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Obscured AGB stars in the Magellanic Clouds

I. IRAS candidates

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Abstract.[1] We have selected 198 IRAS sources in the Large Magellanic Cloud, and 11 in the Small Magellanic Cloud, which are the best candidates to be mass–loosing AGB stars (or possibly post–AGB stars). We used the catalogues of Schwering & Israel (1990) and Reid et al. (1990). They are based on the IRAS pointed observations and have lower detection limits than the Point Source Catalogue. We also made cross–identifications between IRAS sources and optical catalogues.

Our resulting catalogue is divided in 7 tables. Table 1 lists optically known red supergiants and AGB stars for which we found an IRAS counterpart (7 and 52 stars in the SMC and LMC, respectively). Table 2 lists "obscured" (or "cocoon") AGB stars or late–type supergiants which have been identified as such in previous works through their IRAS counterpart and JHKLM photometry (2 SMC and 34 LMC sources; no optical counterparts). Table 3 lists known planetary nebulae with an IRAS counterpart (4 SMC and 19 LMC PNe). Table 4 lists unidentified IRAS sources that we believe to be good AGB or post–AGB or PNe candidates (11 SMC and 198 LMC sources). Table 5 lists unidentified IRAS sources which could be any type of object (23 SMC and 121 LMC sources). Table 6 lists IRAS sources associated with foreground stars (29 SMC and 135 LMC stars). Table 7 lists ruled out IRAS sources associated with HII regions, hot stars, etc ...

We show that the sample of IRAS AGB stars in the Magellanic Clouds is very incomplete. Only AGB stars more luminous than typically $10^4\ L_\odot$ and with a mass-loss rate larger than typically $5\,10^{-6}\ M_\odot$/yr could be detected by the IRAS satellite. As a consequence, one expects to find very few carbon stars in the IRAS sample. We also expect that most AGB stars with intermediate mass–loss rates have not been discovered yet, neither in optical surveys, nor in the IRAS survey.

Key words: circumstellar matter – Stars : late–type –Stars : mass-loss – Stars : AGB and post-AGB – supergiants

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[1] Tables 1 to 8 are also available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsweb.u-strasbg.fr/Abstract.html

1. Introduction

During the past 10 years, the observations of the IRAS satellite (Neugebauer et al. 1984) have led to the discovery of a few thousand mass-loosing stars on the Asymptotic Giant Branch (AGB). Some of them are heavily "obscured", in the sense that they lose mass at such a rate ($\sim 10^{-5}\ M_\odot$/yr or more) that their circumstellar envelope becomes optically thick to the stellar radiation. IRAS observations, as well as observations of the millimeter lines of CO and of the OH maser emission, have considerably improved our knowledge on their mass–loss rates. However, further studies are severely hampered by the lack of knowledge of the distances, and hence of the luminosities.

The Magellanic Clouds have reasonably well known distances, and they are far enough to consider that all the stars belonging to the same galaxy are at the same distance, with a small uncertainty. In the optical and NIR range, a huge amount of work has been performed in the Small and Large Magellanic Clouds (SMC and LMC) to search for M supergiants and AGB stars. In the LMC, the most complete works, spatially speaking, have been performed by Westerlund and co–workers (Westerlund 1960, 1961; Westerlund et al. 1978; Westerlund et al. 1981), Sanduleak & Philip (1977), and Rebeirot et al. (1983), leading to the discovery of several hundred M stars and a few hundred C stars. These surveys were, however, limited in sensitivity and could only detect the brightest stars (I<13.5). A deeper survey (I<17), but spatially limited, has been performed by Blanco and co–workers (Blanco et al. 1980, Blanco & McCarthy 1983, Frogel & Blanco 1990). The SMC has been less studied. The work of Blanco et al. (1980) was the first objective prism survey of this galaxy. This, and the subsequent work of Blanco & McCarthy (1983) turned up a few hundred carbon and M–type stars. Reid & Mould (1990) selected AGB star candidates from V and I–band photometry in a $0.8^{\circ 2}$ area. Recent works concentrated mainly on carbon stars (Westerlund et al. 1986, Rebeirot et al. 1993) and lead to the discovery of about 2000 of them.

Complementary to previous surveys, people started to search for long–period variables (LPVs) through IJHK(L) photometry (see e.g. Feast et al. 1980, Glass & Lloyds Evans 1981, Glass & Feast 1982, Wood et al. 1983, Wood et al. 1985, Glass

& Reid 1985, Reid et al. 1988, Hughes 1989, Feast et al. 1989, Hughes & Wood 1990). There are now about 1000 LPVs known in the LMC. The most important result of these works is certainly the relations between the luminosity and the period.

As previous studies were based on optical or near-infrared observations, the resulting samples of stars do not contain optically very thick sources which would be hardly detectable at such wavelengths. In the following we will distinguish between optically identified stars, i.e. stars with optically thin dust shells (typically J–H<2) easily detectable in the optical range, and "obscured" stars, i.e. stars with optically thick dust shells (typically J–H>2) and without optical counterpart. Note that such a separation between optical and obscured stars is partly arbitrary as the transition between optically thin and thick dust shells is of course continuous. The separation is more historical as, complementary to optical surveys, people started to search for AGB stars with high mass–loss rates selecting candidates in the IRAS survey, and confirming (or not) the nature of the selected IRAS sources through JHKLM photometry.

In 1986, Elias et al. selected IRAS sources from the Point Source Catalogue (PSC) with a 12 μm flux density, S_{12}, larger than 2 Jy, and among them discovered two supergiants similar to Galactic OH/IR stars, PSC 04553–6825 and PSC 05346–6949. The same year, Wood et al. selected IRAS–PSC sources with $S_{25} \gtrsim 0.7$ Jy and a S_{25}/S_{12} ratio similar to those of Galactic OH/IR stars. They detected the maser emission of OH in PSC 04553–6825. This star has an optical counterpart with spectral type M7.5 (Elias et al. 1986). Its optical counterpart was in fact previously known, one can find it as number 64 in Table II of Westerlund et al. (1981). Wood et al. (1992) extended the previous study and detected OH emission in 5 IRAS–PSC sources. They also determined the period of 9 objects in the LMC. In total, they present a list of 3 SMC and 16 LMC sources that they believe to be late–type stars with thick dust shells. However, in section 4.2. we show that, among these 19 sources, only 9 are actually good candidates being obscured AGB stars or late–type supergiants, the others beeing associated with optically known M supergiants, or with blue supergiants, or even with an HII region or a galaxy. The work by Whitelock et al. (1989) in the SMC is also based on the Point Source Catalogue. They monitored in the JHK(L) bands 5 sources with S_{25}/S_{12} ratios corresponding to a colour temperature of a few 100 K. Among these 5 sources, 2 are long–period variables without optical counterparts, 1 is associated with an M star, 1 is a peculiar carbon star, and 1 is associated with a blue supergiant.

In addition to the survey observations, IRAS also made pointed observations, with orthogonal scan directions, notably in the direction of the Magellanic Clouds. The corresponding detection limits are fainter than those of the PSC. The IRAS pointed observations cover the major part of the SMC and the LMC, except the outer regions. These data have been reduced and published in a catalogue by Schwering & Israel (1990). Part of these data in the LMC has also been reduced by Reid et al. (1990) with the aim of searching for obscured AGB stars. They also made photographic I plates and give possible optical counterparts of some IRAS sources. With additional JHK observations, Reid (1981) discovered 10 "cocoon" stars, i.e. AGB stars with optically thick dust shells, associated with IRAS sources. He also showed that, for these "cocoon" stars, the optical counterpart proposed by Reid et al. was in fact not associated with the IRAS source as he found a much redder object close to the IRAS position. More recently, based on the source selections presented here, Zijlstra et al. (1996), in the second paper of this series (hereafter called paper II), identified 16 additional AGB stars with optically thick dust shells and estimated their mass–loss rates.

In this paper, we will first adress the question: "What are the properties of AGB stars detected by IRAS in the LMC ?" (section 2). In section 3, we present our selection of IRAS sources, from the catalogues of Schwering & Israel (1990) and Reid et al. (1990) in order to find AGB stars candidates. We systematically searched for optical identifications of all the selected IRAS sources. In section 4 we present final tables, optical stars with an IRAS counterpart in Table 1, obscured AGB stars or supergiants without optical counterpart in Table 2, planetary nebulae in Table 3, unidentified IRAS sources that we think to be good obscured AGB (or post–AGB) stars candidates in Table 4, and foreground stars in Table 6. In section 5 we discuss on the reliability of IRAS observations at flux levels close to the detection limits and compare both catalogues.

2. What are the properties of AGB stars detected by IRAS in the LMC ?

Previous works by Elias et al. (1986), Wood et al. (1986, 1992), Reid et al. (1990), and Reid (1991) have shown that some red supergiants and AGB stars have been detected by IRAS in the LMC, at least at 12 μm. As the distance of the LMC is about 50 kpc, one may however be surprised that IRAS could detect AGB stars so far away. A comparison with stars of our Galaxy could allow us to answer this question and to define the physical properties of such stars. Reid et al. give part of the answer based on the most optically thick OH/IR stars known in the Galaxy, and on the "prototype" of optically thick carbon stars, IRC+10216. They conclude that AGB stars with similar physical properties should "be detected with ease" in the IRAS survey.

Lets consider as an example one of the most extreme carbon star AFGL 3068 (Price & Walker 1976), and the well known O–rich star WX Psc. AFGL 3068 is particularly optically thick as [K–L]=7 (le Bertre 1992). WX Psc has a known optical counterpart but is not optically thin as the 10 μm silicate feature is slightly self-absorbed. Assuming an intrinsic luminosity of $10^4\ L_\odot$, their distances would be 0.95 and 0.54 kpc respectively (see e.g. Loup et al. 1993). At 50 kpc, such stars would have 12 μm IRAS flux densities of 0.25 and 0.13 Jy, and 25 μm IRAS flux densities of 0.28 and 0.11 Jy, respectively . The sensitivity limit of the IRAS–PSC is 0.25 Jy at 12 and 25 μm, and 0.15 and 0.22 Jy in the catalogue of Schwering & Israel (1990). Therefore a source like AFGL 3068 could be detected in the LMC, but not easily, and WX Psc would not be detected (or by chance as Schwering & Israel report a few 12 and 25 μm detections at a level of 0.07 Jy). The intrinsic luminosity of these 2 stars could be larger than $10^4\ L_\odot$, but also smaller, and in addition their luminosity varies by more than a factor 2.

In an attempt to get a more complete overview, we have used the sample of Galactic sources whose CO emission in the rotational transitions J=1–0 or/and J=2–1 has been detected (Loup et al., 1993). Though this sample is strongly observationally biased, it contains all the chemical types (O–rich, C–rich, and S stars), and covers the whole range of mass loss rates (10^{-7} to $10^{-4}\ M_\odot.yr^{-1}$). This sample contains about 400

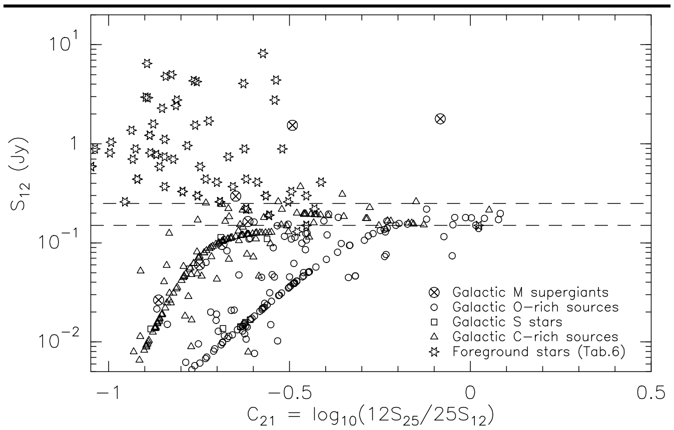

Fig. 1. Location of galactic AGB stars and M supergiants detected in the CO (1–0) or CO(2–1) lines (Loup et al. 1993) in a $[C_{21}, S_{12}]$ diagram as if they were located in the LMC. Distances were calculated from bolometric fluxes and assuming a luminosity of $10^4\,L_\odot$ for AGB stars, $10^5\,L_\odot$ for M supergiants. S_{12} was then scaled to 50 kpc. Symbols are defined in the Figure. The two correlations seen for M and C stars come from the bolometric correction of van der Veen & Rugers and are not real (see also section 2). The two dashed lines correspond to the detection limit of the PSC (0.25 Jy at 12 μm) and of Schwering & Israel (0.15 Jy). Also plotted in Figure 1 are the foreground stars listed in Table 6. One can see that, for most of them, their location in the diagram would be sufficient to determine that they do not belong to the LMC.

AGB stars and a few M supergiants. Their bolometric luminosities have been calculated from optical, JHKL(M), and IRAS photometry, when enough data were available; ortherwise they were estimated using the bolometric correction to IRAS data of van der Veen & Rugers (1989). Distances have been estimated assuming an intrinsic luminosity of $10^4\,L_\odot$ for the AGB stars, and $10^5\,L_\odot$ for the supergiants, corresponding to bolometric luminosities of –5.25 and –7.75, respectively.

Figure 1 shows their IRAS color $C_{21} = log(12S_{25}/25S_{12})$ as a function of their 12 μm IRAS flux density scaled to 50 kpc. The dashed lines indicate the IRAS–PSC and Schwering & Israel sensitivity limits, 0.25 and 0.15 Jy. Note that the faintest sources at 12 μm in Schwering & Israel have $S_{12} = 0.07$ Jy. The two correlations appearing in Figure 1 for O–rich and C–rich stars only reflect the bolometric correction of van der Veen and Rugers (1989) and are not real. It appears clearly that, whatever the value of C_{21}, very few AGB stars could be detected in the PSC if they are not more luminous than $10^4\,L_\odot$. The situation is a little better with the IRAS pointed observations, but we still expect that most AGB stars with $L \leq 10^4\,L_\odot$ have not been detected by IRAS. The faintest "obscured" AGB star discovered until now actually has a bolometric luminosity of –5.1 (8700 $L_\odot$), and a 12 μm flux density of 0.13 Jy (Reid 1991, Reid et al. 1990). The IRAS color C_{21} can be considered as a rough estimator of the total dust opacity in the circumstellar shell, and hence as a rough estimator of the mass–loss rate (see e.g. Rowan–Robinson et al. 1986, Bedijn 1987, Chan and Kwok 1990). As expected, one sees in Fig.1 that only optically thick AGB stars could be detected by IRAS as the value of S_{12} decreases drastically when C_{21} decreases. Comparing Figure 1 with Figure 9b in Loup et al. (1993), we conclude that most AGB stars detected by IRAS in the LMC should have a mass–loss rate larger than $5\,10^{-6}\,M_\odot.yr^{-1}$. Sources with intermediate mass-loss rates are probably still almost totally undiscovered in the MCs as they would already be too faint for optical surveys, but not optically thick enough to have been seen by IRAS. This is very well illustrated for carbon stars in the Fig. C1 of Groenewegen and de Jong (1993) where they show the theoretical relation between S_{12} and the I magnitude for various bolometric luminosities and mass–loss rates.

The sample of sources detected in CO (Loup et al. 1993) contains only a few supergiants, which does not allow a statistical overview. We consider the example of α Ori, VY CMa, and VX Sgr. If their luminosity is $10^5\,L_\odot$, their mass-loss rates estimated from CO observations are $\sim 10^{-6}$, $4\,10^{-6}$, and $5\,10^{-6}\,M_\odot.yr^{-1}$, respectively. Their 12 μm IRAS flux densities scaled to 50 kpc are 0.07, 1.7, and 0.18 Jy. So even LMC red supergiants should have a relatively optically thick dust envelope to be detected by IRAS.

From the previous considerations we expect the IRAS sample of LMC AGB stars to be very incomplete, strongly biased towards luminous (more than $10^4\,L_\odot$) and optically thick sources (without optical counterpart; mass–loss rate larger than $5\,10^{-6}\,M_\odot.yr^{-1}$). Most AGB stars with a bolometric luminosity fainter than about –5.2, even if very optically thick, have probably not been detected by IRAS. In particular, we therefore expect to find far fewer C–rich stars than O–rich stars in the IRAS sample, though carbon stars are more numerous than late M stars in the MCs (Blanco et al. 1980). Groenewegen & de Jong (1993) reach the same conclusion through a theoretical approach.

3. Selection criteria

The location of AGB stars, post–AGB stars, planetary nebulae, HII regions, and galaxies, in the IRAS two–colour diagram (12–25–60) has been described by many authors (see e.g. van der Veen & Habing 1988). In this paper we use the work by Pottasch et al. (1988, their Figure 1) which gives an overview. We are not only interested in AGB stars and M supergiants, we also would like to include possible post–AGB objects and planetary nebulae. Therefore the problem is mainly to eliminate HII regions and galaxies. According to Figure 1 in Pottasch et al., most HII regions have $(S_{12}/S_{25}) < 0.4$ ($C_{21} > +0.08$) and $(S_{25}/S_{60}) < 0.3$ ($C_{32} = log(25S_{60}/60S_{25}) > +0.14$), and most galaxies have $(S_{12}/S_{25}) < 1$ ($C_{21} > -0.32$) and $(S_{25}/S_{60}) < 0.3$. The knowledge of the 12, 25, and 60 μm IRAS flux densities would allow us to select AGB stars, post–AGB stars and planetary nebulae with great confidence.

The sensitivity limits given by Schwering & Israel (1990) are 0.15, 0.22, and 0.41 Jy at 12, 25, and 60 μm respectively. ¿From the discussion in section 2, or from the work by Reid (1991), we expect that most AGB stars detected by IRAS in the LMC will not be detected at 60 μm, and often will be detected only in one band, at 12 or 25 μm. The selection of sources is then not so straightforward, and we have to use limits on the IRAS flux ratios. In practice, we have to consider two possiblities at 12 μm : detected or not detected, and three possibilities at 25, 60, and 100 μm : detected, not detected, or contaminated by the surroundings. Non detections provide us upper limits on the IRAS flux densities. Contaminated fluxes do not give us any information.

As a first selection, we have removed all the sources that Schwering & Israel find extended (23 sources in the LMC, 49 sources in the SMC). Next we have removed all the sources with $S_{100} > 2S_{60}$ (945 sources in the LMC, 58 sources in the SMC); note that this eliminates all the sources detected at 100 μm but not detected at 60 μm. This criterion removes many HII regions and galaxies which are "cold" objects, preferentially detected at long wavelengths. It could, however, also remove some planetary nebulae.

From these two first selections, we obtained a sample of 923 sources in the LMC, and 142 sources in the SMC. We also added 24 LMC sources, with $S_{100} < 2S_{60}$ or not detected at 60 and 100 μm, listed in Reid et al. (1990) which have not been found by Schwering & Israel (conversely some sources mentioned in Schwering & Israel have not been found by Reid et al.). Then we applied the following selection criteria :

$$(S_{12}/S_{25}) > 1, \text{ whatever } (S_{25}/S_{60})$$
$$\text{or } (S_{12}/S_{25}) < 1 \text{ and } (S_{25}/S_{60}) > 0.3$$

There are several cases where we do not have any information on one of the flux ratios, or where the limit derived on one of the flux ratios is not significant, so we cannot conclude anything. We have divided the initial sample into three groups. Group 1 contains 256 LMC and 37 SMC sources following the selection criteria, and expected to be red supergiants, AGB stars, post–AGB stars, and PNe candidates. Group 3 contains 415 LMC and 62 SMC sources which do not follow the selection criteria, expected to be HII regions or galaxies. Group 2 contains 276 LMC and 43 SMC sources for which the available IRAS data are not conclusive, they can be *à priori* anything.

4. Description of tables

The previous selection based only on IRAS data is a first step to get a global list of candidates. However we expect to find in this list many foreground stars as well as some star clusters, and some IRAS candidates could be associated with optically known red supergiants. We also have to remove from this first list IRAS sources which have been identified in previous works as obscured AGB stars or late–type supergiants, through JHKLM photometry. We therefore tried to find counterparts to the IRAS sources of groups 1 and 2. For that purpose we have extensively used the Simbad database, as well as a compilation of most works on AGB stars and M supergiants in the Magellanic Clouds (see references), as some of them have not been entered in the Simbad database (in particular the surveys by Blanco et al. 1980, and Westerlund et al. 1978, 1981). Cross–identifications are mainly based on the positions of the objects, but also on the consistency between the optical magnitudes and the IRAS fluxes and colours. For IRAS sources already listed in the PSC, we have searched around 30" from the IRAS–PSC position; for new IRAS sources not discovered in the PSC we have searched around 60" as the position given by Schwering & Israel is not more accurate. The IRAS–PSC uncertainty is in principle smaller than 30". However, as the IRAS flux densities of our sources are often close to the sensitivity limit, the position may be less accurate than usual. In addition, we notice that positions given by Schwering & Israel and Reid et al. sometimes disagree by more than 60". On the other hand, the JHKL counterpart of obscured AGB stars is generally close (within 20") to the IRAS–PSC position (see Reid 1991, and Zijlstra et al. 1996, paper II).

Finally, we have divided the IRAS sources into 7 tables which will be described below :

4.1. Tables 1, 2, and 3 : identified objects

Optically known red supergiants and AGB stars are listed in Table 1, obscured AGB stars and late–type supergiants without optical counterparts in Table 2, and planetary nebulae in Table 3. Column 1 lists the LI number as given in Schwering & Israel, and col. 2 the TRM number as given in Reid et al. A "$\star$" in front of the LI number means that the IRAS source was also found in the PSC. Column 3 and 4 list the coordinates as found in Schwering & Israel or in Reid et al. (when the TRM source has not been found by Schwering & Israel); note that Schwering & Israel provide coordinates more accurate than 60" only when the source is also in the PSC, and then they just give the IRAS–PSC coordinates. Column 5,6,7, and 8 list the IRAS flux densities at 12, 25, 60, and 100 μm, respectively, as found in Schwering & Israel (or in Reid et al.); "C" means contaminated, and ":" means that the value is uncertain. Column 9 and 10 list the IRAS colours, $C_{21} = log(12S_{25}/25S_{12})$ and $C_{32} = log(25S_{60}/60S_{25})$. Column 11 gives the group (1, 2 or 3) of the IRAS source as defined in Section 3. When we give two possibilities for the group, the second value corresponds to the group found by using the Reid et al.'s values if the group is different from the one derived from the Schwering & Israel values (see also Table 8). The last column gives the identification : source name, some observational information (between bracket), and a code for references (between square brackets). The list of references is given at the end of the tables, as well as, for Table 1, an overview of the various optical identifications. Table 1 lists 52 LMC and 7 SMC optical stars. Table 2 contains 34 LMC and 2 SMC sources. Among the 34 LMC obscured AGB stars (or late–type supergiants), 16 have been identified recently by Zijlstra et al. (1996, paper II) on the basis of the present work (for selection) and infrared observations in the JHKL' bands and at 10 μm.

The reader will notice that Table 1 contains 2 sources known to be optically thick, in particular the famous PSC 04553–6825 (LI–LMC 181) discovered by Elias et al. (1986) and Wood et al. (1986). This source has an optical counterpart (WOH G064 in Westerlund et al. 1981, spectral type M7.5 in Elias et al. 1986) and is therefore listed in Table 1. PSC 00350–7436 (LI–SMC 5) has an optically thick dust shell as well. As Whitelock et al. (1989) could determine its spectral type, a peculiar carbon star, we list it in Table 1. Other sources in Table 1 do not have optically very thick dust envelopes.

4.2. Comments on the Wood et al's (1992) list

Wood et al. monitored in JHKL 3 sources in the SMC and 16 in the LMC. The results are presented in their Tables 3 and 5. Among the 16 LMC sources, we found that PSC 04553–6825 (LI–LMC 181), possibly PSC 05247–6941 (LI–LMC 976), PSC 05261–6614 (LI–LMC 1033), and PSC 05389–6922 (LI–LMC 1470), have a known optical counterpart of spectral type M : WOH G064, WOH SG264, WOH SG281, and WOH SG455, respectively (Westerlund et al. 1981, see Table 1 caption). They are listed here in Table 1. PSC 04571–6954 (LI–LMC 225) can be identified with the well know S Dor variable HD 268835 of spectral type B8Ia and is listed in Table 7. PSC 05244–6832 (LI–LMC 961) and PSC 05325–6743 (LI–LMC 1274) have extremely red IRAS colours and fall in our group 3. They can be identified with the HII regions LHA 120–N 138D and LHA 120–N 57A, respectively (Henize 1956), and are listed in Table 7. The 3 SMC sources all have very red IRAS colours and fall in group 3 too. There is a probable M supergiant close to PSC 00477–7343 (LI–SMC 57), so we list this source in Table 1. However we think that the association between the IRAS source and the optical star is doubtful. PSC 00521–7054 is identified with a galaxy and is listed in Table 7. Finally, for PSC 01039–7305 (LI–SMC 173) we could not find any identification. However, in addition to its unusual IRAS colours, it also has unusual JHKL colours for an AGB star, so we again list it in Table 7.

Wood et al. also list 14 sources in their Table 4 that they could detect in JHK. Among them, PSC 05027–7124 (LI–LMC 346), PSC 05198–6941 (LI–LMC 816), and PSC 05280–6910 (LI–LMC 1100), belong to groups 1 or 2. They are however in Table 7 as associated with the blue supergiant HD 269006, two hot stars, and NGC 1984, respectively. The other objects all belong to group 3 and have very red IRAS colors. We list all of them in Table 7, either because they are associated with hot stars, or with HII regions, or because the NIR colors are much too blue compared to the IRAS colors. We do not exclude that the NIR colors actually correspond to an AGB star, however the association with the IRAS source is unlikely.

4.3. Tables 4 and 5 : unidentified IRAS sources

Unidentified IRAS sources from group 1 are listed in Table 4 (AGB stars, post–AGB stars, and PNe candidates), and those from group 2 in Table 5 (IRAS data insufficient to conclude on their nature). Columns 1 to 10 are the same as in Tables 1, 2, 3. For some sources we found one or several objects close to the IRAS position, but we think that the association with the IRAS source is unlikely. In particular, we found some IRAS sources close to optical C stars or LPVs, but the IRAS flux densities are much too bright compared to what one expects from the optical and JHKL properties of the stars. Such cases are listed at the end of the Tables. Table 4 contains 198 LMC and 11 SMC sources, so about 6 times more new obscured AGB stars candidates than what is already known as listed in Table 2.

4.4. Table 6 : foreground stars

It contains all the sources from groups 1 and 2 found or believed to be foreground stars. The columns are the same as in Tables 1, 2, and 3. Identifications of foreground stars are based on the V (or I) magnitude of the star, and/or its spectral type, and/or its heliocentric velocity. Most of them have M, K, F, G giant or dwarf types. For three sources in the LMC, we did not find any optical star at the location of the IRAS source. However, their location in Figure 1 shows that they are very likely foreground stars. Table 6 contains 135 and 29 stars in the fields of the LMC and the SMC, respectively.

4.5. Table 7 : ruled out objects

It contains all the sources, from groups 1 and 2, that we have ruled out after the selection described in section 3. They are mostly associated with star clusters, or/and hot stars, Wolf–Rayet stars, or blue luminous variables; there are also a few HII regions and galaxies. Table 7 contains 76 LMC and 15 SMC sources, including the group 3 sources from Wood et al. (1992, see section 4.2).

5. Discussion

Despite the selection criteria we use, there are 6 stars of group 3 in Table 1, and 3 in Table 2. All these sources have S_{100} larger than S_{60}, or a very large S_{60}/S_{25} ratio, which is normally characteristic of HII regions and galaxies. A look at the IRAS maps show that these sources are located in regions with a high background at 100 and 60 μm, and that S_{100} and/or S_{60} are contaminated. Three sources, LI-LMC 932, 1107, and 528, are also found by Reid et al. (1990). They do not give any 100 μm flux, and find no or a fainter 60 μm flux. Using the fluxes determined by Reid et al., these sources would belong to group 1 or 2 (see Table 8). We expect that probably a few good AGB candidates have been ruled out of our list for similar reasons, rejected because of a high 100 or/and 60 μm flux due to contamination. There is however no systematic way to pick up such sources, the only way would be a careful examination of IRAS maps for all of them. The case of planetary nebulae is more marginal. In Table 3, 9 sources belong to group 3. However, they are normally very cold objects and their IRAS flux ratios are close to the limits of our selection criteria.

Conversely there are several rejected sources in Table 7 belonging to group 1. Most of them are, however, associated with star clusters, or hot stars, which is not contradictory with belonging to group 1. There are a few very interesting sources, blue luminous variables and Wolf–Rayet stars which deserve more studies. The few sources of group 1 associated with HII regions all have very cold IRAS colors, close to the limits of our selection criteria.

In Figure 2, we have plotted the location of optically known stars (Table 1, Fig. 2a), obscured AGB stars (Table 2, Fig. 2b), and planetary nebulae (Table 3, Fig. 2c), in the same kind of diagram as the one presented in Figure 1 for galactic sources and foreground stars (Table 6). One would expect that optical stars have C_{21} smaller than −0.3 ($S_{12} \sim S_{25}$), however in Figure 2a 28% of the sources have $C_{21} > -0.3$. Most stars in Table 1 are M supergiants. In our Galaxy, it is known that some M supergiants have a "cold" circumstellar envelope though not optically thick. To model their energy distribution, Rowan–Robinson & Harris (1983) had to use a dust temperature at the inner radius of the dust shell of only typically 500 K, far below the dust condensation temperature. This would reflect either a peculiar mass–loss history, or the fact that the dust condensates much further from the star than in M giants. It might be that the same phenomenon occurs in some M supergiants of the LMC.

However, here we work with fluxes close to the detection limit and we should first invoke the uncertainty of these fluxes. Both Schwering & Israel and Reid et al. give a typical calibration uncertainty of 15%, leading to an uncertainty of ± 0.13 on C_{21}, though Reid et al. note that this uncertainty can be much larger for some sources. In Table 8, for sources in common to Schwering & Israel and Reid et al., we present a comparison of the various determinations of IRAS fluxes. Clearly, the disagreement between Schwering & Israel and Reid et al. is often much larger than 15%. In fact, as noted by Reid et al., there is a systematic disagreement for S_{12} and S_{25}. Reid et al. underestimate S_{12} and S_{25} by typically 25% compared to Schwering &

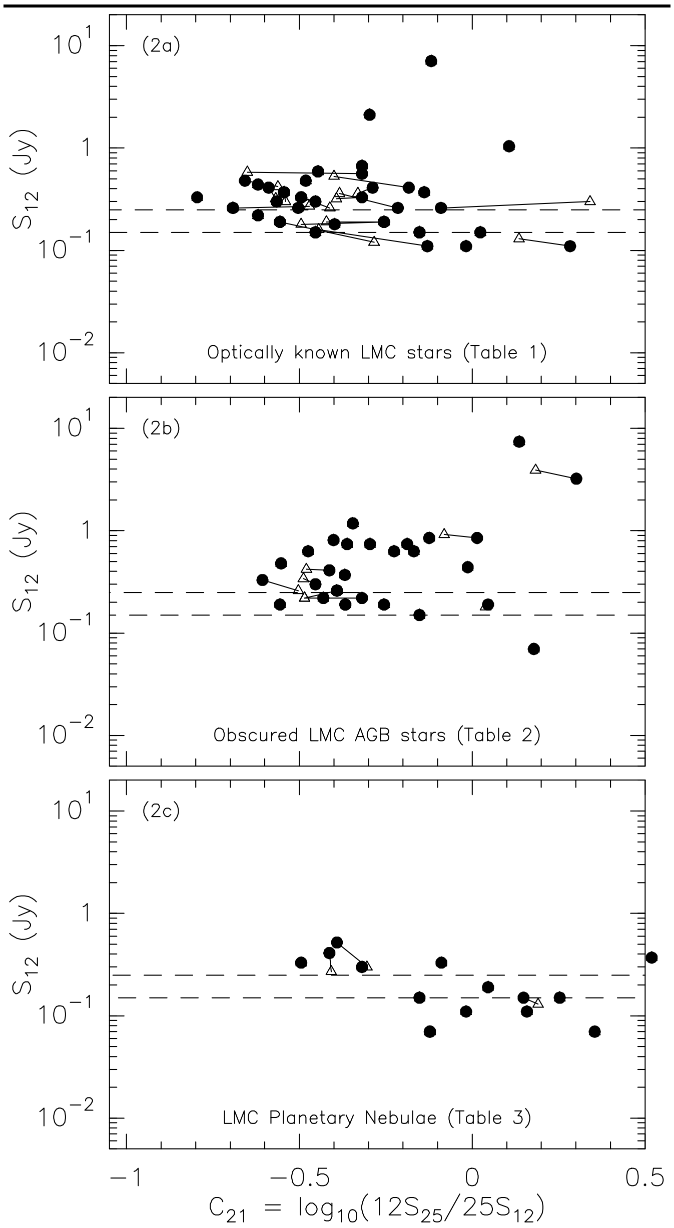

Fig. 2. Location of sources found in Table 1 (Fig. 2a), Table 2 (Fig. 2b), and Table 3 (Fig.2c) in the [C_{21},S_{12}] diagram. Full dots correspond to the IRAS fluxes determined by Schwering & Israel, open triangles correspond to IRAS fluxes determined by Reid et al. One can see that the disagreement between both determinations is often much larger than the "standard" adopted calibration uncertainty of 15% on IRAS fluxes (corresponding to ± 0.13 on C_{21}). On average, taking into account the large uncertainty on IRAS fluxes (see section 5), obscured AGB stars are colder than sources with optical counterparts, as expected.

Israel, and by 10% compared to the PSC. Reid et al. say that 10% is acceptable as it is inside the admitted 15% uncertainty. This is correct when one considers one source, but in a statistical sample they should not find any systematic deviations. Clearly, IRAS fluxes have not been determined with the same method by Schwering & Israel and by Reid et al. As a consequence, there is also a systematic deviation in the value of C_{21} which is generally underestimated by Reid et al. compared to Schwering & Israel. The typical uncertainty on C_{21} that we derive from Table 8 is ± 0.25, and hence only a few sources in Table 1 really have a cold C_{21} colour (Fig. 2a) . For them, one could also doubt that the IRAS source is actually associated with the optically identified star.

With such uncertainties in IRAS fluxes, the list of obscured AGB star candidates given in Table 4 probably misses a few objects whose 60 and/or 100 μm fluxes are contaminated. Conversely, a few sources in Table 4 might be associated with HII regions. However, we think that this list is the most complete one can make in a systematic way, and is quite reliable as it can be seen in Table 1 and 2 for identified objects. This list contains 6 times more sources than known obscured AGB stars listed in Table 2. Therefore further studies should be performed to clearly identify them. We expect that many of them will be identified through the IJK' observations of the DEep Near Infrared Survey of the southern sky (DENIS).

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