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MHD simulations of astrophysical jets including electron energy time evolution

T. Ohmura[1], M. Machida[1], K.E. Nakamura[2], Y. Kudoh[3],
Y. Asahina[4,5], H. Sakemi[1] and R. Matsumoto[6]
[1]Kyushu University, [2]Kyushu Sangyo University, [3]Kagoshima University,
[4]Kyoto University, [5]NAOJ and [6]Chiba University
e-mail (speaker): ohmura@phys.kyushu-u.ac.jp

Astrophysical jets in microquasars and active galactic nuclei are well observed from the radio bands to gamma-ray. The radio and X-ray emission of the jets can be generated by synchrotron radiation of non-thermal electrons, by thermal bremsstrahlung of thermal electrons, or by inverse Compton scattering of soft photons which is produced by thermal/nonthermal electrons (Bosch-Ramon & Khangulyan 2008). Since the cooling time of electrons is shorter than the propagation time of the jet except the region near the central object, in-situ acceleration/heating of electrons have been studied. The candidates of the acceleration/heating site are bow shock ahead of the jet, the terminal shock at the end of the jet beam, and internal shocks of the jet. The electrons can also be heated by the Coulomb collision with ions.

In low density jets in which the collision time of electrons and ions is longer than the propagation time of the jet, the temperature of electrons and ions can be different. Such two-temperature plasma has been studied in the context of optically thin hot accretion flows (Ichimaru 1977, Narayan & Yi 1994) in which ions are heated by release of the gravitational energy of the accreting matter. In low density jets, ions and electrons can be heated in terminal shocks and internal shocks but electrons can be cooled by emitting radiation. Therefore, low density jets should be two-temperature plasma.

Norman et al. (1982) has been studied for jets propagation and has shown the main structure of jets using hydrodynamical (HD) calculations. Subsequently, magnetohydrodynamical (MHD) simulations and relativistic HD simulations were carried out (e.g., Clarke et al. 1986; van Putten 1993). These studies have focused on dynamics of kinetic energy dominant jets. Recently, morphology and stability of the Poynting-flux jets have been studied (e.g., Li et al. 2006, Tchekhovskoy & Bromberg 2016). However, the two-temperature jets have not been studied yet.

The purpose of our study is to clarify the electron temperature distribution of jets. We present the results of the jets propagation under the two-temperature treatment. We assume a neutrally charged plasma, i.e., the number density of electrons and ions set equal. We further approximate that the electron flow velocity is the same that of ions. Our simulations include bremsstrahlung radiation cooling for electrons and energy exchange between electrons and ions via Coulomb collisions. We neglect synchrotron, inverse Compton scattering, gravity and other electron heating.

The jet dynamics and morphology of two-temperature MHD are similar to that discussed in previous work of MHD simulations because of one-fluid approximation. Figure 1 shows snapshot of our numerical result. The electron temperature distribution ($r > 0$) is different from ion one ($r < 0$) , though the injected plasm have same temperature. We assume that the electron entropy is conserved across the shocks. Therefore, ions heat up at the terminal shock, and a hot spot is created. On the other hand, electron temperature around a hot spot does not increase because the entropy of electron is conserved and the Coulomb Coupling does not work sufficiently. We found that ions temperature is about ten times higher than electrons one.

During this talk, we will talk about our new results of 3D MHD simulations. 3D effect affects jets structure, especially a hot spot. We will calculate surface brightness and compare to observations.

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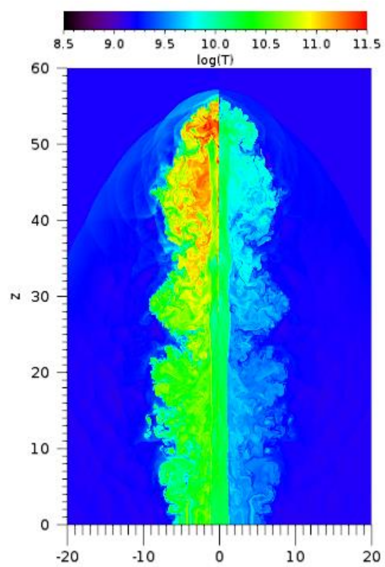

Figure 1, Snapshot of the ion temperature($r < 0$) and the electron temperature($r > 0$)