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Close binaries : abundances and mass loss

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Abstract. Spectroscopic studies of evolved components in close binary systems show abundance anomalies and suggest that they have suffered extensive mass loss The late type secondary components in Algol systems show C deficiency ([C/Fe] = −0.5) and N overabundance ([N/Fe] = +0.5). The very low mass (0.18 $M_\odot$) secondary of S Cnc also shows C deficiency of [C/Fe] = −0.5. The primary components of Algol systems are found to show normal C abundance to moderate C deficiency. The primary components of S Cnc, HU Tau, S Equ and TV Cas are found to show nearly normal abundance of carbon. The presence of only moderate C deficiency even in the secondary components of very low mass ratio Algol systems such as S Cnc suggests that there was mixing in the secondaries after the Roche lobe overflow.

The primary component of β Lyr is found to be He rich, extremely overabundant in N, and very underabundant in C and O. These abundances clearly show that we are seeing completely processed CNO cycle matter on the surface of the primary component of β Lyr. These abundances suggest that more than 80% of the initial mass of the primary was lost and the nuclear processed core is exposed to view. The primary of V453 Sco also shows CNO abundance anomalies similar to that found on the primary of β Lyr. V356 Sgr, RY Scuti and HD 72754 appear to be in an evolutionary stage similar to that of β Lyr and are expected to show CNO abundance anomalies.

The primary components of hydrogen poor close binary systems show overabundance of He and N. These primary components are most likely He supergiants of ~ 1 $M_\odot$ overflowing their Roche lobes for a second time. The excess UV flux (1250 Å to 1700 Å) in these systems suggests that the secondary components are O B stars. The presence of stellar wind profiles of N V, C IV, and Si IV etc similar to that observed in O B supergiants and giants clearly shows stellar wind and mass loss from these systems. Stellar wind mass loss and warm-dust shell around these systems shows that mass transfer is not conservative.

In addition abundance anomalies and mass loss aspects of symbiotic stars, planetary nebulae with close binary central stars and the binary nature of Barium stars are very briefly discussed.

Key words : close binaries—spectroscopy—mass loss

1. Introduction

The evolution of stars in close binaries is influenced by mass transfer between the components and mass loss from the system. Close binaries in an advanced stage of evolution may be the result of severe mass loss and mass transfer events If one of the components evolves and experiences extensive mass loss then its nuclear processed core can be exposed. If part of the matter lost from one component is accreted by the other component it may also show nuclear processed material on its surface. Observations indeed suggest the presence of both these types of components in some of the close binary systems. It is now generally accepted that nonconservative evolutionary models give better agreement between the theory and observations for various types of close binaries. The presence of components with C, N, O abundance anomalies and also the presence of very low mass ($< 0.2\ M_\odot$) evolved components suggests that they evolve through extensive mass loss from the system. In this review a report on abundances and mass loss aspects of close binary systems is presented.

2. Algol systems

In Algol type close binary systems, the more massive primary is an early-type (B--A) main sequence star and the less massive secondary is an evolved star typically a subgiant or giant of late spectral type (F—G—K). It is now generally accepted that Algol systems have resulted from a large-scale transfer of mass and mass loss. The very existence of the Algol type binaries in which the less massive late type component is the more evolved of the two stars is a strong evidence of the past mass loss from the late type star as a result of its evolution (Crawford 1955; Kopal 1955). The present late type star was originally the more massive of the two and thus evolved off the main sequence before its initially less massive companion could evolve.

2.1. *Secondaries of Algol systems*

Until recently the inforamtion on the secondary components had been obtained primarily from radial velocity and photometric studies. Uncontaminated spectra (not contaminated by the primary components light) of the late type secondary components of Algol systems can be obtained only in the totality phase of the primary eclipse.

Metal abundnace [Fe/H]

Miner (1966) utilized narrow-band photometry to study 12 Algol secondaries. The photometric index that Miner measured was interpreted as indicating underabundance of metals. However more recently Parthasarathy *et al.* (1979) pointed out that the photometric index that Miner used as an indicator of metal abundance measured the strength of the G band at 4300 Å. The weakness of this index in the 12 Algol secondaries indicates the weakness of CH which is a major-contributor to the G band. This would suggest an underabundance of carbon in Algol secondaries. The generally accepted view that the Algol secondaries are metal poor is not valid. A spectrum synthesis analysis of the 6400 Å region spectrum of the secondaries of U Cep and U Sge clearly shows that their metal abundance is normal (solar) [Fe/H] = 0.0 ± 0.3 (Parthasarathy *et al.* 1979, 1983). We have also compared the 8620 Å region spectra of the secondries of U Cep and U Sge with the spectra of the standard stars and found that the secondaries of U Cep and U Sge have normal (solar) Fe abundances (Parthasarathy *et al.* 1979).

Carbon and nitrogen

In addition to [Fe/H] abundance we need to know the CNO abundances on the surface of the secondary components of Algol systems to understand their evolutionary stage and mass loss aspects. If an evolved component in an Algol system has lost mass down to layers previously processed by the CN cycle it should now show C and N abundance anomalies relative to normal red giants. The very low mass secondaries ($< 0.2\ M_\odot$) in a few Algol systems (*e.g.* AS Eri, S Cnc, DN Ori) are supposed to be in the last phase of mass loss/mass transfer and are expected to have helium core surrounded by a thin hydrogen burning envelope. Therefore, determination of CNO abundances in the very low mass Algol secondaries is all the more important. A spectrum synthesis analysis of CH lines in the interval 4290 Å to 4328 Å in the spectra of secondaries of U Cep, U Sge and S Cnc shows that they are carbon deficient, [C/Fe] = −0.5 (Parthasarathy *et al.* 1983). The carbon abundance of [C/Fe] = −0.5 was found by matching the synthetic and observed spectra in the 4290-4328 Å region. The spectrum intervals to which CH is a minor contribution (*e.g.* 4283 Å to 4290 Å, 4315 Å to 4322 Å and 4330 Å to 4337 Å) the observed and synthetic spectra match for [Fe/H] = 0.0, similar to the result obtained from the synthesis of 6400 Å region (Parthasarathy *et al.* 1979, 1983). This is an additional evidence that the secondaries of U Cep, U Sge are not deficient in metals. The spectral types, T_{eff}, [Fe/H], and [C/Fe] of the secondaries of U Cep, U Sge, and S Cnc derived from the spectrum synthesis analysis are given in table 1.

Table 1. Fe, C and N abundances of the late type secondaries of Algol systems

Secondary of	Sp	T_{eff}	mass	log *g*	[Fe/H]	[C/Fe]	[N/Fe]	[O/Fe] Assumed normal
U Cep	G8 III-IV	5000 K	2 8 $M_\odot$	3.50	0.0	−0.45	+0.50	0
U Sge	G3 III-IV	5600 K	1.9 $M_\odot$	3.27	0.0	−0.50	+0.55	0
S Cnc	KO III	4750 K	0.18 $M_\odot$	2.25	0.0	−0.50		

For N abundance we synthesized the 4190 Å to 4223 Å and 3860 Å to 3887 Å region spectra which contain (CN $\Delta v = -1$ and 0 sequences respectively. N abundance of [N/Fe] = 0.5 in the secondaries of U Cep and U Sge was derived by matching the synthetic and observed spectra (Parthasarathy *et al.* 1983).

The Algol secondaries are G and K giants and subgiants, therefore we can assume that the O abundance is normal similar to the observed in field G and K giants (Lambert & Ries 1981). The CH density in the photospheres of late type stars is affected by both the C and the O abundances; however at T_{eff} in the range of 5000 to 5600 K there is little loss of C to CO. The [OI] lines at 6300 Å and 6363 Å yield reliable O abundance; these lines however are relatively weak. In the spectra of Algol secondaries these lines get blended with the nearby other atomic lines, because the spectrum is broadened as a result of the higher rotational velocity of the secondaries. However high signal to noise spectra of secondaries in totally eclipsing long period Algol systems in which the rotational velocity of the secondary will be relatively low will enable us to derive O abundance through spectrum synthesis of the [OI] lines In Algol secondaries we do not expect oxygen abundance to be different from that of normal field G and K giants, which have normal abundance of oxygen In these stars the convective envelope is predicted not reach the oxygen-depleted hydrogen-burning shell. Therefore there is no convection of the oxygen depleted matter Hence the photospheric abundance of oxygen is unaffected However it is important to derive oxygen abundance in the very low mass secondary components (< 0.2 $M_\odot$) of Algol system such as S Cnc, DN Ori etc. Since these stars have a helium core surrounded by a very thin hydrogen burning envelope and appear to have lost about 80% of their initial mass.

The C ([C/Fe] = −0.5) deficiency in S Cnc secondary and the C ([C/Fe] = −0.5) deficiency and N ([N/Fe] = +0.5) overabundance in the secondaries of U Cep and U Sge are very similar and are also more marked than in the typical field G or K giant (table 1). The C deficiency and N overabundance of the secondaries are the result of conversion of C to N by the CN cycle, while the secondaries were on the main sequence, followed by mixing to the surface These abundances are therefore observational evidence in favour of the generally accepted idea that the secondaries of Algol (semidetached) systems are post main-sequence objects.

If we accept conservative mass transfer models then the minimum masses of the main-sequence progenitors of the present secondaries of U Cep, U Sge and S Cnc were 3.5 $M_\odot$, 3 8 $M_\odot$ and 1 24 $M_\odot$ respectively The present masses of the secondaries of U Cep, U Sge and S Cnc are 2.8 $M_\odot$, 1.9 $M_\odot$ and 0.18 $M_\odot$ respectively. Comparison of the initial minimum masses and the present masses of the secondaries of U Cep, U Sge and S Cnc Suggests 20%, 50%, and 80% mass loss respectively. However it is now clear that properties of Algol systems cannot be explained in the framework of the conservative approximation (Plavec 1973; Ziolkowski 1970; Refsdal, Roth & Weigert 1974; Giuricin & Mardirossian 1981). Recent investigations show that Algol systems are the result of case B evolution (mass transfer/mass loss after the end of central hydrogen burning) and that they have lost considerable amount of mass and angular momentum (Refsdal, Roth & Weigert 1974; Giuricin, Mardirossian & Mezzetti 1983; Iben & Tutukov 1984). Mass loss and mixing act together to produce at the surface the products of thermonuclear synthesis that have occurred in the deep interior of the mass losing star

The variation of C, N, O, He etc. abundances with mass fraction for a 5 $M_\odot$ star at the onset of shell hydrogen burning (Just before crossing the HR gap) shown in figure 2 of Iben (1967) can be used to compare C, N abundances of the secondaries of U Cep and U Sge. Iben & Tutukov (1984, figure 13) have shown the evolution of the surface abundances of elements that participate in CNO burning for a binary with a main-sequence donor of initial mass 1.25 $M_\odot$, which can be used to compare the C abundance of the secondary of S Cnc. The actual mass of the progenitors of the Algol secondaries is very uncertain; it is however not crucial for the present purpose, because the variation of composition with mass fraction is nearly independent of mass over a wide mass range. The outer 50% of the mass is not affected by CN cycling and interior to this shell of mass fraction ~ 0.25 in which C has been almost completely converted to N by CN cycle. In these above mentioned regions the burning of H to He or conversion of O to N by the CNO cycle has not taken place. There is little change in abundances until the mass losing component has lost outer 50% of the mass. Algol secondaries which have lost 80% of their initial mass are expected to show extreme C deficiency [C/H] = −1.5 and large overabundance of N. The observed C deficiency [C/Fe] = −0.5 in the 0.18 $M_\odot$ secondary of S Cnc suggests that the material is mixed. Mass lost during the Roche lobe overflow prior to the onset of mixing was entirely unprocessed envelope material. At the time of mixing in the secondaries there was less unprocessed material and therefore less dilution of the CN cycle processed material. Mass loss subsequent to mixing does not alter the surface composition of the secondaries. This explains why the S Cnc secondary which has suffered extensive mass loss does not show extreme C deficiency which we expect in the absence of mixing. The 0.18 $M_\odot$ secondary of S Cnc has a He core of 0.17 $M_\odot$ and a thin H burning shell of 0.01 $M_\odot$. The core mass is too small to allow core H burning. The 0.17 $M_\odot$ He core of the secondary of S Cnc suggests that its initial mainsequence mass was about 2 $M_\odot$. The structure of the secondary of S Cnc is similar to the structure of the 0.2 $M_\odot$ secondary of AS Eri described by Refsdal, Roth & Weigert (1974) who conclude that the system has lost 65% of the angular momentum. The past evolution of AS Eri and S Cnc type systems with very low mass secondaries ($< 0.2\ M_\odot$) is hard to predict. There are many possibilities for the initial conditions.

2.2. *Primaries of Algol systems*

The present primary components in Algol systems are main sequence stars of spectral type late B to early A. In the conservative mass transfer models the primaries have accreted all the matter lost as a result of the Roche lobe overflow of the secondaries If the Algol primaries have accreted large amounts of mass lost by the secondaries down to the layers of nuclear processed zones then we expect CNO abundance anomalies not only in the secondaries but also in the primaries. However if most of the matter lost from the secondary at the time of Roche lobe overflow is lost from the system then the chemical composition of the primary is not altered. In addition to the abundance analysis of Algol secondaries, abundance analysis of Algol primaries is also important to understand their evolution, mass loss/mass transfer events. Recently C abundances of few primaries of Algol systems were determined by Cugier & Hardorp (1988); De Greve & Cugier (1989), Cugier (1989) using the C II lines at 1324 Å and 1335 Å in the ultraviolet (IUE) spectra. These C abundances of primaries of β Per, λ Tau, U CrB, TX UMa, U Her, δ Lib, U sge, R CMa and RS Vul are given in table 2. The C abundance in the primaries of δ Lib, U Sge, RS Vul, U Her is normal. However the primaries of TX UMa, U CrB, λ Tau and β Per show slight C deficiency ([C/H] = −0.3). The primary of U Sge shows normal C abundance and the secondary shows C deficiency ([C/Fe] = −0.5). These results suggest that the material lost during the Roche lobe overflow was lost from the system, if it was accreted by the primary it was mostly unprocessed outer envelope of the secondary. The primary of S Cnc is a B9.5V star of 2.3 $M_\odot$ and the secondary a late type giant of 0.18 $M_\odot$ (Popper & Tomkin 1984. Etzel & Olson 1985). We compared the high resolution UV spectrum of S Cnc primary (in the region of 1324 Å and 1335 Å C II lines) with the UV spectra of standard stars of similar spectral type. Preliminary analysis suggests that the C abundance in S Cnc primary is nearly normal (table 2). There is no evidence for significant C deficiency. From a comparison of the 1324 Å and 1335 Å C II lines in the UV spectra of low mass ratio Algol primaries HU Tau, S Equ and TV Cas with the spectra of standard stars of similar spectral type and solar composition we find that the primary components of HU Tau, S Equ and TV Cas have nearly normal C abundance

Table 2. C abundance of the primary components of Algol systems

Primary of	Sp	mass of primary $M_\odot$	mass of secondary $M_\odot$	T_{eff} primary K	[C/H]
U Her	B2 IV	7.0	2 7	22200	−0 12
λ Tau	B3 V	6 4	1 7	18000	−0 40
U Sge	B7 5 V	5 7	1 9	12250	+0 05
U CrB	B6 V	4 7	1 3	14800	−0 41
δ Lib	A0V	4 6	1 6	9900	−0 07
RS Vul	B5 V	4.4	1 4	16700	+0 06
HU Tau	B8 V	4 3	1 2	12000	Nearly normal C abundance
TV Cas	B9 V	3.8	1 6	10400	Nearly normal C abundance
β Per	B8 V	3 6	0 79	13000	−0 39
TX UMa	B8 V	3 6	1 1	12900	−0 25
S Equ	B8 V	3.1	0.4	12000	Nearly normal C abundance
S Cnc	B9.5 V	2.3	0.18	10500	Nearly normal C abundance
R CMa	F1 V	1 0	0.17	7500	0 0

(table 2) We find no dependence of the C abundance of the primary on the mass ratio of the system and on the mass of the secondary component. However these results need to be confirmed by a detailed NLTE C abundance analysis of the primaries of the Algol systems mentioned above.

R CMa is another interesting system with a 0.17 $M_\odot$ secondary. More recently Tomkin & Lambert (1989) have determined C, N, O, S and Fe abundances in the F type primary of R CMa They find that F1 V primary of R CMa to show [C/Fe] = −0.2, [N/Fe] = +0.3, and [O/Fe] = +0.2 (Table 2). There is no significant C deficiency in the primary of R CMa. If the present primary components of S Cnc and R CMa received unmixed matter from the secondaries during the Roche lobe overflow down to the layers of CNO processing zones then the primaries should show extreme C deficiency and large N overabundance The observed abundances of the primary and secondary components of Algol systems suggests that (i) most of the matter lost from the present secondary at the time of Roche lobe overflow was lost from the system, (ii) there was mixing in the secondaries before the Roche lobe overflow. The time of onset of mixing is uncertain. It may have taken place before or after the Roche lobe overflow. It depends on the initial mass and separation which are difficult to estimate. Mixing after the Roche lobe overflow may show significant C deficiency on the surface of the secondaries than mixing before Roche lobe overflow. If mass transfer is conservative the mass gaining component may also experience mixing as it starts accepting large amount of matter from the component which is experiencing Roche lobe overflow. Because of this mixing the primaries of algol systems do not show significant C deficiency. However recent numerical studies of evolution Algol systems (Iben & Tutukov 1984; Yungelson *et al.* 1989) suggest that magnetic stellar wind is an important factor in the evolution of particularly the low mass Algol systems.

Iben & Tutukov find that a magnetic stellar wind drives primordially separated main-sequence components in pre-algol systems close enough together for the first massinverting mass transfer event to occur and then continues to drive mass transfer in the emergent Algol system. As of today only three Algol secondaries have C abundance estimates. C abundance estimates are available for about 13 Algol primaries. Most of these estimates are based on C II 1324 Å and 1335 Å lines. These UV lines are strong and appear to be sensitive for NLTE. The CNO abundance determination of several more algol primaries and secondaries using the blue visible and near-IR regions of the spectrum is needed in order to understand the evolutionary processes, mixing and mass loss/mass transfer events in them. Most of the Algol secondaries are in slow mass loss/mass transfer phase. From IUE spectra of U Cep, Kondo *et al.* (1981) found evidence for mass loss from the system. From an analysis of the UV spectra of several close binary systems, Kondo (1989) finds that a fraction of the matter flowing out of the masslosing component is accreted by the companion and the remainder is lost from the binary system. Another piece of evidence for mass loss/mass transfer and activity is that some of the algol systems were found to show transient accretion discs (Batten *et al* 1975; Plavec & Polidan 1975, Batten, 1988, Kaitchuck, Honeycutt & Schlegel 1985 and references therein)

2.3. *β Lyrae and related stars*

β Lyrae is understood to be near the end of the rapid phase of mass transfer. The system is still in an active phase of mass transfer and mass loss. Hack *et al.* (1975) (see also Wilson 1974; Ziolokowski 1976) note that the rate of period increase of about 18 seconds yr^{-1} can be explained by a conservative mass transfer rate of the order 5×10^{-5} $M_\odot$ per year. From an analysis of the eclipse light curves and radial velocity variations Huang (1963), Woolf (1965) and Wilson (1974) find that the visible B type component is of 2 $M_\odot$ and the invisible secondary is a 12 $M_\odot$ B type main sequence star embedded in an optically thick disc. The visible primary has filled its Roche lobe and transferred and still transferring matter to the secondary. Sahade & Wood (1978) and Sahade (1980) reviewed the observational results, problems and models of this system. The absolute visual luminosity of the primary is found to be $M_v = -4.1$ (Dobias & Plvec 1985; Abt *et al.* 1962), which clearly suggests that the visible primary is a luminous giant and overluminous for its mass. Ziolkowski (1976) calculated an evolutionary model for *β* Lyrae. He followed the evolution of a binary system with initial parameters $M_1 = 10$ $M_\odot$, $M_2 = 3.7$ $M_\odot$, $P = 3.44^d$ and assuming that total mass and orbital angular momentum are conserved. He finds that the present 2 $M_\odot$ primary is the remnant of the initially 10 $M_\odot$ star which filled its Roche lobe shortly after the exhaustion of hydrogen in its centre (case B of binary evolution) and transferred 80% of its mass to the present secondary. Conservative mass transfer models suggest that the helium-enriched core of the mass donor is uncovered in case B mass exchange. If the mass transfer in *β* Lyr was conservative the present primary's initial mass was more than 7 $M_\odot$. Various models suggest that initial mass of the primary to be 12 $M_\odot$. Thus the primary which has lost 80% its initial mass should now show the nuclear processed interior. Comparison with the 9 $M_\odot$ and 15 $M_\odot$ evolutionary models of massive main sequence stars derived by Iben (1966 a, b) suggests that if a star is near exhaustion of the H in the core and if outer 80% of its envelope is lost, it should show extreme C deficiency, large overabundance of N, under abundance of O, and moderate overabundance of He. Thus the present 2 $M_\odot$ primary of *β* Lyr is the CNO processed core of a $\sim$ 12 $M_\odot$ star. Therefore we expect to see CNO abundance anomalies on the surface of the primary component of β Lyr. From the curve of growth analysis Boyarchuk (1959) found large over abundance of He (He/H ~ 25) in the atmosphere of the primary component of β Lyr. Hack & Job (1965) and Leushin *et al.* (1977) find moderate He over abundance (He/H = 1.5). The CNO abundance analysis was made by Leushin *et al.* (1979) and Leushin & Snezhko (1980). However their estimates of CNO abundances disagree with one another and their C abundance estimate appears to be uncertain.

Recently we (Balachandran *et al.* 1986) have determined accurate CNO and He abundances in the primary of β Lyr. Our estimates of CNO and He abundances are based on detailed analysis of high signal to noise Reticon spectra in the blue, visible and near infrared regions. The He, C, N, O, Fe, and Ne abundances in the primary component of β Lyr determined by us (Balachandran *et al.* 1986) are given in table 3. We

Table 3. Abundances of the brighter visible component of β Lyr and related stars

	Period (days)	Sp0	T_{eff} (K)	mass visible primary ($M_\odot$)	mass secondary $M_\odot$	[He]	[C]	[N]	[O]
β Lyr	12.9	B6 ep	13300	2	12	0.78	−1.13	+1.51	−1.01
V 453 Sco	12.0	B0.5 Iae	26000	13.7	25		−1.29	+0.41	−0.91
V 356 Sgr	8.9	A2 II	8600	4.7	12	C is very underabundant in the A2II star of V 356 Sgr			
RY Scuti	11.1	Bep	28000	11	35	RY Scuti primary may be rich in He and N			
HD 72754	33.7	B8 Iep		4.5	15	Primary is N rich			

Notes: (i) The spectral types, T_{eff} and abundances given above are for the bright visible components.
(ii) The spectral types of the bright visible primaries should be used with caution as these components show He, C, N, O abundance anomalies.
(iii) The secondary components in most of these systems are massive under luminous. The massive secondaries are embedded in thick accretion disks. The masses of the components in RY Scuti and HD 72754 are uncertain.
RY Scuti shows emission lines of [FeIII], NIII, HeII, [OIII], [NII] etc.

find that the β Lyr primary is He rich (N[H] = 0.4, N(He) = 0.6) and extremely overabundant in nitrogen (≈ 20 times more abundant than in the sun). Carbon and oxygen are highly underabundant relative to N(C/N $\leqslant 0.011 \pm 0.02$ and O/N $\leqslant 0.025 \pm 0.05$). The C/N and O/N ratios of abundances in the atmosphere of the primary component are very much different from the solar C/N = 5 and O/N = 8 ratios. The CNO abundances, C/N and O/N ratios are close to the equilibrium values of the CNO cycle. These results clearly demonstrate that we are seeing completely processed CNO cycle matter on the surface of the primary component of β Lyr. These abundances suggest that more than 80% of the initial mass of the primary was lost and that the nuclear processed core is exposed to view. Since the primary component of β Lyr is He rich, C and O poor and overabundant in N we should be cautious in assigning a specitral type to it. Our analysis of the spectra of primary of β Lyr suggests T_{eff} = 13300K. We should use the temperature rather than assigning a spectral type of B6 or B8 to the primary of β Lyr, it is not a normal star.

The ultraviolet spectra of βLyr show violet shifted P Cygni lines of N v, C IV, Si IV, Al III, C II, Si II, Al II, Mg II, which suggest stellar wind and massloss from the primary (Hack *et al.* 1976, 1977, 1980, 1981, Aydin *et al.* 1988). From an analysis of these P Cygni profiles Mazzali (1986) estimated the mass loss rate to be 2×10^{-7} $M_\odot$ yr^{-1}. From an analysis of He I 5876 feature Etzel & Meyer (1983) also suggest stellar wind mass loss from the primary component of β Lyr. The IRAS observations (12 μm : 5 Jy, 25 μm : 2.3 Jy, 60 μm : 0.8 Jy) show evidence for warm (~ 600 K) dust around β Lyr. This dust has formed as a result of mass loss from the system.

There are very few known systems that are in an evolutionary stage similar to that of β Lyr. V453 Sco, V 356 Sagittarii and RY Scuti appear to be related to β Lyr.

V453 Sco (HD 163181)

V453 Sco was found to be a N rich B0.5 Ia star by Walborn (1972). Spectroscopic and photometric studies (Hutchings 1975; Madore 1975; Woodward & Koch 1975) revealed that it is a β Lyrae type system with an orbital period of 12d. The large strength of N lines detected by Walborn suggested overabundance of N in the atmosphere of the B0.5I star of V453 Sco. Kane, McKeith & Dufton (1981) made a detailed CNO abundance analysis. They found that the primary B0.5Ia component of V453 Sco is underabundant in carbon and oxygen while N is overabundant. The CNO and C/N, O/N abundances are given in table 3.

Depletion in C and O, and N overabundance in the atmosphere of the primary component of V453 Sco suggests that at least 50% of the initial stellar mass must have been lost so that material which was initially in the convective core is exposed. The present mass of this component is of the order 13 $M_\odot$. (Hutching 1975; Woodward & Koch 1975). The secondary is a 25 $M_\odot$ star embedded in a disc and may be similar to the secondary in β Lyr. The UV spectra of V 453 Sco show violet shifted N v, C IV and Si IV stellar wind lines suggesting stellar wind mass loss from the system.

V 356 Sgr

This is a peculiar Algol system. It is a 8.9d period semidetached system consisting of a B4V primary and a giant A2II secondary. Wilson & Caldwell (1978) from an analysis of light curves find that the B4V star is embedded in a geometrically and optically thick disc. Recently Ziolkowski (1985) made calculations of evolutionary models of V356 Sgr. He found that A2II component which has filled its Roche lobe is now burning hydrogen in a shell (case B) and the present state of V356 Sgr cannot be realized through a non-conservative evolution of binary system. From an analysis of the ultraviolet spectra obtained during the totality Polidan (1988) finds that the evolved A2II component is extremely underabundant in C. The A2II star in V356 Sgr appears to have lost more than 50% of its initial mass. The present mass of the A2II star is 4.7 $M_\odot$ and that of B3V component is 12.1 $M_\odot$ (Popper 1980). Ziolkowski (1985) has shown that the system cannot be the result of conservative mass transfer. Therefore the initial mass of the A2II star was more than 12.1 $M_\odot$, and it has lost at least 70% of the initial mass. Detailed CNO abundance analysis of the A2II component in V356 Sgr using the blue visible and near IR spectra need to be carried out. HD 72754 (B8Ie) (Thackeray 1971) also appears to be system similar to β Lyr and shows strong N lines. N over abundance is expected in the B8 component of this system. A detailed CNO abundance analysis of this system is required.

RY Scuti (Bep)

This is an another peculiar close binary system which may be in an evolutionary stage similar to β Lyr (Cowley & Hutchings 1976). This is a radio and infrared source. The visible primary is a B type emission line star which apears to overflow its Roche lobe. The secondary is more massive than the primary and may have an accretion disc similar to that of β Lyr. The primary component is expected to show overabundance of He and N and an underabundance of C and O similar to that of primary of β Lyr (Antokhina & Cherepashchuk 1988; Kumsiashvili 1989). The IRAS far-infrared observations (table 6) show evidence for the presence of warm dust around the system, which suggests mass loss from the system.

W Serpentis stars

Plavec (1980) suggested that W Serpentis type stars are in an evolutionary stage similar to that of β Lyr. Plavec suggested that RX Cas, SX Cas, V367 Cyg, W Cru, β Lyr and W Ser, AR Pav, HD218393 (KX And), HD 72754 and HD 51480 are similar to W Ser. These systems are mass-transfering binaries (case B) in which the present mass transfer rate is of the order 10^{-6} to 10^{-4} $M_{\odot}$ yr^{-1}. Plavec & Koch (1978) and Plavec (1980, 1989) detected strong emission lines of Nv, Civ, Siiv, Feiii, Aliii, Cii, Siii etc. within and outside the eclipses. They suggested that these lines are predominantly formed by scattering in an induced stellar wind. Like β Lyr, W Serpentis stars appear to be semidetached systems near the end of rapid mass transfer, with optically and geometrically thick accretion discs around the present massive stars. In β Lyr, V 356 Sgr V 453 Sco, RY Scuti, υ Sgr, and KS Per (HD 30353) the present secondary is more massive than the primary and it is invisible and appears to be embedded in an accretion disc. The primary components in all these systems are less massive than their secondary components and show CNO, H and He abundance anomalies. The ultraviolet spectra of most of these systems show evidence of stellar wind and mass loss. High resolution ultraviolet spectra of W Ser stars may reveal P Cygni type character in the emission lines and may yield estimates of mass loss from these systems. The knowledge of CNO abundances in W Ser is important to understand the mass transfer and mass loss process and the evolutionary connection and sequence between these stars and Algol type systems.

3. Hydrogen poor close binary systems

In addition to CNO abundance anomalies there are a few close binary systems that show severe H deficiency and overabundance of He. υ Sgr, HD 30353 (KS Per), LSS 4300 and CPD-58°2721 (LSS 1922) comprise the small group of hydrogen poor close binary systems. The details of these systems are given in table 4. These are single lined spectroscopic binaries. The secondaries are more massive than the primaries and there are no traces of the secondaries to be seen in the visible spectrum. The primaries are hydrogen poor He rich A type supergiants.

The binary system υ Sgr is one of the best known representative of the group of hydrogen poor stars. Hack & Pasinetti (1963) made a coarse analysis of the spectrum of the B8-A2 Ia component and derived abundances of various elements. They estimated

Table 4. Hydrogen poor close binaries

	Sp	T_{eff}	Period days	$f(m)$ $M_\odot$	m_1 primary $M_\odot$	m_2 secondary $M_\odot$
υ Sgr	B8 Ipe	10500 K	138	1.7	1	3
HD 30353 (KS Per)	A5 Ipe	9000 K	363	3.6	1	5
LSS 4300	B6 Ipe	14400 K			1	
CPD-58° 2721 (LSS 1922)	B6 Ipe	14000 K	43	1.0	1	2

Notes : Spectral types of these stars should be used with caution, as these stars show strong lines of He and weak lines of H. The spectra of these stars are very different from that of normal stars The masses of the visible A type supergiants and invisible secondaries are uncertain. Excess flux in the UV(IUE) region suggests that the secondaries are O-B stars embedded in accretion discs.

that $n(\mathrm{H})/n(\mathrm{He}) = 0.025$. More recently Leushin & Topiliskaya (1989) made a detailed abundance analysis of the primary. They find extreme H deficiency and over abundance of He, C and N. N is more over abundant than C and O. These abundances clearly suggest that the present primary has lost all the hydrogen outer envelope and the CNO processed material has been exposed at the surface. Schonberner & Drilling (1984) estimate $n[\mathrm{H}]/n[\mathrm{He}] = 0.0005$ and $n[\mathrm{N}]/n[\mathrm{C}] = 20$.

The spectrum of HD 30353 (KS Per) resembles that of υ Sgr in many aspects. Wallerstein, Greene & Tomley (1967) and Lee & Nariai (1969) have found $\mathrm{H/He} = 10^{-4}$, $n\mathrm{C}/n\mathrm{N} = 10^{-3}$ and $n\mathrm{O}/n\mathrm{N} = 2 \times 10^{-2}$ from a coarse abundance analysis.

Recently Schonberner & Durilling (1984) analysed the spectrum of LSS 4300 which is also similar to υ Sgr and HD 30353. From a preliminary model atmosphere analysis of the spectrum of LSS 4300 thedy find $n(\mathrm{H})/n(\mathrm{He}) = 0.003$ and $n(\mathrm{N})/n(\mathrm{C}) = 20$.

The chemical composition of the A type supergiants in these three systems (table 5) reveal that they are extremely hydrogen poor and He rich. The primary components in these three systems have suffered extensive mass loss during the Roche lobe overflow and as a result the nuclear processed core is exposed to view. These stars can be described as He supergiants. They are N rich unlike extreme He stars and hydrogen poor carbon stars, which are carbon rich. Schonberner & Drilling (1983, 1984) suggested that the primaries in these hydrogen poor binaries are overflowing their Roche lobes for a second time during helium shell burning phase (case BB mass exchange of Delgado & Thomas 1981). The A type primaries in these systems are He supergiants which have degenerate CO core of 0.894 $M_\odot$ and a helium rich envelope of 0.013 $M_\odot$. The extremely hydrogen poor atmospheres of υ Sgr, HD 30353 and LS 4300 cannot be explained by case B mass

Table 5. Abundances in the atmospheres of hydrogen poor close binary systems

	υ Sgr	KS Per	LSS 4300	Sun
H	8.7	7.6	9.0	12.00
He	11.98	11.6	11.5	11.00
C	9.73	6.2	8.0	8.69
N	10.13	9.2	9.3	7.99
O	9.3	7.5	—	8.91
Ne	10.3	8.5	—	8.5
Si	7.87	7.6	7.8	7.6
S	7.46	7.8	—	7.2

exchange. υ Sgr and HD 30353 are wide systems. The primaries in such wide systems fill their Roche lobes only after the formation of a degenerate CO core.

Recently Iben & Tutukov (1985) suggest that initial separations in these systems are large enough to permit the primary to develope a large helium core prior to the first episode of mass loss and then to go on to develope a surface devoid of hydrogen during a second mass loss episode. Their study also indicates that if one assumes mass loss on a thermal time scale while the radius is larger than some predetermined value case C mass transfer will also in some instances expose at the surface layers which are essentially devoid of hydrogen. It may also be possible to produce systems having the properties of υ Sgr and KS Per even from initially wide systems in which component masses are not comparable but common-envelope action causes pronounced orbital shrinkage and causes most of the mass from the primary to escape from the system instead of accreting on to the secondary.

The ultraviolet flux distribution (1250 Å to 1900 Å) of υ Sgr and HD 30353 suggests that the secondary components in these two systems are late O or early B stars (Hack *et al.* 1980; Duvignau *et al.* 1979; Parthasarathy *et al.* 1986, 1989). The secondary components in these two systems may be evolved objects and may have accretion discs which are obscuring the secondary a phenomenon similar to that of the secondary of β Lyr.

The high resolution ultraviolet spectra (1250 Å to 3200 Å) of these two systems show shortward shifted stellar wind profiles of Nv, CIV, SiV, CII, AIII, AlIII, MgII and FeII. The terminal velocities from Nv, CIV and SiIV lines are about -813 km s^{-1} and -650 km s^{-1} for υ Sgr and HD 30353 respectively. The stellar wind is similar to that observed in O-B supergiants and giant and clearly indicates the mass loss from these two systems. The mass loss rate is found to be about 6.2×10^{-7} $M_\odot$ yr^{-1} (Parthasarathy *et al.* 1986, 1989). The shell lines in the high resolution UV spectra of these two systems suggests for the presence of extended atmosphere and multiple shells. The presence of strong broad and violet shifted Nv, CIV absorption lines in the UV spectra of these two systems require a temperature of the order of 35000 K. In radiative equilibrium models Nv lines are not expected in stars cooler than $T_{\rm eff} = 35000$K. In single supergiants and giants cooler than B1 the Nv resonance doublet is either very weak or absent. Abbot *et al.* (1982) find that Nv lines are almost absent in stars clearly less luminous than $M_{\rm bol} = -7$. The stellar wind seen in the UV resonance lines of υ Sgr and HD 30353 is radiatively driven similar to that observed in O-B stars. Stellar wind and mass loss are also expected in LSS 4300 and CPD$-58°2721$. The characteristics of these two are very similar to υ Sgr and HD 30353. These four hydrogen poor close binaries are found to show small amplitude long-period light variations (Morrison 1988 and references therein). A detailed photometric investigation of υ Sgr and HD 30353 has failed to detect any evidence for eclipses but has revealed the presence of quasi-periodic variation which is clearly identified with radial pulsation of the A type supergiant primaries in their fundamental mode (Morrison 1988).

The far infrared (IRAS) observations of β Lyr, υ Sgr HD 30353 and LSS 4300 RY Sct show the presence of warm dust around these systems. The far-infrared (12-100 μm) IRAS fluxes and dust temperatures are listed in table 6. Stellar wind from these system and warm dust around them are direct observational evidence for the mass loss from these systems. The presence of circumstellar dust and mass loss from these systems clearly indicates that conservative mass transfer models are not adequate to understand the evolution of close binary systems.

Table 6. Far-infrared observations showing evidence for the presence of warm dust around few evolved close binaries

	Observe IRAS fluxes (Jansky)				
	12 μm	25 μm	60 μm	100 μm	T_d dust temperature
β Lyr	5.01	2.28	0.8	1.0	600 K
υ Sgr	136.6	44.13	8.01	2.58	1000 K
HD 30353	1.58	0.52	0.4	1.31	1000 K
LSS 4300	6 78	3.07	8.68	—	750 K
RY Scuti	44.29	22.83	22 73	—	500 K

4. Symbiotic stars

Nussbaumer *et al.* (1988) investigated a sample of symbiotic stars for their CNO abundance ratios. They found that symbiotic stars show very little scatter in their C/N and O/N ratios indicating that they represent objects in a common evolutionary stage. Comparison with the CNO abundance ratio of symbiotics with related objects such as red giants novae and planetary nebulae reveals that symbiotic objects best fit the CNO abundance ratios of normal red giants This finding of Nussbaumer *et al.* (1988) supports the idea that symbiotics are binaries in which a hot ionizing source illuminates the stellar material of a red giant star. The hot star in some of the symbiotics is a hot white dwarf. The yellow symbiotics (which consists of F or G giants and a hot companion) are found to show circumstellar dust shell with characteristics similar to the dust shells of planetary nebulae. Analysis of IRAS data of yellow symbiotics M1-2, AS201, Cn-1-1, Wray 157 and HD 149427 suggests that they are young planetary nebulae containing a binary nucleus. (Parthasarathy & Bhatt 1989). M1-2, AS201 and Cn1-1 show evidence for the presence of evolved hot companions.

5. Planetary nebulae with close binary central stars

The existence of close binary planetary nebulae nuclei was predicted by Paczynski (1976). Paczynski suggested that a main sequence companion spiralling down inside a red-giant envelope and ultimately spinning the common envelope up to breakup. This common envelope interaction would produce a close binary (consisting of a red-giant core plus a main-sequence secondary) lying inside a nebular shell that would be ionized by UV radiation from the hot core. The common envelope evolution removes substantial mass and angular momentum from the system. Seven planetary-nebula nuclei are now known to be binaries (Bond 1988) with orbital periods less than one day. These systems are likely to be the result of common envelope evolution during which a wide binary was converted to a close binary surrounded by an ejected red giant envelope. Bond (1988) finds that 10-15% planetary nebulae nuclei are close binaries. The hydrogen poor binaries like υ Sgr and HD 30353 with long periods may also go through the common envelope phase. The close binary central stars of planetary nebulae are observational evidence for mass loss and non-conservative evolution.

Bond suggests that the descendants of close-binary planetary nebulae nuclei are probably the cataclysmic variables. The cataclysmic variables GK Per, 0623 + 71 are surrounded by nebulae and have characteristics of old planetaries. These objects are direct evidence that cataclysmic variables originate through planetary ejection in a binary system. The nebula surrounding these binary planetary nebulae nuclei show CNO abundance anomalies. The evolution of the binary central stars of planetary nebulae may produce double white dwarf system which are considered to be progenitors of type I supernovae.

6. The binary nature of barium and related stars

Barium stars (Ba II stars) are population I G and K giants with overabundance of carbon and s-process elements. The CH stars also have similar C and s-process over abundances they appear to be just population II analogues of the Ba II stars. From an analysis of radial velocity variations of several barium and CH stars McClure & Woodsworth (1989) concluded that all barium and CH stars are binaries with low mass companions. The low mass companions to BaII and CH stars appear to be ;white dwarfs (Bohm-Vitense 1980) The luminosities of BaII and CH stars suggest that they are not AGB stars It is therefore unlikely that carbon and s-process elements could have been mixed up to the atmosphere of these objects by the helium shell flash mechanism. The binary nature of barium and CH stars with white dwarf companions suggest that the present white dwarf companious were once carbon (AGB stars) stars which evolved and overflowed their Roche lobes and transfered C and s-process rich matter to the companions which are present BaII and CH stars (McClure & Woodsworth 1989 and references therein). They found that the orbital periods of Barium and CH stars to range from 80d to up to longer than 10 yr. The separation of the binary components in Ba II and CH stars, therefore, appear to have an upper limit beyond which mass transfer is impossible. However the BaII and CH stars may also be the result of accretion instead of the Roche lobe overflow. The Barium and CH stars were the result of the accretion of a part of the matter ejected through a superwind and planetary nebula by a C and heavy element-rich asymptotic giant branch star. The end result is a barium or CH star with a white dwarf companion Also it is now becoming clear that all non-technetium (T_c) peculiar red giants are binaries with white dwarf companions. The present white dwarf companions when they went through the AGB stage of evolution lost C and heavy element rich matter to its companions which are the present peculiar red giants with no T_c. These are cooler and more evolved analogs of the Ba stars.

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