QUASI-PERIODIC OSCILLATIONS ASSOCIATED WITH SPECTRAL BRANCHES IN ROSSI X-RAY TIMING EXPLORER OBSERVATIONS OF CIRCINUS X-1

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ABSTRACT

We present Rossi X-Ray Timing Explorer (RXTE) All-Sky Monitor observations of the X-ray binary Circinus X-1 that illustrate the variety of intensity profiles associated with the 16.55 day flaring cycle of the source. We also present eight observations of Cir X-1 made with the RXTE Proportional Counter Array over the course of a cycle wherein the average intensity of the flaring state decreased gradually over ~12 days. Fourier power density spectra for these observations show a narrow quasi-periodic oscillation (QPO) peak that shifts in frequency between 6.8 and 32 Hz, as well as a broad QPO peak that remains roughly stationary at ~4 Hz. We identify these as Z-source horizontal and normal branch oscillations (HBOs/NBOs), respectively. Color-color and hardness-intensity diagrams (CDs/HIDs) show curvilinear tracks for each of the observations. The properties of the QPOs and very low frequency noise allow us to identify segments of these tracks with Z-source horizontal, normal, and flaring branches that shift location in the CDs and HIDs over the course of the 16.55 day cycle. These results contradict a previous prediction, based on the hypothesis that Cir X-1 is a high-M atoll source, that HBOs should never occur in this source.

Subject headings: stars: individual (Circinus X-1) — stars: neutron — stars: oscillation — X-rays: stars

1. INTRODUCTION

The X-ray binary Circinus X-1 is unique in its complex temporal and spectral variability. A 16.55 day cycle of flaring is observed in the X-ray (Kaluzienski et al. 1976), optical (Moneti 1992), IR (Glass 1978), and radio bands (Whelan et al. 1977). The high degree of stability of the period of this cycle is evidence that it is the orbital period. The onset of flaring has been suggested to be the result of enhanced mass transfer occurring near periaston of a highly eccentric binary orbit (Murdin et al. 1980; Oosterbroek et al. 1995).

The X-ray profile and average intensity of the 16.55 day cycle has varied considerably over timescales of years (see e.g. Dower, Bradt, & Morgan 1982; Stewart et al. 1991; Oosterbroek et al. 1995; Shirey et al. 1996, hereafter Paper I). Observations with the Rossi X-Ray Timing Explorer (RXTE) All-Sky Monitor (ASM; 2–12 keV) showed Cir X-1 in a sustained bright state with a baseline intensity level of ~1.0 crab (75 counts s\(^{-1}\); 1060 \(\mu\)Jy at 5.2 keV) and strong flaring up to as high as 3.5 crab (Paper I). The flaring state began during the day following phase zero (based on the radio ephemesis of Stewart et al. 1991) and typically lasted 2–5 days (see Fig. 1 and discussion below). The ratio of count rates in different ASM energy channels showed dramatic spectral softening at the onset of the flaring state and gradual hardening during the remainder of each cycle (Paper I). Similar behavior was seen in Ginga ASM observations folded at the 16.55 day period (Tsunemi et al. 1989). Near phase zero, some of the cycles observed with the RXTE ASM also showed brief dips below the 1 crab level. Observations of dips near phase zero in Cir X-1 with ASCA (Brandt et al. 1996) and the RXTE Proportional Counter Array (PCA) (Brandt et al. 1998) indicate the presence of both a strongly absorbed spectral component and an unabsorbed component.

Observations of type 1 X-ray bursts demonstrate that Cir X-1 is a low magnetic field neutron star (Tennant, Fabian, & Shafer 1986). Additional type 1 bursts have not been observed from Cir X-1 since the EXOSAT discovery, possibly because the source intensity has been higher during subsequent observations.

The rapid X-ray variability of Cir X-1 at times resembles that of both “atoll” and “Z” low-mass X-ray binaries (LMXBs) as well as black hole candidates (Oosterbroek et al. 1995). Quasi-periodic oscillations (QPOs) were reported at 1.4, 5–20, and 100–200 Hz in EXOSAT data (Tennant 1987, 1988). Based on these data, it has been suggested that Cir X-1 is an atoll source that can uniquely reach the Eddington accretion rate and exhibit normal/flaring branch QPOs at 5–20 Hz (Oosterbroek et al. 1995; van der Klis 1994). Observations made during nonflaring phases with the RXTE (PCA) showed a QPO peak that varied from 1.3 to 12 Hz, flat-topped low-frequency noise (LFN), and a broad peak that varied from 20 to 100 Hz (Paper I). The two QPO frequencies and the cutoff frequency of the flat-topped noise were highly correlated. These QPOs are likely to be essentially the same phenomenon as those previously seen in EXOSAT observations at 5–20 and 100–200 Hz.

In this paper we present additional RXTE ASM observations of Cir X-1 that further illustrate how its intensity profile varies from one 16.55 day cycle to another. We also present the results of RXTE PCA observations made over the course of one cycle in which the intensity declined unusually gradually from the flaring state to the quiescent level. This slow transition allows us to demonstrate how the time-variability properties of the source are related to its spectral properties.

2. OBSERVATIONS

The RXTE ASM has now provided 2–12 keV light curves for over 45 orbital cycles of Cir X-1 since 1996 February. Throughout all these cycles, the baseline intensity has remained near 1.0 crab. The variety of intensity profiles is illustrated in Figure 1, which shows ASM light curves and hardness ratios for three cycles. In many cycles, after 3–5 days in the flaring state the intensity is quite steady for the
FIG. 1.—RXT E ASM light curves (1.5–12 keV) for three 16.55 day cycles of Cir X-1 showing different flaring profiles. Each intensity point corresponds to a 90 s exposure by one of the three ASM cameras, and the hardness ratio (HR), defined as the ratio of counting rates for 5–12 to 3–5 keV, is shown in 1 day averages. The 3–5 to 1.5–3 keV hardness ratio exhibits very similar behavior and is not shown here. The intensities are for Cir X-1 after background and other sources in the field of view have been subtracted. The Crab Nebula yields ~75 counts s⁻¹. Vertical dashed lines indicate phase zero based on the radio ephemeris of Stewart et al. (1991). Day zero corresponds to (a) 1997 April 23.87, (b) 1996 August 2.14, and (c) 1997 February 16.69. For cycle (c), the intensity ranges (I[2.0–18]) seen in the eight RXT E PCA observations (I–VIII in time order) are also shown.

The choice of energy bands used in constructing these diagrams can affect the appearance of spectral tracks. For observations showing a single branch, only the length and slope of the branch is affected. Observations V and VI each show two branches. The orientation of these branches is discussed in more detail below.

The tracks in the CD and HID are reminiscent of the correlated spectral/intensity behavior of Z and atoll class LMXBs, which also shows correlations of temporal properties with position along tracks or branches in CDs and HIDs (Hasinger & van der Klis 1989). Thus, we have investigated how the temporal properties of Cir X-1 are related to position in the CD or HID. For this purpose, we divided the HID track for each of the eight observations into three

### TABLE 1

| Observation | Julian Date | Phase | Mean Intensity (crab) |
|-------------|-------------|-------|-----------------------|
| I           | 2450497.90  | 0.10  | 2.3                   |
| II          | 2450499.98  | 0.23  | 1.8                   |
| III         | 2450501.69  | 0.33  | 1.6                   |
| IV          | 2450503.66  | 0.45  | 1.5                   |
| V           | 2450505.80  | 0.58  | 1.2                   |
| VI          | 2450507.31  | 0.67  | 1.3                   |
| VII         | 2450509.35  | 0.79  | 1.1                   |
| VIII        | 2450511.62  | 0.93  | 1.0                   |

*Midpoint of 2–3 hr observation (~6 ks of data per observation).  
1.0 crab ≈ 13,000 counts s⁻¹ (2–32 keV).
regions (Fig. 3b). The choice of numbers for each region was motivated in part by the timing results discussed below, but the numbers serve mainly as reference labels rather than as meaningful quantities (such as Z “rank number”).

3.2. Power Density Spectra

Fourier power density spectra (PDSs) were computed using 16 s segments with 244 \( \mu \)s \( (2^{-12} \text{ s}) \) time bins. This was done for both the full 2–32 keV energy range and for four energy channels: 2.0–4.8, 4.8–13, 13–18, and 18–32 keV. The Leahy-normalized power spectra (Leahy et al. 1983) were converted to the fractional rms normalization by dividing by the background-subtracted count rate in the selected band. The expected Poisson level, i.e., the level of white noise due to counting statistics, was estimated taking into account the effects of deadtime (Morgan, Remillard, & Greiner 1997; Zhang et al. 1995, 1996) and subtracted from each PDS; this method tends to slightly underestimate the actual Poisson level. For each of the 24 HID regions defined in Figure 3, an average PDS was calculated from the power spectra corresponding to points in that region. The PDSs were then logarithmically rebinned.

The average PDS (2–32 keV) for each HID region is shown in Figure 4. During the extended active state (observations I–VI), a broad peak is often observed near 4 Hz; this feature is prominent in PDSs from observations III–VI, weak in observation II, and indistinguishable from a flat-topped component in observation I (see below). A
strong narrow QPO feature is seen at frequencies from 6.8 to 13 Hz in observations VII and VIII. In some cases, especially at higher photon energy (see Fig. 5), a harmonic peak is observed at twice the frequency of this QPO. A weak narrow QPO feature is present at frequencies above 20 Hz in regions II-1 and VI-1. A sharp “knee” is present at similar frequencies in regions II-2, III-1, IV-1, VI-2, VI-3, and possibly I-1. Broad high-frequency noise is sometimes seen, e.g., at ~100 Hz in observation VIII (Fig. 5b).

There is an underlying red continuum spectrum of noise in all of the regions of the HID, but the shape and low-frequency slope of the continuum vary over a wide range.

The narrow QPO peaks and the low-frequency noise in the PDSs from the “quiescent” 1 crab observations (VII and VIII) resemble previously observed PDSs (Paper I; Oosterbroek et al. 1995; Tennant 1987). Those PDSs also contained narrow QPO features with centroid frequencies in the range 1.3–20 Hz and similarly shaped low-frequency noise. The broad high-frequency component that we detect in the present observations is similar to the 20–100 Hz QPO seen in earlier PCA observations (Paper I) and to the 100–200 Hz QPO observed with EXOSAT (Tennant 1987).

The weak narrow QPO feature above 20–30 Hz in regions II-1 and VI-1 occurs near the knee of the low-frequency noise component. This similarity to the LFN and prominent QPO at lower frequency in observations VII and VIII suggests these higher frequency oscillations are produced by the same physical process as the lower frequency
FIG. 4.—Averaged and rebinned power density spectra (2–32 keV) for each of the three HID regions for each observation. Poisson noise has been subtracted from each PDS (see text).

FIG. 5.—Averaged and rebinned power density spectra for HID region VIII-3 in three energy bands. A harmonic peak of the 7.6 Hz QPO is clearly visible in the high-energy channel (c). The broad high-frequency peak, most clear in (b), occurs near $\sim$100 Hz in this observation. The low-frequency noise cuts off less sharply as energy increases.

QPOs. In observations II and VI, this QPO feature is visible in region 1 as a small peak that fades in region 2 and becomes only a “knee” in region 3 (see Fig. 4). Thus we assume that this knee is related to the QPO. Similar knees are present in regions III-1, IV-1, and possibly I-1. We include a narrow QPO component in fits of PDSs that show a knee above 20 Hz but identify these cases as “unpeaked” in the discussion below.

Likewise, although no peak appears in the PDSs from observation I, a broad noise component has roughly constant power below about 4 Hz and drops off above that
frequency, forming a "knee" that might indicate the presence of the 4 Hz QPO component. The PDS for region I-1 somewhat resembles those of regions III-1 and IV-1 in that all show a break in the power spectrum near 4 Hz and a second knee or change in slope near 30 Hz. We include a broad QPO component in fits of the PDSs for observation I, but we identify these cases as "unpeaked."

The PDSs were fit with models comprising both broadband and QPO components: a power law for the very low frequency noise (VLFN), an exponentially cutoff power law for the broad low-frequency noise, a Lorentzian for the broad QPO near 4 Hz, Lorentzians for the narrow QPO and its first harmonic, a broad Lorentzian for the high-frequency peak, and a second power law to fit the residual Poisson noise at high frequency. The model for each PDS consisted of two to five of these components, depending on which components were necessary for an acceptable fit. The frequency of the harmonic (when present) of the narrow QPO was fixed at twice the fundamental frequency. For the fits of the PDSs from the four narrower energy channels, the QPO centroid frequencies were fixed at the values determined from the 2–32 keV PDSs. There were generally not enough counts to obtain useful PDS fits for the 18–32 keV channel. For use in performing the fits, we estimated the variance of each power in each binned and averaged PDS by calculating the sample variance of the powers in the individual PDSs that were averaged to obtain each point and dividing the result by the number of the powers used in computing the sample variance.

The centroids of the narrow variable-frequency QPO and the ~4 Hz QPO were measured accurately whenever a clear peak was visible. However, in cases where these components are weak or unpeaked, the centroids were less well constrained. The centroid of the broad high-frequency peak and the cutoff frequency of the LFN were often poorly constrained.

Figure 6 shows the frequency of the broad and narrow QPOs versus intensity (2–18 keV). The frequency of the narrow peak is generally correlated with intensity, starting at 6.8 Hz at 1 crab and reaching 32 Hz at 1.3 crab. At higher intensity, this QPO is sometimes present above 20 Hz and is often unpeaked (i.e., a knee). In observations III–VI, the broad QPO is clearly present at 3.3–4.3 Hz. This QPO component was included in the fits of the PDSs from observations I and II, and the resulting frequencies (2.1–4.5 Hz) are shown as unfilled squares (indicating a weak peak or a knee) above 20 kcounts s\(^{-1}\) in Figure 6.

The ratio of the width of the narrow QPO peak to its centroid frequency ($\Delta v/v$) is about 0.15 when at 6.8–13 Hz. At higher frequencies this QPO becomes broader, with $\Delta v/v \sim 0.4$. When the broad QPO near 4 Hz is strong, we find that $\Delta v/v \sim 1$, and when it is weak $\Delta v/v \sim 2–3$.

Figure 7 illustrates the dependence of the rms amplitude of the QPOs upon photon energy. Typical values for the rms amplitude of the 6.8–13.1 Hz QPO at 2–4.8, 4.8–13, and 13–18 keV are 4%, 5%, and 8%, respectively (Fig. 7a), indicating a weak trend of increasing rms amplitude at higher photon energy. The amplitude of the broad QPO increases significantly at higher photon energy. For clearly peaked 4 Hz QPOs, the rms amplitude is typically about 3%, 8%, and 18% in these three energy bands (Fig. 7b). The rms values vary considerably when these components are weak or unpeaked but their amplitudes still generally increase with energy (Fig. 7c).

![Fig. 6](image_url) **Fig. 6.** Centroid frequency of the QPOs versus intensity ($I$ [2.0–18]). A filled circle represents the narrow QPO and a filled square represents the broad ~4 Hz QPO (all points below 5 Hz are the broad QPO). Unfilled circles and squares indicate the approximate frequency of a knee or very weak peak that may be associated with the narrow and broad QPO, respectively. Error bars on frequency measurements (filled points only) represent 90% confidence intervals for a single parameter ($\Delta x^2 = 2.7$). In many cases, the error bar for the QPO frequency is smaller than the plot symbol.

![Fig. 7](image_url) **Fig. 7.** Rms amplitude of QPOs versus photon energy (a) for the narrow QPO at 7.2 Hz (solid dot) and (b) for an example of the broad 4 Hz QPO (solid box). In panel (c), unfilled circles and boxes indicate the rms amplitude of a component forming a knee or very weak peak that may be associated with the narrow and broad QPOs respectively. The broad QPO points have been offset slightly to the right in energy for clarity. Errors on QPO amplitudes represent 90% confidence intervals.
the tracks in the HID as horizontal, normal, and flaring branches (HB/NB/FB), where each 6 ks observation of Cir X-1 appears to have captured a snapshot of portions of one or two of the branches. The spectral branches appear to shift around as the flaring gradually subsides, rather than forming a stable Z pattern. It is likely that the shapes of the spectral branches become distorted somewhat during these large shifts. We now describe the inferred properties of each of the spectral branches in more detail.

4. DISCUSSION

4.1. Horizontal Branch

HID regions VIII, VII, and VI-1 show a narrow QPO peak at 32 Hz on a roughly horizontal segment (region VI-1) and a knee at 37 Hz on the right end of this segment (region VI-2). The apex of region VI-2 brings a transition to the 4 Hz QPO, which is dominant on the downward branch of this track (region VI-3). This is very similar to the HB/NB transition in Z sources.

When Cir X-1 is in “quiescence” in observations VII and VIII, the “horizontal branch” turns upward and becomes vertical in the HID. For comparison, RXTE PCA observations of Cir X-1 from 1996 March 10–19 that show a narrow QPO peak at 1.3–12 Hz (Paper I) are almost entirely confined to the 12.3–14.7 kcounts s\(^{-1}\) (2–21 keV) intensity range. The HID tracks for these observations lie along a nearly vertical line, and probably represent sections of the “horizontal” branch.

Observation II may also be on part of the HB, since a weak narrow QPO appears to evolve into a knee and increase in frequency from 22 to 30 Hz as the intensity increases. However, the broad QPO is also weakly visible in PDSs for this observation. The fact that observations II, VI, VII, and VIII all show little variation of the hard color used in Figure 3a suggests that observation II may be associated with the other HB observations.

4.2. Normal Branch

The 4 Hz QPO is observed when the source intensity rises above the “quiescent” 1 crab level (~13 kcounts s\(^{-1}\)). It is roughly stationary in frequency (3.3–4.3 Hz when clearly peaked) and broader than the HBO. The feature is easily seen in observations III–VI; at these times the location in the HID moves along diagonal tracks. The ~4 Hz frequency and motion along diagonal tracks in the HID is consistent with the 4–7 Hz NBOs observed at nearly constant frequency on the NB of typical Z sources (Hasinger & van der Klis 1989). We therefore identify the broad 4 Hz QPO as a normal branch oscillation, and the diagonal tracks for observations III–VI as shifted normal branches.

The broad QPO component may be also present in the highest intensity observations as a weak feature in observation II and in the form of a break near the 4 Hz QPO frequency in observation I. We also note that at the top of the normal branch (regions I-1, III-1, IV-1, VI-2) a knee above 30 Hz is present in addition to the NBO component.
A similar broad 4 Hz QPO is present in observations from 1996 March 5–6 made immediately before phase zero of the cycle showing the 1.3–12 Hz narrow QPO.

4.3. Flaring Branch

Beyond the left apex of the normal branch a short upturned branch is observed in HID region V-3 and possibly region III-3. The PDS for these regions are dominated by very low frequency noise, which is typical for flaring branches, and no QPO peaks are obviously apparent. We note that in the well-established Z sources neither NBOs nor HBOs are present on the flaring branch, except for Sco X-1 and GX 17+2, in which the NBO evolves into a 6–20 Hz QPO (van der Klis 1995 and references therein).

The left end of the spectral track for observation V bends upward in the HID shown in Figure 3b, but bends downward in the CD in Figure 3a. This behavior is demonstrated more clearly in Figure 9, which shows CDs and HIDs for observations V and VI. When a broad color ([I(6.3–13)]/[I(2.0–6.3)]) is used as the ordinate of the diagrams (Figs. 9a and 9b), the track for observation V turns upward on the left end. When a harder color ([I(13–18)]/[I(8.5–13)]) is used as the ordinate (Figs. 9c and 9d), this branch turns downward. The CD and particularly the HID version based on the harder color show the most clear similarity to canonical Z diagrams, with the temporal behavior of observations V and VI being generally consistent with horizontal, normal, and flaring branches. The broad-color HID (Fig. 9b) shows evidence for a shift of the normal branch that does not show up in the other three diagrams of that figure.

4.4. Relation to Other Sources

Our observations reveal spectral branches that shift in the CD and HID as Cir X-1 evolves from a soft, high-intensity state to a hard, lower-intensity state. The ASM light curves and hardness ratios (Fig. 1) show that this evolution occurs periodically with the 16.55 day cycle, thus suggesting that the CD/HID shifts may also be periodic. Shifts of the "Z" pattern in CDs and HIDs have been observed in the so-called Cyg-like Z sources: Cyg X-2 (Kuulkers, van der Klis, & Vaughan 1996), GX 5-1 (Kuulkers et al. 1994), and GX 340 + 0 (Kuulkers & van der Klis 1996). However, the shifts do not occur periodically in those sources, nor do they have the magnitude of the shifts observed in Cir X-1.

The flaring branch of Cir X-1 turns upward when a soft or broad color is used on the vertical axis. When a harder color is used, this branch turns downward but then bends to the left. In the Cyg-like Z sources, the flaring branch sometimes turns upward or starts toward higher intensity and then loops back to lower intensity (Kuulkers et al. 1994, 1996; Kuulkers & van der Klis 1996; Penninx et al. 1991). In some cases, these sources are observed to "dip" while on

![Figure 9](image-url)
the flaring branch (Kuulkers et al. 1994; Penninx et al. 1991; Wijnands & van der Klis 1997) with tracks that turn down and then to the left, similar to that of Cir X-1 in Figure 9c.

The left end of the horizontal branch in Cir X-1 turns upward and becomes vertical at low intensity (Fig. 8). On this section of the branch, HBO frequencies are low: 6.8–13 Hz in observations VII and VIII and 1.3–12 Hz in the earlier 1996 March observations. A similar effect was reported in GX 5–1 (Lewin et al. 1992; Kuulkers et al. 1994), in which the HB turns upward at the low-intensity end while HBOs are observed at relatively low frequency (13–17 Hz). In fact, Lewin et al. (1992) suggested that other Z sources might show such an upward turn of the HB if their intensities and QPO frequencies became sufficiently low.

The 5–20 Hz narrow QPO was detected with EXOSAT at an intensity similar to the quiescent level observed by RXTE. We note that absorption dips are responsible for much of the structure seen in the CD shown for that observation; however, the HIDs show that the narrow QPO occurred on an upturned left end of a horizontally oriented track as in our data (see Figs. 2–4, 8, and 10 in Oosterbroek et al. 1995). At higher intensity during the same observation, the narrow QPO was not present, and we note that some of the high-intensity PDSs show hints of a broad peak near 4 Hz. We thus conclude that the behavior observed by EXOSAT during that observation is related to the Z-like behavior we observe with RXTE.

Most of the other EXOSAT observations took place when Cir X-1 was significantly lower in intensity than the “quiescent” level of the current observations. The CDs and HIDs for these EXOSAT observations did not show tracks that could clearly be identified as Z or atoll. Their power spectra were generally dominated by VLFN, which is typical of atoll sources in the banana state, and sometimes also showed a broad red noise component resembling atoll high-frequency noise (Oosterbroek et al. 1995). However, these power-spectral shapes are not unique to atoll sources: power spectra for black hole candidates in the high state are dominated by VLFN, as are those of the current observations on the low-intensity end of the normal branch and on the flaring branch (i.e., regions III-3 and V-3).

Cir X-1 was expected to never show HBOs since atoll-like behavior was taken as evidence that the magnetic field is not strong enough to allow the magnetospheric beat frequency mechanism (MBFM) to operate (van der Klis 1994; Oosterbroek et al. 1995). However, it is also possible that the HBOs are not produced by the MBFM. The results presented here demonstrate both HBOs and NBOs in Cir X-1 and show no evidence for atoll behavior. Since the atoll-like behavior observed with EXOSAT occurred at lower intensity than in the present observations, it is possible that they do represent a different state of the source. If Cir X-1 actually can show atoll behavior as well as the Z-like behavior shown here, then we would have new clues to the differences between the two types of sources. Such observations would challenge the hypothesis that differences in both M and magnetic field distinguish these two classes.

5. SUMMARY

Our results from an analysis of RXTE observations of Cir X-1 reveal behavior similar to that of Z sources, and, in particular, allow us to identify temporal and spectral signatures of the horizontal, normal, and flaring branches. The spectral variability of Cir X-1 is seen to correspond to tracks in a HID that are similar in direction to the typical direction in the HID of Z sources in general, but the locations of the tracks corresponding to each branch move from observation to observation in a systematic manner.

To be specific, in the current observations of Cir X-1, the horizontal branch is characterized by the presence of relatively narrow 6.8–32 Hz QPO features in the PDS. The track in the HID of the horizontal branch is horizontal at the high intensity end and becomes vertical at the low intensity end, where the source is “quiescent”, i.e., has an intensity near 1 crab and is characterized by a relatively low degree of variability on timescales longer than 1 s. The normal branch is characterized by broad 4 Hz QPOs and by motion in the HID which generally falls along tracks that run diagonally from hard high-intensity locations to soft low-intensity locations. There are also time intervals when the PDS is dominated by VLFN. We identify these intervals as excursions onto the flaring branch.

The large-amplitude intensity variations associated with the active/flaring state of Cir X-1 can be divided into three categories: (1) motion across the horizontal portion of the horizontal branch and along the normal and flaring branches, (2) shifts of the spectral branches, and (3) absorption dips. While our RXTE observations have allowed us to recognize and distinguish these different types of variability, there is still much to be understood about the physical mechanisms responsible.

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