Bulge Formation and Inside-Out Quenching in z~2 Galaxies

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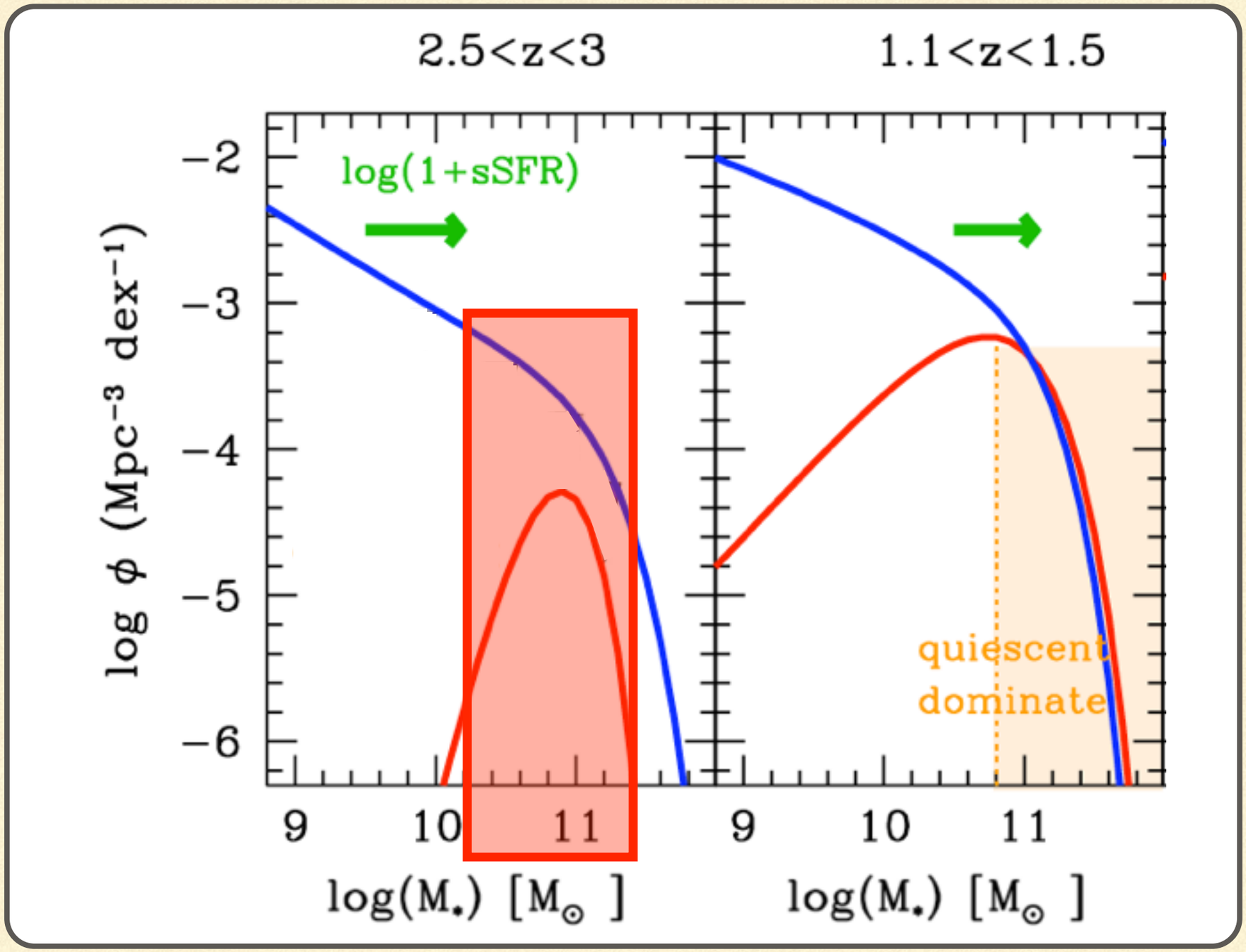
Mass Functions of Star-Forming and Quiescent Galaxies



e.g., Peng+ (2010); Ilbert+ (2013); Muzzin+ (2013)

Questions

“Galaxies are not points!” (Mark)

- How do the stellar mass and SFR in bulges and disks build up in galaxies with cosmic time?
- Which physical process(es) derive the evolution of the density profiles?
- How does shut down of star-formation (“*quenching”)* progress in massive galaxies?

SINS/zC-SINF Program

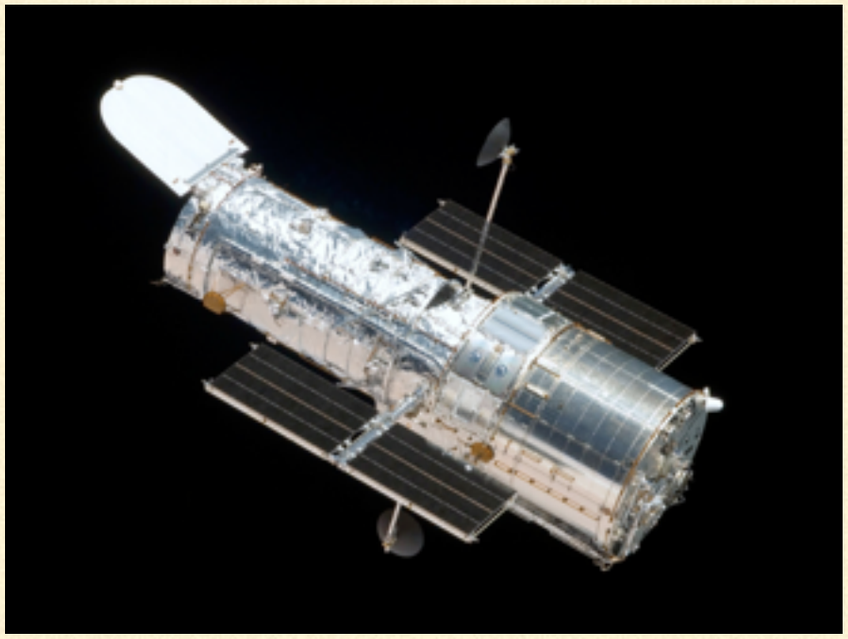
Newman et al 2013, Förster-Schreiber et al 2014, Genzel et al 2014ab

Reinhard's Talk

55 HST/WFC3 Orbits

Co-PIs: Förster Schreiber & Carollo

Tacchella+ (2015a)



J+H-band imaging (4000A-break)
➜ continuum morphologies
➜ stellar mass distribution

300 hr VLT/SINFONI AO

PI: Renzini

Förster Schreiber+ (2015, in prep.)

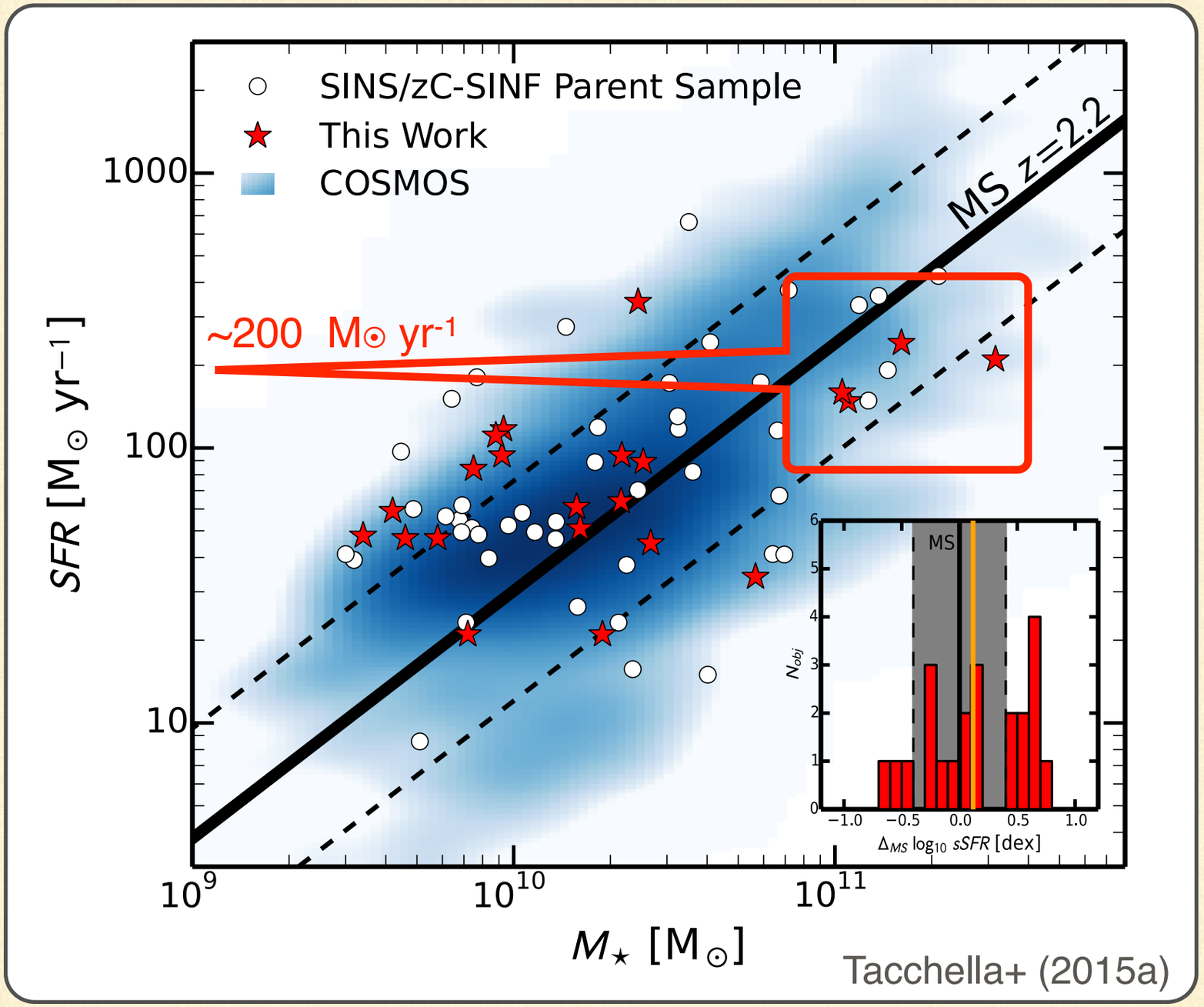
K-band Integral Field Spectroscopy
➜ Hα emission line maps
➜ ionized gas kinematics

29 galaxies at a spatial resolution of ~1-2 kpc !

Local comparison of stellar mass density and SFR density *within* galaxies

Sample on the Main Sequence

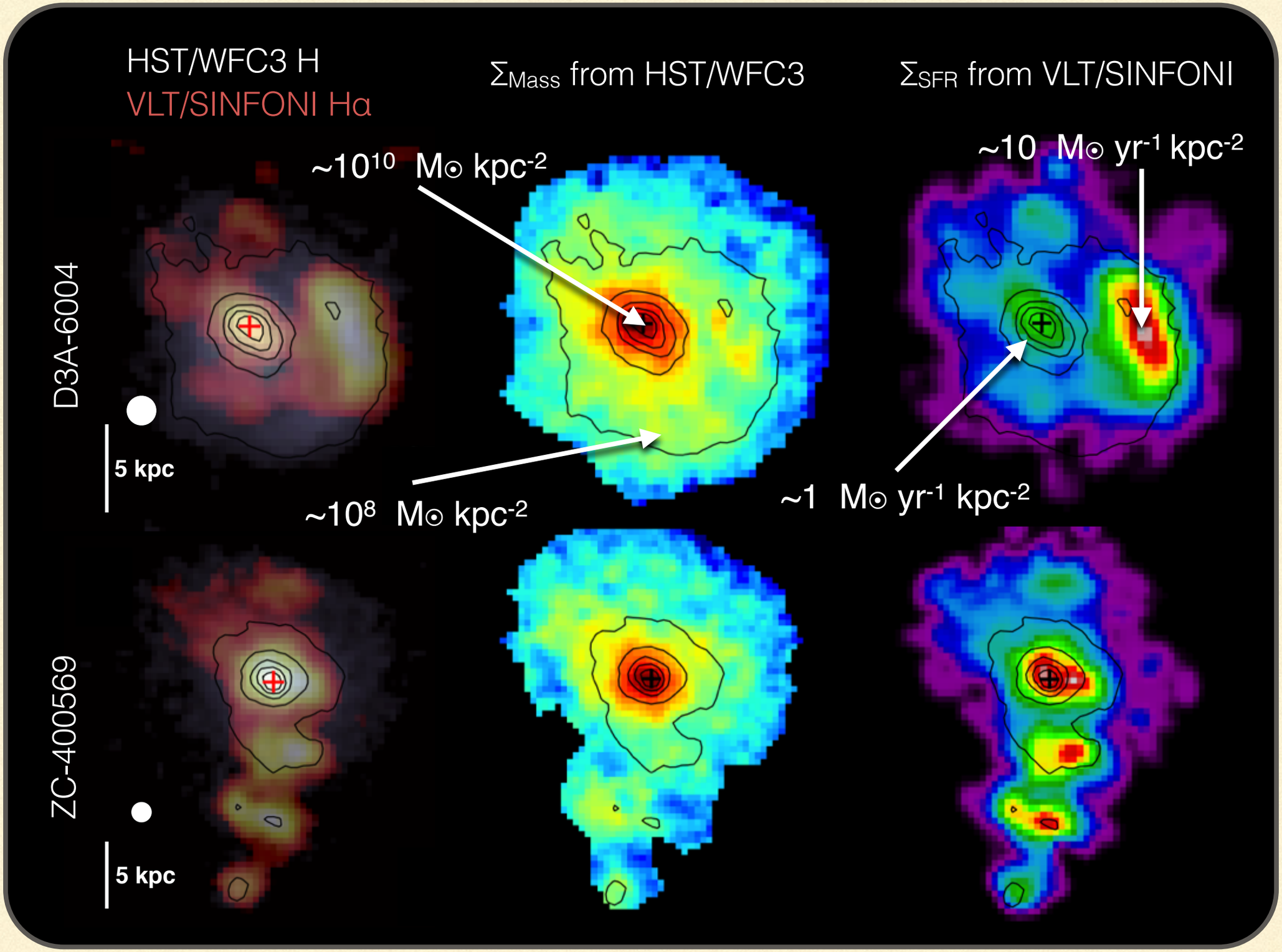
- covering a wide range of the M-SFR plane
- representative of the star-forming “Main Sequence”



Tacchella+ (2015a)

e.g., Daddi et al 2007; Noeske et al 2007; Rodighiero et al 2011; Whitaker et al 2012

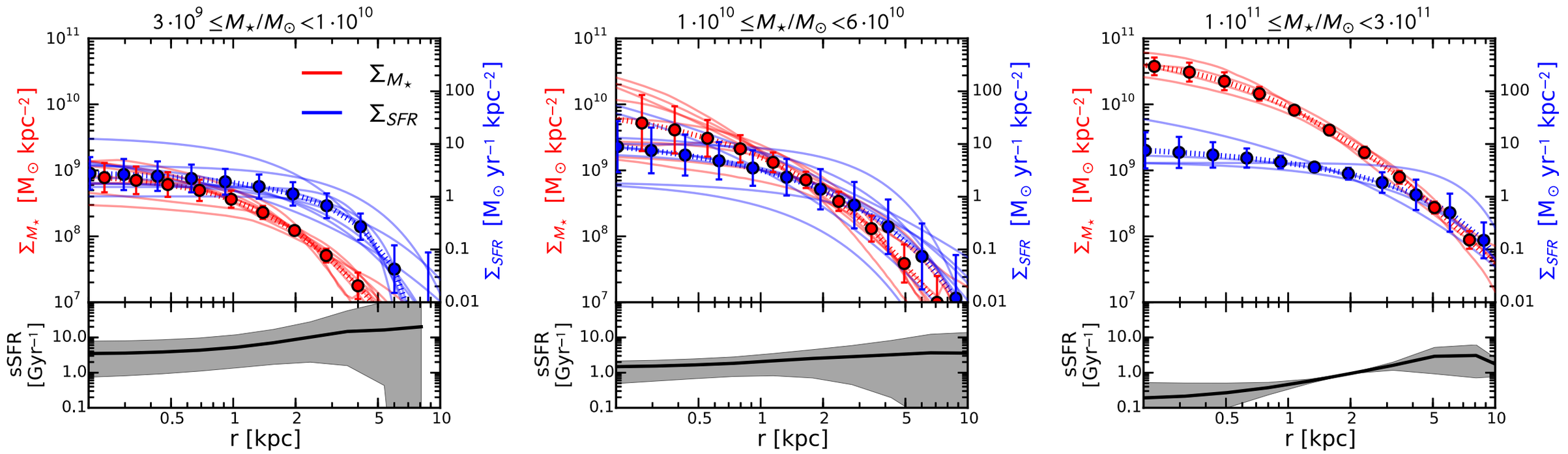
Stellar Mass and SFR on 1-2 kpc



Tacchella+ *Science* (2015b)

Distribution of Stellar Mass and Star Formation Density

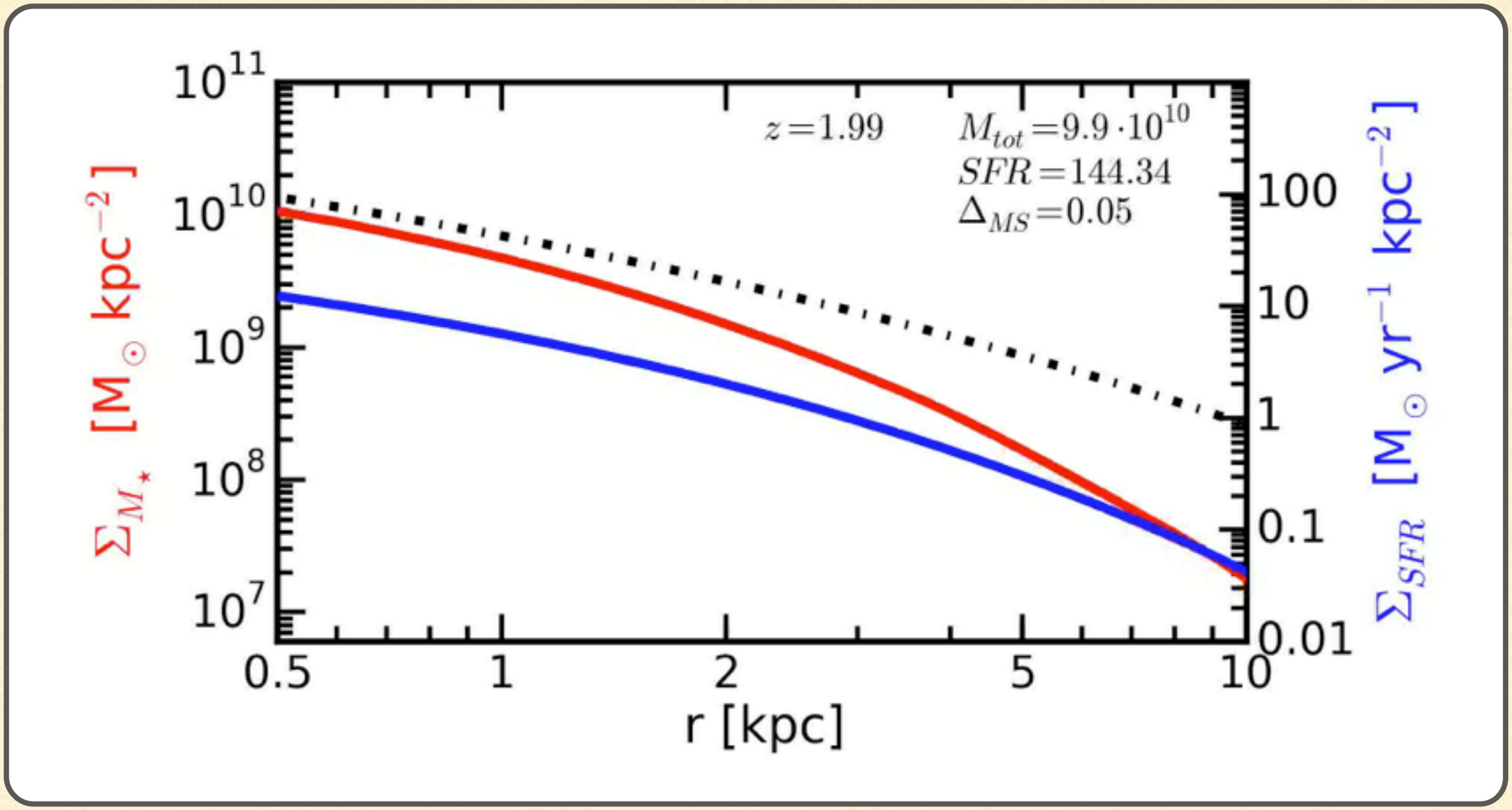
low mass --------> high mass



- Stellar mass more centrally concentrated than SFR density
- Steeper stellar mass density profiles with increasing mass
- Most massive galaxies have suppressed central sSFR

Tacchella+ *Science* (2015b)

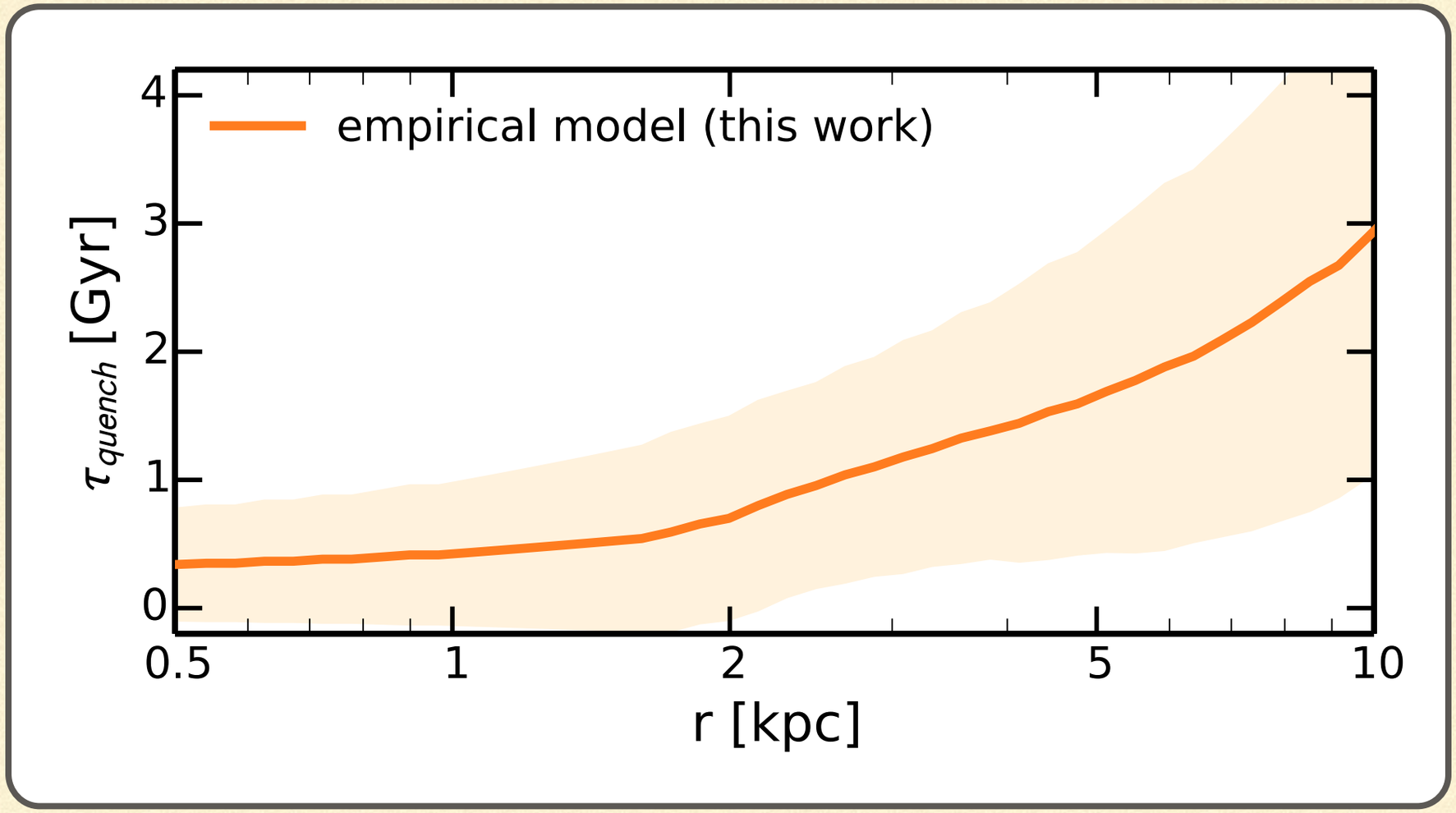
Quenching Timescales within M★ ~ 10^{11} M⊙ z~2 Galaxies



- evolve Σ_M profile using Σ_{SFR} profile
- star formation history constrained to Main Sequence at all z

Tacchella+ *Science* (2015b)

Quenching Timescales within M★ ~ 10^{11} M⊙ z~2 Galaxies



➜ infer how quenching progresses with radius:

inside-out quenching!

AGN?
Gas supply cut-off?
morphological Q?
…?

Tacchella+ *Science* (2015b)

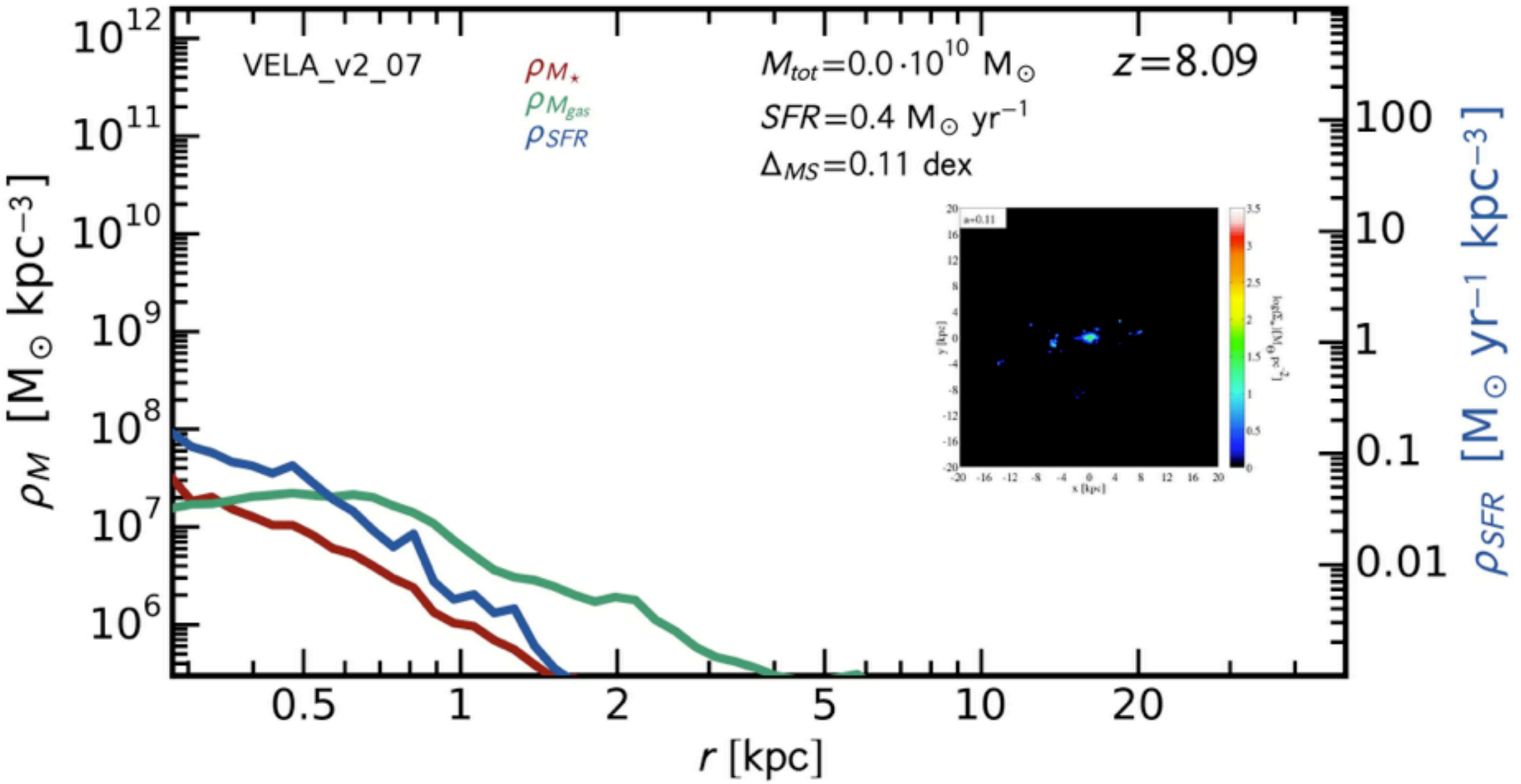
Zoom-in Cosmological Simulations with ART

Kravtsov+ 1997, 2003; Ceverino+ 2009, 2010, 2014

Talks by Daniel & Colin

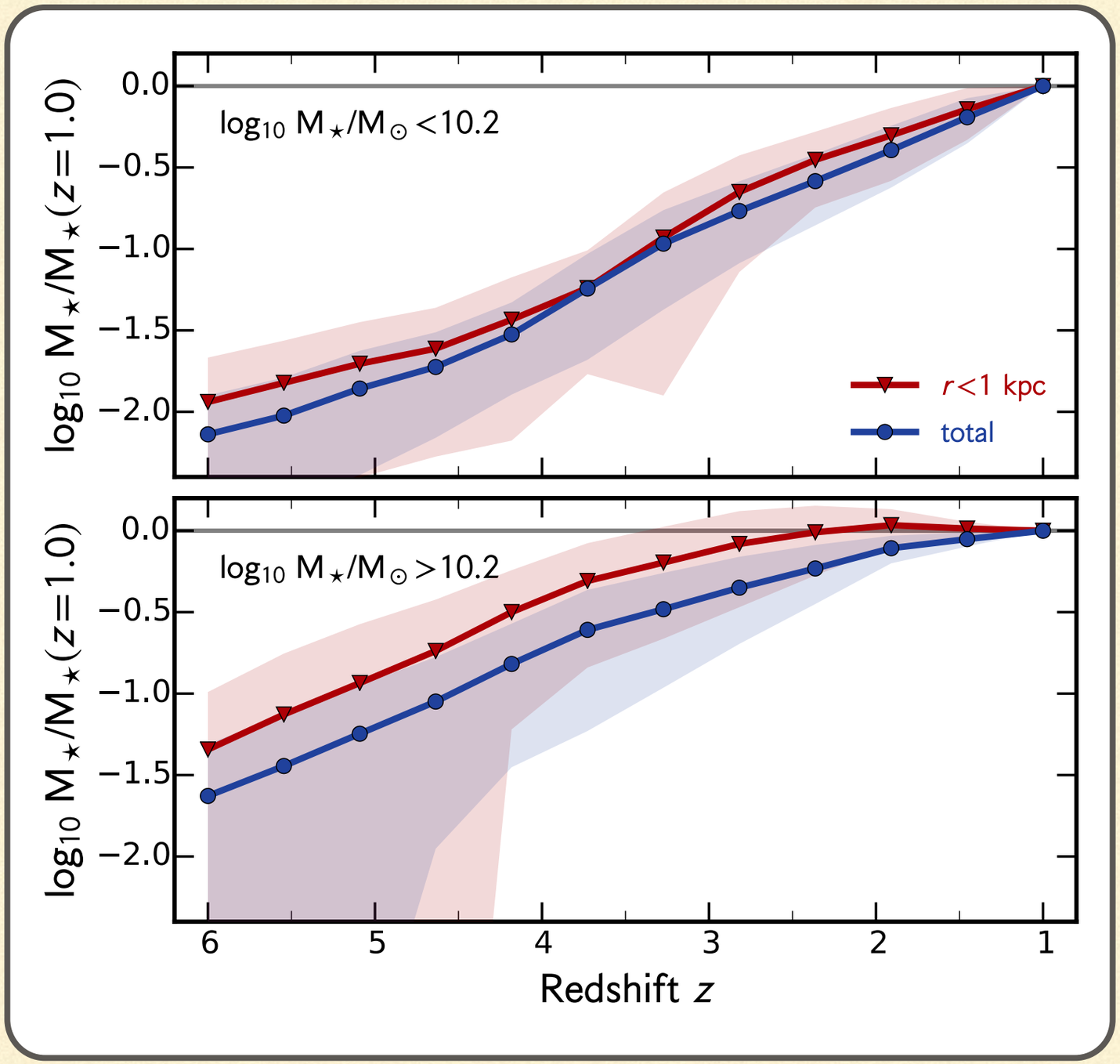
- **26 simulations** with identical initial conditions
- halo masses of 10^{11}–10^{12} M⊙ at z~2
  stellar masses of **2×10^{9}–6×10^{10} M⊙** at z~2
- maximal AMR resolution of **~25 pc**
- thermal & radiative feedback from stellar winds and SNe
  ➜ no shutdown of cooling
- no AGNs

Evolution of Density Profiles in Simulations



Tacchella, Dekel, Carollo+ (in prep)

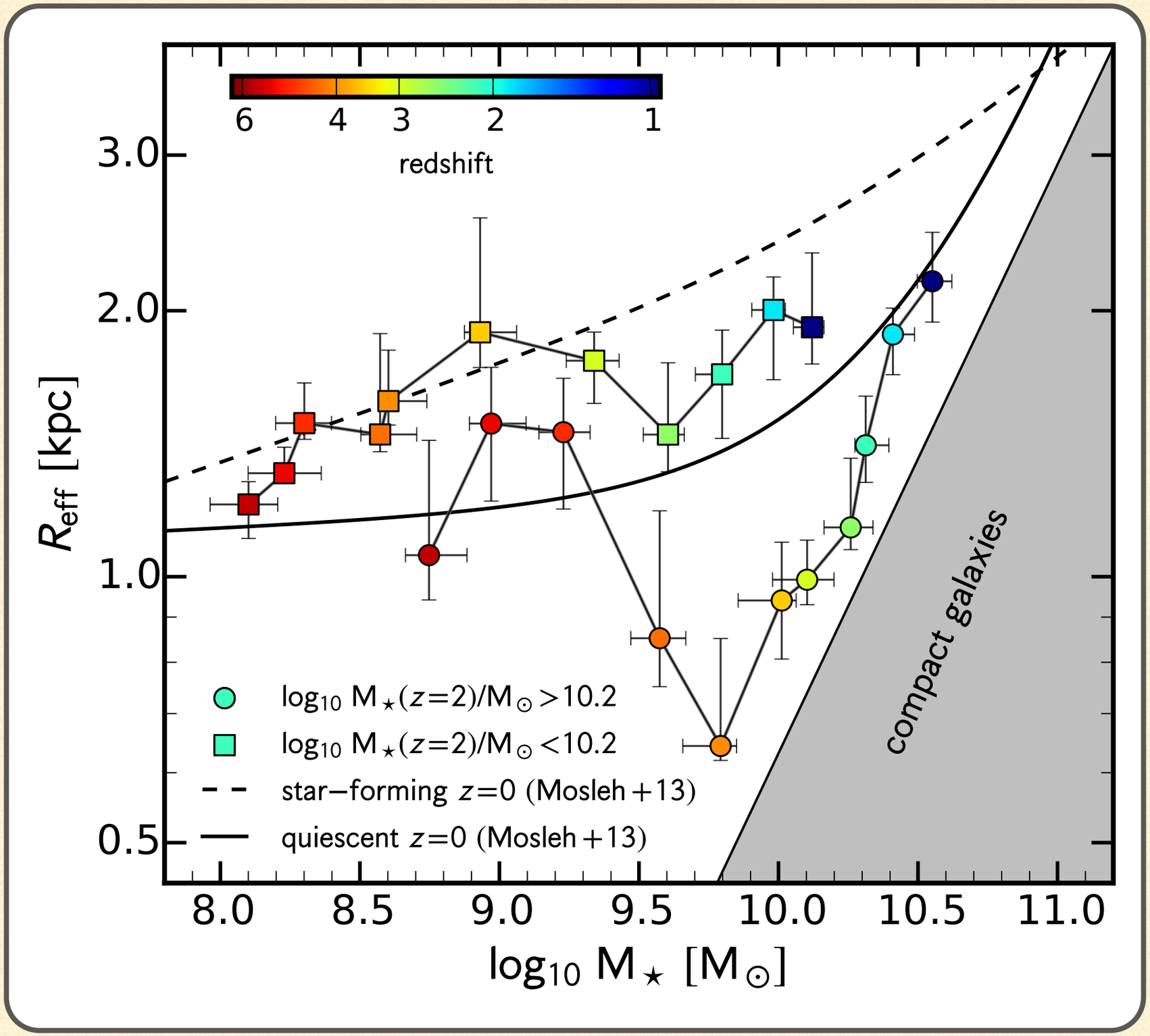
Simulations: Stellar Mass Growth



- low mass: rate of stellar mass increase the same at all radii
- high mass: concurrent growth at high-z; saturation of central stellar mass at z~3

Tacchella, Dekel, Carollo+ (in prep)

Evolution of the Average Size



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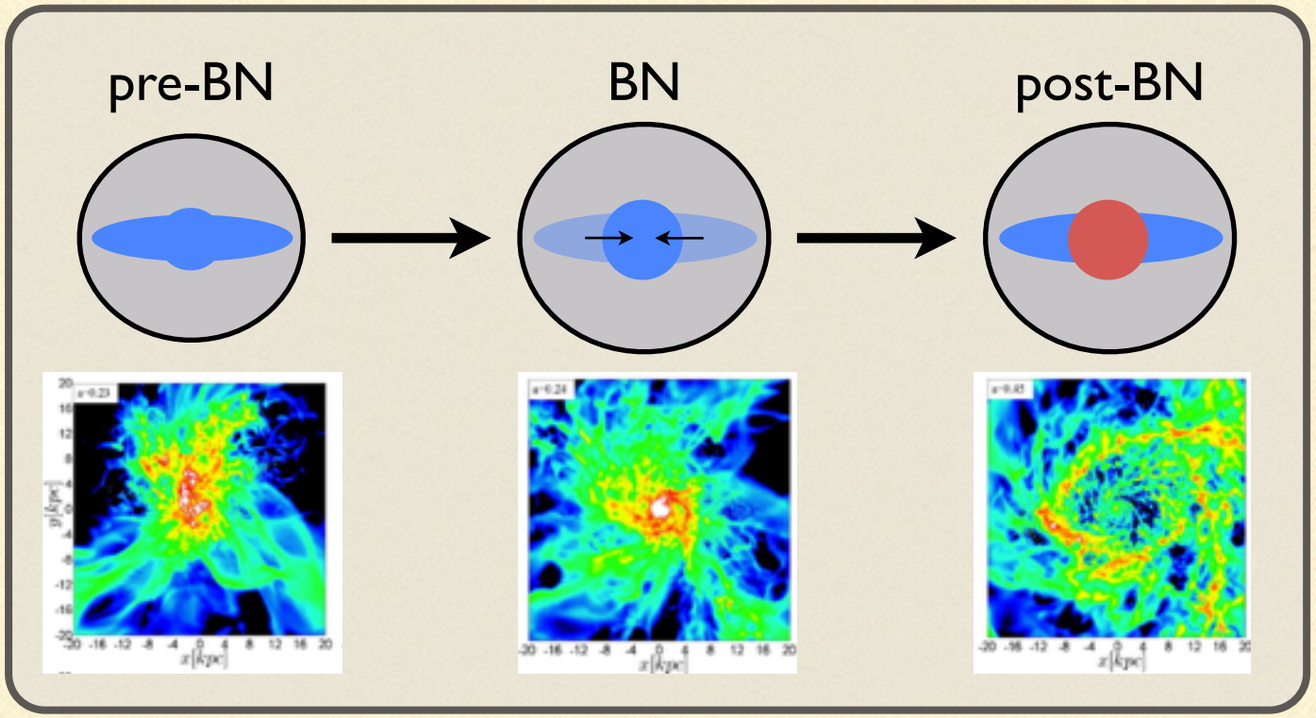
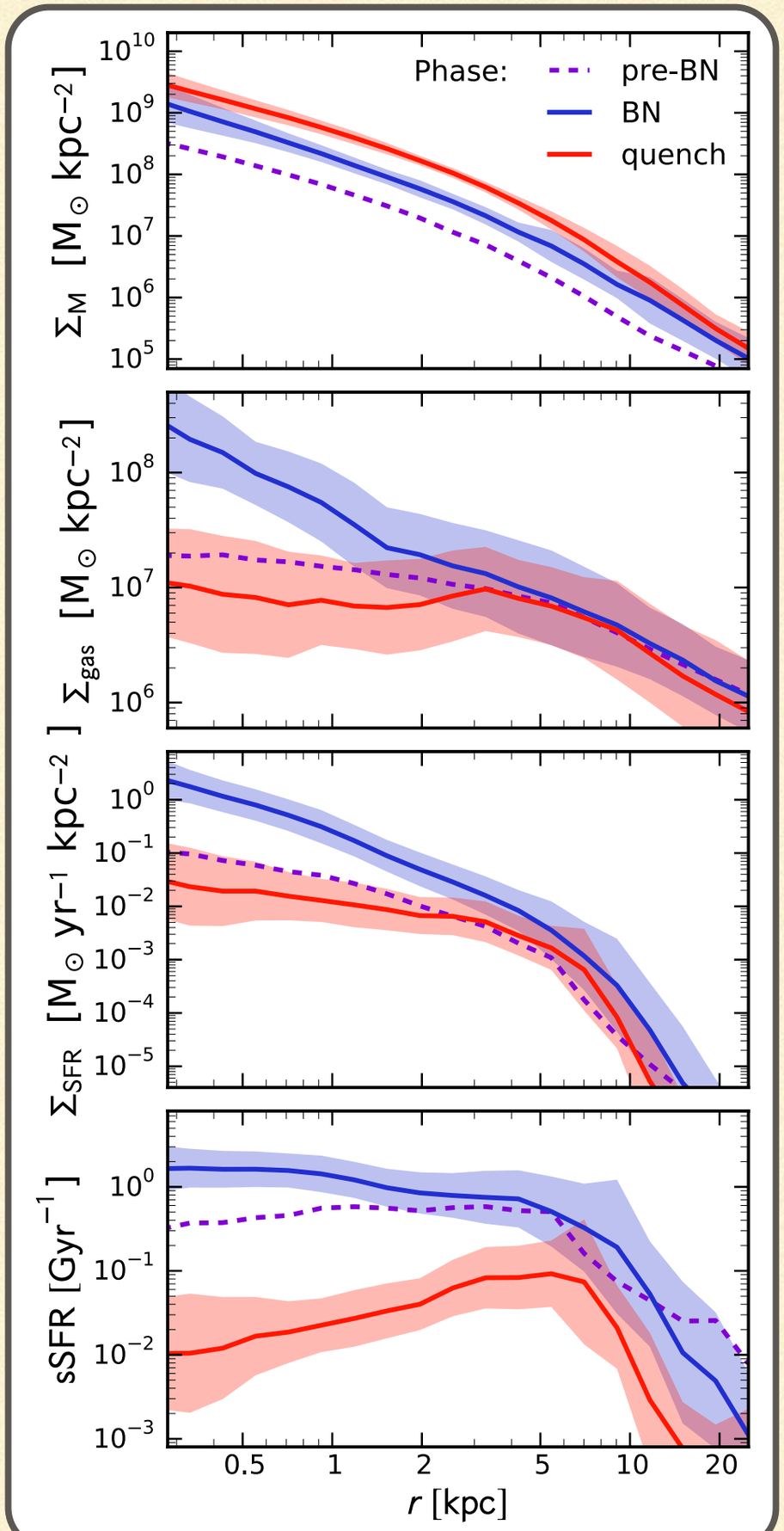
Phase of Compaction



- stellar mass profiles:
  - growth self-similar
  - convergence

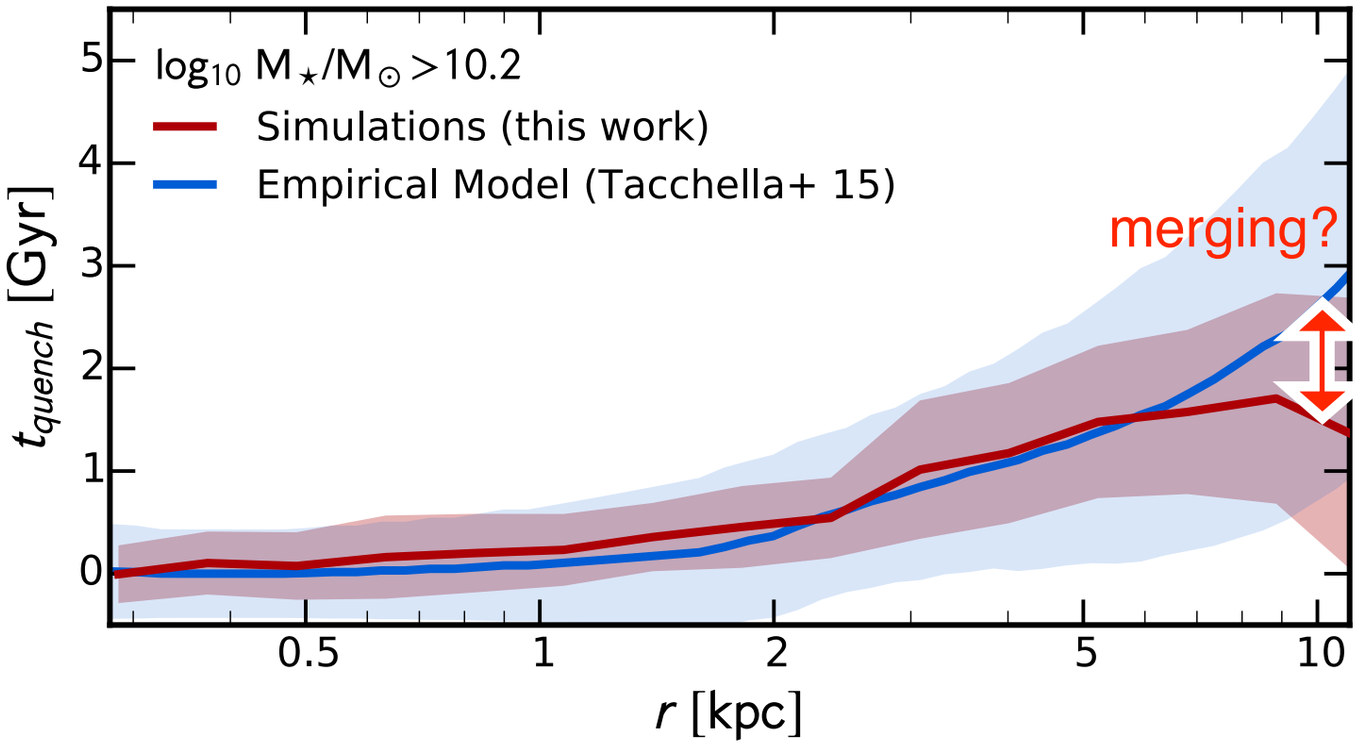
- gas mass and SFR profiles:
  - cusp in the blue nugget phase
  - ring thereafter

- sSFR profiles:
  - inside-out quenching

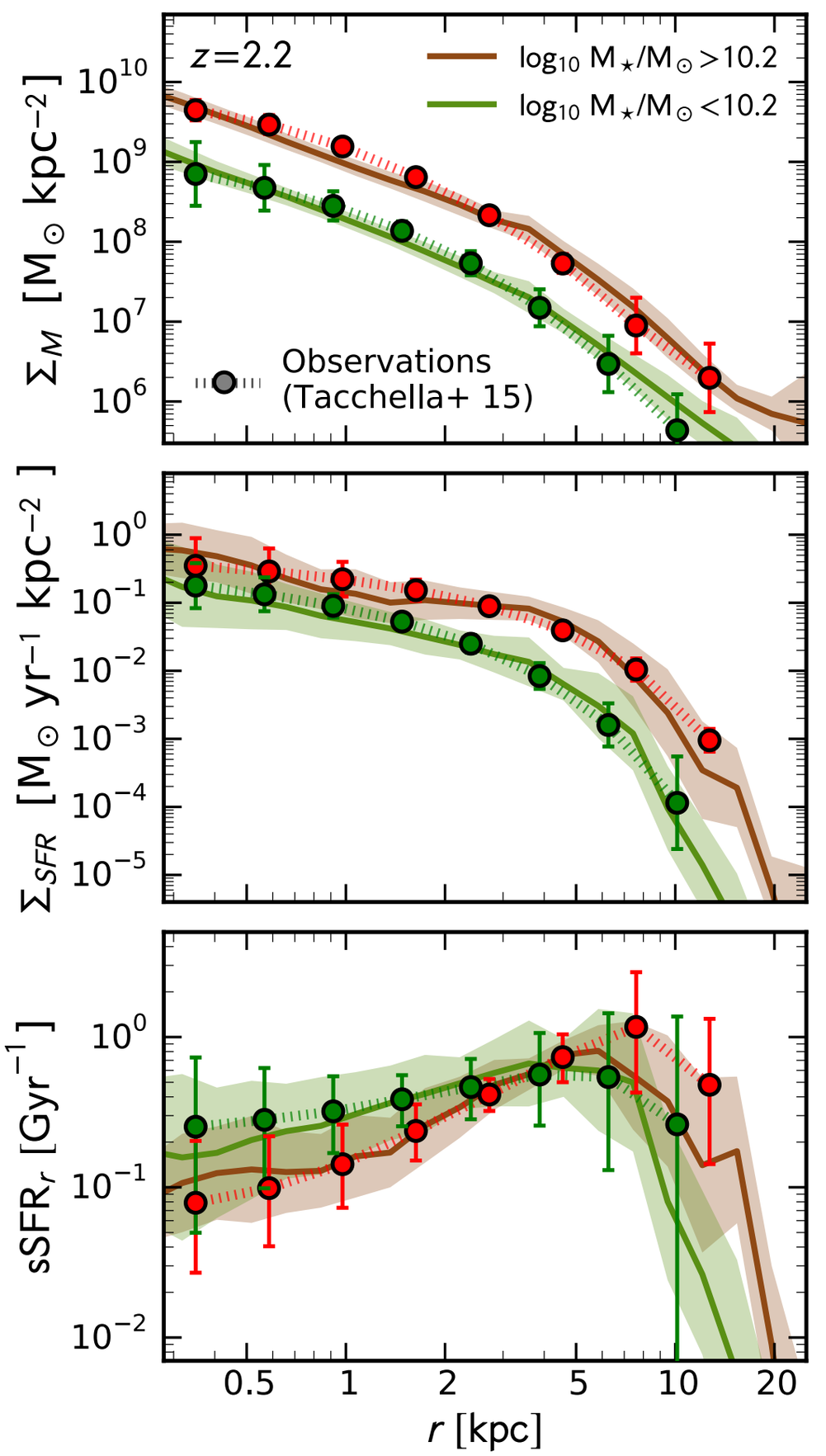


Tacchella, Dekel, Carollo+ (in prep)

Comparison: Simulations — Observations



➜ similar quenching progression in empirical model and simulations



Tacchella, Dekel, Carollo+ (in prep)

Conclusions

- Observations of z~2 star-forming galaxies:
  - massive z~2 galaxies have central stellar mass density similar to today's massive ellipticals
  - reduced star-formation activity first in the center ➜ quench inside-out

- Simulations:
  - stellar mass assembly (incl. inside-out quenching) consistent with observations

- Evolutionary pattern:
  - internal gas processes are key
  - wet compaction event typically occurs at z~2-4 ➜ cuspy gas and SFR profile
  - peak in SFR and the associated feedback marks the onset of gas depletion from the central 1 kpc, which leads to quenching of the central SFR
  - star-forming ring that forms by fresh gas ➜ quench inside-out
  - long-term quenching in hot massive halos at low redshifts, when $t_{rep} > t_{dep}$