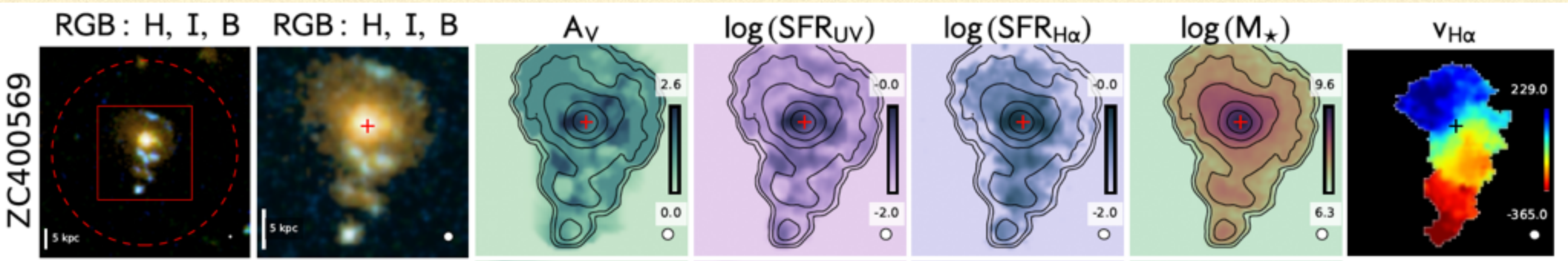
Spatially resolved stellar mass growth in galaxies at z~2: growth of bulges and disks



Sandro Tacchella

ETH Zurich ➜ CfA

C. M. Carollo, A. Dekel, N. M. Förster Schreiber, A. Renzini

D. Ceverino, A. Cibinel G. Cresci, C. DeGraf, R. Genzel, P. Lang, S. Lilly, C. Mancini,
N. Mandelker, M. Onodera, J. R. Primack, A. Shapley, L. Tacconi, M. Trenti, J. Woo, S. Wuyts, G. Zamorani

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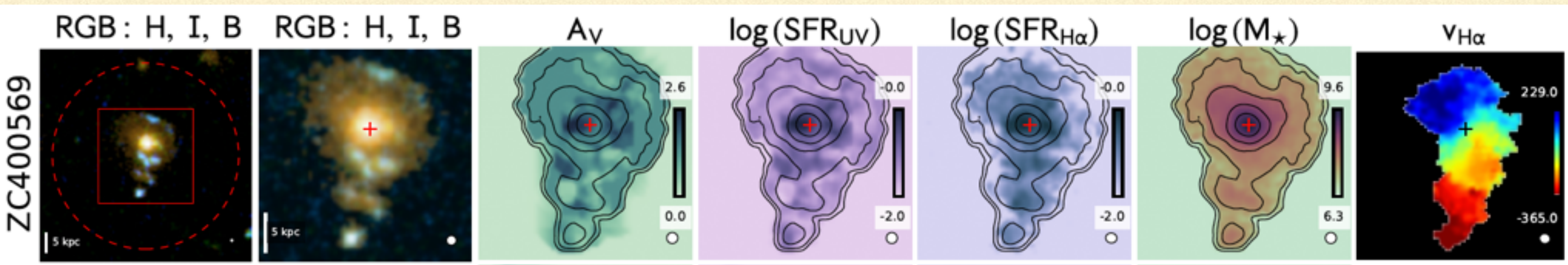
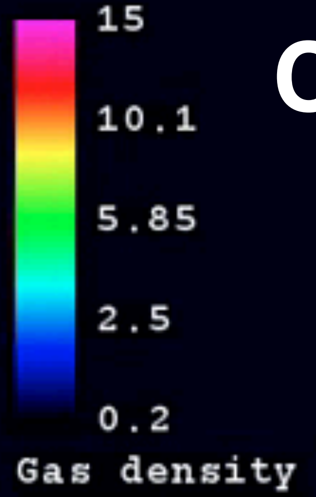


- When (and where) do the stellar mass of the central bulge component and the outer disk component form?
- Which physical process(es) confine the star-forming galaxies into a Main Sequence and how do galaxies evolve on it and leave it?



Cosmological zoom-in simulations with ART (VELA)

Kravtsov+ 1997, 2003; Ceverino+ 2009, 2010, 2014; Zolotov+ 2015
Tacchella+ 2016ab

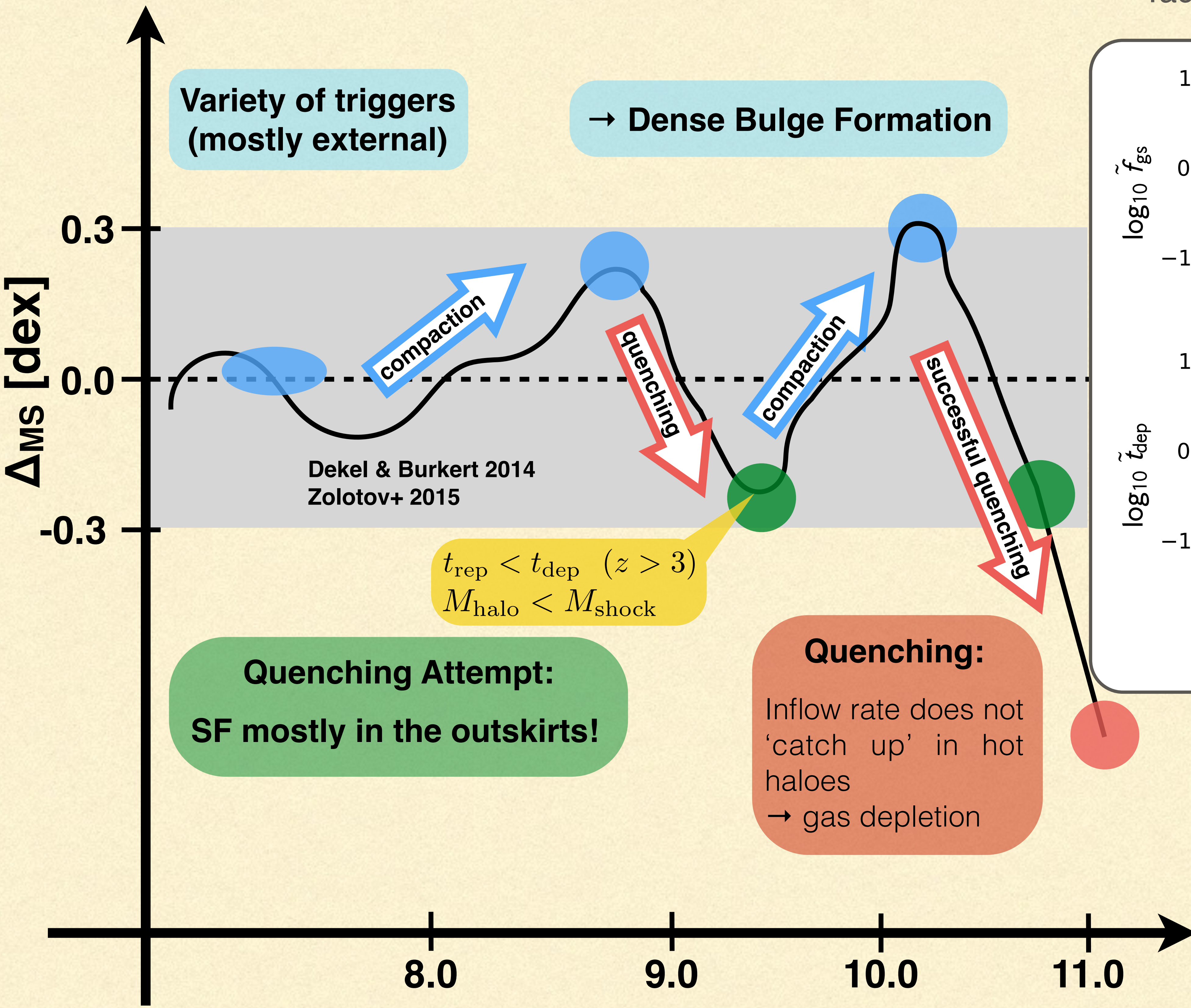
- **26 simulations**
- halo masses of ~10^{11}–10^{12} $M_\odot$ at z~2
  stellar masses of ~10^{9}–10^{11} $M_\odot$ at z~2
- maximal AMR resolution of ~25 pc
- thermal & radiative feedback from stellar winds and SNe
- no AGN feedback

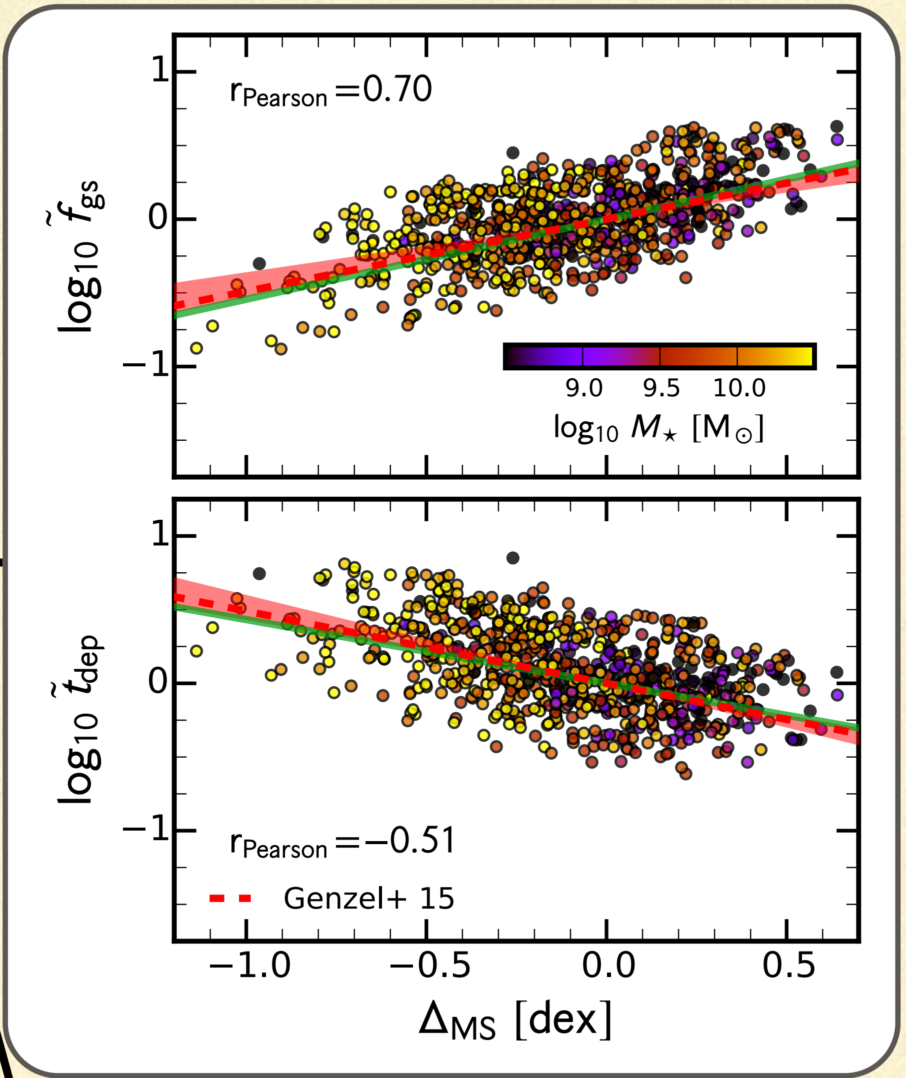
time=1

visualization team at NASA Ames

How do galaxies sustain their Main Sequence equilibrium?

Tacchella+ *MNRAS* (2016ab)

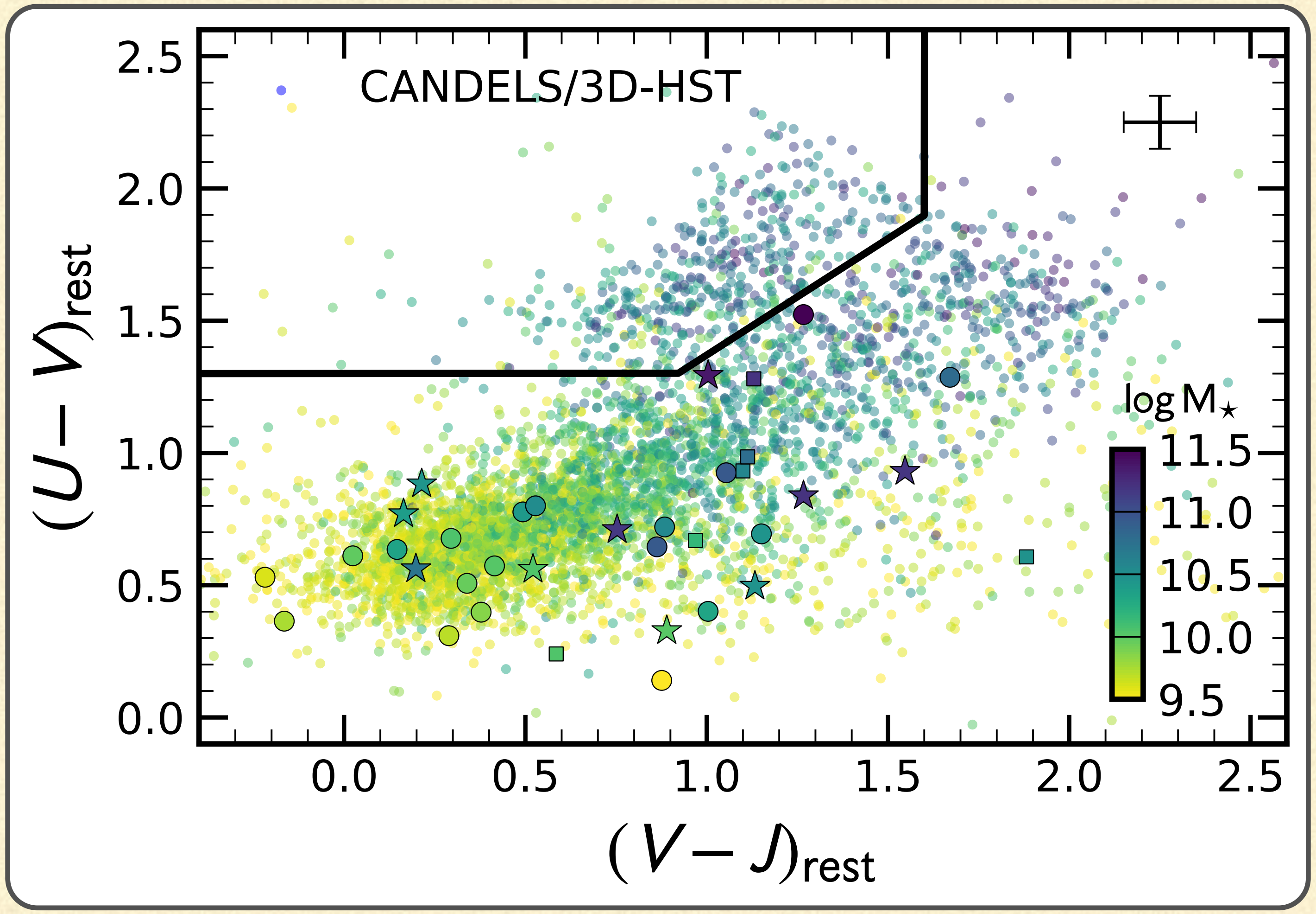




Star-forming galaxies at z~2:

Newman+13; Förster Schreiber+14; Genzel+14ab,17; Burkert+16; Tacchella+15ab,17

AO SINS/zC-SINF Program



- sample selection driven by observability of Hα with SINFONI AO
- sample lies on the Main Sequence

300 hr VLT/SINFONI AO

PI Renzini

K-band Integral Field Spectroscopy

➜ SFR from Hα emission line

➜ ionized gas kinematics

Andi's talk

55 HST/WFC3 Orbits

PIs Förster Schreiber & Carollo

J+H-band imaging (4000A-break)

➜ continuum morphologies

➜ stellar mass distribution

43 HST/WFC3+ACS Orbits

PIs Carollo & Förster Schreiber

B+I-band imaging (UV continuum)

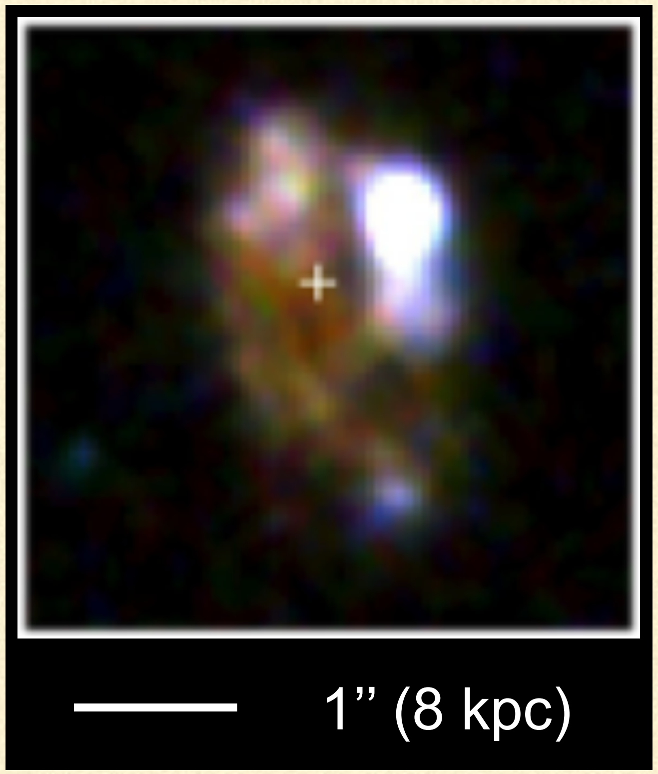
➜ dust attenuation distribution

➜ SFR from UV

Kinematics, stellar mass density, SFR density [Hα and UV], and dust attenuation *within* 'Main Sequence' galaxies at a spatial resolution of ~1-2 kpc!

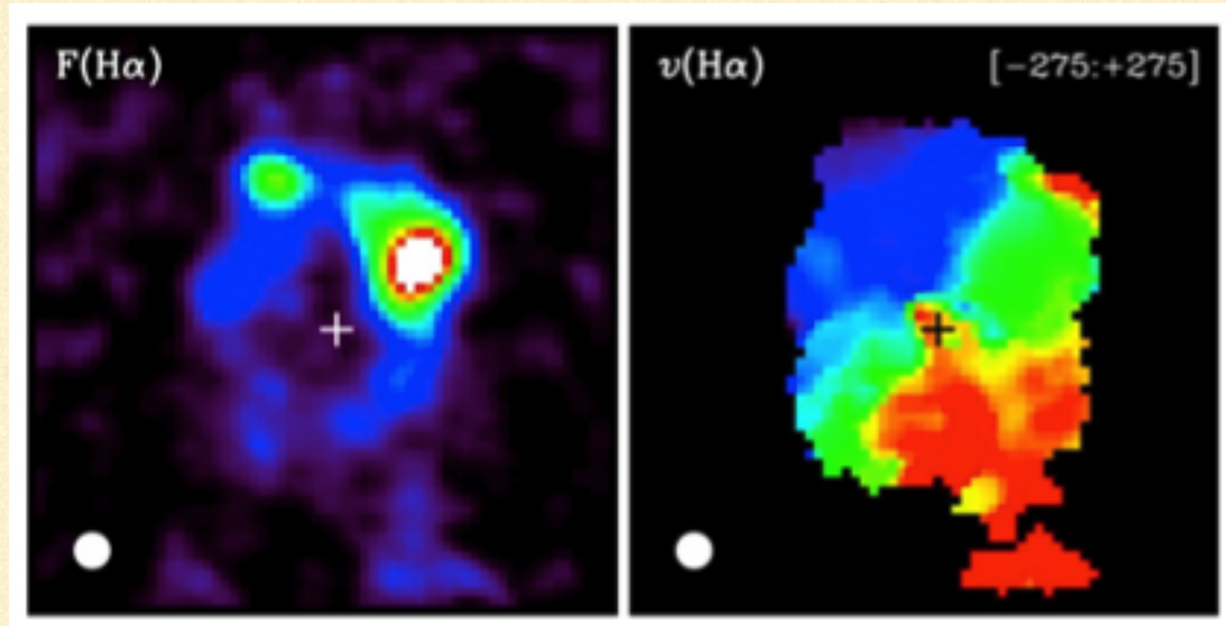
The need for AO: K20-ID7 (z=2.2)

HST IJH

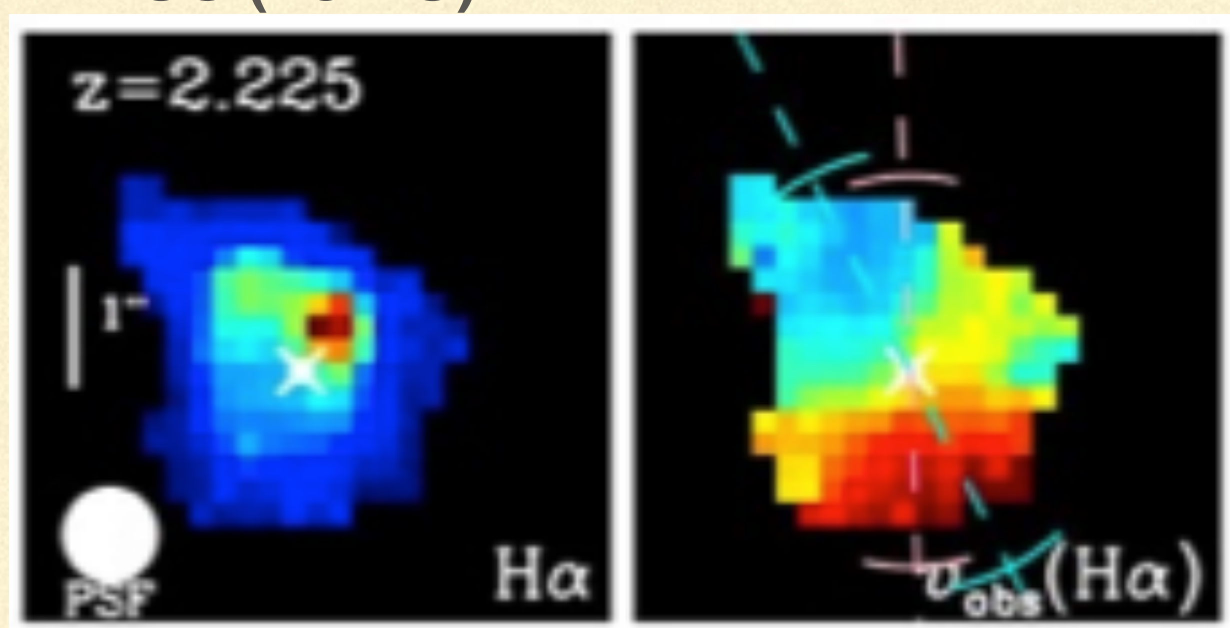


$M_\star$ = 4 x 10^{10} $M_\odot$
SFR = 210 $M_\odot$/yr
F(Hα) = 2 x 10^{-16} cgs

SINFONI (AO)

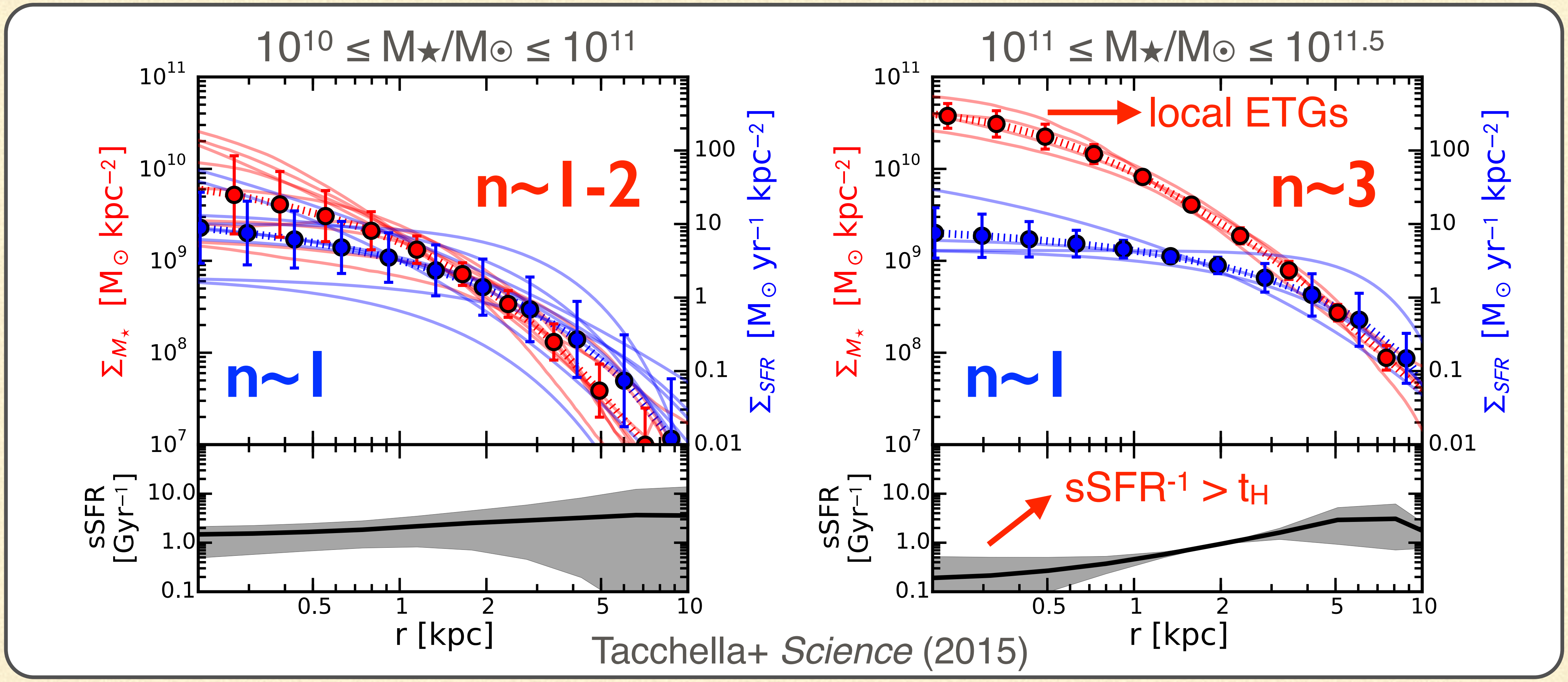


KMOS (no AO)



Newman+ (2013);
Förster Schreiber+ (in prep);
Tacchella+ (2015ab)

Star-forming galaxies at z~2:
Distribution of stellar mass and SFR density

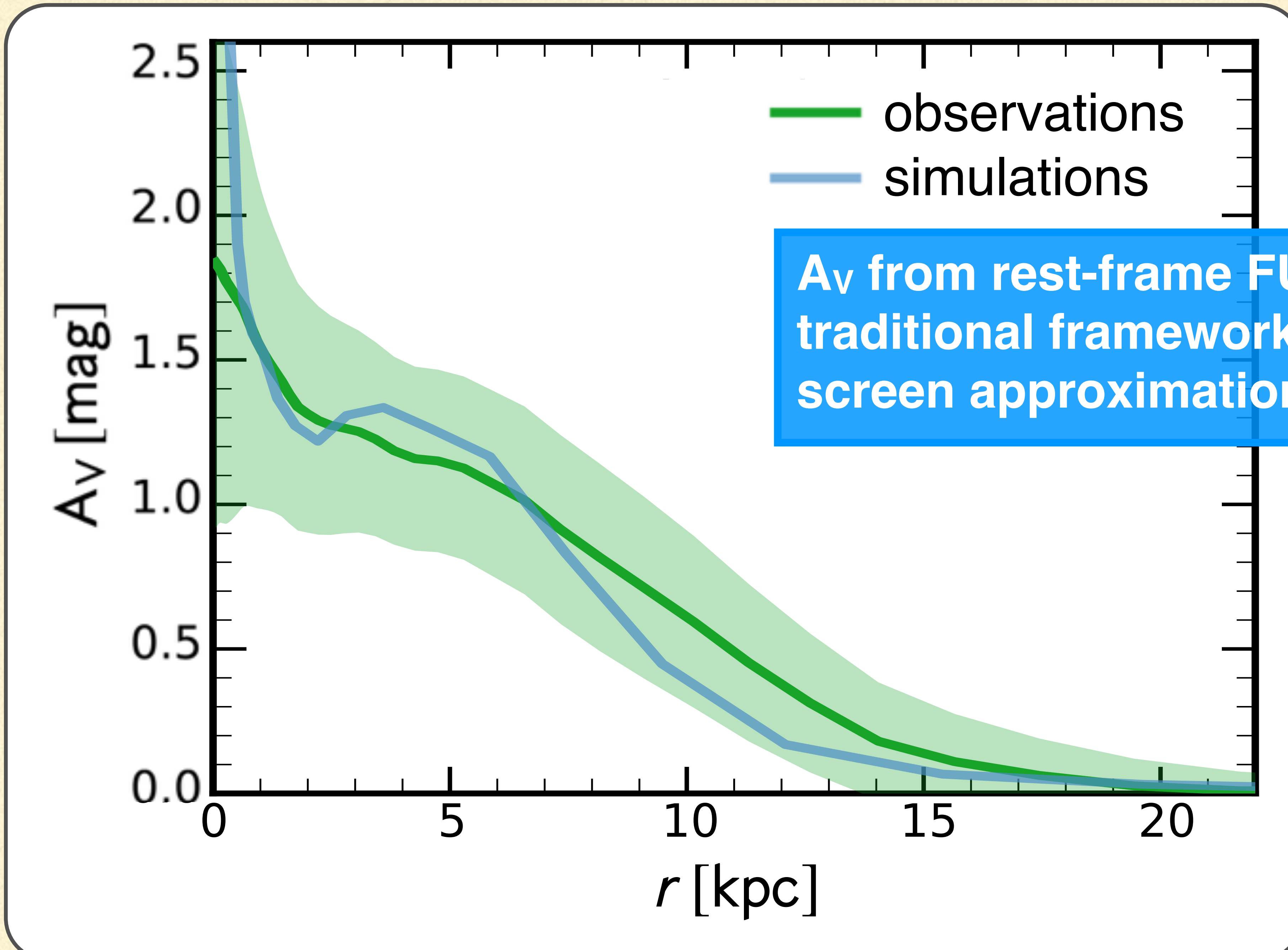


- Steeper stellar mass density profiles with increasing mass and flat sSFR profiles
  - ➜ centers builds up hand-in-hand with total stellar mass
  - ➜ evolution along the Σ_1 -M⋆ (structural) sequence (see also van Dokkum+13, Barro+17)
- Most massive galaxies have suppressed central sSFR
  - ➜ central stellar mass densities comparable with z~0 population (see also Saracco+12)
  - ➜ heavily star-forming outskirts around ~***quenched centers*** (see also Genzel+14)

talk by Sandy and my talk on Monday

or dust attenuation?

Distribution of dust attenuation: A_V profiles

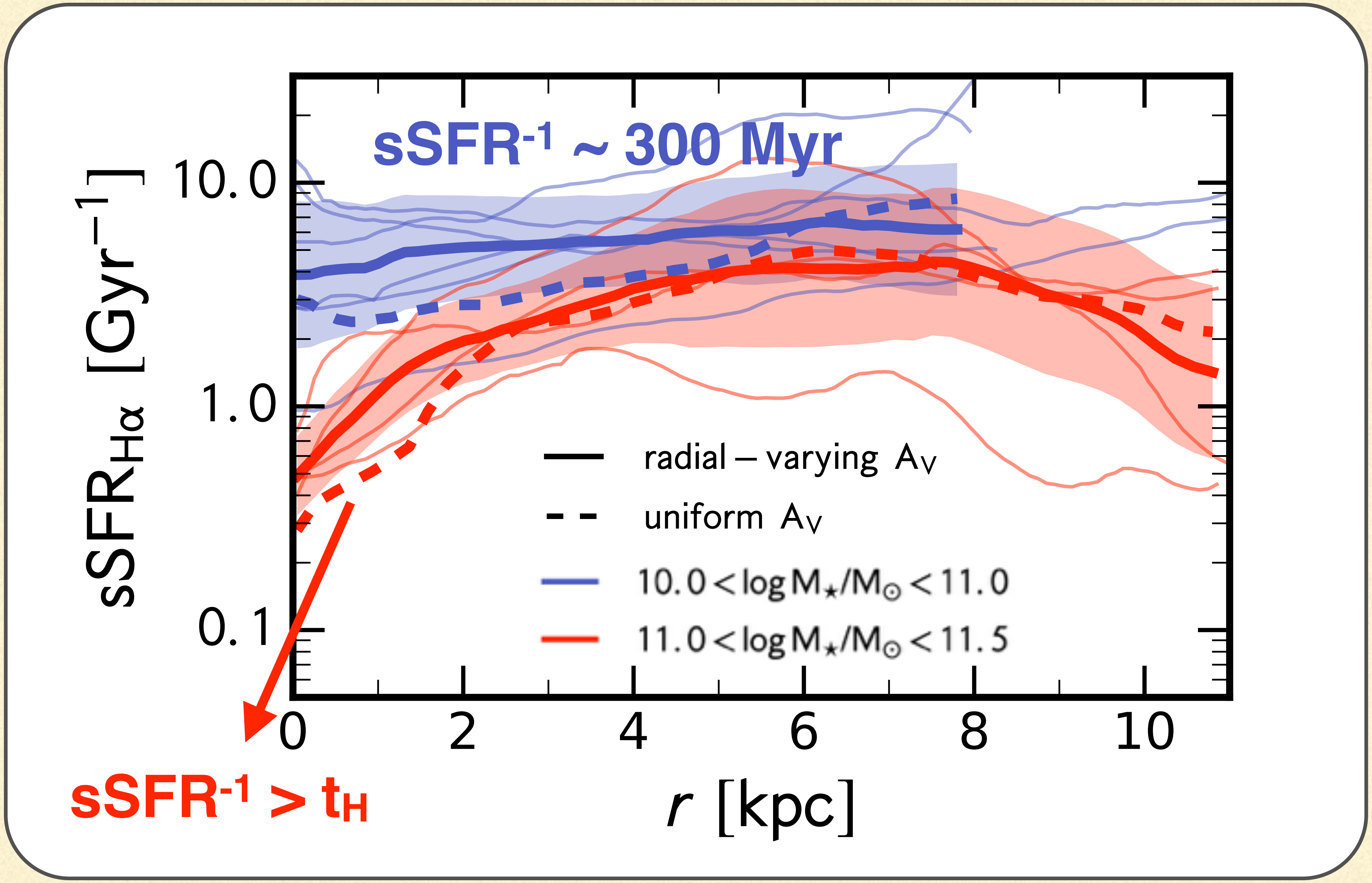


A_V from rest-frame FUV-NUV color: traditional framework of the uniform screen approximation

- variation in individual profiles
- dust attenuation rises towards the center (see also Wuyts+ 2012; Hemmati+ 2015)
- substantial attenuation out to large radii (A_V ~ 0.5 mag @ 10 kpc)

Tacchella+ (2017)

Growth of galaxies due to star formation

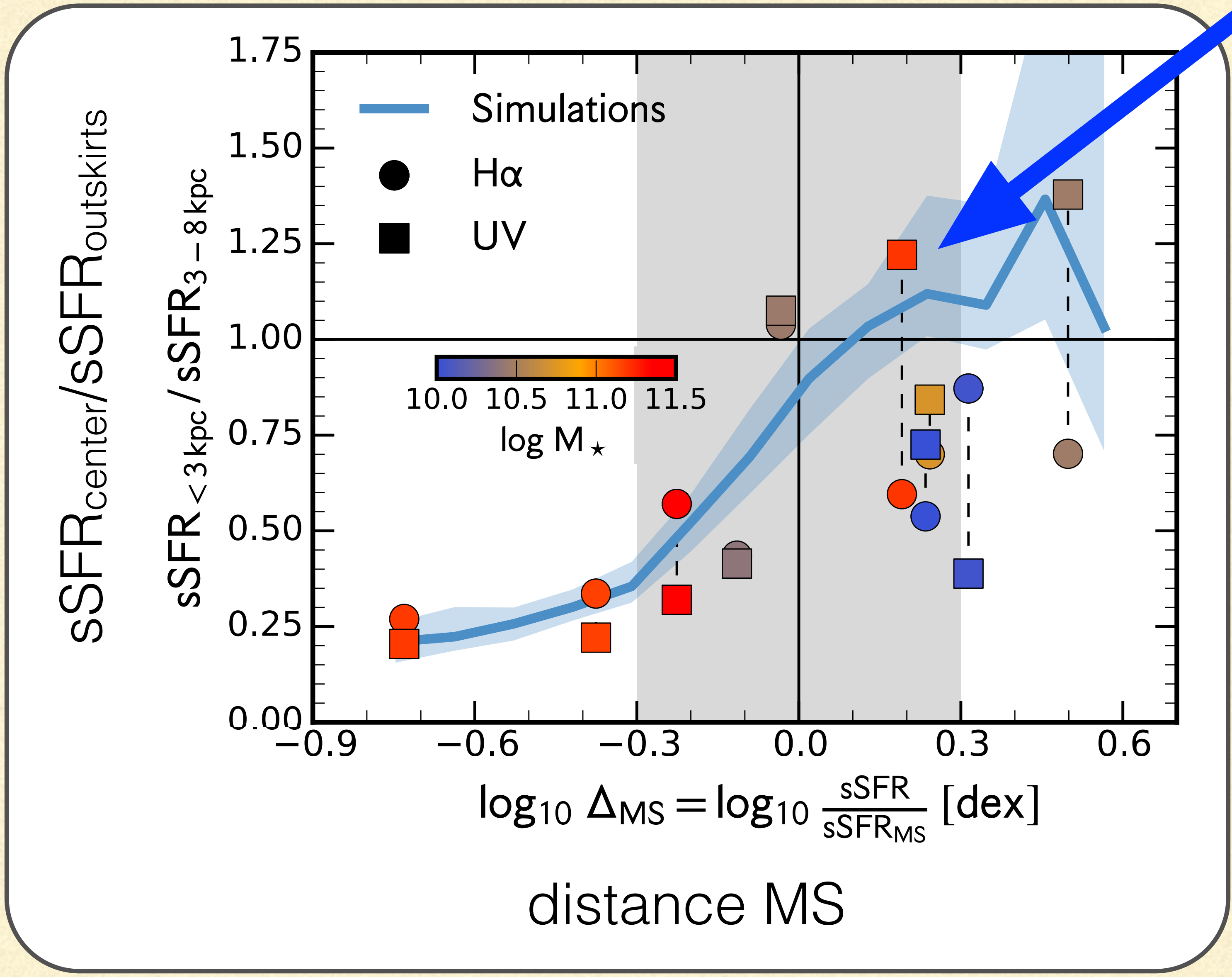


- lower-M galaxies have flat sSFR profiles, i.e. growing self-similarly
  ➜ **concurrent growth of center ("bulge") and outskirts ("disk")**
- higher-M galaxies have rising sSFR towards the outskirts, i.e., they grow / quench inside-out
  ➜ **growth of outskirts ("disk")**

Tacchella+ (2017)

sSFR distribution within galaxies on the Main Sequence: observations and simulations

ALMA: Barro+16 / Tadaki+17



- galaxies above the MS ridge:
  ➜ higher sSFR in their centers
  ➜ **build-up of core ("bulge")**

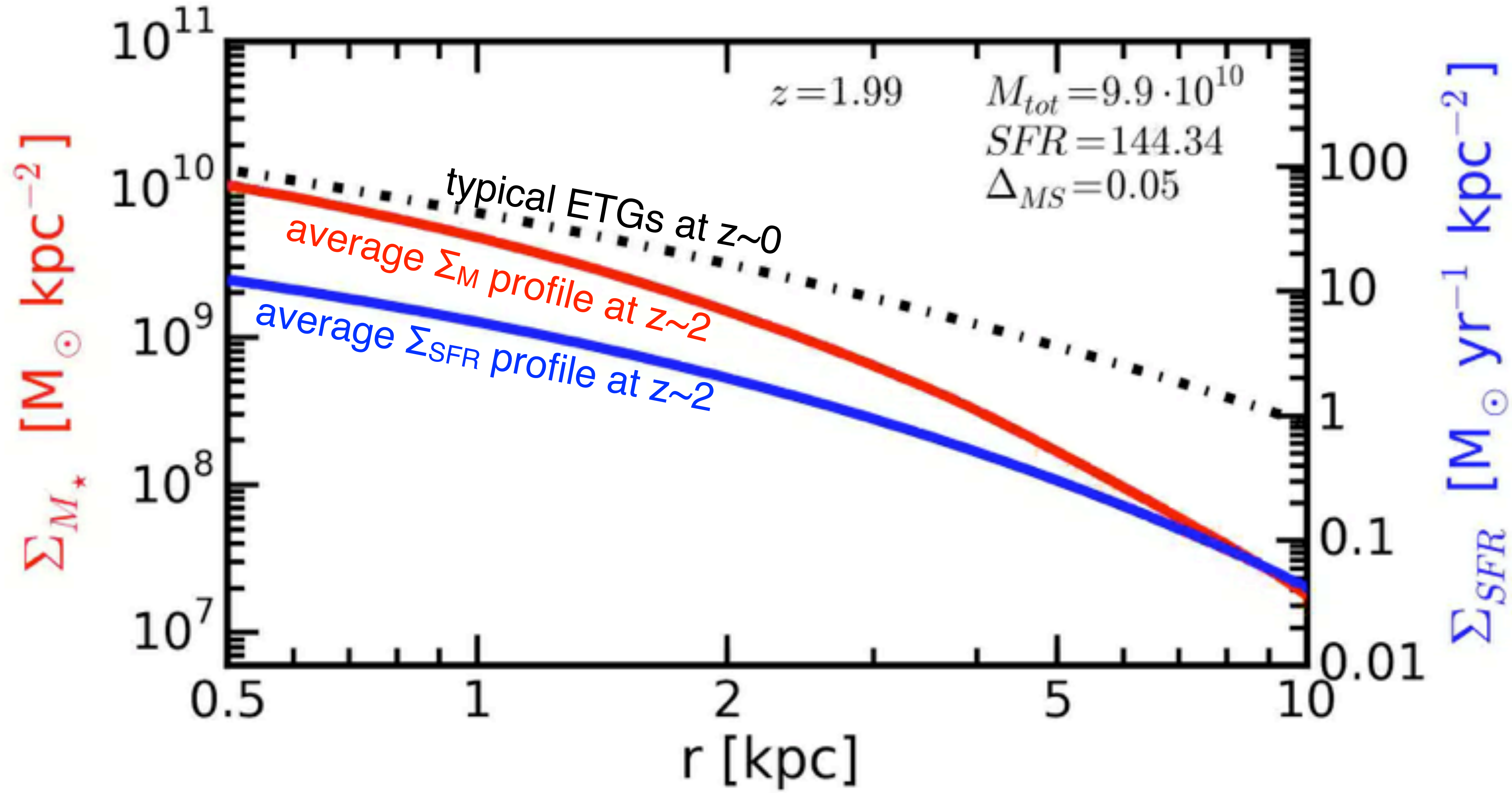
- galaxies below the MS ridge:
  ➜ higher sSFR in their outskirts
  ➜ **build-up of outskirts ("disk")**

- dust correction is key!

Tacchella+ (2017)

Quenching Timescales within $M_\star \sim 10^{11}$ $M_\odot$ z~2 Galaxies

How do galaxies leave the MS and cease their star formation?

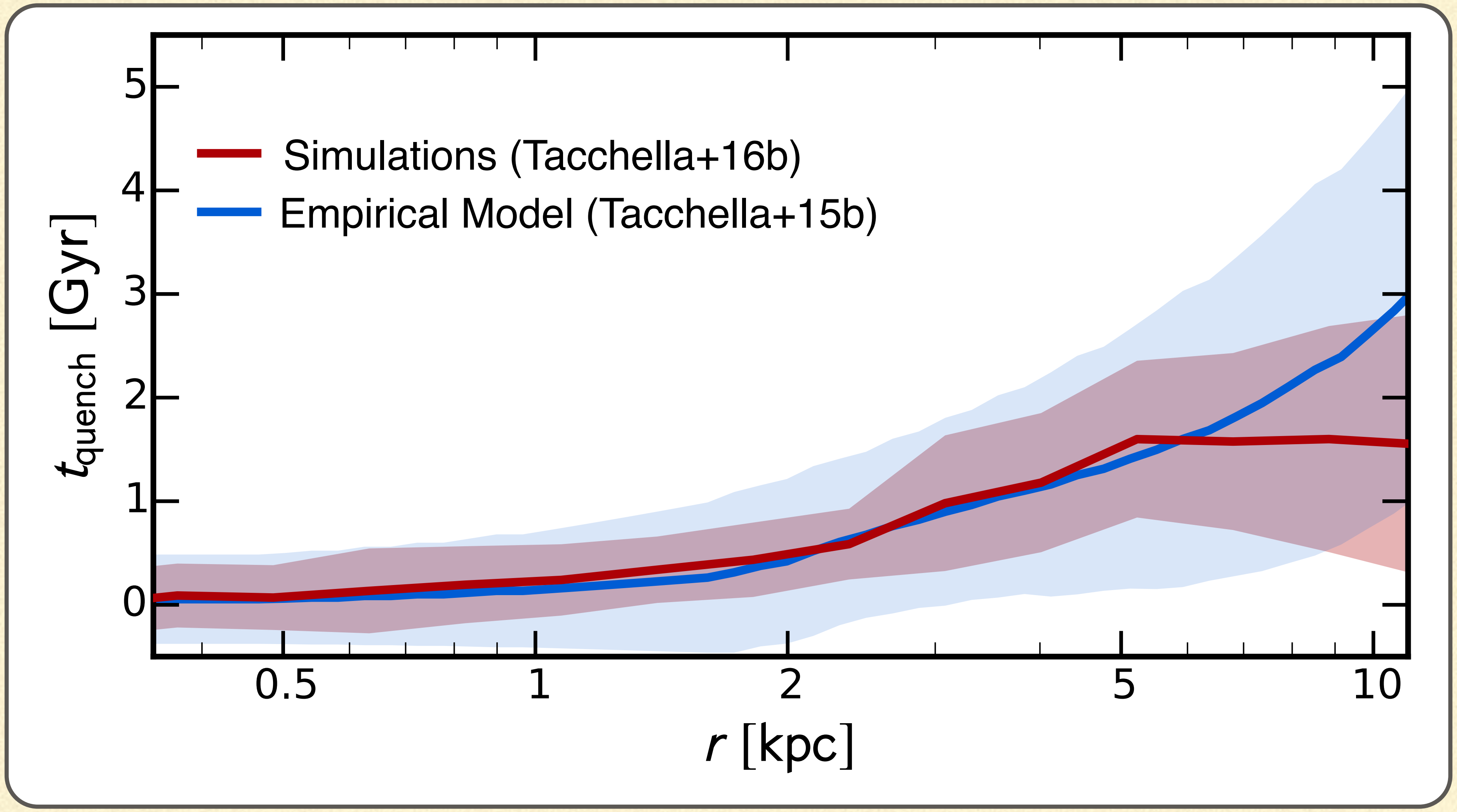


- evolve Σ_M profile using Σ_{SFR} profile
- star formation history constrained to Main Sequence at all z

Tacchella+ (2015b)

Quenching Timescales within $M_\star \sim 10^{11}$ $M_\odot$ z~2 Galaxies

How do galaxies leave the MS and cease their star formation?



nucleus-driven outflows (AGN)? e.g., Förster Schreiber+14; Genzel+14a
morphological Q? e.g., Martig+09; Genzel+14b
Gas supply cut-off? e.g., Feldmann+15; Peng+15
…?

simulations: suppression of the gas flow towards the central region of the galaxy due to the low gas mass in the disk, which is caused by a hot halo and / or a low cosmological accretion rate

Conclusions

- below 10^{11} M⊙, average sSFR profile is roughly flat (sSFR~3 Gyr^{-1})
  ➜ concurrent growth of inner component (“bulge”) and outskirts (“disk”)
  ➜ oscillations about the Main Sequence? ➜ SFHs of individual galaxies

- ≥10^{11} M⊙, sSFR profile decreases towards the center (sSFR~0.3 Gyr^{-1})
  ➜ suppression of their star-formation activity in their inner cores ➜ not due to dust effects
  ➜ simulations suggest that at early epochs gas-rich gas-inflows (compaction events) lead to the formation of a spheroidal-like component, and subsequent inside-out quenching
  ➜ witness the dissipative formation of M* ETGs