The State of Magnetars

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On behalf of the GBM
Magnetar team

Magnetars are magnetically powered NS

- ~29 sources to date: 23 confirmed, 5 candidates, 1 RPP; 11 in 2008-2014

- All but two (LMC, SMC) are MW sources

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

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

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

- $B \sim [1-10] \times 10^{14}$ G (mean surface dipole field: $3.2 \times 10^{19} \sqrt{P\dot{P}}$) - **BUT:** SGRs J185246.6+003317, $B < 4.1 \times 10^{13}$ G; 0418+5729, $B = 6.2 \times 10^{12}$ G; 1822.3-1606, $B \sim 2.0 \times 10^{13}$ G

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

- No evidence for binarity

The magnetar conjecture

The neutron star is powered by its super strong B-field = 10^{14-15} G. To create such fields requires the collapse of a fast rotating star (1-3 ms) with very high convection rates (magnetic Reynolds number ~10^{17}). Ideal efficiency can generate ~ 10^{16}G (Duncan and Thompson 1992, 1993).

However: The magnetic energy has to be less than the gravitational binding energy of the neutron star (Lai 2001) providing an upper limit of:

$$\frac{4\pi R^3}{3}\left(\frac{B^2}{8\pi}\right) \gtrsim \frac{GM^2}{R}.$$

$$B \lesssim 10^{18}\left(\frac{M}{1.4\ M_\odot}\right)\left(\frac{R}{10\ \mathrm{km}}\right)^{-2}\ \mathrm{G}.$$

NS populations comprising Magnetars

Soft Gamma Repeaters (SGRs)

Anomalous X-ray Pulsars (AXPs)

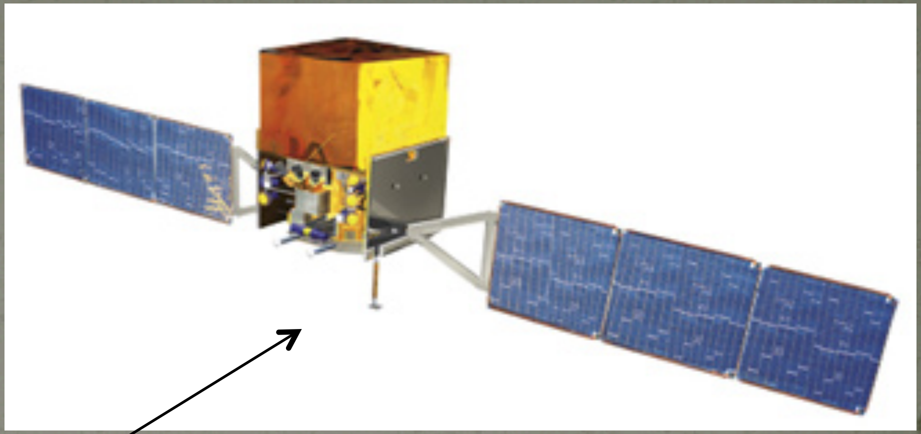
Dim Isolated Neutron Stars (DINs)

Compact Central X-ray Objects (CCOs)

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

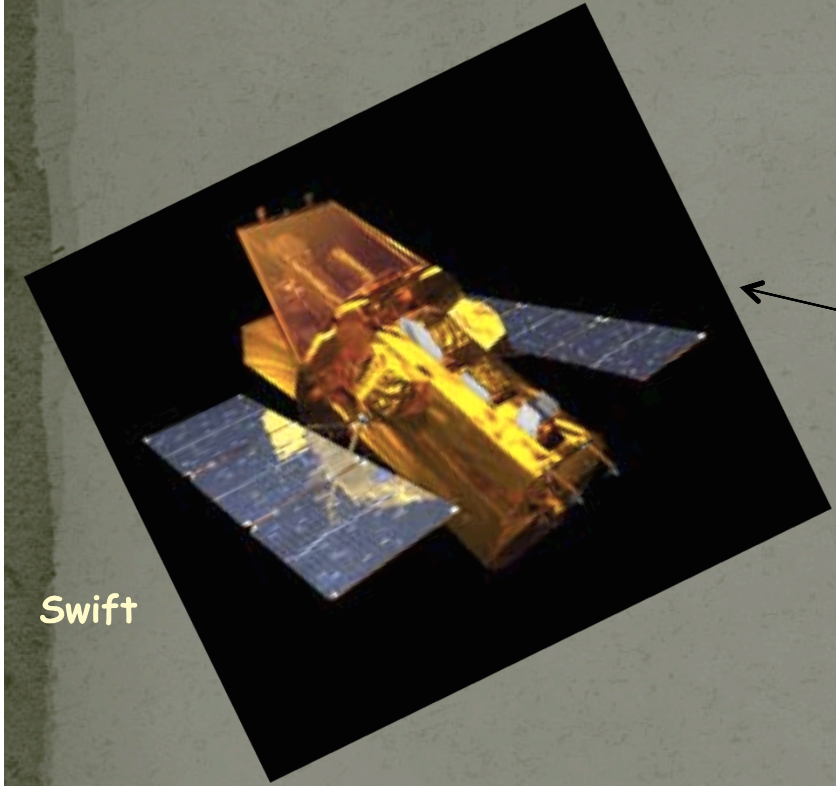
IDEALLY we should call them all MGC XXXX±YYYY as in MaGnetar Candidate followed by coordinates in RA, Dec

Magnetar detection missions



Fermi

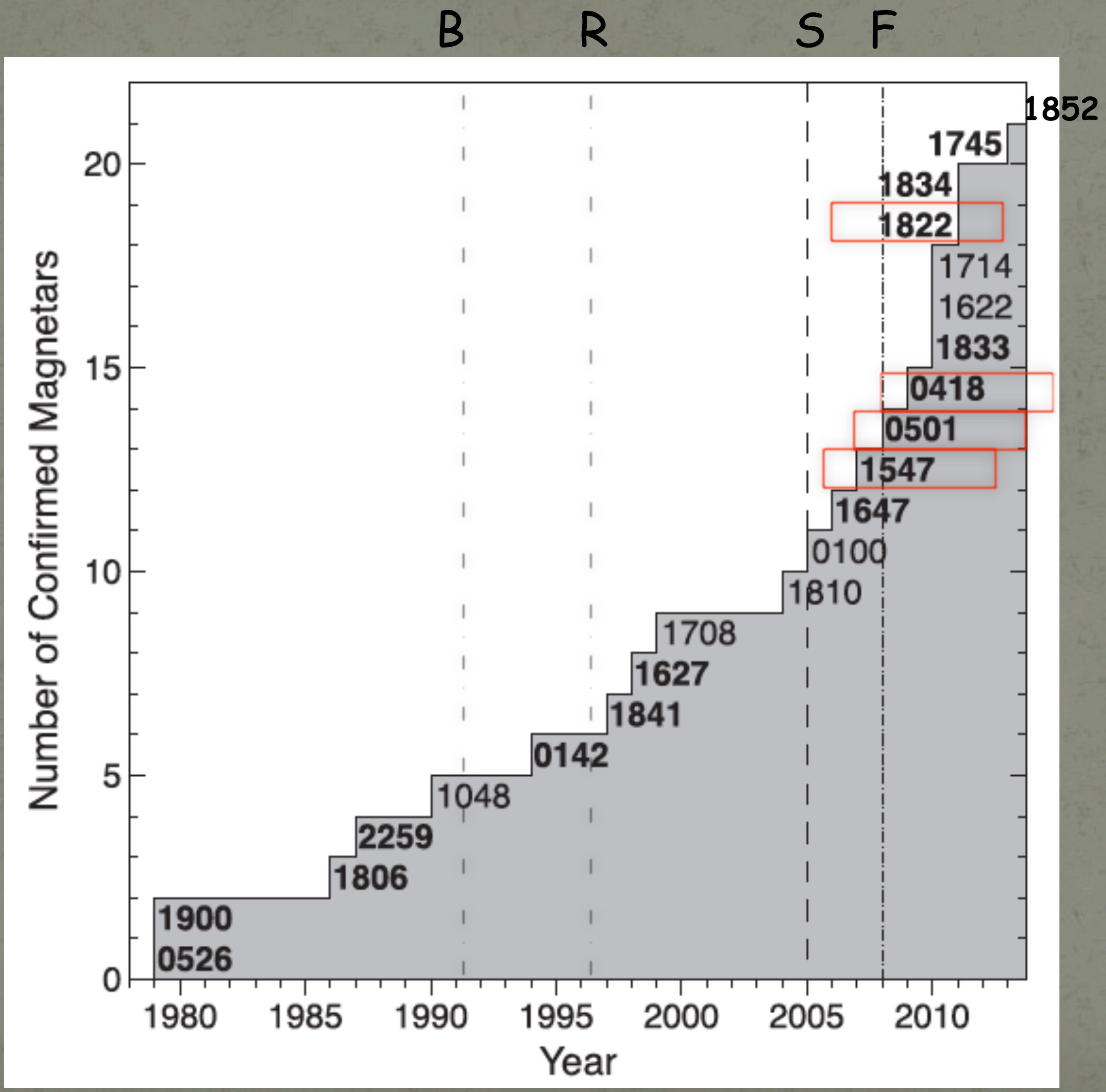
IPN



Swift

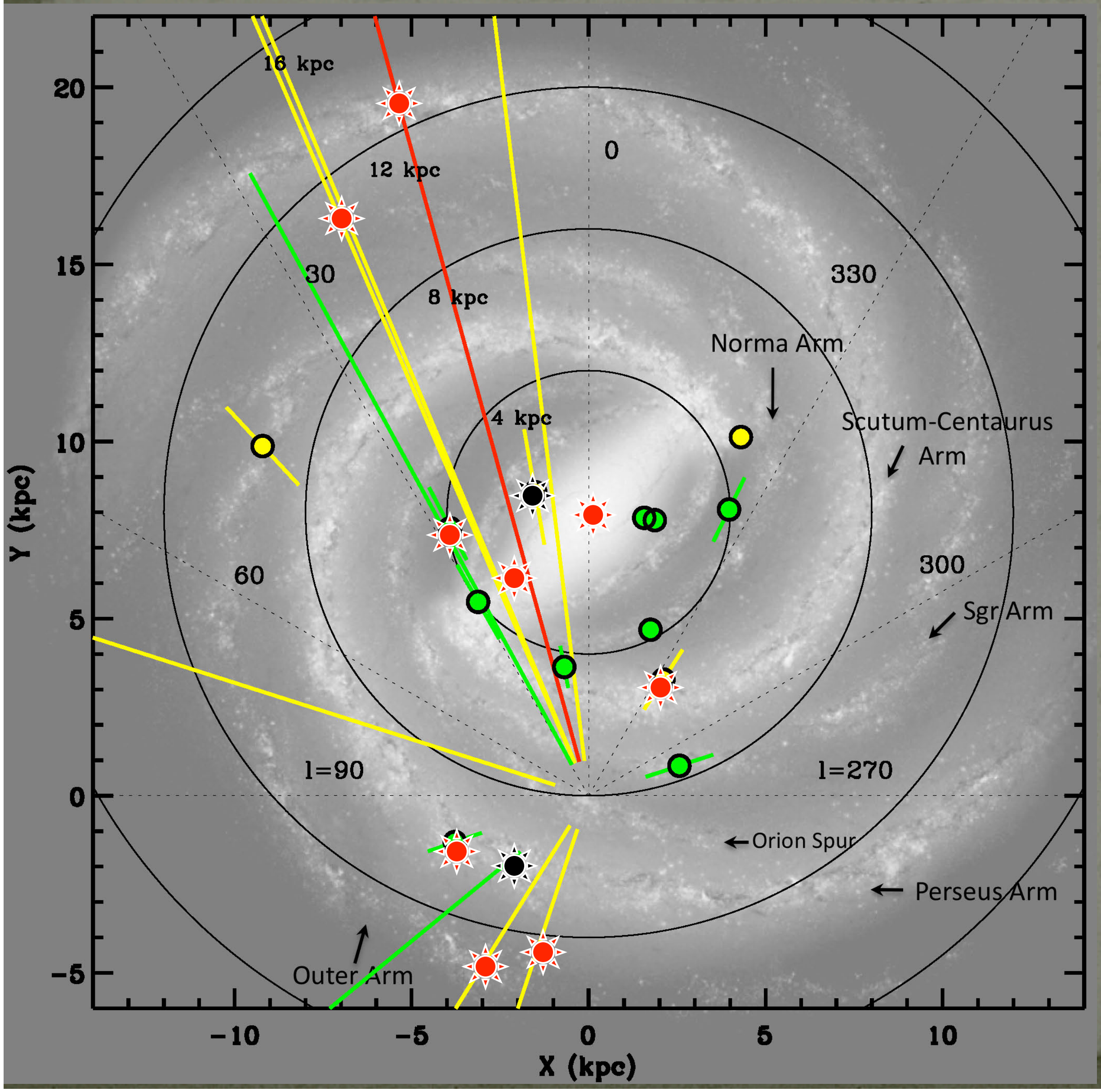
IPN: WIND, 2001 Mars Odyssey, INTEGRAL, RHESSI, Swift, MESSENGER, Suzaku, AGILE, and Fermi

Magnetar detection rates



Olausen & Kaspi, ApJ 2014

Magnetar Distribution in our Galaxy



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

✹ Old source reactivation

🟨 SGRs

🟩 AXPs

CRADLE

Kouveliotou et al. 2011

Magnetar States

- Quiescent
- Active
  - Several 100s of bursts (storms) – 4 sources
  - Giant Flares (3 sources one each)
  - Few 10s of bursts (3 sources)
  - <10 bursts (10 sources)
  - No bursts (4 sources)

Quiescent Emission Properties

Magnetar Timing Properties

From the **quiescent** pulsed X-ray emission we can calculate:

The minimum surface dipole field in vacuum :

$B = 3.2 \times 10^{19} (P\dot{P})^{1/2}$ G (minimum magnetic field strength in vacuum);

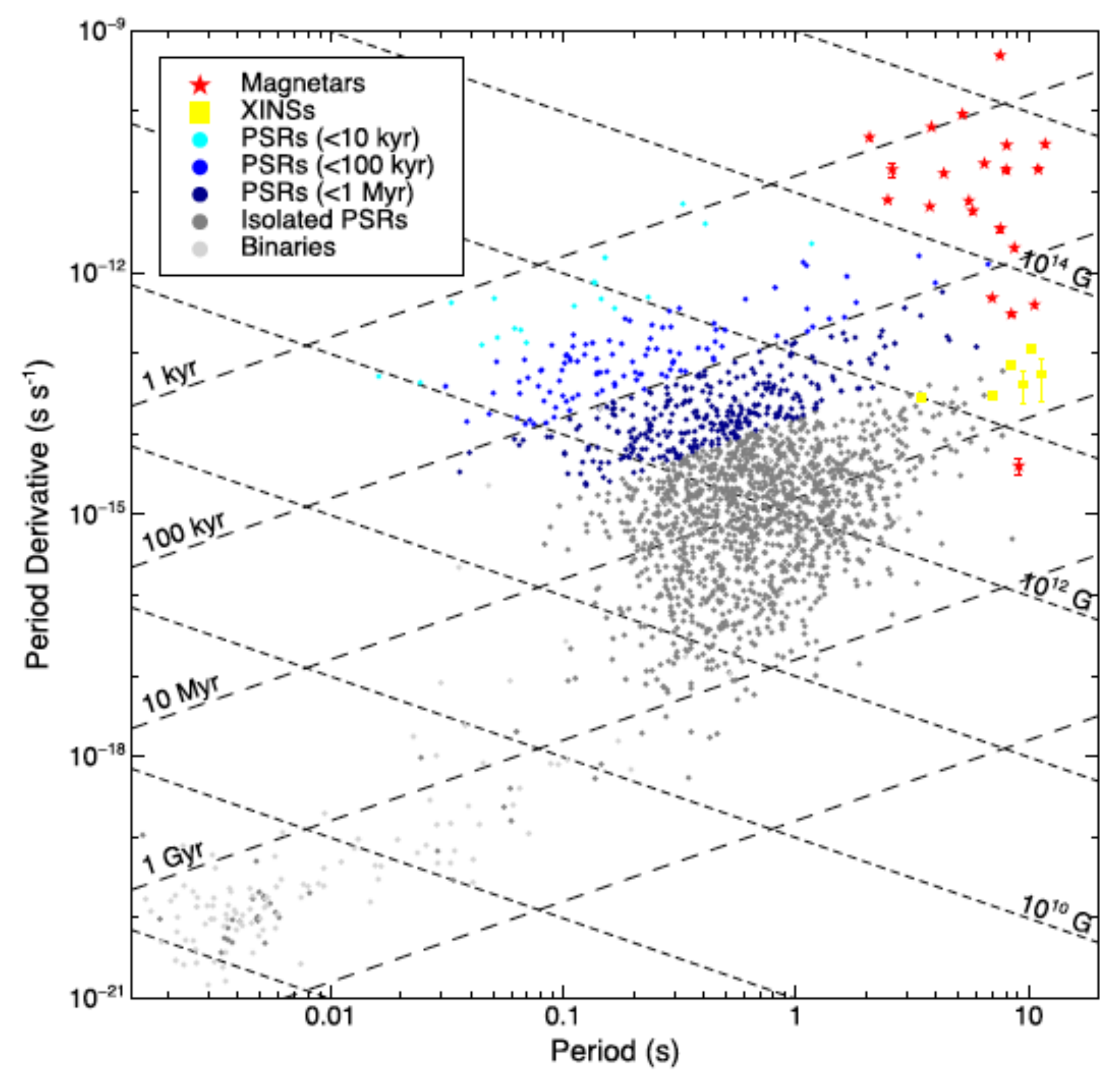
The spindown luminosity:

$\dot{E} = 4\pi 2I\, P/\dot{P}^3$ ($I = 10^{45}$ g cm^2);

The characteristic age:

$\tau_c = P/ 2\dot{P}$

p-pdot Diagram

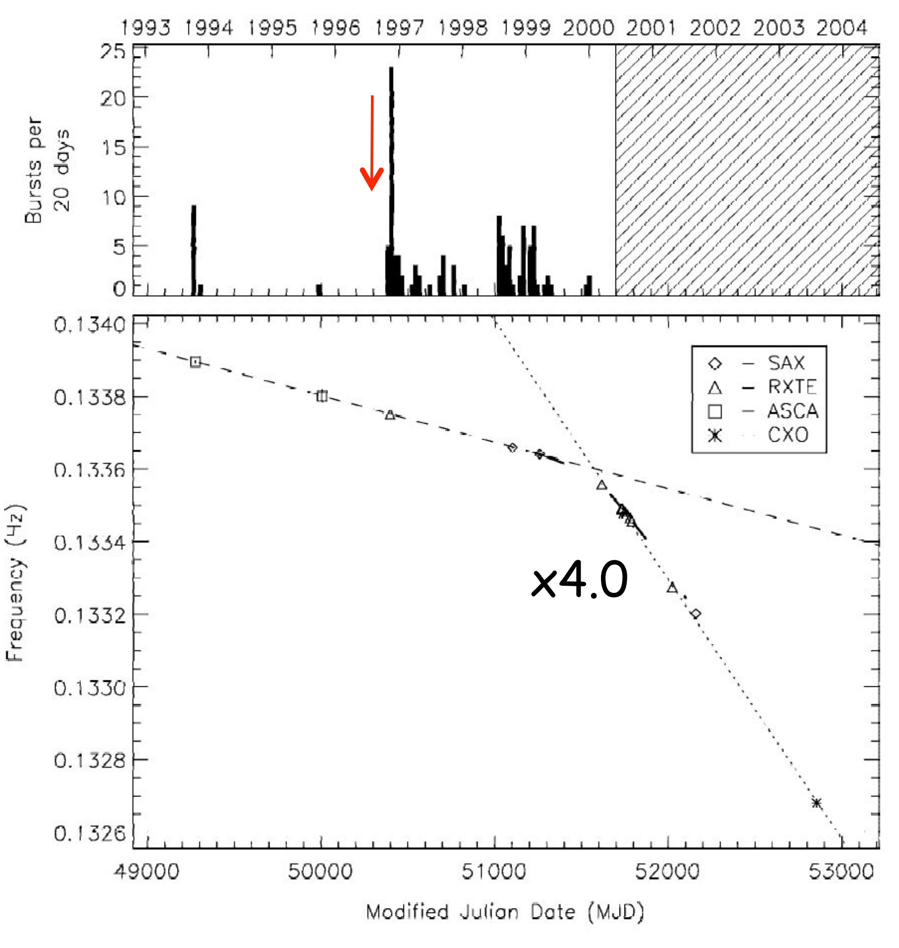


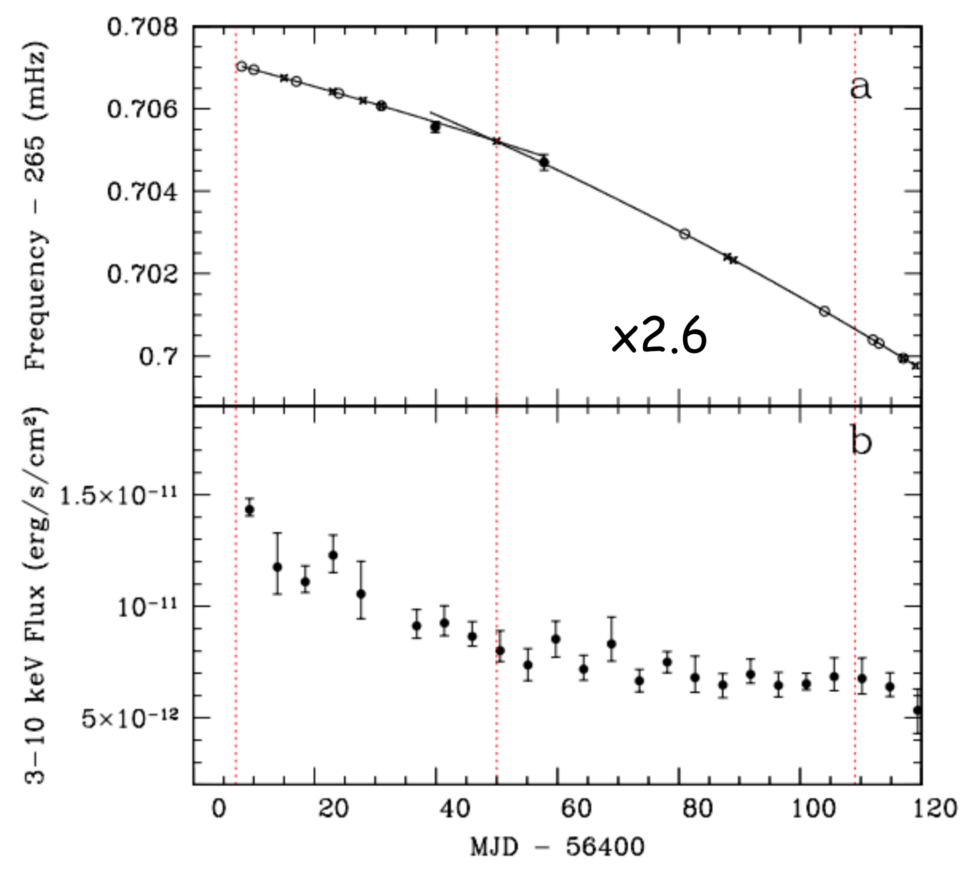
Olausen & Kaspi, ApJ 2014

Burst effects – or not…

SGR 1806-20

SGR J1745-2900

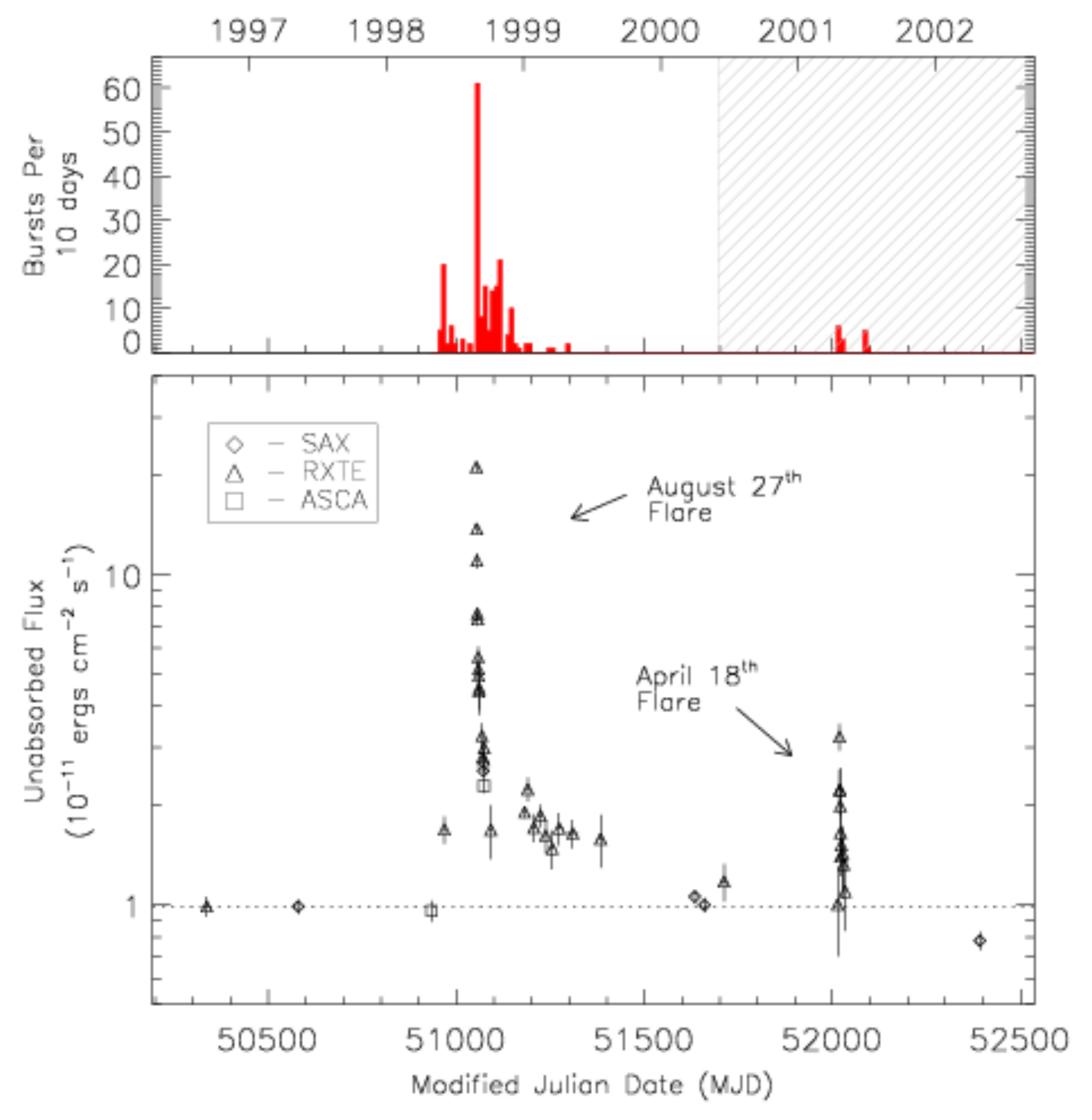




Woods et al 2002

Kaspi et al. 2014

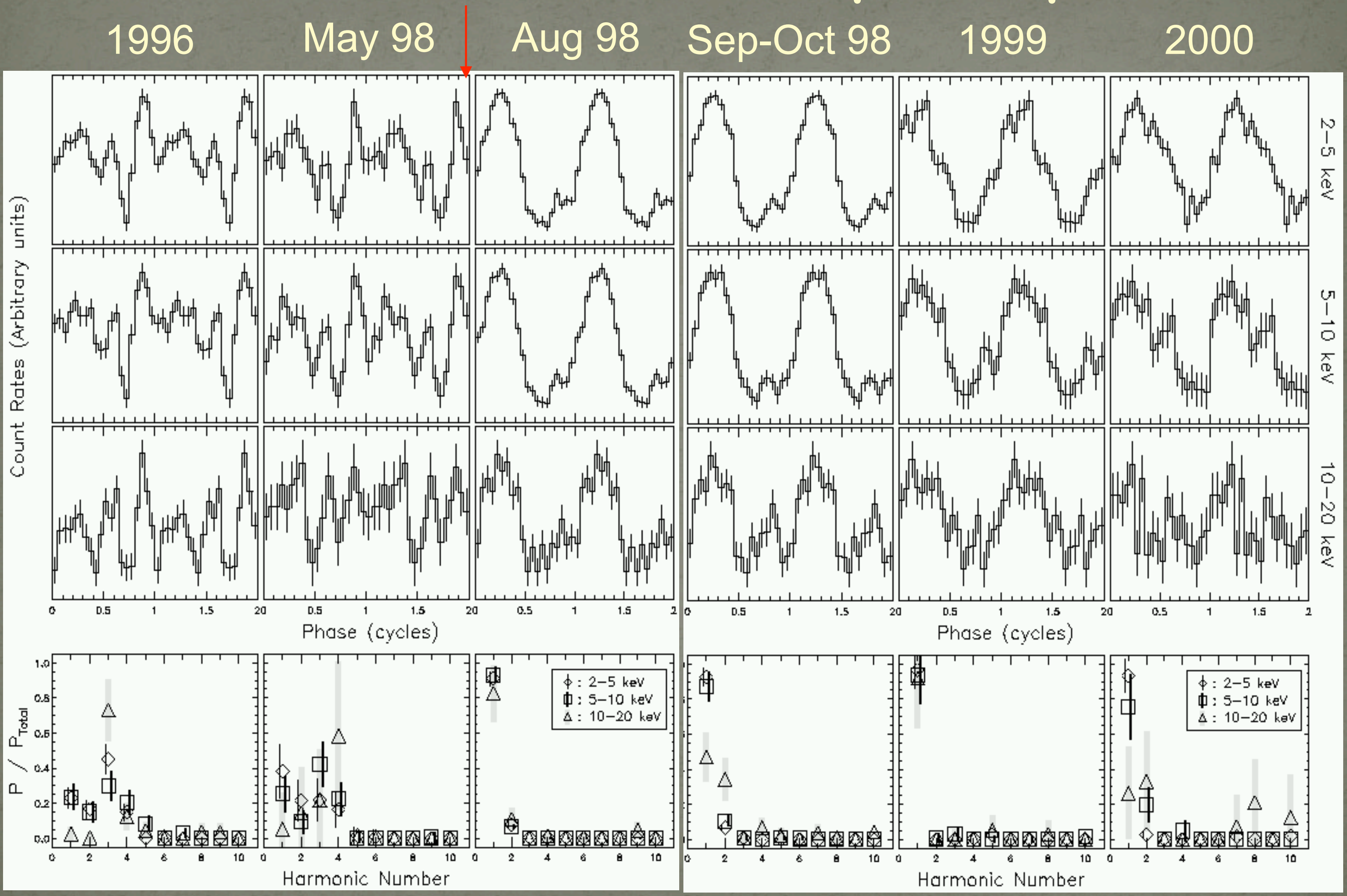
Outburst effect in the persistent flux



SGR 1900+14

Woods et al. 2002

Outburst effect in the pulse profile

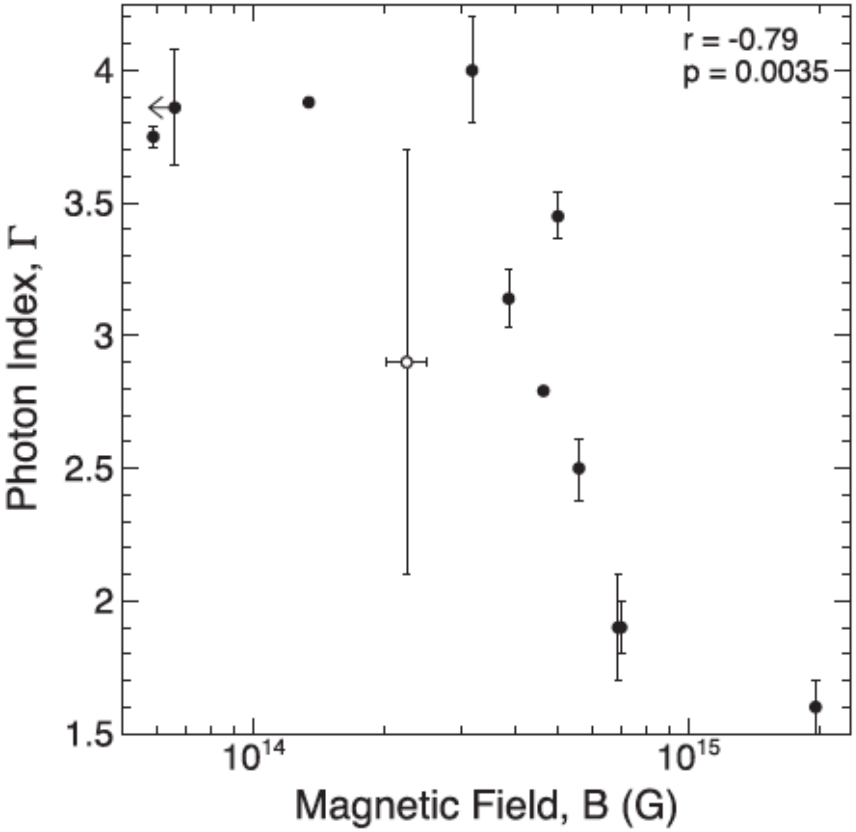


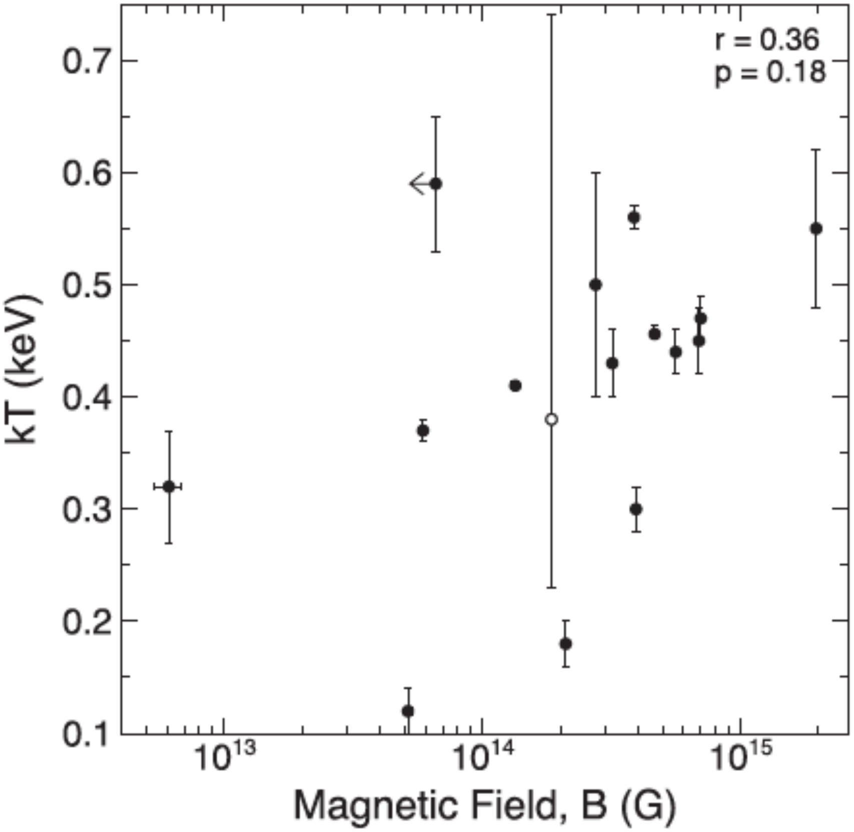
1996 May 98 Aug 98 Sep-Oct 98 1999 2000

Gogus et al. 2002

Spectral Properties

Most spectra are best fit with an absorbed PL + BB



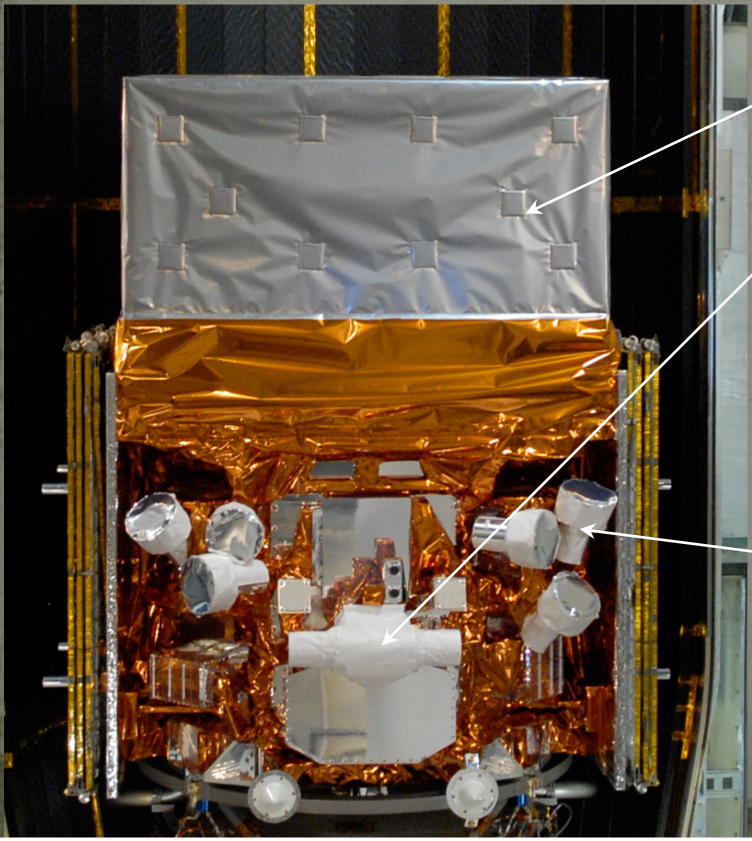


Olausen & Kaspi, ApJ 2014

Active Emission Properties: BURSTS

The Fermi/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)

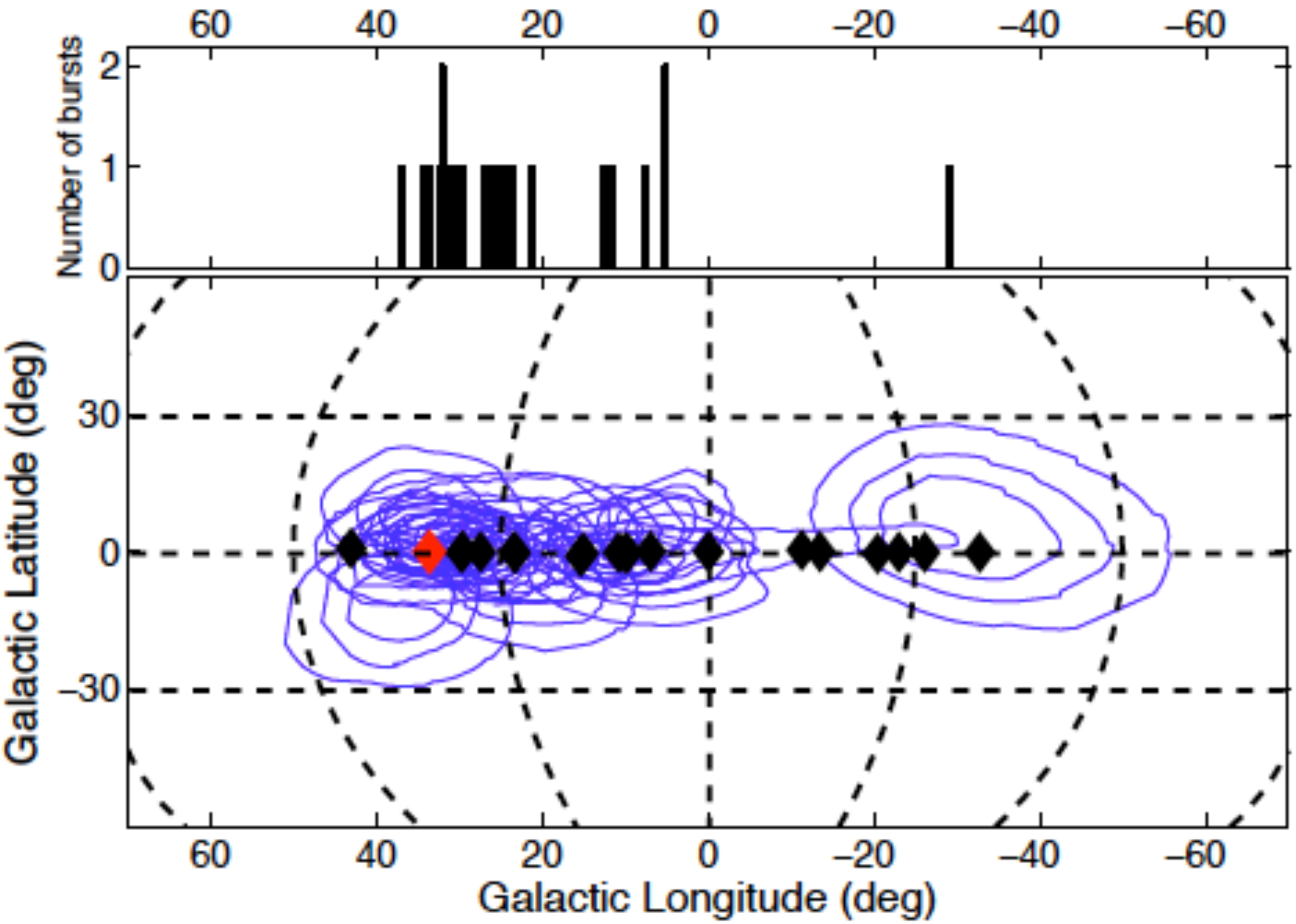
GBM BGO detector.
200 keV -- 40 MeV
126 cm^2, 12.7 cm
Triggering, Spectroscopy
Bridges gap between NaI and LAT.

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

GBM Magnetar Project: 16 papers + GBM 5-yr Magnetar Burst Catalog

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	7 117/331+ 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	Multiple error boxes include new source 3XMM J185246.6+003317

Unknown source locations



Collazzi et al. 2014

SGR J1550-5418
(AXP 1E1547.0-5408)

◆ P = 2.069s

◆ $\dot{P} = 2.318 \times 10^{-11}$ s/s and $B = 2.2 \times 10^{14}$ G

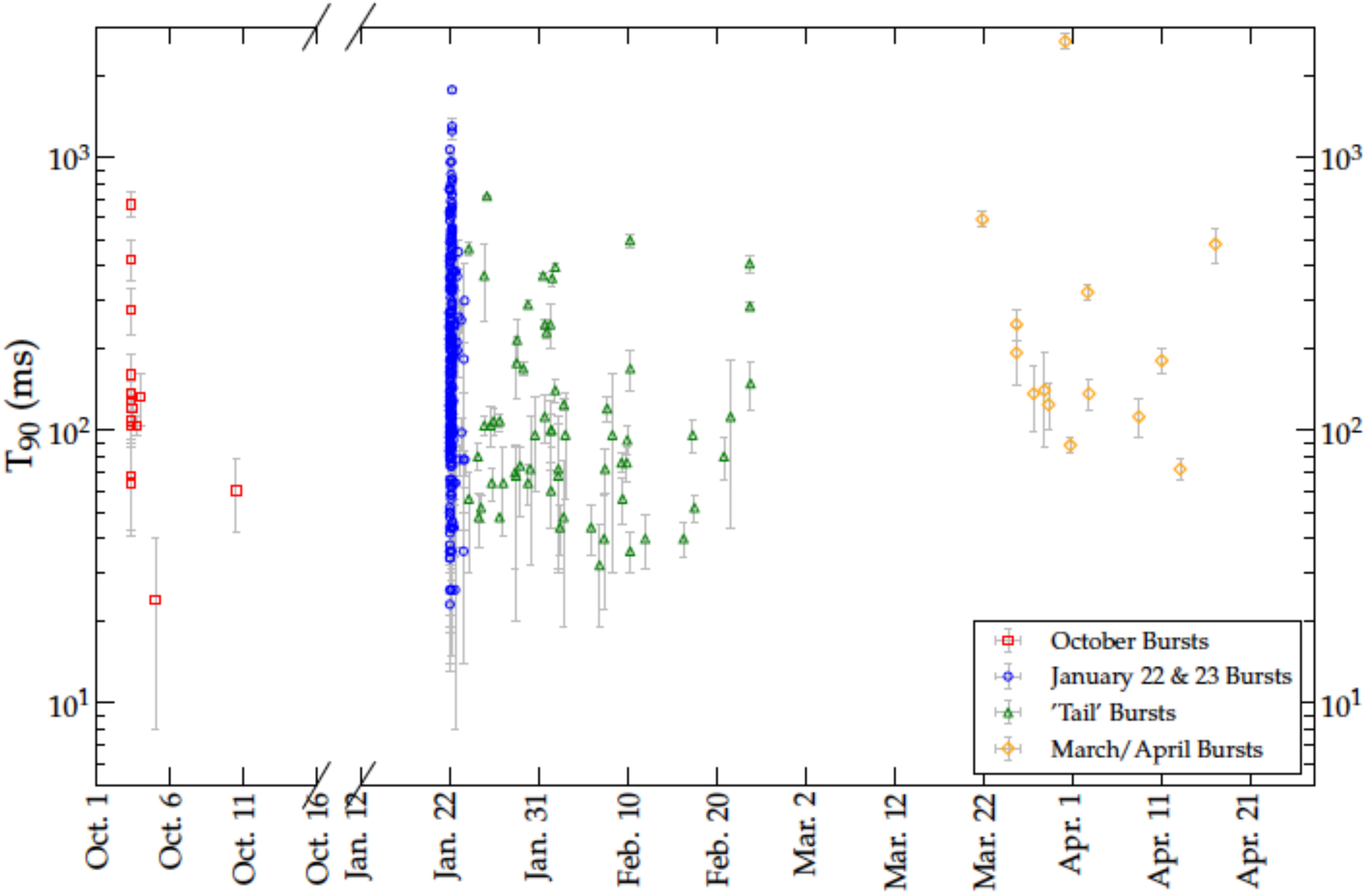
◆ Near IR detection, Ks = 18.5±0.3

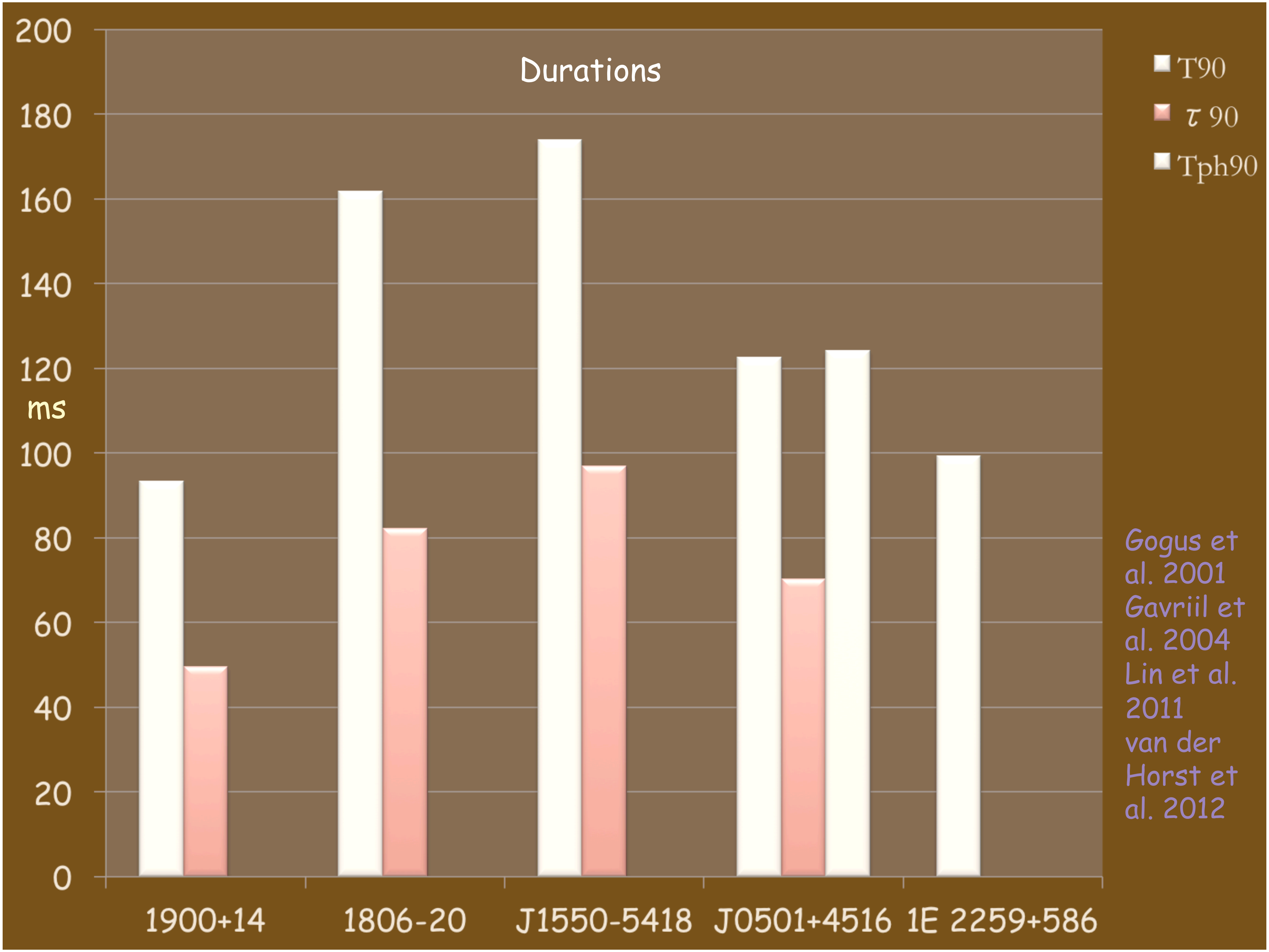
◆ GBM triggered on 132 events from the source in three episodes; 2008 October, 2009 January & March. Once more on 2013 June.

◆ 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

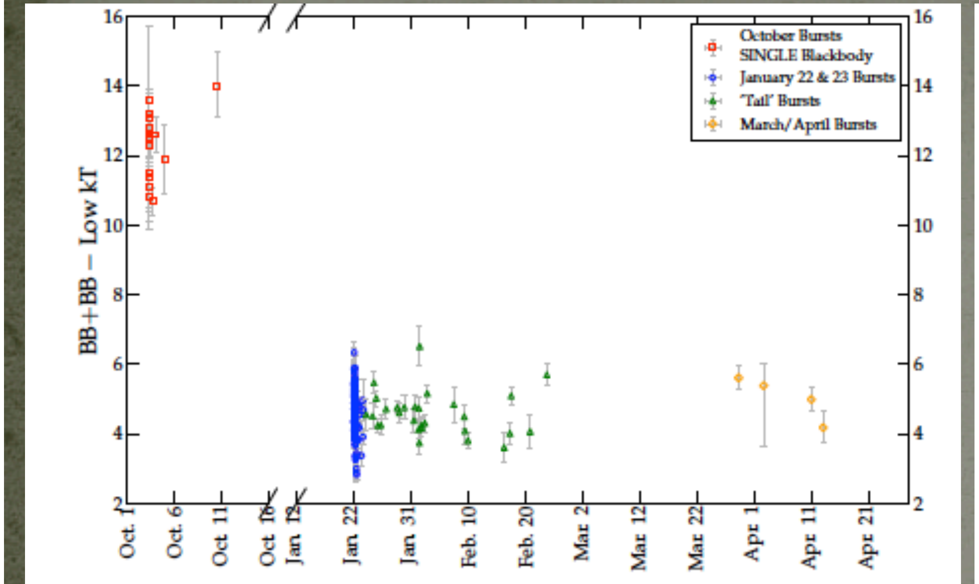
SGR J1550 – 5418: Temporal

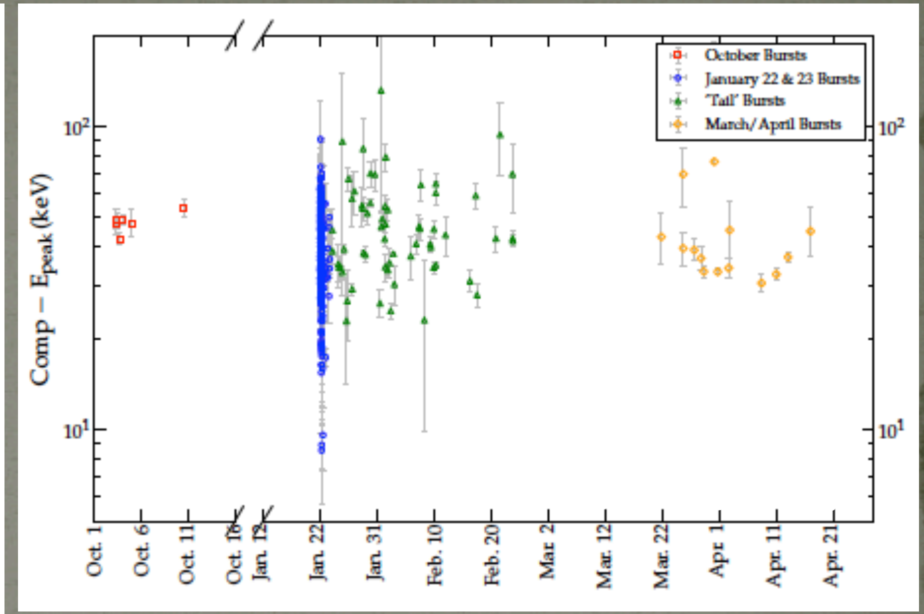


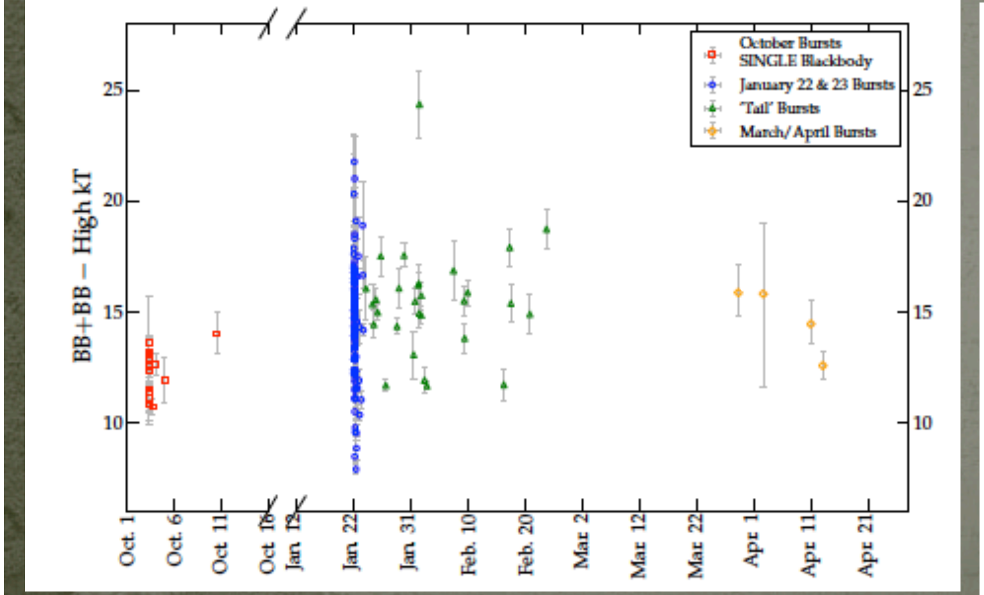


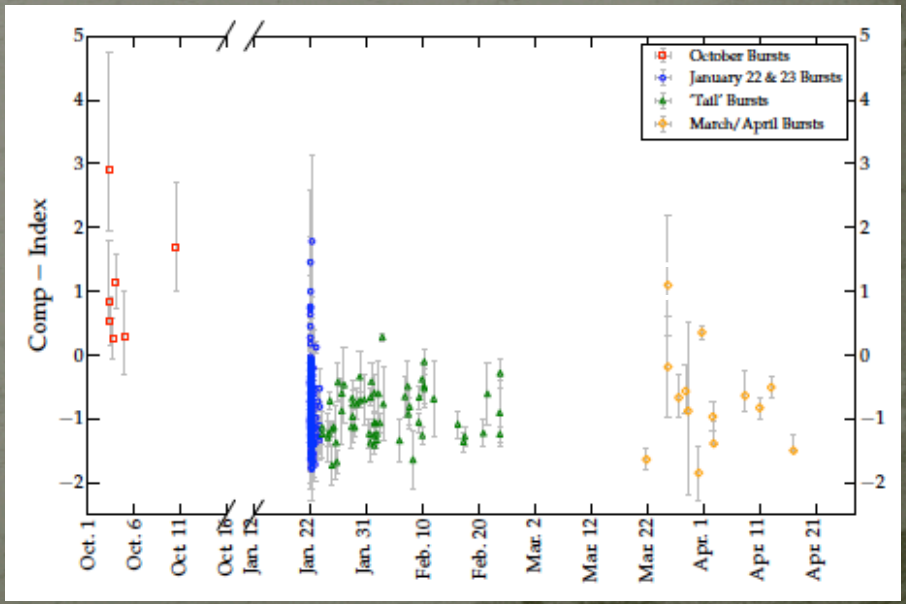
Gogus et al. 2001
Gavriil et al. 2004
Lin et al. 2011
van der Horst et al. 2012

SGR J1550 - 5418: Spectral

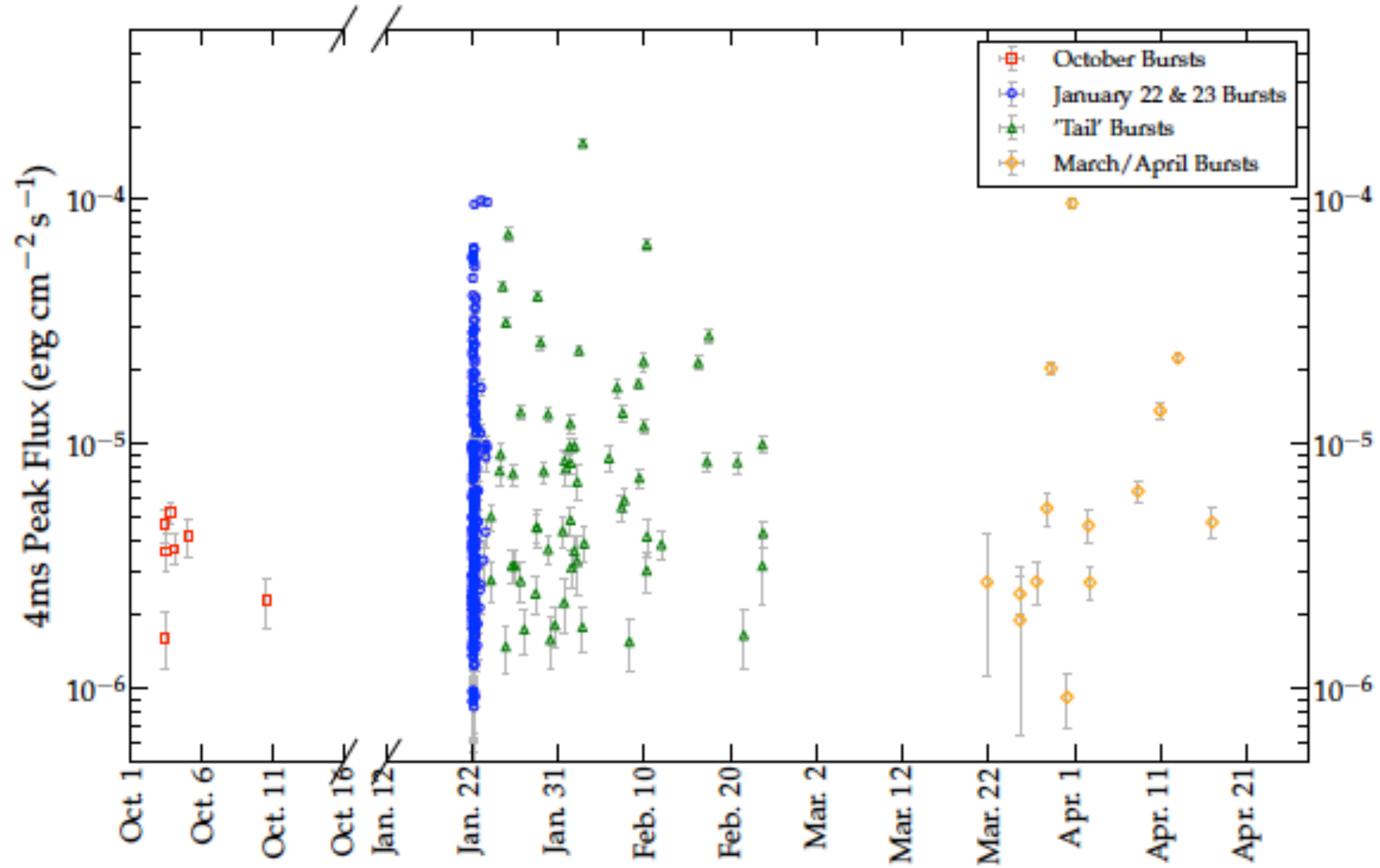




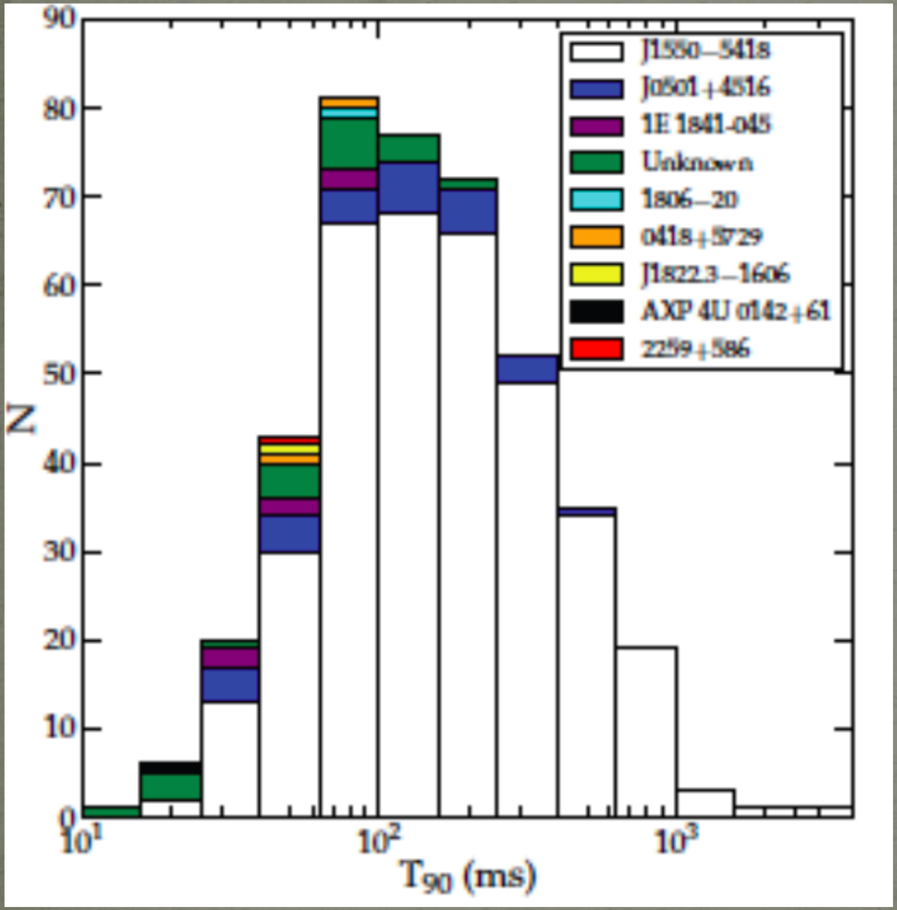


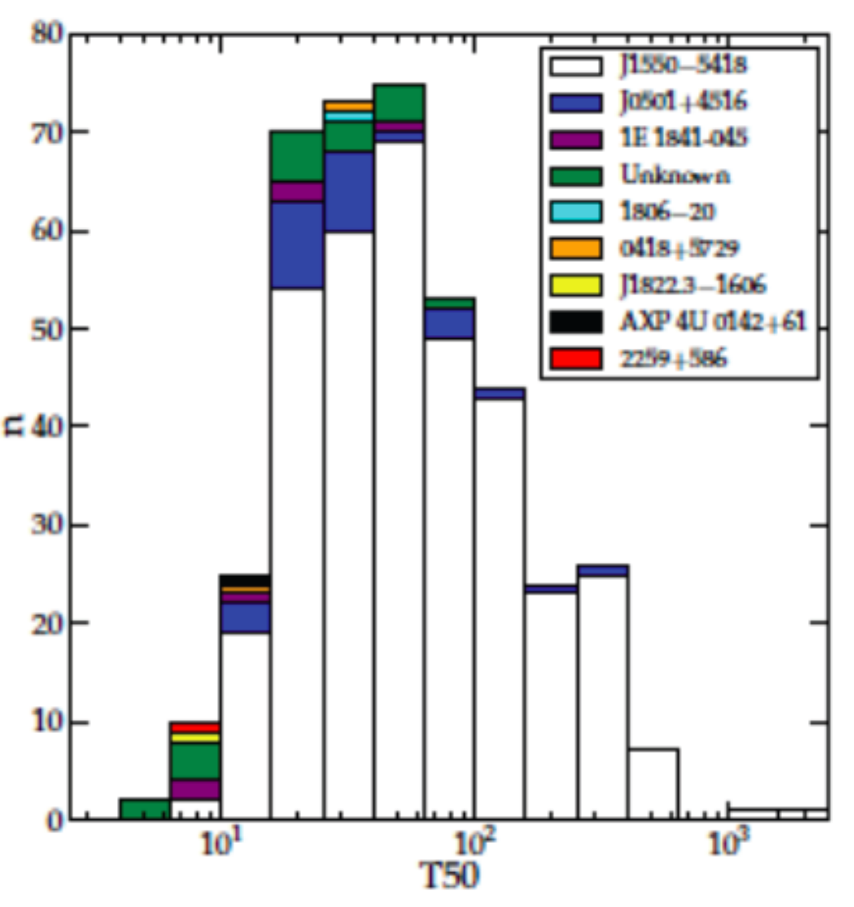


SGR J1550 – 5418: Spectral



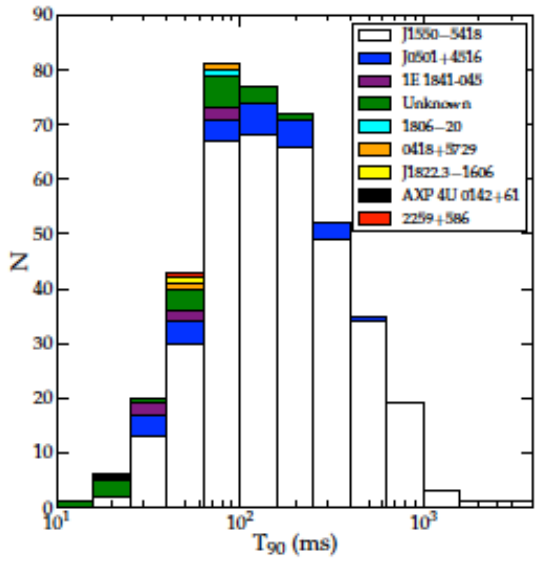
All triggers: temporal properties

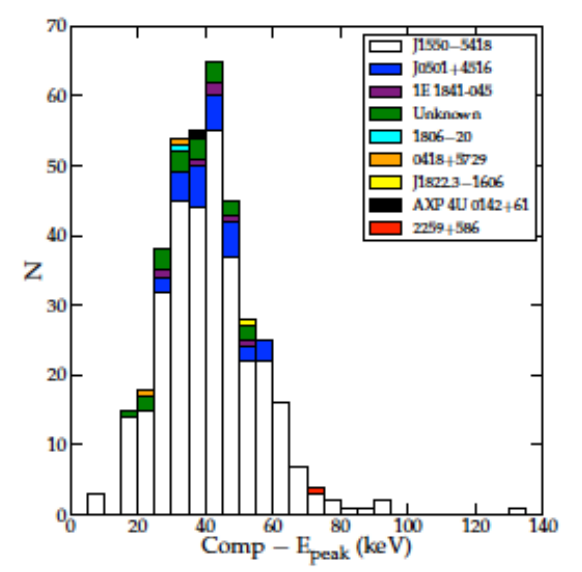


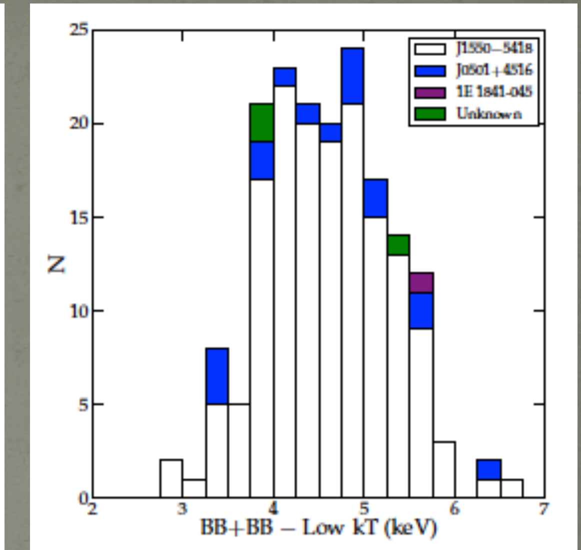


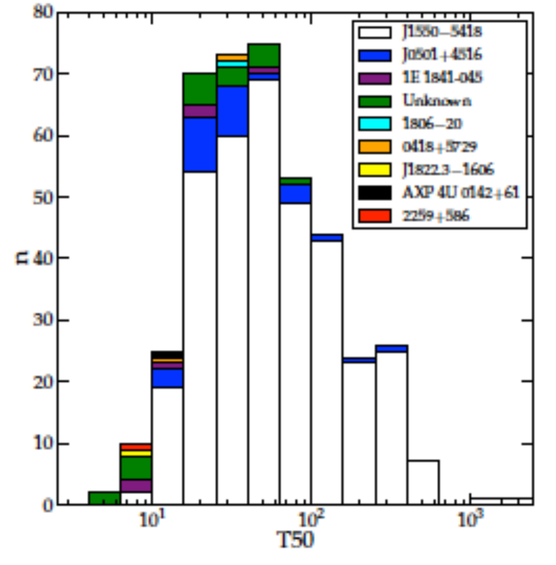
Unknown event avg T_{90} = 61 ms (known avg ~100 ms)

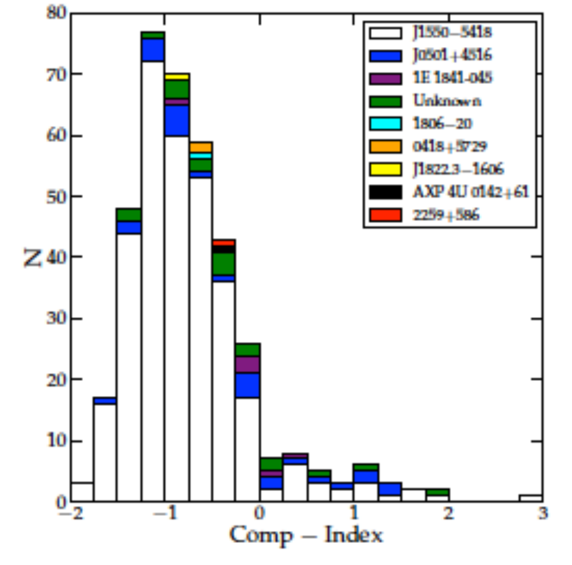
All triggers: comparative properties

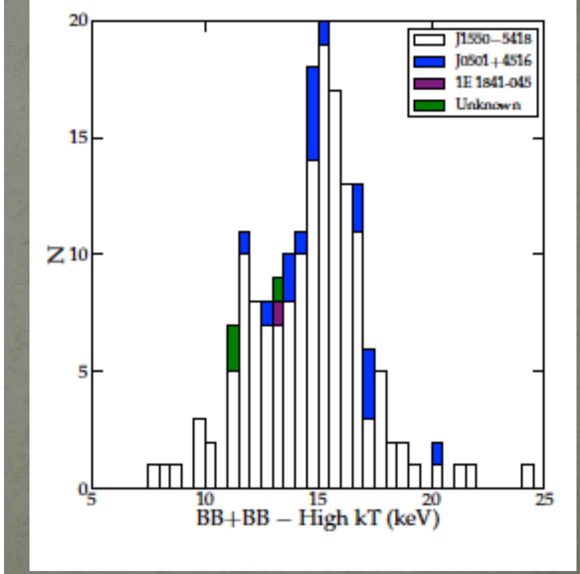












BURST ENERGETICS

1550-5418
Fluence: 7×10^{-9}–1×10^{-5} erg/cm^2
E=(2×10^{37}-3×10^{40}) d_5 erg
Flux: 8×10^{-7}-2×10^{-4} erg/cm^{2}s
L: 5×10^{38} -1×10^{41} erg/s
Total Energy Release: $6.6\times10^{41}d_5$ erg (8-200 keV)

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

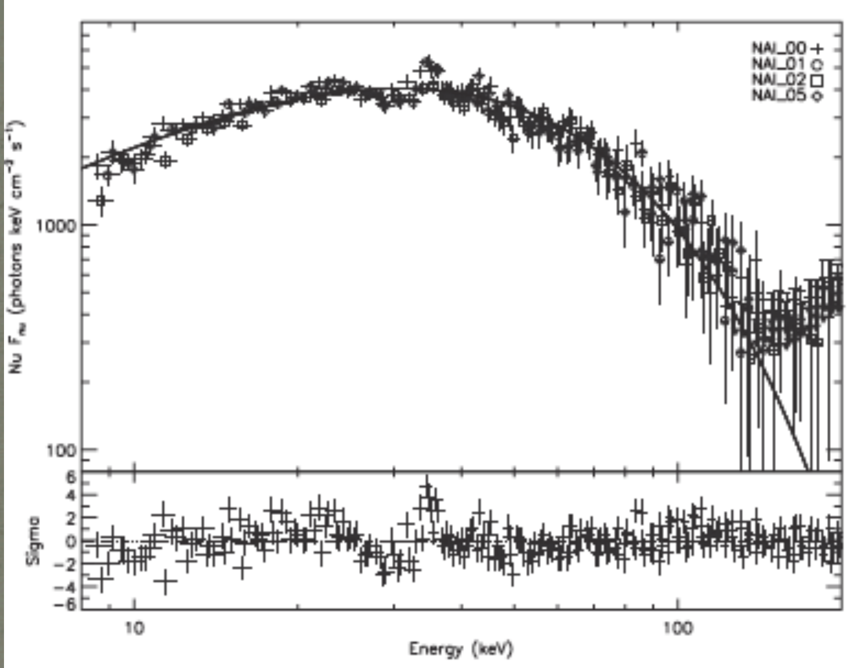
Time resolved spectroscopy of the 50 brightest bursts from SGR J1550-5418

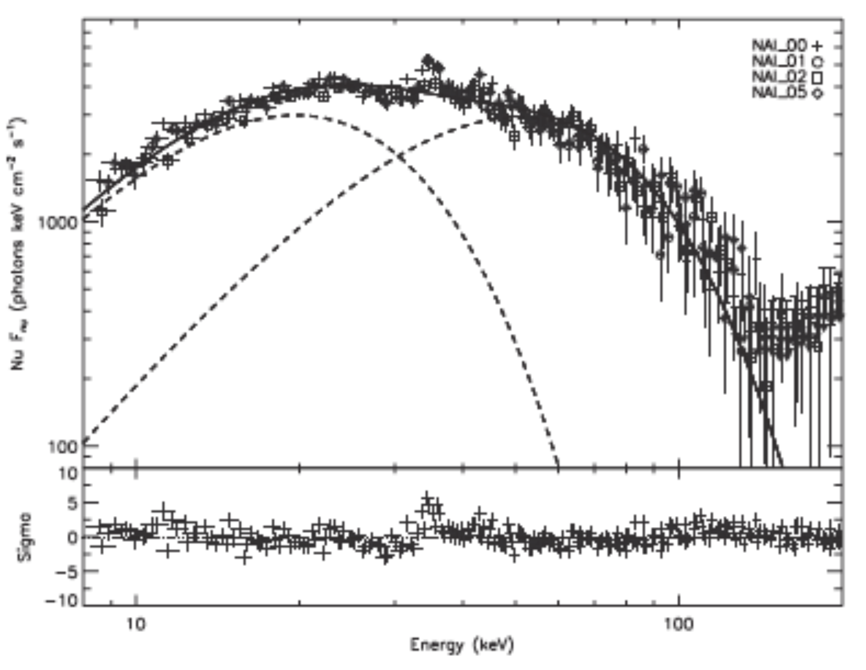
Younes et al. 2014

Selection Criteria for the initial sample of 63 bursts:

Fluence (8-200 keV) $>10^{-6}$ erg/cm^2
Average flux (8-200 keV) $> 10^{-5}$ erg/cm^2 s

GBM-only fit, 8-200 keV

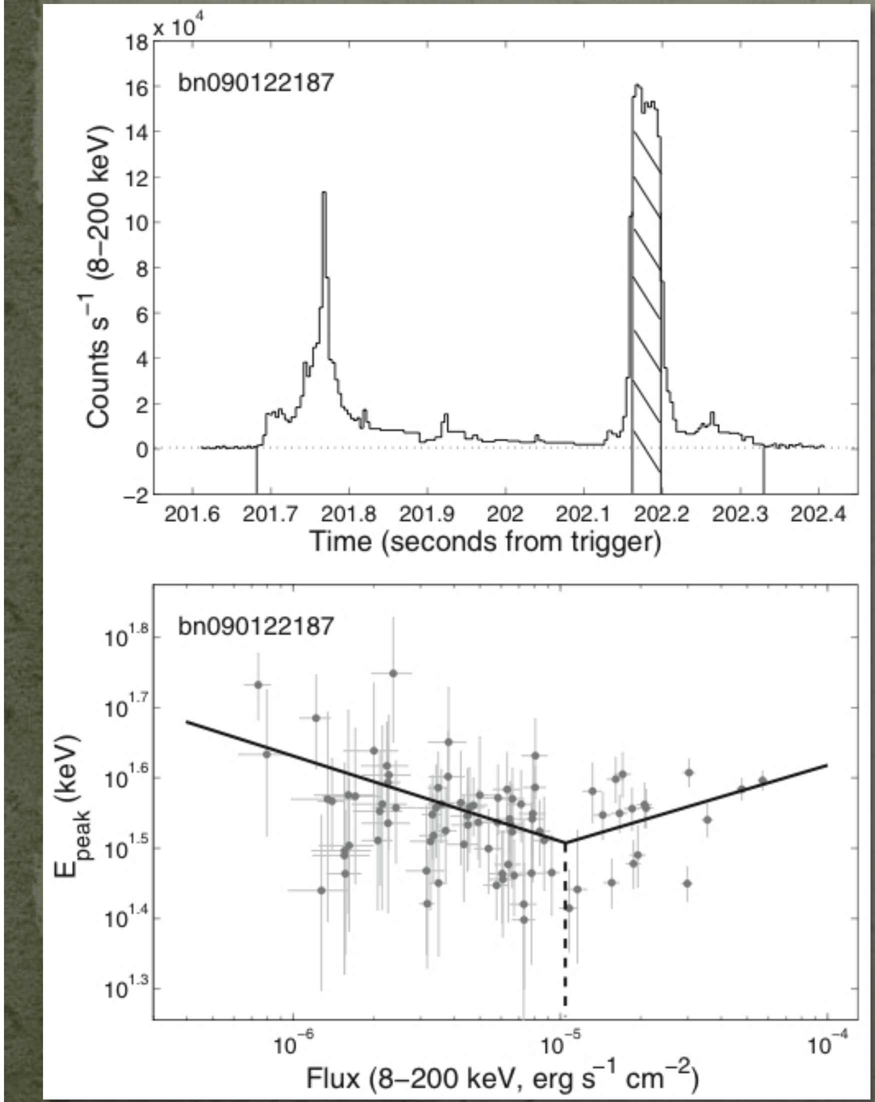


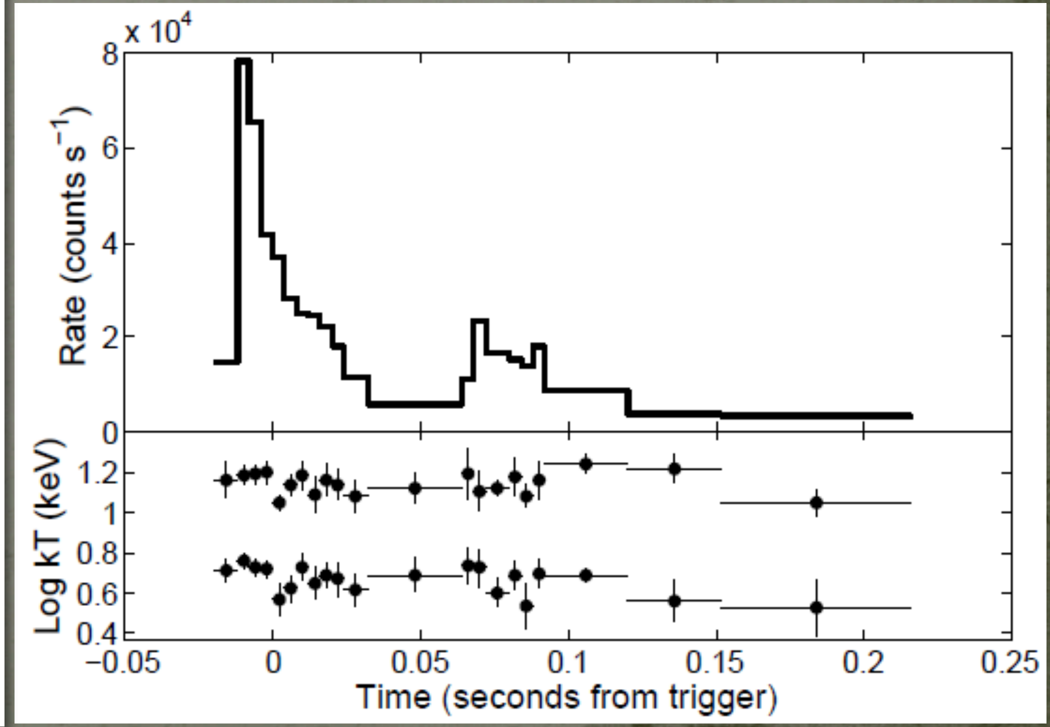


PL with HE exponential
cutoff (COMPT)
49 bursts, 1393 time bins

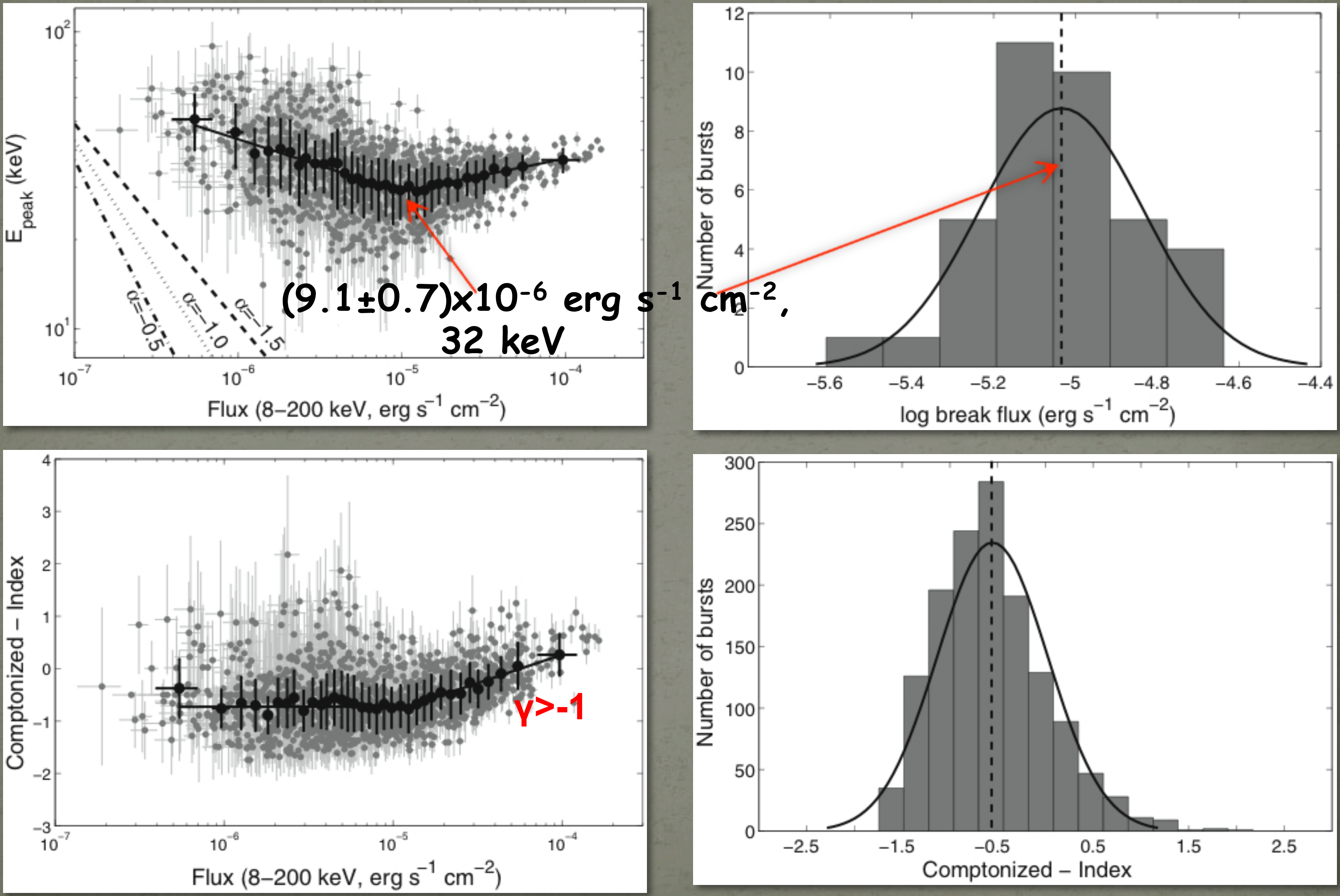
Two Black Bodies
48 bursts, 994 time bins

- Fit each **4 ms** bin with 2BB and COMPT models
- Follow evolution of fit parameters





COMPT results

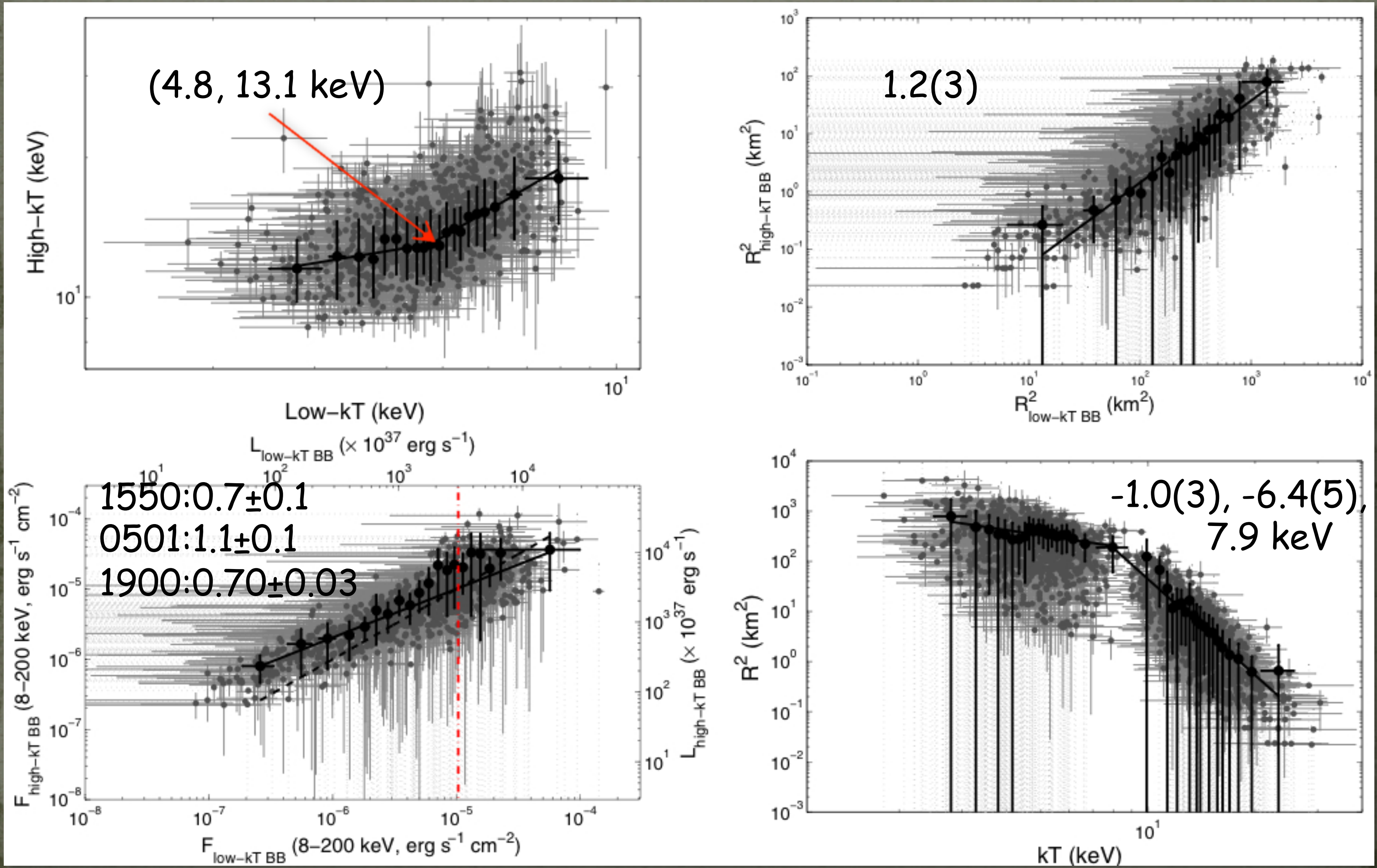


$(9.1\pm0.7)\times10^{-6}$ erg s^{-1} cm^{-2},

32 keV

$\gamma>-1$

2 BB results

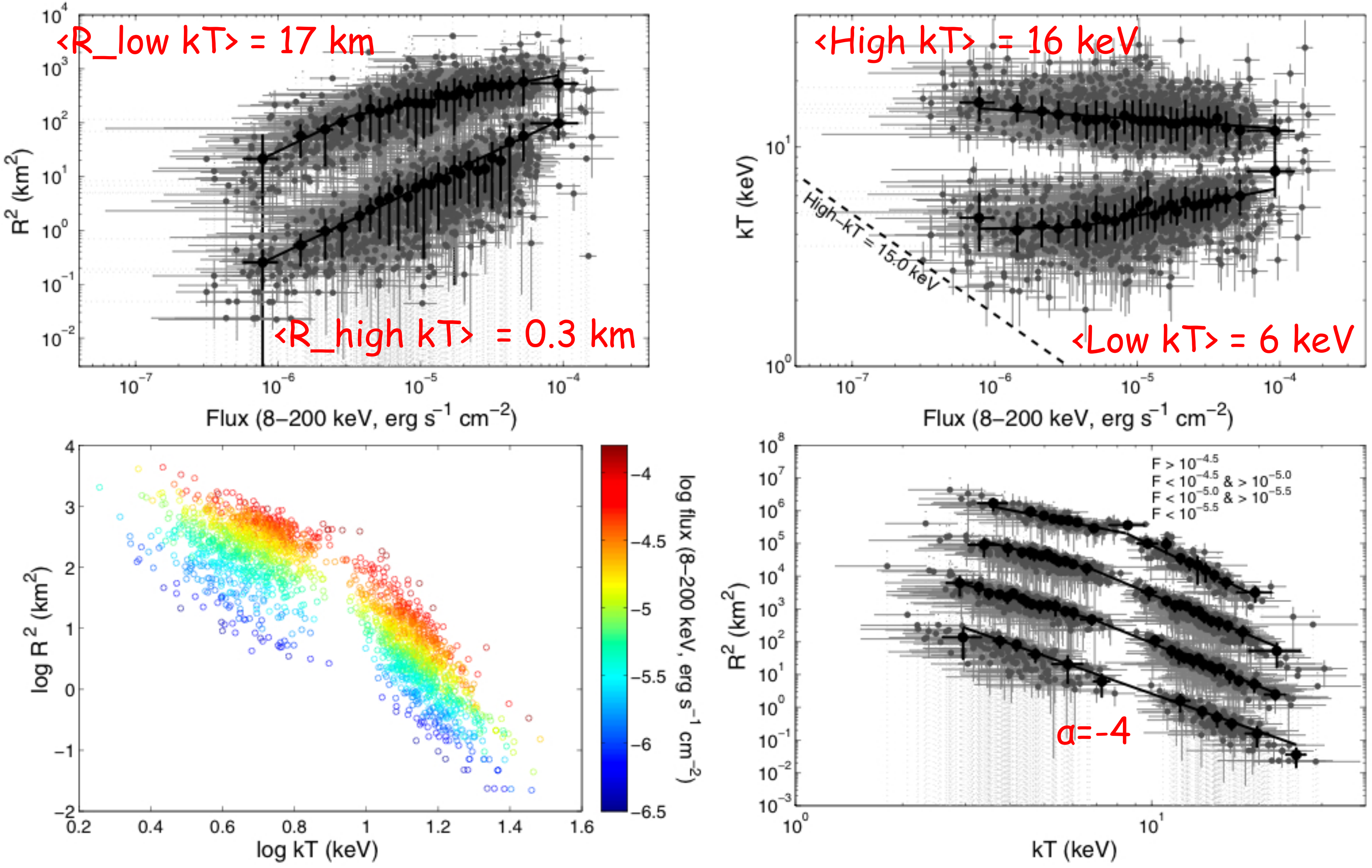

(4.8, 13.1 keV)

1.2(3)

1550:0.7±0.1
0501:1.1±0.1
1900:0.70±0.03

-1.0(3), -6.4(5),
7.9 keV

2 BB: Flux dependence



- Two thermally emitting regions during bursts
  - Highly coupled with energy equipartition between the two
  - kT_high: 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.

New trends - conclusions

- **COMPT:**
  - E_{peak} – flux correlation: break at 10^{-5} erg cm^{-2} s^{-1}
  - index – flux correlation break at same flux
- **2BB:**
  - high-kT: R^2 increases & kT decreases with flux
    → adiabatic cooling of fireball
  - low-kT:
    - < $10^{-5.5}$ erg cm^{-2} s^{-1}: R^2 increases & kT constant with flux
    - > $10^{-5.5}$ erg cm^{-2} s^{-1}: R^2 saturates & kT increases with flux
    - saturation R = 30 km → maximum fireball R → internal magnetic field > 4.5×10^{15} G
  - flux dependence of R^2 – kT correlation

OVERALL

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. Power of high-time resolution spectral studies of 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

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 : **SEE NEXT TALK!**
- 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, GEMS

Serendipitous Discoveries:

Always welcome!

The GBM Magnetar Team

- C. Kouveliotou (NASA/MSFC, USA), G. Younes (USRA, USA), S. Guiriec (UoMD, USA), A. von Kienlin (MPE, Germany)
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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)
- J. Granot (The Open University, Israel)
- J. McEnery, N. Gehrels, A. Harding (NASA/GSFC, USA)