A ^{12}CO ($J = 1 \rightarrow 0$) and ($J = 2 \rightarrow 1$) atlas of circumstellar envelopes of AGB and post-AGB stars

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Abstract. We present the results of a ^{12}CO ($J = 1 \rightarrow 0$) and ($J = 2 \rightarrow 1$) survey on a sample of 46 objects classified as AGB and post-AGB stars. We have obtained fully sampled high resolution maps of their ^{12}CO ($J = 1 \rightarrow 0$) emission by combining visibilities from the IRAM interferometer with short spacing observations from the IRAM 30 m telescope. Properties of their circumstellar envelopes like fluxes, radii, and positions are derived from model fits to the visibilities and compared to the results obtained from ^{12}CO ($J = 2 \rightarrow 1$) maps observed at the IRAM 30 m telescope. From the ^{12}CO ($J = 1 \rightarrow 0$) observations we have derived mass loss rates for 38 stars and established an empirical relation between the CO photodissociation radius of an envelope and the measured radius in the ($J = 1 \rightarrow 0$) emission.

Key words: Atlases — stars: AGB, post-AGB — stars: circumstellar matter — stars: mass-loss — stars: evolution — radio lines: stars

1. Introduction

The ultimate stage of the red giant evolution, namely their transition from the Asymptotic Giant Branch (AGB) to the Planetary Nebulae (PNe), and the mechanisms and chronology of events driving them to expell the bulk of their mass in less than a million years (in some cases 10000 years), constitutes one of the less known, albeit most exciting topics in stellar evolution. The whole evolution of the morphological, dynamical and chemical layout of envelopes from the AGB to the PNe stage through the state of a proto-planetary nebula (PPN), strongly depends on the massive ejection of stellar material during this stage.

Such a copious mass loss process necessarily leads to substantial changes in the stellar structure and appearance especially when the amount of mass ejecta becomes comparable to the mass of the star. Since the dominant process which brings back recycled stellar material to the interstellar medium is thought to be the formation of PNe, the mass loss process also greatly affects the composition of the interstellar gas and dust, its enrichment in heavy elements and the interstellar isotopic ratios.

During their high mass loss phase, the AGB stars are surrounded by dust and gas expanding envelopes which, if thick enough, are readily detectable in molecular radio line emission. In particular, high resolution observations of the rotational transitions of ^{12}CO , in the millimetric and submillimetric ranges, yield unique data on the envelope geometry, mass loss rate and dynamics.

Since the middle of the eighties, a large number of surveys, using the largest available single dish radiotelescopes, have been devoted to searches for ^{12}CO ($J = 1 \rightarrow 0$) and ($J = 2 \rightarrow 1$) emission in the circumstellar envelopes of evolved stars, on the basis of various selection criteria. See for instance the pioneering work of Knapp & Morris (1985), the compilation of ^{12}CO and HCN data by Loup et al. (1993), and, among the recent large surveys, that of Olofsson et al. (1993). The first targets of these studies were the brightest infrared sources or less opaque envelopes around well known evolved stars. Since 1988, the IRAS colour-colour diagram (van der Veen & Habing 1988) has been extensively used to increase the sample of dusty AGB stars, based on their characteristic infrared colours, it has also proved to be a powerful tool to select various classes of objects. Surveys based on CO observations at higher frequencies are still rare (Young 1995; Stanek et al. 1995). Presently, the number of circumstellar envelopes detected in CO radio emission around evolved stars (AGB, proto- and Planetary Nebulae) is larger than 700.

Fig. 1. Distribution of the sample of AGB and post-AGB stars (listed in Table 4) in the IRAS colour-colour diagram for O ($\circ$), C ($\bullet$), S ($\diamond$) and indeterminate ($*$) chemical types. Regions defined by van der Veen & Habing (1988) are drawn as landmarks. S_{12} , S_{25} and S_{60} are the IRAS-PSC flux densities, not colour corrected

Due to the limited sensitivity and spatial resolution of radiotelescopes, the maps of CO emission around evolved stars are much less numerous (around 50) and essentially devoted to the most evolved objects (PPN or PN), which have generally been selected for some peculiar morphology (bipolar, ring like, ...). Since the first maps, obtained at the end of the eighties (see e.g. Healy & Huggins 1988), most observations have been done with single dish telescopes.

Recently several selected objects have been extensively mapped by interferometric techniques (see for instance Bujarrabal et al. 1997). To our knowledge, atlases of CO maps, obtained and analyzed in uniform conditions, around relatively large samples of evolved stars, are however almost inexistent. The pioneering work of Bujarrabal & Alcolea (1991) presents ^{12}CO ($J = 1 \rightarrow 0$) and ($J = 2 \rightarrow 1$) mapping, with the IRAM 30 m telescope, of the circumstellar gas around 10 evolved stars of various chemical and variability types. More recently, the envelopes of 18 evolved stars, ranging from AGB to PN and showing various chemical types, have been mapped with the Caltech Submillimeter Observatory in ^{12}CO ($J = 3 \rightarrow 2$) (Stanek et al. 1995).

We present here an atlas of ^{12}CO ($J = 1 \rightarrow 0$) and ^{12}CO ($J = 2 \rightarrow 1$) maps of a sample of 46 AGB and post-AGB stars based on IRAM 30 m telescope and interferometer observations. The ^{12}CO ($J = 1 \rightarrow 0$) data come both from the interferometer and the 30 m telescope and are combined to circumvent the missing short-spacing problem. To get some additional information on CO excitation in the envelopes, we have also obtained fully sampled ^{12}CO ($J = 2 \rightarrow 1$) maps with the 30 m telescope. The stars sample is presented in Sect. 2, the 30 m telescope observations

and ^{12}CO ($J = 2 \rightarrow 1$) data analysis in Sects. 3 and 4, the interferometer observations and ^{12}CO ($J = 1 \rightarrow 0$) data analysis in Sects. 5 and 6. Statistical results on various envelope parameters (flux, size, mass loss rate, ...) derived from these observations are described in Sect. 7 and an individual presentation of peculiar objects is given in Sect. 8. In Sect. 9 we draw our conclusions.

2. The sample

The initial criteria we have applied for the selection of a representative sample of AGB and post-AGB stars were: line strength, IR colors and chemical composition. All the stars in the sample were already known from previous observations to be relatively strong CO emitters with intensities, in units of main beam temperatures, larger than 0.5 K and 1.0 K in the ($J = 1 \rightarrow 0$) and ($J = 2 \rightarrow 1$) transitions, respectively. The circumstellar envelopes were further selected by their IR colors, to sample as evenly as possible the IR color diagram (see Fig. 1 and Table 3), and by chemical composition. Finally, to take advantage of the sensitivity and resolution of the IRAM interferometer we have restricted our sample to high declination stars which would be either unresolved, or barely resolved, at the 30 m telescope.

Our initial sample contained 53 AGB and post-AGB stars: 24 O-type stars, 25 C-type stars, 2 S-type stars and 2 of uncertain composition, according to the compilation by Loup et al. (1993). The selected stars are listed in Tables 2 and 4.

3. IRAM 30 m observations

3.1. Observing conditions

The ^{12}CO ($J = 1 \rightarrow 0$) and ^{12}CO ($J = 2 \rightarrow 1$) observations were carried out simultaneously with the IRAM 30 m telescope, Spain (Baars et al. 1987), in three runs between October 1990 and August 1993.

The telescope was equipped with 3 mm and 1 mm SIS receivers operating simultaneously in single side-band mode. The antenna temperature scale was calibrated every 10 minutes by successively observing a cold load, a room temperature load and the sky. The calibration accuracy, checked on well known molecular sources (Mauersberger et al. 1989) was found to present an uncertainty of less than 20%. The main beam temperatures T_{MB} reported in the figures and in Table 4 are related to the antenna temperature scale T_{A}^* by $T_{\text{MB}} = T_{\text{A}}^*/\eta$, where η , the ratio of the main beam to the forward beam efficiency, is equal to 0.45 for the ^{12}CO ($J = 2 \rightarrow 1$) observations and 0.60 for the ^{12}CO ($J = 1 \rightarrow 0$) observations.

The backends were at both frequencies filterbanks of 512 or 256 channels 1 MHz wide, providing a velocity

resolution of 2.60 km s^{-1} at the frequency of the ^{12}CO ($J = 1 \rightarrow 0$) line (115271.2 MHz) and 1.30 km s^{-1} at the frequency of the ^{12}CO ($J = 2 \rightarrow 1$) line (230538.0 MHz).

In October 1990 and May 1991, the observations were made in position switching mode, with a reference position $150''$ east to the star position. In August 1993, the secondary mirror was wobbled every 3 s, with an amplitude of $240''$ (this technique provides very flat baselines).

The pointing was checked every hour or less on nearby continuum sources. It was found to remain accurate within $5''$ during this time interval. To avoid distortion due to pointing drifts, the maps were taken with short integration times (between 1 min and 3 min on each position) and completed in less than 1 hour. When longer integration times were needed to achieve the required signal to noise ratio, the maps were observed several times, with pointing checks in between, and subsequently added, using the shift-and-add technique described in Sect. 3.2.

In October 1990, the maps were observed with a grid spacing of $5''$ in right ascension and declination. In May 1991 and August 1993, the spacing was taken equal to $7.5''$. Considering the telescope half power beam widths of $13''$ for the ^{12}CO ($J = 2 \rightarrow 1$) observations and $21''$ for the ^{12}CO ($J = 1 \rightarrow 0$) observations, these spacings ensure that the maps are fully sampled.

A total of 46 circumstellar envelopes have been mapped in ^{12}CO ($J = 2 \rightarrow 1$) emission. 20 envelopes were mapped in October 1990, under fine weather conditions. The SSB system temperature was typically 600 K at 3 mm and 1000 K at 1 mm. 12 envelopes were observed in May 1991, in less favorable conditions, with system temperatures of the order of 1000 K and 2000 K, respectively. The observations of 11 objects were completed in August 1993, in good weather conditions with system temperatures of the order of 800 K and 1200 K, respectively. In particular, the maps of 5 envelopes (IRC+10011, IK Tau, CIT6, IRC+20370, RAFGL3068) observed by Loup (1991) were extended during this run. For 3 envelopes (RX Boo, χ Cyg and R Cas), we reproduce and reanalyse here the observations (June 1990) obtained and published by Bujarrabal & Alcolea (1991).

3.2. Data reduction

The single-dish data were reduced using the CLASS software package. Only linear or parabolic baselines were subtracted from the spectra. When several maps of the same object were observed, we checked that the lines intensities were in agreement and that the positions of the integrated intensity contours coincided within better than $1.25''$ in right ascension and declination. When the shift between two maps was found to be larger, one of the maps was shifted relative to the other in steps of $2.5''$ in each direction. After relative recentering the maps were added to obtain a single data cube. After this stage, the reductions

of the ^{12}CO ($J = 1 \rightarrow 0$) and ($J = 2 \rightarrow 1$) data differ, since the ^{12}CO ($J = 1 \rightarrow 0$) observations obtained with the IRAM 30 m telescope were combined with the data from the IRAM interferometer before further processing. This is discussed in Sect. 5.2.

To increase the signal to noise ratio, the ^{12}CO ($J = 2 \rightarrow 1$) spectra were smoothed to 2.6 km s^{-1} , the velocity resolution of the ^{12}CO ($J = 1 \rightarrow 0$) data, except for 8 envelopes with relatively narrow lines: R And, RAFGL482, R Aur, RS Cnc, Y CVn, V CrB, χ Cyg and T Cep.

4. Data analysis: $^{12}\text{CO}(J = 2 \rightarrow 1)$

4.1. Positions

The envelope central positions adopted to perform the ^{12}CO ($J = 2 \rightarrow 1$) observations are those reported by Loup et al. 1993. Due to pointing uncertainties and to the shift-and-add technique used to combine several maps, discrepancies between these coordinates and the actual map centers are meaningless. In the position-velocity diagrams, however, the zero position of the ^{12}CO ($J = 2 \rightarrow 1$) maps is chosen to correspond to the maximum of the ^{12}CO ($J = 2 \rightarrow 1$) emission.

4.2. Fluxes and main beam temperatures

The ^{12}CO ($J = 2 \rightarrow 1$) main beam temperature T_{MB} reported in the parameter summary of each envelope and in Table 4 is the average of the three central 1 MHz channels in the spectral profile observed towards the envelope center. Channels affected by a galactic CO contribution have been omitted.

The flux density reported in the summary and in Table 4 is the average value of the three central channels in the spatially integrated ^{12}CO ($J = 2 \rightarrow 1$) spectral profile $S(v)$ of each envelope. The integrated flux density profile has been obtained by adding the spectra with a uniform weight on a regular grid with a spacing d . The flux spectrum in Jy is given by

$$S(v) = \frac{2k}{\lambda^2} d^2 \sum_{i,j} T_{ij}(v) \quad (1)$$

where $T_{ij}(v)$ is the main beam temperature observed at velocity v and positions (i, j) , and where the grid spacing d expressed in radians is either $7.5''$ or $5''$ depending on the map, and k is the Boltzmann constant.

A comparison of the spatially integrated flux spectrum $S(v)$ with the flux spectrum collected in the telescope beam towards the envelope central position, $S_0(v)$, allows comparison of the envelope extent with the beam size: if both fluxes coincide, the envelope is unresolved by the telescope beam. For a gaussian beam of half power beam width h (in radians), the relation between the main beam

temperature profile $T_{00}(v)$ observed towards the envelope center and the flux spectrum in the central beam $S_0(v)$ is

$$S_0(v) = \frac{2k}{\lambda^2} \frac{\pi h^2}{4 \ln 2} T_{00}(v) \quad (2)$$

which is equivalent to a conversion factor of 7.35 Jy/K for the ^{12}CO ($J = 2 \rightarrow 1$) line observed at the 30 m telescope. Both flux spectra, integrated $S(v)$ and central $S_0(v)$ are plotted for comparison for each envelope (see Atlas). The 30 m telescope half power beam width at 230 GHz, was estimated to be $13'' \pm 1.5''$, including beam smearing effects due to tracking errors.

We also give in Table 4 the total ^{12}CO ($J = 2 \rightarrow 1$) emission of the envelope (i.e. the flux integrated both spatially and over velocity).

4.3. Velocities and line shapes

The star systemic velocity V_{lsr} and the envelope expansion velocity V_{exp} have been derived from the full width at zero level (FWZL) of the ^{12}CO ($J = 2 \rightarrow 1$) lines. To minimize the effect of noise on the derivation of the FWZL, we have defined as the extreme line channels those for which the 20% to 90% intensity contours still show a centrally peaked pattern. The resulting velocities are given in the parameters list of each envelope and in Table 4. The errors are typically one channel half-width (1.3 km s^{-1} for most envelopes, 0.7 km s^{-1} for the 8 narrow line envelopes mentioned above).

We must keep in mind that this calculation of the expansion velocity tends to overestimate the true value of this parameter when the line profiles present conspicuous wings, the origin of which is expected to be related to local velocity dispersion or to the presence of bipolar outflows independent of the general envelope expansion. Fitting a truncated parabola systematically leads in such cases to lower estimates of the expansion velocity. This discrepancy can be significant in stars with low expansion velocities. In particular for objects in which the emission of the bipolar outflows is dominant, the meaning of an expansion velocity determined in this way, is just the maximal projection on the light of sight of the axial velocity.

Most envelopes present sharp-edged and round-topped lines, as expected for optically thick emission coming from a spherically expanding envelope. In a few cases (OH127.8+0.0, U Cam, S Cep IRC+60427) an interstellar ^{12}CO ($J = 2 \rightarrow 1$) contribution appears as a narrow peak or dip in the spectrum. As far as the signal to noise ratio of the data allows to conclude, some envelopes show “unusual” line shapes, with wings or shoulders, which suggest changes in the mass loss activity of these stars (see for instance U Cam, T Dra, RS Cnc and M1-92).

4.4. Sizes and asymmetries

To derive a more quantitative estimate of the envelope size in the ^{12}CO ($J = 2 \rightarrow 1$) line, we have fitted as a function of the velocity channel a 2D gaussian to the observed spatial distribution. Plots of the fitted minor and major axis (without beam deconvolution) and of the centroid shifts relative to the mean centroid position are shown for each envelope as a function of the channel velocity.

In a spherical expanding envelope with a constant (or monotonically increasing) radial velocity, the radius of the region emitting at a given radial velocity V_z or $-V_z$ with respect to the systemic velocity is proportional to $\sqrt{1 - (V_z/V_{\text{exp}})^2}$. A decrease of this radius with the absolute value of V_z is, therefore, expected. As shown in the figures, such a behaviour is indeed observed in most sources, although the uncertainties in the measured size is high.

Once deconvolved from the telescope beam (h), the fitted major and minor (M and m) axes averaged over the three central channel maps provide a measure of the envelope size (L and l)

$$L = \sqrt{M^2 - h^2} \quad l = \sqrt{m^2 - h^2} \quad (3)$$

and a quantitative estimate of its asymmetry, given by the parameter

$$f = (L - l)/(L + l). \quad (4)$$

We have carried out a worst-case beam deconvolution to filter out envelopes with intrinsic elliptical shapes and mask out those whose asymmetry is possibly due to beam distortion. For this deconvolution, the telescope beam was assumed to be elliptical ($14.5'' \times 11.5''$) and its position angle was made to coincide with the position angle of the gaussian fit. This deconvolution provides a lower limit L_{min} to the actual envelope major axis and an upper limit l_{max} to its actual minor axis. We have then performed a conservative selection of the “non-spherical” envelopes, considering that any real departure from circular symmetry shows up even in the lower limit to the asymmetry parameter f_{min} given by

$$f_{\text{min}} = (L_{\text{min}} - l_{\text{max}})/(L_{\text{min}} + l_{\text{max}}). \quad (5)$$

When f_{min} is lower than 0.1, which corresponds to a difference smaller than 20% between the axis limits, or when the sizes L and l are not determined with better accuracy than 5σ , the envelope is considered as spherical. We choose such a highly conservative limit to rule out any asymmetry due to possible uncertainties in the determination of the telescope beam or of the envelope sizes. In such a case, we give a single size in the identification panel of each star and in Table 5, which is the average of the fitted axes deconvolved by a circular beam of width $h = 13''$

$$s = \sqrt{(M + m)^2/4 - h^2}. \quad (6)$$

Otherwise, the envelope is considered as asymmetric. Table 5 contains the envelope deconvolved minor l and

major L axis (assuming a circular beam h) and the resulting asymmetry parameter f .

In addition, the plot of the envelope emission centroid versus velocity provides informations on the geometry and kinematics: for a spherically expanding envelope the centroid is expected to keep the same position at any velocity. On the other hand, if there is departure from overall spherical symmetry, the centroid is expected to move along an axis of symmetry. This behaviour is particularly obvious for RS Cnc, M1-92 and R Cas but exists also possibly for a few other envelopes, namely for Y CVn, χ Cyg, T Cep, IRC+40540 and IRC+60427.

5. IRAM interferometer observations

5.1. Observing conditions

A total of 52 objects was mapped at the frequency of the ^{12}CO ($J = 1 \rightarrow 0$) line with the IRAM interferometer (PdBI) placed at Plateau de Bure, France (Guilloteau et al. 1992). The observations consisted in multi-configuration snapshots, each object being typically observed in four different configuration at various times over a period of two years (see Table 1 – December 1990 to April 1992). The objects were observed typically at two hour angles in each configuration, each hour angle consisting of 4-minute integrations on primary calibrators interspersed with two 20-minute periods of on-source integration time.

The observing parameters were consistent from one run to the next. Two antennas were equipped with SIS mixers, while the third had a Schottky mixer. All receivers were operating in double side band (DSB) mode. The cross-correlator was set to a bandwidth of either 40 MHz or 80 MHz with a nominal channel spacing of 0.625 MHz. Because of channel apodization, the effective frequency resolution was 1 MHz, or equivalently 2.6 km s^{-1} at the frequency of the ($J = 1 \rightarrow 0$) transition. We used a redundant correlator setting with 64 channels per baseline, instead of 128. The on-source integration time equivalent to single-baseline observing was 4.5 hr on average. The point source sensitivity, derived from emission-free channels, was 50 mJy on average, and was consistent with system temperatures of 500 K and atmospheric phase decorrelations of 10 to 30 degrees. The IRAM continuum correlator, which was operating simultaneously over a bandwidth of 500 MHz consisting of 10 contiguous 50 MHz channels, was used mainly for the purpose of calibration. However, as a valuable by-product, we were able to measure with the central 400 MHz the continuum flux at 112 GHz of CIT 6, μ Cep (tentatively detected) and 19480+2504, and to give 5σ sensitivity upper limits for all other sources.

5.2. Data reduction

Data calibration was effected in the baseline-based manner using the CLIC (Lucas 1991) interactive software package. We used whenever available either 3C 273 or 3C 345 as bandpass calibrator. Phase and amplitude calibrations were carried out with the sources listed in Table 1.

Conventional image restoration algorithms like CLEAN produce maps without sidelobes and without features that a synthesized antenna pattern can show as a consequence of missing information. Accordingly, these methods imply interpolation or extrapolation of information that can be retrieved under “reasonable” assumptions, only when the objects are of small extent, compared to the size of the primary field of view. However, when the emission structures are large with respect to the beamsize of an individual dish (spacings smaller than the dish diameter are for obvious physical reasons fundamentally inaccessible to measurements by an interferometer), short spacing information needs to be supplied. We circumvented this difficulty by using the 30 m telescope to measure the missing information.

While the IRAM interferometer is ideal for achieving the required high resolution, emission structures larger than $17''$ are essentially resolved out: $17''^{-1}$ down to about $4''^{-1}$ is the typical range of spatial frequencies to which our observations were sensitive. This results in interferometric maps in which regions of negative intensity surrounding small-scale structures can hardly be removed. For envelopes larger than $20''$, including the 30 m data recovered typically 50% of the flux missing from the maps obtained from interferometer data alone.

The 30 m telescope was used to obtain maps sampled at twice or more the telescope beamwidth, those maps that completely cover the region of the interferometer primary beam and that greatly account for the missing flux. Short spacing visibilities were created from the single-dish data and combined with the interferometer samples using the data reduction scheme described below. Depending on the signal-to-noise ratio, however, only short-spacing visibilities up to 20–25 m were kept to avoid spurious effects in the merging process.

The following steps were taken with the GILDAS (Guilloteau & Forveille 1989) software package in combining data from the IRAM 30 m telescope and the IRAM interferometer, once the initial data processing of single-dish and interferometer data was carried out:

- resample the interferometer data to a frequency resolution of 1 MHz to be consistent with the single-dish observations,
- correct the antenna temperatures for the forward gain to obtain main beam temperatures, T_{MB} , and apply the standard conversion factor to convert the single-dish data from T_{MB} to the interferometer units Jy beam^{-1} ,

Table 1. Flux densities of the interferometric calibrators at the frequency of the ^{12}CO ($J = 1 \rightarrow 0$) transition. The fluxes are in units of Jy. Observational periods are labeled A–J and are compiled in Table 4 for every star in the sample (e.g. period C observations were carried out between February and April 1991)

Epoch	— A —	— B —	— C —	— D —	— E —	— F —	— G —	— H —	— I —	— J —	
Calibrator	12/90	01/91	02/91	04/91	07/91	08/91	08/91	11/91	12/91	02/92	04/92
3C 84	7.90	7.90	7.50	7.50	7.00	7.00	7.00	6.50	6.50	6.00	6.00
3C 345	5.06	7.60		9.90	9.40	10.20	10.00	7.60	7.60	8.10	8.00
3C 454.3	10.50	7.80			5.08		8.21	6.70	5.90		4.80
3C 273	22.90	27.80	39.30		28.60				25.70	23.40	26.00
3C 120								1.35	1.85	1.28	
NRAO530		7.22	7.30								
NRAO150								1.42	1.29	1.40	1.40
0048−09									2.96		
0133+47								0.40	0.47	0.45	0.72
0212+735		0.91		0.52							
0224+671	0.96	1.07	0.93	0.99	0.79		0.85	0.98	0.89	1.14	1.42
0234+285	2.25	2.55									
0235+164								1.15	1.36	2.54	
0552+398											2.23
0607−157											3.74
0605−085											1.04
0735+178											2.03
0716+714											0.45
0727−115											1.19
0851+202								3.15	2.33	1.60	
0923+392	2.75	3.67		4.76				3.45	3.41	3.65	3.75
1044+719	0.54	0.71		0.59							
1308+326								1.60			
1413+135								1.92	2.84	2.08	
1418+546	1.03			1.36	1.18						
1732+389	0.66	0.74		0.85	1.01						
1741−038					2.03	1.99	2.30				
1749+096	1.90	2.38		2.19	2.37	2.02	1.92	1.97		2.83	2.39
1823+568	0.85	0.82	1.23								
1830−211					2.70	2.86					
1828+48	1.45	1.52	1.56		1.00						
1928+738		1.83					1.24				
1954+513					1.33	0.81					
2005+403	1.25	1.17	1.62		1.12	1.24	1.05	1.18	1.11	1.08	1.16
2007+776	1.23	1.90		1.66							
2037+511	1.95	1.70	1.28	1.68	1.01		1.23				
2200+420		2.67			1.53			1.18	1.23	1.79	2.00
2223−052											2.30
2234+282	0.92	0.96		0.80							
2318+049		0.71									

- interpolate irregularities in the spatial sampling of the single-dish data (missing or bad sampling points) using a CLEAN based algorithm. The purpose of this step is to avoid an all too poor representation of the large emission structure when the sampling was too irregular,
- deconvolve the single-dish maps by dividing their Fourier transforms by the Fourier transform of the $22''$ beam of the 30 m telescope (assumed to be gaussian), multiply the inverse Fourier transform of the result by the $42''$ primary beam of the interferometer, and Fourier transform back to the uv -plane to obtain single-dish visibility tables,
- recenter the single-dish and the interferometric emission centroids, determined from averaging blue ($V \leq -V_{\text{exp}}/3$) and red ($V \geq V_{\text{exp}}/3$) velocity maps, to the phase tracking center of the interferometer. Errors in the pointing ($2'' - 4''$ are reported for the 30 m telescope) need to be removed as accurately as possible. Since the 30 m velocity maps contribute

Table 2. ^{12}CO ($J = 1 \rightarrow 0$) observational summary for the 7 objects for which the combination of single-dish data with interferometric data was not carried out. Noise estimates (1σ) are for a spectral resolution of 2.6 km s^{-1}

Coord.	Name	30 m		PdBI		Comment
		Observations	rms (mK)	Observations	rms (mJy)	
06 : 52 + 06	CL Mon	Poor map	96	None	—	^{12}CO ($J = 2 \rightarrow 1$): see atlas
09 : 42 + 34	R LMi	Zero spacing only	116		94	Marginal detection
18 : 28 + 21	AC Her	Zero spacing only	25		94	No detection
18 : 34 − 05	OH 26.5+0.6	Zero spacing only	85		106	Strong galactic CO confusion
18 : 56 + 06	OH 39.7+1.5	Zero spacing only	150		82	Marginal detection
21 : 41 + 58	μ Cep	Poor map	38		112	$S_{112} = 21(5) \text{ mJy}$
22 : 17 + 59	OH 104.9+2.4	Zero spacing only	80		89	Marginal detection

predominantly to the large scale structure, residual uncertainties should not significantly affect the results.

- generate visibility tables that combine both single-dish and interferometer data from which visibility plots along circular uv trajectories are created. The single-dish weight is scaled according to the mean weight of the short spacings interferometer visibilities in order to provide single-dish and interferometer uv cells of similar weight,
- check the compatibility of single-dish and interferometer data in the common uv regions (spacings in the 15–25 m range) and, depending on the signal-to-noise, account for possible flux calibration errors, η_C , by scaling the single-dish visibilities to the interferometer visibilities. η_C was found to vary between 0.5 and 2. In general, however, the two data sets agreed to about 20%.

The 7 objects listed in Table 2 were discarded from the original sample.

6. Data analysis: $^{12}\text{CO}(J = 1 \rightarrow 0)$

6.1. Positions

We have used interferometric maps (not combined data) to determine star positions. Mostly VLA positions were used for the primary phase calibrators. We have ignored phase errors due to inaccuracies in the assumed baselines, as the distance Δs between the stars and their calibrator(s) was generally below 15 degrees. Actually, baseline errors ΔB at the frequency ν of the ^{12}CO ($J = 1 \rightarrow 0$) transition lead to a maximum phase error $2\pi\nu\Delta B\Delta s/c$ of a few degrees, somewhat smaller than the atmospheric phase fluctuations recorded on the shortest baselines, typically 10–30 degrees. On average, this corresponds to absolute positional errors of about 1/10 of the synthesized beam, or equivalently $0.5''$. The star positions listed in Table 4 were obtained by averaging the positions of the

fitted emission centroids in the blue ($V \leq -V_{\text{exp}}/3$) and red ($V \geq V_{\text{exp}}/3$) velocity maps. When two-component elliptical gaussians were used to fit the CO brightness distribution (see Sect. 6.4) we used the positions of the gaussian ascribed to the inner, more compact shell surrounding the central star.

Except for 12 stars, most of the positions listed in Table 4 are in excellent agreement with those given in Loup et al. (1993). The stars for which the positional difference is larger than $3''$ are noted in the caption to Table 4. Single-dish ^{12}CO ($J = 2 \rightarrow 1$) maps were used just in the case of CL Mon and HD 187885 for which no ^{12}CO ($J = 1 \rightarrow 0$) interferometer data were available.

6.2. Fluxes and main beam temperatures

To properly bootstrap the fluxes of the stronger calibrators (mostly 3C 84 and 3C 273), we have made measurements of these, in conjunction with planets, with the antennas operating in the autocorrelation mode. We have then referred the weaker calibrators to the first ones in the more sensitive interferometric mode. Since more than half of the calibrators were used to calibrate more than one source (e.g. 2005+403 was used alternatively for 10 stars), remaining errors in the flux density scale of those were largely removed by cross-checking the interferometric visibility profiles on a sample of stars across the whole set of array configurations. After readjusting discontinuities in the visibility profiles attributed to errors in the amplitude calibration, we expect the fluxes of the main calibrators to be accurate within 10%. Table 1 lists the flux of all the calibrators used in the survey. Despite an accurate relative flux calibration, the absolute calibration scale is probably not better than 15%.

The spatially integrated ^{12}CO ($J = 1 \rightarrow 0$) fluxes have been estimated from the combination of both, single-dish and interferometric visibility profiles. We have fitted either one or two elliptical gaussian components to the real part

Table 3.

Ident	Name	Region	Chem. type	Distance (kpc)	Photod. radius (10^{17} cm)	Mass loss ($10^{-6} M_{\odot} \text{ yr}^{-1}$)
00:04+42	KU And	IIIa	O	0.82	2.3	9.6
00:21+38	R And	IIIa	S	0.38	1.2	1.0
01:03+12	IRC+10011	IIIa	O	0.54	2.1	7.9
01:30+62	OH 127.8+0.0	IIIb	O	1.46	1.3	2.6
03:18+70	RAFGL 482	VII	C	1.71	2.9	4.3
03:22+47	IRC+50096	VII	C	0.62	2.0	3.5
03:37+62 ^d	U Cam	VIa	C	0.65		
03:50+11	IK Tau	IIIa	O	0.26	1.4	3.8
04:30+62	04307+6210	II	C	0.95	3.0	8.5
04:56+56	TX Cam	VII	O	0.33	1.0	2.3
05:13+53	R Aur	II	O	0.35	0.9	1.1
06:01+07	RAFGL 865	IIIa	C	1.80	5.1	16.0
06:33+38	UU Aur	VII	C	1.23	2.0	3.0
06:52+06 ^a	CL Mon	VIa	C	0.48		
09:07+31	RS Cnc	II	O	0.26	0.7	0.6
10:13+30	CIT 6	VII	C	0.38	2.8	7.2
12:42+45	Y CVn	VIa	C	0.34	0.9	0.6
12:54+66 ^d	RY Dra	VII	C	0.65		
14:21+25	RX Boo	IIIa	O	0.20	0.7	0.8
15:47+39	V CrB	I	C	0.82	1.2	1.0
17:29+17	IRC+20326	IIIa	O	0.79	3.3	15.0
17:43+50 ^c	V814 Her	V	O	0.65		
17:55+58	T Dra	VII	C	0.91	1.9	2.9
18:05-22	VX Sgr	IIIa	O	0.41		
18:24+23	RAFGL 2155	VII	C	1.00	3.9	11.0
18:39+17	IRC+20370	VII	C	0.60	2.3	4.0
19:16+23	RAFGL 2362	IIIb	O	2.04	3.5	19.0
19:19+09	OH 44.8-2.3	IIIb	O	1.30	2.8	12.0
19:24+11 ^{be}	IRC+10420	IIIb	O	6.12	17.0	510.0
19:32+27	V1129 Cyg	VII	C	0.79	2.1	5.1
19:34+29 ^c	M1-92	VIII	O			
19:48+25 ^b	19480+2504	IV	C	0.71	1.3	1.9
19:48+32 ^d	χ Cyg	I	S	0.15		
19:50-17 ^a	HD 187885	V	?			
19:54+30	RAFGL 2477	IIIb	C	2.41	6.0	30.0
19:59+40	RAFGL 2494	IIIa	C	1.15	3.6	12.0
20:02+39 ^b	20028+3910	V	?	0.29	0.7	0.6
21:08+68	T Cep	II	O	0.14	0.3	0.2
21:31+56	21318+5631	IIIb	C	1.23	3.1	8.4
21:35+78	S Cep	VII	C	0.46	1.8	3.8
22:27+54 ^b	HD 235858	V	C	0.23	0.8	0.6
23:16+16	RAFGL 3068	IIIa	C	0.95	4.0	11.0
23:25+10	RAFGL 3099	IIIa	C	1.30	3.1	5.8
23:32+43 ^d	IRC+40540	VII	C	0.65		
23:32+65 ^b	23321+6545	V	C	0.54	0.9	0.9
23:49+61	IRC+60427	IIIa	O	0.56	1.2	2.9
23:55+51	R Cas	II	O	0.20	0.7	0.8

^a No (1-0) data.^b No distance given by Loup et al. (1993). Photodissociation radius derived from the relationship R_{CO} vs. θ_{CO} . Distance derived from CO modeling.^c No distance given by Loup et al. (1993) and CO modeling does not converge.^d No parameter derived as envelope is asymmetric or ring-like.^e CO modeling gives two solutions. The alternative is $D = 0.76$ kpc, $R_{\text{CO}} = 2.1 \cdot 10^{17}$ cm and $\dot{M} = 14 \cdot 10^{-6} M_{\odot}/\text{yr}$.

Table 4. See text

Ident	Name	α_{J2000}	δ_{J2000}	112 GHz				$CO J = 1 \rightarrow 0$				$CO J = 2 \rightarrow 1$					
				Flux (mJy)	V_{exp} (km/s)	V_{lsr} (km/s)	Epoch	Flux (Jy)	T_{mb} (K)	Epoch	V_{exp} (km/s)	V_{lsr} (km/s)	Flux (Jy)	I (Jy.km/s)	T_{mb} (K)	Epoch	
00:04+42 ^b	KU And	00:06:52.74 (.03)	43:05:03.2 (.4)	< 14.0	20.0	-21.7	J	8.6	291	1.3	J	20.8	-20.0	32.0	878	2.8	Oct. 90
00:21+38	R And	00:24:01.93 (.04)	38:34:37.3 (.8)	< 20.0	9.4	-16.1	ABC	14.9	210	1.5	ABC	9.1	-16.0	49.4	713	3.6	May 91
01:03+12	IRC+10011	01:06:26.00 (.04)	12:35:53.0 (.5)	< 12.8	19.5	9.5	IJ	22.7	731	2.8	IJ	19.5	9.0	75.0	1802	3.3	July 88
01:30+62	OH 127.8+0.0	01:33:51.19 (.04)	62:26:53.4 (.5)	< 15.6	12.0	-54.6	ABC	1.0	17	.3	ABC	11.7	-55.3	5.6	116	.8	Oct. 90
03:18+70 ^b	RAFGL 482	03:23:37.22 (.04)	70:27:04.7 (.5)	< 16.0	8.1	-16.1	DEFJ	10.8	124	2.2	DEFJ	7.8	-15.9	36.2	409	3.4	May 91
03:22+47	IRC+50096	03:26:29.55 (.03)	47:31:48.5 (.4)	< 19.2	14.7	-16.5	J	19.7	437	2.3	J	15.6	-16.0	55.3	1151	4.0	Oct. 90
03:37+62	U Cam	03:41:48.06 (.05)	62:38:54.6 (.5)	< 11.2	25.8	7.2	GHIJ	3.6	156	.7	GHIJ	26.0	7.4	18.9	738	1.6	Aug. 93
03:50+11	IK Tau	03:53:28.85 (.03)	11:24:22.2 (.5)	< 11.6	19.5	35.8	J	20.7	725	1.7	GHI	20.8	34.3	80.8	2387	4.2	May 90
04:30+62	04307+6210	04:35:17.54 (.03)	62:16:24.0 (.4)	< 12.4	20.8	-48.1	J	13.8	366	.9	J	19.5	-47.3	55.3	985	1.9	Oct. 90
04:56+56 ^b	TX Cam	05:00:51.17 (.03)	56:10:54.2 (.5)	< 11.6	19.5	10.5	J	7.9	222	1.3	J	19.5	10.3	55.0	1422	3.8	Oct. 90
05:13+53	R Aur	05:17:17.63 (.06)	53:35:09.8 (.9)	< 22.0	9.8	-1.0	J	5.7	96	.9	J	9.8	-1.9	31.8	425	2.8	Oct. 90
06:01+07 ^b	RAFGL 865	06:04:00.14 (.03)	07:25:52.2 (.5)	< 44.0	13.8	43.6	J	16.2	339	3.2	J	14.3	42.7	45.5	946	3.2	Oct. 90
06:33+38	UU Aur	06:36:32.78 (.03)	38:26:43.9 (.5)	< 14.0	11.8	8.0	J	5.1	95	1.4	J	11.7	7.3	24.7	426	2.0	Oct. 90
06:52+06 ^a	CL Mon	06:55:36.62	06:22:44.9									24.7	27.7	5.6	233	.8	Oct. 90
09:07+31	RS Cnc	09:10:38.85 (.04)	30:57:47.1 (.5)	< 11.6	6.9	7.2	J	9.5	96	1.6	J	7.8	7.0	88.7	616	7.1	Oct. 90
10:13+30	CIT 6	10:16:02.34 (.03)	30:34:18.3 (.6)	13.3 (2.5)	18.7	-2.0	GHI	83.1	2506	5.4	GHI	20.8	-3.3	155.4	3972	7.0	Aug. 93
12:42+45	Y CVn	12:45:07.87 (.04)	45:26:24.6 (.6)	< 14.4	9.7	19.6	ABC	6.4	92	1.0	ABCD	7.8	20.7	24.1	283	2.0	May 91
12:54+66	RY Dra	12:56:25.89 (.03)	65:59:39.1 (.4)	< 12.8	13.0	-7.3	ABC	2.3	53	.5	ABC	10.4	2.0	48.8	671	3.0	June 90
14:21+25 ^c	RX Boo	14:24:11.62 (.05)	25:42:13.1 (.5)	< 14.4	10.4	3.6	GHI	8.6	132	.9	GHI	6.5	-98.7	18.5	200	1.1	May 91
15:47+39	V CrB	15:49:31.23 (.03)	39:34:18.0 (.4)	< 16.4	8.2	-99.4	ABC	4.1	51	.8	ABC	15.6	-4.0	51.3	1020	3.3	Oct. 90
17:29+17 ^b	IRC+20326	17:31:55.27 (.04)	17:45:20.9 (.5)	< 10.8	15.8	-4.8	J	34.2	714	2.4	J	11.7	-34.7	11.8	215	1.5	Aug. 93
17:43+50	V814 Her	17:44:55.43 (.03)	50:02:40.3 (.5)	< 14.8	13.0	-33.8	ABC	6.5	127	.9	ABC	11.7	-34.7	11.8	215	1.5	Aug. 93
17:55+58	T Dra	17:56:23.38 (.03)	58:13:06.7 (.4)	< 10.4	14.3	-13.5	ABC	6.2	141	1.1	ABC	13.0	-14.6	36.3	838	1.7	May 91
18:05+22	VX Sgr	18:08:04.06 (.02)	-22:13:26.2 (.9)	< 65.2	20.4	4.4	E	1.8	140	.5	E	20.8	3.4	12.5	701	1.1	Oct. 90
18:24+23 ^b	RAFGL 2155	18:26:05.81 (.03)	23:28:46.7 (.5)	< 12.4	14.6	60.8	ABCD	33.5	711	3.0	ABCD	13.0	60.0	78.0	1582	3.0	May 91
18:39+17	IRC+20370	18:41:54.57 (.02)	17:41:08.5 (.3)	< 10.4	13.8	.6	GHI	31.0	680	3.6	GHI	14.3	.0	97.2	1965	4.4	Aug. 93
19:16+23	RAFGL 2362	19:18:14.62 (.04)	23:49:28.0 (.6)	< 14.4	18.7	28.8	EF	3.8	129	.5	EF	18.2	29.2	5.8	158	.8	Oct. 90
19:19+09	OH 44.8-2.3	19:21:36.56 (.05)	09:27:56.3 (.6)	< 17.2	16.3	-69.7	DEF	9.8	260	.8	DEF	16.9	-70.7	6.5	152	.9	Oct. 90
19:24+11	IRC+10420	19:26:48.03 (.09)	11:21:16.9 (.9)	< 12.4	41.6	74.5	J	4.4	283	.9	J	37.7	77.1	26.7	1504	2.6	Oct. 90
19:32+27	V1129 Cyg	19:34:09.97 (.03)	28:04:08.3 (.5)	< 17.2	23.6	-10.4	J	7.7	314	1.0	J	23.4	-12.0	37.5	1426	1.9	Aug. 93
19:34+29 ^b	M1-92	19:36:18.87 (.04)	29:32:49.9 (.5)	< 20.0	31.2	.6	ABCD	4.5	252	.6	ABCD	32.5	.3	7.7	415	1.1	Oct. 90
19:48+25 ^b	19480+2504	19:50:08.18 (.04)	25:11:56.4 (.6)	27.7 (4.3)	18.2	40.8	ABCD	3.6	95	.5	ABCD	9.8	10.0	90.9	1338	6.1	June 90
19:48+32 ^c	X Cyg	19:50:33.91 (.04)	32:54:50.8 (.5)	< 13.6	11.0	10.8	GHI	31.2	509	3.5	GHI	10.4	25.0	8.2	161	1.1	Oct. 90
19:50+17 ^a	HD 187885	19:52:52.64	-17:01:50.1									10.4	25.0	8.2	161	1.1	Oct. 90
19:54+30	RAFGL 2477	19:56:48.38 (.04)	30:44:00.4 (.6)	< 14.0	22.7	5.3	EF	6.4	120	1.1	EF	20.8	5.8	13.2	305	1.6	Aug. 93
19:59+40 ^b	RAFGL 2494	20:01:09.05 (.03)	40:55:39.2 (.5)	< 15.2	22.0	28.0	EF	10.6	358	1.7	EF	19.5	29.3	38.8	1073	2.8	Aug. 93
20:02+39 ^b	20028+3910	20:04:35.90 (.04)	39:18:45.4 (.6)	< 24.4	17.3	4.3	ABC	3.5	90	.8	ABC	15.6	4.0	6.5	130	.9	Aug. 93
21:08+68	T Cep	21:09:31.79 (.05)	68:29:26.8 (.9)	< 16.4	9.9	-2.0	EF	1.7	21	.3	EF	6.5	-1.7	13.8	110	1.2	Oct. 90
21:31+56	21318+5631	21:33:22.75 (.03)	56:44:34.8 (.5)	< 13.2	18.0	2.3	DEF	11.6	301	1.9	DEF	18.2	2.6	22.5	499	2.1	Oct. 90
21:35+78	S Cep	21:35:12.59 (.07)	78:37:27.8 (.9)	< 18.4	22.8	-13.6	ABC	10.8	453	1.2	ABC	22.1	-16.3	36.8	1267	1.9	May 91
22:27+54	HD 235858	22:29:10.29 (.04)	54:51:07.0 (.5)	< 13.2	10.0	-27.5	BCDE	30.4	418	3.1	BCDE	10.4	-28.4	74.5	921	5.3	May 91
23:16+16 ^b	RAFGL 3068	23:19:12.63 (.04)	17:11:33.2 (.5)	< 23.2	15.0	-28.4	GH	36.3	801	4.8	GH	14.3	-31.0	123.1	2394	5.4	Aug. 93
23:25+10 ^b	RAFGL 3069	23:28:17.15 (.03)	10:54:36.9 (.4)	< 17.2	10.7	45.9	BCDE	15.4	220	3.0	BCDE	10.4	47.0	37.7	511	4.1	May 91
23:32+43	IRC+40540	23:34:27.43 (.04)	43:33:01.9 (.5)	< 11.2	15.5	-16.9	J	41.5	886	4.1	J	13.0	-17.0	163.3	3117	7.6	Oct. 90
23:32+65	23321+6545	23:34:22.65 (.04)	66:01:50.5 (.6)	< 14.8	15.2	-56.5	ABCD	2.9	75	.7	ABCD	14.3	-53.7	9.9	198	1.4	May 91
23:49+61	IRC+60427	23:52:04.89 (.03)	61:48:13.1 (.5)	< 13.2	18.8	-13.4	BCD	2.7	77	.6	BCD	19.5	-13.7	15.8	546	1.5	Aug. 93
23:55+51 ^c	R Cas	23:58:24.75 (.03)	51:23:19.1 (.5)	< 11.2	11.4	26.8	GHI	7.3	26	1.6	GHI	14.3	24.7	78.0	1409	3.8	June 90

^a coordinates are from Loup et al. (1993).^b coordinates differ by more than 3'' from Loup et al. (1993).^c single-dish observations are from Bujarrabal & Alcolea (1991).

of the global visibility profile of each star. As a result, we have derived the integrated flux from the fitted value at zero spacing for each velocity channel. When either the uv coverage was inadequate or the line strength insufficient to account for possible departures from circular symmetry, we have fitted only circular gaussian components. Just in the case of U Cam, we have fitted a circular ring to the visibility profiles corresponding to the central velocities.

The spatially integrated fluxes listed in Table 4 are peak values. Each value was determined by averaging the flux in a small range of velocities centered on V_{lsr} . This range of velocities is delimited by an horizontal bar in the integrated ^{12}CO ($J = 1 \rightarrow 0$) flux vs velocity plots.

Particular care was given to fields with significant emission far from the tracking center (e.g. 04307+6210, CIT6, χ Cyg, IRC+40540) as here the quality of the single-dish contribution appears to be far more important than the interferometric one for the determination of the integrated fluxes.

The main beam temperatures listed in Table 4 were determined directly from the peak integrated ^{12}CO ($J = 1 \rightarrow 0$) flux densities. The main beam temperature, T_{MB} , is related to the integrated flux by $S = \eta_{\text{C}} \times \gamma \times T_{\text{MB}}$, where η_{C} accounts for residual calibration errors and where $\gamma = 4.8 \text{ Jy K}^{-1}$ is the nominal point source sensitivity of the 30 m telescope at the frequency of the ^{12}CO ($J = 1 \rightarrow 0$) transition. However, T_{MB} is not exactly the main beam temperature as measured by the 30 m telescope in extended sources, it must be much larger in very extended sources.

6.3. Velocities and line shapes

If available, only interferometric data were used to determine the expansion velocity in the ^{12}CO ($J = 1 \rightarrow 0$) line. As for the ^{12}CO ($J = 2 \rightarrow 1$) lines, the velocity was not determined by profile fitting but from edge channel maps still showing emission features. Terminal V_{exp} and systemic V_{lsr} velocities of the circumstellar envelopes were determined from channel maps prior resampling to the frequency resolution of the 30 m telescope.

Centroid and expansion velocities measured from the ^{12}CO ($J = 1 \rightarrow 0$) line are listed in Table 4. The same comments pointed out in Sect. 4.3 on the meaning of our estimation of the expansion velocity and on the presence of profile anomalies also hold here.

6.4. Sizes and asymmetries

We have obtained envelope sizes by fitting either one or two elliptical gaussian components to the real part of the combined visibility profiles in the range $-V_{\text{exp}}/3 \leq V \leq V_{\text{exp}}/3$. The envelope size θ_{CO} of a circular gaussian visibility profile was derived according to $\theta_{\text{CO}} = 2 \log 2 / (\pi D / \lambda)$

where D/λ is the HWHP projected baseline of the profile in units of the observing wavelength. In case of elliptical gaussians a size is fitted along the major and minor axes. The gaussian curves corresponding to the fitted envelope sizes in the direction of maximum and minimum extension are shown for each star on the individual ^{12}CO ($J = 1 \rightarrow 0$) pages (central panel, second row) of the atlas.

As for the ^{12}CO ($J = 2 \rightarrow 1$) data we have determined the asymmetry of the envelope from the major and minor axes (see Table 5 – consult the atlas for the velocity dependence of the asymmetry). Double elliptical gaussian were used for 17 envelopes, three of which (IRC+10011, HD 235858, RAFGL 3068) show a clear asymmetry in the compact, central component, two (RAFGL 2155 and χ Cyg) in the extended, outer component, and one (IRC+40540) in both components. IK Tau has a visibility profile which is apparently too complex to be fitted by a double component profile.

Except for U Cam, where we have fitted a circular ring, almost all visibility profiles are well-approximated by gaussian profiles.

7. Statistical results

The actual number of envelopes mapped in ^{12}CO ($J = 1 \rightarrow 0$) with combined data from the IRAM interferometer and the IRAM 30 m telescope and mapped in ^{12}CO ($J = 2 \rightarrow 1$) with the IRAM 30 m telescope is 46. Two objects have been mapped in ^{12}CO ($J = 2 \rightarrow 1$) only (CL Mon, HD 187885) and two in ^{12}CO ($J = 1 \rightarrow 0$) only (RY Dra and 19480+2504).

7.1. Table contents

The results of the ^{12}CO ($J = 1 \rightarrow 0$) and ^{12}CO ($J = 2 \rightarrow 1$) maps analysis are given for each object and summarized in Tables 4 and 5. The first column of Table 4 contains the abbreviated IRAS designation and the second gives the most common name. The next two columns show the equatorial coordinates (epoch J2000) of the source, obtained by fitting interferometric data alone, and the estimated errors. Column 5 lists either the flux density of the radio continuum at 112 GHz or gives 5σ upper limits. Columns 6–11 and 12–17 tabulate the results obtained in the ($J = 1 \rightarrow 0$) and ($J = 2 \rightarrow 1$) line emission, respectively: the terminal ^{12}CO velocity of the envelope (i.e. the expansion velocity or the maximum projected velocity), the systemic velocity with respect to the local standard of rest, the spatially integrated flux density at the systemic velocity, the velocity integrated lined intensity, and the main beam temperatures as observed towards the star position. The epochs of observations for the interferometer are in Col. 12, for the 30 m telescope in Col. 17.

Table 5 lists the results of the gaussian fits. Columns 3–12 and 13–17 give the results for the ^{12}CO ($J = 1 \rightarrow 0$)

Table 5. See text

Ident	Name	CO $J = 1 \rightarrow 0$					CO $J = 2 \rightarrow 1$				
		Flux ₁ (Jy)	Major ₁ ($''$)	Minor ₁ ($''$)	PA ₁ ($^\circ$)	Asym ₁	Flux ₂ (Jy)	Major ₂ ($''$)	Minor ₂ ($''$)	PA ₂ ($^\circ$)	Asym ₂
00:04+42 ^a	KU And	8.6 (2)	12.7 (0.3)								
00:21+38	R And	14.9 (3)	16.8 (4)								
01:03+12 ^a	IRC+10011	14.4 (6)	26.9 (1.4)				8.3 (5)	9.8 (4)	6.8 (5)	-45 (7)	.18 (.04)
01:30+62	OH 127.8+0.0	1.0 (1)	2.1 (1.0)								U
03:18+70 ^a	RAFGL 482	10.8 (5)	7.9 (6)								
03:22+47	IRC+50096	14.9 (4)	25.4 (1.0)				4.8 (4)	7.4 (6)			
03:37+62 ^b	U Cam	3.6 (1)	18.6 (4)	4.5 (.8)	RING						
03:50+11	IK Tau	20.7 (3)	17.6 (4)								
04:30+62 ^a	04307+6210	10.7 (3)	33.8 (1.1)								
04:56+56 ^a	TX Cam	4.6 (4)	20.1 (1.5)				3.1 (2)	8.4 (5)			
05:13+53	R Aur	5.7 (3)	13.6 (8)				3.3 (4)	6.8 (6)			
06:01+07	RAFGL 865	16.2 (3)	10.2 (4)								
06:33+38	UU Aur	5.1 (2)	10.6 (4)								
06:52+06 ^a	CL Mon										
09:07+31	RS Cnc	9.5 (2)	9.6 (6)								
10:13+30	CIT 6	68.3 (8)	34.9 (5)								
12:42+45	Y CVn	6.4 (4)	12.8 (1.3)				14.8 (8)	10.3 (4)			
12:54+66	RY Dra	2.3 (1)	10.4 (7)	6.7 (5)	56 (6)	.22 (.05)					
14:21+25	RX Boo	8.6 (6)	13.7 (8)								
15:47+39	V CrB	4.1 (2)	7.0 (3)								
17:29+17	IRC+20326	29.1 (5)	27.5 (7)								
17:43+50	V814 Her	4.3 (3)	25.3 (2.0)	10.5 (1.6)	-77 (4)	.41 (.07)					
17:55+58	T Dra	6.2 (2)	16.8 (9)								
18:24+23	RAFGL 2155	28.3 (6)	25.9 (8)	19.2 (6)	-38 (4)	.15 (.02)					
18:39+17	IRC+20370	23.6 (7)	25.7 (1.0)								
19:16+23	RAFGL 2362	3.8 (2)	7.4 (5)								
19:19+09 ^a	OH 44.8-2.3	7.0 (8)	16.5 (1.7)								
19:24+11	IRC+10420	4.4 (1)	13.7 (7)								
19:32+27	V1129 Cyg	5.4 (4)	19.4 (1.3)								
19:34+29	MI-92	4.5 (2)	5.4 (4)				2.8 (7)	7.9 (1.4)			
19:48+25	19480+2504	3.6 (3)	5.2 (7)				2.3 (3)	6.3 (6)			
19:48+32 ^a	χ Cyg	31.2 (5)	22.5 (6)	17.3 (5)	-24 (4)	.13 (.02)					
19:50-17 ^a	HD 187885										
19:54+30	RAFGL 2477	6.4 (2)	6.0 (4)								
19:59+40	RAFGL 2494	10.6 (3)	9.0 (3)								
20:02+39	20028+3910	3.5 (3)	11.1 (7)								
21:08+68	T Cep	1.7 (3)	7.3 (1.6)								
21:31+56	21318+5631	8.7 (6)	12.8 (1.0)								
21:35+78	S Cep	10.8 (2)	18.7 (4)								
22:27+54	HD 235858	18.5 (8)	21.0 (9)								
23:16+16 ^a	RAFGL 3068	31.3 (5)	20.6 (6)				11.9 (8)	6.6 (3)	4.9 (4)	-43 (6)	.15 (.05)
23:25+10	RAFGL 3099	15.4 (3)	9.3 (3)				5.0 (2)	3.7 (3)	2.8 (4)	-11 (18)	.14 (.08)
23:32+43 ^a	IRC+40540	32.7 (7)	33.7 (8)								
23:32+65	23321+6545	2.9 (1)	4.4 (3)								
23:49+61	IRC+60427	2.7 (1)	6.4 (5)	23.7 (6)	18 (3)	.10 (.02)	8.8 (6)	10.5 (6)	7.4 (4)	-65 (7)	.17 (.04)
23:55+51	R Cas	7.3 (3)	16.6 (1.0)								

^a errors in the sizes and in the position angles are underestimated because of a limited or uneven sampling of the uv -plane.^b a ring-like shaped structure with a $18.6''$ diameter and a $4.5''$ wide cavity.

and $(J = 2 \rightarrow 1)$ transitions, respectively. Columns 3–7 (index 1) tabulates the flux density, the major and minor sizes, the position angle (east to north) and the degree of asymmetry of the main envelope component. When a second component was fitted to the visibility profile, the results are given in Cols. 8–12 (index 2). The major axis is marked “U” (unresolved) when the envelope was found to be roughly equal or less than the estimated beamsize of the 30 m telescope, and is marked “?” when the data was too scarce or noisy to allow any size determination.

7.2. Atlas contents

The results of the ^{12}CO ($J = 1 \rightarrow 0$) and ($J = 2 \rightarrow 1$) data analysis are presented at the end of the paper. There are two pages for each object, one for each transition. The pages are ordered by increasing right ascension. The page heading identifies the ^{12}CO transition and the star’s most common name and coding in equatorial coordinates (epoch B1950). Each page is divided in four panel rows:

row 1: while the three panels on top of the ^{12}CO ($J = 1 \rightarrow 0$) page show channel maps obtained from the combination of the interferometric and single-dish data, the panels on top of the ^{12}CO ($J = 2 \rightarrow 1$) page show channel maps obtained from single-dish data alone. The integrated velocity intervals for the panels are roughly $-V_{\text{exp}} \leq V \leq -V_{\text{exp}}/3$, $-V_{\text{exp}}/3 \leq V \leq V_{\text{exp}}/3$ and $V_{\text{exp}}/3 \leq V \leq V_{\text{exp}}$. The range of velocities used for the central panel is indicated in the integrated flux panel. The synthesized beam obtained from the combination of the two data sets is shown in the inset. The contour levels are marked in the wedge on top of each panel and start at five sigma. Map units are in Jy/beam and K km/s. The ^{12}CO ($J = 2 \rightarrow 1$) maps were not recentered to zero offset, the central position being undetermined deviations up to $2.5''$ are possible.

row 2: the left panel ^{12}CO ($J = 1 \rightarrow 0$) shows the integrated flux obtained at zero spacing by fitting gaussian profiles to the visibilities. The error bar is set to the one sigma noise level $W^{-1/2}$, where W is the weight of the single-dish data at zero spacing. The central panel shows the global visibility profile for velocities in the $-V_{\text{exp}}/3 \leq V \leq V_{\text{exp}}/3$ range and gaussian curves representing the major and minor axes of the fitted profiles. The uv-coverage is shown to the right.

The left panel ^{12}CO ($J = 2 \rightarrow 1$) shows the flux integrated over the channel maps (continuous line) and the flux towards the star position (dashed line). The central and right panels show the apparent full widths along the major and minor axes, prior to beam deconvolution.

row 3: the major and minor axes of the gaussians which were fitted to the global visibility profile are shown in the left and central panels of the ^{12}CO ($J = 1 \rightarrow 0$) page. The asymmetry parameter $(L-l)/(L+l)$, where

Fig. 2. Comparison of integrated ($J = 2 \rightarrow 1$) vs. ($J = 1 \rightarrow 0$) ^{12}CO fluxes. The dotted line traces envelopes in the optically thick $F_{230}/F_{115} = 4$ limit

L and l are the major and minor axes respectively, is shown to the right.

The ^{12}CO ($J = 2 \rightarrow 1$) left panel shows the radial intensity profile (continuous line) and the presumed shape of the single-dish beam (dashed line). Positional offsets in right ascension and declination were obtained by fitting gaussians to the channel maps and are given in the central and right panels.

row 4: the ^{12}CO ($J = 1 \rightarrow 0$) panel displays positional offsets in right ascension and declination (left and center) and position angle (north to east) as obtained by fitting gaussians to the global visibility profiles.

The ^{12}CO ($J = 2 \rightarrow 1$) panel lists the name of the source, the equatorial coordinates (epoch J2000) obtained by fitting only interferometric data, the interferometric on-target time for equivalent single-baseline observations, the number of snapshots, the synthesized beam and the one sigma noise level in the ^{12}CO ($J = 1 \rightarrow 0$) channel maps shown in the top panel row, the primary calibrators, the amount of flux retrieved by the interferometer, and it summarizes the results found in both the ^{12}CO ($J = 1 \rightarrow 0$) and ($J = 2 \rightarrow 1$) transitions.

We have not included the low-declination source VX Sgr in the atlas and in Table 5, as the data quality was too marginal.

7.3. Statistical error estimates

Positional errors are normally distributed, whereas errors in flux density and width, as a consequence of their positivity, are not. To quantify the uncertainties in position, width and flux we have carried out Monte-Carlo simulations. We modeled circular gaussian profiles

sampled at twice the angular resolution of the telescope with normally distributed noise. The results (see also the Appendix) show that the probability to underestimate the width of a gaussian depends on the signal-to-noise ratio in the samples. At signal-to-noise ratios larger than 10 the probability to underestimate or overestimate the width is almost even, the probability distributions become gaussian and the uncertainties can well be approximated by standard deviations. Similar results are found for the flux density estimates.

7.4. Integrated fluxes

We have first compared the relative ^{12}CO ($J = 2 \rightarrow 1$) / ($J = 1 \rightarrow 0$) intensities in our source sample. In Fig. 2 we show the integrated flux of both lines (Sects. 4.2, 6.2); the dotted line represents the expected ratio for optically thick emission and a common excitation temperature, which is equal to 4. As we see, the optically thick ratio agrees well with observations in most cases. In two oxygen rich objects, RS Cnc and R Cas, the observed ratio is higher than expected. The CO profiles in these stars are peculiar and do not show the parabolic or flat-topped shape expected for optically thick lines. It is then possible that in RS Cnc and R Cas the J -dependence of the opacity leads to the observed high line ratio. In other objects, like the carbon rich CIT 6 and the oxygen rich IRC+20326, the ($J = 2 \rightarrow 1$) / ($J = 1 \rightarrow 0$) relative intensity is smaller than 4. This is not likely to be due to pure opacity effects but to a particularly low excitation of the ($J = 2 \rightarrow 1$) line. Note that it is not impossible that in certain cases the excitation and line-strength effects cancel, which could yield line ratios close to the optically thick limit. However, the systematic presence of optically thick emission in the ^{12}CO lines is confirmed by the general properties of the observed profile shapes (Sects. 4.3 and 6.3) and we conclude that such departures from the optically thick situation are rare.

There certainly is a strong correlation (see Fig. 4) between the CO luminosity and the physical extent of the envelope. Such a correlation may be partially due to the effects of the errors in the assumed distance on these parameters, since the distance value enters the determination of both the luminosity and linear size. However, such errors are not expected to exceed a factor 2, which is not enough to explain the empirical relation. Moreover, a correlation between the envelope thickness and the radius of the CO emitting region is expected if this is mainly given by CO photodissociation (see below). We accordingly think that the relation depicted in Fig. 4 between the CO luminosity and the CO radius is, at least partially, real. We also can see in Fig. 4 that oxygen rich envelopes seem to be less extended and luminous than carbon rich ones. This could be a direct consequence of the selection criteria used to set up

Fig. 3. Comparison of the envelope sizes in the ^{12}CO ($J = 1 \rightarrow 0$) and ($J = 2 \rightarrow 1$) line emission. In the density bounded limit (dotted line), when the envelope runs out of ^{12}CO molecules, both the ($J = 1 \rightarrow 0$) and ($J = 2 \rightarrow 1$) transitions trace the same regions. The size of envelopes smaller than the $13''$ beam of the 30 m telescope is generally overestimated

the star sample. In fact, the selected oxygen rich sample is on average $3\times$ closer than the carbon rich one, which consequently resulted in a typically $10\times$ more luminous than the carbon star sample. However, we did not select nearby oxygen rich stars and farther carbon rich objects, we just chose the most intense (and better studied) sources. This distance factor mainly reflects the fact that oxygen rich stars are more abundant and then can be found closer to us. Again, if the distance errors are not very large, the separation between the different groups in Fig. 4 is real and we must conclude that absolute CO luminosities are larger in carbon rich stars.

7.5. Expansion velocities

We have measured the ^{12}CO ($J = 2 \rightarrow 1$) and, when available, the ($J = 1 \rightarrow 0$) terminal velocity for all the circumstellar shells in our sample. The expansion velocities are, as expected, significantly similar for both CO lines. Only in ten objects the differences exceed 10%, and only in three stars, V CrB, T Cep and R Cas, the differences exceed 20%. In all these cases the difference between the expansion velocities derived from the ^{12}CO ($J = 1 \rightarrow 0$) line and from the ($J = 2 \rightarrow 1$) line can be considered as negligible due to the noise level, uncertainties in the baselines or lack for spectral resolution. V CrB and T Cep show weak and narrow CO lines which, particularly at 115 GHz, makes difficult a good measurement of the line width. In spite of the peculiar profiles of R Cas which are quite different in both lines, a close inspection reveals again that the adoption of the same FWHM for both lines would not be incompatible with our data.

Fig. 4. CO luminosity vs. linear size for oxygen, carbon and S ([C/O] ~ 1) chemical types

Although most sources show, as we have mentioned, the rounded or flat-topped profiles characteristic of circumstellar envelopes, anomalies are (at some level) present in a non-negligible number of stars. Some sources show more or less prominent spikes (U Cam, RS Cnc, R Cas, OH127.8+0.0, 04307+6210, S Cep) or relatively intense wings (M1-92, IRC+10420). In some cases, like U Cam, the profile seems in fact to be composite due to the particular structure of the envelope. Except for the two peculiar sources M1-92 and IRC+10420 with expansion velocities well above 25 km s^{-1} , most of the velocities seem to fall all over the range found for AGB envelopes. M1-92 is known to present a high-velocity bipolar outflow that contributes to most of the profile width. This is probably also the case of IRC+10420. Both sources are described more in detail in Sect. 8.

7.6. Sizes and asymmetries

The envelope sizes measured in both lines are compared in Fig. 3. As we see, many stars show size ratios close to 1, as expected if the observed radii were given by a cut-off of the CO density at a given point. A certain number of stars, however, shows a somewhat larger size in the ($J = 1 \rightarrow 0$) line, which must be due to level population effects, since this line is of course easier to excite (in contrast opacity effects would lead to larger sizes in the ($J = 2 \rightarrow 1$) line). This conclusion is strengthened by the fact that most sources showing a significant discrepancy with the hypothesis of a common spatial cut-off for both lines, like CIT 6 and IRC+20326, also show a low ($J = 2 \rightarrow 1$) to ($J = 1 \rightarrow 0$) ratio. But we must note that others, in particular IRC+40540, are anomalous in relative size but not in relative intensity: IRC+40540 which is carbon rich, shows clearly parabolic CO profiles (see also notes on individual envelopes).

Fig. 5. Comparison of measured sizes and calculated photodissociation radii in 31 envelopes. Photodissociation radii are calculated according to Loup et al. (1993). The dotted line is a linear fit (see Eq. 7)

Most envelopes are found to show a significantly circular appearance. However, the global visibility profiles show that there is a non-negligible number of stars with peculiar circumstellar envelopes. It appears that many of these are surrounded by an inner envelope and an outer shell with morphologies that are not easily interpreted owing to the limited resolution achieved here. The bulk of the CO emission is in general found in the outer envelope which mostly appears spherical symmetric. The presence of an inner envelope, in some case indirectly suggested by a central tip in the spectral profile, suggests quite a substantial, if not abrupt, change in the mass loss rate in the envelopes of these stars testifying for a thermally pulsing activity. Some of these stars may already have left the AGB.

Another finding is that a fairly large number of these envelopes shows a more or less pronounced asymmetry. The ^{12}CO ($J = 2 \rightarrow 1$) observations firmly establish the existence of a pronounced morphological asymmetry in the outer envelope of RAFGL 2155 and χ Cyg, an asymmetry which is likely to be due to an anisotropic interstellar UV radiation field. In some objects, however, departure from sphericity occurs already in the innermost regions. This is in particular the case of the envelopes around RAFGL 3068 and IRC+40540, and possibly also around RAFGL 3099 (not indicated in Table 5). As shown in Table 5 and in the atlas, there are hints for developing asymmetries in many other stars, but the limited dynamical range hardly allows to draw clear conclusions.

7.7. Mass loss rates and photodissociation radii

We have used our ^{12}CO ($J = 1 \rightarrow 0$) data to perform a self-consistent calculation of the envelope mass loss rate $\dot{M}$

and photodissociation radius R_{CO} , following the method described by Loup et al. (1993). The input parameters are:

- 1: the envelope expansion velocity measured in ^{12}CO ($J = 1 \rightarrow 0$) and listed in Table 4,
- 2: the distance of the star derived from the bolometric fluxes, as given by Loup et al. (1993 – Table 2 herein),
- 3: the main beam temperature of the ^{12}CO ($J = 1 \rightarrow 0$) line as seen by a 7 meter telescope (the calculation assumes that the envelope is unresolved) which we derive from the integrated ^{12}CO ($J = 1 \rightarrow 0$) flux (Table 4).
- 4: the fractional CO abundance which was assumed to be constant and equal to $5 \cdot 10^{-4}$ for oxygen rich stars and 10^{-3} for carbon rich stars and S-type stars (Zuckerman & Dick 1986).

We show in Table 3 the calculated photodissociation radii and mass loss rates, together with the assumed distances and some other properties. In Fig. 5 we show the comparison of the computed photodissociation radii of these envelopes, R_{CO} and their measured half-maximum radii, θ_{CO} . The correlation between both parameters is obviously significant.

In our procedure, the photodissociation radius is calculated from the CO total intensity (through the mass loss rate), therefore Fig. 4 reveals the existence of a correlation between the CO luminosity and the envelope size. In the case of optically thick emission, a relation of this kind can be expected, the radius being approximately identified with the point at which the line emission becomes optically thin and from which the emission starts decreasing sharply. However, in such a case the extent of the ($J = 2 \rightarrow 1$) line, which is always the most opaque, would have systematically shown a larger size than the ($J = 1 \rightarrow 0$) line, which is not the case in our data, see Sect. 7.4. Accordingly we conclude that the correlation shown in Fig. 5 indicates that the effects of photodissociation dominate the CO envelope size.

It is also noticeable in Fig. 5 that the measured envelope radius is always smaller than the calculated photodissociation radius. This is indeed expected, as the radius θ_{CO} is equivalent to the size of the envelope at half the maximum intensity (see Sect. 6.4) whereas the photodissociation radius R_{CO} delimits a spherical region around the star in which the total mass of CO molecules is contained. The size of this region is mainly given by the intensity of the interstellar UV radiation field and the mass loss rate, since the molecule shielding from the external field depends on the envelope opacity.

Unquestionably, the mass loss processes that take place are certainly not smooth, steady and spherical in all the circumstellar envelopes of the sample. However, except for RY Dra, V814 Her, RAFGL 2155, χ Cyg and IRC+40540 which are slightly asymmetric at larger scales, for U Cam which has a detached shell, and for all envelopes with a hint for asymmetry (see Table 5), all other envelopes in the sample can reasonably be considered as spherical from

an observational point of view and the simple model described above was applied to them.

Thus, leaving aside all envelopes of non-spherical appearance, we derived from a sample of 31 stars an empirical formula with which we estimate the photodissociation radius R_{CO} of an envelope from the measured CO radius θ_{CO} at half maximum intensity

$$R_{\text{CO}} = 1.5 \times \left[\frac{\theta_{\text{CO}}}{''} \right] + 8.4'' . \quad (7)$$

Even though, this relation (dotted line in Fig. 5) may not be too appropriate for estimating the photodissociation radius of an envelope, we have subsequently used it to compute the photodissociation radius of envelopes of, to our knowledge, unknown distances. Accordingly, by reversing the computational scheme described by Loup et al. (1993), we derived estimates for the mass loss rates and the distances of IRC+10420, 19480+2504, 20028+3910, HD 235858 and 23321+6545 (see Table 3). The calculations, however, were inconclusive for IK Tau and CIT 6, the last one showing hints for an asymmetric structure.

7.8. Non-detections and marginal detections

We have already seen in Table 2 that for 7 sources the quality of our data did not allow a proper interpretation. In some cases, galactic contamination was important, in others the CO emission was too weak. For OH39.7+1.5 and OH104.9+2.4 both contamination and weak emission are noticed. AC Her was not detected, we therefore do not confirm a previous tentative detection (Alcolea & Bujarrabal 1991) at a level of $T_{\text{MB}}(2 \rightarrow 1) \sim 0.1$ K, although our noise rms at this frequency is about 0.04 K, not low enough to draw definitive conclusions. In some sources like R LMi and μ Cep the ($J = 2 \rightarrow 1$) line is intense, but the ($J = 1 \rightarrow 0$) emission is too weak. In R LMi our $T_{\text{MB}} \sim 0.1$ K is compatible with the data by Bujarrabal et al. (1989). Le Borgne & Maunon (1989) give an intensity $T_{\text{MB}}(2 \rightarrow 1) \sim 0.15$ K for μ Cep. Our data confirm this figure, but we found the ($1 \rightarrow 0$) line too weak (~ 0.04 K) to be accurately mapped. We only show CL Mon in the ($J = 2 \rightarrow 1$) emission, the ($J = 1 \rightarrow 0$) data was too scarce.

8. Individual envelopes

U Cam is a carbon-rich star that has probably experienced a change in its mass loss (Oloffson et al. 1990). The ^{12}CO radial visibility profile and the integrated flux profile have revealed a detached shell of $10''$ radius surrounding the central star. Recent observations with the PdBI in the HCN ($J = 1 \rightarrow 0$) line emission support this picture (Lindqvist et al. 1996).

04307+6210 is classified as carbon-rich M-star (Groenewegen 1994, formerly associated to IRC+60144, an optically visible star of 12 magnitude). The ^{12}CO

($J = 1 \rightarrow 0$) radial visibility profile and the spiky integrated emission profile suggest that the star is surrounded by an inner $\sim 8''$ and an outer $\sim 34''$ shell, one of the two largest in our sample. This leads to the conclusion that variations in the mass loss of 04307+6210 have already taken place.

RS Cnc is classified as an MS giant, a thermally pulsing AGB star whose surface is enriched from dredged up material. The star for which Ake and Johnson (1988) suggest a binary nature, is surrounded by a thick envelope with thermal line emission detected in several molecules (HCN, CS, SiO...). The position-velocity diagram in both lines testifies the clear bipolar nature of the ^{12}CO envelope. The spiky emission profile which does not appear to follow the velocity gradient of the broader peak, recalls the position-velocity diagram of the broad and narrow emission components observed in X Her (Kahane & Jura 1996). These properties are indications that the envelope does not show the expected spherical structure in isotropic expansion, being possibly in a phase of strong evolution.

CIT 6 is a carbon-rich star, the most intense and one of the most extended sources in our catalog. The envelope appears slightly asymmetric but no systematic variation with the velocity of the emission centroid is found. Our interferometric maps show the CO emission to be distributed in two components, in a compact one and in a weak and extended halo, both centered on the same position. Other sources show a similar behaviour (see for instance, IRC+10011, 04307+6210, IRC+20326, RAFGL 2155, IRC+20370, χ Cyg, and RAFGL3068), although less clearly.

Y CVn is classified as a carbon-rich star, the brightest J-type star known in the optical. Izumiura et al. (1996) report the detection with ISOPHOT of a very large, slightly asymmetric, detached dust shell surrounding the central star. Though the envelope is not asymmetric ($f < 0.1$) according to our analysis, the ($J = 2 \rightarrow 1$) position-velocity diagram show presumably the kinematical signature of a faint asymmetry developing in the innermost regions around the star.

RAFGL 2155 is a carbon-rich star which shows a systematic behaviour in the emission centroid position as a function of velocity, for both transitions, with a general displacement from south-east to north-west of a few arc-sec. As in other sources, this behaviour probably corresponds to the presence of a circumstellar component in bipolar expansion.

IRC+10420 is an oxygen-rich star surrounded by a heavy cool envelope. The nature of the star is still controversial: Hvrinak et al. (1989) propose a post-AGB star evolving towards a young planetary nebula (PN), Oudmajer et al. (1994) a very luminous hypergiant undergoing an extremely rapid evolution towards a cool Wolf-Rayet star.

The complex width and velocity-position diagrams suggest a very clumpy envelope, quite different from a spherical shell. The object is probably the precursor of very excited and structured PN, as NGC 6302 and NGC 7027. We determined the distance according to the method described in Sect. 7.7. We found two possible estimates $D = 6.12$ kpc, which is close to the value commonly adopted, and $D = 0.76$ kpc (see also Kastner et al. 1995).

M1-92 also known as Minkowski's Footprint, is a well studied proto-planetary nebula. Both, the ^{12}CO ($J = 1 \rightarrow 0$) and ($J = 2 \rightarrow 1$) observations reveal the clear bipolar morphology of the $6''$ dense shell, remnant of the AGB stage. Recent interferometric observations in the ($J = 1 \rightarrow 0$) line emission bear evidence of two $3''$ wide cavities along the nebular axis, probably formed by the passage of a bipolar bow shock (Bujarrabal et al. 1994b, 1997). This supports the idea that stellar wind interaction is the process that very likely dominates the circumstellar dynamics of post-AGB stars and of M1-92 in particular.

T Cep is an oxygen-rich Mira variable. The ^{12}CO ($J = 2 \rightarrow 1$) velocity position diagram (the ^{12}CO ($J = 1 \rightarrow 0$) data is probably sensitivity limited) shows the north-west south-east signature of an axial velocity gradient, the velocity increasing steadily with distance from the central star.

RAFGL 3068 is a well-known carbon-rich star (Sopka et al. 1989) with strong emission ^{12}CO profiles of nearly parabolic shape. The radial ^{12}CO ($J = 1 \rightarrow 0$) visibility profile is characteristic of a large outer circumstellar nebula surrounding a compact inner envelope. The outer shell is presumably detached (this is suggested by the ringing features in the visibility profile) and strongly bipolar. The position angle which is almost fixed at ~ -30 deg is likely to be due to an uneven sampling of the uv -plane.

RAFGL 3099 is a carbon-rich Mira variable. Though the ^{12}CO ($J = 1 \rightarrow 0$) emission traces essentially a spherical morphology, as suggested by the visibility profile, the ($J = 2 \rightarrow 1$) emission is slightly asymmetric. Moreover, channel maps obtained at the nominal velocity sampling of the interferometer show a linear but faint signature in the position velocity diagrams typical of an expanding circumstellar envelope with axial symmetry (south-east – north-west).

R Cas is an oxygen-rich star presenting an aspherical configuration (Tuthill et al. 1994), probably related to the influence of a binary companion. The star is surrounded by a large, optically thick circumstellar envelope whose radial ^{12}CO ($J = 1 \rightarrow 0$) visibility profile show little if no deviation from circular symmetry (Bujarrabal et al. 1994a). The data, however, reveal a remarkable kinematical continuity (south-east – north-west) in both the ^{12}CO ($J = 1 \rightarrow 0$) and ^{12}CO ($J = 2 \rightarrow 1$) position velocity diagrams which clearly supports the idea that the circumstellar dynamics is confined to an axially symmetric structure.

9. Summary

We have carried out an atlas of the ^{12}CO ($J = 1 \rightarrow 0$) and ($J = 2 \rightarrow 1$) line emission in a selected sample of AGB and post-AGB stars. The survey observations of 46 circumstellar envelopes reported in this paper significantly improve the data available from previous ^{12}CO surveys. The main results we obtained from the work are:

- We have determined interferometric positions for 44 envelopes. Interferometric positions are not available for CL Mon and HD 187785. As a rule, the absolute positional accuracy in the data is estimated to about $0.5''$.
- We have set 5σ upper limits to the radio continuum at 112 GHz of 42 stars and determined the radio flux of CIT 6 and 19480+2504 to ~ 13 mJy and ~ 28 mJy, respectively. We tentatively detected μ Cep in the radio continuum.
- We have measured terminal and systemic velocities of 44 envelopes. Except perhaps for V CrB, T Cep and R Cas, the difference in the ^{12}CO ($J = 1 \rightarrow 0$) and ($J = 2 \rightarrow 1$) terminal velocities can be considered as negligible.
- The line shapes show for the most part the typical signature of optically thick envelopes. There are, however, line profiles with a strong central spike characteristic of a two-component envelope that in some cases may be related to the presence of detached shells as in U Cam, RS Cnc, R Cas, OH127.8+0.0, 04307+6210, S Cep and possibly T Dra. In addition, we found two line profiles with relatively strong wings, an indirect indication for aspherical mass loss activity, in M1-92 and IRC+10420.
- We have determined ^{12}CO ($J = 1 \rightarrow 0$) and ($J = 2 \rightarrow 1$) flux densities and integrated intensities for almost all the stars in the sample. Consistency in the ($J = 1 \rightarrow 0$) results was achieved by minimizing possible calibration errors in the single-dish data, that is, by readjusting appropriately the single-dish flux density scale to the interferometric one. In a number of stars we found discrepancies with previous works.
- We analyzed the morphology, size and asymmetry of 46 envelopes. Within the sensitivity of our observations, AGB and post-AGB envelopes can be considered for the most part as of spherical appearance. There is, however, evidence for an inner shell surrounding the central star and/or for a significant envelope asymmetry in about 30% of the envelopes of our sample.
- The position-velocity diagrams of the oxygen rich RS Cnc, M1-92 and R Cas show a remarkable kinematical continuity in both the ^{12}CO ($J = 1 \rightarrow 0$) and ^{12}CO ($J = 2 \rightarrow 1$) line emission, an indication that the circumstellar dynamics in these stars is confined to an axially symmetric morphology. Further envelopes but with less pronounced kinematical signature are found in Y CVn, RAFGL 2362, T Cep and 23321+6545.
- We have calculated mass loss rates and ^{12}CO photodissociation radii for 38 stars. We have also established an empirical relation between the ^{12}CO photodissociation radius of an envelope and the measured CO extent at half maximum intensity. This results indicates that very probably the CO extent is given by the envelope radius inside which CO is not photodissociated by interstellar UV radiation.

Appendix

The derivation of estimates for the uncertainties in flux S , position η , and width θ of a one-dimensional gaussian brightness distribution centered at $\eta = 0$ and sampled at locations $\eta_j = \pm j \cdot \theta_B/2$ ($j = 0 \dots N$, θ_B is the beamwidth) with additive noise ϵ of zero mean and variance σ_N^2

$$B_j(S, \theta) = S \exp(-((\eta_j - \eta)^2/2\theta^2))|_{\eta=0} + \epsilon(\eta_j, 0, \sigma_N^2) \quad (8)$$

requires the use of non-linear regression. A Gaussian profile is indeed non-linear in η and θ according to

$$\delta B/\delta \eta \sim \eta B \theta^{-2} \quad \text{and} \quad \delta B/\delta \theta \sim \eta^2 B \theta^{-3}. \quad (9)$$

Though non-linear regression is required to derive estimates of the uncertainties in S , η and θ , we used an approach suggested by the iterative Gauss-Newton method (Bates & Watts 1988) to derive a linear approximation to these estimates in the limit of high signal-to-noise ($= S/\sigma_N$). In this case the one sigma confidence limit for the position η in the limit of high N can be written to

$$\sigma_\eta^{-2} \cong \sigma_N^{-2} \cdot \lim_{N \rightarrow \infty} \sum_{j=0}^N (\delta B_j/\delta \eta_j)^2 \quad (10)$$

with similar expressions for σ_S^{-2} and σ_θ^{-2} . According to equation (10) the uncertainties in S , η and θ for the gaussian brightness distribution B are given by

$$\sigma_S^{-1} \cong \sigma_N^{-1} \cdot \left(\lim_{N \rightarrow \infty} \sum_j^N j^4/4^{(jR)^2} \right)^{-1/2} \quad (11)$$

$$\sigma_\eta^{-1} \cong 4\sqrt{2} \log 2 \cdot \sigma_N^{-1} R^{-1} \theta^{-1} S \times \left(\lim_{N \rightarrow \infty} \sum_j^N j^2/4^{(jR)^2} \right)^{-1/2} \quad (12)$$

$$\sigma_\theta^{-1} \cong 2 \log 2 \cdot \sigma_N^{-1} R^{-1} \theta^{-1} S \times \left(\lim_{N \rightarrow \infty} \sum_j^N 4^{-(jR)^2} \right)^{-1/2} \quad (13)$$

where $R = \theta_B/\theta$. Note that in the $R = 1$ limit (i.e. an unresolved object) the uncertainties can roughly be estimated to $\sigma_S \cong \sigma_N$, $\sigma_\eta \cong (\theta_B/2)(\sigma_N/S)$ and $\sigma_\theta \cong \theta_B(\sigma_N/S)$. The errors in the estimates are reasonably small for samples with $\text{snr} \geq 10$. In analogy, statistical estimates for S , η and θ according to the two-dimensional case were approximated to $\sigma_S \cong 0.7\sigma_N$, $\sigma_\eta \cong (\theta_B/2)(\sigma_N/S)$ and $\sigma_\theta \cong \theta_B\sigma_N/S$ and found to be better than 20% for data with $\text{snr} \geq 10$.

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Source name:		CL Mon				
Source center (J2000):		06 ^h 55 ^m 36.62 ^s (—) 06°22'44.9" (—)				
Array on-source integration time:		— hr				
Number of snapshots:		—				
Synthesized beam:		— mJy, beam ^{−1}				
rms in ¹² CO (J=1-0) maps:		—				
Phase calibrators:		— %				
Array flux / Total flux:		—				
Size (")		V _{Exp} (km/s)	V _{LSR} (km/s)	Flux (Jy)	T _{MB} (K)	
—		—	—	—	—	—
¹² CO (J=1-0)	9.7	24.7	27.7	5.6	0.77	
¹² CO (J=2-1)