2017/2/21 IAUS 331 “SN 1987A, 30 years later”@Reunion Island

Properties of X-ray emission of an aspherical shock breakout

Yukari Ohtani (NAOJ),
Akihiro Suzuki (Kyoto Univ.),
Toshikazu Shigeyama (Univ. of Tokyo), and Masaomi Tanaka(NAOJ)

Shock breakout

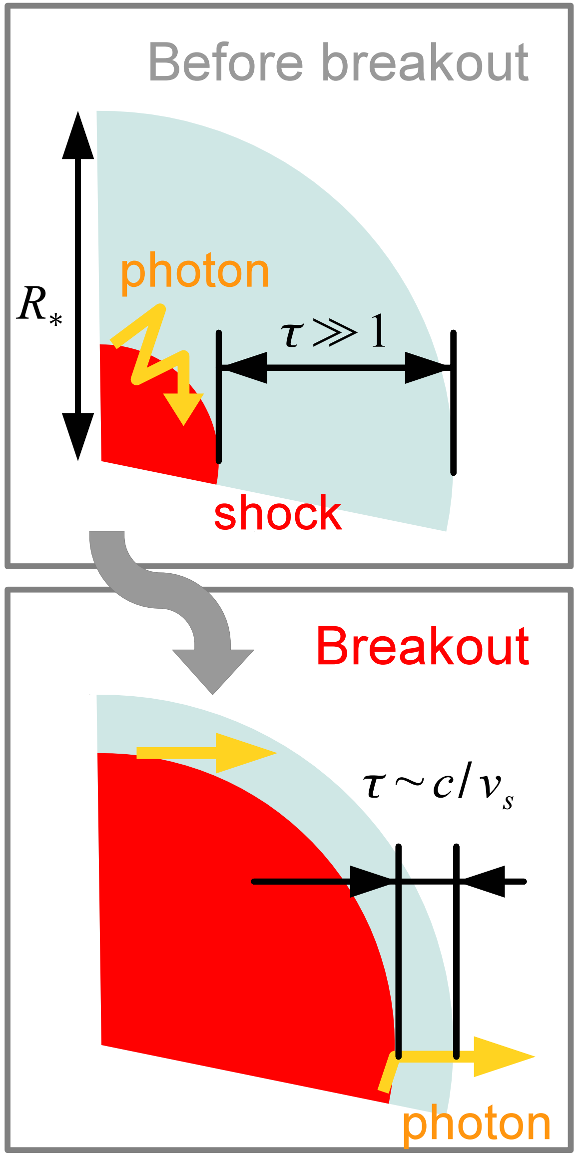
Bright UV/X-ray emission when the shock reaches the stellar surface

When V_{diff} exceeds V_s , photons can escape upstream

- V_{diff} : diffusion time of photons
- V_s : shock velocity

Timescale

- light crossing time of the size of the emission region
- diffusion time of photons



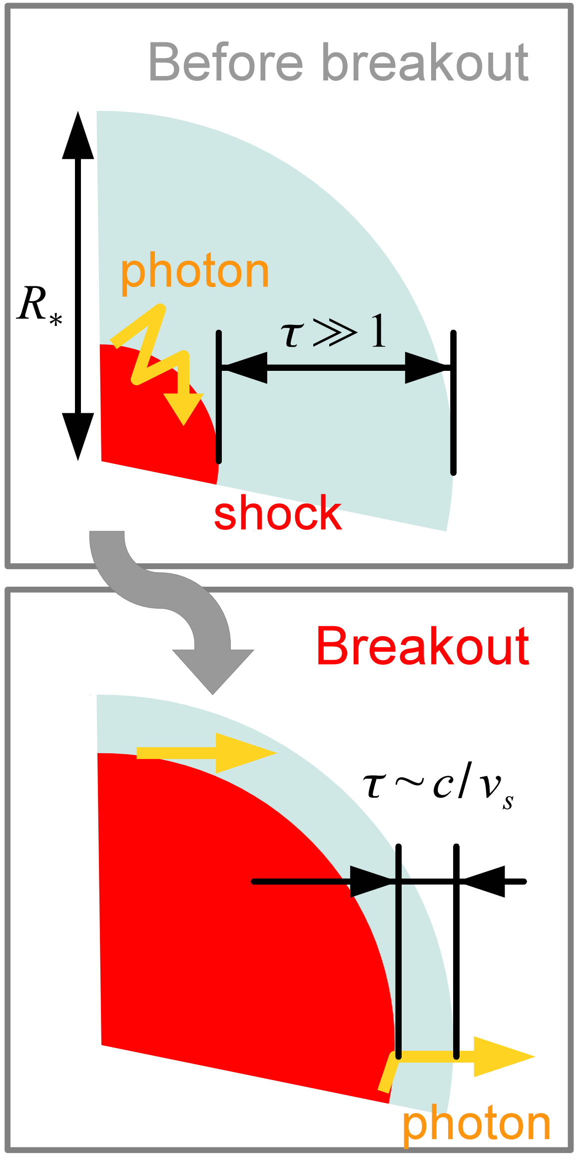
Shock breakout

Highly sensitive to

✳ **motion of the shock**

✳ **distribution of the surrounding matter**

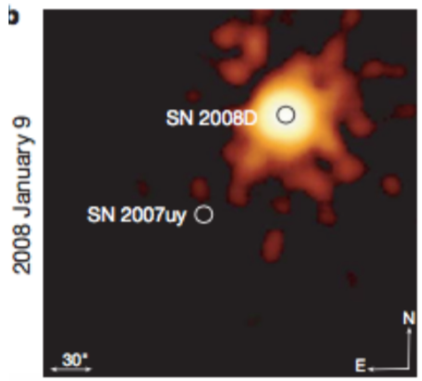
- SN explosion mechanisms
- stellar evolution just before the explosion



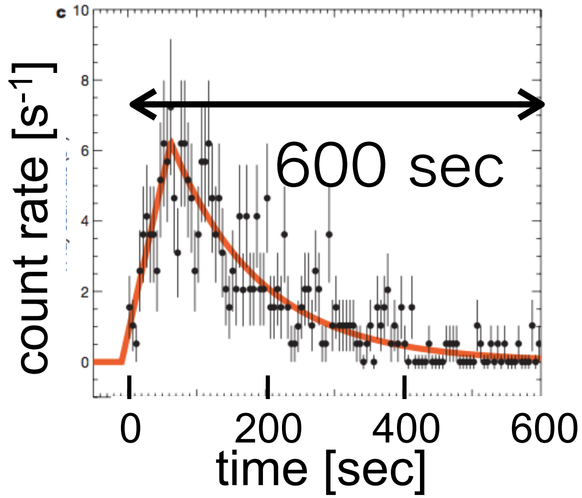
XRO 080109/SN 2008D

(Soderberg et al., 2008)

- Type Ib SN
- lasting ~ 600 sec
  (→ R_b ~10^{12} cm > WR star → **CSM**)



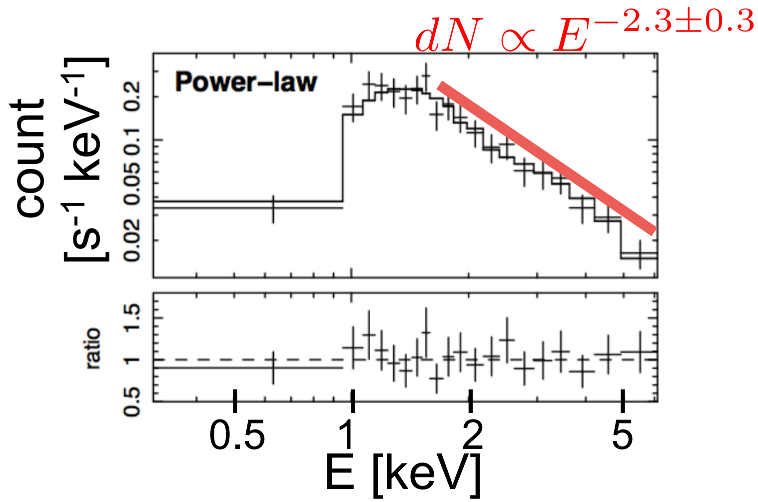
- **X-ray light curve**
  - **rapid rise & exponential decay**



Shape of the shock ?

(e.g., Suzuki & Shigeyama 2010a, Couch et al., 2011)

- **X-ray spectrum**
  - **power-law distribution**



Influence of bulk Compton scattering ?

Shock velocity

(Suzuki & Shigeyama 2010b)

Purpose of this study

How the emission properties of SN shock breakout emission in a CSM depend on

- **the motion of the shock wave ?**
  - SN explosion mechanism

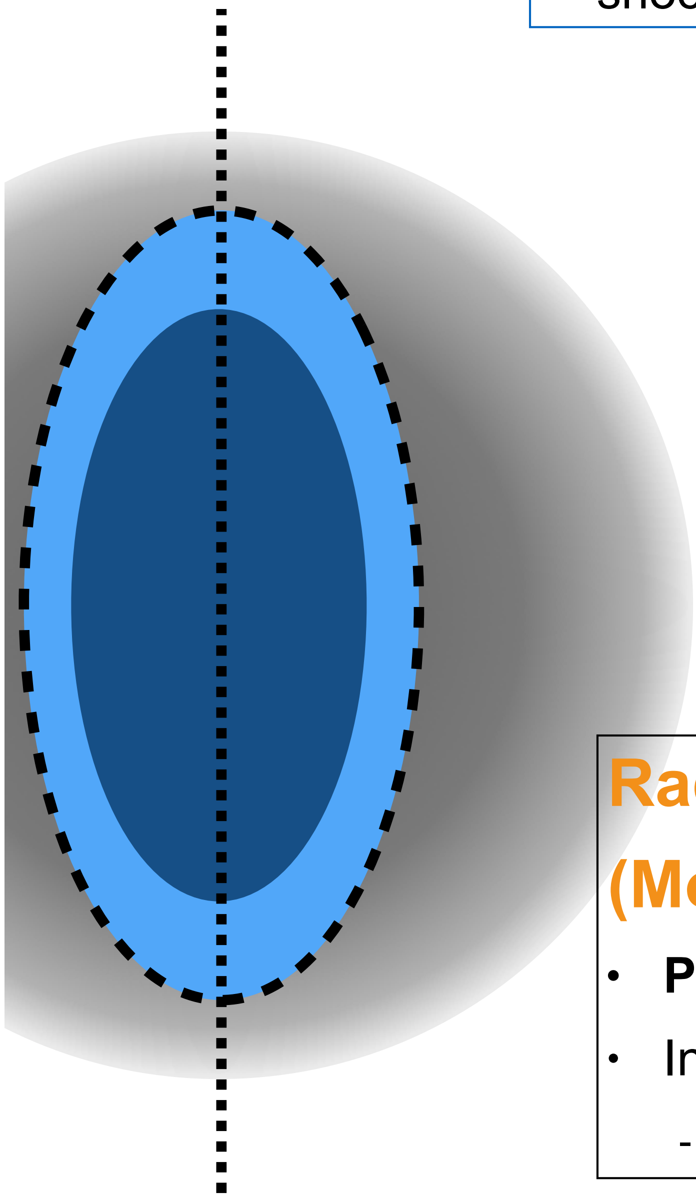
- **the distribution of the CSM ?**
  - last stage of stellar evolution

Settings

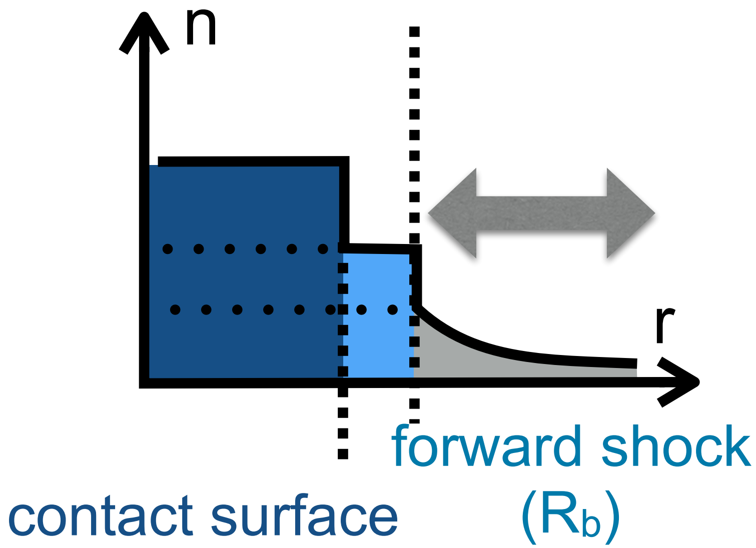
Toy model:

Ellipsoidal shock
- shock velocity Vs

Stationary CSM
- Mdot



The shock breaks out



Radiative transfer calculation (Monte-Carlo method)

- **Photosphere = shock front**
- Interaction
  - **Inverse-Compton scattering** & Free-free absorption

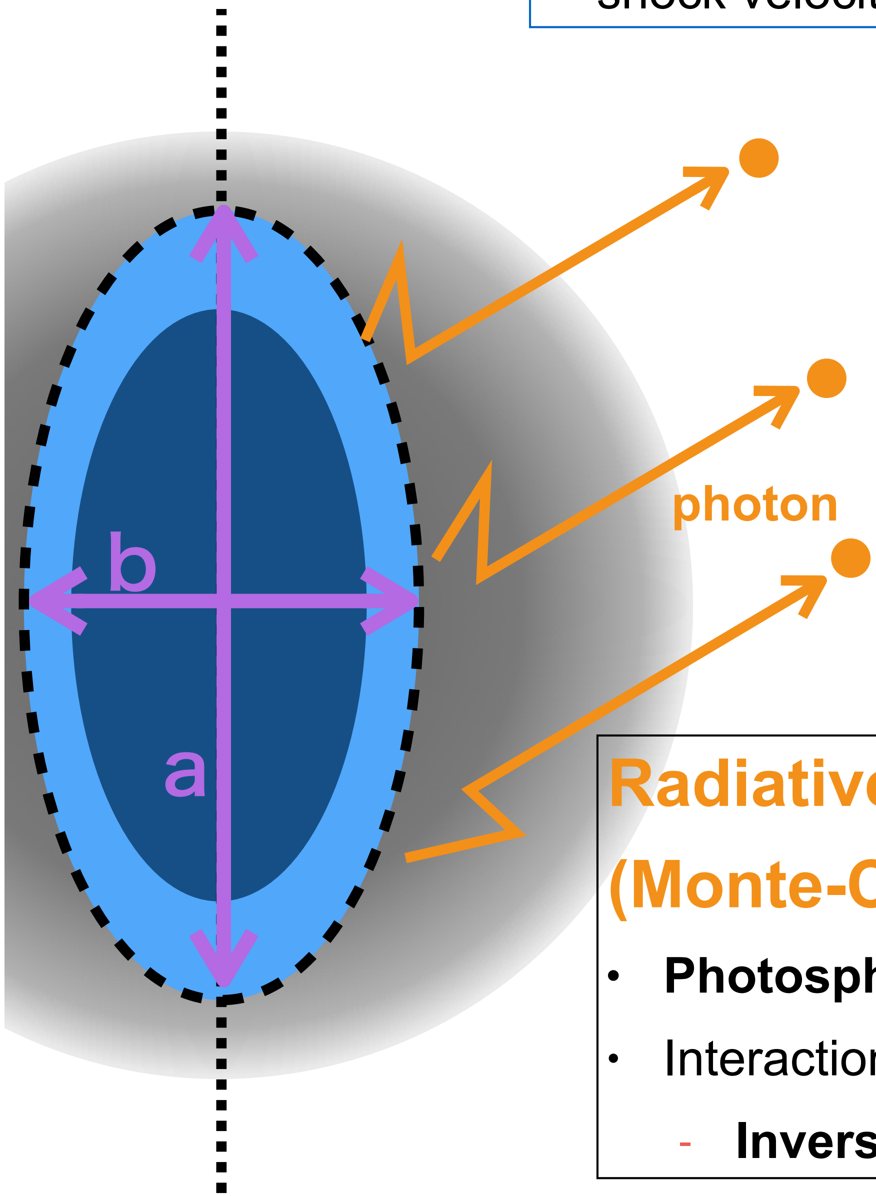
Settings

Toy model:

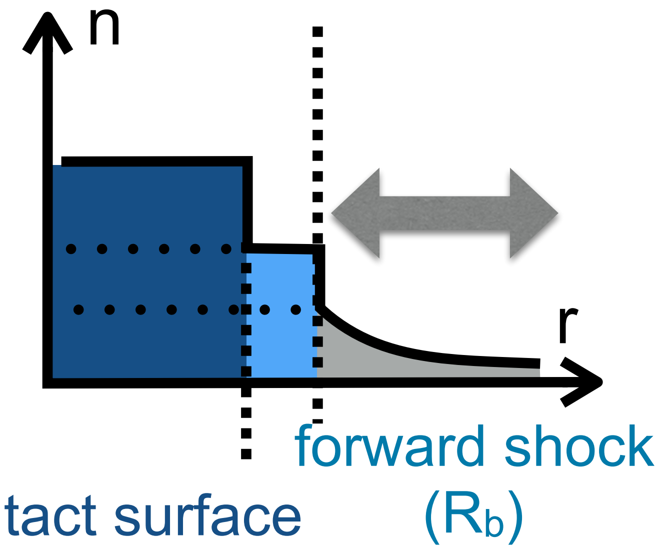
Ellipsoidal shock
- shock velocity Vs

→

Stationary CSM
- Mdot



The shock breaks out



Radiative transfer calculation (Monte-Carlo method)

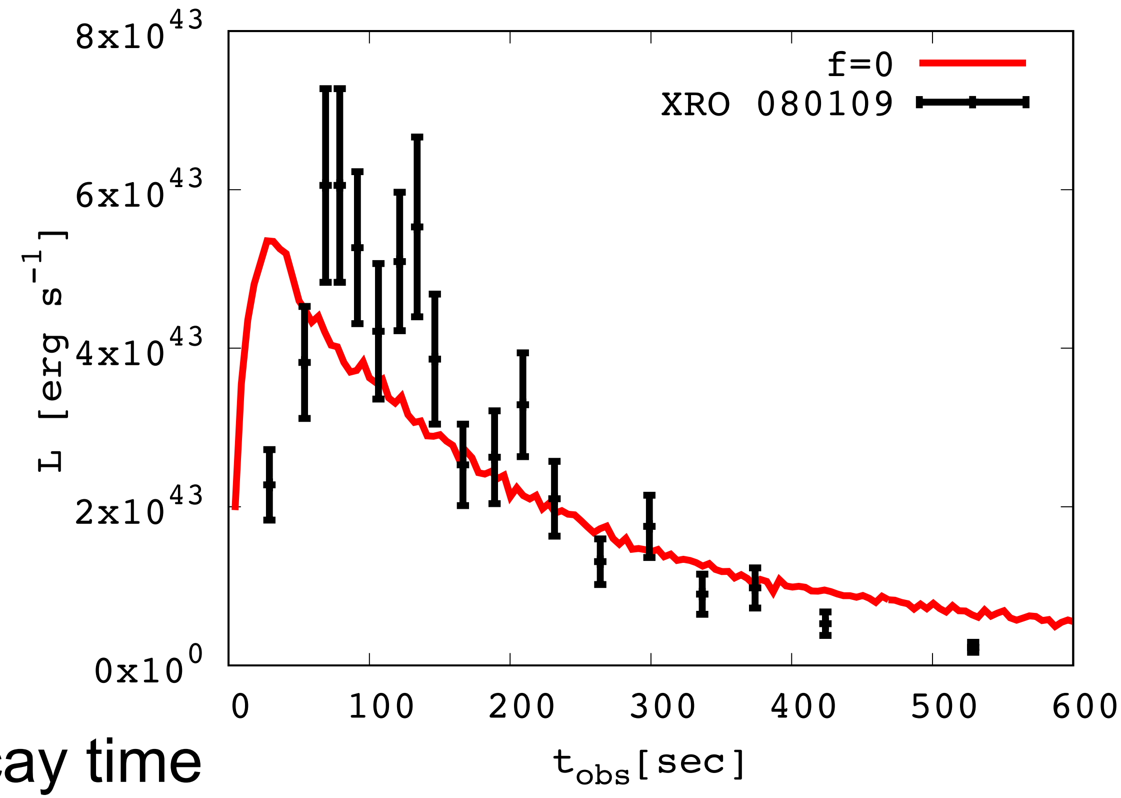
- **Photosphere = shock front**
- Interaction
  - **Inverse-Compton scattering** & Free-free absorption

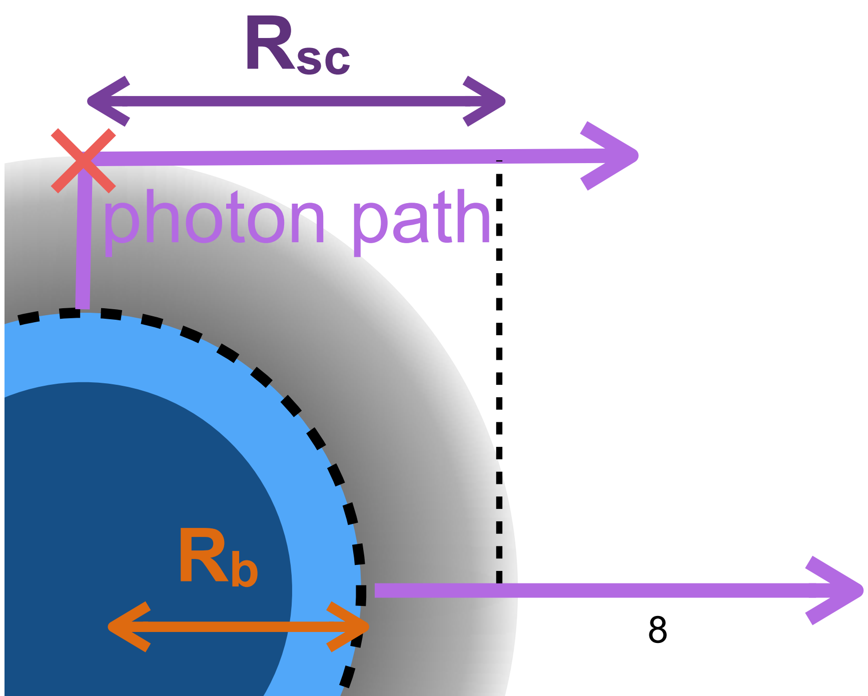
$$f = \frac{a - b}{a}$$

Spherically symmetric case (f=0, Vs=0.6c, Mdot=5 x 10^{-4} Msun /yr)

rise time

- light crossing time of the breakout radius (R_b) ~ 30 sec



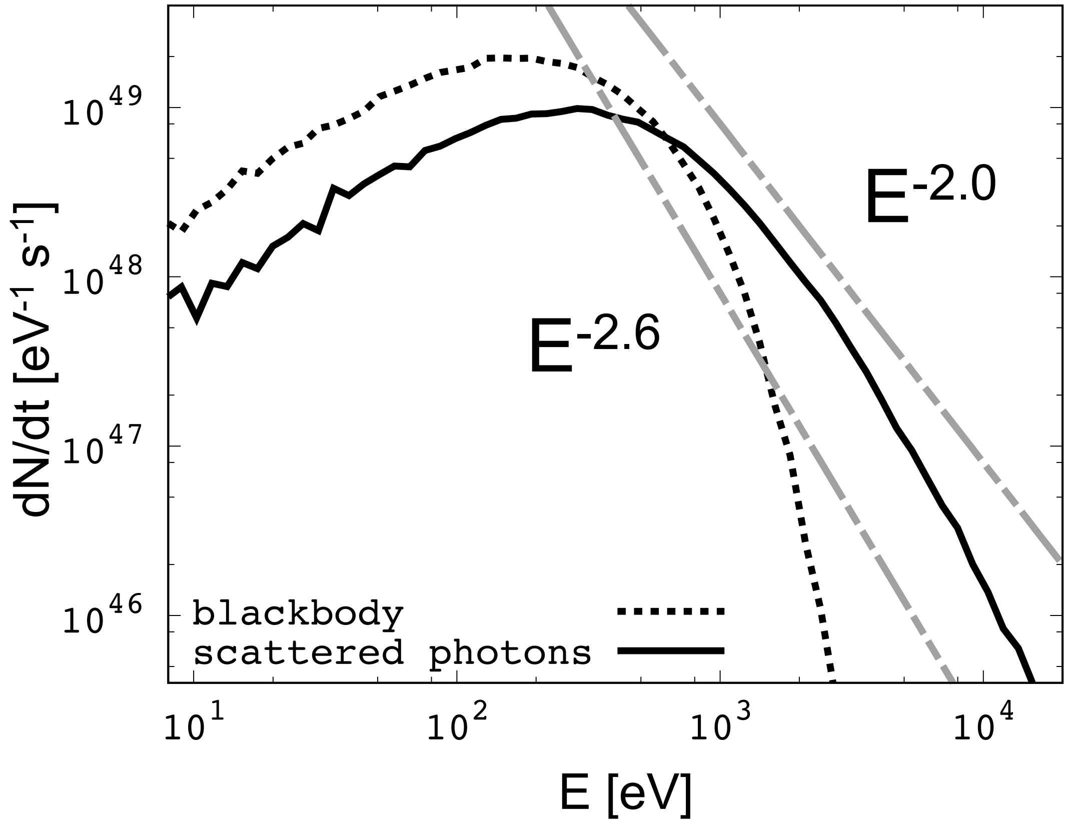


decay time

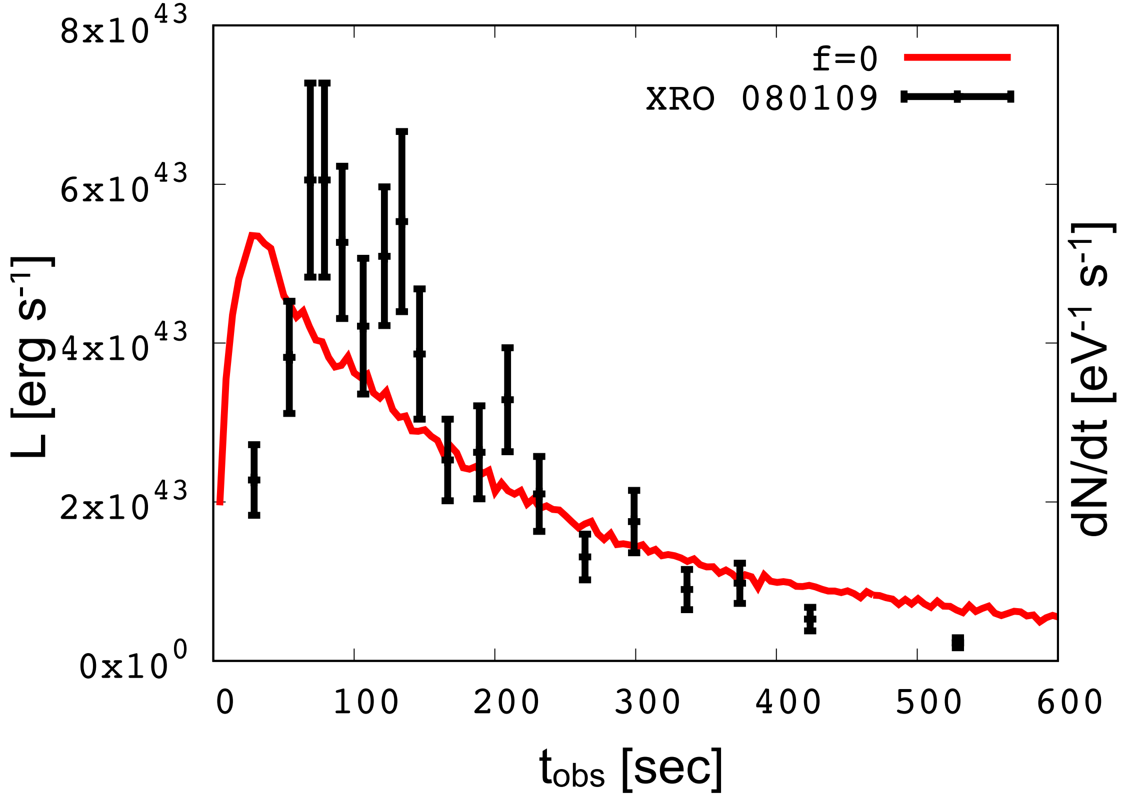
- light crossing time of the radius R_{sc} where photons are scattered at the last time ~ 10^{13} cm/c~1000 sec
- diffusion timescale in the unshocked CSM is short enough (several hundred sec)

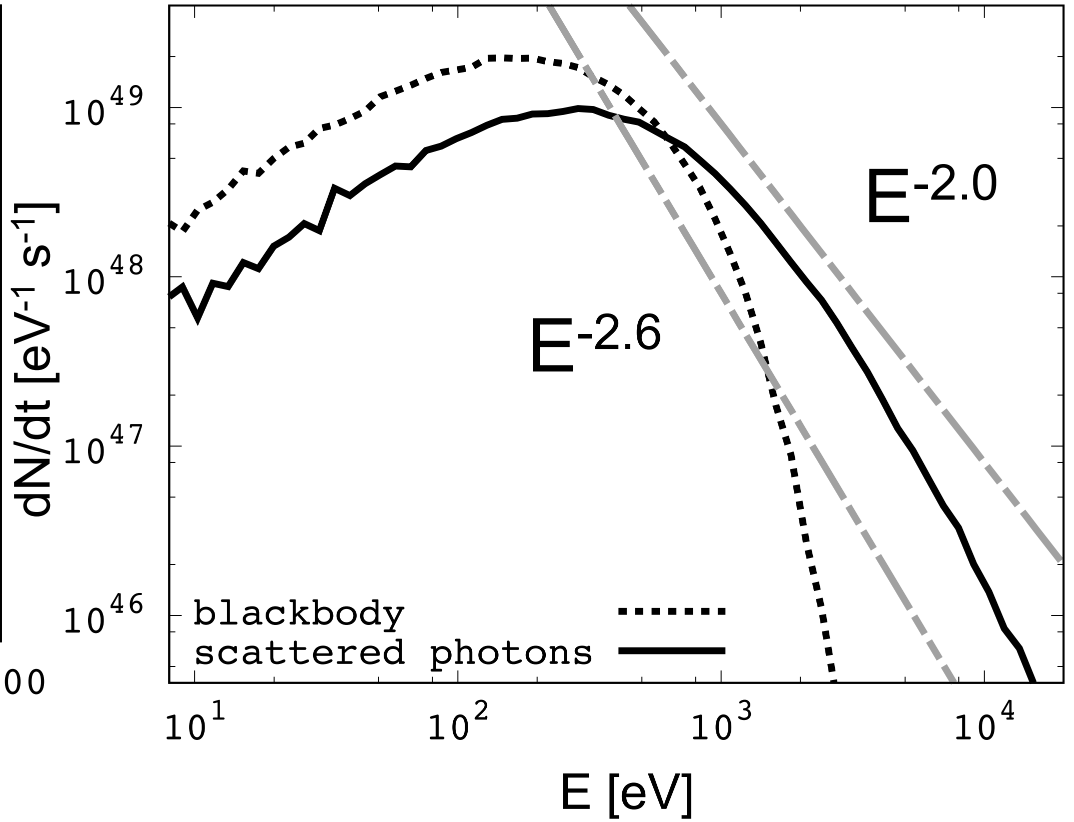
Spherically symmetric shock (f=0)

- The maximum photon energy = electron kinetic energy



Comparisons with XRO 080109 (f=0)





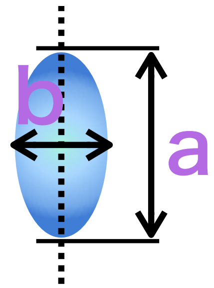
It is possible to explain the overall shape of the observed X-ray light curve and spectrum by considering emission from a spherical shock wave.

- Mdot=5x10^{-4} Msun yr^{-1}
- V_s ~ 0.6c

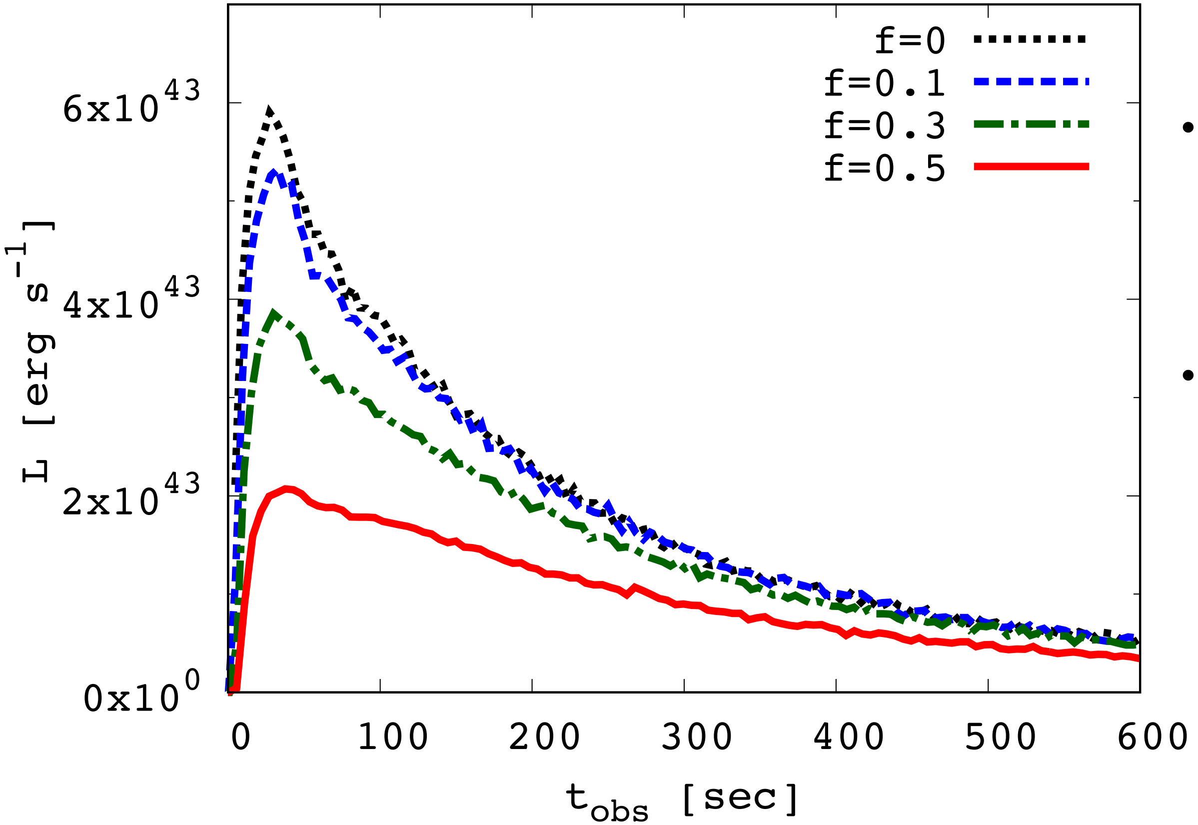
Asymmetric shock (f>0)

Dependence on the shock asphericity

$$f = \frac{a-b}{a}$$



(Θ=[80,90] deg)



- rise time → light crossing time of the breakout radius
- decay time → light crossing time of the radius R_{sc} where photons are scattered at the last time

No difference in the rise & decay timescales.

(The luminosity is velocity dependent.)

Conclusions

- It has been suggested that shock breakout can contain information on the shock asphericity and CSM
- Radiative transfer calculation by taking bulk-Comptonization into account

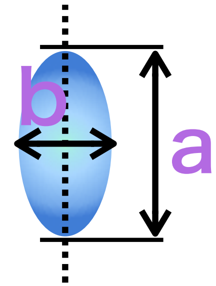
- **We reproduce the observed X-ray light curve and spectrum of XRO 080109 with**
  - **Mdot ~ 5 x 10^{-4} Msun yr^{-1}**
  - **Vs ~ 0.6c**

- The overall shape of the X-ray light curve and spectrum do not significantly change with the degree of shock asymmetry
- **The light curve and the spectrum would be uniquely determined by the wind mass loss rate and the shock velocity**

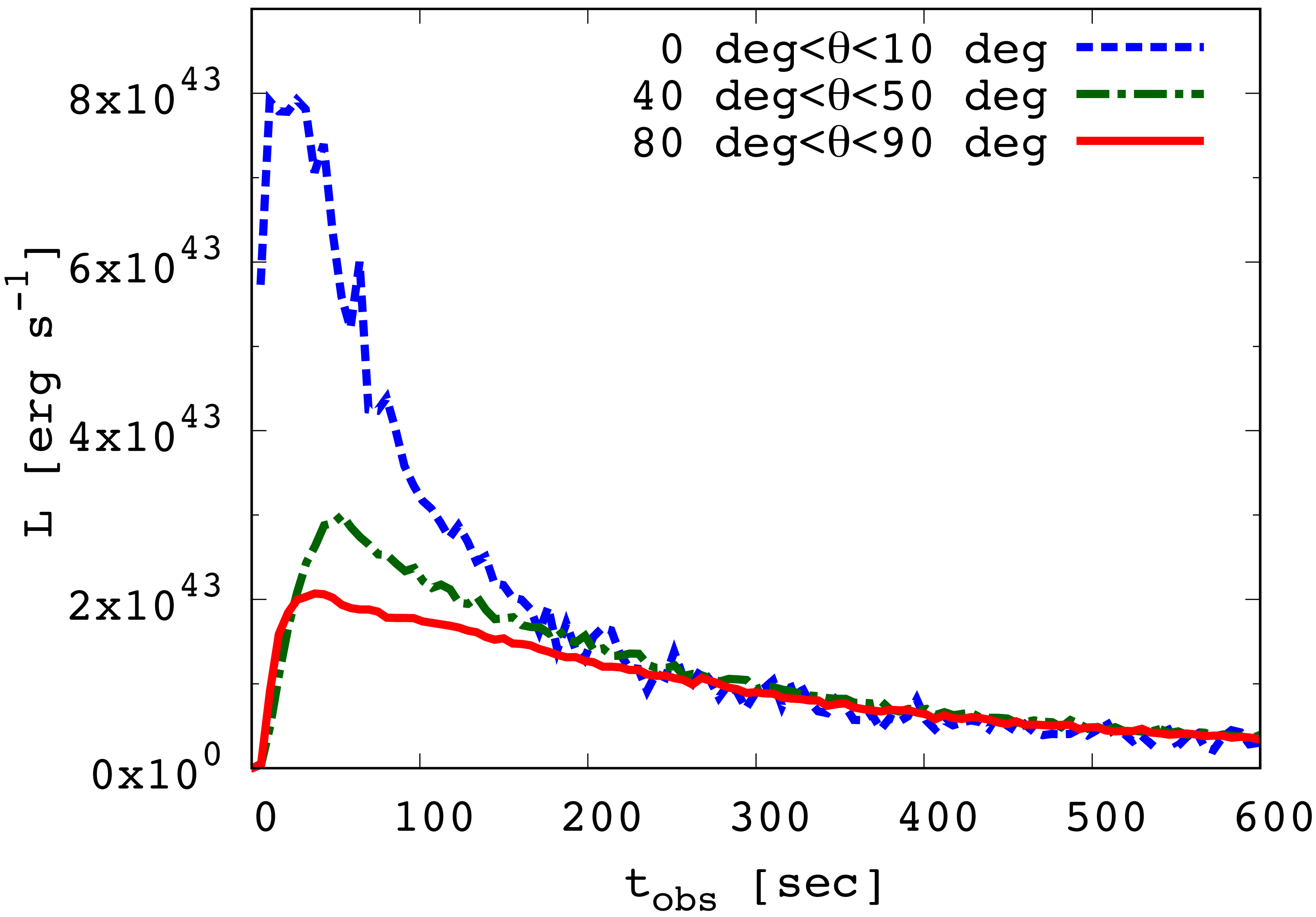
Thank you for your attention !

Asymmetric shock (f>0)

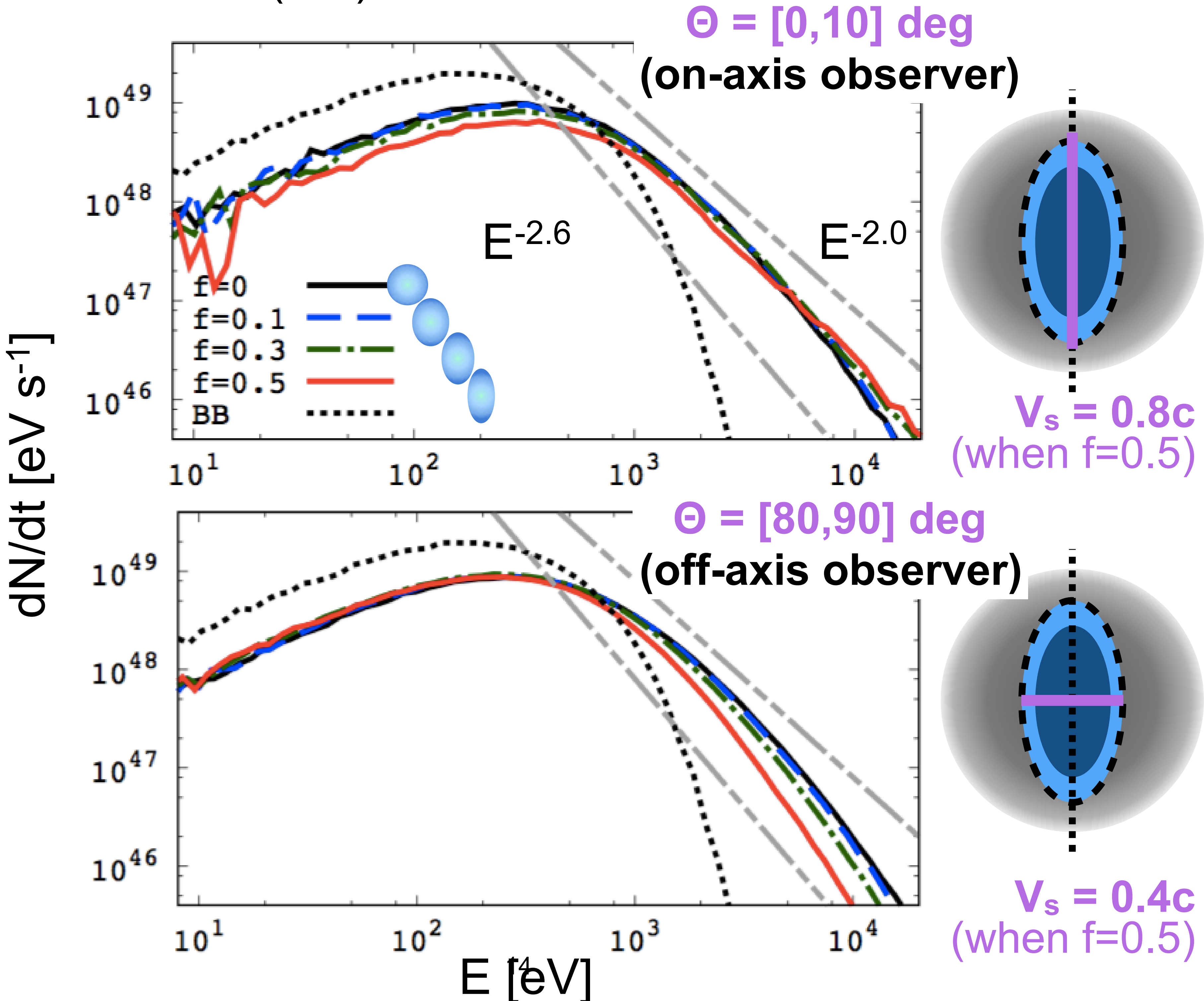
$$f = \frac{a - b}{a}$$



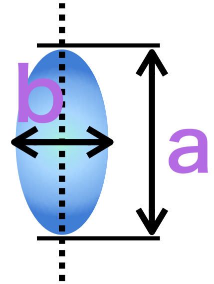
Θ-dependence (f=0.5)



Asymmetric case (f>0)



Light curves in different energy bands



- E < 0.3 keV
- 0.3 keV < E < 10 keV

$$f = \frac{a - b}{a}$$