# EXTREMELY BRIGHT GRB160625B WITH MULTI-EPIDOSES EMISSION: HINTS FOR LONG-TERM EVOLUTION OF THE GRB EJECTA

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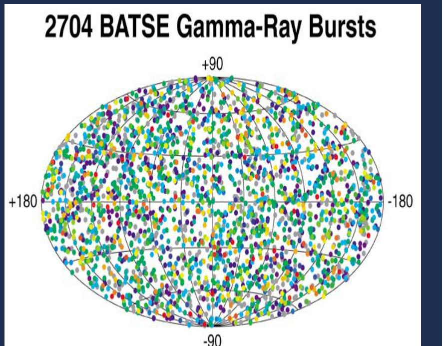
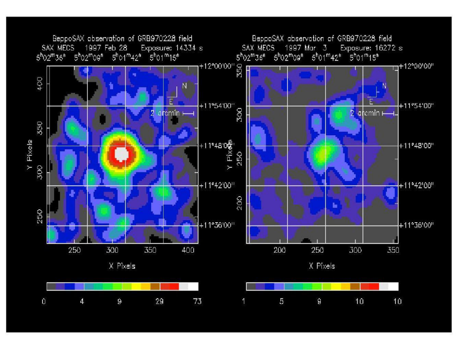
# Outline

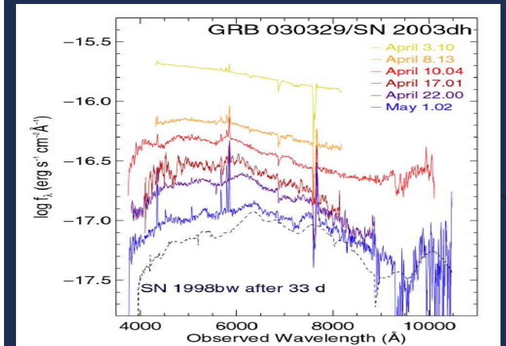
- **Introduction of background and observations**
- **Standard fireball model**
- **GRB 160625B**
  - observation properties
  - long-term evolution of ejecta
  - possible central engine
- **Summary**

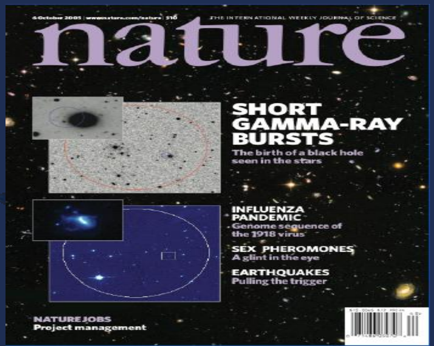
# 1. Brief History

- 1967 (Vela): **Discovery**
- 1973-1991： Misleading, no any more progress
- 1991-1997（BATSE Era）： **Long vs short,** Isotropic Distribution, Band spectrum; Fireball model; predicted the afterglow.
- 1997-2004（BeppoSAX and HETE-2 Era）：
  - Afterglows → Cosmologic origin (1997 Science breakthrough )
  - Long GRB-SN connection→ GRB980425/SN1998bw, 030329/SN 2003dh (1999, 2003 Science breakthrough)
- 2004- (Swift Era): **AG of Short GRBs; Late X-ray Flares; High-z GRBs; Canonical X-ray AG LC (**2005 Science breakthrough**)**
- 2008- (Fermi Era): **GeV photons emission in L/S GRBs, delay of HEPs**





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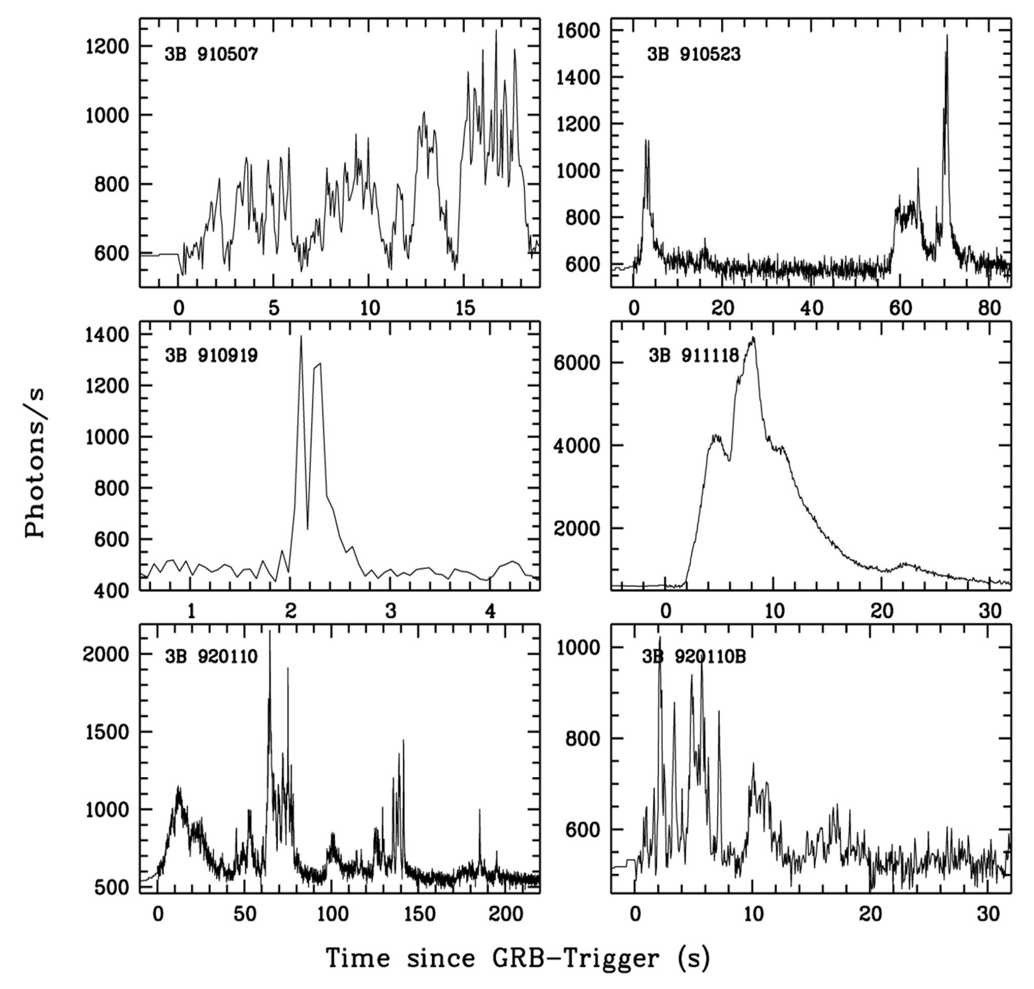
# Prompt emission

## GRB LCs-complicated



- Irregular LCs

- Duration

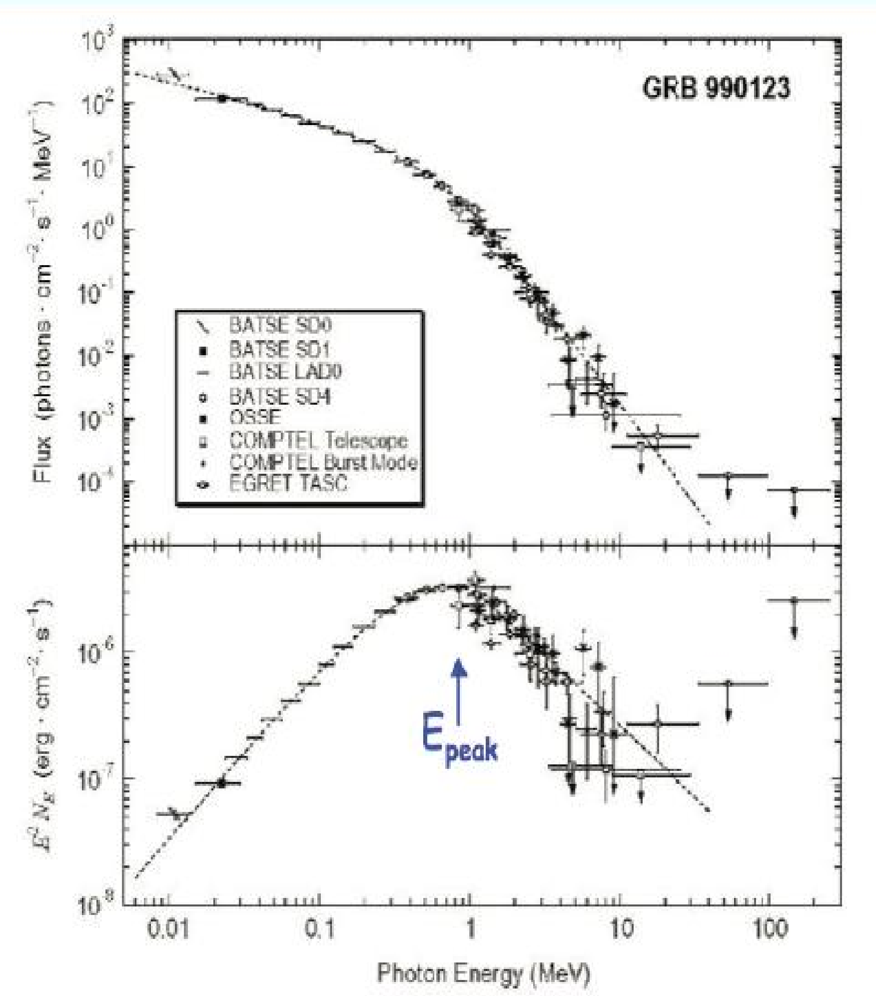
  ～ ms － 1000 s

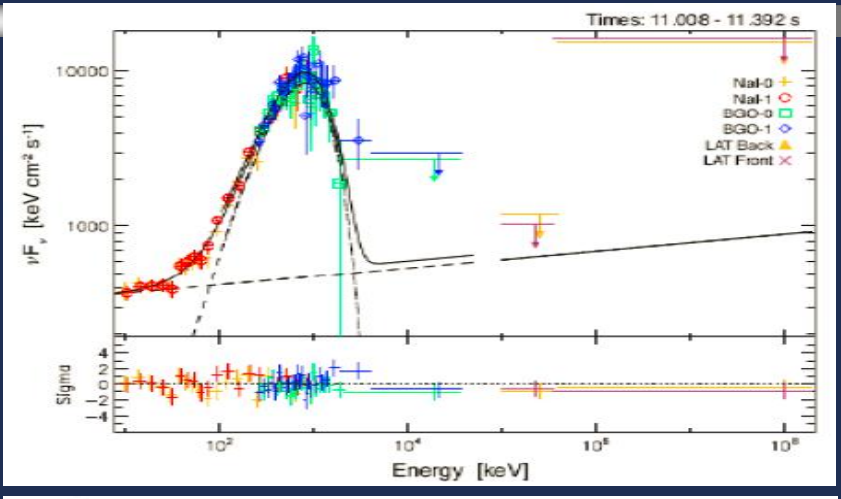
- Time variational

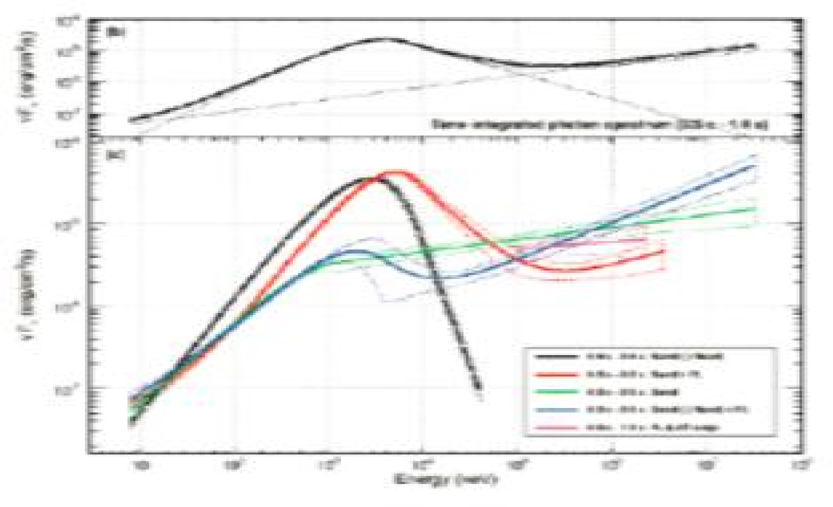
  ～ 1ms ，

  or ～ 0. 1ms

# Non-thermal, smoothly joint broken power law spectrum



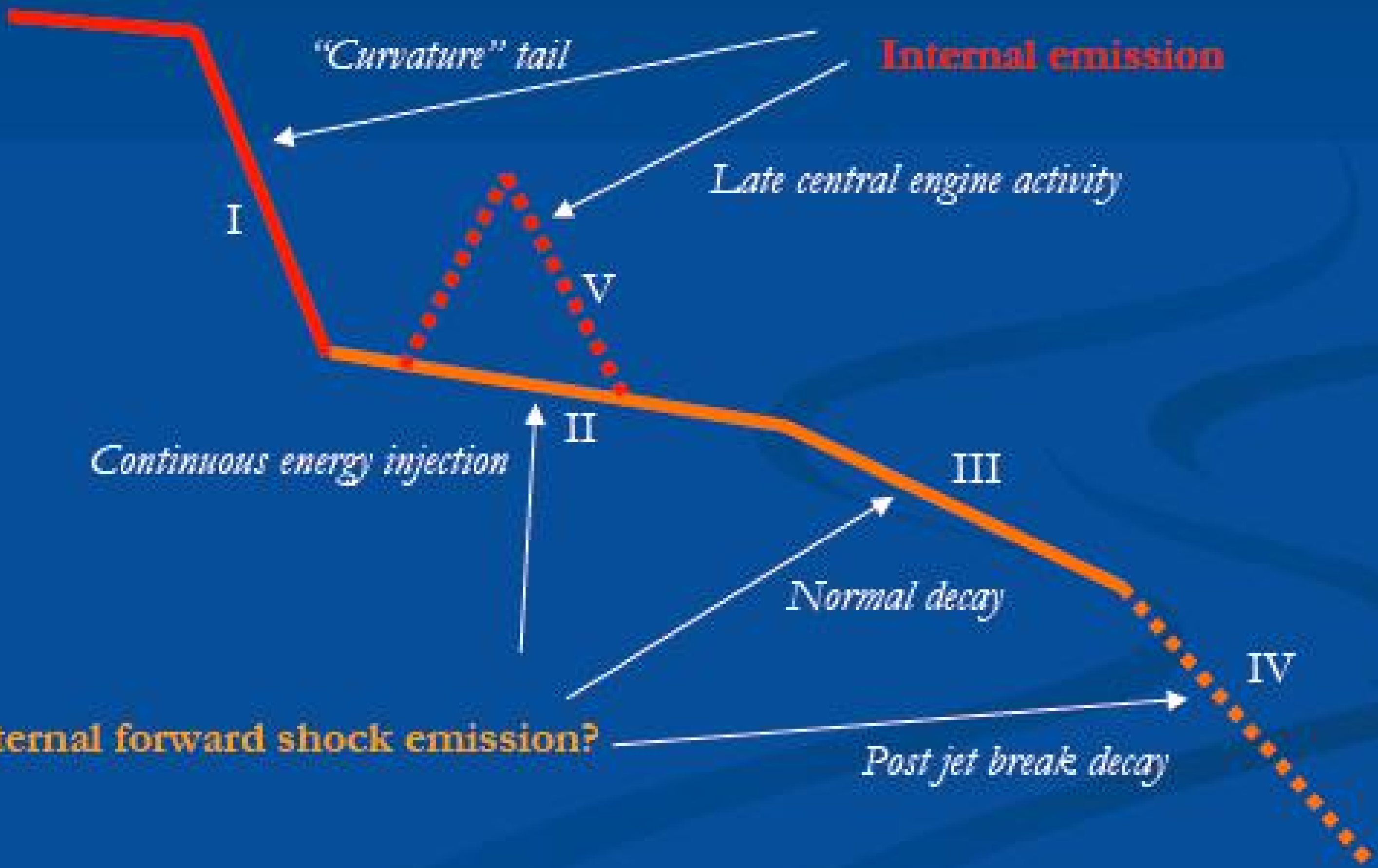




**Briggs et al 1999；Abdo et al 2009**

# Canonical lightcurves: Internal or external?

(Zhang et al. 2006; Nousek et al. 2006)



*"Curvature" tail*

**Internal emission**

*Late central engine activity*

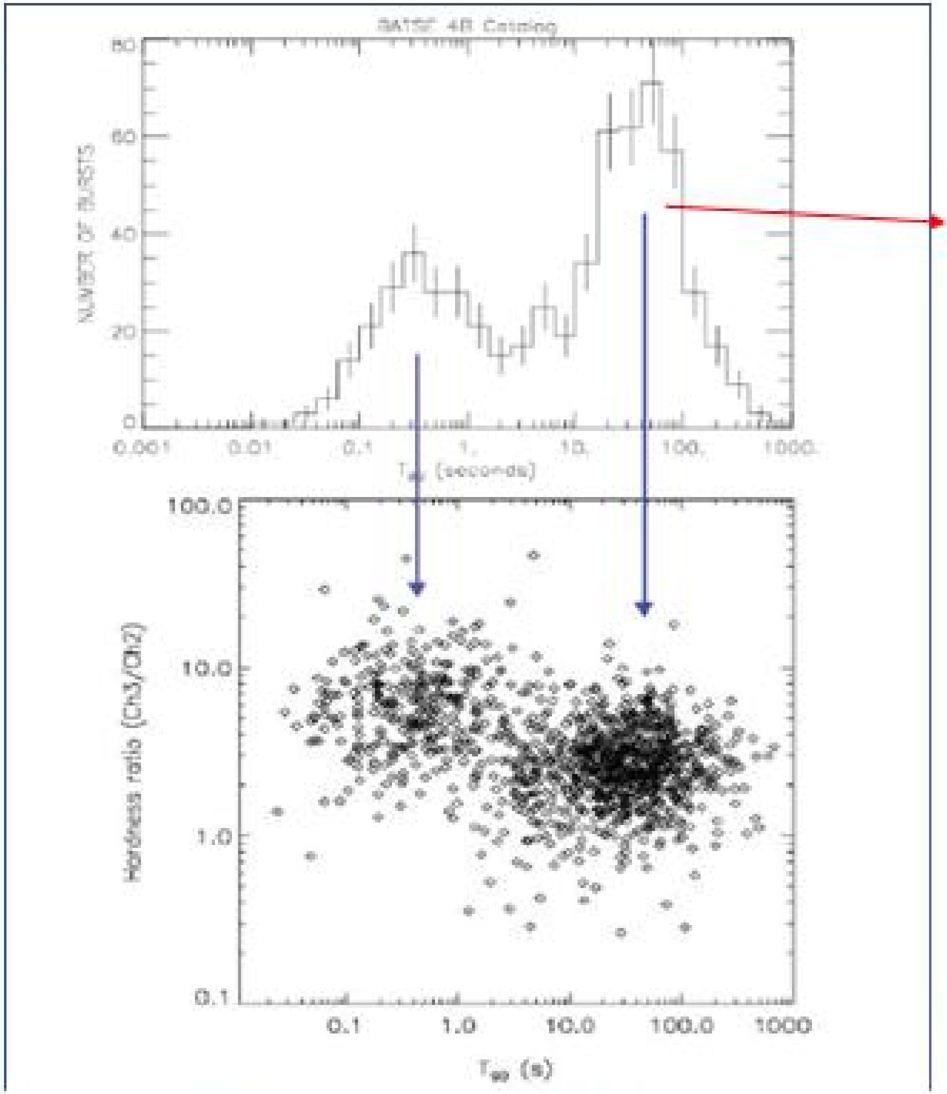
*Continuous energy injection*

*Normal decay*

**External forward shock emission?**

*Post jet break decay*

# Collapsars: model for long GRBs



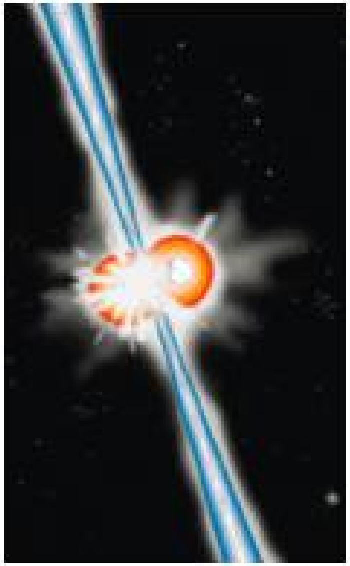
Kouveliotou et al. 1993

Massive stars.
"collapsar" model

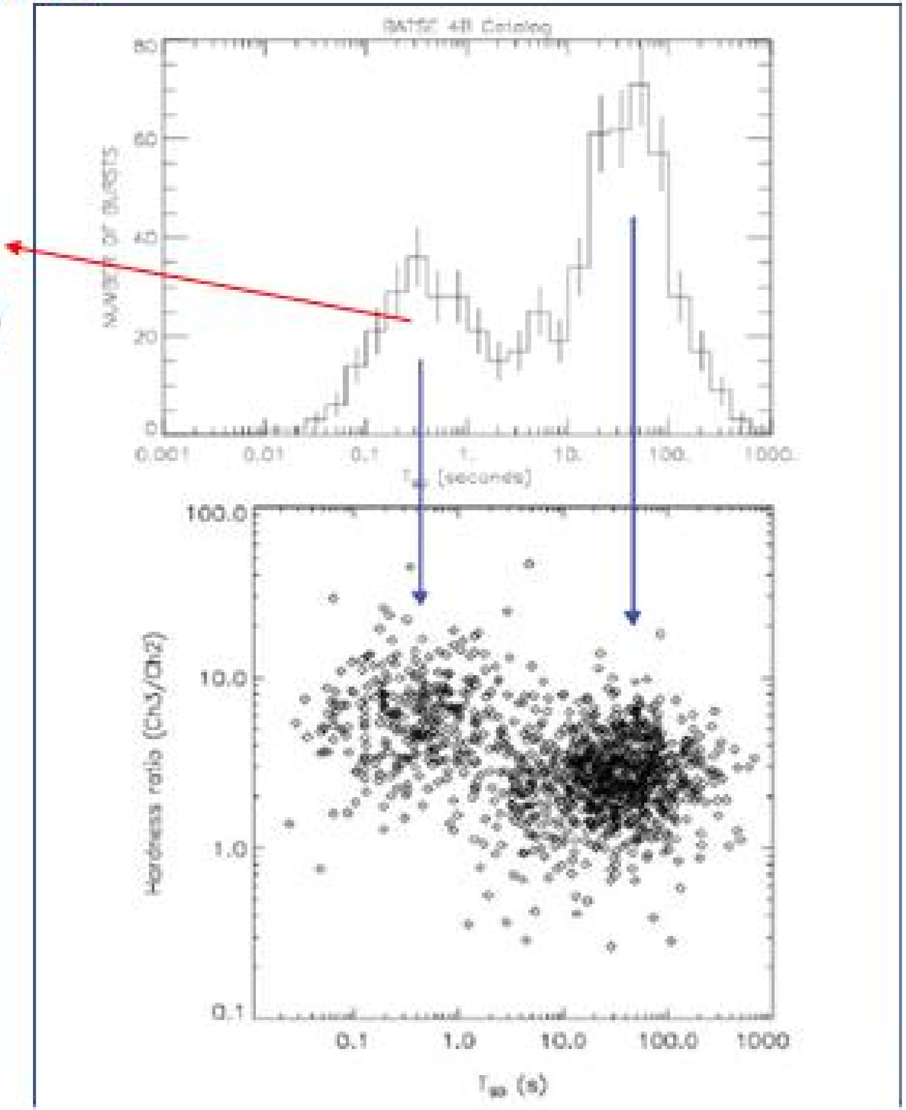
Long/Soft (Type II)

- GRB/SN associations
- Long GRB host galaxies are star-forming galaxies
- With a stellar envelope, the accretion time scale can be "long"

# Compact star mergers: model for short GRBs



Mergers of two compact
NS-NS and NS-BH systems
Short/Hard (Type I)



- None has a SN signature.
- Typically at outskirts of the host galaxies
- In regions of low star formation in star-forming galaxies
- Numerical simulations suggest that the durations of the bursts are typically “short”

# Two types of central engines

(1) Black hole + accretion disk systems (Eichler et al. 1989; Woosley 1993; Narayan et al. 2001; MacFadyen et al. 2001):

$$L_{\rm GRB} = \zeta \dot{M} c^2 = 1.8 \times 10^{51} \ {\rm erg\ s^{-1}} \ \zeta_{-3} \left( \frac{\dot{M}}{1 \ {\rm M_\odot \ s^{-1}}} \right)$$

Neutrino-dominated accretion flow

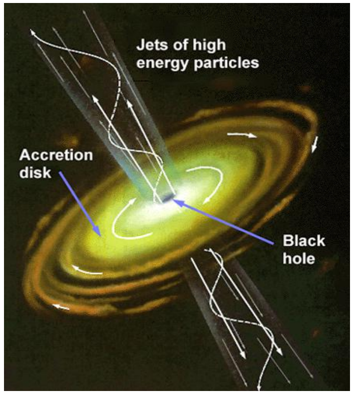
**High accretion rate--hot plasma ---Close to the inner disk---neutrino cooling effective--disk temperature drops, density increases,**

**Spin energy of the BH → Blandford-Znajek mechanism:**

$L_{BZ} \sim 3*10^{50} B_{15}^2 (M_{BH}/3M_{sun})^2 a^2 f(a)$ erg s$^{-1}$

for $a \sim 1$, $M_{BH} \sim 3M_{sun}$ and $B \sim 10^{15}$ Gauss.

(Poynting-flux dominated outflow)



# Q: If a black hole may not be formed immediately, but instead that a highly magnetised rapidly rotating pulsar, or magnetar may formed

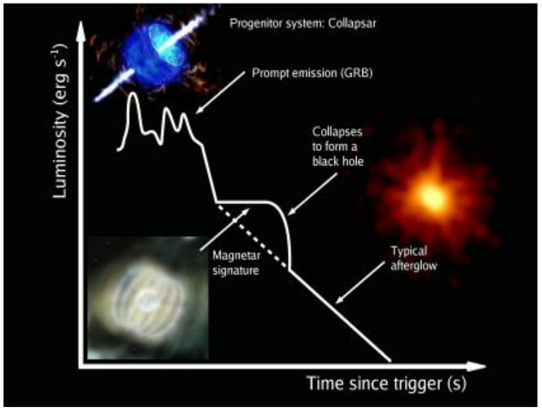
**(2) Millisecond magnetar** (rapidly spinning-highly magnetized neutron star)

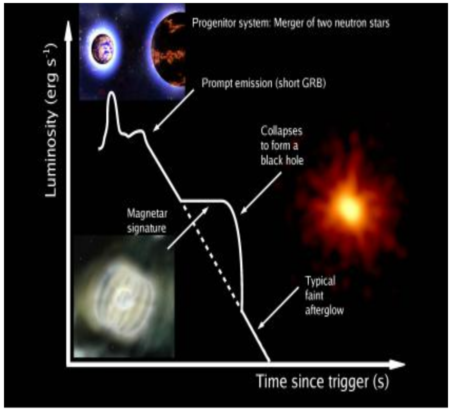
**Rotational energy** (Usov 1992; Duncan & Thompson 1992; Dai \& Lu 1998; Metzger et al 2011)

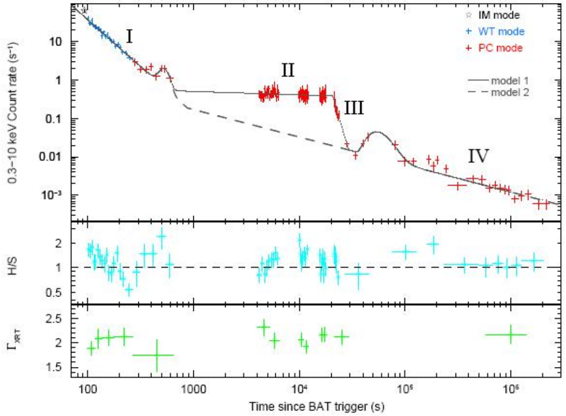
$$P(t) = P_0\left(1 + \frac{4\pi^2}{3c^3}\frac{B_p^2 R^6}{I P_0^2} t\right)^{1/2}$$

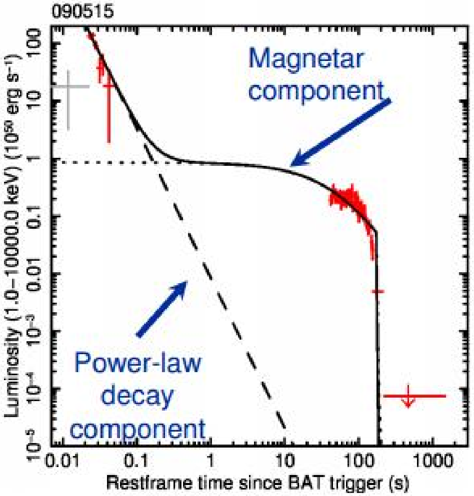
$$= P_0\left(1 + \frac{t}{\tau}\right)^{1/2}$$

$$M_{max} = M_{TOV}(1 + \alpha P^{\beta})$$

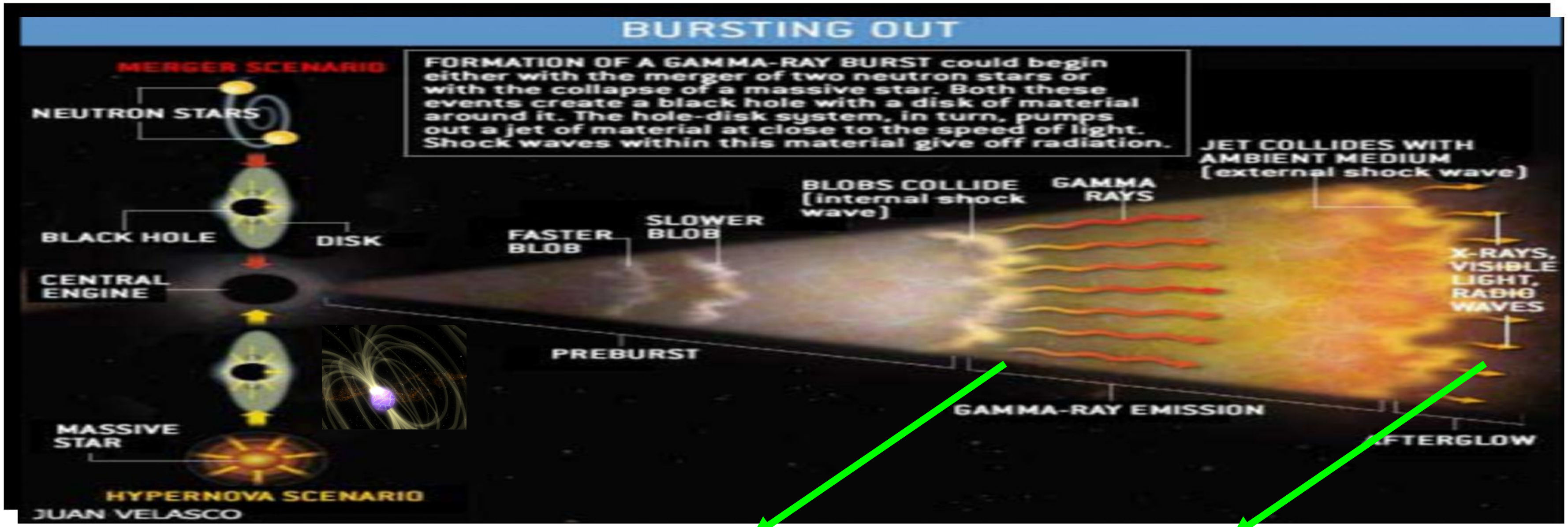








# Picture of Standard fireball model



FORMATION OF A GAMMA-RAY BURST could begin either with the merger of two neutron stars or with the collapse of a massive star. Both these events create a black hole with a disk of material around it. The hole-disk system, in turn, pumps out a jet of material at close to the speed of light. Shock waves within this material give off radiation.

**Internal shock ?**

**magnetic dissipation?**

**photosphere ?**

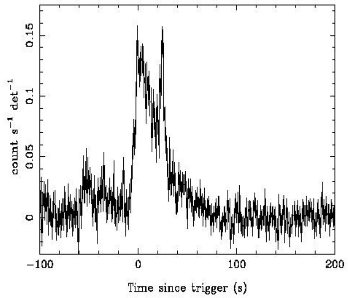
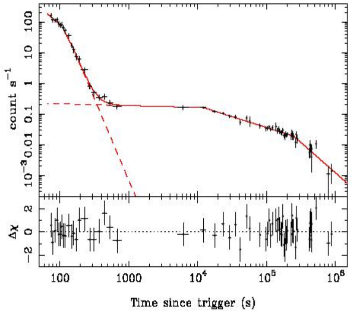


FIG. 1.— BAT light curve of GRB 050315 in 1 s bins.



## Prompt emission

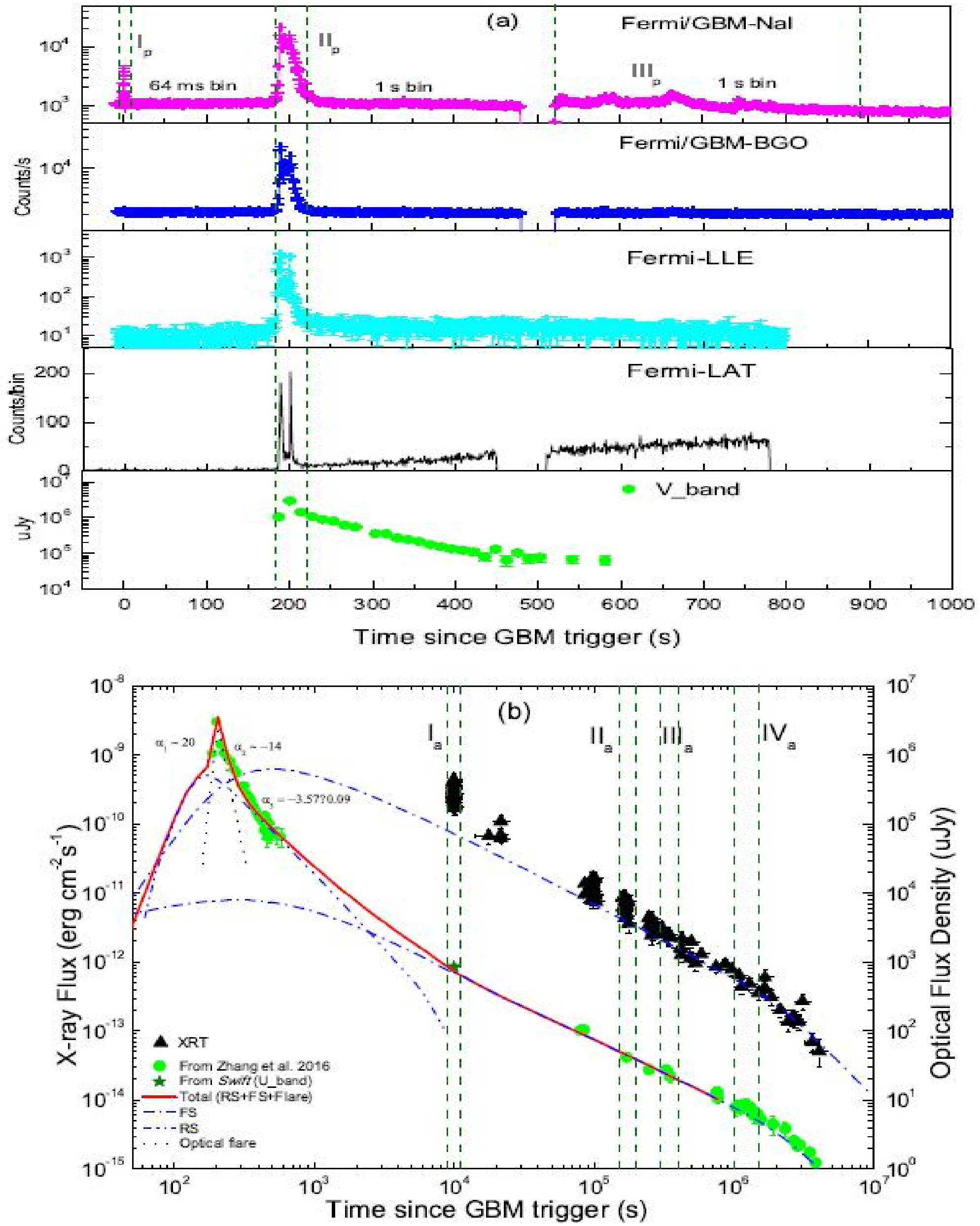
## Afterglow emission

**External shock**

M\eszaros and Rees, 1993; Rees and Meszaros, 1994; Vaughan et al. 2005

# GRB 160625B

- Observed by Swift and Fermi
- Three episodes emission
  - a short-hard precursor
  - bright main emission
  - long-term extended emission
- Duration: tens of seconds
- z=1.406
- $E_{iso,r}$~$3*10^{54}$ erg, $L_{iso}$~$4*10^{53}$ erg/s

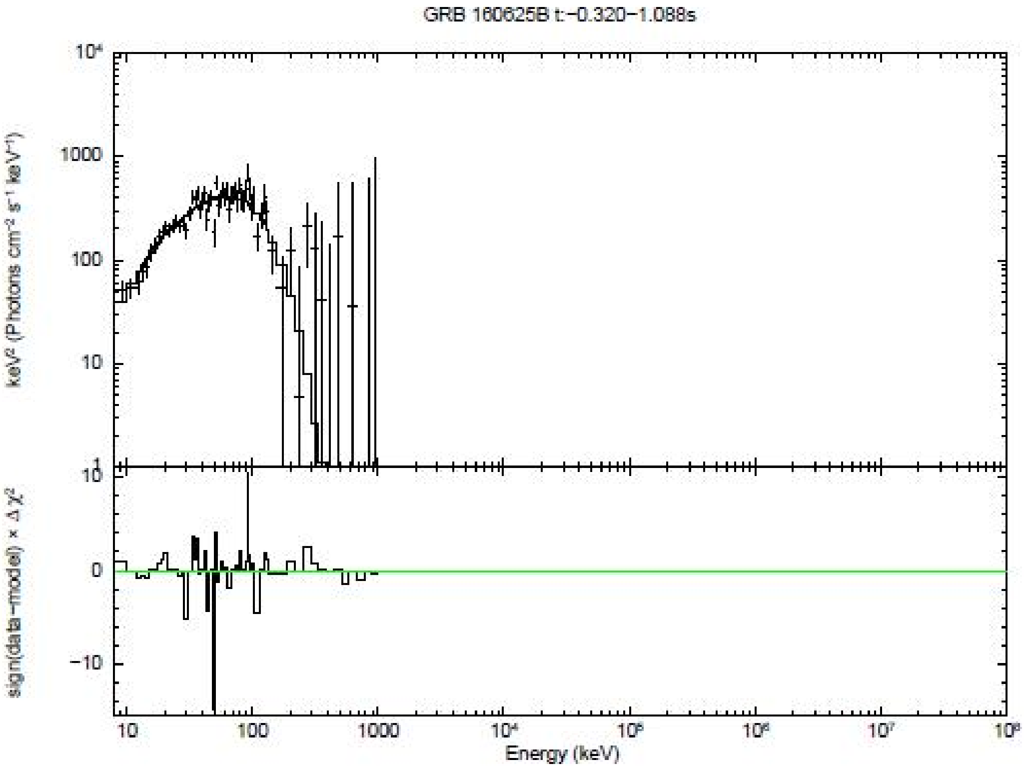


# Thermal spectra

## Multi-color blackbody (mBB)

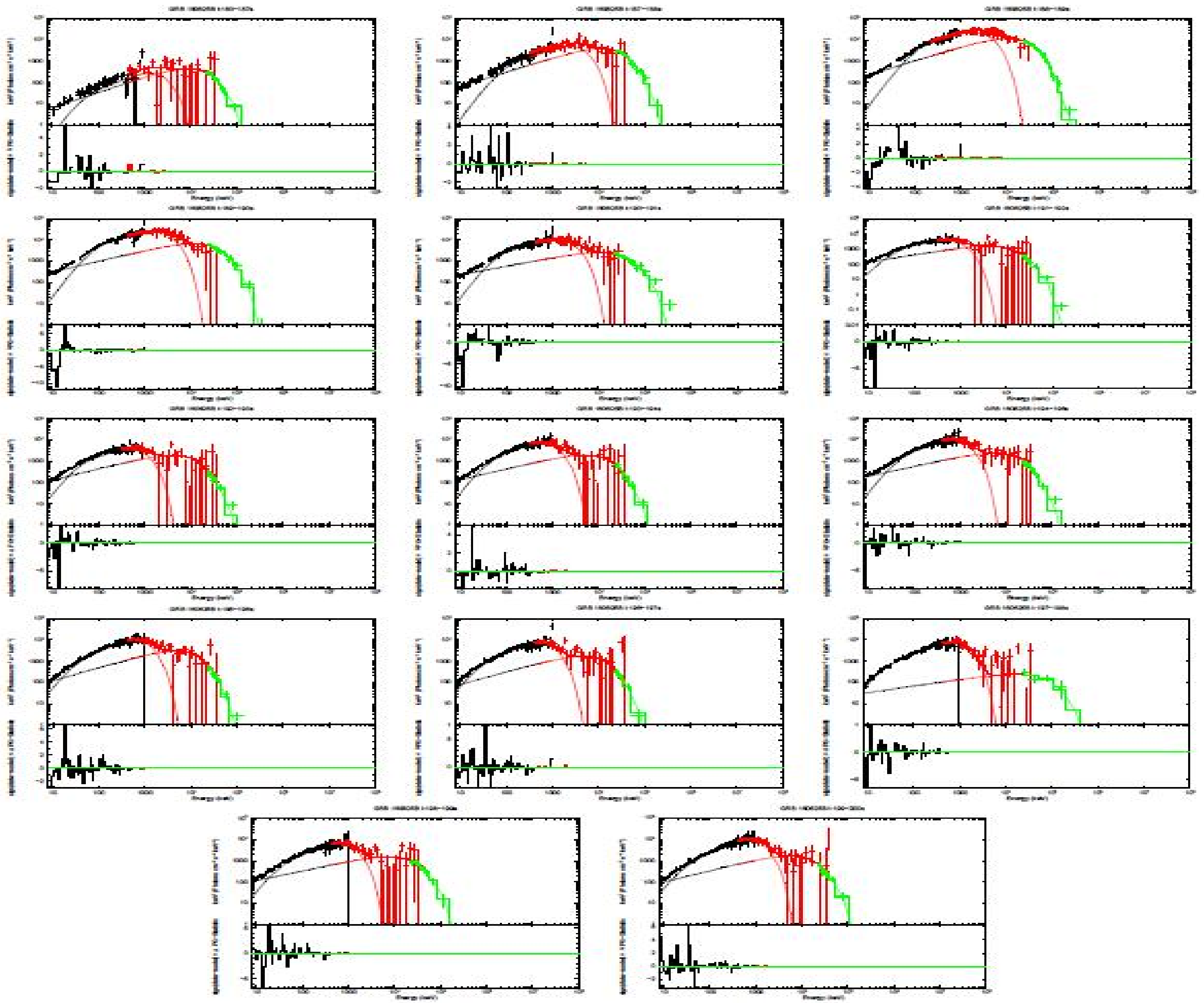
$$F_{\mathrm{MBB}}(\mathrm{E}, \mathrm{T}_{\max}) = \int_{\mathrm{T}_{\min}}^{\mathrm{T}_{\max}} \frac{\mathrm{dA(T)}}{\mathrm{dT}} \frac{\mathrm{E}^3}{\exp[\mathrm{E/kT}] - 1} \qquad F(T) = F_{\max}\left(\frac{T}{T_{\max}}\right)^q$$

Ryde et al (2010)

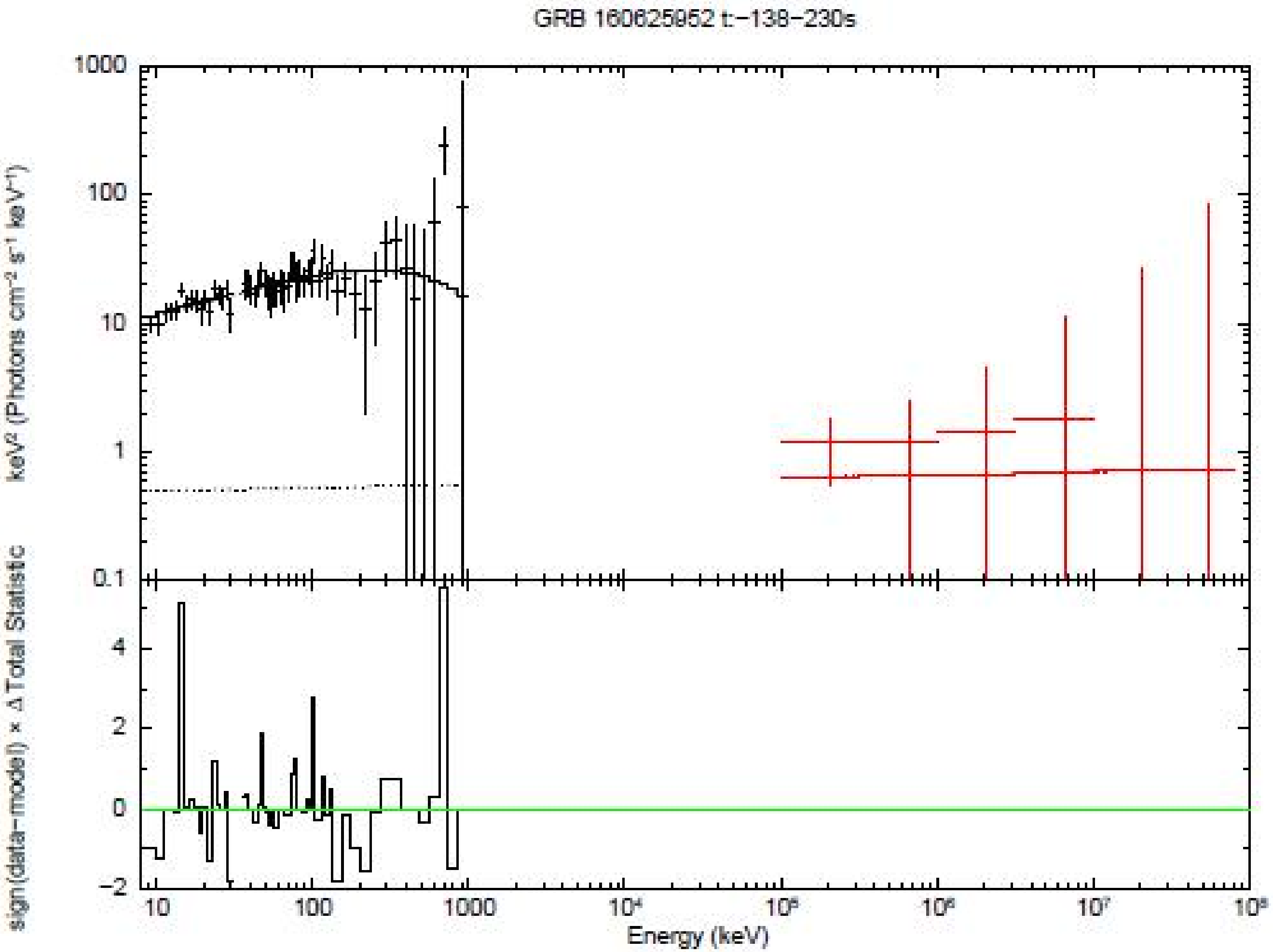


Precursor

# Main emission: (MBB+CPL)



# Extend emission: (CPL+PL)



# Estimated Lorentz factor

$$\Gamma_0 = [(0.16)(1+z)^2 D_{\rm L} \frac{Y \sigma_{\rm T} F^{\rm obs}}{2 m_{\rm p} c^3 \Re}]^{1/4} \qquad \Re = (\frac{F^{\rm obs}_{\rm BB}}{\sigma T^4_{\rm max}})^{1/2} \qquad F^{\rm obs} = F^{\rm obs}_{\rm BB} + F^{\rm obs}_{\rm non-BB}$$

Pe'er et al (2007)

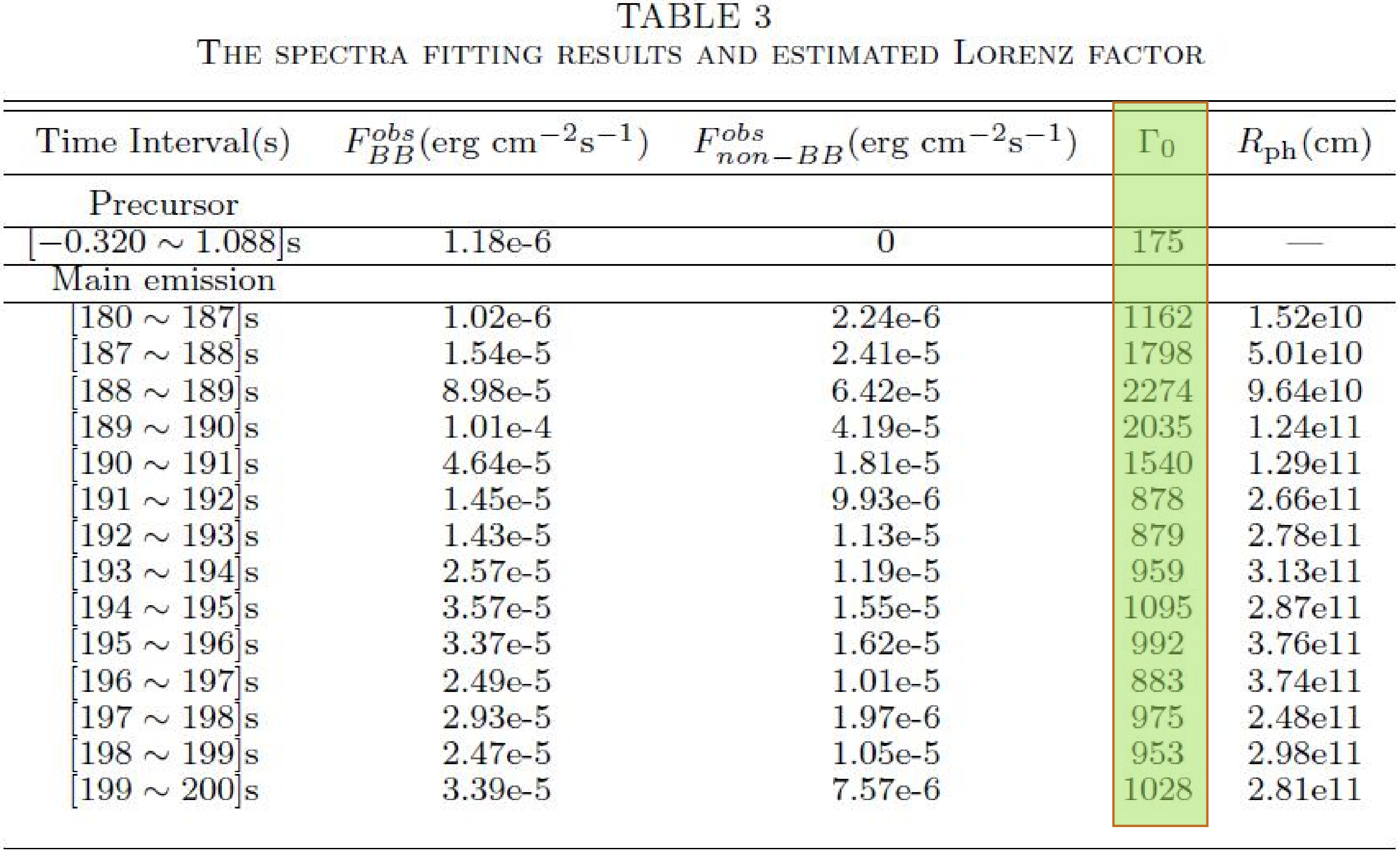
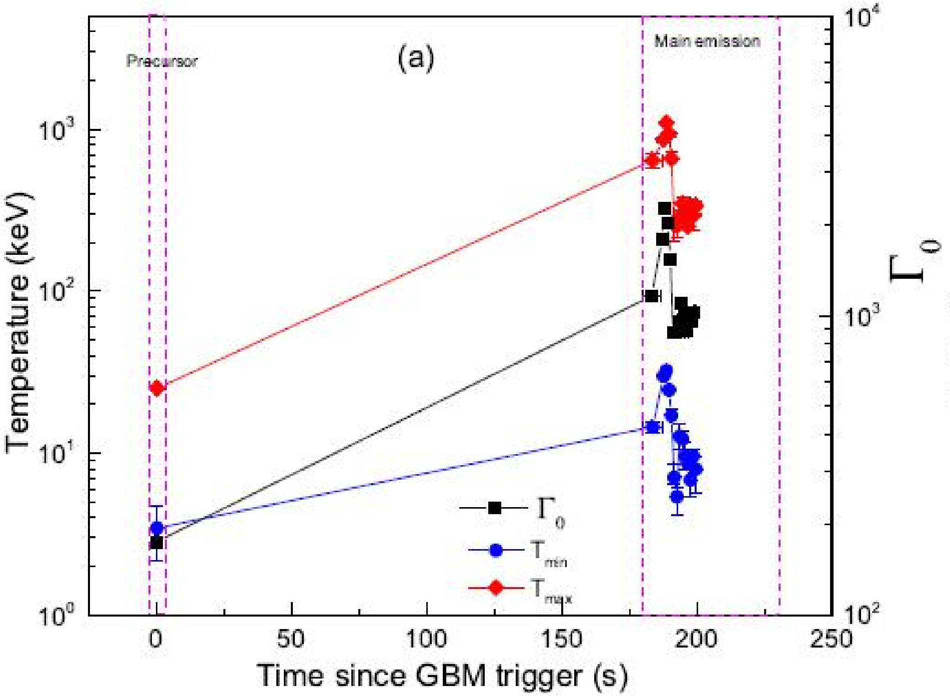


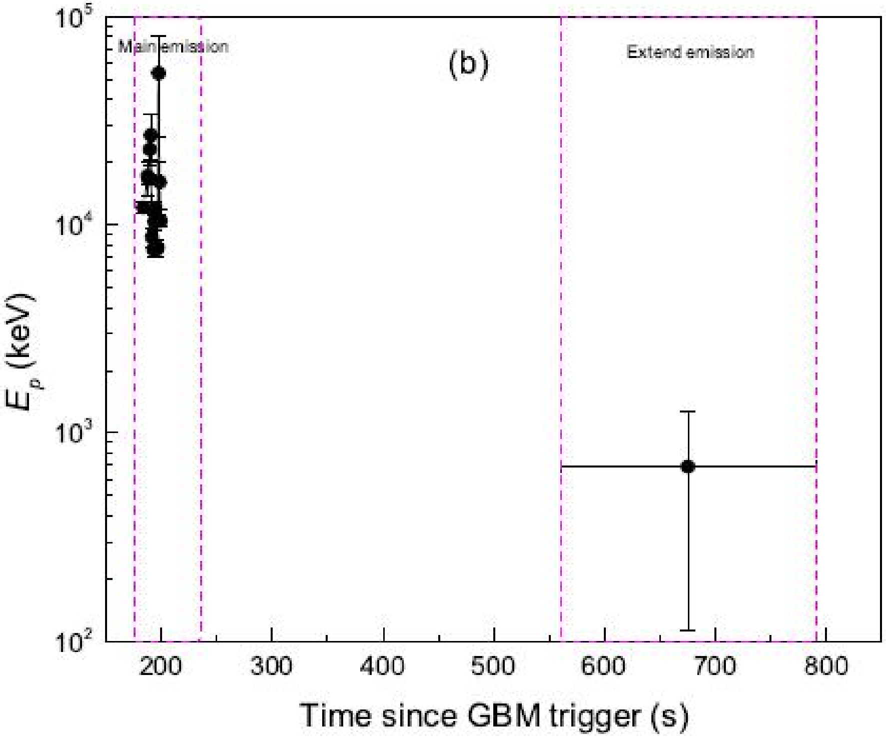
TABLE 3

THE SPECTRA FITTING RESULTS AND ESTIMATED LORENZ FACTOR

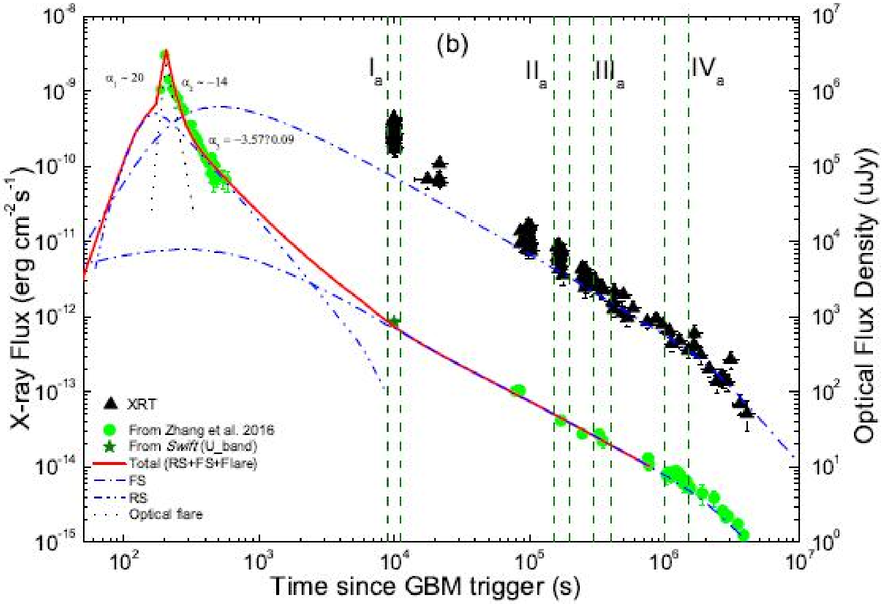
| Time Interval(s) | $F^{obs}_{BB}$(erg cm$^{-2}$s$^{-1}$) | $F^{obs}_{non-BB}$(erg cm$^{-2}$s$^{-1}$) | $\Gamma_0$ | $R_{\rm ph}$(cm) |
|---|---|---|---|---|
| Precursor | | | | |
| $[-0.320 \sim 1.088]$s | 1.18e-6 | 0 | 175 | — |
| Main emission | | | | |
| $[180 \sim 187]$s | 1.02e-6 | 2.24e-6 | 1162 | 1.52e10 |
| $[187 \sim 188]$s | 1.54e-5 | 2.41e-5 | 1798 | 5.01e10 |
| $[188 \sim 189]$s | 8.98e-5 | 6.42e-5 | 2274 | 9.64e10 |
| $[189 \sim 190]$s | 1.01e-4 | 4.19e-5 | 2035 | 1.24e11 |
| $[190 \sim 191]$s | 4.64e-5 | 1.81e-5 | 1540 | 1.29e11 |
| $[191 \sim 192]$s | 1.45e-5 | 9.93e-6 | 878 | 2.66e11 |
| $[192 \sim 193]$s | 1.43e-5 | 1.13e-5 | 879 | 2.78e11 |
| $[193 \sim 194]$s | 2.57e-5 | 1.19e-5 | 959 | 3.13e11 |
| $[194 \sim 195]$s | 3.57e-5 | 1.55e-5 | 1095 | 2.87e11 |
| $[195 \sim 196]$s | 3.37e-5 | 1.62e-5 | 992 | 3.76e11 |
| $[196 \sim 197]$s | 2.49e-5 | 1.01e-5 | 883 | 3.74e11 |
| $[197 \sim 198]$s | 2.93e-5 | 1.97e-6 | 975 | 2.48e11 |
| $[198 \sim 199]$s | 2.47e-5 | 1.05e-5 | 953 | 2.98e11 |
| $[199 \sim 200]$s | 3.39e-5 | 7.57e-6 | 1028 | 2.81e11 |

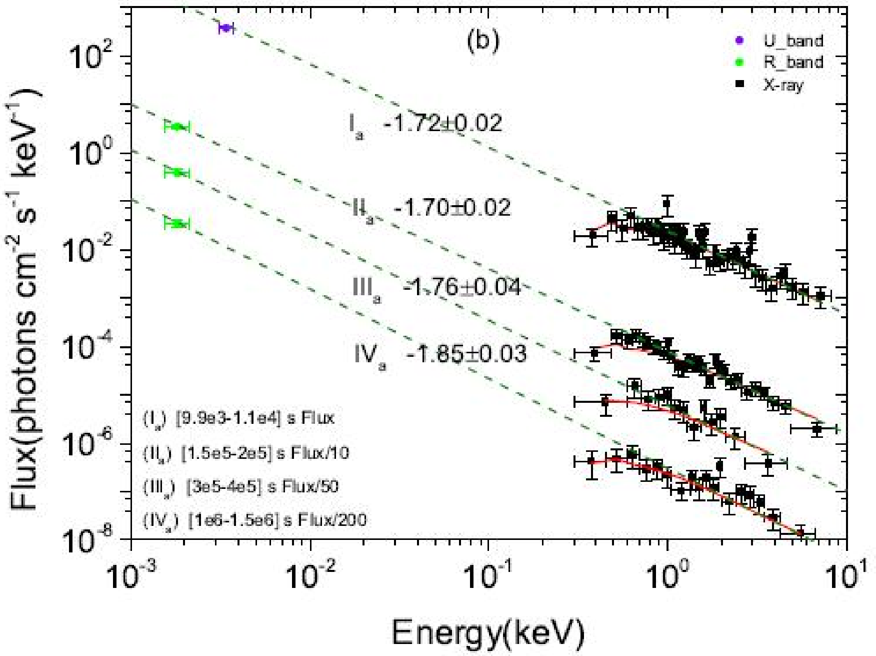
# Evolution of T_min, T_max, and Gamma_0





# Multi-wavelenght spectra





**Consistent with external shocks**

$$\theta_{\mathrm{j}} = 12.04^\circ \pm 2.23^\circ$$

$$E_{\mathrm{K,iso}} = (1.72 \pm 0.12) \times 10^{55}\mathrm{erg}$$

# Central engine

$E_K = E_{K,iso} f_b$ $\quad$ $E_\gamma = E_{\gamma,iso} f_b$ $\quad$ $f_b = 1 - \cos\theta_j \simeq (1/2)\theta_j^2,$

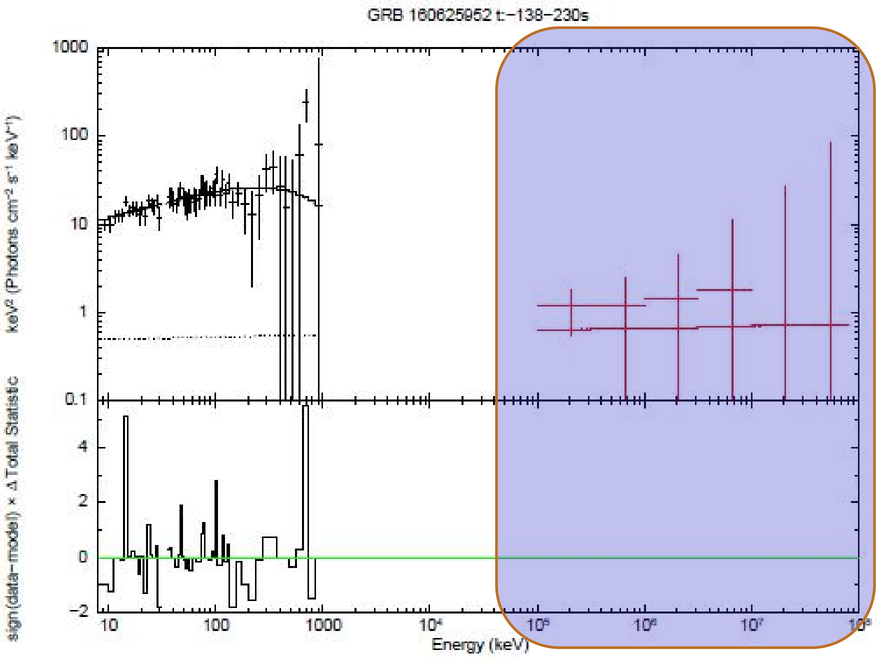
**Magnetar (×):** $E_{\rm rot} = \frac{1}{2} I \Omega_0^2 \simeq 2 \times 10^{52}\ {\rm erg}\ M_{1.4} R_6^2 P_{0,-3}^{-2}$

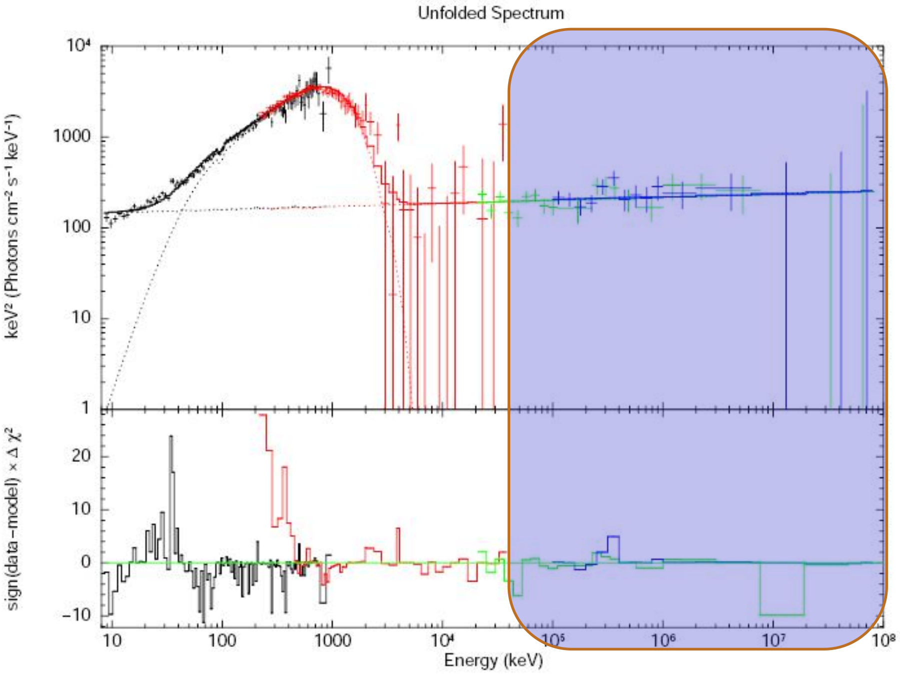
$$E_\gamma + E_{\rm K} \gg E_{\rm rot},$$

**NDAF model (√):** $L_{\nu\bar{\nu}} \simeq 1.1 \times 10^{52} {\rm erg\ s^{-1}} (\frac{\rm M}{\rm M_\odot})^{-3/2} (\frac{\rm \dot{M}}{\rm M_\odot/s})^{9/4}$

# High energy emission with LHAASO

GRB的高能峰在哪？高能辐射区域在哪？高能粒子的加速机制？





# Conclusions

- **Long-team evolution of ejecta**
  - precursor---> photosphere
  - Main emission--->photosphere+internal shock
  - Extend emission--->internal shock
- **Early optical and later X-ray**
  - likely a prompt optical, but has reversed shock contributions.
  - later afterglow is consistent with standard external shock model.
- **Central engine: NDAF model**

# Thanks