Part 2: The Database

The Galaxy and its Companions: Contributed Papers

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Near-Infrared Catalogue of the Magellanic Clouds: DENIS (Deep Near-IR Southern Sky Survey)

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Abstract. We report here on a preliminary analysis of the DENIS new IR point source catalogue of the Magellanic Clouds. After subtracting the contribution of foreground stars we interpret the colour-colour diagrams and colour-magnitude diagrams that characterize the Asymptotic Giant Branch (AGB). The AGB stars cause a clear bump in the luminosity function and they are distributed in two distinct regions, according to the spectral type (C-rich and O-rich), in the colour-luminosity diagram.

1. Observations and Data Reduction

The DENIS survey (Epchtein et al. 1997) offers a new opportunity to probe and analyse the infrared colour properties of the AGB populations of the Magellanic Clouds. The DENIS instrument is observing simultaneously in three photometric bands: I (0.8 μm), J (1.25 μm) and K_s (2.15 μm) using the 1 meter ESO telescope at La Silla, Chile. The hemisphere is divided into three zones of 30° in declination. Each zone is divided in strips of $12'$ wide and each strip is composed of 180 images of $12' \times 12'$ with an overlap of $2'$ in declination.

We present and analyse here the data obtained in two areas of the Large Magellanic Cloud (LMC), and one of the Small Magellanic Cloud (SMC). The area in the SMC is centered at $\alpha(J2000)$ = 00:56:00 and has an extension of $\approx 40'$, those in the LMC are centered at α = 05:08:00 and α = 05:27:20, respectively, with an extension of $\approx 1°$. The SMC observations have been completed at

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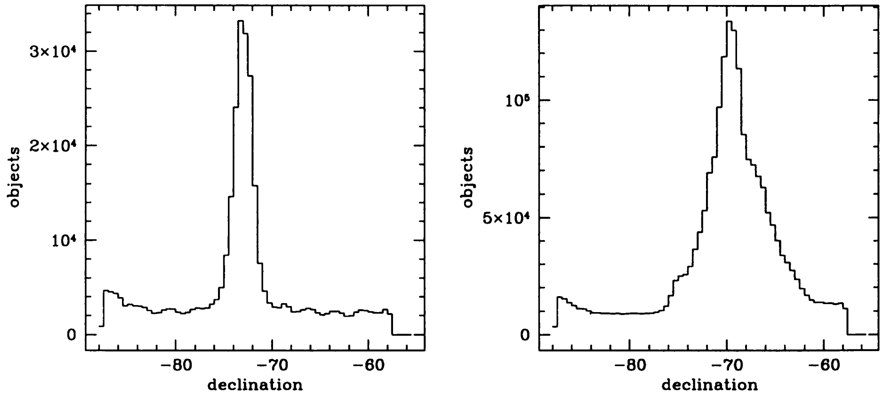

Figure 1. SMC (left) and LMC (right) histograms of the number of detected sources versus declination of all strips considered.

the beginning of the present season while the instrument is currently observing the remaining part of the LMC.

The data reduction takes place in two steps, the first at the *Paris Data Analysis Centre (PDAC)* and the second at the *Leiden Data Analysis Centre (LDAC)*. The image cleaning, the flat-fielding, the sky subtraction and the PSF calculation are carried out at PDAC. The point source extraction made using the **SExtractor** package (Bertin & Arnout 1996) and the astrometric and the photometric calibrations are performed at LDAC.

2. The Separation of Foreground and Magellanic Stars

The advantage of the DENIS observing mode, based on 30° long strips, is that a strip crossing a Cloud also contains information on the galactic star contribution. Figure 1 shows the histograms of the number of sources found across the SMC and the LMC, respectively. The galactic contribution is rather uniform in the full range of declination.

The galactic component is made of giants and dwarfs. In the colour-magnitude diagram (Fig. 2, left), these foreground objects distribute along two clearly distinct sequences: dwarfs have $I-J\sim 0.4$ and giants have $I-J\sim 0.8$. This diagram contains other interesting groups of objects: the bluest group with $I-J\sim 0$ might be formed by upper main sequence LMC stars while the reddest group by late-type (RGB and AGB) LMC stars; the vertical sequence with $I-J\sim 1.0$ might be formed by supergiants and/or early AGB LMC stars. We conclude that the "pollution" of the LMC AGB component by foreground stars is probably negligible. In order to estimate the number of foreground stars that contaminate the Magellanic Clouds sample, and to remove this component statistically, we have applied the following method: i) we divide the colour-colour plane in bins of 0.25 mag square (Fig. 3); ii) we determine the average of the number of foreground objects per bin. From Fig. 1 it follows that $-61\geq\delta(\mathrm{LMC})\geq-77$ and $-69\geq\delta(\mathrm{SMC})\geq-77$; iii) we subtract randomly that number from each bin. We estimate that the galactic contribution is of the

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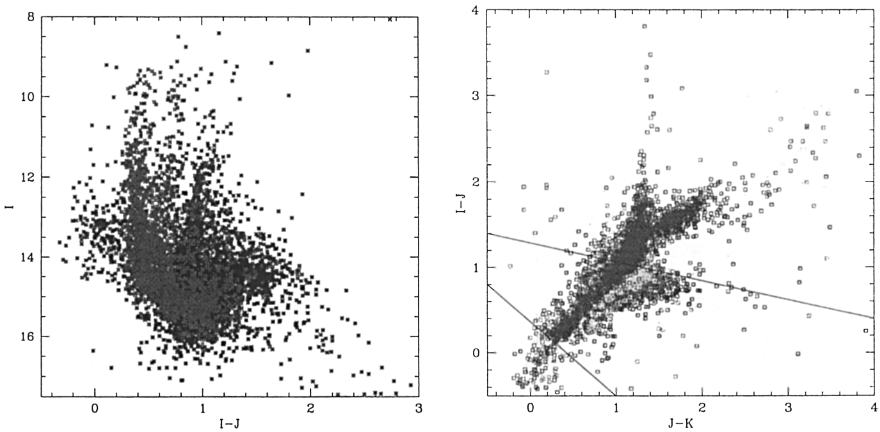

Figure 2. Colour-magnitude diagram I versus $I-J$ (left) and colour-colour diagram $I-J$ versus $J-K$ (right) of one strip of LMC sources.

order of 17.5% and 24.5% towards the LMC and the SMC, respectively, if we only consider sources detected in three photometric bands.

Figure 2 (right) shows a DENIS colour–colour diagram of one strip of the LMC. Late type stars, belonging to the LMC, are mainly distributed above the upper line. We distinguish three main regions: the first corresponds to the RGB (both colours around 1.2); a second corresponds to à branch with an extension towards large values of $J - K_s$, and a third corresponds to a branch at roughly constant $J - K_s \sim 1.2$ extending towards larger values of $I - J$. These latter branches are populated mainly, respectively, by C-rich AGB stars and O-rich AGB stars, the colours can be explained in terms of molecular blanketing and mass loss effects (Loup et al. 1998). Sources with $J - K_s \geq 2$ are losing mass and they can be either C-rich AGB stars or O-rich AGB stars. Below the lower line there are some Main Sequence or blue loop LMC stars. Between the two lines the galactic contamination dominates. Different gray shades correspond to different photometric errors. We have limited the discussion to a photometric error less than 0.2 mag in three bands. The branch at $I - J \sim 0.8$ extending to larger values of $J - K_s$ is sensitive to the photometric errors (higher values for larger $J - K_s$) and most of these sources are faint in all three photometric bands.

Figure 3 also shows the histograms of the number of sources versus declination in four particular bins. From top to bottom: $0.75 < J - K_s < 1.0$ and $0.75 < I - J < 1.0$, $0.75 < J - K_s < 1.0$ and $0.5 < I - J < 0.75$, $0.5 < J - K_s < 0.75$ and $0.5 < I - J < 0.75$, $0.5 < J - K_s < 0.75$ and $0.25 < I - J < 0.5$.

3. Magellanic RGB and AGB Stars

To characterize the AGB evolutionary stage we define five regions; see Fig. 5: the bolometric luminosities (Loup et al. 1998) as a function of $(J - K_s)_0$. We used

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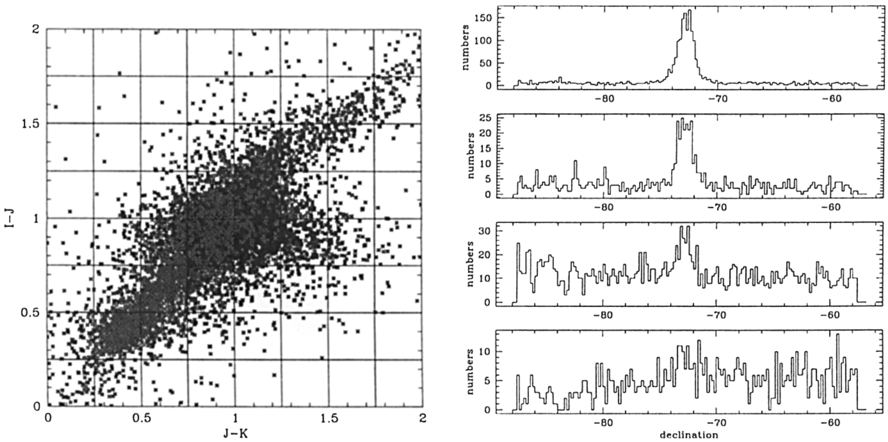

Figure 3. Colour-colour diagram and bin histograms (see text) for one strip of the SMC.

a distance modulus of 18.5 for the LMC and 18.9 for the SMC. Region 1 (not drawn in Fig. 5) is formed by the bulk of stars at low luminosity and contains RGB and AGB stars in the early phase (E-AGB). Region 2 mostly contains O-rich AGB stars in the Thermal Pulsing phase (TP-AGB) with spectral type later than M3/5. It contains a few C-rich AGB stars as well. Region 3 is almost entirely formed by C-rich AGB stars as confirmed by the cross-identification with spectroscopically identified C stars by Blanco et al. (1980), and more recently with the on-going work of Cannon et al. (see article in these Proceedings). The $(J-K_s)_0$ sequence of C-stars in this region is mostly due to molecular blanketing (Loup et al. 1998). Region 4 contains mass-losing AGB ("obscured") stars. According to Frogel & Blanco (1983) region 5 contains early M type stars of luminosity type I and II. They are probably much younger (10^8 Gyr old) and more massive than objects in region 1, 2 and 3 (few Gyr old). This region is obviously much more populated in the SMC than in the LMC. These objects clearly belong to the Clouds as can be seen from Fig. 3: first bin.

Table 1. Number of objects per region

Cloud	2	3	4	5	2/5	3/5	3/2	3/(2+5)
SMC	552	417	55	761	0.73	0.55	0.75	0.32
LMC	14571	3394	448	3089	4.72	1.1	0.23	0.19

Note: This division has a statistical purpose. Table 1 shows the total number of objects in each region and we also indicate preliminary ratios.

Figure 5 shows the luminosity distribution of all the sources in Fig. 4. The cut-off at the lowest luminosity only reflects the sensitivity limits of DENIS. On the other side, the steep decline which clearly appears at $M_{\rm bol} = -3.4$ and -3.6 for the LMC and the SMC, respectively, marks the tip of the RGB (it is visible

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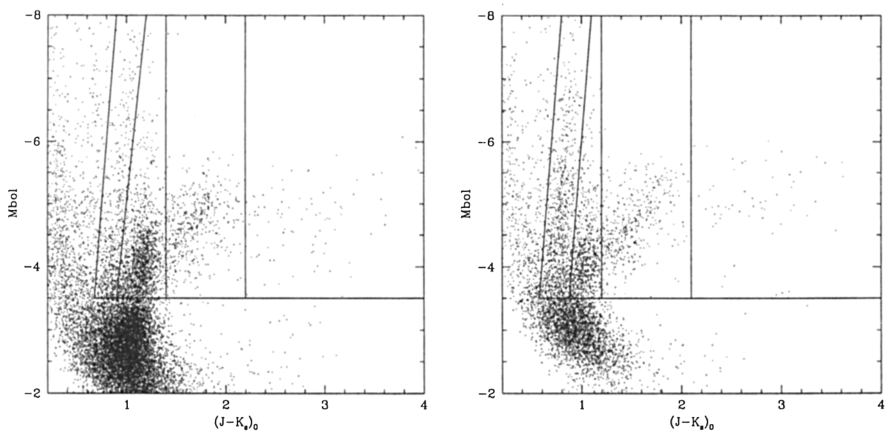

Figure 4. Colour-luminosity diagrams $M_{\rm bol}$ versus $(J-K_s)_0$ for LMC (left) and SMC (right) sources. We call region 1 the main bulk of stars and, from left to right, region 5, 2, 3, and 4 the closed areas.

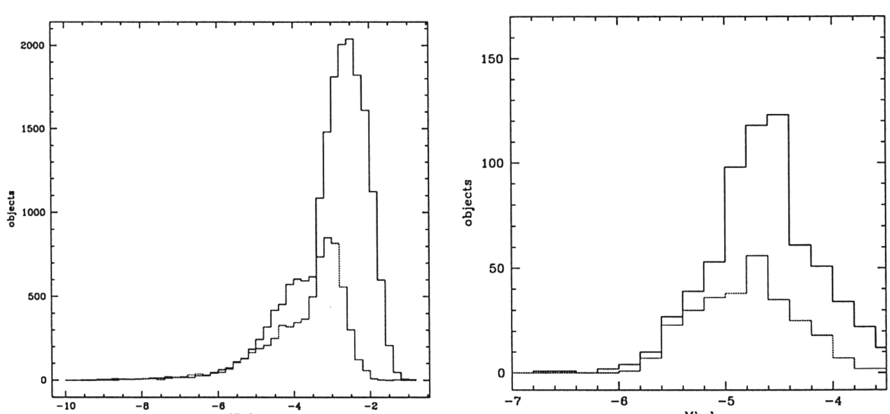

Figure 5. Luminosity functions. All sources displayed in Fig. 4 on the left and only the bulk of C stars on the right (region 3 and 4 - see text). Continuous line for the LMC and dashed line for the SMC.

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in Fig. 4). Finally, at higher luminosity, there is a clear bump due to AGB stars in the Thermal Pulsing phase (see Fig. 5: left).

4. Conclusions

The DENIS photometric bands well describe the AGB population in the Magellanic Clouds. Cross-identification with other catalogues helps to understand the three DENIS measurements. The production of the DENIS Point Source Catalogue is planned to be ready by the end of 1999. With all data available we look forward to test evolutionary models and to study the surface distribution of different types of objects.

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Discussion

Glass: Are those stars with high $J-K$ real?

Cioni: Sources with $J-K>2$ are real if they are not close to the limiting magnitude of the survey. This means that sources with $J-K>2$ and $K\sim14$ might not be real while most of the red AGB have $K<12.5$.

Pritchet: You have given number ratios of C and M stars in different regions of the CMD. For studies of more distant galaxies in integrated light, it would be useful to have luminosity or flux ratios contributed by these same regions. Have you done this?

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Cioni: I have not done this yet. But it is certainly very important because AGB stars, C-rich and M-rich strongly contribute to the IR light.

Catchpole: Do you know where the Miras are in the two-colour diagram? They will almost certainly not lie in the same region as the M stars.

Cioni: I have not checked directly yet where the Miras are. My next step is to cross-identify the DENIS data with known catalogues of variables. Anyway, in the color-color diagram, I expect them to have redder colours compared to non-variable stars for example.

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