The Accreting Pulsar XTE J1946+274: Further Indication for a Cyclotron Line from Suzaku?

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Abstract

We present a timing and spectral analysis of the X-ray pulsar XTE J1946+274 observed with *Suzaku* towards the end of a weak outburst in 2010 October and compare it with previous results. XTE J1946+274 is an X-ray transient with a Be-type companion and a neutron star with a ~**15.8 s pulse period.** For this analysis we used both XIS(0,1,3) and PIN data. From the latter we confirm the previously determined pulse period and create pulse profiles for several energy bands. Despite a difference in the 20-60 keV flux of more than about one order of magnitude, we observe a **comparatively good match between the pulse profiles for *Suzaku* and *RXTE*/PCA**, the latter obtained during a different, brighter outburst in 2010, for the 20-40 keV energy range (while small differences are present in the 10-20 keV range). The X-ray spectrum can be well described by a **Fermi-Dirac cutoff power law model** along with a narrow **Fe Kα fluorescence line at 6.4 keV**. The strength of the Fe line is consistent with the continuum vs. line flux correlation observed in different outbursts of the source. We also investigate the possible presence of a **Cyclotron Resonance Scattering Feature (CRSF) at 35 keV**, which was detected in data from a previous outburst in 1998, and find marginal evidence for it in the Suzaku data. From an earlier analysis of the brighter 2010 outburst, a possible CRSF residual at 25 keV was reported, which is not visible in the *Suzaku* data.

Introduction and Data Reduction

The accreting X-ray pulsar XTE J1946+274 was discovered in 1998 by the All-Sky Monitor (*ASM*) on the Rossi X-Ray Timing Explorer (*RXTE*) when the source had a three-month long outburst (Smith & Takeshima, 1998; Wilson et al., 1998).

Located at a distance of 8-10 kpc, a B0-1V-IVe spectral-type star was determined by Verrecchia et al. (2002) to be the optical companion in the binary system. The orbital period of the neutron star is ~169.2 days and the orbital inclination is ~46° (Wilson et al., 2003).

Here we analyzed a 42 ks *Suzaku* observation that occured on 2010 October 12 (ObsID 405041010). As seen can be seen in Figure 1, the data were taken during a minimum between the second and third outburst of the 2010 outburst series, when the flux was ~10 mCrab. We extracted data obtained with the X-ray Imaging Spectrometer (XIS, Koyama et al., 2007), and the PIN instrument from the High X-ray Detector (HXD, Takahashi et al., 2007). We reprocessed the XIS and PIN data and extracted data products following the *Suzaku* Data Reduction (or ABC) Guide.

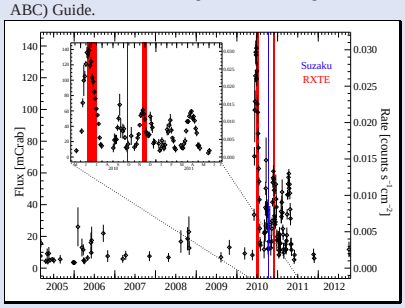

FIGURE 1:

Swift-BAT lightcurve (15–50 keV) produced with a binning of 3 d and a S/N greater than 2; the blue vertical line represents the time of the *Suzaku* observation, while the red-vertical lines represent the *RXTE* observations analyzed by Müller et al. (2012). The upper-left panel shows a closer view of the series of outbursts in 2010–2011.

Pulse Profile

On the high time-resolution PIN screened barycenter corrected events (no binary correction) that have a 61 μs we applied epoch folding and found a new **period of 15.750034(18) s**, where the error was calculated through triangular approximation, consistent with *Fermi*-GBM (http://f64.nsstc.nasa.gov/gbm/science/pulsars/lightcurves/xtej1946.html).

Figure 2 shows energy resolved pulse profiles obtained with the newly determined period for XIS 0, PIN and PCA. The *RXTE*/PCA pulse profiles are from the outburst in 2010 June. The number of phase bins for XIS, PIN and PCA is 8, 128 and 128, respectively. The period value the *Suzaku* and *RXTE* events were folded on is 15.750034 s and 15.764 s, respectively. The profile values were normalized to the average count rate.

All the pulse profiles <40 keV are consistent in general structure. They are double-peaked, with a strong and a weak minimum with an additional narrow peak feature before the deep minimum. In comparison to the deep minimum, the shallow minimum appears deeper at energies <5 keV. A similar general behavior was found by Wilson et al. (2003) during two outbursts observed with *RXTE*/PCA in 1998 and 2001 and by Paul et al. (2001) during two outbursts observed with IXAE in 1999 and 2000.

The shapes of the profiles obtained from the different outbursts are very similar, especially at higher energies, despite a big difference in flux (e.g. 1.57×10^{-9} ergs s^{-1} cm^{-2} [10–20 keV] for PCA and 5.54×10^{-10} ergs s^{-1} cm^{-2} [10–20 keV] and for Suzaku).

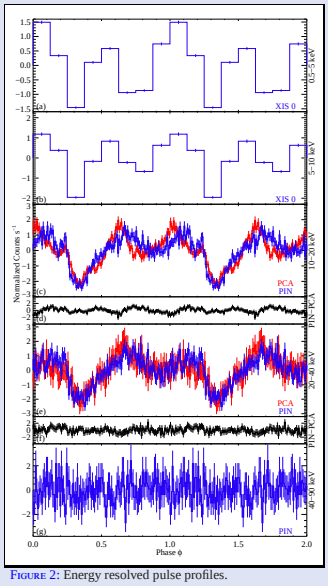

FIGURE 2: Energy resolved pulse profiles.

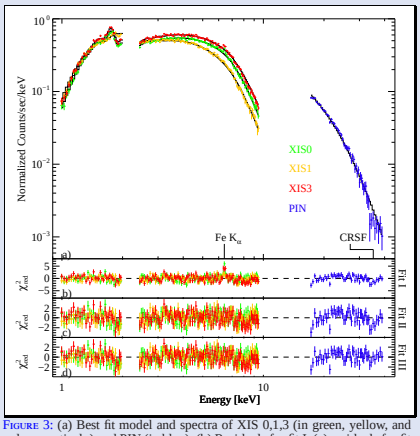

FIGURE 3: (a) Best fit model and spectra of XIS 0,1,3 (in green, yellow, and red, respectively) and PIN (in blue), (b) Residuals for fit I, (c) residuals for fit II, (d) residuals for fit III (see text for details).

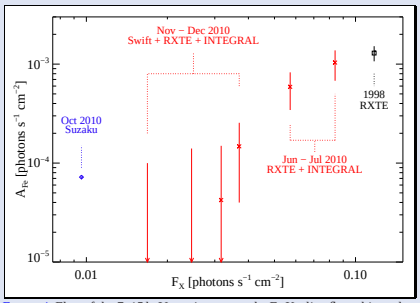

FIGURE 4: Flux of the 7–15 keV continuum vs. the Fe Kα line flux: this analysis (blue) and analysis by Müller et al. (2012) (red and black).

Spectral Analysis

N_H $\times10^{22}$ cm^{-2}	Γ	E_{cut} keV	E_{fold} keV	E_{Fe} keV	τ_{Fe} $\times10^{-5}$	E_{CRSF} keV	τ_{CRSF}	χ^2_{red}/dof
$1.67^{+0.02}_{-0.03}$	$0.56^{+0.02}_{-0.03}$	10^{-13} $^{+0.001}_{-10^{-13}}$	$8.90^{+0.32}_{-0.44}$	6.41(3)	$8.85^{+1.47}_{-1.53}$	$35.14^{+1.59}_{-1.34}$	$2.48^{+1.47}_{-1.38}$	1.18/446

Fixed σ_{Fe} = 0.1 keV and σ_{CRSF} = 2.0 keV.

Continuum

We performed spectral fits of the XIS and the PIN spectra using `Xspec`. The XIS spectra were taken in the energy range 1–9.4 keV(excluding the Au edge calibration residuals at 2.0–2.4 keV) and the PIN spectra in the range 17–37 keV. We fitted the empirical model known as a **Fermi-Dirac Cutoff** with a cross calibration constant, an absorption model (TBnew_feo – http://pulsar.sternwarte.uni-erlangen.de/wilms/research/tbabs/), a Gaussian emission line and a Gaussian optical depth profile in order to compare it to the analysis of Müller et al. (2012).

Our final **best fitting model** is shown in Figure 3 and its parameters are listed in the table above. It can be described as:

const × **TBnew_feo** × (**FDCO** + **GAUSS$_{Fe}$**) × **GABS$_{CRSF}$**.

The residuals in panel (b) of Figure 3 were obtained by fitting only the **continuum (fit I)**, the ones in panel (c) are from fitting the **continuum with the Fe Kα line (fit II)**, and panel (d) shows the residuals from the final fit of the **continuum with the Fe Kα line and CRSF feature included (fit III)**.

Also we fitted three other continuum models for accreting X-ray pulsars: a powerlaw with a high energy cutoff ('CUTOFFPL'), a negative and positive powerlaw with exponential cutoff ('NPEX'), and a high energy cutoff ('HIGHECUT'). These models resulted in comparable statistical fits (χ^2_{red} ~ 1.12).

Fe Line

We found evidence of an Fe Kα emission feature at 6.4 keV that we fit with a Gaussian line model. The significance of this detection is 99.4% (2.06 σ). **The correlation between the Fe Kα flux and the 7–15 keV flux is consistent with the results of Müller et al. (2012) as can be seen in Figure 4.**

Cyclotron Resonance Scattering Feature

For an outburst from 1998 Heindl et al. (2001) found a CRSF at ~35 keV from *RXTE* data, while in 2010 Jun–Jul and 2010 Nov–Dec 2010 Müller et al. (2012) found a marginal significance of a CRSF at ~25 keV from *RXTE, INTEGRAL* and *Swift* data.

We determined the significance of the possible **cyclotron line feature at 35 keV** using Monte Carlo Simulations with 1000 simulated spectra. The probability that the CRSF is an actual spectral feature is 2.75σ (99.40%), while Müller et al. (2012) found a detection significance for the feature at 25 keV of 1.8σ in the brightest outburst.

Conclusions

- The *Suzaku* spectral continuum obtained at low flux is different from the spectra analyzed by Müller et al. (2012) ($0.74 < \Gamma < 1.04$, 14 keV $< E_{cut} <$ 19.4 keV, 6.0 keV $< E_{fold} <$ 8.1 keV). We also confirmed these differences using two-parameter contours.
- The *Suzaku* observation supports a cyclotron line energy of 35 keV CRSF (Heindl et al., 2001) rather than of 25 keV CRSF (Müller et al., 2012). However, neither a 35 keV feature with parameters fixed at the *Suzaku* values nor one with parameters fixed at the Heindl et al. (2001) values is consistent with the brightest observation of Müller et al. (2012). Thus, there is a possibility that the CRSF energy changes between outbursts.
- Fe Kα emission feature, detected at 6.4 keV, has a continuum–line flux correlation consistent with previously analyzed outbursts, correlation which extends to low fluxes.
- The pulse profile obtained with the new pulse period consistent in general structure with the previous *RXTE*/PCA results from 2010, 2001, and 1998 indicating that there are no strong changes in the accretion column structure during this time.

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