Magnetar observations in the Swift-Fermi Era

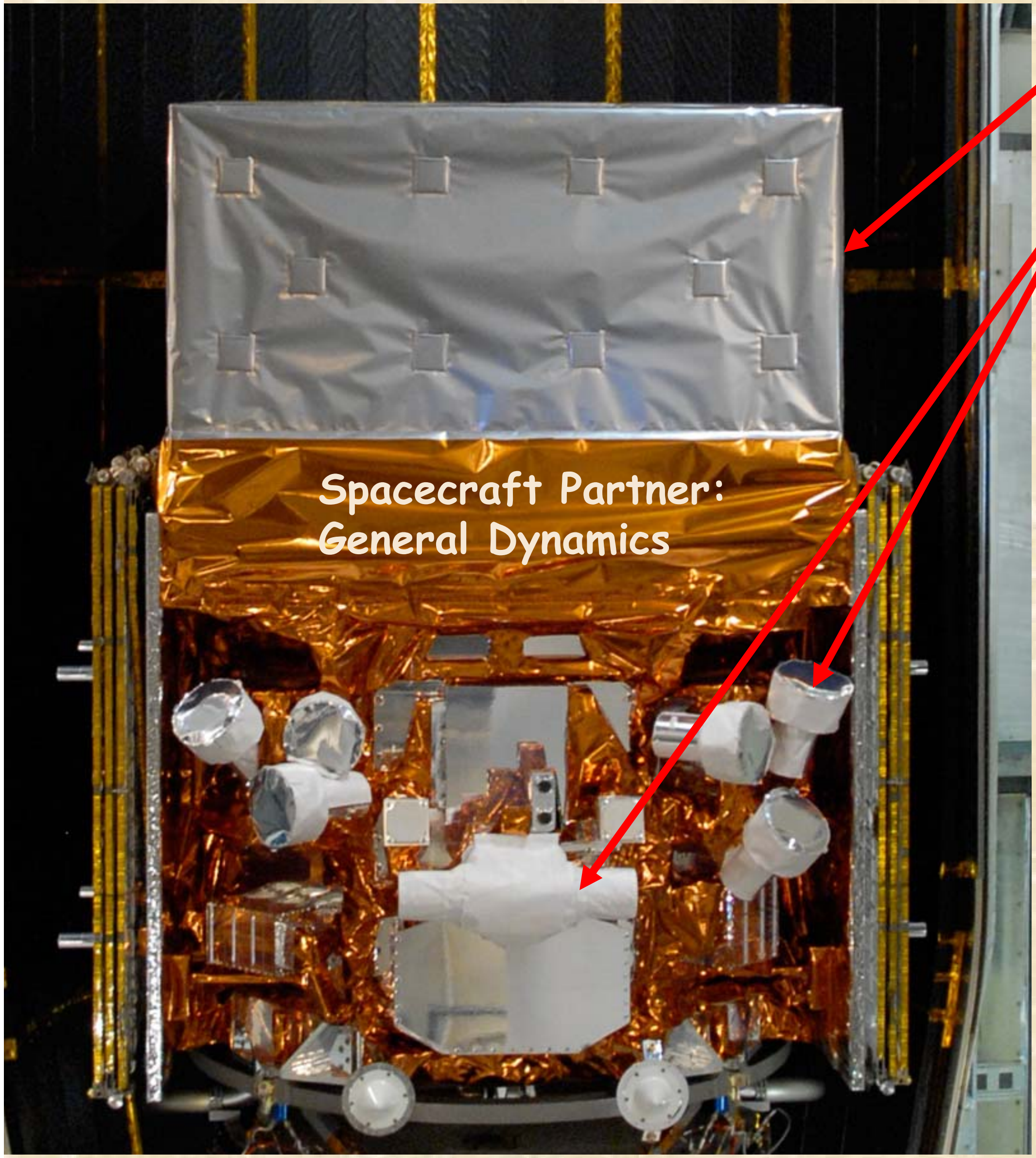
C. Kouveliotou (NASA/MSFC)
on behalf of

Magnetar Team

E. Gogus, Y. Kaneko (Sabanci University, Turkey)
E. Ramirez-Ruiz (UCSC, USA)
J. Granot (University of Hertfordshire, UK)
P. Woods (Corbid Tec, USA)
A. von Kienlin (MPE, Germany)
A. van der Horst (NPP, USA)
A. Watts, M. van der Klis, R. Wijers, L. Kaper (U. of Amsterdam, The Netherlands)
M. Finger (USRA, USA)
C. Wilson-Hodge (NASA/MSFC, USA)
A. Pe'er (STScI, USA)
J. McEnery, N. Gehrels (NASA/GSFC, USA)
S. Wachter (Caltech/IPAC, USA)
V. Kaspi (McGill University, Canada)

The Fermi Observatory

Launched 2008 June 11



Large AreaTelescope (LAT)
20 MeV ->300 GeV

Gamma-ray Burst Monitor (GBM)
NaI and BGO Detectors
8 keV - 40 MeV

KEY FEATURES

- Large field of view
  LAT: 20% of the sky at any instant; in sky survey mode, expose all parts of sky for ~30 minutes every 3 hours. GBM: whole un-occulted sky at any time.
- Over 7 decades energy range
  8 keV - 300 GeV

GBM

- 4 x 3 NaI Detectors with different orientations.
- 2 x 1 BGO Detector either side of spacecraft.
- View entire sky while maximizing sensitivity to events seen in common with the LAT

The Large Area Telescope (LAT)

GBM BGO detector.
200 keV -- 40 MeV
126 cm^2, 12.7 cm
Spectroscopy
Bridges gap between NaI and LAT.

GBM NaI detector.
8 keV -- 1000 keV
126 cm^2, 1.27 cm
Triggering, localization, spectroscopy.

- GBM **Triggered** sources
  - Gamma-ray bursts (GRBs)
  - Soft gamma repeaters (SGRs) aka magnetars
  - Terrestrial gamma flashes (TGFs)
  - Short transients detected by on-board trigger algorithm
  - Solar Flares
- **Non-triggered** sources
  - Pulsed sources detected by power spectral analysis and/or epoch folding
  - Longer-term transients and persistent sources detected by Earth occultation

Magnetars are magnetically powered neutron stars

- ~17 are discovered to date – three in 2008-2010 – Only 2 extragalactic sources

- Discovered in X/γ-rays; radio, optical and IR observations: Short, soft repeated bursts

- $P = [2\text{-}11]$ s, $\dot{P} \sim [10^{-11}\text{-}\ 10^{-13}]$s/s

- $\tau_{spindown}(P/2\dot{P})$= 2-220 kyrs

- $B\sim[1\text{-}10]\times10^{14}$ G (mean surface dipole field: $3.2\times10^{19}\sqrt{P\dot{P}}$)

- Bright sources, $L\sim10^{33\text{-}36}$ erg/s , >> rotational E-loss

- No evidence for binarity so far (fallback disks?)

- SNe associations?

Neutron star populations which may comprise Magnetars:

Soft Gamma Repeaters (SGRs)

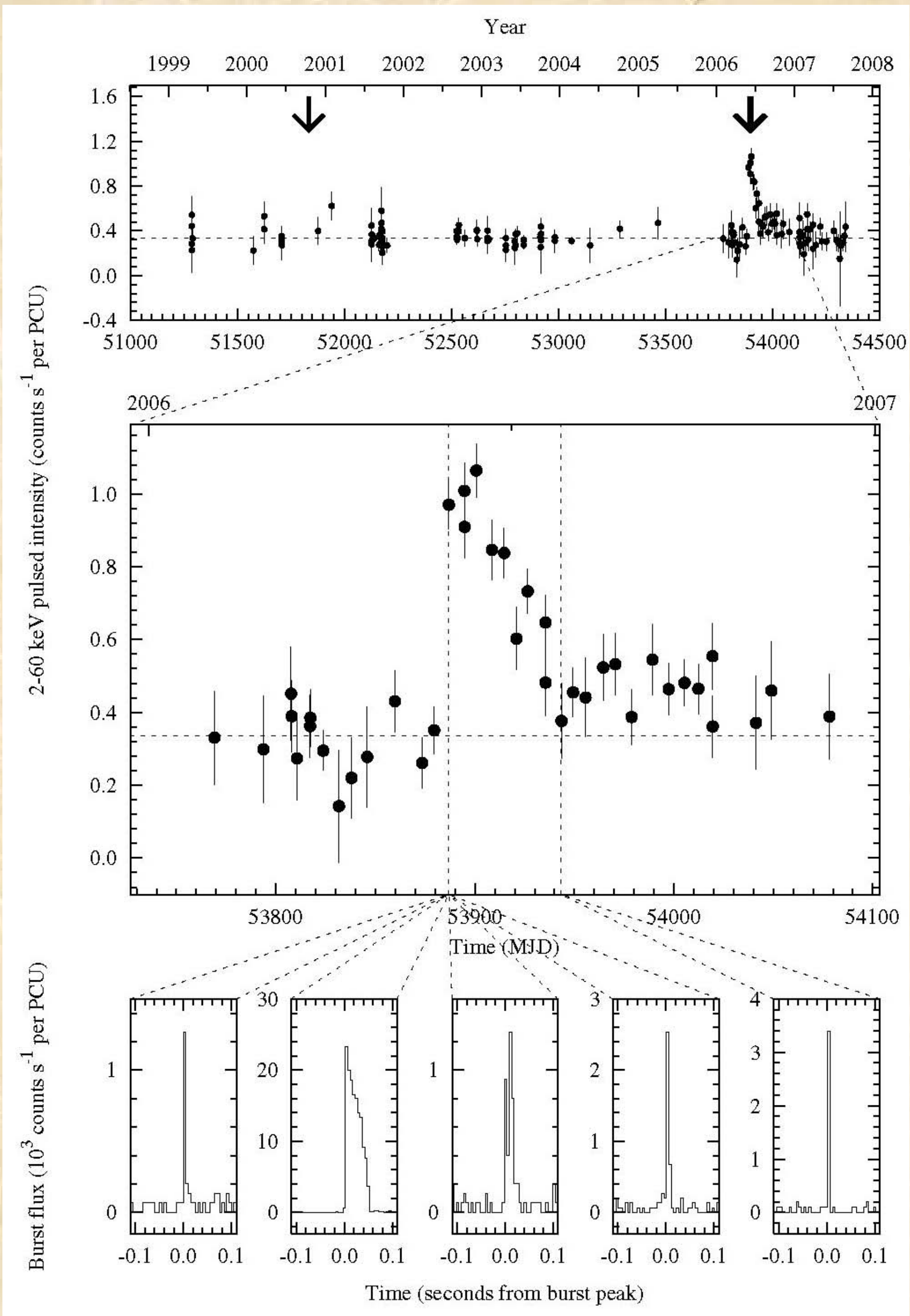
Anomalous X-ray Pulsars (AXPs)

Dim Isolated Neutron Stars (DINs)

Compact Central X-ray Objects (CCOs)

Rotation Powered PSRs?! **PSR J1846−0258**

PSR J1846−0258/Kes 75



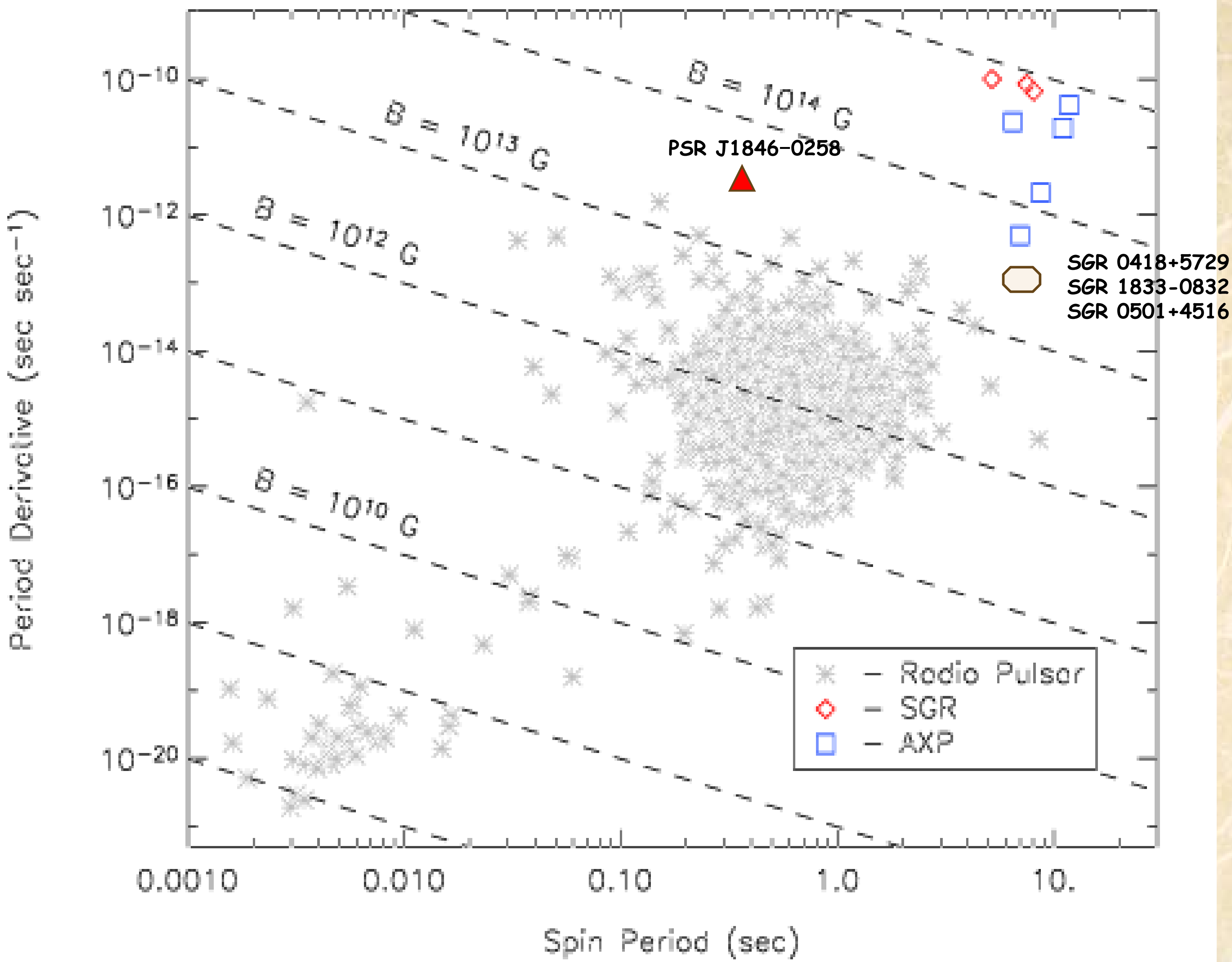
- Magnetar-like X-ray bursts were detected from the young pulsar PSR J1846−0258.

- Rotation-powered PSR with an inferred surface dipolar magnetic field of 4.9×10^{13} G, P_s=0.3 s, Age ~ 900 yrs

- Bursts accompanied by a sudden flux increase ($200L_x$) and unprecedented change in timing behavior (spin up->spin down).

- Is there a continuum of magnetic activity that increases with inferred magnetic field strength?

Gavriil et al 2008



B = 10^14 G
B = 10^13 G
B = 10^12 G
B = 10^10 G
PSR J1846-0258
SGR 0418+5729
SGR 1833-0832
SGR 0501+4516
– Radio Pulsar
– SGR
– AXP
10^-10
10^-12
10^-14
10^-16
10^-18
10^-20
Period Derivative (sec sec^-1)
0.0010
0.010
0.10
1.0
10.
Spin Period (sec)

GBM Magnetar Key Project

PI: Chryssa Kouveliotou

SGR Source	Active Period	Triggers	Comments
J0501+4516	08/22/08-09/03/08	26	New source at Perseus arm
1806-20	11/29/08	1	Old source - reactivation
J1550-5418	10/03/08-10/20/08 01/22/09-02/24/09 03/22/09-04/17/09	7 117 14	Known source – first time exhibiting burst active episodes
J0418+5729	06/05/09	2	New source at Perseus arm

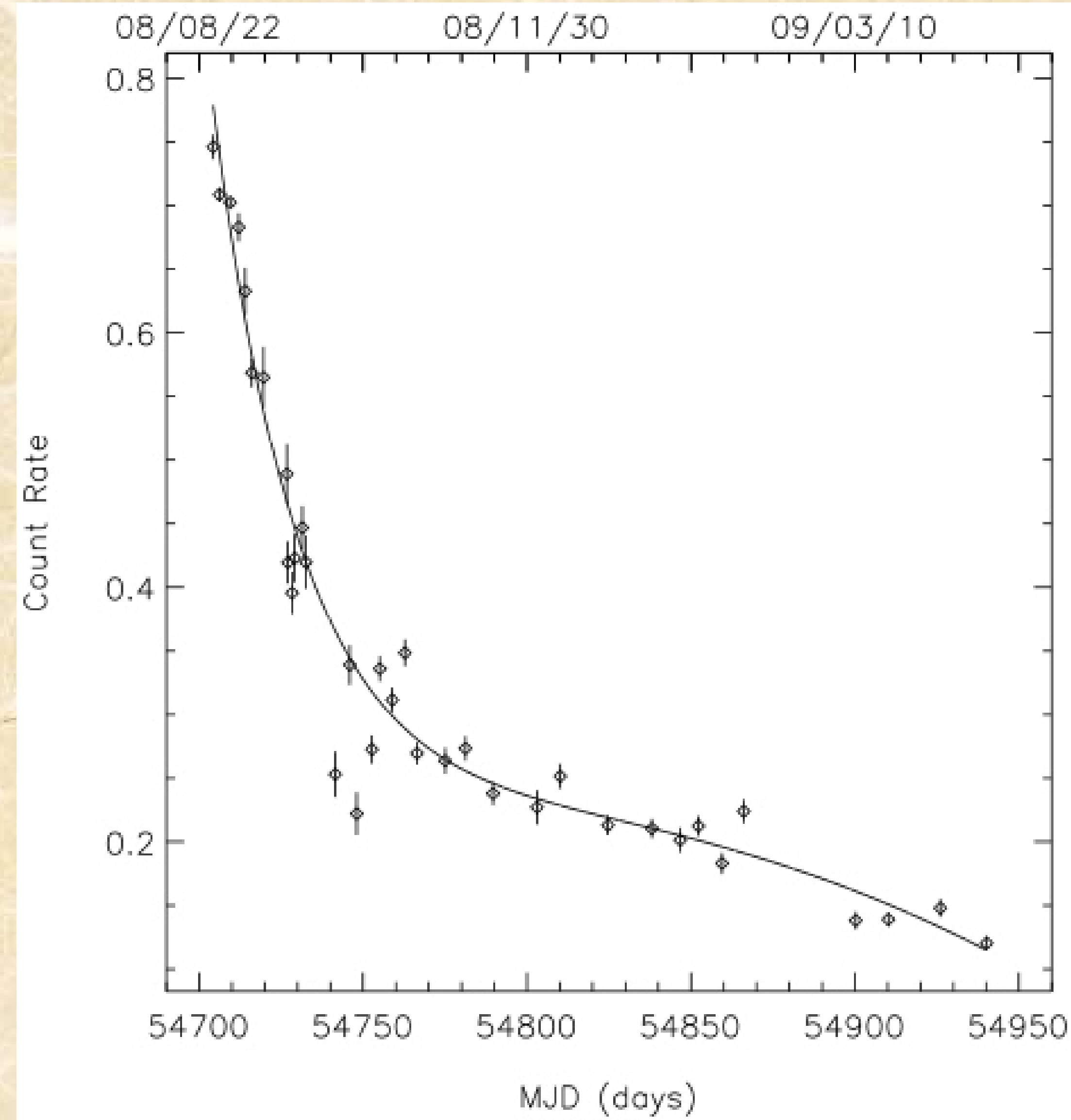
SGR 1833-0832 discovered 10/03/19 with Swift and RXTE – no GBM detection

http://gammaray.nsstc.nasa.gov/gbm/science/magnetars

SGR 0501+4516

- Swift triggered on 4 bursts on 22 August 2008
- RXTE ToO program triggered ~4 hours after the first Swift trigger for 600 s
- P = 5.7620 s (ν=0.173547943(1) Hz) was reported ~ 9 hours after the first Swift trigger!
- $\dot{P}$ = 7.4980x10^{-12} ($\dot{\nu}$=-1.752(8) x 10^{-13} Hz/s) and B = 2.1 x 10^{14} G
- CXO HRC location: RA = 05h 01m 06.756s DEC = +45d 16m 33.92s (0.1" error)
- IR Counterpart with UKIRT, K~18.6 (Tanvir & Varricatt 2008)
- GBM triggered on 26 events from the source – total of 56 events in ~ 3.5 days

Persistent emission properties

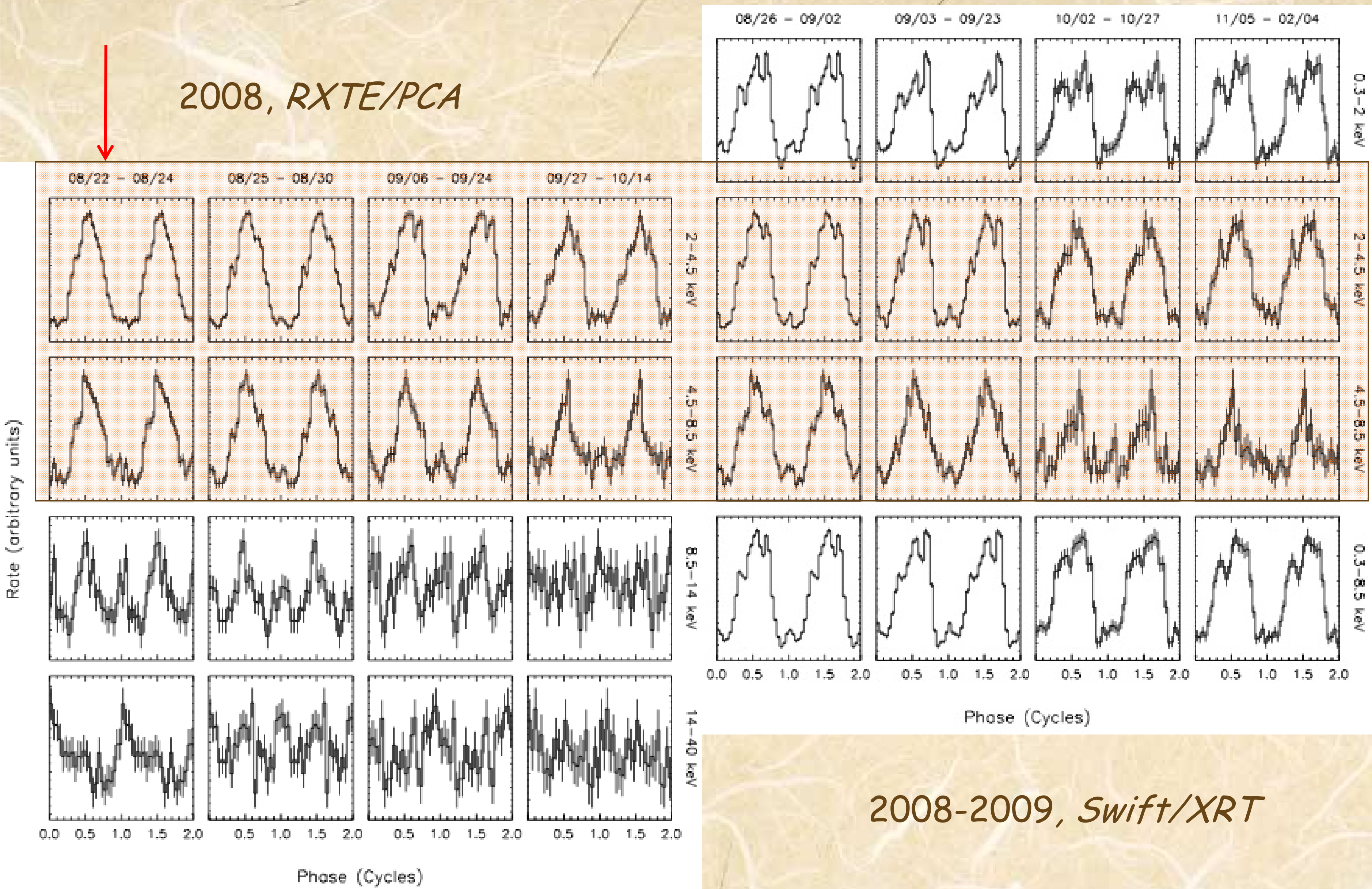


Swift observations between 412 and 546 days after the source activation in 2008, show that the flux remained constant at ~ 7×10^{-12} erg/cm^2 s for over a year after the first 100 days of decline.

This corresponds (assuming a distance of 2 kpc) to
$L = 3.3 \times 10^{33}$ erg/s

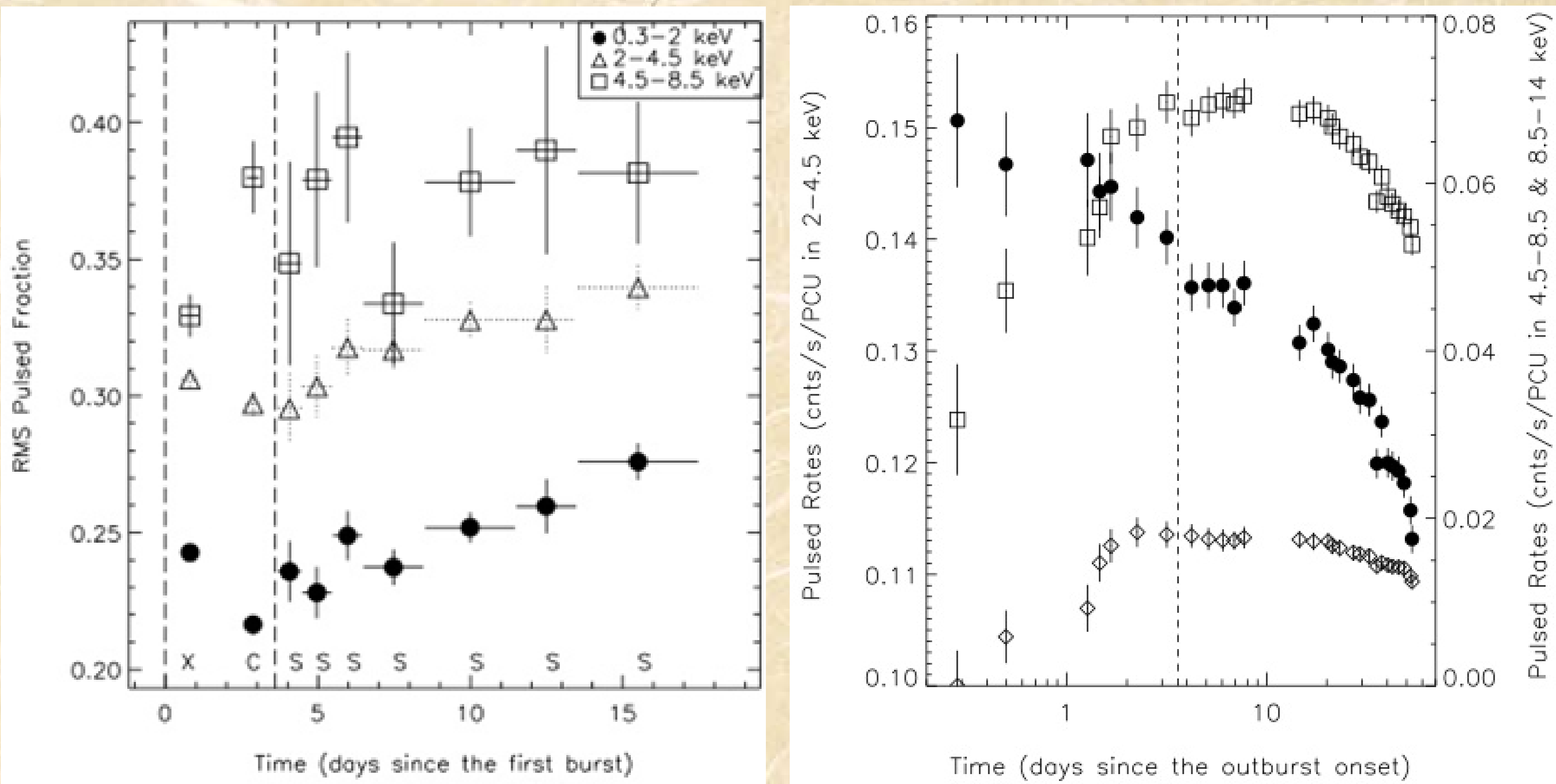
Gogus et al 2010

2008, *RXTE/PCA*



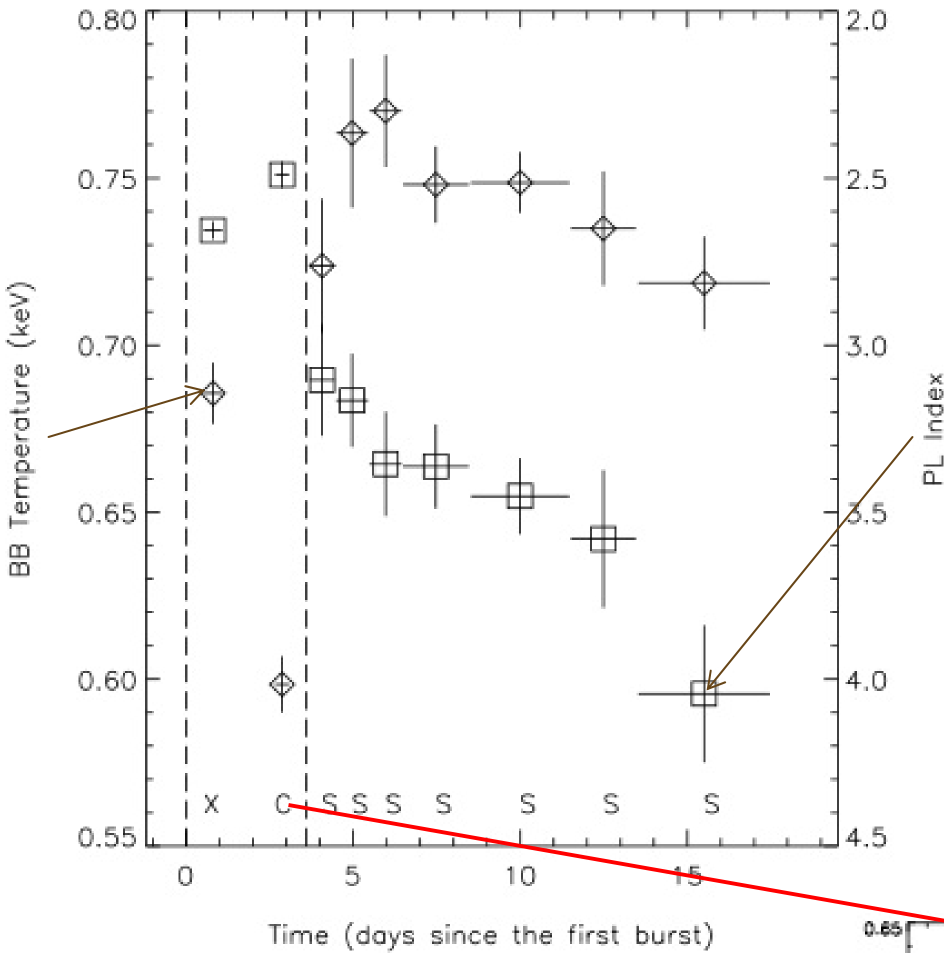
2008-2009, *Swift/XRT*

Gogus et al 2010

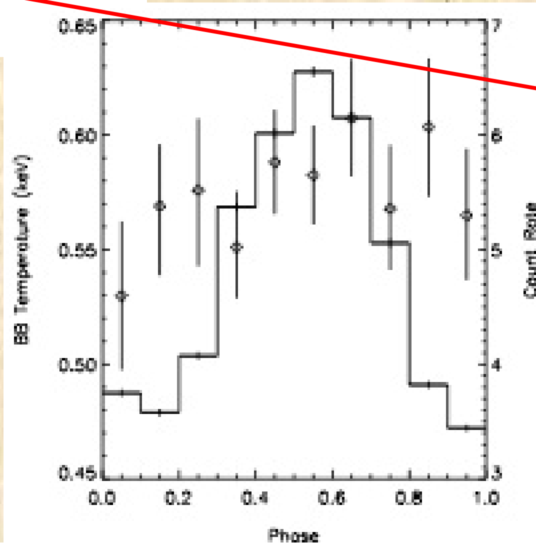


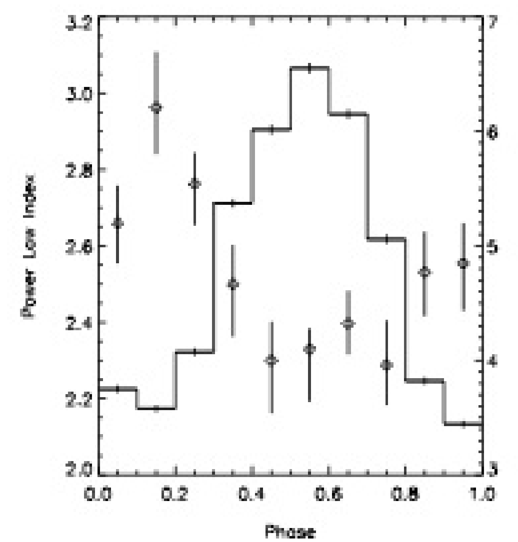
Gogus et al 2010

Persistent source spectra



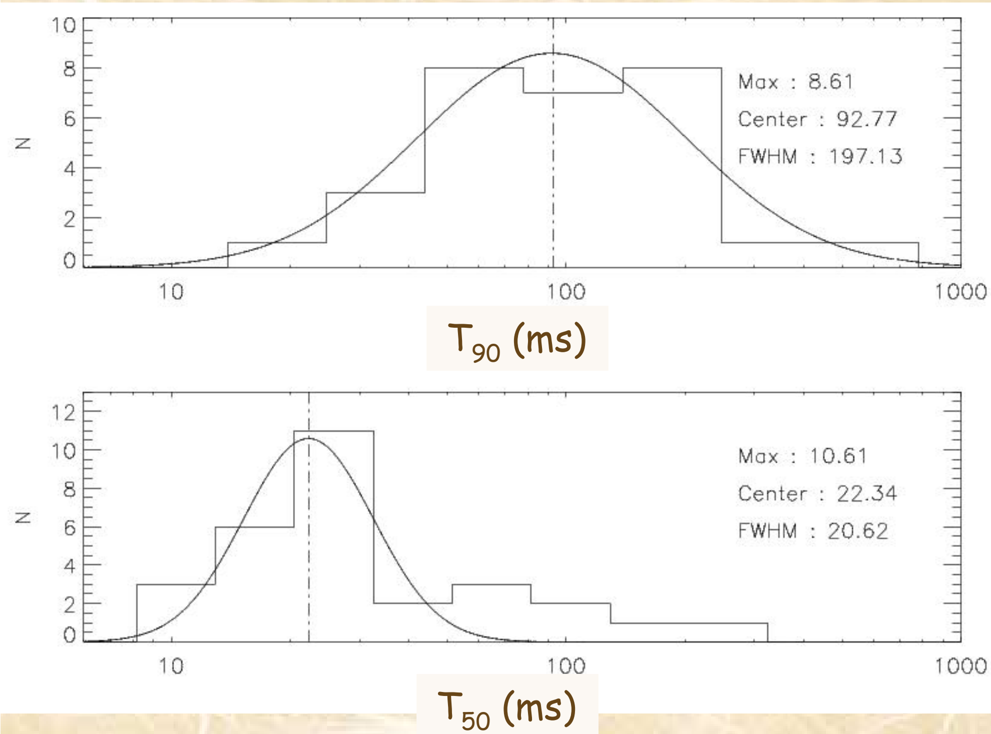
Phase-resolved spectra (BB+PL) during the fourth day after activation. The BB component remains constant corresponding to an emitting region size of R=0.3 km.

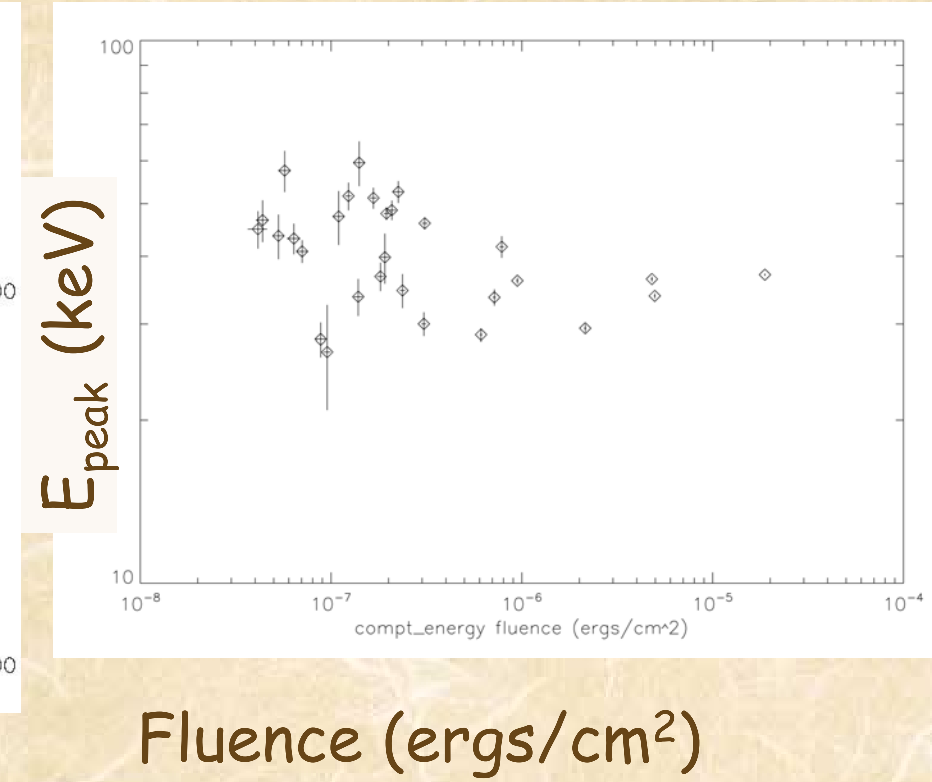




Gogus et al 2010

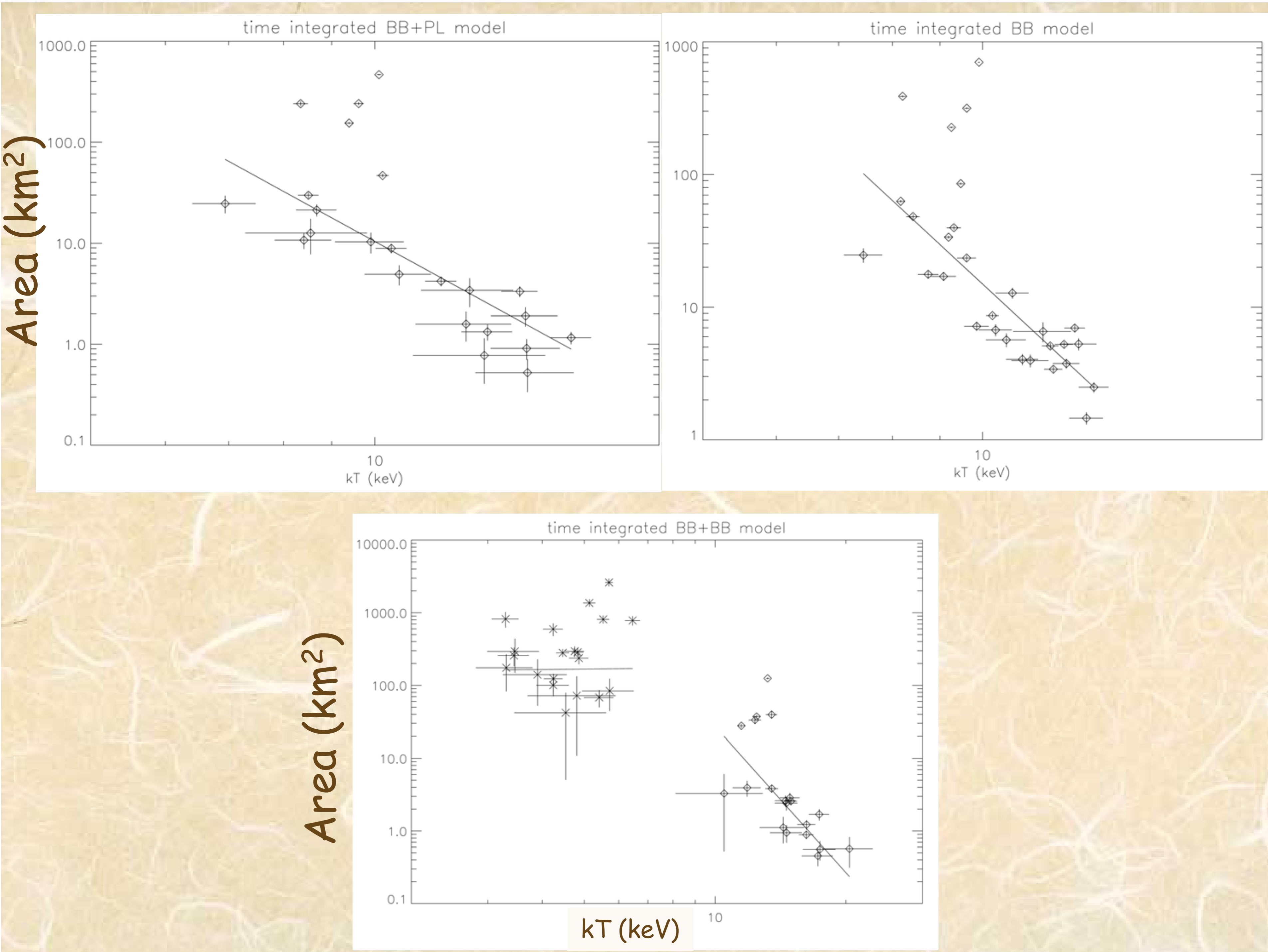
GBM recorded a total of 29 Bursts





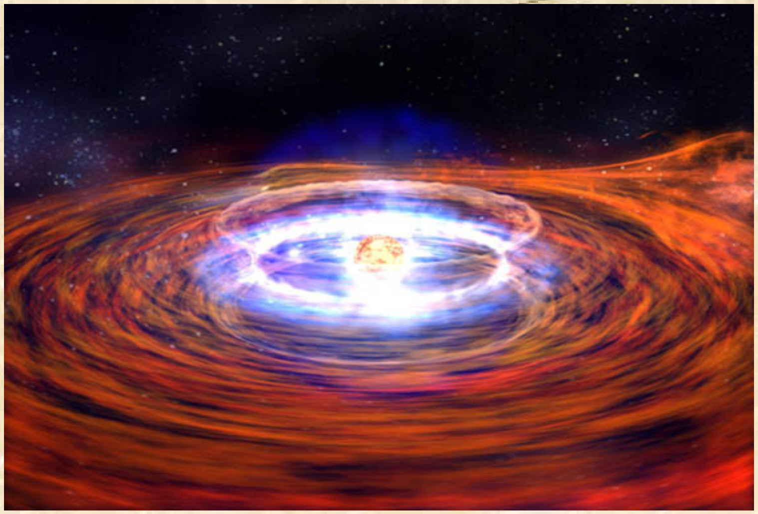
Average burst energy (at 2 kpc)= 1.5×10^{38} erg
(2×10^{37} – 9×10^{39} erg)

Lin et al 2010


time integrated BB+PL model
1000.0
100.0
10.0
1.0
0.1
10
kT (keV)
time integrated BB model
1000
100
10
1
10
kT (keV)
time integrated BB+BB model
10000.0
1000.0
100.0
10.0
1.0
0.1
10
Area (km^2)
Area (km^2)
kT (keV)

PRE in thermonuclear bursts

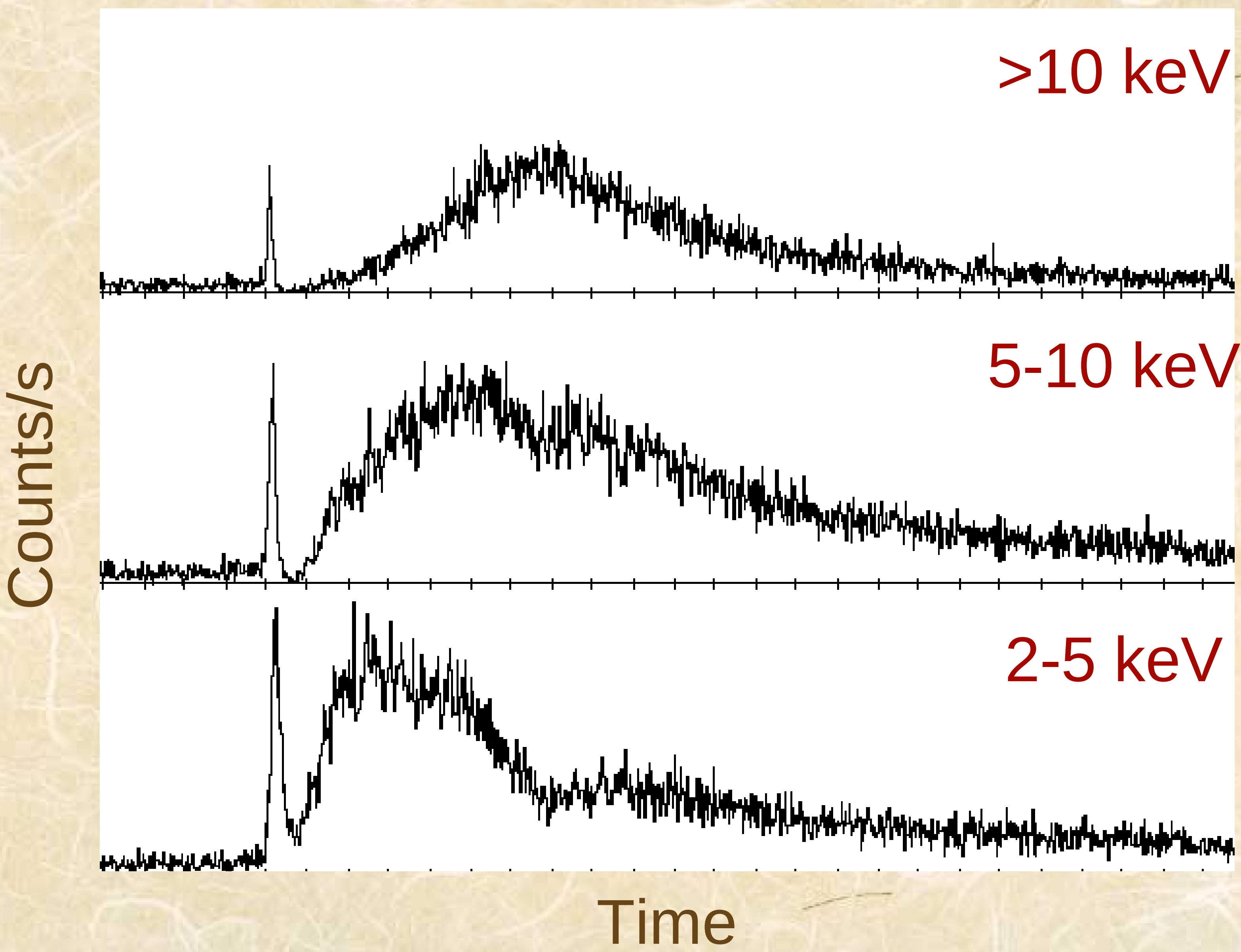
- Luminosity reaches Eddington limit, triggering Photospheric Radius Expansion (PRE).
- Expanding layers cool, leading to a multi-peaked light curve.
- Standard candle to measure a neutron star distance or mass/radius and hence equation of state.



$$L_{\mathrm{Edd},\infty} = \left[\frac{4\pi c G M}{\kappa(1+z_{\mathrm{ph}})} \right]$$

Watts et al 2010

PRE in thermonuclear bursts



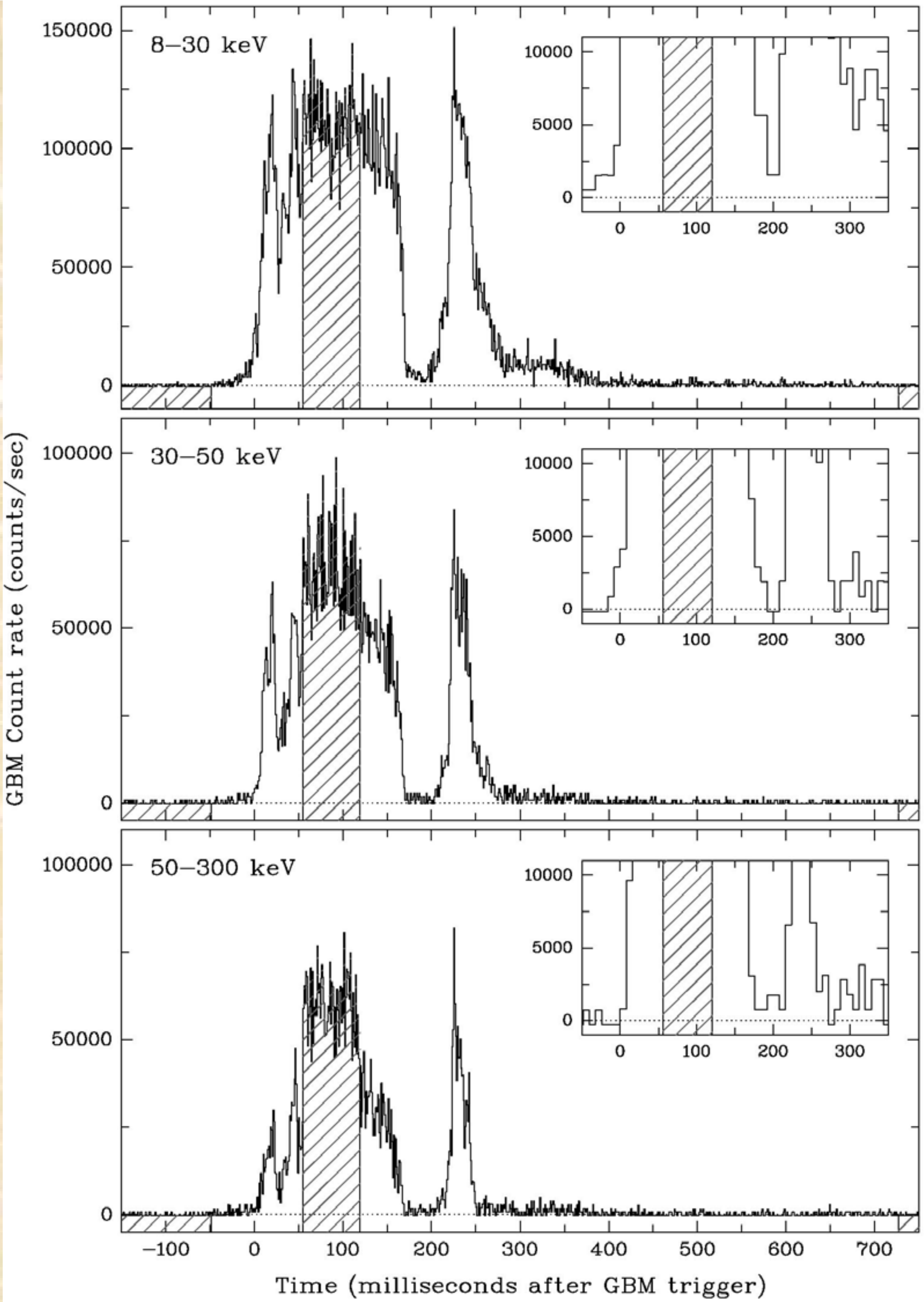
PRE in magnetar bursts

- Identifying PRE during a magnetar burst would give us the magnetic Eddington limit. If the magnetic field is known (e.g. from timing) this would again constrain distance/equation of state.

$$F_{\rm crit} \approx 10^{-2}\ {\rm ergs/cm^2/s} \left(\frac{B}{10^{14}\ {\rm G}}\right)\left(\frac{1\ {\rm keV}}{E_\gamma}\right) \times \left(\frac{1\ {\rm kpc}}{d}\right)^2 \left(\frac{L_{\rm Edd}}{2\times 10^{38}\ {\rm ergs/s}}\right)$$

Miller 1995

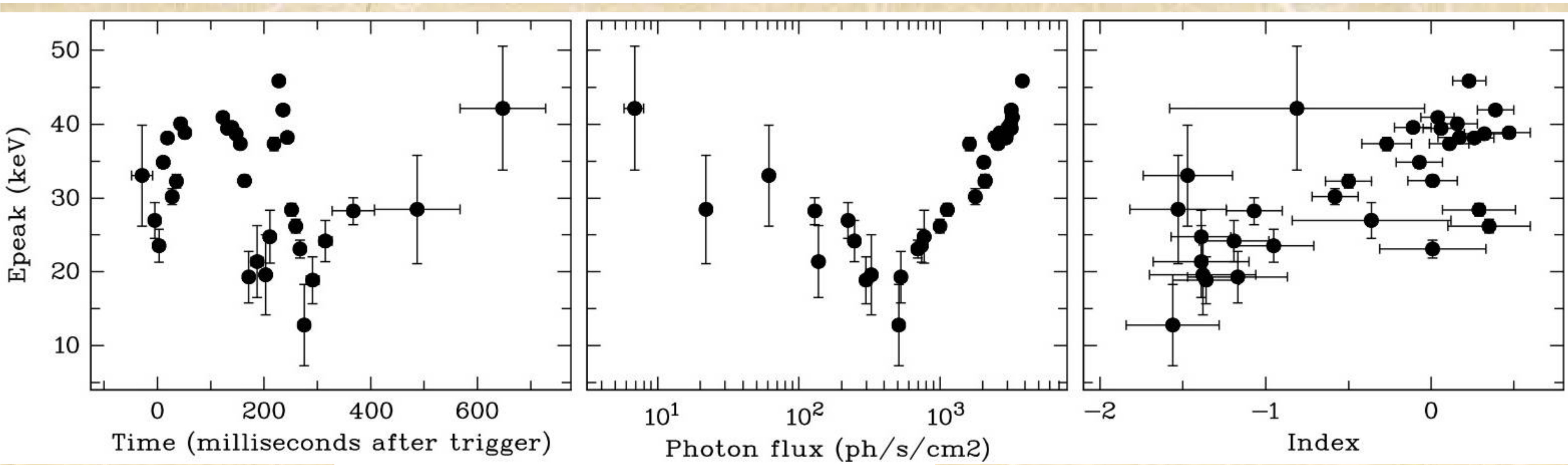
- PRE can only occur under certain burst emission scenarios. A PRE burst will therefore also constrain the burst trigger mechanism, a major unknown.

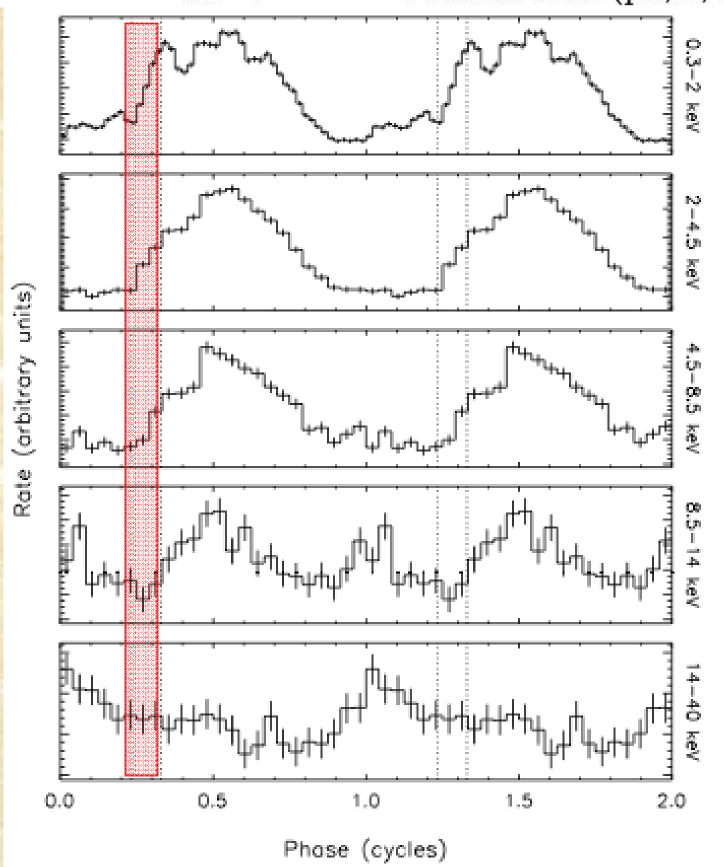


The first magnetar candidate PRE burst

- Distance and field strength known.
- Predicted critical flux matches that recorded by GBM!
- Emission becomes softer during the dip in the light curve.

Watts et al 2010



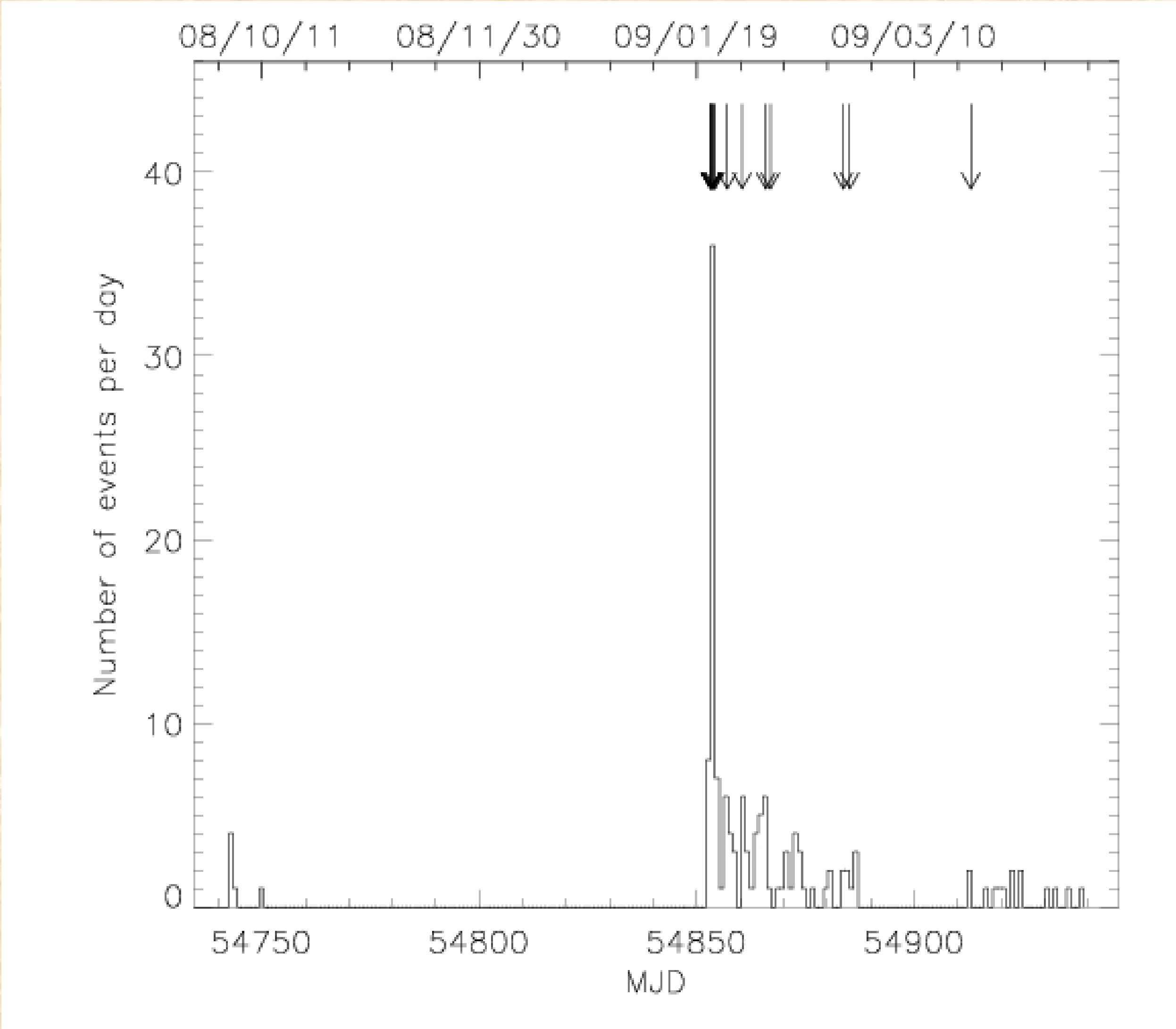


Watts et al. 2010

SGR 1550-5418
formerly known as AXP 1E1547.0-5408
formerly known as an *ASCA* CCO in G327.0-0.13

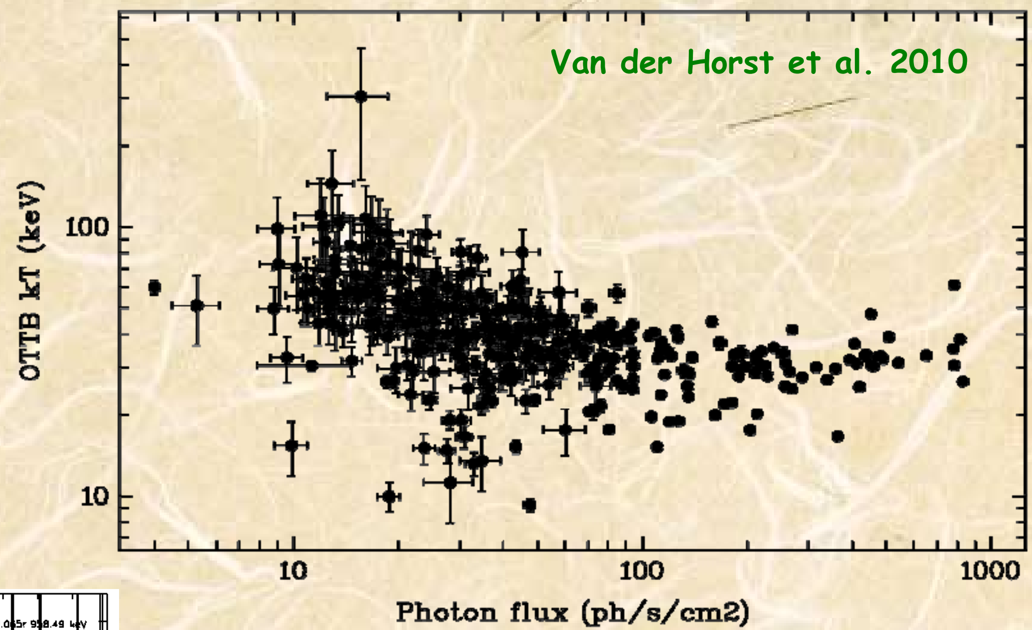
- Three episodes detected with GBM: Oct. 2008, Jan. & Mar. 2009
- P = 2.069s
- $\dot{P} = 2.318 \times 10^{-11}$ s/s and $B = 2.2 \times 10^{14}$ G
- Near IR detection, Ks = 18.5±0.3
- GBM triggered on 131 events from the source; many more in the data

SGR 1550-5418 Bursting Activity

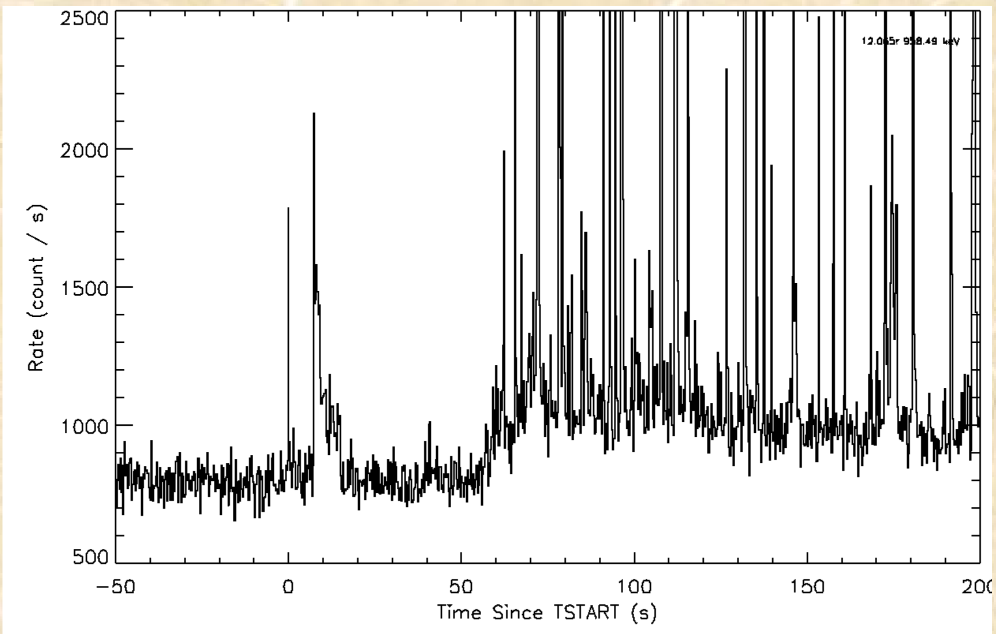


Von Kienlin et al. 2010
Van der Horst et al. 2010

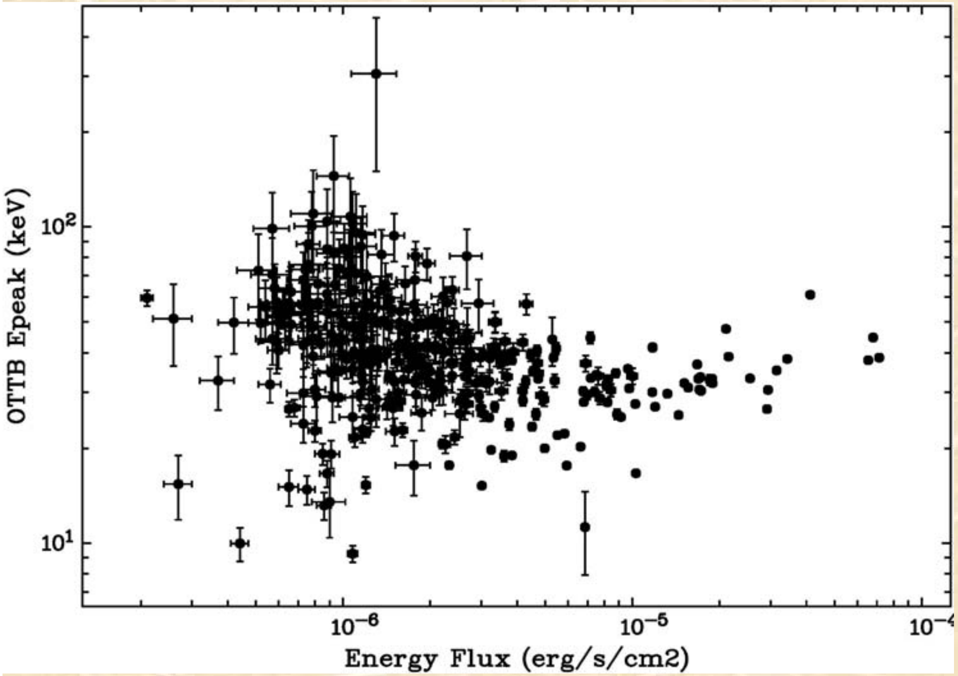
Magnetar in a Frenzy: SGR J1550-5418

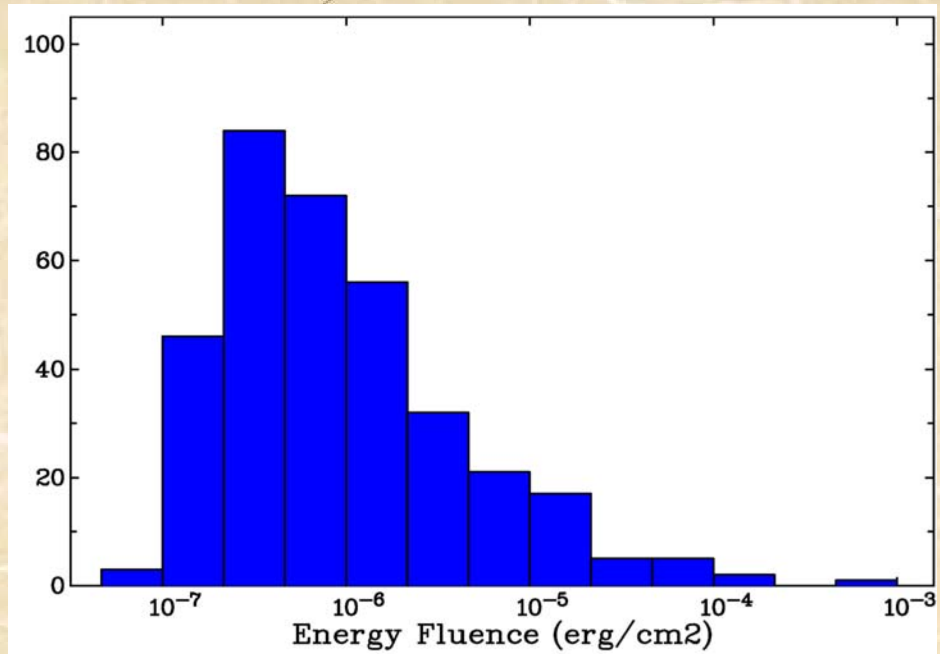


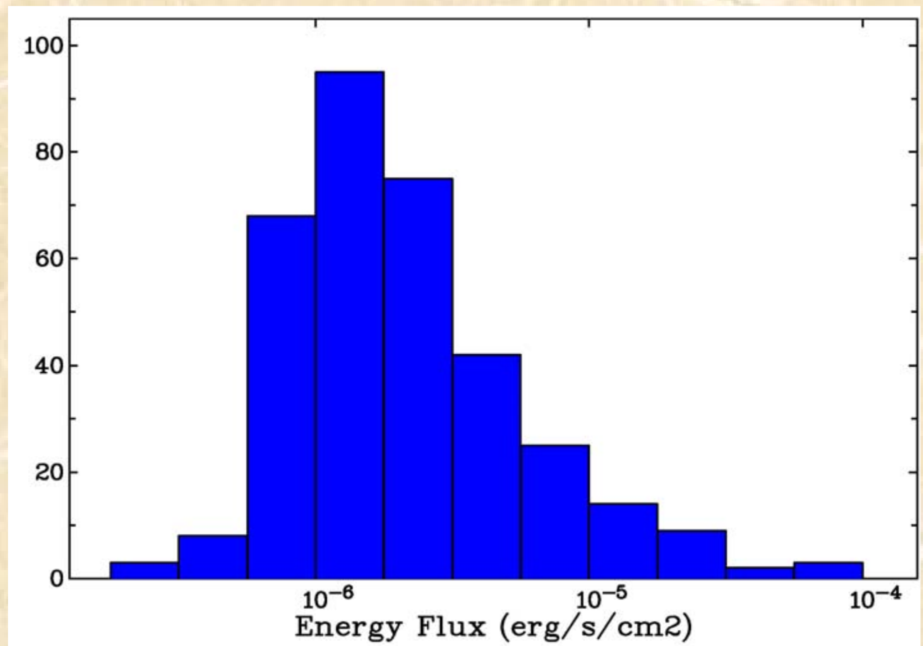
450 bursts on one day…



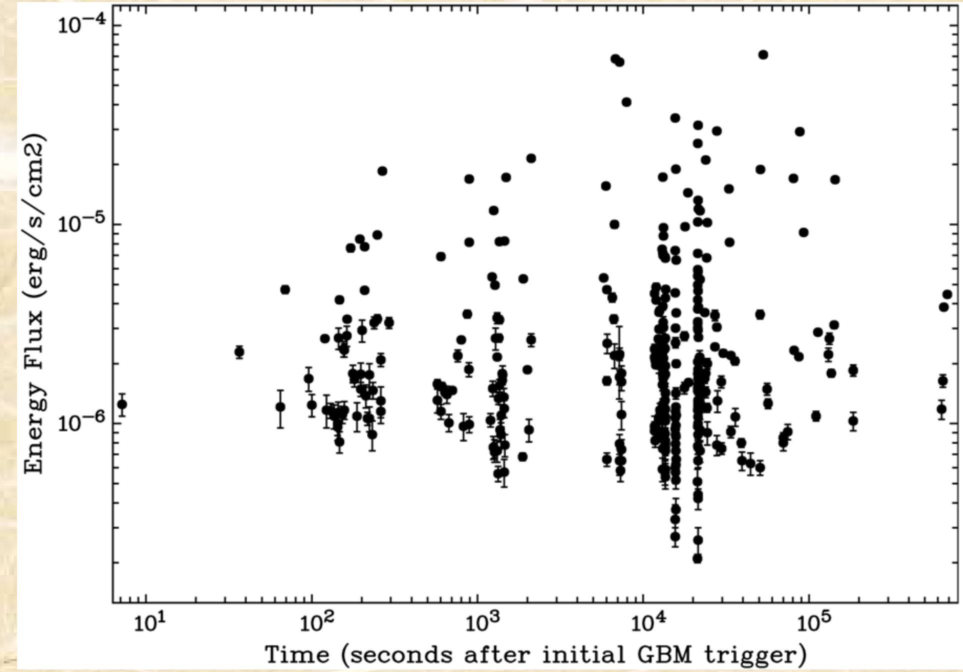
…even when the Earth is in the way!

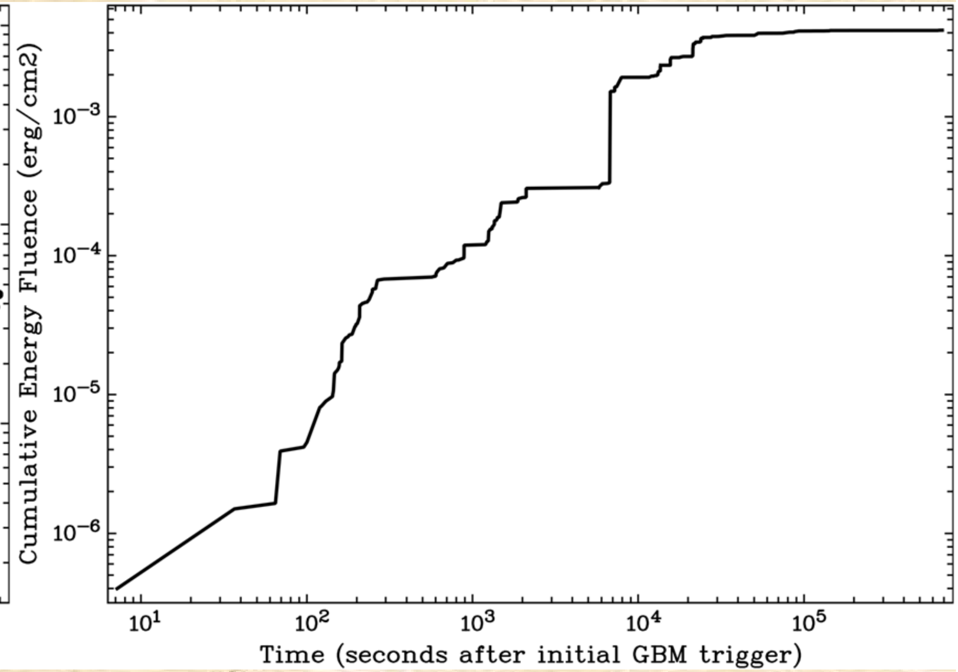






Van der Horst et al. 2010

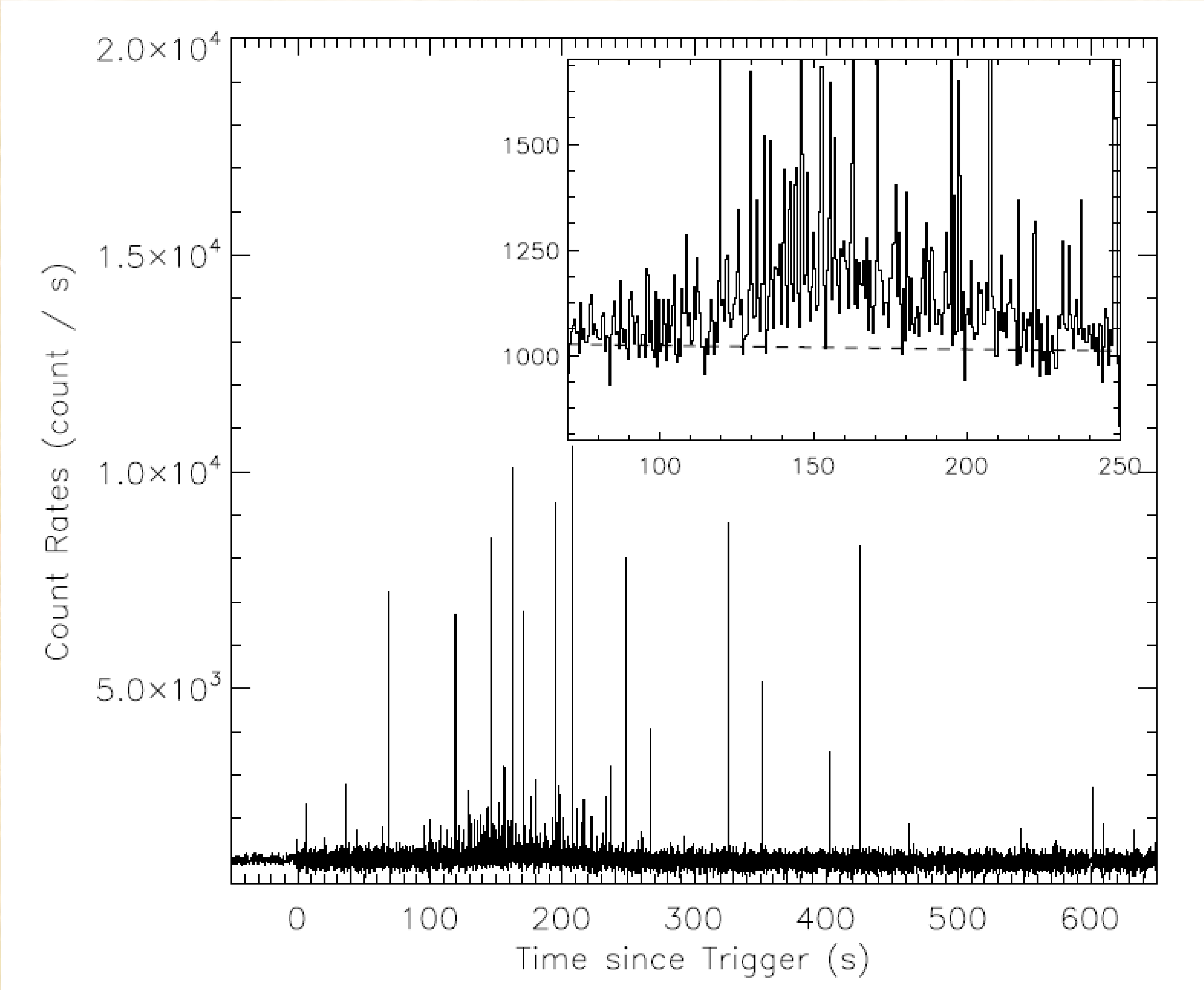




Adopting a distance to the SGR of 5 kpc, we estimate a total isotropic-equivalent energy release of 10^{42} ergs during this activation.

Van der Horst et al. 2010

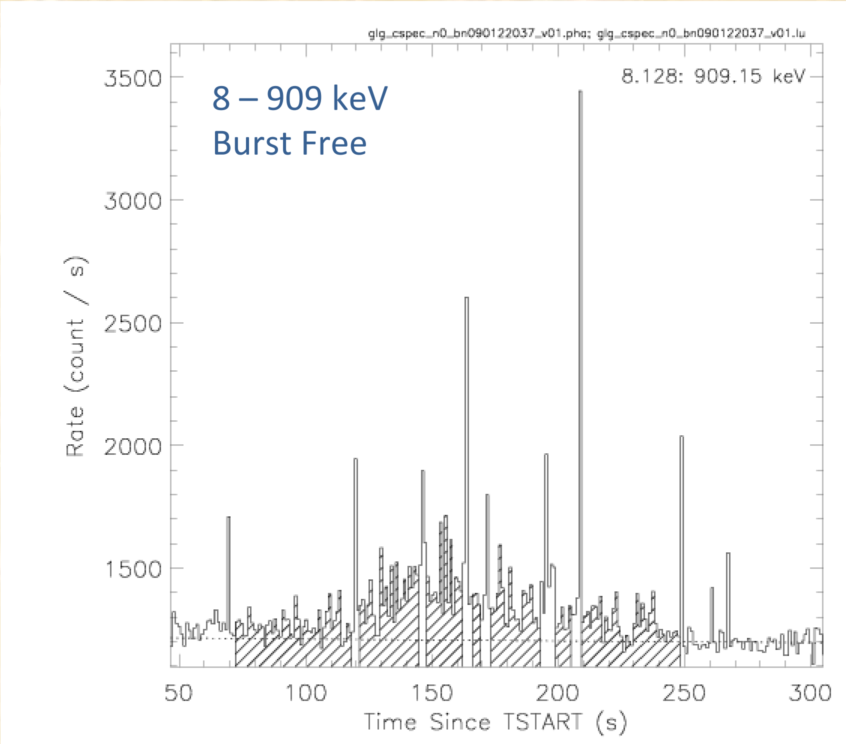
Magnetar twist and shake…

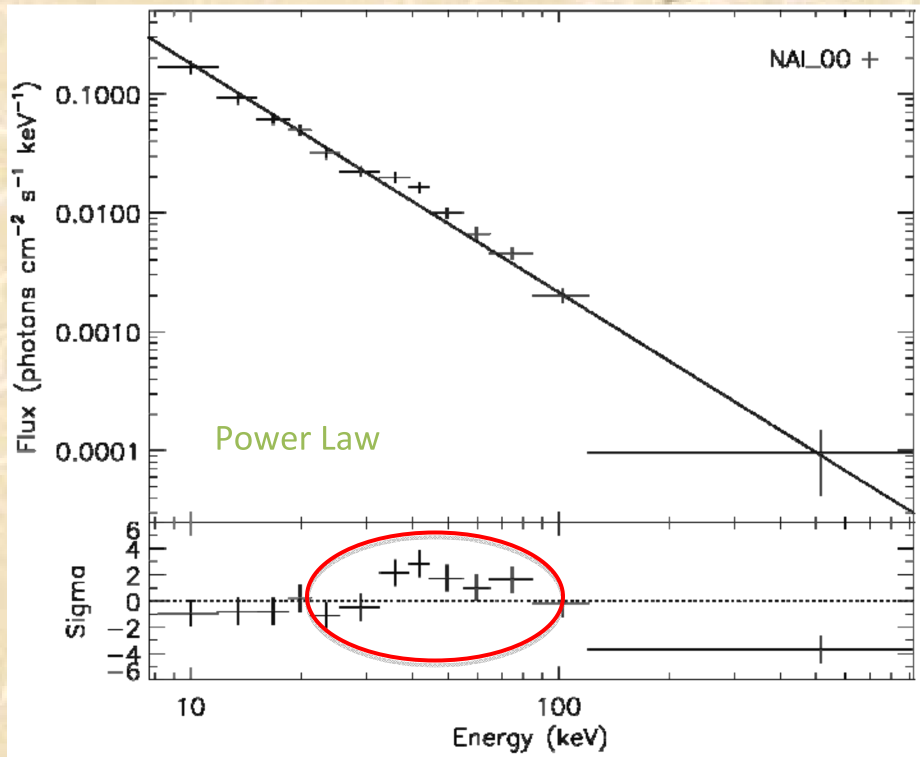


Kaneko et al. 2010

Spectral Analysis

Time Integrated Spectrum [T_0 + 72 - 248 s]





Total Energy

4.3×10^{40} ergs

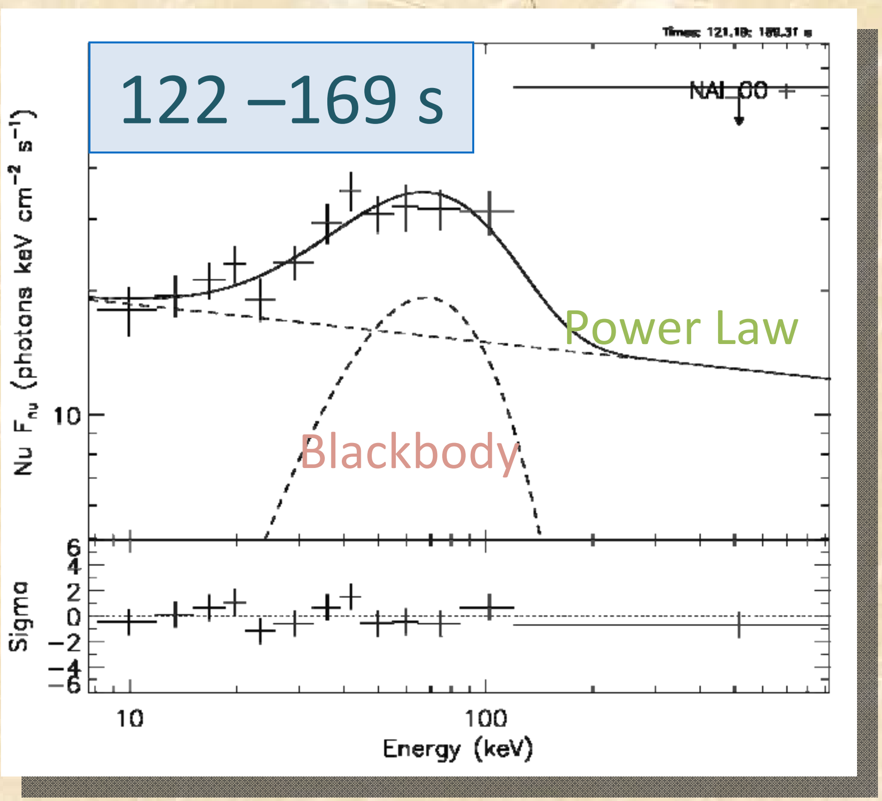
Additional Blackbody (kT = 18 keV) :
DCstat = 13.5 (for 2 DOF)

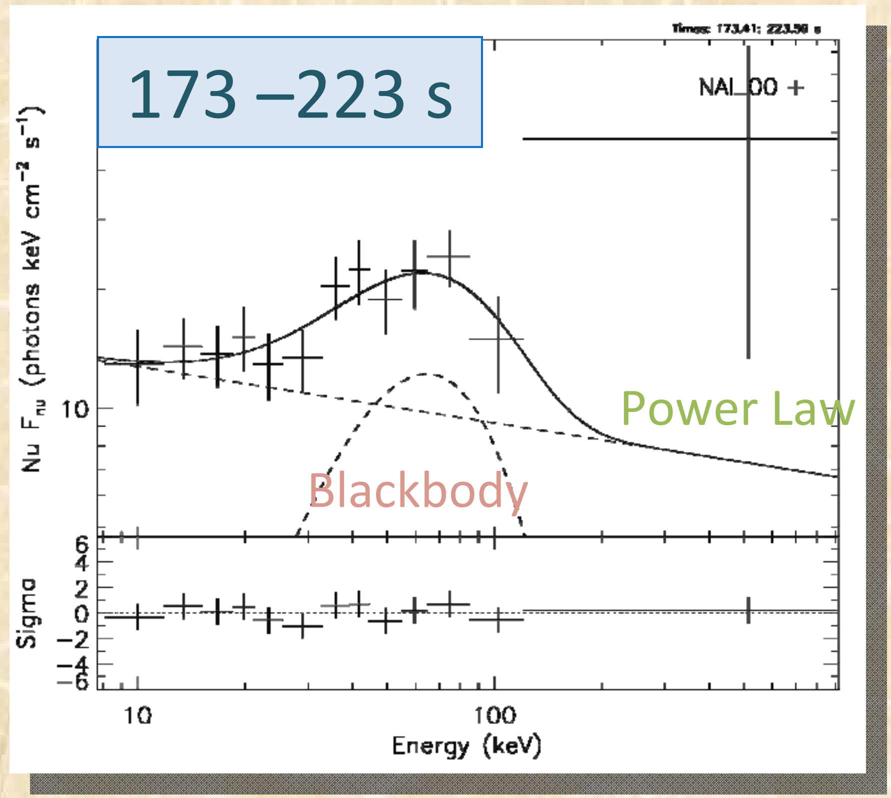
Kaneko et al. 2010

Time Resolved Spectra ($n F_n$)

[T_0 + 72 - 117, 122 - 169, 173 - 223 s]

74 - 117 s Power Law only (Blackbody is not needed)





F_{BB}/F_{TOTAL} = 26% 25%

Kaneko et al. 2010

Evidence for the Blackbody Component

Temporal Properties	Spectral Properties
• Pulsations most significant in **120 – 210 s**	• Blackbody required in **122 – 223 s**
• Pulse fraction peaks in **50 – 74 keV**	• Blackbody *kT* ~ 17 keV (**Wien peak ~50 keV**)
• Pulsations not seen above 110 keV	• $F_{BB} \rightarrow 25\%$ $F_{PWRL} \rightarrow 75\%$

Kaneko et al. 2010

Blackbody: Radius of the Emitting Region

Assuming a hot spot of radius R_{HS} on the neutron star surface

For D = 5 kpc, kT = 17 keV :

$A_{HS} \approx 0.044\ (D/5\ \mathrm{kpc})^2\ \mathrm{km}^2$

$\rightarrow$ $\boldsymbol{R_{HS} \approx 120\ \mathrm{m}}$

which is the size of the magnetically-confined hot plasma and is << 1% of the NS surface area

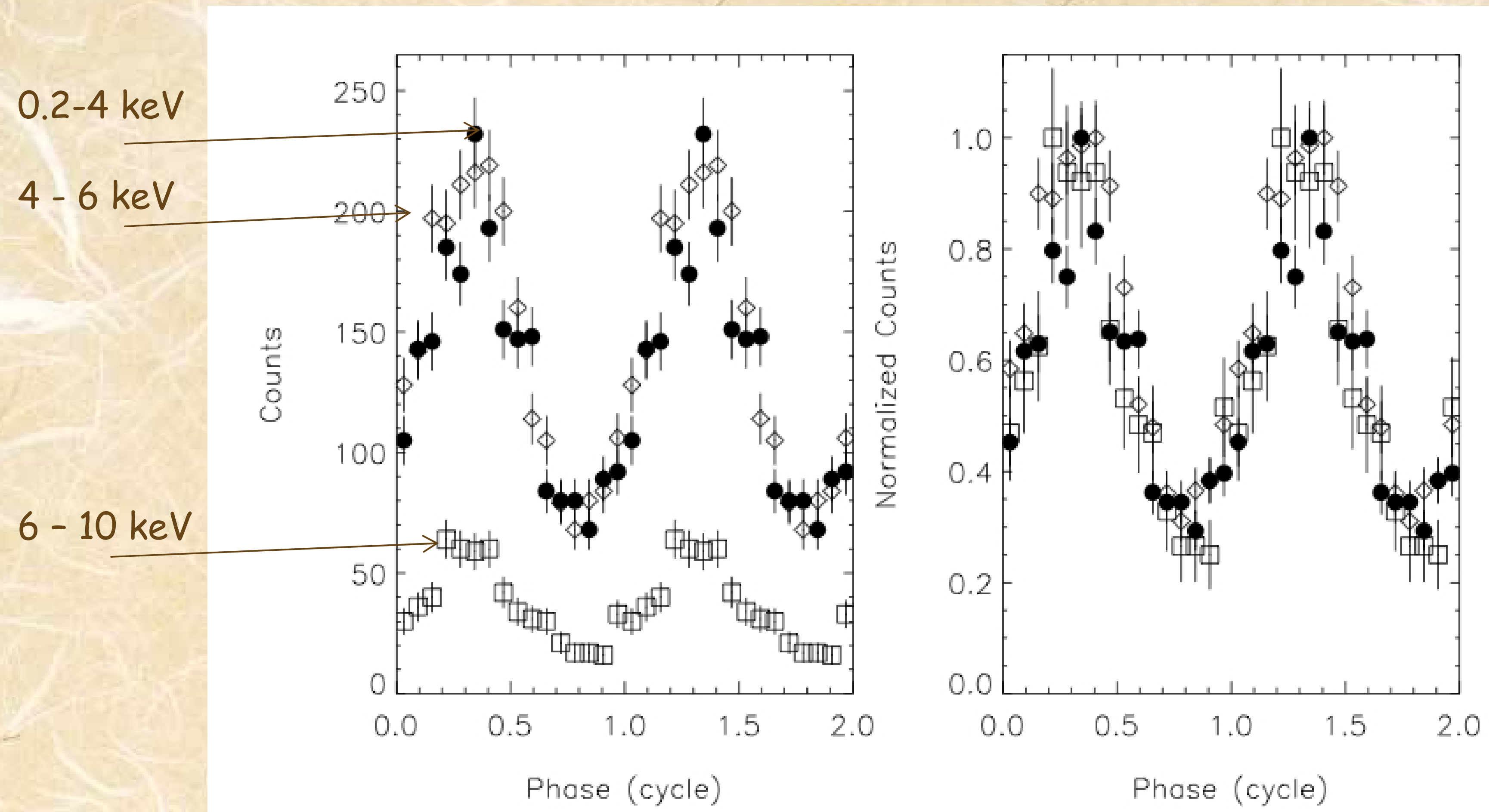
Kaneko et al. 2010

SGR 0418+5729

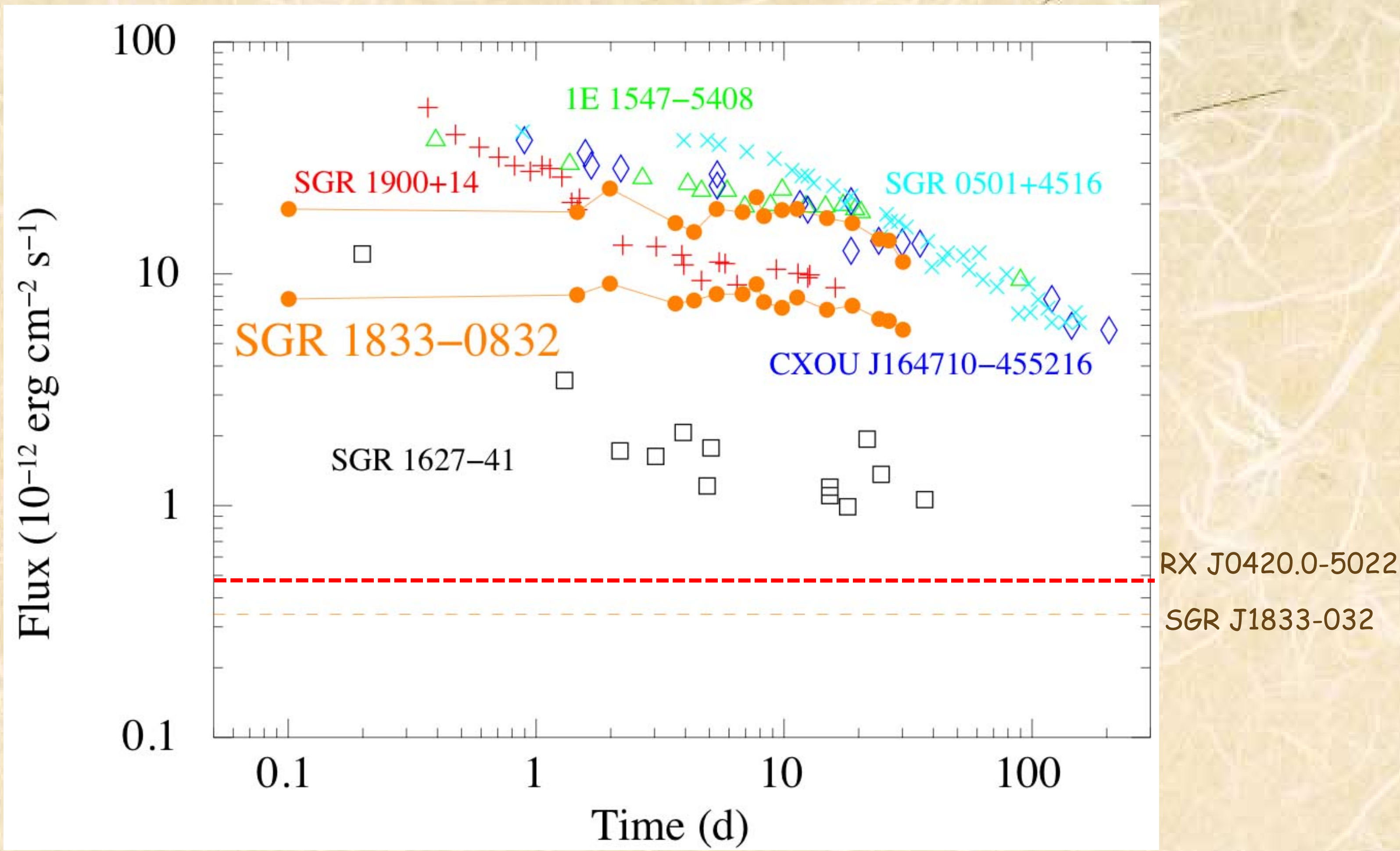
- GBM triggered on 5 June 2009 – new source confirmed with IPN
- RXTE ToO program triggered ~ 4 days after the GBM triggers
- P = 9.0783(1) sec
- $\dot{\nu} \sim 2 \times 10^{-14}$ Hz/s at 3σ and $B < 10^{14}$ G
- CXO location: RA = 04h 18m 33.867s, Dec = +57d 32' 22.91"
- No IR (Ks > 21.3, Wachter et al 2009) or optical (R > 24, Ratti, Steeghs & Jonker 2009) counterpart detected
- GBM triggered on 2 events from the source

SGR 1833-032

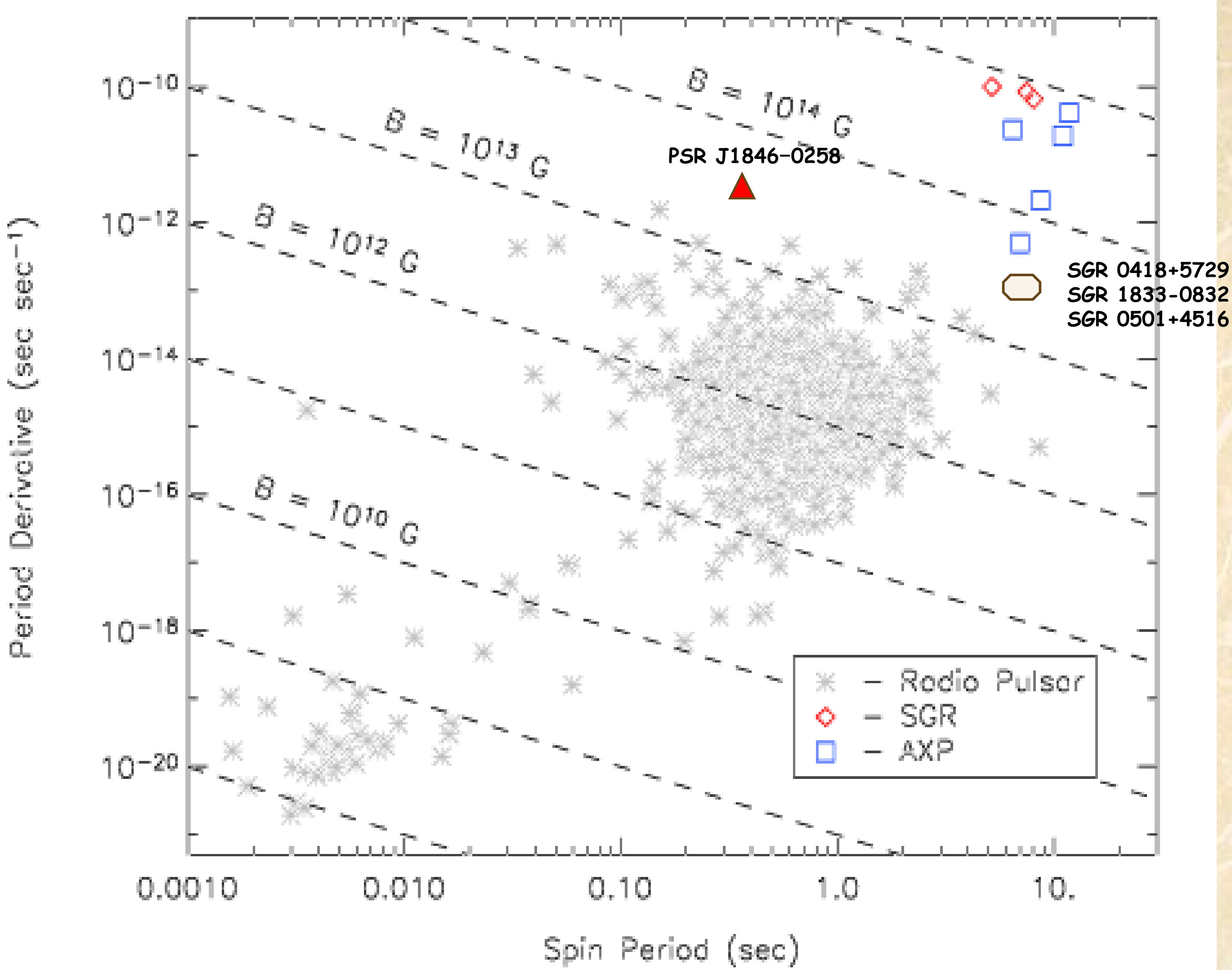
- Swift/BAT triggered on 19 March 2010 (also seen with INTEGRAL, Kuiper & Hermsen 2010)– new source confirmed with XRT
- RXTE ToO program triggered <3.25 hours after the BAT trigger
- P = 7.5654091 sec
- $\dot{P} \sim 4.39 \times 10^{-12}$ s/s at 3σ and $B = 1.8\times10^{14}$ G
- CXO location: RA = 18h 33m 44.37s, Dec = -08d 31' 07.5"
- No IR (Ks > 22.4) counterpart detected
- RXTE detected 4 more events from the source



Gogus et al 2010

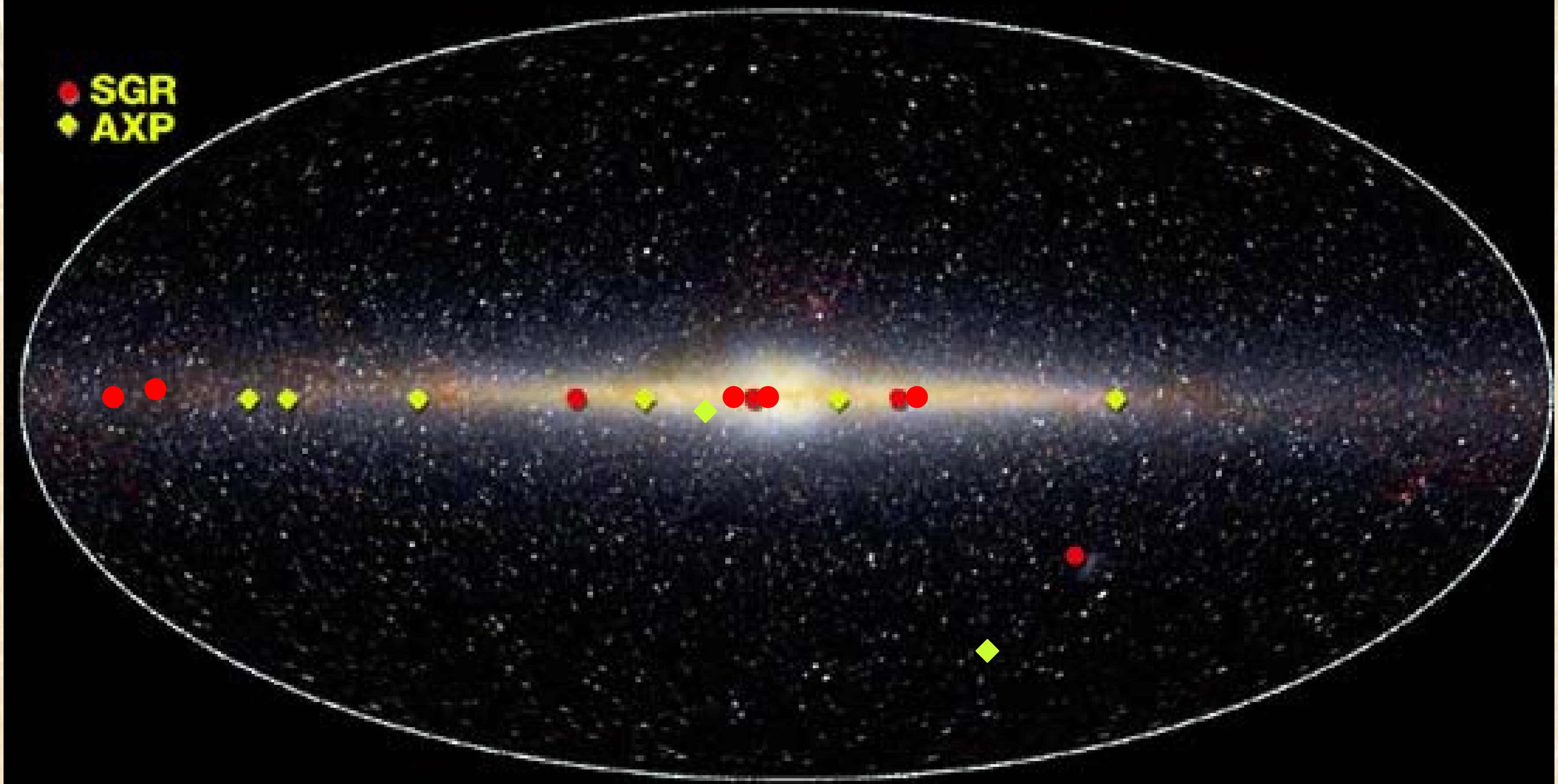


Gogus et al 2010

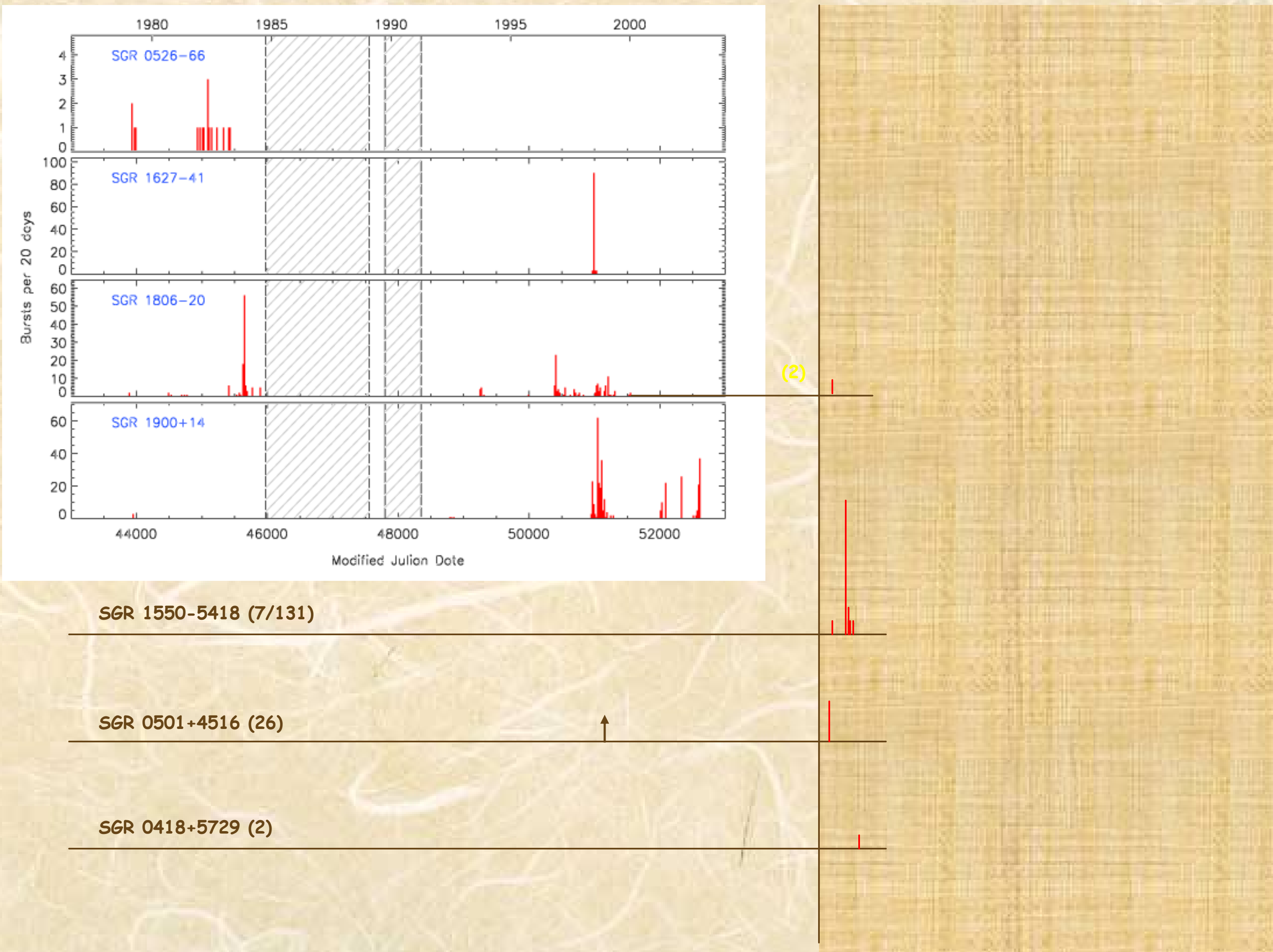


Period Derivative (sec sec⁻¹)
Spin Period (sec)
B = 10¹⁴ G
B = 10¹³ G
B = 10¹² G
B = 10¹⁰ G
PSR J1846-0258
SGR 0418+5729
SGR 1833-0832
SGR 0501+4516
– Radio Pulsar
– SGR
– AXP
0.0010
0.010
0.10
1.0
10.
10⁻¹⁰
10⁻¹²
10⁻¹⁴
10⁻¹⁶
10⁻¹⁸
10⁻²⁰

Magnetar Candidates



SGR burst time history with Fermi/GBM



CONCLUSIONS II

We still do not understand the differences – if any – between AXPs, SGRs and rotationally powered pulsars, in:

persistent emission spectra

glitching properties

magnetic field strengths

burst fluences and spectra

The associations of magnetars with SNRs, and their environments and track possible proper motions, now with two best candidates

The progenitor properties of magnetars, such as mass and cluster memberships

Could we identify PRE in magnetar flares and probe the neutron star EOS?