Stellar Populations as Building Blocks of Galaxies
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The VMC survey and the SFH of some Local Group Galaxies

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Abstract. The K_s-band magnitude distribution of carbon-rich and oxygen-rich asymptotic giant branch stars within Local Group galaxies like the Magellanic Clouds, NGC 6822, M33 and SagDIG is easily obtained from ground-based observations. Appropriate stellar evolutionary models covering a range of metallicities and star formation rates are used to produce theoretical distributions that allow us to derive the history of star formation across these galaxies. I will show the result of these studies and discuss the application of this technique to more distant systems as well as deeper observations, like those that VISTA will provide, to improve our understanding of, in particular, the Magellanic Clouds.

Keywords. Surveys, infrared: stars, stars: late-type, galaxies: Local Group

1. The VMC survey

The VISTA Public Survey of the Magellanic System (VMC) has been recommended by the ESO Public Survey Panel and the ESO Observing Programme Committee to form part of the core programme of VISTA. This new telsecope, soon to be commissioned, will host a near-infrared wide-field camera (VIRCAM). The VMC originated from an international collaboration and will provide the community with a unique dataset to study the Magellanic System stellar population and structure.

These data will cover entirely the major components of the system (Fig. 1): a wide area comprising the Large Magellanic Cloud (LMC), the Small Magellanic Cloud (SMC), the Bridge connecting them and a few fields in the Stream where the stellar content is expected to be large. Across five years observations in the Y, J and K_s filters will be obtained. Three epochs in Y and J and 12 epochs in K_s will constrain the mean magnitude of short-period variable (RR Lyrae and Cepheid stars) and the periodicity of long period variable stars. Both the Bridge and SMC areas will also be covered at optical wavelengths by the VLT Survey Telescope (VST).

The main VMC science goals are: to derive the global and spatially resolved star formation history (SFH) of the system and its three-dimensional (3D) geometry. These require a depth of $K_s = 20.3$ with a S/N= 10. The SFH will be measured from the interpretation of mainly giant stars and main sequence turn off stars using stellar evolution models as well as three-body simulations of the system. The 3D-geometry will be obtained from: the period-magnitude relation of RR Lyrae and Cepheid stars (where the period will come from large-scale optical surveys like EROS-II for the LMC and VST observations for the other components of the system), the distribution of stars in the red clump phase of evolution and stellar clusters. VMC data will also allow us to reduce the uncertainty on the measurement of the distance to the LMC by a factor of two, to derive the mass of obscured AGB stars discovered recently by the Spitzer infrared space telescope, to study the formation of stars of about a solar mass, to uncover the missing number of Planetary

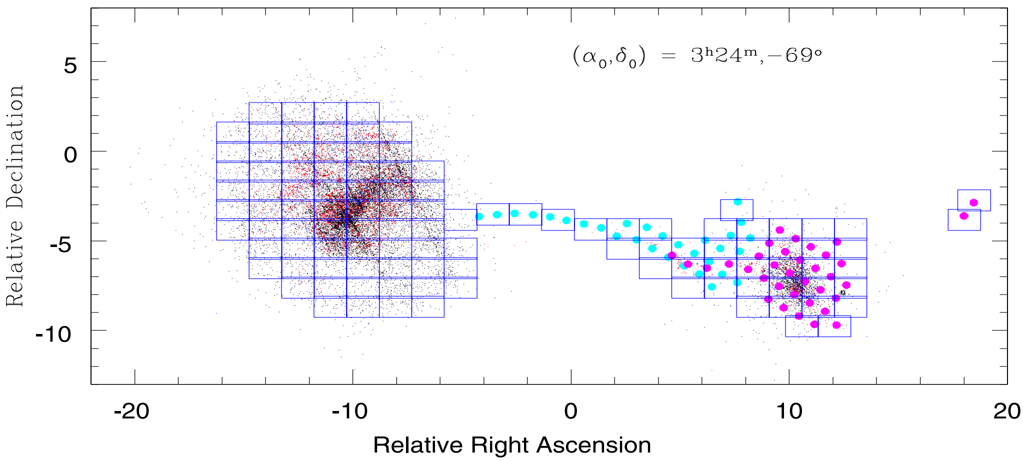

Figure 1. Distribution of VISTA tiles across the Magellanic System. Underlying small dots indicate the distribution of C stars, clusters and associations while thick dots show the location of VST pointings.

Nebulae and eventually to constrain the proper motion of the Magellanic Clouds that the ESA space mission GAIA will accurately measure.

2. Metallicity and SFR of Local Galaxies

A near-infrared wide-field view of galaxies allow us to derive their global properties and, in particular, to study the distribution of the mean-age and metallicity of their stellar population. This work, using data from the DENIS and 2MASS surveys has been published this year on the Magellanic Clouds (Cioni, *et al.* 2006a, 2006b, 2006c). A similar work on the Magellanic type galaxy NGC 6822 has recently been submitted (Cioni, *et al.* 2007a), as well as on the faint irregular galaxy SagDIG (Gullieuszik, *et al.* 2007), while a study of the nearby spiral galaxy M33 is currently in preparation (Cioni, *et al.* 2007b).

2.1. *The K_s method*

Carbon-rich (C-rich) and oxygen-rich (O-rich) asymptotic giant branch (AGB) stars can be distinguished using the near-infrared colour-magnitude diagram ($J - K_s$, K_s). Other criteria involve optical broad- or narrow-band photometry or low-resolution spectroscopy. Their observed number distribution as a function of K_s magnitude compared with theoretical distributions created using theoretical models allow us to create maps of the most probable metallicity (Z) and star formation rate (SFR) of the underlying stellar population. The comparison, evaluated using the χ^2 test, has been made across spatial regions (sectors of elliptical coronae) containing a statistical significant number of stars. For example, the subdivision of the area covered by M33 comprises 3500 O-rich AGB stars and 300 C-rich AGB stars in each of five concentric ellipses; a histogram was created for each of eight sectors per ellipse.

Theoretical distributions have been created using the TRILEGAL code to simulate stars according to a SFR, age-metallicity relation and initial mass function. In particular, luminosity, effective temperature and gravity have been interpolated among stellar evolutionary tracks from: Bertelli, *et al.* (1994) for massive stars and Girardi, *et al.* (2000) for low- and intermediate-mass stars including the recipe for thermal pulsing AGB stars by Marigo, Girardi & Bressan (1999). Bolometric tables were used to derive magnitudes and include photometric errors. A combination of different model parameters (SFRs and

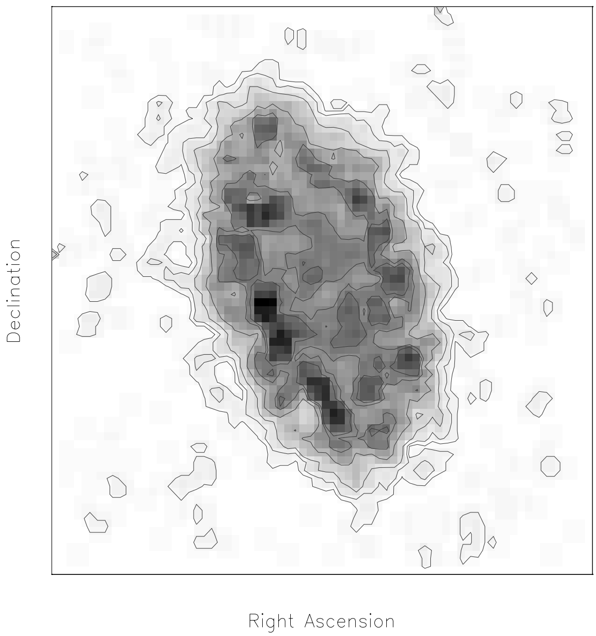

Figure 2. Distribution of the C/M ratio across M33. C-rich and O-rich AGB stars above the tip of the RGB have been selected using the colour-magnitude diagram ($J - K_s$, K_s). Darker regions correspond to higher ratios. Contours are at: 0.25, 0.5, 1.0, 2.0, 3.0, 3.5 and 4.0.

Zs) results in a different number of C- and O-rich AGB stars as well as in a different location in the ($J - K_s$, K_s) space. The best fit model (= the lowest χ^2) is assigned to a given area and a spatial map of best Z and best SFR is created.

2.2. *Applications: main results*

The LMC stellar population appears younger in the East than in the West and the bar has a composite stellar population, see also Cioni (2007c). Metallicity maps do agree with the distribution shown by the C/M ratio (the ratio between C-rich and O-rich AGB stars). Maps were also corrected for the orientation of the galaxy in the sky and for the effect, if present, of differential extinction.

The SMC stellar population appears more metal rich in a ring surrounding the central part of the galaxy. A region of increasing metallicity moves anti-clockwise with increasing time perhaps tracing the dynamical evolution of the galaxy and/or the propagation of star formation in agreement with the results suggested by Harris & Zaritsky (2004).

The stellar population of NGC 6822 derived from observations obtained at the WHT in La Palma appears on average 8 Gyr old. There is excellent agreement between the overall metallicity trend with direct measurements of [Fe/H] in individual stars in the inner galaxy. The outer halo appears metal poorer and older.

The stellar population of M33 derived from observations obtained at the UKIRT telescope appears on average $7 - 8$ Gyr old and it is metal poor. The distribution of high C/M ratio values, corresponding to a lower metallicity (Battinelli & Demers 2005), traces the structure of the major spiral arms presenting a puzzle to its interpretation. Usually, spiral arms are associated with the youngest and therefore the metal richest regions of a galaxy. The effect of differential reddening and of the structure of the galaxy on the

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C/M ratio is negligible while it is fundamental in the distribution of metallicity and SFR obtained from the number density of AGB stars. This correction has not yet been implemented and, in fact, preliminary results suggest that the North-East of the galaxy is more obscured than the South-West of it.

Although SagDIG contains a limited population of intermediate-age stars, C-rich AGB stars were carefully identified and their distribution analyzed as for the previous galaxies. Near-infrared observations were, in this case, obtained from the NTT telescope in La Silla. The population of SagDIG appears on average 4 Gyr old and with [Fe/H]< -1.3 dex.

3. Conclusions

Inhomogeneities in Z and SFR as those derived here can be interpreted via simulations of the spatial distribution of stars. This has been done for the LMC accounting also for the effect of its interaction with the SMC and the Milky Way, see Bekki & Cioni (2007). If stars formed in clumps of $\leqslant 10^7 M_\odot$ or smaller they constitute today the field stellar population of the LMC. Each clump has a certain age and metallicity and although stars from different clumps appear spatially mixed, it is possible that they do preserve the age and metallicity of the gas cloud from which they formed. Thus, identifying these components provides a fossil record of the galaxy history which ultimately will be explained with the availability of the kinematics information on the different stellar populations.

The K_s method will be applied to other galaxies in the Local Group as soon as suitable data will become available, but also to more distant galaxies resolved into stars. Understanding giant stars is a key to understand not only an extreme aspect of stellar evolution, but also to understand global properties of galaxies and to trace their history. These studies are essential for new sensitive instruments which probe the Universe at near-infrared wavelengths!

Acknowledgements

I would like to acknowledge the collaborative work of Leo Girardi, Paola Marigo and Harm Habing, especially the theoretical effort, on the reconstruction of the metallicity and mean-age distribution of galaxies. I would also like to thank the VMC team for contributing to the success of the VMC proposal.

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Discussion

Meixner: Do your AGB model colors include the dust emission in the near-IR, especially at the K band?.

Cioni: The Padova models, as far as I know, but P. Marigo could give you more details about it, do not include much dust. However for most of the AGB stars with $J - K_s < 2$ it should not have a large effect. In addition the models are calibrated on the AGB stars of the Magellanic Clouds to reproduce the CMDs well.

Bland-Hawthorn: The notion of age mapping is interesting on any timescale. I think you need to work towards mass-weighted ages rather than light-weighted ages if you want to relate to a physical process, e.g. dynamical perturbation.

Cioni: This is true. What the method gives now is an indication that something is there but needs to be followed-up with for example kinematical data.

The speaker (middle) with Ben Panter. Left: Brian Marsteller

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