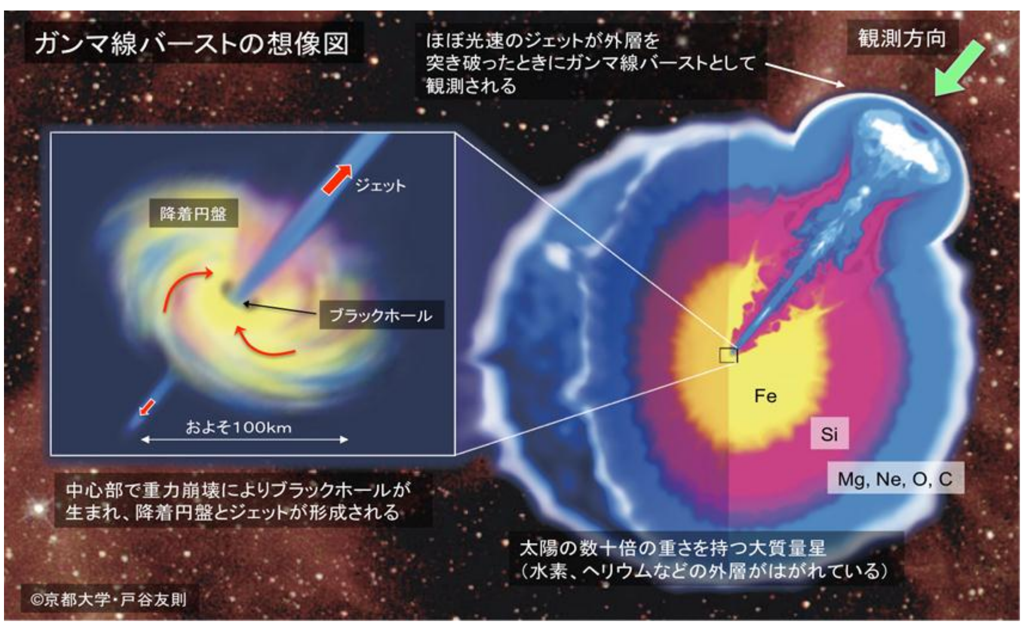
Opening angle of GRB jet

$\theta_j \sim C x \Gamma_0^{-1}$ (C~1/5)

Akira MIZUTA(KEK)

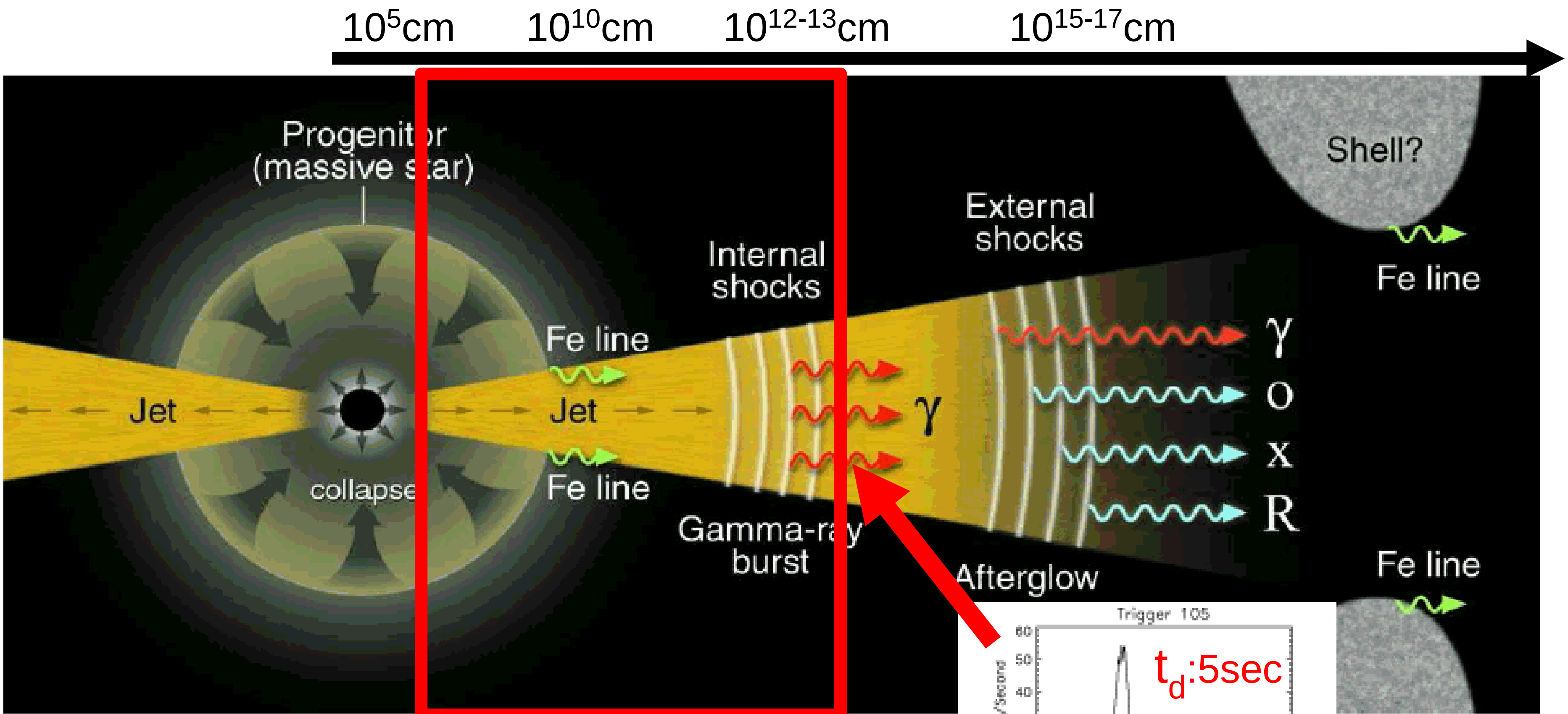
collaboration with Kunihito IOKA(KEK)

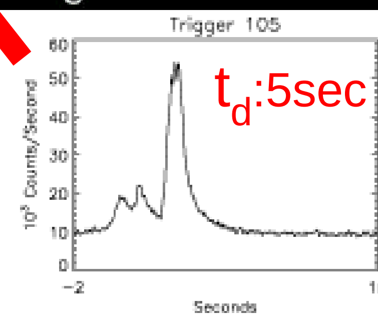


Quarks to Universe in Computational Science(QUCS 2012)
@NARA Prefectural New Public Hall
16.12.2012

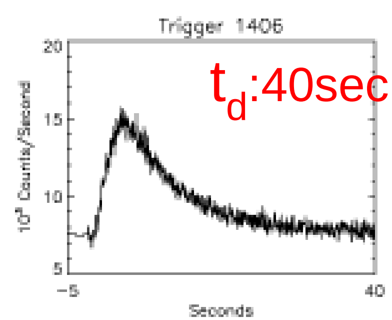
Gamma-ray bursts (GRBs)

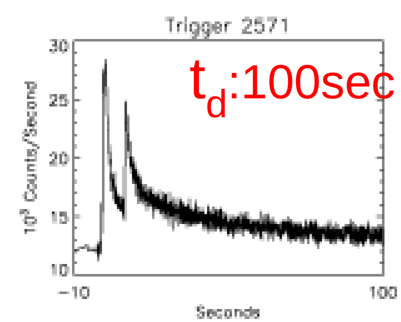
~most energetic explosions in the Universe after Big Bang~



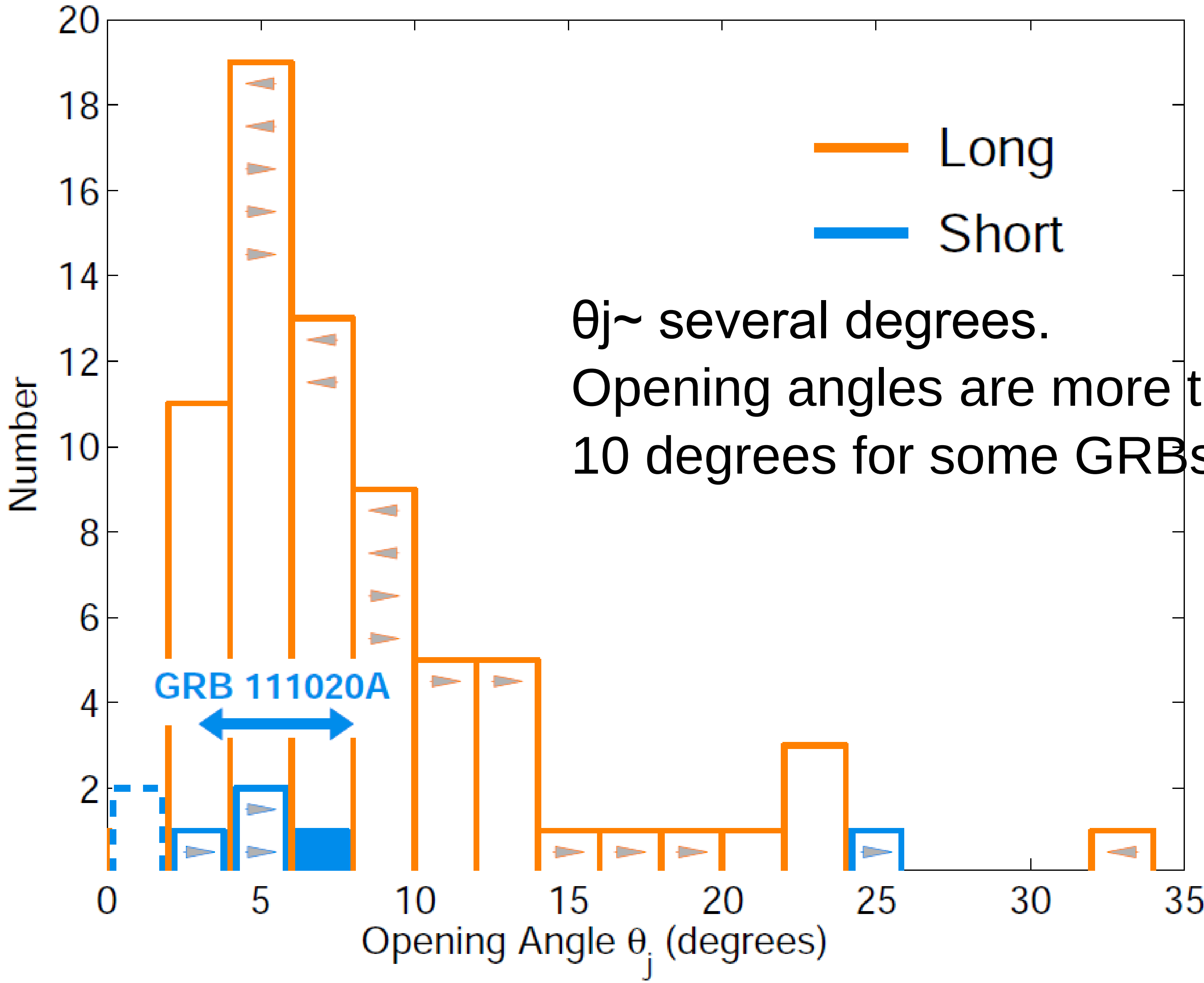


- GRBs are very bright events (can be good probe of ancient Universe)
- Some of GRBs originate from massive star collapse, i.e., special type supernova.
- GRBs are collimated and highly relativistic outflows (relativistic jets)





Opening angle of GRB jets



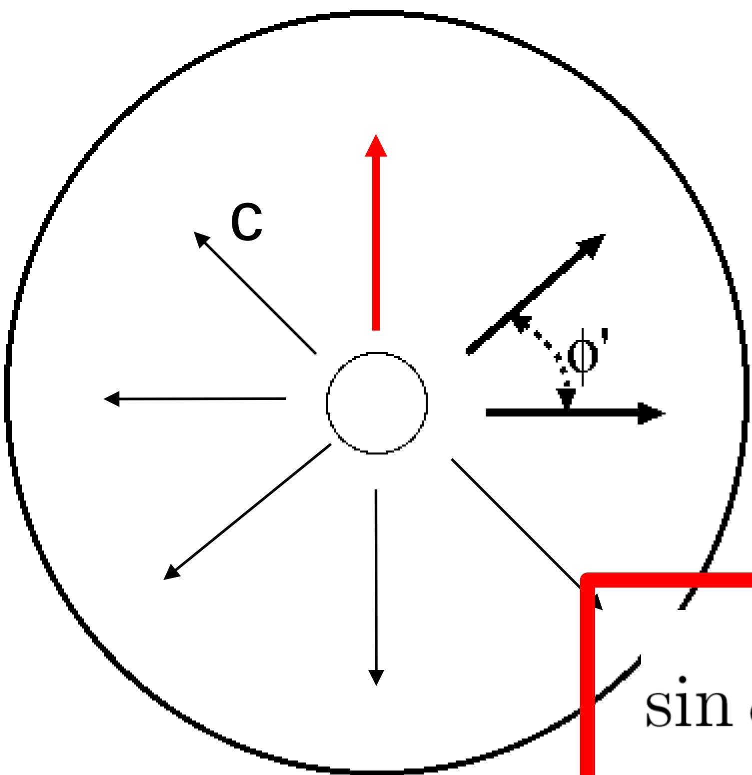
θj~ several degrees.
Opening angles are more than 10 degrees for some GRBs

Fong et al. (2012)

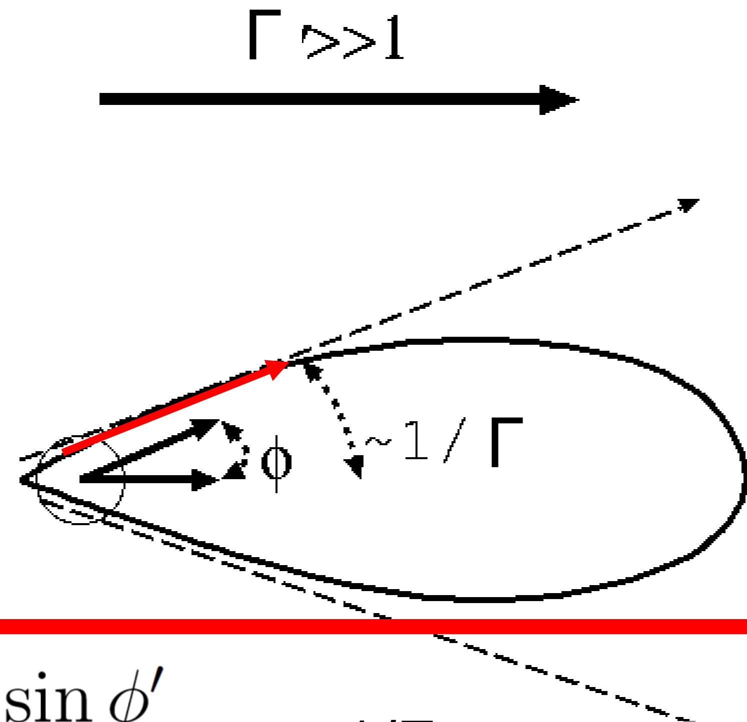
Relativistic beaming effect

GRBs are radiation from relativistic jets (Γ>100/ v>0.9999c)).

Fluid rest frame
isotropic emission



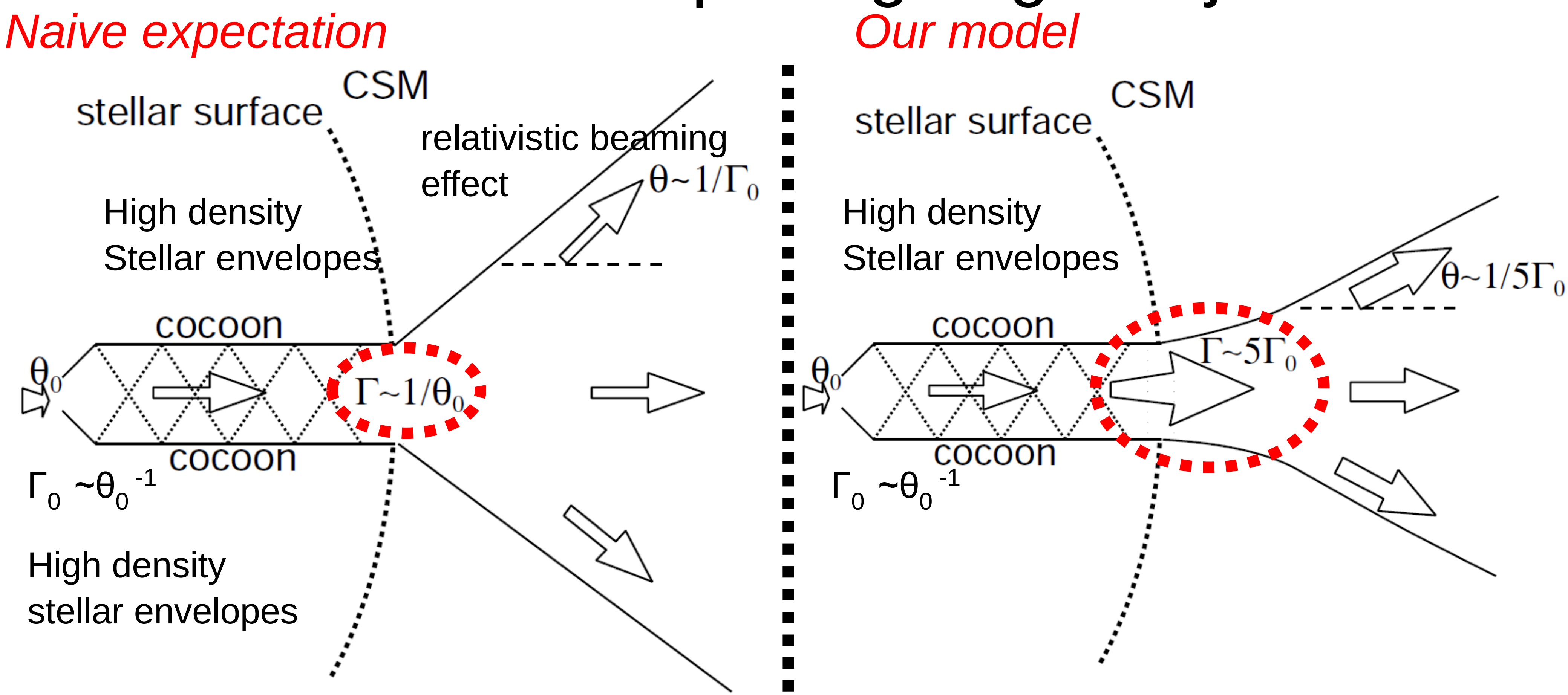
Observer frame
Lorentz transformation



$$\sin\phi = \frac{1}{\gamma}\frac{\sin\phi'}{1+\beta\cos\phi'}$$ =1/Γ (for Φ'=π/2)

Angle Φ' in fluid rest fame is transformed to angle Φ.
Radiation/ fluid motion concentrates in half opening angle 1/Γ.
Relativistic beaming effect can be applied for relativistic isotopic adiabatic expansion.

What determines opening angel of jets ?



For the jet from massive stars, the jet is influenced by the interaction with stellar envelopes.

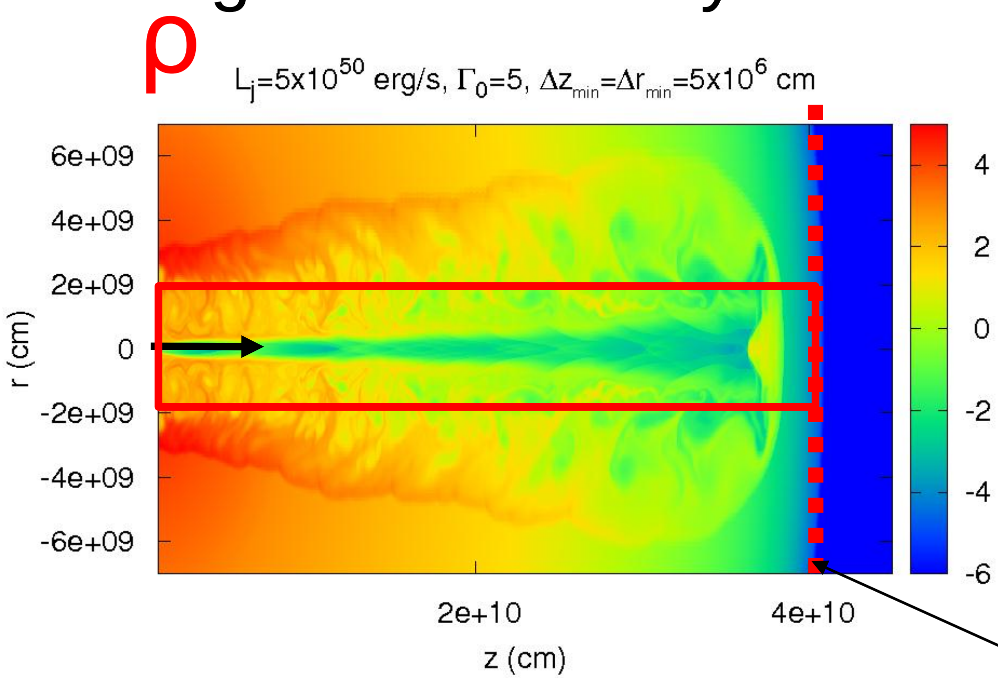
Before jet breakout, the jet is not well accelerated (Γ~O(10)).

Numerical simulations by Zhang et al.,Mizuta et al., Lazzati et al., Nagakura et al.

Analytic work by Bromberg et al. (2011)

How about after jet breakout ? There is large density jump at the stellar surface. It is not trivial how the opening angle of jets evolves.

High resolution hydro. simulations(2D, axisymmetric)



High resolution grid points are devoted At least in the jet and cocoon.

$\Delta z_{min}=\Delta r_{min}=10^7$cm or $=5\times10^6$cm

$E_j=5\times10^{50}$erg/s, $r=8\times10^7$cm

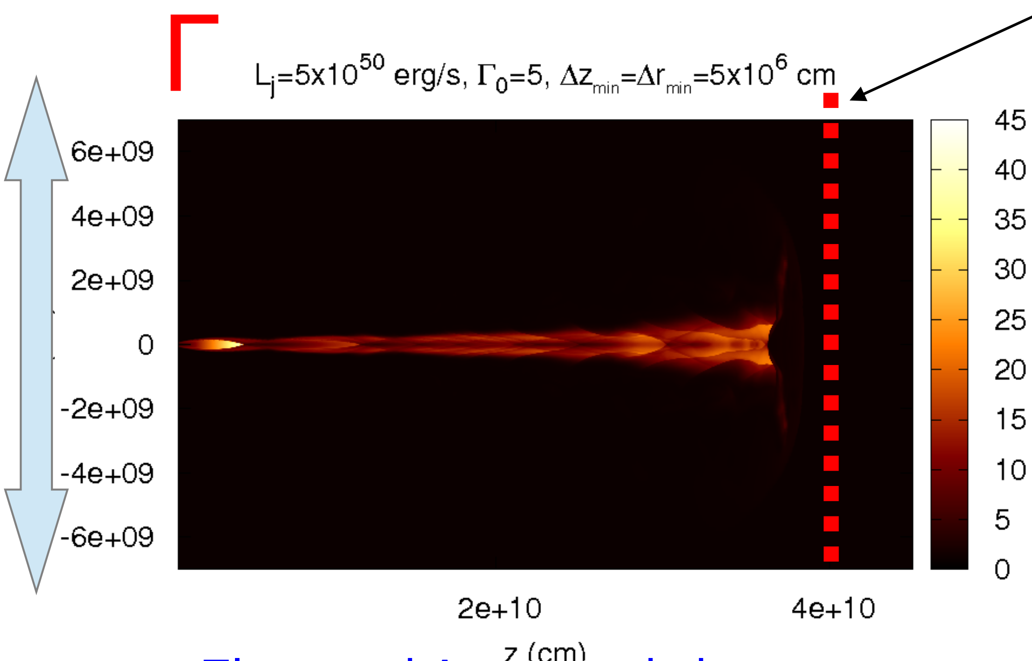
$\eta=h_0\Gamma_0=533$

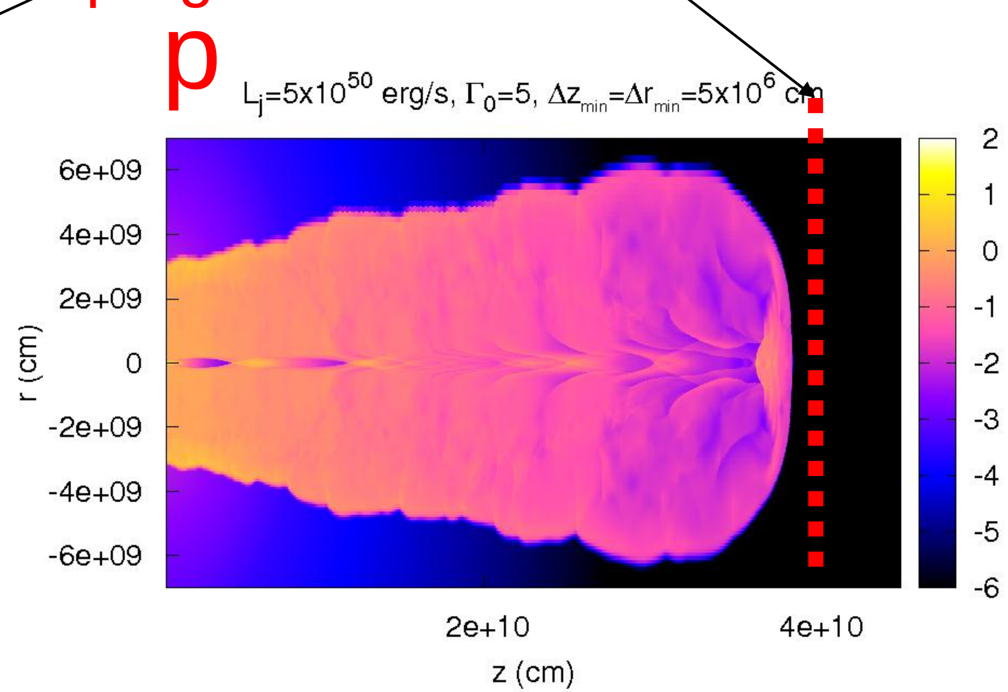
$\Gamma_0=2.5, 5, 10$

Progenitor : Woosley & Heger(2006)

$M\sim14M_{sun}$, $R^*=4\times10^{10}$cm

progenitor surface



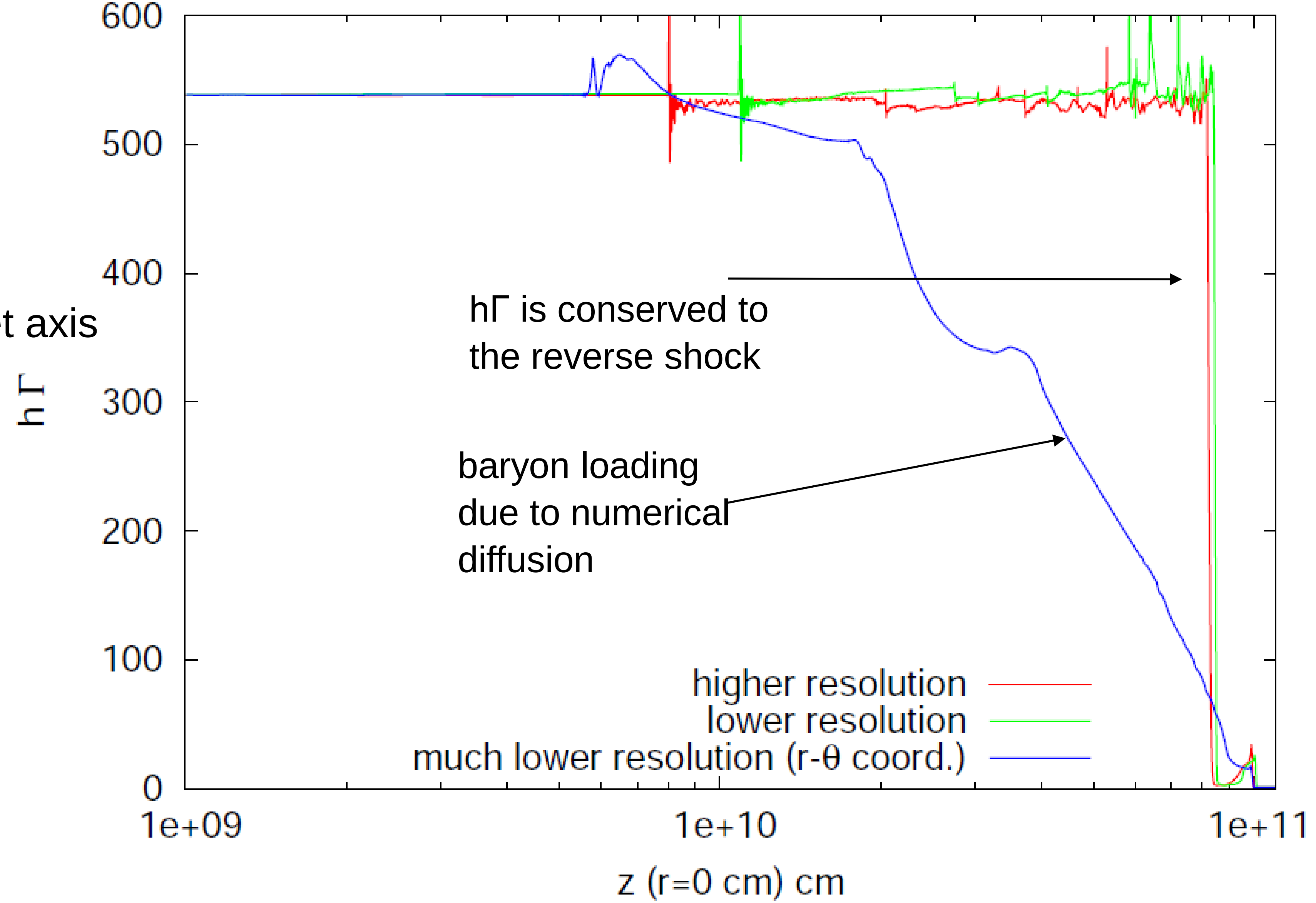


Elongated:Aspect ratio is not correct

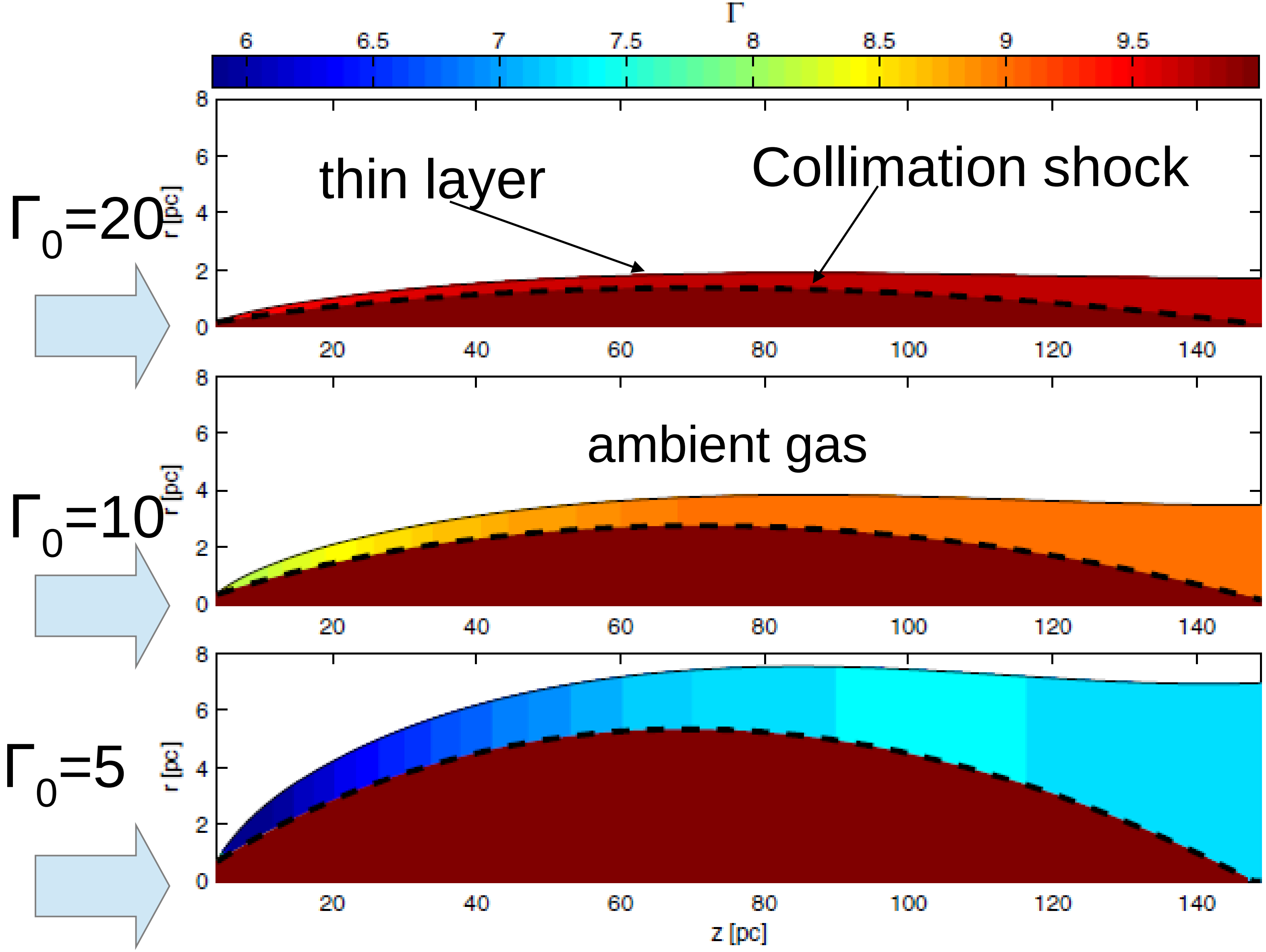
Why is high resolution necessary ?

hΓ (=const along stream line, steady state :Bernoulli's principle)

Along jet axis



Why is high resolution necessary ?

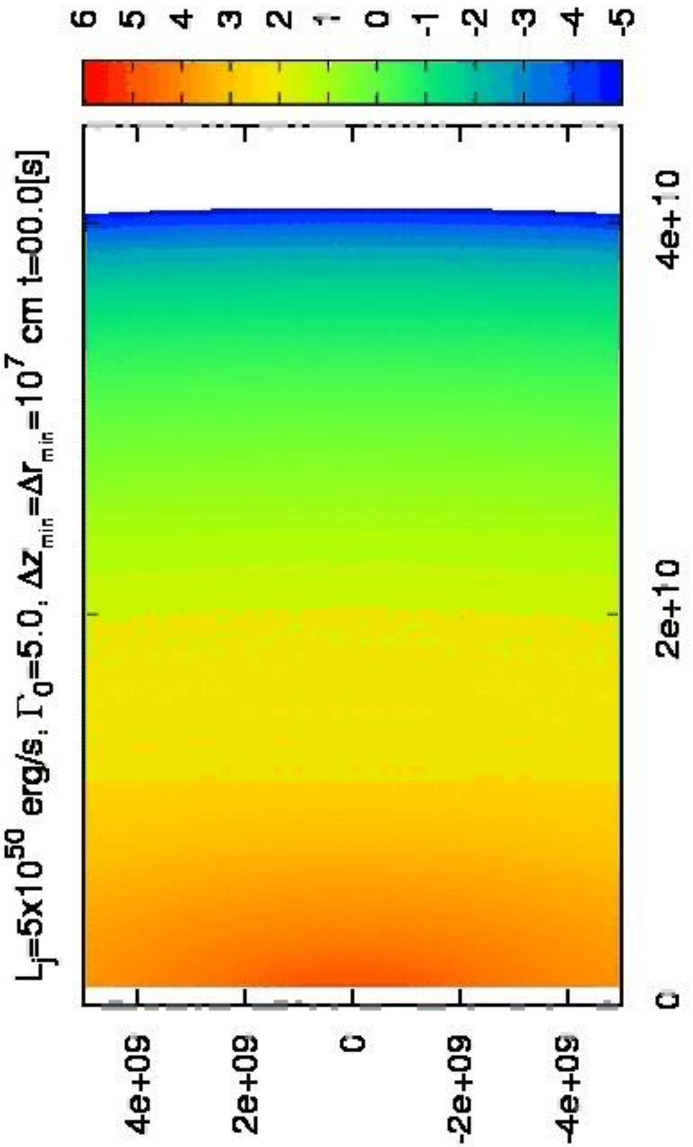


$\theta_0 = 1/\Gamma_0$

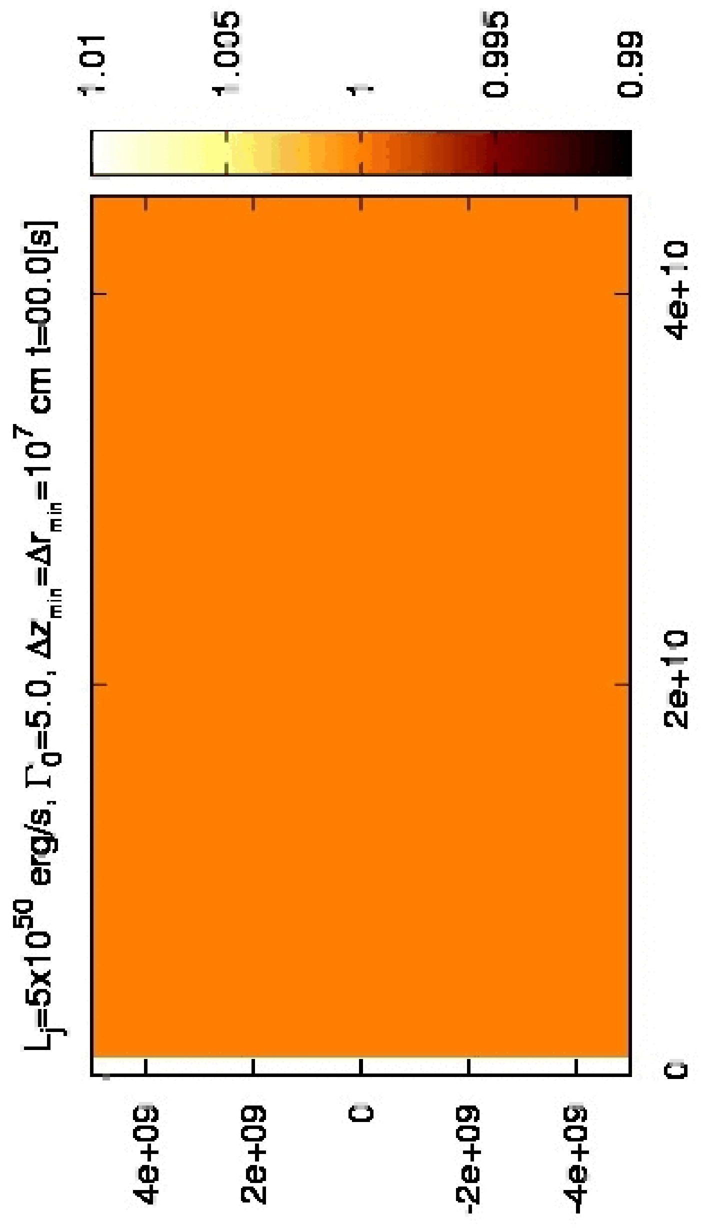
Bromberg, Levinson (2009)

Γ_0=5

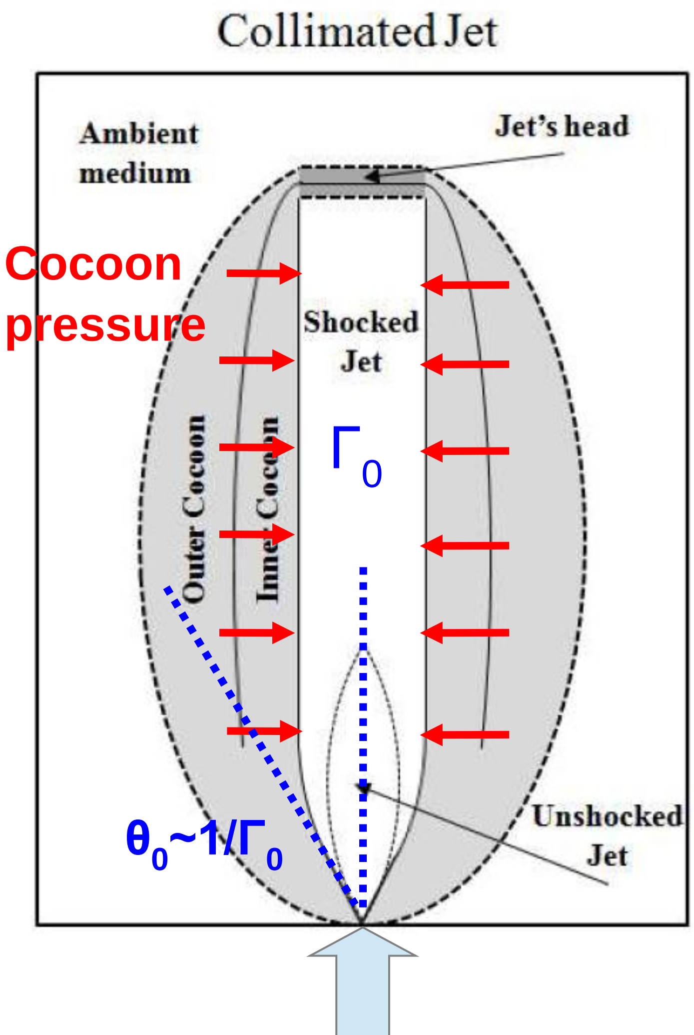
mass density

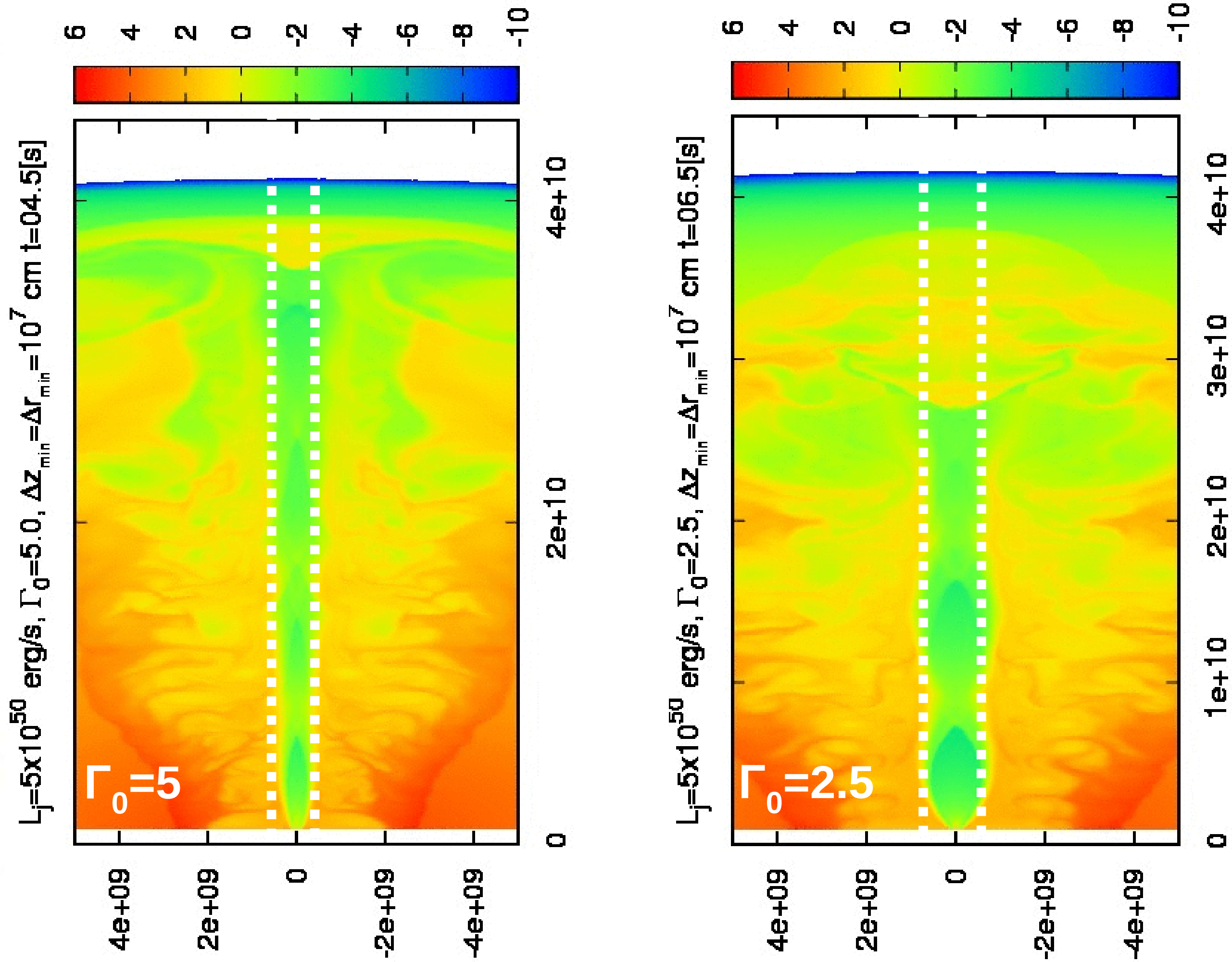


Lorentz factor



Cocoon confinement (Before break)



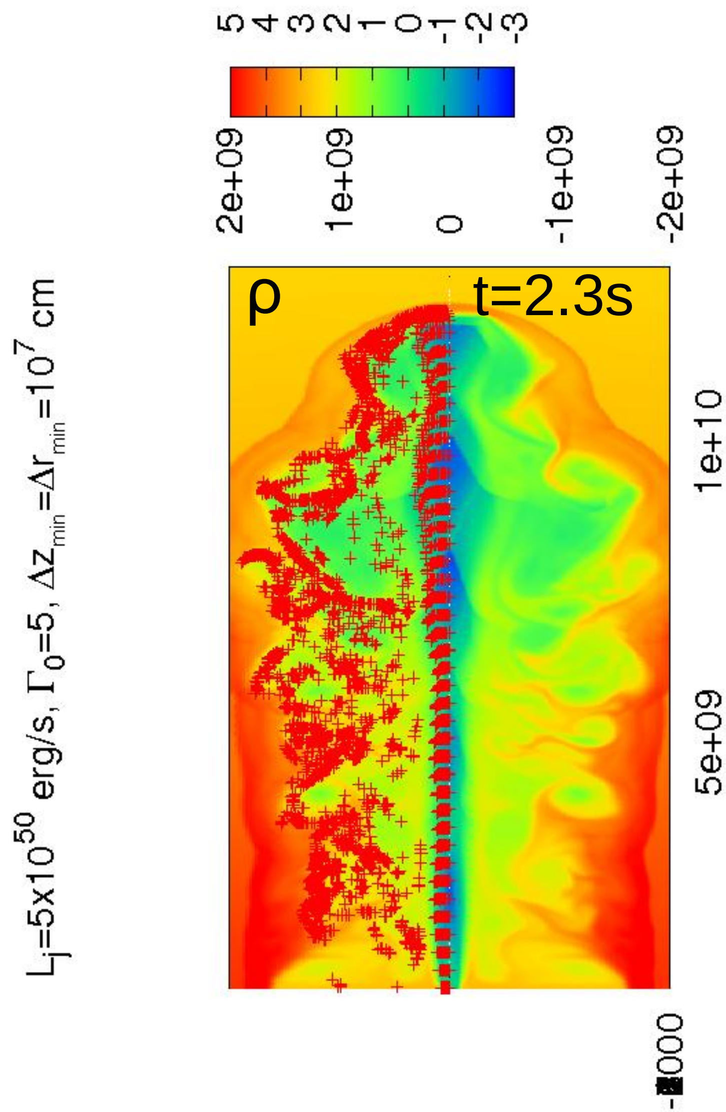


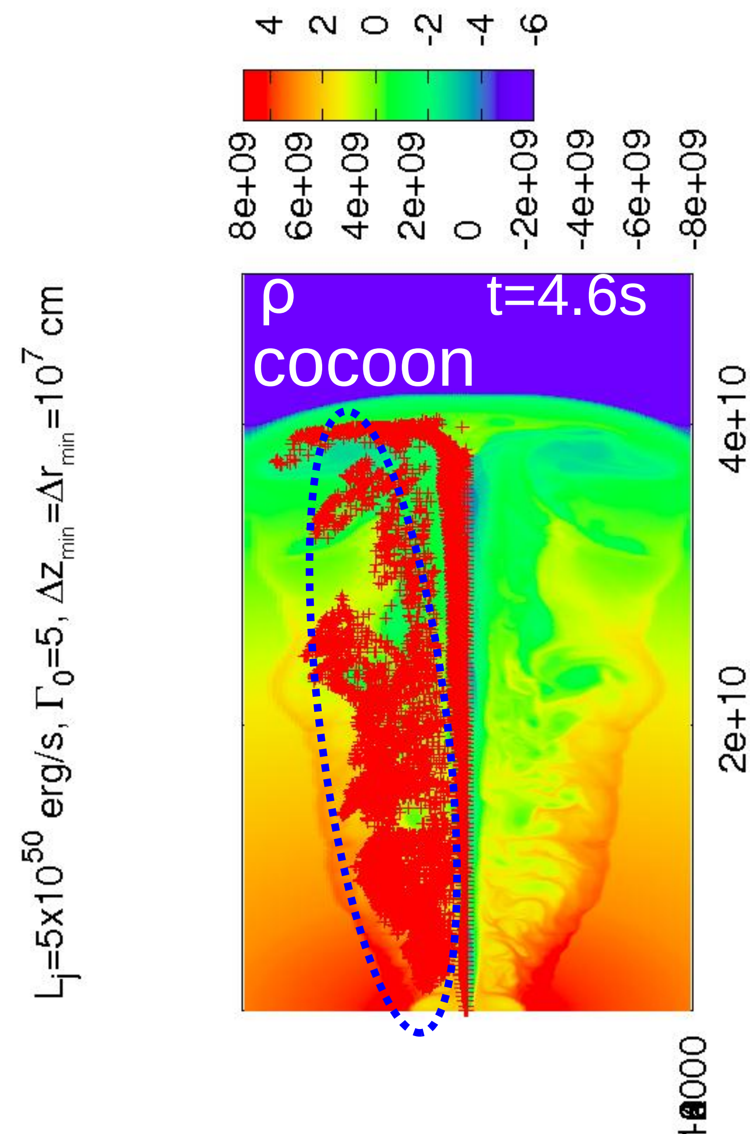
Bromberg + (2011)
collimation shock
+
Cylindrical jet ($\Gamma \sim \Gamma_0$)

After collimation shock, jet is almost cylindrical shape as Bromberg et al. predicted.
Some oblique shocks can be seen inside the jet

See also Komissarov & Falle 1998

Probe particles

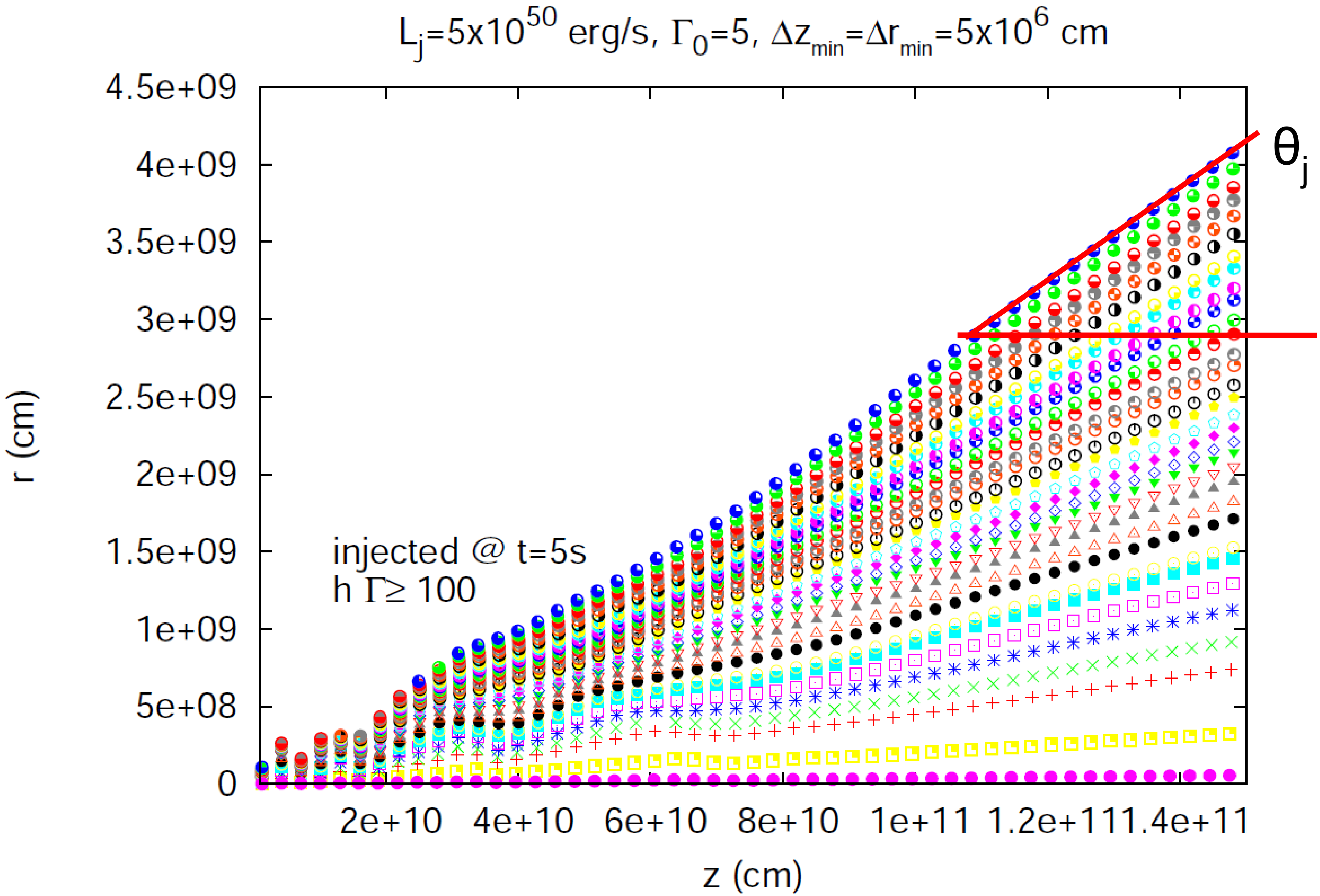




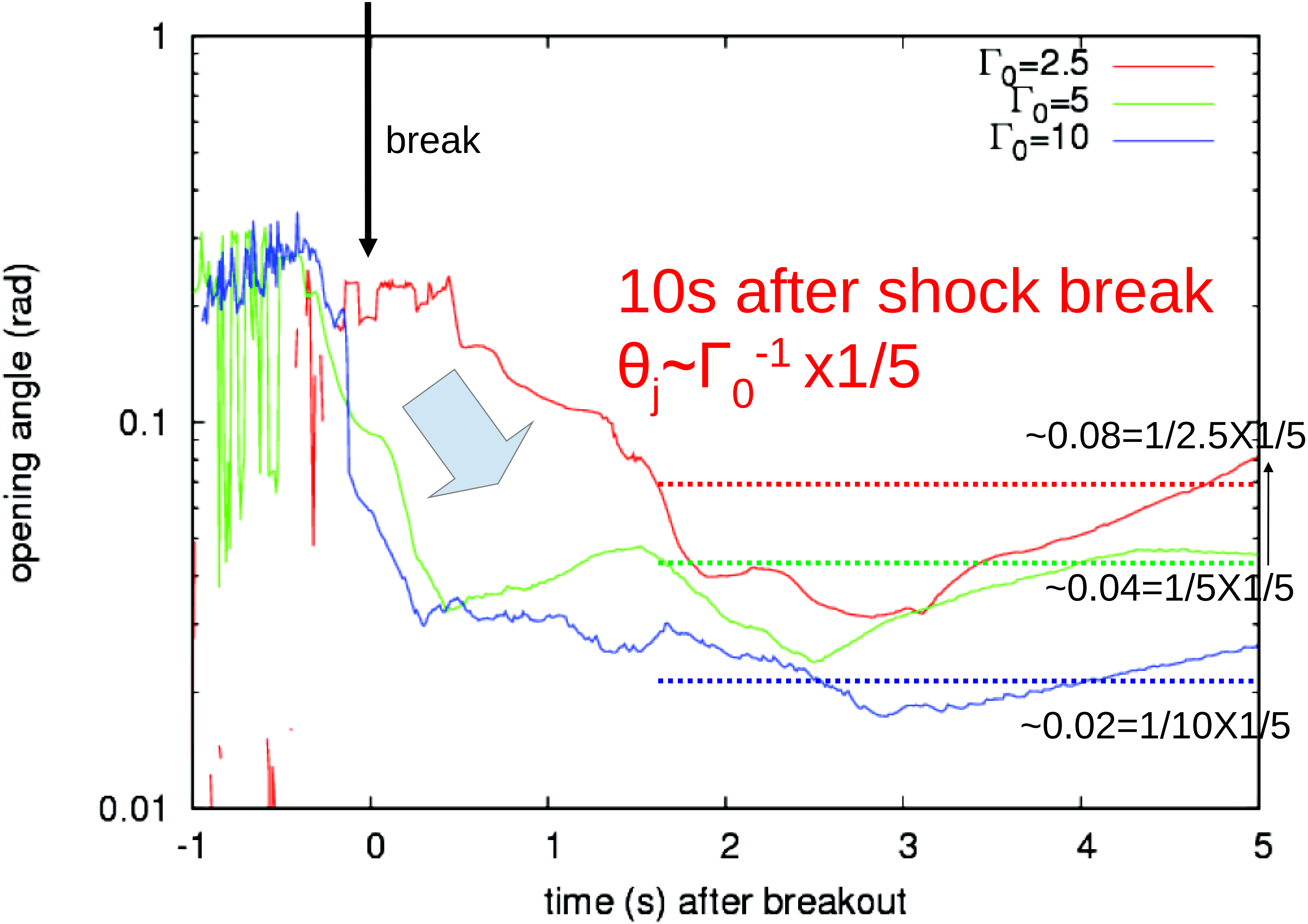
Every 0.01s, 32 particle are injected with the jet

particle trace $\boldsymbol{x}_{new}=\boldsymbol{x}_{old}+\boldsymbol{v}_{r,z}\times\Delta t$

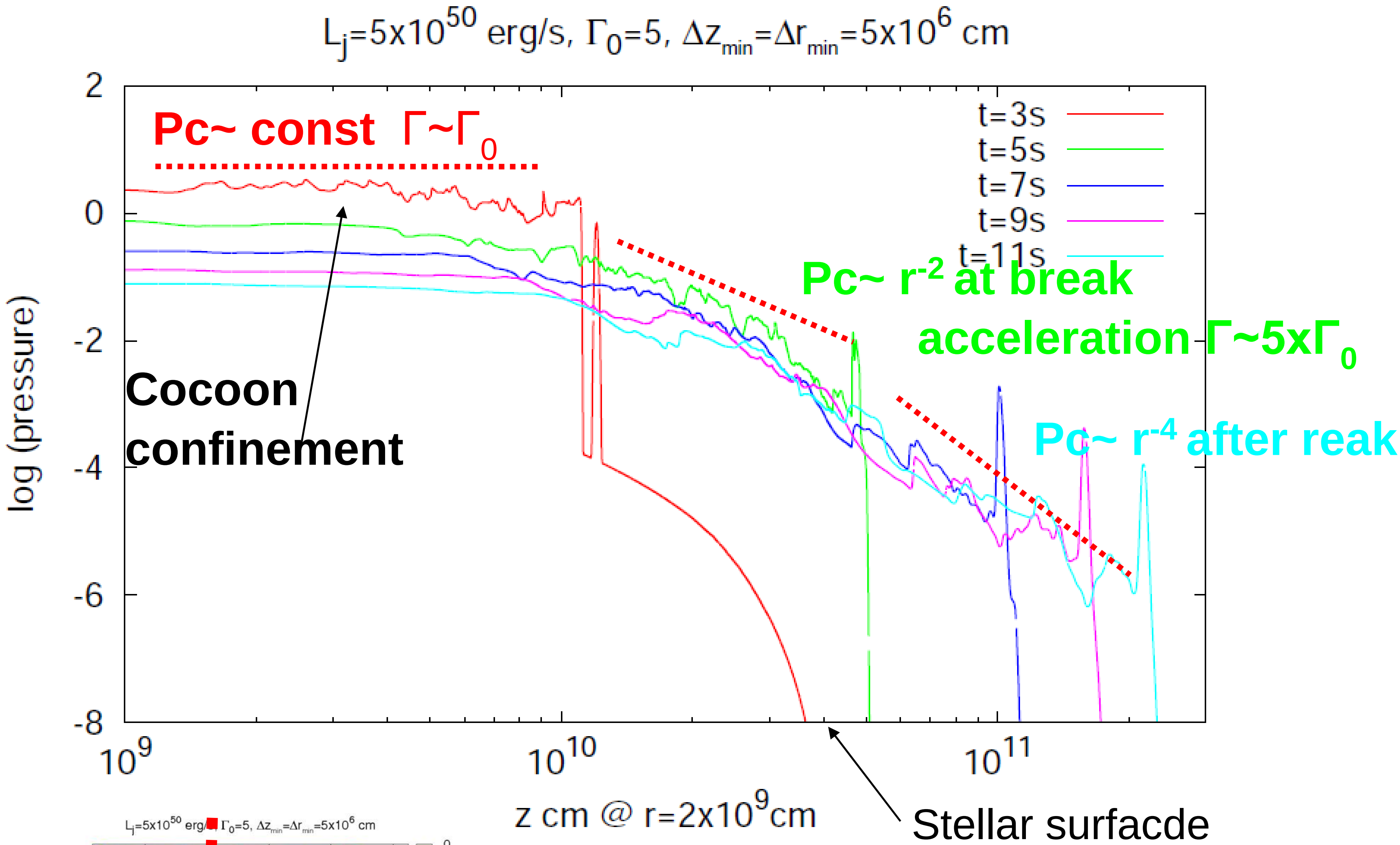
Particle traces injected at t=5 s



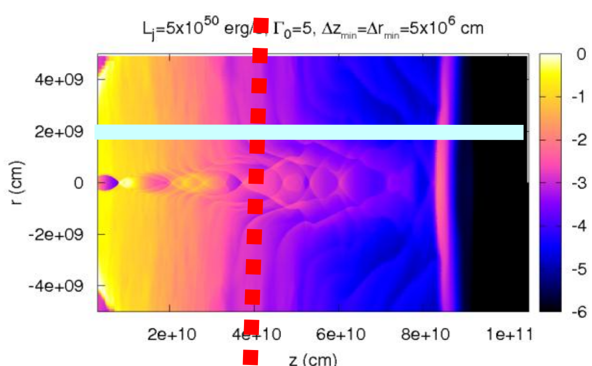
Time evolution of jet opening angles



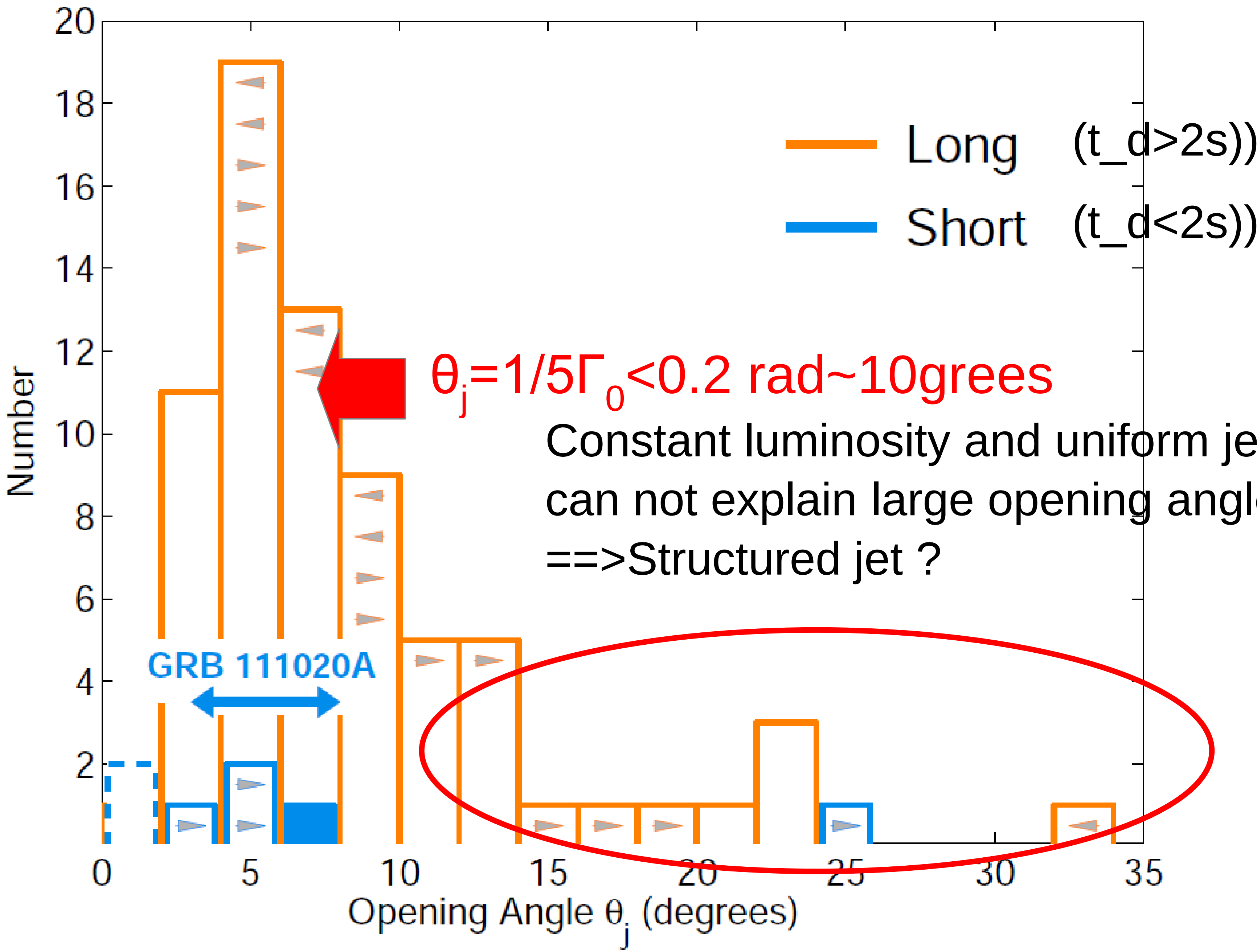
1D Pressure profile in the cocoon



p



Distribution of opening angle of GRB jets



$\theta_j = 1/5\Gamma_0 < 0.2$ rad~10grees

Constant luminosity and uniform jet
can not explain large opening angle jets
==>Structured jet ?

Fong et al. (2012)

Conclusion

- High resolution calculation of jet from collapsars to reduce numerical baryon loading
- Pressure drop in the cocoon just before the break due to exponential drop of the progenitor's mass density profile
  Lorentz factor increases to about $5x\Gamma_0$ at the break.
- The opening angle after the break for first several seconds

$$\theta_j \sim C x \Gamma_0^{-1} \quad (C \sim 1/5)$$

- Structured jet is proffered for large opening angle jets. (ex. GRB120422A short duration, low luminosity)

Future works

- Long-term evolution of jets with large computational domain.
- 3D simulations to see the multidimensional effect