On Magnetar Bursts

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The GBM Magnetar Team

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- A. Watts, A. van der Horst, D. Huppenkothen, M. van der Klis, R. Wijers, T. van Putten (U. of Amsterdam, The Netherlands)
- M. Baring (Rice University, USA)
- J. Granot (The Open University, Israel)
- E. Ramirez-Ruiz (UCSC, USA)
- J. McEnery, N. Gehrels (NASA/GSFC, USA)

Magnetars are magnetically powered NS

- 26 sources to date – six in 2008-2013 – All but two (LMC, SMC) are MW sources

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

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

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

- $B \sim [1\text{-}10] \times 10^{14}$ G (mean surface dipole field: $3.2 \times 10^{19} \sqrt{P\dot{P}}$) ; SGR J0418+5729 with $B < 7.5 \times 10^{12}$ G, SGR 1822.3-1606->$B \sim 2.7 \times 10^{13}$ G

- Luminosities range from $L \sim 10^{32-36}$ erg/s

- No evidence for binarity

- SNe associations

NS populations comprising Magnetars

Soft Gamma Repeaters (SGRs)

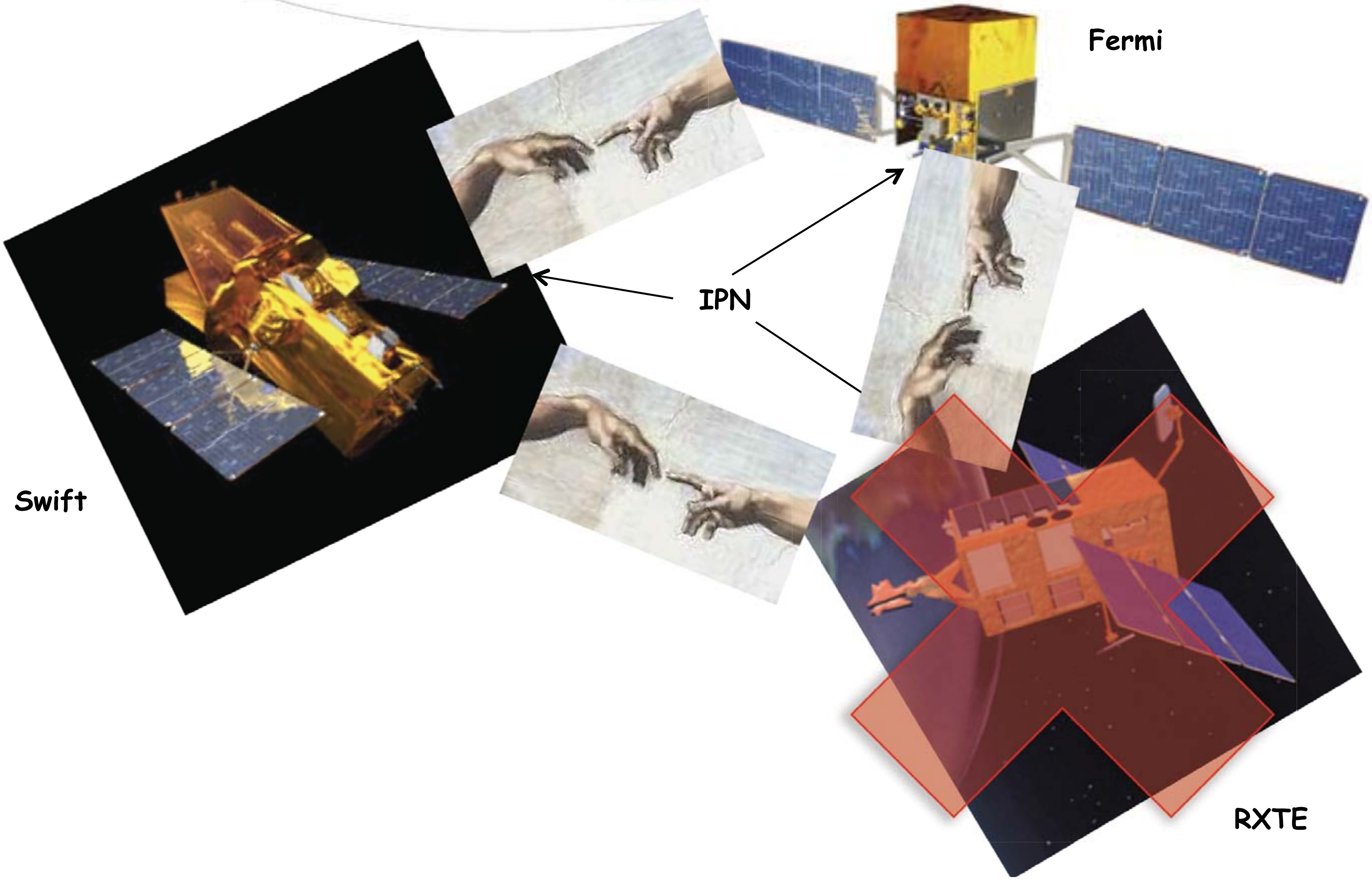
Anomalous X-ray Pulsars (AXPs)

Dim Isolated Neutron Stars (DINs)

Compact Central X-ray Objects (CCOs)

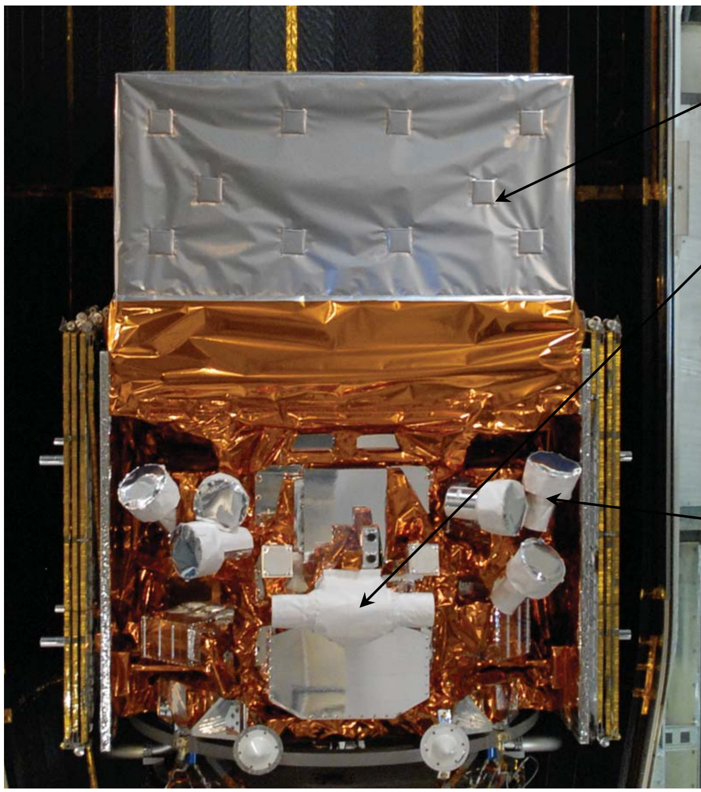
Rotation Powered Pulsars (PSRs J1846–0258 & J1622-4950)

2008-2013: Good years for Magnetars!



The Gamma-ray Burst Monitor

- 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
Triggering, Spectroscopy
Bridges gap between NaI and LAT.

GBM NaI detector.
8 keV -- 1000 keV
126 cm^2, 1.27 cm
Triggering, Localization, Spectroscopy.

GBM 5-yr Magnetar Burst Catalog

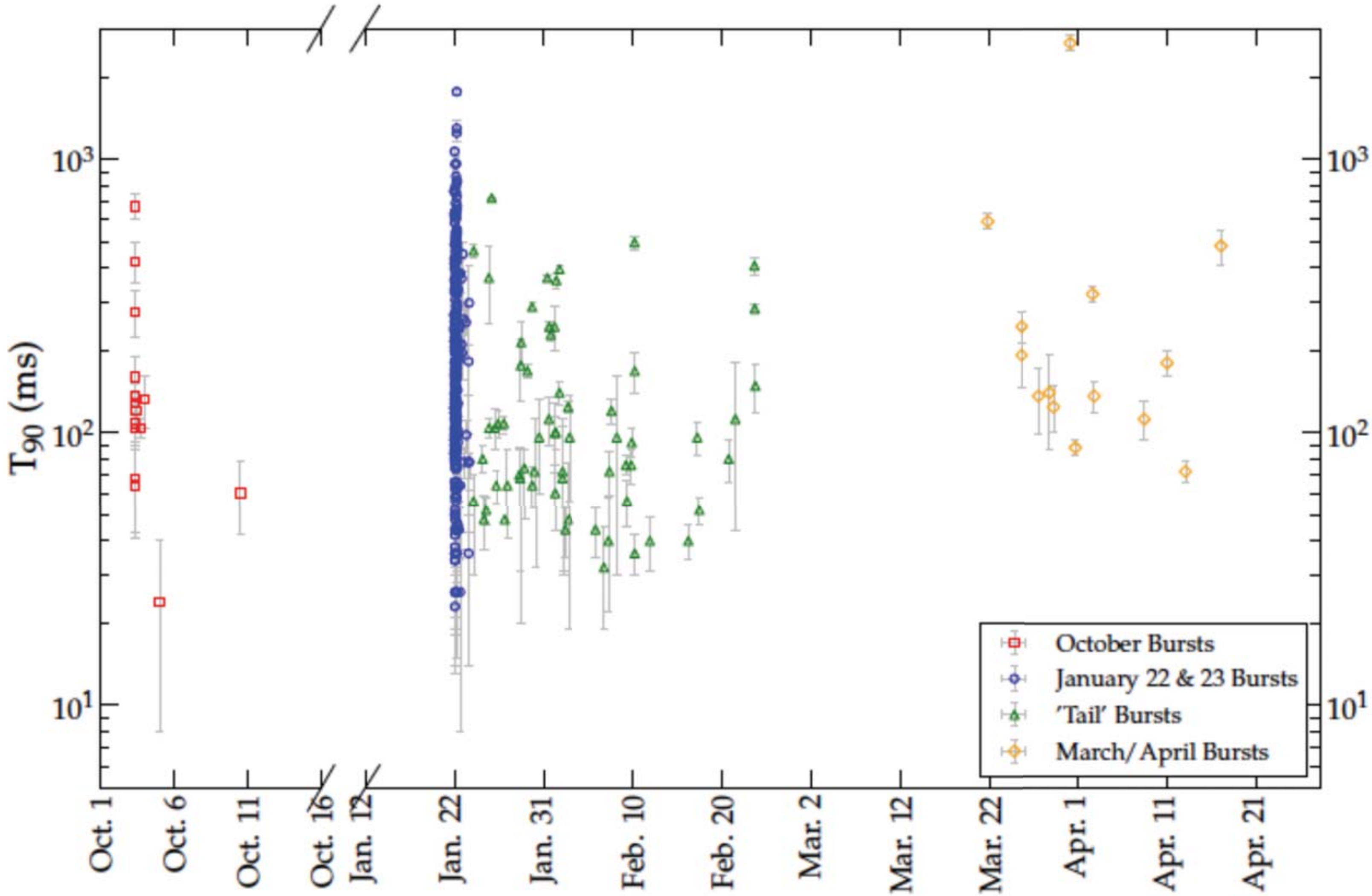
Collazzi et al., 2014

Magnetar	Active Period	Triggers	Comments
SGR J0501+4516	Aug/Sep 2008	26	**New source** at Perseus arm
SGR J1550-5418	Oct 2008 Jan/Feb 2009 Mar/Apr 2009 June 2013	7 331 + 14 1	Known source – first burst active episodes
SGR J0418+5729	June 2009	2	**New source** at Perseus arm
SGR 1806-20	Mar 2010	1	Old source - reactivation
AXP 1841-045	Feb 2011 June/July 2011	3 4	Known source – first burst active episodes
SGR 1822-1606	July 2011	1	**New source** in galactic center region
AXP 4U0142+61	July 2011	1	Old source - reactivation
1E 2259+586	April 2012	1	Old source - reactivation
Unconfirmed Origin	2008-2013	21	Error boxes contain several source candidates

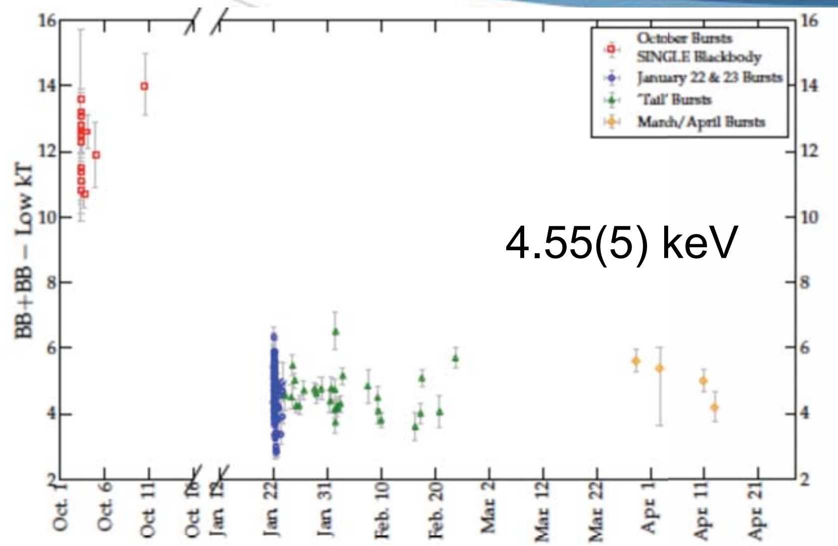
SGR J1550-5418
formerly known as AXP 1E1547.0-5408
formerly known as an ASCA CCO in G327.0-0.13

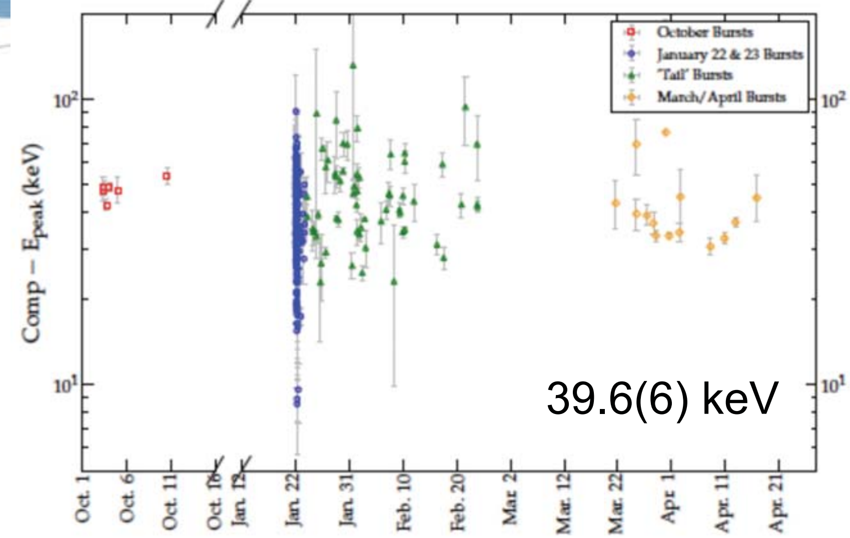
- $P = 2.069s$
- $\dot{P} = 2.318 \times 10^{-11}$ s/s and $B = 2.2 \times 10^{14}$ G
- Near IR detection, Ks = 18.5±0.3
- GBM triggered on 132 events from the source in three episodes; 2008 October, 2009 January & March. One more burst 2013 June.
- Only three other sources have exhibited in the past such "burst storms": SGR 1806-20, SGR 1900+14, SGR 1627-41
- T_{90} burst duration = 155 (10) ms for 353 (unsaturated) bursts

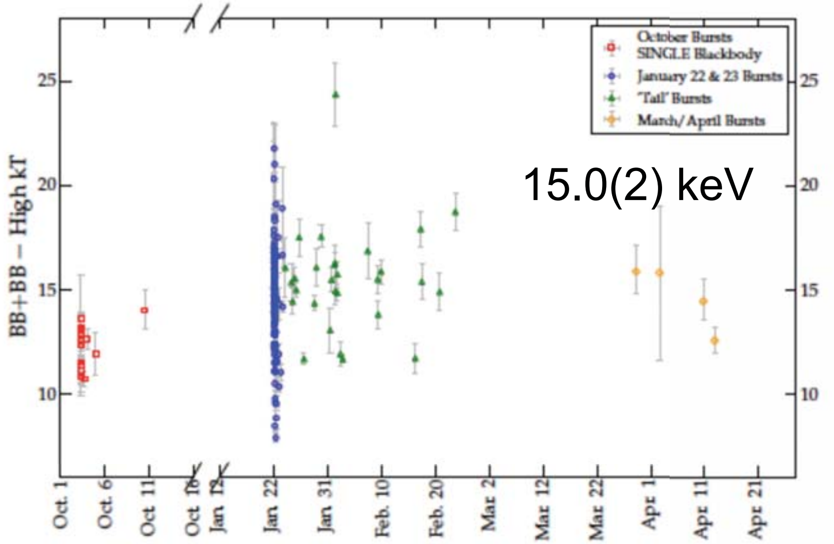
SGR J1550 – 5418: Temporal

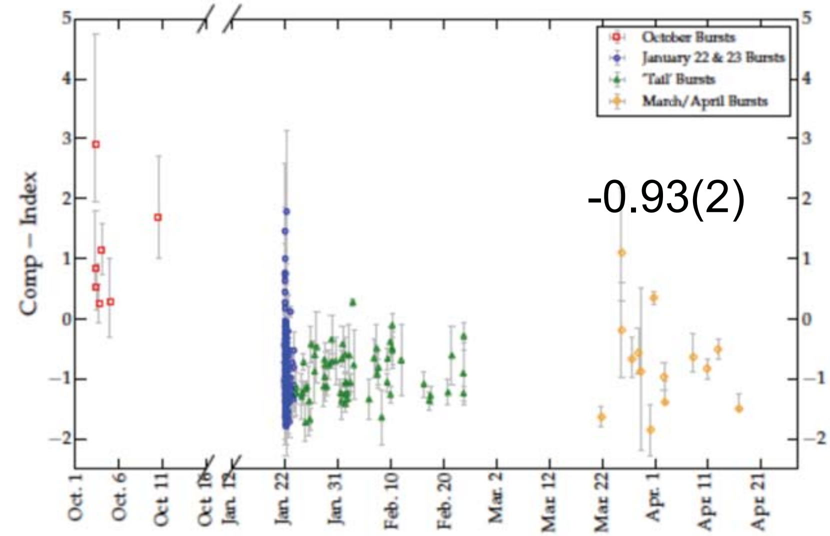


SGR J1550 – 5418: Spectral









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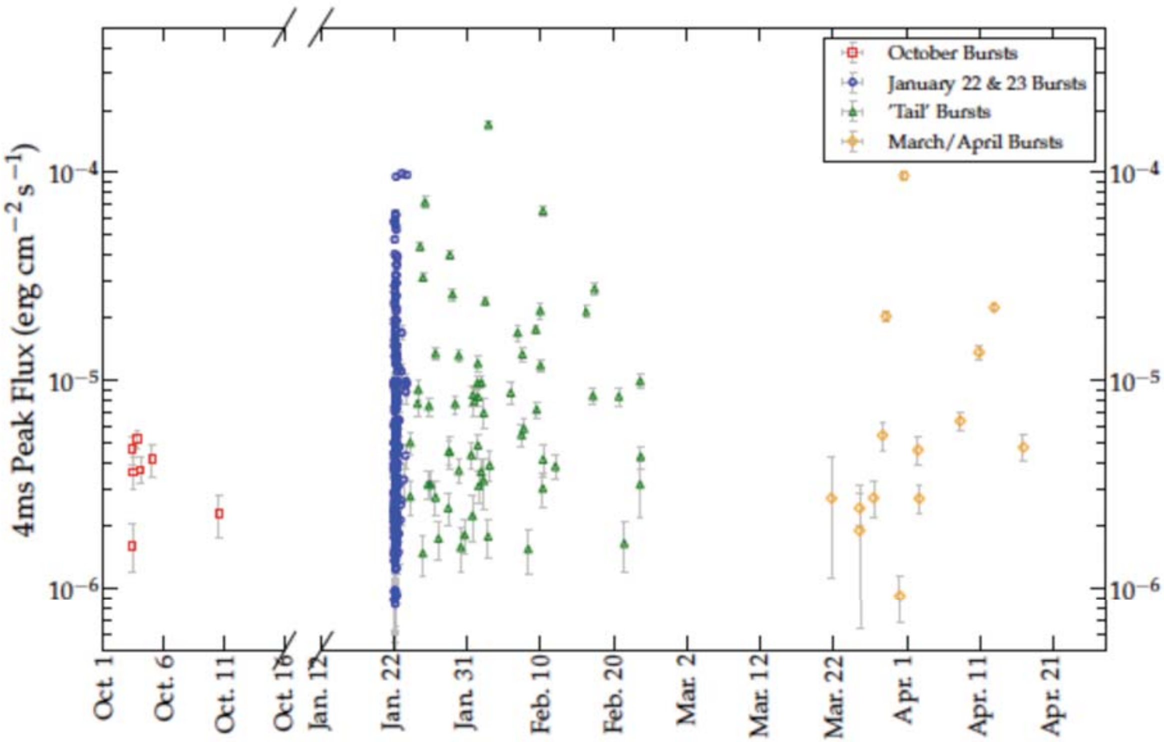
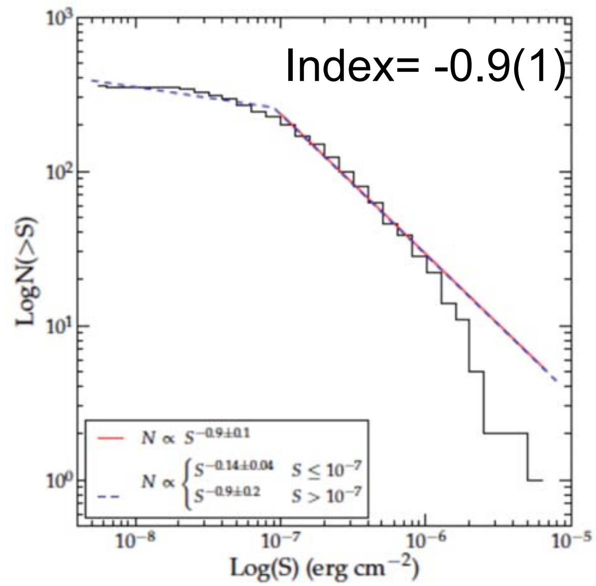
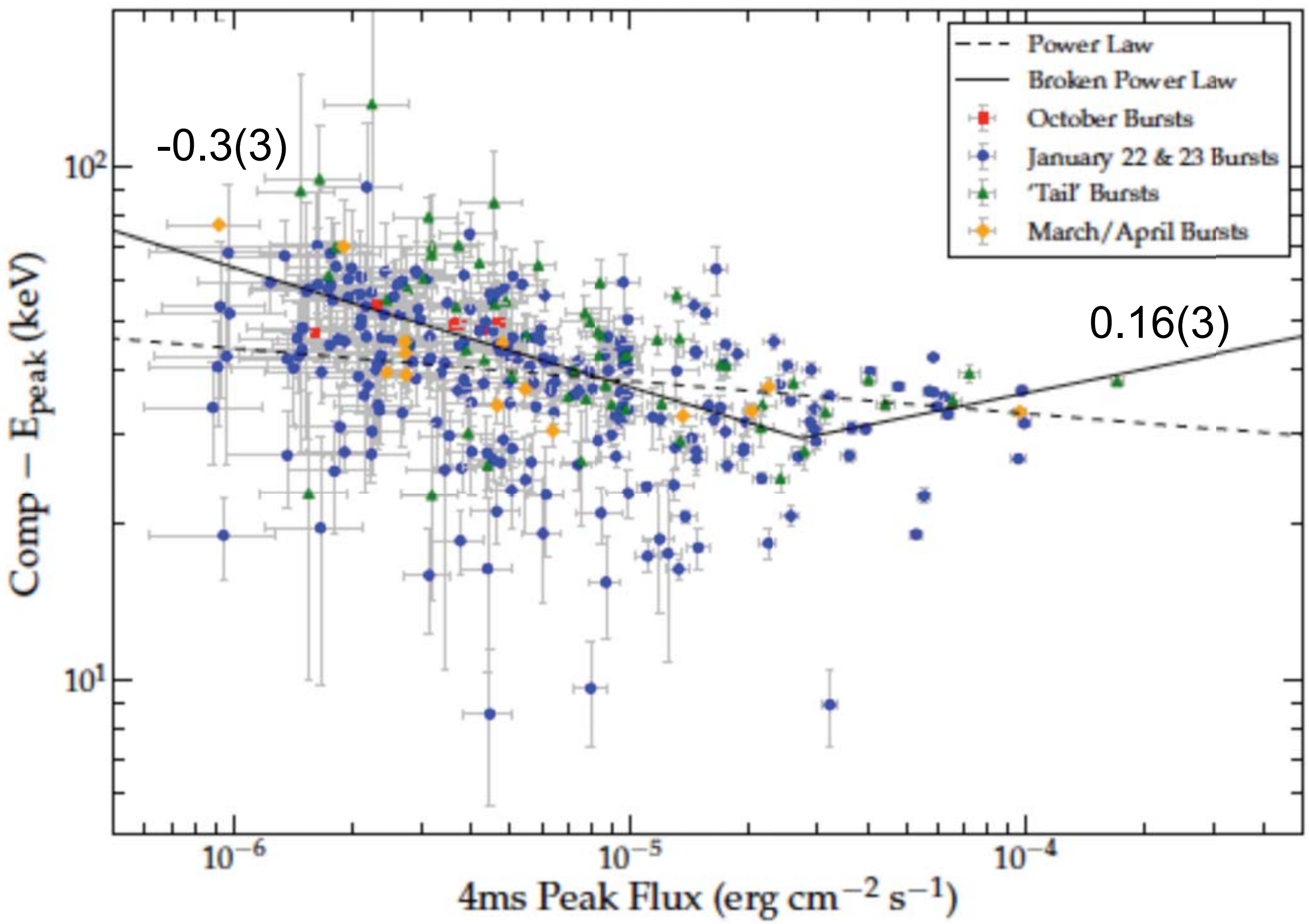


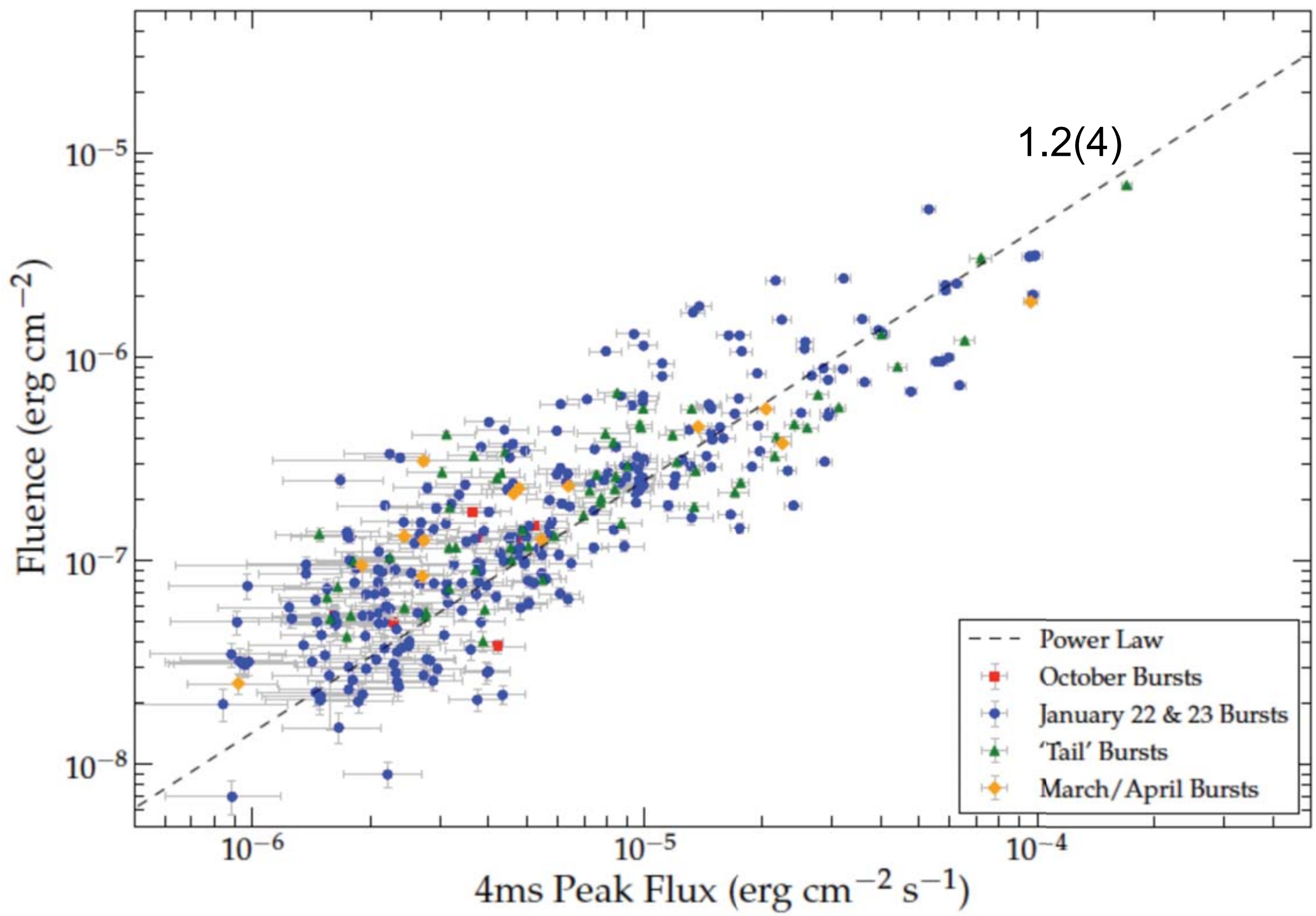


SGR J1550 – 5418: Correlations

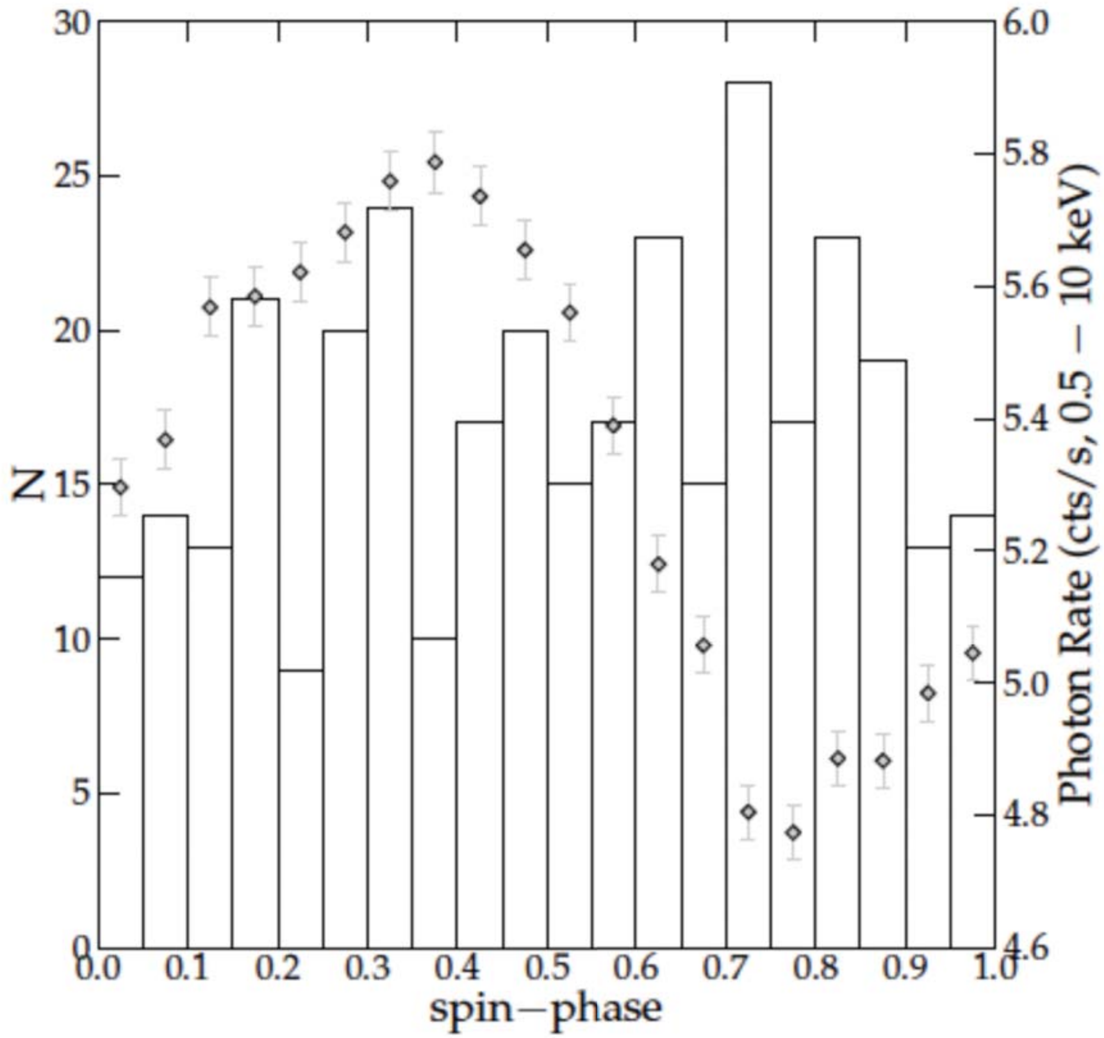


- GBM data → E_{peak} as hardness indicator. More accurate than hardness ratios
- Large flux/ fluence range: not a simple (anti-) correlation?
- Similar to SGRs J0501+4516, 1806-20, 1900+14

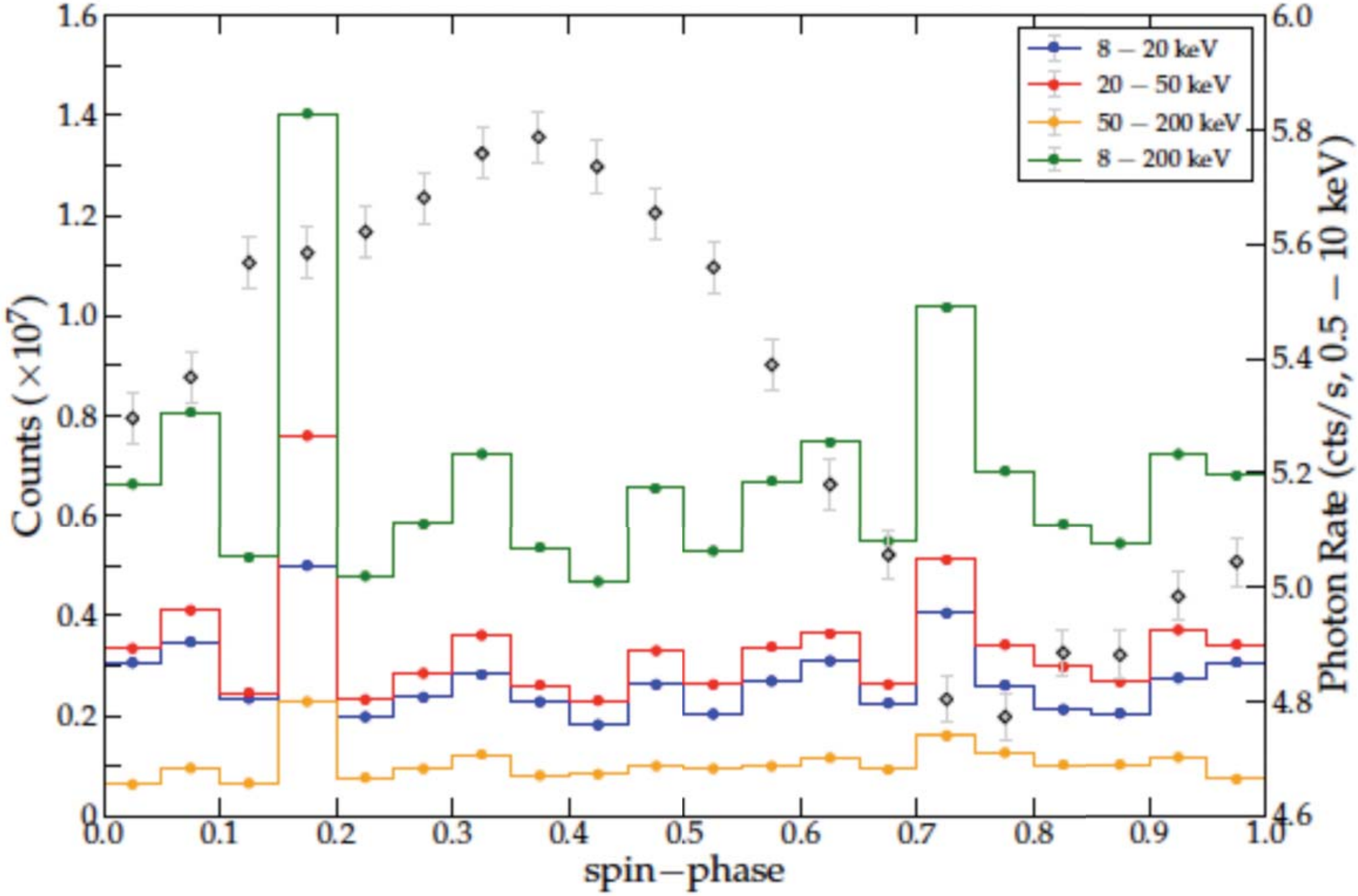
SGR J1550 – 5418: Correlations



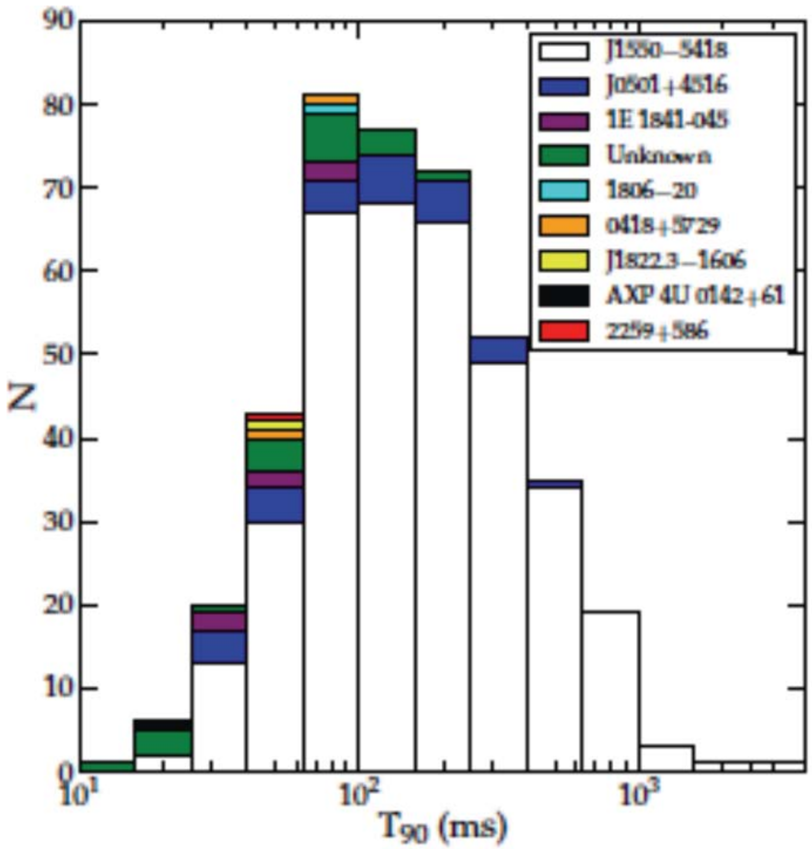
SGR J1550 – 5418: phase correlations

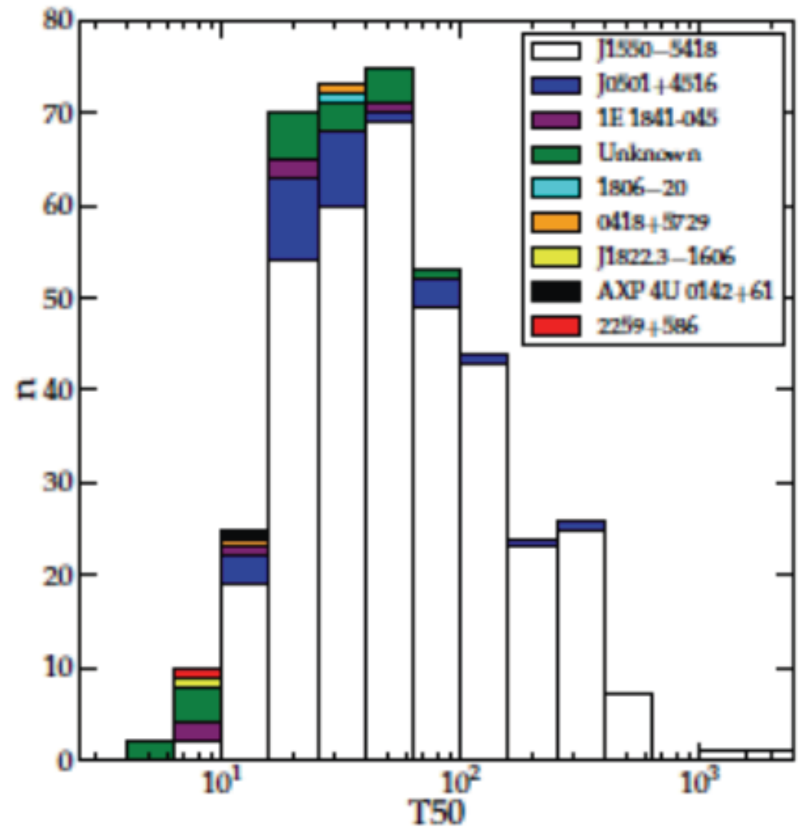


SGR J1550 - 5418: phase correlations



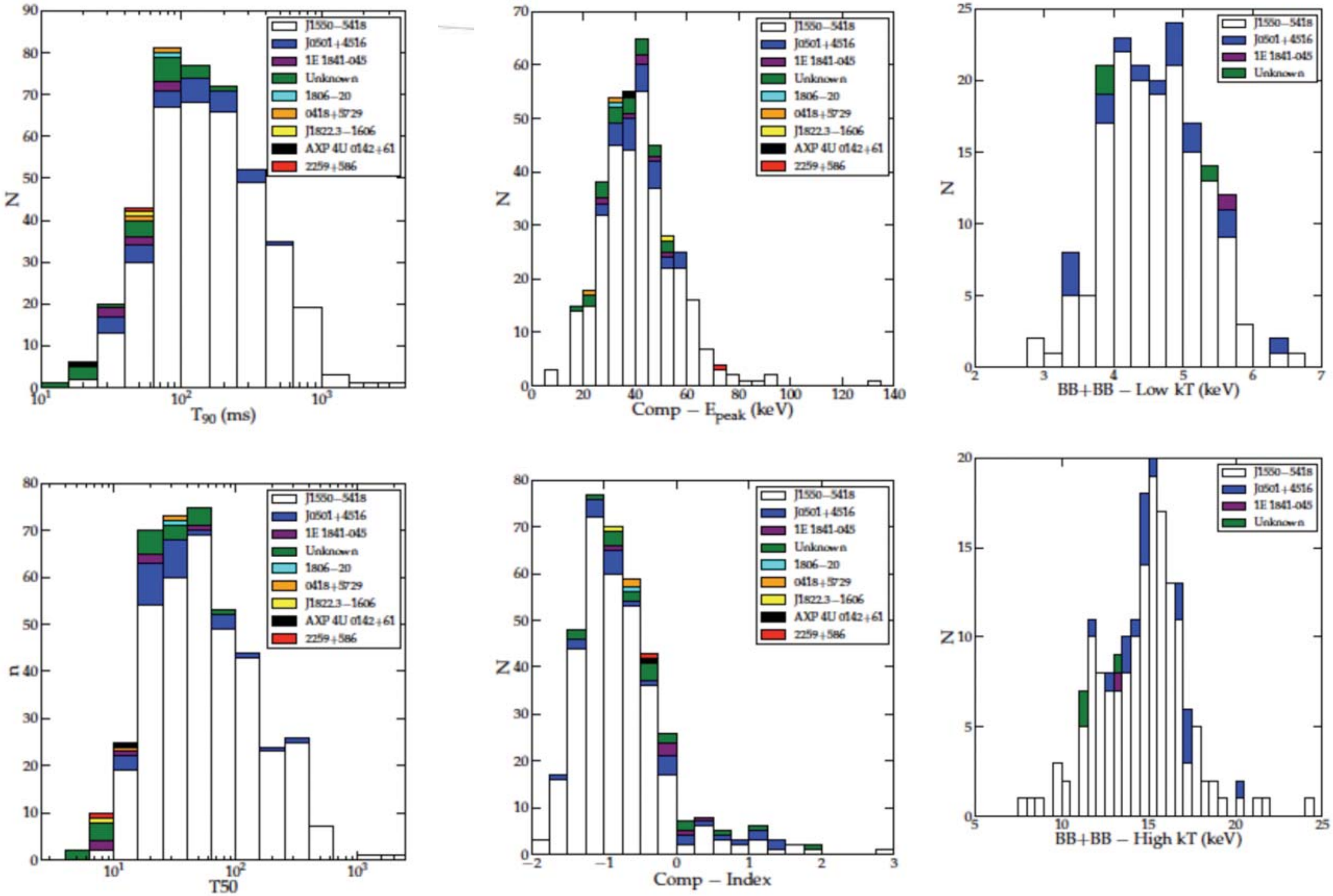
All triggers: temporal properties



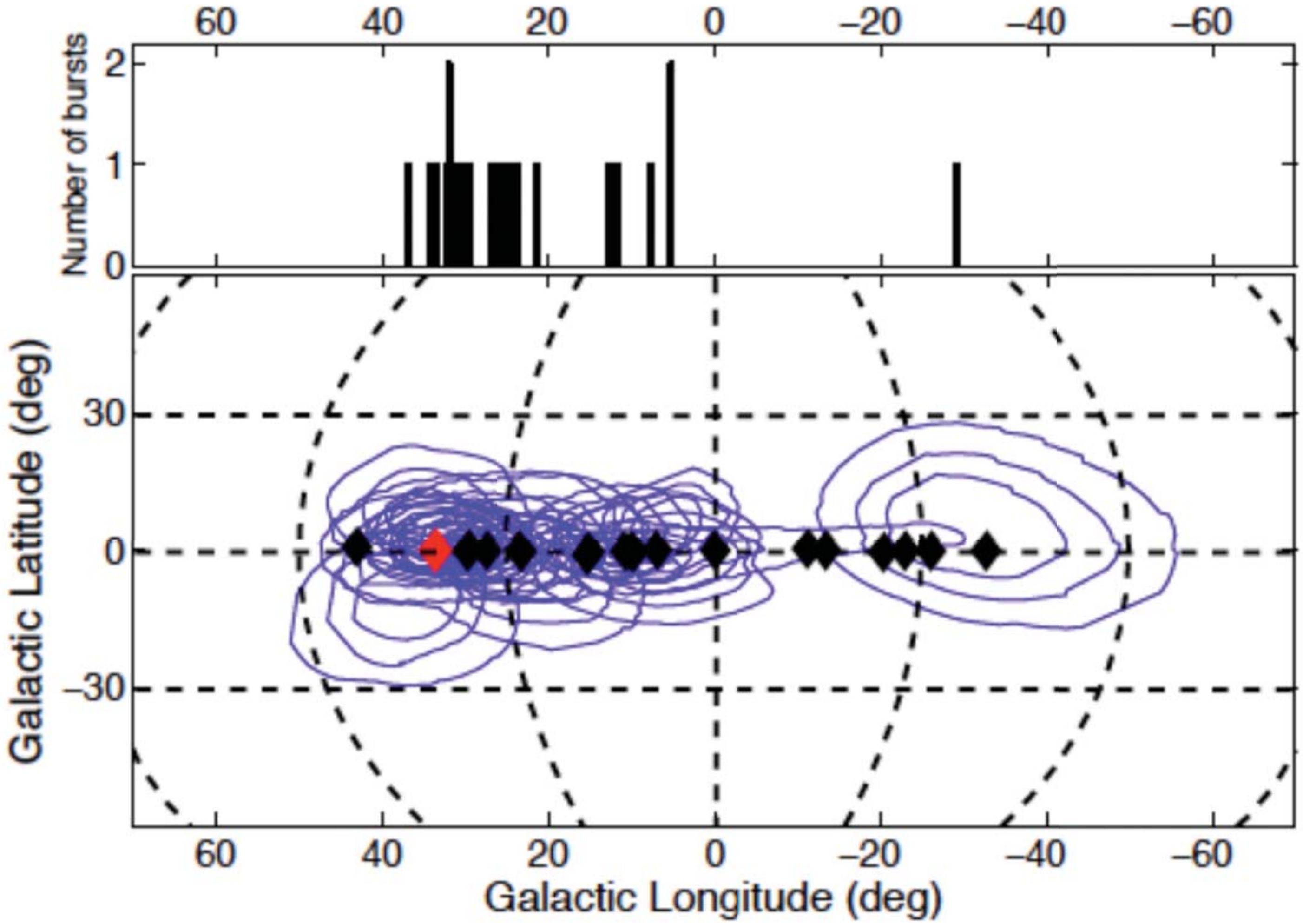


Unknown event avg T_{90} = 61 ms (known avg ~100 ms)

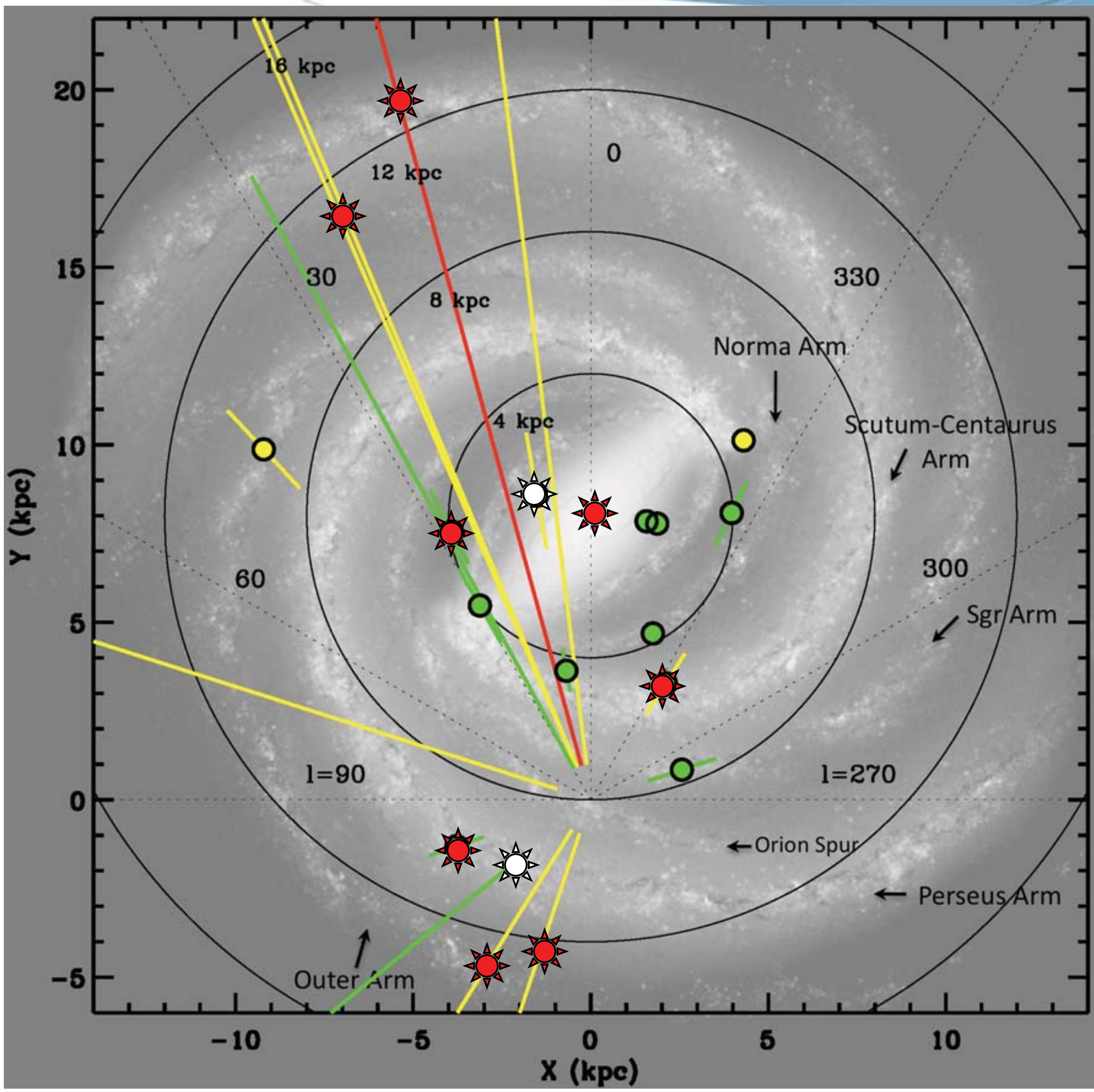
All triggers: comparative properties



Unknown source locations



Magnetar Distribution in our Galaxy



NEW: GBM Bursts detected since Fermi launch SYNERGY: Swift-Fermi-RXTE-IPN

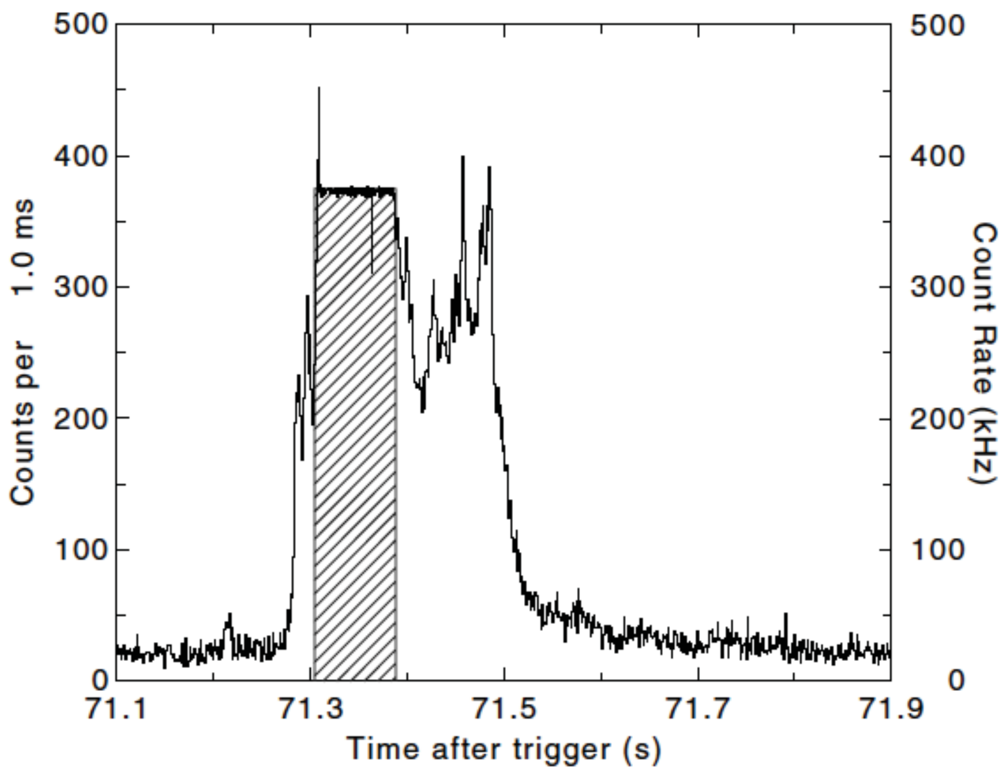
Old source reactivation

SGRs

AXPs

Kouveliotou et al. 2011

SGR J1550-5418 — Example of a burst



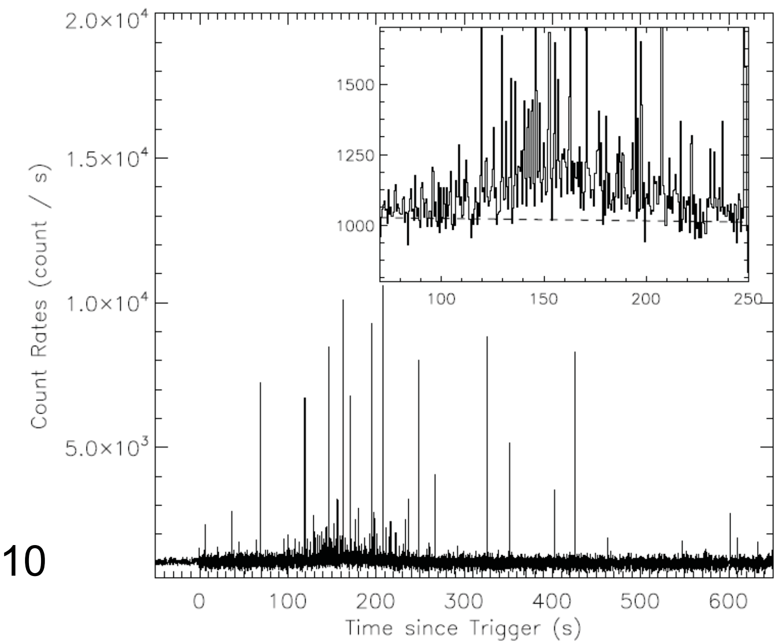
- GBM Burst example for SGR J1550-5418.
- Saturation periods clearly seen. Excluded from all analyses.

SGR J1550-5418

- $P = 2.1\ s, \dot{P} = 2.32 \times 10^{-11}\ s^{-1}$
- $\Rightarrow B \sim 2.1 \times 10^{14}$ G

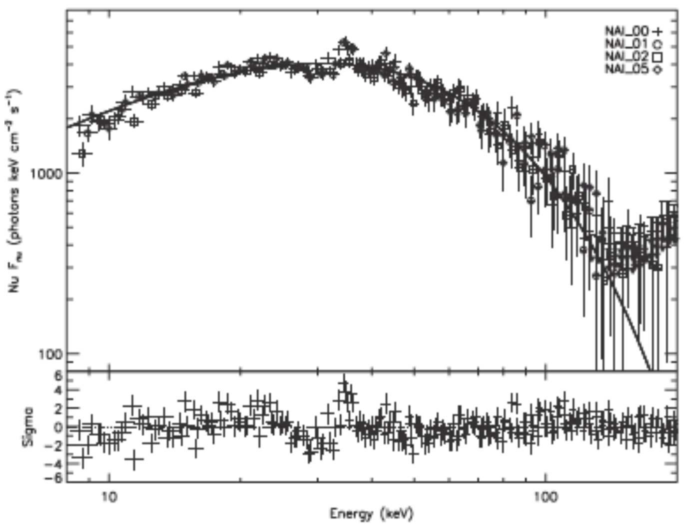
- Entered high level of activity in 2008-2009
  - Hundreds of bursts on 22 January 2009 seen with many high-energy instruments, e.g., FERMI/GBM (van der Horst et al. 2012)

Kaneko et al. 2010



SGR J1550-5418 — Spectral modeling

GBM-only fit, 8-200 keV



Power-law with high energy exponential cutoff

Classical Comptonization problems

$$< E_{\rm peak} > \approx 40 \text{ keV}, < \gamma > \approx -1$$

$$\gamma = 1/2 - (9/4 + 4/y_{\rm B})^{1/2}$$

$$y_{\rm B} = (4kT_{\rm e}/m_{\rm e}c^2)\max\{\tau_{\rm B}, \tau_{\rm B}^2\}$$

Ribicki & Lightman (1979)

SGR J1550-5418 — Spectral modeling

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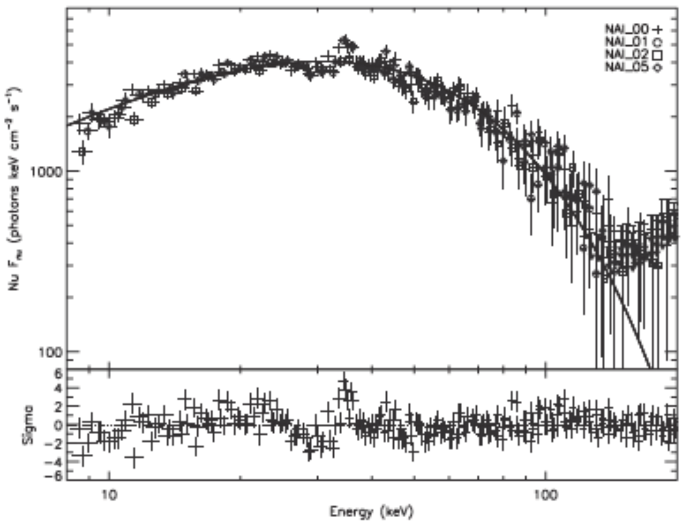

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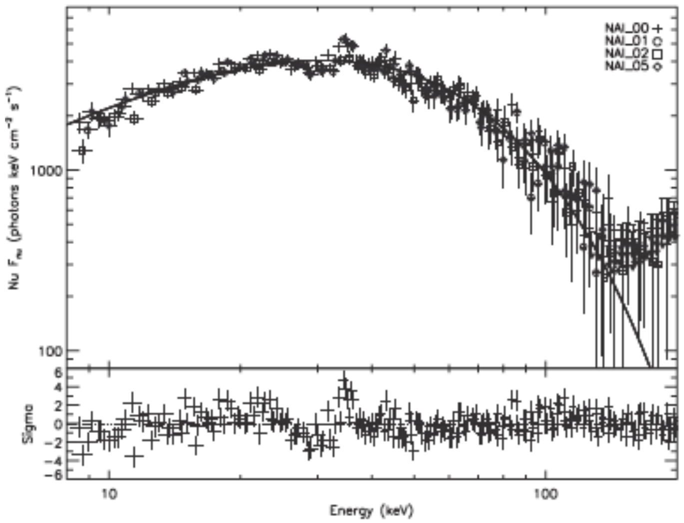
Ribicki & Lightman (1979)

$\tau_{\rm B} >>$ to accomplish such a spectral curvature → will lead to thermalization

SGR J1550-5418 — Spectral modeling



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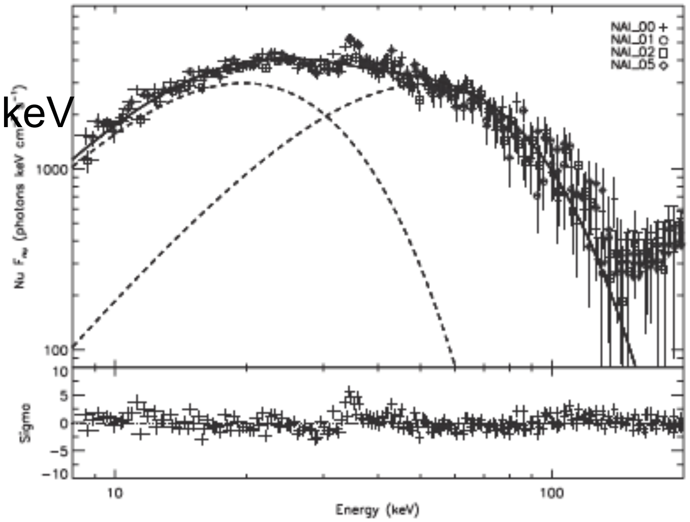

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to accomplish such a spectral curvature

$\tau >>$ ➡ will lead to thermalization

Two thermally emitting regions, 2BB

$$kT_{\rm high} \approx 13\ {\rm keV}, kT_{\rm low} \approx 6\ {\rm keV},$$

$$R_{\rm high\_kT} \approx 0.3, R_{\rm low\_kT} \approx 17\ {\rm km}$$

$$R^2 = FD^2/\sigma T^4$$

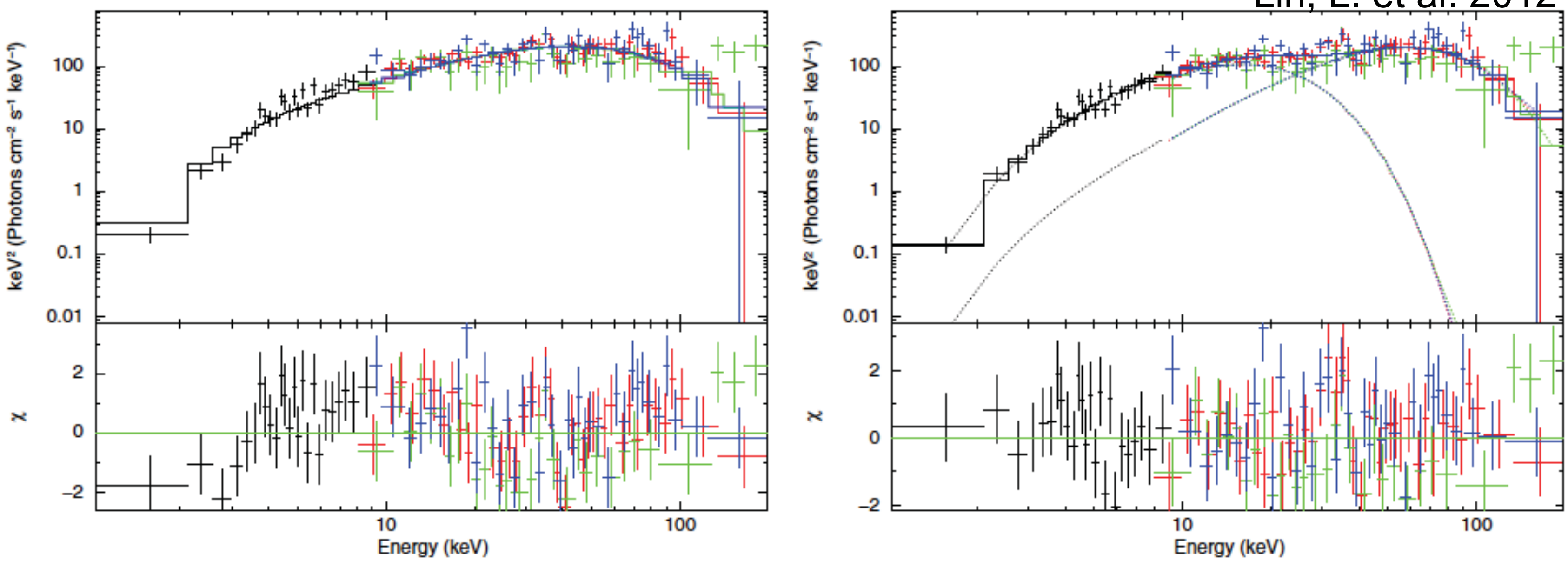
Could be thought of as footpoints and surface layer of fireball

$$P = 2 - 12\ {\rm s}, P = 10^{-11} - 10^{-13}\ s\ s^{-1}$$

SGR J1550-5418 — Spectral modeling

GBM+Swift fit, 1-200 keV

Lin, L. et al. 2012



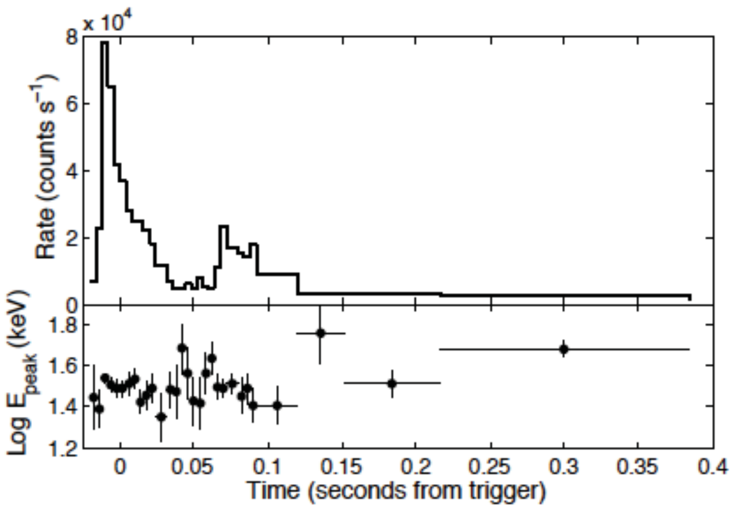
Low-energy residuals with the Comptonized model
Perfect fit with the 2BBs

2BBs spectral parameters consistent with GBM only fits

SGR J1550-5418 — Spectral modeling

Time resolved spectroscopy of 50 brightest bursts

- Fit each bin with Comp. model.
- Follow evolution of fit parameters



$$P = 2 - 12 \text{ s}, \dot{P} = 10^{-11} - 10^{-13}\ s\ s^{-1}$$

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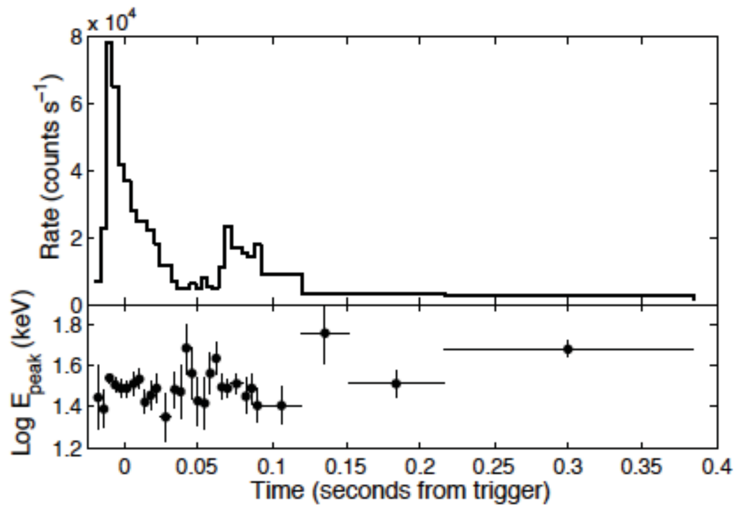

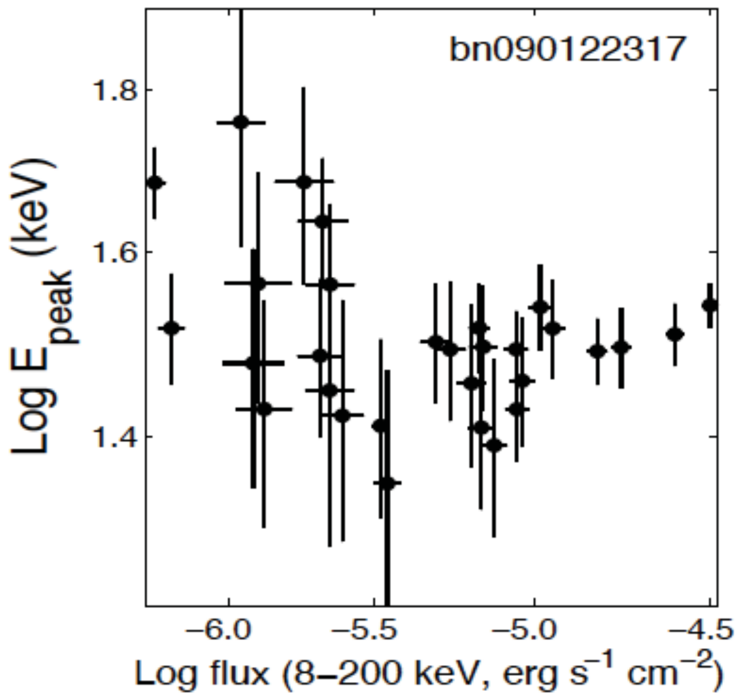

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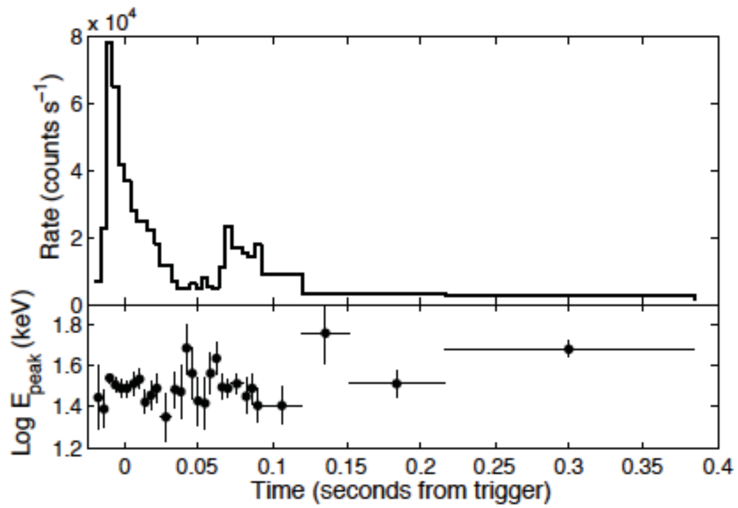

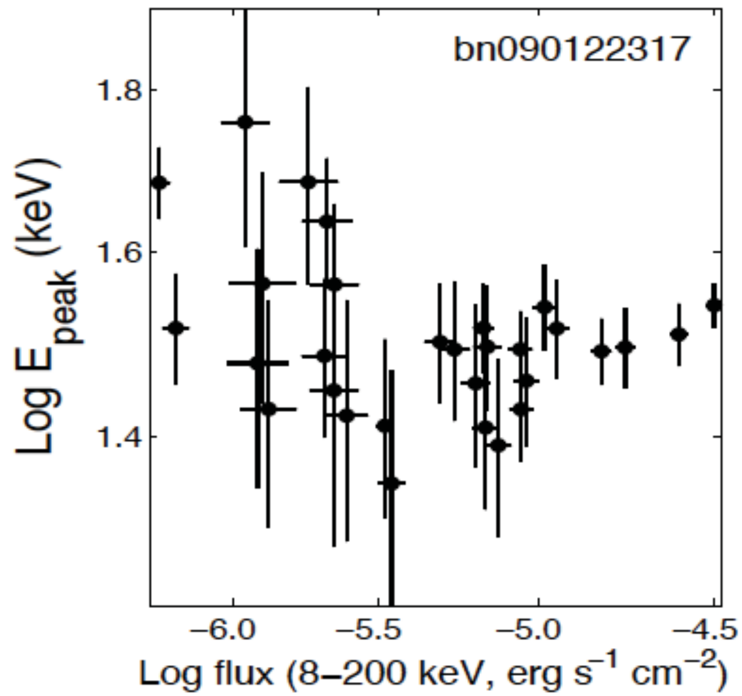

Similar spectral evolution for all 50 bursts.

Look for correlations of all 50 bursts

simultaneously

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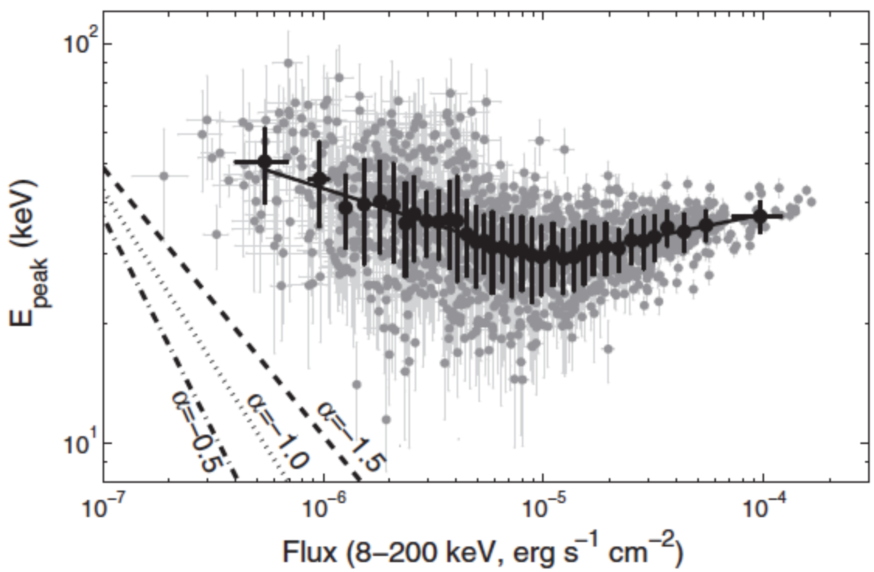
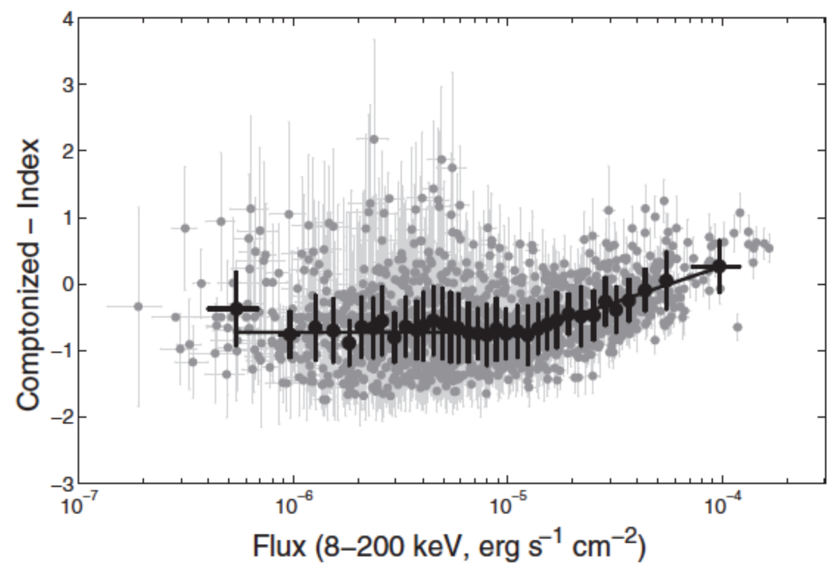


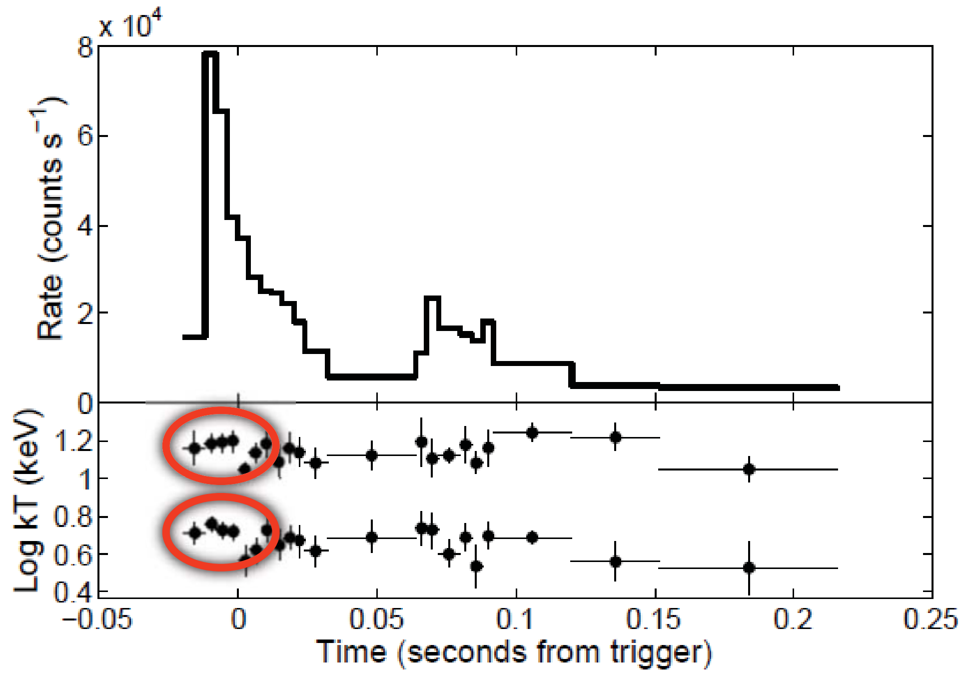


Index $\gamma > -1$!!!

SGR J1550-5418 — Spectral modeling

Time resolved spectroscopy of 50 brightest bursts

- Fit each bin with 2BB model.
- Follow evolution of fit parameters



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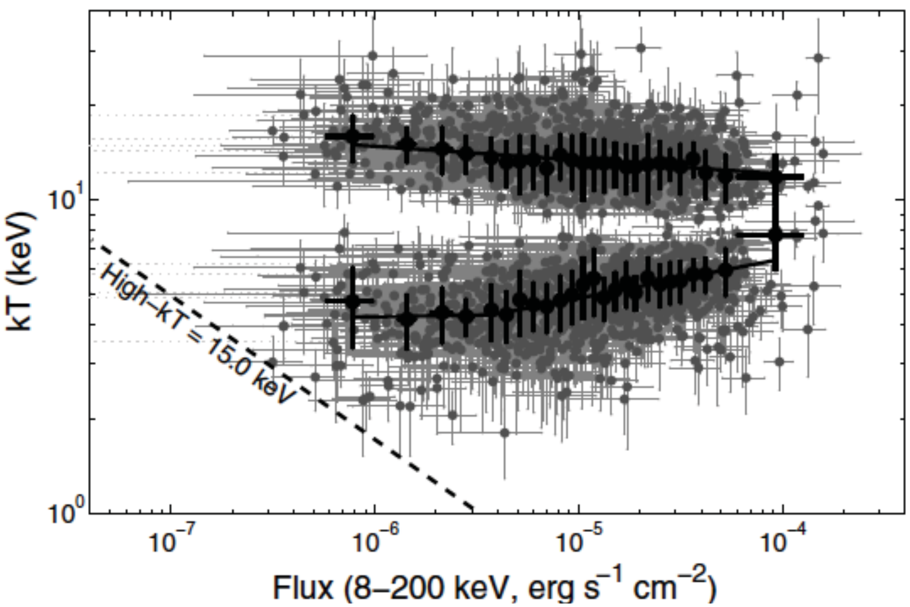

$< \mathrm{High\_kT} > \sim 13$ keV

$< \mathrm{Low\_kT} > \sim 6$ keV

Younes et al. 2014, ApJ., 785,52

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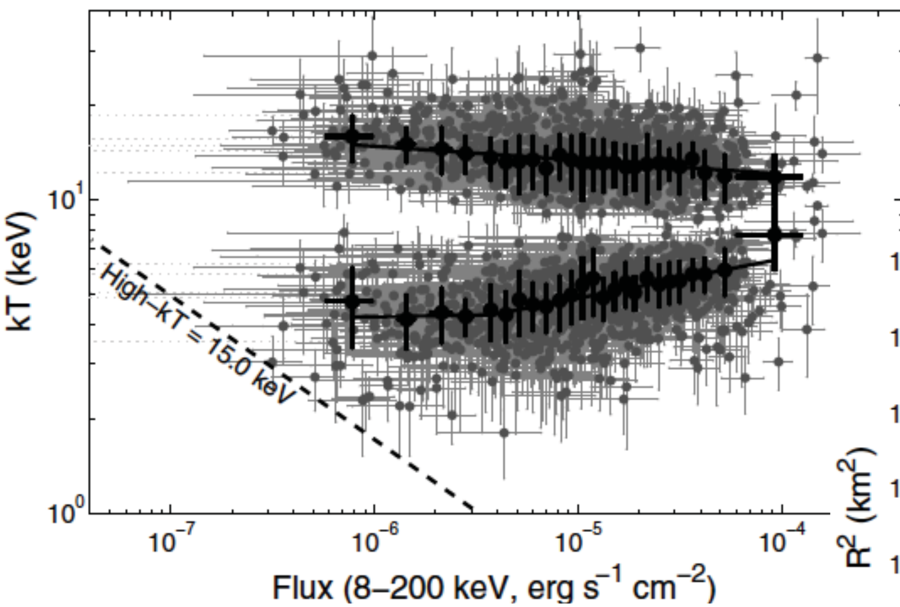
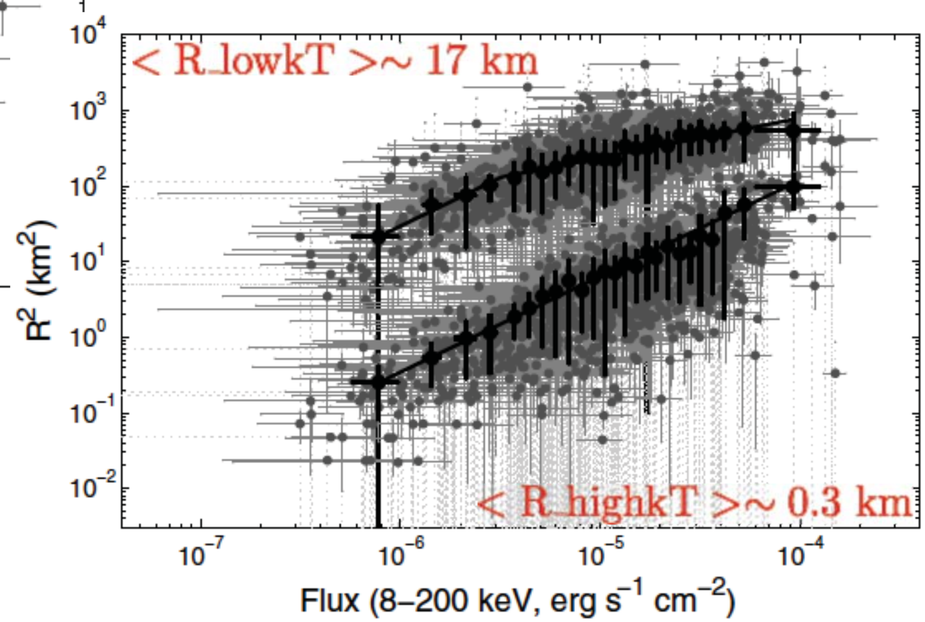


< High_kT >~ 13 keV

< Low_kT >~ 6 keV



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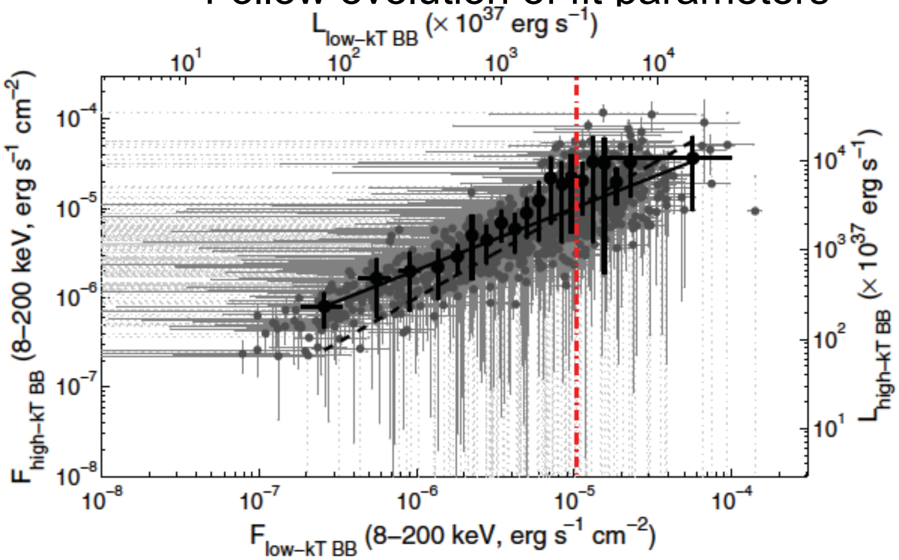

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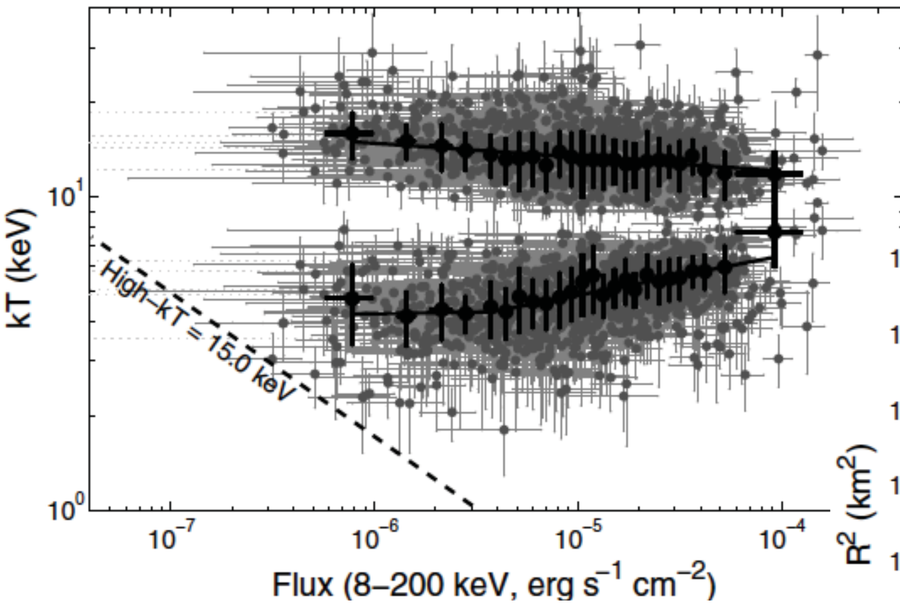

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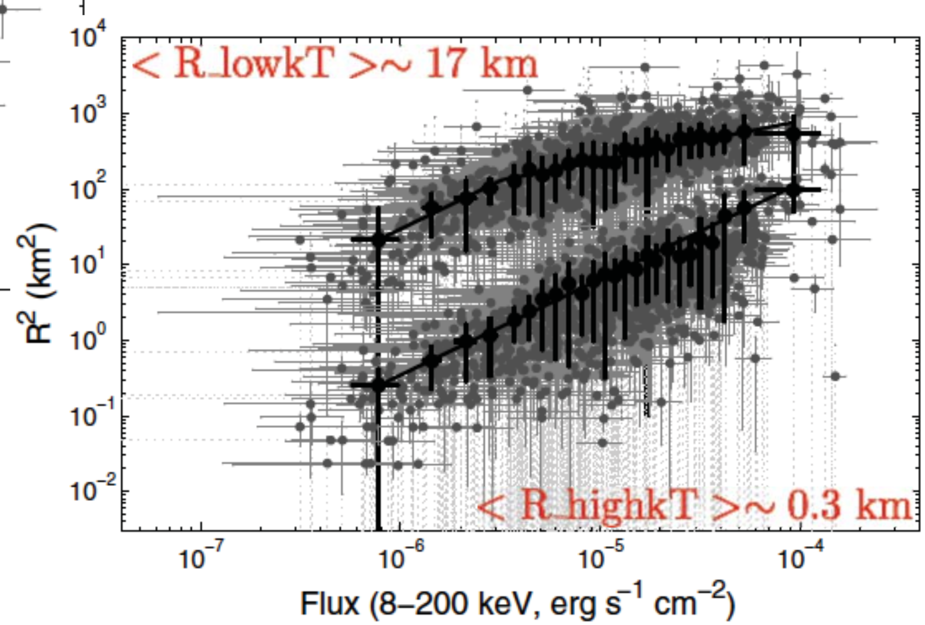

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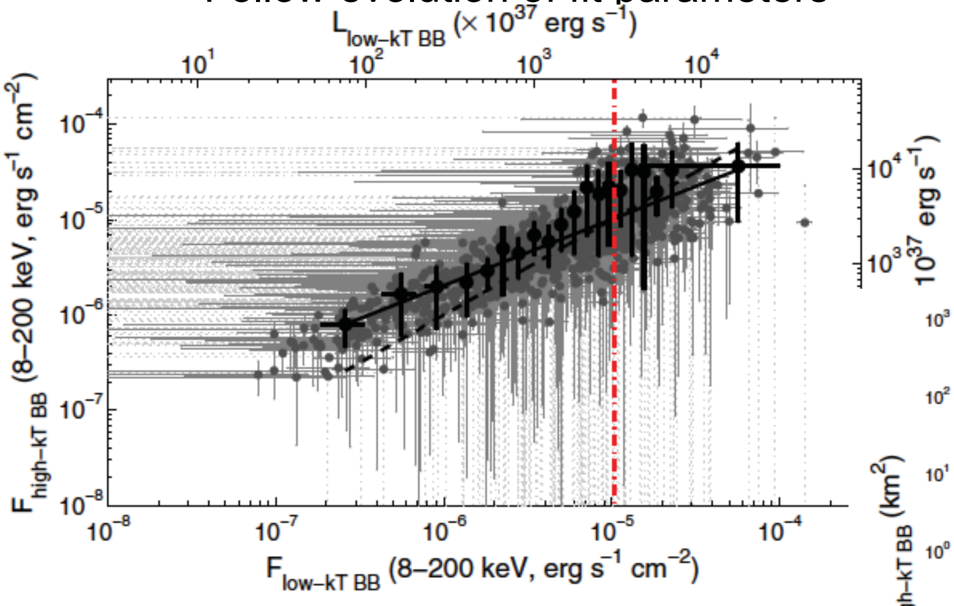

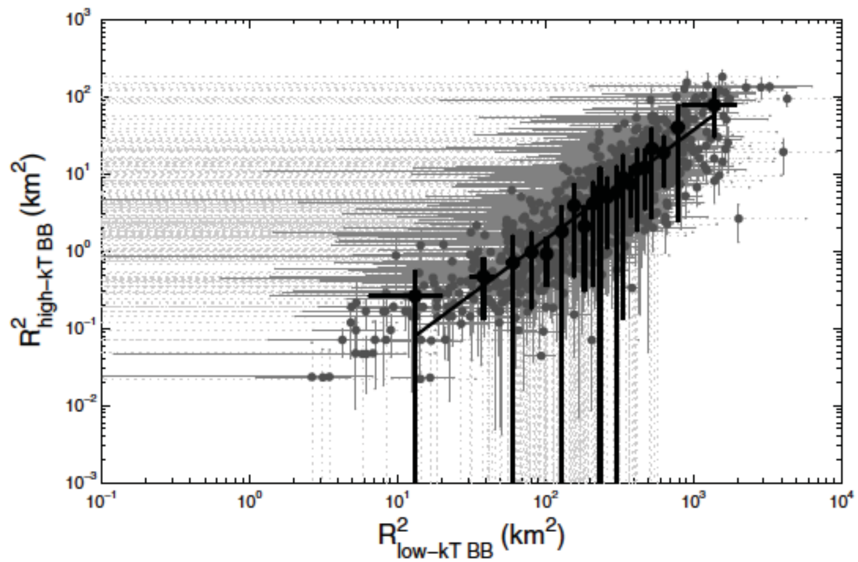

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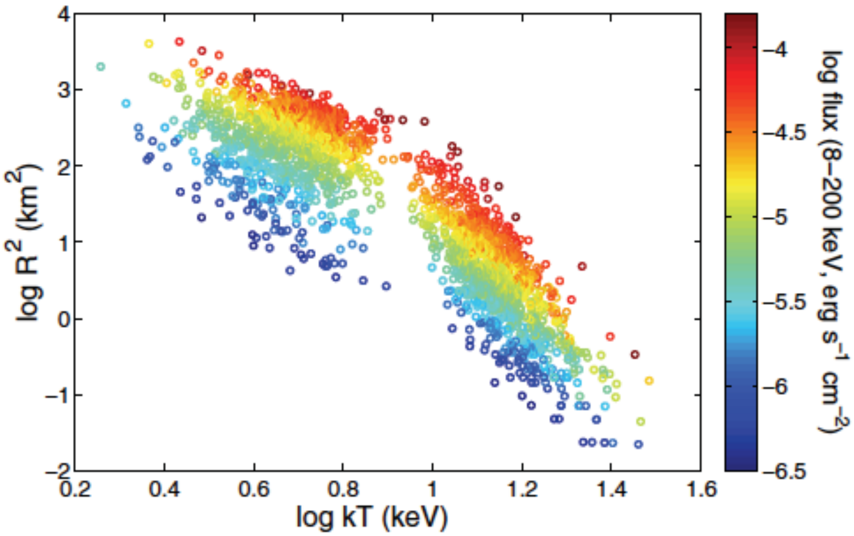

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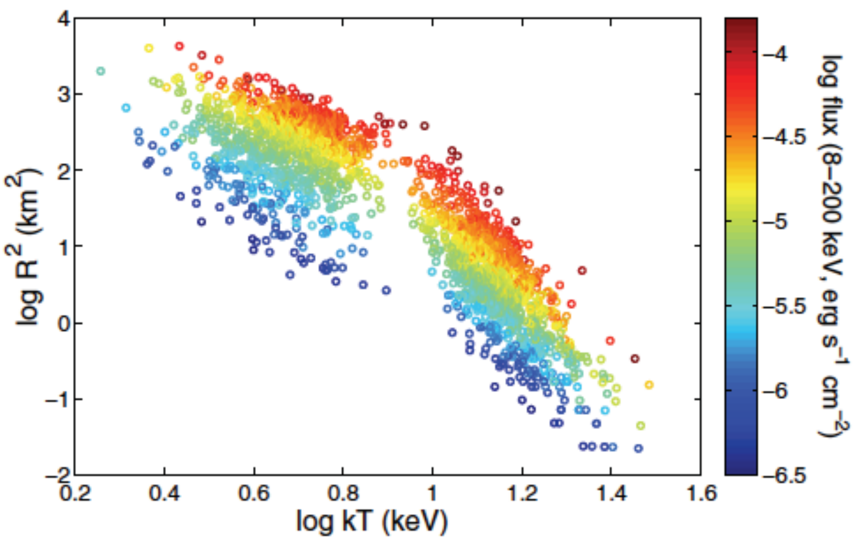

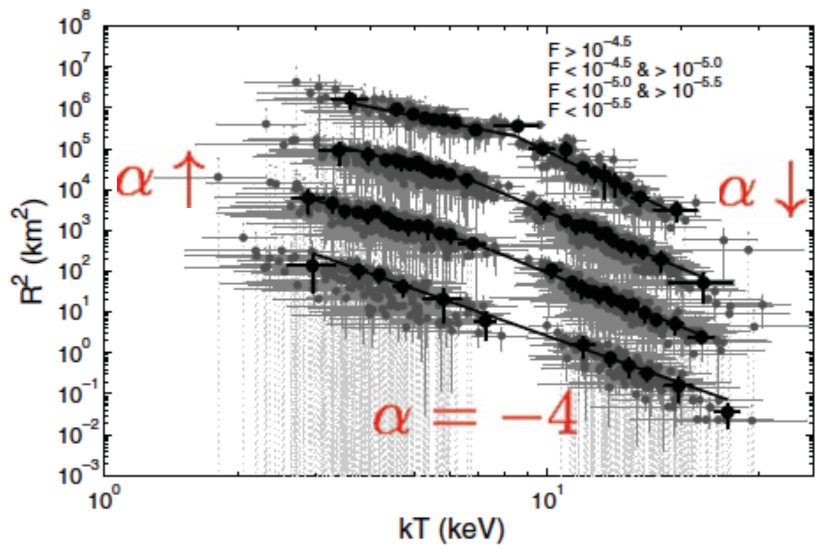

Flux Range (erg s^{-1} cm^{-2})	Slope below $kT_{\rm break}$	Slope above $kT_{\rm break}$	$kT_{\rm break}$ (keV)
$F > 10^{-4.5}$	-2.2 ± 0.3	-5.3 ± 0.4	9 ± 1
$10^{-5.0} < F < 10^{-4.5}$	-2.8 ± 0.3	-4.6 ± 0.4	7 ± 1
$10^{-5.5} < F < 10^{-5.0}$	-3.0 ± 0.3	-4.4 ± 0.5	7 ± 1
$F < 10^{-5.5}$	-3.8 ± 0.4[a]		

Note. [a] A single PL fit to the data.

Younes et al. 2014, ApJ., 785,52

SGR J1550-5418 — Spectral modeling

Time resolved spectroscopy of 50 brightest bursts

- Two thermally emitting regions during bursts
  - Highly coupled with energy equipartition between the two
  - kT_high: adiabatically expanding/contracting region — Could be thought of as the footprints of the plasma fireball.
  - kT_low: more complicated to interpret! — Representing the outer surface layer of the plasma?
  - $R^2 - kT^4$ relation places the plasma close to the surface of the NS.

Younes et al. 2014, ApJ., 785,52

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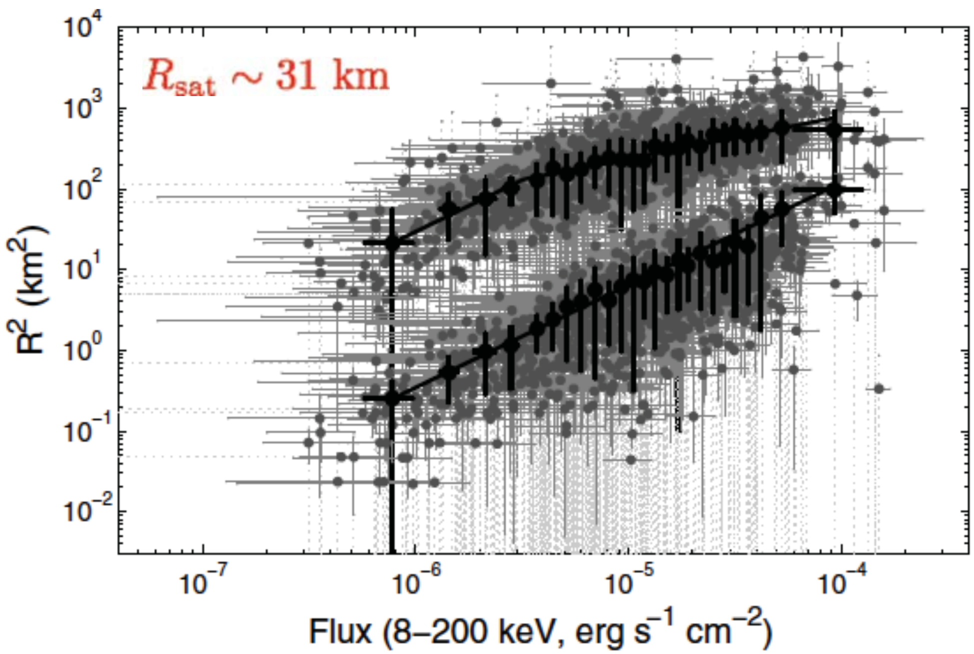
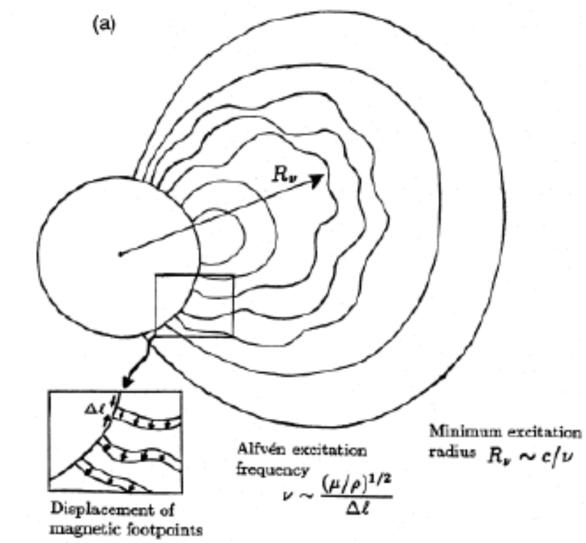
- Follow evolution of fit parameters





$$R_\nu \sim 10\, B_{15}^{-2} \left(\frac{\theta_{\max}}{10^{-3}}\right) \left(\frac{V_\mu}{1.4\times 10^8}\right) l_5 \text{ km},$$

$R_\nu < R_{sat,}$ or insufficient excitation

Younes et al. 2014, ApJ., 785,52, Thompson & Duncan 1995

SGR J1550-5418 — Spectral modeling

Time resolved spectroscopy of 50 brightest bursts

- Fit each bin with 2BB model.
- Follow evolution of fit parameters

$$R_\nu \sim 10\ B_{15}^{-2} \left(\frac{\theta_{\rm max}}{0.1}\right) \left(\frac{V_\mu}{0.8 \times 10^8\ {\rm cm\ s^{-1}}}\right)^{-1} l_5\ {\rm km}$$

$$R_\nu < R_{\rm sat}$$

$$B \gtrsim 4.5 \times 10^{15} \left(\frac{R_{\rm max}}{30\ {\rm km}}\right)^{-1/2} \left(\frac{\theta_{\rm max}}{0.1}\right)^{1/2} \left(\frac{V_\mu}{0.8 \times 10^8\ {\rm cm\ s^{-1}}}\right)^{-1/2} l_5^1/2\ {\rm G}$$

$$E_{\rm max} \sim 4 \times 10^{40}\ l_5^2\ B_{15}^{-2} (\theta_{\rm max}/0.1)^2\ {\rm erg} \Longrightarrow B \lesssim 5.8 \times 10^{17} (\theta_{\rm max}/0.1) l_5\ {\rm G}$$

Younes et al. 2014, ApJ., 785,52

Conclusion

- Strength of high-time resolution in studying magnetar bursts
  - Track the evolution of the emitting regions
  - Put to test the emission from a photon-pair plasma fireball
  - Prediction of intrinsic parameters of the system

- Motivation for a more in depth theoretical calculation of emergent spectrum of magnetar bursts, with the many physical and geometrical effects.

ENERGETICS

Fluence: 7×10^{-9}–1×10^{-5} erg/cm^2

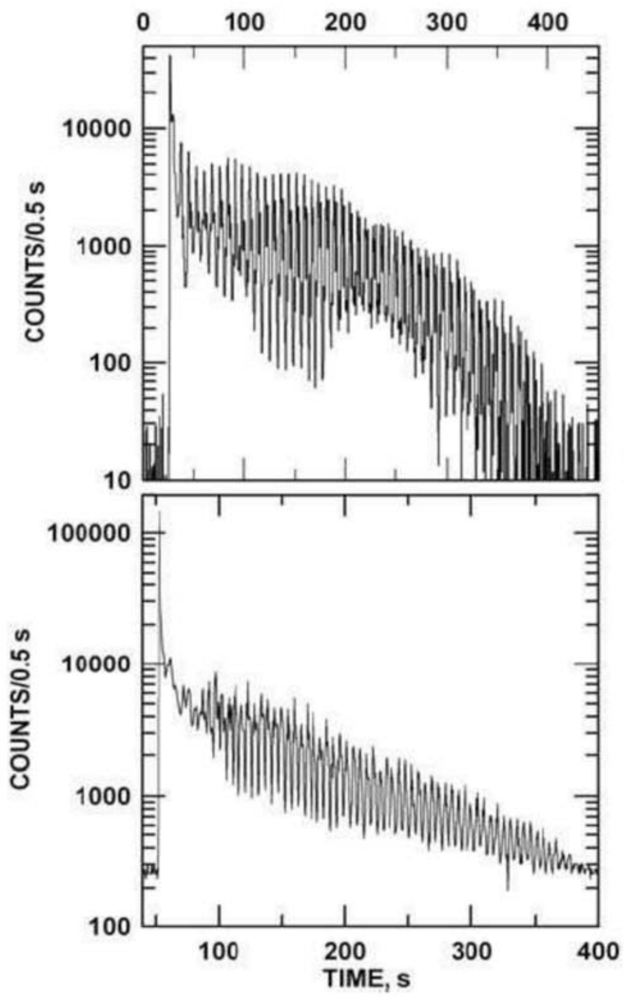
E=$(2\times10^{37}$-$3\times10^{40})\ d_5^2$ erg
Flux: 8×10^{-7}-2×10^{-4} erg/cm^{2}s
L: 5×10^{38} -1×10^{41} erg/s

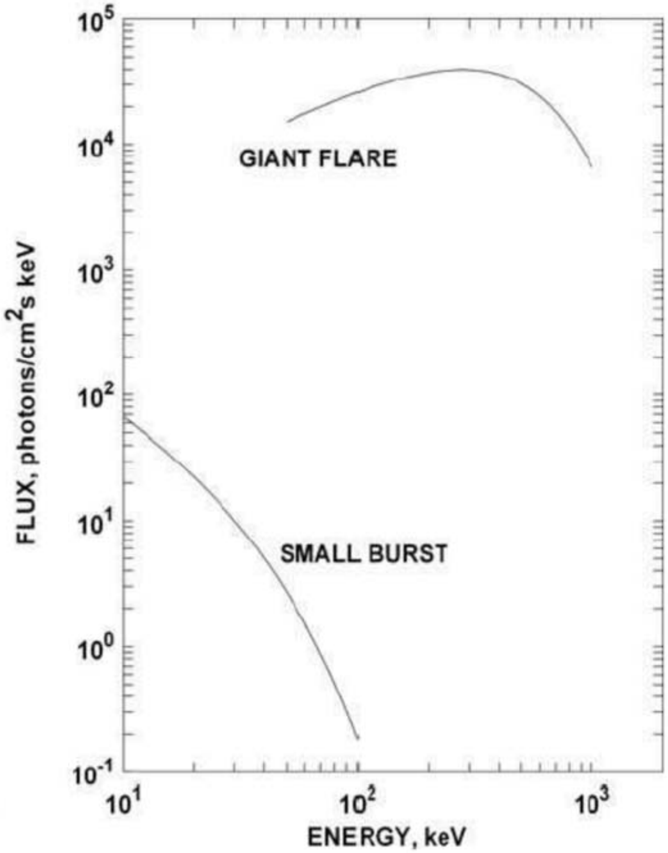
1806-20: 3.0×10^{36}-4.9×10^{39}erg
1900+14: 7×10^{35}-2×10^{39}erg
1627-41: 10^{38}-10^{41} erg
0501+4516: 2×10^{37}-1×10^{40}erg
1E2259+586: 5×10^{34}-7×10^{36}erg

Total Energy Release:
$6.6\times10^{41}d_5^2$ erg (8-200 keV)

Magnetar Giant Flares

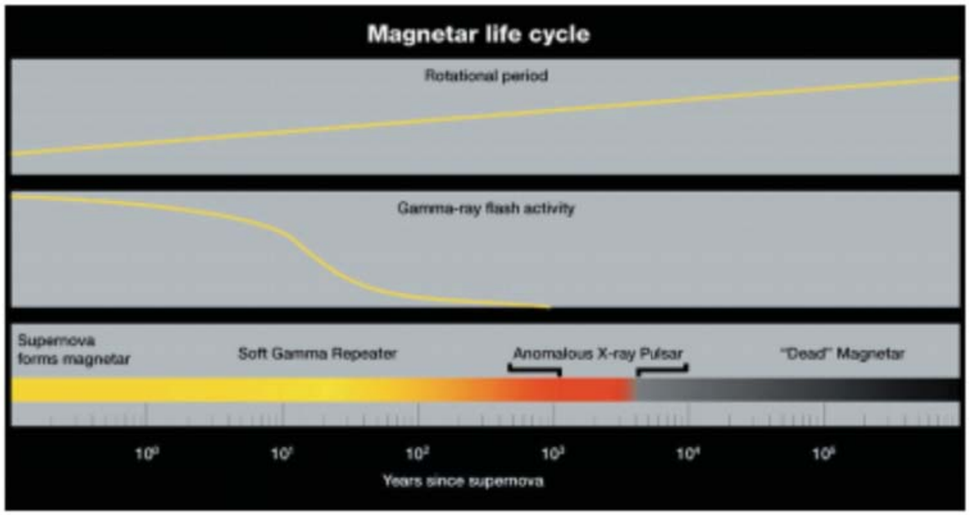
E up to 3×10^{46} erg
1 erg cm^{-2} at Earth





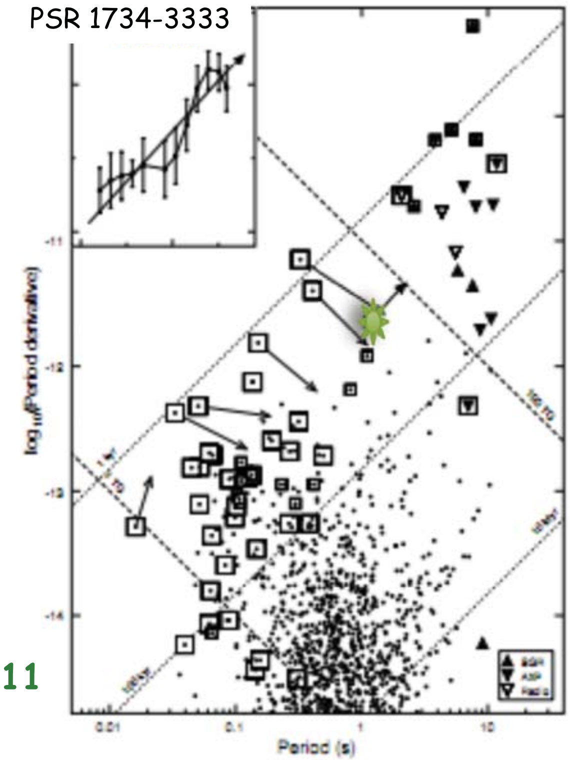
Hurley 2008

5. Evolutionary links?



Kouveliotou 1999

PSR 1734-3333



Espinoza etal 2011

What is the evolutionary link between different types of sources?

Rotation powered PSRs -> SGRs -> AXPs -> DINS

(Kouveliotou 1999, Perna & Pons 2011, Turolla etal 2011, Espinoza etal 2011)

Fermi MAGNETAR Facts

1. Since the Fermi launch, GBM has detected bursts from 8 sources: one third of the total population in five years!
2. The GBM magnetar burst spectra provide the first evidence for an unusual hardness E_{peak} – flux relationship.
3. Evidence for higher energetic content in SGR bursts than in AXP bursts.
4. Upper limits on the LAT emission detection only.

What Next?

The next five years of Magnetar observations:

- Population studies of magnetars
- Understand the links between PSRs – Magnetars – DINS
- Systematic searches for seismic vibrations in magnetar bursts- independent B-field measurement: STAND BY ON THESE RESULTS
- Giant flare detection becomes a strong possibility (for a rate of 1/ source/10yrs, we expect one in the next three years – last was in 2004)
- Confirm pulsed emission breaks >100 keV will constrain E_{max} of particles and localization of emission

Overarching theoretical issues:

- Localize the burst energy injection possibly on or near the NS surface to determine the injection mechanism
- Detection of gravitational waves from magnetar Giant Flares
- Determination of the magnetic Eddington limit

Synergy with new observatories:

NuSTAR, LIGO, LOFAR, AstroSAT, SVOM

Serendipitous Discoveries:

Always welcome!