PSR B1509−58

Monitoring with *RXTE* from 1996 to 2005

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Source

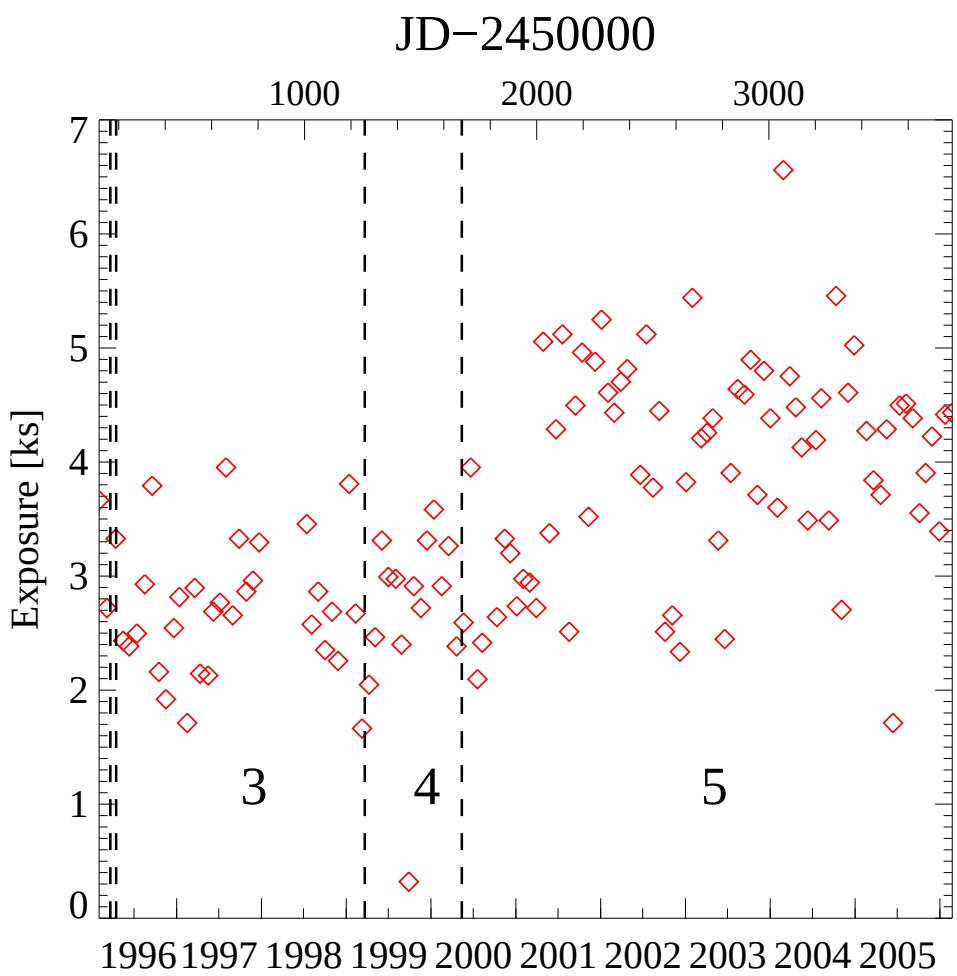
- current *RXTE*-PCA PCU 2 rate, 3–20 keV top layer: 14.5 counts/s (Crab 1800 counts/s)
- $D \sim 4.2$ kpc
- $P \sim 150$ ms
- unusually high $\dot{P}$
- characteristic age ~ 1600 yr

Ginga (Kawai 93)
CGRO (Ulmer 93, Matz 94, Kuiper 99)
RXTE (Marsden 97, Rots 98)
BeppoSax (Cusumano 01)
Chandra (Yatsu 05, DeLaney 05)
INTEGRAL (Forot 06)

RXTE Monitoring

- about 1 ObsID/month
- here: AO1–AO10
  1996–2005
- PCA calibration epochs 3–5
- average exposure 2.7 ks → 4.1 ks in 2001, for less PCUs
- HEXTE not rocking in epoch 3

30704: 6 ObsIDs offset
80803-01-07-01: no GoodXenon
90803-01-09-02: enhanced bkg
40704-01-09-00: short



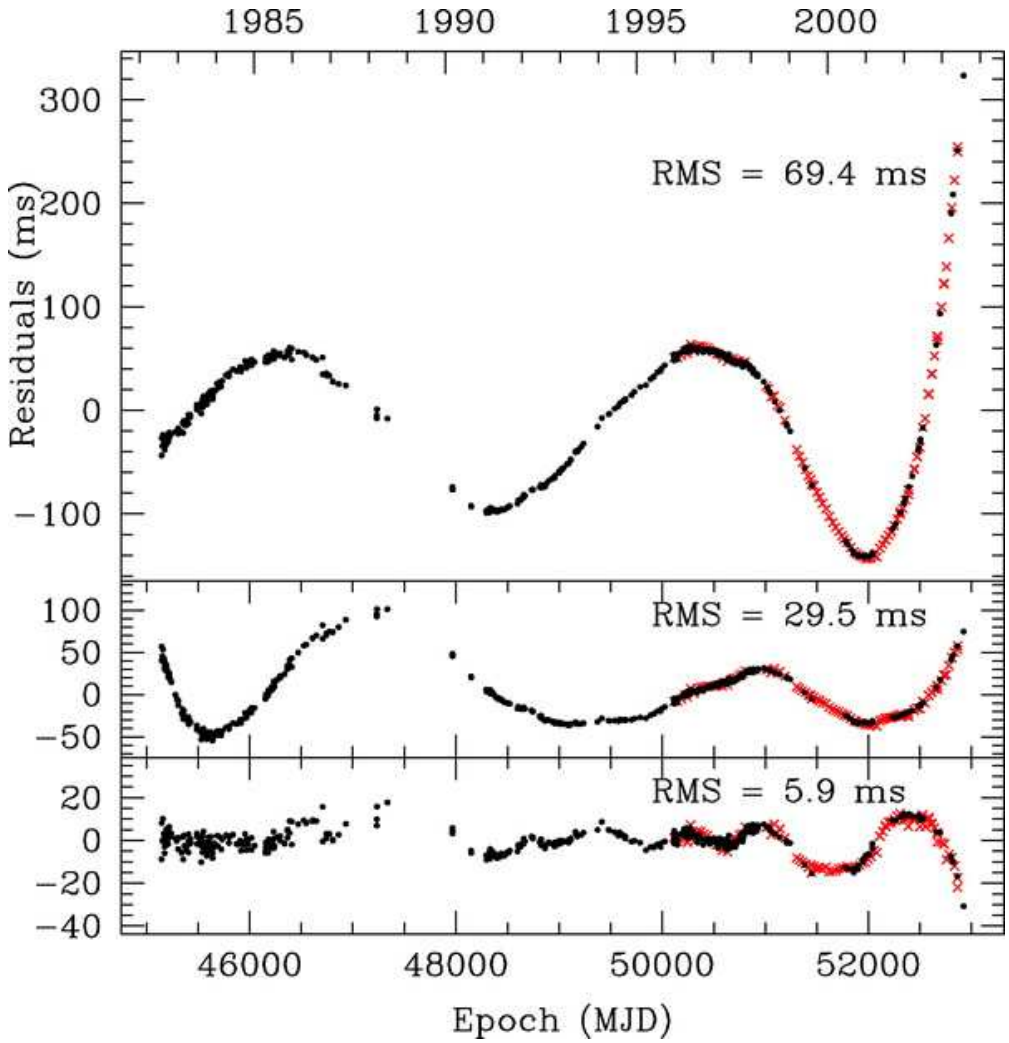
RXTE: Timing & Early Spectra

Phase-Coherent Timing

- Livingstone et al., 2005
- radio & *RXTE*-PCA residuals wrt Taylor expansion in Φ (3rd-5th derivative in ν)

Early Spectra

- Marsden et al. (1997) Rots et al. (1998)
- monitoring aspect not explored



Spectroscopy

Outline

- Pulse-phase-averaged
  - monitoring (PCA)
  - time-averaged (PCA+HEXTE)
- Pulse-phase-resolved *(work in progress)*
  - monitoring (PCA on-pulse)
  - time-averaged (PCA+HEXTE)

Goals

- determine source stability
- identify possible calibration effects
- most detailed phase-resolved analysis

Rates

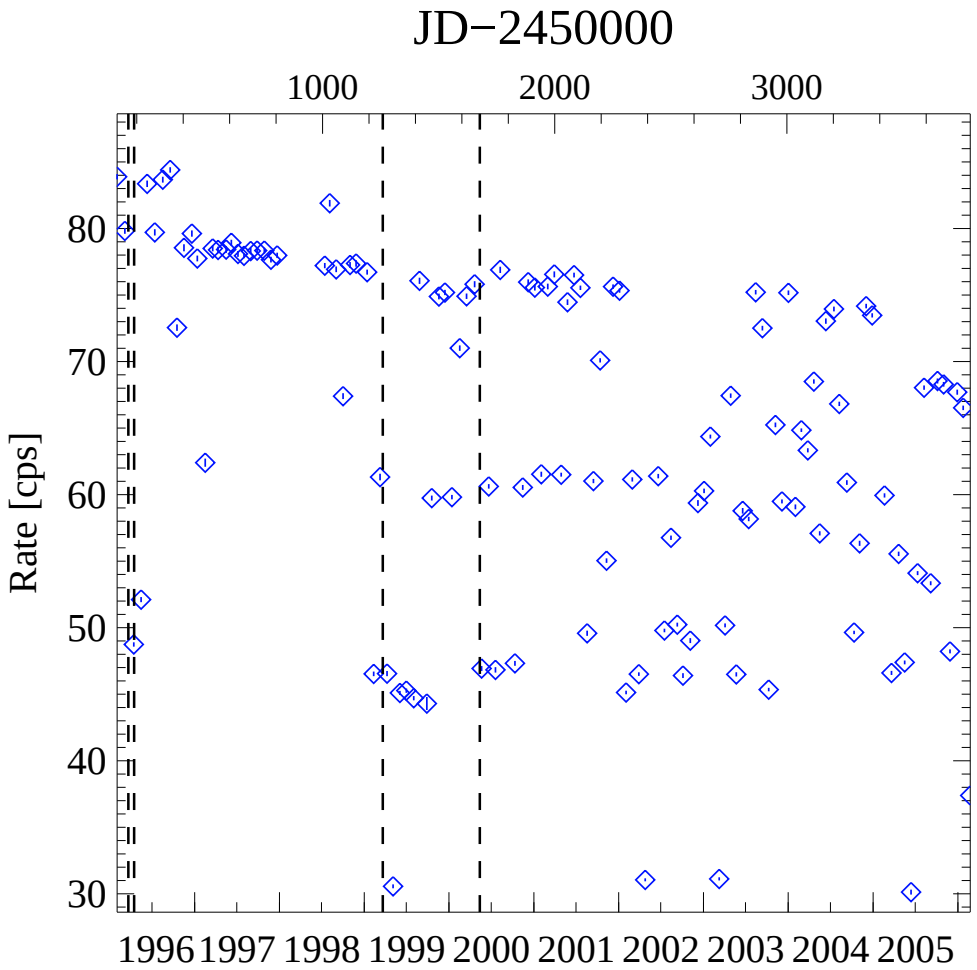
- 3-20 keV, top layer
- “faint” bkg subtracted
- version eMv20051128

all available PCUs

- $<$1999: 5 PCUs on
- $>$1999: $<$5 PCUs on
- $>$2001: sub-ObsIDs, different # of PCUs

PCU 2

- on during all ObsIDs
- best calibrated
- gradual decrease, modeled in response



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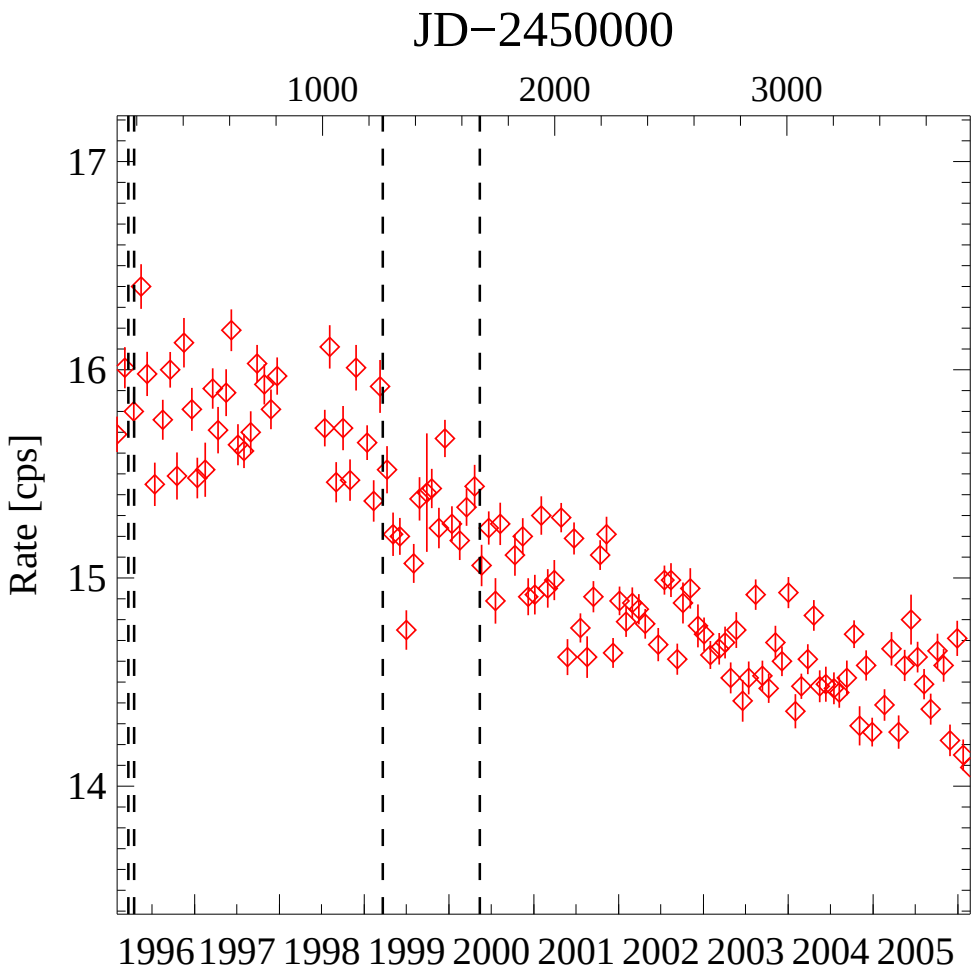


Spectral Model

- **`phabs*(power+gauss)`** **Standard2f Data Mode**
- 3-20 keV, “faint” bkg
- background as correction files
- no systematics, typical χ^2_{red}=0.7–0.8

all available PCUs

1. all parameters free (E_{Fe}, σ_{Fe} restricted), top layer
2. the same for all layers

PCU 2, top layer

1. all parameters free (E_{Fe}, σ_{Fe} restricted)
2. E_{Fe}=6.4 keV, σ_{Fe}=0.1
3. $N_{\mathrm{H}} = 0.6$

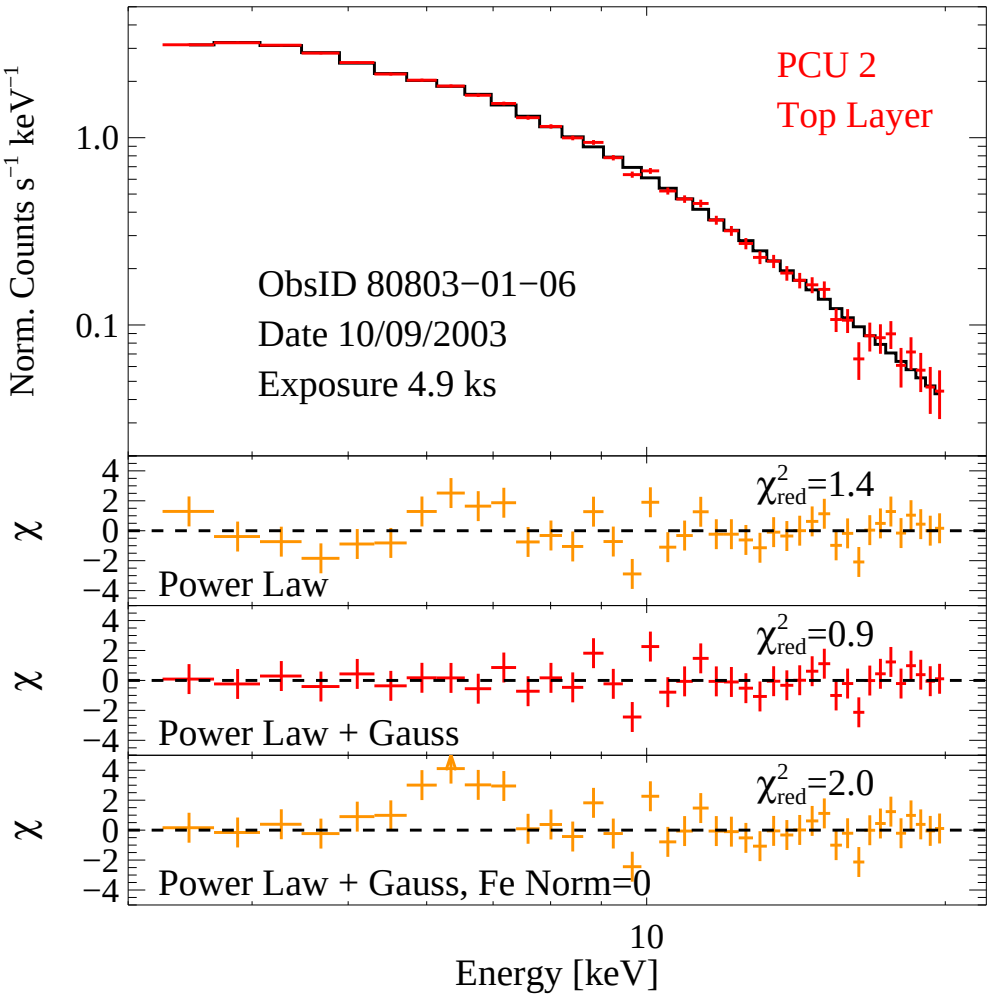
Spectral Fit Parameters

Typical Monitoring Observation

$N_H{}^a$	=	$0.63^{+0.74}_{-0.63}$
Γ	=	$2.06^{+0.06}_{-0.06}$
$A_\Gamma{}^b$	=	$7.4^{+1.0}_{-0.9}$
E_{Fe} [keV]	=	$6.5^{+0.3}_{-0.3}$
σ_{Fe} [keV]	=	$0.4^{+0.4}_{-0.4}$
$A_{Fe}{}^c$	=	$2.1^{+1.8}_{-0.9}$
EW [eV]	=	133
$F_{4-10\,keV}{}^d$	=	9.6
$A_{bkgcorr}$ [%]	=	5.4

$^a 10^{22}/cm^2$, $^b 10^{-2}$ $\frac{ph}{keV cm^2 s}$ @1keV

$^c 10^{-4}$ $\frac{ph}{cm^2 s}$, $^d 10^{-11}$ $\frac{erg}{cm^2 s}$



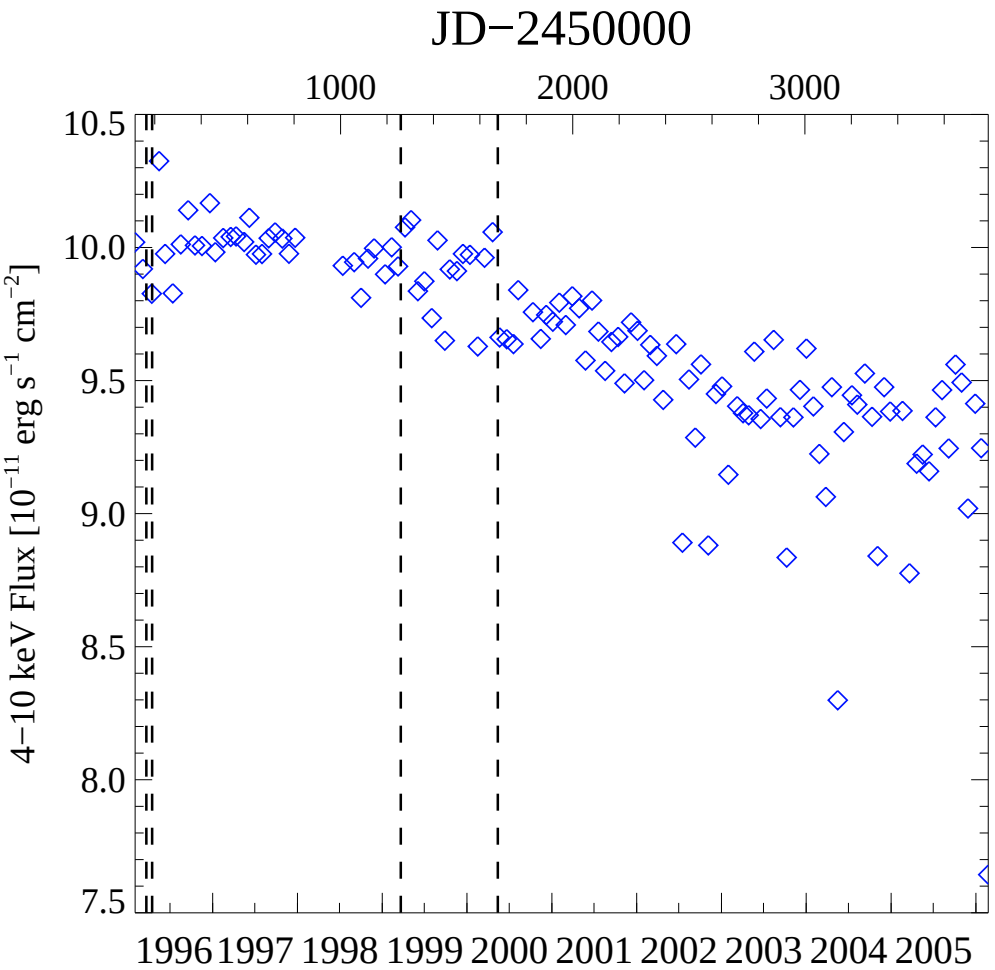
(Absorbed) Flux Evolution

all available PCUs

- ∼7% down since 2000
- clear drop at epoch 4/5 boundary
  ⇒ **calibration effect**

PCU 2

- no drop at epoch 4/5 boundary
- maybe gradual decline of ∼2% since 2000
  ⇒ **calibration?**
- use PCU 2 data for time-averaged and phase-resolved



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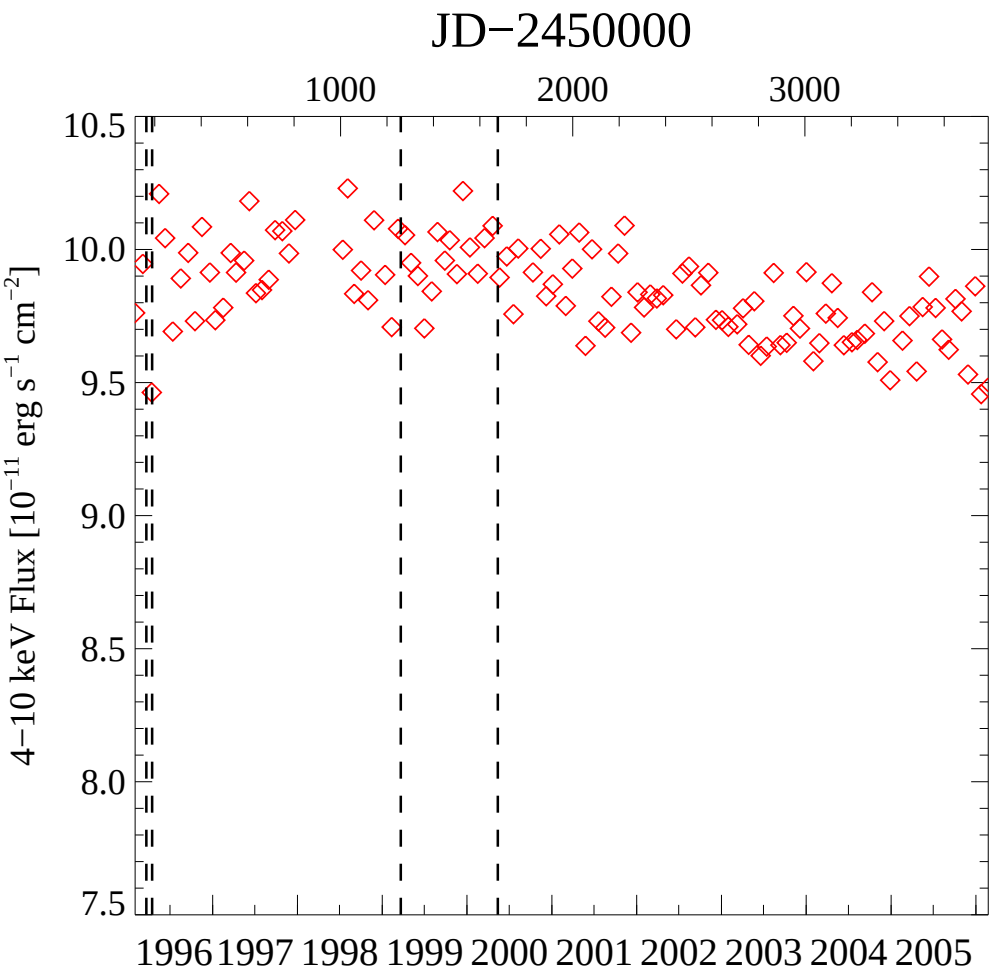

Power Law Norm & N_H

Calibration effect visible in other parameters?

all available PCUs

- $\sim$10% drop in power law normalization
- N_H increasingly difficult to determine

PCU 2

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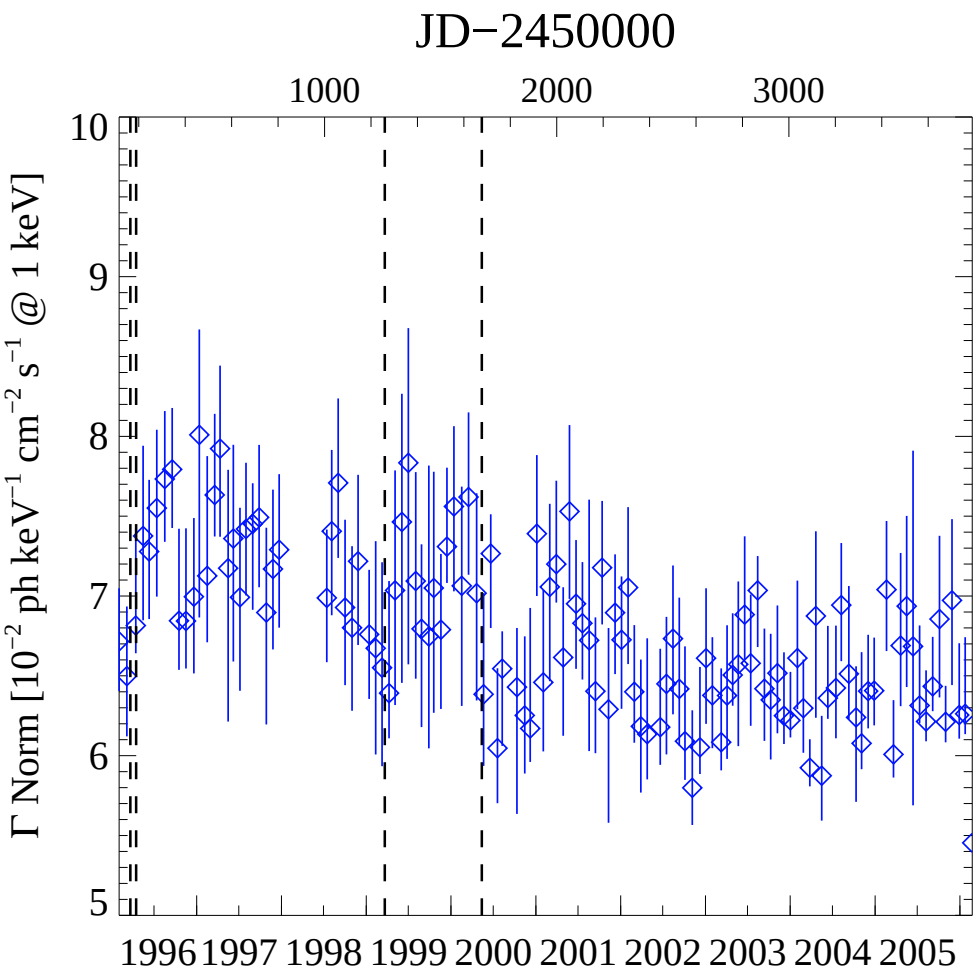
  $\Rightarrow$ why 2% flux drop?
- N_H constrained to $< 1.5 \times 10^{22}$ cm^2 only



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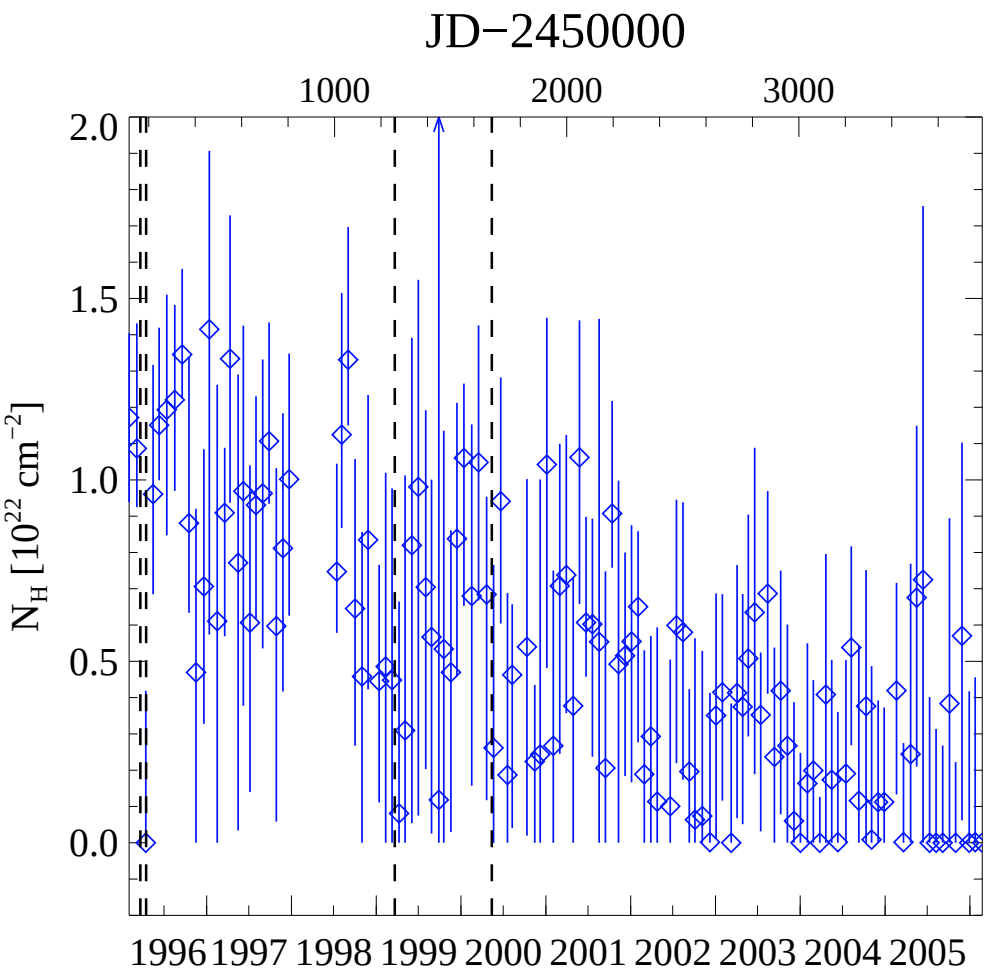

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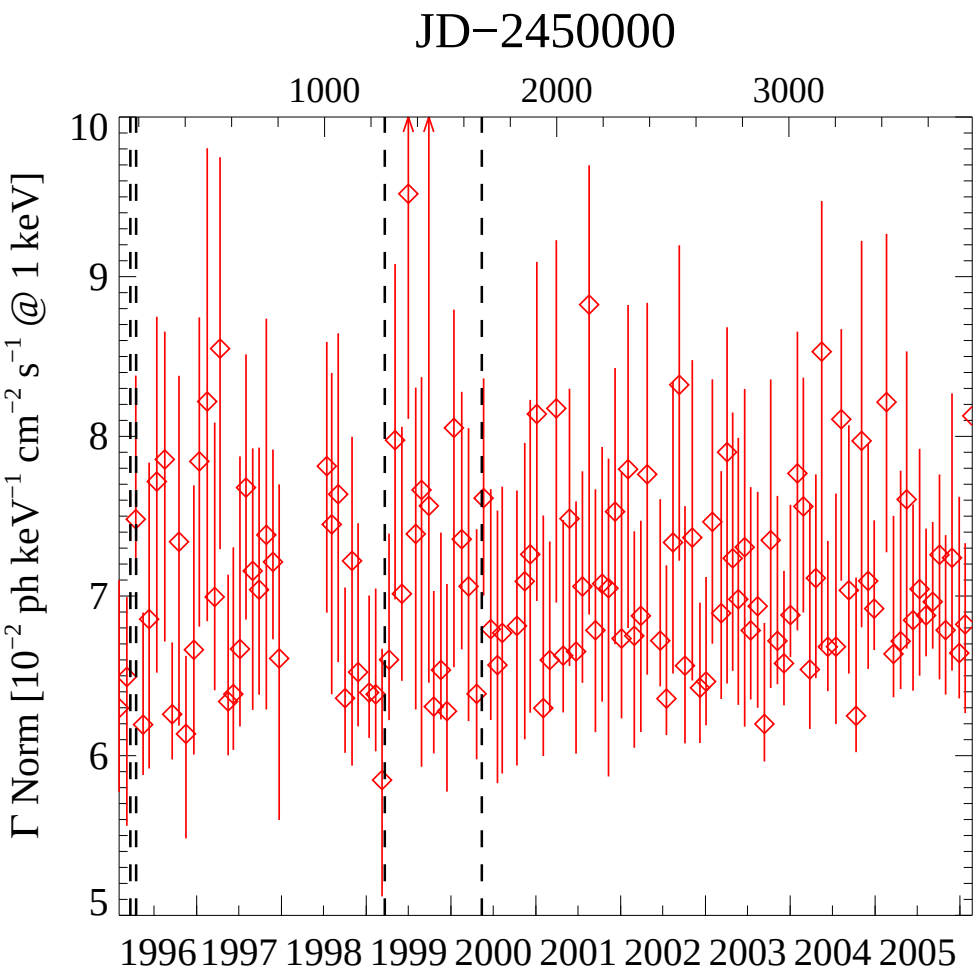


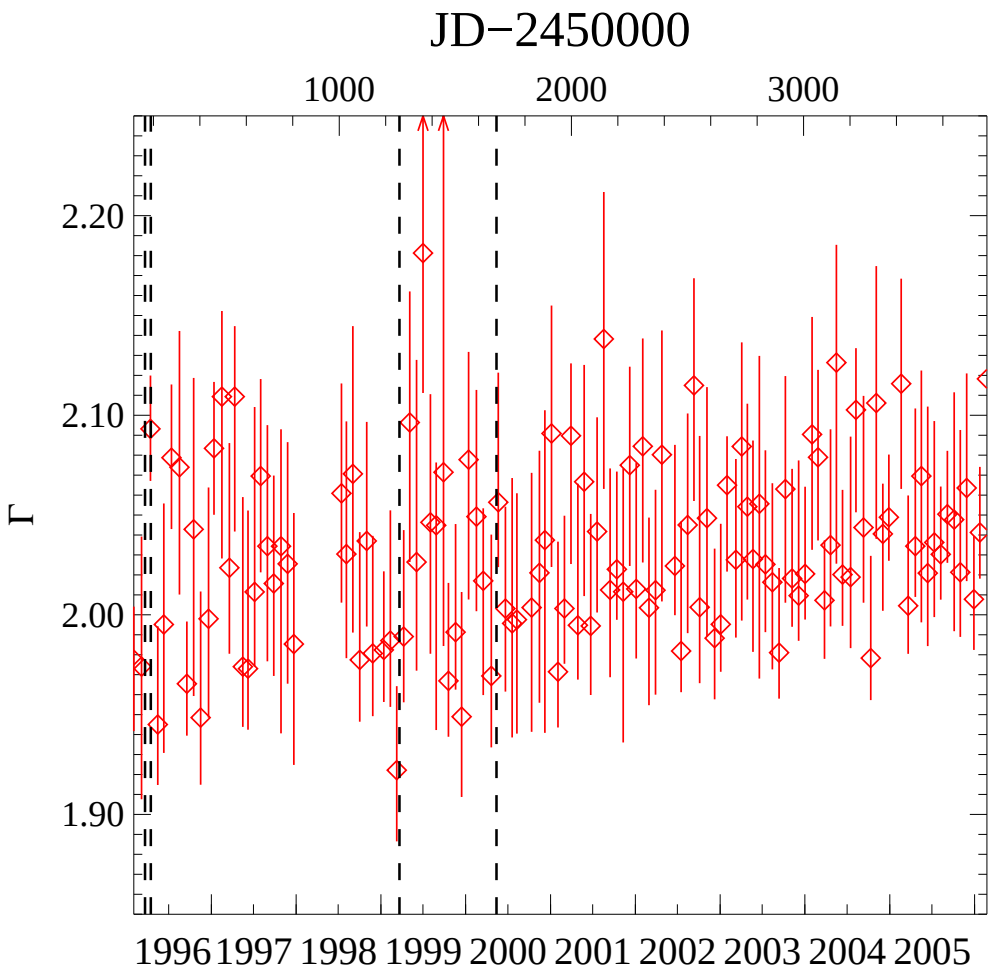
Power Law Index

PCU 2

- 4–10 keV flux drop ⇔ marginally softer (norm @ 1 keV)
- Gaussian distribution with $\Gamma = 2.03$, $\sigma_\Gamma = 0.05$

all available PCUs

- no trend in Γ
- Gaussian distribution with $\Gamma = 2.02$, $\sigma_\Gamma = 0.03$



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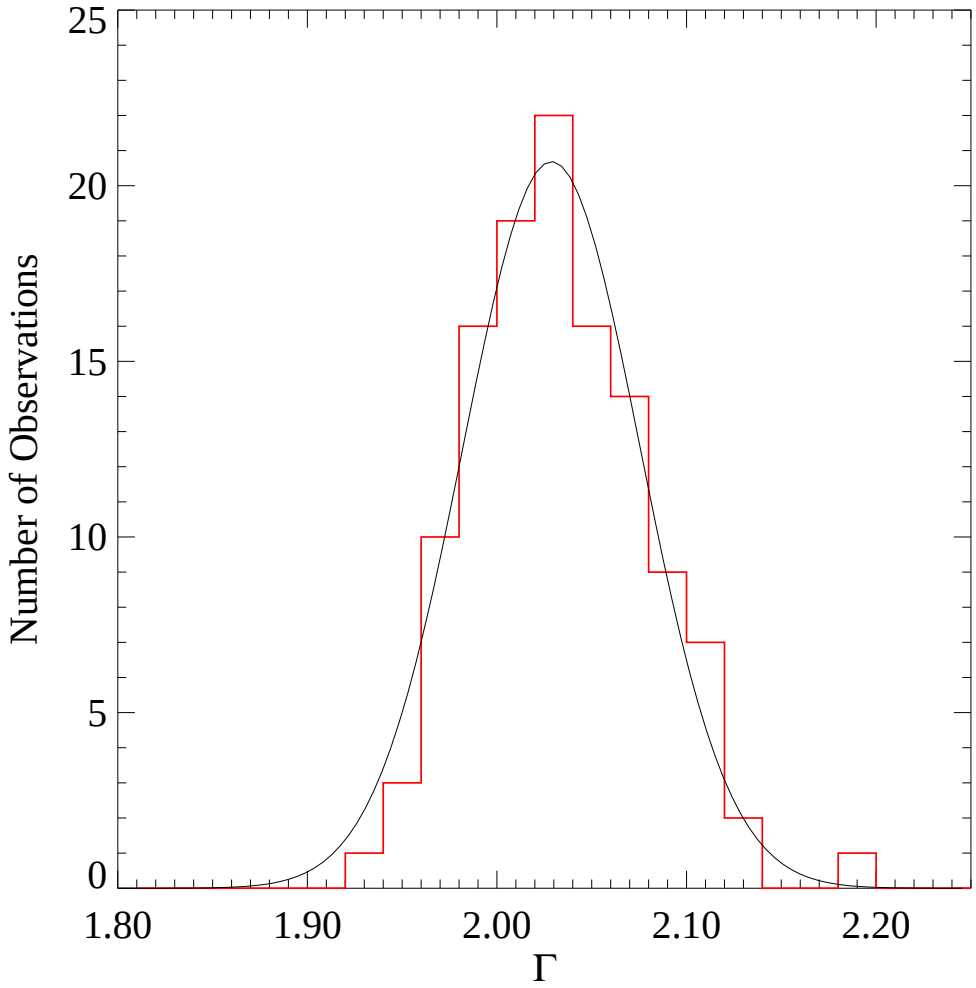

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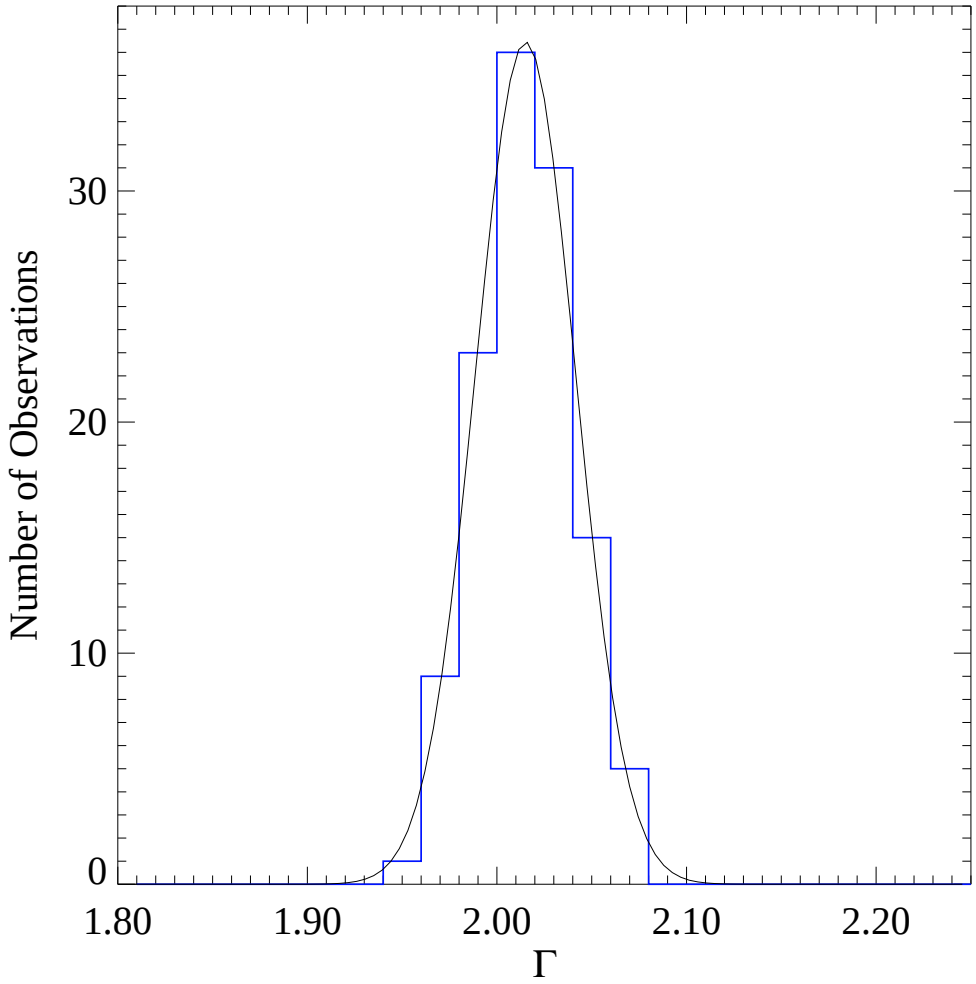
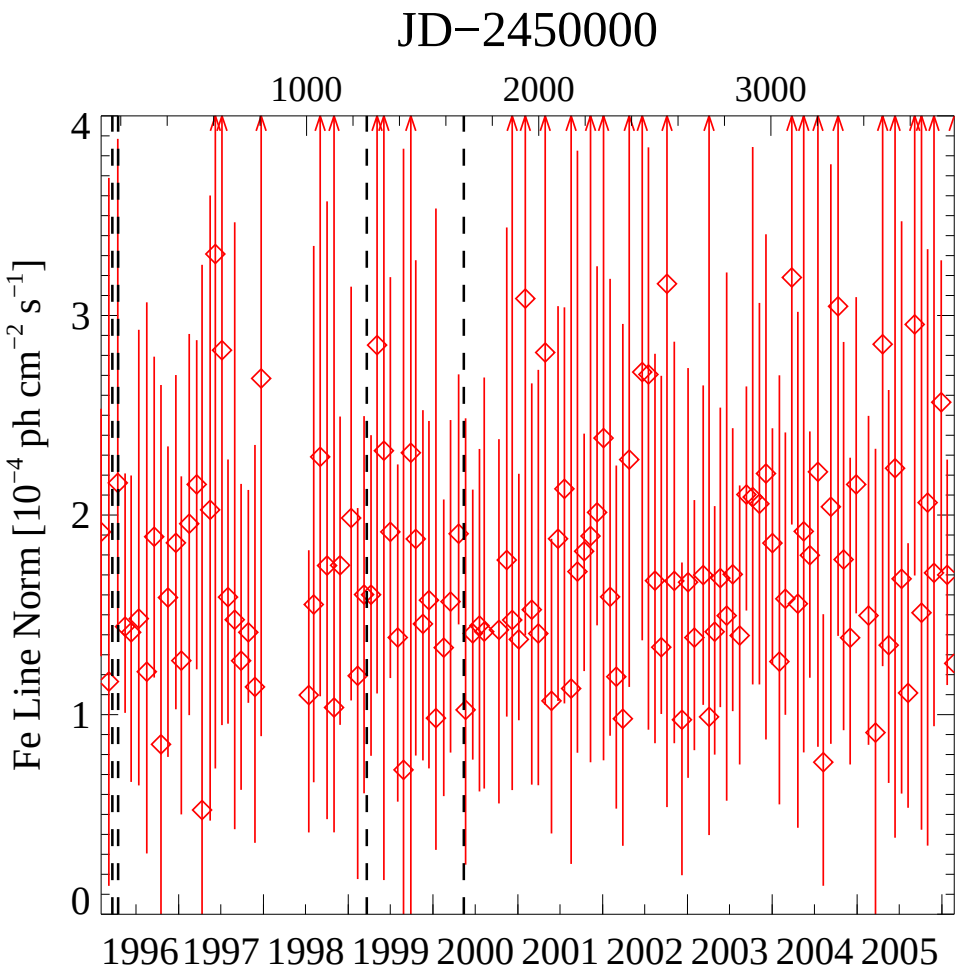


Iron Line

PCU 2

- E_{Fe} constrainable to 6–7 keV (uncertainties often peg)
- σ_{Fe} consistent with 0
- norm not consistent with 0
- norm stable and, especially for *frozen* E_{Fe} *and* σ_{Fe}, well constrained



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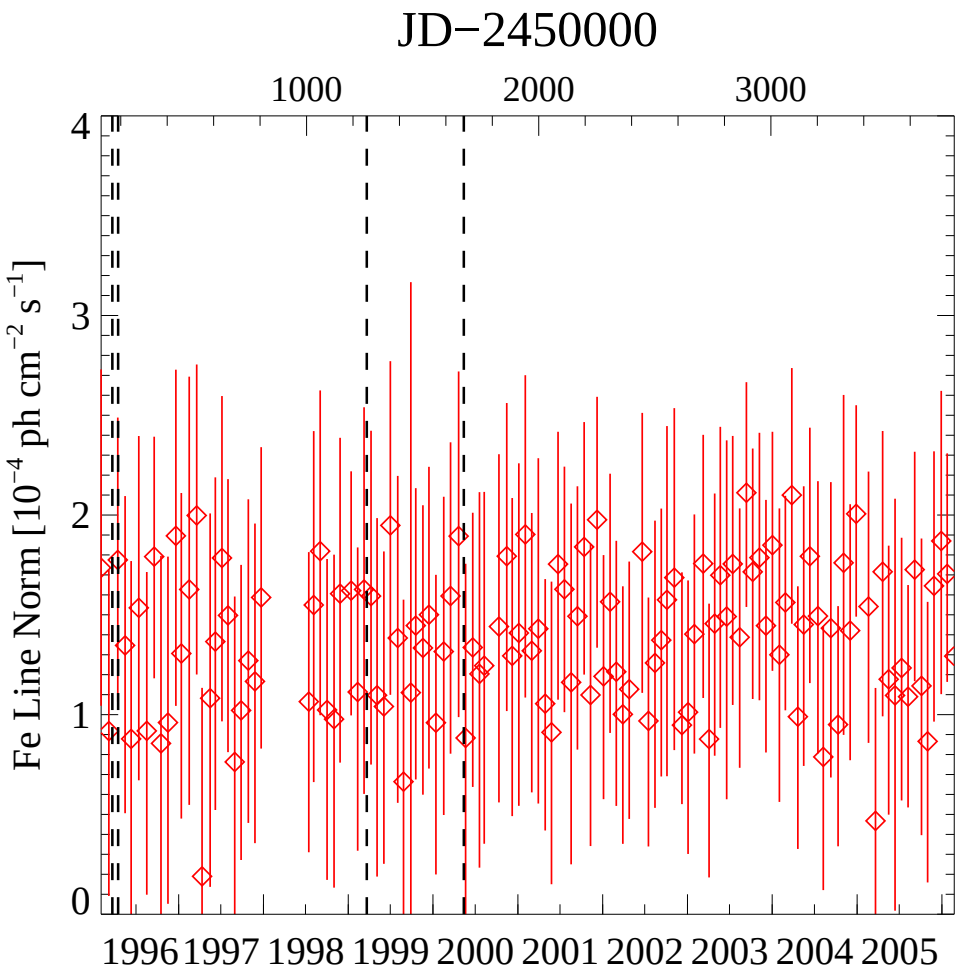


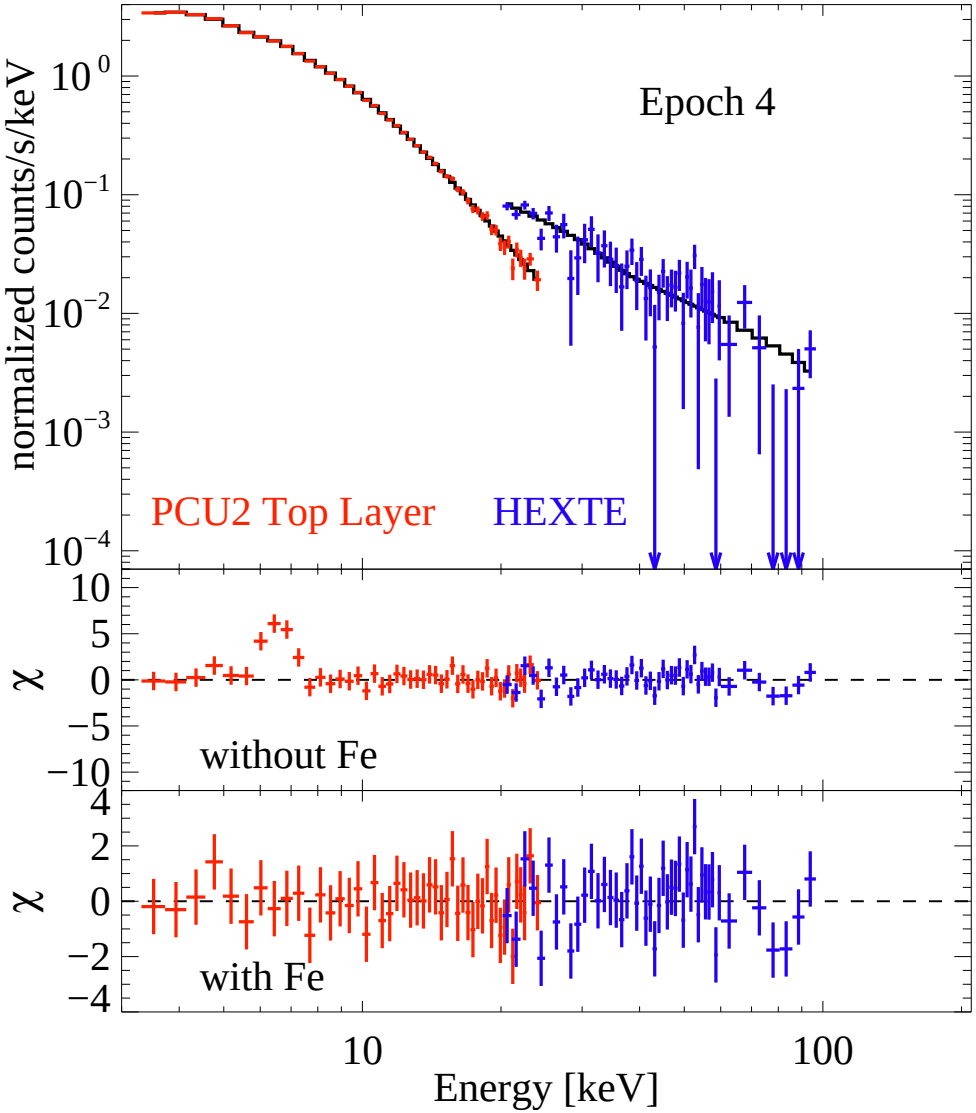
Long-Term Stability, PCU 2

Avg. Parameter	1996–1997	2004–2005
exposure [ks]	2.8±0.1	4.1±0.2
3–20 keV rate [cps]	15.82±0.05	14.53±0.04
4–10 keV flux [10^{-11} $\frac{\text{erg}}{\text{cm}^2\text{s}}$]	9.92±0.04	9.71±0.02
N_H [10^{22} cm^{-2}]	0.54±0.09	0.30±0.07
Γ	2.02±0.01	2.05±0.01
A_Γ [10^{-2} $\frac{\text{ph}}{\text{keVcm}^2\text{s}}$ @ 1keV]	0.071±0.001	0.072±0.001
bkg correction [%]	2±1	0.3±3
χ^2_{red}	0.68±0.03	0.70±0.05

Epoch-Averaged Spectra

- PCU 2 Top:
  3–25 keV
  0.5% systematics
  epoch 5: Xe L edge
- HEXTE:
  epoch 3: no bkg
  epoch 4: 20–100 keV
  epoch 5: 20–200 keV

Previous background model, fits will be redone.



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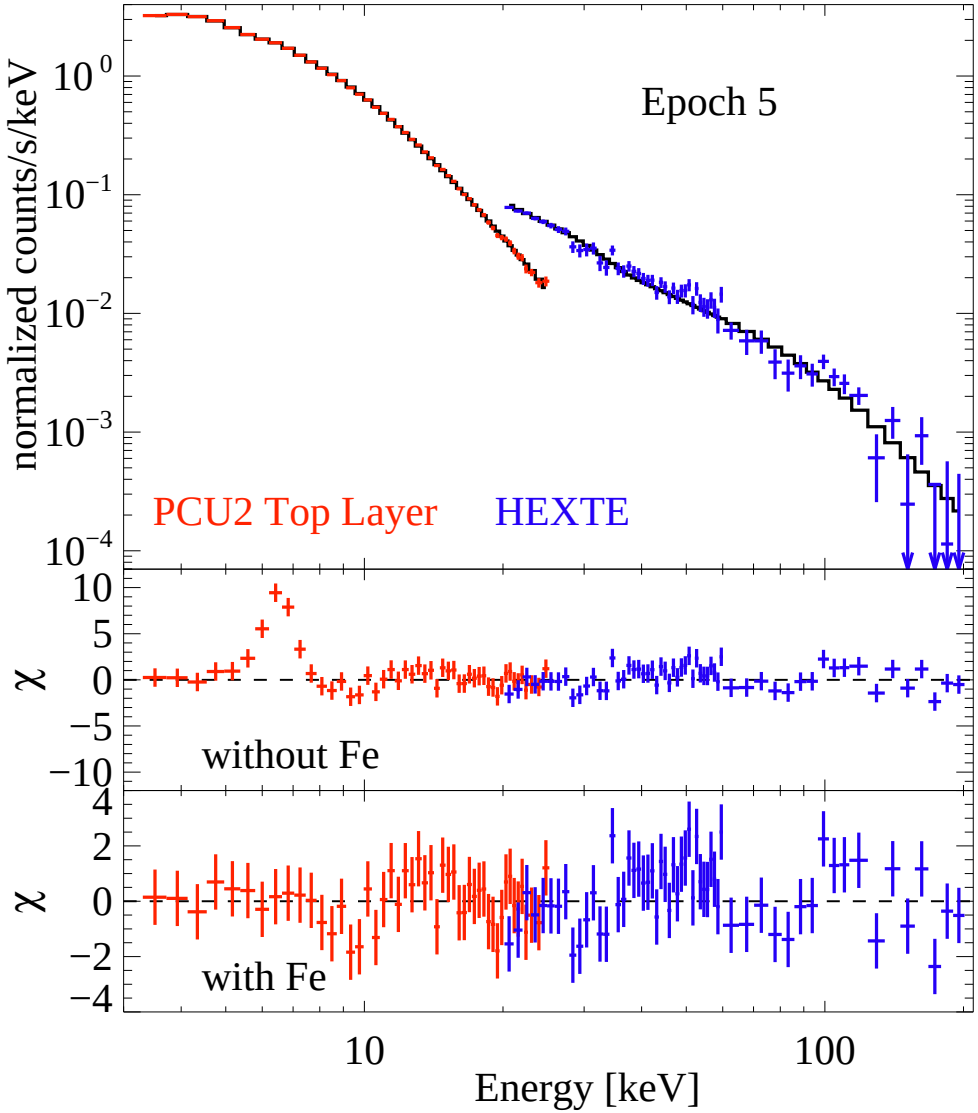


Epoch-Averaged Parameters

Parameter	Epoch 3	Epoch 4	Epoch 5
exp. PCA/HEXTE [ks]	81.2/–	37.6/24.0	224.6/179.7
$N_{\rm H}[10^{22}/{\rm cm}^2]$	$0.60^{+0.09}_{-0.1}$	$0.59^{+0.17}_{-0.28}$	$0.39^{+0.09}_{-0.1}$
Γ	$2.02^{+0.01}_{-0.01}$	$2.03^{+0.02}_{-0.02}$	$2.03^{+0.00}_{-0.01}$
EW	74	77	83
$F_{4-10\,{\rm keV}}$ $[10^{-11}\,\frac{\rm erg}{{\rm cm}^2{\rm s}}]$	10.01	10.03	9.85
flux constant (HEXTE)	–	$0.84^{+0.04}_{-0.06}$	$0.84^{+0.02}_{-0.02}$
$\chi^2_{\rm red}/{\rm dof}$	0.83/46	0.88/89	1.11/89

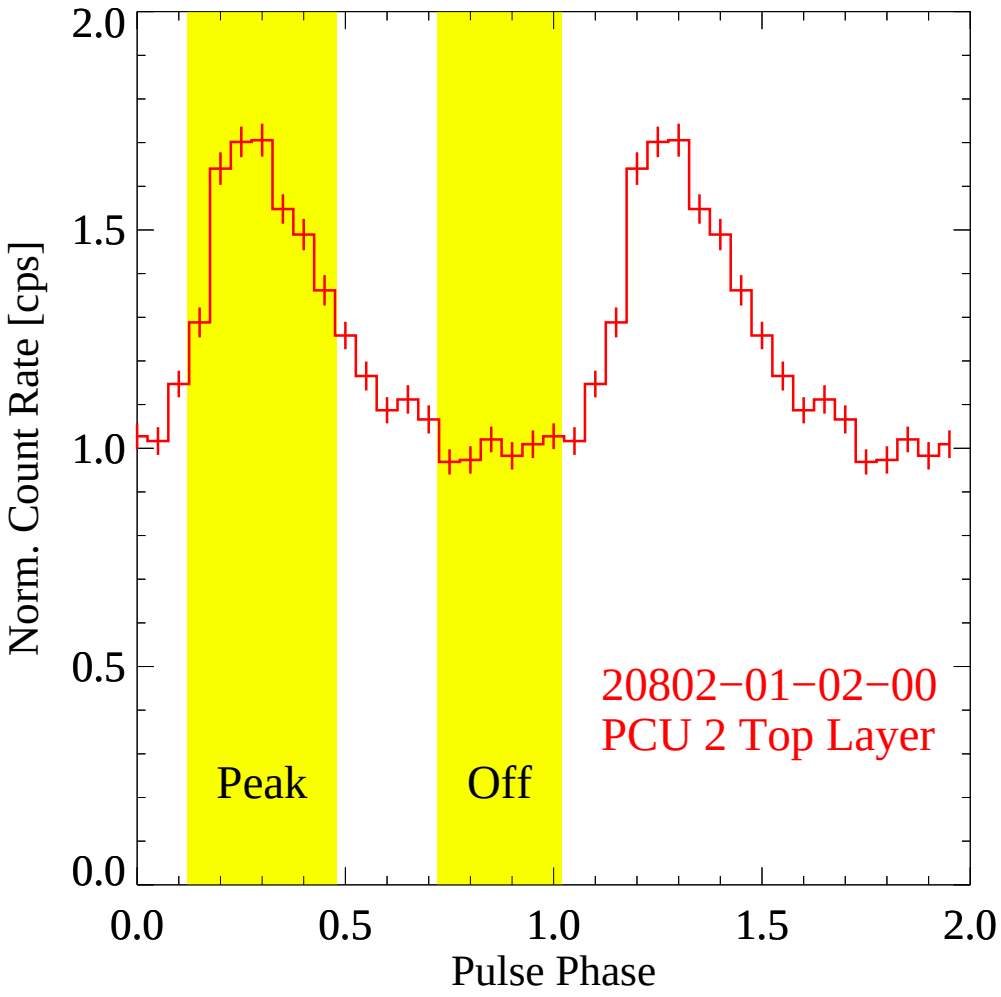
Monitoring Pulse Profiles

Extraction

- filter **GoodXenon**
- rsp, bkg: `seextract`
- **pha2** (Φ- & *E*-bins): `(ik)fasebin`
- 5 ephemrides from `www.atnf.csiro.au`
  ΔΦ: -0.05, 0., 0., 0.02, 0.
- offset from radio by 0.27 (Kawai et al., 1991)

Examples

- 1/ephemeris, random
- 3–40 keV, 0.05 Φ-bins normalized to off-pulse



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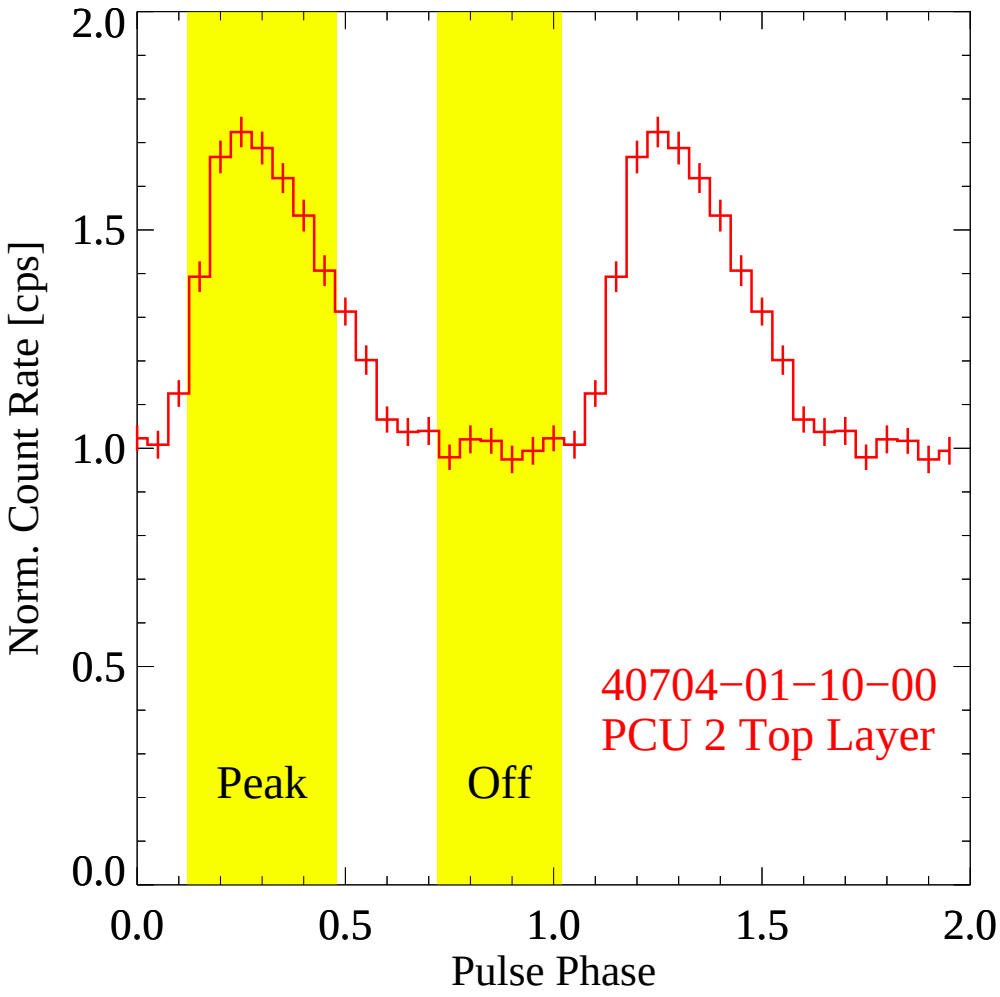

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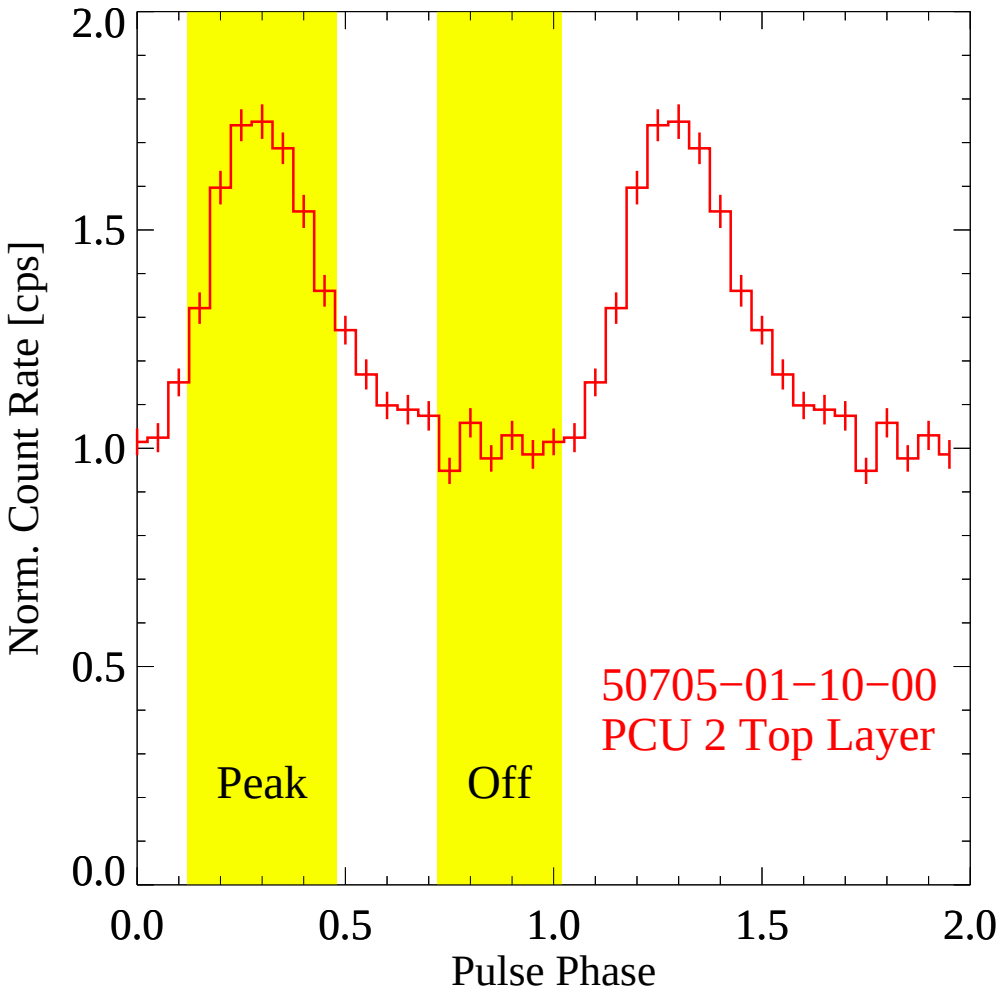

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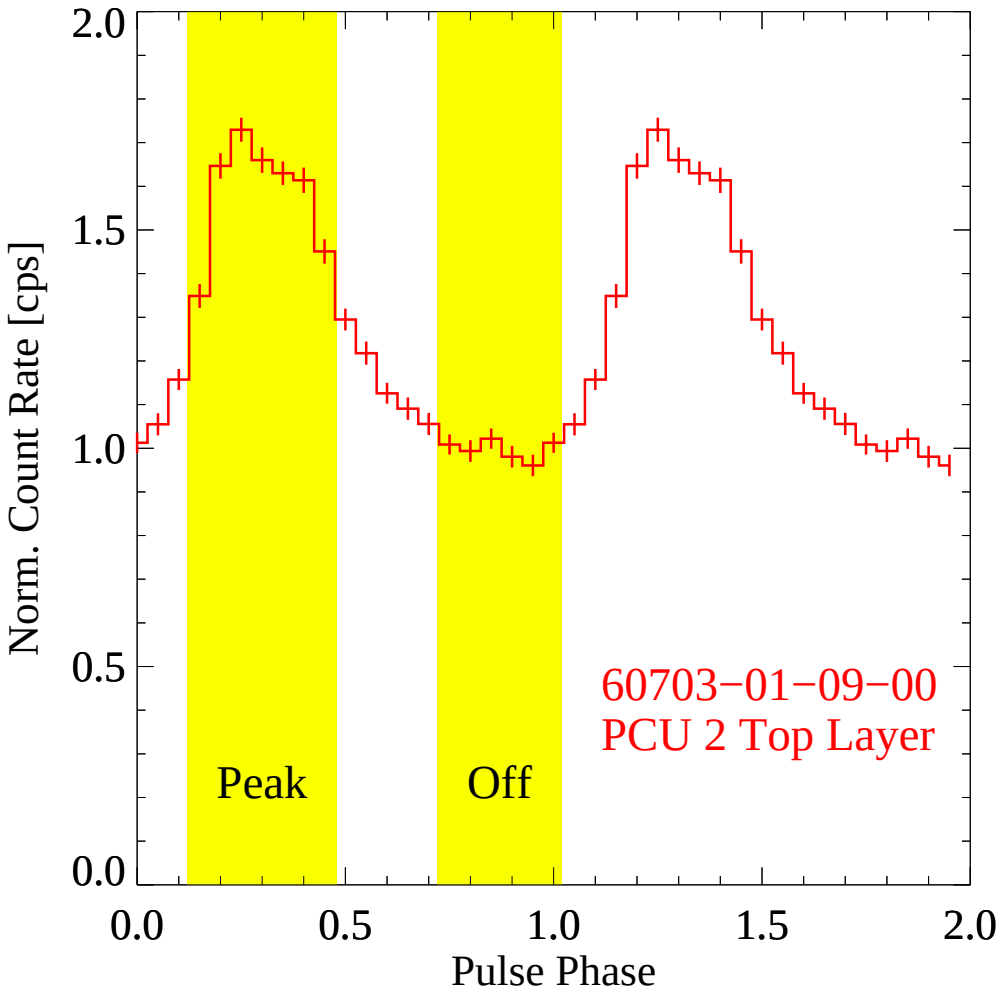

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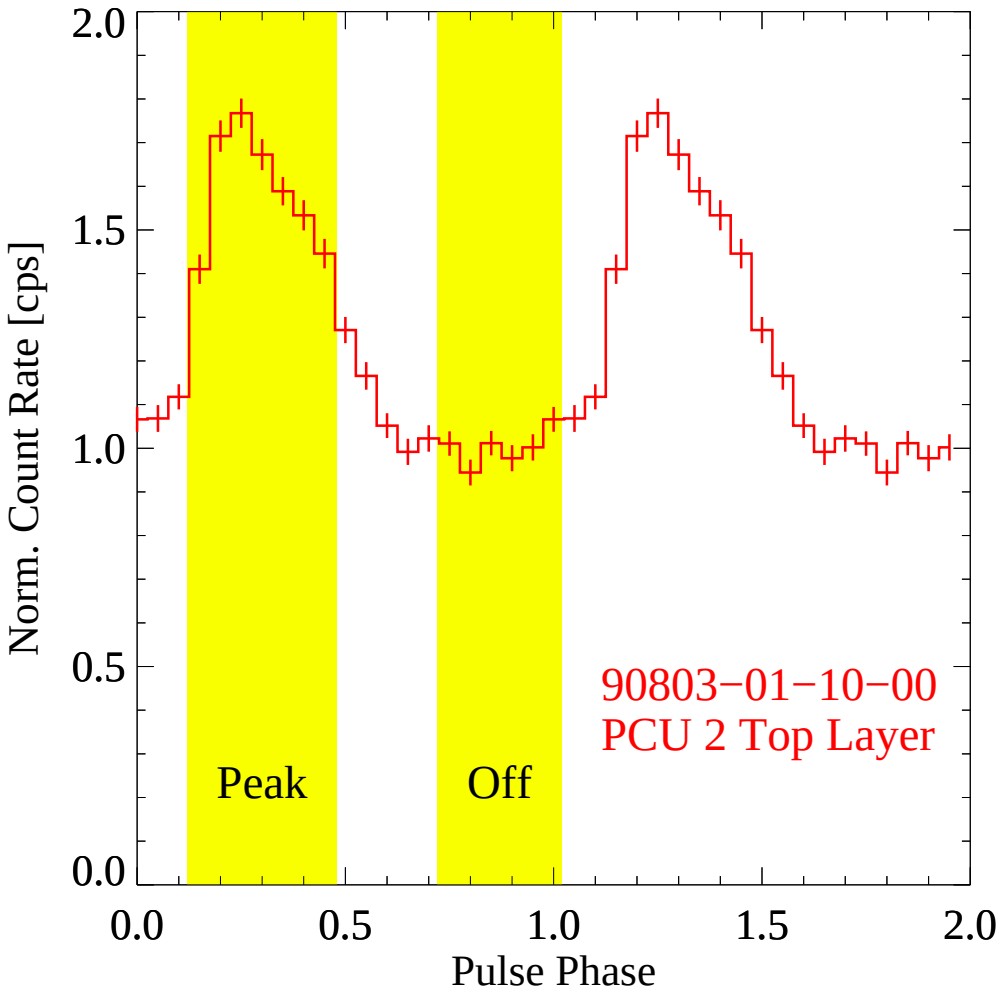

Pulse – Off-Pulse Fit

add sub-ObsIDs

Φ=0.12–0.48 $\Leftrightarrow$ peak.pha
Φ=0.72–1.02 $\Leftrightarrow$ off.pha
(Rots et al., 1998)

data 1:1 peak.pha
back 1:1 off.pha

phabs$\times$**power**

Typical Parameters		
N_H [10^{22} cm^{-2}]	=	$3.3^{+3.7}_{-3.3}$
Γ	=	$1.4^{+0.2}_{-0.2}$
$A_\Gamma{}^a$	=	$1.1^{+0.6}_{-0.4}$
$F_{4-10\,\mathrm{keV}}{}^b$	=	4.4

^{a} $10^{-2}\ \frac{\mathrm{ph}}{\mathrm{keV\,cm^2\,s}}$ @ 1keV,
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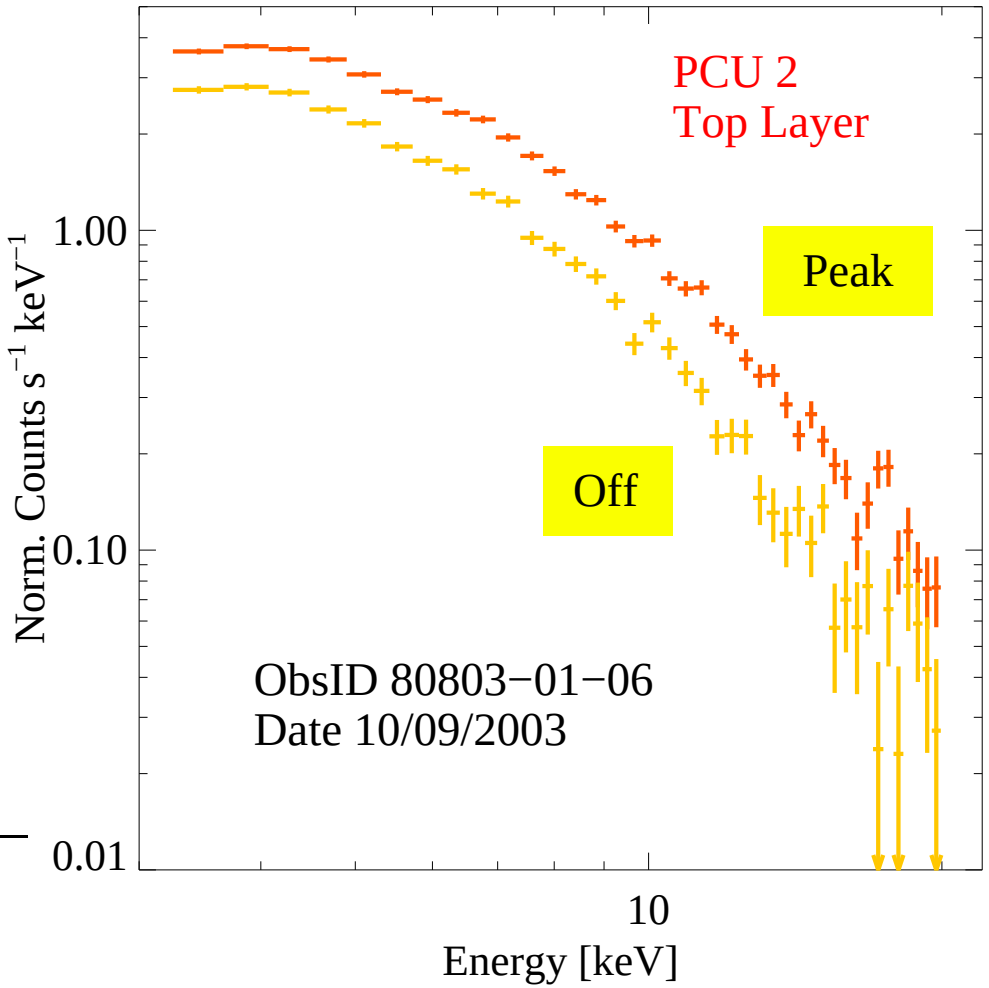

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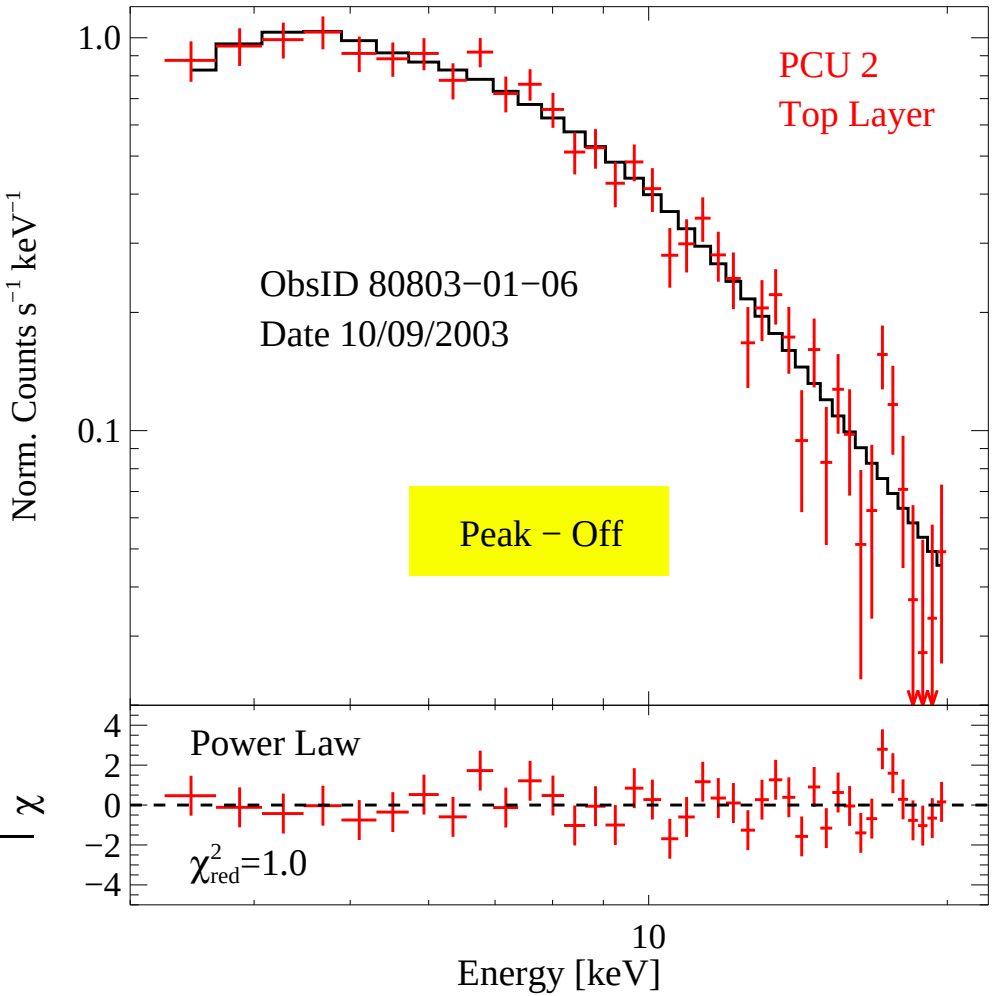
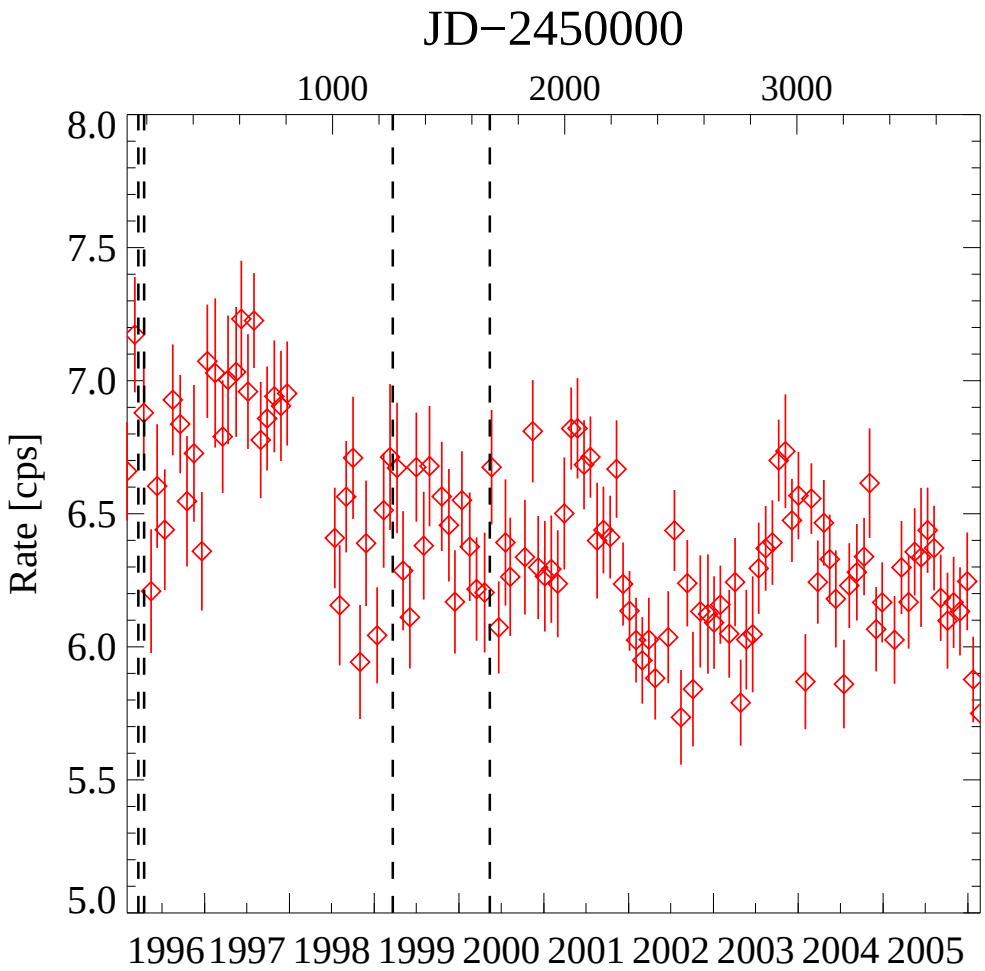


Pulsed Rate & Flux Evolution

- rates less constrained, still overall declining
- $F_{4\text{–}10\,\mathrm{keV}}$: no trend
  $F_{10\text{–}20\,\mathrm{keV}}$: decline?
  (pulsed flux harder)
- 1996/1997–2004/2005 flux comparison: 3–5% decline

Average General Parameters

- $\chi^2_{\mathrm{red}} = 1.00 \pm 0.05$
- exposures: 1.02(4) ks $\Rightarrow$ 1.52(7) ks



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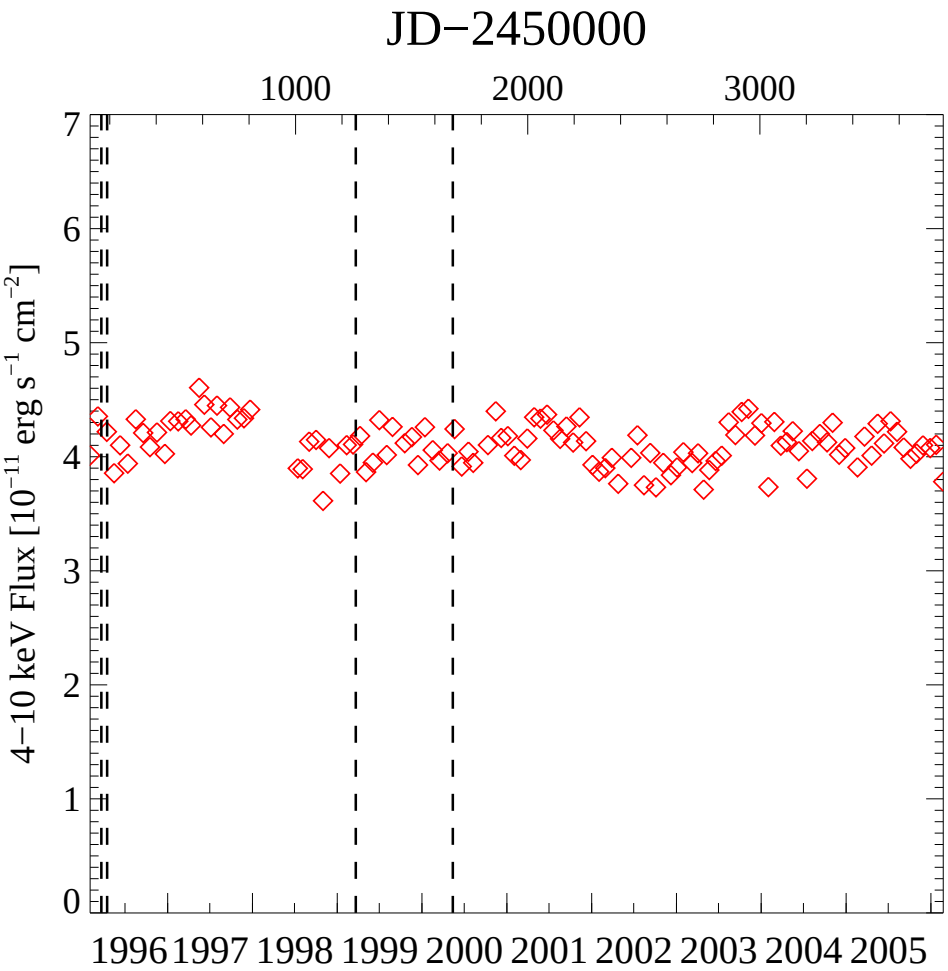

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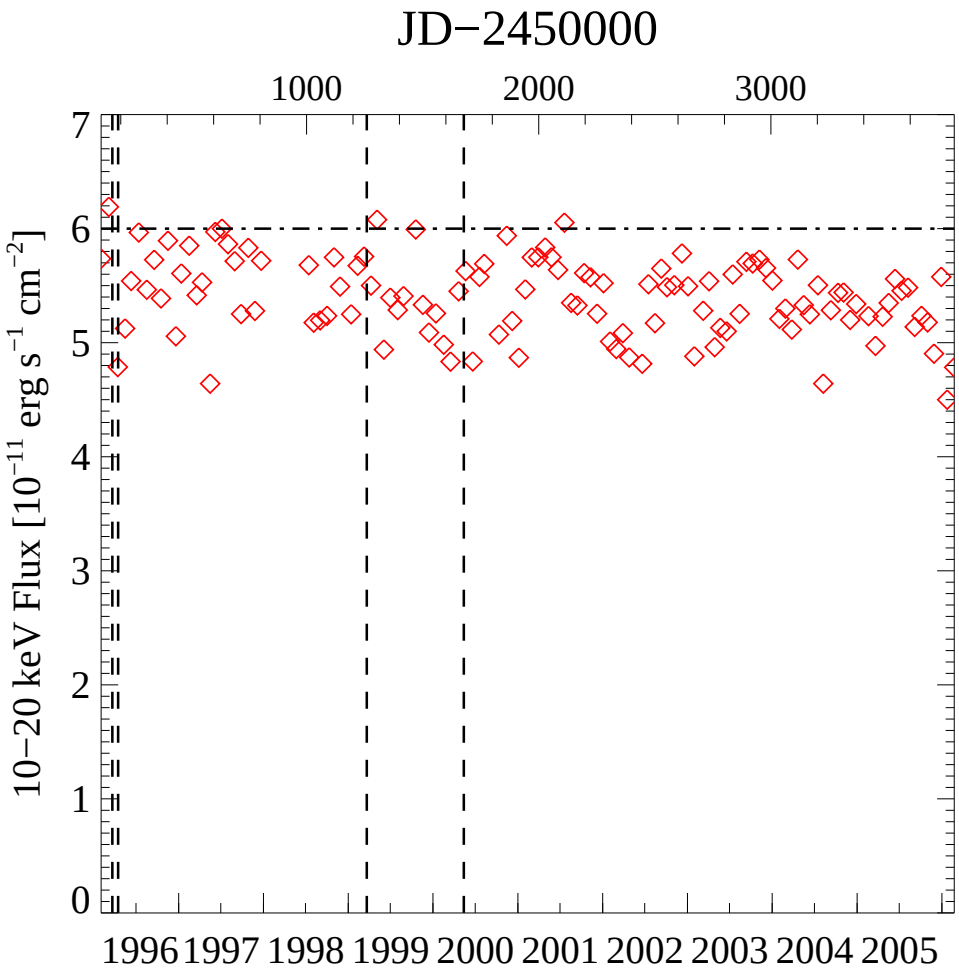


Pulsed Component N_H & Γ

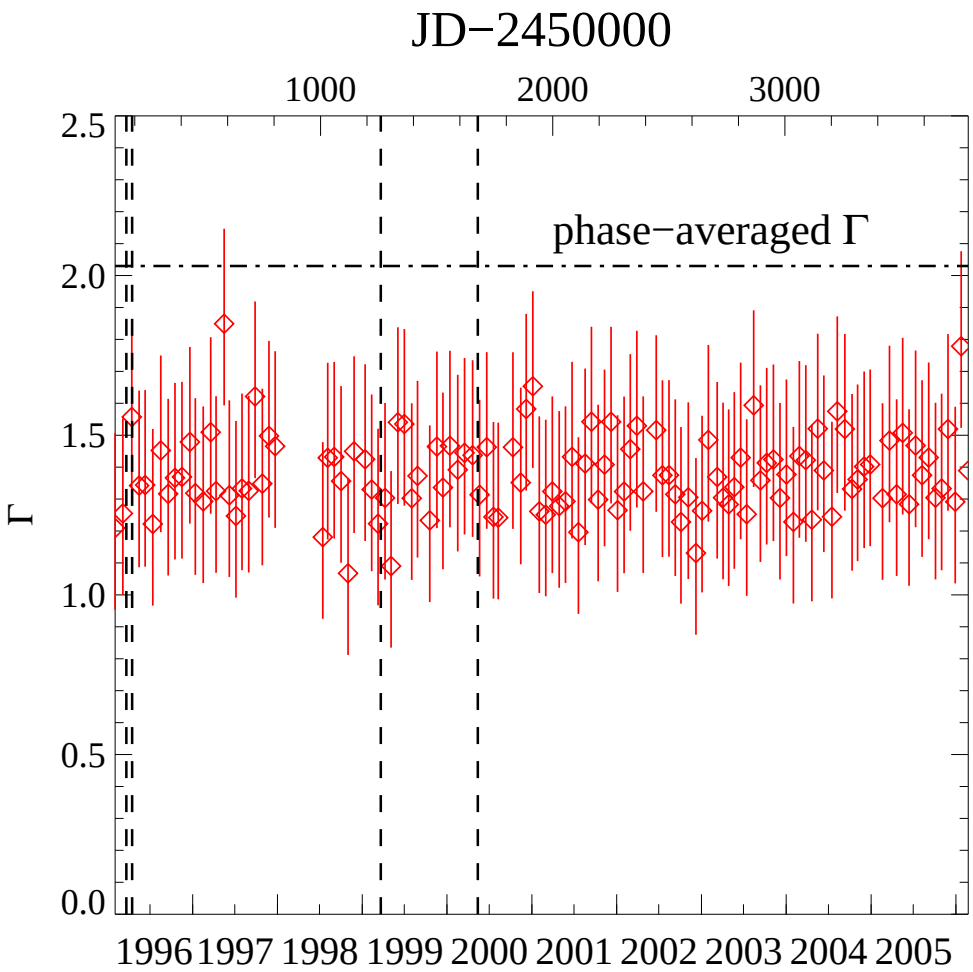
Comparison to *phase-averaged*

- average $N_H \uparrow$: $(2-3)\times10^{22}\,\mathrm{cm}^{-2}$ (mostly consist. with 0)
- harder, Gaussian distribution: $\Gamma=1.36$, $\sigma_\Gamma=0.11$

Consistent with previous *time-averaged* results:

Kawai et al., '93: $N_H\uparrow$, $\Gamma\sim1.30(5)$

Rots et al., '98: $N_H\uparrow$, $\Gamma\sim1.35(1)$



Pulsed Component N_H & Γ

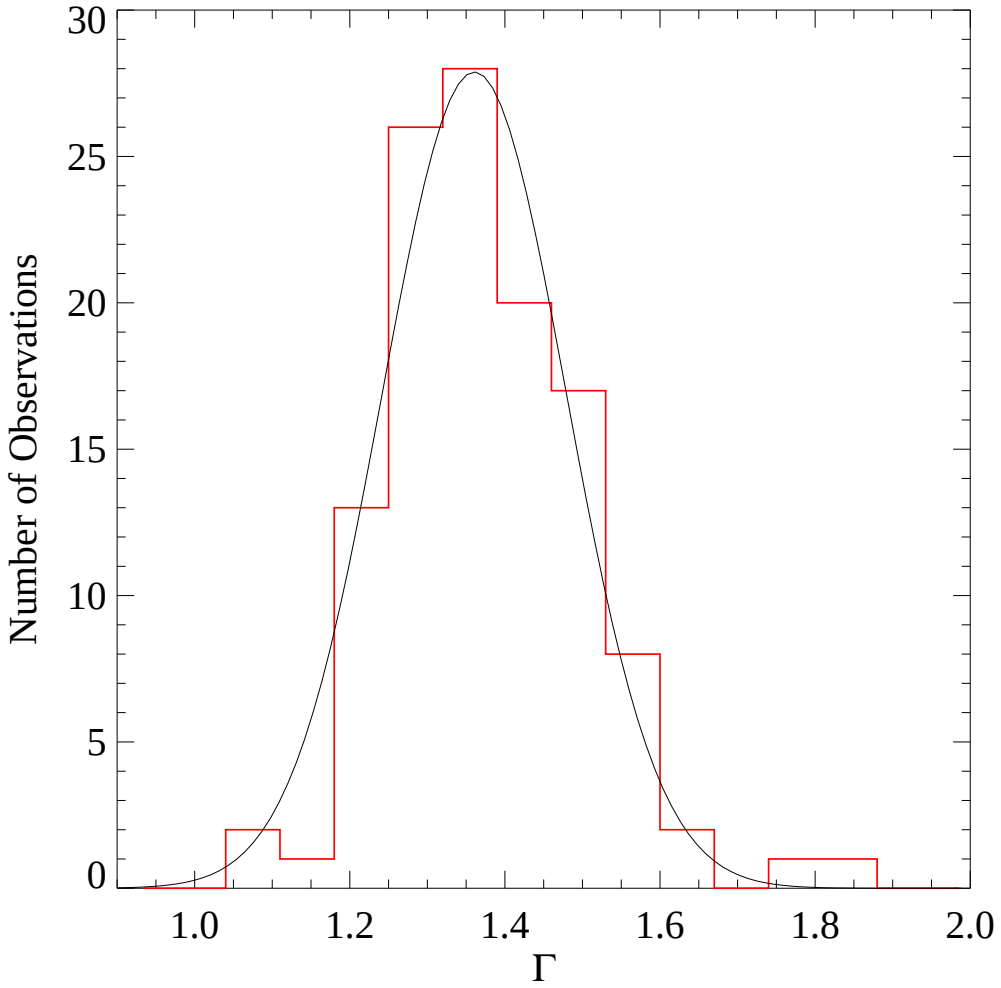
Comparison to *phase-averaged*

- average $N_H \uparrow$: $(2-3)\times10^{22}\,\mathrm{cm}^{-2}$ (mostly consist. with 0)
- harder, Gaussian distribution: Γ=1.36, σ_Γ=0.11

Consistent with previous *time-averaged* results:

Kawai et al., '93: $N_H\uparrow$, $\Gamma\sim1.30(5)$

Rots et al., '98: $N_H\uparrow$, $\Gamma\sim1.35(1)$

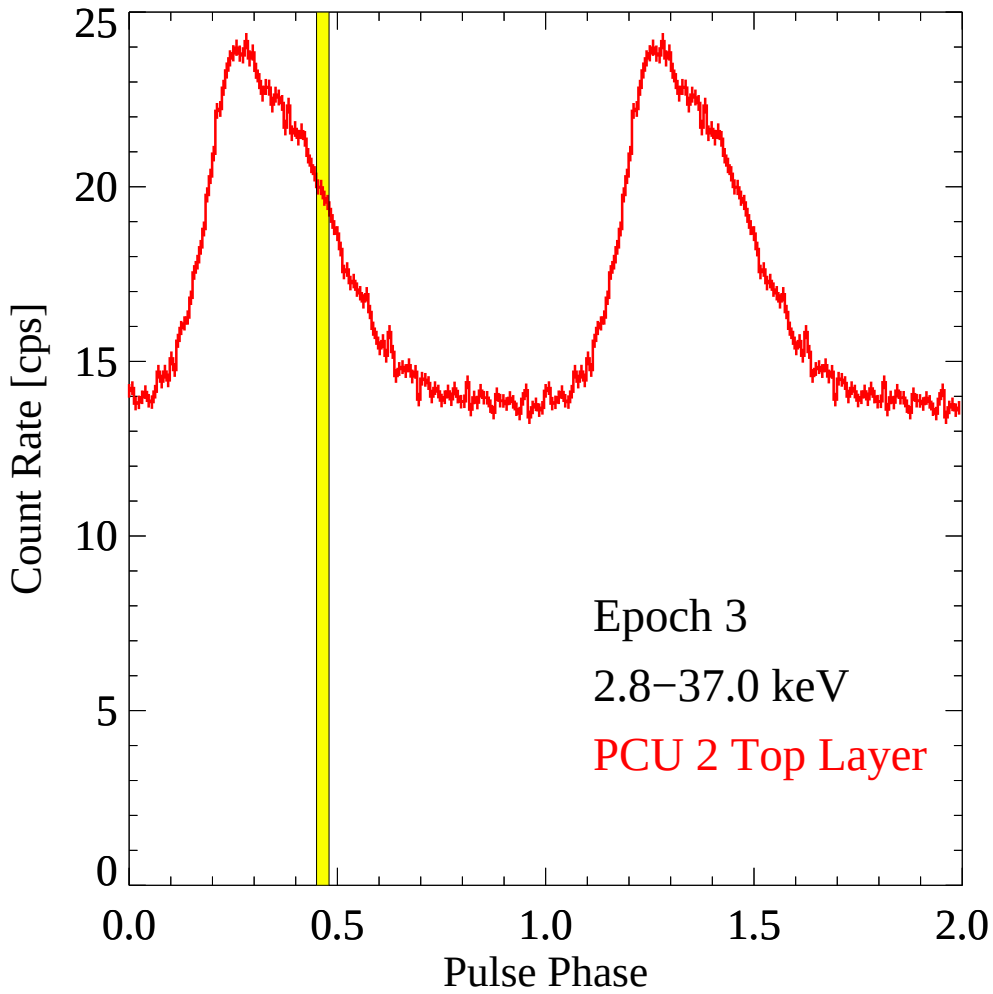


Epoch-Averaged Pulse Profiles

Epoch 3	81.2 ks
Epoch 4	37.6 ks
Epoch 5	224.6 ks

Next Step

- phase-resolved spectroscopy for $\Delta\Phi \sim 0.03$ bins
- highest resolution so far (?)



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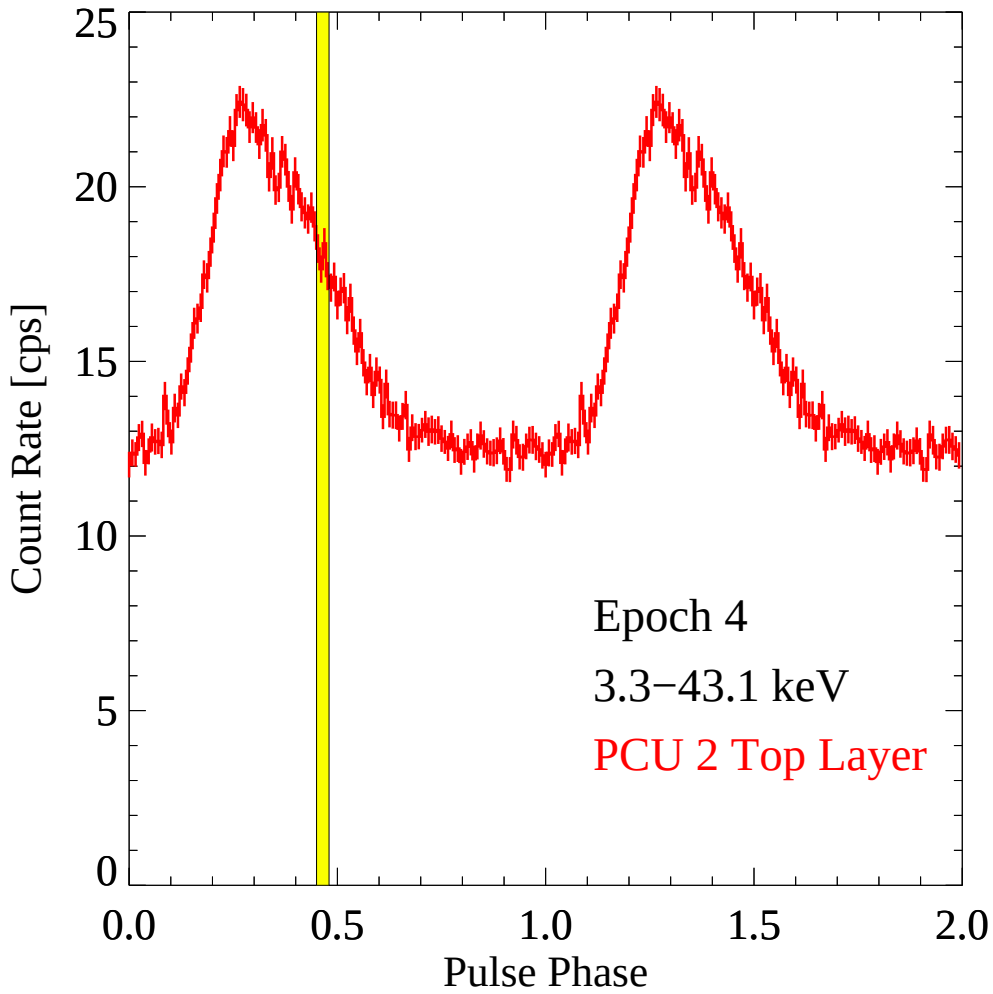

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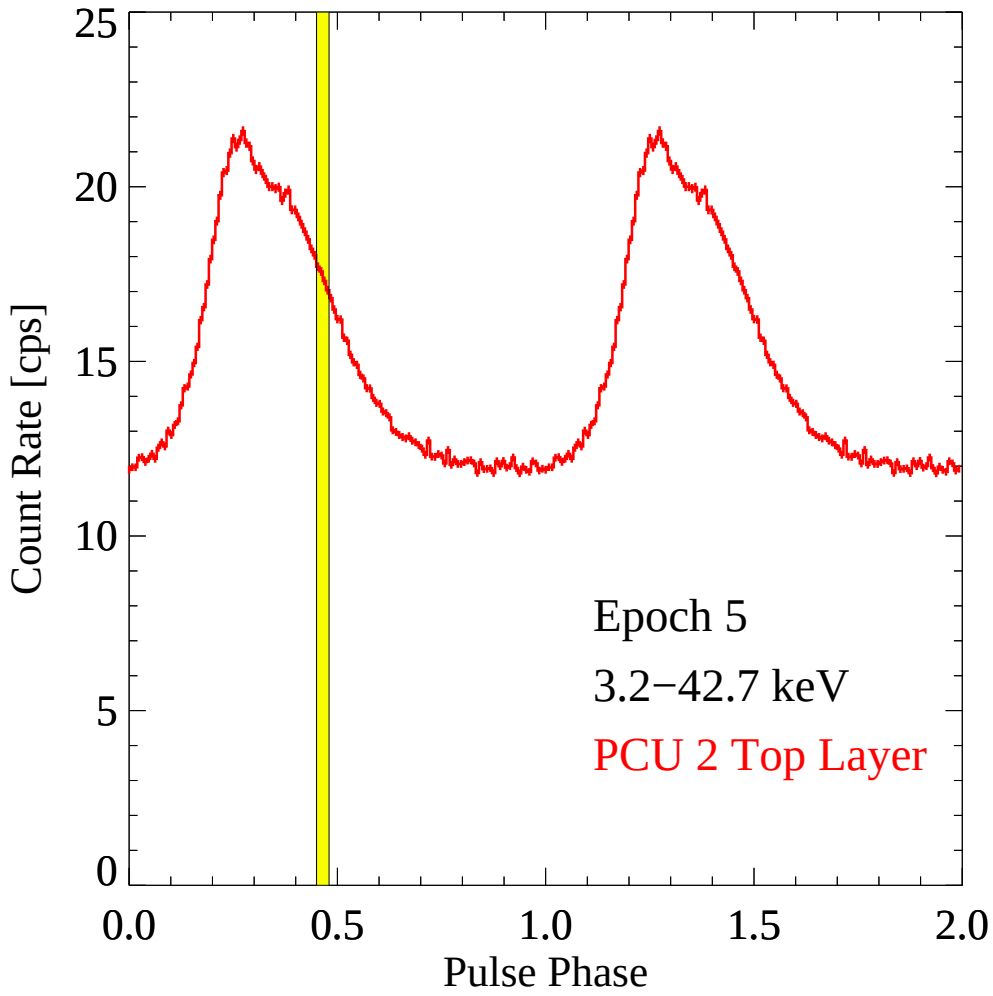

To Do

- revise PCA+HEXTE epoch averaged & phase-averaged spectra
- create HEXTE epoch averaged pulse profiles
- check energy dependence of the pulse profiles
- model PCA+HEXTE epoch averaged & phase-resolved spectra
- are the (calibration) trends $F \downarrow$, $\Gamma \uparrow$, $N_{\mathrm{H}} \downarrow$ also visible in:
  - other PCUs individually?
  - other 0.01 Crab sources?