"3D-HST/CANDELS: The structural evolution of galaxies as a function of stellar mass since z=3"

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and the 3D-HST collaboration

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Cottrell Scholar Award
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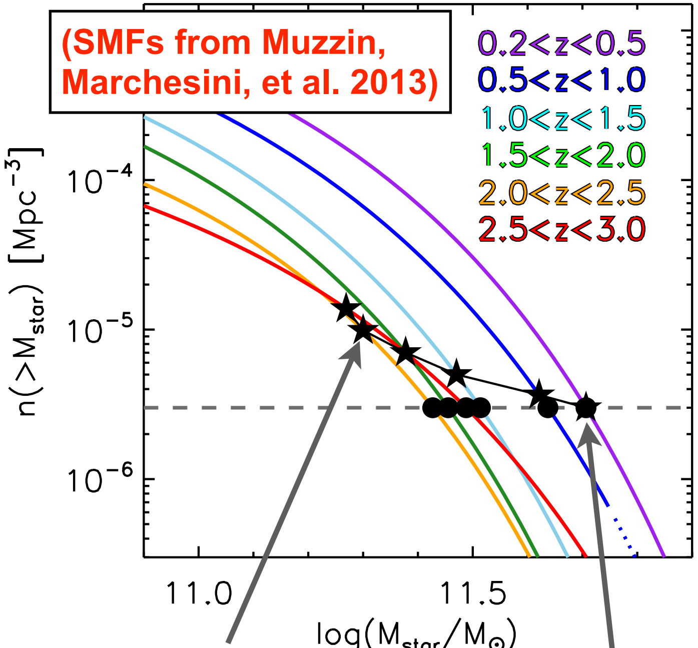
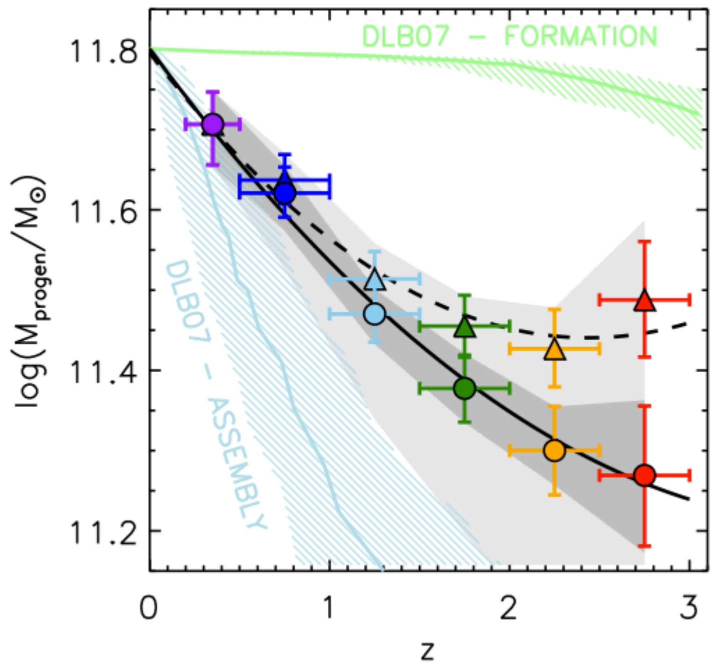
Getting a Grip on Galactic Girths

February 2-6, 2015 - IPMU (Tokyo)

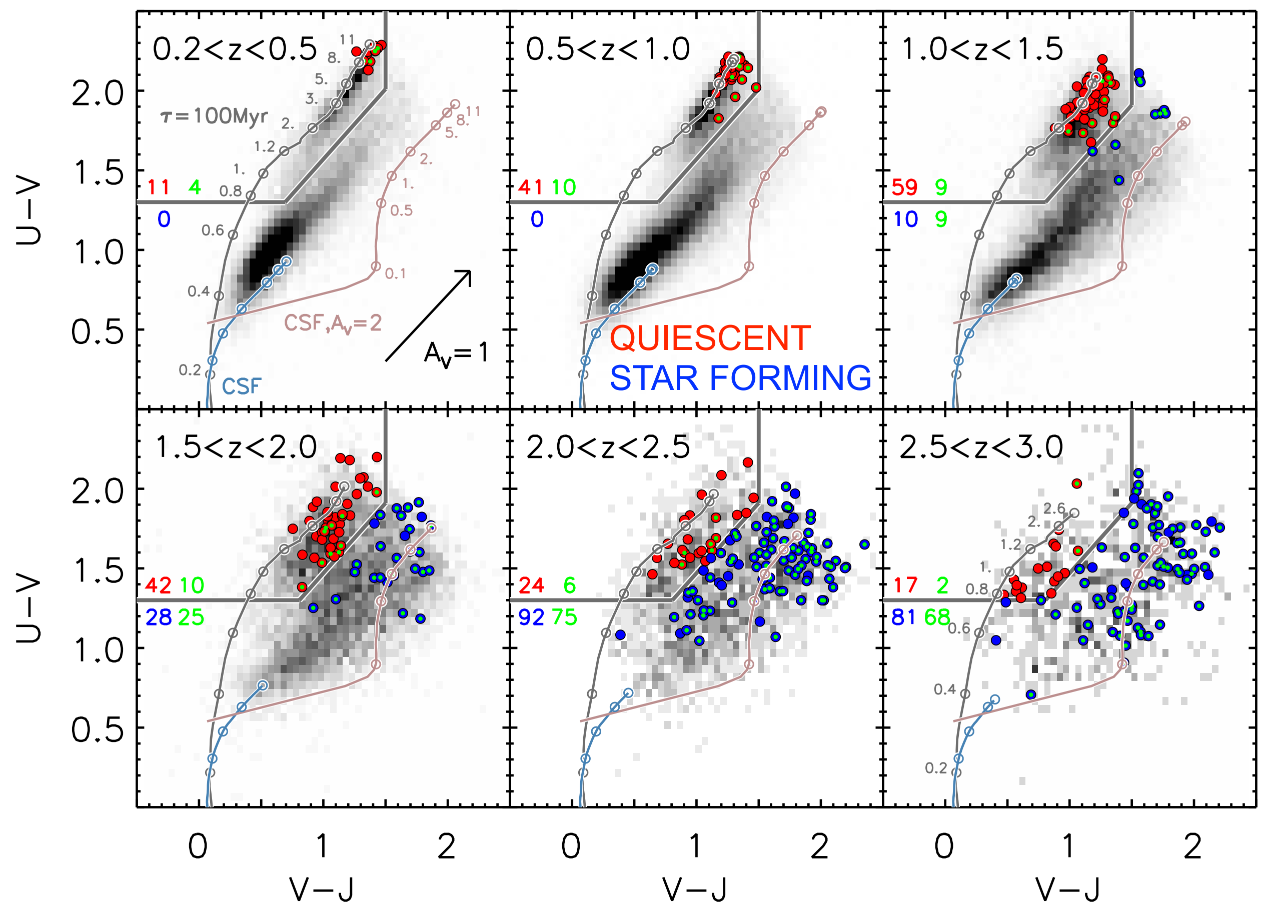


★ Abundance matching
(Behroozi, Marchesini, et al. 2014)

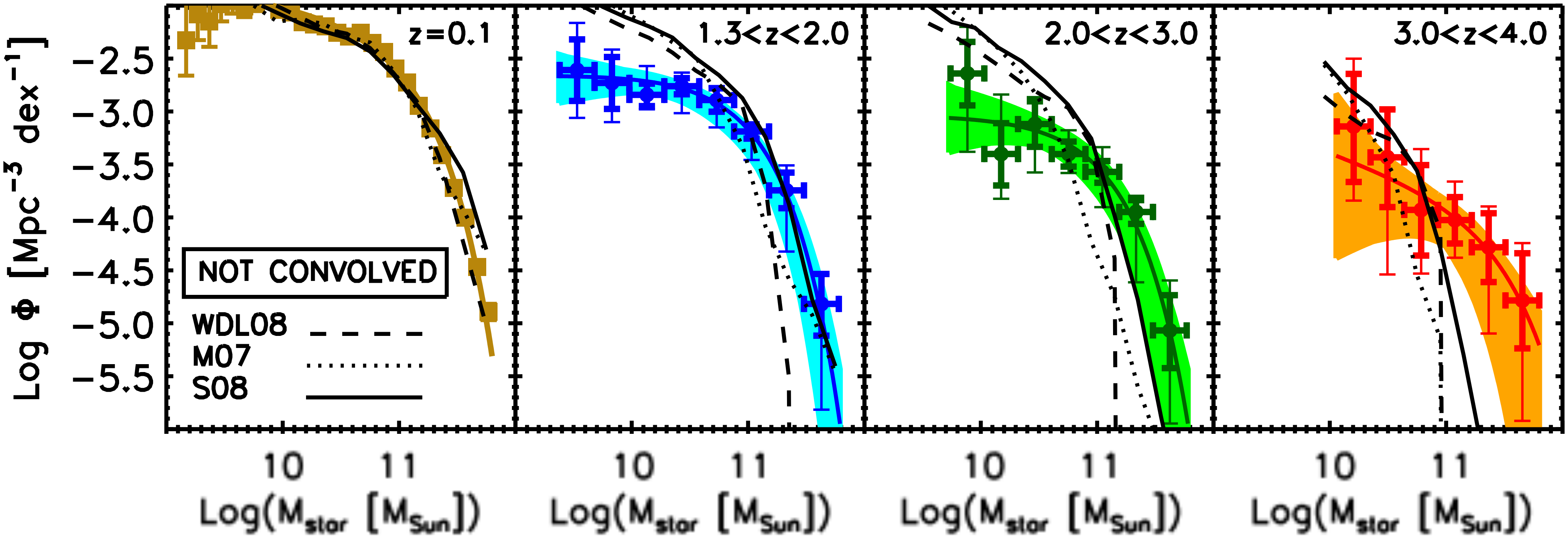
● Fixed cumulative number density
(e.g., Brammer, DM, et al. 2011; Leja et al. 2013)



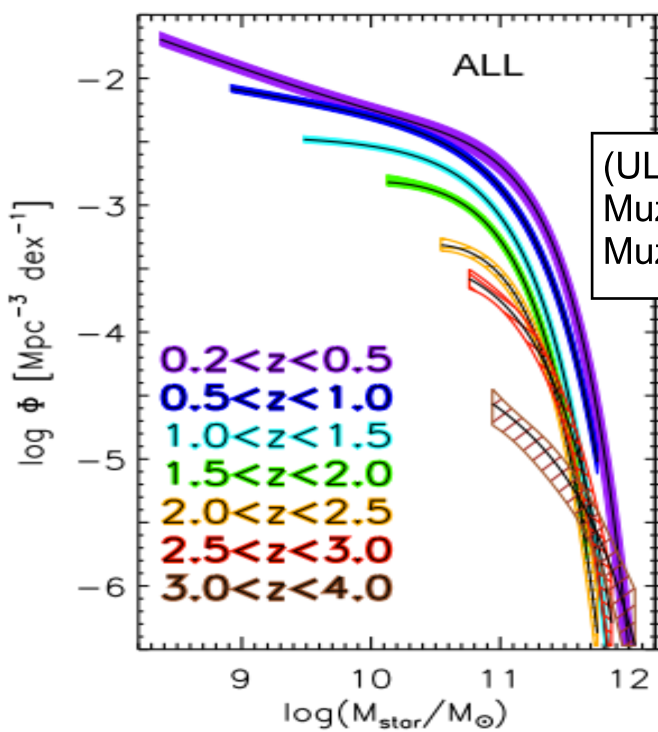
(Marchesini et al. 2014)



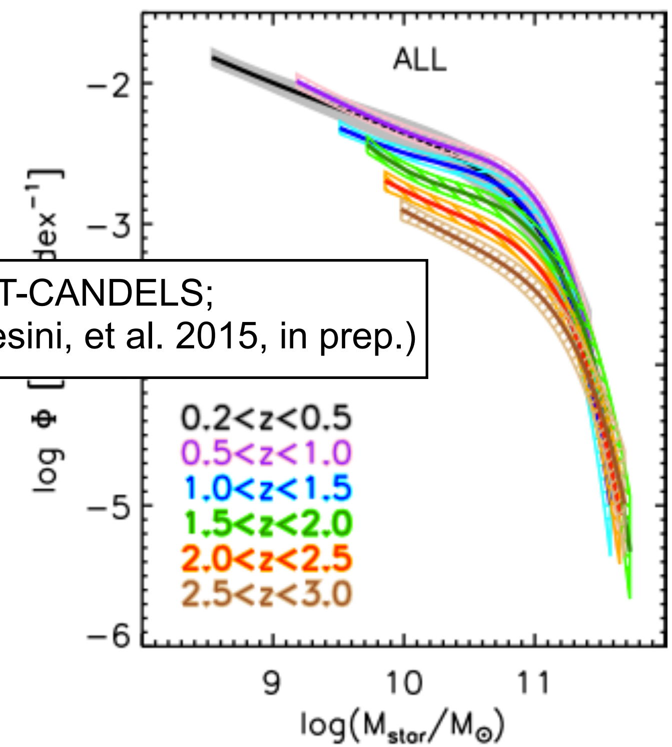
Evolution of the Stellar Mass Function (SMF)



(MUSYC+FIRES+FIREWORKS;
Marchesini et al., 2009)

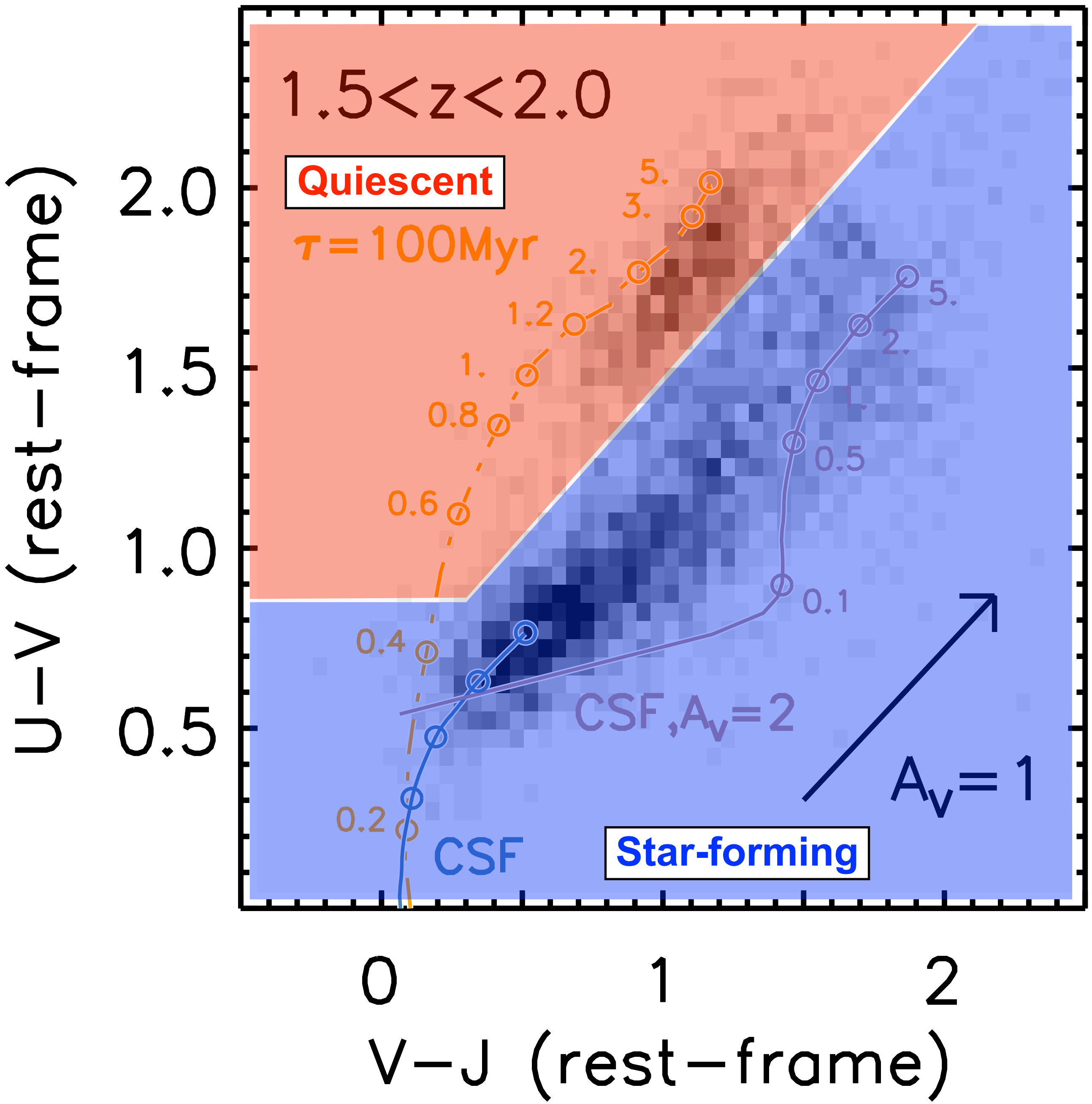


(ULTRAVISTA DR1;
Muzzin, Marchesini, et al. 2013a;
Muzzin, Marchesini, et al. 2013b)



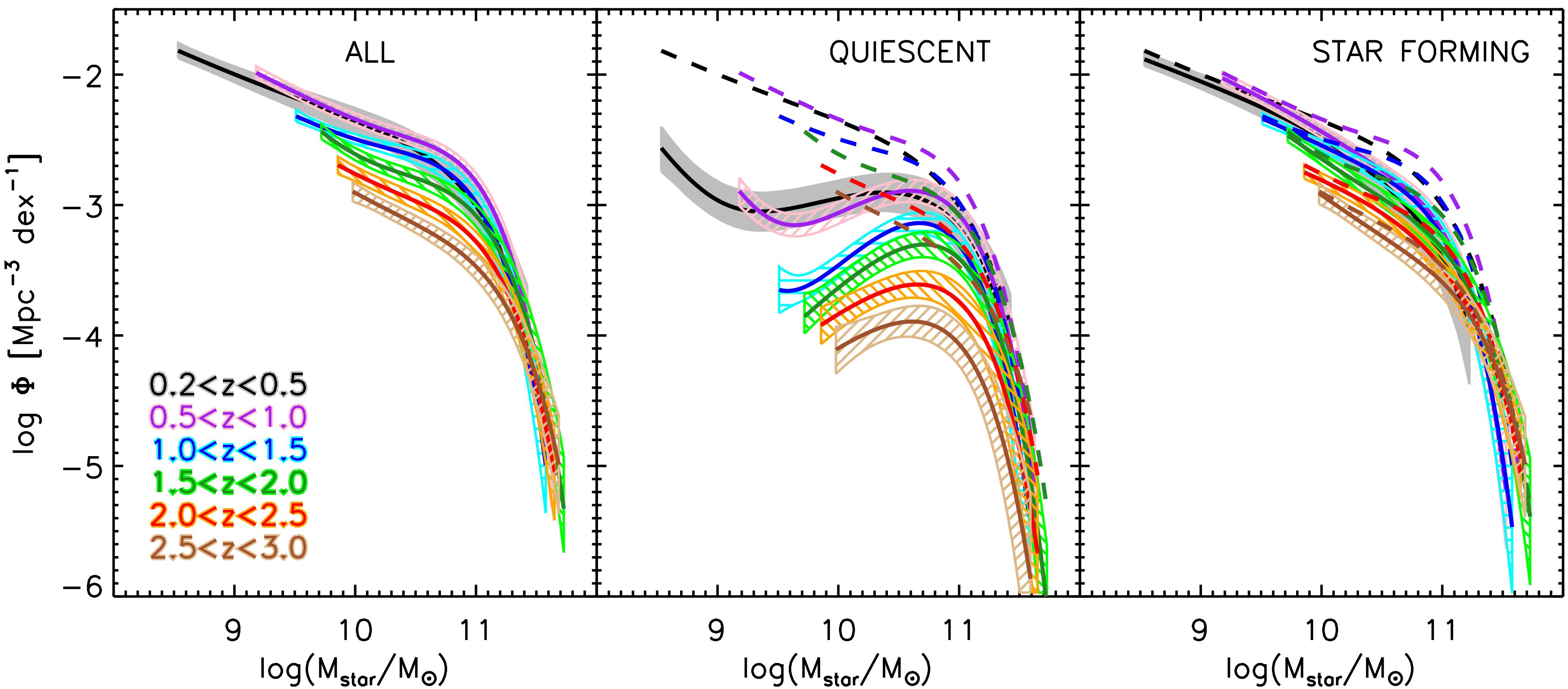
(3DHST-CANDELS;
Marchesini, et al. 2015, in prep.)

The UVJ diagram to separate Quiescent and Star-forming Galaxies



(3DHST-CANDELS)

Evolution of the Stellar Mass Function (SMF)

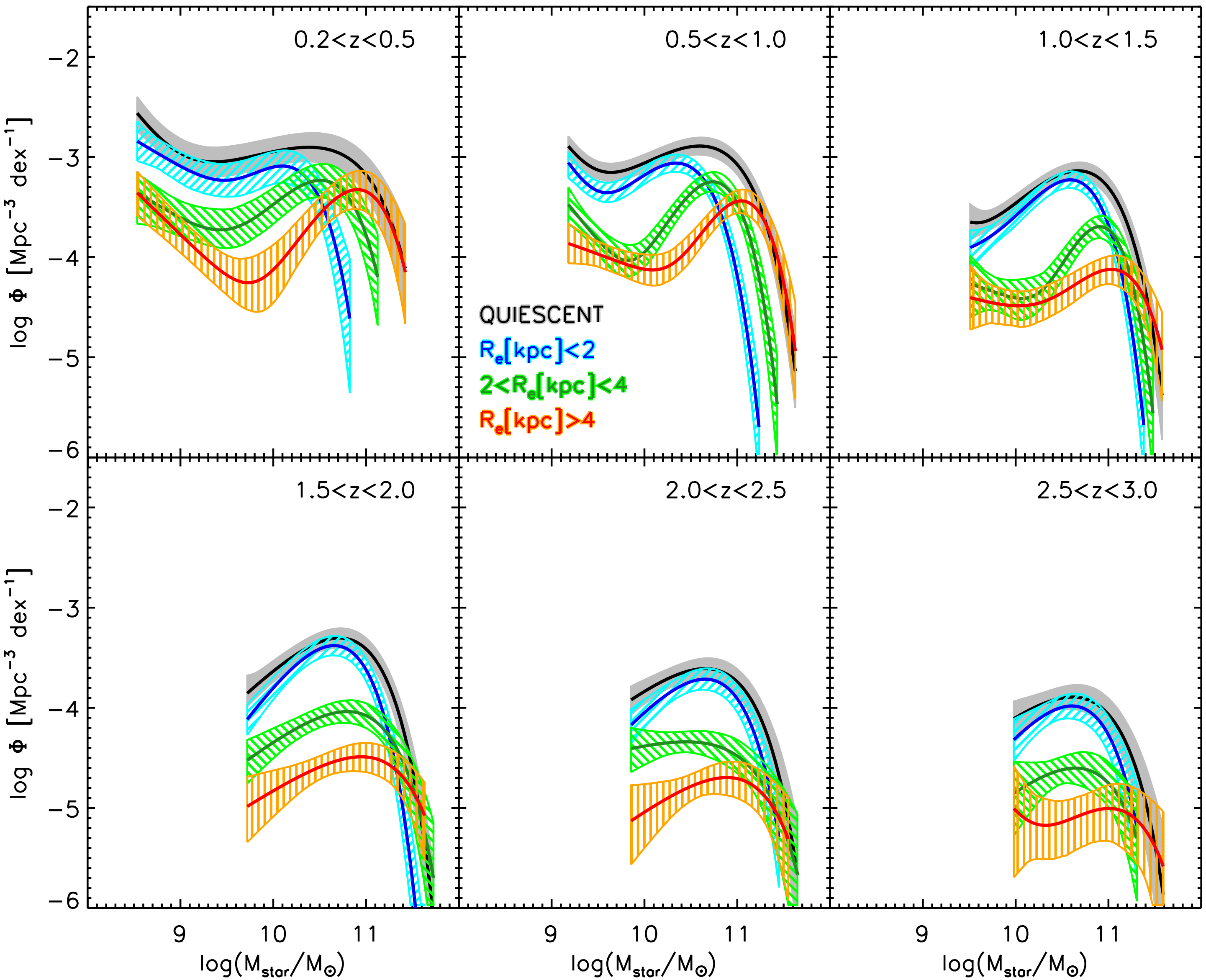


(Marchesini et al. 2015, in prep.; see also Muzzin, Marchesini, et al., 2013; and many many others)

3D-HST + CANDELS

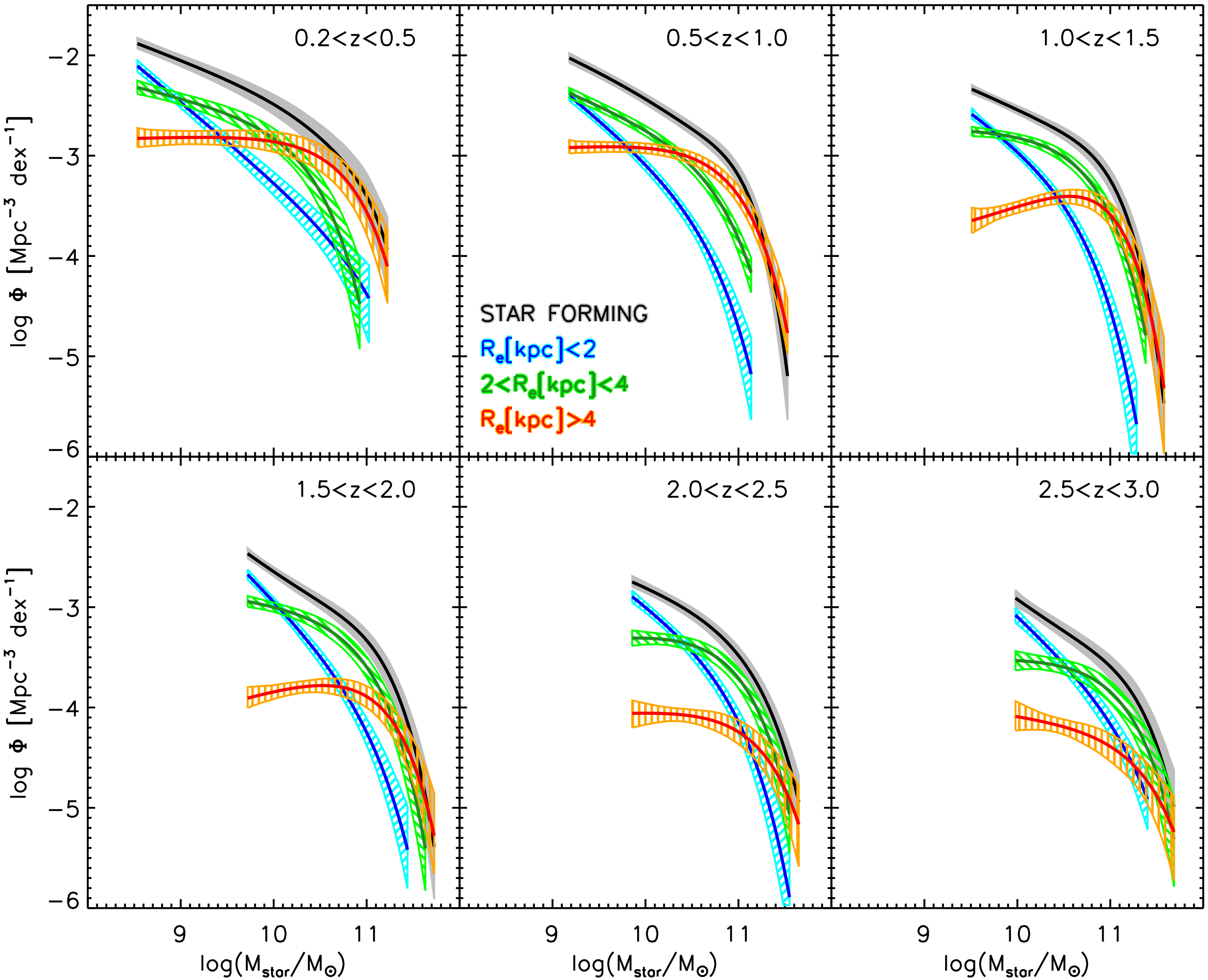
- Multi-wavelength photometry in AEGIS, COSMOS, UDS, and GOODS-N/S produced by the 3D-HST collaboration (Skelton et al. 2014)
- Grism redshifts from 3D-HST
- Effective surveyed area: **891.1 arcmin^2** over **5 independent fields**
- **21717 galaxies** at 0.2<z<3 with **H_{160}<25.1 AB** (completeness far better than 90%)
- **16.5% with z_{spec}, 39.1% with** reliable **z_{grism}**, 44.4% with z_{phot}
- **Standard definition of M_{star}** adopted (not the integral of SFH)
- Structural parameters (size and Sersic index) from van der Wel et al. (2012, 2014)
- Six redshift intervals: **0.2<z<0.5** (2437 galaxies), **0.5<z<1.0** (6799 galaxies), **1.0<z<1.5** (5229 galaxies), **1.5<z<2.0** (3745 galaxies), **2.0<z<2.5** (2228 galaxies), **2.5<z<3.0** (1279 galaxies).

SMF of quiescent galaxies as a function of **SIZE**



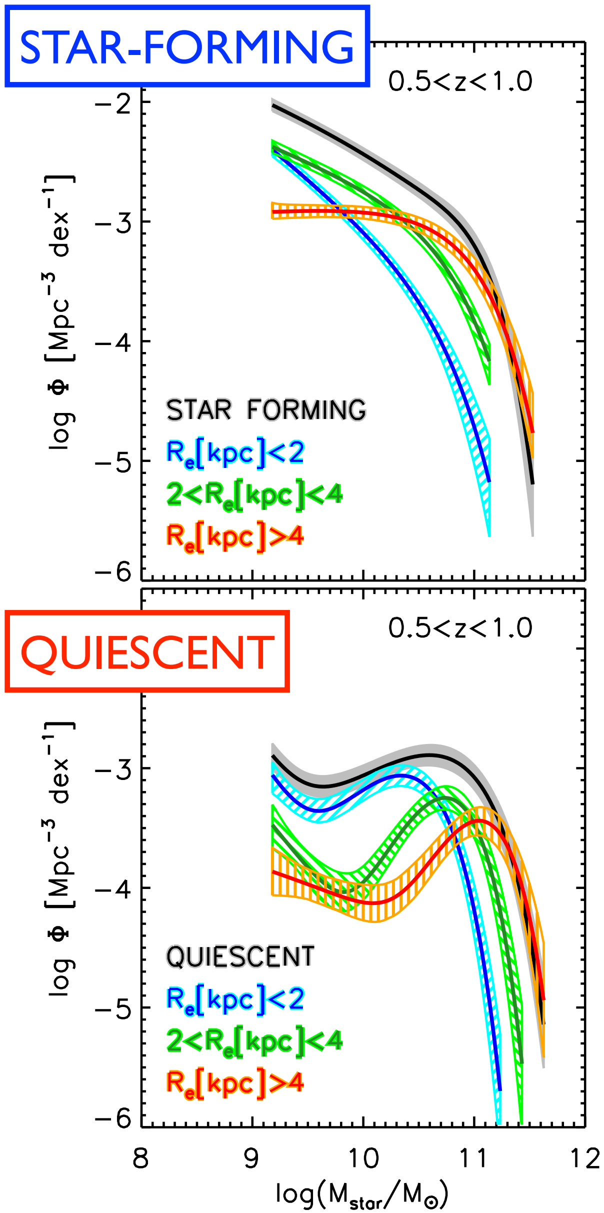
- At z<1, large galaxies dominate high-mass end of the SMF of quiescent galaxies; small galaxies dominate the low-mass end.
- Increasing importance with redshift of small galaxies at high-mass end; large galaxies non negligible only for most massive galaxies.
- At 2.5<z<3, quiescent galaxies mostly small, except for most massive.
- At all redshifts, the most massive galaxies are large (Re>4 kpc).

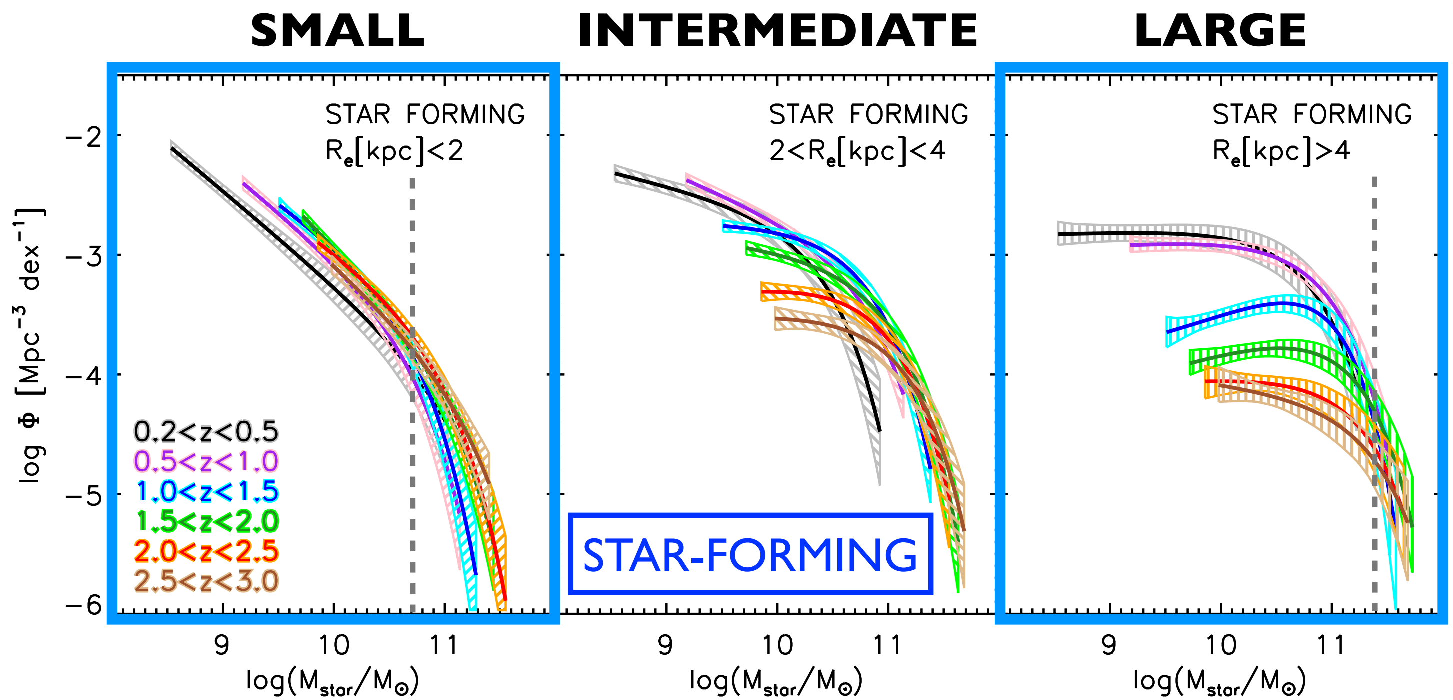
SMF of star-forming galaxies as a function of **SIZE**



- Very different evolution compared to the quiescent galaxies.
- At high redshift, typical SF galaxies have intermediate sizes; large SF galaxies are rare, and small galaxies contribute significantly only at lgM<11.
- With cosmic time, the relative contribution of small galaxies decreases, while that of large galaxies increases, dominating the high-mass end at z<1.5.

Evolution with redshift of SMFs of quiescent and star-forming galaxies as a function of SIZE

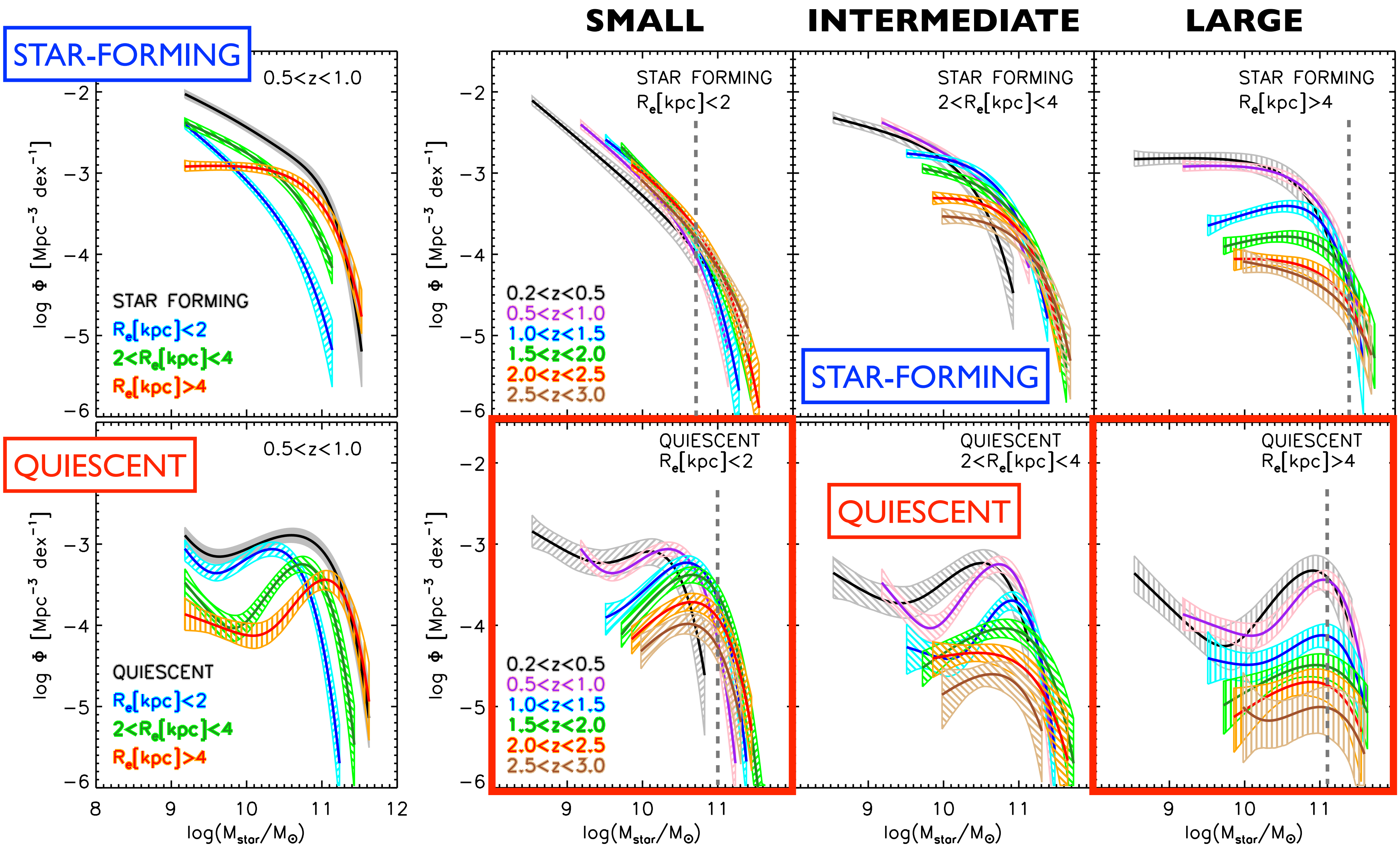




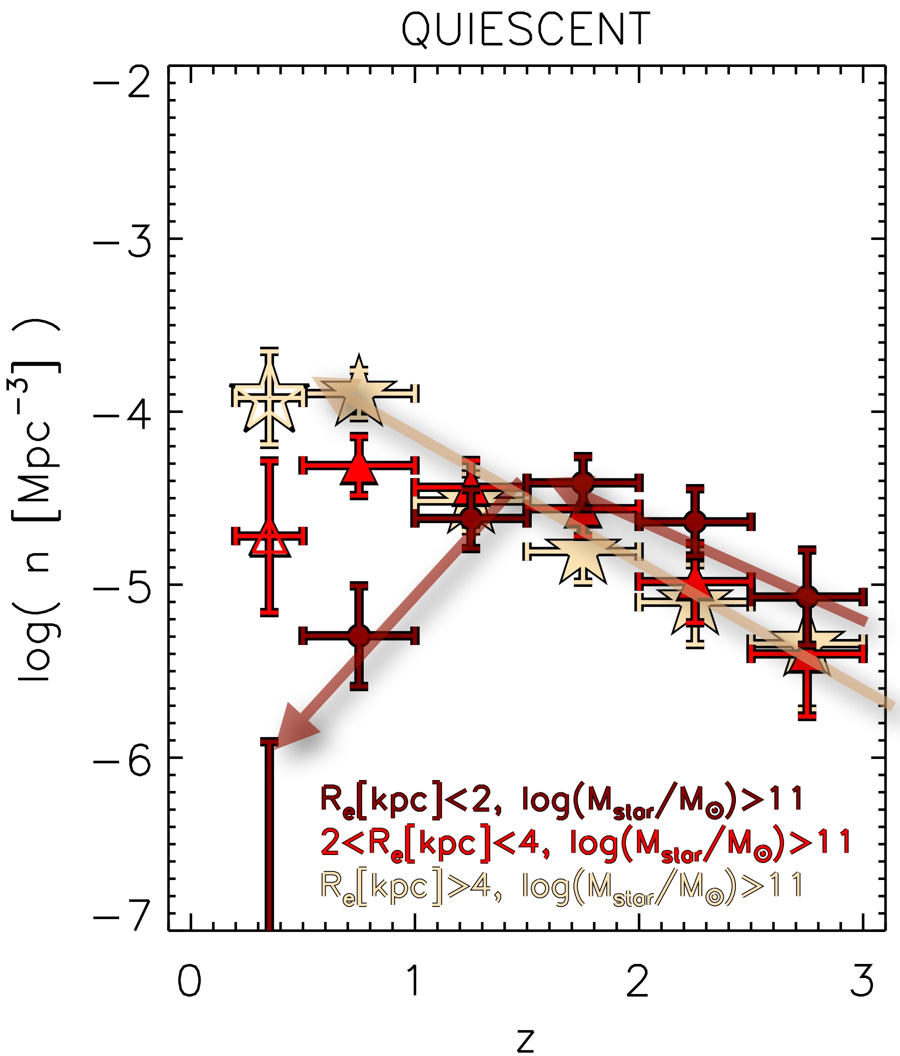
- Star-forming galaxies become progressively larger with cosmic time

Q1: Why are small SF galaxies not evolving much in number at lgM<10.7, whereas dramatic growth of the number of intermediate and large SF galaxies with lgM<11? How do we interpret this?

Evolution with redshift of SMFs of quiescent and star-forming galaxies as a function of SIZE

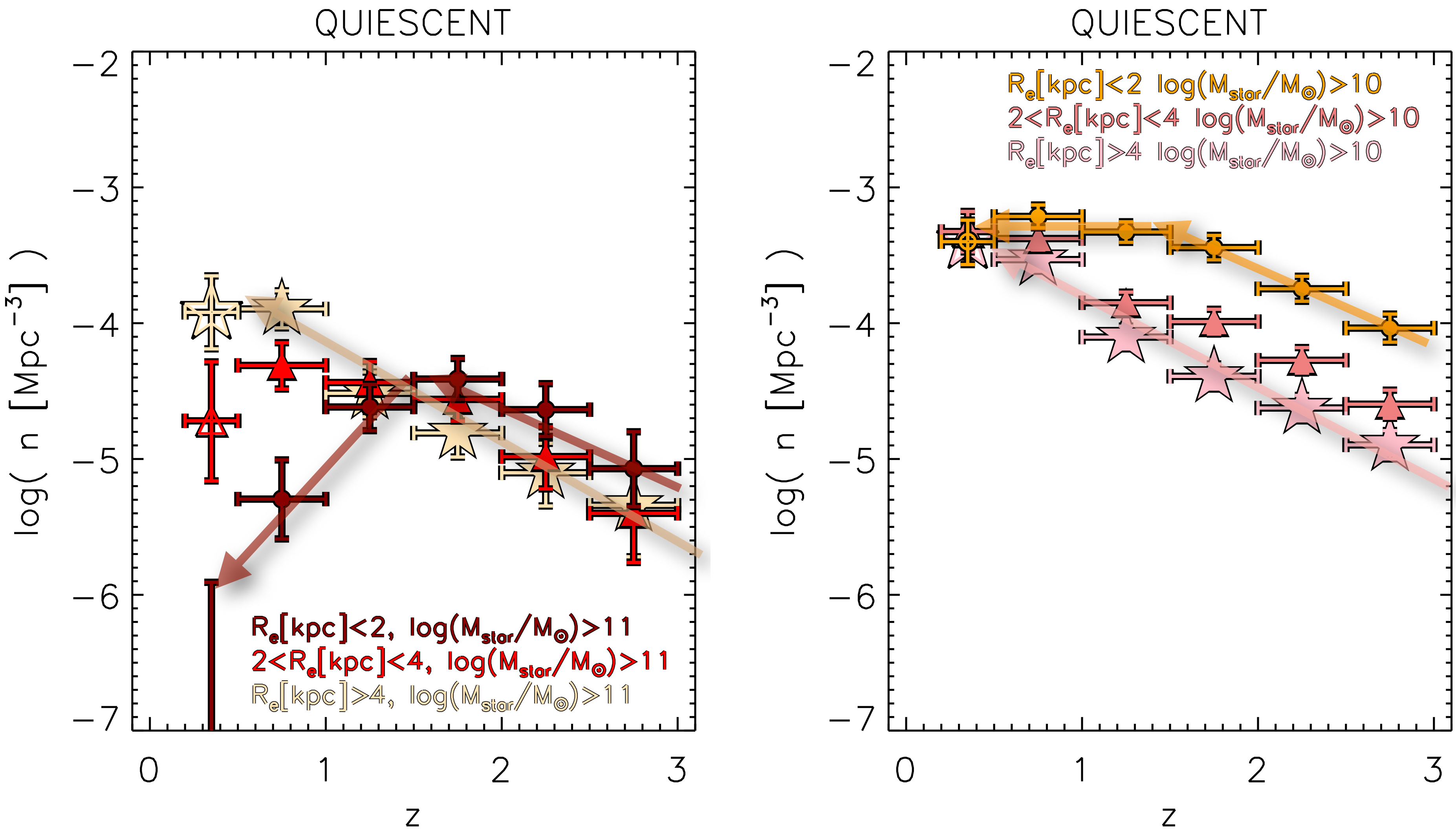


Evolution with redshift of the **number density** of **quiescent** galaxies of different **SIZES**



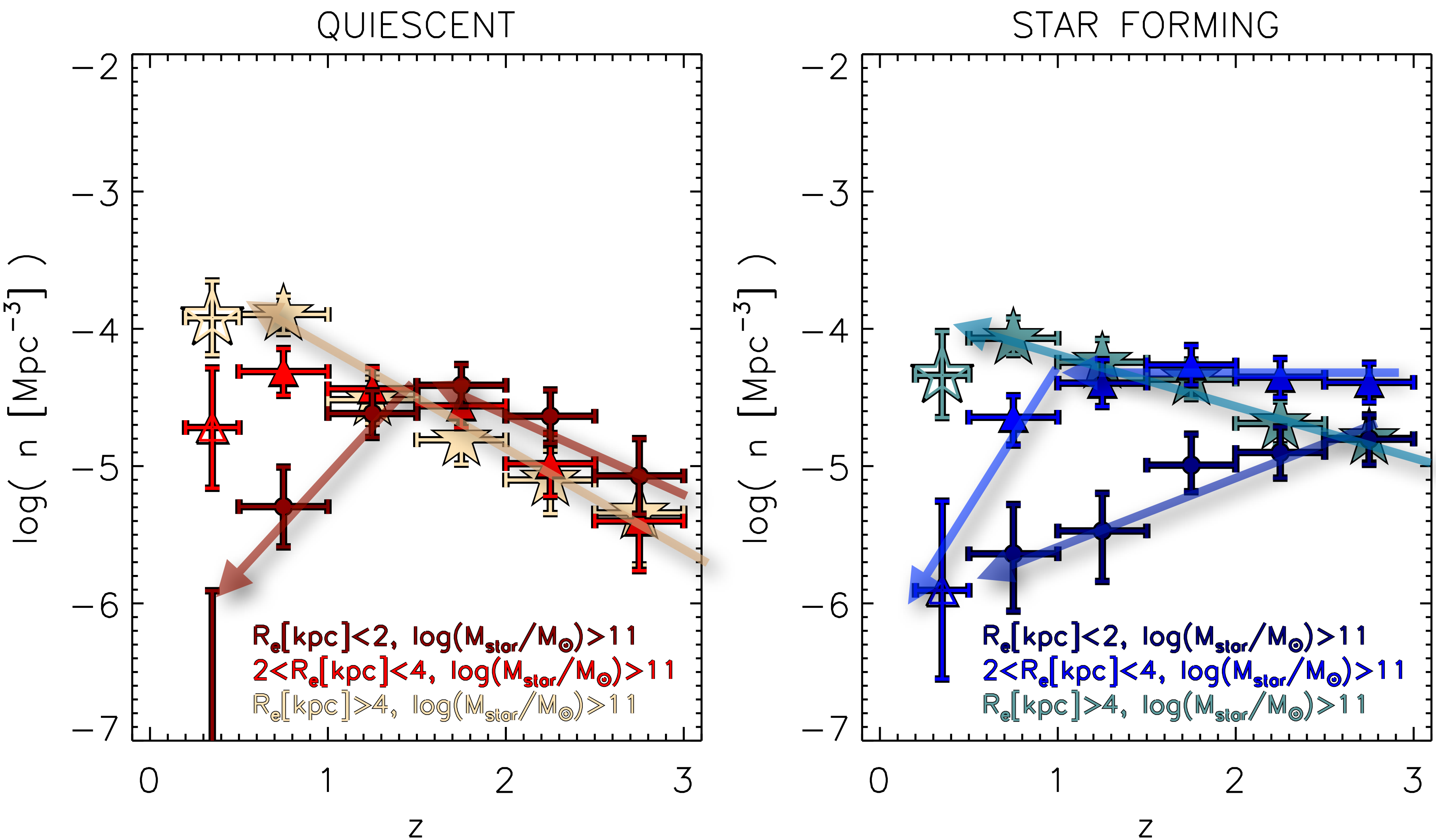
- Small galaxies dominate the population of massive quiescent galaxies at high z. Their number density grows by a factor of ~7 from z=3 to z=1.5, and then decreases rapidly by 10x fro z=1.5 to z=0.5. At 0.2<z<0.5, small massive quiescent galaxies are very rare.
- Large increase (~30x) of the number density of massive large quiescent galaxies from z=3 to z=0.5. Large (R_e>4 kpc) galaxies dominate the massive quiescent population at z<1

Evolution with redshift of the **number density** of **quiescent** galaxies of different **SIZES**



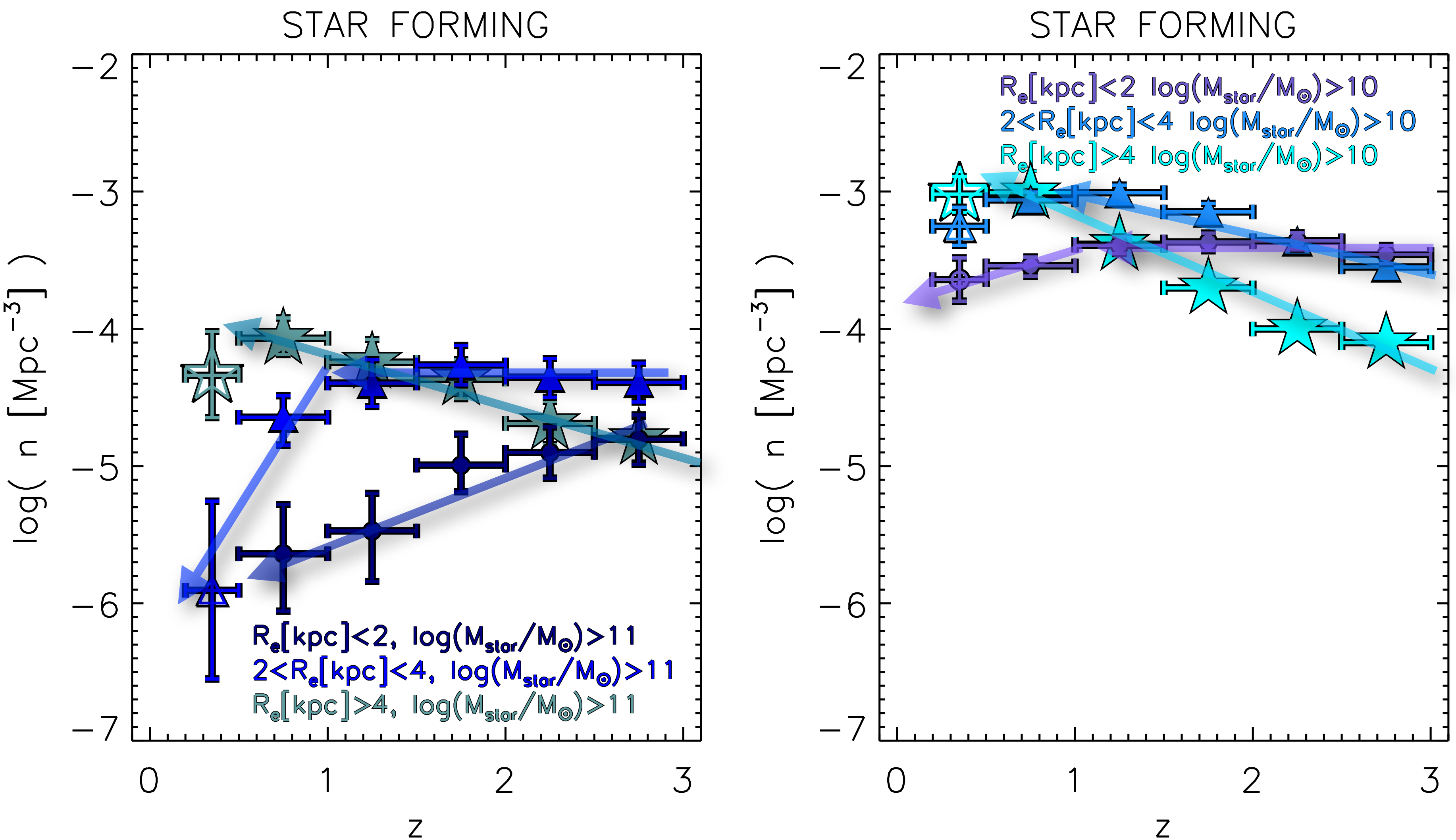
- Small galaxies dominate the population of lgM=10-11 quiescent galaxies at z>1. The number density of small, quiescent galaxies with lgM>10 increases with time down to z~1.5, and then it remains roughly constant (differently from lgM>11 small quiescent galaxies)
- The number density of large quiescent galaxies with lgM>10 increases steadily with time by ~30x from z=3 to z=0.5.

Evolution with redshift of the **number density** of **star-forming** galaxies of different **SIZES**



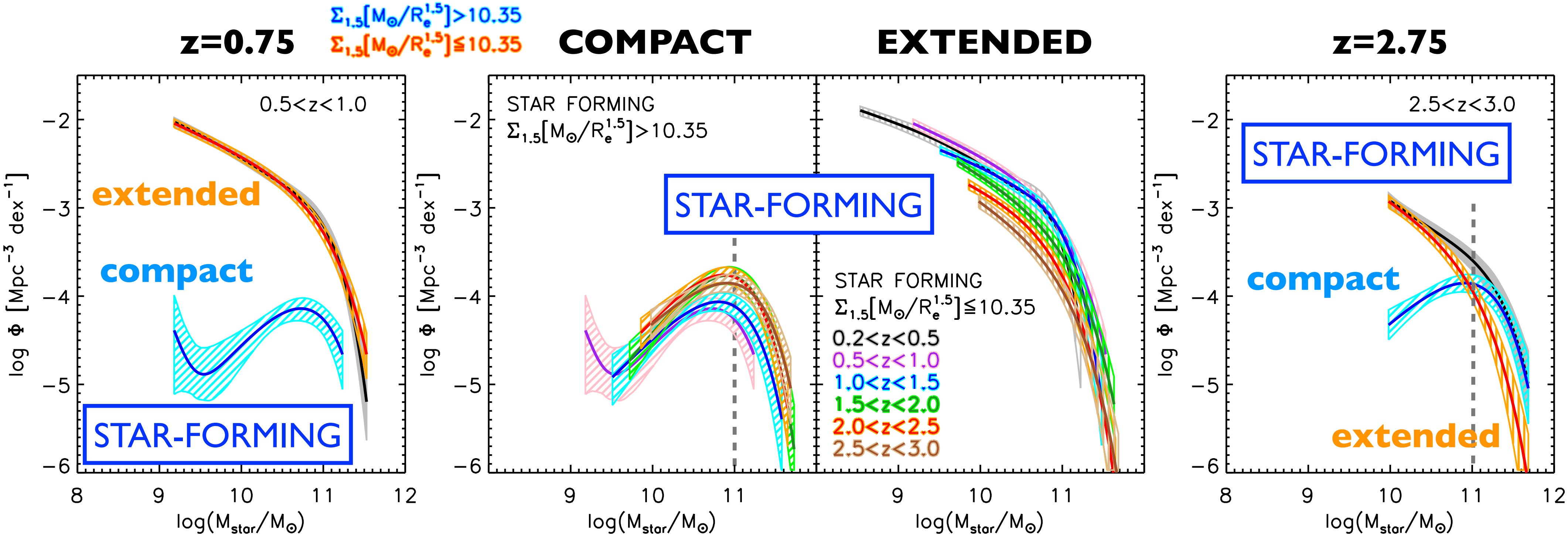
- The number density of small, massive SF galaxies decreases steadily from z=3 to z=0.5 by a factor of ~8, and more than 10x down to z=0.2.
- Intermediate size galaxies are dominant type among massive SF population at high z, with density roughly constant down to z~1, then decreasing rapidly.
- Density of large, massive SF galaxies increases with time, becoming dominant at z<1.5

Evolution with redshift of the **number density** of **star-forming** galaxies of different **SIZES**

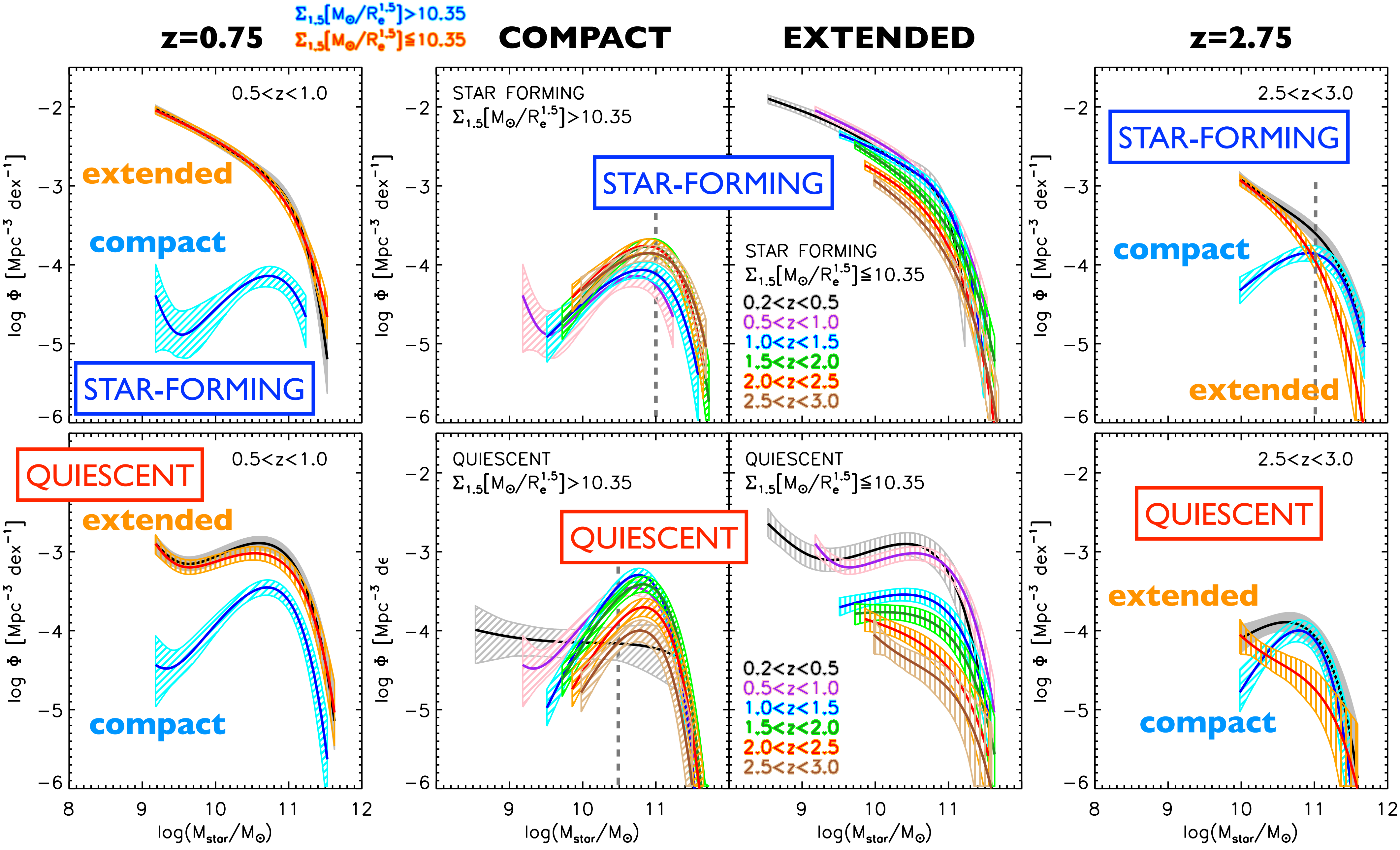


- The number density of small, SF lower-mass galaxies remains roughly constant with time, with slight decrease at z<1
- The number density of intermediate size, lower-mass SF galaxies grows slowly with time; fast growth of the number density of large SF Galaxies.

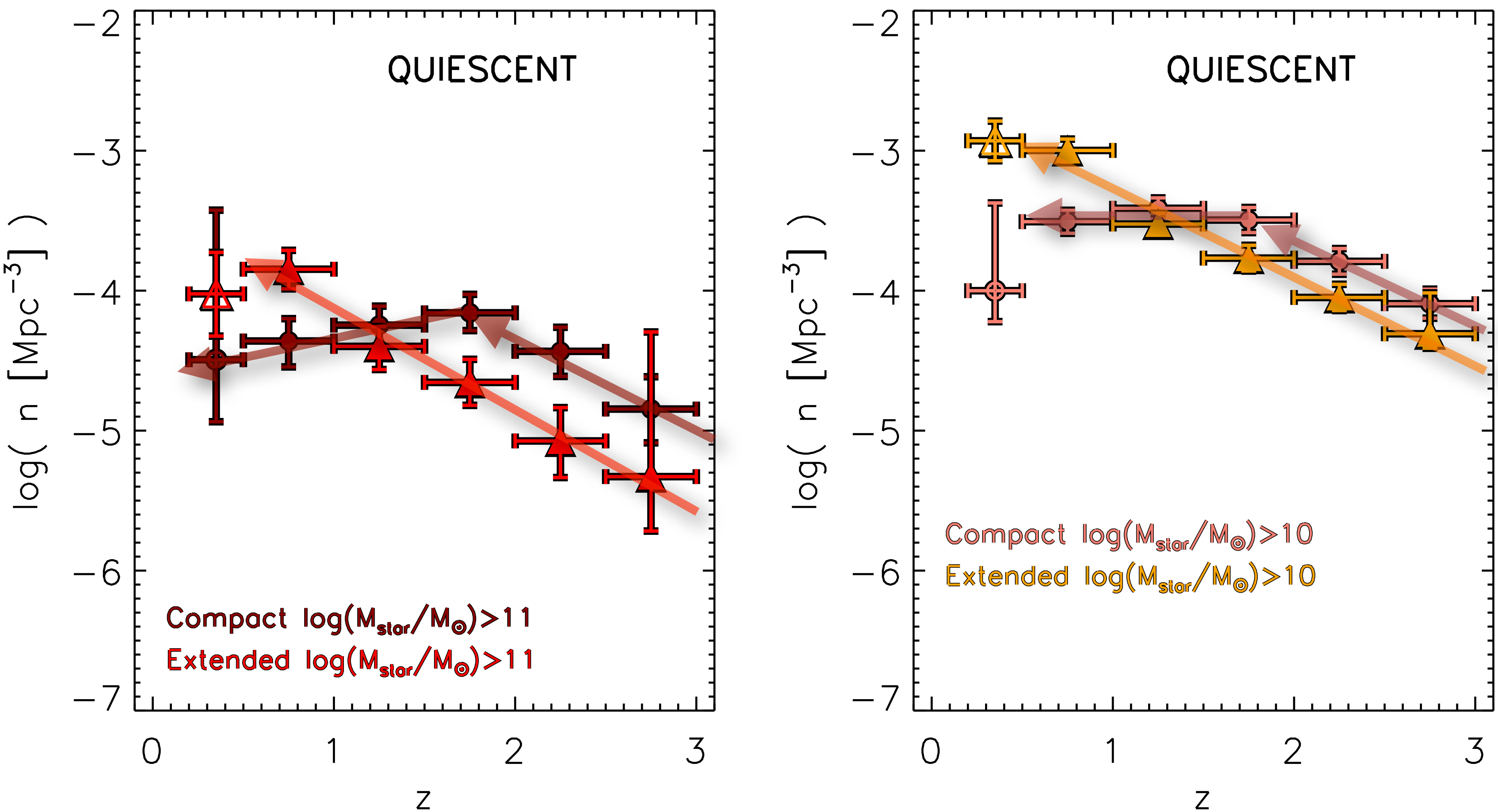
Evolution with z of the **number density** of **quiescent** and **star-forming** gals. of different **COMPACTNESS**



Evolution with z of the **number density** of quiescent and star-forming gals. of different **COMPACTNESS**

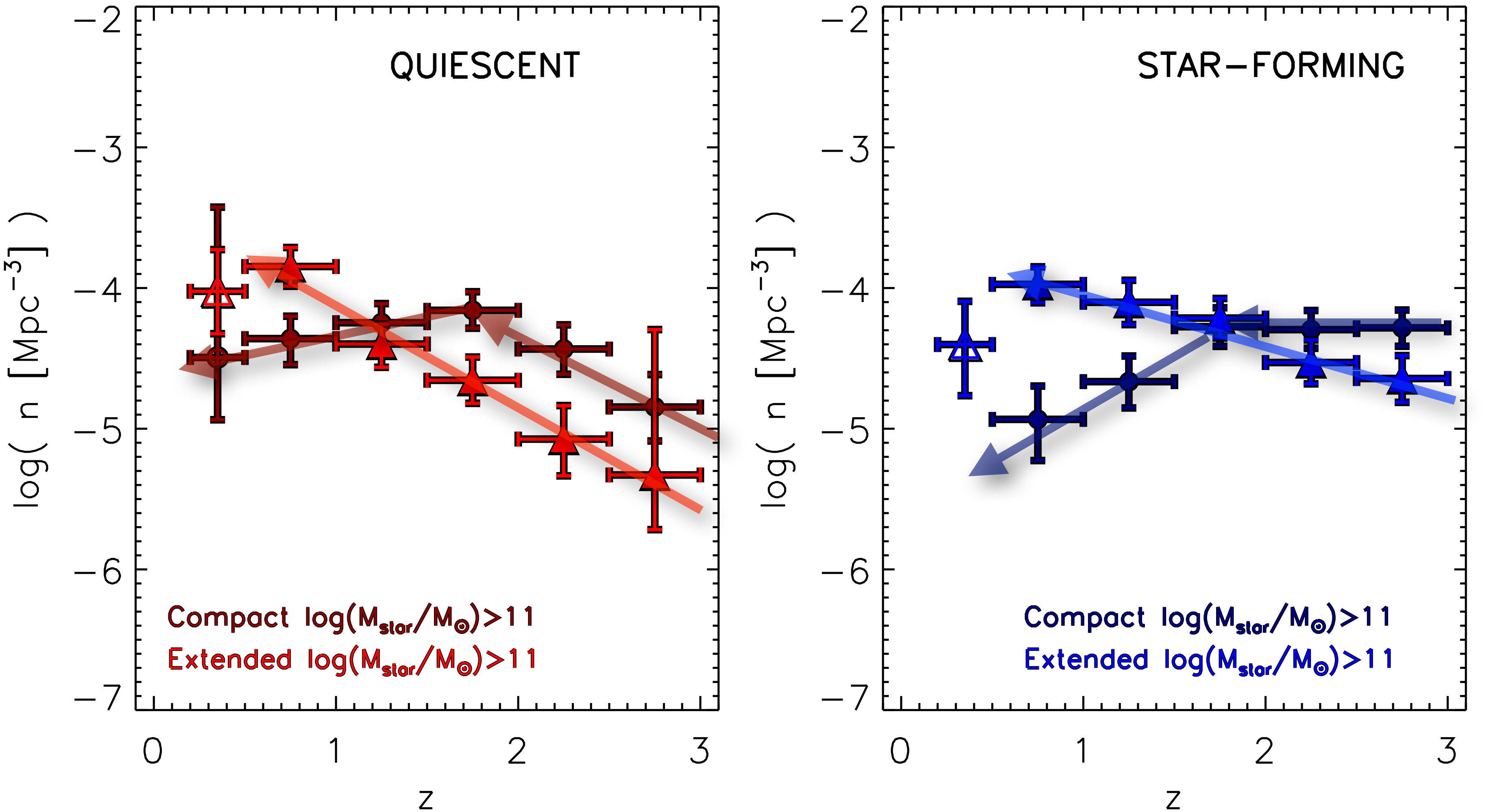


Evolution with z of the **number density** of **quiescent** galaxies of different **COMPACTNESS**



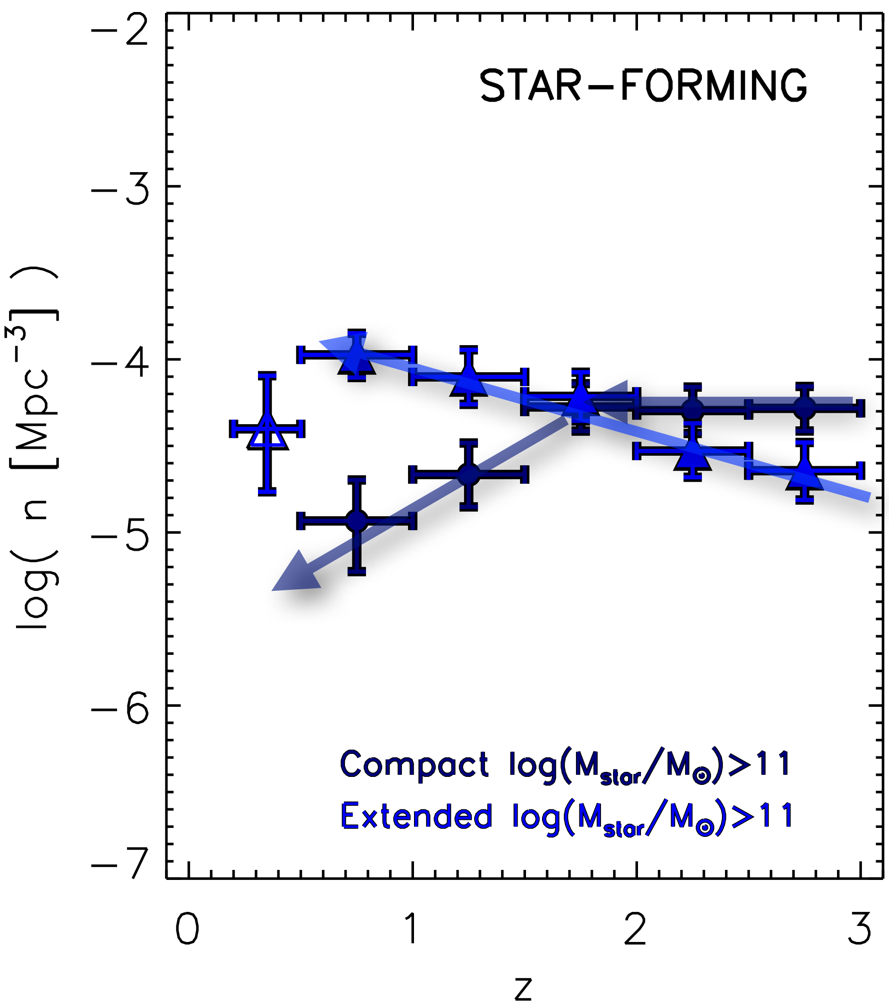
- Number density of compact massive (lgM>11) quiescent galaxies increases rapidly with time from z=3 to z=1.5, and then decreases slowly. The number density of extended massive quiescent galaxies increases steadily from z=3 to z=0.5 by 30x.
- Similar trends for lower-mass galaxies (lgM>10), but number density of compact quiescent galaxies consistent with remaining constant at z<2

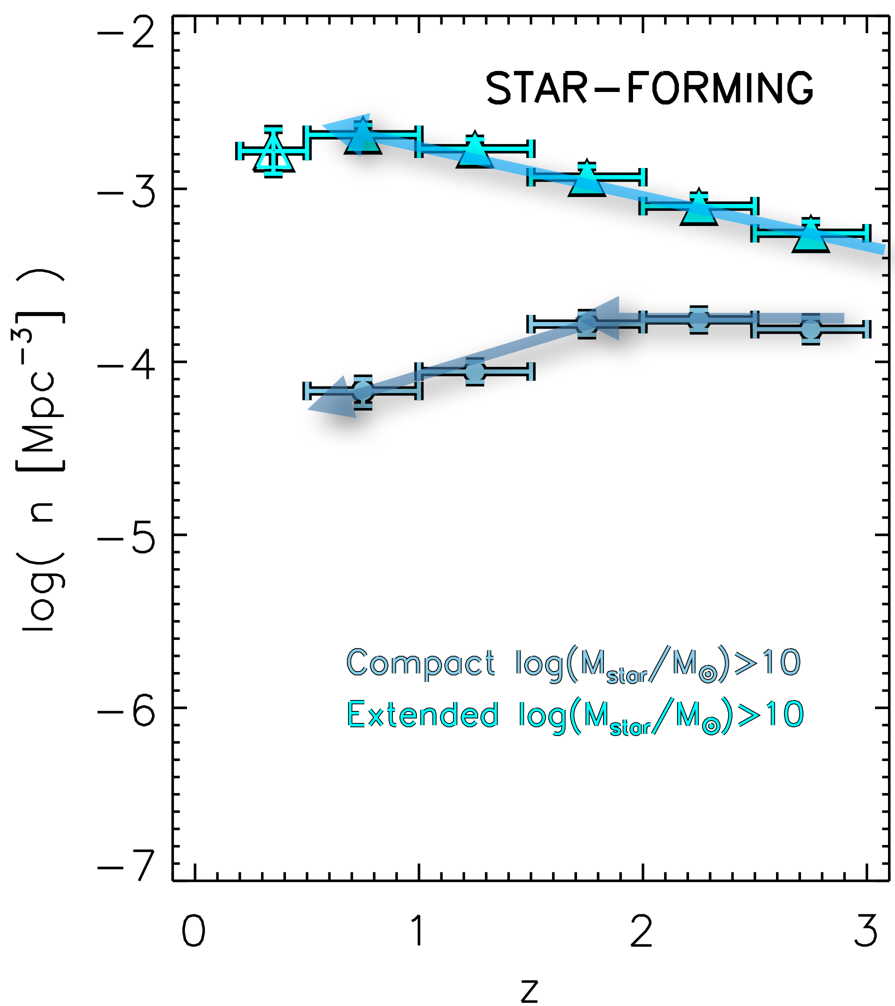
Evolution with z of the **number density** of **quiescent** galaxies of different **COMPACTNESS**



- Very different behavior for massive SF galaxies. The number density of compact SF galaxies remains constant from z=3 to z~1.75, and then it decreases by 4x down to z=0.5.
- The number density of extended massive SF galaxies steadily increases with time by 7x from z=3 to z=0.5.

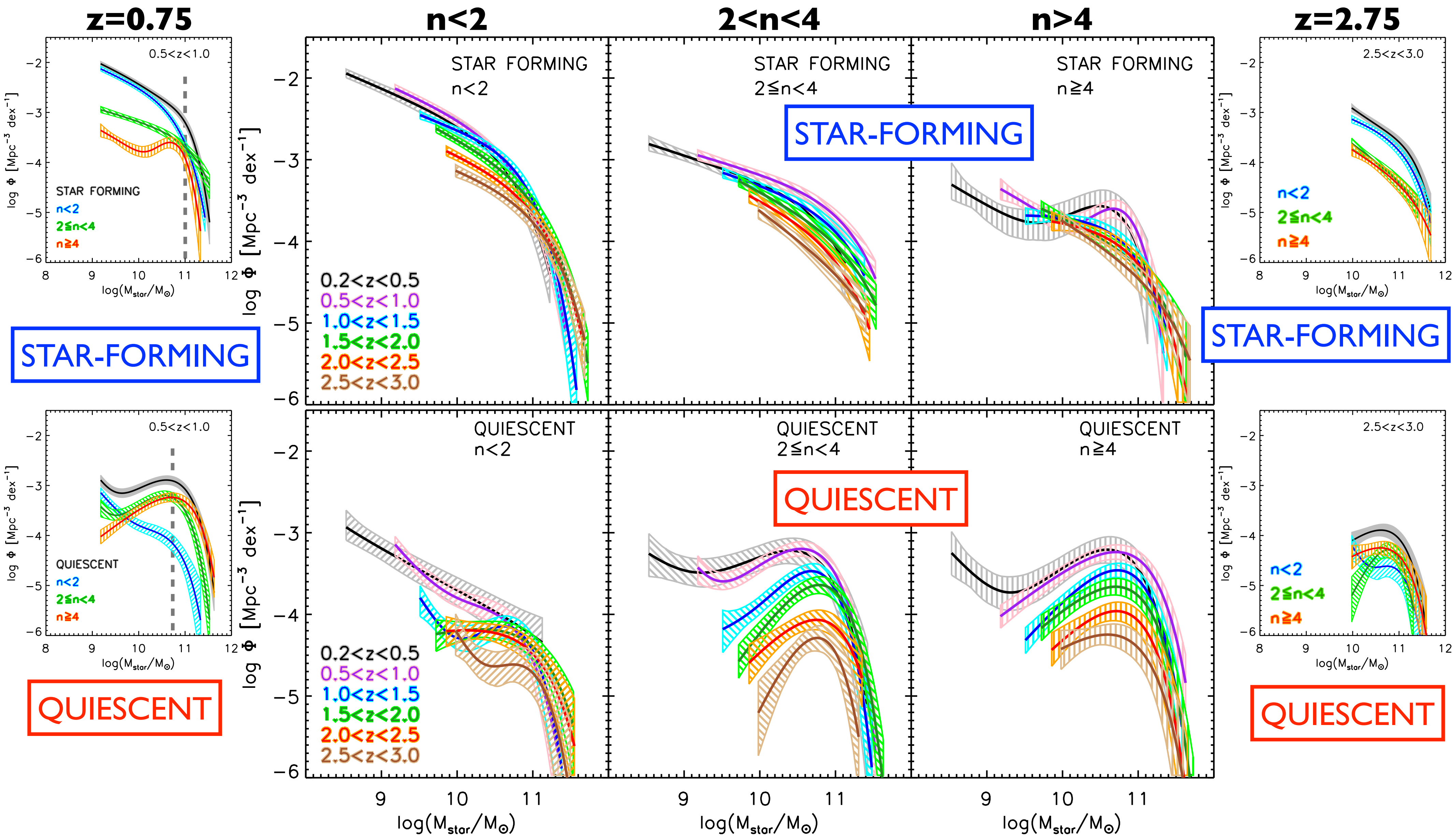
Evolution with z of the **number density** of **star-forming** galaxies of different **COMPACTNESS**



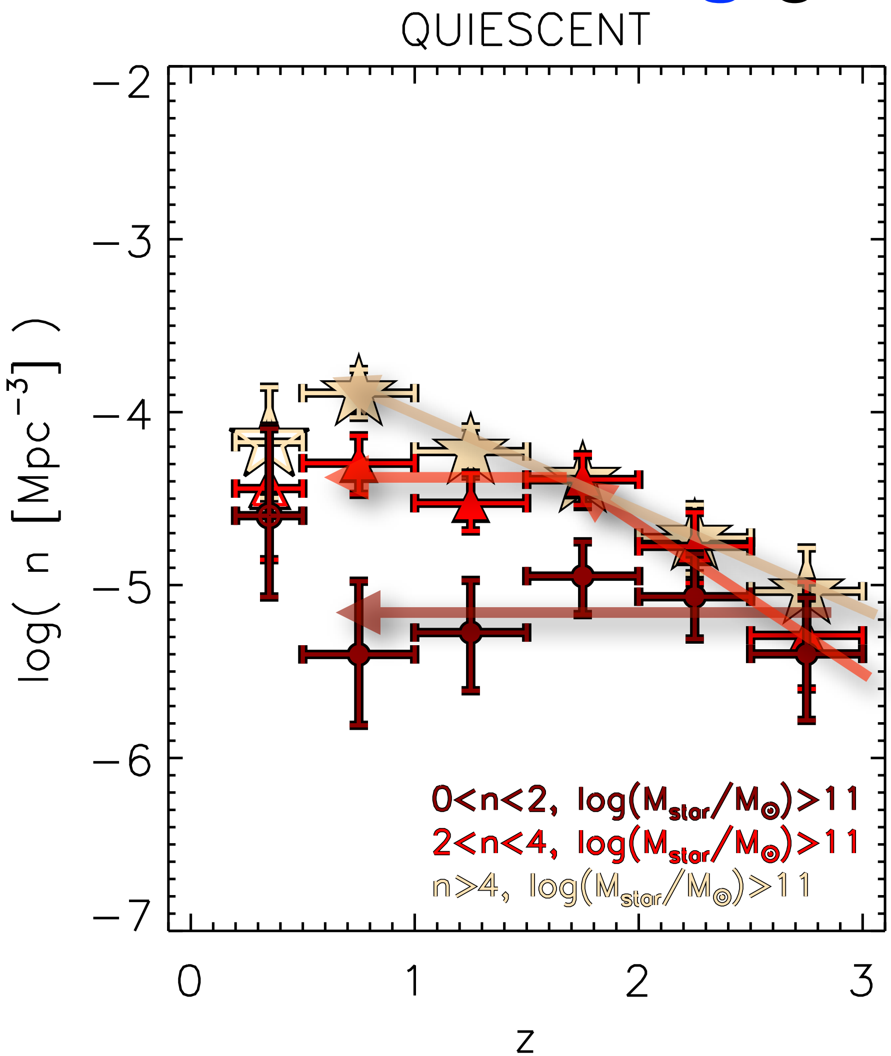


- SF galaxies with lgM=10-11 dominate the number density
- A similar trend is seen for lower mass SF galaxies, but extended lower-mass galaxies dominate the number density at all redshift, and their relative contribution to the overall SF population increases with time

Evolution with z of SMFs of quiescent and star-forming galaxies as a function of SERSIC

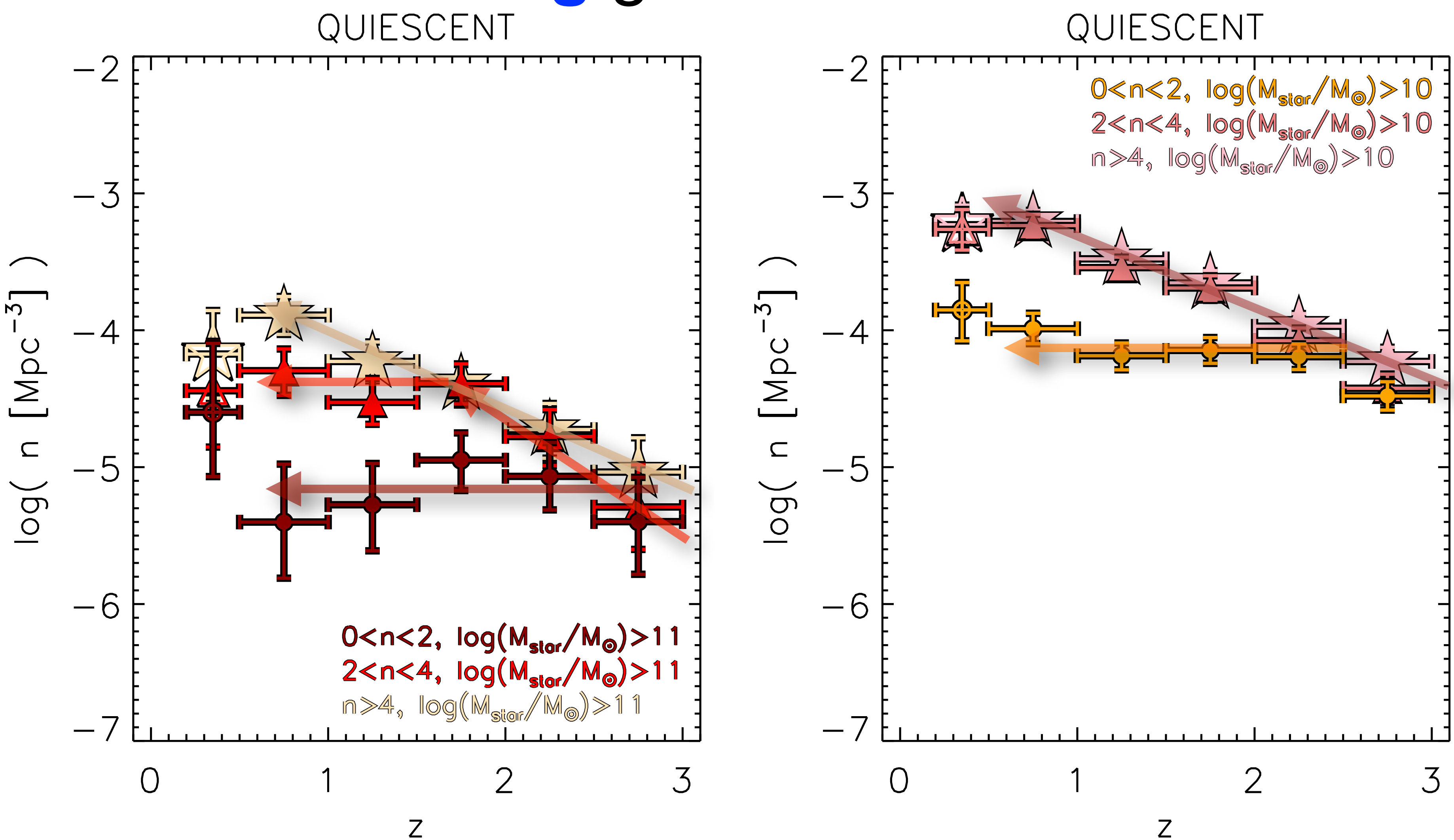


Evolution with of the **number density** of quiescent and star-forming gals. of different **SERSIC**



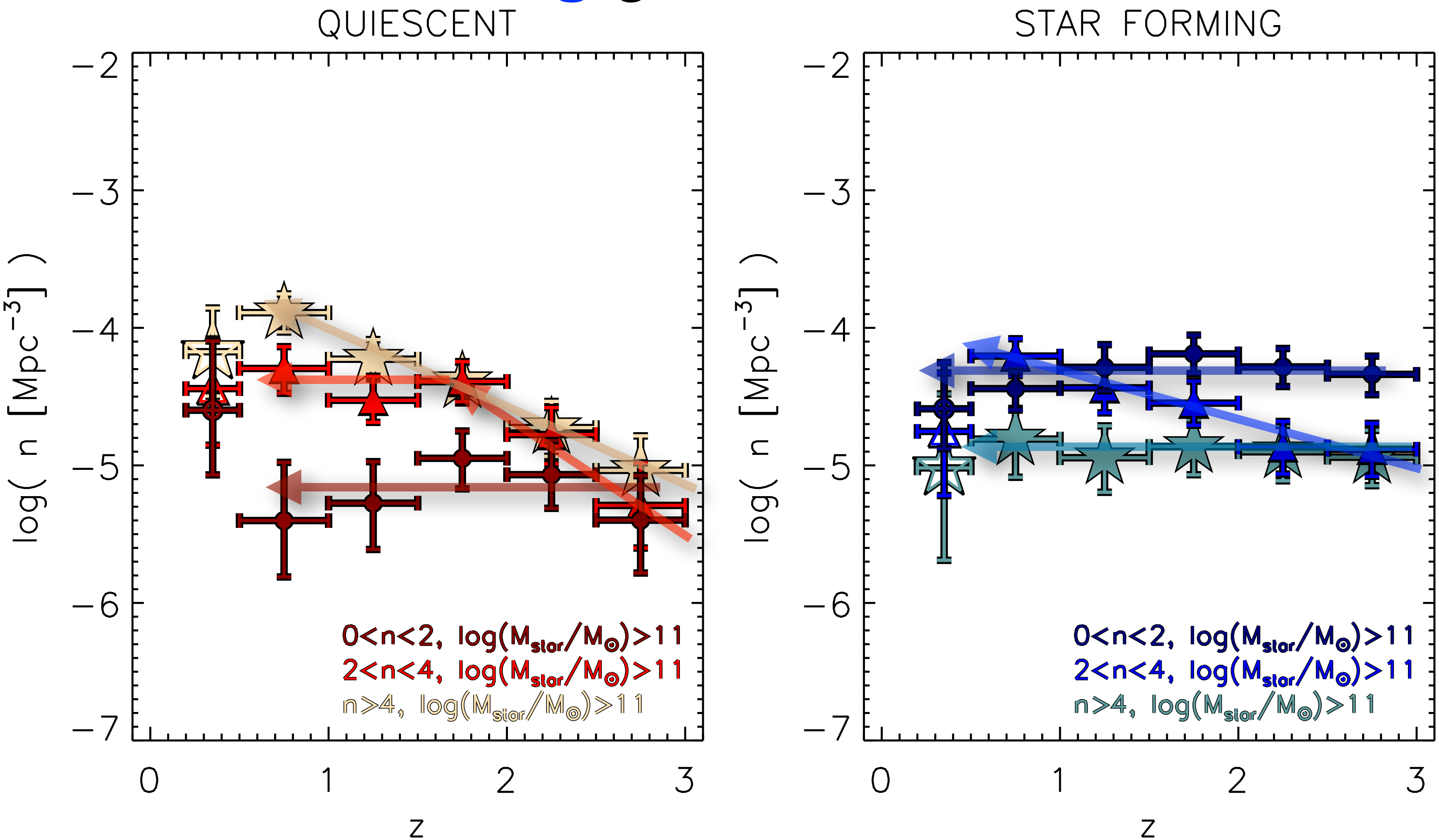
- For massive (lgM>11) quiescent galaxies, low-n galaxies contribute significantly to the number density of quiescent galaxies only at 2.5<z<3; their number density remains roughly constant.
- The contribution of large and intermediate n galaxies increases rapidly with cosmic time.
- At z>1.5, large and intermediate n galaxies contribute equally, while at z<1.5 galaxies with n>4 dominate the number density of massive, quiescent galaxies.

Evolution with of the **number density** of quiescent and star-forming gals. of different **SERSIC**



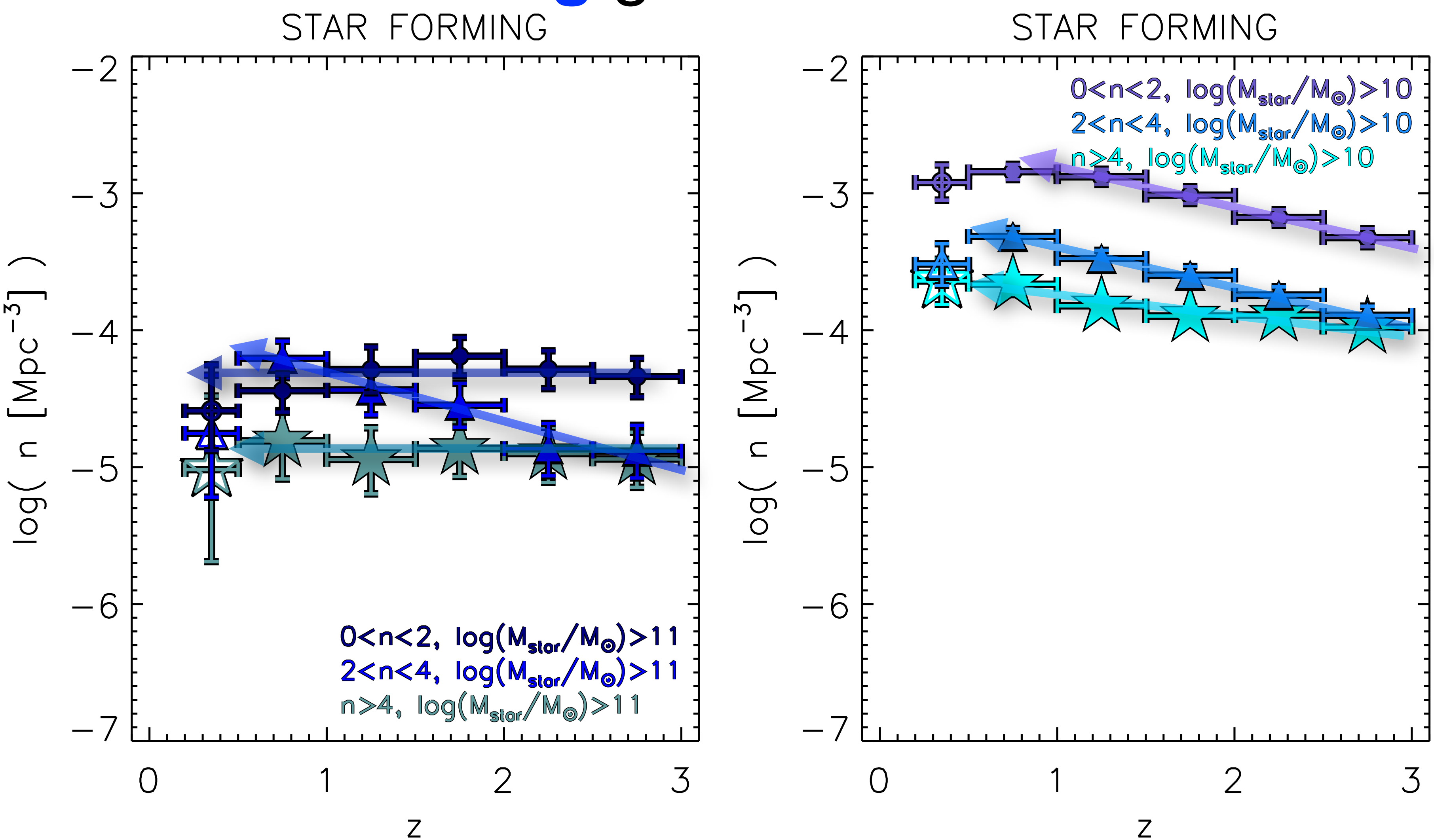
- For lower-mass quiescent galaxies, similar trends: significant growth (>10x) in the number density of galaxies with n>2 from z=3 to z=0.5.
- Contribution of lower-mass quiescent galaxies with n<2 negligible at z<2, and relatively numerous only at high redshift.

Evolution with of the **number density** of quiescent and **star-forming** gals. of different **SERSIC**



- The number density of massive SF galaxies is dominated by low-n objects; their number density remains roughly constant with redshift
- SF galaxies with large n are rare and their number density does not evolve with redshift
- At high-z, SF galaxies with intermediate n are not numerous, but their contribution increases with time, becoming dominant at z<1 at the high-mass end (e.g., bulge building up with time?)

Evolution with of the **number density** of quiescent and star-forming gals. of different **SERSIC**



- The number density of lower-mass star-forming galaxies is dominated by galaxies with n<2 (3x more numerous than star-forming galaxies with n>2)
- The number density of SF galaxies with n<2 increases with time from z=3 to z=0.5 by 3x.
- The number density of SF galaxies with n>4 grows much less with time, roughly constant from z=3 to z=1.

QUIESCENT GALAXIES:

- At high z, quiescent galaxies mostly small and compact, with very wide range in Sersic index; at z<1, large/extended/n>4 galaxies dominate the massive end [$\lg(M_{star}/M_{Sun})>11$].
- At any redshift, most massive quiescent galaxies appear large/extended.
- Number density of small massive ($\lg(M_{star}/M_{Sun})>11$) galaxies grows from z=3 to z=1.5, and then decreases to lower z. Similar for compact massive galaxies.
- Dramatic build-up of large/extended galaxies with time. The number density of n>2 galaxies increase with time rapidly, and by z~1.5, n>4 galaxies become dominant at $\lg(M_{star}/M_{Sun})>11$.

STAR-FORMING GALAXIES:

- At high redshift, SF galaxies mostly intermediate size and n<2 objects; compact galaxies dominate the massive end. The SMF of small galaxies does not evolve at $M_{star}<5\times10^{10}M_{Sun}$, whereas number density of large galaxies increases rapidly, especially at low-mass end.
- At low redshift, large galaxies with 2<n<4 dominate the high-mass end; SF galaxies are extended at all masses. Low-mass galaxies have n<2.

- **Q1:** are we seeing the build-up of the bulge component in disk galaxies?

- ☑ Galaxies grow bigger over time. Small quiescent galaxies disappear at high masses (i.e., they grow in size with time), BUT increase in number at low masses; yet, the number density of small star-forming galaxies remains roughly constant at the low-mass end.

- ☑ Small SF galaxies quench, and the number of small quiescent galaxies grows. IF MASSIVE, the small quiescent galaxies grow in size very efficiently; IF LOW MASS, small quiescent galaxies do not grow much in size.

- ☑ **Q2:** is this the effect of central/satellite? i.e., massive small galaxies grow in size by “eating” satellites, whereas the small, low-mass quiescent galaxies are the satellites...

- ☑ **Q3:** What is the best approach to interpret the observed evolution of the SMFs of quiescent and star-forming galaxies with different structural parameters?

  This is a complementary approach to following progenitors/descendants...