Abundance gradient in Local Group galaxies using Asymptotic Giant Branch stars

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Abstract. Simultaneous $IJK_s$ observations allow us to statistically select AGB stars, both M and C type, from RGB and younger or foreground stars in nearby galaxies. Regions of different metallicity identified from the distribution of the C/M ratio show a considerable variation across the surface of the Magellanic Clouds and NGC 6822.

1 Introduction

Asymptotic Giant Branch (AGB) stars are useful indicators of the properties of a galaxy. They trace the intermediate–age population (between 1 and several Gyr), are often the brightest and isolated objects and can be observed beyond a Mpc. Furthermore, because there are two kinds of AGB stars: oxygen-rich (O-rich or M-type) and carbon-rich (C-rich or C-type), their ratio is a powerful indicator of metallicity. AGB stars are found mostly in Irregular, Spiral and Elliptical galaxies in the Local Group. In particular there are about 30000 AGB stars in the Large Magellanic Cloud (LMC), about 8000 in the Small Magellanic Cloud (SMC) and about 3000 in the central region of NGC 6822. A handful of AGB stars are also found in some Spheroidal and Dwarf Spheroidal galaxies. It is important, for the purpose of this paper to remember that there are more C-rich AGB stars in metal poor systems.

Since 1981 Pagel wrote that metal abundance in external galaxies exhibits radial gradients. Searches for AGB stars in the solar neighborhood ([16]), the Magellanic Clouds ([2]) and Baade’s Window ([12]) have shown that the C/M ratio correlates with metallicity in the sense: a higher ratio corresponds to a lower metallicity. Theoretically the C/M ratio indicates the metallicity of a system because in a metal poor environment the location of the giant branch shifts to warmer temperatures and less carbon atoms are needed to form C stars ([17], [15]).

Studies of AGB stars in the Magellanic Clouds (MCs) have strongly improved thanks to optical and near-infrared (near-IR) large scale surveys: DENIS, 2MASS, MACHO, EROS, OGLE, MCPS. Similar surveys of other Local Group galaxies, especially in the near-IR wave and monitoring are taking place.

2 [Fe/H] Abundance

2.1 The Large Magellanic Cloud

Using the DENIS catalogue towards the MCs (DCMC) [5] defined a photometric criteria to select stars of a different type and age. In the $(I – J, I)$ diagram
AGB stars, irrespectively of type, are easily distinguished as a plume of objects above the tip of the red giant branch (TRGB – [7]), from RGB stars that are fainter and from younger stars or foreground sources, that have much bluer colours ([4]). The distribution of AGB stars across the LMC describes a smooth and regular elliptical structure without clear signs of spiral features. The same AGB stars, because of different molecule that dominate their atmosphere, are separated in O-rich and C-rich at $J - K_s = 1.4$: C-rich stars are redder than O-rich stars. The separation is a function of metallicity. Our $IJK_s$ selection criteria includes also O-rich AGB stars of early M spectral sub-type (M0+) located below the $K_s$-TRGB. In addition most AGB stars with a thick circumstellar envelope ($J - K_s > 2.2$) are excluded because they are located below the $I$-TRGB; these can be O-rich as well as C-rich.

The distribution of the C/M ratio (Fig. 1) is rather clumpy. Regions with an high ratio are progressively located in the outer part of the galaxy suggesting that the metallicity decreases from the center to the outer galaxy. This gradient has been recently confirmed by [1] fitting the RGB in the $(J - K_s, K_s)$-2MASS diagram in different locations. In agreement with [8] the bar is more metal rich than the inner disk region and towards the bridge connecting the MCs the metallicity is low (Arm B region) as suggested by [15]. Calibrating the C/M in terms of [Fe/H] as discussed in Sect. 2.4 we obtain a variation of 0.75 dex. Comparing with the extinction map by [20] the C/M0+ ratio is not the result of differential extinction.

2.2 The Small Magellanic Cloud

A similar study, as presented above, has been done also for the SMC using DCMC data. Figure 2 shows the distribution of the C/M ratio. Here a clear gradient is
Fig. 2. Distribution of the C/M ratio in the SMC.

not present, however, there are clumps of high ratio (or low metallicity) located in the outer borders of an inner region, while the outermost parts of the galaxy have a much lower ratio. The variation of Fe/H also corresponds to 0.75 dex. An indication of a similar metallicity distribution has been found by [14]. The authors combined $UBVI$ data from the Magellanic Cloud Photometric Survey (MCPS) with theoretical isochrones by [11]. They conclude that a population about 2.5 Gyr old with $Z = 0.008$ is associated to an outer, perhaps uncertain, ring, the latter encloses clumps of objects about 1–1.5 Gyr old with $Z = 0.001–0.004$.

2.3 NGC 6822

NGC6822 is an isolated Irregular galaxy in the Local Group in many ways similar to the MCs (i.e. of intermediate [O/H] abundance). Because of its low latitude it is affected by a moderate extinction ($E(B-V) = 0.25 - 0.45$) and contamination by foreground stars. It started to form stars about 10 Gyr ago with a rate that increased in the past 3 Gyr. Using $IJK_s$ data from the William Herschel telescope in La Palma I and Habing have surveyed the inner $20' \times 20'$ of the galaxy down to about 1 mag below the TRGB ([3]). These are the first near-IR observations that cover the whole galaxy; [9] observed in $J$ & $K_s$ only three very small regions. Using a similar selection technique as for the MCs we have studied the distribution of AGB stars and of the C/M ratio (Fig. [3]). The latter corresponds to a variation of $[Fe/H]$ of 1.89 dex, about twice as much as that found within the MCs. This agrees with the spread derived by [19] from RGB stars. Clumps of high ratio (or low metallicity) are distributed in two NS semi-circles around the central bar, that has on the other hand a much lower
ratio. At least some clumps correspond to regions of high HI column density ($N_{\text{HI}}$).

### 2.4 Calibration of C/M versus [Fe/H]

In order to relate the C/M to [Fe/H] we have used values available in the literature from the compilation by [13] – see also this proceeding. Though a correlation is clearly present (Fig. 4) the fit is rather uncertain: measurements of [Fe/H] might be in error by 0.2 dex while the number of AGB stars up to 50%.

In fact the former rely on just a few stars or HII regions and the latter on the extrapolation to the whole galaxy of the number of objects detected in small survey areas often from incomplete and inhomogeneous samples. In order to improve this relation we have recently obtained spectra of about 300 AGB stars in NGC 6822 to measure the Ca II triplet and derive, using the most up-to-date calibration between these features and [Fe/H], an estimate of the metallicity. These values will be averaged in bins that contain a significant number of AGB stars and hopefully we will be able to put further constraints on the C/M versus [Fe/H] relation.

It is possible that the C/M also depends on the local star formation history. In collaboration with Girardi, Marigo & Habing we are comparing the luminosity function of AGB stars in the MCs, in different locations, with a theoretical luminosity function to address this aspect.

### 3 Other Abundances

Work in progress on the analysis of FLAMES spectra of a sample of AGB stars in the LMC will allow us to derive the metallicity and the abundance of other
Fig. 4. Relation between the C/M ratio and [Fe/H] in the Local Group.

elements that play a key role in the evolution of AGB stars. Preliminary results from data obtained during the science verification of the instrument are very encouraging and were followed by new observations in order to reach a necessary statistical sample to study abundances as a function of magnitude, colour and period.

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