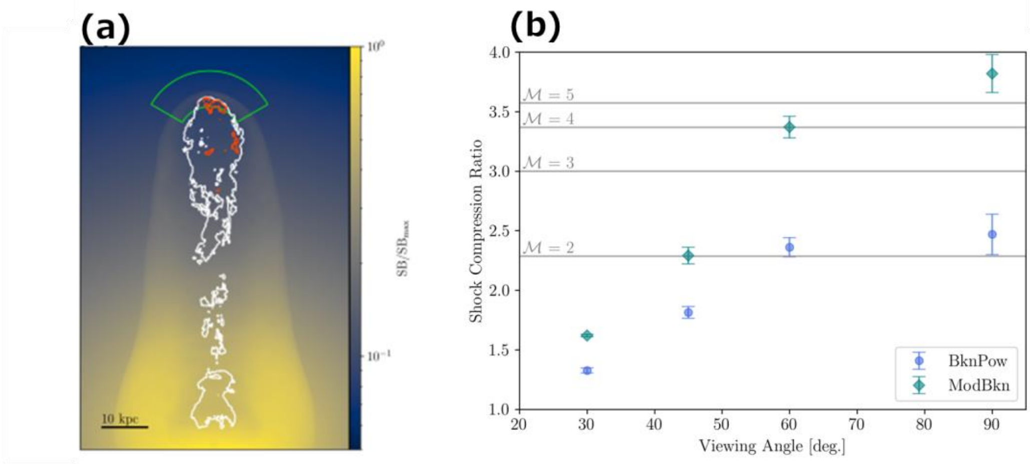

Figure 1. (a) Simulated X-ray surface brightness of an AGN jet at a 60 degree viewing angle with radio intensity (white and red) contours overlaid. (b) Shock compression ratio estimated from the X-ray surface density profile as function of the viewing angle.