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Galaxy evolution as it appears at z < 1

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We study spectral evolution of galaxies in a magnitude limited sample in a pencil beam of 10' x 7.5' from z = 1 down to 0.3. We bin our individual galaxy spectra to obtain representative high S/N spectra based upon large apparent cosmological structures. We divide the resulting average spectra in three groups: galaxies with pure absorption line spectra, galaxies with emission lines and blue continua, and galaxies with emission lines and red continua. We further divide emission-line galaxies in star-forming galaxies, Seyferts, and LINERs by using emission-line ratios and derive stellar fractions from population synthesis models.

We estimate the *downsizing* in emission-line galaxies between z = 0.9 and z = 0.45 in our pencil-beam and the *archeological dowsizing* in a cluster at $z = 0.29$, and find the following results: (1) strong star formation in emission line galaxies, (2) aging in emission line galaxies, (3) aging in absorption systems, are shifting from bright to faint systems as cosmological time increases. Each redshift bin is repopulated in new starbursts. Therefore at redshifts z <1 galaxy formation is downsizing both in luminosity and number density. Cold Dark Matter (CDM) models are hierarchical in the sense that large halos are built from the merging of small halos. Our observations indicate that at z < 1 star formation and halo assemblage are no more in phase.

Several analysis have shown that there is still a large gap between CDM simulations and observable parameters, and explored various solutions: the abundance of haloes of various masses forming at a given time is very broad, the gravitational sequence of halo formation may be modified by the galaxy formation physics which may change the efficiency of galaxy formation, simulations that incorporate a shutdown seem to be able to reproduce downsizing trends, gravitational shifts in halo formation time are enhanced by the inclusion of AGN feedback. All these attempts however point out a weakness in the CDM halo hypothesis: its low predictive power. It is as if dark matter is closer to baryons than CDM is.

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1. Introduction

Cold Dark Matter (CDM) models are hierarchical in the sense that large halos are built from the merging of small halos. Some observations of ellipticals in clusters however, suggest that star formation and halo assemblage are not in phase [1]. There are scenarii, consistent with observations, in which the final assembling of the red-sequence can be observed well below $z = 1$ [2]. More than a decade ago, Cowie [3] suggested that while the most massive galaxies were formed early in the Universe, star formation is progressively shifted to smaller systems, the so-called downsizing effect. This effect had been confirmed by several later studies [4], [5]. The downsizing detected in samples of galaxies at different redshifts has been termed "downsizing in time" to be distinguished from the "archaeological downsizing" which refers to the observation that less massive early type galaxies formed their stellar populations later and over a longer time span than the more massive ones [6], [7]. Down-sizing seems to be in conflict with hierarchical structure formation.

We revisit the question of downsizing in emission-line and absorption-line galaxies in a new sample between $z = 0.9$ and $z = 0.45$.

2. Results

Our observations, data, analysis (spectral extraction, flux calibrations, methods, quantitative analysis of stellar populations) are described in details in [8], and the main results summarized in the present poster, can be found in [9].

2.1- We have applied population synthesis models (SSP) to the 10 brightest and 10 faintest absorption line galaxies in a cluster at $z = 0.29$, and compared the stellar populations with those in bright abosption systems at $z = 0.82$. The SSP models indicate that on average about 80% of the stars in the 10 faintest galaxies are younger than 2.5 Gyr, i.e. were born at $z < 1$. In comparison, 80% of the stars contributing to the spectrum of the brightest absorption galaxies are older than 2.5 Gyrs. The striking similarity between the spectra of faint galaxies at $z = 0.29$ and those of bright galaxies at $z = 0.8$, the *archeological dowsizing,* is exemplified in Fig. 1 (top, left).

2.2- We have plotted in Fig. 1 (top, right) average normalized spectra of emission-line galaxies in redshift bins from $z = 0.29$ to $z = 0.9$. The most conspicuous spectral change with redshift is a decrease in flux redward of the G-band from $z = 0.29$ and $z = 0.43$ to higher z coupled to an increase to the blue of [OII] from $z = 0.65$ to $z = 0.82$ and higher z. This rotation of the normalized spectra implies a systematic change in the galaxy populations entering the sample with redshift: more star forming galaxies at higher z, and more galaxies with old stars at lower z.

The values of the parameters $\mathrm{D}(40000)$ and $\mathrm{EQW}([\mathrm{OII}])$ in the average *red* spectrum at $z = 0.9$ are close to those measured on the average *blue* spectra at $z = 0.29$ and $z = 0.43$ which are also fainter. To quantify this *down-sizing* effect from $z = 0.9$ to $z = 0.4$ we determined the range of luminosities for which galaxies have spectra similar to luminous galaxies at $z = 0.9$ and found a difference of $1.2 - 1.7$ magnitudes that is a factor of 4. Residuals are shown in Fig. 1 (bottom, left). The down-sizing in emission-line galaxies in the range $0.3 \leq z \leq 1$ is twofold: both the luminosity and the frequency of starbursts decrease with time. It is as if the strongest mode of star formation switches off progressively from the brightest to the faintest systems.

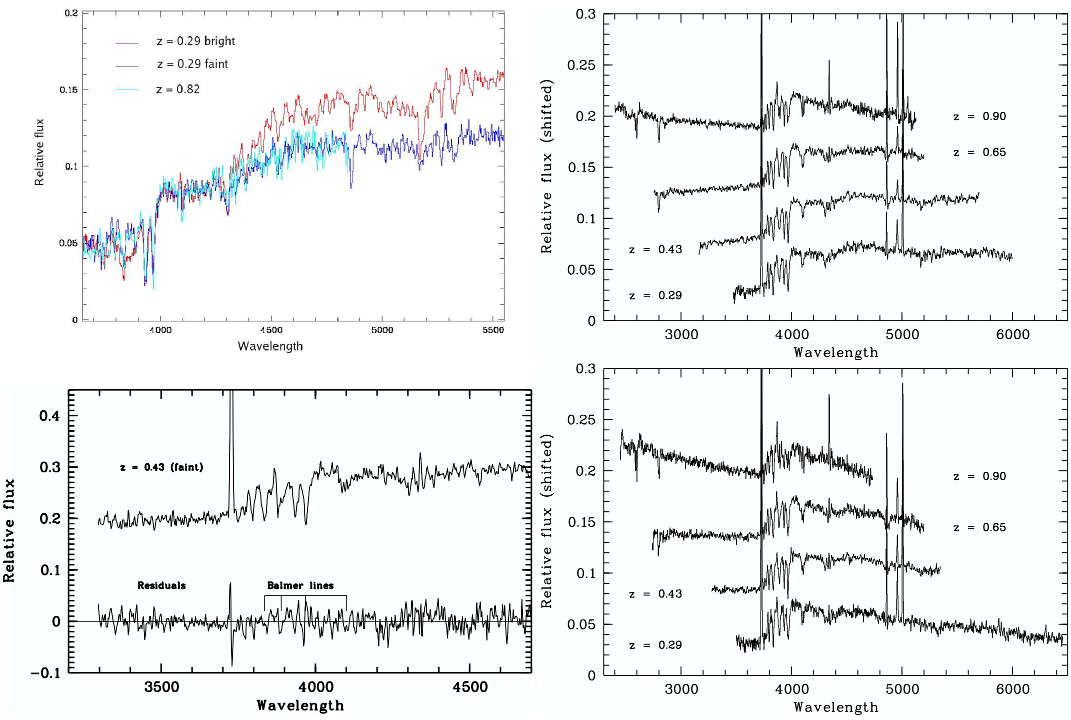

Figure 1: Top, left: Normalized spectra of the 10 brightest (in red) and the 10 faintest (in blue) absorption-line galaxies in the cluster at $z = 0.29$, and the full sample of absorption-line systems at $z = 0.82$ (in cyan). Top, right: Normalized composite spectra of emission line galaxies. Bottom, left: Combined spectrum of emission systems in the $z = 0.43$ redshift bin selected in the magnitude range $21.5 \leq R \leq 22.4$ and residuals between this spectrum and that of bright emission-line galaxies at $z = 0.9$. Bottom, right: Composite spectra of the blue half of emission-line galaxies.

2.3- The results of SSP models clearly show that star formation in red emission-line galaxies is fading at $z < 0.5$ and most of the stars in the observed spectra at $z > 0.5$ are younger than 2.5 Gyr. They indicate that the bright red emission-line galaxies at $z < 0.5$ are the oldest.

2.4- Average spectra of blue galaxies in the redshift bins z = 0.29, 0.43 and 0.65 in Fig 1 (bottom, right) are basically indistinguishable from each other: they correspond to starbursts showing strong [OII] and bright UV. The population of Seyferts being small, the spectra of most of blue objects are dominated by an ongoing stellar bursts. The three redshift bins are separated by $\sim$ 1Gyr each in cosmic time, so the starbursts that we are observing in one bin will not be classified as starburst in the next (lower z) bin. At $z > 0.68$ the blue emission-line galaxies are even bluer.

3. Discussion and Conclusion

We find the following results: (1) strong star formation in emission line galaxies, (2) aging in emission line galaxies, and (3) aging in absorption systems, are shifting from bright to faint systems as cosmological time increases, and (4) the populations of starburst galaxies must be continuously repopulated between $z \sim 1$ and $z \sim 0.3$. Our observations clearly indicate that at $z < 1$ star formation and halo assemblage are no more in phase. Nevertheless the abundance of haloes of various masses forming at a given time is very broad and is not a simple hierarchical model in which large halo form at a late time [10]. The gravitational sequence of halo formation may be further modified by the galaxy formation physics which may change the efficiency of galaxy formation as function of halo mass. Simulations that incorporate a shutdown seem to be able to reproduce downsizing trends [11]. Gravitational shifts in halo formation time are also enhanced by the inclusion of AGN feedback [12], [13], [14]. All these attempts however point out a common weakness in the CDM halo hypothesis: its low predictive power. It is as if dark matter is closer to baryons than CDM is. A channel of transform, as suggested long ago by relations of structure in spirals [15], might help.

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