Monitoring PSR B1509-58 with *RXTE*: Spectral Analysis 1996-2010

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We present an analysis of the X-ray spectra of the young, Crab-like pulsar PSR B1509-58 (pulse period P~151ms) observed by *RXTE* over 14 years since the beginning of the mission in 1996. The uniform dataset is especially well suited for studying the stability of the spectral parameters over time as well as for determining pulse phase resolved spectral parameters with high significance. The phase averaged spectra as well as the resolved spectra can be well described by an absorbed power law.

Introduction

The pulsar PSR B1509−58 was discovered in *Einstein X-Ray Observatory* data from 1979 and 1980 by Seward & Harnden (1982). The pulsar is associated with the supernova remnant G320.4−1.2 (MSH 15−52) in the constellation Circinus.

Seward et al. (1984) established PSR B1509−58 as one of only a few known Crab-like sources, i.e., a young pulsar powering a synchrotron nebula. PSR B1509−58's nebula is considerably larger, its surface brightness is lower and the pulse period of P~151ms is slower than that of the Crab. Due to a very high spin-down rate of $\dot{P}$~1.5×10−12 s s^{-1}, however, the characteristic age $P/2\dot{P}$ of PSR B1509−58 is ~1.6×10^{3} yr (e.g., Zhang & Cheng 2000), i.e., comparable to that of the Crab (~1.3×10^{3} yr).

Phase Averaged Spectra

From approximately monthly monitoring observations of PSR B1509−58 time averaged PCA (PCU2 top layer, Jahoda et al. 1996, 2006) and HEXTE (cluster A and B, Rothschild et al. 1998) spectra were created by averaging individual monitoring spectra between MJD 50188 and 51259 (epoch 3), MJD 51259 and 51677 (epoch 4), and from MJD 51677 onward (epoch 5). Fig. 1 shows the epoch averaged counts spectra for epoch 5. Some spectral parameters and their uncertainties for the three fits are given in Table 1. No systematic uncertainties have been added to the spectra before modeling them.

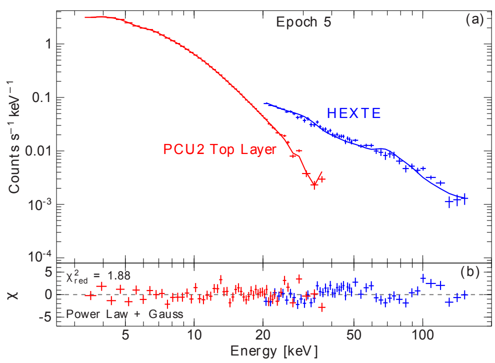

Figure 1. (a) PCU2 top layer and HEXTE counts spectra obtained by accumulating all suitable monitoring spectra of epoch 5 and best simultaneous fit model (absorbed power law with an iron line) (b) Best fit residuals.

Table 1. Best fit parameters for the averaged spectra of epochs 3, 4 and 5.

Parameter	Epoch 3	Epoch 4	Epoch 5
Γ	2.021±0.001	2.022±0.002	2.0256±0.0003
A_Γ $[10^{-2}\,\mathrm{keV}^{-1}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}]$	7.44±0.02	7.46±0.02	7.196±0.004
N_H $[10^{22}\,\mathrm{cm}^{-2}]$	0.73±0.03	0.79±0.04	0.65±0.02
E_Fe [keV]	$6.41^{+0.33}_{-0.01}$	$6.60^{+0.06}_{-0.15}$	$6.493^{+0.068}_{-0.004}$
EW [eV]	64	68	70
c_HEXTE	0.64±0.05	0.77±0.04	0.81±0.01
$A_\mathrm{Bkgcorr,PCA}$ [%]	-0.3	-0.2	+0.2
$A_\mathrm{Bkgcorr,HEXTE}$ [%]	+0.7	+0.5	+0.5
χ^2_red/dof	1.16/104	0.85/97	1.88/103
$F_{4-10\,\mathrm{keV}}$ $[10^{-11}\,\mathrm{erg\,cm^{-2}s^{-1}}]$	10.22±0.02	10.21±0.02	9.84±0.01
$F^\mathrm{unabs}_{4-10\,\mathrm{keV}}$ $[10^{-11}\,\mathrm{erg\,cm^{-2}s^{-1}}]$	10.44±0.02	10.44±0.02	10.02±0.01
$F_{10-20\,\mathrm{keV}}$ $[10^{-11}\,\mathrm{erg\,cm^{-2}s^{-1}}]$	7.55±0.01	7.54±0.02	7.21±0.01
$F_{20-200\,\mathrm{keV}}$ $[10^{-11}\,\mathrm{erg\,cm^{-2}s^{-1}}]$	25.11±0.04	25.02±0.07	21.98±0.02

Pulse Period Ephemeris

The pulse phase resolved analysis for the PCA is based on high time-resolution `GoodXenon` event mode data, filtered for PCU2 top layer events. Ephemerides for PSR B1509−58 were calculated from the pulse frequencies of each observation. The reference epoch was set to t_0(MJD) = 52921.0, the averaged time of the monitoring (see Fig. 2, Tab. 2). With this result barycentered pulse phase- and energy resolved source count rates (pha2 files) were created using a modified version of the FTOOL `fasebin` (Kreykenbohm et al. 2002).

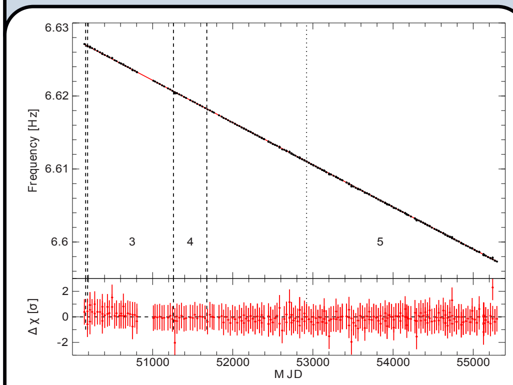

Figure 2. Frequencies of each observation with the best fit of a polynomila of quartic grade.

Table 2. Best fit parameters for the ephemerides of PSR B1509-58.

ν $[\mathrm{s}^{-1}]$	$\dot{\nu}$ $[10^{-11}\,\mathrm{s}^{-2}]$	$\ddot{\nu}$ $[10^{-21}\,\mathrm{s}^{-3}]$	$\dddot{\nu}$ $[10^{-29}\,\mathrm{s}^{-4}]$
$6.61032 \pm 1 \cdot 10^{-6}$	-6.697±0.002	1.18±0.24	1.77 ± 0.36

Phase Resolved Spectra

All pulsed (i.e. peak minus backphase) and unpulsed (regular background) spectra were added up to an averaged spectra for the three epochs 3-5, respectively. For the averaged phase resolved spectra, as for the phase averaged spectra before, an absorbed power law was fitted (energy range 3-150 keV). The pulsed spectra shows no indication for including an iron line at 6.4 keV. The line is part of the unpulsed spectra and hence of the PWN of PSR B1509-58. The best fit parameters are shown in Table 3.

Table 3. Best fit parameters for the pulsed spectra for the three epochs.

Parameter	Epoch 3	Epoch 4	Epoch 5
Γ	1.338±0.004	1.383±0.007	1.376±0.002
A_Γ $[10^{-2}\,\mathrm{keV}^{-1}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}]$	0.93±0.01	1.06±0.01	0.986±0.004
N_H $[10^{22}\,\mathrm{cm}^{-2}]$	2.04±0.26	2.88±0.40	2.50±0.10
c_HEXTE	0.65±0.06	0.75±0.07	0.75±0.02
χ^2_red/dof	1.08/126	1.05/100	1.23/127
$F_{4-10\,\mathrm{keV}}$ $[10^{-11}\,\mathrm{erg\,cm^{-2}s^{-1}}]$	4.40±0.05	4.48±0.07	4.29±0.01
$F^\mathrm{unabs}_{4-10\,\mathrm{keV}}$ $[10^{-11}\,\mathrm{erg\,cm^{-2}s^{-1}}]$	4.64±0.05	4.83±0.07	4.58±0.01
$F_{10-20\,\mathrm{keV}}$ $[10^{-11}\,\mathrm{erg\,cm^{-2}s^{-1}}]$	5.79±0.05	5.79±0.09	5.53±0.02
$F_{20-200\,\mathrm{keV}}$ $[10^{-11}\,\mathrm{erg\,cm^{-2}s^{-1}}]$	58.15±0.58	53.83±0.80	51.96±0.21

Table 4. The same as Table 3 but for the unpulsed spectra.

Parameter	Epoch 3	Epoch 4	Epoch 5
Γ	2.223±0.002	2.229±0.002	2.2652±0.0006
A_Γ $[10^{-2}\,\mathrm{keV}^{-1}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}]$	8.78±0.03	8.88±0.05	9.88±0.02
N_H $[10^{22}\,\mathrm{cm}^{-2}]$	1.07±0.05	1.08±0.08	1.33±0.02
E_Fe [keV]	$6.59^{+0.15}_{-0.10}$	$6.63^{+0.15}_{-0.18}$	$6.57^{+0.02}_{-0.06}$
EW [eV]	101	85	82
c_HEXTE	0.68±0.09	0.71±0.10	0.68±0.02
$A_\mathrm{Bkgcorr,PCA}$ [%]	-1.5	-0.9	+0.0
$A_\mathrm{Bkgcorr,HEXTE}$ [%]	+0.1	-0.2	-0.1
χ^2_red/dof	1.10/123	0.98/118	2.67/95
$F_{4-10\,\mathrm{keV}}$ $[10^{-11}\,\mathrm{erg\,cm^{-2}s^{-1}}]$	8.27±0.03	8.26±0.04	7.99±0.01
$F^\mathrm{unabs}_{4-10\,\mathrm{keV}}$ $[10^{-11}\,\mathrm{erg\,cm^{-2}s^{-1}}]$	8.53±0.03	8.52±0.04	8.30±0.01
$F_{10-20\,\mathrm{keV}}$ $[10^{-11}\,\mathrm{erg\,cm^{-2}s^{-1}}]$	5.21±0.02	5.19±0.02	4.86±0.05
$F_{20-200\,\mathrm{keV}}$ $[10^{-11}\,\mathrm{erg\,cm^{-2}s^{-1}}]$	12.93±0.04	12.78±0.06	10.76±0.01

Pulse Profiles

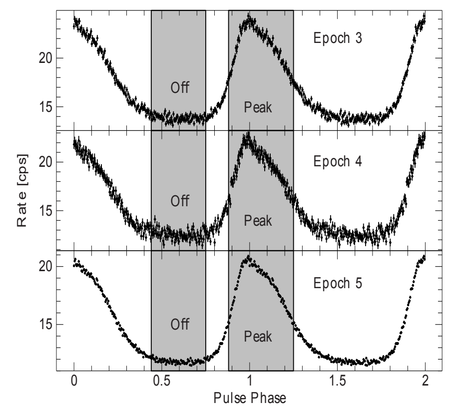

Figure 3. Pulse profiles for the energy range 3-43 keV of PSR B1509-58 for the three major epochs 3, 4 and 5.

Pulse profiles in the energy range 3-43 keV for the three major epochs are shown in Fig. 3. The peak was centered to phase 1.0 by shifting the pulse profiles. The decline in rate between epochs is an instrumental effect and is accounted for in the calibration of the PCU2 top layer. A clear division in peak Φ=0.88−1.25 and off-peak Φ=0.44 −0.75 is possible. For the pulsed emission phase Φ=0.5-0.7 was used as background so that there is only emission seen that comes from the pulsar and not from the pulsar wind nebula (PWN) around.

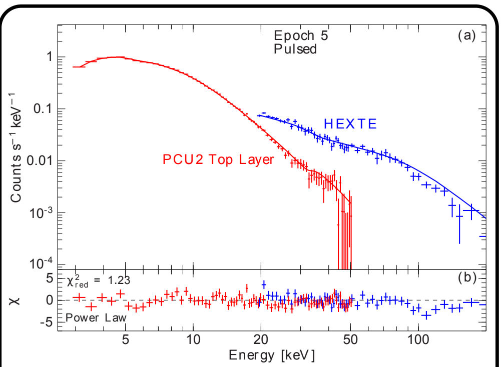

Figure 4. PCU2 top layer and HEXTE counts spectra of the pulsed emission of epoch 5. Residulas are shown for an absorbed power law.

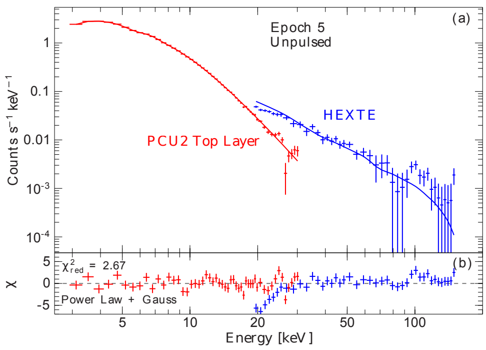

Figure 5. The same as Fig. 4 but for the unpulsed spectra.

We could decribe the spectra by an absorbed power law and get values that are consistent with earlier results. But it is seen that this model did not fit for every spectra. Therefore we will try to fit different models to the spectra and find the best fit model.

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Jahoda, K., Markwardt, C. B., Radeva, et al., 2006, ApJS, 163, 401
Jahoda, K., Swank, J. H., Giles, A. B., et al., in Proc. EUV, X-Ray, and Gamma-Ray Instrumenation for Astronomy VII, 1996, Vol. 2808, 59
Kreykenbohm, I., Coburn, W., Wilms, J., et al., 2002, A&A, 395, 129
Rothschild, R. E., Blanco, P. R., Gruber, D. E., et al, 1998, ApJ, 496, 538
Seward, F. D., & Harnden, Jr. F. R., 1982, ApJ, 256, L45
Seward, F. D., Harnden, Jr. F. R., Szymkowiak, A., et al., 1984, ApJ, 281, 650
Zhang, L., & Cheng, K. S., 2000, A&A, 363, 575

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