HOW TO SWITCH ON AND OFF A GRB??

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S. CAMPANA, G. GHISELLINI, D. BURLON, P. D'AVANZO, S. COVINO, G. GHIRLANDA, A. MELANDRI, R. SALVATERRA, S. VERGANI, V. D'ELIA, B. SBARUFATTI, G. TAGLIAFERRI

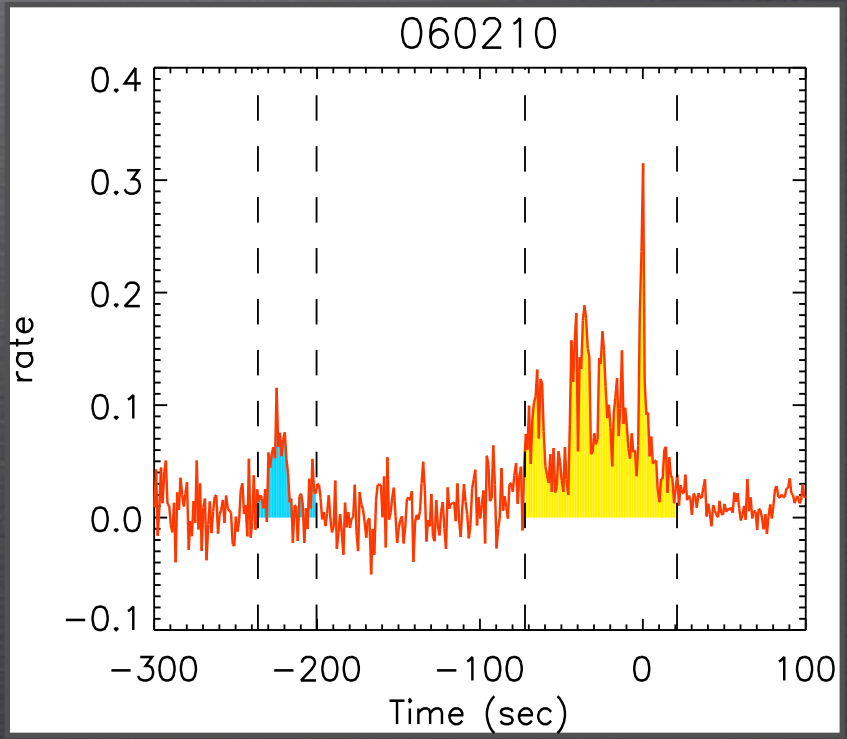
GRB IN THE MULTI-MESSENGER ERA, June 15-19, 2014, Paris

Why?? Precursors in GRBs

Emission episodes prior to the main prompt emission in **~15% of Long GRBs**:

- quiescent time ~ T_{90}

Koshut et al. 1995
Lazzati 2005
Ramirez-Ruiz & Merloni 01
Burlon et al. 2008, 2009
Troja et al., 2010



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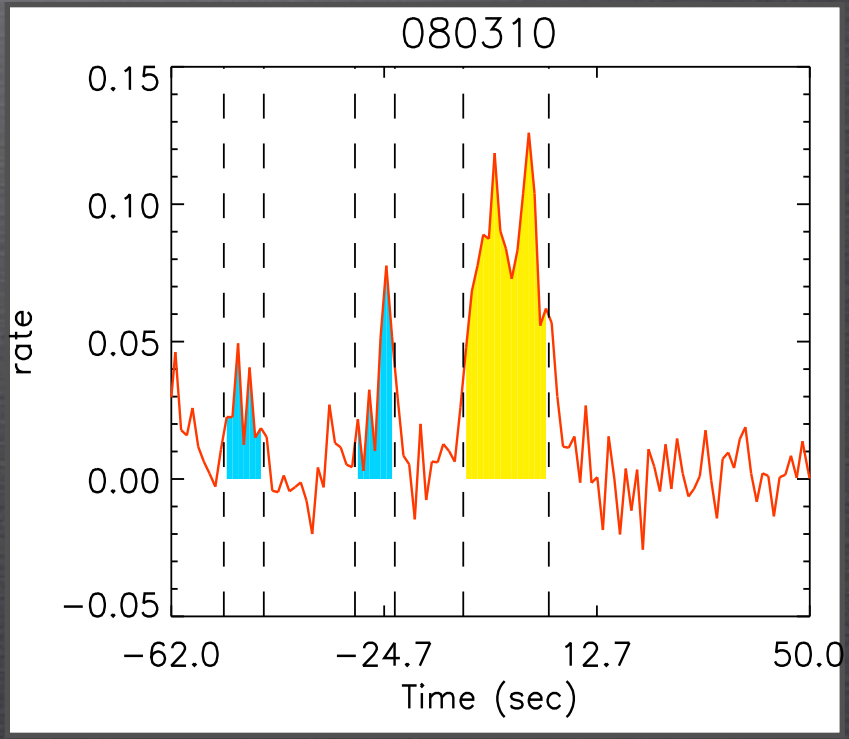

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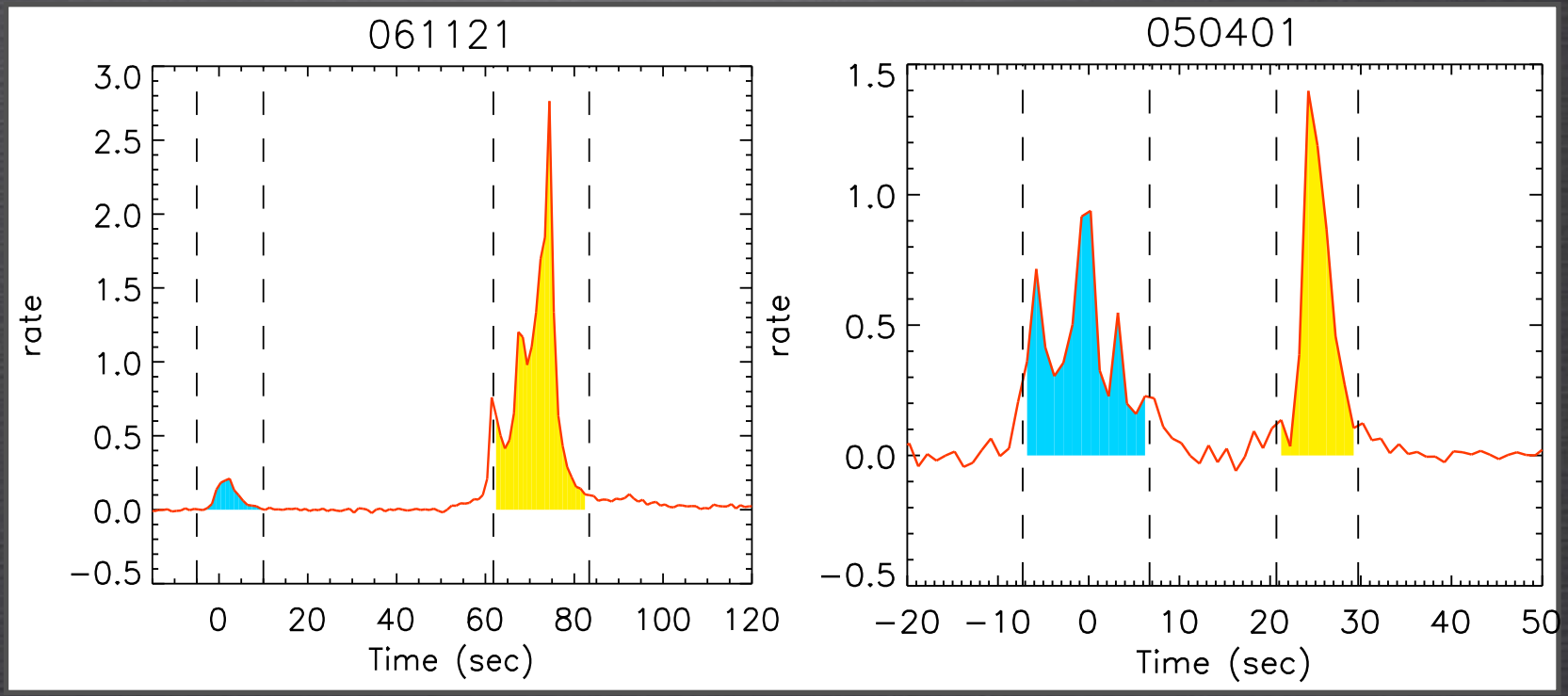

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Several proposals developed:

- **Two steps collapse** ➡ single precursor

Wang & Meszaros 2007
Lipunova et al. 2009

- **Shock breakout through the stellar envelope** ➡ single precursor ➡ thermal spectrum for the precursor

Ramirez-Ruiz et al. 2002
Wang & Meszaros 2007

- **Photospheric emission** ➡ single precursor ➡ thermal spectrum for the precursor

Meszaros & Rees 2000
Ruffini et al. 2001
Daigne & Mochkovitch 2002
Li 2007

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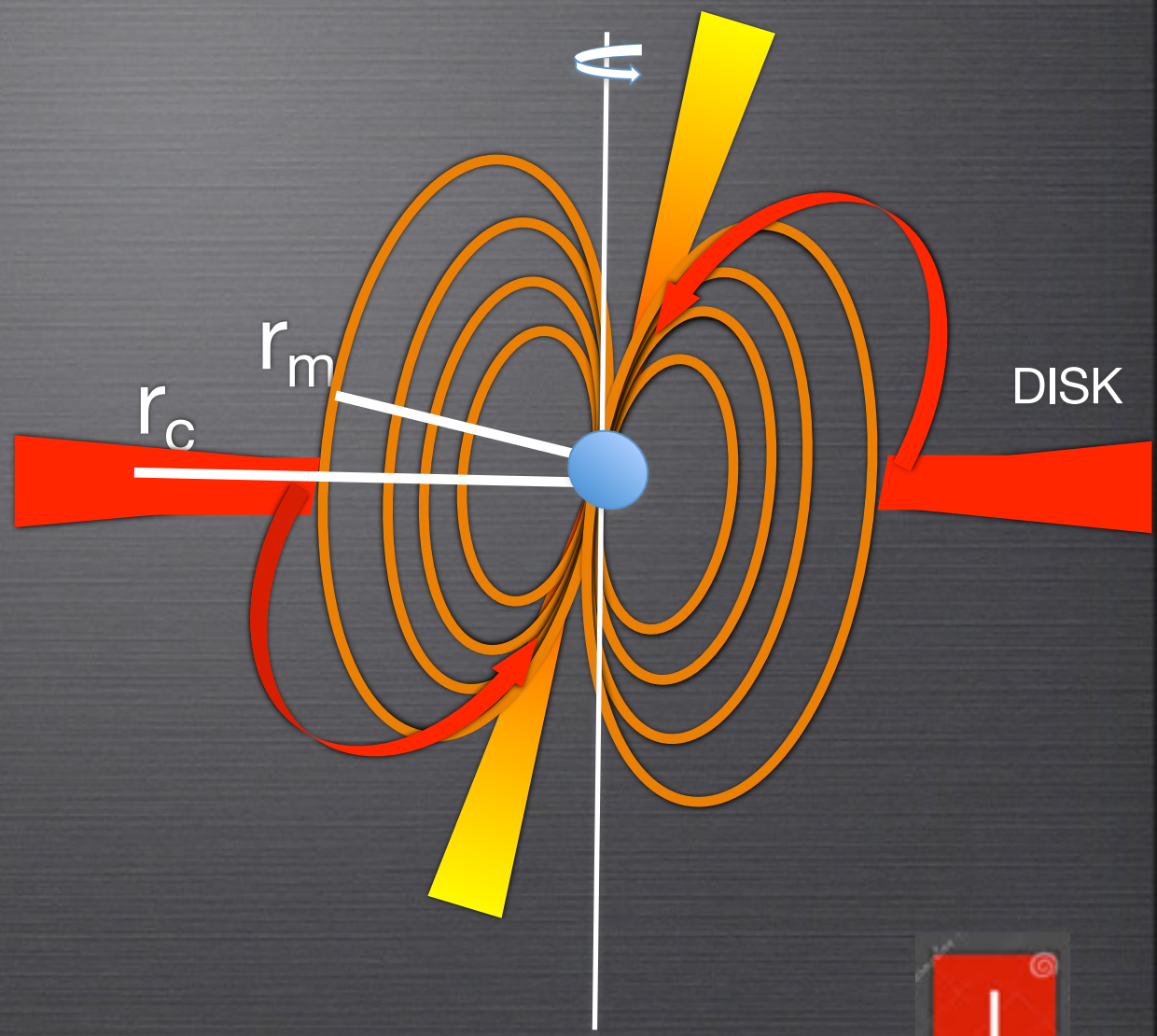
So, how to switch on and off a GRB?
With a **millisecond Magnetar**
powered by **Accretion**

Usov 1992
Duncan & Thompson 1992
Dai & Lu 1998
Zhang & Meszaros 2001
Metzger et al. 2011

How?? Accretion-powered Magnetar

⇒ Accretion phase

$r_m < r_c$



How?? Accretion-powered Magnetar

Accretion phase

⇒ Propeller phase

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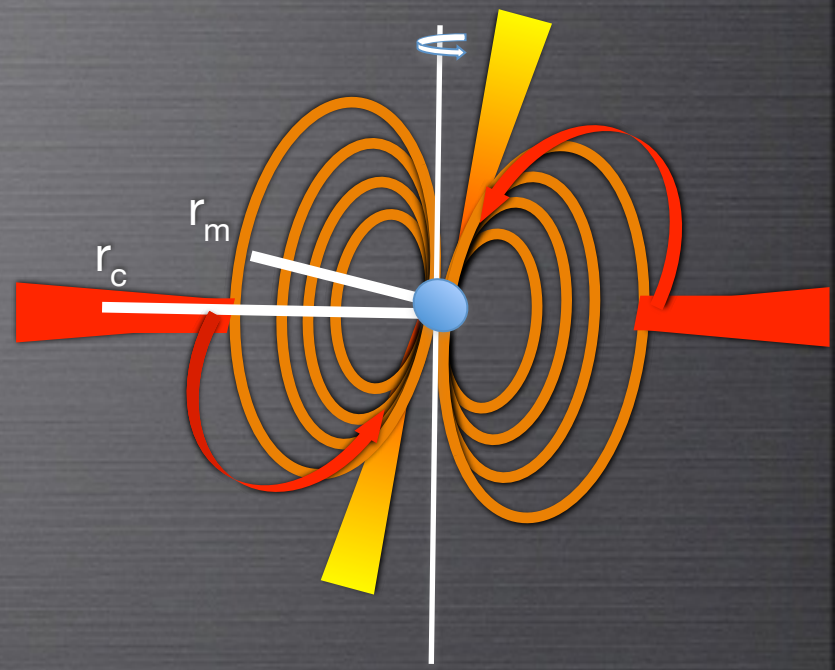
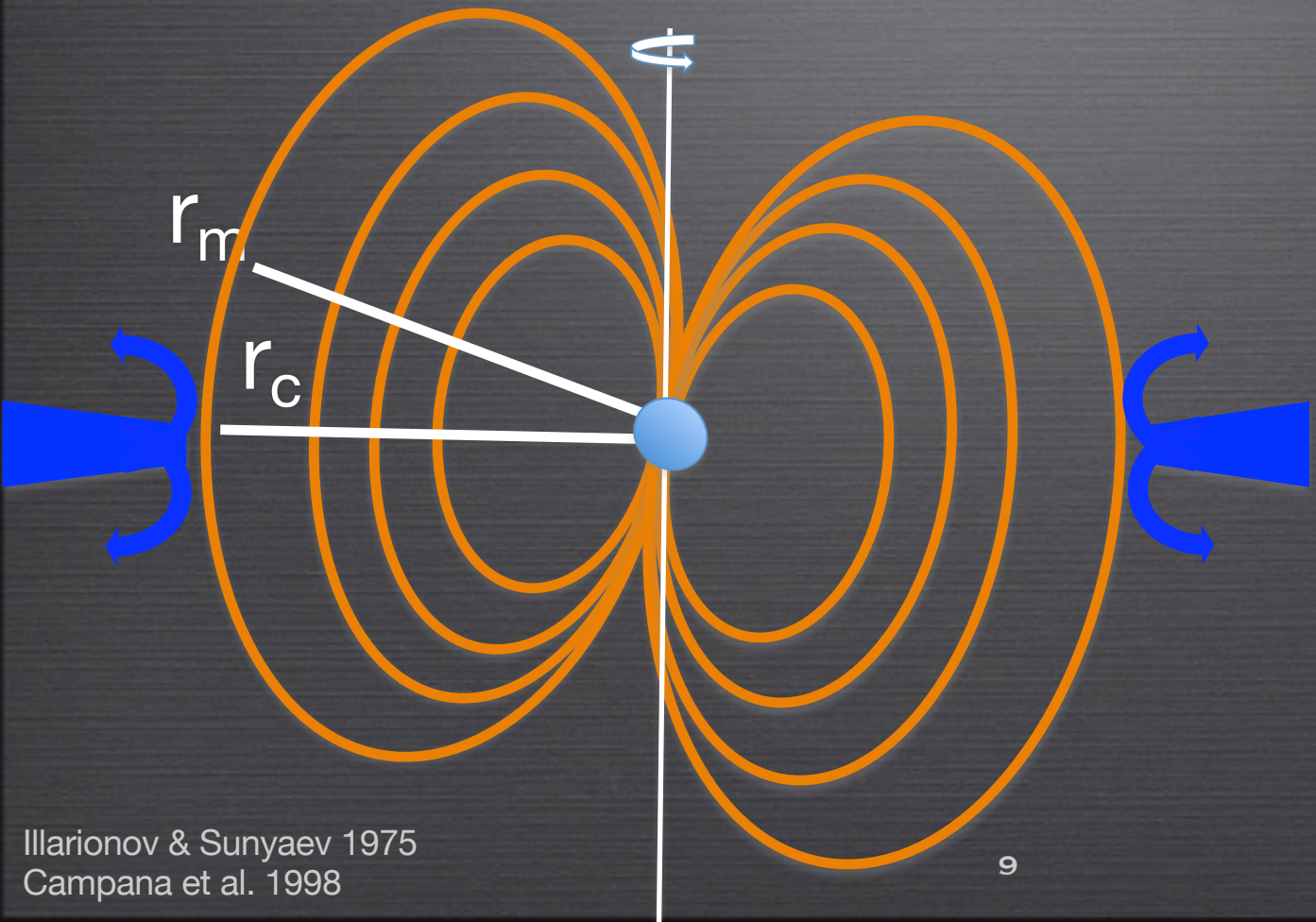
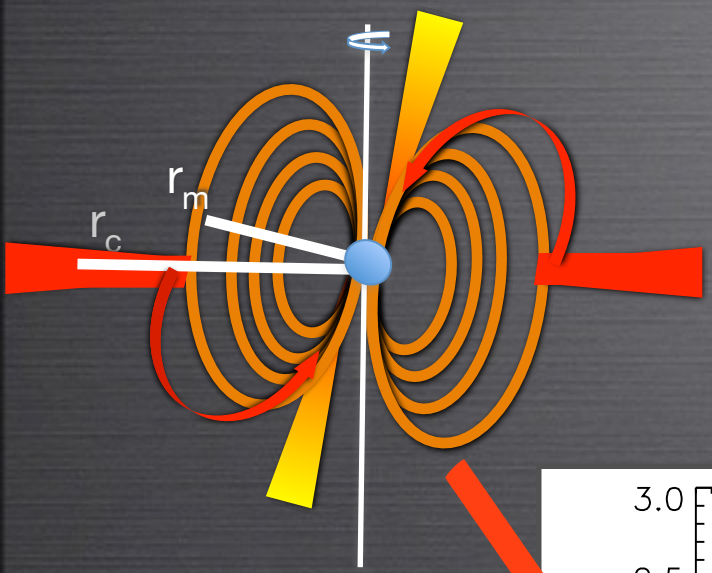
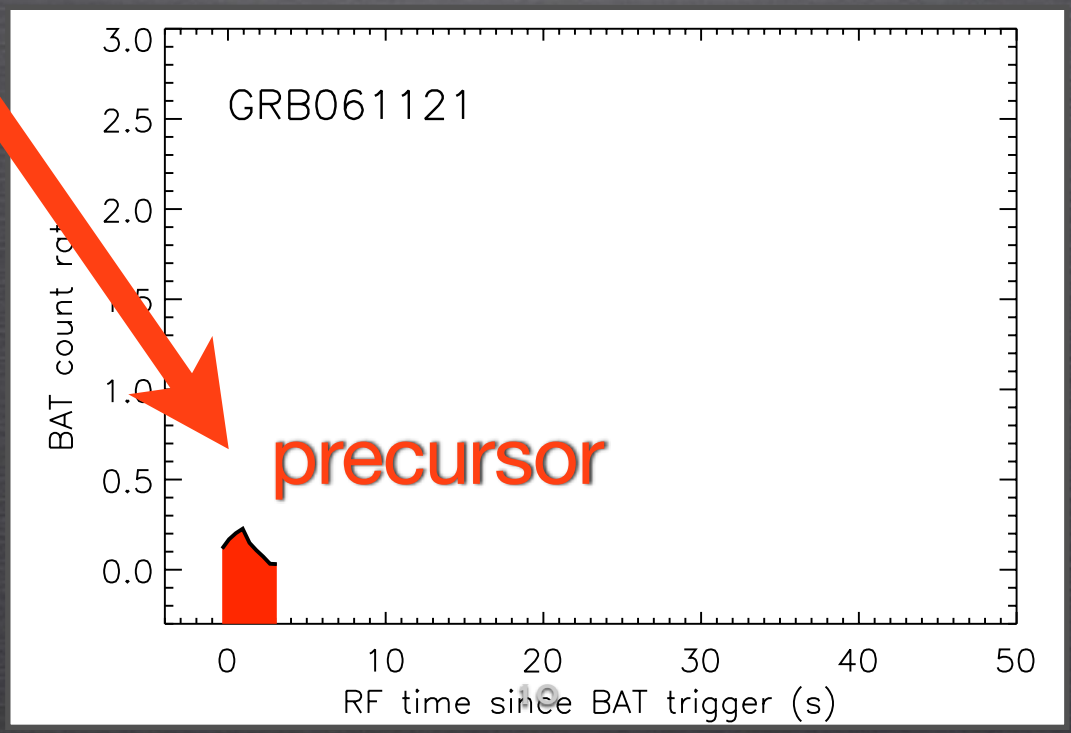




Illarionov & Sunyaev 1975
Campana et al. 1998

Quiescent times?? A propeller phase





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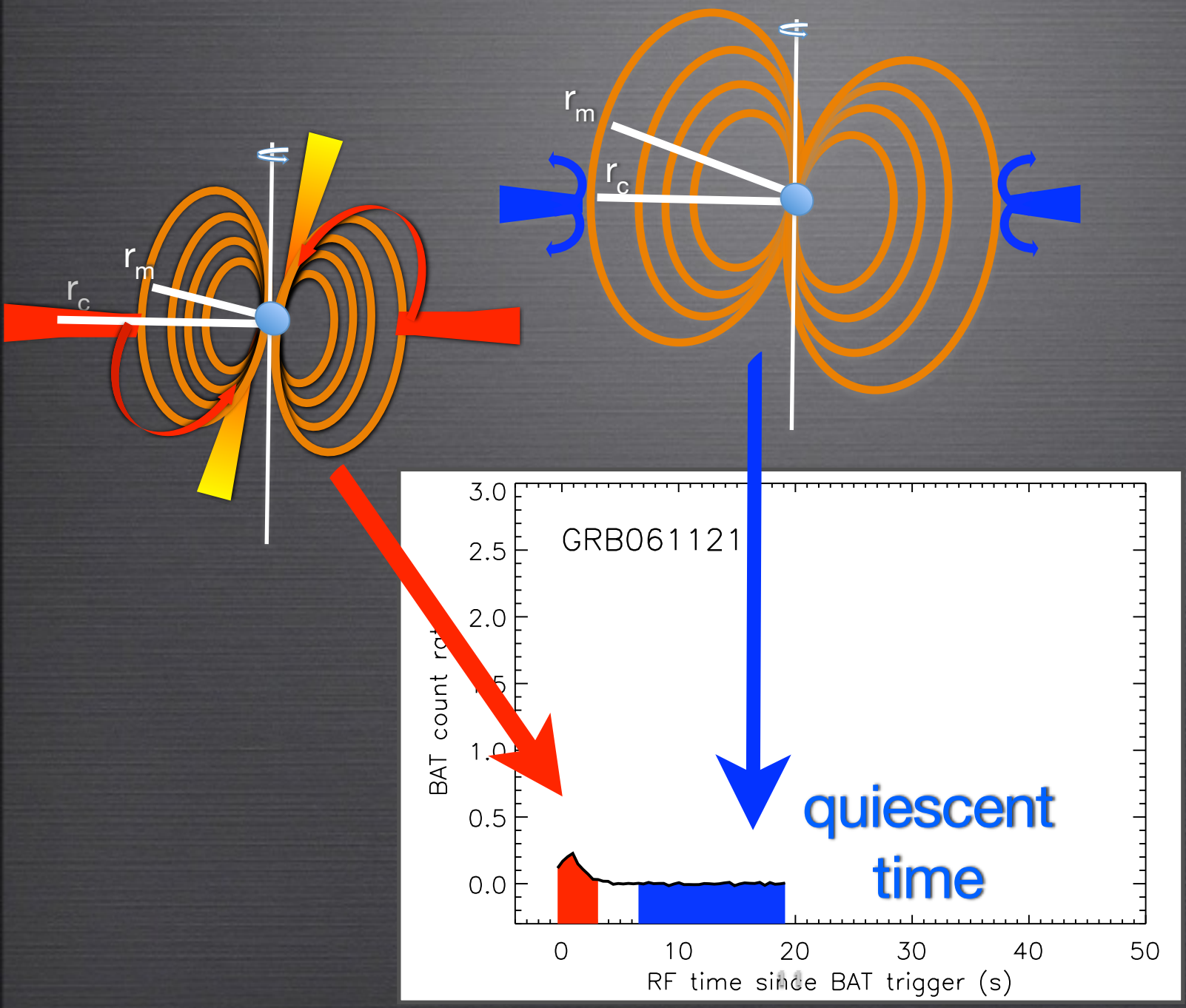

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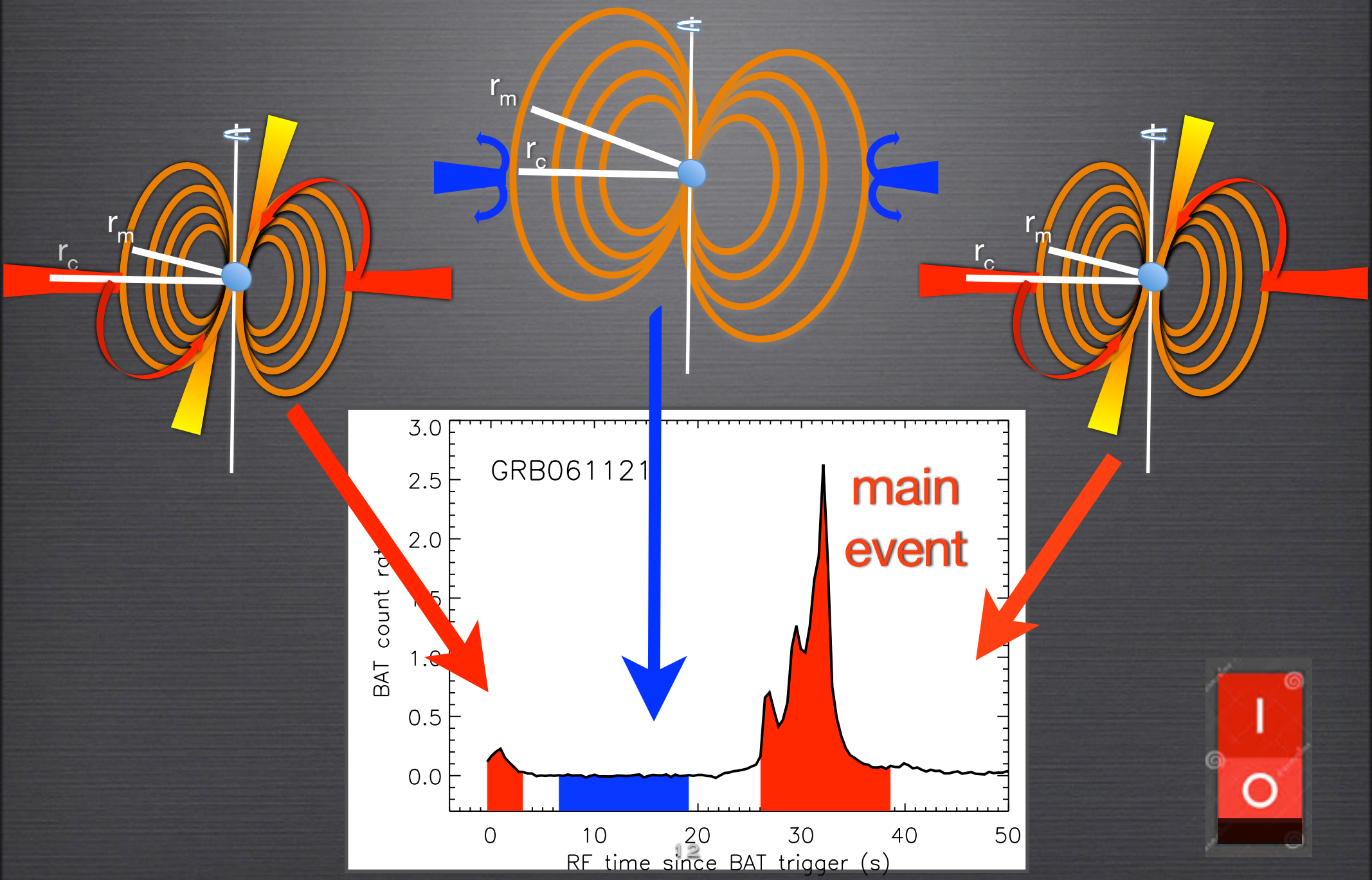
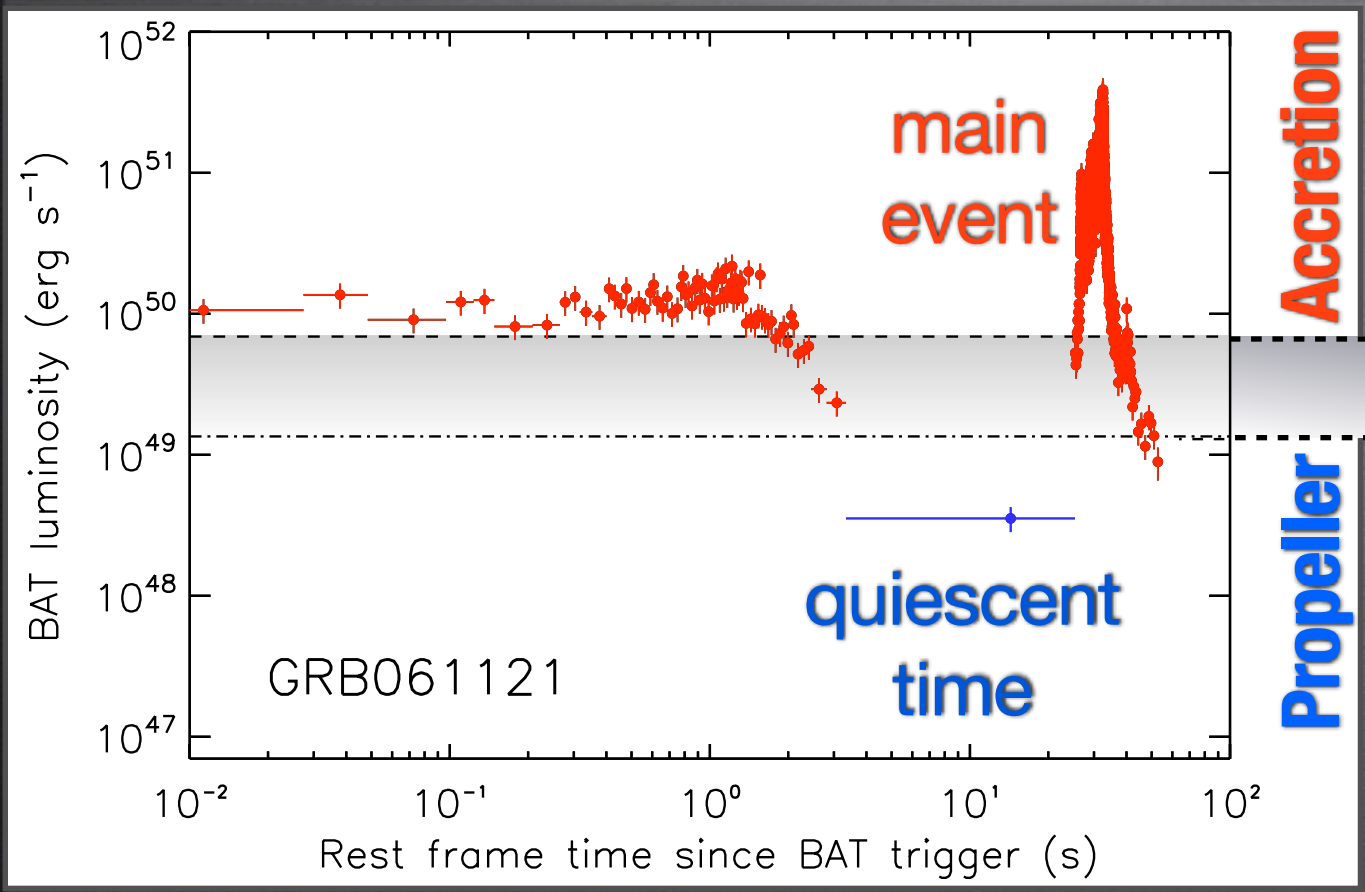
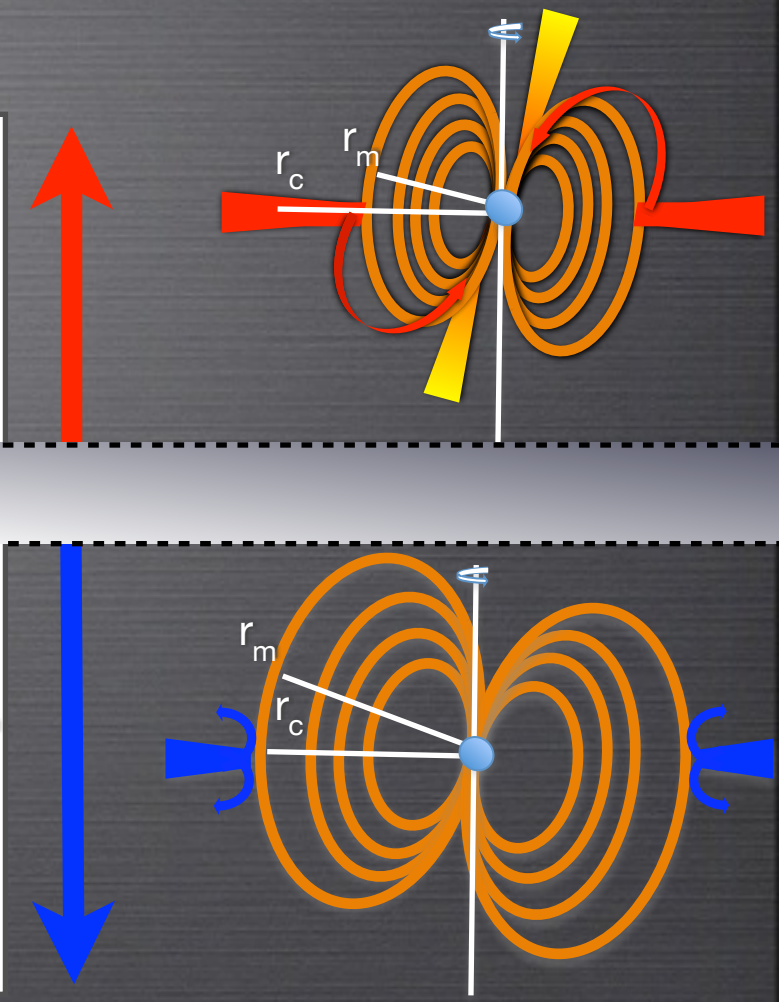


The Prompt Emission Luminosity

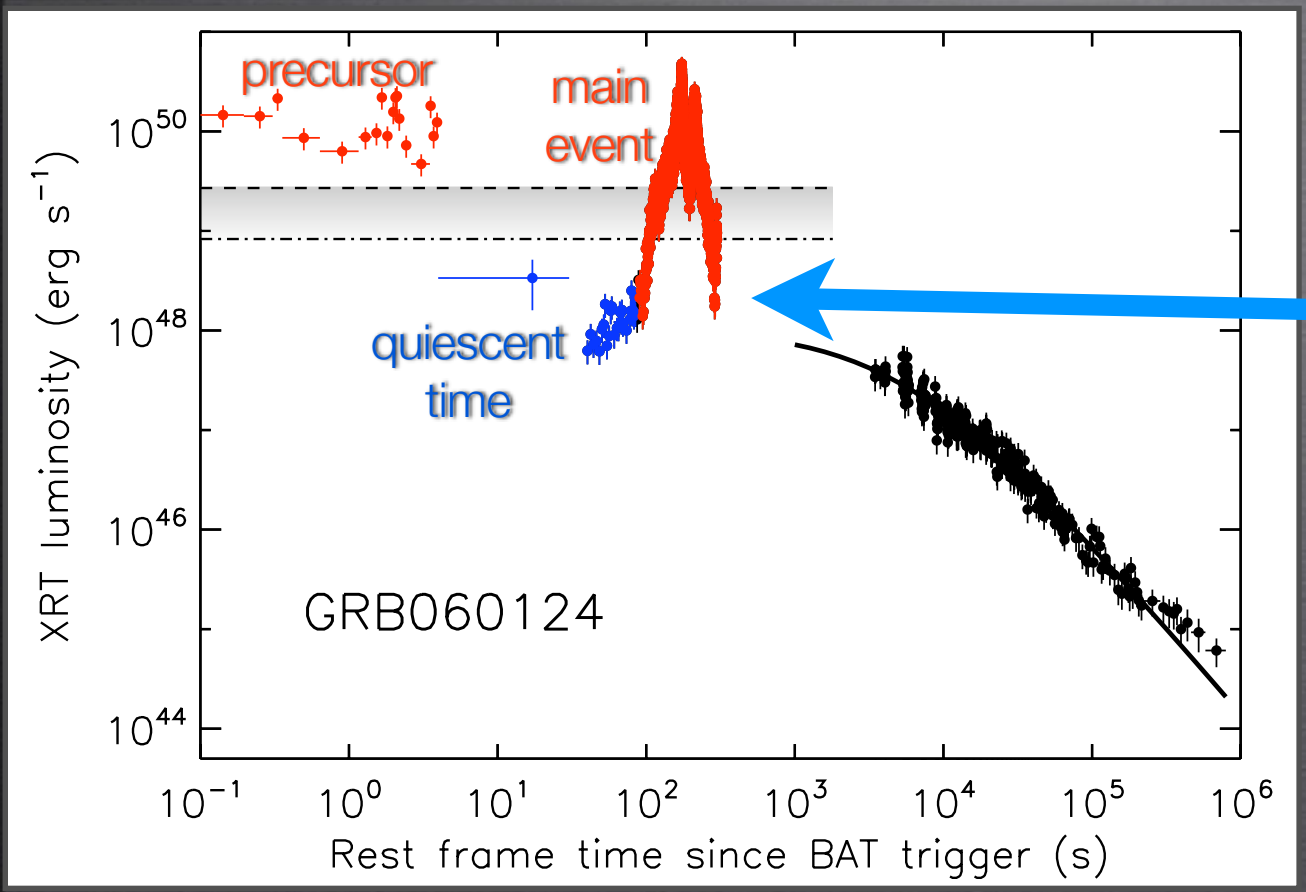


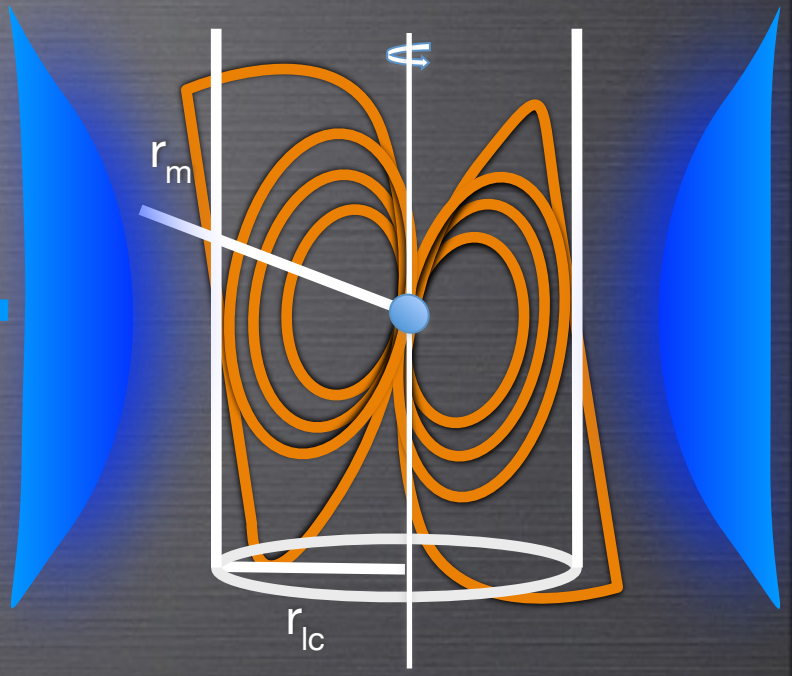


$$L_{\rm min} = 4 \times 10^{50} B_{15}^2 \, P_{-3}^{-7/3} \, {\rm erg\,s^{-1}}$$

$$L(r_{\rm m}) = 2 \times 10^{50} B_{15}^2 \, P_{-3}^{-3} \, {\rm erg\,s^{-1}}$$

The end of the Prompt Emission





Ejector phase

$r_m > r_{lc}$

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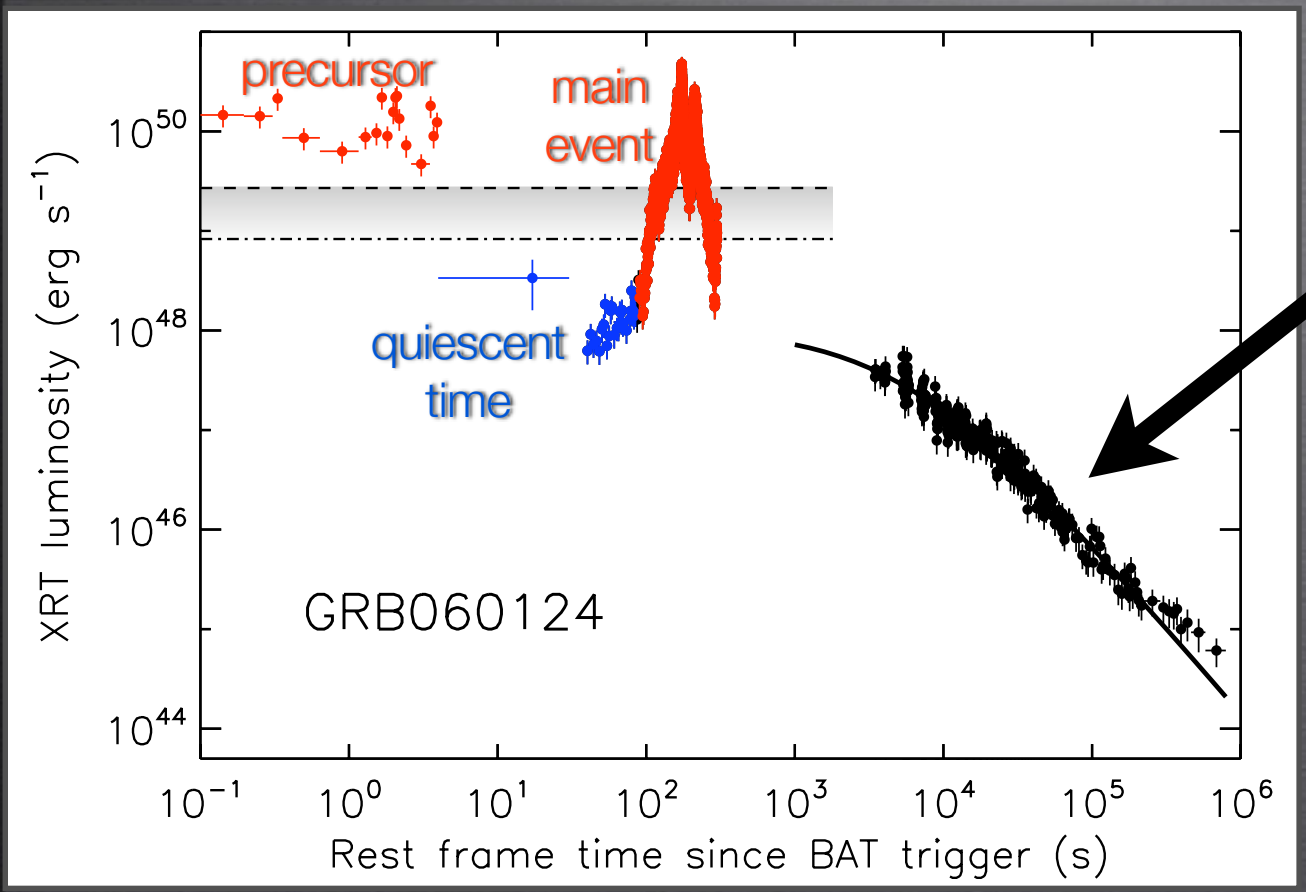

The magnetar can still influence the GRB emission with its **spin-down power** that is directly related to B and P

Dai & Lu 1998
Zhang & Meszaros 2001
Corsi & Meszaros 2009
Lyons et al. 2010
Dall'Osso et al. 2011
Metzger et al. 2011
Rowlinson et al. 2013

Precursors in the BAT6 sample

The Astrophysical Journal, 749:68 (7pp), 2012 April 10 doi:10.1088/0004-637X/749/1/68

A COMPLETE SAMPLE OF BRIGHT *SWIFT* LONG GAMMA-RAY BURSTS. I. SAMPLE PRESENTATION, LUMINOSITY FUNCTION AND EVOLUTION

R. Salvaterra[1], S. Campana[2], S. D. Vergani[2,3], S. Covino[2], P. D'Avanzo[2], D. Fugazza[2], G. Ghirlanda[2], G. Ghisellini[2], A. Melandri[2], L. Nava[4], B. Sbarufatti[2], H. Flores[3], S. Piranomonte[5], and G. Tagliaferri[2]
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[2] INAF, Osservatorio Astronomico di Brera, via E. Bianchi 46, I-23807 Merate (LC), Italy
[3] Laboratoire GEPI, Observatoire de Paris, CNRS-UMR8111, Univ. Paris-Diderot 5 place Jules Janssen, 92195 Meudon, France
[4] SISSA, via Bonomea 265, I-34136 Trieste, Italy
[5] INAF, Osservatorio Astronomico di Roma, via Frascati 33, 00040 Monte Porzio Catone, Rome, Italy
Received 2011 December 5; accepted 2012 February 3; published 2012 March 23

- bright long GRBs observed by BAT
- almost complete in redshift

ideal to search for precursors!!!!

Precursors in the BAT6 sample

17% of GRBs with precursors in the BAT6 (3% multiple)

Precursors vs. Main Event:

- **non-thermal spectrum**, with similar spectral indices
- precursor comprises a **substantial amount of energy** (~20%)
- moderate correlation bw peak luminosity (energy) of precursor and main event
- correlation bw quiescent time and duration of the **following** emission episode <- **accumulation mechanism into play!**

Koshut et al. 1995
Lazzati 2005
Ramirez-Ruiz & Merloni 01
Burlon et al. 2008, 2009

B and P from the late X-ray Emission

ENERGY INJECTION FROM SPINNING-DOWN NEWLY BORN NS INTO THE FORWARD SHOCK

$$E(t) = \frac{L_i}{t^{k'}} \int_{t_\circ}^{t} \frac{t^k}{(1+at)^2} + E_\circ \left(\frac{t_\circ}{t}\right)^{k'}$$

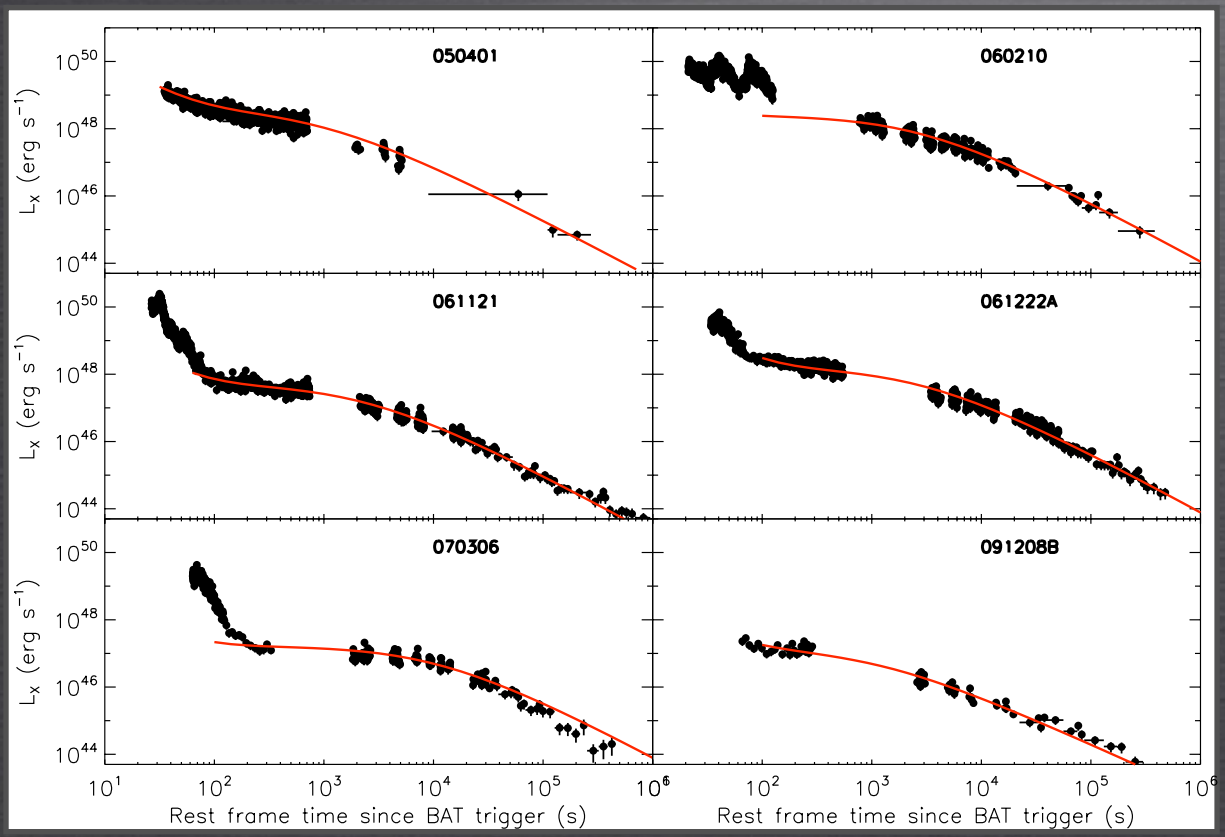
Dall'Osso et al. 2011

⇦

$a \sim B^2/P^2$

$L_i \sim B^2/P^4$

⇩



Name	z	B^p (10^{15} G)	P^p (ms)
050318[a]	1.44	4.00	3.06
050401	2.90	5.67 ± 0.27	2.61 ± 0.04
060210	3.91	2.34 ± 0.07	1.83 ± 0.02
061007[a]	1.26	4.00	3.06
061121	1.31	6.03 ± 0.12	4.40 ± 0.03
061222A	2.09	2.79 ± 0.04	2.25 ± 0.01
070306	1.50	2.33 ± 0.10	3.60 ± 0.05
091208B	1.06	18.6 ± 1.1	9.70 ± 0.21

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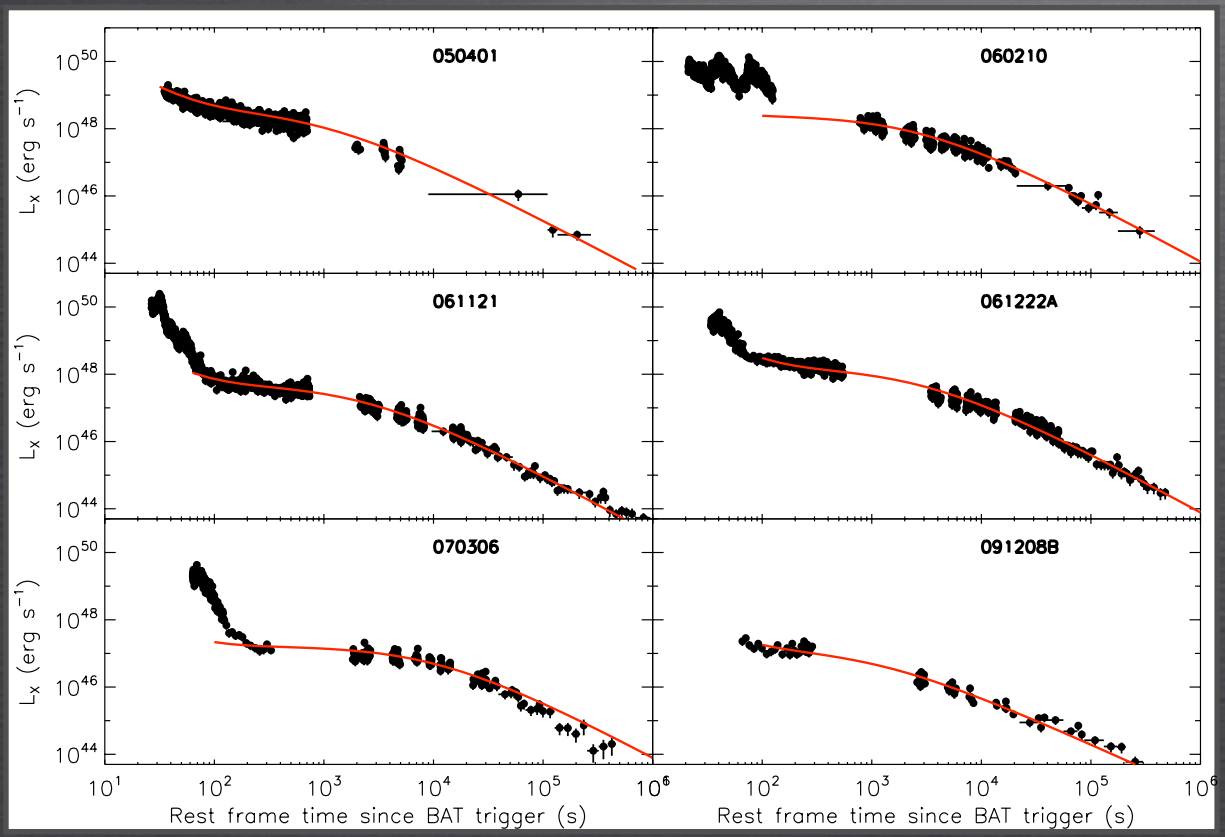

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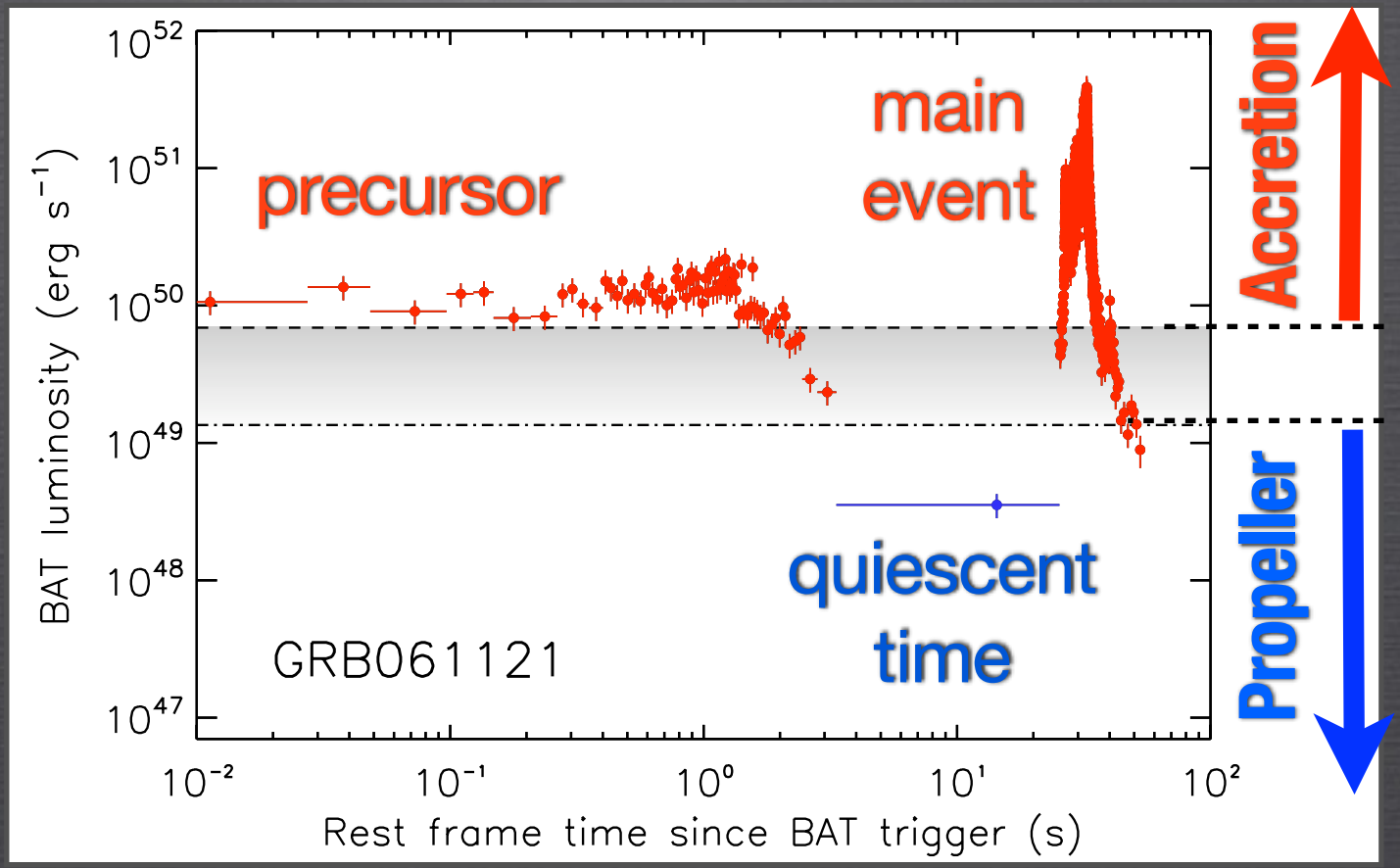
$\langle B \rangle = 4 \times 10^{15}$ G

$\langle P \rangle = 3.06$ ms

Predictions about the Prompt Emission Luminosity



peak luminosities of both precursor and main event are **above L_{min}**

Predictions about the Prompt Emission Luminosity

Summary of the prompt emission properties of GRBs with precursors in the BAT6 sample as observed by BAT (15 – 150 keV).

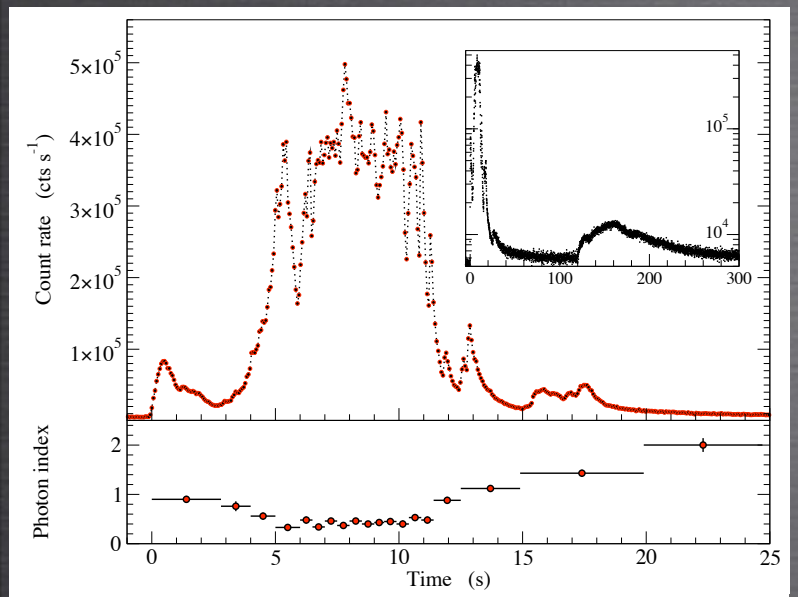
Name	z	$F^{\rm p}$	$f^{\rm p}$	$T_{90}^{\rm p}$	$t_{\rm pk}^{\rm p}$	$\Gamma^{\rm p}$	$F^{\rm me}$	$f^{\rm me}$	$T_{90}^{\rm me}$	$t_{\rm pk}^{\rm me}$	$\Gamma^{\rm me}$	$f_{\rm min}$
050318	1.44	2.5	12.6 ± 1.5	6.65	0.82	2.11 ± 0.24	10.7	22.9 ± 1.6	$-^{a}$	29.13	1.90 ± 0.0	15.9
050401	2.90	74.1	62.0 ± 18.0	9.14	0.49	1.51 ± 0.09	37.8	99.9 ± 7.8	8.00	24.00	1.38 ± 0.0	6.6
060210	3.91	4.6	7.7 ± 2.8	9.65	-224.00	1.55 ± 0.26	63.9	23.4 ± 2.2	167.16	0.44	1.46 ± 0.0	1.6
060904A-1	–	12.9	5.9 ± 1.1	35.90	5.08	1.46 ± 0.08	57.4	43.6 ± 2.0	37.90	55.80	1.52 ± 0.0	–
060904A-2	–	7.9	7.9 ± 1.1	18.50	30.60	1.64 ± 0.08	–	–	–	–	–	–
061007	1.26	58.7	56.2 ± 5.2	12.79	6.82	1.12 ± 0.05	380.7	154.9 ± 3.6	54.40	45.19	1.04 ± 0.0	5.8
061121	1.31	6.6	12.5 ± 1.3	7.83	2.04	1.63 ± 0.08	133.1	199.5 ± 3.7	29.45	74.48	1.31 ± 0.0	5.9
061222A-1	2.09	2.8	6.1 ± 1.4	14.3	1.99	1.41 ± 0.14	67.1	79.4 ± 1.8	47.20	87.00	1.22 ± 0.0	1.3
061222A-2	2.09	6.8	18.6 ± 1.7	20.00	26.30	1.76 ± 0.10	–	–	–	–	–	–
070306-1	1.50	3.1	6.5 ± 2.0	7.70	-115.60	1.29 ± 0.28	38.7	29.5 ± 1.4	67.60	98.27	1.64 ± 0.0	3.3
070306-2	1.50	10.2	6.9 ± 2.0	26.00	2.03	1.54 ± 0.20	–	–	–	–	–	–
080602	$\sim 1.4^{c}$	15.2	19.1 ± 3.6	17.66	0.73	1.34 ± 0.14	13.1	28.2 ± 2.0	9.96	60.10	1.06 ± 0.0	–
091208B	1.06	7.9	37.1 ± 6.0	3.95	0.48	1.97 ± 0.20	22.9	104.7 ± 7.2	5.78	8.79	1.75 ± 0.1	40.2

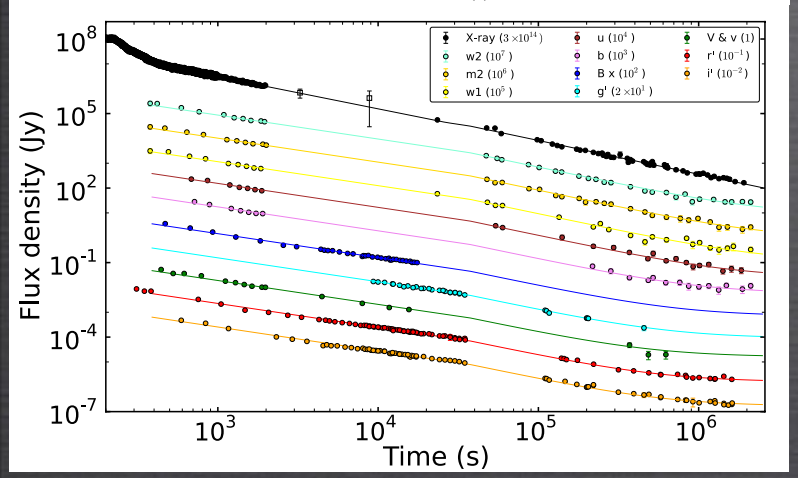
- peak luminosities of both precursor and main event are **above L_{min}**
- simple FRED precursors when **$L^{P}_{pk} \sim L_{min}$**
- complex multi-peaked structure when **$L^{P}_{pk} > L_{min}$**

Conclusions

- Precursor properties (17% of GRBs) explained if central engine is an **accretion-powered Magnetar:**
  - ➡ emission <-> accretion power
  - ➡ quiescence <-> propeller phase
- Late X-ray emission powered by the **spin-down of the Magnetar:**
  - ➡ direct and independent estimate of B and P
  - ➡ prompt luminosity above L_{min}
- Potentially **larger fraction** of GRBs originates from accretion-powered Magnetars

GRB 130427A: the "ordinary monster"





GRB 130427A at a glance:

- super-bright (detected by several high-energy satellites)
- well monitored afterglow (GeV, X-rays, OT, radio)
- nearby (z=0.34)
- associated with Type Ic SN
  - ➡ first powerful GRB associated to SN
  - ➡ benchmark to test standard models

Maselli et al. 2013
Fermi LAT & GBM collaborations 2013
Golenetskiiet al. 2013
Verstrand et al. 2013
Levan et al. 2013
Xu et al. 2013
Melandri et al. 2014

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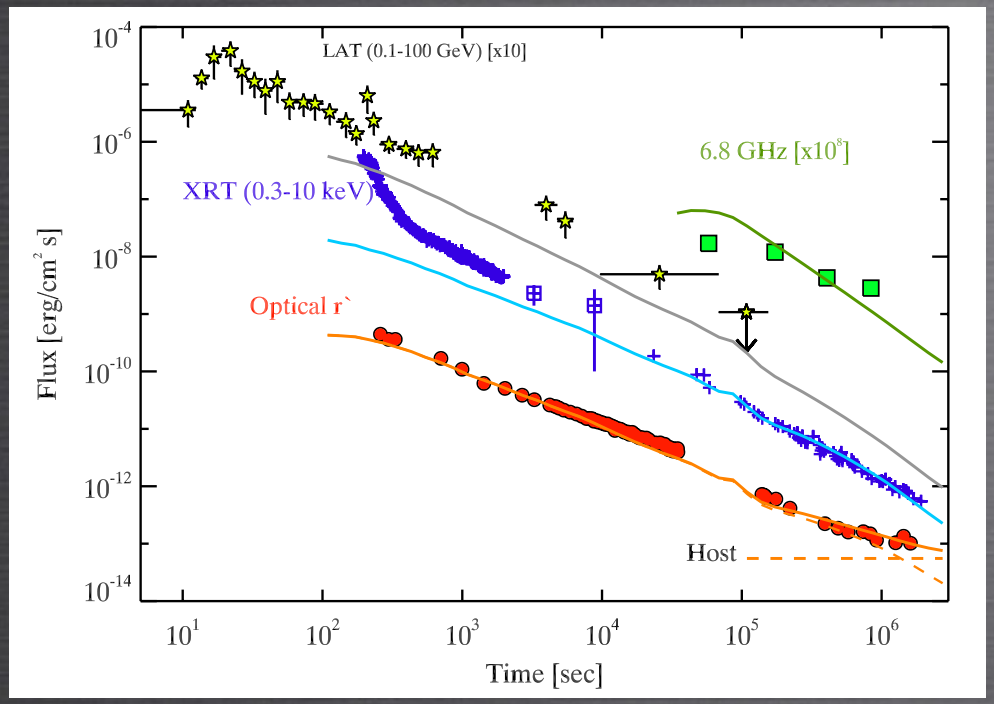

Afterglow after 26 ks is **forward shock** emission in **homogeneous** medium with a **jet break**

Maselli et al. 2013

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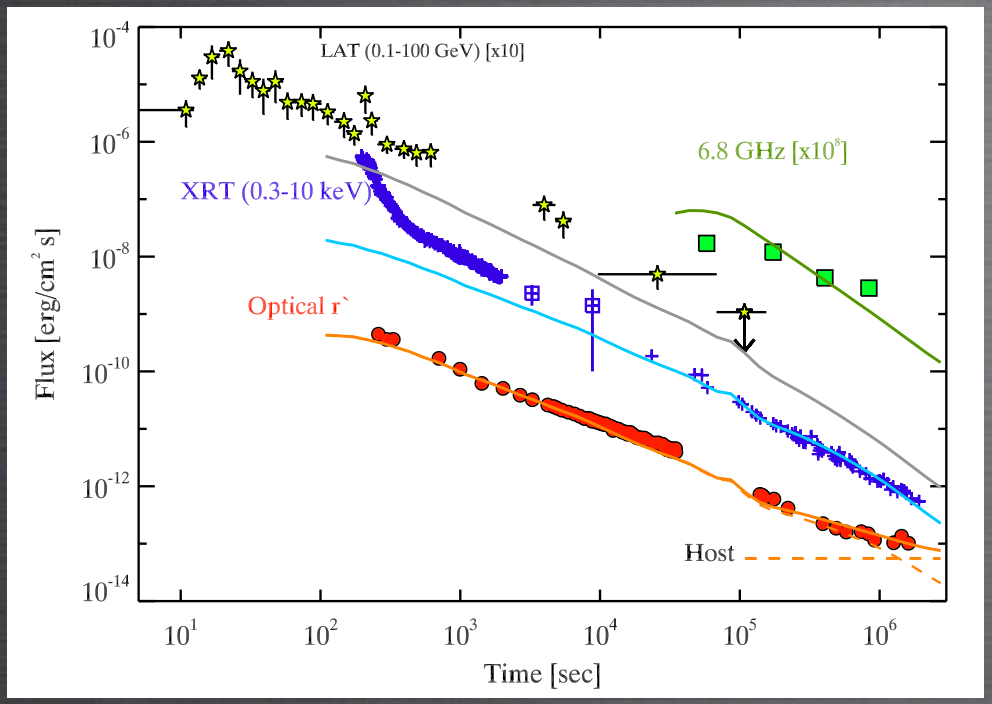
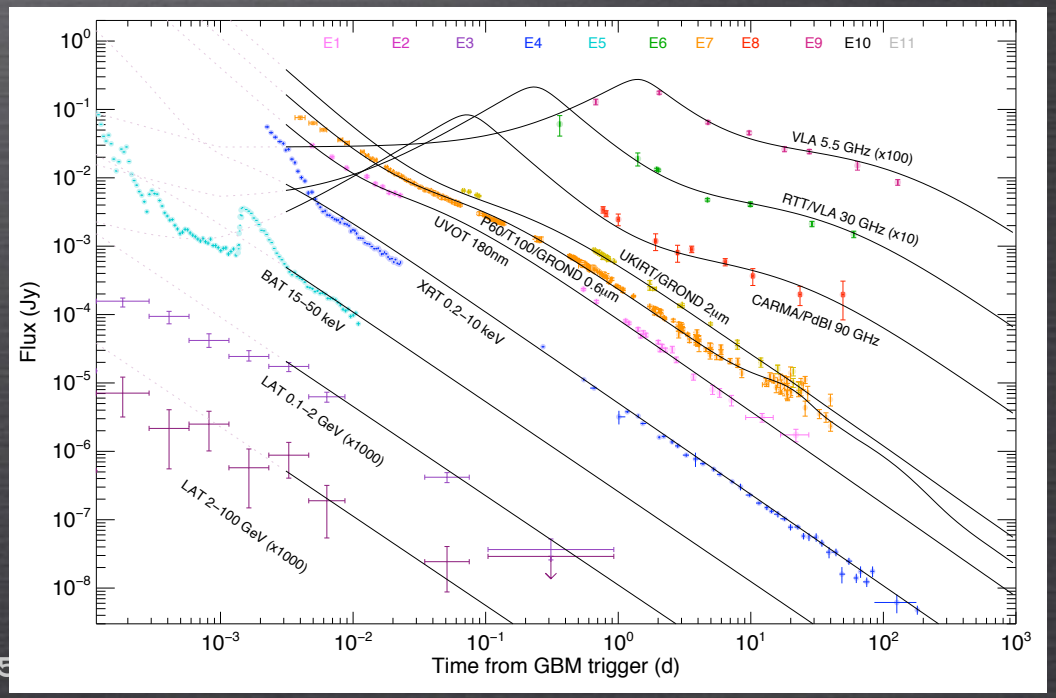


Afterglow after 26 ks is **forward shock** emission in **homogeneous** medium with a **jet break**

Maselli et al. 2013

Afterglow is **forward + reverse shock** emission in **wind-like** medium



Laskar et al. 2013
Perley et al. 2013
Verstrand et al. 2013
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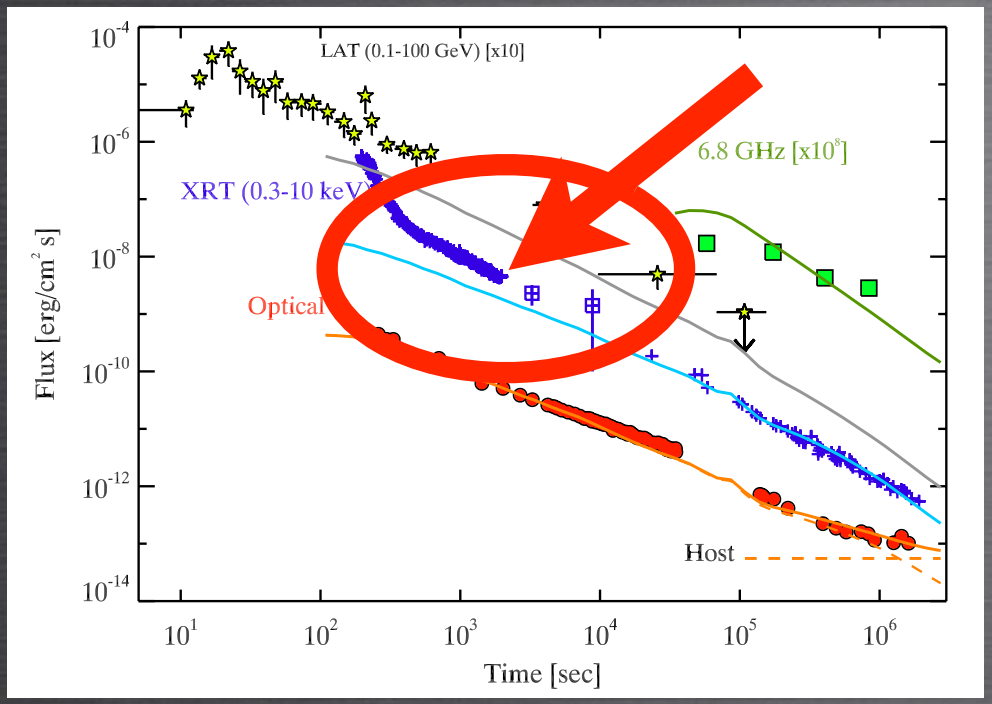

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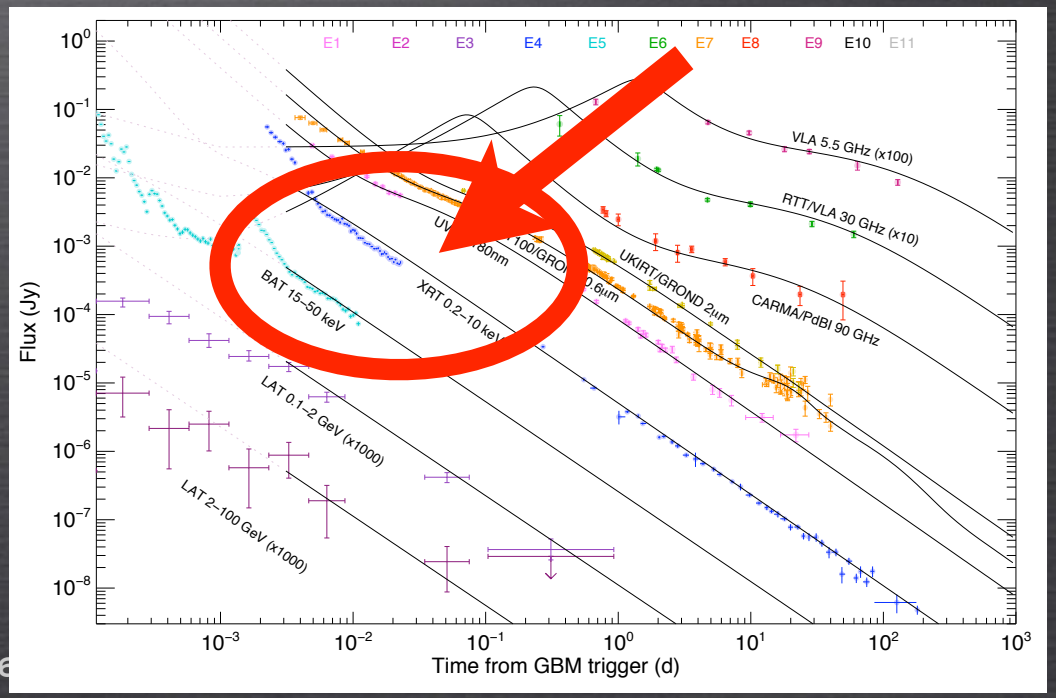

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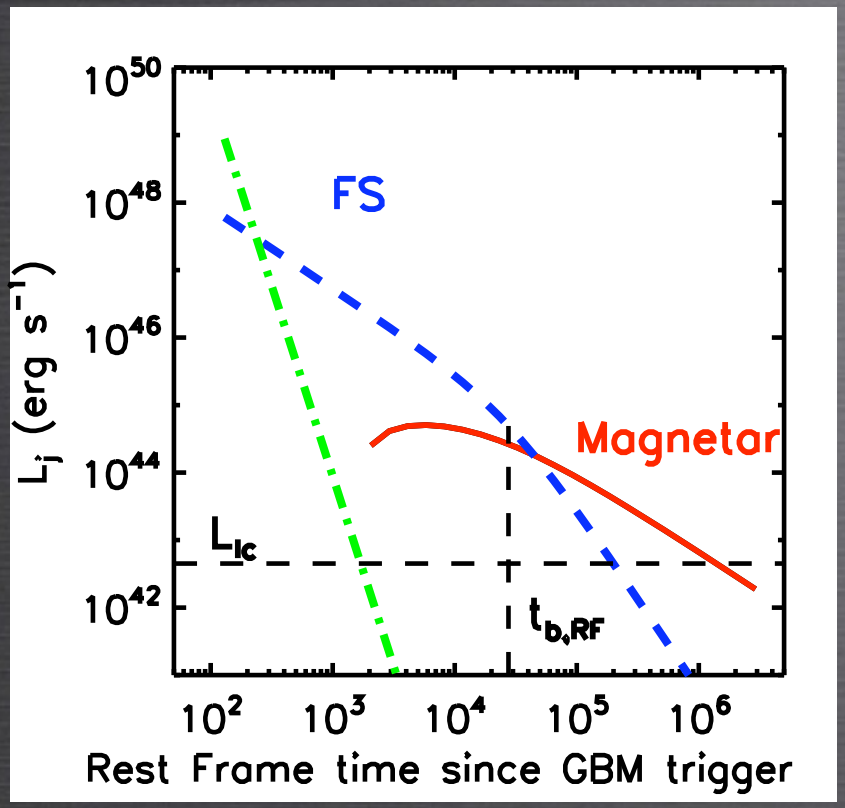

Recipe for X-ray emission:

- forward shock emission + jet break
- steep decay (prompt emission)
- **wind of the magnetar**

Bernardini et al. 2014

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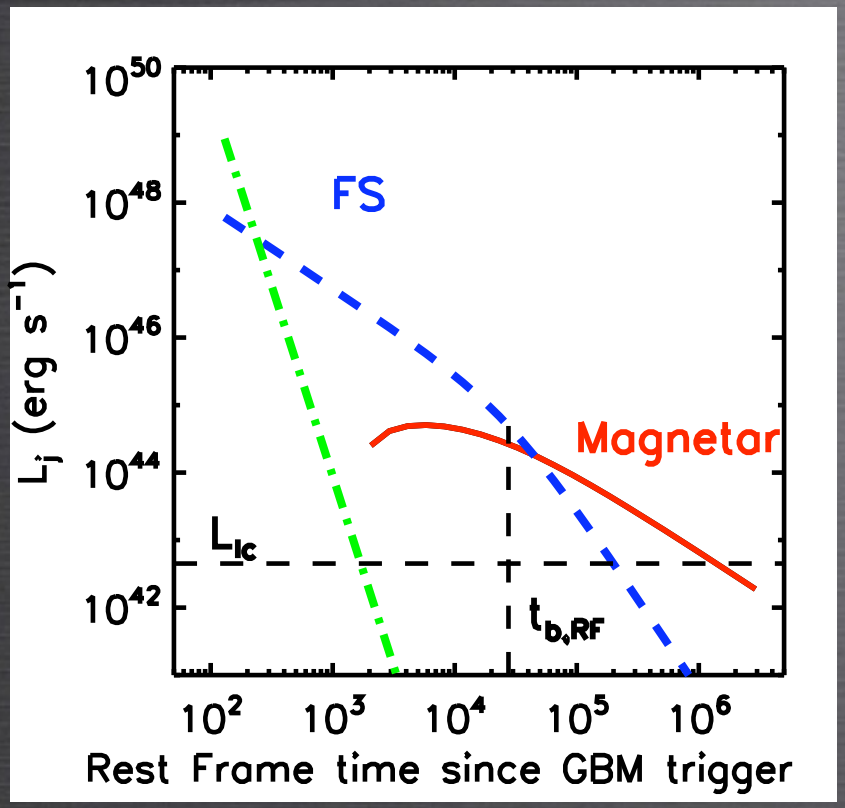

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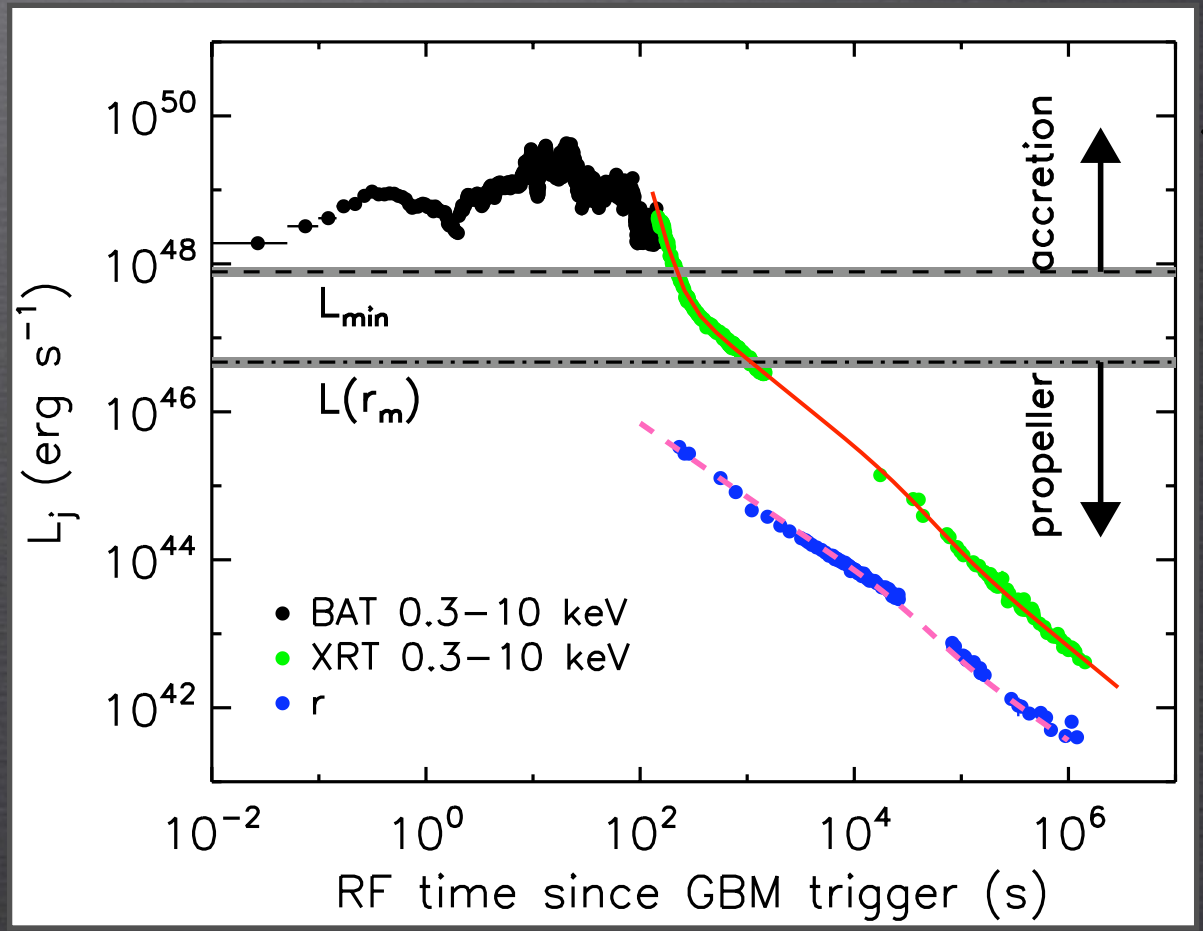

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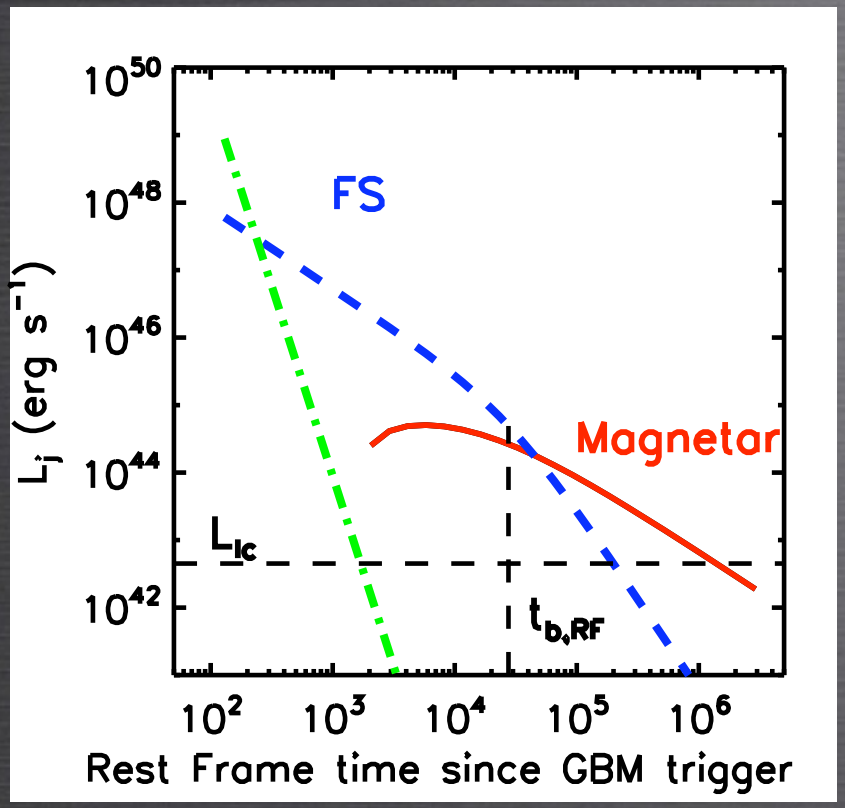

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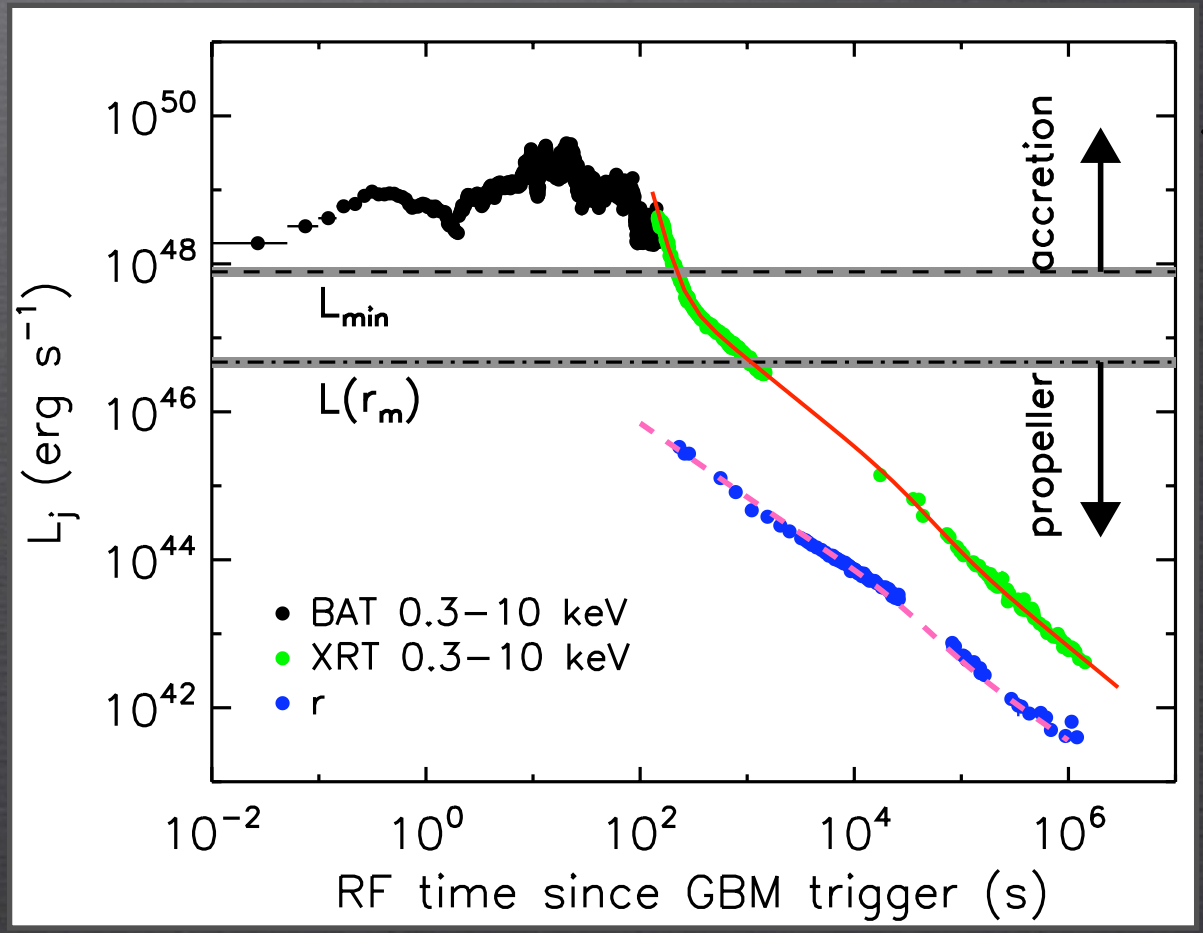


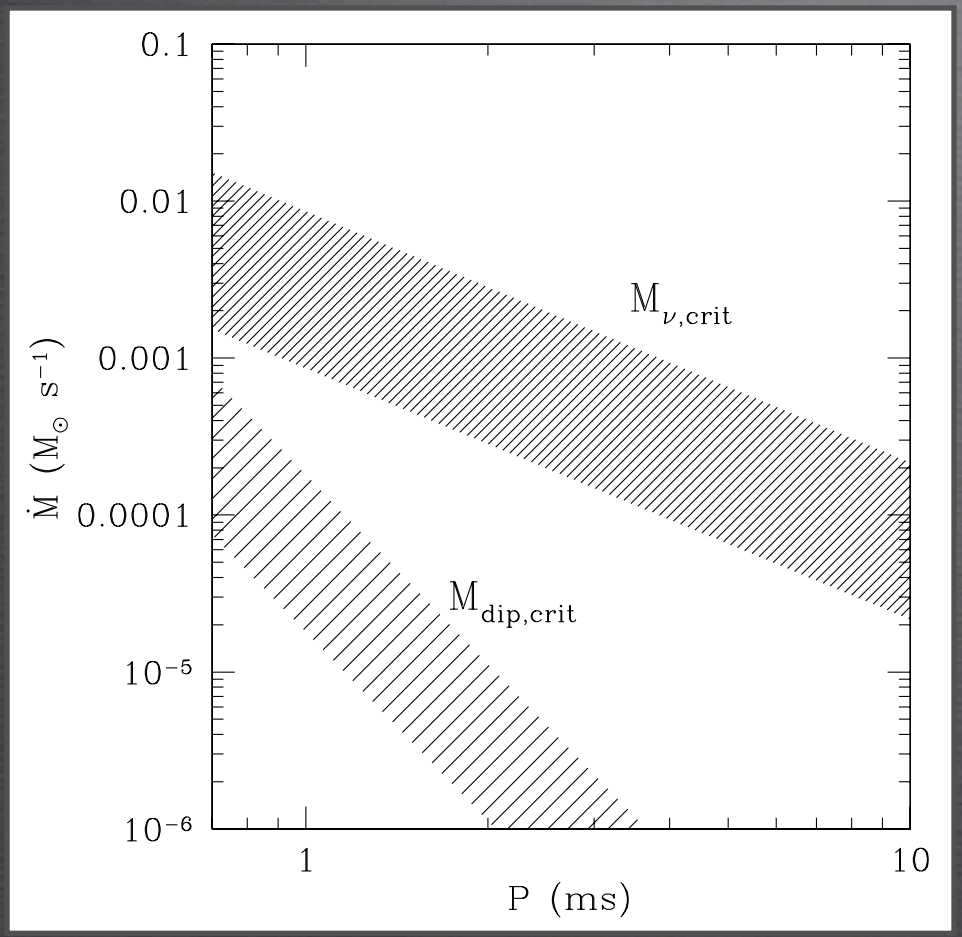
B= 10^{16} G
P= 24.2 ms

Bernardini et al. 2014

Conclusions

- Precursor properties (17% of GRBs) explained if central engine is an **accretion-powered Magnetar**
- Late X-ray emission powered by the **spin-down of the Magnetar**
- Potentially **larger fraction** of GRBs originates from accretion-powered Magnetars
- Still many open issues... However accretion-powered magnetars may be regarded as a plausible central engine for long GRBs (also for short GRBs, see Gompertz et al. 2014)

Critical accretion rate for fallback



$$p_{\rm ram} = \frac{\dot{M}}{8\pi}\left(\frac{2GM}{r^5}\right)^{1/2}$$

$$L_{\rm dip} = \frac{\mu^2\Omega^4}{6c^3}$$

$$L_\nu = \left(\frac{\mu^2\Omega^4}{\dot{M}_\nu}\right)^{2/5}\dot{M}_\nu$$

Piro & Ott 2011

Production of ultrarelativistic jet

- a heavily thermally driven outflow from the surface prevents the outflow to be accelerated to high Lorentz factor

Dessart+2009

However:

- role of strong magnetic field:

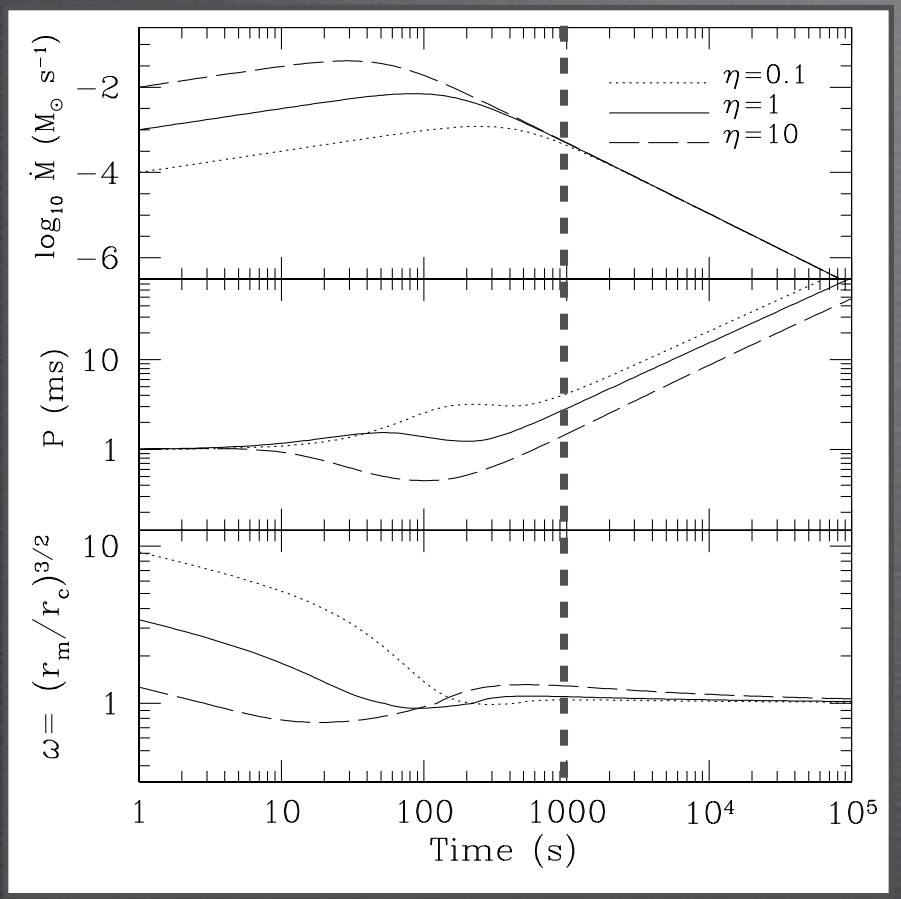
➡ mass-loss rate along the polar region is only a fraction of the total

➡ switch to magnetically driven neutrino wind

Zhang & Dai, 2010

Correct determination of mass-accretion rates and magnetic fields involved is needed to assess this issue!!!!

Spin evolution of the magnetar



$$I \frac{d\Omega}{dt} = N_{\rm dip} + N_{\rm acc}$$

$$N_{\rm dip} = -\frac{\mu^2 \Omega^3}{6c^3}$$

$$N_{\rm acc} = n(\omega)(GMr_m)^{1/2}\dot{M}$$

Piro & Ott 2011