Monte Carlo Simulation for Thermal Radiation from GRB Jet

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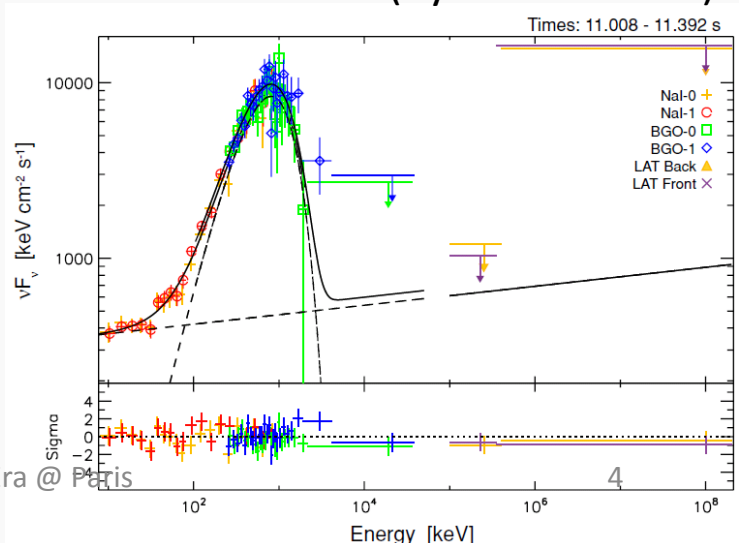
Introduction

Models for the prompt emission

- Internal shock model
  - A standard scenario for a long time.
  - Some problems (e.g., low energy spectral index)
- Photospheric (thermal emission) model
  - Thermal emission from relativistic jets
  - Some GRBs exhibit blackbody like feature (e.g., GRB090902B).

(Ryde et al 2010)



Photospheric emission?

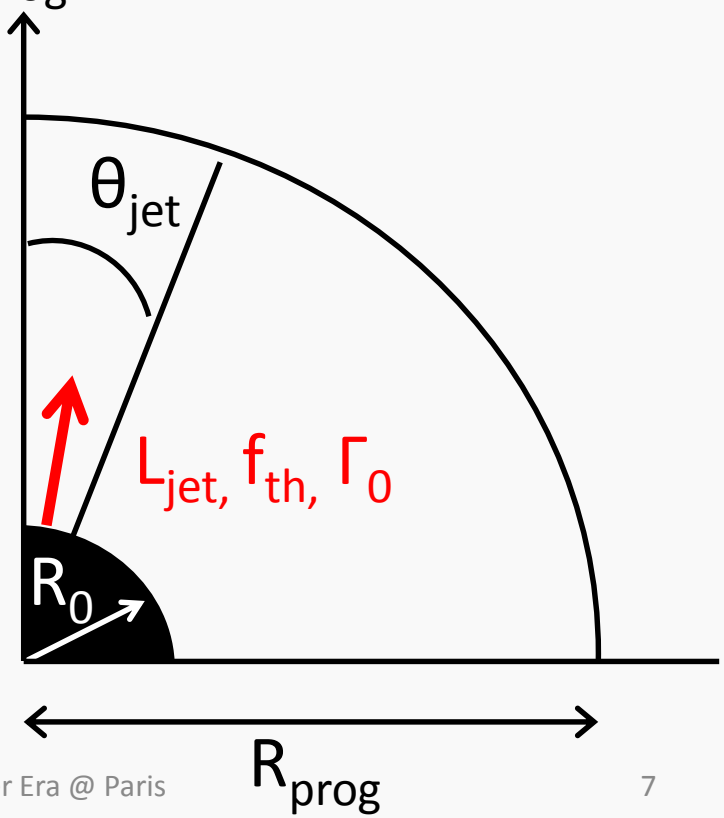
- The dominant opacity source in the jet is electron scattering.
- The photosphere is a surface of τ_{scat}=1.
- The actual position of the photon production is much inner region. (e.g., Beloborodov 13)

→ Necessity of the radiative transfer

Method

Hydrodynamic simulation

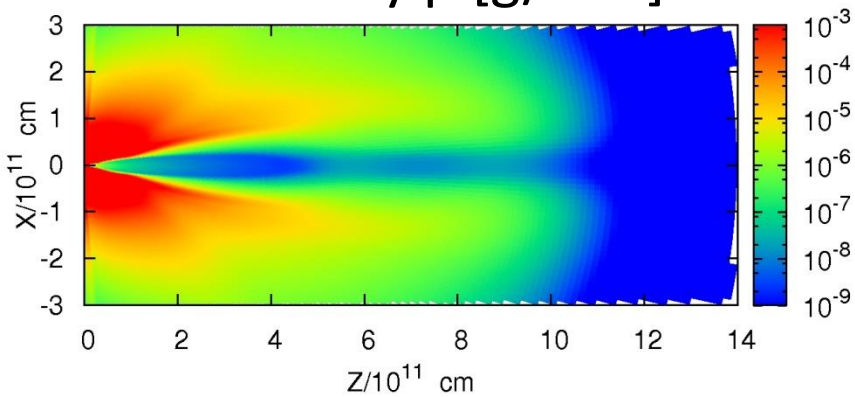
- ✓ 2D relativistic hydrodynamics (Tominaga 2009)
- ✓ Setup
  - Progenitor: $15M_{sun}$ WR star ($R_{prog} \sim 2.3 \times 10^{10}$cm)
  - $\Gamma_0=5$
  - $\Theta_{jet}=10^\circ$
  - $L_{jet}=5.3 \times 10^{50}$ erg s^{-1}
  - $f_{th}=0.9925$ ($e_{int}/\rho c^2=80$)
  - (log r, θ) = (600, 150) grids from $R_0=10^9$cm



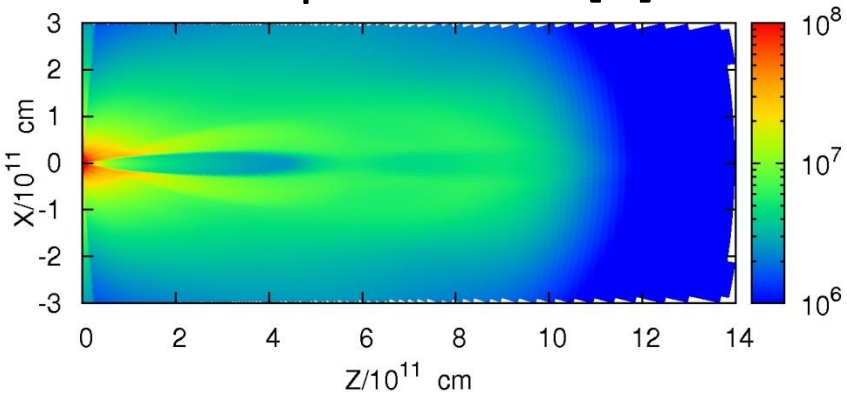
Hydrodynamic simulation

- We use a snapshot at 40s for the structures of the jet and cocoon.

Density ρ [g/cm^3]



Temperature T [K]



The photon production site

- The effective optical depth τ_*

For static medium (Rybicki & Lightman 79)

$$\tau_*^{\rm NR} \sim \sqrt{\tau_{\rm a}(\tau_{\rm a}+\tau_{\rm s})}$$

For relativistic flows (Shibata et al. 2014)

$$\tau_*^{\rm R} = \left\{ \frac{\Gamma^2}{3}(\beta^2+3) + (\Gamma\beta)^2 \frac{\tau_{\rm s}}{\tau_{\rm a}} \right\}^{-1/2} \frac{\sqrt{\tau_{\rm a}(\tau_{\rm a}+\tau_{\rm s})}}{\Gamma(1-\beta\cos\theta_{\rm v})}$$

$$\tau_{\rm a} = \Gamma(1-\beta\cos\theta_{\rm v})\alpha' L \qquad \tau_{\rm s} = \Gamma(1-\beta\cos\theta_{\rm v})\sigma' L$$

The photon production sites

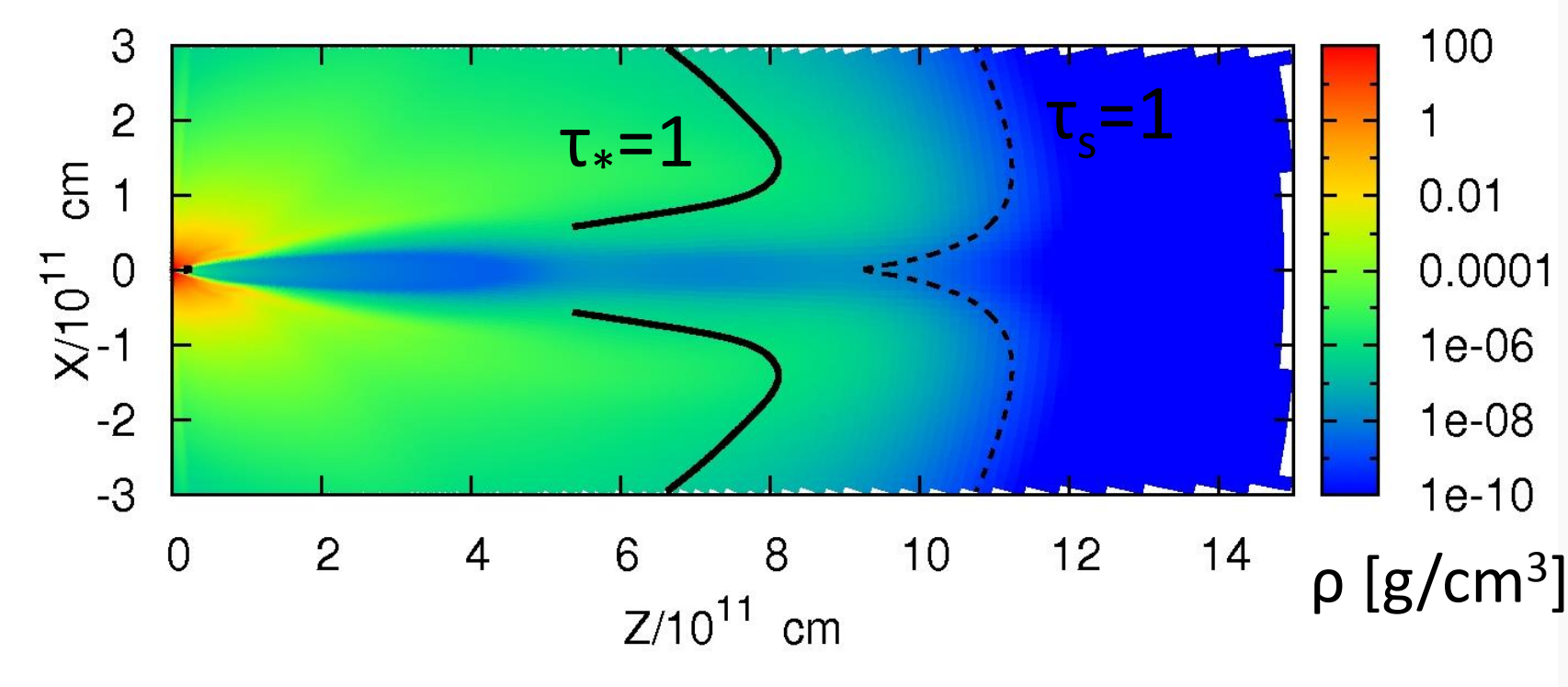
- τ_* to a radius R_*

$$\tau_* = \int_{R_*}^{\infty} \left\{ \frac{\Gamma^2}{3}(\beta^2+3) + (\Gamma\beta)^2 \frac{\sigma'}{\alpha'} \right\}^{-1/2} \sqrt{\alpha'(\alpha'+\sigma')}dr$$

- σ' : electron scattering
- α' includes
  - Free-free absorption ($e + p + \gamma \rightarrow e + p$)
  - Double Compton absorption ($\gamma + \gamma + e \rightarrow \gamma + e$)

We find the R_* which satisfies $\tau_* = 1$

The photon production sites



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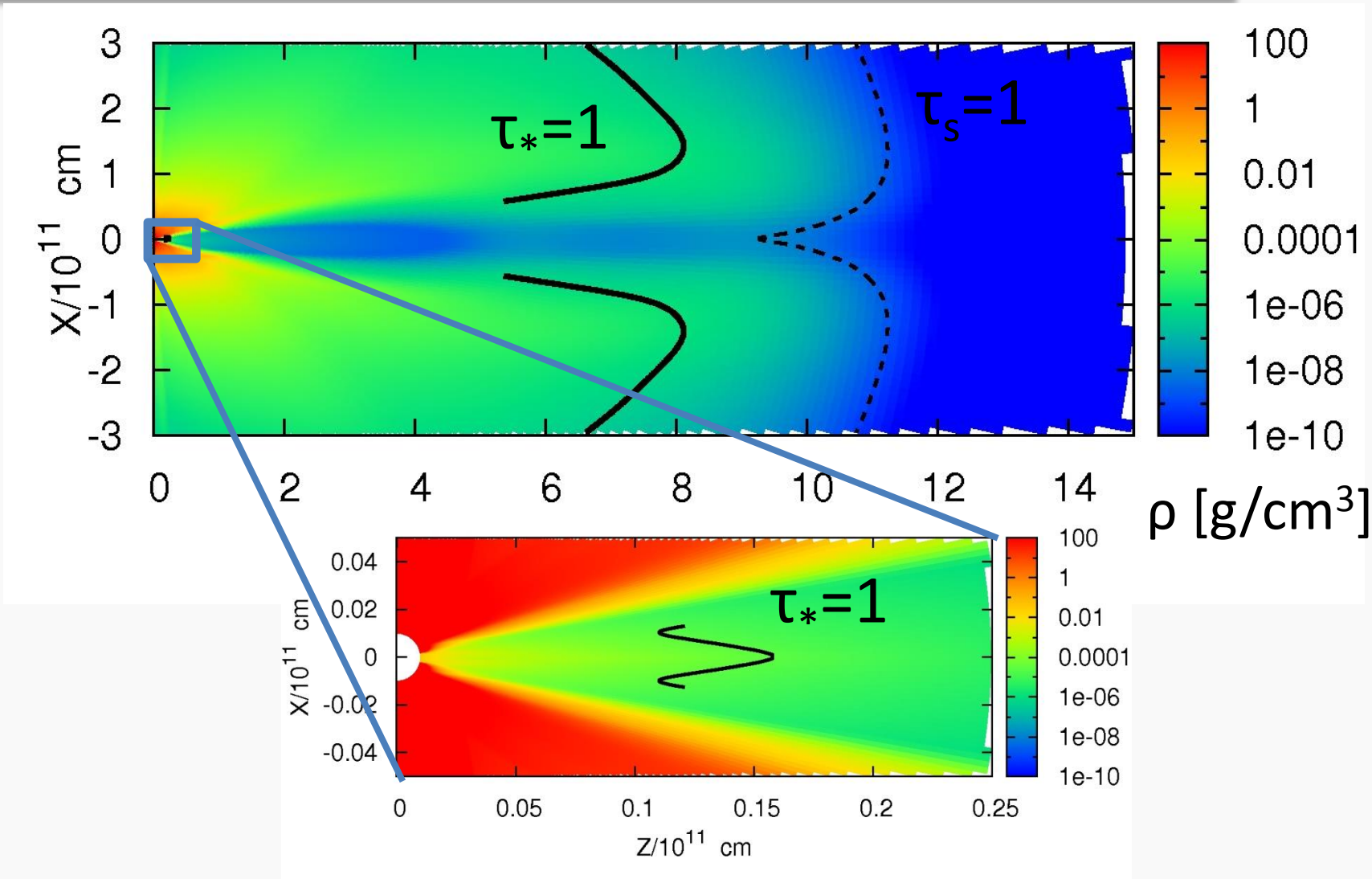
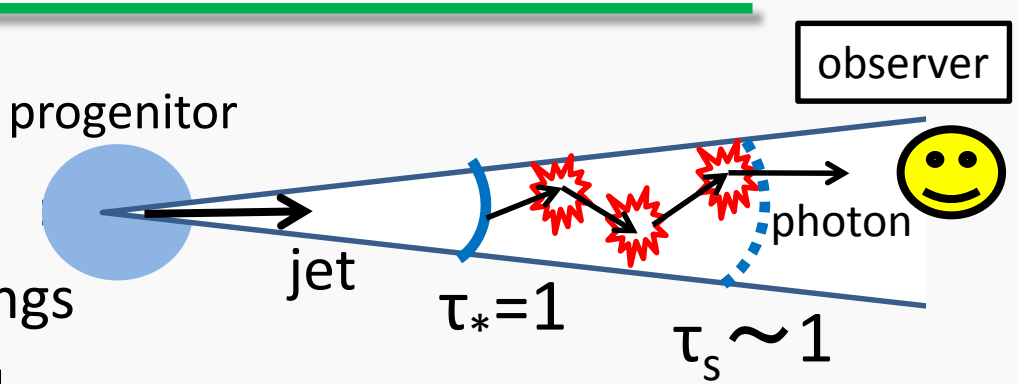
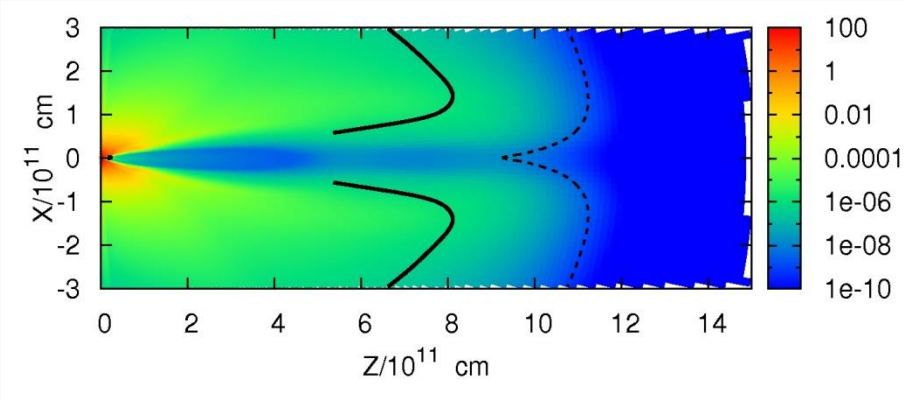


Radiative transfer

- ✓ Numerical code
  - Monte Carlo method
  - Calculate Compton scatterings
  - Photons are injected at $\tau_* = 1$



- ✓ Photon injection
  - Spatial distribution: $n_\gamma \propto T^3$
  - Planck distribution with local plasma temperatures
  - Isotropic in the comoving frame

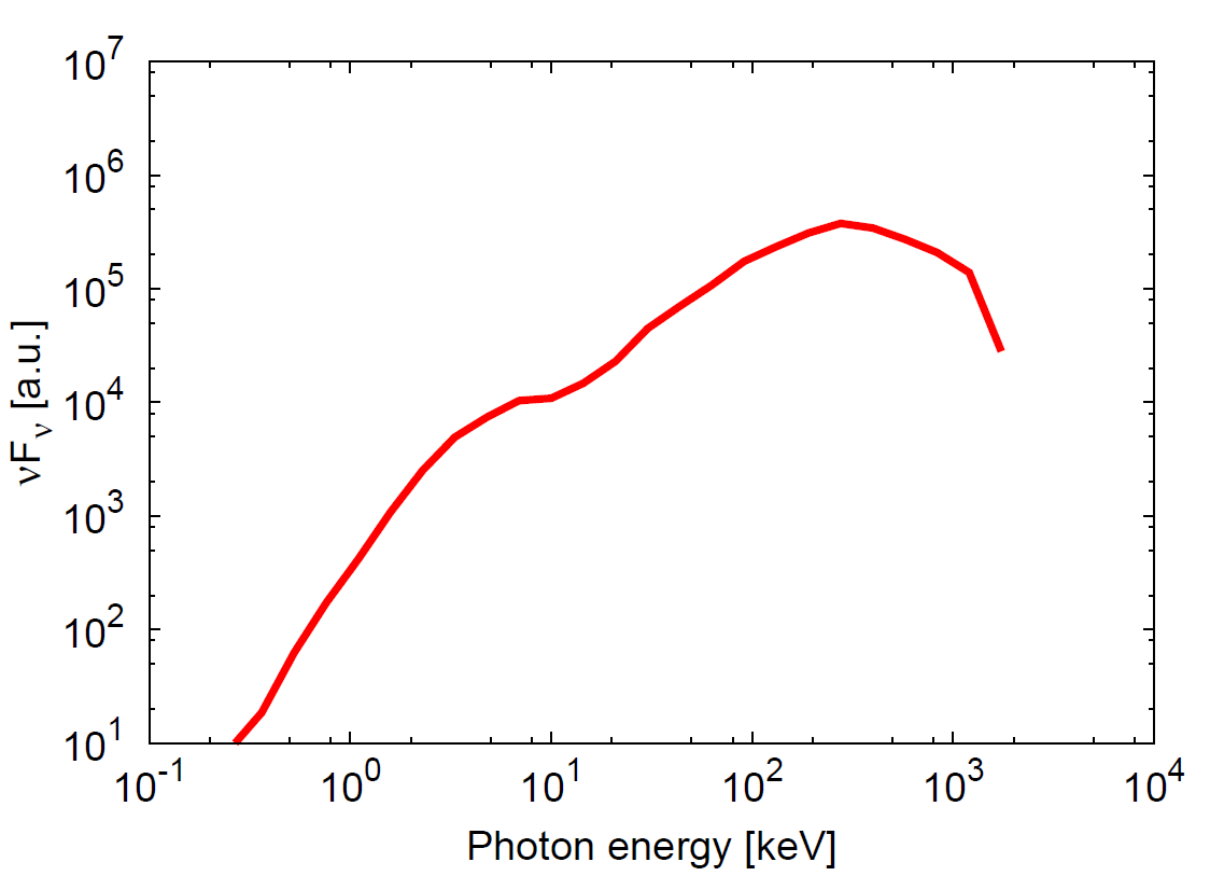


We use a snapshot at t=40s for the jet and cocoon structure.

Results

Observed spectrum

- $E_{peak} \sim 300$keV
- NOT a blackbody
  - wider than B.B.
- A bump like feature at low energies



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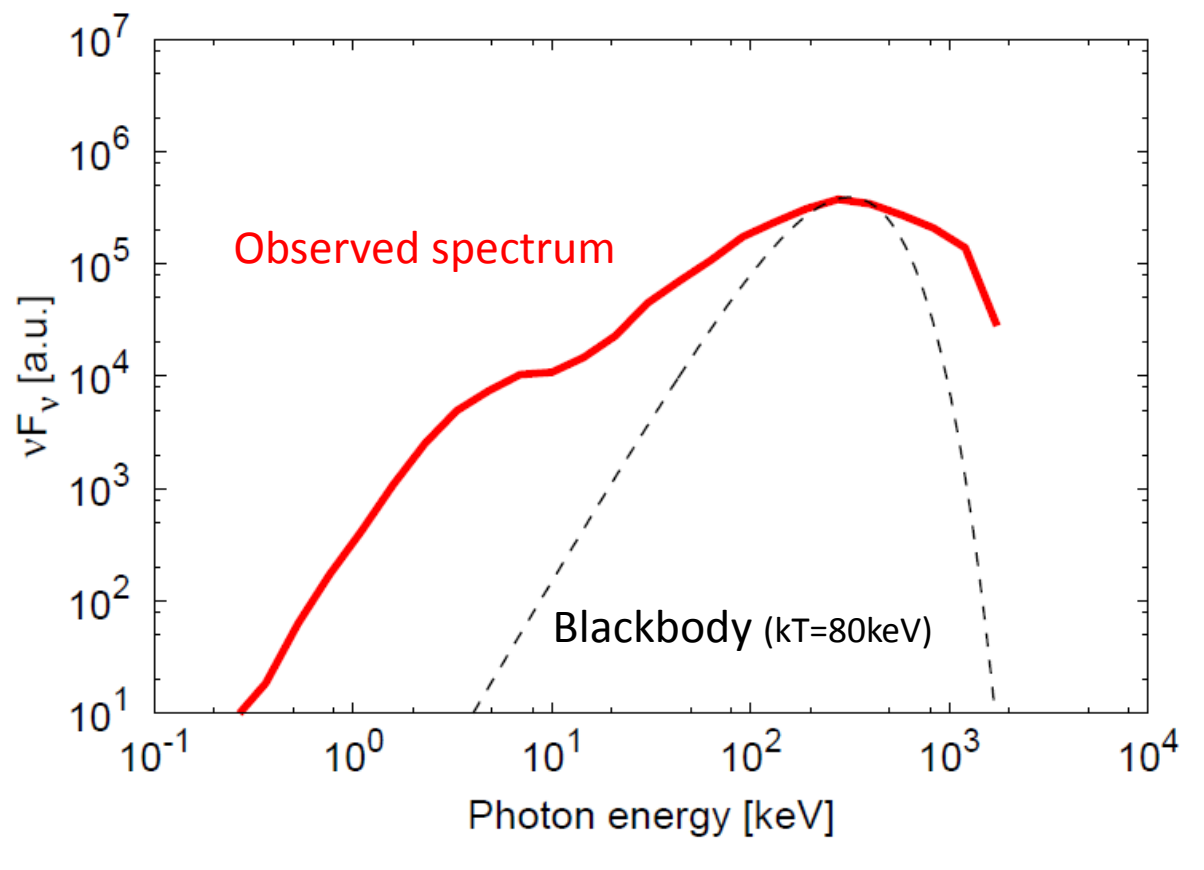
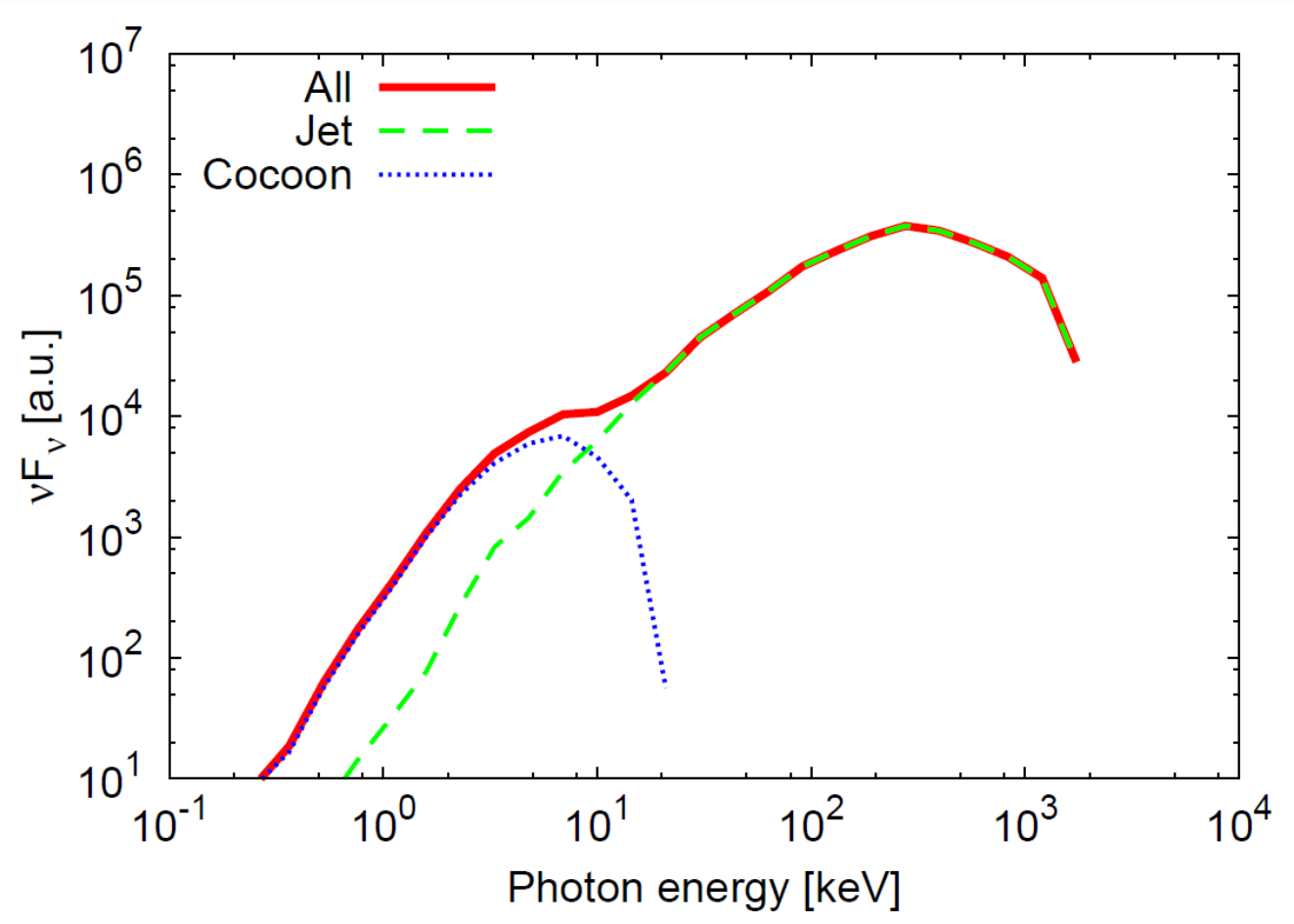


Origin of the bump?



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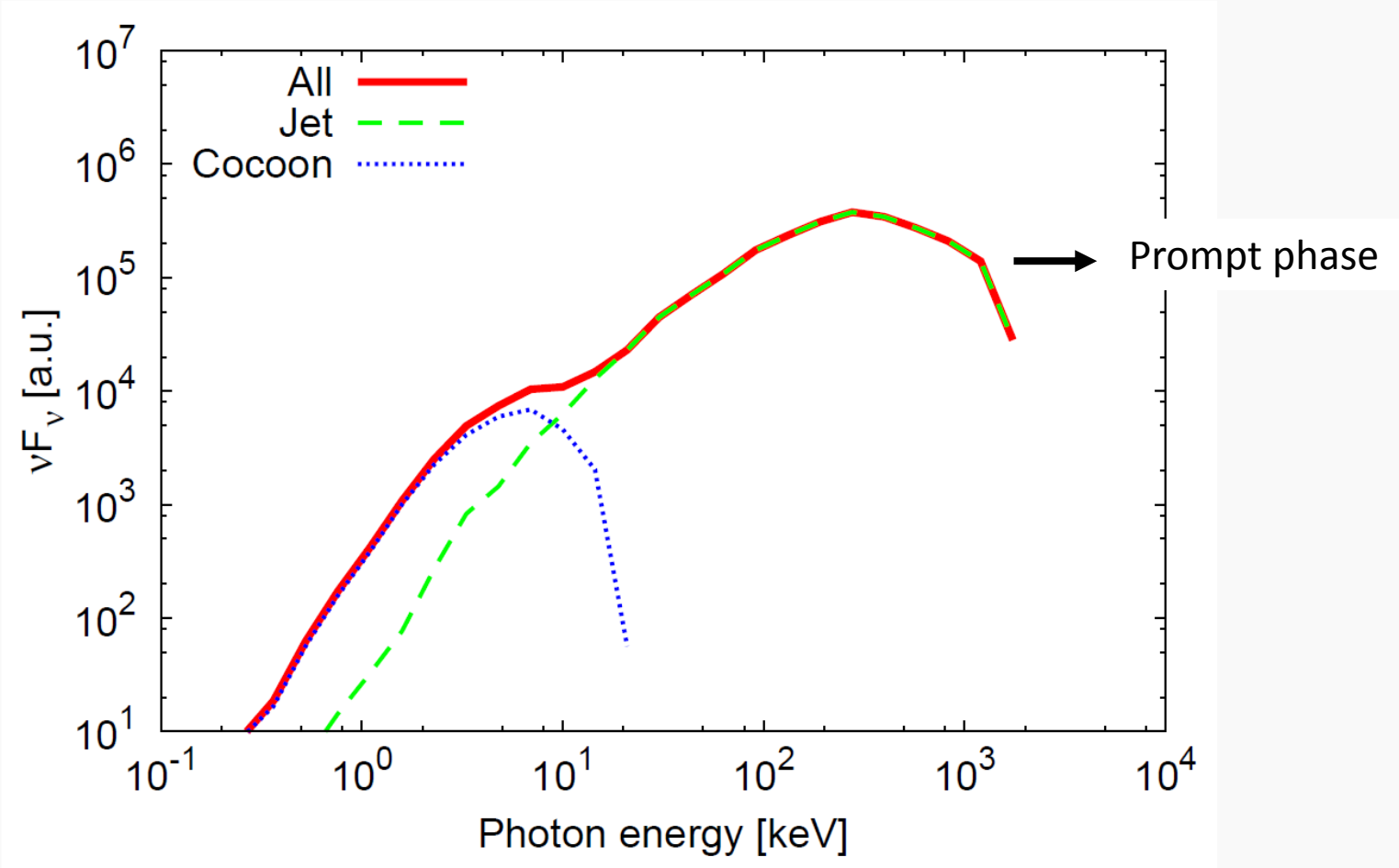

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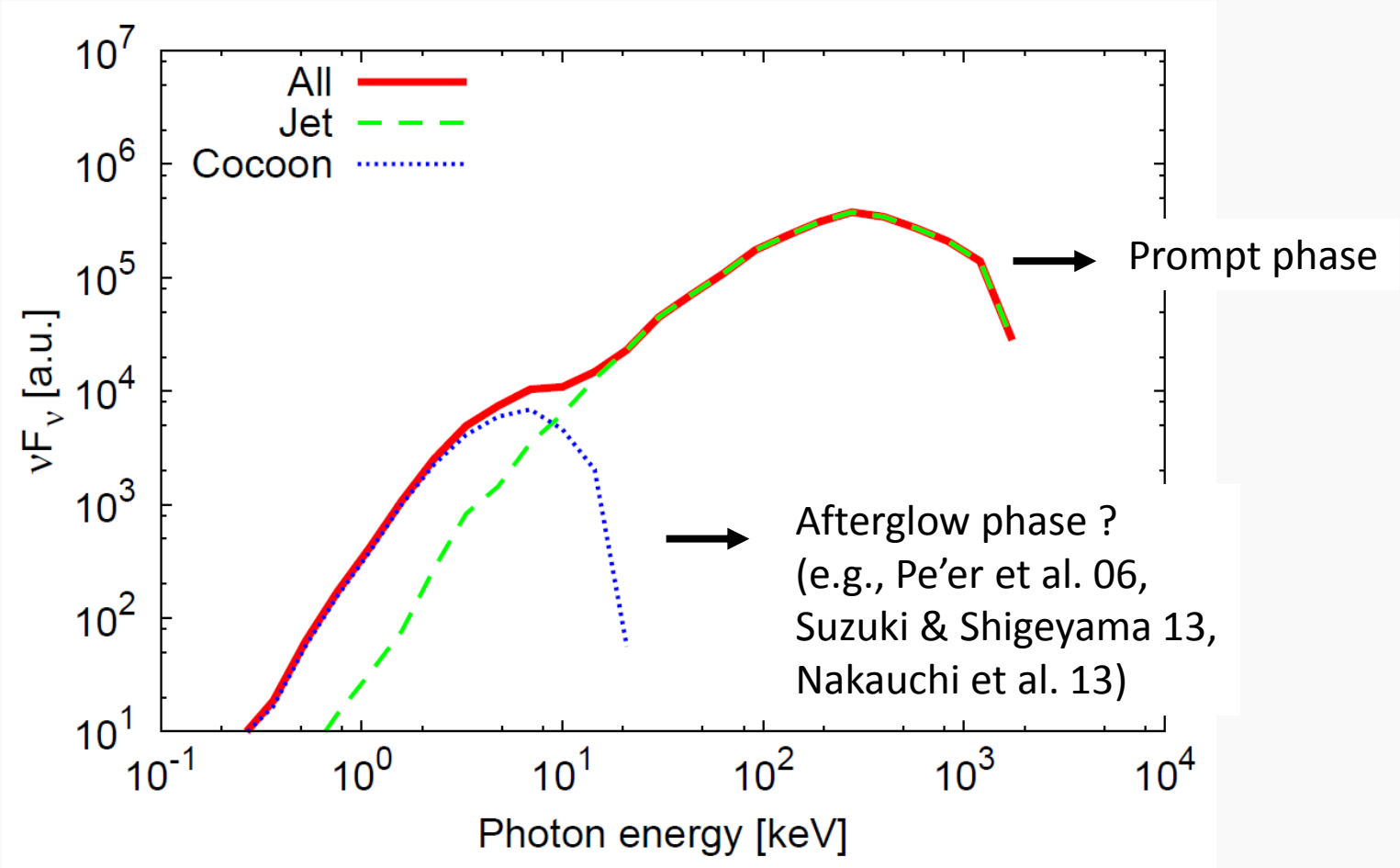
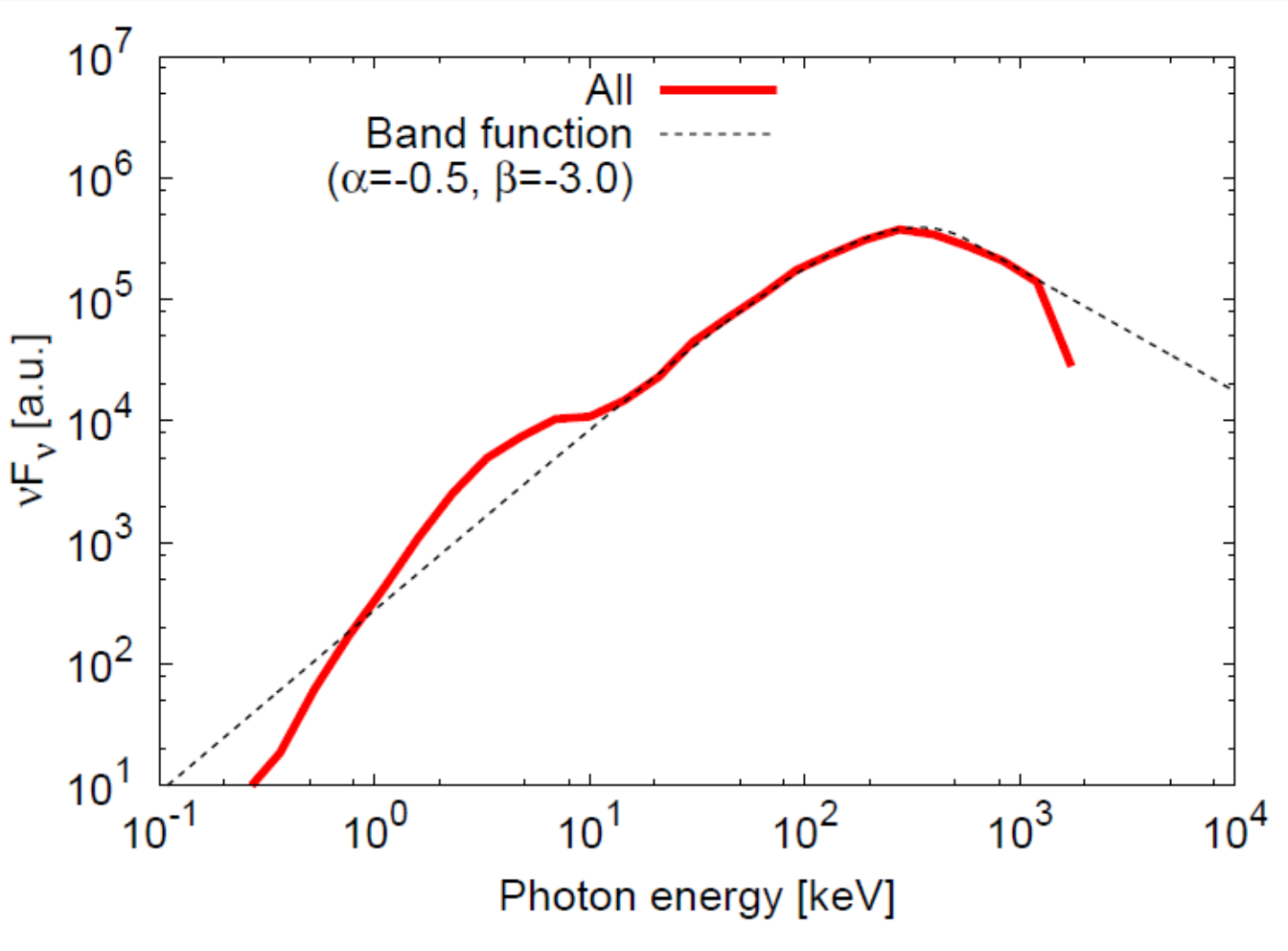


Comparison with the observations



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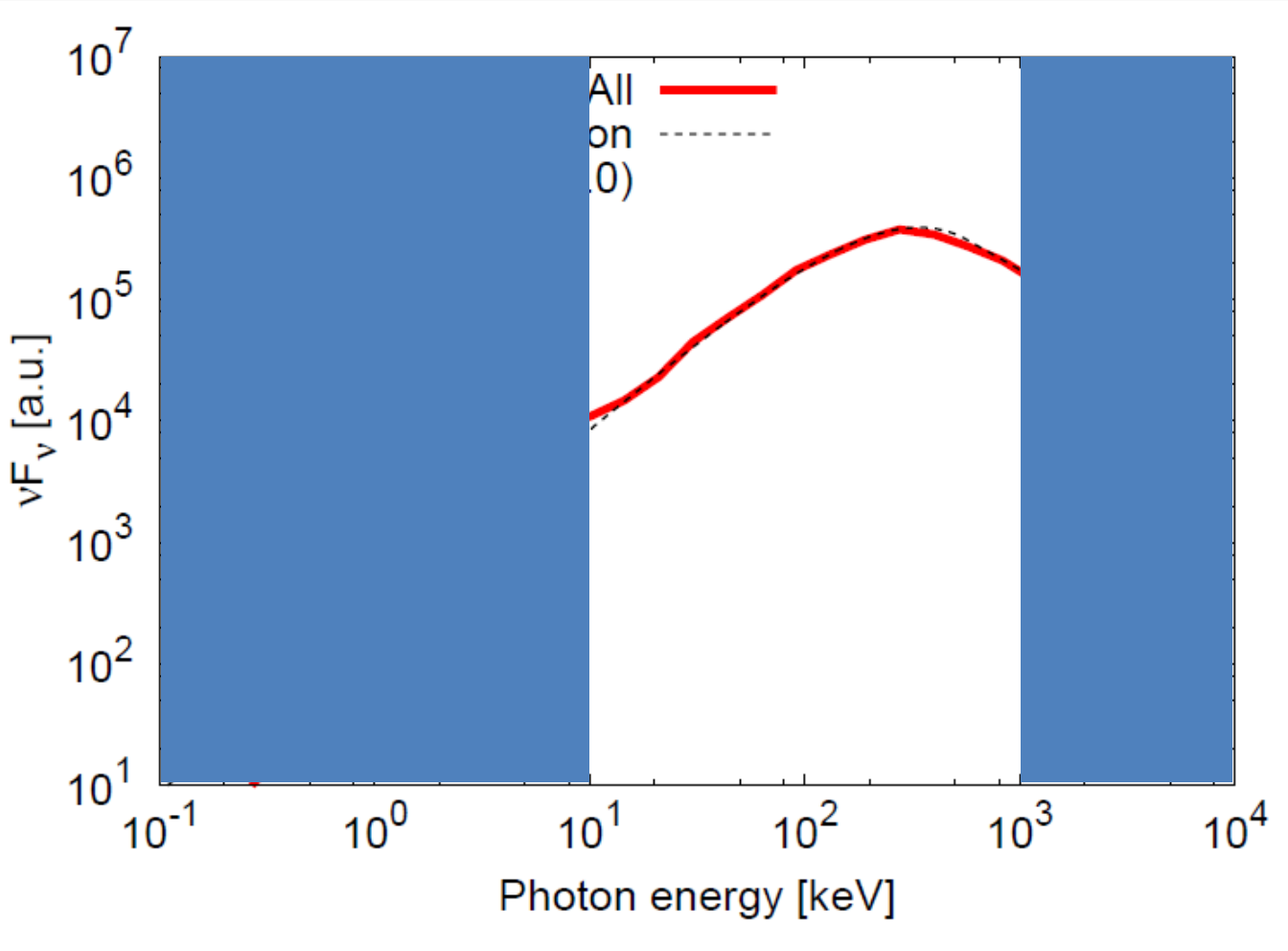
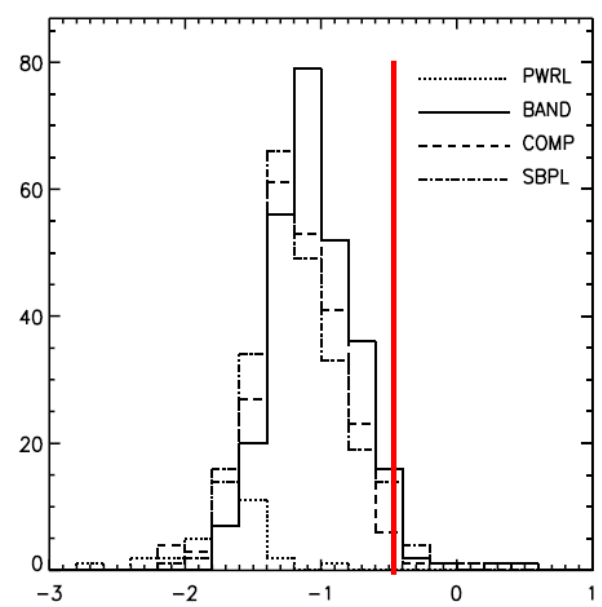
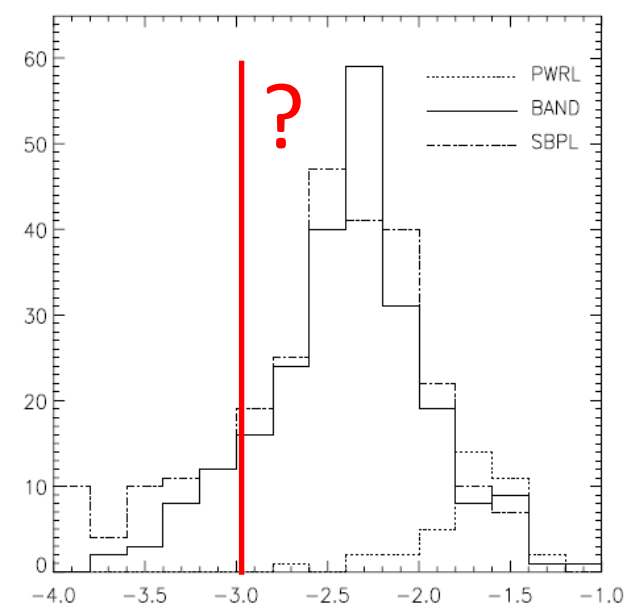


Comparison with the observations

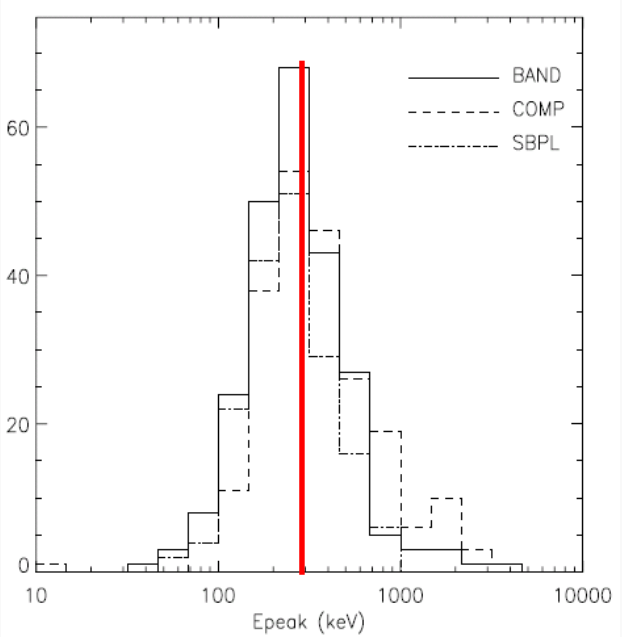
Kaneko et al 2006



low energy index (α)



high energy index (β)



peak energy (E_{peak})

Summary

Summary

- ✓ We calculate radiative transfer for the thermal radiation from GRB jet.
- ✓ The spectrum consists of higher energy jet component and lower energy cocoon component.
- ✓ The thermal radiation from GRB jet is NOT a blackbody but may be Band-like spectrum.