Breaking the Limits 2016
Arbatax Park Resort

September 23, 2016

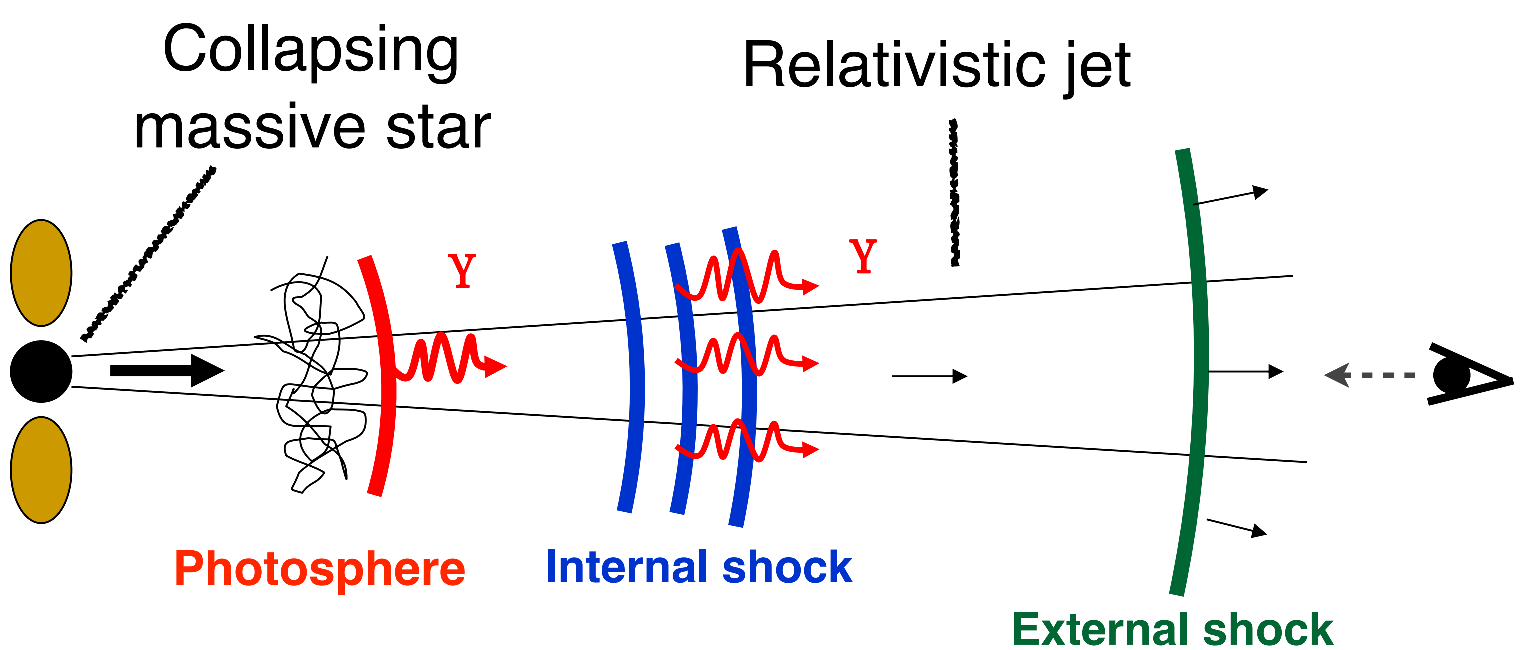
Coupled Computation of Radiative Transfer with Relativistic Hydrodynamics Relevant to GRB Emission Process

Ayako Ishii
(Tohoku University)

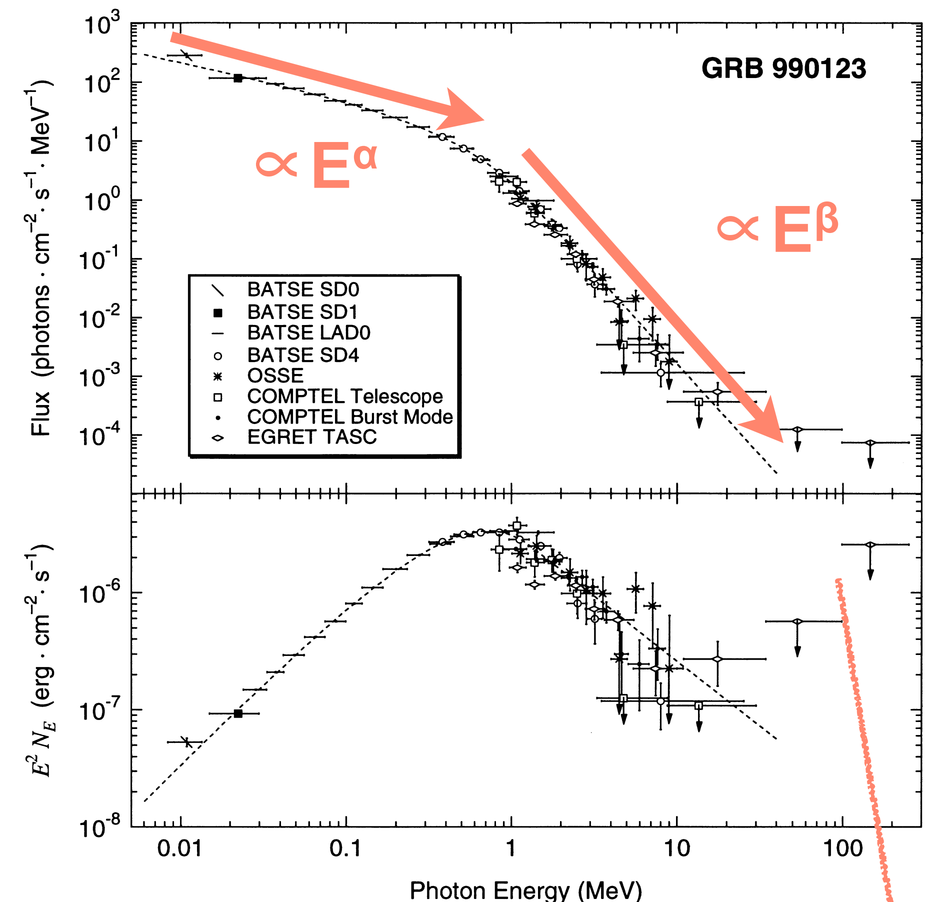
http://www.astroarts.co.jp/news/2013/08/08grb/index-j.shtml

Naofumi Ohnishi (Tohoku Univ.)
Hiroki Nagakura (Caltech)
Hirotaka Ito (RIKEN)
Shoichi Yamada (Waseda Univ.)

Gamma-ray burst (GRB)



Mechanism of Long GRB



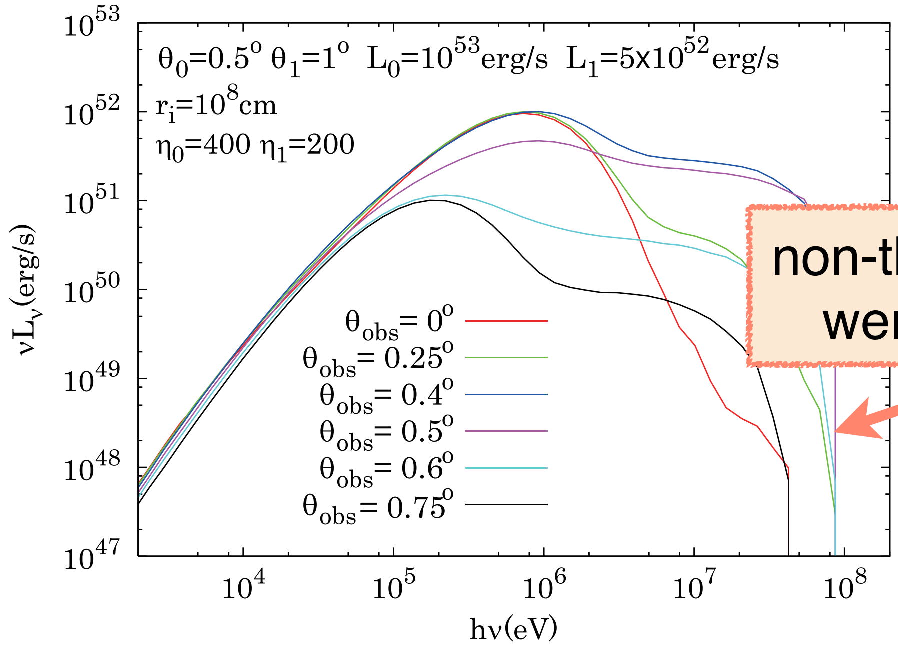
Briggs et al. 1999

- The most energetic explosion in the universe

$\alpha \sim -1$, $\beta \sim -2.5$

- GRBs are classified depending on gamma-ray emission time
  - ✓ Short GRB ($\lesssim 2$ s) → Compact star binary merger
  - ✓ Long GRB ($\gtrsim 2$ s) →Collapsing massive star
- A broken-power-law spectrum is observed
- Detailed emission mechanism is unknown

Numerical reproduction of GRB spectrum

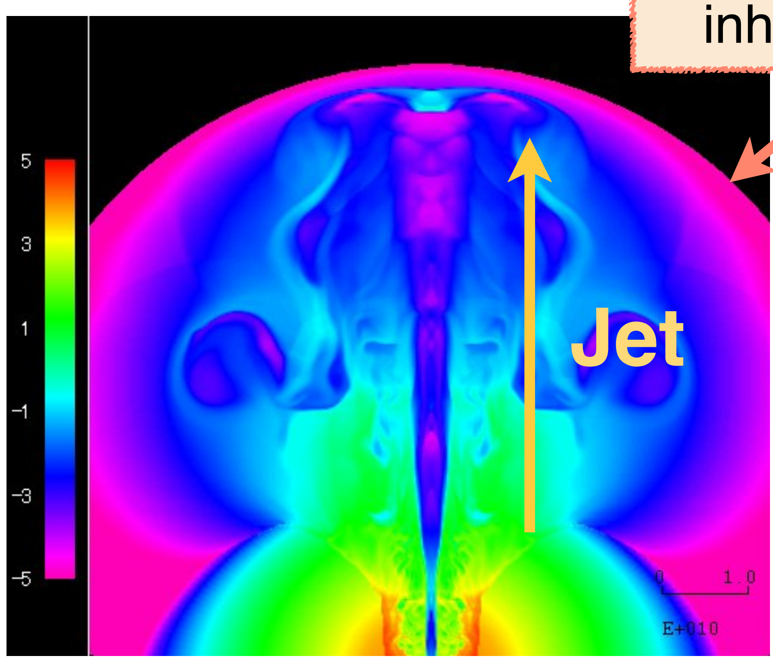


Ito et al. 2013

non-thermal spectra were generated

- Radiative transfer computations were implemented on steady modeling flowfield
  (Pe'er & Ryde 2011, Ito+ 2013, Shibata+ 2014)
- Multi-dimensional relativistic hydrodynamics simulations were performed
  (Aloy+ 2000, Mizuta+ 2006, Nagakura+ 2011)

Jet structure develops inhomogeneously

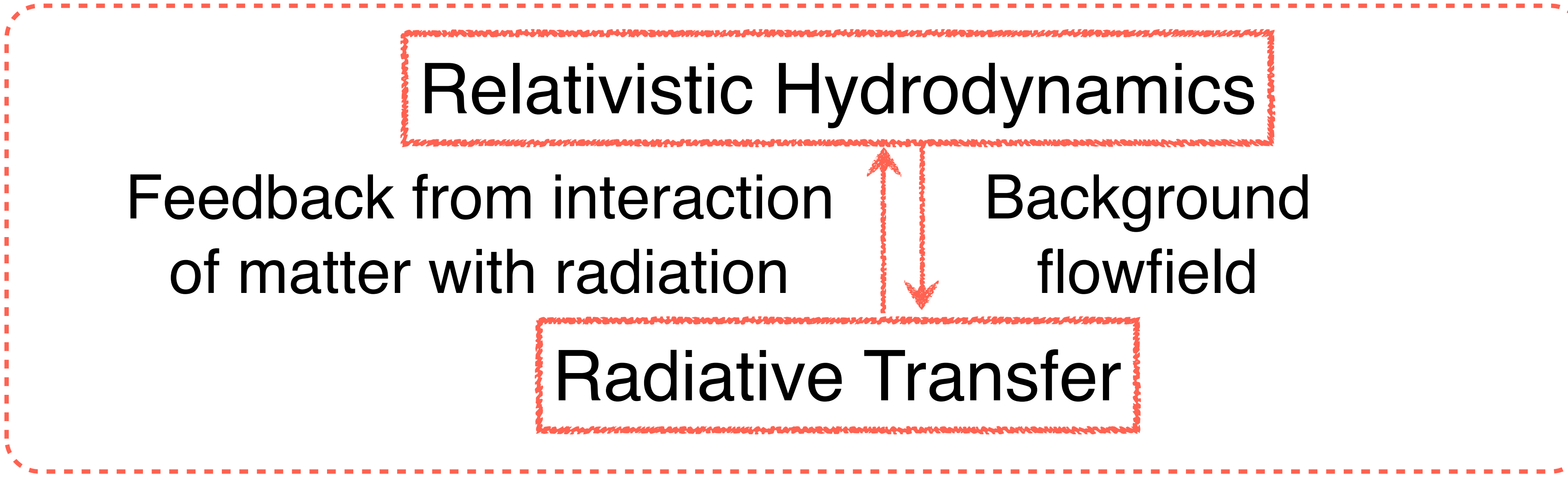


Nagakura 2010

Radiative transfer computation should be implemented on unsteady background

Coupled computation of radiative transfer with relativistic hydrodynamics

Coupled computation



Requirements for coupled computation in GRB

- Ultra-relativistic flow velocity (Lorentz factor $\Gamma \gtrsim 100$)
- Strongly anisotropic radiation
- Radiation mediated shock (A. Levinson 2008, R. Budnik 2010)

Previous works

- Coupled computation of Monte Carlo radiative transfer (MCRT) with relativistic hydrodynamics
  (N. Roth and D. Kasen 2015, A. M. Beloborodov 2016)
- Appropriate simulation conditions of MCRT with ultra-relativistic hydro were examined (Ishii+ 2015, Ishii+2016 (submitted))

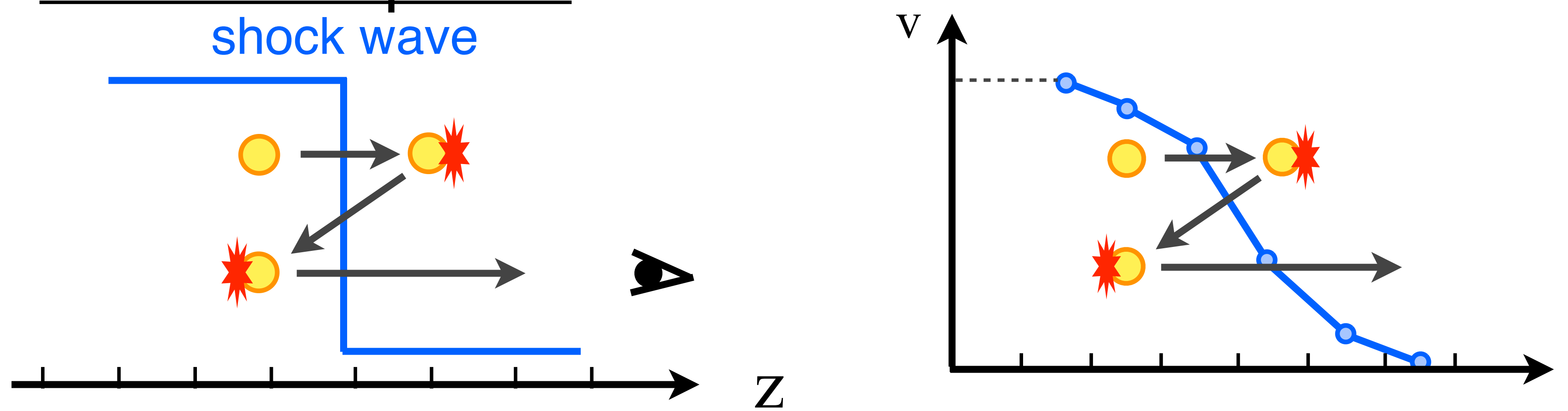
Objectives

Goal

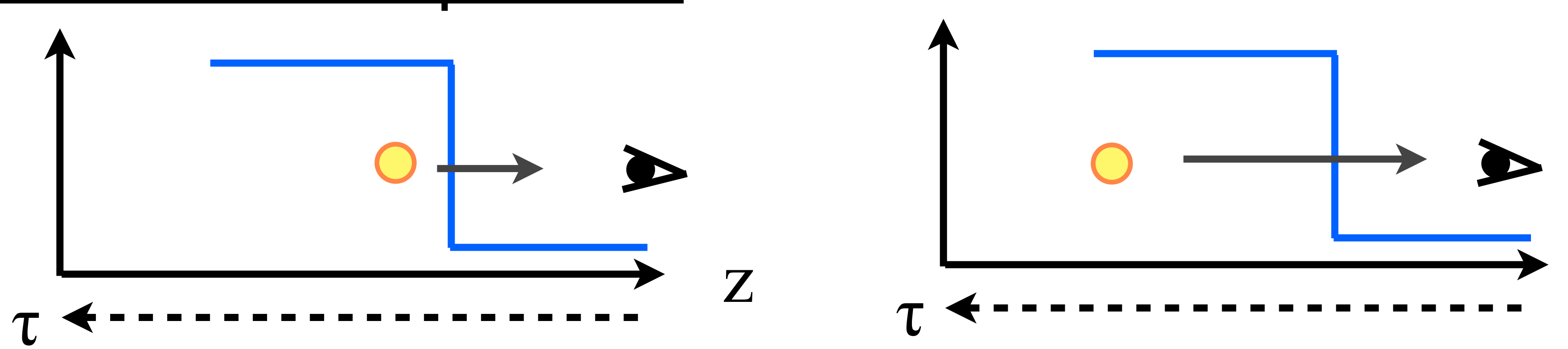
Reproducing GRB emission spectra by coupled computation

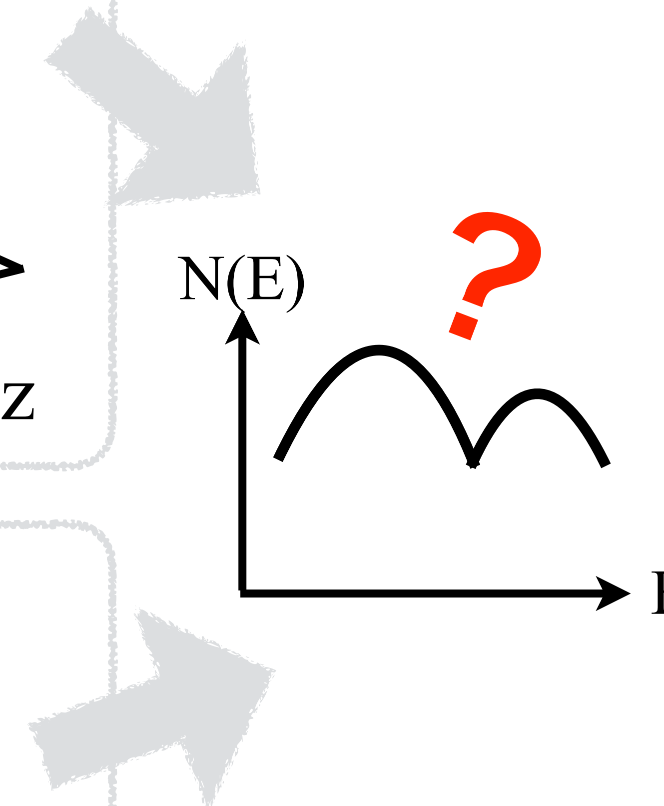
Preliminary for coupled computation…

Shock steepness



Initial emitted position





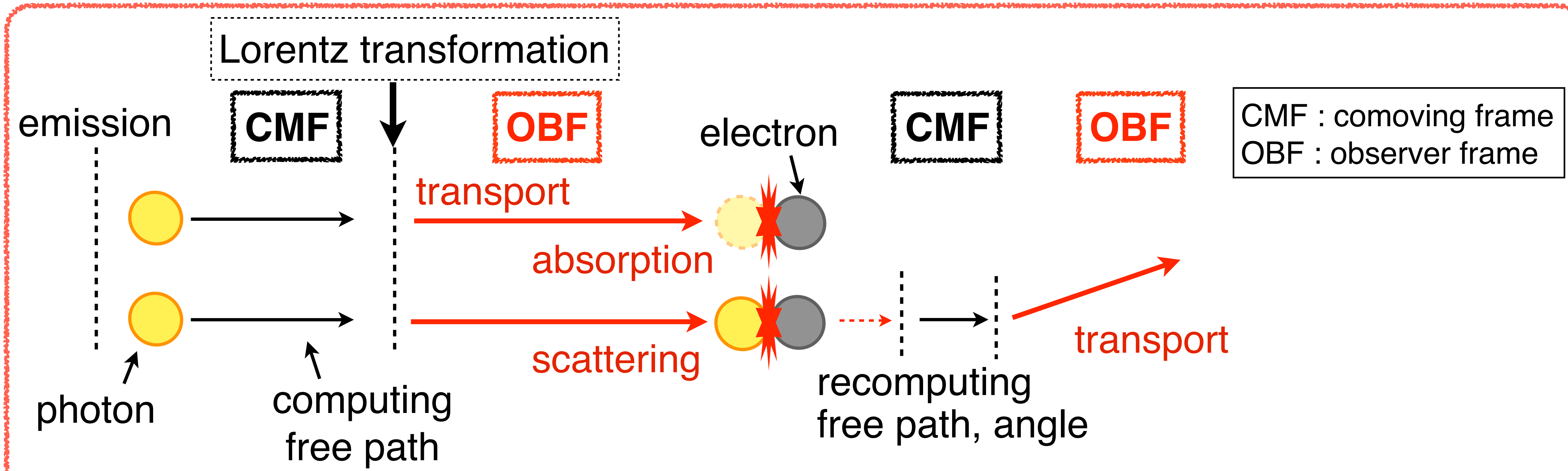
1D hydro flowfield without feedback

Numerical method

Radiative transfer equation including scattering

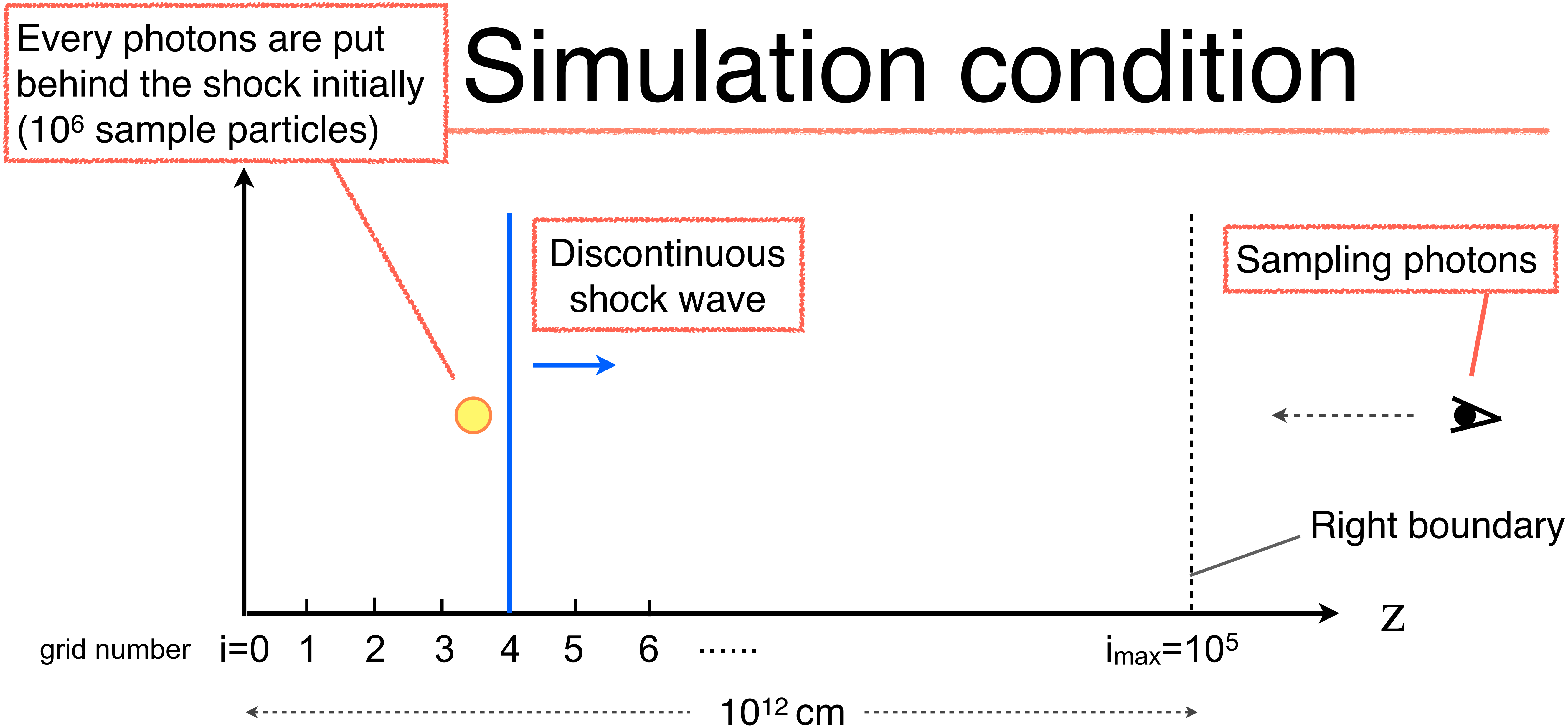
$$\left(\frac{1}{c}\frac{\partial}{\partial t} + \mathbf{\Omega}\cdot\nabla\right) I = j + \frac{\rho}{4\pi}\int\int \sigma I \phi d\nu' d\mathbf{\Omega}' - [k+\sigma]\,\rho I$$

Computed in comoving frame



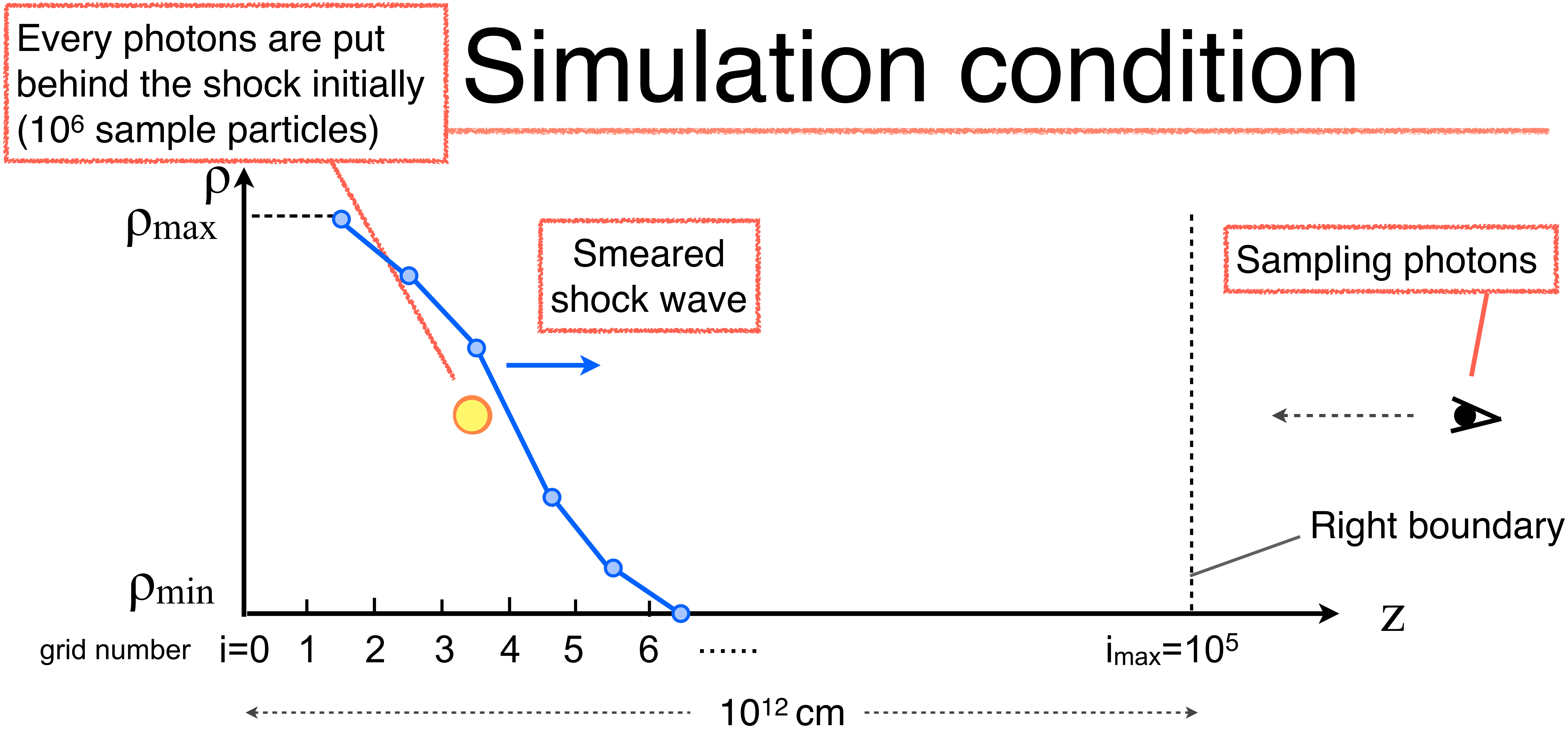
Monte Carlo method
with Compton scattering
no absorption

Simulation condition



- Photons are tracked with a moving discontinuous or smeared shock wave, and sampled at the right boundary
- The shock front is artificially smeared in density distribution (ρ_{max} and ρ_{min} satisfy Rankine-Hugoniot relations)
- Flow velocity is determined by the equation of continuity

Simulation condition

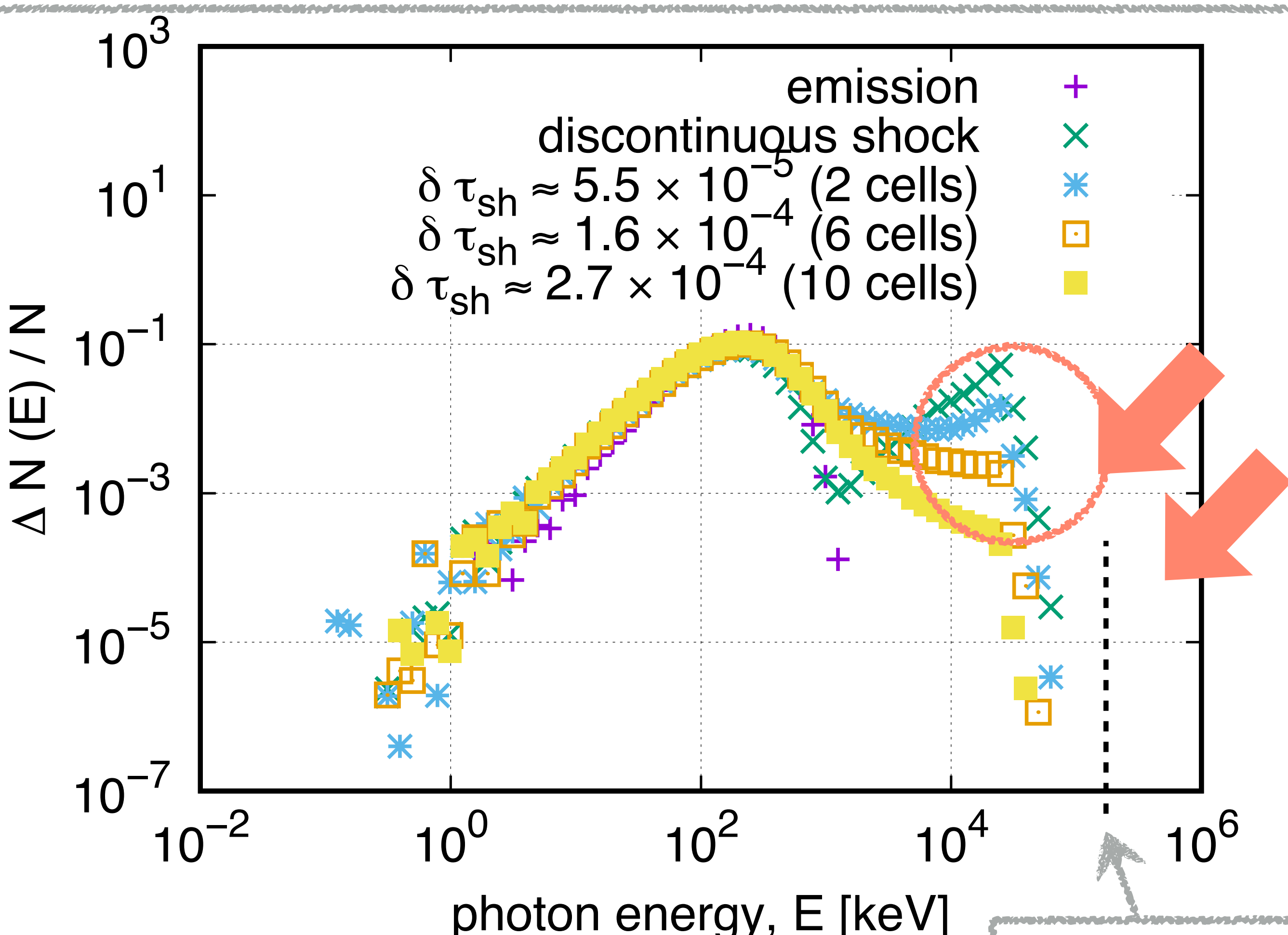


- Photons are tracked with a moving discontinuous or smeared shock wave, and sampled at the right boundary
- The shock front is artificially smeared in density distribution (ρ_{max} and ρ_{min} satisfy Rankine-Hugoniot relations)
- Flow velocity is determined by the equation of continuity

Spectra with different shock widths

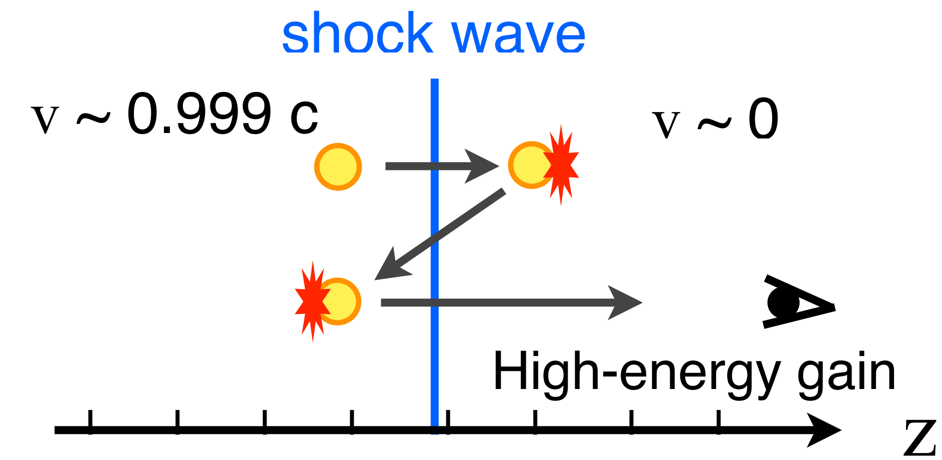
$$\delta\tau_{sh} = \frac{w_{sh}}{s_{ini}}$$

w_{sh} : shock width
s_{ini} : photon initial mean free path

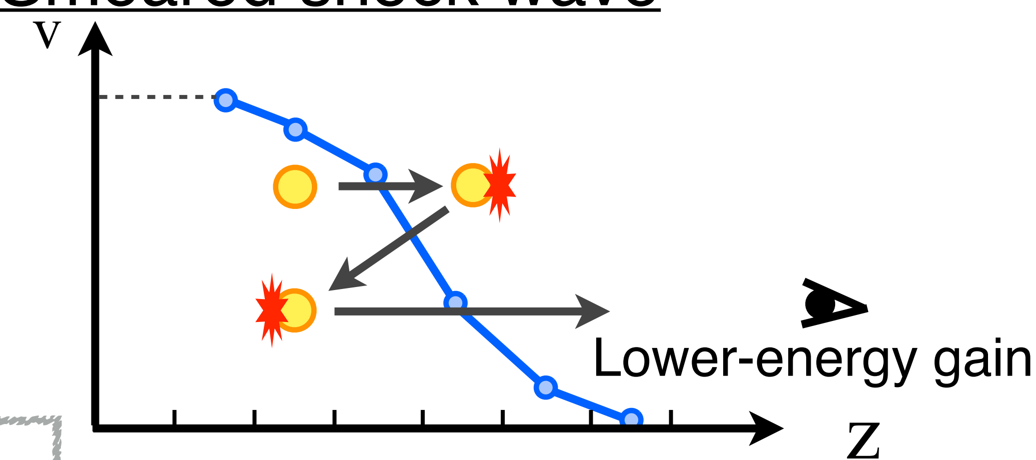


Compton scattering
cut off

Discontinuous shock wave

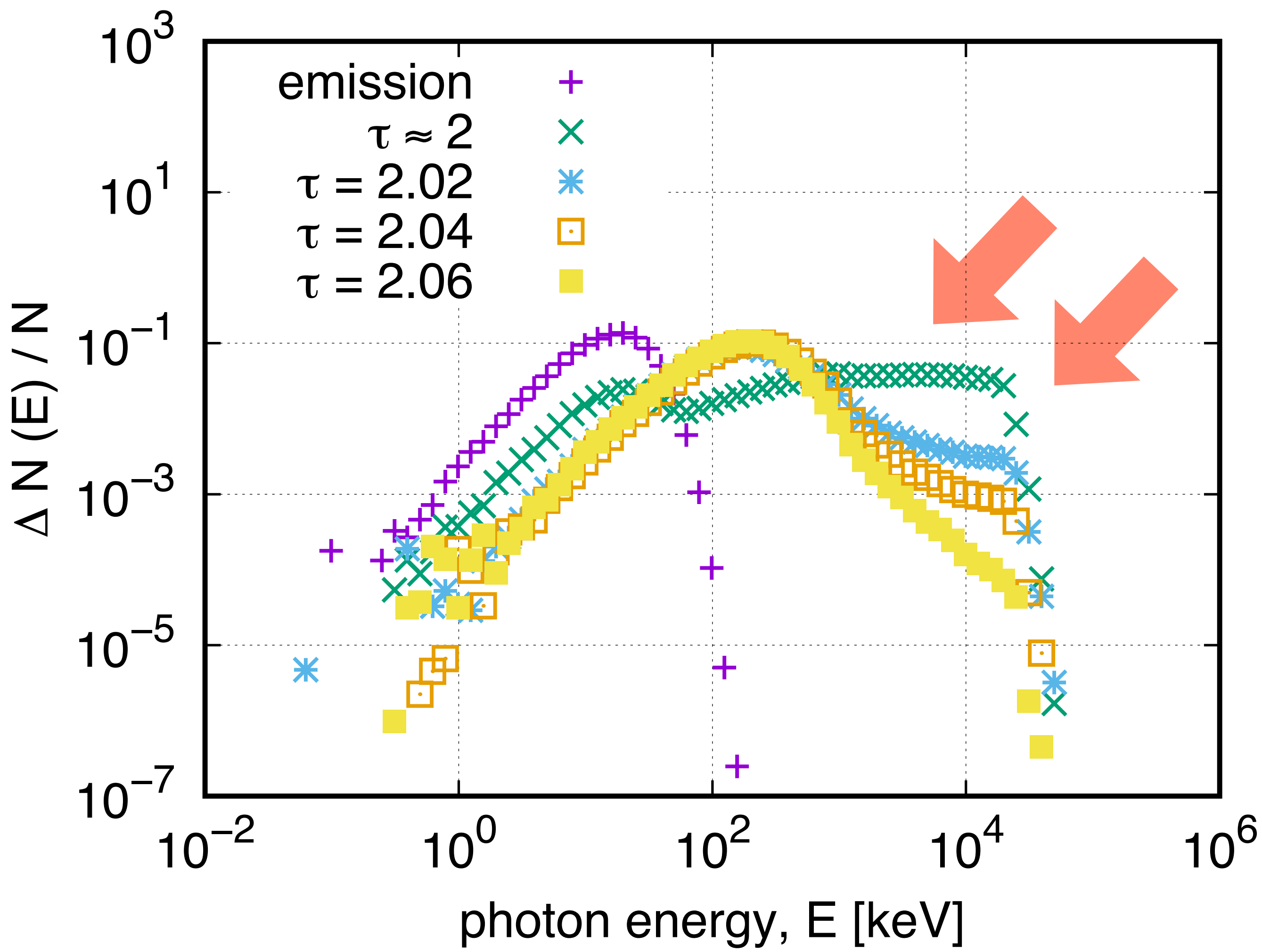


Smeared shock wave

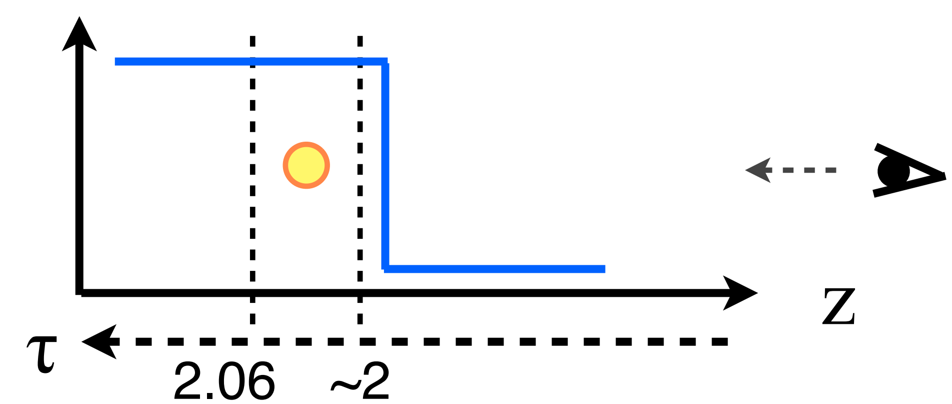


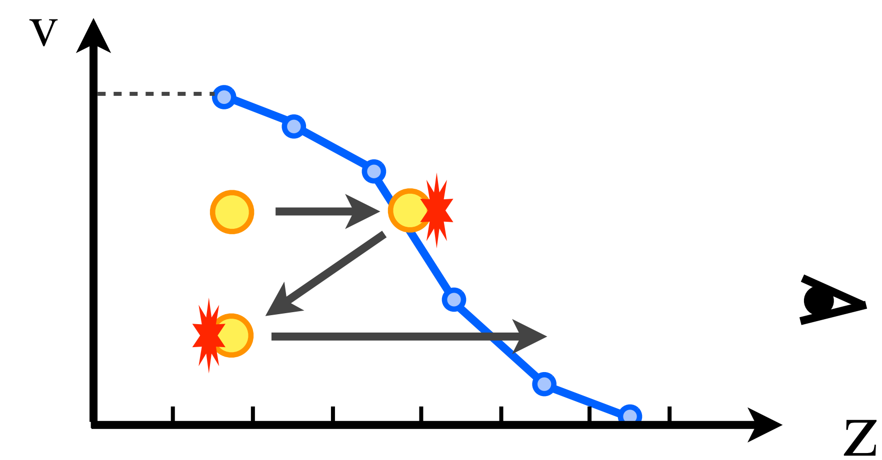
- High-energy component decreases as shock width increases
- In the smeared shock, energy gain by inverse Compton scattering process decreases due to small velocity jump

Spectra with different emitted positions



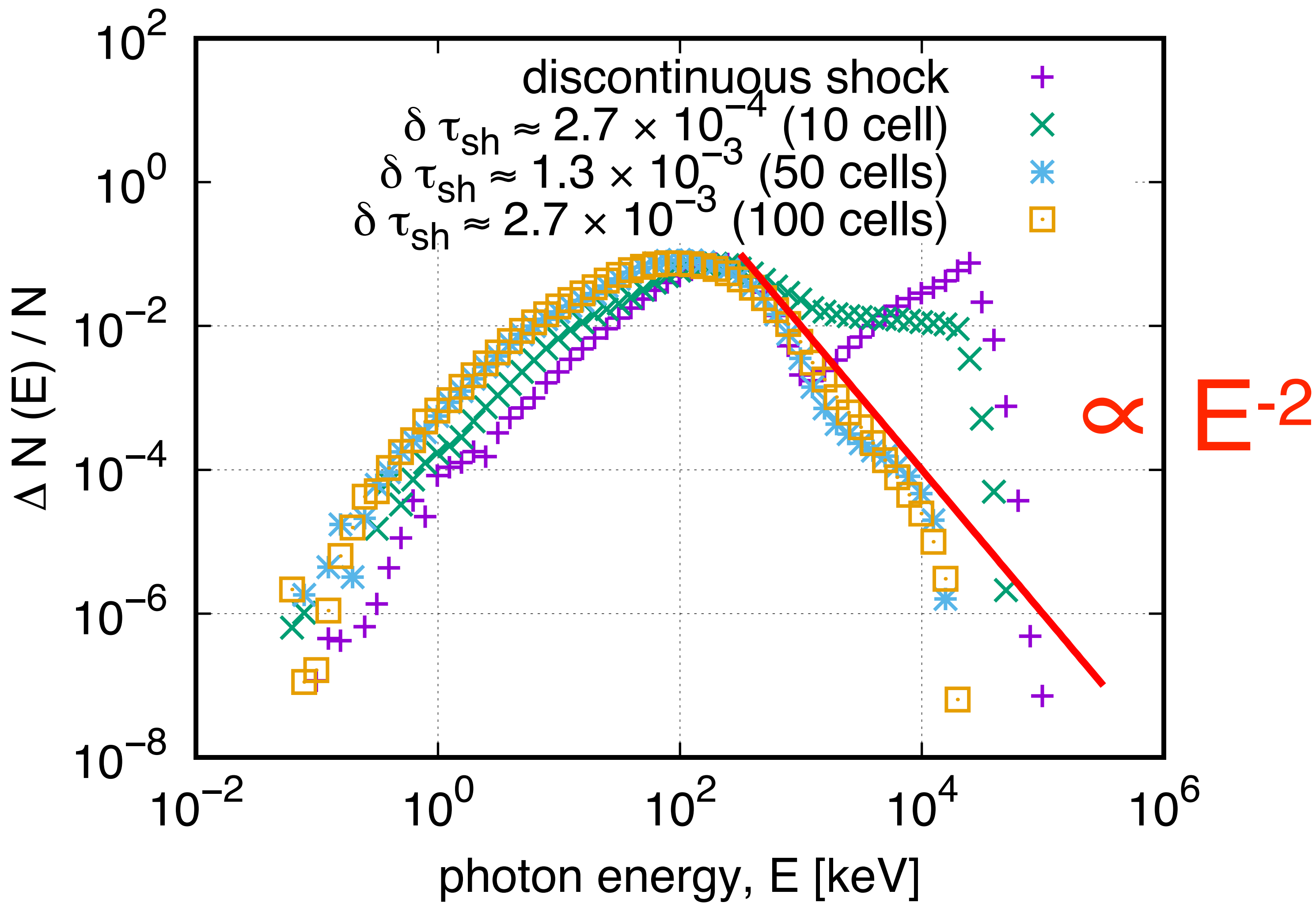
Set up of emitted positions with τ





- High-energy component decreases as initial emitted position becomes deep in optical depth
- With large τ, photons undergoing inverse Compton scattering decreases since photons hardly travel across the shock front

Overlapping spectra with different τ



- Spectra with photon emitted position of τ = 2 - 2.06 are overlapped
- β value approaches the observational one with extended shock front
- Hydro simulation may produce such a widely smeared shock front by numerical diffusion
  →appropriate simulation conditions are required for precise prediction

Summary

Effect of shock steepness and photon initial emitted position on radiative transfer computation has been examined

- High-energy component of spectra decreases as shock width increases
- High-energy component decreases as initial emitted position becomes deep in optical depth
- The β value approaches the observational one with widely smeared shock front

Future works

- Coupled computation of MCRT with 1D relativistic Lagrangian hydro
- Computing radiation mediated shock structure
- Examining the effect of radiative mediated shock structure on the emitted spectra

Thank you for your attention !