Hydrodynamical Jet Simulations with Passive Magnetic Fields

Christopher Kaye[1], Tim Cawthorne[1] and Philip Hughes[2]

[1]University of Central Lancashire, [2]University of Michigan

ckaye@uclan.ac.uk

① Aims and Motivations

Simulations of radio jets require a random component of magnetic field to reproduce all attributes of the polarized emission (e.g. Zamaninasab et al., 2013). In this work, **only an initially random magnetic field will be used**, and we plan to:

i. Compare the signatures of recollimation shocks predicted (especially polarization) by this numerical work and semi-dynamical models.

ii. Examine whether bright, polarized knots in radio jets can be modelled as recollimation shocks.

iii. Investigate whether Daly and Marscher (1988) were correct to propose that radio cores in jets are the first in a series of recollimation shocks.

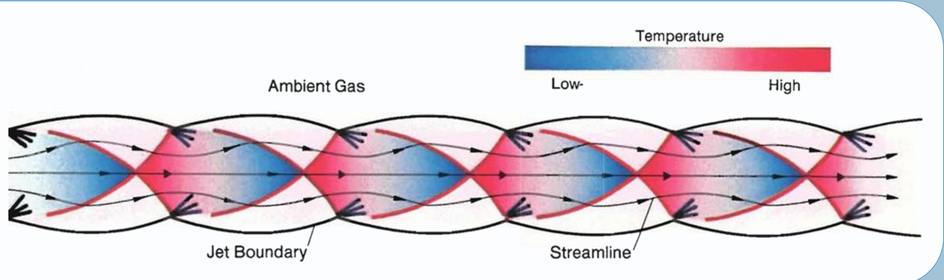
We hope to better understand how the magnetic field inferred from the polarization data can be used to probe jet dynamics, and to predict the flux and polarization distribution of jets and recollimation shocks in the optically thick/thin transition.

② Context

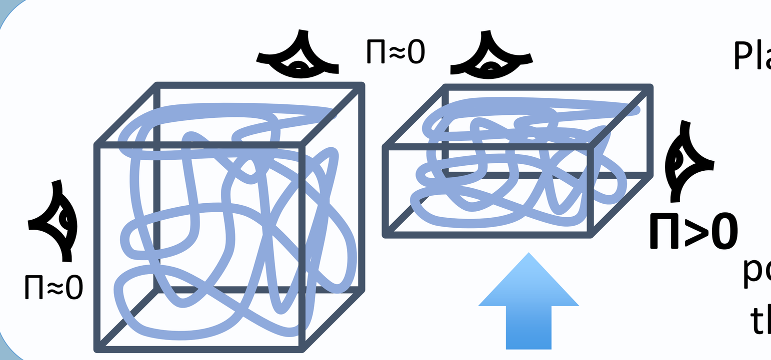
Relativistic jets from active galactic nuclei remain collimated over distances up to the megaparsec scale. Recollimation shocks form as the system attempts to find a pressure equilibrium between the initially overpressured jet and the dense intergalactic medium (IGM) it propagates through.

The supersonic jet will initially expand laterally and overshoot the equilibrium point, becoming underpressured with respect to the IGM. The IGM will then compress the jet inwards, again passing the equilibrium point, such that a series of shocks form.

Recollimation shocks are shown as the red 'x' structures.
(Image from Los Almos Science, Spring/Summer 1985)



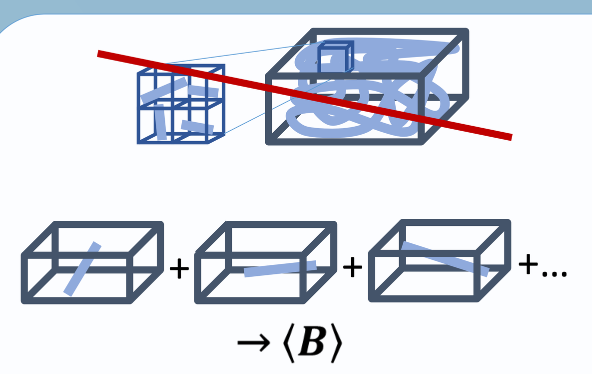
Synchrotron radiation is the main source of radio emission from jets, the polarization of which is magnetic field dependent. Suppose a cube of plasma containing a **random magnetic field is compressed** along one axis; for an observer near the compression plane, the polarization of the emission increases as the magnetic field becomes more ordered. Hence, shocks leave **polarization signatures in the radio emission**.



Plasma compression increases random magnetic field ordering and synchrotron radiation's degree of polarization Π, dependent on the line-of-sight orientation.

③ Methodology

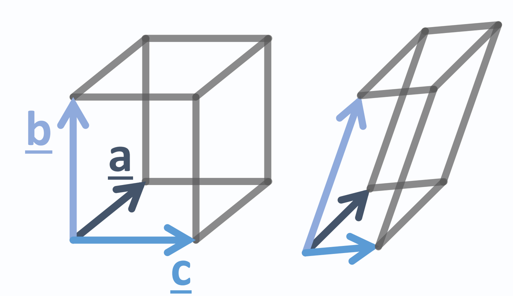
Matthews and Scheuer (1990) produced a two-dimensional, non-relativistic jet simulation in which marker particles injected at the jet's base propagated with the flow. Each particle, having an initially orthogonal unit **vector triad** attached to it, **traced the distortion of its associated fluid element** by shear and compression. For each element they then **determined the Stokes parameters** this would produce by averaging over all possible initial magnetic fields.



We do not split the magnetic field into discrete cells.

We average over all possible injection fields to determine the result for an initially random field.

Using the **numerical three-dimensional relativistic hydrodynamics code** produced by Hughes et al. (2002), **we will simulate flows in which the magnetic field is dynamically unimportant**. A scheme has been implemented, similar to that of Matthews and Scheuer's, to **monitor the deformation of the fluid at each point on a grid**. We accomplish this by advecting initially orthogonal unit vector triads with the fluid, which may change in magnitude and orientation as they propagate with the flow.



Each vector triad monitors a parallelepipedic volume of fluid:

$$V = (\underline{\mathbf{a}} \times \underline{\mathbf{b}}) \cdot \underline{\mathbf{c}}$$

④ Code Developments

Multiple simulation epochs of an **overpressured, planar jet impinging an ambient medium** are shown in figure 1. Each colour-map shows the velocity profile of the simulation, and the line plots show **concordant density profiles, both calculated by the code, and determined from the vector triads**. For an initially unit-density fluid, the density $\rho = 1/|(\underline{\mathbf{a}} \times \underline{\mathbf{b}}) \cdot \underline{\mathbf{c}}| \approx 1/|\underline{\mathbf{c}}|$ for this planar case.

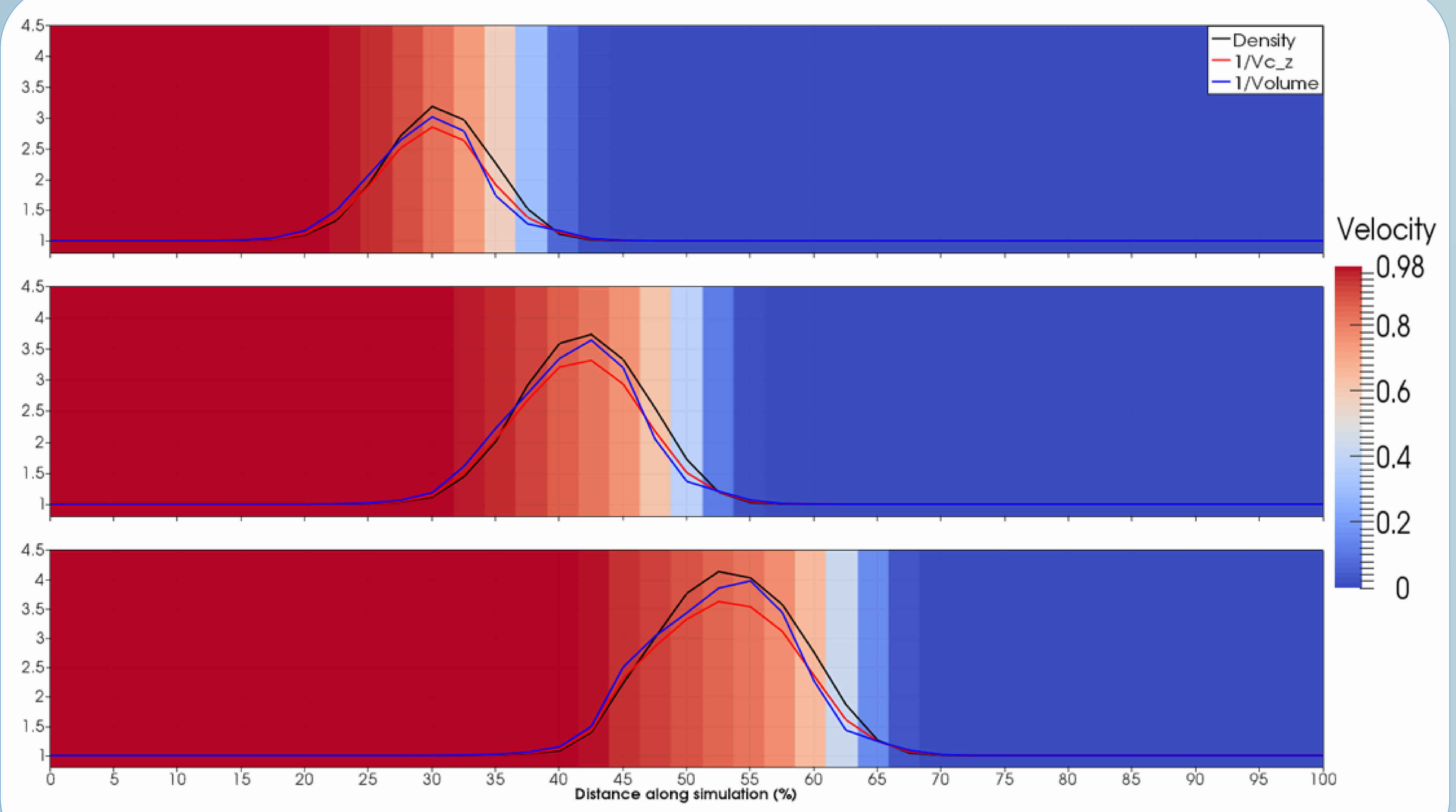


Figure 1: Shock-front properties over three different epochs.

An issue identified in the course of this work has been the **development of very large amounts of shear at the inlet plane**, where the jet and its surroundings meet. This artefact arises because of unresolved velocity gradients in this region, which leads to these highly sheared triads leaking into the centre of the jet. In order to resolve this "contamination" issue, the **inlet boundary layer for the parallelepipeds was increased** by a factor of five to span the first ten rows from the jet base, while the hydrodynamic boundary layer only spans the first two, as shown in the figure 2 line-plot.

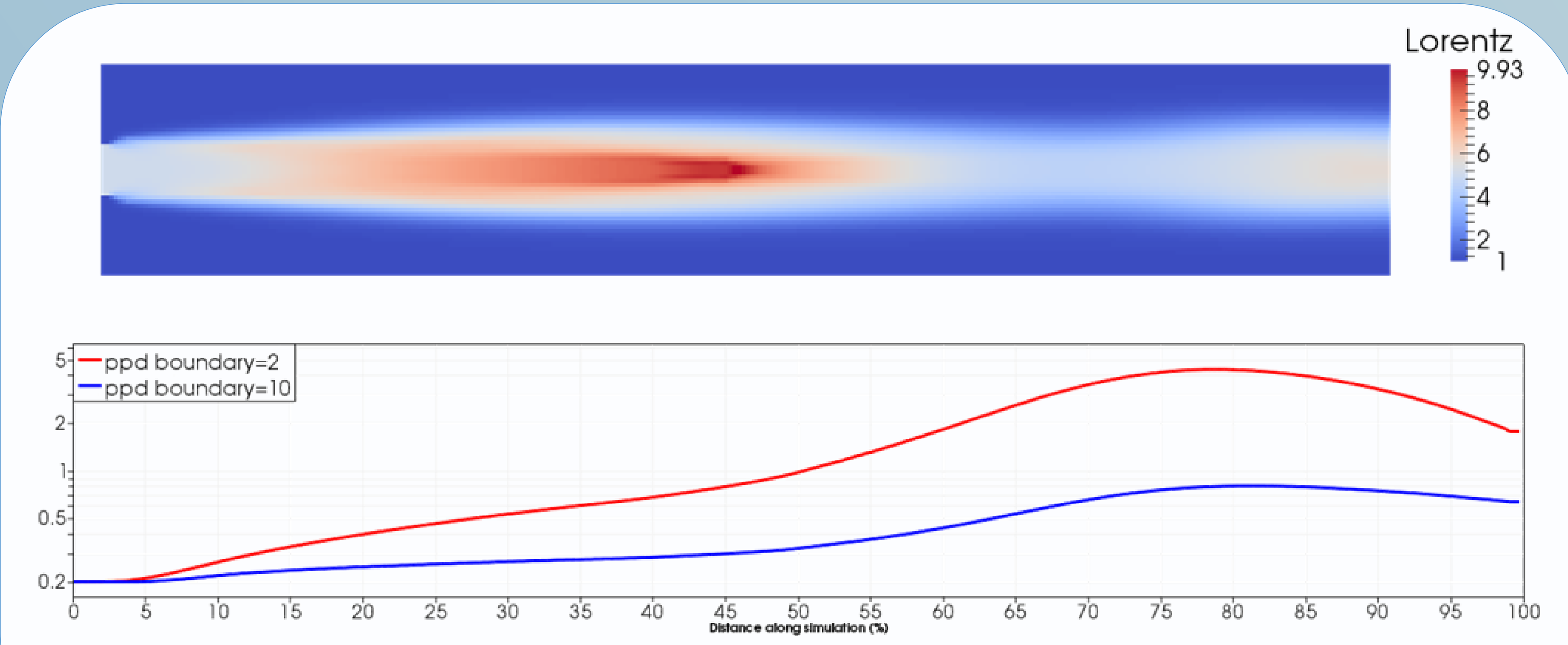


Figure 2: Cross-section of an overpressured jet (upper figure), and a profile along the jet-axis of the axis-parallel parallelepiped (PPD) component (lower figure) for standard and 5x inlet-boundary thickness.

⑤ Conclusions and Future Work

Figure 1 shows that **parallelepipeds monitor volume deformation correctly;** the density calculated by the simulation and the densities determined from the vector triads are in agreement across multiple epochs. However, figure 2 shows that while the velocity profile associated with the recollimation shock displays the expected jump, the vector triads do not display the expected pattern of compression and rarefaction. Reducing the amount of shear able to propagate into the jet clearly helps, but it can be seen that there is still an unexpected growth in the shear along the direction of the jet-axis.

At present we are investigating the origin of this growth, which is potentially unphysical.

Once this issue has been resolved, the **radiative transfer of the Stokes parameters** I, Q and U will be carried out using the methodology of Matthews and Scheuer, and using the results of Cawthorne and Hughes (2013) will allow us to address the optically thick/thin transition.

Acknowledgements

C. Kaye receives a Science & Technology Facilities Council studentship.

References

Cawthorne, T. V., and Hughes, P. A. 2013, ApJ **771**, 60
Daly, R. A., and Marscher, A. P. 1988, ApJ **334**, 539
Hughes, P. A., Miller, M. A., and Duncan G. C. 2002, ApJ **572**, 713
Matthews, A. P., and Scheuer P. A. G. 1974, MNRAS **242**, 616
Zamaninasab, M., et al. 2013, MNRAS **436,** 3341

uclan
University of Central Lancashire