

GRB残光のスペクトル の時間進化

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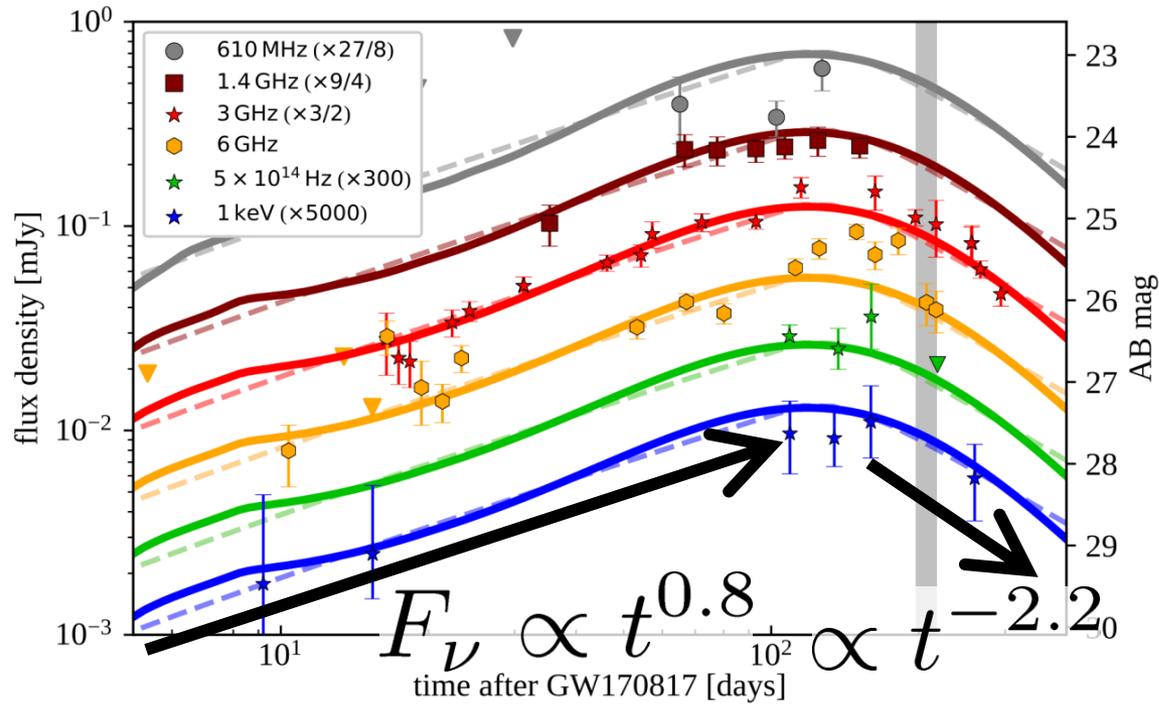
1. Introduction

2. Method

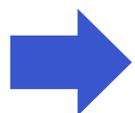
3. Results

4. Conclusion

GRB170817A 残光の光度曲線 (Ghirlanda+19)



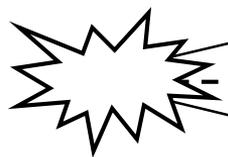
- 緩やかな増光、ピーク後の急減衰
- 非熱的単一ベキ型スペクトル
- VLBI による超光速運動の検出



相対論的ジェットからの
シンクロトロン放射

衝撃波面

中性子星合体



ジェット軸

θ

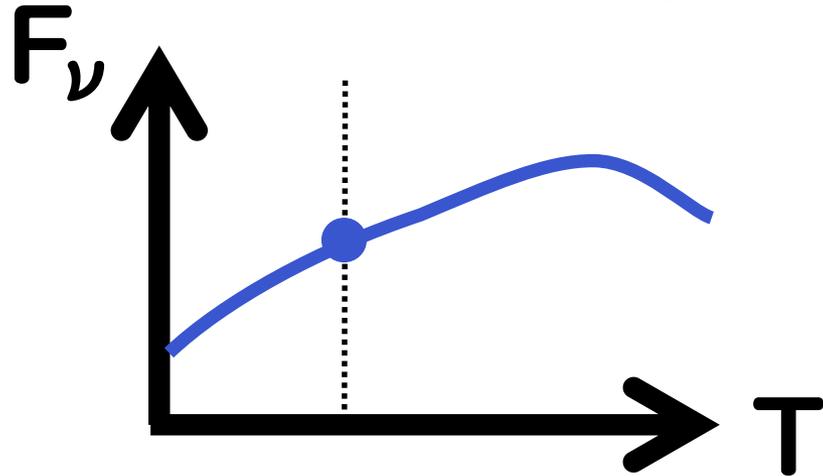
forward shock で
加速された電子からの
シンクロトン放射
(ビーミングされる)

放射領域 S



観測者

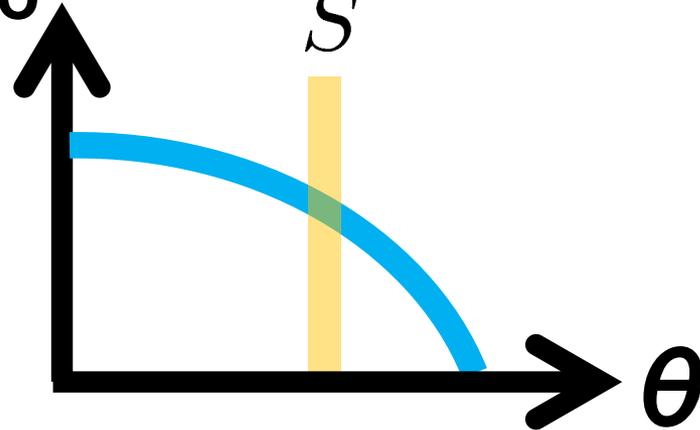
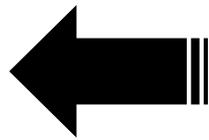
残光の光度曲線



E_{iso}

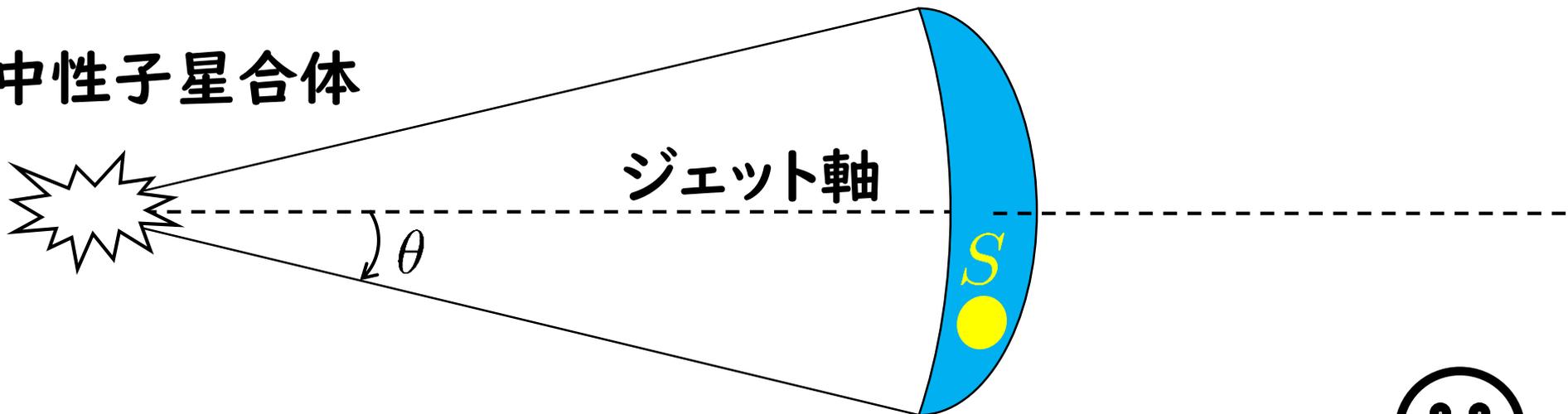
ジェット構造

S

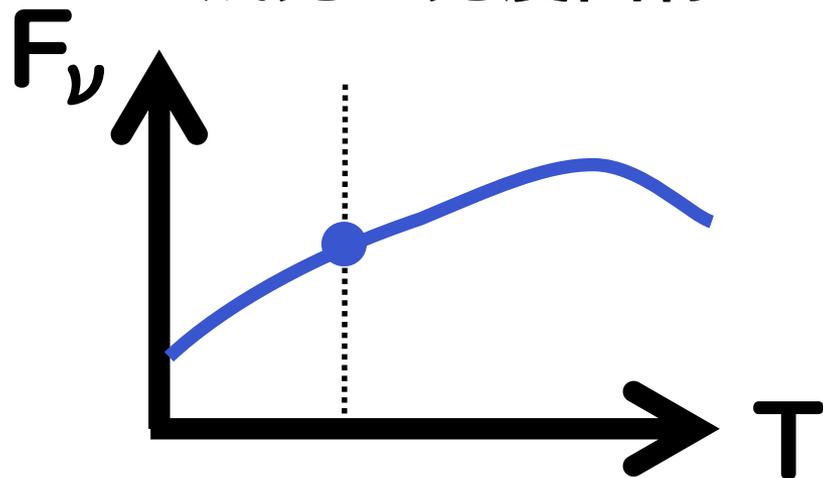


衝撃波面

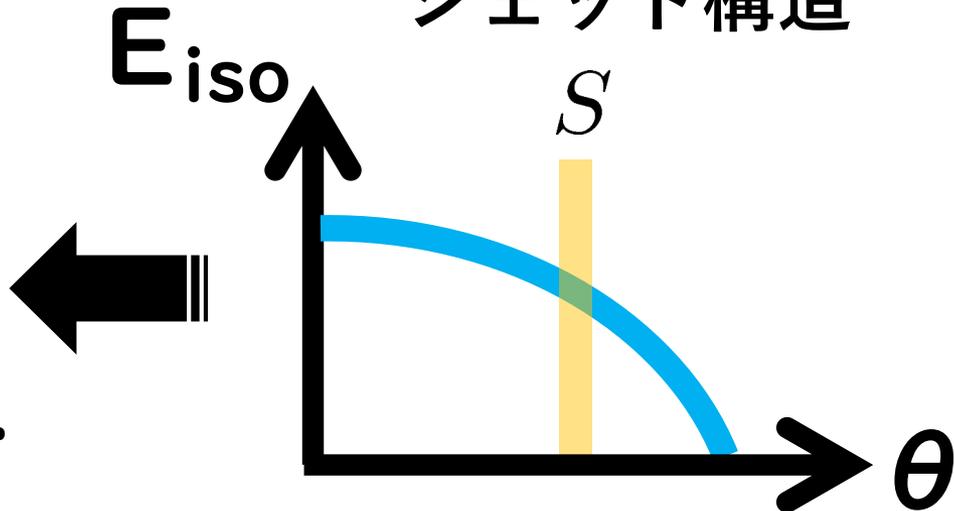
中性子星合体



残光の光度曲線



ジェット構造

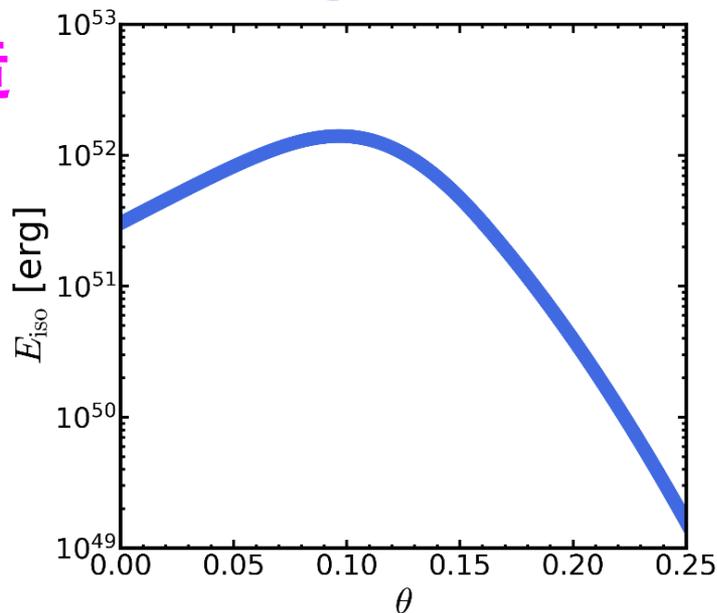


KT & Ioka (2020a,b) Hollow-cone jet

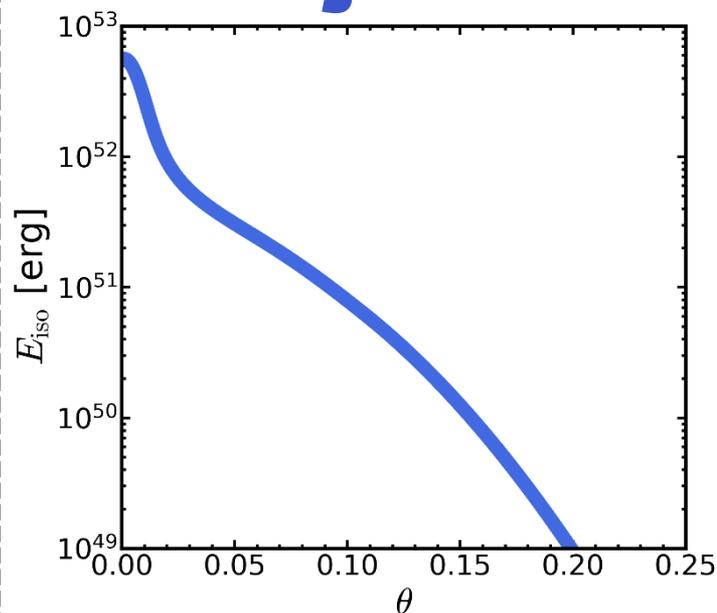
ジェット構造

$$E_{\text{iso}}(\theta)$$

新しい構造!

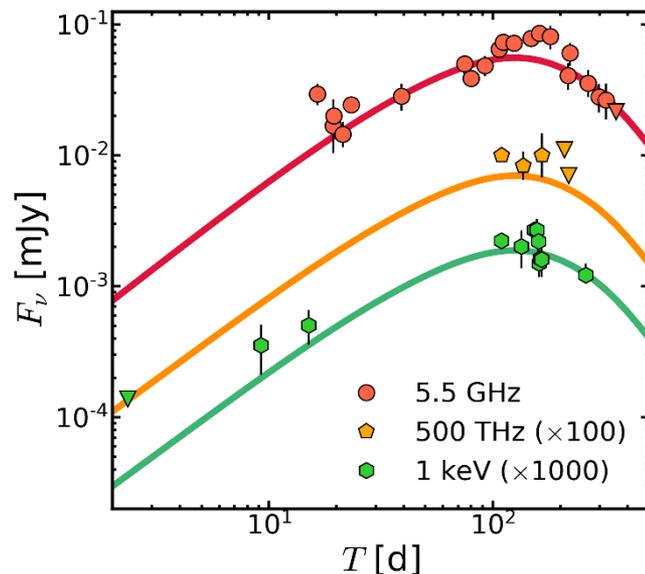
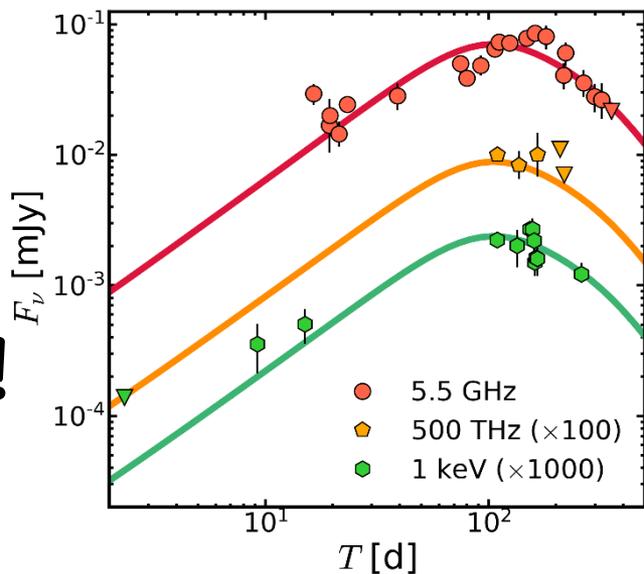


Spindle jet

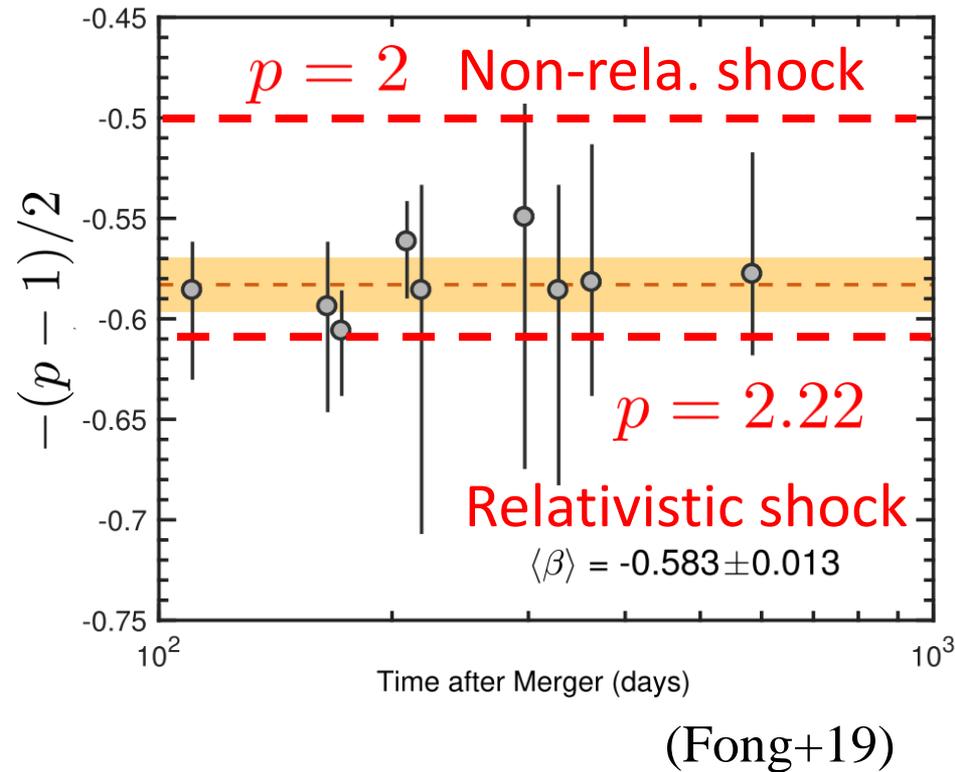
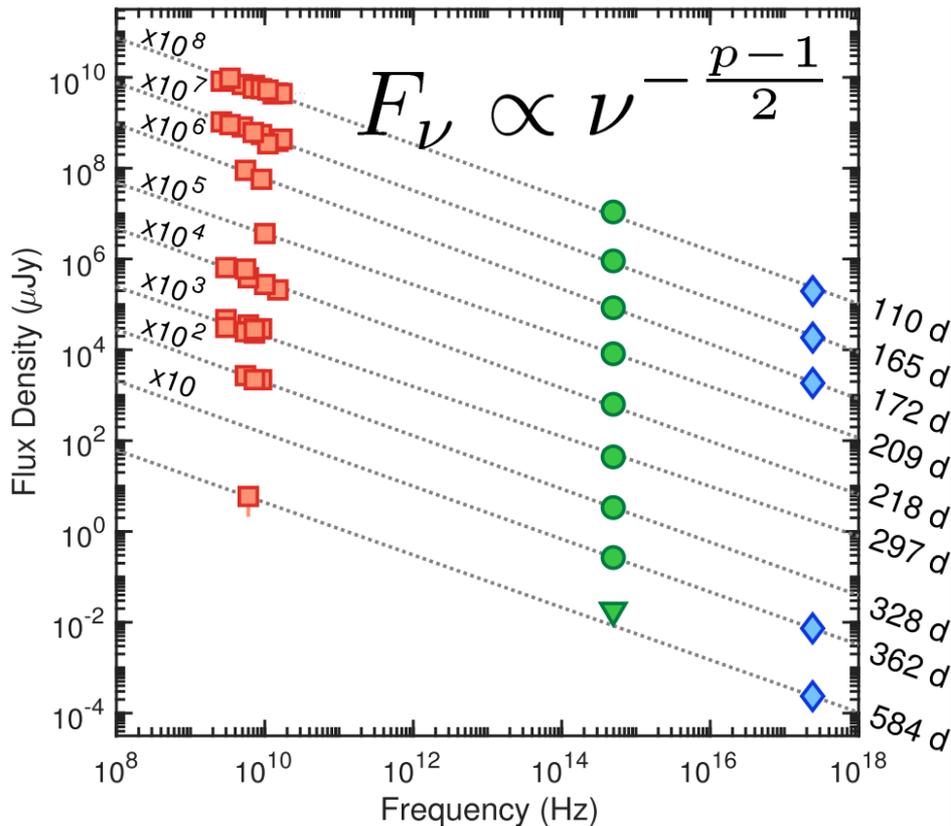


残光の
光度曲線

観測と無矛盾!



Spectrum: power-law from radio to X-ray

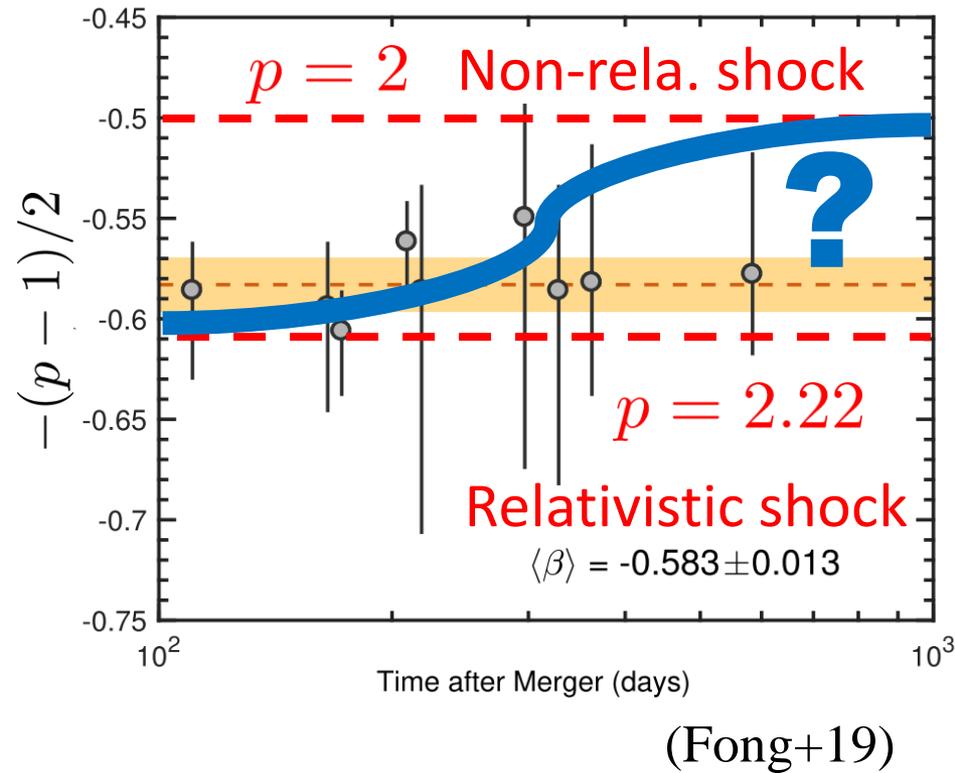
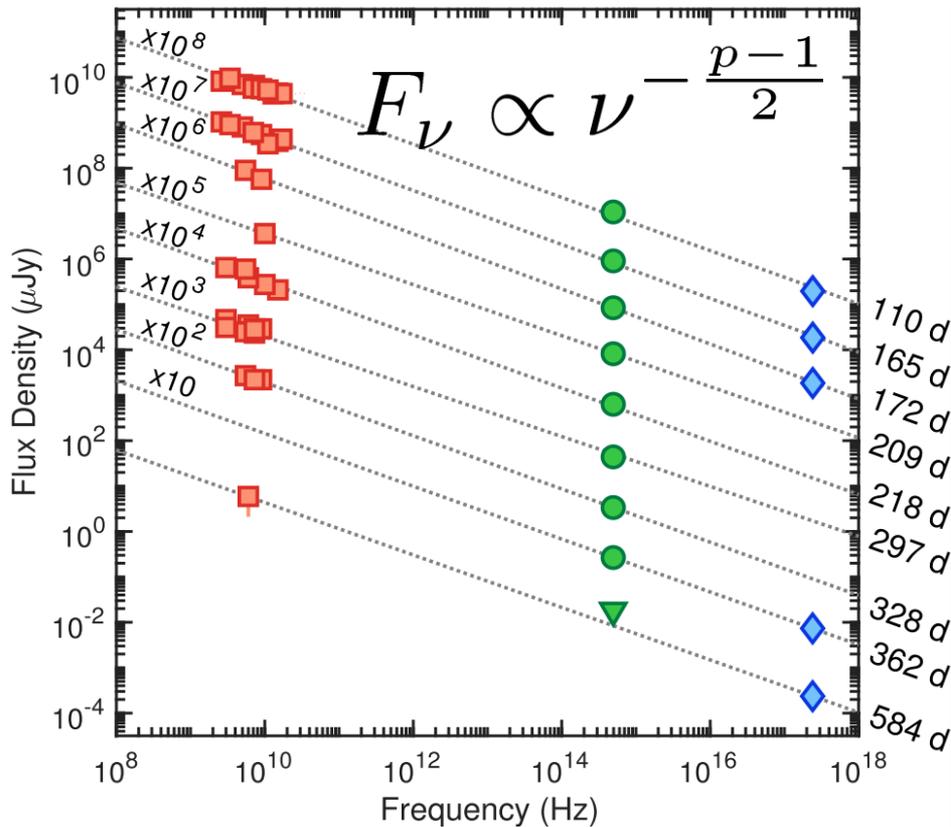


p: energy spectral index of the accelerated electrons

$$f(E)dE \propto E^{-p}dE$$

† electron power-law index p can change depending on the shock speed (e.g., Keshet & Waxman 05)

Spectrum: power-law from radio to X-ray

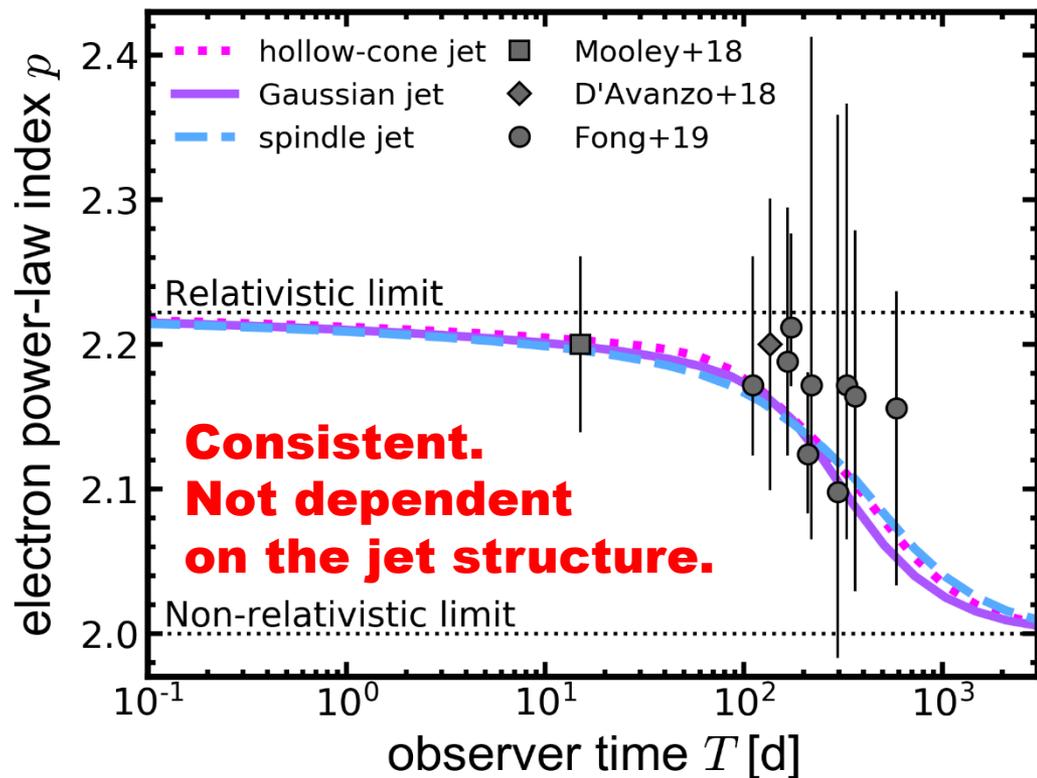
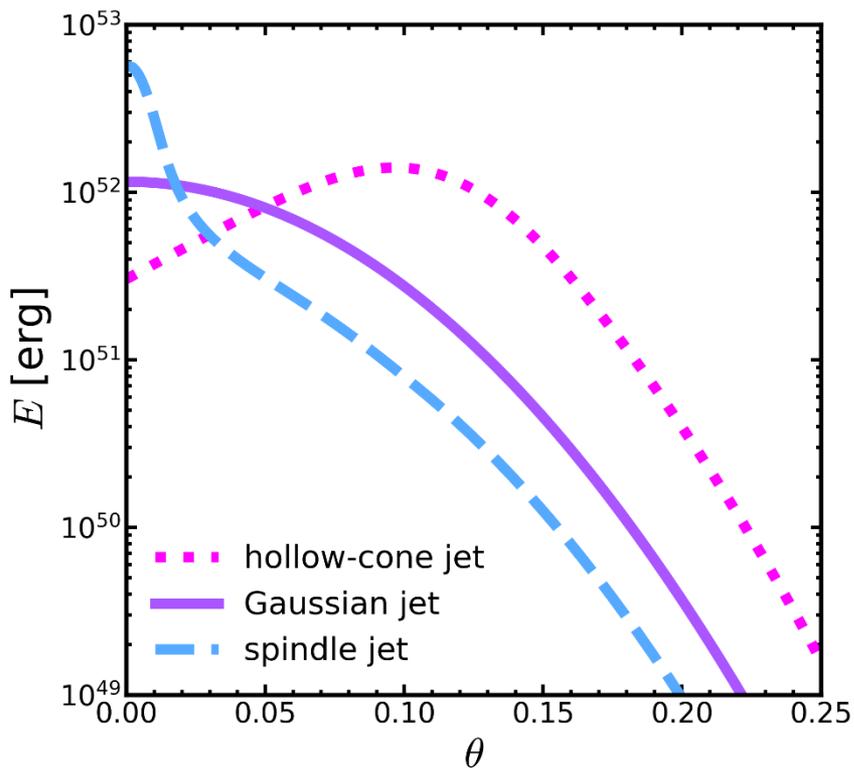


p: energy spectral index of the accelerated electrons

$$f(E)dE \propto E^{-p}dE$$

† electron power-law index p can change depending on the shock speed (e.g., Keshet & Waxman 05)

結果の一部を先見せ：



詳細は後程

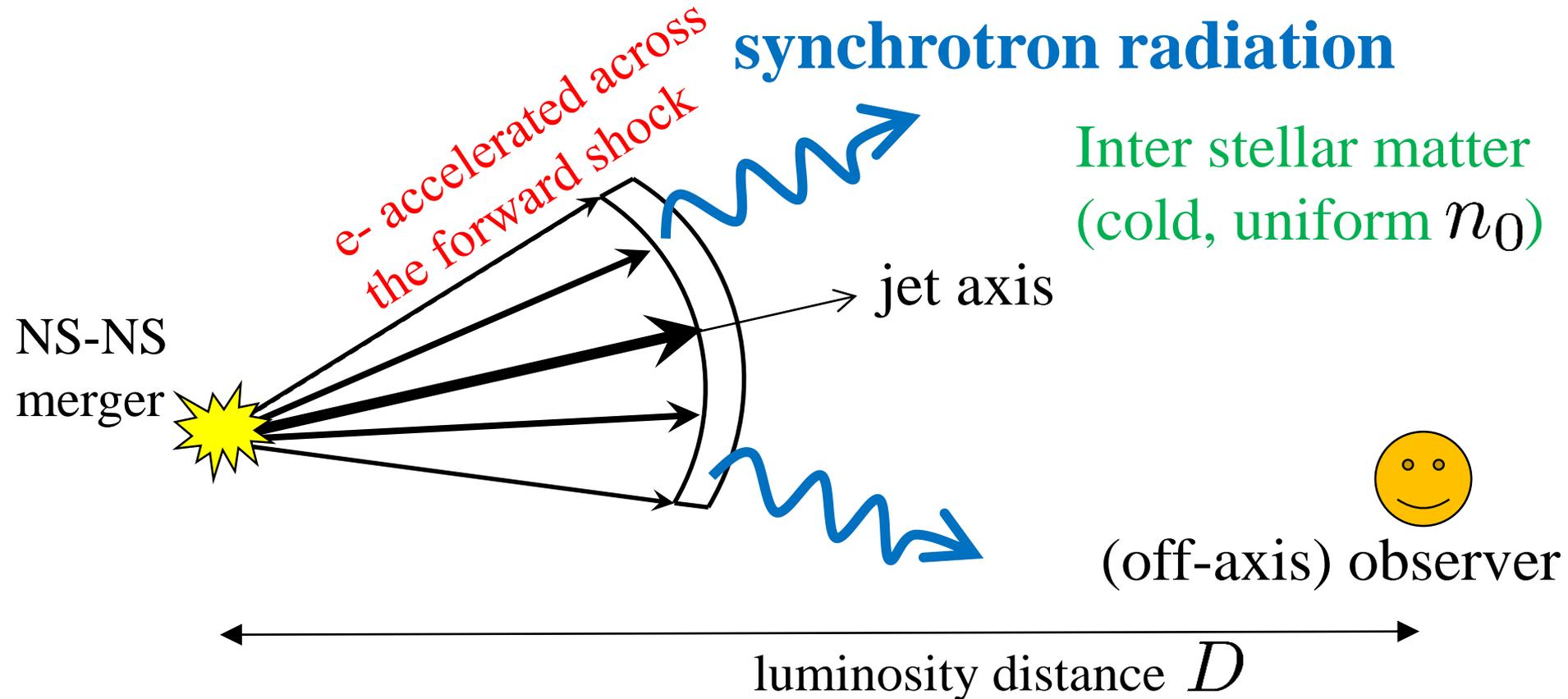
Method

to calculate the afterglow

- * Jet model
- * Particle acceleration

Structured jet: $E_{\text{iso}}(\theta)$

Sari+98, van Eerten+10



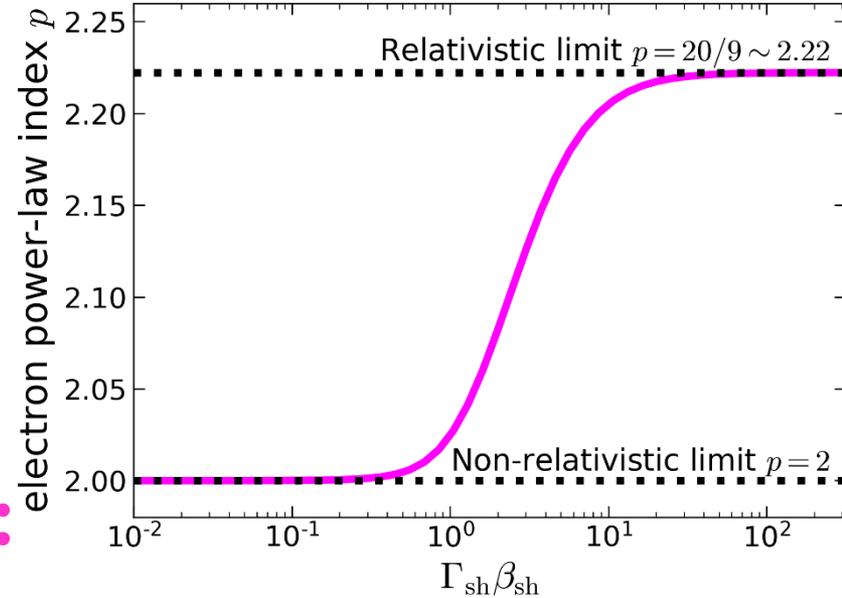
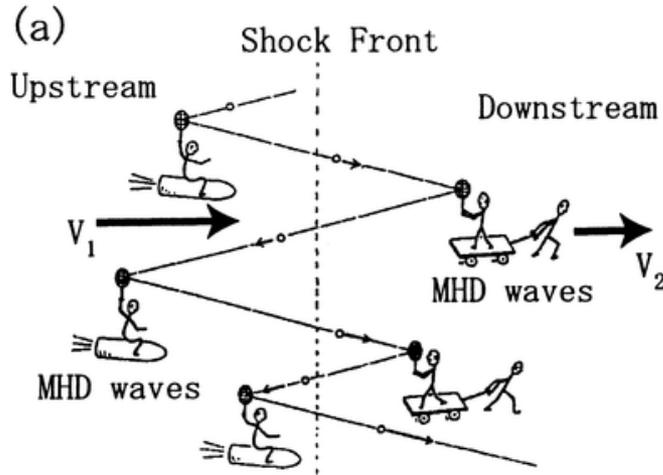
shock evolution: $\Gamma_{\text{sh}}^2 \beta_{\text{sh}}^2 = C_{\text{BM}}^2 t^{-3} + C_{\text{ST}}^2 t^{-6/5}$

$$C_{\text{BM}}(\theta) \propto E_{\text{iso}}^{1/2}(\theta) n_0^{-1/2} \quad C_{\text{ST}}(\theta) \propto E_{\text{iso}}^{1/5}(\theta) n_0^{-1/5}$$

Each segment expands as if it were a portion of a spherically expanding shell (e.g., Kumar & Granot 2003):

加速電子のエネルギーベキ指数 p

w/ Juttner-Syngé EoS



Keshet & Waxman (2005):

- * parallel shock (磁場と衝撃波法線が平行)
- * isotropic diffusion
- * Relativistic effects

$$p = \frac{3\beta_u - 2\beta_u\beta_d^2 + \beta_d^3}{\beta_u - \beta_d} - 2$$

$\beta_{u,d}$: 衝撃波上流(下流)の流速@shock rest frame

残光モデル (van Eerten+10) 仮定: 軸対称ジェット, cold uniform ISM

シンクロトロン放射/自己吸収 + 相対論的效果

$$F_\nu(T) = \frac{1}{4\pi D^2} \int d\Omega \mu R^2 \left. \frac{\epsilon'_{\nu'} (1 - e^{-\tau_\nu})}{\alpha'_{\nu'} \Gamma^3 (1 - \beta\mu)^3} \right|_{t=t(T, \Omega)}$$

Sari+98, Granot+99, van Eerten+10

放射率: $\epsilon'_{\nu'}(E_{\text{iso}}, n_0, \epsilon_B, \epsilon_e, p)$

吸収率: $\alpha'_{\nu'}(E_{\text{iso}}, n_0, \epsilon_B, \epsilon_e, p)$

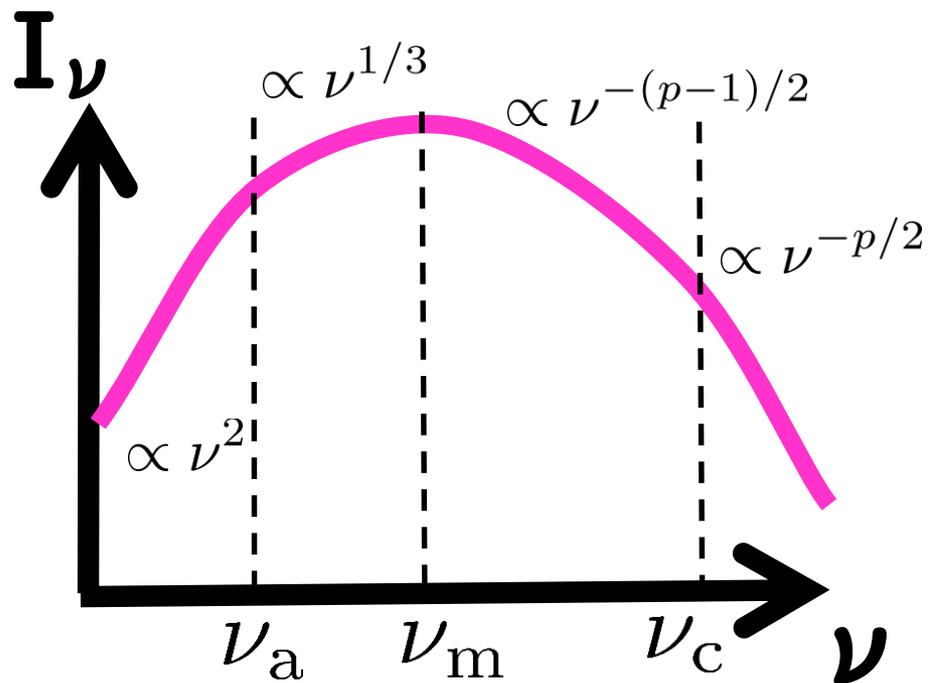
n_0 : ISM数密度

ϵ_B : 磁場エネルギーへの転換率

ϵ_e : 加速電子のエネルギーへの転換率

p : 電子のエネルギースペクトル指数

optical depth: $\tau_\nu = \alpha_\nu \frac{\Delta R}{\mu}$



衝撃波
ダイナミクス

Blandford & McKee 76 + Sedov & Taylor

Thin shell 近似

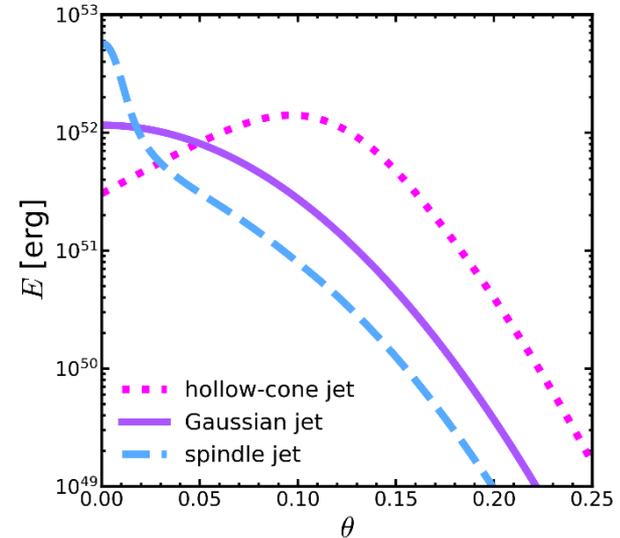
$$\Delta R = R / [12\Gamma^2 (1 - \beta_{\text{sh}}\mu)]$$

power-law index p の時間進化について調べる

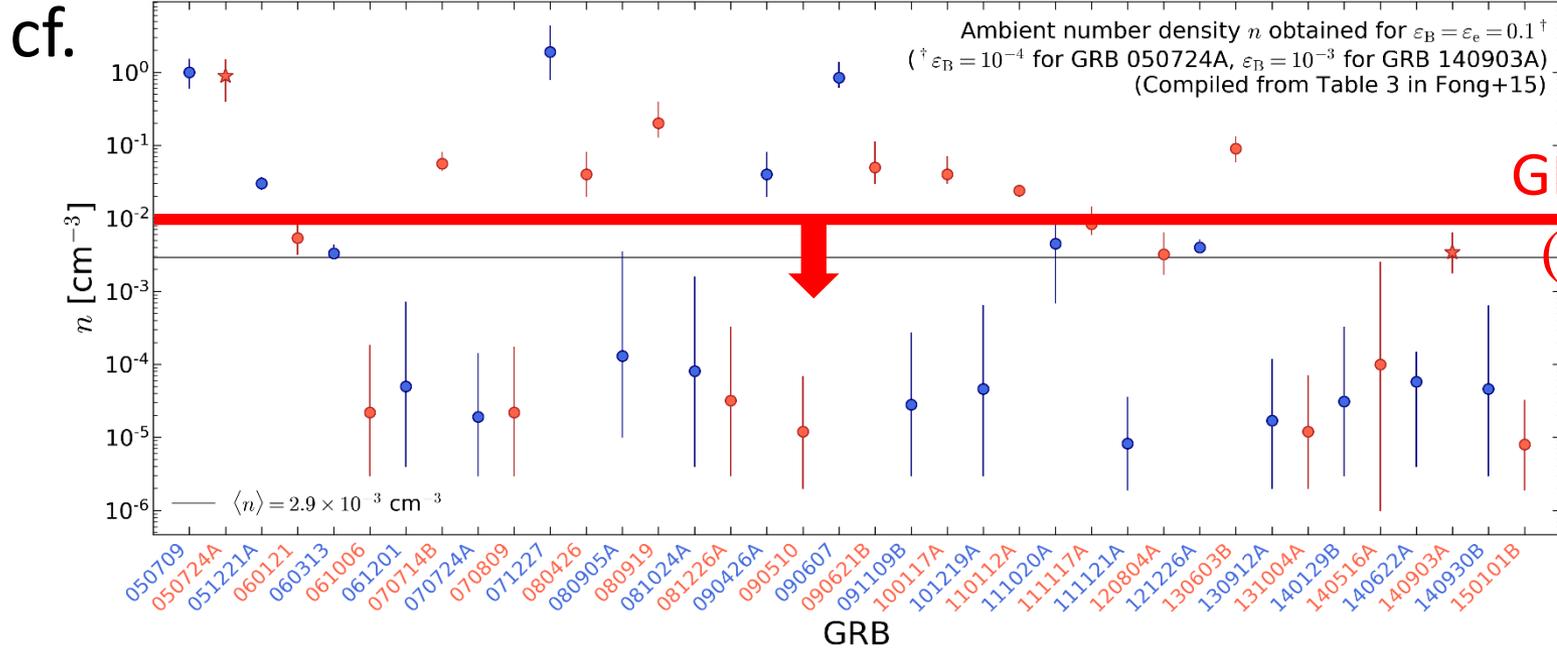
1. ジェット構造による違い

どのジェット構造でも
GRB 170817A 観測と整合的か？

Model parameters n_0 , ϵ_B , ϵ_e , θ_v
残光光度曲線を説明できる、
KT & Ioka (2020b)と同じものを使う



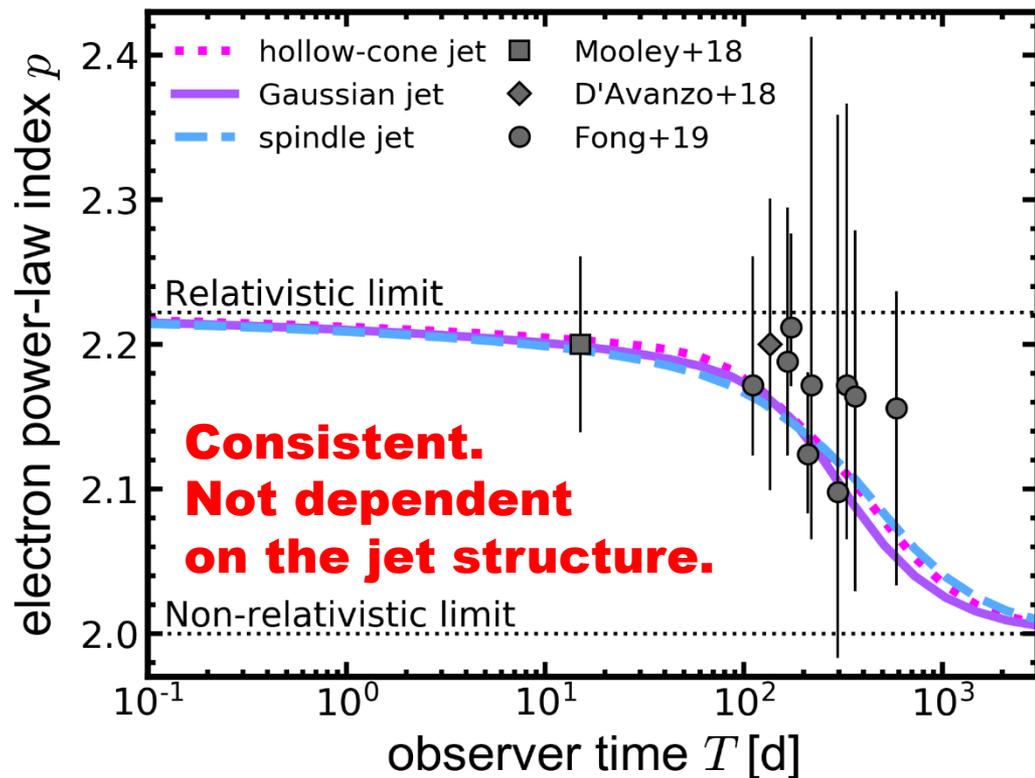
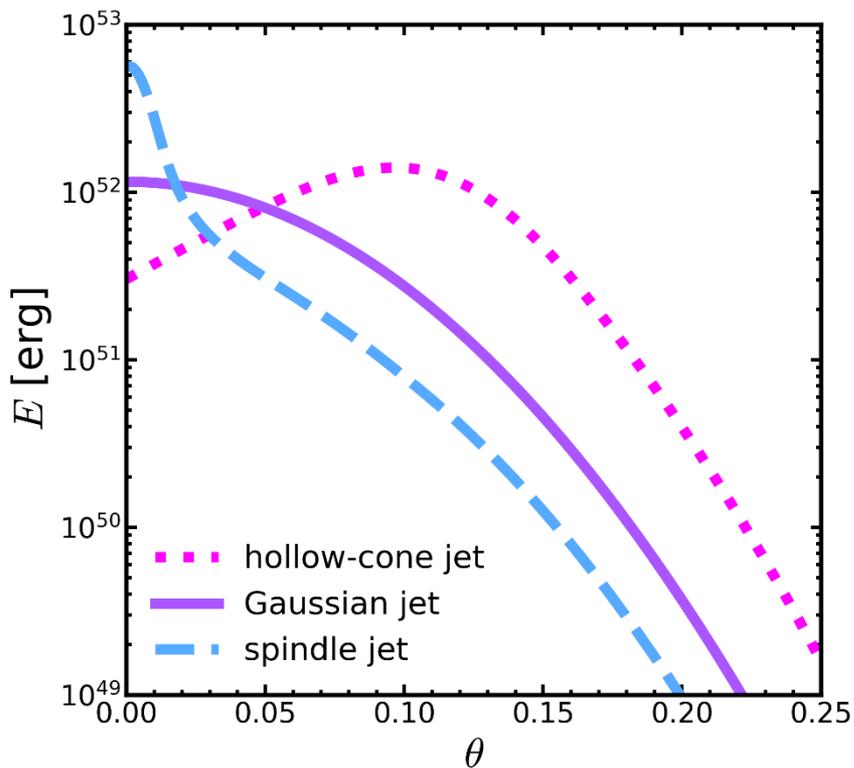
2. ISM 密度依存性 高密度環境で似たイベントが発生したら？



GRB 170817A
(Hajela+19)

Results

1. ジェット構造依存性



w/ a fiducial parameter set for GRB 170817A:

$$n_0 = 10^{-3} \text{ cm}^{-3} \quad \varepsilon_e = 0.1 \quad \theta_v = 0.387 = 22.2^\circ$$

hollow-cone jet:

$$\varepsilon_B = 4.1 \times 10^{-5}$$

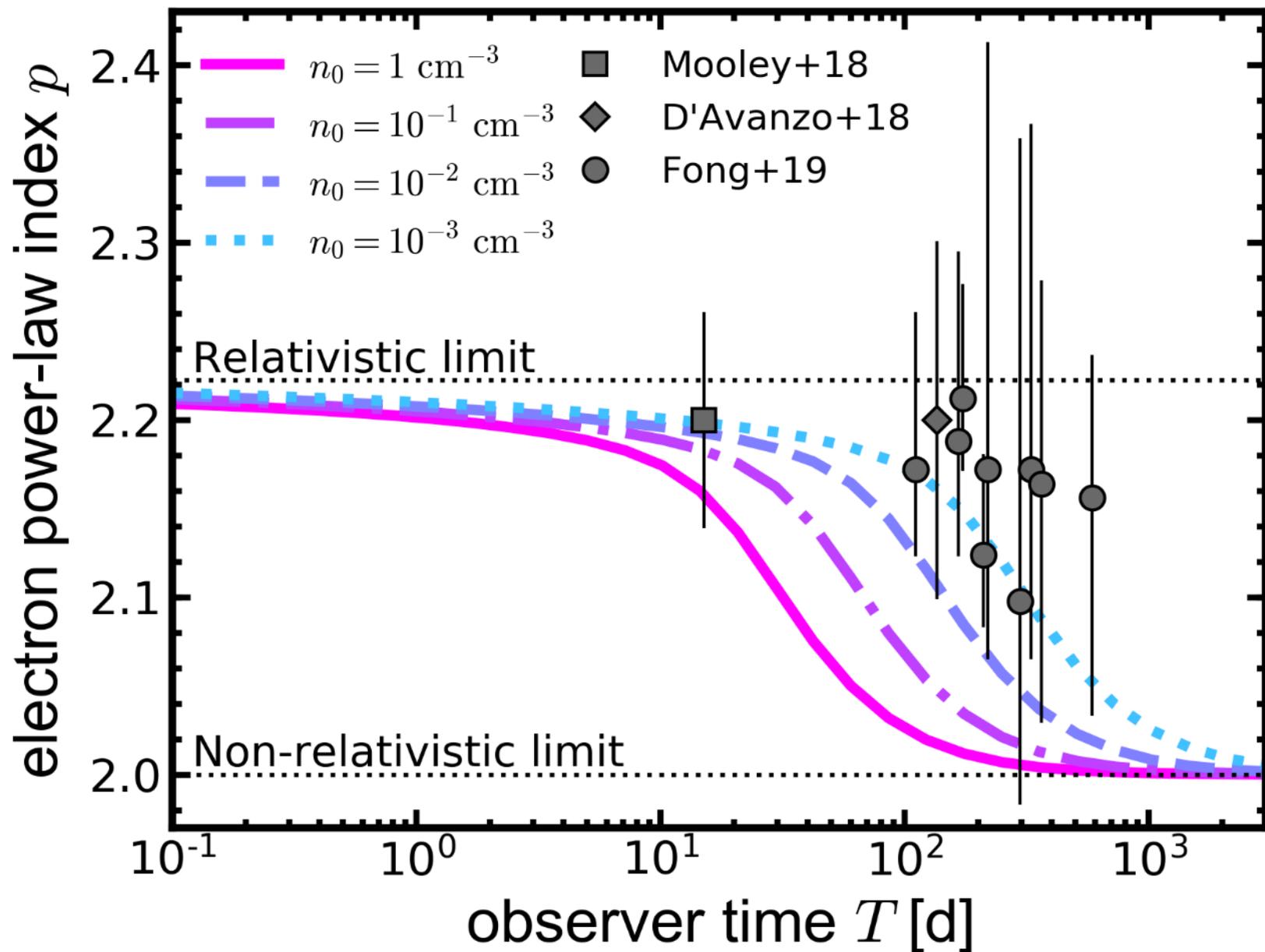
Gaussian jet:

$$\varepsilon_B = 2.4 \times 10^{-4}$$

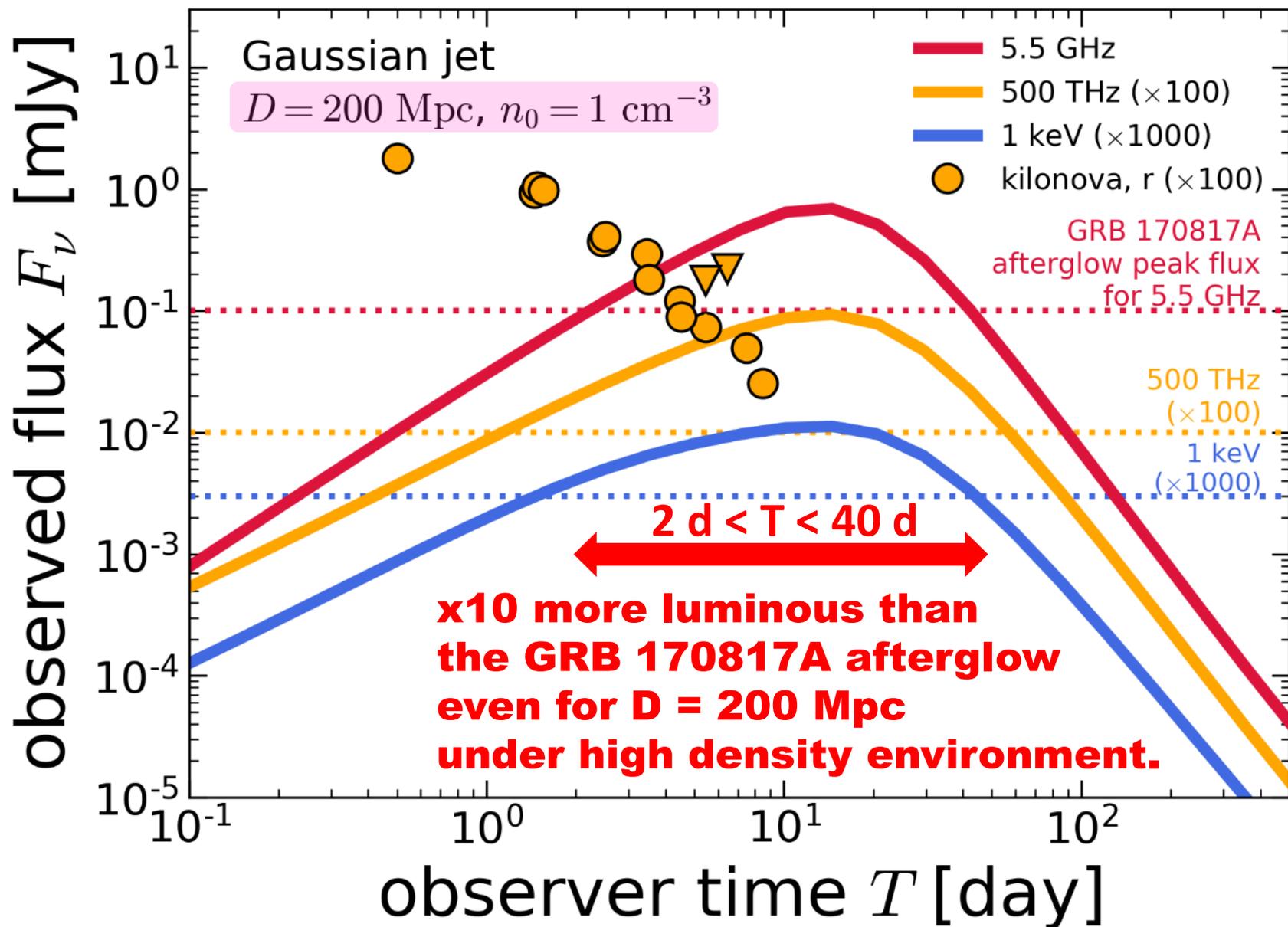
spindle jet:

$$\varepsilon_B = 6.6 \times 10^{-4}$$

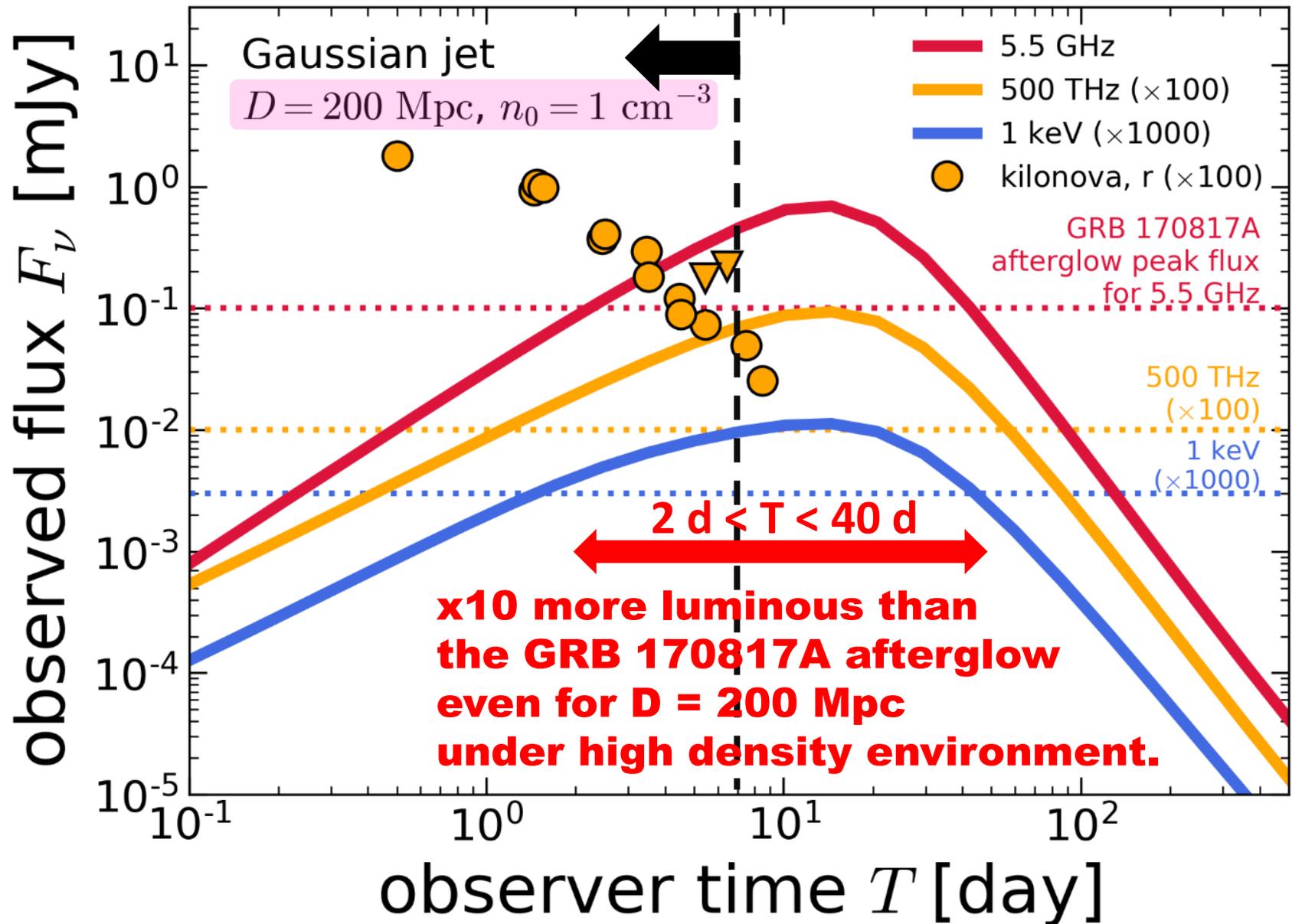
2. ISM 密度依存性



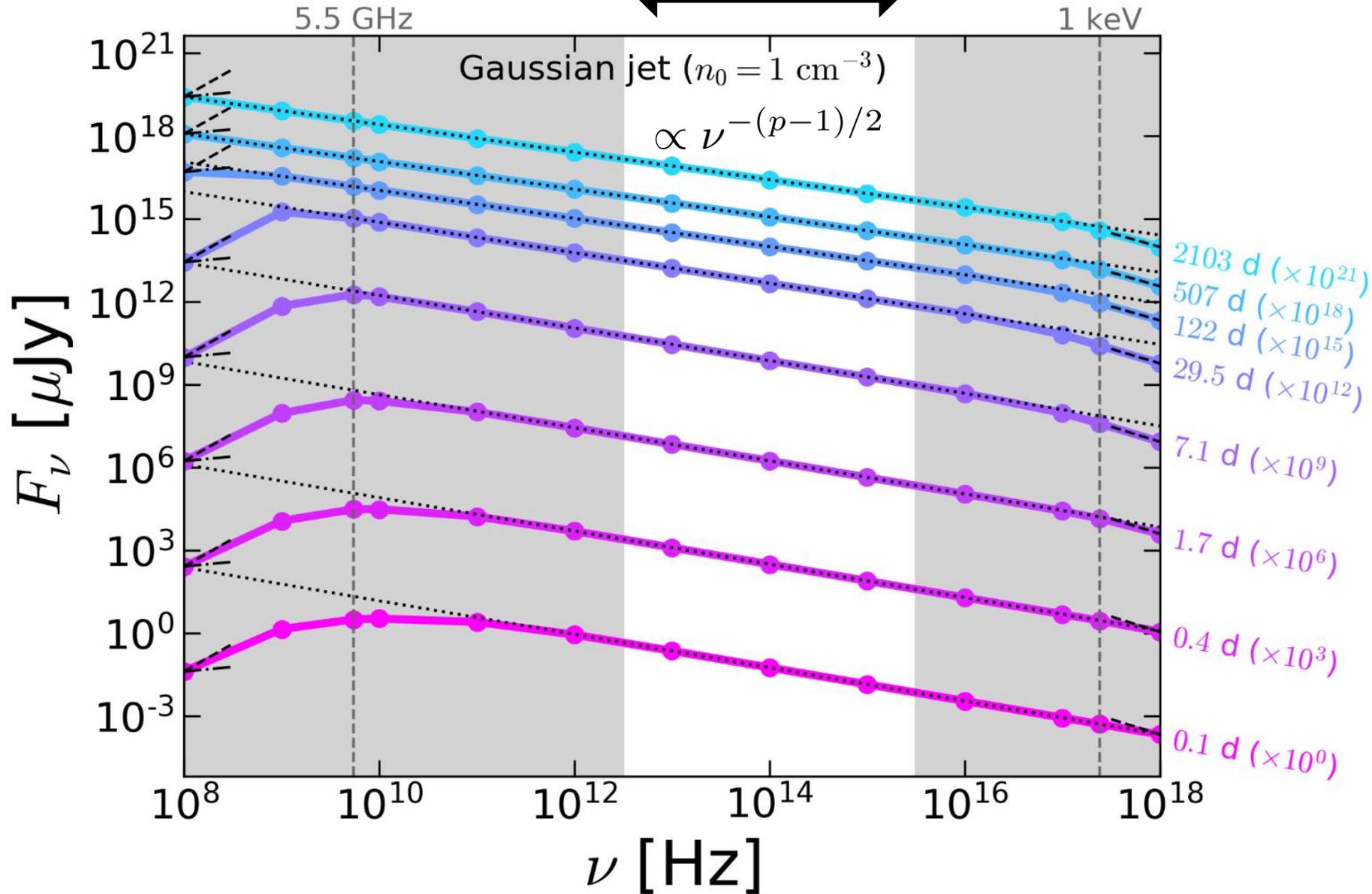
観測可能性: 高密度環境ならば遠くても見える



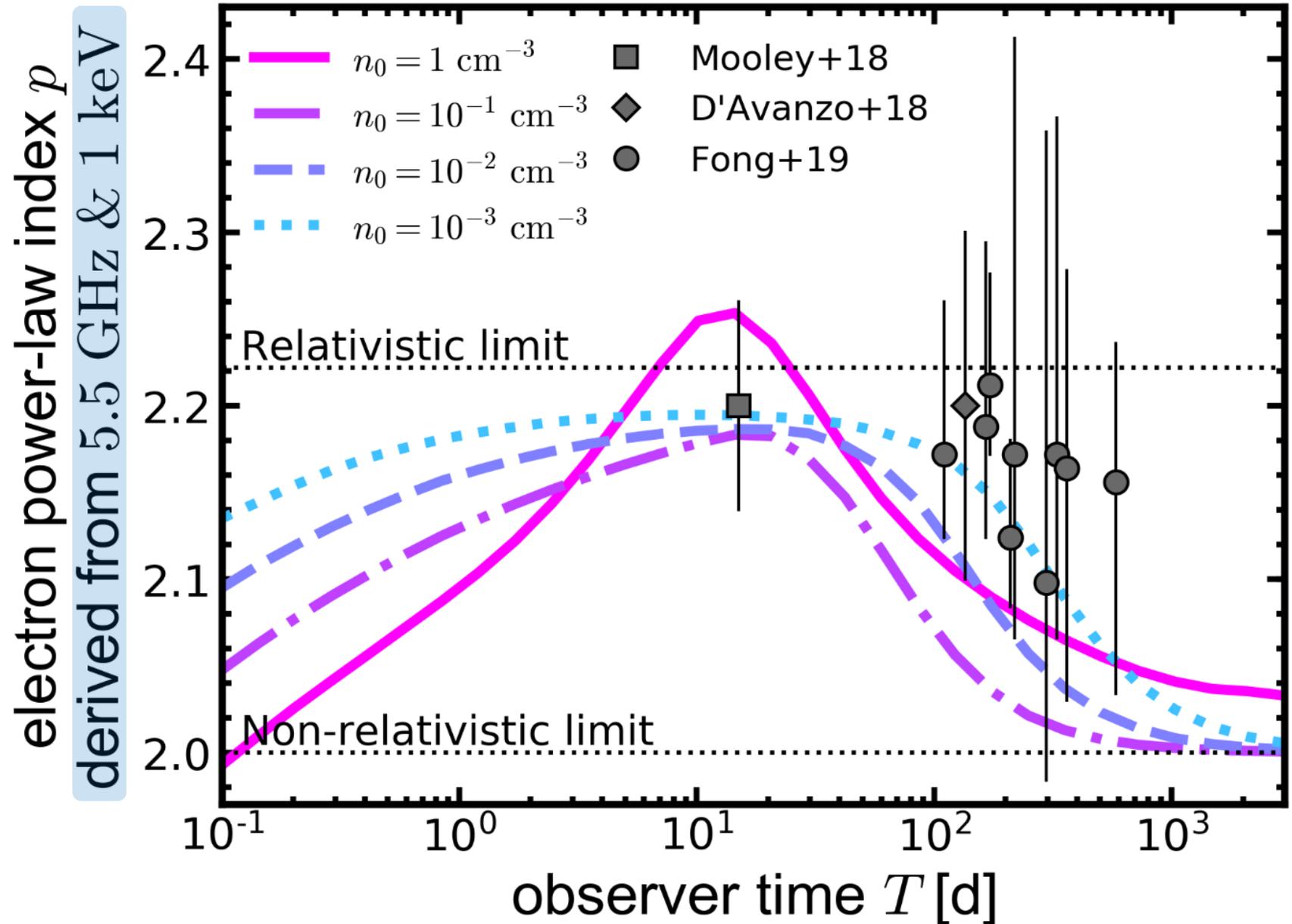
However, optical and IR bands would not be available due to the kilonova emission for $T < 70$ d.



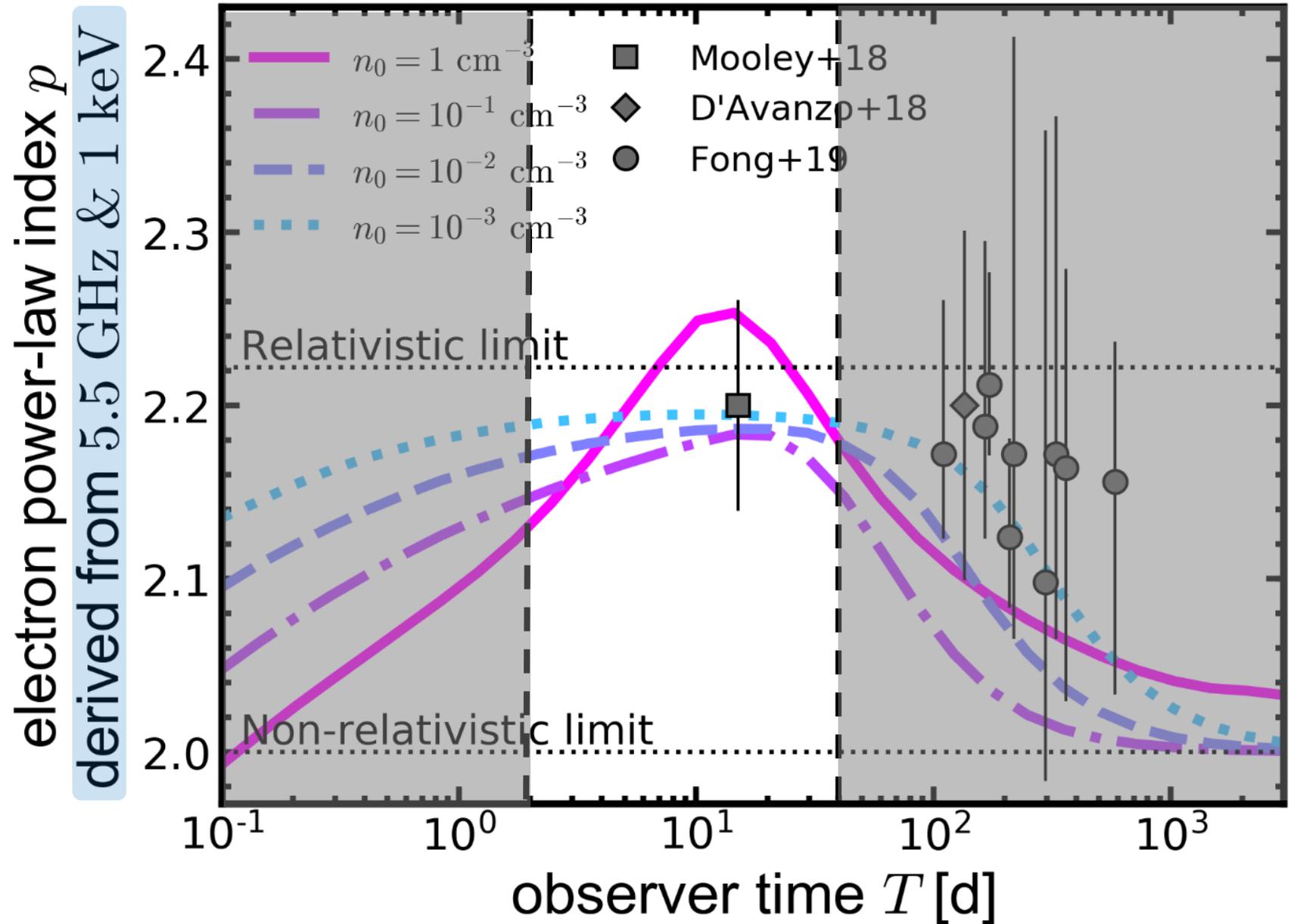
赤外～可視：afterglow が kilonova に隠される (for $T < 70$ d)



実効的スペクトル指数の時間進化



実効的スペクトル指数の時間進化



Conclusion

将来 GRB 170817A と同様のイベントが
高密度環境で起これば、
スペクトルの時間進化が観測可能!!
(**数日～数十日**のタイムスケール)

今後の課題

- * 粒子加速モデル依存性
(今回は Keshet & Waxman 05 のみ)
→ 粒子加速モデルの観測による検証?