SPECTROSCOPIC STUDY OF CARBON STARS WITH THE ISO-SWS

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Abstract.

We have observed ten carbon stars with different mass-loss rates using the Short Wavelength Spectrometer (SWS) on board ISO. We found that not only the spectral energy distribution and the dust features, but that also that the strength and/or shape of molecular absorption features in the infrared spectrum varies with the near-infrared color temperature, i.e. with the thickness of the circumstellar envelope.

1. Introduction

The chemical composition, the molecular abundances and the process of dust formation in the photospheres and in the circumstellar shells of late-type stars is best studied using infrared spectroscopy. As part of the guaranteed time observing program of the Infrared Space Observatory [1] (ISO; Kessler et al. 1996), we have carried out SWS observations of more than 30 AGB stars with different chemical compositions (C/O ratio) and mass-loss rates. The aim of this program (AGBSTARS, P.I. T. de Jong) is to study the infrared spectra of a representative sample of AGB stars for better understanding of various phenomena taking place in the atmosphere and

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the circumstellar envelope, as a function of mass-loss rate and evolutionary phase.

In this paper, we present preliminary results of our analysis of the SWS spectra of ten carbon stars.

2. Observations

Observations were carried out with the Short Wavelength Spectrometer (SWS; de Graauw et al. 1996) on board ISO. The AOT01 observing mode was used, which covers the wavelength range between 2.38 to 45.2μm with a resolution of R=300–1000. Data were reduced by using the SWS Interactive Analysis System, the standard reduction package developed by the SWS Instrument Dedicated Team. Small discrepancies in flux between different instrumental bands were corrected by scaling with respect to band 1b (2.6–3.0μm).

The objects listed in Table 1 were selected from the sample of bright carbon star (Groenewegen et al. 1992). They are classified into four groups according to the near-infrared color temperature (T_{NIR}; Willems 1988a,b), supposed to be an indicator of the thickness of the envelope.

TABLE 1. The carbon star sample.

Name	Group	Obs.Date	Speed[1]	T_{NIR}
S Sct	II	29/04/96	2	3170
V Aql	II	29/04/96	2	3030
R Scl	II	28/11/96	2	3060
V Cyg	III	05/02/96	1	1240
RU Vir	III	20/07/96	2	1150
IRC+40540	IV	02/12/96	2	570
IRC+10216	IV	31/05/96	4	540
AFGL 2155	IV	13/05/97	1	510
AFGL 2256	V	13/03/97	1	450
AFGL 3068	V	29/11/96	2	320

[1]Scan speed of SWS AOT01. Corresponding spectral resolutions are $R \sim 300$ for speed 1 & 2 and $R \sim 1000$ for speed 4, respectively.

3. Overall spectra and dust features

Figure 1 shows full SWS spectra of the ten carbon stars. It is easily seen that the spectra of stars in the same group are almost identical while they are quite different between different groups. Similar changes are seen in the near-infrared color temperature. Table 1 lists T_{NIR} re-determined by us based on the present measurements by fitting a blackbody to the SWS data in the wavelength range between 3.5 and 4.0μm. T_{NIR} changes from one group to the next roughly by a factor of 2, and is about the same among stars in the same group.

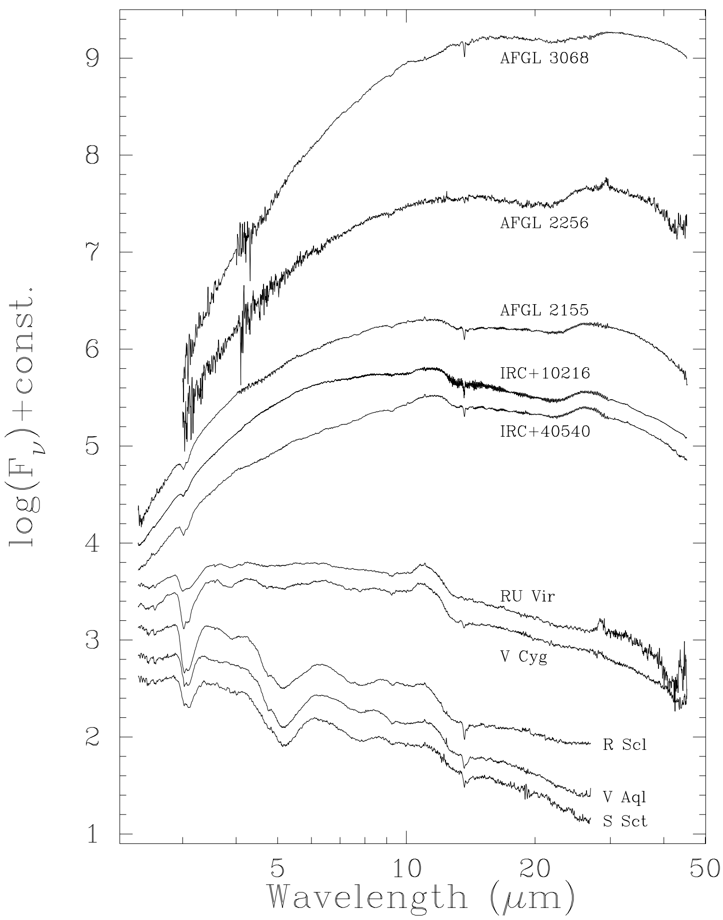

Figure 1. SWS spectra of carbon stars. The spectra are ordered in a sequence of decreasing T_{NIR} from bottom to top. They are shifted arbitrarily for the sake of comparison. The wavelength ranges longward of 27μm in group II stars and shortward of 3.0μm in group V stars are not shown because of low S/N. Features seen at 9.3, 10.05, 11.05μm and around 28μm in some stars are spurious and can not be trusted.

Two clear dust features are recognized in the spectra. The SiC feature, having a peak around 11μm, becomes most prominent in the group III stars. In the group II stars the feature is weak because of small optical depth in the circumstellar shell. Two stars in group IV show a flat-topped shape of the feature. This can be explained by the self-absorption around the peak wavelength (Speck Barlow, & Skinner 1997). In group V stars this feature is almost absent or even seen in absorption.

The other conspicuous dust feature is the "30μm feature", first discovered by Forrest, Houck, & McCarthy (1981). We clearly detect this feature in stars of group IV and V. It seems to appear already in group III stars, although the detection is marginal because of calibration uncertainty. The shape and strength of the feature does not vary systematically with the magnitude of the mass-loss rate.

4. 3μm region

Figure 2 compares the near-infrared spectra of five stars of groups II, III and IV. The spectra are normalized with respect to a blackbody with temperature T_{NIR}.

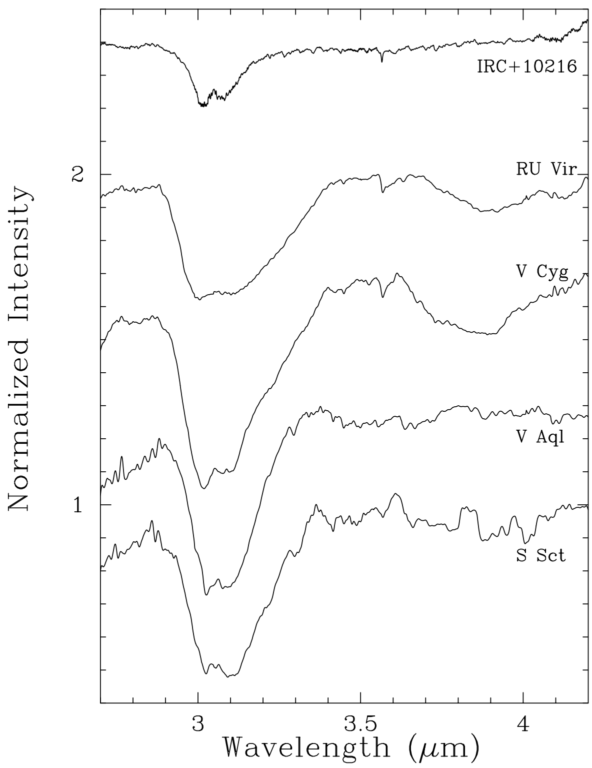

Figure 2. Spectra of carbon stars between 2.7 and 4.2μm.

The wavelength region (2.7 – 4.2μm) is dominated by absorption bands due to C_2H_2 and HCN (e.g., Ridgway, Carbon & Hall 1978). In fact, because of the heavy molecular absorption, it is very difficult to determine the real continuum in the spectra. The slopes of the spectra and the strength of the features in Figure 2 thus cannot be compared in a simple manner.

There are at least two clear differences between group II and III stars. First, the 3.05μm feature is broader in group III than in group II. The difference is mostly in the right (longer wavelengths) shoulder of the feature. The second point is that there is an additional broad absorption feature around 3.8μm in group III stars, while the region is rather flat in S Sct and V Aql. The reasons for these differences are not clear. According to numerical calculations of carbon star spectra (Loidl et al. this issue), the broadening of the 3.05μm feature and the 3.8μm feature could be due to hotbands of C_2H_2 in an extended atmosphere with a temperature between 1000K and 1500K. The layer could be the quasi-static region between the atmosphere and the circumstellar postulated by Tsuji et al. (1997; also this issue). If this is the case, the absence of these additional absorptions in the group II stars implies that the structure of the outer layer of the atmosphere is different between group II and III stars.

5. 14μm region

In the 14μm region, there are absorption bands due to the bending modes of the C-H bond. Figure 3 shows spectra of six carbon stars in this wavelength region.

The deepest absorption at 13.7μm actually consists of Q-branches of three different transitions of C_2H_2. The molecule has other transitions at 13.89 and 13.96μm, which are also recognized in all stars. HCN features are hardly seen in these spectra. Simple LTE model calculations were carried out to fit the spectra. Two independent parameters, a column density and an excitation temperature of the molecule are determined to minimize the χ^2. We found that the column density is about $10^{18\pm0.5}$ and the excitation temperature is about 1200 ± 300K for all group stars. No significant trend with T_{NIR} is seen. The model fits the spectrum of AFGL 3068, the star with thickest envelope in the sample, reasonably well while the model spectrum is incomplete for group II stars. This discrepancy may be due to the effect of hotbands of C_2H_2 which are not included in the present calculations.

6. Summary

Using the ISO-SWS we are now for the first time able to systematically study the spectra of carbon stars as a function of mass-loss rate over a broad infrared wavelength range. Previous speculation based on the IRAS data (Willems 1988a,b) that T_{NIR} is an useful indicator of the infrared behavior of carbon stars is confirmed. The changes are rather systematic from one group to the other, although the real physics behind these changes is not well understood. Contributions of hotbands of abundant molecules such as C_2H_2 and HCN should be taken into account.

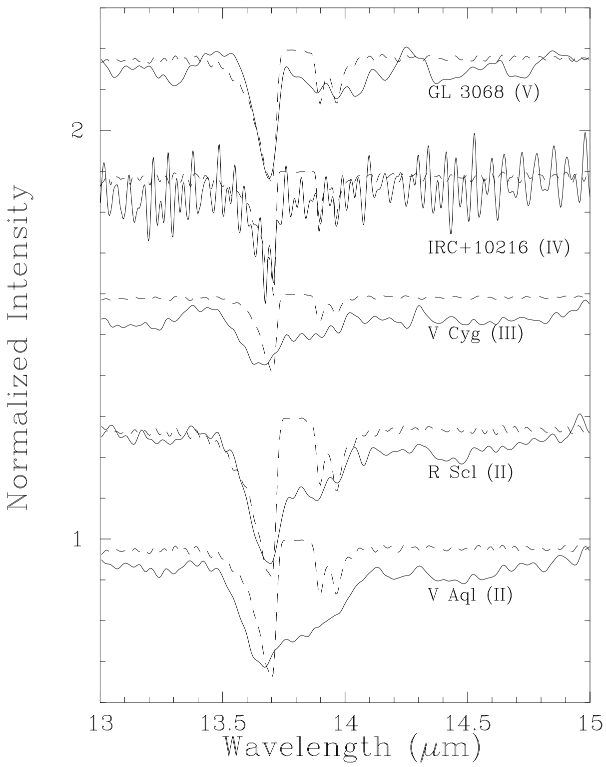

Figure 3. C_2H_2 absorption bands around 14μm. Note that fringes contaminate the spectra, especially that of IRC+10216. The model spectra are plotted as dashed lines.

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