Spectral evolution of Hydra A jets

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Introduction

Modern powerful supercomputers allow us to perform detailed numerical hydrodynamic modelling of extragalactic jets from parsec to kpc scale. However, incorporation of non-thermal particle evolution and radiative transfer in the hydrodynamic calculation is still computationally challenging because it introduces additional dimensions (particle energy, frequency and direction of radiation) to the problem.

A computationally feasible approach is to complement the magneto-hydrodynamic (MHD) simulations by additional schemes that track the evolution of the non-thermal particle distribution and perform ray tracing to produce synthetic radio image.

In this first stage, we evolve a power-law particle distribution in post-process considering adiabatic changes and frequency dependent synchrotron radiative losses of the non thermal electrons. We apply our synthetic radio emission calculations to simulations of relativistic jets with the hydrodynamical code PLUTO. The simulations include models of the radio galaxy Hydra A focussing on the role of spectral evolution in the brightness of inner knots, and the flaring zones.

The parameter space for the jet is set based on our previous study (Nawaz et al. 2016) of the source.

We present the preliminary results produced by our newly developed spectral evolution algorithm.

Hydra A

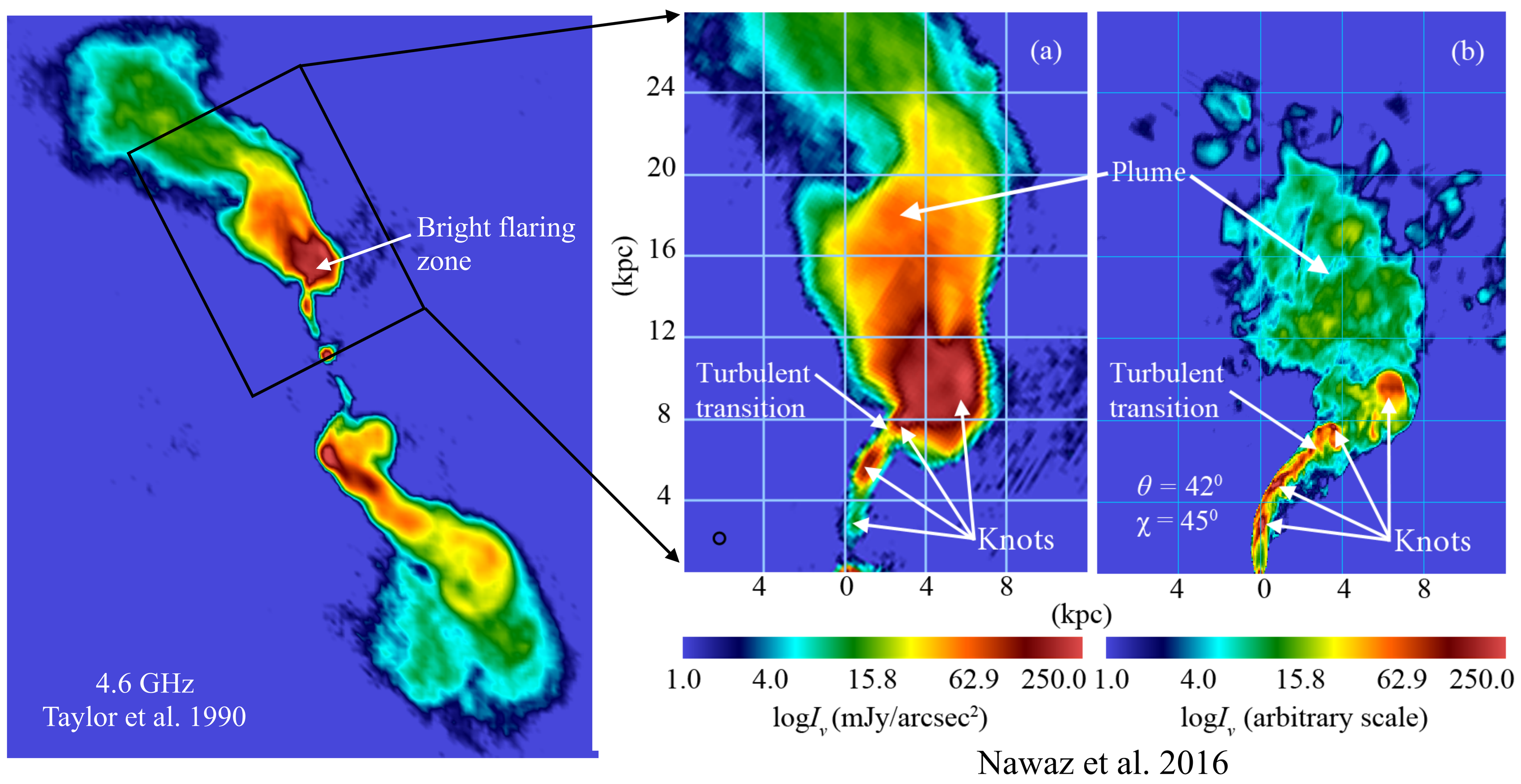

Figure 1. VLA image of Hydra A at 4.6 GHz; Comparison of the simulated precessing jet and the northern jet of Hydra A.

Hydra A is an iconic radio galaxy in a nearby cool core cluster. It is a well studied source in both radio and X-ray and hence detailed modelling of this source will enable us to understand the extragalactic jets and their interaction with the environment.

In our previous study we simulated the Hydra A northern jet with a 3D precessing jet-ICM model. The precessing jet model successfully reproduced the key structures of the northern jet, such as correctly spaced bright knots, the jet curvature and the jet to lobe transition, etc (see Figure 1).

Two prominent features of the Hydra A northern jet, namely, i) increasing bright knots downstream and ii) a bright flaring zone, were absent in the purely hydrodynamic model.

This necessitates a further development of our model to a magnetised jet interacting with a magnetised environment and an incorporation of the study of spectral energy evolution.

A key feature of our RMHD jet model is that, for an insignificant initial magnetic pressure in the jet with respect to the particle pressure, the magnetic pressure increases downstream. In such case synchrotron cooling time is much higher than the dynamic time scale of the source. Therefore, the positive correlation between the emissivity and magnetic field causes a gradually brighter knots downstream.

Spectral Evolution

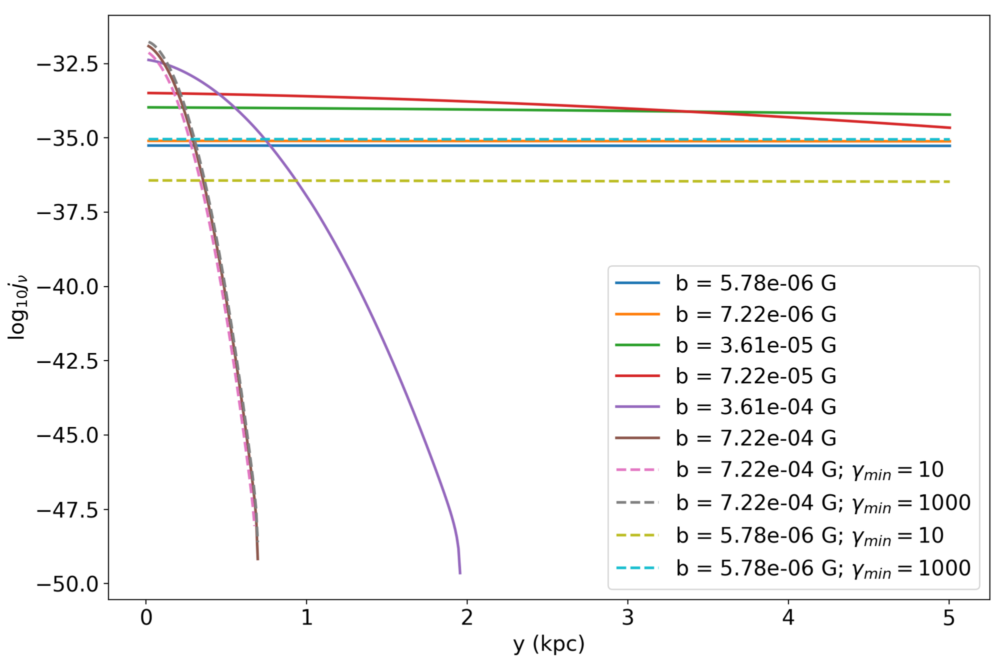

Figure 2. For an idealised background with constant density, pressure and magnetic field, evolution of emissivity along the propagation axis for different initial magnetic fields and $\gamma_{\rm min}$. All solid lines are for $\gamma_{\rm min} = 100$.

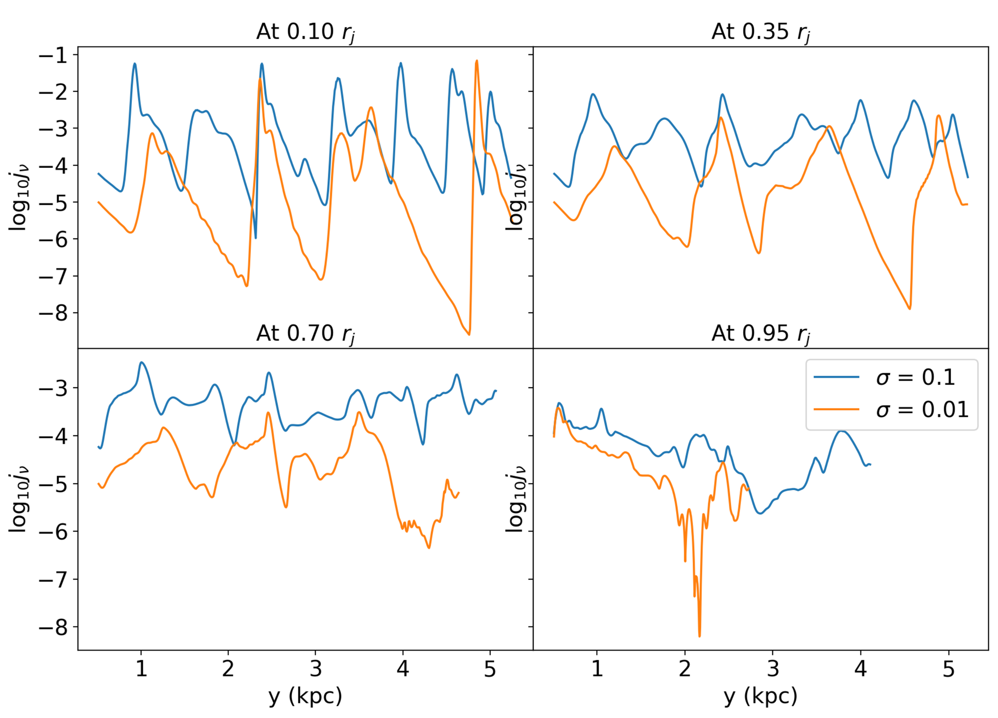

Figure 4. Evolution of emissivity along jet axis for Lagrangian particle initialised at 4 different locations across the jet base. Two curves represent two models with different initial $\sigma = b^2/2p_{\rm jet}$.

We use a Lagrangian scheme for calculating the transport of non-thermal particles based on that of Mimica et al. (2009). In this method, the distribution of the non-thermal particles is tracked in both spatial and energy domain. The initial positions of the non-thermal particles (NTP) at the jet base, advected following the background velocity field while the energy spectrum and the particle distribution evolve according to

$$\frac{dp}{dt} = a(t)p + b(t)p^2$$

where, p is the momentum of NTP. Factors $a(t)$ and $b(t)$ account for the adiabatic and synchrotron losses, respectively. The NTP distribution is discretised in the energy domain and approximated by a piecewise power-law. The synchrotron emissivity and absorption coefficient are calculated directly from the NTP distribution and the thermodynamic quantities of the background relativistic fluid. Finally, we compute emission solving the radiative transfer equation along a given line of sight.

A preliminary result of the application of spectral evolution algorithm on a simulated RMHD jet is shown in Figure 5.

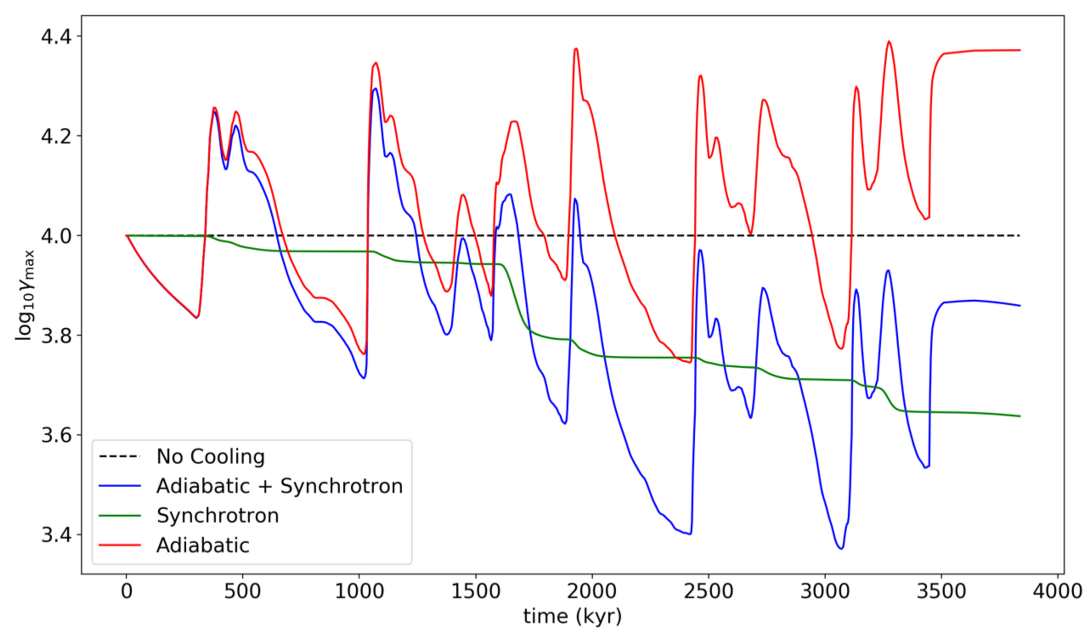

Figure 3. Spectral energy evolution with time for different processes along the jet axis.

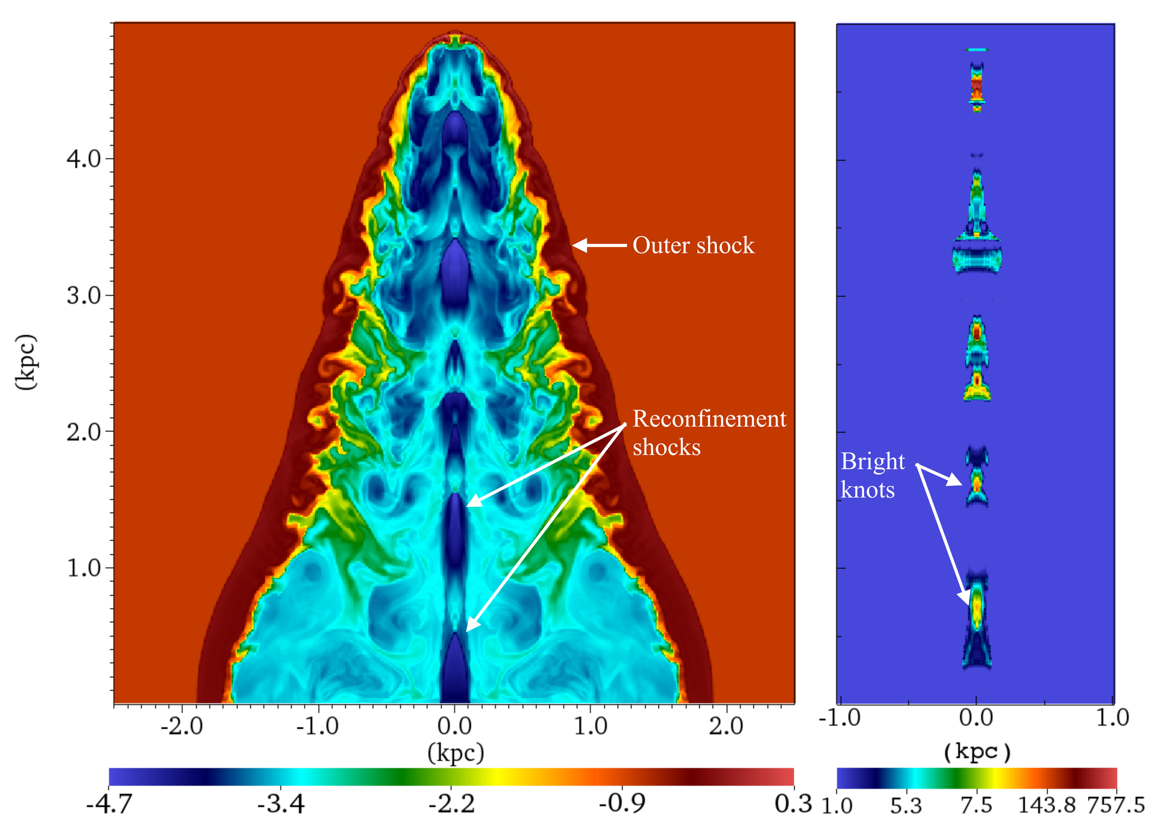

Figure 5. Left: Logarithmic density image shows the early evolutionary stage of the jet. Right: A synthetic radio image produced by applying the radiative transfer algorithm.

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Reference:

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