Bulletin de la Société Royale des Sciences de Liège, Vol. 80, 2011, p. 648 - 652

First results on the optical campaign devoted to the gamma-ray binary candidate HD259440

Michaël De Becker[1,2] , M. Virginia McSwain[3], and Christina Aragona[3]

[1] Department of Astrophysics, Geophysics and Oceanography, University of Liège, Belgium
[2] Observatoire de Haute-Provence, Saint-Michel l'Observatoire, France
[3] Department of Physics, Lehigh University, USA

Abstract: Quite recently, a very high-energy gamma-ray source has been detected in the Monoceros region. This source belongs to the category of TeV emitters with no identified counterpart at other wavelengths, even though it may be coincident with other high-energy sources detected with other observatories (ROSAT, CGRO). However, it is interesting to note that the error box of this TeV source admits the possibility that the Be star HD259440 is at the origin of the high-energy emission. This may be possible only if that Be star is member of a still undetected binary system including a compact (neutron star or black hole) companion, therefore belonging to the very scarce category of gamma-ray binaries. We describe here the first results of the optical campaign devoted to HD 259440, with emphasis on the investigation of its multiplicity, using spectra obtained at the Observatoire de Haute-Provence (OHP) and at the Kitt Peak National Observatory (KPNO).

1 Scientific context

Recently, a TeV source has been detected by HESS in the Monoceros region: HESS J0632+057 (Aharonian et al. 2007). This region is rather complex, and several associations with objects known at other wavelengths seem plausible. In the context of the VHE emission from astronomical sources, binary systems made of an early-type star and of a neutron star/black hole are particularly important. Along its orbit, the compact star is likely to accrete material from the wind of the early-type star on its surface. Such an accretion process is known to be very efficient at producing high-energy photons. Among these high-mass X-ray binaries (HMXB), one can distinguish the sub-class of microquasars, which are considered as good candidates for the production of VHE γ-rays. Microquasars are X-ray binaries which produce jets. In this category, LS 5039 and LSI +61° 303 have been identified as VHE γ-rays sources, although their classification as microquasars is still somewhat controversial (Romero et al. 2007). On the other hand, Cygnus X-3 has been detected both by Fermi (Abdo et al. 2009) and AGILE (Tavani et al. 2009), and is an uncontroversial high-mass microquasar. Cygnus X-1 has also been detected in the very high energy gamma-ray domain with MAGIC (Albert et al. 2007). In the context of such binaries including a compact object, VHE γ-rays may be produced by synchrotron self-Comptonization, where a hard-X-ray photon produced by the synchrotron mechanism is up scattered up to much higher energies through a Comptonization mechansim, in the presence of relativistic electrons accelerated in the jets. External Compton emission can be important as well, since the stars are quite luminous, therefore providing the wealth of photons likely to be upscattered up to very high energies. According to these scenarios, microquasar-like objects are good candidates for a γ-ray emission in the TeV domain likely to be detected with an observatory such as HESS. Another possiblity comes from the high density of the stellar winds of HMXBs. The dense matter fields in the region where the jets exists can lead to strong collisions between jets and wind material. The collisions can therefore lead to neutral pion production and decay, and hence to production of VHE γ-rays and neutrinos (Romero et al. 2003). It should be noted that, in the case of these accreting γ-ray binaries, the orbital period is generally not very long (at most several weeks), except in some cases where an accreting neutron star in a long orbit might produce VHE gamma-rays (Orellana & Romero 2005, Orellana et al. 2007).

Beside these accreting binaries, we may also consider the case of non-accreting longer period binaries where the secondary turns out to be a pulsar. This is the case of the 3.4-year Be + pulsar binary PSR B1259-63, whose TeV emission was detected by HESS during periastron passage (Aharonian et al. 2005). In this scenario, the interaction of the relativistic wind from the pulsar with the stellar wind of the primary constitutes a viable scenario to explain the detected VHE emission (see Dubus 2006 for a discussion of this scenario). Here again, the presence of a compact companion in HD 259440 – even though on a wider orbit – constitutes a valuable working hypothesis to interpret the nature of HESS J0632+057.

In both cases, if HD 259440 is a still undetected binary system whose secondary is a neutron star – or even a black hole – it could be the counterpart of HESS J0632+057. A multiplicity investigation of this star is therefore needed in order to check this interpretation, and we describe here the first results obtained in this context.

2 Observations

We observed the target 7 times with the SOPHIE échelle spectrograph mounted on the 1.93 m telescope at the Observatoire de Haute-Provence (OHP, France) using the high efficiency mode (R=40000). Two observations occurred in March 2009, and five in October 2009. The data consist in 39 orders covering the wavelength range 3872-6943 Å . The spectra were corrected for the blaze and flat-fieded, before being wavelength calibrated using Th/Ar spectra obtained maximum 2 hours before or after the sky exposure. We used exposure times between 45 and 90 minutes. The spectra present an average S/N ratio ranging between 80 and 220, depending on the exposure time and on weather conditions. We also retrieved archive SOPHIE spectra of the same target obtained between October 2007 and February 2008, with exposure times of 5 to 15 minutes. We note however that the S/N ratio of the latter is generally significantly lower than those obtained in 2009 (i.e. down to about 40 in the worst cases).

We also observed HD 259440 using the Kitt Peak National Observatory (KPNO) Coudé Feed (CF) telescope with the F3KB detector between 2008 October 17 and November 21. We used both blue and red spectral setups each night and generally obtained two spectra of HD 259440 in each. The blue spectra (R=9500) cover a wavelength range 4130–4570 Å , and have a S/N ratio of 50–140. The red spectra (R=12000), span a wavelength range of 6400–7050 Å , and have a S/N of 100–250. The spectra were zero corrected, flat-fielded, and wavelength calibrated using standard procedures in IRAF1. Two blue optical spectra were finally obtained at the KPNO 2.1m telescope using the GoldCam Spectrograph on 2008 December 12–13, with a resolving power of 2100–3100. These observations cover a wavelength range of 3700–4900 Å and a S/N ratio of 125–150. For details on the data set and on the data processing procedure, we refer to Aragona et al. (2010).

3 The multiplicity of HD259440

3.1 Searching for a companion

We measured the radial velocity of the star using first the KPNO time series, on the basis of the He I line at 4471 Å . These measurements did not lead to any detection of a significant radial velocity shifts during the 35 nights of the KPNO campaign. We obtained a standard deviation of the radial velocities of 20.1 km s^{-1}. We note that we did not notice any slow trend of increasing or decreasing radial velocities across the time series, likely to reveal a putative variation on a time basis much longer than that of the time series.

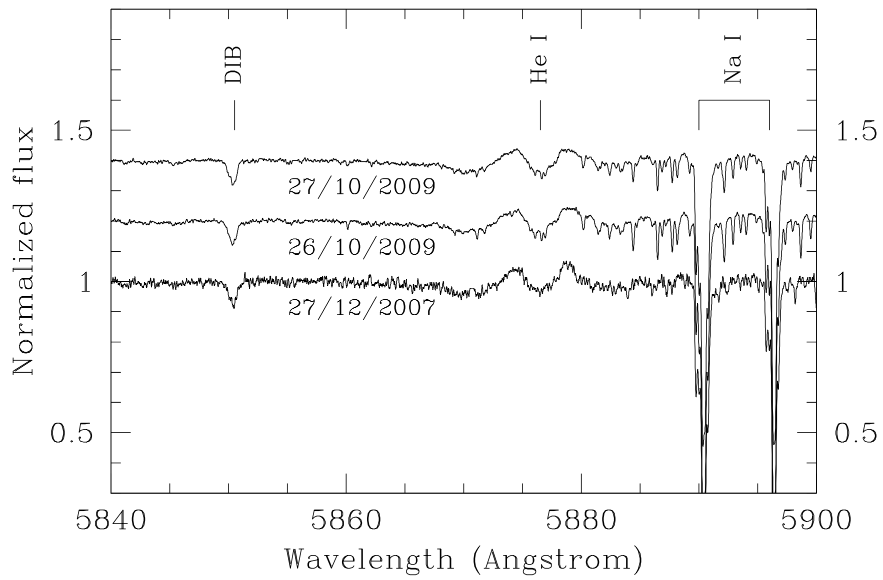

Figure 1: Spectrum of HD 259440 between 5840 and 5900 Å obtained with the SOPHIE spectrograph at three different epochs.

We also estimated the radial velocities on the basis of the OHP data set. Considering the rather low signal to noise ratio of the blue part of the échelle spectra, we refrained from using blue lines to measure radial velocities. Considering the shape of the line profile and the overall signal to noise ratio of the time series, we focused on the He I line at 5876 Å (see Fig. 1). We measured the radial velocity by fitting Gaussians to the central absorption component of the profile. These measurements led to a standard deviation of the radial velocities of 6.7 km s^{-1}. Considering the natural width and shape of the spectral lines used for these measurements, such a value is rather close to the expected accuracy on the radial velocities of the target. We therefore did not detect any significant radial velocity variation on the basis of our time series.

3.2 Constraints on the multiplicity

In the absence of evidence for the presence of a companion, we can only conjecture on the probability to have missed the binary, provided HD 259440 is not single. We adopted the procedure described by Garmany et al. (1980), and more recently used by Mahy et al. (2009).

The mass function of the primary component is given by:

$$f(m) = \frac{M_1 \sin^3 i}{q\,(1+q)^2} = 1.0355 \times 10^{-7}\, K^3\, P\,(1-e^2)^{3/2} \quad (1)$$

where M_1 is the primary mass (in $M_\odot$), K is expressed in km s^{-1}, e represents the orbital eccentricity, $q = M_1/M_2$ and P defines the orbital period (in days).
Equation 1 is transformed on $\sin i$, we insert $2\sigma_{RV}$ as an upper limit on K and assume a zero eccentricity. Therefore, we obtain:

$$\sin i \;\leq\; 9.392 \;\times\; 10^{-3}\, \sigma_{RV}\, (1-e^2)^{1/2} \left(\frac{P\, q\, (1+q)^2}{M_1}\right)^{1/3} \quad (2)$$

Making the assumption of a random distribution of the orbital directions in space, we can write the probability that the orbital inclination is smaller than the value obtained from Equation 2 as:

$$\int_0^{i_{up}} \sin i \; di \;=\; 1 - \cos i_{up} \quad (3)$$

This approach requires the knowledge of several quantities. First, we need an upper limit on the variation of the radial velocities. The strongest constraint comes from the OHP data, and we will consider the 6.7 km s^{-1} value. For the mass ratio, we need the value of the primary mass. We used the KPNO spectra to estimate the effective temperature and the gravity of the primary, through line fitting of a TLUSTY BSTAR2006 model (Lanz & Hubeny 2007). We then confronted the best-fit parameters to evolutionary tracks from Schaller et al. (2002), yielding a mass of about 16 M$_\odot$. Details on the adopted procedure are given in Aragona et al. (2010).

On the basis of these numbers, we computed the probability to have missed the putative binary because of a too low orbital inclination, for different assumed secondary masses (assuming a neutron star as the secondary, we considered values of 1.5, 2.0 and 2.5 M$_\odot$). We assumed also different values for the eccentricity (0.0, 0.2, 0.4 and 0.6), and in each case we computed the probability for a range of period values. The results are plotted in Fig. 2. We see in these plots that the present data can not reject that HD 259440 might be a still undetected binary system, mostly if we are dealing with a long period eccentric binary system.

4 Concluding remarks

Our multiplicity study of the Be star HD 259440 did not reveal any hint for the presence of a companion. However, our analysis put constraints on the probability to have missed a putative binary because of a too low inclination of the system: we may still be dealing with an undetected long period eccentric binary. In such a scenario, HD 259440 could belong to the class of non-accreting gamma-ray binaries like PSR 1259-65, or possibly harbour an accreting neutron star in a long-period orbit.

Acknowledgements

We thank the staff and observers at the Observatoire de Haute-Provence for the service mode observations, and especially Dr. H. Le Coroller for the scheduling of the observations. Our thanks go also to Yves Gallant, Bertrand Plez, and Guillaume Dubus for the obtaining of the archive SOPHIE data we used in this study.

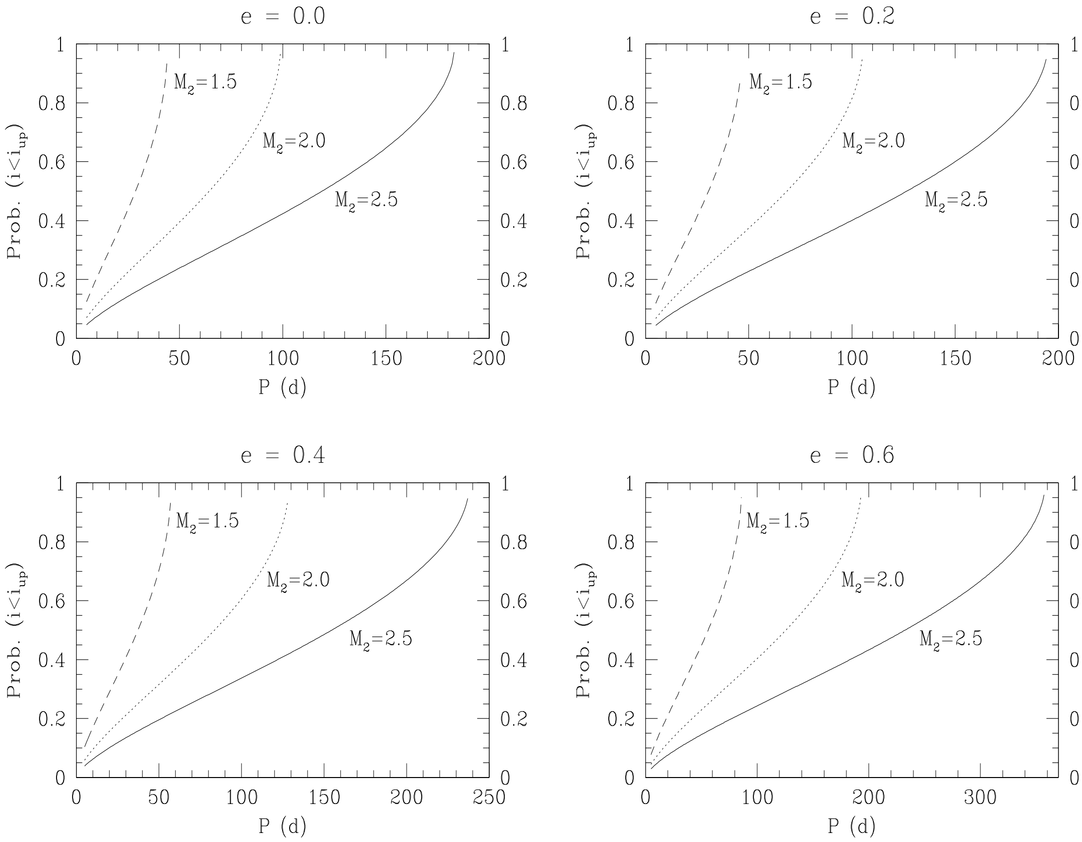

Figure 2: Probability to have missed the binary because of a too low inclination angle as a function of the orbital period, for eccentricities equal to 0.0, 0.2, 0.4, and 0.6, respectively. In each panel, three different secondary masses have been assumed.

References

Abdo, A.A., Ackermann, M., & Ajello, M. 2009, Science 326, 1512
Aharonian, F.A., Akhperjanian, A.G., Aye, K.-M., et al. 2005, A&A 442, 1
Aharonian, F.A., Akhperjanian, A.G., Bazer-Bachi, A.R., et al. 2007, A&A 469, L1
Albert, J., Aliu, E., Anderhub, H., et al. 2007, ApJ 665, 51
Aragona, C., McSwain, M.V., & De Becker, M. 2010, ApJ 724, 306
Dubus, G. 2006, A&A 456, 801
Garmany, C.D., Conti, P.S., & Massey, P. 1980, ApJ 242, 1063
Lanz, T. & Hubeny, I. 2007, ApJS 169, 83
Mahy, L., Nazé, Y., Rauw, G., et al. 2009, A&A 502, 937
Orellana, M., & Romero, G.E. 2005, Ap&SS 297, 167
Orellana, M., Romero, G.E., Pellizza, L.J., & Vidrih, S. 2007, A&A 465, 703
Romero, G.E., Torres, D.F., Kaufman Bernadó, M.M., & Mirabel, I.F. 2003, A&A 410, L1
Romero, G.E., Okazaki, A.T., Orellana, M., & Owocki, S.P. 2007, A&A 474, 15
Schaller, G., Schaerer, D., Meynet, G., & Maeder, A. 1992, A&AS 96, 269
Tavani, M., Bulgarelli, A., Piano, G., et al. 2009, Nature 462, 620