FAINT INFRARED FLARES FROM THE MICROQUASAR GRS 1915+105

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ABSTRACT

We present simultaneous infrared and X-ray observations of the Galactic microquasar GRS 1915+105 using the Palomar 5 m telescope and Rossi X-Ray Timing Explorer on 1998 July 10 UT. Over the course of 5 hr, we observed six faint infrared (IR) flares with peak amplitudes of ~0.3–0.6 mJy and durations of ~500–600 s. These flares are associated with X-ray soft-dip/soft-flare cycles, as opposed to the brighter IR flares associated with X-ray hard-dip/soft-flare cycles seen in 1997 August by Eikenberry et al. Interestingly, the IR flares begin before the X-ray oscillations, implying an “outside-in” origin of the IR/X-ray cycle. We also show that the quasi-steady IR excess in 1997 August is due to the pileup of similar faint flares. We discuss the implications of this flaring behavior for understanding jet formation in microquasars.

Subject headings: black hole physics — infrared: stars — stars: individual (GRS 1915+105) — X-rays: stars

1 INTRODUCTION

As the archetypal Galactic microquasar, GRS 1915+105 offers unique observational opportunities for investigating the formation of relativistic jets in black hole systems. To date, two types of ejection events have been observed from this system. The first of these, the “major” ejections, produce bright (~1 Jy) resolvable radio jets that move with apparent velocities of \(v_{\text{app}} = 1.25c\) and actual space velocities of \(v \sim 0.9c\) (Mirabel & Rodriguez 1994; Fender et al. 1999). The jets transition quickly from optically thick to optically thin spectra and then fade on timescales of several days. Because of the rarity of these events, coordinated pointed X-ray observations have not been possible to date.

The second type of ejection event consists of X-ray oscillations with hard power-law dips and thermal flares and associated synchrotron flares in the infrared (Eikenberry et al. 1998a, 1998b) and radio bands (Mirabel et al. 1998; Fender & Pooley 1998). We refer to these events as “class B” flares to distinguish them from the larger “class A” major ejection events. These smaller events have peak intensities in the range ~100–200 mJy from the infrared (IR) to radio bands, and the time of peak flux exhibits apparent delays as a function of wavelength, which may indicate the expansion of a synchrotron bubble (Mirabel et al. 1998). The flares fade on timescales of several minutes and tend to repeat on timescales from ~30 to 50 minutes (i.e., Pooley & Fender 1997; Eikenberry et al. 1998a).

In this Letter, we present a third type of IR flare from GRS 1915+105: faint (submillijansky) IR flares associated with X-ray soft-dip/soft-flare cycles. In §2, we present the observations and analysis of these flares. In §3, we discuss the implications of the flares for understanding relativistic jet formation in microquasars. In §4, we present our conclusions.

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to the hard X-ray dips associated with class B IR/radio flares. Furthermore, the rises of the IR flares in Figure 2 appear to precede the X-ray oscillations. Note that for the first two X-ray dips, there are IR flares ~1500–1800 s later, suggesting a possible correspondence between X-ray dips and highly delayed IR flares. However, if this were the case, we would expect X-ray dips at ~24,600 and ~30,300 s, to match the observed IR flares at 26,200 and 31,900 s. Since we do not see X-ray dips at these times, we conclude that the actual IR/X-ray correspondence has IR flares preceding X-ray dips by ~200–600 s. Thus, these observations are the first to clearly demonstrate the time ordering of associated X-ray dips and IR flares in GRS 1915+105.

### 2.2. 1997 August Observations

We also observed GRS 1915+105 simultaneously with the Palomar 5 m telescope and RXTE on 1997 August 13–15 (see also Eikenberry et al. 1998a, 1998b). The basic observational parameters were similar to those for 1998 July described above. On 1997 August 14–15, we observed a series of class B IR flares with their corresponding X-ray cycles of hard dips and thermal flares. We also noted that at times the IR flux from GRS 1915+105 showed a noticeable quasi-steady IR excess (Fig. 3, top), much lower than the flux levels from the class B flares themselves, but higher than the apparent baseline IR emission of ~3.6 mJy on those nights. Interestingly, the episodes of excess IR emission appear to be associated with rapid X-ray oscillations (Fig. 3, bottom) that seem to resemble the X-ray cycles seen in 1998 July (Fig. 2). Motivated by the X-ray/IR association we observed in the 1998 July data, we performed detailed X-ray spectral analyses of X-ray oscillations in both epochs. Figure 4 shows the resulting best-fit parameters to typical X-ray oscillations from both epochs at 1 s time resolution using the XSPEC package and an absorbed multitemperature blackbody + power-law model (identical to those described in Muno, Morgan, & Remillard 1999). Not only are the morphologies of the events quite similar (although the 1997 August cycle is ~3 times faster), but the key spectral parameters of blackbody temperature and power-law index seem to evolve in a virtually identical manner for both epochs. These similarities in both morphology and spectrum confirm that the X-ray cycles from 1998 July and 1997 August are indeed the same phenomenon. Furthermore, note that the blackbody temperature drops and the power-law index rises during the X-ray dip, both of which effects cause a softening of the X-ray spectrum during the dip. The X-ray dips associated with class B flares, on the other hand, show a decrease in the blackbody temperature and a marked decrease in the power-law index, making them spectrally hard. Thus, the events we discuss here differ from those associated with class B flares.

Based on these results, we then hypothesize that the IR excess seen in 1997 August 14–15 during the X-ray oscillations may be due to faint infrared flares such as those seen in Figures 1 and 2. Since the X-ray oscillations are separated by ~20–40 s in 1997 August and the typical width of the faint IR flares is ~500 s, many flares will be superposed on one another to create the appearance of a quasi-steady IR excess such as we observe. If we assume that each X-ray oscillation in Figure 3 (bottom) has an associated IR flare and we approximate that flare as a Gaussian with ~0.3 mJy amplitude and 160 s FWHM (consistent with the faintest 1997 July flares), we can calculate a predicted IR excess of 1.3 mJy. This value is a close match to the actual observed excess of ~1.0 mJy we observed (Fig. 3).

### 3. DISCUSSION

Based on these observations, we surmise that we have found a new type of IR flare associated with X-ray oscillations in GRS 1915+105. These events differ significantly from the previously known class B events in their IR brightness as well as the timescale, morphology, and spectral characteristics of the X-ray oscillations. In keeping with our proposed classification scheme for such flares—class A being major ejection events and class B being the ~100–200 mJy (dereddened) IR/radio flares associated with hard X-ray dips—we assign these faint IR flares associated with soft X-ray dips the label “class C.”

The 1998 July observations are useful not only in allowing us to identify this new phenomenon, but also in allowing us to determine the timing relationship between the X-ray and
IR oscillations. Previous observations of class B events (e.g., Eikenberry et al. 1998a) have been unable to unambiguously determine whether the IR/radio flares come from an ejection at the beginning of the preceding hard X-ray dip, at its end, or simultaneously with a soft X-ray “spike” seen during the dip. Mirabel et al. (1998) suggest that the ejection occurs at the time of the spike, based on timing/flux arguments and an expanding plasmoid (van der Laan) model for their IR/radio data. However, this model predicts an IR peak flux density ~20 times higher than observed, and thus this issue remains unresolved for now.

There are several physical phenomena that might produce the class C behavior, but our understanding may be helped by recently published X-ray/radio observations of Feroci et al. (1999). Using BeppoSAX and the Ryle Telescope, they report an X-ray event very similar in both flux and spectral evolution to those we report here. Furthermore, they observed a ~40 mJy radio flare that peaked ~1000 s after the X-ray event. If we assume that this is a class C event and furthermore that it had an (unobserved) IR flare similar in flux density and timing to those we observed, then we must conclude that the flares have a flat peak flux density over several decades of frequency ($F_{\nu} \propto \nu^{-0.15}$), with longer wavelengths delayed compared to shorter wavelengths. This behavior closely resembles that of class B flares (Mirabel et al. 1998) and thus suggests that the class C flares are also due to synchrotron emission from an expanding plasma bubble.

The fact that the IR flares precede the X-ray oscillations suggests an “outside-in” model for these events. In such a model, a disturbance far from the black hole propagates inward, first creating the synchrotron flare. Then, as the disturbance reaches the innermost portion of the accretion disk, which produces the majority of the thermal X-ray flux, it creates the X-ray flare-dip-flare cycle. Several possibilities may explain these observations. If we assume that class C events are due to ejection events that occur before the inner disk is perturbed, we must conclude that the innermost portion of the accretion disk is not the site of origin for the ejections, contrary to what is generally believed for microquasars (and other relativistic jet systems). An alternative interpretation may be that the IR/radio flare comes from a plasma bubble created by a magnetic reconnection event in the accretion disk, which would generate a disturbance in the accretion flow. Theorists have hypothesized that such reconnection events may be commonplace in systems in which jets are powered by magnetocentrifugal launching mechanisms. Yet another interpretation could be that the jets in GRS 1915+105 are not composed of discrete events, but are continuous low-luminosity outflows punctuated by the appearance of occasional high-luminosity shock events propagating through the flow (as has been suggested for the case of relativistic jets in active galactic nuclei). In this case, the class C events could be due to a reverse shock propagating through the jet back toward the disk. As it nears the inner disk, the shock would first produce a synchrotron bubble, generating the IR (and eventually radio) flares, and then reach the inner disk itself to disrupt the X-ray emission, as observed.

4. CONCLUSIONS

We have reported a new type of IR/X-ray oscillation in the microquasar GRS 1915+105. These oscillations show faint (~0.5 mJy) IR flares with durations of ~500 s and are associated with X-ray cycles of soft dips and thermal flares. This distinguishes them from previously known GRS 1915+105 behaviors that show either major radio flares (class A) or brighter (~100–200 mJy) IR/radio flares accompanied by X-ray events with hard dips and thermal flares (class B). Thus, we label these events as class C events.

Combining our observations with X-ray/radio observations of a single class C event by Feroci et al. (1999) indicates that the class C events are due to synchrotron emission from an expanding plasmoid. Furthermore, in the class C events the IR flare precedes the onset of the X-ray cycle by several hundred seconds, suggesting an “outside-in” model for them. Several possibilities exist for explaining this behavior, including magnetic reconnection events in the outer disk or reverse shocks propagating through a continuous jet medium.
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