New Views of the Magellanic Clouds
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Massive Binary Stars in the Magellanic Clouds

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Abstract. We discuss the present status of knowledge for massive binary stars in the Magellanic Clouds. New data for known binaries, and radial velocity orbits for new binaries are reported.

1. Introduction

Many stars in the Magellanic Clouds are observed to have luminosities corresponding to stars more massive than 100 $M_{\odot}$, when compared with the theoretical mass-luminosity relation or evolutionary tracks. However, the empirical mass-luminosity relation is unknown in the Magellanic Clouds, and in our Galaxy it is well known only up to about 25 $M_{\odot}$. Therefore, the masses derived from stellar luminosities in the Magellanic Clouds lack the much needed empirical verification. Studies of binary stars are necessary for estimates of empirical stellar masses.

This is a progress report about our ongoing observing program of searches and studies of massive binary stars with OB and Wolf-Rayet (WR) type components in the Magellanic Clouds.

2. Observations

Our observations have been obtained:

1. between 1980 and 1990, at CTIO, Chile, we used the Cassegrain IT spectrograph on the Yale 1-m telescope. The detector consisted of photographic plates with fine grain emulsion until 1985, and an image tube with a CCD after 1985. These spectra cover the wavelength range $\lambda\lambda$3700-4800Å.

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2. after 1992 at Complejo Astronómico El Leoncito (CASLEO), San Juan, Argentina, with the Cassegrain and echelle spectrographs on the 2.15m telescope. A CCD was used as the detector.

The photographic observations were digitized with a Grant engine at La Plata. The digital data were processed and measured for determination of radial velocities using IRAF routines.

3. Results and Discussion

In what follows we will present spectral data, radial velocities, and velocity curve fits of some massive binaries both in the LMC and SMC, as results of our continuing observing program of OB and WR type stars.

3.1. Massive Binaries in the Large Magellanic Cloud

Sk−67°105 The first double-lined O type spectroscopic binary discovered in another galaxy than our own, was the O4f+O6 type system Sk−67°105 in the LMC (Niemela & Morrell 1986). This binary was subsequently also found to show light variations (Haefner et al. 1994). We have obtained further spectra of Sk−67°105, which improve the binary period, and confirm the previous orbital elements and spectral types of the components. However, due to the short binary period (3.3 days), and early spectral types of the components, this system probably has considerable interaction effects. Therefore it may not be particularly suitable for a comparison with evolutionary tracks of single stars. Figure 1 illustrates the spectrum of this binary.

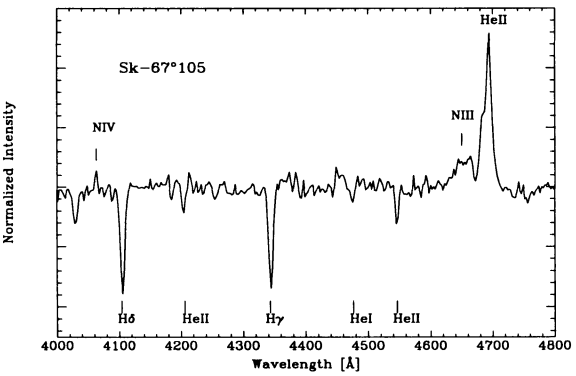

Figure 1. A blue spectrum of Sk−67°105, obtained at CASLEO.

HV 2241 An orbit based on the radial velocities of the eclipsing binary HV 2241 has been published by Niemela & Bassino (1994), who found spectral types of O7V and O8III: for the binary components, and minimum masses of 34 $M_{\odot}$ and 17 $M_{\odot}$, respectively. This binary has been the subject of a recent CCD light curve study by Prichart et al. (1998), who derived an orbital inclination of 85°.

Our new higher S/N CCD spectra agree with the previous radial velocity orbit, but we find a slightly different spectral type for the secondary. Figure 2

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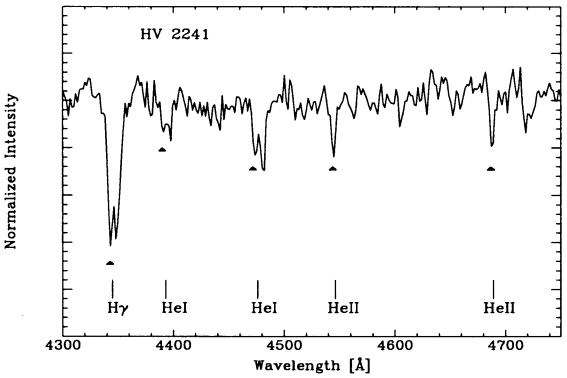

Figure 2. A CCD spectrum of HV 2241 obtained at CASLEO, showing double lines. The spectral lines corresponding to the primary are indicated by filled triangles.

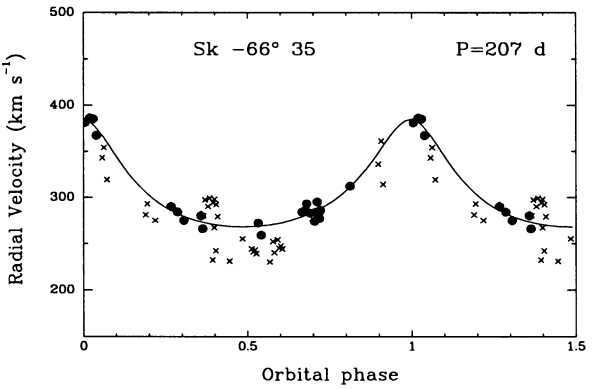

Figure 3. The observed radial velocities and derived orbit of Sk−66°35. Filled circles represent high resolution echelle spectra, and crosses lower resolution Cassegrain spectra.

shows a blue spectrum of HV 2241 obtained during the orbital phase of maximum separation of the spectral lines. This spectrum clearly indicates that the primary component is of spectral type O7V, but the spectral type of the secondary appears somewhat later than estimated previously, since the He II absorption lines of this component are very faint. The secondary probably is of spectral type O9-B0III. HV 2241 is a potentially very interesting binary system for a high accuracy study of stellar masses in the LMC.

Sk−66°35 This bright blue supergiant has been classified as BC1Ia by Fitzpatrick (1991). From observations obtained between 1985 and 1998 we have found Sk−66°35 to be a single-lined binary system with a period of 207 days. A preliminary radial velocity curve is shown in Figure 3.

Sk−71°34 A preliminary orbit for this O+WN type binary has been reported by Niemela (1991). A slightly different, but still preliminary, radial velocity orbit including our new data is shown in Figure 4.

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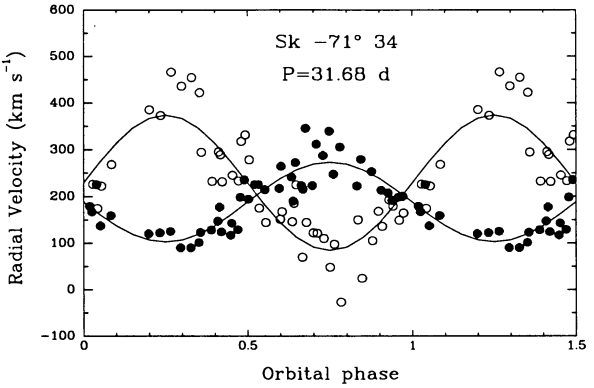

Figure 4. Radial velocity variations of the Nv emission line of the WN component (open circles) and the absorption lines of the O type component (filled circles) in the spectrum of Sk−71°34.

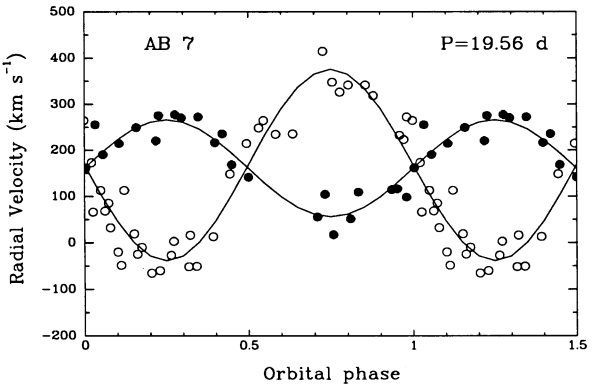

Figure 5. Radial velocity variations of the HeII λ 4686Å emission (open circles) and of the absorption lines of H and He (filled circles) in the spectrum of AB7 phased with the period of 19.56 days. The lines represent the orbital solution from Table 1.

3.2. Massive Binaries in the Small Magellanic Cloud

SMC/AB7 The star number 336a in the catalog of SMC members (Azzopardi & Vigneau 1975) is a WN type star also known as SMC/AB7 (Azzopardi & Breysacher 1979). Moffat (1988) classified this star as WN3:+O7: and found the radial velocity to be variable.

The blue optical spectrum of AB7 is dominated by the broad HeIIλ 4686Å emission line of the WN component. We have combined our radial velocities of this line with the data published by Moffat (1988), and find the most probable period of the radial velocity variations to be 19.56 days. Figure 5 shows the radial velocity orbits of both the absorption and emission lines phased with this period. The orbital elements, listed in Table 1, indicate that AB7 is a very massive binary, certainly deserving further study.

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HD 5980 This eclipsing binary is the brightest WR star in the SMC. Surprisingly in 1994 HD 5980 began a LBV-like eruption (Barbá et al. 1995) transforming its spectral type from WN3 to WN6 to WN11. After the outburst, only one spectrum, of approximate type WN6, has been visible and its radial velocity variations follow those of the component which formerly was considered to have a WN3 type spectrum. An intriguing question remains: is the behaviour of HD 5980 an exception or the rule for massive binaries?

A recent discussion of the behaviour of HD 5980 can be found in e.g. Niemela et al. (1999).

4. Conclusions

In Table 1 we have summarized the most relevant information for the binaries discussed in the present paper. However, despite of years of observations, many of the parameters in this Table, especially the data for the longer period binaries, are still preliminary values. Information for the orbital inclinations is only available for the first two stars in Table 1. We note in particular that the mass ratios of O+O and O+WR binaries appear to be quite similar.

Table 1. Orbital Parameters for Massive Binaries in the Magellanic Clouds.

Star	Period (days)	Spectrum	e	K_1 km s^{-1}	K_2 km s^{-1}	$M_1 sin^3 i$ $M_\odot$	$M_2 sin^3 i$ $M_\odot$
Sk-67°105	3.301	O4f+O6:	0.0	224	355	41	26
HV 2241	4.342	O7+B0III:	0.0	162	322	34	17
Sk-66°35	207	BC1Ia	0.34	58	..	..	..
Sk-71°34	31.68	O7+WN3	0.0:	85	145	25	15
AB7	19.56	O6+WN3:	0.0:	105	207	41	21
HD 5980[1]	19.26	WN3:+WN4:	0.28	128	226	50	28

[1]The values for HD 5980 are for data before the LBV eruption (cf Niemela et al. 1997)

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Discussion

Phil Massey: In our PSF photometry of NGC 346 (Massey, Parker, & Garmany 1989, AJ, 98, 1305) we found that HD 5980 was better fit by two stars rather than one, with a separation of a few tenths of an arcsec. Now, I've never completely believed this result - PSF fitting is not the technique of choice for separating unresolved doubles - but I wonder if the absorption lines in HD 5980 might not be due to a distant third companion. I suppose that a couple of WFPC observations obtained a decade or so apart could establish or refute the existence of such a companion.

Walborn: There is no optical companion to HD 5980 in a WFPC2 image down to 3 mag fainter. Of course, the resolution of 0.1 arcsec corresponds to 7000 AU at 70 kpc, so there is plenty of room for unresolved companions.