Chandra and RXTE spectroscopy of the Galactic microquasar 
XTE J1550−564 in outburst

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ABSTRACT
On two occasions, we obtained nearly simultaneous ≃4 ks snapshot observations of the Galactic black hole and microquasar XTE J1550−564 with Chandra and RXTE near the peak of its 2000 May outburst. The low-energy sensitivity of Chandra and the resolution of the High Energy Transmission Grating Spectrometer (HETGS), coupled with the broad energy range and large collecting area of RXTE, have allowed us to place constraints on the outburst accretion flow geometry of this source in the ‘intermediate’ X-ray state. The 0.65–25.0 keV continuum spectra are well described by a relatively hot (kT ≃ 0.8 keV) accretion disc and hard (Γ ≃ 2.3) coronal power-law components. Broad, relatively strong Fe Kα emission line (WKα ≃ 170 eV) and smeared absorption edge components consistent with FeXXV are strongly required in joint spectral fits. The resolution of the Chandra/HETGS reveals that the broad Fe Kα emission lines seen clearly in the individual RXTE spectra are not the result of an intrinsically narrow line.

Key words: accretion, accretion discs – black hole physics – line: profiles – relativity – X-rays: bursts – X-rays: stars.

1 INTRODUCTION
XTE J1550−564 is a transient Galactic black hole. At the time of writing, four outbursts – each separated by clear quiescent periods – have been observed from this source. Radio observations during its 1998–1999 outburst revealed optically thick emission, with apparent superluminal motion (vjet > 2c) (Hannikainen et al. 2000). As a result, XTE J1550−564 was further classified as a ‘microquasar’. Recently, Orosz et al. (2002) have constrained the mass of the black hole primary in this system through optical observations of the source in quiescence (9.86 < MBH < 11.58MJ).

The accretion flow geometry of Galactic black holes in outburst may change considerably with the mass accretion rate (ṁ), which is often assumed to be traced directly by the soft X-ray luminosity (see, however, Homan et al. 2001). In transient outbursts, the soft X-ray luminosity may suddenly rise, and decay over a period ranging between days and months; from quiescence to the outburst peak, the luminosity may increase by a factor of 106 or more. In all such systems, periods of characteristic X-ray timing and spectral behaviours and correlated multiwavelength properties are observed that are known as ‘states’ (for reviews, see Tanaka & Lewin 1995; Belloni 2001; Done 2002; for a critical discussion see Homan et al. 2001). The existence of states probably indicates that only certain accretion modes and geometries are allowed in Galactic black hole systems.

At luminosities below LX ∼ 1034–35 erg s−1, the geometry is particularly uncertain; the accretion disc may be recessed to Rin ≃ 102–4Rg, where Rg = GMBH/c2 (see, e.g., Esin, McClintock & Narayan 1997; for a competing description see Ross, Fabian & Young 1999). In contrast, near peak outburst luminosity (LX ∼ 1037–38 erg s−1) there is general agreement that the accretion disc...
may extend to the marginally stable circular orbit. In such cases, the disc may serve as a probe of the general relativistic regime around the black hole.

This regime can be explored through continuum spectroscopy (e.g. through the multicolour disc blackbody model, Mitsuda et al. 1984), studies of high-frequency quasi-periodic oscillations (QPOs) in the X-ray light curve (probably associated with the Keplerian frequency at the marginally stable circular orbit), and through studies of Fe Kα line profiles and X-ray reflection spectra (Fabian et al. 1989; George & Fabian 1991; Ross et al. 1999; Miller et al. 2002a). XTE J1550−564 and GRO J1655−40 are the only two dynamically constrained Galactic black holes for which each of these tools has revealed evidence of an accretion disc at the marginally stable orbit, and perhaps evidence of black hole spin (Sobczak et al. 1999, 2000; Homan, Wijnands & van der Klis 1999; Remillard et al. 1999; Strohmayer et al. 2000). We obtained two nearly simultaneous observations of XTE J1550−564 with Chandra and RXTE near the peak of its 2001 May outburst, at source luminosities of \( L_X \approx 1.5 \times 10^{38} \text{ erg s}^{-1} \) and \( L_X \approx 1.0 \times 10^{38} \text{ erg s}^{-1} \) for \( d = 5.3 \text{ kpc} \) (Orosz et al. 2002). Our short \( \approx 4 \text{ ks} \) observations with Chandra were designed for a much brighter source; the sensitivity achieved does not permit detailed studies of the Fe Kα line region. However, we are able to confirm that broad Fe Kα emission lines in the RXTE spectra are not caused by an intrinsically narrow line.

2 OUTBURST HISTORY AND OBSERVATION

XTE J1550−564 was discovered on 1998 September 7 (Smith 1998), by the All Sky Monitor (ASM) aboard the Rossi X-ray Timing Explorer (RXTE). A radio (Campbell-Wilson et al. 1998) and optical counterpart (Orosz, Bailyn & Jain 1998) was quickly identified. The ensuing outburst lasted until 1999 June, and displayed some of the most remarkable behaviour yet seen in an X-ray nova, e.g. an initial flare that reached a flux level equivalent to 6.8 Crab (1.5−12 keV, RXTE/ASM), very rapid state transitions and strong (7 per cent rms) QPOs at frequencies as high as 285 Hz (Sobczak et al. 2000; Homan et al. 2001). On 2000 April 2, new source activity was noticed by the RXTE ASM (Smith et al. 2000). XTE J1550−564 was active in X-rays for nearly 70 d thereafter, and reached a peak flux of \( \sim 1 \text{ Crab} \) (ASM, 1.5−12 keV); it was also seen out to 300 keV with BATSE aboard CGRO, and simultaneously in optical bands (Maselli & Soria 2000; Jain & Bailyn 2000). Spectrally inverted radio emission, probably from a compact jet, is detected in the low/hard state, and a possible discrete ejection event at the low/hard–intermediate-state transition (Corbel et al. 2001). The ASM light curve and (5–12 keV)/(3–5 keV) hardness ratio of this outburst is shown in Fig. 1. The light curve of the first outburst of XTE J1550−564 departed radically from a typical profile (Homan et al. 2001), but the second outburst is more similar to a fast-rise exponential-decay (or ‘FRED’) envelope.

Near the peak of this outburst, Miller et al. (2001a) report simultaneous high-frequency QPOs at 188 and 276 Hz. These QPOs appear in an approximate 2:3 ratio similar to the 300- and 450-Hz QPOs found in observations of GRO J1655−40 (Strohmayer et al. 2001). If these QPOs are tied to the Keplerian frequency at the marginally stable circular orbit, they provide evidence for black hole spin. Tomsick, Corbel & Kaaret (2001a) and Kalemci et al. (2001) discuss the spectral and timing properties, respectively, of the declining phase of this outburst.

On 2001 January 28, RXTE found XTE J1550−564 to be in the low/hard state, with a timing noise of 40 per cent rms and a spectrum well described by a power law with \( \Gamma = 1.52 \) (Tomsick et al. 2001b). On 2002 January 10, RXTE again found XTE J1550−564 to be in the low/hard state. Belloni et al. (2002) report that the timing and spectral properties are typical of the low/hard state in this short outburst.

The second outburst of XTE J1550−564 met the trigger criteria for our approved Chandra AO-1 target of opportunity (TOO) programme, and our RXTE AO-5 TOO programme. In all, we made seven observations of XTE J1550−564 with Chandra (18 observations with RXTE). Of these, here we report on the first two observations only (see Table 1), when the source was brightest. Of the remaining Chandra observations, in two cases the HETGS failed to insert, and in two other cases the source intensity was too faint.
for our graded, continuous-clocking observational mode to yield good spectra, but the source was clearly detected (for a good discussion of the continuous clocking mode, see Marshall et al. 2001). Imaging data from a final observation will be presented in a separate work.

3 DATA REDUCTION

3.1 RXTE modes and selections

The RXTE data we report here were obtained through pointed observations of the proportional counter array (PCA), which consists of five individual proportional counter units (PCUs). Owing to gain uncertainties in PCU-0 following the loss of its propane layer, we exclude data from this detector. With this exception, we include data from all layers of all active detectors (see Table 1; for observation R1 this includes PCUs 2–4; for observation R2 this includes PCUs 1–4). The data were reduced using the lheasoft suite (version 5.1). We apply the standard ‘goodtime’ and detector ‘deadtime’ corrections. The background was calculated using the ‘bright source’ model within lheasoft. Response matrices were made using the tool ‘pcarsp’.

At the resolution of the PCA, the spectrum of the Crab nebula is known to be a simple power law. We fit a spectrum from the Crab obtained on 2000 May 14 (as close to our observations as possible), with a power-law index of 1.8 (Knight 1982) and a column density of 3.2 × 10^{21} cm⁻² (Massaro et al. 2000). Below 3 keV, residuals are very large, and so we fix 3 keV as our lower-fitting bound. Similarly, above 25 keV, residuals in fits to the Crab are large, and our data from XTE J1550–564 becomes dominated by the background flux, so we adopt this energy as an upper-fitting bound. As we wish to address the iron line region in XTE J1550–564, we consider residuals as a function of energy in power law fits to this Crab observation. We find that with the addition of 0.4 per cent systematic errors in the 3–8 keV band, and 0.8 per cent systematic errors in the 8–25 keV band, the reduced χ² fitting statistic drops to 1.0 (similar results were obtained by Tomsick et al. 2001a). Therefore, we add this energy-dependent systematic error to our PCA data from XTE J1550–564.

3.2 Chandra modes and selections

XTE J1550–564 was observed with the Chandra HETGS using the ACIS-S charge-coupled device (CCD) array operating in continuous clocking (CC) mode. Because XTE J1550–564 had flared to 6.8 Crab (1.5–12 keV) during its 1998 outburst, avoiding damage to the ACIS array was a paramount concern. To this end, we employed a large dither (20-arcsec amplitude) to spread the most intense parts of the zeroth order over many pixels. Furthermore, the zeroth-order aim point was shifted toward the top of the chip via a SIM-Z translation of +10.0 mm from the nominal S3 aim point. A +1.33 arcmin Y-offset was used to place the iron Kα region of the HEG −1 order on ACIS-S3. Finally, we blocked out rows 367–467, eliminating any read out of zeroth-order photons. This blocking acted to limit any telemetry saturation that would result from the zeroth-order counts. The CC mode was employed to limit pile-up of the dispersed spectrum and to achieve 3-ms time resolution.

As our observing mode is non-standard, the data are not well suited to reduction via the tools available in the CIAO suite. We have managed to build robust, custom software to reduce and analyse our data. We first correct for bad aspect times (e.g. slewing, see Table 1). The events are then examined in projected chip x space to correct for ‘hot’ pixels that report erroneously large event numbers (a list of bad pixels is available through CIAO). ACIS-S4 sometimes produces ‘streaks’ which appear in the ACIS chip image (see http://asc.harvard.edu); the events were removed using a 50-column median filter, rejecting deviations greater than 3σ. The spacecraft dither pattern is removed by calculating the mean chip x position as a function of time, which is a sine wave. We are able to interpolate the dither-corrected chip x position of each event by removing this sine wave. With the dither removed, it is possible to calculate the wavelength corresponding to each chip x value via the grating equation. A linear gain correction is performed on each of the four independent readout and amplifier modes on each ACIS-S chip. Finally, we extract first-order MEG and HEG events and background regions, and apply the appropriate response matrices.

Indeed, although we have blocked out the zeroth-order photons, we are able to accurately locate the position of the zeroth order, and therefore are able to convert accurately from chip x space to wavelength or energy space via the grating equation. To do this, we make use of the fact that the ACIS chips are silicon-based, and that silicon has an absorption edge at 1.8395 keV. For an assumed zeroth-order position, then, we can examine the location of this edge in the HEG +1 and HEG −1 spectra (which are on opposite sides of the zeroth-order position) and iterate the assumed zeroth-order position until the edge is seen at the same energy in both (see Fig. 2).

As per Marshall et al. (2001), we perform an effective area correction, and add 5 per cent systematic errors to the dispersed spectra. Owing to the fact that our Chandra observations were offset towards the top of the ACIS-S array, less of the HEG −1 and MEG +1 orders were read out in comparison to the HEG +1 and MEG −1 orders. Moreover, with the spacecraft dither, the portions of the HEG −1 and MEG +1 spectra dispersed far from the zeroth order were moved on to and off the ACIS-S array. This is reflected in the spectra we obtained from the truncated orders, which show significant deviations from the shape expected based on the spectra obtained with RXTE. Therefore, we only consider the HEG +1 and MEG −1 spectra from our Chandra observations.

Even after rebinning by a factor of 10, flux bins below 0.65 keV in the MEG −1 spectrum are consistent with zero. The HEG +1 spectrum suffers from low effective area below 1.0 keV, displaying a

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Table 1. Observation log. These observations were made shortly after the outburst maximum, during the ‘intermediate’ X-ray state. ‘Good time’ is the non-slewing observation time. C1 and C2 are the Chandra observations, R1 and R2 are the RXTE observations.

| No | Obs. ID | Date (UT) | Start time | Day (year 2000) | Expt (s) | Good time (s) |
|----|--------|-----------|------------|----------------|---------|---------------|
| C1 | 680    | 05/03/00  | 21:10:40   | 122.9          | 3380    | 2670          |
| C2 | 681    | 05/06/00  | 12:54:09   | 125.5          | 3770    | 2170          |
| R1 | 50134-02-04-00 | 05/03/00 | 16:33:20 | 122.7          | 4860    | 4860          |
| R2 | 50134-02-06-00 | 05/06/00 | 12:50:08 | 125.5          | 3960    | 3960          |

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Figure 2. The count spectrum of XTE J1550–564 near the instrumental silicon absorption edge. The dashed line is the laboratory edge energy (1.8395 keV). The dotted line is the edge minimum, which we can align to within the instrumental resolution. This provides an effective means of establishing the zeroth-order position, and therefore energy as a function of position on the ACIS-S array. This is necessary as we blocked the zeroth-order photons with a spatial window to prevent telemetry saturation.

flux trend inconsistent with the MEG −1 spectrum. These energies serve as lower-fitting bounds. We exclude data from regions near gaps in the ACIS-S CCD array. In the MEG −1 spectrum we exclude the 0.74–0.80 keV band. There is another gap between 2.2–3.0 keV in this grating order, and at higher energies the effective area of the HEG is higher. We therefore adopt 2 keV as an upper-fitting bound for the MEG −1 order. We exclude the 1.3–1.4 and 3.2–4.2 keV bands in the HEG +1 spectrum, and set 10.0 keV as an upper-fitting bound (this is the effective upper energy limit of the HEG).

4 ANALYSIS AND RESULTS

The reduced spectra were analysed using XSPEC version 11.1.0 (Arnaud 1996). All errors quoted in this paper reflect the difference between the best-fitting value, and the value of the parameter at its 90 per cent confidence limits.

We fit the spectra from the Chandra/HETGS and the RXTE/PCA spectra simultaneously; spectra R1 and C1 are nearly simultaneous, and spectra R2 and C2 are simultaneous (see Table 1). Joint fits are desirable to characterize the continuum emission, as the range of the Chandra/HETGS is well suited to measuring the soft spectral component expected from an accretion disc, and the RXTE/PCA range is well suited to constraining the hard power-law spectral component.

Fits with a model consisting of interstellar absorption (‘phabs’ in XSPEC), a multicolour disc (MCD) blackbody component (Mitsuda et al. 1984), and a power-law component did not yield acceptable fits ($\chi^2/\nu > 5$). Fits with Comptonization models such as ‘COMPTT’ (Titarchuk 1994) and the ‘bulk motion Comptonization’ model (Shrader & Titarchuk 1999) gave slightly worse fits. This is principally caused by strong residuals in the Fe Kα region. We therefore add a broad Gaussian line and smeared edge (‘smedge’ within XSPEC; Ebisawa et al. 1994). This is the same model used by Sobczak et al. (2000) in fits to the 1998–1999 outburst of XTE J1550–564, and to be consistent with this prior work we fix the width of the edge to 7.0 keV, and the width (FWHM) of the line to 1.2 keV. The addition of a relatively neutral line plus edge combination ($E_{\text{line}} = 6.40, E_{\text{edge}} = 7.1$ keV) does improve the fit considerably ($\chi^2/\nu \approx 3$), but this is not an acceptable fit. When the Gaussian and smeared edge energies are allowed to float, values consistent with helium-like Fe XXV ($E_{\text{line}} = 6.68$, $E_{\text{edge}} = 8.83$ keV) are preferred statistically. We fix these values in our final model, and acceptable fits are achieved: $\chi^2/\nu = 0.996$ (R1+C1), $\chi^2/\nu = 1.017$ (R2+C2).

Table 2. The results of fitting the RXTE/PCA and Chandra/HETGS spectra (rebinned by a factor of 10) jointly. There are 334 bins and 321 degrees of freedom for each joint fit. The model consists of photoelectric absorption, a multicolour disc blackbody component, and a power-law component, and a broad Gaussian plus smeared edge (‘smedge’) in the iron Kα region. The Gaussian and smeared edge energies are fixed at 6.68 and 8.83 keV, respectively, corresponding to Fe XXV. Neutral Fe features and spectral models without a broad line and edge give significantly worse fits to the data.

| Obs.       | $N_{\text{H}}$ (10$^21$ cm$^{-2}$) | $kT_{\text{MCD}}$ (keV) | $N_{\text{MCD}}$ | $\Gamma_{\text{pl}}$ | $N_{\text{pl}}$ | $N_{\text{line}}$ (10$^{-3}$) | EW$_{\text{line}}$ (eV) | $\tau_{\text{edge}}$ | red. $\chi^2$ |
|------------|---------------------------------|--------------------------|------------------|----------------------|----------------|-------------------------------|------------------------|---------------------|-----------------|
| R1+C1      | 8.0$^{+0.4}_{-0.3}$             | 0.790$^{+0.008}_{-0.008}$ | 2100$^{+100}_{-100}$ | 2.36$^{+0.01}_{-0.01}$ | 2.38$^{+0.07}_{-0.07}$ | 5.7$^{+0.7}_{-0.7}$ | 160$^{+20}_{-20}$ | 1.34$^{+0.06}_{-0.07}$ | 0.996 |
| [3pt] R2+C2| 8.0$^{+0.4}_{-0.3}$             | 0.753$^{+0.007}_{-0.008}$ | 3200$^{+200}_{-200}$ | 2.32$^{+0.01}_{-0.01}$ | 2.90$^{+0.07}_{-0.08}$ | 7.7$^{+0.7}_{-0.9}$ | 180$^{+20}_{-20}$ | 1.39$^{+0.06}_{-0.05}$ | 1.017 |
respectively. We measure power-law indices of $2.36 \pm 0.01$ and $2.32 \pm 0.01$, respectively. The unabsorbed fluxes measured via our model are listed in Table 3; in the energy range we consider the disc flux to be approximately 60 per cent of the total. These spectral results are consistent with the XTE J1550–564 being in the intermediate state at the time of our observations (this is confirmed by X-ray timing results, see Miller et al. 2001a). The broad Fe Kα emission line is relatively strong and highly significant; we measure equivalent widths of $160 \pm 20$ and $180 \pm 20$ eV, respectively. We measure the optical depth of the smeared edge to be $1.34 \pm 0.07$ and $1.39 \pm 0.06$, respectively.

For a known source distance and inclination, the MCD model gives a measure of the inner disc radius via the model normalization. Assuming the mean values for the black hole mass ($M_{\text{BH}} \approx 10.7 M_\odot$), system inclination ($i \approx 73.1^\circ$), and distance ($d \approx 5.3$ kpc) reported by Orosz et al. (2002), we measure inner disc radii of $\approx 45$ and $\approx 56$ km (corresponding to $R_{\text{in}} \approx 2.8 R_g$ and $3.5 R_g$, respectively). As these values are within the marginally stable circular orbit ($R_{\text{in}} = 6R_g$) for a non-spinning (Schwarzschild) black hole, they may imply a black hole with significant angular momentum in XTE J1550–564.

### 4.1 Testing for narrow features

To further examine whether or not a single emission line might merely be smeared by the PCA response to produce the broad Fe Kα line required in joint fits, we calculated the 95 per cent confidence upper limits on the strength of single-bin emission lines in the Chandra/HETGS spectra (see Fig. 4). Owing to Auger

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| Obs. | Range (keV) | Total (10^{-8} cgs) | MCD (10^{-8} cgs) | Power law (10^{-8} cgs) | Line (10^{-11} cgs) |
|------|------------|---------------------|------------------|------------------------|-------------------|
| R1+C1 | 0.5–10.0   | 2.4^{+0.2}_{-0.1}   | 1.5^{+0.1}_{-0.1} | 0.9^{+0.02}_{-0.03}    | 6.1^{+0.7}_{-0.7} |
| R1+C1 | 0.65–25.0  | 2.3^{+0.1}_{-0.1}   | 1.4^{+0.1}_{-0.1} | 0.89^{+0.02}_{-0.03}   | 6.1^{+0.7}_{-0.7} |
| R2+C2 | 0.5–10.0   | 3.0^{+0.2}_{-0.1}   | 1.9^{+0.1}_{-0.1} | 1.12^{+0.02}_{-0.03}   | 8.3^{+0.8}_{-0.8} |
| R2+C2 | 0.65–25.0  | 2.9^{+0.1}_{-0.2}   | 1.7^{+0.1}_{-0.1} | 1.12^{+0.03}_{-0.04}   | 8.3^{+0.8}_{-0.8} |
destruction, intermediate Fe ion species are not likely to be observed; relatively few narrow Fe Kα lines (e.g. Fe I, XXV, XXVI at 6.40, 6.68 and 6.97 keV, respectively) are expected. It is clear that the upper limits on line features at these energies are a fraction of the \(\simeq 170\) eV equivalent width of the broad lines required in joint fits. The spectra we obtained are of too coarse a sensitivity to detect narrow emission or absorption features such as those found in the high/soft state of XTE J1650–500 (Miller et al. 2002b).

5 DISCUSSION

We have analysed spectra from two nearly simultaneous *Chandra* HETGS and *RXTE* observations of the Galactic microquasar XTE J1550–564. We jointly fit the 0.65–25.0 keV spectra with a continuum model consisting of two components: a multicolour disc blackbody (probably from an accretion disc) and a power law (probably from a corona). This simple model described the data better than Comptonization models. The data strongly require the addition of a broad Gaussian emission line and smeared edge features consistent with Fe XXV (see Section 3 and Table 2). This model may be regarded as an approximation to a full reflection model in the 0.65–25.0 keV band.

The multicolour disc blackbody model yields a measure of the inner accretion disc edge. Our fits give inner disc radii of \(R_a \approx 2.8 R_g\) and 3.5\(R_g\), which suggests that XTE J1550–564 may harbour a spinning black hole. If the Shimura & Takahara (1995) colour correction is applied (\(R_{in,ST} = f^2 \cdot R_{in,MCD}, f = 1.7\) for stellar-mass black holes) black hole spin is not required. However, this correction may be overly simplified. Merloni, Fabian & Ross (2000) have detailed more systematic difficulties with the inner disc models of this model, but suggest that the MCD model may give acceptable inner disc measures at high \(n_i\). The 284–Hz QPO found in the 1998–1999 outburst of this source (Homan et al. 1999, 2001) and the 276–Hz QPO found in this outburst (Miller et al. 2001a) also suggest a spinning black hole.

Broad Fe Kα emission-line studies may provide another means of diagnosing the accretion flow geometry and black hole spin, as these lines are plausibly produced by irradiation of the inner disc (Fabian et al. 1989). We find that lines with widths of 1.2-keV (FWHM) adequately describe our data. Intrinsically narrow lines (with widths fixed at zero, as per a line with a FWHM less than the *RXTE/PCA resolution*) give significantly worse fitting results. Moreover, the *Chandra/HETGS* spectra confirm that the line is not likely to be caused by an intrinsically narrow line that is smeared by the resolution of the *RXTE/PCA* (see Section 3 and Fig. 4). The sensitivity achieved with our *Chandra/HETGS* snapshot observations is not sufficient to constrain the parameters of more sophisticated line models that can estimate the inner disc extent more directly (and thereby black hole spin, e.g. Miller et al. 2002a). The 1.2-keV (FWHM) width we adopt in fits with a Gaussian model is not broad enough to require black hole spin, but it does suggest significant Doppler shifting. Compton broadening may also contribute to the observed linewidth.

Our best-fitting spectral model is the same as that adopted by Sobczak et al. (2000) in fits to *RXTE* spectra from the 1998–1999 outburst. The parameters we measure are broadly consistent with those reported previously when XTE J1550–564 was found to be in the very high or intermediate states. The properties of these states are quite similar, and they are only distinguished by relative luminosity (if multiple such states are observed, the most luminous may be called the ‘very-high’ state, and the others ‘intermediate’ states). The Fe Kα emission-line equivalent widths we measure (\(W_{Kα} = 160 ± 20 and 180 ± 20\) eV) are consistent with the strongest lines reported by Sobczak et al. (2000). We speculate that the sensitivity and energy range of the *Chandra/HETGS* spectra have allowed for a better characterization of the continuum spectrum, and therefore a better characterization of the line parameters as well.

At present, few very high and intermediate states have been observed relative to the more common high/soft and low/hard states. The spectra we have observed are similar to other very high and/or intermediate states observed in the *RXTE* and *BeppoSAX* era, including: XTE J1650–500, GRO J1655–40, GRS 1739–278, XTE J1748–288, and *RXTE* J2012+381 (Borozdin et al. 1998; Sobczak et al. 1999; Miller et al. 2001b, 2002b; Campana 2002).

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