2014/07/08 RIKEN-IPMU-RESCEU seminar

Theoretical expectation of supernova shock breakout in the relativistic limit

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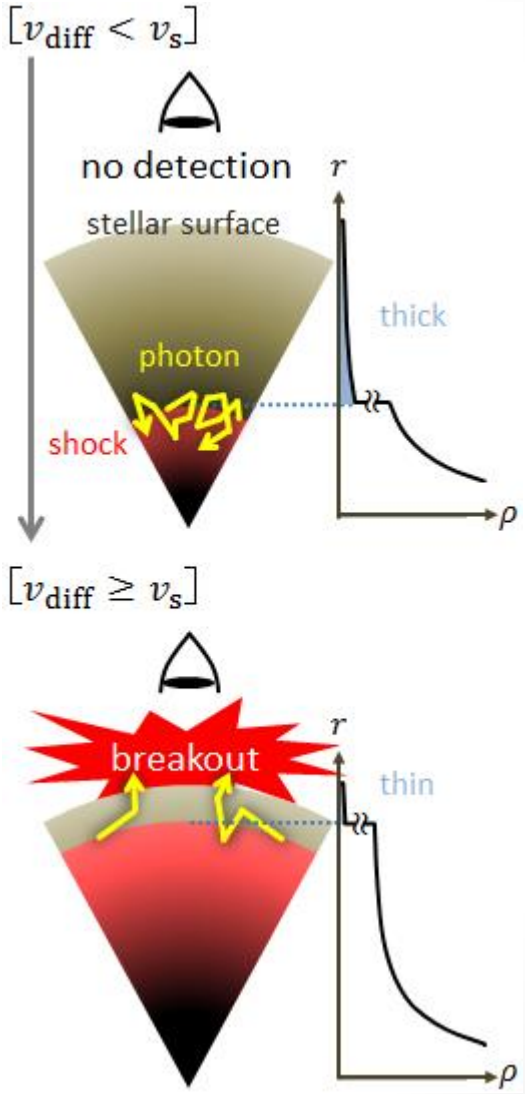
SN shock breakout

Luminous X-ray/UV transient results from the shock passing through the stellar surface

- $\Delta t \sim R/c \lesssim 10^4$ s
- $L_{\rm peak} \gtrsim 10^{43}$ erg s^{-1}



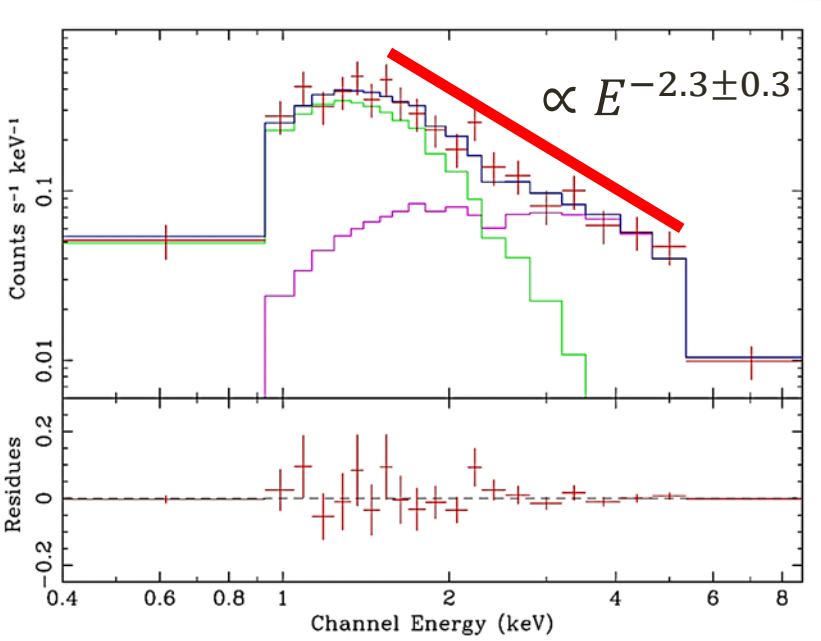
XRO 080109/SN 2008D

detected by Swift/XRT

- $\Delta t = 600$ s
- $L_X = 6 \times 10^{43}$ erg s^{-1}
- $E_X = 2 \times 10^{46}$ erg

- non-thermal component

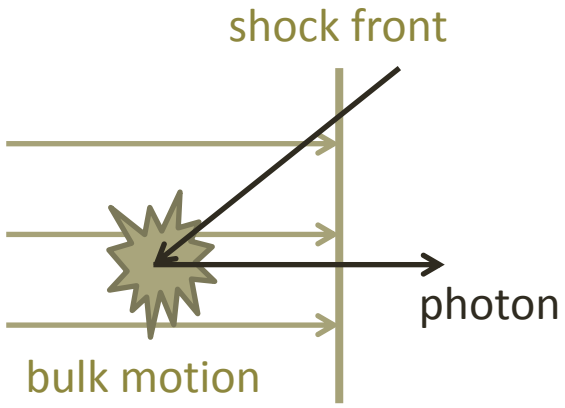
(Soderberg et al. 2008)

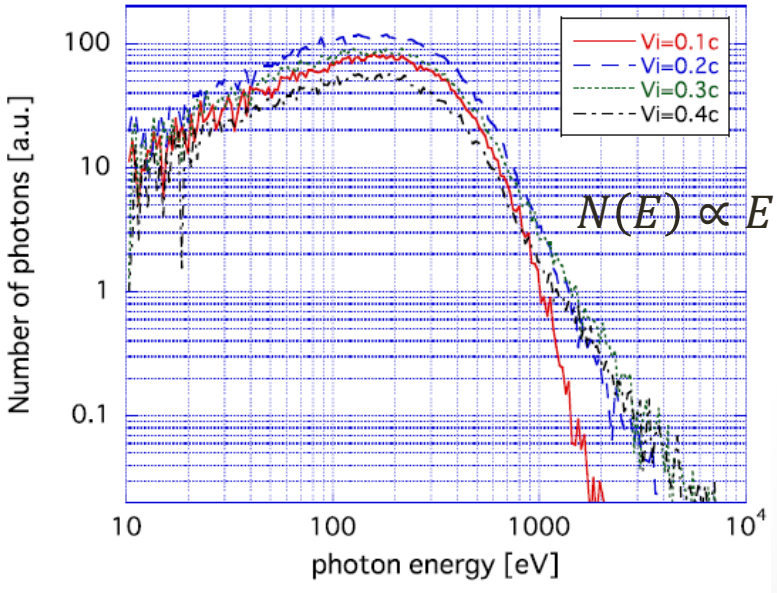


Li, L.-X. (2008)

bulk Compton effect

Repeated scattering by high velocity electrons moving in the radial direction boost the photon energy.





Suzuki and Shigeyama (2010)

When $V_s \geq 0.3\ c$, the non-thermal component of XRO 080109 can be reproduced.

SB in the relativistic jet

- Wolf-Rayet star
- shock Lorentz factor ~ 100
- γ-ray photons
- correlation with GRBs

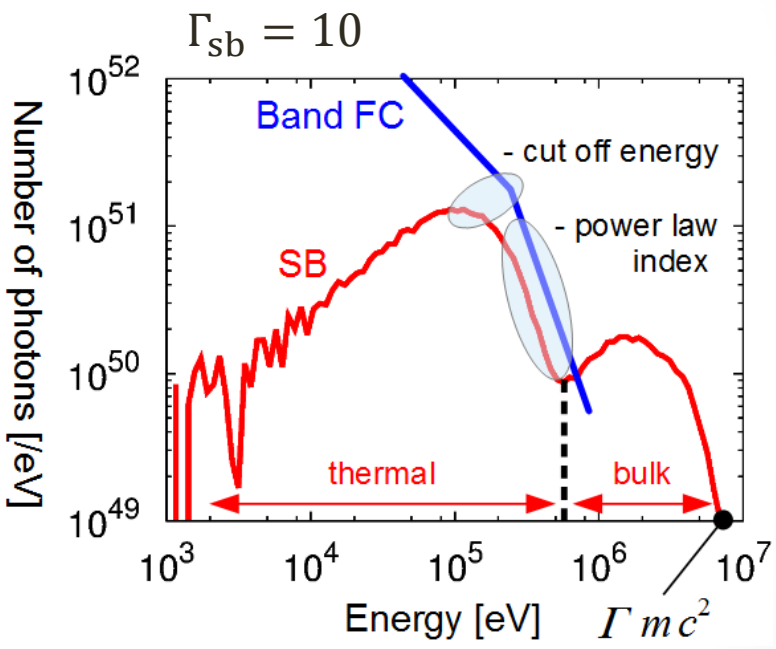
SB at stellar surface

thermal

- integration of Doppler shifted blackbody radiation

non-thermal

- comparable to the electron rest energy in the comoving frame



(Ohtani et al. 2013)

SB at stellar surface

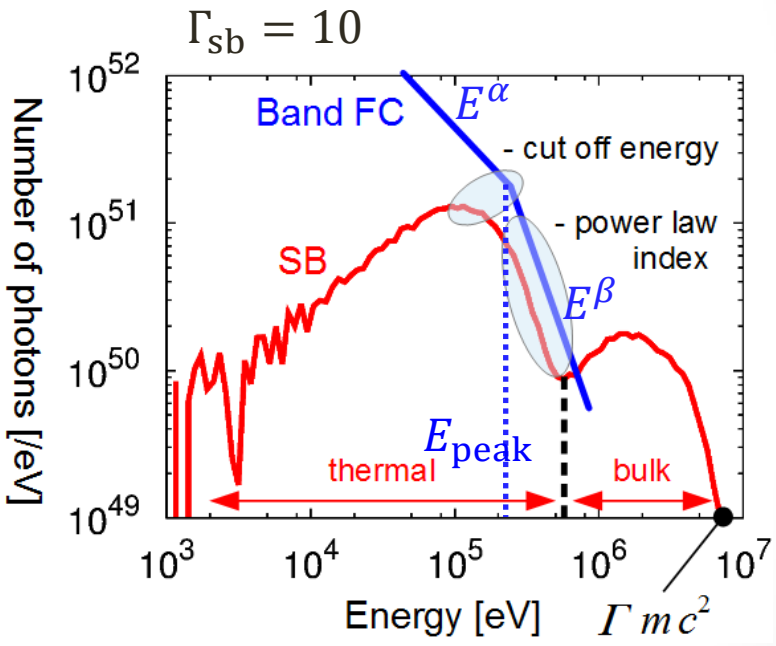
Consistent with GRBs

- cut-off energy
- the logarithmic slope of the higher energy side of the Band FC

Inconsistent with GRBs

- the lower energy side of the Band FC
- duration ($\ll 2$ s)
- total energy ($< 10^{49}$ erg s^{-1})

(Ohtani et al. 2013)



$\alpha = -1.0$	$+0.9$
$\beta = -2.5$	-2.2
$E_{\rm peak} = 250$ keV	120 keV

SB in the CSM

- thermal radiation at lower temperatures than that of the stellar surface
  - lower energy component of the Band FC ?

- larger size of the region
  - extended duration ?

Model

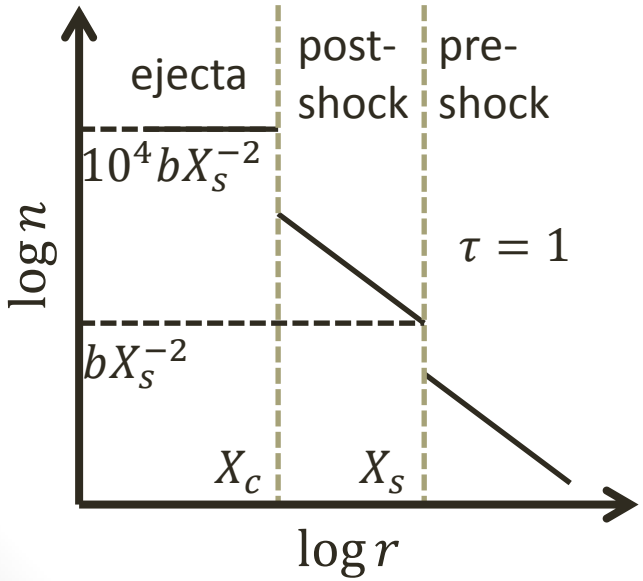
Blandford and McKee (1976)

Initial

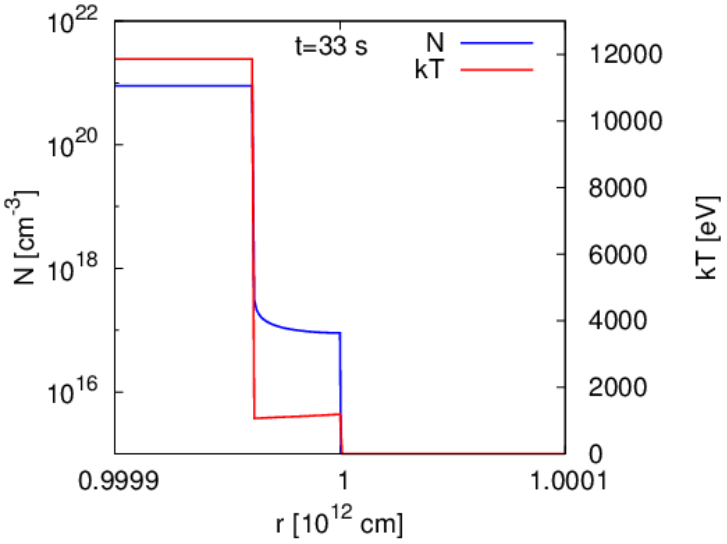
- $n \propto r^{-k}, k = 2$

shock

- $\Gamma \propto t^{-m/2}, m = 0$

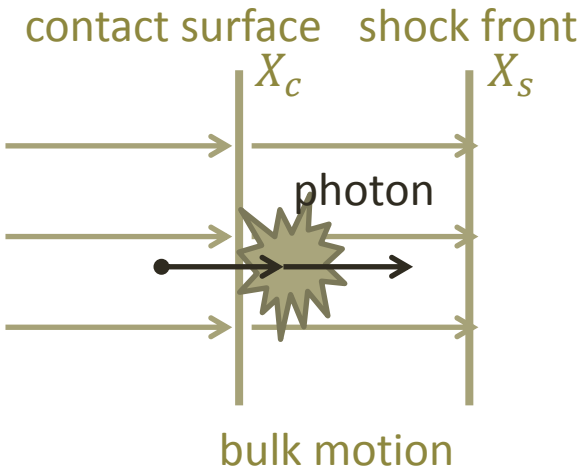


$\Gamma = 100, R_{\rm sb} = 10^{12}$ cm

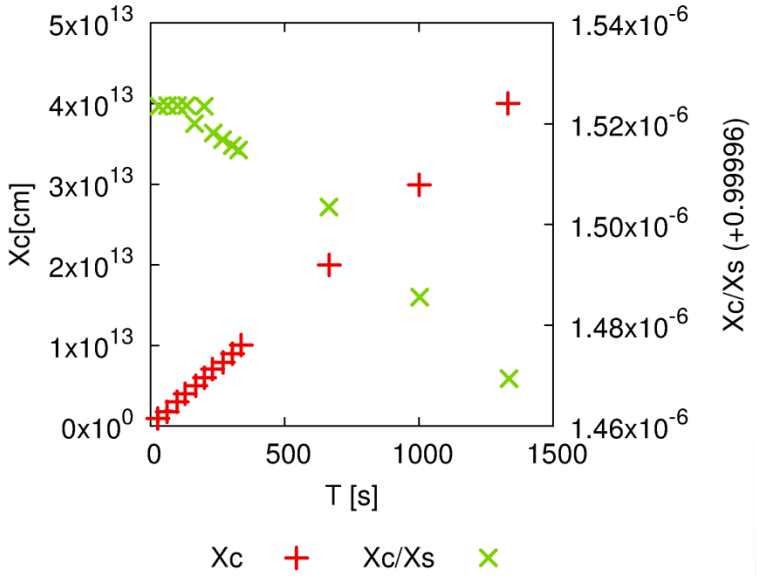


MC code

inverse Compton scattering + free-free absorption



photosphere: the position at which 50% of generated photons can be escaped, and other photons are absorbed



Most of photons are generated behind the contact surface.

Generation of photons stops when the shocked matter become thin.

Overview of photon traveling

"straight on" photons (= radial)

- enhanced upto $E_{\max} = \Gamma mc^2$
- scattering dominant

"deviated" photons (≠ radial)

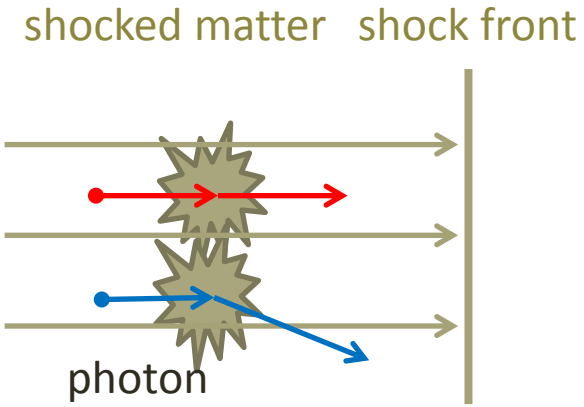
- degrated
- absorption dominant

$\alpha_s = \sigma_{\mathrm{KL}} n \propto n$

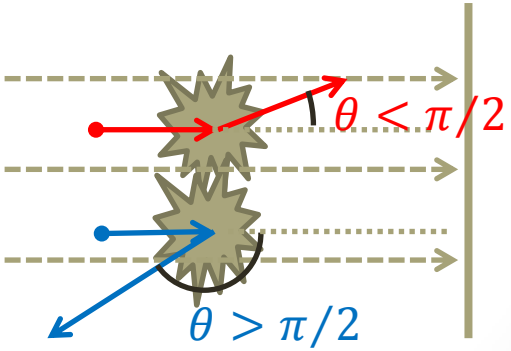
$\alpha_{\mathrm{ff}} \propto \left(1 - e^{-E/k_b T}\right) n^2$

"Deviated" photons are tend to be generated at later time than "straight on" photons.

in the observer's frame

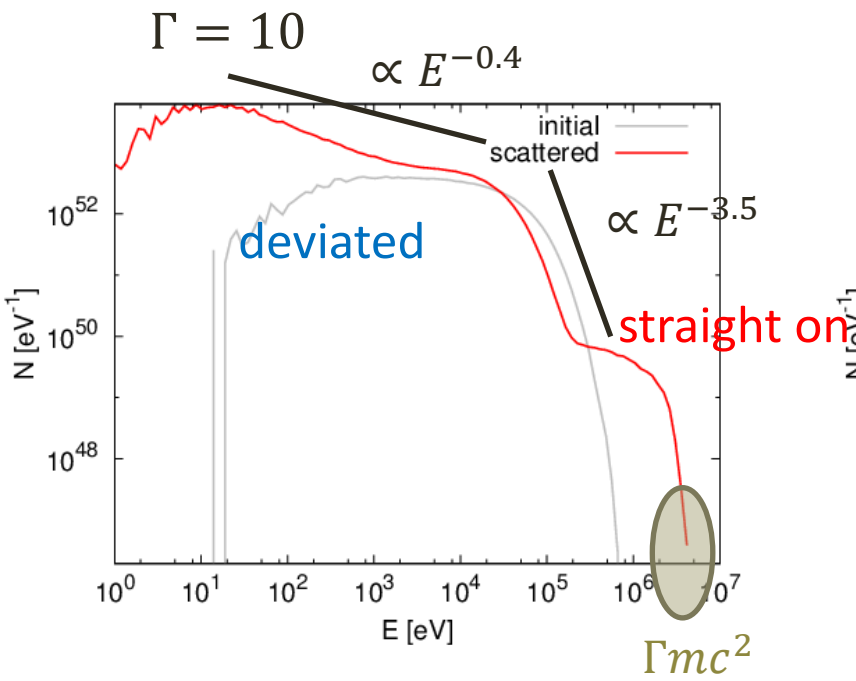


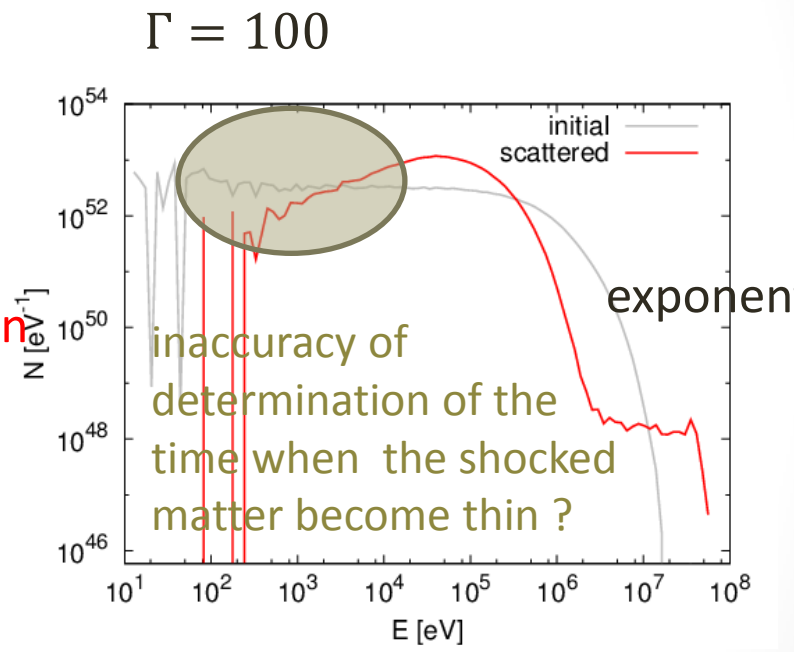
in the comoving frame



Spectra

initial photon = integration of the Doppler shifted blackbody emission



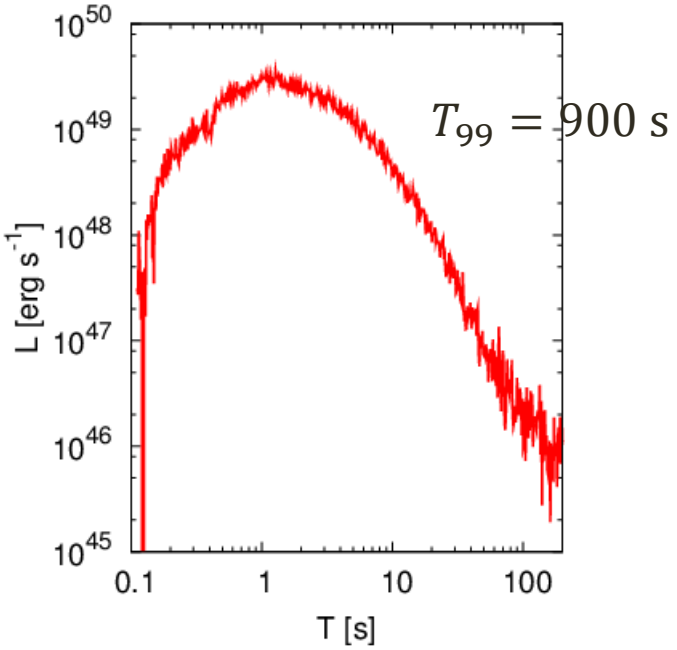


breakout needs to occur in accelerating phase ?

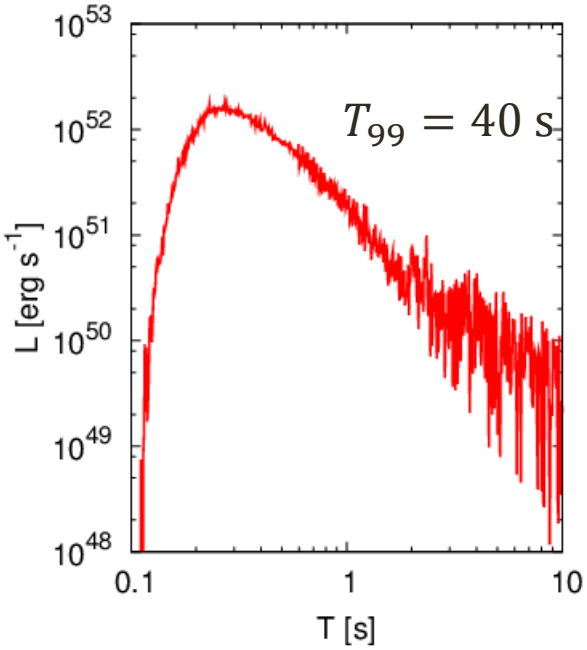
Light curve

< 0.3 keV: removed

$\Gamma = 10$



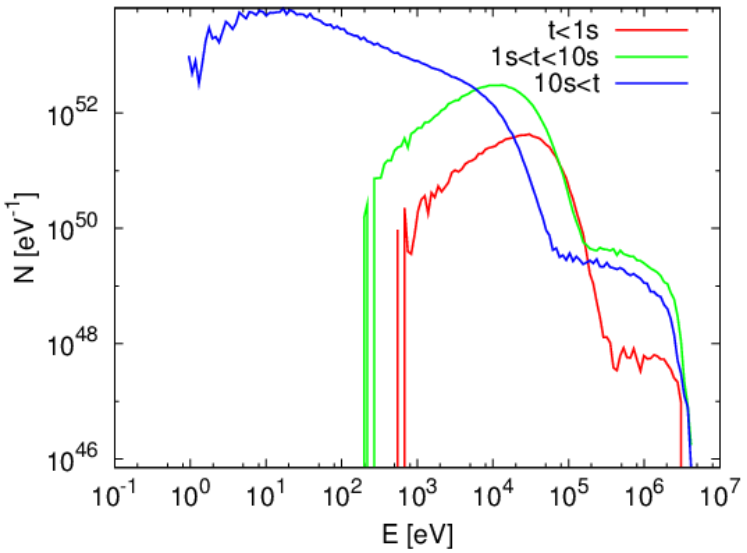
$\Gamma = 100$



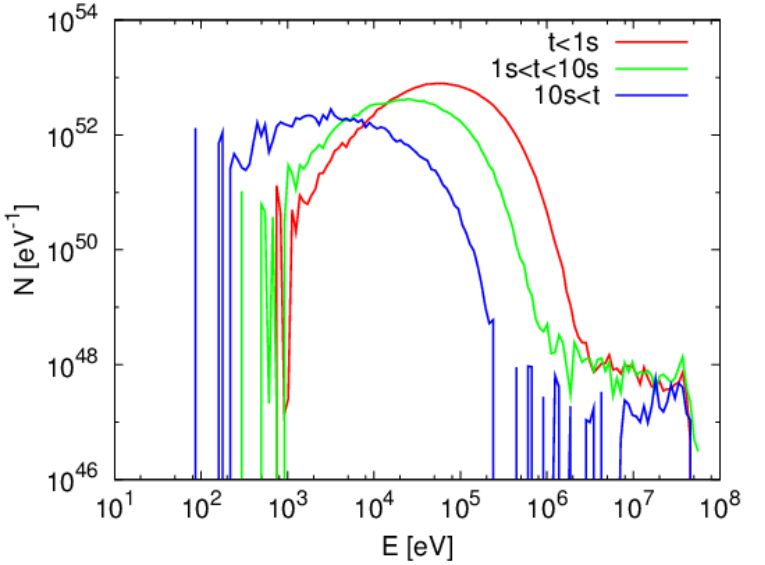
- The timescale is determined by diffusion. ($\propto 1/\Gamma$)
- Low-energy photons are tends to delay.

Spectral evolution

$\Gamma = 10$



$\Gamma = 100$



"Deviated" photons are tend to delay by several seconds in their arrival time.

Summary

radiation from the shocked matter in CSM (constant Γ)

- duration $\gtrsim 10$ s
- early: high energy bulk component
- later: lower energy

- not power-law, but exponential

our next calculation: breakout at the accelerating phase