Photospheric thermal radiation from GRB collapsar jets

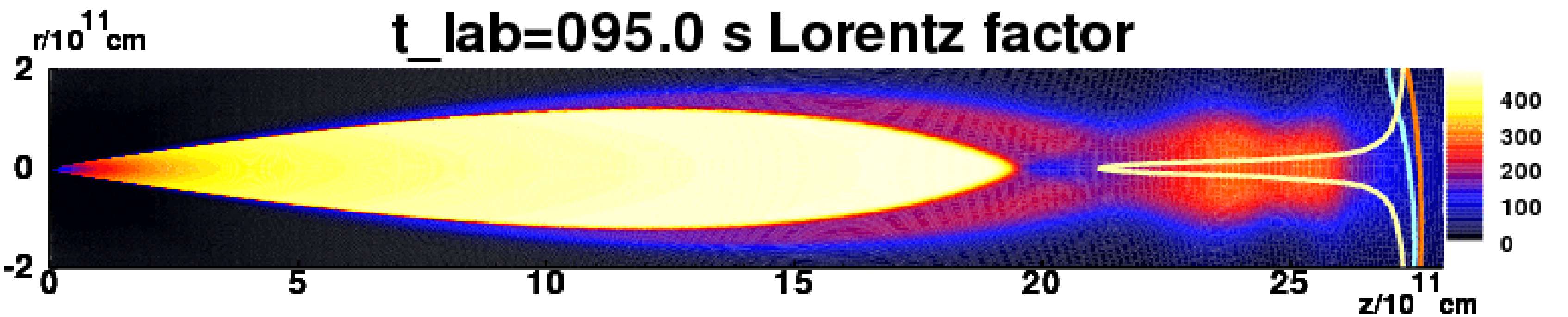
1. Gamma-ray burst (GRB)
2. Model
3. Hydrodynamics
4. Thermal radiation
   Light curve, spectrum,
5. Summary

Akira MIZUTA(KEK)

AM, Nagataki, Aoi

(ApJ, 732 26, 2011)

AM + (in prep)



素核宇融合による計算基礎物理学の進展研究会
@合歓の郷 2011.12.05

相対論的流体方程式の数値的解法 I [1]

水田晃[2]

原子核研究
講義録
　相対論的流体方程式の数値解法 I ('11春) II ('11秋), III('12春 : 予定)
http://www2.yukawa.kyoto-u.ac.jp/~mizuta/

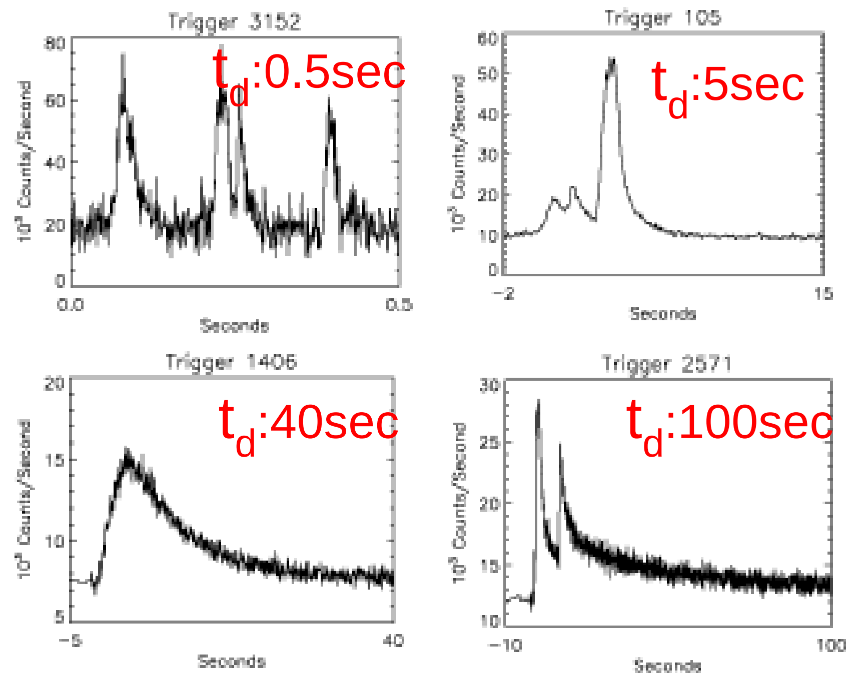
Notes on the **numerical method to solve special relativistic hydrodynamic equations** based on the resume prepared for the seminar last year.
In Japanese.
I appreciate the participants for giving me so many questions. Any comments, questions, and suggestions are welcome.

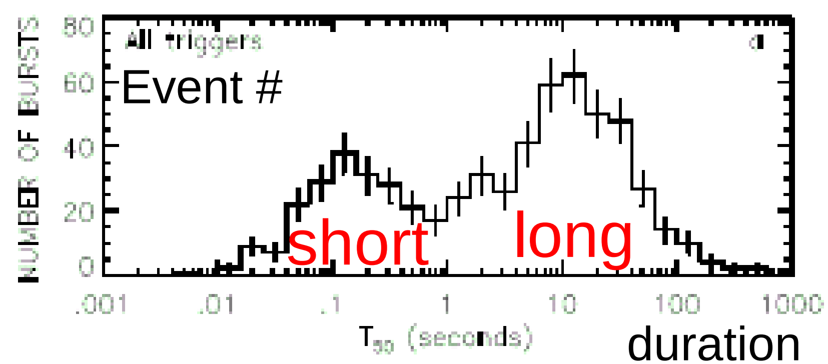
Gamma-ray Burst (GRB) :The most energetic explosion after Big-Bang

- transient event (~10 s, gamma-ray ~ a few hundred KeV)
  explosion energy~10^{52}erg
  From relativistic collimated jet
  Lorentz factor 100-1000

- No typical light curve pattern.
  Time variability in milli to a few sec.
  Divided into two groups in duration of the radiation
  long burst v.s. short burst

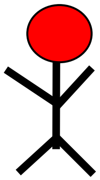
- cosmological event
  GRB 090423 z=8.2
  GRB 090429B z=9.4 ? (~600 million year after Big-Bang)
  Good tool to study high redshift Universe, c.f normal SN up to z~1.2





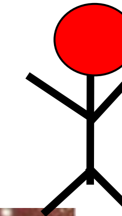
William et al. (1999) ApJS distribution of GRB duration from BATSE catalog

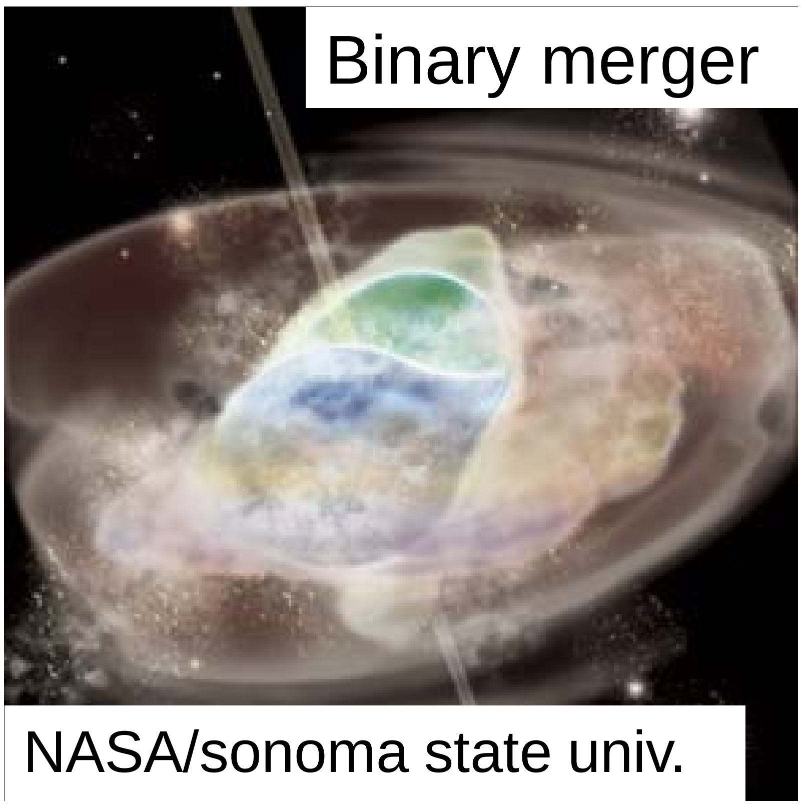
At least some of Long GRBs are special type of supernova explosions of massive stars.

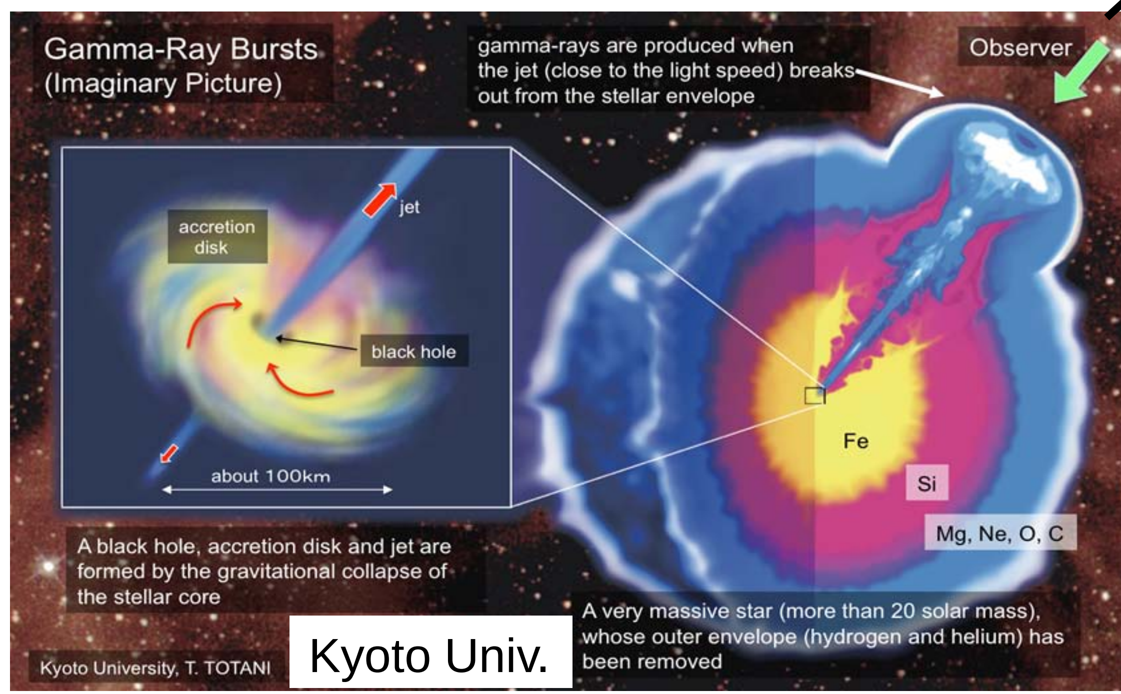


short burst ?

long burst





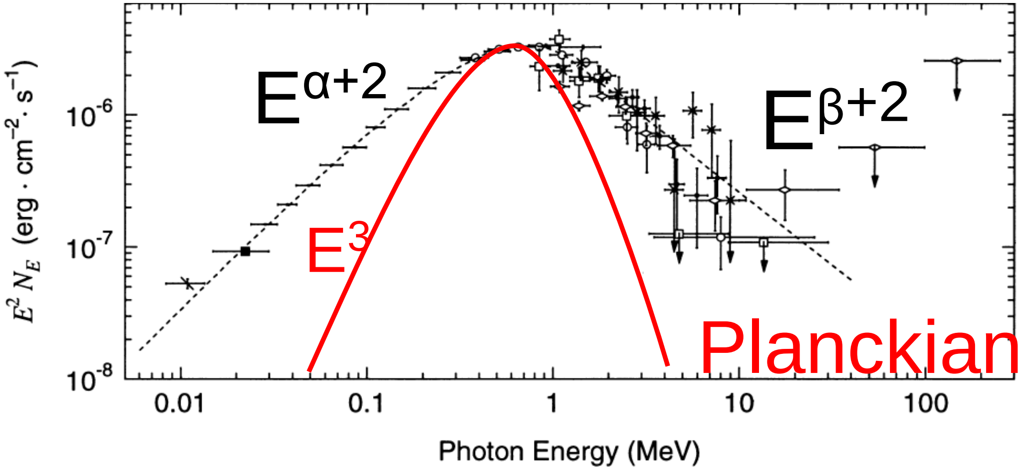


GRB980425/SN1998bw
GRB030329/SN2003dh
XRF060218/SN2006aj
GRB091127/SN2009nz
XRF100316D/SN2010bh

Sekiguchi-san's talk
Kiuchi-san's talk

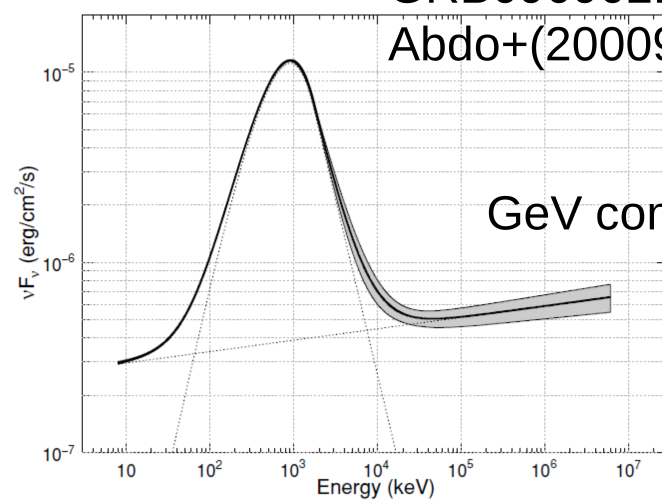
Central engine
Kajino-san's talk
Nagataki-san's talk

Spectrum of GRB prompt emission
Band function: Broken power-law



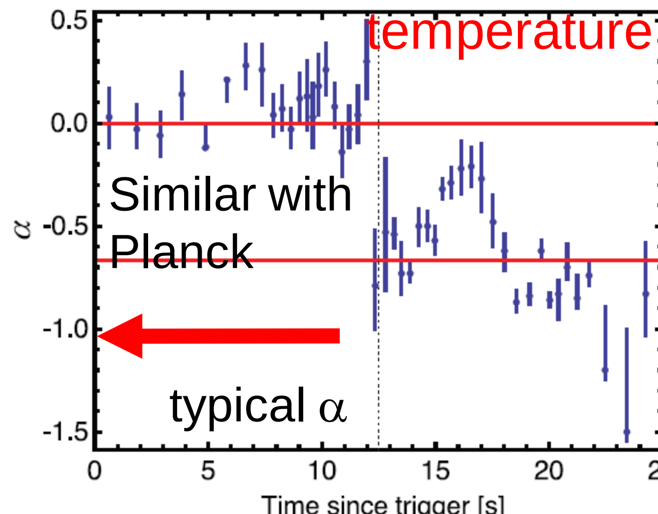
GRB990123 Briggs et al. (1999)

GRB090902B
Abdo+(20009)



How can the photospheric
thermal radiation be seen ?
Thermal radiation; light curve, spectrum
viewing angle effect
--jet like explosion

Hydrodynamics of jet propagation
Photospheric thermal radiation



GRB090902B Ryde et al (2010, 2011) thermal-like component was found.

Hydrodynamic simulations (time dependent, jet)

+

photospheric thermal radiation by post process

--find a photosphere (optical depth =1)

--black body radiation (local temp + Lorentz boost)

Quantitative discussion is possible !!

-direct comparison with light curves, spectrum, etc.

Mizuta +'11,Lazzati et al. '09 '11, Nagakura+ '11

To estimate non-theremal radiation (synchrotron emission)
so many assumptions are necessary.

– Spectrum for non-thermal electrons

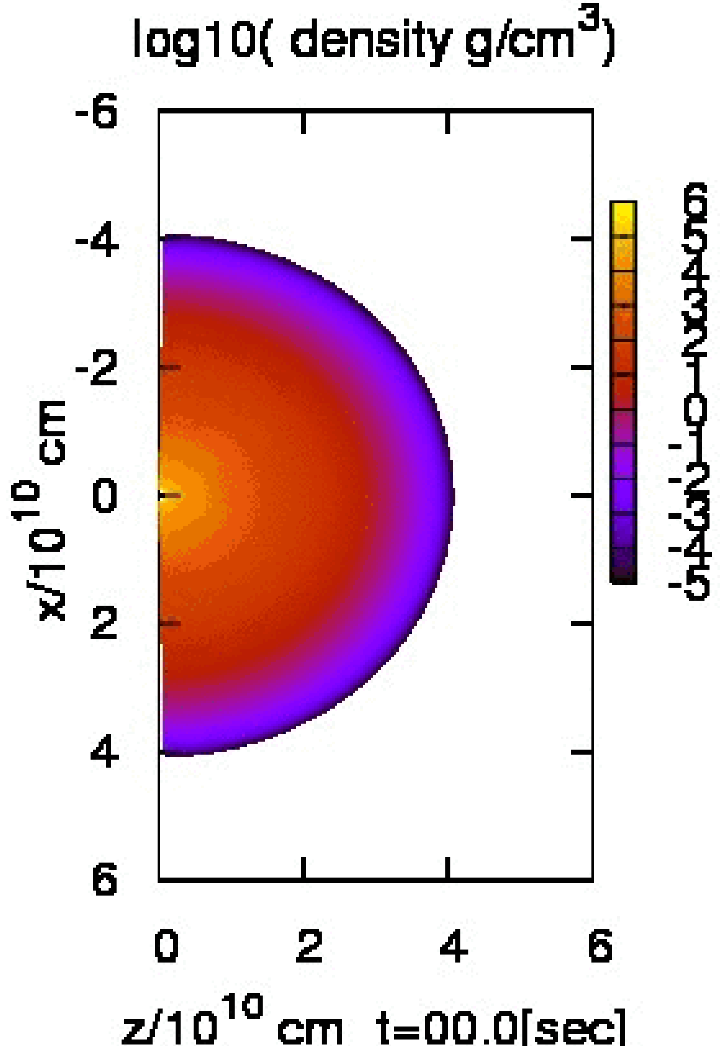
(f(E) ひれい E^{-alpha})

– When, where and how much are electrons accelerated ?

– Strength of magnetic field

Lj=5.e50 erg/s [0:100s] Opening angle 10 degrees

Γ_0=50, ε_0/c^2=80 (h_0~106) Γ_max~$h_0\Gamma_0$(Bernoulli's principle)



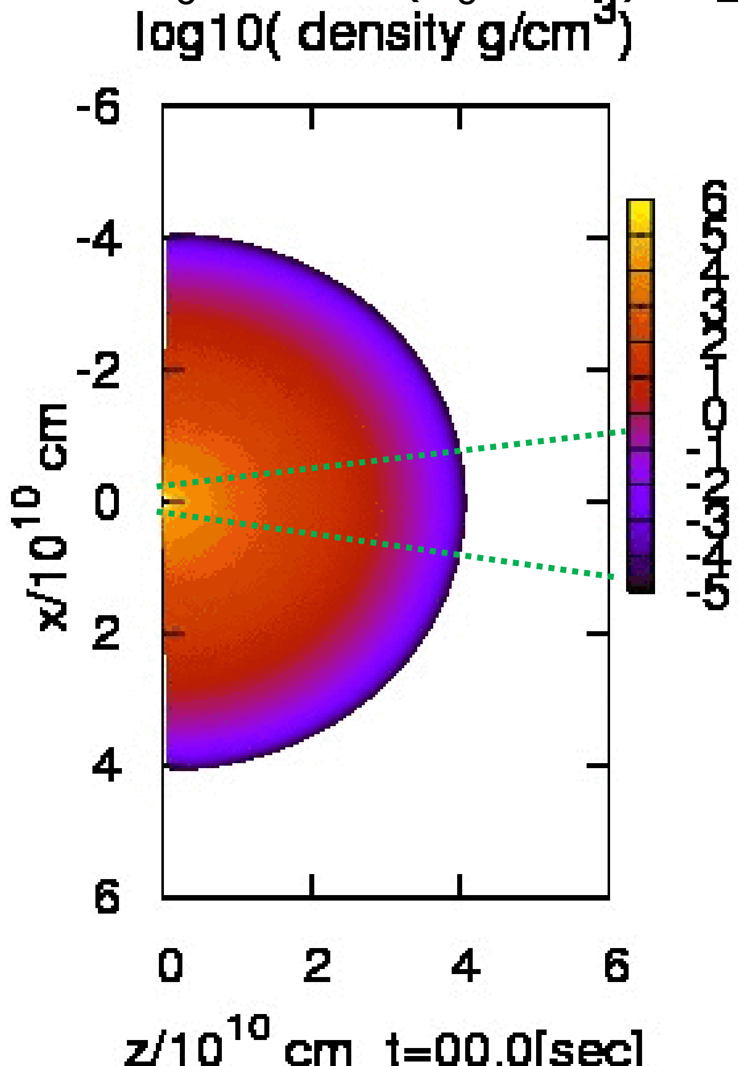
2D (r x θ) axisymmetric, progenitor 14_sum,R*=4.e10cm (Woosley & Heger (2006)) + wind (r>R*) $\rho \propto r^{-2}$

2D-rela- hydro code(constant specific heat ratio=4/3)

Mizuta et al. (2004,2006) + MPI

Lj=5.e50 erg/s [0:100s] Opening angle 10 degrees

Γ_0=50, ε_0/c^2=80 (h_0~106) Γ_max~$h_0\Gamma_0$(Bernoulli's principle)



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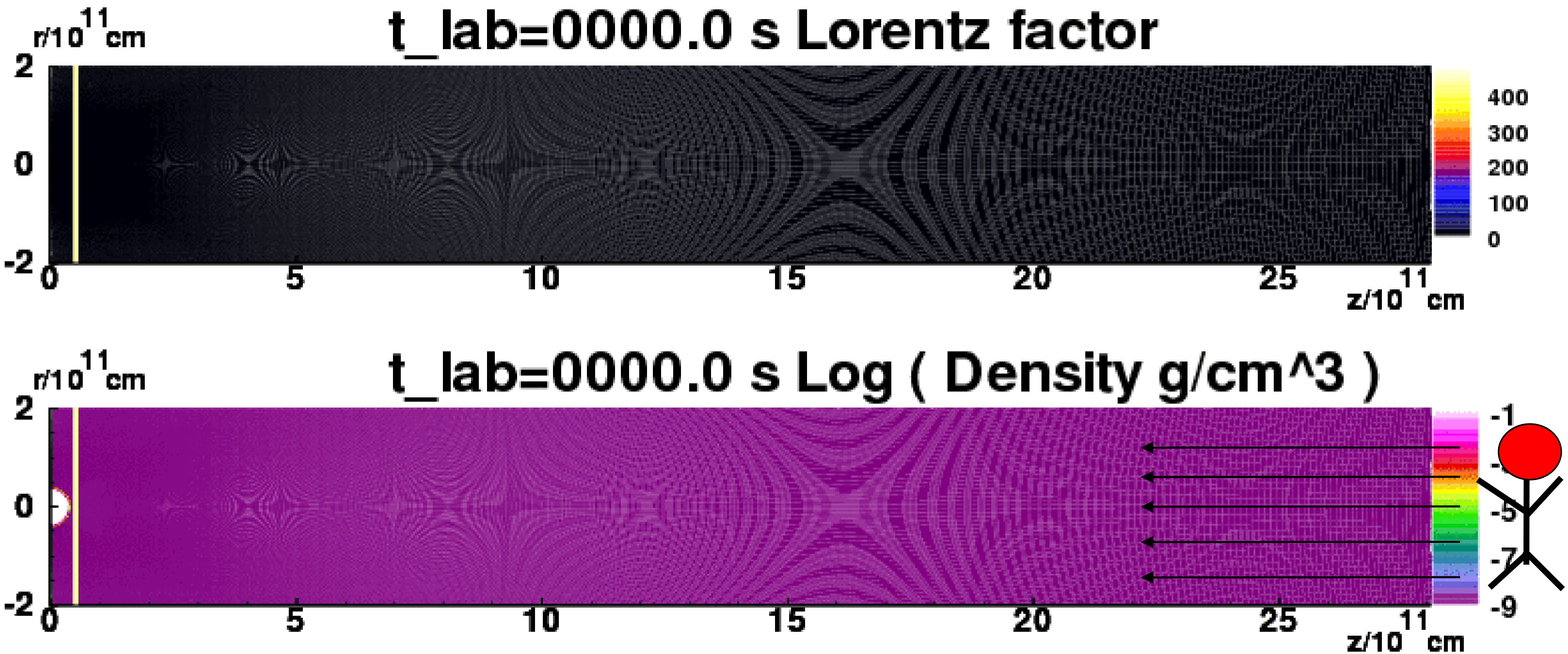


$\theta = 0$

$\theta = 5$

$\theta = 10$

The photosphere separates from forward shock as time goes on.
If there is large beaming factor along the photon ray, the location photosphere lay deep inside the jet.

Post process calculation is also parallelized by MPI.

● Another approach

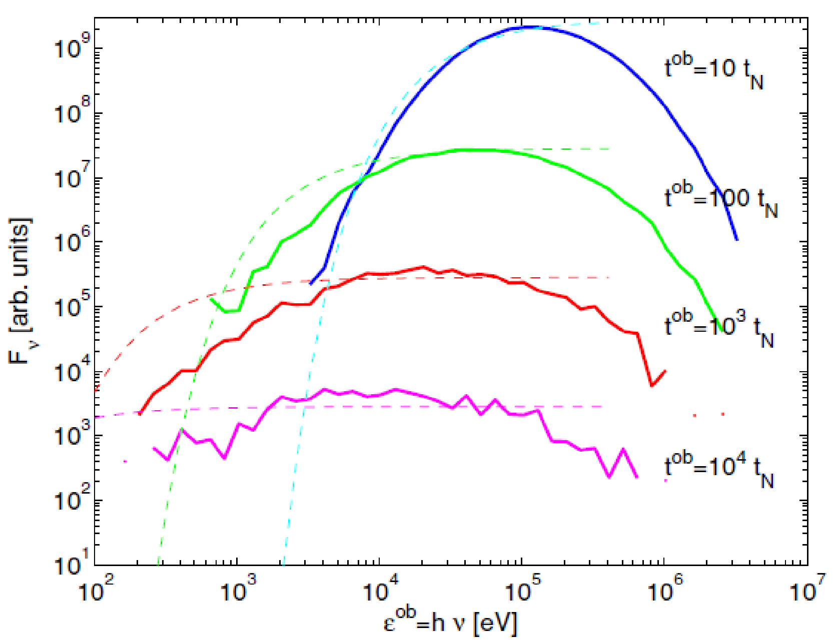
Hydro – “spherical steady state”

+

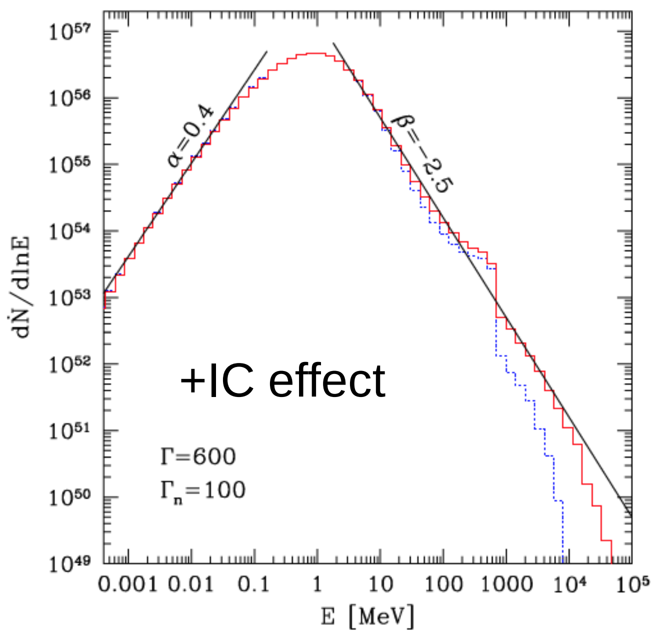
Monte Carlo simulation (photon transport)

Initial seed photon – around photosphere

Not necessary to assume T_gas~T_rad

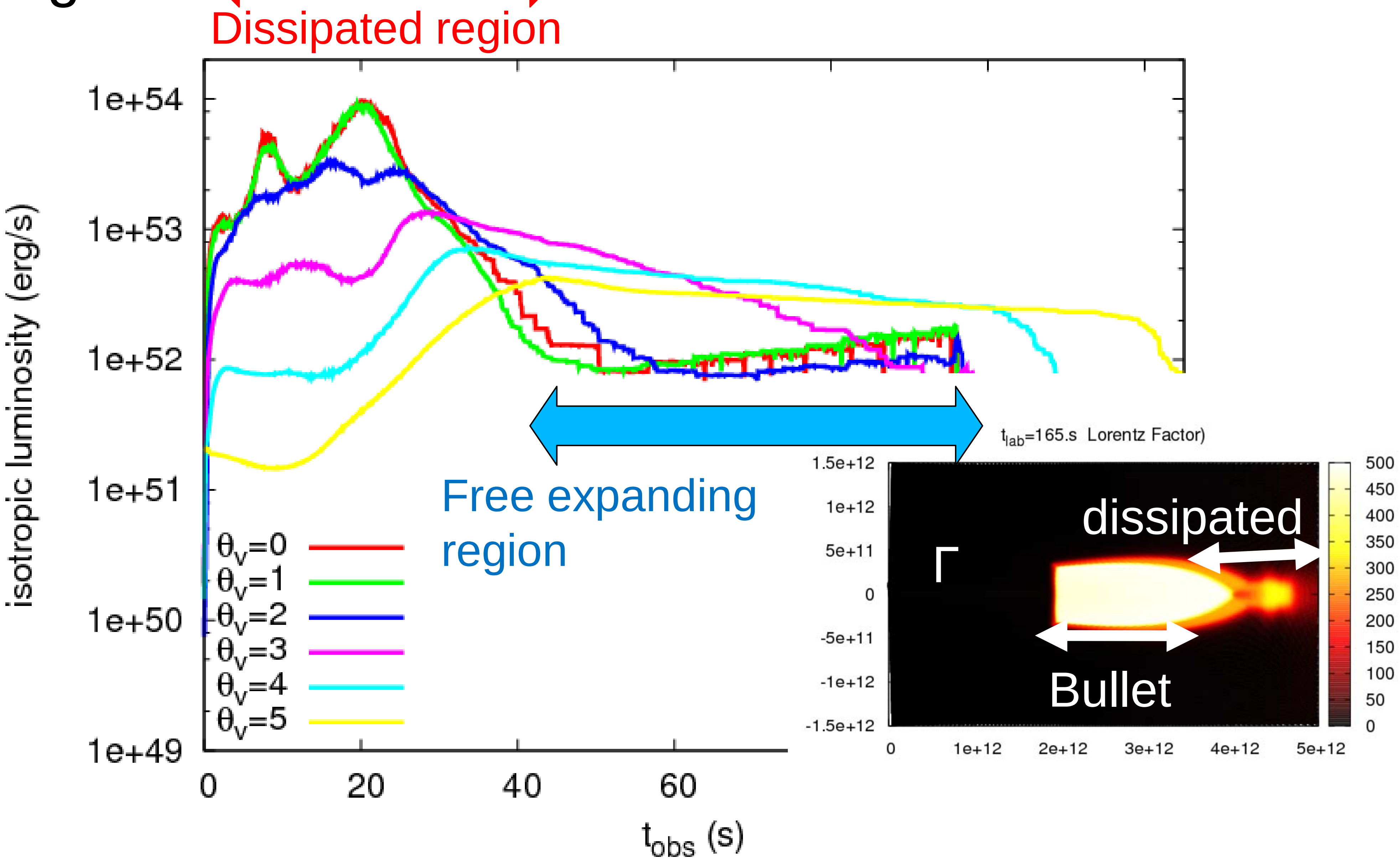


Pe'er (2008)



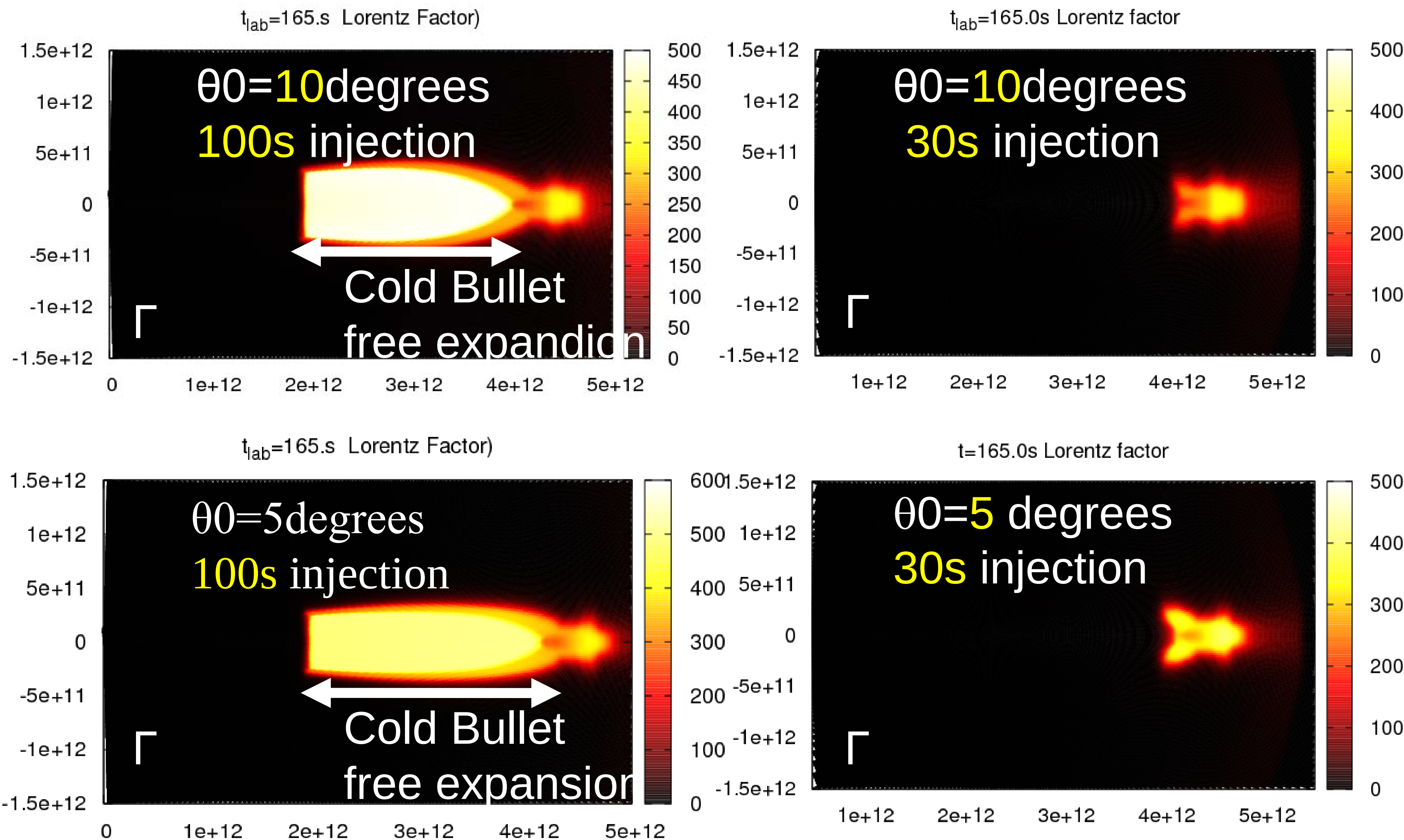
Beloborodov(2010)

Light curve

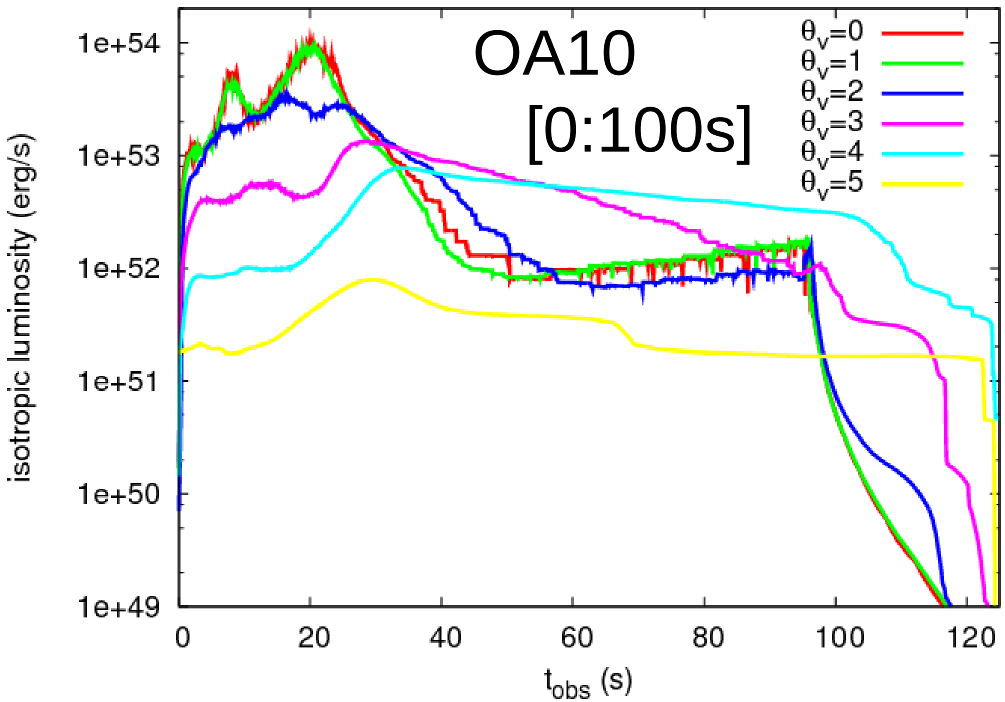


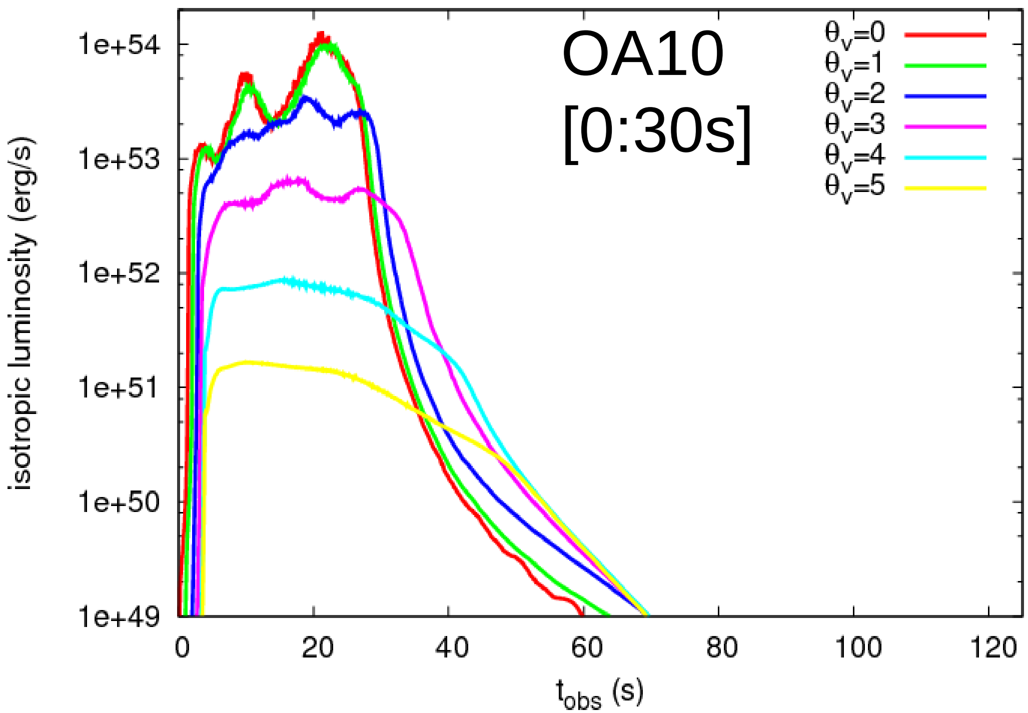
Duration of light curve ~ jet injection.
A few seconds time variability in early phase caused by internal discontinuity in the jet.

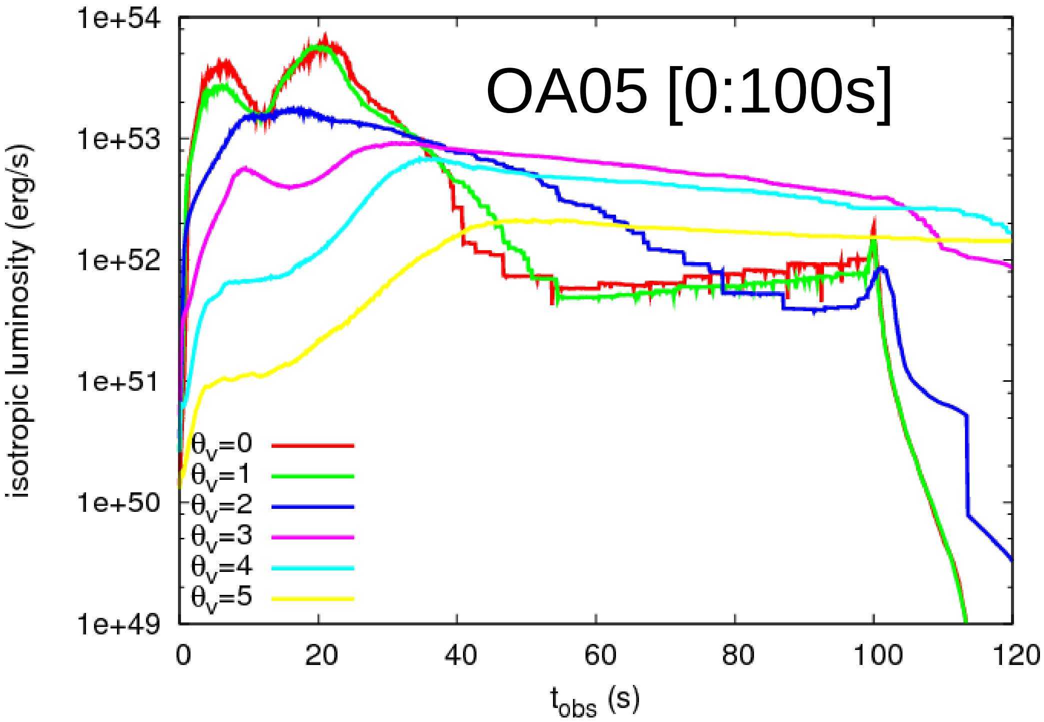
Duration / initial half opening angle

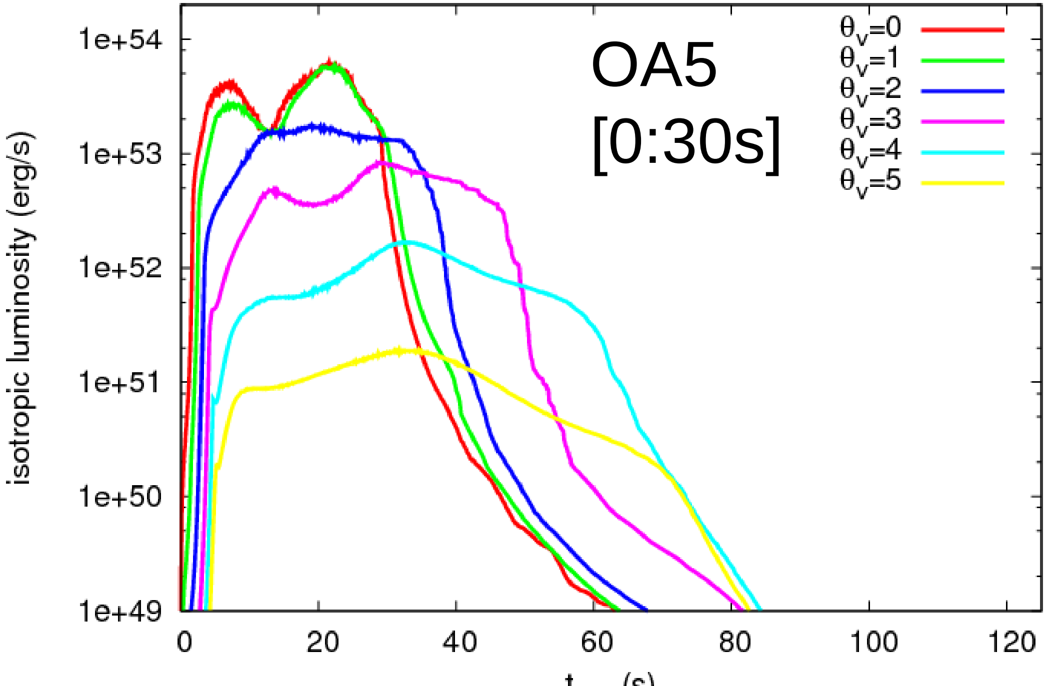


Light curves

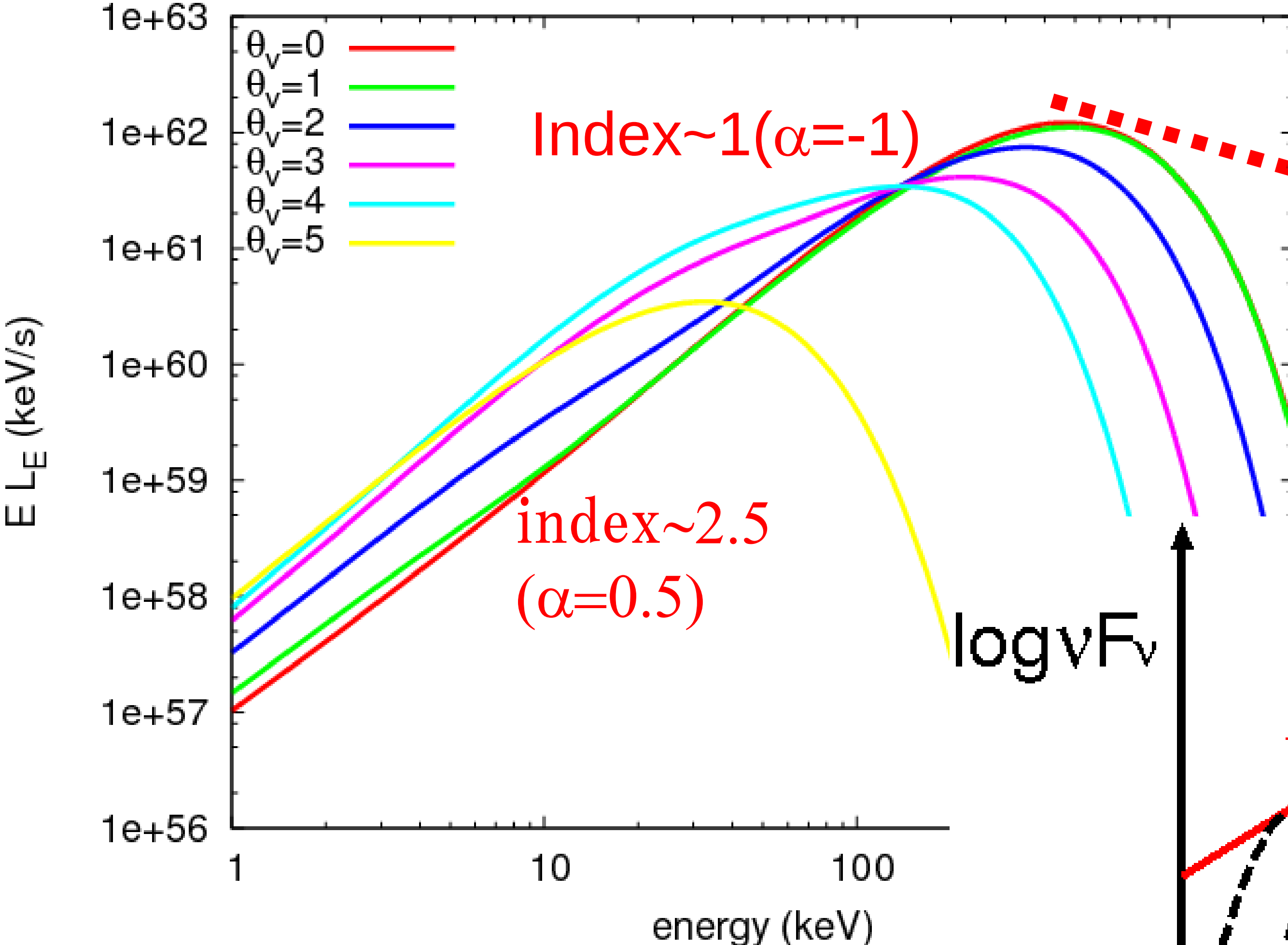




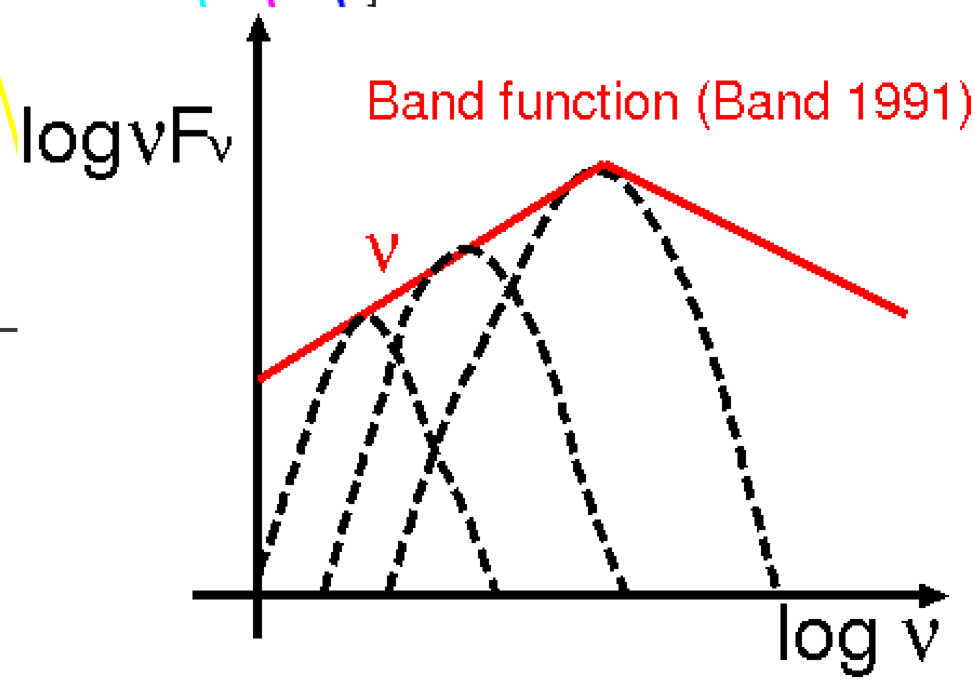




Spectrum by numerical hydrodynamics

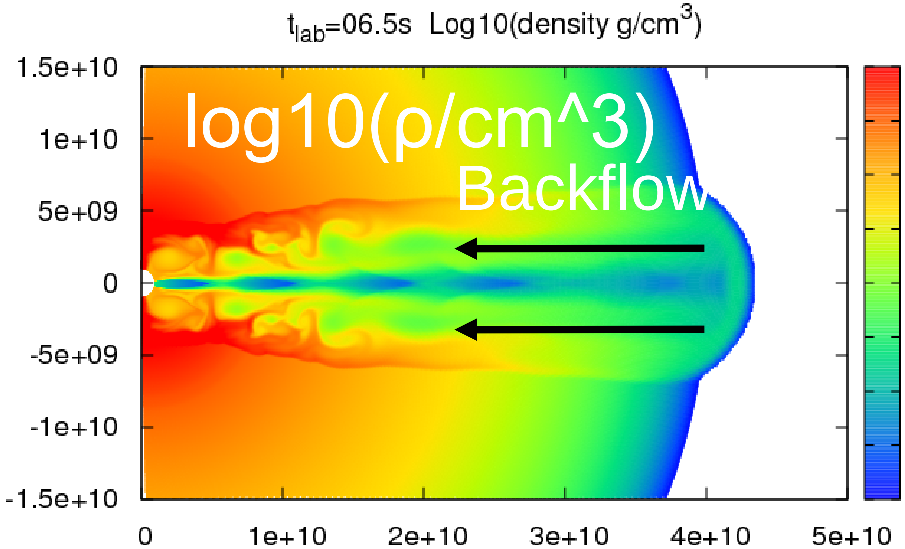


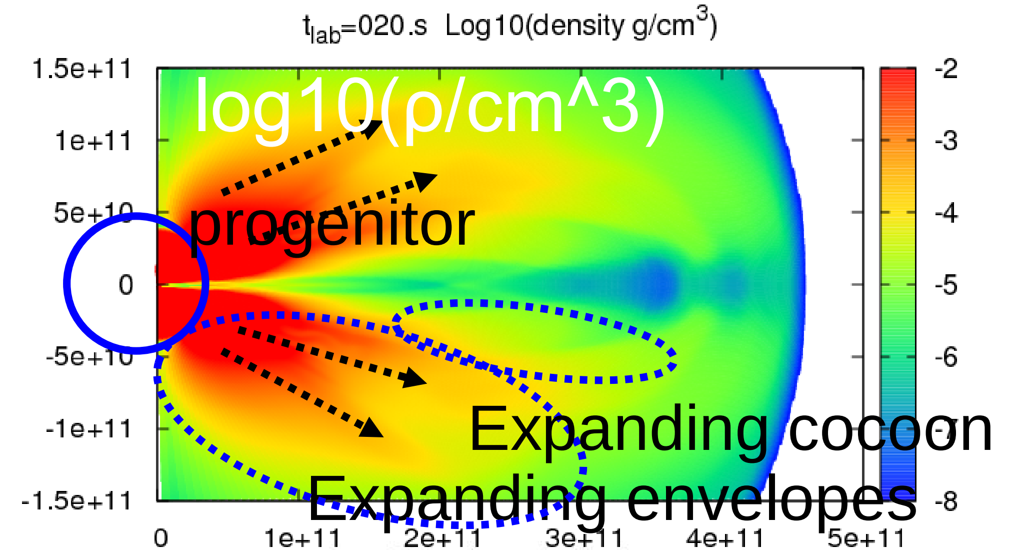
IC or another process is necessary to explain above the peak energy.

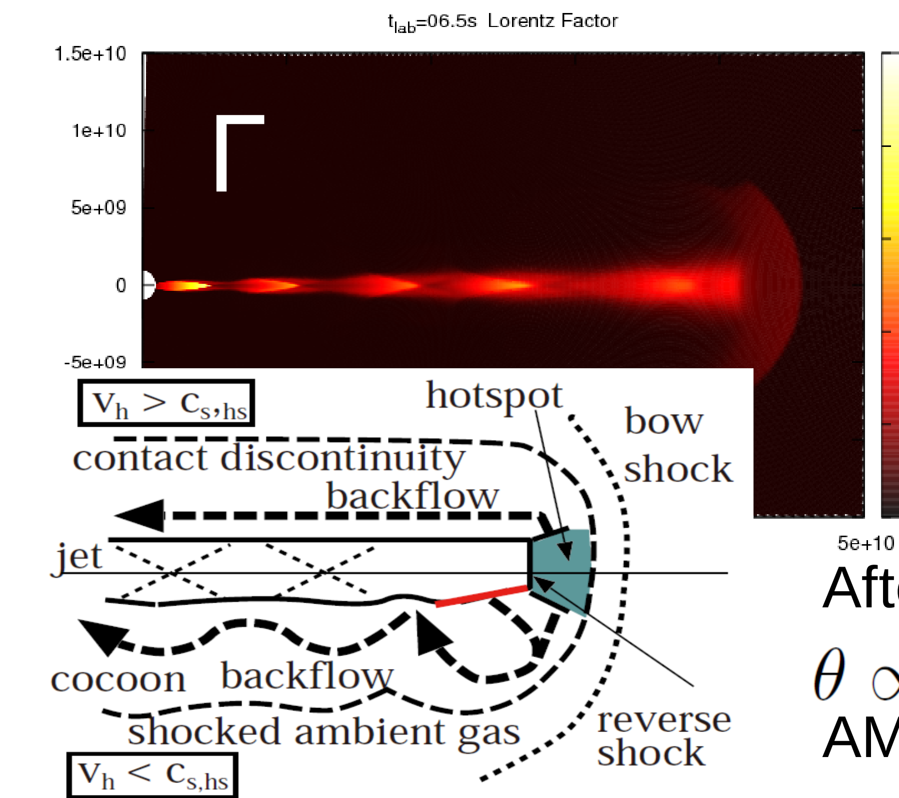


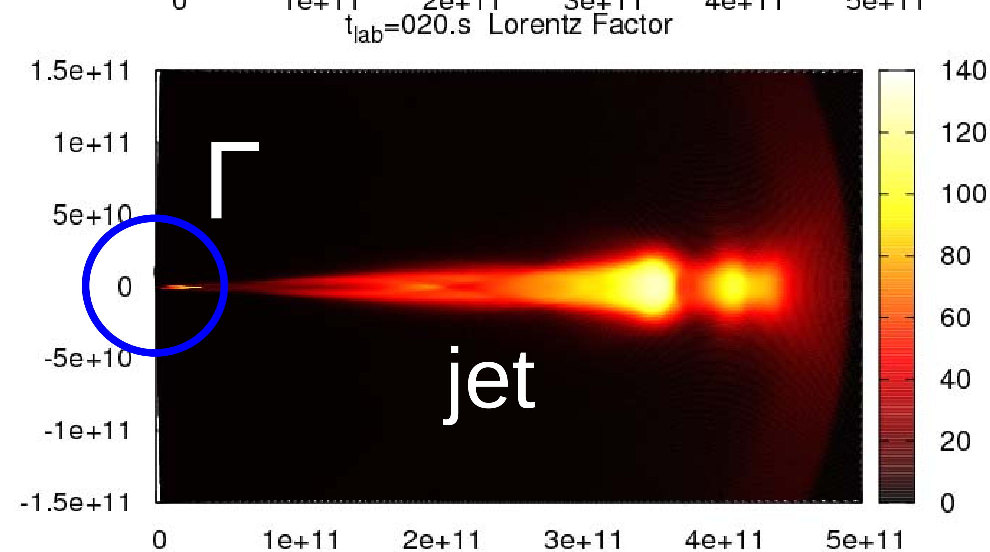
θ_0=10degrees
100s injection

Cocoon baryon loading problem









After shock break, $\theta \propto r^{\lambda-1}, \quad (\lambda < 1)$? Ioka,Ohira,Kwanaka, AM(2011) . High resolution calculation can answer this problem.

Summary

Luminosity of photospheric thermal radiation is comparable to observed one in GRBs.

A wide variety of light curves (a few seconds time valiability, flat structure) are presented by changing jet parameters and observers viewing angle.

Spectrum

– close to Planckian (for observers $\theta <\sim 2$)
– Band like spectrum (for observers $\theta > 2$)

High resolution calculation is ongoing.
Hydrodynamic simulation + Monte Carlo simulation is planned.