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SPECTROSCOPIC OBSERVATIONS OF SC STARS

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SUMMARY

A search has been carried out for stars similar to the SC type star UY Cen, and twelve are listed in Table I. The six stars newly assigned to the group were selected for observation on the basis of an objective prism survey by Henize. The spectroscopic characteristics defining the group are discussed and the differences from CS stars like R CMi noted. Radial velocities are listed for eight SC stars (making a total of ten with known velocity). A rough estimate of the absolute magnitude ($M_V \sim -2$) and a velocity dispersion of 31 ± 7 km s^{-1} are derived. These figures suggest that the stars are giants of intermediate age and mass. The nine stars of the group which have been adequately studied are all lithium rich, one of them superlithium rich. In contrast both the C and S types apparently each contain lithium poor stars. The frequency of superlithium rich stars also appears to be higher in the combined SC and CS group (2 out of 18 stars) than in either the C or the S classes. The wavelength of the lithium line in SC stars agrees with that expected for Li^7. Theoretical suggestions by Cameron and Fowler on lithium production in late type giants are briefly discussed in the light of these observations.

1. INTRODUCTION, OBSERVATIONS AND GENERAL DISCUSSION

It has been known for many years that there exists a small number of cool stars which cannot be easily fitted into any of the three classes M, S or C. Two such stars which have been studied in the red region at high dispersion are FU Mon (Teske 1956) and UY Cen (Catchpole, to be published). These two stars are characterized by weakness of molecular features, though ZrO and CN are both present, and by the great strength of the lines of certain elements, e.g. La, Y, Ba, Zr, Sr, which are s-process (Burbidge *et al.* 1957) elements. Bidelman (1950, 1953), (following Fujita) suggested that the stars of this type are intermediate between the S type and the C type stars and have a C/O ratio of unity (so that nearly all C and O is locked up in CO). We shall refer to such stars as SC stars. This group of stars though small in number may be of considerable importance for our understanding of the evolutionary status and composition abnormalities of cool stars. The aim of the present work has been (1) to discover more members of the class, (2) to determine their radial velocities, and (3) to study lithium in these stars.

The brightest member of the class known to us is UY Cen and for the purposes of the present paper we define the SC stars as ones closely similar in spectroscopic features to UY Cen. Our work is based on the following series of spectra taken with the Radcliffe 74-in. (1·88-m) reflector.

TABLE I

Star	$\alpha(1900)$ l^{II}	$\delta(1900)$ b^{II}	Na D strong	ZrO	CN	Sr I strong	Ultra-violet opacity	General	$\frac{6708 \text{ Li I}}{6573 \text{ Ca I}}$
GP Ori	$4^h 57^m{\cdot}1$ $186^\circ{\cdot}0$	$+15^\circ 11'$ $-15^\circ{\cdot}8$	Yes	< UY Cen		Yes	Yes	*	
FU Mon	$6^h 17^m{\cdot}1$ $206^\circ{\cdot}6$	$+3^\circ 28'$ $-4^\circ{\cdot}9$	Yes	≈ UY Cen	≈ UY Cen		*		1·1
V372 Mon	$6^h 36^m{\cdot}5$ $207^\circ{\cdot}9$	$-4^\circ 30'$ $-0^\circ{\cdot}1$	Yes	≈ UY Cen			*	≈ UY Cen	
Henize 244	$8^h 46^m{\cdot}0$ $285^\circ{\cdot}6$	$-70^\circ 41'$ $-17^\circ{\cdot}0$	Yes	≈ UY Cen	≈ UY Cen	Yes	Yes		1·0
Henize 250	$10^h 14^m{\cdot}7$ $285^\circ{\cdot}4$	$-60^\circ 30'$ $-3^\circ{\cdot}5$	Yes	≈ UY Cen	≈ UY Cen	Yes	Yes		1·2
Henize 120	$12^h 11^m{\cdot}0$ $298^\circ{\cdot}0$	$-55^\circ 43'$ $+6^\circ{\cdot}3$	Yes	present*		Yes	Yes	≈ UY Cen	≈ 1:
UY Cen	$13^h 10^m{\cdot}7$ $307^\circ{\cdot}6$	$-44^\circ 11'$ $+17^\circ{\cdot}9$	Yes	Yes	Yes	Yes	Yes		1·0
AM Cen	$13^h 40^m{\cdot}9$ $311^\circ{\cdot}3$	$-52^\circ 51'$ $+8^\circ{\cdot}6$	Yes	< UY Cen	≈ UY Cen	Yes	Yes		0·8
VY Aps	$15^h 48^m{\cdot}9$ $314^\circ{\cdot}8$	$-74^\circ 12'$ $-16^\circ{\cdot}1$	Yes	≳ UY Cen	≳ UY Cen	Yes	Yes		1·0
Henize 166	$16^h 33^m{\cdot}9$ $330^\circ{\cdot}2$	$-57^\circ 21'$ $-7^\circ{\cdot}4$	Yes	≈ UY Cen	≈ UY Cen	Yes	Yes		≫ 1
LQ Ara	$16^h 42^m{\cdot}7$ $328^\circ{\cdot}2$	$-60^\circ 51'$ $-10^\circ{\cdot}6$	Yes	> UY Cen		Yes	Yes	≈ UY Cen	≈ 1
S Lyr	$19^h 09^m{\cdot}1$ $58^\circ{\cdot}6$	$+25^\circ 50'$ $+7^\circ{\cdot}1$	Yes	> UY Cen				≈ UY Cen	

Notes on Table I

See Text for description of Table I.

There are notes on each star below. An asterisk in the table draws attention to a particular point in the note.

Notes

GP Ori. Slight tendency towards R CMi but more nearly resembles UY Cen. Bidelman (1950) and earlier work by others shows, (1) similarity to FU Mon; (2) strong Na D lines; (3) weakness of bands (suggesting SC type); and (4) strong Sr I 4607 A. See also Keenan (1954), Spectrum of visual region illustrated by Morgan, Keenan & Kellman (1943) (GP Ori = $+15°$ 726).

FU Mon. High dispersion study by Teske (1956) with earlier references. Very similar to UY Cen in red (by comparison with Catchpole's high dispersion study of UY Cen). High ultra-violet opacity according to Stephenson (1967).

*V*372 *Mon*. Stephenson (1967) places in SC class and finds high ultra-violet opacity.

Henize 244. ZrO possibly slightly weaker than in UY Cen. Henize has doubtful S type and Na D very strong.

Henize 250. Henize has doubtful S type and Na D very strong.

Henize 120. Henize lists as S type but ZrO intensity uncertain and Na D strong. ZrO possibly variable.

UY Cen. High dispersion study in red (Catchpole) shows close similarity to FU Mon. Probably the brightest star of the class. Henize has doubtful S type and Na D very strong. Like GP Ori (Bidelman 1953).

AM Cen. Like GP Ori (Feast 1954, 1956).

VY Aps. Henize has doubtful S type and Na D very strong.

Henize 166. Lithium star. Henize has S type (ZrO intensity uncertain) and Na D possibly very strong.

LQ Ara. ZrO stronger than in UY Cen and CN possibly weaker but ultra-violet opacity and general strength of atomic lines points to SC stars. Henize has S type and Na D strong.

S Lyr. Terrill (1969) (infra-red objective prism) notes that though ZrO is seen, infra-red CN becomes as strong near maximum as is usual only in C stars. This strongly suggests that it is a SC star. Henize has ZrO = 5U (i.e. strong but uncertain).

(A) DY plates, coudé spectrograph 13 A mm^{-1} in the red region, for UY Cen only.

(B) DZ plates, coudé spectrograph 30 A mm^{-1} in the red region, for many of the stars discussed.

(C) DV plates, coudé spectrograph 82 A mm^{-1} in the red region, for all the stars discussed.

(D) DZ plates, coudé spectrograph 15 A mm^{-1} in the blue region.

(E) Cc plates, Cassegrain two-prism spectrograph 48 A mm^{-1} at Hγ.

(F) Cd plates, Cassegrain two-prism spectrograph 86 A mm^{-1} at Hγ.

[(D)–(F)] Blue region covered on at least one of these dispersions for most stars discussed.

Table I lists stars which appear to be sufficiently like UY Cen in spectroscopic features to be classified with it. The table contains a summary of the reasons for making this classification. We have made use of the following criteria.

(1) There is a very marked drop in the intensity of the continuum for $\lambda < \sim 4500$ A. It was pointed out a long while ago (Feast 1954, 1956) that AM Cen and GP Ori which belong to the group show this strong ultra-violet opacity which is similar to that found in some C stars. Our plates show the effect quite definitely for nine of the stars in Table I and it has been noted in two of the other stars by Stephenson (1967). For the remaining star (S Lyr) we have no spectra in the blue region and are not aware of any published report of the blue region. Bidelman (1950) noted the great strength of Sr I 4607 A in GP Ori and this is indeed a characteristic of all the nine stars in Table I for which we have observed the ultra-violet opacity.

(2) The sodium D lines are extremely strong. In GP Ori the combined (unresolved) equivalent width of $D_1 + D_2$ is 56 A (McKellar & Stilwell 1944) and in UY Cen the combined (whole) width at half intensity is 32 A. Such strong D lines occur also, of course, in some C stars (e.g. WX Cyg, WZ Cas, U Cyg have equivalent widths for $D_1 + D_2$ of 45, 55 and 65 A respectively (Sanford 1950)).

(3) Catchpole's detailed study (to be published) of the red region of UY Cen at 13 A mm^{-1} and Teske's (1956) on FU Mon at 20 A mm^{-1} show clearly the presence of both ZrO and CN in these stars though they are quite weak. This can be seen in the reproduction in Teske's paper. Our DZ plates (30 A mm^{-1}) are generally quite well suited to study these molecules particularly the ZrO bands with heads at 6473 A etc., and CN lines particularly 6478·5 A. Where suitable DZ plates are available an estimate of the intensity of ZrO and CN relative to their strengths in UY Cen is given in Table I. We also require the general overall appearance of the spectrum (i.e. the absolute and relative strengths of the metal lines) to match UY Cen rather closely. The DV (82 A mm^{-1}) spectra in the red have sufficient resolution for ZrO (6473 A etc) to be easily detected in UY Cen etc. CN is present mainly as blends with atomic lines at this dispersion and where DZ plates are not available we give an indication from DV plates of the general overall match to UY Cen in the red. We have taken particular account (besides ZrO) of the blend at 6444 A to which CN is probably a principal contributor.

Whilst differences (e.g. in ZrO and CN strength) are apparent from star to star, we believe that the stars in Table I constitute a rather well-defined group though the membership of S Lyr, for which we have less spectroscopic material than for the other stars should be confirmed by additional work. Many of the stars in Table I are variable in light and in a few cases there is evidence for variations of spectrum with time. It would therefore be unwise to require exact agreement of band strengths etc., for membership of the class. Our definition of the SC class is in fact more stringent than has sometimes been used. There are a number of stars of which R CMi and R Ori are the best known, which may also be intermediate between the C and S classes. DV spectra (82 A mm^{-1} in the red region) of these stars show that they are rather readily distinguished from stars like UY Cen. ZrO is absent or very weak and CN is stronger than in UY Cen. They seem to be closer to the C stars than UY Cen is. This has indeed been recognized by Bidelman (1953) and Stephenson (1970). Whilst it seems likely that the UY Cen stars and the R CMi stars are closely related and perhaps indicate the existence of a continuous sequence between the C and S stars (UY Cen stars nearer to S type, R CMi stars nearer to C type) we have preferred to confine the present discussion to stars closely similar to UY Cen. We thus omit in the discussion Henize 84 (10^{h} 03·0 $-59°$ 39 (1900)) which our spectra indicate to be more like R CMi than UY Cen. Dr Keenan has suggested to us that the designation SC might be used for stars similar to UY Cen and CS for stars similar to R CMi. We shall adopt this nomenclature in the present paper. The term CS has frequently been used in the past indiscriminately for either group. There is some evidence also for stars which lie between the SC stars and the S stars but these will not be discussed here.

Six of the stars in Table I are already in the literature as SC stars or possible SC stars. The notes to Table I give some references. The other six stars are listed as closely similar to UY Cen for the first time in the present paper. Candidates for SC stars were chosen on the basis of Henize's work. He carried out an objective prism survey covering the Southern Hemisphere and part of the Northern Hemisphere from Bloemfontein. From these plates he identified a large number of S type or suspected S type stars. Although the catalogue has not yet been prepared for publication, Dr Henize kindly placed it at our disposal some years ago. UY Cen occurs in Henize's catalogue as a doubtful S type star with very strong sodium D lines. He lists a number of other stars with weak or doubtful ZrO and very strong D lines and these are obvious candidates for SC stars. We have observed all the Henize stars with strong or very strong D lines (Henize intensity 3 or 4). Of the six stars in the Henize Catalogue with very strong (Int. 4) D lines, five appear in Table I as SC stars. The one exception is TV Vel which we omit since C_2 bands ($\sim$4737A) are clearly present on our spectra. Of the three stars in the Henize Catalogue with strong (Int. 3) D lines two are found to be SC stars whilst the third requires further investigation. Thus the use of the Henize Catalogue has enabled us to double the number of known SC stars. In addition since the Henize Catalogue contains 264 S or suspected S type stars, for 128 of which he gives estimated D line intensities, it strongly confirms the view that very strong D lines do not occur in normal S stars.

The SC stars are very red objects but little quantitative work has been published on their magnitudes or colours. Henize 120 has been found to be a light variable (Bateson 1970) and to have V = 7·9 to 8·8, $(B-V)$ = 2·3 to 2·5 and $(U-B)$ = 2·0 to 3·2. Dr P. J. Andrews kindly observed AM Cen on one occasion (1965 May 25) and found $V = 8·4$, $(B-V) = 2·70$, $(U-B) = 2·85$. The colours are similar to some carbon stars which is not too surprising in view of the observed ultra-violet opacity. Four of the stars in Table I are far enough north to be in the region covered by the Cal. Tech. 2μ survey (Neugebauer & Leighton 1969). Three of them occur in the Catalogue.

	K	I	$I-K$
V372 Mon	2·91	7·03	4·12
FU Mon	1·58	5·66	4·08
GP Ori	2·11	6·44	4·33

The fourth star is S Lyr a variable of large range in V so that it could possibly have been faint at the time of the Cal. Tech. Survey.

2. RADIAL VELOCITIES, KINEMATICS, ABSOLUTE MAGNITUDE

One of our aims has been to measure radial velocities of the objects listed in Table I in the hope of obtaining at least a preliminary insight into the kinematics of the group. Radial velocities for the stars are listed in Table II. For the spectrum DY 940 (13 A mm^{-1}) of UY Cen the velocity is the mean of 436 lines in the region 5413A to 6897A. These lines are those (out of a total of 1158 lines measured) which have been assigned one identification only in the line list of Catchpole (to be published). The interagreement of the lines indicates a standard error of the mean of

TABLE II

Radial velocities of SC stars

Star	M_V	Plate No.	Heliocentric JD	Radial velocity	No. of lines
GP Ori	8·5:	+79 km s^{-1} (Sanford 1949)			
FU Mon	8·5:	−23·6±0·8 km s^{-1} (Teske (1956))			
Henize 244	8·7:	DZ 1404	2438898·2	+26	21
		DZ 1409	2438899·2	+26	20
				+26	
Henize 250	9·0:	DZ 1405	2438898·4	**+12**	20
Henize 120*	7·9:	DZ 1592	2439222·4	**+5**	8
UY Cen	7·0:	DY 940	2438509·4	−22	436
		DZ 531	2437746·5	−23	19
		DZ 1410	2438899·3	−15	15
		DZ 1411	2438899·3	−19	21
				−20	
AM Cen	8·4:	DZ 471	2437715·6	−22	14
		DZ 1412	2438899·4	−23	21
				−22	
VY Aps	8·4:	DZ 1406	2438898·4	**−40**	21
Henize 166	10·0:	DZ 1407	2438898·6	−10	11
		DZ 1413	2438899·5	−16	18
				−13	
LQ Ara	8·4:	DZ 1408	2438898·6	−6	8
		DZ 1593	2439222·6	−3	9
				−4	

* Henize 120. Hα emission measured at −22 km s^{-1}.

0·3 km s^{-1}. The other velocities are derived from plates of the DZ series, 30 A mm^{-1} in the red region. Twenty-one lines were used for measurement. These lines were chosen on the basis of the line list of UY Cen as lines that would probably be unaffected by blending at 30 A mm^{-1}. The laboratory wavelengths of these 21 lines form the basis of the system. After an analysis of all the line residuals, some of the lines were adjusted slightly in wavelength. This means that the overall velocity system is fixed by the laboratory wavelengths but that spectra on which only a few lines were measured are brought onto a more consistent system with the other spectra. The finally adopted wavelengths are listed in Table III.

TABLE III

Lines used for reduction of DZ plates with principal contributors and multiplet numbers

λ (A)	
5956·73	Fe I (14)
6039·71	V I (34)
6062·90	Zr I (3) Fe I (63) Ba I (7)
6102·72	Ca I (3)
6122·20	Ca I (3)
6143·14	Zr I (2)
6273·46	Ti I (1)
6330·11	Cr I (6)
6357·03	Zr I (2)
6402·16	Y I (2)
6439·16	Ca I (18)
6448·20	Sc I (1)
6501·20	Cr I (16)
6555·79	Ti I (102)
6557·56	Y I (1)
6572·72	Ca I (1) Cr I (16)
6613·81	Fe I (13)
6624·87	Fe I (13)
6650·92	?La I
6762·36	Zr I (1)
6793·78	Y I (1)

The number of stars in the class with measured velocities is small (10 stars). Nevertheless, it seems possible to obtain some indication of the kinematic characteristics of the group. Solving the first order differential galactic rotation formula by least squares for $\overline{\mathrm{Ar}}$, i.e.

$$\overline{\mathrm{Ar}} = \frac{\sum Vo(\sin l \cos b)(\cos l \cos b)}{2\sum [(\sin l \cos b)(\cos l \cos b)]^2}.$$

Where Vo is the radial velocity corrected for local solar motion, and taking the local solar motion and A = 14·3 km s^{-1} kpc^{-1} from Feast & Shuttleworth (1965), one obtains a mean distance $r = 0{\cdot}8 \pm 0{\cdot}9$ (s.e.) kpc. Evidently the group shows little evidence of differential galactic rotation. However the figures allow some limit to be placed on the mean absolute magnitude of the stars. Unfortunately only very rough estimates of apparent magnitude are available for most of the stars. Table II includes estimated visual magnitudes (at maximum light in the case of known variables). These depend on (1) the photoelectric measures discussed in Section 1, (2) the magnitudes in Kukarkin *et al.* (1969, 1970), (3) magnitudes from the B.D., Co.D., C.P.D., and H.D., catalogues, (4) magnitudes estimated by Wray (1968), (5) magnitudes at the time of the spectroscopic observations, estimated using exposure meter readings and densities of the spectra compared with those for stars of known magnitude observed at about the same time. A colour index of $2^{m}\cdot 5$ has been assumed in converting photographic to visual magnitude. Despite the extreme roughness of these magnitudes they give a mean of $V = 8\cdot 5$ which is probably satisfactory for our present purpose and also indicate that the majority of the stars have brightnesses fairly close to this mean. Using this mean V, Table IV gives values of the visual absolute magnitude (M_V) for various assumed values of r. Mean absorption corrections A_V were applied from the equation

$$A_V = 0\cdot 14 \operatorname{cosec} b[1 - \exp(-10 \sin b)]$$

(van Herk 1965), using the mean galactic latitude of the stars ($|\bar{b}| = 10°\cdot 8$), and the corresponding mean distance from the galactic plane ($|\bar{z}|$) is listed. As Table IV shows, the galactic rotation solution yields $M_V = -1\cdot 6$ with an increase in brightness to $M_V = -3\cdot 4$ if r is increased by one standard error. A lower limit to the brightness may be estimated from the fact that, as Table IV shows, $|\bar{z}|$ becomes very small as r is reduced. It seems unlikely that $|\bar{z}|$ can in fact be very small especially in view of the moderated velocity dispersion derived below (for example $|\bar{z}|$ for older Population I stars is 160 pc according to Oort 1957). A lower limit to the brightness of $M_V \sim 0$ appears appropriate. The best estimate for the absolute magnitude (i.e. $M_V \sim -2$) agrees with the absolute magnitude of C stars (~ -2, Gordon 1968) and of S stars (~ -1, Keenan 1954, Feast 1953a).

TABLE IV

Assumed r (kpc)	$\lvert\bar{z}\rvert$ pc	$\bar{A}_V$	M_V
1·7	318	0·7	−3·4
0·8	150	0·6	−1·6
0·5	94	0·5	−0·5
0·27	50	0·3	+1·1

The velocity dispersion (after correcting for galactic rotation) is moderately high (31 ± 7 km s^{-1}) and is similar to that obtained by Keenan & Teske (1956) for small amplitude S stars (36 km s^{-1} from 14 stars) or for another selection of S stars by Keenan (1954) (24 ± 5 km s^{-1} from 17 stars) (both these dispersions are derived by multiplying the published mean random velocity by the Gaussian factor 1·2533). The individual velocities quoted in Table II indicate that velocity changes (e.g. due to pulsation of the stars) do not contribute significantly to the computed dispersion (the scatter in the individual velocities indicates an observational velocity dispersion of ~ 3 km s^{-1}). The computed dispersion indicates that the stars belong to an intermediate age group. They are neither halo objects (velocity dispersion of order of 100 km s^{-1}) nor young (spiral arm) objects (dispersion $\sim$10–12 km s^{-1}). It should be noted that if one forced on the data the hypothesis that the stars were extremely young objects then at least two of the ten would have to be runaway objects (defining them in the usual way as objects with peculiar velocities > 35 km s^{-1}, i.e. greater than three times the velocity dispersion of young objects). The two stars in question are GP Ori and FU Mon (the only two with known velocities prior to the present programme). Four DV spectra (82 A mm^{-1} in the red) of GP Ori in 1969–1970 indicate that it still has a high positive radial velocity (i.e. an interpretation in terms of motion in a binary orbit is unlikely). The actual velocity is not given here since the velocity system with this camera is still under discussion. This high radial velocity of GP Ori (+66 km s^{-1} with respect to the local standard of rest) cannot be significantly altered by corrections for differential galactic rotation since the star is at $l^{II} = 186°$. Similarly in the case of FU Mon (−39 km s^{-1} w.r.t. l.s.r.) the velocity is the wrong sign for the effects of differential galactic rotation. Data on many more SC stars would be required to entirely eliminate the runaway star hypothesis. However at the present the conclusion that the stars belong to an intermediate age group appears to be the more probable interpretation of the data. We cannot of course rule out the possibility that the individual stars have a fairly wide range of ages.

TABLE V

Star	l^{II}	b^{II}	Sco–Cen *V* predicted	*V* observed	*V* predicted minus *V* observed
Henize 120	298°·0	+6°·3	+18·2	+4	+14
UY Cen	307°·6	+17°·9	+15·5	−21	+36
AM Cen	311°·3	+8°·6	+15·3	−23	+38

Three of the SC stars lie in the direction of the Sco–Cen association. They are listed in Table V together with their radial velocities and the radial velocities predicted for them if they are members of the association. The predicted velocities were computed using solution 1 for Sco–Cen radial velocities by Thackeray (1967). Evidently the stars do not belong to the association.

3. LITHIUM IN SC STARS

Li I 6708A appears to be present in all SC stars observed at moderate dispersion. On a 13 A mm^{-1} plate of UY Cen a wavelength of 6707·78 A is measured (referred to the mean velocity of the other lines). In FU Mon Teske (1956) obtained 6707·80 A whilst the mean lithium line wavelength determined from 14 spectra of the eight stars with DZ (30 A mm^{-1}) plates (Table II) is 6707·817 ± 0·016 A (the standard error being determined by the interagreement of the different spectra). These measures are all very close to that expected for Li^7 (6707·81 A) rather than Li^6 (6707·97 A). The problem of line identification in UY Cen will be discussed elsewhere (Catchpole) but it appears that we may conclude with some confidence that the line under discussion is primarily due to lithium (any blending being due only to minor contributors). Whilst a detailed treatment of possible blends from very high dispersion spectra would be necessary to entirely rule out the possibility of some contribution from Li^6, we may at least conclude that there is no evidence of Li^6 in the present data which are consistent with the hypothesis of pure Li^7.

Some guide to the abundance of lithium may be obtained by determining the ratio of equivalent widths of Li I 6708 A to Ca I 6573 A as was done in carbon stars by Torres-Peimbert & Wallerstein (1966). In FU Mon Teske (1956) obtained Li I 6708 E.W. = 0·58 E.W. and Ca I 6573 A = 0·52 A. In UY Cen at 13 A mm^{-1} we find Li I E.W. = 0·52 A, Ca I E.W. = 0·51 A. The ratios Li E.W./Ca E.W. for a number of other SC stars as measured on 30 A mm^{-1} spectra* are listed in Table I. In a few cases the $\approx$ sign indicates an eye estimate of the ratio. Except in one case where the Li I line is extremely strong, the ratio of equivalent widths is always close to unity and the mean Li 6708 A equivalent width is near 0·5 A. For a ratio of unity for these equivalent widths, log Li I/Ca I is about $-4{\cdot}3$ (cf. Torres-Peimbert & Wallerstein 1966). Log Li/Ca will be somewhat larger due to an allowance for ionization. There are a number of both C type and S type stars known with about this lithium abundance and they may be described as lithium rich (in the terminology of Boesgaard 1970). However, both in the C types and the S types there are apparently stars with considerably lower abundances of lithium (log Li/Ca $< -6{\cdot}0$ for S stars and, probably, $< -5{\cdot}7$ for C stars, cf. Boesgaard (1970), Torres-Peimbert & Wallerstein (1966), Wallerstein & Conti (1969)). Such stars appear to be rare or absent in the SC group.

The one SC star with outstandingly different lithium equivalent width is Henize 166 which has a very strong lithium line (E.W. ~ 3 A). The star should be classed with the small group of lithium stars (super-lithium rich in Boesgaard's terminology). As was pointed out previously (Feast 1968), Henize 166 gave evidence that lithium stars are not restricted to C type stars (the three well known lithium stars WZ Cas, WX Cyg and T Ara being of C type).

Warner & Dean (1970) have recently studied lithium in a group of CS and SC stars. We have spectra of all their ten stars and classify them as follows. Five are CS stars (R CMi, R Ori, W Cas, Stephenson Anon $5^h\ 56{\cdot}5+6°\ 38'$, Case 598)†. Three are SC stars (GP Ori, FU Mon, V 372 Mon); all of these are in Table I. For BD $-8°$ 1900 we have a spectrum (DV, 82 A mm^{-1} in the red) which shows ZrO absorption moderately strongly. Hα is in absorption (this is normal in many S stars but not in SC stars at this dispersion) and Na D is not as strong as in SC stars. The star may well be related to the SC stars. Stephenson (1965) lists it as such whilst Mayall (1951) classifies it as an N type star. However our spectrum would probably place it either in the S types or between the S types and the SC stars and we did not include it in Table I. Warner and Dean note that lithium is present in all these stars. It should however be noted that for the CS star R CMi Boesgaard (1970) gives equivalent widths of Ca I 6573 = 0·62 A, Li I 6708 = 0·38 A, i.e. a ratio of 0·6, lower than that found in any SC star (Table I). Boesgaard's curve of growth analysis of R CMi gives log Li/Ca = $-5{\cdot}6$.

Finally, Warner and Dean list Case 621 which they have discovered to be another lithium star (Li E.W. ~ 4A). We have confirmed the great strength of lithium in this star. In the red the star matches R CMi well (apart from the lithium line) and this would lead us to place the star in the CS group. However we find there is a marked depression of the continuum in the region 6160–6220 A which we have not seen in the other SC and CS type stars we have examined. The depression appears to be the same as that noted by Sanford (1950 and earlier references) in some cool C type stars (e.g. U Cyg) and identified by him as due to CaCl. Further work is desirable on this star. Possibly it is somewhat cooler than the other CS and SC stars.

* Considerable care needs to be exercised in studying lithium at much lower dispersions than this. In UY Cen there is a group of lines near 6709 A with equivalent width $\sim 0{\cdot}8$ A which is blended with 6708 A Li I at 82 A mm^{-1}.

† The first three of these stars were grouped together by Keenan (1954). Our spectrum of W Cas was obtained with the 98-in. Isaac Newton Telescope at 60 A mm^{-1} in the red region.

These results indicate that if we accept Case 621 as a CS type lithium star (despite its spectral peculiarity) and take the CS and SC types together as intermediate between the C and S classes then there is a high frequency of lithium stars in this combined class (2 lithium stars out of a total of 18 stars). Lithium stars are apparently less common amongst the C stars. Feast (1953b) found one amongst 50 southern C stars whilst Warner & Dean (1970) found no lithium stars in a sample of 158 northern C stars. The frequency of lithium stars amongst the S types is less well known. We hope to discuss a survey of S type stars separately. One S type lithium star (T Sgr) has been reported (Keenan 1967; Boesgaard 1970) and another has appeared in our survey but the frequency of occurrence is probably not very high. If we interpret the difference between the C and S stars as primarily a matter of C/O ratio then it would appear that whilst lithium stars can occur for C/O both greater and smaller than unity, they are particularly frequent for $C/O \sim 1$. Clearly it would be important to know whether the C type and S type lithium stars have any characteristics suggesting a relation to the CS/SC groups rather than to the 'pure' C or S types (e.g. it is not clear whether the weakness of C_2 bands in the C type lithium stars WX Cyg and (especially) WZ Cas (Keenan & Morgan 1941; Sanford 1944) is a pointer in this direction or not).

The very high lithium abundance in certain late type stars and its much lower abundance in otherwise quite similar stars has long been a theoretical puzzle. Recently Cameron & Fowler (1971) have rediscussed an earlier suggestion by Cameron (1955) for lithium formation in cool stars. If, at a certain stage, some giant stars develop a very extensive but temporary outer convection envelope extending down to the helium burning shell then, if the details are suitably arranged, Cameron and Fowler find that large amounts of heavy elements can be produced by the s-process. Furthermore at one stage the $^3He(\alpha, \gamma)\,^7Be$ reaction produces considerable amounts of ^7Be which is convected to cooler regions before undergoing the reaction $^7Be(e^-, \nu)\,^7Li$. It of course remains to be seen whether the necessary conditions are found to occur when one carries out detailed calculations. Cameron and Fowler had particularly in mind the problem of the super lithium rich stars all of which are also apparently s-process rich as well. It would be of interest to know whether or not detailed calculations suggest that super lithium rich stars should also frequently have $C/O \sim 1$ as the observations suggest. Since the amount of lithium produced by the Cameron–Fowler type mechanism appears to depend critically on the details of the internal evolution of the star, it seems reasonable that one should expect stars with a considerable range of lithium abundance to be formed by the process (i.e. that one might explain lithium rich as well as super-lithium rich stars amongst the heavy metal stars in this way). The fact that we find no evidence for Li^6 in SC stars is clearly in line with these ideas since only Li^7 is predicted by the Cameron process. A possible difficulty which should be mentioned is that, as discussed above, the SC stars are probably not high mass stars whereas Cameron and Fowler show that their mechanism may be expected to operate most effectively in relatively massive stars ($\sim 5\,M_\odot$).

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