Effects of jet structure on the photospheric emission in gamma-ray bursts

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Collaborators

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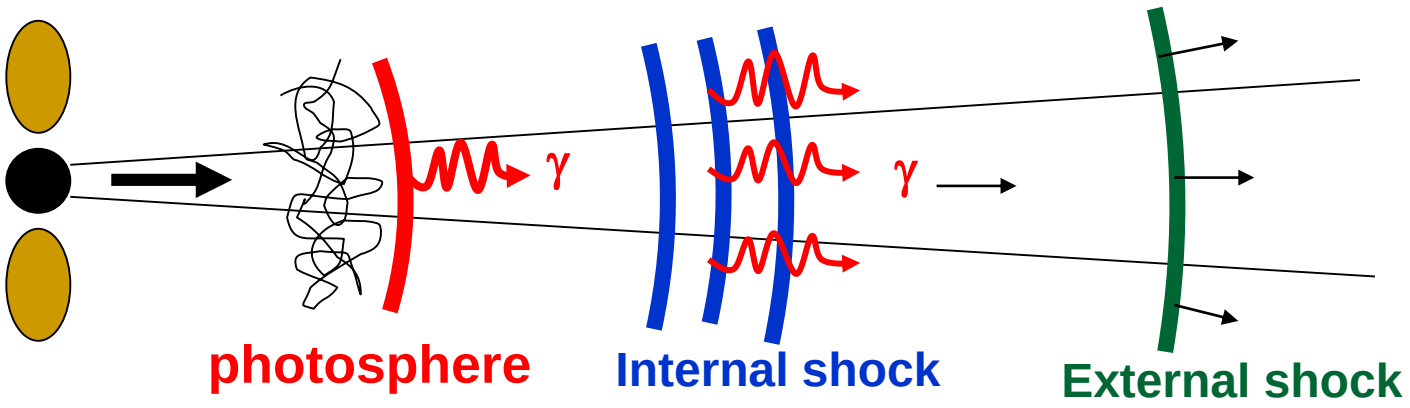
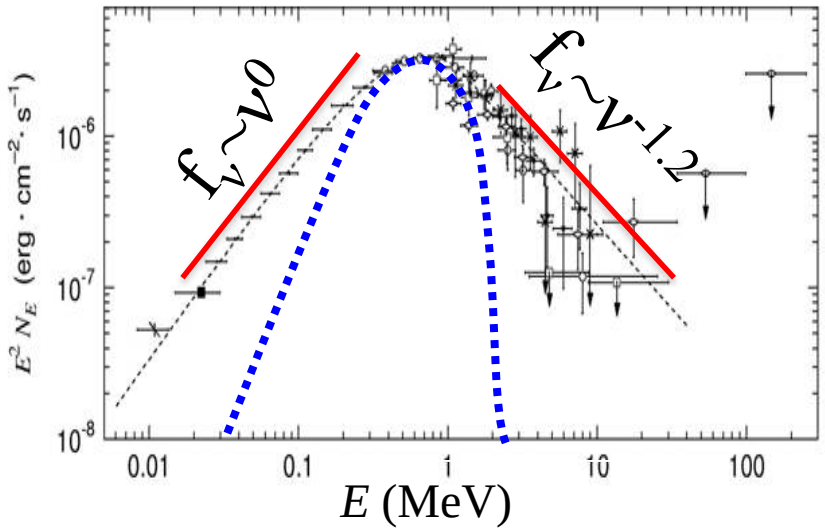
Model for Emission Mechanism



Photospheric Emission Model

Natural consequence of fireball model

(e.g., Rees & Meszaros 2005, Pe'er et al.2005, Thompson 2007)



- ⊙ High luminosity
- ⊙ Peak at ~1 MeV
- ✕ Non-thermal appearance

Dissipative process

high energy tail is reproduced by the relativistic pairs produced by dissipative processes

Magnetic recconection

Giannios & Spruit 2007, Giannios 2008, 2012

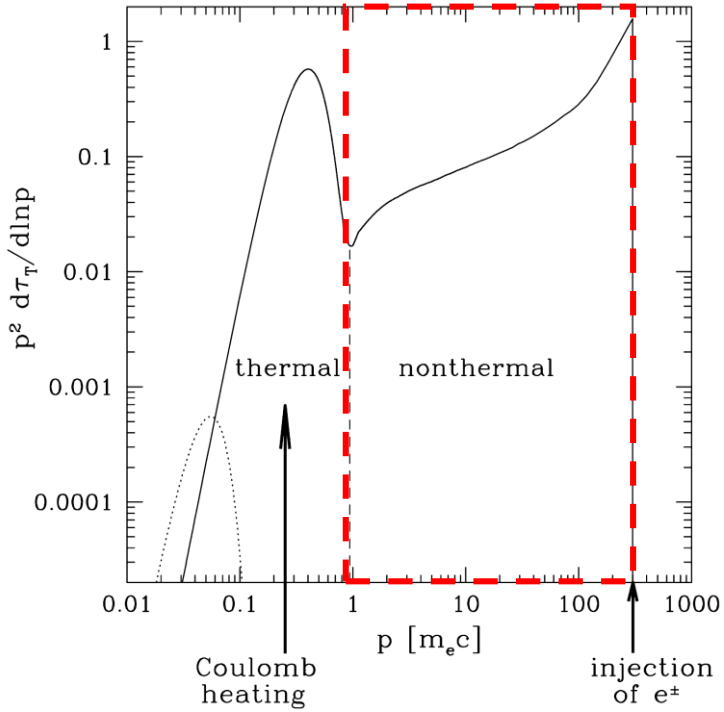
Repeated Shock

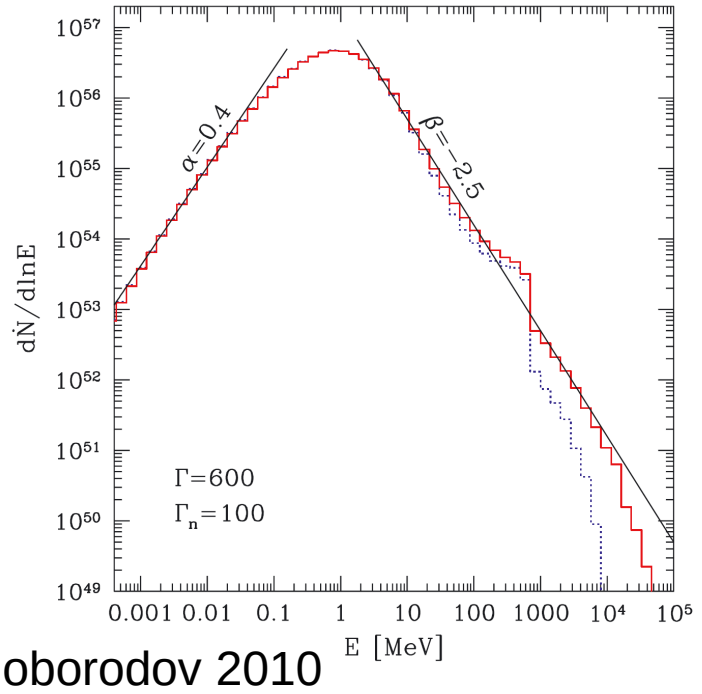
Ioka + 2007, Lazzati & Begelman 2010

Proton-neutron collision

Derishev 1999, Beloborodov 2010, Vurm+2011

relativistic pairs upscatter thermal photons

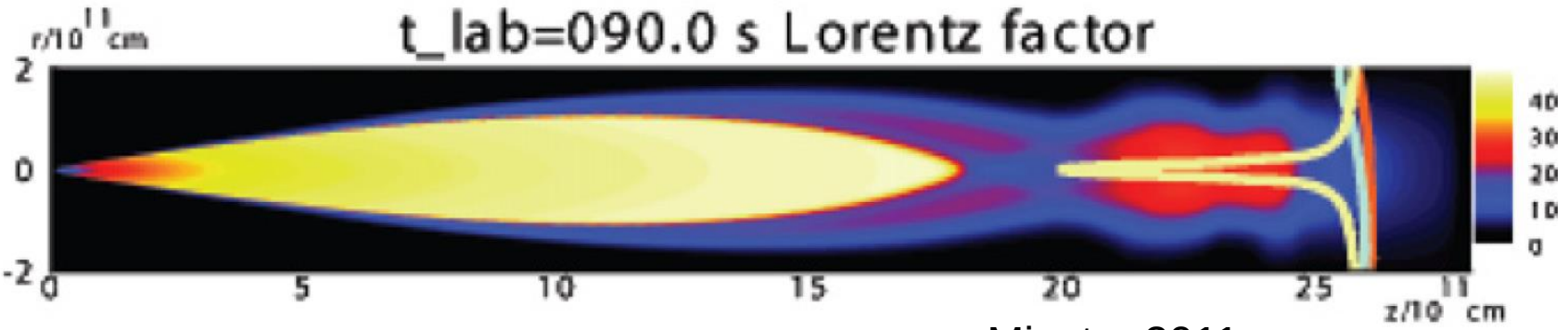




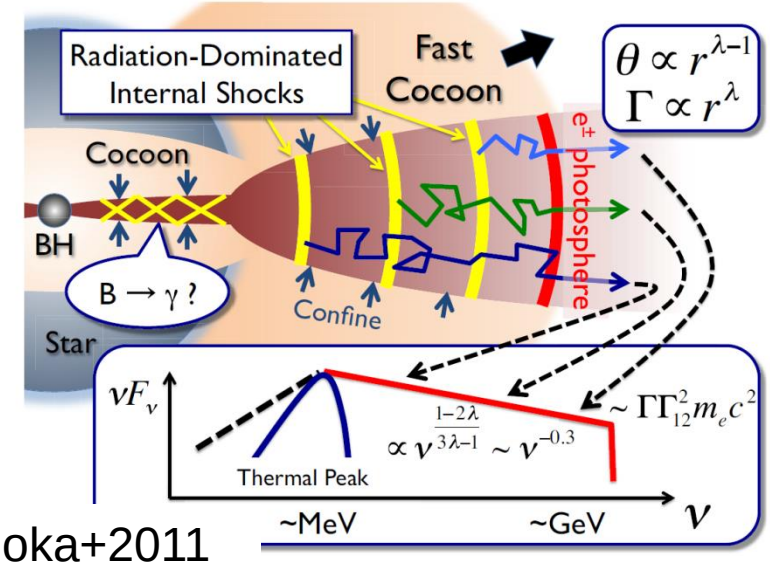
Beloborodov 2010

Geometrical brodening

Structure of the jet can give rise to the non-thermal spectra



Mizuta+2011



Ioka+2011

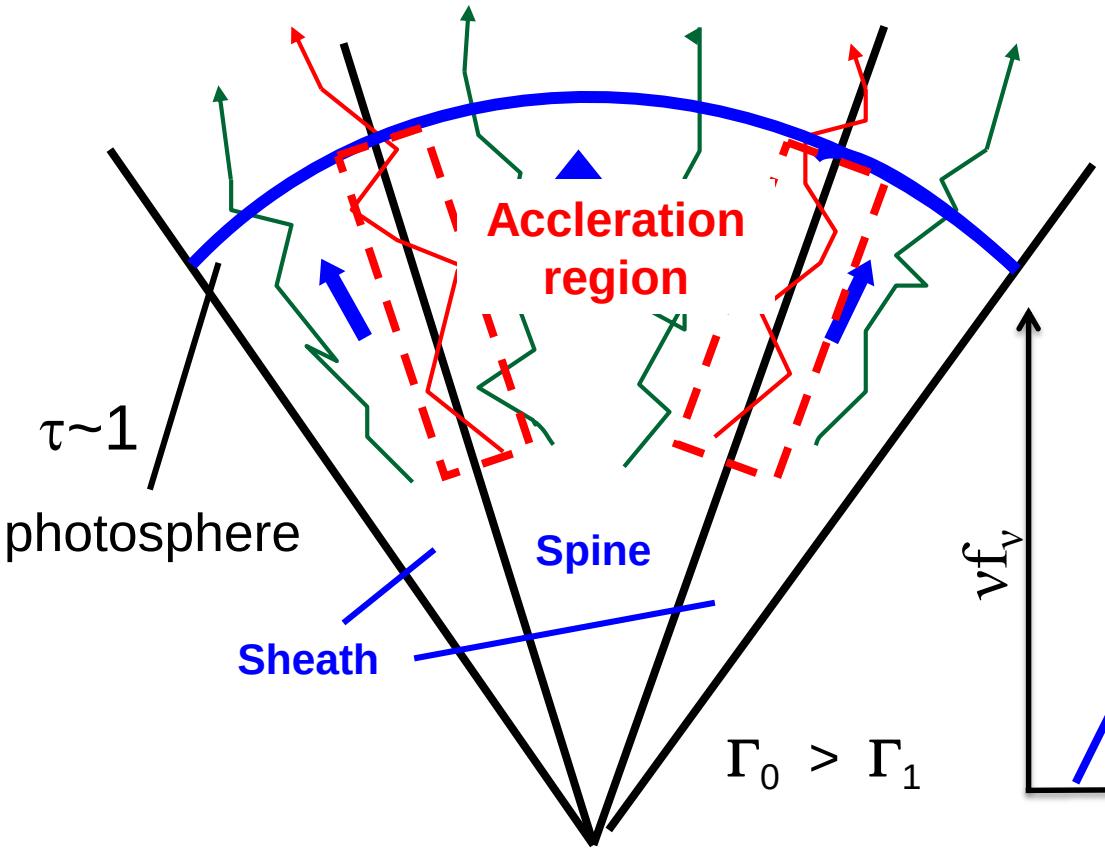
spectrum broadens even in the absence of relativistic pairs

Multi-dimensional structure of jet may be a key to resolve the difficulty

Our focus: Effect of the jet structure on the emission

Find the jet structure that can explain the observation

Stratified Jet structure

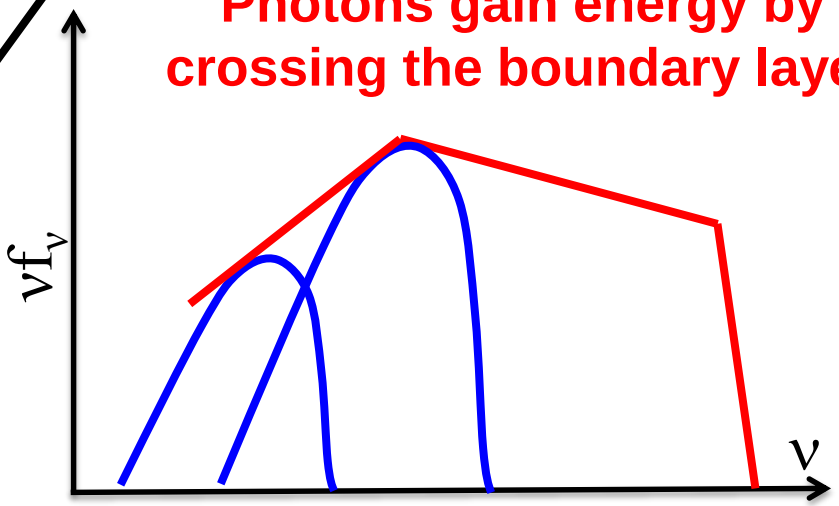


2 effects on the spectra

(I) multi-color effect
see also Lundman + 2013

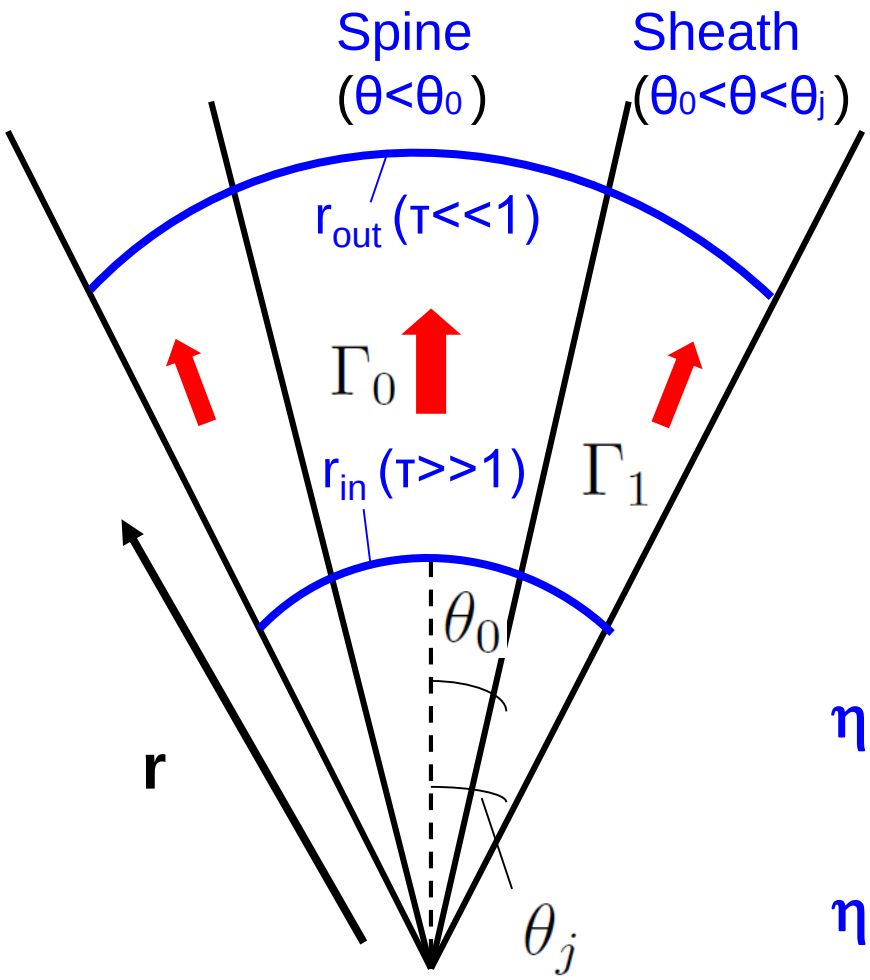
(II) Fermi acceleration of photons

Photons gain energy by crossing the boundary layer



Propagation of photons are solved by Monte=Carlo method

Two-component jet

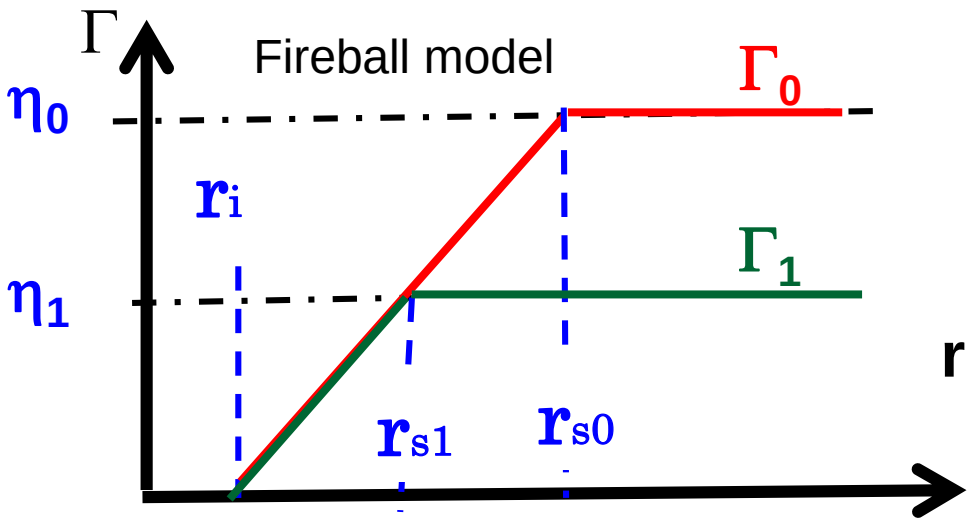


Calculation Range

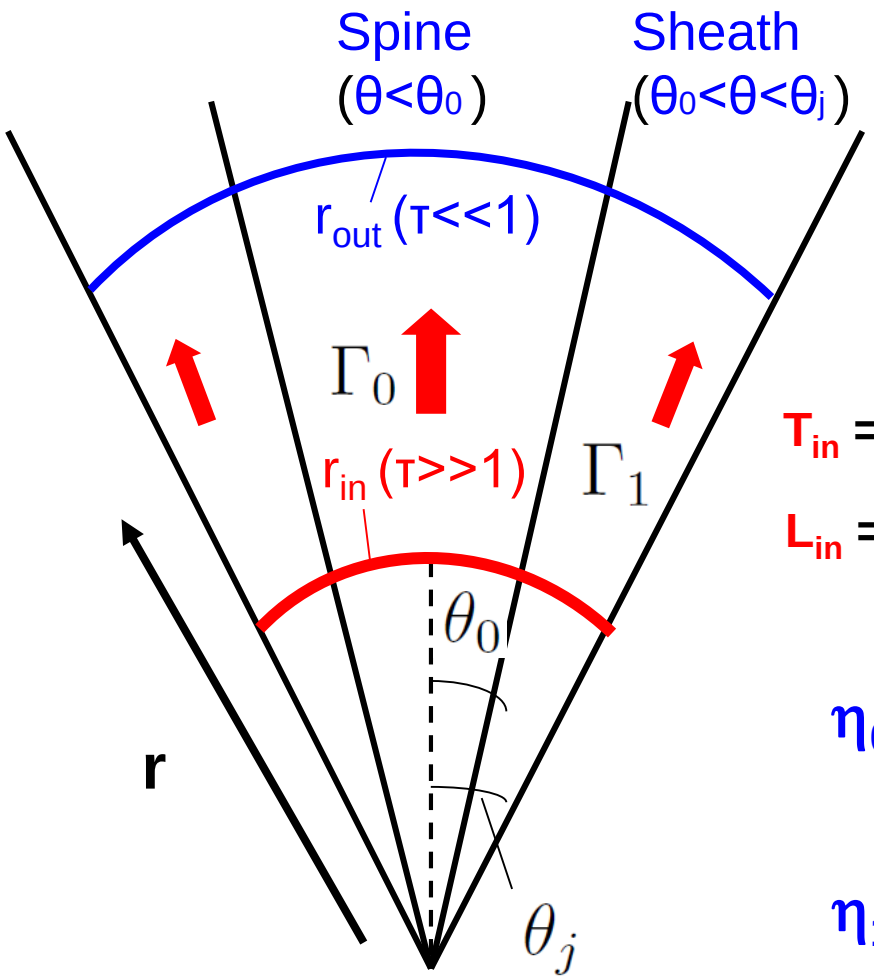
$r_{in} = r_{s1} << R_{ph}$

$r_{out} = 500 R_{ph} (\tau \sim 2 \times 10^{-3})$

$$R_{\rm ph} = \frac{\sigma_{\rm T} \dot{N}_e}{4\pi \Gamma_0^2 \beta c}$$:photospheric radius



Two-component jet

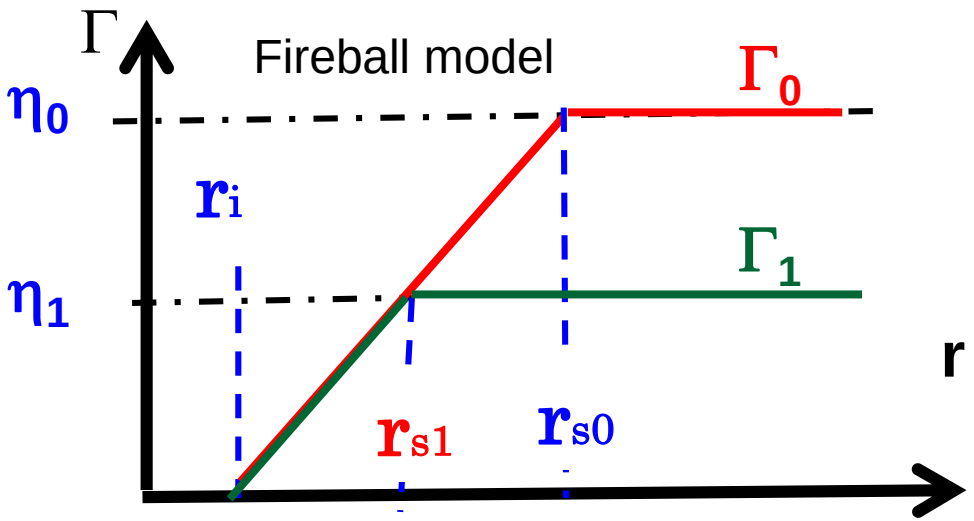


Initial Condition

Inject thermal photons at the inner boundary

$T_{in} = 0.9\, r_8^{1/6} \Gamma_{400}^{8/3} L_{53}^{-5/12} (r_{in}/10^{11}\mathrm{cm})^{-2/3}$ keV

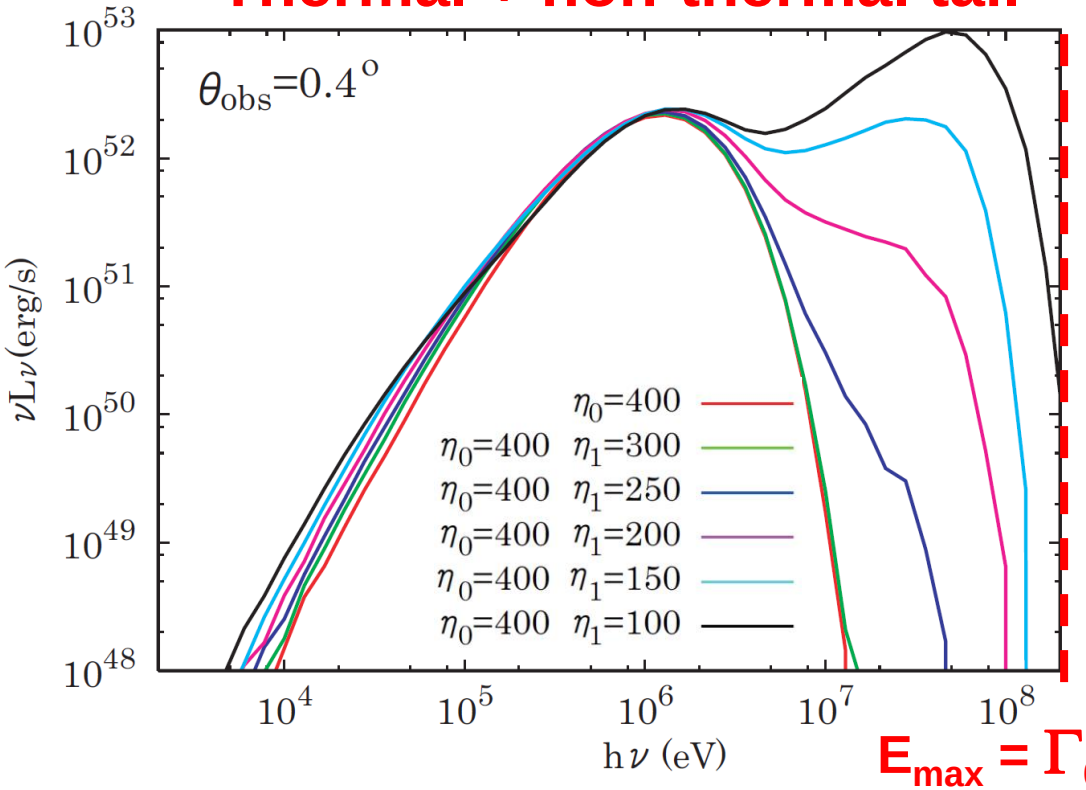
$L_{in} = 5.4 \times 10^{52}\, r_8^{2/3} \Gamma_{400}^{8/3} L_{53}^{1/3} (r_{in}/10^{11}\mathrm{cm})^{-2/3}$ erg/s

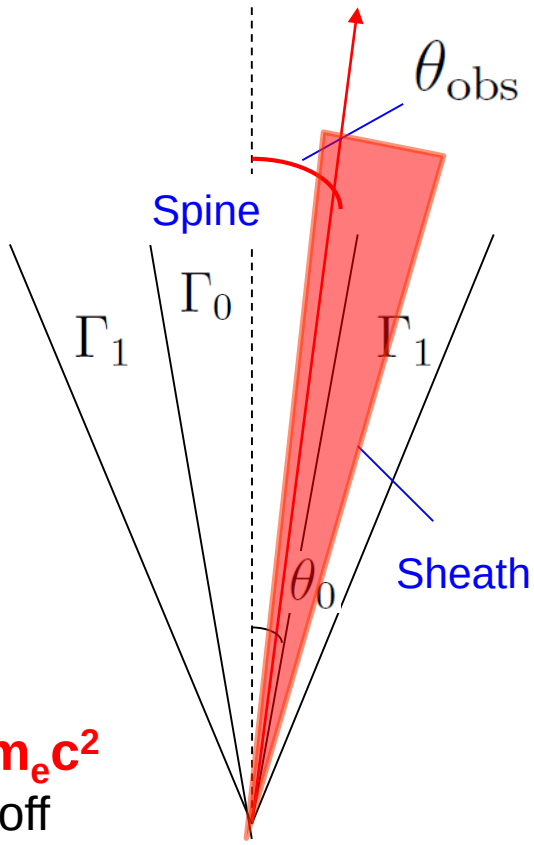


Two-component jet

Γ_0=400 θ_j=1° θ_0=0.5° θ_{obs}=0.4°

Thermal + non-thermal tail





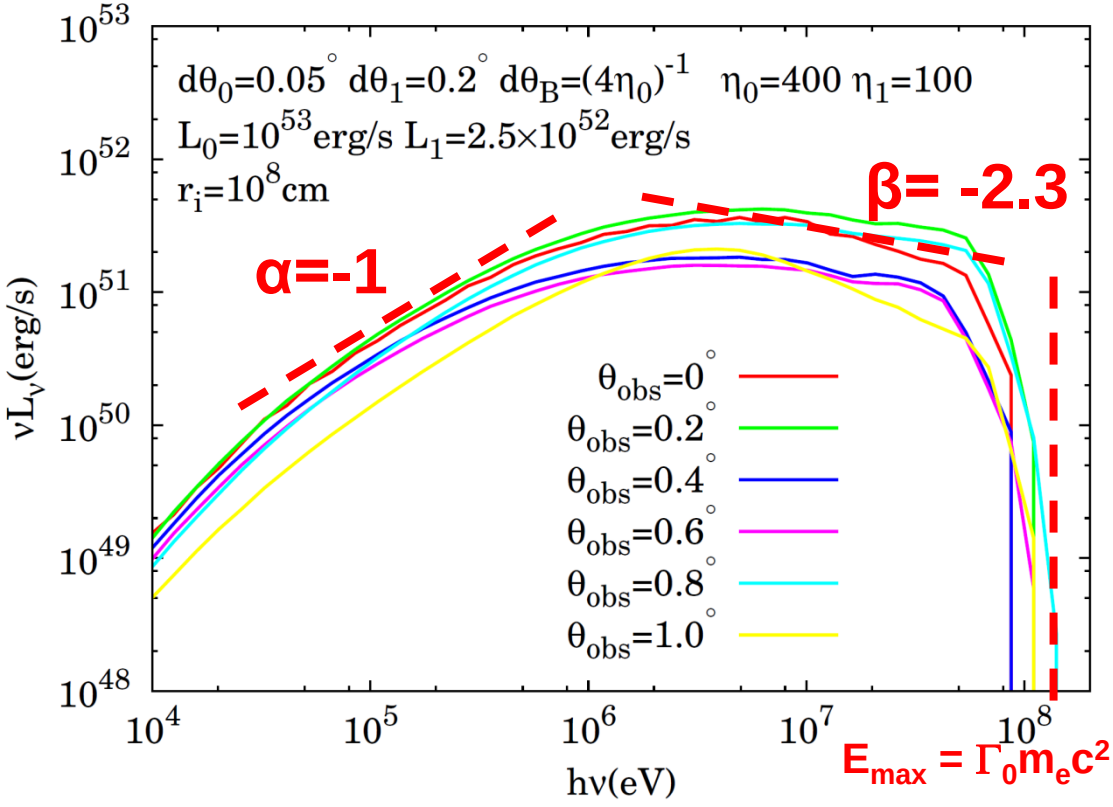
$E_{max} = \Gamma_0 m_e c^2$

Klein-Nishina cut-off

Non-thermal tail becomes prominent as the relative velocity becomes larger

But limited only for narrow range of observer angle $|\theta_{obs} - \theta_0| < \Gamma^{-1} \sim 0.14° \ \Gamma_{400}^{-1}$

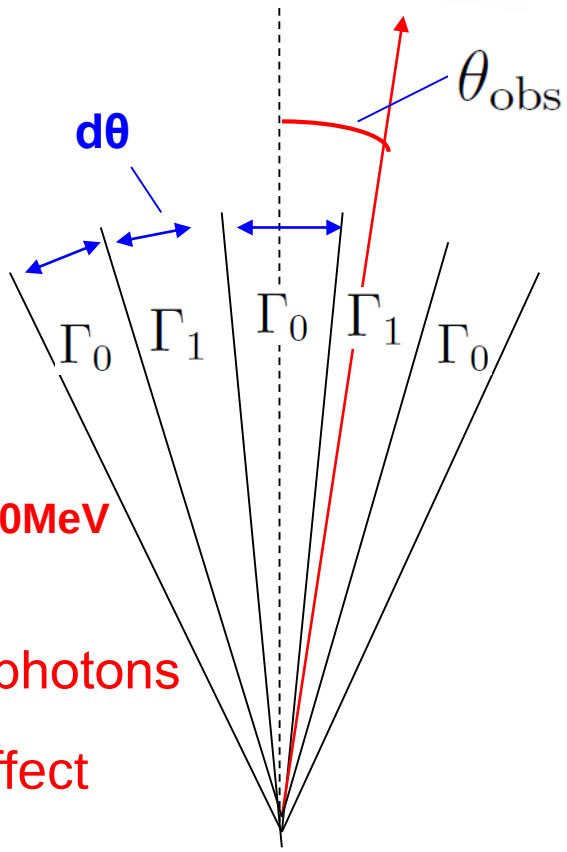
Multi-component jet



$E_{max} = \Gamma_0 m_e c^2 \sim 100$MeV

Γ_0=400 Γ_1=100

$d\theta_0=0.05^\circ$ $d\theta_1=0.2^\circ$



Interval of velocity shear $d\theta < 2\Gamma^{-1}$

high energy spectra (β) is reproduced by accelerated photons

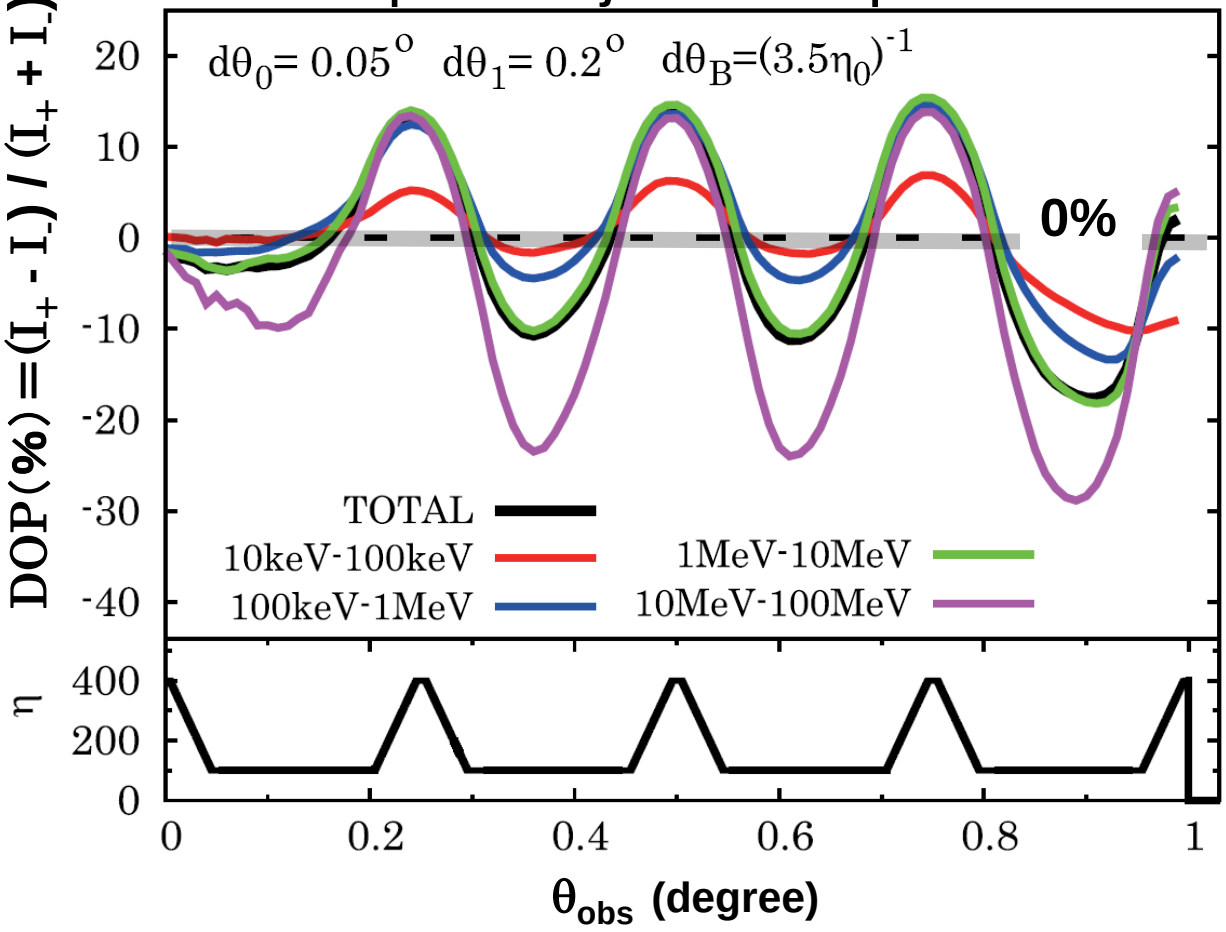
Cut off at ~ 100 MeV

Low energy spectra (α) is reproduced by multi-color effect

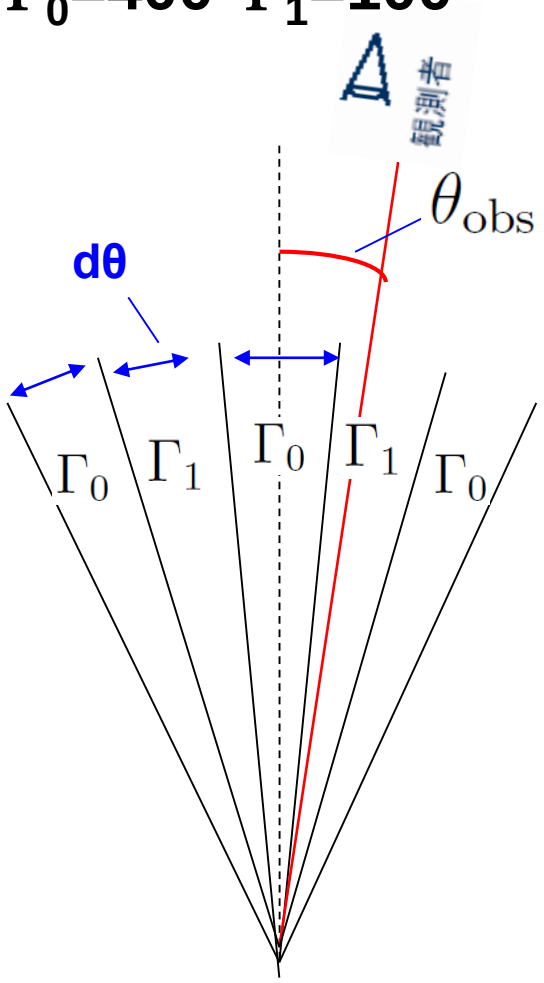
see also Lundman + 2013

polarization

multi-component jet that reproduces Band spectra



Γ_0=400 Γ_1=100



High polarization degree (>10%) is predicted

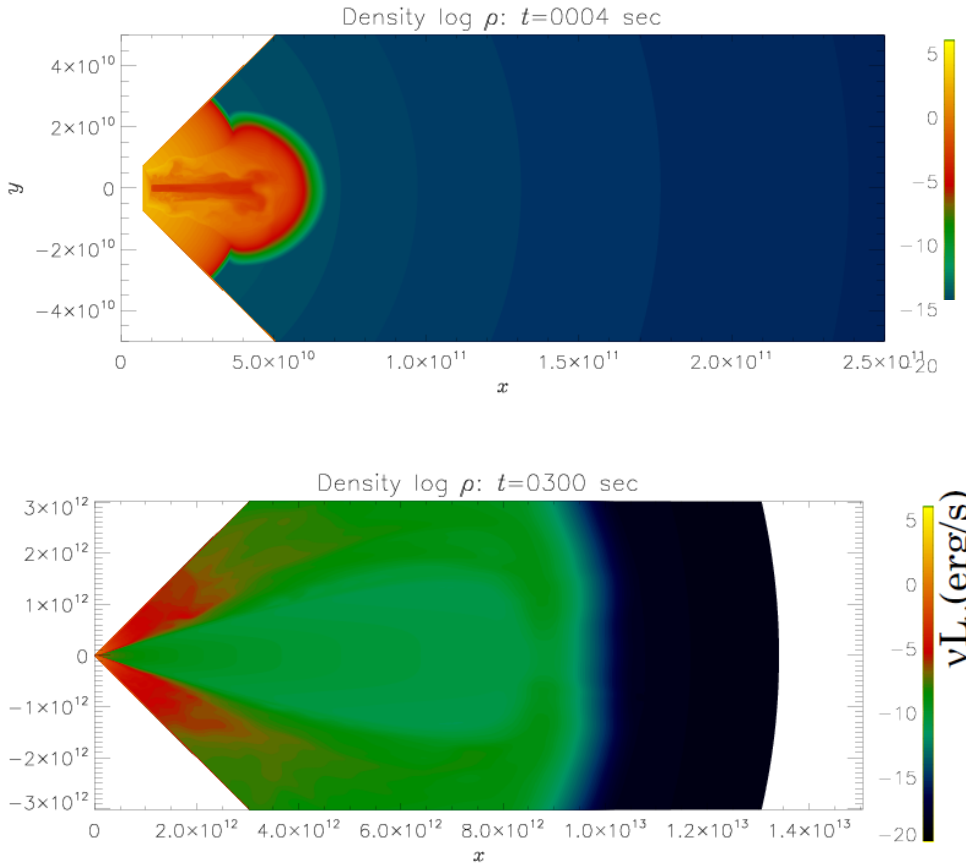
See also Lundman + 2014

Future missions such as Tsubame and POLAR may probe such an emission

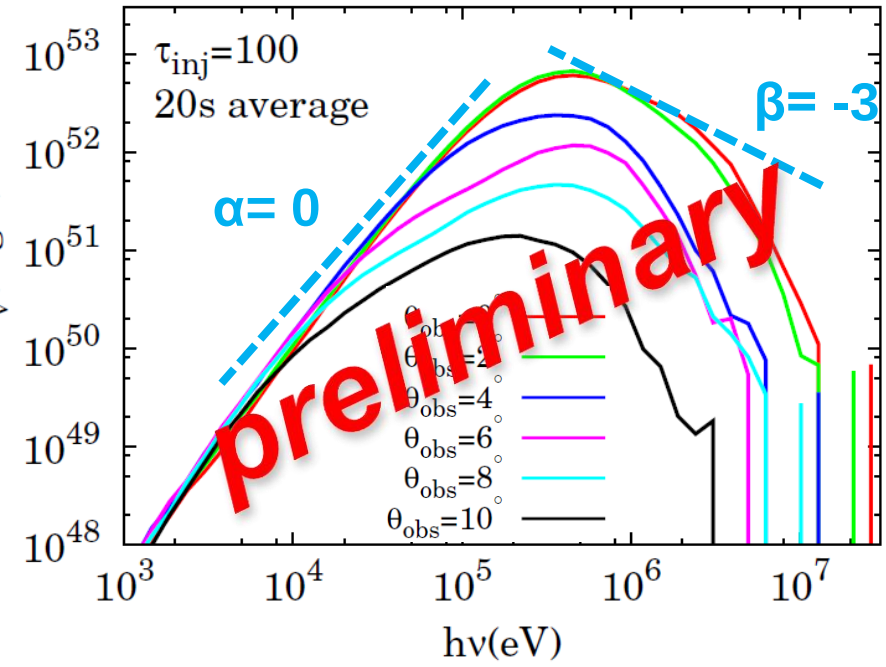
On-going project

3D Hydrodymical simulation of relativistic jet as a background fluid

simulation by Dr. Matsumoto



Detail of spectra, polarization and lightcurves for more realistic case can be obtained



Summary

- Stratified jet can produce a power-law non-thermal tail above the peak energy

  non-thermal particle is not required

- Multi-component jet can reproduce Band function irrespective to the observer angle

  β is reproduced by the accelerated photons

  α is reproduced by the multi-color effect

- Polarization signature is not negligible in the structured jet

  High DOP (>10%) is predicted for the jet structure that reproduces Band function

Futrure works

- Photon accelerations in various structures

  shocks, turbulence

- Hydrodymical simulation of relativistic jet as a background fluid