MASSES AND EVOLUTION OF CATACLYSMIC BINARIES

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Abstract. The determination of masses and mass ratios of cataclysmic binaries is discussed. It is suggested that these systems started as wide binaries, which have lost substantial amounts of mass and still more substantial amounts of angular momentum.

1. Discussion of the Mass Ratios and the Masses

Mass ratios of cataclysmic binaries (CBs) can be determined either by measuring the radial velocities of both components or by making use of a method which was suggested by Warner (1973). However, it is found that the theoretical relation expected to exist between the ratio $K_1/v \cdot \sin\, i$ and the mass ratio M_1/M_2 (see e.g. Kruszewski, 1967; Flannery, 1975; Lubow and Shu, 1975) which was earlier used by Warner (1973) to derive the mass ratios of CBs cannot be verified on the basis of present observational data. Here K_1 denotes the radial velocity of the white dwarf primary and $v \sin i$ the projected velocity of the gas ring around it. Therefore mass ratios derived on the basis of the above relation can hardly be reliable.

On the other hand it is found that the observed mass ratios, obtained by measuring the radial velocities of both components, of CBs having a main-sequence secondary are all not far from unity. This however can be understood as due to the following facts. Firstly, a lower limit for the mass ratios exists, due to simple stability arguments based on the Roche geometry and the mass-radius exponent of the semi-detached component only, and means that these systems have to be stable against rapid mass transfer. Secondly, an upper limit exists due to observational selection regarding M_2 (resulting in a lower limit of M_2, i.e. $M_2 > 0.9\, M_\odot$) and the fact that the mass of the primary cannot exceed the white dwarf limit (i.e. $M_1 < 1.4\, M_\odot$).

The masses of the secondaries can be derived rather easily and accurately if they are assumed to be semi-detached main-sequence stars. Then, by making use of the Roche geometry and a mass-radius relation for the main sequence secondary in combination with Kepler's third law, an expression results which relates the period P of the binary to the mass of the secondary M_2 and the mass ratio M_1/M_2, i.e. $P = P\,(M_2; M_1/M_2)$. This relation mainly depends on M_2 whereas its sensitivity to the mass ratio is much weaker. Therefore this relation offers the possibility of determining the secondaries' masses rather accurately (i.e. within about ±10%) from the period only, even in those cases where the mass ratio is not known exactly.

The masses of the white dwarf primaries can therefore be determined in those CBs whose mass ratios are known from observations. As a result it is found that they are not a constant $1.2\, M_\odot$ as was earlier suggested by Warner (1973) but lie in the range between about $0.7\, M_\odot$ and $1.3\, M_\odot$. Furthermore the assumption of a mass ratio near to unity for all CBs removes the discrepancy between the mean mass of single white dwarfs and the mean mass of white dwarfs found in CBs.

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2. The Evolution of CBs

On the basis of present theories of stellar evolution there is no doubt that only an evolution of a close binary according to type C (Lauterborn, 1969) can result in the formation of white dwarfs in binaries as massive as those found in CBs. Furthermore the mass of the white dwarf to be produced as a result of such an evolution is mostly determined by the initial angular momentum of the binary system (Refsdal and Weigert, 1971). This is mainly due to the fact that the total radius of a red giant (having a central core which is essentially a white dwarf) depends on its core mass (i.e. the mass of the white dwarf) and not on its total mass. Since the initial angular momentum necessary for an evolution of type C is rather large, W UMa systems have to be excluded as possible progenitors of CBs (Ritter, 1975).

Furthermore the assumption of conservative mass exchange throughout such an evolution leads to final systems having a rather large period and a rather massive main sequence secondary far from being semi-detached (Lauterborn, 1969), clearly in contradiction to what is observed for CBs. Therefore the observed CBs offer a strong indication that the mass exchange does not occur conservatively. A further strong indication for substantial mass loss during the foregoing evolution of CBs arises from a comparison of the relative fraction of exhausted material found in CBs with the relative fraction of exhausted material resulting from conservative evolution. In addition the initial systems must have had a high angular momentum since otherwise the central core could not have grown enough before the onset of mass exchange; and this large angular momentum has to be removed until the evolution ends in a CB. Thus it seems unavoidable that CBs undergo substantial losses of mass and angular momentum during their foregoing evolution (Ritter, 1975).

By comparing the total mass and the angular momentum of an initial system able to produce a massive white dwarf with the total mass and the angular momentum of a CB having a white dwarf of the corresponding mass it is possible to estimate the total losses of mass and angular momentum connecting the initial with the final systems. This then permits an estimate of the mean specific angular momentum to be lost, which is given by $\nu = [\log(J_i/J_f)/\log(\mathfrak{M}_i/\mathfrak{M}_f)]$. Here J_i and J_f denote the initial and the final angular momentum, respectively, and $\mathfrak{M}_i$ and $\mathfrak{M}_f$ the initial and final total mass system. From the comparison of reasonable initial systems (i.e. those undergoing an evolution of type C) with CBs it is found that in general $3 \lesssim \nu \lesssim 4$.

Possible mechanisms for removing enough mass with the appropriate specific angular momentum could be either mass loss through the outer Lagrangian point or the mechanism suggested by Paczynski (1976) and Ostriker (1976).

References

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DISCUSSION

Webbink: I have two comments to make. Firstly, regarding the mass ratio of cataclysmic binaries, I have done a very similar study of the stability of the secondary against rapid mass transfer. I find that secondaries less massive than $\sim 0.65\,M_\odot$ are unstable against mass loss on a dynamical timescale for lower ratios of secondary to primary mass than indicated by the main sequence (thermal equilibrium) mass-radius relationship. Thus the white dwarf components of these systems must be somewhat more massive than the red components in order to preserve stability against rapid mass transfer. Secondly, regarding the scenario in which cataclysmic binaries are remnants of very late mass transfer (late case B or case C), it is tempting to identify the apparent gap of observed CB periods between 0.075 and 0.130 days with the discontinuity in core masses, at given radius, between giant branch and asymptotic giant branch. If all CBs originate in this fashion, we should expect such a gap, corresponding to the discontinuity in core masses between those primaries reaching mass transfer just prior to the helium flash, and those reaching the Roche lobe only during the later asymptotic branch evolution.

Ritter: As to your first remark, my arguments for a lower mass ratio of cataclysmic binaries are valid only as long as the mass losing component is dynamically stable. Of course below $M \sim 0.65\,M_\odot$ my arguments are no longer applicable. Moreover in a more sophisticated analysis one should also take into account the results about the mass radius relations presented by Faulkner in order to derive more reasonable lower limits for the mass ratios. As to your second remark, I completely agree.

Flannery: The radial velocity separation between peaks of double emission lines often indicate Keplerian radii for the orbiting gas which are outside the Roche lobe of the white dwarf. There may well be low density gas, visible by recombinations, in the outer lobe which has nothing to do with the actual disk.

Warner: The measurement of $V \sin i$ must be done in a consistent fashion – I have always used the outer edges of the emission lines rather than the separation between doubled components (when present). There is then a good correlation between mass ratio and $K_1/V \sin i$. This is illustrated by Smak's new value of K_1 in U Gem which completely removes the discrepancy shown by this star (as discussed in my review in this volume, p. 85).

Smak: A word on the theoretical background: what should be measured as $V_{\mathrm{disk}} \sin i$ for this purpose is the velocity at the particular radius inside the disk which corresponds to the momentum supplied by the stream.