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HI AND CO STUDY OF CIRCUMSTELLAR ENVIRONMENTS

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Abstract. Circumstellar shells around red giants are built over long periods of time that may reach several 10^6 years. They may therefore extend over large sizes ($\sim$ 1 pc, possibly more) and different complementary tracers are needed to describe their global properties. We have undertaken a programme designed to gauge the properties of matter in the external parts of circumstellar shells around AGB stars and to relate them to those of the central sources. We present 21-cm H I and CO rotational line data obtained on an oxygen-rich semi-regular variable, RX Lep. These emissions indicate a stellar outflow at a velocity of $\sim$ 4 km s^{-1} and a rate of $\sim 2\ 10^{-7}$ M$_\odot$ yr^{-1}, for a duration of $\sim 5\ 10^4$ years. The modeling of the H I line-profiles obtained at several different positions shows that the outflow is slowed down by the ambient ISM, and that the external parts of the circumstellar shell are dominated by gas at $\sim$ 200 K, as in the well-known "detached shell" around the carbon star Y CVn. The H I source is elongated in a direction opposite to the proper motion of the central star, as it is presently being discovered in more and more cases.

1 Introduction

Low and intermediate mass stars ($\sim$ 0.8 to 6 M$_\odot$, on the zero-age main sequence) lose a large part of their mass ($\sim$ 0.2–5 M$_\odot$) during their evolution from the main sequence until their final fate, as white dwarfs of $\sim$ 0.6–1 M$_\odot$. This process is believed to take place mainly during the asymptotic giant branch (AGB) phase, although for the low mass stars ($\sim$ 0.8 to 2 M$_\odot$) a significant fraction ($\sim$ 0.2 M$_\odot$) might be lost during the first red giant branch phase. Therefore AGB stars are surrounded by expanding circumstellar shells that are built during several 10^4 years or more, and that may extend over large distances. Molecular line emissions show that some sources may reach a size of the order of 0.1 pc in radius (e.g. IRC +10216, Fong et al. 2003). This is certainly a lower limit, since molecular species are expected to be photo-dissociated by the ambient interstellar radiation field. Indeed, IRAS has revealed that many AGB stars are associated with extended emissions at 60 and 100 μm (Young et al. 1993a) indicative of sizes that could reach 1 pc. However the continuum infrared emission cannot provide clues on the kinematics in these external parts of circumstellar shells.

With this line of thought, and taking advantage of the refurbishment of the Nançay Radiotelescope, we started in 2001 a systematic observing programme aimed at using the atomic hydrogen line at 21-cm as a diagnostic tool for the circumstellar environment around late type giants. The idea of observing H I in late-type giants was not new, but the attempts to detect it were until recently largely unsuccessful (e.g. Zuckerman et al. 1980), so that only one AGB star, Mira, had been detected (Bowers & Knapp 1988). This was surprising because hydrogen should be the most common element in late-type star ouflows. For a stellar effective temperature, $T_{\rm eff}$, larger than 2500 K hydrogen should be in atomic form from the atmosphere outwards (Glassgold & Huggins 1983). On the other hand, for $T_{\rm eff} < 2500$ K, it should be in molecular form from the atmosphere out to a radius, typically 0.1 pc, at which H_2 is expected to be photo-dissociated by the interstellar radiation field, unless self-shielding preserves it in clumps.

In this contribution we present the results that we have obtained on one of the best observed sources in our programme, RX Lep. A complete report on this source can be found in Libert et al. (2008).

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2 RX Lep

RX Lep is an oxygen-rich semi-regular variable of type M6III (HR 1693), probably in the early-phase of the AGB. The central star effective temperature has been estimated to be 3300 K by Dumm & Schild (1998). Therefore following Glassgold & Huggins (1983) we expect that circumstellar hydrogen is mostly in atomic form.

The parallax measured by Hipparcos (Perryman et al. 1997) places RX Lep at 137 pc from the Sun. The proper motion, corrected for the Sun motion towards the apex (Dehnen & Binney 1998), is 35 mas yr^{-1} in right ascension (RA) and 58 mas yr^{-1} in declination (Dec). This translates to a motion in the plane of the sky of 44 $km\,s^{-1}$ in the North-East direction (PA $\sim 31°$).

With the SEST we have detected RX Lep in the CO (2-1) line. We derive a stellar radial velocity $V_{lsr} =$ 28.9 $km\,s^{-1}$, in agreement with previous data obtained in the optical range. From the line profile and using the method of Winters et al. (2003), we obtain an expansion velocity, $V_{exp} = 4.2$ $km\,s^{-1}$, and a mass-loss rate, $\dot{M} \sim 1.7\ 10^{-7}\ M_{\odot}\ yr^{-1}$. Combining with the Hipparcos proper motion, we get a 3-D space velocity of 53 $km\,s^{-1}$.

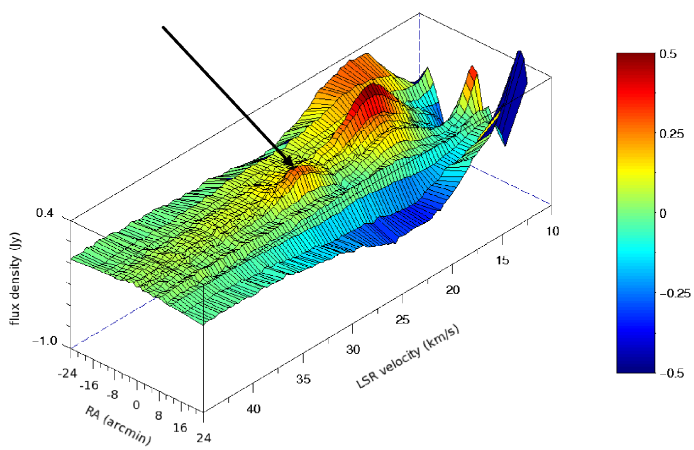

Fig. 1. 3-D position-velocity representation of the H I flux density; West is to the left. The arrow points to the expected location of the source.

RX Lep was observed in the H I line at 21 cm with the Nançay Radiotelescope between February 2005 and February 2008. At 21 cm, the telescope beam has an FWHM of 4′ in RA and 22′ in Dec. We have mapped the emission in the position-switch mode with steps of 2′ in RA and 11′ in Dec, i.e. half the beam FWHM in both directions. The main difficulty in observing the H I emission from circumstellar shells arises from the overlapping interstellar emission (see Gérard & Le Bertre 2004) and this is probably one of the main reasons for the lack of success in previous investigations (the other one being the selection of cold targets in which hydrogen is mostly molecular). We have developped a new approach in order to analyze this confusion, and to extract genuine circumstellar emission (Libert et al. 2008). In Fig. 1, we show a position-velocity diagramme in which the RX Lep emission can be discriminated against the interstellar emission. However, this has been possible only because in the direction of RX Lep and in the spectral range around its radial velocity the confusion by interstellar emission stays moderate, and also because the source is relatively bright.

The resulting spectral map is presented in Fig. 2. RX Lep is clearly detected on the central position and at several offset positions. The line profile is quasi-gaussian with an FWHM = 3.8 $km\,s^{-1}$, and a central velocity, $V_{lsr} = 28.8$ $km\,s^{-1}$, in excellent agreement with the velocity derived from the CO line. The profile does not seem to vary significantly with position. In our survey of H I emission, quasi-gaussian line profile is the rule rather than the exception (Gérard & Le Bertre 2006). This type of line-profile is an indication of a slowing down of the stellar outflows in the external part of circumstellar shells. For instance the emission from the carbon star Y CVn is well reproduced by a model in which the stellar outflow is expanding up to a distance at which it is slowed down by the surrounding circumstellar matter that has been accumulating over time (Libert et al. 2007a, b). This circumstellar matter forms a slowly expanding shell (Young et al. 1993b), sometimes referred to as a "detached shell". The same modeling provides a satisfactory fit to the line profiles obtained towards RX Lep, when assuming that the central star has undergone a constant outflow of matter ($V_{exp} = 4.2$ $km\,s^{-1}$,

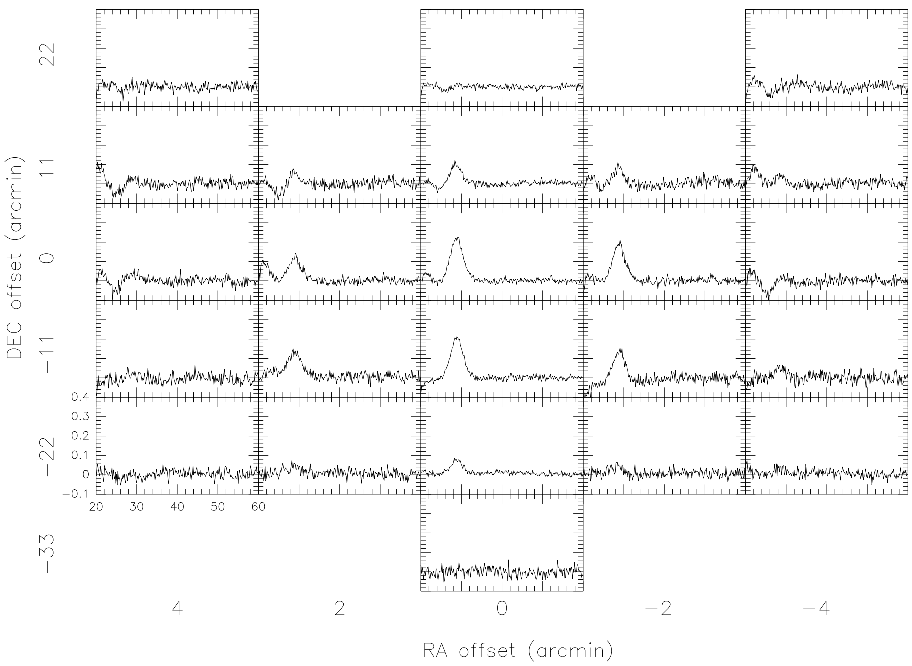

Fig. 2. H I map of RX Lep. The steps are 2′ in RA and 11′ in Dec.

$\dot{M} = 1.7\ 10^{-7}\ M_\odot\,yr^{-1}$) for 4.3 10^4 years.

In contrast to Y CVn, for which the spatial distribution of the emission is roughly circular and centered on the central star, we find that for RX Lep it is clearly offset to the South-West and elongated along the North-South direction. This can be seen on the map by comparing the flux on the central position to that 2′ West, or that 11′ South. Assuming a gaussian distribution of the brightness, we estimate the size (FWHM) of the source at 2.3′ in the East-West direction and 15′ in the North-South direction, and the offset with respect to the central star at −0.4′ in RA and −4.4′ in Dec. Therefore the source seems elongated and offset in a direction which is approximately opposite to that given by the proper motion.

3 Discussion

There is growing evidence that the external parts of circumstellar shells are shaped by their motion relative to the ambient ISM. Using the VLA Matthews & Reid (2007) have found that the H I emission discovered recently around RS Cnc (Gérard & Le Bertre 2003) is elongated in a direction opposite to its proper motion. The same morphology is apparent in Mira (Matthews et al. 2008). The latter case is particularly interesting because GALEX has discovered in the FUV (∼ 1500 Å) a 2-degree long tail associated to Mira (Martin et al. 2007). The H I emission correlates with the FUV on large scales, but not on smaller scales ($\lesssim$1′). Finally, Ueta et al. (2006) have imaged with Spitzer the nebula discovered by IRAS around R Hya (Young et al. 1993a). At 70 μm it has a parabolic structure with a summit located ahead of the star in the direction of the space motion, suggesting an association with a bow-shock interface. This interpretation is corroborated by the presence of Hα emission co-spatial to the nebula. Wareing et al. (2006) have modeled this source and predicted the existence of a tail of ram-pressure-stripped AGB material stretching downstream.

All these elements suggest that the elongated shape of RX Lep is connected to its motion through the ISM. Villaver et al. (2003) have performed numerical simulations of the evolution of a low mass star moving through the ISM. They find that circumstellar shells are progressively distorted and become elongated in the direction of motion (e.g. left panel in their figure 1). There is perhaps a 25° difference between the RX Lep proper motion and the elongation of the shell. It might be due to the intrinsic motion of the local ISM. Such intrinsic motions have already been identified in the solar neighborhood (Lallement et al. 1995).

Based on this discussion, we propose for RX Lep the schematic description shown in Fig. 3. The central star is losing matter at a rate of ∼ 2 $10^{-7}\ M_\odot\,yr^{-1}$. The outflow is slowed down at a termination shock, ∼ 0.02 pc

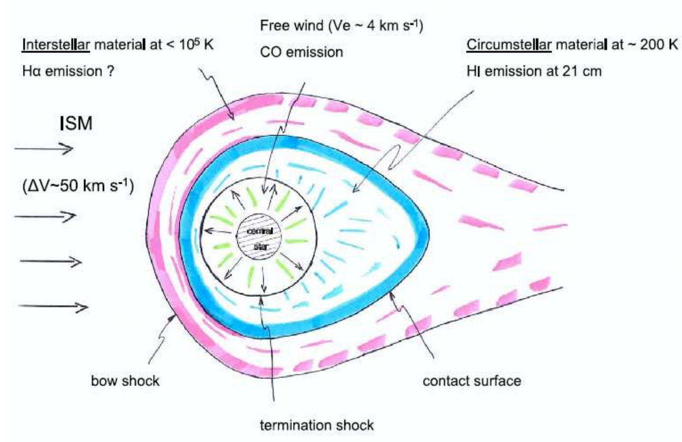

Fig. 3. Cartoon description of the RX Lep circumstellar environment (adapted from Villaver et al. 2003, cf left panel in their figure 1). The drawing is not to scale; the H I emission comes from an elongated region of $\sim 0.1\,\mathrm{pc} \times 0.7\,\mathrm{pc}$.

from the central star, leading to the formation of a "detached shell" of circumstellar matter at $\sim 200\,\mathrm{K}$, which, except for the shape, looks quite similar to that of Y CVn. The H I emission that we have detected comes predominantly from this region that is elongated due to the space motion of the central star. Outside the contact surface we have a region dominated by the interstellar material that has been flowing through the bow shock and that we probably cannot detect at 21 cm because it has been excited to a temperature of $\sim 50\,000\,\mathrm{K}$.

4 Conclusion

Our previous study of the H I emission around Y CVn has illustrated how the ambient ISM can slow down stellar outflows (Libert et al. 2007a, b). The present study illustrates a second effect, i.e. the shaping of circumstellar shells by their motion through the ISM. This second effect was predicted by Villaver et al. (2003). The discovery by GALEX of an extended tail associated to Mira shows that this shaping can lead to a disruption of the external regions of circumstellar shells, and ultimately to the injection of circumstellar material in the ISM.

The circumstellar environment of RX Lep provides an excellent illustration of this shaping phenomenon. The combination of CO and H I data was essential to get a global description of this circumstellar shell.

In our H I survey (Gérard & Le Bertre 2006) we have found several other cases of asymmetrical distribution of the intensity. The effect seems to be general and therefore the 21-cm line provides a useful tracer of the dynamic interaction between the external regions of circumstellar shells and the ISM.

Acknowledgements
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