1. INTRODUCTION

GRS 1758−258 and its sister source, 1E 1740.7−2942, were the first objects dubbed “microquasars” (Mirabel et al. 1992; Mirabel 1994). Their X-ray spectra are typical of Galactic black hole candidates (BHCs), and they are apparently associated with the time-variable cores of amorphous scale double-lobe radio sources, reminiscent of extragalactic radio sources. This morphology, seen on a parsec scale within the Milky Way, earned them their nickname. GRS 1758−258 and 1E 1740.7−2942 are the brightest persistent sources in the Galactic bulge above ∼50 keV (Sunyaev et al. 1991). Their timing characteristics are typical of the black hole low/hard state (Main et al. 1999; Smith et al. 1997; Heindl et al. 1993; Sunyaev et al. 1991), and they consistently emit near their brightest observed levels, although they vary over times of days to years. Their X-ray emission properties are readily likened to the canonical BHC Cygnus X-1. In fact, together with Cyg X-1, they are the only known persistent, low-state BHCs, and all three sources have maximum luminosities around 3 × 10^37 ergs s^{-1}. Radio jets have now been observed in Cyg X-1, furthering the similarity (Stirling et al. 2001).

However, GRS 1758−258 and 1E 1740.7−2942 are quite different from the Galactic superluminal radio sources (e.g., GRS 1915+105 and GRO J1655−40) more typically thought of as microquasars. The X-ray emission from these objects is much brighter and more spectacularly variable. Their radio jets, too, are brighter and are highly variable, being unresolved or absent except during exceptional ejection events that last only weeks. In contrast, the radio lobes of GRS 1758−258 and 1E 1740.7−2942 are quite stable (Martí et al. 2002).

The association of GRS 1758−258 and 1E 1740.7−2942 with their corresponding radio counterparts has been based primarily on relatively coarse (∼10") X-ray positions and the very unusual (and yet nearly identical) nature of the radio sources. Some hint of correlated radio and hard X-ray emission was found for 1E 1740.7−2942 (Mirabel et al. 1993), and recently Cui et al. (2001) confirmed the X-ray/radio association for 1E 1740.7−2942 by using Chandra to obtain a precise X-ray position. In this Letter, we do the same for GRS 1758−258, and using the fine resolution of the High Resolution Camera (HRC), we place limits on emission from any arcsecond-scale jets.

2. OBSERVATIONS

We observed GRS 1758−258 four times with Chandra. Table 1 lists the observation dates and durations. Two observations with the imaging detector of the HRC (HRC-I) were made in 2000 September–October spanning an intermediate-to-hard spectral transition (identified with the Rossi X-Ray Timing Explorer [RXTE]; Smith, Markwardt, & Heindl 2001; Smith et al. 2001). Another HRC-I observation and an Advanced CCD Imaging Spectrometer (ACIS)/High Energy Transmission Grating (HETG) observation were made back to back in 2001 March following a dramatic hard-to-soft transition to a very low flux state (Smith et al. 2001). Figure 1 shows the RXTE/Proportional Counter Array (PCA) light curve with our Chandra observations indicated. In each observation, a highly significant point source was detected at a location consistent with the known GRS 1758−258 position. In this Letter, we discuss the accurate X-ray position and morphology of GRS 1758−258 as observed with the HRC and in the HETG zero-order image. Preliminary results, both spatial and spectral, from these observations were reported in Heindl & Smith (2001).

3. ANALYSIS AND RESULTS

The HRC observations were processed with ASCDS version R4CU5UPD14.1, and the ACIS-S observation with version R4CU5UPD14.5. All four data sets were processed with CALDB version 2.4. This is particularly important for the HRC data since CALDB versions 2.2 and later incorporate up-to-date “degapping” coefficients that are necessary to provide artifact-free images (A. Kenter 2001). For this work, we applied the absolute pointing corrections available as of 2002 May 2,1 which accounts

1 See http://asc.harvard.edu/cal/Hrc/degap.html.
2 See http://cxc.harvard.edu/cal/ASPECT/celmon.
for the slight differences from the results reported in Heindl & Smith (2001). We used CIAO 2.2 (Chandra Interactive Analysis of Observations) tools throughout these analyses.

3.1. Source Location

To determine the position of GRS 1758−258, we extracted an image of the central region of the field for each observation, binned at the full level-2 events file resolution (∼0.13 pixel$^{-1}$ for the HRC and ∼0.49 for ACIS-S). We then applied the CIAO tool “WAVDETECT” to find the coordinates of the source. The uncertainty in the location of the source within the image is small compared with the overall Chandra aspect uncertainties. According to Chandra X-Ray Observatory Center documents, the rms uncertainty in absolute position determinations at the time of our observations was 0.6, corresponding to a 90% confidence radius of $R_{\text{rms}} = 0.9$ for a single pointing. The measured deviation of our four positions is 0.41 rms, consistent with these calibrations. We averaged the four measurements (applying equal weights to each and assuming the advertised 0.6 rms uncertainty) to derive $R_{\text{rms}} = 0.45$. This assumes that the positions are Gaussian-distributed and that no systematic error causes an offset in the resulting mean position. We note that two observations were made with spacecraft roll angles near 90° (see Table 1) while the others had roll angles near 270°. This would tend to cancel any roll angle–dependent systematic offsets.

Figure 2 shows the measured source locations from our four Chandra observations as well as the estimated confidence region. The ACIS-S/HETG position (400163) was based on the zeroth-order image. While the image was significantly piled up, we expect a negligible effect on the position (H. Marshall 2001, private communication). The Chandra 0.45 radius error circle is centered at (J2000) R.A. = 18h01m12s.39, decl. = −25°44′35.9″. The 5° error circle from XMM is also indicated (Goldwurm et al. 2001).

![Fig. 1.—RXTE/PCA light curve of GRS 1758−258 in two energy bands. Our Chandra observations (see Table 1) are indicated by dotted vertical lines. Observations 400163 and 400164 were made consecutively and so appear as a single line near 2001.2. The 1996–1997 flux history appears very similar to 1998, with the source remaining quite stable within a factor of ∼2.](image1)

![Fig. 2.—Error circles for GRS 1758−258. The 90% confidence Chandra error circle (0.45 radius) includes the 0.1 VLA-C radio position of Martí et al. (1998). Positions from the four individual observations are indicated by crosses and labeled by sequence number. Coordinates are offsets from the radio position: (J2000) R.A. = 18h01m12s.39, decl. = −25°44′35.9″. The 5° error circle from XMM is also indicated (Goldwurm et al. 2001).](image2)

![Fig. 3.—Point-spread function (PSF) sigmas of Gaussian fits to slices through the image peak as a function of azimuthal angle for the three HRC observations of GRS 1758−258 and, for comparison, AR Lac. For clarity, each observation has been offset, and the mean value of sigma labeled and indicated by a dotted line. The amplitude of the variations are indicated at the right.](image3)

### Table 1

| Sequence Number | Date       | Instrument | Exposure (ks) | Roll Angle (deg) |
|-----------------|------------|------------|---------------|-----------------|
| 400085          | 2000 Sep   | HRC-I      | 1             | 270.5           |
| 400131          | 2000 Oct   | HRC-I      | 10            | 268.5           |
| 400164          | 2001 Mar   | HRC-I      | 10            | 89.8            |
| 400163          | 2001 Mar   | ACIS-S*    | 30            | 90.1            |

* HETG order zero.
We note that a second source (designated CXOU J180106.1−253903; R.A. = 18°01′06″1, decl. = −25°39′03″0, and $R_{\text{maj}} = 0′′9$) was detected in all three HRC pointings, and a third (CXOU J180031.0−254154; R.A. = 18°00′31″0, decl. = −25°41′53″9, and $R_{\text{maj}} = 1′′7$) was marginally detected in a single pointing (see Table 2). The Chandra position for CXOU J180106.1−253903 is 0′′76 from a USNO-A2 star with red and blue magnitudes of 14.7 and 15.9, respectively. While this star may be the optical counterpart of CXOU J180106.1−253903, no astrometric reference lies within 5″ of CXOU J180031.0−254154. A single precision frame tie, particularly 6′ off-axis, is inadequate to improve dead-reckoning astrometry. Therefore, we have not applied any aspect correction based on the possible identification of CXOU J180106.1−253903.

3.2. Image Analysis

To search for extended emission (e.g., jets) that would appear as asymmetries in the image peak, we performed Gaussian fits to slices through the peak taken over a range of position angles. We performed the same analysis on an HRC observation of the RS Canum Venaticorum binary AR Lacertae. AR Lac is expected to be a point source and, given its very low column density ($N_{\text{HI}} < 2 \times 10^{18} \text{ cm}^{-2}$; Kaastra et al. 1996), should also lack any significant scattering halo. Figure 3 shows the resulting Gaussian sigmas plotted as a function of slice position angle in detector coordinates for all three GRS 1758−258 and the AR Lac HRC observations. In all cases, a roughly sinusoidal variation is seen with an amplitude of ~0.06. The phase of the variation is the same in all observations. We note that observation 400164 has a slightly higher amplitude (0′′08), but because the phase is unchanged and the overall size of the effect is so small, we conclude that this is not indicative of source structure. We therefore attribute these variations to instrumental effects and conclude that GRS 1758−258 is consistent with a point source.

4. DISCUSSION

Goldwurm et al. (2001) recently used XMM data to derive a 5″ error radius for GRS 1758−258. This work, which is consistent with their result, reduces the area of the error region by 2 orders of magnitude. The coincidence of the subarcsecond Very Large Array (VLA) and Chandra error circles seals the association of GRS 1758−258, the X-ray source, with the variable radio source (“VLA-C”; Marti et al. 1998). From radio source counts (Condon 1984), we estimate a chance probability of ~10$^{-3}$ for a radio source brighter than VLA-C (0.2 mJy) to fall in the Chandra error circle. Marti et al. (1998) identified two candidate counterparts to VLA-C in I- and K-band images. The brighter and closer candidate was found, through multiband photometry and near-infrared spectroscopy, to be most likely an early K giant. Revised astrometry (Rothstein et al. 2002) of infrared observations by Eikenberry et al. (2001) confirm that this star (labeled “A”) is consistent with VLA-C at the 3 σ level. The second candidate of Marti et al. (1998) is likely a main-sequence F star but is inconsistent with the astrometry of Rothstein et al. (2002). Furthermore, Smith, Heindl, & Swank (2002) have found a low-amplitude (~4%), 18.45 ± 0.10 day periodic modulation of the GRS 1758−258 X-ray emission observed with RXTE. This period fits well with the orbit of a Roche lobe–filling K giant companion (Rothstein et al. 2002), and so a more complete picture of GRS 1758−258 is emerging. With the X-ray/radio association confirmed and periodic X-ray emission pointing to a K giant, GRS 1758−258 appears to be a black hole with an intermediate-mass giant companion.

GRS 1915+105 (Greiner, Cuby, & McCaughrean 2001), GRO J1655−40 (Shahbaz et al. 1999), XTE J1550−564 (Orosz et al. 2002), and now GRS 1758−258—all four of the black hole microquasars in low-mass systems—have evolved companions. Meanwhile, jets have not been observed in the more common black hole soft X-ray transients (SXTs) with main-sequence companions. This prompts us to examine the connection between giant companions and jet activity. Perhaps an evolved companion overflows its Roche lobe by a large factor, providing a higher typical accretion rate. These four objects are persistent or quasi-persistent, having very different time histories from the standard SXT “fast rise and exponential decay” light curve. The SXT outbursts are driven by an accretion instability following long periods of relatively low accretion rates (see, e.g., Cannizzo 1998). Possibly steady, high-rate accretion provides an environment conducive to jet formation.

Finally, we note that the present lack of X-ray jets is completely consistent with the energetics of the radio lobes. Rodriguez, Mirabel, & Marti (1992), assuming a distance of 8.5 kpc, estimated the luminosity of the radio lobes to be ~10$^{40}$ erg s$^{-1}$ and their energy content to be roughly 10$^{44}$ ergs. With a typical X-ray luminosity of a few times 10$^{37}$ ergs s$^{-1}$, the present lobes could have been energized by a small fraction of the X-ray power over a period as short as a few years. In fact, given the long lifetime (~3 × 10$^4$ yr) of the radio lobes, this indicates that either the duty cycle for or the efficiency of feeding the jets (or both) is very low.

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