Spectroscopic Analysis of Dwarf Ellipticals in the Fornax Cluster

1. Abstract

Different theories and ideas about the formation history of the big zoo of galaxies have been developed in the past decades. For galaxies inside clusters one of the main mechanisms governing their formation and evolution is environmental effects such as ram-pressure stripping (Lin & Faber 1983), harassment (Moore et al. 1998), or starvation (Larson et al. 1980). An ideal source to investigate the role of environment are dwarf galaxies, since they have low mass and low density and thus are more vulnerable to environmental effects.
Dwarf galaxies despite their plain appearance and smooth light distribution have complex characteristics (Lisker 2006), which indicate the influence of environment in their past. *Spatial distribution of dwarfs*: early-type dwarf galaxies (dEs) outnumber all other galaxy types in dense environment, like clusters, while late-type low-luminosity galaxies are the dominant population in the fields (e.g. Dressler 1980, Sandage et al. 1985, and Ferguson \& Bingelli 1994). *Inner structure vs. local density of dEs*: A substructure-density relation is seen in early-type dwarf galaxies, such that dEs with blue center or no nucleus are mostly found in low-density cluster regions, dEs with disks in intermediate-density regions, and nucleated dEs in high-density regions of the cluster (Ferguson \& Sandage 1989, van den Bergh 1986, and Lisker et al. 2007). Kinematics vs. local density of dEs: pressure supported dEs are mostly found in high density regions of cluster, whereas in lower density regions like outskirts the angular momentum of dEs increases and dEs are largely rotationally supported. Also fast rotators in the outer part of the cluster rotate faster than fast rotators in the inner parts of the cluster (Toloba et al. 2009, van Zee et al. 2004a, and Toloba et al. 2015).

2. Scientific Questions

- Are dEs and giants describe the same scaling relation?(FP, FJ, etc.).
- What is the DM contents of faint cluster dEs?
- What is the physical role of environment in the evolution of dEs?
- What is the fraction of rotational over pressure support in dEs?
- etc.

- FUTURE WORK
- Can we detect effects of starvation or ram-pressure on dEs?
- How do the stellar populations of dEs depend on environment ?

3. Analysis

We extracted stellar kinematics and stellar populationfrom absorption-line spectra of our galaxies by using the penalised Pixel Fitting (pPXF) routine of Cappellari & Emsellen (2004). pPXF basically is a maximum penalized likelihood approach in pixel space, with the aim of finding an optimal temple with the minimum template-galaxy mismatch errors. It finds the best-fitting linear combination of input stellar templates by convolving them with the line-of-sight velocity distribution of the input galaxy's spectra, and then the best-fitting parameters are determined by non-linear chi-squared minimization in pixel space (logarithmically binned in wavelength).
Moreover, We computed the uncertainties by (100 realizations) Monte Carlo simulations. In each loop the best-fitted spectra is disturbed by random spectra convolved by the sigma of the difference between original and best-fitted template spectra.

The best match for SAMI-Fornax's wavelength range and spectral resolution is single-age single-metallicity population models of PĂGASE-HR (Le Borgne et al. 2004). PĂGASE-HR is the result of applying the PĂGASE.2 code on ĂLODIE. ĂLODIE is a high resolution stellar library of 1959 spectra for 1503 stars with R=10 000 at lambda=550 nm

4. Sample & Data

The SAMI Fornax project started in 2015 with the Sydney-AAO Multi-Object Integral-field (SAMI) spectrograph on the Anglo-Australian Telescope (AAT), with aim of studying the origin and the inner workings of dwarf galaxies inside Fornax cluster. As results of three commisions in 2015B, 2016B and 2018B, we have 37 dwarf galaxies, 14 giant elliptical galaxies with good spectra.
SAMI is an integral-field spectrograph equipped by 13 fiber-based IFUs called hexabundles, and 26 pluggable sky fibers (Bryant et al. 2014). Each hexabundle with a field-of-view of 15" diameter, is made of 61 1.6" optical fibers. These hexabundles have physical size <1 mm, with a filling fraction of 73 per cent and together with sky fibers each fits into pre-drilled holes in a field plate. The plug plate with about 1 degree field-of-view is installed a the AAT's Prime Focus Camera top end and so hexabundle's face is placed at the focal plane of the telescope.
To study structure of low-mass galaxies such as dEs in Fornax cluster, high resolution spectra and high S/N were needed. With 1500V gratings in blue and 100R gratings in red, our data has resolution of ~5100 (FWHM = 1.0Å) in blue ($\sim 4660-5430$Å) and ~4300 (FWHM = 1.6Å) in red ($6250-7350$Å). Which means potentially reaching around 25 km/s and 30 km/s velocity dispersion in blue and red respectively. And with fourteen ~30 minutes exposure times for each field gaining high S/N became possible. Moreover compared to single IFU instruments we can simultaneously observe 12 galaxies and one calibration star which significantly increases the observation rate.

Fig.1

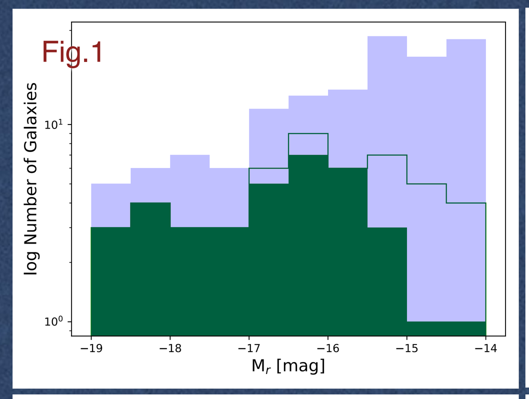


Fig.2

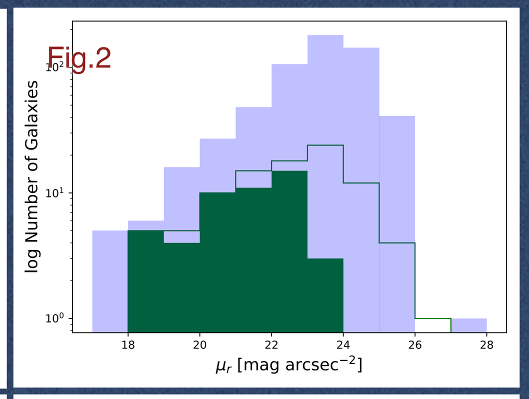


Fig.3

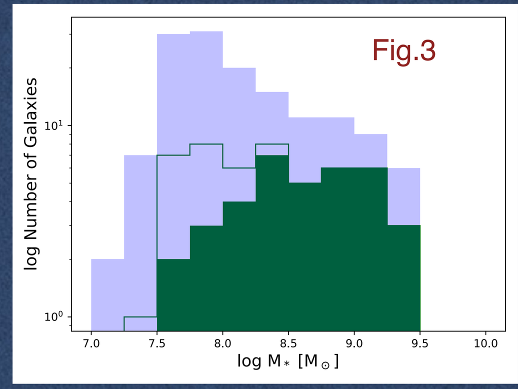
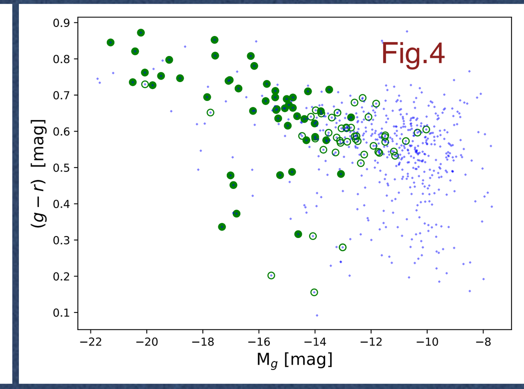


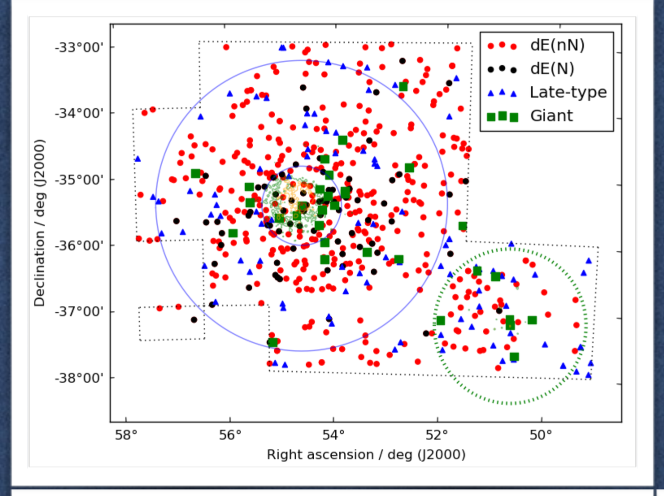
Fig.4

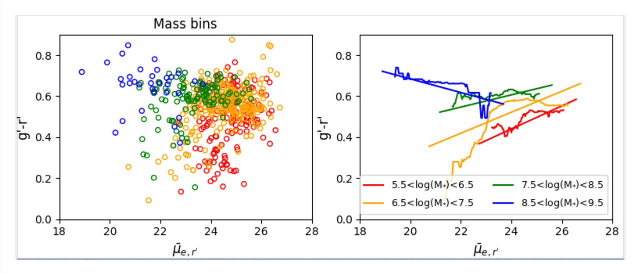


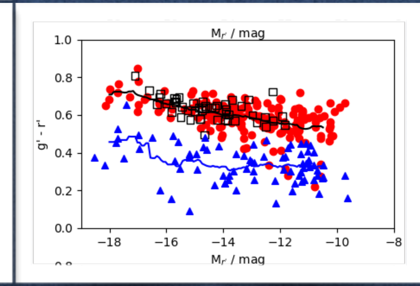
Our sample was selected based on Fornax Deep Survey (FDS). Considering the aim was to study star formation and evolution of dEs within Fornax cluster, the primary survey targets are FDS galaxies that cover $-18 < M_r < -14.5$ and $17 < \mu_r < 23$, also in different environments from center of the cluster to outside of its virial radius (4° or 1.4 Mpc) such as dEs in Fornax A.

(Fig. 4) The $(g-i)$ vs M_g colour-magnitude diagram for our sample (green circles), compared to that from the full FDS sample (blue crosses). We primarily target galaxies on the red sequence, but do include some blue galaxies that satisfy our selection criteria.

(Fig. 1, 2& 3) The logarithm of the number of galaxies as a function of surface brightness, absolute magnitude and stellar mass. The open green histogram shows the distribution for all observed SAMI-FDS galaxies, while the solid green histogram indicates only those for which we were successful in measuring stellar kinematics. The pale blue histogram indicates the distribution for the full FDS sample.





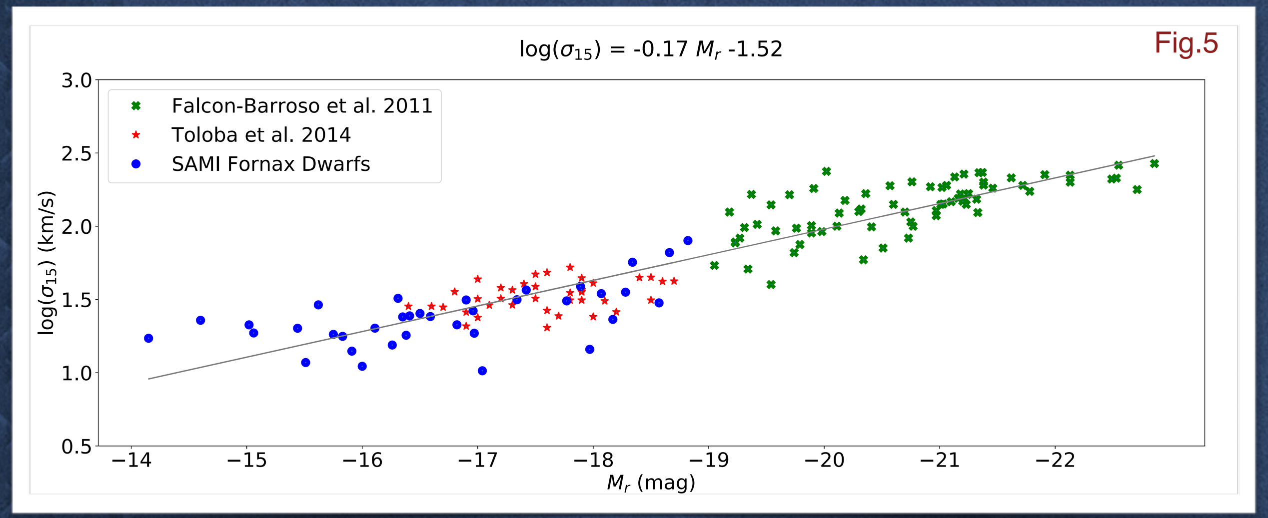


5. Results

Faber-Jackson Relation

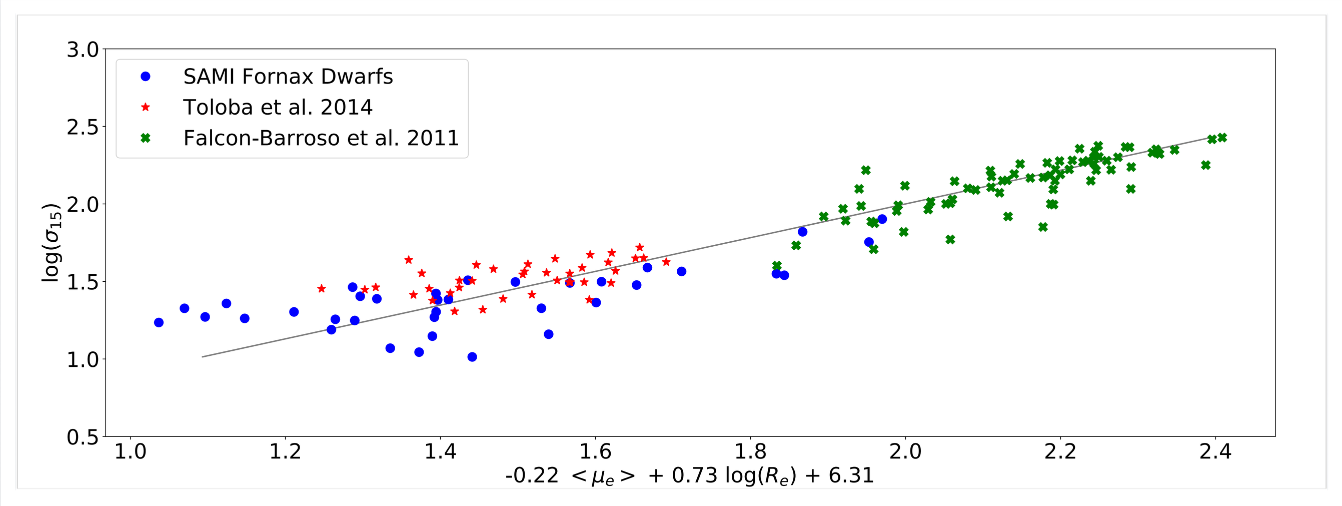
One of the first discoveries in early-type galaxies was that their stellar velocity dispersion correlates with their luminosity (Faber& Jackson 1967). This two dimensional relation $L \sim \sigma^{\alpha}$ Faber-Jackson relation is in fact a projection of Fundamental Plane. It has been shown that the slope of this relations gets shallower as it goes to fainter objects (Davies et al. 1983). In Fig.5 we go down to faint low-mass galaxies of $M \sim 10^{7.4} M_{\odot}$.
We see ???

Fig.5



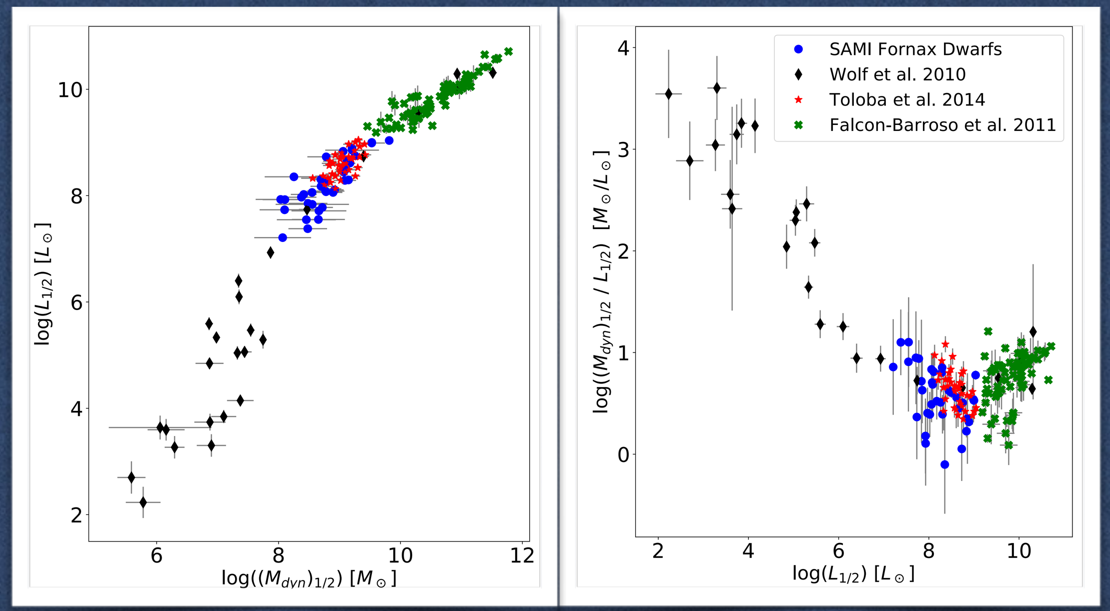
Fundamental Plane

The empirical Fundamental plane which is a bivariate relation (Brosche 1973, Dressler et al. 1973 and Djorgovski \& Davis 1987) between R_e(the half light ration radius of the galaxy), I_e(the mean surface brightness within R_e in flux units), and σ (the galaxy internal velocity dispersion), is an indication of galaxies being in virial equilibrium $R_e \propto \sigma^2 I_e^{-1} (M/L)^{-1}$ (Binney \& Tremaine 2008).
We see ???



Dynamical Mass vs. Luminosity

Not considering the difference between radial and tangential velocity dispersion weakens our ability to reach accurate conclusions about structure and formations of galaxies. This becomes more important in calculating dynamical mass of a galaxy by only having its 2d observed radial properties. Wolf et al. 2010 showed that within r_3 radius this difference is insignificant.
We see ???



Dynamical Mass vs. Stellar Mass

Similar to Venhola et al. 2019 we estimate the stellar mass of the sample galaxies using the empirical relation observed between the g'-i' color and mass-to light (M/L) ratio by Taylor et al. (2011) while transforming the r'-band total magnitudes into i'-band, by applying the r'-i' color (measured within Re).
We see ???