

8.2.4 High Frequency Quasi-Periodic Oscillations

Arguably, HFQPOs (see §6.2) are likely to offer the most reliable measurement of spin once the correct model is known. Typical frequencies of these fast QPOs, e.g., 150–450 Hz, correspond respectively to the frequency at the ISCO for Schwarzschild BHs with masses of 15–5 $M_{\odot}$, which in turn closely matches the range of observed masses (Table 1). As noted in §6.2, these QPO frequencies (single or pairs) do not vary significantly despite sizable changes in the X-ray luminosity. This suggests that the frequencies are primarily dependent on the mass and spin of the BH. Those BHs that show HFQPOs and have well-constrained masses are the best prospects for constraining the value of the BH spin (a_*).

The four sources that exhibit harmonic pairs of frequencies in a 3:2 ratio (see §6.2) suggest that HFQPOs arise from some type of resonance mechanism (Abramowicz & Kluźniak 2001; Remillard et al. 2002a). Resonances were first discussed in terms of specific radii where particle orbits have oscillation frequencies in GR (see Merloni et al. 1999) that scale with a 3:1 or a 3:2 ratio. Current resonance concepts now consider accretion flows in a more realistic context. For example, the “parametric resonance” concept (Abramowicz et al. 2003; Kluźniak et al. 2004; Török et al. 2005) describes oscillations rooted in fluid flow where there is a coupling between the radial and polar coordinate frequencies. As a second example, one recent MHD simulation provides evidence for resonant oscillations in the inner disk (Kato 2004); in this case, however, the coupling relation involves the azimuthal and radial coordinate frequencies. If radiating blobs do congregate at a resonance radius for some reason, then ray tracing calculations have shown that GR effects can cause measurable features in the X-ray power spectrum (Schnittman & Bertschinger 2004).

Other models utilize variations in the geometry of the accretion flow. For example, in one model the resonance is tied to an asymmetric structure (e.g., a spiral wave) in the inner accretion disk (Kato 2005). In an alternative model, state changes are invoked that thicken the inner disk into a torus; the normal modes (with or without a resonance condition) can yield oscillations with a 3:2 frequency ratio (Rezzolla et al. 2003; Fragile 2005). All of this research is still in a developmental state, and these proposed explanations for HFQPOs are basically dynamical models that lack radiation mechanisms and fail to fully consider the spectral properties of HFQPOs described in §6.2.

Theoretical work aimed at explaining HFQPOs is motivated by the following empirical result that is based on a very small sample of three sources: XTE J1550–564, GRO J1655–40 and GRS 1915+105. These sources are presently the only ones that both exhibit harmonic (3:2) HFQPOs and have measured BH masses. As shown in Figure 12, their frequencies appear to scale inversely with mass (McClintock & Remillard 2006), which is the dependence expected for coordinate frequencies (see Merloni et al. 1999) or for diskoseismic modes in the inner accretion disk (Wagoner 1999; Kato 2001). If these HFQPOs are indeed GR oscillations, then Figure 12 further suggests that the three BHs have similar values of the spin parameter a_* . Obviously it is of great importance to attempt to confirm this result by obtaining the requisite frequency and mass measurements for additional sources.