Atomic hydrogen in AGB circumstellar environments. A case study: X Her

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ABSTRACT
We report the detection of the H I line at 21 cm from the circumstellar shell around the AGB star X Her using the position-switching technique with the Nançay Radio Telescope. At the star position the line shows 2 components: (i) a broad one (FWHM ∼ 13 km s⁻¹) centered at −72.2 km s⁻¹, and (ii) a narrow one (FWHM ∼ 4 km s⁻¹) centered at ∼ −70.6 km s⁻¹. Our map shows that the source associated to the broad component is asymmetric with material flowing preferentially towards the North-East. This source extends to ∼ 10⁶ (∼ 0.4 pc) from the star in that direction. On the other hand, the narrow component is detected only at the star position and indicates material flowing away from the observer. The total mass of atomic hydrogen is ∼ 6.5 × 10⁻³ M☉ which, within a factor 2, agrees with the estimate obtained from IRAS data at 60 μm.

Key words: stars: AGB and post-AGB – (stars:) circumstellar matter – stars: late-type – stars: mass-loss – (ISM:) planetary nebulae: general – radio lines: stars.

1 INTRODUCTION
Low and intermediate mass stars (1 < M/M☉ < 6-8) lose most of their mass during their evolution on the first red giant branch (RGB) and on the asymptotic giant branch (AGB). This phenomenon is known mainly from indirect arguments. One of the reasons is that mass loss develops irregularly on very different timescales, some of which may be short compared to the stellar evolution, e.g. down to a few years. It has therefore been difficult to establish a balance of the mass loss for the various types of stars. Furthermore, most of the ejected matter is in the form of hydrogen. Although very abundant this element is difficult to detect in circumstellar shells. In any direction on the sky, the H I line at 21 cm is dominated by galactic interstellar emission (Hartmann & Burton 1997). On the other hand, the low excitation rotational lines of molecular hydrogen are in the infrared range (28 and 17 μm) and difficult to observe from the ground.

Glassgold & Huggins (1983, GH1983) have discussed the nature of circumstellar hydrogen. For stellar effective temperatures (T eff) larger than 2 500 K, hydrogen should be mainly in atomic form. On the other hand for T eff ≤ 2 500 K hydrogen should be molecular in the upper atmosphere and in the inner circumstellar shell. Molecular hydrogen will eventually be photo-dissociated by the interstellar radiation field (ISRF) in the outer circumstellar shell, at distances of the order of typically 10¹⁷ cm.

The past attempts to detect the H I line at 21 cm from mass losing red giants have failed, except on Mira (Bowers & Knapp 1988). Nevertheless, after the renovation of the Nançay Radio Telescope (NRT), we succeeded in detecting H I from various circumstellar shells using a new observing technique (Le Bertre & Gérard 2001; Gérard & Le Bertre 2003, Paper I; Le Bertre & Gérard 2004, Paper II). The reason is that this telescope is well adapted to the detection of extended low-level surface brightness sources and that we now systematically explore the spatial distribution of the emission by using the position-switching technique with different beam offsets. Indeed the circumstellar emission is extended and, for closely sources, may reach a size of ∼ 1 degree over the sky (Paper II).

The emission line at 21 cm is a particularly useful tracer of circumstellar shells because its flux translates directly into a quantity of hydrogen (knowing the distance, which is relatively easy for AGB sources). Also hydrogen is a major component of red giant circumstellar shells so that the conversion to total mass is less liable to abundance ratio uncertainties. Furthermore, atomic hydrogen is not easily photo-ionized by the ISRF, and can be used as a probe of the most external parts of the shells where stellar winds interact with the Interstellar Medium (ISM). Indeed our H I spectra on one source (Y CVn) show the effect of the slowing-down of circumstellar material by the surrounding ISM (Paper II).
Young et al. (1993b) also found that the IRAS data at 60 μm imply a slowing-down in the outer shells of AGB stars. In this paper, we show spatially resolved data on the environment of the red giant X Her. We have developed a model of H1 emission and compare its predictions with our data.

2 SOURCE PROPERTIES

The position of the star X Her (IRAS 16011+4722) has been determined by Hipparcos (Perryman et al. 1997): α2000.0 = 16h 02m 39.17s, δ2000.0 = +47° 14.25.28"$, which translate to galactic coordinates: b1l = 74.46", b1l = 47.79°. The proper motion, $-68$ and $+64$ mas yr$^{-1}$ in equatorial coordinates, is towards the North-West.

2.1 stellar properties

The star is a long-period semi-regular variable (SRb) with a period of 95.0 days (General Catalogue of Variable Stars). Light variations are small ($ΔV < 0.5$ mag.) and irregular. A period analysis of V and I photometric data over 1600 days (Lebzelter & Kiss 2001) yields a main period of 101 days and several ill-defined longer ones. It has a variable spectral type, from M6 to M8. Dumm & Schild (1998) estimate the stellar effective temperature at 3 161 K, and Dyck et al. (1998) at 3 281 ± 130 K. Therefore we adopt $T_{\text{eff}} \approx 3 200 K$ and, according to GH1983, atomic hydrogen should be the dominant species in the stellar atmosphere. The parallax has been measured by Hipparcos, 7.26 ± 0.70 mas. In the following we adopt a distance of 140 pc.

For a K magnitude of $-1.42$ (Jura & Kleinmann 1992) and a red-giant bolometric correction of 2.7 (Le Bertre et al. 2001), the luminosity should be around 4 800 L⊙. This clearly places X Her on the AGB. However it should not be strongly evolved as searches for technetium failed (Little et al. 2001), the luminosity should be around 4 800 L⊙, respectively. Olofsson et al. (2002) obtain similar results, but the expansion velocities are smaller (2.2 and 6.5 km s$^{-1}$, respectively) because they account for the effect of turbulent broadening.

Nakashima (2005) has produced a map of the circumstellar environment of X Her in the CO (1-0) line with the BIMA interferometer. Like KJ1996 he finds that the redshifted emission is offset to the North-East, and the blueshifted emission, to the South-West. He estimates the position angle of the bipolar structure axis at 61° in the plane of the sky. The structure associated to the narrow spectral feature is tentatively ascribed to a rotating disk.

Gonzalez-Delgado et al. (2003) have observed the SiO (2-1) thermal emission from X Her. Like for CO, the line-profile is composite with 2 components whose central velocities and widths agree with the CO ones (Table 1).

X Her was detected neither in the OH maser main lines (Lewis et al. 1995), nor as an H2O maser at 22 GHz (Lewis 1997).

3 OBSERVATIONS

The NRT is a clear aperture radio-telescope with a tiltable flat reflector illuminating a fixed sphere. The aperture is rectangular with effective dimensions 160 m × 30 m (as long as the declination is smaller than 53°, which is the case of X Her). The beam has thus a HPBW of 4′ in right ascension and 22′ in declination. The point source efficiency is 1.4 K Jy$^{-1}$ at 21 cm and the beam efficiency, measured on the Moon, 0.65. Sources are tracked for about one hour around meridian by moving a focal carriage bearing the receivers (the main collecting fixed mirror being over-sized in right ascension). Stray radiation and side-lobes have been minimized through a careful design provided by CSIRO (van Driel et al. 1996; Granet et al. 1999) and can be readily evaluated by examining elementary scans obtained at different hour angles. Drift scans obtained on radio-continuum point sources show that the beam profile is as expected from an unobstructed rectangular aperture, with secondary lobes < 5%. However, internal reflections between the horn and...
the spherical mirror may occur and produce an oscillation in the spectra with a period of 536 kHz (or 113 km s\(^{-1}\) at 1420 MHz). This artefact, usually called “specular reflection”, is exactly removed when using the position-switch mode of observation, whereas, in the frequency-switch mode, it can be kept down to 0.15 K by selecting an offset equal to a multiple of 536 kHz. In principle, there is no stray radiation for sources with declination smaller than 53\(^\circ\), above which the tiltable plane mirror starts to diaphragm the main beam of the fixed spherical mirror. However, we may get direct spill-over from the sky around the spherical primary reflector due to an incomplete apodisation inside the focal system. Continuum emission is perfectly removed in both modes, but line emission, if any, may remain when using the frequency-switch mode.

For the observations we adopted the same approach as for EP Aqr and Y CVn (Paper II). A frequency-switch (f-switch) spectrum was first acquired on the source (as defined by the star optical position) to estimate the H\(_i\) background emission and thus check the feasibility of the project. Galactic H\(_i\) emission is clearly detected at \(V_{lsr} > -50\) km s\(^{-1}\) (Fig. 1). The galactic emission stays below 0.5 K in the velocity range expected for X Her. The H\(_i\) emission from X Her itself can be suspected directly on this f-switch spectrum between \(-80\) and \(-60\) km s\(^{-1}\) as an excess of about 0.1 K around \(-70\) km s\(^{-1}\).

However the Leiden-Dwingeloo “Atlas” of Hartman & Burton (1997) shows H\(_i\) emission at \(\sim 0.6\)\(^\circ\) North-West of X Her in the range \(-100\) to \(-60\) km s\(^{-1}\). The Dwingeloo telescope has a HPBW of 36\(^\prime\) and the Atlas data were observed at 0.5\(^\circ\) spacings in both galactic coordinates. This cloud (hereafter Cloud I, \(l = 75.0\)\(^\circ\), \(b = 47.5\)\(^\circ\)) is responsible for a contamination of our data North of X Her. On this Atlas one sees also a second source (Cloud II, \(l = 77.0\)\(^\circ\), \(b = 48.5\)\(^\circ\)), but further to the North-West (\(\sim 2\)\(^\circ\)). These 2 sources seem aligned with a large arc-shaped structure that is above the galactic plane and stretches from \(l = 200\)\(^\circ\) to \(l = 80 - 100\)\(^\circ\). However both clouds are compact (\(\Theta \sim 1\)\(^\circ\)) and seem more likely related to the compact high-velocity clouds (CHVCs) discussed by de Heij et al. (2002). CHVCs are compact and isolated on the sky with a core-halo structure. The X Her position does not fall exactly on one of the Atlas grid points, but H\(_i\) emission, at the same velocity as seen in Fig. 1 is detected at a 0.1 K level on the nearest point. This emission may come from a diffuse halo associated to Cloud I as those detected by de Heij et al. around several CHVCs.

Incidentally a feature at \(+40\) km s\(^{-1}\), that the Leiden-Dwingeloo Atlas do not show, is visible in our spectrum. It is an artefact due to galactic H\(_i\) emission, around \(\sim 16\)\(^\circ\) in right ascension and \(\sim 35\)\(^\circ\) in declination, coming directly into the focal system from around the spherical primary mirror. We have checked that this artefact is perfectly removed when using the position-switching technique.

The spectra obtained in the position-switch mode with the star placed in the central beam are presented in Fig. 2. The spectral resolution corresponds to 0.16 km s\(^{-1}\). The off-positions are taken at \(\pm n\) NRT beams in the East-West direction, with \(n = 1, 2, 3, 4\) and 8. The symmetrical off-positions are averaged and subtracted from the spectrum obtained on the source, yielding a source spectrum corrected from an underlying background interpolated successively between \(+4\)\(^\circ\), \(+8\)\(^\circ\), \(+12\)\(^\circ\), \(+16\)\(^\circ\) and \(+32\)\(^\circ\). This procedure is ef-

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**Table 1. Observational results of X Her molecular radio line emissions taken from the literature.**

| line | \(V_{lsr}\) | \(V_{exp}\) | \(V_{lsr}\) | \(V_{exp}\) | Reference |
|------|------------|------------|------------|------------|-----------|
| CO 2-1 | \(-72.8 \pm 0.8\) | \(8.5 \pm 1.0\) | \(-73.2 \pm 0.4\) | \(3.2 \pm 0.5\) | Knapp et al. (1998) |
| CO 3-2 | \(-73.2 \pm 0.5\) | \(9.0 \pm 1.0\) | \(-73.1 \pm 0.3\) | \(3.5 \pm 1.4\) | Knapp et al. (1998) |
| CO 3-2 | \(-73.0\) | \(8.0\) | \(-73.1\) | \(3.1\) | Kerschbaum & Olofsson (1999) |
| SiO 2-1 | \(-73.0\) | \(8.0\) | \(-72.0\) | \(2.2\) | González-Delgado et al. (2003) |
Figure 2. Upper panel: Spectra obtained in the position-switch mode with the source centered (“on”) and the off-positions taken in the East-West direction at ±4′, ±8′, ±12′, ±16′ and ±32′ (thin lines), and baseline-subtracted f-switch spectrum (thick line). For clarity the spectra are successively shifted upwards by 0.05 Jy and labelled with the corresponding offsets. Lower panel: average of the 3 position-switch spectra (±4′, ±8′, ±12′) presented in the upper panel.

Figure 3. X Her position-switch spectra (thin lines) and modelled spectra (Sect. 5.2; thick lines). From bottom to top: (i) the off-position is taken at +4′, (ii) the off-position is taken at −4′, (iii) the off-positions at + and −4′ are averaged.

is hardly present at ±1 beam and grows as the beam throw increases. Its intensity reaches a maximum at ±3 beams and stays constant beyond. This is confirmed by the comparison with the f-switch spectrum displayed at the top of Fig. 2 for which a third-order baseline fitted to the −100, −83 km s\(^{-1}\) and −65, −50 km s\(^{-1}\) ranges has been subtracted (see Fig. 4 lower panel). The broad component is detected on this baseline-subtracted f-switch spectrum with the same centroid velocity and the same intensity as in the ±12′ position-switch spectrum. While our symmetric East-West position-switching technique is efficient in removing the linear gradient of the background H\(_i\) emission, the quadratic term stays and is no longer negligible at large beam throws. This is particularly clear on Fig. 2 (top) at ±32′ where extraneous wings appear in emission on the blue side and in absorption on the red side of the X Her profile. The negative signature around −60 km s\(^{-1}\) is probably connected to the rising main galactic H\(_i\) emission (see Fig. 1). For the display in the lower panel of Fig. 2 we have averaged only the spectra up to ±3 beams. From these position-switch spectra one can estimate a source size \(\phi \lesssim 20′\).

However, the brightness distribution is very asymmetric as can be seen on Fig. 3 where the reference spectra at ±1...
beam East and West are subtracted separately. One notes that Comp. 1 is extended East and that it is even more intense at 1 beam East than on the star position.

The differences between the 2 reference spectra (n“East”−n“West”) confirm these results: Comp. 1 is visible at 1 and 2 beams East and Comp. 2 is absent in all the reference spectra (Fig. 3). No emission is detected West of the central position. We stress that, in contrast to what we have done in Paper II, these differences are not normalized. One can note that the galactic H\textsc{i} have done in Paper II, these differences are not normalized.

We have also explored the H\textsc{i} brightness distribution in the North-South direction (Fig. 4) by steps of $11''$ (i.e. 1/2 beam). There is no emission South of X Her. Comp. 1 is detected at 1/2 beam North and probably also at 1 beam North. This indicates that Comp. 1 is offset towards the North. Unfortunately, the northern spectra are contaminated by emission around $-80$ km s$^{-1}$.

In Fig. 5 we present a “map” of the H\textsc{i} emission around X Her. To construct this map we have used the reference spectra obtained at 3 beams East of X Her, because the East-West extent of the source is limited to $\pm 10''$ and because the reference spectra West of X Her are contaminated by Cloud I. Noteworthily, this cloud shows up clearly around $-11''$ and $-22''$. The off-positions are taken at $\pm 12''$ (3 beams). For clarity the spectra are successively shifted by steps of 0.1 Jy and labelled with the corresponding positions in declination.

### 4 DESCRIPTION OF THE ENVELOPE MODEL

In order to guide the interpretation of our spatially resolved spectra we have performed numerical simulations of the 21 cm (1420 MHz) emission from an H\textsc{i} circumstellar envelope. We assume that the matter is flowing radially from the central star. Because $h\nu \ll kT$, the brightness temperature is assumed to be directly proportional to the H\textsc{i} column density. This hypothesis is valid as long as the hydrogen temperature is larger than 10 K. The emission is also supposed to remain optically thin ($\tau \ll 1$). For a constant H\textsc{i} mass loss of $10^{-6}$ M$_\odot$ yr$^{-1}$ and a constant expansion velocity of 5 km s$^{-1}$, this hypothesis would break down at $10^{18}$ cm from the central star, or 0.08$''$ at 140 pc (i.e. much less than the NRT beam size).

The emission from the shell is convolved with the telescope response. First, in order to perform simple checks or tests, we adopt a constant response within an elliptical beam of minor axis $4''$ in the East-West direction and major axis $22''$ in the North-South direction (hereafter “boxcar” response). Second, for a better fit to the observations, we
adopt the response of a rectangular aperture which is given by the product:

$$R(x, y) = \left( \frac{\sin x}{x} \right)^2 \times \left( \frac{\sin y}{y} \right)^2$$  \hspace{1cm} (1)

normalized such that the FWHM is 4' in right ascension and 22' in declination (hereafter “sinc” response).

4.1 spherical geometry

For a spherically symmetric shell, the density and the velocity depend only on r, the distance to the central star. In Fig. 7 (top) we show the results of our model for a source with a constant expansion velocity and unresolved by the telescope beam ($\phi = 4'$). As expected, the line profile is rectangular for the boxcar response and no flux is detected at the position offset by 4' in the East-West direction. When the more realistic sinc response is considered, the centre of the profile is depressed and the missing flux is obtained at an offset of 4' from the sidelobe of the beam profile. If the source is extended ($\phi = 8'$, bottom), a double-horn profile is obtained. The absence of such profiles in our data indicates that the velocity is not constant in the regions probed by our observations (cf. the discussion in Paper II).

In Fig. 8 we show the line profiles obtained for a model with a velocity decreasing linearly with r, the mass loss rate in H\textsubscript{i} being kept constant. The ISM will unavoidably slow down the expansion velocity once the densities become comparable (e.g. Young et al. 1993b). The velocity and mass loss rate laws are arbitrary as the purpose is only to illustrate the effect of a velocity gradient on the line-profile. The time to build such an hypothetical shell would be 73.1 $10^3$ years, as compared to 9.5 $10^3$ years in the V=constant case (Fig. 7, bottom).

4.2 non-spherical geometry

As there is evidence from our H\textsubscript{i} data and from CO rotational lines data that the X Her shell is not spherically symmetric, we have generalised the geometry of the model to the axi-symmetric case. The density and the velocity are defined in a source reference frame that can be orientated in any direction with respect to the line of sight (but we keep the hypothesis that the velocity is radial). We have...
checked on spherical cases that we find the same results as in the previous Section (although with considerably increased computing time).

As an example we give in Fig. 7 the results from a hemispheric source with the same parameters as those used for the top panel of Fig. 4. The centre of the corresponding sphere is placed at the centre of the beam. The axis of the hemisphere is inclined by an angle $i$ with respect to the plane of the sky (the axis is in the plane of the sky and pointing to the West for $i = 0^\circ$). The flux is one half of that obtained from a complete sphere. One notes that in the boxcar case the profile is rectangular for $i = 0^\circ$ and for $i = +/−90^\circ$; in the latter cases the centroid velocity is shifted by $−/+/V_{\text{exp}}/2$.

1 More generally a rectangular profile is obtained for an unresolved circular cone whose axis is perpendicular to the plane of the sky.

5 APPLICATION TO X HER

In the following, we adopt a “sinc” response with parameters corresponding to the NRT at 21 cm. We also adopt a stellar radial velocity of $−73.1$ km s$^{-1}$ (Hinkle et al. 2002).

5.1 spherical model

The source is assumed to have 2 shells with outflow velocities decreasing from the central star (Paper II). The two shells are invoked to explain the spectrally broad component which is spatially resolved (Comp. 1), and the spectrally narrow component which is not spatially resolved (Comp. 2).

For the inner shell we adopt an internal radius corresponding to $0.1'$ and an external one, to $1'$, with a velocity decreasing linearly from $3$ km s$^{-1}$ to $1$ km s$^{-1}$. The value $3$ km s$^{-1}$ is a compromise between the estimates of K1998 and KJ1996. The flux of matter is kept constant and corresponds to $0.3 \times 10^{-7}$ M$_\odot$ yr$^{-1}$ in atomic hydrogen, in agreement with the estimate of K1998 for the total mass loss rate of the slow wind.

For the outer shell we adopt an internal radius of $2'$ and an external one, to $10'$, with a velocity decreasing from $10$ to $2$ km s$^{-1}$. The starting value corresponds to the estimate obtained from the CO profiles by K1998 and KJ1996. The flux of matter is set to $0.7 \times 10^{-7}$ M$_\odot$ yr$^{-1}$ in H$_1$.

The fit to the H$_1$ line profile obtained on the central position (Fig. 10) is almost satisfactory, although Comp. 2 is clearly red-shifted by about $2$ km s$^{-1}$ with respect to the model narrow emission coming from the inner shell. Furthermore, as expected, the profiles obtained away from the star position (not shown here) are not correctly reproduced. The model gives too much flux West and too little East. The same effect is noted in the North-South direction.
The emission associated to Comp. 1 can be understood with a source (Source (1)) which is roughly symmetric with respect to the plane of the sky because the centroid velocity corresponds to the star radial velocity. But it has to be strongly weighted towards the North-East. We adopt a circular cone with an opening angle of $2 \times 75^\circ$ and axis in the plane of the sky ($i = 0^\circ$) at a position angle, $PA = 45^\circ$. The inner limit is defined by a sphere of radius, $2'$, and the outer one by a sphere of radius, $10'$. The velocity is assumed to decrease linearly from $12 \text{ km s}^{-1}$ at the inner limit, to $2 \text{ km s}^{-1}$ at the outer limit.

The emission associated to Comp. 2 is clearly redshifted with respect to the stellar radial velocity. This can be understood with material flowing within a hemisphere (Source (2)) whose axis is orientated in the direction opposite to the observer ($i = -90^\circ$; see Fig. 10). The inner radius is set at $0.1'$ and the outer one at $1'$; the expansion velocity is taken to decrease from $5 \text{ km s}^{-1}$ at $0.1'$, to $4 \text{ km s}^{-1}$ at $1'$.

For both sources the flux in atomic hydrogen is assumed to be constant. A fair adjustment to the data (see Fig. 10) is obtained by selecting fluxes corresponding to $0.74 \times 10^{-7} \text{ M}_\odot \text{ yr}^{-1}$ (Source (1)) and to $0.70 \times 10^{-7} \text{ M}_\odot \text{ yr}^{-1}$ (Source (2)). With the parameters adopted for Sources (1) and (2), the times to build these sources are $57 \times 10^3$ and $810^3$ years, resp., which translates to hydrogen masses of $4.2 \times 10^{-3}$ and $5.6 \times 10^{-4} \text{ M}_\odot$. This is a factor 1.3 lower than the direct estimate from the map (Sect. 3), probably because our model tends to underestimate the flux density towards the East (Fig. 10).

### 5.2 non-spherical model

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### 6 DISCUSSION

The position-switch spectra presented in Sect. 3 show a compact H1 emission approximately centered on the X Her position and covering the range $-85$ to $-60 \text{ km s}^{-1}$. The line-profile can be decomposed in 2 components: (i) a broad one (FWHM $\sim 13 \text{ km s}^{-1}$) centered at $-72.2 \text{ km s}^{-1}$ (Comp. 1), and (ii) a narrow one (FWHM $\sim 4 \text{ km s}^{-1}$) centered at $-70.6 \text{ km s}^{-1}$ (Comp. 2). The emission associated to Comp. 1 has a size of about $10'$ and is offset to the East and to the North by about $4'$. Comp. 2 is not resolved spatially ($\phi \leq 4'$) and is detected only at the star position. We cannot strictly exclude that this emission traces a sub-structure within the halo of Cloud I. However, the radial velocity of Comp. 1 and its spectral extent closely match those of X Her in CO and SiO (Table 1), and Comp. 2 is, within one beam ($\pm 2'$), coincident with this star. Furthermore CO has been detected in the direction of X Her at a velocity that fits the optical one and the interferometric map obtained with BIMA (Nakashima 2005) shows a spatial coincidence to within a fraction of an arcsec. Finally an IRAS emission extended at $60 \mu\text{m}$ ($\phi = 12'$) is associated to X Her (Young et al. 1993a). Conversely CO emission is rarely associated to HVCs and, with our position-switch observing procedure, we have now found H1 emission in the directions of more than 20 AGB sources in the same velocity range as in CO. Therefore, it seems very probable that the H1 emission detected with our position-switching technique is tracing matter belonging to the circumstellar environment of X Her and we...
The H\textsubscript{I} emission at 21 cm from X Her

Figure 11. H\textsubscript{I} spectrum obtained with the NRT on the star position (thin line) and modelled spectrum (Sect. 5.2; thick line). The modelled spectrum is the sum of 2 components: (i) a broad one (dotted line) produced by material flowing preferentially in the plane of the sky towards the North-East, and (ii) a narrow one (dash-dotted line) produced by material flowing away from the observer. The vertical line indicates the star radial velocity ($V_{\text{lsr}} = -73.1$ km s\textsuperscript{-1}).

Figure 12. Comparison between the X Her spectra obtained at various positions (Fig. 6; thin lines) and the modelled spectra (Sect. 5.2; thick lines). Left panel: spectra at 11' North; centre panel: spectra at the X Her declination; right panel: spectra at 11' South.
adopt this viewpoint in the following. On the other hand,
we do not consider that Clouds I and II are related to X
Her (for instance through past ejection-events) because its
proper motion is towards the North-West, i.e. towards them.
These 2 clouds may be each at any distance from the Sun
along closeby lines of sight and likely belong to the CHVC
class.

The H\textsc{i} emission profile of X Her is quite comparable
to those of RS Cnc (Paper I) and EP Aqr (Paper II): a narrow
component is superimposed on a broader one. The narrow
feature is not spatially resolved by the NRT ($\phi < 4^\circ$) whereas
the broad one is resolved. These 3 sources are M-type SRb
with stellar effective temperature higher than 3 000 K, and at
about the same distance ($\sim 130$ pc). They also belong to the
small class of sources with composite CO profiles (K1998).
At this stage we stress that the H\textsc{i} source associated to Y
CVn probably belongs to a different class: although it shows
also a narrow component superimposed on a broader one,
the narrow component is spatially resolved while the broad
one is not.

The presence of atomic hydrogen close to these 3 central
stars ($\lesssim 2 \times 10^{17}$ cm) lends support to the GH1983 model
which predicts that hydrogen should be mostly atomic in
the atmospheres and inner envelopes of stars with effective
temperature larger than 2500 K.

It is also worth noting that these 3 sources show a sili-
cate emission around 10 $\mu$m plus an unidentified dust feature
around 13 $\mu$m (Speck et al. 2000; Sloan et al. 2003). The
occurrence of the 13 $\mu$m dust feature appears correlated with
the existence of a warm CO$_2$ layer close to the central star
(Justtanont et al. 1998). Our data also suggest a possible
relation of the 13 $\mu$m-carrier formation with a H\textsc{i}-rich at-
mosphere.

A surprising characteristic is that the centroid velocities
of the 2 spectral components do not exactly coincide.
Comp. 1 is at $\sim -72.2$ km s$^{-1}$, close to the other radio line
emissions and to the star radial velocity (Hinkle et al. 2002).
Comp. 2 is at $\sim -70.6$ km s$^{-1}$ and clearly red-shifted by $\sim
2-3$ km s$^{-1}$. In Paper II, we noted that for EP Aqr the broad
(1) and narrow (3) components are at the same velocity,
but are also shifted by $\sim 2-3$ km s$^{-1}$ with respect to the CO
ones (K1998). For RS Cnc, one also observes a shift by $\sim
-2$ km s$^{-1}$ (Paper I and K1998). These shifts are small but
real and should be explained, especially in view of the widths
of the narrow components which are of the same order.
For instance, the case of EP Aqr, the narrow H\textsc{i} and CO
components basically do not overlap. The case of X Her is
particularly interesting because, thanks to the monitoring of
CO lines in the near-infrared range by Hinkle et al. (2002),
the star radial velocity is known accurately, and because the
2 H\textsc{i} velocities differ. In these conditions, the velocity shift
of Comp. 2 can only be explained by matter flowing prefer-
entially away from the observer with respect to the central
star.

The asymmetry in the H\textsc{i} brightness distribution con-
ﬁrms that matter from X Her is flowing in preferred direc-
tions. It suggests that aspherical outflows may develop on
large scale early in the AGB phase, well before the plan-
tetary nebula phase, at variance to the common vision (e.g.
Sahai et al. 2003). X Her is probably a young AGB given
the absence of technetium mentioned earlier.

The modelling of the H\textsc{i} emission that we have devel-
oped supports these interpretations of the 2 spectral com-
ponents observed in X Her. Assuming 75 % of the mass in
atomic hydrogen, we find a circumstellar mass of $\sim 6.4 \times 10^{-3}$
$M_\odot$, of which Source (1) accounts for the main part. This
estimate is in good agreement with that obtained by Young
et al. (1993b) from IRAS data at 60 $\mu$m (they find 0.009 $M_\odot$ at
a distance of 220 pc which translates to $\sim 0.004$ $M_\odot$ at 140
pc). The velocity laws that we have adopted are somewhat
arbitrary. The fitting of the quasi-Gaussian profile of Comp.
I requires a velocity decreasing outwards (Paper II). This
may result from a succession of mass loss episodes with ve-
locity increasing with time, although it is hard to avoid an
overshooting of the outer shells by the inner ones. A more
likely explanation is the interaction of the stellar wind with
the ISM (Young et al. 1993b). For Comp. 2, as the corre-
sponding source is not resolved, we cannot distinguish be-
tween a negative velocity gradient and a positive one. Fi-
ally, we find that the two different episodes of mass loss
develop at about the same rate, and are separated by a lapse
of about 3000 years, but the duration of this lapse is only
weakly constrained. A better spatial resolution would cer-
tainly help to constrain these velocity laws as well as con-
strain the variation of the mass loss rate as a function of
time.

The mass loss rates that we find for the 2 episodes cor-
respond to $\sim 10^{-7}$ $M_\odot$ yr$^{-1}$. These estimates compare well
with those obtained from the modelling of the broad CO
components (K1998) and from IRAS data at 60 $\mu$m (Young
et al. 1993b). It may be surprising that, in the end, the
H\textsc{i} narrow component does not appear to be related to the
CO narrow components. In fact one should note that they
only partially overlap in velocity. Also the NRT H\textsc{i} beam
($4^\prime \times 22^\prime$) is much larger than the beams used for CO (e.g.
30$^\prime$ for CO(2-1) and 20$^\prime$ for CO(3-2), K1998). Furthermore
the CO photo-dissociation diameter is only $\sim 10^\prime$ (K1998).
KJ1996 note that “drastic variations of line shapes from one
position to another indicate that this envelope presents a
complex small scale velocity structure”. Therefore the ma-
terials responsible for these narrow components are certainly
distinct. Nevertheless they could still belong to the same
kinematical structure. However our modelling tends to indi-
cate that it may not even be the case. Finally the recent work
of Nakashima (2005) who suggests that the narrow CO(1-0)
component traces in fact a disk in Keplerian rotation rather
than an outflow brings further indication that the narrow
CO and H\textsc{i} components are not related.

The narrow H\textsc{i} component with a preferred direction at
$i \approx -90^\circ$ could be associated to the bipolar flow detected in
CO(2-1) by KJ1996. They find that it should be inclined at
a small viewing angle corresponding to $i \approx -75^\circ$. The pro-
jection on the sky of the red-shifted cone should be at a position
angle $\approx 60^\circ$ (Nakashima 2005). It is therefore of interest to
consider the possibility that Source (2) has the same ori-
tnation as the bipolar CO flow. We performed a modelling
where Source (2) is a hemisphere as in Sect. 5.2 ($r_{\text{in}}=0.1'\prime$,
$r_{\text{out}}=1'\prime$), but with $i = -75^\circ$ and PA $= 60^\circ$ (Fig. 13). The fit
that we obtain is still satisfactory, but we need to keep a
maximum velocity at $\approx 5$ km s$^{-1}$, which is much less than
the velocity estimated by KJ1996 for the CO bipolar flow
($\approx 10$ km s$^{-1}$). Also the fit to the position-switch spectra is
somewhat degraded. We conclude that Source (2) may have
The $H\alpha$ emission at 21 cm from $X$ Her

resolved spatially ($\phi < 4'$) while the broad one is extended. These properties are similar to those observed on EP Aqr and RS Cnc, two sources which share with $X$ Her many other common properties.

The two spectral components are centered at slightly different velocities, which is a strong indication that the mass loss is not spherically symmetric. The spatial distribution of the $H\alpha$ brightness also points to a non-symmetric geometry.

Our spatially resolved $H\alpha$ data can be modelled with 2 sources: (i) a flow in a direction close to the plane of the sky whose properties match approximately those obtained from the IRAS data at 60 $\mu$m, (ii) a second flow within a hemisphere opposite to the observer that may be related to the bipolar flow observed in CO. The masses of atomic hydrogen associated with these two components are $\sim 4 \times 10^{-3}$ and $6 \times 10^{-4} M_\odot$, respectively. The HI data probe the circumstellar shell of $X$ Her over a large region ($\sim 0.4$ pc) that has been filled during a long time ($\sim 10^5$ years). During this long period the geometry of the outflow has probably changed significantly. Finally, the interaction of the stellar wind with the ambient ISM may affect the H I spatial distribution as well as the spectral profiles.

The total $H\alpha$ mass and production rates measured here are in agreement with those deduced more indirectly from CO and IRAS data. The $H\alpha$ and IRAS 60 $\mu$m angular extents are comparable, although the IRAS source size could have been limited by the dust temperature gradient.

More generally, our data illustrate the need of a large spectral resolution ($\sim 10^6$), that is provided by the heterodyne technique, for describing the geometry and the kinematics of late-type giant outflows. Furthermore a better imaging, with a finer spatial resolution, would also be essential to reconstruct the history of mass loss over the past $10^5$ years.

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