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The case for massive, evolving winds in black hole X-ray binaries

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Abstract

In the last decade, high-resolution X-ray spectroscopy has revolutionized our understanding of the role of accretion disk winds in black hole X-ray binaries. Here I present a brief review of the state of wind studies in black hole X-ray binaries, focusing on recent arguments that disk winds are not only extremely massive, but also highly variable. I show how new and archival observations at high timing and spectral resolution continue to highlight the intricate links between the inner accretion flow, relativistic jets, and accretion disk winds. Finally, I discuss methods to infer the driving mechanisms of observed disk winds and their implications for connections between mass accretion and ejection processes.

Keywords: accretion, Accretion disks; Black hole physics; Stars: winds, outflows; X-rays: binaries; X-rays: individual

1. Introduction

In the last 20 years, we have seen the discovery of a multitude of highly-ionized absorbers in moderate and high-resolution X-ray spectra of black hole and neutron star X-ray binaries (e.g. Ebisawa, 1997; Kotani et al., 1997; Brandt and Schulz, 2000; Kotani et al., 2000a; Kotani et al., 2000b; Lee et al., 2002; Sidoli et al., 2001, 2002; Schulz and Brandt, 2002; Parmar et al., 2002; Boirin and Parmar, 2003; Boirin et al., 2004; Boirin et al., 2005; Miller et al., 2004, 2006a,b, 2008; Miller et al., 2011; Neilsen and Lee, 2009; Neilsen et al., 2011, 2012a; Neilsen and Homan, 2012; Ueda et al., 2004, 2009; Martocchia et al., 2006; Kubota et al., 2007; Blum et al., 2010; Reynolds and Miller, 2010; King et al., 2012a; Díaz Trigo et al., 2006, 2007, 2009, 2012; Diaz Trigo et al., 2012). Often these absorbers are blueshifted, indicative of hot outflowing gas, i.e. accretion disk winds. The prevalence of disk winds in X-ray binaries suggests that these outflows may play a crucial role in the physics of accretion and ejection around compact objects. In this brief review, I discuss some recent developments in the influence of ionized disk winds around black holes.

2. Black hole accretion disk winds and the disk-jet connection

Much of the recent work on accretion and ejection processes in black hole outbursts has focused on radio/X-ray correlations (e.g. Gallo et al., 2003; Corbel et al., 2003; Fender and Belloni, 2004; Fender et al., 2004, 2009, although see e.g. Gallo et al., 2012 and references therein for lingering questions about the precise nature of these correlations). Briefly, we now know that typical black hole transients emerge from quiescence in X-ray hard states that produce steady, compact jets. They rise in luminosity in this (probably radiatively inefficient; e.g. Esin et al., 1997) hard state, until at some point they undergo a transition towards a much softer state, possibly dominated by a radiatively-efficient disk. This transition has also been associated with major relativistic plasma ejections and the disappearance of steady jets. Eventually, the luminosity falls and they return to quiescence via the hard state.

Over the last decade, this canonical picture of the "disk-jet connection" has proved to be a fruitful way to

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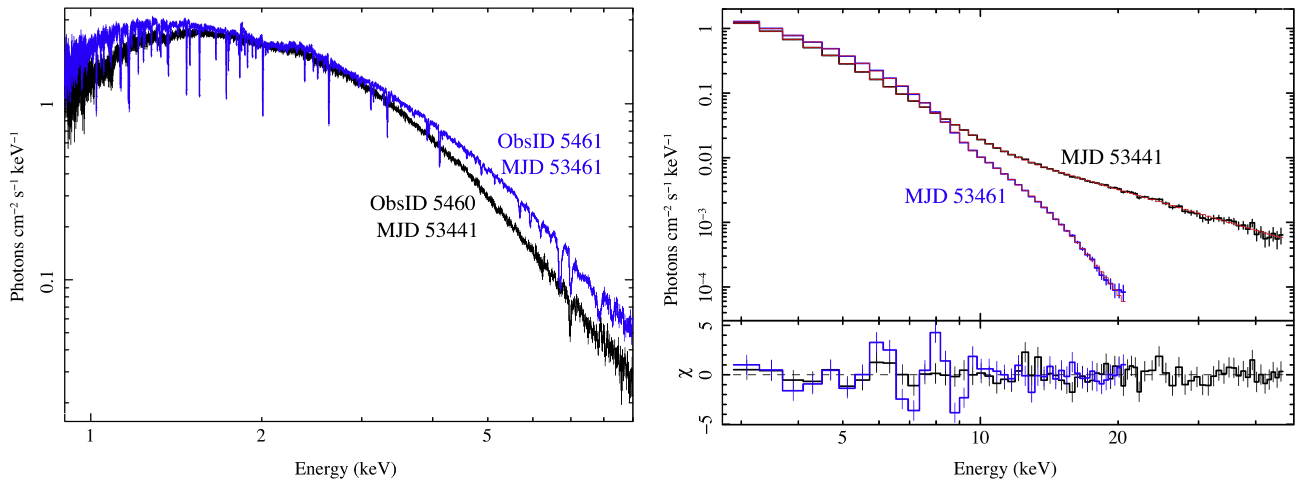

Fig. 1. Spectra of GRO J1655−40 from Neilsen and Homan (2012). () In both panels, black is the spectrum of the hard state and blue is the spectrum of the softer state. **Left:** *Chandra* HETGS spectra show only a single line during the first observation, but a rich series of lines from the accretion disk wind in the softer state. **Right:** *RXTE* PCA show significant differences in the corresponding broadband X-ray spectra, but we argue (Section 2.1) that the changes in the ionizing flux cannot explain the differences in the lines.

characterize accretion and ejection processes around stellar-mass black holes, and has become the backbone of our understanding of the spectral and timing behavior of black hole transients. But this story cannot be complete, for it fails to describe or account for the presence or the influence of another mode of mass ejection: highly-ionized accretion disk winds, whose behavior in outburst is only now becoming clear.

Just three years after the launch of *Chandra*, Lee et al. (2002) argued that winds could be associated with the accretion disk, although they were not confined to disk-dominated states. Miller et al. (2008) confirmed that in both GRO J1655−40 and GRS 1915+105, absorption lines were stronger in spectrally soft states (see also Neilsen and Lee, 2009). They suggested that higher ionizing flux might be responsible for the changes in the winds, but left open the possibility that other (e.g. geometric) changes might be required as well. Thus it remained unclear how or why winds might change on outburst time scales: were they steady, passive bystanders that simply responded to variations in the ionizing flux, or did they play a role in outbursts, appearing and disappearing just like jets?

2.1. *A case study in evolving winds*

With two high-resolution *Chandra* HETGS observations of accretion disk winds separated by less than three weeks (Miller et al., 2008; Neilsen and Homan, 2012), the 2005 outburst of the microquasar GRO 1655−40 presents an ideal backdrop against which to test the hypothesis that winds do not evolve during outburst. The *Chandra* and *RXTE* spectra are shown in the left and right panels of Fig. 1, respectively. The first observation (shown in black) took place during a hard state, while the second observation (shown in blue)[2] occurred during a much softer state. And while the first observation contained an Fe XXVI absorption line near 7 keV, the second provided an extremely rich absorption line spectrum that has been studied in great detail (Miller et al., 2006a; Netzer, 2006; Miller et al., 2008; Kallman et al., 2009; Neilsen and Homan, 2012; see Section 3 for a discussion of the origin of this wind).

Here, let us consider the question: why are the two *Chandra* absorption line spectra so different? Are the differences driven by changes in the photoionizing flux from the hard state to the soft state, or did the wind physically evolve over those 20 days? Our detailed analysis (Neilsen and Homan, 2012) indicates that the wind must have evolved significantly between the two *Chandra* observations. This argument can be understood both qualitiatively and quantitatively:

1. A comparison of the hard state and soft state PCA spectra in Fig. 1 reveals a clear excess of photons with $E > 10$ keV, which we usually think of as ionizing photons. Thus, at first glance it seems plausible that changes in the ionizing flux could explain the differences in the lines. In fact, however, *the ionization of this wind is determined primarily by soft X-rays*, since many of the visible ions during the softer state, like O, Ne, Na, Mg, Al, and Si, are effectively transparent to hard X-rays (due to their small cross-sections above 10 keV). Since the soft X-ray spectra of the two observations are quite similar, we conclude that the change in the relevant ionizing flux is negligible and cannot, in and of itself, explain the observed differences in the lines.

[2] For interpretation of color in Fig. 1, the reader is referred to the web version of this article.