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The physics of disk winds, jets, and X-ray variability in GRS 1915+105

Joseph Neilsen[1,2], Julia C. Lee[1,2] and Ron Remillard[3]

[1]Harvard University Department of Astronomy, Cambridge, MA 02138, USA

[2]Harvard-Smithsonian Center for Astrophysics, Cambridge, MA 02138, USA

[3]MIT Kavli Institute for Astrophysics and Space Research, Cambridge, MA 02139, USA

Abstract. We present new insights about accretion and ejection physics based on joint *RXTE/Chandra* HETGS studies of rapid X-ray variability in GRS 1915+105. For the first time, with fast phase-resolved spectroscopy of the ρ state, we are able to show that changes in the broadband X-ray spectrum (*RXTE*) on timescales of seconds are associated with measurable changes in absorption lines (*Chandra* HETGS) from the accretion disk wind. Additionally, we make a direct detection of material evaporating from the radiation-pressure-dominated inner disk. Our X-ray data thus reveal the black hole as it ejects a portion of the inner accretion flow and then drives a wind from the outer disk, all in a bizarre cycle that lasts fewer than 60 seconds but can repeat for weeks. We find that the accretion disk wind may be sufficiently massive to play an active role in GRS 1915+105, not only in quenching the jet on long timescales, but also in possibly producing or facilitating transitions between classes of X-ray variability.

1. Introduction

Of all the known Galactic black holes, GRS 1915+105 is undoubtedly the most prolific source of state transitions. Discovered as a transient by GRANAT in 1992 (Castro-Tirado *et al.*), it has remained in outburst for the last 18 years and is typically one of the very brightest sources in the X-ray sky. It is also one of the most variable: its X-ray lightcurve consists of at least 14 different patterns of variability, most of which are high-amplitude and highly-structured (Belloni *et al.* 2000, Klein-Wolt et al. 2002, Hannikainen *et al.* 2005). It is believed that many of these variability classes, which are labeled with Greek letters (Belloni *et al.* 2000), are limit cycles of accretion and ejection in an unstable disk (Belloni et al. 1997, Mirabel *et al.* 1998, Tagger *et al.* 2004).

Of its many classes of X-ray variability, three of the best studied are the χ state, which produces steady optically thick jets (see, e.g. Dhawan *et al.* 2000, Klein-Wolt *et al.* 2002), the β state, a wild 30-minute cycle with discrete ejection events (Mirabel *et al.* 1998), and the ρ state, which is affectionately known as the heartbeat state for the similarity of its lightcurve to an electrocardiogram (see Figure 1, right panel) and which consists of a slow rise followed by a short bright pulse, repeating with a period of roughly 50 s (Taam, Chen, & Swank 1997, Belloni *et al.* 2000). And while these variability classes have clearly established strong connections between the accretion disk and the jet, the physical processes behind this disk-jet connection have yet to be completely revealed.

2. Results and Discussion

In an effort to quantify the physics of these unusual variability classes and the disk-jet connection in GRS 1915+105, we recently analyzed ~ 10 years of high-resolution *Chandra* HETGS observations of this black hole X-ray binary (Neilsen & Lee 2009) and performed follow-up with detailed variability analysis (Neilsen *et al.* 2010b). In our long-term study, we found that during states dominated by jet activity, the X-ray spectra revealed a

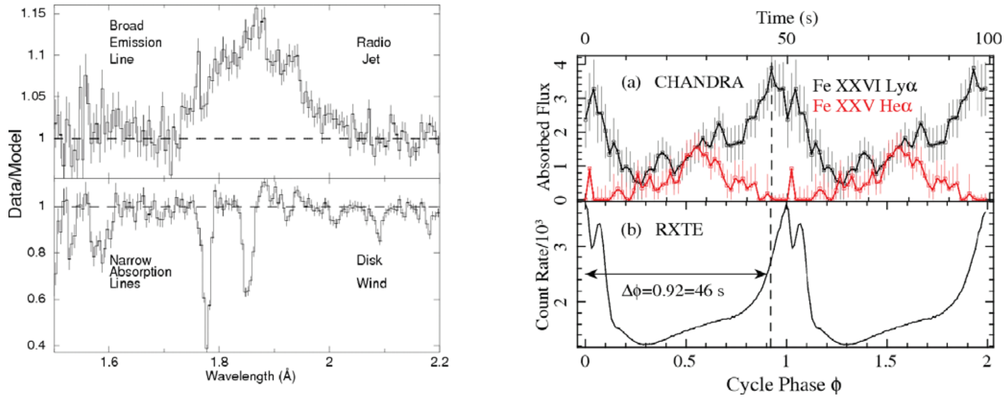

Figure 1. Two results from high-resolution X-ray spectroscopy of GRS 1915+105, clearly indicating links between the disk, wind, and jet on many different timescales. **Left:** The wind-jet connection on long timescales, based on Neilsen & Lee (2009), where we show that the disk wind may carry enough gas away from the black hole to halt the flow of matter into the jet. We detect the wind and the jet via their characteristic spectral signatures: (top) a broad iron emission line produced when the base of the jet illuminates the inner disk, and (bottom) narrow, blueshifted absorption lines originating in the highly-ionized disk wind. **Right:** Phase-resolved spectroscopy of the accretion disk wind in the ρ state from Neilsen *et al.* (2010b), showing strong flux and ionization changes in the disk wind on timescales of 5 seconds. The X-ray lightcurve, phase–folded over many cycles, is shown for comparison. Since the X-ray luminosity variations are insufficient to produce the observed ionization variability, our phase-resolved spectral analysis requires changes in the structure of the wind on timescales much less than one minute.

broad iron emission line, which we argued must originate when the jet illuminates the inner accretion disk. In contrast, we found that states where the jet is quenched display strong, narrow, blueshifted absorption lines from a highly-ionized accretion disk wind (see also Miller *et al.* 2008). We were able to demonstrate that the strength of this wind is anticorrelated with the *fractional* hard X-ray flux, which is therefore a useful diagnostic of both the accretion state and outflow physics. Furthermore, we discovered that the wind carries enough matter away from the black hole to suppress the jet, so that mass ejection is regulated in GRS 1915+105 (Figure 1, left panel).

To explore the implications of this result on short timescales and reveal fast (1 s) changes in the accretion flow, we have also performed the very first phase-resolved spectroscopy of the ρ variability class in GRS 1915+105 (Neilsen et al. 2010b) using a joint *RXTE/Chandra* observation. Through a combination of X-ray timing and both broadband and high-resolution X-ray spectroscopy, we show for the first time that changes in X-ray continuum on timescales of seconds (as probed by *RXTE*) are associated with measurable changes in absorption lines (*Chandra* HETGS) from the accretion disk wind (Fig. 1, right panel). Because the X-ray luminosity does not change enough to produce the observed ionization, the density of the disk wind must be modulated periodically on these timescales (see Lee et al. 2002 for additional evidence of wind structural changes).

From our broadband spectral analysis, we find spectroscopic evidence for a *local* Eddington limit (Fukue 2004, Lin *et al.* 2009) and the radiation pressure instability in the inner accretion disk (e.g. Lightman & Eardley 1974, Belloni *et al.* 1997). Our phase-resolved spectral analysis also allows us to detect bremsstrahlung emission from material evaporating from the inner accretion flow (see also Janiuk & Czerny 2005). Follow-up comprehensive analysis of all *RXTE* observations of the ρ state (Neilsen *et al.* 2010a) suggest that this periodic evaporation process is an essential component of this strange class of variability.

3. Conclusion

In summary, our combined X-ray timing and spectral analysis probing timescales from 1 second to 10 years reveals new evidence for physical processes that connect the accretion disk, the radio jet, and the accretion disk wind. Because the implied mass loss rate in the wind could be much higher than the accretion rate in the inner disk, we argue that the wind may be massive enough to play an integral role in GRS 1915+105, not only in quenching the jet on long timescales, but also in possibly producing or facilitating transitions between classes of X-ray variability (Shields *et al.* 1986, Neilsen & Lee 2009, Luketic *et al.* 2010, Neilsen *et al.* 2010b).

References

Belloni, T., Mendez, M., King, A. R., van der Klis, M., & van Paradijs, J. 1997, *ApJ Lett.*, 479, L185
Belloni, T., Klein-Wolt, M., Mendez, M., van der Klis, M., & van Paradijs, J. 2000, *A&A*, 355, 271
Castro-Tirado, A. J., Brandt, S., & Lund, S. 1992, *IAU Circ.* 5590
Fender, R. P. & Belloni, T. 2004, *ARAA*, 42, 317
Dhawan, V., Mirabel, I. F., & Rodriguez, L. F. 2000, *ApJ*, 543, 373
Fukue, J. 2004, *PASJ*, 56, 569
Hannikainen, D. *et al.* 2005, *A&A*, 435, 995
Janiuk, A. & Czerny, B. 2005, *MNRAS*, 356, 205
Lee, J. C., Reynolds, C. S., Remillard, R. A., Schulz, N. S., Blackman, E. G., & Fabian, A. C. 2002, *ApJ*, 567, 1102
Lin, D., Remillard, R. A., & Homan, J. 2009, *ApJ*, 696, 1257
Lightman, A. & Eardley, D. M. 1974, *ApJ Lett.*, 187, L1
Luketic, S., Proga, D., Kallman, T. R., Raymond, J. C., & Miller, J. M. 2010, *ApJ*, 719, 515
Klein-Wolt, M., *et al.* 2002, *MNRAS*, 331, 745
Miller, J. M., Raymond, J., Reynolds., C. S., Fabian, A. C., Kallman, T. R., & Homan, J. 2008, *ApJ*, 680, 1359
Mirabel, I. F. *et al.* 1998, *A&A*, 330, L9
Neilsen, J. & Lee, J. C. 2009, *Nature*, 458, 481
Neilsen, J., Lee, J. C., & Remillard, R. A. 2010a, *ApJ Lett.*, submitted
Neilsen, J., Remillard, R. A., & Lee, J. C. 2010b, *ApJ*, submitted
Shields, G. A., McKee, C. F., Lin, D. N. C., & Begelman, M. C. 1986, *ApJ*, 306, 90
Taam, R. E., Chen, X., & Swank, J. H. 1997, *ApJ*, 485, L83
Tagger, M., Varniere, P., Rodriguez, J., & Pellat, R. 2004, *ApJ*, 607, 410

Discussion

Falcke: Did you ever try to phase-stack radio data? E.g., with the VLM you should be able to get second-scale integration times.

Neilsen: We can't actually phase-fold the radio data because the time resolution is 32 seconds for a 50 second oscillation. But whe have an approved EVLA observation for the next summer where will have 3-second resolition and we will be able to do this.

Kalemci: What can you say about the power law index and disk/power law flux ratio when the strong broad band noise is observed?

Neilsen: I don't know the powe law/disk ratio off the top of my head. But I can tell you that this one interval that looks like the hard state (but lasts only 5 seconds) corresponds to the minimum of the cycle, and it is spectrally hard. However, the power law contributes less than about 50% of the luminosity.

Mirabel: What are the speeds of these winds?

Neilsen: The X-ray absorption is blueshifted by around 1000 km/s, but it varies from around 400 km/s to as much as 1600 km/s. In general, for our data, the higher the ionization, the faster the wind.

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