On the multiplicity of the non-thermal radio emitters 9 Sgr and HD 168112*

Gregor Rauw[1†], Hugues Sana[1‡], Eric Gosset[1†], Michaël De Becker[1], Julia Arias[2], Nidia Morrell[3], Philippe Eenens[4] and David Stickland[5]

[1]Institut d'Astrophysique, Université de Liège, Belgium
[2]Facultad de Ciencias Astronómicas y Geofísicas, Universidad Nacional de La Plata, Argentina
[3]Las Campanas Observatory, The Carnegie Observatories, La Serena, Chile
[4]Departamento de Astronomia, Universidad de Guanajuato, Mexico
[5]Rutherford Appleton Laboratory, Chilton, UK

Abstract: We discuss the first results of our ongoing optical spectroscopic monitoring campaign of the two O-type stars 9 Sgr and HD 168112. Both objects display a non-thermal radio emission and were considered as single stars. Based on a large set of high-resolution spectra, we find that 9 Sgr is clearly an eccentric SB2 binary with an orbital period of several years. On the other hand, no evidence for radial velocity variations attributable to binary motion is found in our spectra of HD 168112.

1 Introduction

One of the most intriguing features of early-type stars is the non-thermal radio emission that is observed for some of them. This emission is interpreted as synchrotron radiation, implying that the winds of these stars harbour a population of relativistic electrons. The most likely acceleration sites of these relativistic electrons are hydrodynamic shocks. Such shocks are known to exist at the interface between the stellar winds of the components of early-type binary systems and over the last few years, it has become more and more obvious that many of the non-thermal radio emitters are indeed binary systems (Dougherty & Williams 2000 and references therein; see also Van Loo, these proceedings).

Over the last few years, we have been investigating the multi-wavelength (radio, optical, X-ray and γ-ray) properties of a sample of non-thermal radio emitting O-type stars (see e.g. Rauw et al. 2002, De Becker et al. 2004a, 2004b, 2005, Blomme et al. 2005). Some of our targets (9 Sgr, HD 168112, Cyg OB2 #8a) were previously considered as single stars. We therefore initiated a spectroscopic monitoring of these stars, to uncover yet unknown binary systems.

*Based on data collected at the European Southern Observatory (La Silla, Chile), the Complejo Astronómico El Leoncito (Argentina) and the Observatorio Astronómico Nacional of San Pedro Mártir (Mexico)

†Research Associate FNRS (Belgium)

‡Research Fellow FNRS (Belgium)

"Massive Stars and High Energy Emission in OB Associations"; Proc. JENAM 2005 *Distant Worlds*, Liège (Belgium), eds. Rauw et al., p. 85-88

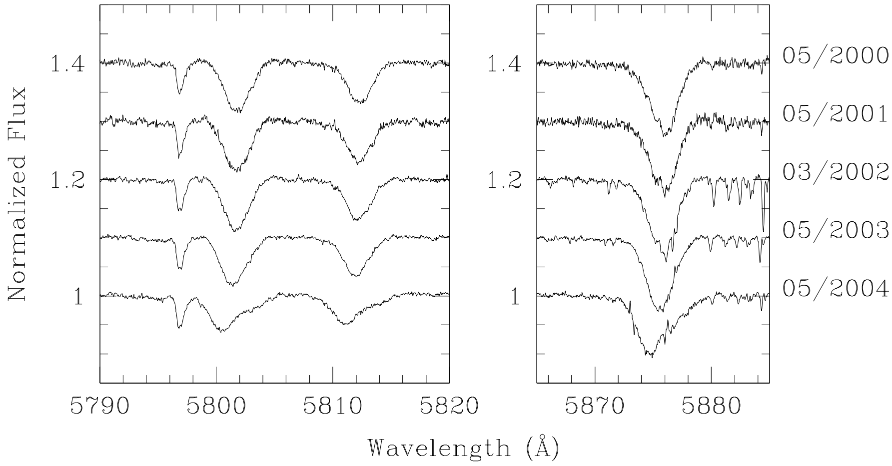

Figure 1: Variations of the C IV $\lambda\lambda$ 5801, 5812 and He I λ 5876 line profiles in the FEROS spectra of 9 Sgr.

A first result of this campaign was presented by De Becker et al. (2004b) who showed that Cyg OB2 #8a is in fact an eccentric spectroscopic binary system with a period of 21.9 days. Here, we discuss preliminary results for 9 Sgr and HD 168112.

2 9 Sgr

In the course of our ongoing monitoring campaign of the O4 V((f$^+$)) star 9 Sgr, we have gathered a total of 31 spectra with the FEROS echelle spectrograph (R = 48000). The data were obtained between 1999 and 2002 at the ESO 1.5 m and since 2003 at the 2.2 m telescopes at La Silla (Chile). In addition, one spectrum was taken with the EMMI instrument in echelle mode (R = 7700) at the New Technology Telescope (La Silla) in 2002. The data taken in 2004 reveal a clear SB2 signature in the C IV $\lambda\lambda$ 5801, 5812 and He I λ 5876 lines: the core of these lines is clearly shifted towards the blue, whilst the red wing shows the presence of a fainter secondary component (see Fig. 1). The ESO data are complemented by 5 spectra obtained in 1995 with the REOSC echelle spectrograph (R = 15000) at CASLEO. Despite their rather low signal to noise ratio, these data play a crucial role since they reveal an SB2 signature similar to that observed in 2004 and to the one already observed in 1987 by Fullerton (1990).

To measure the radial velocities of the two components of 9 Sgr, we have first applied a simultaneous fit of two Gaussians to the spectra obtained during 2004 i.e. near maximum separation. For the other spectra, we have measured the radial velocity (RV) of the line core. The latter values most likely reflect the primary RVs. As a next step, we then applied the spectral disentangling method of González & Levato (2005) to separate the spectra of the primary and secondary component and to determine the RVs. In this approach, we have used the primary RVs derived hereabove as the starting values of the iterative procedure. The results are shown in Fig. 2. Note that secondary RVs obtained when the RV separation is small are quite uncertain. Our results indicate that 9 Sgr is most probably an eccentric SB2 binary system with an orbital period of order 8 – 9 years.

The disentangled spectra of the primary and secondary components yield a brightness ratio of about 4 ± 1 ($\Delta m_V \simeq 1.5 \pm 0.3$) from the ratio of the EWs of the C IV and He I absorptions.

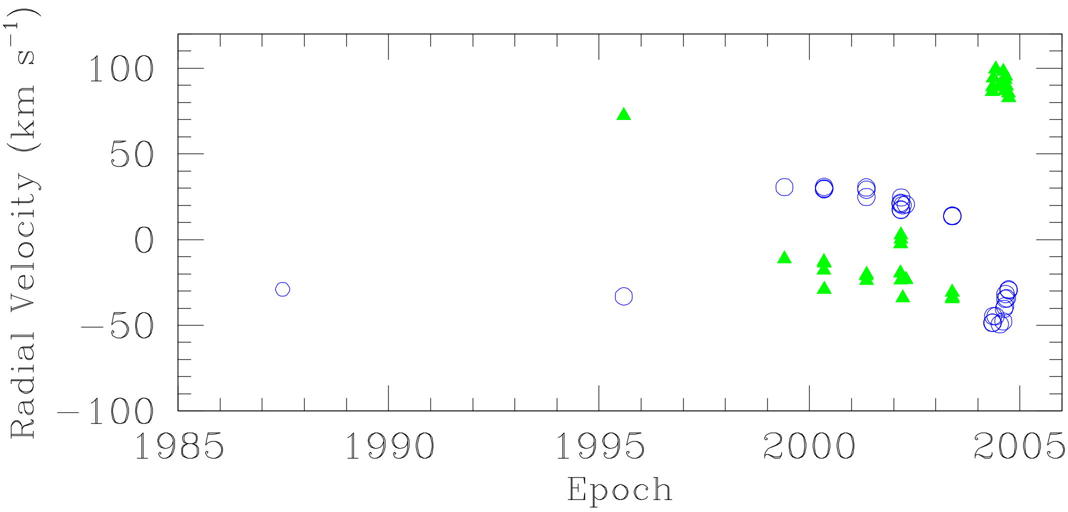

Figure 2: Radial velocities of 9 Sgr as determined using the González & Levato (2005) disentangling method (except for the first observation taken from Fullerton 1990). Open circles and filled triangles indicate the RVs of the primary and secondary components respectively. All RVs were obtained from the C IV $\lambda\lambda$ 5801, 5812 and He I λ 5876 lines.

3 HD 168112

In addition to the data discussed by De Becker et al. (2004a), we have obtained 15 new FEROS spectra spread over six months in 2004. This brings the total number of our echelle spectra of HD 168112 to 25 spanning a total time interval of 1233 days. Our present time series allows us to investigate variations on time scales from a few days to about 10 months as well as from about 1.5 to 4 years. Due to the sampling, periods shorter than one day, between about 10 and 15 months or longer than about 4 years are not well constrained by our data.

We have measured the heliocentric RVs of the strongest absorption lines in our spectra. The RVs of individual lines show little evidence for variability. The 1-σ dispersions range from 1.6 km s^{-1} for the He II λ 5412 line to 6.5 km s^{-1} for He II λ 4686, the latter line being probably affected by wind variations. We averaged the RVs of the Hγ, Hβ, He II $\lambda\lambda$ 4200, 4542, 4686, 5412; He I λ 5876 and C IV $\lambda\lambda$ 5801, 5812 lines. The results are shown in Fig. 3. No obvious trend is apparent on the RV data. The 1-σ dispersion amounts to 3.3 km s^{-1}.

For the time scales covered by our data, we assume that the amplitude of RV variations K is less than $2 \times \sigma = 6.6$ km s^{-1}. Using Kepler's law for a binary system of eccentricity e, period P, mass ratio $q = m1/m2$ yields

$$K = \frac{\sin i}{\sqrt{1-e^2}} \left(\frac{2\,\pi\,G\,m_1}{P\,q\,(1+q)^2} \right)^{1/3}$$

Assuming a mass of 50 $M_\odot$ for the O5.5 III(f$^+$) star in HD 168112, we focus on three different values of the mass ratio: $q = 1$, $q = 5$ (corresponding roughly to a B2 V secondary) and $q = 10$ ($\sim$ B6 V secondary). Some results are illustrated in Table 1 below. This table provides the largest acceptable inclination that can be accommodated within our upper limit on K, as well as the probability to have such a low inclination for a random distribution of orbital inclinations.

Of particular interest are the values for $P = 500$ days in Table 1. Indeed, this corresponds roughly to the 1.4 year period suggested by Blomme et al. (2005) to match both the radio and X-ray light curve. We see that in order to have a colliding wind interaction (which probably

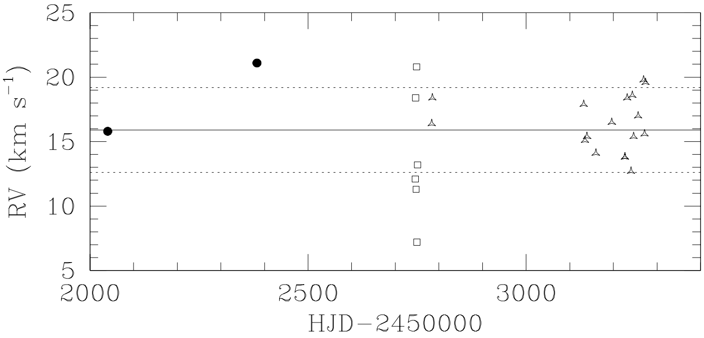

Figure 3: Average RVs of 9 absorption lines in the spectrum of HD 168112. Different symbols stand for data obtained with different instruments. The solid and dotted lines yield the mean as well as the mean ± 1-σ respectively.

requires $q \leq 5$) for such a period, the inclination would have to be less than about 20°. Using Kepler's law and assuming a 1.4 year orbital period, we estimate that $a > 4.61$ AU, which at a distance of 2 kpc yields an angular separation of > 2.3 mas, which should make the companion detectable with the VLTI. A no detection would be a serious challenge for the binary scenario for non-thermal radio emission in O-type stars.

Table 1: Upper limits on the orbital inclination if HD 168112 were a binary with $e = 0$ for different values of P and q. Also indicated is the probability that i be lower than $i_{\rm lim}$ assuming a random distribution of orbital directions in space.

P	10 days			100 days			500 days			1000 days		
q	1	5	10	1	5	10	1	5	10	1	5	10
$i_{\rm lim}(°)$	1.6	5.9	11.1	3.6	12.7	24.6	6.1	22.1	45.4	7.7	28.4	63.7
$p(i \leq i_{\rm lim})(\%)$	0.04	0.5	1.9	0.2	2.5	9.1	0.6	7.4	29.7	0.9	12.0	55.7

Acknowledgements

The Liège team is greatly indebted to the F.N.R.S. for multiple assistance. This research is also supported in part by contract P5/36 ”PAI” and through the PRODEX projects.

References

Blomme R., Van Loo S., De Becker M., et al., 2005, A&A, 436, 1033
De Becker M., Rauw G., Blomme R., et al., 2004a, A&A, 420, 1061
De Becker M., Rauw G., Manfroid J., 2004b, A&A, 424, L39
De Becker M., Rauw G., Blomme R., et al., 2005, A&A, 437, 1029
Dougherty S.M., Williams P.M., 2000, MNRAS, 319, 1005
Fullerton A.W., 1990, PhD thesis, University of Toronto
González J.F., Levato H., 2005, A&A, in press
Rauw G., Blomme R., Waldron W.L., et al., 2002, A&A, 394, 993