Revista Brasileira de **Física**, Vol. **8, Nº** 2, **1978**

Search for Black-Holes: The Nature of the Unseen Companions of the Systems HD 152 667 and HD 72 754

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Recebido em **21** de Novembro de **1977**

The nature of the unseen companions in the single spectroscopic binary systems *HD* 152 667 and HD 72 754 is analysed. In the first system, the secondary is likely to be a normal B4 main sequence star while in HD 72 754, the secondary, in spite of being the more massive star, is not detected. We cannot at the present, disregard the possibility that this massive object be associated with a collapsed star - a black-hole.

A natureza das companheiras invisíveis dos sistemas binários espectroscópicos simples *HD* 152 667 e HD 72 754 é investigada. No primeiro sistema, a companheira é provavelmente uma estrela normal B4 da sequência principal, enquanto a companheira de HD 72 754, embora "invisível", é a mais massiva do sistema. Presentemente, não podemos afastar a possibilidade que tal objeto esteja associado a um buraco-negro.

1. INTRODUCTION

Black-holes can be detected through their gravitational effects. Therefore the chances to detect such an object are greater if we look into binary systems. Indeed, several systems have been proposed as possible candidates: ε Aur[1], Beta Lyrae[2], BM Ori[3], and in spite of all these suggestions, only Cygnus X-1, which is associated with an X-ray source, remains as the strongest exarnple (see, for instance, Pacheco and Steiner[4]).

In the present work we report the analysis of two other binary systems,

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which show single spectra and have a relatively high mass function. These systems are HD 152 667 and HD 72 754.

HD 152 667 was classified by Walker[5] as a B0 Iae star. Its period is about $7^{d}.84818$ and its mass function is 0.76 $M_{\odot}$. The Balmer lines of its spectrum present *P* Cygni profiles, indicating an expanding outer envelope with an average velocity of about 300 km.s^{-1}. The first *UBV* observations of this star were reported by Cousins and Lagerway[6] and further spectroscopic observations by Hill et *al.*[7] would indicate the presence of short period variabilities ($P' = 0^{d}.6147$) in the radial velocity curve.

The spectroscopic period of HD 72 754 is $33^{d}.732$ and the derived mass function is 8.96 $M_{\odot}$. Its spectral type is B2 Ipe and photometric as well as spectroscopic observations were reported respectively by Thackeray et *al.*[8] and Thackeray[9]. This system has characteristics which ressemble those of Beta Lyrae and W Cru, but the light variations is most probably due to the ellipsoidal effect.

Thse systems were observed photoelectrically with UBV filters during the 1976 observational season (southern autumn and winter) at the Abrahão de Moraes Observatory, in Valinhos.

In the subsequent sections we present the observational data on both systems, as well as the analysis concerning the nature of the unseen companion of those stars.

2. OBSERVATIONAL DATA

Our observations were carried out using the 61 cm telescope of the São Paulo University and photon counting techniques. The observations were reduced by the usual standard procedures and the main comparison stars used in the program were: HD 150 742 for HD 152 667 and CD-481686 for the other system. The photometric parameters of these stars, obtained from absolute photometry in two nights are:

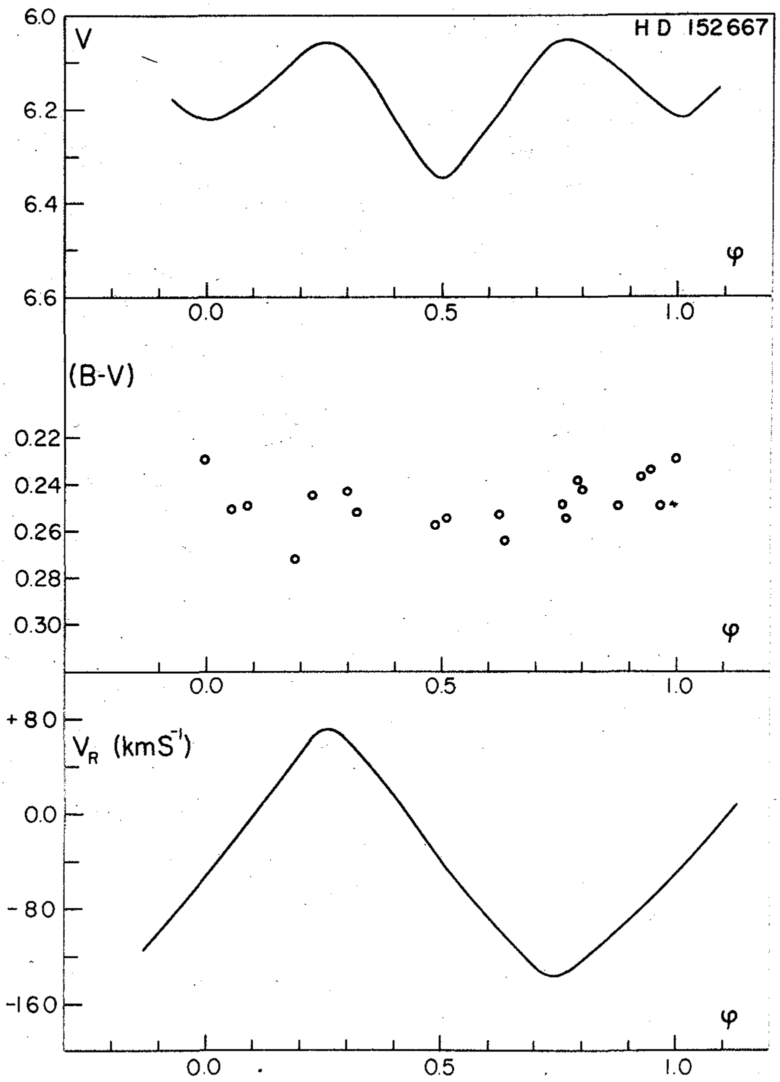

Fig.1 - Smoothed V light curve, Valinhos (B-V) data points and smoothed radial velocity curve respectively, as a function of the orbital phase. Phase 0.0 corresponds to the "eclipse" of the secondary star.

HD 150 742 $V = 5\overset{m}{.}61 \pm 0\overset{m}{.}01$ $(B-V) = -0\overset{m}{.}09 \pm 0\overset{m}{.}01$ $(U-B) = -0\overset{m}{.}69 \pm 0\overset{m}{.}02$

CD-481686 $V = 7\overset{m}{.}33 \pm 0\overset{m}{.}01$ $(B-V) = -0\overset{m}{.}06 \pm 0\overset{m}{.}01$ $(U-B) = -0\overset{m}{.}25 \pm 0\overset{m}{.}02$

Figure 1 shows for HD 152 667 the smoothed V light curve obtained from our data and those of Cousins and Lagerway[6], as well as our $(B-V)$ observations and the smoothed radial velocity curve, from Walker's[5] and Hill's et *al.*[7] data. As we have mentioned before, the data by Hill et *al.* would suggest the presence of short period variabilities in this star. Rittē[10] has Fourier analysed all the available photornetric data and he has not found any evidence for such a variability.

Figure 2 shows the V light curve and the radial velocity curve for HD 72 754.

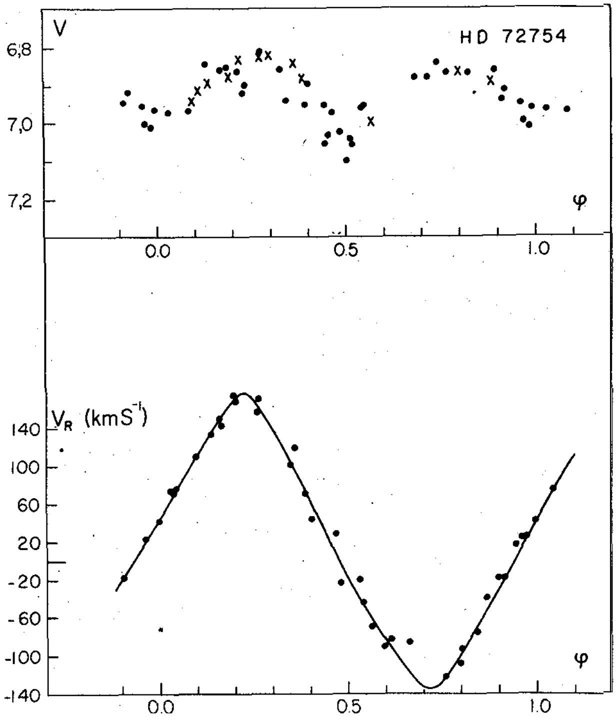

Fig.2 - V light curve and. radial velocity as a function of the orbital phase. The solid line corresponds to an orbital solution calculated by Sodré[18].

The average colors of *HD* **152** 667 obtained by us are compatible with the spectral type if they were corrected by a color excess of $E(B-V) = 0^m.52$, corresponding to a reddening of A_V = 1'16. Since the absolute visual magnitude is about $M_V = -6^m.3$, the distance of the system turns out to be 1.4 kpc. In the case of HD **72** 754, the color excess is $E(B-V) = 0^m.35$ ($A_V = 1^m.1$) and the derived distance is about 2.3 kpc, taking into account that the absolute magnitude of the primary star is $M_V = -6^m.0$.

The light variability in both systems is probably duetothe ellipsoidal effect, namely, rotation of a star distorted by tidal forces. This is supported by the radial velocity curve and also by the fact that the colors are practically constant with the orbital phase. The deeper minimum at phase 0.5 (unseen companion in front of the primary star) is probably caused by the gravity darkening effect.

3. THE NATURE OF THE UNSEEN COMPANIONS

If we interpret the light variation as being due to the distortions produced by the unseen secondary star, then, the light variation amplitude is a function of the form

$$m = m(\tau_0, u, q, R/a, i) \qquad (1)$$

where τ_0 is the gravity darkening coefficient, u is the limb darkening coefficient, q is the secondary (unseen) to primary mass ratio, R/a is the ratio between the average radius of the primary and the separation of the stars and i is the inclination orbital angle. The explicit equations for the ellipsoidal effects can be found, for instance, in Kopal and Kitamura[11].

The other equations relating the above paramaters are: the mass function of the system

$$f = M_2 \frac{q^2}{(1+q)^2} \sin^3 i \qquad (2)$$

and Kepler's third law

$$M_2 = \frac{4\pi^2}{P^2} \frac{a^3}{G} \frac{q}{(1+q)} \tag{3}$$

where M_2 is the secondary mass, P is the orbital and G is the gravitational constant.

In order to solve the system of equations above, we remark the following point: f, P and m are obtained directly from the spectroscopic and the photometric data. The coefficients u and τ_0 are calculated theoretically from models of stellar atmospheres. Therefore, the unknows of our problem are M_2, q, i and R/a. Since we have only three equations, no unique solution is possibie. Generally a fourth relation is introduced, as in the case of X-ray binaries. (Pacheco[12]; Sodré[13]), which corresponds to the assumption that the primary star fills the Roche critical surface. However, in the present case, such an assumption is not justified. Therefore, we have adopted the following procedure: fixing a value for the primary star radius R, the equations (1), (2) and (3) enable us to calculate q M_2 and a as a function of the inclination angle i. These results are not sensitive to i, if i , 70^{0}. On the other hand, the spectral type of the primary star enables to assign it an effective temperature and then, to calculate the absolute bolometric magnitude through the relation

$$M_b = 42.36 - 10 \log T_e - 5 \log R/R_{\odot} \tag{4}$$

Under these conditions, we can plot the bolometric magnitude as a function of the mass of the primary M_1 (calculated for each fixed value of R) and compare with the theoretical evolutionary mass - luminosity relation. In this case, we used the mass-luminosity relation given by Stothers[14], which is appropriated for the blue-supergiants stars in the helium burning stage. We have also used two different temperature calibrations (Johnson[15]; Stalio[16]), which delimitate the shaded regions shown in figures 3 and 4.

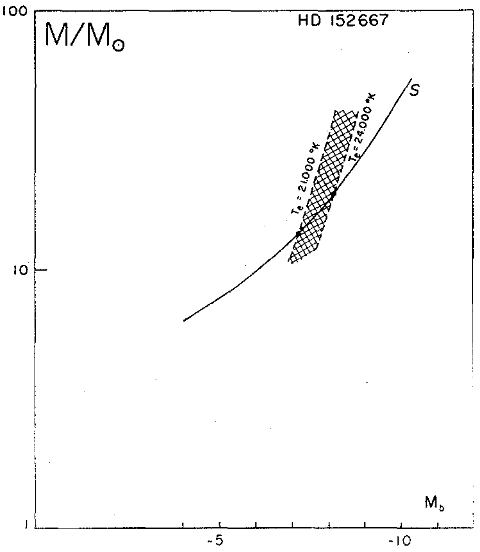

Fig.3 - Mass-luminosity relations for *HD* 152 667. Solid line labeled *S* is the Stothers'relation. The temperatures indicated are from Johnson and Stalio.

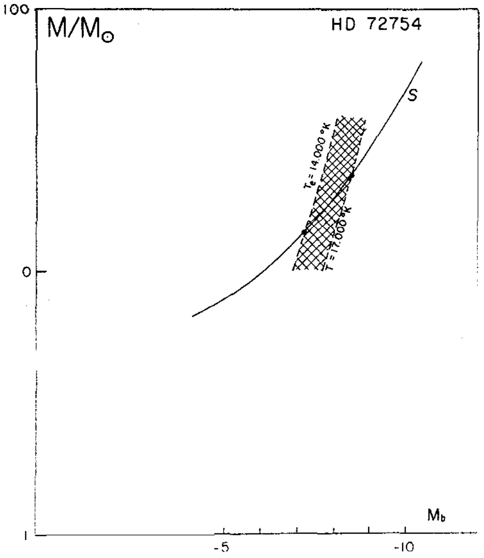

Fig.4 - Mass-luminosity relations for HD 72 754. Solide line *S* is fro Stothers and temperatures, as before, from Johnson and Stalio.

From the analysis of these figures, we can establish that the primary star parameters are within the interval

Star	M_1/M_0	$R/R_\odot$	M_V	M_b
HD 152 667	14 to 20	18 to 22	$-5^m.0$ to $-6^m.0$	$-7^m.2$ to $-8^m.2$
HD 72 754	14 to 28	42 to 52	$-5^m.7$ to $-6^m.6$	$-7^m.2$ to $-8^m.5$

Figure 5 shows the plot of the secondary mass as a function of the primary mass (calculated, as already mentioned, for each fixed value of *R*) and the constraints obtained above. Therefore, the mass of the unseen secondary is in the range

HD 152 667	$7.0 \leq M_2/M_\odot \leq 8.5$
HD 72 754	$23 \leq M_2/M_\odot \leq 32$

The figures corresponding to the upper limits should be more realistic for *HD* 152 667, since in this case, the primary mass is quite compatible with estimates for other similar blue-supergiants (Hutchings[17]). The secondary mass is compatible with that of a *B*4 main sequence star. The magnitude difference between the primary and the secondary is about 4^m,

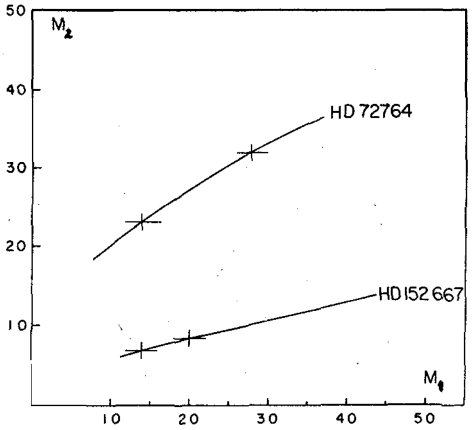

Fig.5 - Secondary mass a function of the primary mass. Crosses indicate the constraints discussed in the text.

if this assumption is correct and this may also explain why the secondary spectrum is not seen.

On the other hand, the analysis of the system HD 72 754 is more complicated. The secondary (unseen star) is certainly the object more massive in the system. Such a conclusion was already reached by Thackeray[9]. Considering the lower limits as being those more near the reality, the mass of the secondary would correspond to that of an 09 main sequence star. In this case, the magnitude difference between both stars would be about $1\overset{m}{.}2$ and the secondary should be marginally detectable. Besides this difficulty, we are obliged to invoke a strong mass transfer in the past, otherwise we would have the less massive star in a more advanced evolutionary stage. In this case, our results concerning the mass estimates should be taken cautiously, since we don't exactly know the consequences for the evolution of a star which has suffered a strong process of mass transfer, In particular, the mass-luminosity relation would be modified. Another possibility is that the unseen secondary be a collapsed object - a black-hole. Since the primary star doesn't fill the Roche lobe and there is also no evidence for a stellar wind, the collapsed object cannot be powered and this may explain the absence of X-ray emission. Of course, this should presently be considered as only a possibility. Since spectroscopically the system presents several features like strong H emission lines cut by very sharp absorption, varying with the orbital phase, He I absorption lines, probably associated with an outer ring, it is premature to draw any conclusion about the nature of the secondary. Certainly more observations are required.

4. CONCLUSIONS

The results of the present analysis point towards the increasing difficulty in to find black-hole candidates. The unseen secondary of HD 152 667 is probably a B4 main sequence star and it is probably not even un underluminous object. However, the situation of HD 72 754 is quite different. The analysis of this system is difficulted by the presence of several spectroscopic features which are not yet understood and which wuld be the consequence of a strong mass transfer process in the past. We cannot eliminate the possibility that the secondary be associated with a collapsed object or with an underluminous star. More observational and theoretical work on this very peculiar system are necessary before a firm conclusion about the nature of the secondary could be established.

This research was realized as a part of a scientific colaboration program between France and Brasil, through the Centre National de la Recherche Scientifique (CNRS) and Conselho Nacional do Desenvolvimento Científico e Tecnológico (CNPq). The author is also indebted to A. Damineli Neto, who has actively participated in the observational program.

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