arXiv, 27.06.2016, IK

arXiv:1606.07571v1:

VOLGA

View On the Life of GAlaxies

DETECTION OF PROMINENT STELLAR DISKS IN THE PROGENITORS OF PRESENT-DAY MASSIVE ELLIPTICAL GALAXIES

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Submitted to The Astrophysical Journal

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- Several studies have shown that at $z \approx 2$ a considerable fraction of the massive galaxies (stellar mass 10^{11} Msun) are compact compared to their local counterparts.
- The rarity of compact massive galaxies at the present time implies a considerable size increase in the last 10 billion years.
- Toft+2014: red nuggets на z=2 являются потомками SMG (sub-millimeter galaxies) на z=3.
- 95% of SMGs have pure or disk-dominated galaxies (Targett+2013). van der Wel+2011: 50% of massive galaxies at z>2 are disk dominated.

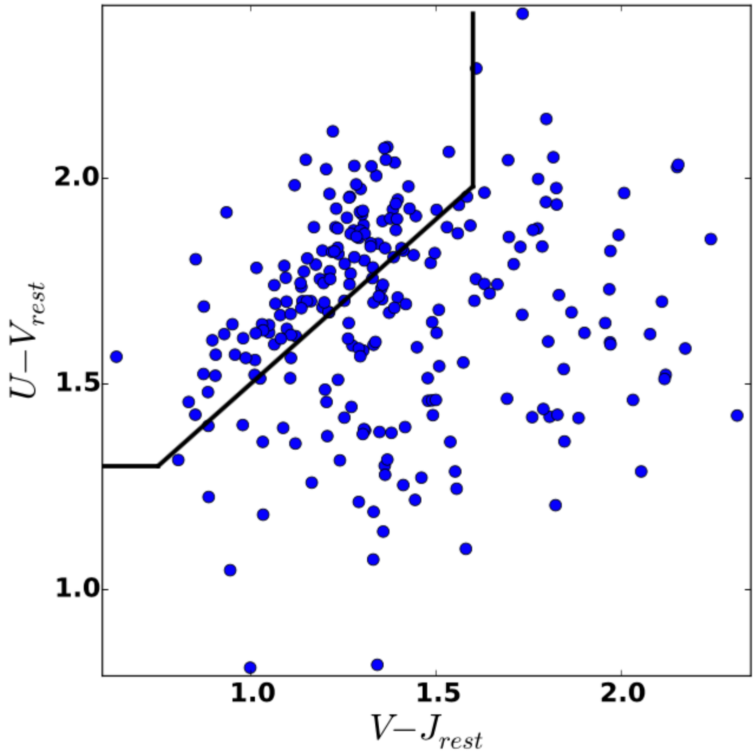


FIG. 1.— UVJ color-color diagram is used for distinguishing quiescent galaxies from star-forming galaxies. The quiescent galaxies populate the top left region of the diagram.

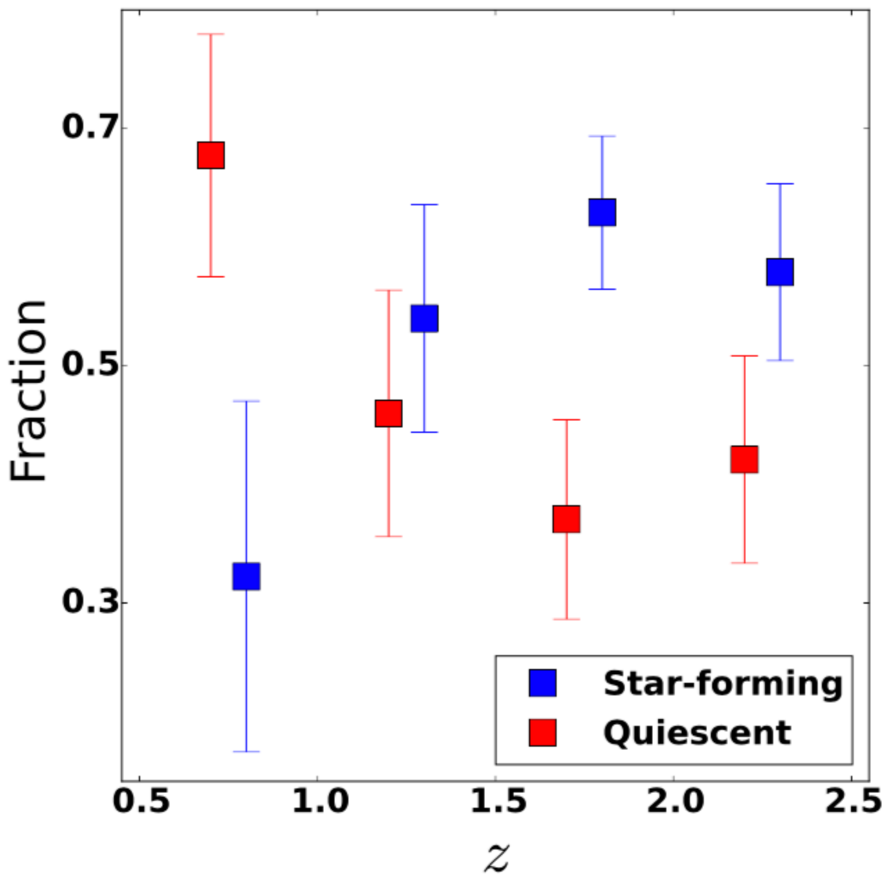


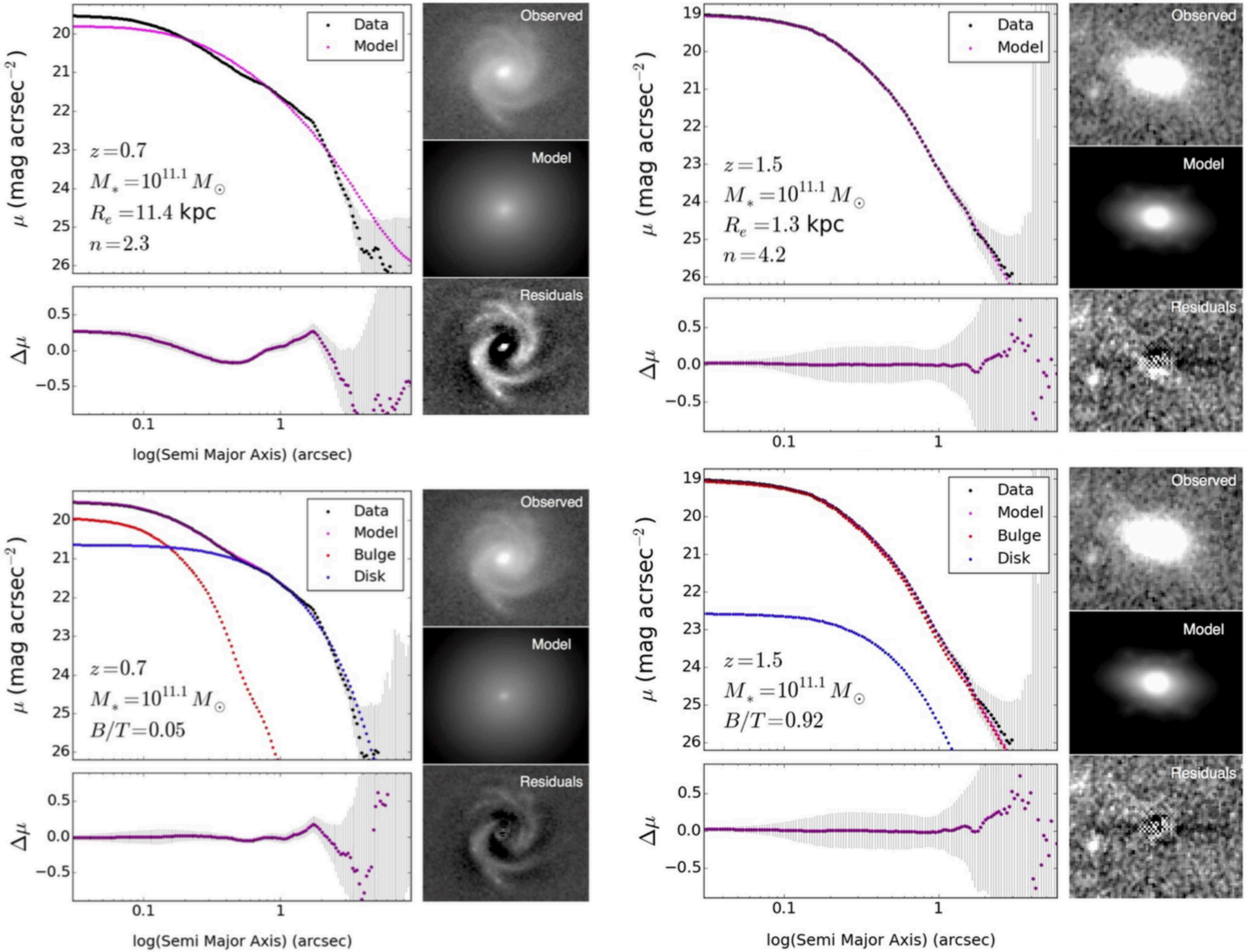
FIG. 2.— Fraction of massive star-forming and quiescent galaxies in redshift range $0.5 < z < 2.5$. Error bars show our sample proportions standard deviation.

H-BAND – SELECTED SAMPLE

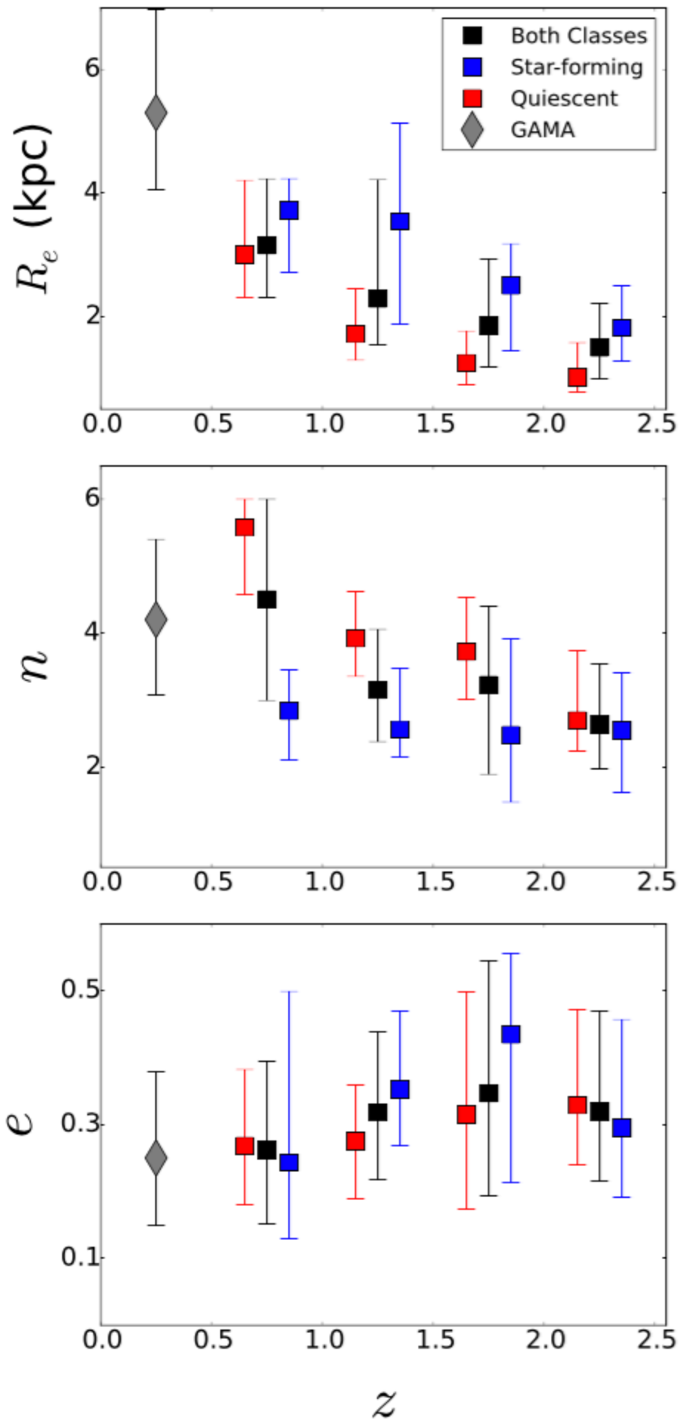
Redshift Bin (1)	$\log(M_\star/M_\odot)$ (2)	N (3)	Quiescent Fraction (4)
$0.5<z\leq1.0$	11.02–11.27	31	0.68±0.10
$1.0<z\leq1.5$	10.95–11.20	51	0.45±0.10
$1.5<z\leq2.0$	10.85–11.10	89	0.37±0.08
$2.0<z\leq2.5$	10.74–10.99	77	0.41±0.09

NOTE. — Massive galaxies selected from five different CANDELS fields: COSMOS, UDS, GOODS-South, GOODS-North, & EGS. UVJ diagram is used for distin-

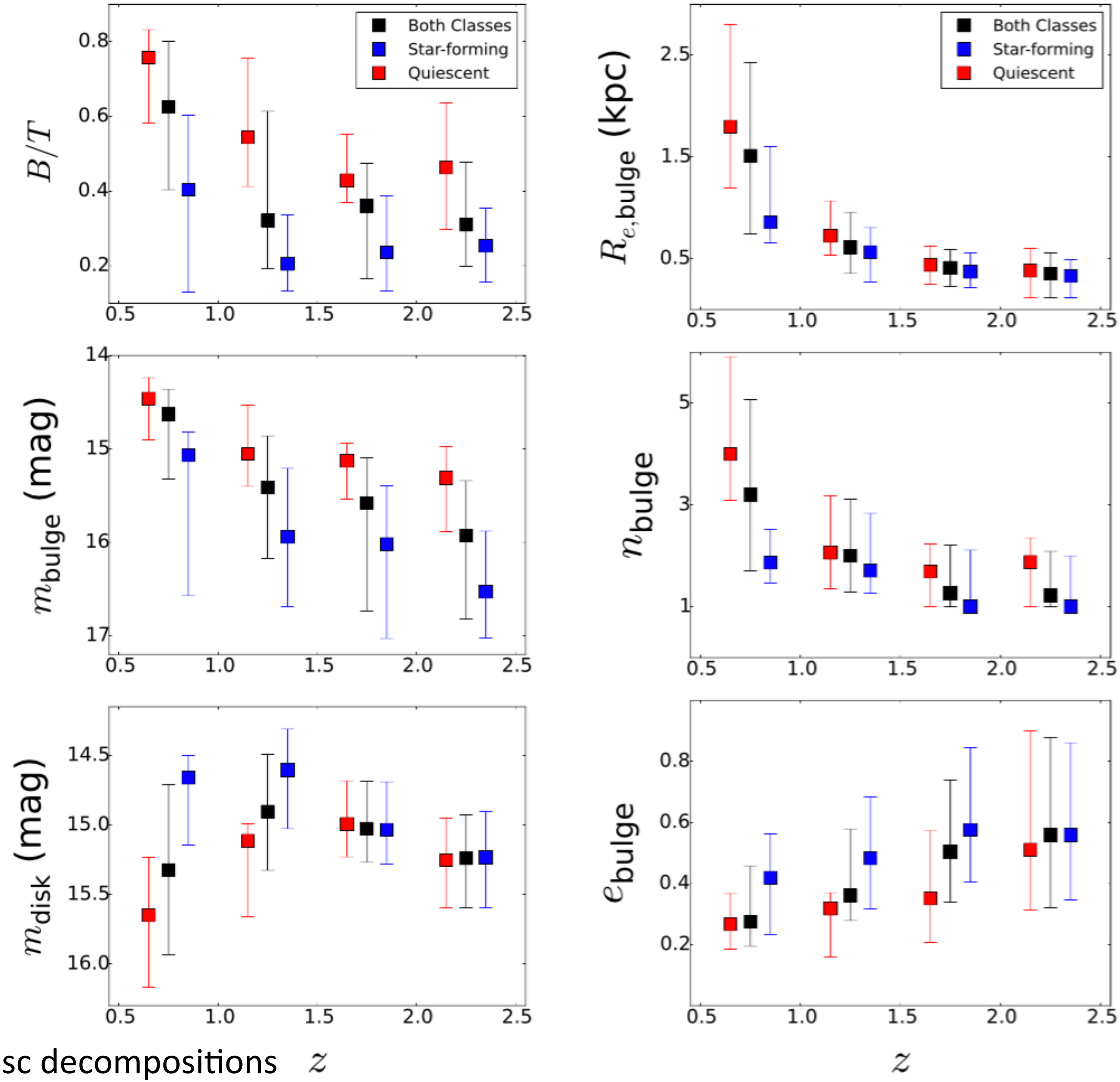
- Number density technique
- Our sample consists of ~250 massive galaxies



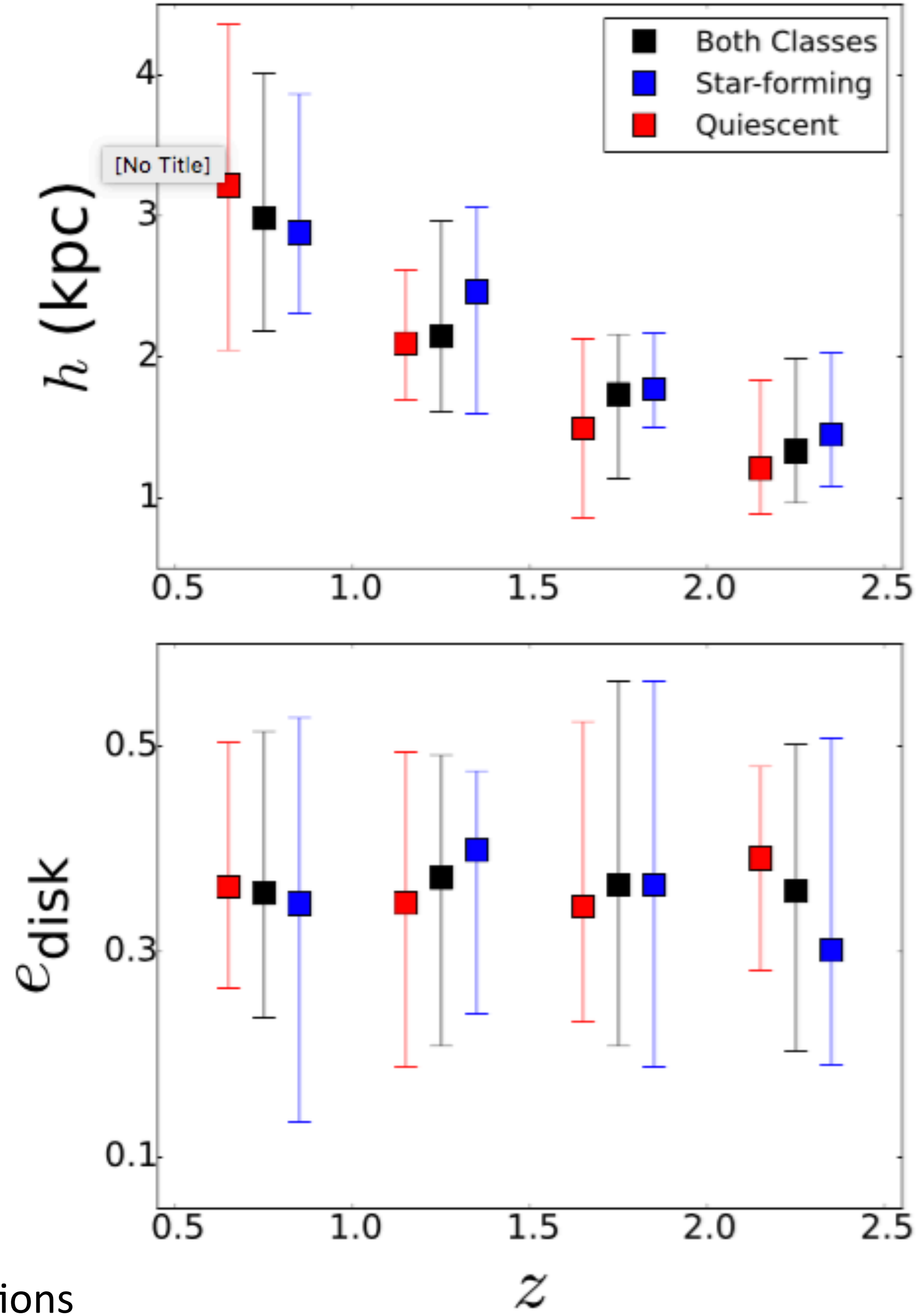
Data
Model
Observed
Model
Residuals
$z=0.7$
$M_*=10^{11.1}\,M_\odot$
$R_e=11.4$ kpc
$n=2.3$
μ (mag acrsec^{-2})
$\Delta\mu$
log(Semi Major Axis) (arcsec)
Data
Model
Observed
Model
Residuals
$z=1.5$
$M_*=10^{11.1}\,M_\odot$
$R_e=1.3$ kpc
$n=4.2$
μ (mag acrsec^{-2})
$\Delta\mu$
log(Semi Major Axis) (arcsec)
Data
Model
Bulge
Disk
Observed
Model
Residuals
$z=0.7$
$M_*=10^{11.1}\,M_\odot$
$B/T=0.05$
μ (mag acrsec^{-2})
$\Delta\mu$
log(Semi Major Axis) (arcsec)
Data
Model
Bulge
Disk
Observed
Model
Residuals
$z=1.5$
$M_*=10^{11.1}\,M_\odot$
$B/T=0.92$
μ (mag acrsec^{-2})
$\Delta\mu$
log(Semi Major Axis) (arcsec)



One Sersic models



Bulge-disc decompositions



Bulge-disc decompositions

TABLE 5
ESTIMATED FRACTION OF MASSIVE GALAXIES WITH A PROMINENT STELLAR DISK USING DIFFERENT DIAGNOSTICS

	$B/T \leq 0.5$ (1)			Spiral Structures (2)			Edge-on Disks (3) e > 0.6		
redshift bin	Quiescent	Star-forming	Both	Quiescent	Star-forming	Both	Quiescent	Star-forming	Both
$0.5<z\leq1.0$	0.17±0.07	0.67±0.11	0.36±0.07	0.05± 0.04	0.30±0.14	0.13±0.06	0	0.40±0.15	0.13±0.06
$1.0<z\leq1.5$	0.50±0.12	0.86±0.06	0.72±0.06	0	0.67±0.09	0.37±0.07	0.35±0.10	0.74±0.08	0.56±0.07
$1.5<z\leq2.0$	0.64±0.09	0.90±0.04	0.81±0.05	0	0.18±0.05	0.11±0.03	0.48±0.09	0.50±0.07	0.49±0.05
$2.0<z\leq2.5$	0.53±0.09	0.93±0.04	0.77±0.05	0	0.05±0.03	0.03±0.02	0.50±0.09	0.36±0.07	0.42±0.06

NOTE. — Col. (1) Massive galaxies with bulge-to-total ratios less than 0.5. Col. (2) Massive galaxies with visually detectable spiral structures. Col. (3) Edge-one massive galaxies with $e > 0.6$.

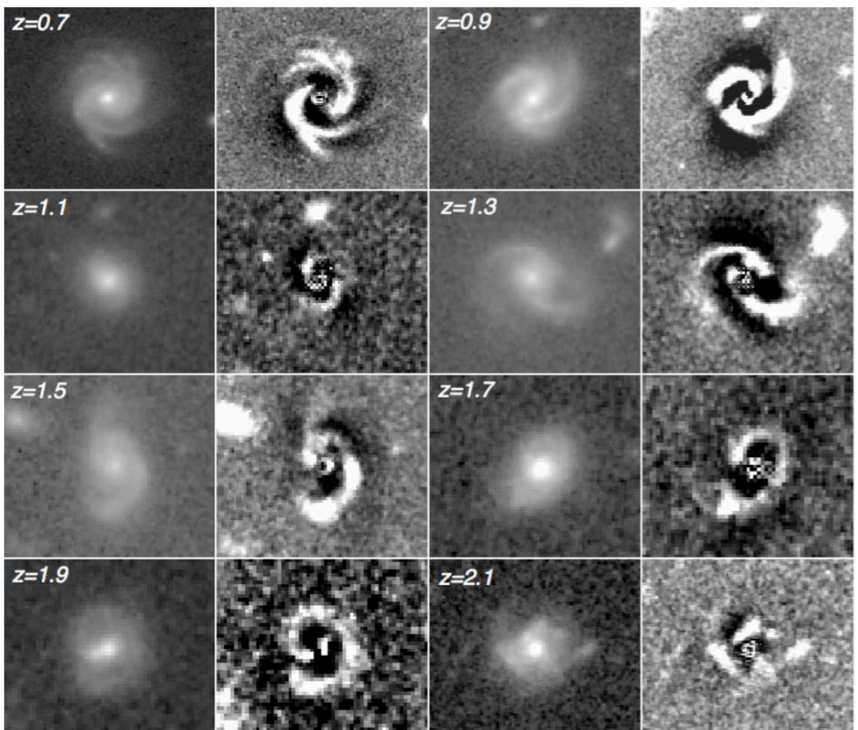


FIG. 9.— Examples of galaxies with apparent spiral structures at different redshifts. The residual images, after removal of the bulge+disk model from the original galaxy image, allows for more effective detection of fine substructure.

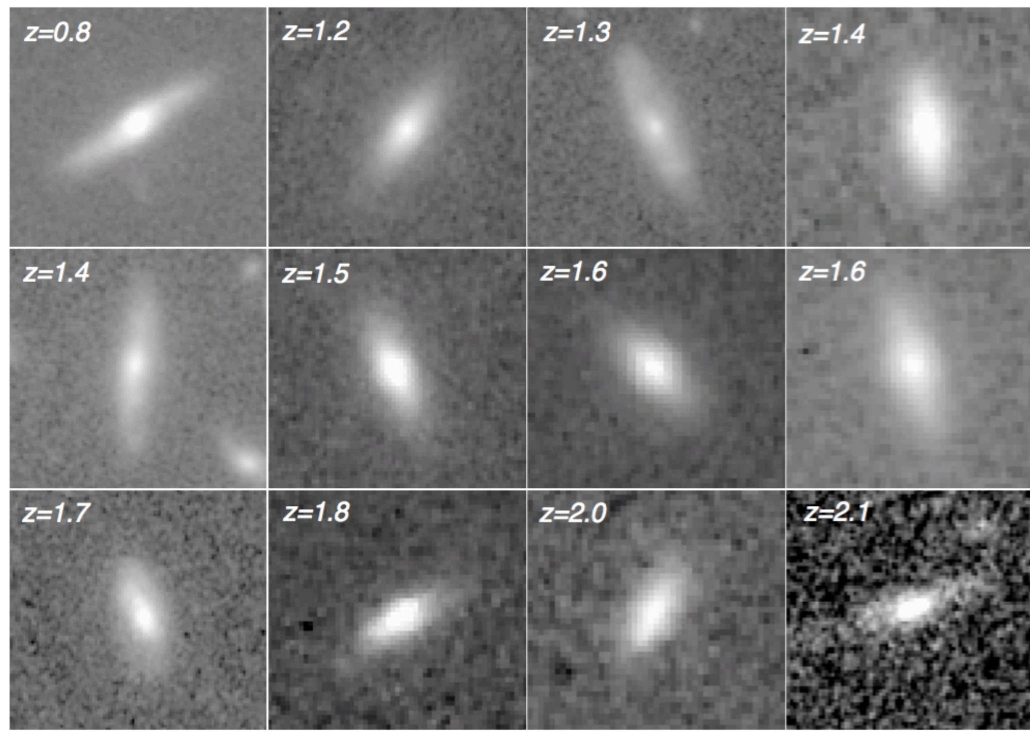


FIG. 10.— Examples of massive galaxies with an edge-pn disk at different redshifts.

Accretion onto quiescent galaxies continued at least down to z ≈0.5, whereas their star-forming counterparts seem to have topped growing by z≈ 1.

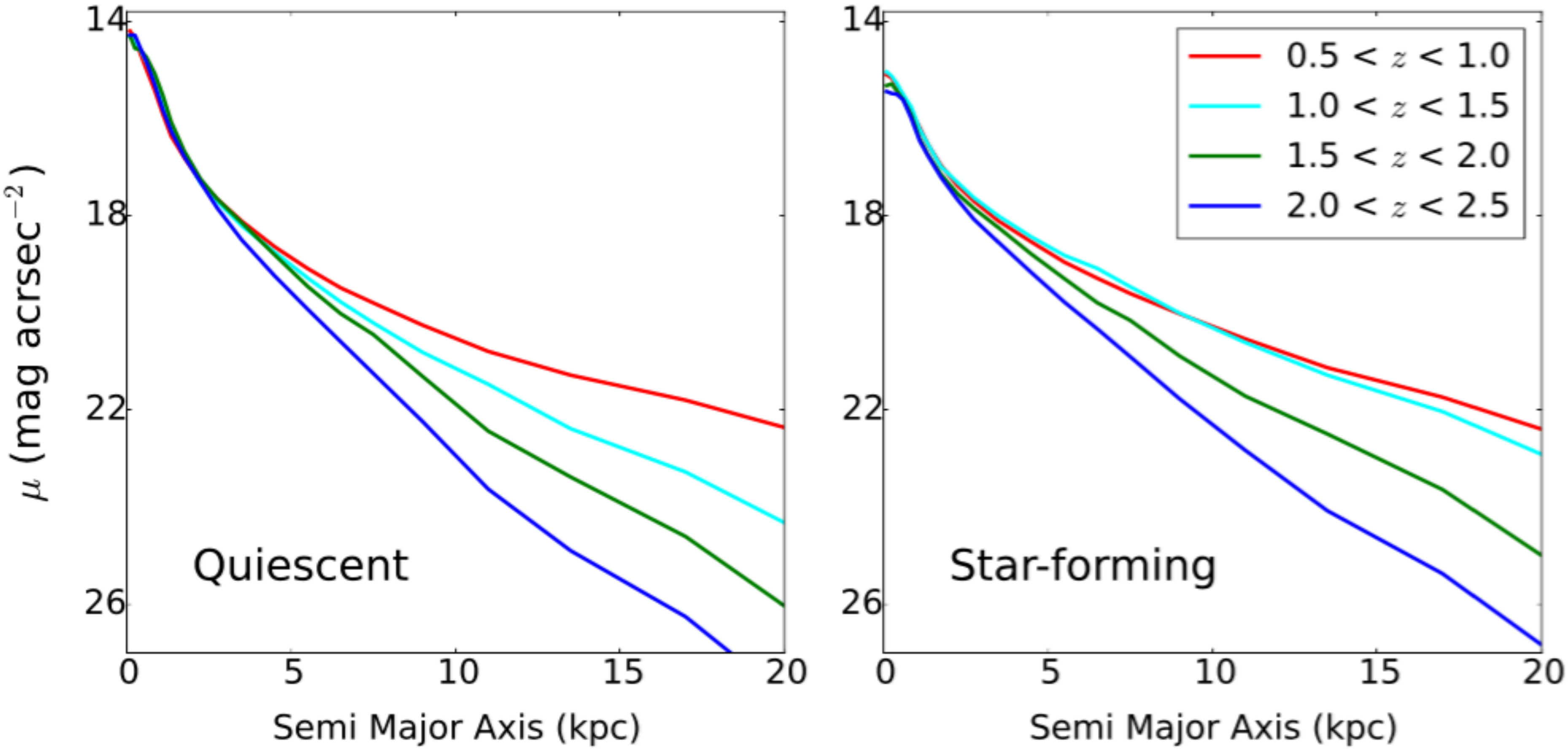


FIG. 11.— The inside-out growth of massive galaxies. Median light distributions of massive quiescent and star-forming galaxies are shown in four redshift bins. While the inner few kpc of these galaxies has been almost intact since $z \approx 2.5$, over time more material is accreted in their outskirts. Accretion onto quiescent galaxies continues at least down to $z \approx 0.5$, while it seems that star-forming galaxies stop accreting by $z \approx 1.0$. The inner region of quiescent galaxies are brighter and have a higher density than the centers of star-forming galaxies.

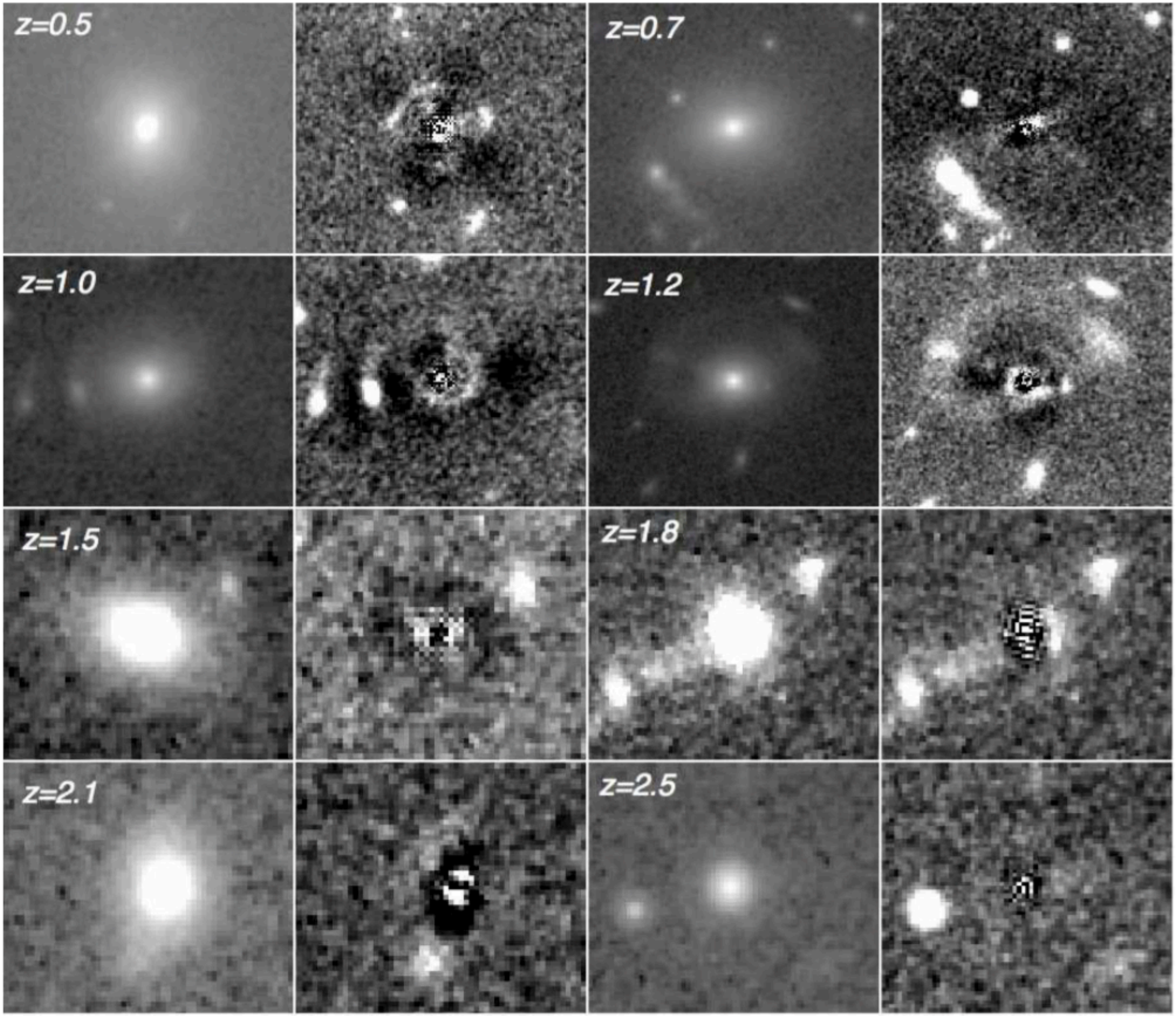


FIG. 12.— Examples of galaxies with tidal features or potentially nearby neighbors, at different redshifts. The residual images, after removal of the bulge+disk model from the original galaxy image, allows for more effective visual detection of non-axisymmetric features.

Summary

- The fraction of quiescent massive galaxies is higher at lower redshifts.
- Both star-forming and quiescent galaxies have increased their sizes significantly from $z \approx 2.5$ to the present time, and the growth has occurred inside-out.
- The global Sérsic index of quiescent galaxies has increased over time (from $n \approx 2.5$ to $n > 4$), while that of star-forming galaxies has remained roughly constant ($n \approx 2.5$).
- The distribution of global ellipticities has changed mildly with time, becoming rounder toward lower redshifts.
- The typical value of B/T has increased with decreasing redshift, both for the quiescent and star-forming subsamples. By z 0.5, massive quiescent galaxies (with B/T 0.8) begin to resemble the local elliptical galaxies. Star-forming galaxies have a lower median B/T at each redshift bin.
- The evolution of Sersic index, ellipticity, and B/T suggests that both star-forming and quiescent galaxies have a significant stellar disk at early times, which systematically became less prominent toward lower redshifts.
- A considerable fraction of our sample have visually detectable spiral structures or thin disks observed nearly edge-on, which further confirms that high-z massive galaxies have prominent stellar disks.
- While minor dry mergers can explain the inside-out growth of massive galaxies, major mergers are needed to destroy their stellar disks between redshift 2.5 and the present time.
- While the disks of star-forming and quiescent galaxies evolve similarly, their bulges follow different evolutionary trajectories. The size increase of the bulges of quiescent galaxies is more significant and their Sérsic indices and axial ratios are, on average, higher than their star-forming counterparts.