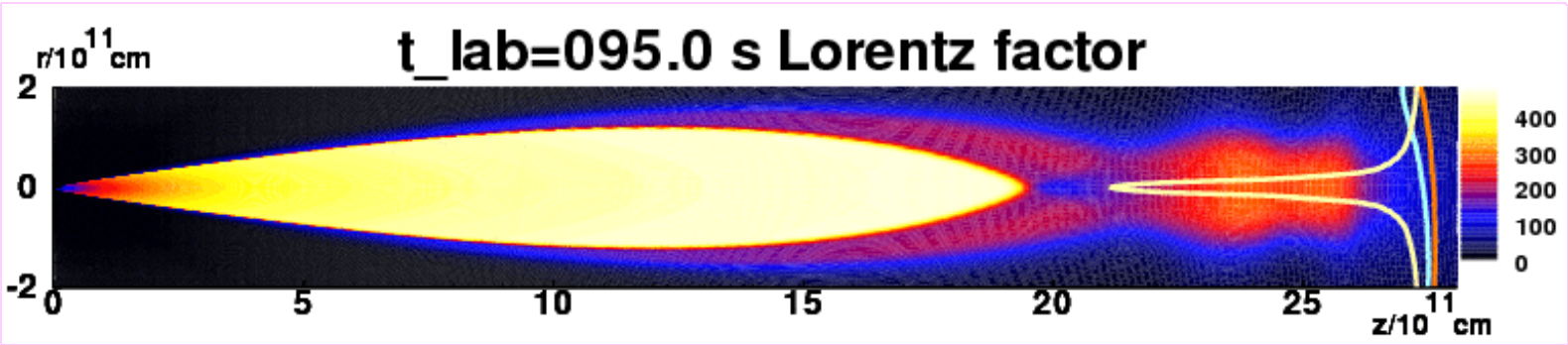
コラプサー起源のガンマ線バーストジェットからの熱的放射

Akira MIZUTA(KEK)

AM, Nagataki, Aoi
(ApJ, 732 26, 2011)
AM + (in prep)

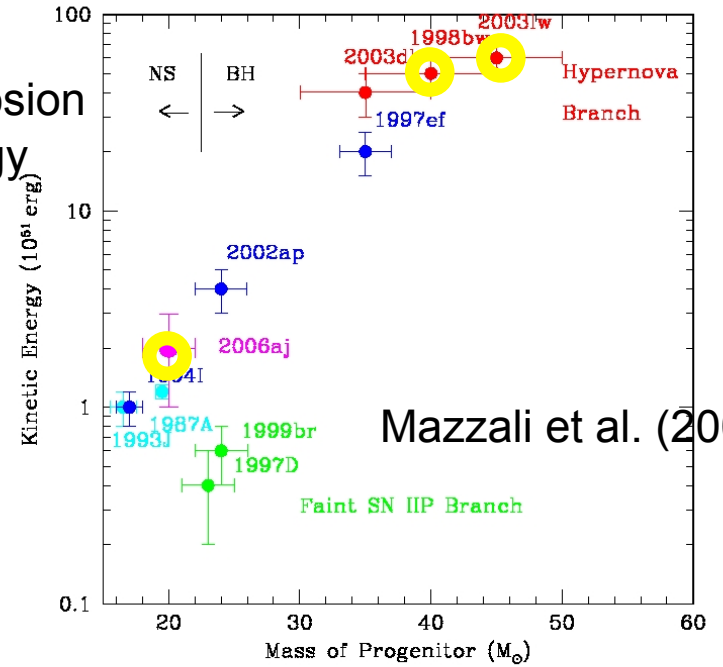


超新星爆発と数値シミュレーション
＠京大　2011.12.28

GRBと超新星爆発

GRBの直後に大質量星の最期、
重力崩壊型超新星爆発が見つかる.
ex. GRB980425/SN1998bw,
GRB030329/SN2003dh
XRF060218/SN2006aj.
GRB091127/SN2009nz
XRF100316D/SN2010bh

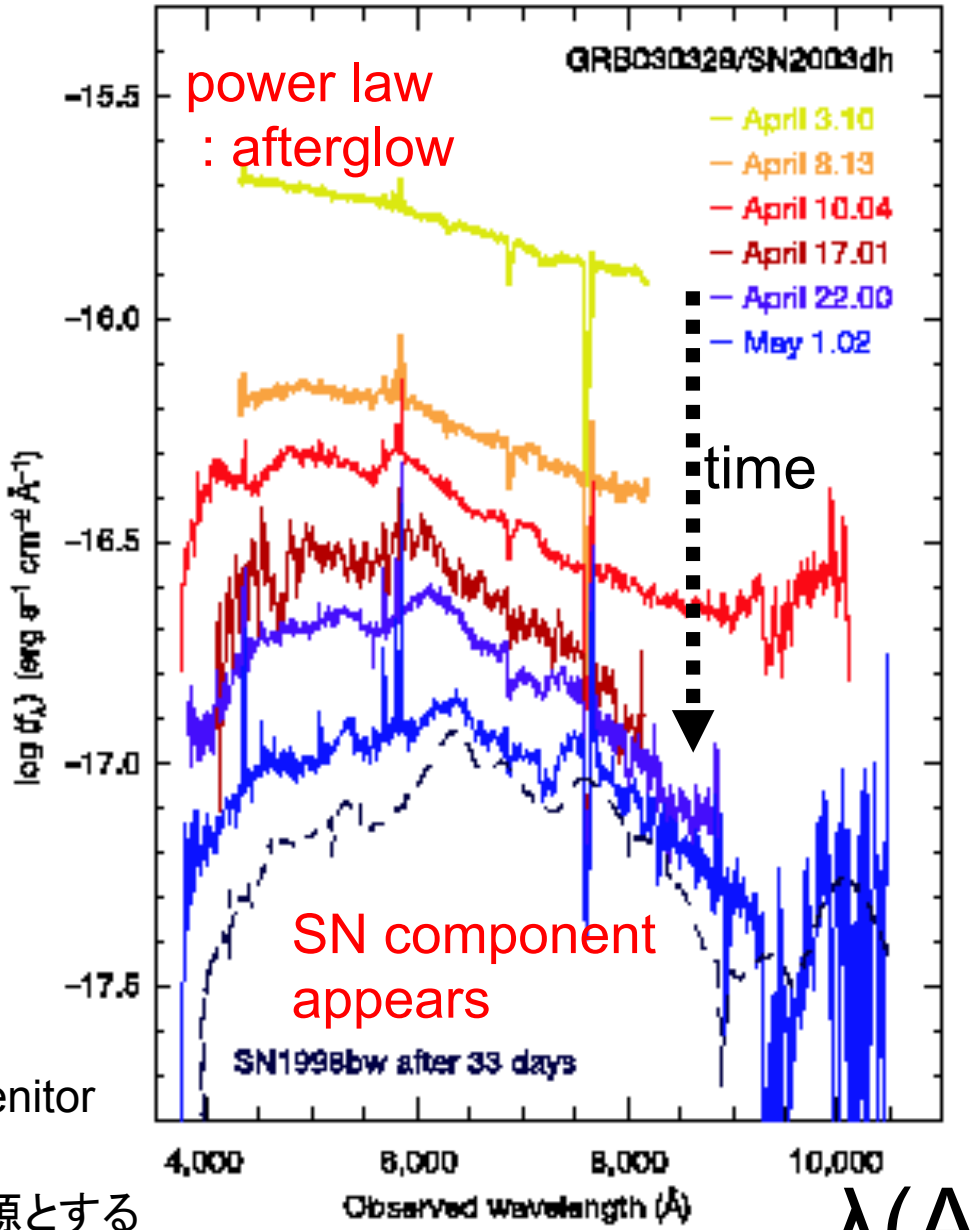
Explosion energy



Mazzali et al. (2006)

Progenitor mass

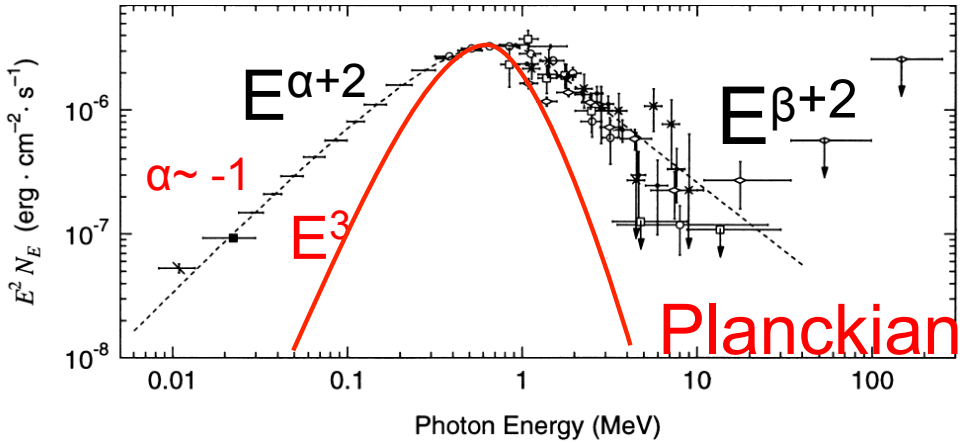
Spectrum :after a few days
~ after a month from the burst



λ(A)

GRBの少なくとも一部は特異な超新星爆発を起源とする

Spectrum of GRB prompt emission
Band function: Broken power-law



GRB990123 Briggs et al. (199

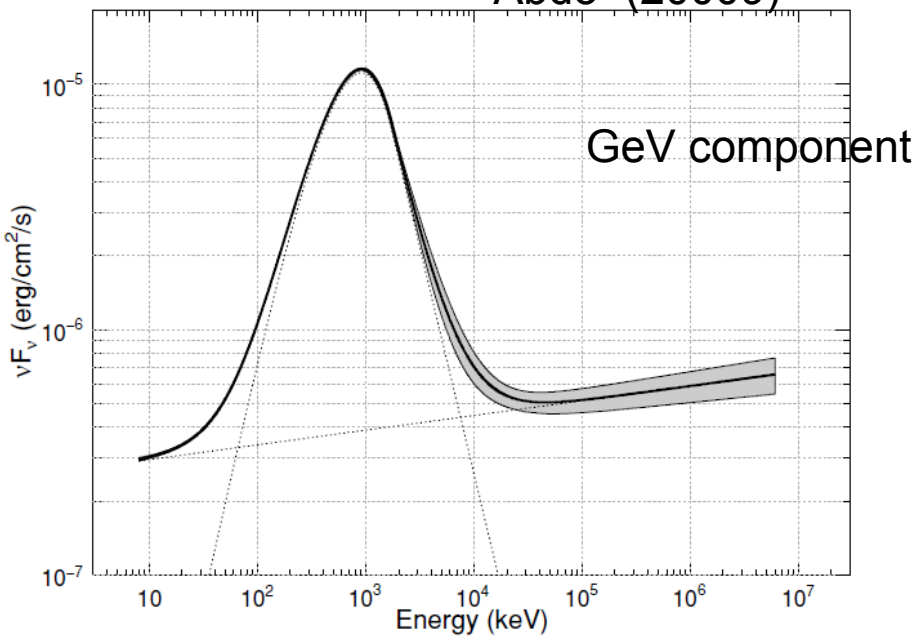
単純なファイアボールの膨張では
熱的放射は1温度のスペクトルが
期待される($T_{obs}=T_{local}$ Γ=const)

$$N_E(E) = A\left(\frac{E}{100\ \mathrm{keV}}\right)^{\alpha} \exp\left(-\frac{E}{E_0}\right), \qquad (\alpha-\beta)E_0 \geq E$$

$$= A\left[\frac{(\alpha-\beta)E_0}{100\ \mathrm{keV}}\right]^{\alpha-\beta} \exp(\beta-\alpha)\left(\frac{E}{100\ \mathrm{keV}}\right)^{\beta}, \qquad (\alpha-\beta)E_0 \leq E$$

Spectrum fitting function
Band function (Band et al. 1993)

GRB090902B
Abdo+(20009)



熱的放射は効率が良いが
スペクトルの再現等で問題がある

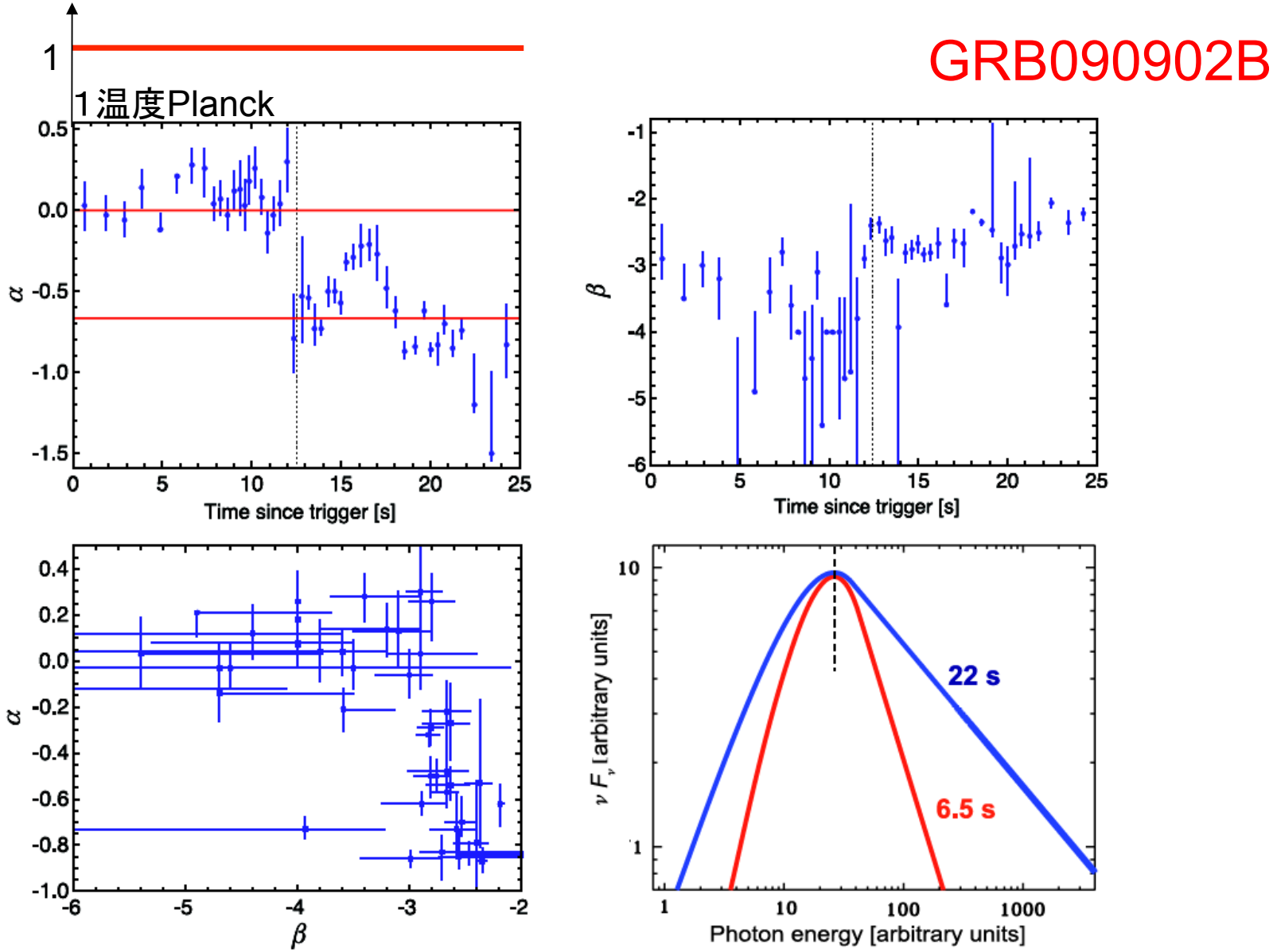
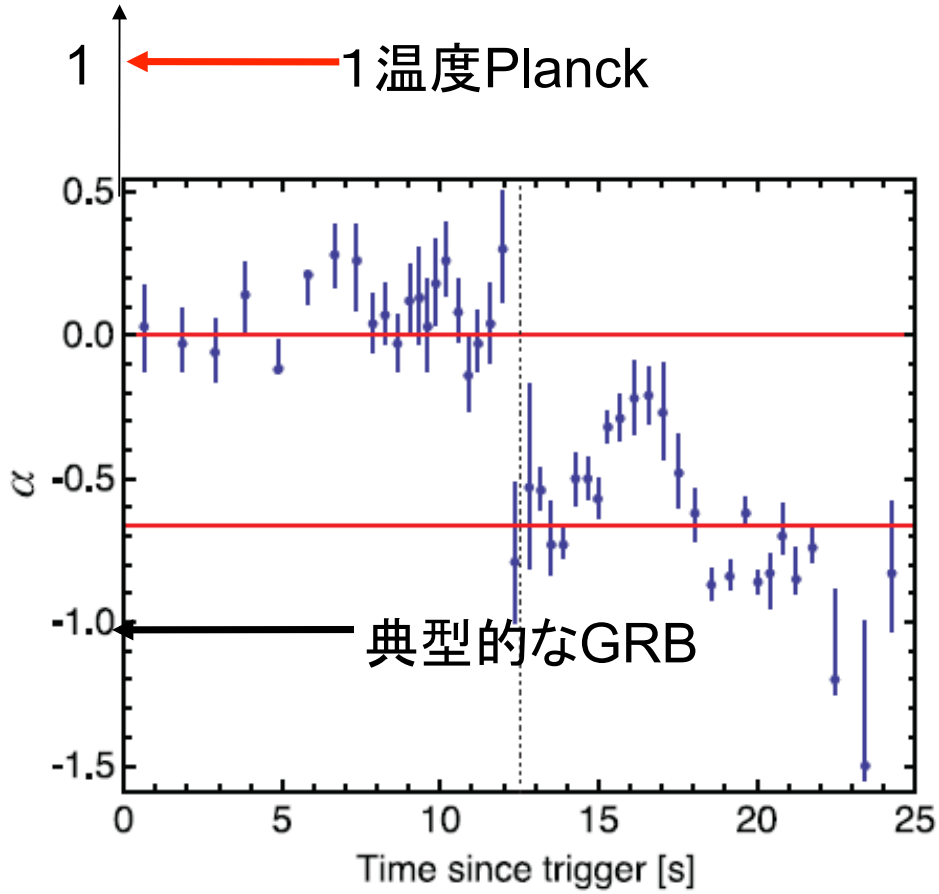
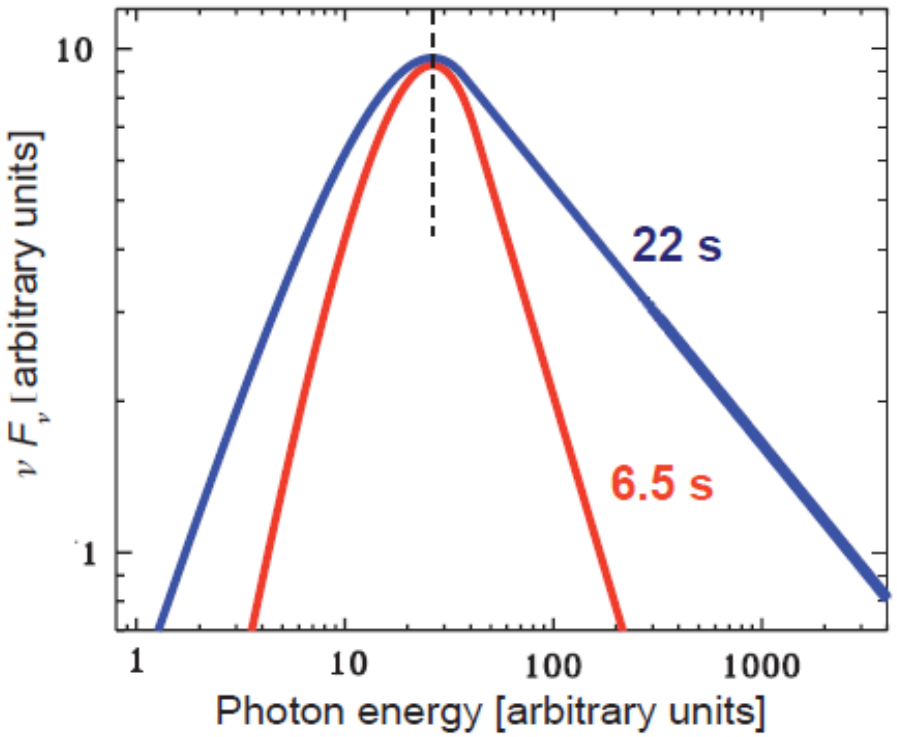
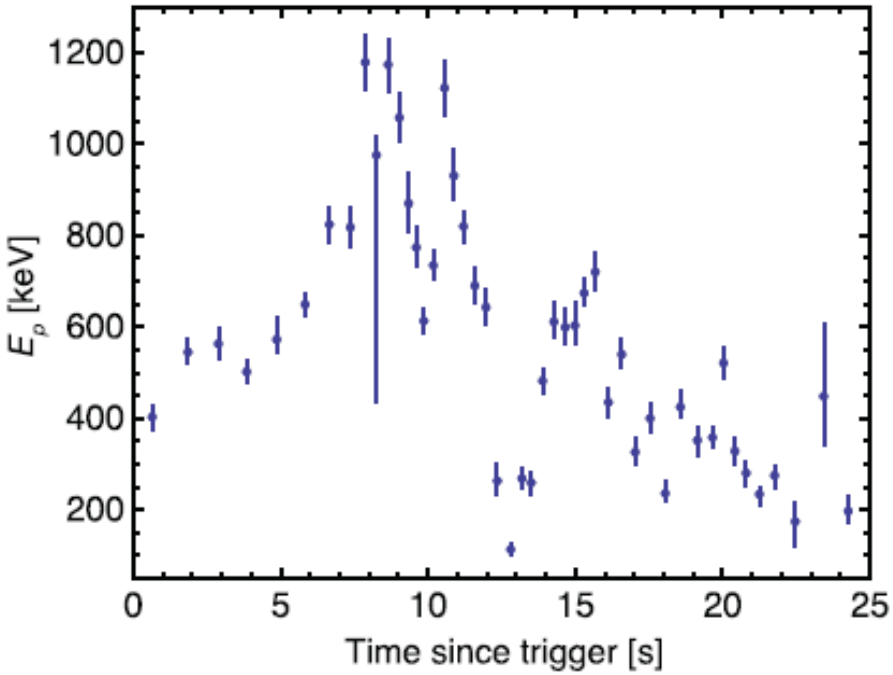


Figure 2. Evolution of the MeV component in GRB090902B. Upper left-hand panel: evolution of low-energy photon index α. Two horizontal lines are shown, which correspond to $\alpha = 0$, the most extreme value expected for inverse Compton models and $\alpha = -2/3$, expected for optically thin synchrotron emission for a slow cooling electron population. The dashed line indicates 12.5 s. Upper right-hand panel: evolution of the high-energy PL index β. Lower left-hand panel: correlation between α and β. Note that some points have only one-sided error bars indicating that they are unconstrained in the other direction. Lower right panel: peak-aligned Band functions corresponding to the fits at two different times, illustrating the spectral broadening. These two times include the narrowest and the broadest Band spectra.

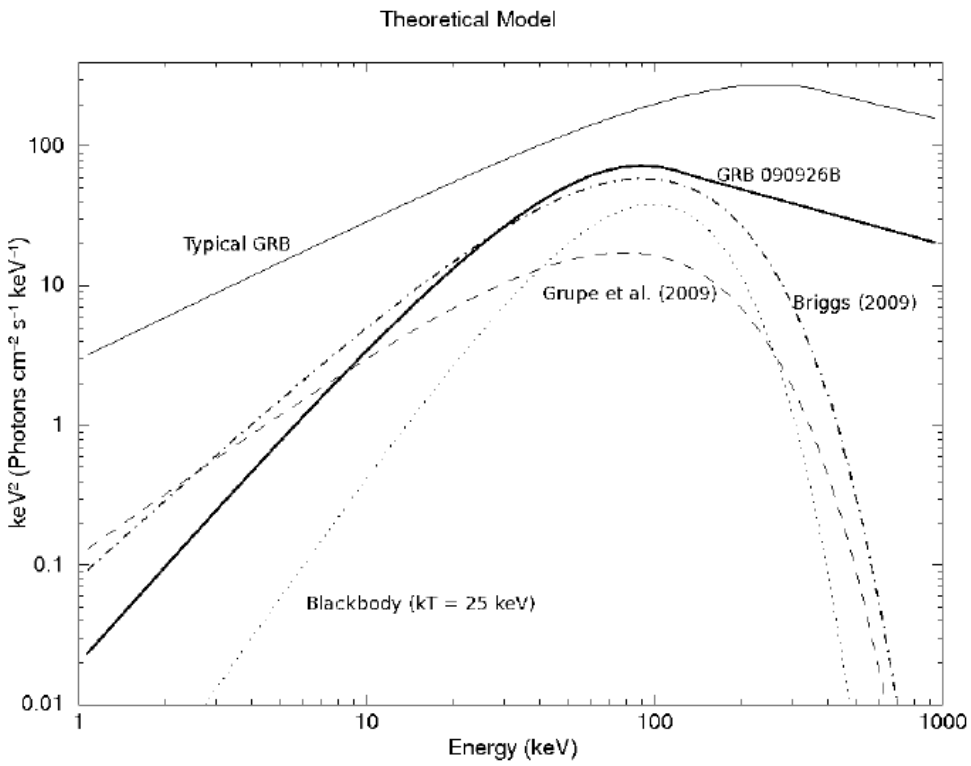
GRB090902B
(Ryde + 2011)





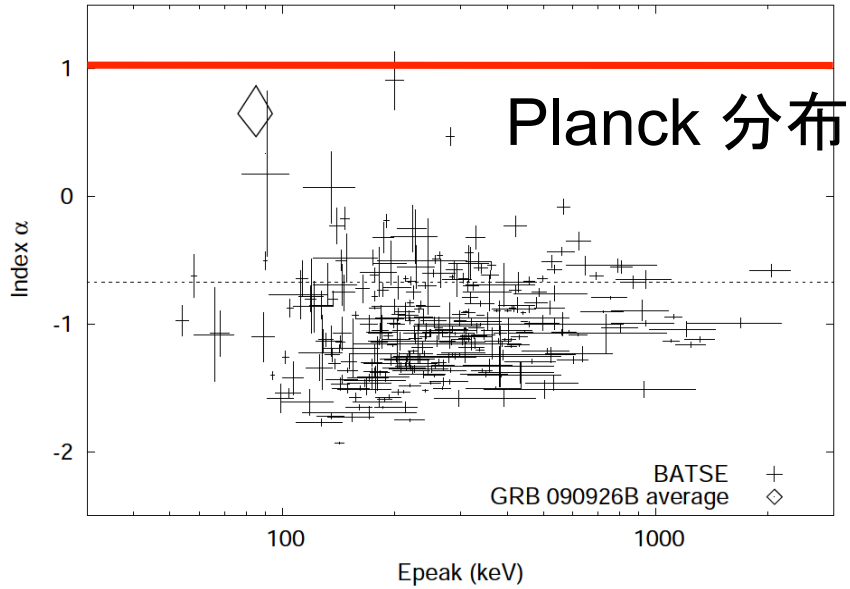


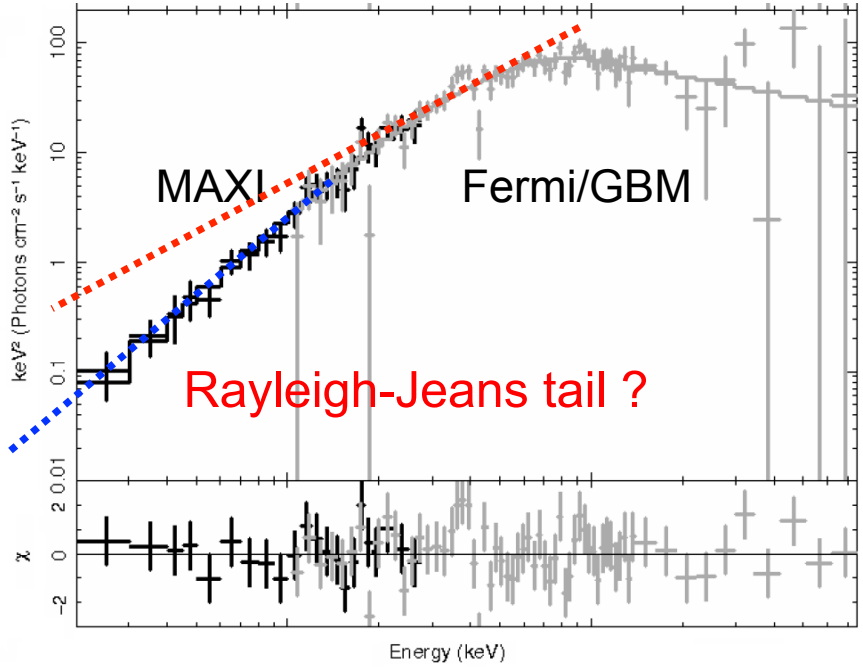
GRB090926B



Serino et al. (2011)

低エネルギーピーク
ハードなスペクトル(Planck like)





Photospheric モデル

●流体 – 球対称、定常

+

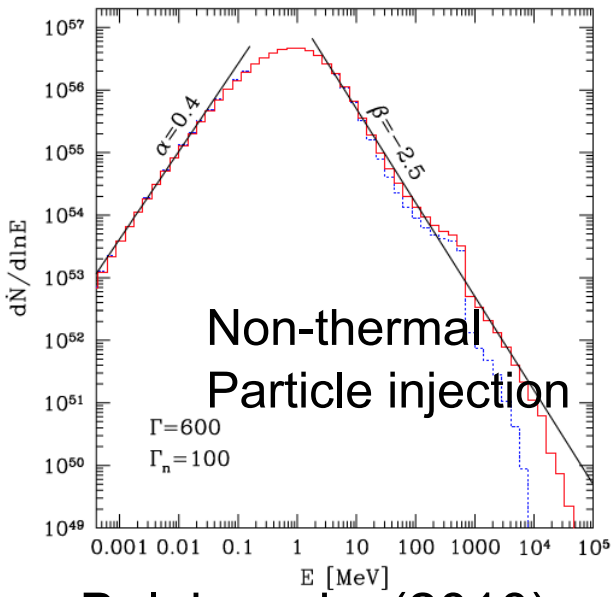
Monte Carlo simulation (photon transport)
Pe'er (2008, 2011),Beloborodov(2010)

●流体シミュレーション

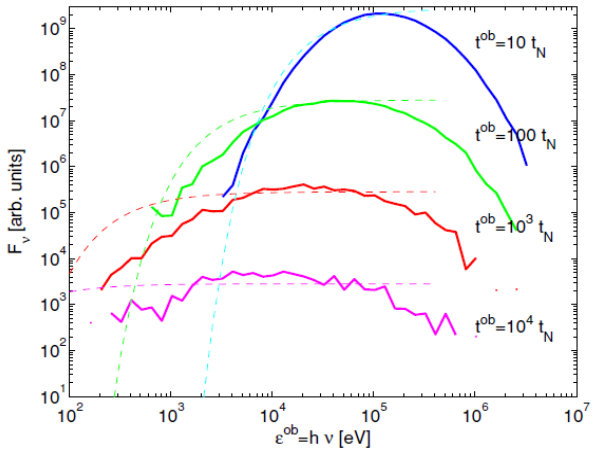
＋

ポスト計算（τ＝1からの黒体放射）
Lazatti +(2009,2011) Nagakura + (2011)
Mizuta+ (2011)

ジェット状の爆発で
熱的放射はどのように見えるのか？
光度曲線、スペクトル
視線方向依存性



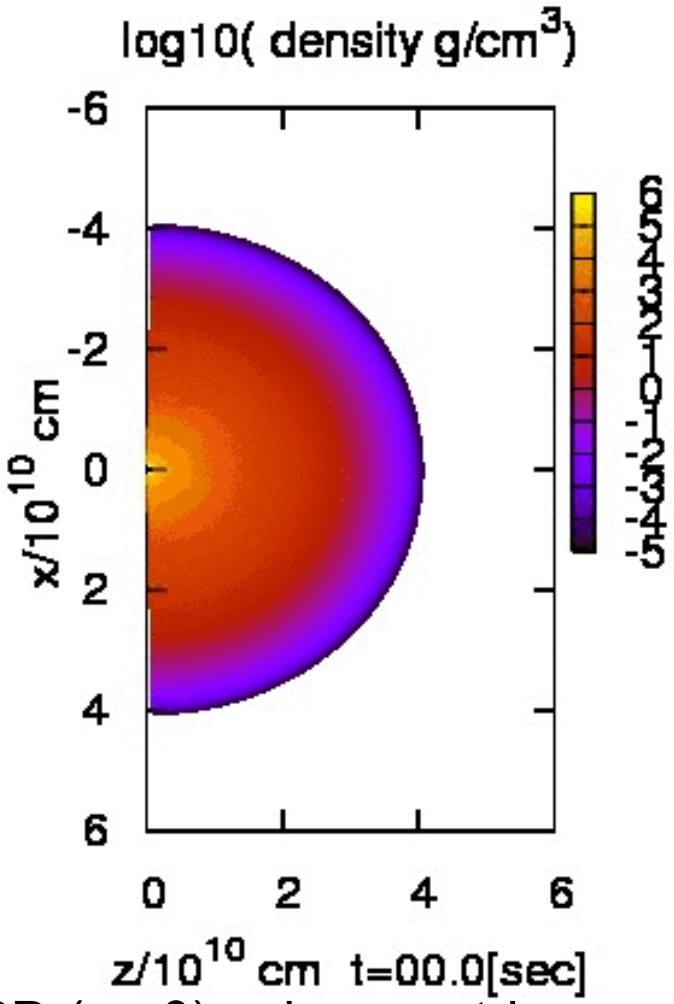
Beloborodov(2010)



Pe'er (2011)

Lj=5.e50 erg/s [0:100s] Opening angle 10 degrees

Γ_0=5, ε_0/c^2=80 (h_0~106) Γ_max~$h_0\Gamma_0$(Bernoulli's principle)



2D (r x θ) axisymmetric, progenitor 14_sum,R*=4.e10cm (Woosley & Heger (2006)) + wind (r>R*) $\rho \propto r^{-2}$

2D-rela- hydro code(constant specific heat ratio=4/3)

Mizuta et al. (2004,2006) + MPI

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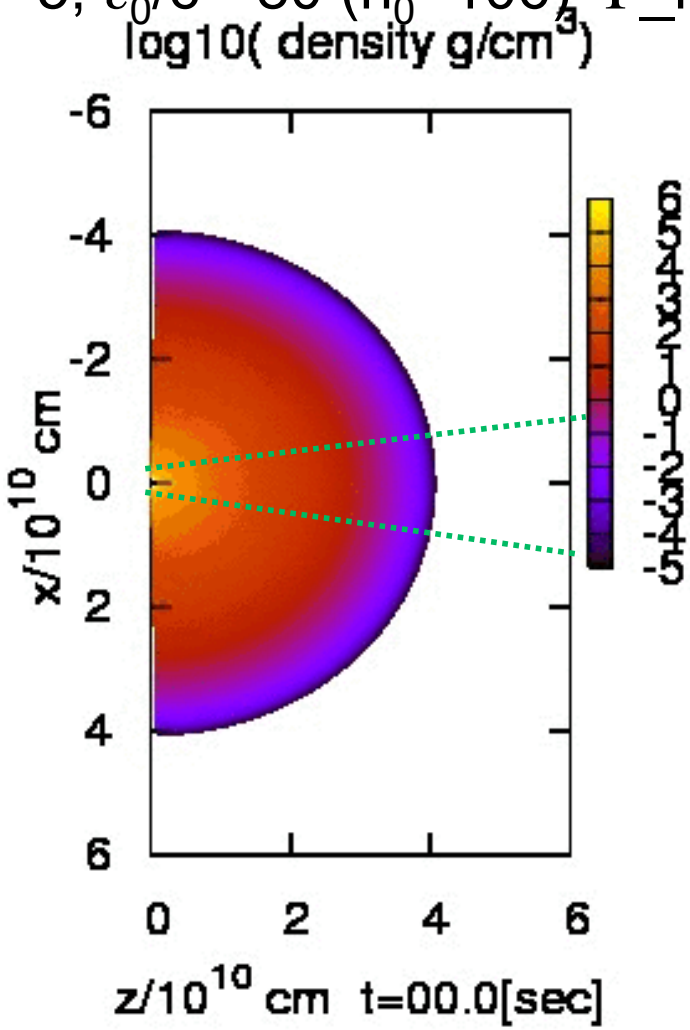

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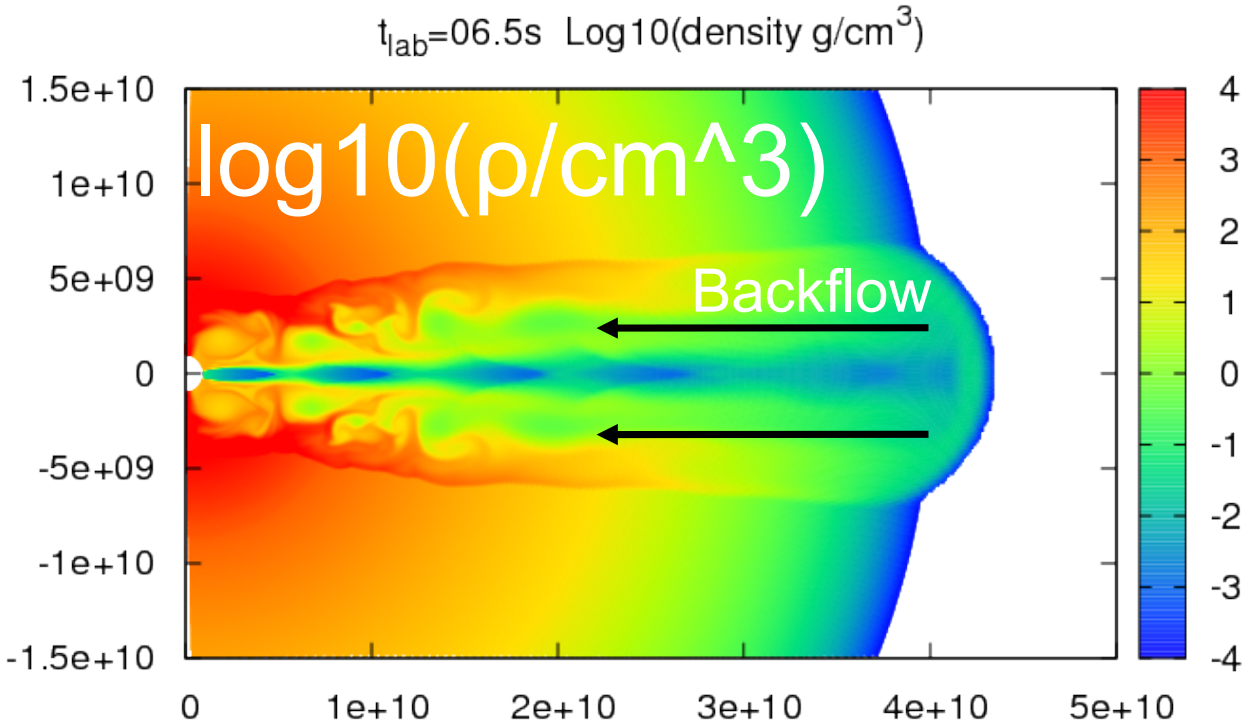
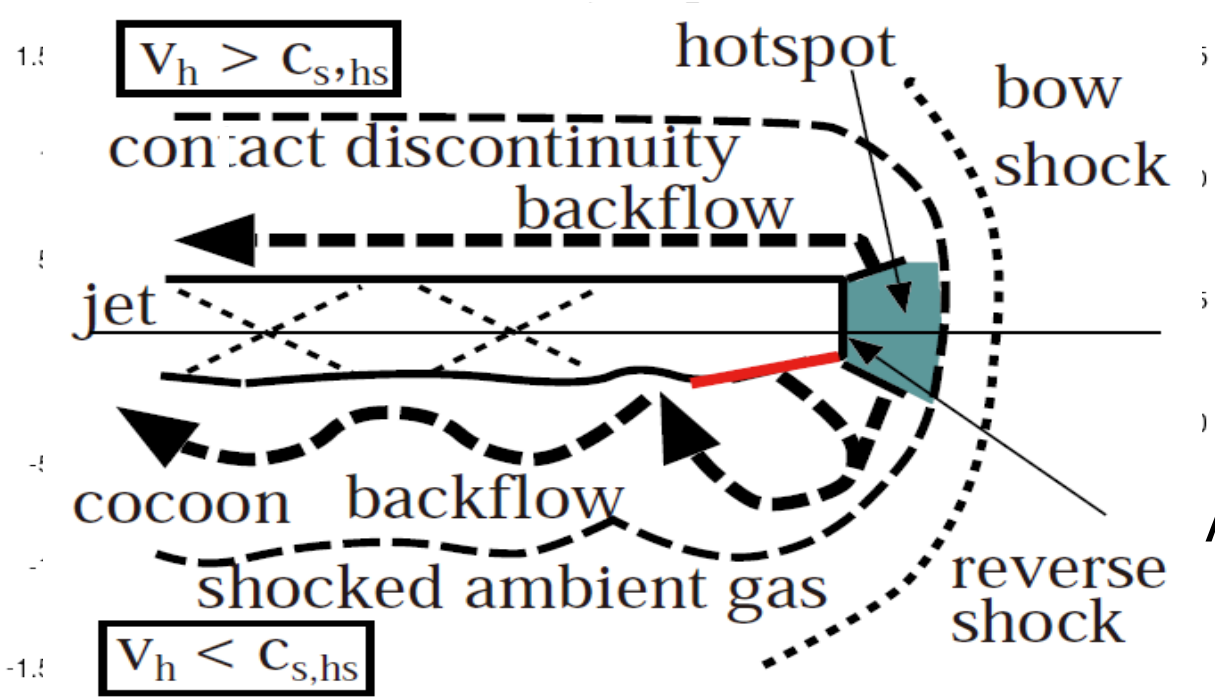




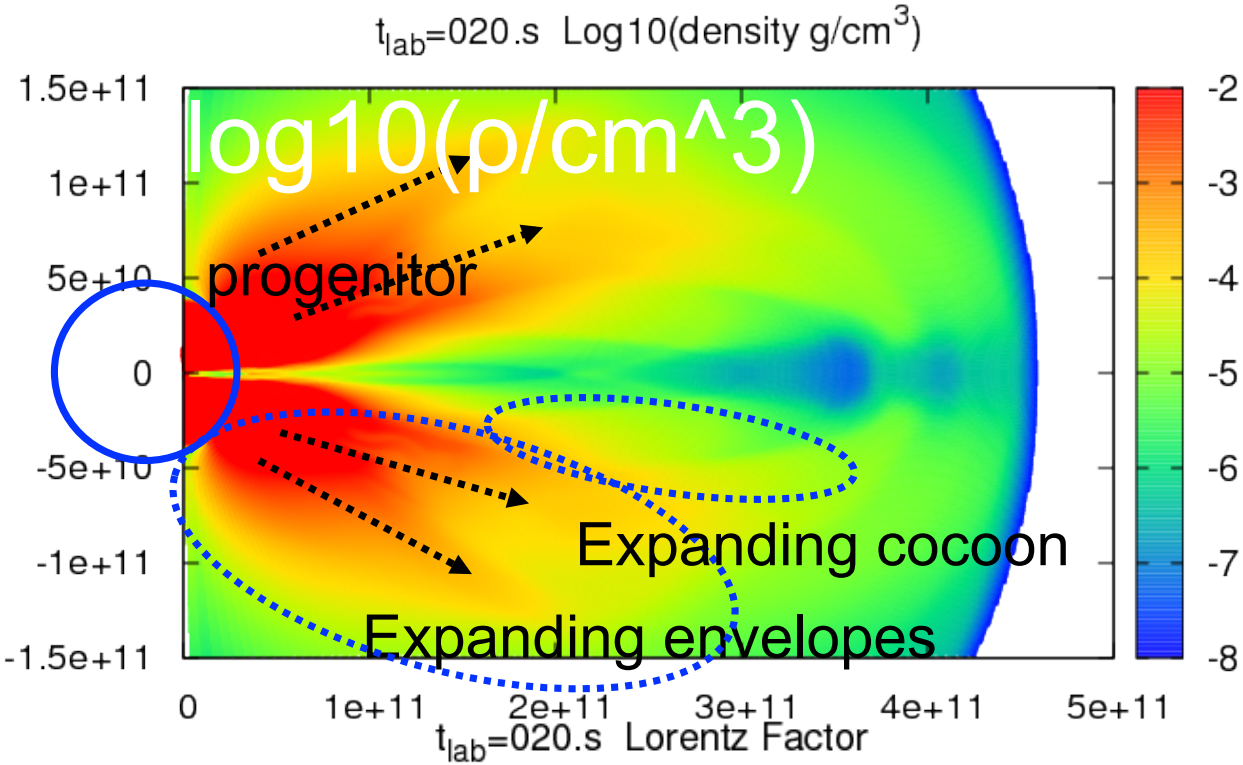
Shock-break

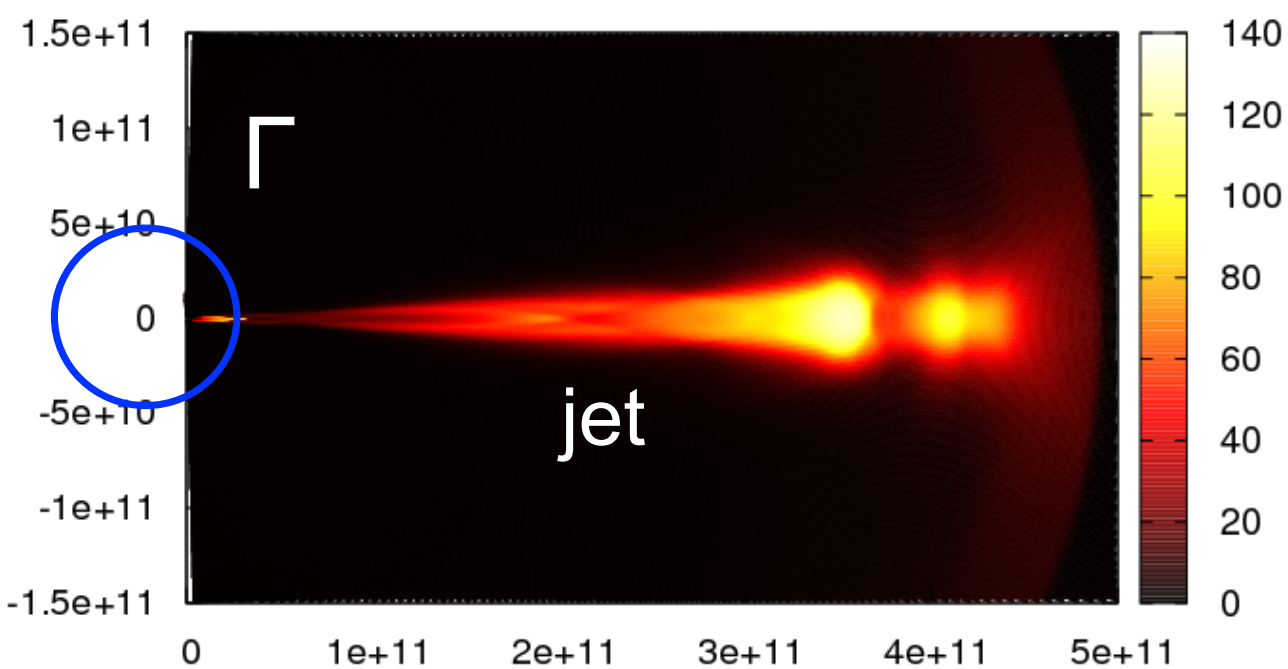
Interaction between jet and progenitor envelopes.

High pressure cocoon confinement and a bent backflow enhance the appearance of internal oblique shocks.

The jet includes knotty structure.

AM, Kino, Nagakura('10)

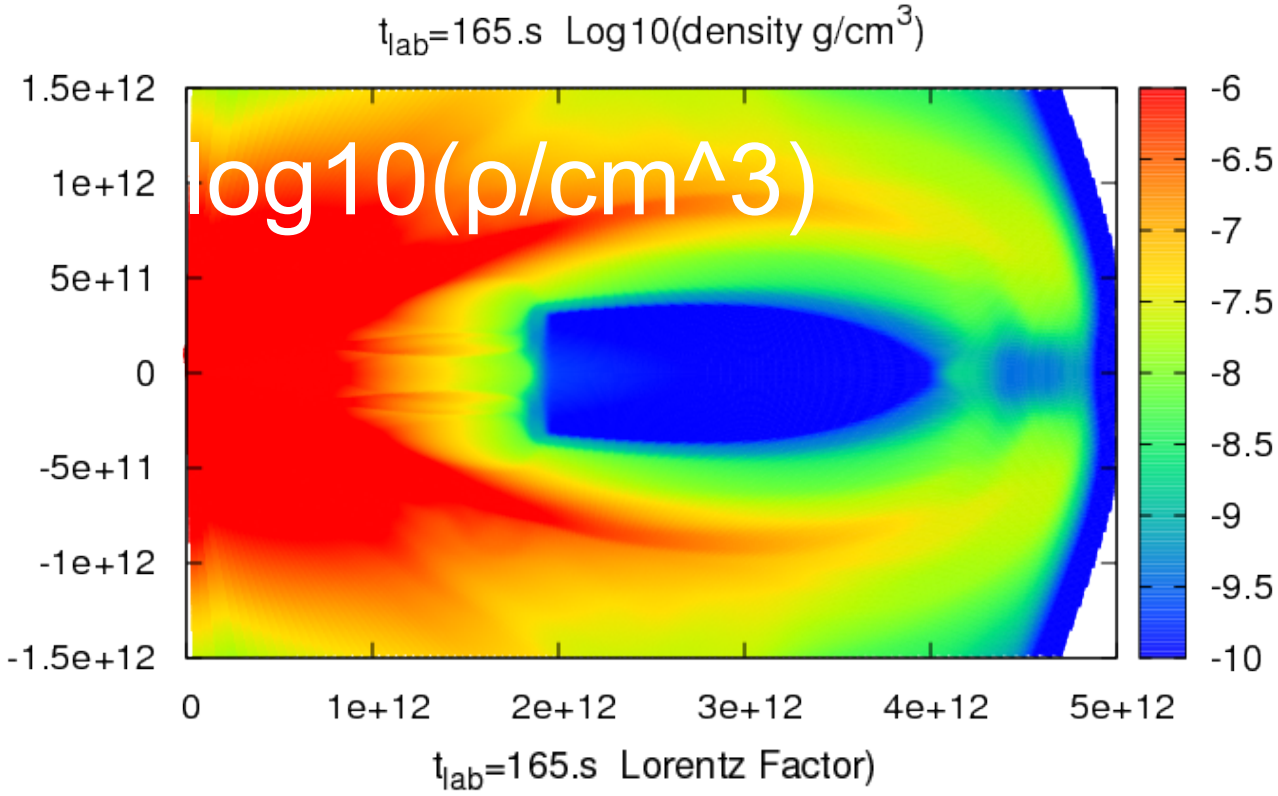




After shock-break I r~10^11cm

ジェット先端では
ブレイク前、ブレイク直後
での親星外層との相互作用で
絞られ、ジェット内部に
不連続構造を形成

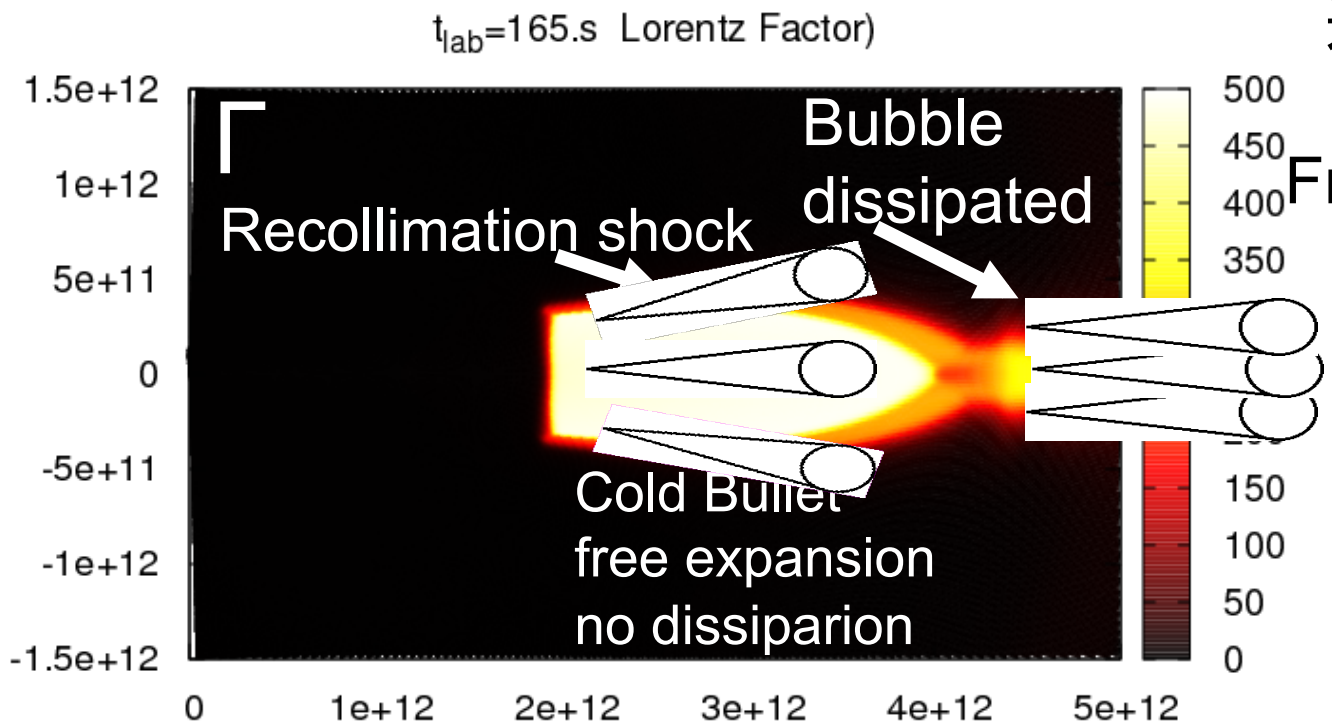
～親星の半径の10倍程度の
スケールまでジェットは
自由膨張できない



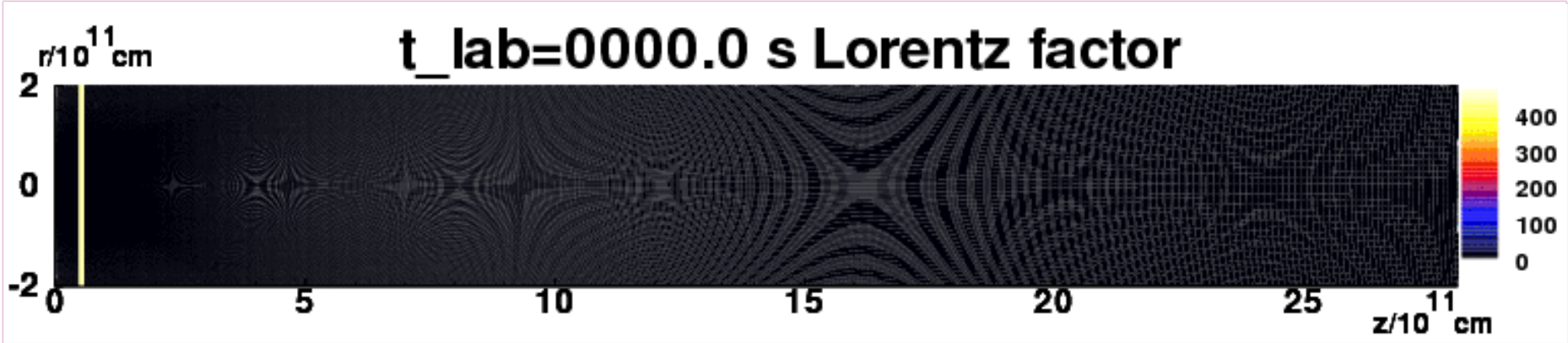
After shock-break II
r~10^12 cm

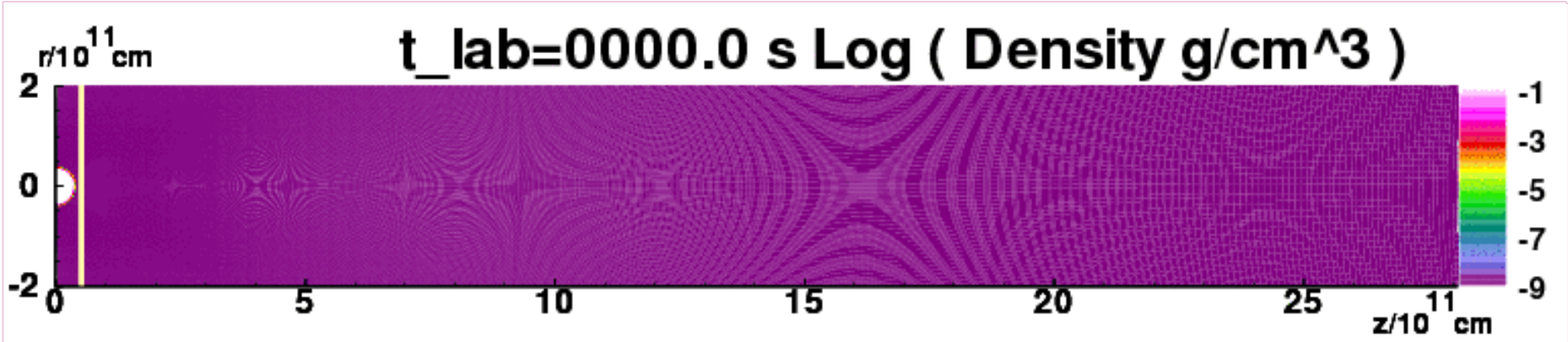
Free expanding region
で最大ローレンツ因子
~500
(=Γ0*h0=533)

dissipated region
速度ベクトル// z 軸



Free expanding region
速度ベクトル// 動径方向





θ=0

θ =5

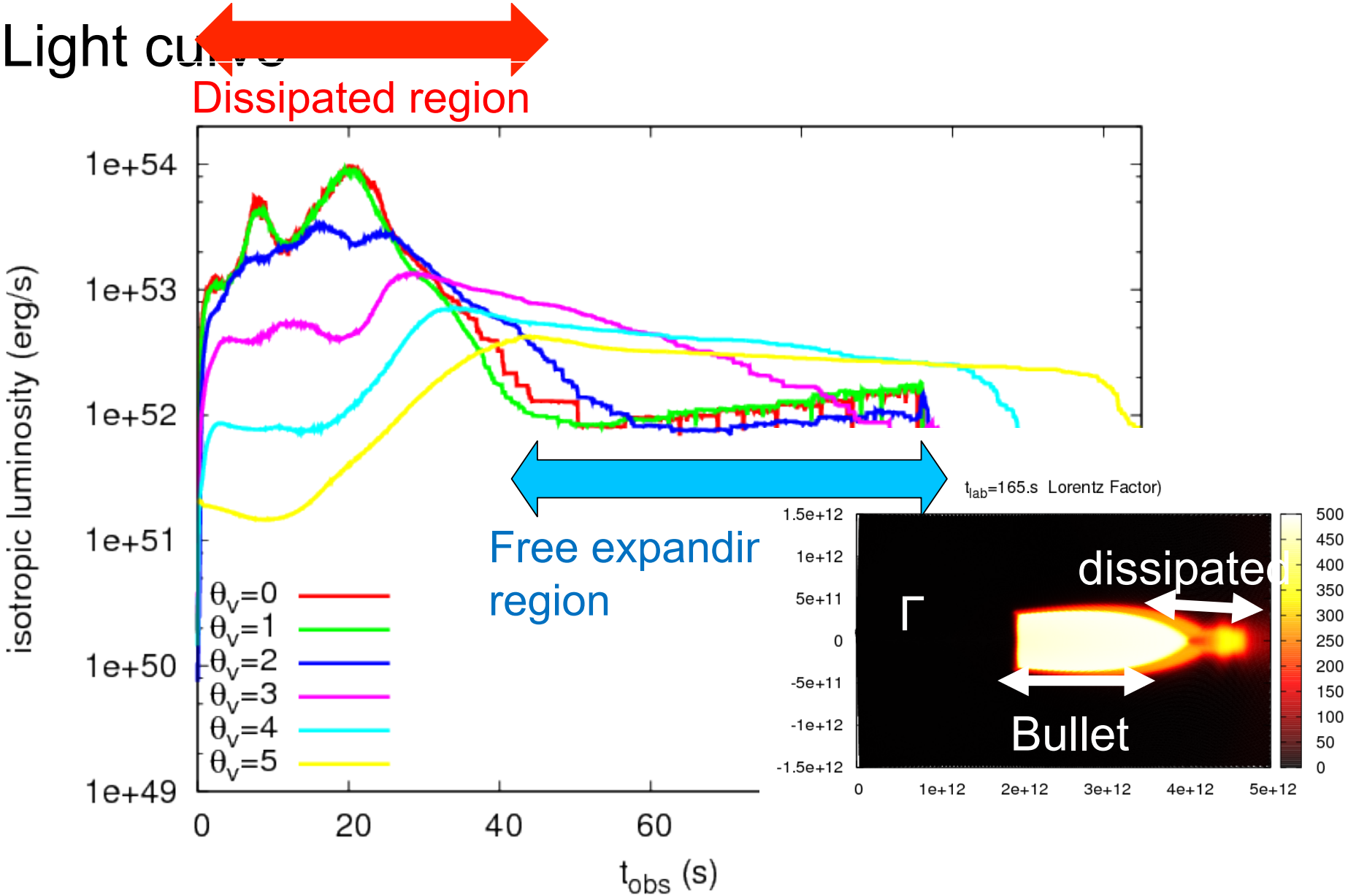
θ =10

$$\tau = \sigma_T \int_R^\infty \boxed{\Gamma(1-\vec{\beta}\cdot\hat{n})} n dl$$

1/beaming factor ~ 1/Γ (for β // n: LOS)

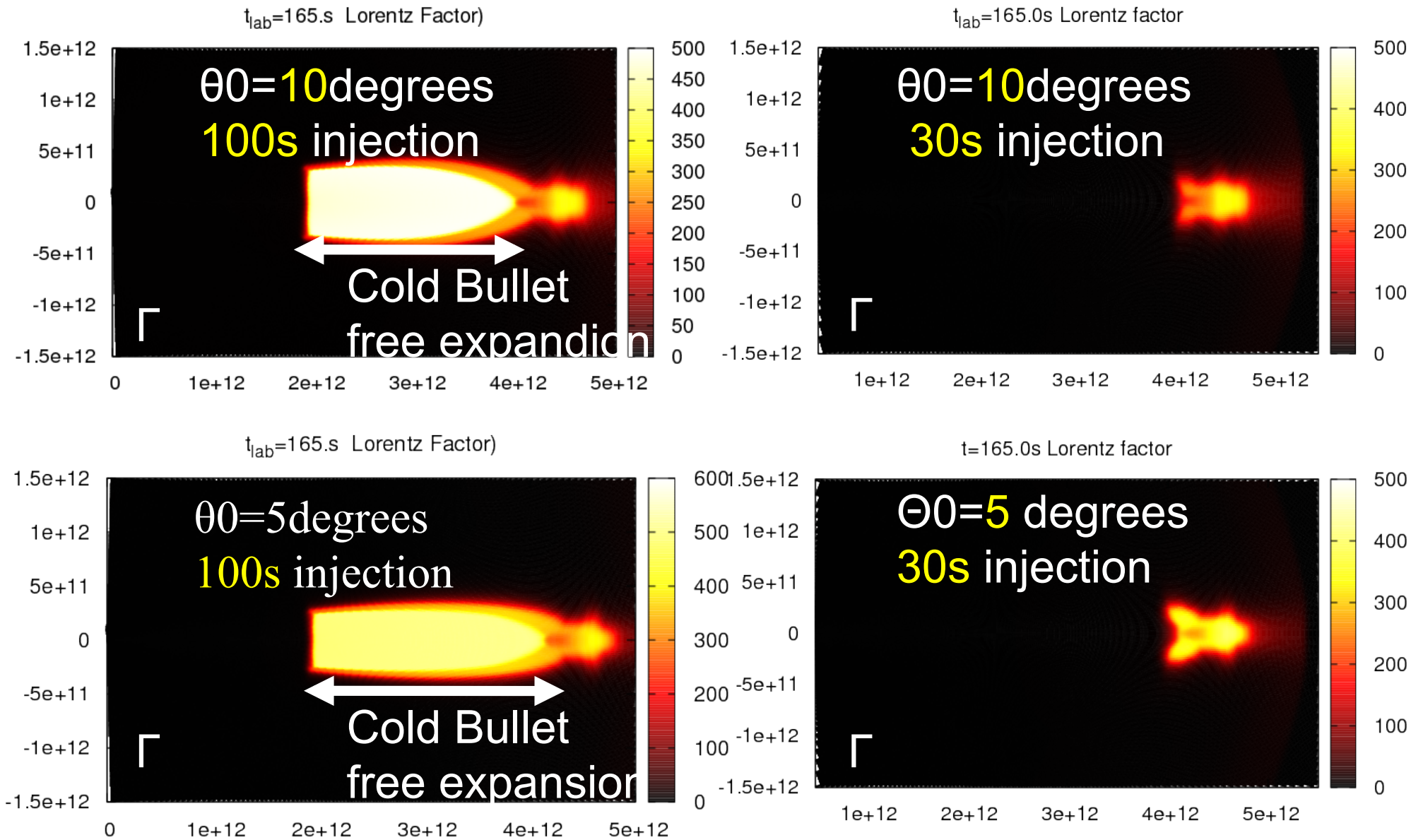
$$L_{\rm obs} = \frac{ac}{4}\int \boxed{\frac{T^4}{\Gamma^4(1-\vec{\beta}\cdot\hat{n})^4}} dS$$

Light curve

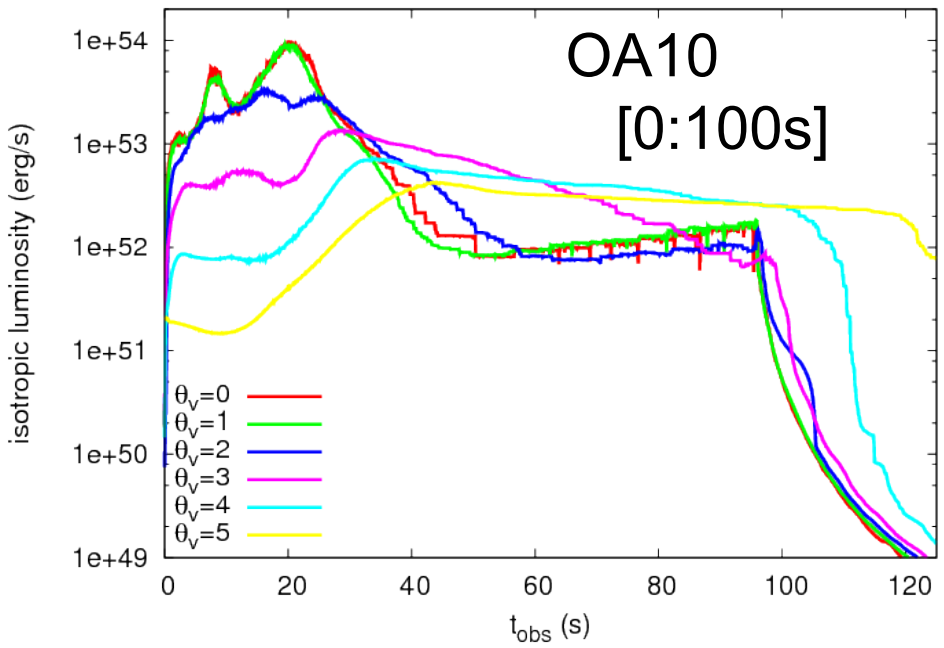


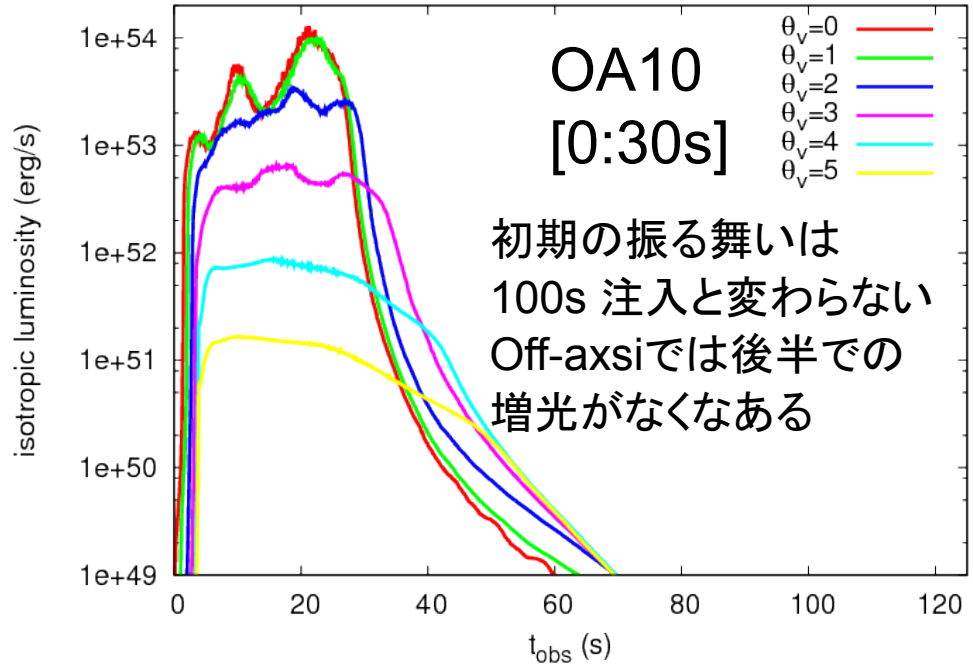
Duration of light curve ~ jet injection.
A few seconds time variability in early phase caused by internal discontinuity in the jet.

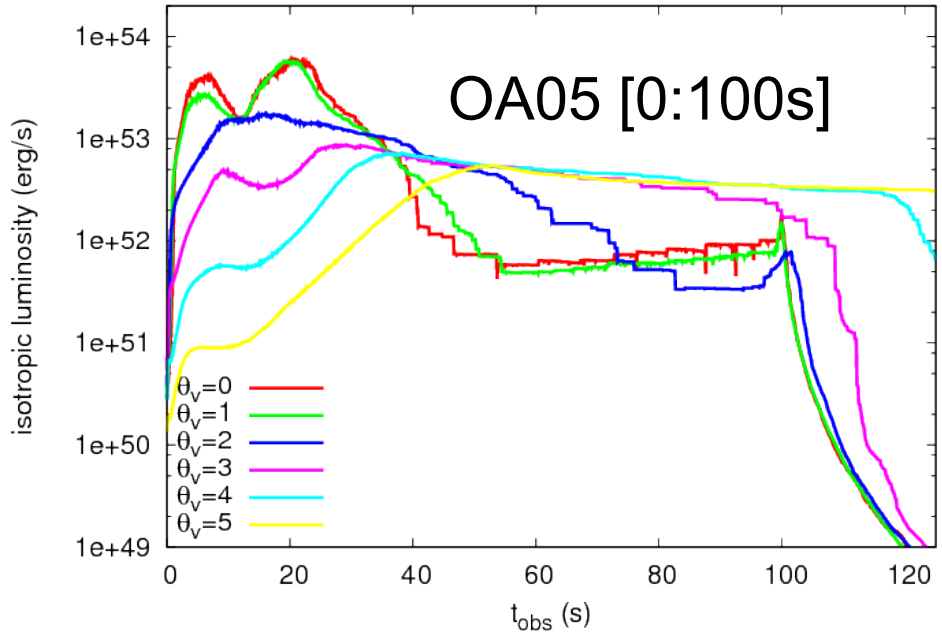
Duration / initial half opening angle

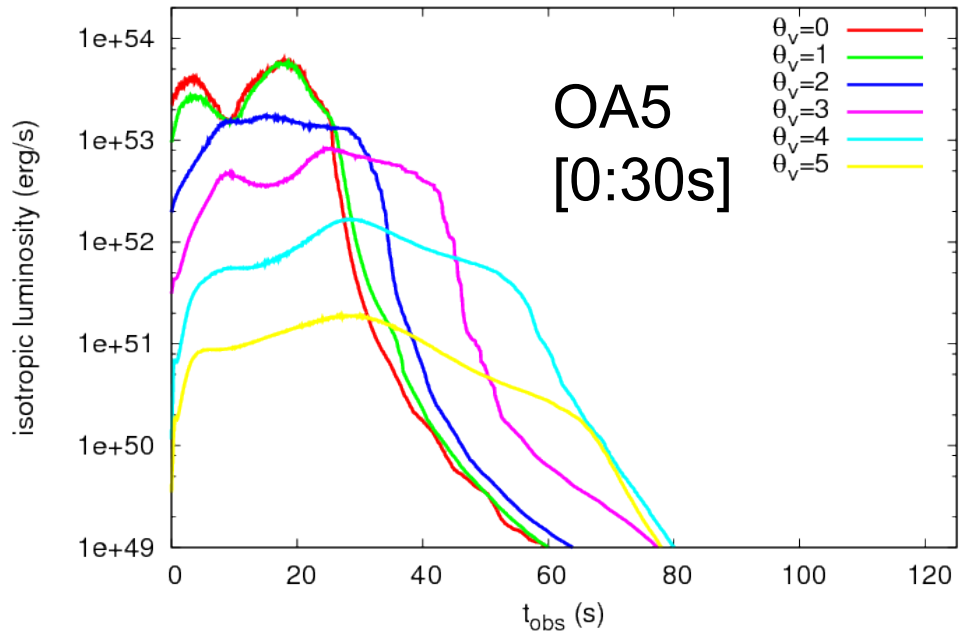


Light curves



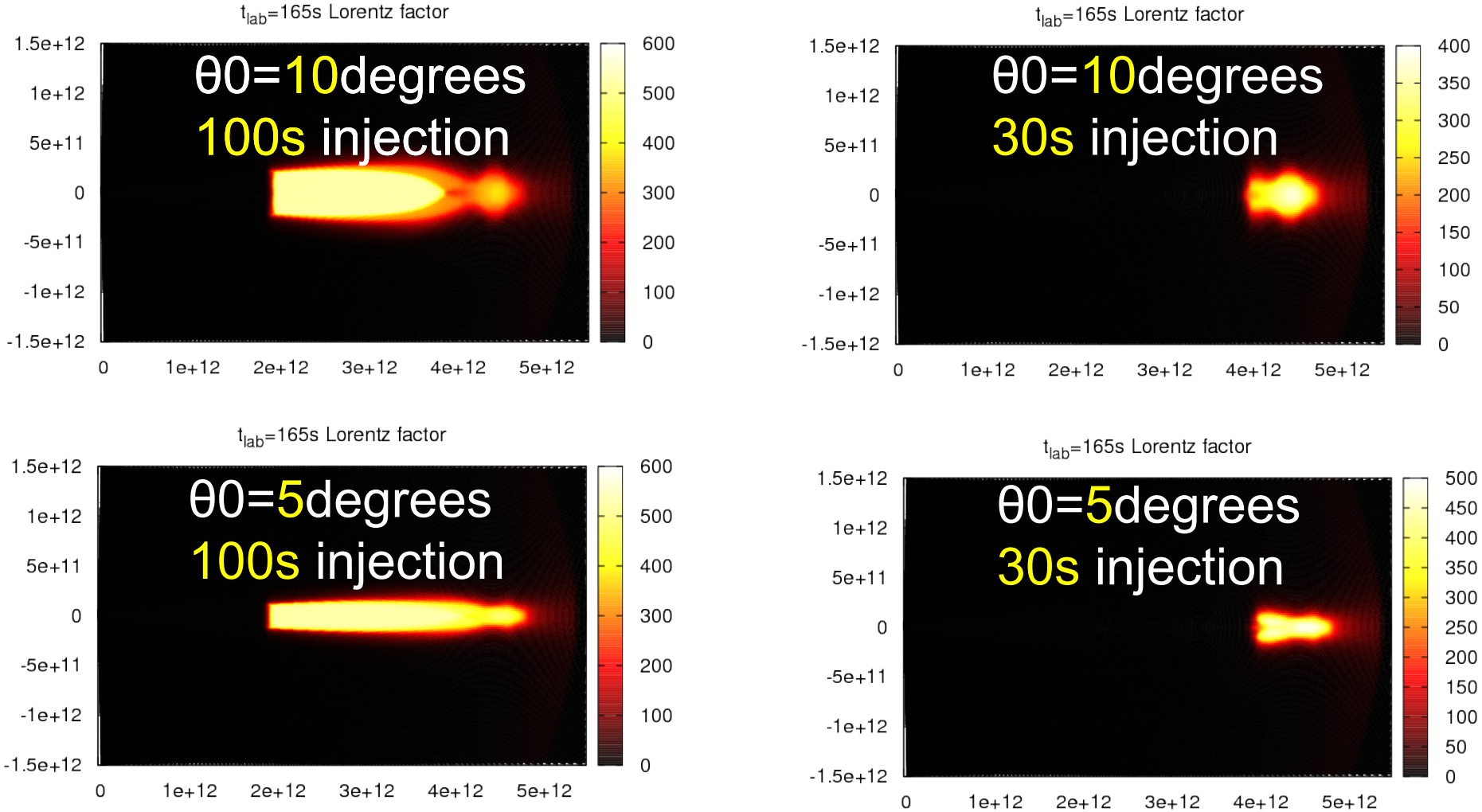






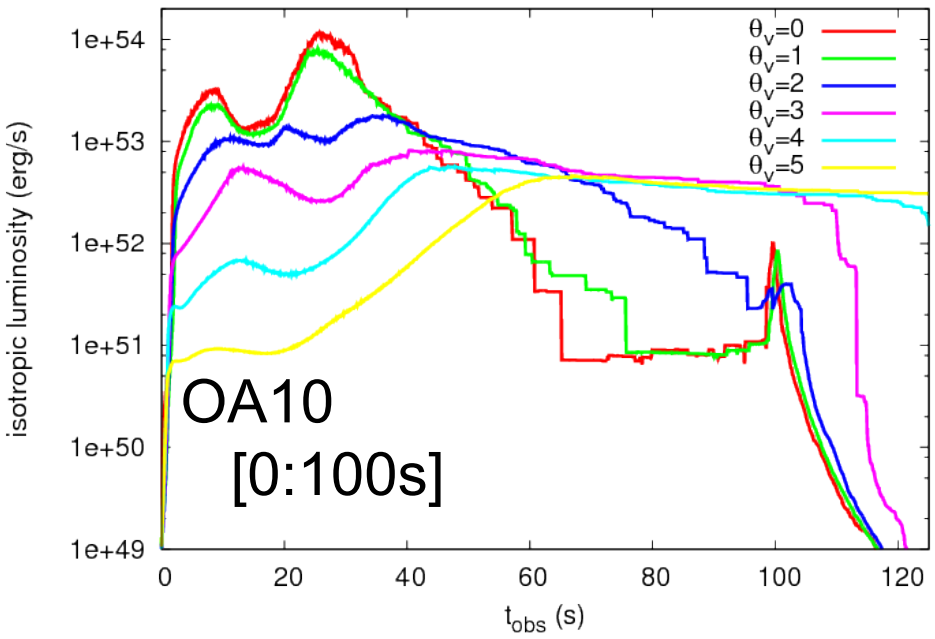
Lj=5.e50 erg/s [0:100/30s] Opening angle 10/5 degrees

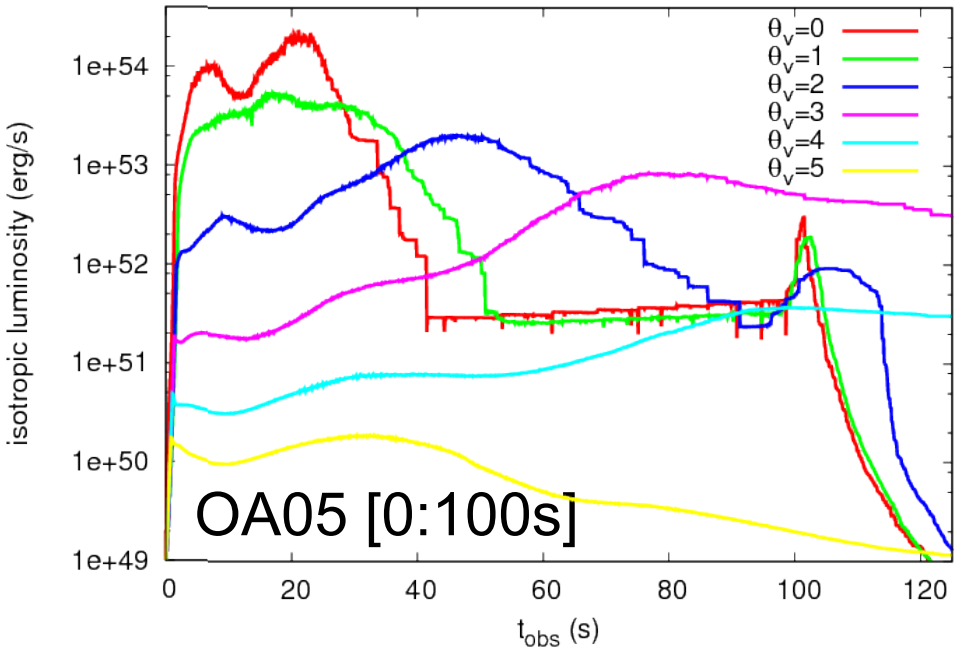
Γ_0=100, h_0~5.3@r_{min}=10^9cm Γ_max~$h_0\Gamma_0$(fixed)

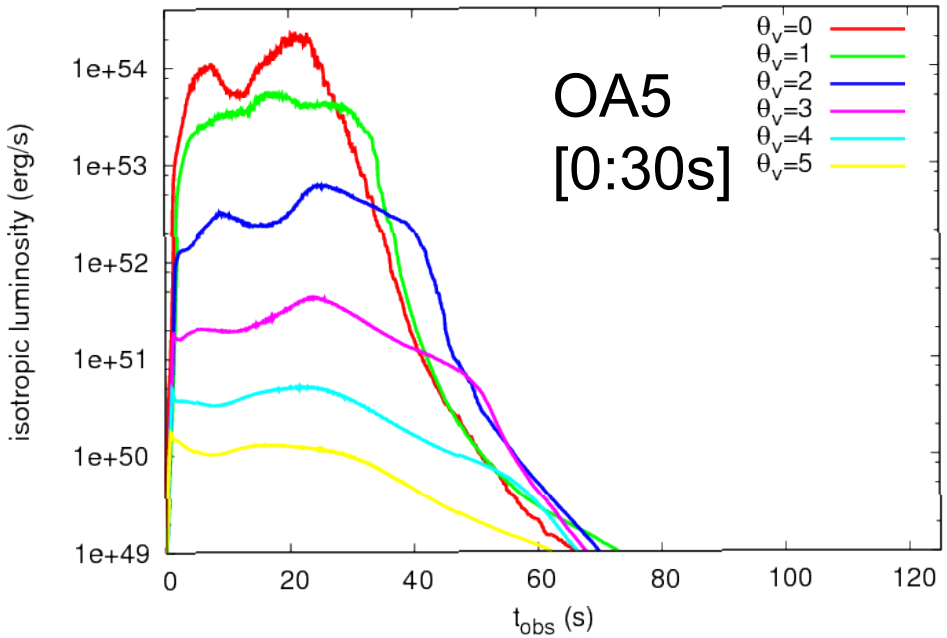


much narrower structure

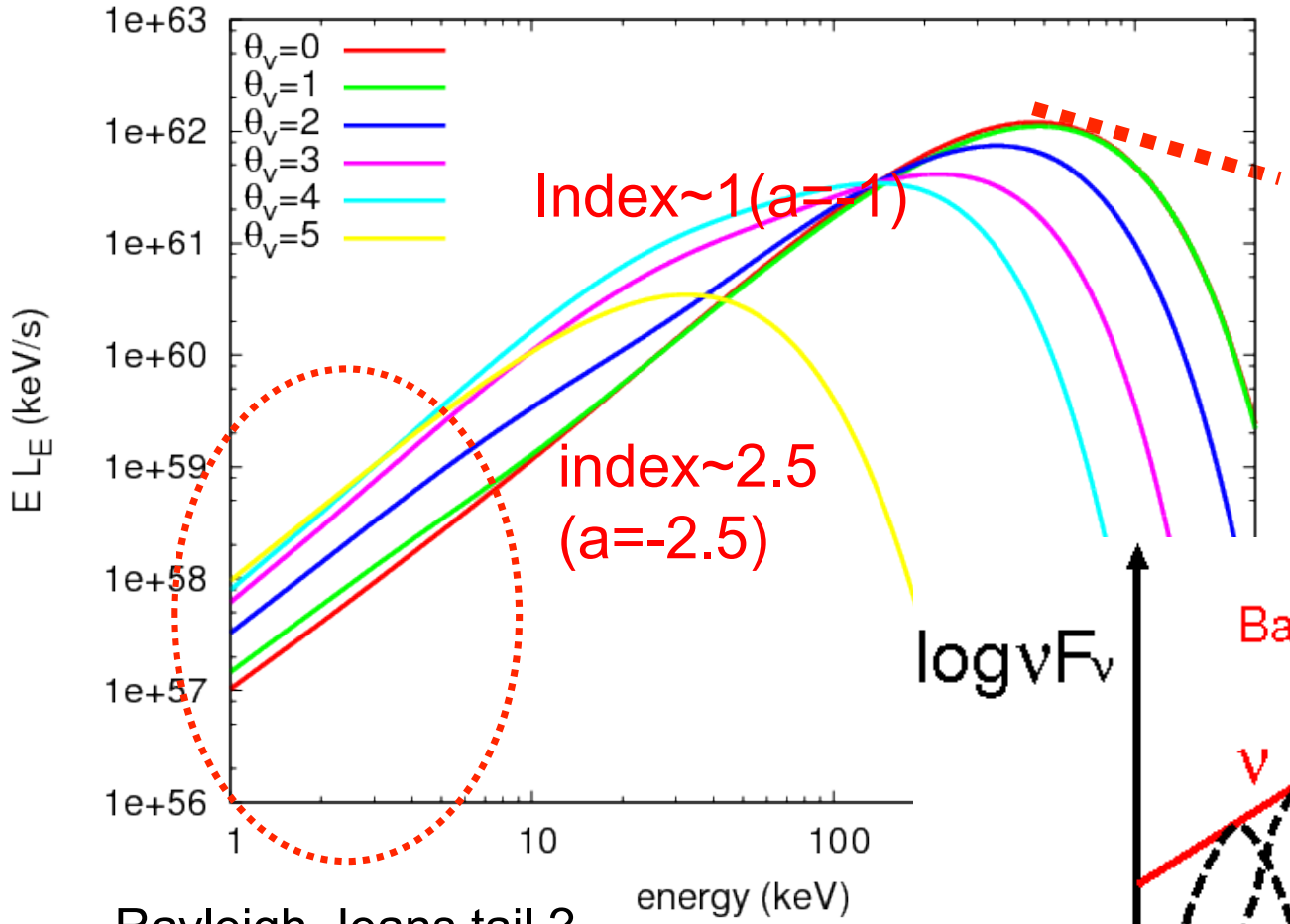
Light curves







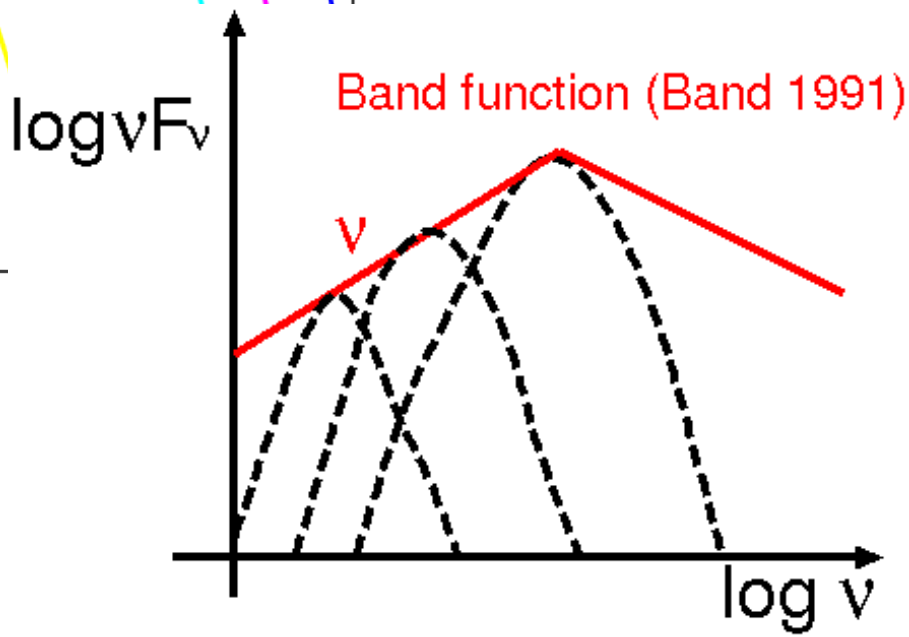
Spectrum by numerical hydrodynamics



高エネルギー成分は
IC等の非熱的な叩き上げが
必要

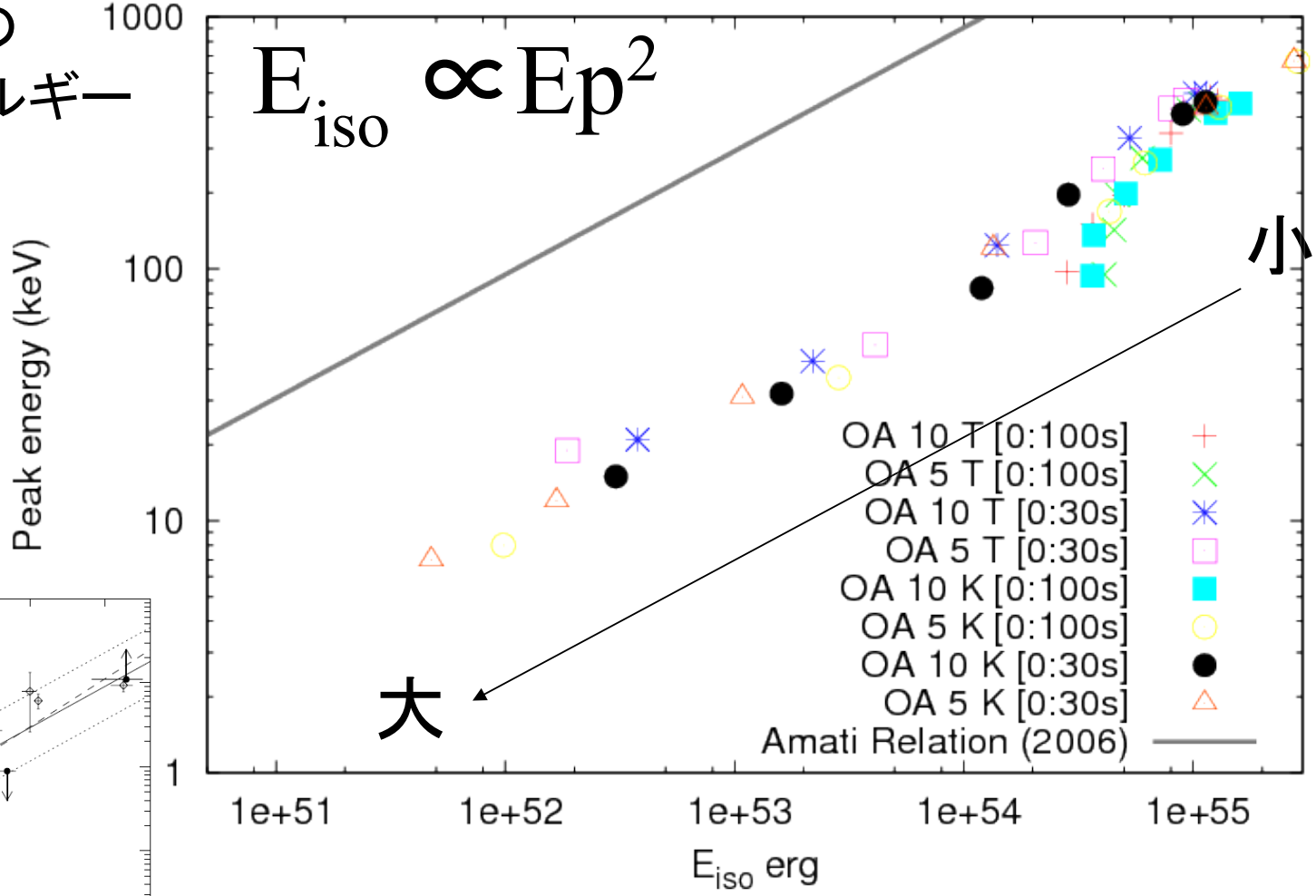
Rayleigh-Jeans tail ?
GRB090926B

θ0=10degrees
100s injection

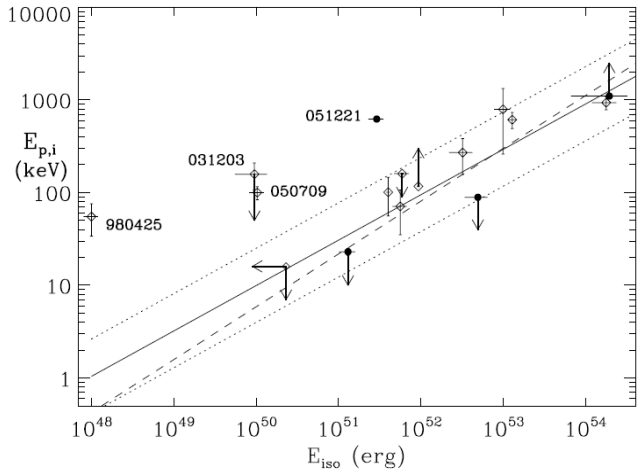


Numerical Amati Relation
GRB は z>1 での距離指標？

スペクトルの
ピークエネルギー



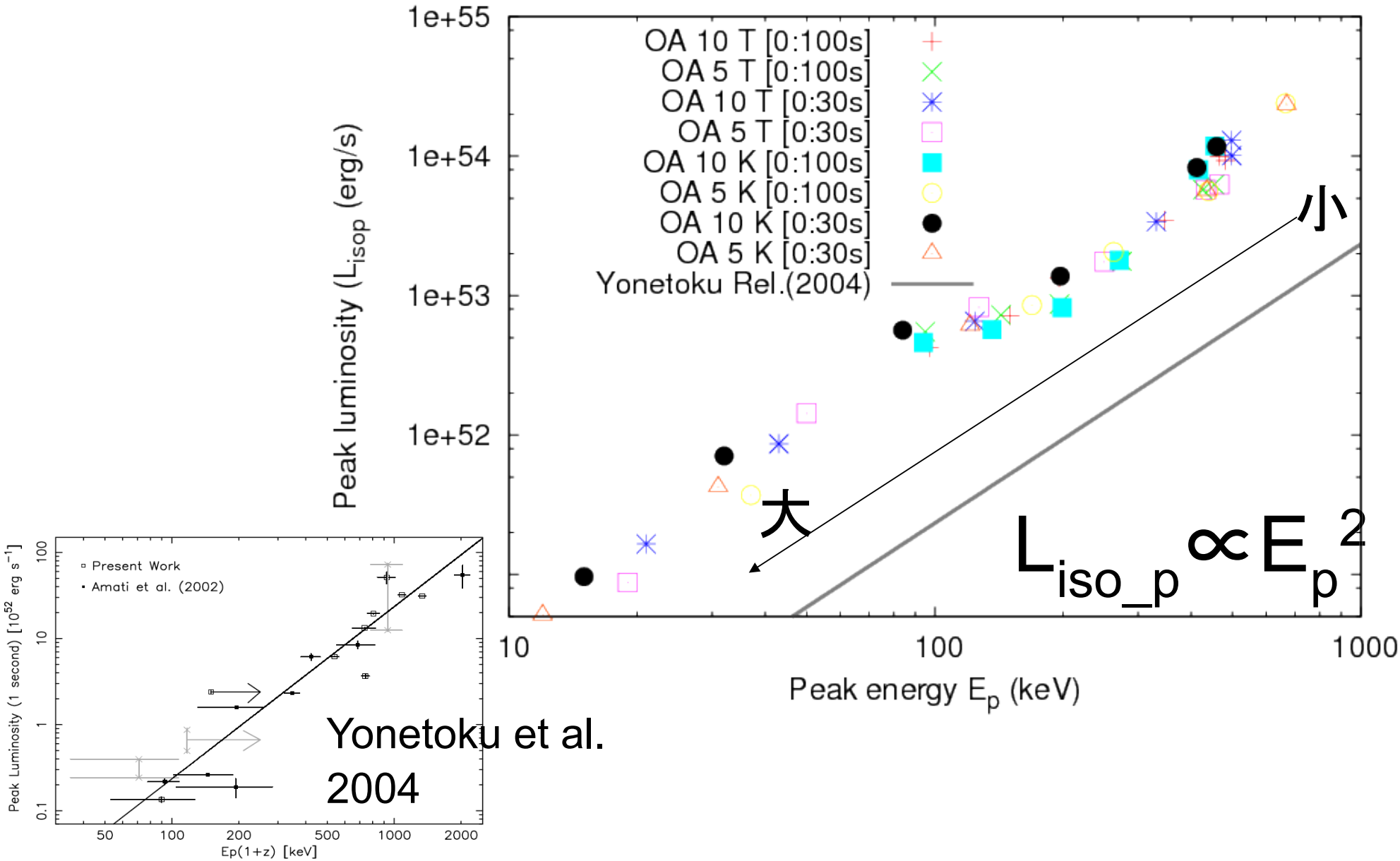
Amati 関係式
(Amati 2002,2006)



等方放射を仮定した時の全放射エネルギー

統計的解析から得られた経験則

Numerical Yonetoku Relation is also found !!



Summary

コラプサーからのジェットはブレイク前、直後の親星との
相互作用で生じる内部衝撃波に起因する密度、ローレンツ因子が不連続に分布する dissipated region (星の半径 x 10倍程度)を形成

速度ベクトル // ジェット軸
明るい、秒スケールの時間変動 for on-axis observer

更に注入が続くと、Free expanding 構造が形成される

速度ベクトル // 動径方向
明るい for off-axis observer

視線方向、ジェット継続時間で様々なタイプの光度曲線

Spectrum – off axis になるほどソフト（Planck like – Band like)

Numerical Amati and Yonetoku relations
(数値流体シミュレーションで経験則の物理を解明できるか？