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# Identification of the donor in the X-ray binary GRS 1915+105*

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**Abstract.** We report on the results of medium-resolution spectroscopy of GRS 1915+105 in the near-infrared $H$ and $K$ band using the 8 m VLT at ESO. We clearly identify absorption bandheads from $^{12}$CO and $^{13}$CO. Together with other features this results in a classification of the mass-donating star in this binary as a K-M III star, clearly indicating that GRS 1915+105 belongs to the class of low-mass X-ray binaries (LMXB).

**Key words.** stars: binaries – infrared: stars – stars: individual: GRS 1915+105

## 1. Introduction

GRS 1915+105 (Castro-Tirado et al. 1994) is the prototypical microquasar, a galactic X-ray binary ejecting plasma clouds at $v \approx 0.92\,c$ (Mirabel & Rodriguez 1994). It exhibits unique X-ray variability patterns (Greiner et al. 1996) which have been interpreted as accretion disk instabilities leading to an infall of parts of the inner accretion disk (Belloni et al. 1997). Based on its X-ray properties GRS 1915+105 is suspected to be the most massive stellar black hole candidate in the Galaxy (Morgan et al. 1997). It is one of only two galactic sources which are thought to contain a maximally spinning black hole (Zhang et al. 1997). It is therefore of great importance to know some details about the system components in order to understand the conditions which lead to the unique X-ray, radio, and IR characteristics.

Previous infrared spectroscopy at Palomar (Eikenberry et al. 1998), UKIRT (Mirabel et al. 1997; Harlaftis et al. 2001) and the VLT (Martí et al. 2000) has shown that the He II emission line is variable, most probably depending on the X-ray activity. In particular, Eikenberry et al. (1998) found variations in line flux of 5 on 5–10 min timescales, suggesting that these IR lines are radiatively pumped by (presumably) jet ejection events rather than high X-ray luminosity. Based on the IR spectral variability and on its position on the IR H–R diagram, Castro-Tirado et al. (1996) suggested that GRS 1915+105 is a LMXB. On the contrary, based on the detection of He I, Mirabel et al. (1997) and Martí et al. (2000) suggested that the donor in GRS 1915+105 is a high-mass O or B star, and that accretion occurs predominantly from the wind of the donor.

## 2. Observations and results

We wished to search for absorption signatures due to the donor in the binary system GRS 1915+105. Since GRS 1915+105 is a strongly variable infrared source, believed to predominantly caused by synchrotron emission of ejected material (Eikenberry et al. 2000; Greiner et al. 2001), this required high signal-to-noise as well as good spectral resolution in order to beat the strong veiling. We therefore used the infrared spectrometer ISAAC on the 8 m VLT Antu telescope on Paranal (ESO, Chile) to obtain $H$ and $K$ band spectra.

The short wavelength (0.9–2.5 $\mu$m) arm of ISAAC is equipped with a $1024 \times 1024$ pixel Rockwell HgCdTe array with an image scale of $0\farcs147$/pixel. Using the medium resolution grating (0.8 Å/pixel in the $H$ band, 1.2 Å/pixel in the $K$ band) yields a spectral resolution of ~3000 with a $1''$ slit. Observations were performed in 1 (2) adjacent $H$ bands, and 2 (3) adjacent $K$ bands on 20/21 July 1999 (24/25 July 2000).

Science exposures consisted of several 250–300 s individual exposures which were dithered along the slit by $\pm 30''$. In order to correct for atmospheric absorption, the nearby star HD 179913 (A0 V) was observed either before or after each science exposure. The initial data reduction steps like bias subtraction, flatfielding and co-adding were performed within the *Eclipse* package (Devillard 2000).

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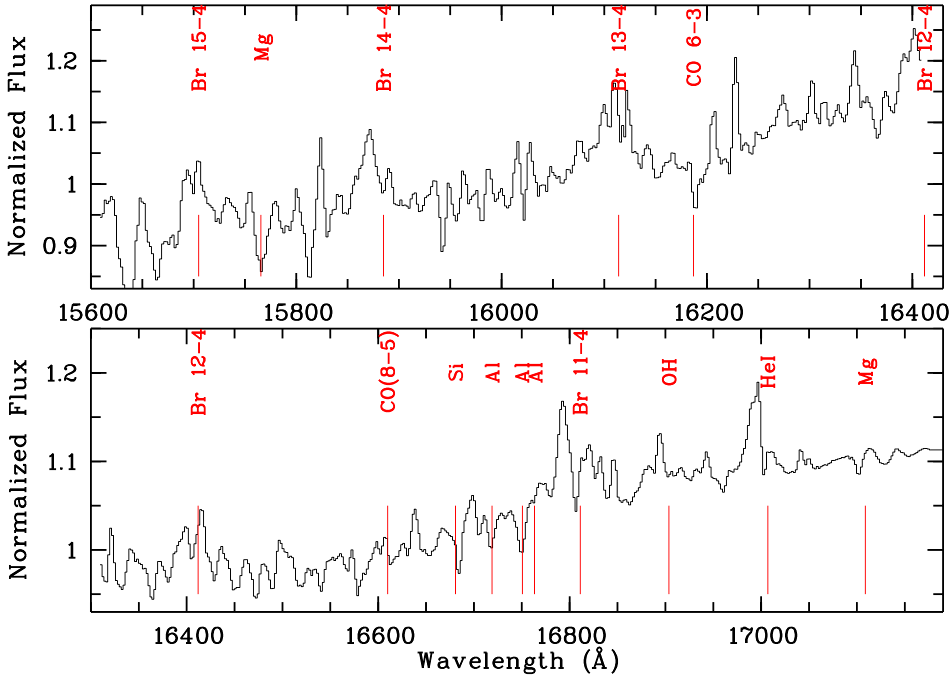


**Fig. 1.** Normalized spectrum of GRS 1915+105 in the $H$ band. The top panel represents a 6000 s exposure from 1999, while the bottom panel shows the sum of the 2 images taken in 1999 and 2000 (total exposure of 8400 s). The spectra were rebinned to 2 Å resolution. Obvious detected lines are marked by vertical lines and labels, as well as the location of lines mentioned in the text.

**Table 1.** Observation log.

| Wavelength | 21-07-1999 | Exposure | 24-07-2000 | Exposure |
|---|---|---|---|---|
| 1.56–1.64 $\mu$m | | | 0:33–2:15 | 10*600 s |
| 1.63–1.72 $\mu$m | 5:43–6:25 | 8*300 s | 2:20–4:03 | 10*600 s |
| 2.06–2.17 $\mu$m | 4:20–4:59 | 12*180 s | 4:19–5:10 | 10*300 s |
| 2.17–2.29 $\mu$m | | | 5:11–6:03 | 10*300 s |
| 2.29–2.41 $\mu$m | 6:35–7:18 | 8*300 s | 6:21–7:31 | 10*300 s |

The extraction and wavelength calibration was done using an optimal extraction routine within the MIDAS package.

The spectra of the 2 grating settings covering the $H$ band are shown in Fig. 1, and of the 3 grating settings covering the $K$ band in Fig. 2. The $K$ band top panel shows the strong Br $\gamma$ and He I emission lines known from previous low-resolution spectroscopy (Castro-Tirado et al. 1996). Similarly, we see Brackett series in emission from 11–4 (Br $\eta$) to 15–4 (Br $\lambda$) in the H band. We do not find He II emission as reported by Castro-Tirado et al. (1996), Eikenberry et al. (1998) and Martí et al. (2000), supporting their conclusion that this is a variable feature probably related to the X-ray state and jet ejection activity. We note that during our 1999 ISAAC observation of GRS 1915+105 was in a state of low activity at X-rays and radio, though the time from the last radio flare and towards the next radio flare were different to the Martí et al. (2000) observation.

Both, the H as well as He I lines are clearly resolved, having $FWHM$ ~10−15 Å at a resolution of 5 Å (in the $H$ band). If this were due to rotational Doppler broadening, it would correspond to a velocity of $v \sin i \sim$ 200–300 km s$^{-1}$. In most cases, these H/He I lines are not gaussian, but have a central depression. Given the fact that the inclination of the binary system is $i \sim$ 70 deg $\pm$2 deg (Mirabel & Rodriguez 1994) one indeed may anticipate a double-lined shape. We do not find P Cyg profiles in the Br $\gamma$ and He I as reported by Martí et al. (2000).

In addition, we find for the first time several absorption lines which allow us to make a rough identification of the donor in the GRS 1915+105 binary. In the $K$ band we clearly identify $^{12}$CO absorption band heads characteristic of a low temperature ($T < 7000$ K) star (e.g. Kleinmann & Hall 1986). Though weak, we also identify the $^{13}$CO (2,0) and $^{13}$CO (3,1) transitions, indicating a luminosity class III or brighter (e.g. Wallace & Hinkle 1997). We also identify the Na doublet (2.20624/2.20897 $\mu$m), and possibly the Ca triplet (2.26141/2.26311/2.26573 $\mu$m), Al I (2.10988 $\mu$m) and the Mg I doublet (2.10655/2.10680 $\mu$m) in absorption. Note that the CN doublet (2.0910/2.0960 $\mu$m), which in supergiants is more prominent than Al/Mg, is not detected. In the $H$ band, we identify Mg I (1.5749 $\mu$m) (though $^{12}$CO (4,1) may also contribute), $^{12}$CO (6,3) and $^{12}$CO (8,5) in a ratio which is consistent with MK standards (Meyer et al. 1998), and Al I (16718.9/16750.6 $\mu$m). Comparing the 2.3–2.4 $\mu$m spectrum from 20/21 July 1999 with that taken on 24/25 July 2000 (after heliocentric correction), we find that the CO band head systems are shifted by 60 km s$^{-1}$ relativ to each other. The easiest interpretation is Doppler motion, and therefore indicates that the CO absorption is indeed of photospheric origin and not due to absorption in a static, cold, circumstellar medium. Thus, we conclude that we have identified the donor in GRS 1915+105, and that it is a late-type, K-M giant.

We have tried to confirm the luminosity class more quantitatively by using the veiling-independent indicator $r = \log[EW(^{12}\mathrm{CO}(2,0))/(EW(\mathrm{Na})+EW(\mathrm{Ca}))]$ (Ramírez et al. 1997). Because of the low significance of the Ca triplet, our measurement has a large error: $r = 0.25\pm0.20$. This value falls in between the ranges covered by dwarfs

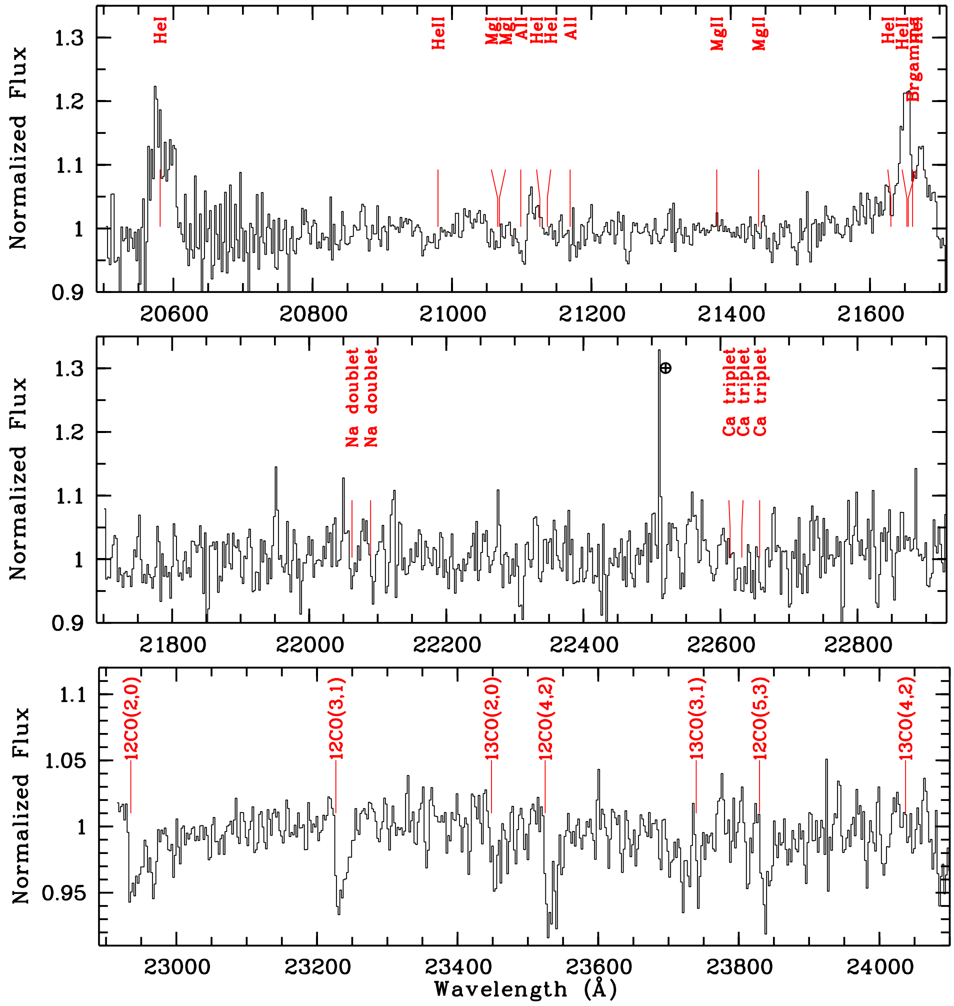


**Fig. 2.** Spectrum of GRS 1915+105 in the $K$ band, normalized by division through the continuum as derived from a spline fit. The top two panels correspond to 3000 s exposure, while the bottom panel shows a sum of 4 images (total exposure 9400 s). All spectra were rebinned by a factor of 2.

($-0.2 \lesssim r \lesssim 0$) and giants ($0.4 \lesssim r \lesssim 0.6$) (Ramírez et al. 1997). The ratio of equivalent widths of $^{12}$CO to $^{13}$CO which depends on luminosity class (Campbell et al. 1990), has been measured for the seven transitions covered (lower panel of Fig. 2) to $\sim 3 \pm 1$, again supporting a giant classification.

Using the $H$ band spectra, we also considered the veiling-independent temperature/luminosity discriminant $EW$(OH 1.6904 $\mu$m)/$EW$(Mg 1.5765 $\mu$m) vs. $EW$(CO 1.6610 $\mu$m + CO 1.6187 $\mu$m)/$EW$(Mg 1.5765 $\mu$m) as proposed by Meyer et al. (1998). The OH line is, unfortunately, only marginally detected, and therefore only the luminosity class cannot be constrained. The temperature estimate yields $\sim 4800^{+200}_{-500}$ K, which would suggest a late-G or $K$ spectral type (Houdashelt et al. 2000), but since the CO bands are weak, the error again is too large to allow more detailed refinements.

In order to determine the luminosity of the donor, the veiling was roughly determined by comparison of our flux-calibrated 2.35 $\mu$m spectrum of GRS 1915+105 with that of a K2 III standard star, observed with the same settings. The flux calibration of the GRS 1915+105 spectrum was done using the acquisition image taken immediately before the spectrum which itself was photometrically calibrated with local field standards (see Greiner et al. 2001) to yield $K = 13.2$ mag for GRS 1915+105. We therefore took the K2 III star spectrum, scaled to a brightness in the range 13.5–16.0 mag and added a flat continuum such that the total $K$ band brightness is 13.2 mag. A comparison of the depths of the CO band heads with those in the GRS 1915+105 spectrum (Fig. 3) gives a magnitude of $K = 14.5{-}15.0$ for the donor, uncorrected for extinction. With a distance of $\sim$11 kpc (Fender et al. 1999) and an $A_K = 3$ mag (Greiner et al. 1994; Nagase et al. 1994; Chaty et al. 1996) extinction correction, this implies an absolute magnitude of $M_K = -2... -3$, consistent with the giant classification.

This identification of the donor of GRS 1915+105 as a K-M giant implies a rather narrow mass range of 1.0–1.5 $M_\odot$. Typical spherical mass-loss rates of such stars are much too low to sustain the high accretion luminosity of GRS 1915+105 via accretion from the donor's

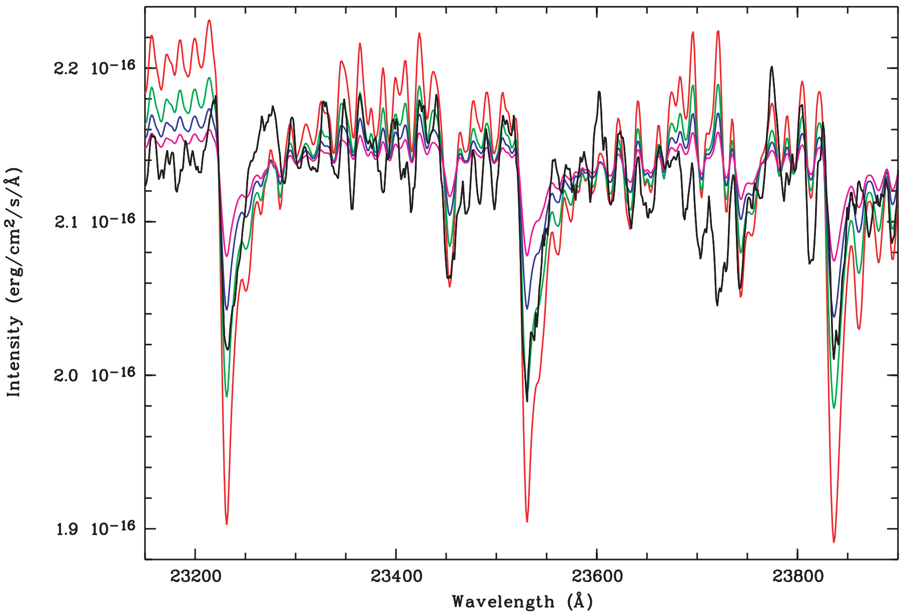


**Fig. 3.** Spectrum of GRS 1915+105 in the 2.32–2.39 $\mu$m range (thick black line; uncorrected for extinction) compared to the spectrum of the K2III star HD 202135 scaled to magnitudes of 14.0 (red), 14.5 (green), 15.0 (blue) and 15.5 (pink) and artificially veiled with a flat continuum such that the total $K$ band brightness is 13.2 mag. Comparing the equivalent widths of the $^{12}$CO(3,1) $^{12}$CO(4,2) and $^{12}$CO(5,3) bandheads between the GRS 1915+105 spectrum (−1.3 Å, −2.3 Å, −0.7 Å) and those 4 "synthetic" spectra (red: −4.0 Å, −3.1 Å, −2.4 Å; green: −2.6 Å, −1.9 Å, −1.5 Å; blue: −1.5 Å, −1.2 Å, −0.9 Å; pink: −0.8 Å, −0.7 Å, −0.7 Å) implies that the donor of GRS 1915+105 has an unveiled magnitude of 14.5–15 mag (prior to extinction correction).

stellar wind. We therefore suggest (not too surprisingly) that accretion should occur via Roche lobe overflow. This is consistent with the constraints derived by Eikenberry & Bandyopadhyay (2000).

We note that our identification of GRS 1915+105 as a LMXB, as earlier proposed by Castro-Tirado et al. (1996), contradicts the findings of Mirabel et al. (1997) and Martí et al. (2000) who, on the basis of VLT-ISAAC spectra of lower resolution and $S/N$ ratio, argued for a massive OB-type companion. Our donor identification suggests a origin of the He I lines different from the photosphere of the OB star (Mirabel et al. 1997; Martí et al. 2000). In fact, He I emission is often observed in LMXBs and cataclysmic variables to be uncorrelated with the donor, but originating presumably in the accretion disk or disk wind.

The presence of clear donor absorption features will now allow a search for the periodic Doppler shifts due to orbital motion, as well as a determination of the mass of the compact object using radial velocity measurements of the donor.

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