OBSERVATIONAL EVIDENCE FOR ATMOSPHERIC CHEMICAL COMPOSITION PECULIARITIES RELEVANT TO STELLAR EVOLUTION

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ABSTRACT

Abundance peculiarities in successive stages of stellar evolution are reviewed. Main-sequence stars show anomalies in lithium and, on the upper main sequence, the Am, Ap and Bp effects, which may be largely due to separation processes, and helium and CNO anomalies to which nuclear evolution and mixing could have contributed. Red giants of both stellar Populations commonly show more or less extreme variations among the C, N, O isotopes, sometimes accompanied by s-process enhancement, due to mixing out in various evolutionary stages. Detailed anomalies expected from galactic evolution are also briefly considered. Novae show strong effects in C, N, O and synthesis of heavier elements is displayed by the supernova remnant Cassiopeia A.

1. INTRODUCTION

Forty years ago, known abundance peculiarities were confined to the cool carbon and S stars, and it is still quite a good approximation to regard the vast majority of stars observed as having the same composition apart from minor variations in the metal: hydrogen ratio. When examined in detail, however, hardly any two stars are identical, particularly with regard to delicate features like Li and $^{12}C/^{13}C$. So it is convenient to regard the Sun (for which we have the most data) as a standard, describing departures from it as "abnormalities". These are generally interpreted as a consequence of four types of process:

A. Nuclear reactions and mixing in the star itself, having a direct bearing on its evolution.

B. Variations with time and position in the composition of the interstellar medium (ISM) from which the star was formed, resulting from galactic evolution which has been influenced in turn by the evolution of supernovae and other stars, now dead, which have

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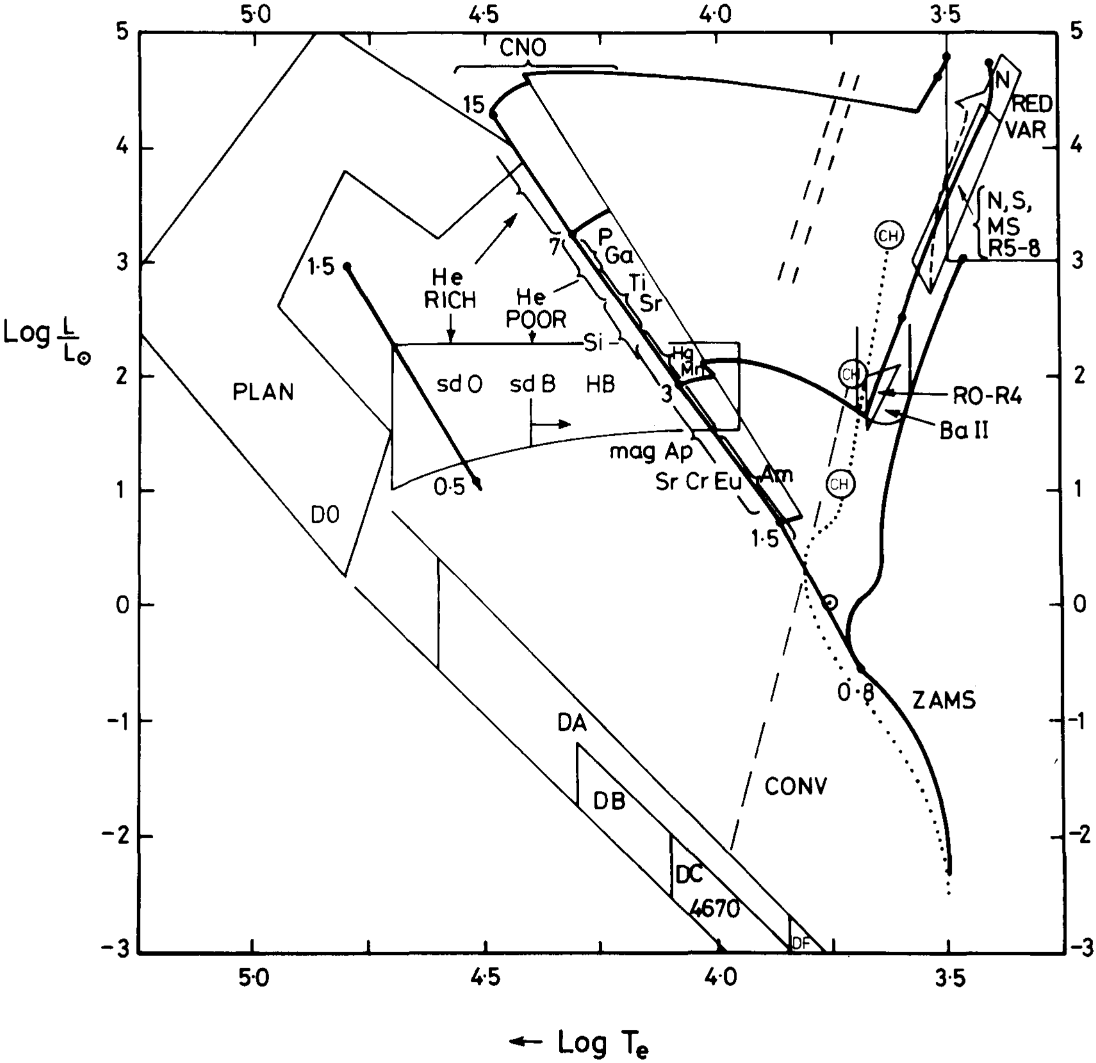

Figure 1. Approximate position of stars showing various abundance anomalies in the HR diagram. Full lines, ZAMS and partial evolutionary tracks adapted from Paczynski (1970) with masses marked along the ZAMS. The helium main sequence, planetary nebula, horizontal-branch and white dwarf regions are also shown, following Greenstein and Sargent (1974), and white dwarf classes after Weidemann (1975). The dotted line shows a schematic main sequence and evolutionary track for Population II, while various broken lines show roughly the cepheid instability strip, the transition to surface convective zones, and the He shell-flashing locus for Population I after Scalo (1976).

enriched the ISM.

C. Diffusive separation processes.

D. Selective or unselective accretion from the ISM.

In what follows I shall describe some abundance peculiarities observed in successive stages of stellar evolution from the main sequence onwards with special reference to category A above, with a brief aside on category B. Category C will be discussed by G. Michaud in these Proceedings.

2. STARS NEAR THE MAIN SEQUENCE

Apart from the light elements, especially Li, few anomalies might have been expected to occur near the main sequence, but in fact there is quite a number. (The light elements are discussed by Mrs A.M. Boesgaard in these Proceedings.) Most of these anomalies occur on the upper part of the main sequence (Figure 1) where convective envelopes are absent and the majority of stars are rapid rotators. Among the sharp-lined stars, one tends to find either small-amplitude variability or the various abundance anomalies associated with Bp, Ap and Am stars, although there are a few well-known stars with low v sin i and apparently normal abundances like τ Sco, γ Peg (a variable), ι Her and α Lyr. Conversely, some stars manage to spin quite fast and yet have anomalous abundances. I shall not discuss the Am and Ap stars because there will be a contribution on the subject by Michaud; see also recent reviews (Preston 1974; Baschek 1975).

Among early B stars, however, there are also He and C,N,O abundance anomalies whose status is not at all clear (see Figure 1). Helium-poor stars, cooler than about 20,000 K, can probably be explained by diffusion, but what of the intermediate helium-rich stars with He/H $\simeq$ 1 that are generally found somewhere near the main sequence at higher temperatures? The interpretation of these stars has been discussed by Hunger (1975). One well-known example is σ Ori E, a spectrum variable with variable Hα emission, v sin i = 150 km s^{-1} and a period of 1.19 days. Osmer and Peterson (1974) analysed σ Ori E and a group of more slowly rotating He-rich stars from the Michigan spectral survey and pointed out that between the He-rich stars and the Bp (He-poor) stars there seems to be a well-defined boundary in the T_{eff} -log g plane that is populated by the three interesting transitional cases 3 Cen A (with ^{3}He), ι Ori B (with ^{3}He) and a Cen (He variable). They concluded that all these peculiarities are due to diffusion with high temperatures and radiation-pressure driven mass loss favouring levitation of He to the surface, and suggested that a similar effect may operate in sd O stars. Hunger and his collaborators, on the other hand, while accepting that this may be the right explanation for σ Ori E and a few other stars, find lower values for the gravities and masses of most of the sharp-lined stars and suggest that these are well-mixed objects evolving to or from the helium main sequence. To complicate the issue further, Hesser et al. (1976) have studied the light curve of variable emission from σ Ori E and find a double eclipse pattern reminiscent of the U Gem stars. They therefore suggest that there is a low-mass collapsed companion with an accretion disk, that originally supplied the excess helium to the primary by mass transfer.

Another somewhat mysterious set of abundance anomalies are displayed by C,N,O in slowly rotating stars of spectral types between O9 and B6 and all luminosity classes that also tend to be radial-velocity and spectrum variables. These were discovered in classification work by the Jascheks, Walborn and others and the few abundance analyses that have been carried out reveal striking variations in N abundance with no very consistent pattern in other elements (see review by Baschek 1975). The existence of these anomalies can cause some difficulty in using galactic stars as standards to find the underabundance of nitrogen in stars of the Small Magellanic Cloud (Osmer 1973), which is believed to be primarily due to differences in the enrichment history of the ISM. The interpretation of the C, N, O anomalies is still unclear and more quantitative data are needed, but they could be associated with pulsationally driven mass loss (Baschek and Scholz 1974).

Another possible cause of CNO abundance anomalies, suggested by Paczyński (1973), is mixing by meridional circulation in rapidly rotating stars between about 3 and 10 solar masses. Preston and Paczyński (1974) accordingly looked for evidence of depletion of carbon in rapidly rotating stars of types B3-B5, but failed to find it. Alternatively, some authors have suggested that after-effects of this process might be present in red giants, where it would be distinguished from the effects of convective mixing-out of CNO products predicted by Iben (1965) by a steep increase in N/C ratio with mass. Statistical investigations of CN strength in red giants (Harmer and Pagel 1973; Demers 1975) do not generally show such an effect, as most of the variation in CN strength can be accounted for by the atmospheric parameters (effective temperature, gravity and metal abundance), but there are one or two cases where it could have operated, in particular the K0 II-III giant 37 Com which has weak CH, $^{12}C/^{13}C = 3.4$ and relatively broad lines (Yamashita 1967; Tomkin et al. 1976). If so, however, it must be either a fairly unusual effect or one operating mainly in supergiants.

3. RED GIANTS OF POPULATION I

The possibility of surface abundance changes in stars evolving up the red giant branch was first pointed out by Iben (1965) as a consequence of "mixing-out" by penetration of the outer convective envelope to regions previously affected by the CNO cycle. If it penetrates deeply enough, it reaches the zone where the CNO cycle has reached equilibrium and almost all carbon has been changed into nitrogen, which would lead to an enhancement of the N/C abundance ratio at the surface. Except in a few cases there is not too much evidence that this happens; among a few bright stars analysed by Greene (1969) only the supergiant ε Peg showed N/C appreciably enhanced (by a factor of 4). Statistical studies of Population I red giants likewise show few CN anomalies, as has already been mentioned, the main exception being some of the so-called "super metal-rich" stars like μ Leo which are not markedly rich in iron (Blanc-Vaziaga et al. 1973; Peterson 1976a), but do have exceptionally strong CN.

If the outer convective zone penetrates somewhat less deeply, it mixes out a region where the C,N,O cycle has not reached equilibrium, but there is a peak in ^{13}C, due to the first reaction of the cycle, at the outer edge of the H-burning core, which permits enrichment of the atmosphere from ^{13}C/^{12}C = 1/90 to about 1/30, or from 1/40 to about 1/20 (Dearborn et al. 1976); larger initial values than 1/40 are unlikely in view of interstellar observations. In the last three years or so a great deal of new and exciting work on this topic has been carried out on ^{12}C/^{13}C ratios deduced from red CN bands in yellow and red giants supplemented by the 2μ CO band in the reddest stars, mainly by Lambert and his group at Texas (Dearborn et al. 1975; Hinkle et al 1976; Tomkin et al 1976). The results are summarized in an HR diagram by Tomkin et al. (1976). The majority of stars have ^{12}C/^{13}C $\geqslant$ 18, explicable by mixing, but considerably more ^{13}C is found in some of the more luminous stars, with more than about twice the mass of the Sun, and also in some metal-deficient stars like Arcturus and γ Leo. These pose an interesting problem for stellar evolution, since most of them are not bright enough to be expected to have undergone helium shell flashes (log $L/L_\odot \geqslant 3$) and various exotic mechanisms have been proposed to account for these results: meridional mixing (already mentioned); severe mass loss in the main sequence or early subgiant stage; mixing at the helium flash; thermal instability in the H-burning shell; and the engulfing of low-mass companions. None of these mechanisms seems quite sufficient by itself and the further exploration of this problem, preferably with better data on elemental abundances of C, N and O, will be a topic of "burning interest" as Tomkin et al. have put it.

Somewhat related to these effects is the oxygen isotope ratio ^{17}O/^{18}O. Since the CNO cycle is a tri-cycle owing to the long life of the ^{17}O (p,α) ^{14}N reaction, the simple mixing mechanism can cause traces of ^{17}O to be mixed out and significantly affect ^{17}O/^{16}O in the atmospheres of the more massive stars (Dearborn and Schramm 1974). In agreement with this, features of C ^{17}O have been observed in a few red supergiants, IRC +10216 (for which ^{16}O/^{17}O ≃ 400 compared to a terrestrial ratio of 3000), α Sco and α^1 Her (Rank et al. 1974; Maillard 1974).

The other abundance anomalies affecting Population I red giants are more conspicuous, so that they have been known for a long time, but affect only a minority of the stars. These fall into four main categories (Figure 1):

Table 1

Some Abundances in Cool Giants

	M,MS	S	SC,CS	C
[Fe/H]	$\sim 0^{1}$			
C/O	$\leqslant 0.95^{2}$	0.95 to 0.99	0.99 to 1.01	$\geqslant 1$
$^{12}C/^{13}C$	7 to 20^{3}	25^{3} (χ Cyg)		3.5 to $40^{4,5}$
[N/Fe]				$\sim 0^{5}$
[O/Fe]				$0:^{5,6,7}$
[Zr/Ti]	-0.3 to $+0.4^{8}$	+0.4 to $+1.2^{8,9}$		+0.9 to $+1.9^{9}$ (WZ Cas $\sim +0.5^{9,10}$)
Tc?	some^{11} (Miras)	some^{11}	RZ Peg^{12}	some^{11}
[Li/Ca]	-2.1 to $+0.4^{13,14}$	$\leqslant 3.3^{9,14}$	~ 1.0 $(\text{SC})^{16}$	-1 to $+2^{9}$ WZ Cas $\sim +5^{17}$

References to Table 1

1. Huggins 1973.
2. Scalo and Ross 1976.
3. Hinkle *et al*. 1976; Tomkin *et al*. 1976.
4. Fujita 1970.
5. Kilston 1975.
6. Thompson 1974.
7. Querci and Querci 1976.
8. Boesgaard 1970.
9. Catchpole and Feast 1976.
10. Utsumi 1970.
11. Peery 1971; Cohen 1973.
12. Peery *et al*. 1971.
13. Merchant 1967.
14. Boesgaard 1970b.
15. Bretz 1966.
16. Catchpole and Feast 1971.
17. Hirai 1969.

(a) and (b) The BaII stars and early R stars which coincide with K giants in the HR diagram.

(c) Cool giants, mostly variables, of the sequence M, MS, S, SC, CS, C (or N) which is primarily a sequence of increasing carbon abundance relative to oxygen (Scalo and Ross 1976).

(d) Hydrogen-deficient carbon stars like R CrB and the closely related extreme helium stars, appearing with high luminosities over a wide range of temperatures.

The first problem in trying to understand these stars is to place them in the HR diagram, and the positions shown are largely inspired by the recent discussion by Scalo (1976). The majority of all these types seem to be old disk stars (Eggen 1972a,b) with masses slightly above that of the Sun, although a few are younger and presumably much more massive (e.g. the Ba star ζ Cap and the Large Magellanic Cloud Carbon stars). Most S and N stars lie to the right of the broken line in Figure 1 which is the predicted locus of helium shell flashes, whereas the BaII and early R stars are well below and to the left of this line, but they are suitably placed to have undergone helium core flashes. According to Williams (1975), a few per cent of all G and K giants have a noticeable enhancement of barium.

As regards composition, the Ba stars are comparatively easy to analyse and quite a lot is known; one recalls the important work of Burbidge and Burbidge (1957) which helped to establish the s-process. The most extensive data available now are for ζ Cap (Tech 1971) for which, within the errors, all s-process elements from Sr up to Pb are enhanced by about a factor of 10, whereas Sc, Cu, Zn and Nb, as well as Ge, Eu and Gd, are not noticeably enhanced, so that these elements presumably have no significant contribution from the s-process. Most known BaII stars have enhanced carbon features, but this does not seem to be a necessary condition, as is shown by o Vir (Williams 1972, 1975) and HD 101013 (Branch and Bell 1975). $^{12}C/^{13}C$ ratios seem to be quite large.

The properties of carbon stars have been reviewed in a very good article by Wallerstein (1973). Among early R stars most is known about HD 156074 (Greene et al. 1973) which shows some symptoms of the CNO cycle: $^{12}C/^{13}C \simeq 4$, N is enhanced, O somewhat depleted and other elements fairly normal as though nitrogen were acting as a neutron poison; RU Cam seems to be quite similar.

Abundances in the cool M,S and N stars are much more difficult to find because the abundance of molecules in their spectra prevents decent equivalent-width measurements and makes the structures of the atmospheres both hard to calculate and excessively dependent on the input assumptions. Nevertheless there seems to have been some progress in recent years; in particular, the presence of C_2 implies that carbon stars typically do not show mainly equilibrium products of the C, N, O cycle. The $^{12}C/^{13}C$ ratios no longer look so remarkable in view of the results for more ordinary giants, while at the same time it has turned out that N stars have s-process elements enhanced just about as much as S stars if not more. Table I contains some recent results of abundance determinations in cool giants, based on work by Scalo and Ross, Kilston, Boesgaard, Catchpole and Feast and others. (Square brackets denote change in logarithm of abundance ratio relative to the Sun.) The basic pattern suggests that the atmospheres show varying degrees of enhancement of carbon, s-process elements and lithium, presumably due to repeated incursions of the outer convective envelope into the inter-shell region, but it is difficult to be much more specific.

Important clues to the nature of BaII and carbon stars, as well as of planetary nebulae, are likely to come from the so-called "Rosetta Stone" FG Sge (Langer _et al_. 1974), which is rapidly evolving to the right of the HR diagram at a luminosity of about $10^4 L_\odot$ and suddenly became a barium star between 1965 and 1969 when its spectral type was near F0. Here apparently we can see the effects of helium shell flashes, mixing and mass loss taking place partly in real time, so to speak, and the future evolution of this star will obviously be followed with great interest.

The last type of nuclear abundance anomaly shown by Population I giants is that of the hydrogen-deficient carbon stars (Warner 1967), probably closely related to the hotter extreme helium stars (Hunger 1975). The composition and kinematics of helium stars suggests that one had a normal star of slightly above a solar mass in which the hydrogen and carbon originally present were changed into helium and nitrogen through hydrogen burning and then further carbon was added to what are now the surface layers by helium burning, while in the cooler but otherwise similar R CrB-like stars one finds Li but no excess of s-process elements. The impression that one has from these stars, which must be evolving quite rapidly, is that one may be looking directly into an inter-shell region after removal of the hydrogen-rich outer layers (Schönberner 1975).

4. STARS OF POPULATION II

The most marked abundance anomaly shown by stars of extreme Population II, that is to say those in globular clusters and nearby field stars of extremely high velocity, is of course the overall deficiency of heavy elements from carbon upwards by factors between 10 and 1000 and the corresponding weak line blanketing revealed by photometric indices like ultra-violet excess. Much effort has been devoted to the search for abundance anomalies in individual elements that could be attributed to a different history of galactic enrichment affecting the material from which these stars were born and the existence of such effects is still a matter of doubt and controversy which has been extensively discussed in the literature (Pagel 1973; Peimbert 1973a; Unsöld 1974; Peterson 1976b). To summarize the situation briefly, extragalactic HII regions show interesting abundance anomalies in nitrogen which may be a secondary nucleosynthesis product (Talbot and Arnett 1974); similar effects may occur in metal-weak stars, but this is still not certain and it certainly does not occur in all cases (Harmer and Pagel 1970; Sneden 1974). Odd-numbered elements like V and Mn seem to be slightly overdeficient, but the effect is marginal; among s-process elements, Ba seems definitely overdeficient when $[Fe/H] < -2$, but by factors of 20 or less, and Sr, Y and Zr by much smaller factors, which implies that no star that can be seen now was formed until after the iron-group elements had been subjected to a substantial amount of s-processing. The ratio of carbon to iron is fairly constant, but that of oxygen does seem to vary, in the sense that metal-deficient objects are significantly less deficient in oxygen (Peimbert 1973b; Lambert *et al.* 1974), which could be a sign that the progenitors of oxygen evolved more rapidly than those of iron (cf. Chevalier 1976). However, most of these remarks apply to nearby field stars, and the situation in globular clusters and/or near the galactic centre could be different (Hesser *et al.* 1976).

Apart from these difficult problems, the evolved stars of Population II show a similar gamut of abundance peculiarities as do those of Population I, including He-poor stars sometimes showing other peculiarities (the B subdwarfs, Searle and Sargent 1972), He-rich stars (the O subdwarfs) and a variety of C, N, O anomalies among the red giants, both above and below the expected locus for helium shell flashing and both with and without enhancement of s-process elements.

An attempt to classify the abundance peculiarities is given in Table II. Among field stars one sees both enhanced carbon features (CH stars) and a tendency among the more luminous extremely deficient stars like, for instance, HD 122563 to have nitrogen enhanced at the expense of carbon (Sneden 1973, 1974). This could be related to a similar effect seen in asymptotic giant branch stars of the extremely metal-weak globular clusters M 92 and NGC 6397, but it would be odd if all the field stars were actually AGB stars. One then thinks of the possibility of mixing out along the first ascent of the red giant branch, but in that case what are we to make of the planetary nebula in M 15 where N is extremely deficient (Peimbert 1973)? Detailed quantitative analyses of stars on both giant branches of, say, 6397 would be helpful in settling this question.

The CH stars appear at various luminosities (see Figure 1) and possibly cover a continuous range from $M_V \simeq -2$ to $+2$. The brightest ones (which are the three CH stars in ω Cen) are presumably products of helium shell flashing followed by mixing out, but the remarkable discovery of subgiant CH stars by Bond (1974) raises a serious problem in connection with this, and Bond himself suggested that some stars undergo large-scale mixing after either a shell or a core flash which brings them back down to the neighbourhood of the main sequence.

Apart from CH stars, a great variety of CN and s-process anomalies have been found in globular clusters. An accurate discription is difficult owing to the observational limitations; for instance in a large number of cases we only know that CN is strong from DDO photo-

Table II

Abundance anomalies among Population II Red Giants and Subgiants

Brief Description	Where Observed
A: mainly strong carbon features:	
CH stars with ^{13}C,N markedly enhanced	Field[1]; ω Cen (within 1^m of RG tip)[2,3]
CH stars without ^{13}C,N markedly enhanced	Field[4], $M_V \simeq 0$
Subgiant CH stars	Field[5], $M_V \simeq +2$
CN strong	ω Cen (mainly red edge)[6,7]; M22, M71, 47 Tuc, 6352[7]
CN strong, no C_2	ω Cen (tip and red edge)[3,8]; M5, M10[9]; 47 Tuc[10]
s-process, no C_2; various CN,CH	ω Cen (tip and red edge)[3,8]
B: weak carbon features:	
Weak CH, strong NH	M 92 (AGB)[11]; 6397 (AGB)[12]
C deficient, N enhanced	Field, $M_V \lesssim 0$, [Fe/H] $\lesssim -1.6$[13]

References to Table II

1. Climenhaga 1960; Wallerstein 1969.
2. Harding 1962; Bell and Dickens 1974; Bond 1975.
3. Dickens and Bell 1976.
4. Wallerstein and Greenstein 1964; Harmer and Pagel 1973.
5. Bond 1974.
6. Norris and Bessell 1975.
7. Hesser, Hartwick and McClure 1976
8. Mallia 1976.
9. Zinn 1973b.
10. Bell *et al*. 1975.
11. Zinn 1973a; Butler *et al*. 1975.
12. Mallia 1975.
13. Sneden 1973, 1974.

metry. Where spectra exist, observers are not always unanimous as to whether CH and s-process elements are enhanced, although they agree on CN and C_2. And finally, the apparent confinement of strong CN stars to the less metal-weak globular clusters can itself be a sort of selection effect because in extreme cases like M 92 CN would still be invisible even if it were enhanced by a very large factor. Apart from these difficulties, an intricate variety of effects seems to occur, particularly in ω Cen which is noted for the great width of its red giant branch in (B-V). Freeman and Rodgers (1975) give evidence that some or all of this effect arises from an inhomogeneity in initial metal abundance analogous to that in elliptical galaxies, while Norris and Bessell (1975) and Mallia (1976) suggest that it is due to different kinds of mixing process exemplified by the anomalies listed in the Table which, according to spectrum synthesis studies by Dickens and Bell, can be largely attributed to an enhancement of nitrogen. Quite possibly both effects occur, the incidence of anomalies being itself a function of primeval composition, but it must also be noted that the behaviour found in 47 Tuc is quite different from that of field stars of similar metallicity (Hesser, Hartwick and McClure 1976) so that more than one composition parameter would have to be involved.

5. FINAL STAGES OF EVOLUTION

The later stages of stellar evolution comprise planetary nebulae, white dwarfs and supernovae. A related question is that of the abundances in common novae, which may undergo a special kind of C,N,O nucleosynthesis resulting from mass transfer on to a white dwarf (Starrfield _et al_. 1974).

The composition of planetary nebulae is of special interest as an indication of the nature of the outer layers (presumably above the hydrogen shell source) ejected by red giants when they reach the appropriate stage. In general the abundances of He, O and Ne are found to be more or less as expected from stars of the usual Population I range of compositions (Kaler 1970; Osterbrock 1974), but there are signs of enhancement of N (Peimbert and Torres-Peimbert 1971; Boeshaar 1975) which suggest that at some stage the mixing-out process may become more effective than has so far been suggested by observations of most of the red giants themselves, although in M giants and carbon stars an enhancement by a factor of 2 or 3 could easily pass unnoticed. In agreement with theory, the nitrogen enhancement in planetary nebulae seems to diminish or disappear at low metal abundances; in the extreme case of K 648 in the globular cluster M 15, N is deficient by at least a factor of 40, possibly matching the metal-deficiency of the cluster as a whole, while O and Ne are deficient by only a factor of 10 (Peimbert 1973). There are some difficulties in the determination of abundances from emission lines, since nitrogen is only detected from [NII] which is very sensitive to the presence of condensations (Kirkpatrick 1972; Webster 1976); but this effect can be allowed for in a semi-empirical way. Unfortunately the elements observable in planetary nebulae and in red giant atmospheres are still sufficiently orthogonal that no particular class of red giant can be excluded as a source of planetaries on grounds of composition.

White dwarfs have extremely strange compositions at their surfaces which have been very well reviewed by Weidemann (1975). These are suggestive of diffusion and perhaps other processes and will not be discussed further here. Novae, on the other hand, are extremely interesting in showing marked overabundances of C,N and O (Antipova 1974); a recent example is Nova Cygni 1975 (Figure 2), which had an unusually high temperature at maximum and rather weak absorption lines among which, however, NII was by far the dominant species after hydrogen (Andrews 1975; see Figure 2). From the model of Starrfield et al. (1974), involving energy release from the fast CNO cycle operating on C and O in the white dwarf component when it accretes mass from its companion, it is possible (though not certain) that interesting isotopic effects should occur. These were looked for in the 4215 band of N Her 1934 by Lambert and Sneden (1975), who found some signs of ^{13}C and possibly ^{15}N, although these odd isotopes are certainly not dominant. The observations provide some constraints on the models, though not very strong ones: a model with pure ^{13}C is not allowed, for example, but pure ^{12}C could be allowed if the ^{13}C is made by some other means.

"Last scene of all, in this strange and eventful history," is the supernova outburst wherein one can expect to see effects of nucleosynthesis beyond the C, N,O group and up to the iron group and r-process elements. The only evidence I am aware of for abundance anomalies in supernovae themselves (as opposed to their remnants) comes from the study of the Type I supernova 1972e in NGC 5253 by Kirshner and Oke (1975) who identified several prominent emission bumps on the spectrum two years after maximum with [FeII]. Assuming an excitation temperature of 5000 K, the total luminosity in [FeII] implied a mass of about 10^{-2} $M_\odot$ in the form of Fe^+, which, with an estimated mass for the whole envelope of ~1 $M_\odot$, gives [Fe/H] ≃ 1, a marginally significant enrichment which has inspired the suggestion that iron is supplied to the ISM by Type I supernovae rather than Type II (Chevalier 1976).

Among supernova remnants, only the young ones can be expected to show abundance anomalies because after a few thousand years or so they sweep up more than their own mass of interstellar material. This leaves us with just two objects: the Crab Nebula, in the filaments of which only He (and perhaps marginally N) are noticeably overabundant (Davidson 1973), and the 300-year old supernova remnant Cas A, which is the most interesting case. The nebulosity is a highly reddened incomplete shell broken up into two components: fast-moving condensations or knots with emission lines of [OI], [OII], [OIII], [SII], [SIII] and [ArIII], but nothing else detected, and a smaller number of slowly moving condensations or flocculi having Hα, strong [NII] and weak [OII] (Minkowski 1968; Peimbert and van den Bergh 1971; Searle 1971).

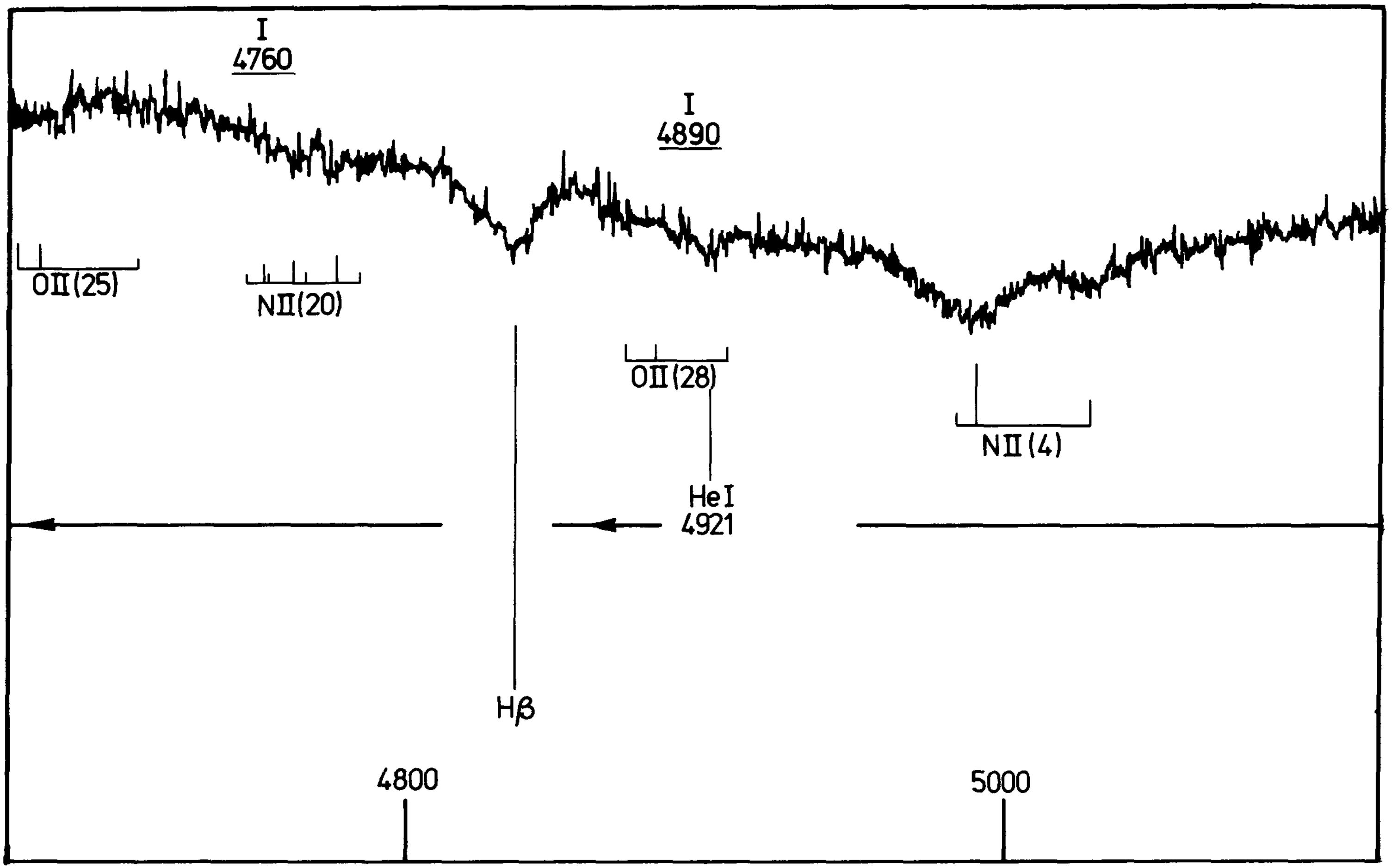

Figure 2. Spectrum of Nova Cygni 1975 taken on August 29.9 with the 0.75 m telescope at RGO, showing relative strength of NII lines.

The abundance analysis involves considerable uncertainties, but it seems clear that O, S and Ar are strongly enhanced in the fast-moving and rather dense knots (Peimbert 1971), presumably as a consequence of nucleosynthesis, while the almost stationary flocculi are most readily interpreted as swept-up remnants of a fossil HII region with enhanced nitrogen abundance that was formed from the hydrogen envelope of the supernova and ionised during the outburst, as there are no ionizing stars in the vicinity. Arnett (1975) has compared the inferred abundances in the Crab and Cas A with evolutionary models of massive supernovae and finds reasonable qualitative agreement, particularly with the inference from Type II light curves that the outburst is preceded by the ejection of a hydrogen-rich circumstellar shell, modified by CNO processing, that subsequently gives rise to the knots and filaments through Rayleigh-Taylor instability (Falk and Arnett 1973). Thus, in at least one case, the observer's supernova and the theoretician's supernova have at last come close enough together for fairly detailed comparisons to be attempted and there is direct evidence that supernovae can indeed supply heavy elements to the ISM.

6. CONCLUSION

To summarise the upshot of this talk briefly, both the observational determination and the theoretical prediction of abundance peculiarities have come sufficiently far that quite detailed things can be inferred about the effects of stellar evolution in certain cases, particularly the existence and extent of surface mixing not only after helium shell flashes but all the way up the giant branch. On the other hand we do not know where all the details fit in, e.g. what is the precise significance of seeing s-process elements and Li in certain cases while we do not see them in others, why do we see both peculiar and normal (or at least less peculiar) stars in the same part of the HR diagram and why do some stars show abundance peculiarities at much lower luminosities than one might have expected? Perhaps by the next I.A.U. Assembly we shall have a more systematic collection of information which will help to throw light on these questions.

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Postscript – On the question of C,N anomalies in metal-weak globular clusters, R P Kraft (private communication) has recently found some anomalous stars on the giant branches of M 92 and M 15, as well as on the AGB.