XMM-Newton results on Magnetars

Eradicating a prejudice

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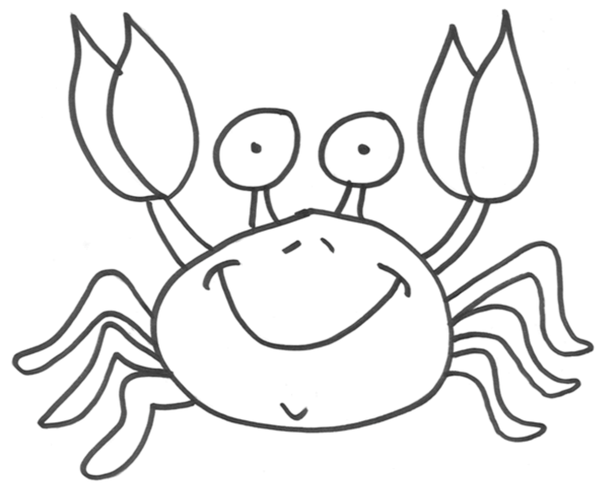
X-ray astronomer's prejudice:

"Contrary to accreting binaries and AGNs, isolated neutron stars are constant X-ray sources"

aka: the Crab Effect



What is a Magnetar ?

Isolated neutron star powered by magnetic energy $B \sim 10^{14}$-10^{15} Gauss

How do we observe magnetars ?

1) "Persistent" X-ray emission

$L_X \sim 10^{35}$ erg/s soft: kT~0.5 keV

P ~ 5-12 s spin-down 10^{-11} –10^{-13} s/s

$dE_{ROT} / dt \ll L_x$

2) Short (<1 s), super-Eddington bursts kT~30 keV

3) Giant Flares - rare events! $L \sim 10^{44}$ – $>10^{46}$ ergs

How many are known ?

9 AXPs + 4 SGRs in our Galaxy and in Magell. Clouds

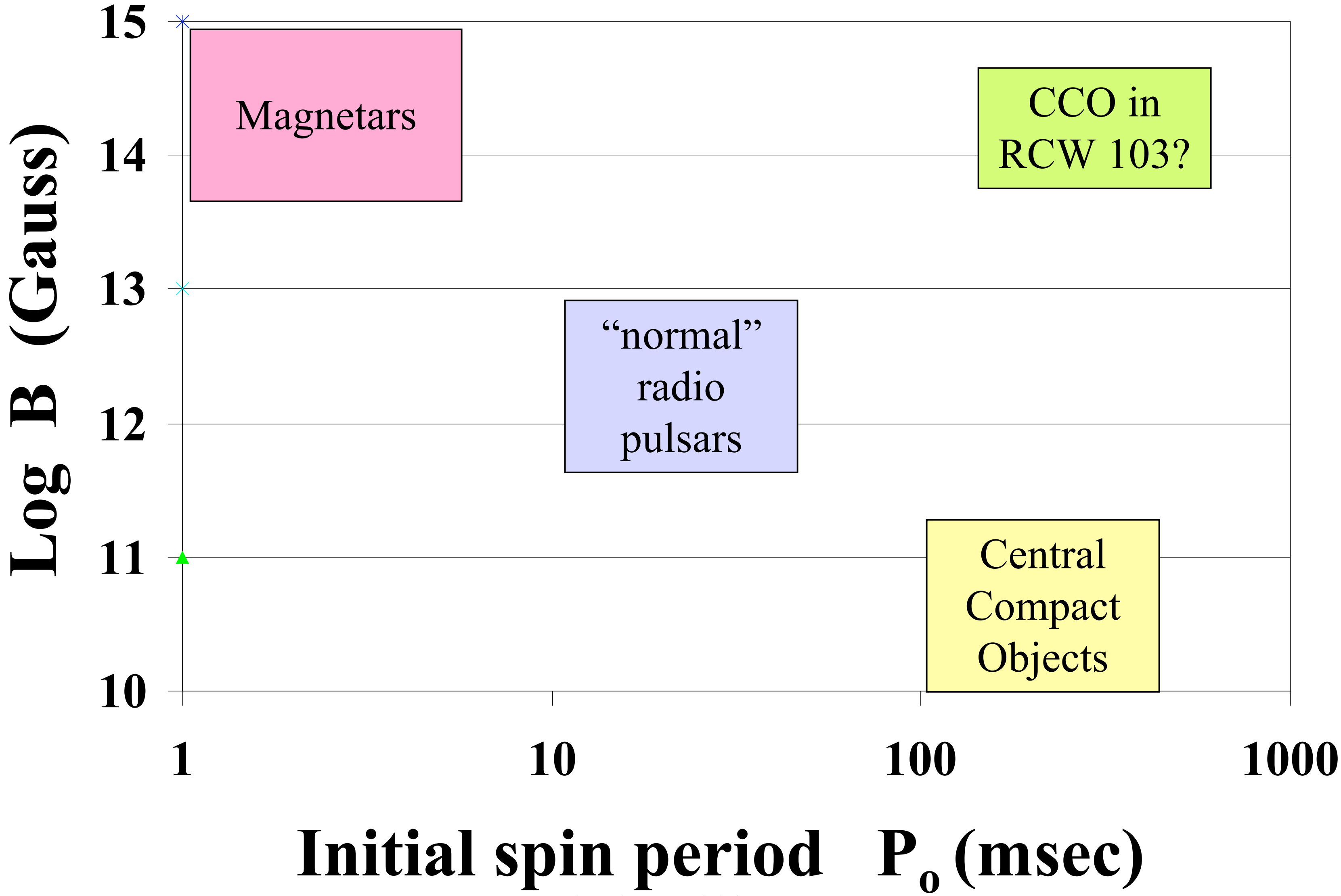
Importance of Magnetars

- **Physics**:
  unique laboratories to study processes in high magnetic fields

- **Astrophysics**:
  a different perspective on neutron stars and massive stars evolutionary end points

  we are biased by 40 yrs of radio pulsars observations

A variety of initial conditions



S.Mereghetti - Madrid 4-6 June 2007

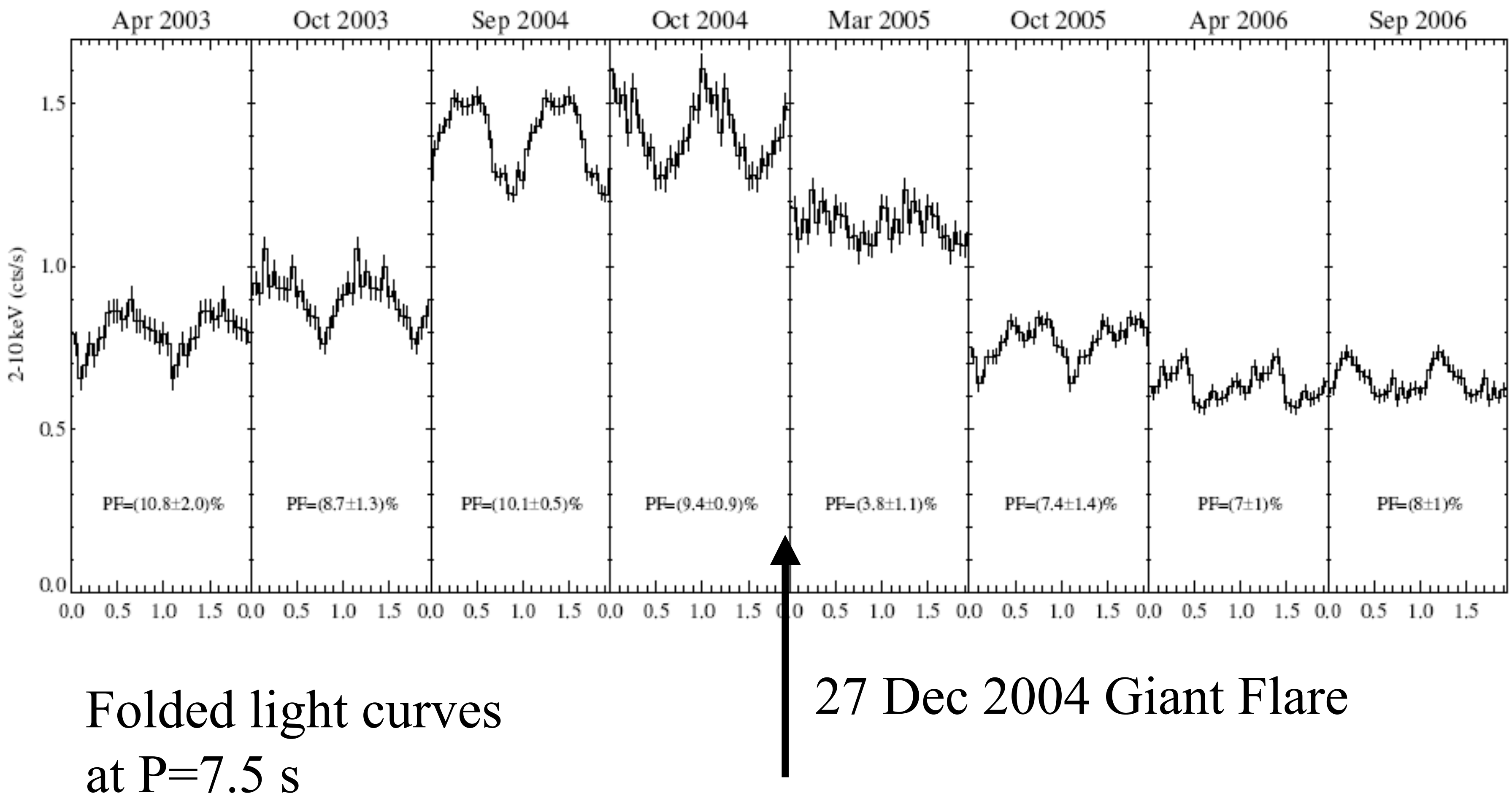
SGR 1806-20

(source of the famous December 2004 Super Giant Flare)

XMM-Newton results in:

Mereghetti et al. 2005, ApJ 628, 938
Tiengo et al. 2005, A&A 440, L63
Esposito et al. 2007, in preparation

8 XMM-Newton observations of SGR 1806-20

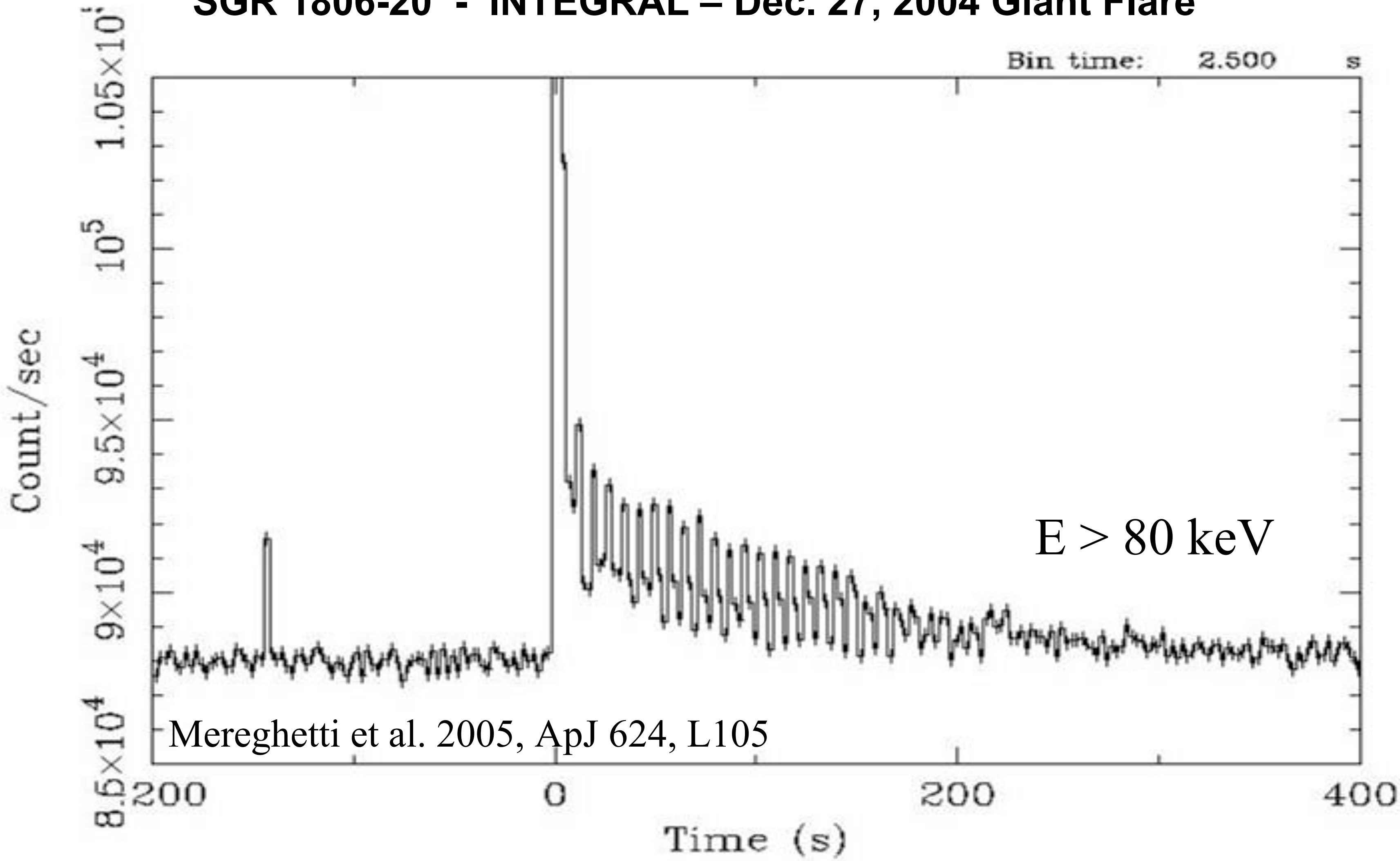


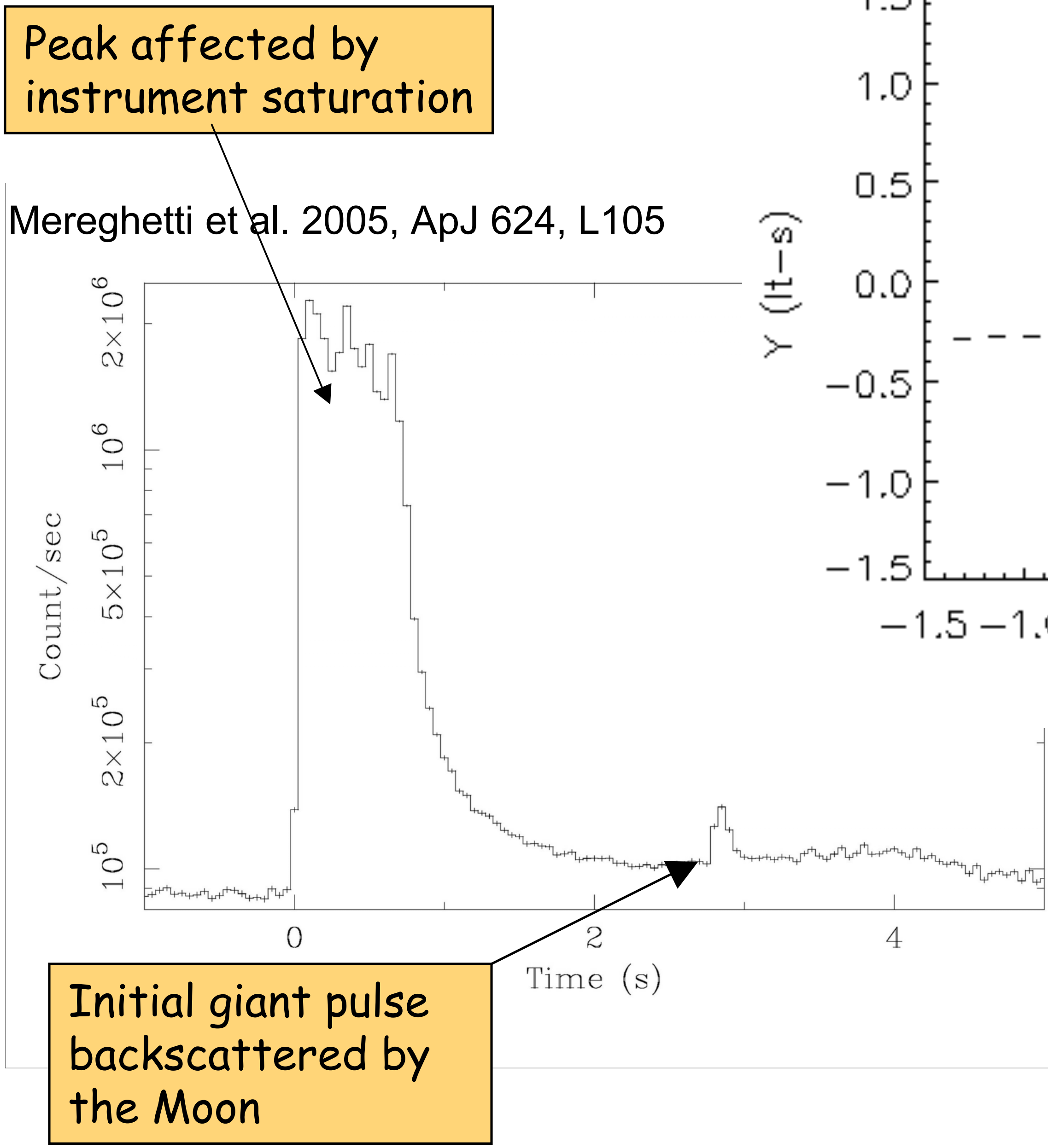
Folded light curves
at P=7.5 s

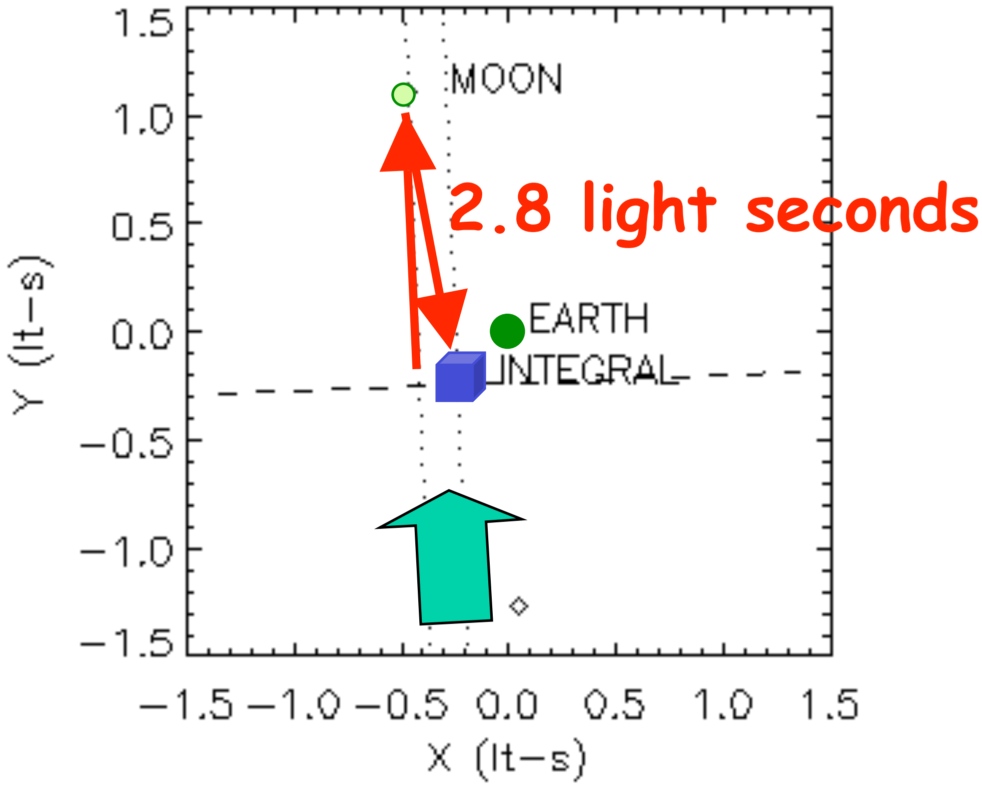
27 Dec 2004 Giant Flare

The strongest ever observed from a SGR

SGR 1806-20 - INTEGRAL – Dec. 27, 2004 Giant Flare





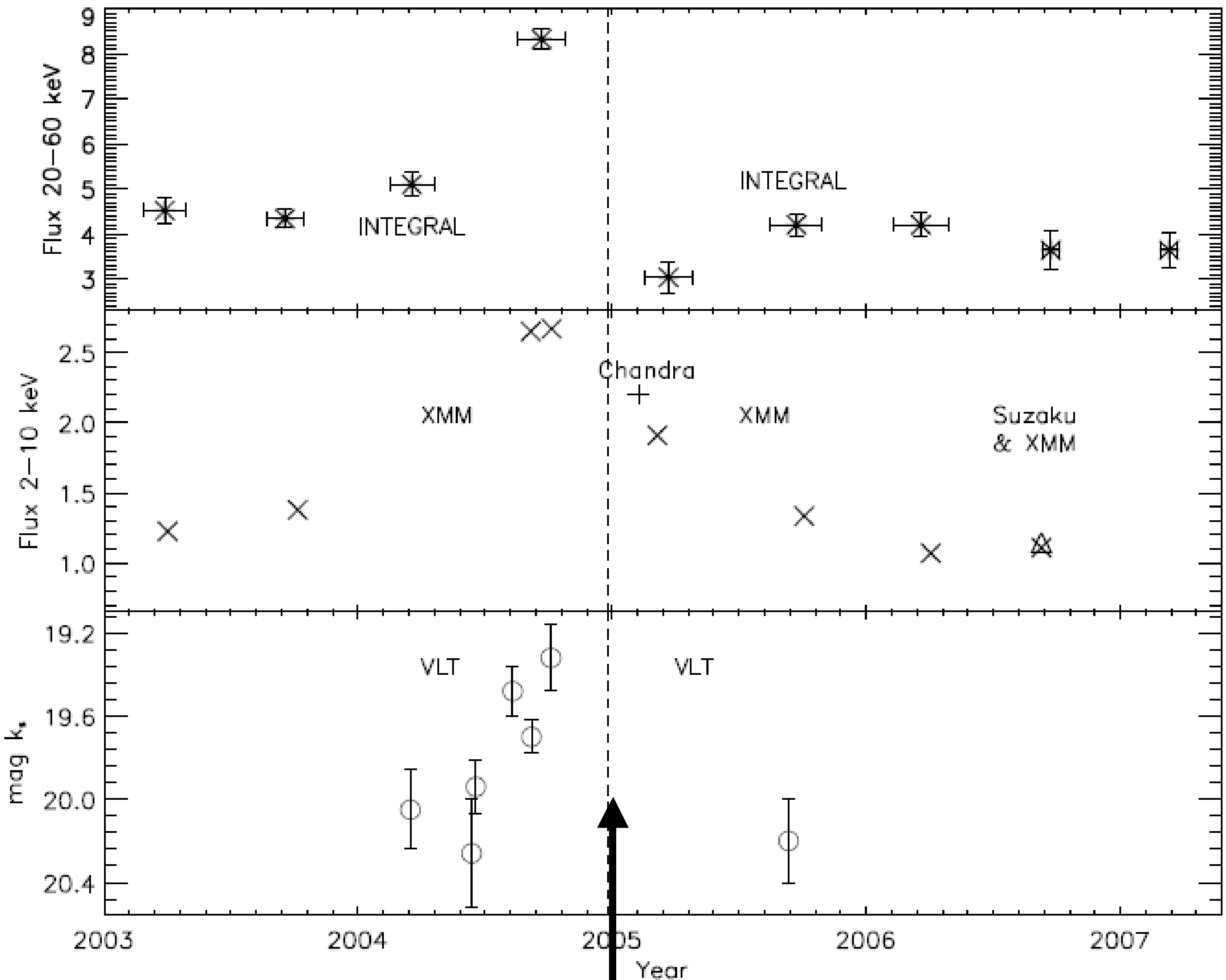


SGR 1806-20
Giant Flare
2004 Dec 2004

Hard X-rays

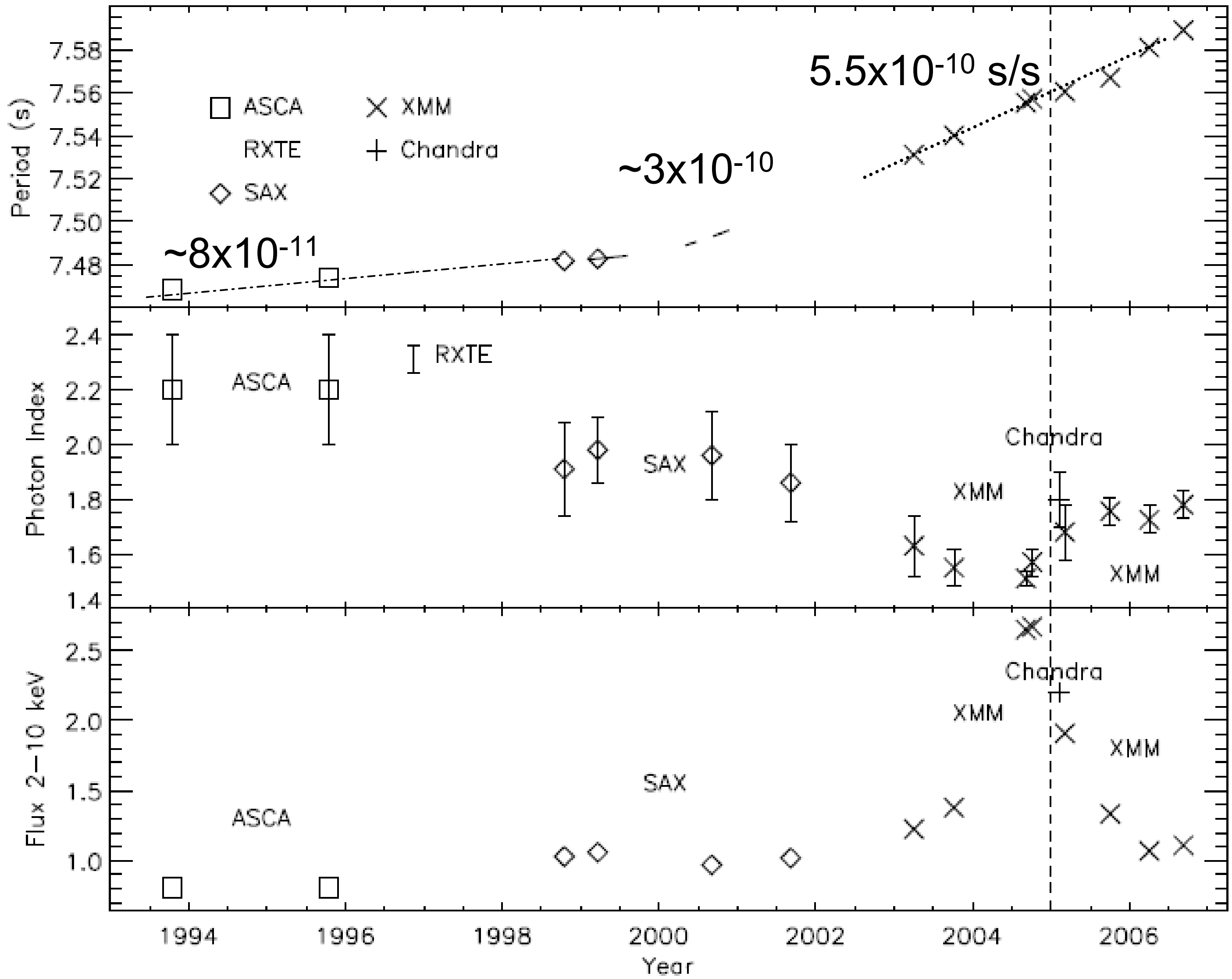
Soft X-rays

Near Infra Red



Dec. 2004 Giant Flare

(Mereghetti et al. 2005b, Tiengo et al 2005, Rea et al. 2005)



SGR 1806-20 – Summary of results:

- Overall spectral hardening on ~ ten years timescale
- Increase in spin-down rate
- Hardness vs. spin-down rate correlation
- In late 2004 also increase in bursting rate and in intensity of 20-100 keV emission
- After Giant Flare: spectral softening,   decrease in pulsed fraction, reduction in spin-down rate

→ **in agreement with twisted magnetosphere model**

Twisted magnetospheres

(Thompson, Lyutikov & Kulkarni 2002)

- Twisted internal B field provide source for helicity of magnetosphere by shearing the NS crust
- Currents in twisted magnetosphere produce hard spectral tails by resonant scattering
- Twisted field produces stronger braking than dipole
- → both spin-down rate and spectral hardness increase with increasing twist of the magnetosphere
- At the same time stresses in the crust increase causing a higher rate of bursts
- Major B reconfiguration occurs with the Giant Flare → change in light curve and spectrum

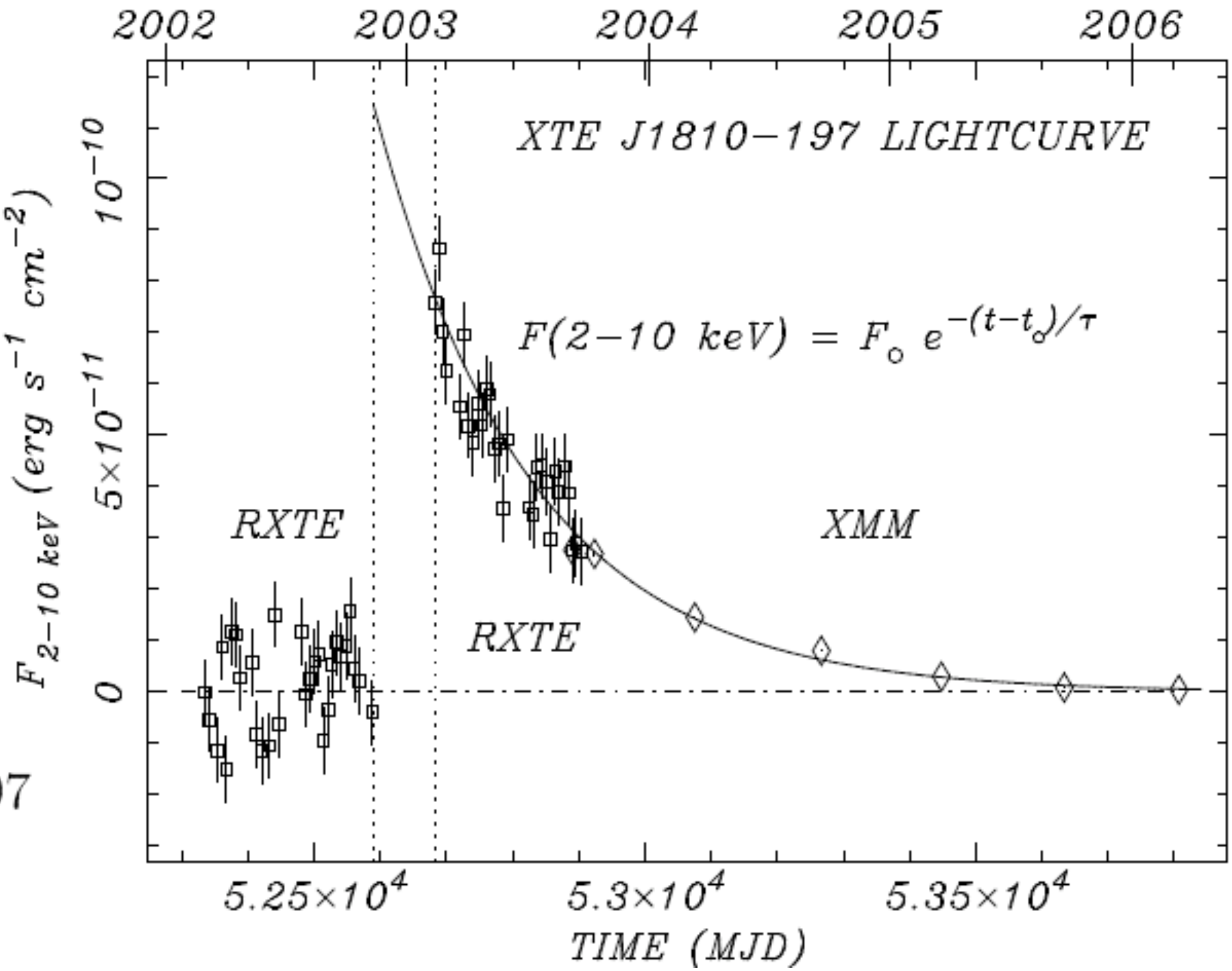
XTE J1810-197

The transient AXP

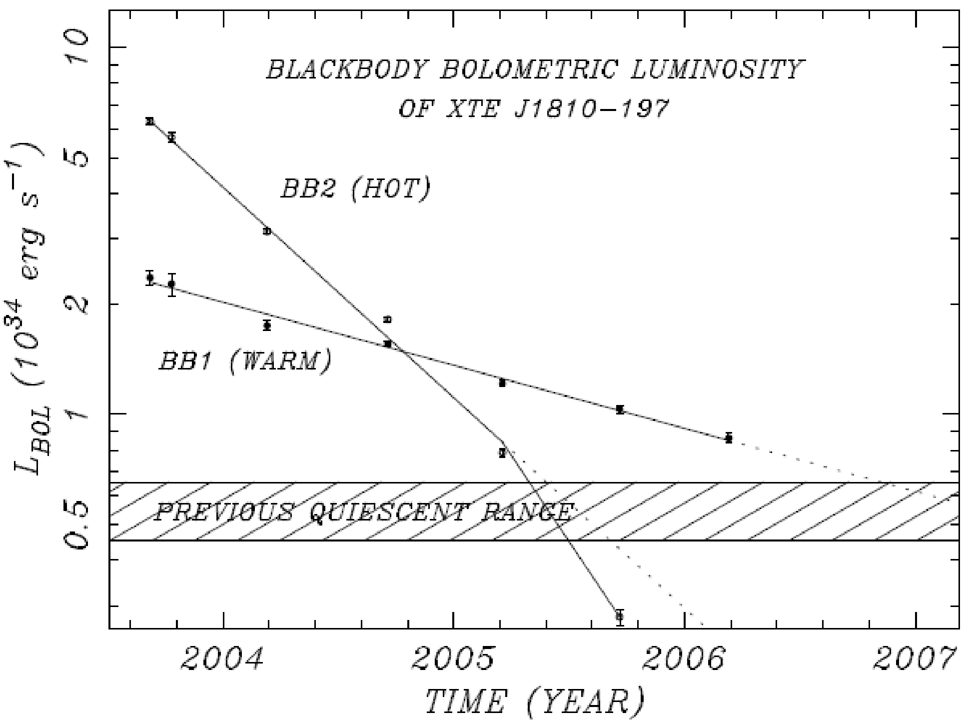
XMM-Newton results in:

Gotthelf et al. 2004, ApJ 605, 368
Rea et al. 2004, A&A 425, L5
Gotthelf & Halpern 2005, ApJ 632, 1075
Gotthelf & Halpern 2006, astro-ph/0608473

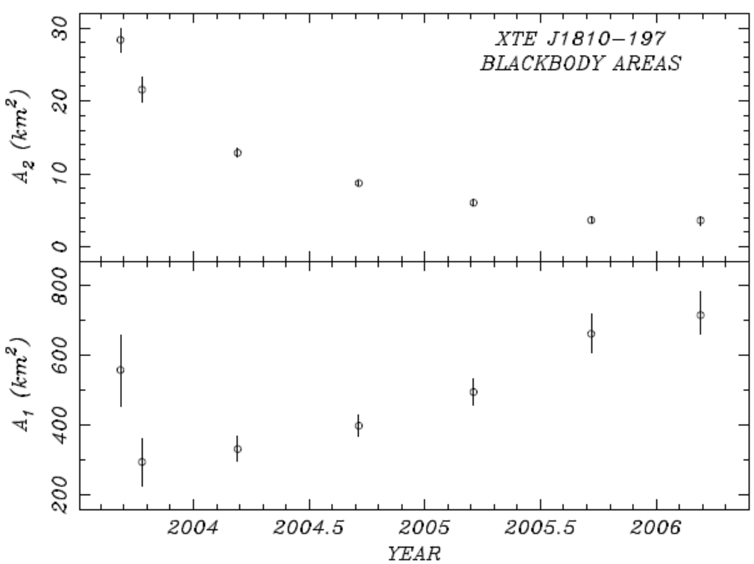
XTE J1810-197: the transient AXP

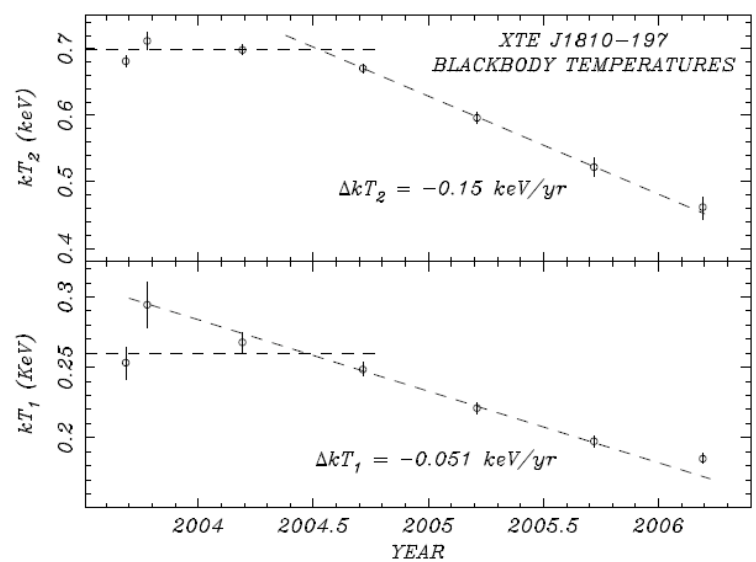


97



Phenomenological model based on 2 blackbody emitting concentric regions





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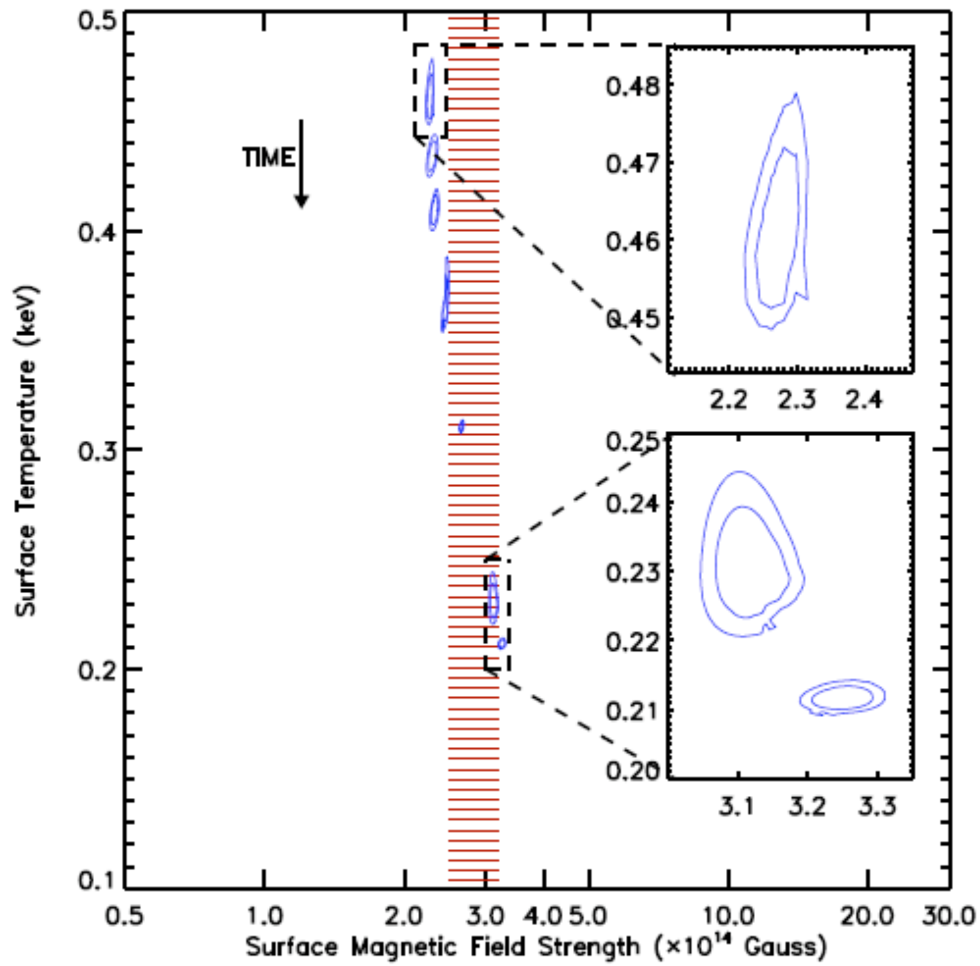
Results from fits with physical model of NS atmosphere with reprocessing in magnetosphere

Güver et al. 2007, arXiv:0705.3713

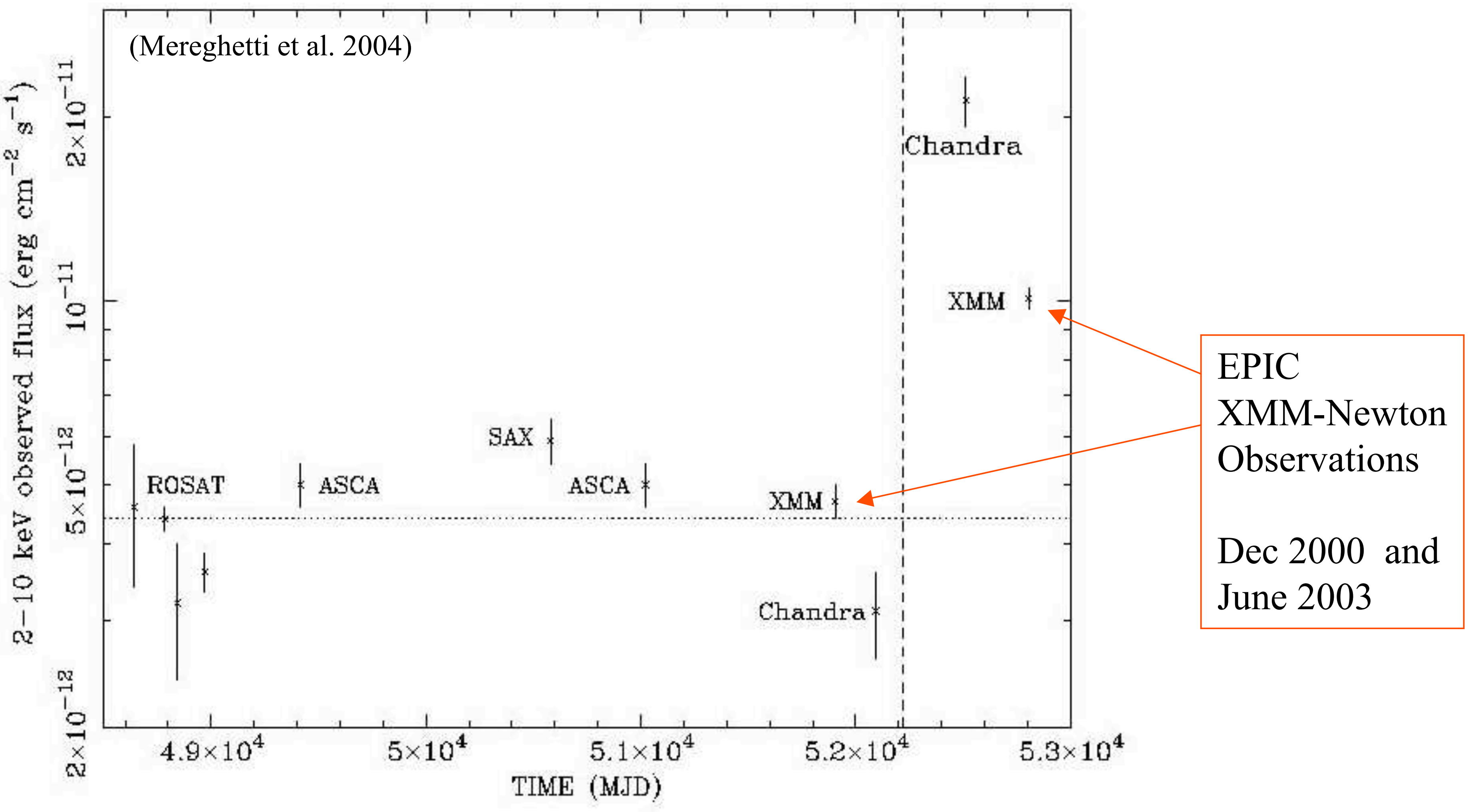


AXP 1E 1048.1-5937

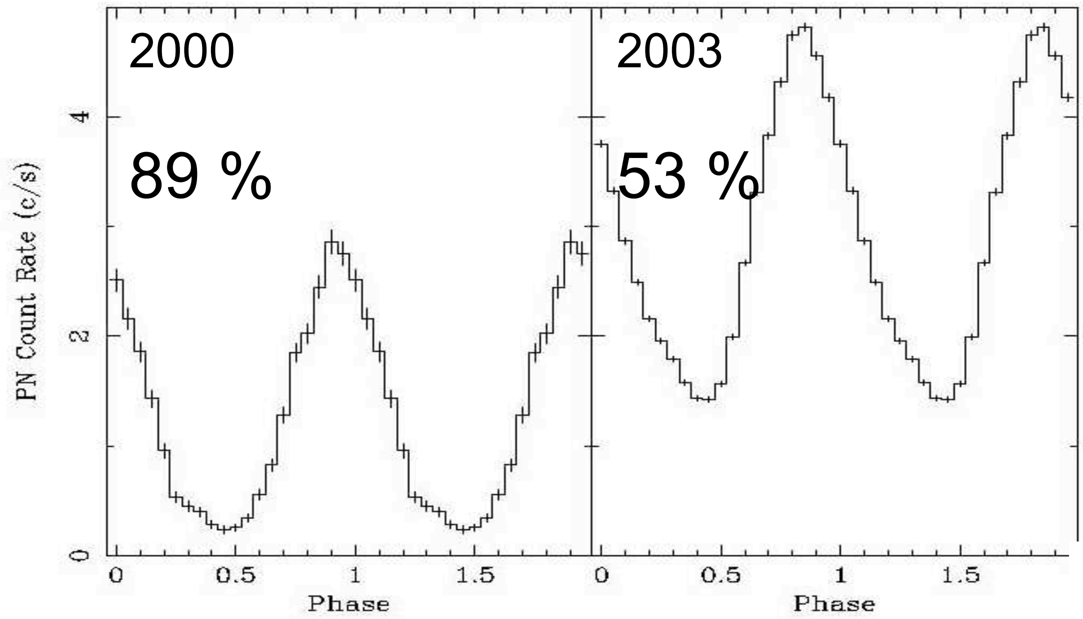
XMM-Newton results in:

Tiengo et al. 2002, A&A 383, 182
Mereghetti et al. 2004, ApJ 608, 427
Tiengo et al. 2005, A&A 437, 997

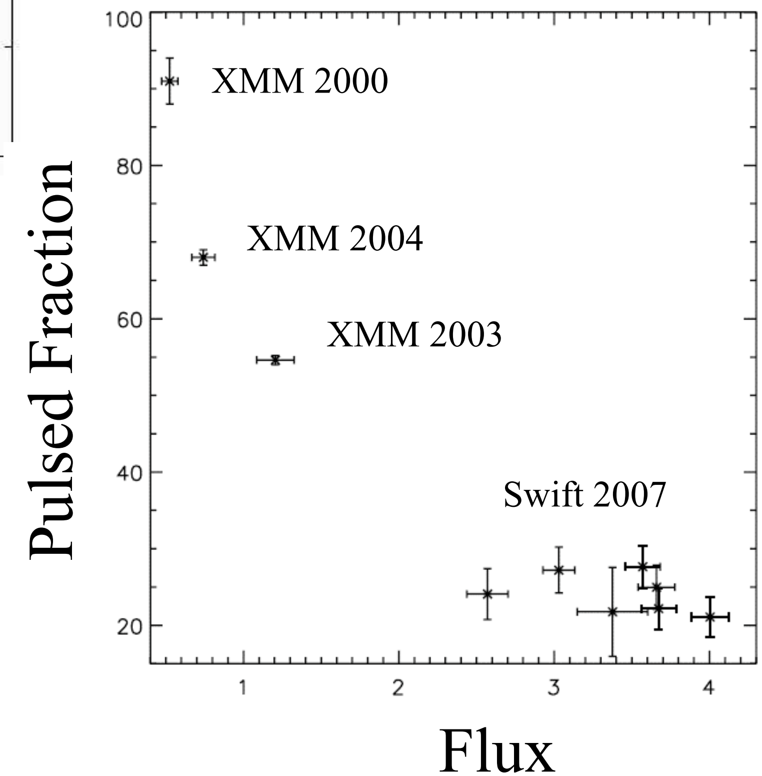
Evidence for significant variability in 1E 1048.1-5937



1E 1048.1-5937



Anti-correlation between flux and pulsed fraction



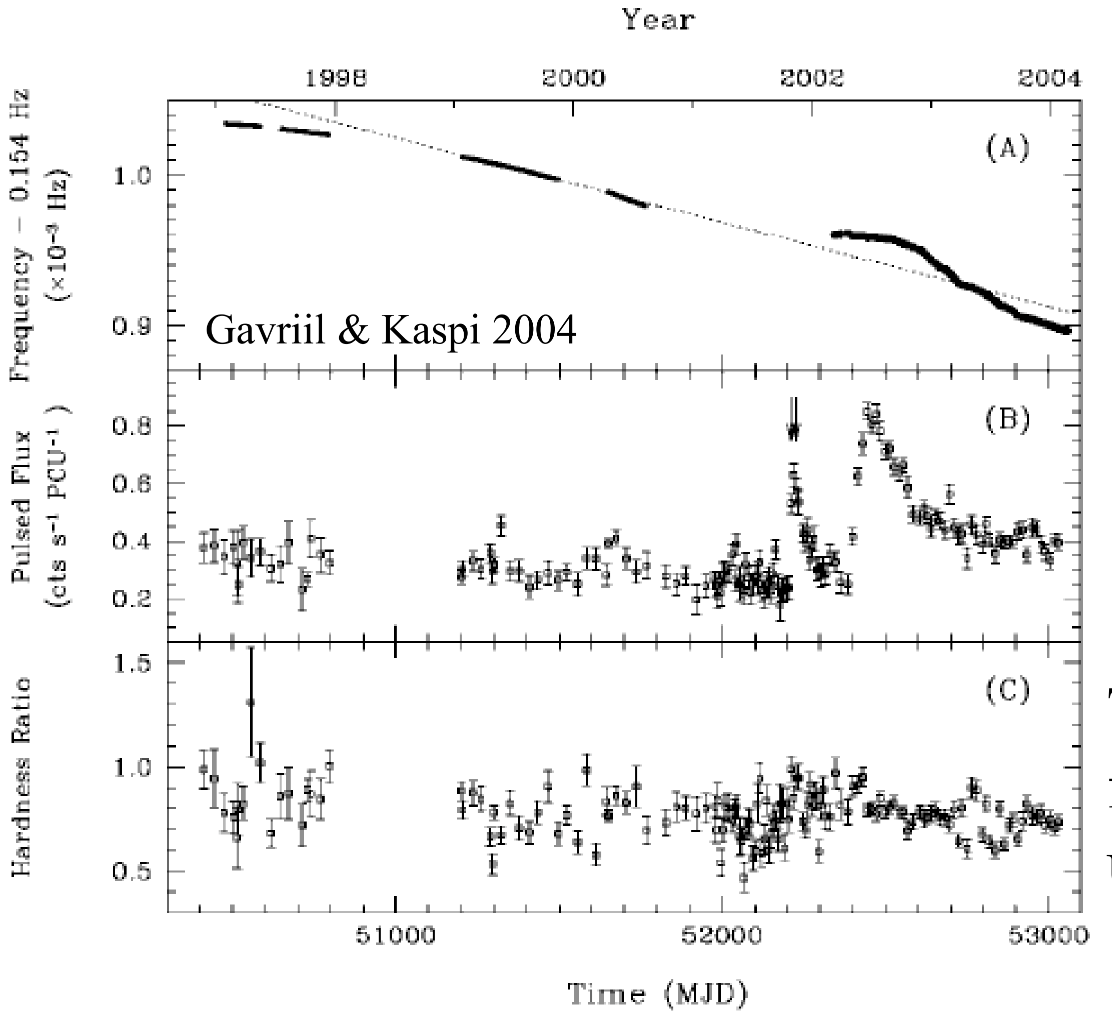


FIG. 1.—Spin, flux, and spectral history of 1E 1048.1−5937. (*a*) Observed

RXTE can measure only the **pulsed** flux

The inferred outburst fluence can be significantly underestimated

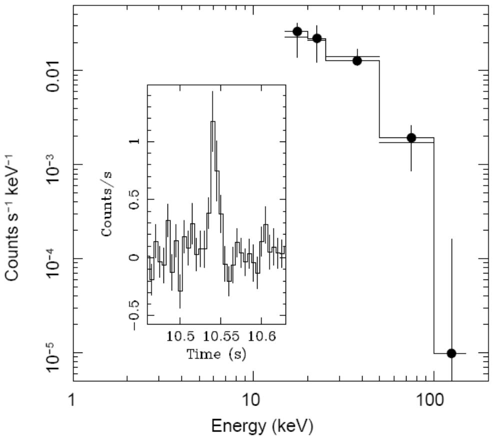
CXOU J164710.2–455216
The transient AXP in Westerlund 1

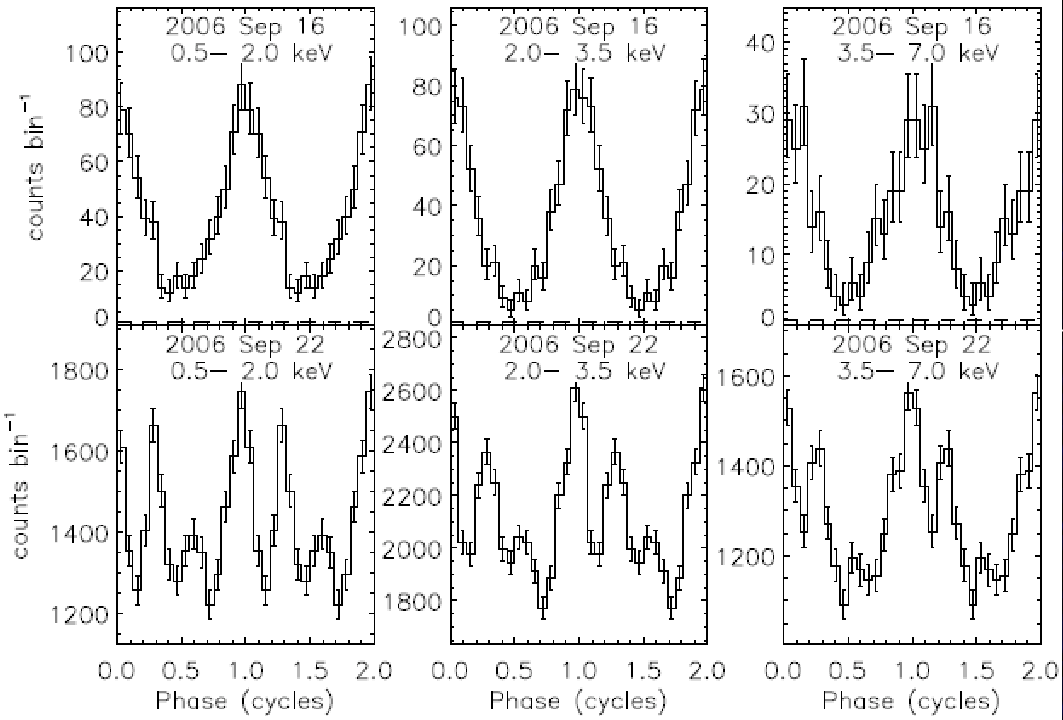
XMM-Newton results in:

Muno et al. 2007, MNRAS in press
Israel et al. 2007, ApJ in press

Swift-BAT burst
on Sept 21, 2006

→ XMM-Newton ToO





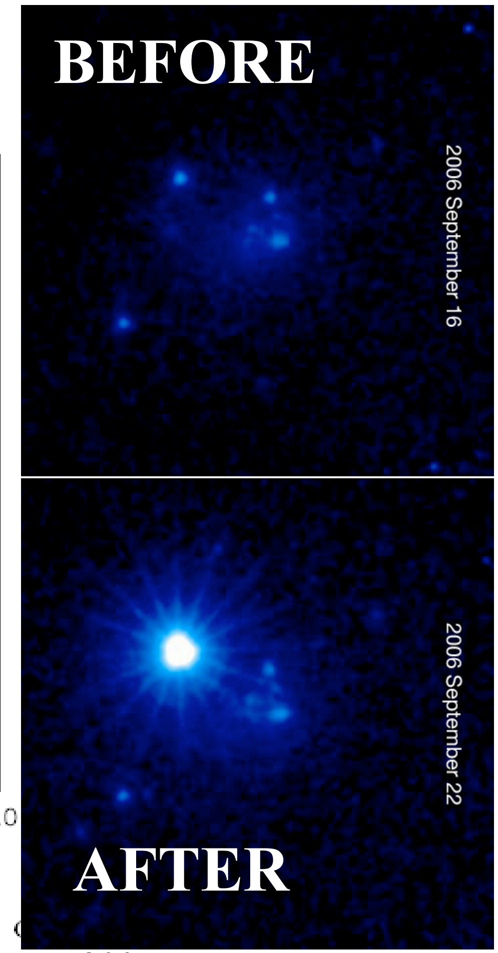


Figure 3. Pulse profiles of CXOU J164710.2-455216 taken c

RXJ 1856.5-3754

XMM-Newton discovery of long-sought pulsations

Tiengo & Mereghetti 2007, ApJ 657, L101

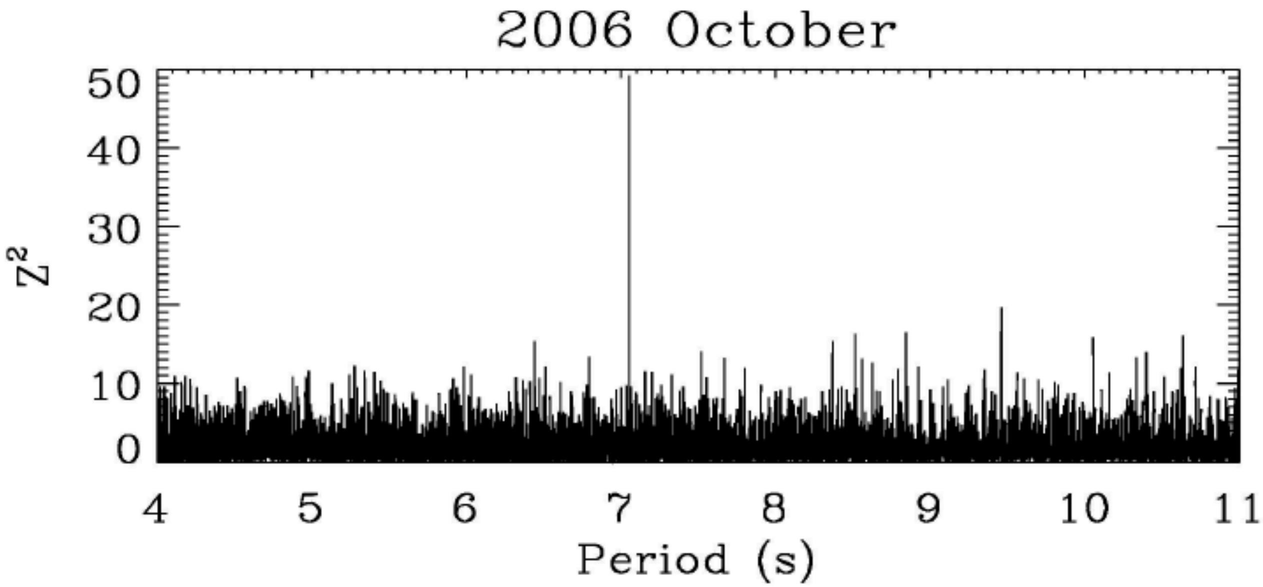
The Magnificent Seven

- Discovered by ROSAT as soft X-ray sources without optical counterpart
- Thermal spectrum (kT~50-100 eV), low absorption ($N_H \sim 10^{20}$ cm^{-2}), pulsations (3-12 s) → isolated nearby (~100 pc) neutron stars
- Among ~2000 neutron stars only the M7 have purely thermal spectra → we directly observe the hot (~10^6 K) NS surface
- B ~ few 10^{13}—10^{14} G (from broad lines and spin-down) → could be the descendant of Magnetars

RXJ 1856.5-3754

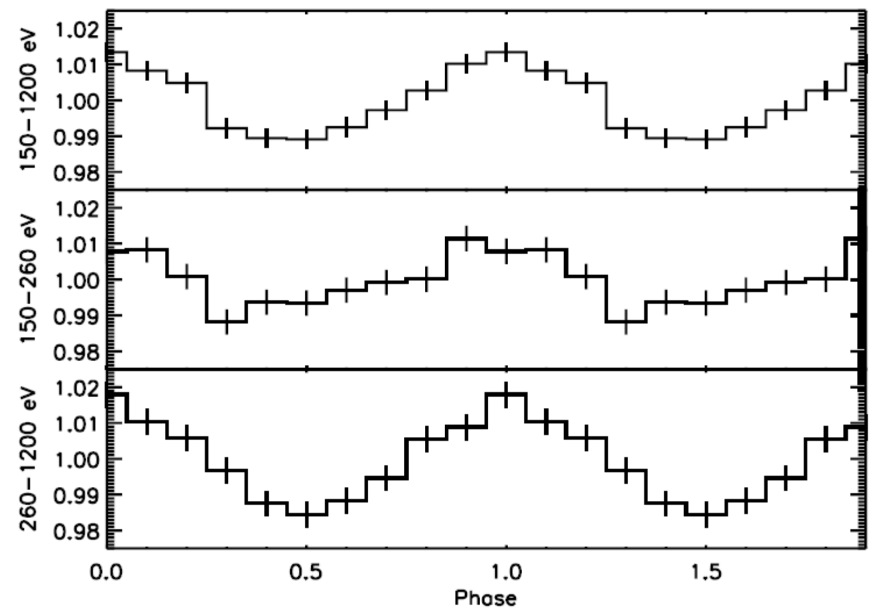
- The brightest of the "Magnificent Seven"
- Used as calibration source for EPIC
- Featureless thermal spectrum
- Distance measured through HST parallax of optical counterpart
- No pulsations found (u.l. of 1.5% on PF)…
  …until Oct 2006 XMM-Newton observation

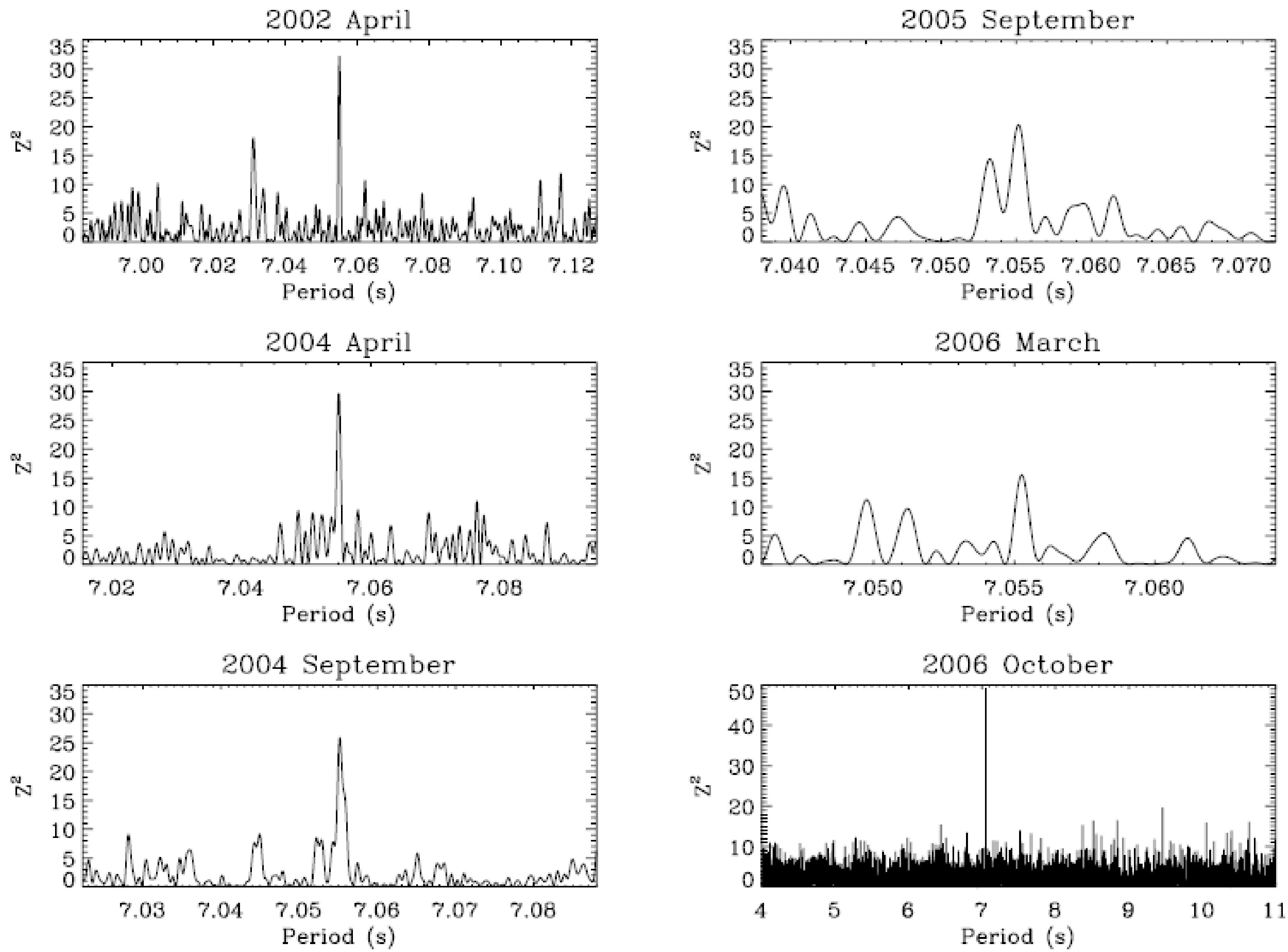
(Tiengo & Mereghetti 2007, ApJ 657, L101)



P=7 s discovered in October 2006 EPIC data

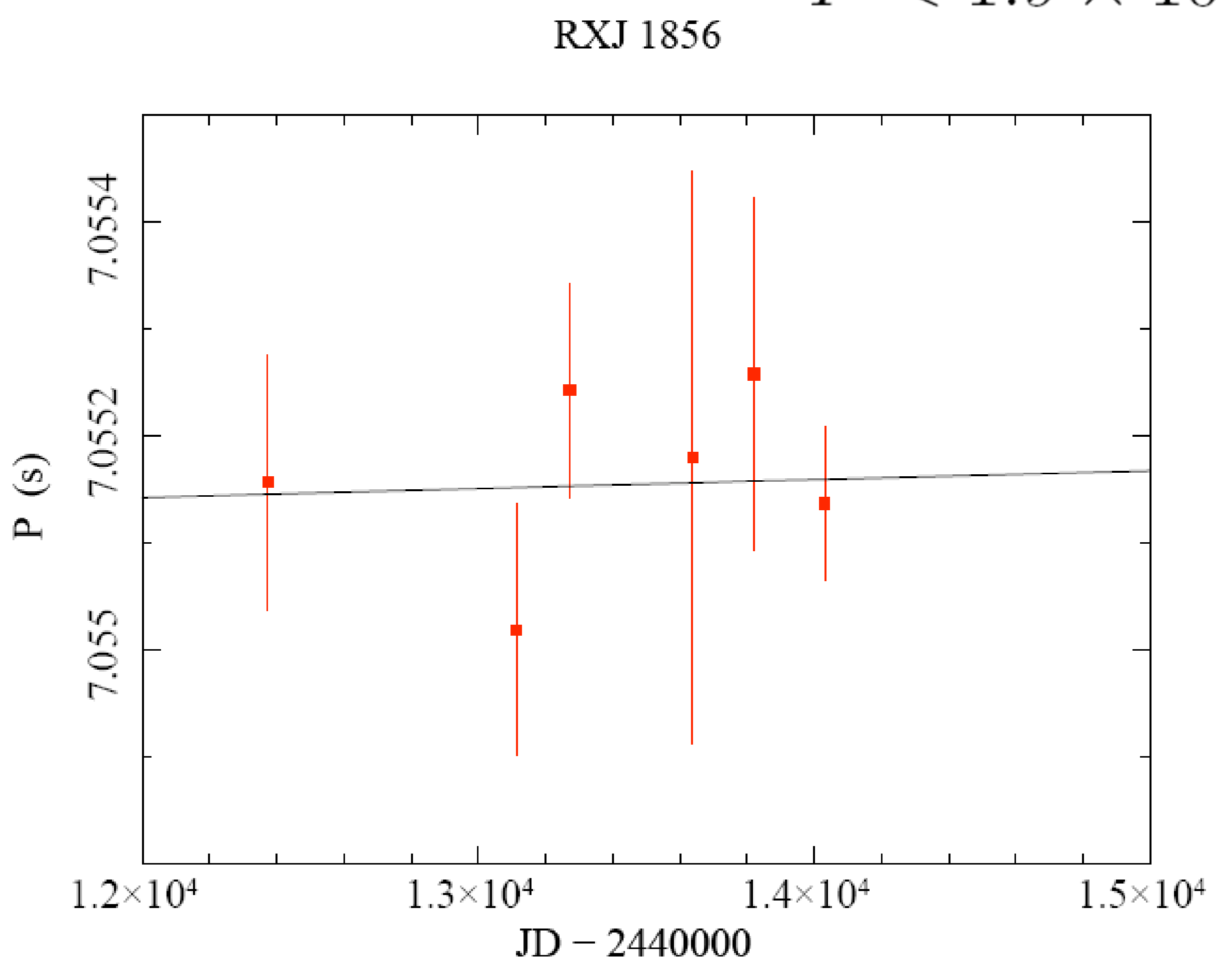
Very small pulsed fraction: 1.2%

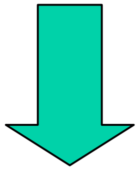



2002 April
2005 September
2004 April
2006 March
2004 September
2006 October
Z²
Period (s)

Knowledge of magnetic field is essential for modeling of thermal emission…
But current data do not allow to measure the period derivative

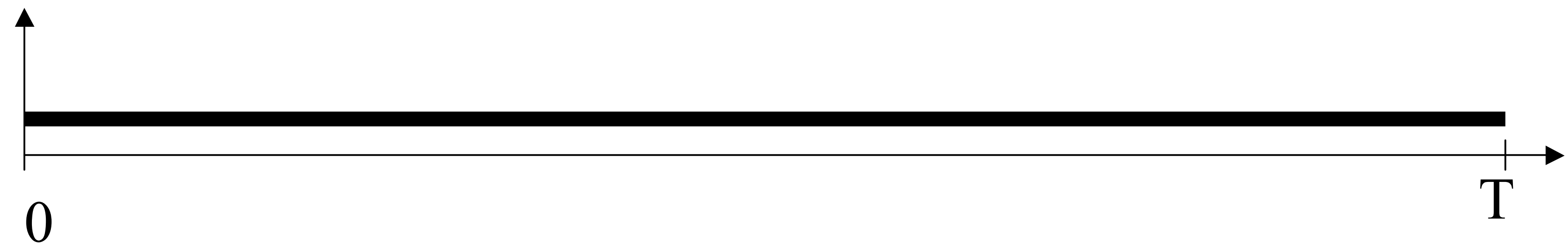
$$\dot{P} < 1.9 \times 10^{-12}\ \mathrm{s\ s^{-1}}\ (90\%\ \mathrm{c.l.})$$



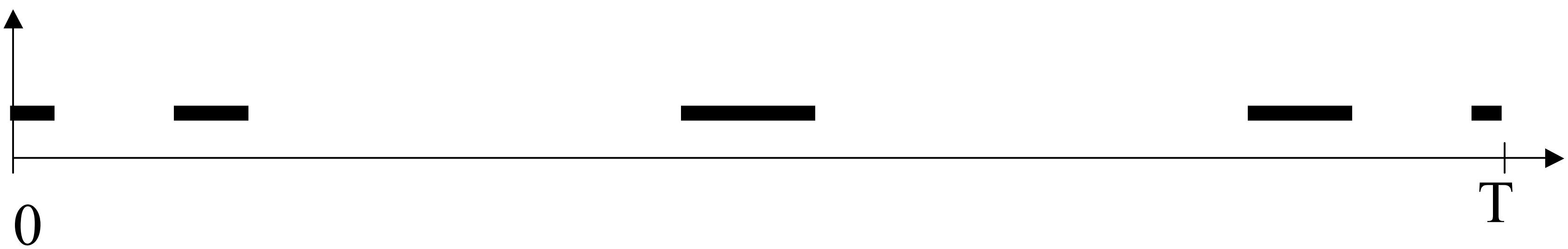


$B < 1.2\ 10^{14}$ G

Timing accuracy depends on observation length…

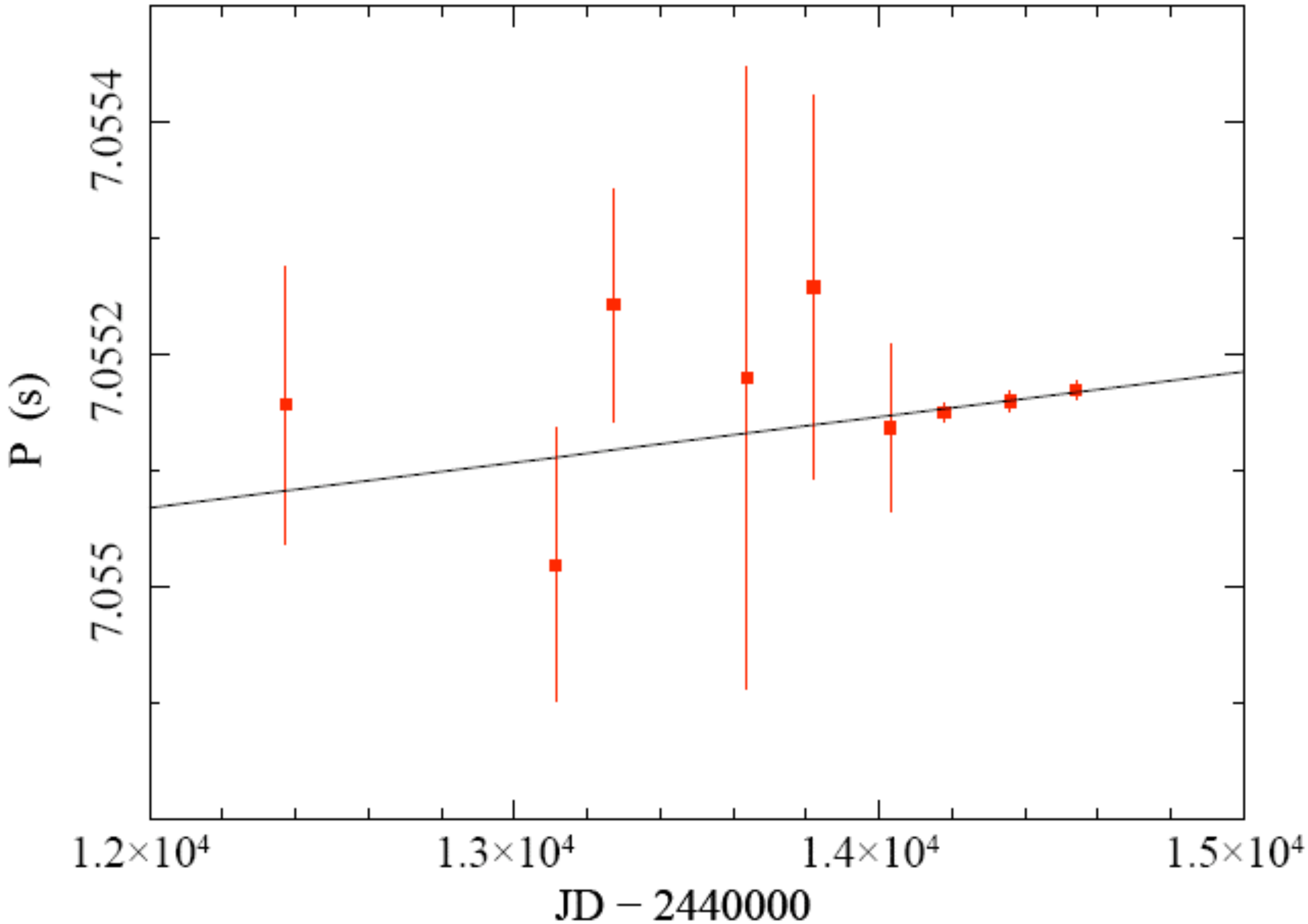


…but a few short observations are equivalent to a long one, provided phase connection is kept



Analogous to radio interferometry

RXJ 1856



Future prospects for XMM observations of Magnetars

A few key objects should be regularly observed every visibility period (i.e. twice per year) with adequate exposure to get high quality phase resolved spectra and pulse profiles

ONLY XMM CAN DO IT

Target of Opportunity observations after bursts, flares, and timing irregularities (e.g. glitches)

COULD BE EASIER IF TOO PROPOSALS ACCEPTED IN AOs

Multiple observations planned for phase connected timing

VERY IMPORTANT AFTER RXTE END OF OPERATIONS

Multi-wavelength coverage is important

e.g. COORDINATION WITH INTEGRAL SHOULD BE EASY