GRB Jet Propagation Inside A Star

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We Know That

- at least some GRBs are made from the death of massive stars (Fact)
- GRB outflows are relativistic jets (Theory)
- the jets need to escape from massive stars

- Progenitor: Collapsar, Magnetar, He-BH, He-He, ...

- How to make jets?

- Poynting Flux?

- Supernova

- Let's not worry about the above issues first. Let's ask a simple question.
  Can jets get out of the stars?

Yes, they can!

- A common misconcept: All stellar material on its way will be swept by the jet.
- The magic is the bow shock, which pushs stellar material sideways, and the cocoon, which can protect the jet beam.
- Relativity helps too. Instabilities do not have enough time to grow.

Relativistic Jets From Collapsors

S.E. Woosley's Group

Initial Model: he15

480 radial zones, 200 angular zones

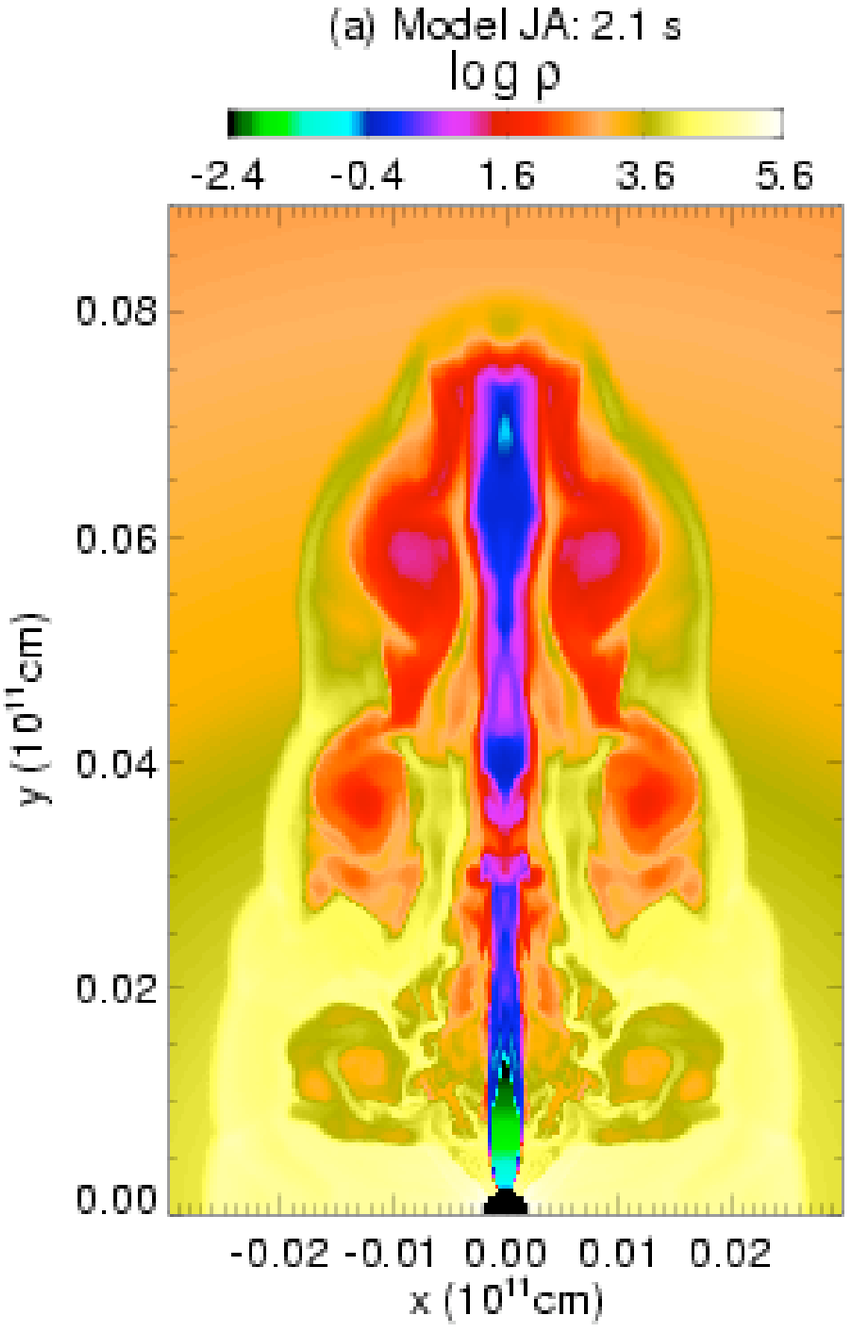
Energy Deposition Rate: 10^{51} ergs/s

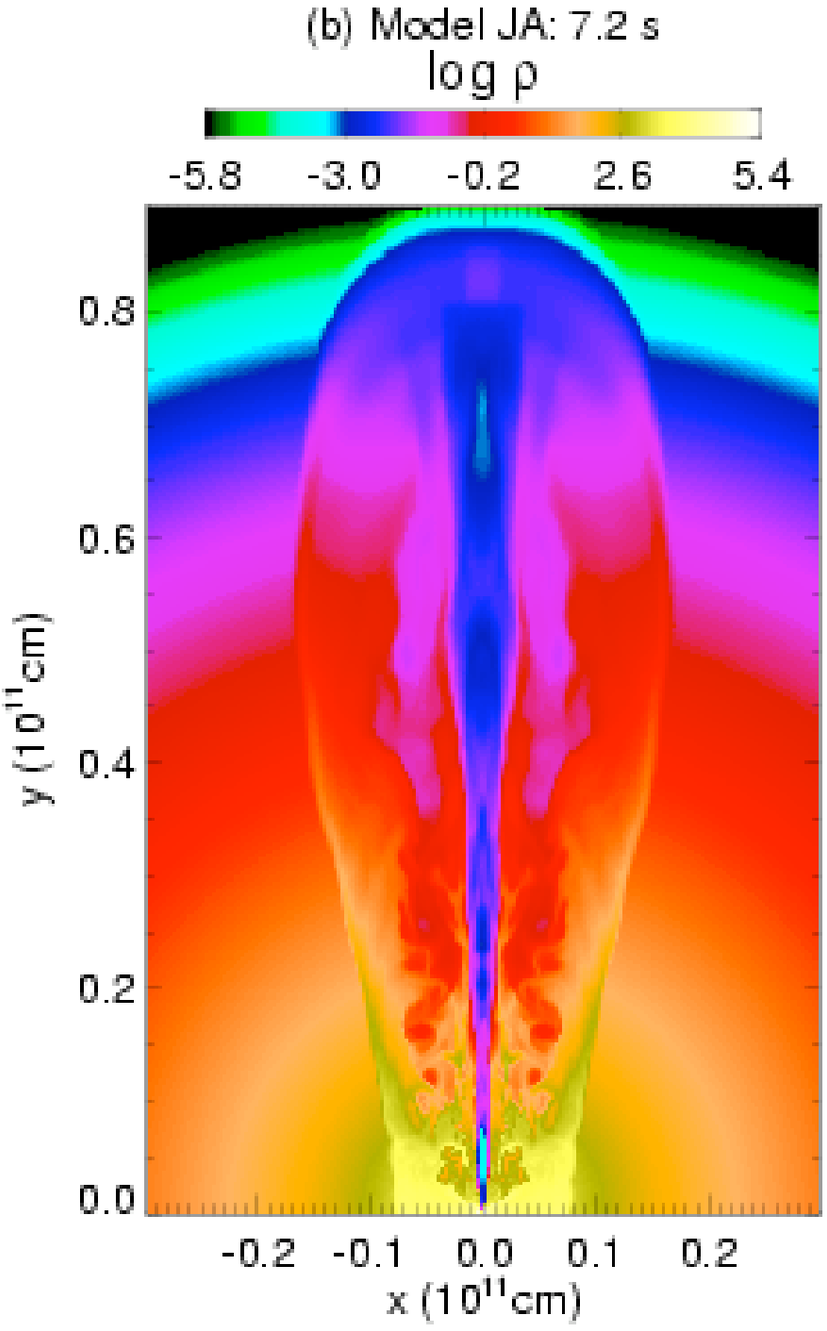
Half Opening Angle: 20

$f_e(E_{th}/E_{tot})$: 0.67

Lorentz Factor: 50

1/10 of star





Edge

Model 2B

gamma 1.0 10.5 20.0

log rho -10.0 -4.0 2.0

gamma

log rho (t=4s)

log rho (t=18s)

log rho (t=8s)

log rho (t=40s)

log rho (t=10s)

log rho (t=70s)

(10^11 cm)

(10^11 cm)

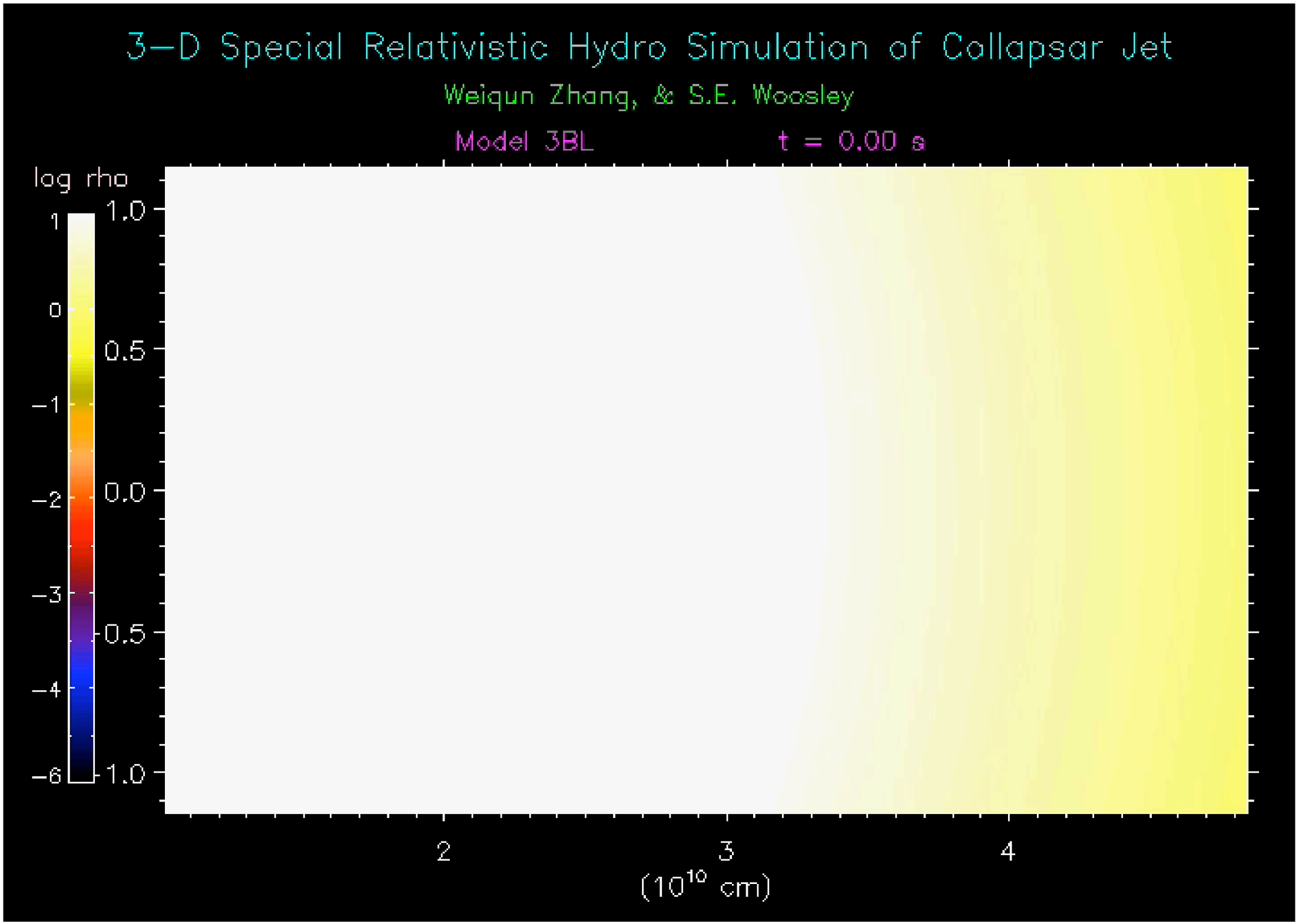
- Ultrarelativistic core (~200)
  Mildly relativistic wings (~5)
  Viewing Angle ==> ???

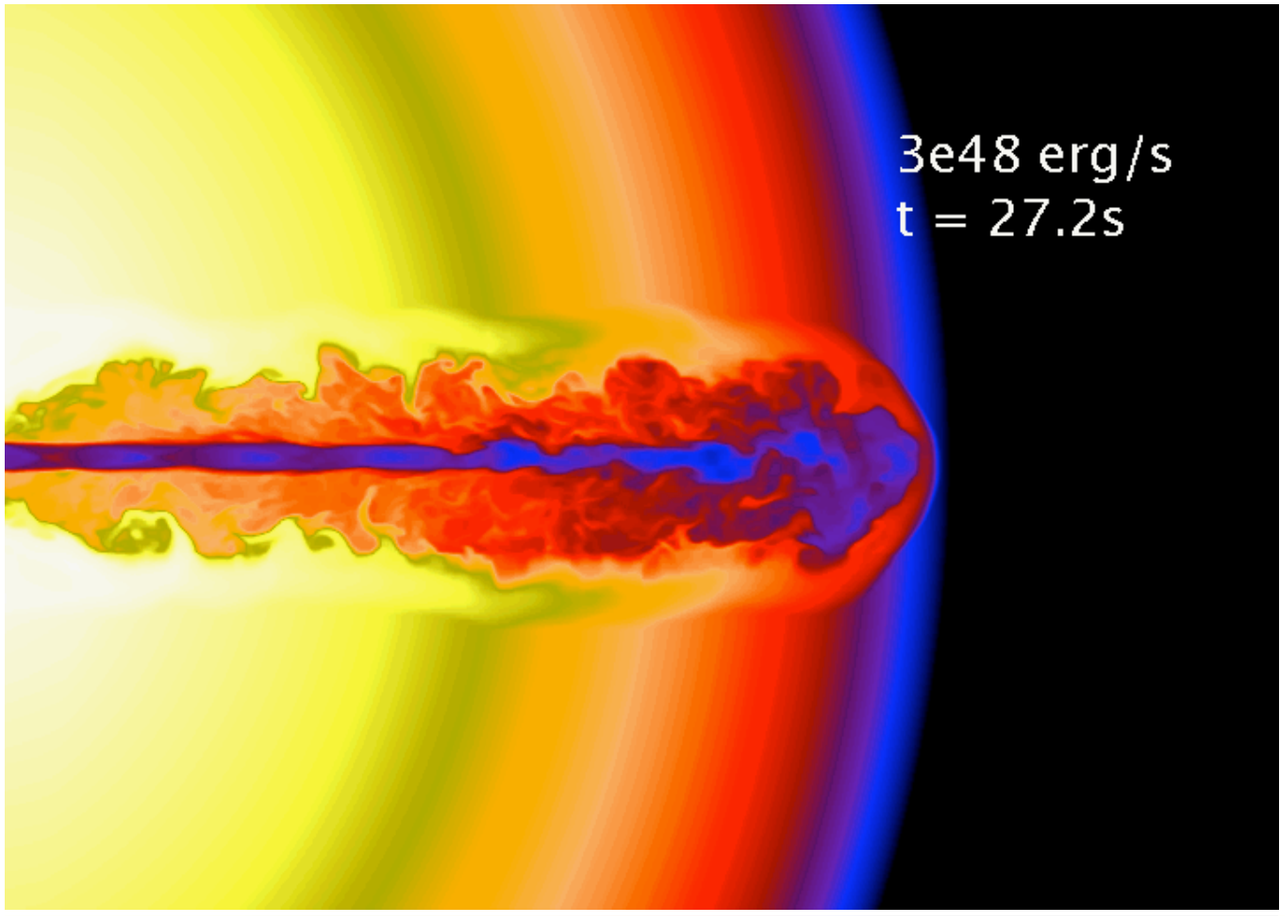
- It takes ~10 s to break out.
  Star: 3 light-second
  "Wasted" energy: 10^50 erg/s * 7s~10^51
  Even if the jet is dominated by B, ...

- Lorentz factor
  Initial injection: ~10
  Final: 200
  How? Initial jet is hot.

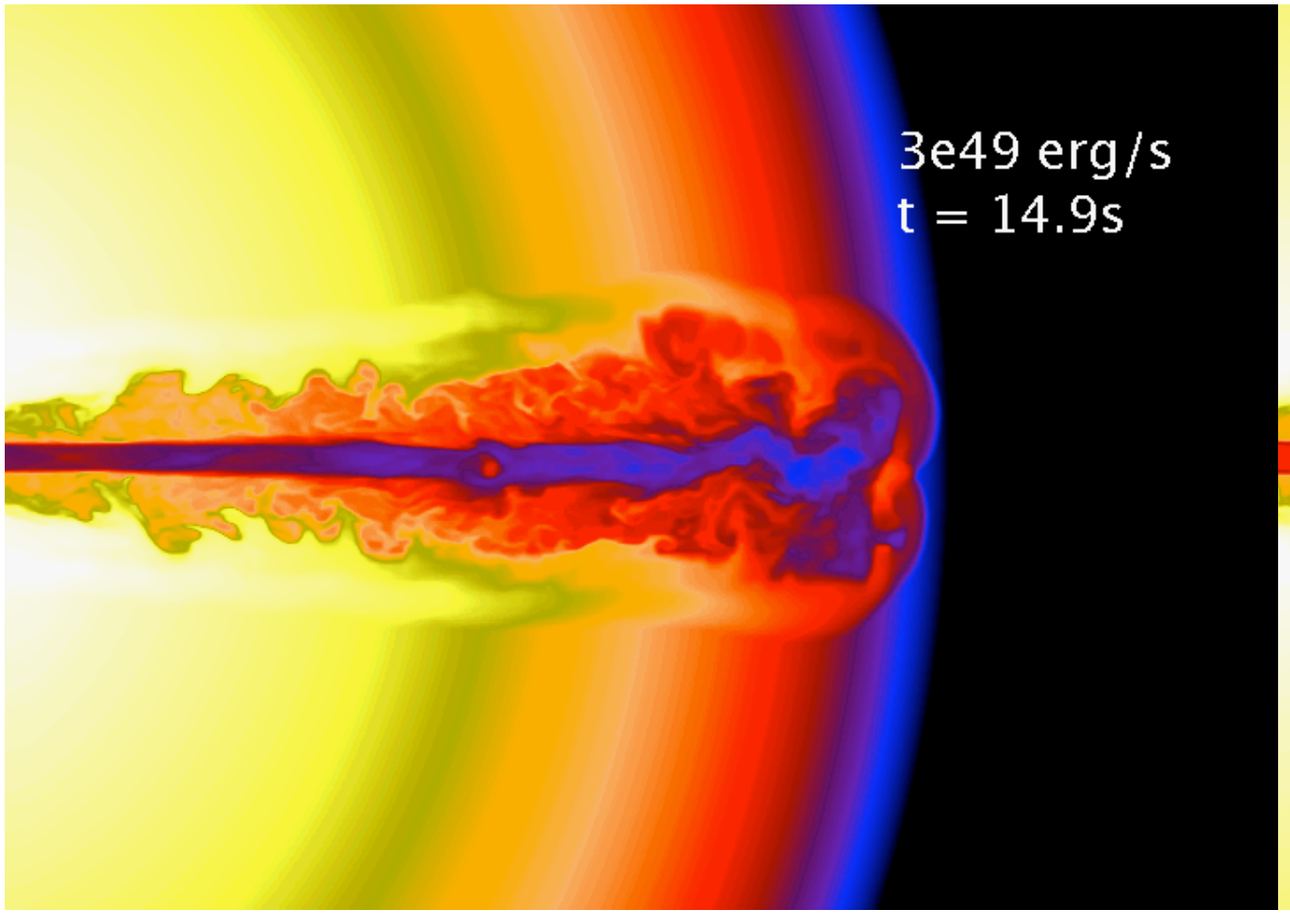
(Model dependent)

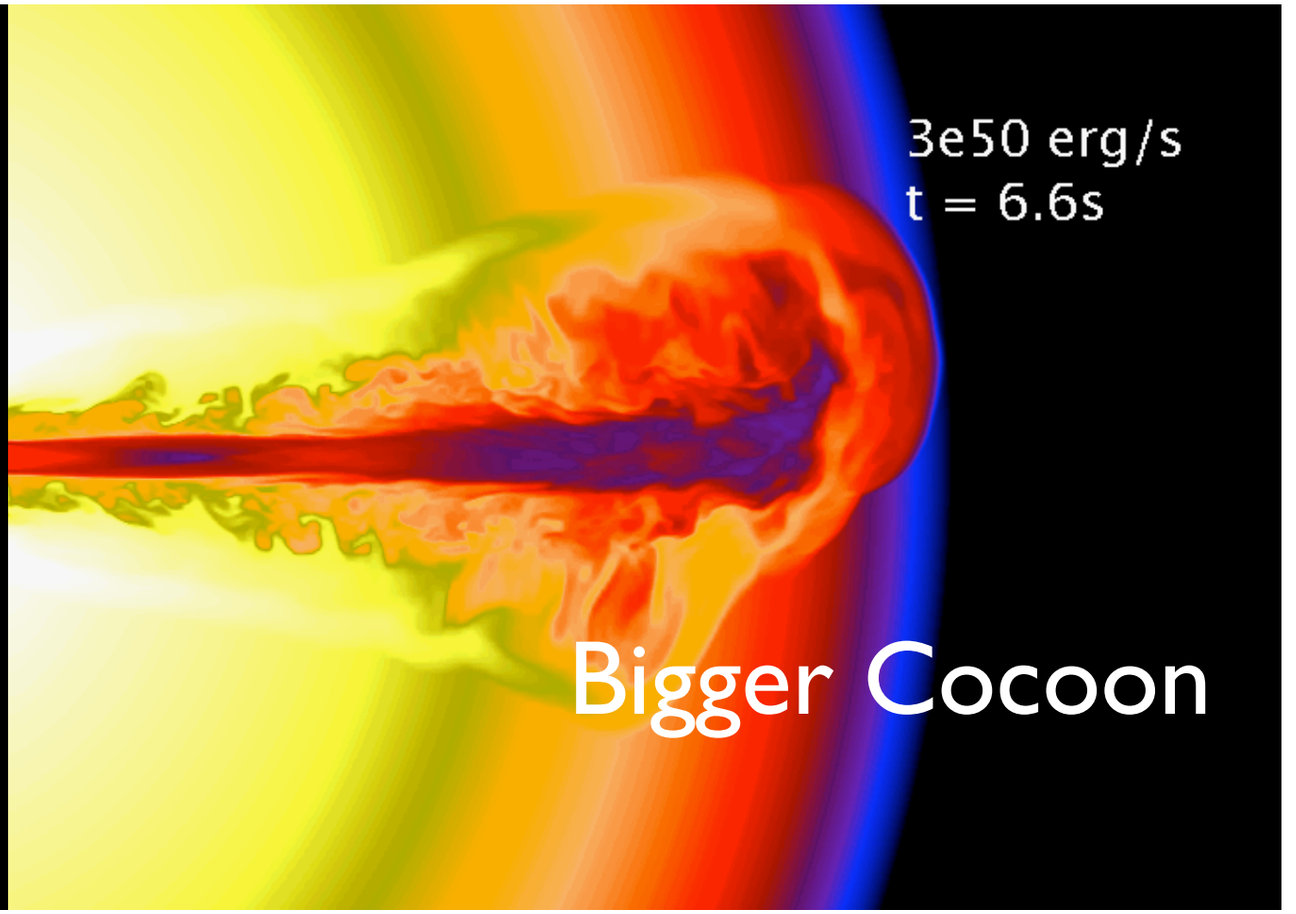
3D


3-D Special Relativistic Hydro Simulation of Collapsar Jet
Weiqun Zhang, & S.E. Woosley
Model 3BL
t = 0.00 s
log rho
1
0
−1
−2
−3
−4
−6
1.0
0.5
0.0
0.5
1.0
2
3
4
(10^10 cm)



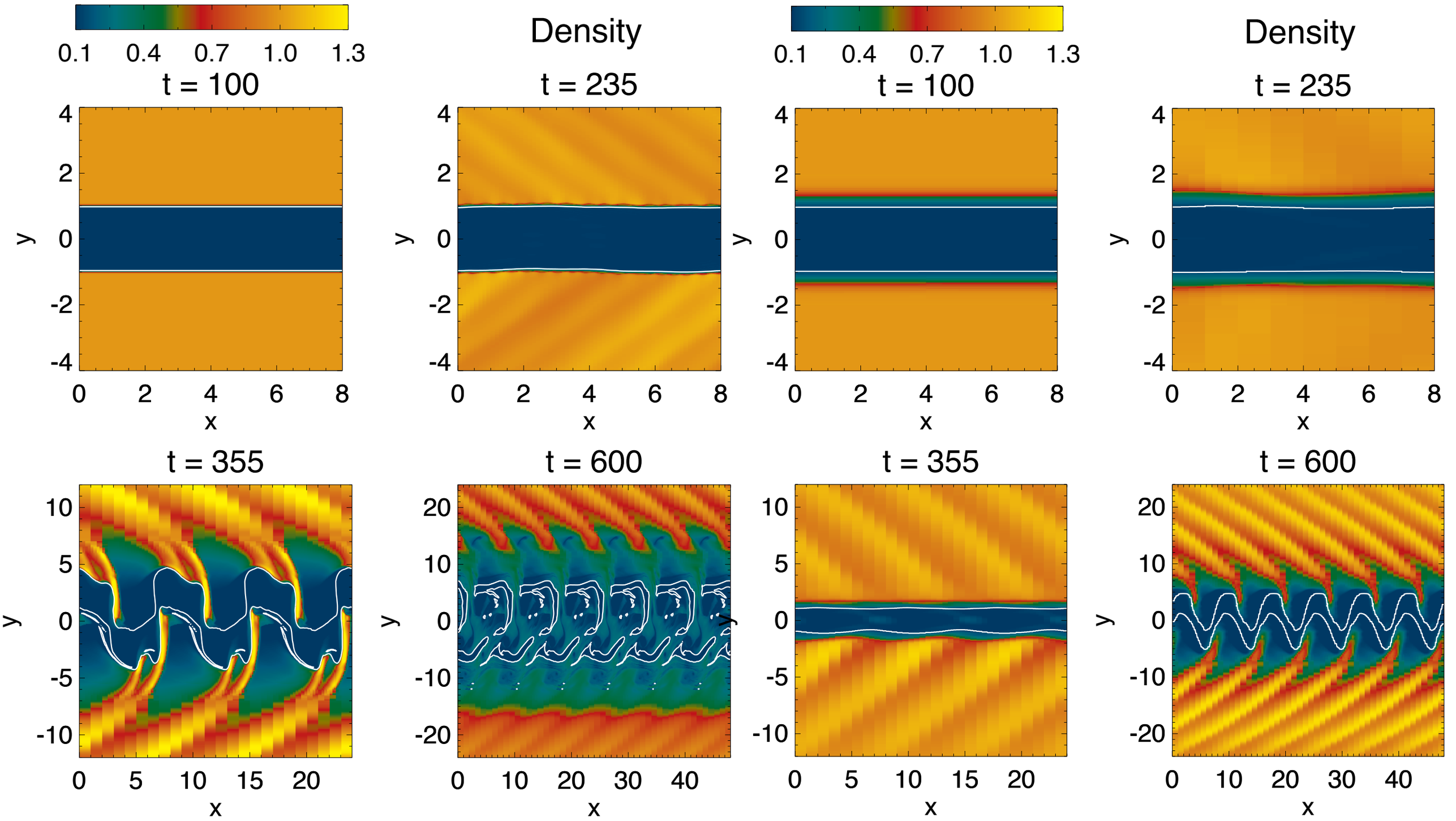
Edot	t	E
3e48	27	0.08
3e49	15	0.4
3e50	7	2





Kelvin-Helmholtz

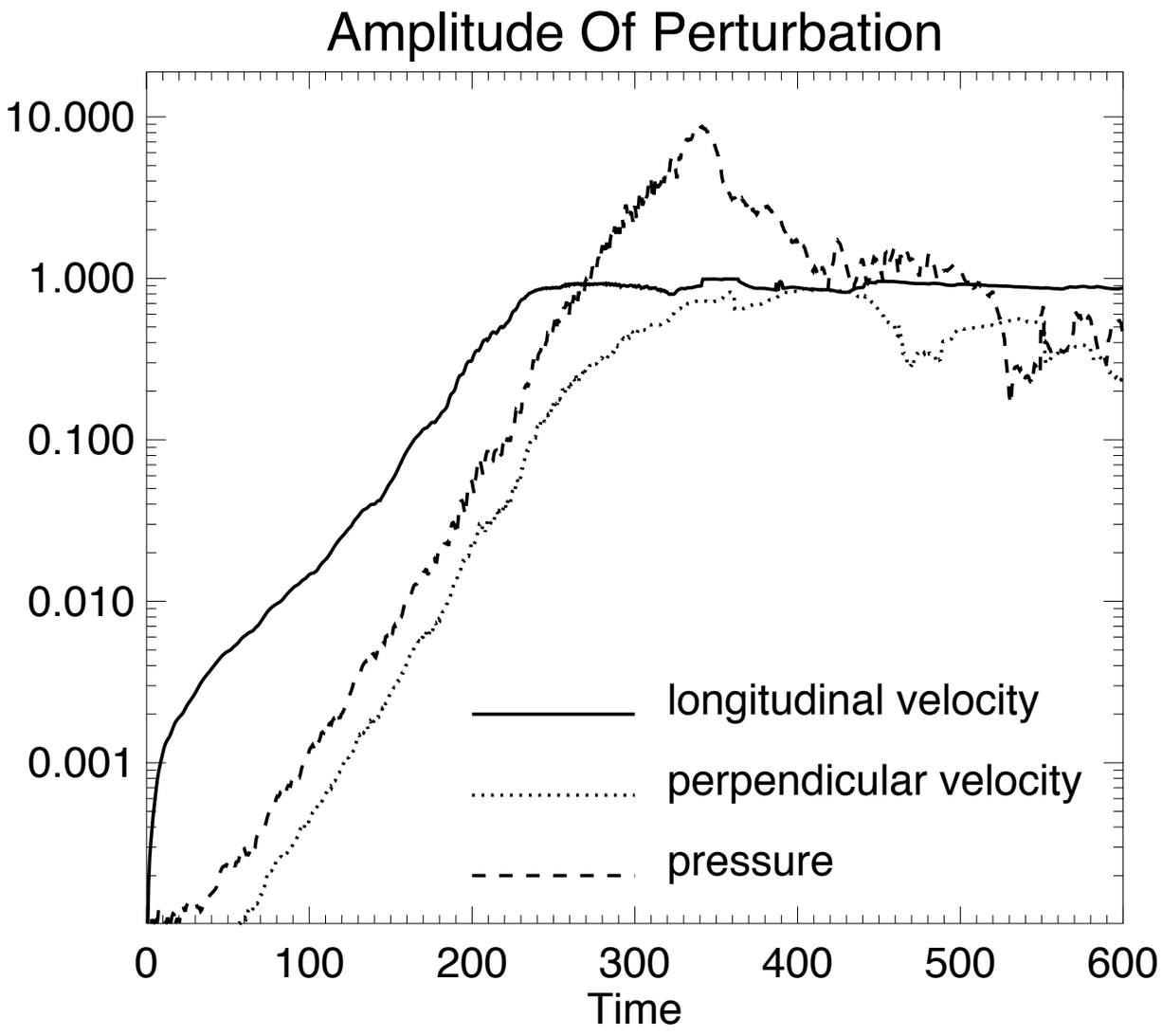
- Relativity makes it hard to develope
- It can grow to the nonlinear regime when the jet is thin.
- Too much is bad, but a little bit is good.

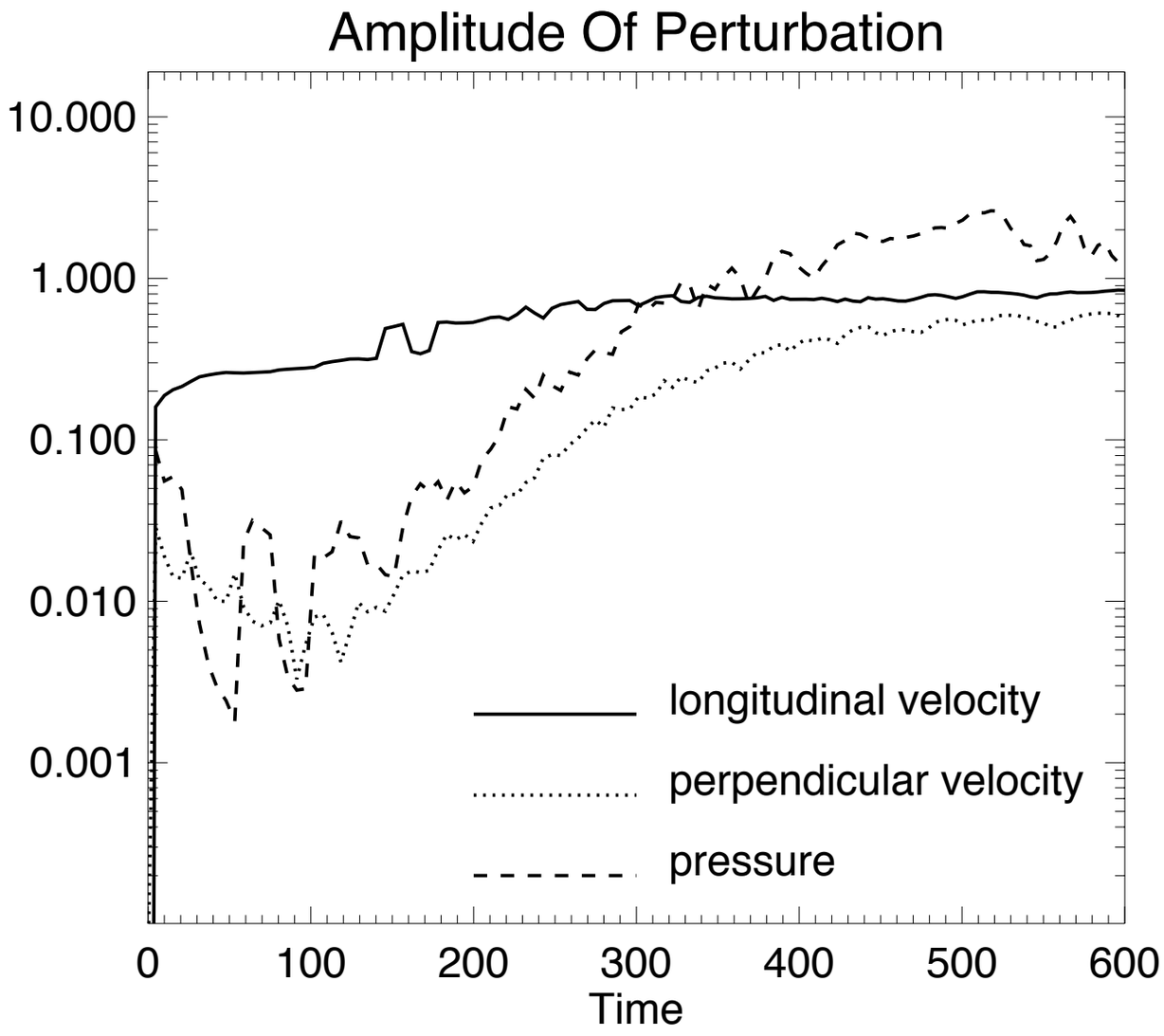


High-resolution gamma = 10 Low-resolution

We repeated Model D10 of Perucho et al. 2005.

Resolution is the key!



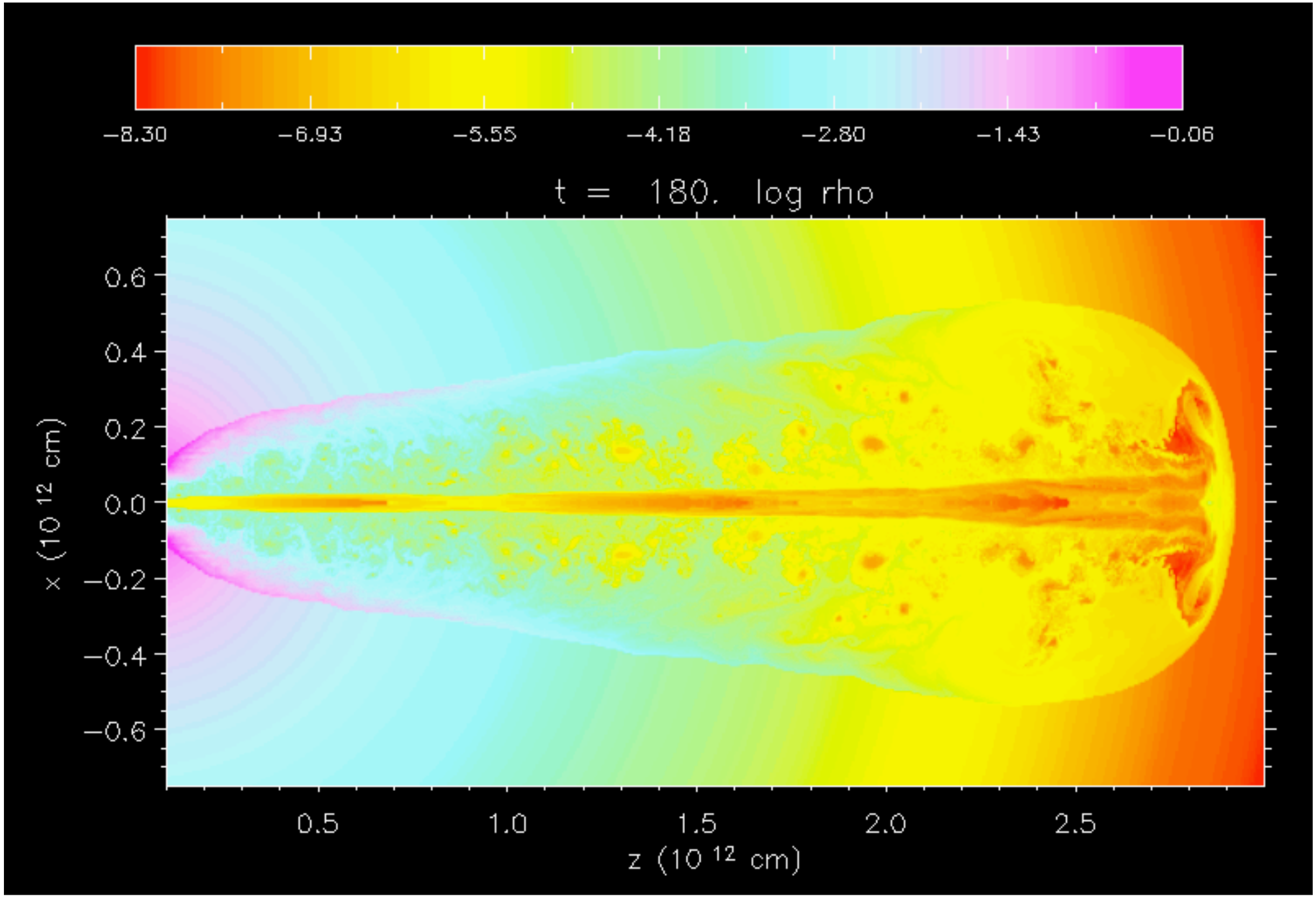


High-resolution

Low-resolution

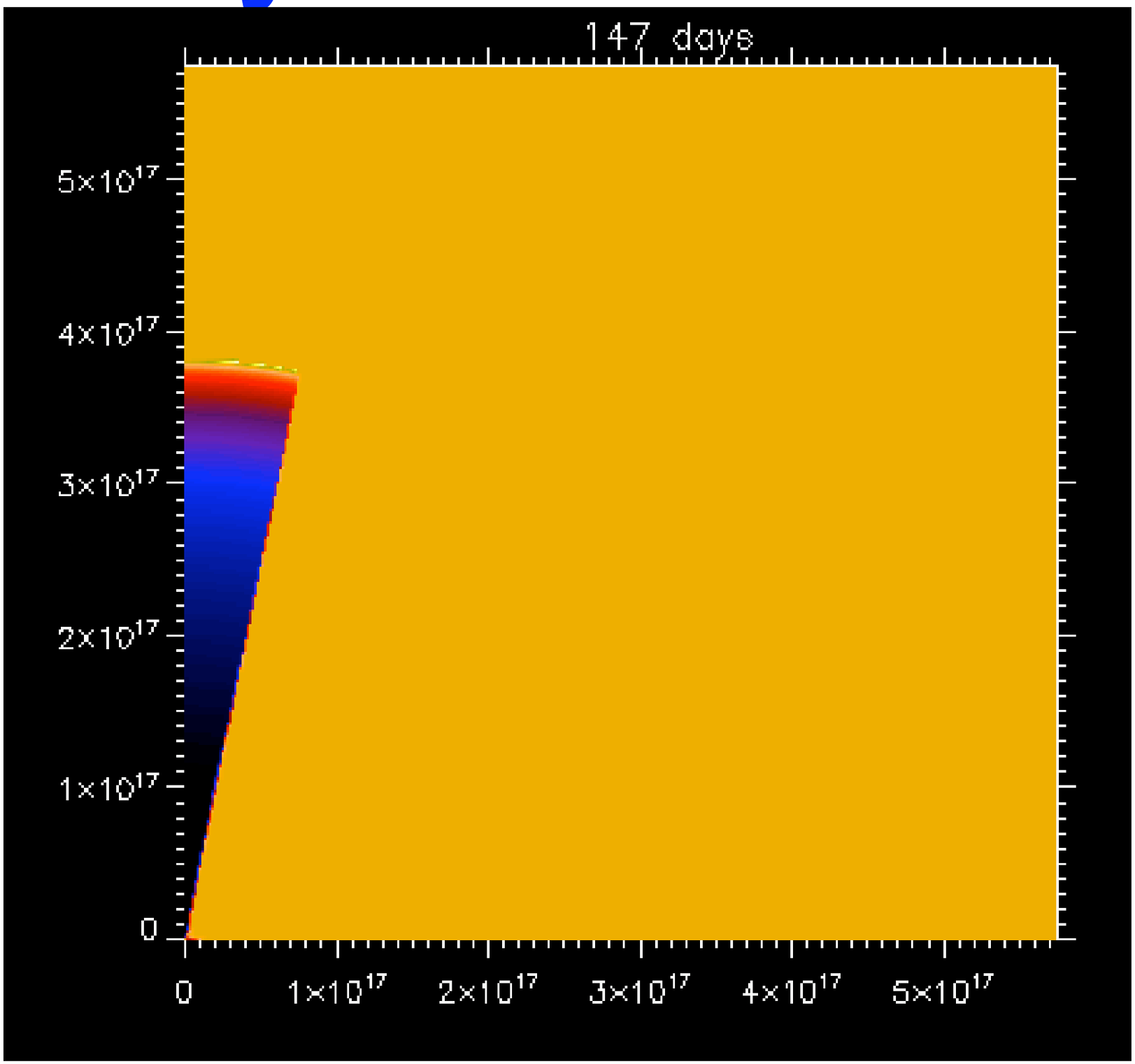
Grow exponentially, then saturate

Blue Supergiant



If the engine can last a few hundred seconds, ...
Instabilities?

Jet outside



AMR: 14 levels of refinement