Two component jets: relativistic 2.5D simulations

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Abstract

Observations of jets show evidence of a structure in the direction perpendicular to the jet axis. Two-component jets have been already examined for relativistic hydrodynamic and relativistic magnetized jets with poloidal magnetic field. Previous work focused on a two-component jet consisting of a highly relativistic inner jet and a slower - but still relativistic - outer jet surrounded by an unmagnetized environment. These jets were susceptible to a relativistic Rayleigh-Taylor-type instability, depending on the effective inertia ratio of the two components. This work is now extended by taking into account the presence of a non-zero toroidal magnetic field. Different types of toroidal magnetic field are examined, to identify possible differences in the evolution of the jet, as the new component may stabilize the jet or trigger instabilities on a different time scale. The simulations are performed using the open source, parallel, grid adaptive, MPI-AMRVAC code.

I. Introduction

Almost 100 years after their discovery, observations of astrophysical jets provide evidence of a structure perpendicular to the jet axis, believed to be present in different scales, from young stellar object (YSO) jets to active galactic nuclei (AGN) jets ([1],[2]). In most jets we can distinguish a fast, low density inner component and a slower, but still relativistic, heavier outer component ([3]). We examine the effects of differential rotation between the two components of such jet, choosing suitable parameters for AGN jets.

II. Two-component jet configuration

Previous work ([4],[5]) focused on hydrodynamic or jets with a purely poloidal magnetic field, which were susceptible to a relativistically enhanced Rayleigh-Taylor instability. We now extend this work by adding a toroidal field component. The Lorentz factor is $\gamma \approx 30$ for the inner and $\gamma \approx 3$ for the outer jet, in agreement with observations of AGN jets ([6]).

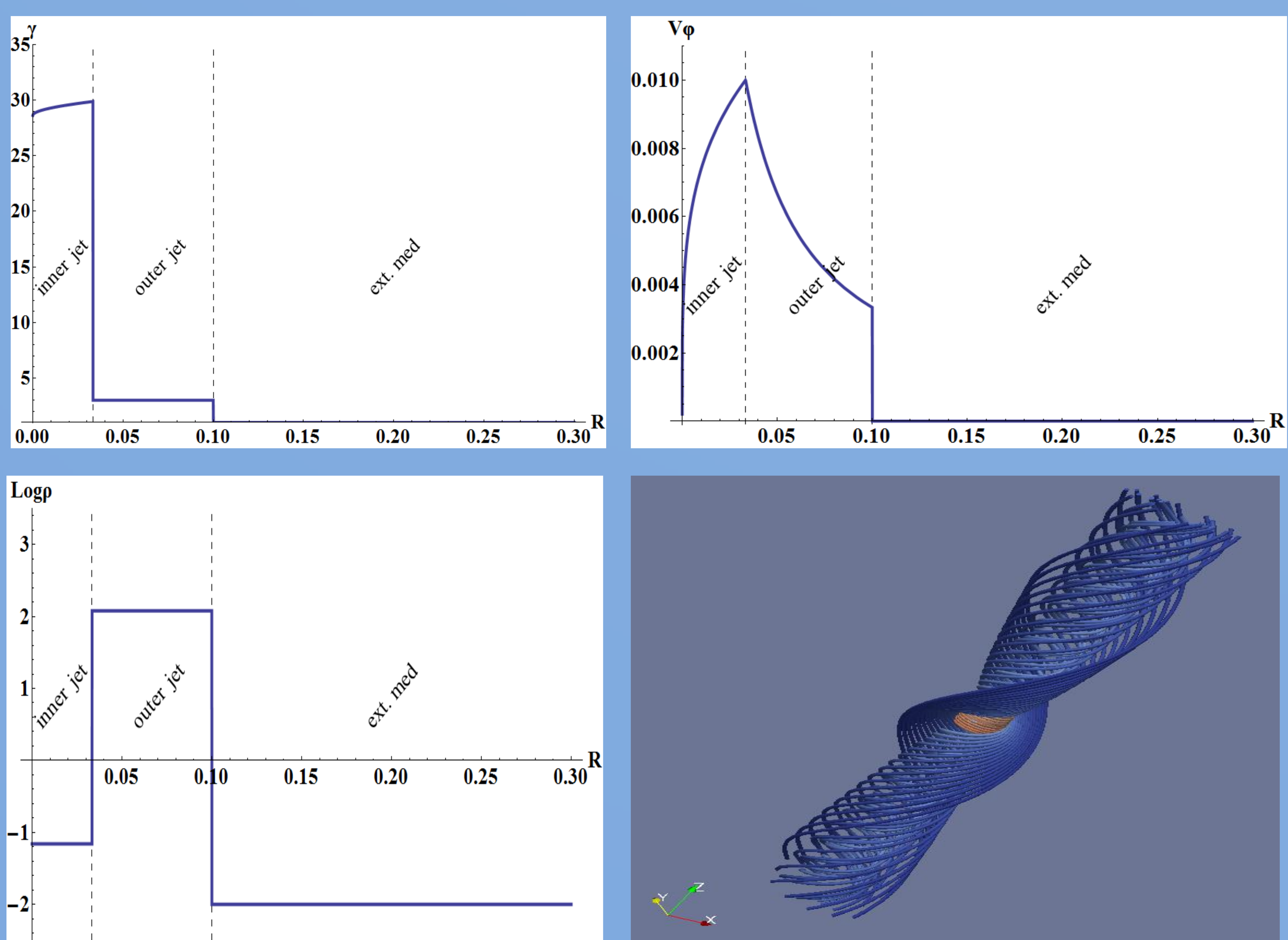

Fig 1. Clockwise from top left: Lorentz factor, toroidal velocity, magnetic field lines and density at t=0

III. Simulations with MPI-AMPRVAC

We examine a cross section of the jet on a plane perpendicular to the jet axis, far from the central source, when the jet is mostly accelerated and collimated. A base resolution 128^2 is used with 3 adaptive mesh levels (AMR), leading to an effective resolution of 512^2. Each simulation runs for 3 rotation times of the inner jet, or 195.84 years. We present two cases, with magnetization σ=0.1 and σ=0.001 respectively

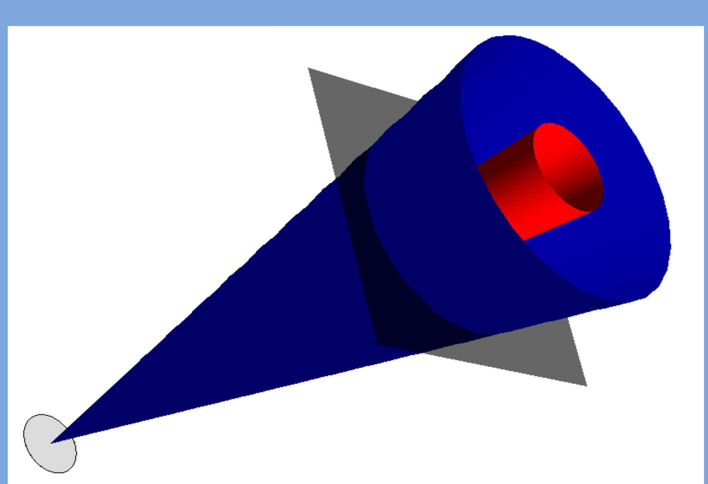

Fig.2 Sketch of a two component jet.
Red: Low density & high γ
Blue: High density & low γ
We examine a plane perpendicular to the axis

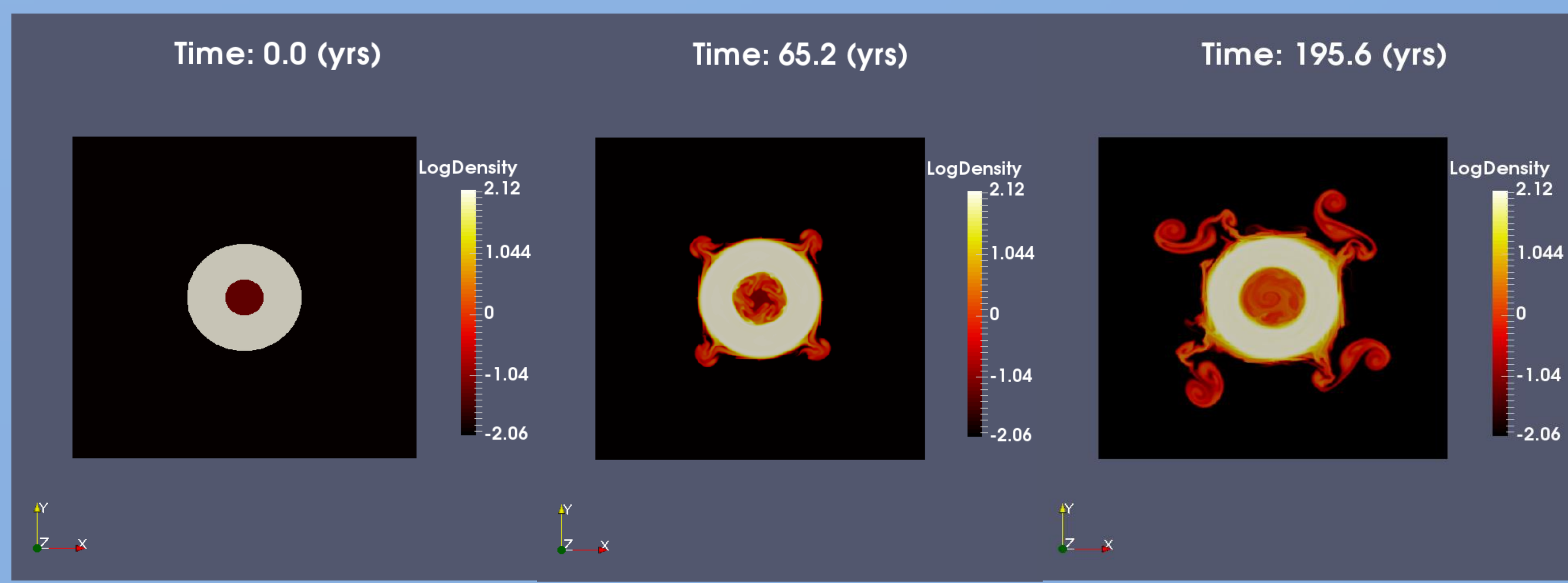

Fig 3. Density (log) at 0, 1 and 3 rotations of the inner jet. Case σ=0.1

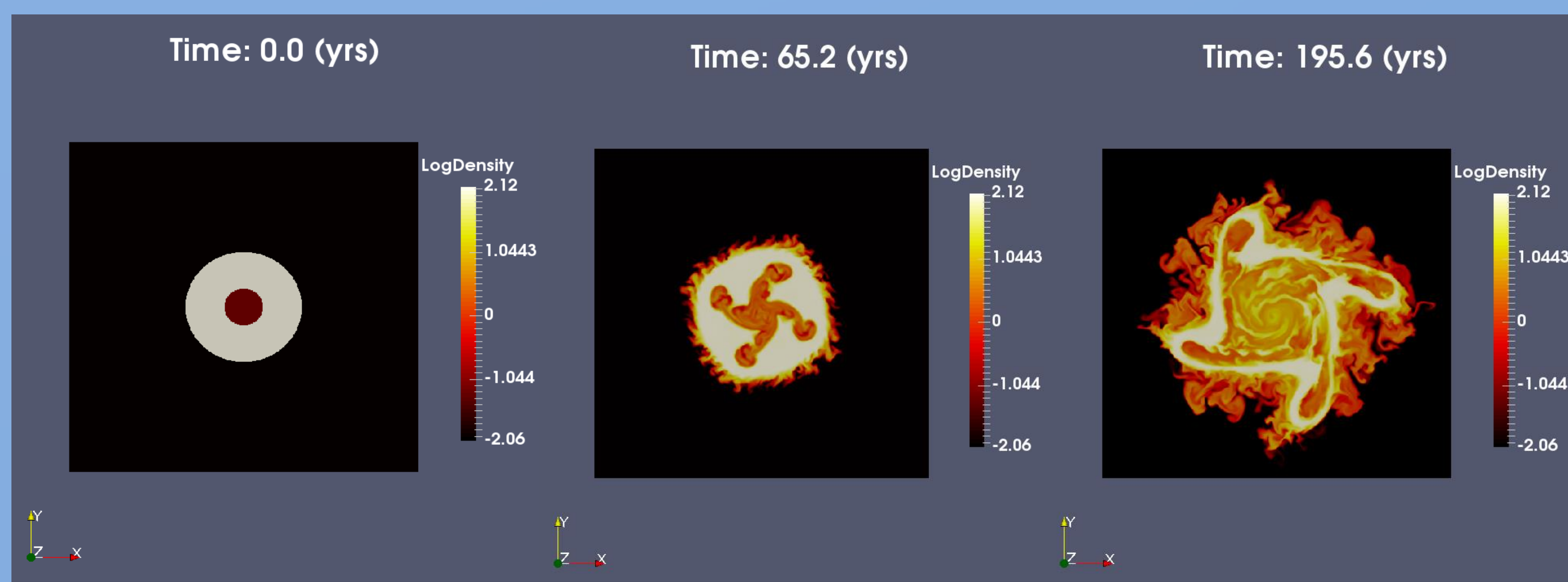

Fig 4. Density (log) at 0, 1 and 3 rotations of the inner jet. Case σ=0.001

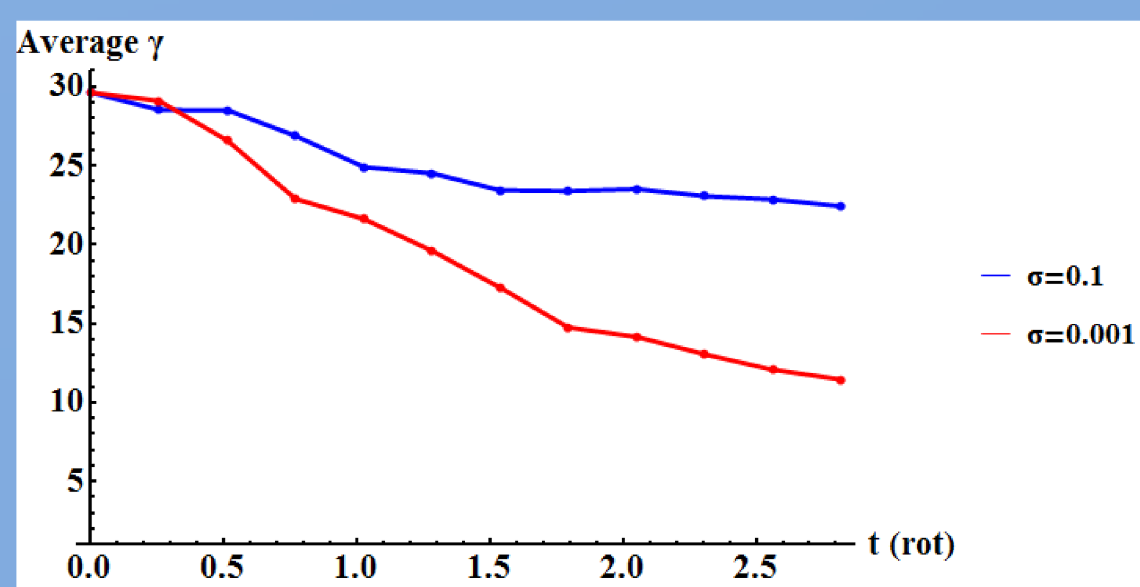

Fig 5. Average Lorentz factor with time, in rotations of the inner jet

IV. Discussion

The jet is decelerated due to a relativistically enhanced Rayleigh-Taylor type instability induced by differential rotation. By adding a toroidal magnetic field component, we notice that higher σ values lead to a slower deceleration and mixing is less strong. A semi-analytical interpretation of these facts is the importance of the magnetic tension term in the radial component of the momentum equation. Future work includes full 3D simulations of two component jets and the creation of synthetic radio maps, allowing direct comparison with actual observations.

Acknowledgements

Research grant from the Flemish Supercomputer Centre (VSC) for the *OPERA* project is acknowledged. This work is a part of CHARM/IUAP (https://wis.kuleuven.be/CHARM).

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