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Projected phase space of massive clusters of galaxies

Relations between stellar parameters and locus

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Abstract. We investigate the dynamical properties of clusters of galaxies and how their dynamical stage is related to the star formation history of the member galaxies. Our study is based on 177 systems from the Yang catalog in the redshift domain $0.03 < z < 0.1$ and with halo masses greater than $10^{14} M_{\odot}$. We show, in this preliminary work, how we associate a galaxy with a given stellar mass, age, metallicity, specific Star Formation Rate and $[\alpha/Fe]$ to its locus on the Projected Phase Space (PPS), aiming to connect the dynamics of the cluster with the main quenching mechanisms operating on galaxies. Here we show differences between galaxy population in clusters which the velocity distribution follow a Gaussian distribution in comparison with those which it follows a Non-Gaussian

Resumo. Neste trabalho nós investigamos o equilíbrio dinâmico de aglomerados de galáxias e como isto está relacionado ao histórico de formação estelar das galáxias membro. Para isso utilizamos 177 sistemas do catálogo de Yang com redshift na faixa 0.03<z<0.1 e com halos mais massivos que $M \geq 10^{14} M_{\odot}$. Mostramos neste trabalho preliminar como associamos os parâmetros estelares relacionados a uma galáxia com o seu locus no espaço de fase projetado, com o intuito de relacionar a dinâmicoa do aglomerado com os principais mecanismos de extinção de formação estelar atuando nas galáxias.

Keywords. Galaxies: groups: general – Galaxies: clusters: intracluster medium – Galaxy: evolution

1. Introduction

Galaxy evolution is ruled by parameters that are both external and internal to the system. AGN and stellar feedback are related to the inner properties of the galaxy, while the ICM density is an external factor related to the environment. This complex equilibrium between external vs internal properties is a longstanding question in galaxy evolution, known as *nature vs. nurture*.

The effect of external factors becomes more highlighted in overdense systems as clusters of galaxies. Effects such as RAM-Pressure stripping have stronger impact in galaxies within clusters, altering their star formation rate, for example. Systems of this kind have been systematically studied in order to understand the environmental effects in galaxies.

Recent findings shows a relation between the cluster dynamical stage and galaxy-member properties.The most probable equilibrium state for gravitationally bound systems is shown to be described by a Maxwell-Boltzmann distribution (Lynden-Bell 1967). When projected along the line of sight, it is translated to a Gaussian distribution. The deviation from Gaussianity hence is considered to trace the system's degree of deviation from a relaxed state. Multi-component (non-gaussian) systems present a higher fraction of star forming galaxies when compared to one-component (gaussian) systems, increasing with clustercentric distance (Cohen, et al. 2017). Also, there is a clear segregation between population properties of central and satellite galaxies in Gaussian systems, while this does not hold true to the Non-Gaussian ones (Ribeiro, et al. 2013).

In this preliminary work, we propose a study of the projected phase space as a whole. We use simulations to define regions in the PPS corresponding to different populations within the cluster. The different populations are characterized according to their time since infall. We show here how we relate the dynamical stage of each cluster with the quenching mechanisms acting on the member galaxies. Throughout this work we adopt a ΛCDM model, with $H_0 = 72$ km s^{-1} Mpc^{-1}, $\Omega_M = 0.27$ and $\Omega_\Lambda = 0.73$.

2. Data and Methods

Here we use data from the Sloan Digital Sky survey - 7th Data Release. We selected systems in the redshift range $0.03 < z < 0.1$ and with r-band magnitude $m_r < 17.77$, corresponding to the completeness limit of the survey. The clusters are selected using the locations defined in the Yang catalog Yang, et al. (2007). The membership is defined via shiftgapper technique with a maximum radius of $2.5h^{-1}$ Mpc (3.5 Mpc for $h^{-1} = 0.72$). Restricting our sample to clusters with at least 20 members we end up with 319 systems.

Each system is then classified with respect to the gaussianity of its velocity distribution. The classification is done using the Hellinger Distance method, which measures the separation between two different distributions (de Carvalho, et al. 2017). Furthermore, we restricted our sample to systems in which the confidence level of the classification is higher than 70%, calculated with a bootstrap technique, and with a minimum mass of $10^{14} M_{\odot}$. The cutoff in mass is to guarantee a consistent performance of the Hellinger Distance measure. This reduces the sample to 177 clusters of galaxies, which 143 are classified as Gaussian and 34 as Non-Gaussian. Stellar parameters such as mean Age and Metallicity for each galaxy are estimated using the STARLIGHT program (Cid Fernandes, et al. 2005), which performs a spectral fitting using MILES as the base for the single stellar population (SSP).

3. Regions in the Projected Phase Space

The galaxy population of each system is divided according to its locus in the projected phase space. Here we normalize the radial and velocity components by the virial radius, R_{200}, and velocity dispersion, σ, respectively. The regions are defined according to Rhee, et al. (2017), tracing the time of infall for each locus. Fig. 1 shows the separation for two different clusters, one of each class, in the PPS and how this translates to different parameters space. The top 4 panels correspond to the system Yang 49 (Gaussian) and the bottom 4 to Yang 21 (Non-Gaussian).

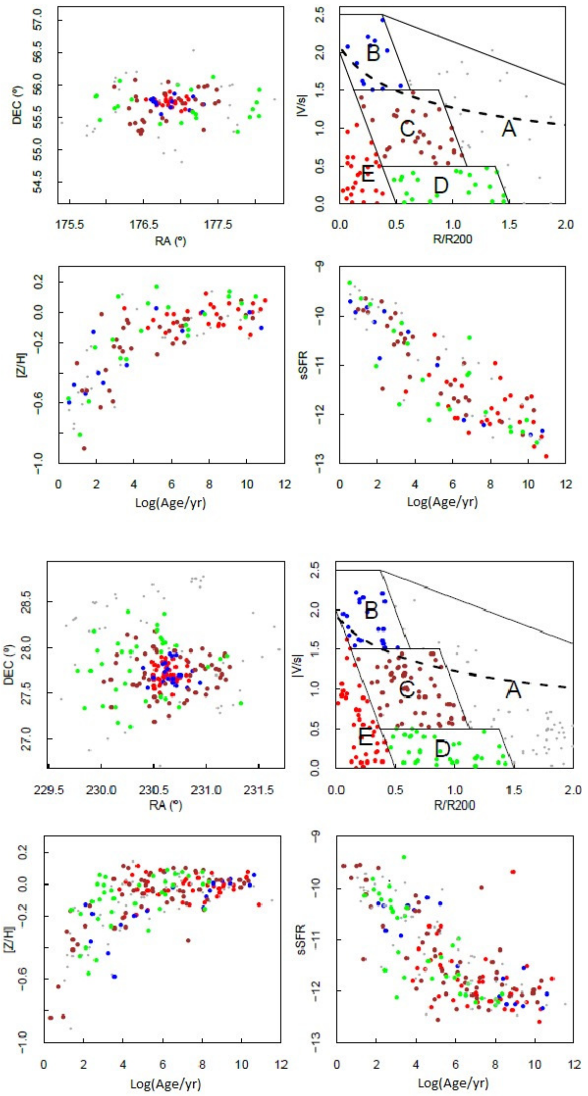

Figure 1. Different galaxy populations in different parameter spaces. The top four panels shows the distribution for the system Yang 49 (Gaussian), the bottom four panels are relative to Yang 21 (Non-Gaussian). Galaxies are represented by the same color in all plots.

Comparing the two cases here shown, it is noticeable an overdense region in the metallicity *vs.* age space for the Non-Gaussian case, indicating that even galaxies entering in the cluster now are older and have a high metallicity, suggesting that they were pre-processed before entering the cluster. This is also noticeable in the sSFR *vs.* age tail in the two cases.

4. Stellar Population Parameters *vs.* Dynamical Stage

Another possible approach is to look for clusters (in the statistical meaning) in the parameter space and study how they translate to the PPS. Using a non-parametric Gaussian Mixture Model we defined different clusters in the sSFR *vs* Age space and the checked how the different clusters are distributed in the PPS. A non-parametric approach avoids non-based choices for the number of components.

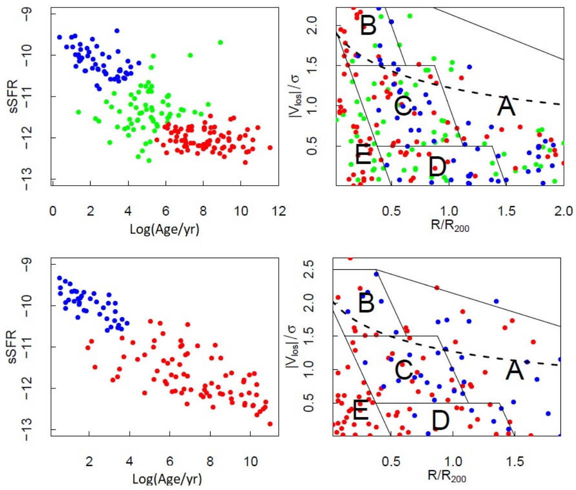

Figure 2. sSFR vs Log(Age) space (left) and PPS (right) for the same two clusters in Fig.1: Yang 21 (top) and Yang 49 (bottom). Galaxies are represented by the same color in the two spaces.

This preliminary result shows a third component in Non-Gaussian systems when compared to the Gaussian ones. This is in accordance with the results shown in the introduction. While in Gaussian systems there are two well separated populations, the third component in Non-Gaussian clusters may alter this well established separation, making the population in those systems more uniformly distributed. Besides, the virialization region in the Gaussian case contains only galaxies from one cluster, while the same region for Non-Gaussian groups are occupied by galaxies from two different clusters.

5. Next Steps

We plan to make a statistical study about each region and study the global properties of the *PPS* for Gaussian and Non-Gaussian clusters. We intend to study the association between the dynamical state of a cluster and the star formation history of the galaxies occupying specific locations on the Projected Phase-Space.

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