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Morphology and Structure of High-redshift Massive Galaxies in the CANDELS Fields† ⋆

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Abstract Using the multi-band photometric data of all five CANDELS (Cosmic Assembly Near-infrared Deep Extragalactic Legacy Survey) fields and the near-infrared (F125W and F160W) high-resolution images of HST WFC3 (Hubble Space Telescope Wide Field Camera 3), a quantitative study of morphology and structure of mass-selected galaxies is presented. The sample includes 8002 galaxies with a redshift $1 < z < 3$ and stellar mass $M_* > 10^{10}\ M_\odot$. Based on the Convolutional Neural Network (ConvNet) criteria, we classify the sample galaxies into SPHeroids (SPH), Early-Type Disks (ETD), Late-Type Disks (LTD), and IRRegulars (IRR) in different redshift bins. The findings indicate that the galaxy morphology and structure evolve with redshift up to $z \sim 3$, from irregular galaxies in the high-redshift universe to the formation of the Hubble sequence dominated by disks and spheroids. For the same redshift interval, the median values of effective radii (r_e) of different morphological types are in a descending order: IRR, LTD, ETD, and SPH. But for the Sérsic index (n), the order is reversed (SPH, ETD, LTD, and IRR). In the meantime, the evolution of galaxy size (r_e) with the redshift is explored for the galaxies of different morphological types, and it is confirmed that their size will enlarge with time. However, such a phenomenon is not found in the relations between the redshift ($1 < z < 3$) and the mean axis ratio (b/a), as well as the Sérsic index (n).

Key words galaxies: evolution, galaxies: fundamental parameters, galaxies: structure, galaxies: high-redshift

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1. INTRODUCTION

The morphology and structure of galaxies are important characteristics to represent the physical properties of galaxies, and they are related to other physical properties of galaxies. The morphological differences of galaxies may imply the differences in the experienced formation and evolution processes. In the nearby universe, the morphological and structural characteristics of massive galaxies (stellar mass $M_* > 10^{10}\ M_\odot$) are represented by the Hubble sequence[1], in which the galaxies are divided into Elliptical galaxies (E), Lenticular galaxies (S0), Spiral galaxies (S) and Irregular galaxies (Irr) according to their morphologies. Depending on the relative size of nuclear bulge, the disk structure and the tightness of spiral arm, the spiral galaxies can be divided into 3 subclasses, namely Sa, Sb and Sc. The elliptical and lenticular galaxies are commonly referred to as early-type galaxies, while the spiral and irregular galaxies are referred to as late-type galaxies[2]. Late-type galaxies exhibit the low stellar mass surface density, young age, blue color, strong dust extinction, high star formation rate, and they are mainly located in the low density regions, whereas the early-type galaxies have opposite characteristics[3]. In addition, the late-type spiral galaxies have a gas-rich exponential disk structure and active star formation, while the early-type galaxies exhibit the bulge-dominated elliptical morphology and have no or very weak star formation. Therefore, on the basis of star formation activity, galaxies can be divided into star forming galaxies (SFGs) and quiescent galaxies (QGs)[4].

More than 80% galaxies in the sample of nearby massive galaxies exhibit an ellipsoidal morphology, while others show a disk-like or irregular structural characteristic[2,5−6]. Whether the same result also exists in the medium and high-redshift galaxies is an issue of great concern to astronomers. The development of deep-field multi-band surveys, particularly the high-resolution optical and near-infrared images of Hubble Space Telescope (HST) have provided important original data for solving this kind of problems. Researches show that the rest-frame optical morphologies of the massive galaxies with high redshifts ($z > 1$) more likely exhibit the irregular and disperse structures[2], and that the physical scales (effective radius r_e, from which half of galaxy's total luminosity is emit) of nearby massive galaxies are larger than those of high-redshift galaxies of the same type and similar mass[7−37]. For early-type galaxies, the differences of physical scales between the nearby and high-redshift galaxies are 2 to 4 times, the differences are more prominent for late-type galaxies, which are about 3 to 5 times. In addition, for the galaxies of similar redshift and mass, the effective radii of early-type galaxies are smaller than those of late-type galaxies. The classification methods used in the above research results are mainly based on the color-color diagram classification criteria (e.g., U–V vs. V–J, briefly called as UVJ) or the Sérsic index n, in which galaxies are divided into the star forming galaxies and quiescent galaxies (or the early-type and late-type galaxies), and there is no detailed classification according to the specific morphologies of galaxies. For example, the late-type galaxies include the early-type disk galaxies (similar to the Sa and Sb of nearby galaxies), late-type disk galaxies