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EQUIVALENT WIDTH MEASUREMENTS IN OPTICAL SPECTRA OF GALAXIES IN LOCAL CLUSTERS: HINTS ON THE STAR FORMATION HISTORY IN CLUSTERS

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Abstract. Equivalent widths of spectral lines in the optical spectra of galaxies are commonly used to characterize their stellar populations and to get some insight on their evolution. Here we describe a new method to measure automatically equivalent widths of spectral lines with a good accuracy. This makes possible to classify galaxies according to the presence/absence and intensity of [O II] and Hδ lines. Based on these classification criteria, we give a description of the characteristics of the star-forming and post-starburst galaxies in local clusters, and their dependence on the cluster characteristics.

Key words: galaxies: classification, starburst, clusters

1. INTRODUCTION

The fact that the evolution of galaxies depends on their environment is known at least three decades long: the galaxies in the field, in local clusters and in distant clusters have different characteristics reflecting their evolution history.

The lack of blue, late-type galaxies at the centers of the local clusters is one of the characteristics that differentiates high redshift rich clusters where Butcher & Oemler (1978) discovered a population of blue, star-forming galaxies, and their lower redshift counterparts. This is one of the most striking examples of evolutionary effects that take place in galaxies residing in dense environment. Consequently, galaxy clusters are very important place for the invesigation of evolutionary effects, since they can be used to prove an extremely wide range of physical conditions, from the dense cores, to the outermost low-density regions.

The Wide-field Imaging Nearby Galaxy cluster Survey (WINGS, Fasano et al. 2006)[1] is a project with the aim to study differences of the cluster population in the

[1] http://web.oapd.inaf.it/wings/new/ index.html

local universe ($0.04 < z < 0.07$) and the influence of the environment on physical properties of cluster galaxies. This survey has already provided to astronomical community a homogeneous and high quality set of photometric and spectroscopic data for 77 and 48 galaxy clusters, respectively. The WINGS project provides the largest set of homogeneous spectroscopic data for galaxies belonging to nearby clusters, allowing not only the secure detection of cluster members, but also to study their stellar population contents.

In this context, spectral lines are of fundamental importance to characterize the properties of galaxies providing a quick and simple way to classify them on their star formation history (Couch & Sharples 1987; Dressler & Gunn 1983 ; Dressler & Gunn 1992; Dressler et al. 1999). The advantage of this method is the use of only two lines, [O II] at 3727 Å and Hδ at 4101 Å, which are easily observable in optical spectra up to redshift $z \sim 1$, allowing in this way a self-consistent comparison between high and low redshift clusters.

The situation of high and low redshift dataset has been quite weird until a few years ago: while a lot of homogeneous and good quality data were present for high-z cluster galaxies (e.g., EDISCS, MORPHS...), the status at lower redshift was far from being optimal. No systematic and complete survey had been undertaken before WINGS: data at low redshift included sparse observations of Virgo and Coma, some clusters in the SDSS fields, or old data yielding very uncertain morphologies and unreliable magnitudes. With the advent of modern large CCD camera, taking data simultaneously on a large portion of the cluster is now possible.

Here we describe a new method, developed in our previous work (Fritz et al. 2007), for measuring automatically equivalent widths of the most prominent optical spectral lines and computing the related uncertainties in the WINGS spectra. This allows to classify spectra and compare the characteristics of our low-redshift sample with higher redshift galaxies, providing some clues to the evolutionary processes in clusters.

2. THE WINGS SPECTROSCOPIC SURVEY

Out of the 77 cluster fields imaged by the WINGS photometric survey (Varela et al. 2009), 48 were also observed spectroscopically. The reader should refer to Cava et al. (2009) for a complete description of the spectroscopic sample, including completeness analysis and quality check. Here we will briefly summarize the main features of the project that are more relevant for this presentation.

Medium resolution spectra for ~ 6000 galaxies were obtained during several runs at the 4.2 m William Herschel Telescope (WHT) and at the 3.9 m Anglo-Australian Telescope (AAT) with multifiber spectrographs (WYFFOS and 2dF, respectively), making it possible to reliably measure redshifts of more than 6000 galaxies in the cluster fields. About 60% of the galaxies in the spectroscopic sample are classified as cluster members, so the number of known members of the WINGS clusters has been increased by a factor of 3 (Cava et al. 2009). For the WHT and AAT spectra, the fiber apertures were $1.6''$ and $2''$, and the spectral resolutions ~ 6 and ~ 9 Å FWHM, respectively. The wavelength coverage ranges from ~ 3590 to ~ 6800 Å for the WHT observations, while spectra taken at the AAT covered the ~ 3600 to ~ 8000 Å range.

3. LINE MEASUREMENTS AND SPECTRAL CLASSIFICATION

Given the large amount of spectra in the WINGS spectroscopic sample, we developed an automatic method capable of yielding accurate enough measurements of the most relevant optical spectral lines.

For measuring equivalent widths, the choice of the continuum is a critical issue. In general, one would require that the line profile is fully included, and that the measurement is made without being affected by proximity of other lines or noisy features. Defining the line profile by adopting a fixed wavelength range, centered on the central λ of each line, cannot be a reliable choice because: (1) the line-width can depend on the EW itself (being larger as its value increases) or on kinematics of the galaxy; (2) on a blind-measure approach, it is not possible to verify whether the noise dominates the line or not.

The algorithm measures EW of a line, no matter if in absorption, emission, or including both components, by first defining its full width – $\Delta\lambda$ – which is symmetric with respect to the nominal (theoretical) line's center. The edges of this interval are used to define both the spectral continuum (red markers at the extremes of the green-dashed line in the upper panel in Figure 1) and the range over which the line is measured. The spectral continuum is approximated by a straight line and the EW value is found by summing the dashed areas, divided by the average continuum value: positive values are taken when the line is in absorption, i.e. below the continuum level, and negative when it is in emission, or above the continuum level. To find the proper EW value, the line is first measured over a very short range, and then various values of the EW are computed as a function of $\Delta\lambda$, which is increased at steps of 1 Å, starting from the initial width of 4 to 8 Å, depending on which line is measured, and going up to ~ 80 Å.

So, in order to recognize the absorption + emission pattern, it is first checked whether the EW trend curve (see an example in the lower panel of Figure 1) starts with negative or positive values, for those lines which can be both in absorption and emission (e.g., hydrogen lines). If small values of $\Delta\lambda$ yield a negative EW, then the presence of an emission + absorption pattern is expected, and the EW determination is treated accordingly.

Adopting the same spectral classification as defined by Dressler et al. (1999), which was conceived to study distant clusters, we divide the spectra of our sample into six classes, based on the EW of [O II] and Hδ. The spectra for which none of the two lines was detected are classified as *noisy*. The broad physical meaning of such classification is discussed in detail by Poggianti et al. (1999); we briefly summarize it in the following:

- *e(a)* emission-line spectra with a strong Hδ line ($EW > 4$ Å), the signature of the presence of A-type stars;
- *e(b)* emission-line spectra, typical of star-bursting system;
- *e(c)* emission-line spectra, typical of continuum-like star formation pattern;
- *k* spectra resembling those of K-type stars, typical of passive-evolving galaxies;
- *k+a* or *a+k* spectra displaying a combination of signatures typical of both K- and A-type stars.

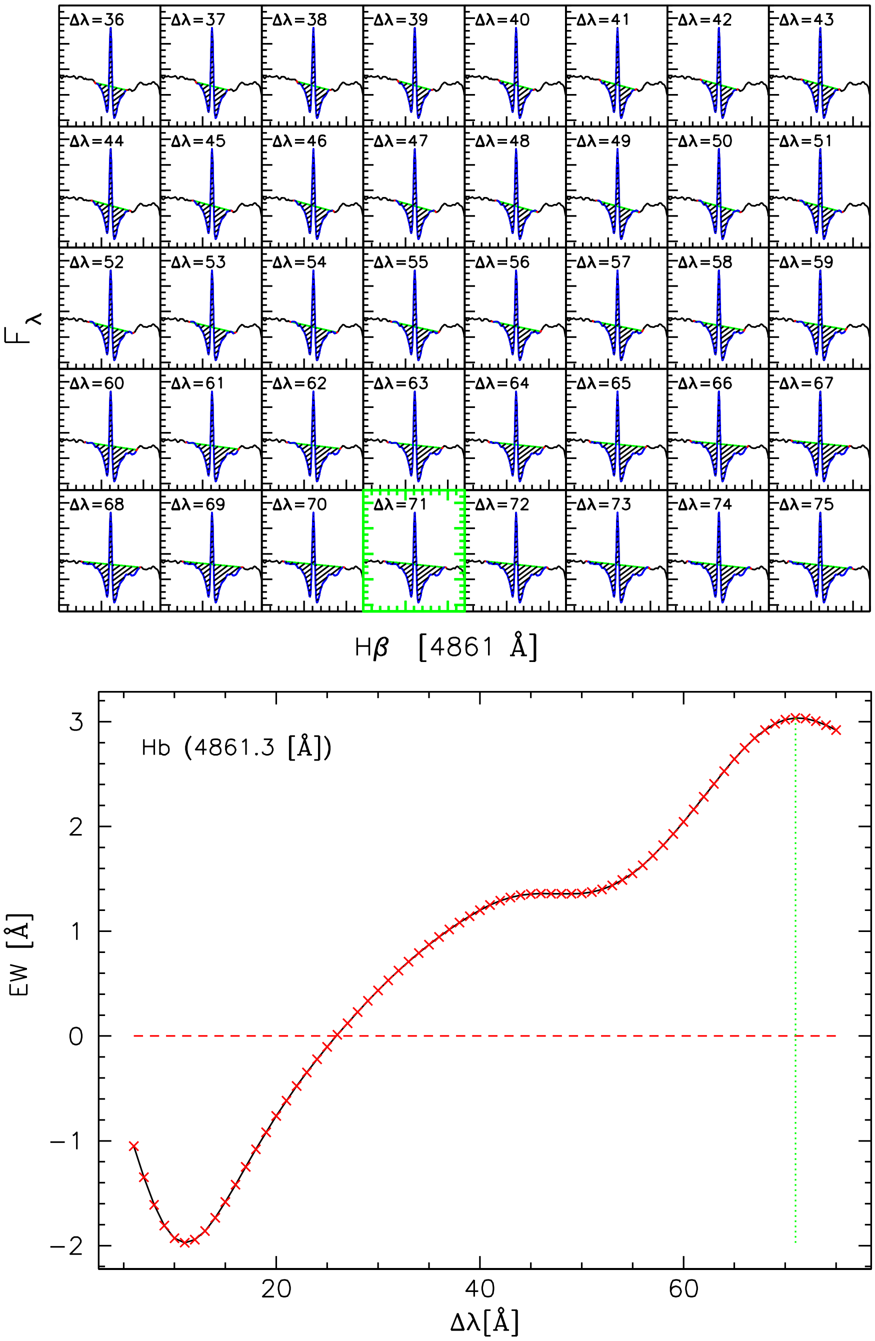

Fig. 1. Explanation how our *EW* measurement method works on the observed Hβ line: the top panel shows how the *EW* of the line is iteratively measured at increasingly broader bands which are used to define the continuum level. The analysis of the *EW* trend curve, plotted on the lower panel, provides the correct observed value, shown by the vertical green line. In this case, when both emission and absorption components are present, it corresponds to the second zero of the first derivative of the trend curve itself.

Following this classification, all the emission-line galaxies (the *e* class, in the Dressler & Gunn 1992 classification scheme) are those in which the process of star formation takes place at the moment of their observation, or they host either a LINER or an active galactic nucleus. Among the emission-line class, galaxies whose spectra are dominated by the Balmer lines in absorption, are classified as *e(a)*, where the letter 'a' indicates strong presence of A-class stars with deep hydrogen absorption lines. The *e(b)* (bursting) class includes galaxies with very strong emission lines, as those produced by a burst of star formation. Finally, we classify as *e(c)* (continuous) those spectra which display lines of moderate intensity, both in emission and absorption, similarly to what is expected from a continuous star formation process, typical of classical spiral galaxies. The other types are typical of 'passive' spectra, the *k* class being dominated by old stars (older than ~ 2 Gyr), and the *k+a* and *a+k* classes with evidence of increasing presence of A stars, which are a commonly recognized as a signature of a relatively recent (< 1 Gyr) burst of star formation.

4. PROPERTIES OF POPULATION IN GALAXIES OF THE LOCAL CLUSTERS

We now analyze properties of our galaxy sample as a whole, discussing the characteristics of the various spectral types as a function of luminosity, morphology and position in the cluster. We were able to successfully classify about 90% of the spectra of our survey (both members and background galaxies), based on [O II] and Hδ (and Hβ, when needed). Spectra without the classification either have a very low *S/N*, or the lines were not measured due to strong artifacts affecting their profiles.

We found that the population of galaxies in local clusters is dominated by the *k* spectral type, including about 40% of galaxies in our spectral sample, followed by the *e(c)* class ($\sim$ 28%). The post-starburst classes represent about the 10% of our sample while the two other emission-line classes, *e(a)* and *e(b)*, contain 8% and 3%, respectively.

In the left panel of Figure 2, we compare the distribution of the absolute V-band magnitude, computed from the best fit model for various spectral classes.

While the distribution *e(a)*, *e(b)*, and the two post-starburst classes *k+a* and *a+k*, peaking at about $M_V \sim -19/-18.5$, is very similar, the *e(c)* distribution not only displays a tail towards brighter magnitudes, but it also shows a peak at higher luminosities ($M_V \sim -19.5$). The V-band luminosity distribution of galaxies with a *k*-like spectrum is clearly different: peaking at $M_V \sim -21$, this class has the most luminous tail in the distribution while lacking, at the same time, a significant population of objects with absolute magnitudes lower than $M_V \sim -19$. It is interesting to compare the luminosity distribution of galaxies in local clusters to that found in clusters at higher redshift. The ideal sample for such a comparison was observed in the frame of the MORPHS collaboration, which observed galaxies in clusters at redshifts in the 0.37–0.56 range, providing a representative luminosity function down to $M_V < -19.0 + 5 \cdot \log_{10}(h)$, well matching the completeness limit of our spectroscopic sample. Dressler et al. (1999) present a comparison of the V-band luminosity functions for the six spectral types with the same definitions. Comparing the luminosity distributions at high and low redshifts, we find negligible differences as far as the emission-line galaxies are concerned. The presence of a higher fraction of fainter galaxies in the WINGS

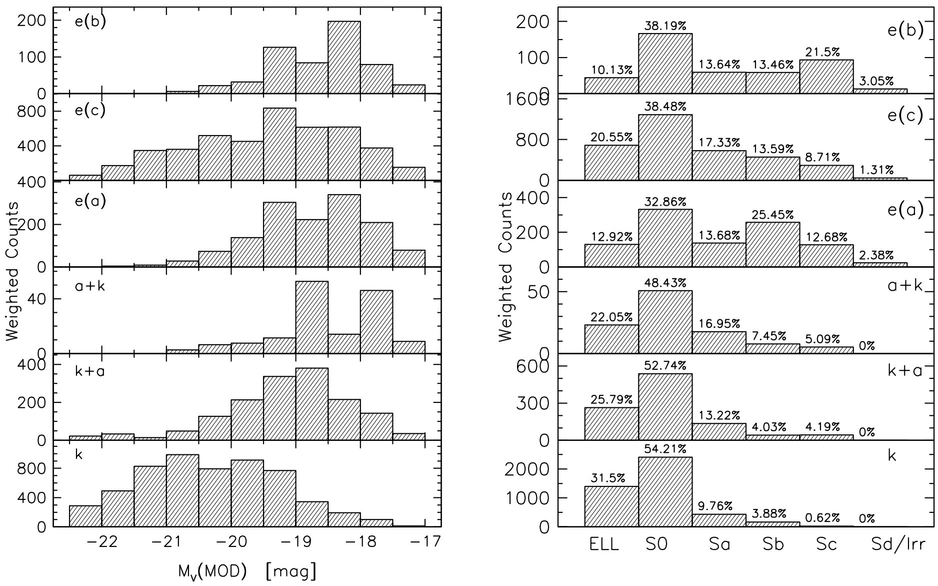

Fig. 2. Left panel. The shaded histograms represent the numbers of galaxies of the six spectral types, as a function of the absolute V magnitude. **Right panel**. Occurrence of morphological types as a function of spectral class. The percentages refer to the number of objects with a given morphology with respect to each spectroscopic class. For both plots, data have been weighted by both spectroscopic and geometric completeness.

sample might be due to incomplete sampling of the low-luminosity tail of the distribution in the high redshift sample. The two post-starburst classes, *a+k* and *k+a*, have similar luminosities at both high and low redshifts. At low redshift the V-band distribution peaks at $M_V = -18.5$, one magnitude fainter with respect to that at high redshift. It is quite interesting that *k+a* galaxies show a luminous tail similar to that found in the MORPHS sample. Unlike for the high-z galaxies, the distribution of galaxies of *k* spectral class at low redshifts is clearly different with respect to the post-starburst galaxies. The luminosity distribution, peaking around $M_V = -20.5$, is roughly the same as for high redshifts.

An interesting piece of information is provided by the morphological classes of the galaxies. We use the morphological classification derived from V-band images obtained with the MORPHOT code (Fasano et al. 2011), using a set of parameters which complement the classical concentration, asymmetry and clumpiness indicators. In the right panel of Figure 2, we present the distribution of various morphological types among the six spectral classes. The dominant morphological class is S0, even among the emission-line galaxies.

5. CONCLUSIONS

Even though in a preliminary phase, this work shows that the spectroscopic dataset provided in the frame of the WINGS project, is the ideal low redshift benchmark that was lacking until now in the studies of galaxy evolution in the cluster environment. It will allow us not only to study the changes in stellar population properties in clusters, as a function of the cosmic time, but also to quantify the importance of the characteristics of the clusters both in shaping their morphology and influencing their star formation history and their mass.

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