Modelling the large-scale morphology of AGN jets using fluid-particle hybrid simulations

NATURAL AND AGRICULTURAL SCIENCES UFS

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Introduction

Radio loud Active galactic nuclei (AGN) emit synchrotron emission over a wide region of the electromagnetic spectrum. In these types of AGN the synchrotron emission is predominantly produced by non-thermal electrons in a relativistic jet[1]. In order to study how the observed large scale radio morphology relates to the jet's physical properties, fluid dynamic simulations can be employed. In this contribution we present 3D RMHD simulations of relativistic jet environments created using the PLUTO code (http://plutocode.ph.unito.it/) [2]. The jet model consists of a kinetically dominated jet with a helical magnetic field, injected into a stratified background medium. To model the synchrotron emission, we implemented the PLUTO particle hybrid module [3]. This module injects Lagrangian particles that are representative of non-thermal electrons. The Lagrangian particles are injected with a pre-determined power law distribution and are allowed to evolve with time as they move through the simulation. By making use of this module, we can calculate the synchrotron-self absorption spectrum and integrate it along a line of sight to produce simulated intensity maps. The calculated intensity maps take into account relativistic and geometric effects. We present the simulated intensity maps at different viewing angles with respect to the axis of the jet. The emission can also be calculated for different frequencies which is used to obtain the spectral energy distribution of the synchrotron radiation in the simulated jets.

Fluid-Particle hybrid simulations

A three dimensional (3D) Relativistic magneto-hydrodynamic (RMHD) simulation was created using a Cartesian domain with a resolution of 4 cells/jet radius. A stratified background medium was initially assigned to the domain and a lower proper density jet fluid was injected through a nozzle on the lower *z* boundary. The jet was injected at a constant mass flux with a force-free helical magnetic field (see [4]). The injection parameters are given in Table 1. Figure 1 shows slices of the velocity, density and pressure which illustrates the jet structure that was produced.

Using the PLUTO hybrid framework [3], a sample of Lagrangian particles was continuously injected at the jet nozzle, with a random spatial distribution. Each Lagrangian particle represents a finite ensemble of non-thermal electrons, with an initial power-law energy distribution given in Table 1. The particles propagate along the fluid streamlines and the energy distribution is updated considering adiabatic expansion, shock acceleration and radiative cooling. Figure 2 shows a rendering of the Lagrangian particles in a segment of the jet.

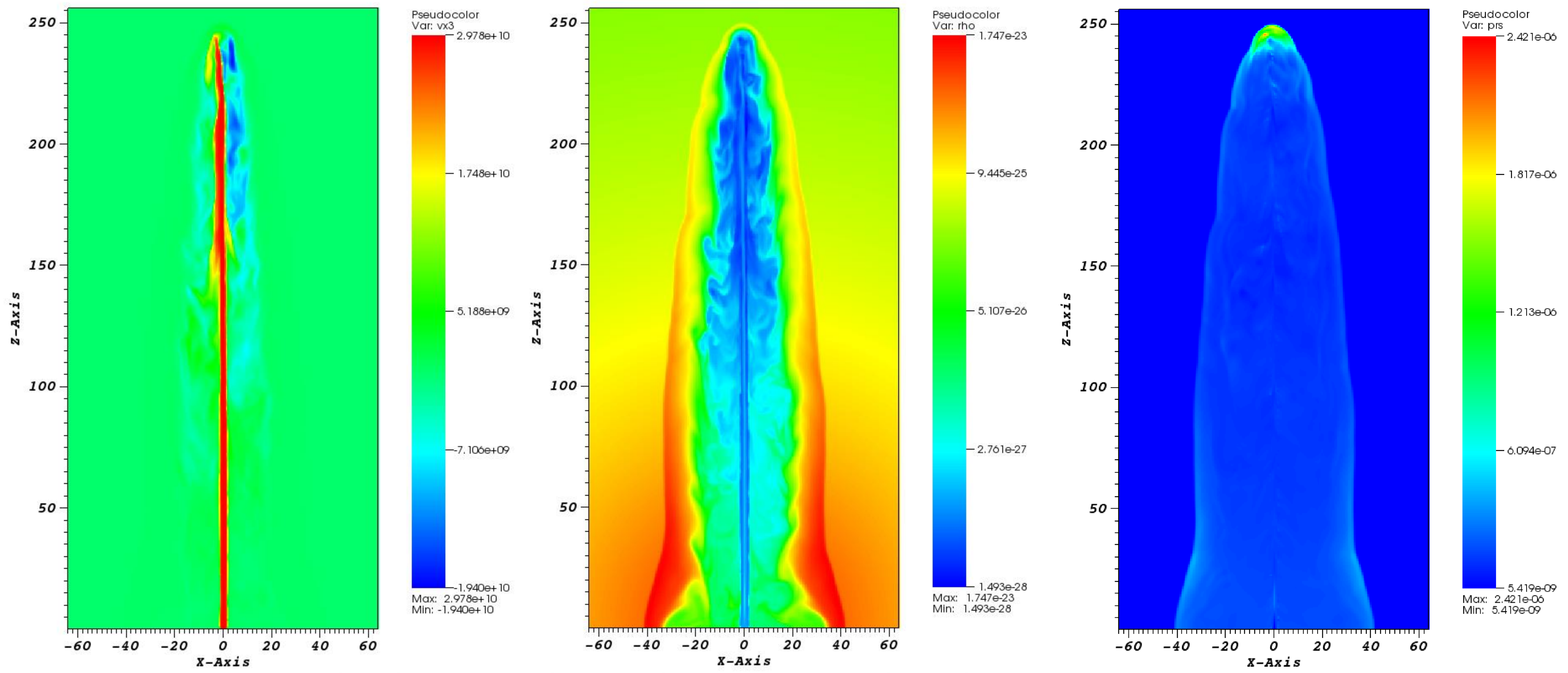

Figure 1: Velocity (left), Density (middle) and Pressure (right) slices through the y-axis of the jet.

Table 1: Simulation parameters

Fluid Parameters	
Lorentz factor	10
Jet/ambient density ratio	10^{-4}
Mach number	10
B-field	10 µG
Injected electron spectrum	
γ_min	10^2
γ_{max}	10^7
p	2.1

Emission modelling

Using the spectral information of the particles the synchrotron emissivity is calculated during runtime by [3],

$$j'_{syn}(\nu', \hat{\boldsymbol{n}}'_{los}, \boldsymbol{B}') = \frac{\sqrt{3e^3}}{4\pi m_e c^2} |\boldsymbol{B}' \times \boldsymbol{n}'_{los}| \int_{E_i}^{E_f} N'(E')F(x)dE', \qquad (1)$$

where $F(x) = x\int_x^{\infty} K_{\frac{5}{3}}(z)dz$ and $x = \frac{\nu'}{\nu'_{cr}} = \frac{4\pi m_e^3 c^5 \nu'}{3eE'^2|\boldsymbol{B}' \times \boldsymbol{n}'_{los}|}$.

In addition, we have added the calculation of absorption coefficients to the module using [4],

$$\alpha'_{syn}(\nu', \hat{\boldsymbol{n}}'_{los}, \boldsymbol{B}') = \frac{\sqrt{3e^3}}{8\pi (m_e c \nu')^2} |\boldsymbol{B}' \times \boldsymbol{n}'_{los}| \int_{E_i}^{E_f} \frac{N'(E')}{E'} \frac{d}{dE'}\left(E'^2 F(x)\right) dE', \qquad (2)$$

These coefficients are relativistically transformed to the observed frame and the integrated along a line-of-sight using ray tracing to produce intensity maps at different frequencies. Figure 3 shows the resulting intensity maps at different viewing angles. The code also provides information for the Q and U stokes parameters[3] that can be used to investigate the polarization (Figure 4). Finally, the spectral energy distribution of the synchrotron intensity maps are shown in Figure 5.

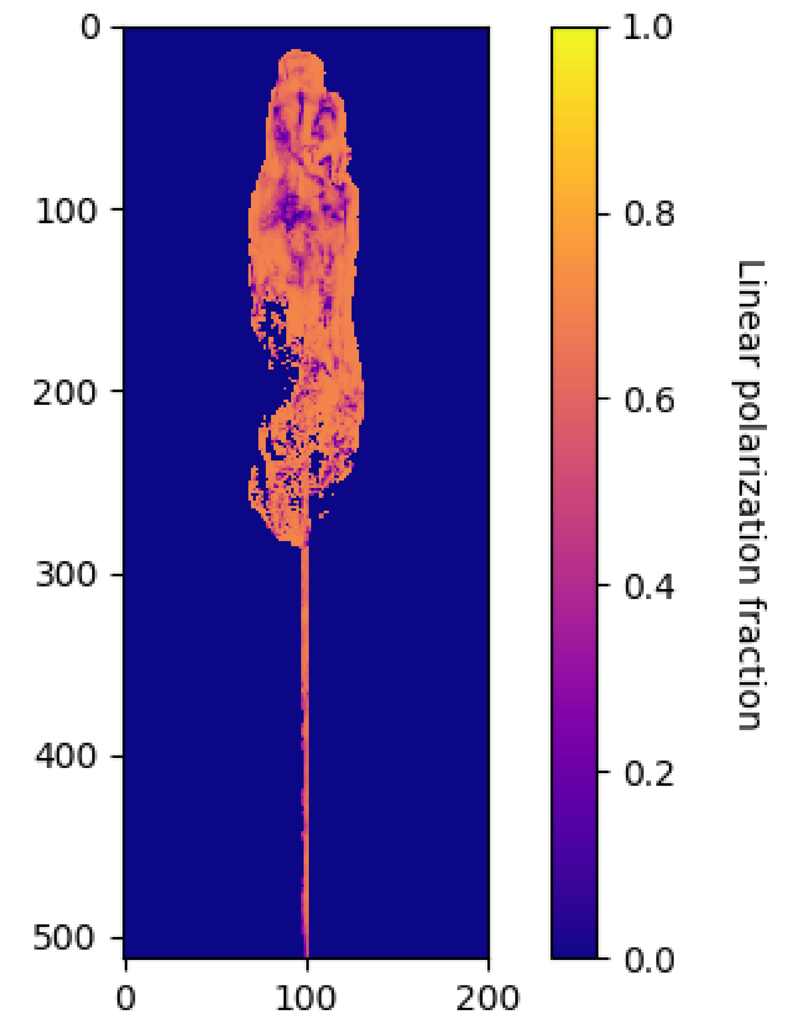

Figure 4: Polarization map as a fraction of the total intensity

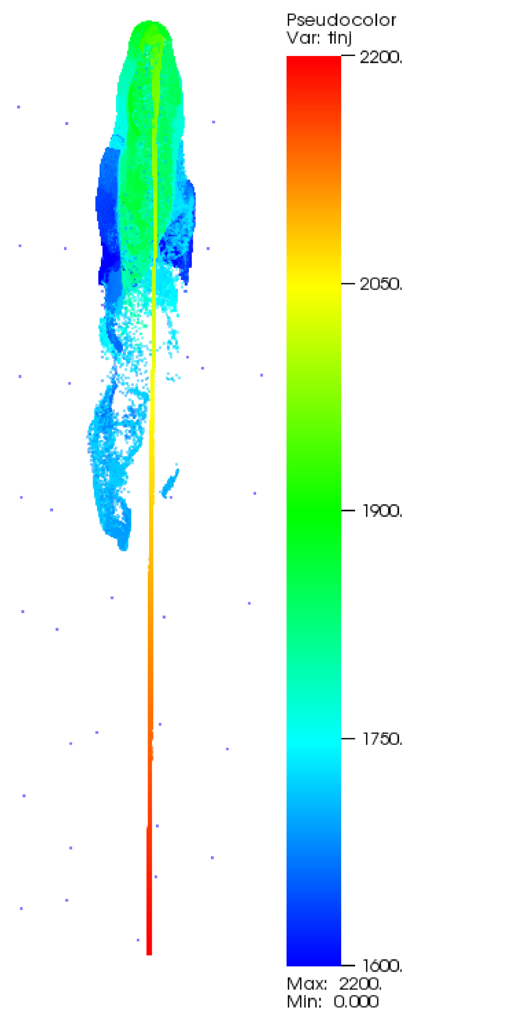

Figure 2: Particle distribution in the 3D simulation

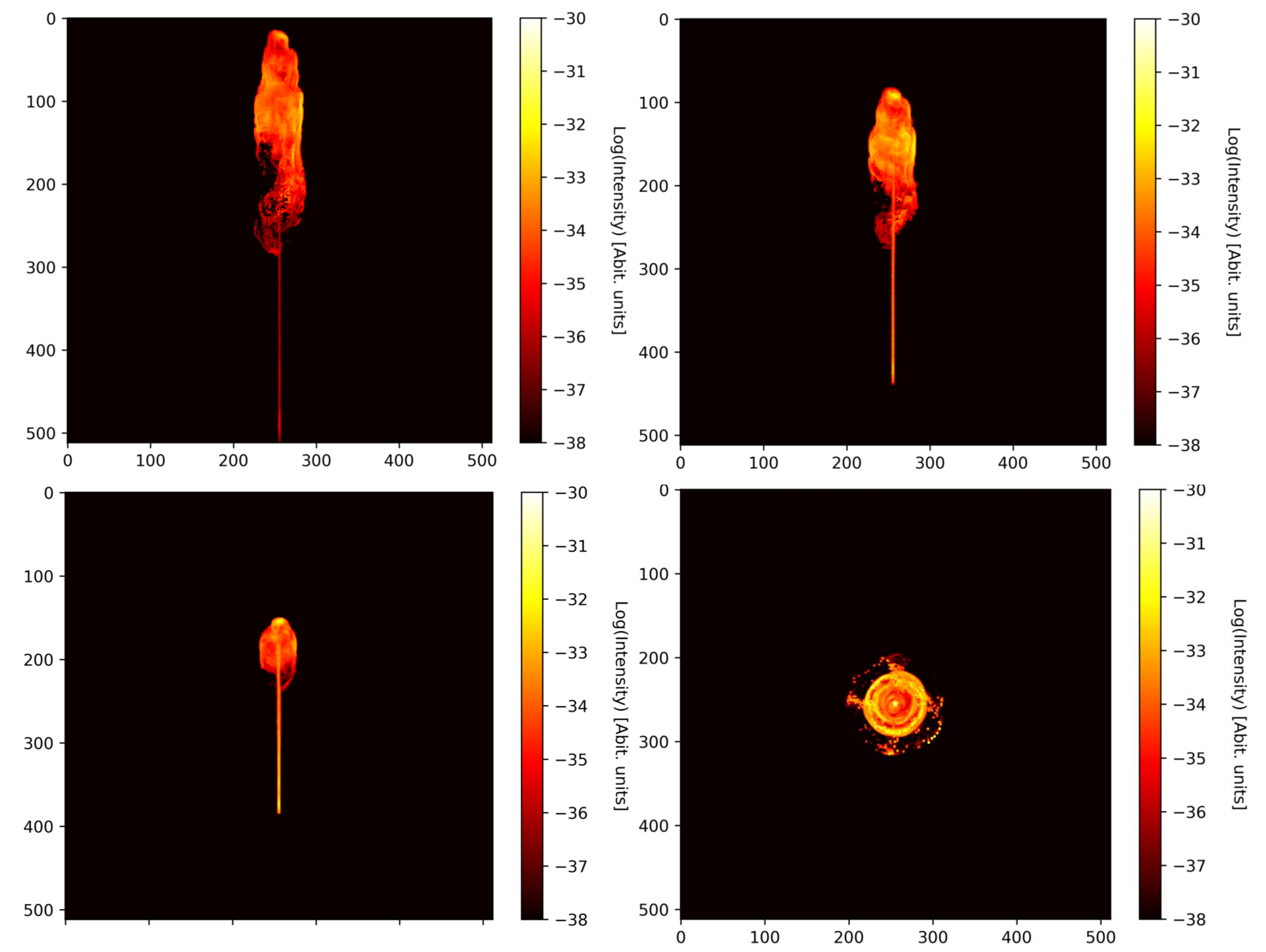

Figure 3: 1.4GHz intensity maps at different angles (top left) 90°, (top right) 45°, (bottom left) 30° and (bottom right) 0° relative to the jet axis,

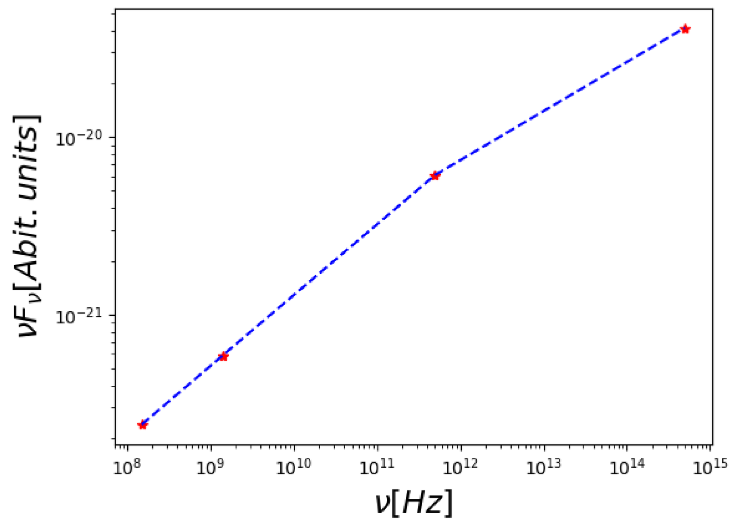

Figure 5: Spectral Energy Distribution of the simulated synchrotron radiation

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