The evolution of a relativistic and collimated jet through a magnetized medium.

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GW/sGRB170817 produced both gravitational waves and a short gamma ray burst. However, the evolution of the relativistic and collimated sGRB-jet through the produced magnetized ambient medium is unknow. Thus, in this work we follow the evolution of a sGRB-jet through an ambient medium with different magnetic distributions via a set of 2D RMHD simulations.

Introduction

GRB170817 was produced by the fusion of two neutron stars, and its final compact object (CO) is still unknown (BH or a NS). Since the configuration of the magnetic field (B) is different depending of the produced CO, thus, we follow the evolution of a relativistic and collimated jet in different B distributions with a set of 2D RMHD simulations.

Methodology

The evolution of a blast wave (BW) or a relativistic jet, propagating through a non magnetized or a magnetized medium (ISM) was followed employing the relativistic magneto hydrodynamical (RMHD) code PLUTO (Mignone et al. , 2007, 2012).

We first verified the code for the MHD limit comparing the evolution of a 2D BW with the Sedov-Taylor (ST) solution (Sedov, 1946; Taylor 1950). Then, we compared the evolution of relativistic 2D Riemann shock vs that from other codes (De Colle et al. 2012). Finally, we ran a set of models in which a short GRB-jet evolved through an ISM with different B distributions.

Table 1

	MHD validation		RHD validation	SGRB jet	
	ST 1	ST 2	2D Riemann**	Jet 1	Jet 2
ρ $(g\ cm^{-3})$*	$3.5x10^{-24}$	$3.5x10^{-24}$	NE, NW, SE, SW	17.32	17.32
P $(g\ cm^{-3})$*	$2x10^{-6}$	$2x10^{-6}$	NE, NW, SE, SW	342	342
E (erg)*	10^{52}	10^{52}	NE, NW, SE, SW	10^{48}	10^{48}
θ*	isotropical	isotropical	–	$10°$	$10°$
Γ_0*	1	1	NE, NW, SE, SW	5	5
B_{ISM} (G)	0	$7.5x10^{-1}$	–	10^{-6} (Vertical)	10^{-6} (Horizontal)

* $\rho = \rho_{jet}$ or $\rho = \rho_{BW}$ depending on the problem (and so forth for the P, E, θ, and Γ)

**The 2D Riemann problem had different ρ, P, E, and Γ in each quadrants (NE, NW, SE, SW) at t=0.

MHD validation

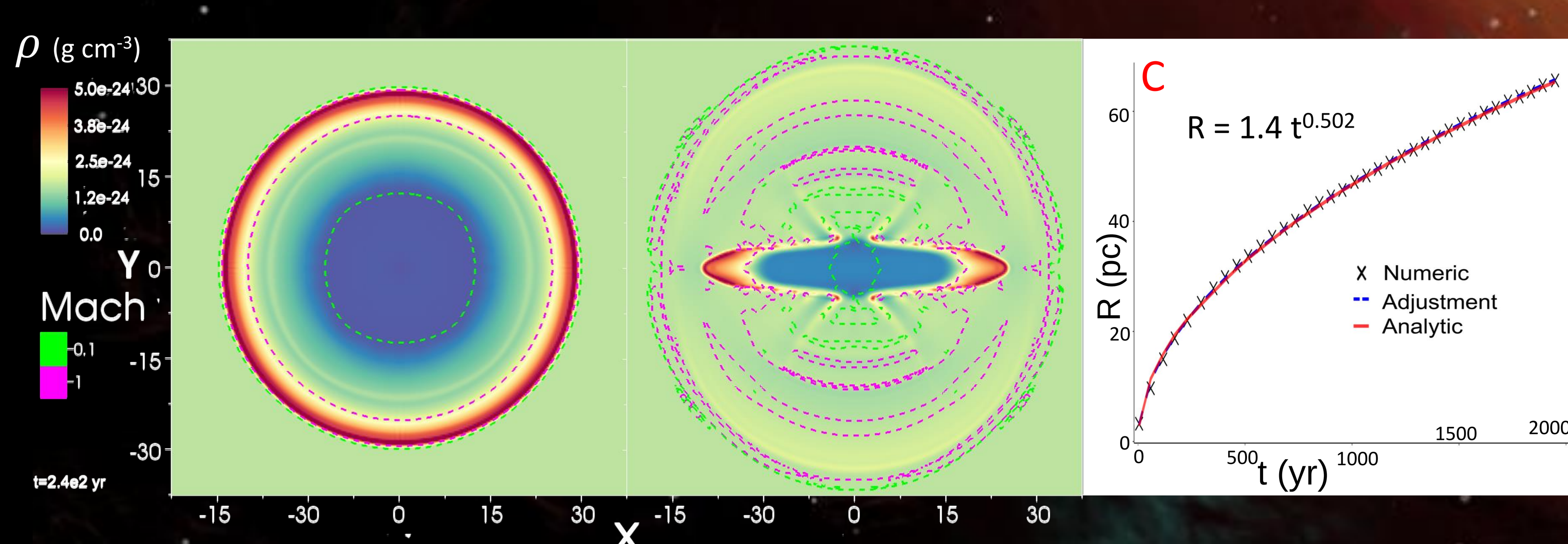

Figure 1. A: Density $(g\ cm^{-3})$ map for a blast wave in an ISM with B=0 G at t=2.4x10^2 yr (case ST 1, see Table 1 for more details). The axis are normalized to 1.5 pc and the shock waves are shown with dashes isocontours. B: Same as A but for an ISM with B=7.6x10^{-2}G (case ST 2). C: Comparation between the analytical model (Fryxell et al. 2000) and the results from ST1.

- The BW with B=0 G expands isotropically (see panel A of Figure 1), and follows the ST solution ($R \propto t^{0.5}$, see panel C of Figure 1).
- For high B the ST solution is only valid in the equatorial zones of the BW. Alfven (∥) and magnetosonic (⊥) shocks are present.

RHD validation

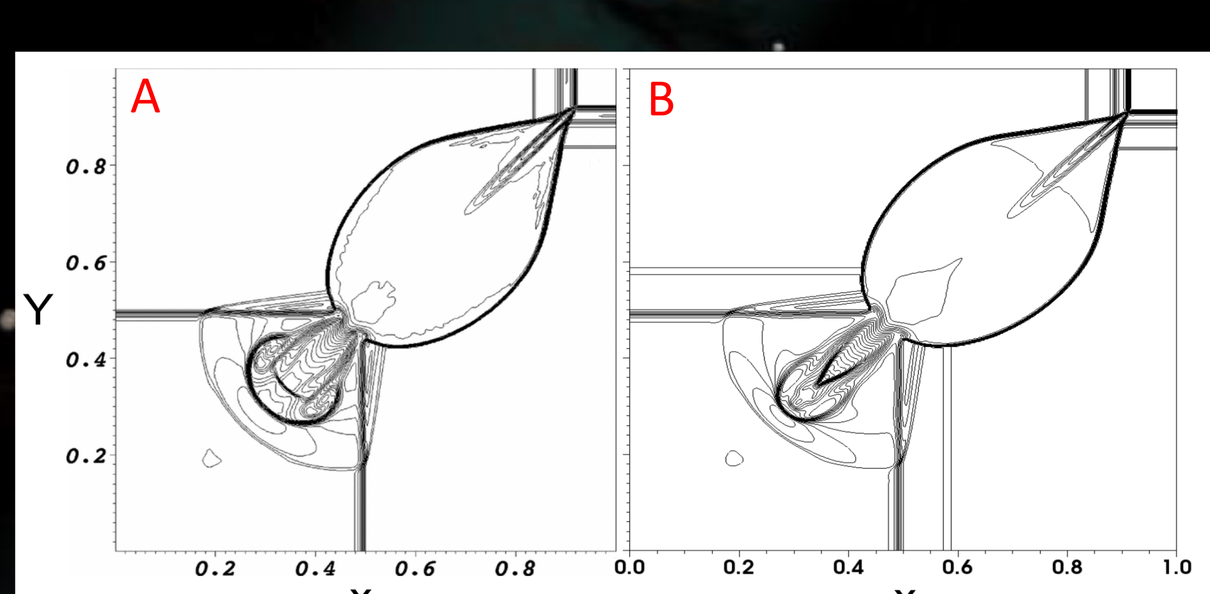

Figure 2. Log(ρ)=0.0067-5.07 at t=0.4 for the 2D Riemann solution (B) vs from De Colle et a. (2012).

- The obtained solution for the 2D relativistic Riemann problem is consistent with that from De Colle et al (2012).

sGRB-jet setup

ISM
- $\rho_{ISM} = 1x10^{-10}\ g\ cm^{-3}$
- $P_{ISM} = 2.0x10^{-9}$ dyn
- $B_{ISM} = 10^{-6}$ G

Top-hat jet
- $L_j = 5.0x10^{47}\ erg\ s^{-1}$
- $r = 4.0x10^{7}$ cm
- $\Delta t = 2.0$ s

(the ρ, P, E, and Γ of jet and the distribution of B_{ISM} are specified in Table 1)

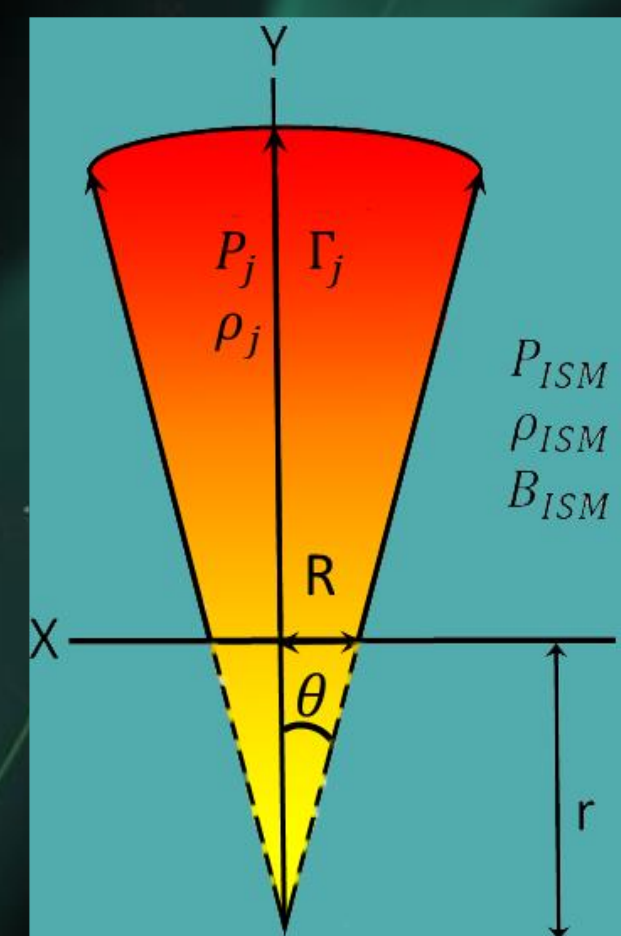

Figure 3. Initial condition for a jet in a constant magnetized medium where $R = r \cdot tan\theta$

Results

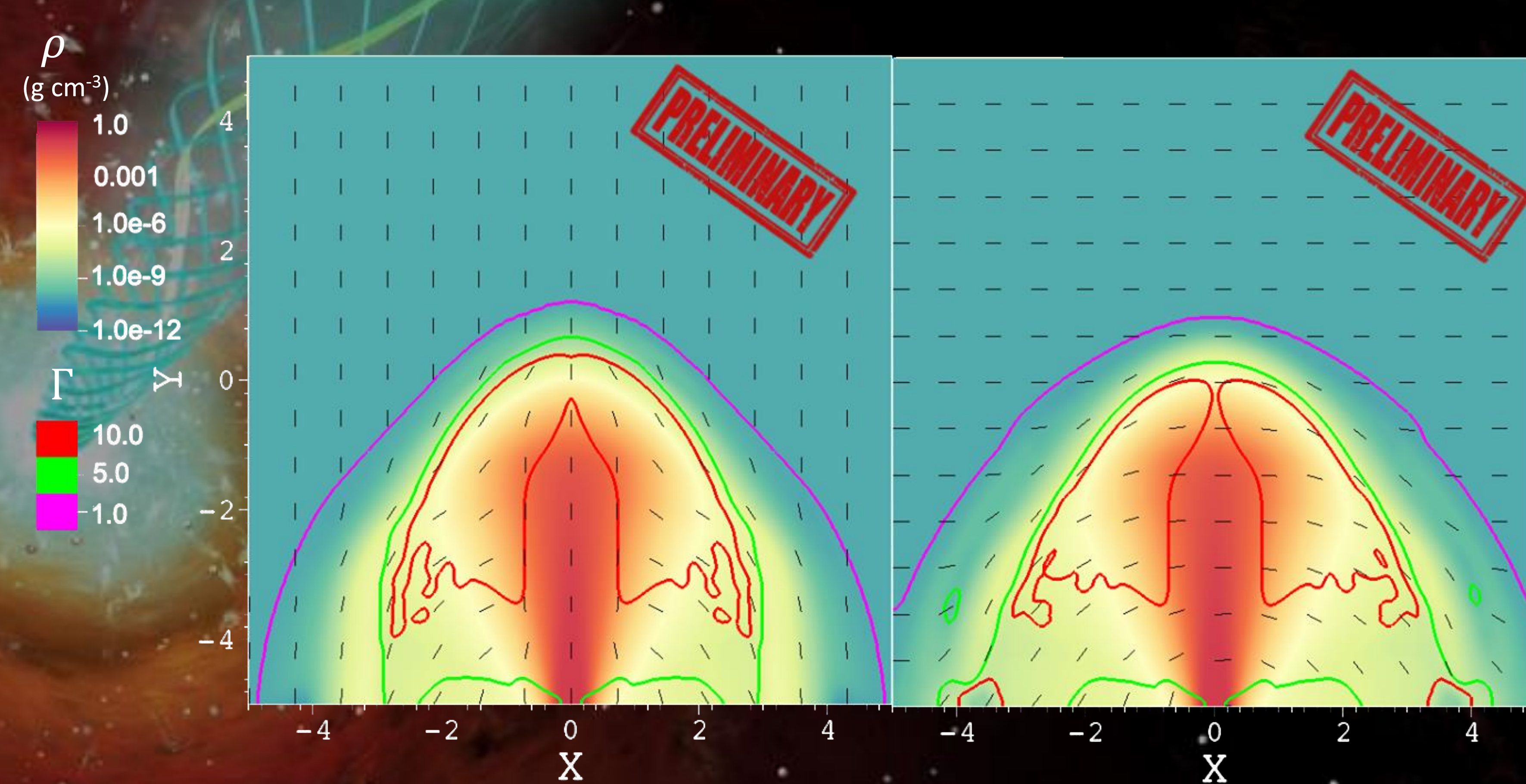

Figure 4. A: Density $(g\ cm^{-3})$ map of a 2DRHD collimated jet moving through an ISM with vertical B field (see Table 1 for more details) at t=2.s. The axis are normalized to 10^{13} cm and the solid isocontours indicate the Lorentz factor of the flow. B: Same as A but for a horizontal field.

- Independently of the ISM's B distribution, the 2DRHD collimated jet is successful.
- The global morphology of the jet is similar for both B distributions. However, there are some differences (specially in Γ) and the jet is 14% more collimated in the vertical B.
- The jet moving through a vertical B, moves 17% faster than in a horizontal B (due to the B force that slows the jet).
- Since the jet perturbates the B field, magnetic waves (Alfven and magnetosonic) can appear.

Conclusions

- We studied the evolution of a 2DRHD jet moving though different magnetized ISMs.
- The used RMHD code (PLUTO) was first validated (successfully for the MHD and RHD limits).
- The global morphology is the same for both B distributions. The magnetic field distribution of the ISM may collimate the relativistic jet.
- In the future, we will study the evolution of different jets through other magnetized ISMs.

References:
De Colle et al. 2012; Fryxell et al. 2000; Mignone et al. 2007, 2012 ; Sedov 1946; Taylor 1950.