1. Properties and Kinematics of the Peculiar Red Giant Stars

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SPECTRAL CLASSIFICATION OF PECULIAR RED GIANTS

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Abstract

Among field stars recent work includes development of classification notation of the strong-CN stars, and the recognition that the barium star with weak CN (HD 130255) may actually be a dwarf barium star. The now established presence of weak-G-band stars on the AGB of globular clusters suggests that such field stars as HD49500 may be in the AGB stage.

Such progress as has been made in the application of modern detectors to the classification of faint stars in the nuclear bulge of our galaxy, and in the Magellanic Clouds, is summarized.

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By the time of the Strasbourg Colloquium of 1984, most of the so-called "peculiar" groups of the cooler stars had been recognized. Since then their spectral definition has been discussed in the book "The Classification of Stars" by Carlos and Mercedes Jaschek (1987), and in the review paper "Spectral Types and Their Uses" (Keenan, 1987).

I shall mention now only one group that has resisted interpretation in terms of the surface composition of its members.

1. The Strong-CN Stars.

These are G- and K-type giants with the blue λ4216 band of CN unusually strong for their temperature and luminosity. The notation developed last year, using positive CN abundance indices (Keenan, Yorka, Wilson, 1987), should serve well enough until analyses of their atmospheres finally answer the question of whether the abundances of the common metals are markedly greater in them than in the sun. They were termed "super-metal-rich" (SMR) by Spinrad and Taylor (1969) but the lack of agreement between published values of their metal abundances led Taylor in 1982 to be more cautious and refer to them merely as Very-Strong-Line stars. There is no doubt about the excess of CN in their atmospheres, however.

The best-known member of the group is μ Leo, which can be considered the prototype. Recently, Harris, Lambert and Smith (1987) have made careful determinations of the abundances of C, N, and O in μ Leo, using infrared bands of CO and CN, along with published data for Ca and [O I] lines. They accepted the metal excess of [Fe/H]=0.48 from the work as Branch, Bonnell and Tomkin (1978). Their results were [C/H]=0.22 [N/H]=0.93 [O/H]=0.32 for the excess abundances compared to the solar values. Alternative analyses with solar metal abundance gave lower concentrations of C, N, and O, but did not remove the excesses. The authors concluded that these abundances were to be expected if μ Leo has undergone the first red-giant dredge-up, and that there was no necessity to invoke the binary coalescence model of Campbell (1986) to explain them, although such a process is not ruled out by the new abundances.

2. HD 130255; A Peculiar Barium Star.

There are a few stars which seem to be mavericks - they refuse to satisfy the tidy definitions that we drew up to specify the members of any of these groups. These truly peculiar stars often turn out to be of the greatest interest from the standpoint of stellar evolution.

One such star is HD 130255 which was listed as a probable barium star by MacConnell, Frye and Upgren (1972), and included in

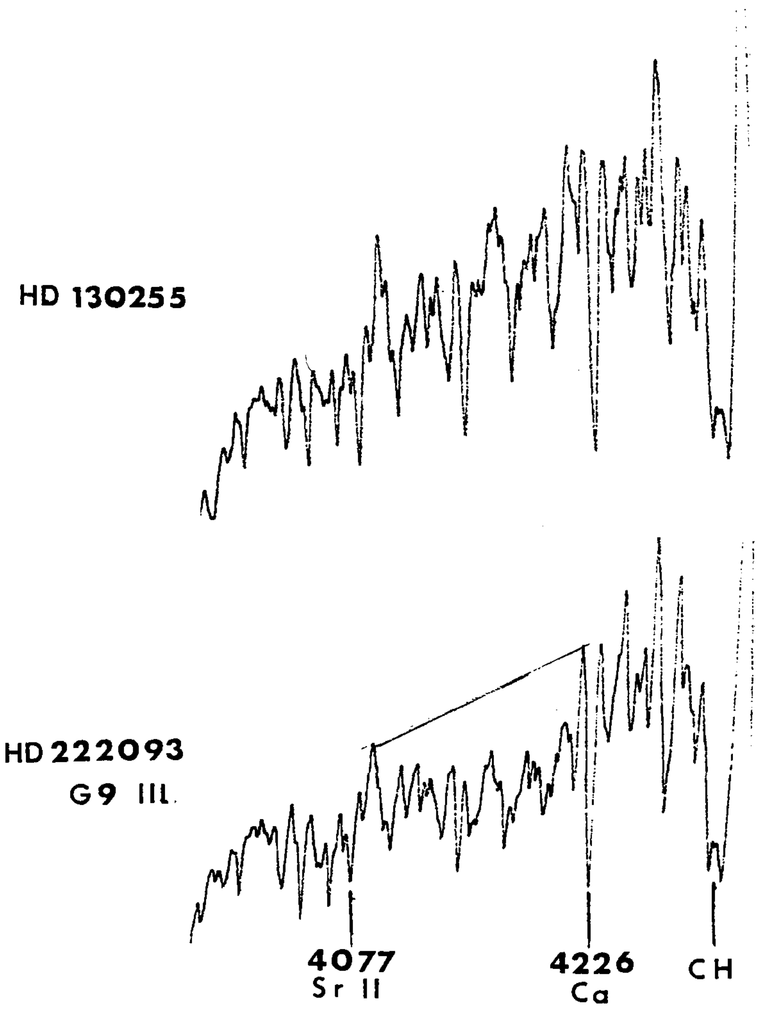

Fig. 1 - Region of the blue CN ΔV=-1 band system. In the typical G9 giant (HD 222093) the extent of the CN absorption can be judged by comparing the local continuum with the interpolated continuum shown by the straight line. The head of the shortward-shaded 0-1 band is at λ 4216.0 A. In HD 130255 the sharp feature at that position is due chiefly to Fe and SrII lines.

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the catalogs of barium stars published by Yamashita and Norimoto (1981) and Lü et al. (1983). These catalogs gave the intensity of Ba 4554 in its spectrum as 1. Three classification spectrograms of HD 130255 were taken by Dr. Pitts a few years ago, but there is an ambiguity in its classification. The SrII and BaII lines would suggest a giant with a mild excess of S-process elements - a type of G9 III Ba1. Fig. 1, however, shows the extreme weakness of the blue CN band, and the 0, 0 band near 3883A is also weak, though in barium stars it is usually so strong as to appear saturated. The weakening would require a CN index of -3 if the star is giant. Since I have never seen another late-G barium star that did not have strengthened CN bands in its spectrum, the alternative possibility is that HD 130255 is one of the long-sought dwarf barium stars. Then the relative strengths of CN and CH would be explained but we should have to classify it as a strong barium star, perhaps G9V Ba2 in order to account for the strength of the SrII and BaII lines. One difficulty with its identification as a dwarf is that the ratio λ4376/λ4383 suggests a higher luminosity. This may not be a fatal objection, for one contributor to the λ4376 blend is a line of Y II, and the abundance of yttrium sometimes is surprisingly high in stars in which even a small neutron flux has occurred.

For HD 130255, $m_V \cong 8.4$ and the components of its proper motion are given in the S.A.O. Catalogue as:

$\mu\alpha = 0^s.0022$, $\mu\delta = -0''.049$.

The motion in declination would be large for a giant, but not surprising for a dwarf. Clearly, there is need for not only a good analysis to give log g and atmospheric abundances for HD 130255, but also for monitoring of its radial velocity. As soon as the luminosity of one such star has been determined, we shall easily be able to recognize and classify any others that may exist.

3. AGB in Globular Clusters and Field Stars.

The most important development in spectral classification, now and in the foreseeable future, is the application of the sensitive new detectors, particularly the CCD, to extend the schemes of classification to distant part of our galaxy and to outlying systems.

Before turning to the really faint stars, however, let us consider classification in the asymptotic giant branches (AGB) of globular clusters. Not all globular clusters have

AGB's so well defined that stars on at least their lower parts (sometimes termed early AGB stars) can be selected just from their positions on luminosity - color diagrams, but this is possible for several of the best-known clusters. As long ago as 1973, Zinn noticed stars with an unusually weak G-band in the AGB of M92. The work was extended to several other clusters with well-defined AGB's (M13, M15 and NGC 6397) by Norris and Zinn (1977) and others. The results have been brought together by G.H. Smith (1987) in his review of the properties of globular clusters.

In all of these clusters CH-weak stars were found in the AGB, and Norris and Zinn concluded that 67% of all the lower AGB stars had weak G-bands, the deficiency in total absorption amounting to as much as 2A. Only a few of the stars that were not clearly on the AGB showed the effect, and in several of those the weakening was doubtful. The clusters were all quite poor in metals, and it was soon noticed (e.g. Mallia, 1978) that some clusters (NGC6752, M22 and 47 Tuc) possess few, if any, weak G-band stars. Later, Smith (1987) pointed out that such stars were generally less common in clusters of intermediate luminosity.

This evidence suggests that when a weak G-band is observed in a G- or K-giant, that star has a high probability of being in the AGB stage - at least for stars of the halo and thick-disk population. It is interesting to look for AGB members among field stars by means of this diagnostic. It is somewhat embarrassing, however, to find that practically all the well-known weak-CH stars are low-velocity population-one objects. This may be partly because the rapid decrease in G-band strength as metal deficiency becomes more extreme makes it difficult to recognize a spectrum in which the band behaves abnormally.

There is one star, however, HD 49500, which is a possible AGB candidate. This star has tended to fall between several stools of classification, the best type that I can give it being K2-III Fe-2 CH-1 H_δ1.

Thus it is slightly metal-deficient, and slightly deficient in the G-band. Since V=7.19, the S.A.O. values for the proper motion, $\mu\alpha$=0".030, and Heard's Vr=+61, would not be inconsistent with its belonging to the thick-disk population. Here again a good analysis of the atmosphere of HD 49500 would help in the classification of similar stars.

There is the obvious possibility that all weak G-band

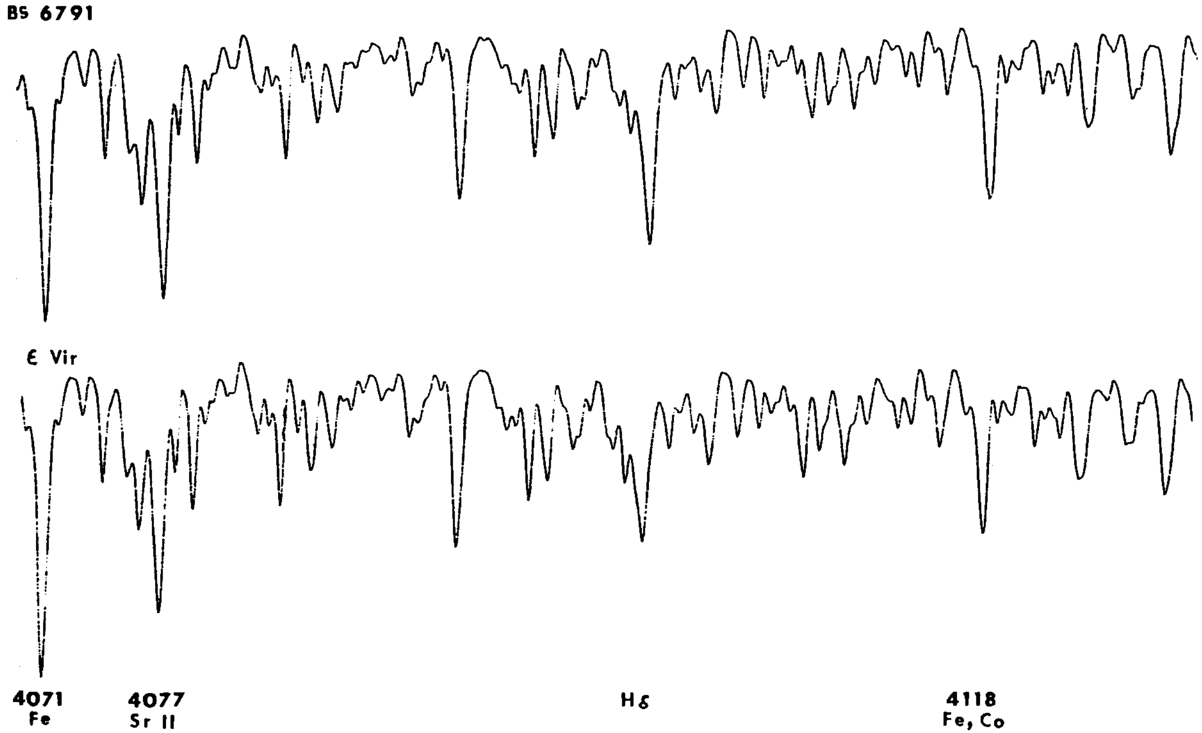

Fig. 2 - Comparison of the weak-G-band star HD6791 (G8 III CN-1 CH-3) with the standard G8 giant ε Vir. Resolution of the Palomar spectrograms was about 0.3A.

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giants can be assigned to the AGB. One constraint on their interpretation is that only the CH band appears to have abnormal intensity in these spectra. Figure 2 shows a short section of two Palomar coude' spectrograms. BS 6791 is one of the well-known weak G-band stars, while ε Vir has often been cited as a standard G8 giant of nearly solar composition. Actually, ε Vir is a rather late G8 star, and BS 6791 is a trifle hotter, as can be seen from the greater strength as H_δ in its spectrum. Although SrII 4077 seems slightly stronger in BS 6791, Ba II 4554 shows no strengthening on the same spectrograms, and since BS 6791 may be slightly the more luminous of the two, there is no convincing evidence of a marked excess of S-process elements in BS 6791. The close agreement of both the relative and the absolute strengths of the lines in these two spectra suggests further that the opacities also in these stars are the same. Thus spectra of fairly high resolution appear to confirm the evidence from low-dispersion classification that the material dredged up into the atmospheres of weak-G-band stars differs from that in normal G or K giants essentially in the conversion of some of the carbon to nitrogen, with little changes in metal abundance.

If next we consider open clusters, even the oldest do not contain enough giants to allow AGB stars to be recognized from their color-magnitute diagrams. The program of Garrison at Toronto to determine a consistent set of spectral types for giants and subgiants in open clusters offers the possibility of detecting even slightly peculiar members.

4. New Programs of Classification of Remote Stars. This survey must be limited to the extension to faint stars of the more accurate classification that can be carried out with resolutions of a few angstroms, and barely mention the immensely fruitful classifications of the low-dispersion surveys. The success of the surveys is due to the fortunate circumstance that the stronger bands of such molecules as TiO, ZrO and CN can be distinguished at scales even below 2000 A/mm. This has made possible the extensive discovery lists of S, SC and C stars, most of which, it is generally agreed, are late AGB stars (cf. Smith and Lambert, 1986). Examples of on-going objective-prism programs are the Abastumani survey of stars down to V=16 within 5° of the galactic plane (Nicolashvili, 1987), and the Case survey which reaches to R=17 and extends

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to high galactic latitudes (Sanduleak and Pesch, 1988). The powerful technique of GRISM spectroscopy, developed by McCarthy, and Blanco, 1978 has been extended by them (Blanco and McCarthy, 1983) and also Westerlund et al. (1986) to the Magellanic Clouds and other galaxies of the local system.

We have now become accustomed to the dominance of M stars in the nuclear bulge of our galaxy (cf. Blanco et al., 1984) in contrast to the much greater frequency of carbon stars in the Magellanic Clouds. Such differences between galactic populations make it the more important to refine the classifications with higher resolution. As early as 1983 Whitford and Rich had examined a sample of K giants in the nuclear bulge observed through Baade's window, using Reticon detectors with resolutions of 2.5 to 4.5 A. The sample has since been extended to 112 stars (Rich, 1988), for which the mean abundance of metals was 1.96 times the solar value. For M giants in the bulge, Whitford (1986) had combined the results of GRISM surveys with photometric data to conclude that they also are metal rich. All of these results are in accord with the evidence for increasing metal abundance towards the nuclear regions of spiral galaxies.

Since Blanco and McCarthy had found no carbon stars in Baade's window, a search for possible ones in that vicinity was carried out by Azzopardi et al. (1985), who found three that seemed fairly definitely to be early carbon stars of rather low luminosity. Lloyd Evans (1985) obtained spectra of one of them, BW-C6, at resolutions of 6A in the red and 2A in the blue, and found it to be a metal-rich R star with strong ^{13}C.

If we turn now to recent work on the Magellanic Clouds, we find copies of objective-prism spectrograms taken with the United Kingdom 1.2m Schmidt telescope used by Kontizas et al. (1987) to classify members of globular clusters in the clouds. At their scales of 830 or 2440 A/mm it was possible only to assign whole types: K, M, C, etc. These data were then used to find the ratios of carbon to M stars and thus to estimate the ages of the clusters.

The value of higher resolution is seen in the work of Lundgren (1987) on M giants and supergiants in the LMC. With the IDS spectrograph on the 3.6m and 1.5m telescopes of ESO at La Silla he was able to identify a number of MS stars. This was the first time that the presence in the Clouds of stars at this stage of AGB evolution was confirmed.

5. I want to finish by considering a question that is important to the planning of future programs. Is it worthwhile to observe spectra at classification resolutions (≅ 2A) when the new detectors make it possible to carry out atmospheric analyses of the same stars at higher resolutions?

I believe that spectral types of these stars are essential, for three reasons:

[1] When one sees an abundance analysis of an unclassified star it is difficult to know how to characterize that star for comparison with others without writing a whole descriptive paragraph. A spectral type is designed to meet this need by giving the most compact summary possible of the luminosity, effective temperature, and atmospheric composition of a star.

[2] As soon as a few good analyses of classified stars in any population become available, the classification indices allow quite accurate interpolation between the physical variables measured in the analyses. Also, the spectral types need less frequent revision than the analyses, which are strongly model dependent.

[3] Since the spectral resolution required for good analysis is usually about five times higher than that required for classification, a classification program with a given telescope and detector generally reaches a limit one or two magnitudes fainter. With the data usually in digital form, either operation will presumably be carried out automatically or semi-automatically, and the saving of telescope time by the classification program is considerable.

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