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# A 1.2 mm MAMBO survey of Post-AGB stars

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## ABSTRACT

*Aims.* We performed a millimetric survey of a sample of 24 post-AGB stars aimed to search for emission from circumstellar matter, in order to investigate the physical properties of the outer parts of the envelopes.

*Methods.* The observations were conducted using the 37-channel Max-Planck Millimeter Bolometer array at the 30-meter IRAM telescope. The continuum emission toward the detected sources was used to quantify the mass of the emitting dust. We combined our observations with data available in literature to construct the spectral energy distribution (SED) of the sources. When the observational data cover a spectral range wide enough, some properties of circumstellar envelopes were derived by comparison with spectra computed using a radiative transfer code.

*Results.* Of the 24 objects in our sample, we detected millimetric continuum emission toward 11 sources. Two other sources were detected at flux level close to  $3\sigma$ . The derived circumstellar dust masses range between 0.4 and  $24 \times 10^{-4} M_{\odot}$ , but these results are affected from the uncertain about the source distances. The parameters derived from the SED fits are consistent with the values characteristic for these kind of object. As confirmed from the flux density extrapolated in the first light channels of the Atacama Large Millimetric Array, such sources would be good targets for future high resolution mapping with the ALMA facility.

**Key words.** Stars:AGB and post-AGB – Circumstellar matter – Planetary Nebulae: general– radio continuum: stars.

## 1. Introduction

Stars on the red giant branch undergo a process of copious mass-loss leading to the formation of a circumstellar envelope (CSE). These envelopes, quilted up by the ejected material, contain atomic and molecular gas and are characteristic of the post Asymptotic Giant Branch (AGB) evolutionary phase, which results in the formation of a Planetary Nebula (PNe). Because of the huge amount of processed material returned to the ISM, this evolutionary phase is very important for the chemical evolution of the Galaxy. Yet, the short transition phase between the end of the AGB and the formation of a new PNe is still poorly understood. In particular, it is quite challenging to understand how the almost symmetric CSE observed around AGB stars transform themselves in the highly structured morphologies observed in high dynamical range optical images of PNs.

The importance of studying objects in the way to PNe resides in the fact that in their CSE the unknown physical mechanisms, that shape the PNe, are already at work, as

HST images of multi-polar outflows in post-AGB stars appear to indicate (Sahai 2001).

Despite of numerous efforts to identify the shaping agent/s in PNs (Sahai & Trauger 1998; Garcia-Segura et al. 2005), there are no observative evidences that support one mechanism in favors to the others (Balick and Franck 1002).

Dust is ubiquitous detected in post-AGB and PNe and, quite often, it is in the form of disks and tori. Some models evocate these structures, whose origin is however under debate, as important ingredient for the mechanism which produces collimated outflows observed in the CSE (Frank et al. 1997; Huggins et al. 2004). In this contest, very important informations can be provided by studying the physical properties of CSE and in particular, the presence and the spatial distribution of the circumstellar dust, as this may help in finding clues to understand the nature of the shaping agent.

Detailed studies of the spectral energy distribution (SED) of a small sample of optically bright post-AGB candidate stars have shown that these objects can be divided into two groups, depending on the shape of the IR excess (Trams et al. 1991; van der Veen et al. 1994): sources with

**Table 1.** Properties of stars in our sample. *IRAS* fluxes come directly from Point Source Catalog (PSC).

Sources with Optical Counterpart							
IRAS Name	RA(J2000)	DEC(J2000)	F <sub>12</sub> [Jy]	F <sub>25</sub> [Jy]	F <sub>60</sub> [Jy]	F <sub>100</sub> [Jy]	
00210+6221	00 23 51.2	+62:38:16	48.5	51.9	12.5	<23.2	
01174+6110	01:20:44.9	+61:26:18	4.1	16.9	33.9	4.1	
04296+3429	04:32:56.6	+34:36:11	12.7	45.9	15.4	<9.2	
05089+0459	05:11:36.1	+05:03:26	7.4	21.9	11.9	3.8	
06530-0213	06:55:32.1	-02:17:30	6.1	27.4	15.1	4.1	
07134+1005	07:16:10.2	+09:59:48	24.5	116.7	50.1	18.7	
07331+0021	07:35:41.1	+00:14:58	15.3	68.1	18.5	3.7	
17436+5003	17:44:55.4	+50:02:39	6.1	184.0	152.0	48.7	
19114+0002	19:13:58.6	+00:07:31	31.3	648.3	515.9	168.1	
20000+3239	20:01:59.4	+32:47:32	15.0	71.0	30.0	<43.1	
20028+3910	20:04:35.0	+39:18:38	41.8	210.8	143.1	46.5	
22223+4327	22:24:30.6	+43:43:03	2.1	37.1	22.4	9.5	
22272+5435	22:29:10.3	+54:51:06	73.9	302.4	96.6	41.0	
22574+6609	22:59:18.4	+66:25:48	9.0	29.5	10.7	2.5	
23304+6147	23:32:45.0	+62:03:49	11.4	59.1	26.6	7.2	
Sources without Optical Counterpart							
07430+1115	07:45:49.8	+11:08:25	7.7	22.9	10.7	2.5	
18454+0001	18:48:01.5	+00:04:47	10.8	14.5	13.6	<384	
18514+0019	18:53:57.9	+00:23:24	4.9	23.4	17.3	<152	
18576+0341	19:00:11.2	+03:45:46	58.5	425.0	274.7	<1660	
19024+0044	19:05:01.5	+00:48:48	2.9	48.8	42.5	15.7	
19075+0432	19:10:00.0	+04:37:06	5.2	28.1	31.8	14.4	
19454+2920	19:47:24.3	+29:28:12	17.3	89.6	54.4	14.7	
20144+4656	20:15:58.3	+47:05:39	1.2	17.0	20.0	<85	
21537+6435	21:55:04.6	+64:49:54	6.9	26.1	13.3	<6.1	

a broad IR excess extending from the near infrared until the far-IR have both hot and cool dust in their circumstellar shells and sources with only a far-IR excess show only the presence of cool dust. The double peaks in the SEDs appear to be characteristic for objects in transitions, but the presence of only cool dust seems to point out objects more evolved towards PNs. Thermal emission from dusty envelopes may extend up to millimeter wavelengths, depending on the temperature of the dust. In particular, millimetric observations are essential to better determine the SEDs of the sources and thus to put more stringent constraints to the model of their circumstellar envelopes. Moreover, millimetric observations will allow to assess the presence of multiple dusty shells to be related to different mass-loss episodes undergone by the stars.

In this paper we present the results of a 1.2 mm survey aimed to detect the millimetric emission from a sample of post-AGB stars for a robust modeling of their circumstellar envelopes. This appears as a first, necessary step in preparation for the use of the new interferometers (i.e. ALMA and CARMA) that, in the very near future, will be able to resolve, in unprecedented spatial resolution, the circumstellar geometry for a full understanding of the shaping mechanisms.

## 2. Observations

### 2.1. Sample selection

In the attempt to determine a possible millimetric emission due to thermal dust emission from the circumstellar envelope, we observed a sample of Post-AGB stars with the 30m IRAM telescope.

Since the dusty envelopes show a clear signature in the far-IR spectrum of the stars, the IRAS colour-colour diagram has been successfully used by several authors in systematic searches for post-AGB objects by looking for sources in-between the locus of the planetary nebulae and late-type AGB stars. Garcia-Lario et al. (1997) compiled a list of stellar objects, characterized by strong F-IR excess, which occupy the same region of the IRAS color diagram as AGB stars and PNs. The sample contains 126 Post-AGB. Among those, a large fraction (70%) represents post-AGB in a very early stage, still heavily obscured in the optical.

Another method of looking for transition objects is concentrated on optically bright objects with an IR excess due to circumstellar dust (Pottash and Parthasarathy 1988; Trams et al. 1991; Oudmaijer et al. 1992). These resulted in the detection of objects scattered in the IRAS

**Table 2.** Measured millimeter fluxes.

Sources with Optical Counterpart				
IRAS Name	Date	Time [s]	Flux [mJy]	Weather <sup>†</sup>
00210+6221	21 Jan 02	1200	...±2.4	B
01174+6110	21 Jan 02	1200	22.9±1.7	B
04296+3429	14 Feb 02	1200	4.4±1.3	A
05089+0459	05 Feb 02	1440	...±1.0	A
06530-0213	14 Feb 02	1200	4.8±1.5	A
07134+1005	07 Feb 02	1200	14.0±1.5	A
07331+0021	07 Feb 02	1200	...±1.9	B
17436+5003	05 Feb 02	1080	15.2±1.1	A
19114+0002	04 Feb 02	480	68.2±3.4	B
20000+3239	21 Jan 02	1200	11.4±1.7	B
20028+3910	21 Jan 02	1200	11.9±1.5	A
22223+4327	04 Feb 02	1200	...±1.5	A
22272+5435	04 Feb 02	1200	35.3±1.7	A
20144+4656	21 Jan 02	1200	...±1.8	B
23304+6147	21 Jan 02	1200	...±1.8	B
Sources without Optical Counterpart				
IRAS Name	Date	Time [s]	Flux [mJy]	Weather <sup>†</sup>
07430+1115	07 Feb 02	1200	...±1.3	A
18454+0001	22 Jan 02	1200	...±1.4	A
18514+0019	21 Jan 02	1200	8.2±1.3	A
18576+0341	03 Feb 02	840	≥45.4±2.2	B
19024+0044	22 Jan 02	1200	...±1.3	A
19075+0432	04 Feb 02	1200	6.2±1.2	A
19454+2920	03 Feb 02	1200	...±4.3	C
20144+4656	05 Feb 02	1200	...±2.7	C
21537+6435	04 Feb 02	1200	6.3±1.6	A

<sup>†</sup> Wheatear condition: A) good, B) poor, C) bad.

colour-colour diagram, as they show different amounts of IR excesses and different IR-colours.

Oudmaijer et al (1992; 1996), looked for transition objects with an optical counterpart by performing a cross-correlation of the SAO optical catalogue with the IRAS point-source catalogue, selecting supergiants with spectral type between B and G and with an IR excess due to circumstellar dust.

To select a sample of possible targets we used the most complete compilations of objects with no optical counterpart, from Garcia-Lario et al. (1997) and of objects with optical counterpart, from Oudmaijer et al (1992; 1996), selecting the stars identified as post-AGB, which are associated with highly evolved post-AGB stars with low-mass progenitors. We further include in the sub-sample of stars with optical counterpart 11 stars, originally not classified by Oudmaijer et al. (1992) as Post-AGB, for which there are compelling observational evidences that are in the post-AGB evolutionary stage (van der Veen et al. 1994; van Wincker 1997).

A small sample of post-AGB stars has been observed in the millimetric band with the JCMT (van der Veen et al. 1994) and the detection rate appeared to be well correlated with the  $F_{60}$  IRAS flux, in the sense that all

the stars with  $F_{60} \geq 10$  Jy have been detected. If the extra infrared excess has the shape of a cold black body, as expected from a more distant dust shell, a  $F_{60} \sim 10$  Jy would imply a 1.3 mm flux higher than 36 mJy and thus easily detectable with the new Bolometer. In order to maximize the probability to have a detectable flux at 1.2 mm we thus selected, from our original sample, only those sources with  $F_{60} \geq 10$  Jy. This reduces our sample to 34 targets.

In this paper we report on the results relative to a subsamples of 24 objects, which are given in Table 1.

## 2.2. The 30m IRAM observations and results

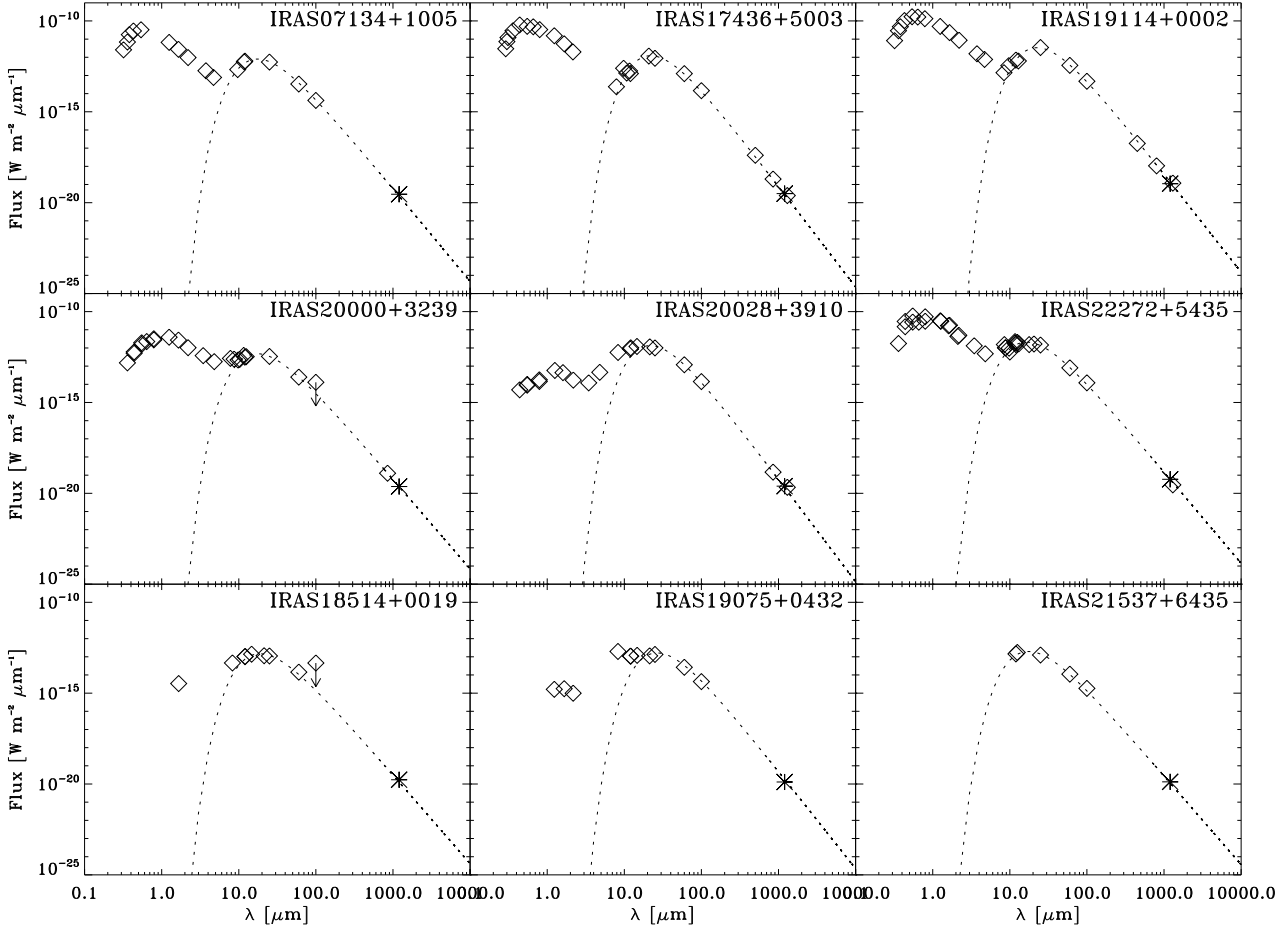
The 37-channel Max-Planck Millimeter Bolometer (“MAMBO”; Kreysa et al. 1998) array at the 30-meter IRAM telescope on Pico Veleta (Spain) was used to perform the survey. The observations were made between 21 January and 7 February 2002, using the standard ON-OFF technique, chopping the secondary mirror of the telescope by about  $50''$  in azimuth, at a rate of 1 Hz. The FWHP of our beam was  $10''.5$  at 1.2 mm.

For each source the observations were typically obtained in blocks of 4 or 5 scans lasting 4 minutes each. Frequent skydip observations have been used to determine atmospheric extinction as function of elevation and time. The data were analyzed using the MOPSI software (Zylka 1998). The flux calibration was performed by observing either Mars and Uranus to determine the flux conversion factor. For each channel the sky noise was subtracted by computing the weight mean of the signals from the surrounding six channels.

In table 2 the resulting 1.2 mm flux densities measured for the detected objects are reported. Out of the 24 observed sources, we carried out 11 detections over the threshold of  $4\sigma$  and two uncertain detections at  $3\sigma$ . Four of the detected and one of the undetected sources overlap the sample observed from Walmsley et al. (1991), by using the 30m IRAM telescope at the wavelength of 1.3 mm, but with a different bolometer. The measured flux densities are in good accordance with the exception of IRAS 22272+5435, which shows a flux level significantly higher.

The sample includes IRAS 01174+6110 and IRAS 18576+0341, which were firstly classified as post-AGB stars on the basis of their IRAS colours, but probably having different nature. IRAS 01174+6110, in fact, is likely an HII region (Kelly et al. 2005), while IRAS 18576+0341 has been recently recognized as new LBV (Pasquali & Comeron 2002; Clark et al. 2003; Umana et al. 2005). For these two objects we just report the measured flux density.

In particular, IRAS 18576+0341 will be object of a future more detailed analysis assembled with radio high resolution results. It is to note that Umana et al. (2005) pointed out that the source’s right ascension is about  $4''$  shifted with respect to values previously reported in lite-



**Fig. 1.** Spectral energy distributions of the emission towards the detected sources. The asterisks indicate measures from this work. The dashed lines show the modified blackbody fits to the long-wavelength data, as discussed in the text (par. 3.1).

rature (Garcia-Lario 1997). Since the first contour level in the 22 GHz map defines a source size close to  $10''$ , it is reasonable to consider the measured 1.2 mm flux as a lower limit.

Some of the detected object in our sample have been detected in  $^{13}\text{CO}$  and/or  $^{12}\text{CO}$  transition  $J=2-1$  at  $\lambda=1.3$  mm, that is within the band of our observations (Hrivnak et al. 2005, Bujarrabal et al. 1992, Bujarrabal et al. 2001). We verified that the contribution of such emission, spreaded in our bandwidth of about 80 GHz, is lower than the errors associated to the measures for all the detected sources but IRAS 19114+0002 and IRAS 22272+5435. In particular, on the basis of the observations by Bujarrabal et al. (1992), we derived for IRAS 19114+0002 an emission, in the MAMBO band, of 15 mJy from  $^{12}\text{CO}$  and of 1.6 mJy from  $^{13}\text{CO}$ ; for IRAS 22272+5435 the contribution of  $^{12}\text{CO}$  emission is about 7 mJy (Hrivnak et al. 2005). In the following calculations, we thus subtracted these contributions from the observed fluxes.

### 2.3. Spectral energy distributions

In order to build up the spectral energy distribution (SED) of the detected sources, updated with our milli-

metric data, and to investigate its corrected low frequencies shape, we combined our MAMBO observations with infrared (2MASS + IRAS + MSX) and optical data available in literature. The data are corrected for the interstellar extinction, with the exception of IRAS 19075+0432 due to the lack of informations about the extinction toward the source. Moreover we have excluded from this analysis IRAS 01174+6110 because of the uncertainty on its nature.

For those objects for which the observations cover a spectral range wide enough, the resulting SEDs (fig. 1) show the typical double peaked shape, with the two peaks corresponding respectively to the optical emission from the photosphere of the central star and to the thermal emission from the circumstellar dust.

## 3. Analysis

### 3.1. Dust Masses

From a theoretical point of view, the mass of the circumstellar dust surrounding the central object can be derived from the observed continuum millimetric flux. Assuming that the flux density measured at this frequencies is to be

**Table 3.** Derived values for the emissivity index, dust mass, absorption coefficient and envelope dust mass.

Source with Optical Counterpart						
IRAS Name	$T_d$ [K]	$p$	$\chi_{1.3}$ [ $cm^2 g^{-1}$ ]	$M_d$ [ $M_\odot$ ]	$d$ [kpc]	
07134+1005	135	1.11	1.75	8.5 (-4)	2.4	
17436+5003	100	1.55	0.88	6.2 (-4)	1.2	
19114+0002	100	1.41	1.09	4.3 (-2)	6.0	
20000+3239	140	0.94 – 1.55	0.88 – 2.1	0.9 – 2.3 (-4)	1.0 <sup>†</sup>	
20028+3910	100	1.65	0.75	2.4 (-3)	2.9	
22272+5435	145	1.03	1.98	6.2 (-4)	1.6	
Source without Optical Counterpart						
18514+0019	130	0.89 – 2.18	0.32 – 2.5	0.6 – 4.8 (-4)	1.0 <sup>†</sup>	
19075+0432	85	1.37	1.2	1.5 (-4)	1.0 <sup>†</sup>	
21537+6435	140	0.87 – 0.97	2.18 – 2.55	4.3 – 5.1 (-5)	1.0 <sup>†</sup>	

<sup>†</sup> Assumed distance.

ascribed to the thermal emission from optically thin and isothermal dust, the dust mass ( $M_d$ ) and the flux density are directly proportional (Hildebrand 1983):

$$M_d = \frac{F(\nu)d^2}{B_\nu(T_d)\chi_\nu}$$

where  $B_\nu(T_d)$  is the Planck function for dust temperature  $T_d$ ,  $d$  is the distance to the source and  $\chi_\nu$  is the dust opacity at the observing frequency. We can thus estimate the dust mass by using the Rayleigh-Jeans approximation:

$$M_d = \frac{F(\nu)\lambda^2 d^2}{2kT_d\chi_\nu}. \quad (1)$$

The value of  $\chi_\nu$  is the major uncertainty that affects the conversion of the millimetric flux density in dust mass. Following Hildebrand's approach, we can extrapolate the dust opacity  $\chi_\nu$  at 1.2 mm from its value at 250  $\mu\text{m}$ , i.e.  $\chi_{250\mu\text{m}} = 10 \text{ cm}^2 \text{ g}^{-1}$ , assuming the power-law dependence  $\chi_\nu \propto \nu^p$ , where  $p$  is the emissivity index and strongly depends on the mineralogical composition of the grain and on their physical shape.

Under the hypothesis of optically thin emission, the emissivity index  $p$  may be derived from the spectral index in the millimetric and submillimetric spectral range, where the dust emits as a blackbody modified by the frequency dependent dust opacity, that is  $F_\nu \propto \chi_\nu B_\nu(T_d)$ .

We thus proceeded iteratively by fitting a modified blackbody to the infrared and millimetric data to estimate the dust temperature, while the emissivity index has been derived from a linear fit in the  $\log \nu - \log \frac{F_\nu}{B(T_d)}$  to the integrated flux density from 100  $\mu\text{m}$  to 1.2 mm. In the case of IRAS 19075+0432, it is to note that the MSX data at 8.28  $\mu\text{m}$  suggest the presence of both warm and cold circumstellar dust.

For sources with only an upper limit on IRAS 100  $\mu\text{m}$  flux, the same analysis as above was performed using the

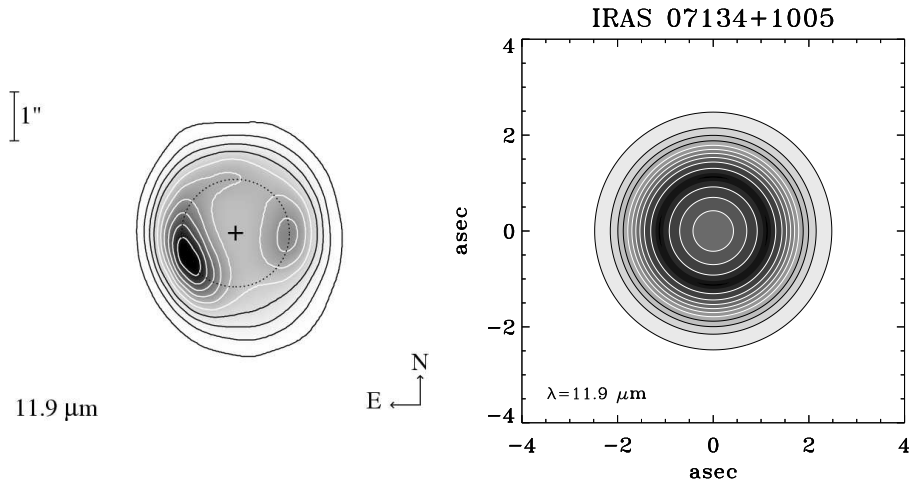
IRAS 60  $\mu\text{m}$  flux to constrain minimum value for  $p$ . In fig. 1 the resulting curves are overplotted to the observed SEDs.

In table 3 the best fit parameters are listed together with the derived dust opacities and masses calculated from the eq. 1 for  $\lambda = 1.2 \text{ mm}$ .

### 3.2. SED modeling with DUSTY code

For six of the detected post-AGB stars, the observations scan a wide spectral range between optical bands and radio regions. All the available informations on the sources, including the results from SED fits with envelope models, have been collected from the literature, in order to verify the compatibility of the previously determined parameters with our 1.2 mm fluxes.

The observed SEDs are plotted in fig. 3, along with best fit SEDs from the radiative transfer code DUSTY (Ivezić et al. 1999). The code allows to calculate the radiative transfer through a spherically symmetric dust shell and determines the spectral energy distribution on the basis of specified properties of the radiation source, dust composition and dust shell properties. In particular, DUSTY allows to use six different types of dust grains which are assumed to be distributed in a spherical shell. For all the sources we assumed Planckian SED for the central star and the modified MRN (Mathis, J.S., Rumpl, W., Nordsieck, K.H. 1977) power law for the grain size distribution  $n(a) \propto a^{-q}$ , where  $a$  is the grain size and  $q$  is fixed to 3.5, as it is commonly used, if not otherwise specified in the text. For more details about the other options we reference to the description in the user manual. When available, we calculated the SED by assuming the stellar and dust parameters taken from previous references in literature, otherwise the best-fit model parameters are sought iteratively by fitting the shape of the observed SED. With the aim of add more observative constrains,



**Fig. 2.** *Left:* Image of IRAS 07134+1005 observed at  $11.9 \mu\text{m}$  by Hony et al. (2003). *Right:* The map simulated at  $11.9 \mu\text{m}$  using the DUSTY code, assuming the parameters reported in table 4. The map has been convolved with a circular beam having HPBW of  $0''.83$ . In both the maps the contours indicate the 5-95% intensity levels in steps of 10%.

we compared the infrared maps of the sources available in literature with the simulated maps obtained from the code at the same observative frequencies. **All the simulated maps have been convolved with the beam of the instrument used to obtain the map used for comparison.** An example of such a comparison is shown in fig. 2 in the case of IRAS 07134+1005. In particular we refer to Hony et al. (2003) for IRAS 07134+1005, Gledhill et al. (2003) for IRAS 17436+5003, Jura & Werner (1999) for IRAS 19114+0002, Ueta et al. (2001) for IRAS 22272+5435 and to 2MASS Atlas Image provided from Infrared Science Archive ([bungo.ipac.caltech.edu/applications/2MASS/IM/interactive.html](http://bungo.ipac.caltech.edu/applications/2MASS/IM/interactive.html)) for IRAS 20000+3239 IRAS 20028+3910. We thus rejected all those solutions that involve shell sizes which don't match the observative constrains according to the rms noise level of the measures.

The remaining four sources of our sample, detected in the survey, were not fitted because of the lack of either data and knowledge of stellar parameters, involving too many degrees of freedom.

A summary of the adopted input parameters used to produce the model fits in fig. 3 is given in table 4. In addition, we report the derived stellar and dust shell parameters beside the physical quantities used in scaling the dusty outputs in accordance with the dusty manual (Ivezić et al. 1999). In all calculations we assumed a density for the grain material of  $3 \text{ g/cm}^3$  and a gas/dust ratio of 220.

The fit's parameter that is mainly constrained from the millimetric and submillimetric measures is the shell outer radius, as these observations probe the cool, outer parts of the CSE. However, the value derived from the SED fit, and reported in table 4, has to be meant as an estimate at the distance from the star where the wind density is close to the ambient density. Thus, the modeled envelope

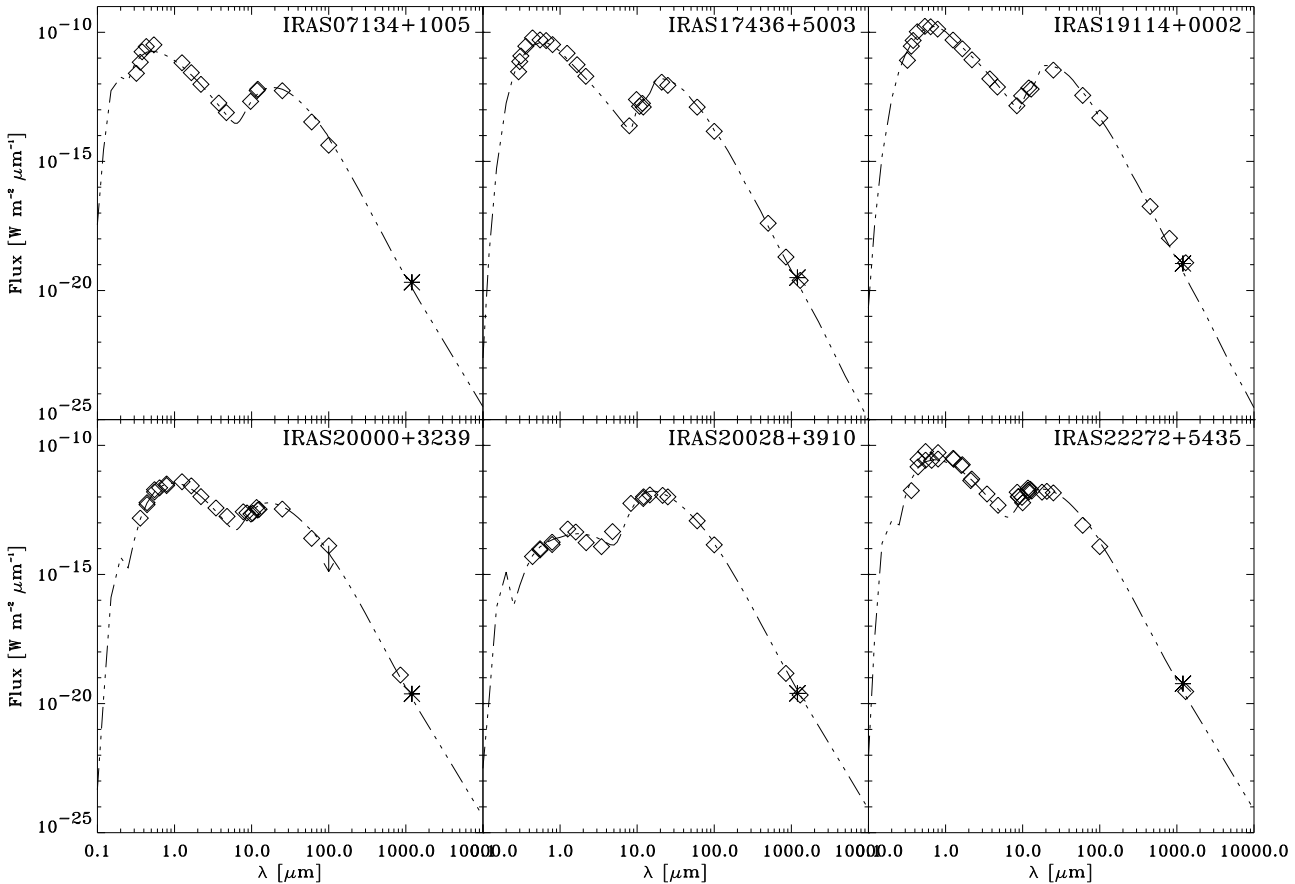
could result to be more extended than the observed one if its outer parts comes to have surface brightness lower or equal to the rms noise level. In particular, it is not surprising that the radii derived for the CSE outer edge result to be much greater than those derived from the near or mid infrared observations, since at those frequencies most of the flux comes from the hotter inner regions of the envelope.

**On the basis of the mass loss rate and shell size derived from the SED fit, we calculated the total envelop mass, assuming a constant wind expansion velocity which has been taken from references in literature. The dust envelope masses derived for a gas/dust ratio of 220 are also reported in table 4. Such values are consistent with those reported in table 3 within a factor of 2. We can thus asses that there is a good agreement between the two dust mass estimates, especially given the rough approximations made in the assumption of constant mass loss rate and in the choice of the gas/dust ratio, which could differ significantly from the assumed value as a function of the C/O ratio.**

The fit of the model to the observed flux distribution for each object is discussed in the next section.

## 4. Results and discussion

*IRAS 07134+1005.* This object is known to have strong features near 21 and  $30 \mu\text{m}$ , whose carrier species have not been firmly identified (Kwok et al. 1989). It is an F5 supergiant having  $C/O \approx 1$  (Van Winckler & Reyniers 2000). Despite of the very simplified dust composition used in our model calculations, the parameters derived from our fit are in good accordance with the ones calculated from Meixner et al. 2004 and Hony et al. (2003), using different



**Fig. 3.** Spectral energy distributions of the emission towards six stars in the sample. The asterisks indicate measures from this work. The dashed lines show the SEDs computed using the DUSTY code.

dust radiative transfer programs, with the exception of the mass loss rate that is larger for a factor of 3 from the one calculated from Hony et al. (2003). On the other hand, our derived value for  $\dot{M}$  agrees with the values obtained from the SED model performed by Hrivnak et al. (2000) and from Jura et al. (2000) on the basis of their mid-IR images of the source.

*IRAS 17436+5003.* It is a F3 Ib supergiant with an oxygen-rich chemistry (Justtanont et al. 1992). Its SED has been modeled by several authors adopting different choices mainly in the selection of grain parameters. While Hoogzaad et al. (2002) and Meixner et al. (2002) adopt the usual grain size distribution  $n \propto a^{-3.5}$  with a minimum size of  $0.18 \mu\text{m}$  and  $0.2 \mu\text{m}$  respectively, Gledhill & Yates (2003) opt for very small grains, using a steep size distribution  $n \propto a^{-6}$  and minimum grain size  $0.01 \mu\text{m}$ , that, as pointed out from the authors, better account for both the SED shape within the whole frequency range and the observed high degrees of near-IR linear polarization. In our calculation we followed the latter way. As a consequence, the dust mass reported in tab. 3 could be underestimate because the assumed dust opacity is derived from an approximated grain model with an average grain size of  $0.1 \mu\text{m}$  (Hildebrand, 1983). This value is a factor of 5 greater than the grain size obtained from the  $n \propto a^{-6}$  distribution

in the adopted range for  $a$ . Assuming for such small grain radius  $\chi_{850\mu\text{m}} = 0.54 \text{ cm}^2 \text{ g}^{-1}$  (Gledhill & Yates 2003), the derived dust mass increases of one magnitude order.

The inner shell radius derived from the SED fit agrees with the value of  $1400 \text{ AU}$  ( $2.1 \times 10^{16} \text{ cm}$  at  $1.2 \text{ kpc}$ ) obtained by Hoogzaad et al. (2002), but is about 30 – 40% larger than the same parameter derived from Gledhill & Yates (2003) and Meixner et al. (2002), who nevertheless used an asymmetric dust model. The outer radius is larger than the values obtained from Hoogzaad et al. (2002) and Meixner et al. (2002), but close to that derived by Gledhill & Yates (2003) and to the extension of  $6''.5$  derived from the CO observation (Bujarrabal et al., 1992).

*IRAS 19114+0002.* It is an oxygen-rich object of spectral type G5 Ia (Hrivnak et al. 1989), but the real evolutionary status of this object is still controversial. It has been classified either as post-AGB star having a luminosity of about  $10^4 L_{\odot}$  and lying at  $1 \text{ kpc}$  (Hrivnak et al. 1989) or as a massive red supergiant with luminosity near  $3 \times 10^5 L_{\odot}$  and lying to a distance of  $6 \text{ kpc}$  (Hawkins et al. 1995).

The expansion velocity of the circumstellar envelope  $v_e \approx 35 \text{ km s}^{-1}$  determined from the profile of the circumstellar CO emission (Zuckerman & Dyck 1986; Bujarrabal et al. 1992) is significantly higher than the typical value of  $15 \text{ km s}^{-1}$  for an AGB star and favors the supergiant

**Table 4.** Input and derived stellar and dust parameters resulting from the fit to the SED.

Property	IRAS	07134+1005	17436+5003	19114+0002	20000+3239	20028+3910	22272+5435
$T_*$ [K]		7250	7500	5660	5000	7000	5300
Chem.		C	O	O	C	C?	C
$T_d$ [K]		150	120	110	170	180	160
L [ $L_\odot$ ]		6000	3440	300000	630	6600	6700
$A_V$		0.5	1.2	2	2.5	1.3	2.5
$r_i$ [cm]		$4.76 \times 10^{16}$	$1.91 \times 10^{16}$	$1.73 \times 10^{17}$	$8.18 \times 10^{15}$	$1.88 \times 10^{16}$	$2.46 \times 10^{16}$
$r_o$ [cm]		$3.48 \times 10^{17}$	$1.53 \times 10^{17}$	$6.88 \times 10^{17}$	$2.05 \times 10^{17}$	$1.88 \times 10^{17}$	$3.11 \times 10^{17}$
$\dot{M}$ [ $\frac{M_\odot}{yr}$ ]		$3.48 \times 10^{-5}$	$3.48 \times 10^{-5}$	$1.09 \times 10^{-3}$	$6.92 \times 10^{-6}$	$8.93 \times 10^{-5}$	$3.12 \times 10^{-5}$
$v_{exp}$ [km/s]		10	15.5	35.0	12.0	16.0	10.0
$M_d$ [ $M_\odot$ ]		$1.66 \times 10^{-3}$	$4.35 \times 10^{-4}$	$2.31 \times 10^{-2}$	$1.63 \times 10^{-4}$	$1.35 \times 10^{-3}$	$1.28 \times 10^{-3}$
Ref.		1, 2, 3, 4	5, 6, 7, 18, 19, 20	3, 8, 9, 10, 18, 19, 21	11, 12, 13, 19, 22	14, 15, 18, 19, 20	13, 16, 17, 18

References - (1) Meixner et al. 2004; (2) Hony et al. 2003; (3) Hrivnak et al. 1989; (4) Van Genderen et al. 1986; (5) Ghedill et al. 2003; (6) Ueta et al. 2000; (7) Skinner et al. 1994; (8) Van der Veen 1994; (9) Hawkins et al. 1995; (10) Thévenin et al. 2000; (11) Kwok et al., 1995; (12) Hrivnak et al. 1995; (13) Volk et al. 2002; (14) Su et al. 2001; (15) Bujarrabal et al. 2001; (16) Hrivnak et al. 1991; (17) Ueta et al. 2001; (18) Walmsley et al. 1991; (19) Gledhill et al. 2002; (20) Likkel et al. 1991; (21) Bujarrabal et al. 1992; (22) Hrivnak et al. 2000.

hypothesis, that is though still doubt (Josselin & Lèbre 1992).

As for IRAS 17436+5003, Gledhill & Takami (2001) pointed out the need to adopt a steep power law for the grain size distribution, in order to agree with the high degrees of linear polarization observed in the near-IR. We have thus adopted the grain size distribution  $n \propto a^{-6}$  with  $a_{\min} = 0.005 \mu\text{m}$  and  $a_{\max} = 0.25 \mu\text{m}$ . **The SED fit gives a  $r_{\text{in}} = 1.7 \times 10^{17}$  cm, which is in good accordance with the inner shell radius of about  $1.5 \times 10^{17}$  cm obtained from both mid-IR images (Jura & Werner 1999) and near-IR imaging polarimetry observations (Gledhill et al. 2001). Such value is very close to the inner shell size of  $1.8 \times 10^{17}$  cm derived, for the assumed distance of 6 kpc, from high resolution CO observations performed from Jura et al. (2001).**

The dust mass obtained is in good accordance with the one derived from Gledhill et al. (2002) on the basis of submillimeter observations.

*IRAS 20000+3239.* Low resolution K-band spectra performed by Davis et al. (2003) showed a rather compact source with angular size lower than  $2''$ , as well Hrivnak et al. (1999) measured  $1''.6$  in diameter in V band. Comparing with the SED parameters derived from Volk et al. (2002), we obtain good accordance for both the mass loss rate and inner shell radius, as well as for the shell mass derived from Gledhill et al. (2002).

*IRAS 20028+3910.* This object is characterized from a bipolar morphology, with the central object highly obscured in optical and near-IR (Su et al. 2001; Ueta et al. 2000). The SED, constructed with the data reported by Su et al. (2001) and references therein, thus shows a mid and far infrared peak much most bright than the one in the near infrared. Neri et al. (1998) fitted the CO 1-0 visibility data with an elliptical gaussian component with

a size of  $3.5'' \times 11.1''$ . The dust mass obtained from our 1.2 mm measures agrees very well with the value calculated from previous submillimeter data (Gledhill et al. 2002).

*IRAS 22272+5435.* It is an extremely carbon rich object and, as IRAS 07134+1005, shows peculiar infrared spectral features. From the analysis of CO 1-0 visibility data, Neri et al. (1998) measured an extended envelope size (FWHM) of  $21''$ . From subarcsecond mid infrared imaging study (Ueta et al. 2001) the dust shell was found to have a toroidal structure with a  $0.5''$  inner radius, which corresponds to  $1.1 \times 10^{16}$  cm at 1.6 kpc. Our fit indicates an inner radius which is consistent with that measured by Ueta et al. (2001) to within a factor of 2. A major discrepancy is found in the estimates of mass loss rate. On the basis of their radiative transfer calculations, in fact, Ueta et al. (2001) derived a wind with  $\dot{M} = 4.1 \times 10^{-6} M_\odot \text{ yr}^{-1}$ . Our value is closer with the mean mass loss rate obtained from the CO study performed Bujarrabal et al. (2001), which is  $1.8 \times 10^{-5} M_\odot \text{ yr}^{-1}$ , when scaled for our assumed distance. The authors report a total nebular mass of  $0.18 M_\odot$ , that gives a dust mass of  $8.0 \times 10^{-4} M_\odot$  for an assumed gas to dust ratio of 220, and which is in good agreement with our estimate.

## 5. Summary and outlook

We have presented the results of 1.2 mm continuum observations for a sample of 24 sources classified as post-AGB. Continuum emission was detected toward 11 objects, while uncertain detection is reported for two other sources.

The circumstellar dust masses were derived from our 1.2 mm measures, assuming that the emission is due to optical thin dust. For the sources of which the distance is known, the circumstellar dust masses range between about  $6 \times 10^{-4} M_\odot$  and  $2.4 \times 10^{-3} M_\odot$ , with exception of IRAS 19114+0002, whose post-AGB nature is, however,

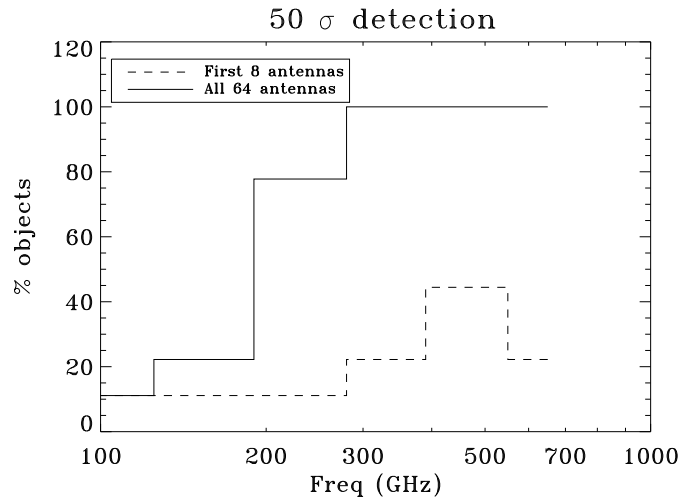
still in question. For the other objects we derived lower dust masses, indicating a more young circumstellar envelope, but the errors in the choice of the common assumed distance could have effected the derived values.

For six of the detected sources, we compared the observed SEDs, constructed with additional data from literature, and the model spectra obtained using a symmetric radiative transfer code. This allowed us to estimate some physical parameters of stars and envelopes which have been compared with previously results reported in literature.

The high detection rate ( $\approx 46\%$ ) seems to support the goodness of our selection rules and an extension of the millimetric survey to the remain targets in our sample is necessary. Stars in our full sample belong to different evolutionary phases in the transition from AGB to PN, as the stars with optical counterpart should be more evolved. Once the full sample will be observed, the comparison between the derived physical properties of different envelopes will provide fundamental informations on this evolutionary phase not fully understood yet.

We still note that the CSEs surrounding such kind of objects appear as good targets for the first light projects for future millimeter arrays such as the Atacama Large Millimeter Array (ALMA). From our fits we derive typical dimensions of CSEs ranging from  $1.5 \times 10^{17}$  to  $1.2 \times 10^{18}$  cm, which, combined with the distances as reported in table 3, correspond to angular sizes from few arcsecs up to  $\approx 13''$ . This implies that such CSEs can be, in principle, mapped, in great details with the foreseen ALMA angular resolutions by using a combination of both compact (to fully recover all the flux) and extended configurations (Wilson et al. 2005). The foreseen capabilities of ALMA will allow, at least for the more compact sources of our sample, and in general for post-AGB sources, to directly map the dusty envelopes at several millimetric and submillimetric frequencies. This could provide a better constrains to the modeling of CSE. Furthermore, a detailed map of CSE could evidence any kind of structured morphologies that can be related to different mass loss episodes, suffered by the star during the AGB evolutionary phase.

To evaluate the possibility to actually resolve and map the CSEs of our sample, we need to compare, at each frequency channel, the expected flux densities with the foreseen ALMA sensitivity. From the fitted SEDs we have then extrapolated the flux densities in the ALMA first light channels, namely 0.5, 0.6 0.9 1.3, 2 and 3 mm. Expected ALMA sensitivities have been calculated by using the ALMA Sensitivity Calculator ([www.eso.org/projects/alma/science/bin/sensitivity.html](http://www.eso.org/projects/alma/science/bin/sensitivity.html)) in the case of first-light, assuming that only 8 antennae will be available, and in the case of the full (64 antennae) array. For both configurations we derived a detection rate close to 100% over the  $3\sigma$  at almost all frequencies. In fig. 4 we show the expected percentage of the studied objects that ALMA will allow to observe with dynamical range greater than 50. It is evident how ALMA will allow us not only to better sample the millimetric range of the



**Fig. 4.** Percentage of objects, detected at 1.2 mm, which are observable with dynamical range greater than 50, assuming calculate ALMA sensitivity with both 8 and 64 antennae.

source SEDs, that up to now is very poor, but also to obtain, in most cases, multifrequencies high resolution maps of the circumstellar matter surrounding the stars of our sample, extended to the sources belonging to the south hemisphere.

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