

Morphological Study of an H δ Absorption Line Selected Sample in EGS Field (Postprint)

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Abstract

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Full Text

Preamble

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Morphological Study of an H δ Absorption Line Selected Sample in EGS Field
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Abstract

The role of galaxy morphology and stellar population properties in galaxy evolution is crucial for understanding the transition from star-forming to quiescent galaxies. We present an analysis of 94 galaxies with $H\delta$ absorption line equivalent widths greater than 2 \AA , selected from the DEEP2 survey EGS field ($0 < z < 1$). The wealth of multi-wavelength coverage enables accurate stellar mass measurements from SED fitting, SFR measurements from UV and MIR, and galaxy population classification based on the UVJ diagram. Using HST F814W images, we performed a morphological analysis and found that most galaxies exhibit disk-like structures, with some showing bulge-dominated profiles. The size of our sample is roughly in between the star-forming and quiescent galaxies, implying a transition of galaxy population. We also examined the role of central stellar density (Σ_1) in galaxy evolution and found that galaxies with higher Σ_1 tend to evolve into quiescent galaxies earlier, supporting the “downsizing” scenario. These findings underscore the importance of size, mass, and central density in galaxy evolution.

Key words: galaxies: starburst -galaxies: evolution -galaxies: formation

1. Introduction

Galaxy formation and evolution are largely determined by their star formation activities. However, star formation in galaxies cannot last forever; otherwise, we would observe much more massive galaxies [?, ?, ?, ?]. Previous research shows that galaxy colors exhibit a bimodality distribution, and the galaxy population can be divided into red sequence and blue cloud in its color-mass diagram [?, ?]. It requires a quenching mechanism for a star-forming galaxy to stop its star formation and transition from the blue cloud to the red sequence to become a quiescent galaxy, as we observe today [?]. The transition zone from the blue cloud to the red sequence is known as the green valley [?, ?, ?, ?]. Star formation quenching is considered to occur in the green valley.

Previous studies of galaxies in the green valley were based on samples selected using ultraviolet (UV)-optical colors [?, ?, ?]. Numerous surveys have produced

large spectroscopic [?] or photometric redshift samples [?, ?, ?, ?, ?, ?, ?, ?] to study galaxy populations and their evolution. Several groups [?, ?, ?, ?, ?, ?] have used colors to select galaxies in the green valley, demonstrating that these galaxies are transitioning from the blue cloud to the red sequence. [?] and [?] studied the morphologies of galaxies in the green valley and how they evolve into quiescent galaxies. [?] proposed a new approach to studying galaxies in the transition zone by using a spectroscopic sample to select galaxies exhibiting $H\delta$ absorption lines in the Balmer sequence. The presence of Balmer absorption lines in galaxy spectra indicates the domination of A-type stars during or after a starburst event. The rising and falling of A-type star fraction in galaxy spectra provide a direct trace of their later-stage evolution, from starburst to quiescent galaxies.

Most galaxies selected by the $H\delta$ absorption line method are green-valley galaxies, with a few being post-starburst galaxies in the red sequence. In this paper, we present a morphological study of a galaxy sample selected based on $H\delta$ absorption lines. The sample was selected from the All-Wavelength Extended Groth Strip International Survey (AEGIS) redshift survey with very extensive multi-wavelength data [?]. We identified green valley galaxies spectroscopically from the sample, enabling a comparison among AEGIS redshift galaxies in blue-cloud, green-valley, and red sequence zones. There are high-resolution Hubble Space Telescope (HST) and James Webb Space Telescope (JWST) images [?, ?, ?, ?] in the AEGIS survey area, providing well-resolved morphologies for the selected galaxies. We investigated how morphological transformation occurred when the $H\delta$ absorption line selected galaxies evolved from green valley to red sequence.

The structure of this paper is as follows. Section 2 presents a detailed selection of our sample in the AEGIS redshift survey. In Section 3, we measure the physical properties of the sample and analyze its evolutionary history. Galaxy evolution of the sample traced by A-type stars and their morphologies are also discussed in this section, and we conclude in Section 4. Throughout the paper, we adopt a flat Λ CDM cosmology with $\Omega_M = 0.3$, $\Omega_\Lambda = 0.7$, and $h = 0.7$, and we use the Salpeter initial mass function (IMF, [?]) for stellar population modeling.

2.1 The Photometric and Spectral Samples in the EGS Field

The Extended Groth Strip (EGS) was one of the four fields in the Deep Extragalactic Evolutionary Probe 2 (DEEP2) survey [?], using the Keck telescopes for spectroscopy and the HST for imaging. The DEEP2 spectroscopic observations (6500–9300 Å) range in the redshift $0.6 < z < 1.2$. We also make use of the MMT/Hectospec spectra, which cover a wavelength range of 3900–9240 Å, complementing the archival observations of targets, especially at $z < 0.6$. The extensive multi-wavelength imaging coverage in the EGS field, spanning from X-ray to radio, makes it a unique data set for studying galaxy evolution, and it became the basis for a survey called the AEGIS [?]. The full wavelength photometry data, ranging from UV to far-infrared (FIR), enable measurements of

stellar mass and star formation rates (SFRs) for galaxies in the AEGIS sample, while X-ray and radio data are used for active galactic nucleus (AGN) identification. The most critical data for our sample selection in this study are the DEEP2 spectra [?] and the HST optical imaging [?]. More recently, HST and JWST have conducted much deeper imaging surveys in the near-infrared (NIR) and mid-infrared (MIR) bands [?, ?, ?], though with much smaller coverage.

Our sample selection was based on the measurement of $H\delta$ absorption lines in the DEEP2 spectra. The full optical band spectroscopy in the EGS field allows detection of $H\delta$ in the redshift range $0 < z < 1$. The morphological study was performed using the HST F814W images of the EGS field. [?] provided the multi-wavelength photometry data for the AEGIS survey.

2.2 $H\delta$ Absorption Line Measurement and Sample Selection

We measured the $H\delta$ absorption line equivalent width (EW) for all spectra in the DEEP2 EGS sample with redshifts in the range $0 < z < 1$. At higher redshifts ($z > 1$), the $H\delta$ line shifted out of the spectroscopic range. The detailed measurement method is described in [?]. The $H\delta$ absorption line EW is defined as follows: the nearby continuum is measured in the wavelength ranges $4041.6 < \lambda < 4079.75 \text{ \AA}$ and $4128.5 < \lambda < 4161.0 \text{ \AA}$ while the absorption line profile is measured in the range $4083.5 < \lambda < 4122.25 \text{ \AA}$. The measurement becomes more complicated when galaxies exhibit both $H\delta$ emission and absorption lines. To address this, we adopted a sophisticated method of iteratively fitting a two-component line. In almost all cases, the absorption line is significantly wider than the emission line. Our method provides robust estimates of the $H\delta$ absorption line EW, even when both emission and absorption lines are present.

For our sample selection, a significant detection of the $H\delta$ absorption line was required. The criteria included both $S/N_{EW} > 3$ and $EW > 2 \text{ \AA}$ to reject poor fitting results, as illustrated in Figure 1. We also added an additional criterion to ensure continuum in the wavelength ranges $4041.6 < \lambda < 4079.75 \text{ \AA}$ and $4128.5 < \lambda < 4161.0 \text{ \AA}$ had at least 5σ significance, which helped reject a substantial number of extremely large EW measurements. A total of 324 galaxies were selected from the area covered by the EGS multi-wavelength photometry. In this project, we aim to study the morphological evolution of starburst galaxies in their last billion years. We further limited our sample to galaxies within the HST F814W imaging coverage in the EGS field. A total of 94 galaxies were selected based on the HST F814W images, with a redshift range of $0 < z < 0.9$.

3 Classification of the $H\delta$ Absorption Line Selected Sample

3.1 Stellar Mass and Star Formation Rate Estimation

The multi-wavelength photometry in the EGS field allows for the estimation of the physical properties of our sample. We fitted the spectral energy distributions (SEDs) using stellar population models [?, ?] and exponentially declining star

formation history (SFH) to estimate the stellar mass for each galaxy in the sample. The stellar masses of the galaxies in this sample span a wide range of $8.5 < \log(M_*/M_\odot) < 11.5$. Additionally, we measured the rest-frame $U - V$ and $V - J$ colors for the galaxies.

Bimodality classification of the galaxies was performed using the UVJ diagram (Figure 2). In Figure 2, 21 galaxies meet the criteria for passive galaxies [?]. The remaining 73 galaxies in the sample are classified as dusty star-forming galaxies. We compared this sample with all galaxies in the CANDELS field at similar redshifts, using the mass-UV-color diagram, and found that most of these galaxies are located in the green valley (Figure 3). As [?] noted, most of the $H\delta$ -selected galaxies are found either above or below the main sequence area. The galaxies in the starburst region are in their later stages, rapidly passing through the main sequence phase to become passive galaxies.

As presented in previous works [?, ?, ?], an $H\delta$ selected sample consists of either starburst or quiescent galaxies. This sample should have a similar SFR distribution. In fact, among the 94 galaxies in this sample, 92 galaxies had the MIPS 24 μ m detections including those identified as quiescent galaxies in the UVJ diagram. We estimated the total SFRs for galaxies in the sample using both UV and IR photometry, following the same method in [?]. The range of SFRs for this sample is $0.1 < \text{SFR} < 100 M_\odot \text{yr}^{-1}$. The specific star formation rate (sSFR), therefore, is in the range of $10^{-12} < \text{sSFR} < 10^{-8} \text{yr}^{-1}$. The mean sSFR for quiescent galaxies is $\log(\text{sSFR}) = -10.3$, and that for star-forming galaxies is $\log(\text{sSFR}) = -9.5$.

3.2 Morphological Evolution of the $H\delta$ Selected Sample

We performed morphological analysis for this sample using their HST F814W images. The quiescent galaxy stamp images are presented in Figure 4, and the starburst ones are shown in Figure 5. The galaxies in this sample cover a redshift range of $0.1 < z < 0.9$, so the observed F814W band samples the rest-frame bands of 4000-8000 \AA . This wavelength range may not be very sensitive to bulges at $z > 0.6$. A visual inspection shows that most galaxies in the sample are disk or spiral galaxies, with some exhibiting compact morphologies. Notably, typical elliptical galaxies are absent, even among those identified as quiescent galaxies in Figure 2. We used GALFIT [?] to fit galaxy profiles in the sample, yielding Sérsic indices and effective radii for each galaxy. Most galaxies have Sérsic indices ~ 1 , consistent with the visual identification. There are seven galaxies with Sérsic indices > 2 , five of which are quiescent galaxies, and two are starbursts. All seven galaxies lie in the redshift range of $0.2 < z < 0.6$. Thus, the effective radius R_e is a more robust morphological parameter for this study.

A critical result is that galaxies with different sizes and masses evolve differently in terms of their SFRs and the production of A-type stars. Figure 6 shows that galaxies with large mass and small size cross the main sequence line to become

quiescent. This suggests that galaxies with higher densities, rather than simply larger masses, evolve earlier. The H δ EW for a galaxy varies differently with its mass and size. Figure 7 shows that large H δ EWs occur in galaxies with modest stellar masses. This is consistent with the simple evolutionary model of H δ in [?] and [?], where H δ increases as the Balmer break strengthens, reaches its peak, and then decreases as the Balmer break continues to increase. As the stellar mass increases with the Balmer break, this explains why very massive galaxies tend to have small H δ EWs. The peak of the H δ EW in our sample occurs in galaxies with modest stellar masses. However, Figure 7 also shows that larger galaxies tend to have higher H δ EWs.

The size-mass relation for this sample is complex. Size-mass relations for different types of galaxies vary significantly. Disk galaxies usually have larger effective radii than those of quiescent galaxies [?]. Sizes for both types of galaxies are correlated with their stellar mass, with the slope for quiescent galaxies being much steeper. Most galaxies in the H δ selected sample neither follow disk nor quiescent size-mass relation in Figure 8 at similar redshifts, but lie between these relations [?]. Massive galaxies in the sample have rather smaller R_e than most quiescent galaxies in CANDELS [?].

Another important morphological parameter is the stellar mass surface density within the central 1 kpc radius, known as Σ_1 . [?] first identified this parameter as a key measure of the galaxy quenching process, which is also strongly related to the central supermassive black hole. Several observational and theoretical studies of galaxies at various redshifts have shown that Σ_1 correlates with stellar mass and can help separate quiescent from star-forming galaxies [?, ?, ?, ?, ?]. We used the same Σ_1 equation as [?] in which Σ_1 is defined in Equation (1) and show the results in Figures 9, 10 and 11.

Our results show that the Σ_1 for galaxies in the sample is correlated with their stellar mass (Figure 11). However, only a few massive galaxies fall above the quiescent galaxy boundary, consistent with their lower sSFRs in Figure 9. Figures 10 and 11 also show that quiescent galaxies tend to have small H δ absorption, indicating a lower fraction of A-type stars in these galaxies. From Figures 4 and 5, we see that some targets have bright neighbors or are located in denser environments, which may lead to a more compact stellar surface density and a higher Σ_1 value. We highlight these targets with bright neighbors in Figure 9 and find no clear trend between environment and central stellar mass density Σ_1 .

In previous studies [?, ?, ?], galaxy evolution exhibits a “downsizing” effect in which massive galaxies evolve to become quiescent galaxies earlier. Current studies (including this one) show that galaxies with high Σ_1 evolve earlier. The correlation between Σ_1 and stellar mass makes it indistinguishable. [?] and [?] studied galaxy populations at various redshifts, and found that in each redshift bin both star-forming and quiescent galaxies can have the same Σ_1 in their $\Sigma_1 - M_*$ plots. This suggests an evolutionary scenario in which a galaxy can evolve across the line to become a quiescent galaxy by increasing its central

density Σ_1 . Galaxies in our H δ selected sample do not show a similar distribution in Figure 11, where star-forming galaxies below the boundary line at the lower mass end and quiescent galaxies lie above the boundary line. This may not be consistent with the scenario of galaxy evolution in the vertical direction in the $\Sigma_1 - M_*$ diagram, but rather with galaxies with high Σ_1 that evolved earlier.

4 Summary

We investigate a sample of galaxies with H δ absorption line EWs $> 2 \text{ \AA}$ from the DEEP2 survey EGS field ($0 < z < 1$). We selected 94 galaxies based on robust H δ detection and HST F814W coverage, which were used for morphological analysis. Stellar masses in this sample range from $8.5 < \log(M_*/M_\odot) < 11.5$, with SFRs spanning $0.1 - 100 M_\odot \text{ yr}^{-1}$. Based on their UVJ colors, we classified the galaxies as quiescent or star-forming.

The morphological analysis revealed that most galaxies in our H δ EW selected sample have disk-like structures, while a few show bulge-dominated profiles. The half-light radii of our sample lie between the star-forming and quiescent galaxy samples, indicating a transition nature of our sample. We found that galaxies with higher central densities (Σ_1) tend to evolve into quiescent galaxies earlier. These results suggest galaxy evolution is strongly influenced by central density, with galaxies exhibiting high Σ_1 evolving more rapidly, supporting the “downsizing” effect. This study highlights the importance of galaxy size, mass, and central density in shaping their evolutionary paths.

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