HIGH S/N ROSAT–PSPC OBSERVATIONS OF THE QUASAR PG 1116+215: POWER LAW SHAPE OF THE SOFT X-RAY SPECTRUM

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1. Observations and data extraction

1.1. The quasar PG 1116+215

The quasar PG 1116+215 (Schmidt and Green, 1983) was selected because it is an intrinsically bright low redshift quasar. With $z = 0.177$ the soft X-ray emission is not significantly redshifted outside the ROSAT band. Its apparent magnitude $m_v = 15.04$ (Véron and Véron, 1989) corresponds to $M_v = -25.0$ for $H_0 = 50$ km s^{-1} Mpc^{-1} and $q_0 = 0$. An additional selection criterion was low $N_{\rm H}$. Radio observations give $N_{\rm H} = 1.44 \times 10^{20}$ cm^{-2} (Elvis, Lockman and Wilkes, 1989).

1.2. ROSAT pointed observations

PG 1116+215 was observed at four different epochs with the ROSAT-PSPC: one observation during the ROSAT All Sky Survey and three pointed observations (Table 1). The first two observations were analyzed with the "old" calibration of the response matrix, which was the default one until December 1992. The last two observations were analyzed with the calibration online at present (July 1993). During the first pointed observation the quasar was at the center of the field and the spacecraft wobble turned off. An unknown fraction of the incident flux was intercepted by the wire structure. The analysis of the counts (within a circle of 180 arcsec radius and not corrected for background) versus time shows that the counts in bins of 400 seconds remained constant within ±15%. These fluctuations are attributed to the effect of the wire structure and small drifts in the satellite attitude. Because there were no large flux variations during the pointed observation, we estimate the uncertainty on the flux to be less than 10%. No count rate variations larger than 10% are present in the light curves of the 2 other pointed observations.

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For the spectral analysis of the pointed observations, the counts were extracted in a circle 125 arcsec in radius centered on the source centroid. Only the signal between channels 11 and 210 was kept in the spectral analysis. The background was determined from a circle 250 arc sec in radius centered 600 arc sec west of the quasar in a region devoid of obvious background sources. The background subtracted spectrum was corrected for dead time and mirror vignetting, divided into bins with S/N $\gtrsim$ 10 in each bin (Table 1) and compared to trial models.

1.3. ROSAT All Sky Survey

PG 1116+215 was observed during the ROSAT All Sky Survey in the period 24–27 November 1990. The source counts were extracted from a circle 400 arcsec in diameter (362 counts). The nearby background was estimated from a circle of the same radius with its center at the same ecliptic latitude as the source (51 counts). A time analysis of the count rate was performed on the source counts before background subtraction following the method of Schaeidt, Hasinger and Trümper (1992) and Molendi, Maccacaro and Schaeidt (1993). There is no clear evidence for variation. $\chi^2_{\rm red}$ is 1.2 consistent with the source being constant.

2. Search for spectral variations through hardness ratio analysis

We made a first investigation of the spectral shape of the PSPC spectra through hardness ratio analysis. In addition to the standard ROSAT hardness ratio, HR, (HR = (H−S)/(H+S) where H and S are the counts in the channel intervals 11–41 and 52–200 respectively), we used two hardness ratios, one in the soft band, HR_S, the other in the hard band, HR_H, defined as follows: HR_S = (B−A)/(B+A), HR_H = (D−C)/(D+C) with A, B, C and D being the counts in the following channel intervals: A 11–41, B 52–90, C 91–150 and D 151–210. No difference in the value of the hardness ratios is detected except for a hardening of the harder part of the spectrum in December 1992, valid at the 1.5σ level.

This is suggestive of and consistent with the emergence in the PSPC range of a hard component as is commonly seen in the EXOSAT and Ginga spectra of Seyfert galaxies and radio quiet quasars (Pounds *et al.*, 1990); (Williams *et al.*, 1992). It is also interesting to note the similarity of the spectral shape in June 1991 and May 1993 whereas the flux differs by a factor 1.5 between the two dates.

3. Power law models of the PSPC spectra

The PSPC spectra at the four epochs of observations were fitted with a power law and photoelectric absorption. A good fit is obtained at each epoch using the galactic $N_{\rm H}$. Furthermore the energy index has the same value of $\Gamma \sim 2.7$ (Table 2). We note here that most of the counts are in the soft part of the PSPC spectra. The relatively large value of HR_H of December 1992 is thus diluted by the contribution of the counts in the soft part of the spectrum to the power law fit. This explains

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why Γ has the same value in December 1992 as at the other epochs in spite of a different value of HR_H; the reduced χ^2 is as expected larger in December 1992.

4. Power law fitting of the PSPC + IUE spectra

IUE spectra of PG 1116+215 were obtained near the time of the PSPC observations of June 1991 and April 1993 (Table 1). In our analysis of the PSPC+IUE spectra we used the same algorithms as we used for fitting the PSPC spectra alone. We present here the results with a power law model.

We ran a fitting procedure to the PSPC+IUE spectra of June 1991 and April / May 1993. The result is that a power law with a photon index $\Gamma = 2.57$, which is close to but statistically different from the index of the power law which fits the PSPC spectra, meets the UV spectrum at its short wavelength end (Table 2a,b). The slope $\Gamma = 2.57$ is less steep than the slope of the PSPC spectra alone but steeper than the slope of the UV spectra.

The IUE spectra after keeping only the continuum windows with the best S/N and free of emission lines have a harder slope than the UV / soft X-ray spectra: $\Gamma = 1.83$ for the SWP+LWP of June 1991, and $\Gamma = 2.16$ for the SWP of April 1993.

5. Conclusions of the power law fits of the PSPC spectra

The conclusion of the fitting exercise, and the main result of this work (Ulrich and Molendi, 1993) is that the high S/N PSPC spectra of PG 1116+215 are well represented by power laws. The photon index ($\Gamma \sim 2.7$) is the same for count rates differing by a factor 1.5. Comptonization of the UV photons by energetic electrons could re-shape the exponential cut off of the inner disk component into a power law similar to the one which is observed. Similarly, excellent single power law fits (+ galactic $N_{\rm H}$) have been found for the high S/N spectra of other bright low z quasars such as GQ Comae and PG 0157+001 (in preparation) suggesting again thermal comptonization of the UV photons.

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TABLE 1
ROSAT and IUE Observations.

ROSAT–PSPC

	Date	Effective exposure (seconds)	Count rate (second^{-1})	Number of spectral bins
Survey	24–27 November 1990	—	1.060	7
A01	29–30 May 1991	24585	1.029	84
A03(1)	20 December 1992	6109	0.993	42
A03(2)	25 May – 1 June 1993	7874	1.560	60

IUE

Date and images		Flux (10^{-14} erg cm^{-2} s^{-1} Å^{-1})
2 June 1991	SWP 41744	2.40 at 1344 Å
17 June 1991	LWP 20619	1.24 at 2640 Å
26 April 1993	SWP 47550	4.30 at 1344 Å

TABLE 2
Results of power law fits(1).

a) Power law fits for the PSPC spectra

Date	Γ	A	$\chi^2/d.o.f. = \chi^2_{red}$
November 1990	2.54	$1.52\ 10^{-3}$	$3.7/5 = 0.74$
June 1991	$2.71^{2.73}_{2.70}$	$1.36\ 10^{-3}$	$105/82 = 1.28$
December 1992	$2.65^{2.69}_{2.62}$	$1.42\ 10^{-3}$	$63.7/40 = 1.59$
May 1993	$2.67^{2.69}_{2.64}$	$2.21\ 10^{-3}$	$44.4/58 = 0.76$

b) Power law fits of the PSPC+IUE spectra

June 1991	2.58	$1.53\ 10^{-3}$
May 1993	2.56	$2.48\ 10^{-3}$

(1) All models with $N_H = 1.44 \times 10^{20}$ cm^{-2}; normalization A in photons cm^{-2} s^{-1} keV^{-1} at 1 keV. Quoted intervals are 90% confidence intervals ($\Delta\chi^2 = 2.71$) on the one interesting parameter (Γ).

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