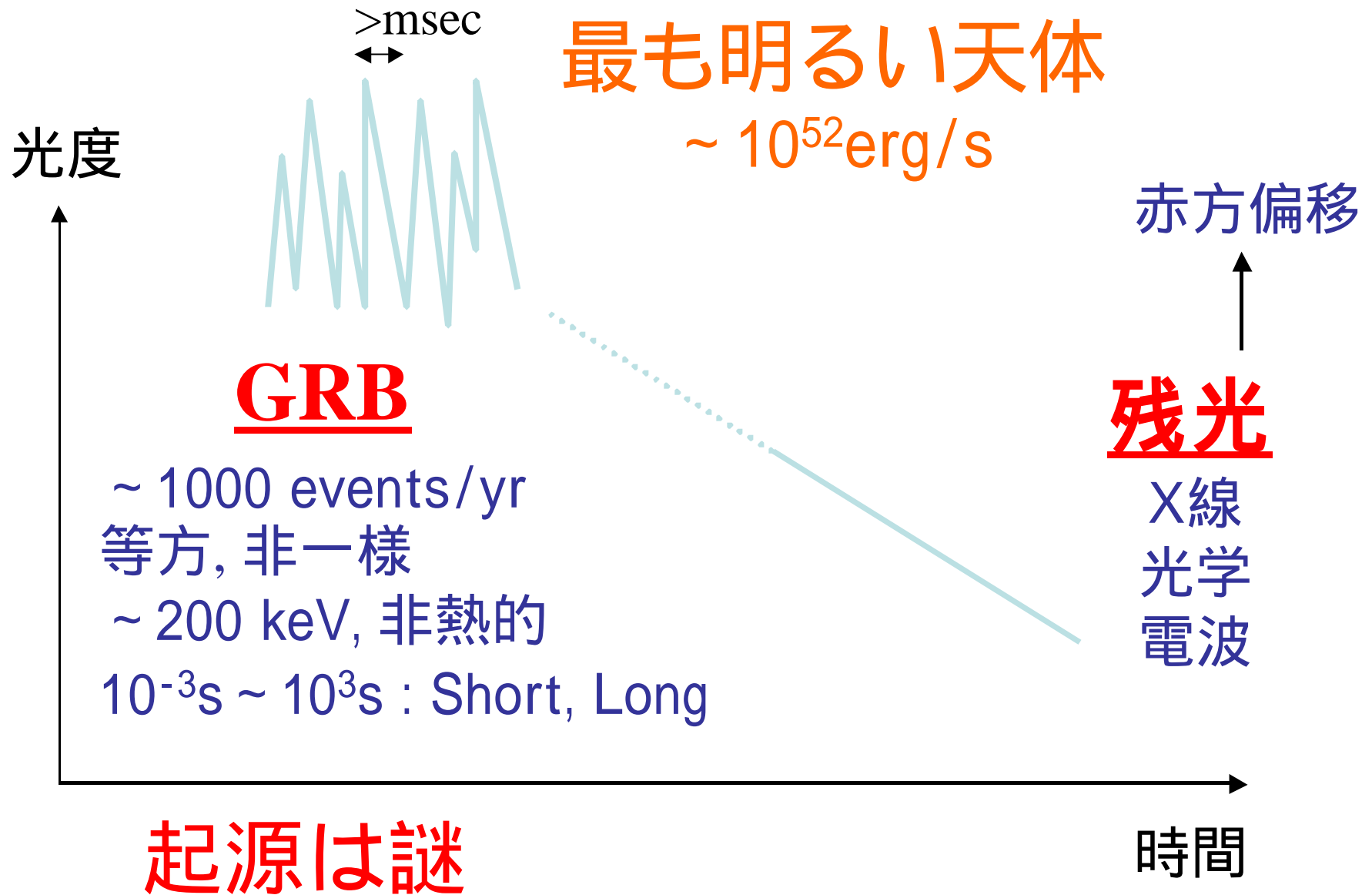


ガンマ線バースト理論の 最近の進展

井岡 邦仁

(阪大理 4月からPennState)

観測のまとめ



標準モデル

optically-thick



内部衝撃波

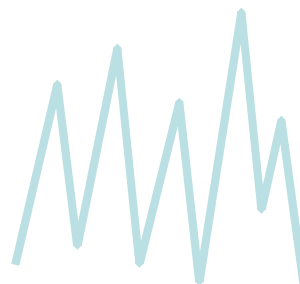
星間物質

$\Gamma > 100$

外部衝撃波

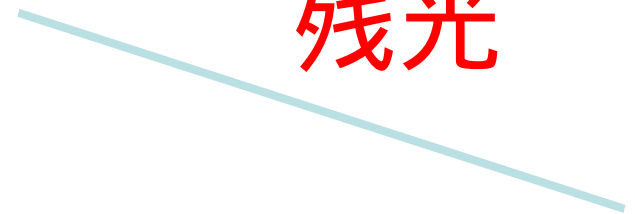
光度

Kinetic energy
Shock dissipation



GRB

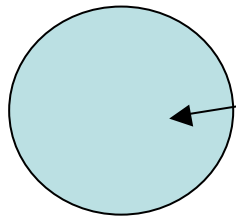
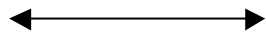
残光



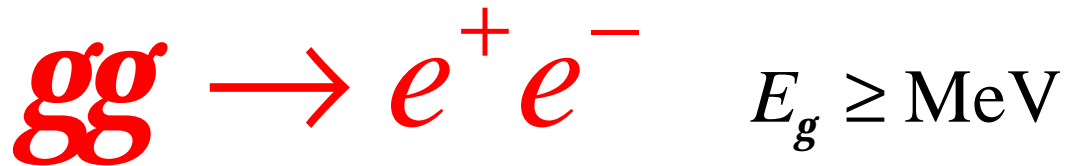
時間

Compactness 問題

$$R \approx cdT \approx 10^8 (dT/10\text{ms}) \text{cm}$$



$$E \approx FD^2 \approx 10^{49} F_{-7} D_{28} \text{erg}$$

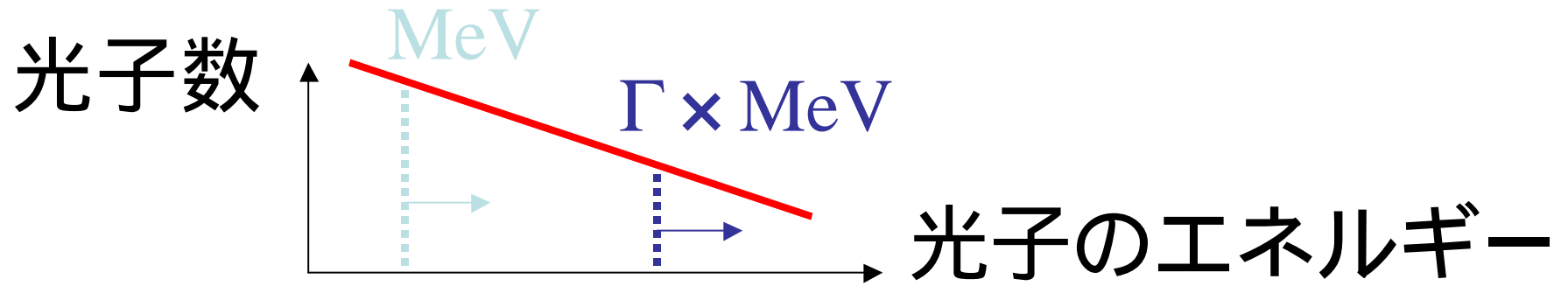


$$t_{gg} : \mathbf{s}_T \frac{FD^2}{R^3 m_e c^2} R : 10^{13} \left(\frac{F}{10^{-7} \text{erg cm}^{-2}} \right) \left(\frac{D}{3\text{Gpc}} \right)^2 \left(\frac{dT}{10\text{ms}} \right)^{-2}$$

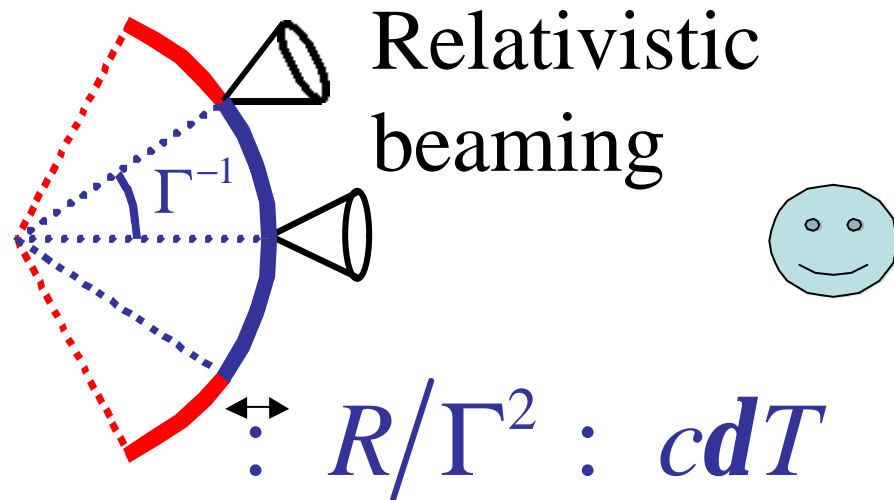
Optically thick \Leftrightarrow Non-thermal

相対論的運動

共同系でのMeV光子を減らせる



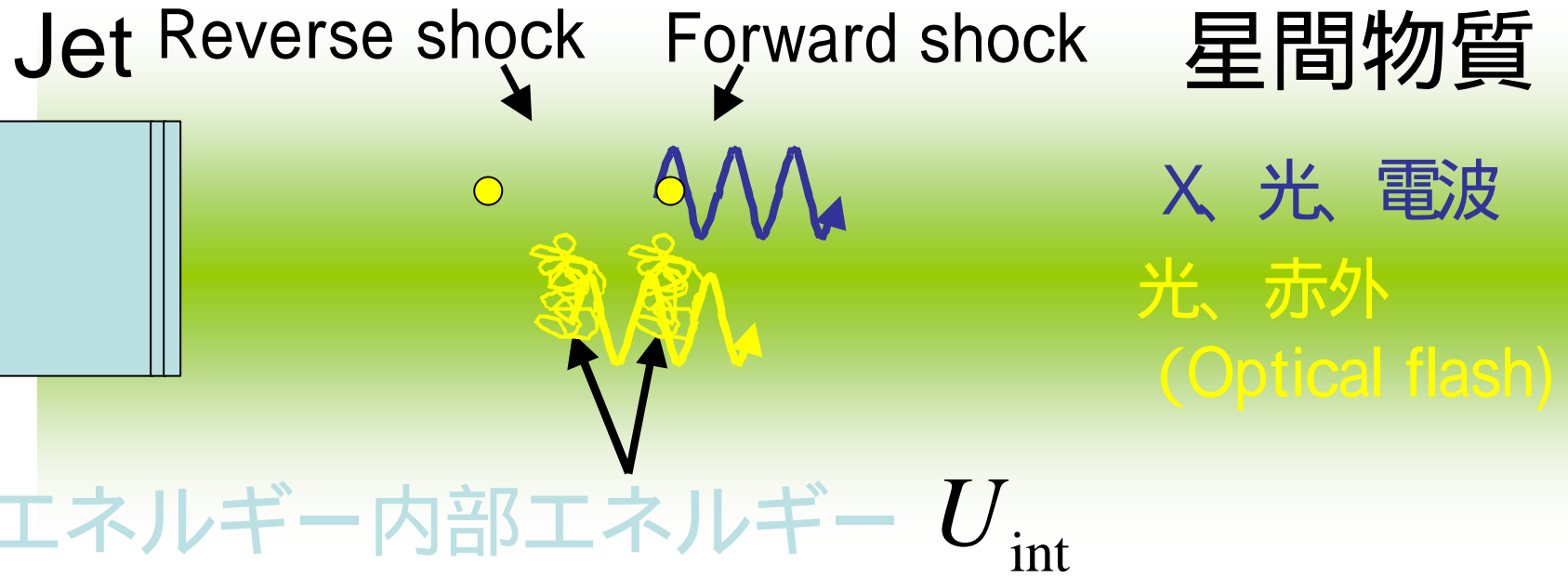
放射領域を cdT より大きく出来る



$$t_{gg} \propto \Gamma^{-4+b_B} : \Gamma^{-6.5}$$

$$\Gamma \geq 100$$

残光の標準モデル



電子のフェルミ加速

$$e_e = U_e / U_{\text{int}} : O(1), N(\mathbf{g}_e) \propto \mathbf{g}_e^{-2} (\mathbf{g}_e > 10^3 \mathbf{g})$$

磁場生成 $e_B = U_B / U_{\text{int}} : O(1)$

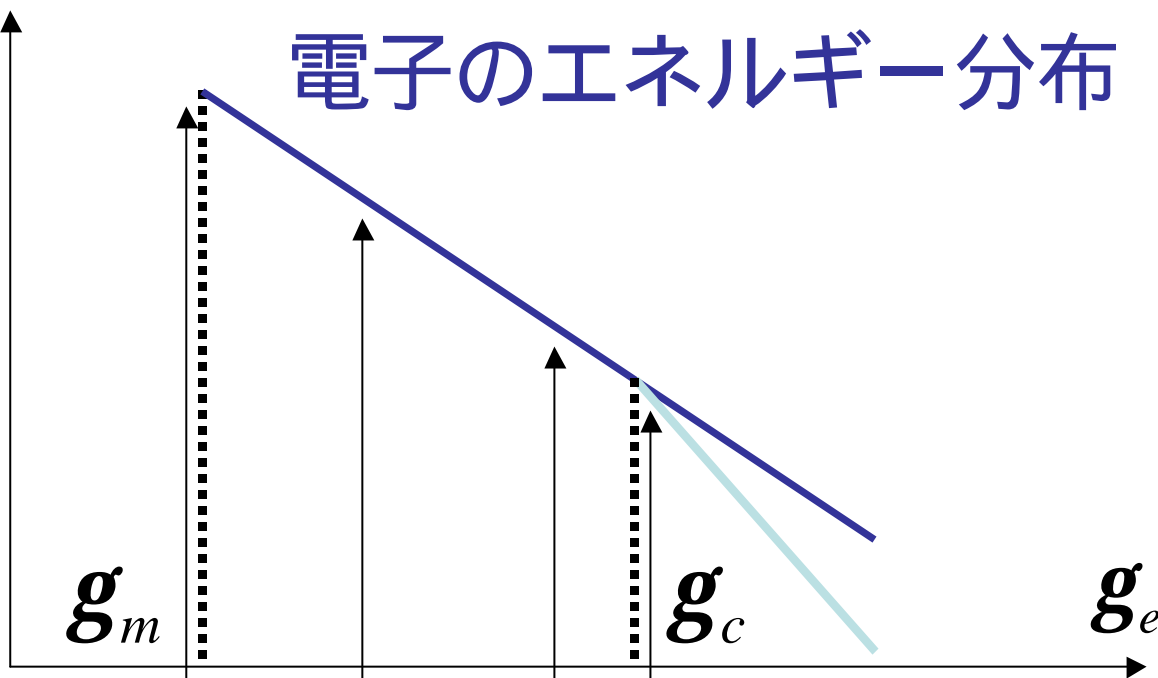
シンクロトロン放射

電子のエネルギー分布

$N(g_e)$

$$P(g_e) = \frac{4}{3} s_T c \frac{B^2}{8p} g_e^2 g^2$$

$$n(g_e) = g g_e^2 \frac{eB}{2p m_e c}$$



F_n

シンクロトロン
自己吸収

$n^{1/3}$

n_m

$n^{-(p-1)/2}$

光子の
スペクトル

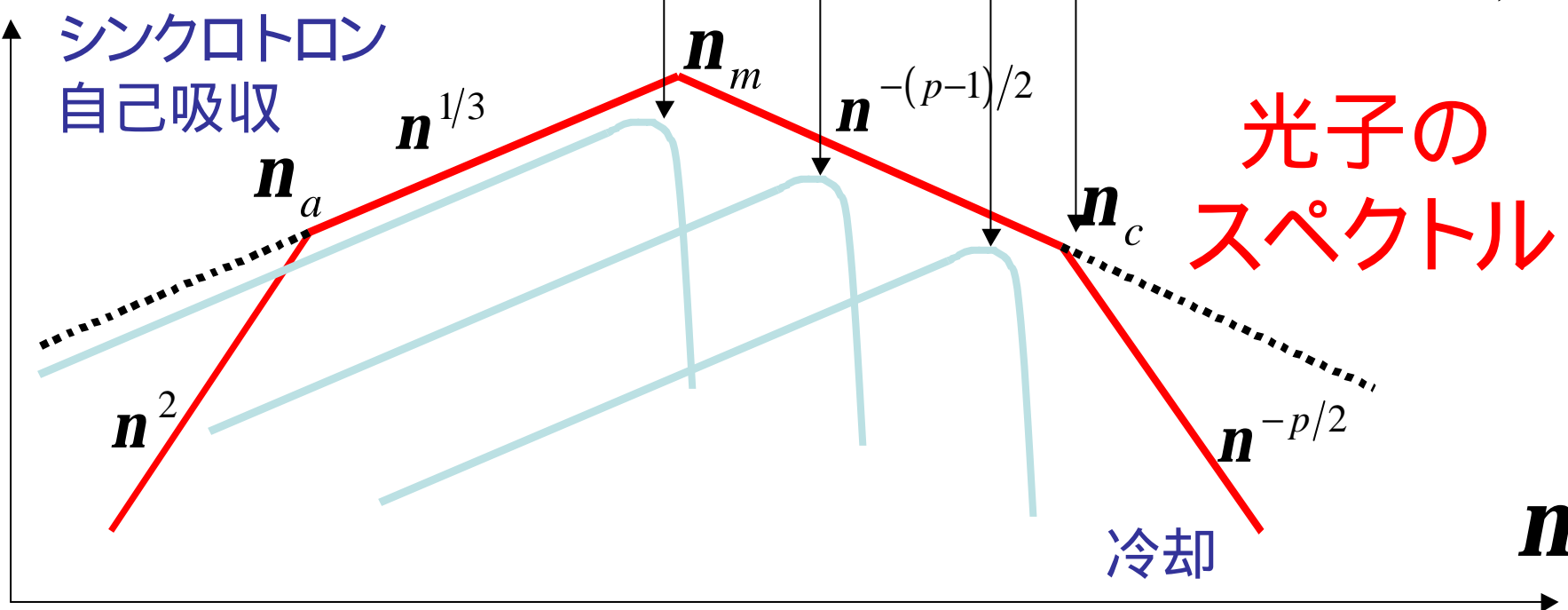
n_c

n^2

$n^{-p/2}$

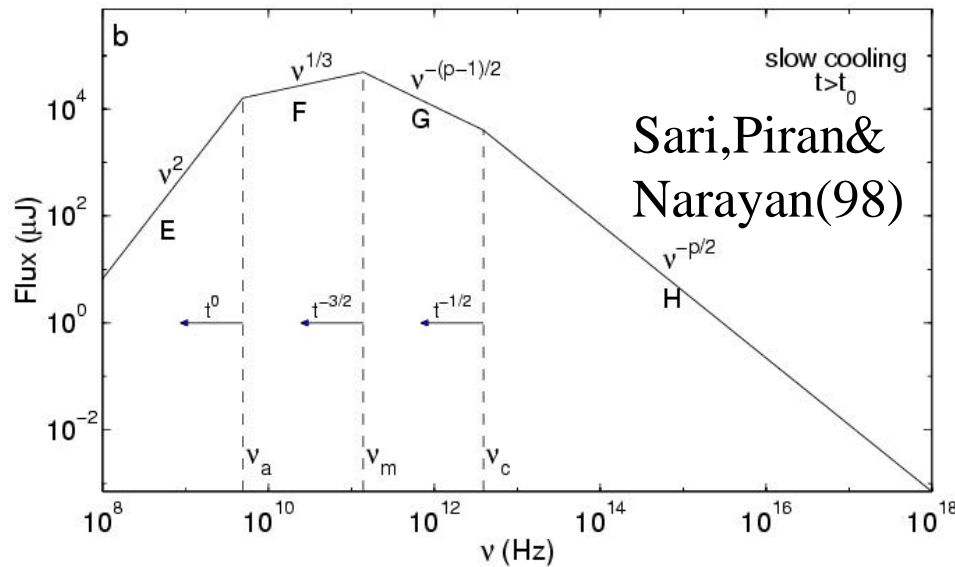
冷却

n



残光モデルの成功

シンクロトロン衝撃波モデル

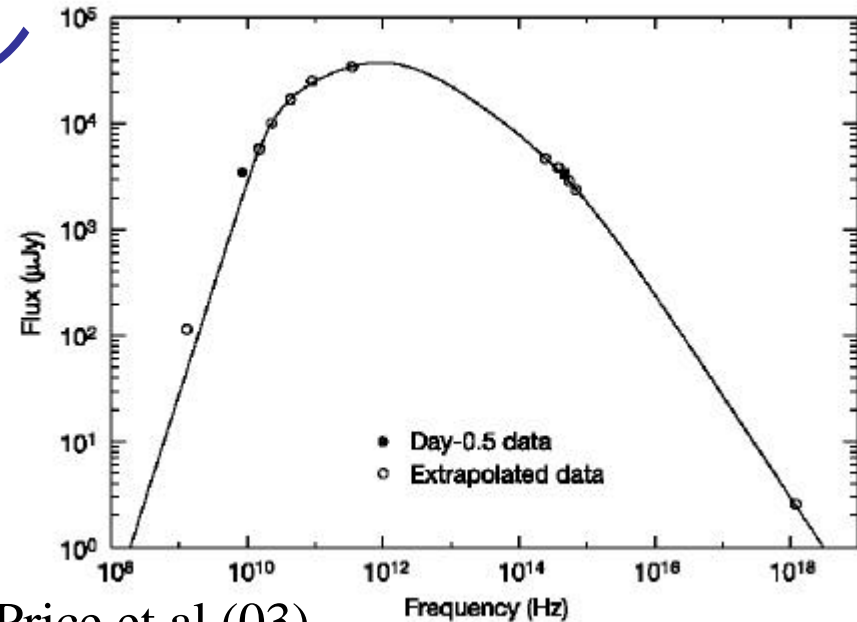


$$\{E, n, e_e, e_B\}$$



$$\{n_c, n_m, n_a, F_{n,max}\}$$

as functions of time

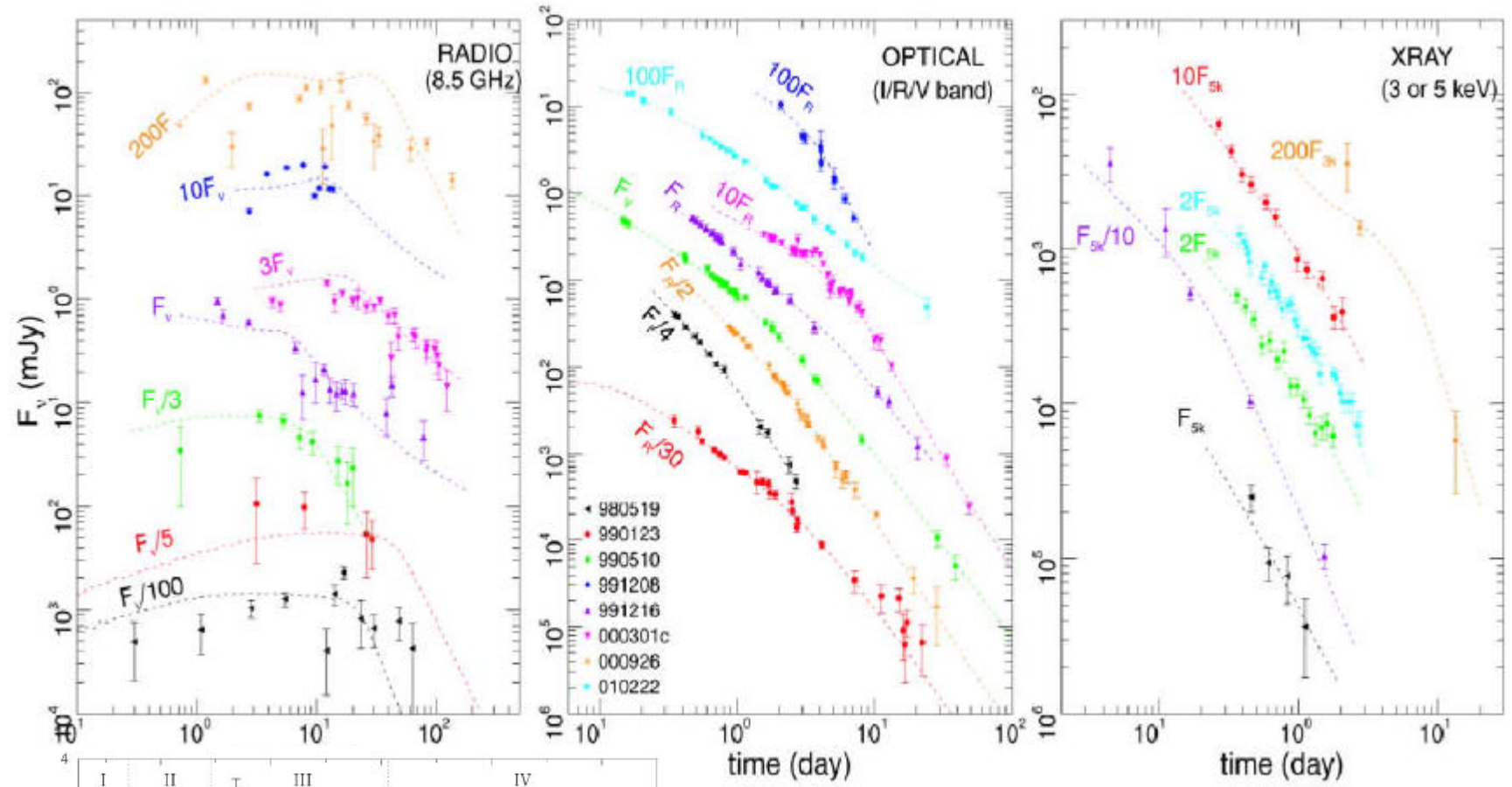


Fitting: $E : 10^{51-54}$ erg

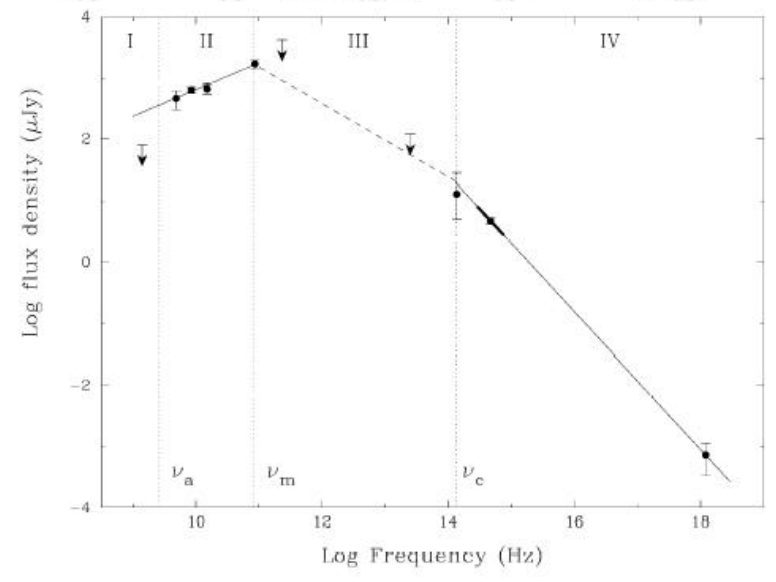
$n : 0.01-100 \text{cm}^{-3}$

$e_e : 0.1$

$e_B : 0.01$

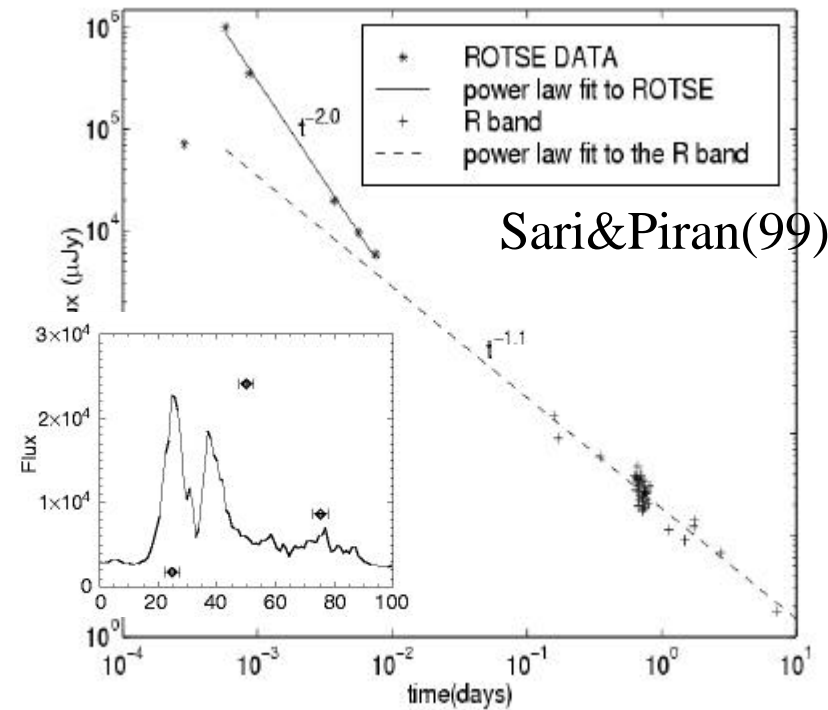
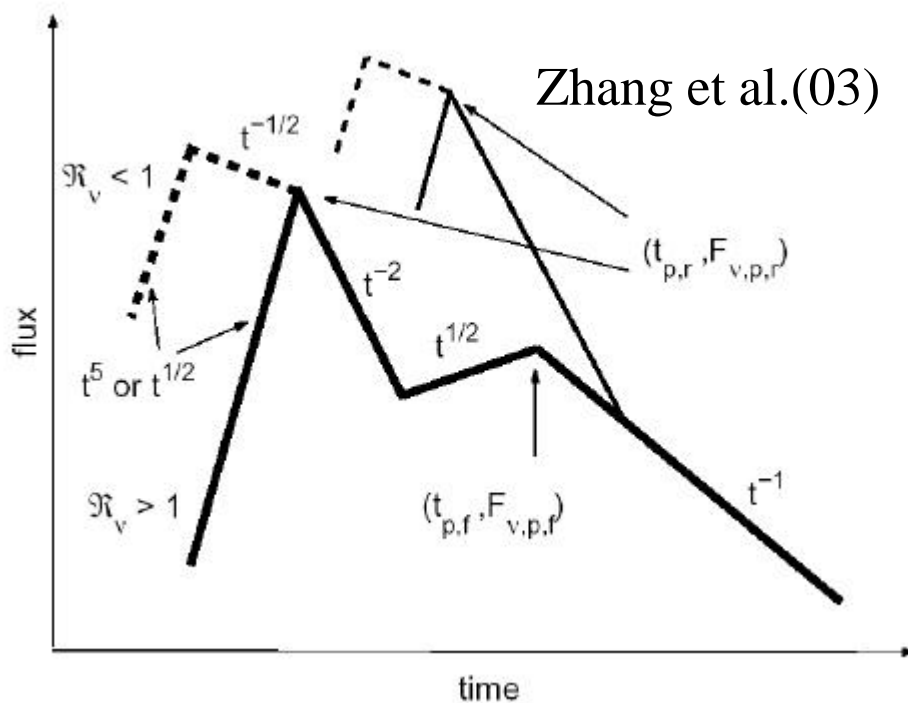
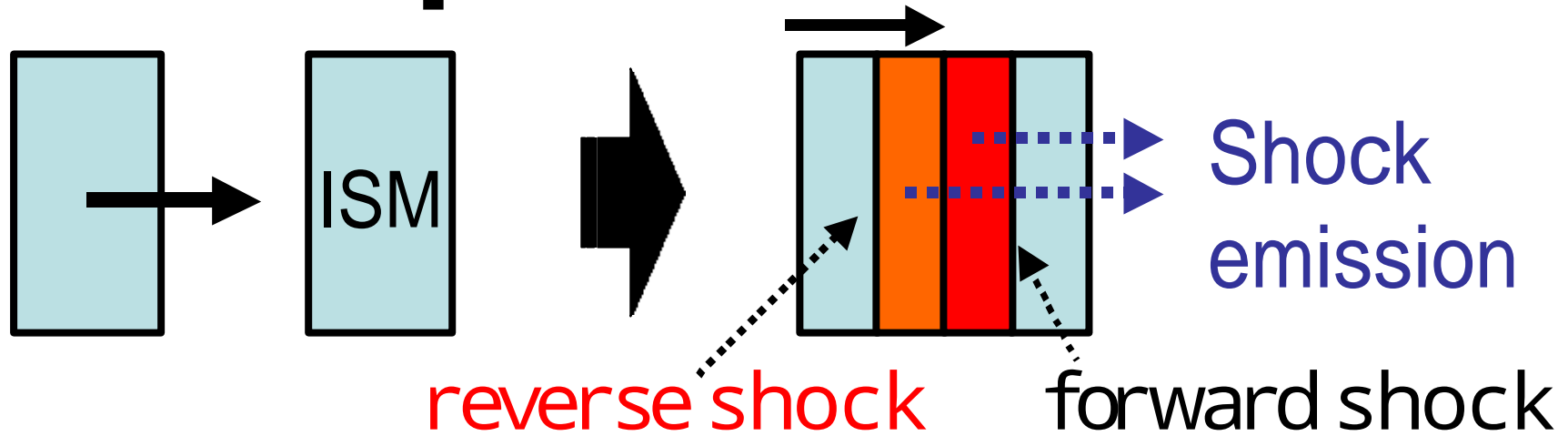


Panaitecu&Kumar(00)



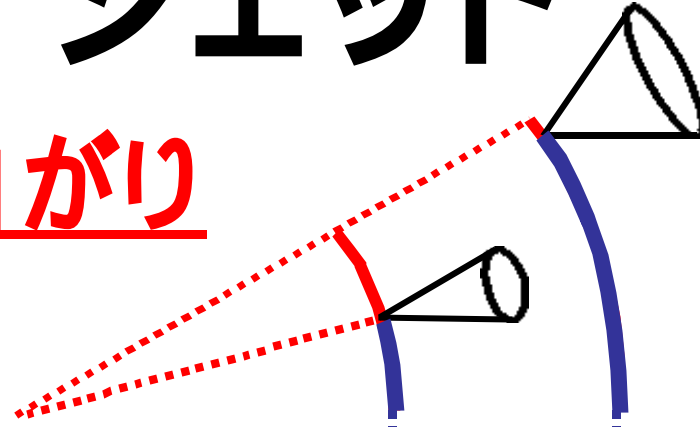
Galama et al.(98)

Optical Flash



ジェット Γ^{-1}

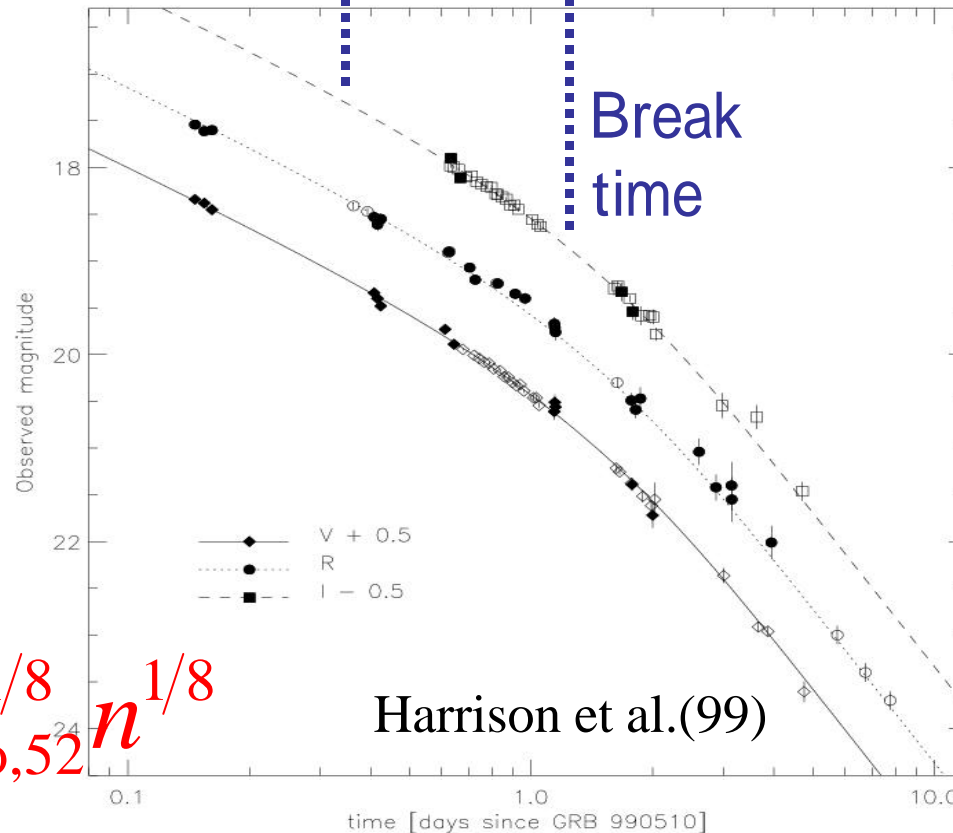
残光の折れ曲がり



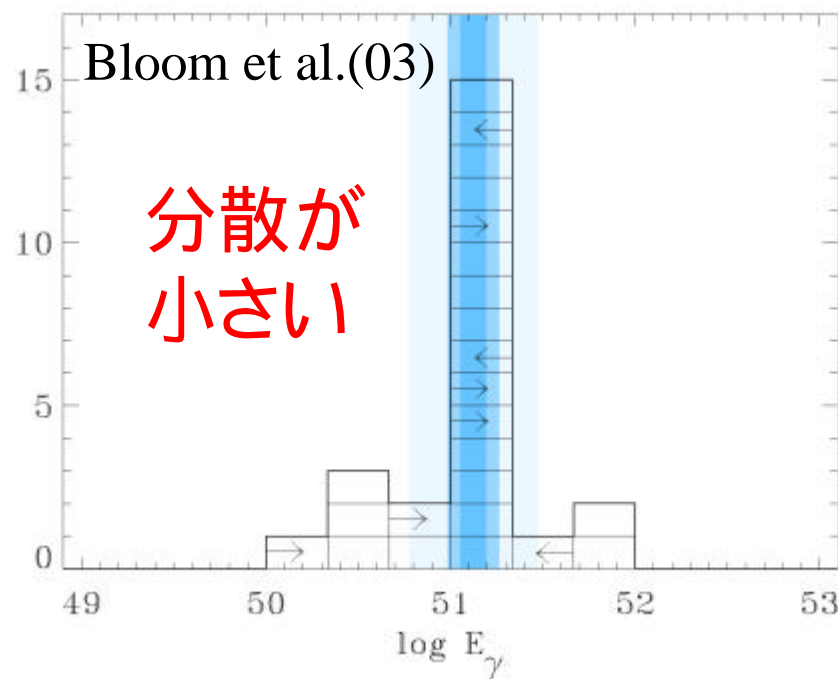
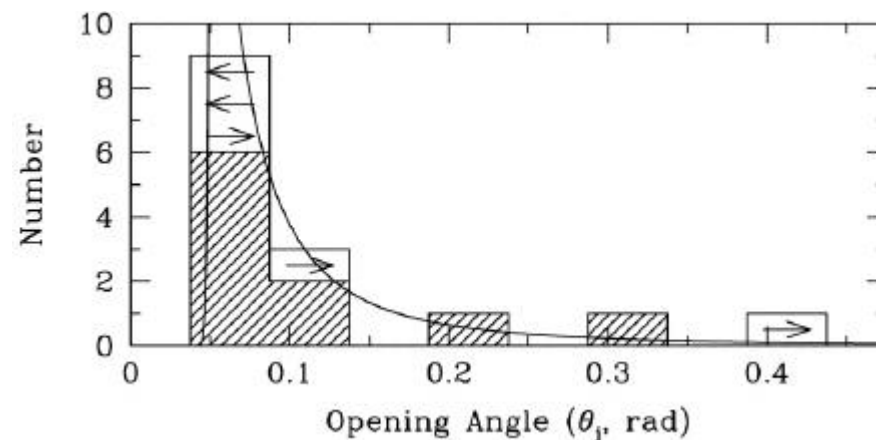
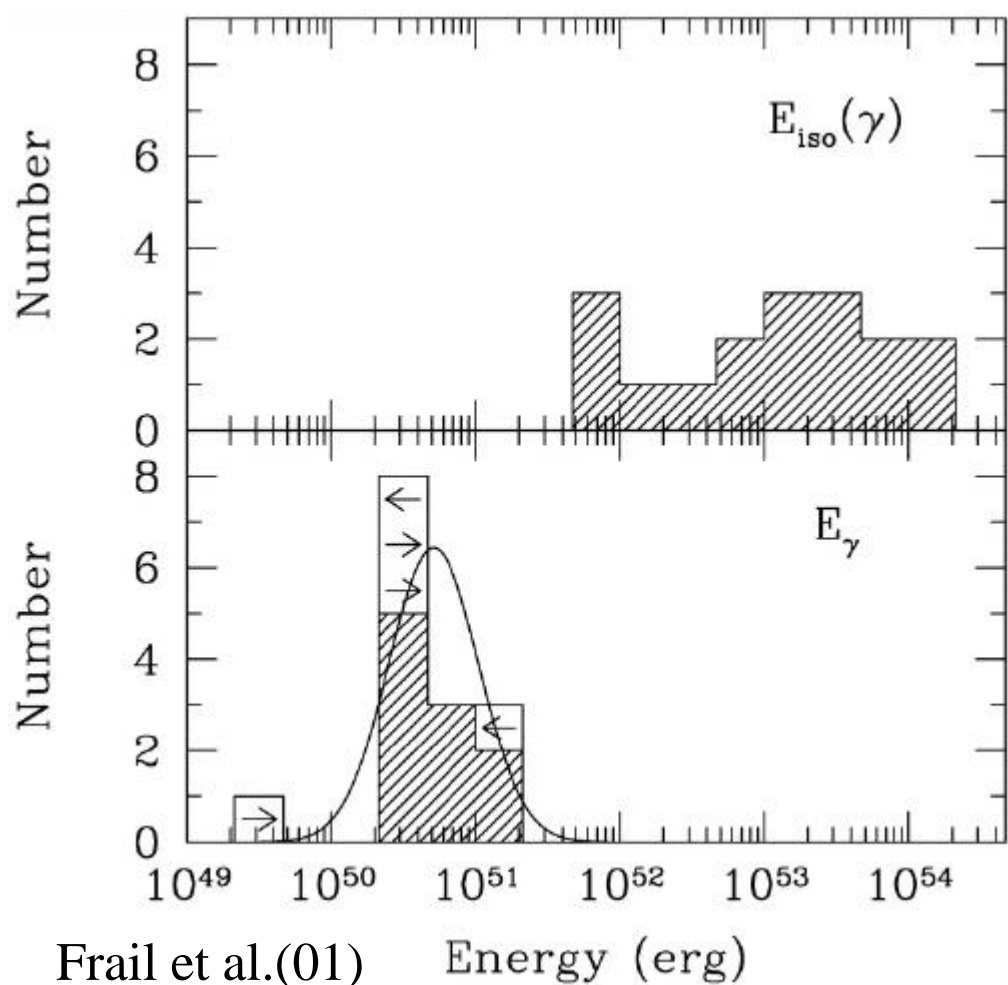
残光は $\theta \sim \Gamma^{-1}$
で折れ曲がる

折れ曲がる時間
ジェットの広角

$$q : 0.057 t_{\text{day}}^{3/8} E_{\text{iso},52}^{-1/8} n^{1/8}$$

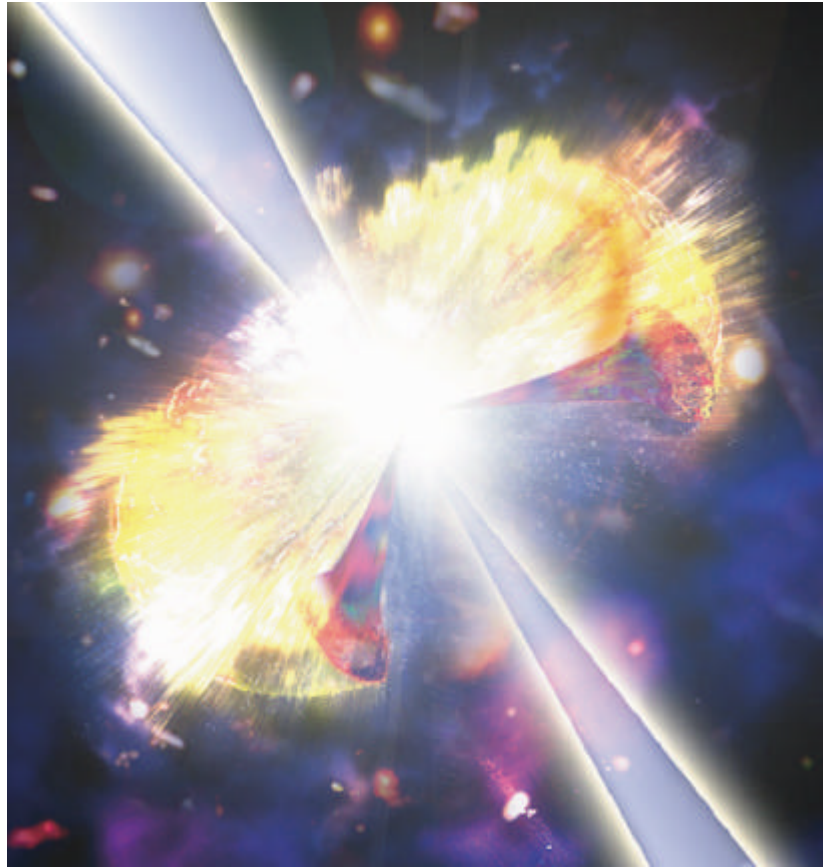


全エネルギーは一定？

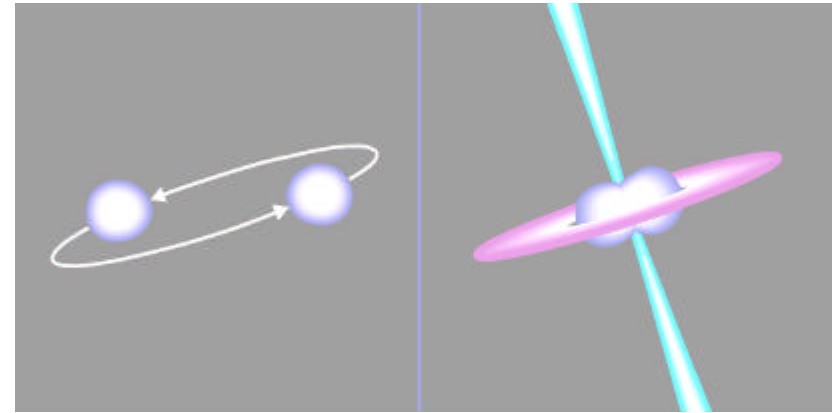


$$E_g \approx E_{\text{iso}} q^2 \approx 10^{51} \text{ erg}$$

起源は重い星の崩壊？



重い星の崩壊
(Hypernova, Collapsar)



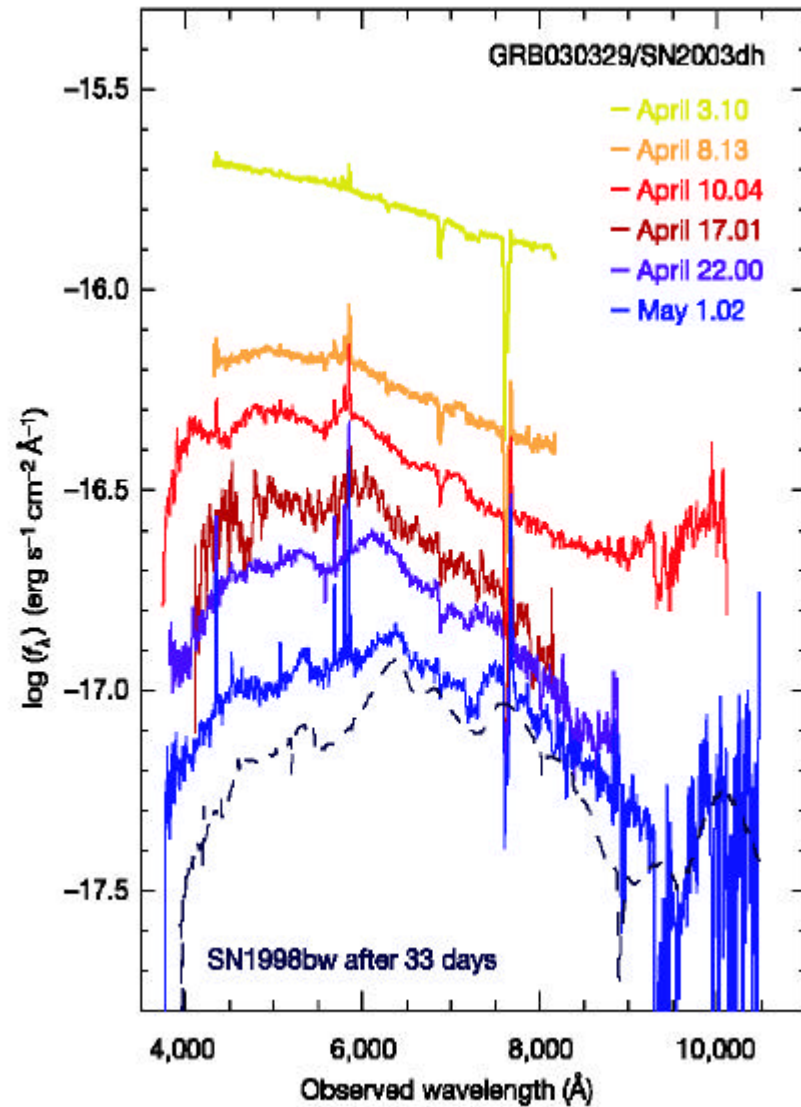
連星中性子星の合体

$$R_{\text{lbc}} \sim 6 \times 10^4 \text{ Gpc}^{-3}\text{yr}^{-1}$$

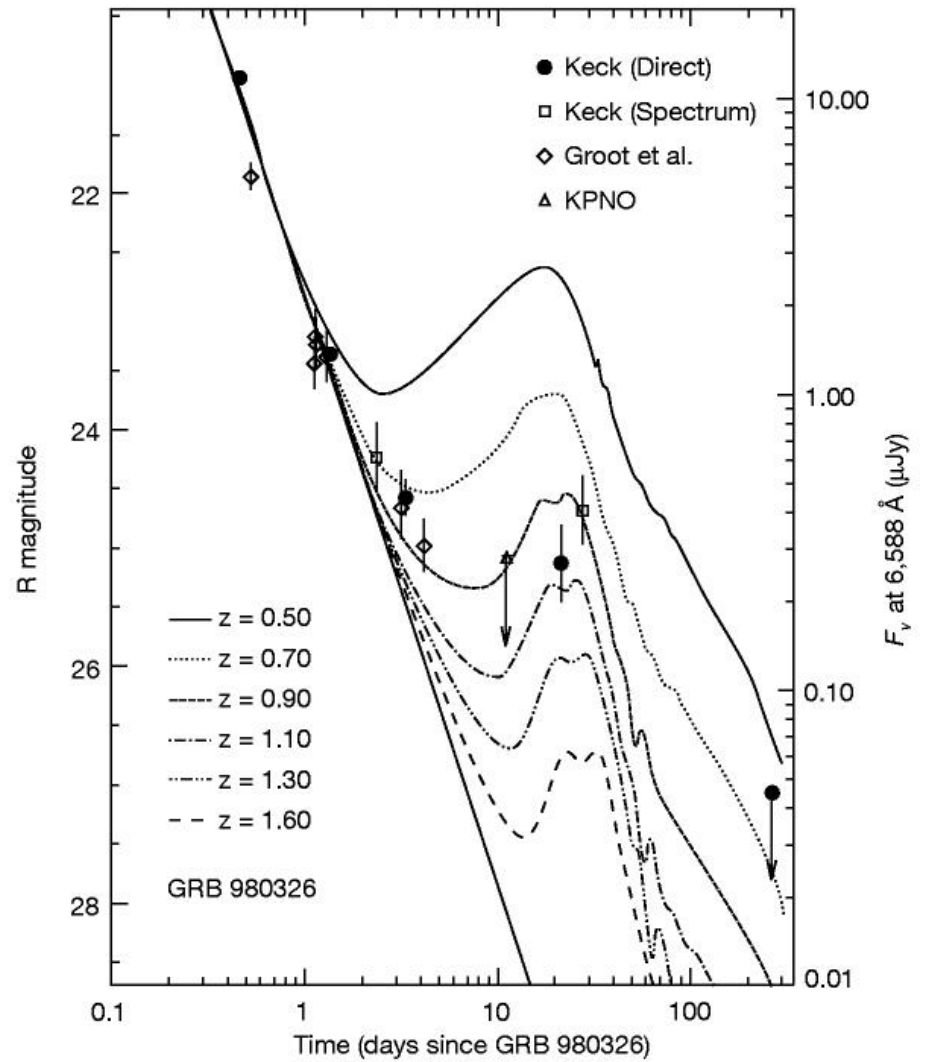
$$R_{\text{m}} \sim 80 \text{ Gpc}^{-3}\text{yr}^{-1} (\times 7)$$

$$R_{\text{GRB}} \sim 0.5(250) \text{ Gpc}^{-3}\text{yr}^{-1}$$

残光中の超新星



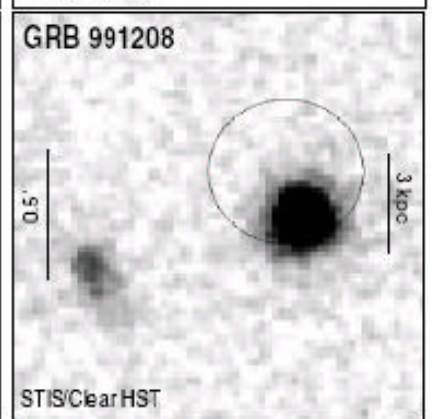
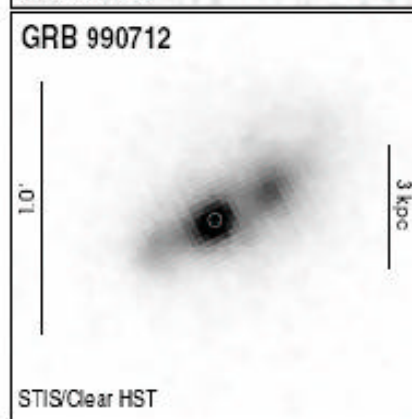
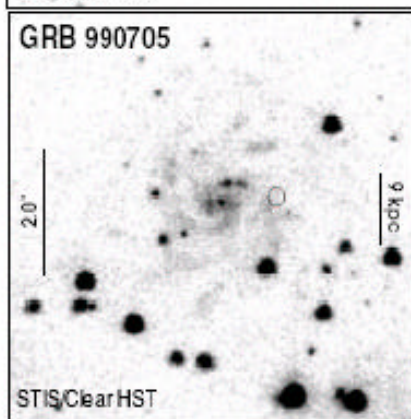
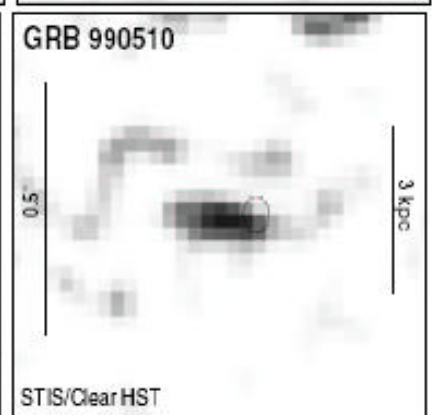
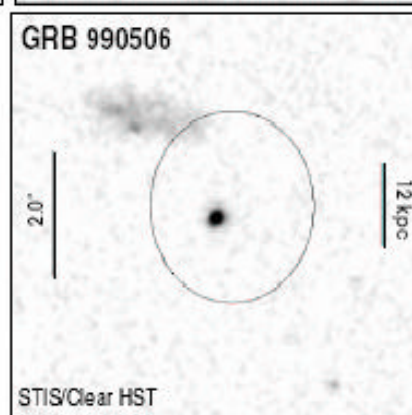
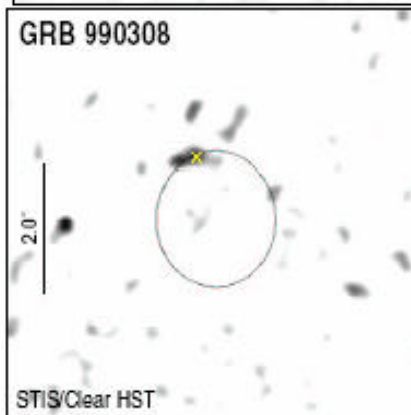
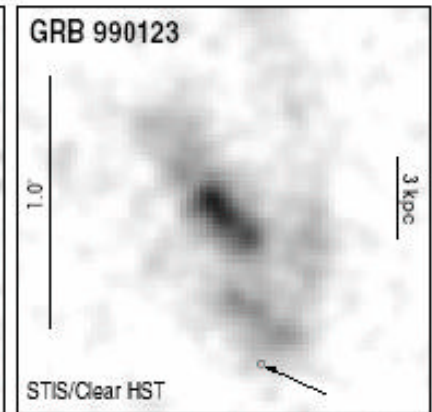
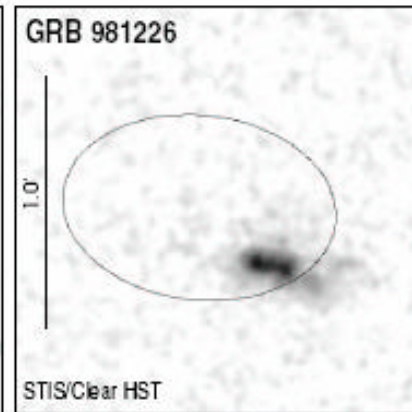
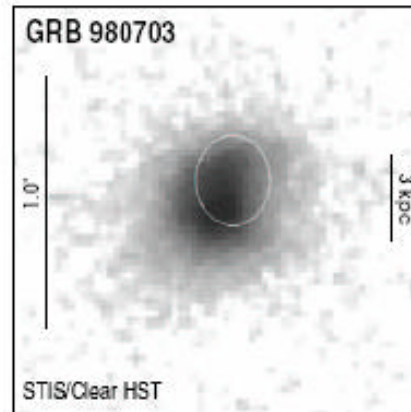
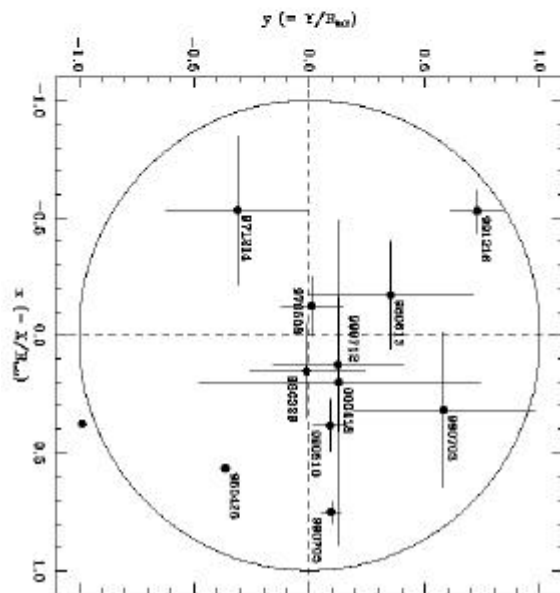
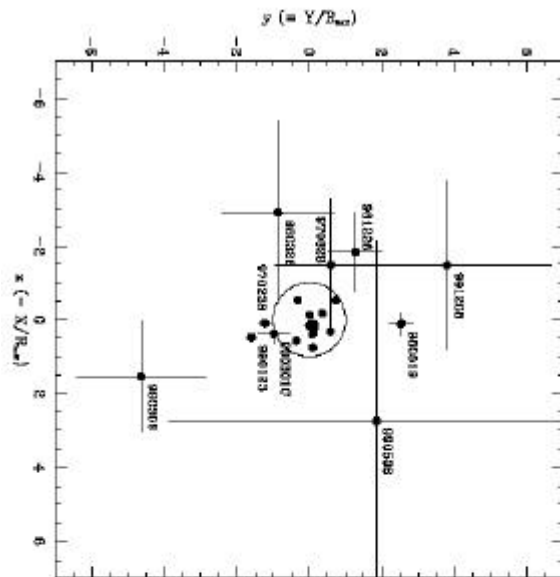
Hjorth et al.(03)



Bloom et al.(99)

母銀河中での位置

Bloom, Kulkarni & Djorgovski (02)



標準的な理解

1. 宇宙論的距離 (Long GRBs)
2. 相対論的ジェット¹の放出: $\Gamma > 100$
3. 内部衝撃波: GRB (?)
4. 外部衝撃波: 残光
5. シンクロトロン衝撃波モデルの成功
6. 全エネルギーは一定 (?)
7. 重い星の崩壊が起源

しかし、、

未解決問題

1. ジェットの加速機構は？
 2. GRBのジェットの構造は？
 3. 宇宙論的道具として？
 4. 他の放射は？ : UHECR, $HE\nu$, $HE\gamma$, GW
 5. Short GRBは何か？
 6. GRBの放射はシンクロトロン放射か？
 7. 無衝突ショックの物理は？
 8. GRBの周りの環境は？
- 、、、 などなど

偏光

加速機構

シンクロトロン放射

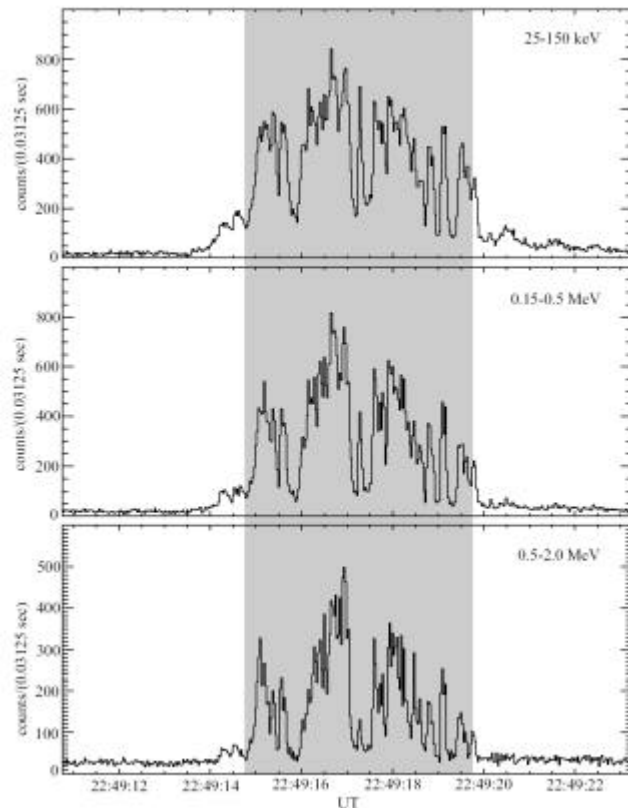
ジェット

ガンマ線偏光

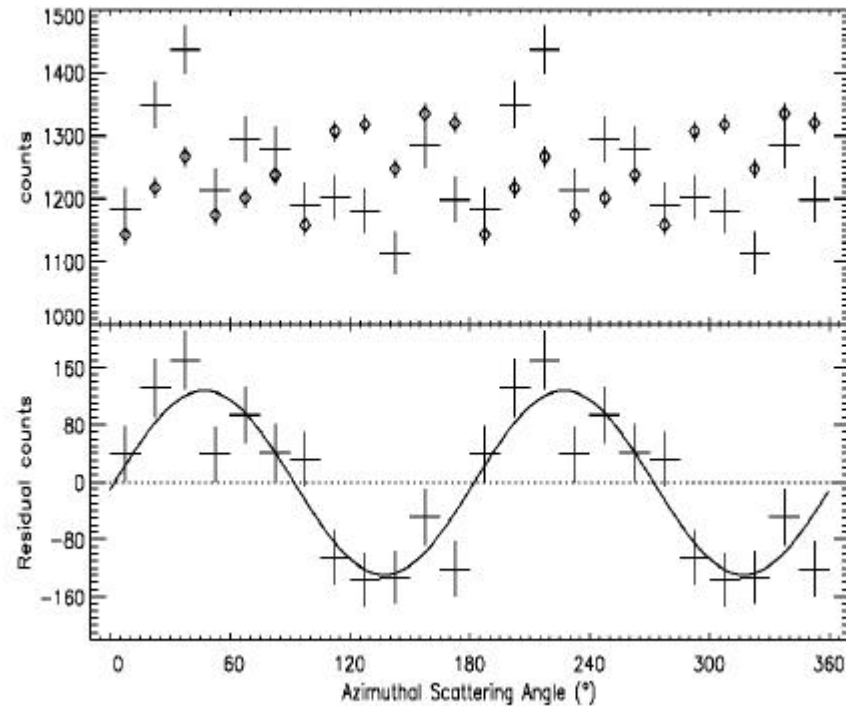
$$\Pi_{\gamma} = 80 \pm 20\% !!$$

RHESSI (3keV-17MeV)

GRB021206

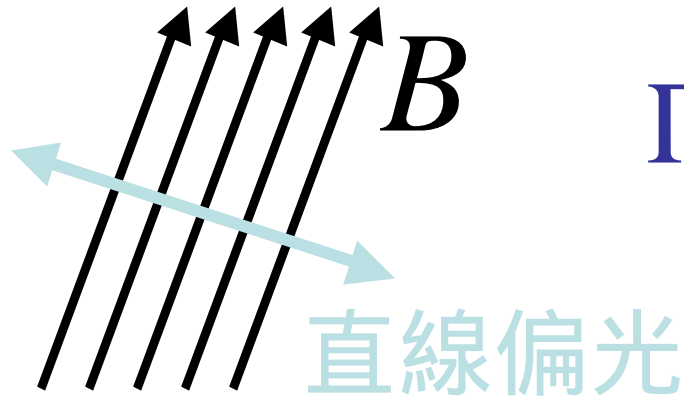


Coburn&Boggs(03)



注: $\Pi_{\gamma} < 4.1\%$ (Rutledge&Fox 03)

一樣磁場？

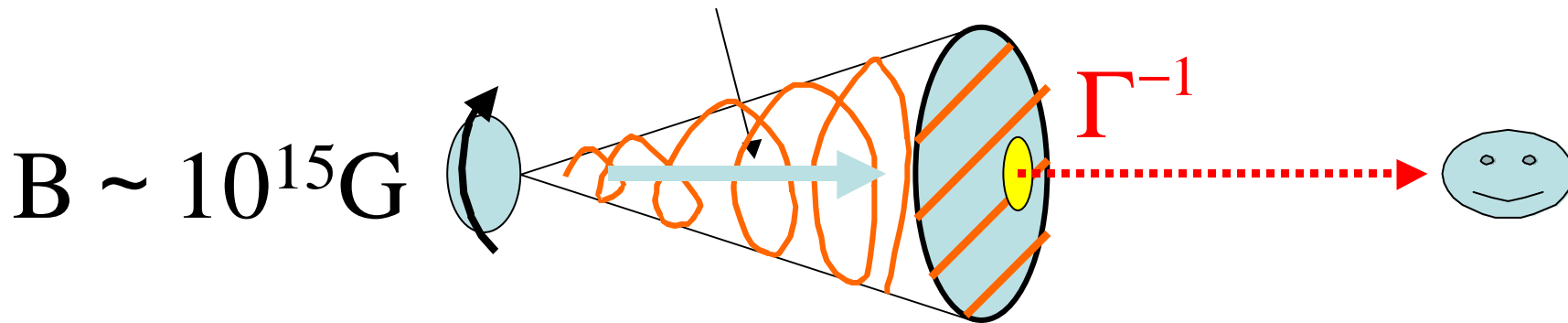


$$\Pi_{\max} = \frac{p+1}{p+7/3} ; 70\%$$

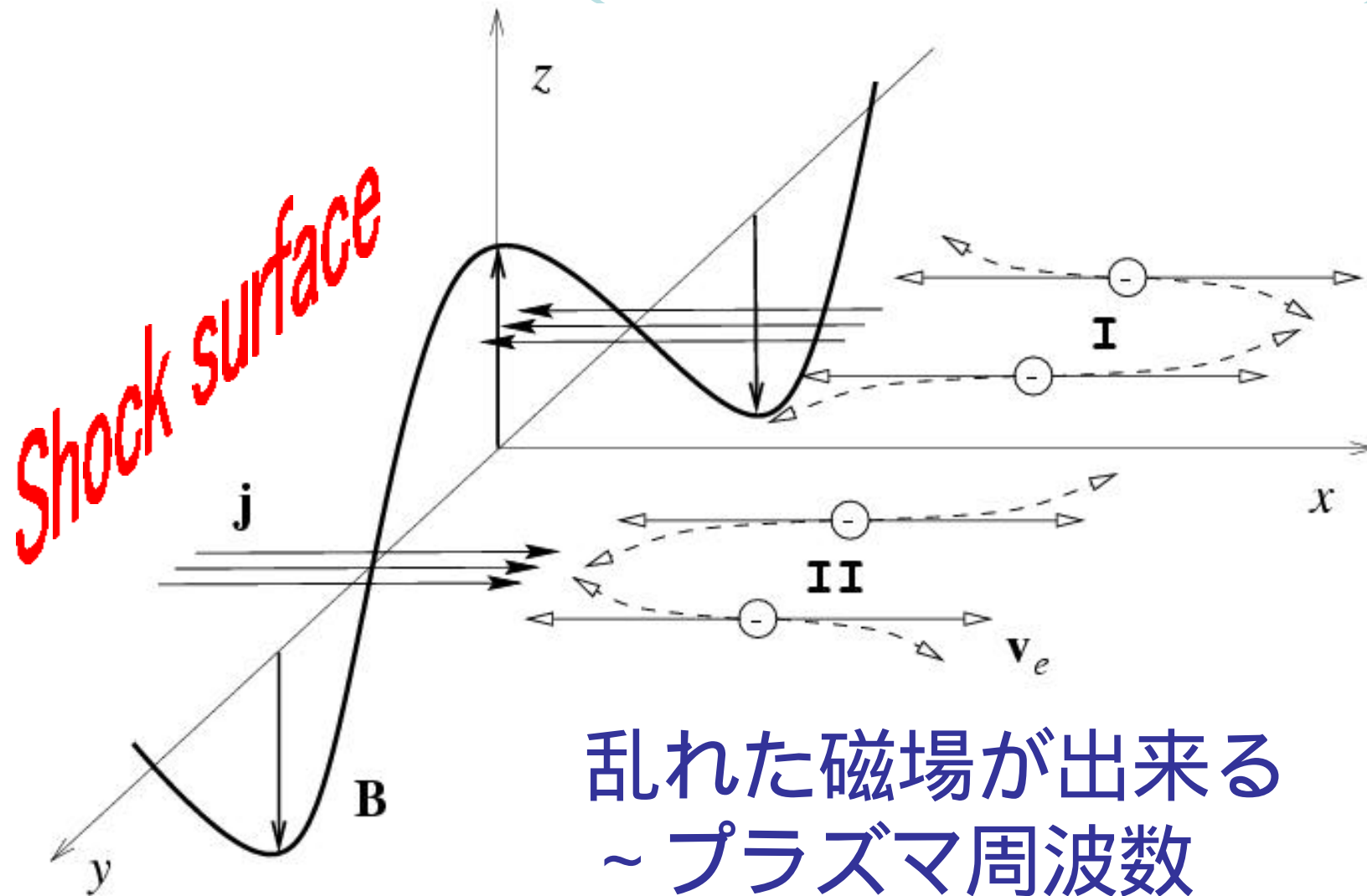
$$N_e(\mathbf{g}_e) d\mathbf{g}_e \propto \mathbf{g}_e^{-p} d\mathbf{g}_e$$

理論的最大値 大規模一樣磁場

磁場による加速？



Weibel不安定性 (プラズマの不安定性)



乱れた磁場が出来る
~ プラズマ周波数

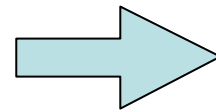
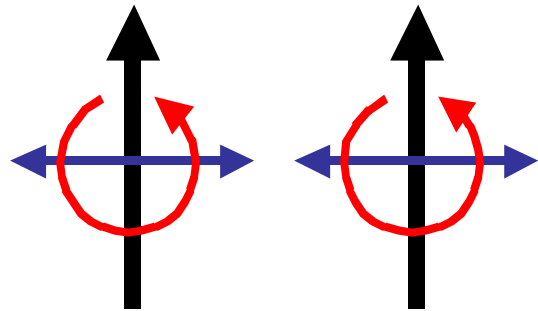
Medvedev&Loeb(99)

FIG. 1.— Illustration of the instability. A magnetic field perturbation deflects electron motion along the x -axis, and results in current sheets (j) of opposite signs in regions I and II, which in turn amplify the perturbation. The amplified field lies in the plane perpendicular to the original electron motion.

円偏光

Matsumiya&Ioka(03)

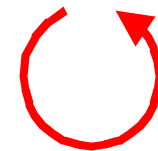
一様磁場



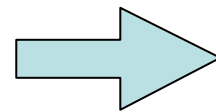
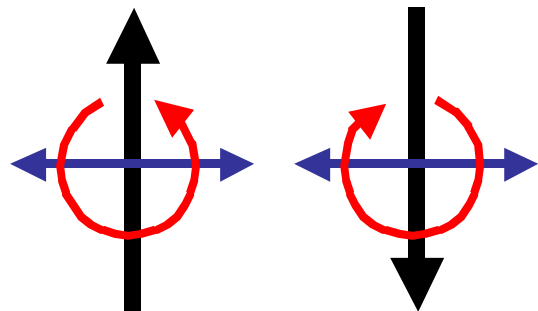
全直線偏光



全円偏光



乱れた磁場



0

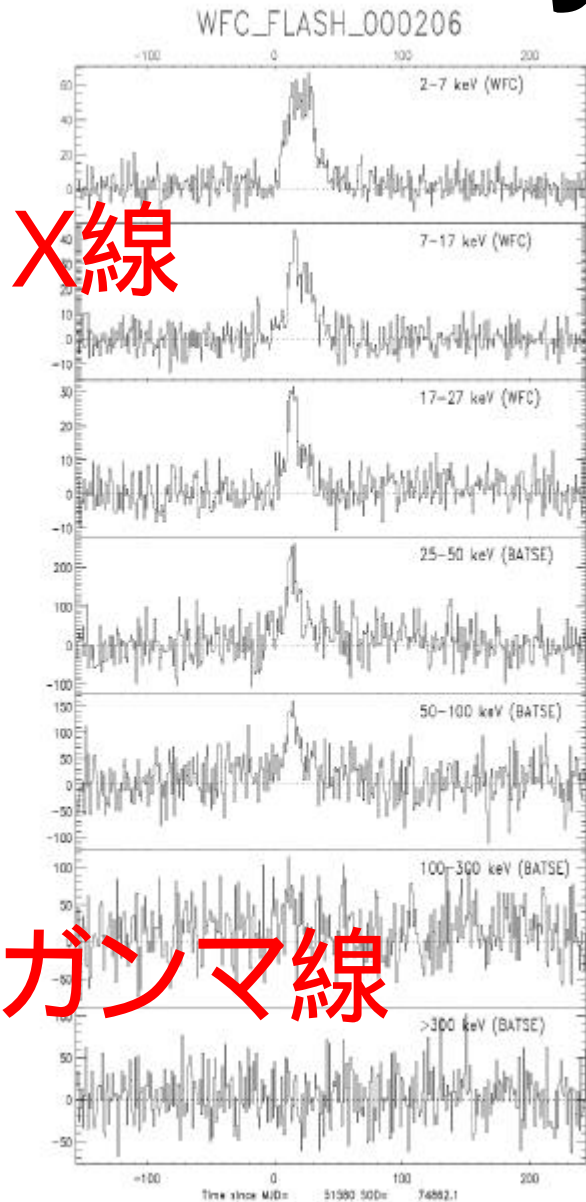
円偏光の観測

一様磁場の証拠！

X線フラッシュ

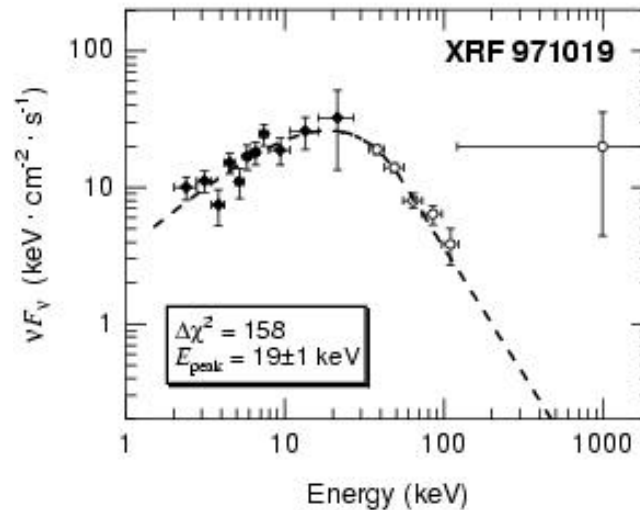
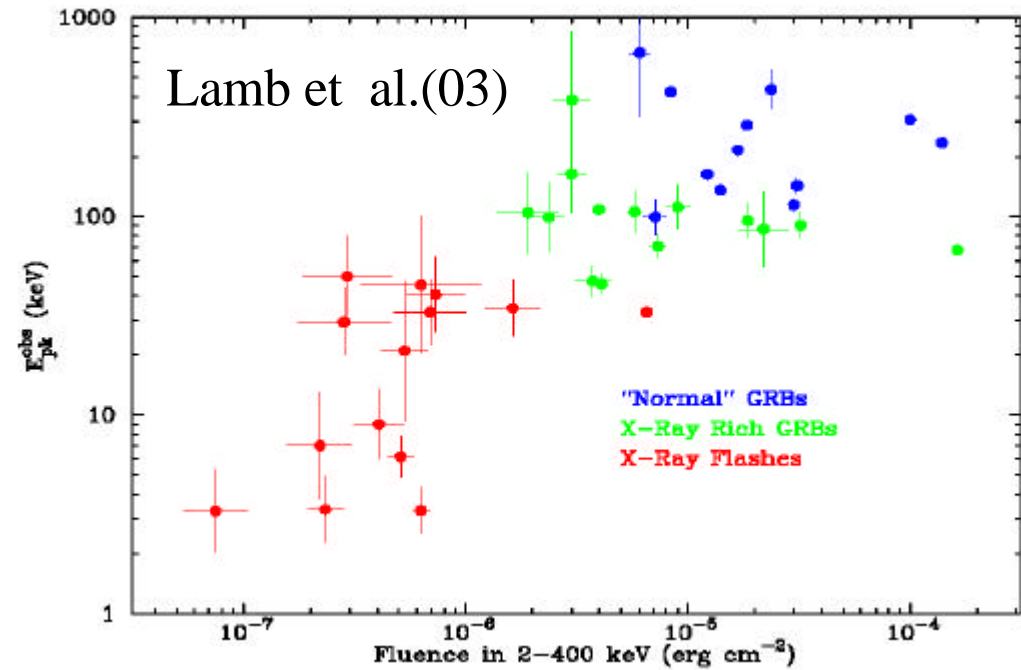
新たなバースト天体
ジェットの構造

X-Ray Flash (XRF)



X線

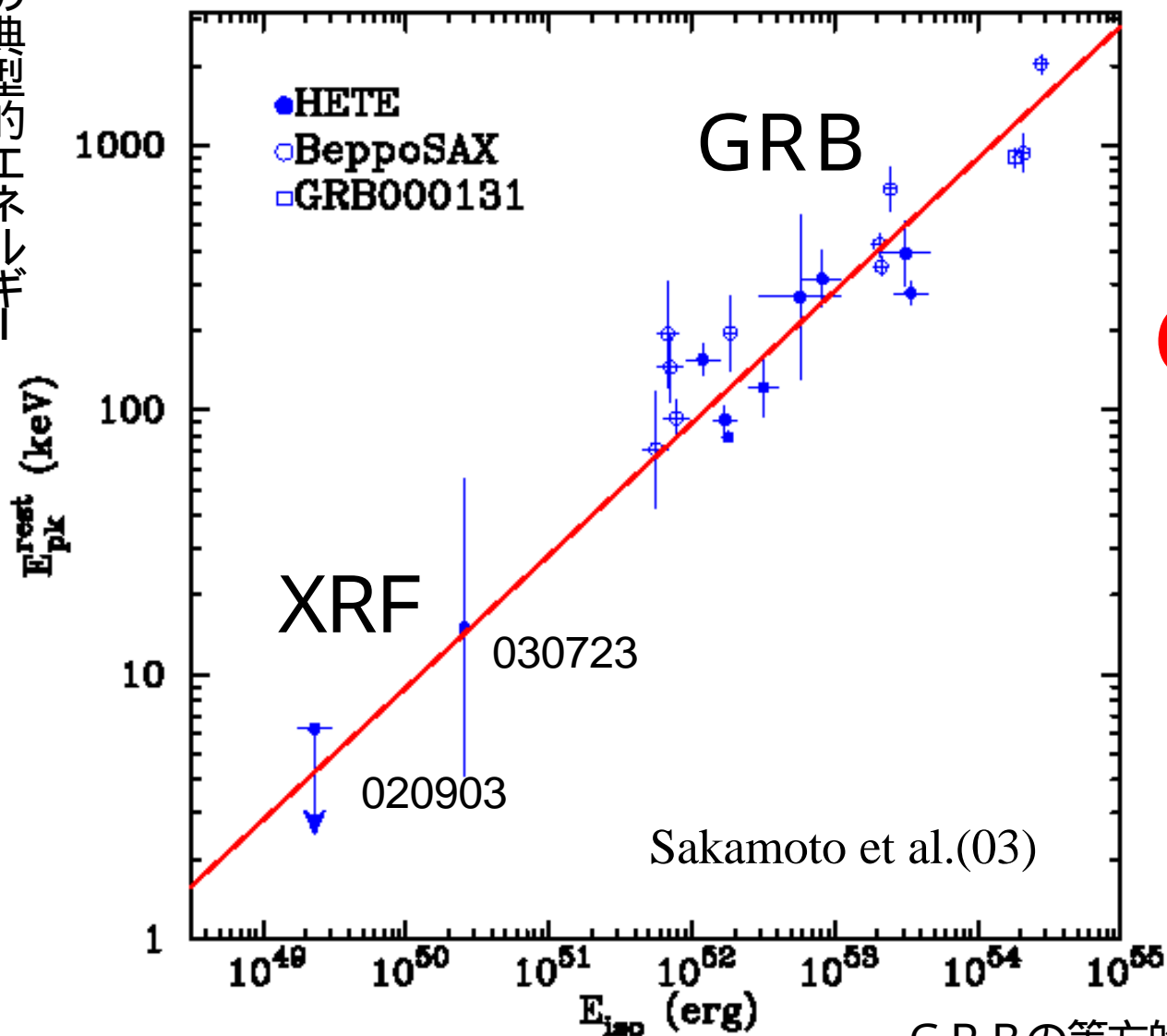
ガンマ線



XRF ~ GRB
except for
small E_{peak}
& fluence

$E_{\text{iso}} - E_{\text{peak}}$ 相関

光子の典型的エネルギー

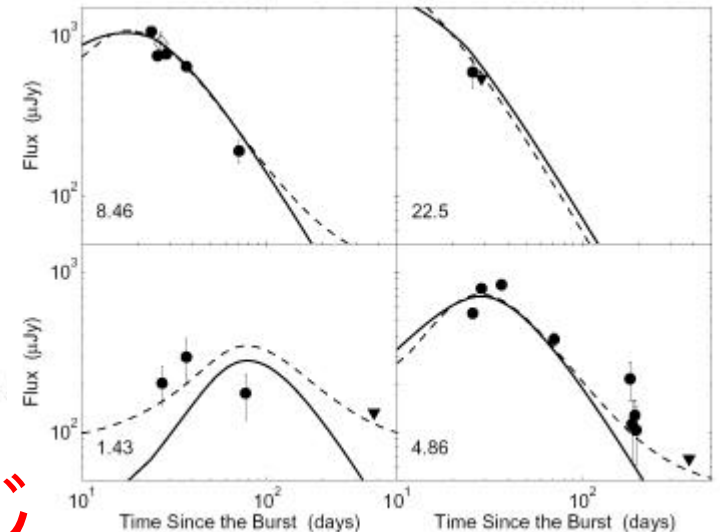
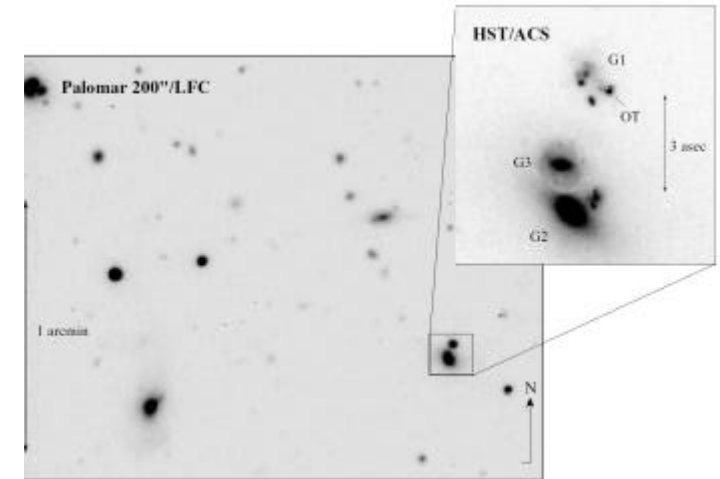
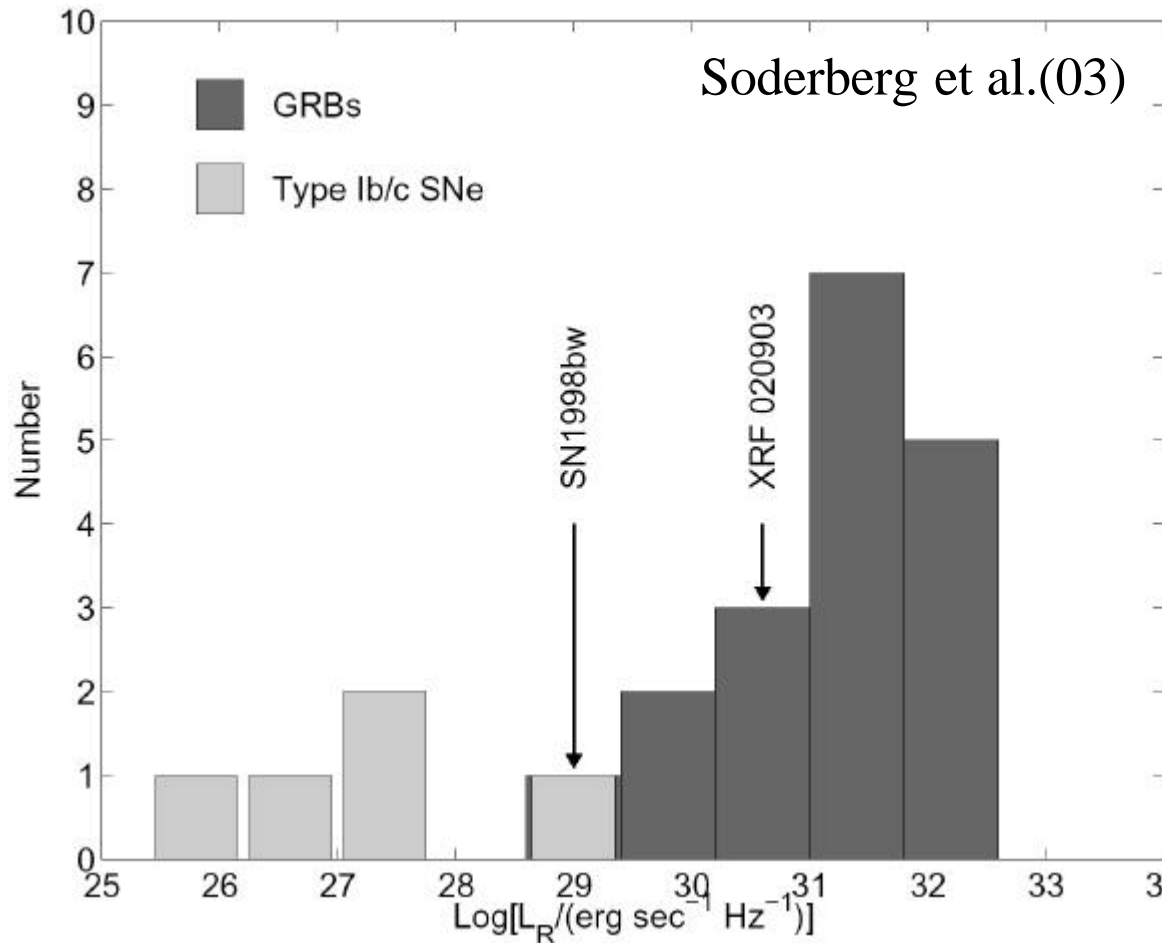


GRB ~ XRF

GRBの等方的エネルギー

XRFの全エネルギー

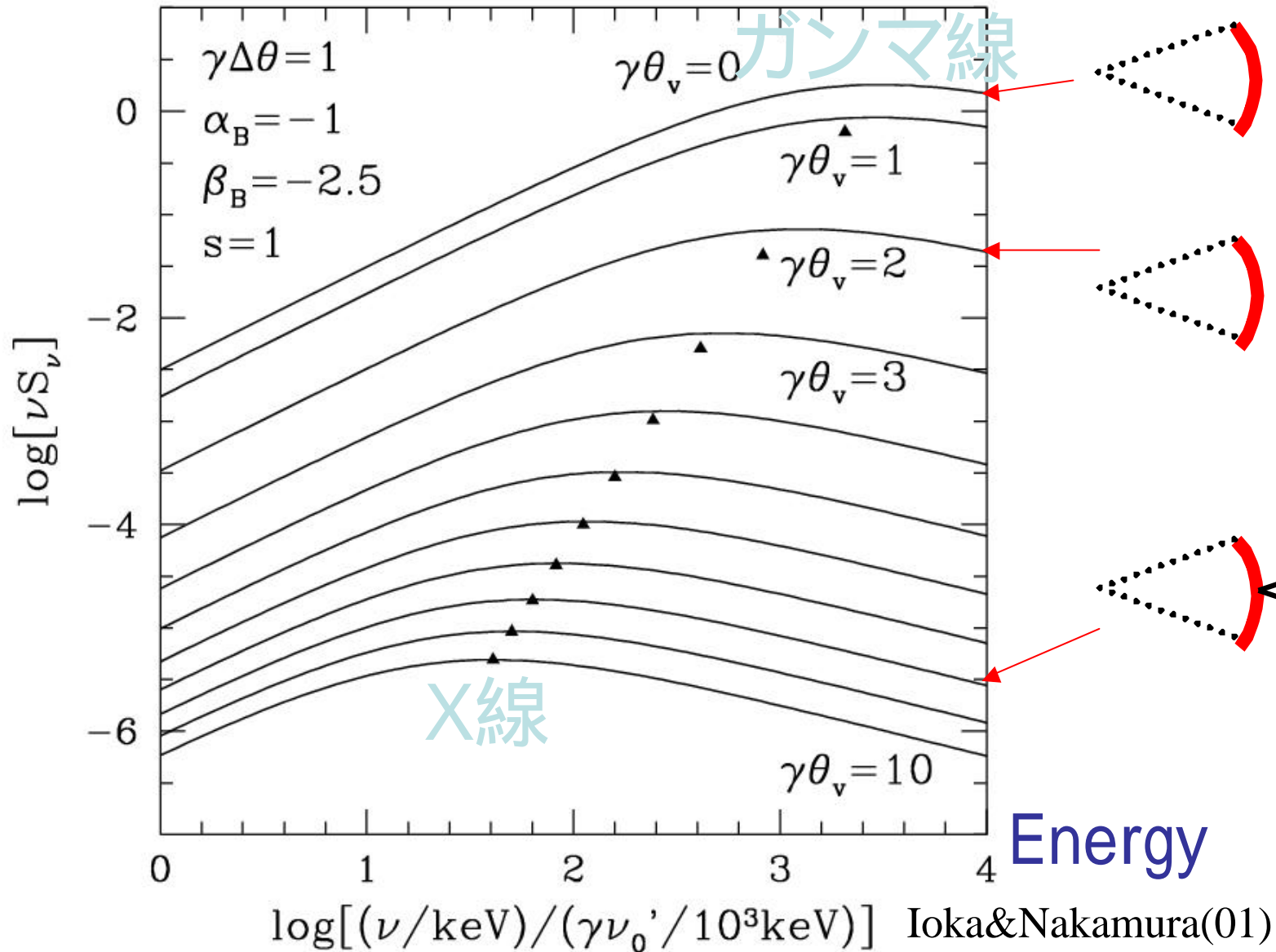
現在分かっているXRFの赤方偏移は1つ



全エネルギーはGRBとほぼ同じ

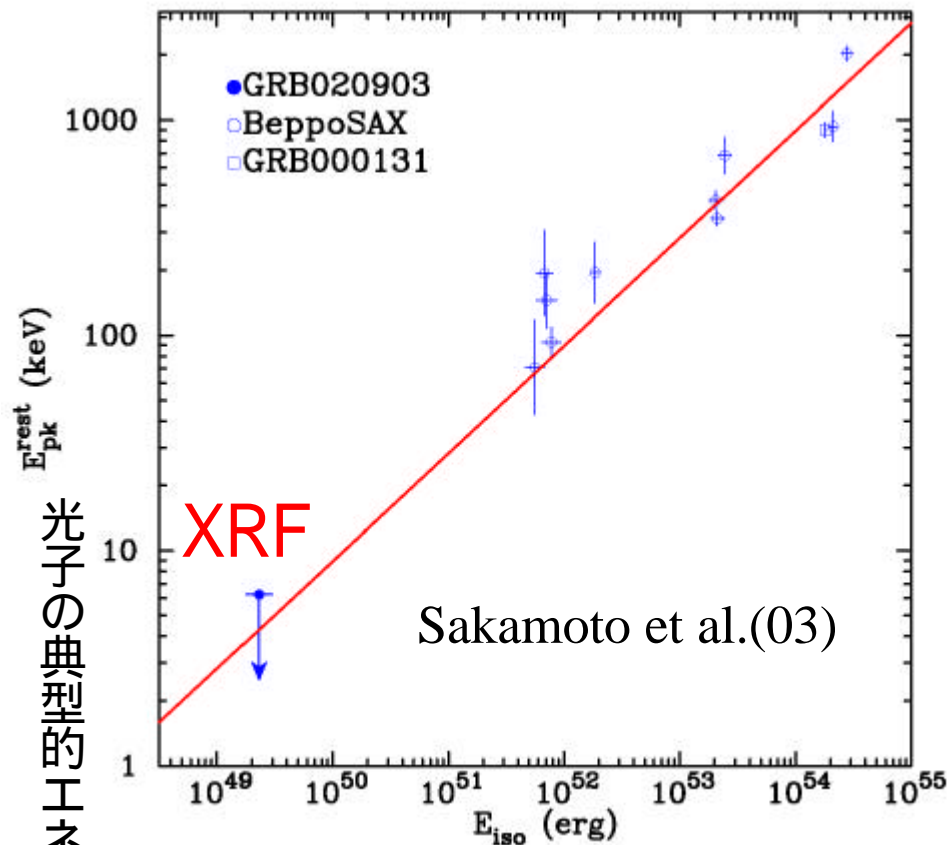
Off-Axis GRB

Fluence



$E_{\text{iso}} - E_{\text{peak}}$ 相関

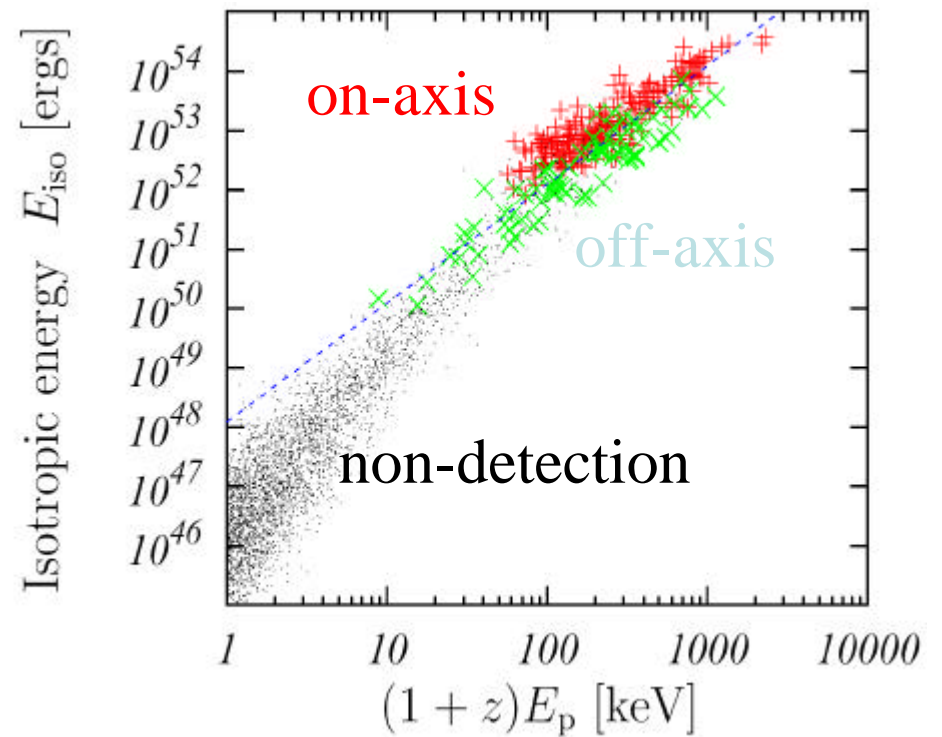
Observation



光子の典型的エネルギー

GRBの等方的エネルギー

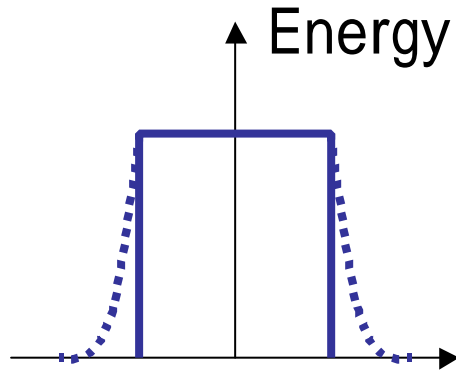
Simulation



Yamazaki, Ioka & Nakamura (04)

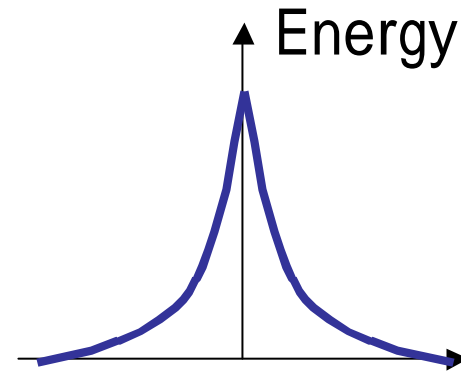
ジェットの構造

Uniform jet



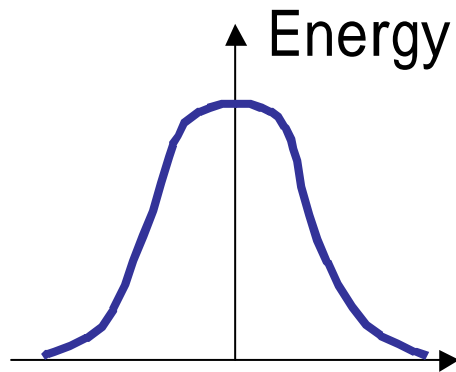
Viewing angle

Power law jet



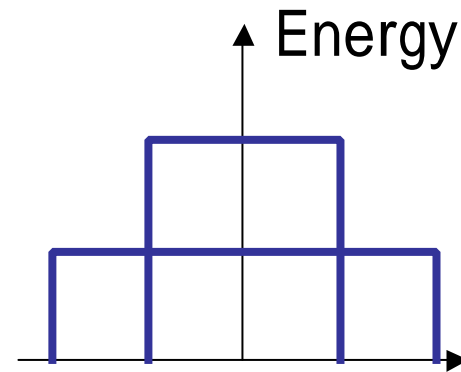
Viewing angle

Gaussian jet



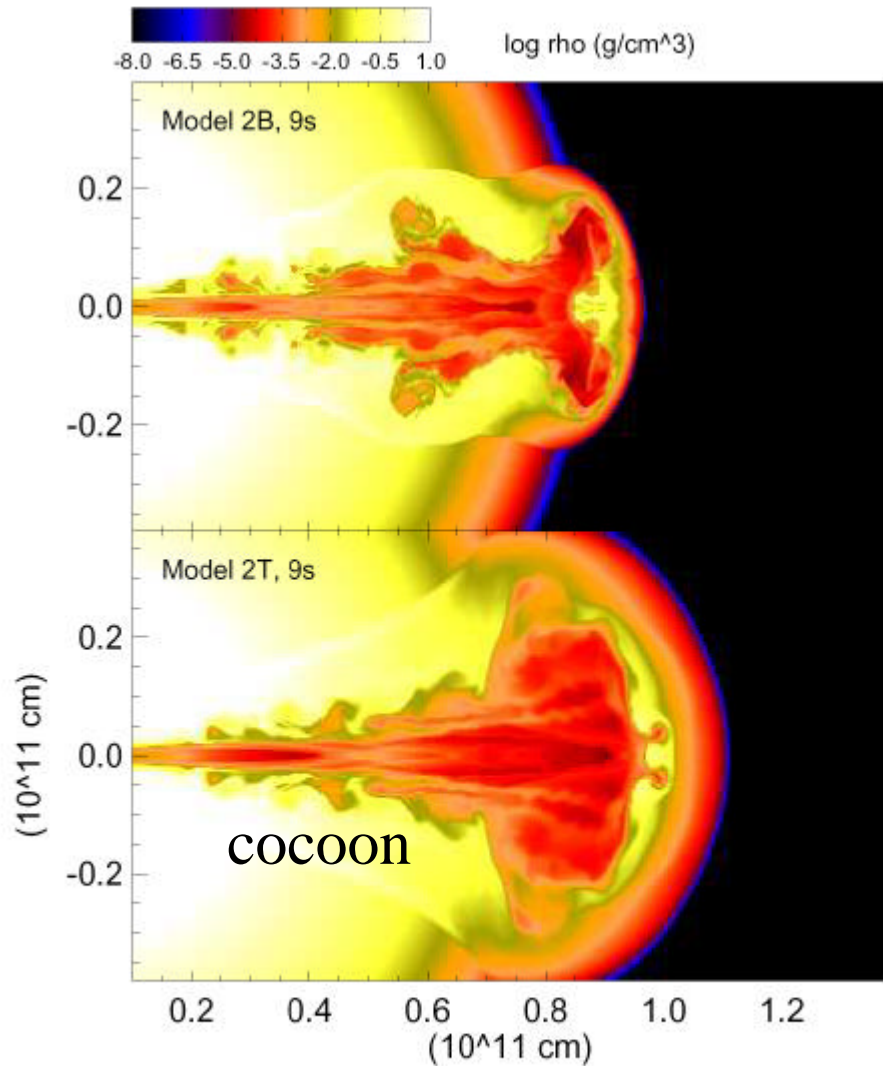
Viewing angle

Two jet



Viewing angle

重い星の中のジェット



Zhang et al.(03)

Fig. 8.— Resolution study in two dimensions. The jets in Models 2B and 2T had identical parameters, but the calculation was carried out in cylindrical grids having different resolution (Table 4). Model 2T had the lower resolution.

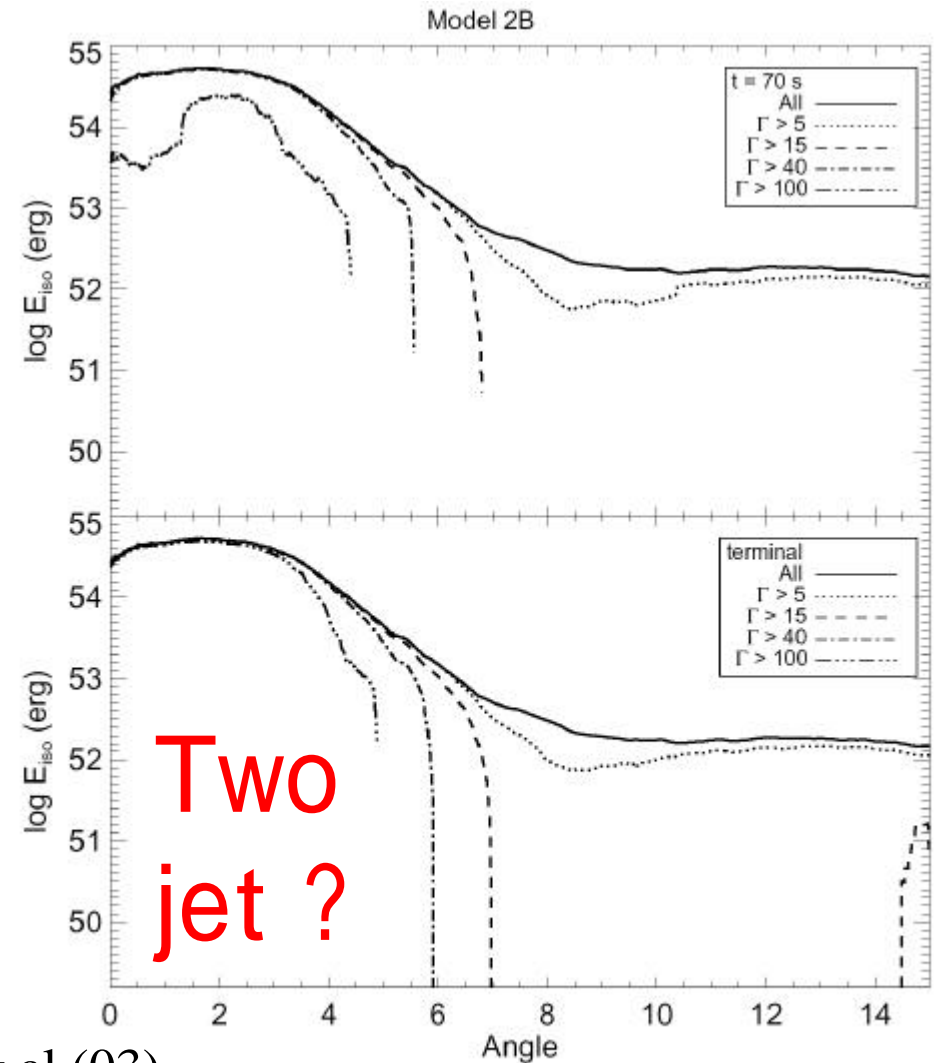


Fig. 6.— Equivalent isotropic energy for Model 2B. See also Fig. 5.

Zhang et al.(03)

GRB 宇宙論

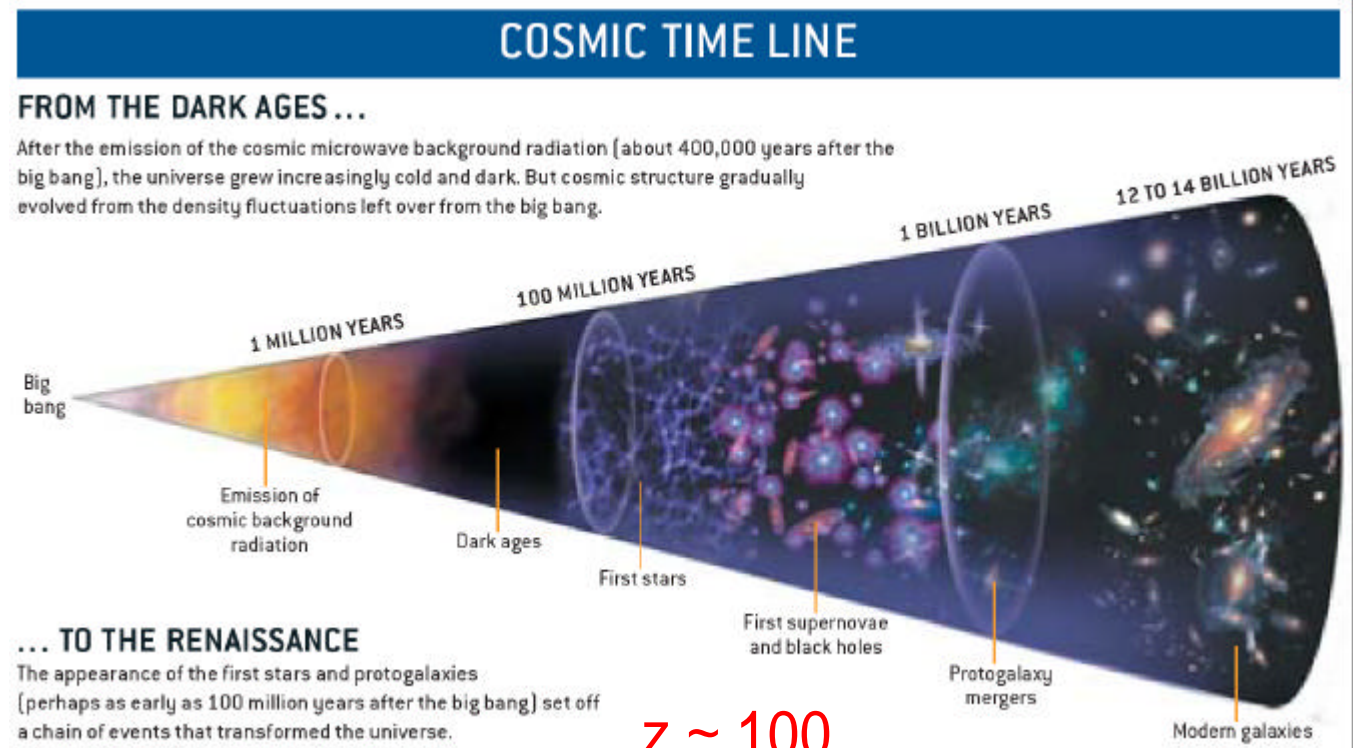
宇宙論的道具としてのGRB

GRB宇宙論

重い星起源 高赤方偏移GRB

クエーサー、
超新星の様に
星形成史
重力レンズ
再電離史

、、、



Larson&Bromm(02)

GRB

$z \sim 100$

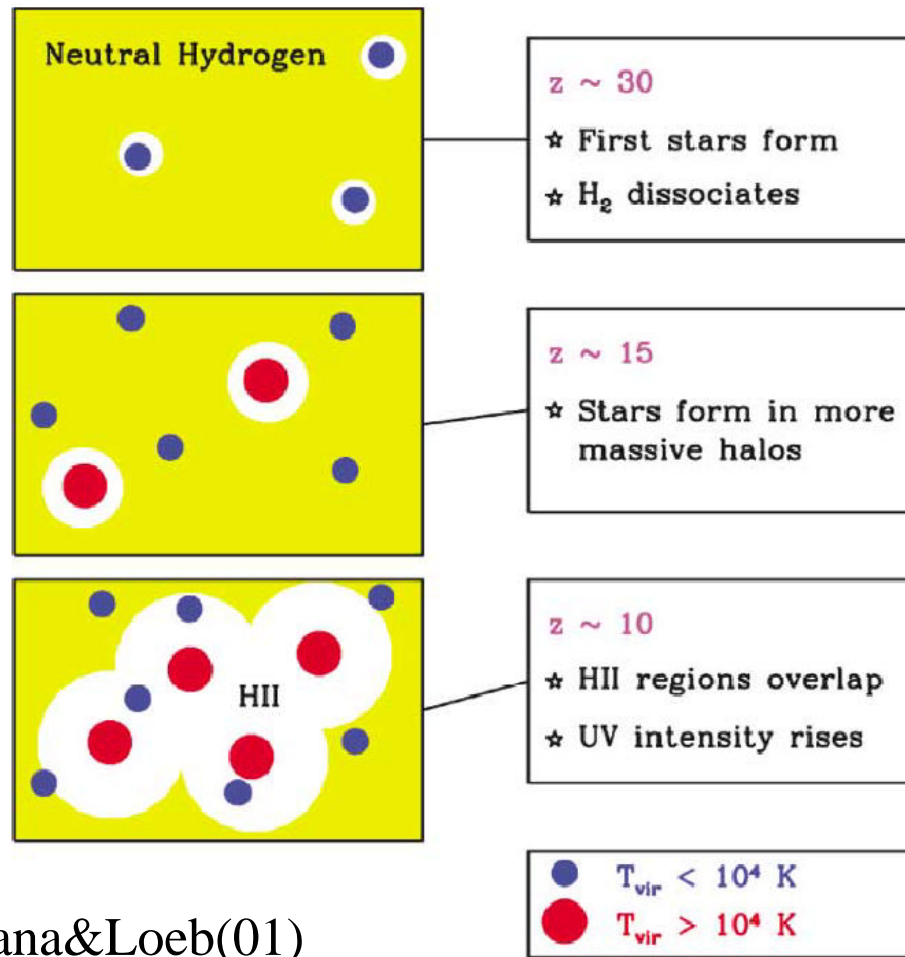


GRBは高赤方偏移
を探るのに有用

QSO, galaxy



宇宙の再電離



再電離の時期
 $6 < z_{reion} < 1000$

$$h\nu_{ion} = 13.6 \text{ eV}$$

星、銀河形成に
重要な情報

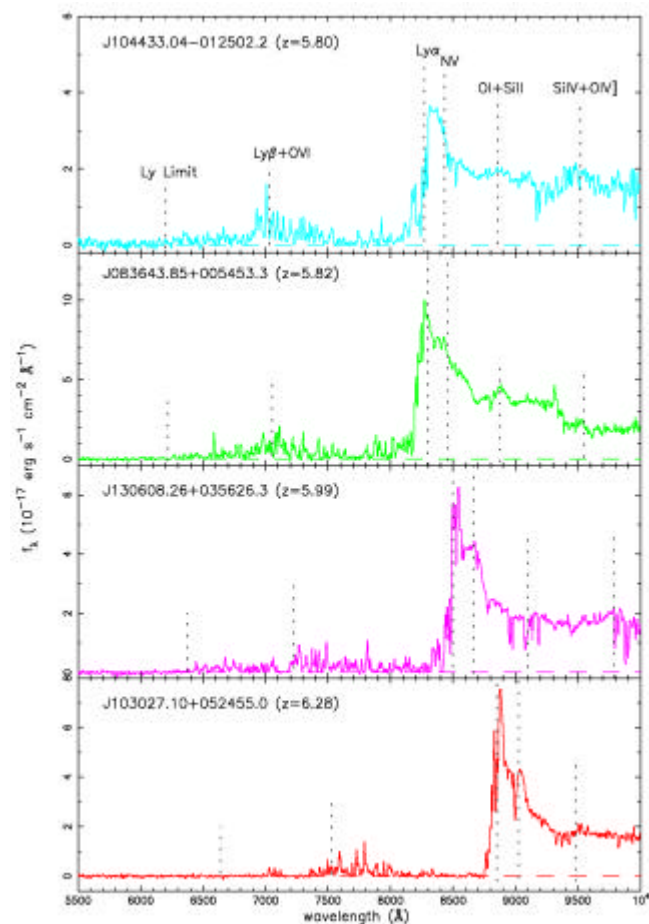
Barkana&Loeb(01)

Fig. 4. Stages in the reionization of hydrogen in the intergalactic medium.

再電離の時期

QSOのLy α 吸収

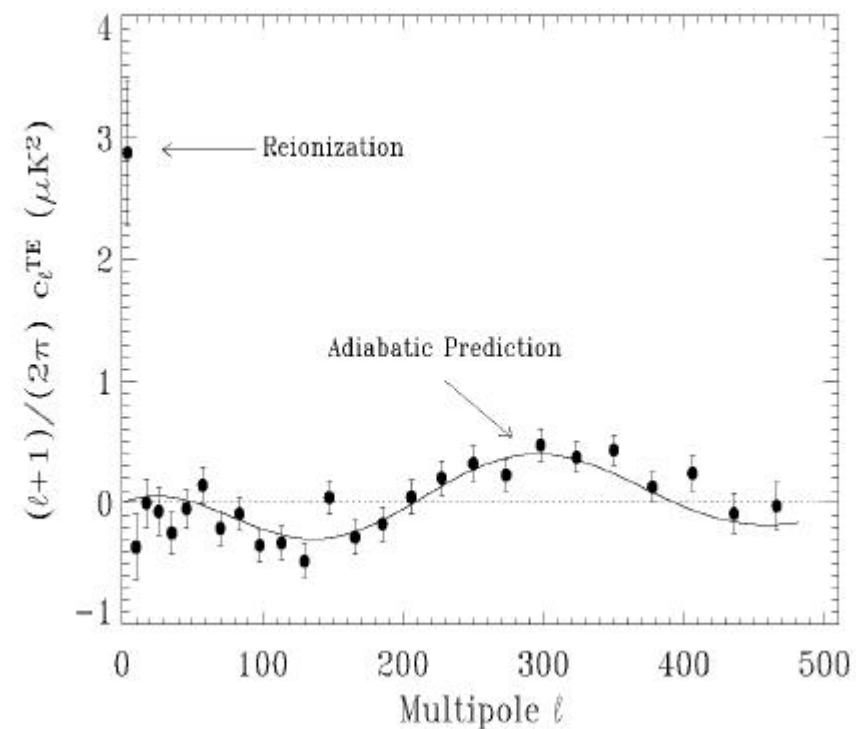
$z_{\text{reion}} \sim 6$



Fan et al.(02)

WMAPの偏光観測

$z_{\text{reion}} \sim 17$

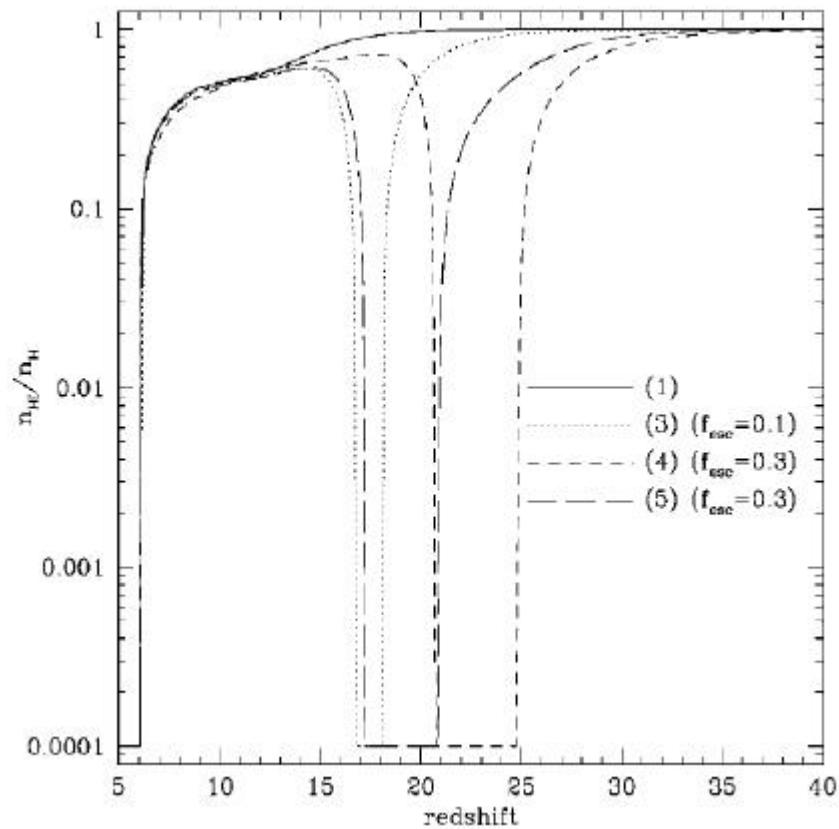


Spergel et al.(03)

Kogut et al.(03)

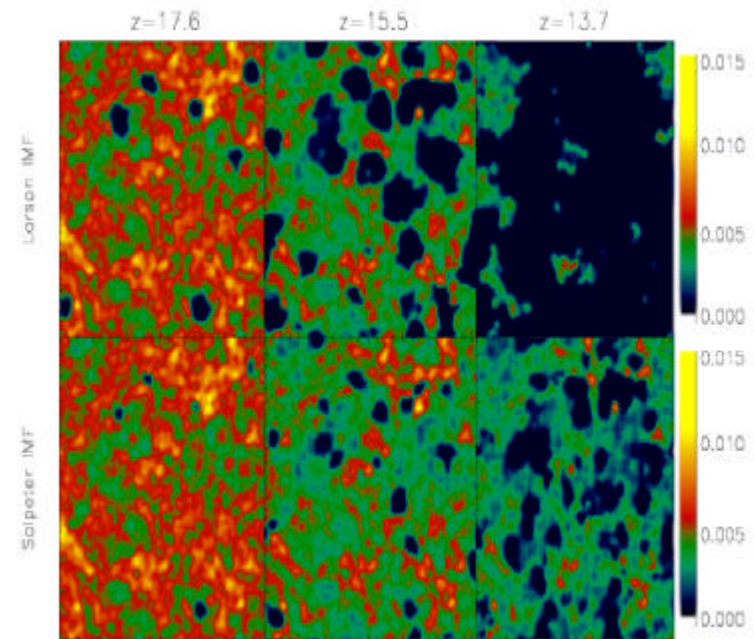
実際の再電離

2回再電離



Cen(03)

非一様再電離



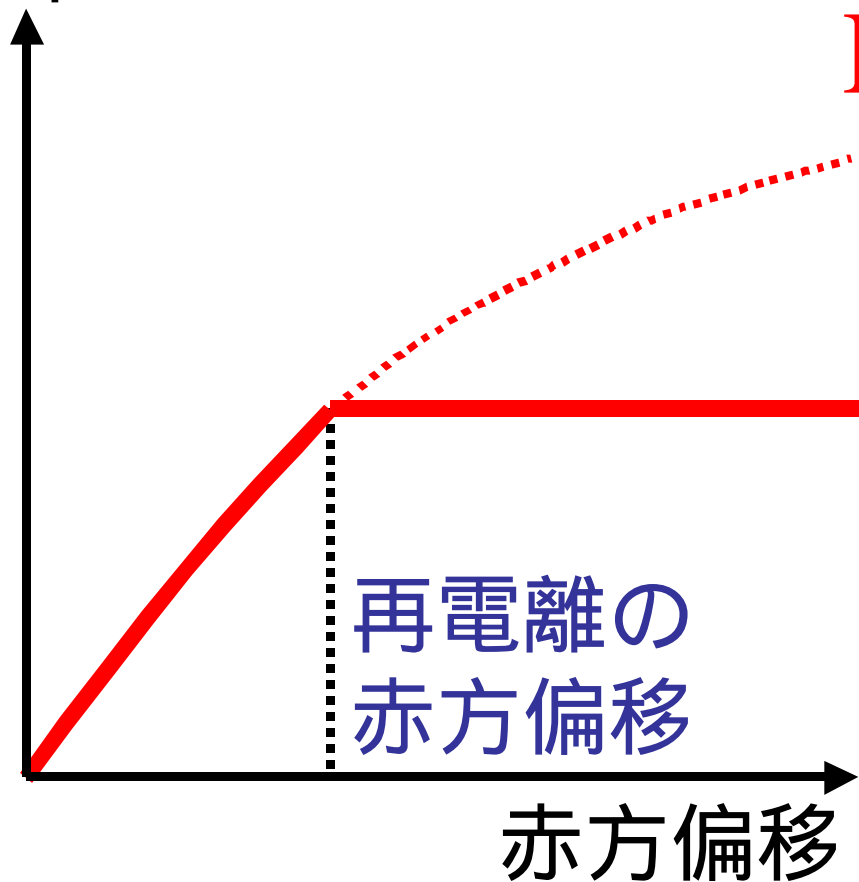
Ciardi, Ferrara & White (03)

Dispersion Measure

(DM)

: 視線上の自由電子の柱密度

Dispersion Measure

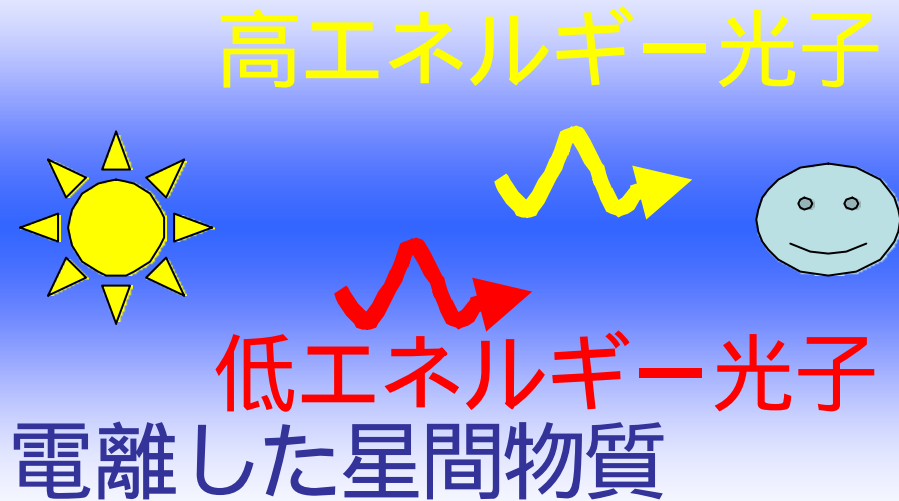


Dispersion Measure

再電離史

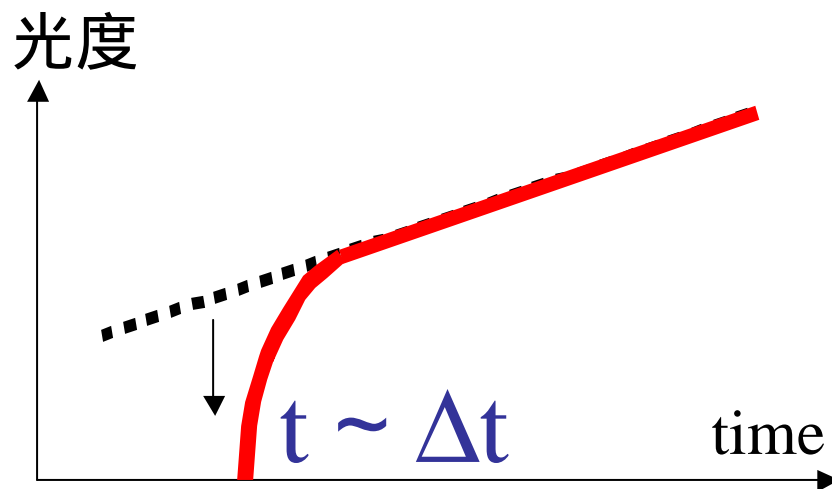
再結合した電子は
DMに寄与しない

残光によるDMの測定



プラズマ中では
光の情報が遅れる

$$\Delta t = 415 \text{ s} \left(\frac{n}{1 \text{ GHz}} \right)^{-2} \left(\frac{\text{DM}}{10^5 \text{ pc cm}^{-3}} \right)$$



光度曲線の歪み
DM
再電離史

Ioka(03), Inoue(04)

GRB 宇宙論

まとめ

謎は明らかにになりつつある

加速機構: 偏光

ジェット of 構造: X線フラッシュ

GRB宇宙論: 初代星, $z > 10$

UHECR, HEn, HEg: 未開拓

重力波: DECIGO/BBO

Swift衛星: 今年

統一モデル

