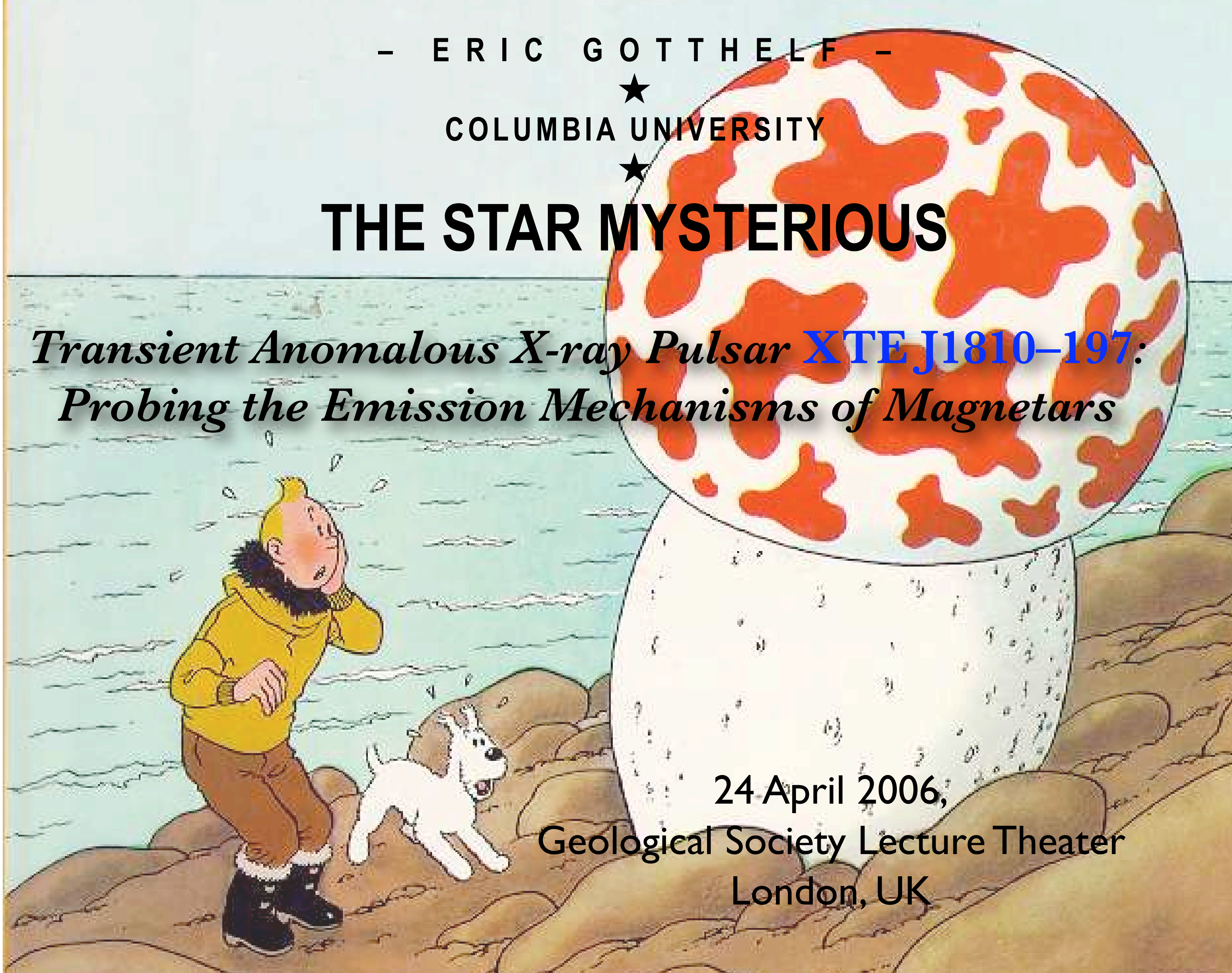

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Transient Anomalous X-ray Pulsar XTE J1810–197: Probing the Emission Mechanisms of Magnetars

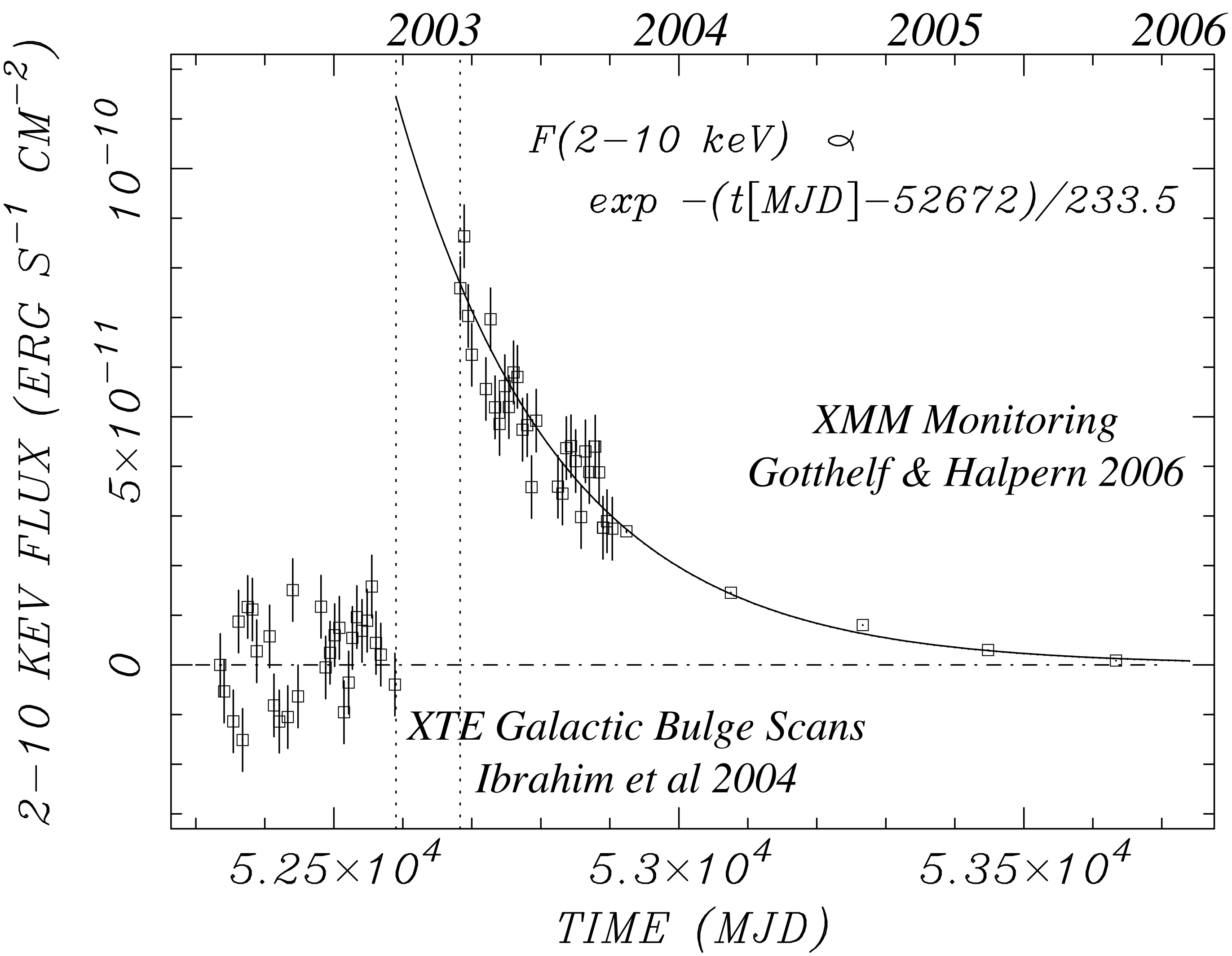
24 April 2006,
Geological Society Lecture Theater
London, UK

Introduction

- *Brief Overview: Transient AXP XTE J1810–197,*
- *Spectral Modeling: PL+BB vs. BB+BB,*
- *XMM monitoring: 3 years / 6 observations,*
- *Emission Geometry: Models & Theory,*
- *Conclusions and Future Work.*

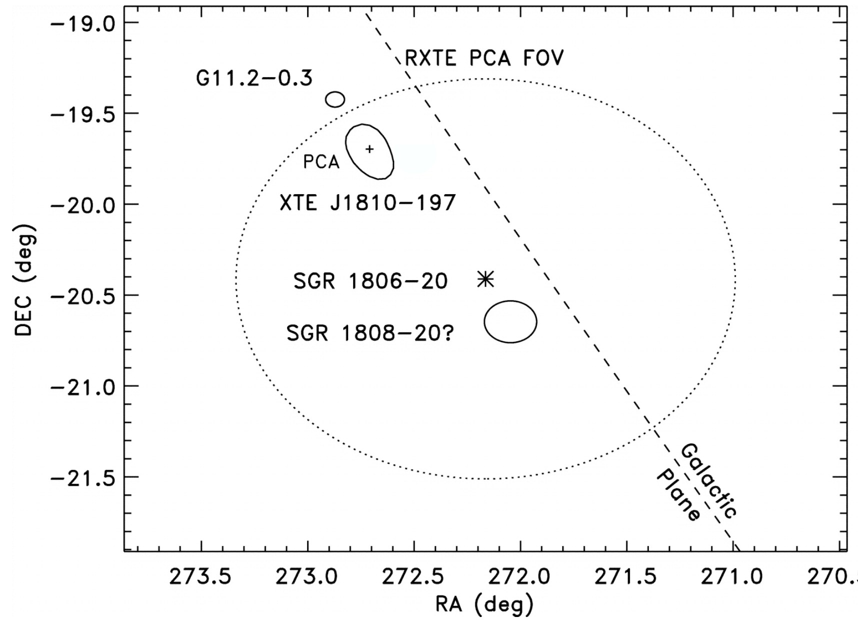
Transient AXP XTE J1810-197

Outburst Onset b/w 17 Nov 2002 and 23 Jan 2003



Discovery of Pulsar XTE J1810-197

XTE observation of SGR 1806-20 yields new AXP in FOV
(*Ibrahim et al. 2004*)



A key object for probing the emission mechanism of magnetars

Unique Observational Properties of an AXPs

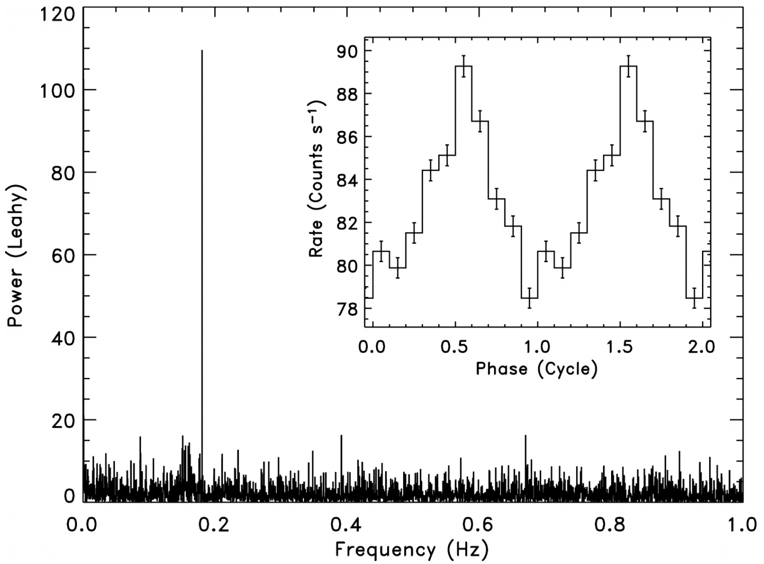
Timing -

1. $P = 5.54\,\mathrm{s} \quad \dot{P} \approx 10^{-11}\,\mathrm{s\,s^{-1}}$

2. $B_p \approx 3 \times 10^{14}\,\mathrm{G} \quad \tau \approx 7.6\,\mathrm{kyr}$

3. *No evidence of orbital motion*

~ 50% pulsed fraction

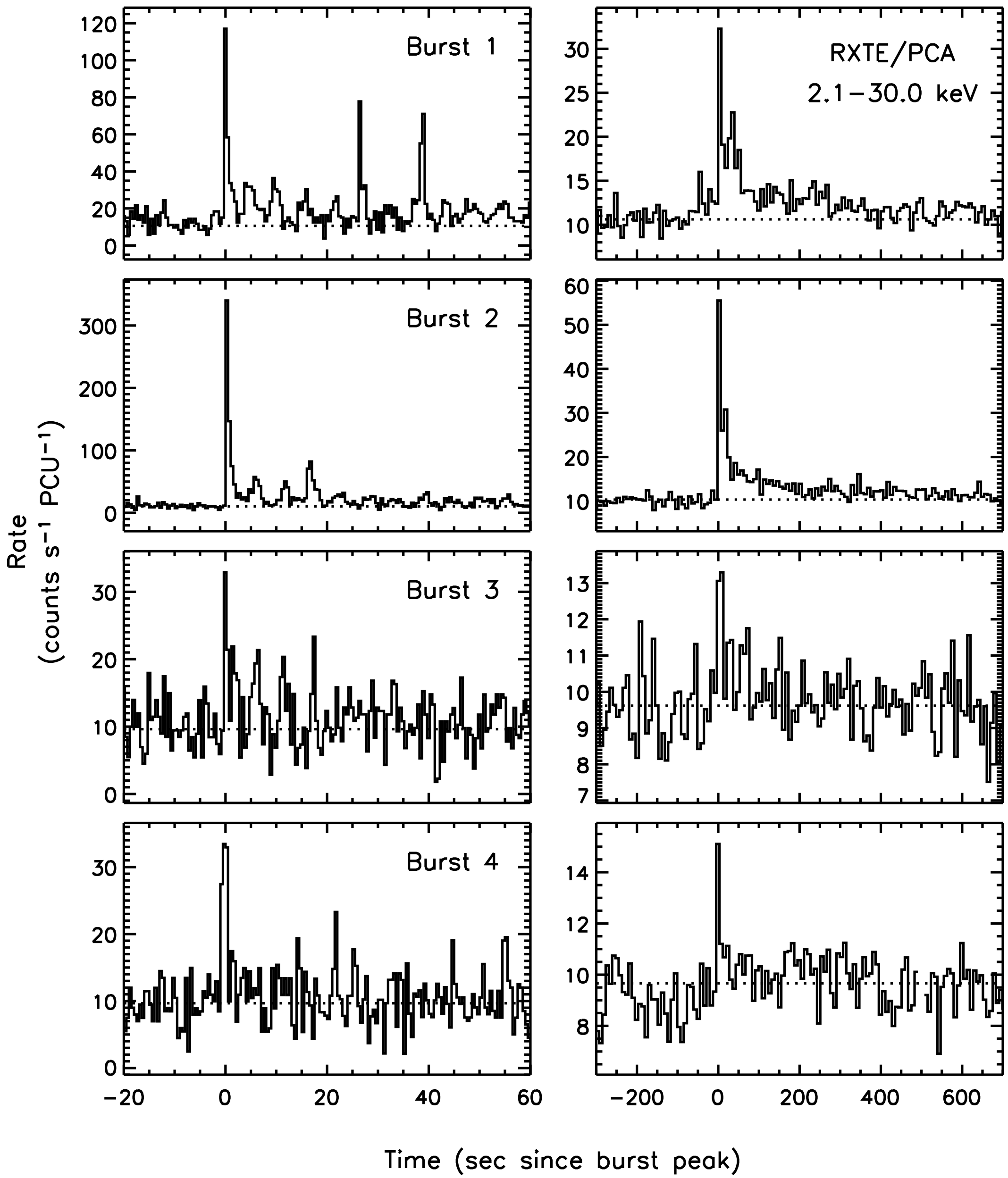


Spectrum -

4. Power-law model, *Γ* ~ 5. 5

Initial $F(2-10) = 5.5 \times 10^{-10}\mathrm{erg\,s^{-1}\,cm^{-2}}$ $\quad \dot{E} \approx 4 \times 10^{33}\,\mathrm{erg\,s^{-1}}$

5. $L_x \sim 50 \times \dot{E}$ for reasonable distances (~ 5 kpc)



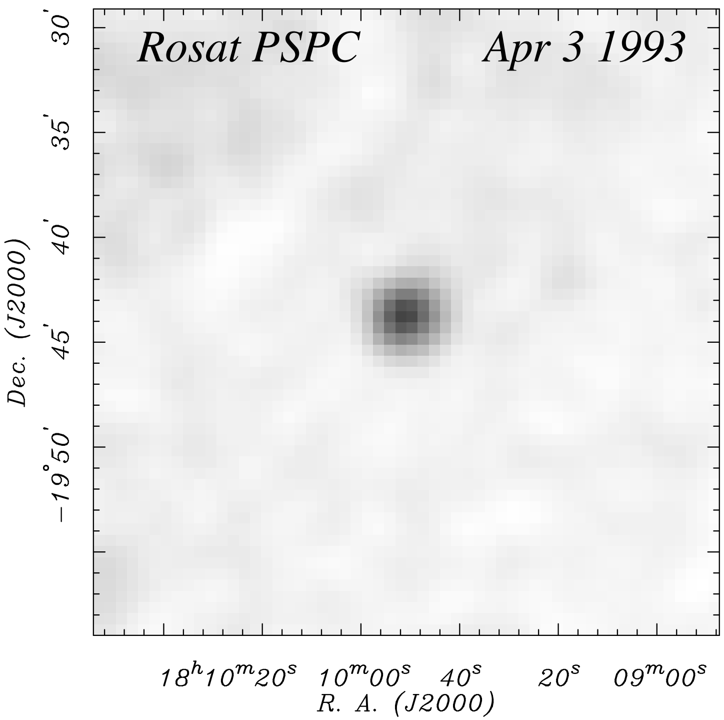
X-ray Bursts from XTE J1810–197

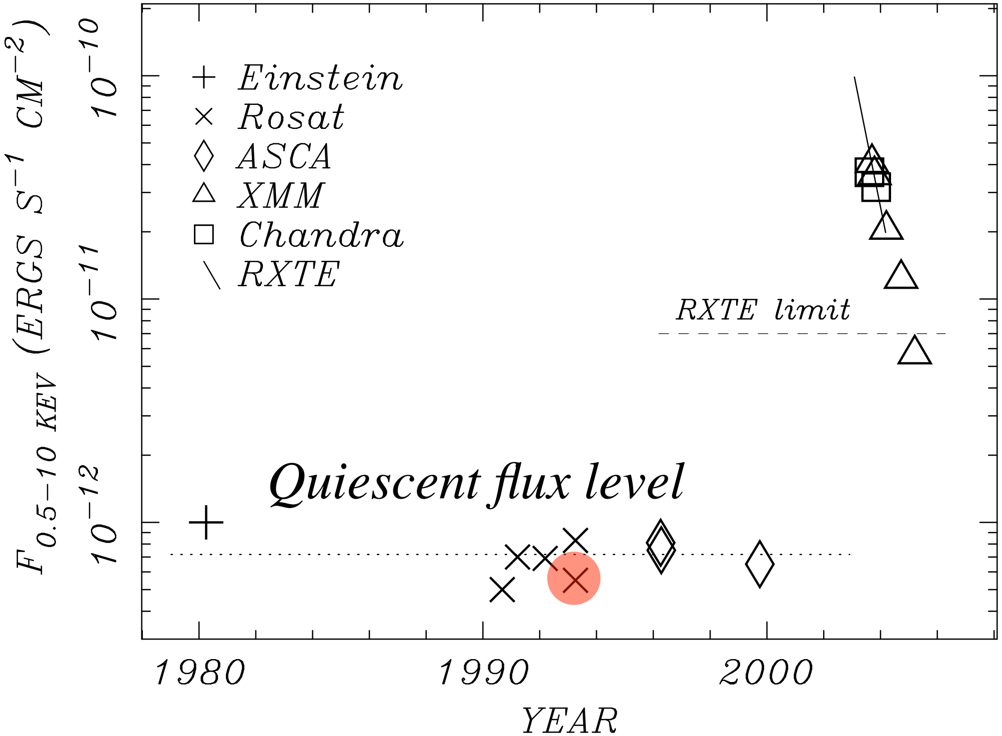
Similar to bursts seen from AXP 1E 2259+586

Further confirmation of a AXP/SGR magnetar

Woods et al. 2005

Flux History of XTE J1810–197: Quiescent X-ray Source





Quiescent spectrum (1993 Apr 03; Rosat/PSPC):

$$F_x(0.5 - 10 \text{ keV}) = 5.5 \times 10^{-13} \text{ erg s}^{-1} \text{ cm}^{-2}$$

$$k\text{T} = 0.18 \pm 0.02 \text{ keV}$$

No pulsations detected, limit <24%

Gotthelf et al 2004

Further Observational Properties of XTE J1810-197

Timing:

Ibrahim et al (2004)
Gotthelf et al. (2004)

- *Spin-down evolution is not steady*
- *No evidence for Doppler shift of a binary*
- *Long orbital periods (<100 d) ruled out*
- *Short orbital periods (>20 min) unlikely*

Optical/IR:

Israel et al (2004)
Rea et al. (2004)
etc...

- *No optical counterpart/companion (e.g., I< 24.3)*
- *Yes, IR Source - Ks = 20.8*
- *Color / X-ray flux ratio consistent w/ AXP*
- *IR variability follows X-ray changes*

Radio:

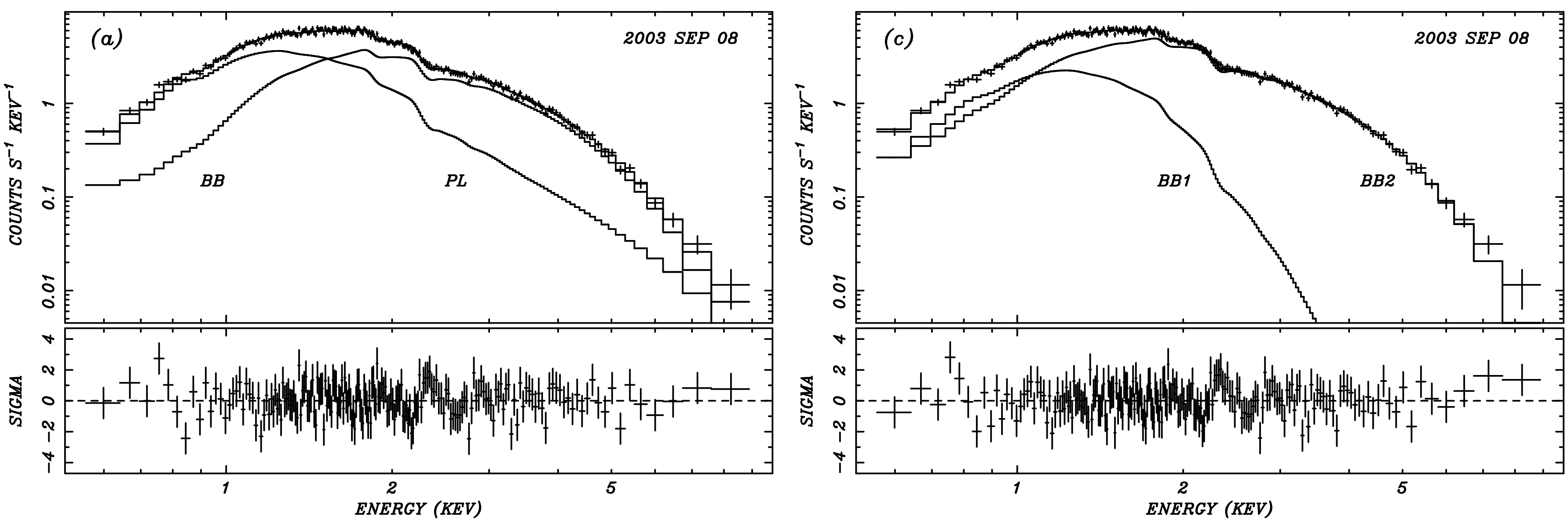
Halpern et al. (2005)

- *Radio detection ~ 1 year later 4 mJy @1.43 GHz*
- *First detection of radio emission from an AXP!*
- *No radio detection/pulsations just after outburst*
- *Prior upper-limits unconstraining*

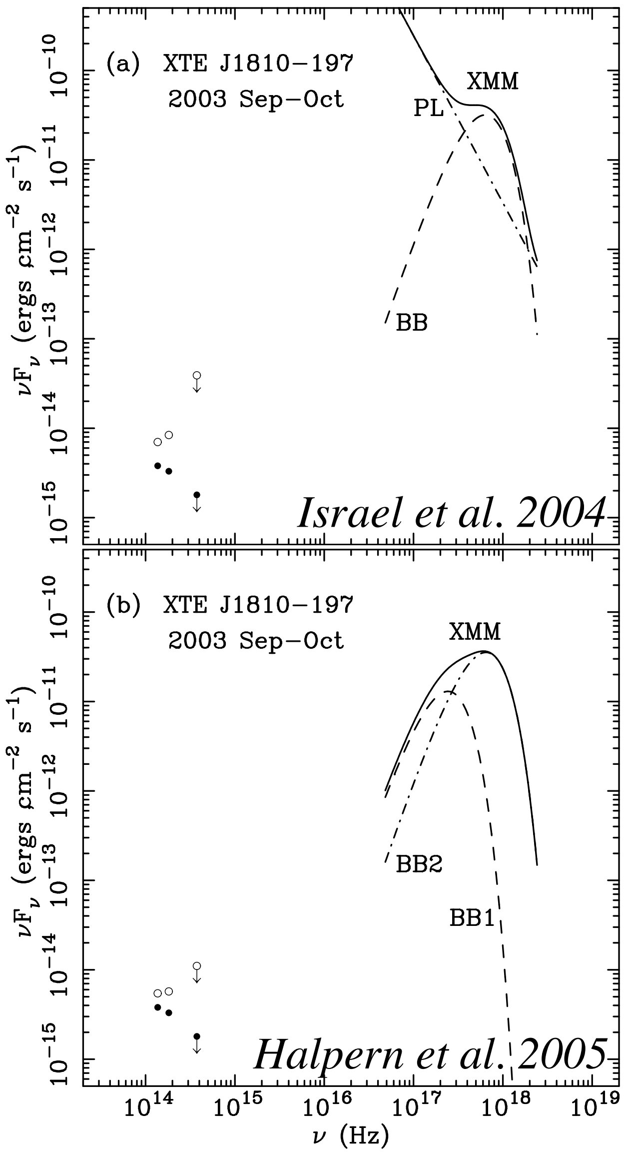
XMM Spectroscopy: what is the Nature of the X-ray Emission from XTE J1810–197?

Power-law vs. Blackbody for the Soft Component?

AXP X-ray spectra are usually fitted with a two component blackbody (BB) plus power-law (PL) model. However, this is a problem in fitting the excess high energy flux...



Broad Band Spectrum of XTE J1810-197



Power-law vs. Blackbody model for Soft Emission Component

Against a PL Model:

1. PL dominates at low, not high energy!

2. PL cannot connect with IR,

3. SSA in unobservable range, source radius/B-field inconsistency,

4. No acceptable physical spectral model.

For the Blackbody Model:

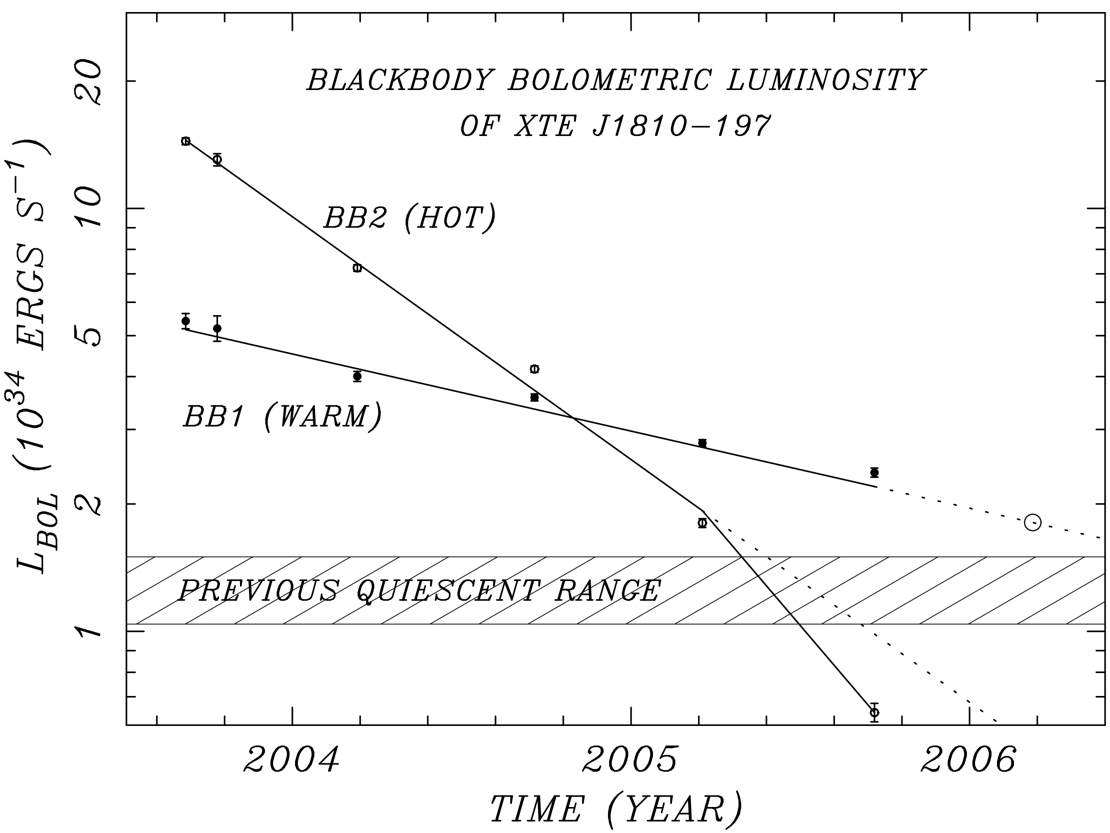
1. Extrapolated spectrum does not exceed IR flux,

2. Cooler BB component covers ~60% of NS surface, ~4% for hotter component, consistent with observed high pulsed fraction,

3. Light curve phase relationship and increased pulsed fraction with energy well explained by concentric hot spot model.

XMM Monitoring of XTE J1810-197

For double blackbody model, flux decay rate of the hot component is thrice as rapid as for the cooler component



Exponential Decay:

$$\tau_1 = 870 \text{ days}$$
$$\tau_2 = 280 \text{ days}$$

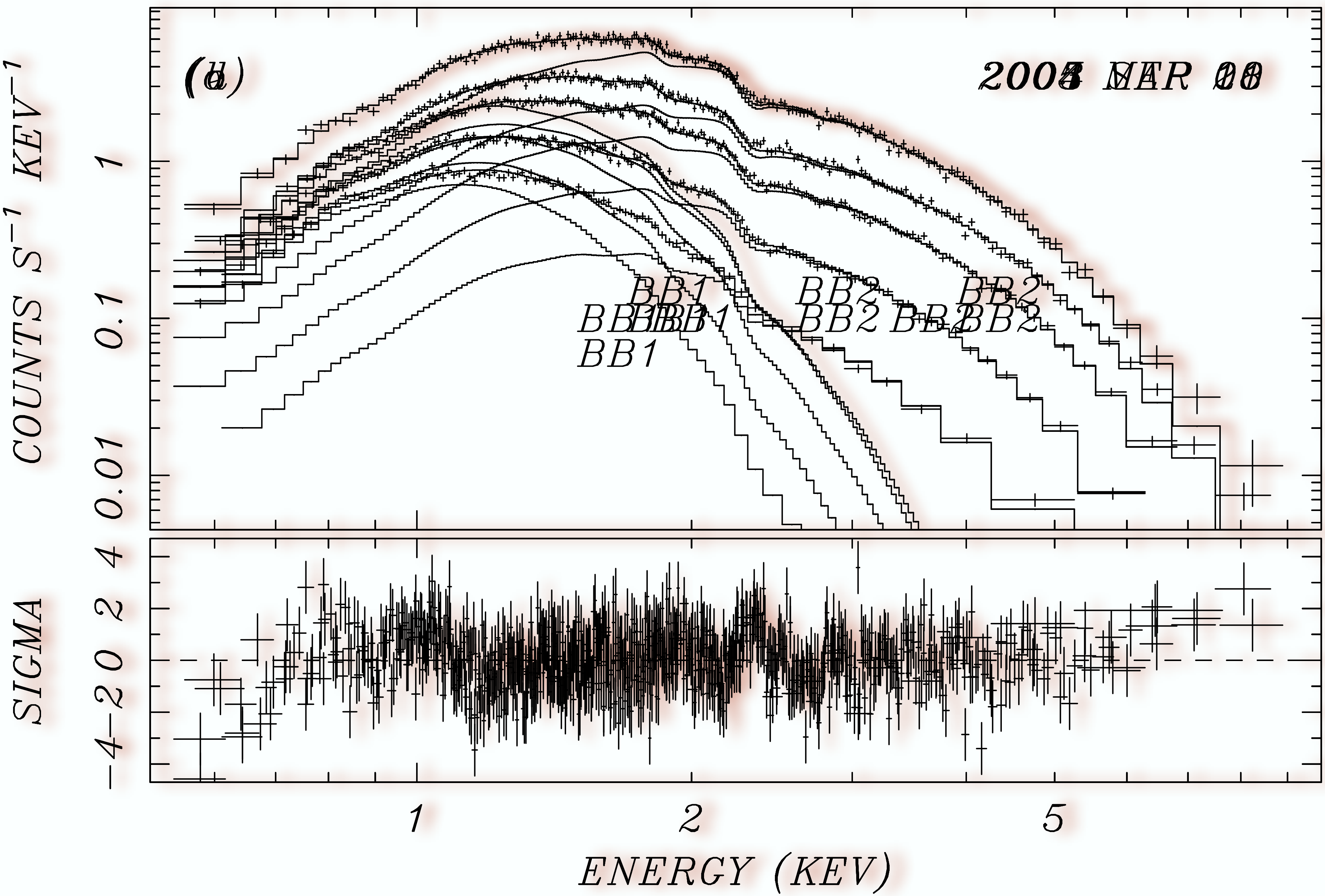
Initial Luminosity:

$$L_1(t_o) \approx 7 \times 10^{34} \text{ erg s}^{-1}$$
$$L_2(t_o) \approx 4 \times 10^{35} \text{ erg s}^{-1}$$

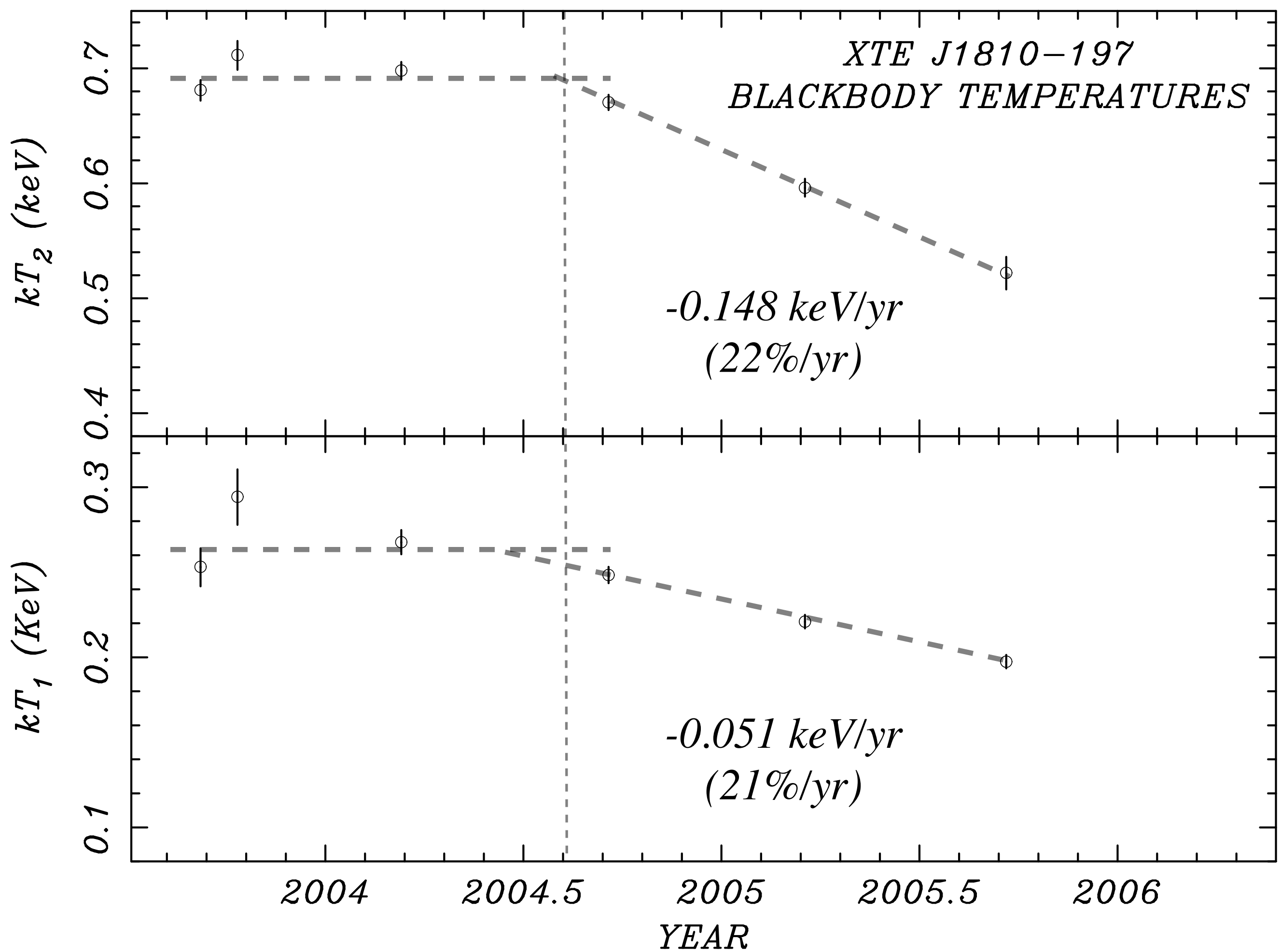
Fluence:

$$f_1 \approx 5 \times 10^{42} \text{ erg}$$
$$f_2 \approx 1 \times 10^{43} \text{ erg}$$

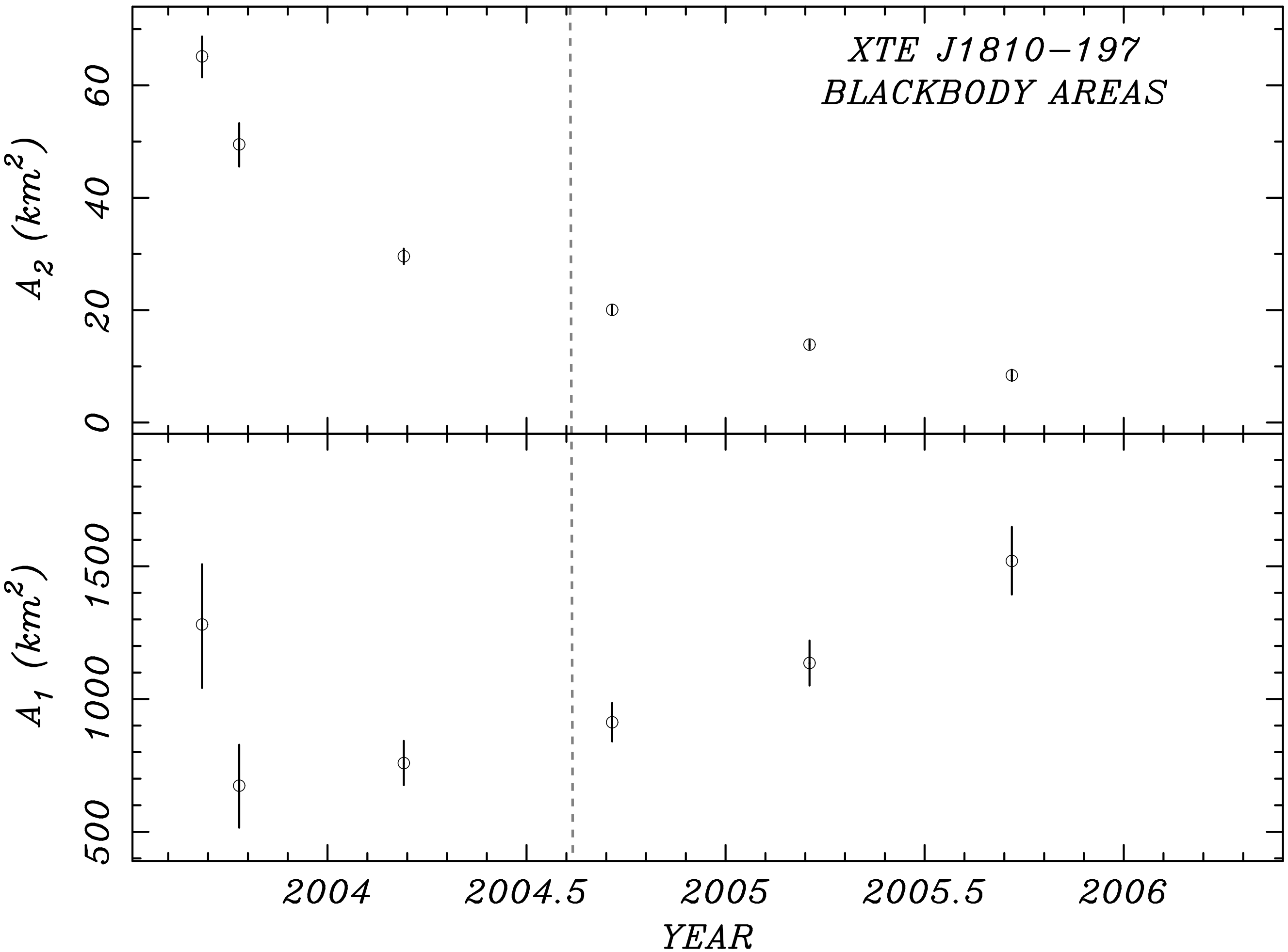
Gotthelf et al 2007


COUNTS S^{-1} KEV^{-1}
1
0.1
0.01
BB1
BB2
SIGMA
4
2
0
−2
−4
1
2
5
ENERGY (KEV)

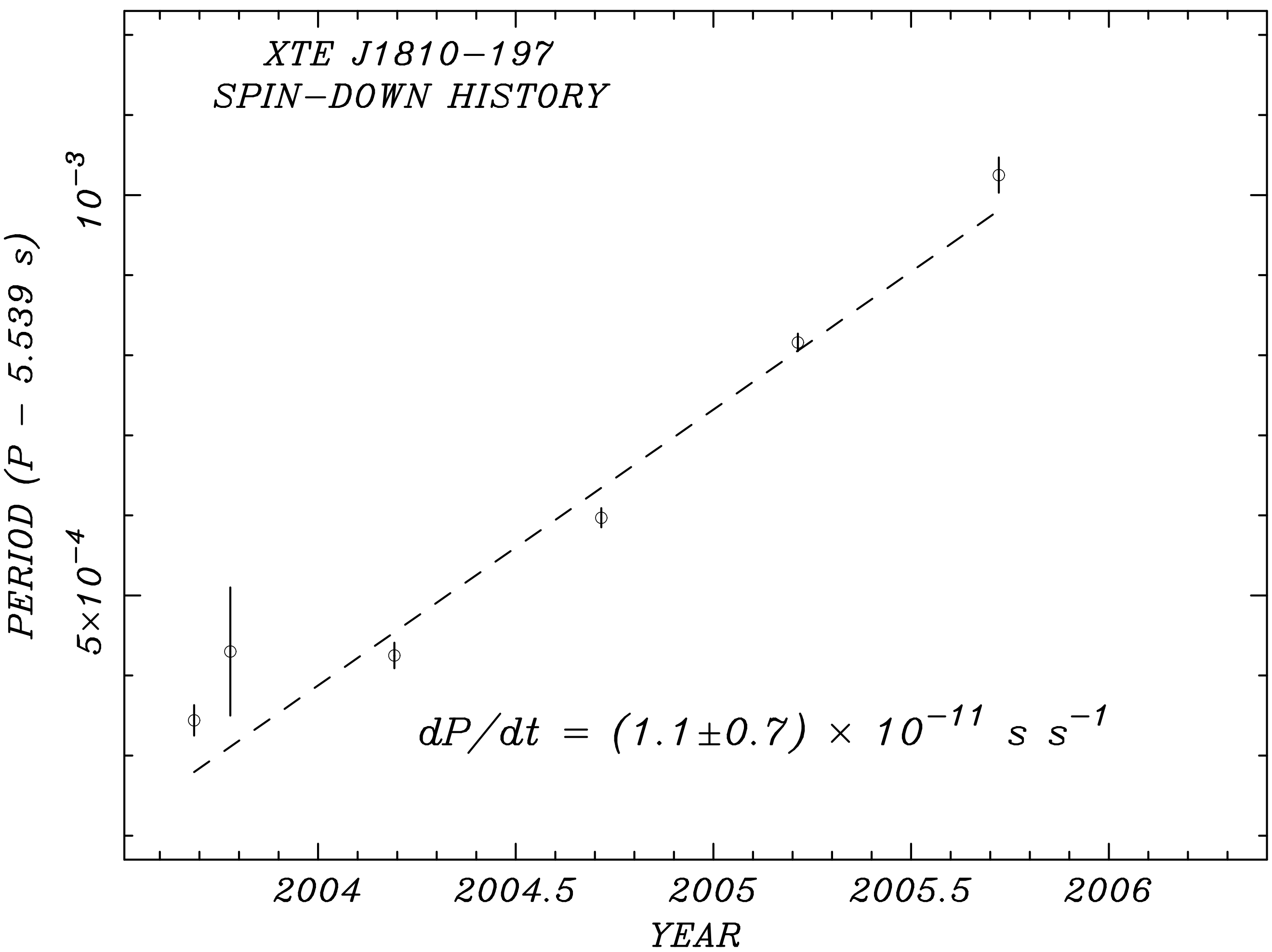
Temperatures derived for the last three data points show a definitive cooling of both BB components over the last year...



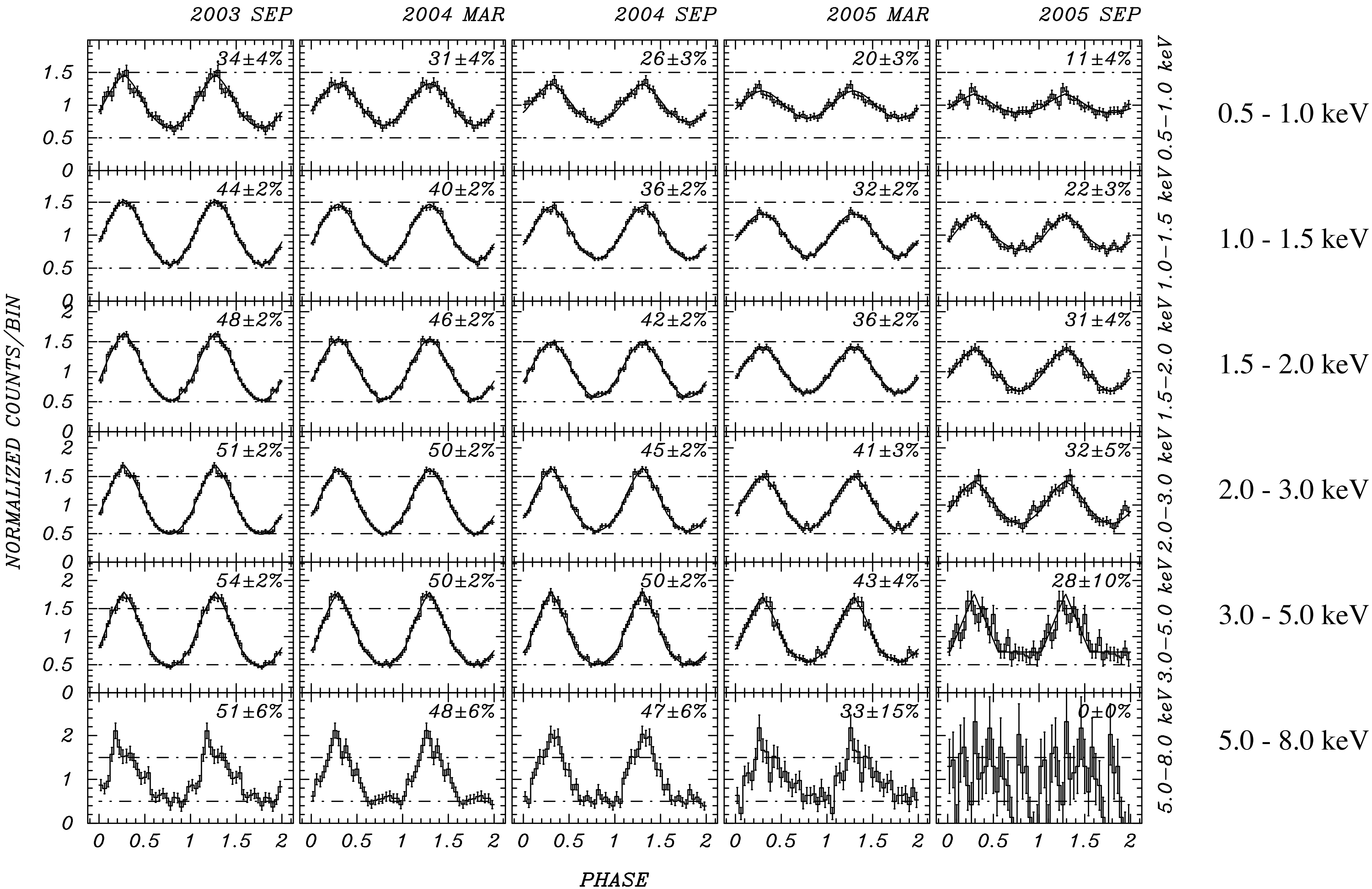
...while the blackbody emission areas follow a unique evolution: the hotter component is shrinking exponentially while the cooler component expands linearly...

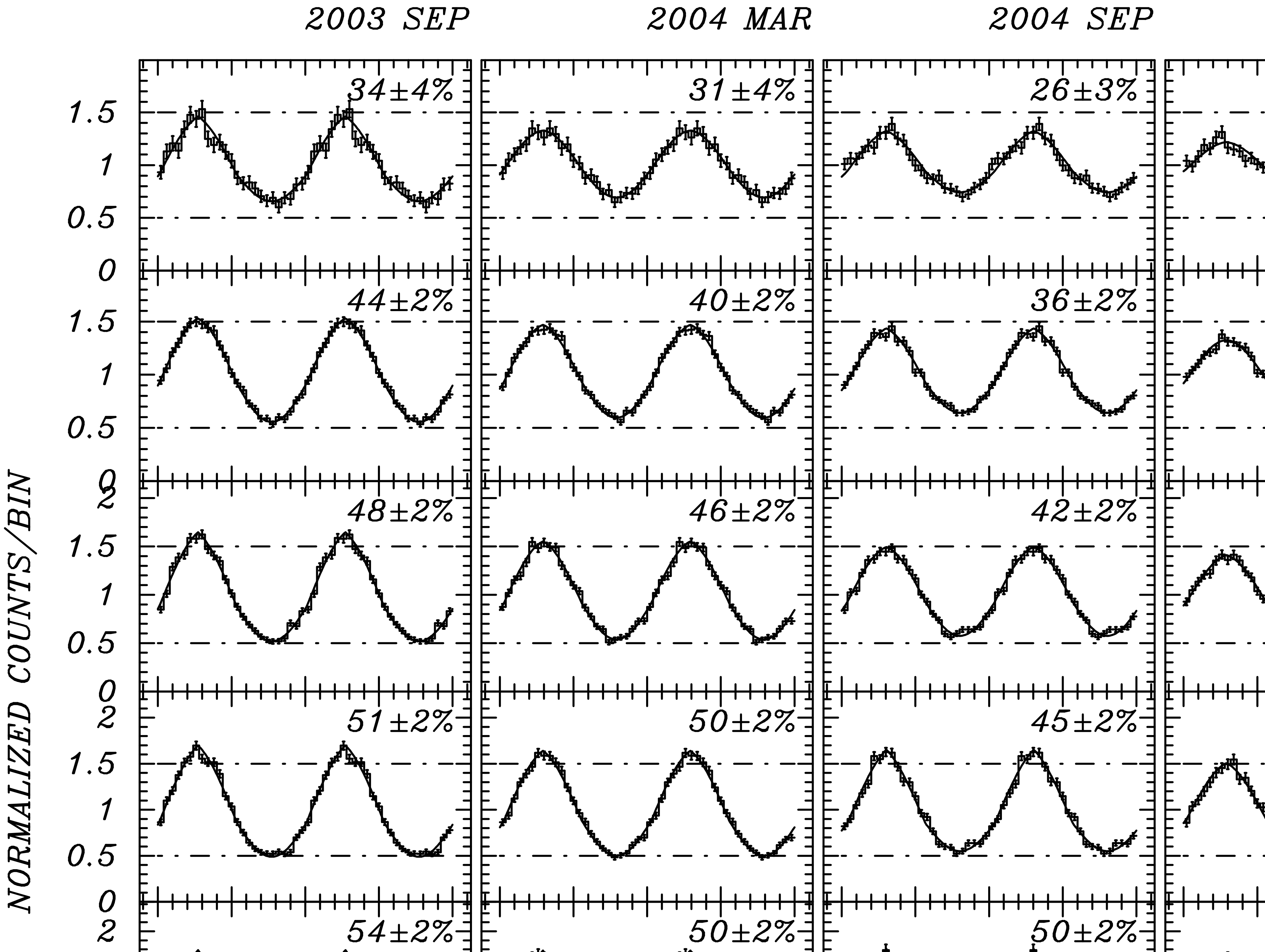


...meanwhile, the pulsar continues its unsteady spin-down.



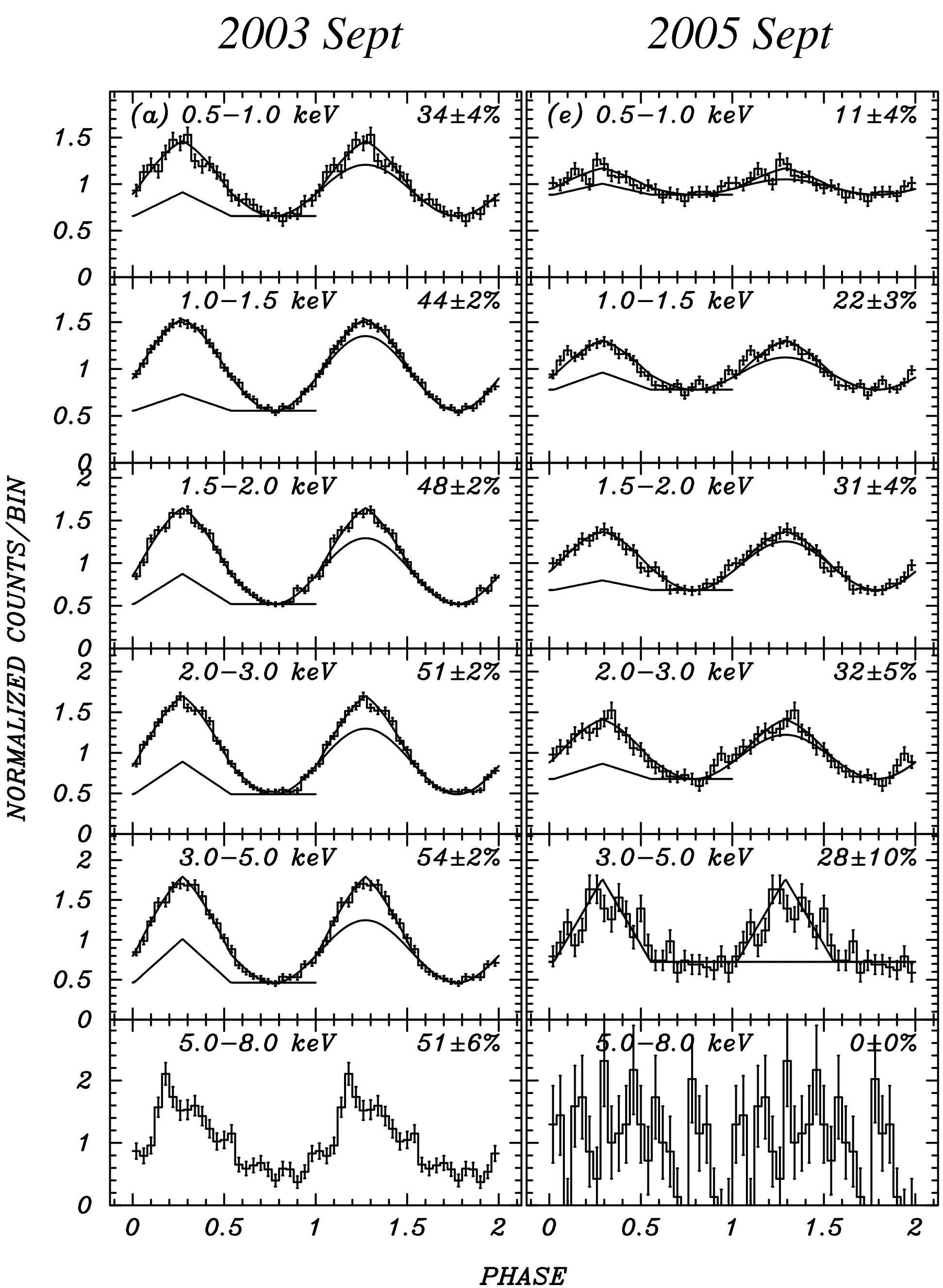
Pulse Profile Evolution vs. Energy-band





2003 SEP
2004 MAR
2004 SEP
NORMALIZED COUNTS/BIN
34±4%
31±4%
26±3%
44±2%
40±2%
36±2%
48±2%
46±2%
42±2%
51±2%
50±2%
45±2%
54±2%
50±2%
50±2%

Pulse Profile Model
Sinusoid + Triangle



$$N(\phi;E,t) = N_S(\phi;E,t) + N_T(\phi;E,t)$$

were,

$$N_S(\phi;E,t) = \alpha(E,t)\,[1+\cos(\phi-\phi_S)] + \gamma_S(E,t)$$

and,

$$N_T(\phi;E,t) = \gamma_T(E,t) + \begin{cases} \beta(E,t)\,[1-2|\phi-\phi_T|/\delta(E,t)] & if|\phi-\phi_T| < \delta/2 \\ 0 & if|\phi-\phi_T| \geq \delta/2 \end{cases}$$

$\beta(E,t)$ = triangle amplitude

$\alpha(E,t)$ = sinusoidal amplitude

$\delta(E,t)$ = triangle FWZM width

$\gamma_S(E,t)$ = unpulsed sinusoidal component

$\gamma_T(E,t)$ = unpulsed triangle component

Interpretation of the Pulse Profiles

- *Pulsed fraction increases with energy,*
- *Modulation decreasing in time, preferentially at low energies,*
- *Two concentric components,*
- *Model as sum of sine+triangle function,*
- *However, not unique superposition of spectral BB components, must be an admixture or different model.*

Modeling Phase-Resolved Spectrum

Perna & Gotthelf

- *Modified NS emission model based on Perna et al. (2001),*
- *Analytic approximation of two concentric hot spots,*
- *Blackbody emission, including GR redshift and light bending,*
- *Try to match spectrum and energy dependent pulse shape,*
- *This may determine viewing geometry, distance, and NS size.*

Theoretical Interpretation as a Magnetar

Coronal model - Beloborodov & Thompson (2006)

- *The large outburst is generated by a starquake, which causes a transition to an active coronal state. Energy is stored in the twisted B-field of the coronal loop,*
- *Particles (mostly e^+e^-) are accelerated in the coronal loop and impact the NS surface with GeV energy. This heats up the loop footprint resulting in the observed sinusoidal modulation,*
- *The luminosity of the coronal loop decays in a few years. The decay rate is determined by ohmic dissipation of current in the excited loop.*