Asymptotic Giant Branch Stars
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ISOCAM and DENIS Survey of 0.5 square degrees in the Bar of the LMC. Detection of the whole TP-AGB Star Population

C. Loup, E. Josselin

Institut d'Astrophysique de Paris, CNRS, 98bis bd Arago, F-75014 Paris, France

M.-R. Cioni, H.J. Habing

Sterrewacht Leiden, Postbus 9513, 2300 RA Leiden, the Netherlands

J.A.D.L. Blommaert, N.R. Trams

ISO Data Centre, Astrophysics Div. of ESA, Villafranca, Spain

M.A.T. Groenewegen

Max-Planck-Institut für Astrophysik, Garching, Germany

C. Alard, P. Fouqué

Observatoire de Paris, France

F. Kerschbaum

Institut für Astronomie, A-1180 Wien, Austria

L.B.F.M. Waters, J.Th. van Loon

University of Amsterdam, the Netherlands

A.A. Zijlstra

UMIST, Manchester, UK

and the DENIS consortium

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Abstract. We surveyed 0.5 square degrees in the Bar of the LMC with ISOCAM at 4.5 and 12 μm, and with DENIS in the I, J, and K_S bands. Our goal was to build a complete sample of Thermally-Pulsing AGB stars. Here we present the first analysis of 0.14 square degrees. In total we find about 300 TP-AGB stars. Among these TP-AGB stars, 9% are obscured AGB stars (high mass-loss rates); 9 of them were detected by IRAS, and only 1 was previously identified. Their luminosities range from 2 500 to 14 000 $L_\odot$, with a distribution very similar to the one of optical TP-AGB stars (i.e. those with low mass-loss rates). Such a luminosity distribution,

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as well as the percentage of obscured stars among TP-AGB stars, is in very good agreement with the evolutionary models of Vassiliadis & Wood (1993) if most of the TP-AGB stars that we find have initial masses smaller than 1.5 to 2 $M_{\odot}$.

1. Introduction

The so-called "obscured" AGB stars are AGB stars in the Thermal-Pulse phase (TP-AGB), losing mass at such rates that the dust formed in their circumstellar envelopes becomes optically thick to the stellar radiation. The maximum of their emission is in the infrared, typically between 2 and 20 μm. The first search for obscured AGB stars in the Large Magellanic Cloud (LMC) has been done by Frogel & Richer (1983), with a moderate success due to their magnitude limit of 11 in the K band, and to the small area surveyed. Later, searches based on the IRAS data have been much more successful, leading to the discovery of more than 50 obscured AGB stars in the whole LMC (Reid et al. 1990; Reid 1991; Wood et al. 1992; Zijlstra et al. 1996; van Loon et al. 1997, 1998). However, due to the sensitivity limit of IRAS (even using the Faint Star Catalogue and the pointed observations), only the brightest or/and reddest sources could be detected by IRAS (Loup et al. 1997). TP-AGB stars with intermediate mass-loss rates, as well as those with high mass-loss rates and low luminosities, were still to be discovered.

We surveyed 0.5 square degrees in the LMC in 5 IR bands, using the DENIS and ISOCAM instruments in order to build a complete sample of TP-AGB stars, with the whole range of mass-loss rates and luminosities, and with as less observational biases as possible. Here we present the first analysis of 0.14 square degrees.

2. Observations and data reduction

Seven fields of 16′x16′, located in the Bar of the LMC, have been surveyed with the infrared camera ISOCAM on board of the Infrared Space Observatory, in the LW1, 4.5μm, and LW10, 12μm, bands, with a pixel size of 6″. Here we present the analysis for 2 fields centered at (J2000) 05:25:22 –69:46:30 (the LMC Optical Center) and 05:29:56 –69:57:50. Data reduction has been performed with the CIA package. PSF reconstruction and point source extraction are done with a software especially developed by Alard to take into account undersampling. The final result is not expressed as a flux density following the IRAS/ISO conventions, but as a magnitude, such as all the infrared magnitudes of Vega (without infrared excess) are 0. We chose this convention in order to have a system consistent with ground-based infrared photometry. Limiting magnitudes are 11 (7 mJy) and 10.5–10 (2–3.5 mJy) in the LW1 and LW10 bands, respectively. The typical uncertainty is 0.2 mag.

The same fields have been surveyed with the three channels instrument of the Deep Near Infrared Southern Sky Survey, DENIS, mounted on the ESO 1m telescope at La Silla (Epchtein et al. 1997). Observations in the I, J, and

K_S bands are simultaneous. Data reduction has been done through the regular pipeline of the survey (Paris and Leiden Data Analysis Centers). Limiting magnitudes are 18, 16, and 14, in the I, J, and K_S bands, respectively. In summary, we thus present the analysis of 0.14 square degrees in the Bar of the LMC, observed in 5 bands from 0.8 to 12 μm.

3. Characterization and cross-identifications

AGB stars have been well studied in our Galaxy up to about 5 kpc, in particular with the IRAS data, and with classical JHKL'MN photometry. Depending on their mass-loss rate, their emission peaks typically between 1 and 20 μm. DENIS and ISO provide the jump in sensitivity required to study AGB stars in the Magellanic Clouds with a similar quality. We chose the LW1 and LW10 bands because they complement the IJK_S bands of DENIS at longer wavelengths, and because LW1 can be compared with the M band, and LW10 is very similar to the IRAS $12\mu m$ band. The combination of both DENIS and ISO data allows to detect all the LMC AGB stars in the Thermal-Pulse phase (TP-AGB) whatever their mass-loss rate.

To characterize AGB stars, and cross-identify DENIS and ISO observations, we use three colour-colour diagrams (CCD) : (I–J, J–K_S), (J–K_S, K_S–LW10), and (K_S–LW10, LW1–LW10), as well as colour-magnitude diagrams. The location of the DENIS-ISO candidates in these diagrams is compared with the location of : (i) galactic sources observed in the J, K, M, and 12 μm bands (from the database of Kerschbaum et al.), (ii) models performed by Groenewegen et al. (1998 and private communication) for C stars, and M stars with silicates, with a large range of dust opacities, and fitting satisfactorily galactic sources. Within some limits, the location in the 3 CCDs also allows to estimate their chemical type in most cases. With the sensitivity of the ISO minisurvey, except a few F-K foreground giants, all point sources detected in LW1 or LW10, and isolated from extended structures, are TP-AGB stars or M supergiants.

The great majority of the sources that we detect are AGB and RGB stars, with no or faint mass-loss, only detected with DENIS (which provides enough information in this case). The 82 sources detected by both DENIS and ISO are either bright stars with low mass-loss rates, or TP-AGB stars with intermediate or high mass-loss rates. In the following, we define obscured AGB stars such as : $\tau(0.5\mu m) \geq 1.0$, corresponding to $(K_S\text{–LW10})_0 \geq 2.3$ and ≥ 3.4 for C-rich and O-rich sources, respectively. In total we detect 2160 sources. About 300 can be statistically selected as TP-AGB stars from their location in the DENIS CCD (Loup 1998; Cioni et al. 1998). Among these TP-AGB stars, 28 are obscured, with $(K_S\text{–LW10})_0$ up to 7.3. Finally, among these 28 obscured AGB stars, only 9 were detected in the IRAS pointed observations (Schwering & Israel 1990), and only 1 was previously identified by Wood et al. (1992). Among the 9 IRAS sources, one finds some of the reddest objects, but not all of them.

4. The luminosity distribution of obscured AGB stars

Traditional methods to estimate bolometric luminosities of AGB stars from IR photometry first convert magnitudes into flux densities from the effective or isophotal zero flux densities, and then integrate over by fitting a blackbody (in general), extrapolating the fit at short and long wavelengths. This method uses two contradictory assumptions : in the first step, the spectral distribution is the same as Vega, and in the second step, it is similar to a blackbody (but much colder than Vega). In this work, we only use integrated in-band fluxes, which at least remove the first assumption in all cases. From the models for C-rich AGB stars and M stars with silicates, and for blackbodies, we compute the percentage of flux actually measured in the 5 bands compared to the total flux emitted by the source, as a function of the various IR colours. From the measured in-band fluxes, colours, and estimated chemical types of our observed sources, we can then estimate their bolometric luminosities by comparing with the models, assuming of course that their spectral distribution is close to the models. Blackbodies systematically underestimate bolometric luminosities. We also compute the uncertainty on each bolometric luminosity estimate from measurement uncertainties, the spread from the various IR colours, and the intrinsic spread of models on the relation between the percentage of measured fluxes and IR colours (typically 2%).

The result is presented in Fig. 1 for all the sources detected by ISO and DENIS, and DENIS only, as a function of $(J–K_S)_0$. Note that obscured AGB stars typically have $(J–K_S)_0 \geq 2.3$. Though we present statictics for only 2160 stars, one distinguishes the Tip of the Red Giant Branch at $M_{bol} \simeq -3.4$ (i.e. 1800 $L_{\odot}$, see Cioni et al. 1998), using a distance of 49 kpc. The bolometric luminosities of obscured AGB stars in the observed fields range between −3.8 and −5.6, i.e. between 2500 and 14000 $L_{\odot}$. Their luminosity distribution is very similar to the one of optical carbon stars (Blanco et al. 1980; Costa & Frogel 1996) and TP-AGB stars with low mass-loss rates (Loup 1998). The only difference which may be noticed is that the lower boundary is smaller for optical stars than for obscured stars.

Though we will need to get the statistics on the 7 fields, our first analysis of 2 fields seems to be in very good agreement with the evolutionary models of Vassiliadis & Wood (1993). For stars of initial mass smaller than 1.5-2.0 $M_{\odot}$, they predict that the average luminosity is almost constant along the TP-AGB phase, with a luminosity ranging between 2000 and 8000 $L_{\odot}$, in excellent agreement with our observations. They also predict that TP-AGB stars undergo important mass-loss during about 15% of the total TP-AGB phase, to be compared to about 9% in our observations.

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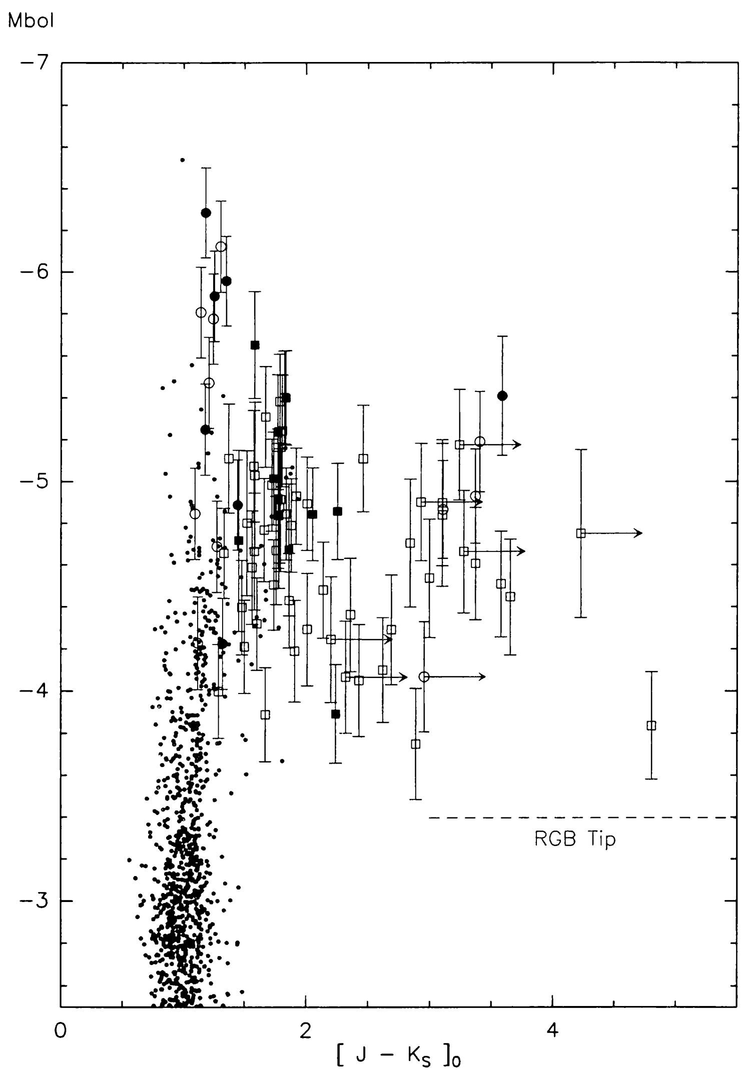
Figure 1. Bolometric luminosities of AGB and RGB stars in 0.14 square degrees in the Bar of the LMC. See Sect. 4. Sources only detected with DENIS are drawn with small dots, without errorbar for clarity (the typical uncertainty is 0.1 mag). Squares indicate C-rich sources, circles O-rich sources, both detected with ISO and DENIS; full squares or circles indicate that the chemical type is known (spectral type or OH maser); open symbols mean that the chemical type is an estimate from CCDs (see Sect. 3). Arrows indicate lower limits on ($J-K_S$) when J is not detected.



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