Photospheric Emission in GRBs

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Collaborators

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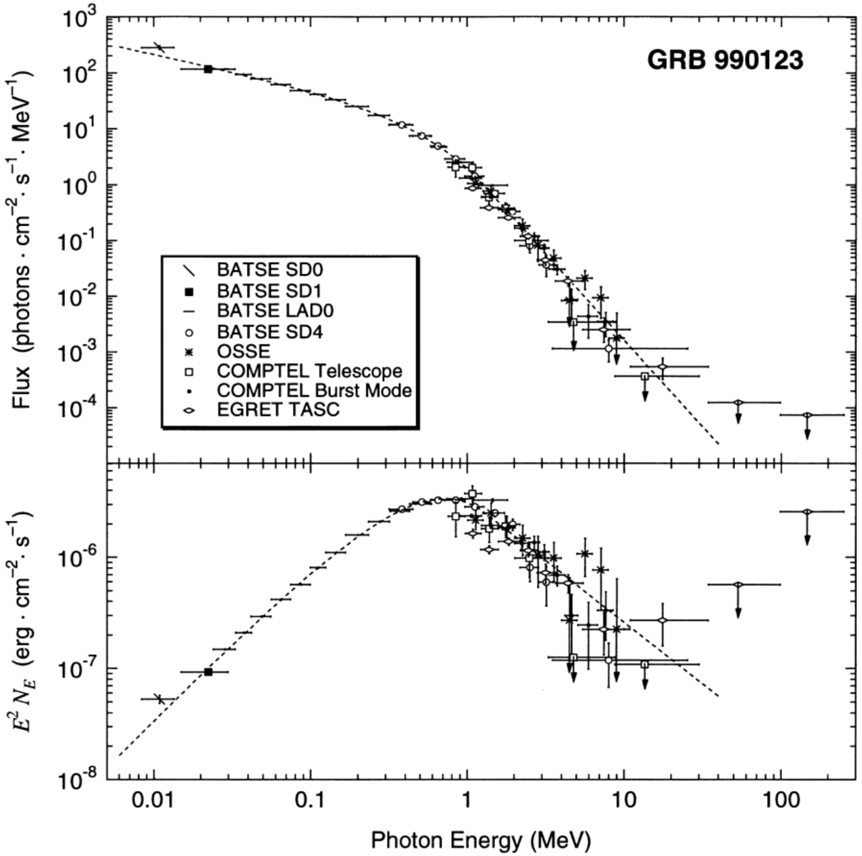
Gamma-Ray Burst (GRB)

Most luminous explosion in the universe

$L_{\gamma,iso} \sim 10^{52} - 10^{54}$ erg/s



Band function

$F_\nu \propto \nu^{-\alpha}$ ($h\nu < E_p$)

$F_\nu \propto \nu^{-\beta}$ ($h\nu > E_p$)

Long GRB

$< E_p > \sim 160$ keV

$<\alpha> \sim -0.9$

Short GRB

$< E_p > \sim 490$ keV

$<\alpha> \sim -0.5$

$<\beta> \sim -2.3$

Nava + 2011

Model for Emission Mechanism

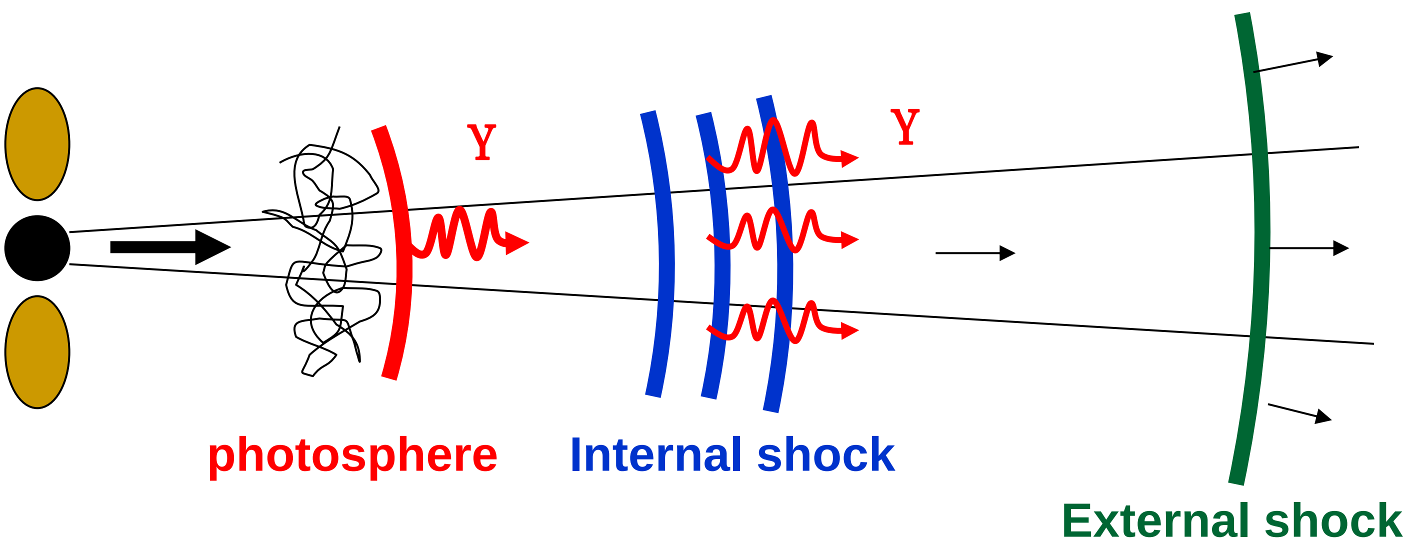
Internal Shock Model

flaw
- ・Low efficiency for gamma-ray production
- ・too hard spectrum in low energy band (α)

Photospheric Emission Model

Natural consequence of fireball model

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



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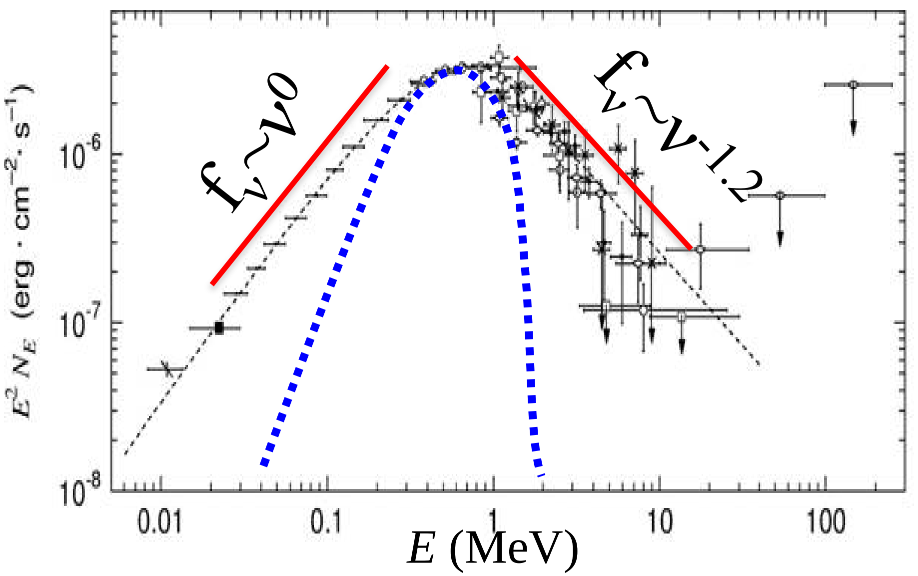


- ⊙ High emission efficiency
- ⊙ Peak at ~1 MeV
- ✕ Non-thermal appearance

Dissipative process

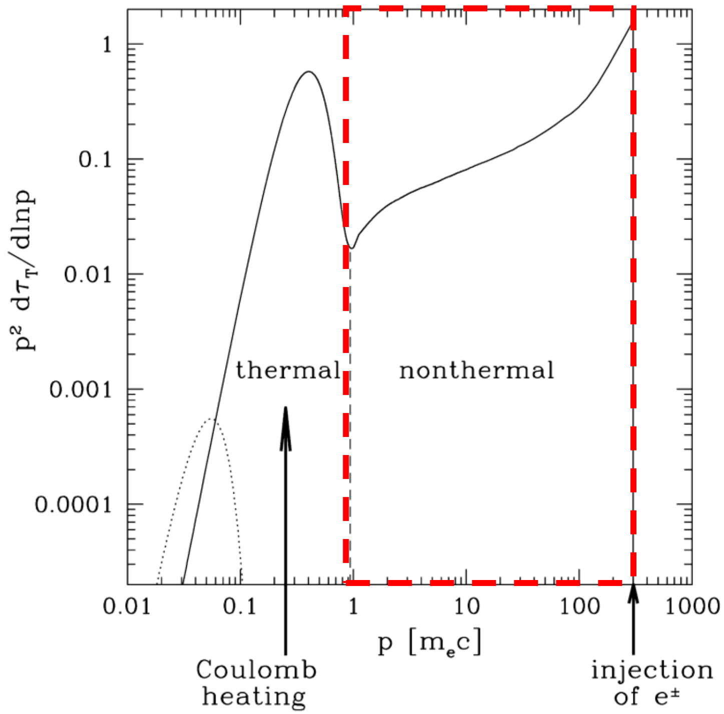
high energy tail is reproduced by the relativistic pairs produced by dissipative processes

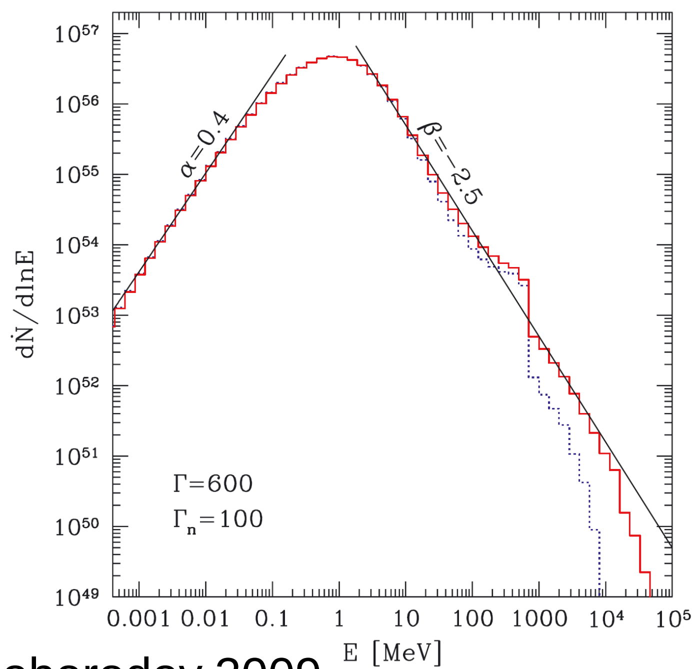
Magnetic recconection
Giannios & Spruit 2007, Giannios 2008

Repeated Shock
Ioka + 2007, Lazzati & Begelman 2010

Proton-neutron collision
Derishev 1999, Beloborodov 2009, Vurm+2011

relativistic pairs upscatter thermal photons

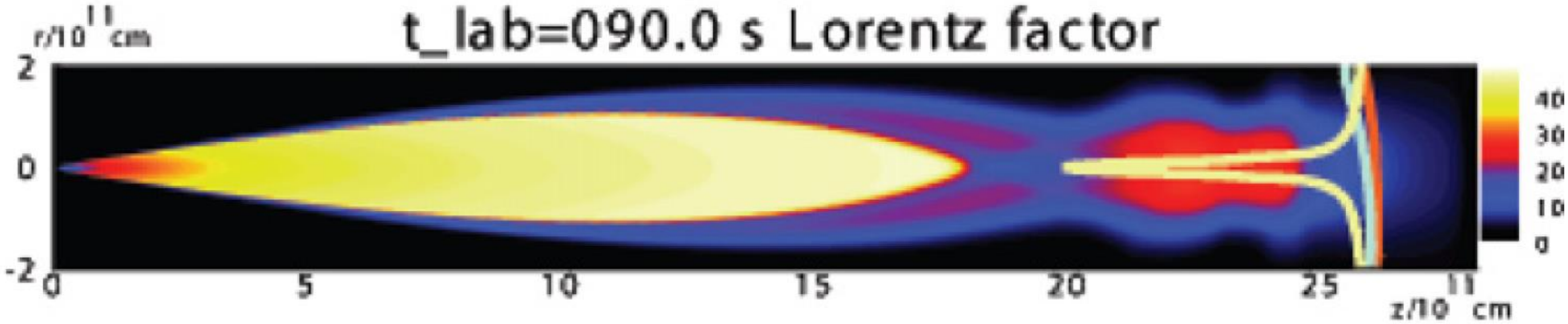




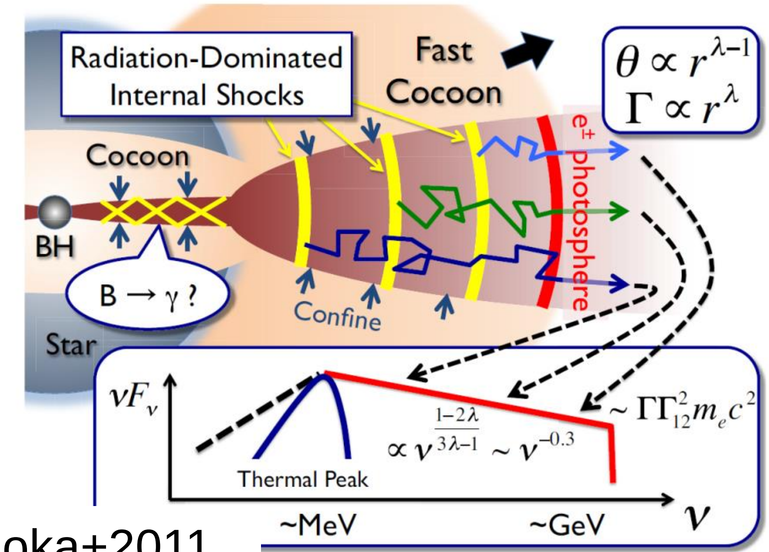
Beloborodov 2009

Geometrical brodening

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



Mizuta+2011



Ioka+2011

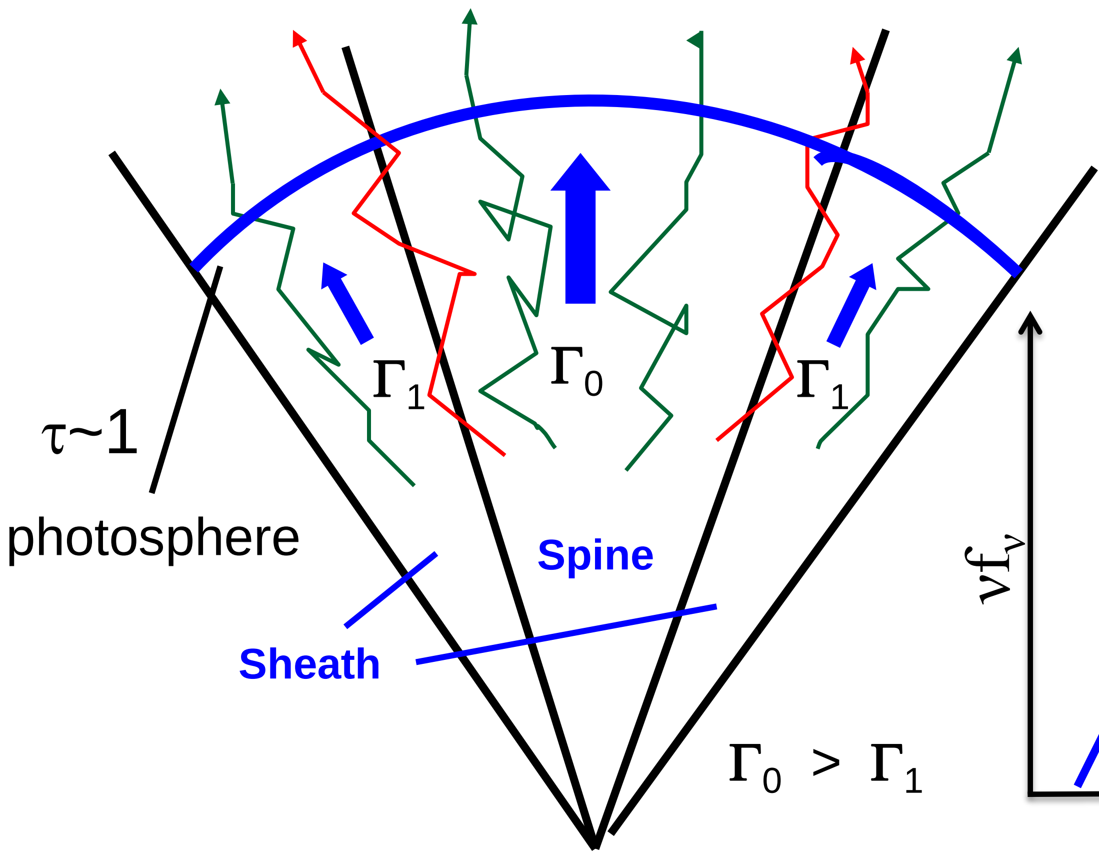
spectrum broadens even in the absence of relativistic pairs

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

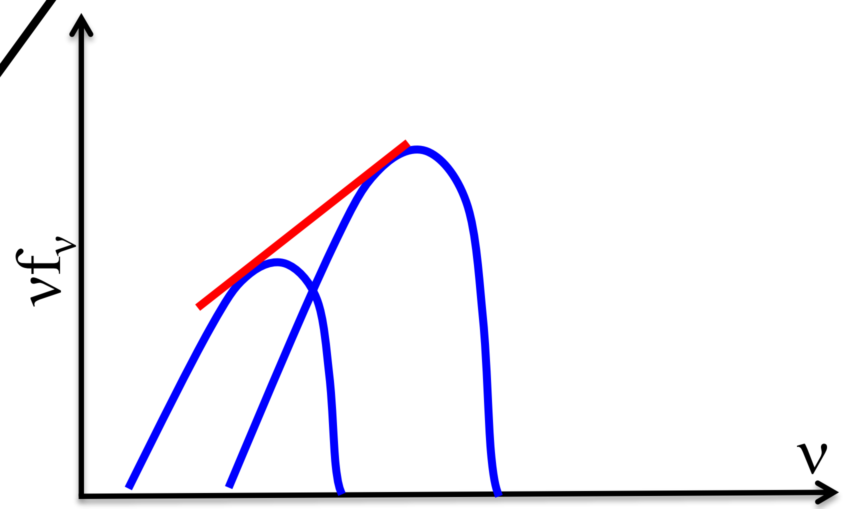
Stratified Jet structure



2 effects on the spectra

(I) multi-color effect

see also Lundman & Pe'er (2013)



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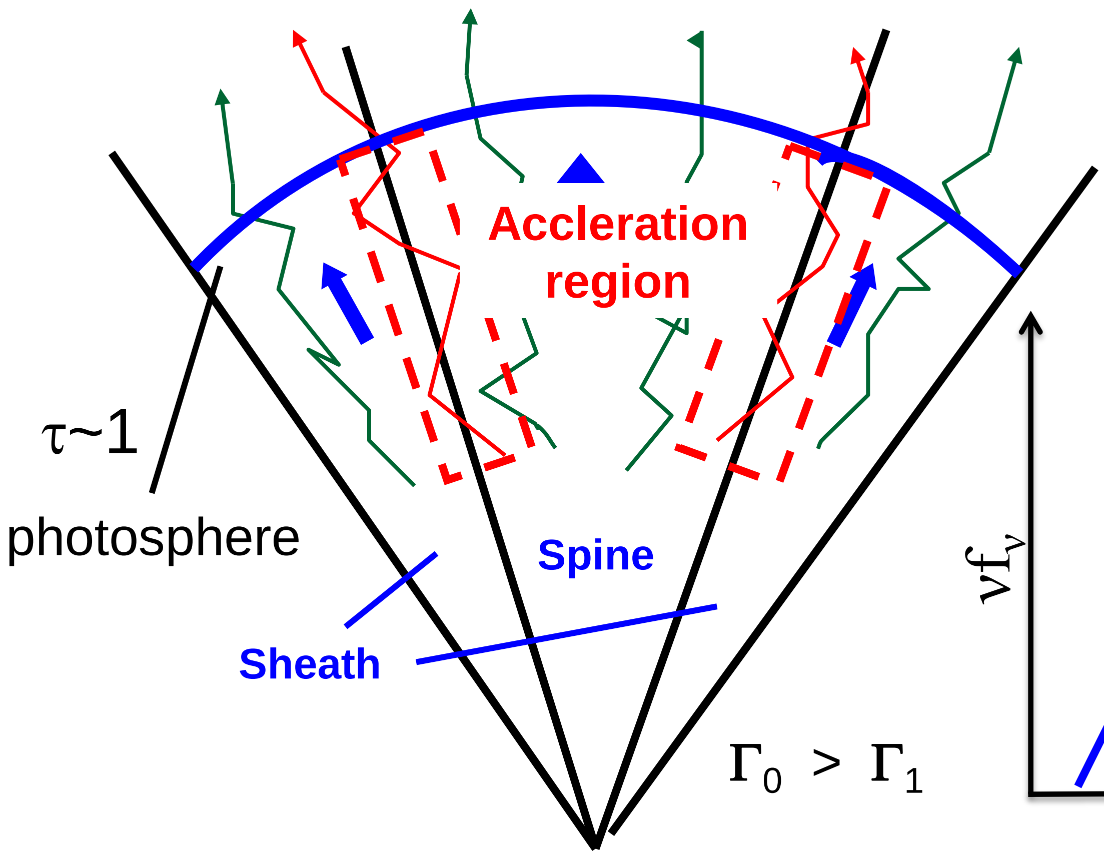

2 effects on the spectra

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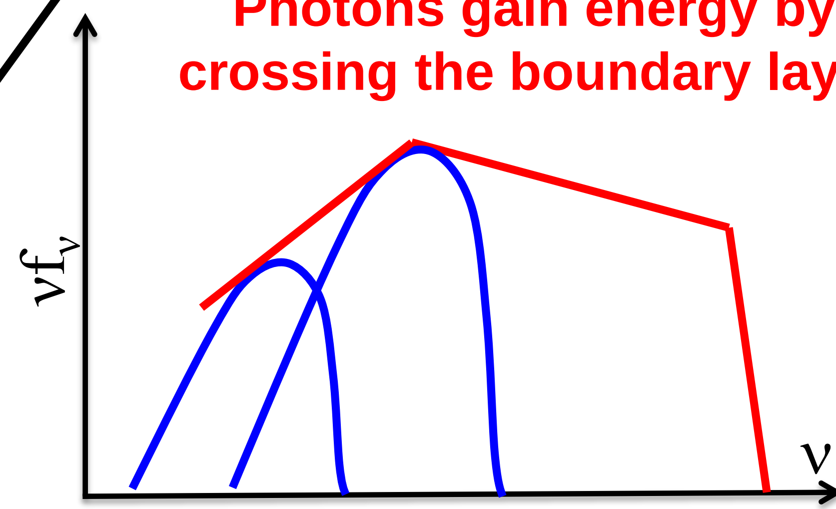
(II) Fermi acceleration of photons

Photons gain energy by crossing the boundary layer



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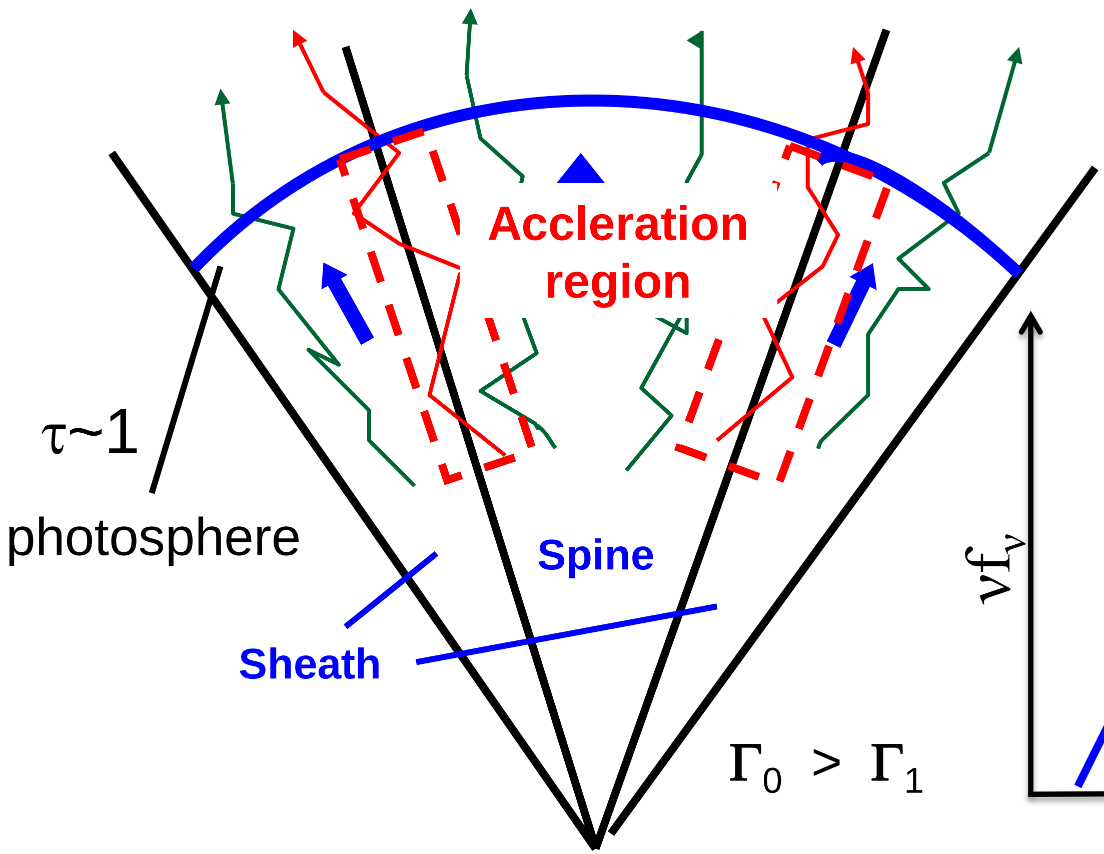

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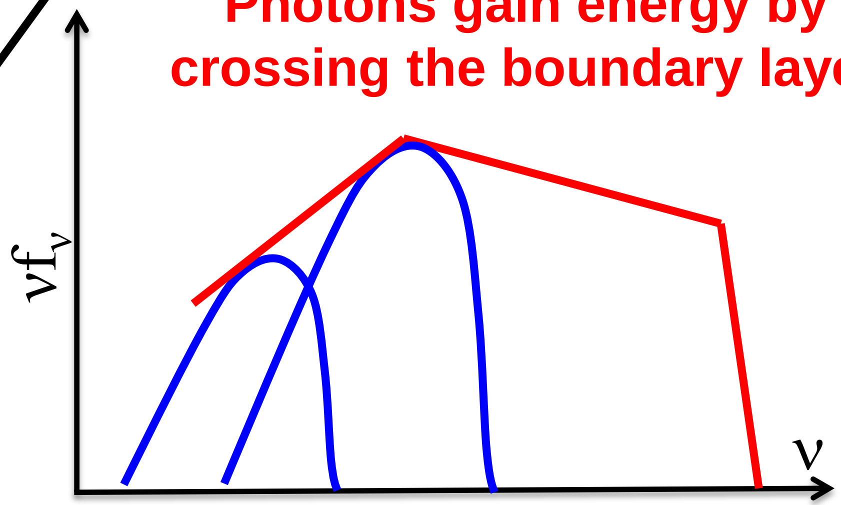
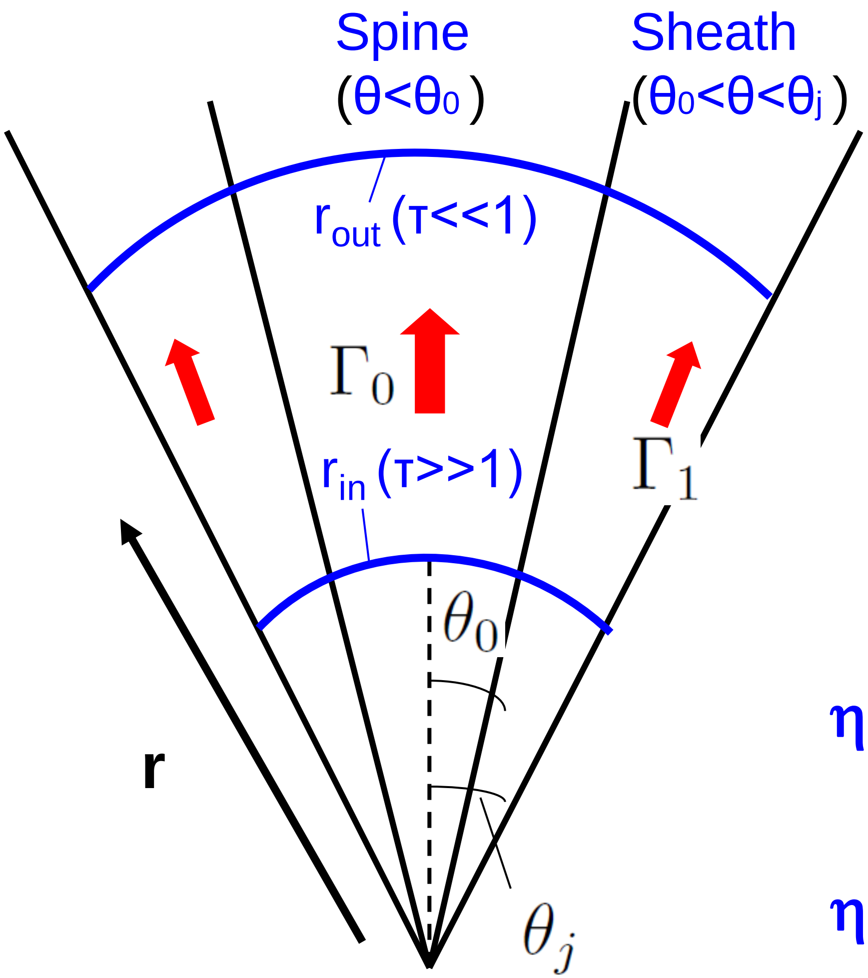


Propagation of photons are solved by Monte=Carlo method

2-component (spine-sheath) jet

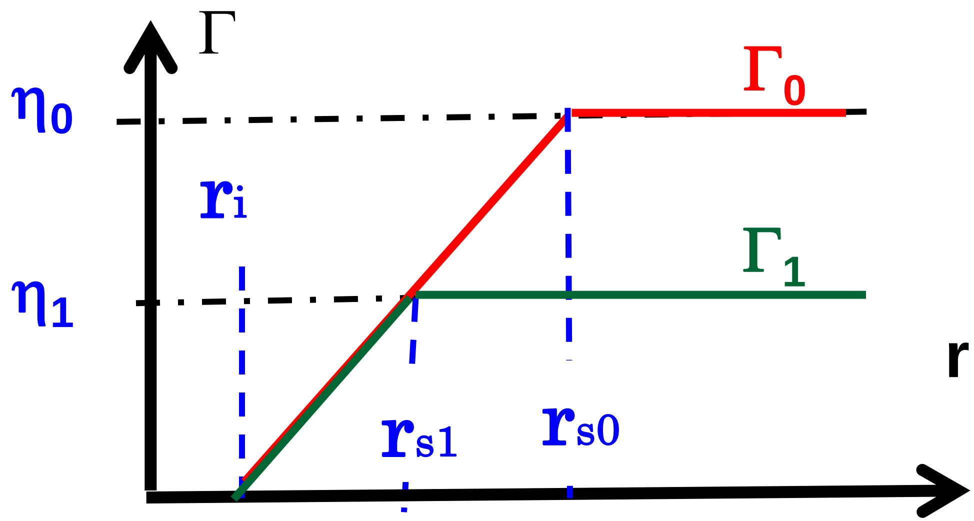


Radial structrue

fireball model (e.g., Piran 2004)

- **η**: baryon loading (terminal Lorentz factor)
- **L**: Kinetic luminosity
- $\mathbf{r}_i$: initial radius

$r_{i0} = r_{i1}$ $\eta_0 > \eta_1$



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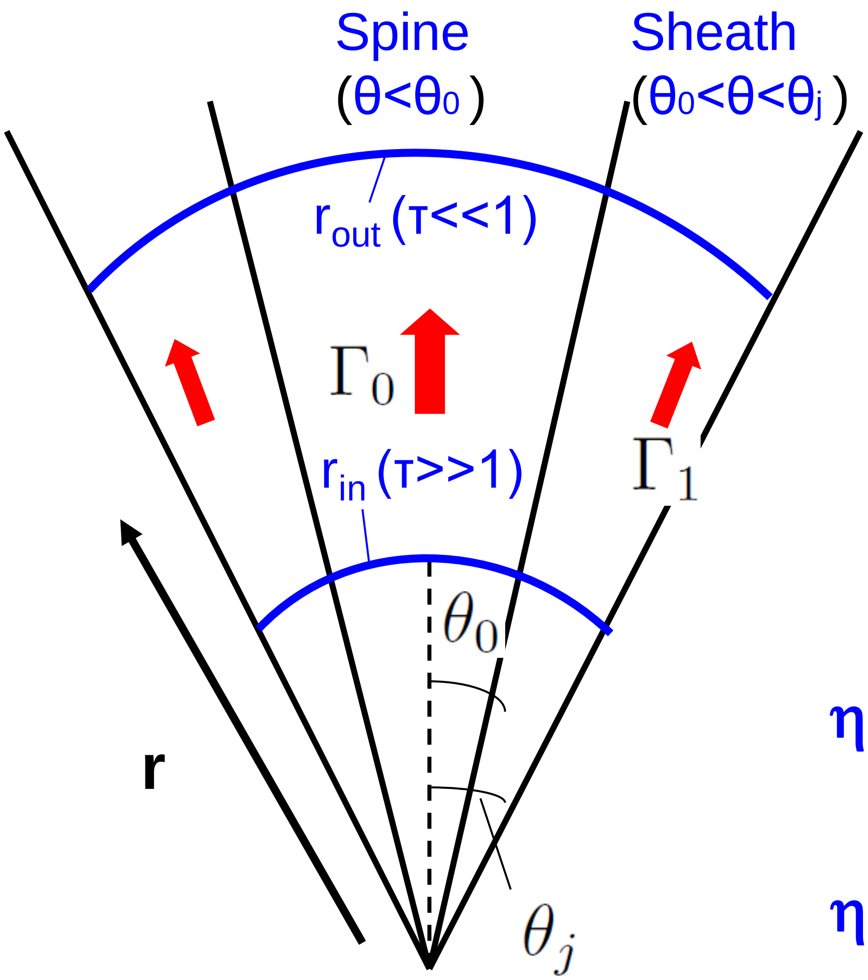
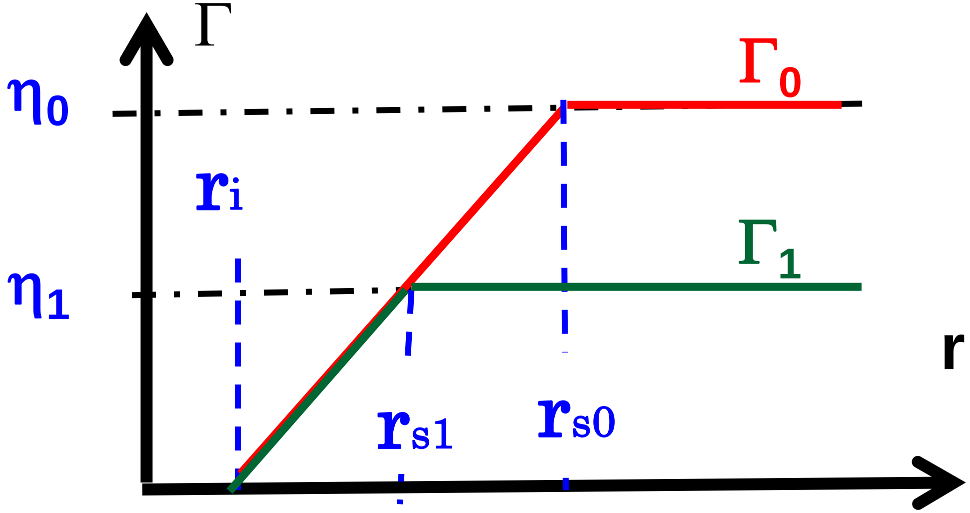


Calculation Range

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

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

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



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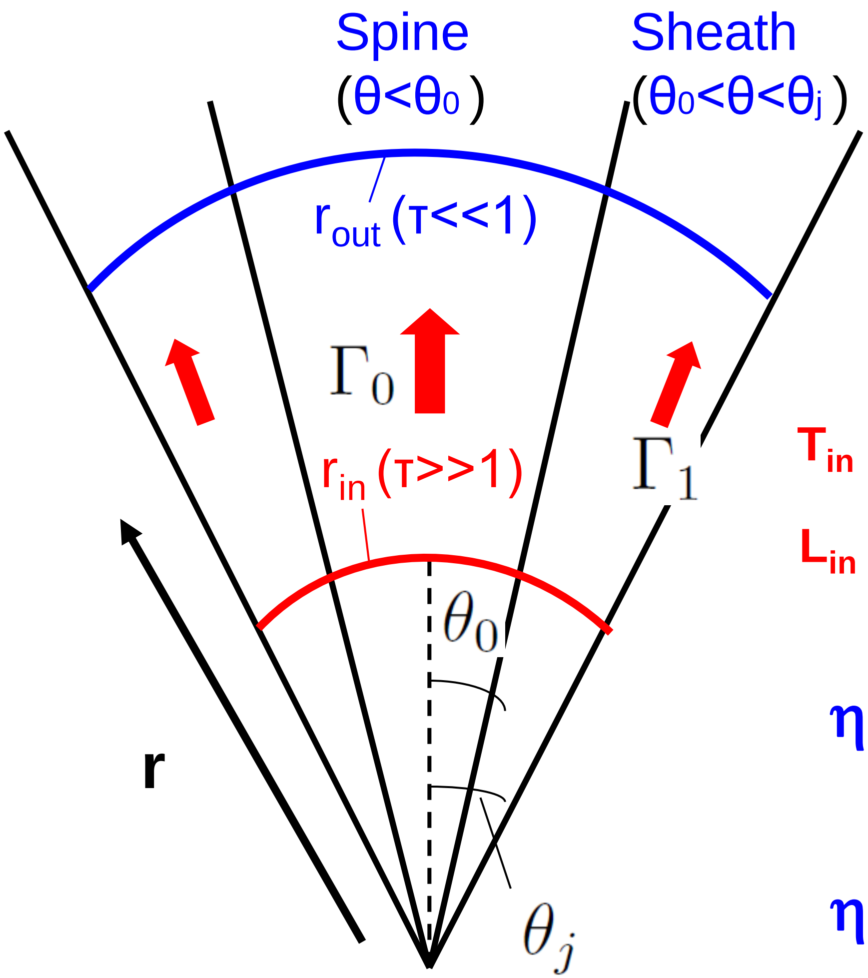
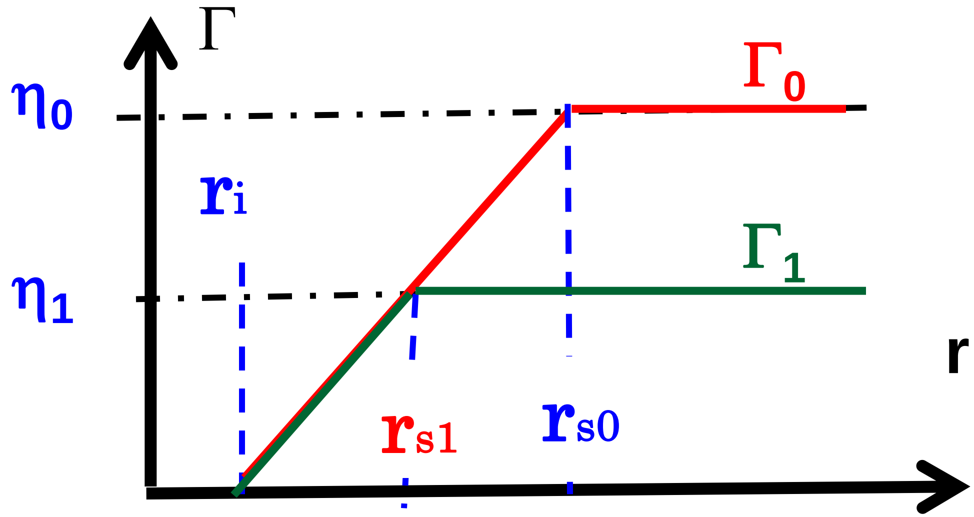


Initial Condition

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



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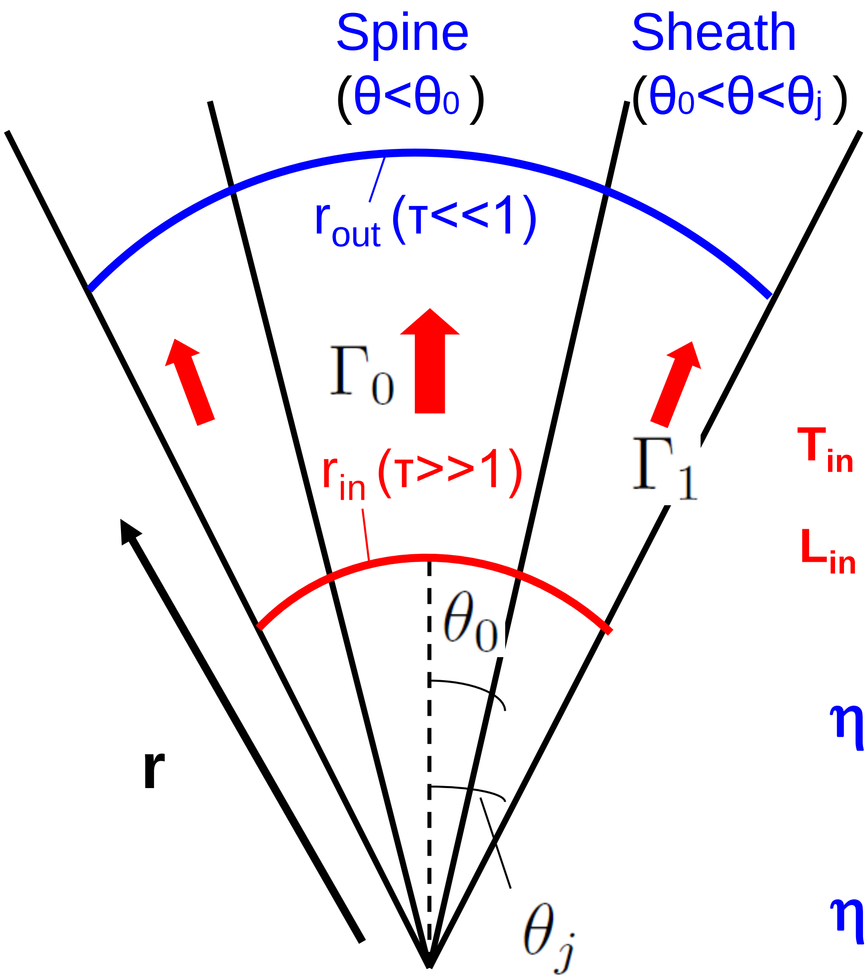

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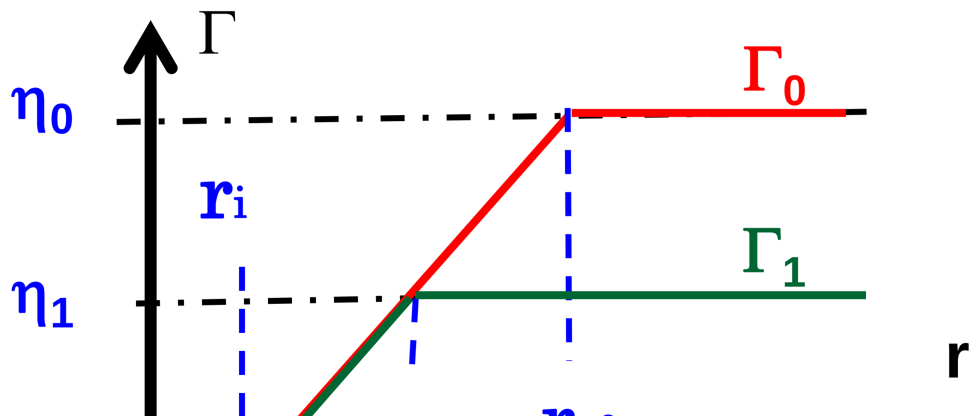
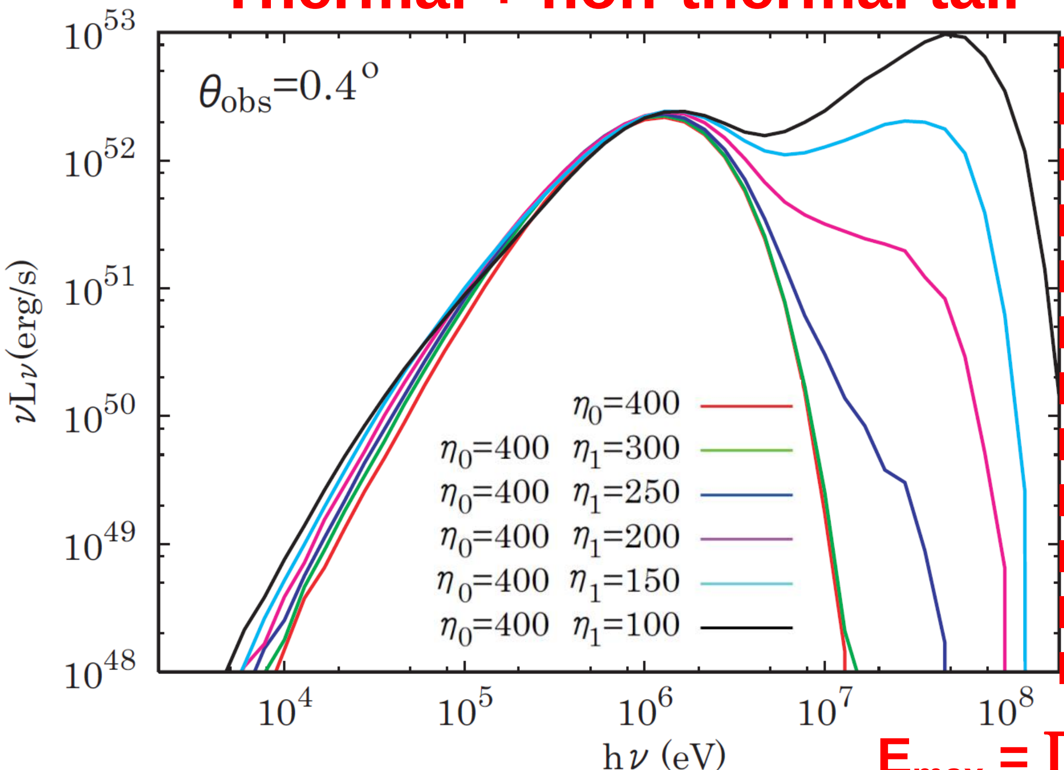


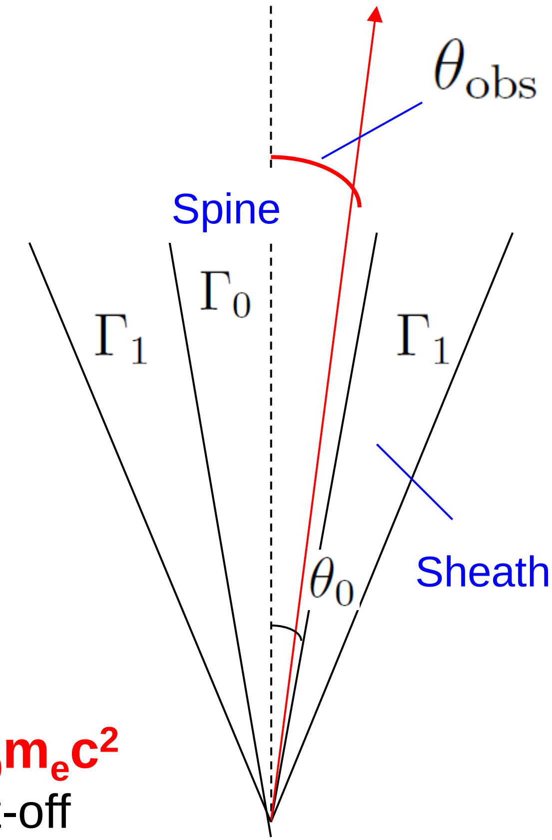
Propagation of photons are solved by Monte=Carlo method

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

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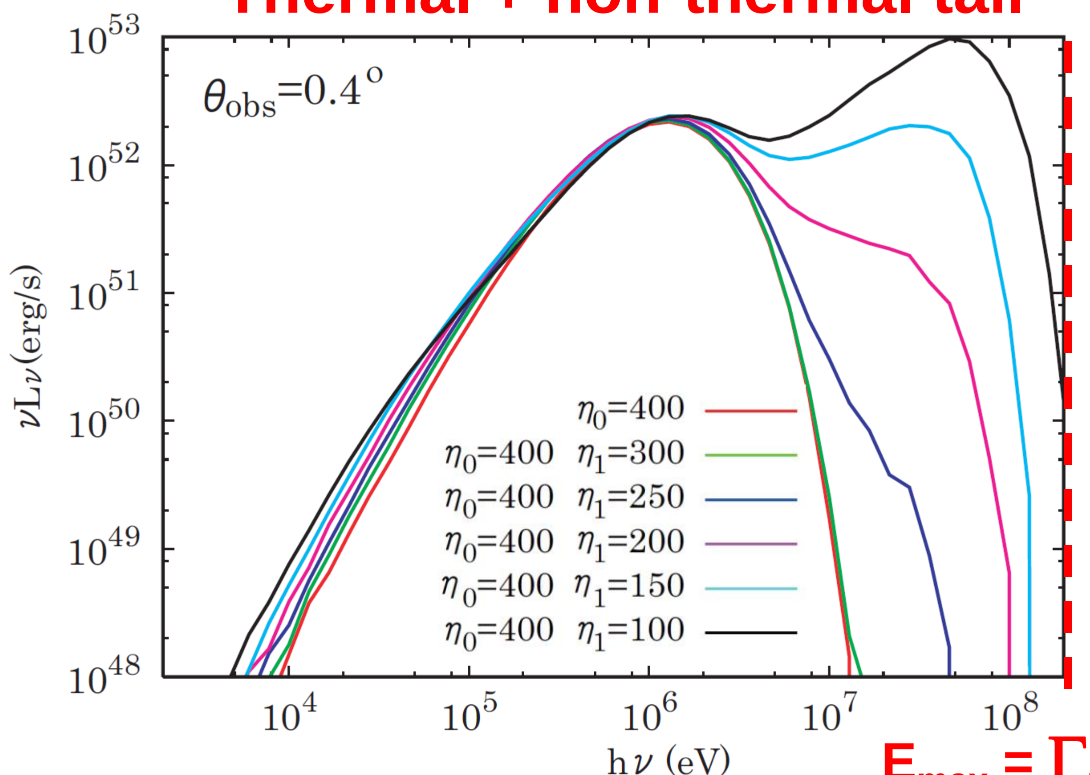
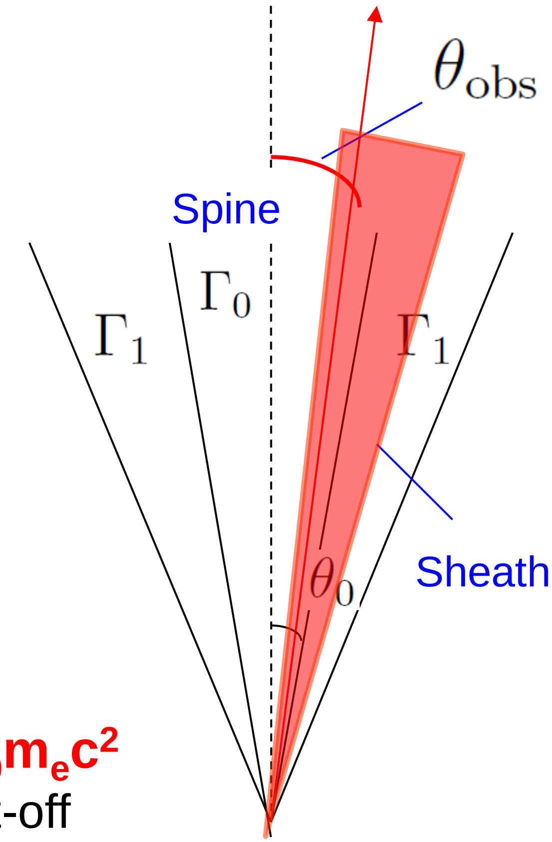




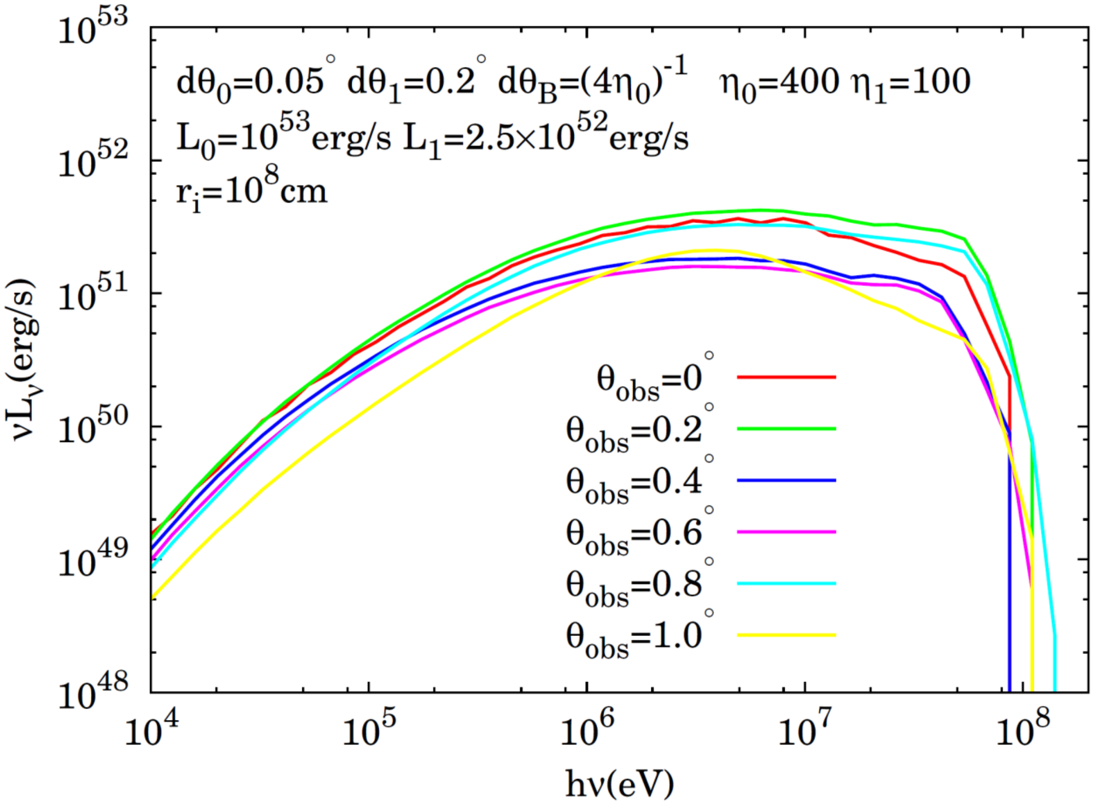
$E_{max} = \Gamma_0 m_e c^2$

Klein-Nishina cut-off

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

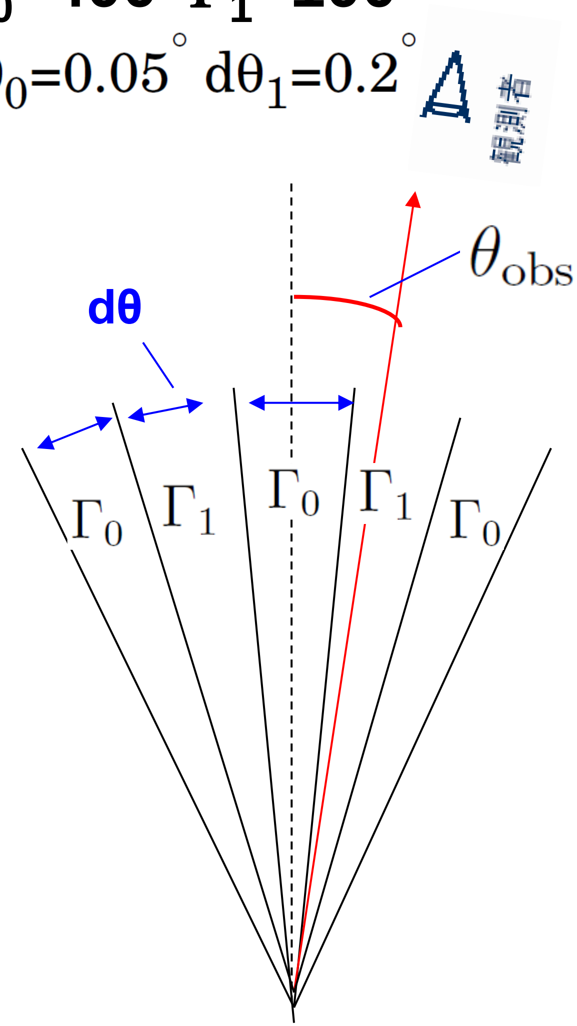
But limited only for narrow range of observer angle **$|\theta_{obs} - \theta_0| < \Gamma^{-1} \sim 0.14° \ \Gamma_{400}^{-1}$**

Multi-component jet



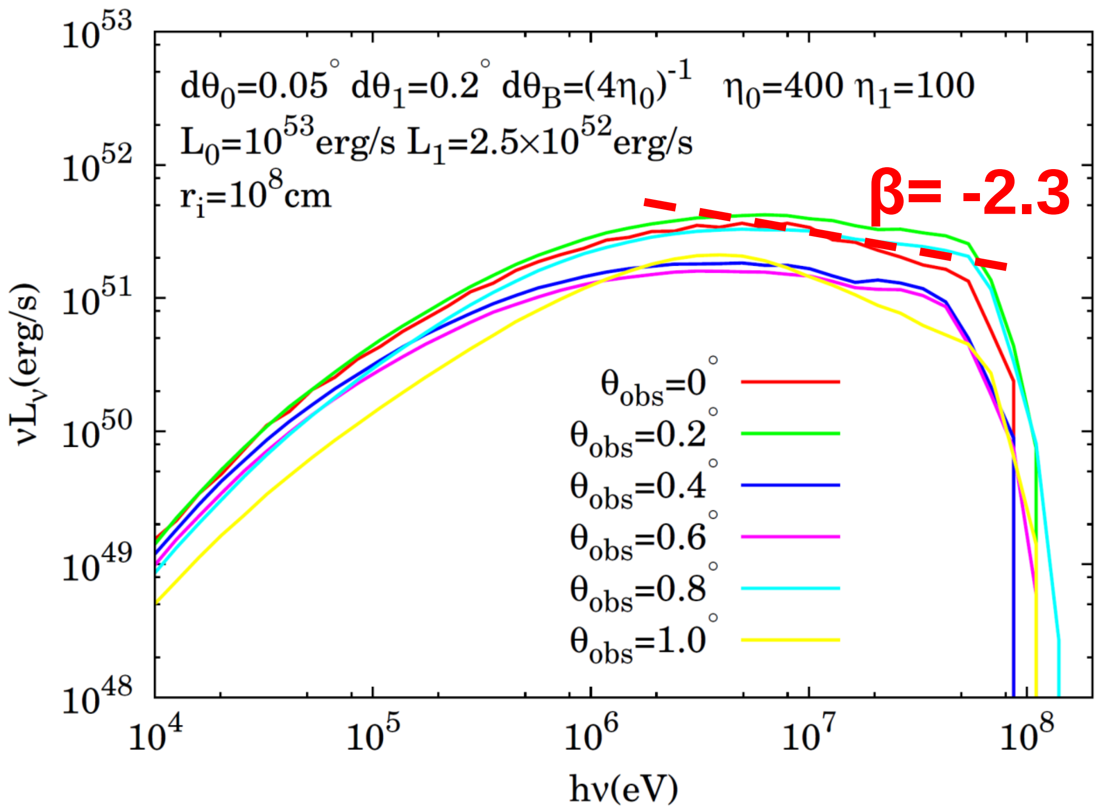
Γ_0=400 Γ_1=100

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



Interval of velocity shear dθ < 2Γ^{-1}

Multi-component jet



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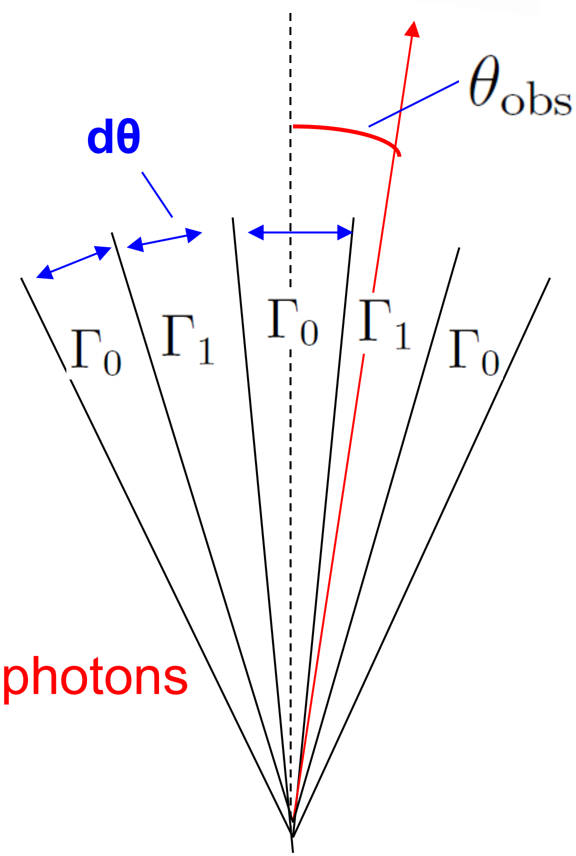
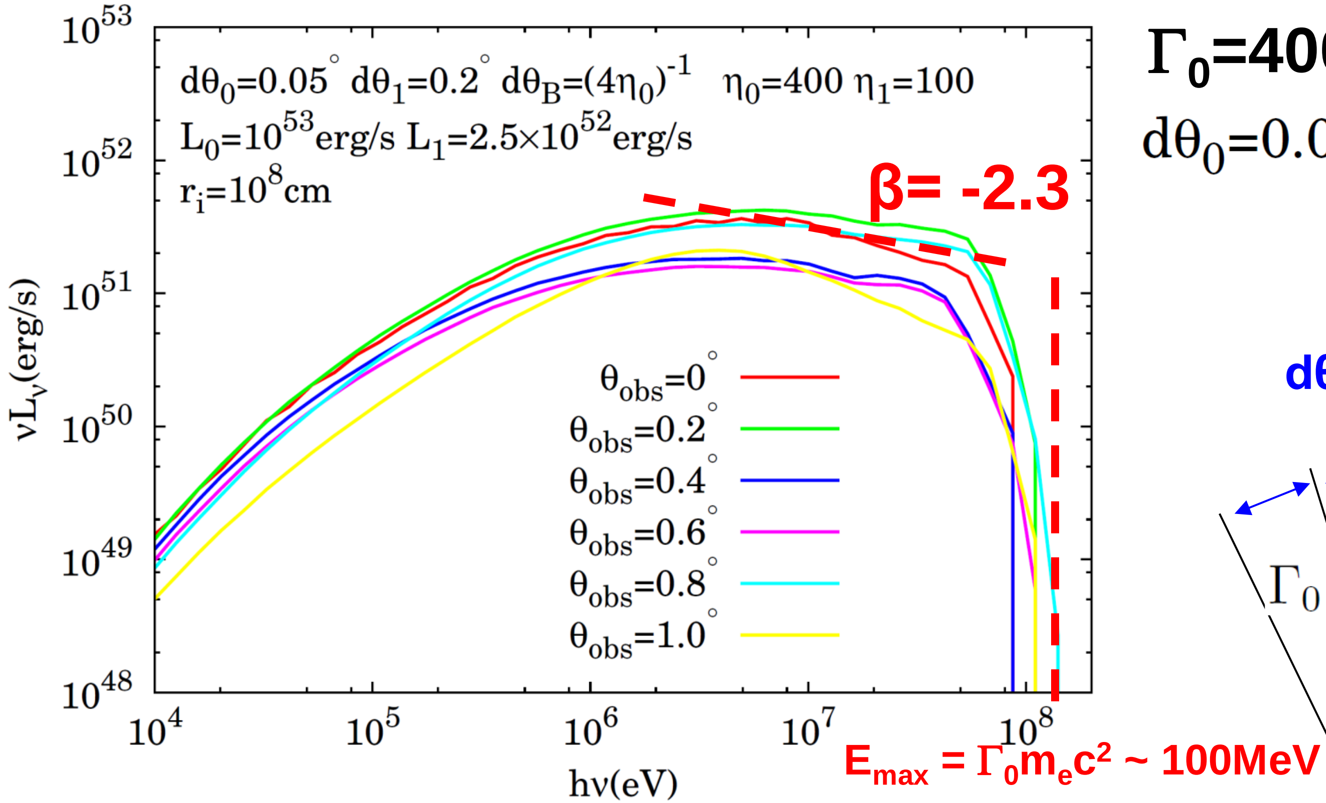


Interval of velocity shear dθ < $2\Gamma^{-1}$

high energy spectra (β) is reproduced by accelerated photons

Multi-component jet



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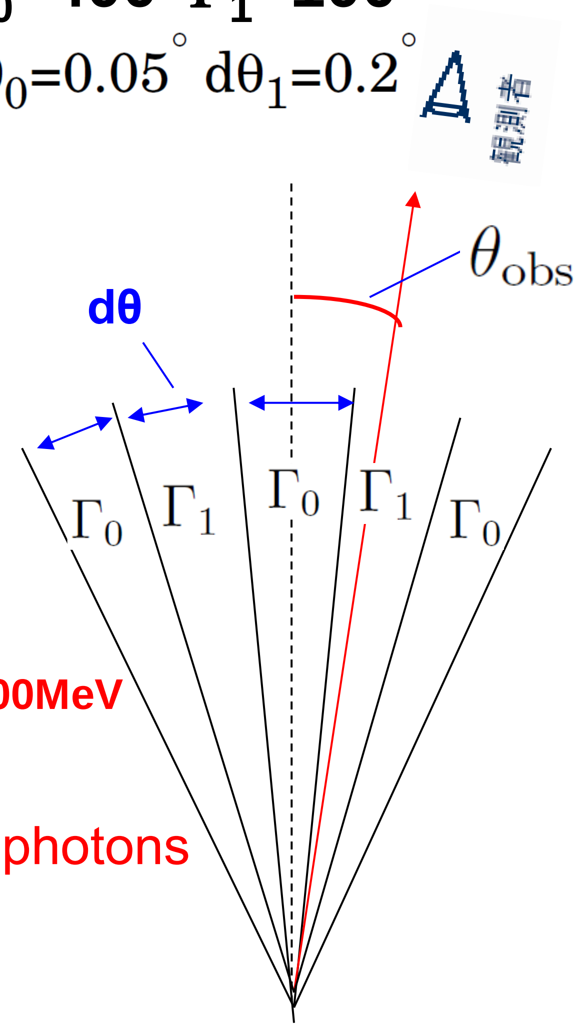

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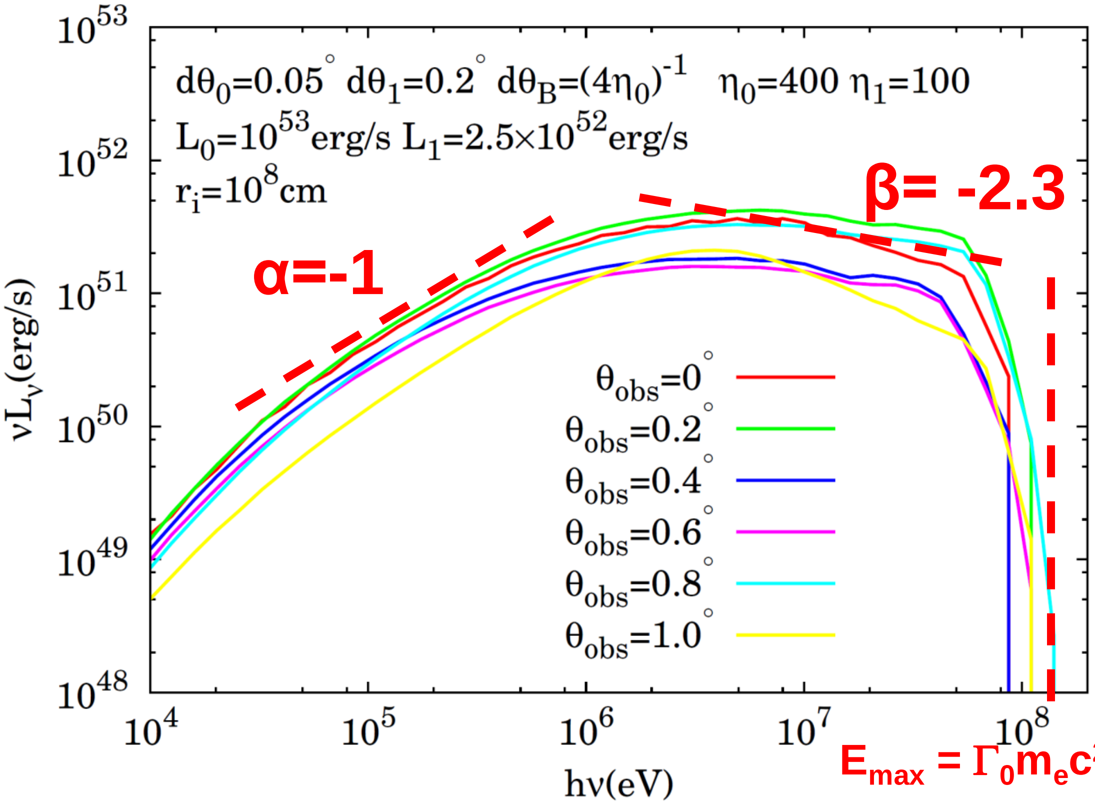
Cut off at ~ 100 MeV

Multi-component jet



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

Γ_0=400 Γ_1=100

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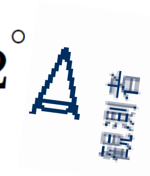
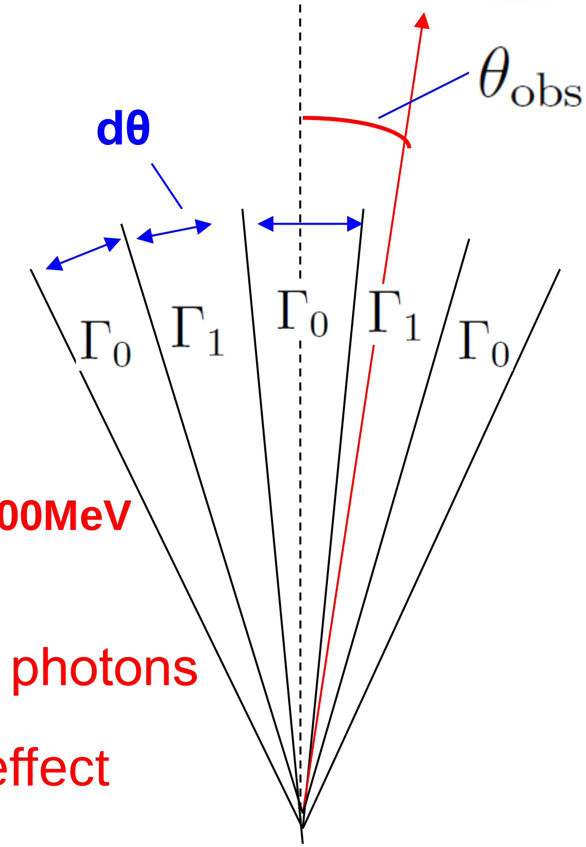




Interval of velocity shear dθ < 2Γ^{-1}

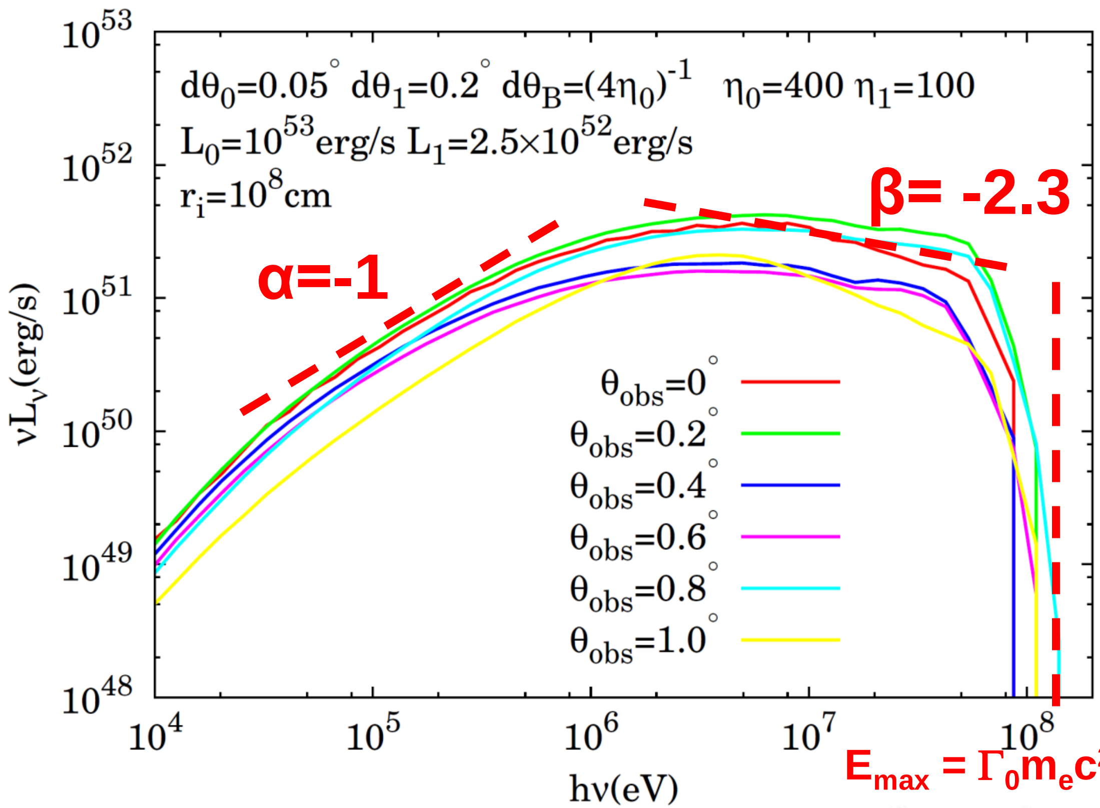
high energy spectra (β) is reproduced by accelerated photons

Cut off at ~ 100 MeV

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

(Lundman & Pe'er 2013)

Multi-component jet



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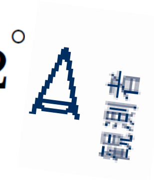
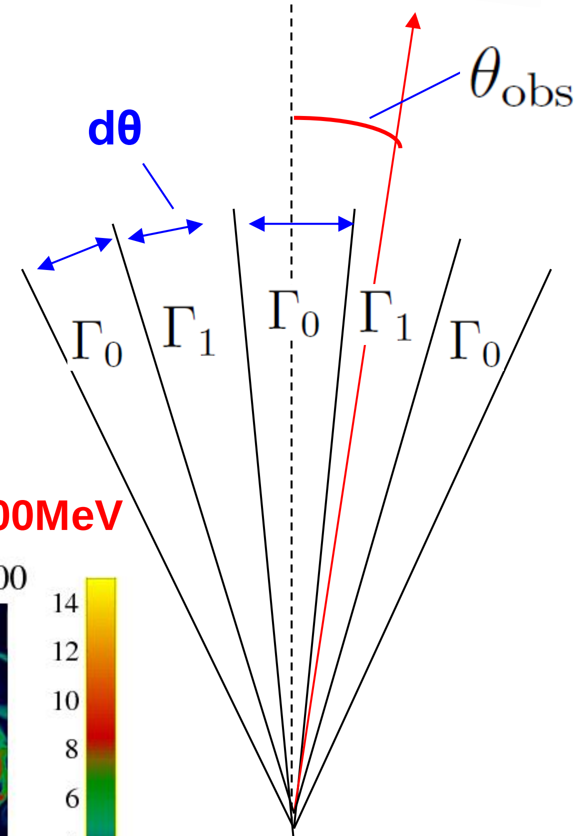
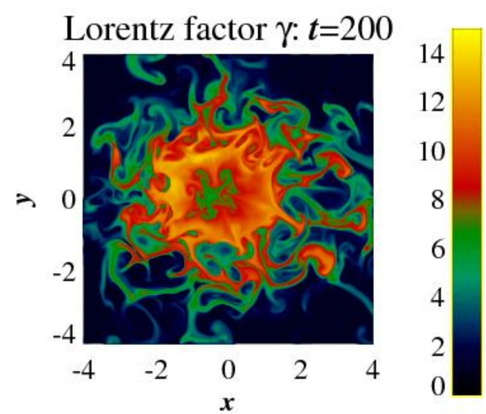




Interval of velocity shear $d\theta < 2\Gamma^{-1}$

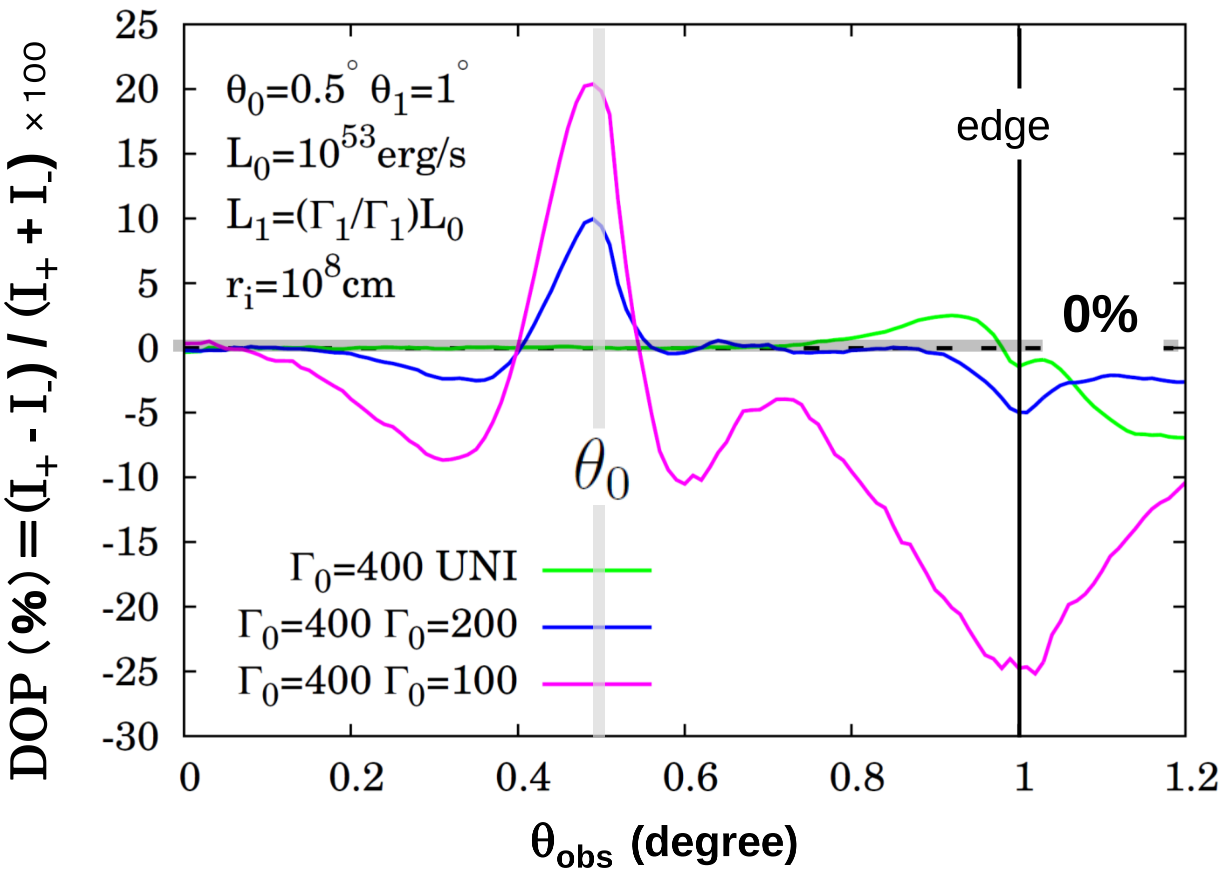
Face on view of jet

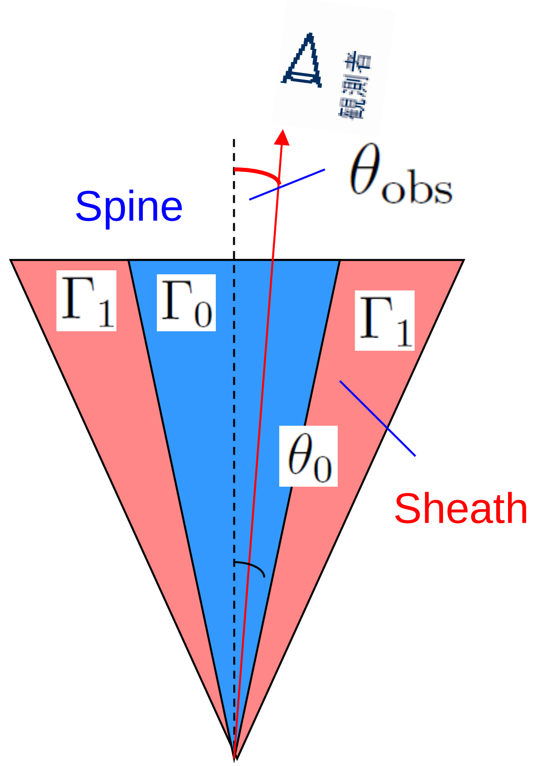


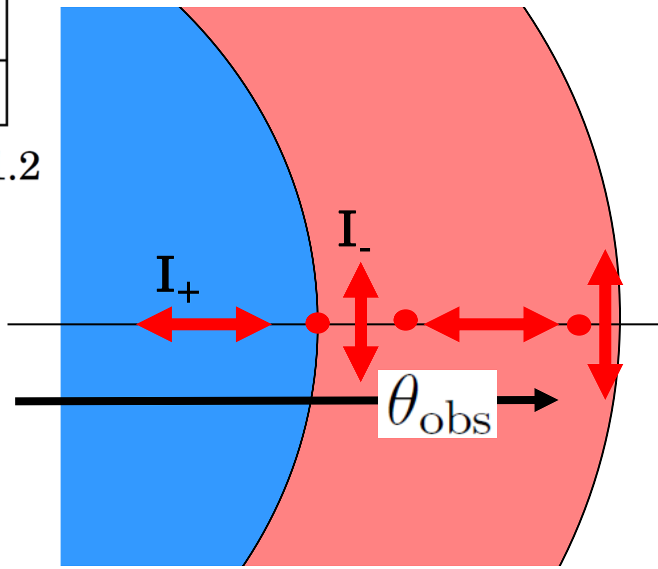
Simulation by Dr. Matsumoto

polarization

two-component jet





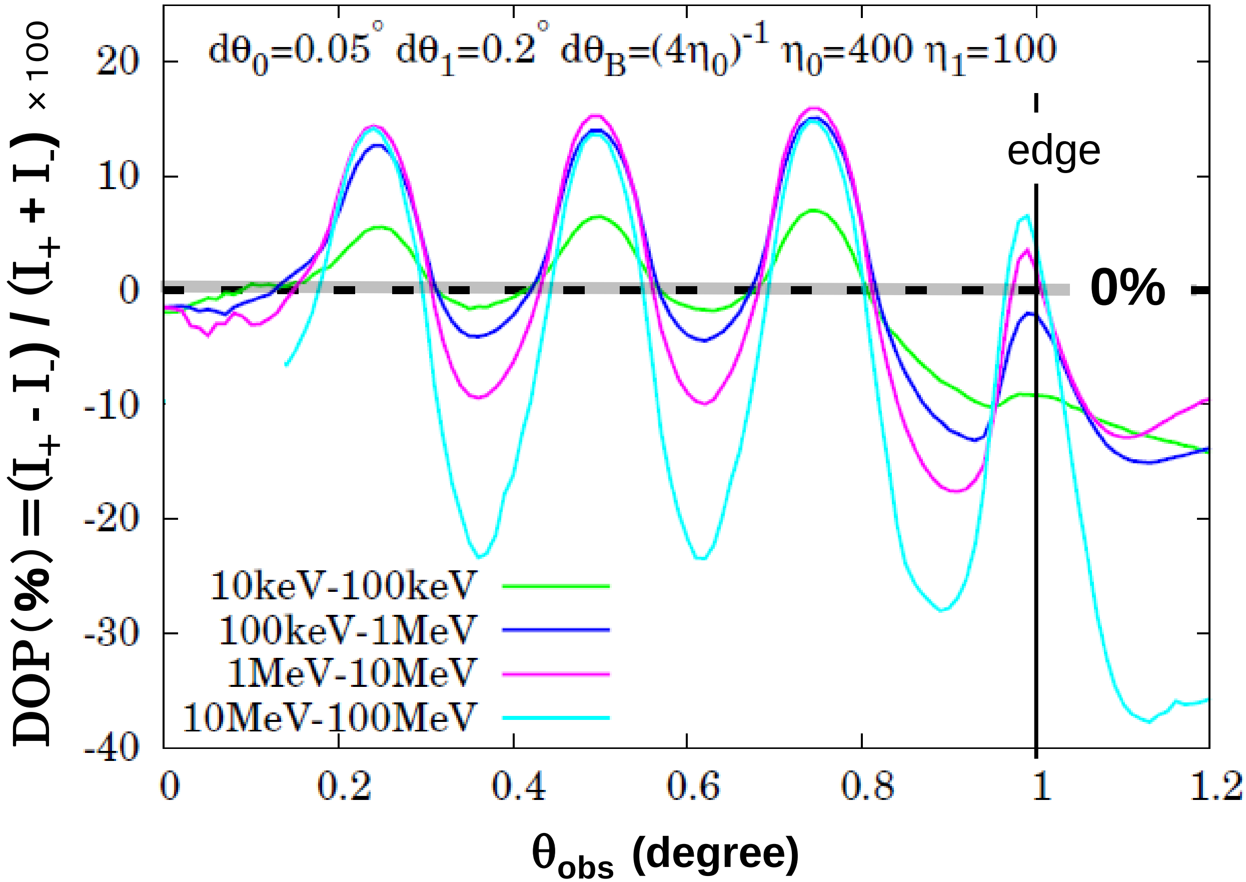


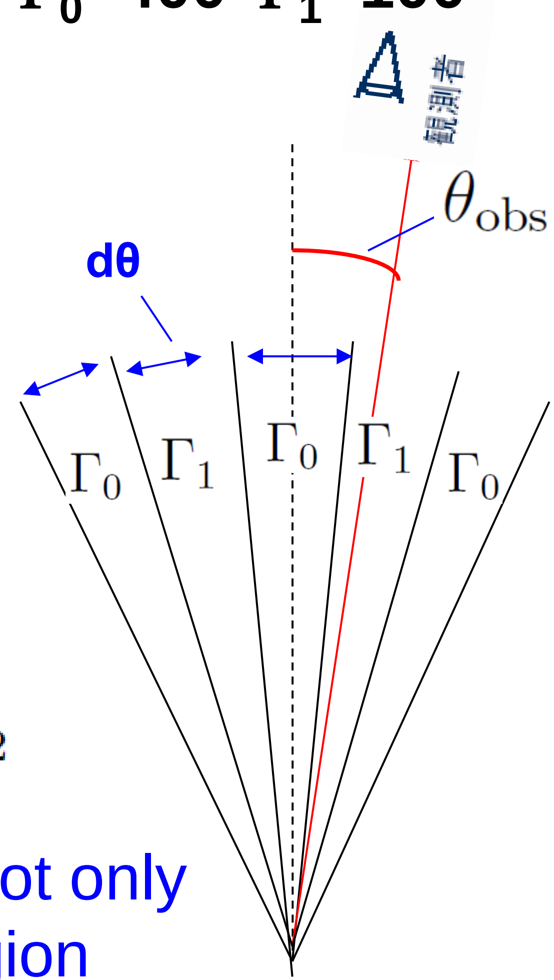
Degree of polarization (DOP) becomes larger as the relative velocity becomes large

polarization

multi-component jet that reproduces Band spectra

Γ_0=400 Γ_1=100



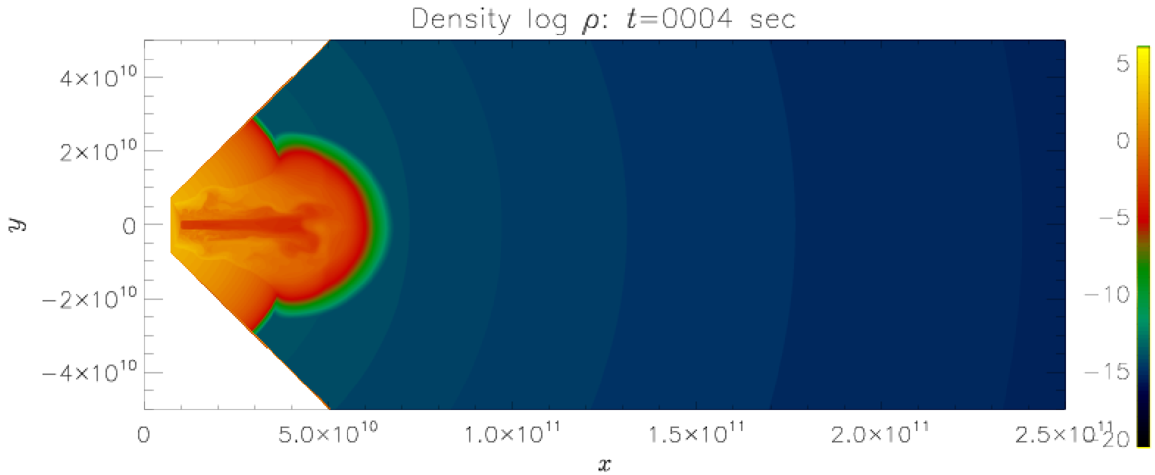


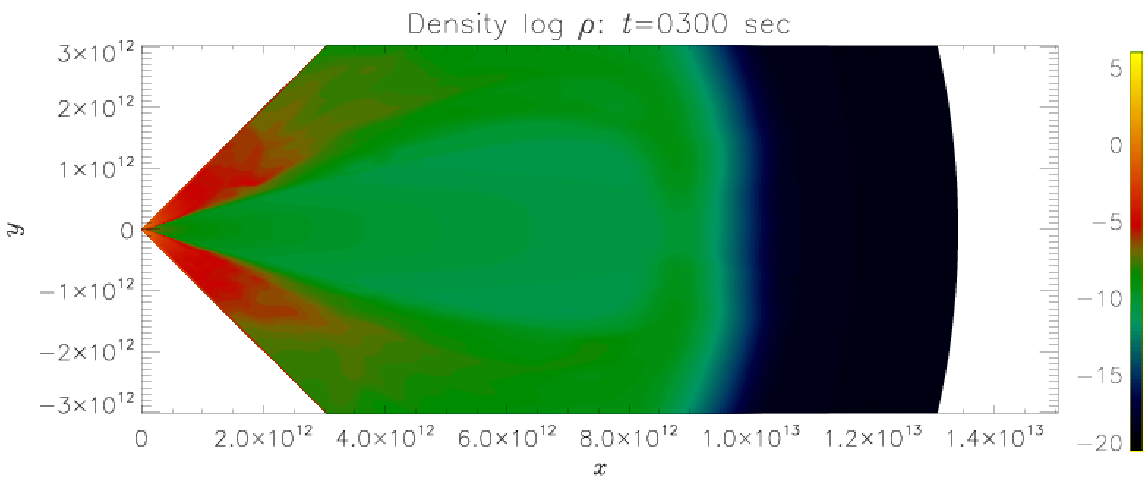
High polarization degree (>10%) is predicted not only in the off-axis region but also in the on-axis region

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

On-going project

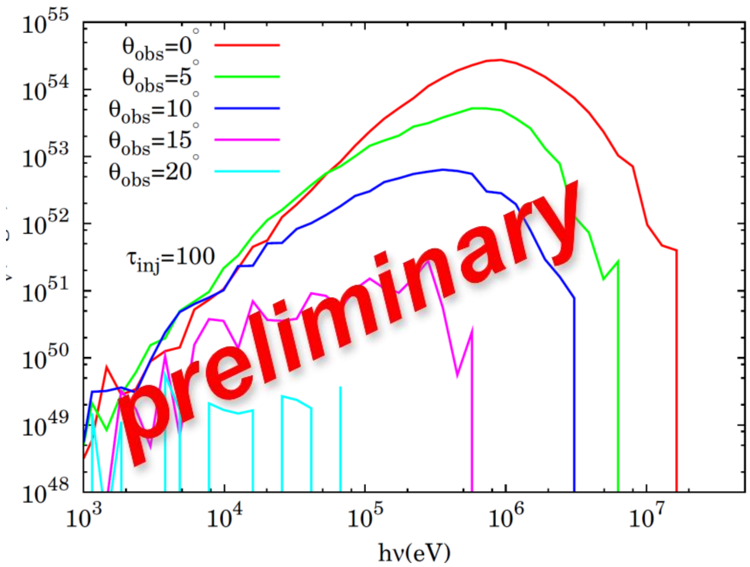
3D Hydrodymical simulation of relativistic jet as a background fluid





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

– Degree of polarization tends to increase as the relative velocity increases

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

<u>Futrure works</u>

・Photon accelerations in various structures

  shocks, turbulence

・Hydrodymical simulation of relativistic jet as a background fluid