ABUNDANCES IN COOL EVOLVED STARS

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Nature has filled the upper right quadrant of the Hertzsprung-Russell diagram with more varieties of peculiar stars and odd chemical compositions than even our most speculative observers and theorists could dream up. To bring some structure to this vast subject I will categorize the phenomena we observe according to our model of stellar evolution, dividing the stars among the first ascent of the giant branch and the core-helium burning phase, the asymptotic giant branch (double shell-burning) phase, and the post-AGB and pre-planetary nebula stars. The types of stars found in these three groups are summarized below.

Warm Giants:
- Ba II Stars
- Early Carbon Stars
- CH Stars
- Subgiant CH Stars
- Weak G-band Stars
- Li-Rich Giants

AGB Stars:
- M Stars
- MS Stars
- S Stars
- N Stars
- SC Stars
- J Stars

Post-AGB Stars:
- R CrB Stars
- Hydrogen-Deficient Carbon Stars
- RV Tauri Stars
- W Vir Stars
- SRd Variables

Two dominant themes run throughout the evolution of late type star compositions: the abundances of the isotopes of carbon, nitrogen, and oxygen, and the abundances of the metals heavier than the iron peak - the neutron capture elements usually associated with the s-process. In addition to these elements, the abundance of lithium can also be a distinguishing characteristic of some groups, and can be used to interpret possible origins for some of these peculiar stars.

The Warm Giants

Most samples of warm giants in the literature are comprised of primarily low mass, old disk stars that fall either on their first ascent of the red giant branch or in the core-helium burning clump immediately following core helium ignition. The abundances of several classes of peculiar warm giants, as well as normal K giants and the Sun, are summarized in Table 1. Looking first at the comparison of the abundances in normal K giants with the predictions of stellar evolution theory for the first dredge-up (Iben and Renzini 1984), we see generally

Table 1: Abundances in the Warm Giants

	C/O	^{12}C/^{13}C	C/N	^{16}O/^{17}O	^{16}O/^{18}O	[Fe/H]	[s/Fe]	binary?
Solar	0.56	89	4.8	2630	490	0.0	0.0	---
Normal K Giants	0.30	6 - 20	1.15	500	500	solar	solar	no
1st Dredge Up	0.4	20 - 30	1.9	2630 - 250	600 - 1000	no change	no change	---
Ba II Stars	0.76	25	2.1	300	500	-0.5 - 0.1	+0.7	yes
Mild Ba II Stars	0.30	20	1.3	>100	>100	~solar	+0.2	yes?
Ba-C Stars	C-rich	---	---	---	---	---	enhanced	?
Subgiant CH Stars	≤1.0	10 - >40	---	---	---	-0.35	+0.7	yes
CH Stars	C-rich	6	---	---	---	<-0.5	+1.4	yes
CH-like Stars	C-rich	(6)	---	---	---	old disk?	+0.3	?
Early R Stars	1.6	<10	2.2	---	---	-0.2	+0.2	no
Weak G-band Stars	0.04	4 - 10	0.08	---	---	0.0	~solar	no
Li-Rich Stars	0.5 - 1.0	22	1.5 - 4	---	---	-0.6 - 0.3	~solar	?

Dominy 1984
Harris and Lambert 1984
Harris et al. 1985a
Kovacs 1985
Krishnaswamy and Sneden 1984
Lambert 1985
Lambert and Dominy 1980
Lambert and Ries 1981
Lambert and Sawyer 1984
Luck 1982
Luck and Bond 1982
Luck and Sneden 1986
McClure 1985
Smith 1984
Sneden 1983
Sneden and Bond 1976
Sneden et al. 1981
Sneden and Pilachowski 1984
Tomkin et al. 1984
Wallerstein and Sneden 1982
Wannier 1985

good qualitative agreement. Material left over from main-sequence CN-cycle hydrogen burning is mixed with relatively pristine material on the stellar surface, reducing the carbon abundance slightly, enhancing the nitrogen abundance, and raising the ^{13}C abundance. The oxygen abundance remains constant for all practical purposes, since stellar interior temperatures are too low for the ON cycle to operate, except that a small amount of ^{16}O is converted to ^{17}O.

The uncertain distances, luminosities, masses, and evolutionary states of field giants confuse our attempts to verify theoretical predictions in detail, but a recent study of the carbon and nitrogen abundances in M67 giants by Brown (1987) offers an excellent observational test. Brown determined carbon and nitrogen abundances for giants from $3.7 > M_V > 0.9$; his C/N ratios are plotted versus absolute magnitude in Figure 1. The first dredge-up begins at M_V=3.5, but it is fully complete by a luminosity of $M_V \simeq 3.0$. The giants of M67 are able to complete the first dredge-up more quickly than expected from theoretical calculations, and the change in the C/N ratio is larger than predicted, as well. The field K giants in Table 1 also show lower C/N ratios than predicted by first dredge-up calculations. Brown offers two hypotheses to explain these results: a) that a real stellar envelope becomes fully convective at lower luminosity than predicted, or b) that the CN-cycled material lies closer to the surface than expected, either due to mass loss of the outer layers of the star or due to a greater extent of the CN-cycled region in the interior.

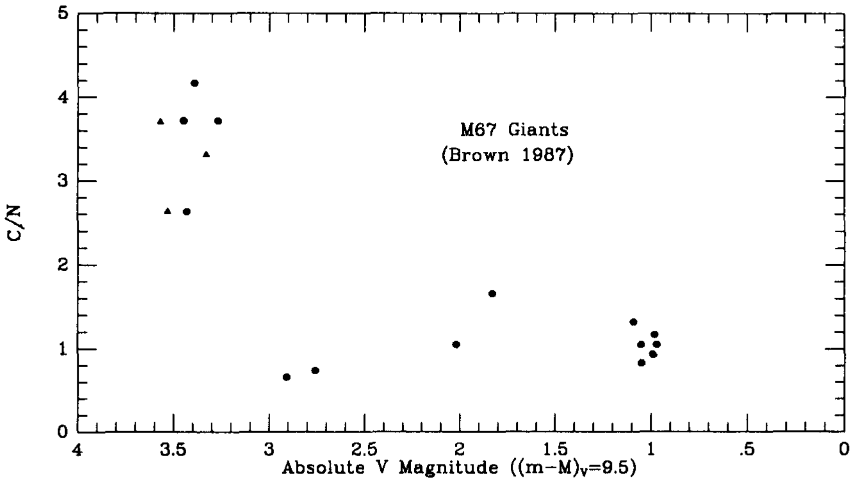

Figure 1 - The C/N ratio in M67 giants vs. absolute magnitude.

The mass loss alternative is contradicted by the detection of lithium in low mass giants, but support for more extensive CN-cycling in the interior is provided by measurements of the ^{12}C/^{13}C ratio in field stars: the well-known Arcturus problem that has been haunting us since carbon isotope ratios were first measured. Theoretical models of the first dredge-up reduce the carbon isotope ratio from the solar value of about 90 to approximately 20-30. Standard models are unable to produce carbon isotope ratios lower than this. Many K giants, however, have $^{12}C/^{13}C$ as low as 7 - 10 (Lambert and Ries 1981), approaching values appropriate for CN-cycle equilibrium. Metal-deficient giants achieve carbon isotope ratios as low as 4 (Sneden et al. 1986). Theorists have addressed this problem by tweaking the standard models to increase the amount of mixing (c.f. Dearborn et al. 1976). Brown's M67 data eliminate some of these alternatives, specifically those invoking mixing during the helium core flash. Models which partially mix the stellar material either on the main sequence or before the first ascent of the giant branch, perhaps through meridional circulation currents or turbulent diffusion, have been the most successful at reproducing the observed composition changes at the first dredge-up.

The compositions of several varieties of peculiar warm giants are also listed in Table 1. These stars differ from normal G and K giants in a variety of ways: lithium is unusually high (or low); carbon is enriched through triple-α nucleosynthesis or depleted through CN-cycle processing; and/or s-process elements are enhanced. The origin of these groups of peculiar warm giants has been a mystery for decades. Their relative rarity in the Galaxy suggests unusual circumstances are required to produce peculiar giants. While their compositional anomalies are reminiscent of double-shell flashes on the asymptotic giant branch, the luminosities of these warm giants are much too low for them to have undergone helium shell

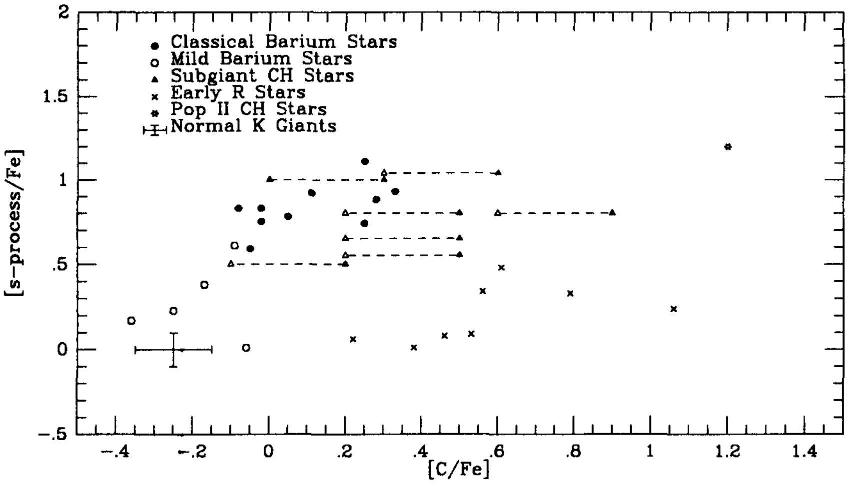

Figure 2 - S-process enrichment vs. carbon enrichment in peculiar warm giants. The expected locus of the subgiant CH stars following the first dredge-up is indicated by open triangles. The barium stars, mild barium stars, subgiant CH stars, and CH stars all seem to follow a common relationship.

flashes. Other explanations must be sought, and three fundamental classes of hypotheses are often invoked: a) mixing at the helium core flash, b) mass transfer from a binary companion, and c) diffusion. Since so many of the groups are now known to be binary stars (McClure 1985), a mass transfer hypothesis seems likely.

The barium stars, and their colleagues the mild barium stars, the marginal barium stars, the semi-barium stars, and the barium-carbon stars, are G and K giants with an excess of carbon, presumably due to the triple-α process, normal abundances of other CNO nuclides, and enhancements of the heavy s-process species Sr-Y and Ba, La, etc. Recent authors have concluded that the differences among the sub-groups of barium stars are mostly in degree. A plot of the relative s-process enrichment vs. carbon enrichment for a mixed sample of these stars (suggested by Lambert 1985) is shown in Figure 2. Data are taken from several authors listed under Table 1. The mild or marginal barium stars follow the same relation between s-process enrichment and carbon enrichment as do the classical barium stars, suggesting a common origin.

Aside from the obvious carbon and s-process enhancements in the barium stars, their compositions are similar to those of other G and K giants. The oxygen and carbon isotope ratios and the lithium (Pinsonneault et al. 1984), nitrogen and oxygen abundances are normal, suggesting red giant evolution has proceeded normally. In a recent study of oxygen isotope ratios in barium stars, Harris, Lambert, and Smith (1985a) argue that if the carbon excess in the barium stars resulted from helium burning in the star itself, either from a core helium flash or from the third dredge-up between helium shell flashes on the AGB, then the star must also have mixed up material from the ^{17}O peak and below, decreasing the surface ^{16}O/^{17}O ratio to less than 200. The observed oxygen isotope ratio establishes that the barium stars are unlikely to have produced the excess carbon (or the excess s-process elements) themselves. Harris et al. conclude that the carbon and heavy elements must have been produced elsewhere, presumably in a more massive, evolving companion, and been dumped onto the surfaces of the barium stars.

The chemical composition of the subgiant CH stars is superficially different from that of the barium stars. While they show similar enhancements of s-process elements relative to iron, the carbon isotope ratio varies widely among the subgiant CH stars, ranging from 10 to >40 for most of the sample, and C/O <1 in all cases (Sneden 1983). In Figure 2, the subgiant CH stars appear to follow a different relationship than the barium stars, but if they are allowed to evolve through a standard first dredge-up event, they will move to the left to overlap the barium stars. The barium stars and the subgiant CH stars may in fact be related. Since the CH stars are also binaries (McClure 1985), a mass transfer explanation for their origin is tempting, although Luck and Bond (1982) offer an alternative at the helium core flash.

The CH stars and the CH-like stars are included in Table 1 for completeness, but we don't know much about them. The CH stars are metal-deficient, Population II giants enriched in carbon and s-process elements. They may be enriched in ^{13}C (Lambert 1985). They appear to be binaries (McClure 1985). The CH stars are probably Pop II barium stars, and to accept their designation as Pop II barium stars. Not much is known about the CH-like stars of Yamashita (1972, 1975), which are Pop I, carbon-rich giants. At low spectral resolution the λ4554 line of Ba II is enhanced. These stars may be related to the barium or barium-carbon stars, but we need more information about their compositions, and especially about their binary status.

The early R stars were the subject of an excellent study by Dominy (1984). They differ from the barium stars in that the s-process elements are not enhanced, they contain significant excess ^{12}C, with C/O ratios of typically 1.6, and evidence of substantial CN-cycle processing, with $^{12}C/^{13}C$ ratios of <10, and N/Fe ratios of a factor of 2-3 above normal K giants. Oxygen is not depleted, however, so the high abundance of carbon (C/O>1) cannot be attributed to the CNO cycle operating near equilibrium. The early R stars are not binaries, unlike the barium stars. Dominy suggests that these stars are a genuine example of mixing at the core helium flash.

Finally we come to two groups of peculiar warm giants which share unusually high abundances of lithium. Some of the weak G-band stars contain lithium as high as the initial "cosmic" abundance of 3.0 found in young main sequence stars (Lambert and Sawyer 1984). Carbon is extremely deficient (a factor of 10 relative to normal K giants), the carbon isotope ratios are very low (from 4 to 10), and nitrogen is enhanced such that the sum C+N is constant. The weak G-band stars are not binaries (Tomkin et al. 1984). The material on the surfaces of the weak G-band stars has clearly been subjected to CN-cycle processing, which would certainly have quickly destroyed the original lithium. It may be necessary to invoke diffusion to explain the unusual lithium abundances (Lambert and Sawyer 1984) and possibly internal mixing on the main sequence to provide the extreme CN-cycle processing. The lithium rich G and K giants are extremely rare, and little quantitative information is available. They appear to be otherwise essentially normal, but with lithium abundances up to the "cosmic" limit.

The Stars on the Asymptotic Giant Branch

The stars on the AGB are difficult to understand not only because so many groups of peculiar stars are present, but also because so many pathological stars occur within each class. Many AGB stars show evidence of recent nucleosynthesis, from the presence of technetium (Merrill 1952, Little-Marenin and Little 1979) and ^{93}zirconium (Zook 1985). The AGB stars have exhausted helium in their cores, and

Table 2: Abundances in the AGB Stars

	C/O	$^{12}C/^{13}C$	[N/Fe]	$^{16}O/^{17}O$	$^{16}O/^{18}O$	[C+N+O/Fe]	[s/Fe]
Solar	0.56	89	0.0	2630	490	0.0	0.0
K Giants	0.30	6-20	+0.5	500	500	0.0	solar
Early M Giants	0.45	~13	+0.4	160-1100	~500	~0.0	solar
MS Stars	0.64	~30	+0.4	900-3000	1100-4700	>0.0	0 - 0.6
S Stars	0.81	~38	+0.5	500-2400	1300-5000	+0.2	+0.65
SC Stars	~1.0	5-53	+1.3	160-400	≥300	0.5	++
N Stars	1.1	~50	0.0	550-4100	700-2400	(~0.2)	1.0-2.0
J Stars	~0.9	3-5	0.0	350-850	uncertain	(~0.2)	solar

Boesgaard 1970
Catchpole 1982
Catchpole and Feast 1971
Dominy and Wallerstein 1987
Dominy et al. 1986
Fujita and Tsuji 1965, 1977
Harris et al. 1987
Harris et al. 1985b
Hinkle and Scarlach 1985
Johnson et al. 1982
Lambert 1985
Lambert et al. 1986
Smith and Lambert 1985, 1986
Torres-Peimbert and Wallerstein 1966
Tsuji 1985, 1986
Utsumi 1986
Wannier 1985

produce energy through two burning shells of hydrogen or helium surrounding an inert carbon core. Above a luminosity of $M_V \sim -3$, this configuration is unstable, leading to thermal pulses (Schwarzschild and Härm 1965) which may induce mixing of the convective envelope with the layers between or below the hydrogen and helium burning shells. For stars of mass greater than about $4-5M_o$ a dredge-up event which penetrates the hydrogen burning shell has been identified with similar effect as the first dredge-up. A series of "third" dredge-up events occur for low and intermediate mass stars during the time between shell flashes. These events bring up helium-burned material enriched in ^{12}C and (probably) the s-process elements.

A selected set of the abundances in AGB giants is given in Table 2. The determination of abundances in AGB giants is a difficult problem, and isotopic ratios are known with much greater certainty than the abundances of individual elements. Indeed, progress in determining the compositions of cool giants is due to the relatively recent availability of high resolution IR spectra (in particular the KPNO 4M FTS) and to improved models for cool stars. To complicate the problem, cool giants are usually variable stars, displaying shock components and multiple velocity structure in their spectra. The compositions of the early M giants resemble the K giants, and in reasonable accord with the predictions of stellar evolution theory, But among the more luminous and more evolved stars, the story becomes more interesting. The MS stars begin to show signs of enrichment of triple-α ^{12}C with an increase in the C/O and the $^{12}C/^{13}C$ ratios. The nitrogen abundance remains unchanged. The sum of C+N+O begins to increase above the solar value, and enhancements of s-process elements appear. Some MS or S stars have large nitrogen excesses (c.f. RS Cnc and HR 8714 in Smith and Lambert 1986), which could result if these stars are more massive than most MS stars, and have undergone an extensive second dredge-up event. The relatively low luminosity of most MS stars would suggest that most of them may be low mass stars.

The MS stars blend smoothly into the S stars, with small increases in the ^{12}C abundance, the C/O ratio, the sum C+N+O, and the abundance of the s-process elements. The nitrogen abundance remains the same as for normal M giants, indicating no further CN-cycle processing. The ^{12}C abundance in MS and S stars is approximately double what it is in normal M giants. If the mass of the convective envelope is about $0.4M_o$, then roughly $3x10^{-3}M_o$ of carbon must be added by the third dredge-up. Only 3-6 thermal pulses are required; only 2-3 pulses are needed to produce the s-process enhancement. The MS and S stars are probably in the early phases of double shell flashing (Smith and Lambert 1986). The carbon and s-process element abundances in MS and S stars are in quantitative agreement with the predictions of third dredge-up calculations.

The SC stars may represent the onset of a new phenomenon, CN-cycle processing of material in the convective envelope. Dominy et al. (1986) have determined C, N, and

O abundances and carbon and oxygen isotope ratios for a sample of SC stars. Unfortunately metal (Fe) abundances are not available and an unambiguous interpretation of their results depends on knowing the metal abundance. Their nitrogen abundances also depend very sensitively on the C/O ratio. The ^{12}C and the s-process abundances, and the C/O ratio have increased above values seen in the MS and S stars. If the low oxygen abundances reported by Dominy et al. represent the original metal content of the stars, the nitrogen abundances are enriched, which suggests further CN-cycle processing of the fresh carbon introduced between thermal pulses. This explanation yields a general excess of C+N+O over the original composition of about a factor of three, requiring >5 thermal pulses. An alternative explanation, proposed by Dominy et al., is that the oxygen abundance is low due to ON-processing. They invoke successive α captures on ^{14}N to deplete the nitrogen and produce ^{22}Ne. The most luminous carbon stars in the Magellanic Clouds are probably SC or CS stars (formerly classified as J stars, see Utsumi 1988), suggesting that this phase of evolution occurs near the tip of the AGB. These stars may be part of the cycle defined by the MS, S, and N-type carbon stars, with the addition of CN cycle processing of ^{12}C-rich material in more massive examples.

Our understanding of the nature and origins of the carbon stars has increased dramatically in recent years, motivated by the discovery and study of so many carbon stars in the Magellanic Clouds. A comprehensive study of the abundances of C, N, and O in N- and J-type carbon stars in the Galaxy was provided by Lambert et al. (1986). Most carbon stars have $1.0 < C/O < 1.6$, and typical values of 1.1. The carbon isotope ratios of the N-type stars range from 30 to nearly 100. While results are ambiguous, oxygen, nitrogen and the metals may be slightly sub-solar. Like the MS and S stars, the N-type carbon stars have oxygen isotope ratios much in excess of theoretical predictions, and of their K and M giant predecessors (Harris et al. 1987). Utsumi (1985) reports that the s-process elements are enriched by factors of 10-100. Abundances in the N-type carbon stars are generally consistent with advanced thermal pulsation models, and with an advancing evolutionary sequence M-MS-S-C. The high ^{12}C/^{13}C ratios reflect the addition of triple-α carbon. The absence of stars with high C/O ratios may be because stars with too much carbon produce copious graphite grains which ultimately shroud the stars' light. The C/O ratio in the heavily obscured carbon star IRC +10° 216, while very uncertain, seems to be >1.7 (McCabe et al. 1979).

The J-type, or ^{13}C-rich stars offer a greater mystery. They differ form N-type stars in having much lower carbon isotope ratios (as low as 3.2, at the CN-cycle equilibrium limit), and they lack enhancements of s-process elements (neglecting such anomalies as WZ Cas). Oxygen and nitrogen may be deficient, although this conclusion will remain uncertain until we really can establish the abundances of the iron peak elements. ^{12}C/O is generally less than unity, but (^{12}C+^{13}C)/O is slightly greater than unity. Oxygen isotope ratios in J stars are lower than in N stars, and are similar to the values in K giants and early M stars. Utsumi (1988) reports that the genuine J-type stars in the Magellanic Clouds are of relatively low luminosity. The origins of the J-type carbon stars pose a special problem. The absence of s-process enhancements probably eliminates a thermal-pulse mechanism. Harris et al. (1987) argue that no form of the CNO-cycle, including hot bottom convection, can account for the composition of the J stars because it is difficult to get C/O>1 and $^{12}C/^{13}C{\sim}3$-5 without also producing a high ^{14}N abundance. They are lead to explosive hydrogen burning as the only recourse, and suggest that for low enough temperatures at the helium core flash, explosive hydrogen burning can achieve low carbon isotope ratios without a nitrogen excess. Such an event may also produce enough ^{12}C to raise C/O above unity. The J-type carbon stars would then be post-helium core flash, rather than AGB, stars. The low oxygen isotope ratios and absence of s-process enhancements support this view. Lloyd Evans suggests that the J stars may form an evolutionary sequence with the early and late R stars.

While oxygen isotopes of the K giants and early M giants fulfill the predictions of the first dredge-up rather well, the AGB giants contain far less of the heavy oxygen isotopes than predicted. Several explanations have been proposed and dismissed by Harris et al. (1985b). The enhancement of ^{16}O by the reaction $^{12}C(\alpha,\gamma)^{16}O$ is unlikely because we don't see enormous oxygen excesses this explanation would require. The ^{18}O cannot be destroyed by convective mixing on the main sequence (with temperatures too low to create ^{17}O) because the oxygen isotopes of the K giants are as expected following the first dredge-up. Destroying the ^{17}O and ^{18}O during helium burning would require processing the entire convective envelope, a difficult prospect. Harris et al. are left to invoke explosive nucleosynthesis at the helium core flash or during helium shell flashing to destroy the heavy oxygen isotopes.

The question of the oxygen isotopes is further complicated by the apparent correlation of the isotope ratios with the neutron exposure parameter (as defined by Cowley and Downs 1980) for MS, S, and N-type carbon stars. If read, this correlation must suggest that the envelope is depleted in ^{17}O and ^{18}O during the AGB lifetime, and in proportion to the number of shell flashing events endured. Depletion of species in the whole envelope by the same mechanism that adds new ^{12}C and s-process elements is difficult. To compound the mystery, the oxygen isotope ratios in the SC stars are consistent with the dredge-up predictions, so any depletion mechanism should not operate in these stars.

The compositions of the AGB stars lead to an evolutionary progression up the asymptotic giant branch and through thermal pulsations of the helium burning shell from the M giants to the MS, S, and N-type carbon stars, and finally to such objects as IRC +10° 216. The SC stars and the J stars do not yet fit smoothly into this sequence.

The Post-AGB Stars

Two subgroups of warmer, luminous supergiants offer candidates for the post-AGB phase of stellar evolution - the group of R CrB stars and hydrogen-deficient carbon stars, and the Population II SRd variables (the 89 Her stars), RV Tauri variables, and the W Virginis stars.

The R CrB variables and related hydrogen-deficient carbon stars show strong carbon features (except CH) and very weak Balmer lines. The R CrB stars are surrounded by circumstellar dust shells, and continue to eject puffs of new circumstellar material on time scales of a month or two; mass loss rates of order $10^{-6}M_o\ yr^{-1}$ are reported by Walker 1986. The compositions of the R CrB stars and hydrogen-deficient carbon stars are were compiled by Lambert (1986). Hydrogen is extremely deficient in both groups ($H/He{\sim}10^{-5}-10^{-6}$), and C/Fe is enriched by typically an order of magnitude over the solar ratio. C/O is typically 2 (more than is measured in the AGB stars, and [N/Fe]~ 1. R CrB itself contains a strong lithium line, indicating a lithium abundance [Li/Fe] near the cosmic value. S-process elements are not enriched (U Aqr is a noted exception). $^{12}C/^{13}C$ is high, typically >50. These stars appear to be nearly exposed stellar cores whose surface abundances contain not only nitrogen enriched material from CNO-cycle processing, but also ^{12}C from helium burning. Very little of the original hydrogen envelope can remain.

Several scenarios for creating such stars have been proposed. Lambert (1986) discussed the possibility of an explosion at the helium core flash ejecting the hydrogen envelope. The remnant would probably be a helium star which would eventually evolve to the region of the R CrB stars. ^{12}C would be produced in the core flash. Webbink (1984) and Iben and Tutukov (1985) proposed that extreme helium stars might also be formed by the merger of two white dwarfs. The third model is that the R CrB stars are the result of continued mass loss on the AGB driven by instabilities in the envelope (helium shell flashes). A helium and carbon rich star would result if most or all of the envelope were driven off. The high Li/Fe ratios in at least some R CrB stars probably supports an AGB origin.

The Population II SRd variable supergiants (89 Her stars), the RV Tauri stars, and the W Virginis stars may qualify as halo post-AGB stars. Their compositions were summarized recently by Bond and Luck (1987b) for the 89 Her stars. Some of these stars show [C/Fe] excesses comparable to the R CrB stars, and the 89 Her stars also show nitrogen enhancements, which indicate the presence of hydrogen burning products at the stellar surface. Small oxygen enhancements are within the range of those seen in Population II stars. Stars with more extreme CNO abundances also show enhanced sulfur abundances. Bond and Luck speculate from the depressed neutron capture element abundances that these stars were originally very metal poor, but are now somewhat hydrogen depleted through mass loss and hydrogen burning. Analysis of

IRAS observations of RV Tauri stars show that these objects have recently (i.e. within the last 500 years) significantly decreased their mass loss rates from a level near $10^{-5} M_o \ yr^{-1}$ Jura (1986). These stars may have recently undergone an episode of very rapid mass loss, as one might expect for stars in the last stages of AGB star evolution. Jura speculates that the RV Tauri stars will become planetary nebulae if they evolve to high temperatures to photo-ionize the surrounding circumstellar material before it dissipates.

Summary

Great progress in observational programs and theoretical studies in recent years has provided a structure within which we can understand some of the processes which create the peculiar red giants. The origin of most groups of the peculiar warm giants can be explained through some form of mass transfer from a more massive and more evolved companion. The compositions of the AGB stars can be understood through the mechanism of mixing from the thermal pulses of stars with helium and hydrogen burning shells. The peculiar AGB stars form a sequence M-MS-S-(SC)-C which is consistent with this picture. Many of the peculiar supergiants can be understood within the context of post-AGB evolution.

Many fundamental problems remain to be solved, and much of the basic abundance data required to guide us are still missing. Some important problems yet before include a) the question of internal mixing on the main sequence to account for the abundance changes seen in the first dredge-up. This problem may have application to the question of the lithium rich giants and the weak G-band stars as well. b) The origin of the early R stars. If they do arise from a violent helium-core flash, we may learn something about the physics of that event. c) We need to obtain much more basic data about the other groups of peculiar warm giants, such as the CH stars and the CH-like stars, and the lithium-rich and weak G-band stars. Are they binaries? What about their compositions? d) How do the M, MS, S, and C stars actually accomplish the mixing required between the helium shell flashes to modify their surface compositions? Can we reproduce their detailed abundance evolution? Can we distinguish among models of the s-process environment using the pattern of enrichment for different species? We need to obtain much more accurate (and reliable) CNO, iron and heavy element abundances than currently available, and for many more stars and more species. e) What happens to the heavy oxygen isotopes during the AGB? Are they destroyed, and how? f) How do the SC stars and the J-type carbon stars fit into the general scheme of things? Their compositions don't match our predictions very well. For the J-type carbon stars, both shell flashes and hot bottomed convection appear to be ruled out. g) What happens to stars at the end of their AGB evolution - do they finally lose their envelopes, and how? How do they evolve to planetary nebulae? Are the R CrB stars and the RV Tauri and 89 Her stars involved?

The last five years has seen great steps forward in our understanding of the evolution of late type giants stars. This Colloquium happens at the right time for us to step back to assess what we have learned and to figure out where to to from here. I anticipate that with the development of new IR detectors, and the construction of new high resolution IR spectrographs with much fainter limiting magnitudes than now available, we will see much more progress in the next five years.

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