A&A manuscript no.
(will be inserted by hand later)

Your thesaurus codes are:
06(08.03.1, 08.03.4, 08.13.2, 08.16.4, 13.09.6)

ASTRONOMY
AND
ASTROPHYSICS
28.4.1994

More (on) red giants with unusual dust shells

M.A.T. Groenewegen

Institut d'Astrophysique de Paris, CNRS, 98 bis Bd. Arago, F-75014 Paris, France

received, accepted

Abstract. Twenty-four M- and MS-stars have been suggested in the literature to show the silicon carbide feature, indicative of a carbon-rich circumstellar shell. By cross-correlating the IRAS LRS atlas with Bidelman's compilation of spectral types for objects in the IRC survey, this sample is enlarged to 39 sources. By carefully examining the LRS spectra, it appears that only one source shows silicon carbide emission. However, there is doubt on the correct association of this IRC source with the IRAS source and on the spectral type of the IRC source. The remaining objects are shown to have no dust, featureless dust, to show the characteristic silicate feature at 18 μm, or to display a broad feature from 10-14 μm which is known from previous studies on the dust around M-stars. I conclude that based on the present sample there is no or weak evidence that silicon carbide dust forms in the shells around M- and MS-stars.

Key words: stars: carbon – circumstellar matter – stars: mass loss – stars: AGB – Infrared: stars

1. Introduction

It is well known that silicate dust is expected to condense out in the cool circumstellar envelopes (CSEs) around oxygen-rich stars and silicon carbide dust and amorphous carbon dust in the CSEs around carbon-rich stars. However, there are stars which seemingly not obey this rule: the carbon stars with silicate dust shells (Willems & de Jong 1986, Little-Marenin et al. 1986) and the M- (and MS-) stars with silicon carbide (SiC) dust (Papoular 1988, hereafter P88 and Skinner et al. 1990, hereafter SGW).

The former group has received much attention. I refer to the recent literature for a discussion on some of the properties of some of the individual members of this group and the possible evolutionary status (binaries; circumstellar disks; the brief phase when a star has recently changed from oxygen-rich to carbon-rich but with the CSE still oxygen-rich) of this group of stars (Lambert et al. 1990, Noguchi et al. 1990, Lloyd Evans 1990, 1991, Barnbaum et al. 1991, Chan & Kwok 1991, Le Van et al. 1992, Chan 1993, Kwok & Chan 1993, Little-Marenin et al. 1994, Engels & Leinert 1994). In the Appendix one additional candidate to the presently known sample of 15 carbon stars with silicate dust shells is suggested.

The group of M- (and MS-) stars with SiC dust has received little attention. However, from an evolutionary standpoint and from the standpoint of dust formation this group would be as interesting as the carbon stars with silicate shells. For example, SGW suggested that the photospheric C/O ratio in the C-stars with silicate dust and the M-stars with SiC dust is close to unity and that the type of dust which condenses out in environments with C/O close to unity is unpredictable.

A total of 24 M-stars (MS-stars are included from now on) have been reported to show the SiC feature. They have been found by cross-correlating a database of M-stars with the LRS-atlas and selecting those stars which are classified as 4n, indicative of SiC emission (P88 found 15 objects in this way; SGW found 11, all included in the sample of P88), and picking out objects with LRS classification 1n (normally indicative of featureless spectra) but believed to show the SiC feature (P88 suggested 9 such objects).

It is well documented that in some cases the automated LRS classification gives unreliable results (e.g. Little-Marenin et al. 1987, Walker & Cohen 1988, Chan & Kwok 1990, Volk et al. 1991, Groenewegen et al. 1992, Volk 1993), including cases where LRS spectra with weak silicate emission were classified as 4n objects. Visual inspection of LRS spectra is necessary to confirm or deny the LRS classification.

In this paper the sample of M-stars which possibly show SiC emission is enlarged to 39 stars by using a larger database of M-stars than considered by P88 and SGW (Sect. 2). The LRS spectra are replotted in a way that allows features to stand out more prominently. The results are discussed in Sect. 3.

Send offprint requests to: M. Groenewegen

Table 1. M-stars which possibly show SiC dust

IRAS-name	IRC number	Name	Sp. type IRC	Sp. type other	LRS	UoC[1]	$T_{\rm BB}$ (K)	Remarks
00186+5940	60008	MZ Cas	M2Iab		45	E	1000	18 μm feature
00245−0652	-10009	UY Cet	M7		14	E	600	18 μm feature
01030−3157	-30013	AD Scl	M9		15	F	1200	weak feature between 10-14 μm
01150+5732	60043	V465 Cas	M5	M3 (1)	41	E	950	18 μm feature
02169+5645	60082	AD Per	M3Iab	M2.5Iab (2)	44	E	700	18 μm feature
05027−2158	-20066	T Lep	M7e	M6e-M9e (2)	15	F	700	weak feature between 10-14 μm
05208−0436	00071	V535 Ori	M4	M4wkS (3)	43	U	700	feature between 9.5-14 μm
05374+3153	30124	NO Aur	M2Iab	M2S (4)	43	E	800	18 μm feature
07568−3226	-30108		M7	A0 (1); Be (5)	42	E	1000	18 μm feature
08555+1102	10199	RT CnC	M4III	M5III (2)	41	E	800	18 μm feature
09057+1325	10203	CW CnC	M6		15	E	650	18 μm feature
11011−6651		KV Car		M4 III (2)	43	E	1200	18 μm feature
13205−1803	-20251		M5		47	F	1800	feature near 13 μm, poor S/N
13244−5904		OS Cen		M6 (6)	41	E	550	18 μm feature
15298+0348	00268	WW Ser	M8e		14	F	700	weak feature between 10-14 μm
15361+2441	20283	LY Ser	M5III	M4III (2)	17	S	3000	no dust
15492+4837	50246	ST Her	M6IIIaS	M6.5S (7)	41	E	700	18 μm feature
16521−2153	-20336	SY Oph	M7	M5III (1)	42	E	650	18 μm feature
17072+1844	20314	BG Her	M3e		43	F	550	featureless dust
17269−2625	-30300		$\geq$ M8	M8 (1)	41	E	670	18 μm feature
17273−2643	-30301		$\geq$ M7	M7 (1)	41	E	600	18 μm feature
17398−4344		TV Sco		M (1)	41	E	500	18 μm feature
17544−2951	-30340	V1717 Sgr	$\leq$ M0	K5(1);Ce:(M0e:) (2)	41	C	750	silicon carbide feature
18093−2107	-20445		M4 redd.	M4I (8)	42	C	800	18 μm feature
18135−1740	-20455		M3 redd.	M2:Iab: (1)	41	E	600	18 μm feature, peculiar
18155−1519	-20461		M4	M4/M5 (1);M3I (9)	43	E	1100	18 μm feature
18222+3933	40315	TW Lyr	M6		41	E	550	feature between 9.5-14 μm
18401+2854	30340	FI Lyr	M9	M1 (1)	41	E	480	18 μm feature
19047−1706	-20538	FQ Ser	M8	M4III (2)	41	E	600	feature between 9.5-14 μm
19306+0455	00443	V1293 Aql	M5III		43	E	900	18 μm feature
20111−4708				M5IIIme (1)	15	F	700	weak feature between 9.5-12.5 μm
20416+1903	20479	ES Del	M7	M1 (1); M10 (2)	41	E	650	weak feature between 9.5-14 μm
21173+6321	60312		M7	M5 (1)	47	S	1000	featureless dust, poor S/N
21321+0136	00504		M6	M3 (1)	18	S	2000	no dust
21377−0200	00507		M5		14	E	650	18 μm feature
21418+4524	50395		M6		43	E	600	featureless dust, poor S/N
21475+5211	50401		M6		43	F	550	featureless dust
21581+5707	60336	GN Cep	M6		42	U	500	18 μm feature
23420+5618	60418	Z Cas	M7e:		41	E	500	feature between 9.5-14 μm

Listed are: Col. (1) IRAS name, Col. (2) IRC number, Col. (3) Variable star name, Col. (4) spectral type of IRC sources from Bidelman (1980), Col. (5) spectral type from other sources if different from previous column. References are coded as follows (numbers given between parentheses): 1=SIMBAD, 2=Kholopov et al. (1985), 3=Stephenson (1984), S134, 4=Stephenson (1984), S149, 5=Hu & Zhou (1990), 6=Bidelman (1954), 7=Stephenson (1984), S903, 8=Lee (1970), 9=Lockwood (1985), Col. (6) LRS classification, Col. (7) Classification of the LRS spectra on the University of Calgary system (see Volk & Cohen (1989); as a reminder: C = silicon carbide emission; E = 9.7 μm silicate emission feature; F = featureless spectra flatter than a stellar blackbody; S = stellar blackbody; U = unusual) Col. (8) temperature of the blackbody fitted to the LRS spectrum, outside the known features, see Fig. 1, Col. (9) Remarks on the dust features in the LRS spectrum.

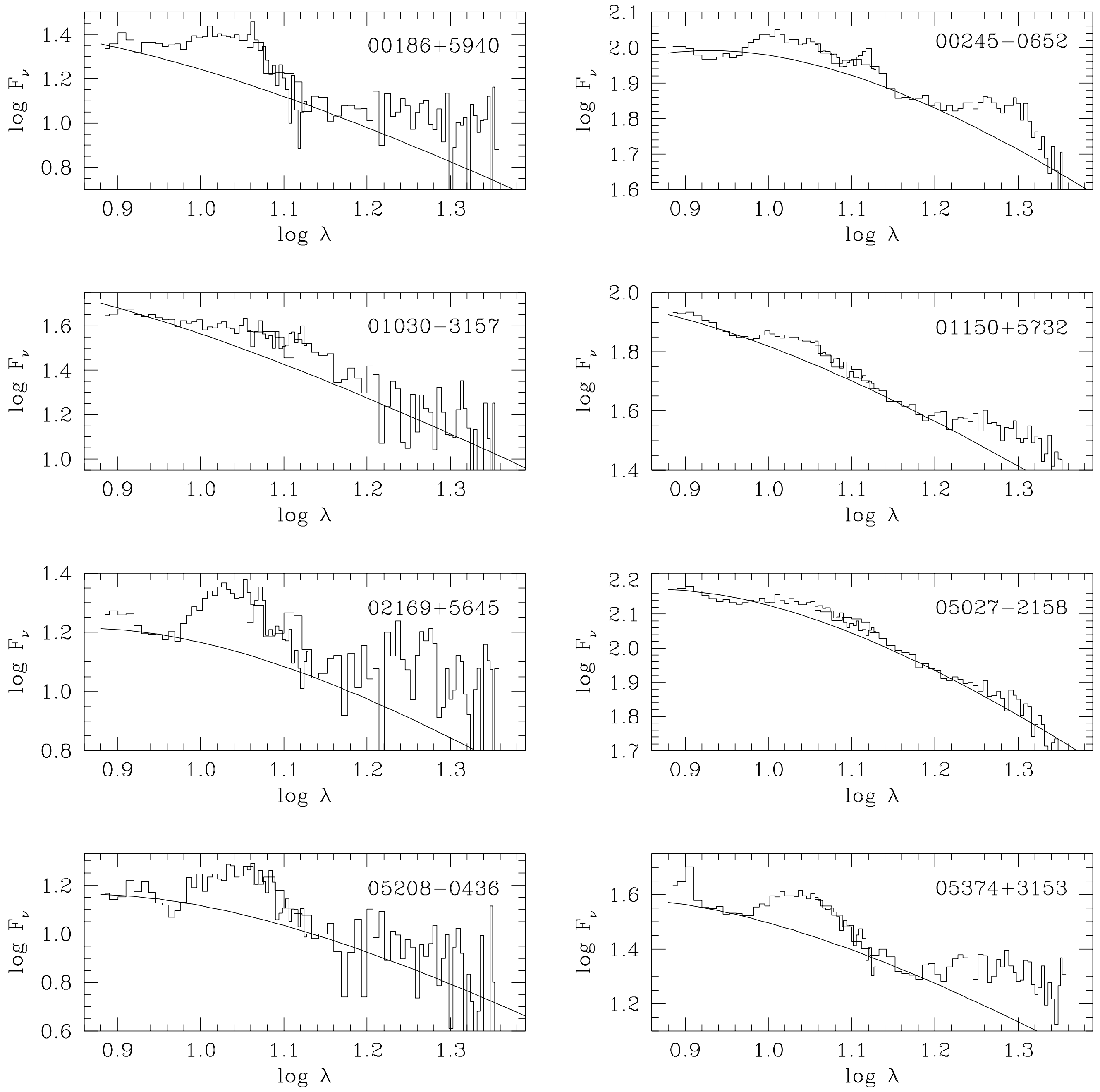

Fig. 1. LRS spectra of the 36 M- and 3 MS-stars suggested to show the silicon carbide feature. Note that the ordinate and abscissa are log F_ν (in Jy) and log λ (in μm), respectively.

2. The sample

Twenty-four stars have been suggested to consist of an M-star with silicon carbide dust in their CSEs (P88, SGW). They were found by correlating a database of M-stars with the LRS atlas and picking out objects with LRS classification 4n, and picking out objects with LRS classification 1n but believed to show SiC. The database of M-stars considered by P88 and SGW consisted of those M-stars in the 3rd edition of the General Catalog of Variable Stars (GCVS, Kukarkin 1965), and in Hacking et al. (1985) [P88], and the Bright Star Catalog (Hoffleit & Jaschek 1984), the Michigan Spectral Catalog (Houck & Cowley 1975) and the updated version of the GCVS (Kukarkin et al. 1969) [SGW], respectively.

In the present study the database of the IRC survey (Neugebauer & Leighton 1969) is used. Spectral types for all IRC stars have been compiled by Bidelman (1980). The 538 stars with LRS classification 4n were correlated on

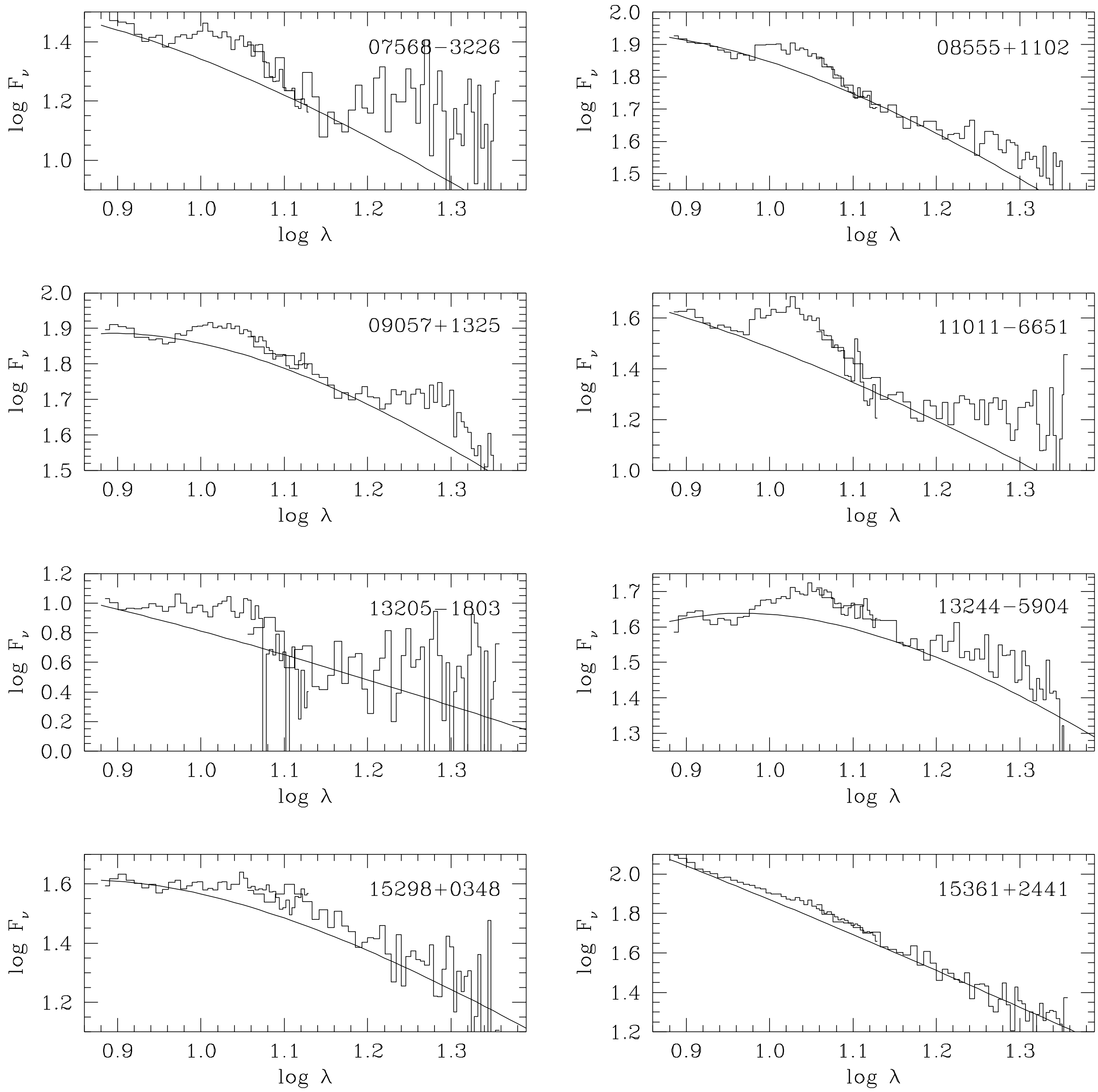

Fig. 1. Continued

position with the 5612 stars contained in the IRC survey. One hundred and fifteen associations were found. According to the spectral types in Bidelman (1980), 84 are carbon stars, 2 are S-stars (DY Gem and WY Cas), for one star (FX Ser) Bidelman quotes both a spectral type of M and C, and 28 are M/MS-stars. Since the M/MS-stars are the interest of this paper, the carbon stars, DY Gem and WY Cas are no longer considered.

The star FX Ser clearly is a carbon star. This has been confirmed by observations in the 0.78-1.05 μm region (Lockwood 1974) and the 2.0-2.4 μm region (Merrill & Stein 1976). The star is detected in HCN (Lucas et al. 1988). The star is not detected as an OH, H_2O or SiO maser source (Benson et al. 1990).

Searching the literature, it was discovered that the spectral type of IRC 60144 (AFGL 595, IRAS 04307+6210), which shows a clear SiC feature, is also often quoted to be carbon rich. The inference of the carbon-rich nature of this object in the literature can be traced back to the presence of strong HCN molecular emission

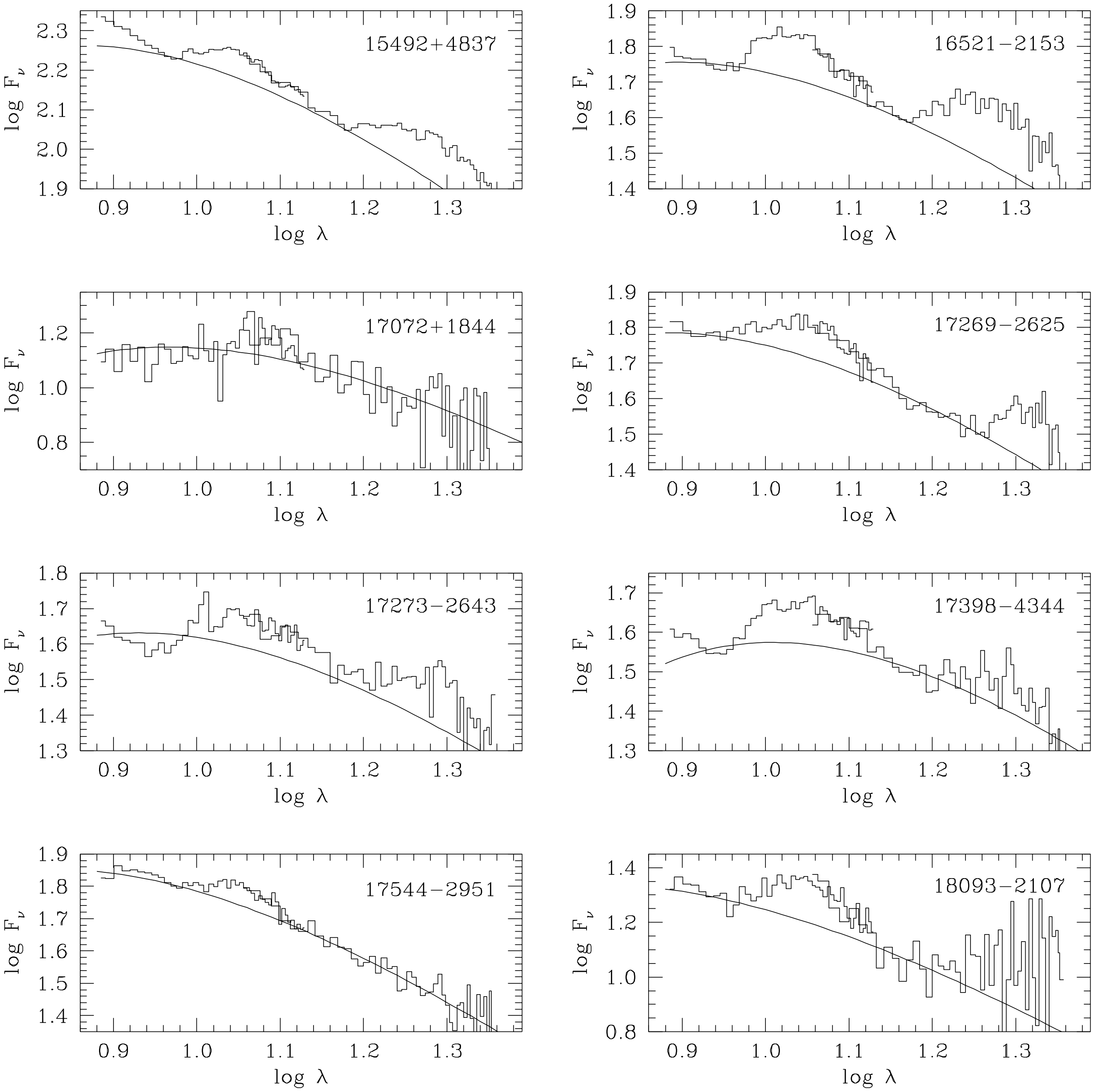

Fig. 1. Continued

relative to CO (Zuckerman & Dyck 1986). Criteria to separate oxygen-rich from carbon stars based on the ratio of velocity integrated intensities are given in Bujarrabal et al. (1994). Based on these criteria, IRC 60144 is a carbon star. This object is no H_2O and OH maser source (Benson et al. 1990), consistent with a carbon-rich nature. The M-star classification can be traced back to the association of IRC 60144 with DO 28389 for which Lee et al. (1947) give a spectral type of M6. Recently, Sun & Hu (1992) observed the 3.1 μm absorption feature, characteristic of carbon stars, in this object. They note that this star has no counterpart on the POSS 'O' plates and a weak counterpart on the 'E' plates. This seems inconsistent with a brightness of 12th magnitude quoted in Lee et al. This suggests that there may be two stars close together on the sky. The evidence suggests that the IRAS source 04307+6210 is a carbon star. IRC 60144 is therefore no longer considered.

Out of the 15 M/MS-stars with LRS classification 4n found by P88 and SGW, 12 are refound by me. The other three (KV Car, OS Cen and TV Sco) have declinations

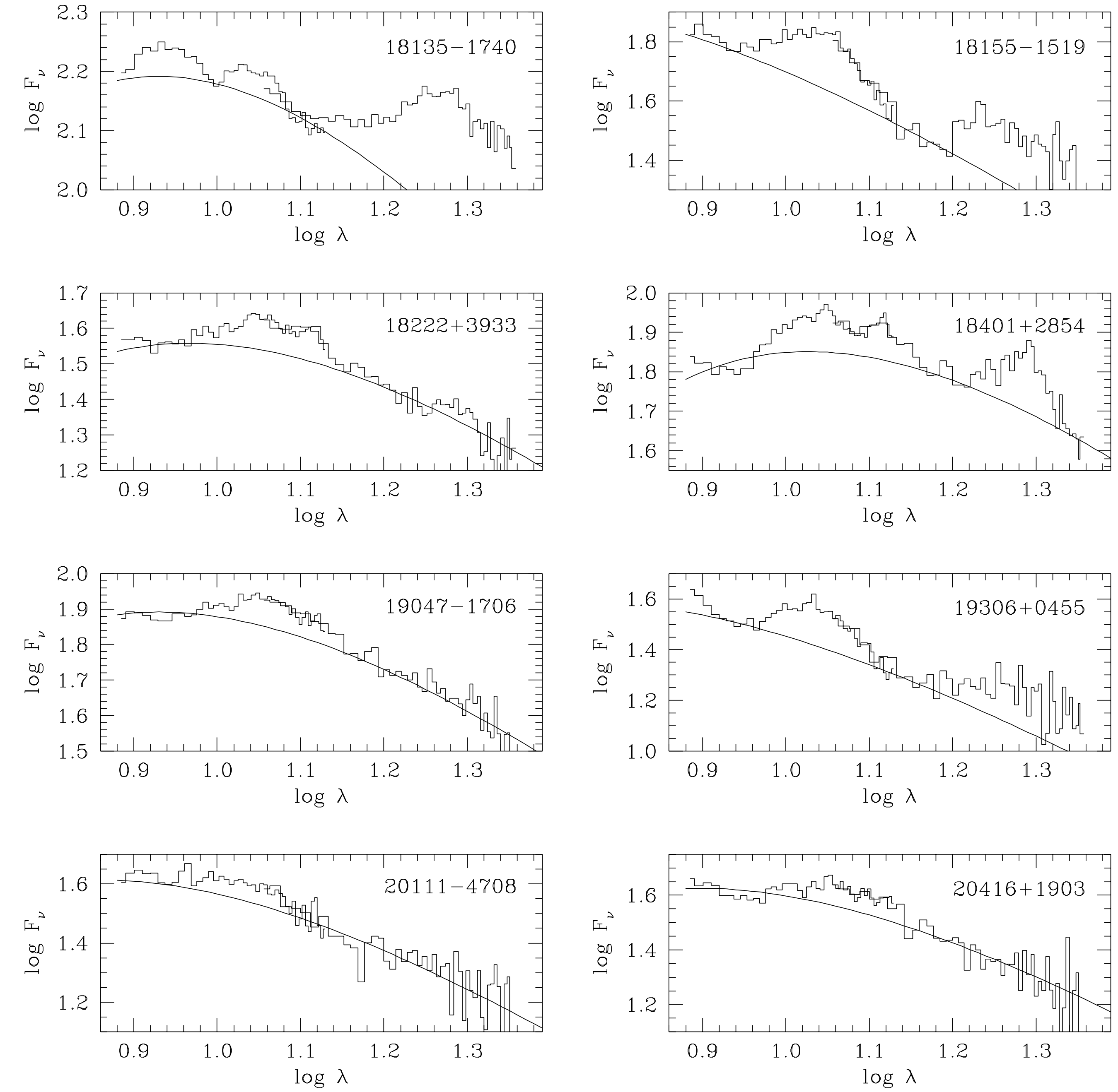

Fig. 1. Continued

south of -32° and therefore are not in the IRC catalog. They are added to the 27 others. Also added are the 9 stars with LRS classification 1n considered by P88 to show the SiC feature. This gives a sample of 36 M- and 3 MS-stars which possibly show a SiC feature. Some relevant data on these stars is listed in Table 1, including the IRAS-names, IRC-numbers, LRS classifications, the names in the GCVS and spectral types. Also included are the classifications of the LRS spectra according to the criteria outlined in Volk & Cohen (1989). These classifications were kindly provided by the referee, Dr. S. Kwok.

The LRS spectra of the 39 stars are presented in Fig. 1. They are plotted as $\log F_\nu$ versus $\log \lambda$ instead of the usual λF_λ versus λ. The advantage of plotting the spectrum is this way is that a blackbody is represented by a straight line of slope –2 for temperatures above ∼1500 K. In this way stars with dust shells (with characteristic temperatures $\lesssim$ 1500 K) are separated from stellar photospheres (with characteristic temperatures $\gtrsim$ 2000 K). A blackbody

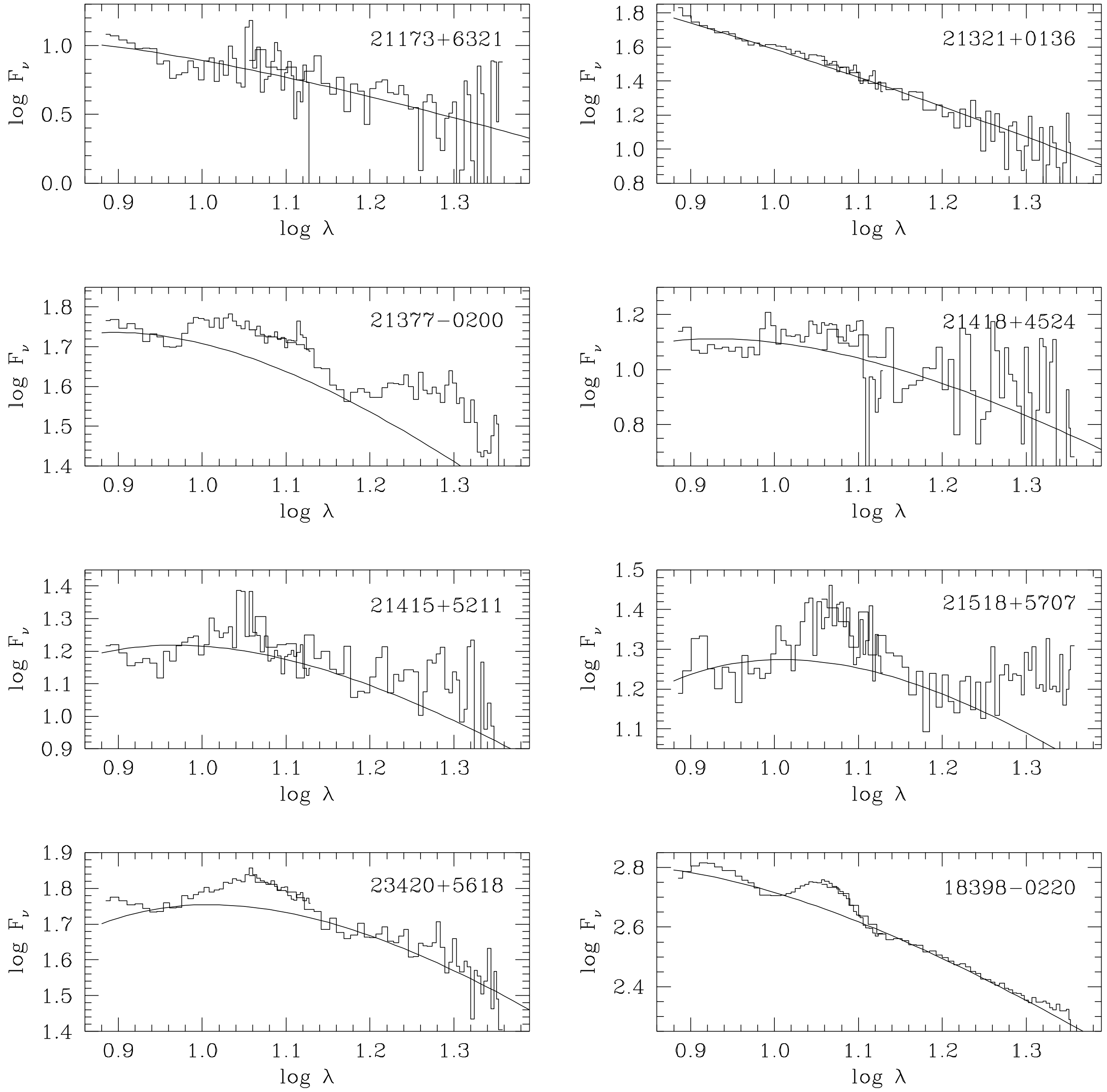

Fig. 1. Continued. The spectrum in the bottom right (IRAS 18398-0220) is of a known carbon star. Its is plotted for comparison purposes.

was fitted to the LRS spectra outside the known emission features. The blackbody temperatures, $T_{\rm BB}$, (usually determined with an accuracy of 10%) are listed in Table 1.

The LRS spectra of the 39 stars can be divided into 4 groups: (1) two stars with $T_{\rm BB} \geq 2000$ which show essentially no dust (15361+2441 and 21321+0136), (2) the majority of stars (22) which show a feature near 18 μm (as well as a feature of some form between ∼9 and ∼14 μm), (3) four stars which have $T_{\rm BB} \leq 1000$ K (indicating the presence of dust) but which show no apparent feature in their LRS spectra, and (4) a group of 11 stars which display a feature of some form between ∼9 and ∼14 μm.

Regarding the stars in group 1, which come from the group of stars with LRS classification 1n of which P88 claimed they show SiC, it is shown that their LRS spectra are consistent with that of stellar blackbodies. There is no evidence for SiC emission.

Table 2. MS, S and SC stars with technetium, an LRS spectrum and C/O ratio

Name	Sp. type	Var[2]	C/O[3]	LRS	LML88[4]	CK93 [5]	Remarks
OP Her	M5IIbS	SRc	0.59	17	no feature	-	featureless dust
Y Lyn	M6S	SRc	0.68	23	S:	E	silicate features at 9.8 and 18 μm
DY Gem[1]	S8,5	SRa	0.88	42	S	F	no 18 μm feature, SiC ??
TV Aur	S5/6	SRb	0.98	-	-	F	featureless dust
RZ Peg	SC6.9/9	M	(1.0)	-	-	C	noisy, may be feature near 11 μm

Notes: [1] DY Gem has been reported to show no technetium, but the star has all the properties of an AGB star; see discussion in Groenewegen 1993. [2] Variability type. [3] C/O ratio from Smith & Lambert. [4] classification in Little-Marenin & Little 1988; S stands for 'S-star feature'; the : means uncertain value. [5] classification of Chen & Kwok (1993) in the Volk & Cohen (1989) system.

Regarding the stars in group 2, the most natural explanation is that the LRS spectrum was misclassified as 1n or 4n. Its proper classification should have been 2n. The stars in this group show the 18 μm feature, characteristic for silicates. The feature these stars display in the 10-14 μm region is different from the classical silicate feature which peaks at 9.8 μm, but is actually very common in Mira M-stars (Little-Marenin & Little 1990, LML90) and in MS and S stars (Little-Marenin & Little 1988, LML88). LML90 suggested that this "broad" feature may be due to aluminium oxide, or due to large grains.

Regarding the stars in group 3, there is no evidence that they show SiC. A LRS classification of 1n seems more appropriate than the actual classification of 4n.

Regarding the stars in group 4, I have compared the LRS spectra to that of known carbon stars to see if the feature in the 10-14 μm resembles that of SiC. An example of a carbon star LRS spectrum is shown in the last panel of Fig. 1 (IRAS 18398–0220; no 4077 in Stephenson 1989). The SiC feature is well confined to the 10.0-13.2 μm region. Only the LRS spectrum of IRAS 17544–2951 (IRC –30340) is similar to that of 18398–0220. All other stars in group 4 show features between 10-14 μm which resemble the "broad" feature of LML90. In fact, of the 7 Miras in the sample, 4 are included in LML90 and all are included in their "broad" silicate class.

There is good agreement between the classification described above and that in the Volk & Cohen (1989) system, in particular 17544–2951 is classified as 'C', indicating SiC emission. The only difference relevant to this paper is that 18093–2107 is also classified to have have a SiC feature. When smoothened to lower resolution the 18 μm in Fig. 1 appears to be real in this object. A 8-20 μ spectrum with a better S/N may resolve this question.

The spectral type of the one candidate for an M-star with SiC emission is in doubt. The spectral types quoted for IRC -30340 range from K5 (the spectral type of an associated SAO star), to $\leq$ M0 (from Bidelman 1980, quoting Hansen & Blanco 1975) and even Ce: (M0e:) (the spectral type of the associated star V1717 Sgr in the GCVS). The coordinates of the SAO star are α=17h 54m 24.32s, $\delta = -29°51'\ 22.5''$ and the brightness is $V = 9.1$. The coordinates of the IRAS source are 26$^s\!\!.$2 and 46$''$, with an error ellipse of 21x5$''$ and a position angle of 91°. The coordinates in the GCVS are 27s and 51$'\!\!.$8 where V1717 Sgr is listed as a Semi-Regular with its (photographic) magnitude varying between 12.7 and 14.9. The location of the IRC source is 27s and 54$''$. This suggests that the IRAS source and V1717 Sgr are unrelated to the SAO star, based on the position and the brightness, respectively. The spectral energy distribution (SED) was constructed using the IRAS data, JHKLM photometry from Guglielmo et al. (1993), the I and K magnitude from the IRC survey and the optical magnitudes from the GCVS. Although taken at different epochs, the SED is relatively smooth, may be suggesting that the IRAS source, the IRC source and V1717 Sgr are indeed one and the same object. As there is doubt on the spectral type of IRC –30340 and this is the only possible candidate for an M-star with silicon carbide dust, an optical spectrum is highly desirable.

3. Discussion

The study in this paper raises the general question of the formation of silicon carbide dust in environments where the number of carbon atoms in the circumstellar shell is less than the number of oxygen atoms. Several papers have been published on the dust around M, MS and SC stars. LML88 found no star displaying the silicon carbide feature among 26 MS and mild S stars, 1 among 31 strong S-stars and 1 among 7 SC stars. LML90 found no SiC displaying star in 291 M Mira variables. I find one possible candidate in a sample of 39 M/MS stars that should be biased in selecting stars with silicon carbide emission. Recently, Chen & Kwok (1993, CK93) classified 0 among 19 MS-stars, 3 among 121 S-stars and 1 among 9 SC-stars as having a SiC feature. In short 7 S/SC-stars allegedly have an SiC feature. There is disagreement even over these few sources. UY Cen classified as showing the SiC feature in CK93 is classified as displaying the 'S-star feature' in LML88. R CMi, classified as possibly showing the SiC feature in LML88 is classified as a stellar blackbody in CK93. BD

-38°4770, classified as showing the SiC feature in LML88 is classified as having featureless dust in CK93.

This illustrates two problems that have to be dealt with. First, the spectra are often noisy, so it has to be decided if there is a feature in the first place. Second, the features displayed in the 10-14 μm region are often different from the classical 9.8 μm silicate feature, so it has to be decided on a phenomenological basis if these features represent new classes. For example, many of the stars classified by LML88 to show the 'S-star' feature, which peaks at about 10.5 μm, are classified as showing the silicate feature in CK93.

One may expect a relation between the C/O ratio in the central star and the composition of the dust. The few MS- and S-stars which show the unstable s-process element technetium (Tc) for which an LRS spectrum and a photospheric C/O determination are available are collected in Table 2. MS- and S-stars without Tc are excluded since they probably are not related to AGB evolution but may be the result of binary evolution (e.g. Groenewegen 1993, Jorissen et al. 1993). The MS- and S-stars without Tc have essentially no dust (Groenewegen 1993). One SC star with Tc, for which a C/O ratio very close to unity may be assumed, is added. There is no apparent correlation between the C/O ratio and dust features. Neither is there an apparent correlation with other abundance indicators as the sample in Table 2 contains stars both rich and poor in ^{13}C (TV Aur ^{12}C/^{13}C=5; Y Lyn ^{12}C/^{13}C=43) or ^{14}N (TV Aur [$^{14}N/M$]=1.2; DY Gem [$^{14}N/M$]=1.2; OP Her [$^{14}N/M$]=0.37)[1]. There is a bias in the sample in Table 2 in the sense that MS- and S-stars for which an abundance analysis has been carried out have been selected to show no large amplitudes in their lightcurves. On the other hand the variability type does not seem to be the main driving force behind the formation of the different features seen in the CSEs as a certain class of features (e.g. silicates, stellar blackbodies, featureless dust) is observed in Mira's, SRs and Lb's (e.g. CK93). Also the few S-stars with the SiC feature contain both Mira's and SRs.

Although the sample in Table 2 is biased towards SRs and may be too small to draw any conclusions, it seems that a larger photospheric C/O ratio does not necessarily imply a higher chance that SiC is formed. This implies that there may be another factor responsible in determining the outcome of the dust condensation process around S-stars. May be this a random process (as suggested by SGW), due to yet unknown particular abundances (determination of the silicon abundance would be of interest in this respect), or may be related to the changes in the CSE during and after a thermal pulse which may induce certain types of dust to form.

At present the formation of SiC in stars with C/O < 1 is not understood. It may be worthwhile to reobserve the 7-20 μm region of the S-stars believed to show SiC since the LRS spectra are often noisy and to perform abundance studies of the central stars.

[1] The mean value in the sample of Smith & Lambert is [$^{14}N/M$]=0.72; [M] stands for ([Ti]+[Fe]+[Ni])/3

Acknowledgements. I thank the referee, Dr. S. Kwok for providing the classification of the LRS spectra on the University of Calgary system. Drs. Alain Omont, René Oudmaijer and Bobby van den Hoek are thanked for their comments. This research has made use of the SIMBAD data base, operated at CDS, Strasbourg, France.

References

Aaronson M., Blanco V.M., Cook K.H., Schechter P.L., 1989, ApJS 70, 637
Aaronson M., Blanco V.M., Cook K.H., Olszewski E.W., Schechter P.L., 1990, ApJS 73, 841
Alknis A., Alksne Z., Ozolina V., Platais I., 1988, Nauchnye Informatsii 65, 162
Barnbaum C., Morris M., Likkel L., Kastner J.H., 1991, A&A 251, 79
Benson P.J., et al., 1990, ApJS 74, 911
Bidelman W.P., 1954, ApJS 1, 175
Bidelman W.P., 1980, Publ. Warner and Swasey Obs., Vol. 2, 185
Bujarrabal V., Fuente A., Omont A., 1994, ApJL 421, L47
Chan S.J., Kwok S., 1990, A&A 237, 354
Chan S.J., Kwok S., 1991, ApJ 383, 837
Chan S.J., 1993, AJ 106, 2126
Chen P.S., Kwok S., 1993, ApJ 416, 769
Engels D., Leinert Ch., 1994, A&A 282, 858
Epchtein N., 1987, A&AS 71, 39
Groenewegen M.A.T., 1993, A&A 271, 180
Groenewegen M.A.T., de Jong T., van der Bliek N.S., Slijkhuis S., Willems F.J., 1992, A&A 253, 150
Guglielmo F., 1993, A&AS 99, 31
Hacking P., et al., 1985, PASP 97, 616
Hansen O.L., Blanco V.M., 1975, AJ 80, 1011
Hoffleit D.R., Jaschek C., 1984, Yale Catalog of bright stars, Yale university press
Houck N., Cowley A.P., 1975, University of Michigan catalog of two-dimensional spectral types from the HD stars, Dept. of Astronomy, Univ. of Michigan, Ann Arbor (Vols. 1-3)
Hu J.-Y., Zhou X., 1990, acta astrophys. sinica 10, 154
Joint IRAS Science Working Group, 1986, IRAS catalogs and atlases, Low Resolution Spectrograph (LRS), A&AS 65, 607
Joint IRAS Science Working Group, 1986, IRAS catalogs and atlases, Point Source Catalog (PSC), US Government Printing Office, Washington
Jorissen A., Frayor D.T.,, Johnson H.R., Mayor M., Smith V.V., 1993, A&A 271, 468
Knapp G.R., Morris M., 1985, ApJ 292, 640
Kukarkin B., et al., 1965, General catalog of variable stars, 3rd edition, Nauka, Moscow
Kholopov P.N., et al., 1985, General catalog of variable stars, 4th edition, Nauka, Moscow
Kwok S, Chan S.J., 1993, AJ 106, 2140
Kurtanidze O.M., Nikolashvili M.G., 1988, Astrofizika 29, 470
Kurtanidze O.M., Nikolashvili M.G., 1989, Astrofizika 31, 507
Lambert D.L., Hinkle K.H., Smith V.V., 1990, AJ 99, 1612
Lee O.J., Gore G.D., Baldwin T.J., 1947, Ann. Dearborn Obs.

5, part 1C
Lee T.A., 1970, ApJ 162, 217
LeVan P.D., Sloan G.C., Little-Marenin I.R., Grasdalen G.L., 1992, ApJ 392, 702
Little-Marenin I.R., 1986, ApJ 307, L15
Little-Marenin I.R., Ramsay M.E., Stephenson C.B., Little S.J., Price S.D., 1987, AJ 93, 663
Little-Marenin I.R., Little S.J., 1988, ApJ 333, 305
Little-Marenin I.R., Little S.J., 1990, AJ 99, 1173
Little-Marenin I.R., Sahai R., Wannier P.G., Benson P.J., Gaylard M., Omont A., 1994, A&A 281, 451
Lloyd Evans T., 1990, MNRAS 243, 336
Lloyd Evans T., 1991, MNRAS 249, 409
Lockwood G.W., 1974, ApJ 192, 113
Lockwood G.W., 1985, ApJS 58, 167
Lucas R., Guilloteau S., Omont A., 1988, A&A 194, 230
Maehara H., Soyano T., 1988, Ann. Tokyo Astron. Obs., 22, 59
Merrill K.M., Stein W.A., 1976, PASP 88, 294
Neugebauer G., Leighton R.B., 1969, two micron sky survey, NASA, SP-3047
Noguchi K., Murakami H., Matsuo H., Noda M., Hamada H., Watabe T., 1990, PASJ 42, 441
Papoular R., 1988, A&A 204, 138
Sanduleak N., Pesch P., 1988, ApJS 66, 387
Skinner C.J., Griffin I., Whitmore B., 1990, MNRAS 243, 78
Stephenson C.B., 1973, A general catalog of cool galactic carbon
stars, Warner & Swasey Obs. vol. 1,no. 4
Stephenson C.B., 1984, A general catalog of S stars, Warner & Swasey Obs., vol. 2, no. 2
Stephenson C.B., 1989, A general catalog of cool galatic carbon stars, 2nd edition, Warner & Swasey Obs., vol. 3, no. 2
Sun A.-Q., Hu J.-Y., 1992, Chin. A&A, 16, 322
Volk K., 1993, PASPC 41, 63
Volk K., Cohen M., 1989, AJ 98, 931
Volk K., Kwok S., Stencel R.E., Brugel E., 1991, ApJS 77, 607
Walker H., Cohen M., 1988, AJ 95, 1801
Willems F.J., de Jong T., 1986, ApJ 309, L39
Zuckerman B., Dyck H.M., 1986, ApJ 311, 345

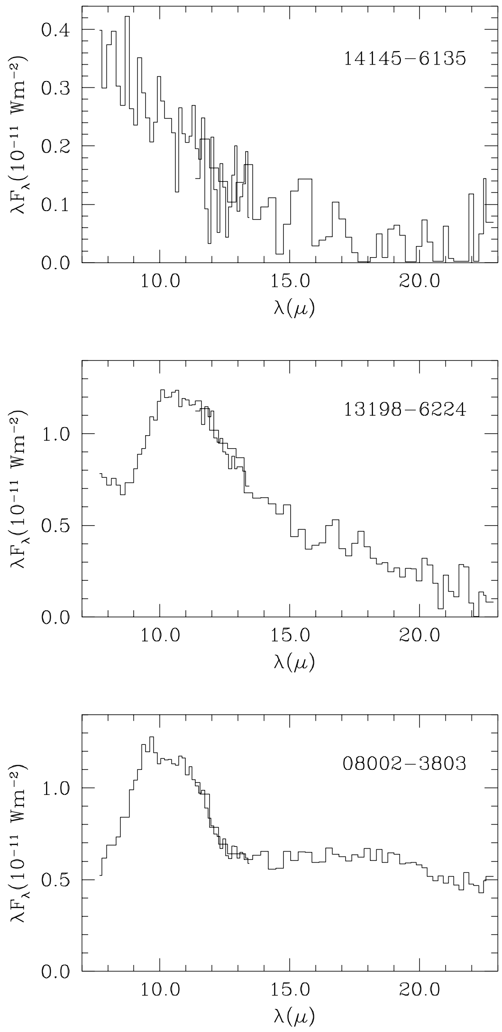

Fig. 2. LRS spectra 14145-6135, 13198-6224 and of 08002-3803, a known carbon star with a silicate feature

A. Appendix: Carbon stars with silicate dust

Until two years ago the number of confirmed carbon stars with silicate dust stood at 7 (Lloyd Evans 1990). They had been found by cross-correlating the stars in the first edition of the General Catalog of Cool Carbon Stars (GCCCS, Stephenson 1973) and carbon stars published in some later surveys with the LRS atlas (JISWG 1986). Recently, Chan & Kwok (1991) and Kwok & Chan (1993) suggested a further 8 candidates by using the 2nd edition of the GCCCS (Stephenson 1989) and extracting LRS spectra from the LRS database.

However, surveys of carbon stars have been published which were not considered in the 2nd edition of the GCCCS (Maehara & Soyano 1988, Sanduleak & Pesch 1988, Aaronson et al. 1989, 1990, Alknis et al. 1988, Kurtanidze & Nikolashvili 1988, 1989). I have correlated the carbon stars in these surveys on position with the Point Source Catalog (PSC, JISWG 1986). The result of this search is tabulated in Table 3.

These surveys list 184 carbon stars not in the 2nd edition of the GCCCS. Only a minority is included in the IRAS PSC, and only two are in the LRS atlas (none are in Volk & Cohen (1989) and Volk et al. (1991), which list additional LRS spectra from the LRS database). They are the stars identified as Cir 38 (IRAS 14145-6135, LRS = 16, suggested to be a CS star), and Cru 1 (IRAS 13198-6224, LRS=24) in Aaronson et al. (1989). The LRS spectra are extracted from the LRS atlas and plotted in Fig. 2, together with the LRS spectrum of Hen 38 (IRAS 08002-3803), one of the known carbon stars with a silicate feature. The spectrum of 14145-6135 shows no feature, but the feature near 10 μm in 13198-6224 is remarkably similar to that in Hen 38. The feature is uncharacteristic of silicon carbide which is much narrower and peaks normally at 11.3 μm. A difference with the LRS spectrum of Hen 38 is that there apparently is no 18 μm feature. There is little doubt on the correct association of the IRAS source with Cru 1. The difference between the IRAS position and the position listed by Aaronson et al. (1989) is 1.5″ in R.A. and 12″ in δ. The

Table 3. Carbon stars not in the 2nd edition of the GCCCS

Survey	listed	new	PSC	LRS
Maehara & Soyano (1988)	128	12	5	0
Sanduleak & Pesch (1988)	33[1]	33	0	0
Aaronson et al. (1989)	490	114	29	2
Aaronson et al. (1990)	500	25	3	0
Alknis et al. (1988)[2]	38	0	0	0
Kurtanidze & Nikolashvili (1988)[2]	83	0	0	0
Kurtanidze & Nikolashvili (1989)[3]	146	0	0	0
	1418	184	37	2

Notes: [1] 19 certain and 14 possible carbon stars. [2] This paper is not referred to in the 2nd edition of the GCCCS, but all stars appear there, even with the proper designation. [3] This paper is not referred to in the 2nd edition of the GCCCS, but all stars appear there.
Listed are: the reference to the survey, the number of objects listed, the number of carbon stars not in the 2nd edition of the GCCCS, and the subset of those listed in the IRAS PSC and the LRS atlas, respectively.

rms errors in the coordinates given for this field in Aaronson et al. (1989) are 2.5$''$ in R.A. and 8$''$ in δ. IRAS 13198–6224 is suggested to be a carbon star with a silicate feature. Near-infrared photometry at JHKLM is listed for this object (at coordinates $49^{s}.5$ and 11$''$; IRAS $50^{s}.2$ and 15$''$) in Epchtein et al. (1985). Extrapolating a blackbody fit to the NIR data predicts a flux at 12 μm a factor of 4 lower than observed with IRAS. This may be due to variability. Extrapolating the blackbody fit to the optical predicts a V magnitude in the range 12-13.

This article was processed by the author using Springer-Verlag LaTeX A&A style file *L-AA* version 3.