

Such features may eventually help us to interpret X-ray states, but at present there are too few results to support any firm conclusions.

4 Emission States of Black-Hole Binaries

4.1 Historical Notes on X-ray States

The concept of X-ray states was born when Tananbaum et al. (1972) observed a global spectral change in Cyg X–1 in which the soft X-ray flux (2–6 keV) decreased by a factor of 4, the hard flux (10–20 keV) increased by a factor of 2, and the radio counterpart turned on. Thereafter, a similar X-ray transition was seen in A 0620–00 (Coe et al. 1976) and in many other sources as well. The soft state, which was commonly described as ~ 1 keV thermal emission, was usually observed when the source was bright, thereby prompting the name “high/soft state”. The hard state, with a typical photon index $\Gamma \sim 1.7$, was generally seen when the source was faint, hence the name “low/hard state”. In this state, the disk was either not observed above 2 keV, or it appeared much cooler and withdrawn from the BH. An additional X-ray state of BHBs was identified in the *Ginga* era (Miyamoto & Kitamoto 1991; Miyamoto et al. 1993). It was characterized by the appearance of several-Hz X-ray QPOs, a relatively high luminosity (e.g., $> 0.1L_{\text{Edd}}$), and a spectrum comprised of both a thermal component and a PL component that was steeper ($\Gamma \sim 2.5$) than the hard PL. This state was named the “very high” state.

Rapid observational developments in the RXTE era challenged the prevailing views of X-ray states in BHBs. First, it was shown that the soft state of Cyg X–1 is not consistent with a thermal interpretation (Zhang et al. 1997b); instead, the spectrum is dominated by a steep PL component ($\Gamma \sim 2.5$). Thus, Cyg X–1 is not a useful prototype for the high/soft state that it helped to define. Secondly, the spectra of BH transients near maximum luminosity were often found to exhibit a steep PL spectrum, rather than a thermal spectrum (McClintock & Remillard 2006). Thirdly, a number of different QPO types were commonly observed over a wide range of luminosities (e.g., Morgan et al. 1997; Sobczak et al. 2000a; Homan et al. 2001). These findings attracted great interest in the nature of the very high state.

During this period, Gamma-ray observations (~ 40 –500 keV) of seven BHBs brought clarity to the distinction between the soft and hard types of X-ray PL components (Grove et al. 1998; Tomsick et al. 1999). Sources in the low/hard state ($\Gamma \sim 1.7$) were found to suffer an exponential cutoff near 100 keV, whereas sources with soft X-ray spectra ($\Gamma \sim 2.5$) maintained a steep, strong and unbroken PL component out to the sensitivity limit of the gamma-ray detectors (~ 1 MeV).

More recently, radio observations have cemented the association of the low/hard state with the presence of a compact and quasi-steady *radio jet* (see Fender 2006; McClintock & Remillard 2006). In brief, the evidence for the association includes the following: (a) the presence of compact jets in *VLBI* images of two BH sources (Dhawan, Mirabel, & Rodriguez 2000; Stirling et al. 2001); (b) correlated X-ray and radio intensities and/or the presence of flat or inverted radio spectra (e.g., Gallo et al. 2003), which allow the jet’s presence to be inferred even in the absence of VLBI images; (c) a 2% linear radio polarization at nearly constant position angle observed for GX 339–4 (Corbel et al. 2000); and (d) the frequently-observed *quenching* of the persistent radio emission that occurs when a BHB switches from the low/hard state to the high/soft state (e.g., Fender et al. 1999).