ACCRETION AND CHEMICAL STRUCTURE OF ALGOLS

Wim Packet
Astrophysical Institute, Vriji Universiteit Brussel
Brussels, Belgium

ABSTRACT

Evolutionary calculations show that during the last, slow stage of mass exchange in close binary systems, matter with gradually increasing molecular weight is transferred. If no mixing occurs the accreting star moves towards a position in the HR diagram hotter than the main-sequence band, in clear contradiction with observational evidence in Algols. So some efficient mixing mechanism must be present. Several mechanisms are examined, some of which can be definitely ruled out. A closer examination of some others is necessary.

1. INTRODUCTION

The purpose of this paper is to draw your attention to an important, but up to now neglected problem concerning the evolution of close binary systems. Consider a close binary undergoing mass exchange. Evolutionary calculations following the behavior of the mass-losing component tells us that it will end up with an atmospheric hydrogen abundance lower than the original zero-age abundance, due to the molecular weight gradient built up by central hydrogen burning. This phase with gradually decreasing surface H-abundance corresponds to the last, slow phase of mass transfer, during which the system resembles Algol-type binaries.

Whenever part of the lost matter is captured by the companion, this star should, in the absence of any mixing in the outer layers, reflect the surface hydrogen abundance of the mass-loser. In this way an inversed μ-gradient could be built up in the outer layers of the mass-gaining star. Direct measurements of the surface H-abundance are difficult, but a hydrogen-poor envelope of some extent can manifest itself indirectly by the following mechanism: lowering the hydrogen abundance causes a decrease of the opacity of the stellar material. This makes the envelope more compact, so that the surface temperature increases. In the HR diagram, the star thus shifts towards a position

M. J. Plavec, D. M. Popper and R. K. Ulrich (eds.), Close Binary Stars: Observations and Interpretation, 211–215.

to the left of the main sequence, provided the hydrogen-poor layer is deep enough. This of course clearly contradicts observation. It is well known that the mass-accreting star in Algols looks like a normal main-sequence star. This is confirmed by our Fig. 1, in which a number of Algol detached components are displayed. With one exception, all stars lie within the main-sequence band and their masses and luminosities correspond to theoretically computed main-sequence models.

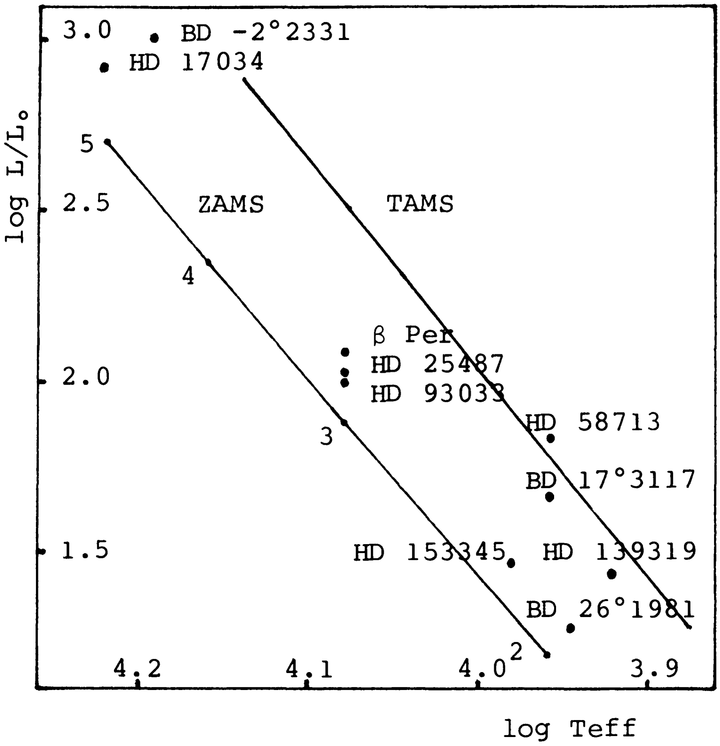

Fig. 1. Observational HR diagram for mass-gaining components in Algol systems. The systems are taken from the catalogue discussed by De Grève and Vanbeveren (1980). Only systems with good determinations of masses, luminosities and effective temperatures and with mass-loser masses between 0.6 and 1.0 $M_{\odot}$ (i.e. in the range of our computations) were retained.

2. COMPUTATIONS

In this section it will be shown that, in the absence of mixing, accreting material with increasing molecular weight μ does indeed shift towards too high effective temperatures to be compatible with observation.

For the mass-losing star, initial masses of $5M_{\odot}$ and $7M_{\odot}$ were taken. As 80% or more of all close binaries evolve through case B mass transfer

(De Grève and Vanbeveren 1980) only this case was considered. The final masses for both stars are 0.6M and 1.0M respectively. Unevolved binaries have a bimodal q-distribution, with peaks around 0.3 and 1.0 (Trimble 1974, 1978; De Grève and Vanbeveren 1979). From Table 1 it is obvious that initial q-values in the peak around 1.0 are excluded. We chose q_1 = 0.2 and 0.3 as representative values. Furthermore it is now established that close binary evolution in most cases will be non-conservative. De Grève and Vanbeveren (1979) find that in order to match observations more than 50% of the matter lost by the contact component must leave the system, with the best correspondence at β = 0.2, where β is the averaged fraction of the lost matter accreted by the other star. Additional support for this can be found in Table 1. In our calculations we used values β = 0.1 and 0.2. Actually we allowed β to vary during the mass transfer stage, with values 0.1, 0.2 and 0.5 during the slow phase of mass exchange. In total, 24 combinations of all parameters are possible. For each combination the evolution was followed from the zero-age main sequence through mass transfer up to core hydrogen exhaustion in the mass-gaining component

Table 1. Masses, maximum initial mass ratio and fraction of accreted material for the observed systems in Fig. 1

Star	M_1	M_2	q_1, max	$\beta(q_1=.2)$	$\beta(q_1=.3)$
HD17034	5.27	0.83	.86	.76	.64
HD25487	3.01	0.82	.49	.34	.22
HD58713	2.69	0.58	.55	.40	.28
HD93033	3.13	0.90	.48	.33	.21
HD139319	2.08	0.87	.33	.15	.03
HD153345	2.18	1.03	.30	.12	.01
BD-2°2331	2.30	1.00	.33	.15	.03
BD17°3117	2.44	0.90	.38	.20	.09
BD26°1981	1.91	0.63	.37	.19	.08
β Per	3.15	0.74	.55	.40	.29

From all these tracks the following general conclusions can be drawn:

As soon as transfer of matter with higher μ starts, the star moves to the left in the HR diagram and follows a track situated to the left of the main-sequence. Effective temperatures are too hot by 1500°K to 3000°K, depending on the amount of mass allowed to be accreted during the slow phase. After termination of mass transfer the stars evolve further, but 60% to 100% of their main-sequence lifetime is spent at the left side of the ZAMS. The luminosity is hardly affected by the anomalous composition of the envelope. Changing the values of q_1 or β (towards higher values) will not affect this picture very much, but will cause the masses of the gainers to become too large compared to observation.

This picture of Algol-evolution clearly does not fit observations. As the discrepancy is solely caused by the hydrogen-poor outer layers, it is clear that in Algols some mixing mechanism must be at work that is efficient enough to redistribute the helium excess across the star on a timescale shorter than the mass transfer timescale. The next section will deal with some possible mechanisms.

3. EXAMINATION OF MIXING MECHANISMS

3.1 For the sake of completeness we must mention the possibility that all matter leaves the system. In this case our problem clearly does not exist. This picture, however, is in contradiction with the theory of formation and structure of disks around close binary components (see e.g. Lynden-Bell and Pringle 1974; Lubow and Shu 1975).

3.2 A deep convective envelope is not present, as all our models have $\log T_{eff} > 3.9$.

3.3 Whem the inverse μ-gradient becomes steep enough, one expects a density inversion to occur, so that the envelope becomes Rayleigh-Taylor unstable. This, however, never occurred in our models, not even in those with an accreted fraction of 10%, which gives the steepest μ-gradient.

3.4 We included diffusion of hydrogen and helium in our evolutionary program, following the formalism developed by Noerdlinger (1977, 1978). The effect was marginal, because the diffusion timescale involved is much longer than the mass transfer timescale. One could argue that the underlying plasma physics are still uncertain, so that our diffusion rate is underestimated, but in order to have any effect the rate should be increasedby at least a factor 1000, which looks very improbable.

3.5 It can easily be seen that in case of accretion through a disk (which is observed in many Algols) the infalling matter has a specific angular momentum (per unit mass) that can easily be an order of magnitude larger than the specific angular momentum of the underlying stellar material. Shear turbulence induced by differential rotation could then act as a mixing agent. For the moment we are unable to describe this process in more detail, as it is quite complicated (in the case of accretion onto white dwarfs, a simplified model has been worked out by Kippenhahn and Thomas (1978)).

3.6 It might be that pulsational instability in the region with inverse μ-gradient causes some mixing. Stothers and Simon (1969) looked for pulsations in massive stars with a homogeneous helium-rich layer on top. This configuration, however, differs too much from ours for their results to be applicable for our purposes.

4. CONCLUSIONS

The results of our investigation can be summarized as follows:

unmixed models for the accreting component in close binaries during the last stage of mass transfer (associated with the Algol binaries) are found at a position hotter than the ZAMS;

convection, Rayleigh-Taylor instabilities, and diffusion are unable to mix in the accreted helium-rich material;

differential rotation and/or pulsational instability could do the job and should be looked at more closely. Three quantities determine the efficiency of the process: the vertical and horizontal extent of the mixed zone, and the timescale of the mixing process.

REFERENCES

De Grève, J.P. and Vanbeveren, D.: 1980, Astrophys. Space Sci., 68, 433.
Kippenhahn, R. and Thomas, H.-C.: 1978, Astron. Astrophys. 63, 265.
Lubow, S.H. and Shu, F.H.: 1975, Astrophys. J. 198, 383.
Lynden-Bell, D. and Pringle, J.E.: 1974, Monthly Notices Roy. Astron. Soc. 168, 603.
Noerdlinger, P.D.: 1977, Astron. Astrophys. 57, 407.
Noerdlinger, P.D.: 1978, Astrophys. J. Suppl. 36, 259.
Stothers, R. and Simon, N.R.: 1969, Astrophys. J. 157, 673.
Trimble, V.: 1974, Astron. J. 79, 967.
Trimble, V.: 1978, Observatory 98, 163.

COMMENTS FOLLOWING PACKET

Ziolkowski: I wonder why your models are so hot even after you stop accretion and permit them to readjust to thermal equilibrium. You probably do not deposit that much helium on them. Is it purely a chemical composition effect?

Budding: How reliably can your data establish the (often assumed) main sequence character of Algol-type primaries?

Packet: It is true that one sometimes assumes the more massive component to satisfy the zero-age mass-luminosity relation in order to establish absolute dimensions. So some of the data we used might indeed be biased in that way. However the discrepancy we find is essentially a discrepancy in effective temperature, and this parameter can be determined directly and rather accurately from spectroscopy.

Lacy (in response to a question by Dr. Budding): A double-line radial velocity curve has recently been determined for Algol by Joc Tomkin of the University of Texas at Austin and the absolute dimensions and masses are now known to within 5 percent or so. These new values do not differ significantly from estimates based on the assumption that the primary star is on the main sequence.