*Dwarf Galaxies: From the Deep Universe to the Present*
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# Star formation and environment: a step in understanding the formation and evolution of local dwarf galaxies

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**Abstract.** We present here the results obtained from studying the resolved stellar populations of two dwarf irregular galaxies in the nearby Universe. These galaxies, DDO 68 and NGC 4449, were studied within the Legacy ExtraGalactic UV Survey, an HST program aimed to uncover the many ways in which the star formation (SF) process occurs at different scales. Thanks to the deep photometry obtained in different bands (from $\lambda$2704 Å to $\lambda$8057 Å), we were able to connect the location and timescales of the star forming regions within the galaxies to merging and interaction with gas clouds and satellites, a crucial aspect of galaxy evolution, even in such small systems. From the color-magnitude diagrams of the analyzed galaxies we were able to recover their star formation history (up to $\sim 2-3$ Gyr ago since we do not observe the oldest main sequence turn-off or horizontal branch, due to the systems' distance), finding that the SF never really stopped, but proceeded continuously even with the succession of high and low activity. The time intervals where we find higher SF rates in the two galaxies well agree with the dynamical timescales of previous interactions events, which might represent a major channel for triggering the SF in relatively isolated galaxies.

**Keywords.** dwarf galaxies, galaxy evolution, star formation, environment

## 1. Introduction

Over the past several years, it has become increasingly clear that the large-scale star formation is determined by a hierarchy of processes spanning a vast range of physical scales, and that different physical processes may lead to star formation in different interstellar and galactic environments. For nearby galaxies, we have the advantage of resolving the single stars, to study their stellar populations and star formation histories (SFHs) with the synthetic color-magnitude diagram (CMD) technique and refine stellar evolution models by comparing them with the data.

Within this framework, we present the results obtained for the dwarf galaxies part of the HST Legacy ExtraGalactic UV Survey (LEGUS), whose aim is to investigate and connect the different scales of star formation, from young stellar clusters to local Universe galaxies (Calzetti *et al.* 2015). Our targets were studied both in the UV and optical bands, in order to recover their SFH from very recent to older epochs and to understand whether and how the star formation process may depend on the morphological, dynamical and environmental properties of the galaxies.

**Figure 1.** HST color-combined images of DDO 68 (left panel) and NGC 4449 (right panel).

In particular, we analyzed DDO 68, a very metal-poor dwarf irregular, and NGC 4449, a Magellanic irregular, finding clear correlations of star formation enhancement with merging and interactions (see Figure 1).

## 2. The synthetic CMD method

To recover the SFH from an observational CMD, a very common approach is the comparison with synthetic models (Tosi *et al.* 1991). The synthetic CMDs are created starting from theoretical evolutionary tracks or isochrones by deriving from them the luminosity and temperature corresponding to the mass and age of the synthetic stars, extracted with a Monte Carlo approach from a random, IMF weighted, sample. They are built as linear combinations of "basis functions" (BFs), i.e contiguous star formation episodes whose combination spans the whole Hubble time. Theoretical (luminosity vs temperature) synthetic CMDs need to be converted into the observational (magnitude vs color) plane adopting the proper photometric conversions, the distance and reddening of the examined galaxy, the photometric errors and blends, and the incompleteness of the data.

By repeating the process for many metallicities, we end up with a library of synthetic CMDs for different ages and metallicities. The comparison between observed and synthetic CMDs is done on the so-called Hess diagrams, i.e. the density of points in the CMD. To this purpose, the BFs, as well as the observed CMD, are pixelated into a grid of color and magnitude bins. In each cell, the BFs are linearly combined to match the number of observed stars in that cell:

$$N(i) = \sum_{Z} \sum_{t} w_{Z,t} \times \mathrm{BF}_{Z,t} \, , \tag{2.1}$$

where $w_{Z,t}$ are the weights of each BF, and represent the SFR at a given time and metallicity step.

We perform the minimization of the residuals between data and models adopting a Poissonian approach, since we need to consider that some parts of the CMD might have a low number of stars. We implemented the construction of the synthetic CMDs and the comparison between models and data in the hybrid genetic code SFERA (Cignoni *et al.* 2015).

## 3. DDO 68

DDO 68 is a dwarf irregular galaxy with an extremely low metallicity ($Z \sim 0.0004$) and a stellar mass of $\sim 10^8$ $M_\odot$ (Sacchi *et al.* 2016). It is one of the most distant targets of LEGUS ($\sim 12$ Mpc) thus, even with the exquisite capabilities of HST, the oldest stellar evolutionary phase we were able to reach is the red giant branch. The $m_{F814W}$ versus $m_{F606W} - m_{F814W}$ CMD is presented in Figure 2.

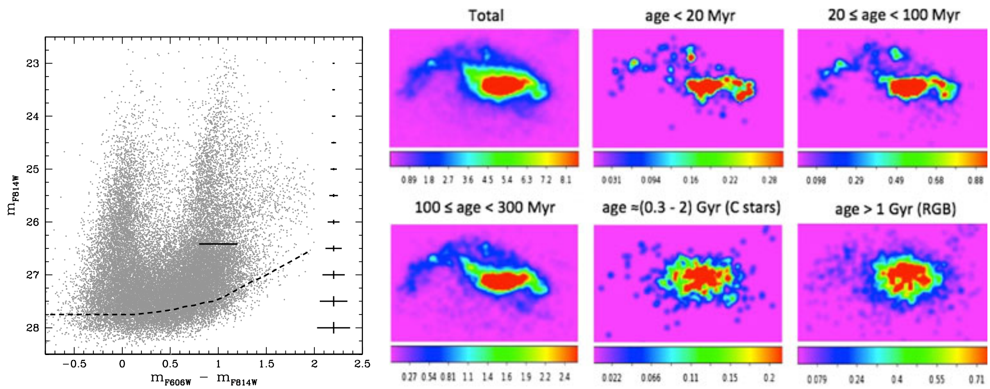


**Figure 2.** Left panel. Optical CMD of DDO 68. The black crosses on the right show an estimate of the photometric errors as a function of the F814W magnitude, the dashed line of the 50% completeness limit, while the horizontal segment marks the magnitude of the tip of the red giant branch (used to derive the distance of the galaxy). Right panel. Density maps of stars in different evolutionary phases within DDO 68.

As shown in the right panel, the stellar populations of this galaxy are distributed differently for different ages, with the youngest ones following the distribution of H$\alpha$ emission (very clumpy) while the oldest ones become more homogeneous and diffuse.

The SFH shows a peak at an age of $\sim 30$ Myr in all regions of the galaxy.

Thanks to new LBT observations, we discovered many streams and satellites around the galaxy. Their interaction with the main body might have triggered this global star formation event (Annibali *et al.* 2016).

## 4. NGC 4449

NGC 4449 is a Magellanic irregular galaxy, more metal-rich ($Z \sim 0.004$) and massive ($M_\star \sim 10^9\ M_\odot$) than DDO 68 (Sacchi *et al.* 2018). It is known to be interacting with many smaller satellites, as signaled also by the very disturbed H I emission that extends well beyond the optical disc, with filaments and shells forming two counter-rotating systems (Hunter *et al.* 1999).

Also in this case, the stellar populations change from very clumpy to almost homogeneous with increasing age. The star forming regions follow the boxy shape of the galaxy, a sign of past and ongoing interaction.

The SFH is ongoing, with the major peak of activity around $\sim 10$ Myr ago, in good agreement with previous determinations (McQuinn *et al.* 2010). In particular, in the central region we performed a comparison between V/I and U/V data, which agree with each other and with H$\alpha$ and FUV emission rates from the literature (as shown in Figure 3).

The most active star forming regions (traced by H$\alpha$ emission from the H II regions) correspond to the location of strong interaction and infalling of smaller satellites. The dynamical time-scales of these interactions are compatible with the two main peaks recovered in the SFH ($\sim 10$ and $\sim 100$ Myr ago).

## 5. Conclusions

The galaxies we analyzed were already active at the oldest look-back time reached by our photometry ($\sim 3$ Gyr since we do not observe features older than the red giant branch) and possibly even before. This allows us to discard the hypothesis that these are young galaxies experiencing their first burst of star formation only in recent epochs, despite

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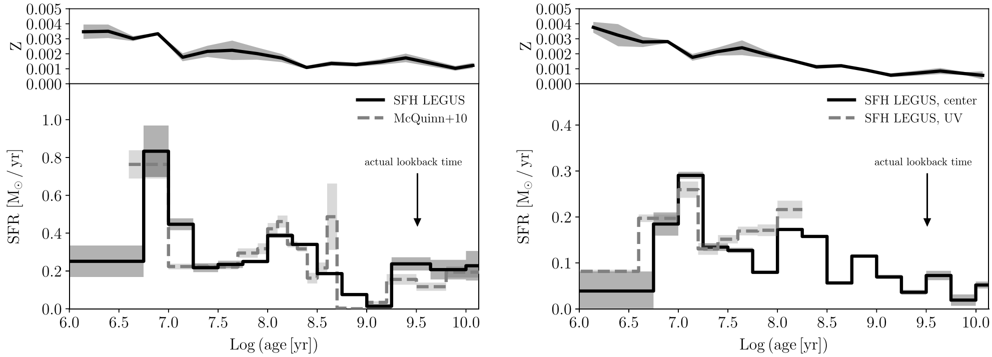


**Figure 3.** Left panel. Evolution of metallicity and SFH of NGC 4449 from F555W/F814W data (black lines) together with a comparison with the literature SFH (grey dashed line from McQuinn *et al.* 2010). Right panel. Evolution of metallicity and SFH of the most central region of NGC 4449 (black lines) compared to the SFH from F336W/F555W data (grey dashed line from Cignoni *et al.* 2018).

them being so metal-poor and gas-rich. They show rather continuous SFHs, although with the alternation of peaks and dips, a "flickering" (or "gasping") star forming mode typically seen in the last 100 Myr of many high resolution studies (McQuinn *et al.* 2010, Weisz *et al.* 2008) and probably connected with the formation of star clusters and associations. Even in such small systems, interaction has a central role in regulating their star formation activity and dynamical properties.

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