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Red Supergiants in Magellanic Cloud Clusters: a Step Towards Modeling Starburst Galaxies

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For the purpose of developing a new population synthesis technique (Bica, 1988) we collected integrated spectra for a sample of populous and concentrated star clusters in our Galaxy and in the Magellanic Clouds.

In the course of this study, we noticed that one blue cluster, NGC 2004 in the LMC, was displaying a peculiar near IR spectrum with strong TiO absorption bands and CaII IR triplet. Having in mind the M supergiant phase, well known from stellar observations and studied in stellar evolution models, we wondered about its possible occurrence on a large scale and its signature in the integrated spectrum of NGC 2004. Because M supergiants represent a time-peaked evolutionary stage, they would obviously offer an interesting opportunity to date starbursts in composite populations. Therefore, we decided to investigate further this possibility.

M Supergiants in Star Clusters

The LMC and SMC being particularly rich in blue populous clusters (Hodge, 1961), we chose 39 of their brightest members. As an example, a digital recording of NGC 2004 from an ESO sur-

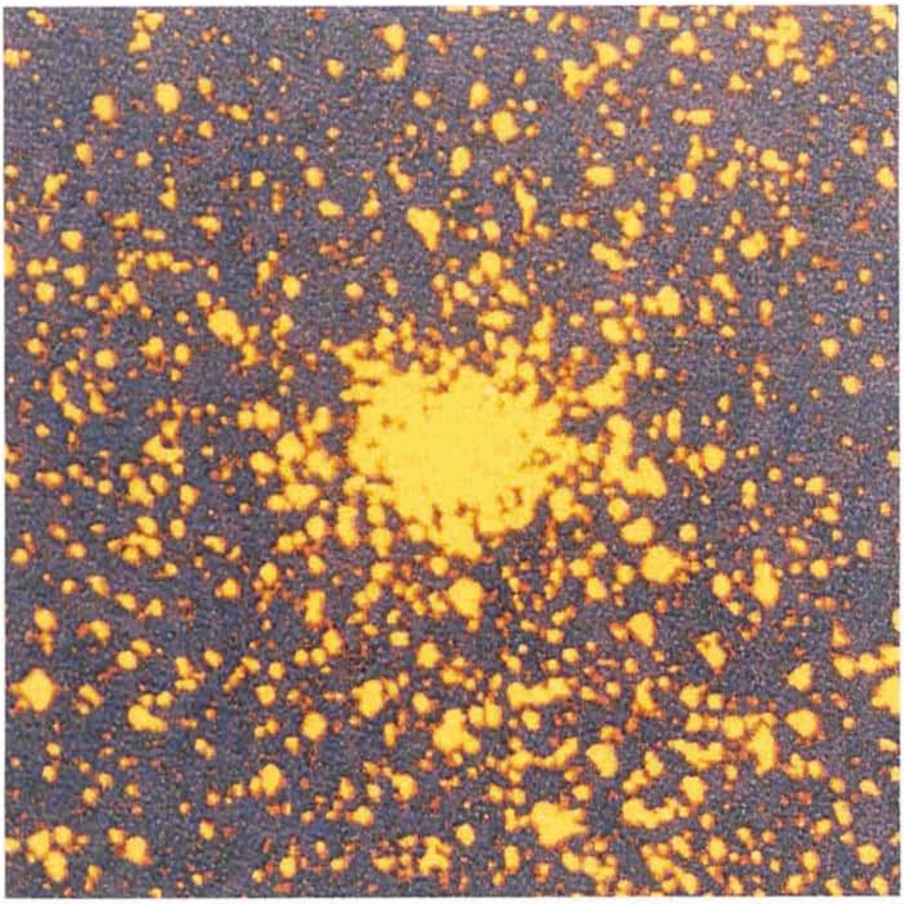

Figure 1: *Digital recording of NGC 2004, from an ESO survey B plate, to illustrate the concentrated globular appearance of our blue Magellanic cluster sample (after Bica and Dottori, 1990).*

vey B plate is shown in Figure 1 : notice the concentrated globular appearance of the cluster, quite suitable for obtaining integrated information.

We have performed spectroscopic observations of the 39 cluster sample at the ESO 1.52-m and 2.2-m telescopes, with a CCD. We used an E-W oriented long slit and we scanned the slit across the star cluster in the N-S direction, over a spatial extent 15″ to 60″, according to the cluster size. The surrounding background was extracted towards the edge of the slit and subtracted from the star cluster spectrum in a standard way. The data covered a spectral range from 5600 to 10000 Å, at a 14 Å resolution (Bica, Alloin and Santos, 1990).

The age calibration of the clusters, described in detail in the latter reference, was worked out from the relationship between blue-violet colours and turnoff ages deduced for a subsample of blue Magellanic clusters for which an HR diagram was available (Van den Bergh, 1981; Searle, Wilkinson and Bagnuolo, 1980; Hodge, 1982, 1983). Remember that the blue-violet range is essentially not contaminated by the flux from cool stars and is very sensitive to age through the Balmer jump.

The observed spectra in the near IR show indeed a spectacular change with age, illustrated in Figure 2 for LMC clusters. We identified two red phases at around 10 and 100 Myr. In Figure 2, each spectrum, at a given age, represents in fact a mean of about 5 clusters so as to minimize eventual stochastic effects related to the very large luminosity and limited number of M supergiants. The cluster grouping has been done following the age bins delineated in Figure 3 which displays the evolution of the equivalent width of strong TiO bands in the near IR.

Regarding the late red phase around 100 Myr, it is certainly related to luminous AGB stars already identified in the LMC field and in individual LMC blue clusters (Frogel and Blanco, 1983). Their quantitative contribution and exact age range of occurrence remain to be modelized in detail in the integrated light of star clusters.

As to the first red phase at 10 Myr, it is quite prominent and we interpret it as being caused by late M supergiants (Alloin and Bica, 1989). Previous JHK photometry independently showed the need for red supergiants to explain the colours of very young clusters (Persson et al., 1983). A theoretical support to the interpretation of the 10 Myr red phase in terms of M supergiants comes along two different lines: (1) evolutionary tracks for 15 to 30 $M_\odot$ stars demonstrate that these stars are good candidates for becoming, at some stage, late M supergiants (Maeder and Meynet, 1988), and (ii) evolution of the integrated light from model star clusters shows a conspicuous red phase around 10 Myr if a small enough time step is used in the computation (Arimoto and Bica, 1989; Prieto, 1990; Schmidt, 1990).

Although the age dependence is dominant in Figure 2, we cannot ignore some metallicity dependence as well, in particular for molecular absorption bands like TiO which are sensitive to Z squared. And indeed, of the three star clusters observed in the SMC, globally less metal rich than the LMC, one cluster NGC 299 appears to be in the red supergiant phase from its flat continuum and strong CaII IR triplet. Yet, its W(TiO) value is far from being as strong as that observed in LMC star clusters going through the same phase (Fig. 3).

We wish to underline the difference between the precise reference to M supergiants and the use of a general red supergiant term which often refers to earlier spectral types. Prior stars correspond to the effect we discuss here as a phase in the integrated spectrum of some LMC clusters and are observed as a well-defined clump of stars at (B-V)

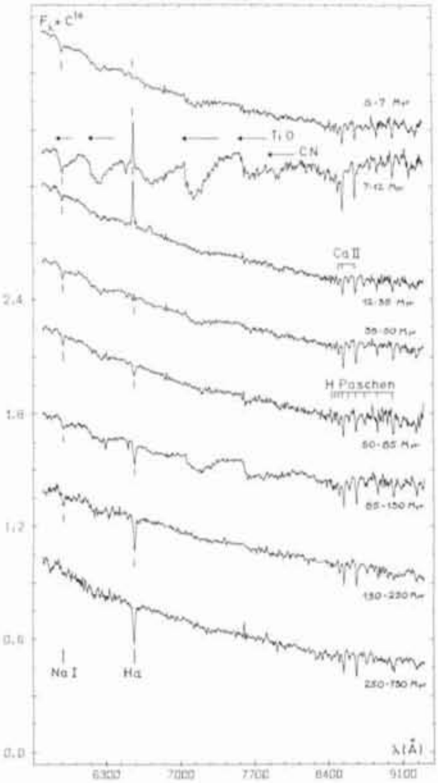

Figure 2: *Age sequence of the LMC blue clusters showing their spectral evolution in the near IR. Notice for the two red phases at 10 and 100 Myr, the enhanced W (TiO) and W(CaII) as well as the continuum slope changes (after Bica, Alloin and Santos, 1990).*

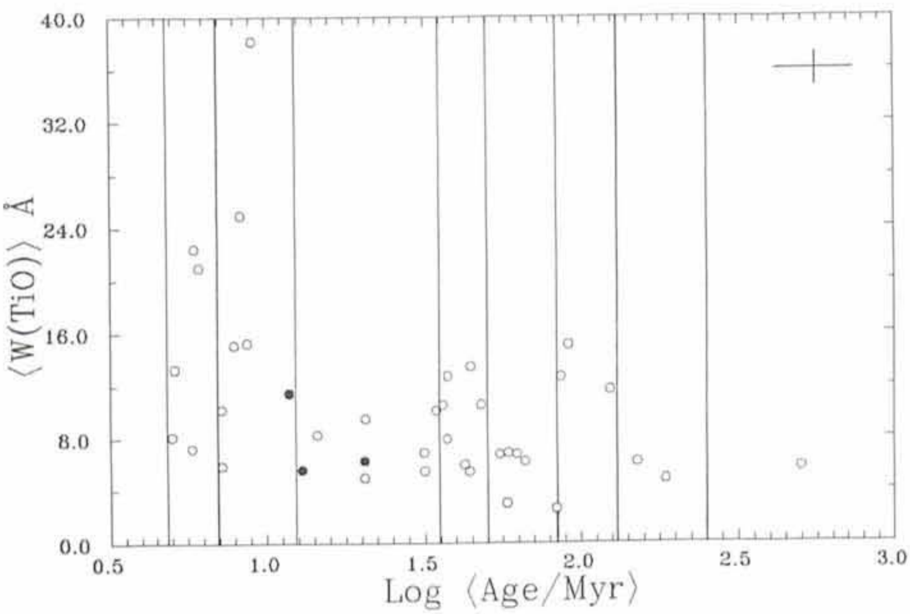

Figure 3: *Evolution of the equivalent width of TiO absorption bands in the near IR. Open circles refer to LMC blue clusters and black dots to the 3 SMC blue clusters. The age bins for grouping cluster spectra, as shown in Figure 2, have been drawn.*

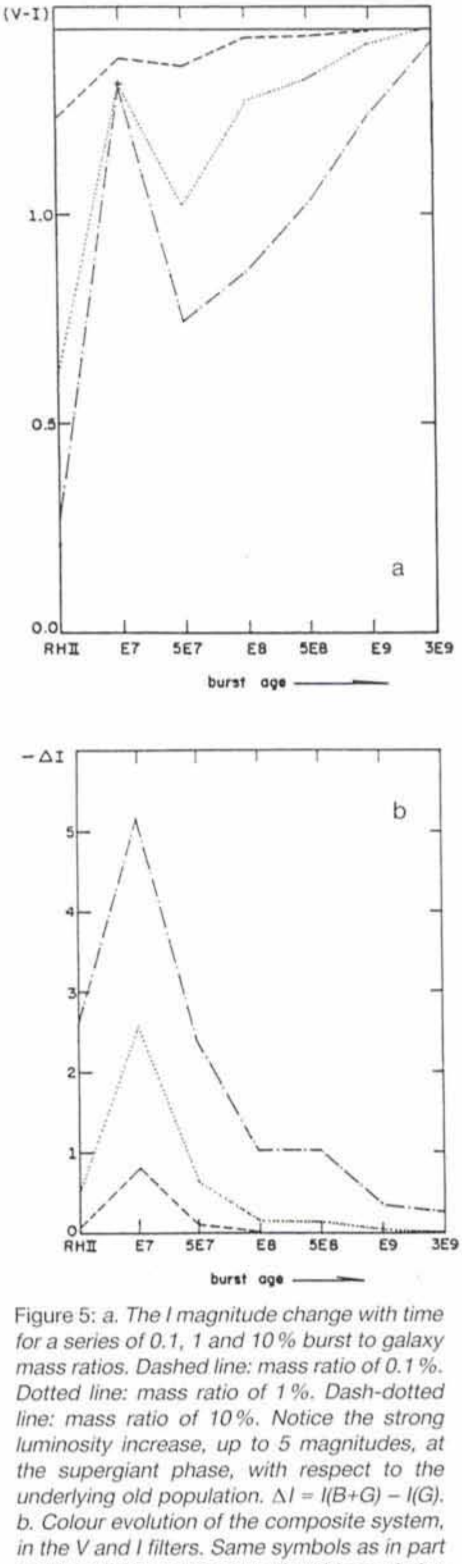

Figure 5: *a. The I magnitude change with time for a series of 0.1, 1 and 10% burst to galaxy mass ratios. Dashed line: mass ratio of 0.1%. Dotted line: mass ratio of 1%. Dash-dotted line: mass ratio of 10%. Notice the strong luminosity increase, up to 5 magnitudes, at the supergiant phase, with respect to the underlying old population. ΔI = I(B+G) – I(G). b. Colour evolution of the composite system, in the V and I filters. Same symbols as in part a. The solid line represents the old population colour.*

~1.7 in the HR diagram of NGC 2004 and NGC 2100 (Robertson, 1974). This clump is also present in Galactic open clusters of similar age at (B-V) ~ 1.8 like those in Mermillod's composite groups NGC 884, 457 and 3766. Such stars are certainly the product of the evolution of stars in the mass range 15 to 30 $M_\odot$, depending on mass-loss rate (Maeder and Meynet, 1988). It is interesting to see that stars more massive than 40 $M_\odot$ do not reach, along their evolution, effective temperatures low enough to produce M supergiants. Consequently, eventual red supergiants in star clusters with ages less than 5 Myr, still associated with emitting gas, are not expected to exhibit M-type spectral features. This would explain why the recently detected HII region with strong absorption at the CaII IR triplet, in NGC 3310 (Terlevich et al., 1990) has no signature of molecular bands.

Towards Starbursts in Galaxies

Starbursts in galaxies might be quite complex and their spectral appearance could depend on many factors such as: the burst strength relative to old population of the underlying galaxy, its metallicity, its age, its duration, the possibility of having a superposition of successive bursts. It is clear from the previous discussion about star clusters that a detailed population synthesis will be necessary to extract all this information. Such a synthesis should not only use the TiO and CaII triplet in the near IR, but also other age and metallicity discriminators like the Balmer jump and Balmer lines, and metallic lines in the far UV.

We have been prompted by the possible use of the M supergiant signature for interpreting composite stellar populations. As a preliminary study, we have performed simulations of a starburst occurring on top of an old population galaxy and followed the spectral evolution of the composite system (Bica, Alloin and Schmidt, 1990). We have considered various mass ratios of the burst with respect to the old population: 0.1%, 1% and 10%. The burst is represented by a star cluster at a given age and the old population by a red, metal-

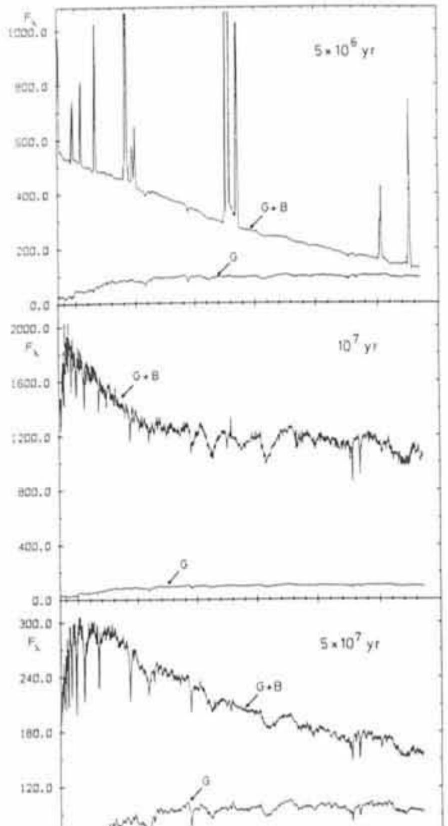

Figure 4: *Spectral evolution from 5 Myr to 50 Myr of the composite light (B+G) in the near IR, of a starburst (B) superimposed on an old population galaxy (G). The mass ratio of (B) to (G) is 1% in that case (after Bica, Alloin and Schmidt, 1990).*

rich nuclear galaxy spectrum. The burst duration, implicit in these simulations, is that of a single generation star cluster, hence, amongst the shortest. Consequently, we could explore in this work only the dependences on the burst strength and age. For illustration, we provide in Figure 4 the early evolutionary stages from 5 to 50 Myr, of the composite spectrum. Notice the rapid spectral changes. The dependence on the burst strength is shown in Figure 5a and b, in terms of absolute luminosity increase and colour evolution of the composite light: the stronger the burst, the longer its impact on the composite system, as expected.

We are not aware that any starburst galaxy has been detected so far with TiO bands as strong as those observed in the LMC blue clusters passing through the M supergiant phase. This suggests that starbursts in galaxies are not time-peaked but rather made of multiple, successive stellar generations. Then, the absence of the M supergiant molecular signature could be understood as the result of dilution effects: the contribution from evolutionary stages outside the 7 to 12 Myr, which are free of molecular absorption, will wash out the molecular bands from the short-living M supergiant phase at 10 Myr. A weak metallicity in the starburst could contribute also to a weakening of the molecular bands. The M supergiant phase in a metal-rich composite population could be prominent only if the burst duration were quite short and the burst age were around 10 Myr. In contrast, the near IR CaII triplet should be a conspicuous feature in most starbursts, because it is present at all evolutionary stages from 6 to 500 Myr (Fig. 2).

We are now in the process of simulating starbursts in low-metallicity galaxies such as dwarf galaxies. In parallel, we are performing direct population synthesis of a sample of 60 dwarf blue and red galaxies.

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The Planetary Nebula NGC 3132: a Three-Dimensional Ionization Model

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1. Introduction

Planetary Nebulae (PNe) are an intermediate stage in the stellar evolution from a red giant star to a white dwarf of stars with masses between 1 $M_\odot$ and about 8 $M_\odot$. Most of the light emitted from PNe consists of emission lines from ions excited by the UV radiation of the hot central star. As the PN consists of material ejected from the red giant star during the AGB Phase, investigations of the morphology and the dynamics of PNe can give information about the mechanisms that cause the mass loss from the red giant star.

The major problem investigating the morphology of PNe is the fact that there is no simple way to get the three-dimensional density distribution in the nebulae. As PNe are optically thin in the light of emission lines, two-dimensional images show the integrated flux emitted from all locations in the line of sight into the direction to the observer. Thus there are several three-dimensional density distributions leading to the same monochromatic image. But most PNe show strong evidence that a spherically symmetric density distribution cannot match with the monochromatic images. Statistical methods lead to systems assuming several PN morphologies representing different evolutionary stages in some morphological classes (Balick, 1987), in which a lot of PNe seem to fit in easily, but it is difficult to justify whether a single PN really shows a specific morphology or not.

One possibility to check at least the consistency of a given density distribution for a single PN is to compare images taken from that PN in the light of different ionization stages of several elements with artificial images calculated with three-dimensional ionization models. Assuming a given density distribution, it is possible to calculate the ionization equilibrium at each location, depending on the temperature, the UV flux from the central star and monochromatic images, that can be compared to observed monochromatic images.

The observational methods for PNe made a big progress in the last years. With the availability of sensitive CCD detectors combined with narrow interference filters it is easily possible to obtain monochromatic images of PNe with high spatial resolution. At La Silla this can be done e.g. with the 2.2-m telescope. Even images in the weak lines like OIII 463.3 nm and sometimes HeII 4686 can be obtained in most cases with exposure times less then 30 minutes. The extended old PNe can at least be imaged in the bright lines like OIII 500.7 nm and NII 658.4 nm. With the B&C spectrographs of the 2.2-m and 1.52-m telescopes combined with CCD detectors it is possible to get spectra of different positions inside the PN. With the 22.4 nm/mm grating at the 1.52-m telescope (15 µm high resolution CCD) we obtained spectra (each in the range from about 400 nm–700 nm) with exposure times between 1 and 30 minutes. The spectral resolution of this grating is sufficient to separate the important emission lines we need for comparison with our model calculations. So the observational presuppositions are given to improve the old spherically symmetric model calculations.