Late-time Chandra Observations of GRB X-ray Afterglows and a Numerical Simulation-based Jet Model

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PENNSTATE
1855

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Collaborators

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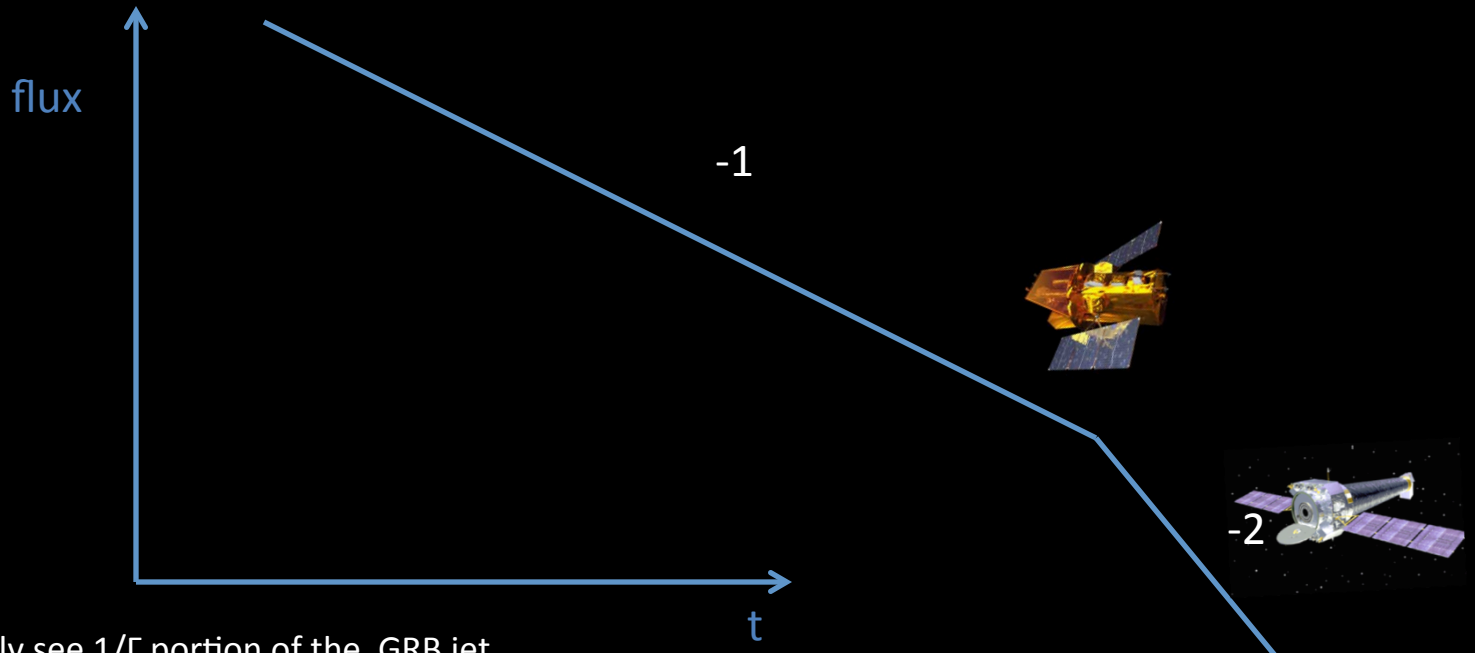
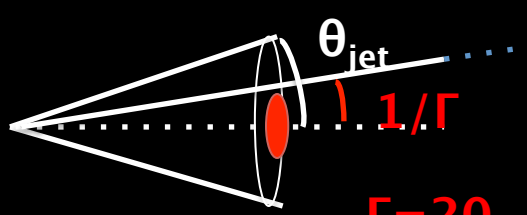
- Geoffrey Scott Ryan (NYU)
- Judith Racusin (GSFC)
- Eleonora Troja (GSFC)

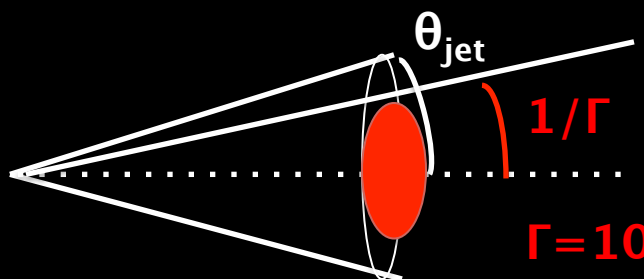
Chandra observes later and deeper

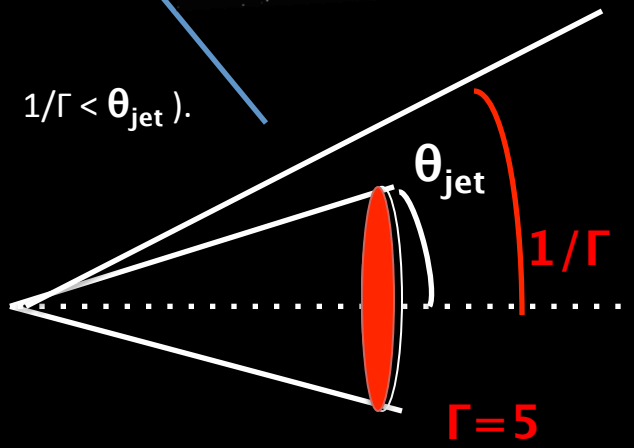
- more capable to detect jet-breaks in GRB afterglows



We only see 1/Γ portion of the GRB jet .
As the jet decelerating, we see more and more portion of the jet (as long as $1/\Gamma < \theta_{jet}$).
A jet-break occurs when the relativistic GRB jet decelerate to $1/\Gamma > \theta_{jet}$

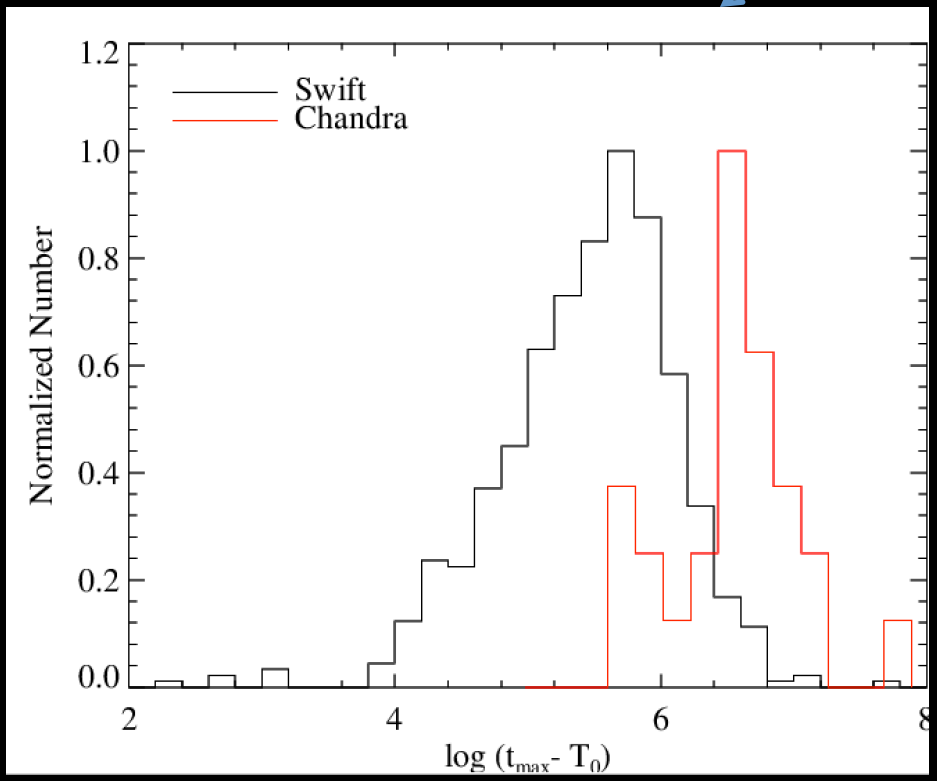




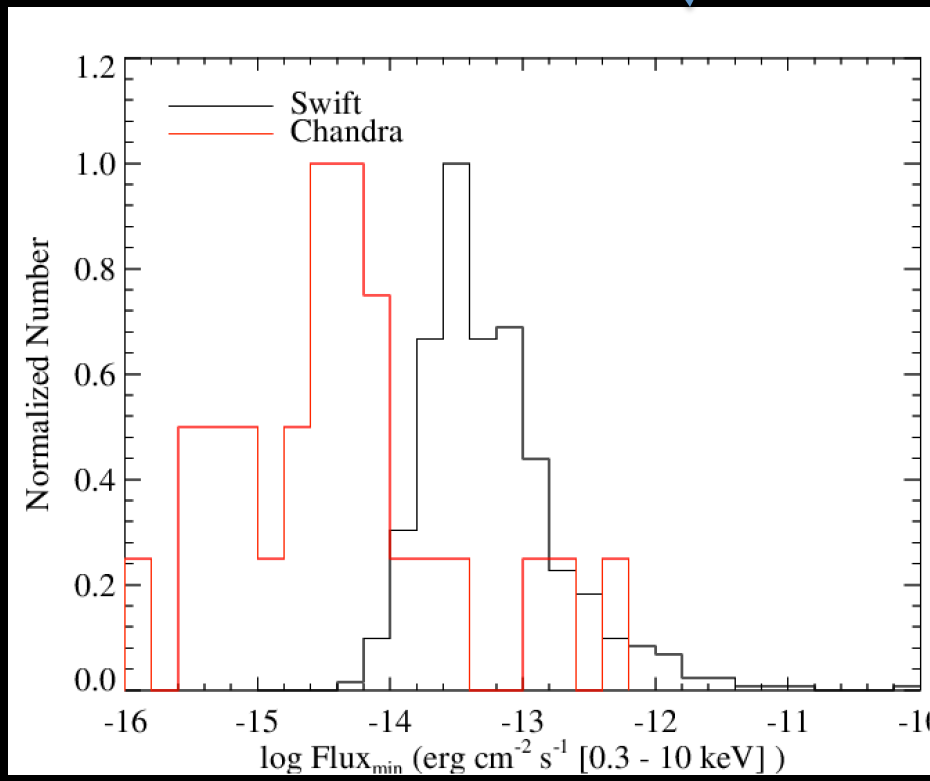


Chandra observes later and deeper

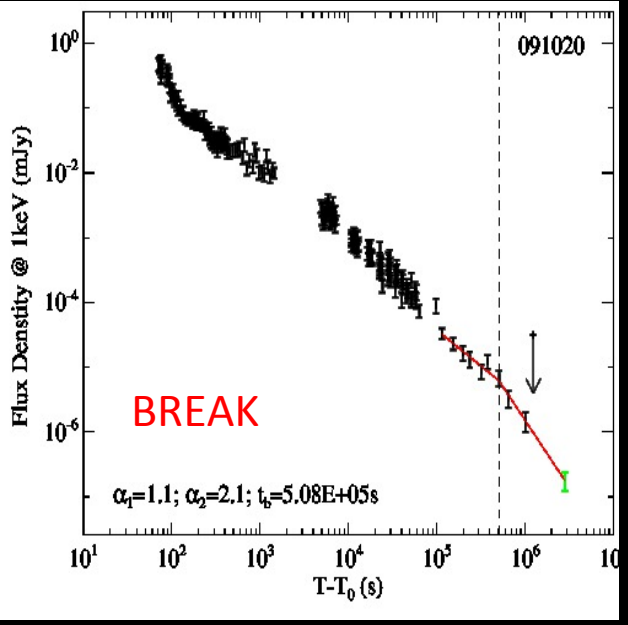
a sample of 27 GRBs with late-time Chandra observations

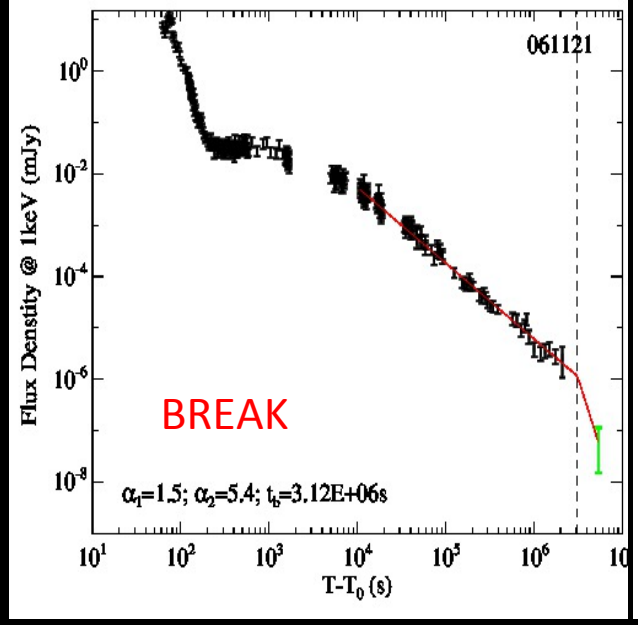


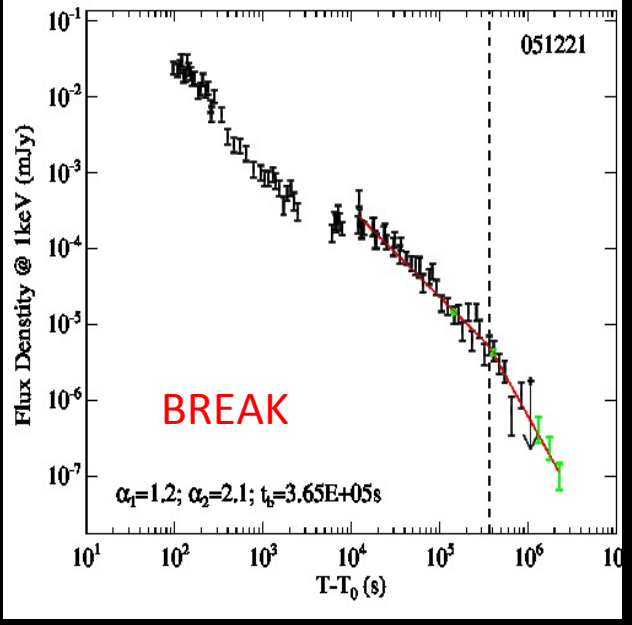
Follow-up time

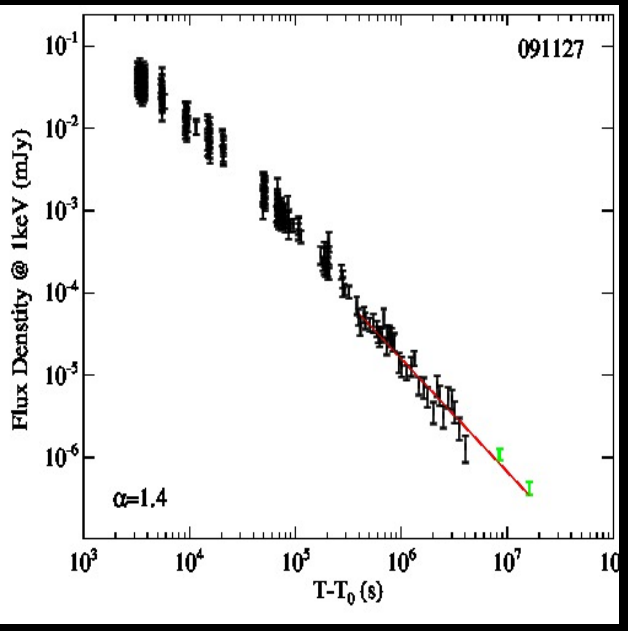


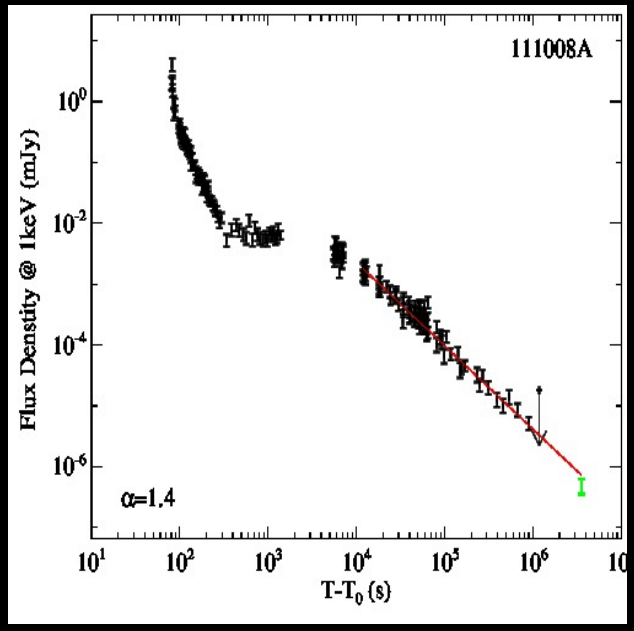
Follow-up flux

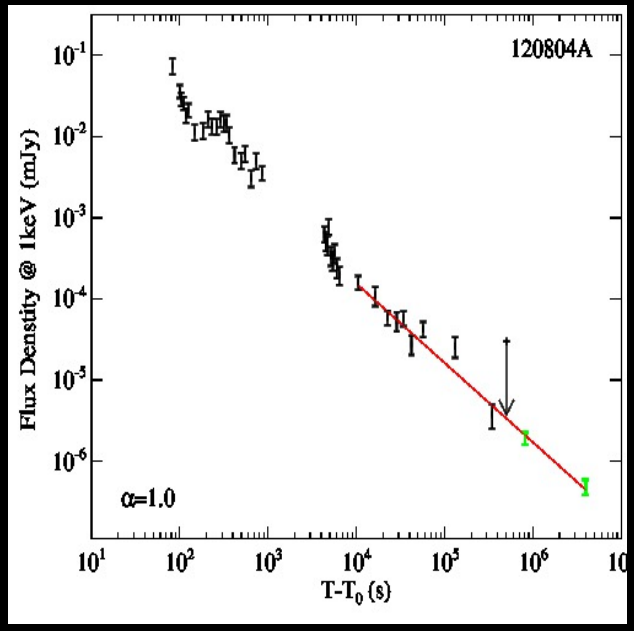

091020
BREAK
α_1=1.1; α_2=2.1; t_b=5.08E+05s
Flux Density @ 1keV (mJy)
T-T$_0$ (s)


061121
BREAK
α_1=1.5; α_2=5.4; t_b=3.12E+06s
Flux Density @ 1keV (mJy)
T-T$_0$ (s)


051221
BREAK
α_1=1.2; α_2=2.1; t_b=3.65E+05s
Flux Density @ 1keV (mJy)
T-T$_0$ (s)


091127
α=1.4
Flux Density @ 1keV (mJy)
T-T$_0$ (s)


111008A
α=1.4
Flux Density @ 1keV (mJy)
T-T$_0$ (s)


120804A
α=1.0
Flux Density @ 1keV (mJy)
T-T$_0$ (s)

What are in the Chandra GRB Zoo?

- Jet-Breaks :
  - shown in 50% of the whole sample (13/27)
  - For comparison, jet-breaks shown in 12% of Swift sample (e.g, Liang et al. 2008, Racusin et al. 2009)

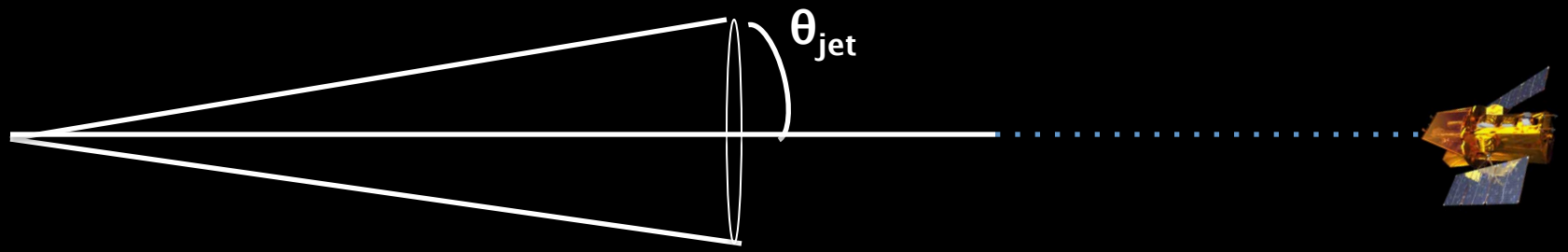
- Later Jet-breaks

  - Chandra jet-breaks occur much later (10 times later) than Swift jet-breaks

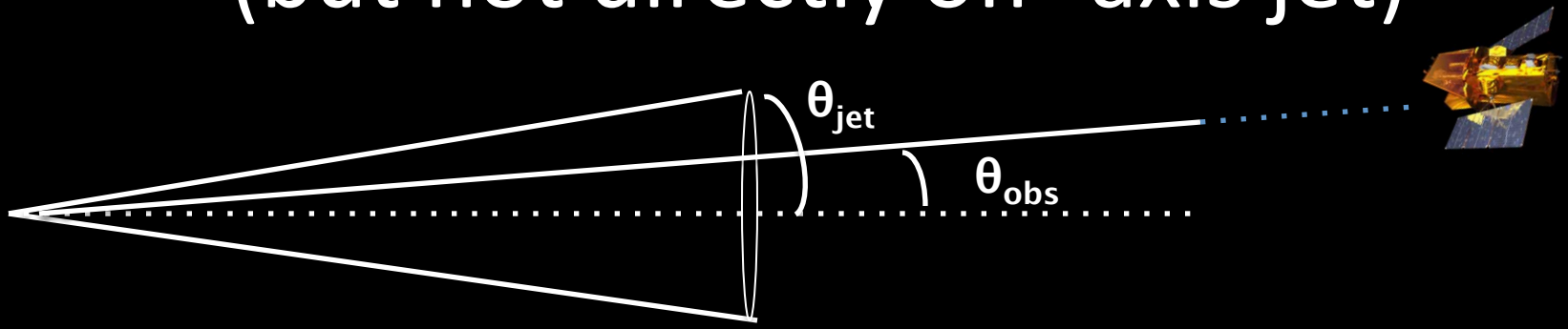
- Non-Breaks :
  - Some bursts show no sign for break up to 1.6×10^7s

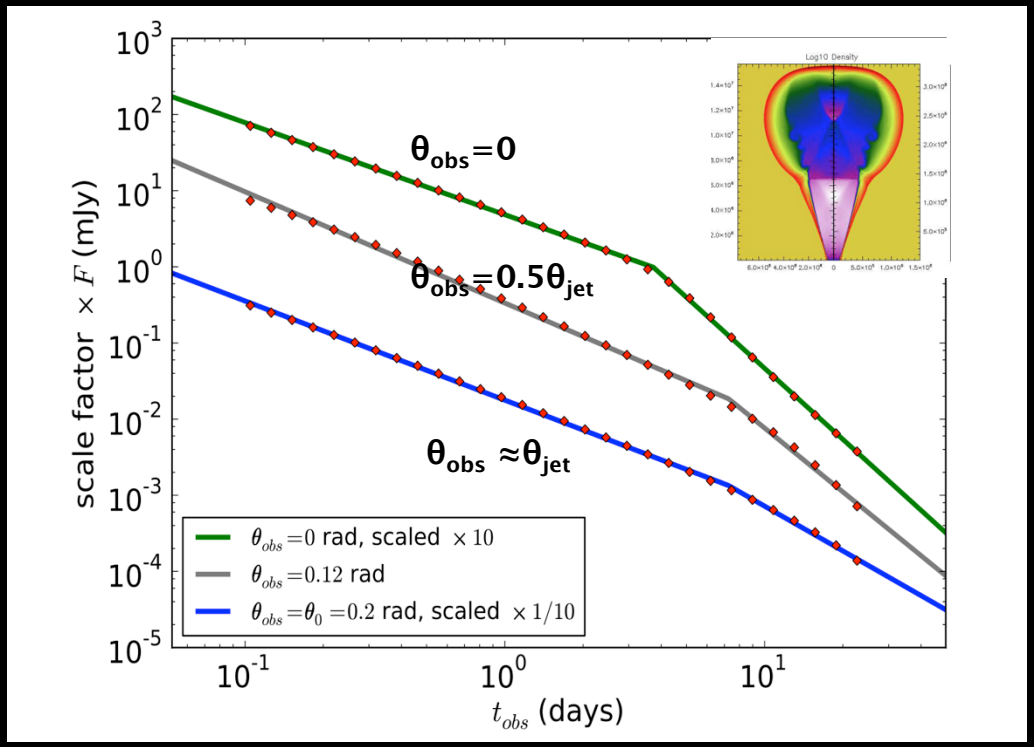
Does No Jet-break mean No Jet?

Why do some jet-breaks are hidden?


θ_{jet}

Large Viewing Angle Jet ?
(but not directly off- axis jet)

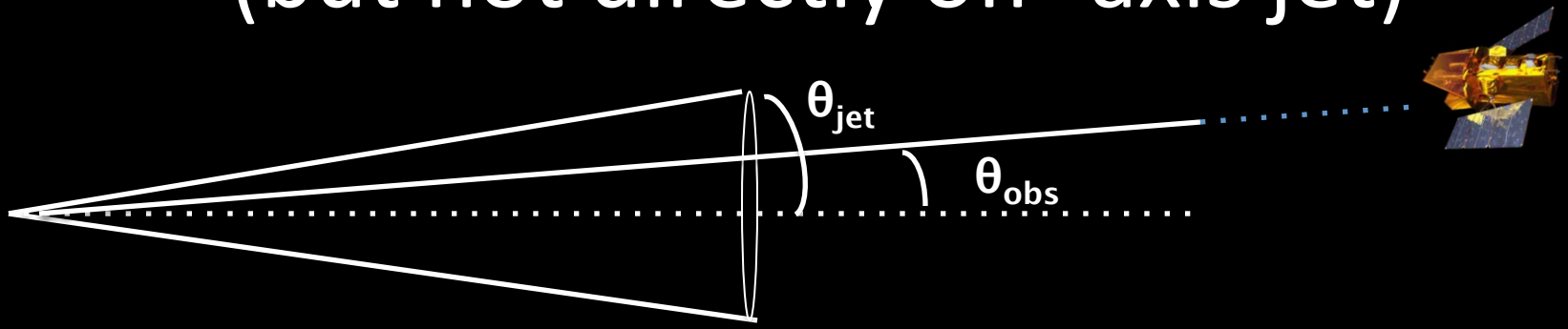


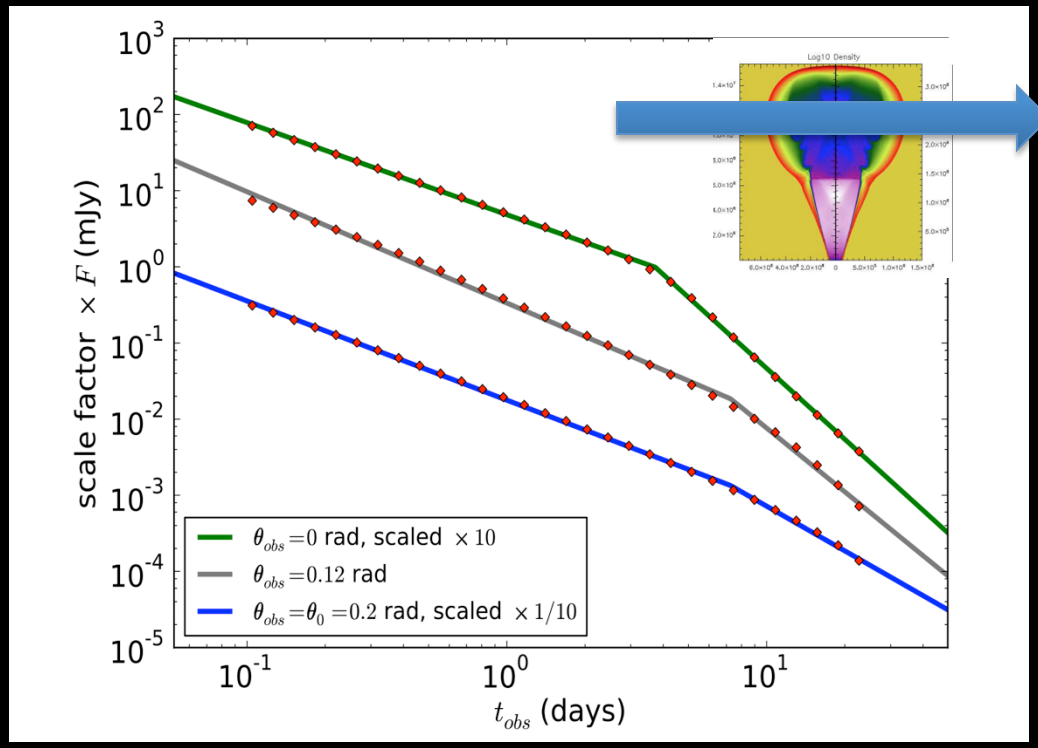


- More "realistic"
- Jet-breaks can be smeared out with large angles

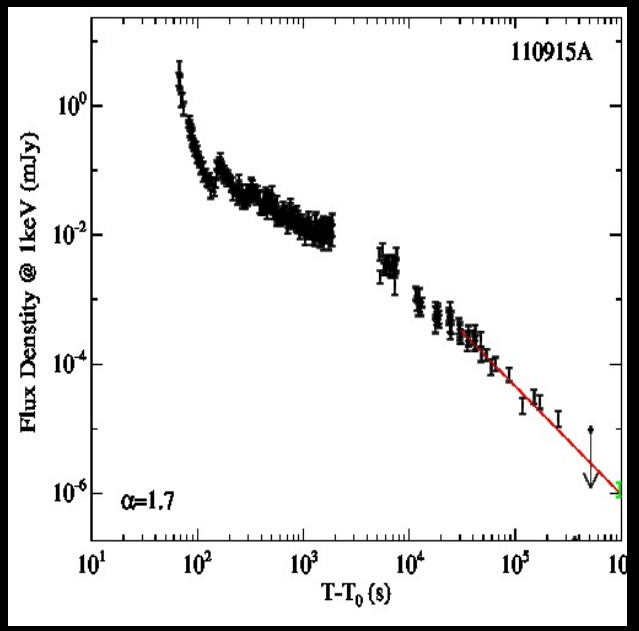
van Eerten & MacFadyen 2012

Large Viewing Angle Jet ?
(but not directly off- axis jet)





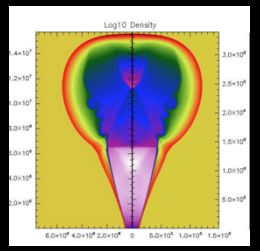
Fit Numerical simulations to Observations



Fit

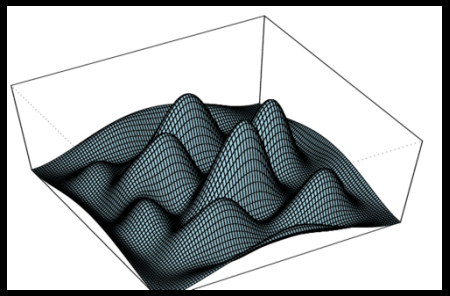
- Thanks to the scaling relations for the full blast wave evolution (van Eerten & MacFadyen,2011, 2012), we do not need to re-run the numerical simulations for every parameter configurations
- 7 free parameters

$$\theta_{jet},\ \theta_{obs},\ E_{jet},\ p,\ n,\ \varepsilon_e,\ \varepsilon_B$$

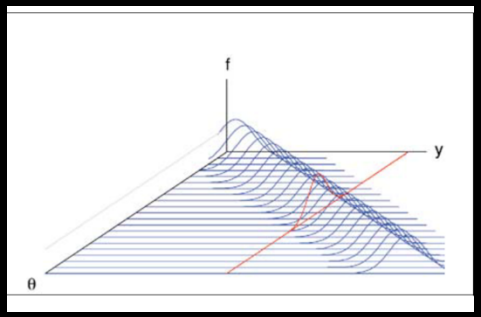


θ_{jet}, θ_{obs}, E_{jet}, p, n, ε_e, ε_B + Numerical table

flux @ X-ray



- Degeneracy between parameters (e.g, n and E_{jet})
- Non-Gaussian p-distribution in parameter space
- Insensitive parameters



Not suited to χ^2 fitting techniques

MCMC fit

Our Codes

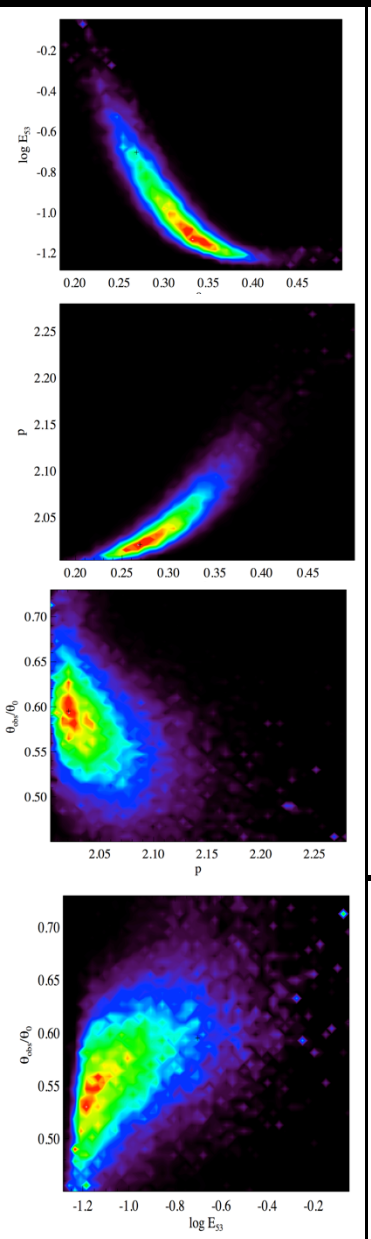
- An observation data handler (for both Swift and Chandra)
  Zhang, B.-B. et al 2007, 2008, 2009
- A numerical-simulation based "TABLE"
  van Eerten et al 2010,2011,2012
- A flux calculator based on the scaling relations

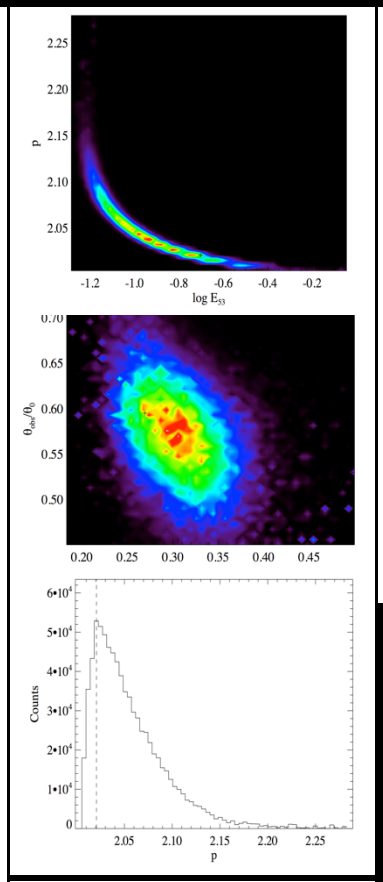
  van Eerten and MacFadyen 2012
- An improved fast MCMC sampler

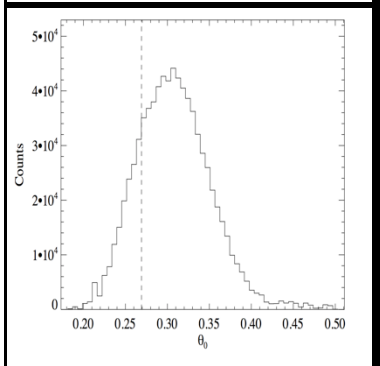
  multi-walker affine-invariant ensemble sampler;
  Foreman-Mackey et al. 2013

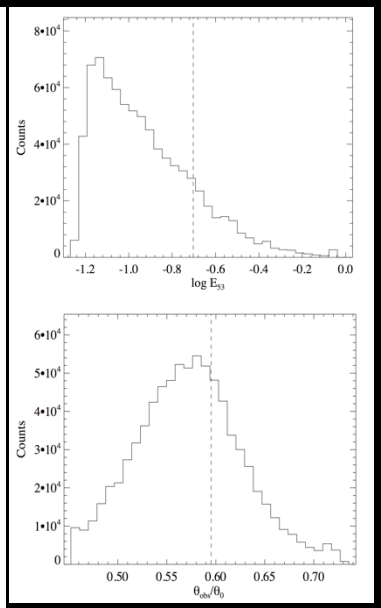
explain the data directly and more physically with numerical simulation

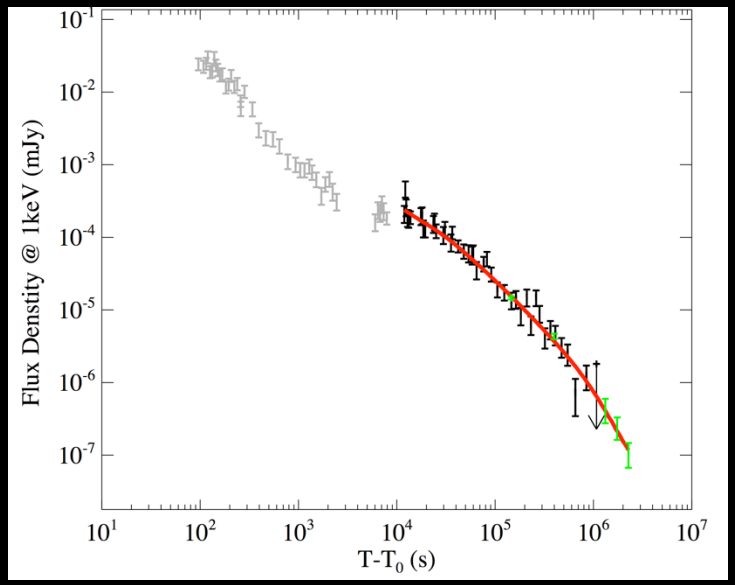
One Example

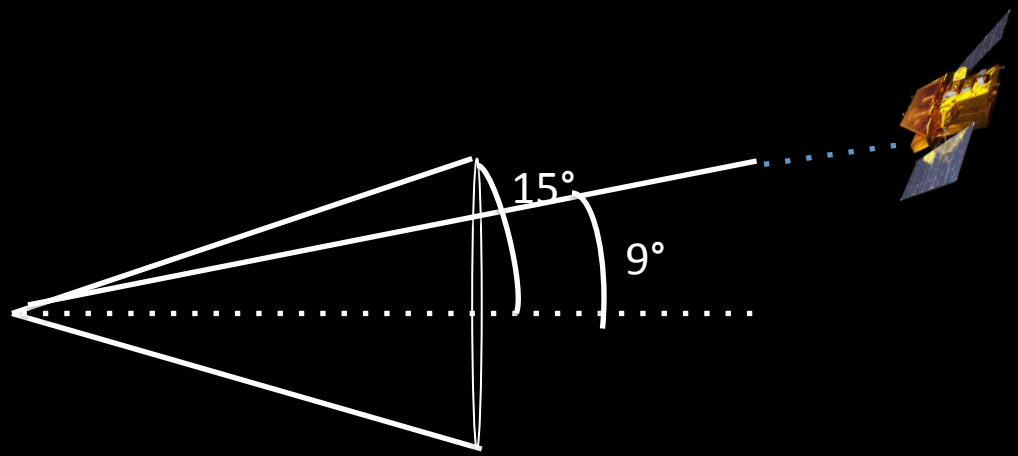

log E_{53}
p
θ_{obs}/θ_0
log E_{53}


p
log E_{53}
θ_{obs}/θ_0
Counts
p

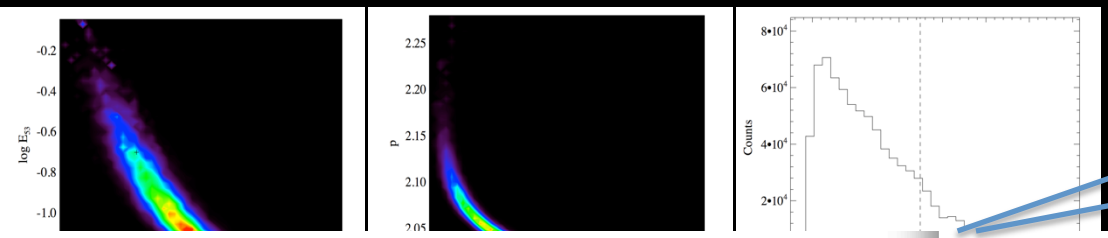

Counts
θ_0

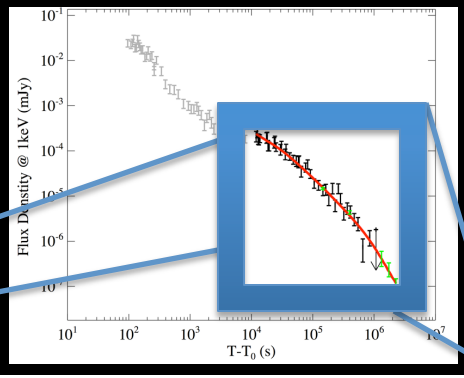

Counts
log E_{53}
Counts
θ_{obs}/θ_0


Flux Denstity @ 1keV (mJy)
T-T_0 (s)

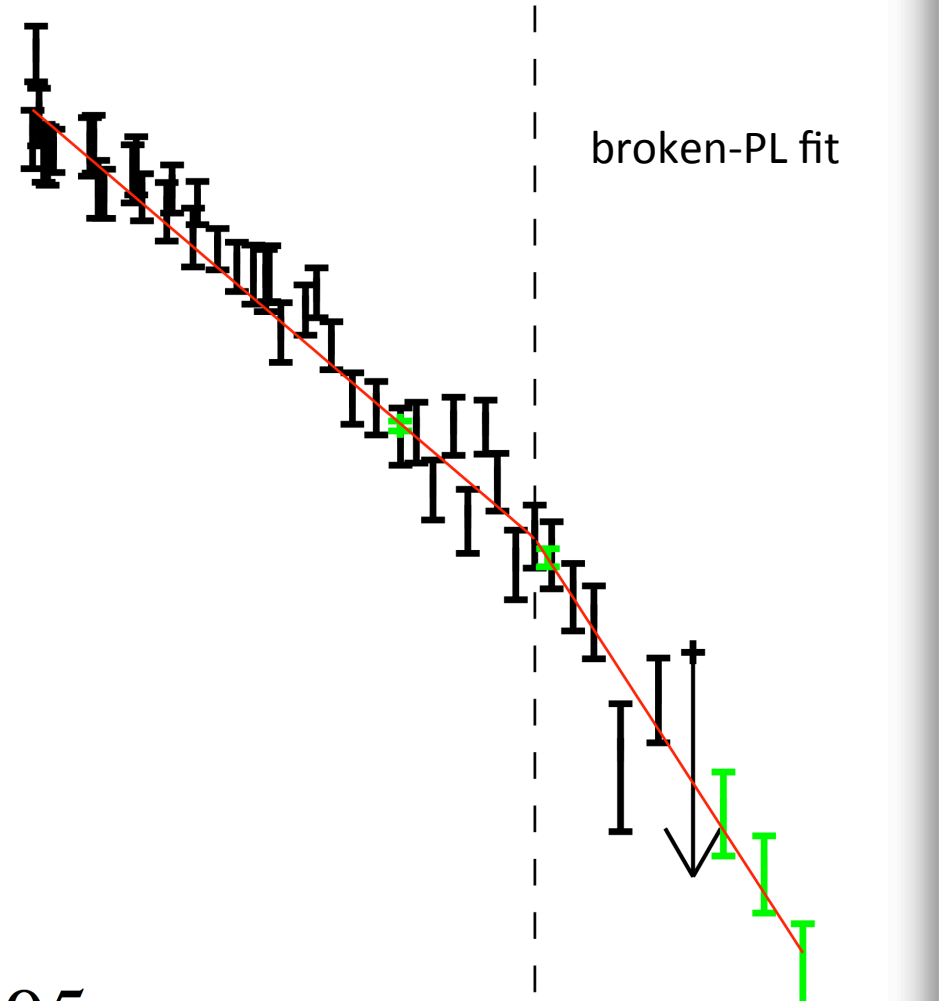

15°
9°

One Example

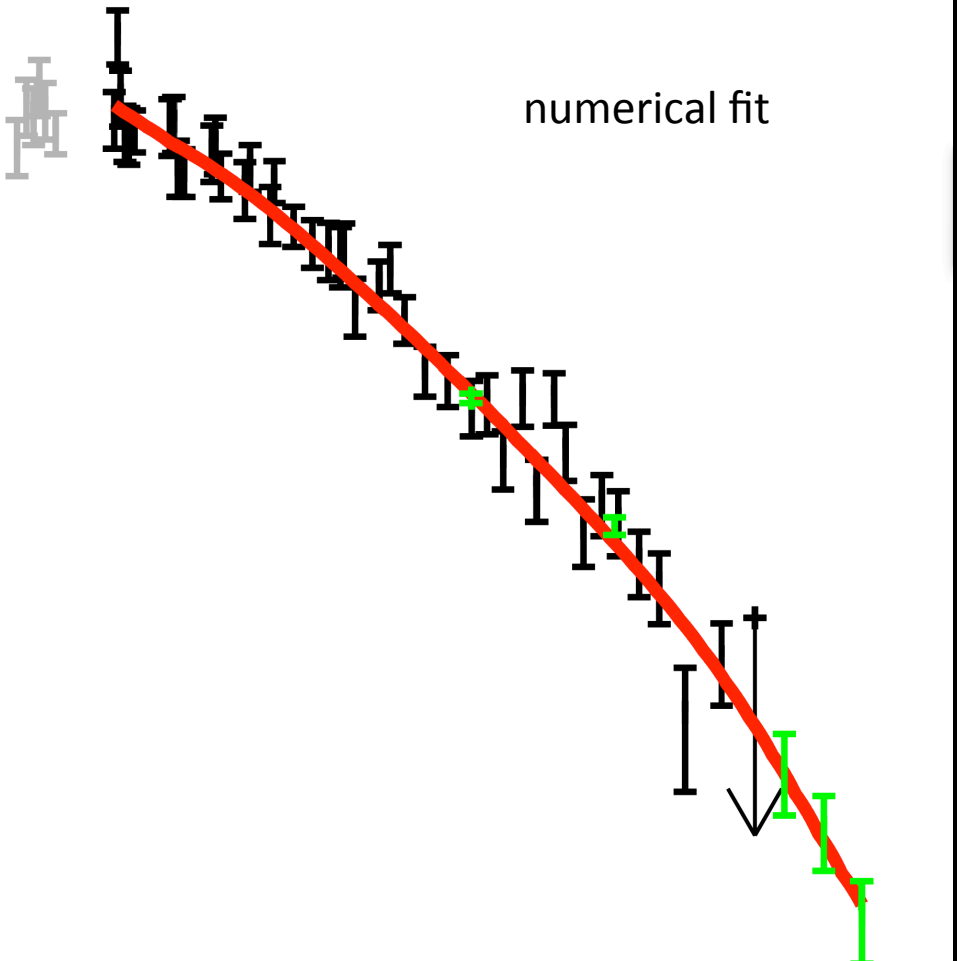




broken-PL fit



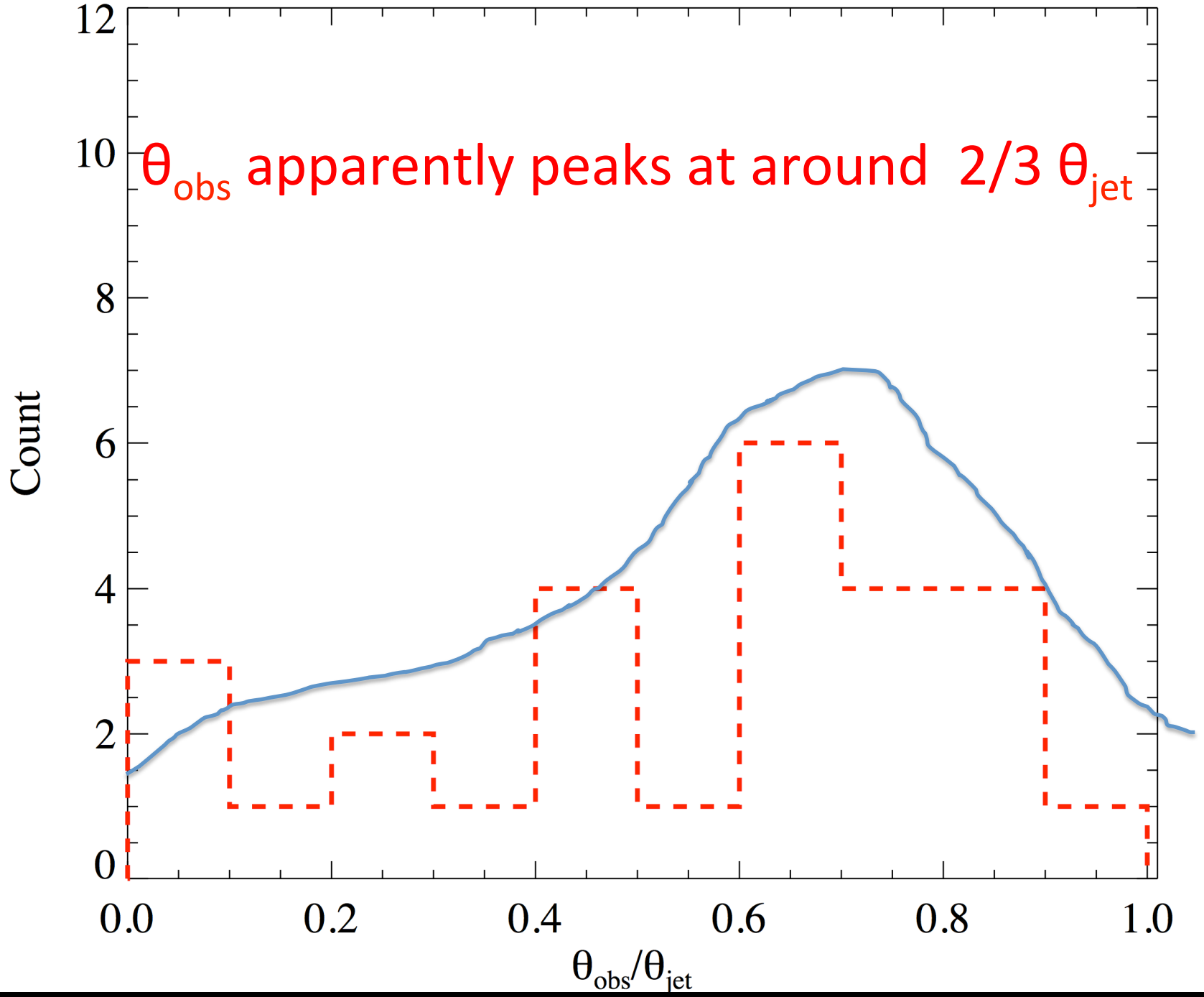
numerical fit



GRB	on-axis				off-axis				
	θ_{jet}	p	log E_{53}	χ^2/dof	θ_{jet}	$\frac{\theta_{obs}}{\theta_{jet}}$	p	log E_{53}	χ^2/dof
	rad		erg		*rad*	*rad*		erg	
051221	$0.40^{+0.10}_{-0.03}$	$2.24^{+0.10}_{-0.07}$	$-1.21^{+0.12}_{-0.06}$	46.7/43	$0.27^{+0.11}_{-0.06}$	$0.60^{+0.13}_{-0.13}$	$2.02^{+0.11}_{-0.02}$	$-0.70^{+0.65}_{-0.51}$	42.3/42
060729	$0.39^{+0.06}_{-0.05}$	$2.46^{+0.03}_{-0.03}$	$0.83^{+0.04}_{-0.04}$	520.9/43	$0.40^{+0.08}_{-0.07}$	$0.97^{+0.03}_{-0.07}$	$2.46^{+0.09}_{-0.09}$	$0.83^{+0.18}_{-0.22}$	520.7/43
061121	$0.33^{+0.04}_{-0.09}$	$2.63^{+0.03}_{-0.05}$	$0.80^{+0.03}_{-0.04}$	157.4/13	$0.21^{+0.05}_{-0.03}$	$0.67^{+0.07}_{-0.07}$	$2.41^{+0.07}_{-0.06}$	$0.65^{+0.05}_{-0.04}$	121.0/13
070125	$0.05^{+0.02}_{-0.00}$	$2.04^{+0.10}_{-0.03}$	$1.16^{+0.31}_{-0.36}$	175.4/21	$0.05^{+0.02}_{-0.00}$	$0.20^{+0.60}_{-0.00}$	$2.04^{+0.16}_{-0.04}$	$1.15^{+0.34}_{-0.52}$	185.3/20
071020	$0.13^{+0.00}_{-0.08}$	$2.03^{+0.27}_{-0.02}$	$0.51^{+1.44}_{-0.38}$	23.8/2	$0.09^{+0.03}_{-0.04}$	$0.79^{+0.01}_{-0.78}$	$2.19^{+0.01}_{-0.19}$	$0.59^{+1.11}_{-0.35}$	20.4/1
080207	$0.33^{+0.02}_{-0.15}$	$2.92^{+0.11}_{-0.11}$	$0.61^{+0.09}_{-0.10}$	27.9/33	$0.31^{+0.04}_{-0.19}$	$0.88^{+0.02}_{-0.88}$	$2.70^{+0.35}_{-0.16}$	$0.47^{+0.23}_{-0.12}$	26.9/32
080319B	$0.27^{+0.08}_{-0.03}$	$2.33^{+0.30}_{-0.26}$	$0.15^{+0.49}_{-0.21}$	134.9/49	$0.32^{+0.03}_{-0.17}$	$0.35^{+0.64}_{-0.35}$	$2.33^{+0.23}_{-0.27}$	$0.16^{+0.37}_{-0.21}$	96.1/48
081007	$0.50^{+0.00}_{-0.10}$	$2.25^{+0.21}_{-0.17}$	$-0.87^{+0.32}_{-0.14}$	32.8/19	$0.49^{+0.01}_{-0.18}$	$0.86^{+0.14}_{-0.20}$	$2.05^{+0.26}_{-0.04}$	$-0.65^{+0.65}_{-0.24}$	22.7/18
090102	$0.43^{+0.07}_{-0.25}$	$2.58^{+0.05}_{-0.04}$	$0.48^{+0.04}_{-0.04}$	108.6/91	$0.32^{+0.18}_{-0.18}$	$0.79^{+0.10}_{-0.28}$	$2.45^{+0.08}_{-0.10}$	$0.40^{+0.06}_{-0.06}$	95.6/90
090113	$0.44^{+0.06}_{-0.20}$	$2.43^{+0.15}_{-0.14}$	$-0.31^{+0.18}_{-0.16}$	14.4/8	$0.33^{+0.17}_{-0.17}$	$0.12^{+0.87}_{-0.12}$	$2.05^{+0.27}_{-0.05}$	$-0.51^{+1.02}_{-0.21}$	0.8/1
090417B	$0.50^{+0.00}_{-0.09}$	$2.56^{+0.04}_{-0.04}$	$-0.34^{+0.04}_{-0.04}$	123.8/11	$0.47^{+0.03}_{-0.22}$	$0.88^{+0.12}_{-0.79}$	$2.37^{+0.19}_{-0.07}$	$-0.46^{+0.36}_{-0.05}$	139.4/11
090423	$0.12^{+0.09}_{-0.05}$	$2.42^{+0.17}_{-0.13}$	$0.63^{+0.07}_{-0.05}$	31.0/42	$0.08^{+0.42}_{-0.03}$	$0.68^{+0.24}_{-0.10}$	$2.19^{+0.37}_{-0.08}$	$0.68^{+0.24}_{-0.10}$	39.2/41
091020	$0.17^{+0.04}_{-0.02}$	$2.36^{+0.05}_{-0.05}$	$0.18^{+0.03}_{-0.03}$	185.0/13	$0.16^{+0.04}_{-0.04}$	$0.65^{+0.07}_{-0.13}$	$2.24^{+0.08}_{-0.10}$	$0.15^{+0.04}_{-0.02}$	176.8/13
091127	$0.13^{+0.03}_{-0.01}$	$2.13^{+0.09}_{-0.03}$	$0.14^{+0.05}_{-0.06}$	724.7/37	$0.50^{+0.00}_{-0.08}$	$0.82^{+0.12}_{-0.07}$	$2.40^{+0.16}_{-0.11}$	$0.20^{+0.35}_{-0.22}$	82.0/56
100413A	$0.17^{+0.33}_{-0.04}$	$2.37^{+0.36}_{-0.33}$	$-0.30^{+0.43}_{-0.21}$	32.7/8	$0.14^{+0.36}_{-0.06}$	$0.47^{+0.53}_{-0.47}$	$2.08^{+0.60}_{-0.06}$	$-0.32^{+0.52}_{-0.18}$	34.5/7
100615A	$0.16^{+0.01}_{-0.03}$	$2.32^{+0.14}_{-0.28}$	$0.32^{+0.23}_{-0.12}$	128.5/26	$0.14^{+0.36}_{-0.05}$	$0.46^{+0.52}_{-0.46}$	$2.09^{+0.35}_{-0.06}$	$0.34^{+0.35}_{-0.13}$	107.3/25
100816A	$0.50^{+0.00}_{-0.14}$	$2.04^{+0.02}_{-0.03}$	$-0.88^{+0.80}_{-0.12}$	37.8/22	$0.50^{+0.00}_{-0.15}$	$0.03^{+0.49}_{-0.03}$	$2.04^{+0.02}_{-0.04}$	$-0.89^{+0.96}_{-0.11}$	38.1/21
101219B	$0.50^{+0.00}_{-0.13}$	$2.00^{+0.00}_{-0.00}$	$0.62^{+0.06}_{-0.70}$	43.7/17	$0.50^{+0.00}_{-0.12}$	$0.01^{+0.59}_{-0.01}$	$2.00^{+0.00}_{-0.00}$	$0.62^{+0.06}_{-0.70}$	43.8/16
110402A	$0.20^{+0.19}_{-0.13}$	$2.69^{+0.39}_{-0.34}$	$-0.76^{+0.35}_{-0.24}$	6.0/6	$0.16^{+0.34}_{-0.11}$	$0.61^{+0.39}_{-0.61}$	$2.53^{+0.54}_{-0.43}$	$-0.90^{+0.65}_{-0.10}$	6.9/5
110422A	$0.07^{+0.02}_{-0.00}$	$2.23^{+0.03}_{-0.03}$	$0.49^{+0.02}_{-0.02}$	443.2/25	$0.06^{+0.01}_{-0.02}$	$0.65^{+0.05}_{-0.06}$	$2.09^{+0.03}_{-0.05}$	$0.74^{+0.25}_{-0.09}$	416.7/25
110503A	$0.14^{+0.01}_{-0.01}$	$2.33^{+0.06}_{-0.06}$	$0.40^{+0.05}_{-0.04}$	181.5/12	$0.18^{+0.11}_{-0.09}$	$0.67^{+0.11}_{-0.22}$	$2.25^{+0.09}_{-0.20}$	$0.37^{+0.26}_{-0.03}$	154.6/12
110709B	$0.06^{+0.01}_{-0.00}$	$2.00^{+0.00}_{-0.00}$	$2.76^{+0.04}_{-0.25}$	634.9/33	$0.06^{+0.00}_{-0.01}$	$0.49^{+0.06}_{-0.08}$	$2.00^{+0.00}_{-0.00}$	$2.79^{+0.01}_{-0.23}$	656.8/32
110731A	$0.38^{+0.12}_{-0.07}$	$2.25^{+0.05}_{-0.04}$	$0.48^{+0.03}_{-0.03}$	61.3/45	$0.43^{+0.07}_{-0.13}$	$0.28^{+0.32}_{-0.28}$	$2.26^{+0.05}_{-0.05}$	$0.49^{+0.03}_{-0.03}$	59.1/44
110915A	$0.07^{+0.03}_{-0.01}$	$2.01^{+0.23}_{-0.01}$	$0.64^{+0.54}_{-0.84}$	127.8/49	$0.06^{+0.11}_{-0.02}$	$0.43^{+0.57}_{-0.43}$	$2.00^{+0.44}_{-0.00}$	$1.24^{+0.19}_{-1.45}$	143.0/48
111008A	$0.10^{+0.02}_{-0.03}$	$2.11^{+0.06}_{-0.08}$	$1.13^{+0.31}_{-0.08}$	175.0/11	$0.09^{+0.03}_{-0.03}$	$0.71^{+0.09}_{-0.11}$	$2.08^{+0.09}_{-0.07}$	$1.22^{+0.64}_{-0.16}$	187.9/11
120804A	$0.50^{+0.00}_{-0.17}$	$2.03^{+0.06}_{-0.03}$	$-0.36^{+0.86}_{-0.30}$	29.5/16	$0.50^{+0.00}_{-0.18}$	$0.02^{+0.62}_{-0.02}$	$2.03^{+0.07}_{-0.03}$	$-0.35^{+0.85}_{-0.34}$	29.5/15
121027A	$0.29^{+0.04}_{-0.09}$	$2.73^{+0.09}_{-0.14}$	$1.33^{+0.14}_{-0.22}$	51.9/46	$0.20^{+0.30}_{-0.09}$	$0.71^{+0.29}_{-0.71}$	$2.38^{+0.45}_{-0.20}$	$0.94^{+0.59}_{-0.24}$	62.5/45

GRB	on-axis				off-axis				
	θ_{jet}	p	log E_{53}	χ^2/dof	θ_{jet}	$\frac{\theta_{obs}}{\theta_{jet}}$	p	log E_{53}	χ^2/dof
	rad		erg		rad	rad		erg	
051221	$0.40^{+0.10}_{-0.03}$	$2.24^{+0.10}_{-0.07}$	$-1.21^{+0.12}_{-0.06}$	46.7/43	$0.27^{+0.11}_{-0.06}$	$0.60^{+0.13}_{-0.13}$	$2.02^{+0.11}_{-0.02}$	$-0.70^{+0.65}_{-0.51}$	42.3/42
060729	$0.39^{+0.06}_{-0.05}$	$2.46^{+0.03}_{-0.03}$	$0.83^{+0.04}_{-0.04}$	520.9/434	$0.40^{+0.08}_{-0.07}$	$0.97^{+0.03}_{-0.07}$	$2.46^{+0.09}_{-0.09}$	$0.83^{+0.18}_{-0.22}$	520.7/433
061121	$0.33^{+0.04}_{-0.09}$	$2.63^{+0.03}_{-0.05}$	$0.80^{+0.03}_{-0.04}$	157.4/137	$0.21^{+0.05}_{-0.03}$	$0.67^{+0.07}_{-0.07}$	$2.41^{+0.07}_{-0.06}$	$0.65^{+0.05}_{-0.04}$	121.0/136
070125	$0.05^{+0.02}_{-0.00}$	$2.04^{+0.10}_{-0.03}$	$1.16^{+0.31}_{-0.36}$	175.4/21	$0.05^{+0.02}_{-0.00}$	$0.20^{+0.60}_{-0.00}$	$2.04^{+0.16}_{-0.04}$	$1.15^{+0.34}_{-0.52}$	185.3/20
071020	$0.13^{+0.00}_{-0.08}$	$2.03^{+0.27}_{-0.02}$	$0.51^{+1.44}_{-0.38}$	23.8/2	$0.09^{+0.03}_{-0.04}$	$0.79^{+0.01}_{-0.78}$	$2.19^{+0.01}_{-0.19}$	$0.59^{+1.11}_{-0.35}$	20.4/1
080207	$0.33^{+0.02}_{-0.15}$	$2.92^{+0.11}_{-0.11}$	$0.61^{+0.09}_{-0.10}$	27.9/33	$0.31^{+0.04}_{-0.19}$	$0.88^{+0.02}_{-0.88}$	$2.70^{+0.35}_{-0.16}$	$0.47^{+0.23}_{-0.12}$	26.9/32
080319B	$0.27^{+0.08}_{-0.03}$	$2.33^{+0.30}_{-0.26}$	$0.15^{+0.49}_{-0.21}$	134.9/49	$0.32^{+0.03}_{-0.17}$	$0.35^{+0.64}_{-0.35}$	$2.33^{+0.23}_{-0.27}$	$0.16^{+0.37}_{-0.21}$	96.1/48
081007	$0.50^{+0.00}_{-0.10}$	$2.25^{+0.21}_{-0.17}$	$-0.87^{+0.32}_{-0.14}$	32.8/19	$0.49^{+0.01}_{-0.18}$	$0.86^{+0.14}_{-0.20}$	$2.05^{+0.26}_{-0.04}$	$-0.65^{+0.65}_{-0.24}$	22.7/18
090102	$0.43^{+0.07}_{-0.25}$	$2.58^{+0.05}_{-0.04}$	$0.48^{+0.04}_{-0.04}$	108.6/91	$0.32^{+0.18}_{-0.18}$	$0.79^{+0.10}_{-0.28}$	$2.45^{+0.08}_{-0.10}$	$0.40^{+0.06}_{-0.06}$	95.6/90
090113	$0.44^{+0.06}_{-0.20}$	$2.43^{+0.15}_{-0.1}$	$-0.31^{+0.18}_{-0.16}$	14.4/8	$0.33^{+0.17}_{-0.7}$	$0.12^{+0.87}_{-0.12}$	$2.05^{+0.27}_{-0.05}$	$-0.51^{+1.02}_{-0.31}$	0.8/1
090417B	$0.50^{+0.00}_{-0.09}$	$2.56^{+0.04}_{-0.04}$	$-0.34^{+0.04}_{-0.04}$	123.8/119	$0.47^{+0.03}_{-0.22}$	$0.88^{+0.12}_{-0.29}$	$2.57^{+0.09}_{-0.07}$	$-0.46^{+0.36}_{-0.05}$	139.4/118
090423	$0.12^{+0.09}_{-0.05}$	$2.42^{+0.17}_{-0.13}$	$0.63^{+0.07}_{-0.05}$	31.0/42	$0.08^{+0.42}_{-0.03}$	$0.68^{+0.24}_{-0.10}$	$2.19^{+0.37}_{-0.08}$	$0.68^{+0.24}_{-0.10}$	39.2/41
091020	$0.17^{+0.04}_{-0.02}$	$2.36^{+0.05}_{-0.05}$	$0.18^{+0.03}_{-0.03}$	185.0/131	$0.16^{+0.04}_{-0.04}$	$0.65^{+0.07}_{-0.13}$	$2.24^{+0.08}_{-0.10}$	$0.15^{+0.04}_{-0.02}$	176.8/130
091127	$0.13^{+0.03}_{-0.01}$	$2.13^{+0.09}_{-0.03}$	$0.14^{+0.05}_{-0.06}$	724.7/370	$0.50^{+0.00}_{-0.08}$	$0.82^{+0.12}_{-0.07}$	$2.40^{+0.16}_{-0.11}$	$0.20^{+0.35}_{-0.22}$	82.0/56
100413A	$0.17^{+0.33}_{-0.04}$	$2.37^{+0.36}_{-0.33}$	$-0.30^{+0.43}_{-0.21}$	32.7/8	$0.14^{+0.36}_{-0.06}$	$0.47^{+0.53}_{-0.47}$	$2.08^{+0.60}_{-0.06}$	$-0.32^{+0.52}_{-0.18}$	34.5/7
100615A	$0.16^{+0.01}_{-0.03}$	$2.32^{+0.14}_{-0.28}$	$0.32^{+0.23}_{-0.12}$	128.5/26	$0.14^{+0.36}_{-0.05}$	$0.46^{+0.52}_{-0.46}$	$2.09^{+0.35}_{-0.06}$	$0.34^{+0.35}_{-0.13}$	107.3/25
100816A	$0.50^{+0.00}_{-0.14}$	$2.04^{+0.02}_{-0.03}$	$-0.88^{+0.80}_{-0.12}$	37.8/22	$0.50^{+0.00}_{-0.15}$	$0.03^{+0.49}_{-0.03}$	$2.04^{+0.02}_{-0.04}$	$-0.89^{+0.96}_{-0.11}$	38.1/21
101219B	$0.50^{+0.00}_{-0.13}$	$2.00^{+0.00}_{-0.00}$	$0.62^{+0.06}_{-0.70}$	43.7/17	$0.50^{+0.00}_{-0.12}$	$0.01^{+0.59}_{-0.01}$	$2.00^{+0.00}_{-0.00}$	$0.62^{+0.06}_{-0.70}$	43.8/16
110402A	$0.20^{+0.19}_{-0.13}$	$2.69^{+0.39}_{-0.34}$	$-0.76^{+0.35}_{-0.24}$	6.0/6	$0.16^{+0.34}_{-0.11}$	$0.61^{+0.39}_{-0.61}$	$2.53^{+0.54}_{-0.43}$	$-0.90^{+0.65}_{-0.10}$	6.9/5
110422A	$0.07^{+0.02}_{-0.00}$	$2.23^{+0.03}_{-0.03}$	$0.49^{+0.02}_{-0.02}$	443.2/259	$0.06^{+0.01}_{-0.02}$	$0.65^{+0.05}_{-0.06}$	$2.09^{+0.03}_{-0.05}$	$0.74^{+0.25}_{-0.09}$	416.7/258
110503A	$0.14^{+0.01}_{-0.01}$	$2.33^{+0.06}_{-0.06}$	$0.40^{+0.05}_{-0.04}$	181.5/122	$0.18^{+0.11}_{-0.09}$	$0.67^{+0.11}_{-0.22}$	$2.25^{+0.09}_{-0.20}$	$0.37^{+0.26}_{-0.03}$	154.6/121
110709B	$0.06^{+0.01}_{-0.00}$	$2.00^{+0.00}_{-0.00}$	$2.76^{+0.04}_{-0.25}$	634.9/330	$0.06^{+0.00}_{-0.01}$	$0.49^{+0.06}_{-0.08}$	$2.00^{+0.00}_{-0.00}$	$2.79^{+0.01}_{-0.23}$	656.8/329
110731A	$0.38^{+0.12}_{-0.07}$	$2.25^{+0.05}_{-0.04}$	$0.48^{+0.03}_{-0.03}$	61.3/45	$0.43^{+0.07}_{-0.13}$	$0.28^{+0.32}_{-0.28}$	$2.26^{+0.05}_{-0.05}$	$0.49^{+0.03}_{-0.03}$	59.1/44
110915A	$0.07^{+0.03}_{-0.01}$	$2.01^{+0.23}_{-0.01}$	$0.64^{+0.54}_{-0.84}$	127.8/49	$0.06^{+0.11}_{-0.02}$	$0.43^{+0.57}_{-0.43}$	$2.00^{+0.44}_{-0.00}$	$1.24^{+0.19}_{-1.45}$	143.0/48
111008A	$0.10^{+0.02}_{-0.03}$	$2.11^{+0.06}_{-0.08}$	$1.13^{+0.31}_{-0.08}$	175.0/113	$0.09^{+0.03}_{-0.03}$	$0.71^{+0.09}_{-0.11}$	$2.08^{+0.09}_{-0.07}$	$1.22^{+0.64}_{-0.16}$	187.9/112
120804A	$0.50^{+0.00}_{-0.17}$	$2.03^{+0.06}_{-0.03}$	$-0.36^{+0.86}_{-0.30}$	29.5/16	$0.50^{+0.00}_{-0.18}$	$0.02^{+0.62}_{-0.02}$	$2.03^{+0.07}_{-0.03}$	$-0.35^{+0.85}_{-0.34}$	29.5/15
121027A	$0.29^{+0.04}_{-0.09}$	$2.73^{+0.09}_{-0.14}$	$1.33^{+0.14}_{-0.22}$	51.9/46	$0.20^{+0.30}_{-0.09}$	$0.71^{+0.29}_{-0.71}$	$2.38^{+0.45}_{-0.20}$	$0.94^{+0.59}_{-0.24}$	62.5/45

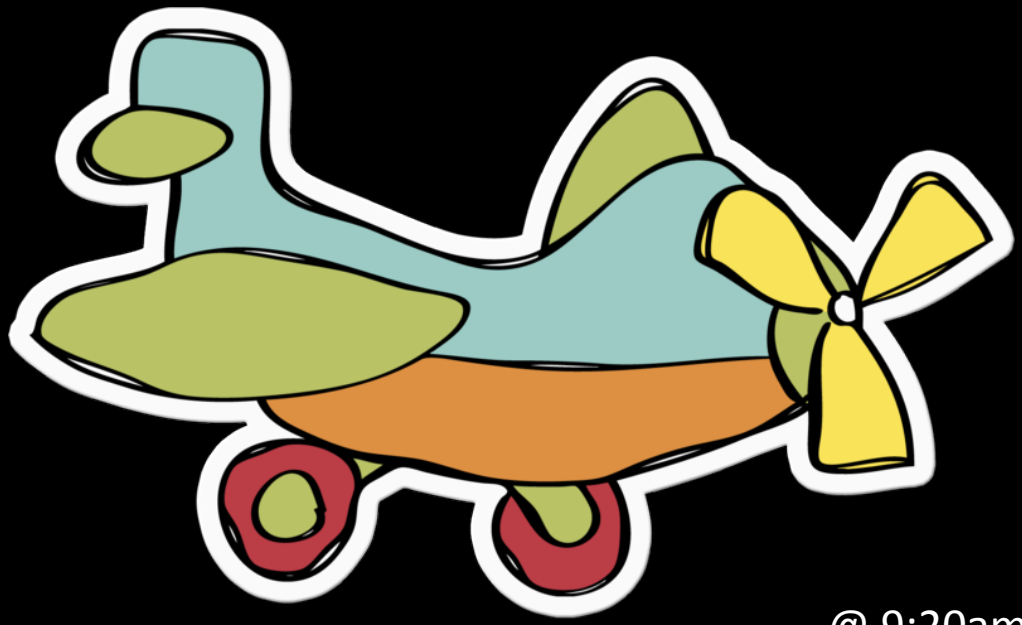
Data naturally favor off-axis jets


θobs apparently peaks at around 2/3 θjet
Count
12
10
8
6
4
2
0
0.0
0.2
0.4
0.6
0.8
1.0
θobs/θjet

Summary

- More jet-breaks (50% vs 12%) in Chandra GRBs
- Late breaks (10^6 vs 10^5 s)
- The hidden jet-break problem can be naturally and physically explained by off-axis jets by fitting numerical results to observational data
- We are more likely not staring at the jet direction, but about 2/3 off –axis.

Thanks !



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