Star formation history of stellar systems in NGC 1316

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Resumen / Las fusiones de galaxias se suelen mencionar en la literatura como lugares ideales para estudiar diversas explosiones de formación estelar desencadenadas durante estos eventos violentos. En ese sentido, el remanente de fusión de edad intermedia NGC 1316 constituye un escenario perfecto para estudiar los complejos eventos de formación estelar a gran escala en el Universo Local. En una serie de trabajos previos confirmamos la existencia de un complejo sistema de cúmulos globulares asociados a dicha galaxia, el cual está dominado por la presencia de una subpoblación inusualmente joven ($\approx 2.1 \times 10^9$ años) y rica en metales ($-0.5 < [Z/H] < 0.5$ dex), posiblemente creados durante el último evento de fusión sufrido por esta galaxia. En este trabajo utilizamos datos espectroscópicos obtenidos a través de Gemini/GMOS para analizar la historia de formación estelar de tres cúmulos globulares asociados a NGC 1316. Es importante mencionar que aunque trabajos recientes muestran la presencia de múltiples poblaciones estelares en cúmulos globulares en la Vía Láctea y galaxias cercanas, este proyecto constituye uno de los primeros estudios de poblaciones estelares múltiples en cúmulos estelares extragalácticos jóvenes.

Abstract / Galaxy mergers are often considered in the literature as ideal places to study diverse starbursts triggered during the merger events. In that sense, the intermediate-age merger remnant NGC 1316 constitutes a perfect case to study complex large-scale star formation events in the Local Universe. In a series of previous works we confirmed the existence of a complex globular cluster (GC) system associated with NGC 1316, which is dominated by the presence of an unusual young ($\approx$ 2.1 Gyr) and metal-rich subpopulation ($-0.5 < [Z/H] <$ 0.5 dex), possibly created during the last merger event. In this work we used high-quality spectroscopic data from Gemini/GMOS to present an analysis of the the star formation history of three GCs associated to this galaxy. Although recent works show the presence of multiple stellar populations in old GCs in the Milky Way and nearby galaxies, this project constitutes one of the first studies to show multiple stellar populations in young extragalactic GCs.

Keywords / galaxies: interactions — galaxies: elliptical and lenticular, cD — galaxies: star clusters: general

1. Introduction

Galaxy mergers are often considered in the literature as ideal places to study starbursts triggered during the merger events. In that sense, the intermediate-age merger remnant NGC 1316 ($\alpha_{J2000} = 3^h\,22^m\,41.7^s$, $\delta_{J2000} = -37^\circ\,12'\,30''$), constitutes a perfect merger scenario to study complex, large-scale star formation events in the Local Universe. This colossal galaxy, which dominates an important sub-group of the Fornax galaxy cluster (Drinkwater et al., 2001), still shows the scars of its recent, violent past of interactions. Among them we can mention morphological features like shells, ripples and complex dust lanes (Fig. 1). Schweizer (1980, 1981) and Iodice et al. (2017) analyzed with great detail the numerous substructures in the central spheroid and the stellar envelope. According to these authors, these tidal structures are relics of the rich history of interaction events that have taken place in this galaxy.

Globular clusters (GCs) can be formed as a consequence of gas-rich merger events, thus their stellar population may unveil the merger history of their host galaxies. In Sesto et al. (2016), we used Gemini/GMOS photometry to establish the presence of different GC subpopulations likely associated with the merger events (see Fig. 7 in Sesto et al. 2016). Subsequently, we carried out a spectroscopic study of 35 GCs located in the inner zone of the GC system of NGC 1316 (Sesto et al., 2018). Using Lick/IDS indices and their comparison with simple stellar population (SSP) models, we confirmed the existence of multiple GC populations associated with this galaxy. The presence of a dominant subpopulation of very young GCs, with an average age of 2 Gyr and relatively high metallicities stands out. However, recent works have shown that old GCs in the Milky Way and nearby galaxies have multiple stellar populations (Li & de Grijs, 2019). Thus, one limitation of our previous work is that it provided only luminosity-weighted properties of SSPs, which can not differentiate whether a given GC is young (thus formed during the merger event), or if it is old but has been forming stars recently.

In this work, our main goal is to obtain the star formation history (SFH) of stellar objects in NGC 1316. We have focused on the behavior of the three objects in our sample with the highest signal-to-noise (S/N) spectra (S/N per Å > 30): GC-728, GC-398 and GC-636 (see Fig. 1). To develop this task we have used the

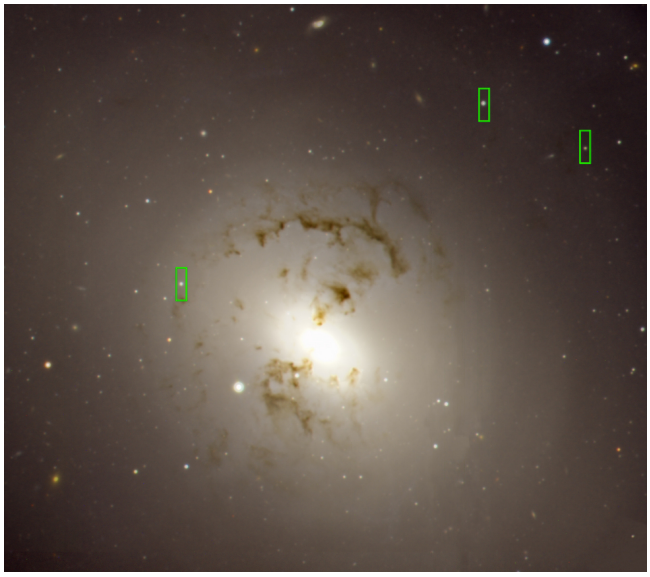

Figure 1: Composite 3-color image of NGC 1316, composed through Gemini/GMOS images in g', r' and i' filters. Shells, ripples and the complex structure of dust present in the innermost part of the galaxy are easily observed. Green rectangles show the location of the three GCs selected in this work (see text).

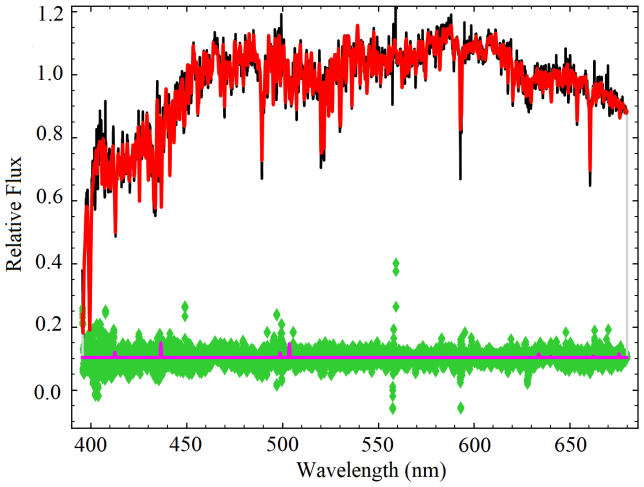

Figure 2: Integrated spectrum of the GC-728 (black line) and the fit of the stellar component and emission lines obtained with pPXF (red and orange lines, respectively). It is important to mention that in this case the presence of emission lines in the spectrum is very difficult to visualize since their contribution is very small. The fit residuals are indicated with green dots below the spectrum, while the magenta lines are the gas-only best-fitting spectrum.

full-spectrum fitting technique (e.g. Faifer et al., 2017; Escudero et al., 2018).

2. Star formation history

We determined the SFH of three objects in our sample using the full-spectrum fitting technique, with the code pPXF (Penalized Pixel-Fitting) (Cappellari & Emsellem, 2004; Cappellari, 2017). This method finds the best combination of synthetic SSP models in order to fit the entire observed spectrum. In this way, the stellar and gas kinematics is recovered, as well as the stellar population of stellar systems. The advantage of using this technique is that all the information available in the spectrum is used, and not just some specific lines, as in the case of Lick/IDS absorption line indices. Furthermore, the different implementations of this method has the advantage of being able to fit multiple star populations for an integrated light spectrum. We selected the SSP models from the MILES libraries (Vazdekis et al., 2010). These models cover an age range $0.03 - 14$ Gyr, metallicities $-2.27 < [Z/H] < 0.4$ dex, and α-element abundances $[\alpha/Fe] = +0.0$ and $[\alpha/Fe] = +0.4$ dex. In order to obtain a smooth solution of the best fitting linear combination of SSP spectra, we use the regularization feature of pPXF. Fig. 2 shows an example of integrated spectrum with the resulting fit.

3. Results

Figure 3 shows the mass-weighted age-metallicity diagram of the three GCs in our sample, which allows visualization of their SFHs. Top panel shows the SFH for the GC-728, indicating that this object has been formed from a single burst about 2 Gyr ago and with high metallicity $[Z/H] \approx 0.4$ dex. However, GC-398 and GC-636 show a completely different behavior in relation to GC-728, that is, their SFHs seem to show they are composed of more than one stellar population. GC-398 appears to be composed of two stellar populations, one of them old (≈ 12 Gyr) and the other young (≈ 1 Gyr), but both with approximately the same mean metallicity ($0.3 - 0.4$ dex). Is it possible that they were formed from the same gas, in two different stages? This young component presents similarities with the population of GC-728, so we could not rule out that these have been formed in the same starburst process. The case of GC-636 is even more complex. We cannot rule out the presence of more than two stellar populations. However, this object is mainly dominated by two very different subpopulations, one with an age of ≈ 5 Gyr and solar metallicity, and the other presents an age of ≈ 10 Gyr and high metallicity.

4. Summary and conclusions

Using high quality spectroscopic data provided by Gemini/GMOS, we obtained the SFH of three GCs associated to the merger remnant NGC1316. To carry out this task, we use the full-spectrum fitting technique, through the code pPXF. This technique has proven to be a robust tool for spectra with SN > 30 (e.g. Boardman et al., 2017). The main conclusions of this work are:

- The results shows that one of the objects, GC-728, correspond to a GC-like object, formed in a single burst around 2 Gyr ago. This result is in good agreement with the luminosity weighted SSP age and metallicity measured using Lick/IDS.

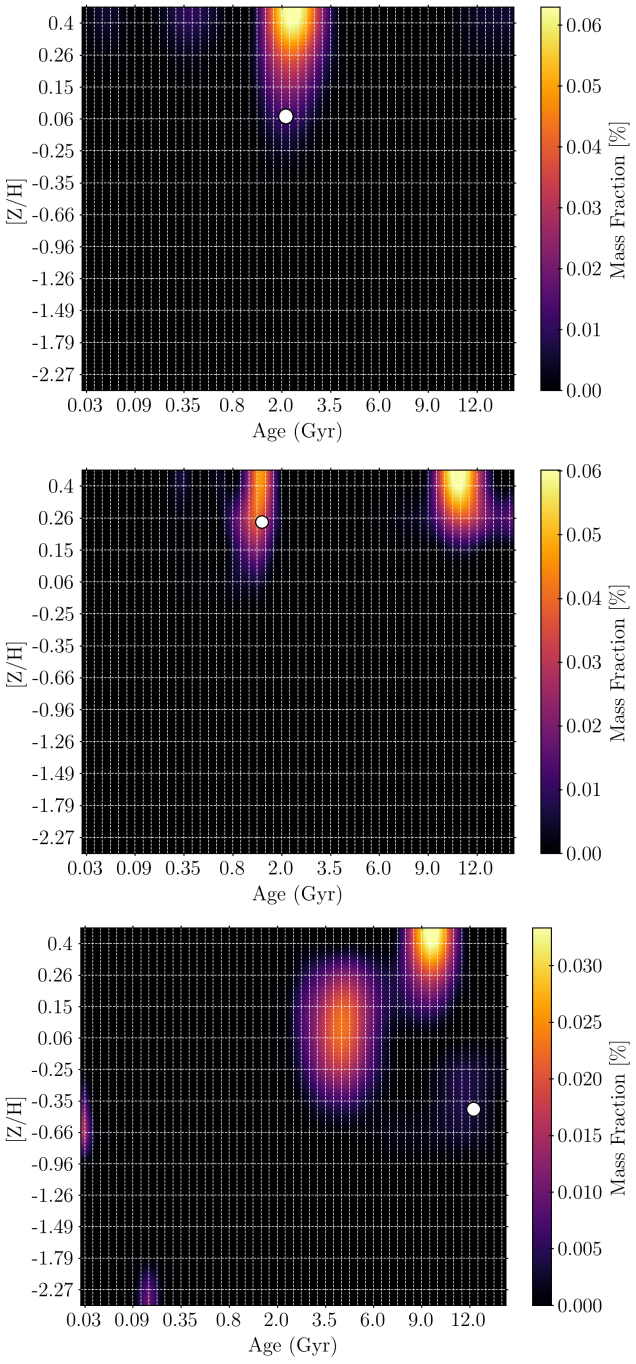

Figure 3: Star formation history of GC-728 (*top panel*), GC-398 (*middle panel*) and GC-636 (*bottom panel*). The different shaded regions indicate the mass-weight assigned by pPXF to each SSP model. Vertical and horizontal dotted lines indicate the age and metallicity values of the used models. White circles indicate the location of the luminosity weighted SSP age and metallicity measured using Lick/IDS indices from Sesto et al. (2018).

- The SFHs of GC-398 and GC-636 seem to show they are composed of more than one stellar population.
- GC-398 is composed of two stellar populations with a great temporal separation between them. One of these populations is in good agreement with the luminosity weighted SSP age and metallicity measured using Lick/IDS.
- In the case of GC-636 we cannot rule out the presence of more than two stellar populations. The result of the analysis of the Lick/IDS indices does not seem to correspond to either of the two main components. This case is even more complex and requires a more rigorous analysis, where other relevant physical properties should be analyzed.
- This result reaffirms the presence of multiple stellar populations in GCs and constitutes one of the first pieces of evidence in GCs located beyond the Local Group.

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