光球面放射の数値シミュレーションから明らかにする米徳関係の起源

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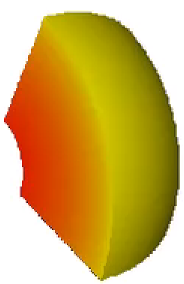
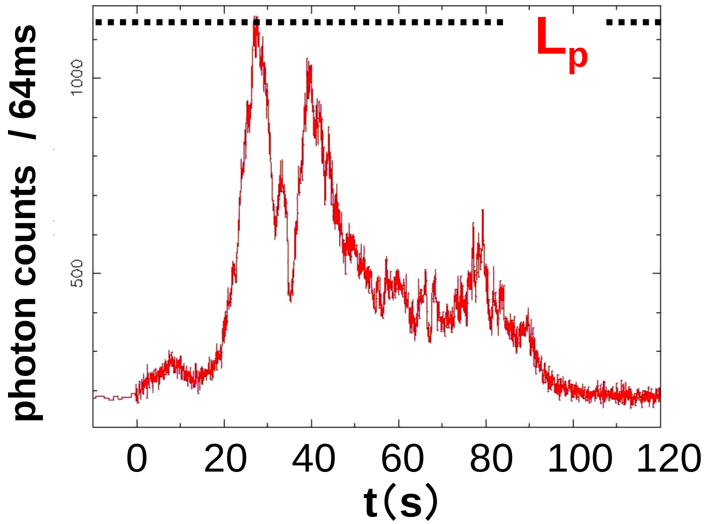


simulation by Dr. Jin Matsutmoto

@ 高エネルギー宇宙物理学研究会 2017/9/5

Gamma-Ray Burst

Most luminous explosion in the universe



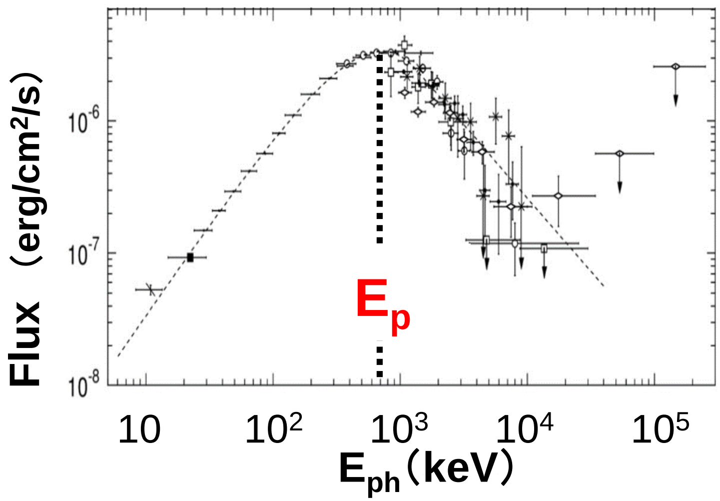
$L_p \sim 10^{50}$ - 10^{54} erg/s

duration

$t_{dur} \sim$ 10ms — 100s

rapid variability

$\delta t \sim$ ms



non-thermal spectrum

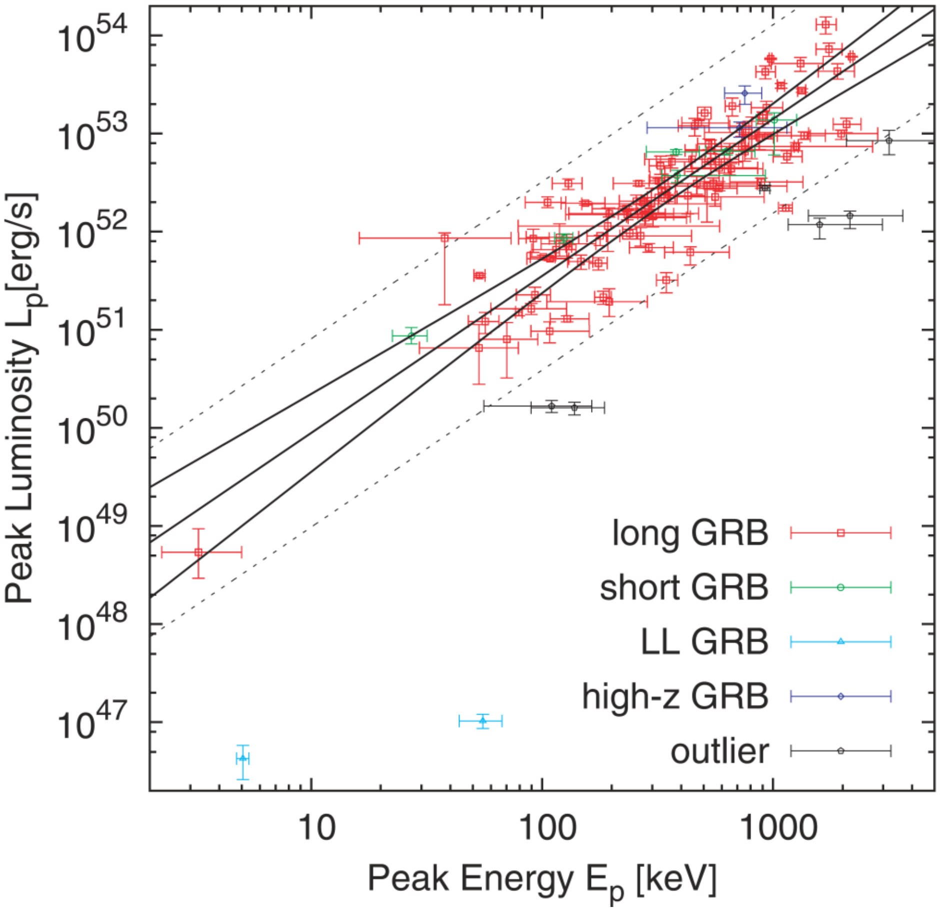
broken power law with sharp peak

$E_p \sim 10^2 – 10^3$ keV

Emission mechanism unetablished

Yonetoku Relation

Tight correlation between E_p - L_p



$$L_p = 10^{52.43\pm0.037} \times \left[\frac{E_p(1+z)}{355\ \mathrm{keV}}\right]^{1.60\pm0.082}$$

Yonetoku + 2004 ; 2010

Important for application to cosmology

Powerful diagnostic for emission mechanism

Models for Emission Mechanism

Internal Shock Model

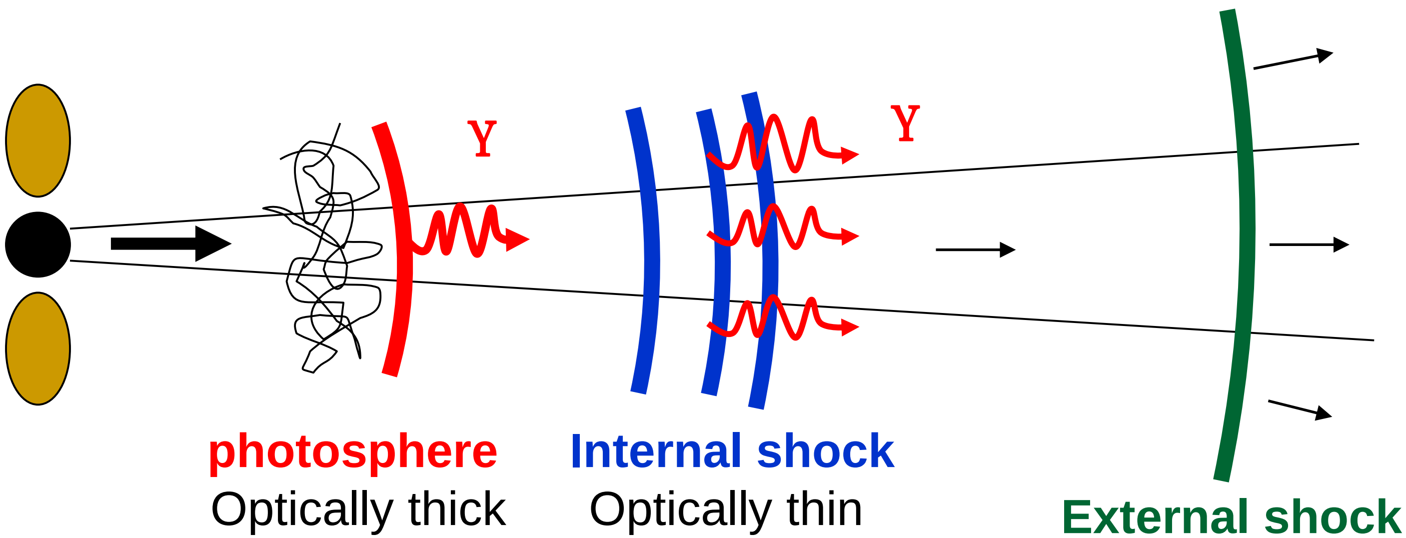
○
- rapid time variability
- non-thermal spectrum

?
- radiation efficency
- hard spectra at low energy
- sharp spectral peak

Photospheric Emission Model

○
- radiation efficiency
- hard spectra at low energy
- sharp spectral peak

?
- non-thermal spectrum
- soft spectra at low energy



Yonetoku relation & Internal shock model

Poor predictability due to ***too many*** parameters

Optically thin synchrotron

$$E_p \propto \Gamma \gamma_p^2 B$$

$$\gamma_p \propto \Gamma_{sh} \varepsilon_e m_p / m_e$$

$$B \propto \Gamma_{sh} [\varepsilon_B n m_p]^{1/2}$$

$$L_p \propto L \varepsilon_e$$ *for fast cooling*

Properties of outflow and physics of collisionless shock must be specified

Self-regulation among various parameters is necessary to reproduce the relation

e.g., Zhang & Meszaros 2002

Yonetoku relation & Photospheric model

Theoretical prediction is (relatively) solid

Optically thick thermal radiation

$$E_p \sim 600\, \Gamma_{400}^{8/3} L_{53}^{-5/12} r_{in,8}^{1/6} \text{ (keV)}$$

$$L_p \sim 1.2 \times 10^{52}\, \Gamma_{400}^{8/3} L_{53}^{1/3} r_{in,8}^{2/3} \text{ (erg/s)}$$

for $r_{ph} > r_{sat}$

Cluster of $E_p \sim 10^2 - 10^3$ MeV naturally achieved

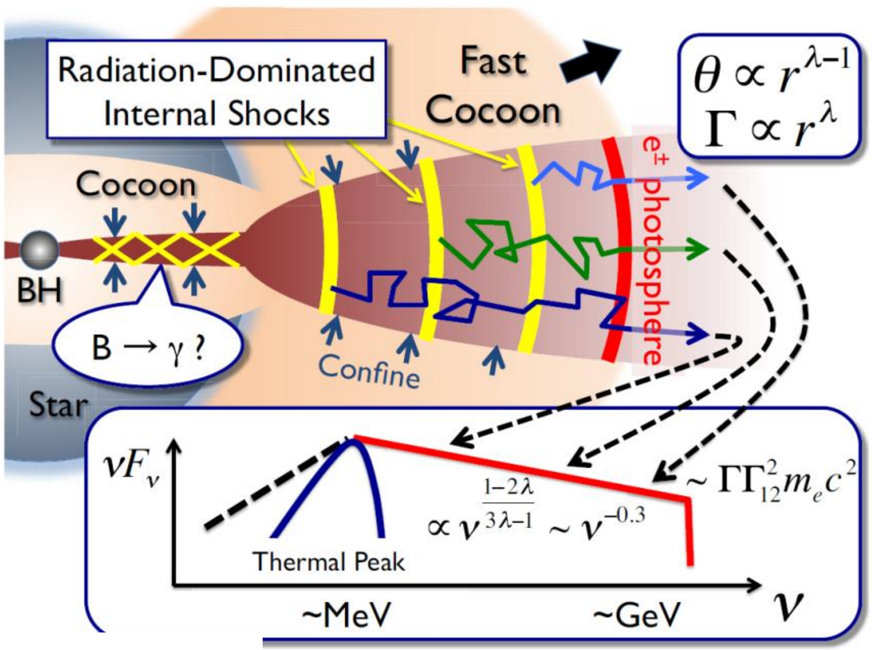
Correlation in outflow properties is necessary to reproduce the relation

e.g., Fan + 2012, Ito + 2013

assumption: 1D steady spherical outflow

Photospheric Emission in GRB jet

Dynamics of Jet have significant effect on the radiation signature



Ioka+2011

Dynamics of Jet and
Radiation transfer must be solved

Previous Studies

steady outflow or 1D model

Pe'er +2005,2006,2011; Giannios 2008; Beloborodov 2010,2011; Vurm+2011,2016; Lundman+2013,2014, Ito+2013,2014, Chhotray 2015

approximated treatment for radiation

Lazzati+2009,2011,2013; Mizuta+2011;Nagakura+2011; Lopez-Camara+2014

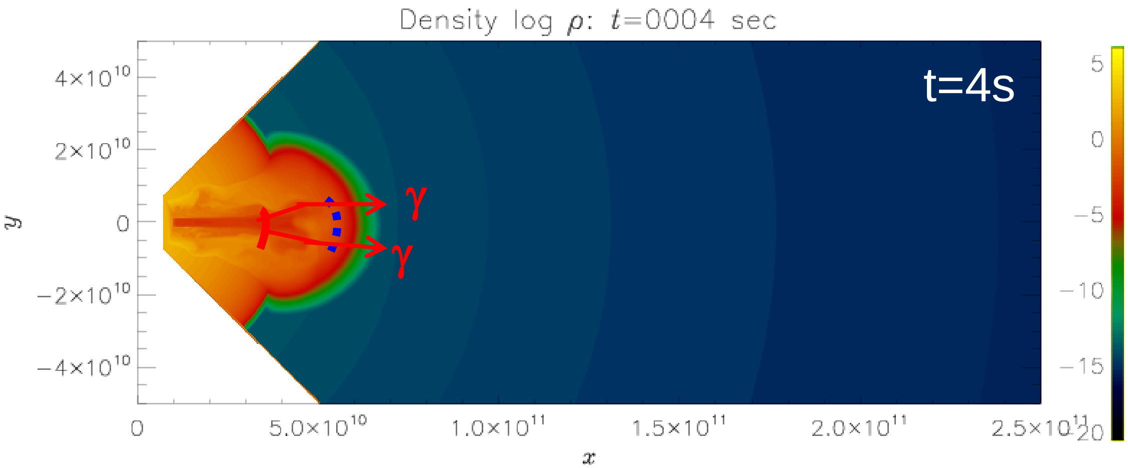
This Study

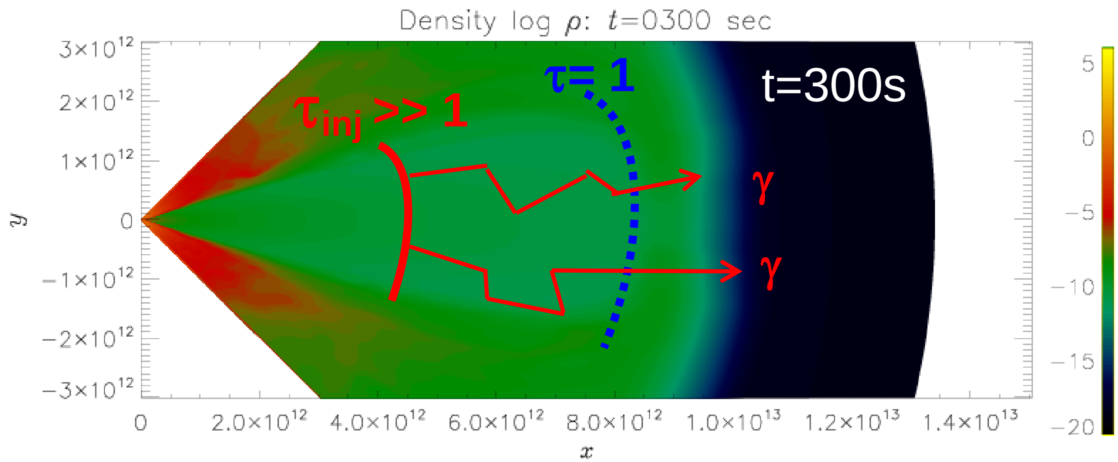
Radiation transfer calculation based on
3D hydrodynamical simulation

See also Lazzati 2016, Parsotan + 2017

3D relativisitic hydrodymaical simulation

Calculation of relativistic jet breaking out of massive progenitor star





Progenitor star

16TI（Woosley & Heger 2006）

$M_* \sim 14M_{sun}$

$R_* \sim 4 \times 10^{10}$ cm

@presupernova phase

Jet parameter

$L_j = 10^{49}, 10^{50}, 10^{51}$ erg/s

$\theta_j = 5^\circ$

$\Gamma_j = 5$

$\Gamma h = 500, 900$

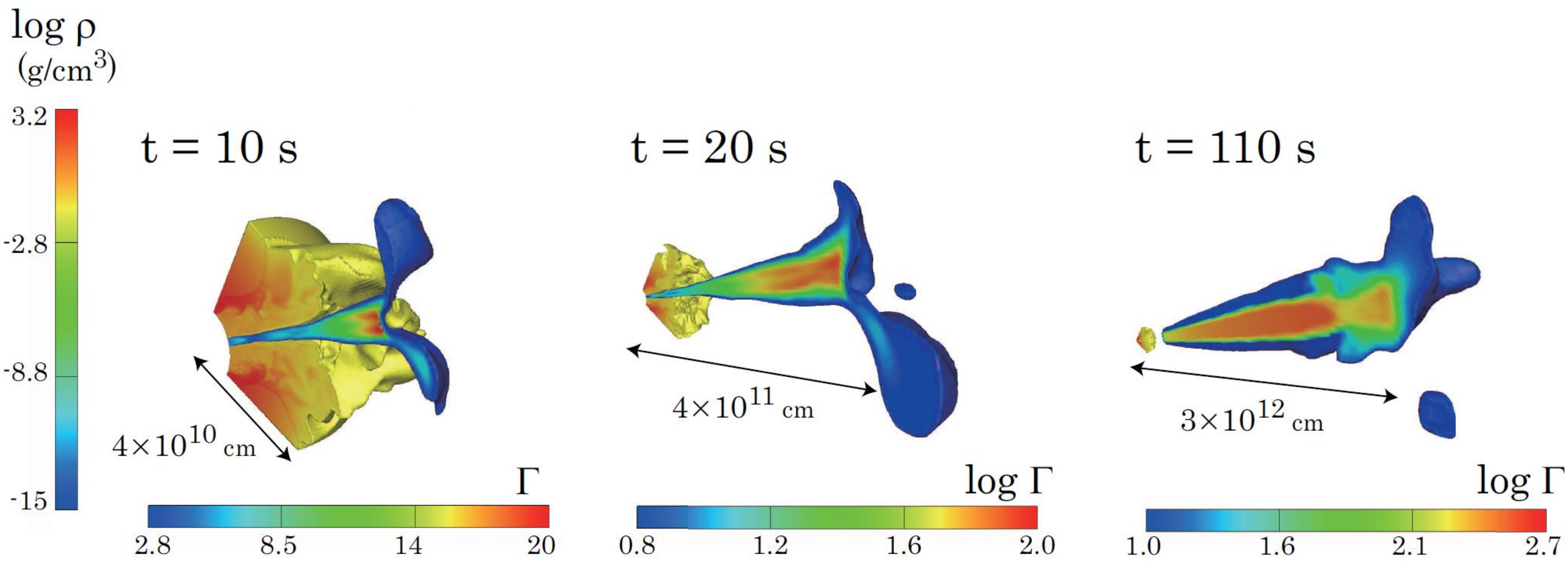
$R_{inj} = 10^{10}$ cm

3models with different power

Radiative transfer calculation

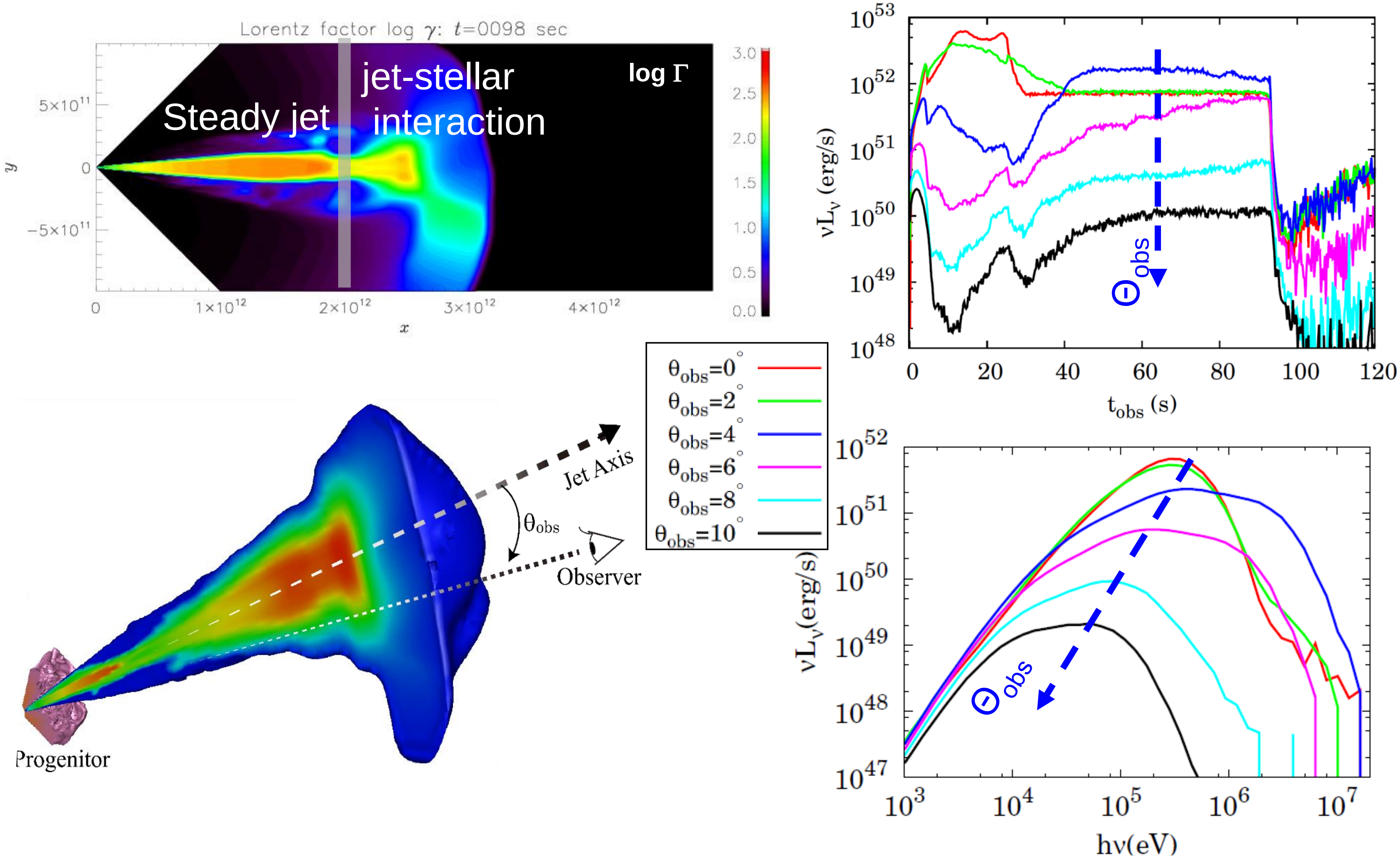
Propagation of photons are calculated until they reach optically thin region

fiducial model $L_j = 10^{50}$ erg/s



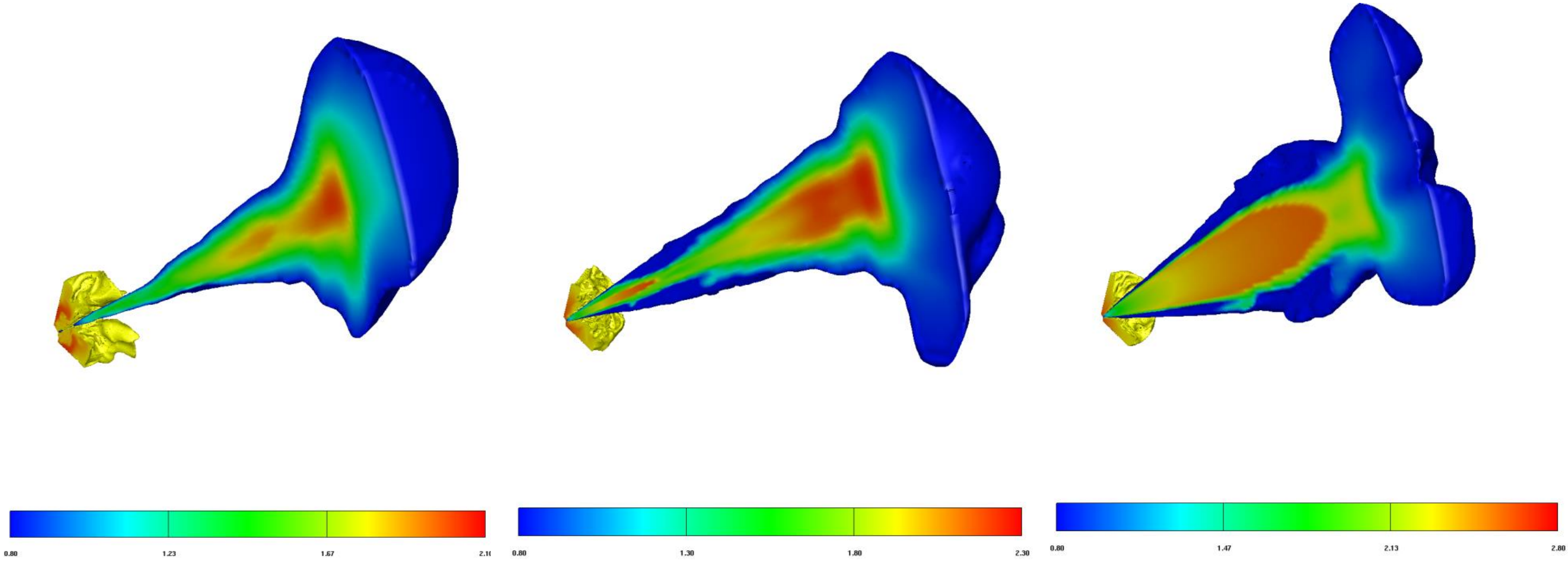
Ito + 2015

fiducial model $L_j = 10^{50}$ erg/s



E_p & L_p decline as Θ_{obs} increases

Dependence on jet power

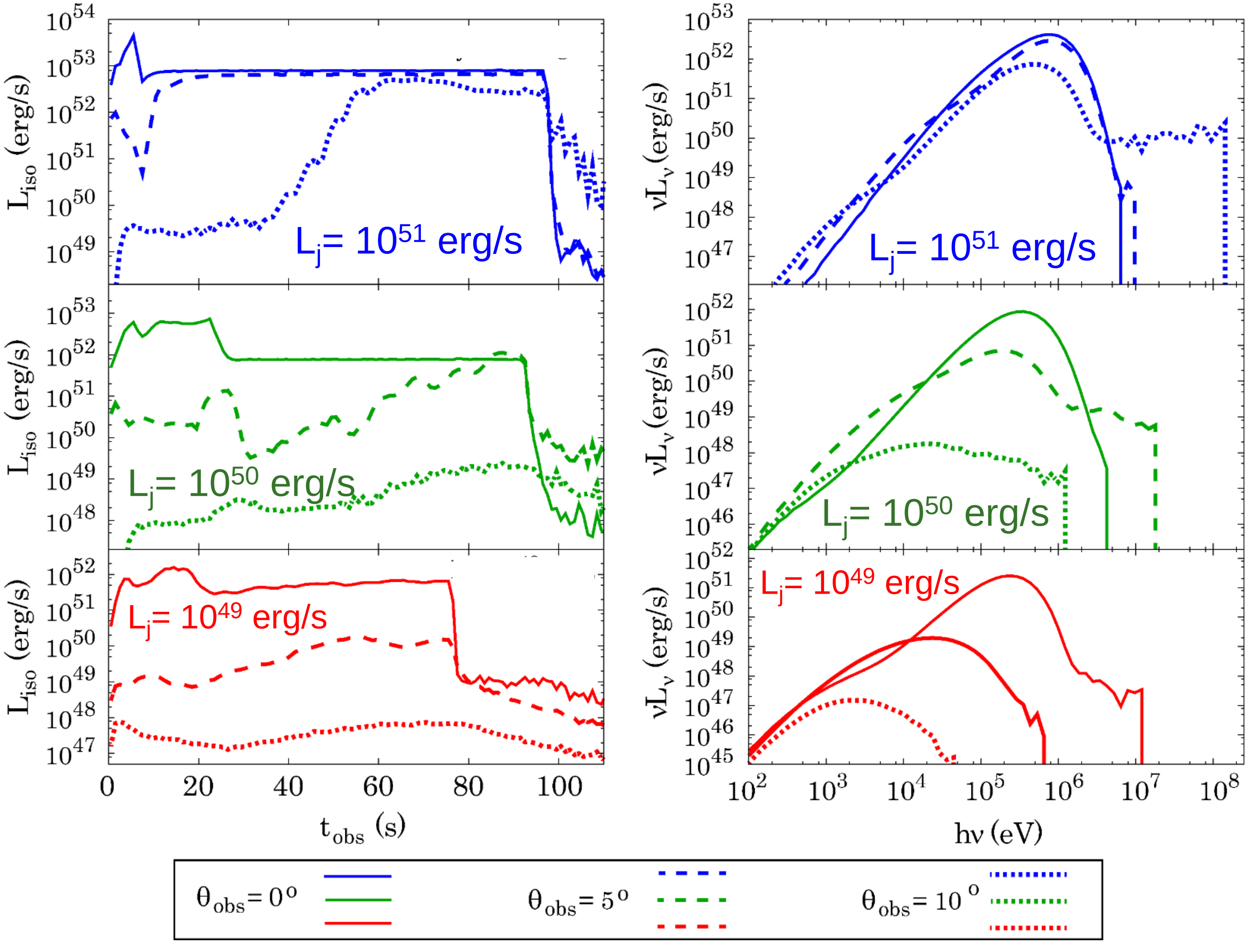


$L_j = 10^{49}$ erg/s **$L_j = 10^{50}$ erg/s** **$L_j = 10^{51}$ erg/s**

t=40s

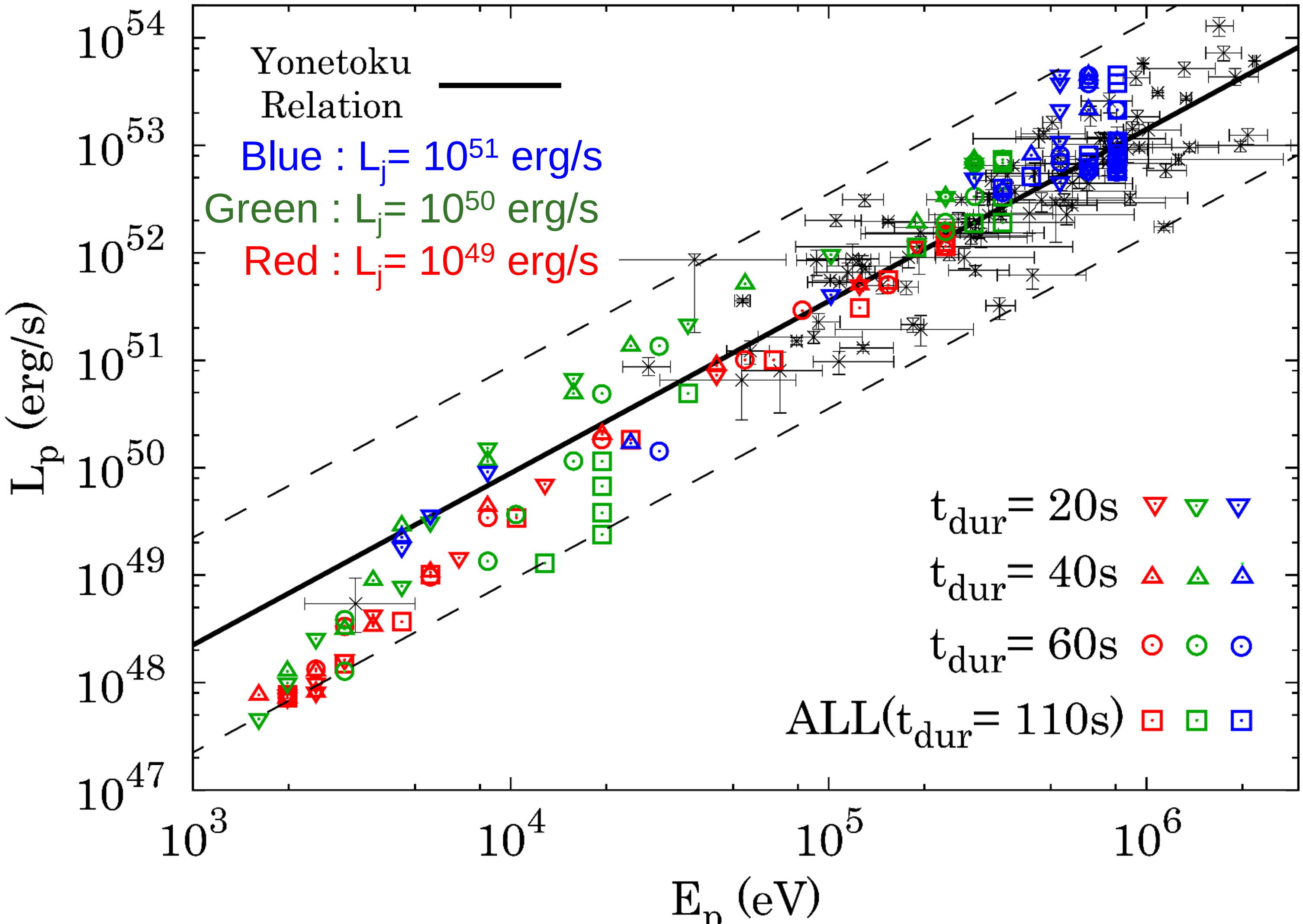
Ito + 2017, submitted

Dependence on jet power



L_p & E_p are systematically higher for higher L_j

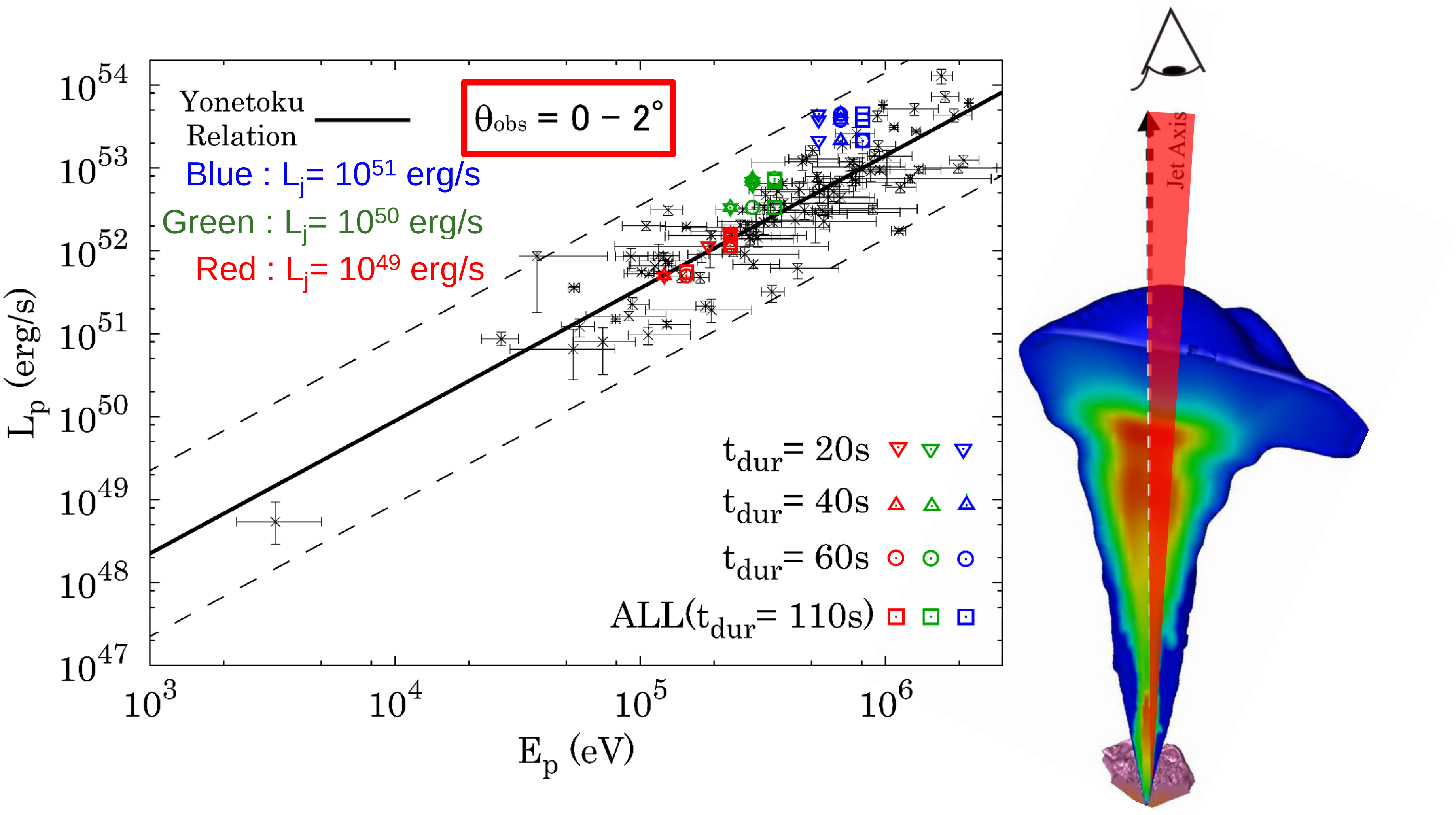
Yonetoku relation



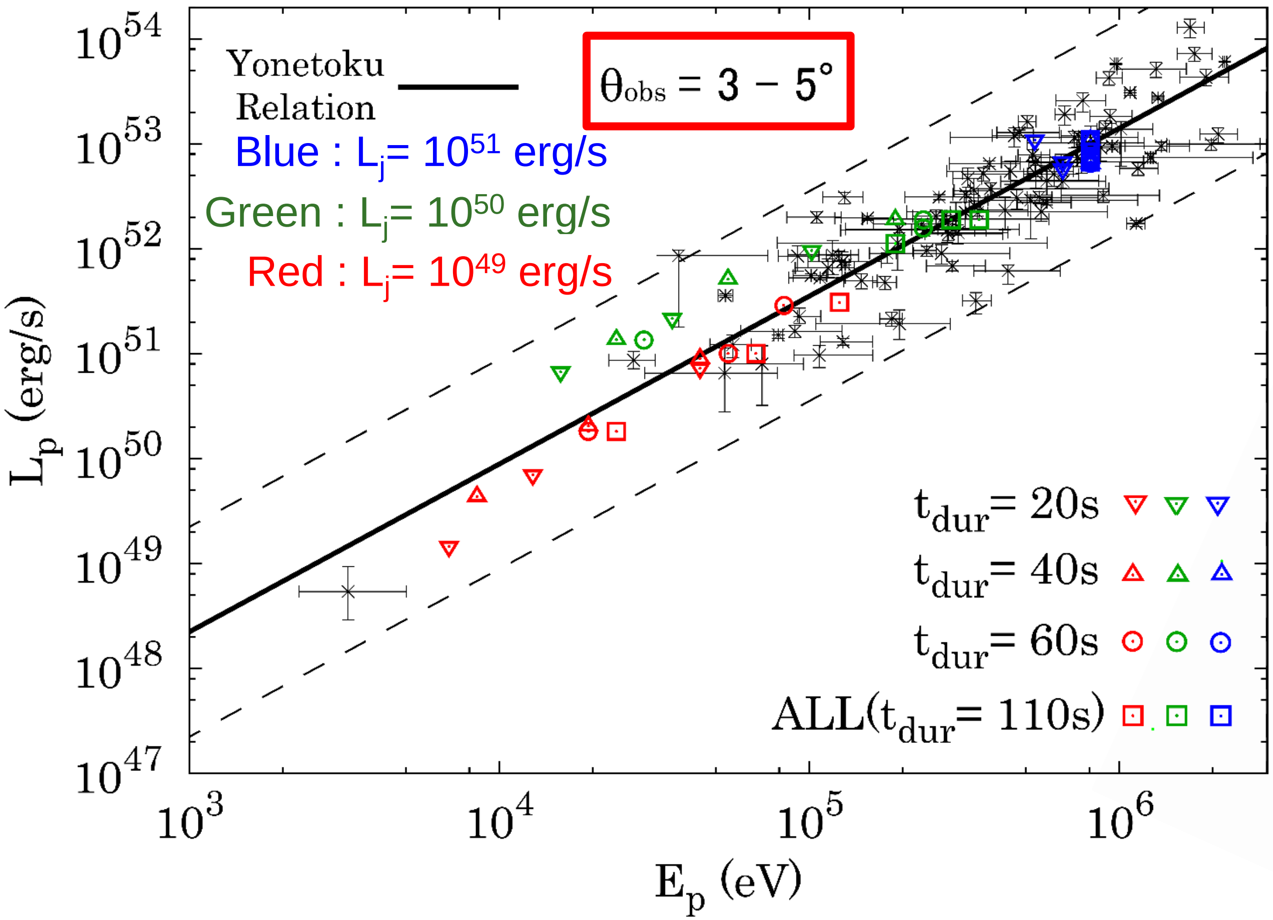
Remarkable match with observations

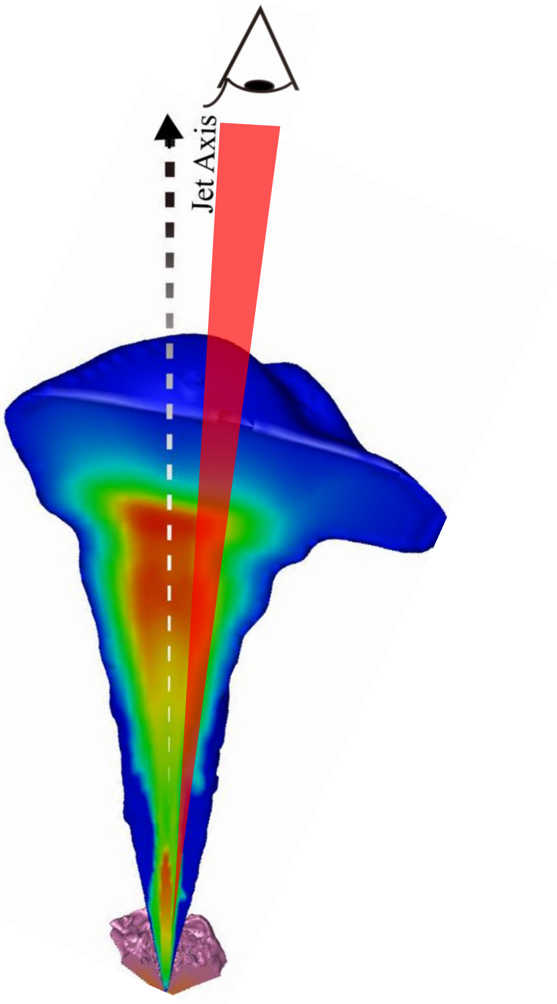
Evidence of photospheric emission as dominant radiation process

Yonetoku relation: viewing angle dependence

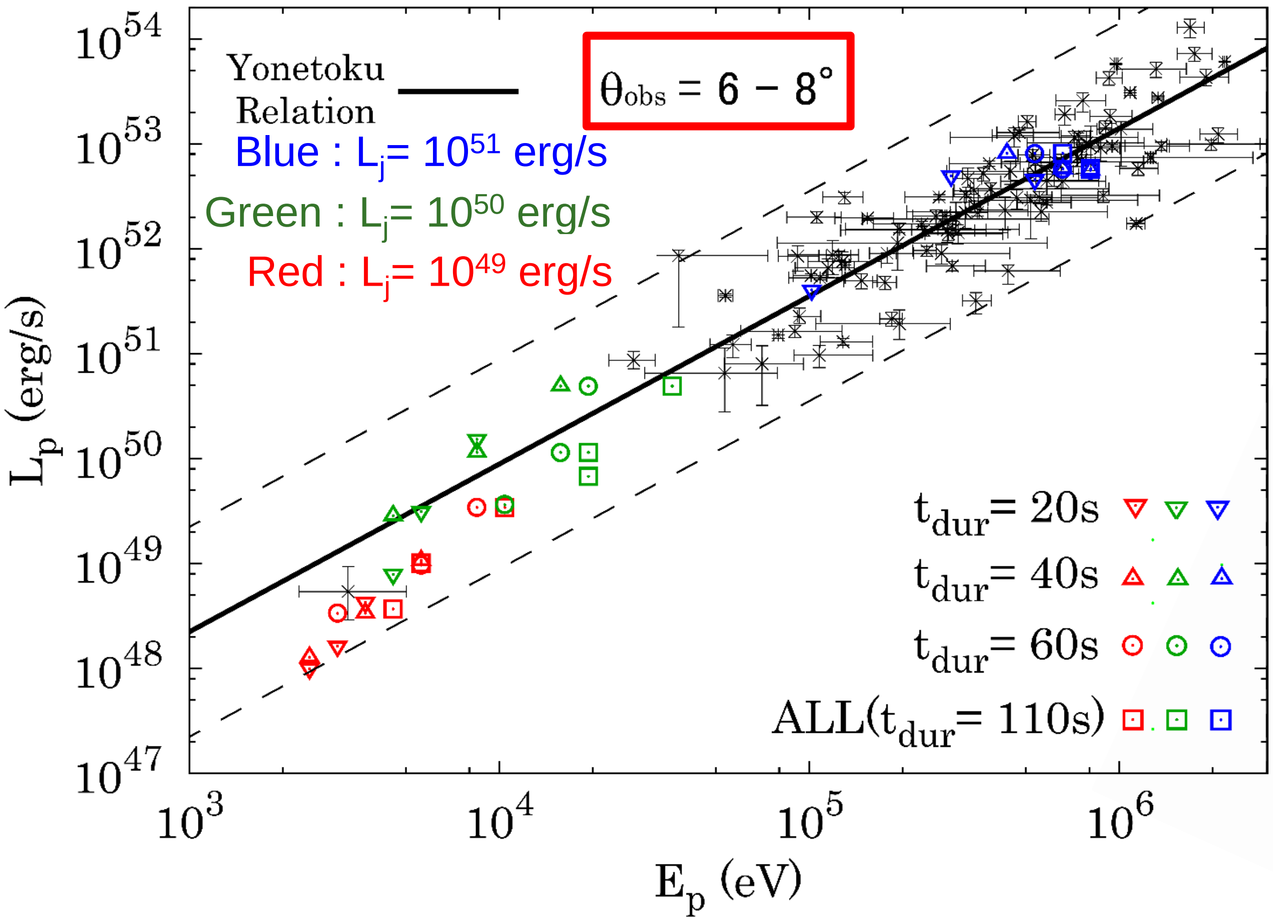


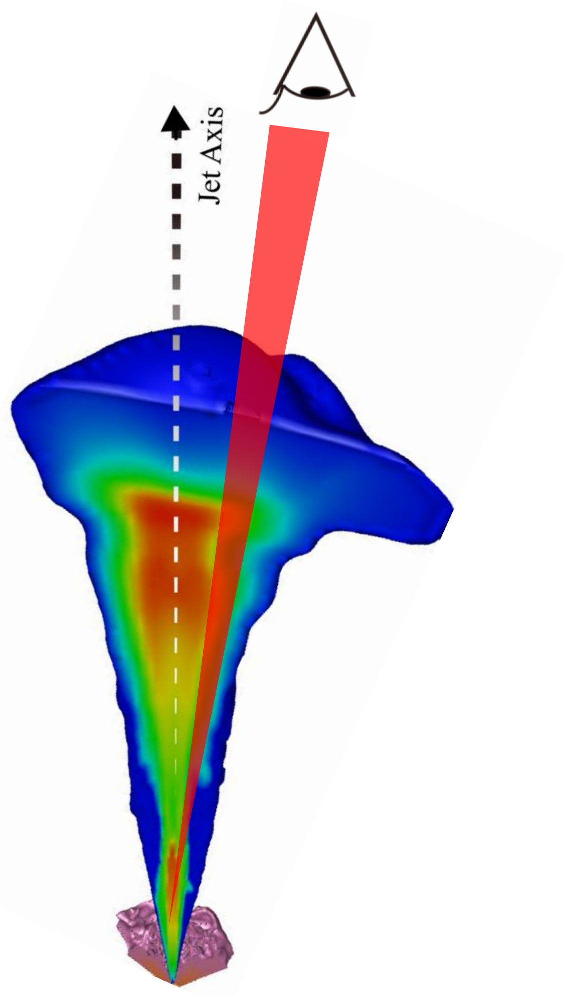
Yonetoku relation: viewing angle dependence



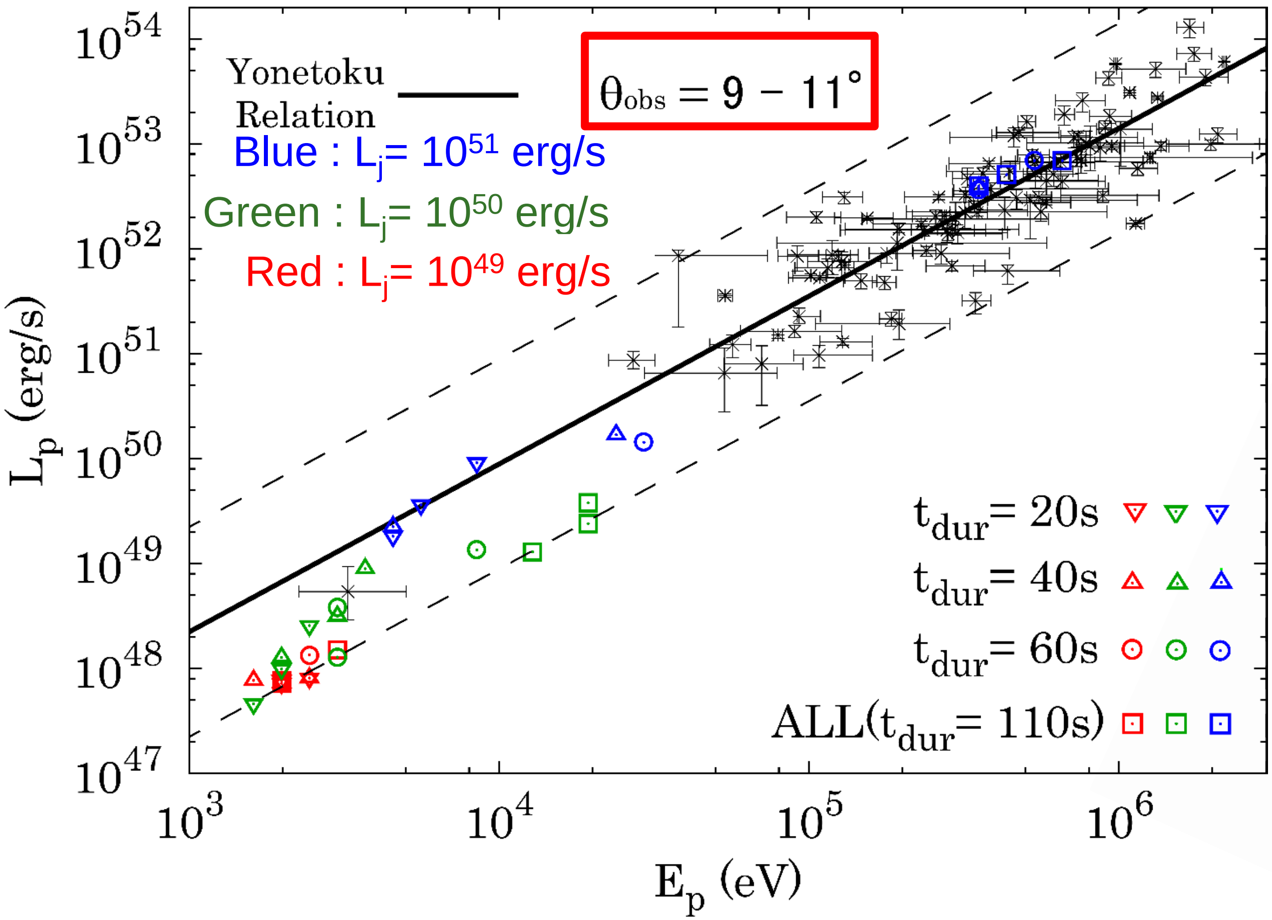


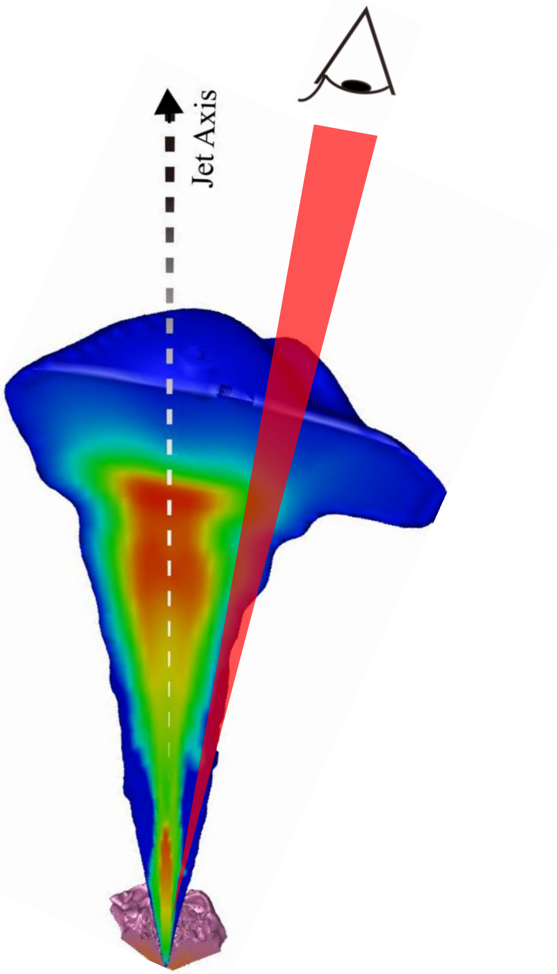
Yonetoku relation: viewing angle dependence





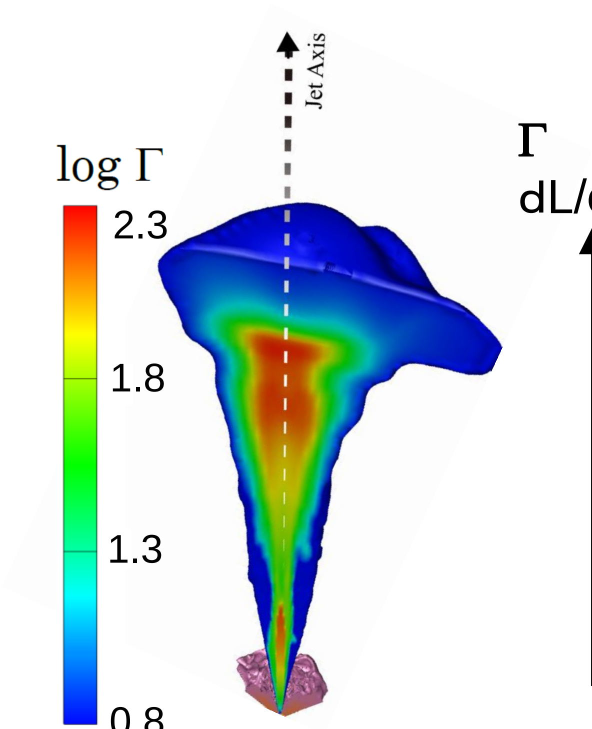
Yonetoku relation: viewing angle dependence

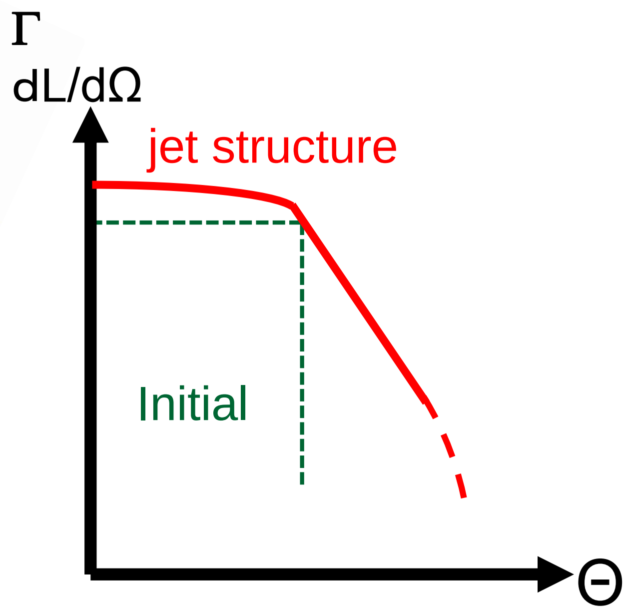




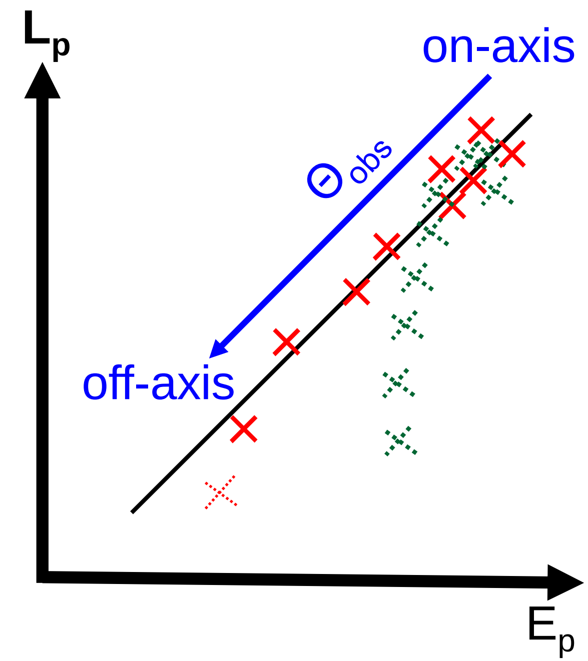
Origin of viewing angle dependence

Lateral structure developed during propagation

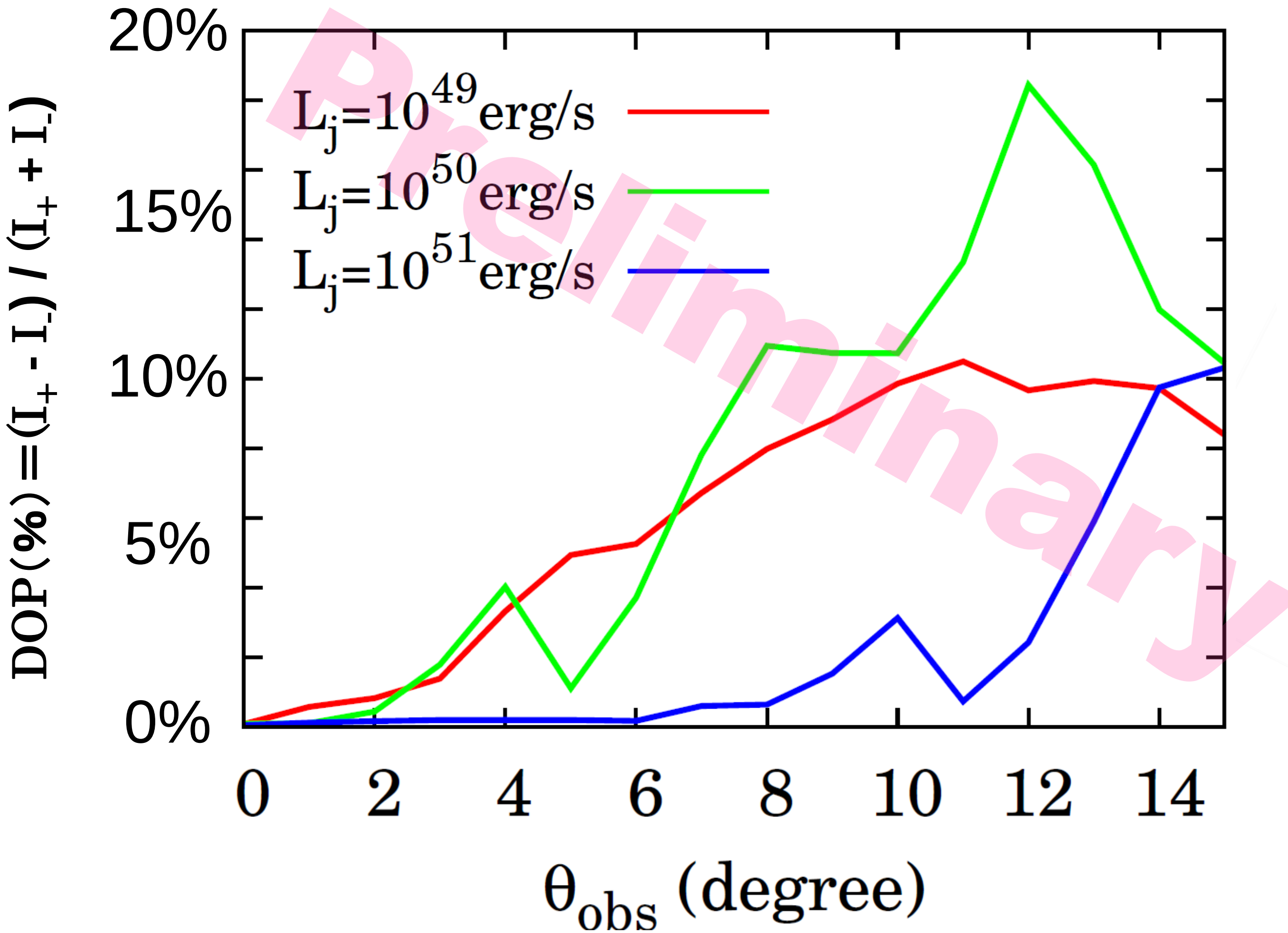


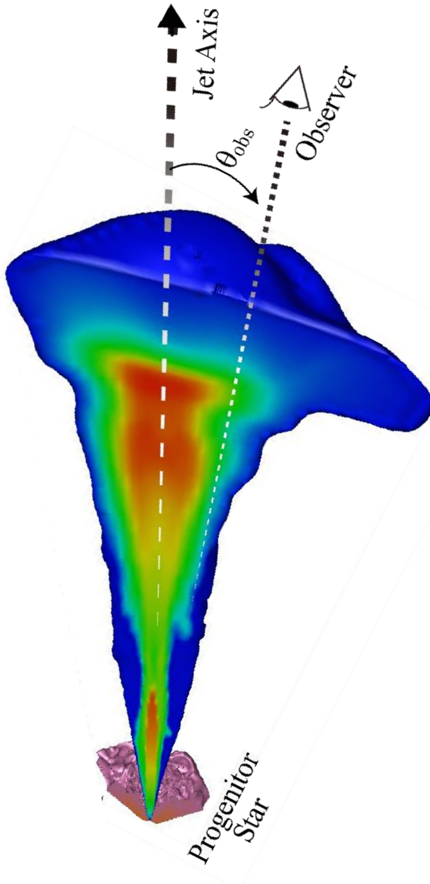


Fast Powerful core
surrounded by decaying wing



polarization





High polarization (>10%) at off-axis regions

Summary

Yonetoku relation is an inherent feature of photospheric emission

Lateral structure of jet developed during propagation is an origin of the correlation between Ep & Lp

This relation holds *regardless* of the jet power

Compelling evidence of photospheric emission as a dominant radiation mechanism for GRBs

Prediction of high polarization at large viewing angle