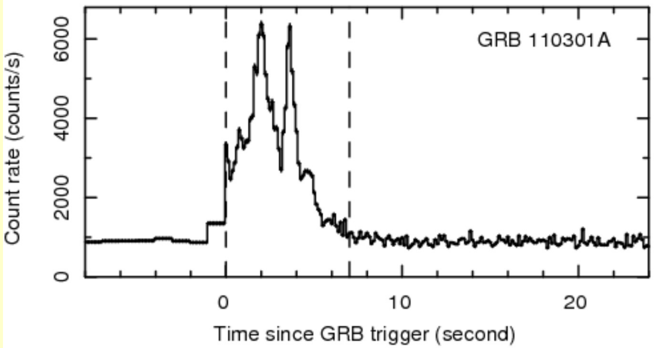
Looking at the black hole that powers Long Gamma Ray Bursts

Antonios Nathanail

Goethe University of Frankfurt

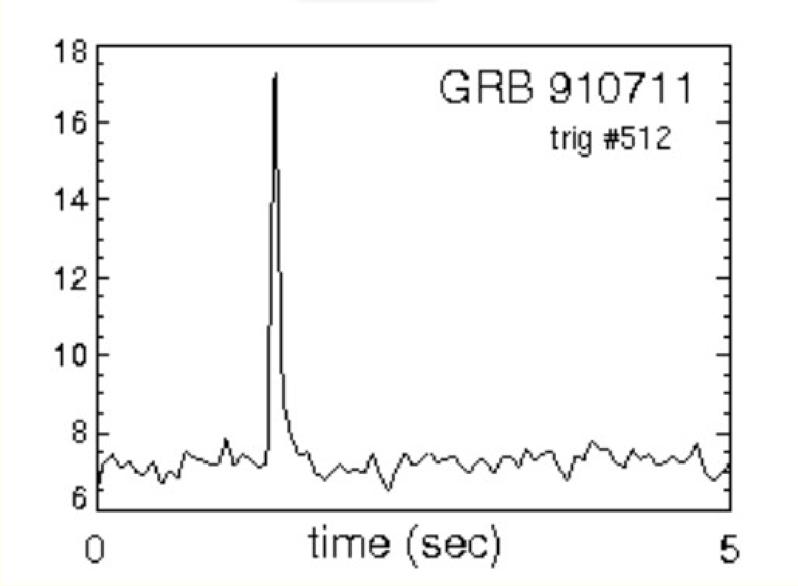
Astro coffee
December 2016



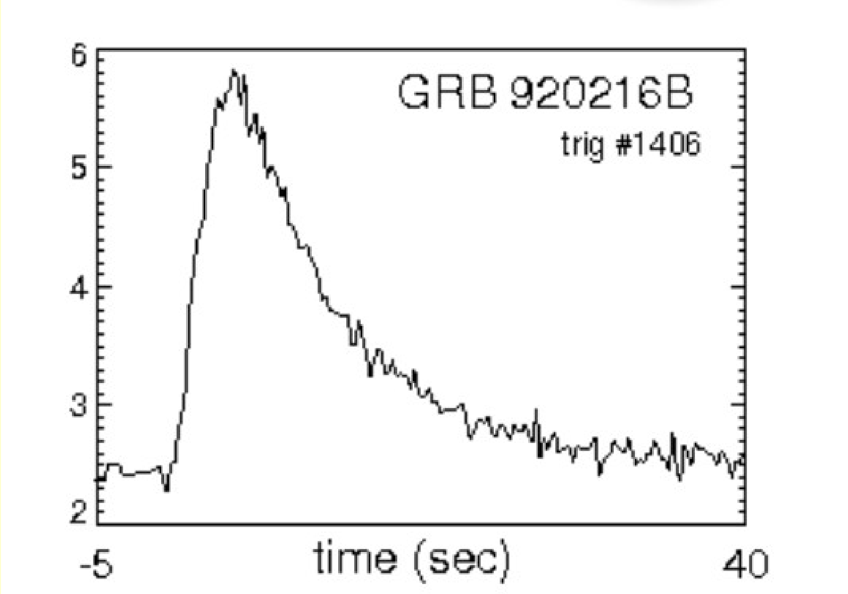
Gamma ray bursts Overview GRBs

Gamma photons

Gamma photons



With BATSE 1990's



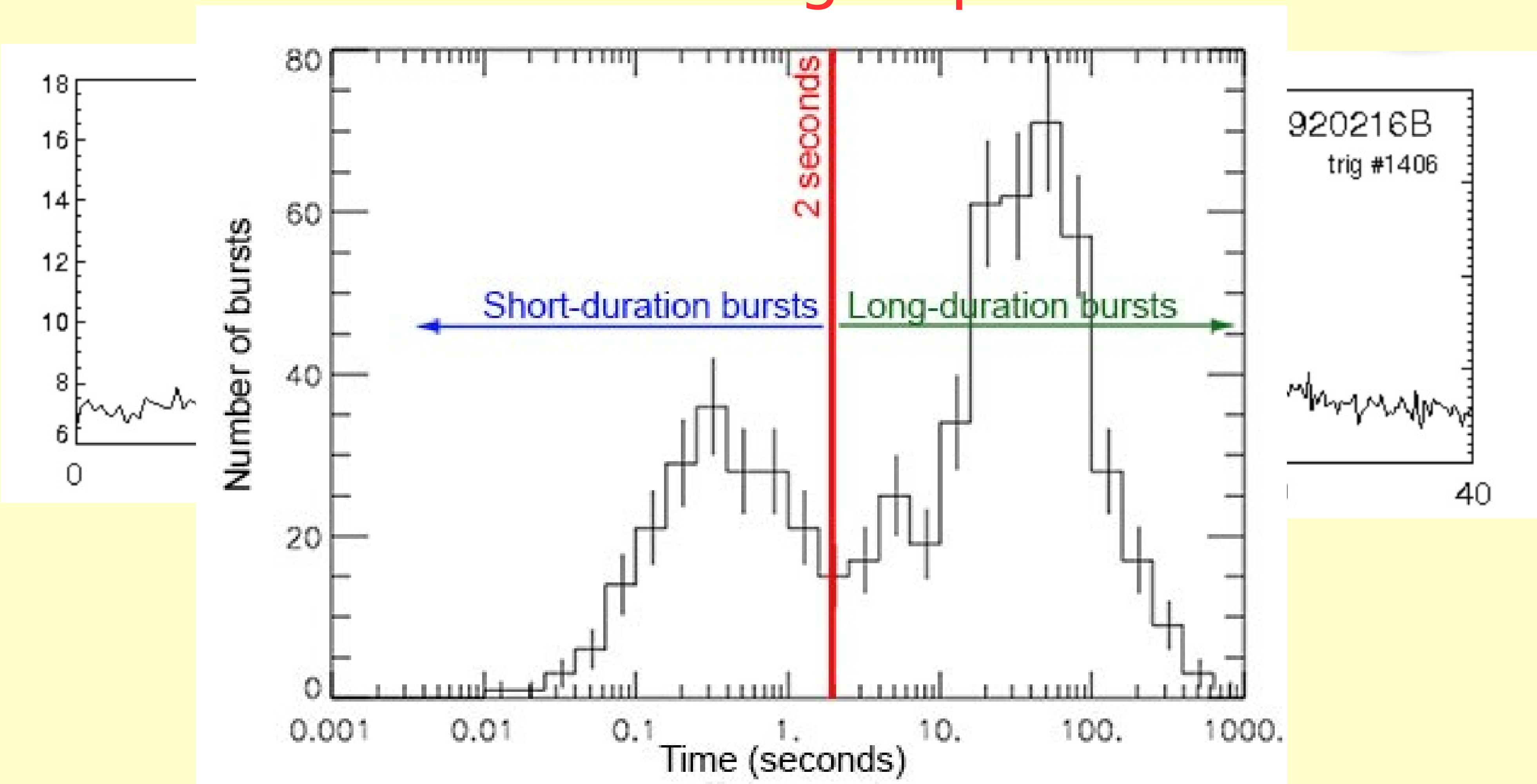
Short GRBs

BATSE on Compton GRO

Long GRBs

Gamma ray bursts Overview

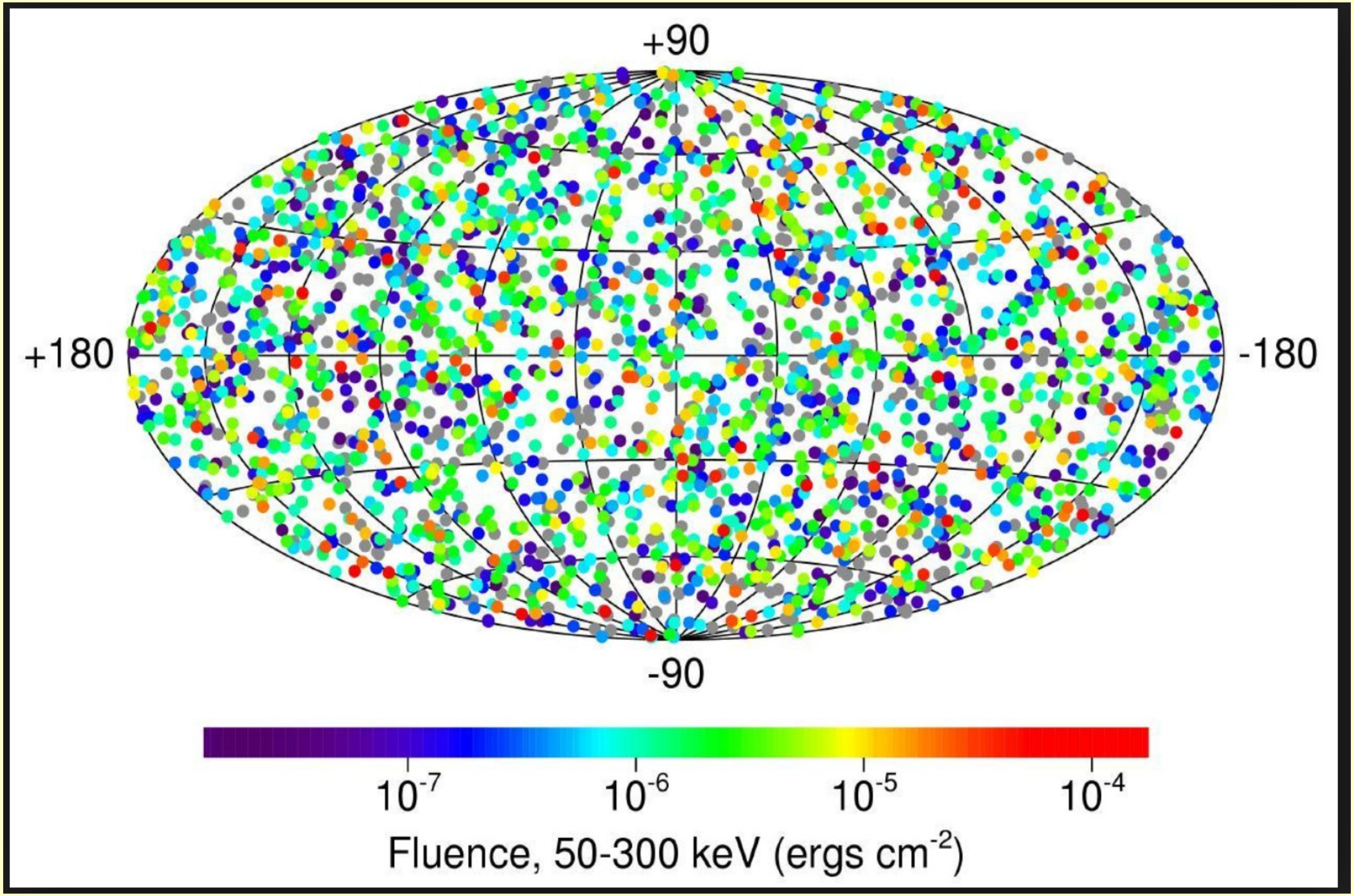
Two subgroups



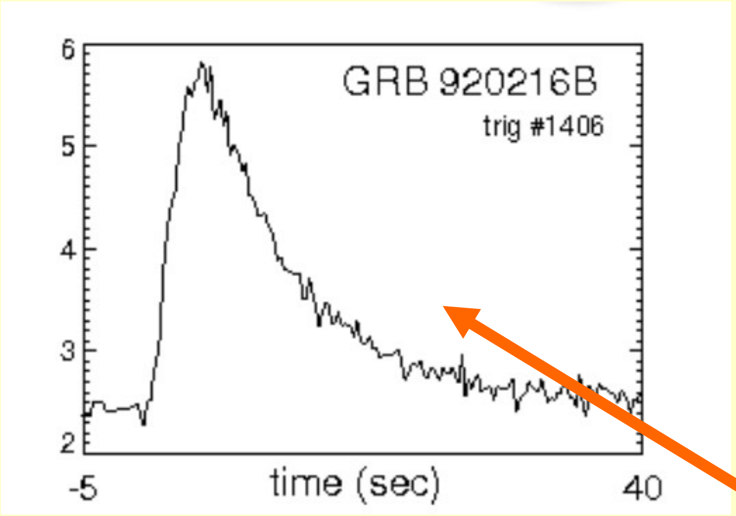
Kouveliotou et al. 1993

Gamma ray bursts Overview

BATSE Gamma ray bursts



GRB Afterglow
X-rays

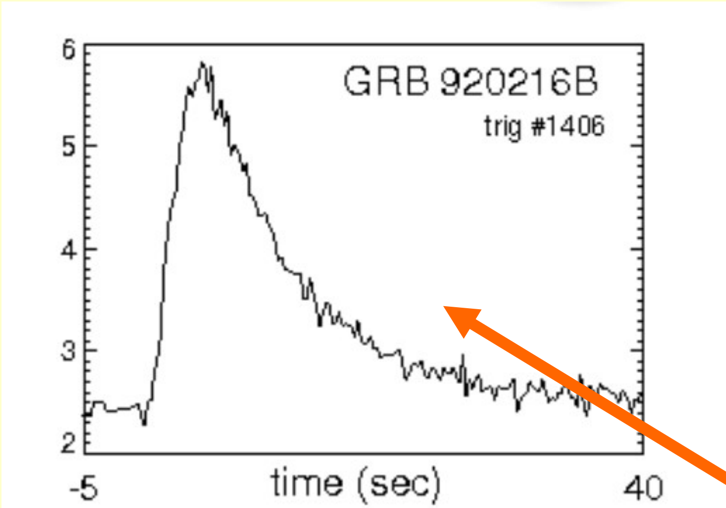


Afterglow Predicted

Paczynski & Rhoads '93
Meszaros & Rees '97

Gamma-rays

GRB Afterglow
X-rays



Afterglow Predicted

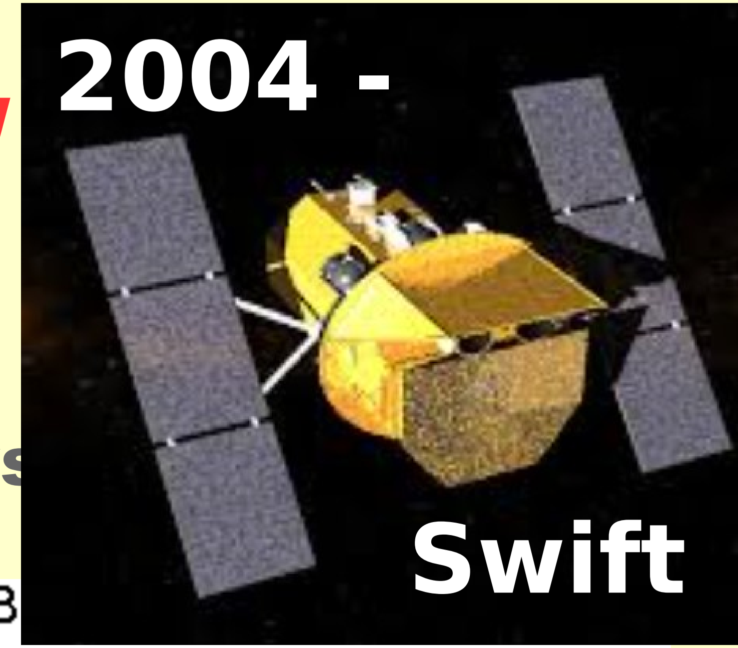
Paczynski & Rhoads '93
Meszaros & Rees '97

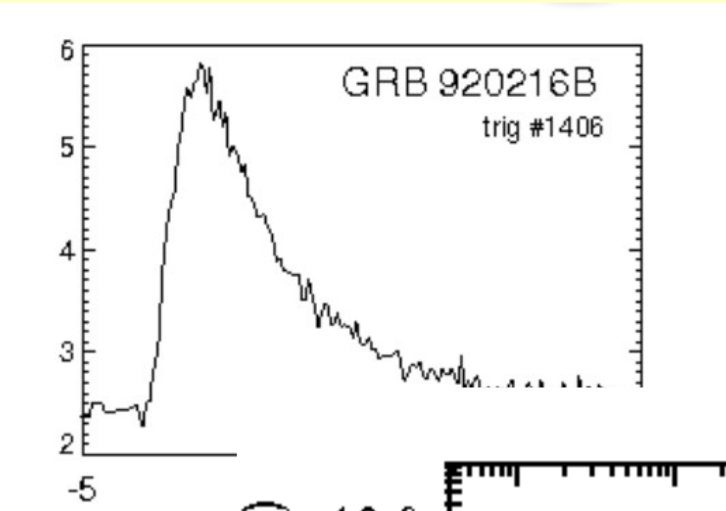
Gamma-rays

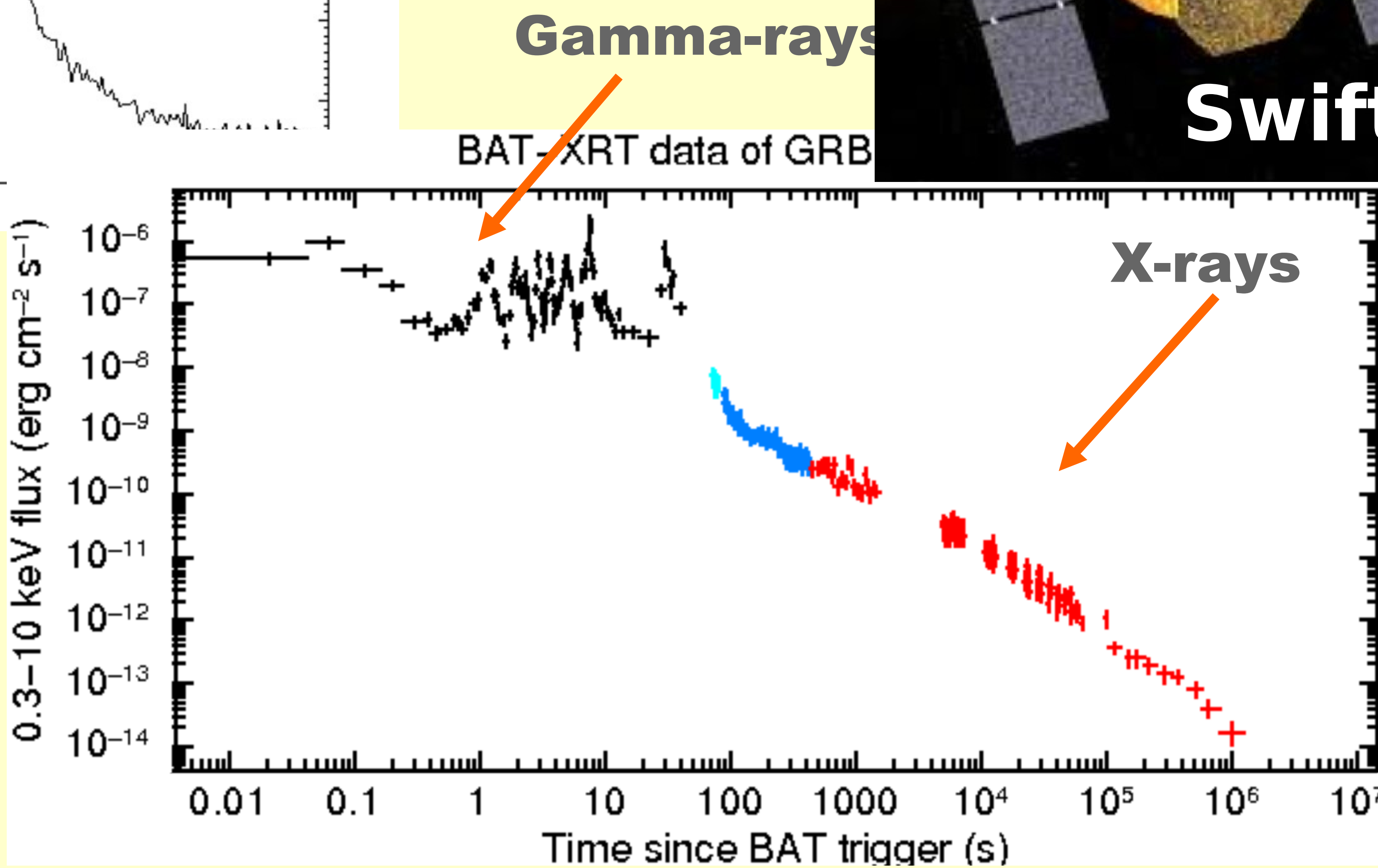
BeppoSAX

1997 fading X-ray emission
accurate measurement of position
determination of distance

GRB Afterglow X-rays

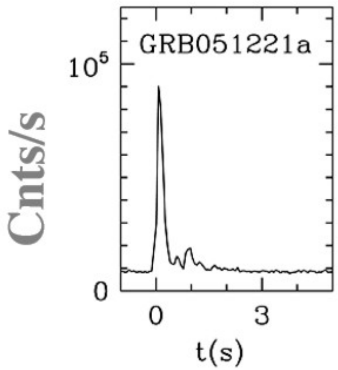




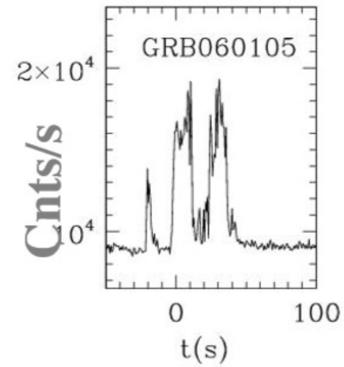


Short vs Long GRBs

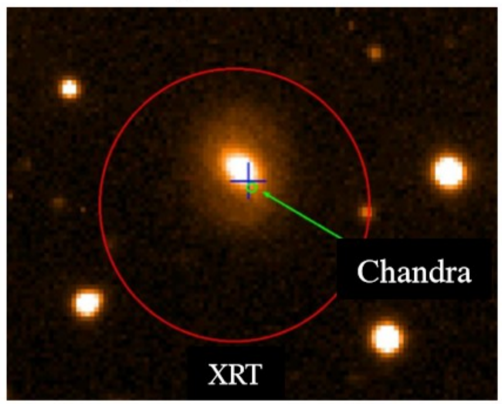
Short GRB



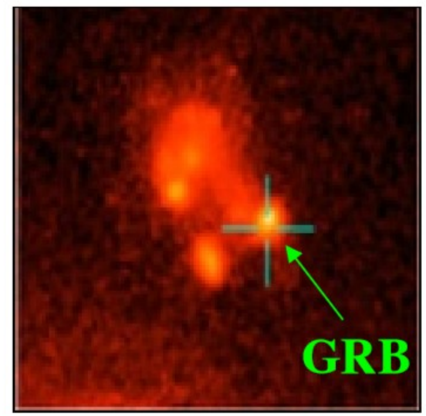
Long GRB



GRB 050724 - *Swift*
elliptical host



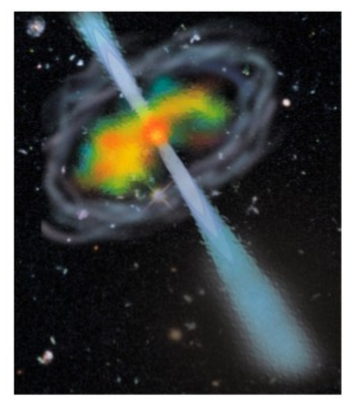
GRB 020903 - *SAX*
SF dwarf host



In non-SF
and SF galaxies

No SNe detected

Possible **merger** model



BH

In SF
galaxies

Accompanied by SNe

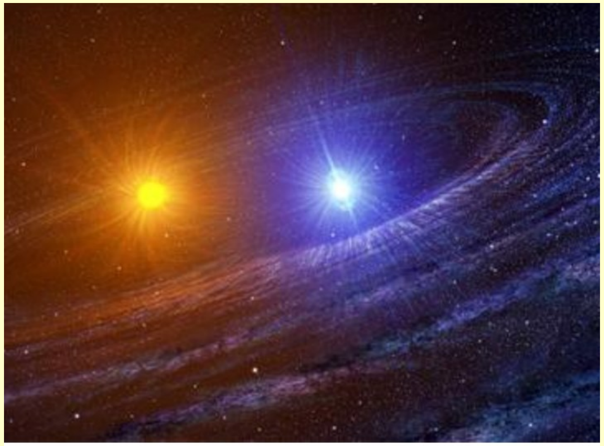
Collapsar model
well supported

Slide: Gerhels

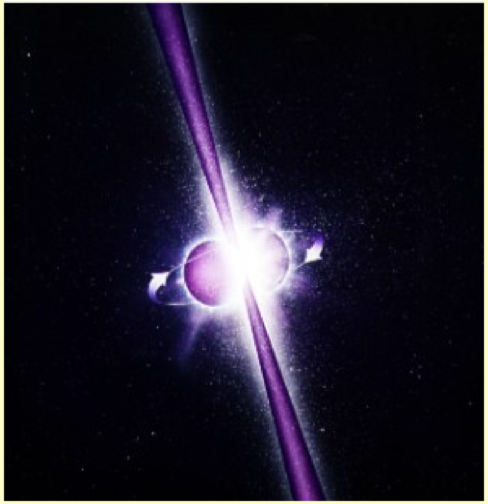
Short Gamma ray bursts
Central Engine

- Open Question …

Binary Neutron star merger



- Long Lasting Magnetar ...



- Quickly Collapses to
  Black Hole ….

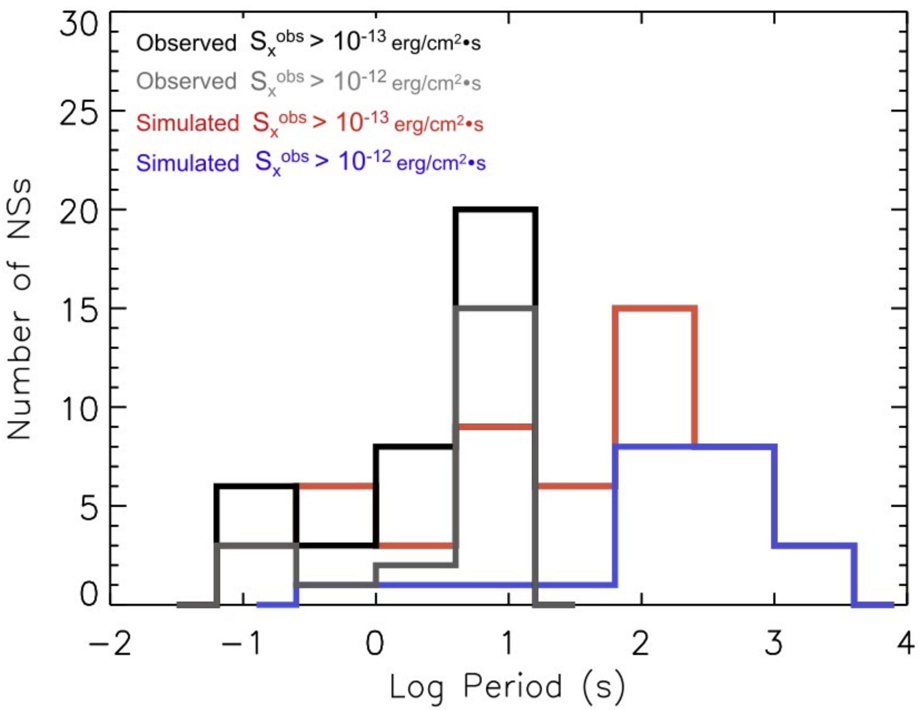
- Afterglow lasting for 10^5 sec

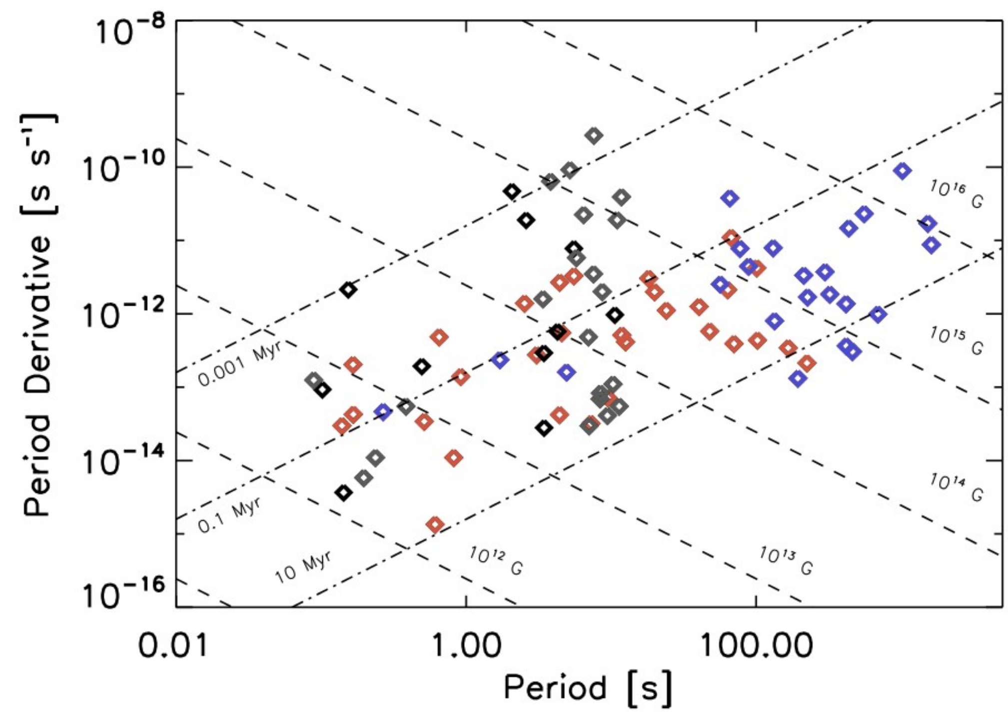
Rezzolla & Kumar 2015
Ciolfi & Siegel 2014

review Berger 2014

Magnetars & Gamma-ray bursts

- Simulating 100 SN-Type-GRBs in 1 Myr in the Milky Way we would expect to have now ~25 “observable” magnetars.
- HOWEVER, the expected X-ray luminosities and spin period distribution of these GRB-magnetars CANNOT be reconciled with what observed in our magnetars.



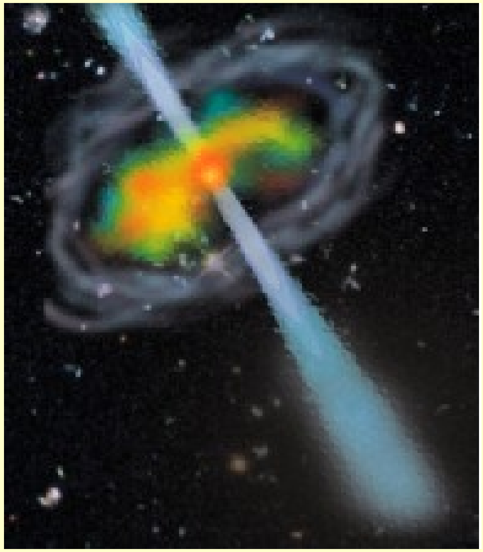


Rea et al. 2015

Long Gamma ray bursts
Central Engine

- Core Collapse of a supermassive star (Wolf Rayet ~ 30 M_{O})

- Stellar Mass Black Hole formed maximally rotating (??),
Strong Magnetic fields

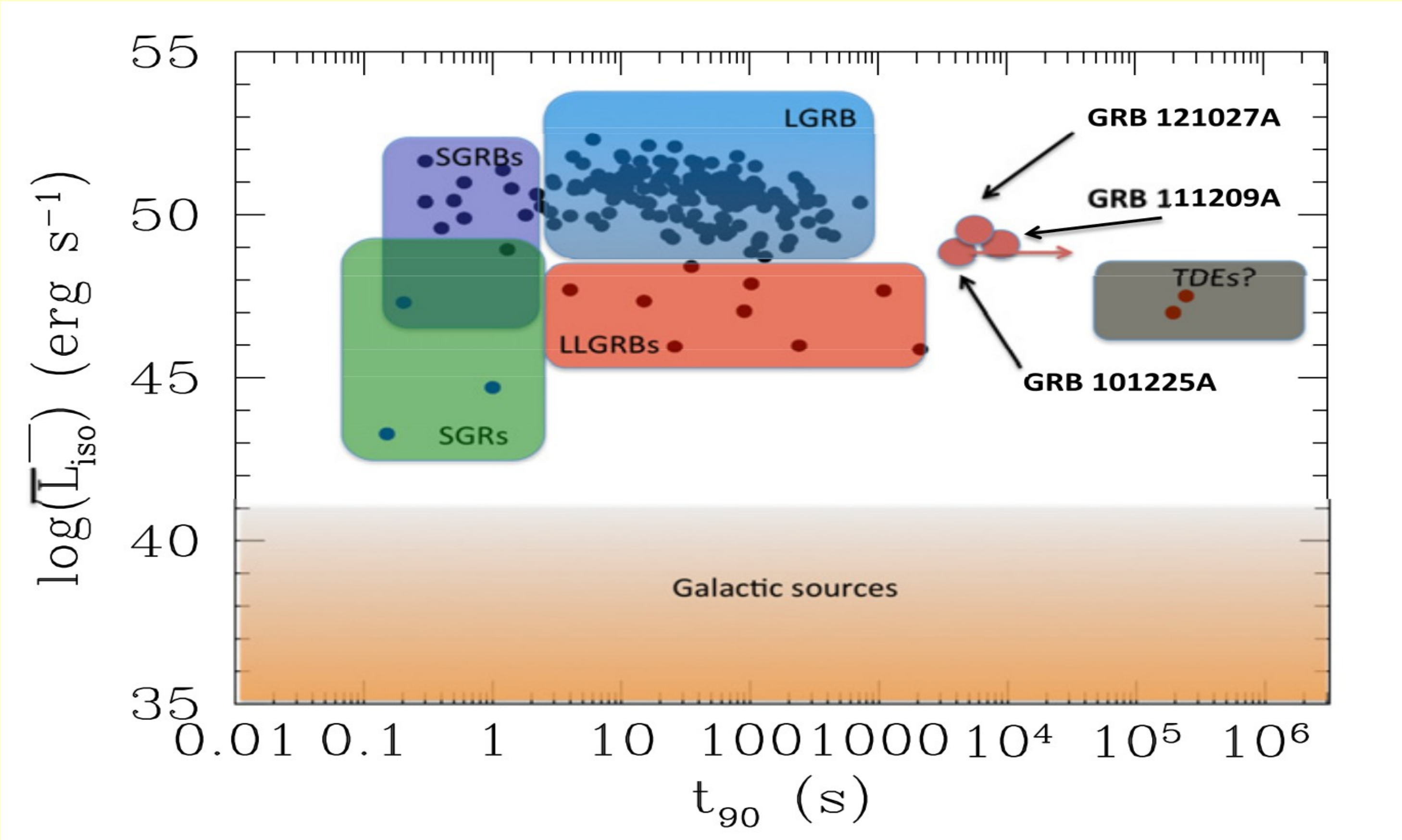


- Hyper-accretion drives the GRB & duration depends to surrounding mass
  (Ultra Long duration???)

- Jet launched, Blandford-Znajek or\and neutrino annihilation

Extensive Literature: review Kumar & Zhang 2014

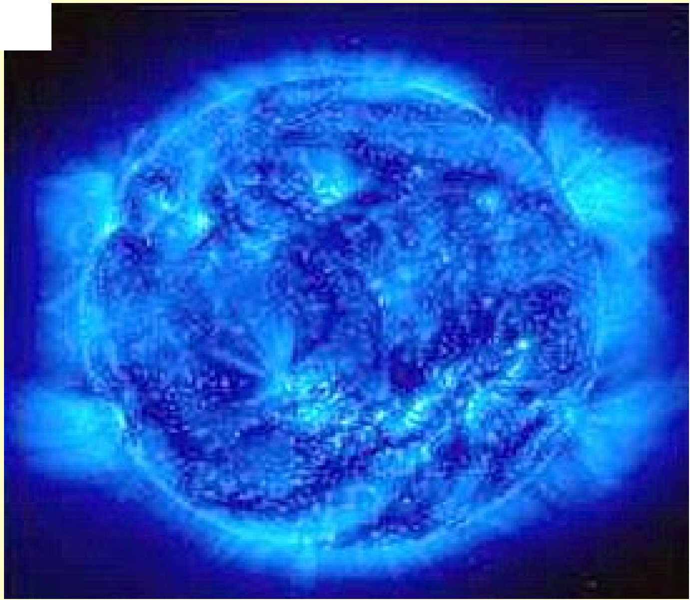
Ultra Long Gamma ray bursts



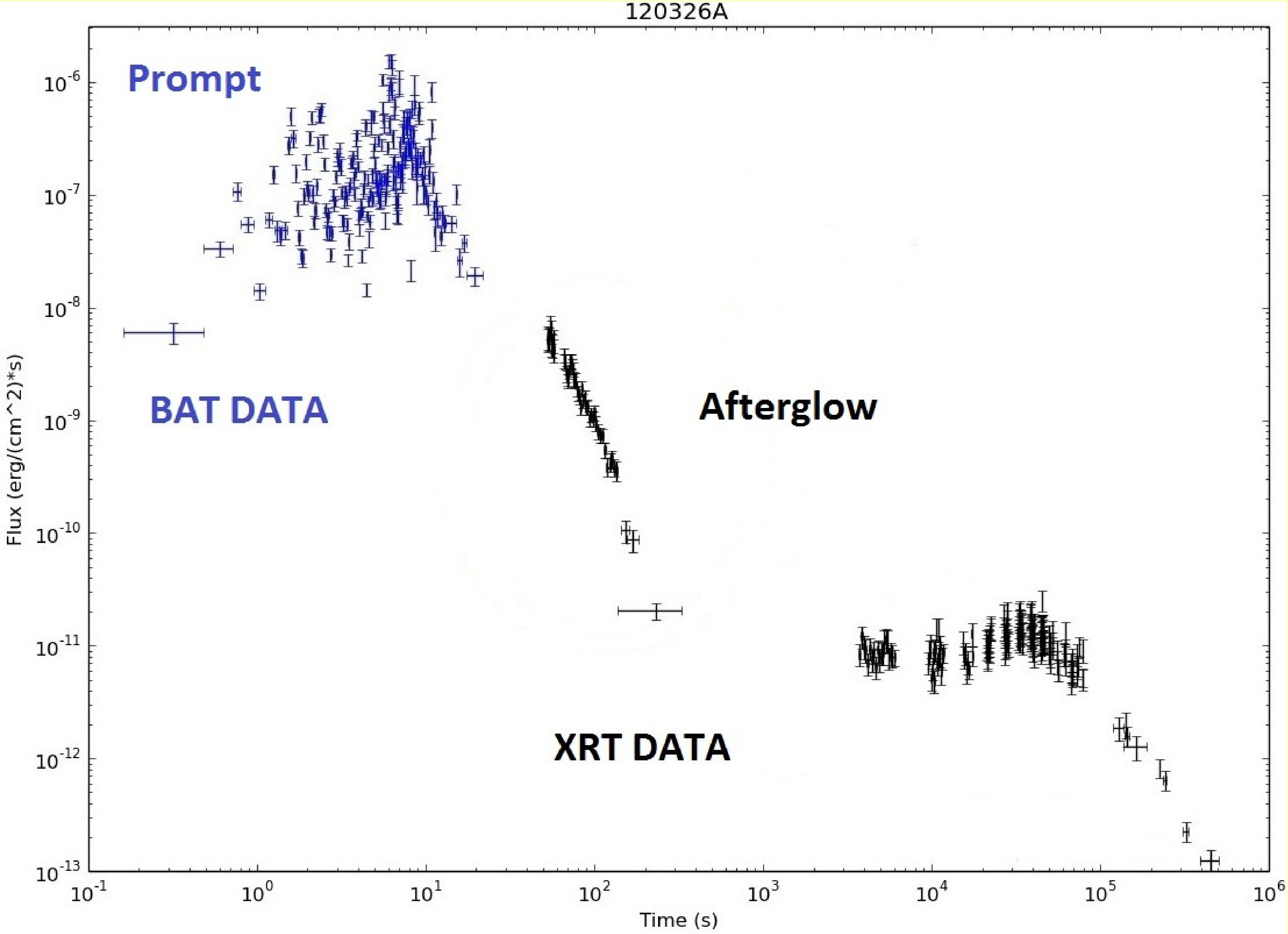
Levan et al. 2014

Gendre et al.2013
Evans et al. 2014
Levan et al. 2014
Nakauchi et al. 2013

Blue Super Giant



ANATOMY OF A BURST



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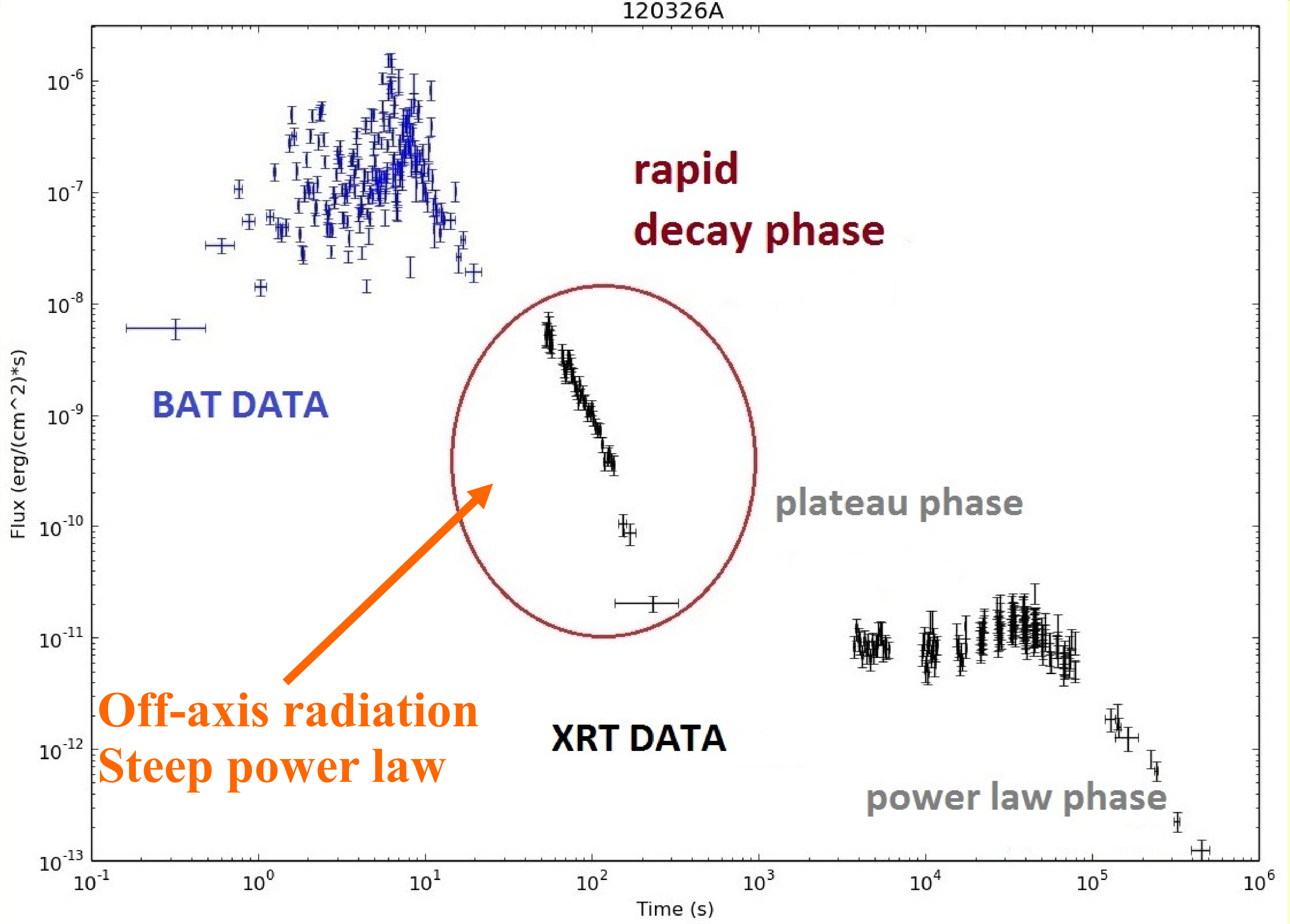
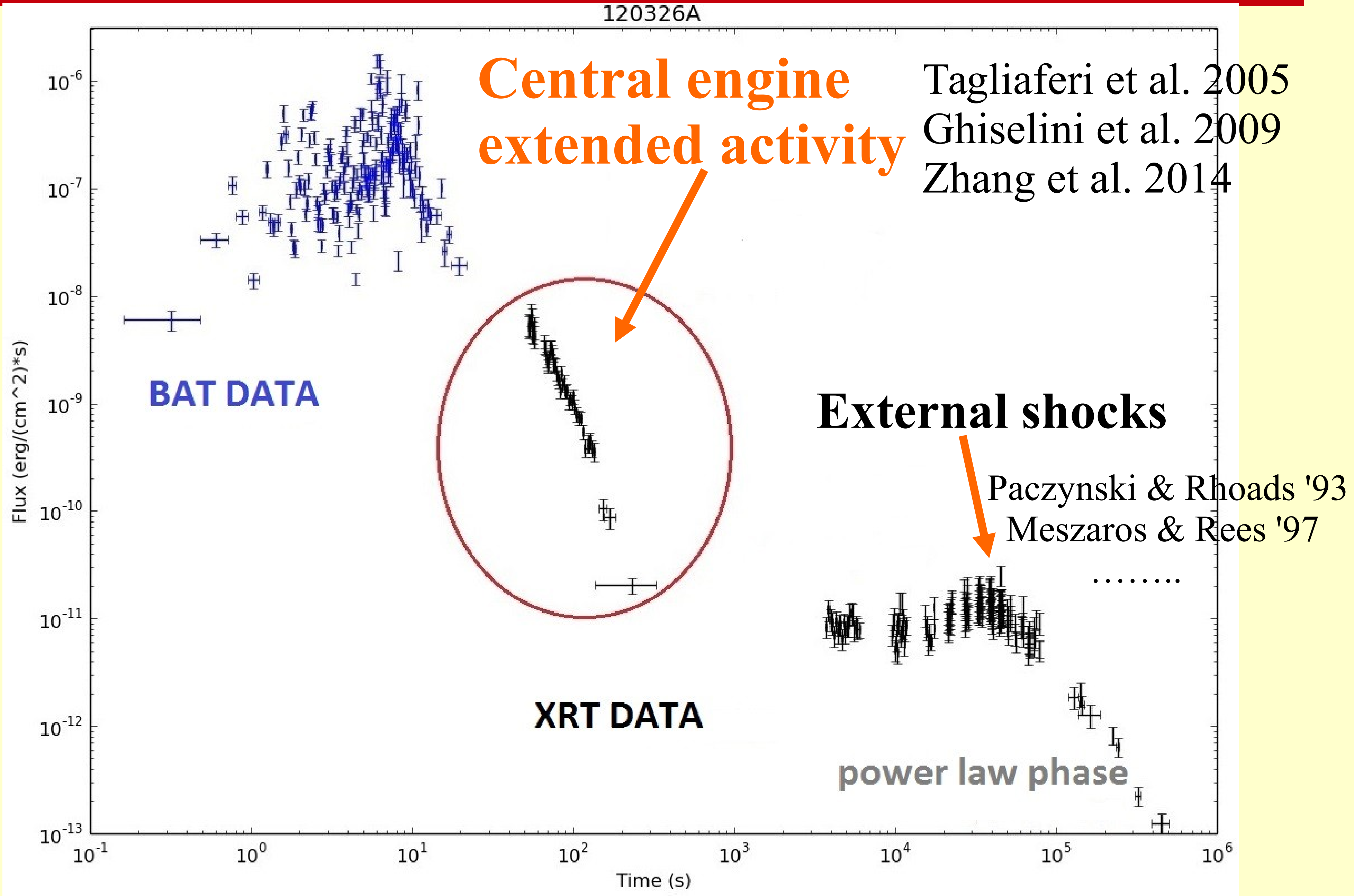
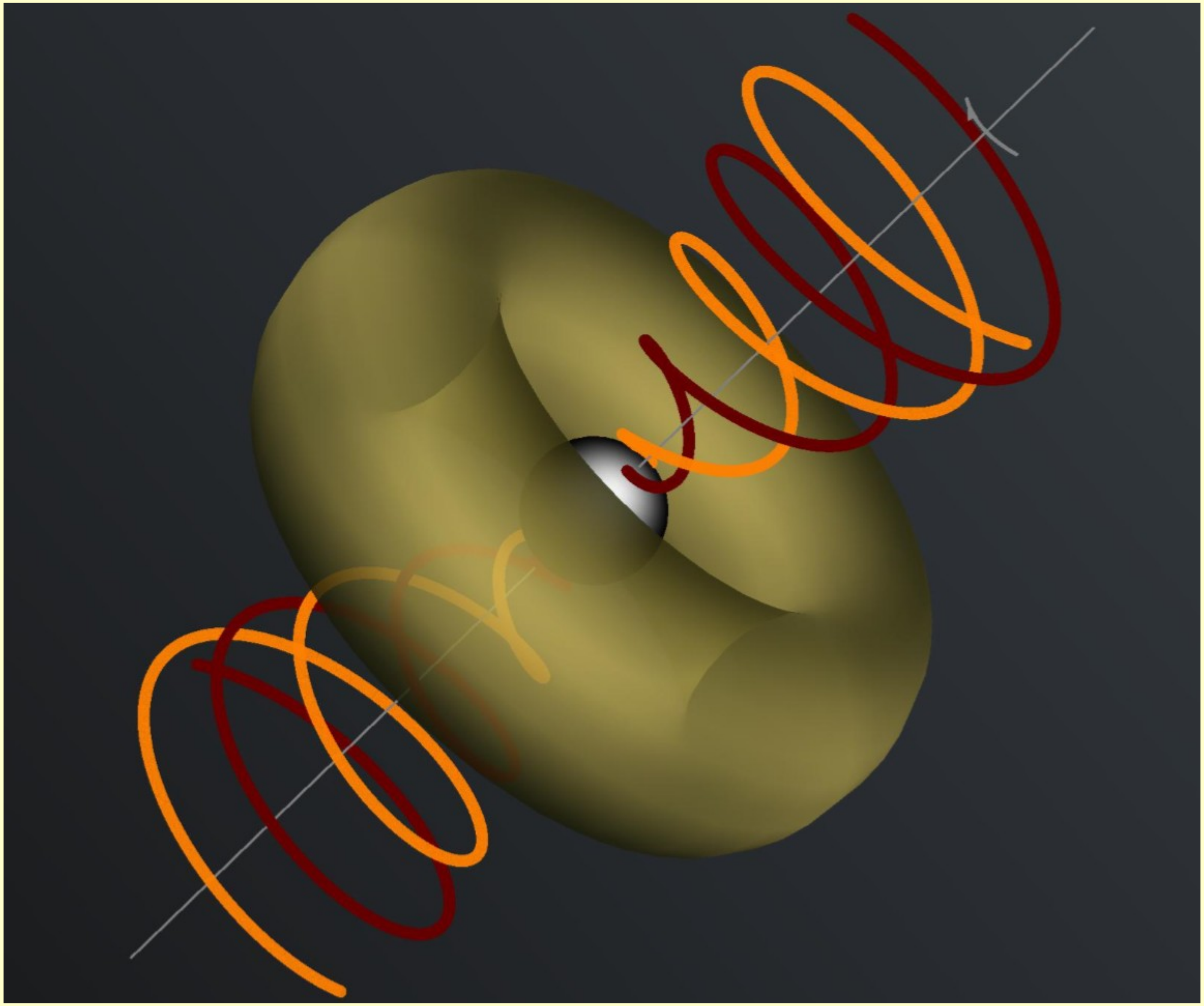


ANATOMY OF A BURST



Small Break for theory



Small Break for theory

Black hole placed in magnetic field
is loosing Energy as …….

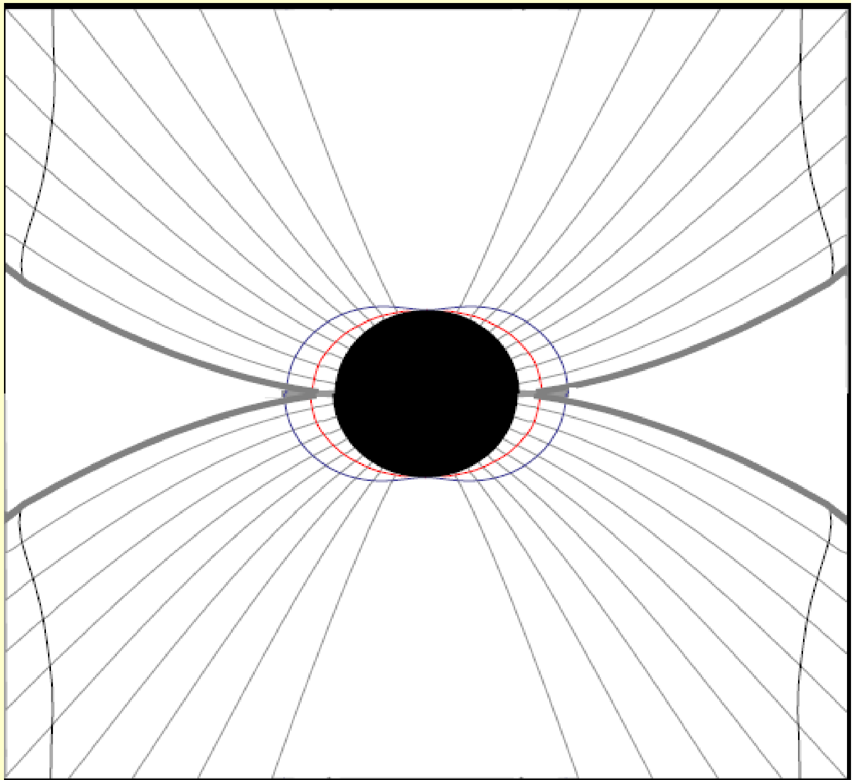
$$\dot{E} \approx -\frac{1}{6\pi^2 c}\Psi_m^2\Omega^2$$

Blanford & Znajek 1977

……...

Nathanail & Contopoulos 2014

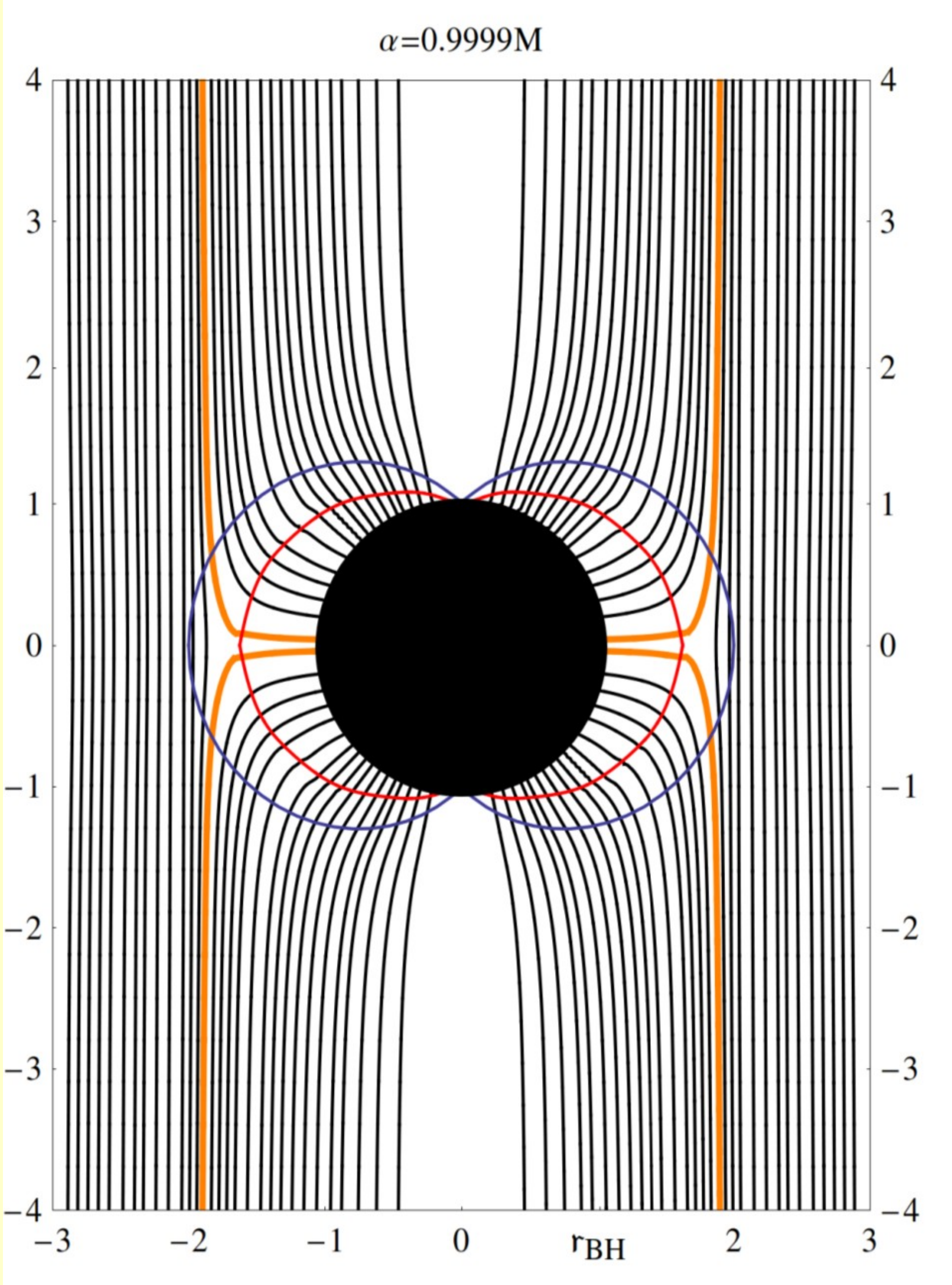
Ψ_m magnetic flux



Small Break for theory

$$\dot{E} \approx -\frac{1}{6\pi^2 c}\Psi_m^2\Omega^2$$

The importance of the ergosphere and the production of poloidal currents



Nathanail & Contopoulos 2017

Small Break for theory

THE ASTROPHYSICAL JOURNAL, 637:914–921, 2006 February 1

THE PROGENITOR STARS OF GAMMA-RAY BURSTS

S. E. WOOSLEY[1] AND A. HEGER[1,2]
Received 2005 August 6; accepted 2005 October 3

Spin of BH

TABLE 2
PRESUPERNOVA MODELS FOR RAPIDLY ROTATING STARS

Mass/Model	J_{init}[a] (10^{52} ergs s^{-1})	v_{rot}[b] (km s^{-1})	Pre-SN Type[c]	$\dot{M}$ WR[d]	Magnetic Field[e]	M_{final}[f] ($M_\odot$)	Fe core[g] ($M_\odot$)	$J_{Fe\ core}$[h] (10^{47} ergs s^{-1})	Period[i] (ms)	a_{BH}[j] (3 $M_\odot$)
16OE	2.5	255	RSG		no	15.57	1.84	523	0.20	(1.8)
16OF	3.3	325	WR	1.0	no	8.97	1.35	318	0.18	(1.1)
16OG	2.5	255	RSG		yes	15.66	1.50	9.6	7.0	0.05
16OH	3.3	325	WR	1.0	yes	9.18	1.45	9.8	7.9	0.03
16OI	3.3	325	WR	0.3	yes	12.21	1.65	55.3	1.5	0.26
16OJ	4.1	400	WR	0.1	no	14.20	1.56	1290	0.06	(5.0)
16OK	4.1	400	WR	1.0	no	8.58	1.52	399	0.21	(1.4)
16OL	4.1	400	WR	1.0	yes	8.68	1.52	14.9	5.6	0.05
16OM	4.1	400	WR	0.3	yes	11.94	1.55	53.3	1.4	0.25
16ON	4.1	400	WR	0.1	yes	14.17	1.78	121	0.85	0.43

...

Why not a slowly rotating black hole

Small Break for theory

- Stellar mass black hole slowly rotating

$$E_{\rm rot} = Mc^2 - M_{\rm irr}c^2$$

$$E_{\rm rot} = Mc^2 \left(1 - \frac{1}{2}\left[(1+\sqrt{1-a^2})^2 + a^2\right]^{1/2}\right)$$

$$E_{\rm rot} \approx \frac{1}{8}Mc^2 \left(\frac{\Omega}{\Omega_{\rm max}}\right)^2$$

Small Break for theory

- Stellar mass black hole slowly rotating $(\alpha = 0.1)$

$E_{\rm rot}$ > 10^{52} erg

$$E_{\rm rot} \approx \frac{1}{8} M c^2 \left(\frac{\Omega}{\Omega_{\rm max}} \right)^2$$

Ω angular velocity

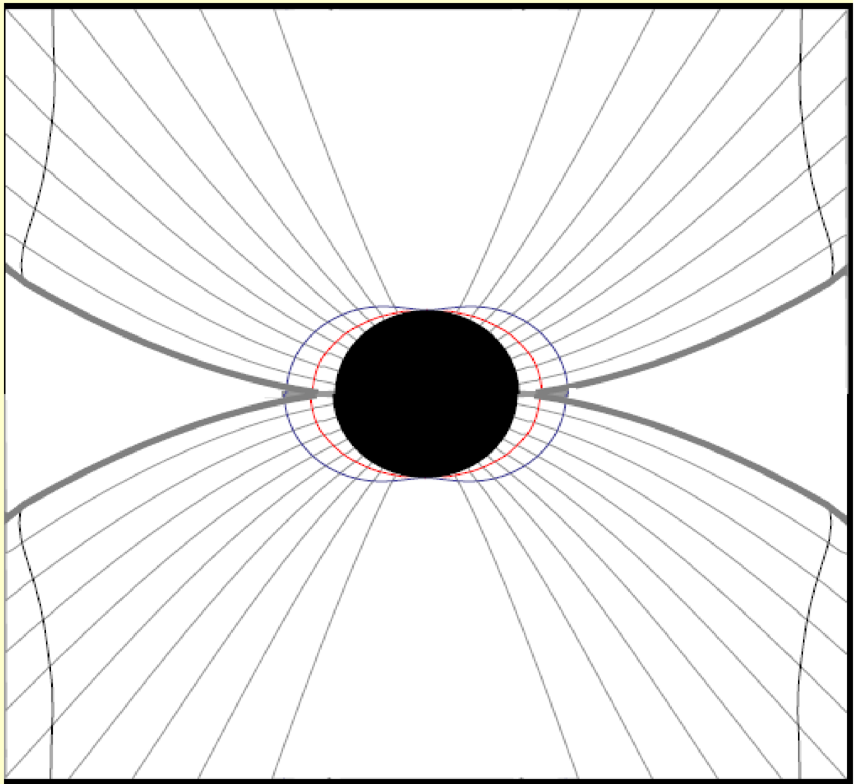
- Strong magnetic fields expected

Loosing Energy as …….

Small Break for theory

Loosing Energy as …….

$$\dot{E} \approx -\frac{1}{6\pi^2 c}\Psi_m^2\Omega^2$$



Blanford & Znajek 1977

………

Nathanail & Contopoulos 2014

Ψ_m magnetic flux

Small Break for theory

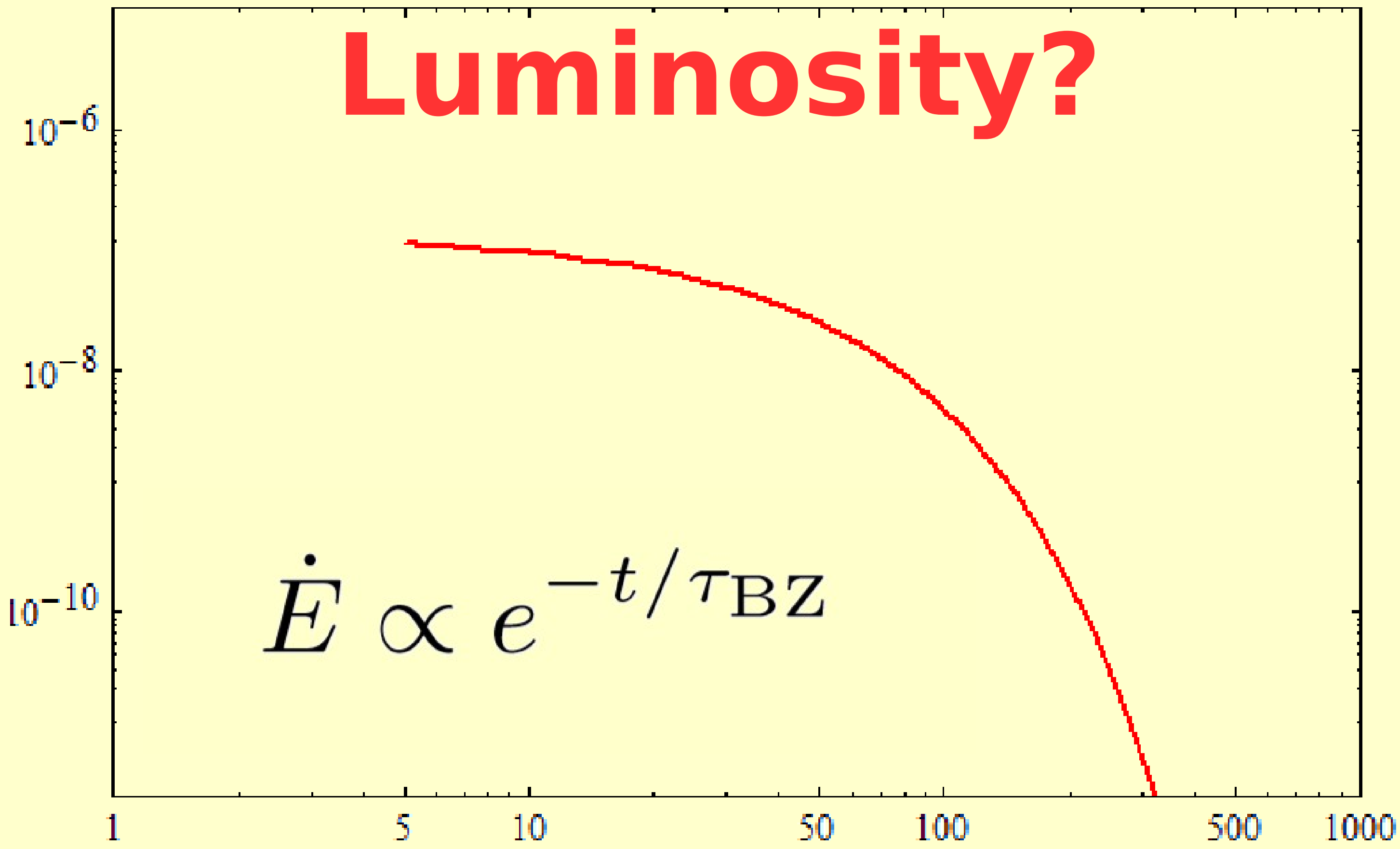
Loosing Energy as …

$$\dot{E} \propto e^{-t/\tau_{\rm BZ}}$$

$$\tau_{\rm BZ} \equiv 50 \left(\frac{B}{10^{15}\ {\rm G}} \right)^{-2} \left(\frac{M}{10 M_{\odot}} \right)^{-1} {\rm sec}$$

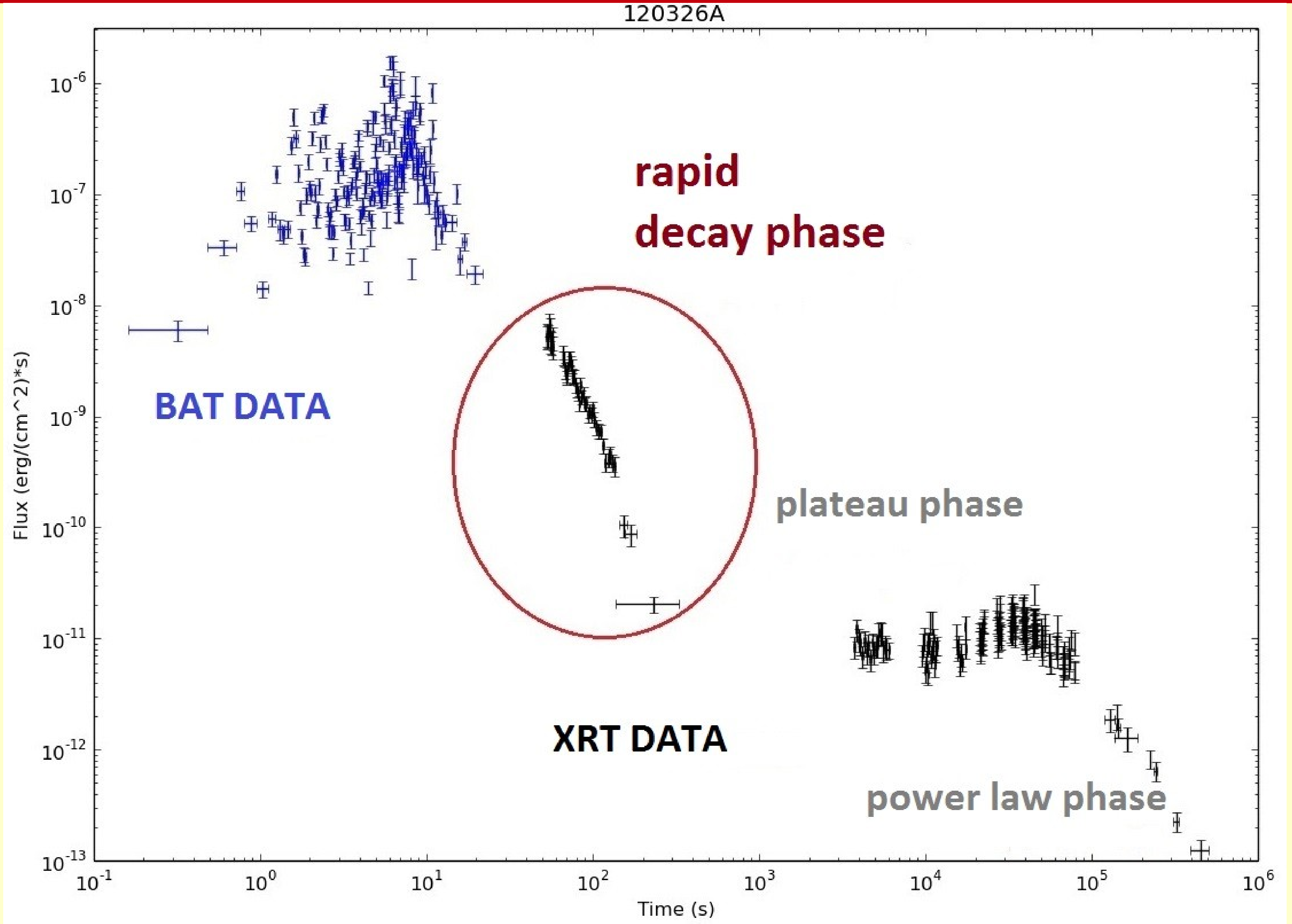
Nathanail & Contopoulos 2015

Can This Be observed Luminosity?

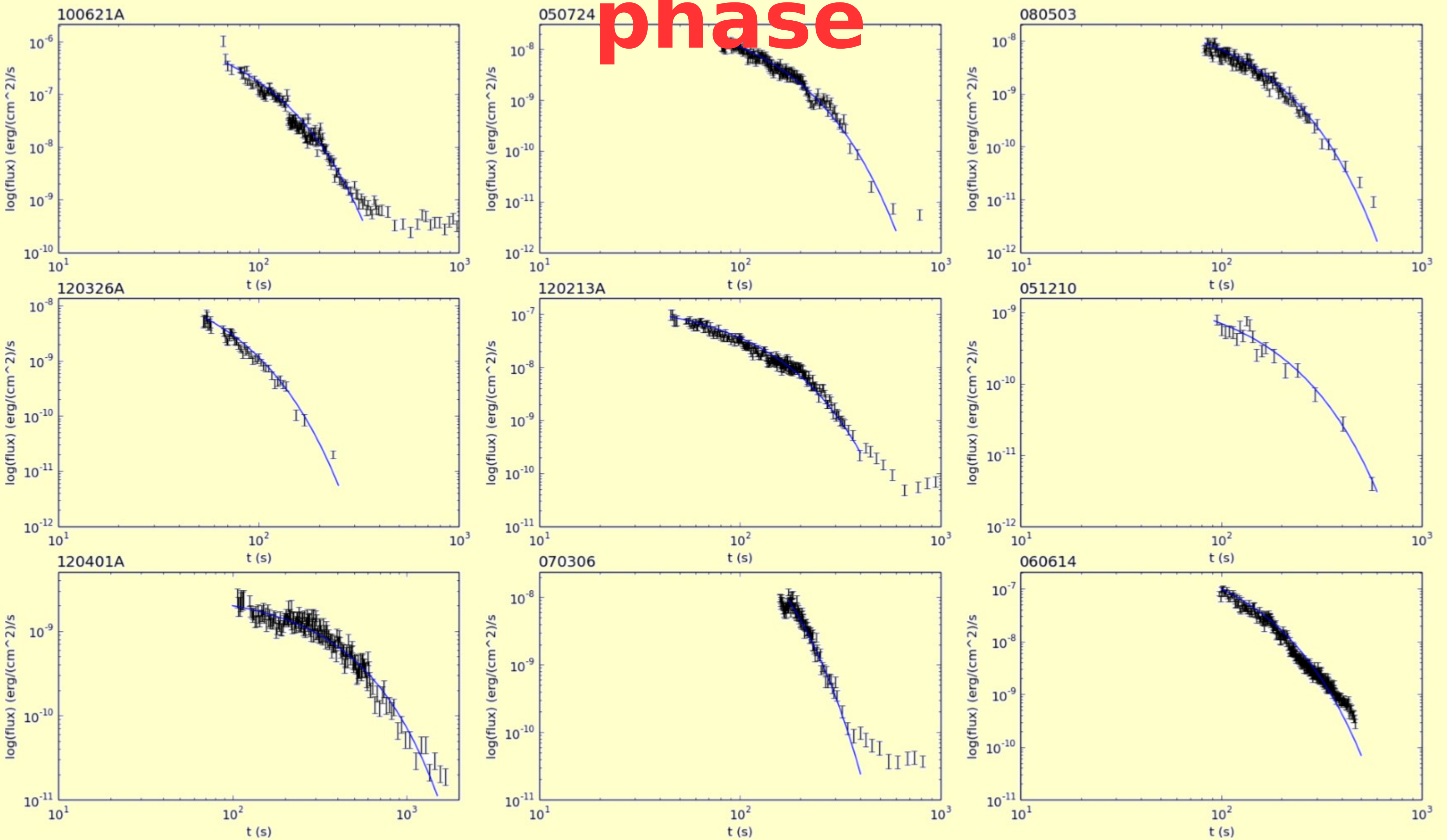


$$\tau_{\rm BZ} \equiv 50 \left(\frac{B}{10^{15}\ {\rm G}}\right)^{-2} \left(\frac{M}{10 M_\odot}\right)^{-1} {\rm sec}$$

ANATOMY OF A BURST



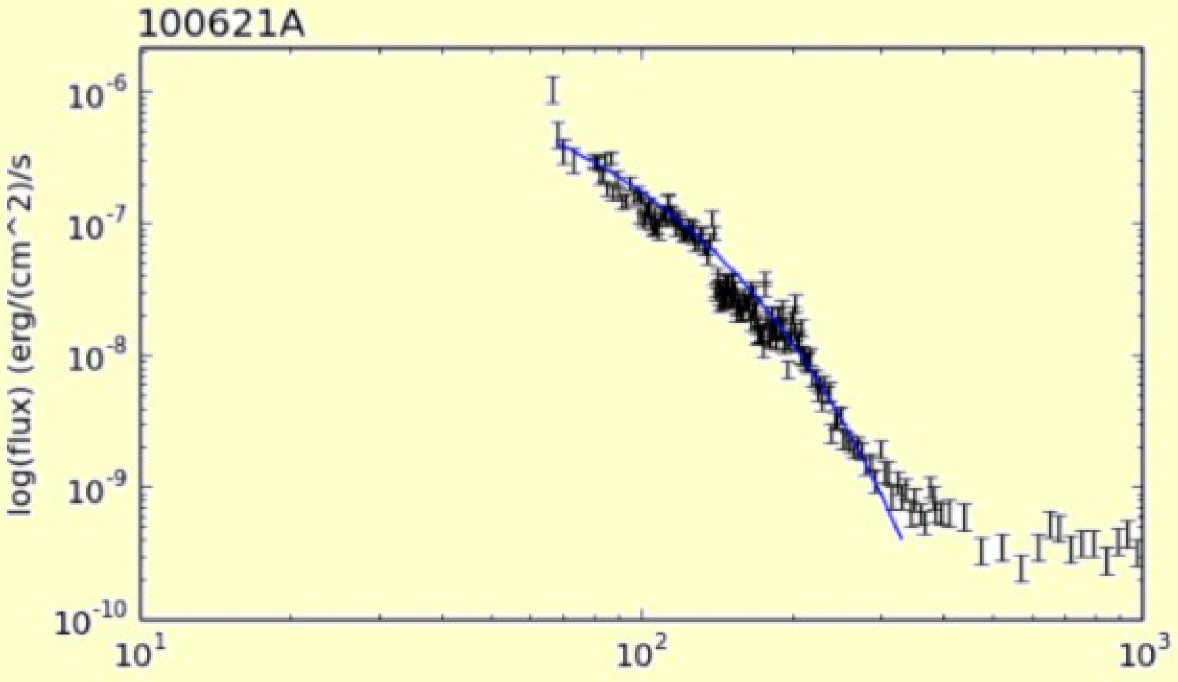
Zoom in the rapid decay phase



Nathanail, Strantzalis & Contopoulos 2015

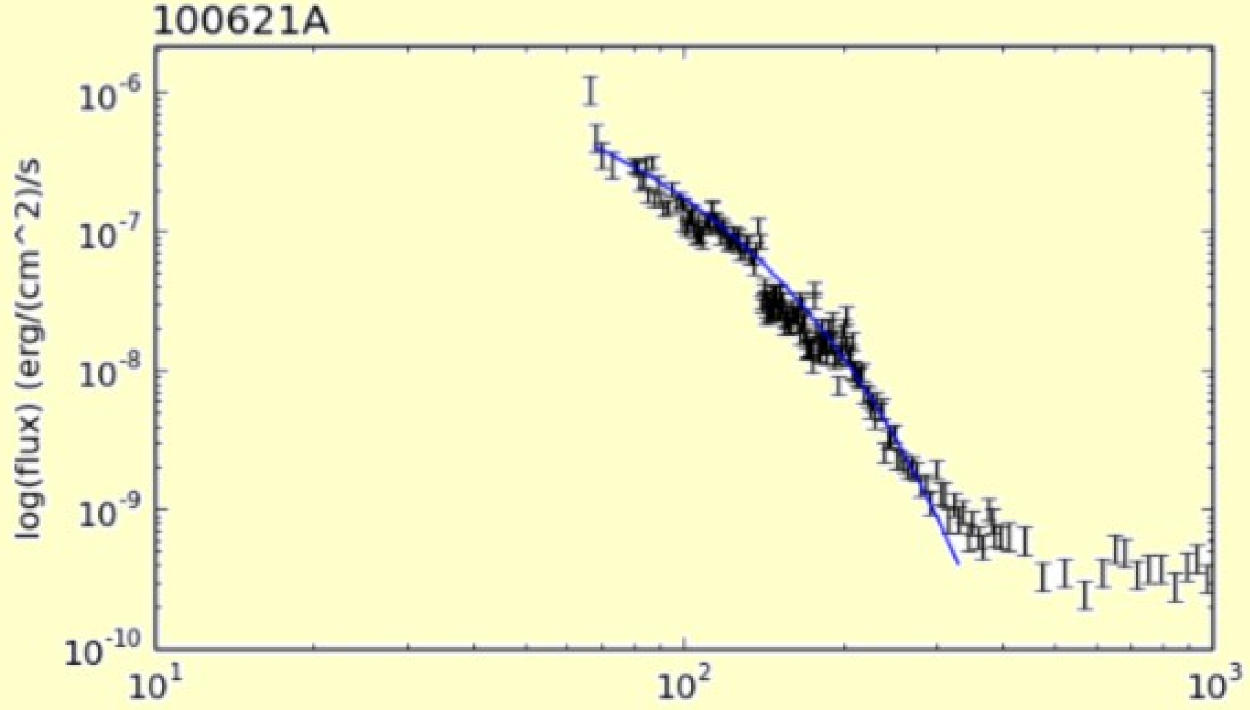
From 343 Long GRBs

30% had this sign



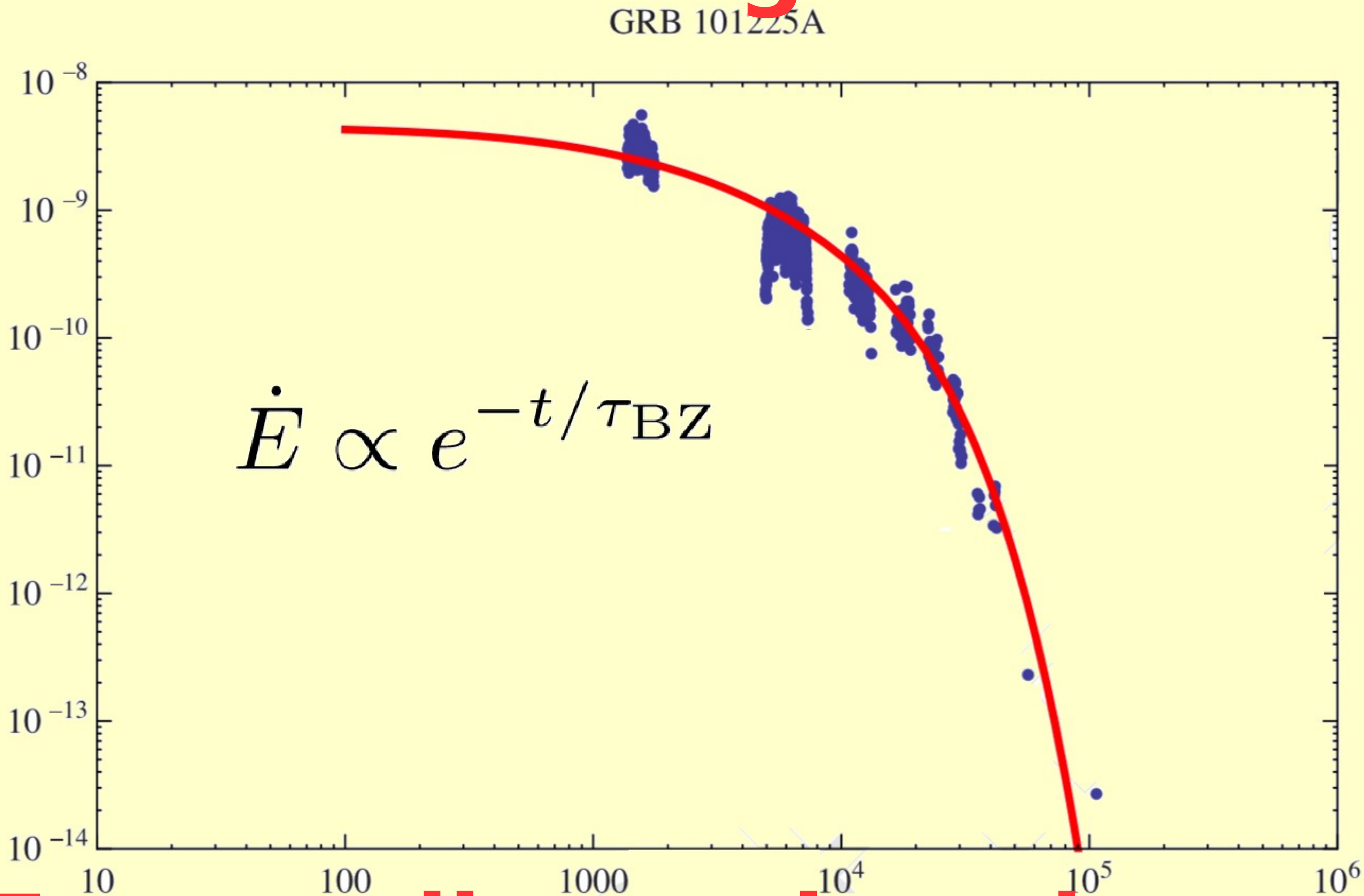
Nathanail, Strantzalis & Contopoulos 2015

Duration of a GRB depends on the magnetic field strength



Nathanail, Strantzalis & Contopoulos 2015

Easy to explain Ultra Long GRBs



Extraordinary duration ...

Nathanail & Contopoulos 2015

From the timescale we can estimate the magnetic field strength at the black hole

$$\dot{E} \propto e^{-t/\tau_{\rm BZ}}$$

$$\tau_{\rm BZ} \equiv 50 \left(\frac{B}{10^{15}\ {\rm G}} \right)^{-2} \left(\frac{M}{10 M_{\odot}} \right)^{-1} {\rm sec}$$

Nathanail & Contopoulos 2015

Nathanail, Strantzalis & Contopoulos 2015

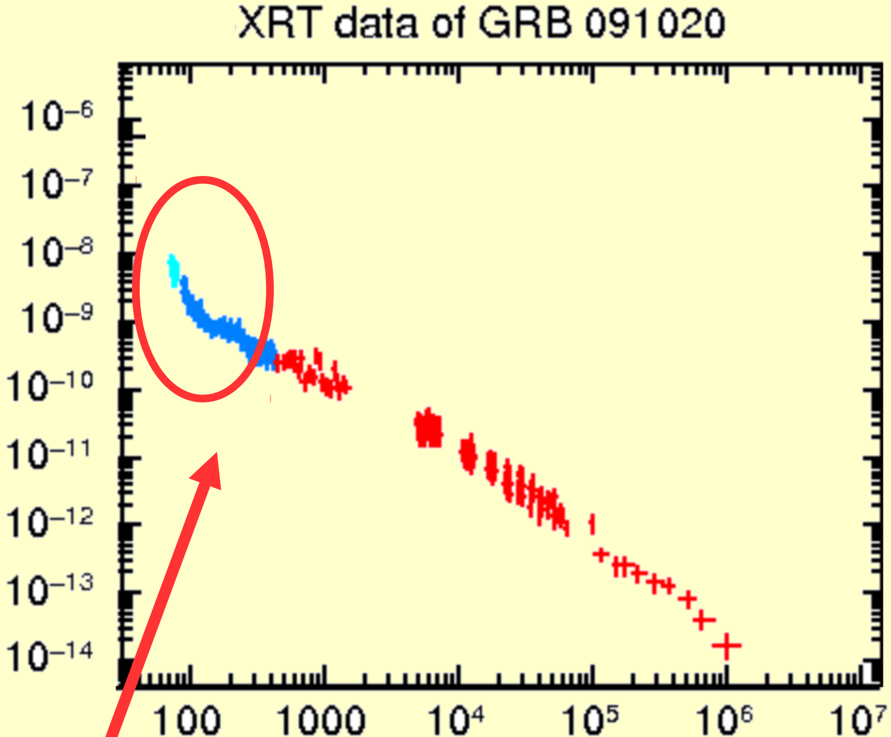
Comparing with Wolf Rayet observations

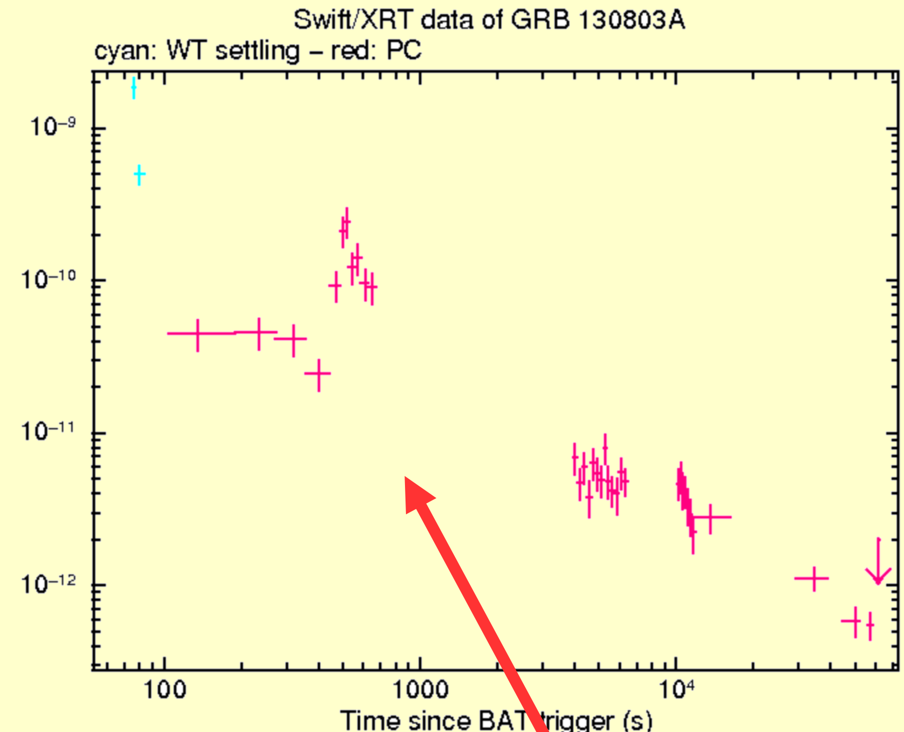
Magnetic flux conservation

Calculate “surface” magnetic field $10 - 100\ \mathrm{G}$

Inside the observable range $22 - 128\ \mathrm{G}$

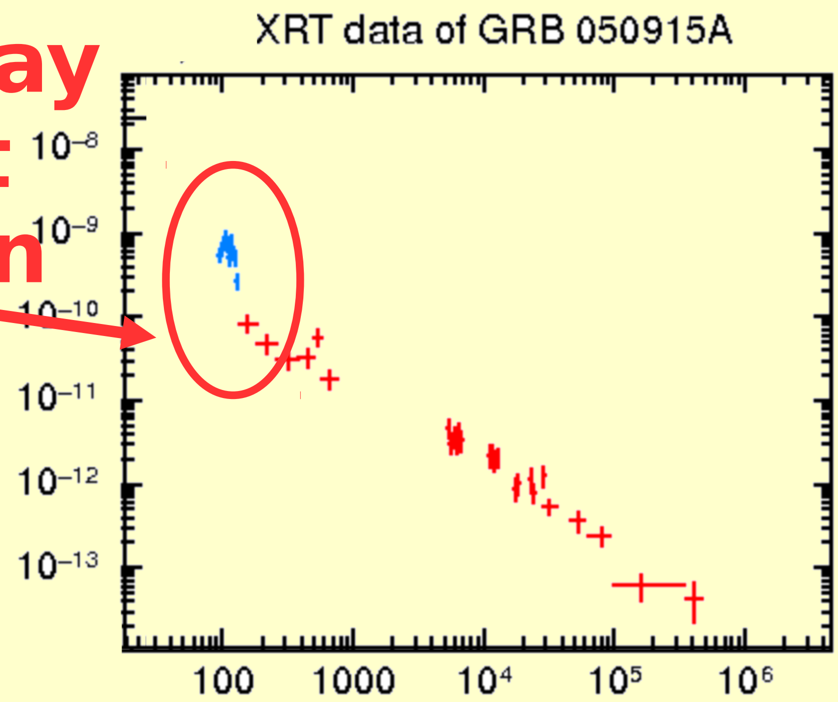
The Rest 70%



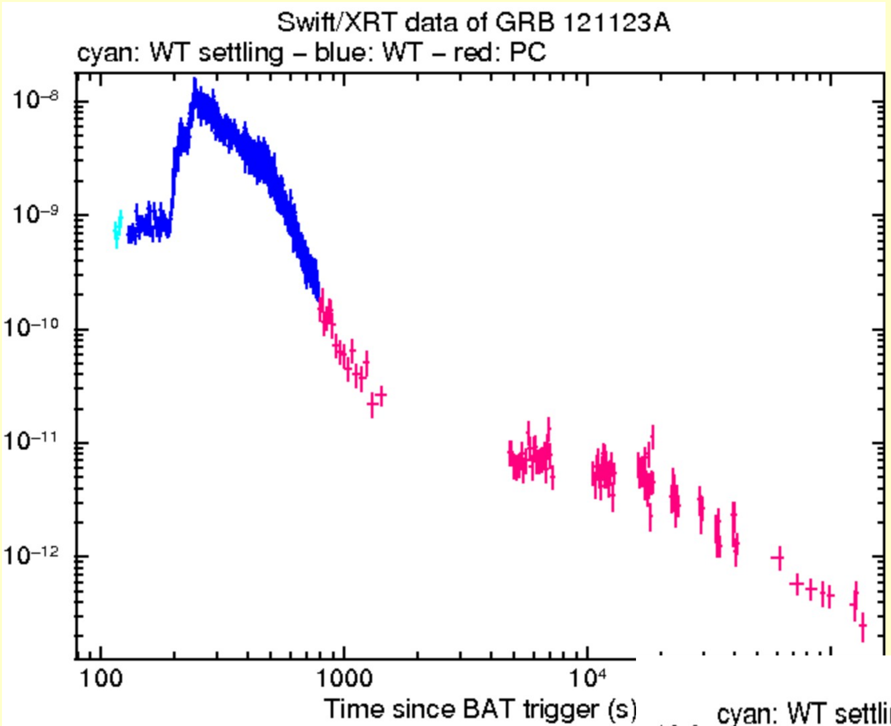


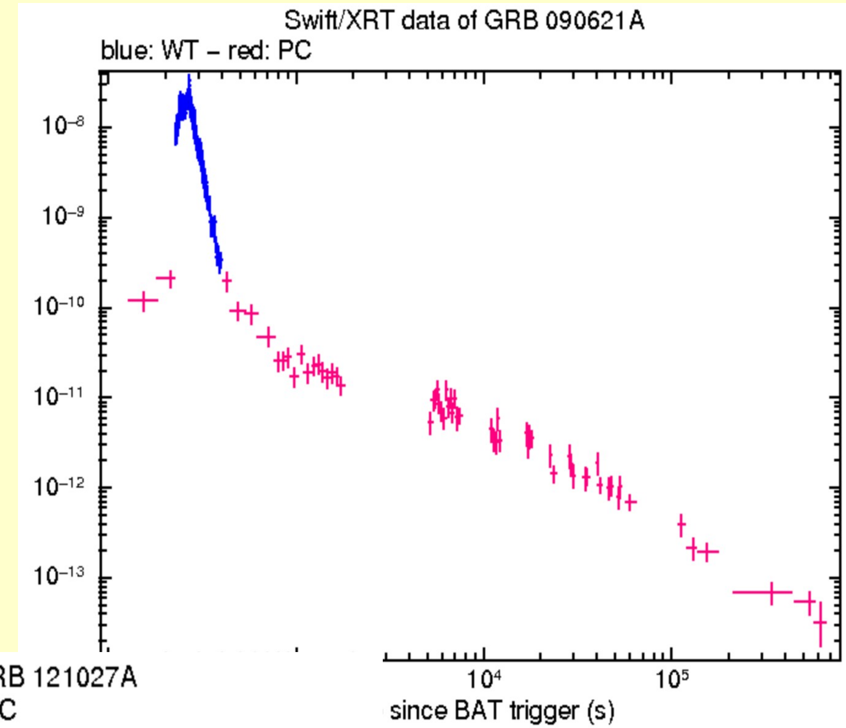
The rapid decay phase is not entirely seen

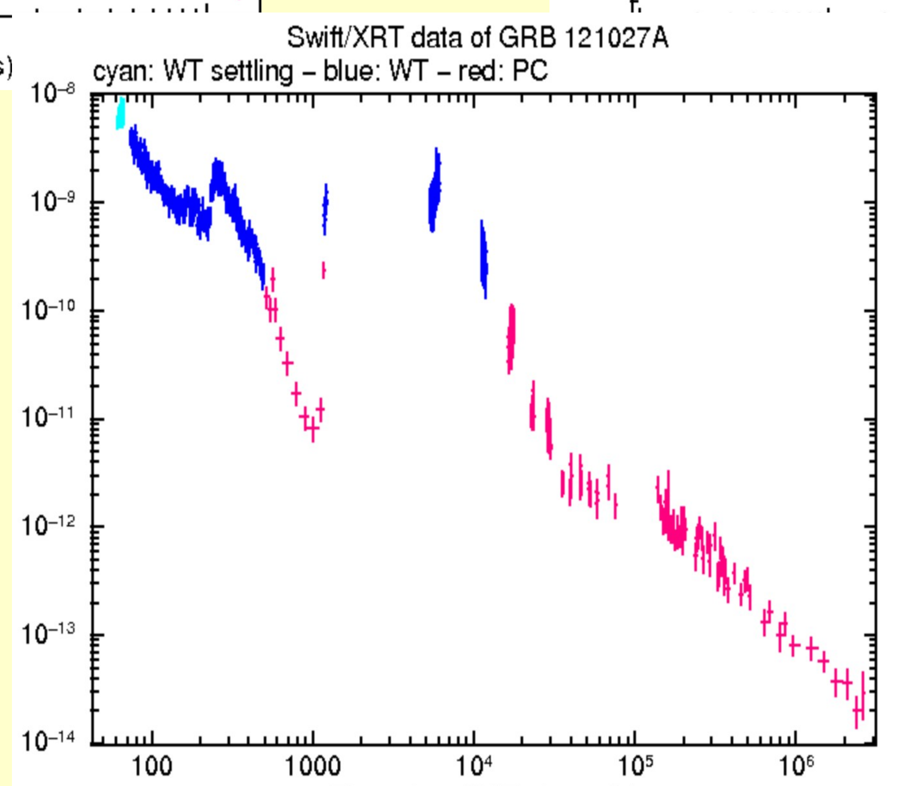
sparse data



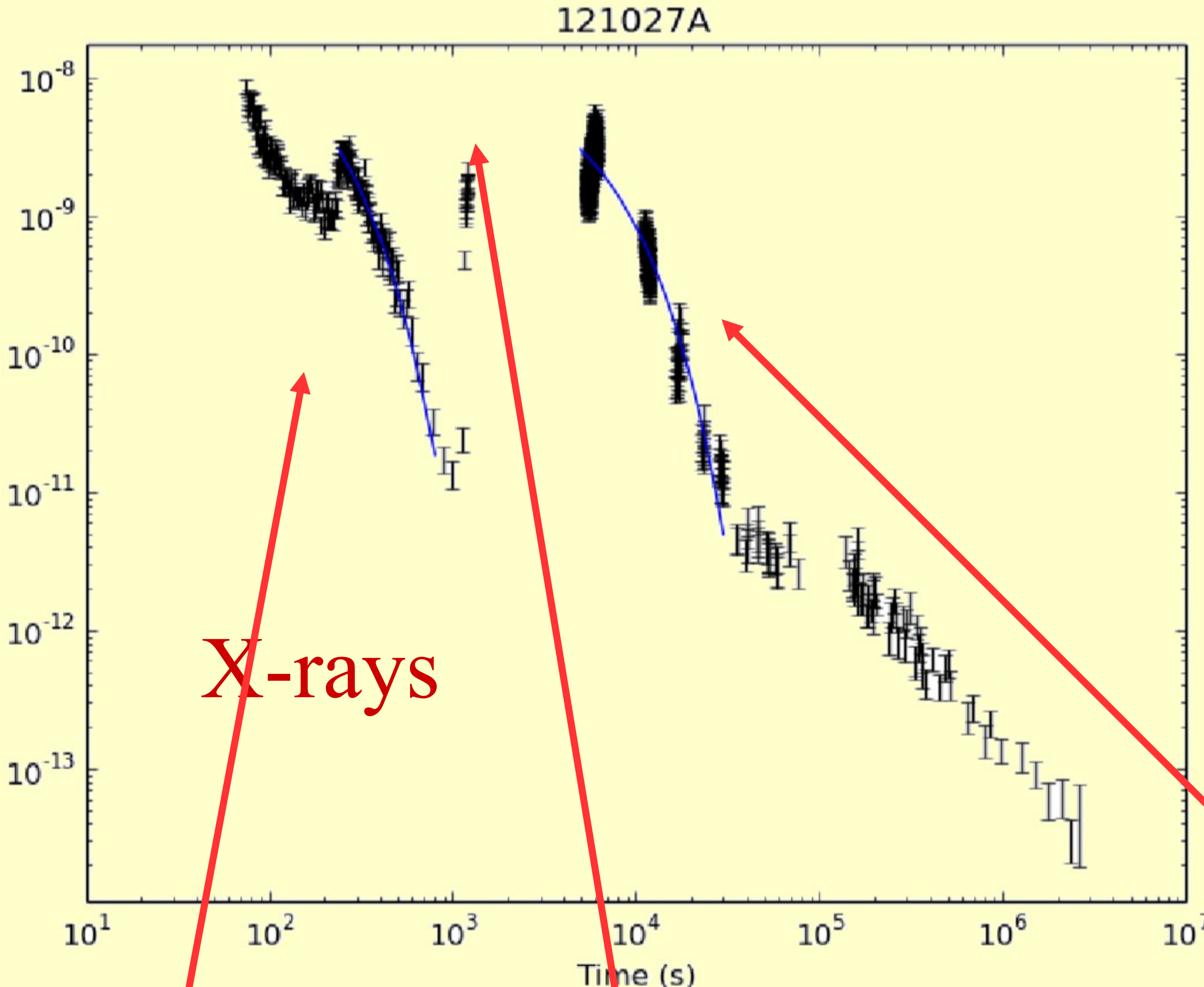
A lot of X-ray Flares







Mass infall - Flaring Activity



Proga & Zhang 2006

magnetic barrier

spin down

mass infall (spin up)

again spin down

in preparation . . .
(haven't done anything from last September)

Key points

- 30% of Long GRBs show signs of Black Hole Spin Down
- Duration of a GRB depends on the magnetic field strength