Disk and Corona Instabilities in GRS 1915+105

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Abstract.

We present time-resolved GRS 1915+105 energy and power spectra observed by RXTE, during an episode where the X-ray intensity makes an extreme dip. If the spectra are modeled in terms of disk and power law components, both have large variations. When the inner disk is disrupted, the power law dominates, exhibiting quasi-periodic oscillations with varying frequency until the inner disk returns.

INTRODUCTION

The source GRS 1915+105 was first discovered in 1992 as an X-ray transient by GRANAT/Watch [1] Subsequent radio observations showed that it produces superluminal jet-like outflows [2]. While the mass of GRS 1915+105 has not yet been determined, its behavior is similar to that of another recently discovered jet-producing transient, GRO J1655-40, whose mass has been quite accurately determined to be 7\(M_\odot\) [3], well above the mass limit for neutron stars. GRS 1915+105 can also be quite luminous (\(L \geq 10^{39}\) erg s\(^{-1}\)), above the Eddington limit for neutron stars. Hence, both GRS 1915+105 and GRO J1655-40 are thought to be jet-producing black hole systems with accretion disks, and have been called “galactic microquasars” in reference to their AGN counterparts.

GRS 1915+105 is a very bright X-ray source, and there are copious X-ray observations by RXTE showing that the source has a rich variety of states [4,5], and a weak 67 Hz QPO which is presumably associated with the inner edge of the accretion disk. We present here time-resolved spectroscopy of GRS 1915+105 as it enters and recovers from a disk disruption episode.

We have analyzed RXTE PCA data taken on 09 Sep 1997. The source was in a state characterized by rapid oscillations (\(\sim 50\) s), followed by extreme dips in the X-ray intensity lasting several hundred seconds. In order to investigate the
FIGURE 1. RXTE observation of GRS 1915+105 showing from top to bottom, the X-ray light curve, inner disk temperature, inner disk radius, photon index, and power density spectrum.
dynamics, data in various PCA modes were combined to construct energy spectra and power spectra at 4 s intervals.

**SPECTRAL VARIATIONS**

The energy spectra were fitted by model emission consisting of a multicolor “disk” black body [6] representing emission from an optically thick accretion disk, and a power law, which may be associated with Compton scattering from energetic electrons. The fitting of the disk model provides information about the temperature and radius at the inner edge of the accretion disk, which are plotted in the second and third panels of Figure 1. It should be noted that no corrections for electron scattering or general relativistic effects have been applied to the calculation of the disk radius [7], so the plotted values should be viewed as an underestimate by a factor of about 3. The power law photon index is displayed in the fourth panel. As can be seen from the plots, the dynamics of the system is quite complex.

One remarkable feature is the extreme dip that occurs from about 1100 s to 1600 s where the X-ray flux, bracketed by rapid X-ray intensity oscillations, drops by a factor of about eight. Such dips have been noted previously [8,9]. The temperature of the disk drops and the radius of the optically thick inner edge increases by a factor of about 5 (the signal is noisy because of the low temperature). A natural conclusion [9], is that the inner portion of the disk is disrupted during the dips: the soft X-rays that remain are interpreted as emission from a residual disk with inner radius of several hundred kilometers.

We note here that the dips appear to be strongly associated with relatively harder power law emission; the onset of the dip is foreshadowed by a decrease of the power law photon index (i.e., hardening) near time 1100 s, and the recovery of the disk occurs only after the power law index has also recovered, sharply at 1600 s in Figure 1. The power law flux itself (not shown) is also much higher during the dip. As the power law component is commonly thought to represent inverse Compton emission from a corona of hot electrons above the disk and/or closer to the black hole, it seems clear that the corona is varying rapidly and is quite closely coupled to the accretion disk.

The small spike that appears in the X-ray light curve near 1600 s signals a dramatic change in the power law component of GRS 1915+105, while it is only weakly apparent in the black body parameters. It precedes a period where the accretion disk gradually recovers. In this observation, the spike is very distinct; in some early observations it is harder to distinguish, as the rapid oscillations begin very soon after the spike. The spike also appears to be associated with radio-emitting outflows. Simultaneous observations by Mirabel et al. [10] reveal an IR and radio outburst, which is consistent with synchrotron emission from an expanding cloud of relativistic electrons. The onset of the outburst is synchronized with the X-ray spike. At present it is unclear how the material in the accretion disk is converted into outflowing material, or how much of the mass is actually ejected.
**VARIABLE FREQUENCY QPO**

The power spectrum also shows a distinct change during the dip episode (shown in the bottom panel of Figure 1, with highest powers being the darkest). A variable-frequency QPO appears between 1100 s and 1600 s, starting at a high of $\sim$12–14 Hz, dips to 2–3 Hz, and then recovers to higher frequencies before disappearing at the X-ray spike. The X-ray spike seems to trigger a significant “quiet” period in the source variability from 1600–2000 s, after which low frequency ($\leq$ 4 Hz) noise begins to dominate, as it does during most of the rapid oscillations. The appearance of the QPO seems to be governed by the presence of a hard power law component (photon index $<3$) and low disk temperatures ($T < 1.7$ keV). The QPO actually reappears very briefly at about 8 Hz as a “U”-shaped feature near 2700 s, when these spectral conditions are satisfied. The frequency itself is clearly correlated with intensity; preliminary work with the dip QPO suggests that the correlation is with the disk luminosity rather than the luminosity of the power law component.

The 67 Hz QPO [4] has been interpreted in terms of phenomena occurring near the radius of marginally stable orbits. If the lower frequency 2–15 Hz QPOs are associated with the disk, and the frequency scales with the distance from the black hole as the Kepler frequency does, then they should come from a radius on the order of $3 - 10$ times larger than the smallest radii observed, that is $\geq 120$ km. The spectral values for the radius of the disk when these QPO are present are not quite this large, although of similar magnitude. The low and high frequency QPOs may however be quite distinct. For example, the luminosity dependence of the frequency and the presence of a second harmonic are properties not seen in the 67 Hz feature. The discussion by Chen et al. [11] applies to these QPO seen during the transient dips as well as to the QPO seen during extended low states. It is also possible that disk variations, oscillations, or precession might modulate the hard X-ray flux to give large amplitude variations of the power law component, which dominates the flux during the dips.

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