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SMR STARS, STRONG-CN STARS, AND R STARS

Philip C. Keenan
The Ohio State University

and

Andree Heck
Observatoire de Strasbourg

RESUMEN

Las estrellas con líneas intensas de CN (incluyendo a las estrellas SRM) y las estrellas de carbón tipo R son similares en cuanto a que ocupan casi la misma región en el diagrama H-R, en su distribucion en el disco intermedio y en que se encuentran en sistemas binarios aproximadamente en la misma proporción que las gigantes G y K ordinarias. Los espectros de ambos grupos no muestran enriquecimiento de elementos producidos a través del proceso-s.

La diferencia principal entre ellas es que la mayoría de las estrellas con CN intenso son ricas en metales, mientras que las estrellas R tienen abundancias casi solares de los metales comunes. Esto sugiere la posibilidad que unas pocas estrellas con CN intenso no sean estrellas SRM y que pudieran ser estrellas R marginales.

ABSTRACT

The strong-CN stars (including the SMR stars) and the R-type carbon stars are similar in that they occupy nearly the same part of the H-R diagram, in that their distribution in the medium-thick disk is similar, and in having about the same proportion of binary systems as are found in ordinary G and K giants. The spectra of both groups are alike in lacking enhancement of the s-process elements.

The major difference between them is that at least most of the strong-CN stars are metal rich, while the R stars have nearly solar abundances of the common metals. This suggests the possibility that a few of the strong-CN stars are not SMR stars, but may be marginal R stars.

Key words: **STARS: CHEMICALLY PECULIAR— STARS: CARBON — STARS: FUNDAMENTAL PARAMETERS**

1. INTRODUCTION

There has been much discussion of the nature of the R stars (Gordon 1967; Dominy 1984), and of the SMR ınd strong-CN stars (Spinrad & Taylor 1969; Schmitt 1971; Taylor & Johnson 1987), but little attention has ›een paid to their significant similarities and differences.

A. Metal-rich (SMR) Stars. The acronym SMR was introduced by Spinrad & Taylor (1969) to characterize hose giants and subgiants that they defined as "super-metal-rich" on the basis of measures of line blanketing n the violet and of strong individual atomic lines and the blue CN band. Because later observers had so much lifficulty in agreeing on the amount of the excess abundances of the elements responsible for these features, Гaylor (1982 a,b) proposed changing the name to VSL (very-strong-line) stars. Since, however, it is precisely he difficulty of deciding whether (or how much) the metallic lines are strengthened that creates a problem, it eems just as well to retain the original designation "SMR stars", keeping in mind the possibility that SMR nay mean only: slightly-metal-rich".

In 1987 Taylor & Johnson reviewed and extended the data, deriving a metallicity parameter, G, for the ;iants. G is a weighted mean of the blanketing indices and the measured strengths of the CN 4215 A band and of lines of iron, magnesium, and sodium. In their Table 4, they list 12 stars with $G > 0.35$ as definite SMI stars, 11 stars with $0.25 < G < 0.35$ as marginal SMR stars, and 10 stars (plus members of the Hyades an M67) as "other evolved stars".

Table 1. CN Strengths in Stars with SMR Indices

BS	HD	Name	G	MK Type	CN Schmitt	CN Griffin	CN Faber
8924	221148	—	0.55	K3- IIIb CN2 Fe1	—	—	0.094
7576	188056	20 Cyg	0.48	K3 IIIb CN2 Fe1	—	0.20	0.142
5582A	132345	18 Lib	0.47	K3- III CN1.5	3	—	0.214
—	174487	—	0.45	—	1	—	—
7352	189984	τ Dra	0.41	K2+ IIIb CN1	—	—	0.134
—	166284	—	0.41	—	3	—	—
—	130705	—	0.40	K3 IIIb: Fe2	3	—	—
4521	102328	—	0.40	K2.5 IIIb CN1	—	—	0.106
—	104998	—	0.39	—	3	—	—
3905	85503	μ Leo	0.39	K2 III CN1 Ca1	1	0.12	0.148
165	3627	δ And	0.36	K3 III CN1	—	0.12	—
—	112127	—	0.35	C-R4 IIIb $C_2$0.5	2	—	—
495	10486	—	0.33	K2 IV (BS)	—	:	—
8413	209707	ν Peg	0.31	K4 III (BS)	—	0.12	—
1805	35620	ϕ Aur	0.31	K3.5 IIIa CN2	1	0.22	0.124
—	9166	—	0.31	—	—	:	—
5826	139669	Θ UMi	0.30	K5- III CN0.5	—	—	-0.018
8482	211006	—	0.30	K2 III (BS)	—	—	—
5370	125560	20 Boo	0.28	K3 III (BS)	—	0.15	0.050
—	29038	—	0.27	—	—	—	—
2429	47205	ν^2 CMa	0.27	K1.5 III-IV Fe1	—	—	0.045
258	5286	36 And	—	K1 IV (BS)	—	?	—
3360	72184	—	0.24	K1.5 IIIb CN0.5	—	0.03	0.053
3369	72324	ν^2 Cnc	0.06	G9 III (BS)	—	0.08:	0.057
3994	88248	λ Hya	0.23	K0 III CN0.5	1	—	0.105
4737	108381	γ Com	0.21	K1 III CN0.5	2	0.12	—
5227	121146	—	0.15	K2 IV (BS)	—	?	—
6136	148513	—	0.23	K4 IIIp (BS)	1	0.09	0.076
6603	161096	β Oph	0.24	K2 III CN0.5	—	0.07	—
7429	184406	μ Aql	0.23	K3- IIIb Fe0.5	—	0.05	—
8974	222404	γ Cep	0.22	K1 III-IV CN1	1	—	—

B. Strong-CN Stars. On the other hand, "strong CN-stars" have usually been defined by either visu estimates or measured absorption of the blue CN band having its observed head at 4216 A (sometimes wit account taken also of the violet 3883 A band). Use of the CN absorption as a luminosity criterion goes back t Lindblad (1922). Observers carrying out objective-prism surveys, particularly Morgan & Nassau, soon bega circulating lists of stars with very strong CN bands. The problem was that enhancement of CN absorption b the luminosity effect could not be separated from the direct effects of atomic abundances from low-dispersic spectrograms alone. The first systematic program to estimate both variables on slit spectrograms (at a sca of A/mm) was carried out by Roman (1952) at Morgan's suggestion. When the blue CN band is very stron the absorption due to the higher vibrational terms extends below 4150 A, and Roman used the term "4150" t designate such stars. She tried to distinguish also the stars in whose spectra the metallic lines were anomalous strong in comparison to the Balmer lines of hydrogen calling then "st-1" stars. Since the SMR stars of Spinrad Taylor are practically all later than K1, the lists of Roman and of Taylor & Johnson have few stars in commo

More extensive lists of strong-CN stars were published later, particularly by Schmitt (1971), who gave estimated CN strengths on a scale extending from 1 to 3. When the strong CN stars were classified on the Revised MK system (Keenan et al. 1987) the rather roughly estimated CN indices were on essentially the same scale, with an index of 0.5 reserved for the many marginal stars in which the positive CN anomaly appeared to be just noticeable.

Do the SMR stars and the strong-CN stars coincide? Table 1 shows the three groups of SMR stars as given by Taylor & Johnson (1987) with their values of G in the fourth column, followed in the fifth column by the Revised MK type from the Perkins Catalog (Keenan & McNeil 1989) or its current revision. In this column types without CN indices are taken from the Bright Star Catalogue. Following the CN indices, Fe indices are given for those stars with spectra in which strengthening of the iron lines and/or Ca 4226 could be seen on the classification spectrograms. All of the SMR stars for which MK types are available, including the third group of "other evolved stars", have positive CN indices.

The sixth column of Table 1 gives the estimated CN strengths of Schmitt (1971), who observed only stars which had been noted from slitless spectrograms as having enhanced CN. In the seventh column is the CN excess of Griffin & Redman (1960), obtained by subtracting the values for normal stars that have the same Revised MK type and luminosity class from their CN ratios. The eighth column shows the δCN of Faber et al. (1985), which are the excesses of the photometrically measured CN absorptions at 4170 A. Their only negative value in Table 1 is that of Θ UMi, which has the late type of K5-. At this temperature the blue CN band is normally so weak in comparison to the overlapping metallic lines that considerable overabundance of CN must be present before the band becomes noticeable. For late K-type stars observations of the red and infrared bands of CN would be more informative.

There are other photometric measurements of CN strengths made with various band widths, such as the DDO intermediate band photometry of Janes & McClure (1971). Like the entries in Table 1, their CN excesses show a considerable scatter, but all tend to confirm the enhancement of CN in SMR stars. Thus it seems safe to conclude that SMR stars are strong CN stars. The converse is not necessarily true (see § 4), for CN absorption alone would not be sufficient to give a very high value of G if there were no general strengthening of the metallic lines.

Recognizing, then, that the class of strong CN stars (at least in the range G8 to K4) contains the SMR stars as a subset, we can proceed to compare the properties of R stars, strong-CN stars, and normal G-K giants of solar composition.

2. POSITION IN THE H-R DIAGRAM

Consider first the regions on the H-R diagram where these several groups are found. The average temperature type of the strong-CN stars (from Table 2 of Keenan, Yorka & Wilson 1987) is K1.6, with a range from G8 to K5. There is an obvious selection effect here because of the difficulty of observing CN outside of this range of types, so we should make comparisons only with normal giants having the same temperatures.

There is uncertainty also in estimating the mean equivalent type for the R stars. This is due to the confusion between late R stars and early N stars, but if we include only early R giants in the range from C-R0 to C-R4 in the Revised MK system (Keenan 1993), then these R stars have an average equivalent type of K1, with a range from G8 to K3.5.

Since the stars in these groups show no evidence of overabundance of the s-process elements, their luminosity classes can be estimated by the usual MK criteria. The only problem is offered by a few R stars with very strong bands of all the carbon compounds, which may distort the strength of some atomic lines. On the whole, though, we can proceed to compare the luminosities of both groups with those of normal giants. For both the R stars and strong-CN stars it is necessary to lump together classes IIIb, III, and IIIa in order to have statistically significant samples.

Various estimates of visual absolute magnitudes, averaged over equal volumes of space, are given in Table 2. Some early data have been omitted from the table because they may have included a few of the more luminous CH stars among the R stars. Since practically all the entries in the table are subject to selection effects and other systematic errors, the scatter in the means is not surprising. Contributing also to the known increase of luminosity for R stars of later types. The mean magnitudes from trigonometric parallaxes are from the Yale parallax catalogue, as of summer, 1992, kindly made available by Van Altena and Lee. The values of M_V for these bright stars average about 0.75 mag fainter than those from the 1962 published catalog. This difference arises from the corrections applied to the Allegheny parallaxes, which comprise most of the data for bright northern stars, and presumably would not appear in the parallaxes of fainter stars. The difference of about one-half magnitude between normal giants and strong-CN stars may be real.

For the early R stars Scalo (1976) had concluded, largely on the basis of Baumert's infrared observations, that they occupy essentially the same part of the H-R diagram as G and K giants of solar composition. The data of Table 2, however, do suggest that the early R stars tend to lie on the upper edge of the ridge of normal red giants, while the strong-CN stars are situated slightly lower.

Table 2. Mean Motions in Galactic Coordinates (km s^{-1})

Group	H	Θ	Z	δΠ	δΘ	δZ	Source
Normal G - K Giants	4.4	−0.4	0.1	20	17	14	Janes & McClure (1971)
Strong-CN Giants	3.7	−15.2	−2.2	35	26	19	Janes & McClure (1971)
R0 to R4 Stars	3.5	−7.4	15.5	48	23	16	McCloud (1947)

3. POPULATION MEMBERSHIP

In their distribution and motions the R stars are distinct from the three other main groups of carbon stars. Since there are only about 22 classified R0 to R4 stars brighter than $V = 9$ (excluding the few Mira variables), estimates of their scale height above the galactic plane are uncertain, but it is generally recognized that they are not confined as closely to the plane as are the more luminous N stars. Nor are they halo objects like the high-velocity CH stars, but their peculiar motions are greater than those of the hydrogen-deficient (CHd) stars, which appear to be supergiants. The R stars lie within what can be called the moderately thick disk, like many of the normal G and K giants, and the strong-CN stars.

Table 3 gives some published estimates of the peculiar motions, and their dispersions, for the three groups. Since the uncertainties are probably comparable to the tabulated values, it is safest to conclude only that so far as their space motions are concerned, all three groups could belong to the same population.

Another characteristic that is important in discriminating between populations is the frequency of binary stars. McClure (1983, 1984) has shown that practically all CH stars and barium stars are spectroscopic binaries, while the majority of strong-CN stars and R stars, like ordinary giants, appear to have constant radial velocities.

Thus, as far as population is concerned, the three groups of stars under examination are similar. One statistical difference, however, is that R stars are much rarer than strong-CN stars, at least in our galactic neighborhood. To the limit of the Bright Star Catalogue ($V = 6.5$), not one R0 to R4 star is known, in contrast to at least 29 strong-CN stars, with probably several more southern stars that have not received MK types.

Table 3. Visual Absolute Magnitudes

Group	M_V	Source
Normal Giants		
G8 - K2	+1.35	$V = 6.0$ to 7.9, (Schmitt 1971, ν)
G7 - K4.5	+1.00	$V < 5.1$, (Keenan 1993, trig. π)
G8 - K3	−0.12	$V < 7.5$, (Egret et al. 1982. V_r,μ)
G7 - K3	+0.18	(Mikami & Heck 1982, V_r,μ)
Strong-CN Giants		
G8 - K2	+1.35	$V = 6.0$ - 10.0, (Schmitt 1971, ν)
G8 - K3.5	+0.46	$V < 5.1$, (Keenan 1993, trig. π)
G8 - K3.5	+1.00	$V < 7.5$, (Heck 1993, V_r, μ)
R Type Stars	+0.5	2 stars (Richer 1975, H and K widths)
R0 - R3:	+0.4	(Gordon 1968, clusters, etc.)
C0 - C3	−0.6	14 stars (Mikami 1986, μ)
C4 - C5	−1.7	31 stars (Mikami 1986, μ)

4. SPECTRUM AND COMPOSITION

It is easy to set up a sequence of stellar spectra arranged according to increasing CN absorption, but this, of ourse, does not necessarily imply any evolutionary connection between the stars selected. Figure 1 shows such set, ranging from an ordinary K0 giant (C) to an R star (A) of similar temperature. Although HD 123121 is a elatively weak and early R star, it is easily distinguished by the presence of the C_2 degraded shortwards from 737 A. The band is not so easily recognized by inspection of photographic spectrograms, which are likely to e overexposed in this region. That may be the reason that Taylor & Johnson (1987) included a similar R star, D 112127, in their list of SMR stars (see Table 1 and Figure 2). These might be termed marginal R stars, ut in this paper that term will be reserved for stars with barely detectable C_2 bands. In Figure 1, spectra B nd C, the features seen near 4737 A can be accounted for by the strong and heavily blended lines of iron and ther metals.

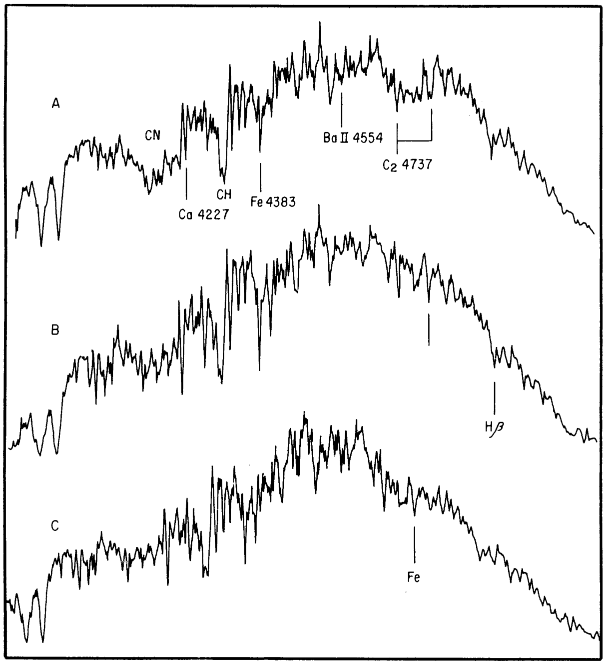

Fig. 1. a) Early carbon star, HD 123121, Type C-R2 III C_2 0.5. b) Strong-CN star, ν Aur. Type K0 III N 1. c) Normal K giant, δ Cnc, Type K0 IIIb.

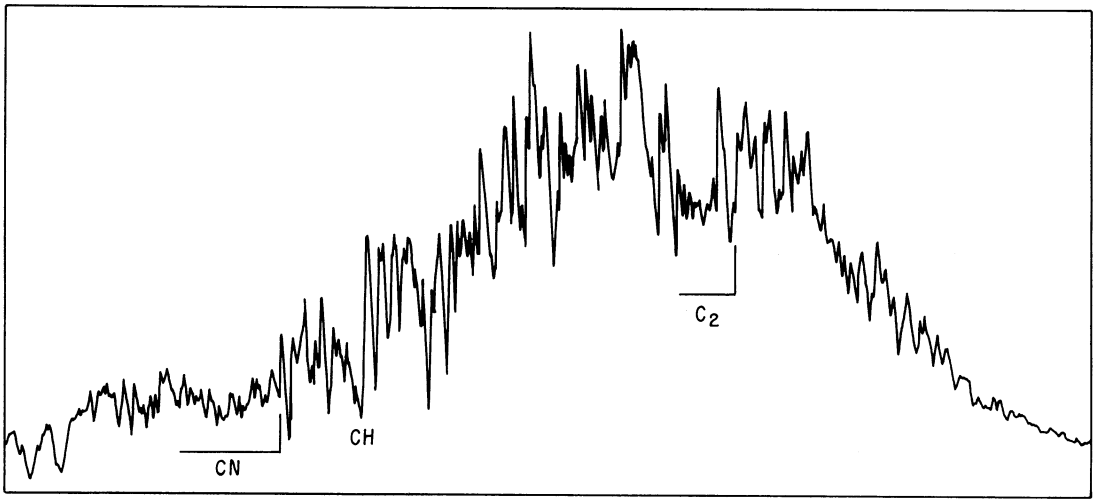

Fig. 2. HD 112127. Type C-R4 IIIb C_2 0.5.

There is one major difference in composition between the R stars and the strong-CN stars. Dominy (198‹ analyzed 11 R0 to R5 stars, finding "near solar" abundances of iron and the other common metals. This seem to rule out any close relationship between R stars and SMR stars (including most strong-CN stars). This migl be expected from the comparative rarity of R stars, unless it can be shown that the R star phase is a short-live one in the history of a star.

5. MARGINAL R STARS

One interesting possibility suggests itself. Among the strong-CN stars are there a few that are not meta rich? Actually, the existence of such marginal R stars was suggested by Faber et al. (1985), although the had not been looking for them. Their composition indices, based on spectra of 9 A resolution, included CN a 4170 A and such light metals as sodium and magnesium, which generally behave similarly to iron, though wit some individual differences. Figure 3 reproduces their Figure 9a, in which δCN was plotted against δMg, excep that a few star names have been added here. If both indices measured only abundances, a positive correlatio would be expected. The anticorrelation shown in the figure was explained by the authors as primarily a gravit effect. The CN band shows a strong positive luminosity effect, while the magnesium feature at 5177 A has negative sensitivity. Since the stars in the measured sample range in luminosity from subgiants to rather brigh giants, the authors reasonably concluded that this accounts for most of the spread, as well as the anticorrelatio Similar behavior had been noticed by McClure (1970) and explained in the same way.

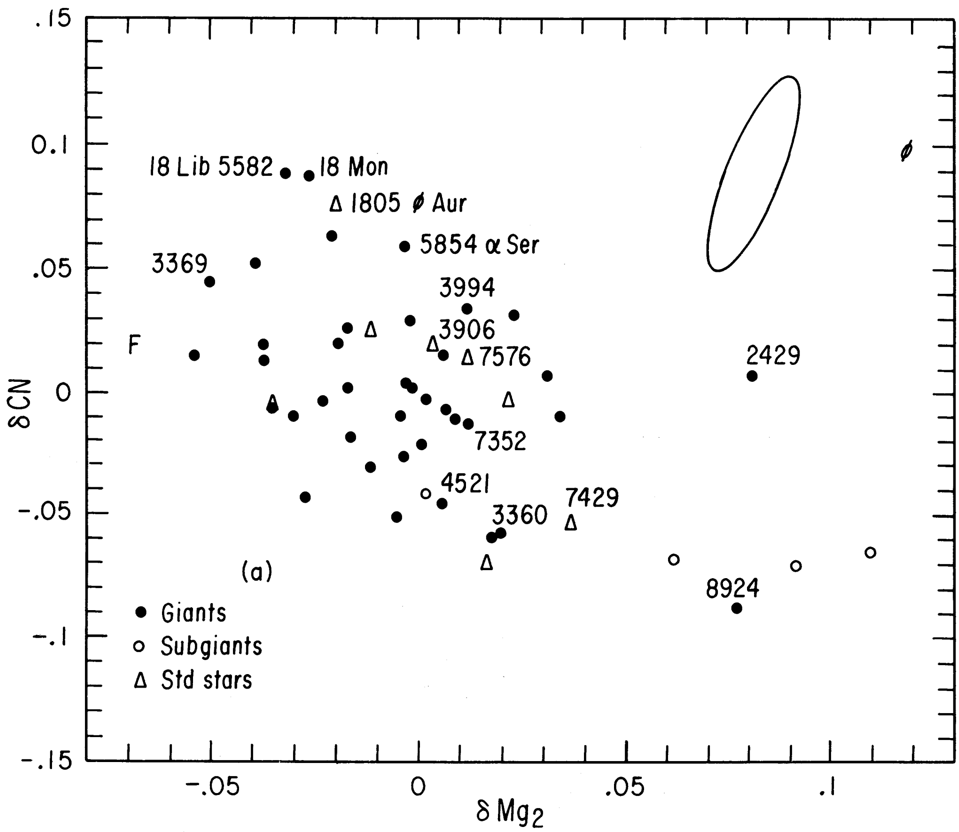

Fig. 3. δCN vs δMg. (Fig. 9a of Faber et al. 1985, with few star names added).

Faber et al. (1985), however, note that the stars in the upper left corner of the diagram (strong CN, wea Mg) might have a greater excess of CN than of metals. In their appendix they give a table in which ϕ Aur, ν CMa, μ Leo, Θ UMi, α Ser, BS 6136, and 20 Cyg are listed as possibly having excess CN.

In order to see whether ordinary classification spectrograms (scale 70 to 80 A/mm) can help decide whethe marginal R stars, that are not really SMR stars, exist, we have carried out a careful re-comparison on thos ıdidates for which several good spectrograms were available. The one metallic line which has seemed to show hancement in the spectra of some metal-rich stars is Ca 4226. Intensity estimates of this line in a number of rmal giants were used to derive the standard curve which is shown by the continuous line in Figure 4. It was rived for luminosity class III, but between G8 and K3 the curves for IIIa and IIIb are almost the same. It only for types K4 and later that the negative luminosity sensitivity of the line is conspicuous near the giant anch.

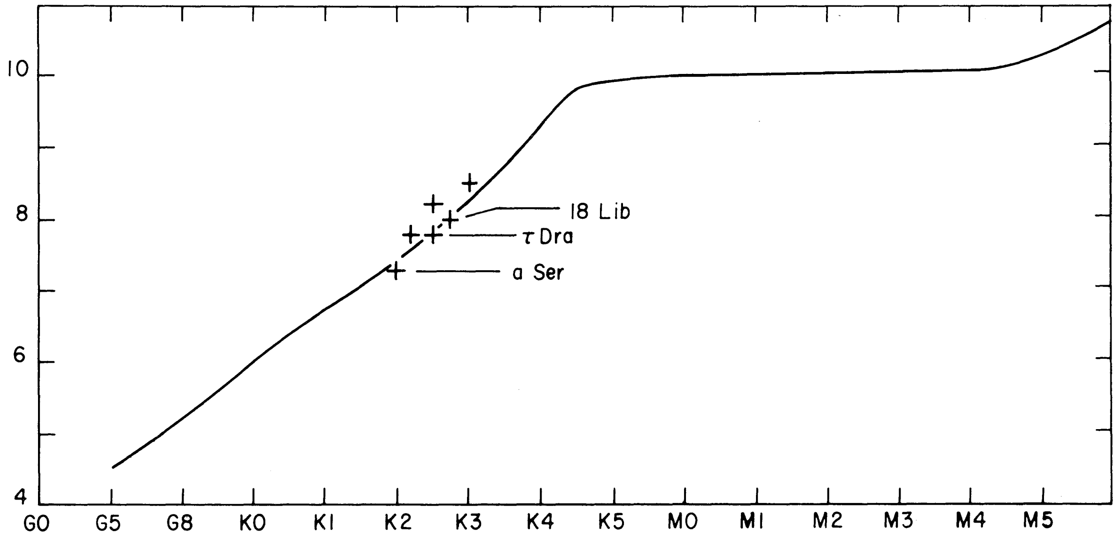

Fig. 4. Estimated strength of Ca 4226 vs MK spectral type, for giants. The crosses represent selected rong-CN stars. The ones above the curve are confirmed SMR stars.

In the figure several strong-CN stars are plotted as crosses. The three points above the line represent the o top stars in Table 1, BS 8924 and 20 Cyg, plus ϕ Aur. Their position in Figure 4 helps to confirm them metal rich. Although ϕ Aur is in the middle group of marginal SMR stars of Table 1, an examination of a ılomar coudé spectrogram taken by O. Wilson confirms the suspicion that it lies slightly above the giant ridge d should be given the luminosity class IIIa. This strengthens the conclusions of Faber et al. (1985) that its sition in Figure 3 is due in part to low gravity. Two stars in Table 1 which might owe their value of G mostly CN are 18 Lib and τ Dra. Both are on or below the normal curve in Figure 4, and 18 Lib has the highest N excess of any star in Figure 3. Thus both remain as possible candidates for marginal R stars, though Faber al. (1985) consider τ Dra a "good SMR candidate".

Although we are continuing to look for stars that seem to have strong CN with normal metals, it seems ear that confirmation of marginal R stars must come from atmospheric analyses that give good abundance terminations. Along with the two stars just mentioned, ν^2 CMa can be suggested as a good candidate for ectrum synthesis.

At present our search for possible marginal R stars is continuing among slightly earlier stars (near K0) that ıy of Spinrad and Taylor's SMR stars. It is generally considered that R stars are on their first ascent of the ant branch, and have undergone a core helium flash (Dominy 1984). Thus it is possible that marginal R stars e more likely to be found among subgiants. γ Cep is an obvious possibility, but other candidates should turn).

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DISCUSSION

Herbig: a) Are any strong-CN or R stars found in galactic or globular clusters? b) Did I understand you t say that binarity is rarer among the R stars than among the N's?

Keenan: a) Strong-CN stars have been found in ω Cen and other clusters which show a dispersion in metallicit; I do not recall any R stars. b) I think that is true, but at the moment I cannot find the paper (by McClure with the measures.

Nissen: Concerning your calibration of the absolute magnitude of the strong CN giants; do you think thes stars have a well-defined luminosity or do they show an intrinsic dispersion in M_V?

Keenan: I suspect a considerable dispersion specially among the R stars. Unfortunately, the data availab now are not accurate enough for individual stars to settle the question.

Wing: I'm wondering about the occurrence of wide visual binaries among the strong CN stars. I seem to reca that the SMR K giant 18 Lib has a G-type main-sequence companion which is also said to be SMR. This woul indicate that the composition of the giant leading to its SMR appearance is not due to evolutionary effects. A there other wide binaries among the stars your discussed?

Keenan: Out of 23 bright stars with CN indices of CN1 or more, 9 (or 39%) are wide binaries.

P.C. Keenan: Ohio State University, Dept. of Astronomy, 174 W. 18th Ave, Columbus, OH 43210 U.S.A.
A. Heck: Observatoire de Strasbourg, 11rue de l'Université, F-67000 Strasbourg, France.