Carbon Stars With Oxygen-Rich Circumstellar Chemistry

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Abstract: Ten new carbon stars with oxygen-rich circumstellar shells have been discovered using IRAS LRS spectral class. The origin of these objects have been briefly discussed. It is likely that they may be a consequence of release of oxygen due to carbon condensation, though other scenarios cannot be ruled out.

Introduction

IRAS LRS spectra show 9.7 μm silicate emission in a large number of stars. The existence of this feature indicates oxygen-rich circumstellar (CS) chemistry. The presence of this feature is denoted in the LRS spectral classification (Olnon and Raimond 1986) by 2n and 6n, where n is a measure of the strength of the feature, and is given in the IRAS point source catalogue as well. Presence of this feature is expected in M stars but not in carbon stars. Therefore, it was a complete surprise when Little-Marenin (1986), Little-Marenin and Wilton (1986), and Willems and de Jong (1986) found ten carbon stars, including a Mira, with silicate emission. This discovery leads to several interesting possibilities about the existence and evolution of such objects.

The Sample

In order to increase the sample of such carbon stars, we have used the IRAS LRS spectral class along with the carbon star (Stephenson 1973) and variable star (Kholopov 1985) catalogues. In this way, we have discovered nine additional stars, all having LRS spectral class 2n. RT Oph, a Mira variable, can also be added to this list if its spectral classification (Kholopov 1985) of M7e(C) is confirmed. Note that the strength of the silicate emission, as denoted by n, is weak in a few cases, and may have resulted from noise in the spectra.

Results

The table gives the complete list of these carbon stars with oxygen-rich circumstellar shells discovered so far. The first ten

Carbon Stars With Oxygen Rich Circumstellar Shell

	R.A. (1950)	Decl. (1950)	CCS No.	Name	Sp. class	LRS	var. class	$\log\frac{S_{12}}{S_{25}}$	$\log\frac{S_{25}}{S_{60}}$	Source
1.	001714.9	+442553	11	VX And	C4,5J (N7)	24	SRa	0.534	0.586	V
2.	011321.1	+253019	63	Z Psc	C7,2 (NO)	22	SRb	0.473	0.541	V
3.	044822.5	+282634	254	TT Tau	C4,2-7,4 (N3)	22	SRb	0.492	0.218	V
4.	071755.2	+250540	716	BM Gem	C5,4J (Nb)	29	SRb	0.252	0.845	L,WD
5.	080017.0	+380330	1003	--	--	27	--	-0.042	0.568	L,WD
6.	085348.8	+200230	1344	T Cnc	C3,8-5,5 (R6-N6)	23	SRb	0.570	0.654	V
7.	085745.6	-603554	--	MC79-11	--	65	--	0.016	0.702	WD
8.	100906.5	-704925	1633	--	N,Mb	22	--	0.368	0.821	WD
9.	133421.7	-561321	2106	RV Cen	N3e	25	M	0.460	0.583	LW
10.	134417.7	-610930	2123	--	C::	27	--	0.135	0.710	WD
11.	175411.9	+111031	--	RT Oph	M7e(C)	22	M	0.339	0.787	V
12.	180037.1	-321310	--	FJF270	--	22	--	-0.051	0.409	WD
13.	185614.9	+141738	2684	UV Aql	C5,4-5 (N4)	22	SRa	0.536	0.456	V
14.	191355.3	+541206	--	NC#83	--	28	--	0.278	0.938	WD
15.	192322.7	+762746	2738	UX Dra	C7,3	23	SRa:	0.533	0.618	V
16.	192454.7	+232948	2733	--	C5,4 (N)	23	--	0.500	0.700	V
17.	194140.8	+342209	2783	--	C	22	--	0.494	0.775	V
18.	203504.0	+595456	2919	V778 Cyg	C4,5J (N)	29	Lb	0.224	0.967	L,WD
19.	231737.3	+465802	3184	EU And	C4,4 (R)	29	SR	0.099	0.961	WD
20.	235842.4	+600439	3214	WZ Cas	C9,2JLi (N1p)	23	SRb	0.509	0.550	V

Notes on the table:

1. $P = 369$ d; $\dot{M} > 1.6 \times 10^{-7}$ $M_{\odot}$/yr (Olofsson et al. 1987); T_{NIR} = 2400 K (Willems 1987)
2. $P = 144$ d, $\dot{M} = 0.4 \times 10^{-7}$ $M_{\odot}$/yr; T_{NIR} = 2800 K
3. $P = 167$ d ($P = 364$ d ?); T_{NIR} = 2550 K
4. Periodic variation during some intervals, and shortly thereafter, not variable
6. $P = 482$ d; $f = 0.35$; T_{NIR} = 2250 K
7. (OH, H_2O)-maser
8. S Star?
9. $P = 446$ d, $f = 0.56$
10. H_2O maser
11. $P = 426$ d but variable; $f = 0.36$; (OH, H_2O)-maser; needs to be confirmed as a carbon star
12. Wrongly put as FJF 272
13. $P = 386$ d; T_{NIR} = 2350 K
15. $P = 168$ d, $f = 0.5$; $\dot{M} = 1.8 \times 10^{-7}$ $M_{\odot}$/yr; light curve may correspond to type E; SB; $P \sim 340$ d
16. T_{NIR} = 2200 K
17. N_{NIR} = 1200 K
18. H_2O maser
19. H_2O maser
20. $P = 186$ d; T_{NIR} = 2650 K; VB A; light variations are sometimes taking place with double period; hydrogen emission not always detected; H_2 IR line detected

columns give serial number, right ascension and declination (epoch 1950) Stephenson's (1973) cool carbon star catalogue number, star name, spectral classification, IRAS LRS spectral class, type of variability, log S_{12}/S_{25}, and log S_{25}/S_{60}. Here S_{λ} is the flux density at wavelength λ in microns from the IRAS point source catalogue. The last column gives the source of discovery - L for Little-Marenin (1986), LW for Little-Marenin and Wilton (1986), V for this paper and WD for Willems and de Jong (1986). Notes at the end of the table give additional information on some of these stars. The spectral classification, especially the C subclass, is not available for about half the stars.

The figure gives a plot of log (S_{12}/S_{25}) vs log (S_{25}/S_{60}). Solid line is the blackbody curve. The number at the top of the star gives the LRS spectral class. The figure shows that most of the sources with weak or moderate strength of silicate emission lie near or below the blackbody line, as is true for normal carbon stars (cf. Willems 1987). However, all sources with spectral class 2n, with n > 7 are above the blackbody line, with smaller values of log (S_{12}/S_{25}) and larger values of log (S_{25}/S_{60}). A line above the blackbody line but slightly inclined to it demarcates the two regions. Note that class 6n may behave slightly differently. The dispersion of log (S_{12}/S_{25}) for weak silicate sources is small, barring a few exceptions, but is large for strong sources. In this sense also, weak silicate sources mimic normal carbon stars. The silicate emission strength appears to increase with increase in log (S_{12}/S_{25}) in the strong silicate sources.

Discussion

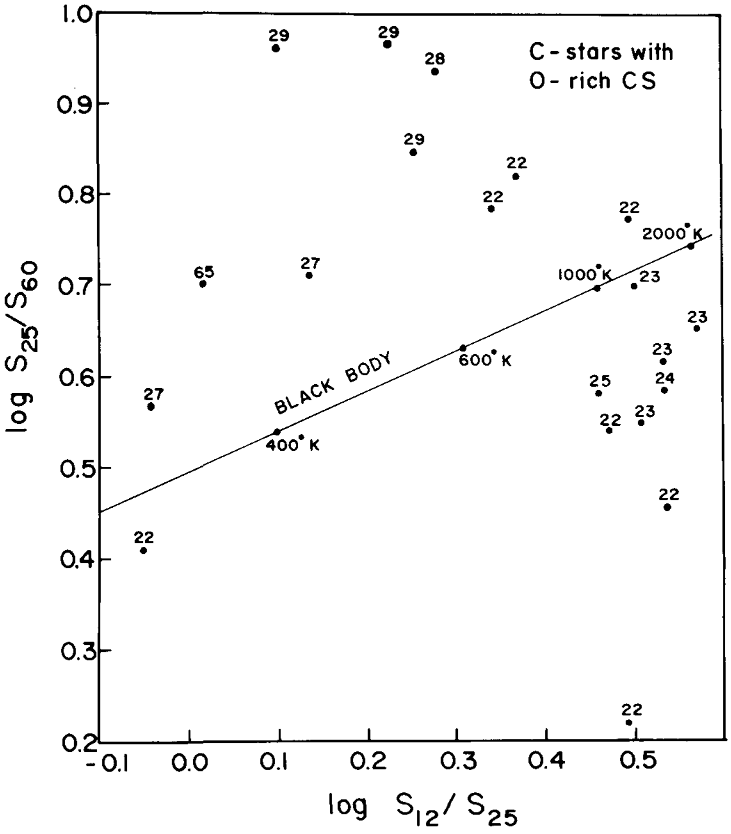
In an attempt to understand the causes of carbon stars showing oxygen-rich circumstellar dust, several possibilities have been advanced by Little-Marenin (1986) and by Willems and de Jong (1986).

1. An unusual chemical equilibrium exists in the CS matter, such that an oxygen-rich environment is produced out of carbon-rich material due to interaction of graphite and SiC grain formation with CO.

2. Due to rapid M → S → C star evolution, the star has become a C star since it (as an M star) ejected the oxygen-rich grains.

3. The system is a binary in which the C star is brighter, but the M star is the mass ejector.

4. This has been rapid, straight M → C star evolution, with oxygen-rich grains produced at the end of the M-star phase, which has now been ended by the conversion to a carbon star, as in 2 above.



A color-color plot -- log (S_{25}/S_{60}) vs log (S_{12}/S_{25}) -- for carbon stars with oxygen-rich circumstellar shells. The number above each star gives the IRAS LRS spectral class. For comparison the solid line denotes a blackbody curve with various relevant temperatures marked.

Little-Marenin (1986) has discussed the first three possibilities but prefers the binary system hypothesis. The observation of water maser emission towards EU And (star no. 19) and the differences in velocity between photospheric absorption lines and the H_2O maser line have led Benson and Little-Marenin (1987) to propose it as the first radio spectroscopic binary, with the C star dominating the optical spectrum and the M star the far infrared; however, the binary nature is yet to be confirmed by observing periodic change in the radial velocity and the fact that the other component is an M star. Note that only two or three are known binary systems in our sample.

Willems and de Jong (1986) have also discussed the binary possibility but ruled it out; they prefer direct evolution from M to C star without passing through the intermediate S-star phase, especially for J-type carbon stars with ^{13}C overabundance. In the table only four stars are known to be J-type, two with strong silicate emission and two with silicate emission of moderate strength. The Mira variable RT Oph was classified earlier as M7e (Kukarkin et al. 1969) but is now classified as M7e (C) (Kholopov 1985); if this is indeed a carbon star, it may be pointing to the scenario suggested by Willem and de Jong (1986).

The above two possibilities, though not ruled out, may not be the answer for all such objects. But the solution via chemical equilibrium (no. 1), if it works, will have wide applicability. Tarafdar (1987) has carried out molecular equilibrium calculations with condensation for carbon-rich elemental composition; these show that condensation can increase the abundance of certain oxygen bearing compounds by several orders of magnitude, giving the appearance of oxygen-rich chemistry. Such calculations, but based on realistic conditions pertaining to circumstellar shells, may lead to a true picture. Such calculations may also hold the mystery of the presence of HCN in the oxygen rich circumstellar shells (cf. Deguchi and Goldsmith 1985).

Conclusion

Search for more carbon stars with oxygen-rich circumstellar shells should be made, and the known ones should be subjected to more detailed observations, besides theoretical calculations for condensation in a carbon-rich circumstellar conditions be undertaken. Then we may know the true nature of these objects.

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