HOW LONG DOES A BURST BURST?

BING ZHANG (UNLV)
on behalf of
BINBIN ZHANG (UAH)

Collaborators:
Kohta Murase, Valerie Connaughton and Michael Briggs

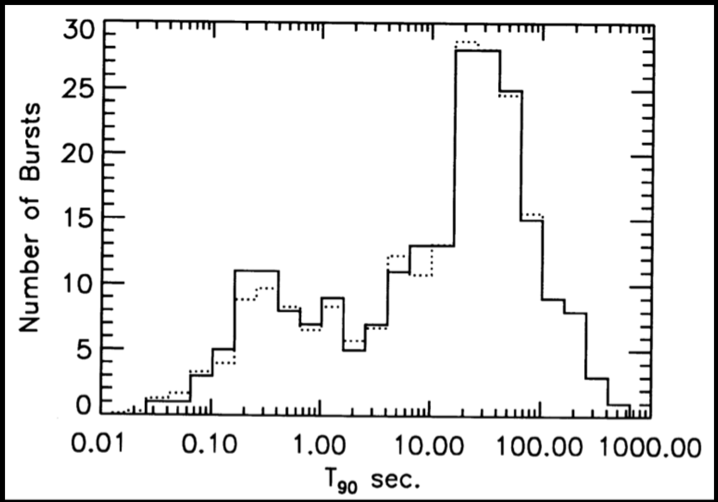
HOW LONG DOES A BURST BURST?

- Q: Are you reinvent T_{90} ?

T_{90}

T_{90} : is a good quantity to characterize GRBs,
but may not reflect the true time scale of the GRB events.

Observationally, T_{90} is energy dependent, instrument dependent



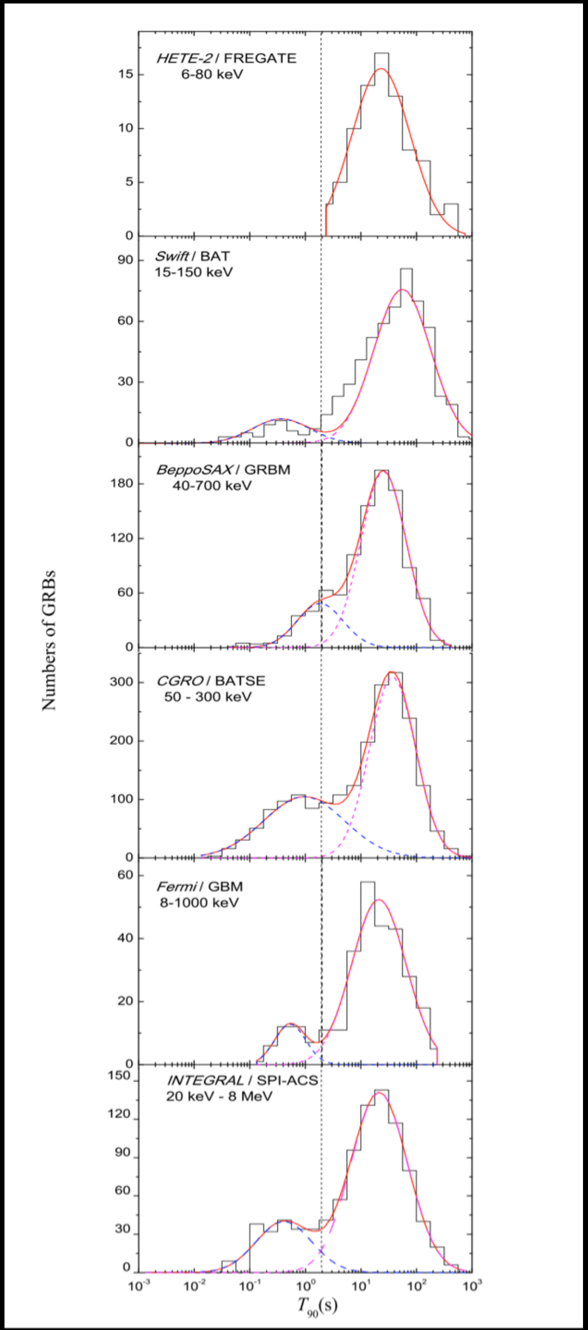
Kouveliotou et al. 1993

T_{90}

T_{90} : is a good quantity to characterize GRBs,
but may not reflect the true time scale of the GRB events.

Observationally, T_{90} is energy dependent, instrument dependent

$T_{90,E1-E2,\ mission}$



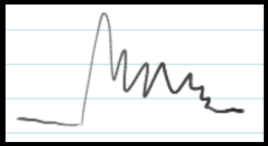
Qin et al 2013
see also Grupe et al. 2013 for updated Swift sample

T_{90}

T_{90} : is a good quantity to characterize GRBs,
but may not reflect the true time scale of the GRB events

Theoretically, T_{90} is most likely underestimated comparing to the true time scale of GRBs.

Theoretically, T_{90} is most likely underestimated comparing to the true time scale.

gamma-ray emission within T_{90} 

(requires) →

internal energy dissipated (via e.g, Internal Shock) within t_{dis}

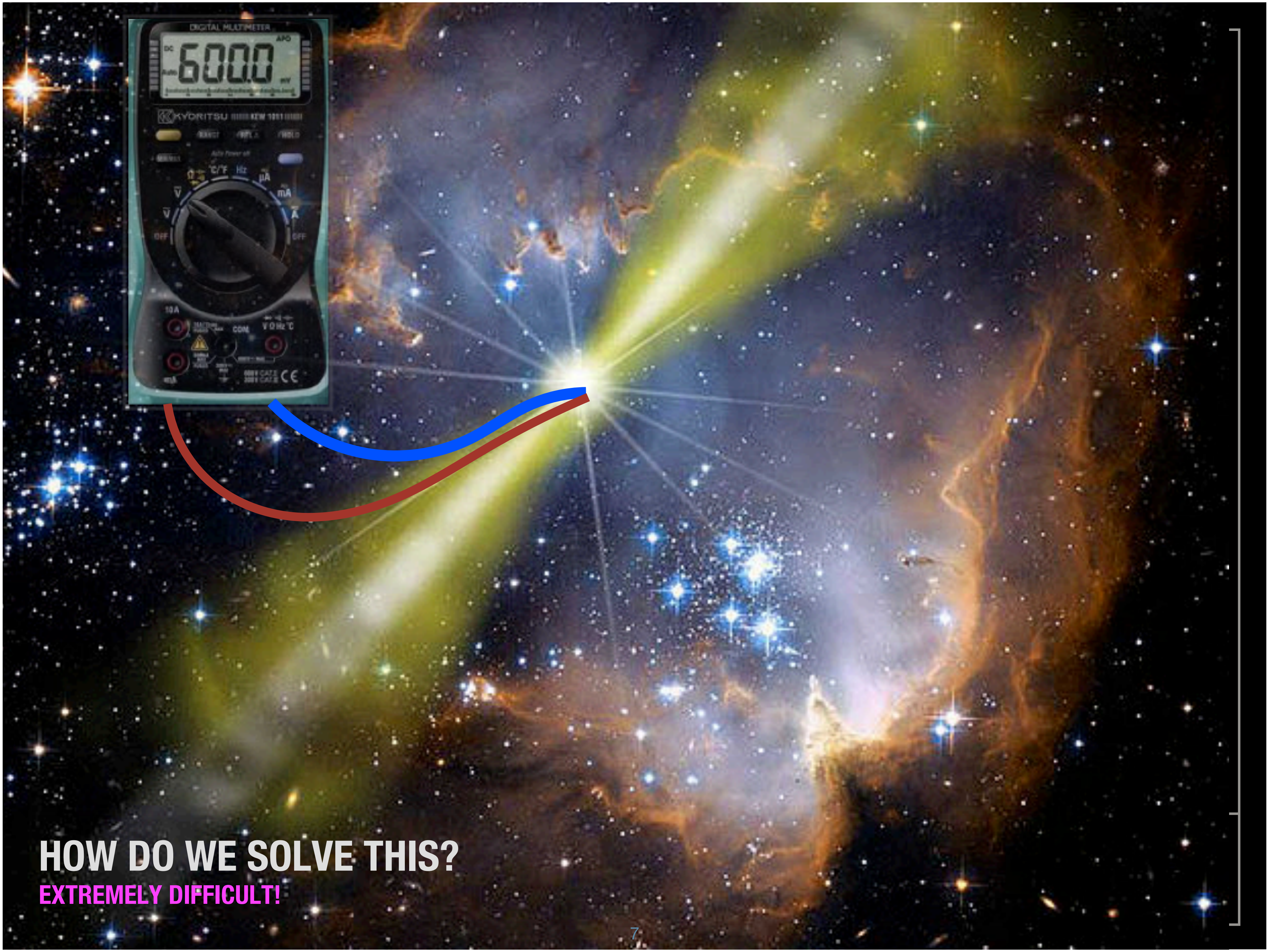
(requires) →

an active relativistic jet within t_{jet}

(requires) →

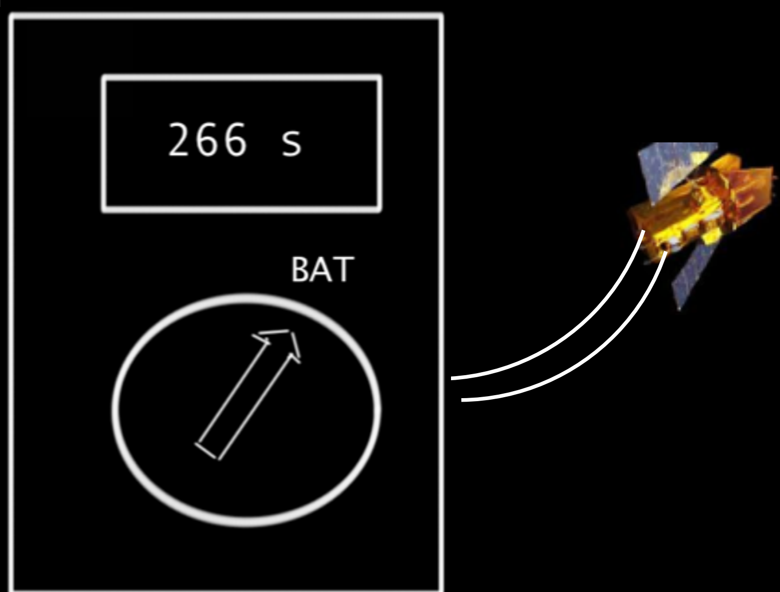
an active central engine within t_{engine}

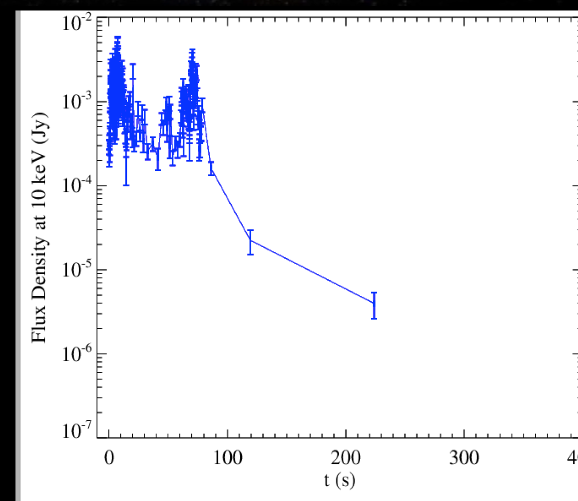
Observational $\boxed{T_{90} < t_{dis} < t_{jet} < t_{engine}}$ Physical



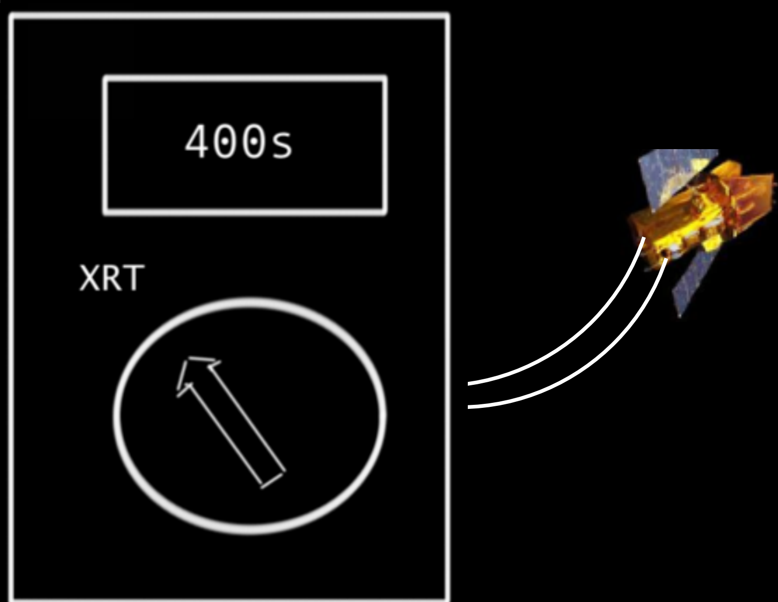
HOW DO WE SOLVE THIS?

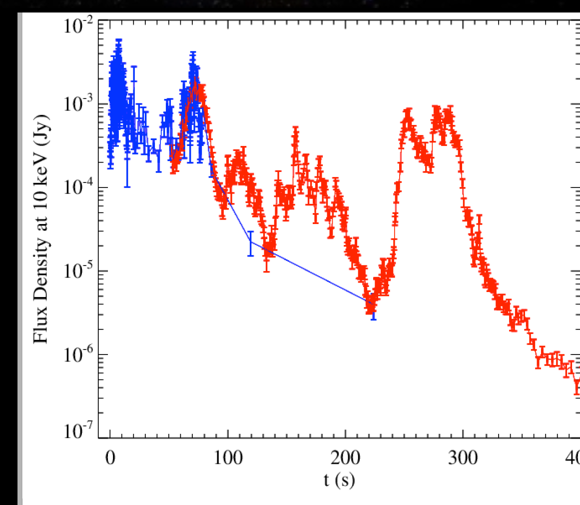
EXTREMELY DIFFICULT!



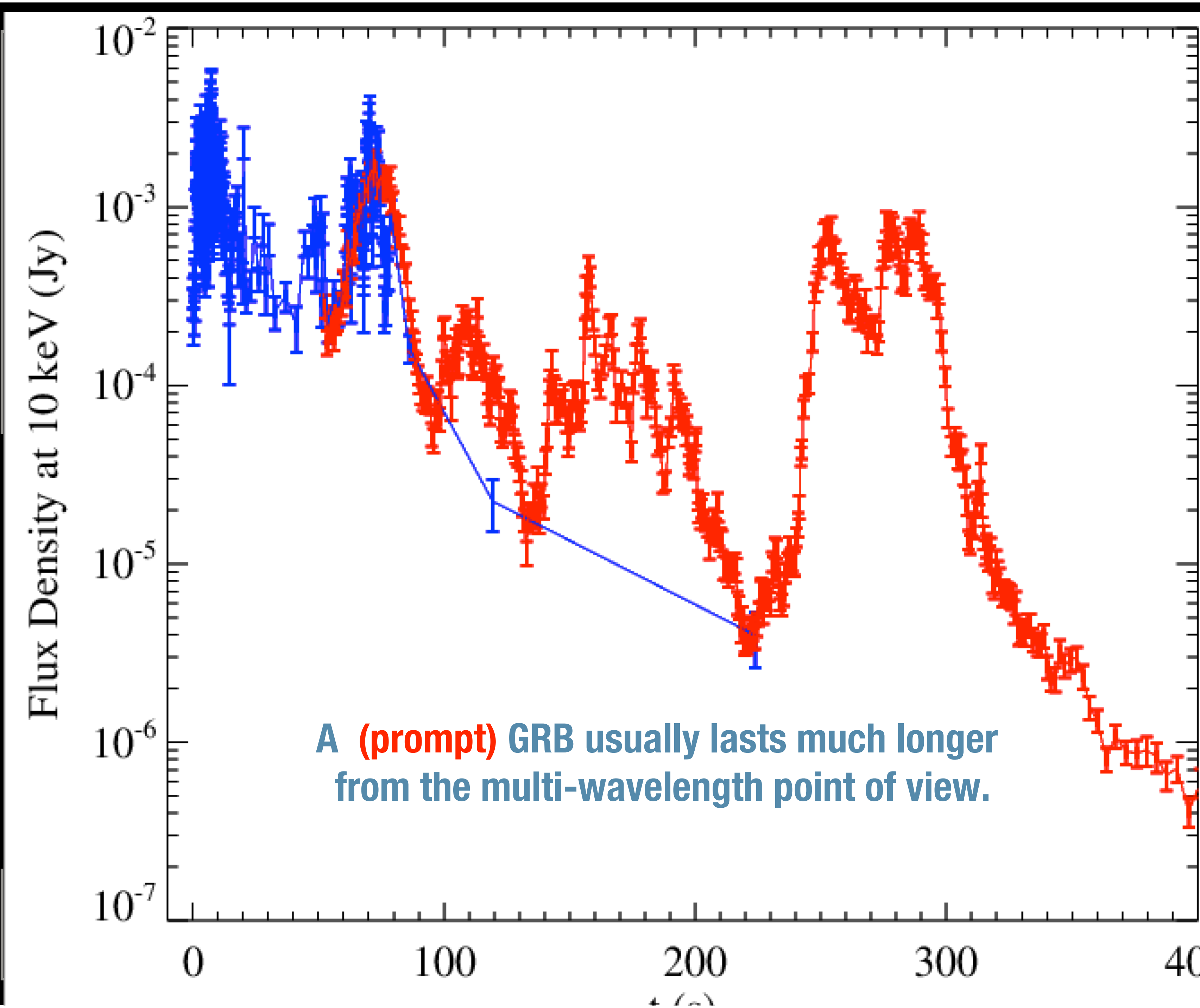


HOW DO WE SOLVE THIS?





HOW DO WE SOLVE THIS?


Flux Density at 10 keV (Jy)
10-2
10-3
10-4
10-5
10-6
10-7
0
100
200
300
40
A (prompt) GRB usually lasts much longer
from the multi-wavelength point of view.

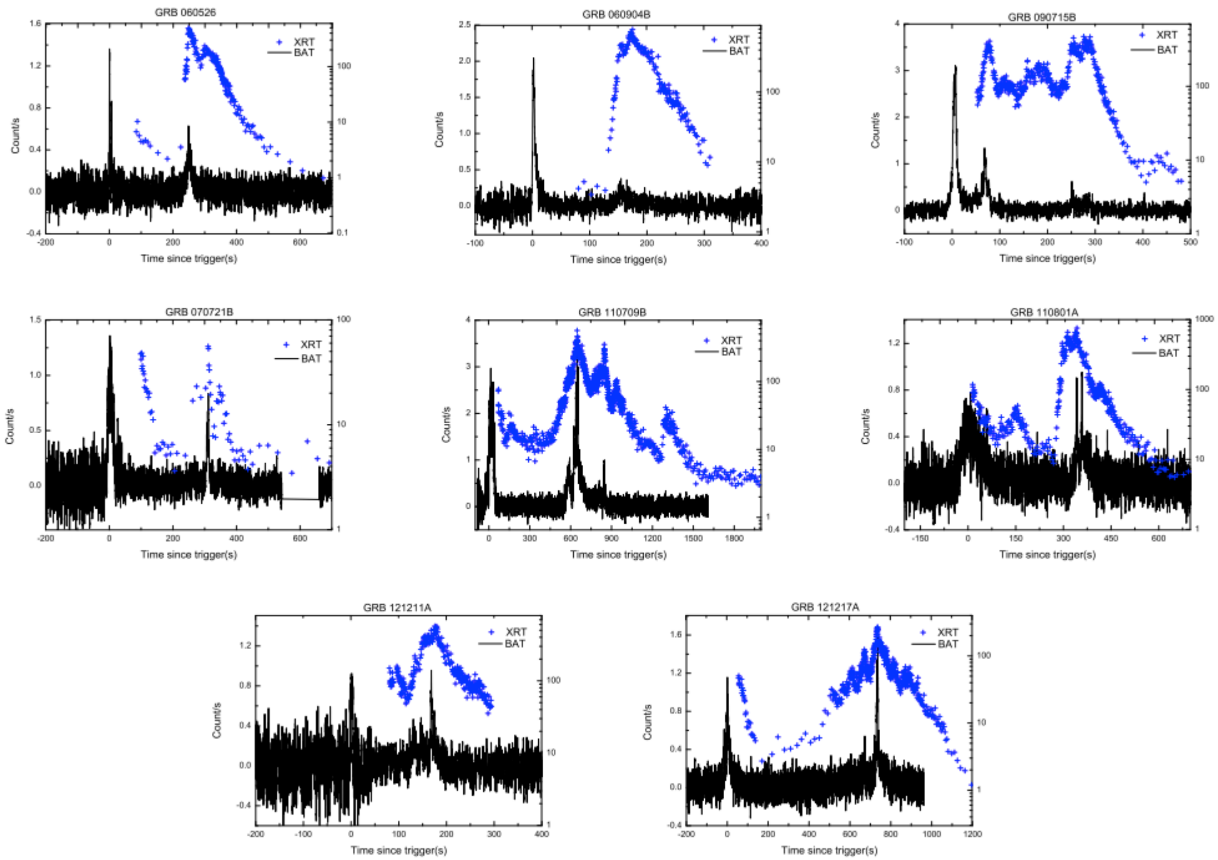


FIG. 8.— Examples of Joint BAT (connected lines) and XRT (crosses) lightcurves for GRBs with a long quiescence phase in the BAT band. The left and right vertical axes of each panel are for the count rate for the BAT data and XRT data, respectively.

Hu et al, 2014, ApJ in press, arxiv 1405.5949

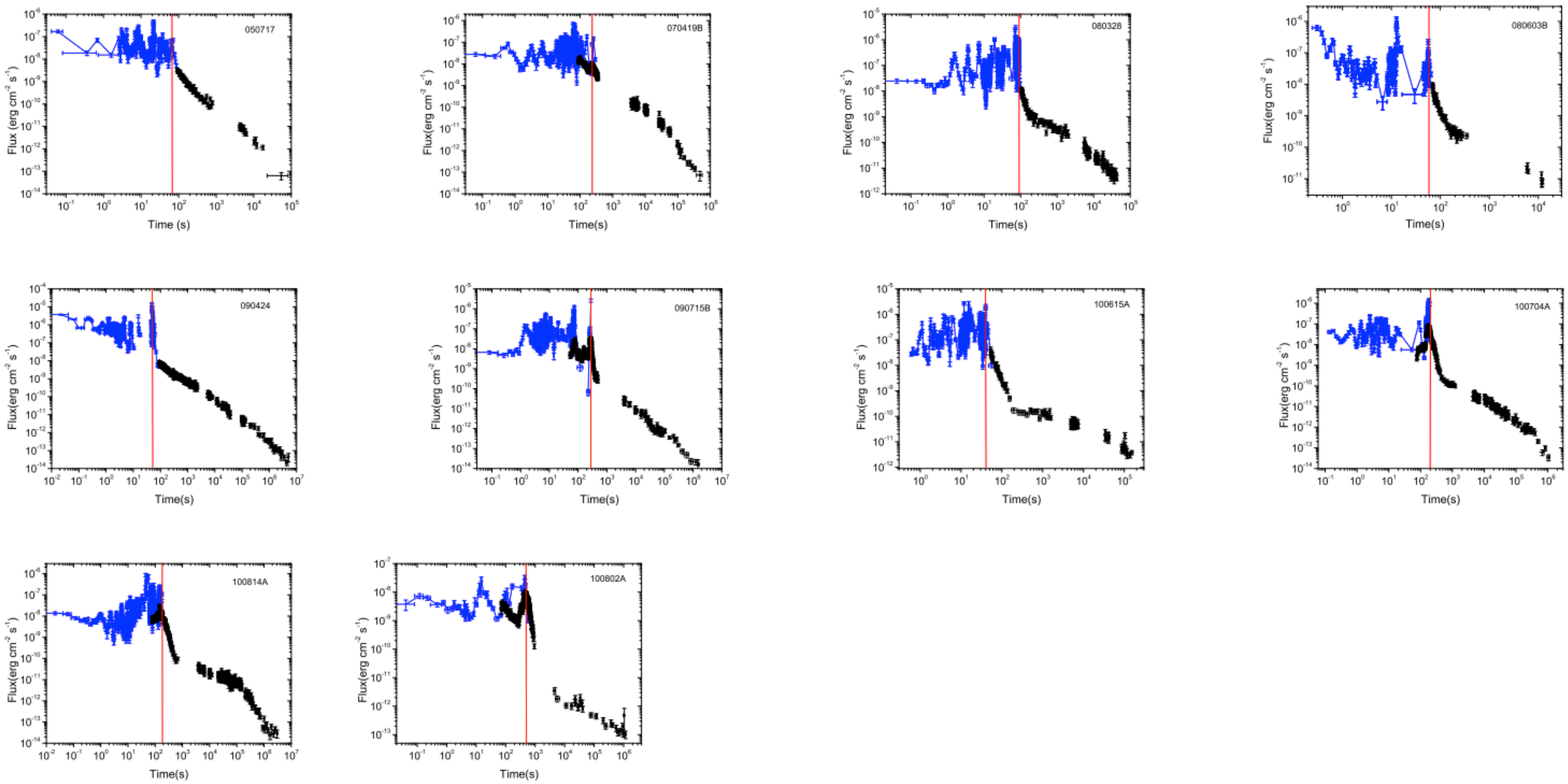
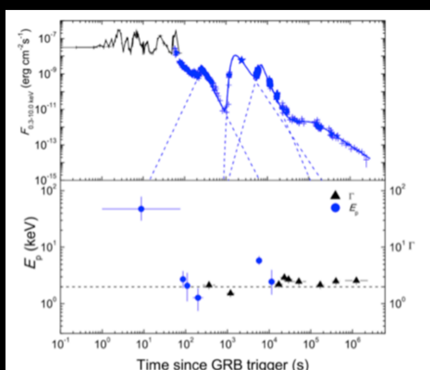


FIG. 9.— Examples of X-ray lightcurves from the BAT trigger to late XRT observational epochs for the GRBs that have no significant flares after T_{90}, where the prompt X-rays (the connected dots) are derived by extrapolating the BAT data to the XRT band. The vertical lines mark the end time of T_{90}.

Hu et al, 2014, ApJ in press, arxiv 1405.5949

Some Extreme Cases (Ultra-Long GRBs)



Peng et al. 2013

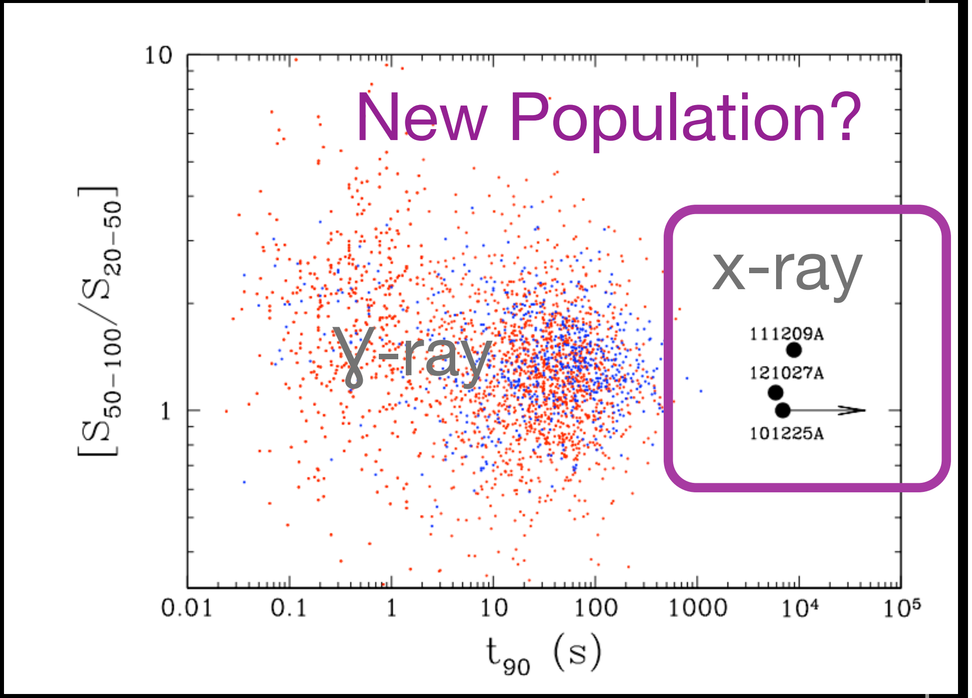
GRB	t_{BAT}	t_{XRT}
130925A	~ 10^4 s	1.2×10^4 s [1]
111209A	~10^4 s	5x 10^4 s [1]
121027A	63 s	“6000 s” [2]
101225A	> 2000 s	“7000 s” [2]

[1] this work

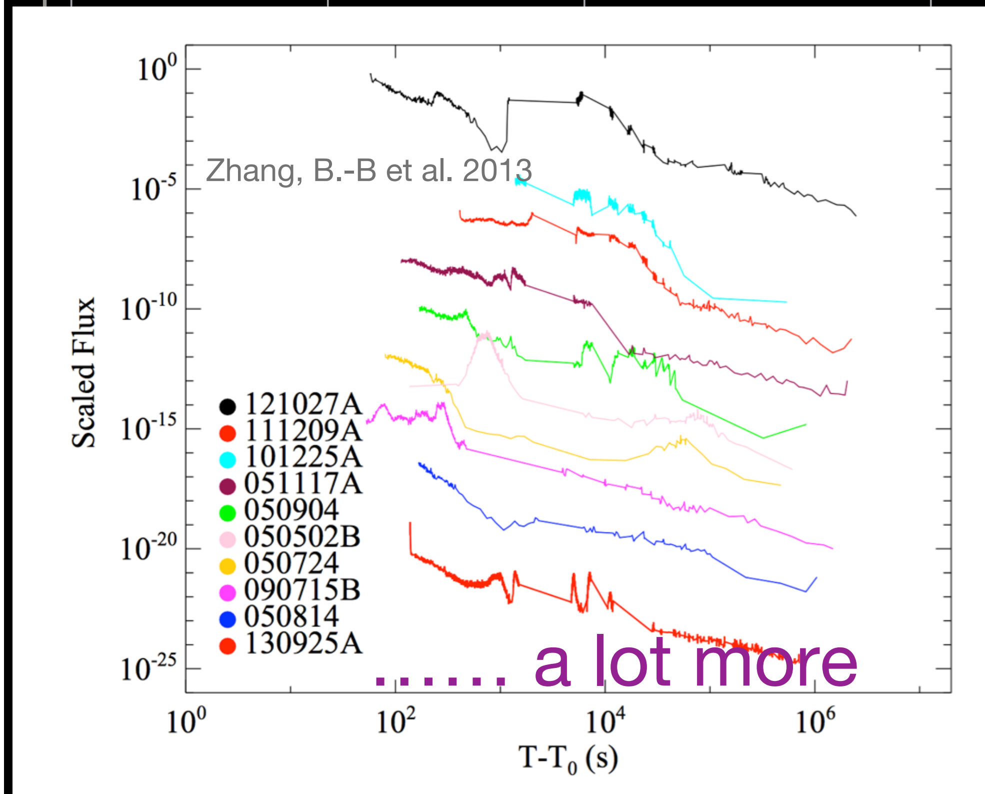
[2] Levan et al. 2013

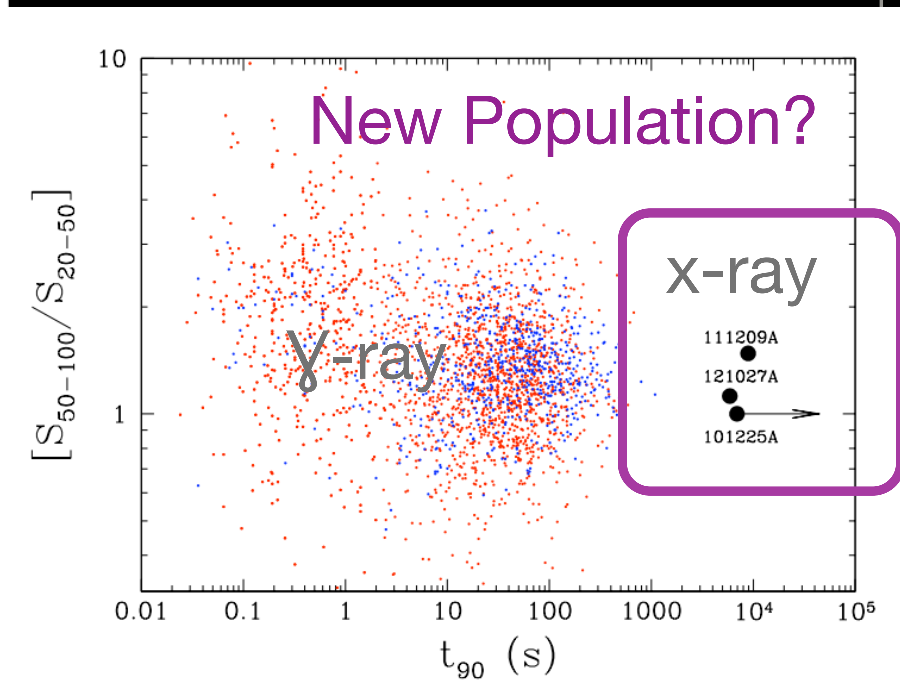
Levan et al. 2013

GRB	t_{BAT}	t_{XRT}
130925A	~ 10^4 s	1.2×10^4 s [1]
111209A	~10^4 s	5x 10^4 s [1]
121027A	63 s	"6000 s" [2]
101225A	> 2000 s	"7000 s" [2]

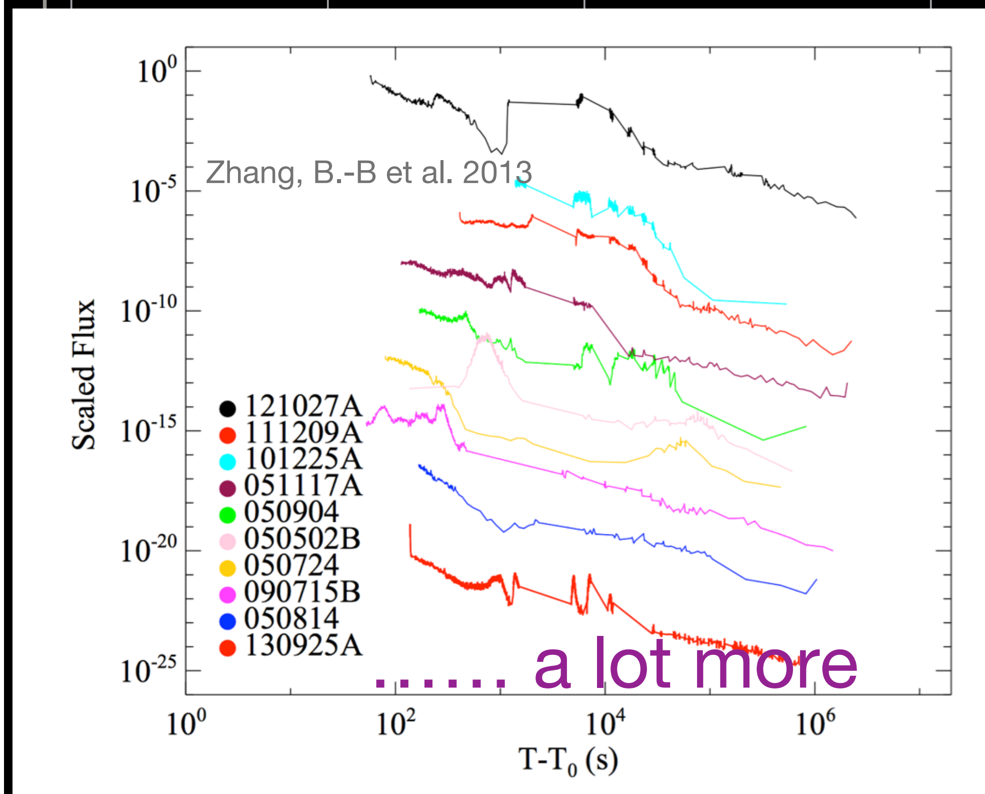


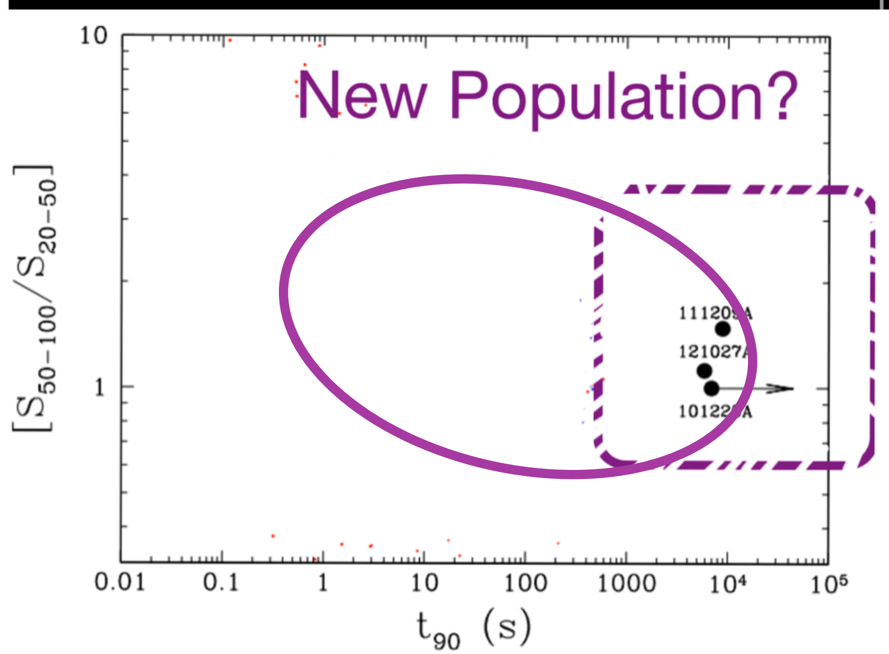
Levan et al. 2013





Levan et al. 2013

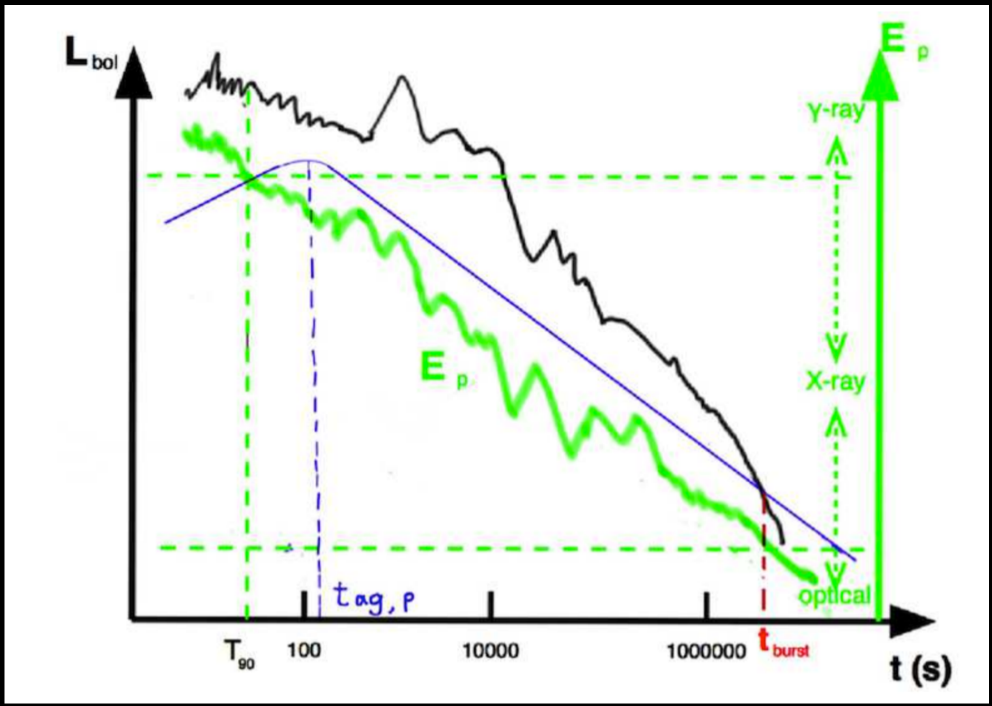




The new population may be not statistically/theoretically required

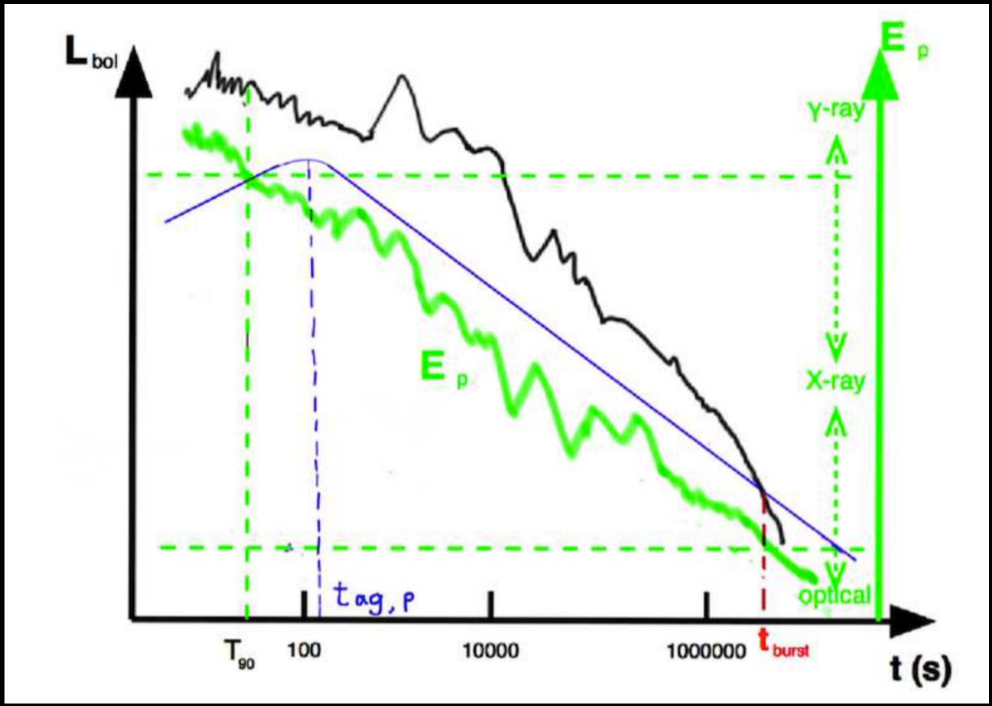
when we carefully understand the true duration of GRBs

t_{burst} - A Natural Model



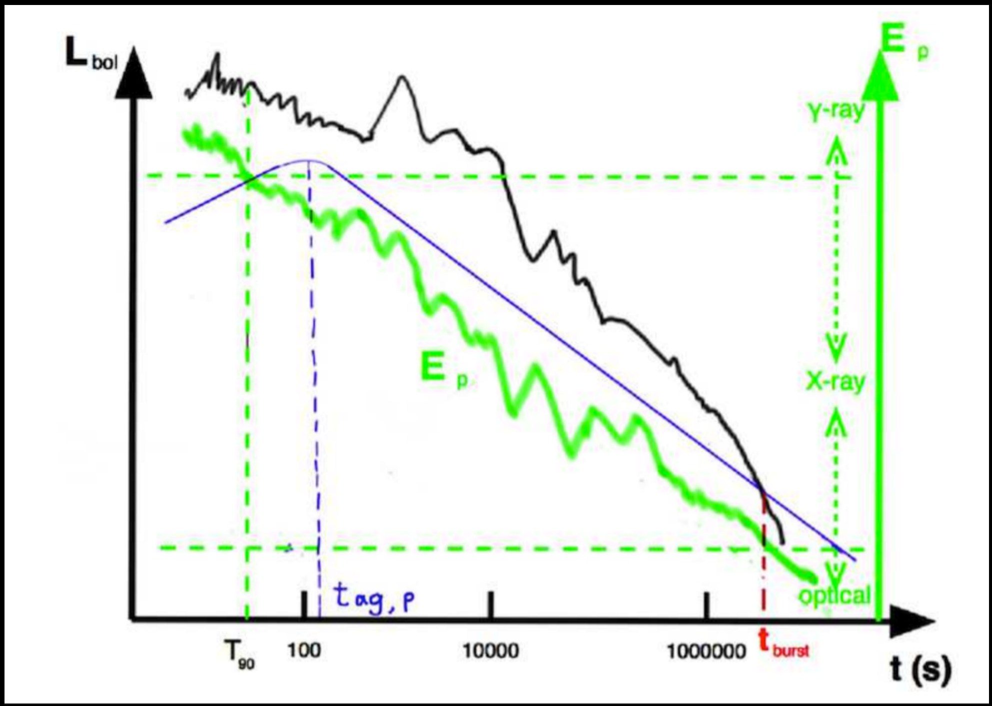
– The GRB central engine continuously ejects energy, with a reducing power

t_{burst} - A Natural Model



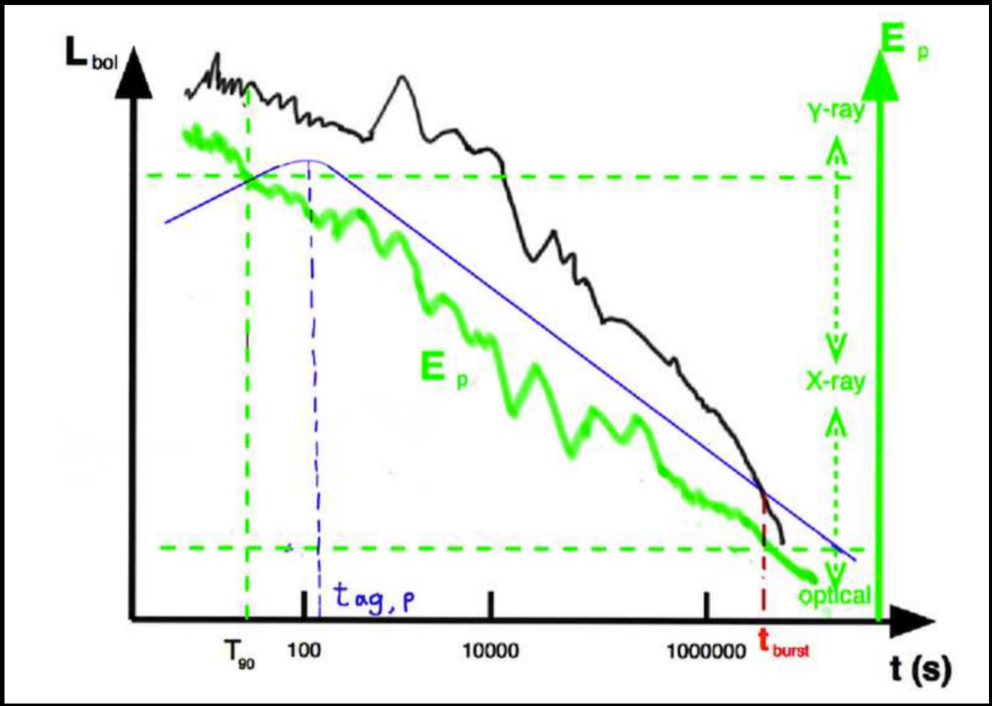
- The GRB central engine continuously ejects energy, with a reducing power
- E_p decreases with time (Lu et al. 2012)

t_{burst} - A Natural Model



— The GRB central engine continuously ejects energy, with a reducing power
— E_p decreases with time (Lu et al. 2012)
— At ~ T_{90} , the signal drops out from the γ-ray band, but it still continues in the X-ray. (a longer pre-drop time will lead a ultral-long GRB in γ-ray band, like 111209A, 130925A).

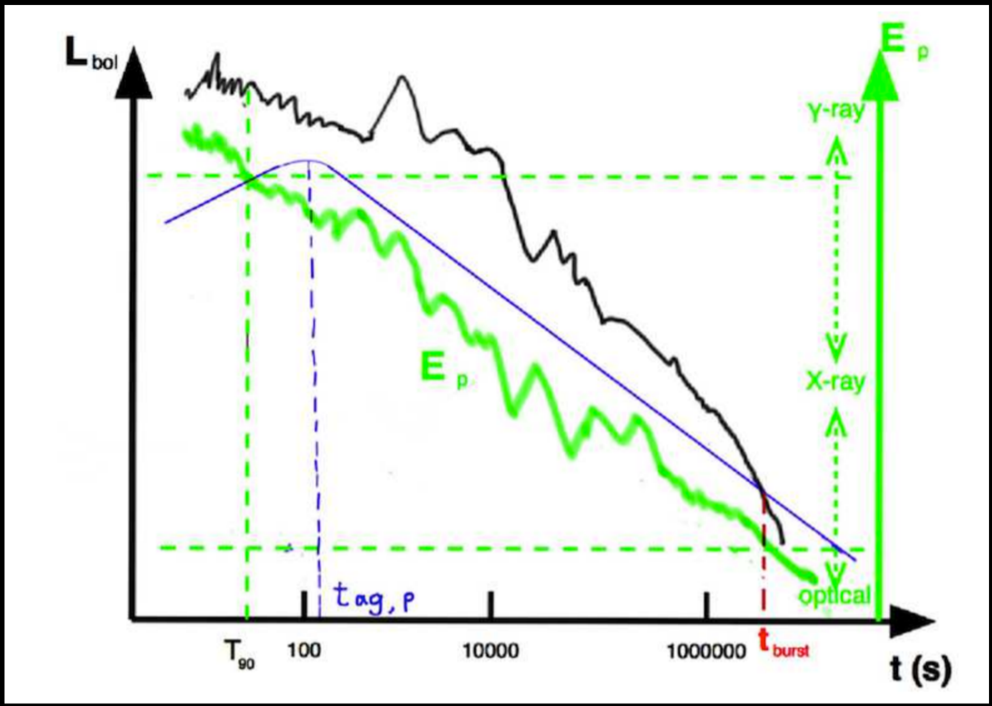
t_{burst} - A Natural Model



— The GRB central engine continuously ejects energy, with a reducing power
— E_p decreases with time (Lu et al. 2012)
— At ~ T_{90} , the signal drops out from the γ-ray band, but it still continues in the X-ray. (a longer pre-drop time will lead a ultral-long GRB in γ-ray band, like 111209A, 130925A).
— the afterglow sets in early on, peaking at $t_{ag,p}$ and decays with time.

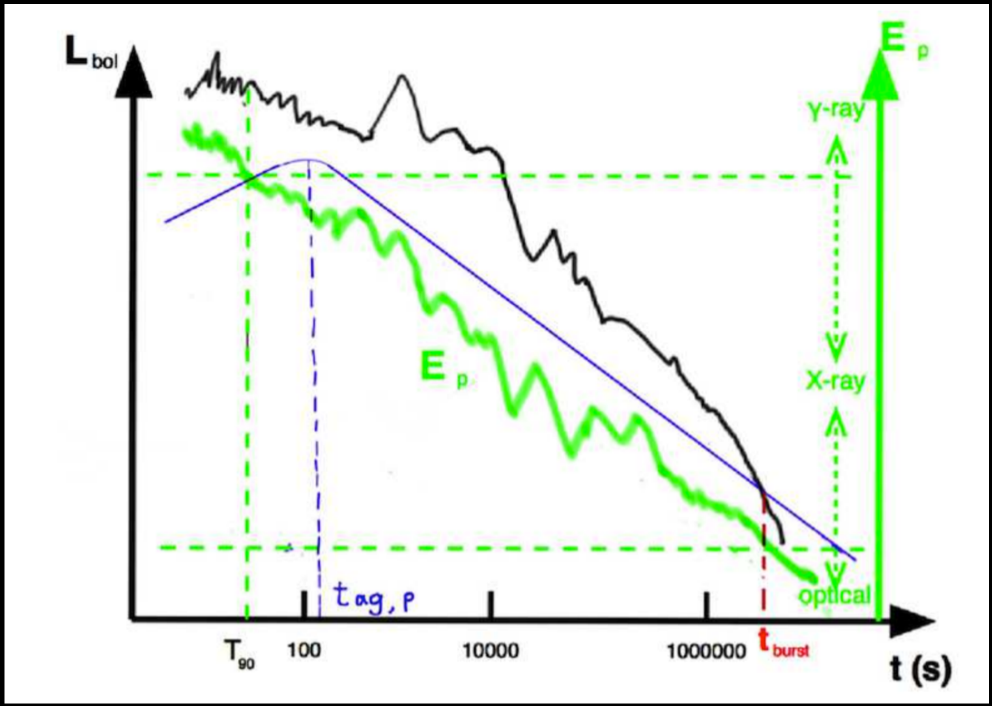
It is initially over-shone by the internal-origin X-ray component, and eventually show up in terms steep-to-shallow transition , at t_{burst}

t_{burst} - the definition



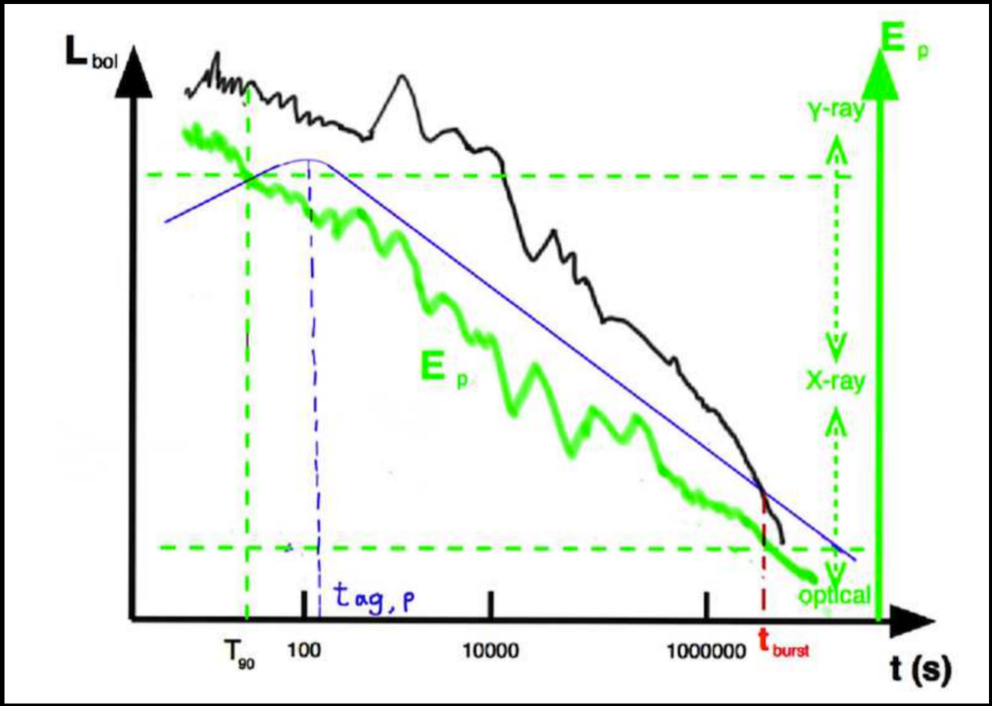
— a theoretically motivated, observable quantity

t_{burst} - the definition



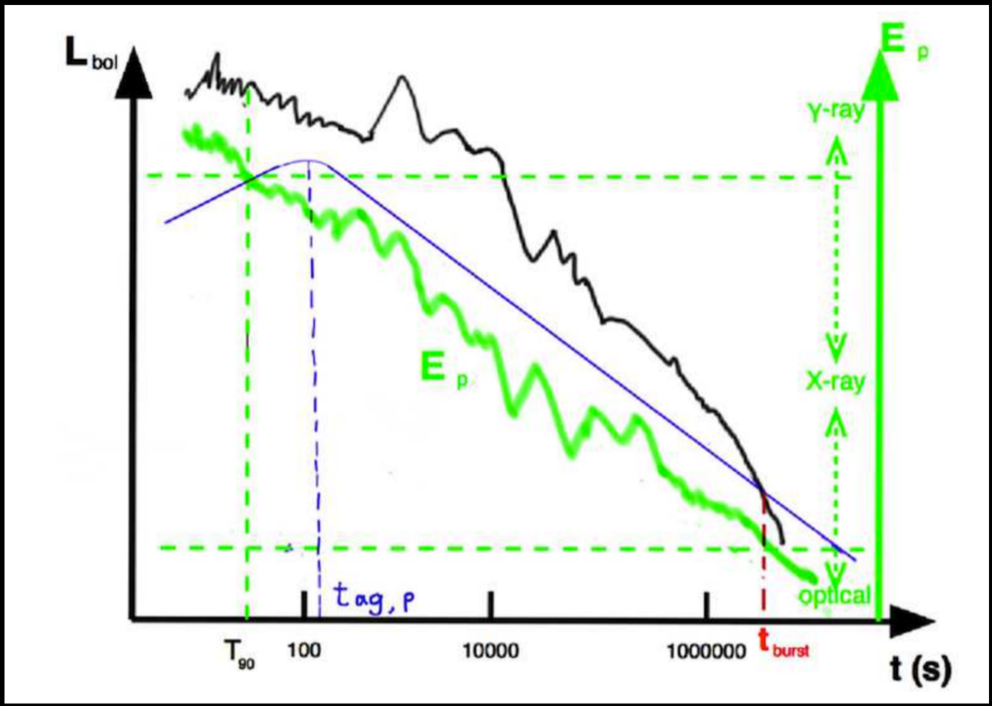
- a theoretically motivated, observable quantity
- during t_{burst}, the observed emission is dominated by internal process (IS or mag. dissp.)

t_{burst} - the definition



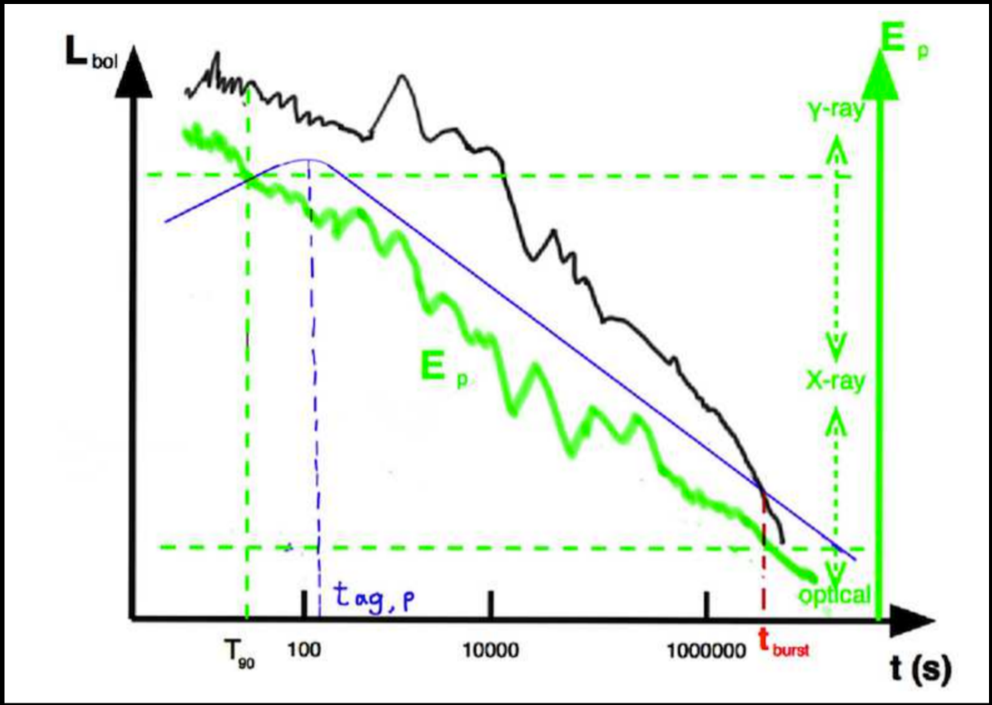
— a theoretically motivated, observable quantity
— during t_{burst}, the observed emission is dominated by internal process (IS or mag. dissp.)
— during t_{burst}, the observed emission is not dominated by the afterglow emission from the external shock

t_{burst} - the definition



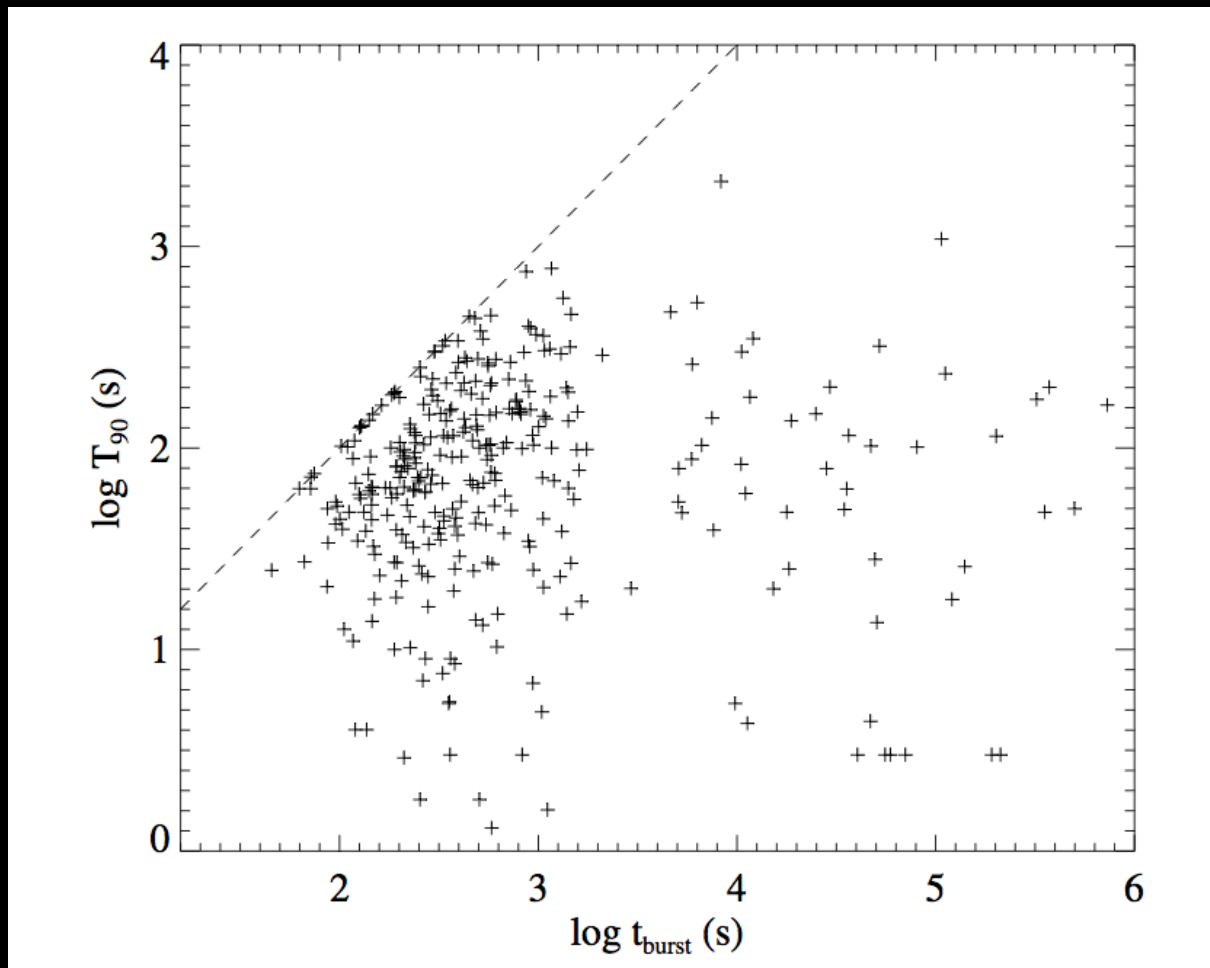
— a theoretically motivated, observable quantity
— during t_{burst}, the observed emission is dominated by internal process (IS or mag. dissp.)
— during t_{burst}, the observed emission is not dominated by the afterglow emission from the external shock
— measured as by the **last** observed steep-to-shallow transition

t_{burst} - the measurement



1) Calculate T_{90}
2) Fit the Swift/XRT light curve as a multi-segment broken power-law
3) Identify the steep-to-shallow transitions, and record the decay slope before the transition;
4) Identify the **last** transition with pre-break slope steeper than -3, and record the transition time.
The burst duration t_{burst} is measured as the maximum of this transition time and T_{90} of gamma-ray emission

T90 NOT EQ T_BURST



t_{burst} - examples

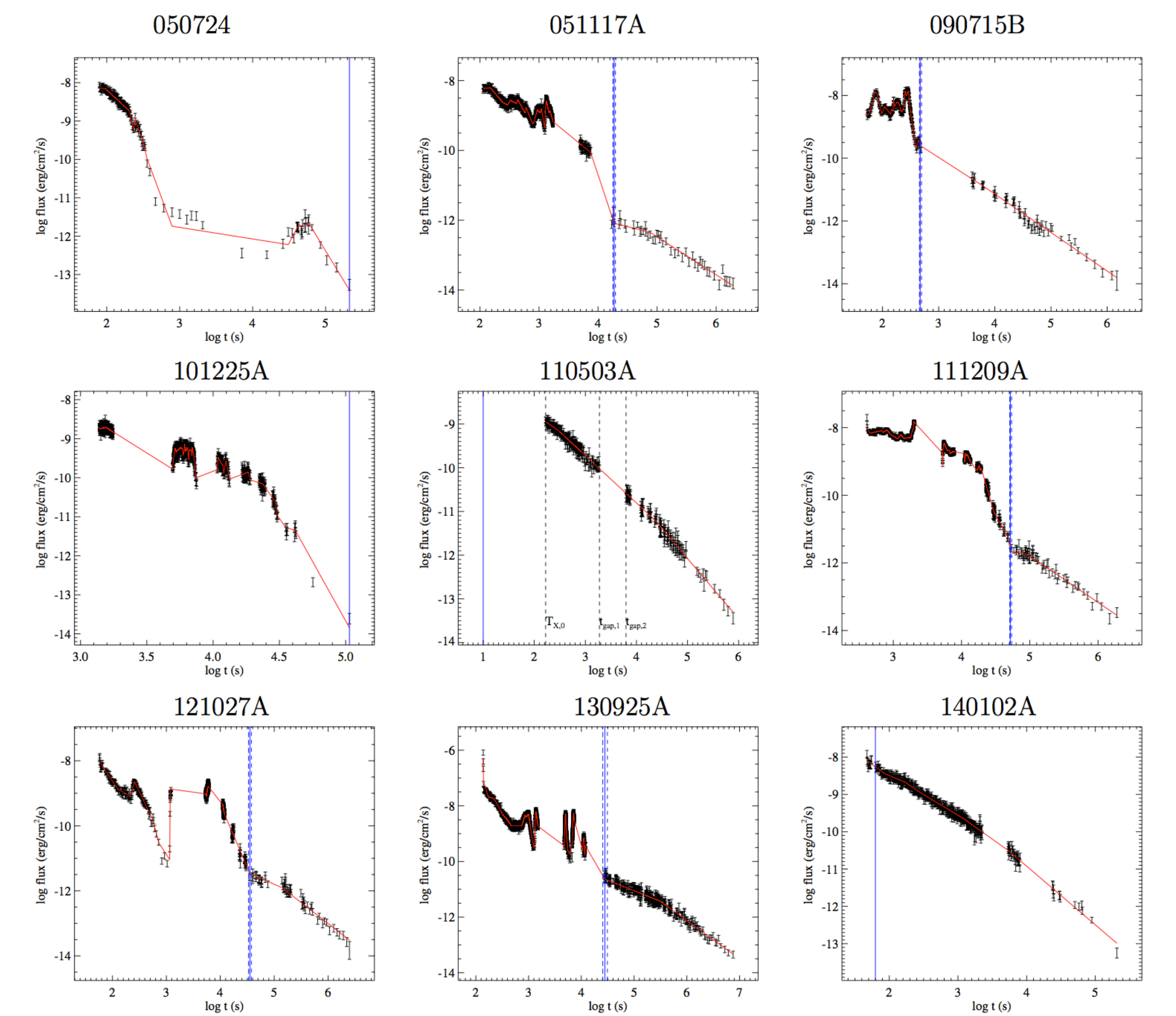
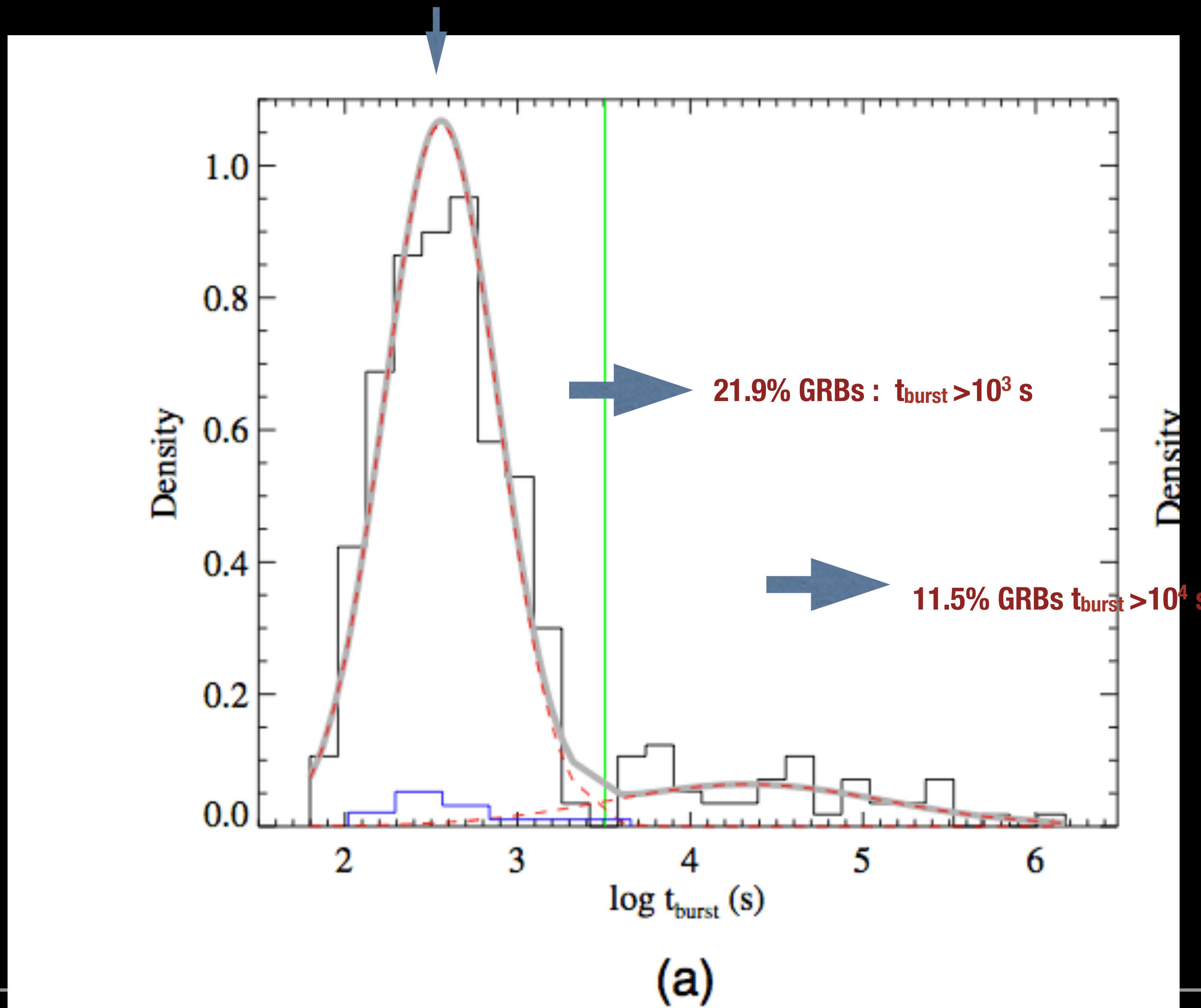


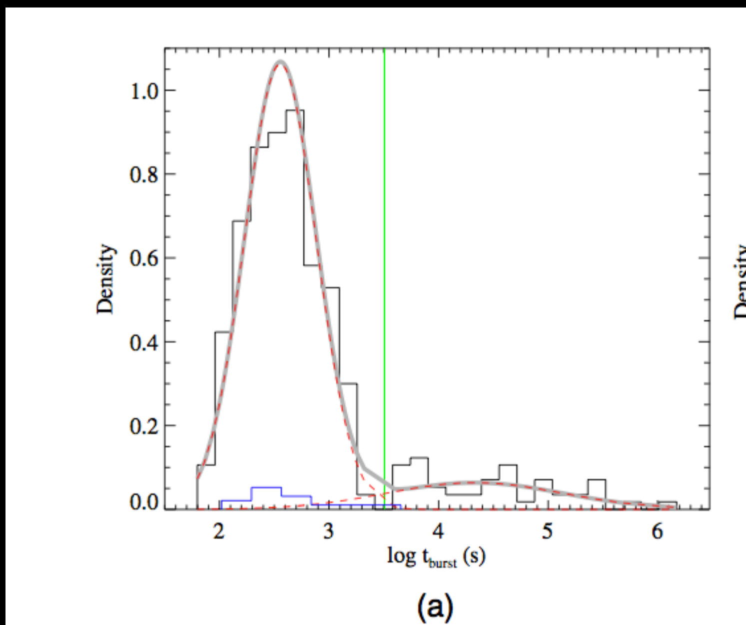
Figure 4. Some examples to show how to constrain $t_{\rm burst}$ with the XRT data. Black points are *Swift*/XRT observations. Red solid line represents the multi-segment

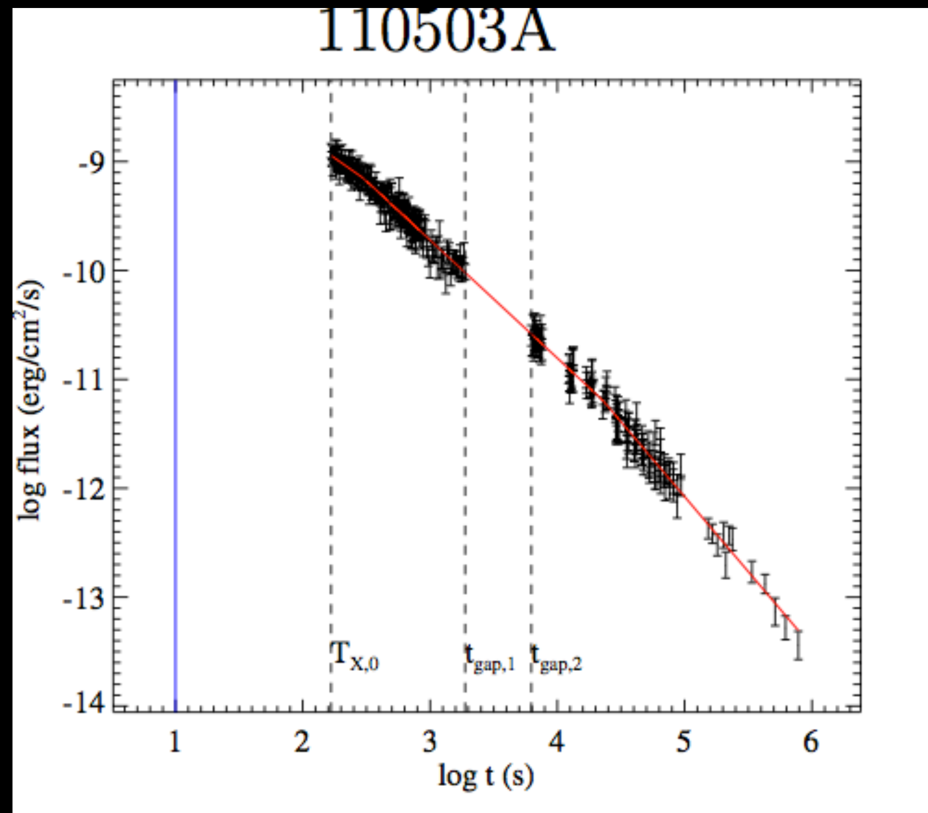
t_{burst} - distribution

peaks 355s



Bimodal?
Probably not.





Uncertainties in the observational gaps

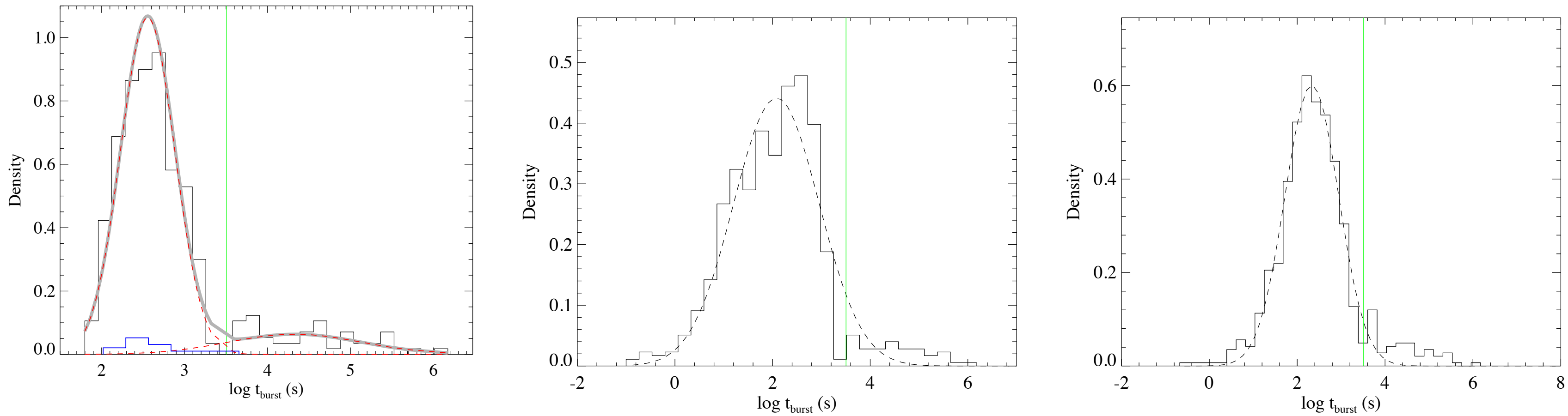
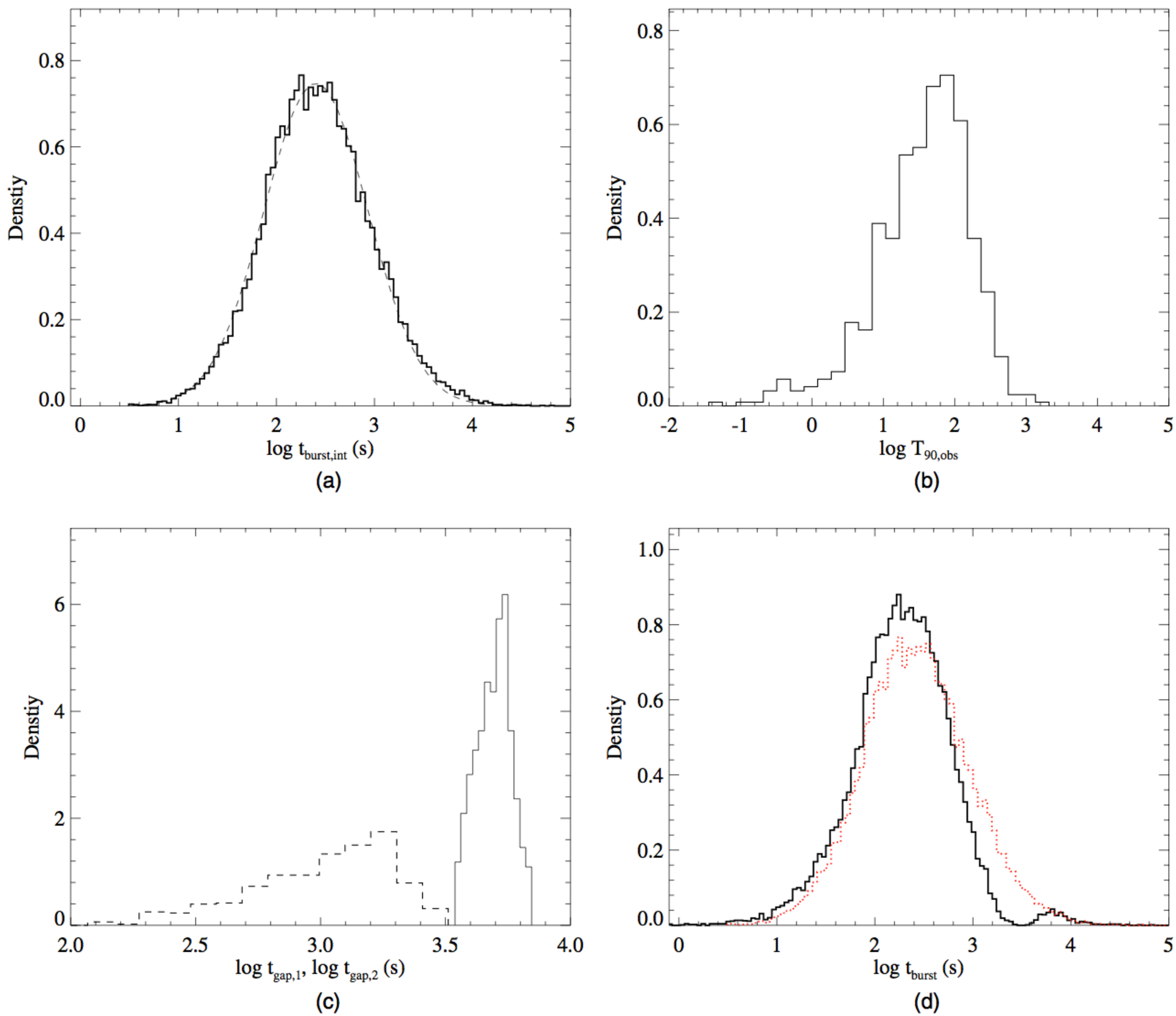
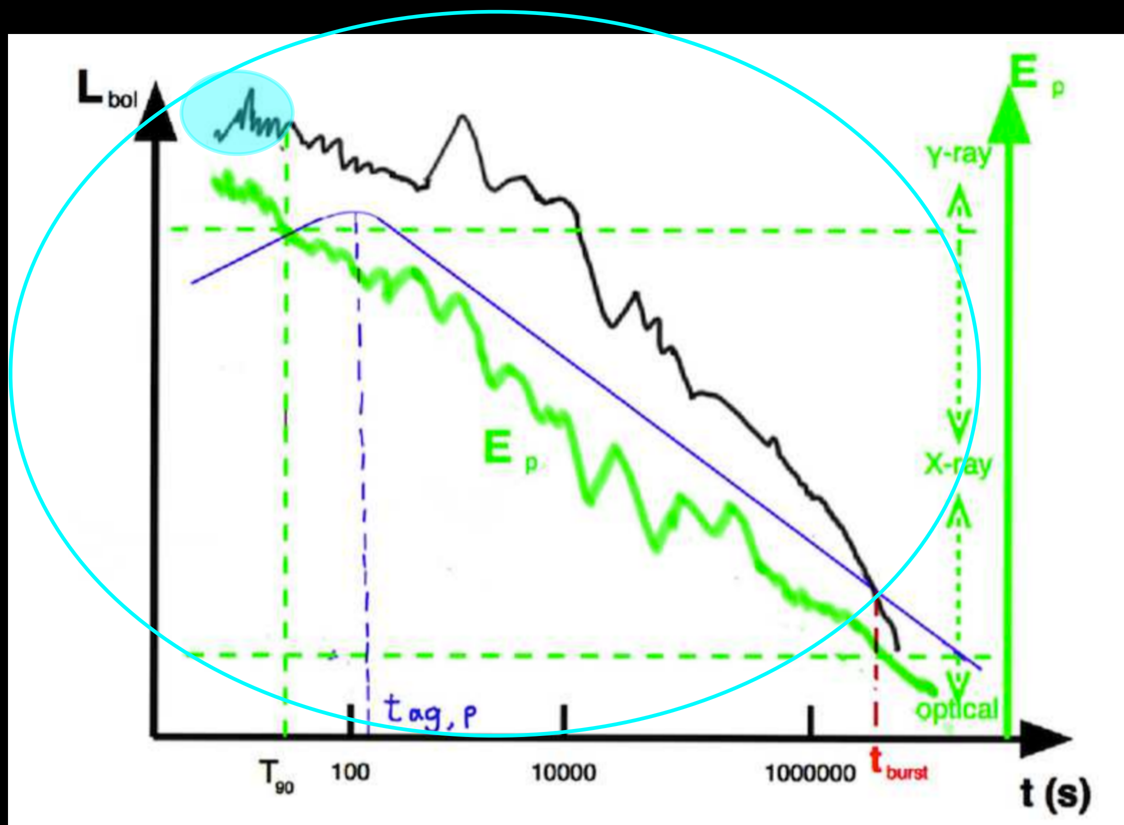


Figure 5. (a) The derived distribution of $t_{\rm burst}$ of the good sample (343 GRBs). The histogram bin sizes are optimized using Knuth's rule (Knuth 2000). The vertical axis "density" is defined as "count/bin size/total count". The derived $t_{\rm burst}$ are plotted as a black solid histogram. The distribution of the short GRBs ($\rm T_{90}$ <2s) in the good sample is plotted as the blue solid histogram. The fit result by a two-component Gaussian distribution is plotted as a thick grey solid line and each component is plotted as red dashed lines. A typical value of $t_{gap,2}$ - $t_{\rm gap,1}$ = 3200 s is plotted as a vertical green solid line. (b) Distribution of $t_{\rm burst}$ for the good sample (343 GRBs) and the uncertain sample (304 GRBs), with $t_{\rm burst}$ of the uncertain sample set to T_{90}. (c) Same as (b), but with $t_{\rm burst}$ in the uncertain sample set to a uniformly-distributed random value between $\rm T_{90}$ and $\rm T_{X,0}$ in logarithmic scale.


Denstiy
log $t_{burst,int}$ (s)
(a)
Denstiy
log $T_{90,obs}$
(b)
Denstiy
log $t_{gap,1}$, log $t_{gap,2}$ (s)
(c)
Denstiy
log t_{burst} (s)
(d)

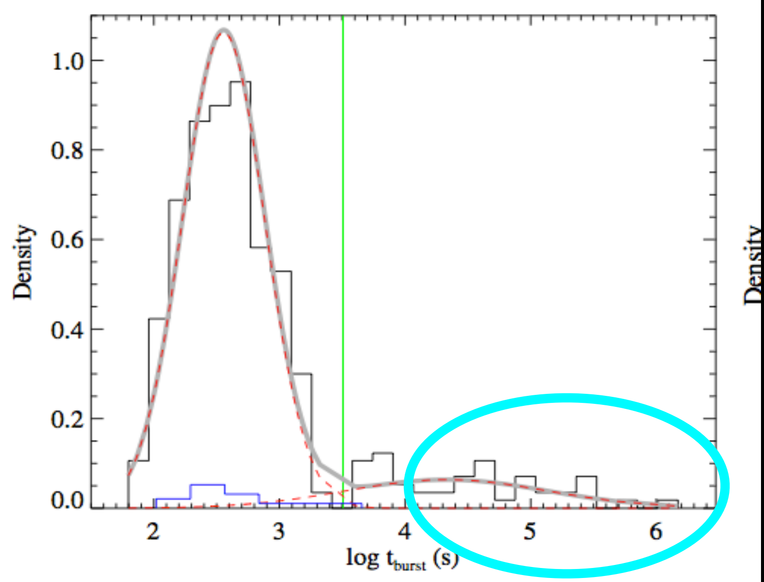
t_{burst} - implications

- a GRB can burst much (> 10 times) longer than T_{90} measurement; typical GRB central engines are active for quite a long time.



t_{burst} - implications

- a GRB bursts much (> 10 times) longer than T_{90} measurement;
  typical GRB central engines are active for quite a long time.
- The ultra-long GRBs might be just tails of whole sample (see also Virgili et al. 2013).



(a)

t_{burst} - implications

— a GRB bursts much (> 10 times) longer than T_{90} measurement; typical GRB central engines are active for quite a long time.

— The ultra-long GRBs might be just tails of whole sample (see also Virgili et al. 2013).

— a large fraction of long GRBs are actually quite long, even though their T_{90} are not extremely long.

t_{burst} - implications

— a GRB bursts much (> 10 times) longer than T_{90} measurement;
typical GRB central engines are active for quite a long time.

— The ultra-long GRBs might be just tails of whole sample (see also Virgili et al. 2013).

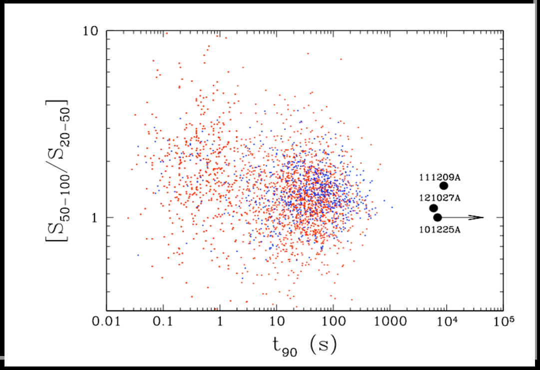
— a large fraction of long GRBs are actually quite long, even though their T_{90} are not extremely long.

— Direct Connection between T_{90} and the progenitor star ? Maybe not.

For example, LGRBs 030329 and 130427A's progenitors are believed to be Wolf-Rayet star, because they have associated Type Ic supernovae, not because of their duration.

sGRB 130603B is likely merger because it might be associated with a kilonova, not because of its short duration.

Similarly, one can not simply argue a burst may be from a blue supergaint just based on their 10^4 s duration.



t_{burst} - implications

— a GRB bursts much (> 10 times) longer than T_{90} measurement;
typical GRB central engines are active for quite a long time.
— The ultra-long GRBs might be just tails of whole sample (see also Virgili et al. 2013).
— a large fraction of long GRBs are actually quite long, even though their T_{90} are not extremely long.
— Direct Connection between T_{90} and the progenitor star ? Maybe not.
For example, LGRBs 030329 and 130427A's progenitors are believed to be Wolf-Rayet star, because they have associated Type Ic supernovae, not because of their duration.
sGRB 130603B is likely merger because it might be associated with a kilonova, not because of its short duration (see Edo's talk).
Similarly, one can not simply argue a burst may be from a blue supergaint just based on their 10^4 s duration.
— Why t_{burst} So long ? — still an open questions.
(e.g, fragmentation in the massive star envelope or the accretion disk, or formation of a magnetic barrier around the accretor)

t_{burst} - implications

— a GRB bursts much (> 10 times) longer than T_{90} measurement;
typical GRB central engines are active for quite a long time.

— The ultra-long GRBs might be just tails of whole sample (see also Virgili et al. 2013).

— a large fraction of long GRBs are actually quite long, even though their T_{90} are not extremely long.

— Direct Connection between T_{90} and the progenitor star ? Maybe not.

For example, LGRBs 030329 and 130427A's progenitors are believed to be Wolf-Rayet star, because they have associated Type Ic supernovae, not because of their duration.

sGRB 130603B is likely merger because it might be associated with a kilonova, not because of its short duration (see Edo's talk).

Similarly, one can not simply argue a burst may be from a blue supergaint just based on their 10^4 s duration.

— Why t_{burst} So long ? — still an open questions.

(e.g, fragmentation in the massive star envelope or the accretion disk, or formation of a magnetic barrier around the accretor)

— the single peak distribution of t_{burst}

— long GRB progenitor stars may have a continuous distribution of mass and size, ranging from compact Wolf-Rayet stars to blue supergiants

t_{burst} - implications

— a GRB bursts much (> 10 times) longer than T_{90} measurement;
typical GRB central engines are active for quite a long time.

— The ultra-long GRBs might be just tails of whole sample (see also Virgili et al. 2013).

— a large fraction of long GRBs are actually quite long, even though their T_{90} are not extremely long.

Making a direct connection between T_{90} and the size of the progenitor star is premature.

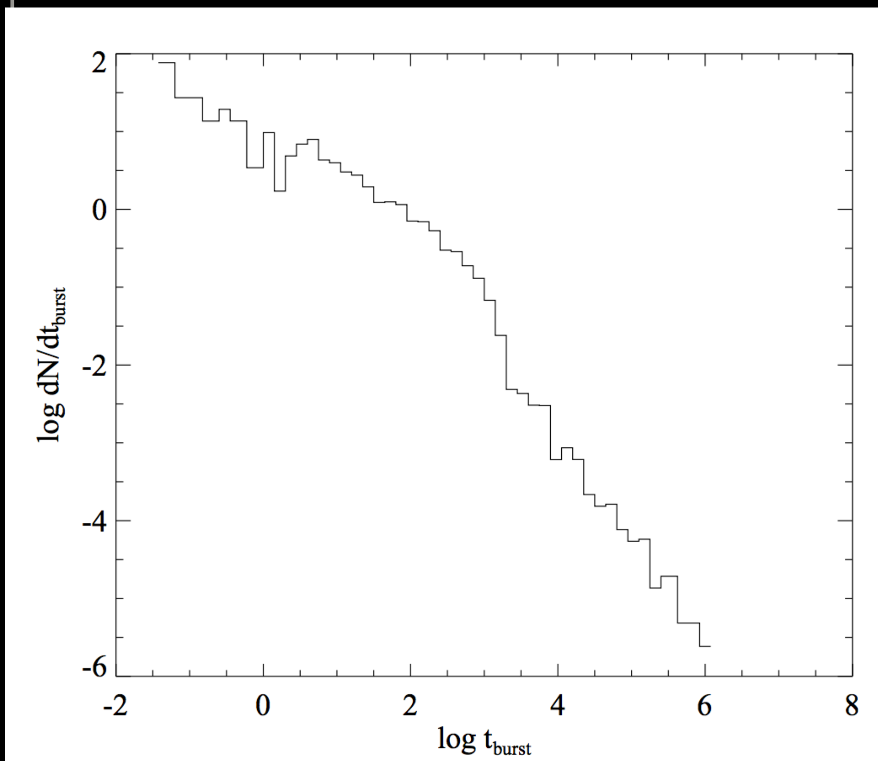
For example, 030329 and 130427A's progenitors are believed to be Wolf-Rayet star, because they have associated Type Ic supernovae, not because of their duration.

Thus, one can not simply argue a burst may be from a blue supergaint just based on their 10^4 s duration.

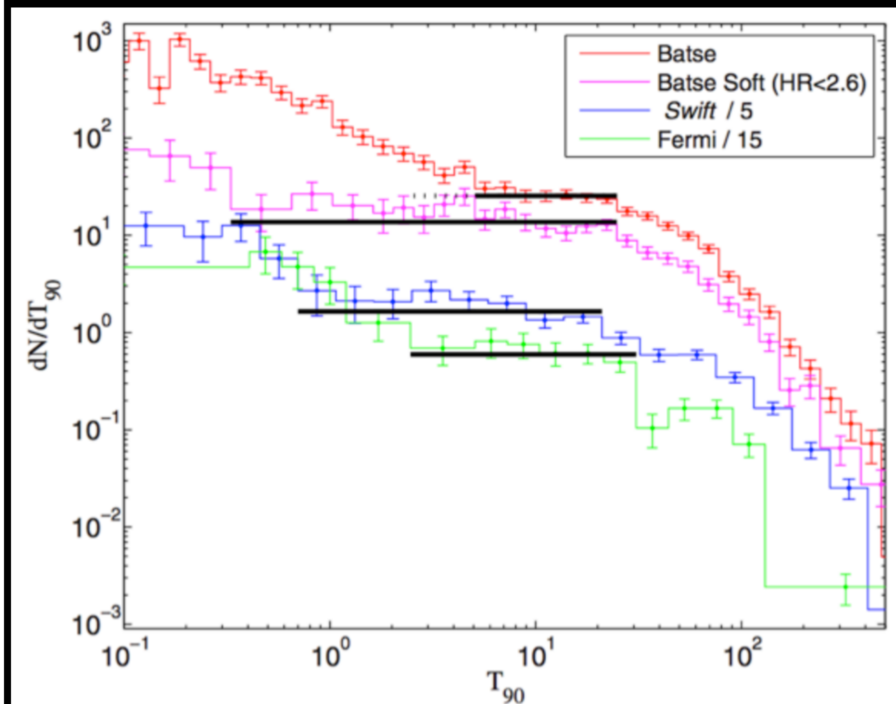
— How to prolong a GRB central engine duration with a compact progenitor star ?
(e.g, fragmentation in the massive star envelope or the accretion disk, or formation of a magnetic barrier around the accretor)

— the single peak distribution of t_{burst}
— long GRB progenitor stars may have a continuous distribution of mass and size, ranging from compact Wolf-Rayet stars to blue supergiants

— We didn't see Bromberg's plateau.



This work



Bromberg et al. 2013

Summary

- **Q: Are you reinvent T_{90} ?**
- **A:**

  No. But our understanding of the duration of a "burst" has been advanced with new observations made by Swift.

  t_{burst} might be more appropriate to describe the real duration of GRBs.
- **Future Swift observations will tell.**

THANKS!

real-time tburst can be found at
http://grbscience.com/tburst.html