Simulations of GRB Jets in a Stratified External Medium

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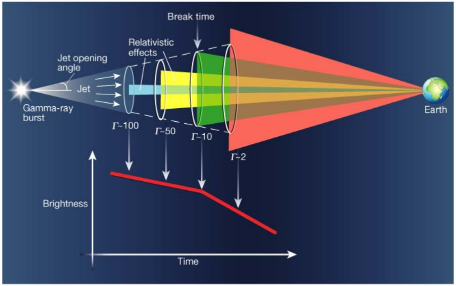
- Jonathan Granot (Hebrew/Tel Aviv/Hertfordshire University)
- Guillermo Garcia-Segura (UNAM)

References

1. De Colle, F. et al., ApJ, 746, 122 (2012)
2. De Colle, F. et al., ApJ, 751, 57 (2012)

1. **Introduction**
2. **Methods**
3. **Results**

Introduction



$$E \sim \gamma^2 M(r_d)c^2 \Rightarrow$$

$$r_d \sim 3 \times 10^{16} \left(\frac{E_{52}}{\gamma_{300}^2 n_0}\right)^{1/3} \text{cm.}$$

The afterglow in a "nutshell":

1. Dynamics:
   - $u = \Gamma v/c \gtrsim 1/\theta_0 \Rightarrow$ Blandford & McKee self-similar solution
   - $u \ll 1 \Rightarrow$ Sedov-Taylor self-similar solution
   - $u \approx 1 \Rightarrow$ Numerical simulations
2. Emission: synchrotron radiation

Motivation

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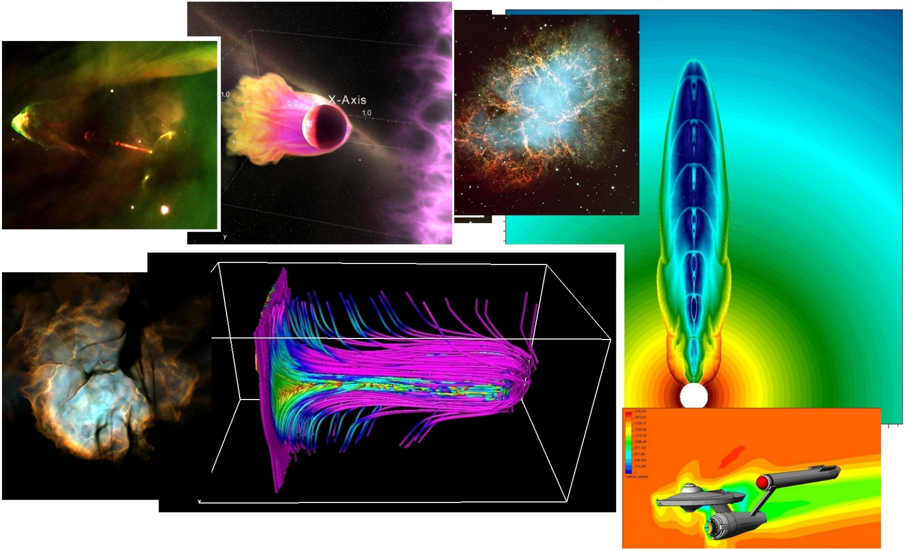
- simple analytical scalings do not provide an accurate description of the afterglow
- numerical studies have been limited to the case of a uniform medium (e.g. *Granot et al. 2001*, *Zhang & MacFadyen 2009*)

We need to compute:

- ✓ The dynamics of the decelerating GRB
- ✓ The radiation coming from the decelerating GRB

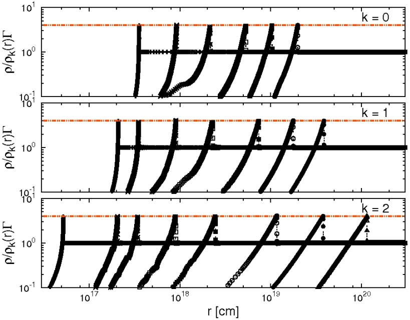
The “SRHD/AMR/MPI” *Mezcal* code



Afterglow radiation calculation

- ✓ From synchrotron radiation
- ⇒ Microphysics of the acceleration and emission processes parameterized by taking $\epsilon_e = \epsilon_B = 0.1$, $p = 2.5$.

1D GRB jets with $\rho \sim r^{-k}$

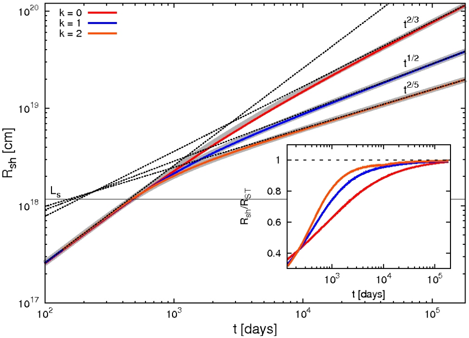


In general: $E \propto \Gamma^2 M v^2 \propto \Gamma^2 v^2 R^{3-k}$

$\Rightarrow L_s \sim 10^{18} \left(\frac{E_{52}}{n_0}\right)^{1/3}$ cm

$\Rightarrow \Gamma v \approx R^{-(3-k)/2}$.

1D GRB jets



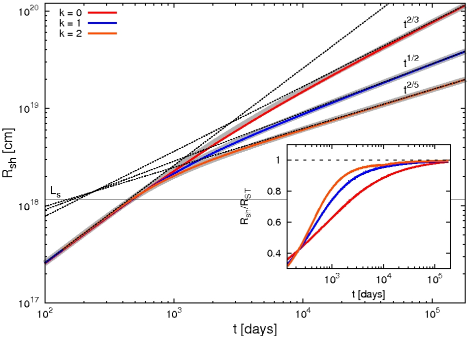
In general: $E \propto \Gamma^2 v^2 R^{3-k}$

$E = R^{3-k}\Gamma^2 \left(c_R v^2 + c_{NR}(1 - v^2)\right)$

$\Rightarrow v = v(R)$

$\Rightarrow R = R(t)$

1D GRB jets



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- Deceleration to non-relativistic speeds in 1d occurs on scales much larger than the Sedov length (see *van Eerten et al. 2010* for the $k = 0$ case)
- L_{nr} increases with k

How well can we recover the BMK scalings?

Post-shock region of order of $R_{\rm sh}/\Gamma^2 \Rightarrow$ simulations are numerical very challenging

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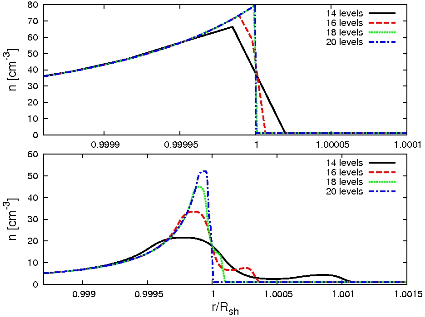
Running SRHD simulations with not enough resolution may give unphysical results!



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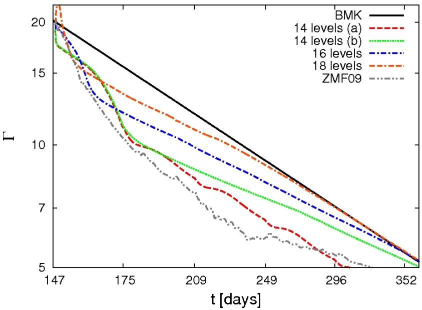

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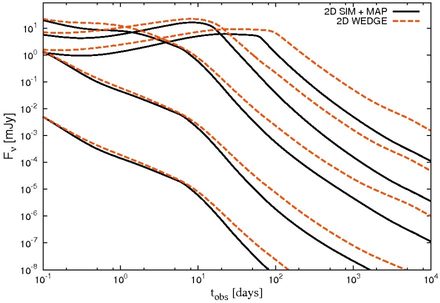
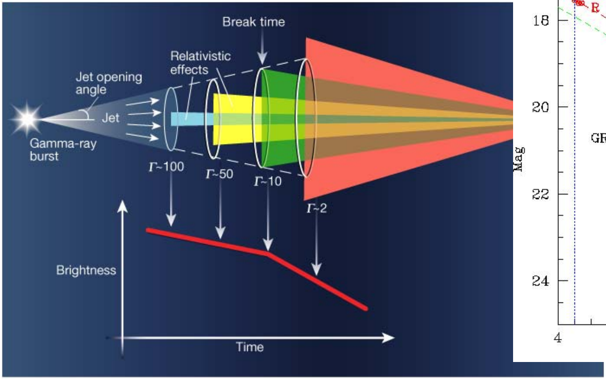
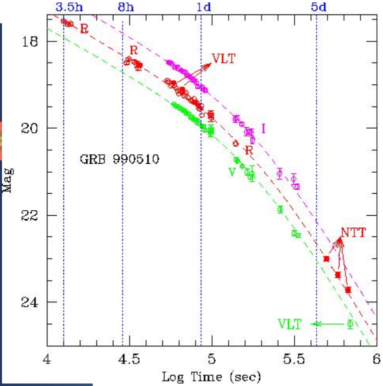
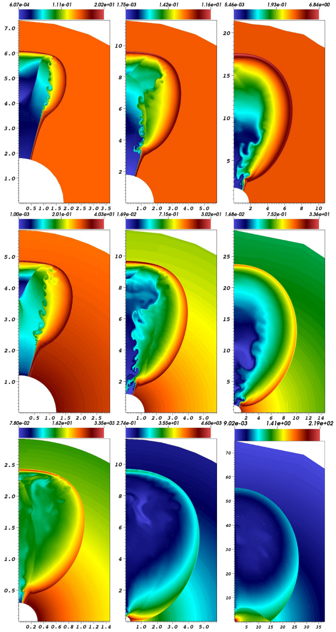


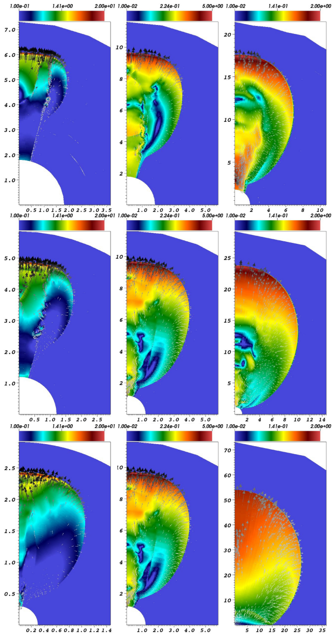
2D GRB jets


Break time
Relativistic effects
Jet opening angle
Jet
Gamma-ray burst
Γ~100
Γ~50
Γ~10
Γ~2
Brightness
Time

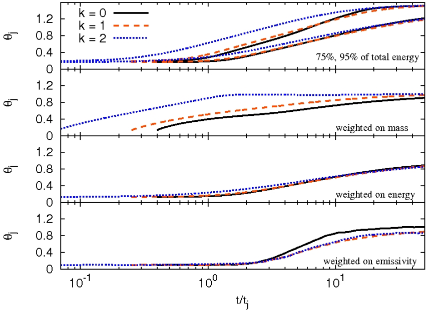

3.5h
8h
1d
5d
R
R
VLT
I
R
V
NTT
VLT
GRB 990510
Mag
18
20
22
24
4
4.5
5
5.5
6
Log Time (sec)



jet initialized as a conical wedge with radial profiles given by the spherical BMK solution
$\Rightarrow$ transient phase with formation of an egg-like shape

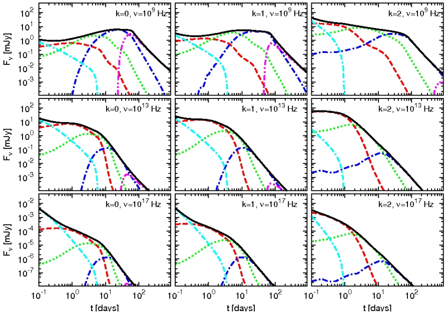


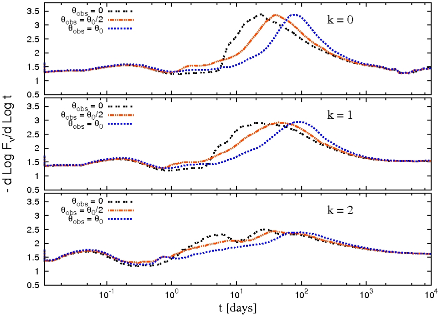
1. expansion velocity remains mainly radial at small angles and non-relativistic at large angles
2. lateral expansion increases with *k*



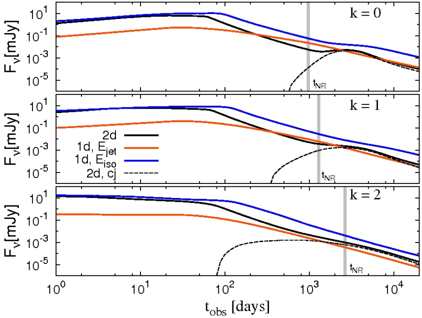
1. swept up external mass ⇒ edge of the jet
2. but most of the energy ⇒ near the head of the jet
3. early expansion is faster with increasing k
4. with increasing k, spherical symmetry is achieved later

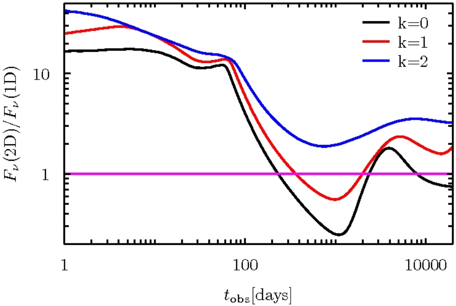
Light curves





Calorimetry

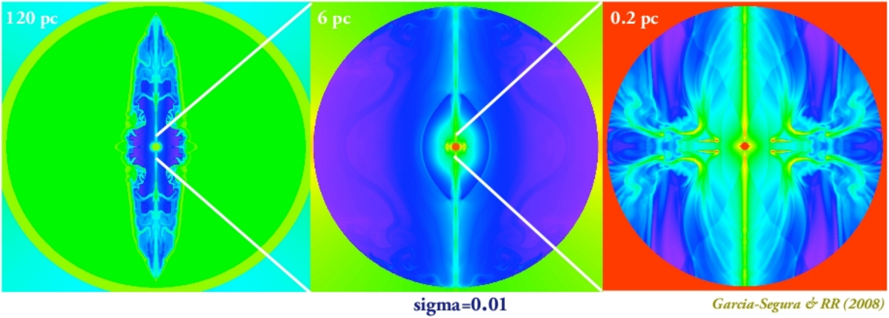




Summary

- Dynamics of the GRB jets are greatly modified by the density stratification
- $k = 2$ vs $k = 0$:
  1. Faster/slower jet lateral expansion at early/late times
  2. Jet break smoother due to the density stratification
  3. Counter-jet contribution smaller
- calorimetry: error in assuming a spherical flow approximation depends on the exact observing time and density stratification.

A more realistic model for a Wolf-Rayet wind



Advertisement: poster P-III-10 (tomorrow in the astro-ph)