SIMULATIONS OF UNSTABLE RECOLLIMATION SHOCKS

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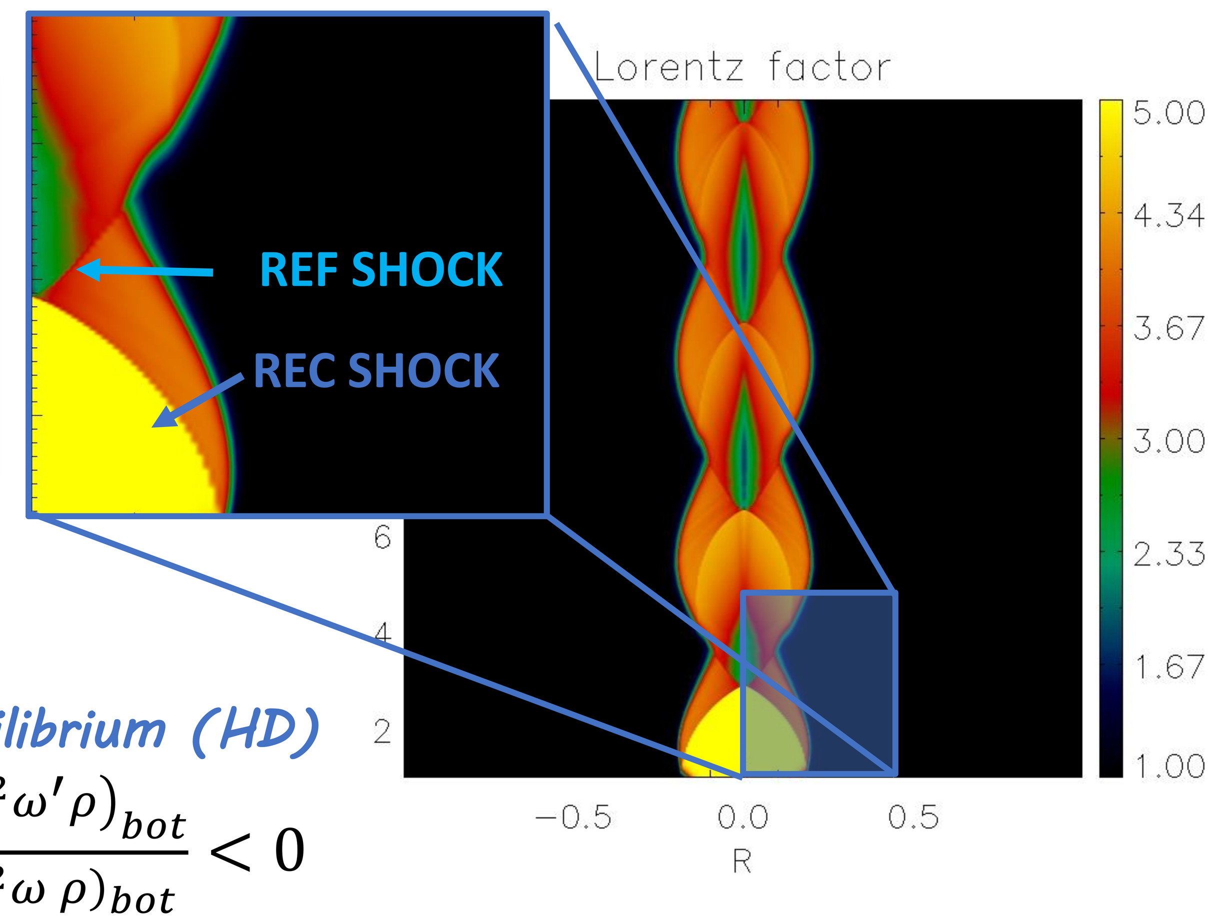
WHAT'S INTERESTING ABOUT RECOLLIMATION SHOCKS?

Shocks are a site of **particle acceleration**. Mildly relativistic shocks can be very efficient, but the phenomenology of **weak oblique/curved shocks** is complex: they **can be unstable**, and lead to interesting dynamics: entrainment of particles, energy release in the medium, and non-trivial high energy emission signatures, from particles that can be accelerated by a combination of **shock and stochastic turbulent acceleration** processes.

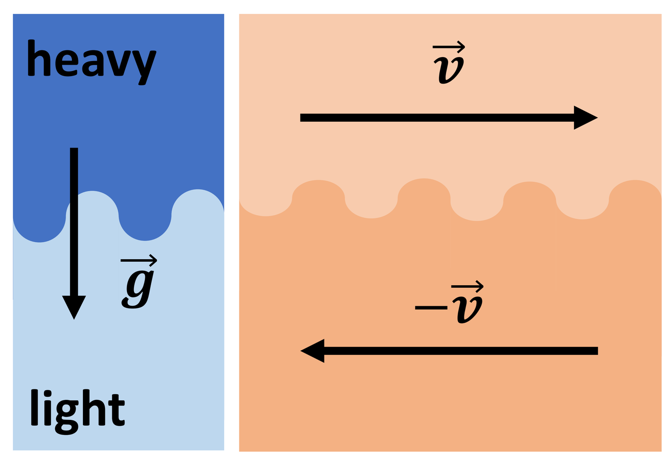
RECOLLIMATION SHOCKS

It is well known from (2D) simulations that pressure confined jets undergo recollimation shocks: **1)** the jets expands and its internal pressure decreases, **2)** the external pressure becomes larger than the inside pressure and stops the jet's expansion, **3)** the relativistic jet is **supersonic**, so the reconfinement drives a **recollimation shock** in the jet, **4)** the jet expands back with a second, **reflection shock** because the still supersonic field lines converge at the axis, **5)** and the process iterates until the jet leaves the inner pressured region. Unless…



THE ROLE OF THE INSTABILITIES

Jets are subject to many instabilities. Among the hydrodynamical (HD), most disruptive, instabilities there are the macro-scale **Rayleigh-Taylor** (RTI) and **Kelvin-Helmholtz** instabilities (KHI).



Relativistic RTI equilibrium (HD)

$$A = \frac{(\Gamma^2\omega'\rho)_{top} - (\Gamma^2\omega'\rho)_{bot}}{(\Gamma^2\omega\,\rho)_{top} + (\Gamma^2\omega\,\rho)_{bot}} < 0$$

Relativistic KHI equilibrium (HD) $M_{rel} = \frac{u}{c_s}\frac{\Gamma}{\Gamma_{c_s}} > \sqrt{2}$

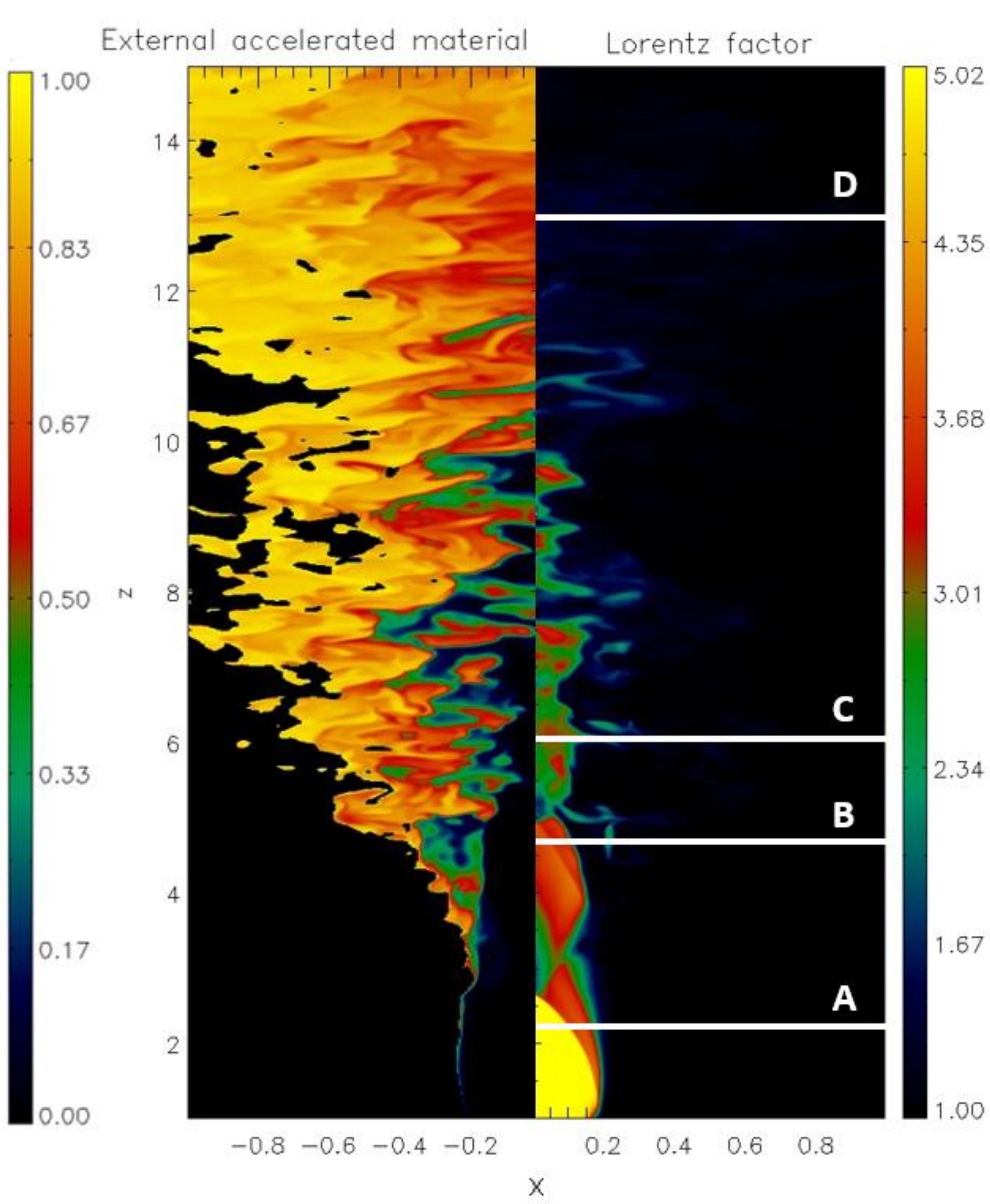
INSTABILITIES AT THE RECOLLIMATION AND REFLECTION SHOCKS

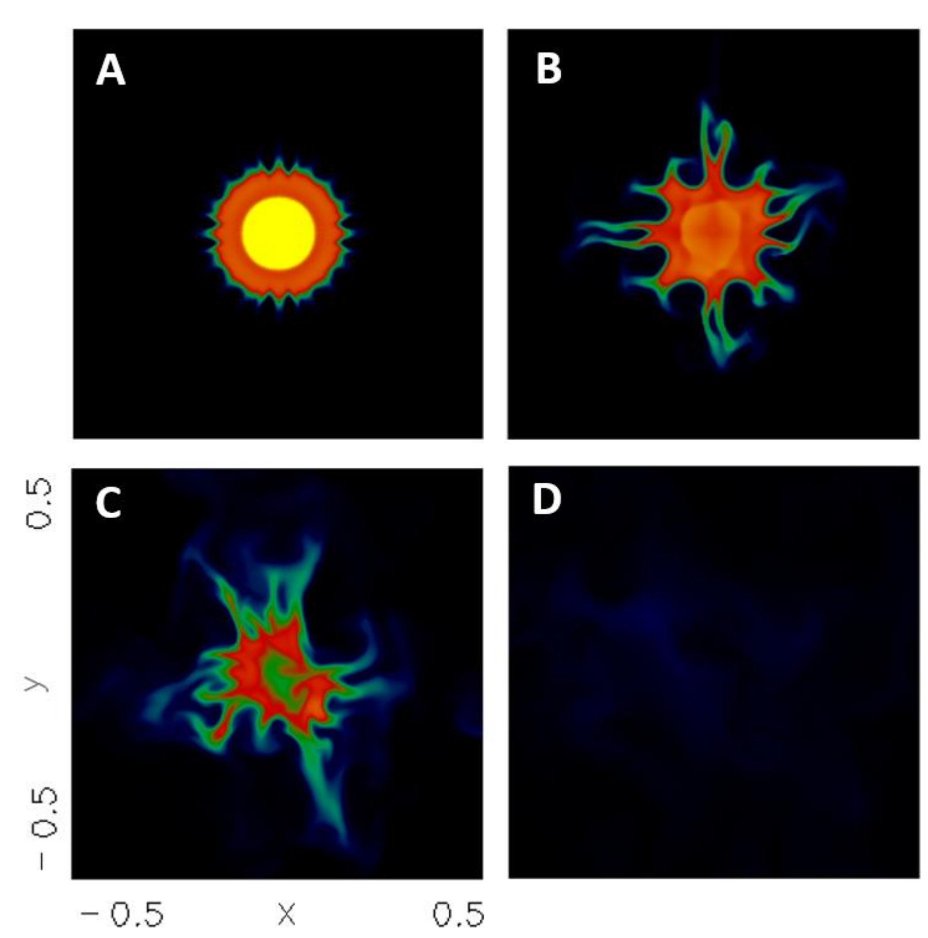
- The RTI grows in '**heavy**' jets, downstream of the shock in the azimuthal direction and **cannot be seen in 2D axisymmetrical simulations**.
- The KHI grows inevitably at the boundary, primarily in the velocity direction.
- Because of the confinement, the instabilities can impact a large portion of the jet.
- The subsequent reflection and recollimation shocks then trigger the impulsive **Richtmyer-Meshkov instability** (RMI) that affects the jet faster. It grows mostly in the **azimuthal direction**, like the RTI.

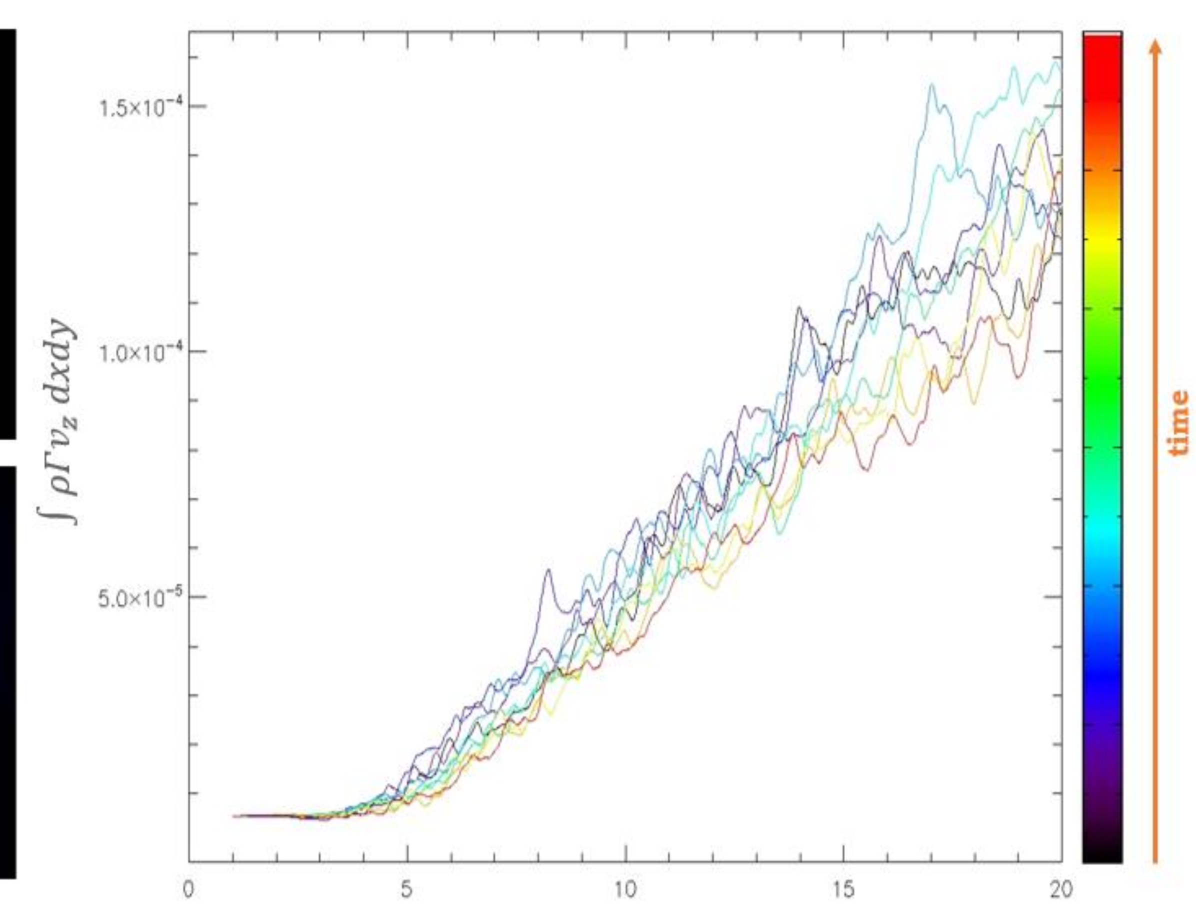
INTERESTING CASE: FR0 TYPE JETS

The standard Fanaroff-Riley classification distinguishes between the FRI and the more powerful FRII classes of AGN jets, while the **FR0 class** has been recently introduced to describe the most compact, lowest power jetted AGNs. Since they are the most abundant, and they hardly reach the kpc scale, thus dissipating most their energy in the galaxy, they might play a crucial role in the evolution of galaxies. With the inferred low Lorentz factors ($\lesssim 5$) and low luminosities ($\lesssim 10^{41\div42}$erg/s) they are the **most prone to these instabilities**.

3D SIMULATION OF A LIGHT, LOW POWER JET: FR0 LIKE







SIMULATION DETAILS

- 3D RHD simulations with the PLUTO code, HLLC solver, RK2 and linear reconstruction.
- Resolution of 35 cells per initial jet radius.
- Ask me for any other detail!

CAPTION

1. First figure displays $y = 0$ slices of: the **tracer of the external material** that is moving, on the left, and of the **Lorentz factor** on the right.
2. Figures A, B, C, D show the **top view of the Lorentz factor** at different altitudes, as indicated in the first figure. The jet is initially hardly unstable (it's light) but after the antinode at $z \simeq 5$ the RMI develops and drags part of the external material.
3. The plot on the right shows the increase in the **mass flux along the axis** because of the entrainment. It slowly decreases in time.

WHAT AM I CURRENTLY DOING?

1. Exploration of the parameter space:
   density contrast ρ_j/ρ_m - jet Lorentz factor Γ - jet temperature T
2. It's been discussed that even a weak toroidal **magnetic field**, $\sigma_{tor} \geq 10^{-2}$, can completely suppress the instability. But what do we know exactly about the magnetic field at recollimation? GRMHD + PIC for the magnetized case.

SOME REFERENCES!

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