SIMULTANEOUS EUVE/ASCA/RXTE OBSERVATIONS OF NGC 5548

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ABSTRACT

We present simultaneous observations by EUVE, ASCA, and RXTE of the type 1 Seyfert galaxy NGC 5548. These data indicate that variations in the EUV emission (at ~ 0.2 keV) appear to lead similar modulations in higher energy (≥ 1 keV) X-rays by ~10–30 ks. This is contrary to popular models which attribute the correlated variability of the EUV, UV and optical emission in type 1 Seyferts to reprocessing of higher energy radiation. This behavior instead suggests that the variability of the optical through EUV emission is an important driver for the variability of the harder X-rays which are likely produced by thermal Comptonization. We also investigate the spectral characteristics of the fluorescent iron K\(_\alpha\) line and Compton reflection emission. In contrast to prior measurements of these spectral features, we find that the iron K\(_\alpha\) line has a relatively small equivalent width (W\(_{K\alpha}\) ~ 100 eV) and that the reflection component is consistent with a covering factor which is significantly less than unity (Ω/2π ~ 0.4–0.5). Notably, although the 2–10 keV X-ray flux varies by ~ ±25% and the derived reflection fraction appears to be constant throughout our observations, the flux in the Fe K\(_\alpha\) line is also constant. This behavior is difficult to reconcile in the context of standard Compton reflection models.

Subject headings: galaxies: individual (NGC 5548) — galaxies: Seyfert — X-rays: galaxies

1. INTRODUCTION

Over the past decade, a moderately coherent picture of the broad band continuum emission from Seyfert AGNs has emerged. In this model, an accretion disk around a supermassive black hole (\(M \sim 10^7–10^8 M_\odot\)) produces thermal emission primarily in the optical and ultraviolet; and a hot, Comptonizing corona above the disk up-scatters these photons to produce X-rays with energies ~ 1–100 keV. Furthermore, the existence of strong fluorescent iron K\(_\alpha\) lines at ~ 6.4 keV and the so-called “Compton reflection humps” above ~ 10 keV in the spectra of type 1 Seyferts indicate that the disk, or some other cold, optically thick material reprocesses the hard X-rays.

Central uncertainties in this model are the geometry of the corona and the disk and how the radiation from one component affects the properties and emission of the other. A cold (\(T \lesssim 10^8\) K), optically thick disk will absorb a large fraction of the incident X-rays and will likely be significantly heated, thus reprocessing the absorbed energy as additional thermal photons. These photons will be available for Compton up-scattering and may provide additional cooling of the coronal electrons thereby decreasing the temperature of the Comptonizing medium. Hence, the size, shape, and location of the corona relative to the disk will affect the temperature and spectral properties of both components.

A related difficulty is the origin of the soft X-ray excess at energies ≥ 0.1 keV which has no plausible explanation within the context of standard thin disk models (Koratkar & Blaes 1999). Any reasonable range of disk temperatures for sub-Eddington accretion is too low to account for this emission as an extension of the disk thermal emission, and an extrapolation of the standard hard X-ray thermal Comptonization spectrum down to these energies severely underpredicts the observed flux. However, Magdziarz et al. (1998) have been able to model the soft X-ray excess and most of the optical/UV as emission from very Thomson thick (\(\tau \sim 30\)) warm (200 eV) Comptonizing clouds above the disk. Despite the ad hoc nature of this model, it makes the definite prediction that the optical, UV and EUV flux should be highly correlated.

Correlated variability studies between different wavebands have been the traditional means of determining which spectral components provide the impetus for others. NGC 5548, in particular, has been involved in several multiwavelength monitoring campaigns, the best known of which were efforts to use optical/UV spectra to characterize the Broad Line Region via reverberation mapping (Clavel et al. 1991; Korista et al. 1995). As a by-product of these investigations, Peterson et al. (1991) compared the light curves of contemporaneous optical (4870 Å) and UV (1350 Å) data from the earlier of these campaigns and showed that essentially no lag exists between spectral bands within the temporal resolution of the observations, ±2 days (see also Clavel et al. 1991). If the observed optical/UV flux in type 1 Seyferts is thermal emission due to the local conversion of gravitational energy in thin accretion disks, then the characteristic radii from which continuum emission at these two wavelengths are produced will be quite different. Any correlated variability between these two bands would then be limited by the sound crossing time in the disk flow. However, Courvoisier & Clavel (1991) have shown that the upper limits on the optical/UV lag for NGC 5548, as well as for Seyferts NGC 4151 and Fairall 9, are several orders of magnitude smaller than the
sound crossing times.

As an explanation for this near simultaneity of the optical and UV, Clavel et al. (1992; see also Malkan 1991) suggested that the variable emission is due to reprocessing of X-rays from a source located very near the central black hole. This interpretation would also be consistent with the observations of NGC 5548 by the EUVE satellite during the 1993 IUE/HST/ground-based BLR reverberation mapping campaign (Marshall et al. 1997; Korista et al. 1995). Marshall et al. obtained contemporaneous EUVE data and found that the EUV (at ~ 0.16keV) also varies with the optical and UV to within ≤ 0.25 days. This result links the soft X-ray excess with the lower wavebands and supports either a reprocessing model or one such as that of Magdziarz et al. (1998). In conflict with the former scenario are the contemporaneous observations of the type 1 Seyfert NGC 7469 by RXTE and IUE (Nandra et al. 1998). Over a 30 day baseline, Nandra et al. found that no simple relationship exists between the variability in the X-rays and UV. Light curves in both wavebands exhibit large, factor of ~2 modulations on 10 day time scales, but the peaks in the UV appear to lead the corresponding maxima in the X-rays by ~ 4 days while the troughs in the two wavebands are nearly simultaneous. Nandra et al. suggest that this behavior may be due to several reprocessing regions which interact at different time scales depending on the flux state. Previous correlated UV/hard X-ray observations of NGC 5548 by Ginga and IUE were only able to place an upper limit of ~ 6 days for the characteristic lag between these two energy bands (Clavel et al. 1992). An earlier observation by EXOSAT did show an apparent lag of ~5 ks between the soft (0.05–2.5 keV) and hard (2–10 keV) X-ray bands, but this was only seen during one of 12 observations, albeit the longest one of 60 ks, and with fairly poor statistics (Kaastra & Bar 1989; see also Nandra et al. 1991).

Another aspect of the behavior of NGC 5548 which bears upon the disk/corona geometry is the putative correlation between the derived reflection fraction and the spectral index of the underlying hard continuum (Magdziarz et al. 1998; Zdziarski, Lubinska, & Smith 1999). Spectral analyses of X-ray data from Galactic black hole candidates and Seyfert AGNs, including NGC 5548, show that the fitted reflection fraction is systematically larger for softer underlying spectra. The natural interpretation of such a correlation is that the reflecting medium is an important source of soft seed photons which affect the cooling of the Comptonizing medium. A larger covering factor implies more soft photons, causing a lower temperature coronal region and therefore a softer spectrum. Since the fluorescent iron line emission presumably also originates in this same cold, Compton reflecting material, it provides an additional diagnostic to explore the relationship between the covering factor and the spectral hardness.

In order to investigate the roles of the various components in the Seyfert disk/corona system of NGC 5548 further, we have conducted simultaneous EUVE, ASCA, and RXTE monitoring observations. This combination of instruments allowed us to study the soft X-ray excess, its relationship to the harder, Comptonized X-ray emission, and the higher energy signatures of X-ray reprocessing in accretion disks, the fluorescent iron line and the Compton reflection component. We describe the observations by the various instruments in § 2. In § 3, we present an analysis of the correlated variability analysis between different energy bands, and in § 4 we examine the power spectra of the various bands. In § 5, we analyze the X-ray spectral properties in detail during each observation epoch. We discuss the implications of our observations for disk/corona models in § 6 and present our summary and conclusions in § 7.

2. THE OBSERVATIONS AND DATA REDUCTION

Great effort was made to ensure that the observations by the various telescopes in this campaign were as simultaneous as possible. Unfortunately, because of differences in time allocation, conflicts with other scheduled observations, differing visibility constraints and other unforeseen complications, absolute simultaneity over our proposed 23 day baseline was not possible. In particular, several data gaps of a few ×10 ks exist in the RXTE data because of scheduling conflicts; the EUVE spacecraft went into “safepoint” mode just prior to one of our shorter monitoring observations; and the final RXTE observation which took place over a 200 ks time period had no contemporaneous EUVE or ASCA monitoring because of visibility constraints. Nonetheless, these data represent some of the highest time resolution broad band monitoring of any AGN.

In order to provide uniformity in referring to the various pointings performed by the three satellites, we have adopted a numbering scheme based on the originally scheduled simultaneous observations. In this scheme, the June 15, June 18–24, July 1 and July 7 observations are numbered 1–4, with the June 18–23 (obs. 2) subdivided as we discuss below. We refer to all the other observations taken by individual instruments by the dates on which they took place.

2.1. EUVE

Our strategy for using EUVE to monitor the soft X-ray flux from NGC 5548 was identical to that employed by Marshall et al. (1997). Photometry was carried out using the Deep Survey (DS) detector with the Lex/B filter, and the pointing was offset from nominal by 0.3 degrees along the direction of the SW spectrometer dispersion axis. This was done in order to avoid the deadspot in the DS detector while largely preserving the capabilities of the SW spectrometer. In extracting the count rates, we employed the analysis of Marshall et al. which accounts for dead-time and “Primbsch” corrections as in the standard EUVE analysis procedure and which also applies a vignetting correction necessitated by the offset pointing. Another important feature of this analysis is its implementation of a maximum likelihood technique using the instrumental point spread function to determine the source and background counts rather than specifying source and background apertures. Further information on these procedures can be found in Marshall et al. (1997).

Table 1 gives the details of our EUVE/DSS observations. The spectral densities we report account for a Galactic column density of \( N_H \approx 1.7 \times 10^{20} \) cm\(^{-2}\) and assume a power-law spectrum with index 0–2 (\( \alpha \approx 1\)). For the narrow effective bandpass (0.70–0.90 Å), the resulting spectral densities we compute are not very dependent on the value of \( \alpha \). The 1998 June 2, June 9, and July 1 observations were simultaneous with Lick observations scheduled on those dates, although the June 2 Lick observation did not occur due to bad weather. As we noted earlier, the EUVE spacecraft went into “safepoint” mode just prior to our June 15 joint ASCA/RXTE observations (cf. Tables 2 & 3), and we did not obtain simultaneous EUVE data for our July 7 ASCA/RXTE observations because of a scheduling error.

2.2. ASCA

2.2.1. Basic data reduction

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ASCA observed NGC 5548 on five occasions during this campaign. The dates, good exposure times, count rates and 2–10 keV fluxes are reported in Table 2. ASCA possesses four detectors: two solid-state imaging spectrometers (SIS0 and SIS1) and two gas-imaging spectrometers (GIS2 and GIS3). These detectors are located at the focal points of four independent but coaligned X-ray telescopes. During our campaign, data from all four detectors were obtained. SIS data taken in both BRIGHT and FAINT mode were combined in order to maximize the total signal and a standard GRADE selection was performed in order to reduce the effects of particle and instrumental background. Data from the SIS were further cleaned in order to remove the effects of hot and flickering pixels and subjected to the following data-selection criteria: the satellite should not be in the South Atlantic Anomaly (SAA), the object should be at least 5° above the Earth’s limb, the object should be at least 25° above the day-time Earth limb, and the local geomagnetic cutoff rigidity (COR) should be greater than 7 GeV/c. Data from the GIS were cleaned to remove the particle background and subjected to the following data-selection criteria: the satellite should not be in the SAA, the object should be at least 7° above the Earth’s limb and the COR should be greater than 7 GeV/c. These steps were performed using XSELECT V 1.4 which is part of the FTOOLS V 4.1 package.

Images, light curves and spectra were extracted from the good data using a circular region centered on the source. For the SIS, an extraction radius of 3 arcmins is used whereas a radius of 4 arcmins is used for the GIS. These regions are sufficiently large to contain all but a negligible portion of the source counts. Background spectra were extracted from source free regions of the same field of view within each of the four ASCA instruments. Background regions for the SIS were taken to be rectangular regions along the edges of the source chip whereas annular regions were used to extract GIS background. Approximately 1% of the photons in the source extraction region were found to be from the background.

2.2.2. The effects of RDD

The effects of radiation damage to the CCD’s of both SIS detectors have reduced the ability of the on-board software to estimate and correct for dark current. This problem is known as residual dark distribution (RDD) and, in these late stages of the ASCA mission, is becoming a major concern. Data taken in FAINT mode can have the effects of RDD partially corrected for during the ground-based reduction process. Unfortunately, due to telemetry constraints, the majority of our data were taken in BRIGHT mode and cannot be corrected.

Operationally, RDD renders the soft end of the SIS spectrum (< 1 keV) untrustworthy. Comparing our SIS0 and SIS1 spectra reveals major discrepancies between these two instruments below 1 keV which are readily attributed to RDD effects. For this reason, we restrict ourselves to the 2–10 keV band when performing spectral fitting with SIS data.

2.2.3. An SIS/GIS discrepancy

The spectral fitting described below was initially performed using the 2–10 keV data from all four ASCA instruments. However, the GIS spectra were found to strongly disagree with the SIS spectra at high-energies (8–10 keV) — the two GIS spectra consistently lay above the two SIS spectra in each and every observation of this campaign. When these spectra are fitted with a spectral model consisting of an absorbed power-law model and a Gaussian emission line (see below), residuals are present in the GIS spectra at energies coincident with the Gold M-edge (2.2 keV) and Xenon L-edge (4.8 keV). This strongly indicates the use of an incorrect GIS gain factor. No linear gain correction could eliminate these residuals simultaneously. Faced with the conclusion that there is a non-linear gain problem in our GIS data, we choose not to use GIS data in any of the spectral fitting reported below.

Further support for the hypothesis that the GIS is in error is given when RXTE-PCA data are fitted simultaneously with these ASCA data. In the overlap band (4–10 keV), the PCA spectra generally agree well with SIS spectra and disagree with GIS spectra. However, to our knowledge, the ASCA and RXTE instruments have not been cross-calibrated. As we discuss below, we have therefore allowed the relative normalization for the spectral models which are fit to data from each instrument to vary, and we have also allowed the spectral index of the hard continuum to vary separately for the SIS and PCA data.

2.3. RXTE

Standard extraction methods were employed to determine the PCA and HEXTE light curves and spectra. The PCA instrument consists of five collimated (1° FWHM) proportional counter units (PCUs) which are numbered 0–4. Each PCU contains three multianode detector layers with a mixture of xenon and methane gas, has a bandpass of 2–60 keV and a geometric collecting area of ~ 1400 cm². The energy resolution of each detector is ~ 8% FWHM at 6.6 keV (Glasser, Odell, & Seufert 1994). PCA data were collected only from PCUs 0–2, since PCUs 3 and 4 were turned on for a smaller fraction of the on-source time due to breakdown. This source is relatively weak, so in order to maximize signal-to-noise, we accumulated events only from the top xenon/methane layer of the PCA. As recommended by the PCA team, data were discarded for the 30 minutes following a SAA passage, during Earth occultation (i.e., when the Earth elevation angle is < 10°), and when there is severe electron contamination. The variability and spectral analyses were greatly facilitated by the recently developed faint source (< 40 cps) background model. It is implemented in the PCABACKEST program and is contained in the model files pca_bkgd_faint1_e03v03.mdl and pca_bkgd_faint240_e03v03.mdl. The first file contains information on the variation on the “L7” rate which is a background rate made up of a combination of 7 rates in pairs of adjacent signal anodes, while the second file is related to the integrated recent particle doses during SAA passages, as measured by the HEXTE particle monitor. SAA passages and doses are recorded in pca_saa_history_v8. Response matrices were constructed using PCARMF v3.5 and PCARSP v2.36. For spectral fitting, we restricted the energy range of the PCA data from 3 to 20 keV.

The HEXTE instrument consists of two clusters of four NaI/CsI-phoswich scintillation counters which are sensitive from 15 to 250 keV with an open area of ~ 900 cm² for each cluster. Beam switching or “rocking” of these clusters between source and background fields provided direct measurements of the HEXTE background with an on-source duty cycle of ~ 60%. As recommended by the HEXTE team, data were discarded for the 2 minutes following a SAA passage and during Earth occultation. Standard deadtime corrections were applied to the Science Archive data. In order to maximize signal-to-noise in the light curves, only counts from absolute detector channels 30–122 were used. As can be seen from Table 3,
the HEXTE count rates were very low, ≲ 1 cps throughout our observations. Hence, statistically meaningful HEXTE spectra could only be accumulated over relatively long integrations, > 4 × 10^4 s, which is substantially longer than the variability time scale seen in the PCA data.

2.3.1. 1E 1415.6+2557

A minor complication in the RXTE analysis is the existence of a contaminating source within the field-of-view of the PCA and HEXTE collimators, 0.5° away from NGC 5548. The source is a BL Lac object, 1E 1415.6+2557, and has been previously observed by ROSAT (Nandra et al. 1993). As an additional precaution, since Nandra et al. reported several additional sources in the ROSAT-PSPC FOV surrounding NGC 5548, we performed a PCA scanning observation of the field to determine if any other contaminants were present (cf. Marshall et al. 1998). Using the collimator response model of the PCA which was provided to us by the PCA instrument team, we fit the scan observations and found that we could account for all the counts in the field adequately with just two sources: NGC 5548 and 1E 1415.6+2557.

During the first four of our RXTE observing periods, the contribution by 1E 1415.6+2557 to our NGC 5548 measurements was determined from ~ 3–5 ks pointings directed at 1E 1415.6+2557 just prior to and after each NGC 5548 observation period. This bracketing was done in case 1E 1415.6+2557 exhibited any variability on 30 ks time scales. We used the aforementioned collimator model to fit the count rates from these two sources simultaneously during the beginning and ending sub-portions of each observation. We then extracted spectra from these sub-portions for each source. The spectra for 1E 1415.6+2557 were fit with XSPEC v10.0.0 using the associated background-subtracted NGC 5548 spectrum as a "correction file"; appropriately scaled to yield the fitted count rates. Table 5 gives the estimated count rates and spectral fits for 1E 1415.6+2557 obtained from this procedure. When there are significant differences in the count rates of 1E 1415.6+2557 for the two bracketing pointings, they are reported separately, i.e., as 2a/b and 3a/b.

For the observations beginning 1998 August 16, we altered our strategy for estimating the flux and spectrum from 1E 1415.6+2557. Rather than relying on scaled spectral correction files extracted from direct pointings at NGC 5548 which are in turn contaminated by flux from 1E 1415.6+2557, we took “background” measurements at the symmetric location on the opposite side of NGC 5548. For the same roll angles, these pointings should contain the same contribution from NGC 5548 as the direct 1E 1415.6+2557 pointings, but since they are ~ 1° away, they should be uncontaminated by 1E 1415.6+2557 itself. Correction files from these pointings were then used in the spectral analysis. We find that the spectrum of 1E 1415.6+2557 during the August 16 observations was somewhat harder and the count rate in the PCA had increased by ~ 40%. We note that this increase is not due to our altered observing strategy as we have also applied the collimator model fitting method and confirm this result. The collimator response for pointings directed at NGC 5548 to photons from 1E 1415.6+2557 is ~ 0.33, so the contaminating contribution to the NGC 5548 light curves will be ~ 2 cps with a modulation of < 0.8 cps, while the PCA count rates for NGC 5548 are typically 20–25 cps. Therefore, in our variability analysis of NGC 5548, we can safely ignore contributions from 1E 1415.6+2557.

3. CORRELATED VARIABILITY

In Fig. 1, we show the EUVE, ASCA-SIS, and RXTE-PCA count rate light curves for the longest of our contemporaneous observation periods. The most distinct feature in all three of these light curves is the large step at ~ 2 × 10^4 s in the figure. This step is more pronounced (~ 40%) at EUV energies than in the harder X-rays (~ 20% for the RXTE-PCA data). After this step, in the RXTE light curve there are several local maxima which recur on ~ 50 ks time scales; similar modulations also appear in the EUVE light curve, but with less certainty due to the relatively poor statistics. As a first order analysis of the spectral variability across these wavebands, we have computed cross-correlation functions (CCFs) for each pair-wise combination.

The method we use is the Z-transformed Discrete Cross-Correlation Function (ZDCF) of Alexander (1997) based upon the DCF method of Edelson & Krolik (1988). In the latter procedure, which was designed to accommodate unevenly and differently sampled data trains, pair-wise combinations of measured flux values from the two light curves are binned according to their relative delays or lags. For the data pairs within each lag bin, a quantity which is essentially Pearson’s linear correlation coefficient is computed (Press et al. 1992). In the continuum limit, this procedure is equivalent to the standard definition of the CCF. Alexander (1997) proposed two modifications of this method: first, the lag bins are defined to contain a specific number of data pairs which should be > 11 in order to ensure convergence; second, the errors are estimated by applying the Z-transform to the correlation function values and using the number of pairs for the given bin and known properties of the Z-transform to estimate the errors. For identical binning, the ZDCF estimates of the CCF are equal to those produced by the DCF, but the uncertainties are better behaved. Auto-correlation functions can also be computed by this method.

Figure 2 shows the ZDCFs for EUVE vs 0.5–1 keV ASCA-SIS, EUVE vs RXTE-PCA, and 0.5–1 keV ASCA-SIS vs RXTE-PCA. In each case, a positive time delay indicates the latter light curve lagging the former. In order to obtain a quantitative estimate of the relative lags, we fit the ZDCF values in the vicinity of the peak with a parabola (solid curves in Fig. 2). This functional form has no specific physical meaning—it is merely a
convenient parametrization of the ZDCF shape near the maximum. From these fits, we see that higher energy light curve modulations are delayed relative to lower energy ones with the variations in the 2–20 keV RXTE-PCA data lagging those of the EUVE by ~ 35 ks and those of the 0.5–1 keV ASCA data by ~ 5 ks. Similarly, the 0.5–1 keV ASCA data lag the EUVE by ~ 13 ks. We determine confidence limits using Monte Carlo methods where for each trial we produce simulated light curves taking the measured light curves as input and assuming Gaussian statistics. In Table 4, we report the mean value of the fitted peaks and the 99.9% C.L.s for each pair of light curves. We have also estimated the cross-correlation function using the Lomb-Scargle method for computing the FFT of unevenly sampled data (see text). Dashed lines show flat, $f^{-1}$, and $f^{-2}$ overlaid on the power spectra. The dotted line shows our estimate of the mean noise level of the ASM data. All PSDs are normalized such that integrating over positive Fourier frequencies yields the root mean square variability, normalized to the mean, for each particular light curve.

4. POWER SPECTRA

We can combine our pointed X-ray observations, which span time scales from approximately $5 \times 10^3$ s to $3 \times 10^5$ s, with observations from the All Sky Monitor (ASM) on board the RXTE spacecraft, which span time scales ranging from days to 3 years. We have used these data to construct an X-ray power spectrum that covers four orders of magnitude in Fourier frequency from $10^{-8} - 10^{-4}$ Hz. The result is presented in Fig. 3. A power spectrum that covers a similar broad range of time scales, but with much better statistics, has been obtained from pointed RXTE observations of the Seyfert 1 galaxy NGC 3516 (Edelson & Nandra 1999).

As the orbital time scales of the RXTE, ASCA, and EUVE spacecraft are approximately 5 ks, significant variability power (due to SAA passages and source occultation) appears on these time scales and at higher harmonics. In addition, for the EUVE spacecraft, we must integrate for approximately 5 ks in order to obtain good signal to noise. We therefore only consider Fourier frequencies $< 10^{-3}$ Hz. The PSDs are constructed from light curves with 5.6 ks time bins for the EUVE data, and 128 s time bins for the RXTE-PCA data. These light curves, however, still contain a number of data gaps, therefore we use techniques for calculating power spectra of unevenly sampled light curves (see Lomb 1976; Scargle 1982). The PSDs are then normalized so that integrating over positive frequencies yields the root mean square (rms) variability relative to the mean (see Belonli & Hasinger 1990a; Miyamoto et al. 1992). The resulting PSDs are then logarithmically binned over frequencies ranging from $f \rightarrow 1.2f$. For the EUVE PSD we calculate that the noise contribution to the rms variability is 11 ± 0.6% of the mean, therefore we subtract this (assumed white) noise level from the EUVE PSD. The noise level of the RXTE-PCA is negligible.

Several results are immediately apparent in Fig. 3. First, we see that the EUVE light curve is more highly variable than the RXTE-PCA light curve, with an rms variability of 18.1 ± 1.4% compared to 7.4 ± 0.6% over the time scales sampled by the PSDs. Both the RXTE-PCA and the EUVE PSDs are approximately $\propto f^{-2}$. The $f^{-2}$ PSD seen for the RXTE-PCA light curve is comparable, in both shape and rms amplitude, to the high-frequency ($> 0.1$ Hz) PSDs seen for galactic black hole candidates (GBHCs), such as Cygnus X-1, observed in their low/hard states (Miyamoto et al. 1992; Nowak et al. 1999).

The low-frequency X-ray PSD is calculated via ASM data. The ASM provides light curves in three energy bands, 1.3–3.0 keV, 3.0–5.0 keV, and 5.0–12.2 keV, typically consisting of several 90 s measurements per day (see Levine et al. 1996; Remillard & Levine 1997; Lohner & Remillard 1997). We have combined all three energy channels into a single channel, and then rebinned the data on 5 day time scales. Here we have filled data gaps (39 out of 233 points) with a linear interpolation, and the power spectrum is then constructed using standard

![Fig. 2.— Cross-correlation functions computed using the ZDCF (Alexander 1997). The bands which are compared are EUVE (0.14–0.18 keV), ASCA (0.5–1 keV), and RXTE-PCA (2–20 keV) (cf. Fig. 1). The solid curves are the parabolas which were fit to find the location of the characteristic lags.](image1)

![Fig. 3.— Power Spectral Densities constructed from RXTE-ASM, RXTE-PCA, and EUVE data (see text). Dashed lines show flat, $f^{-1}$, and $f^{-2}$ overlaid on the power spectra. The dotted line show our estimate of the noise level of the ASM data. All PSDs are normalized such that integrating over positive Fourier frequencies yields the root mean square variability, normalized to the mean, for each particular light curve.](image2)
FFT techniques. We did not subtract the expected noise level calculated from the ASM error bars, as the derived PSD does not flatten at this level. This indicates that either the ASM error bars are overestimated or that they do not follow gaussian statistics.

The derived PSD is approximately flat at low frequencies, shows a possible break at $\approx 7 \times 10^{-2}$ Hz ($\approx 200$ day period), and is consistent with an $f^{-1}$ dependence at higher frequencies. The extent to which the PSD remains flat at low frequencies is uncertain due to the limited time-span of the ASM observations compared to the putative 200 day break period. We note that Czerny, Schwarzenberg-Czerny, & Loska (1999) find a break in the optical power spectrum at a period $\leq 1000$ days. The slope of the ASM-PSD at high frequencies is also uncertain due to the large noise level (shown as a dotted line in Fig. 3). The rms amplitude of the ASM lightcurve, including noise, is $\approx 30\%$. A Lomb-Scargle periodogram yields comparable results, and also shows a formally significant (via the methods of Horne & Baliunas 1986) peak at a 200 day period. This peak is coincident with the break in the PSD, and furthermore the methods of Horne & Baliunas are only strictly valid for a single sinusoidal departure with the break in the PSD, and also shows a formally significant (via the methods of Horne & Baliunas 1986) peak at a 200 day period. This peak is coincident with the break in the PSD, and furthermore the methods of Horne & Baliunas are only strictly valid for a single sinusoidal period buried within pure counting noise.

The overall X-ray PSD is again remarkably similar in both shape and rms amplitude to those seen in the low/hard states of GBHCs. Low state GBHCs such as GX 339–4 (Nowak et al. 1999b) or Cyg X-1 (Belloni & Hasinger 1990a; Miyamoto et al. 1992; Nowak et al. 1999a) typically have an rms amplitude of 30–40%, a flat PSD at low frequency with a break into an $f^{-1}$ spectrum at 0.03–0.3 Hz, and a further break into an $f^{-2}$ spectrum at 1–10 Hz. The X-ray PSD we have found for NGC 5548 is comparable to this except scaled to approximately a factor of $10^6$ lower in frequency (although we do not resolve the break into the $f^{-3}$ spectrum). A similar result was found for the X-ray PSD of NGC 3516 (Edelson & Nandra 1999).

The factor of $10^6$ is comparable to the expected ratio of the X-ray power spectrum at a period $\approx 10^3$ Hz, and a further break into an $f^{-2}$ spectrum at $\approx 10^2$ Hz. The X-ray PSD we have found for NGC 5548 is comparable to this except scaled to approximately a factor of $10^6$ lower in frequency (although we do not resolve the break into the $f^{-3}$ spectrum). A similar result was found for the X-ray PSD of NGC 3516 (Edelson & Nandra 1999).
\[ \beta = 2.5 \] which approximates the expected emissivity in a variety of physical scenarios. The outer radius \( r_{\text{out}} \) is fixed at 1000\( r_g \), where \( r_g = GM/c^2 \) is the gravitational radius of the central black hole. For our chosen value of \( \beta \), the fits are insensitive to the value of \( r_{\text{out}} \) provided that \( r_{\text{out}} > 100r_g \). Although this is a more physical model, the RXTE-PCA data cannot distinguish it from the Gaussian line profile, i.e., there is no improvement in the goodness-of-fit in any of the datasets when the diskline profile is used. We do note, however, that both the broad Gaussian and the diskline fits are consistent with a substantial fraction of the iron emission originating from within \( \sim 20r_g \).

Our final models include the Compton reflection continuum which is implemented in XSPEC as the PEXRAV model (Magdziarz & Zdziarski 1995). We fix the e-folding energy of the underlying hard continuum at 120 keV as determined from fits by Magdziarz et al. (1998) to data from OSSE observations of NGC 5548, and we set the inclination of the planar cold reflector at 30°. We also fix the chemical abundances to be Solar. The relative normalization of this component, \( \mathcal{R}_c \), is left as a free parameter. For an isotropic primary X-ray source, \( \mathcal{R} = \Omega / 2\pi \), where \( \Omega \) is the solid angle subtended by the cold reflecting medium as seen by an observer situated at the X-ray source. This leads to a large improvement in the goodness-of-fit for all of the observations, showing that the Compton continuum (which produces the high-energy spectral hardening) is clearly detected.

### 5.2. Joint ASCA/RXTE spectral fitting

Four of our ASCA observations were scheduled to be contemporaneous with RXTE observations. Joint spectral fitting of simultaneous data from ASCA-SIS and RXTE-PCA can be a powerful technique — it allows us to utilize both the spectral resolution of ASCA and the broad-band sensitivity of RXTE. The results of the joint ASCA-SIS/RXTE-PCA fits for our seven intervals are listed in Table 6. To facilitate direct comparison, we show the fits to the RXTE-PCA data alone which include a broad Gaussian emission line. The addition of the ASCA data does not affect the model fits greatly, although in some cases it allows the iron line width to be resolved.

### 5.3. Observed correlations between spectral parameters

Here we use the results of our spectral fitting of the ASCA and RXTE data to examine spectral variability. In order to ensure that we have a set spectral parameters which have been uniformly analyzed, we consider only those parameters which have been obtained from fits to the RXTE data alone. Spectral parameters from the joint ASCA/RXTE fits yield similar results. Figure 4 shows the photon index \( \Gamma \), the iron line flux \( N_i \), the iron line equivalent width \( W_{\text{Fe}} \), and relative reflection normalization \( \mathcal{R} \) as a function of the 2–10 keV flux, \( F_{2-10} \), of the hard continuum component. For these plots and all of the fits to the spectral trends discussed in this section, we present uncertainties as 1–\( \sigma \) error bars.

#### 5.3.1. The photon index

There is a clear positive correlation between the photon index and the 2–10 keV flux (Fig. 4a). Fitting a simple linear form to this correlation gives

\[
\Gamma = (1.63 \pm 0.04) + (0.030 \pm 0.006) \left( \frac{F_{2-10}}{10^{-11} \text{ erg s}^{-1} \text{ cm}^{-2}} \right).
\]

This simple model does not strictly provide a formally adequate description of the spectral variation with flux, giving a goodness-of-fit of \( \chi^2/\text{dof} = 16.1/8 \). However, we note that most of the contribution to this large value of \( \chi^2 \) is due to the Aug 16–18 data point. Omitting this point, we find \( \chi^2/\text{dof} = 5.7/7 \) with the fit parameters being substantially unchanged. Nonetheless, the fact that the X-ray continuum gets softer when brighter is consistent with the trend observed in previous monitoring campaigns of this source (Magdziarz et al. 1998). However, here we appear to find a somewhat weaker dependence of spectral index on flux.

### 5.3.2. Iron line and reflection features

Correlations of the iron line strength with the continuum flux are of great importance. In the simple X-ray reflection scenario, we would expect \( W_{\text{Fe}} \) to be constant provided that the light crossing time of the fluorescing region is much smaller than the time scale on which spectral variability is being probed. If the light crossing time of the emission line region is much greater than the time scale being probed, a constant iron line flux, \( N_i \), would be expected. When these two time scales are comparable, reverberation effects come into play and both \( N_i \) and \( W_{\text{Fe}} \) will be seen to vary.

Like \( W_{\text{Fe}} \), the parameter \( \mathcal{R} \) should measure the amount of X-ray reflection relative to the direct continuum. Indeed, \( W_{\text{Fe}} \) should be proportional to \( \mathcal{R} \) provided the following conditions are satisfied:

1. The Compton reflection continuum is not starting to dominate the observed continuum at the iron line energies. In practice, this condition implies \( \mathcal{R} < 2–3 \).

2. The ionization state of the illuminated regions of the reflecting medium is fixed.

3. The primary continuum has a fixed energy spectrum. Of course, we have just shown that this is not strictly the case and that the photon index of the primary continuum emission changes by \( \Delta \Gamma \approx 0.2 \) during our campaign in a manner that is well correlated with the 2–10 keV flux. However, the Monte Carlo simulations of George & Fabian (1991) show that such small photon index changes only have a small (less than 10%) effect on the iron line equivalent width.

Apart from inclination dependences (which are usually weak) and ionization gradients, the geometry of either the reflecting medium or the X-ray source does not affect the expected proportionality of \( \mathcal{R} \) and \( W_{\text{Fe}} \).

Our spectral results hint at a more complex picture. Inspection of Fig. 4b shows that the iron line flux is essentially constant. This is borne out by the linear (dotted line) and constant (solid) models which we have fit and which describe these data very well. Apart from effects introduced by the subtle changes in photon index, this implies that \( W_{\text{Fe}} \) is inversely proportional to the flux (Fig. 4c). More formally, fitting the 10 data points in the \( W_{\text{Fe}} - F_{2-10} \) plot with a constant model results in \( \chi^2/\text{dof} = 20.8/9 \) (dotted curve), unacceptable at the 97% level. Assuming, instead, a power-law relationship between these two parameters such that \( W_{\text{Fe}} \propto F_{2-10}^{-\alpha} \) results in a dramatic improvement in the goodness-of-fit with \( \chi^2/\text{dof} = 7.9/8 \) and \( \alpha = 0.9 \pm 0.4 \) (solid curve in Fig. 4c). Thus, these results are consistent with a constant line flux and an equivalent width which is inversely proportional to the continuum flux.
Since the relative normalization of the Compton reflection continuum $R$ should be proportional to $W_{K\alpha}$ under a fairly general set of conditions, we would expect that $R \propto F_{2-10}^{-1}$. Fitting this relationship to the data depicted in Fig. 4c gives $\chi^2$/dof = 14.5/9 (dotted curve). This is formally inconsistent with the data at the 91% level. Using a more general power-law form $R \propto F_{2-10}^{-\alpha}$ leads to a vastly improved fit of $\chi^2$/dof = 3.4/8 with $\alpha = 0.14 \pm 0.60$ (solid curve). This is consistent with a constant relative reflection normalization and implies that $W_{K\alpha}$ and $R$ do not exhibit the proportionality which is normally expected. In order to examine this explicitly, we plot $W_{K\alpha}$ vs $R$ in Fig. 5. The dotted line is the linear relationship expected for a cold reflector with solar abundances for which $W_{K\alpha} = 150 \text{ eV}$ when $R = 1$ (George & Fabian 1991). This model yields $\chi^2$/dof = 73/10 and is definitely in conflict with the data. However, if we fit for the proportionality constant, we obtain $W_{K\alpha} = 259 \text{ eV}$ at $R = 1$ and $\chi^2$/dof = 14.4/9 which is still formally inconsistent with the data at the 89% level.

6. IMPLICATIONS FOR DISK/CORONA MODELS

If we assume that the EUVE light curve is representative of the seed photons for the higher energy X-rays, we can make a simple estimate of the size of the scattering region based upon the delays seen. With each scattering, a seed photon picks up a fractional energy

$$E = E_0 \left(1 + \frac{4k_bT}{m_e c^2}\right)^n,$$

where $E_0$ is the initial seed photon energy and $n$ is the number of scatterings (Rybicki & Lightman 1979). The time delay of this photon with respect to the seed photon source will be roughly proportional to the number of scatterings, $t \approx n\tau$. Here $\tau$ is the mean free path for Thomson scattering (or the size of the corona if it is optically thin). We take the effective photon energy in the 0.5–1 keV ASCA data to be
tween the fluxes in these bands is not possible. One possibility
width are substantially smaller than has been previously seen
above, both the reflection fraction and the iron line equivalent
properties of the corona must be changing.
continuum with increased flux (Fig. 4a) does in fact show that
the corona, changing some combination of the corona temper-
EUVE EUVE EUVE to be somewhat in conflict with models in which the spectral
3 the disk could extend beneath the corona but may be
corona. A constant iron line flux would suggest that a sub-
stantial portion of that emission is produced very far from the
Comptonizing X-ray source, perhaps in the outer disk or ob-
scuring torus, so that the line emission does not vary on time
scales as short as that of the underlying continuum. We would
then expect that the reflection hump is likewise produced in this
same distant material so that its absolute normalization should
also be constant. Unfortunately, there is the additional com-
plexity that the Gaussian and diskline fits to the fluorescent
iron line indicate that the line is broad and redshifted. The line
shapes are consistent with a significant fraction of this emission
originating from an accretion disk within \( \sim 20 r_g \). Furthermore,
spectral fits to the ASCA-SIS data which include a narrow line
at 6.4 keV along with the diskline model yield a narrow com-
ponent that can contribute only about 15% to the total line flux.
Therefore, based on the spectral shapes of the iron line, a sig-
nificant amount of reprocessing by distant cold material is un-
likely.

Wherever the cold reprocessor is located, these results appear
to be somewhat in conflict with models in which the spectral
variability of the underlying continuum is linked to the relative
reflection normalization \( \mathcal{R} \) (Magdziarz et al. 1998; Zdziarski
et al. 1999). In Fig. 6, we plot the relative Compton reflection
normalization versus the photon spectral index of the under-
lying power-law (filled squares, solid contours). As we note
above, these data are formally consistent with a constant value
of \( \mathcal{R} \), but there does seem to be a slight linear trend in the same
sense predicted by the models. For direct comparison, we also
plot in Fig. 6 the spectral parameters found by Zdziarski et al.
(1999; see also Magdziarz et al. 1998) which are derived from
Ginga observations. In this figure, we show the 1–\( \sigma \) error con-
tours for both sets of data. The spectral parameters we find
appear to occupy a different region of the \( \mathcal{R}-\Gamma \) plane than that
found by these previous observations. However, consideration
of systematic uncertainties may alter this conclusion. Ginga-
LAC observations of the Crab have yielded a photon index of
\( \Gamma \sim 2.08 \pm 0.03 \) (Turner et al. 1989) which agrees with early
rocket measurements by Toor & Seward (1974). In contrast,
power-law fits to RXTE-PCA observations of the Crab yield a
significantly softer index of \( \Gamma \sim 2.187 \) (Wilms et al. 1999). If
this difference of \( \Delta \Gamma \sim 0.1 \) is due to a systematic shift in mea-
sured power-law spectral index, then one may be tempted to
shift each of our values of \( \Gamma \) downward by this amount, making

\[
E_e = 0.78 \text{ keV and the effective photon energy of the } 2-20 \text{ keV}
\text{RXTE-PCA data to be } E_{\text{eff}} = 5.4 \text{ keV. Both of these energies}
\text{are determined using the instrument sensitivities in the relevant}
\text{bands and assuming a photon spectral index of 1.9 and a neutral
absorbing column of } 1.7 \times 10^{20} \text{ cm}^{-2} \text{. Using a value of}
k_0T \sim 50 \text{ keV which is found from fits to the OSSE spectrum of}
\text{NGC 5548 (Magdziarz et al. 1998) and the inferred lags of the}
\text{RXTE-PCA and 0.5-1 keV ASCA-SIS light curves relative to that of}
\text{the EUVE, we solve for the characteristic time between}
\text{scatterings and find } t_0 \sim 3.8 \text{ ksec. For a homogeneous corona
with Thomson depth of } \tau \sim 2 \text{ this implies a coronal size scale
of } \sim 2 \times 10^{14} \text{ cm, which is of order } 10 r_g \text{ for a } 10^6 M_\odot\text{ black
hole.}

This interpretation for the relationship between the EUV
and higher energy X-ray flux is not without its complications. First
of all, as we note above, the fractional size of the step in the EUV
is larger than the steps in the higher energy bands. Second,
the amplitude of the EUVE PSD differs from that of the
RXTE-PCA (Fig. 3). Therefore a strictly linear relationship be-
tween the fluxes in these bands is not possible. One possibility
is that the EUVE observations are sampling the Wien tail of a
black-body spectrum so that the observed variations are more
pronounced and are not necessarily characteristic of the bulk
of the seed photons. A more provocative explanation would be
that the increase in soft photon flux produces excess cooling in the
corona, changing some combination of the corona temper-

4 One can also use the direct lag measured between the ASCA-SIS and RXTE-PCA light curves of 5 ks. From that lag, one finds \( t_0 \sim 0.9 \text{ ks.} \)
Also implies a bias in the fitted value of $\alpha_0$. This sort of uncertainty can only be resolved by more sophisticated techniques.

For sufficiently high values of the compactness $\epsilon$, the spectrum will soften and the break will move to lower energies. Hence, any systematic shift of $\alpha_0$ should be made consistent even if one considers the possible systematic errors.

In addition, as the compactness increases, the spectrum will soften and the break will move to lower energies. Hence, any systematic shift of $\alpha_0$ should be made consistent even if one considers the possible systematic errors.

As a final caveat, we note that the strength of the reflection component can be masked by features in the hard continuum which need not be well-represented by a power-law. Stern et al. (1995) point out that for Comptonizing regions, the resulting hard continuum will have spectral breaks just above the peak energies of the twice scattered photons (see also Haardt 1993). For sufficiently high values of the compactness $\epsilon$, the spectrum will soften and the break will move to lower energies. Hence, any systematic shift of $\alpha_0$ should be made consistent even if one considers the possible systematic errors.

The last point, while not definitively constrained by the data, may pose a serious challenge for models of reflection by cold material and will only be resolvable with further detailed temporal and spectral observations. More sensitive studies with future instruments such as XMM would be extremely useful to verify this result.

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7. SUMMARY AND CONCLUSIONS

Here we summarize the main results of this work:

1. The EUV leads the harder X-rays, rejecting scenarios in which the soft X-ray component is produced by reprocessing of harder X-rays. In this respect, these hard X-ray lags are reminiscent of the X-ray lags seen in NGC 7469 (Nandra et al. 1998).

2. However, in contrast to NGC 7469, the shorter lags we find for NGC 5548 are consistent with Compton diffusion time scales for a relatively small corona of size $\sim 10^{14}$ cm.

3. The power spectrum of the X-ray variability shows a break at $\sim 200$ day time scales. The PSD is similar to that seen in NGC 3516; and if one assumes a $10^8 M_\odot$ black hole for NGC 5548, these scales appropriately with mass compared to PSDs seen for the low/hard states of GBHCs such as Cyg X-1 or GX 339–4.

4. The iron line equivalent width and relative reflection normalizations are smaller than those which are typically observed for type 1 Seyferts.

5. The broad, redshifted iron line profiles, the variability of the iron line equivalent width, and the apparent constancy of the relative reflection normalization are difficult to reconcile in the context of simple reflection models.

The FIG. 6. The relative Compton reflection normalization $R$ versus photon spectral index $\Gamma$ for our fits to the RXTE-PCA data (filled squares, solid error contours) and for fits to Ginga data as presented in Zdziarski et al. (1999; unfilled squares, dotted contours). Although the RXTE-PCA parameters are formally consistent with a constant value of $R$, a linear trend may be present. However, the dependence on $\Gamma$ found for these data is weaker that that found by Zdziarski et al. (1999), and these parameters appear to occupy a different part of the $R-\Gamma$ plane. One-sigma contours are shown.

...
REFERENCES

<table>
<thead>
<tr>
<th>Obs. Date</th>
<th>Exp. time (ks)</th>
<th>mean count rate (10^{-2} cps)</th>
<th>Spectral Density at 76Å (Jy)</th>
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<tr>
<td>02 Jun</td>
<td>8.8</td>
<td>18.0 ± 0.6</td>
<td>345</td>
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<tr>
<td>09 Jun</td>
<td>11.5</td>
<td>8.4 ± 0.4</td>
<td>161</td>
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<tr>
<td>2 18 Jun</td>
<td>139.8</td>
<td>9.3 ± 0.1</td>
<td>178</td>
</tr>
<tr>
<td>3 01 Jul</td>
<td>21.3</td>
<td>2.1 ± 0.2</td>
<td>40</td>
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TABLE 1
EUVE-DS OBSERVATIONS

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<tr>
<th>Obs. Date</th>
<th>good SIS exp. time (ks)</th>
<th>good GIS exp. time (ks)</th>
<th>SIS0 count rate (cps)</th>
<th>GIS2 count rate (cps)</th>
<th>2–10 keV flux (10^{-11} erg cm^{-2} s^{-1})</th>
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<tbody>
<tr>
<td>13 Jun 1998</td>
<td>21.2</td>
<td>23.3</td>
<td>2.61</td>
<td>1.56</td>
<td>5.9</td>
</tr>
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<td>20 Jun 1998</td>
<td>111.1</td>
<td>106.3</td>
<td>3.07</td>
<td>1.71</td>
<td>6.9</td>
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<tr>
<td>01 Jul 1998</td>
<td>9.2</td>
<td>10.6</td>
<td>1.66</td>
<td>0.97</td>
<td>4.2</td>
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<tr>
<td>07 Jul 1998</td>
<td>14.7</td>
<td>16.9</td>
<td>1.73</td>
<td>1.08</td>
<td>4.3</td>
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<tr>
<td>19 Jan 1999</td>
<td>8.2</td>
<td>9.0</td>
<td>1.84</td>
<td>1.09</td>
<td>4.7</td>
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TABLE 2
BASIC PARAMETERS OF OUR ASCA OBSERVATIONS OF NGC 5548. THE QUOTED FLUXES ARE THOSE OBSERVED (I.E. SUBJECT TO THE TOTAL LINE-OF-SIGHT ABSORPTION). A SIMPLE POWER-LAW MODEL WAS USED TO MEASURE THESE FLUXES.

<table>
<thead>
<tr>
<th>Obs. Date(s)</th>
<th>target</th>
<th>Good Time (ks)</th>
<th>PCA/PCUs 0–2 rate (cps)</th>
<th>HEXTE rate (cps)</th>
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</thead>
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<td>25.9</td>
<td>1.0</td>
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<td>8.82</td>
<td>4.8</td>
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<td>Jun 19–24</td>
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<td>110.28</td>
<td>28.7</td>
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<td>Jul 7</td>
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<td>19.3</td>
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<tr>
<td>Aug 16–18</td>
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TABLE 3
RXTE OBSERVATIONS

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<th>Instruments</th>
<th>$t_{\text{lag}}$ (ks)</th>
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<td>EUVE vs ASCA</td>
<td>13.1</td>
<td>29.5</td>
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<td>ASCA vs RXTE PCA</td>
<td>5.0</td>
<td>8.0</td>
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TABLE 4
LAGS OBTAINED USING THE ZDCF FOR THE THREE PAIR-WISE COMBINATIONS OF INSTRUMENTS DURING THE 18–23 JUNE 1998 OBSERVATION PERIOD.

<table>
<thead>
<tr>
<th>Obs.</th>
<th>PCA/PCUs 0–2 rate (cps)</th>
<th>$F$</th>
<th>$A$ (10^{-3})</th>
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<tbody>
<tr>
<td>1</td>
<td>4.8 ± 0.2</td>
<td>2.3 ± 0.1</td>
<td>9.8(−1.3/ +3.8)</td>
</tr>
<tr>
<td>2a</td>
<td>3.9 ± 0.3</td>
<td>2.4 ± 0.2</td>
<td>11.6(−2.8/ +3.8)</td>
</tr>
<tr>
<td>2b</td>
<td>4.8 ± 0.3</td>
<td>2.2 ± 0.2</td>
<td>8.8(−2.1/ +2.8)</td>
</tr>
<tr>
<td>3a</td>
<td>5.4 ± 0.2</td>
<td>2.3 ± 0.1</td>
<td>11.1(−2.0/ +2.4)</td>
</tr>
<tr>
<td>3b</td>
<td>4.9 ± 0.2</td>
<td>2.2 ± 0.1</td>
<td>9.3(−1.6/ +2.0)</td>
</tr>
<tr>
<td>4</td>
<td>4.2 ± 0.3</td>
<td>2.3 ± 0.1</td>
<td>11.6(−2.3/ +2.9)</td>
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<tr>
<td>Aug 16–18</td>
<td>7.3 ± 0.2</td>
<td>2.1 ± 0.1</td>
<td>10.8(−1.0/ +1.0)</td>
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TABLE 5
PROPERTIES OF 1E 1415.6+2557.
### Table 6

The parameters obtained from spectral fits to the RXTE and ASCA data. The spectral models consist of Galactic absorption, a fluorescent iron emission line, an underlying cut-off power-law and a Compton reflection component. For fits in the upper part of the table, a broad Gaussian function is used to model the iron line; in the lower part, a diskline model is used. For the joint ASCA-SIS/RXTE PCA fits, we report separate spectral indices for the underlying power-law for SIS and PCA. The 2–10 keV continuum flux is reported for the PCA fits only and is in units of $10^{-14}$ ergs cm$^{-2}$ s$^{-1}$. The iron line flux, $N_{\text{Fe}}$, is in units of $10^{-3}$ ergs cm$^{-2}$ s$^{-1}$, and the inner radius of the diskline model, $r_{\text{disk}}$, is in units of $r_{g} = GM/c^{2}$.

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<tr>
<th>Obs.</th>
<th>$F_{2-10}$</th>
<th>SIS</th>
<th>PCA</th>
<th>$\mathcal{R}$</th>
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<td></td>
<td></td>
<td>1.86 ± 0.03</td>
<td>1.86 ± 0.03</td>
<td>0.34 ± 0.03</td>
<td>6.15 ± 0.11</td>
<td>&lt; 0.41</td>
</tr>
<tr>
<td>1</td>
<td>8.0</td>
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<td>34.50 ± 0.10</td>
<td>6.15 ± 0.11</td>
<td>&lt; 0.41</td>
<td>8.1 ± 0.7</td>
</tr>
<tr>
<td>7.9</td>
<td>1.89 ± 0.03</td>
<td>1.86 ± 0.03</td>
<td>1.86 ± 0.03</td>
<td>0.34 ± 0.03</td>
<td>6.15 ± 0.11</td>
<td>&lt; 0.41</td>
</tr>
<tr>
<td>2.1</td>
<td>7.8</td>
<td>...</td>
<td>34.50 ± 0.10</td>
<td>6.15 ± 0.11</td>
<td>&lt; 0.41</td>
<td>8.1 ± 0.7</td>
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<tr>
<td>2.2</td>
<td>9.8</td>
<td>...</td>
<td>34.50 ± 0.10</td>
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<td>&lt; 0.41</td>
<td>8.1 ± 0.7</td>
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<td>9.7</td>
<td>1.94 ± 0.03</td>
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