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

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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 (Momcheva et al. 2015)
- Effective surveyed area: $891.1 \text{ arcmin}^2$ 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 $z_{\text{spec}}$, 39.1% with reliable $z_{\text{grism}}$, 44.4% with $z_{\text{phot}}$
- $M_{\text{star}}$ from FAST using best redshift
- Structural parameters (size and Sersic index) (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).

- For SMFs as a function of structural parameters (size, compactness), sample limited at $H_{160} < 24.5$ AB for accurate size measurements.
The UVJ diagram to separate Quiescent and Star-forming Galaxies

(3DHST-CANDELS)
The UVJ diagram to separate Quiescent and Star-forming Galaxies

Quiescent

\[ \tau = 100 \text{Myr} \]

CSF, \( A_v = 2 \)

Star-forming

(3DHST-CANDELS)
Evolution of the Stellar Mass Function (SMF)

(Marchesini et al. 2015, in prep.; see also Muzzin, Marchesini, et al., 2013)
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Evolution of the Number Densities
SMFs of quiescent galaxies as a function of SIZE
SMFs of **quiescent** galaxies as a function of **SIZE**

- Mass-dependent build-up of the population of large galaxies with cosmic time
SMFs of quiescent galaxies as a function of SIZE

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- At $z<1$, large galaxies dominate high-mass end; small galaxies dominate the low-mass end.
SMFs of quiescent galaxies as a function of SIZE

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- At $z<1$, large galaxies dominate high-mass end; small galaxies dominate the low-mass end.
- Increasing importance with $z$ of small galaxies at high-mass end; large galaxies non negligible only for most massive galaxies.
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- At $2.5<z<3$, quiescent galaxies mostly small, except for most massive.
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- At $2.5<z<3$, quiescent galaxies mostly small, except for most massive.
- At all $z<3$, the most massive quiescent galaxies are large ($R_e>4$ kpc).
SMFs of star-forming galaxies as a function of SIZE
Very different evolution compared to the quiescent galaxies.
SMFs 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 $\log M<11$. 
SMFs 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 $\log M < 11$.
- The relative contribution of small galaxies decreases with time, 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
SMF of small SF galaxies at log(M) < 10.7 evolves very little; at the high-mass end, small SF galaxies less common at later times.
Evolution with redshift of SMFs of quiescent and star-forming galaxies as a function of SIZE

- **SMF of small SF galaxies at log M < 10.7 evolves very little; at the high-mass end, small SF galaxies less common at later times.**
- **Dramatic evolution of SMF of large SF galaxies.**
Evolution with redshift of SMFs of quiescent and star-forming galaxies as a function of SIZE

- SMF of small SF galaxies at IgM<10.7 evolves very little; at the high-mass end, small SF galaxies less common at later times.
- Dramatic evolution of SMF of large SF galaxies.
- Star-forming galaxies become progressively larger with cosmic time; small SF massive galaxies disappear with decreasing redshift as they quench away (same trend for intermediate-size, but slower evolution)
Evolution with redshift of SMFs of **quiescent** and **star-forming** galaxies as a function of **SIZE**
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Evolution with redshift of SMFs of \textbf{quiescent} and \textbf{star-forming} galaxies as a function of \textbf{SIZE}
SMFs of **QUIESCENT** galaxies as a function of **COMPACTNESS**
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Extended galaxies dominate at all masses at z<1; **compact** quiescent galaxies are very rare at z<0.5.
SMFs of **QUIESCENT** galaxies as a function of **COMPACTNESS**

- Extended galaxies dominate at all masses at $z<1$; compact quiescent galaxies are very rare at $z<0.5$.
- Importance of compact galaxies grows rapidly with redshift, dominating the high-mass end at $z>1.5$. 

![Graph showing SMFs of QUIESCENT galaxies as a function of COMPACTNESS](image)
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Mass-dependent evolution of the SMF of quiescent compact galaxies. Down to z=1.5, density grows at all masses; at z<1.5, the growth at log(M_{star}/M_{Sun})<10.5 slows, while it reverses at log(M_{star}/M_{Sun})>11.
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SMF of extended quiescent galaxies grows with time, dramatically fast at the low-mass end.
SMFs of **QUIESCENT** galaxies as a function of **COMPACTNESS**

- **Extended** galaxies dominate at all masses at $z<1$; **compact** quiescent galaxies are very rare at $z<0.5$.
- Importance of **compact** galaxies grows rapidly with redshift, dominating the high-mass end at $z>1.5$.

**Mass-dependent evolution of the SMF of quiescent compact galaxies.** Down to $z=1.5$, density grows at all masses; at $z<1.5$, the growth at $\log(M_{\text{star}}/M_{\odot})<10.5$ slows, while it reverses at $\log(M_{\text{star}}/M_{\odot})>11$.

SMF of **extended** quiescent galaxies grows with time, dramatically fast at the low-mass end.

Extended galaxies exist even at $2.5<z<3$ in the quiescent population.
SMFs of STAR-FORMING galaxies as a function of COMPACTNESS

EXTENDED

STAR FORMING
$E_{S}([M_{0}/R_{0}^{2}] > 10.35$)
$E_{S}([M_{0}/R_{0}^{2}] \leq 10.35$)

log φ [Mpc$^{-3}$ dex$^{-1}$]

log(M$_{star}$/M$_{⊙}$)

0.2<z<0.5
0.5<z<1.0
1.0<z<1.5
1.5<z<2.0
2.0<z<2.5
2.5<z<3.0

log(M$_{star}$/M$_{⊙}$)
SMFs of STAR-FORMING galaxies as a function of COMPACTNESS

Extended galaxies dominate at all masses at z<1.5; no compact star-forming galaxies at z<0.5.
SMFs of **STAR-FORMING** galaxies as a function of **COMPACTNESS**

- Extended galaxies dominate at all masses at z<1.5; no compact star-forming galaxies at z<0.5.
- At earlier times, compact SF galaxies relatively more important; at z>2, they dominate at log(M_{star}/M_{Sun})>11.

![Graph showing SMFs of star-forming galaxies as a function of compactness](image-url)
SMFs of **STAR-FORMING** galaxies as a function of **COMPACTNESS**

- Extended galaxies dominate at all masses at $z<1.5$; no compact star-forming galaxies at $z<0.5$
- At earlier times, compact SF galaxies relatively more important; at $z>2$, they dominate at $\log(M_{\text{star}}/M_{\odot})>11$. 

![Graph showing SMFs of star-forming galaxies as a function of compactness.](image-url)
Mass-dependent evolution of the SMF of SF compact galaxies. Their SMF decreases with time, faster for galaxies with log(M_{star}/M_{Sun})>11. The SMF of extended SF galaxies evolves slowly, but steadily at all masses, growing with cosmic time, faster at the low-mass end.
SMFs of **STAR-FORMING** galaxies as a function of **COMPACTNESS**

- **Extended** galaxies dominate at all masses at $z<1.5$; no **compact** star-forming galaxies at $z<0.5$
- At earlier times, **compact** SF galaxies relatively more important; at $z>2$, they dominate at $\log(M_{\text{star}}/M_{\odot})>11$.

### Mass-dependent evolution of the SMF of SF compact galaxies.

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- The opposite growths of the SMFs of compact/extended SF galaxies —> SMF of SF galaxies evolving **little at the high-mass end** (with evolution driven by disappearance of compact SF gals.)
Evolution of the number density of quiescent and star-forming galaxies of different compactness.
Density of compact massive quiescent galaxies increases rapidly from $z=3$ to $z=1.5$ by $x8$, and then decreases slowly. The density of extended massive quiescent galaxies increases steadily from $z=3$ to $z=0.5$ by $x40$. 
Density of compact massive quiescent galaxies increases rapidly from $z=3$ to $z=1.5$ by x8, and then decreases slowly. The density of extended massive quiescent galaxies increases steadily from $z=3$ to $z=0.5$ by x40.

Density of compact SF galaxies remains constant from $z=3$ to $z\sim1.75$, and then decreases by x5 down to $z=0.5$. The density of extended massive SF galaxies increases by x7.
Evolution of the number density of quiescent and star-forming galaxies of different size.
Evolution of the **number density of quiescent and star-forming** galaxies of different **SIZE**

Density of small massive quiescent galaxies **increases from z=3 to z=1.5 by x6**, and then decreases rapidly by >10x down to z=0.5. The density of large massive quiescent galaxies **increases steadily from z=3 to z=0.5 by x40**.
Density of small massive quiescent galaxies increases from $z=3$ to $z=1.5$ by $x6$, and then decreases rapidly by $>10x$ down to $z=0.5$. The density of large massive quiescent galaxies increases steadily from $z=3$ to $z=0.5$ by $x40$.

Density of small SF galaxies decreases from $z=3$ to $z\sim0.5$ by $x10$. The density of large massive SF galaxies increases by $x8$, dominant type among SF massive galaxies at $z<1$. 
QUIESCENT GALAXIES:

- At high z, quiescent galaxies mostly small and compact; at z<1 (with range of Sersic index), large/extended (with n>4) galaxies dominate the massive end [\(\log(M_{\text{star}}/M_{\odot})>11\)].
- At any redshift, there exist large/extended among most massive quiescent galaxies.
- Number density of small massive \((\log(M_{\text{star}}/M_{\odot})>11)\) 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.

STAR-FORMING GALAXIES:

- At high redshift, SF galaxies mostly intermediate size objects (with n<2); large SF galaxies are rare and small contribute significantly only at \(\lg M<11\); compact galaxies dominate the massive end. The SMF of small galaxies evolves little at \(M_{\text{star}}<5\times10^{10}M_{\odot}\), whereas number density of large galaxies increases rapidly with time, especially at low-mass end.
- At low redshift, large galaxies (with \(2<n<4\)) dominate the high-mass end at z<1.5; SF galaxies are extended at all masses. Low-mass galaxies have n<2
BACKUP SLIDES
Evolution with $z$ of the **number density** of **quiescent** and **star-forming** galaxies of different **COMPACTNESS**
Evolution with redshift of the number density of quiescent and star-forming galaxies of different sizes.