

Three modes of long wavelength flaring from GRS 1915+105: implications for jet formation

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Abstract.

GRS 1915+105 has exhibited at least three modes of long-wavelength (infrared to radio) flares. Class A flares are the bright (~ 1 Jy) radio events whose apparent superluminal motion in many ways defines the microquasars. Class B flares have intermediate ($\sim 50 - 300$ mJy) flux densities in the IR and radio, and are associated with hard X-ray dipping behaviors. Class C flares are faint ($\sim 5 - 50$ mJy) IR/radio events associated with soft X-ray dips. We discuss each of these classes and their inter-relationships.

Keywords: infrared: stars – X-rays: stars – black hole physics – stars: individual: GRS 1915+105

1. Class A – Large Radio Flares

The discovery of superluminal motions in a radio flare from GRS 1915+105 by Mirabel & Rodriguez (1994) in many ways launched the field of microquasar astrophysics. Such flares have been seen since then (e.g. Fender et al., 1999), and always seem to have peak flux densities of $F_\nu \sim 1$ Jy. The resolved jets with $v = 0.92c$ show spectral evolution from optically thick to optically thin, and seem to recur every few days during an ejection episode. The ejection episodes themselves recur on timescales of a few years. While Harmon et al. (1997) observed an association between the Class A flares and hard X-ray activity, no simultaneous time-resolved X-ray coverage has yet been obtained.

2. Class B – Mid-size IR/Radio Flares

The second class of long-wavelength events were first clearly characterized by Fender et al. (1997), whose same-day IR/radio observations showed flares with flux densities of $F_\nu \sim 50 - 100$ mJy and decay timescales of ~ 10 minutes. The brightness temperature in the radio implied a synchrotron origin for the flares and the constancy of the decay timescale over 4 decades of frequency implied that adiabatic expansion dominates the cooling process.

Eikenberry et al. (1998a,b) observed a long sequence of Class B flares in the IR over two nights in August 1997. These flares had peak flux



densities $F_\nu \sim 200 - 250$ mJy and recurrence timescales of $\sim 30 - 60$ minutes. Simultaneous X-ray observations with RXTE revealed that these flares are associated with complex X-ray behaviors (Figure 1). In particular, the flares come after the hard X-ray dips, during which the blackbody temperature in the inner disk drops while the power-law index hardens. Belloni et al. (1997) first interpreted dips such as these as the *disappearance* of the inner accretion disk, and combined with the observations of Fender et al. (1997) and Eikenberry et al., (1998a,b), we recognize that **these events provide the first direct time-resolved observations of relativistic jet formation in a black hole system.**

Mirabel et al. (1998) made simultaneous IR/radio/X-ray observations of several Class B flares, finding wavelength-dependent time delays, with the longer wavelengths peaking later. Such behavior is roughly consistent with that expected from an expanding van der Laan blob, and extrapolations based on this timing would indicate that the ejection occurs near the end of the hard X-ray dip.

3. Class C – Faint Flares

The existence of a third class of long-wavelength flares was first clarified through IR/X-ray observations by Eikenberry et al. (2000). These flares have peak flux densities in the IR of $\sim 4 - 8$ mJy and are associated with rapid soft X-ray dips (Figure 2), during which the blackbody temperature increases and the power-law index softens (as opposed to the hard Class B dips). These flares also seem to explain the quasi-steady IR excess during similar X-ray behaviors in 1997 (Eikenberry et al., 2000).

It is interesting to note that the IR flares appear to begin *before* the X-ray activity, implying an “outside-in” propagation of the disturbance – opposite of the Class B behavior. The spotty coverage from RXTE makes “aliasing” a problem for verifying this. However, Eikenberry et al. (2000) showed that no constant delay fits with the X-rays preceeding the IR flares, and even a non-steady delay would have to reach up to ~ 3000 seconds. Thus, the “IR-first” explanation seems the least objectionable for the observations.

4. Three Separate Behaviors ?

A key issue here is the reality of the distinction between the three classes presented above. The Class C flares seem distinguishable from

Class B due to the marked differences in their corresponding X-ray behaviors (soft versus hard dips, IR-first versus X-ray-first), as well as differences in recurrence times and amplitudes. Class B flares, on the other hand, behave in many ways like “baby jet” versions of Class A ejections. In particular, the relative amplitudes and decay timescales are roughly consistent with identical ejections, but with ~ 1000 times less mass in the Class B events. However, Dhawan et al. (2000) have used VLBA to resolve the Class B events, and find that their axis of motion differs significantly from the Class A events. Thus, it appears that there are in fact at least 3 distinct modes of jet production in GRS 1915+105.

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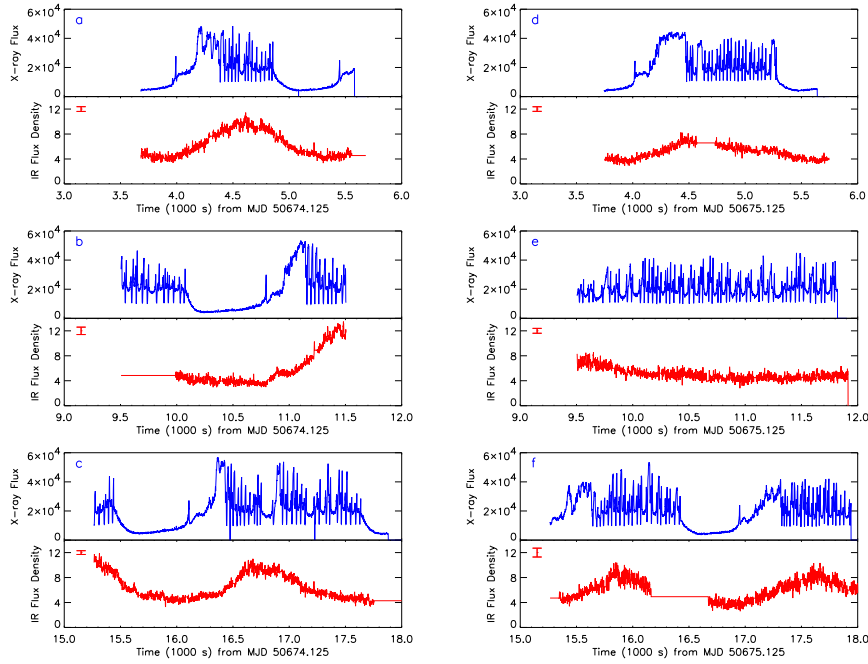


Figure 1. Simultaneous IR/X-ray observations of Class B flares from Eikenberry et al. (1998a).

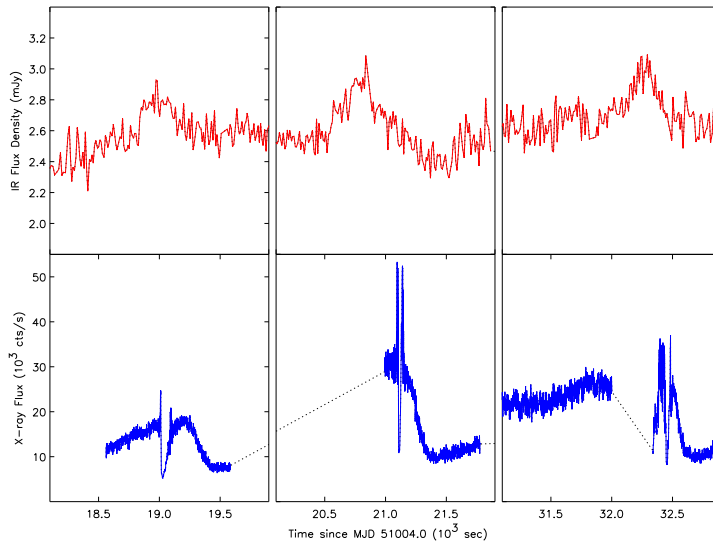


Figure 2. Simultaneous IR/X-ray observations of Class C flares from Eikenberry et al. (2000).