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Letter to the Editor

Irregular structure of the envelope around the carbon-rich star TX Psc

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Summary. Circumstellar envelopes of six oxygen and carbon rich late-type stars were resolved by mapping with the 30m IRAM telescope in the (2-1) and (1-0) transitions of carbon monoxide.

In the envelope around the carbon rich star TX Psc local density enhancements, clumps, were detected which are interpreted as evidence for erratic outflow of matter in the envelope of the semi-regular variable.

The ratios of CO(2-1) to CO(1-0) antenna temperatures lie between 0.5 and 1.5 indicating that some of the CO emission regions are extended relative to the telescope beams. The high ratio of 3.3 for α Ori is most probably due to molecular gas which is substantially warmer than in the other envelopes.

Key Words: stars: circumstellar matter – stars: late-type – stars: long-period variables – radio lines: molecular

1. Introduction

Circumstellar envelopes of late-type giants and supergiants are usually considered to be spherically symmetric and most of the observations confirm this picture.

On the other hand half of the (pre-) planetary nebulae have been found to be bipolar, which is taken as indication for non-spherical mass-loss during the asymptotic giant branch phase (Balick, Preston and Icke 1987). Mapping of the carbon-rich star V Hya revealed possible bipolarity of the envelope structure (Tsuji et al. 1988).

Despite a large number of observations and models the mechanism of mass-loss is not understood. Most of the stars in the mass-loss phase are pulsating; thus the structure of their atmospheres is mainly determined by shock waves (Willson and Bowen, 1986). Compared to static atmospheres those of pulsating stars have a time variable density and temperature distribution and a more complicated velocity field. It might be suspected that pulsational behaviour of the star and the envelope structure are related. It is natural to ask, whether there are other stars apart from V Hya which show a complex envelope structure.

Because the treatment of radiative transfer becomes extremely difficult in aspherical geometry various models for determination of mass-loss-rates assume this simple geometrical case (Knapp and Morris 1985 and Schönberg 1988).

In a larger investigation of CO emission of envelopes around late-type stars some objects were found which do not exhibit a typical flat topped, double peaked of parabolic profiles (Heske 1989a). These are the carbon stars TX Psc and Y CVn, which were our primary targets. V Aql and α Ori, which has an extremely weak (1-0) line, were picked out as well. For a check, two sources with non-peculiar CO lines were added, S Cas and TV Gem.

Name	R.A. h m s	Dec. ° ′ ″	CO(1–0) T_{mb} [K]	CO(1–0) T_{rms} [K]	CO(2–1) T_{mb} [K]	CO(2–1) T_{rms} [K]	$\frac{(2-1)}{(1-0)}$
S Cas	01 15 57.7	72 20 55	0.85	0.18	0.80	0.15	0.9
α Ori	05 52 27.9	07 23 58	0.21	0.05	0.70	0.03	3.3
TV Gem	06 08 50.9	21 52 52	0.25	0.12	0.15	0.10	0.6
Y CVn	12 42 47.1	45 42 38	0.75	0.06	0.85	0.05	1.1
V Aql	19 01 44.0	−05 45 38	0.56	0.05	0.71	0.04	1.3
TX Psc	23 43 50.0	03 12 33	0.73	0.03	0.75	0.03	1.0
			0.45	0.03	0.24	0.03	0.5

Table 1. Observational results.
The last column gives the ratios of the antenna temperatures for the (2-1) and (1-0) transitions. For TX Psc the first values refer to the strong central peak, the second ones to the broad and weak underlying profile.

2. Observations

In August 1988 the stars in table 1 were mapped in the CO (1-0) and (2-1) line simultaneously with the IRAM 30m telescope equipped with SIS receivers for both frequencies and a 1MHz filterbank spectrometer splitted in two parts leading to a velocity resolution of 2.6 and 1.3 km/s respectively. Typical system temperatures were 1100 K at 115.27GHz and 1800 K at 230.54 GHz. The on source integration times of about 10 min per point gave noise temperatures between 0.03 K and 0.1 K. A typical rms noise temperature was 0.05 K. The antenna temperatures in table 1 are corrected for main beam efficiencies (η_{mb}), 0.6 (HPBW = 21″) at 115.27 GHz and 0.45 (HPBW = 14″) at 230.54 GHz.

The maps consist of 13 points, a circle of 8 points with an offset of 20″ and 4 points with an offset of 30″ in right ascension and declination. The order of observation was the following: 20″ offset in right ascension, in declination followed by the (±15,±15) offsets counterclockwise. For TX Psc, α Ori and V Aql 4 additional points with a 10″ offset were observed.

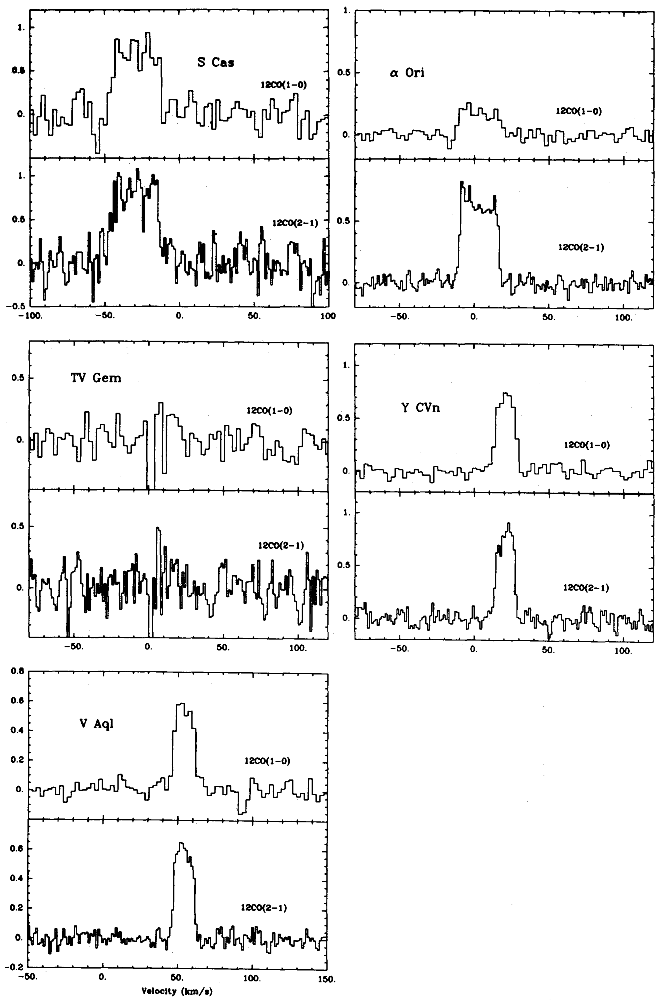

Figure 1. CO(1-0) and CO(2-1) spectra for all observed objects (not Hanning smoothed).

3. Spectra and discussion

3.1 The ratio of the (2-1) and (1-0) CO lines

Figure 1 shows the spectra at the central positions and the parameters of the lines are given in table 1. The ratio of antenna temperatures ($T_{mb}(2-1)/T_{mb}(1-0)$) is expected to be the ratio of the beam areas, $(21/12)^2 = 3.1$, provided that the emission in both transitions is point like with respect to the beam sizes and that the excitation temperatures are equal for optically thick lines. If the (1-0) emission is more extended than the (2-1) emission region this ratio decreases. In table 1 the ratios are listed in column 6. Except for α Ori, all values are confined to a range between 0.5 and 1.5. Keeping in mind the error of ± 0.4 this shows that in these objects the (1-0) emission is comparable or exeeding the extent of the (2-1) emission region. Previous studies of the line ratio on the basis of observations with smaller telescopes reported higher values than presented here (Knapp et al. 1982); but in those observations the molecluar envelope is not resolved with the telescope beams.

The value for α Ori, 3.3, is rather surprising comparing it to the other values in table 1. A natural explanation is that the molecular matter in the envelope around α Ori is substantially warmer than in the other envelopes provided that the emission is optically thin. In this sample of stars only α Ori exhibits radio continuum emission (Seaquist 1967) indicating that the atmospheric temperature must be higher than for the other objects.

3.2 The structure of the envelope around TX Psc (Fig. 2)

Whereas the spectral maps of the other stars do not show any peculiarity in the line profiles in dependence of position the map of TX Psc exhibits two pronounced features (figure 2):

1. The narrow peak centred in the (2-1) spectrum at the systemic velocity appears at the central position and only very weakly at the (−20,0)-position. It can be assigned to a local density enhancement which moves nearly perpendicular to the line of sight. Another possibility could be a maser effect similar which has been discussed for V Hya (Tsuji et al. 1988). Then, a time variability would be expected. In the (1-0) line a similar feature has been detected with higher spectral resolution

position offset ″	″	CO(1–0) $\int_{-2}^{13} T_{mb}dv$	CO(1–0) $\int_{13}^{30} T_{mb}dv$	CO(2–1) $\int_{-2}^{13} T_{mb}dv$	CO(2–1) $\int_{13}^{30} T_{mb}dv$
0	0	4.9	4.7	3.7	3.3
0	20	1.4	1.9*	1.3	1.0
0	−20	1.1	1.5	0.7	1.0
20	0	0.1	0.8*	0.9	0.4
−20	0	2.5	2.6	1.4	0.9
15	15	1.2	1.1	0.2	0.8
15	−15	0.3	1.2*	0.5	0.6
−15	15	2.7	3.5*	1.7	1.3
−15	−15	2.0	1.7	0.8	0.4
10	10	3.5	2.0	−0.8	0.9
10	−10	0.9	1.6	−0.4	−0.2
−10	10	4.5	5.8	2.3	3.1
−10	−10	1.2	0.7	1.0	1.1

Table 2. Line properties for TX Psc.
For each position the integral over the blue and red shifted part of the line is given. The integration boundaries are indicated. At the offset positions indicated by an asterisk (*) the difference between the two integrals exeeds a 3σ value.

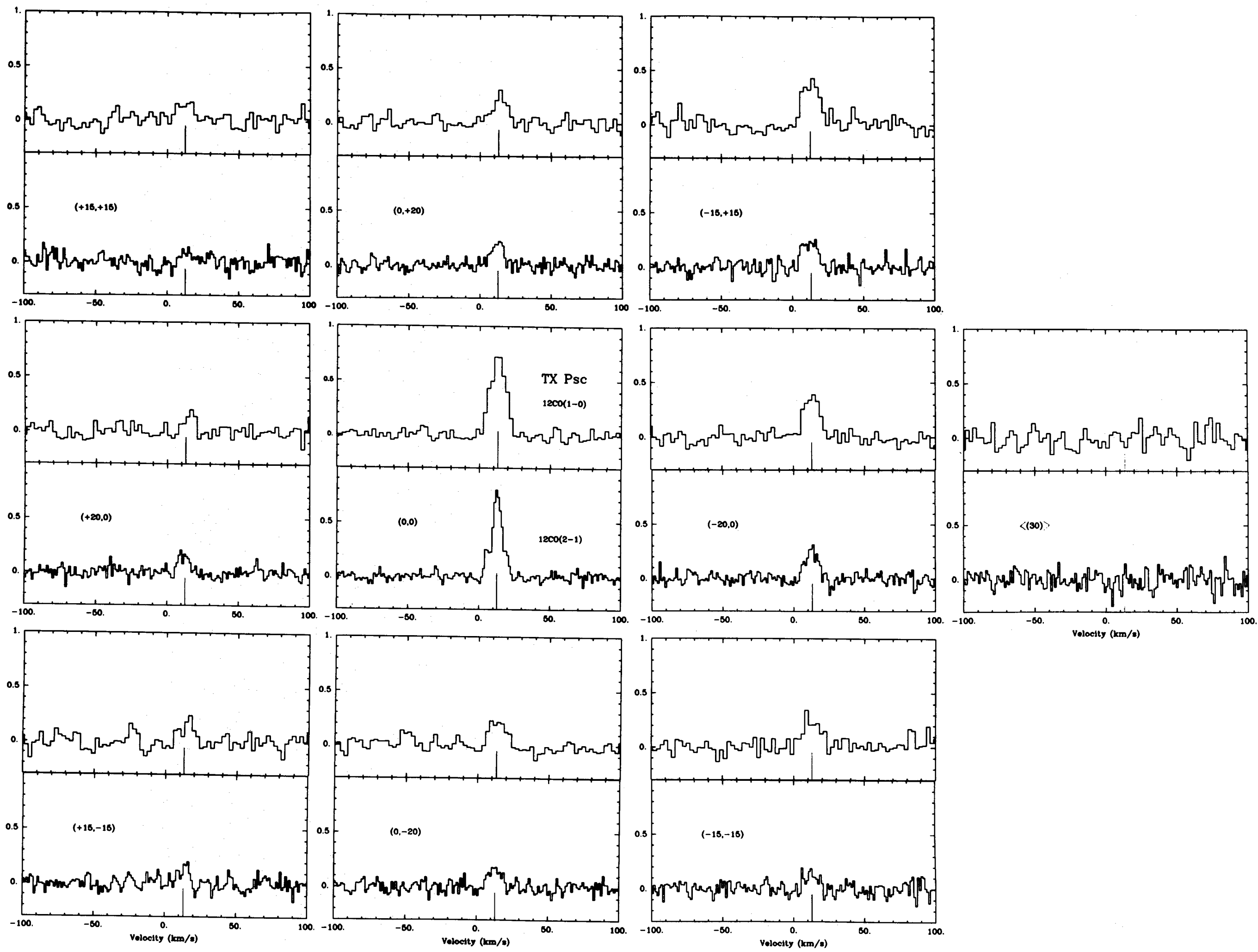

Figure 2. CO map for TX Psc.
In the rightmost spectrum all spectra taken at an offset of 30″ are added. The long tick mark in each spectrum indicates the systemic velocity.

(Heske 1988a). The lower resolution spectrum presented here comfirmes this feature although for a detailed study the resolution is just too low. The broad underlying profile appears on all offset positions within 20″ from the central position suggesting the presence of extended emission.

2. The (1-0) lines at offsets $(0,+20)$, $(+20,0)$ and possibly $(+15,-15)$ show asymmetric line profiles where the maximum emission is red shifted by about 4 km/s. The blue wing in these profiles is only marginally present. The total width of the line profile is still comparable to that at the central position (about 18 km/s). In the (2-1) line the asymmetry is weak. At positions around the offsets mentioned above no asymmetry at all has been detected.

This result is also demonstrated by the integrated properties of the lines. Given the center velocity (13 km/s) the blue and red shifted part of each line was integrated seperately. Table 2 gives these values at all offset positions. The values for the blue shifted parts in the CO(1-0) spectra at $(0,+20)$, $(+20,0)$ and $(+15,-15)$, $(-15,+15)$ are more than 3σ ($\approx 0.5K\ km/s$) lower than the red shifted ones. This is not reflected in the CO(2-1) spectra, the differences are within the 3σ values. Summarizing, these pure numerical results confirm the analysis of the individual line profiles.

As a check we produced contour maps on the basis of the values in Tab. 2 for the red and blue parts of the CO(1-0) lines (Figure 3). The maxima of both line parts are clearly displaced. Whereas the maximum intensity of the blue part coincides with the optical position the maximum of the red part occurs at 10″ offset to the north east. The extended emission in the intensity distribution of the red line part coincides well with the peak intensity of the blue line part. It should be mentioned that a possible pointing drift or mispointing could give rise to a displaced CO emission with respect to the optical position. We therefore do not discuss the relative position of the CO peaks with respect to the optical emission. Any possible pointing drift during the observations would have produced a rather smeared out CO emission which cannot be found in the contour map and, on the other hand could have hardly produced the clear separation of the peaks seen in Fig. 3. All three results results clearly demonstrate the asymmetric structure of the envelope around TX Psc.

Although the overall distribution of the line profiles is compatible with an expanding envelope the asymmetry in three offset positions indicates differences in local column density. One possibility is a bipolar structure of the envelope, but no clear indication found for this. Another possibility is that the structure of the envelope is rather clumpy In the rest of paragraph we will assume that this is the case.

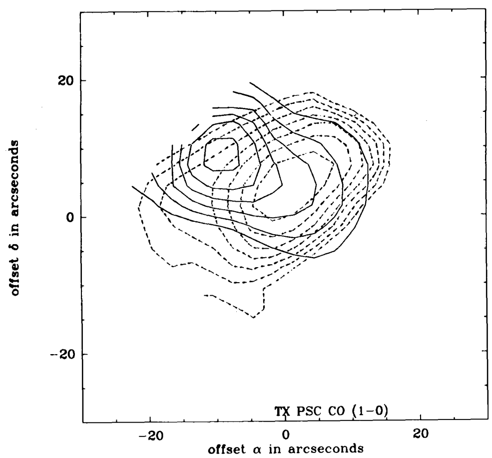

Figure 3. Contour map of the intensity distribution of the blue part of the CO(1-0) line (dashed lines) superposed on the distribution of the red part. The highest contour represents 4.5 K km/s the lowest 1.5 K km/s.

The distance of the density enhancements to the star is about $10^{17}\,cm$ assuming a distance of 300 pc and a luminosity of $10^{3.5}\,L_{\odot}$ which is calculated by matching the observed visual magnitude (Hoffleit 1982) with the infrared continuum of the star (Heske 1989a). For the outflow velocity of these clumps 9 km/s, the expansion velocity in the CO lines, can be assumed. Calculating then a time scale for this event of mass ejection indicates that it must have happened some thousand years ago. This carbon rich star does not exhibit a SiO maser (Heske 1989b) and H_2O maser emission has not been searched for. So the kinematics of the atmosphere and lower circumstellar envelope cannot be derived in order to be compared with our present results of the molecular outflow.

The question is whether this could be due to irregular pulsation since TX Psc is classified as a semi-regular variable (Kukarkin et al.1969) as is V Hya. From SiO and H_2O maser observations it has been argued that the structure of circumstellar envelopes can be very irregular indicating that mass-loss might be not at all a spherically symmetric phenomenon (Alcock and Ross 1985). The data presented here show clearly evidence in one example that this irregular structure is not confined to a region close to the star. It also shows that irregular or semi-regular pulsation can have a sigificant effect on envelope structure.

4. Conclusion

The results of mapping circumstellar envelopes of late-type giants and supergiants points to extended emission regions for the (1-0) as well as for the (2-1) CO lines.

In one example, TX Psc, irregular structure in the molecular outflow has been detected. We suggest that the circumstellar envelope of this carbon-rich star has an irregular structure containing local density enhancements (clumps). It is probable that the pulsational properties of the semi-regular variable produces asymmetries in mass-loss.

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