

$< 20\%$ of the flux (2–20 keV) at the peak of the thermal state. The energy-division tracks for the SPL state (*green triangles*) are not well defined, and the tracks of different sources do not resemble each other. The energy-division diagrams are more effective than the HIDs in delineating intrinsic differences between the SPL and thermal states.

Comparisons between the SPL and thermal states in terms of the photon index (Γ ; e panels of Figures 4–9) are of interest, as these states are sometimes presumed to share a common PL mechanism that is relatively muted during the thermal state. Generally, we find broad distributions in Γ during the thermal state, and in some cases the thermal tracks are shifted from the SPL tracks (e.g., Figures 6e, 7e, 8e). We find no compelling evidence that the PL mechanisms for the thermal and SPL states are the same.

In the following section, we consider one additional observational topic – X-ray QPOs – before discussing the ongoing efforts to relate X-ray states to physical models for BH accretion.

6 X-ray Quasi-Periodic Oscillations

X-ray QPOs are specialized and extraordinarily important avenues for the study of accreting BHs. They are transient phenomena associated with the nonthermal states and state transitions. For definitions of QPOs and analysis techniques, see van der Klis (2005) and some details in §3.2.

QPOs play an essential role in several key science areas, such as probing regions of strong field (§6.2 & §8.2.4) and defining the physical processes that distinguish X-ray states. Thus far in this review, however, QPOs have been considered only tangentially (e.g., §4.2). In this section we focus on the significance of QPOs, their subtypes, and spectral/temporal correlation studies that involve the QPO frequency. Following the literature, we divide the discussions of QPOs into low-frequency and high-frequency groups. In doing so, we disregard the additional, infrequent appearances of very low frequency QPOs (e.g., the QPO below 0.1 Hz in the upper-right panel of Figure 2) that are not understood. Physical models for QPOs are briefly discussed in §7, and the importance of high-frequency QPOs for probing strong gravity is highlighted in §8.2.4.

6.1 Low-Frequency Quasi-Periodic Oscillations

Low-frequency QPOs (LFQPOs; roughly 0.1–30 Hz)) have been detected on one or more occasions for 14 of the 18 BHBs considered in Table 4.2 of McClintock & Remillard (2006). They are important for several reasons. LFQPOs can have high amplitude (integrated rms/mean values of $a > 0.15$) and high **coherence** (often $Q > 10$), and their frequencies and amplitudes are generally correlated with the spectral parameters for both the thermal and PL components (e.g., Munro et al. 1999; Sobczak et al. 2000a; Revnivtsev et al. 2000; Vignarca et al. 2003). With the exception of Cyg X–1, QPOs generally appear whenever the SPL contributes more than 20% of the flux at 2–20 keV (Sobczak et al. 2000a), which is one component of the definition of the SPL state (Table 2; McClintock & Remillard 2006).

LFQPOs can vary in frequency on timescales as short as one minute (e.g., Morgan et al. 1997). On the other hand, LFQPOs can also remain relatively stable and persistent. For example, in the case of GRS 1915+105, a 2.0–4.5 Hz