Circumstellar H\textsc{i} and CO around the carbon stars

V1942 Sgr and V CrB

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ABSTRACT

Context. The majority of stars that leave the main sequence are undergoing extensive mass loss, in particular during the asymptotic giant branch (AGB) phase of evolution. Observations show that the rate at which this phenomenon develops differs highly from source to source, so that the time-integrated mass loss as a function of the initial conditions (mass, metallicity, etc.) and of the stage of evolution is presently not well understood.

Aims. We are investigating the mass loss history of AGB stars by observing the molecular and atomic emissions of their circumstellar envelopes.

Methods. In this work we have selected two stars that are on the thermally pulsing phase of the AGB (TP-AGB) and for which high quality data in the CO rotation lines and in the atomic hydrogen line at 21 cm could be obtained.

Results. V1942 Sgr, a carbon star of the Irregular variability type, shows a complex CO line profile that may originate from a long-lived wind at a rate of $\sim 10^{-7} \, M_\odot \, yr^{-1}$, and from a young ($\lesssim 10^4$ years) fast outflow at a rate of $\sim 5 \times 10^{-7} \, M_\odot \, yr^{-1}$. Intense H\textsc{i} emission indicates a detached shell with 0.044 $M_\odot$ of hydrogen. This shell probably results from the slowing-down, by surrounding matter, of the same long-lived wind observed in CO that has been active during $\sim 6 \times 10^5$ years. On the other hand, the carbon Mira V CrB is presently undergoing mass loss at a rate of $2 \times 10^{-7} \, M_\odot \, yr^{-1}$, but was not detected in H\textsc{i}. The wind is mostly molecular, and was active for at most $3 \times 10^4$ years, with an integrated mass loss of at most $6.5 \times 10^{-3} \, M_\odot$.

Conclusions. Although both sources are carbon stars on the TP-AGB, they appear to develop mass loss under very different conditions, and a high rate of mass loss may not imply a high integrated mass loss.

Key words. Stars: AGB and post-AGB – Stars: carbon – (Stars:) circumstellar matter – Stars: individual: V1942 Sgr – Stars: individual: V CrB

1. Introduction

Low- to intermediate-mass stars, at the end of their main-sequence evolution, become first hydrogen shell-burning red giants (RGB –Red Giant Branch– stars), then hydrogen and helium shell-burning red giants (AGB –Asymptotic Giant Branch– stars). In this second phase they may un-
deterior mass loss at a very large rate ($> 10^{-8}$ M⊙ yr$^{-1}$), even so large that it has a decisive effect on their late evolution (Olofsson 1999). They are surrounded by expanding envelopes of gas and dust that have been extensively observed with radio molecular lines and infrared continuum emission. These tracers are used to estimate mass-loss rates. However the estimates are somewhat ambiguous because the mass-loss rate of a given source may vary on many different timescales. The mass change as a function of time due to mass loss is thus difficult to evaluate, and to connect with stellar evolution models. Furthermore molecular lines probe an extent of the circumstellar shell (CS) that is limited by photo-dissociation, and therefore furnish information mainly on the inner parts of CSs, and on the recent mass loss.

To try to circumvent these difficulties we have started a systematic programme of observations of red giants in the line of atomic hydrogen at 21 cm. We have published some of our results in several recent papers, and first reports on sizeable samples have been presented by Gérard & Le Bertre (2006, hereafter GL2006) and Matthews & Reid (2007, hereafter MR2007). A major difficulty of this programme is the confusion caused by the 21 cm emission from the Interstellar Medium (ISM) that is located on the same line-of-sight as the source of interest. This has a strong impact on the observations which have to be conducted with a specific approach, and on the data processing that aims at providing spectra corrected for the ISM emission. Perhaps more confounding, as circumstellar matter is expected to be at some stage injected in the ISM, the confusion by the local ISM might actually be at least partly of stellar origin, i.e. caused by material ejected at an earlier stage of evolution.

In addition to observing systematically the H I line at 21 cm in a large sample of sources with different properties, it is also important to choose objects for which the Galactic confusion is low and/or can be tracked easily, and therefore corrected accurately. The detailed study of such spectra should serve as a guide to exploit the data that are obtained in more difficult situations.

Here we present our results on two carbon stars, V1942 Sgr and V CrB, for which the confusion is not a serious problem, and which have H I properties that differ radically. Both are N-type carbon stars (CGCS 4229 and CCCS 2293, respectively) and have already been detected in CO rotational lines (Olofsson et al. 1993a). However the only available CO spectrum of V1942 Sgr had a poor signal-to-noise ratio, and for our study it appeared essential to also obtain new CO data of high quality.

**2. V1942 Sgr**

V1942 Sgr is classified as a long-period irregular variable (type Lb). Lebzelter & Obbrugger (2009) have compared the lightcurve properties of Semi-Regular (SR) and Lb variables, and concluded that Lb stars can be seen as an extension of the SRs towards shorter periods and smaller amplitudes. V1942 Sgr is a carbon star on the TP-AGB with a C/O ratio around 1.12 (Olofsson et al. 1993b). Bergeat et al. (2001) estimate its effective temperature, T eff, at 2960 K. The parallax measured by Hipparcos (1.87 ± 0.51 mas, van Leeuwen 2007) places it at 535 pc, which implies a luminosity of 5200 L⊙. From the data obtained by IRAS in the mid-infrared there is no direct evidence that the star is undergoing mass loss (the low resolution 8-22 µm spectrum is featureless). However, Olofsson et al. (1993a) discovered emission in the CO(1-0) rotational line centered at V lsr = −31.5 km s$^{-1}$, close to the expected radial velocity of V1942 Sgr (V lsr = −32.0 km s$^{-1}$ from the General
Fig. 1. Frequency-switched H\textsc{i} 21 cm spectrum obtained with the NRT on the position of V1942 Sgr. The spectrum enlarged by a factor 20 is also shown as a dashed line. The emission from V1942 Sgr is clearly detected at –33 km s\(^{-1}\).

Catalogue of Stellar Radial Velocities). The expansion velocity, \(V_{\text{exp}} = 12.4\) km s\(^{-1}\), is surprisingly large for an Lb variable. From this spectrum Schöier & Olofsson (2001) derive a mass loss rate of \(~2.5 \times 10^{-7}\) M\(_{\odot}\) yr\(^{-1}\) (at 535 pc). Extended emission associated with V1942 Sgr was discovered by IRAS (Young et al. 1993a). The 60 \(\mu\)m data show a resolved shell of external radius 3.2\arcmin, i.e. 0.50 pc.

2.1. H\textsc{i} observations

The H\textsc{i} emission was observed with the Nançay Radio Telescope (NRT), between March 2007 and July 2009, for a total of 85 hours. The NRT beamwidth (FWHM) at 21 cm is 4\arcmin in right ascension (RA) and 22\arcmin in declination (Dec). An ’on’ source frequency-switched spectrum is presented in Fig. 1. The main emission peaks at 50 K around \(V_{\text{lsr}} = 0\) km s\(^{-1}\). A narrow emission feature with a peak of \(~0.3\) K, centered at –33 km s\(^{-1}\), is visible on top of the 0.4 K blue wing of the main peak near 0 km s\(^{-1}\).

Position-switched spectra were also obtained with on-position taken at the position of V1942 Sgr and off-positions, at \(\pm 2\arcmin, \pm 4\arcmin, \pm 6\arcmin, \pm 8\arcmin, \pm 10\arcmin, \pm 12\arcmin, \pm 16\arcmin, \pm 24\arcmin, \) and \(\pm 32\arcmin\). The comparison between the spectra obtained for different values of the throw shows that the interstellar emission varies linearly with offset in the velocity range from –100 to –20 km s\(^{-1}\). It means that the H\textsc{i} background emission around V1942 Sgr shows a gradient in RA which is constant for each velocity. This situation is similar to that encountered for EP Aqr and Y CVn (Le Bertre & Gérard 2004, Figs. 3 and 7). In such a case the source emission can be extracted from the position-switched spectra by subtracting the contribution of the interstellar emission, which is estimated by interpolation between the two extreme off-positions.

The intensity of the emission detected from the source in the position-switch spectra is constant with throw from \(\pm 4\arcmin\) to \(\pm 32\arcmin\). Therefore the source is mostly confined to the central beam (i.e. \(\pm 2\arcmin\).
Fig. 2. H\textsc{i} line profile of V1942 Sgr. The spectrum has been smoothed to a resolution of 0.32 km s\textsuperscript{−1}. The dashed line is a fit obtained with the model described in Sect. 4.1.

in RA; see GL2006, Sect. 2.1). The spectrum obtained at the star’s position is shown in Fig. 2. It has a shape similar to that obtained on Y CVn (Libert et al. 2007) with a narrow emission line superposed on a pedestal extending from −39 to −27 km s\textsuperscript{−1}. The narrow emission is centered at $V_{\text{lsr}} = −32.9$ km s\textsuperscript{−1} and has a quasi-gaussian profile of width 2.95 km s\textsuperscript{−1} (FWHM) and peak intensity 168 mJy. The pedestal is also centered at $\sim −33$ km s\textsuperscript{−1} and has an intensity of $\sim 6\pm2$ mJy. The peak intensity at the central position (178 mJy) agrees with that observed on the frequency-switched spectrum (cf. Fig. 1, with a conversion factor 2.15 K/Jy for the NRT at 21 cm). We have also searched for H\textsc{i} emission at blueshifted velocities down to −48 km s\textsuperscript{−1}, and redshifted velocities up to −18 km s\textsuperscript{−1} (see the CO spectra in Sect. 2.2). We set an upper limit of 2 mJy for emission over this range. Nevertheless, we suspect residual features at −46, −26, and −24 km s\textsuperscript{−1}, possibly peaking at $\sim 3$ mJy.

The spectra of the source in the off-positions are then determined by subtracting the individual position-switched spectra (on–off) and the contribution of the interstellar emission (assuming that it varies linearly with RA) from the central spectrum. Furthermore we have obtained data with the on-positions at 11′ north and 11′ south, and off-positions at ±2′, ±4′, and ±12′, and with the on-positions at 22′ north and 22′ south, and off-positions at ±8′. All these data are used to construct the flux density map of the source presented in Fig. 3.

On this map we see that the intensity at −2′ west is almost the same as on the star, and therefore conclude that the source is slightly offset west from the stellar position. Assuming a gaussian distribution of the intensity, we estimate that the H\textsc{i} source is centered at 0.6′ (±0.1′) west in RA and at 0′ (±1′) in Dec. The size (FWHM) would then be $\sim 1.3$′ in RA and $<5$′ in Dec. The integrated flux in the map is 0.71 Jy×km s\textsuperscript{−1}. Assuming that the emission is optically thin and that atomic hydrogen is at a temperature well above the background (≤ 0.4 K + 4.2 K, Reich & Reich 1986), and using the standard relation, $M_{\text{HI}} = 2.3610^{-7}d^2 \int S_{\nu}dV$, with $M_{\text{HI}}$ in M\textsubscript{☉}, $d$ in pc, and \(\int S_{\nu}dV\) in Jy×km s\textsuperscript{−1}, this flux translates to 0.048 M\textsubscript{☉} of atomic hydrogen at 535 pc.
Fig. 3. Map of the 21 cm H\textsc{i} emission of V1942 Sgr. In each box the label at upper left gives the position (RA, Dec) with respect to the central star in arcminutes.

2.2. CO observations

CO observations of V1942 Sgr were obtained at the IRAM 30-m telescope equipped with EMIR (Eight MIxer Receiver) on June 23, 2009 under average conditions (precipitable water vapor, pwv $\sim 10$ mm). The two rotational lines, 1-0 and 2-1, were observed in parallel. The four EMIR bands were selected to detect the two orthogonal polarizations at 115.2712 and 230.5380 GHz ($T_{\text{sys}} \sim 400$ K, $\sim 800$ K, respectively). High spectral resolutions of 20 kHz and 40 kHz respectively (hence 0.05 km s$^{-1}$) were obtained with the VESPA (Versatile SPectrometer Array) backends. The telescope beamwidths are 21$''$ (at 115 GHz) and 11$''$ (at 230 GHz), and the observations were made in the wobbler-switching mode using a throw of 60$''$ in azimuth.

The spectra are shown in Fig. 4. These new spectra reveal that the line profiles are composite with two components centered on the same central velocity, but with different widths, like those observed by Knapp et al. (1998) and Winters et al. (2003) in several late-type giants, mostly oxygen-rich stars of the SR variability type. The emission extends from $-48$ to $-18$ km s$^{-1}$, and therefore we confirm the large expansion velocity ($\gtrsim 12$ km s$^{-1}$) estimated by Olofsson et al. (1993a).

Each line profile was fitted with two parabolae in order to derive representative expansion velocities (Table I). We estimate the mass loss rates and photo-dissociation radii associated with each component using the same approach as in Winters et al. (2003). We adopt a CO/H mass ratio of $1 \times 10^{-3}$. The differences in the mass loss rates and photo-dissociation radii estimated from the two lines are comparable to the uncertainties of the fits.
Fig. 4. CO (2-1, upper panel) and (1-0, lower panel) spectra of V1942 Sgr obtained with the IRAM-30m telescope. The fits used to derive the wind parameters are also shown (see Table 1).

Table 1. CO line parameters of V1942 Sgr. Formal uncertainties are given in parentheses.

|       | $V_{lsr}$ | $V_{exp}$ | $T_{mb}$ | $M$       | $R_{CO}$ |
|-------|-----------|-----------|----------|-----------|----------|
| CO (1-0) | -33.75  (0.25) | 17.5 (0.5) | 0.12 (0.01) | 6.1 (0.3) $10^{-7}$ | 6.9 (0.2) |
|       | -33.75 (0.25) | 5.0 (0.5) | 0.10 (0.01) | 1.0 (0.1) $10^{-7}$ | 4.0 (0.2) |
| CO (2-1) | -33.25 (0.25) | 17.75 (0.5) | 0.25 (0.02) | 4.3 (0.3) $10^{-7}$ | 5.7 (0.2) |
|       | -33.25 (0.25) | 5.0 (0.5) | 0.20 (0.02) | 6.9 (0.5) $10^{-8}$ | 3.2 (0.2) |

3. V CrB

V CrB is a metal-poor ([M/H] = -1.35) carbon star on the TP-AGB with a C/O ratio around 1.10 (Abia et al. 2001). It is a Mira of period 358 days. Using the period-luminosity relation for carbon Miras of Whitelock et al. (2006), Guandalini (2009) determines a luminosity of 5600 $L_\odot$ and a distance of 547 pc. $T_{\text{eff}}$ is estimated at 2090 K (Bergeat et al. 2001). At such a low temperature (i.e. less than 2500 K) molecular hydrogen is expected to be the dominant species in the atmosphere and in the inner envelope of V CrB (Glassgold & Huggins 1983). Indeed photospheric H$_2$ has been detected in the near-infrared (2.122 $\mu$m) by Johnson et al. (1983). This Mira is presently undergoing mass loss, since, for instance, it shows clear SiC dust emission at 11.3 $\mu$m (Goebel et al. 1981). The source has also been detected in the CO(1-0) and CO(2-1) rotational lines by Olofsson et al. (1993a), and more recently in CO(3-2) by Knapp et al. (1998). Contrary to V1942 Sgr, only one velocity component is visible. The central velocity is at $V_{lsr} = -99.0$ km s$^{-1}$, the expansion velocity, $V_{\text{exp}} = 6.5$ km s$^{-1}$, and the mass loss rate, $\dot{M} \sim 2.1 \times 10^{-7}$ $M_\odot$ yr$^{-1}$ (at 547 pc). With the Plateau-de-Bure IRAM interferometer Neri et al. (1998) find a source of size of 7$''$ in CO (1-0). On the other hand IRAS has not detected extended far-infrared emission associated with V CrB (Young et al. 1993a, their Table 1).
Fig. 5. Frequency-switch HI 21 cm spectrum obtained with the NRT on the position of V CrB. The bar indicates the velocity range of the CO emission.

V CrB was also observed in HI with the NRT for a total of 44 hours. The frequency-switched spectrum shows no feature around the expected velocity of $-99.0\,\text{km}\,\text{s}^{-1}$ (Fig. 5), and only a weak interstellar emission of at most 0.2 K around $-99\,\text{km}\,\text{s}^{-1}$.

We obtained HI data in the position-switch mode of observation with off-positions at $\pm 4^\prime$, $\pm 6^\prime$, $\pm 8^\prime$, $\pm 10^\prime$, $\pm 12^\prime$, $\pm 16^\prime$ and $\pm 24^\prime$. As for V1942 Sgr we find that the interstellar emission varies linearly with offset, in the velocity range $-120$ to $-80\,\text{km}\,\text{s}^{-1}$. We are thus confident that the interstellar contamination can be corrected for accurately. The source is not detected at the star's position and at $\pm 5^\prime$ in RA (Fig. 6 in which we have averaged the spectra obtained at $+$4$'$ and $+$6$'$, and at $-4^\prime$ and $-6^\prime$, in order to improve the sensitivity). By integrating over the velocity range defined by the CO emission, (i.e. $-106$ to $-92\,\text{km}\,\text{s}^{-1}$), an upper limit of 4 mJy$\times$km s$^{-1}$ can be set on the intensity of the HI emission at the V CrB's position in the area defined by the 4$'\times$22$'$ NRT beam. It translates to an upper limit of $3 \times 10^{-4} M_\odot$ in atomic hydrogen at 547 pc. As the source was not found to be extended by IRAS, we do not expect much material outside the NRT beam.

4. Interpretation

4.1. V1942 Sgr

The CO line profiles observed in V1942 Sgr have a characteristic composite profile. This kind of profile has been interpreted as evidence for a succession of mass loss events with different outflow velocities by Knapp et al. (1998) and Winters et al. (2003). However the interferometric data obtained on EP Aqr, a source with such profiles, are difficult to explain with this scenario (Winters et al. 2007). Furthermore, in other cases, X Her (Kahane & Jura 1996) and RS Cnc (Libert et al. 2009), there is evidence that the broad components originate in a bipolar flow. Bipolar flows are believed to develop at the end of the AGB phase when the stars are about to begin their evolution towards the planetary nebula phase (e.g. Sahai et al. 2007).
The HI spectrum obtained on the star’s position shows a pedestal of width 10 km s\(^{-1}\) that could be a counterpart of the narrow CO (1-0 and 2-1) components that have about the same width. The mass in hydrogen corresponding to this pedestal is \(\sim 4 \times 10^{-3} \, M_\odot\). Assuming 90% in H and 10% in \(^4\)He, in number (i.e., a mean molecular weight, \(\mu\), of 1.3), and adopting a mass loss rate of 1 \(10^{-7} \, M_\odot \, \text{yr}^{-1}\) from the narrow CO components (see Table 1), the timescale would be 6 \(10^4\) years, and the radius 0.31 pc (\(\equiv 2\)′). The stellar effective temperature (2960 K) is large enough that we expect most of the hydrogen in atomic form.

On the other hand, there is no HI counterpart to the broad CO components at a level of 2 mJy. This seems to indicate that the broad components correspond to a quite recent phenomenon. Indeed, adopting an upper limit of 2 mJy, the flux is \(< 0.07 \, \text{Jy km s}^{-1}\), and the mass in atomic hydrogen is at most \(5 \times 10^{-3} \, M_\odot\). The timescale is then \(< 10^4\) years.

The HI spectra obtained on V1942 Sgr are very similar to those obtained by Le Bertre & Gérard (2004) and Libert et al. (2007) on Y CVn, a well-documented carbon star with a detached shell discovered by IRAS (Young et al. 1993a) and imaged by ISO (Izumiura et al. 1996). On the central position we detect a pedestal of width 10 km s\(^{-1}\), twice the expansion velocity measured for the narrow CO components. On all positions, we detect a narrow line of width, FWHM \(\sim 3\) km s\(^{-1}\). This narrow profile proves that the stellar wind from V1942 Sgr is slowed down at some distance from the central star. Young et al. (1993b) have interpreted the detached shells that were revealed by IRAS at 60 \(\mu\)m as the effects of a slowing-down of stellar outflows by surrounding interstellar matter. Elaborating on this hypothesis and using the formalism of Lamers & Cassinelli (1999), Libert et al. (2007) developed a model in which the inner radius of a detached shell corresponds
Table 2. Model parameters ($d = 535$ pc).

| Parameter | Value |
|-----------|-------|
| $\dot{M}$ (in hydrogen) | $0.69 \times 10^{-7} \, M_\odot \, yr^{-1}$ |
| $\mu$ | 1.3 |
| $t_1$ | $61 \times 10^3$ years |
| $t_{DS}$ | $5.4 \times 10^5$ years |
| $r_1$ | $0.31$ pc (2.0') |
| $r_f$ | $0.41$ pc (2.64') |
| $r_2$ | $0.47$ pc (3.0') |
| $T_0$ ($T_1^*$), $T_1^*$ | 20 K, 746 K |
| $T_f$ ($= T_2$) | 81 K |
| $v_0$ ($= v_1^*$), $v_1^*$ | 5.0 km s$^{-1}$, 1.27 km s$^{-1}$ |
| $v_f$ | 0.066 km s$^{-1}$ |
| $v_2$ | 0.52 km s$^{-1}$ |
| $n_1^*, n_1$ | 0.45 H cm$^{-3}$, 1.8 H cm$^{-3}$ |
| $n_f^*, n_f$ | 21.0 H cm$^{-3}$, 2.15 H cm$^{-3}$ |
| $n_2$ | 1.66 H cm$^{-3}$ |
| $M_{c, r_1}$ (in hydrogen) | $4.2 \times 10^{-3} \, M_\odot$ |
| $M_{DT, CS}$ (in hydrogen) | $3.7 \times 10^{-2} \, M_\odot$ |
| $M_{DT, EX}$ (in hydrogen) | $6.3 \times 10^{-3} \, M_\odot$ |

The notations are as in Libert et al. (2007). In particular, $t_{DS}$ is the formation time of the detached shell, $M_{DT, CS}$ is the mass of the circumstellar component of the detached shell, and $M_{DT, EX}$ is the external mass accreted in the detached shell.

We are using the same model for V1942 Sgr. For the freely expanding wind ($r < r_1$) we adopt a velocity of 5.0 km s$^{-1}$, i.e. half the width of the pedestal, which corresponds also to the narrow CO components. The broad CO components have no obvious counterpart in H$\alpha$. They probably trace a short lived structure that is restricted to the central part of the circumstellar shell and that has no effect on the large scales probed at 21 cm. The mass loss rate, $\dot{M} = 1.0 \times 10^{-7} \, M_\odot \, yr^{-1}$, is adopted from the CO line fitting (Table 1). The central velocity is taken at $-32.9$ km s$^{-1}$.

We obtain a good fit to the different H$\alpha$ line profiles (Figs. 2 and 7) with the parameters given in Table 2. The external radius, $r_2 \sim 3'$, that we have adopted is compatible with that derived by Young et al. (1993a) from IRAS data at 60 $\mu$m, $r_{ext} \sim 3.2'$, but not the internal radius ($r_1 = 2'$, versus $r_{int} \sim 0.2'$). In our model, $r_1$ is constrained by the parameters obtained from the low velocity CO components and by the intensity of the H$\alpha$ pedestal. We assume that the inner shell is too small compared to the IRAS beam at 60 $\mu$m (FWHM $\sim 2'$) to have been reliably constrained.

4.2. V CrB

V CrB was not detected in H$\alpha$. As there is no significant Galactic confusion, we are quite confident on our upper limit of $3 \times 10^{-4} \, M_\odot$ in atomic hydrogen. For a source losing atomic hydrogen with a mass loss rate of $2.1 \times 10^{-7} \, M_\odot \, yr^{-1}$, it would correspond to a timescale of 2000 years ($\mu = 1.3$).
Fig. 7. Comparison between the H\textsc{i} line profiles obtained on V1942 Sgr and the detached-shell model discussed in Sect. 4.1. Top: average of the two spectra at +2′ (east) and −2′ (west). Middle: average of the two spectra at +11′ (north) and −11′ (south). Bottom: average of the four spectra at 2 arcmin. East & West.
However, the stellar effective temperature is so low (2090 K) that hydrogen should be in molecular form in the atmosphere and outwards (Glassgold & Huggins 1983), until it is photo-dissociated by the interstellar radiation field. To estimate the distance, $R_{\text{ph}}$, at which this happens, we follow the approach of Morris & Jura (1983). Assuming a mean intensity of the ultraviolet radiation between 912 and 1100 Å of $1.9 \times 10^6$ photons cm$^{-2}$ s$^{-1}$ sr$^{-1}$, and that 0.11 of all the absorptions lead to a dissociation, we get $R_{\text{ph}} \approx 410 \, \dot{M}^{1/2}$, with $R_{\text{ph}}$ in pc and $\dot{M}$ in M$_\odot$ yr$^{-1}$. For a mass loss rate of $2.1 \times 10^{-7}$ M$_\odot$ yr$^{-1}$, we obtain $R_{\text{ph}} = 0.2$ pc ($\approx 1.2'$), which corresponds to a dynamical time of $\approx 3 \times 10^4$ years ($V_{\text{exp}} = 6.5$ km s$^{-1}$).

Therefore the non-detection of V CrB in H$\text{i}$ implies that it has not been undergoing mass loss at the present rate for more than $3.2 \times 10^4$ years. Furthermore, when comparing with V1942 Sgr, which is at the same distance, we can state that V CrB has not gone through the same phase of mass loss during the past $5 \times 10^5$ years, because if it had done so it would have been easily detected like V1942 Sgr.

This reasoning assumes that molecular hydrogen is not self-protected within small-scale structures that could develop in the stellar outflow. However the non-detection by IRAS of an extended emission around V CrB (Young et al. 1993a) agrees with our conclusion that mass loss has started only recently.

4.3. Discussion

The V1942 Sgr proper motion measured by Hipparcos is 10.98 mas yr$^{-1}$ in RA and $-5.10$ mas yr$^{-1}$ in Dec. When corrected for solar motion towards apex, and for a distance of 535 pc, it translates to 6.45 mas in RA and $-2.28$ mas in Dec. This implies a motion in the plane of the sky at a velocity of 17 km s$^{-1}$, and at a position angle, PA = 110°. Accounting for the radial velocity, $V_{\text{lsr}} = -33$ km s$^{-1}$, we obtain a 3D space velocity of 37 km s$^{-1}$. The offset with respect to the central star that we find in the H$\text{i}$ map might therefore be an effect of the motion of V1942 Sgr relative to the surrounding
ISM. Such a deformation in H\textsc{i} has already been noted in several cases: Mira (Matthews et al. 2008), RX Lep (Libert et al. 2008), RS Cnc (MR2007 and Libert et al. 2009). GL2006 noted also that many H\textsc{i} sources are offset with respect to the central stars. A visual inspection of the IRAS map at 60\,\mu\,m of V1942 Sgr (Improved Reprocessing of the IRAS Survey: Miville-Deschênes & Lagache 2005) reveals that the image is slightly elongated in RA and shifted west by \(\sim\) 1/2 pixel (\(\equiv 0.75'\)), in agreement with our H\textsc{i} map. Finally, it is worth noting that the central velocity in H\textsc{i} is \(-32.9\pm0.3\) km s\(^{-1}\), whereas in CO it is \(-33.5\pm0.25\) km s\(^{-1}\). The effect is small but consistent with an interaction between the external shell of V1942 Sgr and its local ISM. Shifts in velocity of the H\textsc{i} emission towards the LSR have already been reported in several red giants (GL2006, Matthews et al. 2008).

From their study of circumstellar shells resolved by IRAS, Young et al. (1993b) find that, among nearby AGB stars detected in CO, Miras, in contrast to Semi-Regulars, are in general unresolved. They suggest that the latter have been losing matter for a longer time than the former. In their H\textsc{i} survey of evolved stars GL2006 obtained results that agree with this suggestion. Although their sample was small, several Miras with high mass loss rate could not be detected in H\textsc{i}, whereas SRs were often easily detected. The high quality data that we have obtained on V1942 Sgr and V CrB strengthen the case of SRs undergoing mass loss for a longer time than Miras. One normally assumes that SRs evolve into Miras, and it is puzzling to find no relics of this SR phase around several Miras. SRs might evolve directly in the post-AGB phase, as suggested also by the presence of bipolar outflows which has been reported in several cases (Kahane & Jura 1996, Libert et al. 2009).

Young et al. (1993b) also find that extended sources are observed preferentially around carbon stars and GL2006 obtained a higher rate of detection of carbon stars in H\textsc{i}. However, the case of V CrB seems to suggest that some stars could reach the carbon-rich stage without undergoing substantial mass loss previously. In a systematic investigation of the relations between mass loss and red giant characteristics, Winters et al. (2000) find that the mass loss rate depends critically on stellar parameters such as the effective temperature, which controls the dust formation, and the luminosity, which controls the radiation pressure. V CrB may have switched only recently from the B-regime (with a low and, presently, undetected wind) to the A-regime with a wind at a few \(10^{-7}\) M\(_\odot\) yr\(^{-1}\).

Although both V1942 Sgr and V CrB are carbon stars on the TP-AGB phase, their history of mass loss during the past \(5\times10^5\) years seem to differ radically. If it is correct that the bipolar shaping is a signpost of the end of the AGB, V1942 Sgr (and also the sources with composite CO line profiles) might be on the verge of leaving this phase. Both sources have about the same C/O abundance ratio, 1.12 for V1942 Sgr (Olofsson et al. 1993b) and 1.10 for V CrB (Abia et al. 2001), and the same luminosity, 5200 and 5600 L\(_\odot\), respectively. Also both sources have a low \(^{12}\)C/\(^{13}\)C abundance ratio, 30 for V1942 Sgr (Abia & Isern 1997) and 10 for V CrB (Abia et al. 2001), as compared to \(\sim 40\) for the majority of carbon stars in the AGB phase. The explanation of such low abundance ratios is not known, but could be due to a non-standard mixing process occurring in low-mass stars at the base of the convective stellar envelope (“cool bottom processing”, Nollett et al. 2003).
5. Conclusions

The combination of high velocity resolution CO and H\textsc{i} data is a promising tool to investigate the history of mass loss by evolved stars. The low level of Galactic H\textsc{i} emission and the absence of small-scale structure in this emission have allowed us to obtain H\textsc{i} data of high quality on V1942 Sgr and V CrB with the NRT. We have also obtained high quality CO (1-0) and (2-1) spectra of V1942 Sgr with the IRAM 30-m telescope.

For V1942 Sgr, the CO spectra exhibit composite profiles, that reveal a low velocity wind of \(\sim 10^{-7} \text{M}_\odot \text{yr}^{-1}\) and a high velocity wind, possibly bipolar, of \(\sim 5 \times 10^{-7} \text{M}_\odot \text{yr}^{-1}\). The comparison with the H\textsc{i} spectrum shows that this high velocity wind is recent with an age of at most \(10^4\) years. On the other hand, the low velocity wind appears to have filled a cavity of \(\sim 0.2\) pc in radius and built the detached shell, that was discovered by IRAS, over a period of \(5 \times 10^5\) years. Follow-up observations with the VLA and ALMA would help to improve this scenario, or possibly lead to a new scheme. The narrowness of the H\textsc{i} line profile in V1942 Sgr brings new evidence that AGB stellar winds are slowed down by their surrounding medium as surmised by Young et al. (1993b).

For V CrB, the CO spectra that have been published reveal an outflow with expansion velocity, 6.5 km s\(^{-1}\), and mass loss rate, \(2.1 \times 10^{-7} \text{M}_\odot \text{yr}^{-1}\). The non-detection in H\textsc{i} of V CrB sets an upper limit of \(3.2 \times 10^4\) years for the age of this outflow. In such case of a star with low effective temperature, molecular hydrogen data are obviously needed to constrain better the history of mass loss.

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