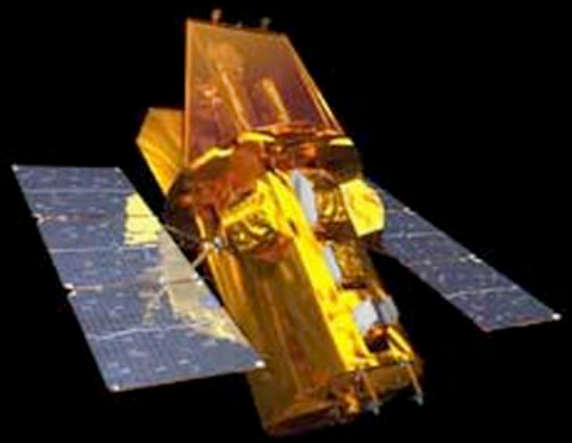
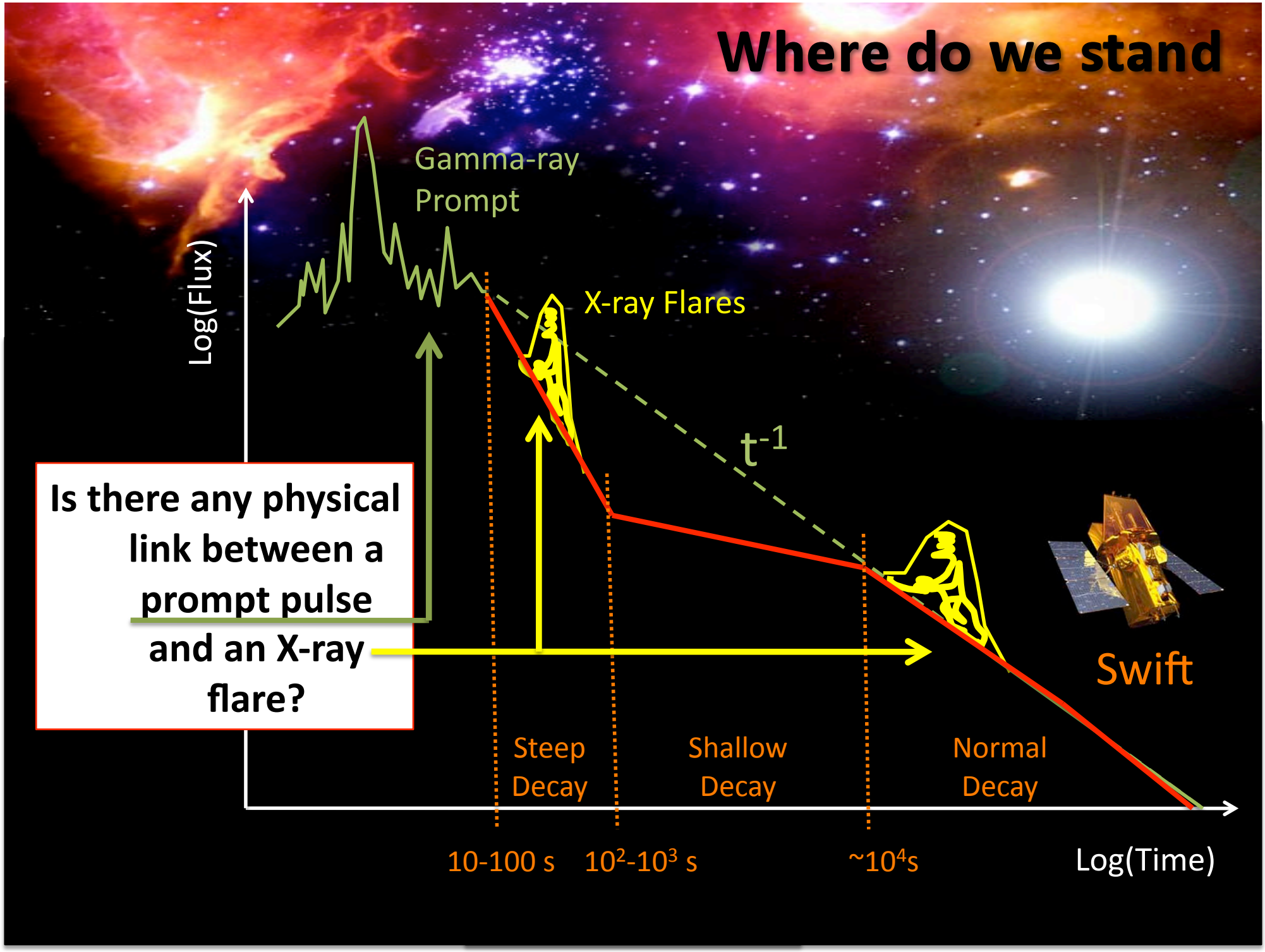
Constraints to hyper-accreting black holes from Gamma-Ray Burst observations

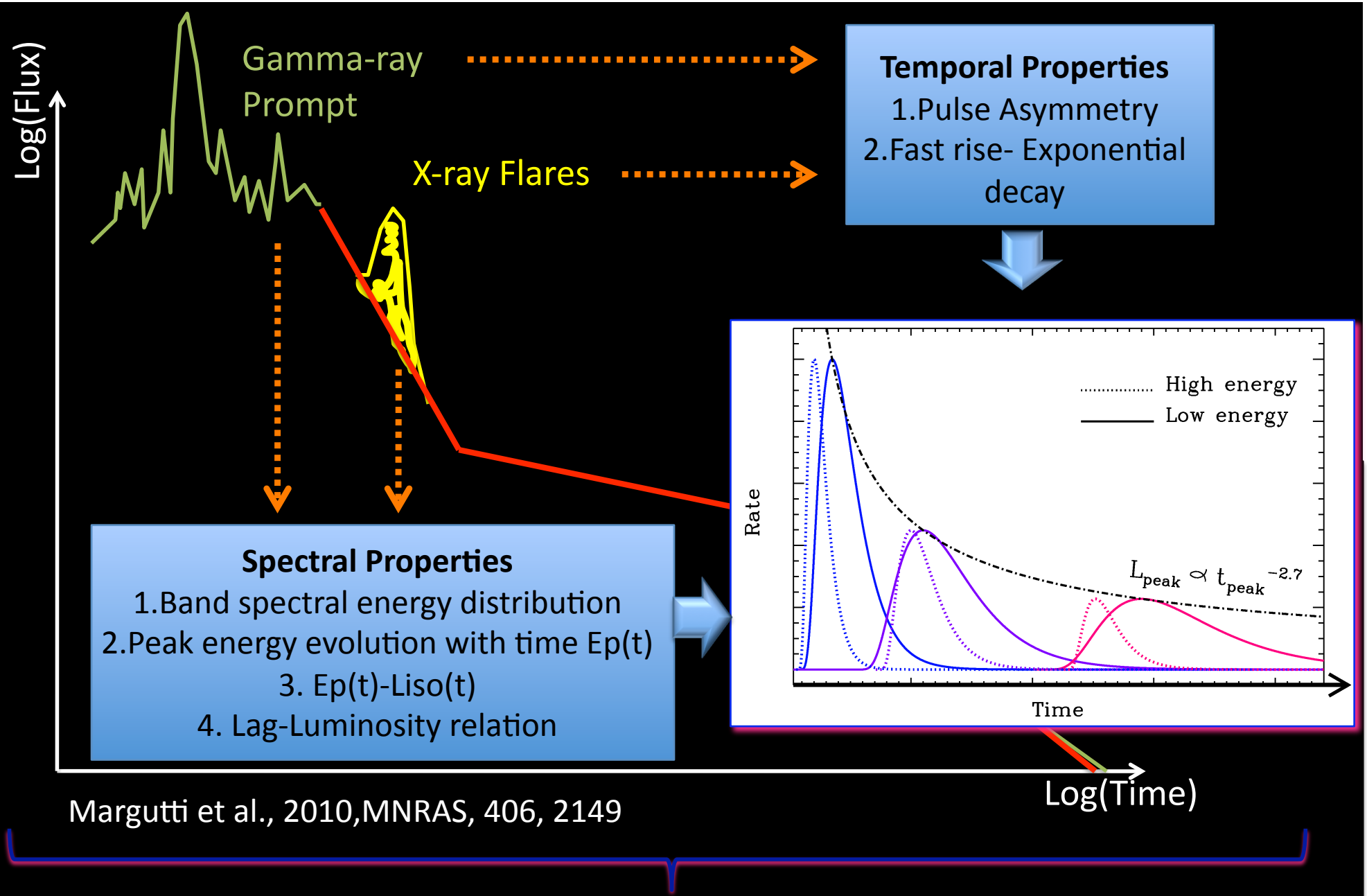


Raffaella Margutti
INAF-OAB; Universita' Milano Bicocca
Swift-XRT team

Annapolis, Nov 2nd

Where do we stand



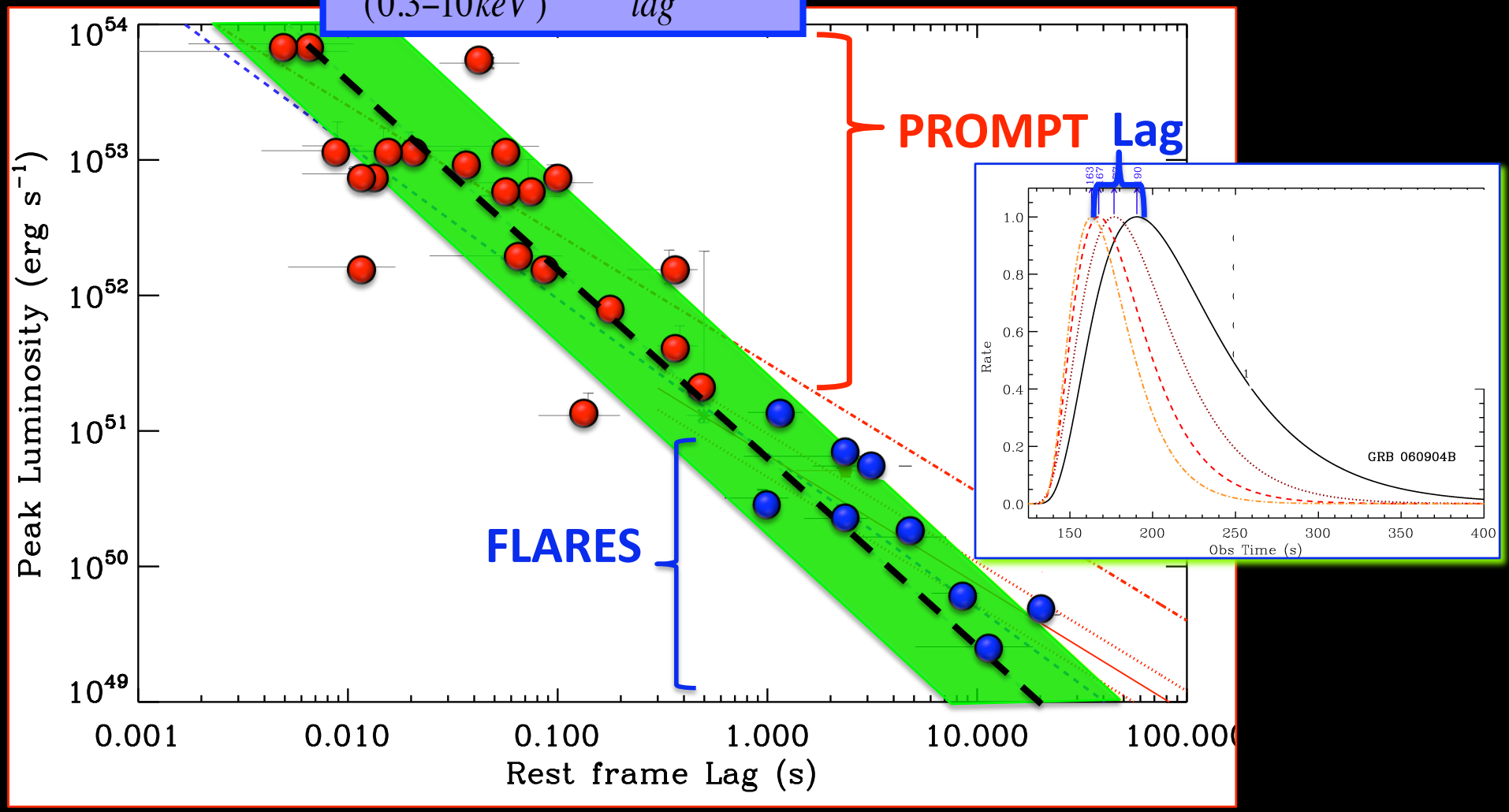


Margutti et al., 2010,MNRAS, 406, 2149

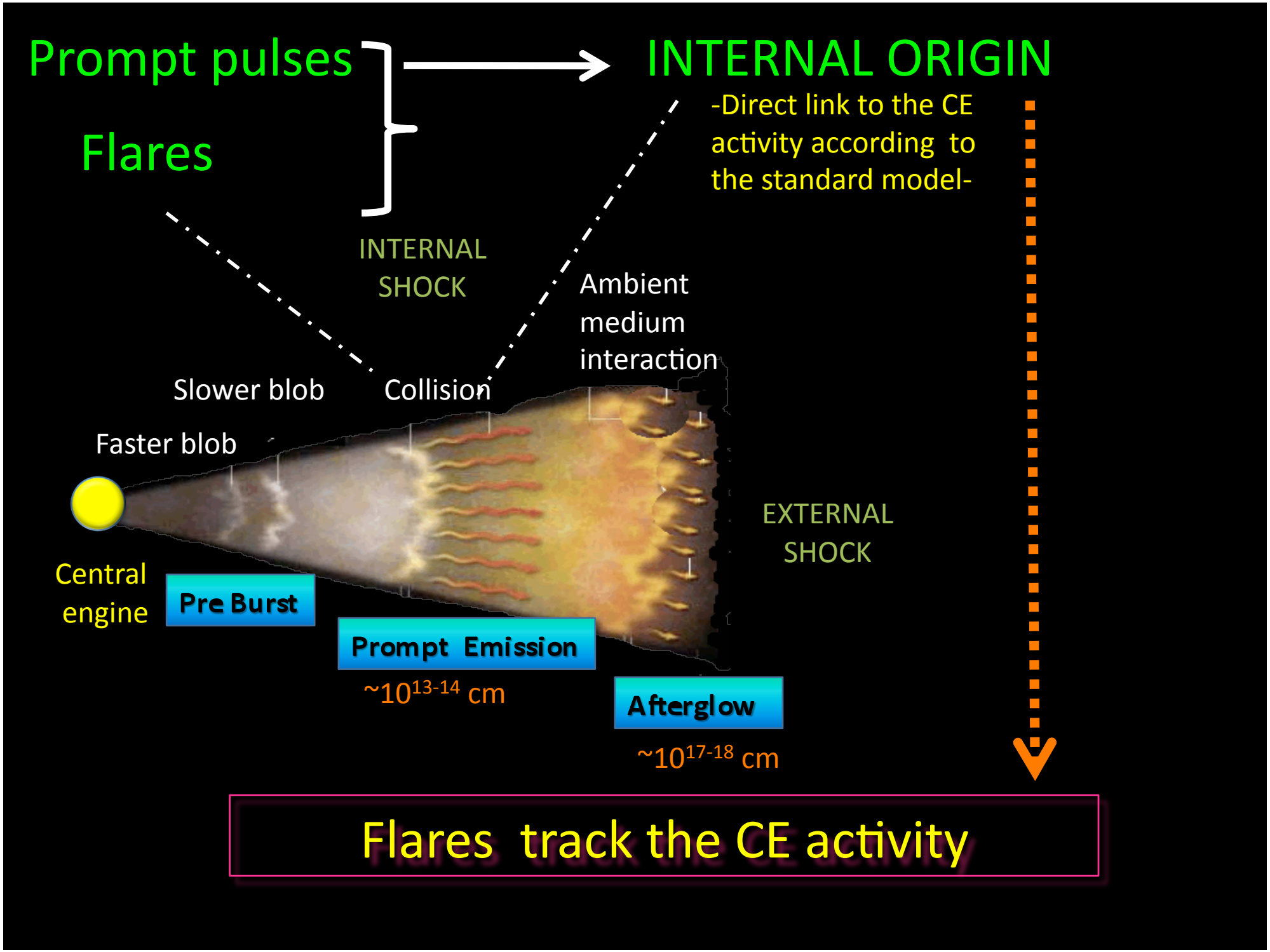
Flares are softer and less energetic time-stretched versions of a prompt pulse

Lag-Luminosity

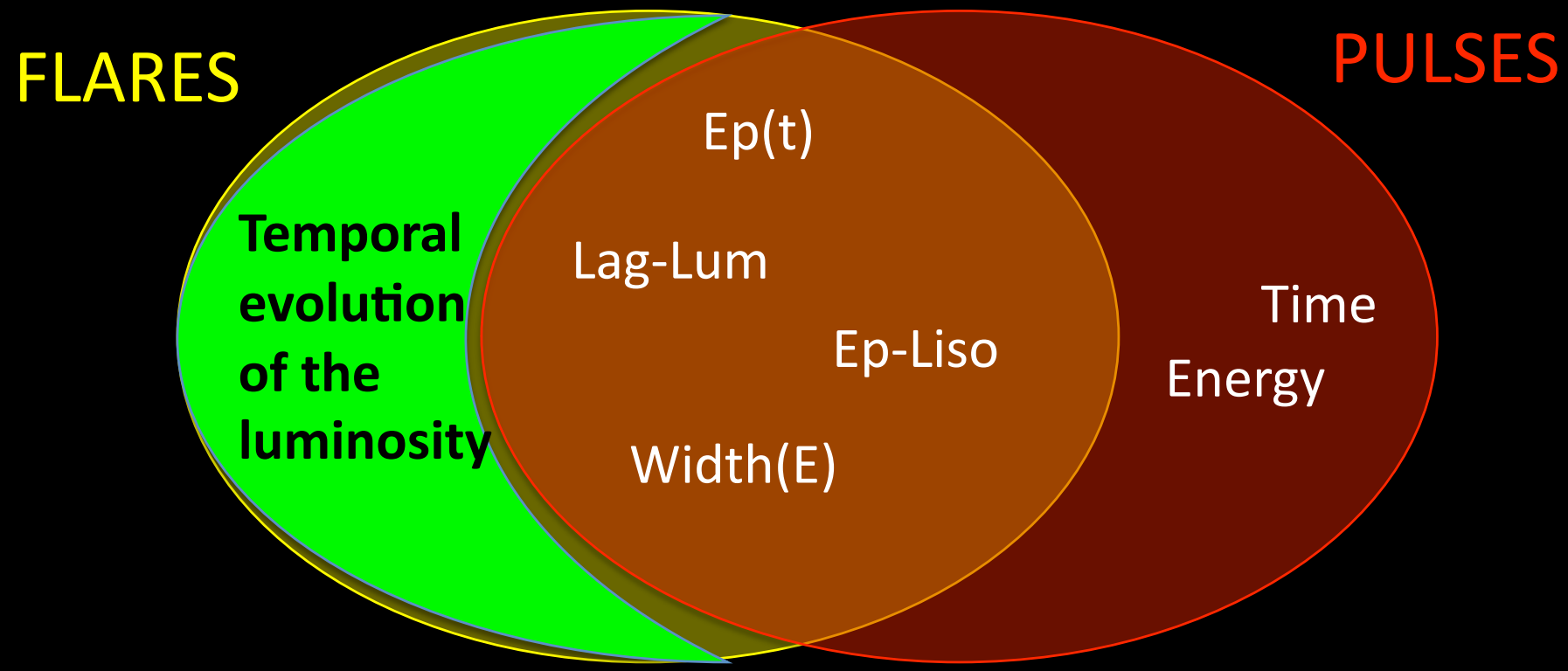
$$L_{(0.3-10keV)} \propto t_{lag}^{-0.95\pm0.23}$$



Margutti et al., 2010,MNRAS, 406, 2149

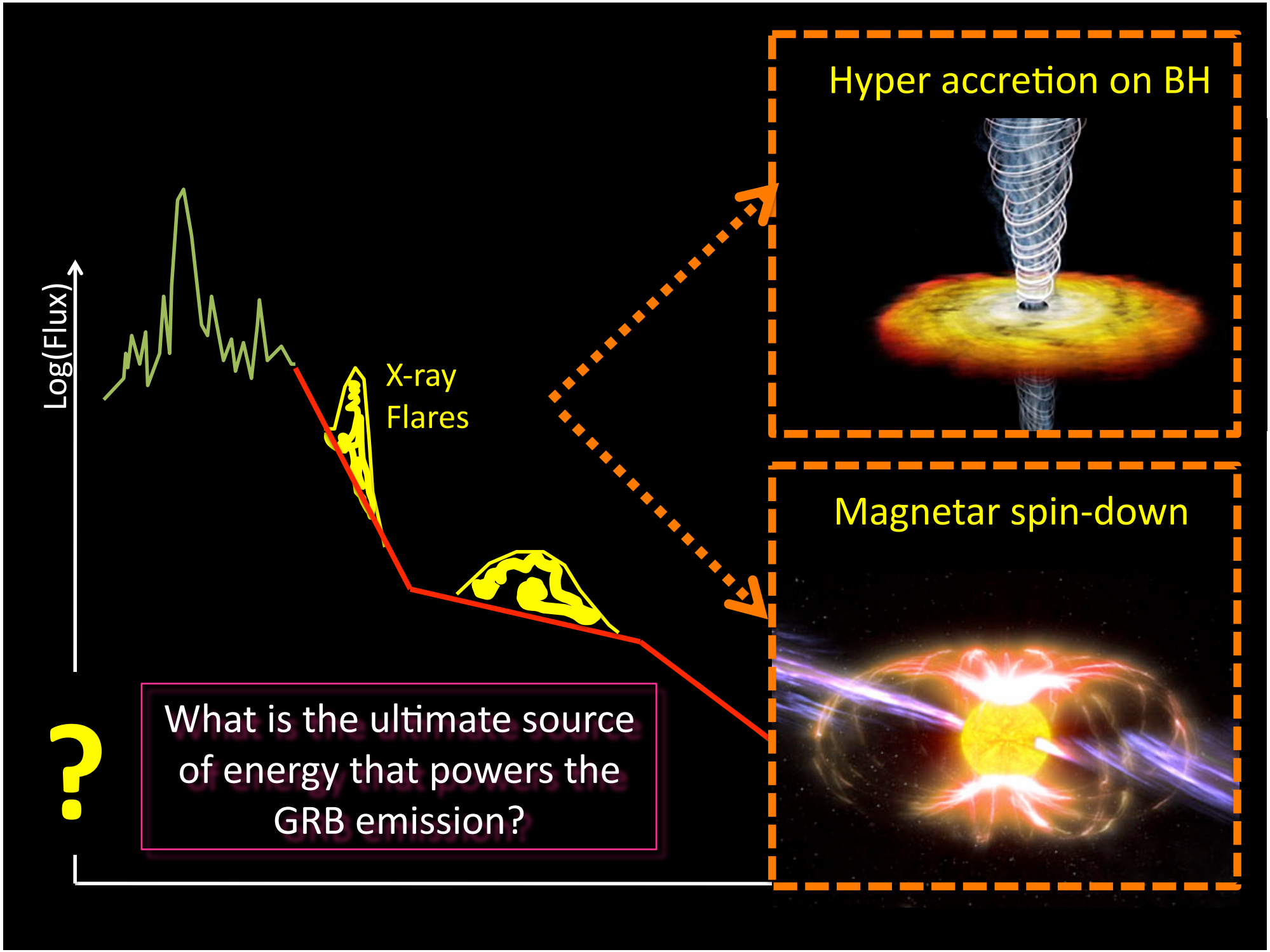

Prompt pulses
Flares
INTERNAL ORIGIN
-Direct link to the CE activity according to the standard model-
INTERNAL SHOCK
Ambient medium interaction
Slower blob
Collision
Faster blob
EXTERNAL SHOCK
Central engine
Pre Burst
Prompt Emission
~10^13-14 cm
Afterglow
~10^17-18 cm
Flares track the CE activity

Flares are softer and less energetic time-stretched versions of a prompt pulse

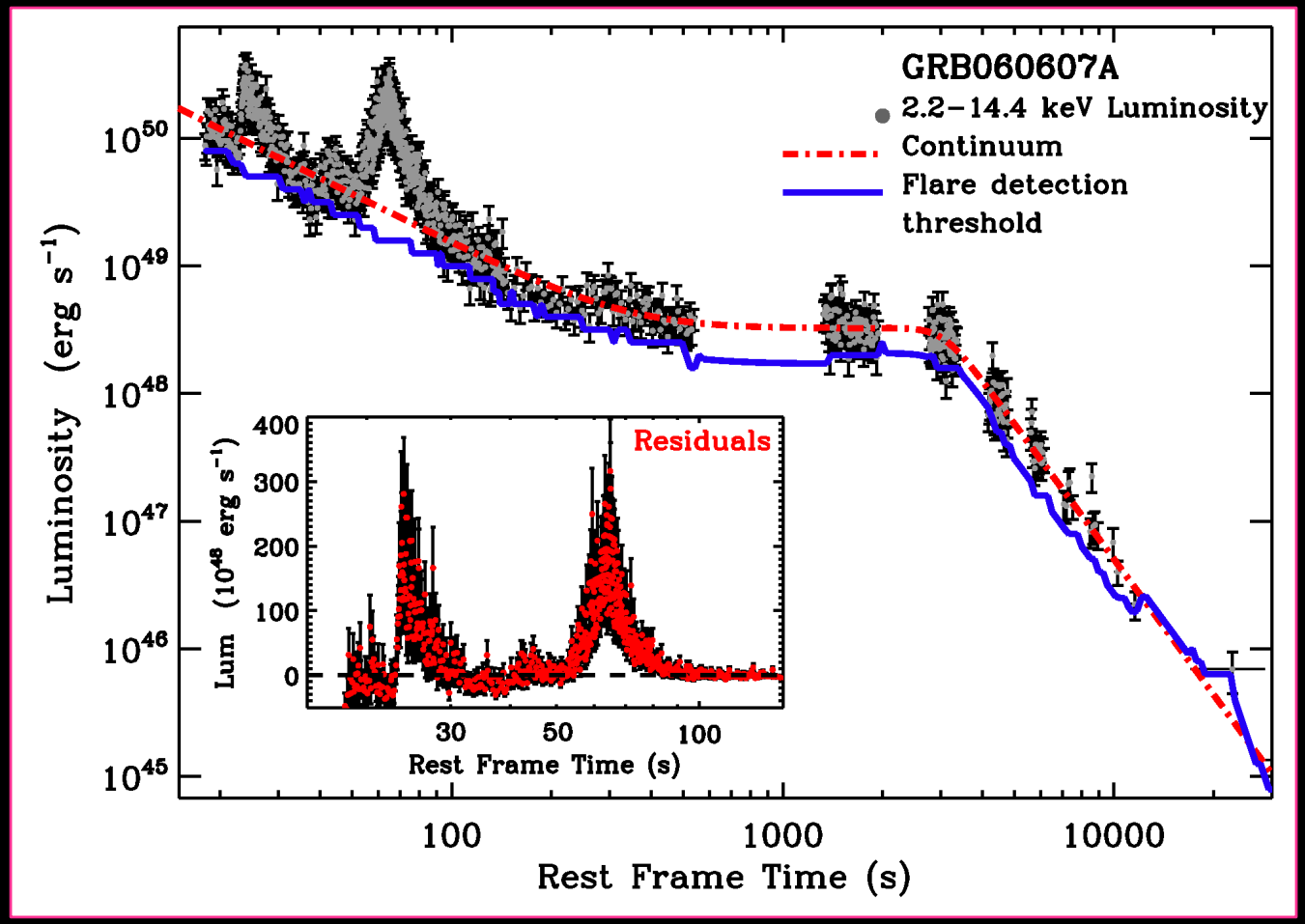


A flare seem to be a TIME-stretched ENERGY-rescaled version of a prompt pulse

OVERLAP= strongly suggestive of a deep link between the two phenomena


Log(Flux)
X-ray
Flares
Hyper accretion on BH
Magnetar spin-down
?
What is the ultimate source of energy that powers the GRB emission?

- 44 long GRBs
-No shape assumption for flares
-Common REST frame band
-Threshold of detection estimate

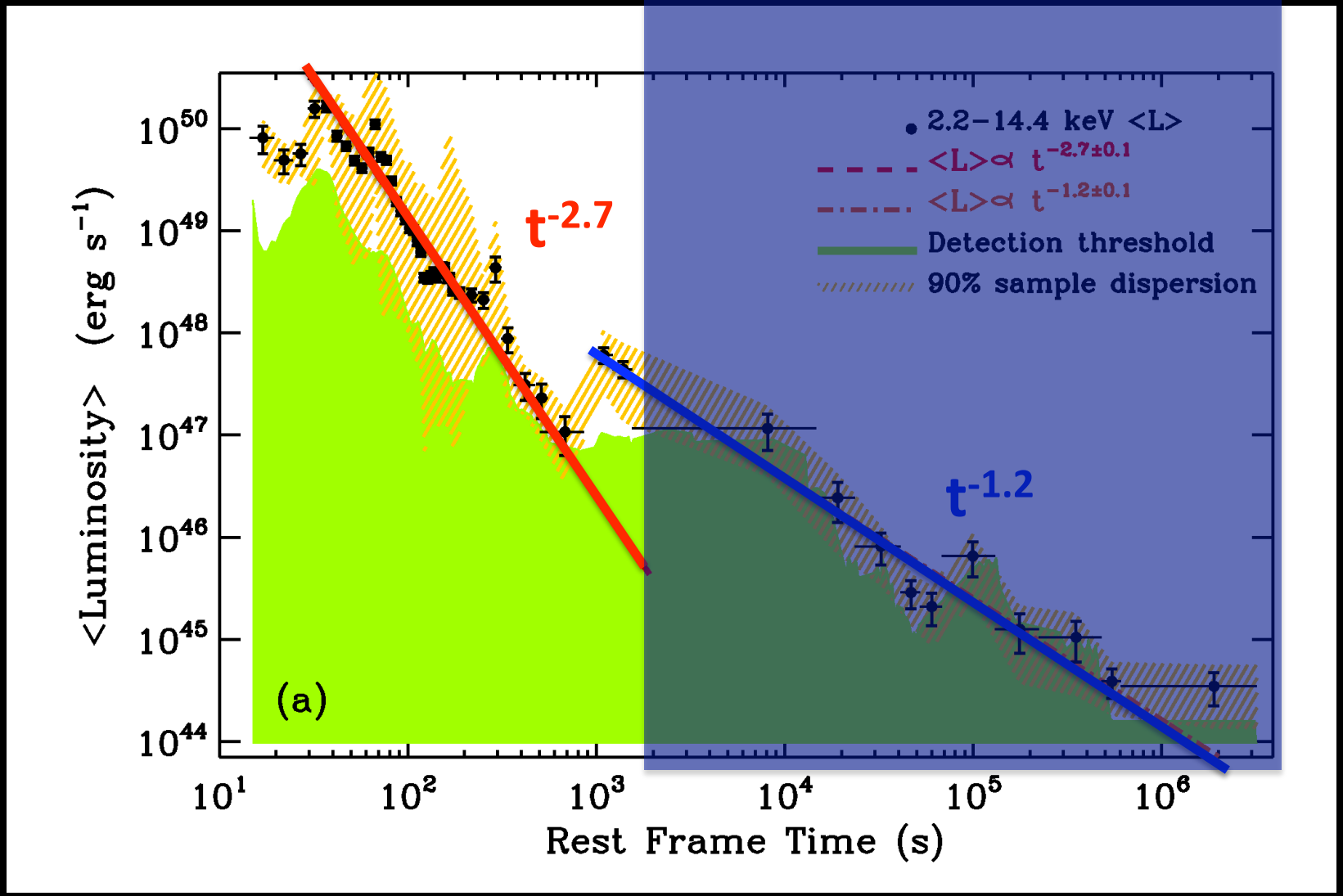


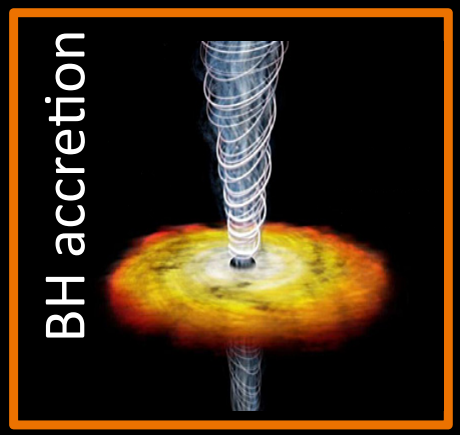
SWIFT 5-years data-base

The Flare Average Luminosity function

$$L_{flare} \propto t^{-2.7\pm0.1}$$

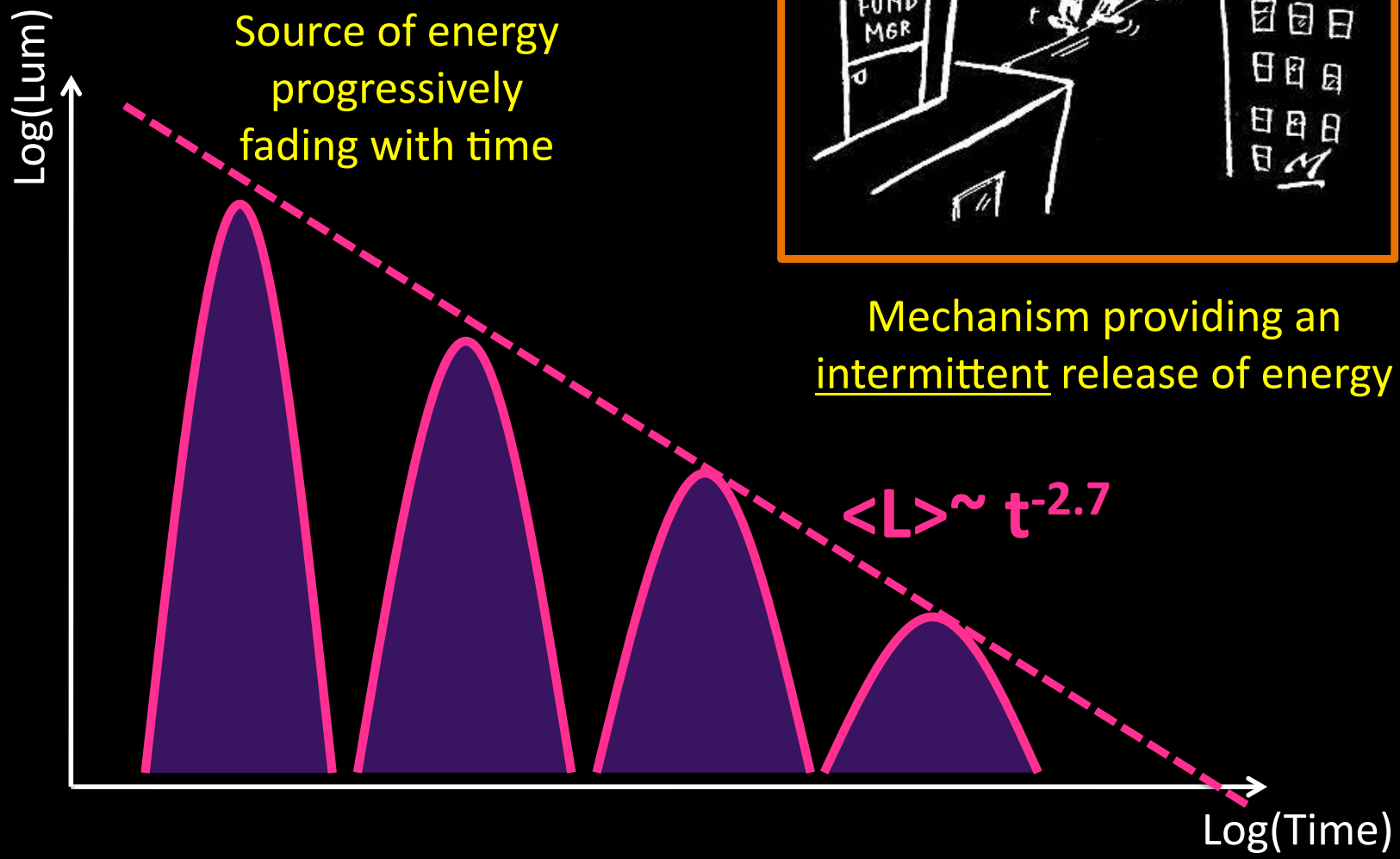
Threshold effect → biased result
The real <L> is likely to be steeper





Source of energy progressively fading with time

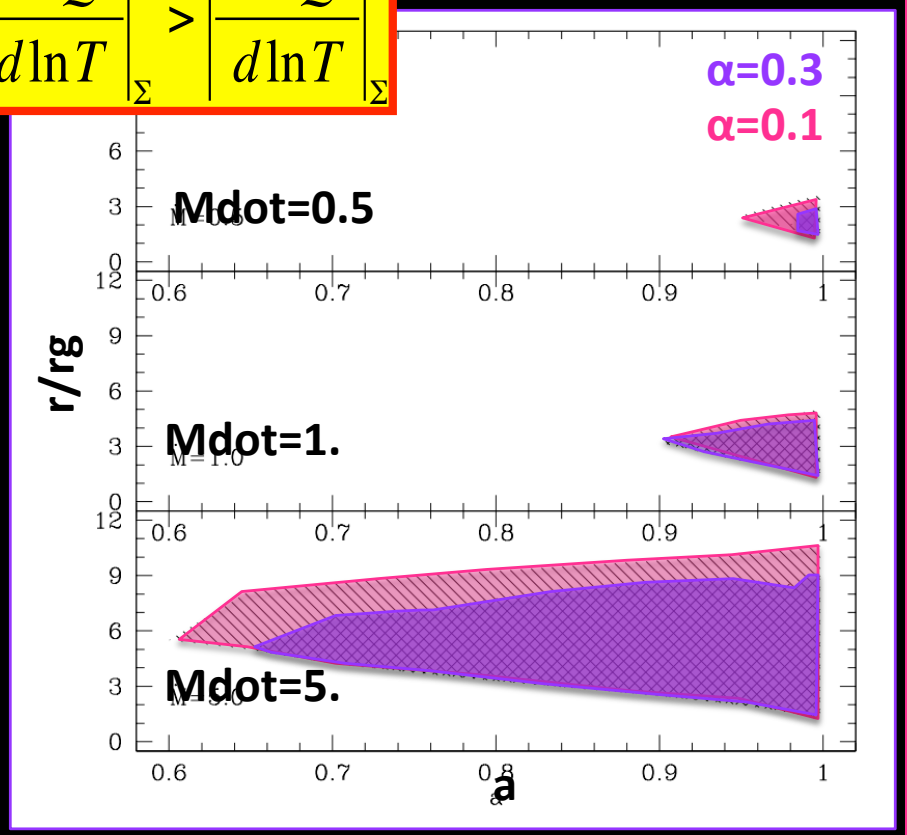
Mechanism providing an intermittent release of energy



GRB accretion disk instability

THERMAL

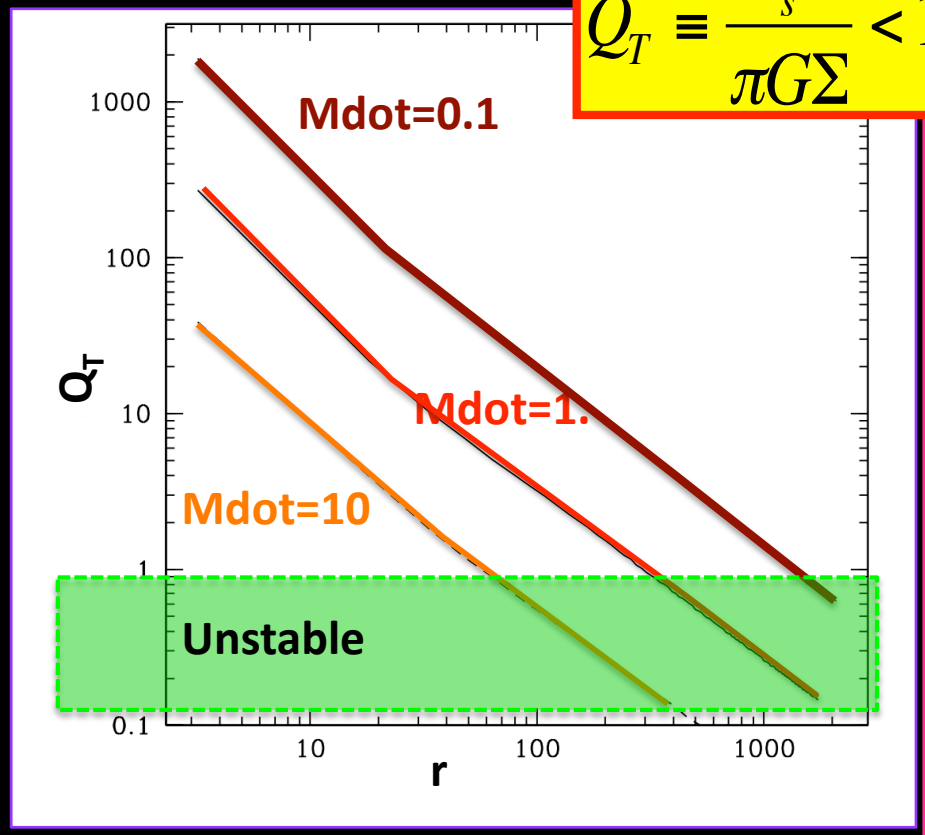
$$\left|\frac{d\ln Q^{+}}{d\ln T}\right|_{\Sigma} > \left|\frac{d\ln Q^{-}}{d\ln T}\right|_{\Sigma}$$



Janiuk 2010

GRAVITATIONAL

$$Q_T \equiv \frac{c_s k}{\pi G \Sigma} < 1$$



Di Matteo 2002

$$L_{flare} \propto t^{-2.7} \quad \Delta t \propto t$$

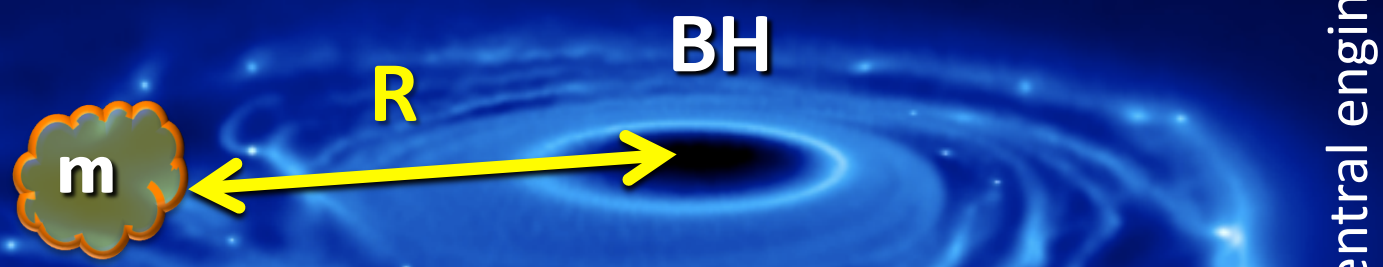
$$E_{iso,flare} \approx L_{flare} \Delta t \propto t^{-1.7}$$

$$m_{blob}(t) \propto E_{iso,flare}(t)$$

$$t \propto R^{\beta} \quad \beta > 0$$

$$m_{blob}(t) \propto t^{-1.7}$$

$$m_{blob}(R) \propto R^{-\delta}$$



GRB central engine

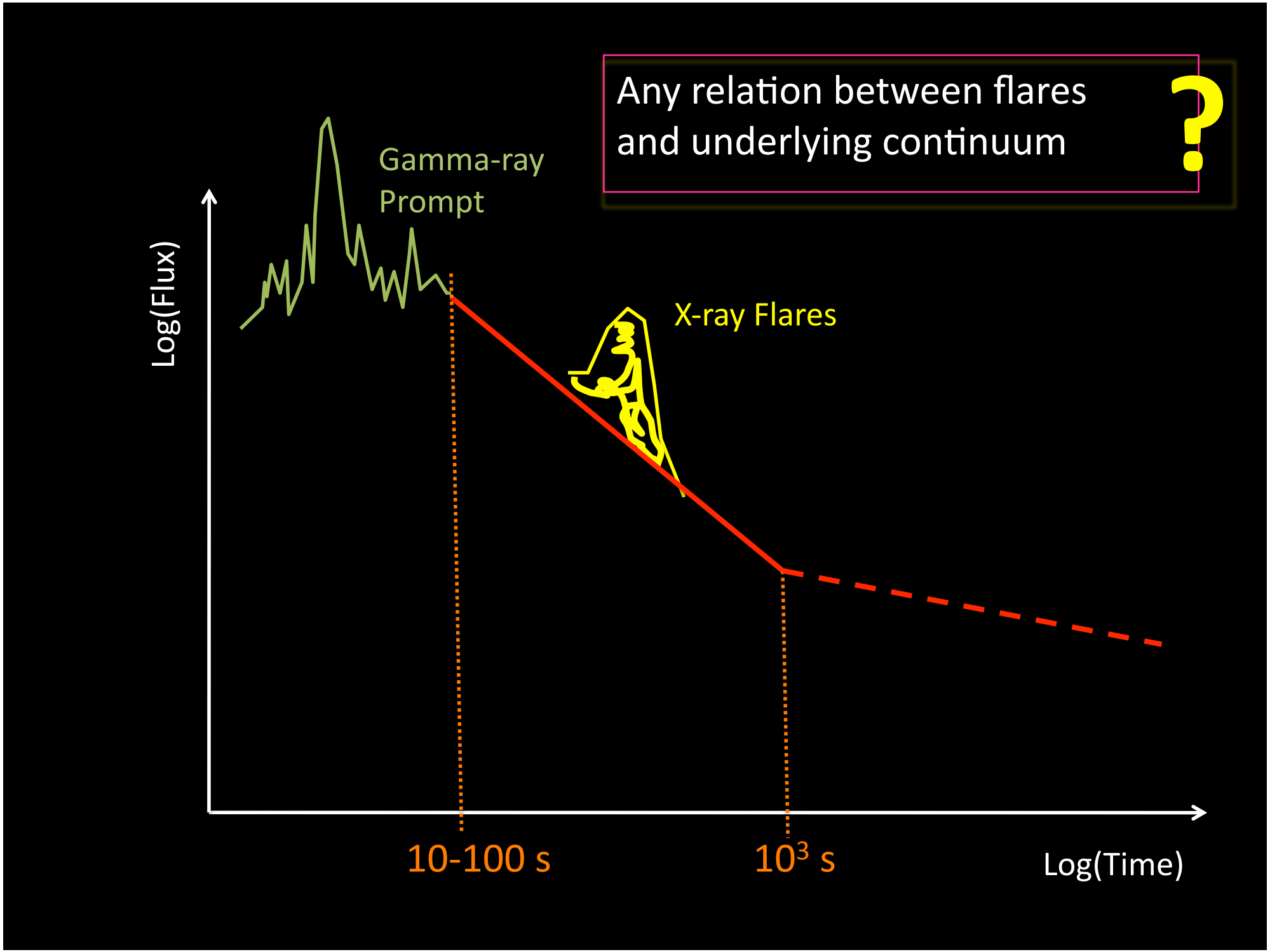
Flares → disk fragmentation

(Perna 2006)

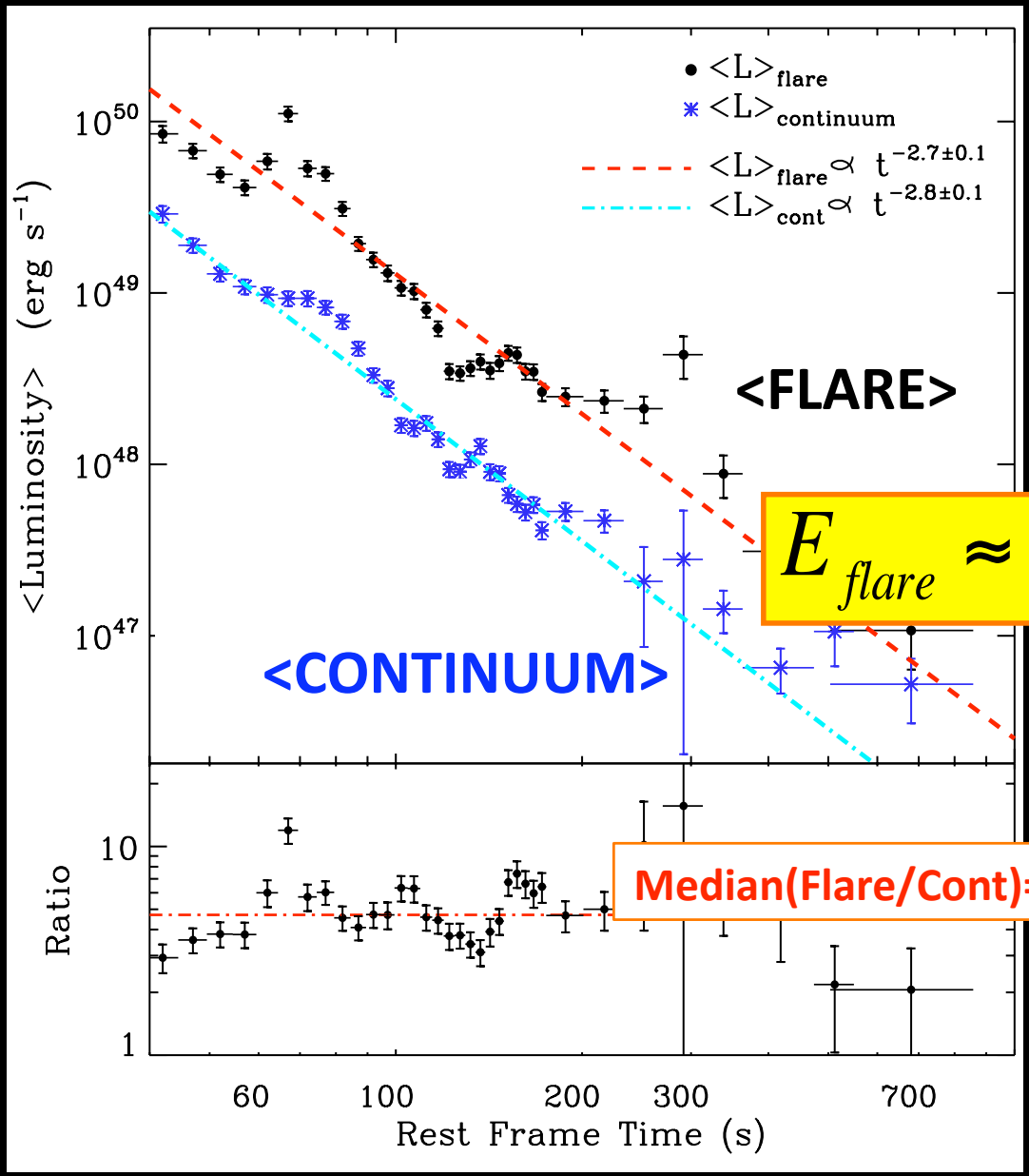
Flares are softer and less energetic time-stretched versions of a prompt pulse

$$L_{flare} \propto t^{-2.7}$$

$$E_{iso,flare} \approx L_{flare} \Delta t \propto t^{-1.7}$$

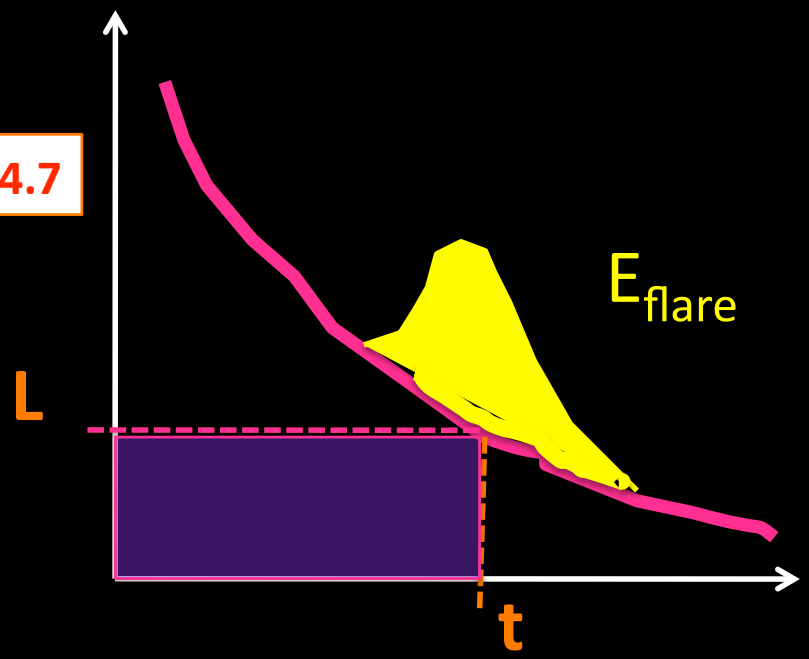

Any relation between flares and underlying continuum
?
Gamma-ray Prompt
X-ray Flares
Log(Flux)
10-100 s
10^3 s
Log(Time)

Flare-Steep decay physical link



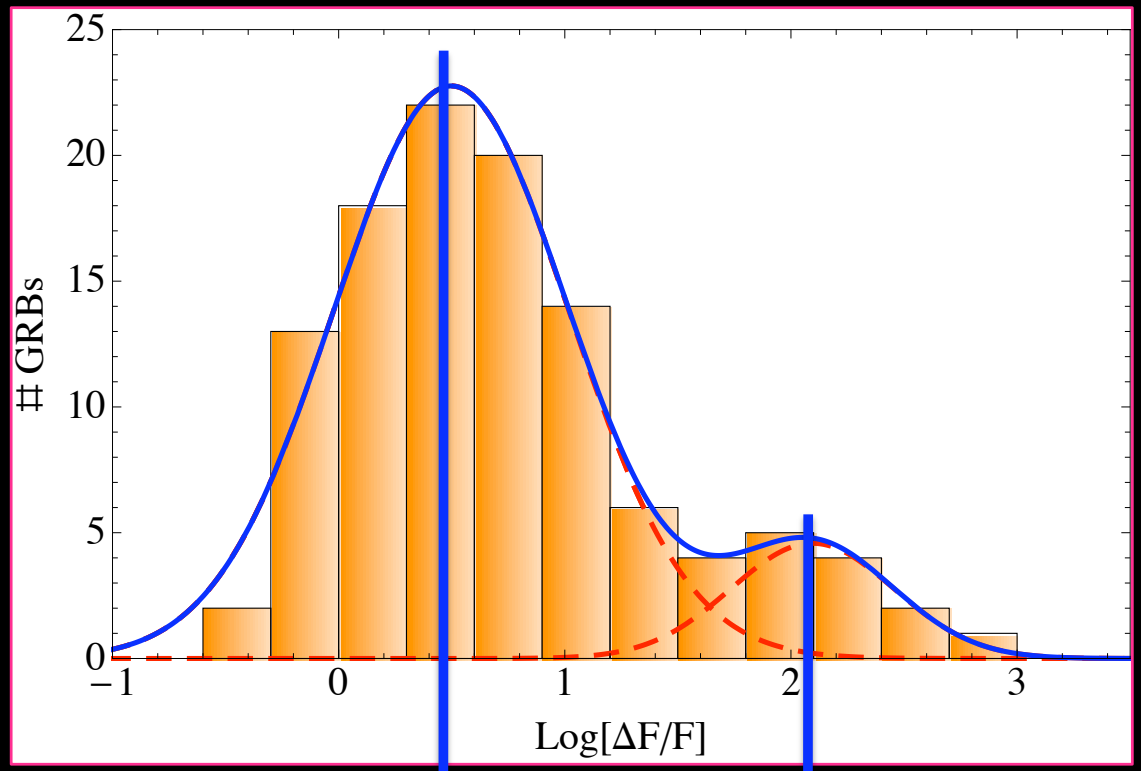
Median(Flare/Cont)=4.7

$$E_{flare} \approx L_{flare}(t)\Delta t \approx L_{steep}(t) \cdot t$$



Flare-to-continuum ratio

Chincarini 2010 sample



$$\left\langle \frac{\Delta F}{F} \right\rangle \approx 4$$

$$\left\langle \frac{\Delta F}{F} \right\rangle \approx 100$$

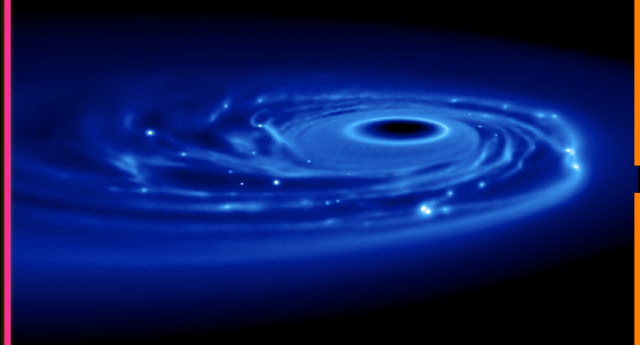
1. Bimodal
2. Two different origins

?

(See Lazzati 2010)

SUMMARY

Flares are softer and less energetic time-stretched versions of a prompt pulse



$$L_{flare} \propto t^{-2.7}$$

$$E_{iso,flare} \approx L_{flare}\Delta t \propto t^{-1.7}$$

Flare – steep decay connection

$$E_{flare} \approx L_{flare}(t)\Delta t \approx L_{steep}(t)\cdot t$$

2 different kind of flares ?

Margutti 2010, MNRAS, 406, 2149; Margutti, 2010, MNRAS accepted (arXiv: 1004.1568)

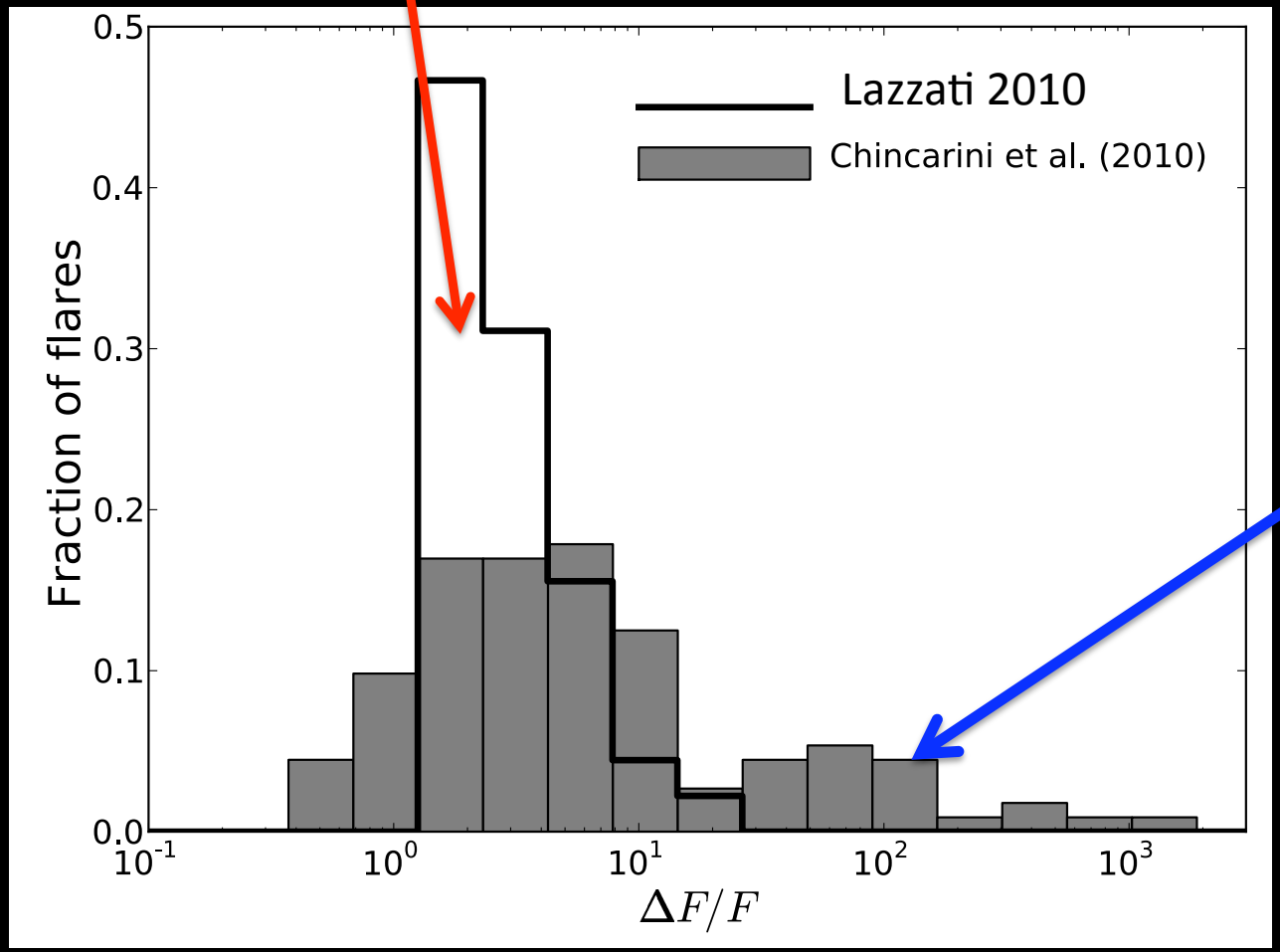
The End

Summary:

FLARES EVOLVE WITH TIME

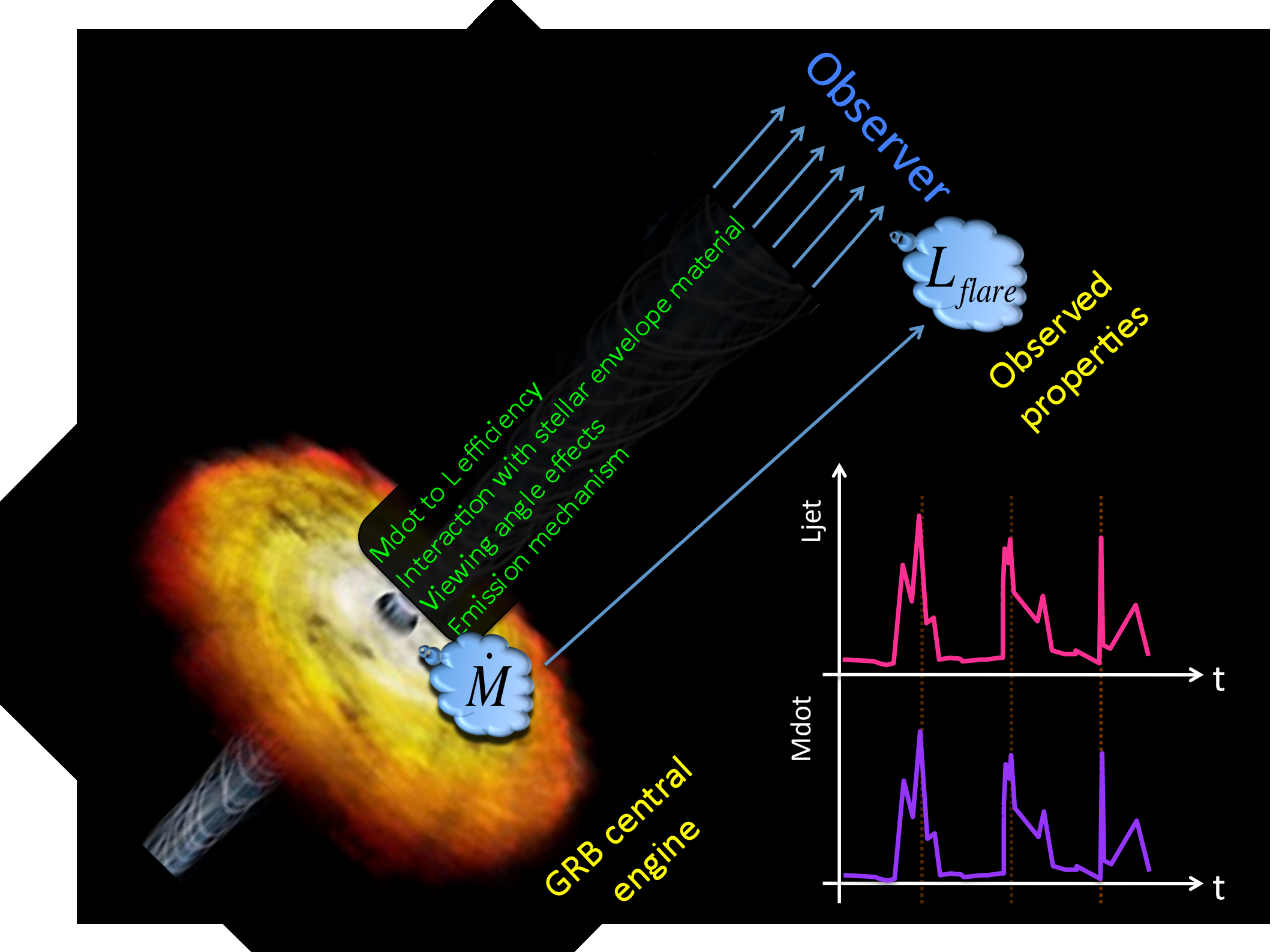
	FLARES	PROMPT	
Width(T)	$w \propto 0.2 t_{peak}$	≈const	
Luminosity(T)	$L_{peak} \propto t_{peak}^{-2.7}$	≈const	
Ep(t)	$E_{peak} \propto Exp(-t)$	≈similar	
Ep(t)-Liso(t)	$E_{peak} \propto L_{iso}^{1.0}$	$E_{peak} \propto L_{iso}^{y}$	
Ep-Liso	?	$E_{peak} \propto L_{iso}^{0.5}$	
Width(E)	$w \propto E^{-0.5 \pm 0.3}$	$w \propto E^{-0.4}$	
Lag-Lum	$L \propto t_{lag}^{-0.95 \pm 0.23}$	$L \propto t_{lag}^{-1.14 \pm 0.1}$	
Eiso	$\approx 10^{51} erg$	$\approx 10^{52-54} erg$	
<L(T)>	$< L > \propto t^{-2.7}$	≈const	
<Eiso(T)>	$E_{iso} \propto t^{-1.7}$	≈const	

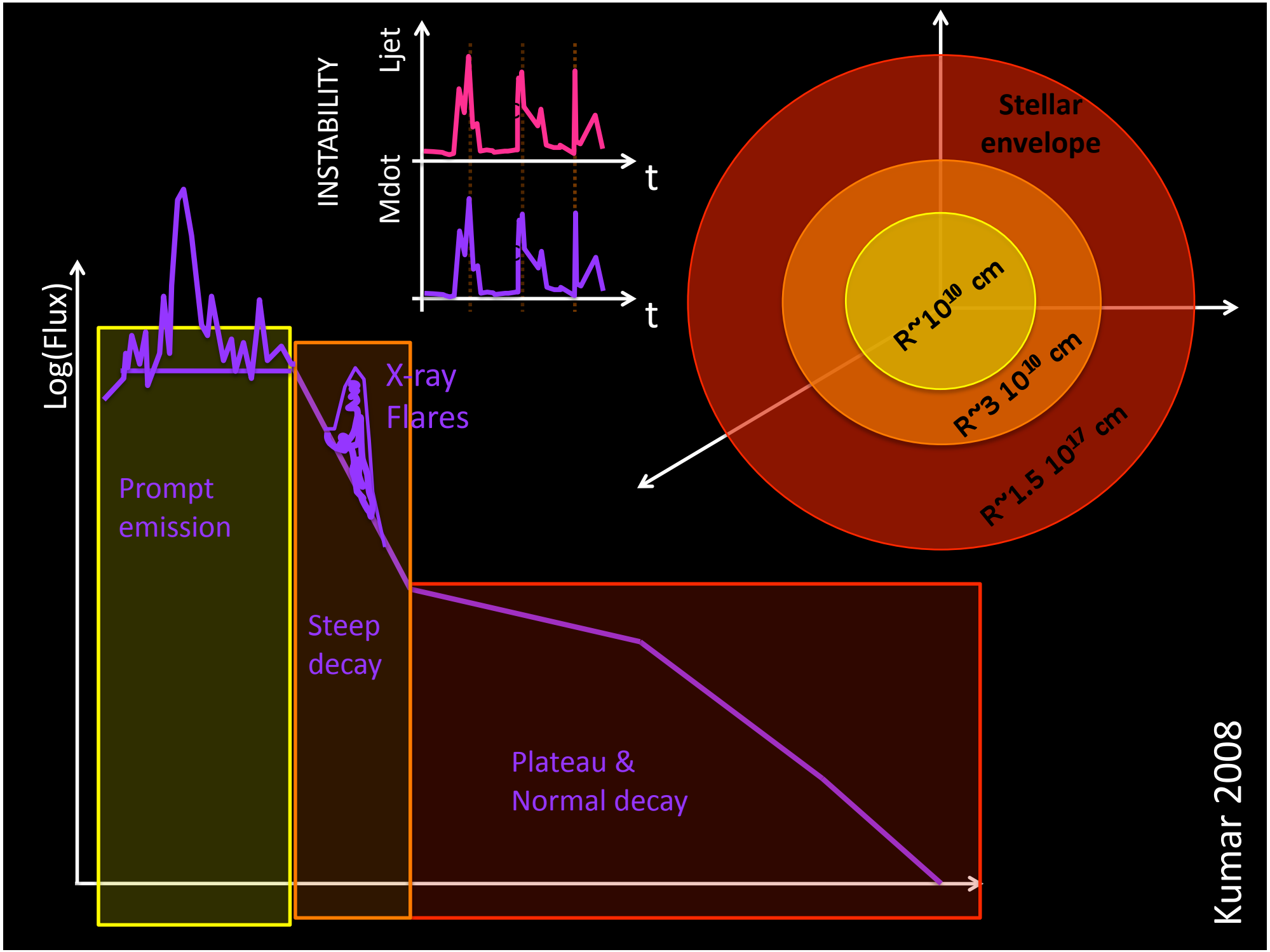
X-ray flares from jet propagation instabilities



X-ray flares produced by temporal variability of the central engine output

Lazzati 2010

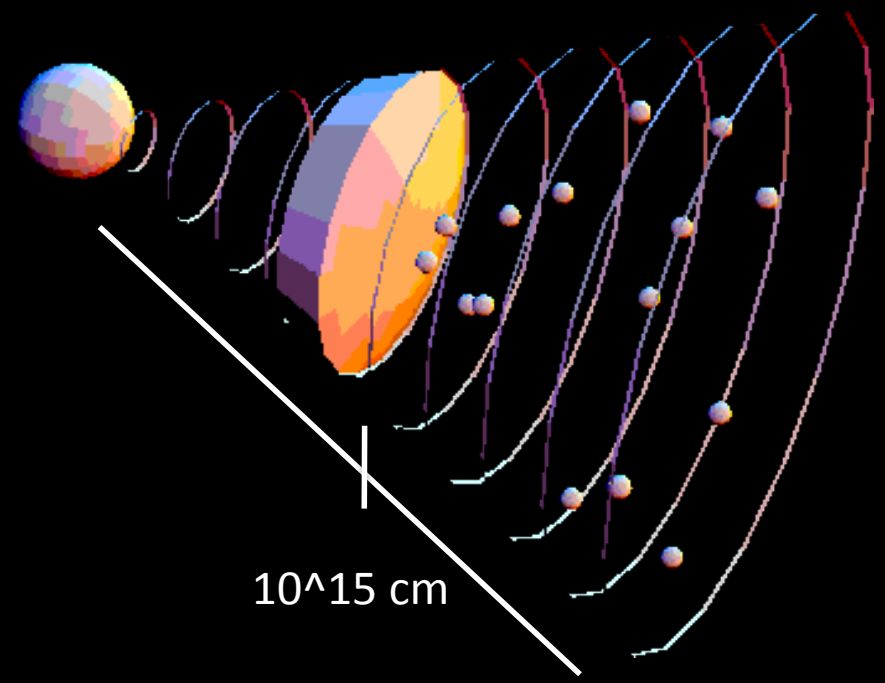

Observer
L_{flare}
Observed properties
Mdot to L efficiency
Interaction with stellar envelope material
Viewing angle effects
Emission mechanism
$\dot{M}$
GRB central engine
Ljet
t
Mdot
t


INSTABILITY
Ljet
Mdot
t
t
Log(Flux)
Prompt
emission
X-ray
Flares
Steep
decay
Plateau &
Normal decay
Stellar
envelope
R~10^10 cm
R~3 10^10 cm
R~1.5 10^17 cm
Kumar 2008

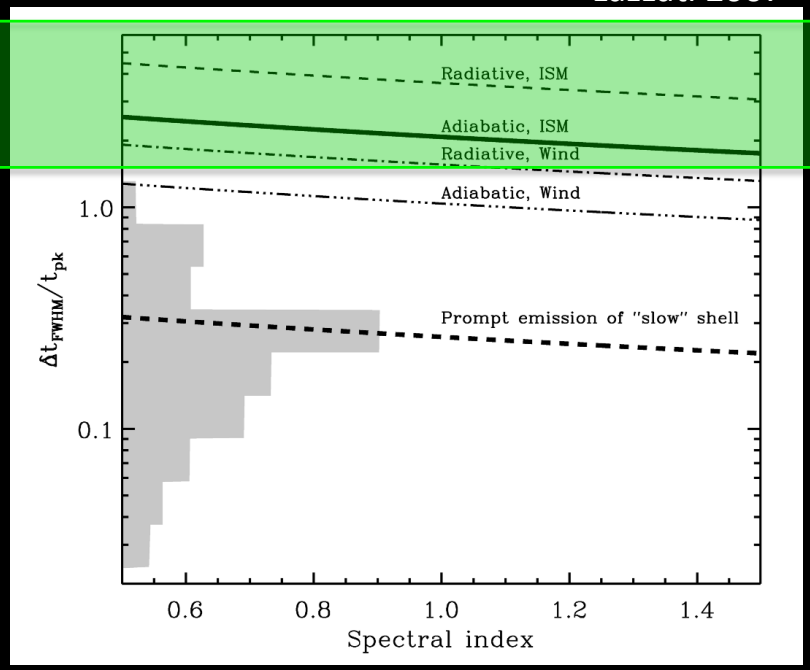
External Origin

prediction

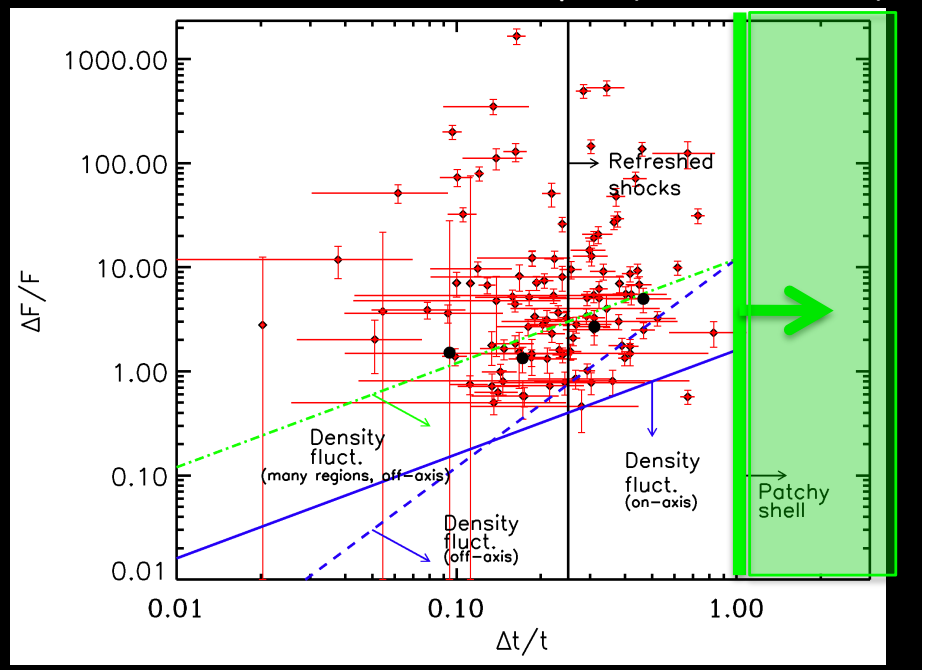
$$\frac{\Delta t}{t} \geq 1$$



Lazzati 2007

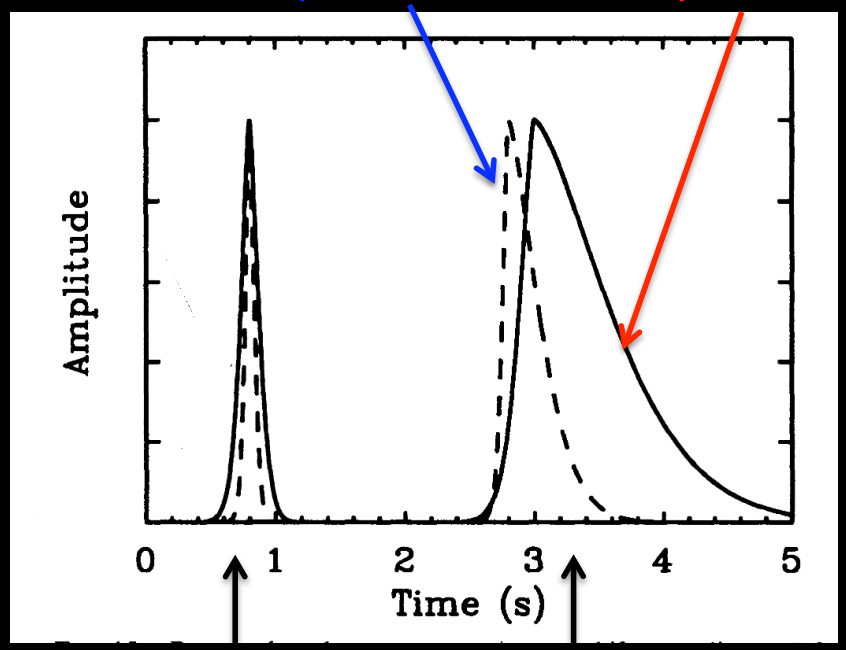


Ioka plot (Chincarini2010)

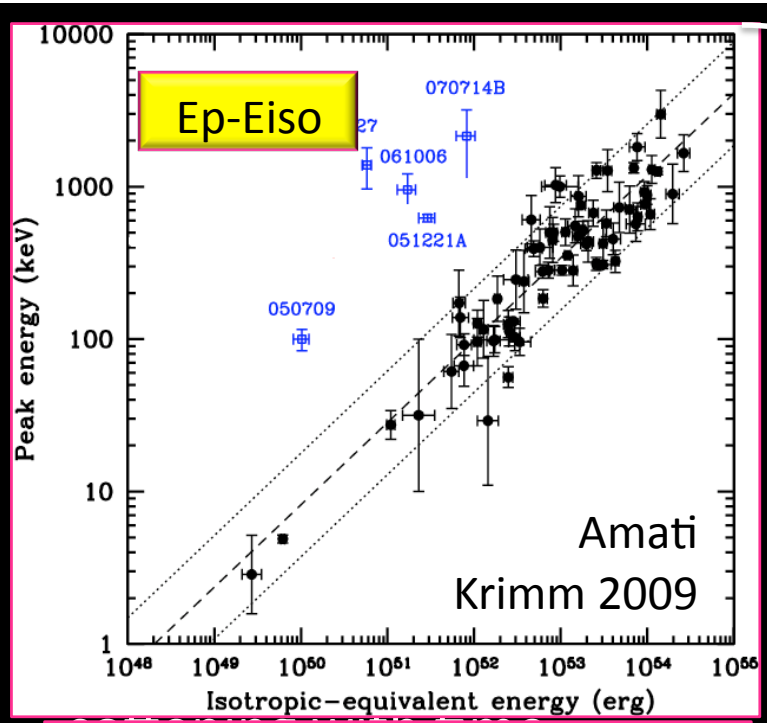


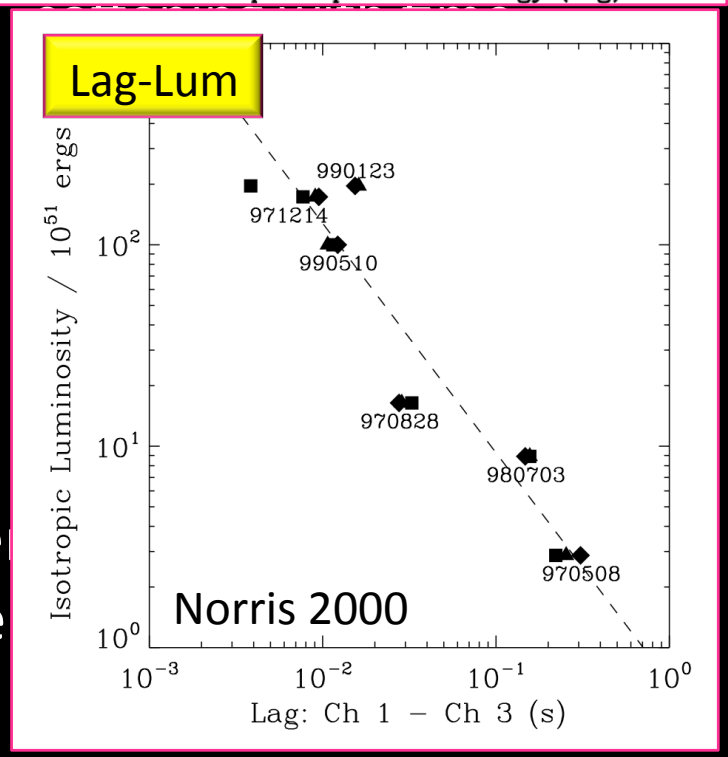
Zhang 2006; Lazzati 2007; Wu 2006; Ioka 2005; Chincarini 2007; Chincarini 2010.

Prompt pulses paradigm:



Norris 1996

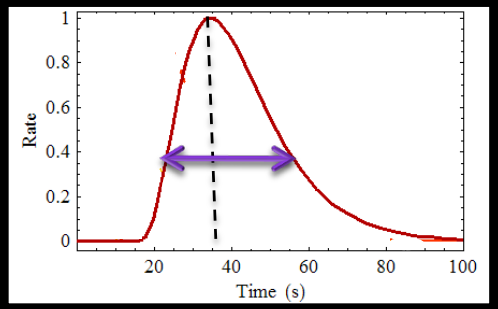




Pulses NOT burst properties (Hakkila 2008, 2009)

The wider the pulse, the softer the e
asymmetric the time profile, the

Width(T)



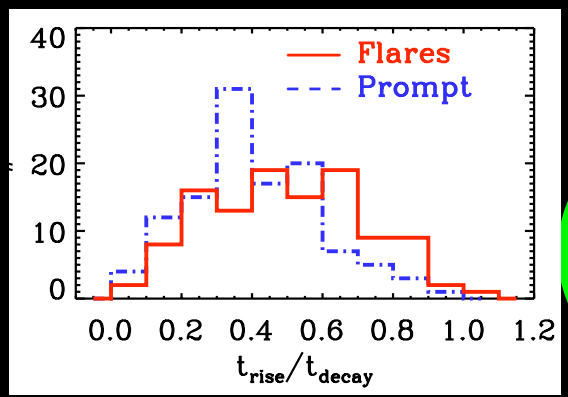
Width=trise + tdecay

$t_{rise} \propto 0.06 t_{peak}$

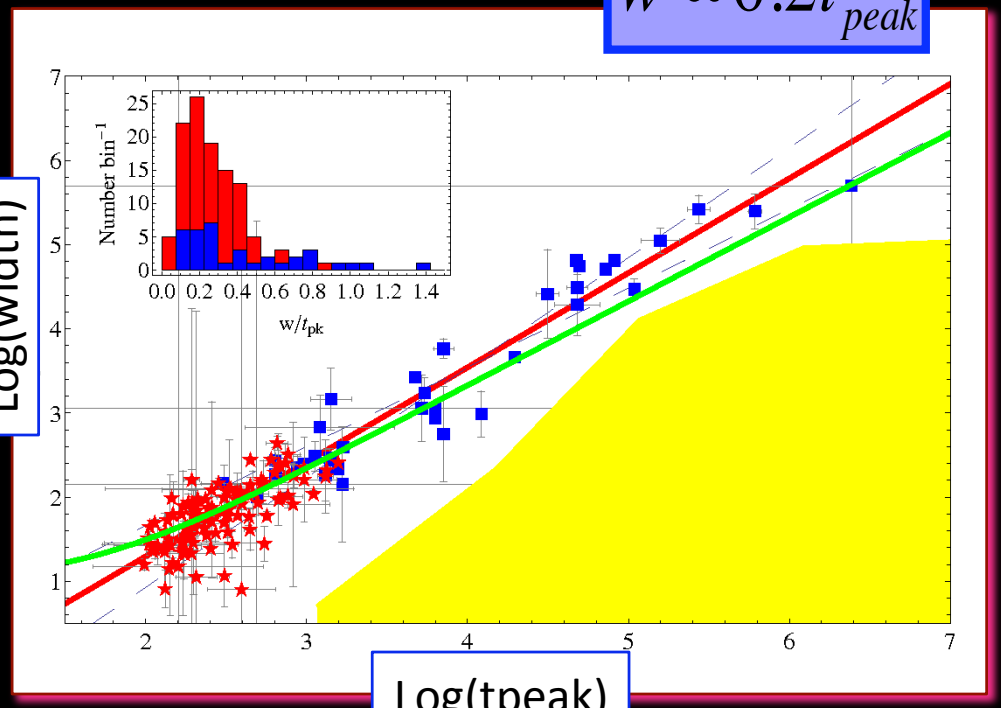
$t_{decay} \propto 0.14 t_{peak}$

$t_{rise} < t_{deacy}$

$t_{decay} \approx 2 t_{rise}$



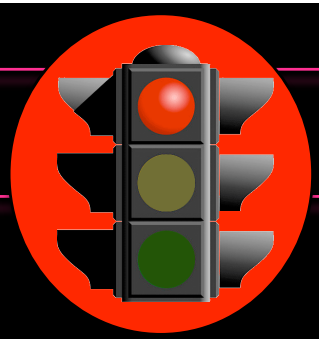
$w \propto 0.2 t_{peak}$



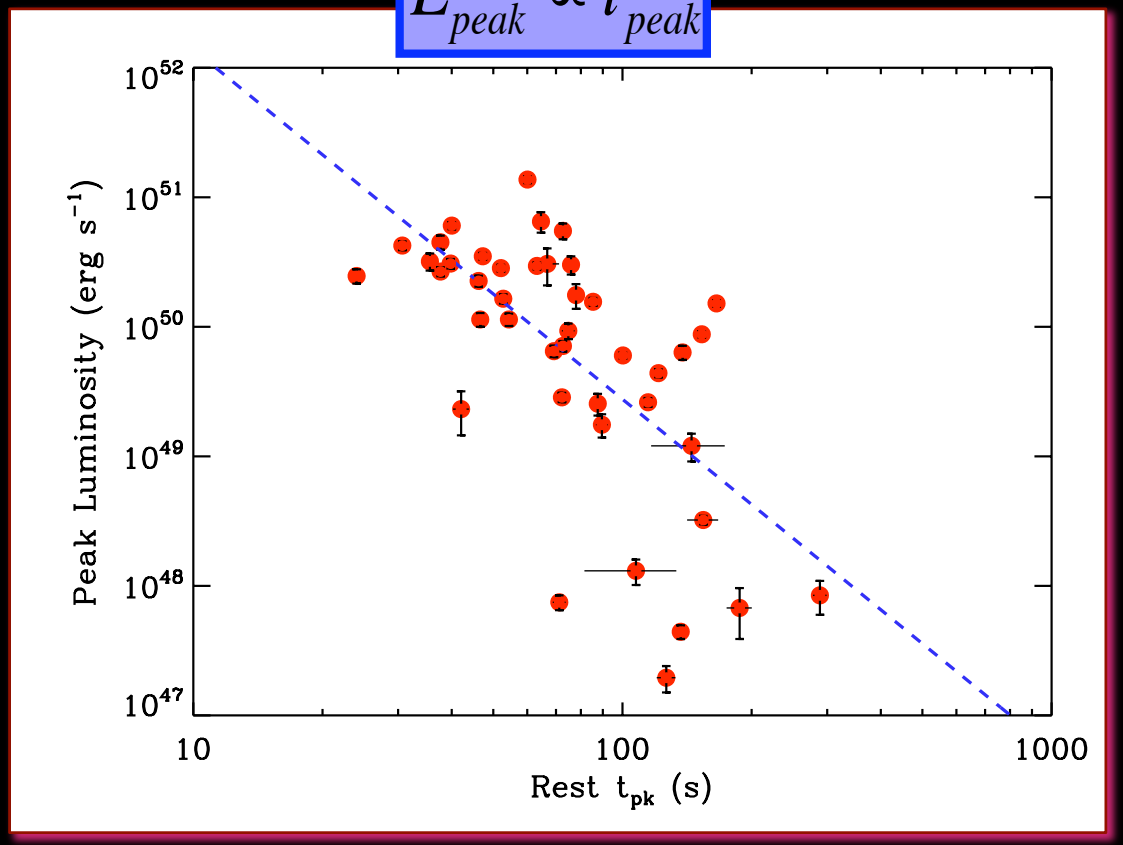
TIME

Asymmetry — Self-similarity

Luminosity(T)



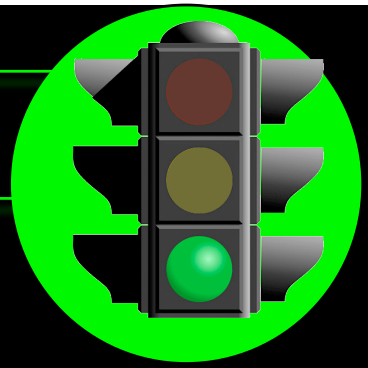
$$L_{peak} \propto t_{peak}^{-2.7}$$



Flares get fainter and fainter

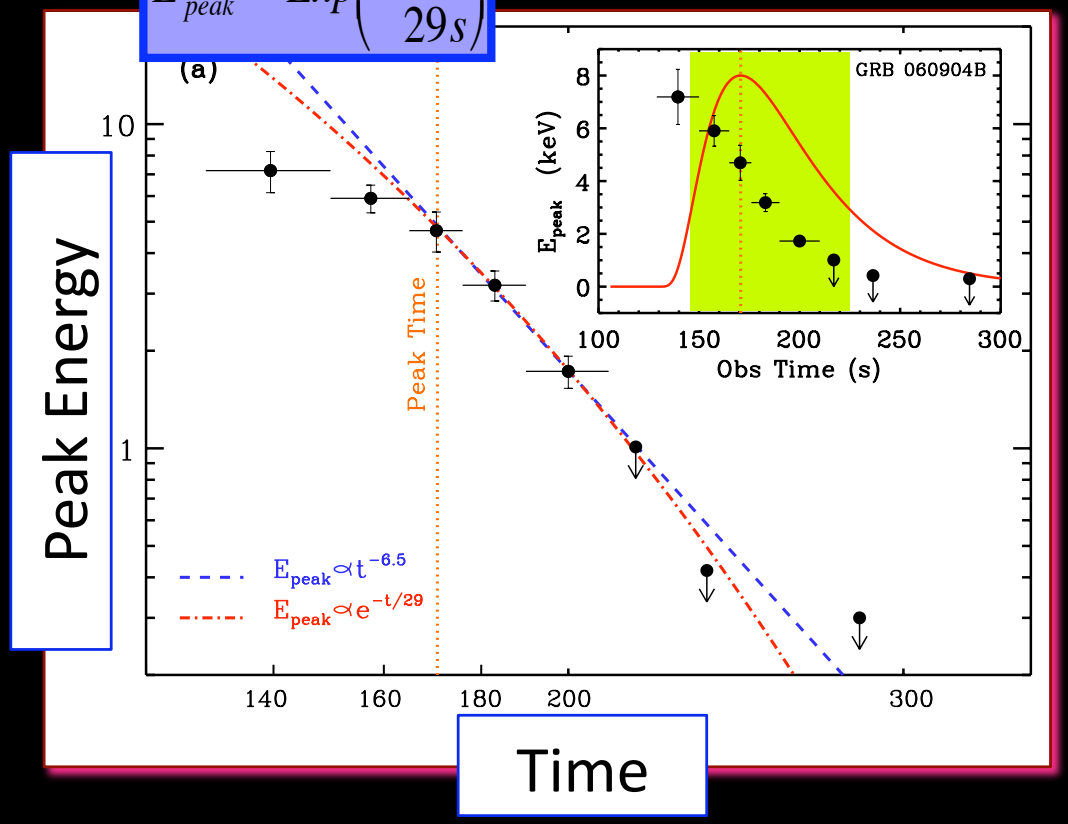
TIME

Spectral Evolution (t)

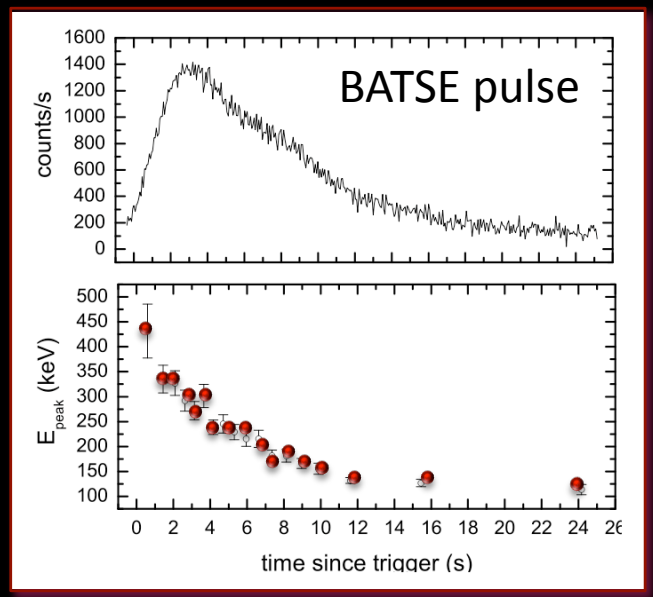


$$E_{peak} \propto Exp\left(-\frac{t}{29s}\right)$$

060904B **Flare:**



Prompt:

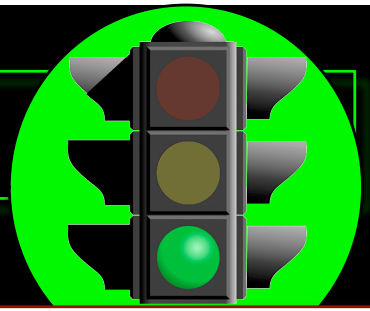


(Peng 2009)

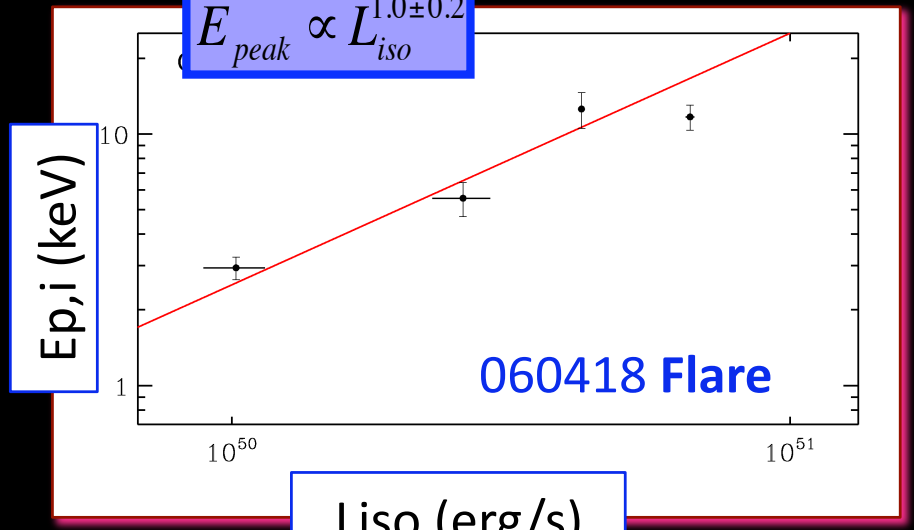
Within single flare and pulses

TIME

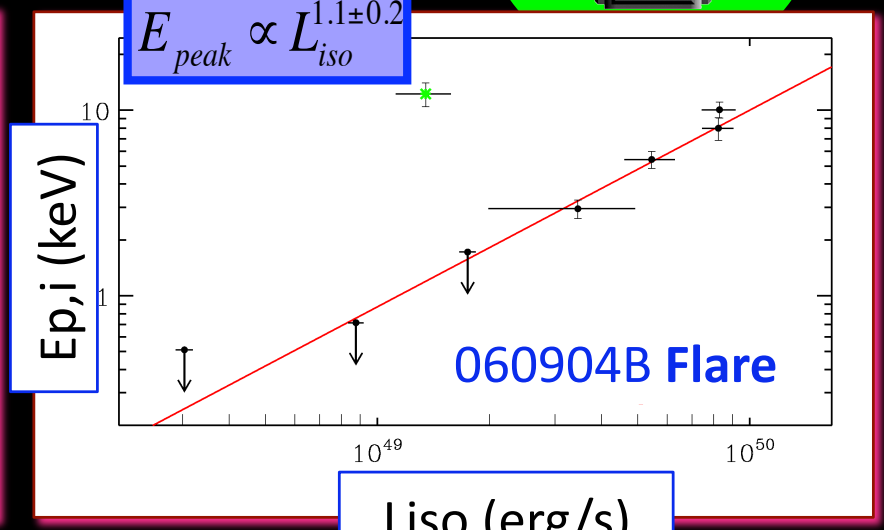
Ep(t)-Liso(t)



$$E_{peak} \propto L_{iso}^{1.0\pm0.2}$$

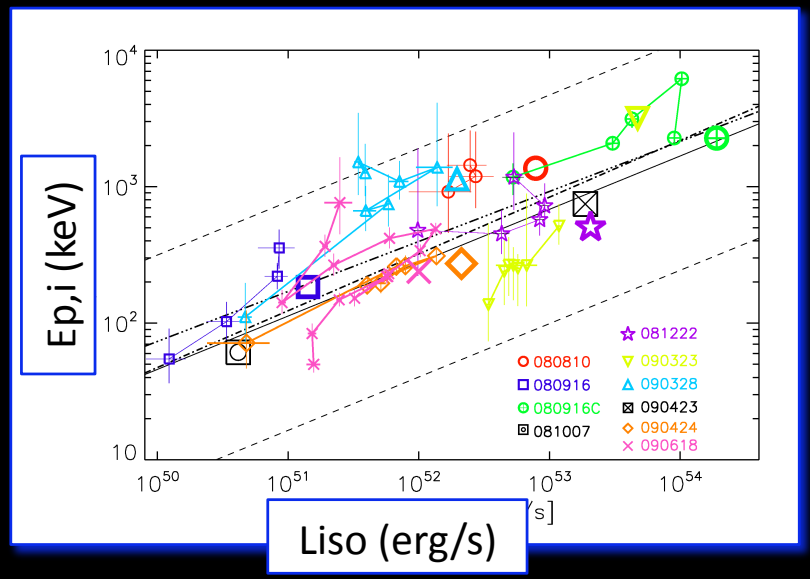


$$E_{peak} \propto L_{iso}^{1.1\pm0.2}$$

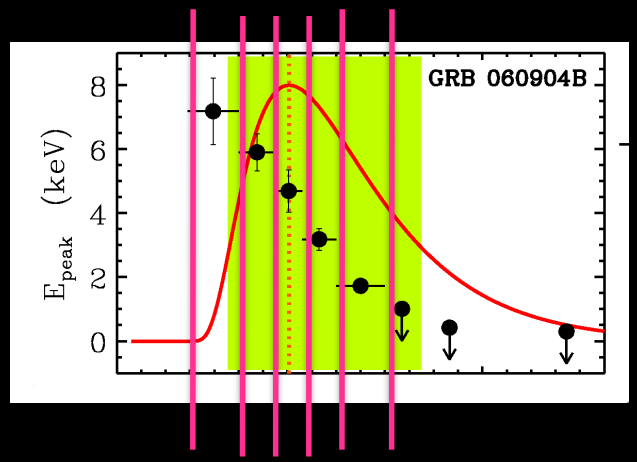


Prompt

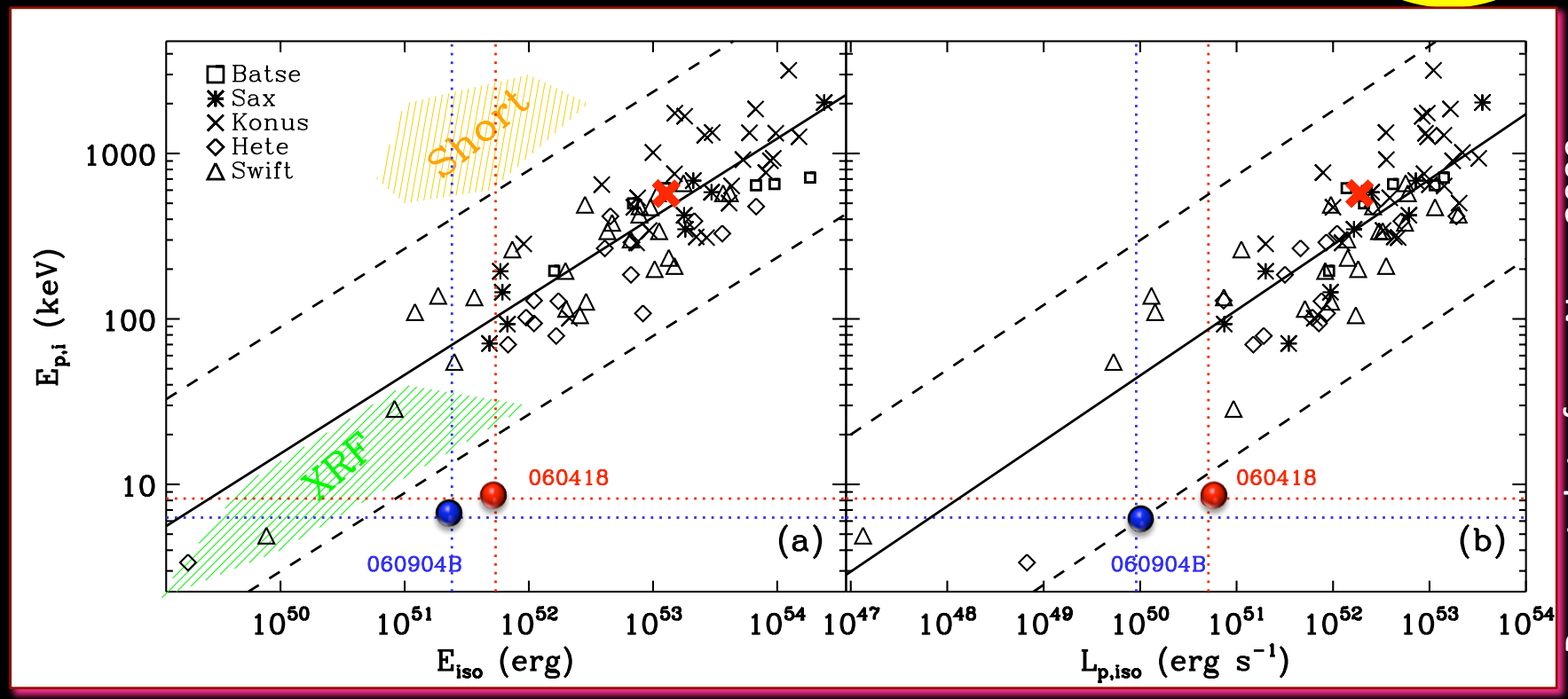
$$E_{peak} \propto L_{iso}^{0.5}$$



Ghirlanda 2010



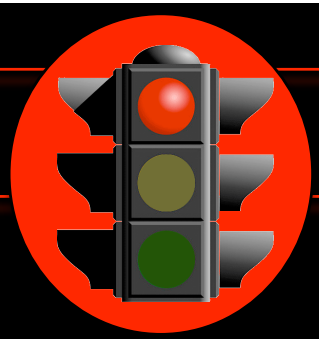
Ep-Liso

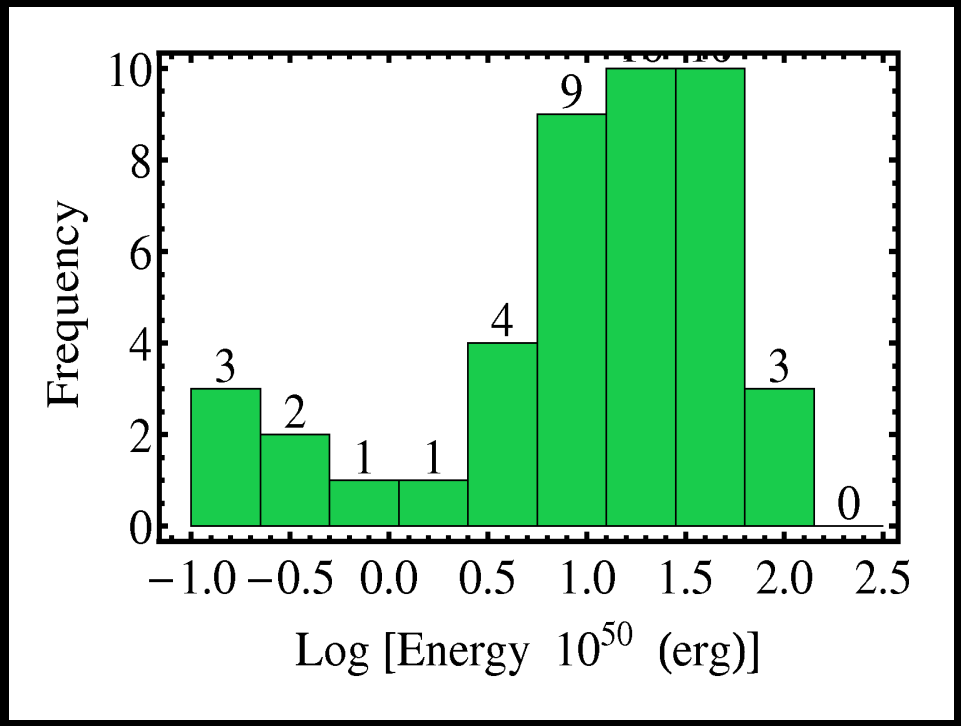


Prompt data from Nava 2009

Flares **Flares**

Flare energetics





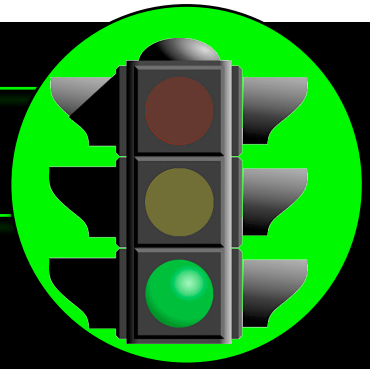
vs.

Eiso(PROMPT)~ 10^{52}-10^{54} erg

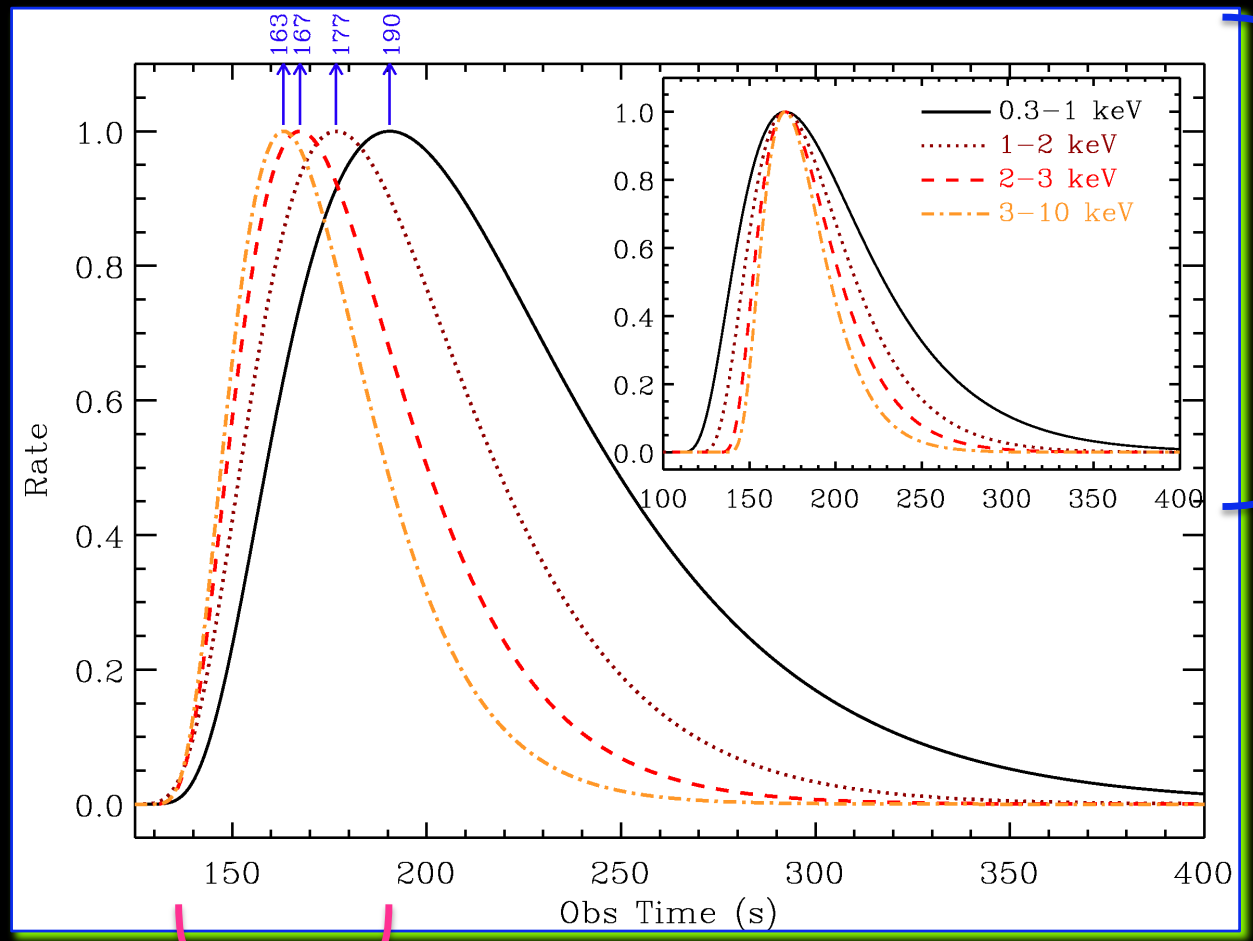
Eiso(FLARE)~ 10^{51} erg

$$\frac{\text{FLARE}}{\text{PROMPT}} < 10\%$$

Width(E)



060904B flare profile



FLARES

$$w \propto E^{-0.5\pm0.3}$$

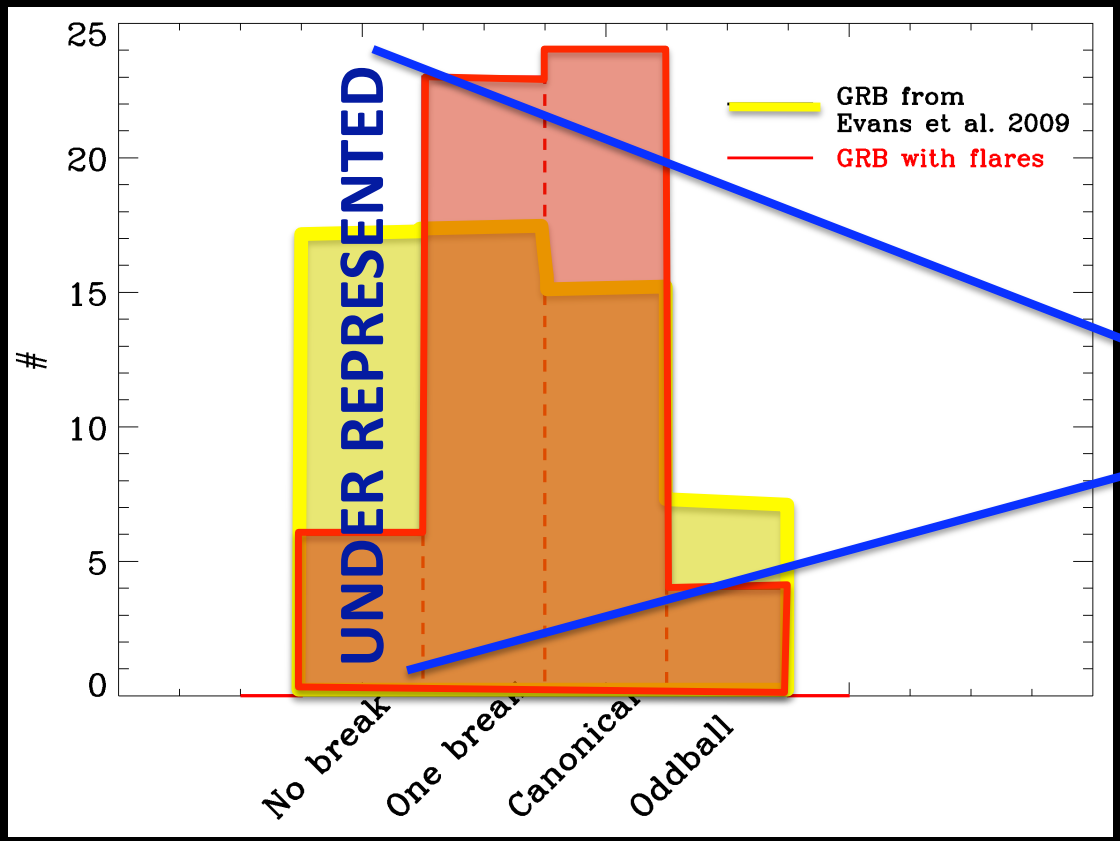
$$t_{rise}(E) \qquad t_{decay}(E)$$

PROMPT

$$w_{prompt} \propto E^{-0.4}$$

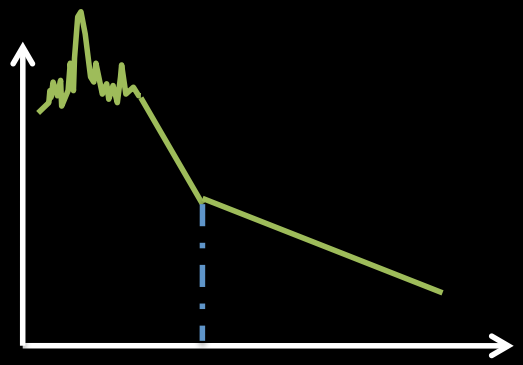
High energy profiles peak **before**

Flare peak Lag

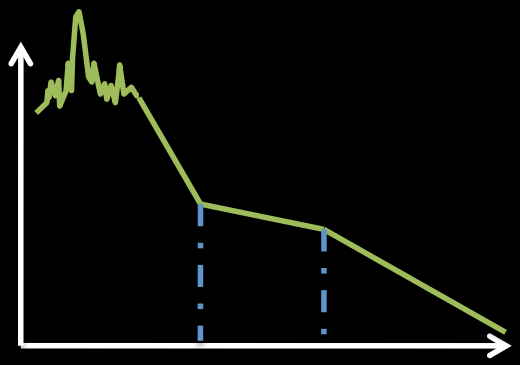


Probability that the two samples are drawn from the SAME population
KS test:
0.9 %

No break

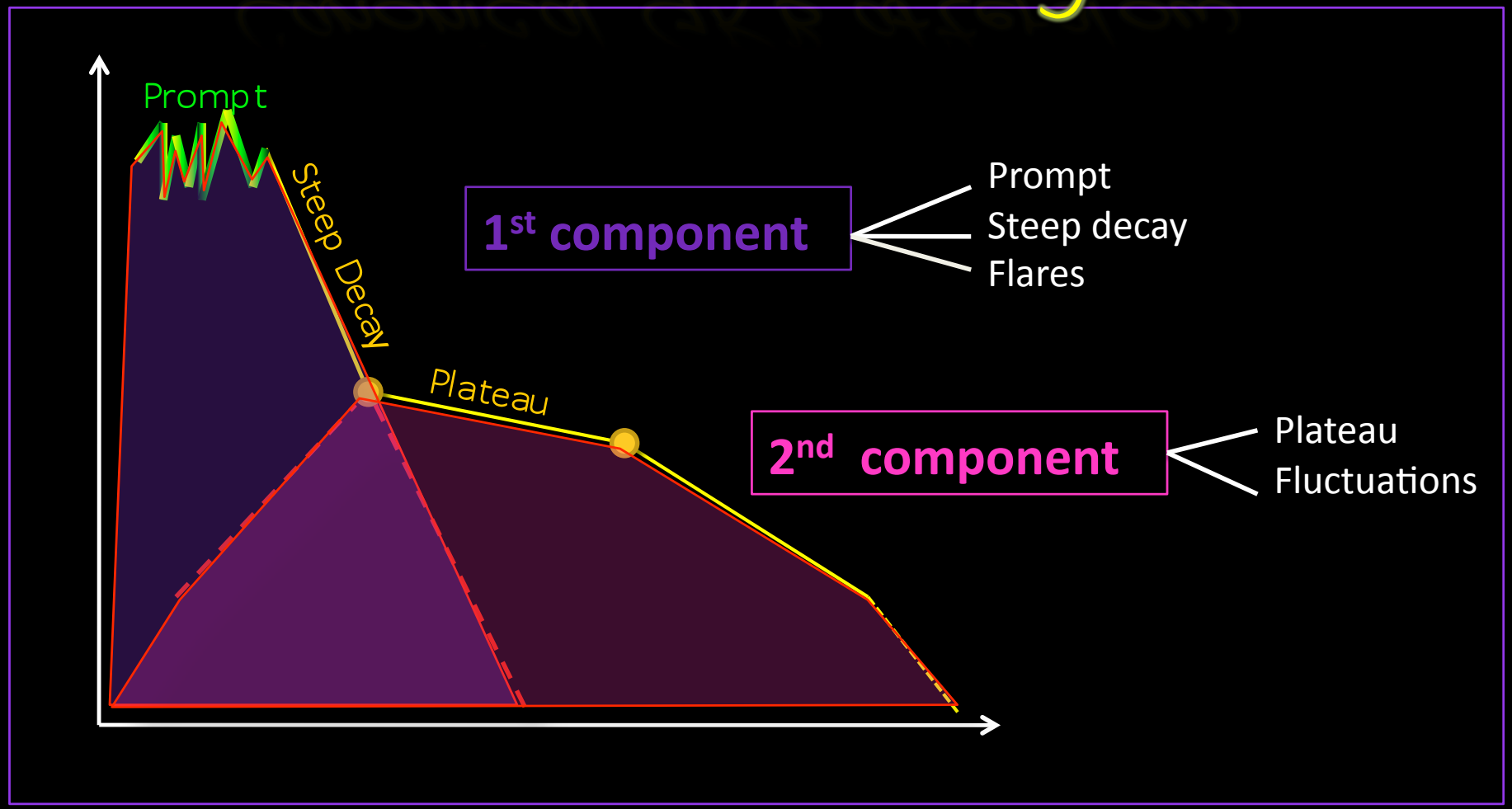


One Break



Canonical

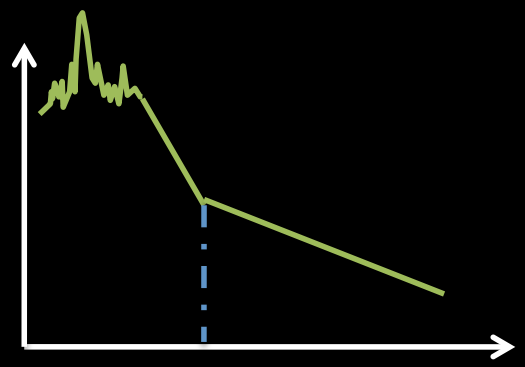
Canonical GRB afterglow



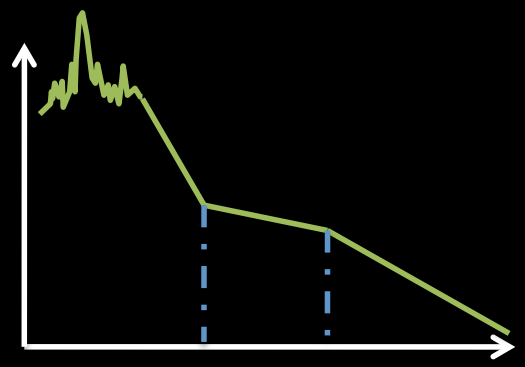
Two components overlapping in time

Margutti et al., 2010, MNRAS, 402, 46

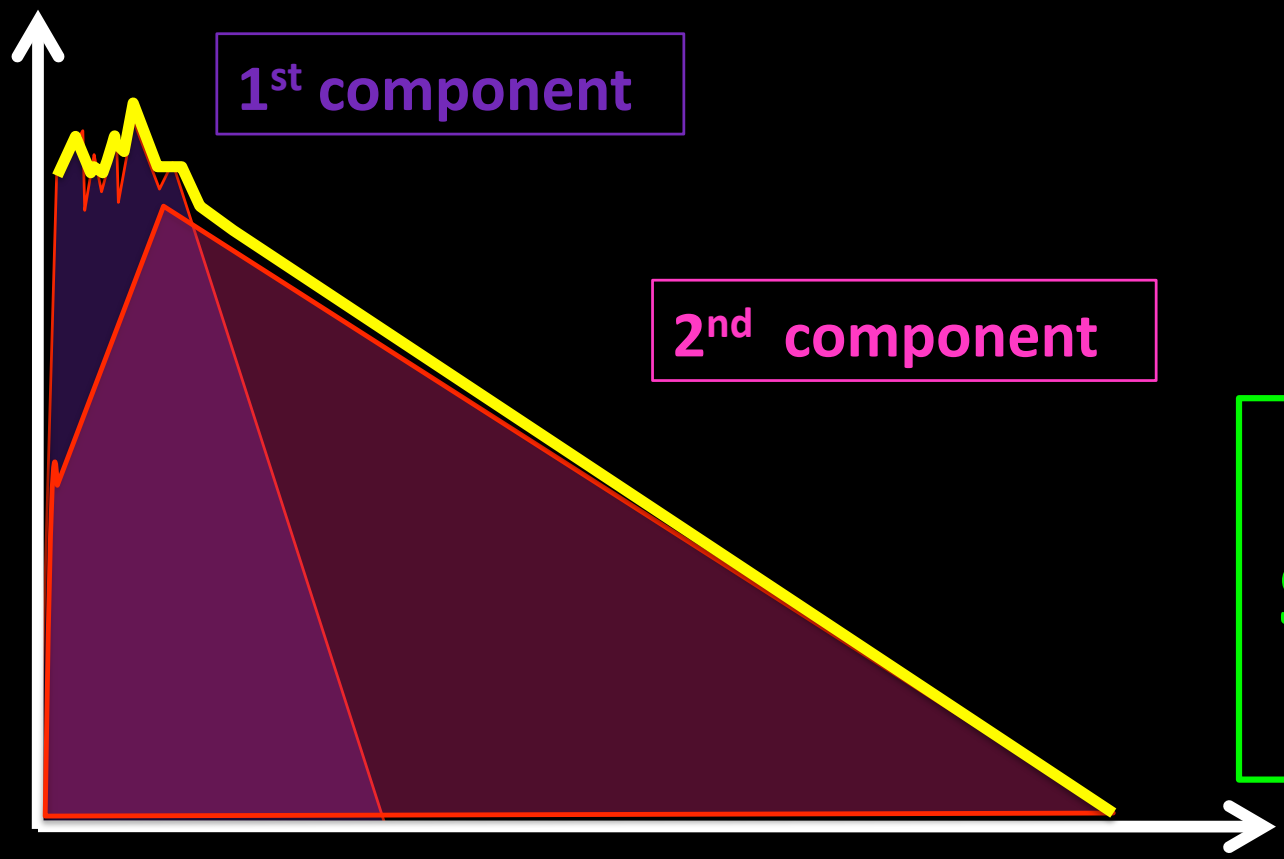
No break



One Break



Canonical



1. Flare-Steep decay connection