A MID-INFRARED SEARCH FOR C_{60} IN R CORONAE BOREALIS STARS AND IRC+10216

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ABSTRACT

Buckminsterfullerene (C_{60}) is suspected to be an important constituent of the Interstellar Medium but to date no certain detection of C_{60} has been made in an astronomical context. Dust-forming material around R Coronae Borealis (RCB) stars may be ideal sites for the formation of C_{60}. The high-temperature, hydrogen-deficient, carbon-rich environment around RCB stars closely mimics the laboratory conditions under which C_{60} forms. It is believed that dust is being formed continually in the atmospheres of the RCB stars during their pulsation cycles. The temperature at which this dust forms could be as high as 4000 K, and can occur in conditions far removed from thermodynamic equilibrium, as long as a mechanism exists to contain carbon atoms within a given volume. A likely form of carbon condensate is fullerenes such as C_{60}. Low Resolution Spectra from *IRAS* show the apparent presence of an emission feature near 8.6 μm in three RCB stars which could possibly be associated with C_{60}. However, the low resolution and poor S/N of these spectra do not permit identification of the features. Therefore, we obtained new observations using the Irshell mid-infrared spectrograph at the NASA Infrared Telescope Facility. We searched the 8.6 μm spectral region of the RCB stars, R CrB, RY Sgr, and V854 Cen. No narrow features were found at a level of 2% of the continuum. However, the carbon star, IRC+10216 did show a possible emission feature centered at 8.6 μm.

1. INTRODUCTION

It is expected that C_{60}, its various fullerene and fullerane complexed analogs,[2] and their ions may exist in significant amounts in the interstellar medium, in carbon-rich objects such as the R Coronae Borealis (RCB) stars, IRC+10216, and in the circumstellar envelopes of certain cool giants (Hecht 1991; Kroto & Jura 1992; Webster 1992; Whitney *et al.* 1993). The possibility that fullerene analogs might be the long-sought-after carriers of the diffuse interstellar bands was first mentioned in the fullerene-discovery paper (Kroto *et al.* 1985), and the hypothesis has been developed further by Kroto & Jura (1992, and references therein). Fullerene and fullerane analogs have also been suggested as the causes of the unidentified emission features observed in the stellar outflow of the Red Rectangle (HD 44179), the unidentified infrared emission features found in such objects as NGC 7027, and the variable component of the interstellar extinction (Kroto & Jura 1992; Webster 1991, 1992, 1993). Several searches of astronomical objects for C_{60} have been unsuccessful (Snow & Seab 1989; Somerville & Bellis 1989; Jeffery 1995). Recently, a possible detection of C_{60}^{+} bands near 9600 Å was reported for interstellar lines of sight (Foing & Ehrenfreund 1994). The circumstellar shells of the RCB stars and IRC+10216 are sites of very complex carbon chemistry (e.g., Millar & Herbst 1994; Goeres & Sedlmayr 1992). Long carbon chains up to C_5 and $HC_{11}N$ have been detected

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[2]Buckminsterfullerene or C_{60}, the soccerball molecule, is the best known fullerene. Fulleranes are formed by attaching hydrogen atoms and complexed analogs are formed by attaching other atoms or molecules.

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in IRC+10216 (Bernath *et al.* 1989; Bell *et al.* 1982). The Swan bands of C_2 and the violet bands of CN have been seen in emission in several RCB stars (e.g., Whitney *et al.* 1992).

An ideal place to search for C_{60} may be the RCB stars. They are a small group of hydrogen-deficient carbon-rich supergiants which undergo very spectacular declines in brightness of up to eight magnitudes in the V band at apparently irregular intervals (Clayton 1995). A cloud of carbon-rich dust forms along the line of sight to the RCB star, eclipsing the photosphere, and producing a rich emission line spectrum. As the dust cloud disperses, the star returns to maximum light. Recent extensive ground- and space-based observations of R CrB, RY Sgr and V854 Cen have allowed us to put together a coherent empirical model of an RCB decline (Clayton *et al.* 1992; Whitney *et al.* 1993). The close connection of pulsational phase with the time of dust formation seen in RY Sgr and V854 Cen implies that the dust is forming near the star (Pugach 1977; Lawson *et al.* 1992). It is likely that dust is forming in close proximity ($< 2R_*$) to the RCB star photosphere, based on time scales for acceleration of the dust, eclipse of the chromospheric region, and dispersal of the dust.

While crystalline graphite can be formed under carefully controlled conditions at low temperatures, the more disordered amorphous graphite is produced in the laboratory from the pyrolysis of organic materials at temperatures of up to 3500 K (Rohlfing 1988). The important factors to consider seem to be whether condensation will occur under conditions of thermodynamic equilibrium and on what time scales the dust will be produced. In considering the case of dust formation in RCB stars, it is likely that the conditions of carbon nucleation will be rather different than that occurring in the outflows of mass-losing red giants for several reasons (Whitney *et al.* 1993). First, in most red-giant stars the observations are consistent with dust forming in a fairly symmetric fashion with mass loss occurring over the entire surface of the star (Danchi *et al.* 1994); while in RCB stars the mass loss seems to occur from particular areas of the surface. Second, in RCB stars the nucleation will proceed in the presence of much smaller amounts of hydrogen than in red giants where the hydrogen abundances are normal (Lambert 1986). Third, RCB stars have shocks propagating through the outer atmospheres, which cause local density enhancements, and certainly provide nonequilibrium conditions. Finally, nucleation of dust in RCB stars will most likely be from a plasma of atoms, compared with red giants in which the dust forms via the reaction of small molecular precursors such as acetylene, HCCH (Tielens 1990).

If we accept that the formation of fullerite dust in the laboratory (see Sec. 2) is a good model for the dust formation process in RCB stars, then we come to several conclusions. First, under such conditions carbon can nucleate to form dust at much higher temperatures than the canonical crystalline graphite temperature. It is likely that a high pressure plasma of carbon, perhaps produced by a shock or pulsation wave, could form a "puff" of carbon dust which is then ejected by radiation pressure. Second, as in the laboratory experiments, the dust produced will not be crystalline graphite but will be more amorphous in character. Finally, and perhaps most intriguingly, since the closed carbon cage fullerenes are observed to form along with the dust during this process in the laboratory, then it seems that RCB stars are ideal sites for the formation of C_{60}. Goeres & Sedlmayr (1992) model RCB dust production and carbon gas chemistry. They find that the assumed temperatures and pressures make the production of large amounts of C_{60} unlikely but that it cannot be ruled out. They also suggest that C_{60} is most likely to be produced and therefore detected in emission at the beginning of an RCB star decline. If detected, C_{60} would be the long-sought-after spectroscopic signature of the RCB dust formation.

2. LABORATORY DATA CONCERNING C_{60}

The nucleation of carbon plasmas in the absence of other species such as hydrogen is interesting, because once atoms "stick" together to form clusters, they will start to form flat, graphitic networks consisting of six-membered rings. However, in such clusters, atoms present at the edges are not fully bonded. These are energetically unstable and can be reduced in number if the clusters incorporate five-membered rings into their networks. This leads to the formation of nonplanar networks which may close to form cages. These cages, called fullerenes, have been extensively studied in these experiments and have been isolated in macroscopic quantities (Krätschmer *et al.* 1990; Taylor *et al.* 1990). The mechanism that produces these fullerenes also produces fullerite dust—not crystalline graphite, but spheroidal material which appears to be made of spiraling layers of nonplanar carbon (Kroto & McKay 1988; Krätschmer & Huffman 1993).

The IR spectral bands of C_{60} have been measured in the laboratory at 7.5, 8.6, 17.5, and 19.0 μm (Frum *et al.* 1991; Nemes *et al.* 1994). Positions for two C_{60}^+ bands also have been measured (Fulara *et al.* 1993) at 7.1 and 7.5 μm. The position of the 8.6 μm line of C_{60} is expected to lie between 8.58 μm at 1000 K and 8.40 μm at 0 K (Nemes *et al.* 1994). The width of the possible C_{60} band is a combination of the rotational structure and the contributions of hot vibrational lines, and scales as the square root of the C_{60} gas temperature (Nemes *et al.* 1994). At 100 K, for example, it is expected to have a FWHM of about 0.04 μm. Or if the gas is much hotter (2000–4000 K), as is likely where the molecules are forming near an RCB star, bandwidths of 0.15–0.18 μm might be expected.

3. EXISTING OBSERVATIONS

Three RCB stars (R CrB, RY Sgr, and V854 Cen) and IRC+10216 were observed from 8–22 μm with the Low Resolution Spectrometer (LRS) on the Infrared Astronomical Satellite (*IRAS*) (Neugebauer *et al.* 1986). The published LRS spectra are averages of individual observations taken at "random" times during 1983. There are four spectra of R CrB and three each of RY Sgr, V854 Cen, and IRC+10216. We have extracted these individual LRS spectra. Table 1 gives the times of observation and V magnitude. We scaled the flux level of each individual spectrum to the Point Source

TABLE 1. LRS observations of RCB stars.

Star	IRAS	Time Tag [1]	JD(2400000+)	m_V
R CrB	15465+2818	820451171	45555.096	6.1
R CrB	15465+2818	831332186	45567.690	6.2
R CrB	15465+2818	848833137	45587.946	9.2
R CrB	15465+2818	852233876	45591.882	9.9
RY Sgr	19132-3336	716085102	45434.302	6.9
RY Sgr	19132-3336	722268340	45441.459	6.5
RY Sgr	19132-3336	880068194	45624.097	6.5
V854 Cen	14316-3920	821945275	45556.826	—
V854 Cen	14316-3920	831404944	45567.774	—
V854 Cen	14316-3920	846185343	45584.881	—
IRC +10216	09452+1330	744012786	45466.626	—
IRC +10216	09452+1330	752734021	45476.720	—
IRC +10216	09452+1330	902537806	45650.104	—

Note to TABLE 1

The time of observation of the individual PSC fluxes obtained from IPAC, measured in tenths of seconds from 1981 January 1.0 (*IRAS* Explanatory Supplement, p. X-15). The LRS usually references the time associated with the orbit- or day-confirmed observations. Hence the times associated with the LRS are usually later than those associated with the PSC observations by either ~103 minutes or ~12 h. The times listed are PSC time tags for R CrB, RY Sgr, and V854 Cen, and LRS time tags for IRC+10216.

Catalog (PSCII) 12 μm flux for each of the stars since the LRS spectra are not photometric. We have also corrected the spectra for the calibration problem associated with the short wavelength end of the spectrum (Volk & Cohen 1989).

Figure 1 shows the average LRS spectra for each of the four stars. The spectra have been averaged as described by Neugebauer *et al.* (1986). These spectra show blackbody continua due to dust emission plus some possible weak emission features. The dust around these stars will inevitably be a mixture of temperatures (e.g., Kelly & Latter 1995). However, a reasonable fit can generally be found to a single temperature in the mid-IR. A temperature can be derived by fitting a blackbody to the PSCII data from 12 to 100 μm. For the RCB stars, the typical dust temperatures are 650–900 K (Walker 1985). A blackbody fit to a single temperature has been made to each spectrum and then subtracted. The residual spectrum for each star is also plotted in Fig. 1. The best fits are R CrB (650 K), RY Sgr (800 K), V843 Cen (900 K), and IRC+10216 (450 K). Walker (1985, 1986) points out that the spectra are very smooth as would be expected from amorphous carbon dust. Small (10% of continuum) apparent features may be created due to uncertainties in the blackbody fit. However, some real emission features appear to be present. In particular, broad residual emission features appear to be present at 8.6 μm for all three RCB stars, and at 11.3 μm for V854 Cen, IRC+10216, and possibly RY Sgr. The LRS has very low resolution ($R=20-60$). Therefore, it samples the spectrum in the 8–9 μm region only every 0.17 μm, and the accuracy of measuring the peak wavelength of a feature is of that order. The emission features were measured in the individual LRS spectra for each star and do not always show clearly in the average spectra plotted in Fig. 1.

Both RY Sgr and R CrB had declines in 1983. The LRS observations caught RY Sgr just coming out of a decline about half a magnitude below maximum light. The R CrB observations were fortuitously well timed to look for molecular emission related to dust formation. The first two spectra were obtained just before the decline began and the latter two were taken about three weeks later when the star was about three and four magnitudes below maximum light (see Table 1). Rao & Nandy (1986) mention that no significant variations in the broadband IR flux were seen in R CrB associated with its decline in 1983. This is typical of RCB declines (Feast 1979). There are no photometric observations for V854 Cen in 1983 although based on its behavior since 1985, there's a good chance it was in decline (Lawson *et al.* 1992).

We have analyzed the individual LRS spectra for the four stars. The LRS spectrum of R CrB at the beginning of its decline on JD 2445555 shows an emission feature at 8.6 μm, extending 15%–20% above a 650 K dust continuum. This feature is also seen by Buss *et al.* (1993) who measure a FWHM on the order of 1 μm. After JD 2445567, an emission excess shortward of 9 μm is seen, but a distinct emission feature is no longer visible. No other features can be identified unambiguously. On JD 2445555 and 2445567, a feature at 19 μm may be present at the 2σ level. No 17.5 μm feature is seen. If the 19 μm feature is real and due to C_{60} then the 17.5 μm feature must be less than half its intensity to remain undetected. All the LRS spectra of RY Sgr appear to indicate a very weak 11.3 μm emission feature, extending about 10% above an 800 K dust continuum. The first spectrum also appears to show a feature around 8.6 μm which becomes more difficult to distinguish in the latter two spectra since additional excess emission is present shortward of 9.5 μm. All V854 Cen spectra show the 11.3 μm feature at the 20%–30% level. An emission excess shortward of 9.5 μm is present, possibly showing an emission peak around 8.2 μm. It is possible that a weaker 8.6 μm feature is present within this excess emission. If the 8.6 μm feature is due to C_{60}, we should expect to see features at 17.5 and 19 μm. However, due to the lower S/N of all the spectra in this wavelength region, bands at the 15%–20% level cannot be identified in the LRS of the RCB stars. The three IRC+10216 spectra show no significant variations. They all show a steep rise in the emission shortward of about 8.6 μm, a broad 11.3 μm emission about 15% above the continuum and a depression at about 13.8 μm associated with C_2H_2+HCN (Little-Marenin *et al.* 1987). The 11.3 μm emission feature is atypical for carbon stars. The feature is double peaked at 11.1 and 11.7 μm with a FWHM of about 1 μm and looks similar to the "rectangular" feature identified by Cohen (1986) in the more heavily obscured carbon stars. This feature is usually associated with SiC and in most carbon stars has a maximum at 11.2 μm and a FWHM of 0.7 μm (Little-Marenin *et al.*

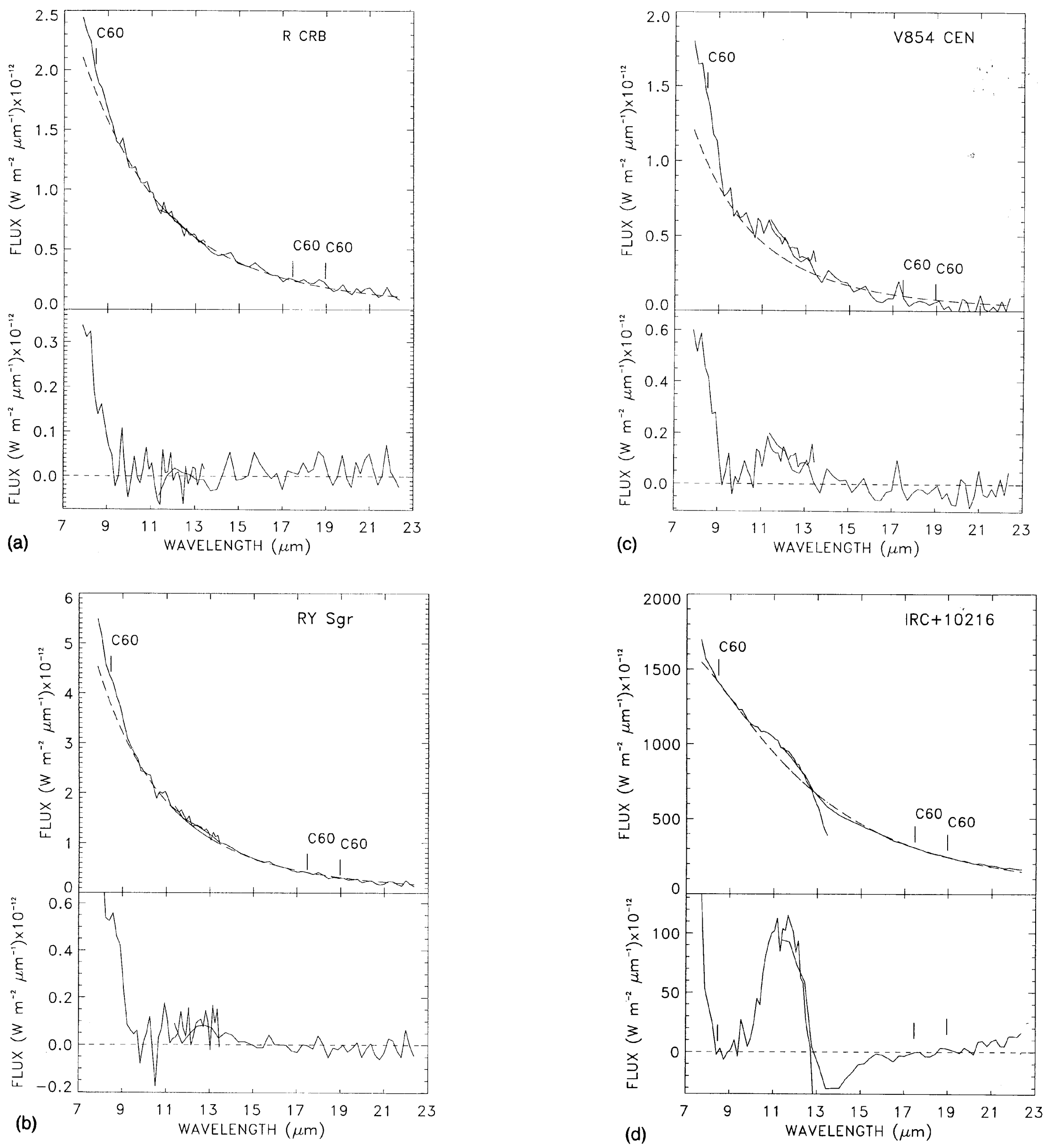

FIG. 1. Average LRS spectra (upper panel) and residual spectra (lower panel) after blackbody subtraction for (a) R CrB, (b) RY Sgr, (c) V854 Cen, and (d) IRC+10216 (see the text).

1987). It is possible that the feature in IRC+10216 is due to a combination of α and β SiC. The two forms of SiC have slightly different maxima and widths (Lorenz-Martins & Lefevre 1993; Blanco *et al.* 1994).

Another possible interpretation of the LRS spectra of RY Sgr and V854 Cen is that these stars show a 10 μm self-absorbed silicate feature. We argue against this interpretation since there is no evidence for a feature at 18 μm, either in emission or partly self-absorbed, as would be expected for silicate grains. Furthermore, for the 10 μm feature to be seen in absorption, we would have to assume a continuum temperature in this region in excess of 1000 K, which is too high to be applicable to a shell optically thick enough to produce self-absorbed features.

4. NEW OBSERVATIONS

The new observations were obtained with Irshell on the NASA Infrared Telescope Facility (IRTF) on Mauna Kea on 1994 June 2–3. Irshell is a mid-infrared (5–25 μm) spectrograph (Lacy *et al.* 1989). Irshell uses an 11×64 Si:As impurity band detector array to obtain 64 point spectra at 11 positions along the slit. The slit was 2″. We used Irshell with a low resolution ($R=1000$) grating and a spectral coverage of about 3%. Telluric lines were used for wavelength calibration. For sources brighter than 10 Jy, Irshell is limited by systematic errors in correcting for instrumental and telluric features. We have found that we can reach a limiting sensitivity of 1% of the continuum by alternating between sources and comparison stars, spending a total of two hours on each. The data were reduced using the SNOOPY program (Achtermann 1992). A dome-temperature blackbody, chopped against the sky, was used to flatfield, make atmospheric corrections, and calibrate intensity. Flux calibrations were made using β Her, τ Sgr, γ Leo, and σ Lib as comparison stars.

At the time of the observations, R CrB was at maximum light, RY Sgr was recovering from a decline at about 2 magnitudes below maximum, and V854 Cen was 4.4 magnitudes below maximum, also recovering from a decline. We observed R CrB, RY Sgr, V854 Cen, and IRC+10216 near 8.6 μm. The atmosphere has almost 100% transmission in this wavelength region, and numerous weak atmospheric lines are available for wavelength calibration. For R CrB, we repeated the observations with overlapping grating settings to be certain of the correction of systematic effects. The Irshell spectra are shown in Fig. 2. The grating setups used produced data between 8.3 and 8.8 μm. Three grating setups were used for R CrB and one each for RY Sgr, V854 Cen, and IRC+10216. The three observations of R CrB agree well within the errors, so they have been combined in Fig. 2. The spectra of R CrB and IRC+10216 approach the limiting sensitivity of 1% (1σ) but the spectra of RY Sgr and V854 Cen are noisier due to their shorter exposure times. The unsmoothed spectrum of V854 Cen, which had the least observing time, shows evidence of fringing in the detector which has not cancelled out perfectly. The spectra of the three RCB stars are very smooth and show no evidence for narrow (~0.2 μm) emission features at a level of a 2%. IRC+10216 does show a real structure including an apparent emission feature with a FWHM$\geqslant$0.2 μm. The spectra plotted in Fig. 2 have been smoothed with a five point boxcar.

5. DISCUSSION

The IR emission features seen in carbon-rich objects are divided into two classes. Objects such as Planetary Nebulae and WC stars with large amounts of UV radiation tend to show the narrow (FWHM~0.2 μm) Polycyclic Aromatic Hydrocarbon (PAH) emission features at 3.3, 6.2, 7.7, 8.6, and 11.3 μm (Buss *et al.* 1993). Nonbinary carbon stars, on the other hand, tend to show broad (FWHM~1 μm) features at 8–9 μm and 11.3 μm (Buss *et al.* 1993). No PAH emission has been detected from a nonbinary carbon star (Jura 1993). The 11.3 μm feature is identified with SiC, or with carbonaceous microparticles with internal hydrogens (Balm & Kroto 1990). Buss *et al.* (1993) investigated the mid-IR (5–23 μm) emission features of a group of stars in transition from the Asymptotic Giant Branch to the Planetary Nebula stage. R CrB is included in this group. They find, in general, that the sources in this group show the narrow PAH emission features at 6.2, 7.7, and possibly 11.3 μm, as well as a very broad "plateau" at 6–9 μm. The 8.8 μm feature, seen in the transition objects, is broad like the feature seen in carbon stars and unlike the narrow PAH feature (Buss *et al.* 1993). Like the RCB stars, all the transition objects show emission features on top of a strong blackbody continuum due to dust. The emission features look quite different in R CrB than in the other transition objects (Buss *et al.* 1993). R CrB has a feature at 6.3 μm rather than 6.2 μm plus emission from 7 to 9 μm that is unresolved. Unlike most of the other transition stars, there is no 3.3 μm feature in R CrB. The 3–3.5 μm spectrum is featureless (Nandy *et al.* 1986). The likely reason for the very different spectra seen in RCB stars is the near absence of hydrogen which will make molecules with hydrogen bonds rare or nonexistent (Whitney *et al.* 1993; Goebel *et al.* 1995). IRC+10216, like other carbon stars, shows no PAH emission at 3.3 μm (Witteborn *et al.* 1990).

There are LRS spectra for about 500 carbon stars. Most show the 11.3 μm SiC feature and many also show an emission feature between 8 and 9 μm (Little-Marenin & Clayton 1993). The relative strength of the 8–9 and 11.3 μm features varies strongly from star to star. In some carbon stars, the 8–9 μm feature is not present and in some it is stronger than the 11.3 μm feature. We have analyzed over 60 carbon stars with excess emission in the 8–9 μm region and find that a significant number (14) have a relatively strong feature that peaks around 8.6 μm (FWHM~1 μm). Most of the other carbon stars show emission features peaking at 9 μm or between 8.0 and 8.2 μm. However, many of these stars appear to have a contribution from a feature at 8.6 μm. The V854 Cen LRS spectra are similar to those of carbon stars, e.g., V781 Sgr (Little-Marenin & Clayton 1993). Perhaps the similarity of V854 Cen to the carbon stars is due to the fact that it has significantly more hydrogen than the other RCB stars. The strength of the 8.6 μm feature in carbon stars has been found to be slightly correlated to abundances determined by Lambert *et al.* (1986). Stars with larger C/O ratios (C/O>1.3) and greater [(C+N+O)/H] deficiencies (< −0.70) tend to have stronger 8.6 μm features. The RCB stars satisfy the first criterion but not the second.

The LRS spectra of the RCB stars and possibly IRC +10216 show emission features close to the wavelength where at least one of the IR C_{60} bands is predicted to lie. The measured positions of the C_{60} bands are marked in Fig. 1. The low resolution of the LRS observations prevents positive identification of the emission features. All three RCB stars in our sample show strong 8.6 μm features. At the resolution of the LRS spectra it is not clear whether these broad (1 μm) features may be blends of narrower features. It seems unlikely that the 8.6 μm feature, seen in carbon stars and in our sample, is due to PAHs since the much stronger 7.7 μm feature appears to be absent. Also, the observed feature is much broader than the 8.6 μm PAH feature. One of the laboratory-measured C_{60} bands lies near 8.6 μm but these bands are also expected to be narrower. We have searched the LRS spectra for evidence of the 17.5 and 19.0 μm C_{60} bands but no unambiguous detection has been made. This is due in part to the low S/N typically present in this region of the LRS spectra. The 7.1 μm C_{60} line is at too short a wavelength to be detected by LRS.

Using Irshell, we searched the wavelength region 8.35 to 8.80 μm in R CrB, RY Sgr, V854 Cen and IRC+10216 covering the likely positions for this C_{60} feature. No broad or narrow features were found in the Irshell data at a level of 2% of the continuum in any of the three RCB stars. However, the carbon star, IRC+10216, did show a significant increase in flux from 8.5 to 8.7 μm. Although significant,

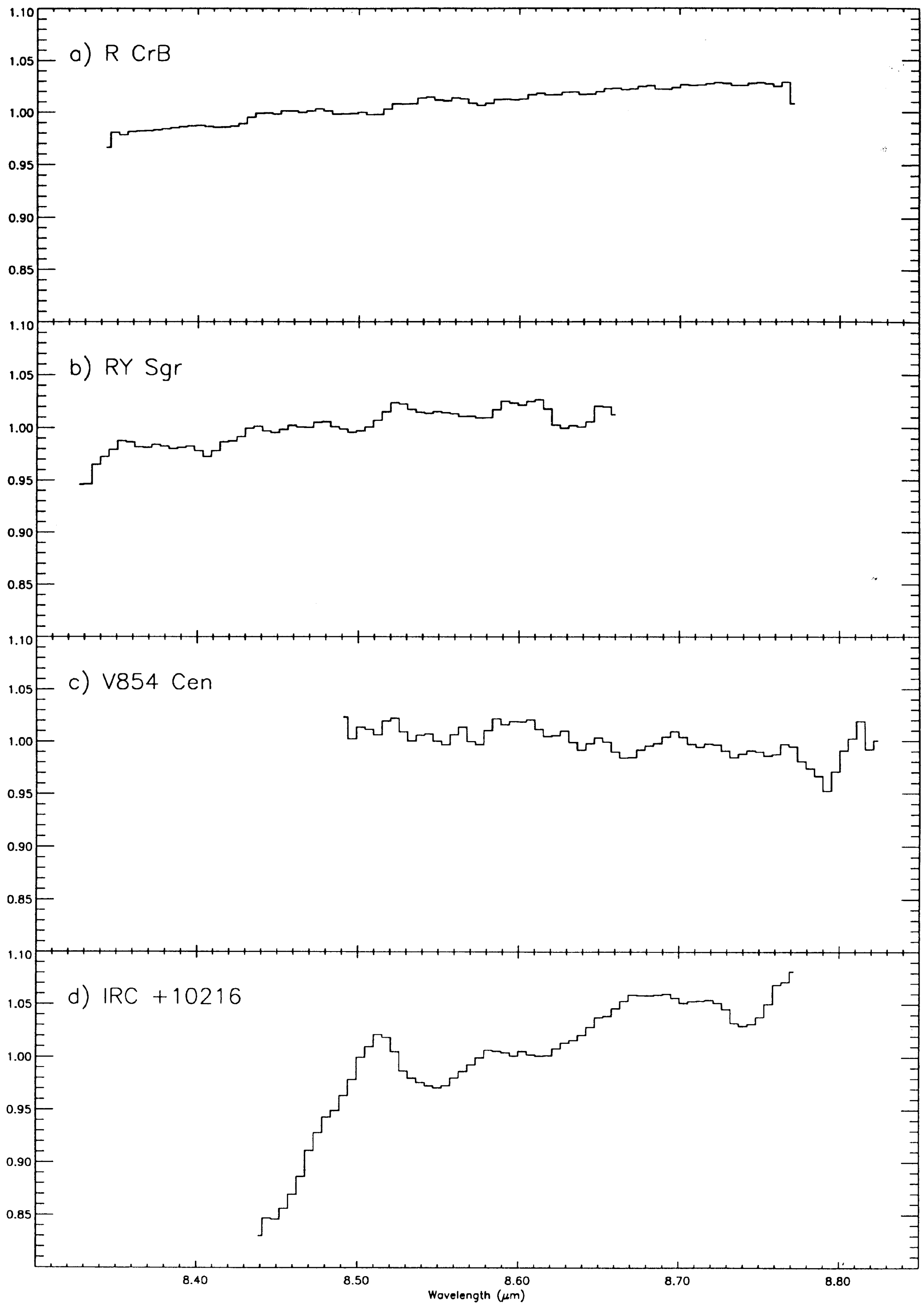

FIG. 2. Normalized Irshell spectra near 8.6 μm for (a) R CrB, (b) RY Sgr, (c) V854 Cen, and (d) IRC+10216.

this emission structure is too weak to have been identified with the LRS. Lacy *et al.* (1989) mapped out an 8.6 μm feature in the Red Rectangular with Irshell at similar resolution to our data. The Red Rectangular spectrum covers a larger wavelength range (8–9 μm) and shows a feature with a width of about 0.2 μm. The structure seen in Fig. 2 for IRC+10216 is consistent with this feature. However, since the wavelength coverage of IRC+10216 with Irshell was less than 0.4 μm, the width and position of this possible feature are very uncertain. It is consistent with having a FWHM of $\geqslant$0.2 μm. The feature measured in the Red Rectangle is likely the PAH feature at 8.6 μm since, unlike IRC

+10216, its spectrum shows the other typical narrow PAH features.

The possible emission feature seen in Fig. 2 for IRC +10216 is also consistent with C_{60}. As a carbon star, IRC +10216 does not show any other narrow PAH feature, so the 8.6 μm PAH feature is not expected to be present. *However, unless another PAH or C_{60} feature in IRC+10216 is detected, a definitive identification is not possible.* The Irshell data for all four stars are only sensitive to narrow features such as those due to PAHs or C_{60} since none has wavelength coverage of more than 0.5 μm. The flat continua seen in the Irshell spectra of the RCB stars are probably part of the broad peak of the 1 μm wide 8.6 μm feature seen in the LRS spectra. The new much higher resolution Irshell data do not show any indication that this broad emission is a blend of narrow features.

We can make a rough estimate of the relative abundance of C_{60} to C_2. The swan bands of C_2 have been observed in emission in several RCB star declines, most recently in V854 Cen (Whitney *et al.* 1992). The integrated flux in the C_2 (0–0) 5165 Å band was measured to be 5.9×10^{-13} erg s^{-1} cm^{-2} when the star was in a deep decline at $\Delta V=8.2$ mag. The gas is not likely to be in LTE since the time for collisional deexcitation is significantly larger than the radiative time (Goeres & Sedlmayr 1992). Therefore, a ratio of the C_{60} to C_2 abundances, assuming that every collisional excitation results in a radiative transition, is ≤0.03. The numbers used in this estimate are very uncertain so this only places an order of magnitude upper limit on relative abundance of C_{60}.

The absence of detectable C_{60} emission around any of the RCB stars indicates that large amounts of C_{60} are not normally present around these stars. It has been suggested that Buckminsterfullerene in the interstellar medium is likely to be ionized and so may be present as C_{60}^+ (Kroto & Jura 1992). On the other hand, we might expect that C_{60} is only present for a short period of time around the beginning of a decline when carbon gas is condensing into dust (Goeres & Sedlmayr 1992; Whitney *et al.* 1993). There is weak evidence from the LRS spectra of R CrB that spectral variations in the 8.6 and 19 μm emission features took place around the time of the 1983 decline. RY Sgr and V854 Cen were both in decline when the Irshell data were obtained but there is no evidence that new dust was forming around these stars at that time. Also, without accurate photometry around the time of the observations we cannot determine whether the pulsation cycles of RY Sgr and V854 Cen were near the phase associated with dust formation. Since none of the RCB stars were in the early stages of a decline when these new observations were obtained, the possibility that C_{60} might be detected in the future in these stars has not been ruled out.

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