曲阜師範大學
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短伽玛暴脉冲统计特性及其对外流结构和演化的意义
Properties of Short GRB Pulses in the Fourth BATSE Catalog: Implications for the Structure and Evolution of the Jetted Outflows

(Li et al., 2020a, ApJ, 892,113)

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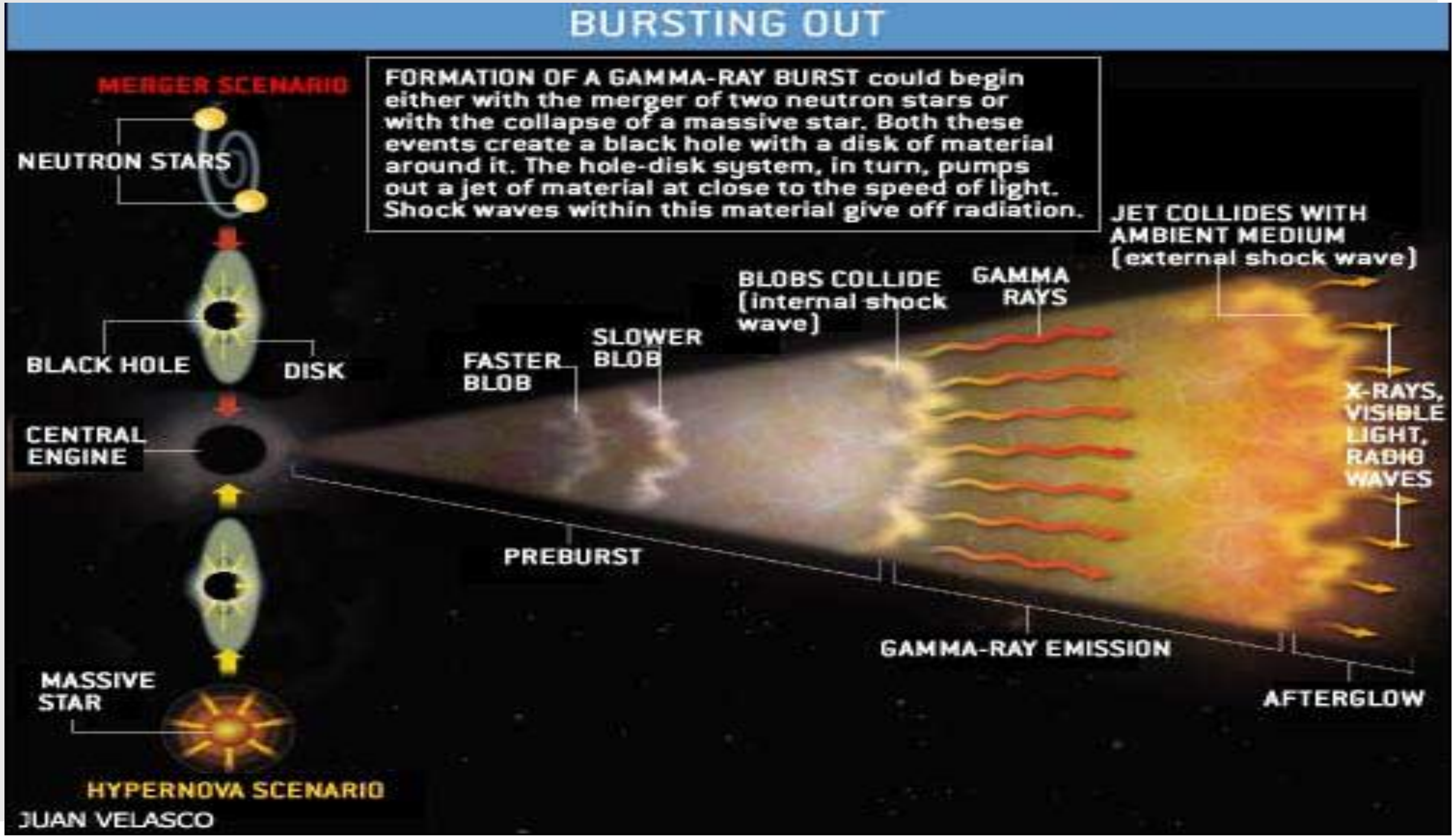
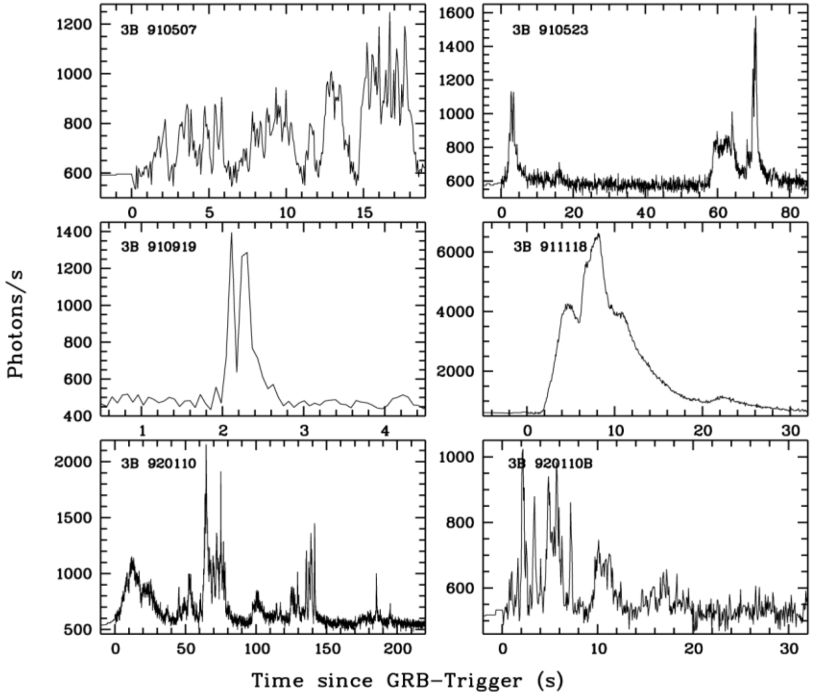


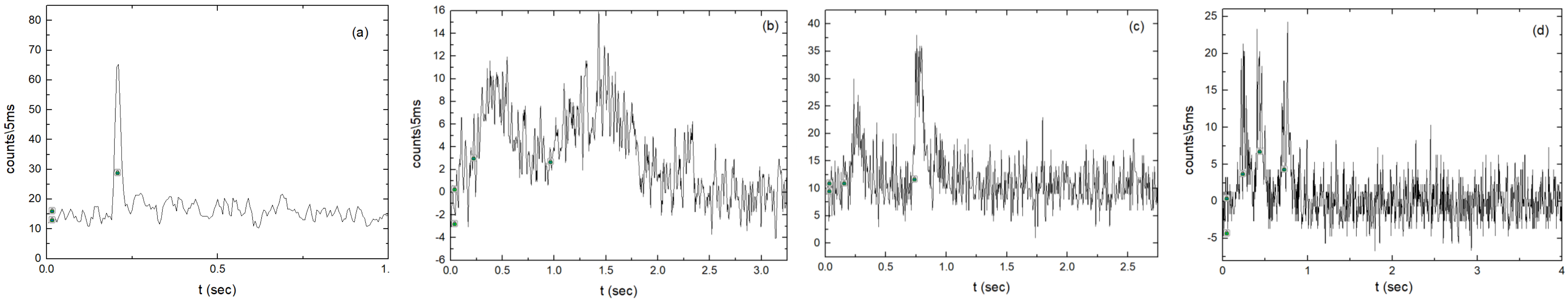
Gehrels et al. 2002



Greiner 1999

Unlike long/intermediate bursts, as many as 90% of short GRBs are single-pulsed. （Hakkila et al. 2018)

1. 研究背景

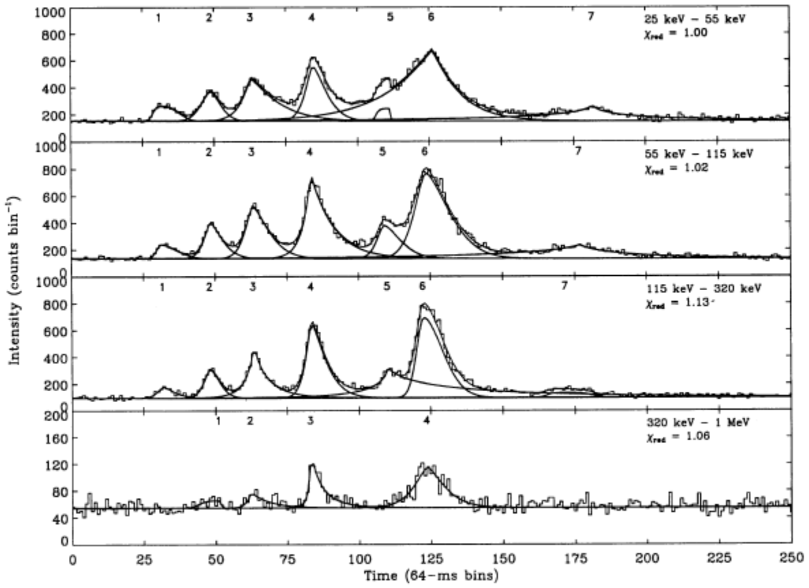


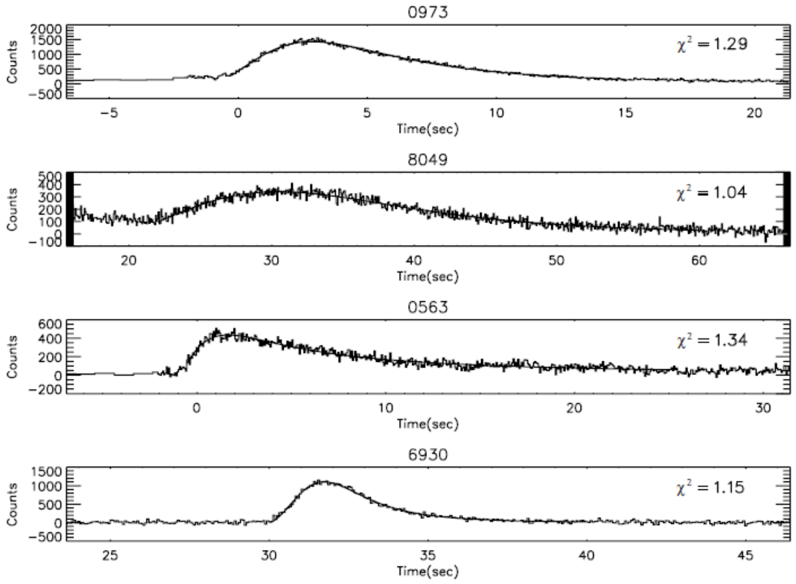
单峰暴与双峰暴，两类双峰暴是否相似？
脉冲形状在不同能道之间是否存在演化？
瞬时伽玛辐射阶段的光变特性-喷流结构？

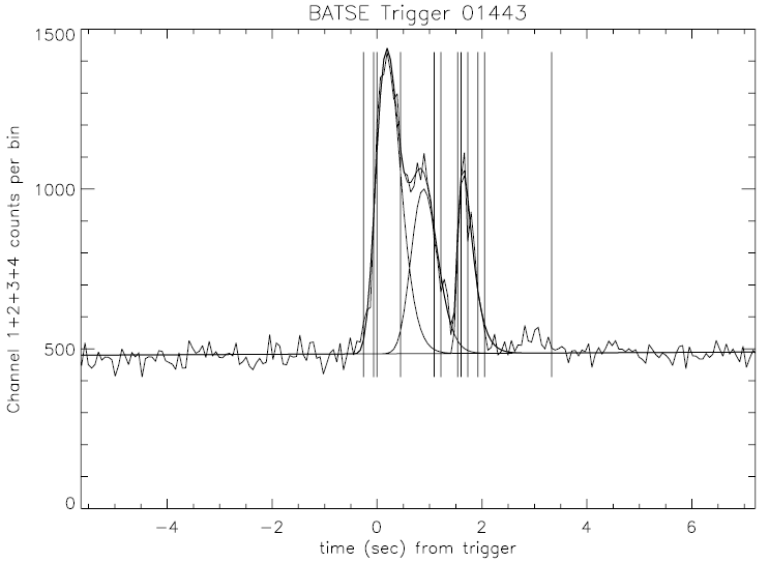
Temporal Properties of Precursors, Main peaks and Extended Emissions of Short GRBs in the Third Swift/BAT GRB Catalog

Li et al., 2020b, ApJS, accepted，**arXiv：2010.10929**

2. 样本选择和处理方法







$$
\begin{aligned}
I(t) &= A \exp\left[-(|t - t_{\max}|/\sigma_r)^{\nu}\right] \quad t < t_{\max}\,, \\
&= A \exp\left[-(|t - t_{\max}|/\sigma_d)^{\nu}\right] \quad t > t_{\max}\,,
\end{aligned}
$$

$$
F(t) = F_m \left(\frac{t}{t_m}\right)^{r} \left[\frac{d}{d+r} + \frac{r}{d+r}\left(\frac{t}{t_m}\right)^{r+1}\right]^{-(r+d)/(r+1)}
$$

$$
I(t) = A\lambda e^{[-\tau_1/(t-t_s)-(t-t_s)/\tau_2]},
$$

Norris et al. 2005

Norris et al. 1996

Kocevski et al. 2003

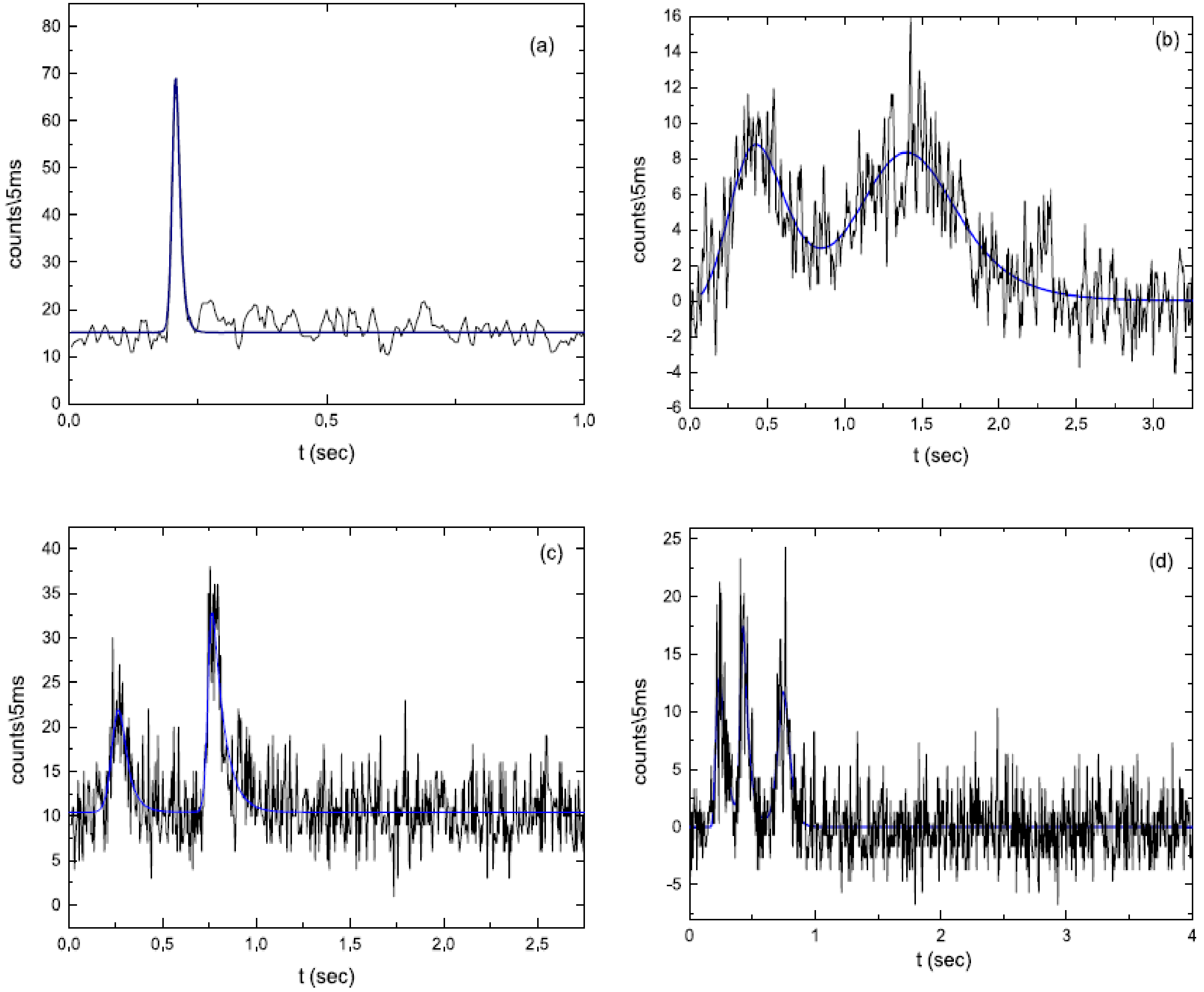
Hakkila et al. (2008,2011,2014,2015,2018)

2. 样本选择和处理方法

- ◆ 100 BATSE sGRBs using 5ms TTE
- ◆ Energy band: Ch1：25keV - 55keV
  Ch2：55keV - 110 keV
  Ch3：110keV - 320 keV
  Ch4：320keV以上

GRBs		数量	比例
Single-peaked (SP)		57	57%
Double-peaked (DP)	Mt-DP	16	16%
	Ml-DP	6	6%
triple-peaked		2	2%
total		81(243)	100%

- ◆ 峰值时间t_m，峰值流量 f_m，半峰全宽 FWHM
- ◆ 上升时间t_r，下降时间t_d，非对称性 t_r/t_d

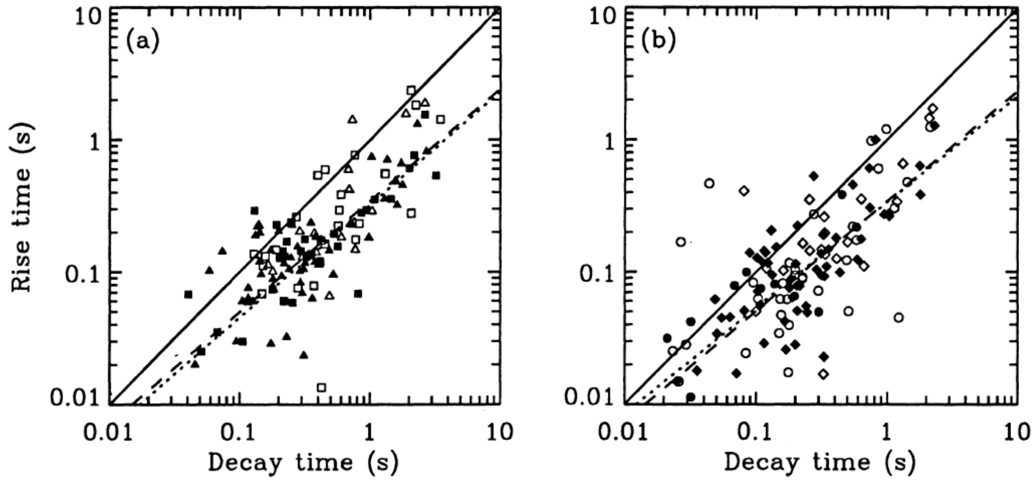


3. BATSE短暴脉冲统计特性及脉冲演化

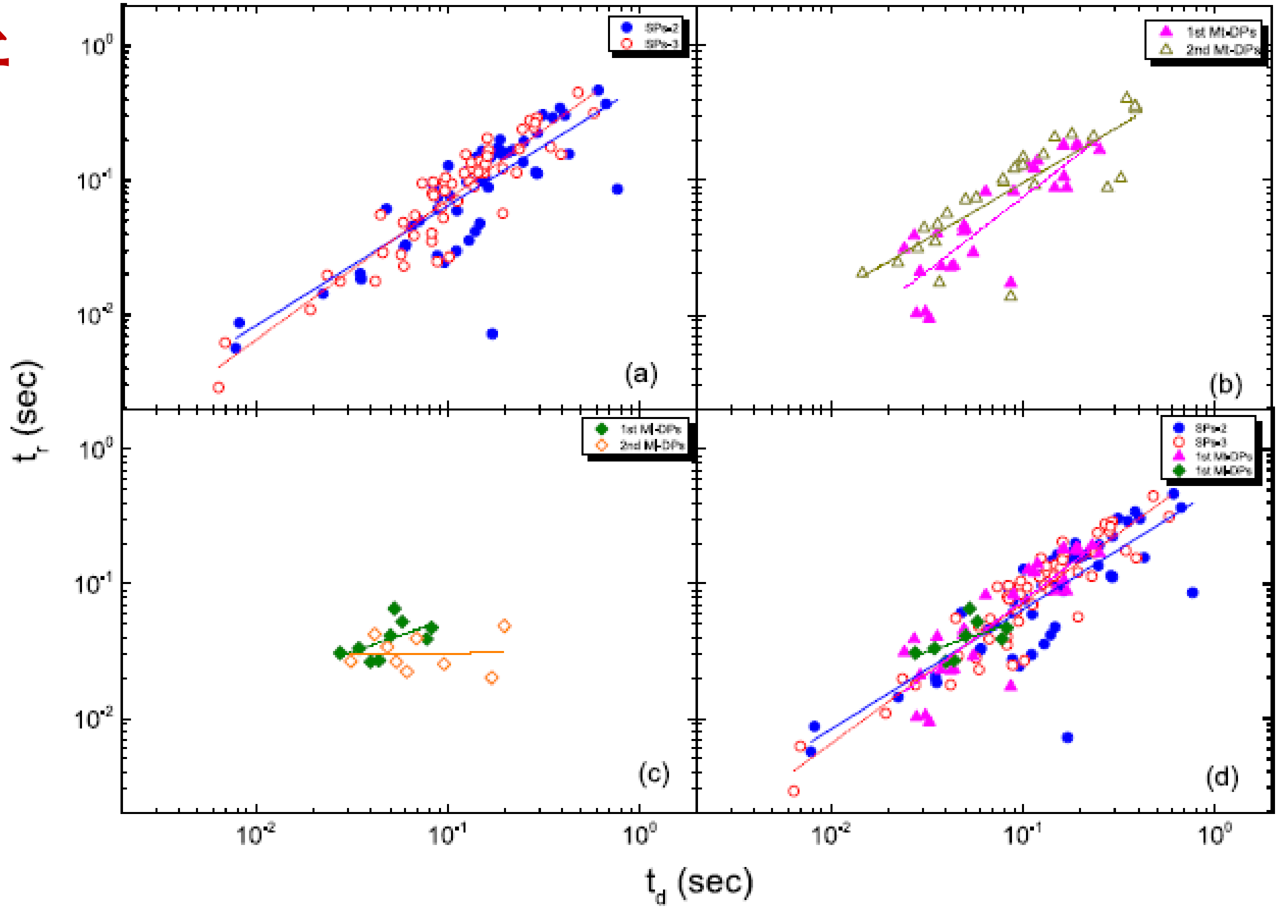
（1）脉冲统计特性的相关性分析

- 上升时间和下降时间的相关性

$$\sigma_r = 0.33\sigma_d^{0.83} .$$



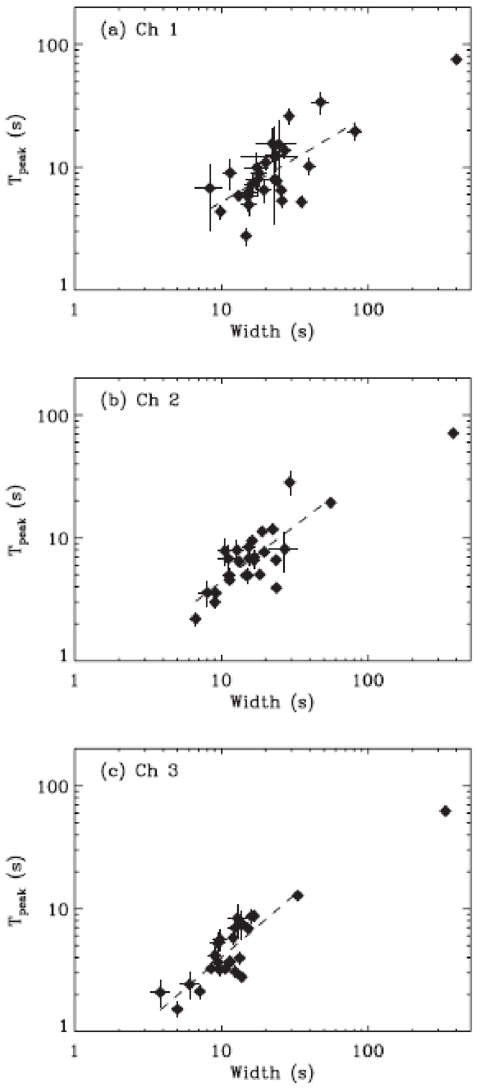
Norris et al. 1996



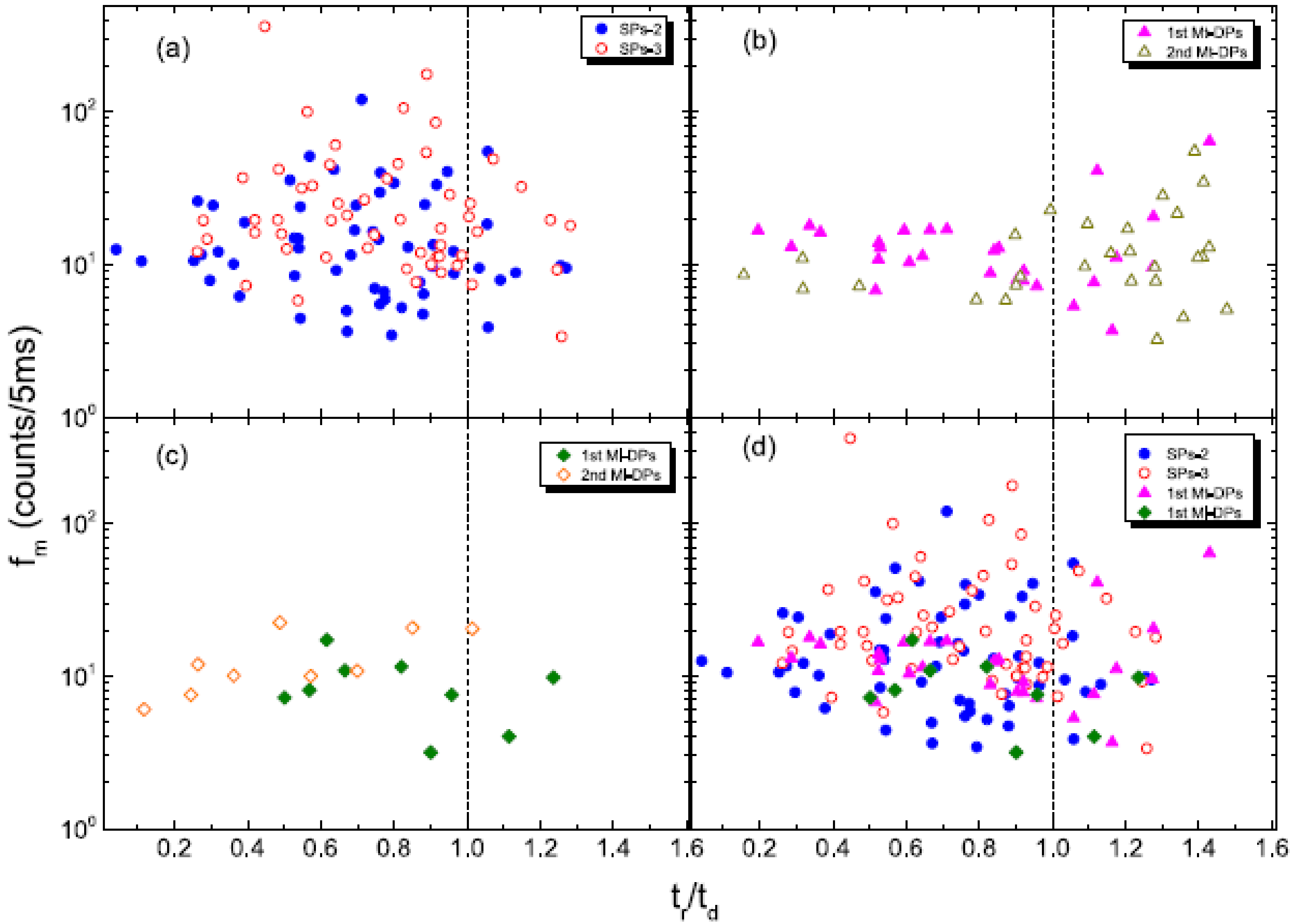
GRB	Class	χ^2_ν	Pearson's r	R	β
SPs	Ch2	3.64	0.80	0.64	0.89 ± 0.09
SPs	Ch3	1.54	0.92	0.85	1.04 ± 0.06
Mt-DPs†	Ch2/3	1.20	0.86	0.73	1.10 ± 0.13
Mt-DPs‡	Ch2/3	1.39	0.84	0.69	0.83 ± 0.11
Ml-DPs†	Ch2/3	0.10	0.57	0.23	0.49 ± 0.27
Ml-DPs‡	Ch2/3	0.14	0.02	−0.14	0.01 ± 0.19

（1）脉冲统计特性的相关性分析

➢ 非对称性与半峰全宽、峰值时间及峰值流量的相关性

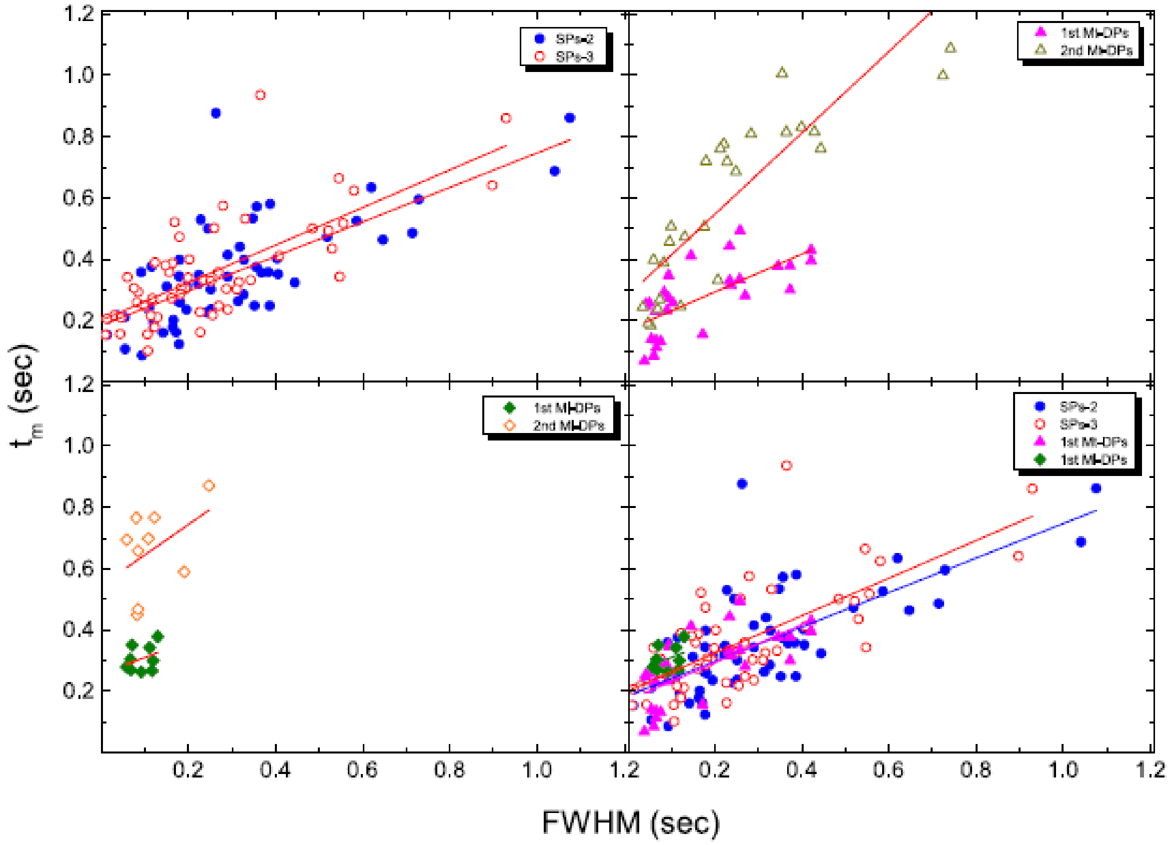


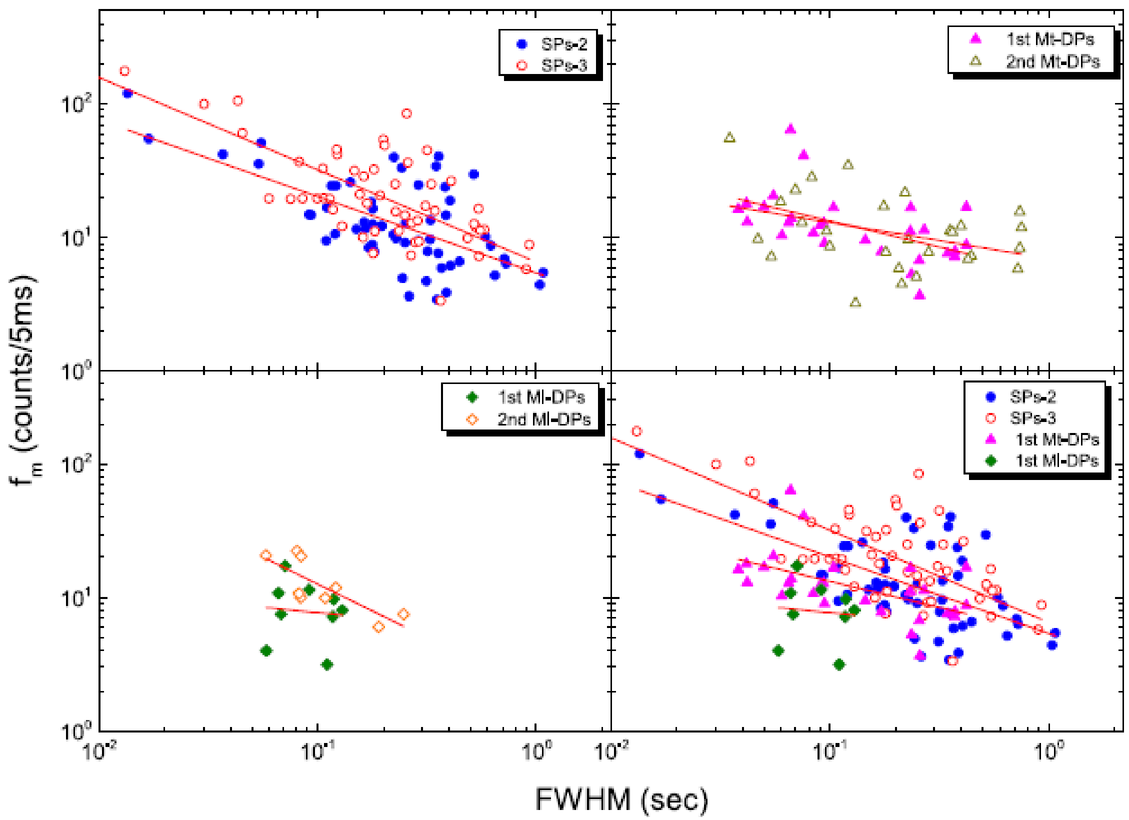
Norris et al. 2005



（1）脉冲统计特性的相关性分析

➢ 半峰全宽和峰值时间及峰值流量的关系

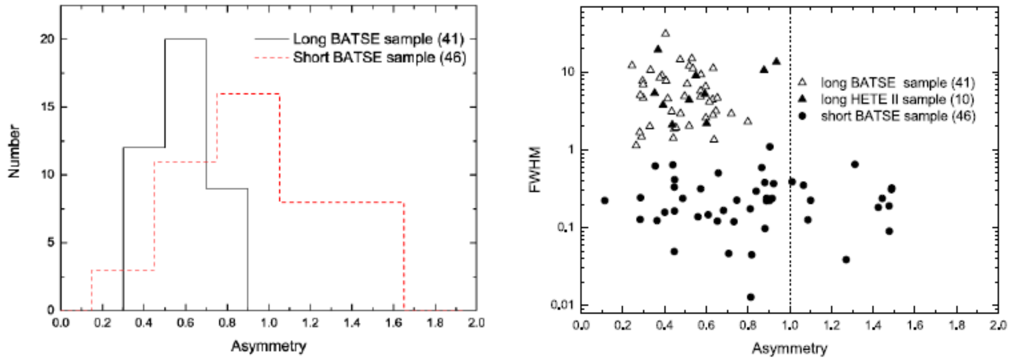




GRB	Class	χ^2_ν	Pearson's r	R	μ
SPs	Ch2	0.78	0.73	0.52	0.56 ± 0.07
SPs	Ch3	0.75	0.72	0.51	0.61 ± 0.08
DPs	Mt-DPs 1st	0.19	0.69	0.45	0.62 ± 0.13
	Mt-DPs 2nd	0.55	0.91	0.81	1.33 ± 0.12
DPs	Ml-DPs 1st	0.01	0.35	0.00	0.54 ± 0.54
	Ml-DPs 2nd	0.13	0.44	0.08	0.99 ± 0.77

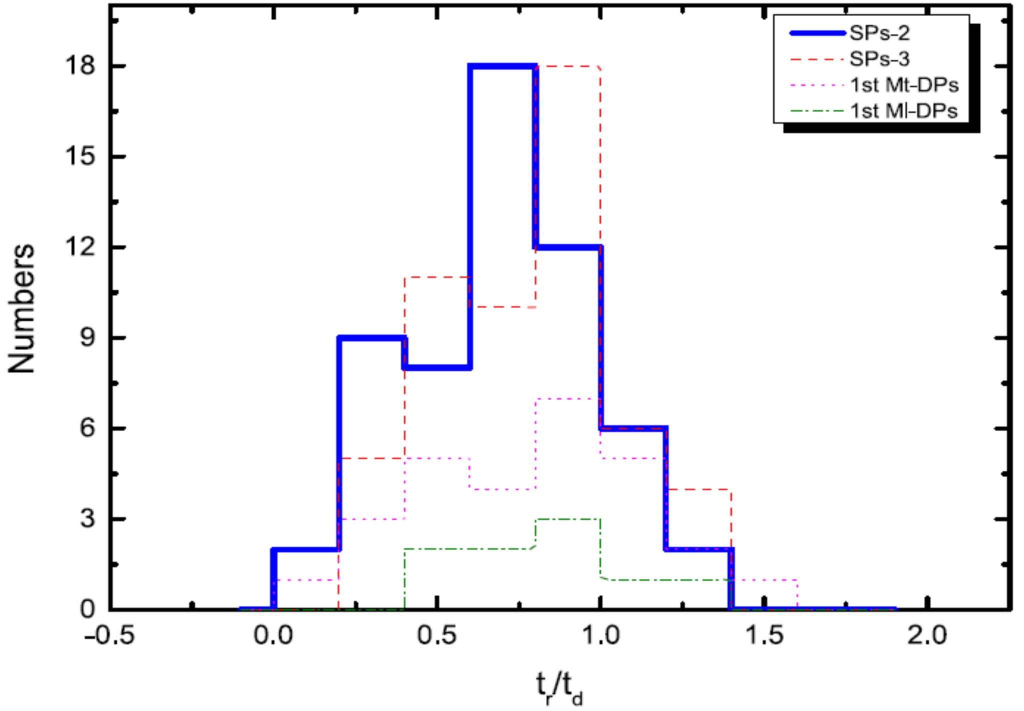
GRB	Class	χ^2_ν	Pearson's r	R	ν
SPs	Ch2	3.63	−0.64	0.40	−0.57 ± 0.09
SPs	Ch3	3.52	−0.73	0.53	−0.69 ± 0.09
DPs	Mt-DPs 1st	1.18	−0.54	0.27	−0.39 ± 0.12
	Mt-DPs 2nd	1.80	−0.38	0.11	−0.27 ± 0.13
DPs	Ml-DPs 1st	0.41	−0.09	−0.13	−0.16 ± 0.65
	Ml-DPs 2nd	0.12	−0.79	0.58	−0.80 ± 0.23

（2）脉冲非对称性的统计特性



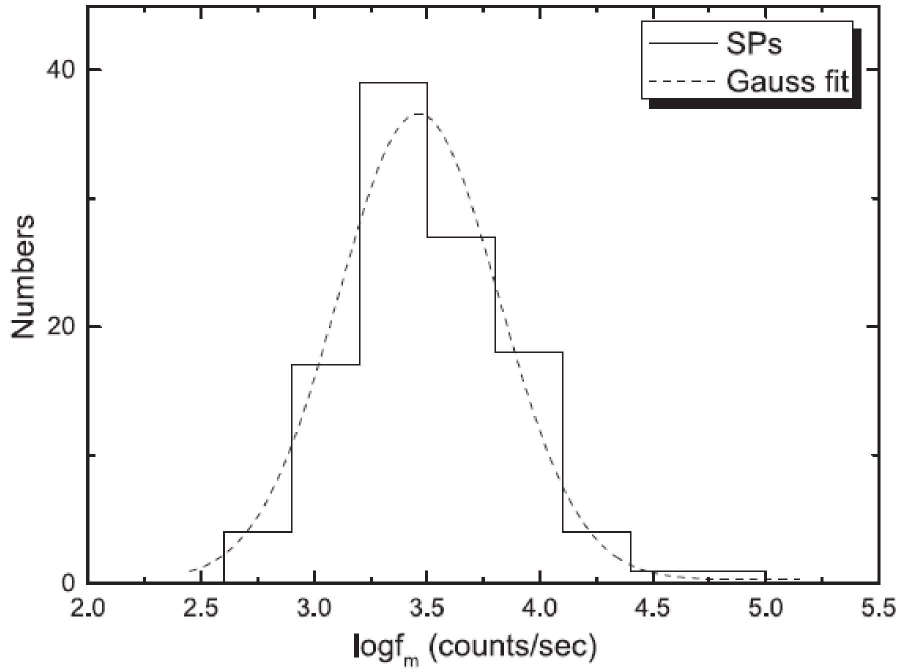
Zhang & Xie 2007

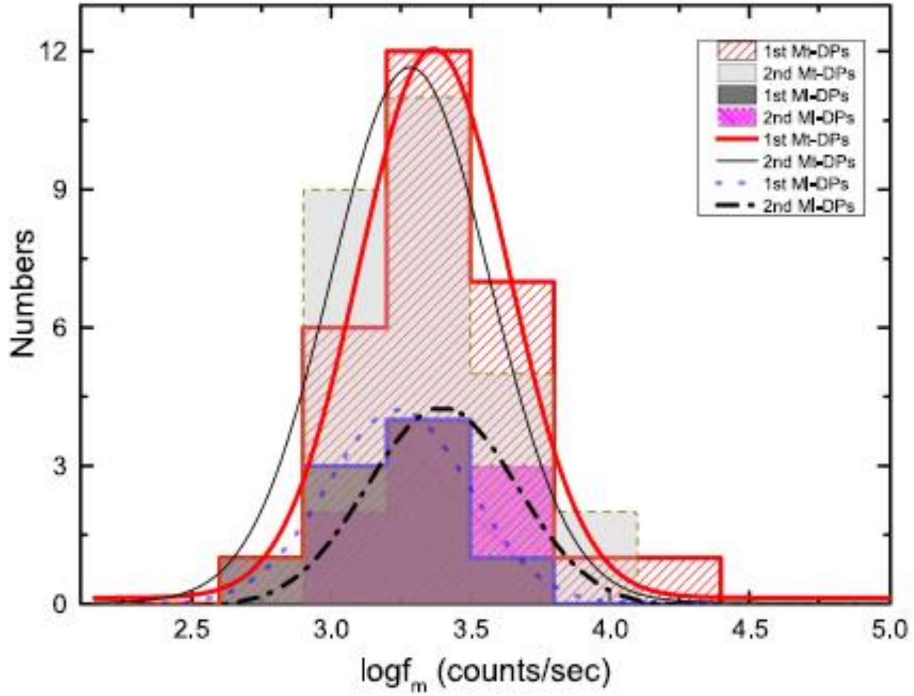
GRB	Number	Maximum	mean(Median)	Minimum
SPs	Ch2+3	1.28	0.73(0.76)	0.04
Mt-DPs	1st	1.23	0.82(0.82)	0.50
	2nd	1.01	0.51(0.49)	0.12
Ml-DPs	1st	1.43	0.80(0.84)	0.20
	2nd	1.48	1.07(1.21)	0.16
Total	⋯	1.48	0.79(0.81)	0.04
TPs	1st	⋯	1.06	⋯
(# 06715)	2nd	⋯	0.57	⋯
	3rd	⋯	1.39	⋯
TPs	1st	⋯	0.56	⋯
(# 07102)	2nd	⋯	0.54	⋯
	3rd	⋯	0.93	⋯



- 短暴比长暴更加对称
- SPs与两类DPs的第一个脉冲非对称性具有相似性。

（3）脉冲峰值流量的统计特性

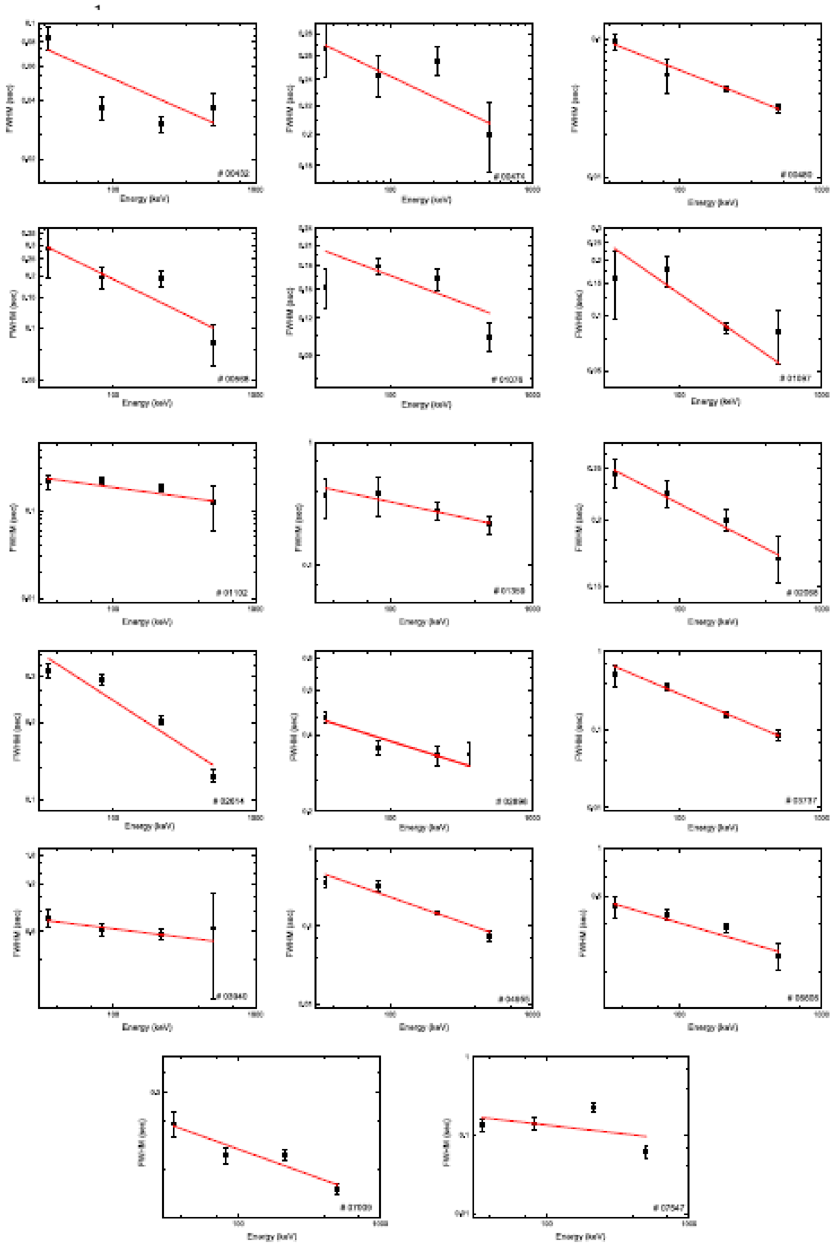




GRB	First (Counts/s)	Second (Counts/s)
SPs	$f_{m,\mathrm{SP}} = 2884.03^{+206.27}_{-192.50}$	
Mt-DPs	$f_{m,\mathrm{Mt1}} = 2344.23^{+54.60}_{-53.36}$	$f_{m,\mathrm{Mt2}} = 1905.46^{+44.80}_{-85.76}$
Ml-DPs	$f_{m,\mathrm{Ml1}} = 1737.80^{+40.48}_{-39.56}$	$f_{m,\mathrm{Ml2}} = 2511.89^{+118.38}_{-113.06}$

- SPs的峰值流量比两种双峰暴的峰值流量大。
- 对于两种双峰暴，统计发现Mt-DP类型的第一个脉冲的峰值流量要高于第二个脉冲的，而Ml-DPs的结果正好相反。

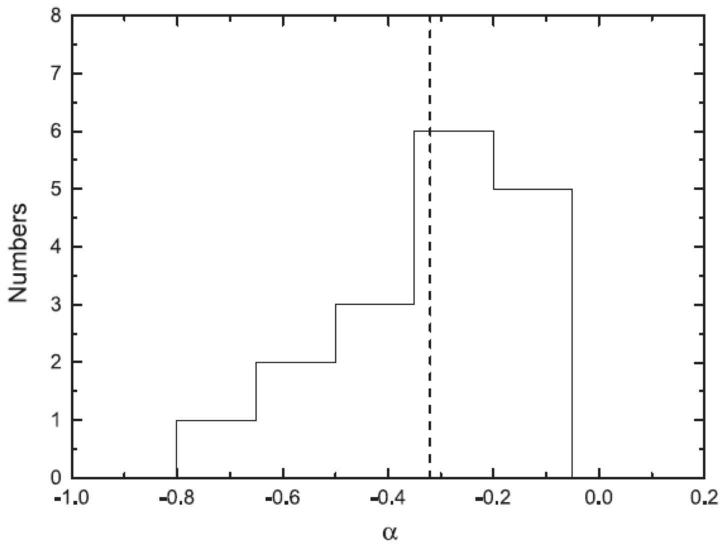
（4）脉冲宽度与能量的关系统计



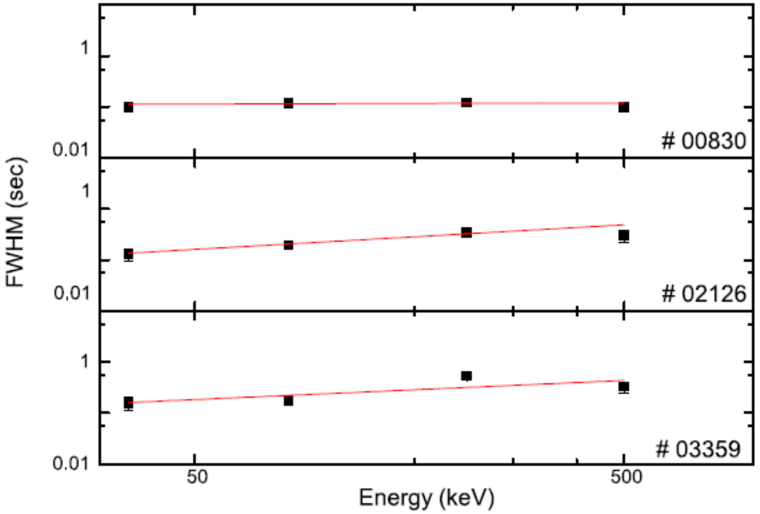
Norris et al. 1996

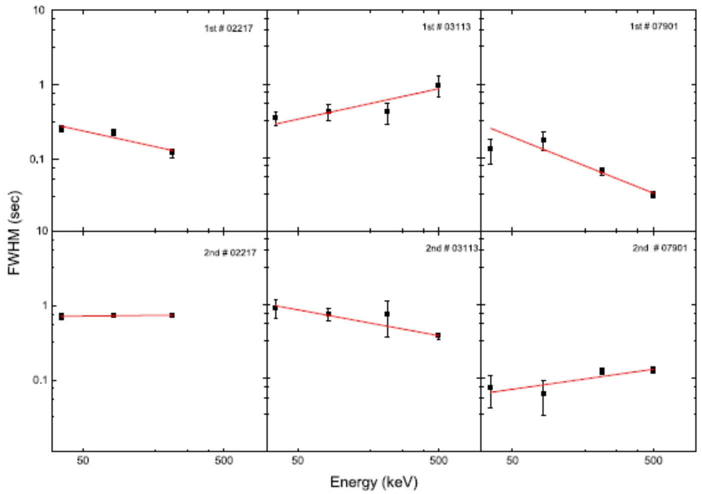
Sample[a]	⟨α⟩	Power-Law Index, α, at Normalized Amplitude[b] 0.2	0.3	0.4	0.5	0.6	0.7	0.8
		$E = E_{low}$[c]						
A	0.41	0.38	0.38	0.40	0.41	0.44	0.46	0.42
S........	0.36	0.32	0.33	0.35	0.36	0.37	0.40	0.38
		$E = E_{mean}$[c]						
A	0.38	0.35	0.35	0.37	0.38	0.41	0.43	0.39
S........	0.33	0.30	0.31	0.33	0.33	0.34	0.37	0.36

[a] A = all pulses, S = separable pulses.
[b] Normalized to unity.
[c] E_{low} is low edge of energy channel. E_{mean} is geometric mean of low and high edges; 1 MeV is assumed as upper edge for channel 4.

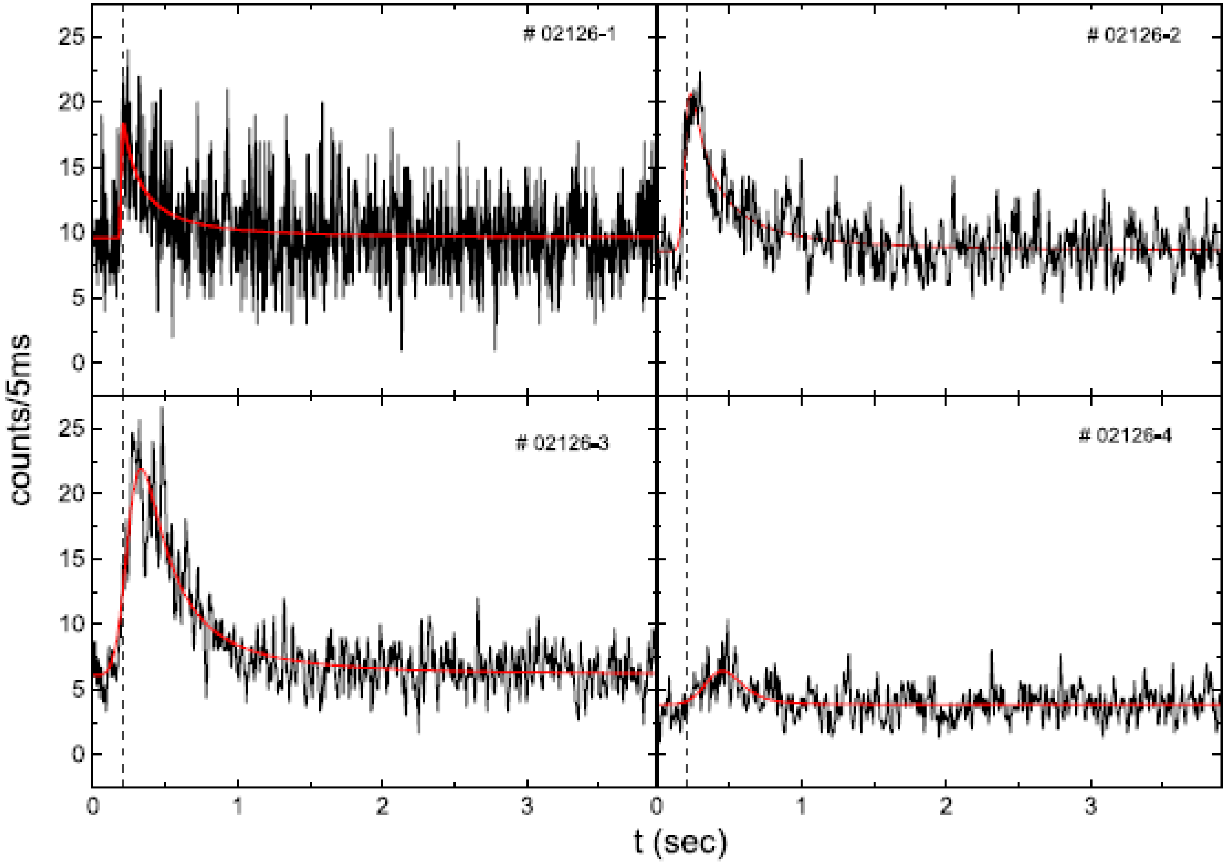


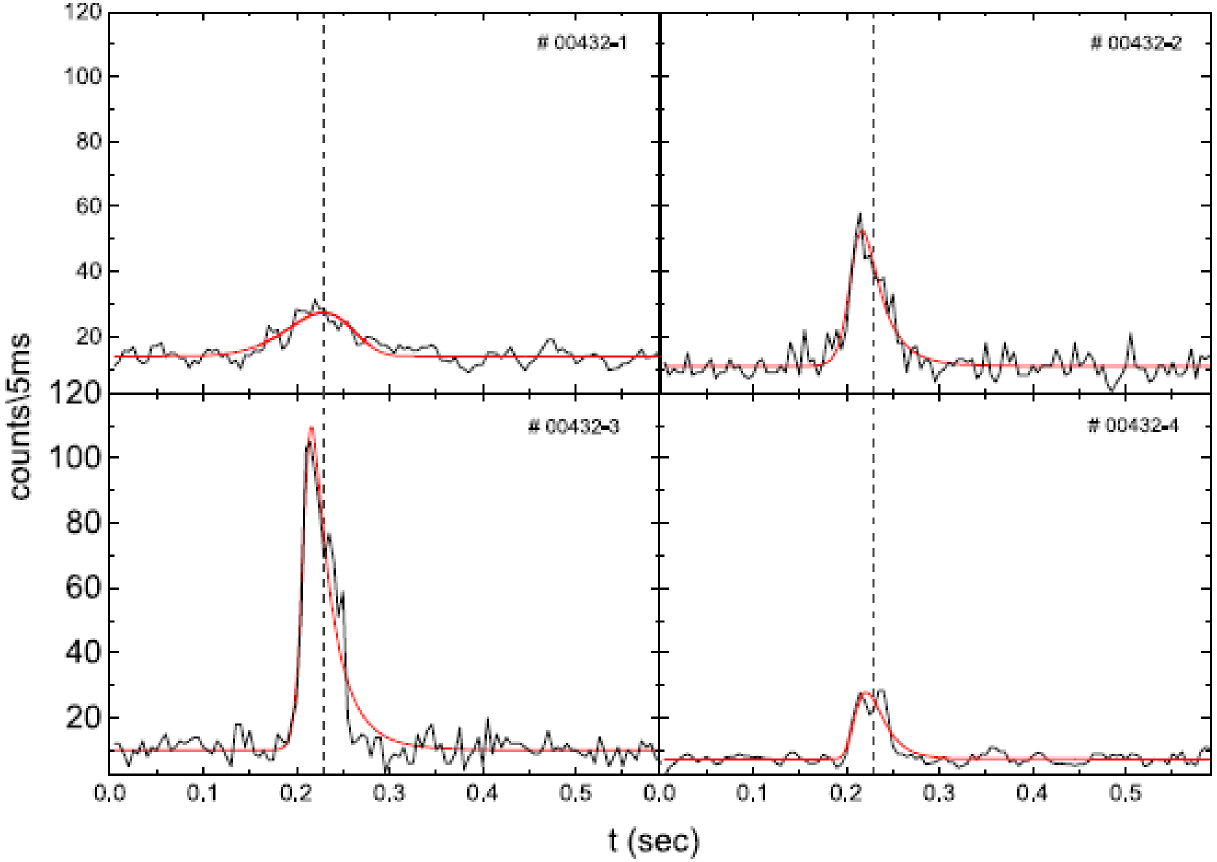
$\alpha \simeq -0.32 \pm 0.03$





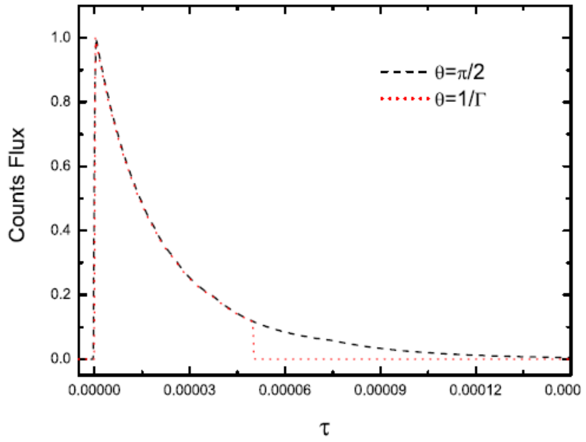
（5）脉冲形状演化

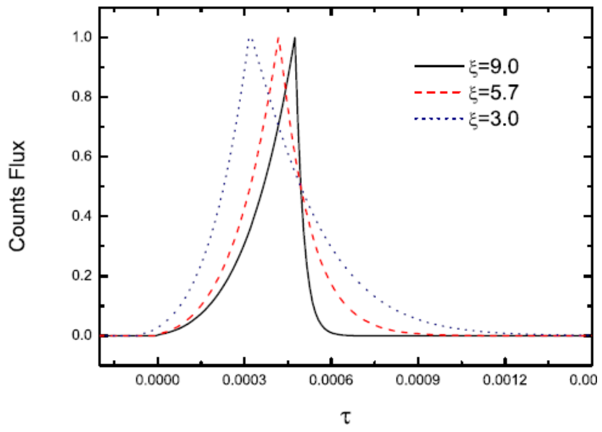


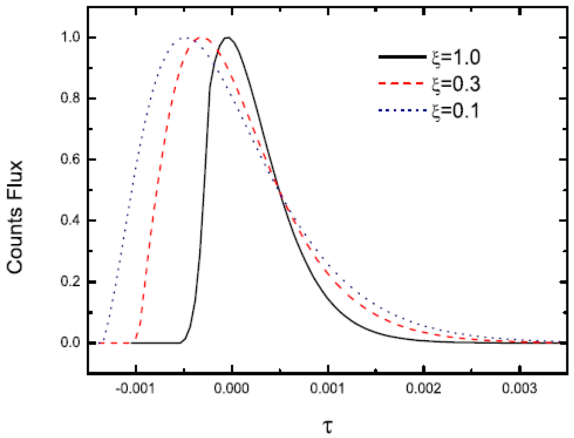


非对称度	Ch1	Ch2	Ch3	Ch4	**Mode**
02126	0.12	0.31	0.49	0.88	Mode I
00432	1.24	0.64	0.56	0.66	Mode II

4. 短暴的外流结构和演化





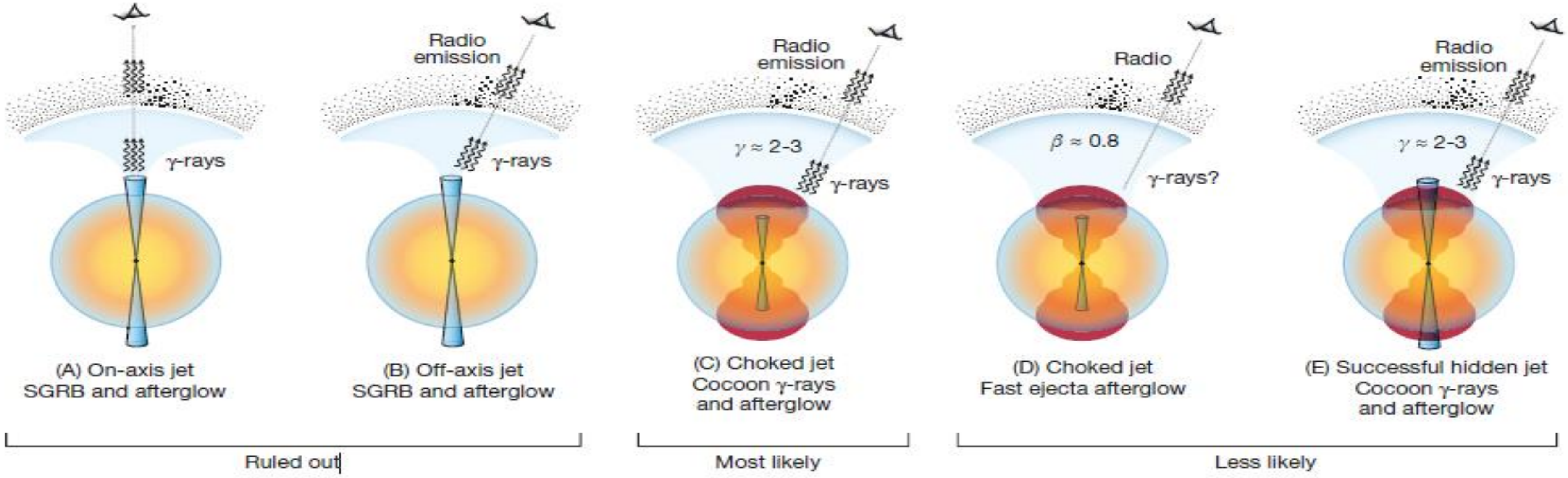


$$T_{\rm ang} = R_c/(2\Gamma^2 c)$$

$$T_{\rm dyn} = \Delta'/(2\Gamma v_{sh}')$$

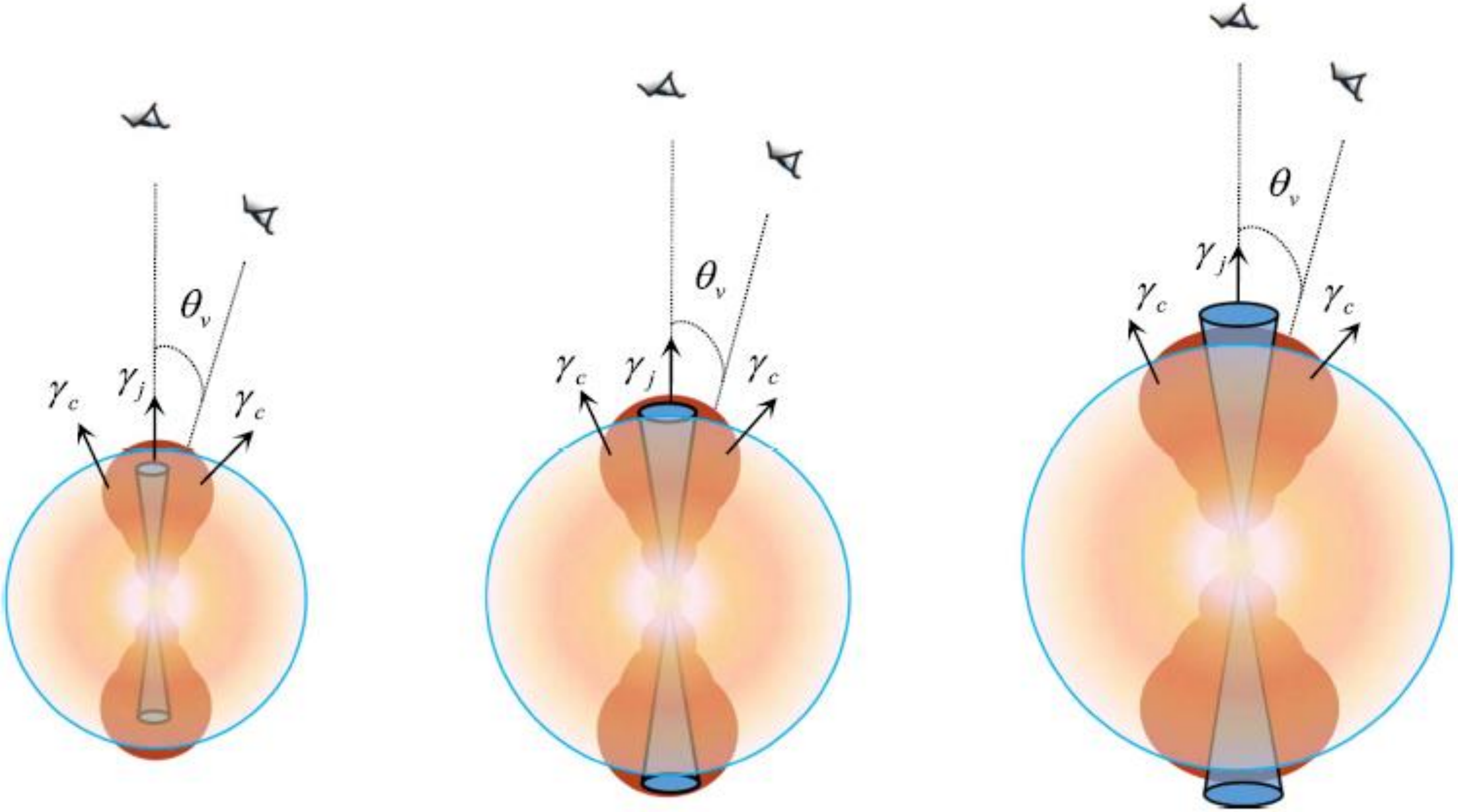
$$T_{\rm syn} = t_\gamma'/\Gamma$$

Zhang et al. 2007



Mooley et al. 2018

4. 短暴的外流结构和演化



(A) stage 1: cocoon-dominated

(B) stage 2: jet breakout

(C) stage 3: jet-dominated

- Mode I: 在第一阶段Cocoon在内部jet的加速下带领其以弱相对论速度运动，由Cacoon辐射主导，由于曲率效应，脉冲形状呈现快上升慢下降。而jet breakout后，jet提供主要的伽玛辐射，动力学时标和冷却时标主导，脉冲形状越来越对称。

- Mode II: 考虑jet外无Cocoon的情况，主要是由动力学时标和冷却时标主导，接着，曲率效应主导，脉冲形状呈现快上升慢下降。

5. 总结

- ◆ SPs和两类DPs的脉冲统计特性研究
- ◆GRB脉冲形状不同能道间的演化，两种不同演化形式
- ◆ 短GRB外流结构和演化的限制

讨论

- ◆ 样本限制
- ◆ GECAM

谢谢