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On the chemical abundances of close binary stars on and near the main sequence*

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Abstract. From a well-known catalogue of stellar abundance determinations there were extracted those which refer to close binary stars. Treated as a single set, the data show no evidence of evolutionary effects on the [Fe/H]—parameter, nor do the cool giants show any such effect as a group The remainder of the study concerns itself with binary systems which are either unevolved or hardly evolved. Solar-like, single-line spectroscopic binaries display a seeming underabundance which, as expected, is a consequence of the diluting continuum from the faint companion star. Metallic-line characteristics prevent recognition of this effect in otherwise similar A-type systems. In contradiction to an earlier claim, it is shown that unevolved B-type binary components show no He anomaly. Lastly, the case for anomalous abundances for RS CVn is shown likely to be a consequence of the coincidence of the Keplerian and spot-activity phases at which the spectrographic data were accumulated.

Key words : close binaries—chemical abundances

1. Introduction

As instrumental throughput and detectivity improve, it will continue to happen that a larger and larger data base of stellar spectroscopic analyses will accumulate. This has been forecast in the successive catalogues of Cayrel de Strobel *et al.* (1981) and Cayrel de Strobel *et al.* (1985, hereafter CBHD) showing an increase of almost 50% from the earlier to the later listing. Since the number of close binaries being discovered among stars hitherto considered to be single ones is also increasing, it is predictable that the accidental analyses of double systems will also increase.

Some workers in the field of close binaries are not familiar with this resource, the cautions with which it must be consulted, and the circumstance that it contains some information which need not be rediscovered with more modern techniques. The present note enlarges on these matters by a reconaissançe of the binary fraction of this data set and by invoking examples of main sequence and near-main sequence binary systems.

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These form almost the trivial case for binaries—neither decisive indication of evolution nor evidence of chemical anomaly is to be expected.

2. The present data base

For present purposes a *close binary* is defined as a system in which the component stars will interact at least once before core degeneracy is attained. Further, interaction is defined as a mass transferring/loss event due to the bound condition of the stars. Thus, a pair of main sequence F-stars in a 10-day orbit, a 2-day system encompassing an A-type main sequence star accompanied by a G-subgiant, and a cool supergiant moving in a 500-day orbit with a B-main sequence star are all examples of close binaries. At least the phase-locked velocity pattern or the eclipsing light curve or (rarely) the composite or symbiotic spectrum is necessary as evidence for the binary condition. One can certainly trace the beginnings of close binary atmospheric analysis at least as far back as Aller & Stoddard (1938).

CBHD was culled for systems which fulfill these criteria. In all, at least 186 of the 1,035 stars (for a limiting frequency of 18%) in the catalogue are really close binary ones, either deliberately or inadvertantly observed for atmospheric analyses.

These data were further sieved for only the analyses which used the sun as a reference. Representations of this material appear in figures 1-3. All but Bp, Am, and Ap

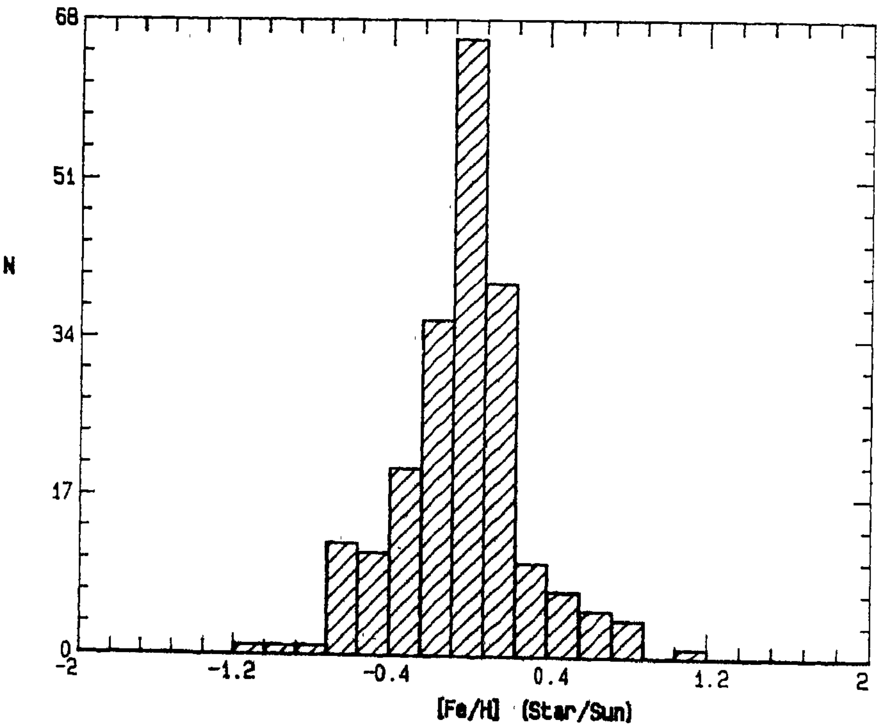

Figure 1. The distribution of the 215 [Fe/H]-determinations given in CBHD for close binaries with Keplerian periods less than 10,000 days and which embody neither Bp nor Ap nor Am stars. The centroid of the distribution occurs at [Fe/H] = +0.02.

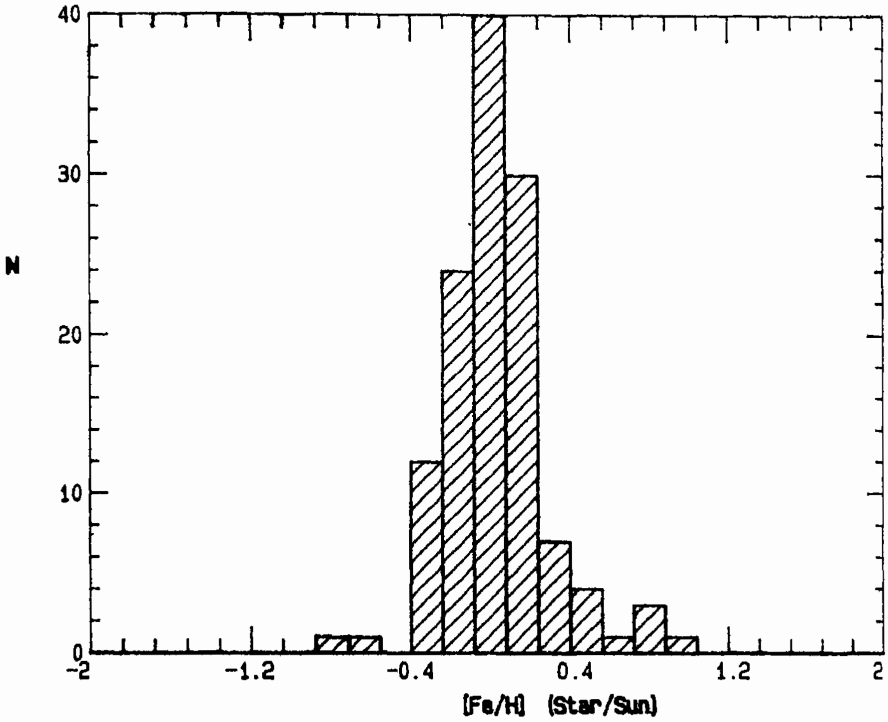

Figure 2. The distribution of the 124 [Fe/H]-determinations given in CBHD for close binaries with luminosity classifications of III, II, or I. Most of these systems are dominated by cool stars. The centroid of the distribution occurs at [Fe/H] = +0.05.

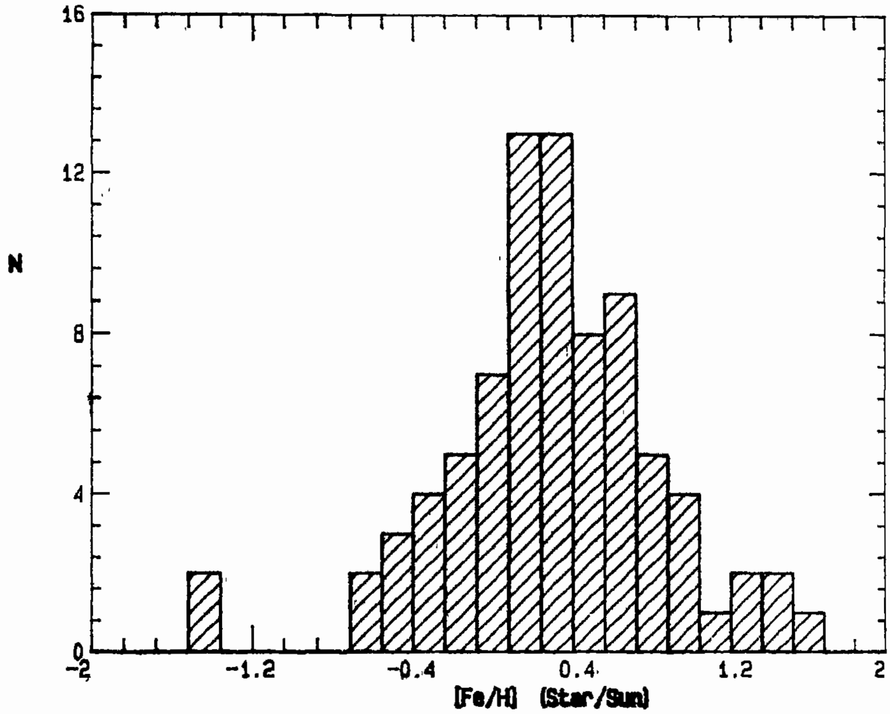

Figure 3. The distribution of the 82 [Ge/H]-determinations given in CBHD for close binaries with Bp, Ap, and Am components. The centroid of the distribution occurs at [Fe/H] = +0.33

binaries are represented in figure 1 whereas figure 2 shows only the results for systems classified as III, II or I. Within the errors, the mean values of the distributions are solar and the one-sigma dispersions (used for all measures of precision in this paper) are each about a factor of two. Thus, the ensembles of these data show no evidence of abundance differences due to binary evolution. Discrimination between stars ascending the RGB and AGB would be expected to express envelope stripping due to mass loss but only four analyses of AGB objects exist in the data set. Figure 3 shows the differential metallicity effects between ordinary pairs and Am, Ap and Bp systems.

None of these three distributions is well fitted by a single Gaussian. As a control, the first 112 analyses in CBHD for supposedly single stars with $-2 < [Fe/H] < +2$ and referred to the sun were also tested. This too is poorly fitted by a single normal distribution. It differs from the distributions in figures 1 and 2 in being displaced to a centroid $[Fe/H] = -0.25$ whereas for the binaries in figures 1 and 2 the centroids are not significantly displaced from $[Fe/H] = 0.00$. Obviously, the single stars contain a considerable number of Pop. II giants and the binaries do not.

3. Solar-type, single-line close binaries

A good test of binary abundances may limit itself to systems which are solar-like so as to diminish effects traceable to different physical atmospheric parameters. From CBHD there were extracted the few main sequence or near-main sequence F- and G-type close binaries with periods not greater than 50 days: HD 4614 (Eta Cas), 13974 (Del Tri), 30455, 78418 (75 Cnc), 98230 (Xi UMa ftr), 124425, and 210027 (Iot Peg). Three of these are actually SB2's but not in the wavelength intervals over which the spectroscopic analyses were made. Additionally, HD 124425 had been referred to 110 Her and not even indirectly to the sun and so was not used. From the references cited in CBHD the abundances normalized to H and referred to the sun were extracted. Normal abundances were taken from Adelman (1986). For the six systems (omitting HD 124425), the results are shown in figure 4.

First of all, Li abundances show a great range, as expected for stars of substantially different ages and are not considered further. More significantly, for species between Na and Ba the binaries show an average depletion of about -0.14 dex with respect to the sun. For an average SB1, this may be understood in a phenomenological way as follows. In the absence of a blending line from the faint star, its overlying continuum dilutes a line strength from the spectroscopically bright star by at least 25%. For weak lines on the linear portion of the curve of growth, a diminution in line strength scales directly into a seeming underabundance. Thus, for a 25% line weakening, one expects to measure a seeming underabundance by about -0.12 dex—essentially the observed value.

From photographic spectra, a precision of $\pm$ 10% to $\pm$ 15% for equivalent widths is rather common. The conclusions which may be drawn by invoking, as above, a few main sequence close binaries may be summarized as follows: (i) The abundance analyses of SB1's can be afflicted by a systematic, one-sided bias error which is comparable to the random error of line strength measurement. (ii) If the distributions of errors of elemental abundances with respect to the sun shows a significant negative bias (as is marginally the case for the entire sample of unevolved pairs, i.e., the difference between the distributions in figures 1 and 2), the possibility of unrecognized binaries among the sample should be investigated.

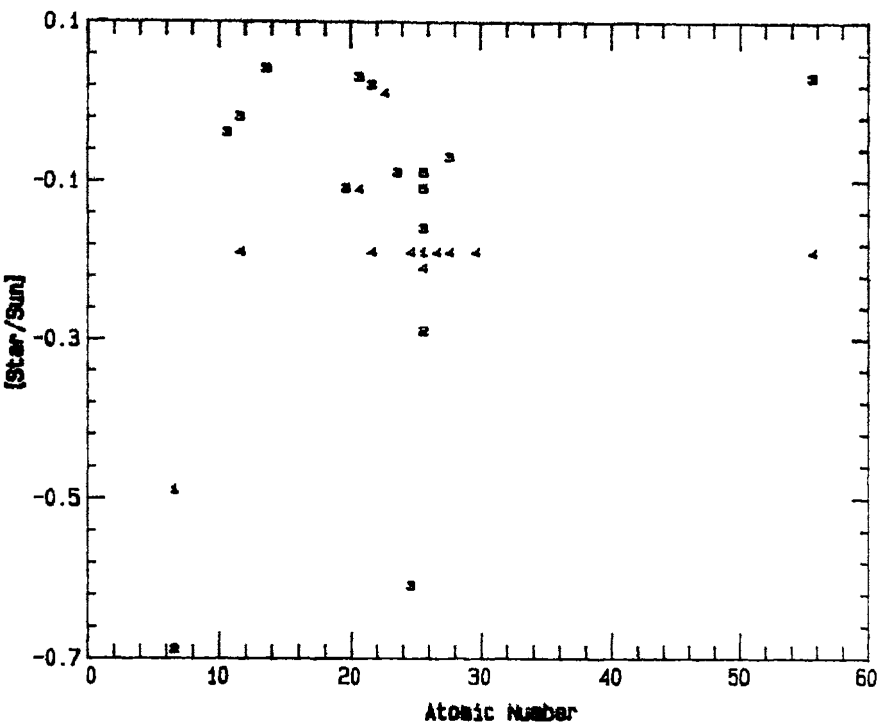

Figure 4. With respect to the sun, the relative abundances of some elements for six single-line, solar-like SB's having Keplerian periods not greater than 50 days The number code 1, HD 4614, 2, HD 13974; 3, HD 30455, 4, HD 78418, 5, HD 98230, 6, HD 210027 For HD 98230 and 210027 only [Fe/H] is available.

4. A- and B-type close binaries on and near the main sequence

An effect of the kind just described can be sought in hotter, single-line binaries. Only HD 2421 and 23964 are to be found in CBHD. Scatter among the results for these stars is very large and no small systematic effect can be recognized. Rather, seemingly large underabundances (with respect to the Sun) persist from C up to the Fe-peak elements and then give way to comparable-size overabundances up to Ba.

This pattern, in fact, is evidenced also by double-line systems over the same range of spectral type. These sample stars are HD 40183 (both components of Bet Aur), 60178/9 (Alp Gem A/B, with all the possible confusions attendant upon the multiplicity of the star), and 107259 (Eta Vir). An obvious unifying factor among both binary types is the Am characteristic.

A different situation appears in Leushin (1985), who attempted to determine He abundances for the hot, bright components of pairs of mostly unevolved and mostly reasonably-known B-stars: V599 Aql, V822 Aql, Sig Aql, AH Cep, CW Cep, EM Cep, Y Cyg, V380 Cyg, IM Mon, U Oph, AG Per, and Alp Vir. The results rest on measures of four lines but are uncorrected for dilution from the overlying continuum of the faint companion of each pair. Averaged over all the systems, log (He) = 11.1 ± 0.2 [referred to log (H) = 12.0], certainly close to the 'cosmic' or solar values. Correction for the diluting continua from the companion stars will not increase the average of log(He) by 0 3. Thus, as expected from stellar structure and the small rates of wind mass loss observed close to the main sequence, no systematic He over- or under-abundance can be documented for these hardly-evolved close binaries.

This conclusion is not consistent with the claim that He content in binary stars is higher than normal even for components which lie near the main sequence The discrepancy cannot be traced to the specific systems which are or are not assigned a main sequence identity This may be seen in the following way. The systems remaining in Leushin's sample are four Algol-like pairs and nine binaries more evolved than the 12 cited in the preceding paragraph but less evolved than the Algols. These subsets give log (He) = 11.0 ± 0 1 (Algols) and 11.3 ± 0.3 (others). Obviously, the errors of these three means forbid distinguishing one from another.

5. Close binaries with spotted photospheres

The spectroscopic literature shows an interesting effect regarding three binaries displaying the RS CVn-syndrome the cool subgiant member of RS CVn observed by Naftilan & Drake (1980), both components of AR Lac analysed by Naftilan & Drake (1977), and an abbreviated study of RW UMa's components by Naftilan (1975). A summary of these results appears in figure 5, wherein the effect is one of seeming underabundance of most elements None of these studies is presented in the detail which

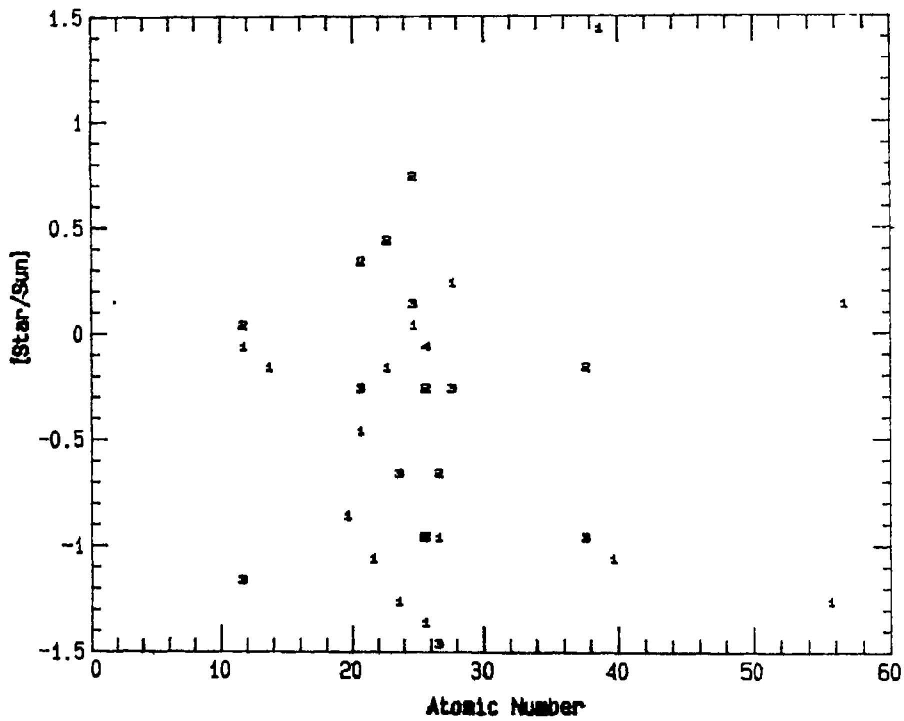

Figure 5. With respect to the sun, the relative abundances of some elements for some of the components of 3 RS CVn-type close binaries. The number code: 1, RS CVn (cool); 2, AR Lac (hot), 3, AR Lac (cool), 4, RW UMa (Hot), 5, RW UMa (cool), For RW UMa only [Fe/H] is available

is historically the model for even coarse spectroscopic analyses Thus, the independent student of this body of work cannot be certain of a certain number of fundamental matters, such as all the measured line strengths.

The evolutionary understanding of these binaries is nearly a universal consensus, *i.e.* the massive component is evolving faster than its companion and, now a subgiant, displays a conspicuous spot cycle as a distortion wave migrating with time in Keplerian phase. Nothing in this evolutionary interpretation leads one to expect any abundance anomalies.

One may first examine the possibility of artifacts causing the measured abundances. Resolution and phase isolation appears to be at least as satisfactory as for many other stars which show no uncommon effects. It is true that, for the hot member of AR Lac, there may be contamination from its companion star, but this appears to be the only possible observational difficulty. The technical, analytical situation may be summarized when it was possible to develop results from both fine and coarse analyses, the results typically agreed quite well.

A likely clue to the understanding of this paradoxical situation is indicated in the seasonal light curves of RS CVn collected by Catalano, Frisina & Rodono (1980). From these light curves, it may be calculated that the spectrographic data were actually taken when the minimum of the activity cycle was located at Keplerian phases between 0.08 and 0.97. Thus, the spotted K-star, isolated at primary totality, displays a very inhomogeneous photosphere and departs from one of the fundamental assumptions underpinning any simple spectroscopic analysis. It can be seen that this simple interpretation makes no appeal to nonthermal effects, which must actually occur due to the magnetic environment of the active regions

There is no such continuity of light curve coverage for AR Lac and RW UMa as exists for RS CVn. Therefore, phasing of the spot activity cycles for the two former binaries cannot be established with confidence and so it cannot be known if the spectroscopic plates were actually taken when spot minimum was in phase with primary eclipse minimum

In principle, an independent approach by intermediate- and narrow-band photometric indices can provide a check on the spectroscopic evidence. Miner (1966) and Koch (1974) have observed RT And, RS Ari, RT CrB, WW Dra, AR Lac, FT Lyr, and BH Vir—all systems akin to RS CVn itself. Either because eclipses are partial or because the stellar radii were unknown or because of contamination from the companion star, none of these results conclusively shows an abundance anomaly. Thus, all the available evidence is provided spectroscopically, which must be examined more closely.

What is known symptomatically about these binary components is that they do show spin rates fast for their evolutionary state; have very active chromospheres and coronae as shown by the visible-band emissions and x- and radio flux levels, respectively; sustain actively-spotted photospheres threaded by magnetic flux tubes; and demonstrate large values of the 'microturbulence' parameter (confused as is the understanding of that concept). The photospheric environment obviously cannot be characterized by a conventional limb-darkening and by unique (P, T)-values and gradients. In the absence of controlled spectroscopic analysis (only for Fe have two ionization stages been investigated and for some species only one line has been available) which would begin to take account of these requirements, the prudent general conclusion must be that the seeming chemical anomalies are not real.

6. Conclusions

Limited as the present state of information is regarding abundance information for unevolved and little-evolved close binary stars, there are a few simple but useful conclusions to be drawn from the data. A small miscellany of results appears in this essay. It has been shown that ignorance of the binary condition introduces a bias into the statistic concerning elemental abundances, the bias being of the order of the precision with which an abundance can ordinarily be established. It has also been shown that specific seeming abundance anomalies for each of hot and cool binaries likely have simpler explanations.

7. Acknowledgements

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