Simulations of relativistic astrophysical jets

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Abstract. In this paper we study simulation of relativistic jets into a uniform ambient medium. We show that the jet evolution depends on the composition parameter.

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1. Introduction, results and conclusion

Numerical simulation is a very powerful tool to study relativistic jets from centre of galaxies and other black hole candidates (Marti et al. 1997). However, most of the simulations are for fluid with fixed $\Gamma$ (i.e., adiabatic index) equation of state (EoS). It has been shown that $\Gamma$ for relativistic gas depends on temperature (Chandrasekhar 1938; Ryu et. al. 2006), as well as, on the composition of the flow (Chattopadhyay and Ryu 2009; Chattopadhyay et. al. 2013). For steady state solutions, it was shown that electron-positron plasma is thermally the least relativistic, but flow with a mixture of positrons, protons and electrons are most relativistic (Kumar et al. 2013; Vyas et. al. 2015). We would like to investigate the same for time dependent studies. The EoS used, relates the enthalpy ($h$) with $\Theta$ and $\xi$ (Chattopadhyay and Ryu 2009) as

$$h = \frac{f + 2\Theta}{2 - \xi + \xi/\eta}; \quad f = (2 - \xi) \left[ 1 + \Theta \left( \frac{9\Theta + 3}{3\Theta + 2} \right) \right] + \xi \left[ \frac{1}{\eta} + \Theta \left( \frac{9\Theta + 3/\eta}{3\Theta + 2/\eta} \right) \right].$$

(1)

Here, $\Theta = kT/m_ec^2$, $T$ is temperature, $k$ Boltzmann constant, $c$ the speed of light, $m_e$ electron mass, $\xi$ is the ratio of proton to electron number densities, and $\eta$ is the ratio of the proton to electron mass. The equation of motion of relativistic fluid is $T^\nu_\nu = 0$ and $(\rho u^\nu)_\nu = 0$, where $T^\nu_\nu$ is the energy momentum tensor of the fluid, $\rho$ is the mass density and $u^\nu$s are the components of four velocity. The flow eigen structure is exactly same as those developed by Ryu et. al. (2006). Figure 1, shows that the
Figure 1. Contours of $\rho$ and 3-velocity vectors are plotted for electron proton fluid $\xi = 1$ (top), flow with $\xi = 0.5$ (middle) and electron-positron flow or $\xi = 0$ (bottom). The initial jet three velocity $v_j = 0.995$, density $\rho_j = 0.1$, radius is 12 cells and ambient density $\rho_a = 100$ and uniform pressure $p = 0.01$. The resolution is $1536 \times 512$ cells. The length is in units of initial jet radius.

Jet morphology and the propagation speed depends on the composition parameter $\xi$. Moreover, the internal structure of the jet, the cocoon etc, all evolve differently depending on $\xi$. This will have immense effect on the radiative properties of jets. So numerical simulation with relativistic EoS is important to study the morphology and evolution of astrophysical jets.

References


