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An IRAC@Spitzer survey of GGCs

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Abstract. A mid-IR deep survey of the central regions of 17 Galactic globular clusters (GGCs), spanning the entire range of metallicity between approximately a hundredth solar up to solar, has been made using the InfraRed Array Camera (IRAC) on board the Spitzer Space Telescope. IRAC is a four-channel camera that provides simultaneous 5.2'×5.2' images at 3.6, 4.5, 5.8 and 8.0 microns. The main goal of our project is the detailed study of mass loss (ML) in first ascent Population II giants whit varying stellar parameters, metal content and Horizontal Branch (HB) morphology.

Key words. Stars: Population II, mass loss – circumstellar matter – infrared: stars

1. Introduction

A sample of 17 massive GGCs, 4–5 per each 0.5 dex bin in metallicity between [Fe/H] = −2.3 and −0.5 and different HB morphologies within each bin has been observed with IRAC onboard Spitzer. 26hr of observing time in Cycle 2 have been allocated to our program (ID #20298). For all these clusters complementary near-IR and UV photometry are available to properly characterize both the red and the blue sequences. Ground-based near-IR photometry of the central region at high spatial resolution has been obtained using IRAC2@ESO2.2m, SOFI@ESO-NTT and NICS@TNG (Ferraro et al. 2000; Valenti et al. 2004; Sollima et al. 2004) and supplemented with 2MASS data in the external region of each cluster. Accurate WFPC2 and ACS HST UV/optical images of the core regions and ground based wide field photometry in the outer regions have been also obtained by our group through a long term project devoted to study the HB morphology of GGCs. According to SPOT-v11.07, the stellar point sources and IRAC sensitivity PET, a frame time of 12 sec and a *25-30 Cycling Positions* dithering pattern with the *Small* Scale Factor, repeated a few times for total on source integration times between 1000s and 2700s in each filter, depending on the cluster distance, allows us to reach the HB level at $M_{\rm bol} \approx 0.0$ (i.e. $13 \leq K \leq 15$) with $S/N \approx 20$. Such a setup is optimized to maximize the spatial coverage and the on source integration time. The brightest 3 clusters in our sample, namely NGC 104, NGC 5139 and NGC 6752 have been observed using the *High Dynamic Range* Readout Mode, to avoid saturation of the brightest tip giants,

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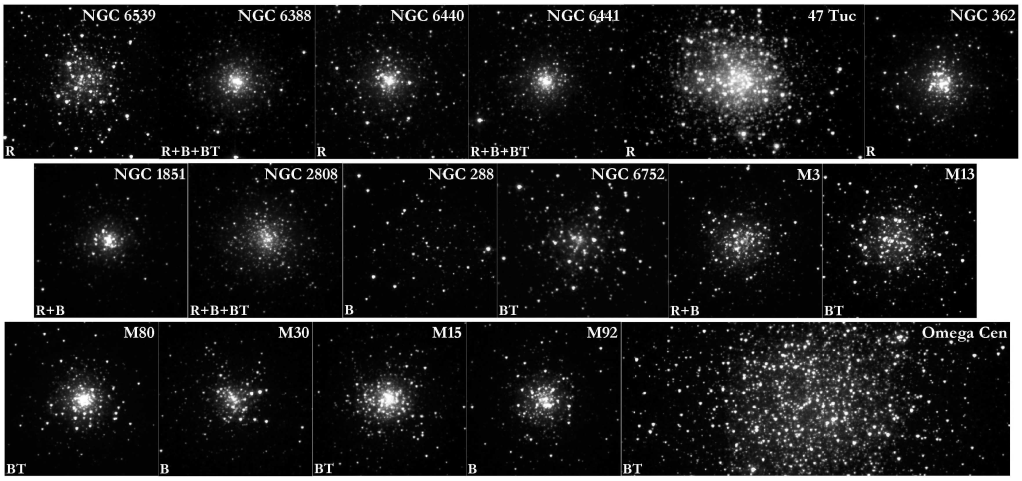

Fig. 1. IRAC@Spitzer 3-color (3.6μm (blue), 6μm (green), 8μm (red)) mosaiced image of the observed GGCs. The HB morphology is also indicated: R=red, R+B=red–blue, R+B+BT=red–blue–blue tail, B=blue, BT=blue tail.

all the others using the normal *Full Array* Readout mode. NGC 5139, the sparsest cluster in our sample, has been mapped using a rectangular 1×4 grid in array coordinates, allowing the mapping of the central $14' \times 5'$ in all the four IRAC filters, while NGC 104 has been mapped using a 1×3 grid to cover the central $9' \times 5'$. All the other clusters will be observed with 2 pointings so that for the central $5' \times 5'$ we have exposures in all 4 IRAC bands.

2. Dust excess and ML rates

The Post BCD mosaic frames from the Spitzer Pipeline (Software Version: S13.2.0) have been photometrically reduced with ROMAFOT (Buonanno et al. 1983), a software package optimized for PSF-fitting in crowded and undersampled stellar fields. The dereddened K_0 magnitudes and $(J - K)_0$ colors have been also used to compute the stellar bolometric magnitudes and effective temperatures, by using the transformation of Montegriffo et al. (1998), reddening and distance modulus from Ferraro et al. (1999). As circumstellar (CS) dust condenses in an outflowing wind, it can be detected as a mid-IR excess. In our pilot project using ISOCAM photometry in the 10 μm window and assuming a νB_ν emissivity, we showed that the bulk of CS dust around the RGB tip giants typically has temperatures in the range 300–500 K. The IRAC bands between 3.6 and 8 μm can also be used to detect this warm dust when coupled with near IR photometry used to properly characterize the stellar counterpart. In order to select candidate stars with dust excess, we define first the mean ridge lines in each of the K_0, $(K - IRAC)_0$ CMDs to define the average color of the stars with purely photospheric emission and to determine the overall photometric errors (σ) at different magnitude bins. Since the 8 μm IRAC band is the most sensitive to warm dust emission, stars are flagged as dusty if they show a $(K - 8)_0$ color excess $\geq n\sigma$. Fig.2 shows the absolute CMDs for metal rich (left pannel) and metal poor (right pannel) GCs. In order to obtain the ML rates we use our modified version of the DUSTY code (Ivezić, Nenkova & Elitzur 1999), to compute the emerging spectrum and dust emission at the IRAC wavelengths. We adopt Kurucz model atmospheres for the heating source and for the dust a mixture of warm silicates with an average grain radius $a = 0.1\,\mu$m. Since GGC stars are generally neither luminous nor metal rich enough for dust driven winds (Willson 2000) to be efficient, we run the DUSTY code un-

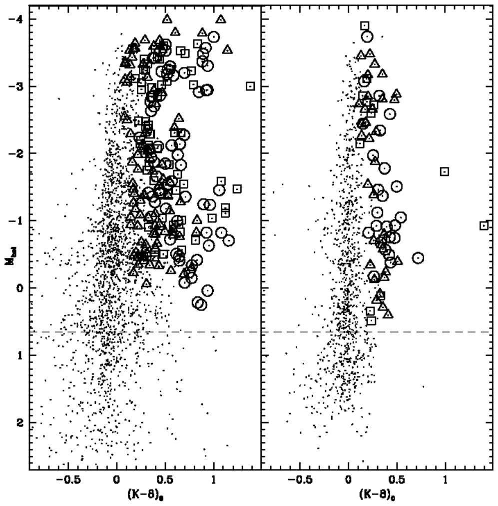

Fig. 2. Absolute CMDs for 3 metal rich and 3 metal poor GCs in the sample. Stars with $(K-8)_0$ color excess excess at a 3σ level are marked. Left pannel: 47 Tuc (triangle), NGC 6388 (square), NGC 6441 (circle). Right pannel: M15 (triangle), M30 (square), M92 (circle). The dashed horizontal line marks the position of the HB level.

der the general assumption of an expanding envelope at constant velocity $v_{\rm exp}$ with a density profile $\eta \propto r^{-2}$, a dust temperature for the inner boundary $r_{\rm in}$ of 1000 K and a shell outer boundary $r_{\rm out} = 1000\times r_{\rm in}$. We then computed a large grid of DUSTY models with stellar temperatures in the 3500–5000 K range and optical depths at 8 μm (τ_8) between 10^{-5} and 10^{-1}. For each star with dust excess, we enter the grid with its empirical stellar temperature and $(K-IRAC)_0$ colors, and we exit with prediction for the optical depth, emerging flux and envelope radius. The mass loss rates are computed by using the formula:

$$dM/dt = 4\pi r_{\rm out}^2 \times \rho_{\rm dust} \times v_{\rm exp} \times \delta \qquad (1)$$

where $\rho_{\rm dust} \propto \rho_g \tau_8 F_8({\rm obs})/F_8({\rm mod}) D^2$ is the dust density, $\rho_g = 3\,{\rm g\,cm^{-3}}$ is the grain density, F_8 are the observed and model fluxes at 8 μm, D the distance and δ the gas to dust ratio. A lower limit to δ is given by $1/Z$ where Z is the global metallicity. $v_{\rm exp}$ is a free parameter, which should scale like $\delta^{-0.5}$ if dust and gas are coupled. The provisional empirical law based on the first set of observations of metal rich GC analized so far (see also Origlia et al. 2007) gives:

$$dM/dt = 4\times 10^{-10} \times (L/gR)^{0.4}_{\odot} \qquad (2)$$

where $L_\odot$, $g_\odot$, and $R_\odot$ are the stellar luminosity, gravity and radius in solar units, whit a 25% average random error. This new law calibrated on Population II RGB stars is significantly flatter than the original Reimers formulation and the one revised by Catelan (2000).

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