Reliable Size Measurement of Massive Galaxies at z~0.5-3.0 in the GOODS-N region with *HST/WFC3* Data
- Probing the Evolution of Sérsic Index -

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Abstract : We analyze the recent released HST/WFC3 IR images in the GOODS-N region to study the evolution of the size and Sérsic index of galaxies. We obtain the morphological parameters of 1,069 massive ($\geq 10^{10} M_\odot$) galaxies at z ~ 0.5–3.0 with GALFIT after examining the reliability with artificial galaxies. With a careful study of the bias and error in the effective radius of GALFIT, r_e, we derive the size-stellar mass relations for 270 quiescent galaxies (QGs) and 799 star-forming galaxies (SFGs). The median sizes of QGs and SFGs increase from z ~ 3.0 to ~ 0.5 by a factor ~ 2.0–2.2, following $r_e \propto (1+z)^{-\alpha}$ with $\alpha = 0.81 \pm 0.17$ and $\alpha = 0.70 \pm 0.07$, respectively. The result of massive QGs is consistent with the general picture of the significant size growth, while the evolution is much slow at $2.0 < z < 3.0$ (α ~ 0.6). For the further understanding of the evolution scenario, we study the evolution of Sérsic index n, which is often referred to as a shape of galaxies, and find that of massive QGs to significantly evolve as $n \propto (1+z)^{-\alpha}$ with $\alpha = 1.46 \pm 0.18$, while those of less massive QGs and SFGs are unchanged (n ~ 1) over the redshift range. We discuss the evolution in size and light profile of high-z galaxies, combining both in-situ and ex-situ process.

1.Brief Introduction

Morphological (Size) Evolution of galaxies at z~1-3 is one of the most interesting topics of the universe. Because the star-formation activity in the universe has peaked at the redshift, the morphological properties of galaxies there are found, with improvement of instruments, to evolve dramatically (Trujillo+07; van Dokkum+09; and many others). With accurate light profile of those galaxies, the evolution of the galaxies over the redshift range has been actively discussed !

2.Data (Fig.1)

2.1.HST/WFC3 IR

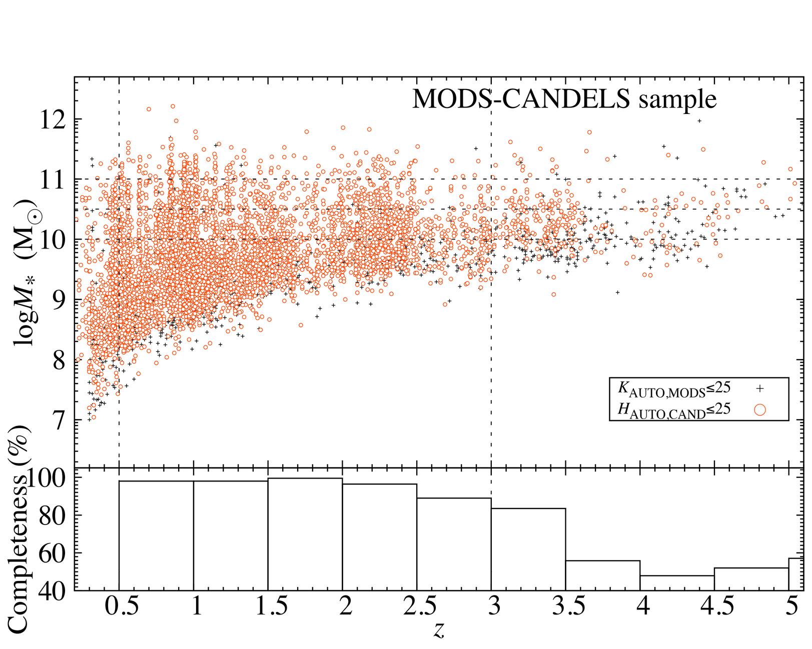
From CANDELS imaging data, we use F160W(H) in GOODS-N region.

FWHM(F160W)~0".18-0".20. H_{AB}<25 for reliable morphological fit (See §3).

2.2.MOIRCS/SUBARU

MOIRCS Deep Survey (K_{AB}~25 mag; 5σ) for phot-z, M_*, SFR.

By using Rest-UVJ, we extract Quiescent galaxies (QGs) from the whole sample, while the other galaxies are classified as Star-forming galaxies (SFGs).



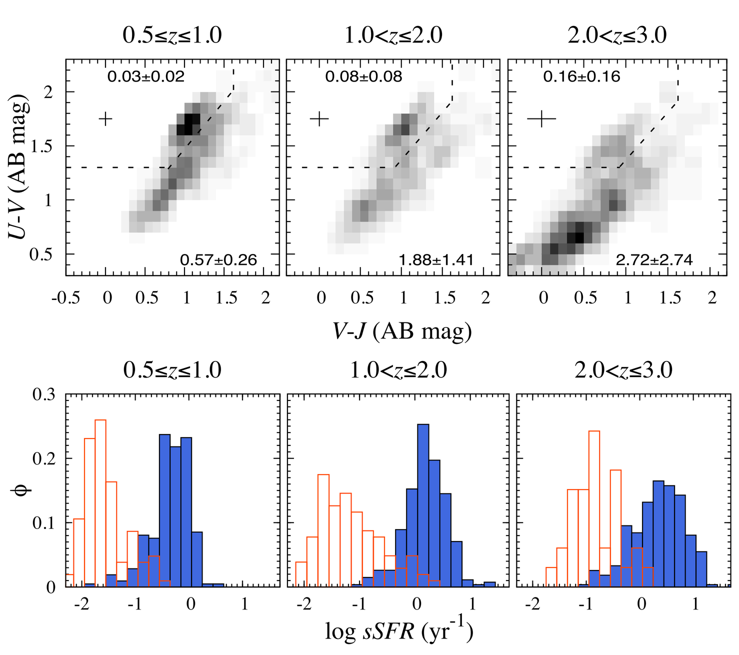
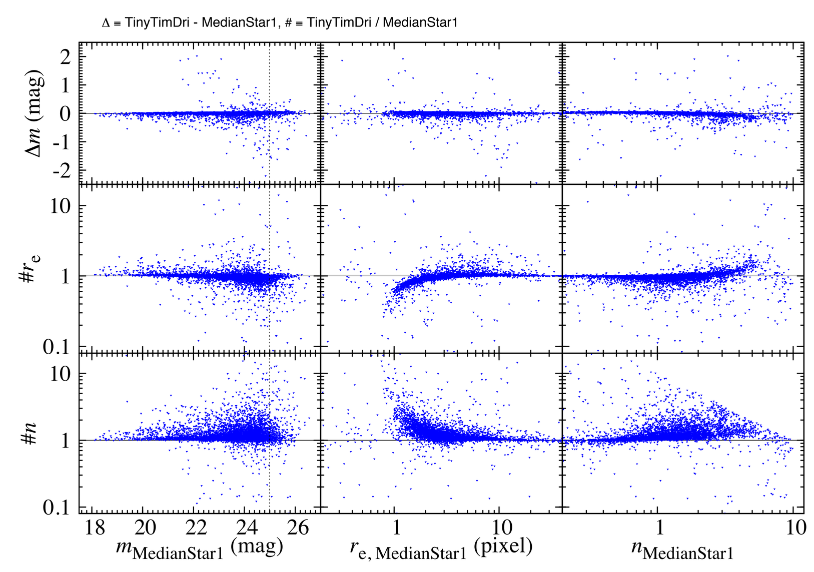


Fig.1(left) : Sample from MODS catalog and CANDELS. The black cross represents the sample with K<25 but fail to be detect or H>25 by SExtractor. The lower panel shows the faction of the sample with M_*>10^{10} $M_\odot$ (MODS limit) and H<25 (CANDELS limit) over the whole sample.

Fig.2(right) : QGs selection following rest-frame UVJ color of Williams+09. The value denoted in each panel is median specific star-formation rate ($sSFR$) for the sample there. The lower panels show the two populations with $sSFR$ as x-axis, to show clear bimodality.



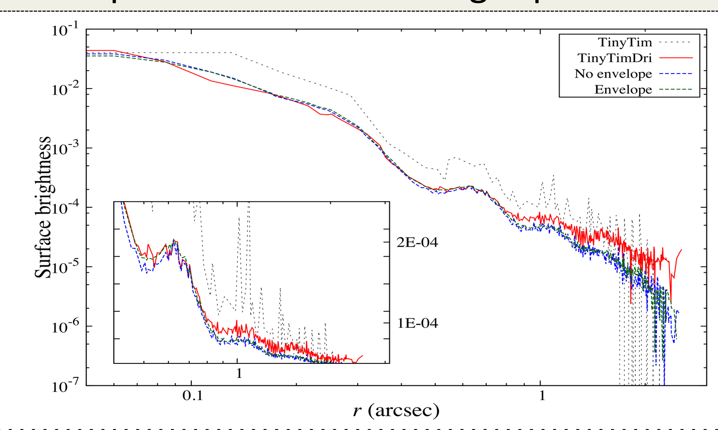


Fig.3 : Comparison of the results of real galaxies with two PSFs; median stacked star and Drizzled-Tiny Tim.

Fig.4 : Comparison of the radial light profiles of the PSFs.

3.Analysis - Size Measurement with GALFIT

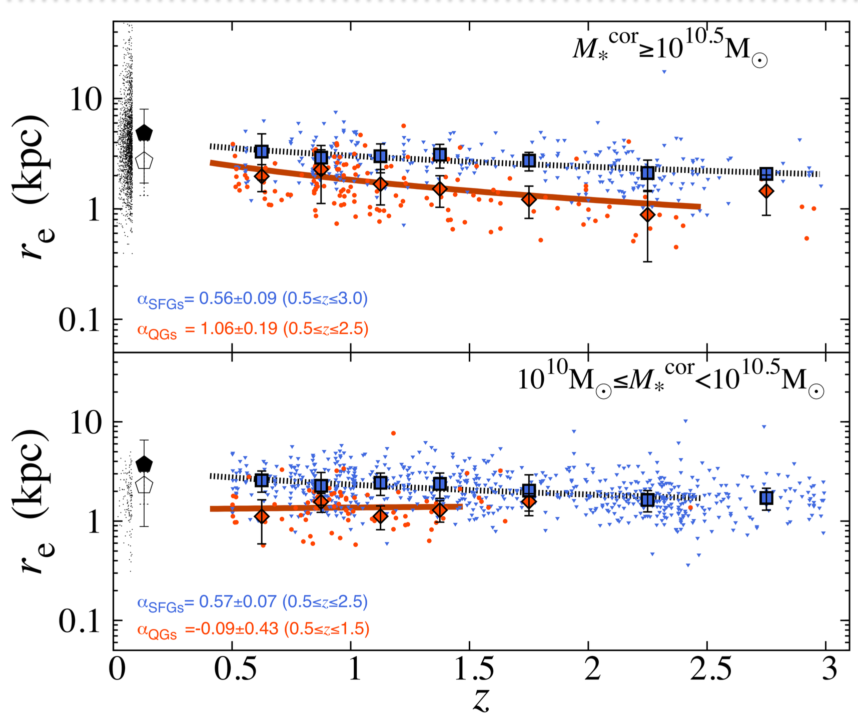
Sérsic Fit by GALFIT(Peng+02) package,

$$\Sigma(r)=\Sigma_0 exp[-b(n)((r/r_e)^{1/n}-1)] \qquad (1)$$

To study the possible bias depending on the apparent magnitude of galaxies, we test GALFIT using 1,000 mock galaxies buried in the F160W image, finding that GALFIT recovers the original profiles up to m_H~25.

We also compare the results with two PSFs; median stacked star and Drizzled-Tiny Tim (Fig.3).

We find significant differences in the derived parameters of galaxies with smaller r_e and larger n. We conclude that this difference comes from a tiny difference of the central few pixels of the PSF profiles (Fig.4), and adopt the median stacked star since it represents the stars in the mosaic image.



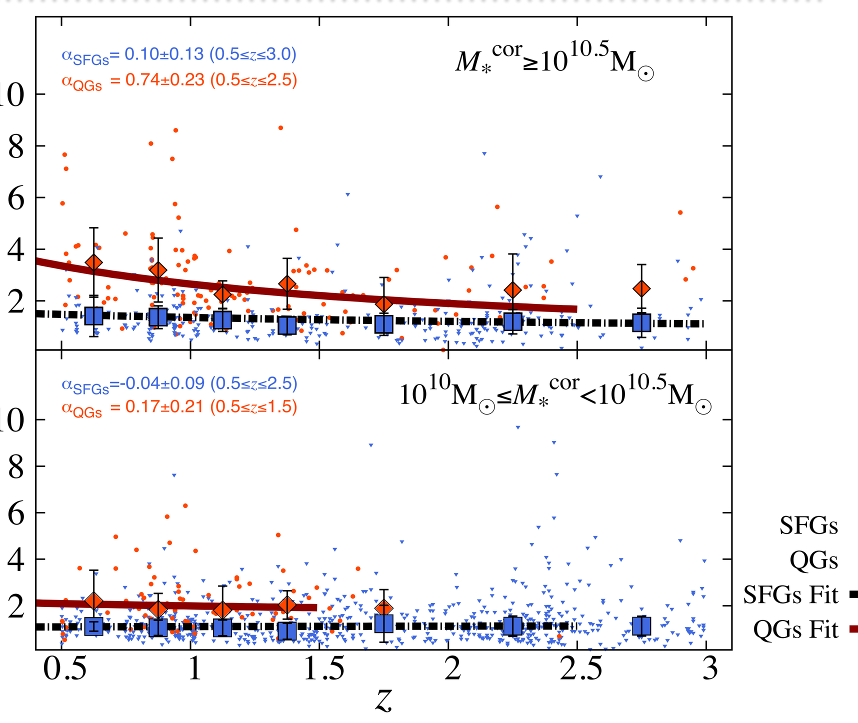


Fig.5(left)/Fig.6(right) : Evolution of r_e (left) and n (right) with redshift. The regressions with r_e $(n) \propto (1+z)^{-\alpha}$ are shown with thick curves.

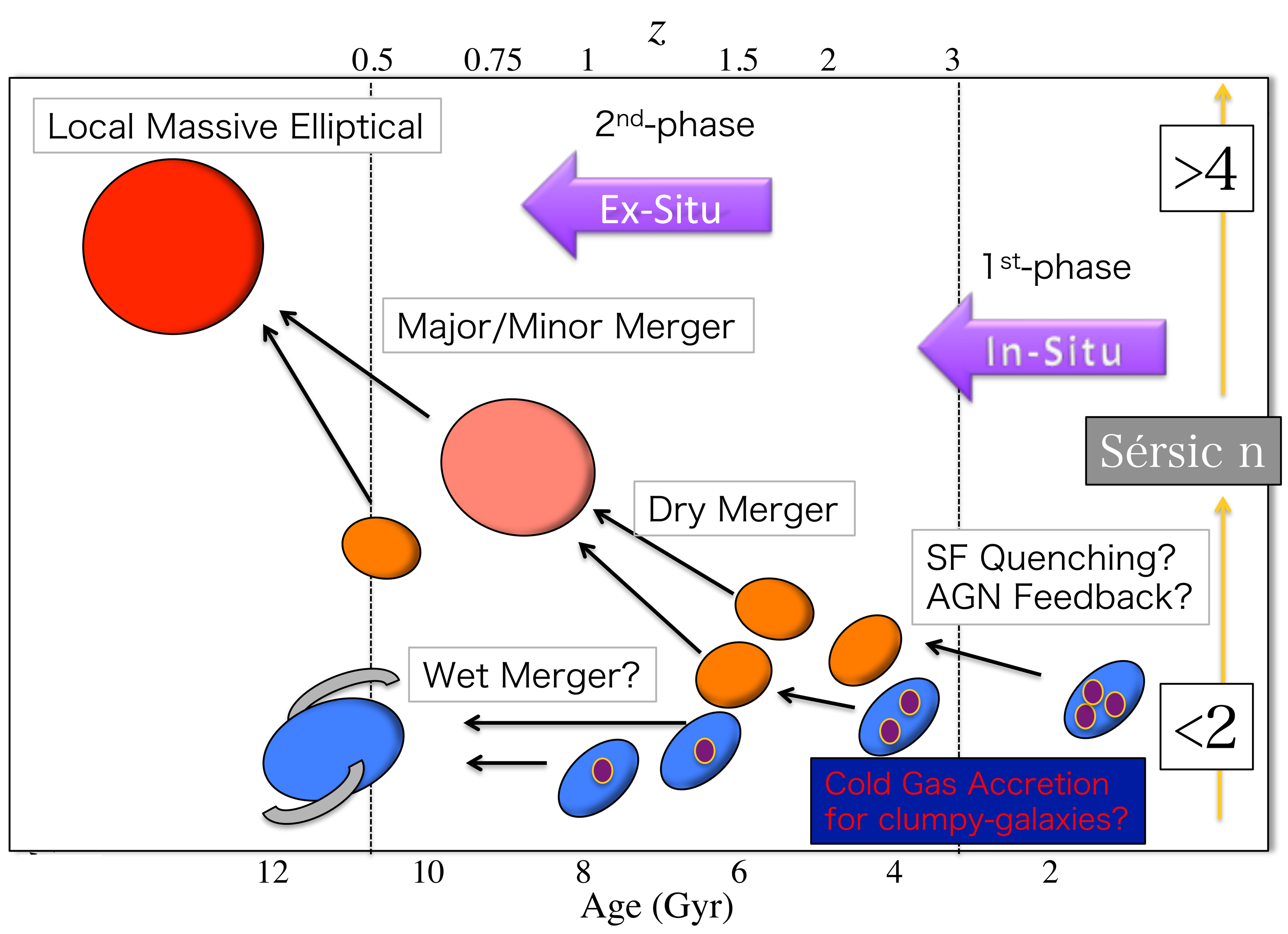


Fig.7 : Schematic view for the evolution of galaxies with redshift as x-axis. The vertical align and sizes for objects roughly represent Sérsic n and r_e derived in the present study, respectively.

In the present study, we mainly refer to the evolution of Red QGs, and there still remain many to be studied to understand the evolution of Blue SFGs.

4.Results and Discussion – How did the local Red Elliptical Galaxies evolve with redshift ? (See Fig.7)

After deriving Sérsic parameters for the sample, we see the evolution in r_e and n over the redshift range for QGs and SFGs in Figs.5 and 6.

Best fit slopes are derived with $r_e, n \propto (1+z)^{-\alpha}$, where α for each slope is shown at the left bottom in the panel. We find size evolution in massive QGs with α~1.06, a factor of 2.5 from z~2.5 to 0.5, while no or weak size evolution in Less Massive QGs and SFGs. The evolution in n also shows similar trend; evolution in Massive QGs (α~0.74) but weak in Less Massive QGs and SFGs. From the two results, we propose **2-phase evolution** for the galaxies from z~3 to 0.5, in the view of the formation of QGs (though large error dominates QGs at z>2.0). In the 1st phase (1.5≦z≦3), SFGs transition into QGs (quenching) mainly by In-Situ process such as star-formation or AGN feedback. Gas-rich (wet) mergers are also favorable because they hardly enlarge the Sérsic n. After that, the 2nd phase (z≦1.5), where gas-poor (dry) merger of QGs dominates (Ex-Situ), contributes an important role for the formation of the elliptical galaxies with larger (*e.g., Naab +09*). The schematic view for the whole scenario is shown in Fig.7.

The above, however, dips only one possible scenario out of the hundreds of complicated formation models. For a further understanding, we need to carefully stydy each *"piece of the puzzle of the GALAXY EVOLUTION"*.