Red giant stars in NGC 5128

Marina Rejkuba

European Southern Observatory, Karl-Schwarzschild-Str. 2, D-85748 Garching, Germany

Abstract. I present a selection of results obtained from VLT FORS1 and ISAAC photometric monitoring of late-type giants in NGC 5128 (=Centaurus A). The combination of optical and near-IR photometry allows to probe the full metallicity range of the stars on the upper red giant branch, thanks to combined low-metallicity sensitivity of the optical and high-metallicity sensitivity of the near-IR bands. The metallicity distribution covers a wide range with the mean value around $[\text{M}/\text{H}] \sim -0.45$ dex. The near-IR monitoring of the variable AGB stars allows to gain insights into the age distribution. The period distribution of these long period variables indicates only about $10\%$ contribution of the intermediate-age component (age $\lesssim 5$ Gyr) to the predominantly old stellar halo. Among the brightest, large amplitude and long period variables only very few have near-IR and optical colors consistent with carbon-rich giants.

1 Introduction and observations

The red giant stars of NGC 5128 (=Centaurus A), the nearest, easily observable giant elliptical galaxy, were resolved first time by Soria et al. (1996), who used WFPC2 camera on board HST to image this galaxy’s halo. Today, with the availability of 8-10m class telescopes in excellent astronomical sites it is possible to obtain similar or even better results with imaging from the ground.

The data presented here have been obtained between April 1999 and July 2002 with FORS1 optical imager and spectrograph and ISAAC near-IR instrument at UT1 Very Large Telescope at ESO Paranal Observatory. Two halo fields were observed once in $U, V, J_s$ and $H$ bands and monitored with 20–24 observations spread over 3 years in $K_s$. The observations, data reductions and photometric catalogues are presented by Rejkuba et al. (2001, 2003a). Some results concerning the metallicity and ages of red giant branch (RGB) and asymptotic giant branch (AGB) stars in the halo of NGC 5128 are shown. Here I plot color-magnitude and color-color diagrams for the north-eastern halo field (Field 1 in Rejkuba et al. 2001). Very similar diagrams, and conclusions, are reached for the second, southern halo field, as well. For more detailed analysis, the interested reader is referred to Rejkuba et al.(2003a, 2003b) and Rejkuba (2004).

2 RGB and AGB in color-magnitude diagrams

Combination of the optical and near-IR colors in a color-magnitude diagram (CMD) allows to probe old and intermediate-age stellar populations. Theoretically, more than two thirds of the light in $K$-band is dominated by cool RGB
Fig. 1. Left: Optical-near IR CMD of halo stars in NGC 5128. Right: Near-IR CMD of the same field.

The horizontal line indicates the position of the RGB tip in both CMDs. Overplotted are the fiducial RGBs for the following old Galactic globular clusters: NGC 6528, NGC 6553, M 69, 47 Tuc, M 107, M 4, M 55, M 30 and M 15, in the order of decreasing metallicity from $-0.2$ to $-1.9$ dex. The dashed slanted line in the $VK$ CMD indicates 50% completeness of the $V$-band photometry. The large number of sources brighter than the RGB tip are AGB variables. Those variables for which reliable periods could be obtained from our 3 yr-monitoring programme are marked with large circles.

and AGB stars. The red dwarfs are too faint to be detected at the distance of NGC 5128, and thus the $VK$ and $JK$ CMDs are entirely dominated by RGB and AGB stars (Fig. 1).

The spread in color of the RGB is larger than the photometric uncertainties, indicating the presence of a spread in metallicity and/or age. The age spread is possible, and indeed most likely (see below), but it cannot entirely account for the range of colors of the RGB stars, which are much more sensitive to metallicity changes. From a comparison with the fiducial RGBs of the old Galactic globular clusters (GGC) with a range of metallicities, and assuming old ages for the stars in the NGC 5128, the most metal-poor stars have metallicities as low as $-2$ dex, while the metal-rich end on the $VK$ CMD, set by the incompleteness of the $V$-band photometry (dashed slanted line), indicates approx. $-0.5$ dex. The most metal-rich giants, which are too faint in the $V$-band due to huge bolometric corrections, emit most of their energy in the near-IR and are thus easily observed in $JK$ CMD (Fig. 1, right). The most metal-rich GGC fiducials overplotted are for NGC 6553 and 6528, Bulge globulars, with $-0.3 \lesssim [M/H] \lesssim -0.2$ dex. There is a small component of red giants in NGC 5128 with metallicities close to and slightly above solar. Their mean metallicity is $-0.45 \pm 0.05$ dex. For comparison, Walsh et al. (1999) measured the mean oxygen-abundance of five planetary nebulae in NGC 5128 to be $[O/H] = -0.5 \pm 0.3$ dex, in agreement with the average metallicity inferred from the RGB color.
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Fig. 2. Period-magnitude diagram for Mira LPVs in NGC 5128. The solid line is a least-square fit to the data points (shown in the figure) and the dashed line is a fit with a fixed slope (−3.47) as measured in the LMC (Feast et al. 1989).

The dotted horizontal line in both CMDs in Fig. 1 is drawn at $K_s = 21.24$ mag, the position of the tip of the RGB as measured from the ISAAC data. The stars brighter than the RGB tip up to $\sim 2$ mag are in the AGB evolutionary phase. There are additional few dozens of relatively bright stars in the $K$-band images with no $J$, nor in $H$-band counterparts. Their stellar profiles and magnitudes indicate that they might be highly dust obscured AGB stars.

3 AGB variable stars

Rejkuba et al. (2003a) measured periods for more than 1000 long period variable (LPV) NGC 5128 halo. The period-magnitude diagram for the LPVs with the most reliable periods is shown in Fig. 2. They form a sequence with the slope (indicated in the figure) which is very close to that of the LMC Mira variable stars (−3.47; Feast et al. 1989). Adopting the zero point of the Mira period-luminosity relation of 0.98 and a distance modulus of the LMC of 18.50, I have obtained a distance modulus to NGC 5128 of $27.96 \pm 0.11$, in excellent agreement with other literature values (see Rejkuba 2004 for more discussion).

Periods of Mira variables can be used to age date stellar population assuming that their metallicities are known. Longer period Miras are expected to have higher mass progenitors, hence to be younger. However, the more metal-rich, the older the star, assuming a constant mass. For example, according to models (e.g. Vassiliadis & Wood 1993), a $1 \, M_\odot$ star will evolve to a Mira variable with a period of $\sim 400$ days. In a solar metallicity population the turn-off age of a $1 \, M_\odot$ star is 7.7 Gyr, while at $[\text{M}/\text{H}] = -0.7$ dex it is $\sim 4.5$ Gyr.
Fig. 3. Period distribution of LPVs in NGC 5128 is compared with: Galactic globular clusters (age $\sim 12$ Gyr, [M/H] $\geq -1$ dex), Milky Way Bulge (age $\sim 10$ Gyr, [M/H] $\sim 0.0$ dex), and the LMC (mostly age $< 3$ Gyr, [M/H] $\sim -0.7$ dex) Mira periods.

A comparison of Mira period distributions in NGC 5128 and 3 other systems with different mean ages and metallicities is shown in Fig. 3. The brightest Miras in NGC 5128 reach $M_K = -8.65$ and have periods in excess of 800 days. The large majority has similar periods to those of Galactic bulge and old globular cluster Miras, but 10% of them have periods in excess of 500 days and are thus probably younger than $\sim 5$ Gyr, unless they all have extremely high metallicities.

4 Are there carbon stars?

Carbon stars are typically found among intermediate-age metal-poor populations. Their presence is a definite proof of an intermediate-age component. If present in NGC 5128 they may come from a recently accreted LMC-type or a small gas-rich spiral galaxy. Carbon stars in the LMC have $1.4 < (J - K_s) < 2$, but the stars redder than $J - K_s > 2$ can either be obscured oxygen or carbon-rich giants. $H - K$ vs. $J - H$ color-color diagram has been a traditional tool for detecting these stars (see Rejkuba et al. 2003 for NGC 5128). In Fig. 4 I show a combined optical near-IR color-color diagram, $J - K$ vs. $V - K$ for all the stars brighter than the RGB tip from the CMD in Fig. 1. The recent models from Marigo (2002) fit the range of colors of late-type oxygen and carbon-rich giants in the Solar neighbourhood in this diagram well. In Fig. 4 NGC 5128 AGB stars are plotted with small filled symbols, Galactic M-stars are from Fluks et al. (1994; open large circles) and C-stars are from Bergeat et al. (2001; large open triangles). Most of the stars in NGC 5128 are located along the oxygen-rich sequence, and only a small number of them are found along the location of
carbon-rich giants. This is expected in a relatively high metallicity environment like that of NGC 5128 halo. However, as shown above there is also a metal-poor tail in this galaxy. Most of it appears to be older than $\sim 5$ Gyr, and only a very small component has intermediate-ages.

Much deeper photometry has been recently obtained with the ACS camera on board of HST. It reaches $V$-band magnitudes of $\sim 30$ and enables to detect additional age-sensitive features, like the AGB bump, red clump and the horizontal branch. The analysis of this new observations will be used to quantify the age distribution of the NGC 5128 halo stars (Rejkuba et al., in preparation).

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