CATACLYSMIC BINARIES CONTAINING A BLACK-DWARF SECONDARY

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ABSTRACT

Cataclysmic binaries with a black-dwarf secondary can in principle be distinguished from those containing a low-mass main-sequence secondary because of the differences of the corresponding eclipse light curves. However, due to the very low intrinsic luminosity of the systems containing a black dwarf, the probability of detection turns out to be smaller than the corresponding probability for an ordinary cataclysmic binary by about 1.5 to 3 orders of magnitude. Therefore, despite the fact that the predicted space density of these objects is quite high, systems containing a black-dwarf secondary must remain essentially undetectable.

I. INTRODUCTION

Recent theoretical investigations of the consequences of angular momentum loss in ultra-short-period cataclysmic binaries (hereafter USPCB's) due to gravitational radiation predict that the corresponding decay of the orbit forces the Roche lobe-filling secondary to mass loss which eventually brings it out of thermal equilibrium and finally transforms it into a hydrogen-rich black dwarf (Paczyński and Sienkiewicz, 1981; Rappaport, Joss and Webbink, 1982; hereafter referred to as PS and RJW respectively). During the transition of the secondary from a low-mass main-sequence star to a black dwarf, the binary period first decreases, goes through a minimum and finally increases when the secondary has become a black dwarf. Therefore, for every orbital period longer than the minimum period there are two possible configurations for an USPCB, one with a main-sequence secondary (hereafter called ordinary systems) and one with a black-dwarf secondary (hereafter called black-dwarf systems). According to RWJ, as many as 20% of all the USPCB's could be black-dwarf systems. The question then arises as to why, up to now, no black-dwarf system has been identified. Is it because the two types of USPCB's cannot be distinguished with present observational techniques or because of observational selection effects? It is the

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purpose of this paper to discuss briefly these questions.

II. SOME PROPERTIES OF BLACK-DWARF SYSTEMS

One of the predictions of PS and RJW is that the change of the orbital period has opposite sign for the two types of systems: it is decreasing for ordinary systems, i.e. as long as the secondary is at or near to the main sequence, and increasing for black-dwarf systems. Based on this property one could therefore identify black-dwarf systems by determining the sign of the period change. In fact, recent observations of the USPCB Z Cha by Cook and Warner (1981) show that the orbital period of this system is increasing. Based on this fact Faulkner and Ritter (1982) tried to work out the physical parameters of this system assuming that the secondary is a black dwarf. However, this assumption leads to inconsistencies with other observational properties. Therefore it was concluded that Z Cha is not a black-dwarf system, despite its increasing period. This, however, demonstrates that the nature of the secondary cannot be reliably inferred from the sign of the period change.

One of the reasons why, in the case of Z Cha, the black-dwarf hypothesis has to be rejected is that it results in contradictions with observed eclipse light curves (Warner, 1974; Bailey, 1979). Turning this argument around, this implies that *black-dwarf systems which undergo a double eclipse produce light curves which are different from those produced by ordinary systems*. In order to study these differences systematically and to investigate whether they can be used as a means of distinguishing between the two types of USPCB's, synthetic eclipse light curves for both types have been computed. The synthetic light curves and details of how they have been computed will be published elsewhere. The main properties of these light curves can be summarized as follows: In ordinary systems the phase lag between the white-dwarf eclipse and the hot-spot eclipse is small and the two eclipses interfere strongly. Many examples of such light curves for different objects are known, e.g. for Z Cha (Warner, 1974; Bailey, 1979), OY Car (Vogt et al. 1981), HT Cas (Patterson, 1981). If, on the other hand, the secondary is a black dwarf, the phase lag between the two eclipses is much larger and in the extreme case the eclipse of the hot spot begins only when the eclipse of the white dwarf has already ended. The difference in the light curves, i.e. in the phase lag of the two eclipses, can be traced back to the difference in mass ratio of the two types of USPCB's. The less massive the secondary star is (keeping the mass of the primary constant), the larger is the phase lag between the two eclipses. This in turn is due to the change with mass ratio of the trajectory of a single particle leaving the inner Lagrangian point, along which the hot spot approximately lies. Since the difference in mass ratio between ordinary systems and black-dwarf systems increases with increasing orbital period, the difference in the light curves is strongest for systems with the longest orbital period and it vanishes for systems having the minimum period. Thus, in principle, the two possible configurations of USPCB's can be distinguished using the morphology of the eclipse light curves.

III. OBSERVABILITY

The above-mentioned distinction involves a double eclipse. Therefore this method applies only to a rather small fraction among the USPCB's. Since in cataclysmic binaries the secondary fills its critical Roche lobe, the probability for the occurence of a double eclipse depends only on the mass ratio of the system and decreases with increasing mass ratio. For a given orbital period and primary mass, the black-dwarf system always has a higher mass ratio than the corresponding ordinary system. Therefore, the probability for the occurence of a double eclipse in a black-dwarf system is always lower, by as much as a factor of 3, when compared with the corresponding value for the ordinary system.

In addition to this not very strong selection effect there is, however, another and much stronger one, favouring the detection of ordinary systems. This is due to the fact that the luminosity of an USPCB is essentially accretion luminosity and that the accretion rate, i.e. the mass transfer rate, in a black-dwarf system is lower by one to two orders of magnitude when compared with the corresponding ordinary system (PS, RJW). As a consequence, in a magnitude limited sample of USPCB's the expected fraction of black-dwarf systems is between ~ 0.03 and ~ 0.001. Considering the still rather small number of known USPCB's (about 25) it is unlikely that a black-dwarf system is among them.

There is yet another effect which could act against the identification of black-dwarf systems. It is again a consequence of the extremely low mass transfer rate in black-dwarf systems. For the predicted values of $\sim 10^{-11}$ to $\sim 10^{-12}$ $M_\odot$/yr (PS,RJW), the outer parts of the accretion disk, where the hot spot is formed, are optically thin (see e.g. Meyer and Meyer-Hofmeister, 1981). It could therefore well be that the hot spot itself is also optically thin, so that there is no bright spot which can be eclipsed. In this case at most a single rather than a double eclipse occurs. This, however, does not allow a distinction to be made between the two configurations of USPCB's.

In conclusion, taking all these selection effects into account, black dwarf systems must remain essentially unobservable or at least unidentifyable, despite the fact that, according to RJW, their space density might be quite high.

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DISCUSSION FOLLOWING H. RITTER'S TALK

EGGLETON: Doesn't a lot of this analysis in fact depend on the assumption that only gravitational radiation is operating to remove angular momentum? If these systems were evolving faster than that it would not, for instance, be surprising if the period increased, even if you are on the non degenerate portion of that curve.

RITTER: If we have objects on the degenerate branch evolving ten times faster, they increase the mass accretion rate by a factor ten, then we get a factor of 30 less of antiselection. So, there might be a small chance to find one or the other of these objects. Also, if the accretion rates are higher, of course, conditions become better with respect to having an observable hot spot which undergoes an eclipse.

MIYAJI: I agree with Eggleton that your definition of degenerate and non degenerate is somewhat misleading. The meaning of these two branches is, that one part is an isentrope and the other part is an n=3 polytrope or something like that. So that if the envelopes are removed from normal stars very rapidly, then the stars will become isentrope even near the main sequence branch, the period can be increased.

RITTER: I do not completely agree because if you remove a lot of matter in a short time from the secondary star, the size of the Roche lobe does not depend on the radius of the star, but the radius of the star has to care about the size of the Roche lobe. These systems are not free in choosing the mass transfer rate, even if you go to another mass, angular momentum loss mechanism. I think you can only increase the orbital period on the, what I call nondegenerate branch, if you lose the mass out of the system with less than the mean angular momentum.

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