Analytic Modeling of the Propagation of Jets Inside Collapsars

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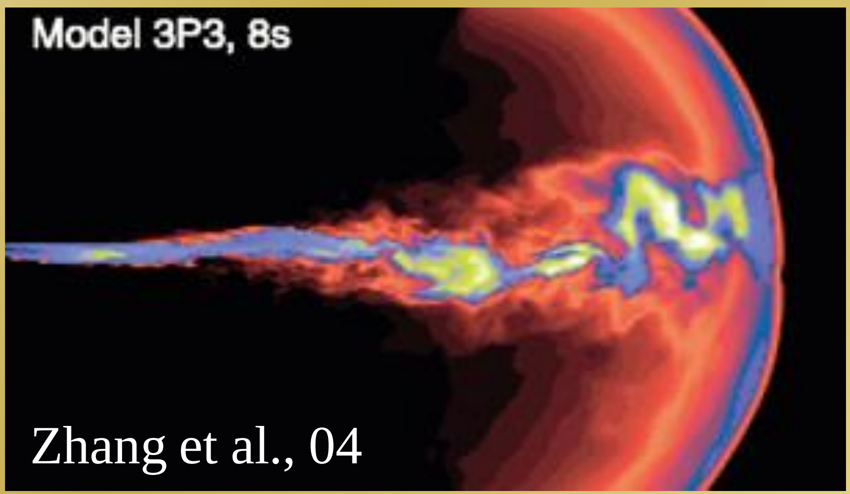
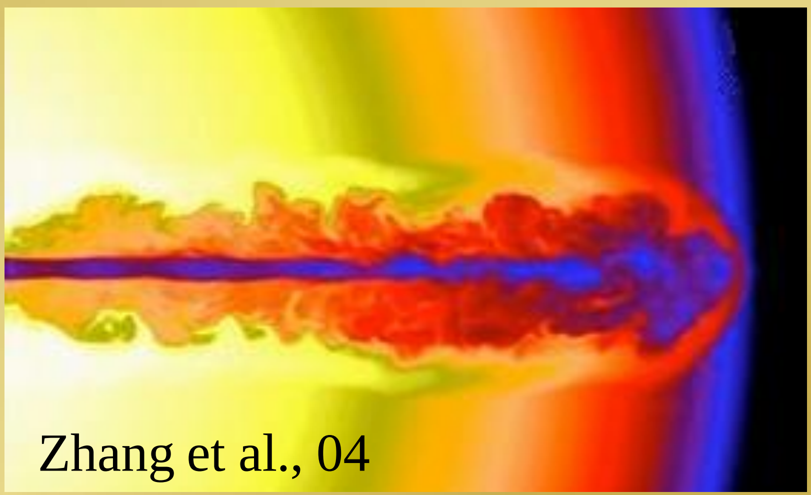
Numerical modeling



Zhang et al., 04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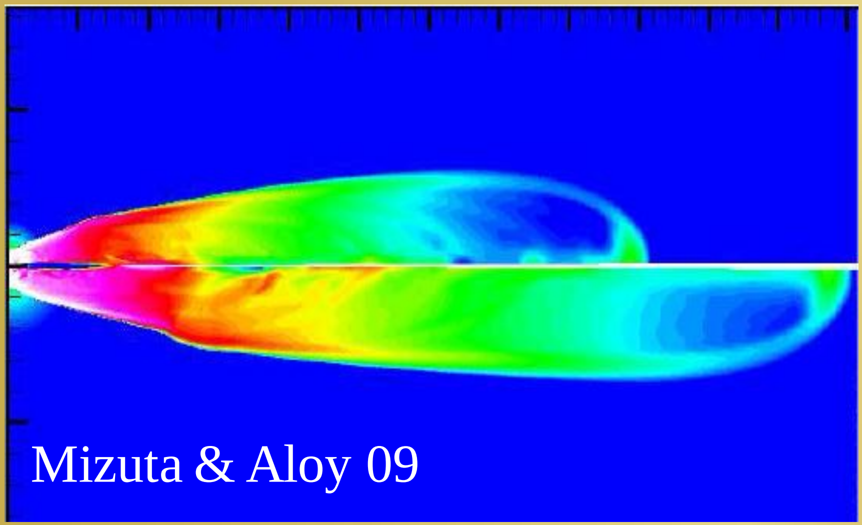
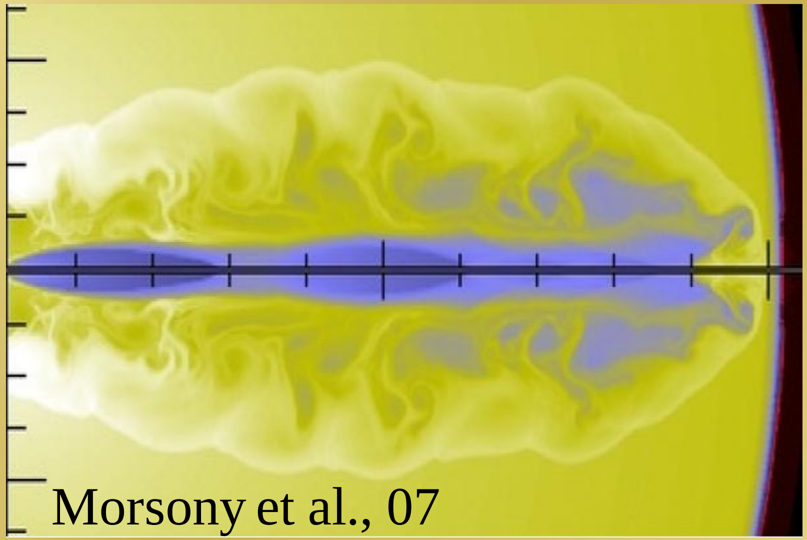
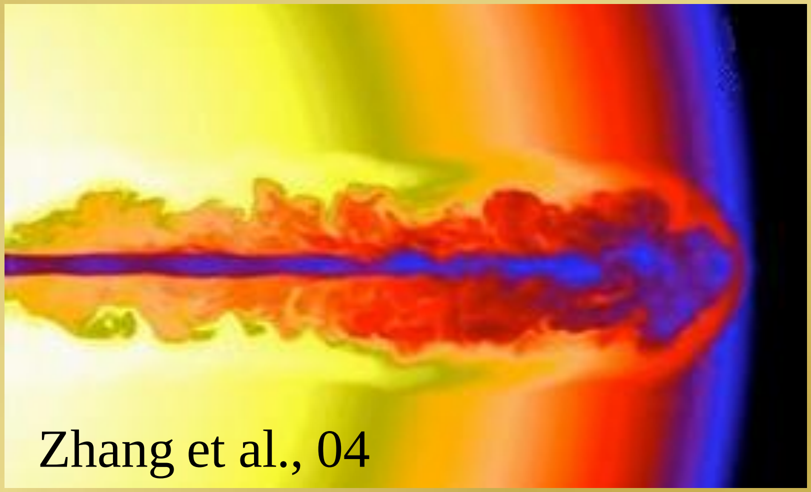
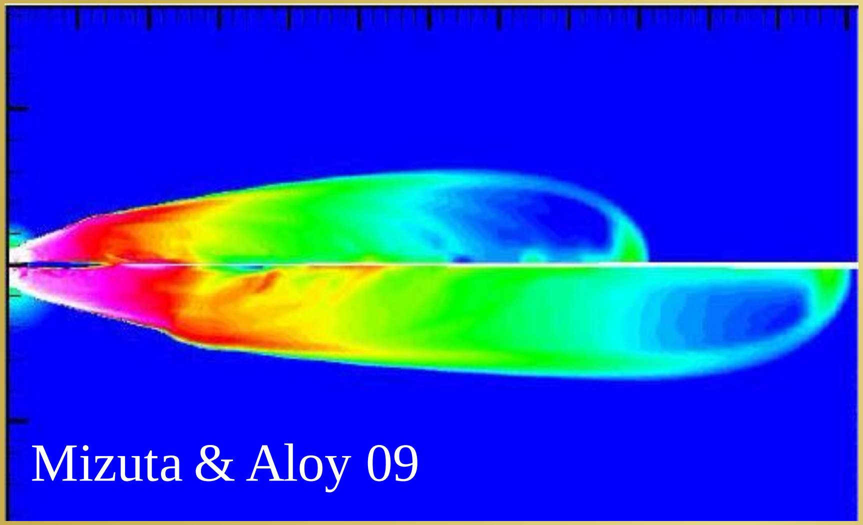

Mizuta & Aloy 09

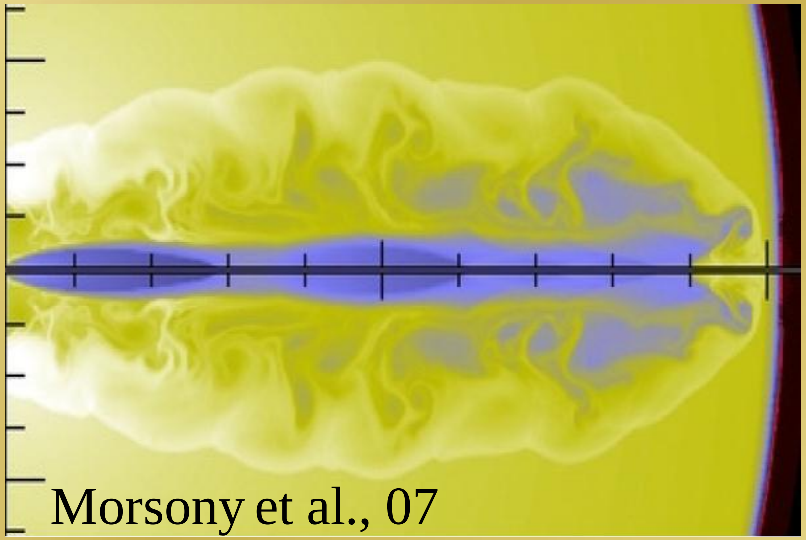

Morsony et al., 07

Numerical modeling

- Jets do break through.
- A Cocoon is created.
- Extremely narrow jets.
- Jet heads are sub-to-trans relativistic







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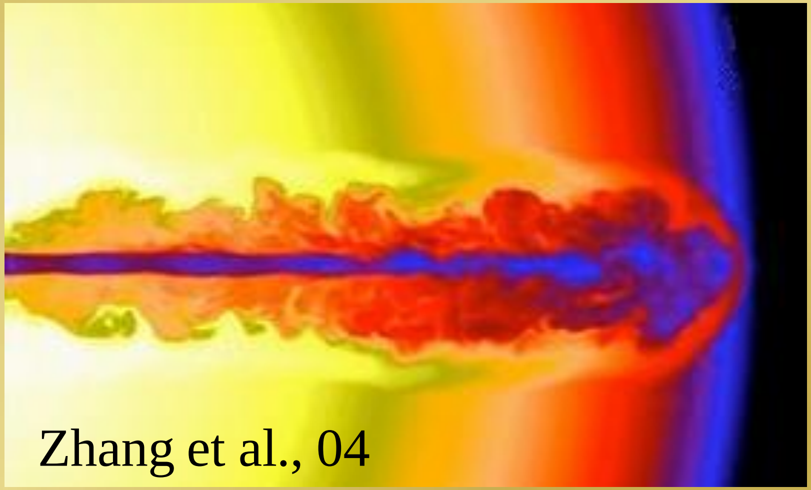
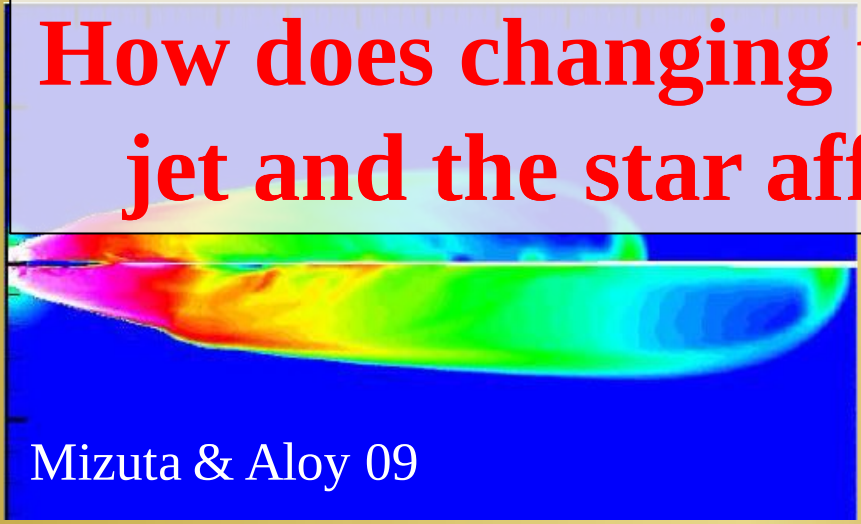


Zhang et al., 04

How does changing the properties of the jet and the star affect the evolution?



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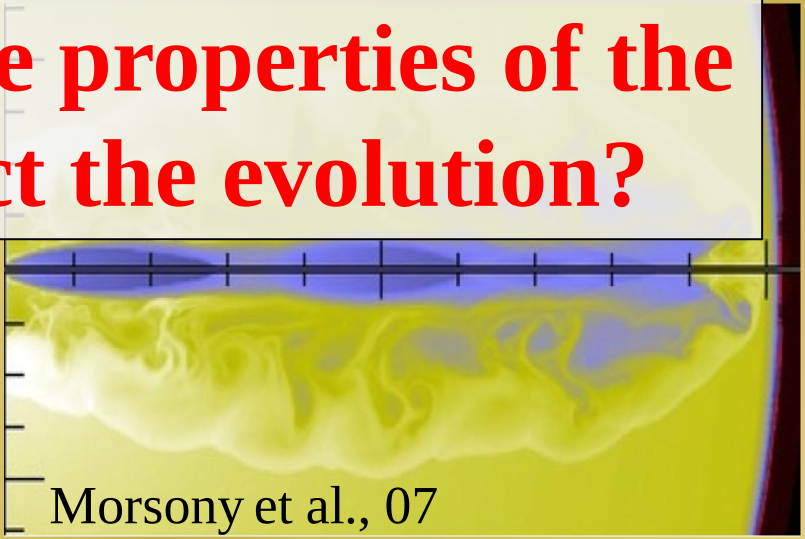
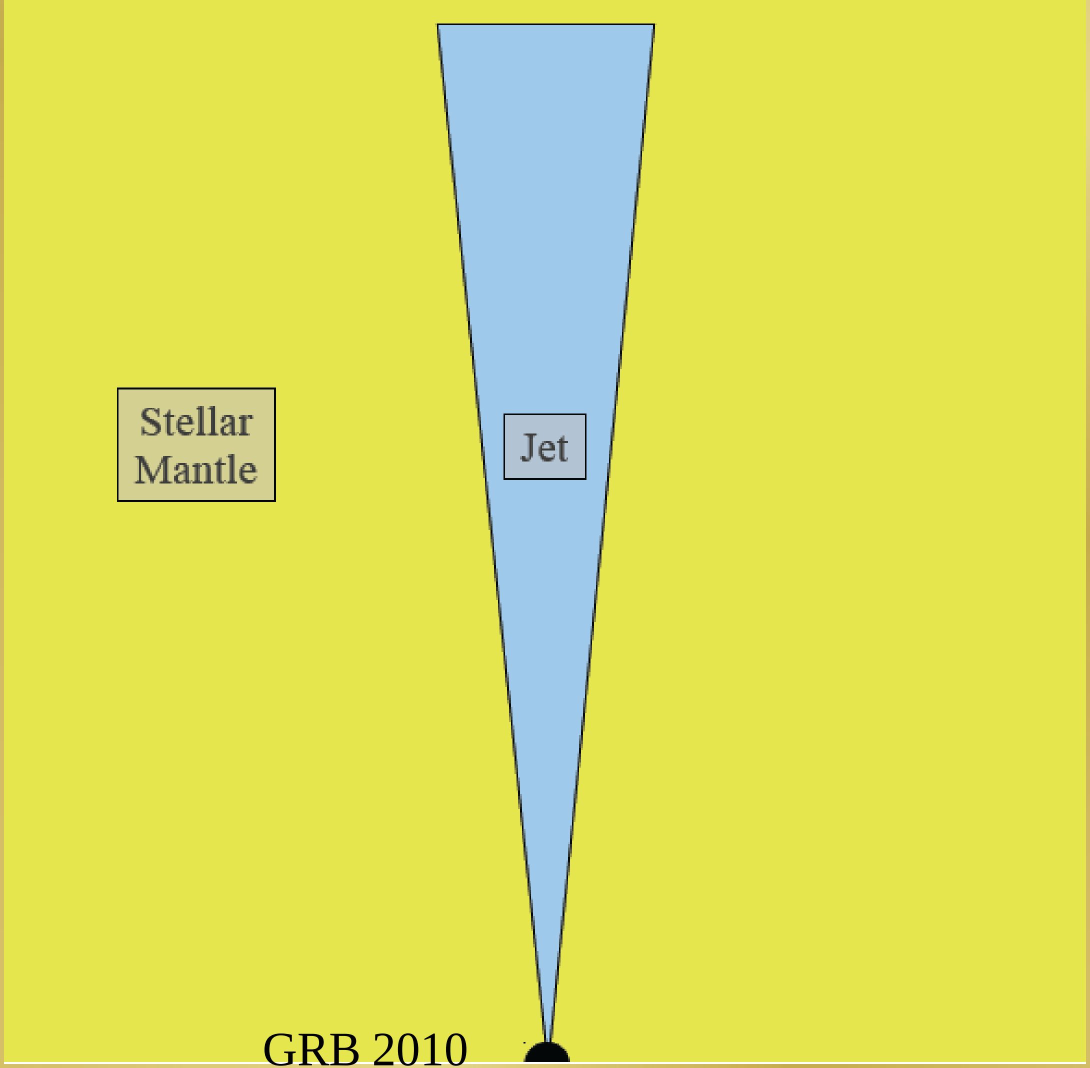


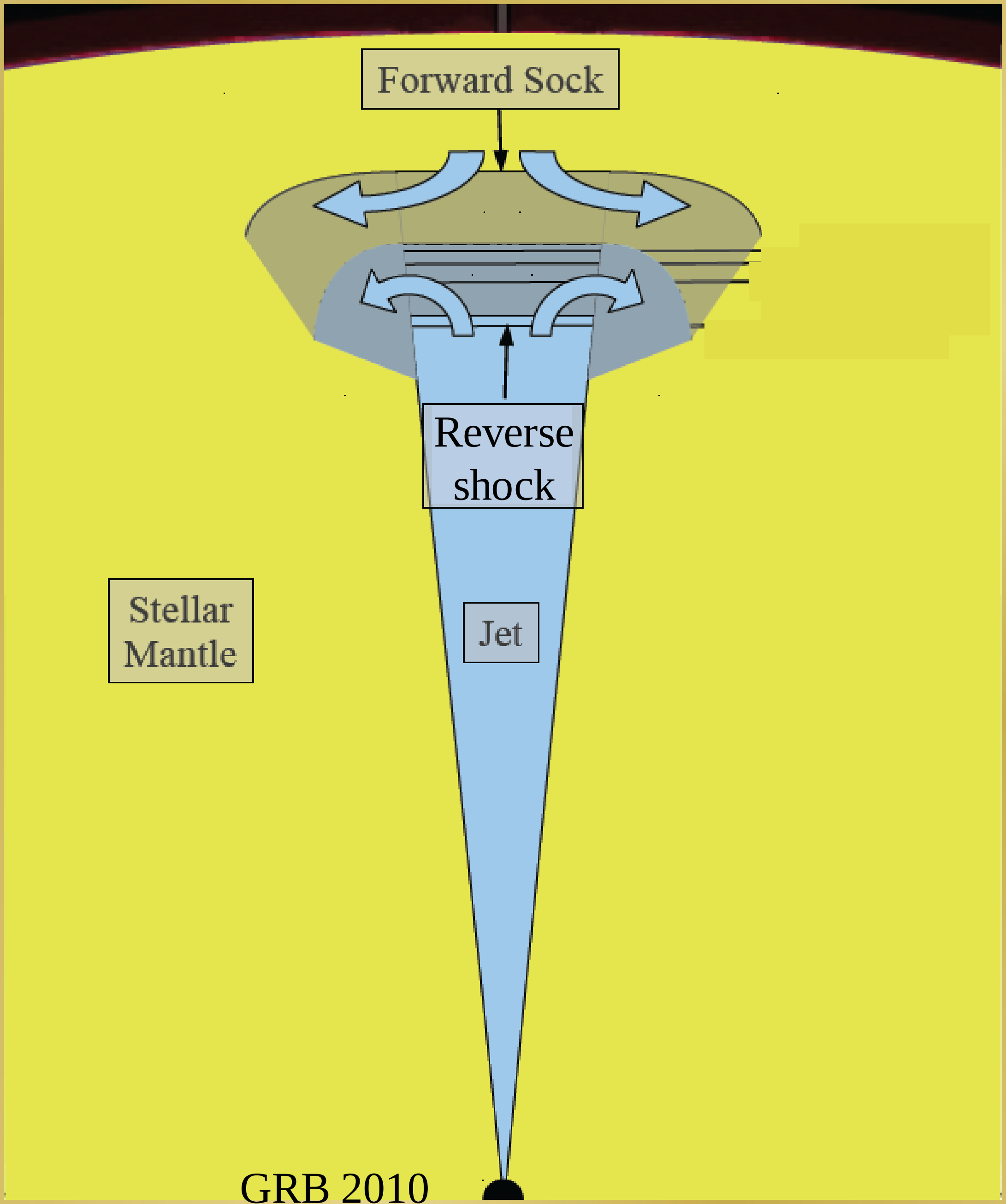
Morsony et al., 07

Analytic Study

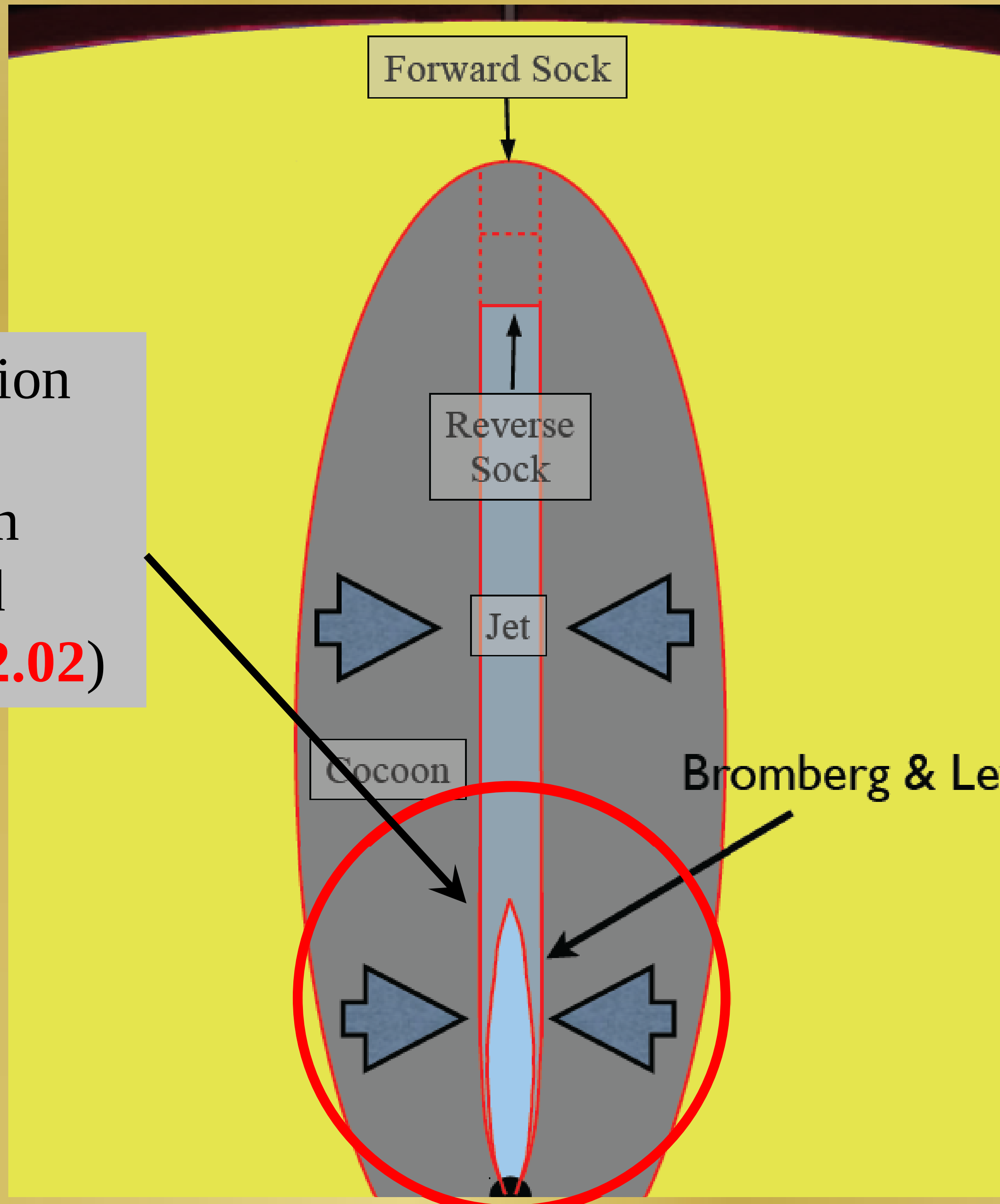
- Several analytic works were done in the past, (e.g. Meszaros & Waxman 01, Matzner 03, Lazzati & Begelman 05).
- But though the importance of collimation shocks in the jet was mentioned it was not fully modeled.
- This work extends previous work and performs for the fist time a self consistent calculation of the jet+cocoon evolution inside the star.

The Jet-Cocoon Model



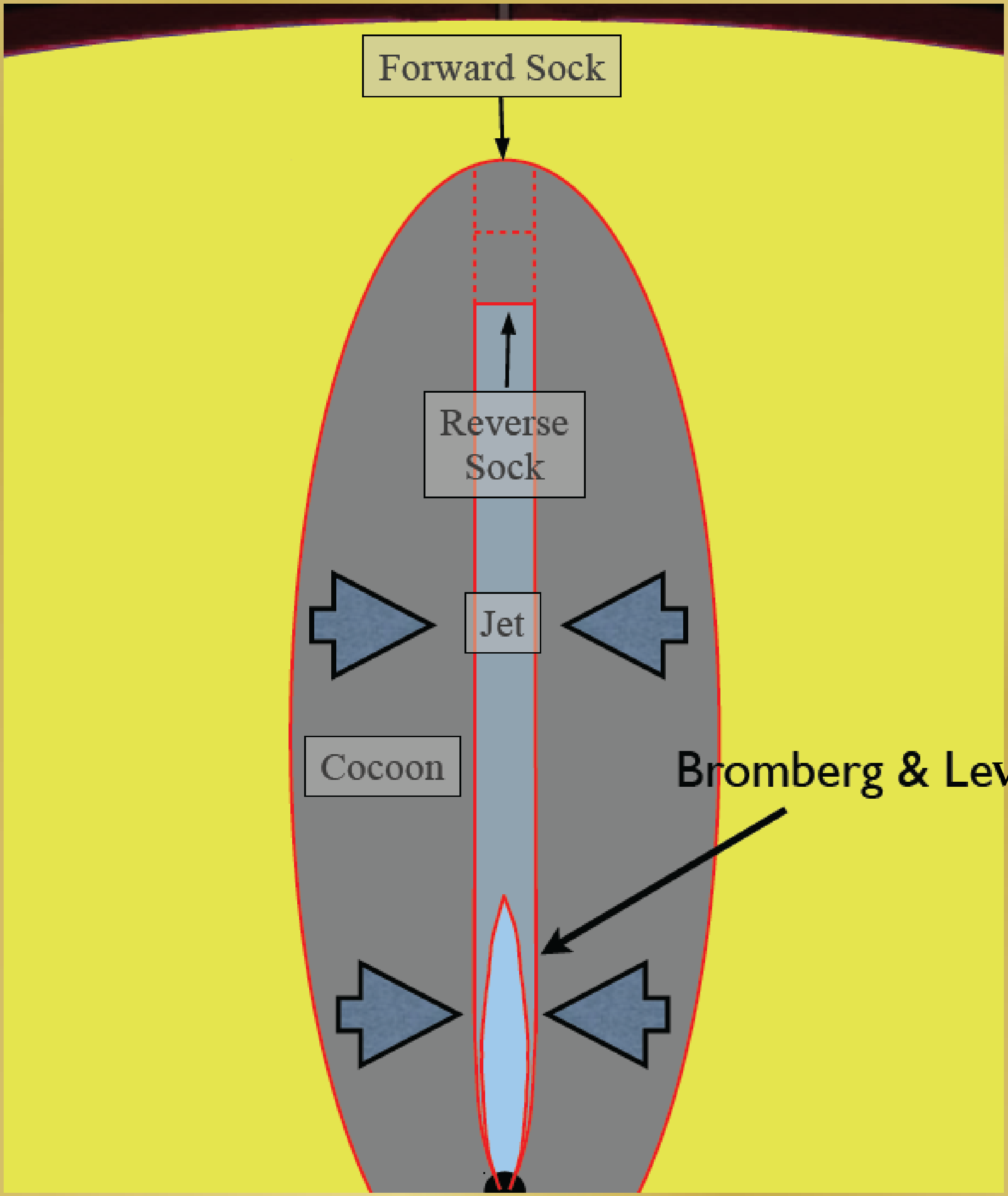


GRB 2010



Collimation Shock – Radiation mediated (**Poster 2.02**)

Bromberg & Levinson 07; 09



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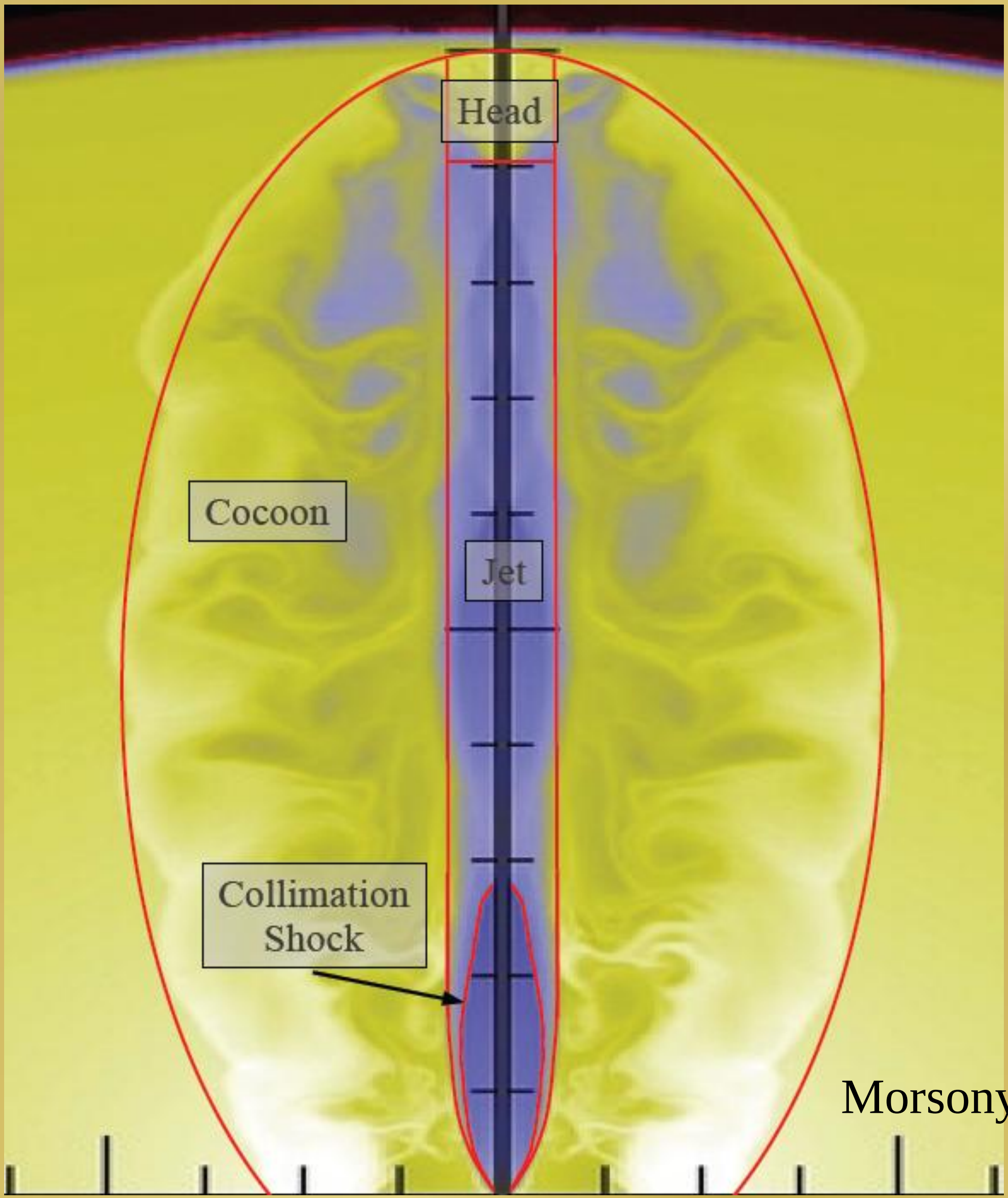
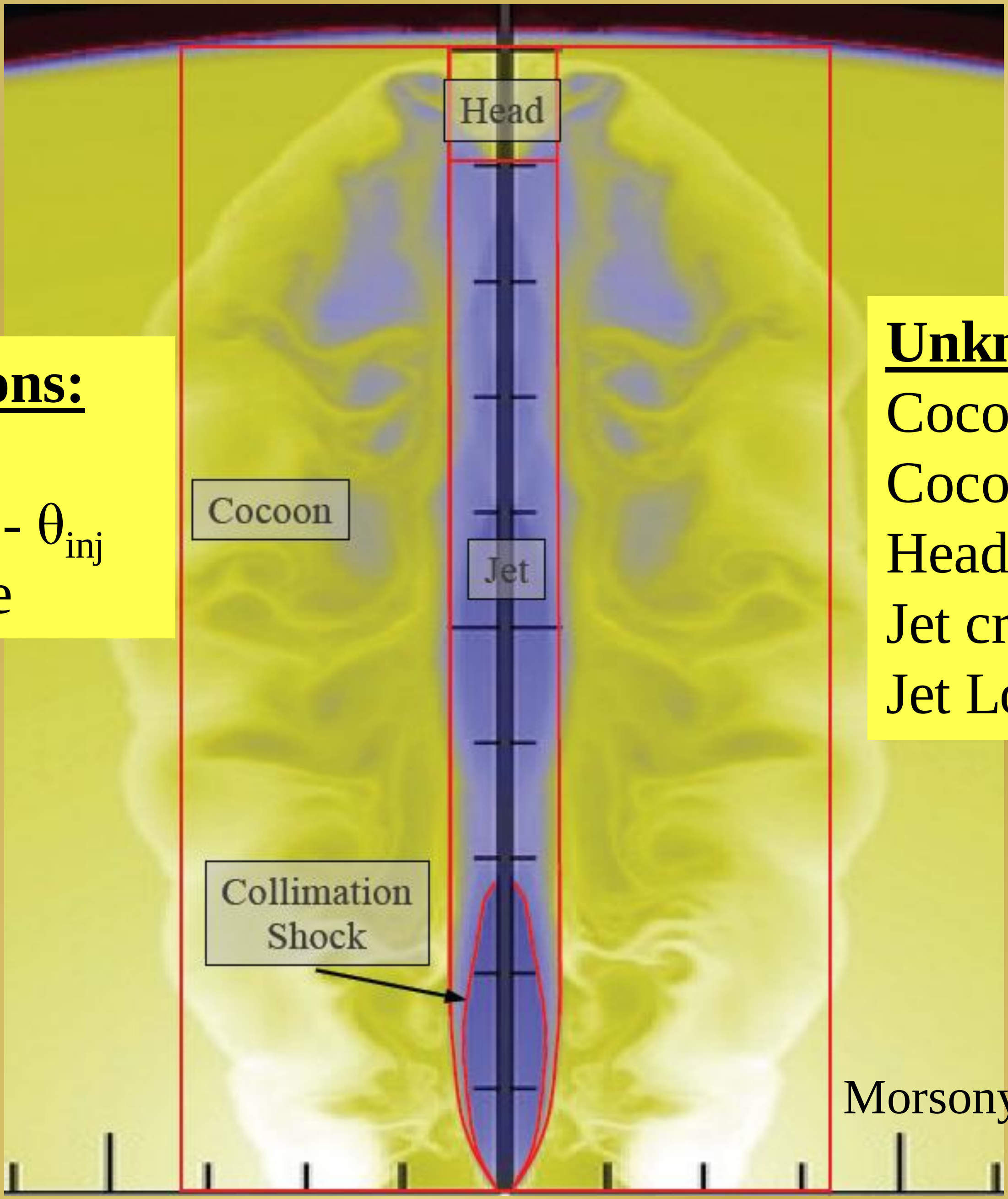


Morsony et al., 07

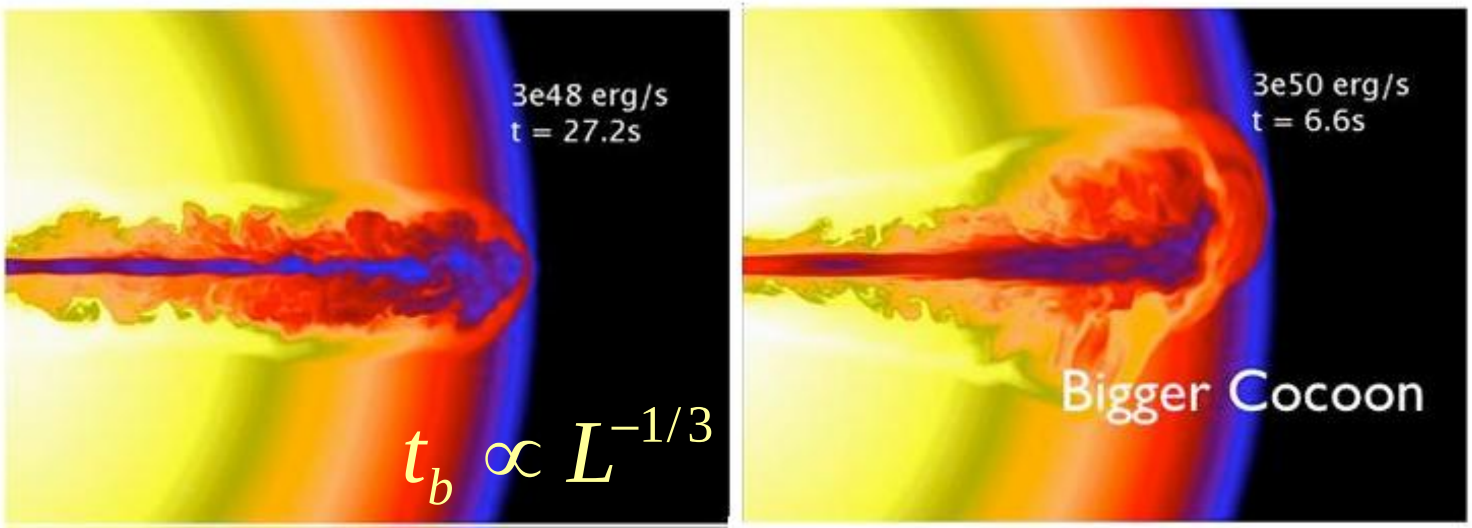
Initial conditions:
luminosity – L_j
Injection angle - θ_{inj}
Stellar structure

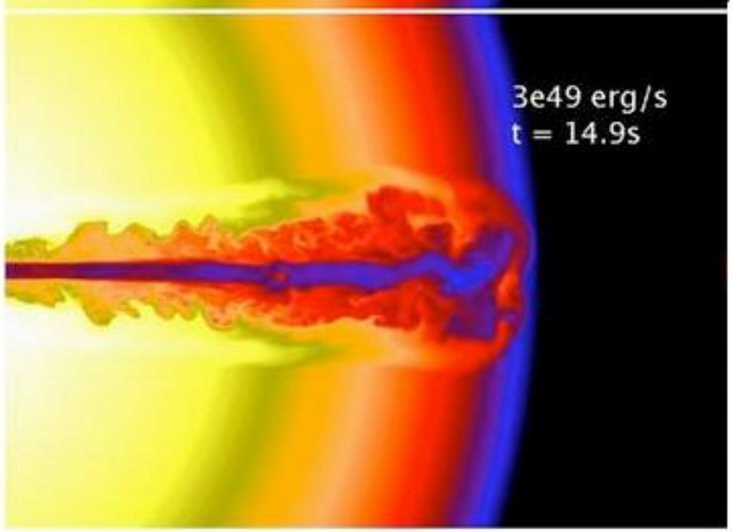


Unknowns:
Cocoon pressure
Cocoon size
Head velocity
Jet cross-section
Jet Lorentz factor

Morsony et al., 07

Comparison with simulations



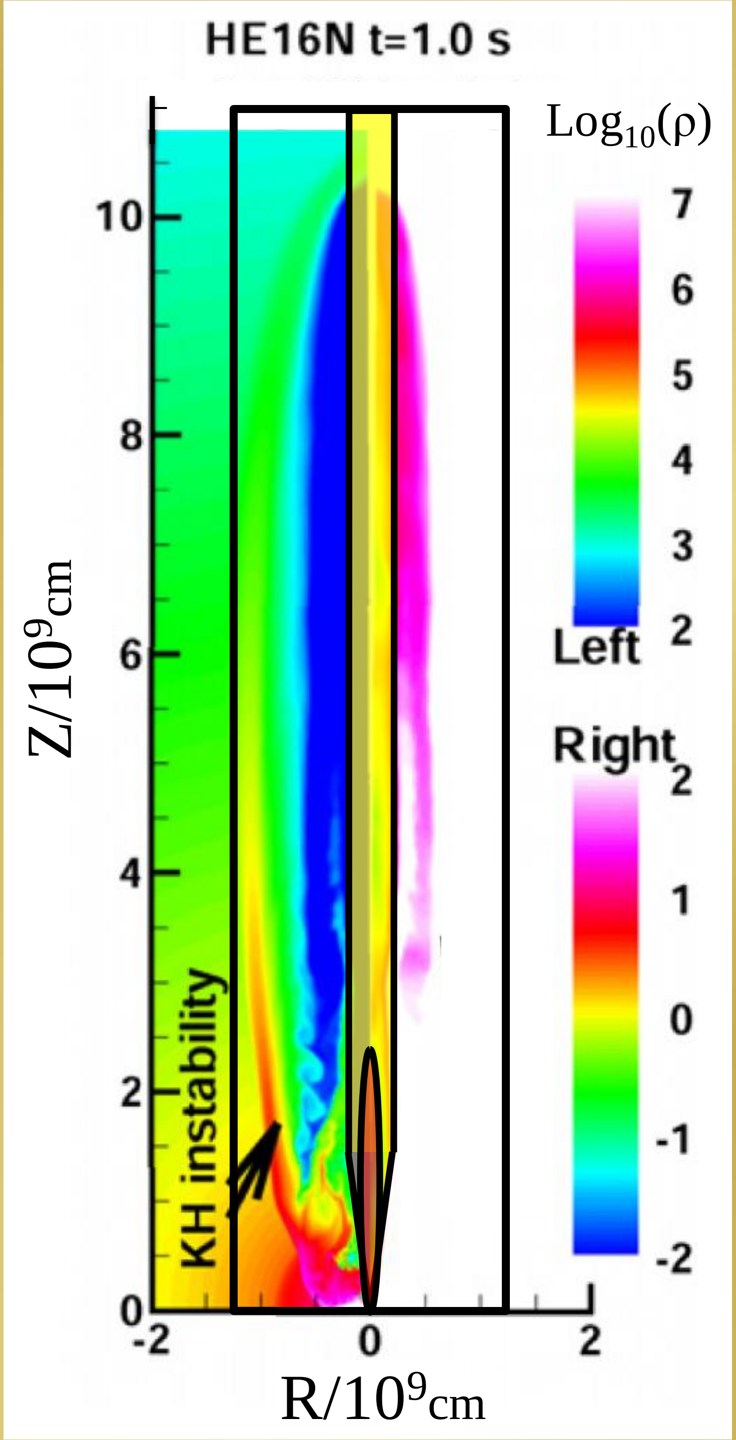


L	t	E_{51}
3e48	27	0.08
3e49	15	0.4
3e50	7	2

Zhang et al., 04

Us:

T
25
12
6



Mizuta & Aloy 09

Analytic estimations – low β_h

$$t_b = 30\,\mathrm{s} \cdot \mathrm{L}_{47}^{-1/3}\, \theta_{10^o}^{4/3}\, \mathrm{R}_{11}^{2/3}\, \mathrm{M}_{15\odot}^{1/3}$$

$$\beta_h(t_b) = 0.1 \cdot \mathrm{L}_{47}^{1/3}\, \theta_{10^o}^{-4/3}\, \mathrm{R}_{11}^{1/3}\, \mathrm{M}_{15\odot}^{-1/3}$$

$$\theta_j(t_b) = 0.1^\circ \cdot \mathrm{L}_{47}^{1/6}\, \theta_{10^o}^{4/3}\, \mathrm{R}_{11}^{7/6}\, \mathrm{M}_{15\odot}^{-1/6}$$

$$\Gamma_j(t_b) = \theta_{\mathrm{inj}}^{-1}$$

$$E_{iso,\min} = 4 \cdot 10^{51} t_{10\sec}^{-2} \theta_{10^\circ}^{2} R_{11}^{2} M_{15\odot} \quad ergs$$

* **The engine must be active until the jet head breaks out.**

Applications I:

- Low luminosity GRBs:
  - wide opening angle θ>10º
  - E_{iso}~10^{48}-10^{49} ergs
  - T_{90}~ 10-1000 sec

$$E_{iso,\min} = 10^{48}\, t_{10^3\,\sec}^{-2}\, \theta_{20^\circ}^{2}\, R_{11}^{2} M_{15\odot} \;\; ergs$$

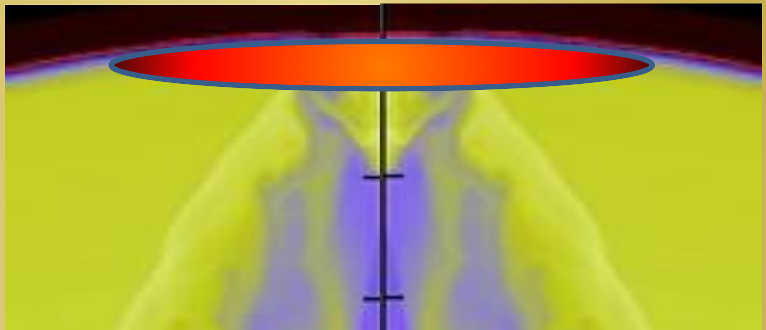
- **Only the longer bursts may originate from jets which break out of the star.**
- **Shorter duration bursts result in failed jets.**

Applications II:

- A weak jet which fail to break ("failed GRB") leads to a hot spot on the stellar envelope.
- Predicted cocoon temperature:

$$KT = 4\, E_{iso,48}^{1/8} R_{11}^{-2/3} M_{15\odot}^{1/24} \quad \textbf{KeV}$$

- Example SN 2008D (Mazzali et al., 2008) usually interpreted as a "shock break out".



Morsony et al., 04

Applications Ia:

- Jet break from first generation stars:

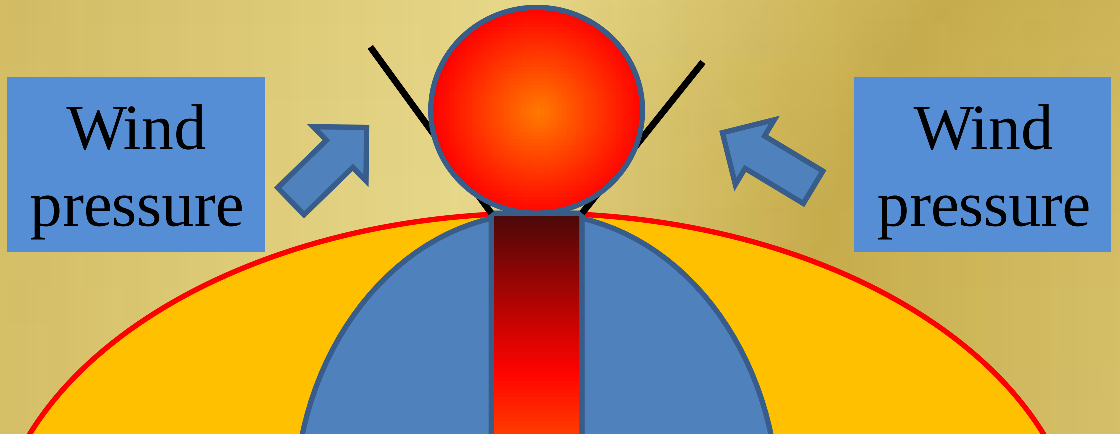
$$E_{iso,\min} = 3\cdot 10^{53}\left(\frac{t}{30\,\sec}\right)^{-2}\theta_{10^\circ}^{2}\,R_{12}^{2}M_{100\odot}\quad ergs$$

* **The engine must be active until the jet breaks out, otherwise all the energy will be dissipated into the cocoon.**

Applications III:

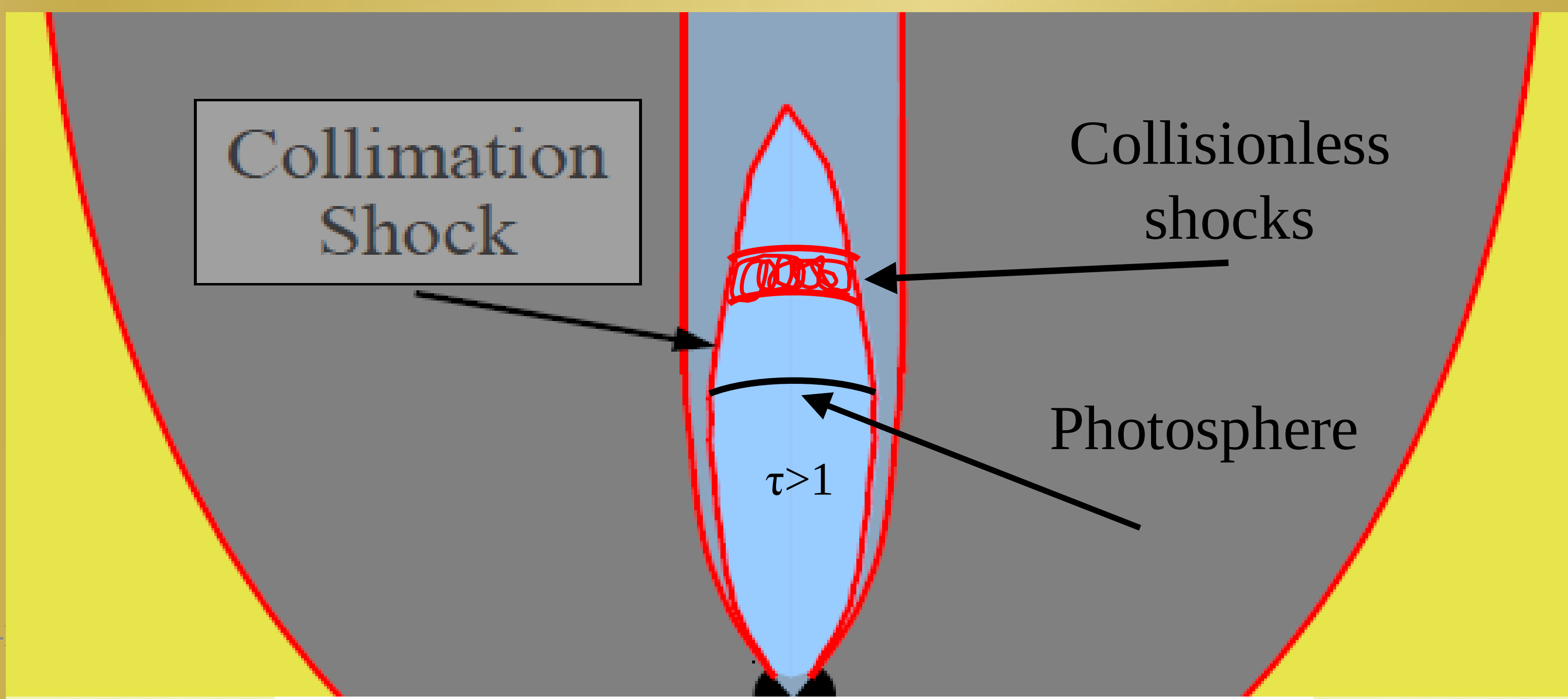
- Post breakout fireball evolution:
  - At breakout hot jet: expands to **$\theta_0 = \Gamma_j(t_b)^{-1} = \theta_{inj}$**
  - Shifted fireball with initial parameters:

    $R_0 \sim 10^9$cm, $\Gamma_0 = \Gamma_j(t_b) = \theta_{inj}^{-1}$.
  - Jet in the star continue to expand: initial conditions evolve.
  - Closer photosphere



Applications IV

- Generation of > 100 GeV neutrinos inside the star requires very large radii or extreme fine tuning of the parameters.



Summary:

- The analytic model can reconstruct the jet-cocoon properties as it propagates in the star.
- Collimation shocks at the base are important.
- Shocks are radiation mediated (**Poster 2.02**).
- Need large stars or fine tuning to generate TeV neutrinos.
- Minimal break energy: $E_{\min} = 4 \cdot 10^{51} \left(\theta_{10^\circ} / t_{10sec}\right)^2 ergs$
- Low energy GRBs with T_{90}~ 10 might be "failed GRBs", or have different progenitor.
- Post breakout dynamics: evolving initial params.
- Many other implications – work in progress.