Photospheric Emission in GRBs

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Collaborators

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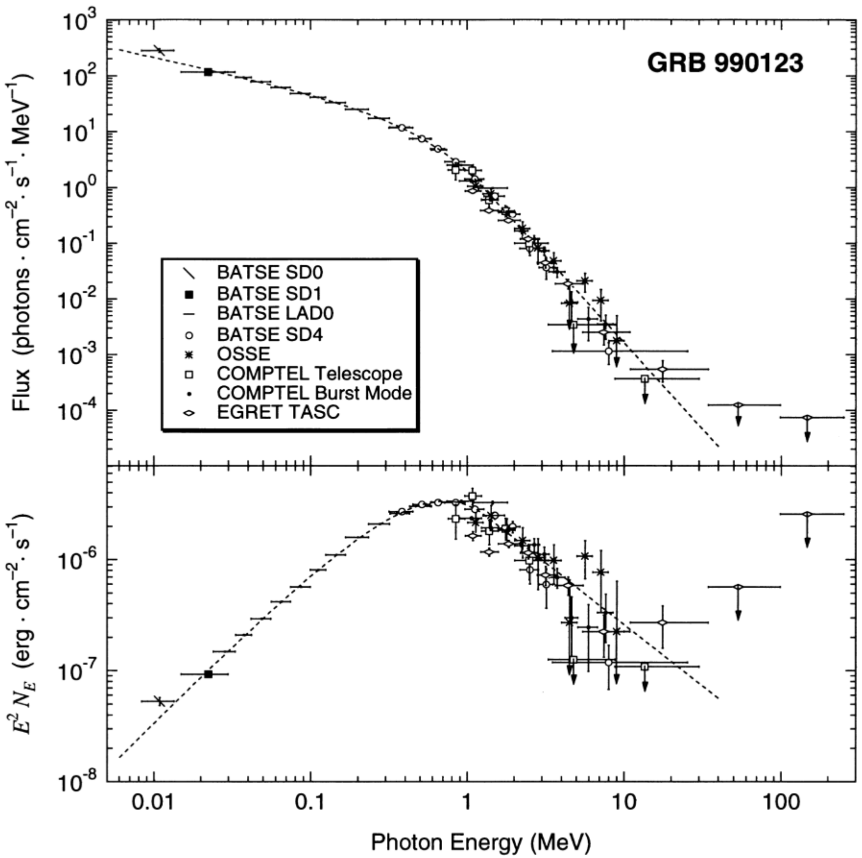
Plan of this talk

- Introduction
  - Brief overview of prompt emission of GRBs
  - Photospheric emission model
- Photospheric emission from structured jet
  - Spetrum and polarization Ito + 2013, 2014
  - Photospheric emission based on 3D jet simulation
- Summary

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

Gruber + 2014

Model for Emission Mechanism

Internal Shock Model

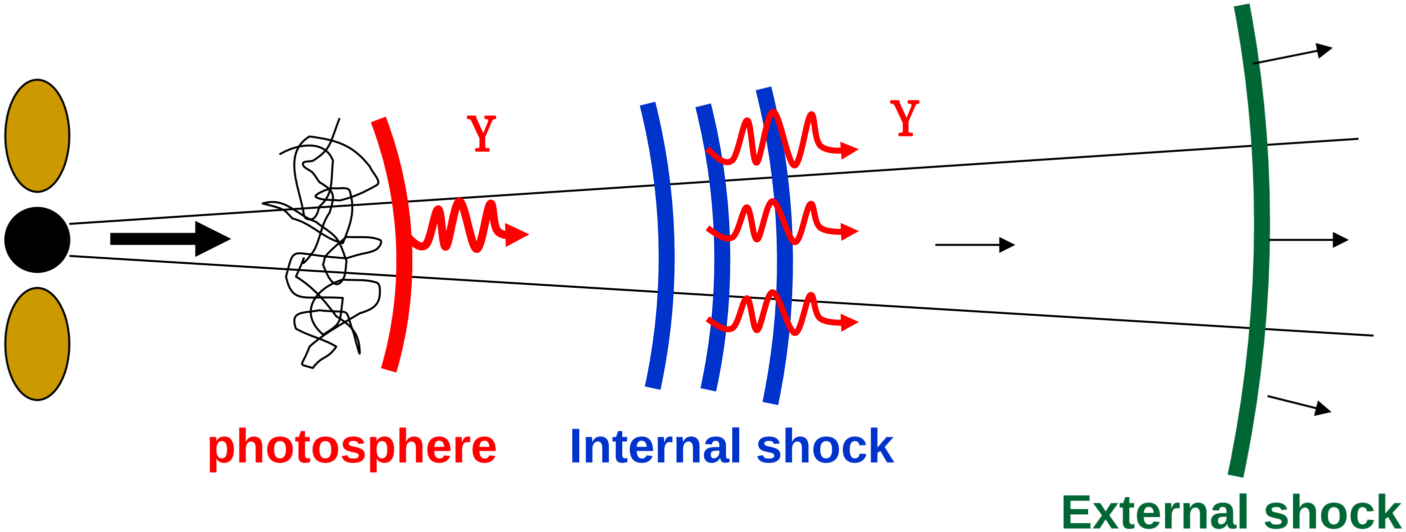
flaw
- Low efficiency for gamma-ray production
- Difficult to model hard spectrum in low energy band (α)

Photospheric Emission Model

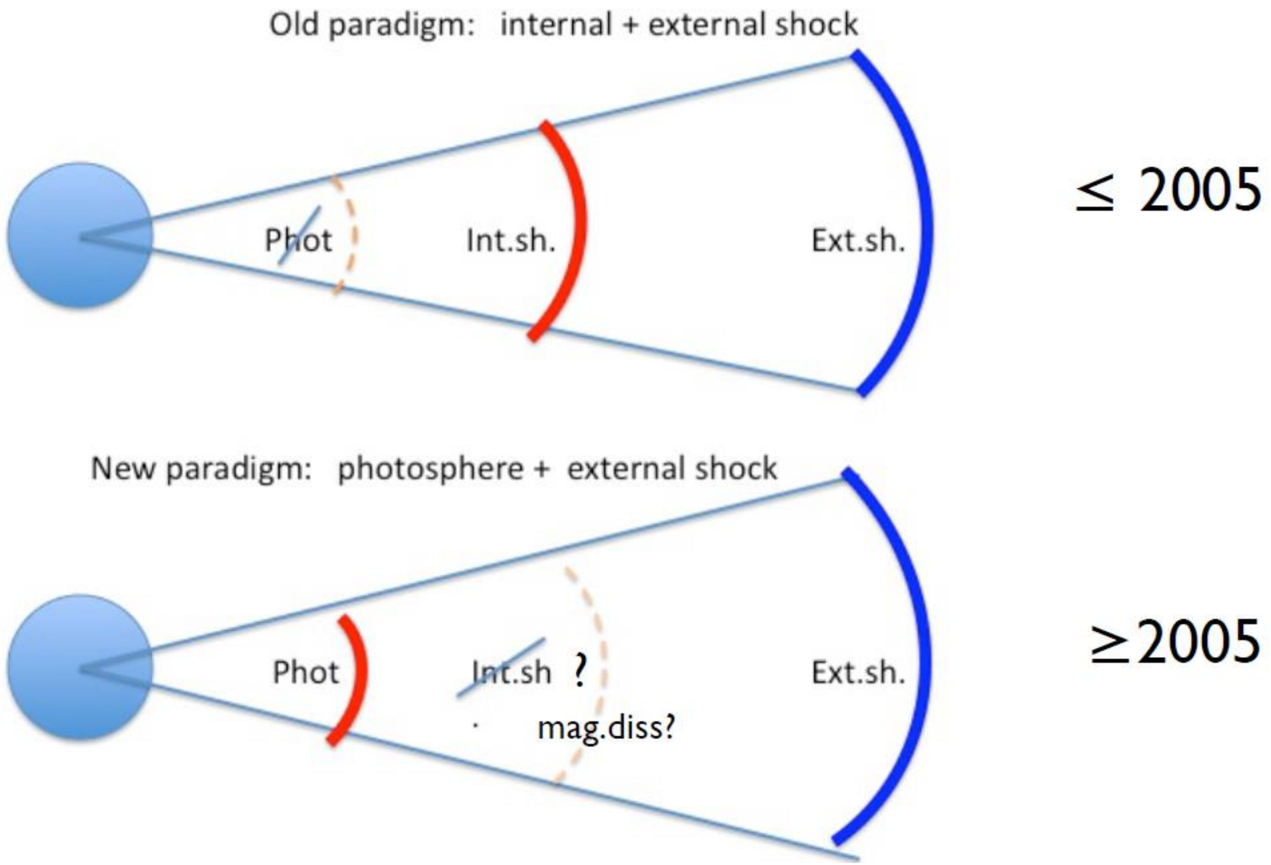
Natural consequence of fireball model

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

- High radiation efficiency
- Clustering of peak enegy ~ 1MeV



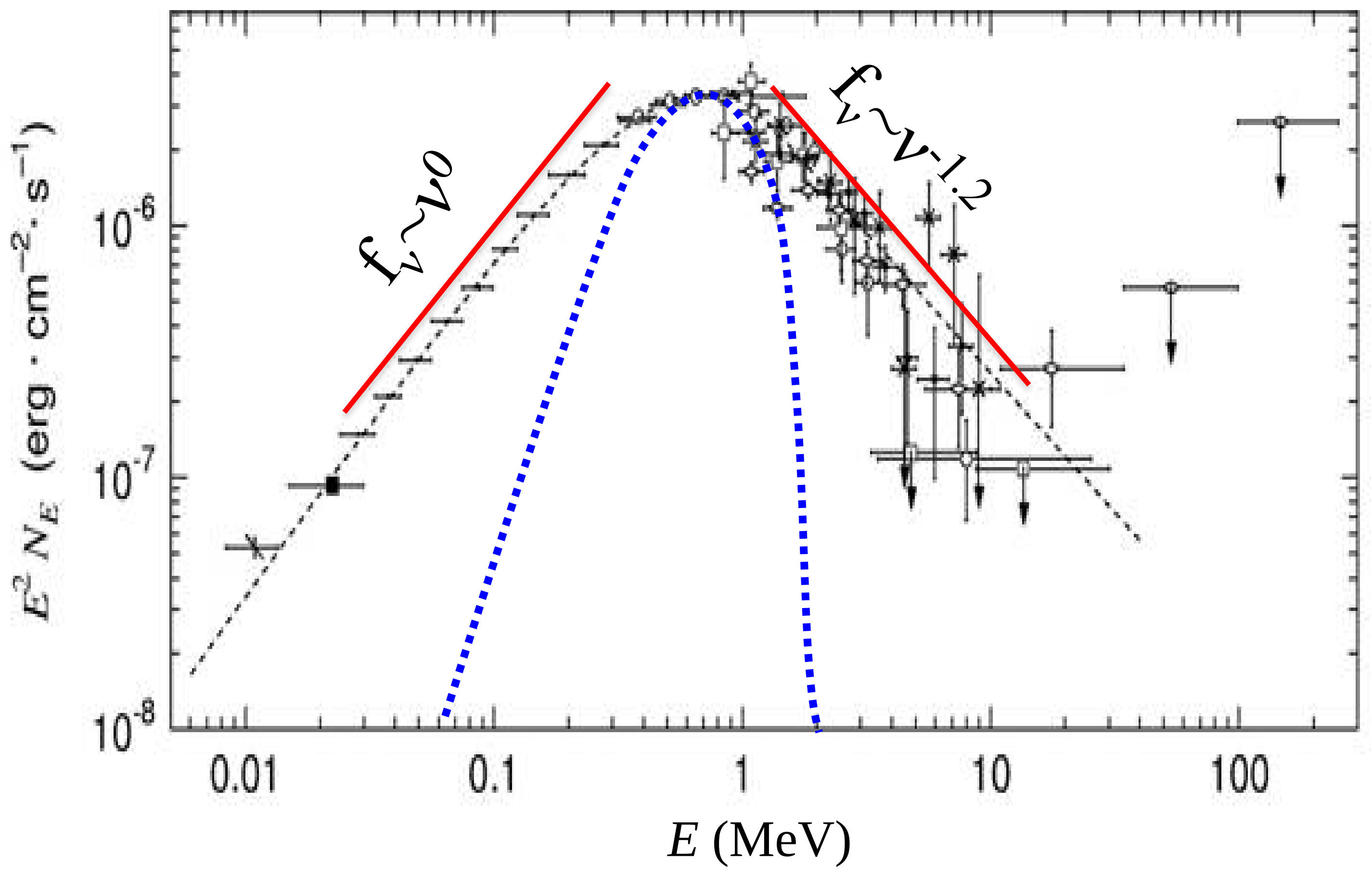
Evolving Fireball paradigm:



Slide from P.Meszaros @ SNGRB in Kyoto 2013

Difficulty in photospheric emission model

non-thermal spectrum



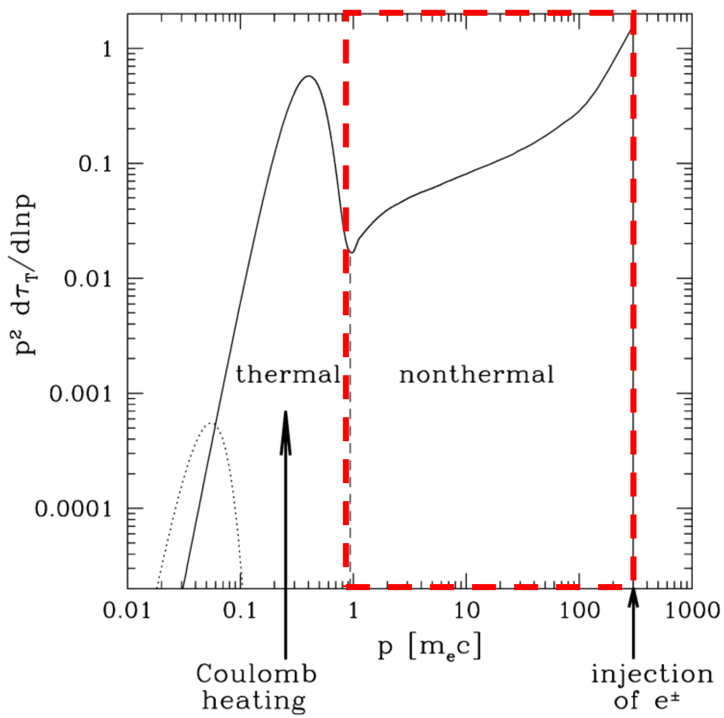
Broadening from the thermal spectra is required

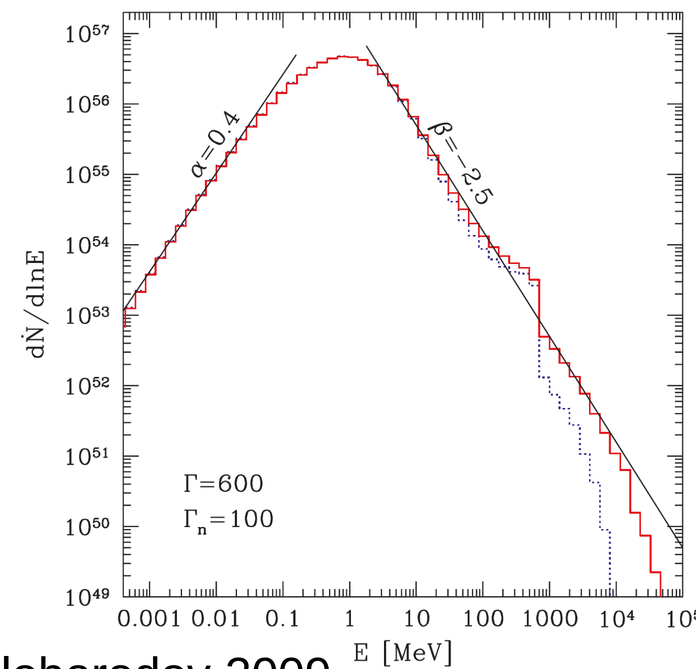
Dissipative process

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

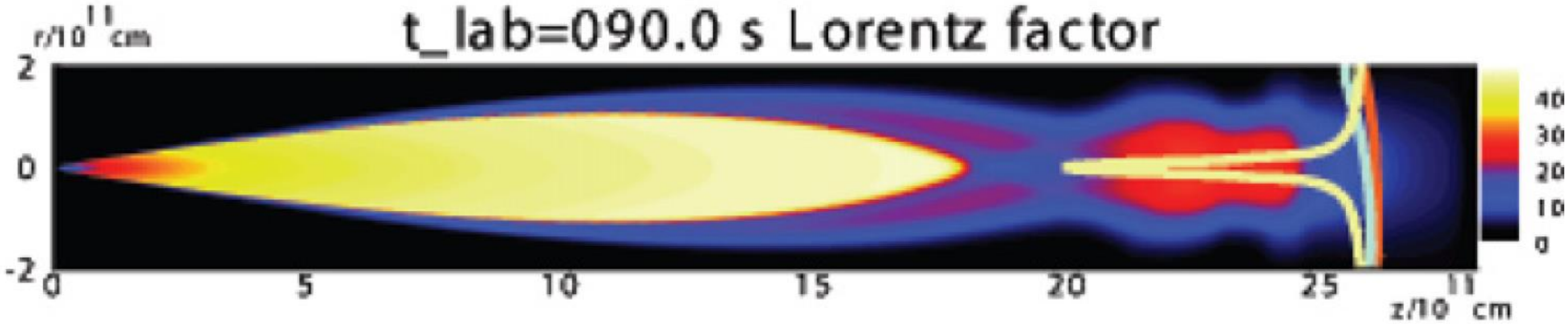




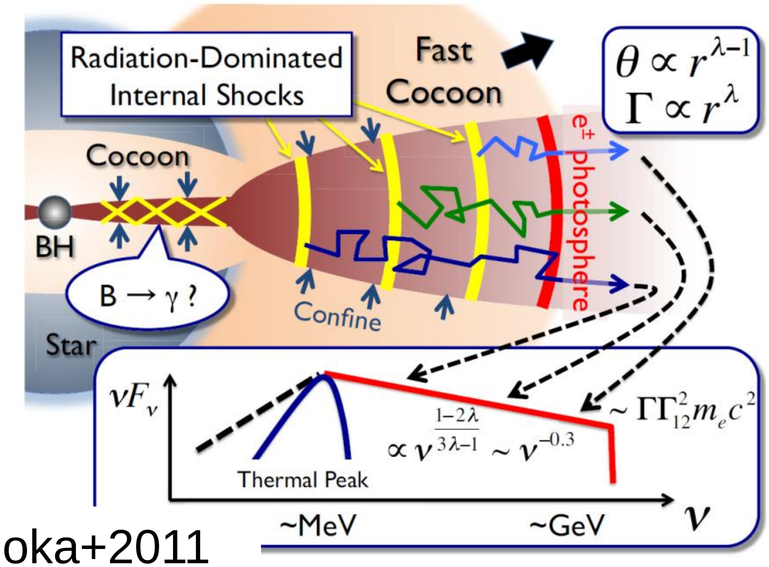
Beloborodov 2009

Geometrical brodening

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



Mizuta+2011



Ioka+2011

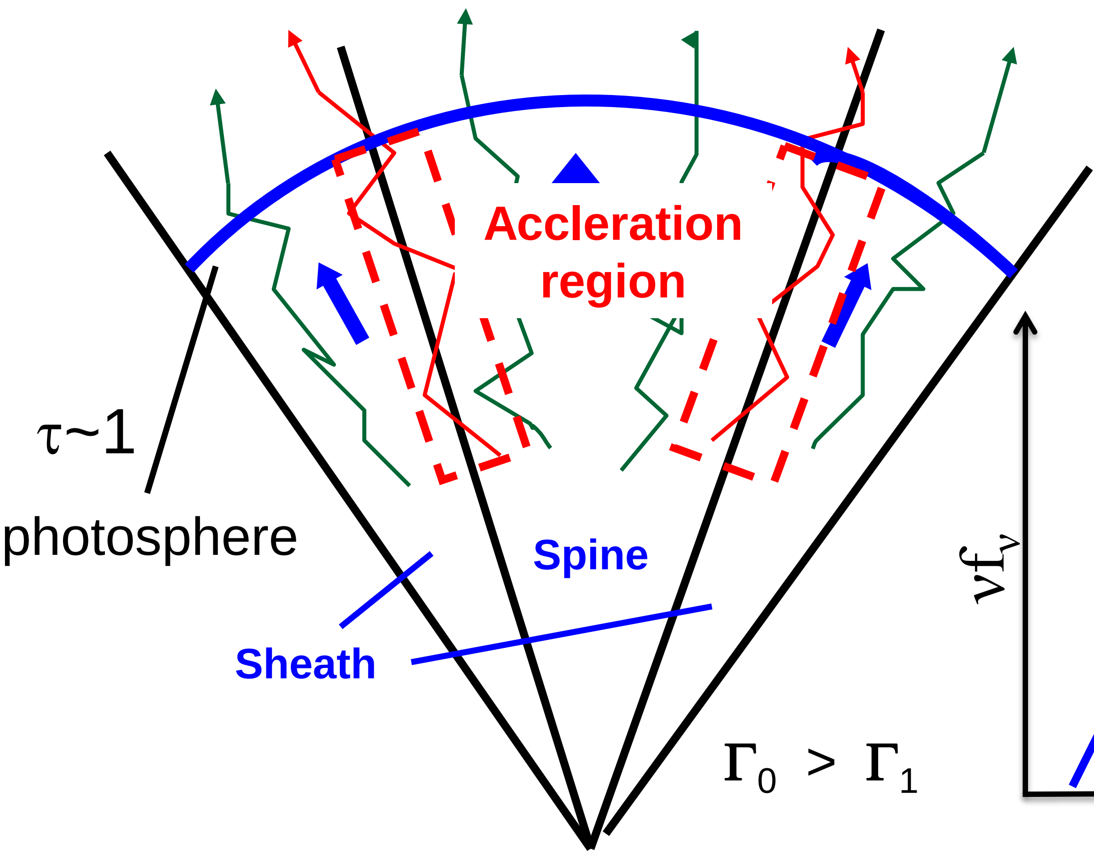
spectrum broadens even in the absence of relativistic pairs

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



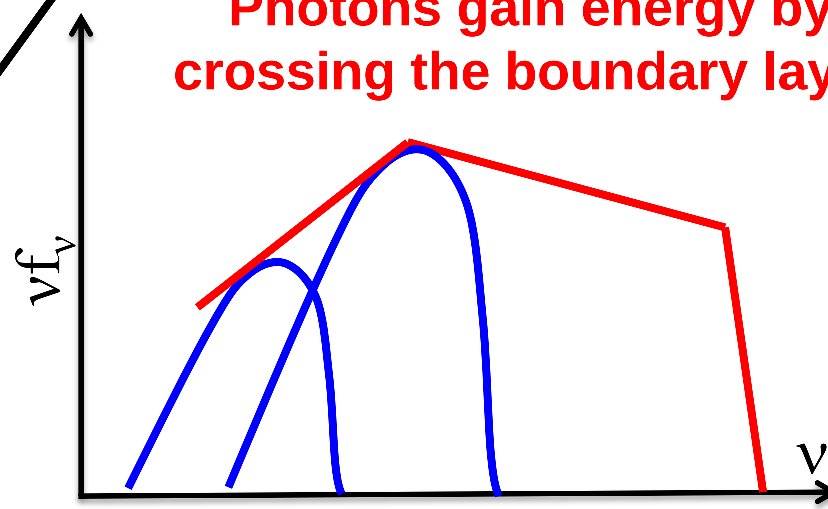
2 effects on the spectra

(I) multi-color effect

see also Lundman + 2013

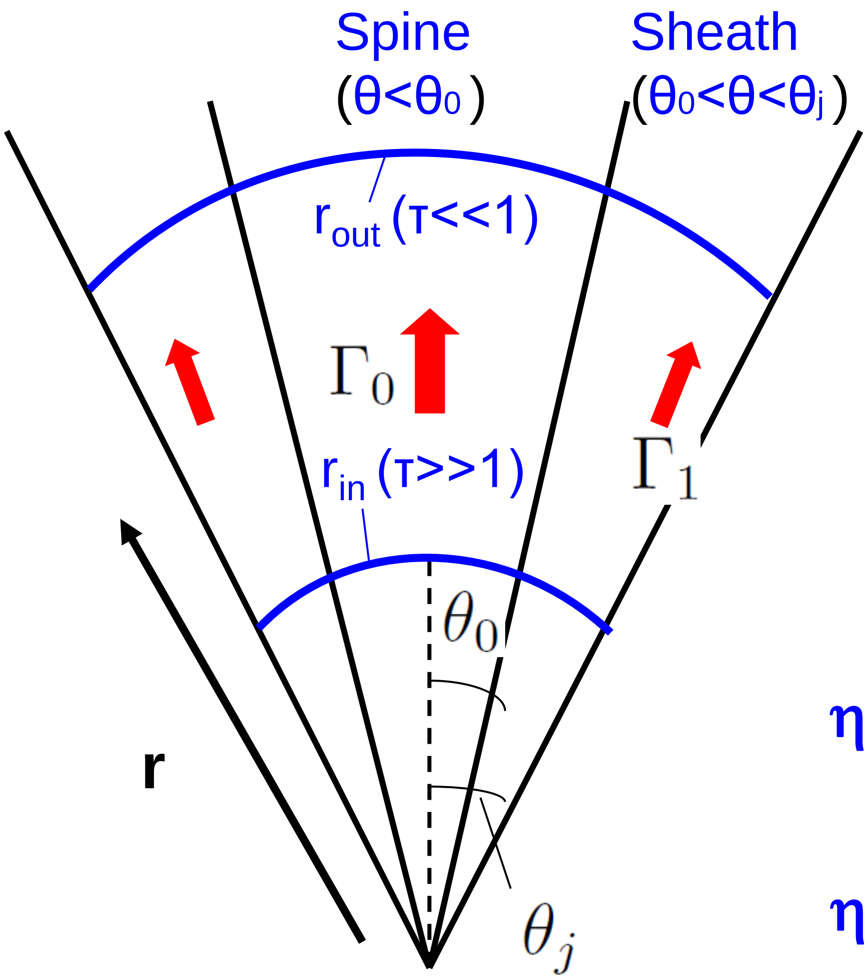
(II) Fermi acceleration of photons

Photons gain energy by crossing the boundary layer



Propagation of photons are solved by Monte=Carlo method

2-component (spine-sheath) jet

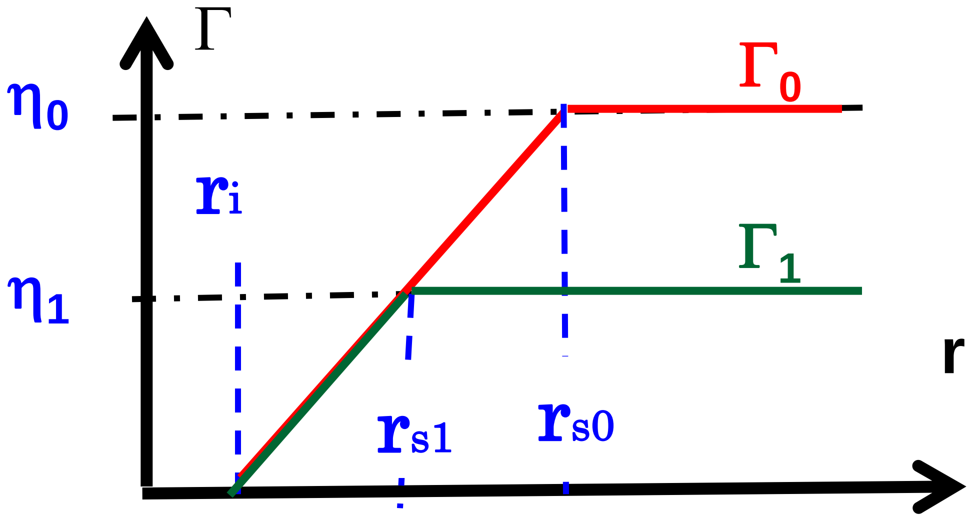


Calculation Range

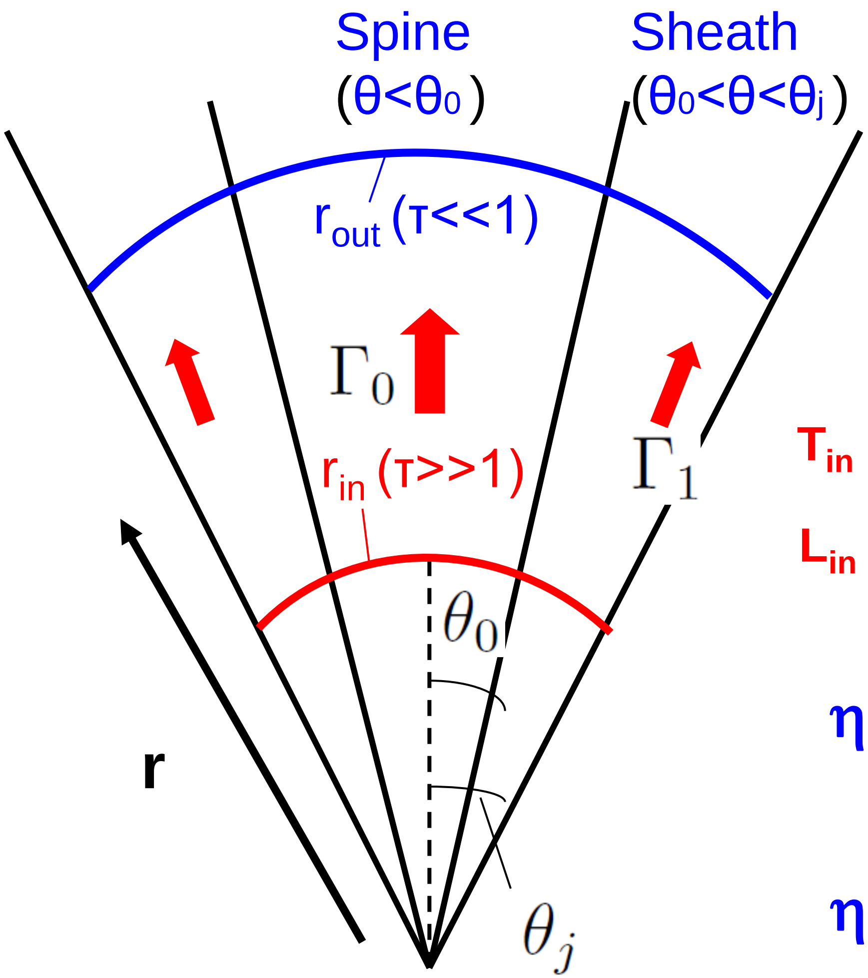
$r_{in} = r_{s1} << R_{ph}$

$r_{out} = 500R_{ph}(\tau \sim 2\times10^{-3})$

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



2-component (spine-sheath) jet

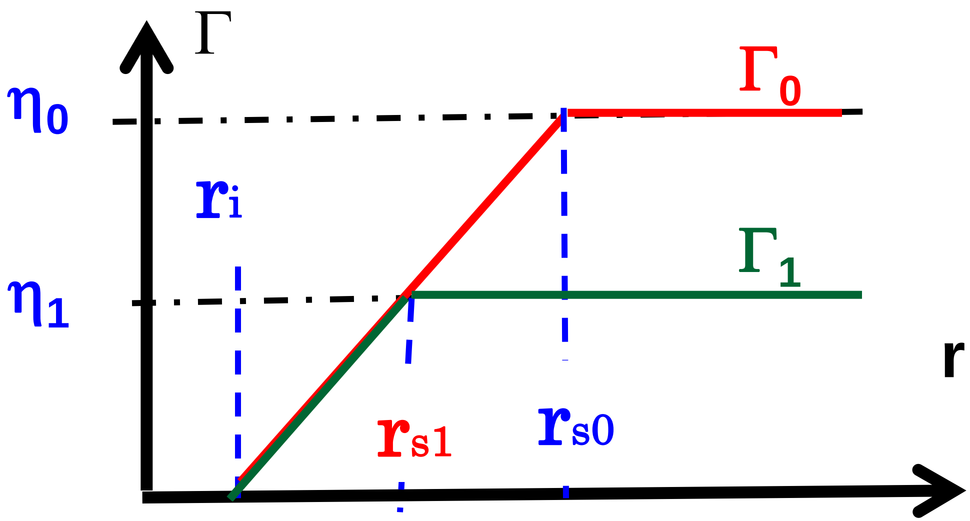


Initial Condition

Inject thermal photons at the inner boundary

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

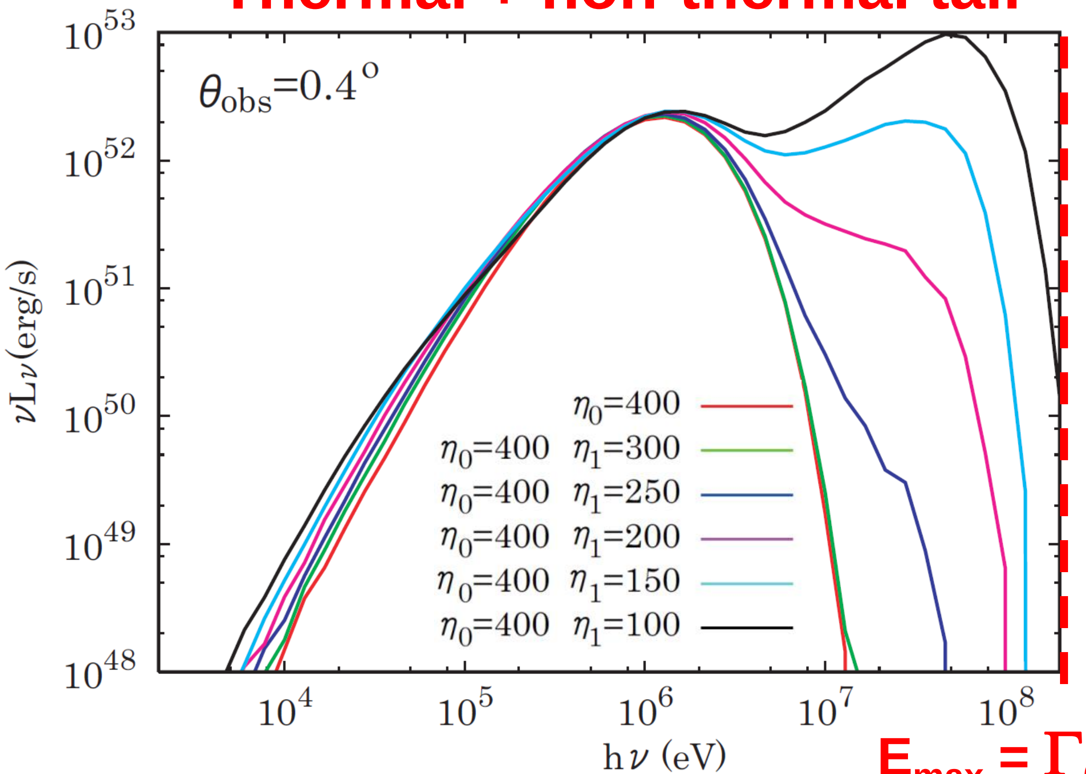
L_{in} = 5.4 × 10^{52} $r_8^{2/3}\Gamma_{400}^{8/3} L_{53}^{1/3} (r_{in}/10^{11}cm)^{-2/3}$ erg/s

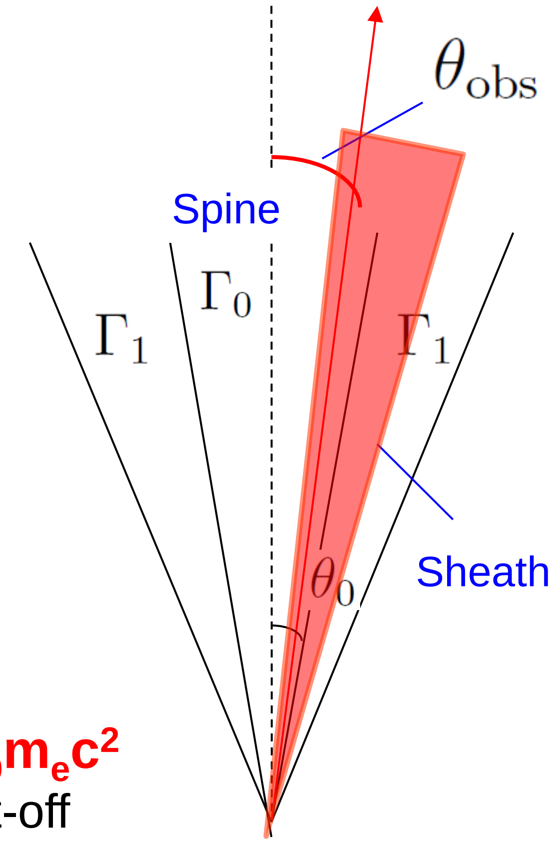


Two-component jet

Γ_0=400 θ_j=1° θ_0=0.5° θ_{obs}=0.4°

Thermal + non-thermal tail





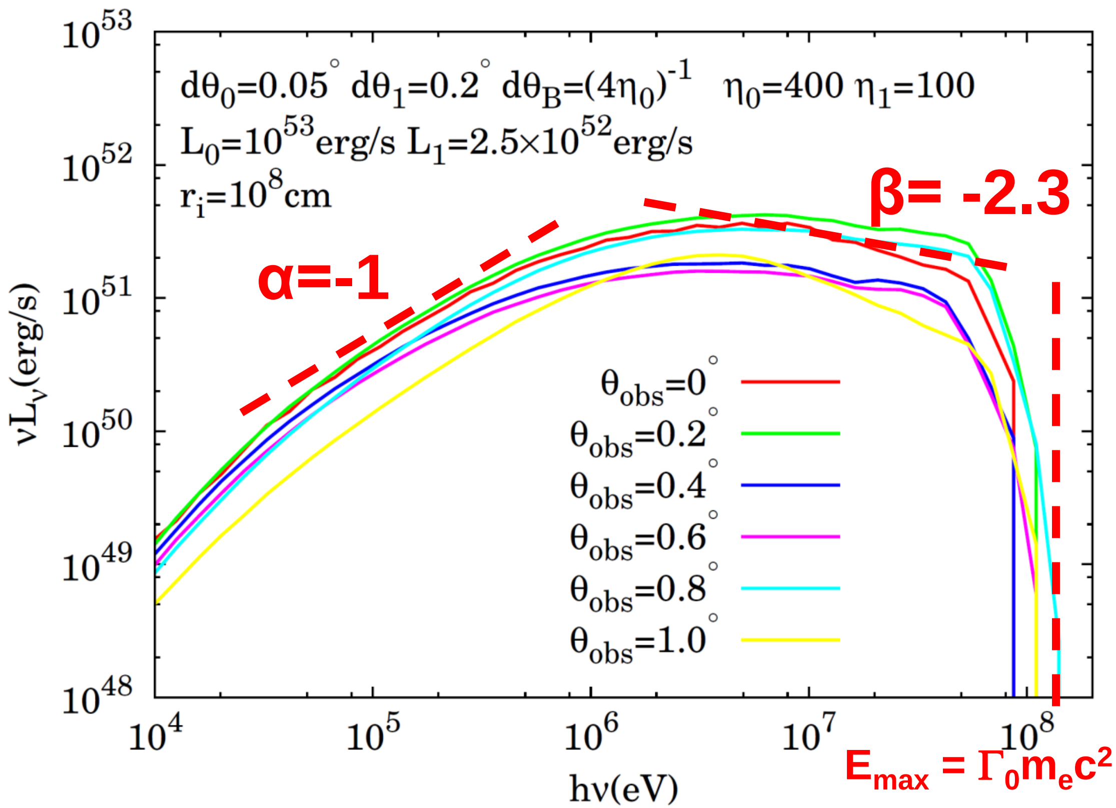
$E_{max} = \Gamma_0 m_e c^2$

Klein-Nishina cut-off

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

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

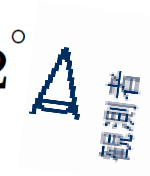
Multi-component jet

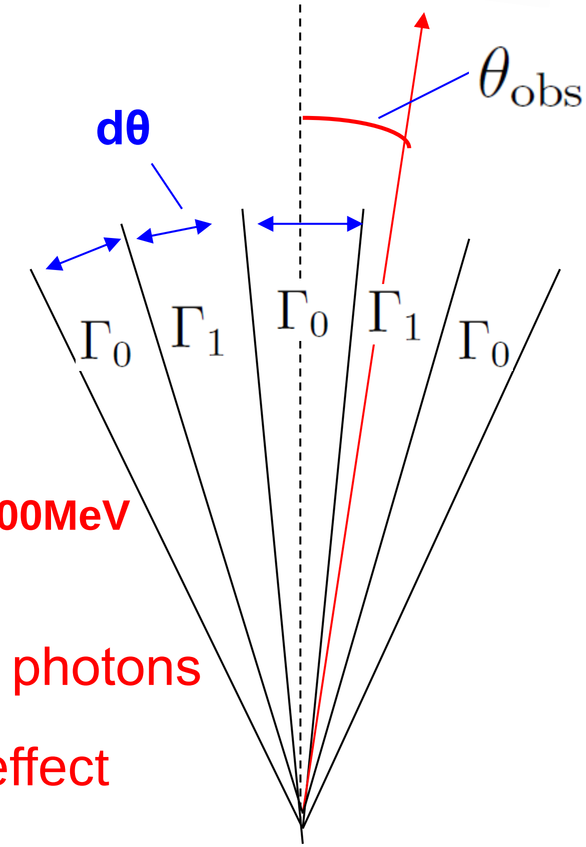


$E_{max} = \Gamma_0 m_e c^2$ ~ 100MeV

Γ_0=400 Γ_1=100

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





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

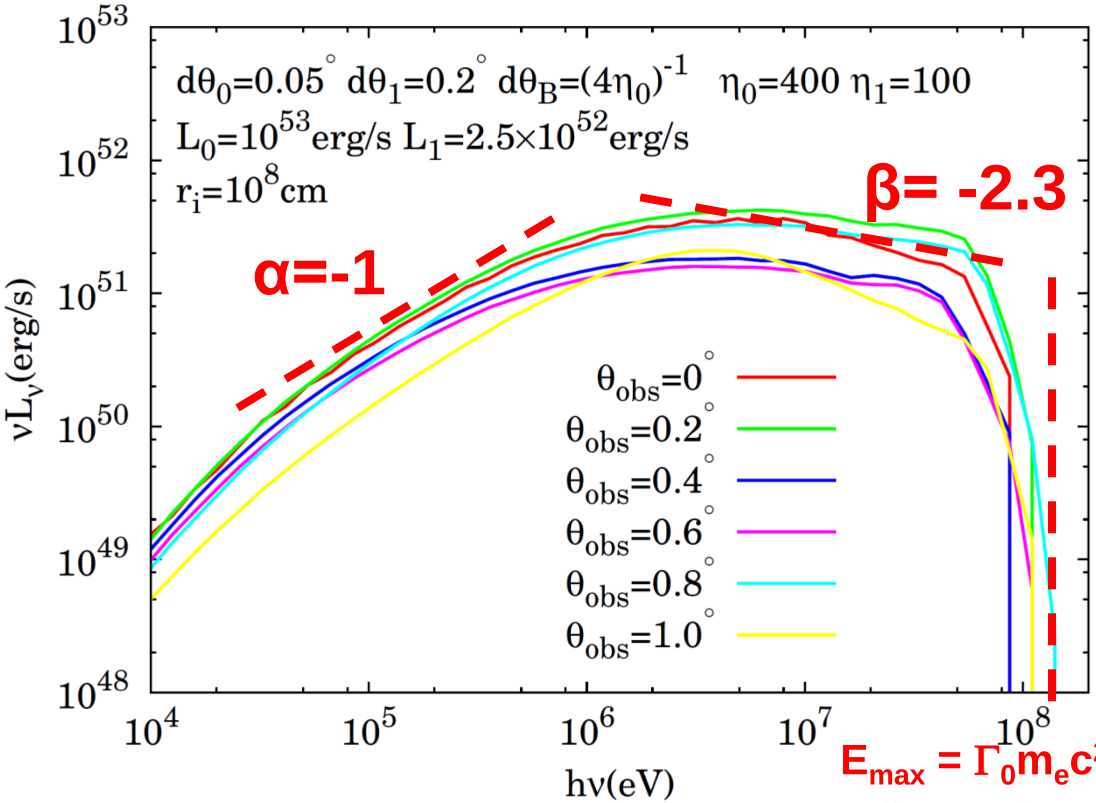
high energy spectra (β) is reproduced by accelerated photons

Cut off at ~ 100 MeV

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

see also Lundman + 2013

Multi-component jet



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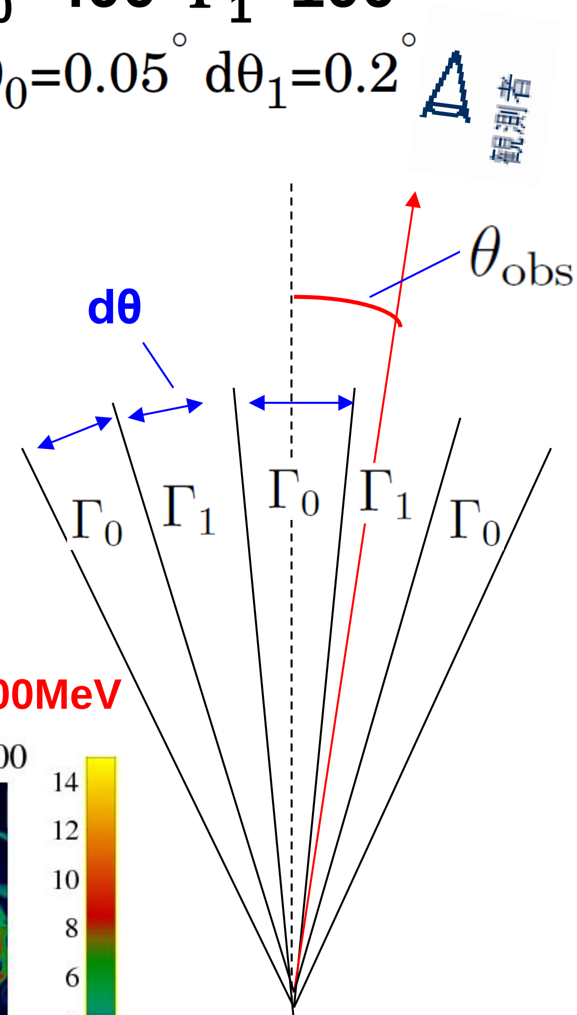

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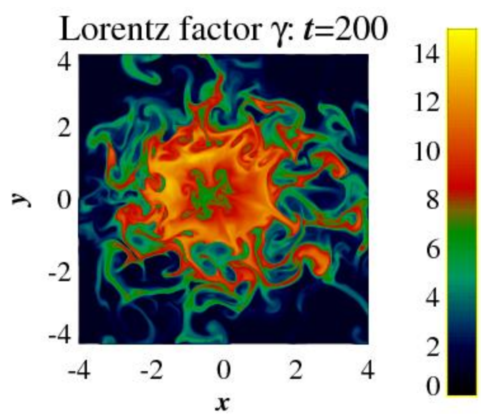
Interval of velocity shear $d\theta < 2\Gamma^{-1}$

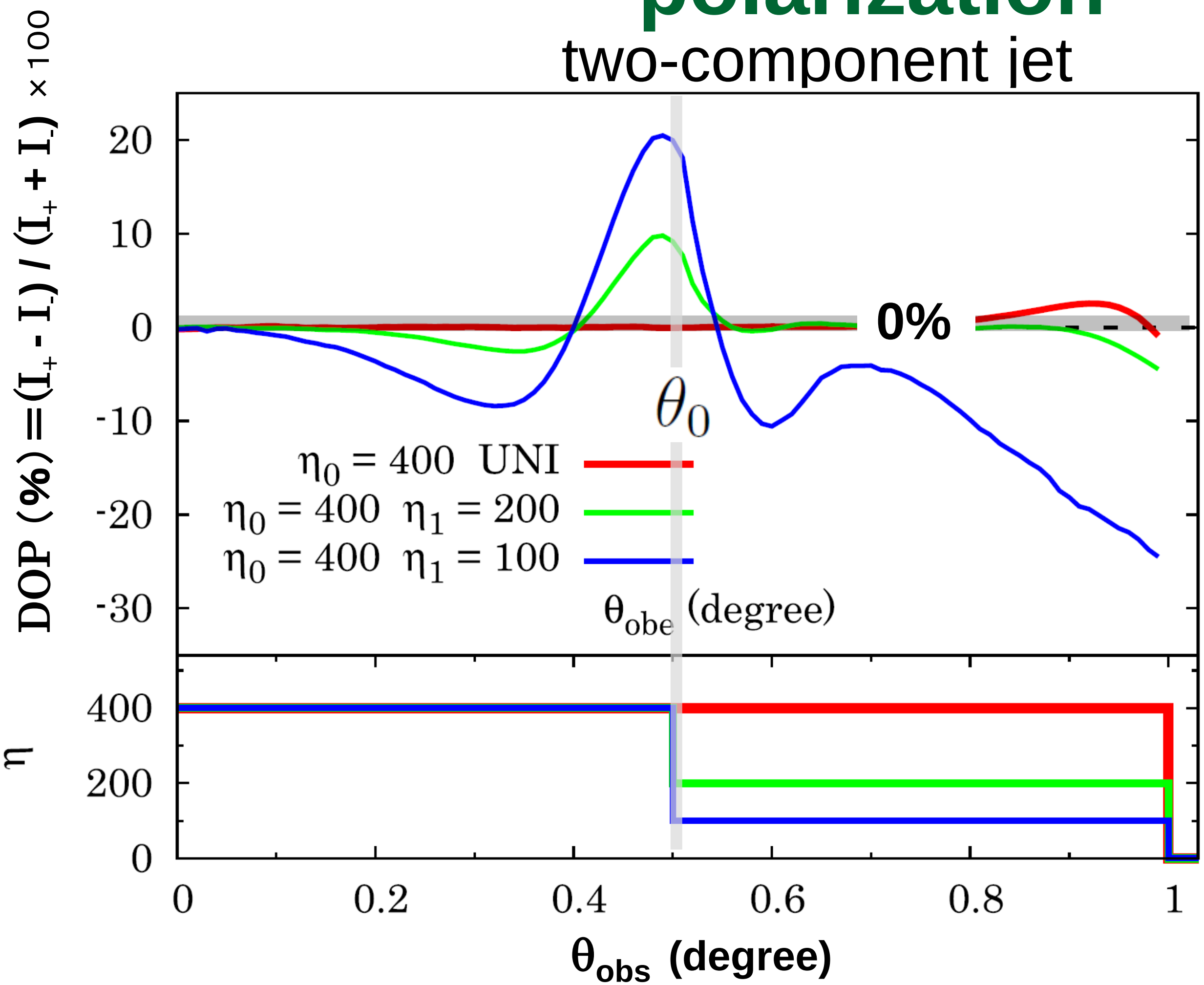


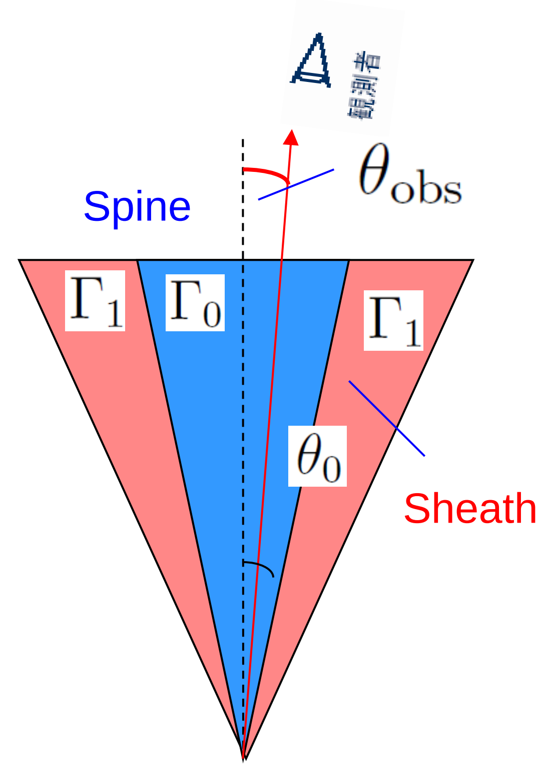
Face on view of jet

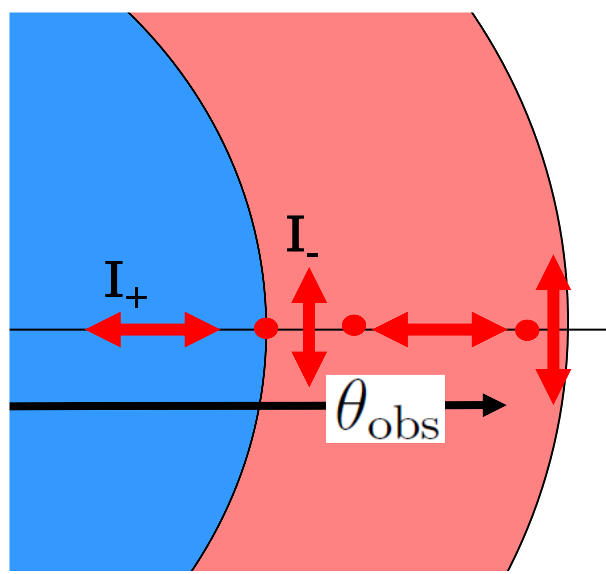
Simulation by Matsumoto-san

polarization

two-component jet



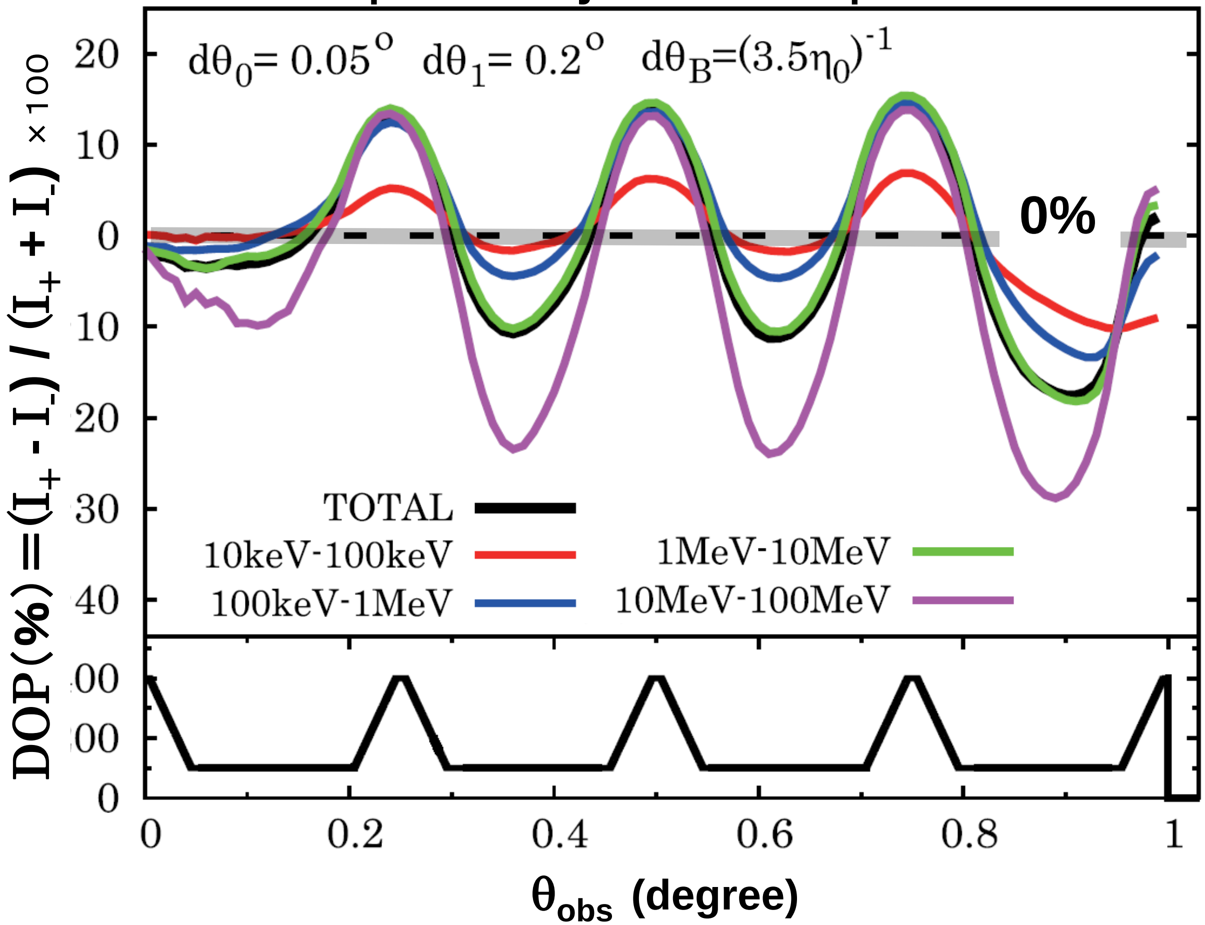




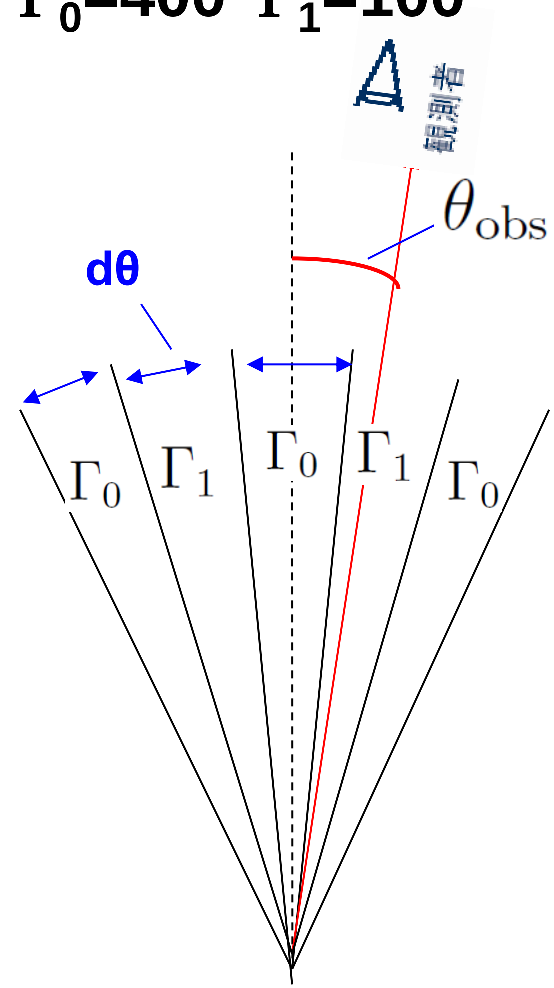
Degree of polarization (DOP) becomes larger as the relative velocity becomes large

polarization

multi-component jet that reproduces Band spectra



Γ_0=400 Γ_1=100



High polarization degree (>10%) is predicted

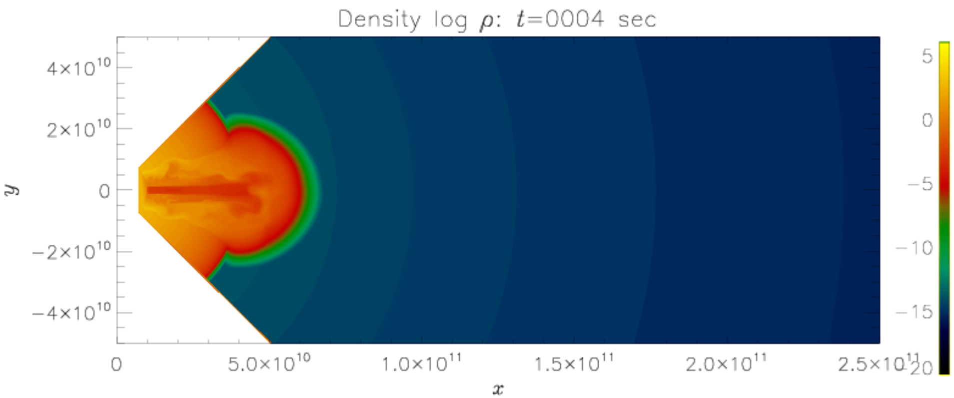
See also Lundman + 2014

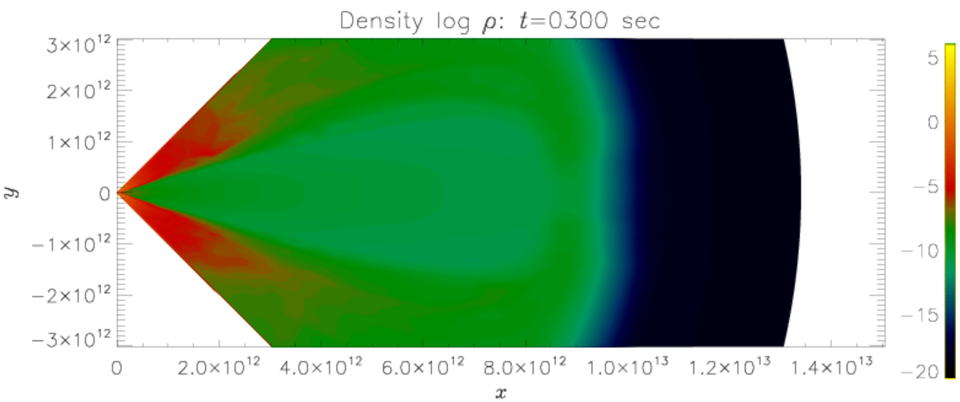
Future missions such as Tsubame and POLAR may probe such an emission

On-going project

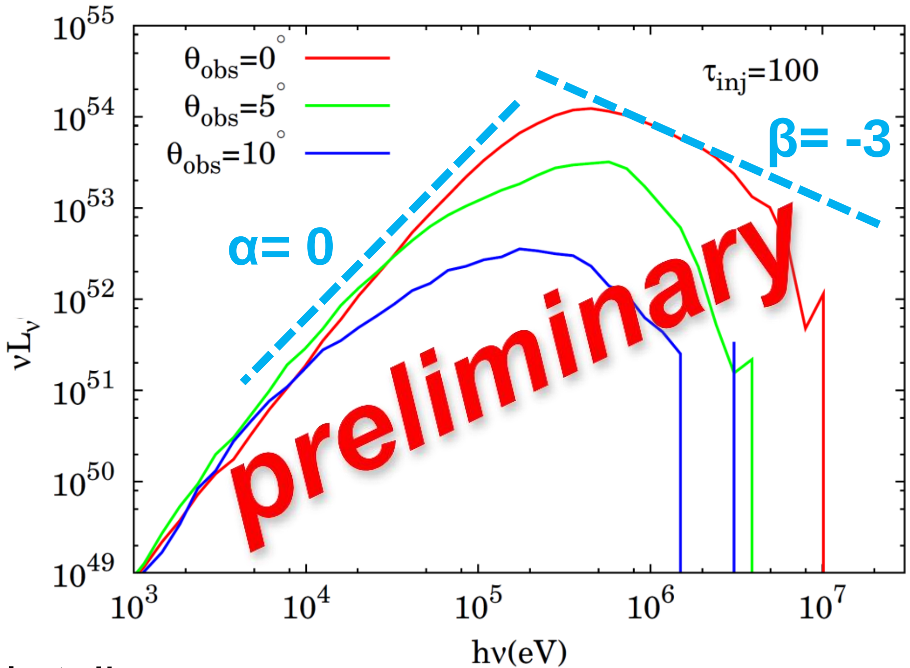
3D Hydrodymical simulation of relativistic jet as a background fluid

simulation by Dr. Matsumoto





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



See also Shibata-san's talk

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