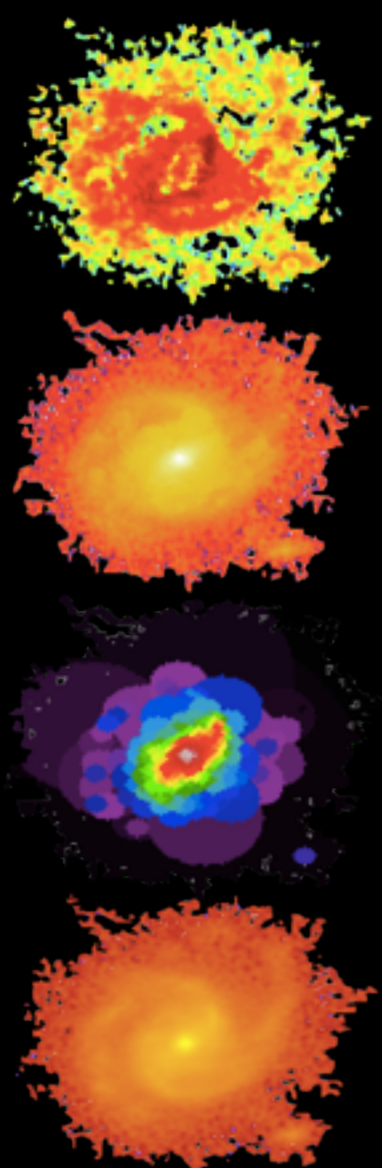
Spatially resolved stellar mass buildup and quenching in massive disk galaxies at $0 \lesssim z \lesssim 1$

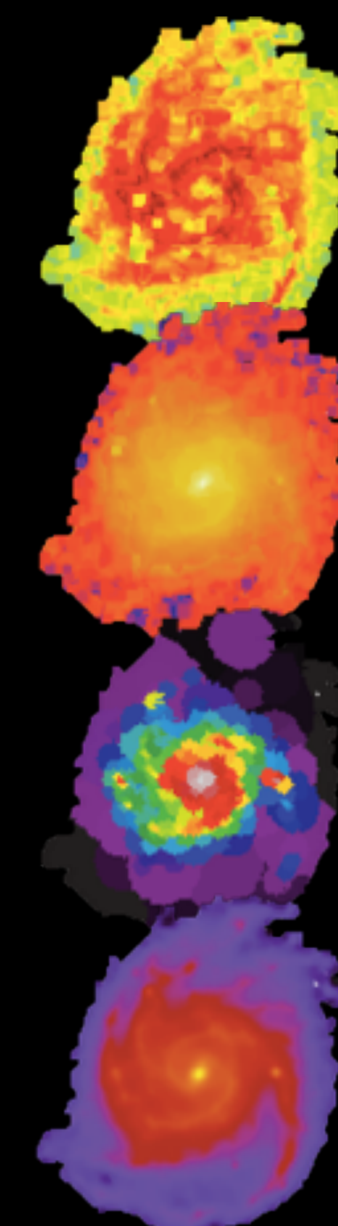


Abdurro'uf (D3)

Masayuki Akiyama

Based on:
Abdurro'uf & Akiyama, 2017, MNRAS, 469, 2806
Abdurro'uf & Akiyama, 2018, arXiv (1802.03782)

Astronomical Institute,
Tohoku University



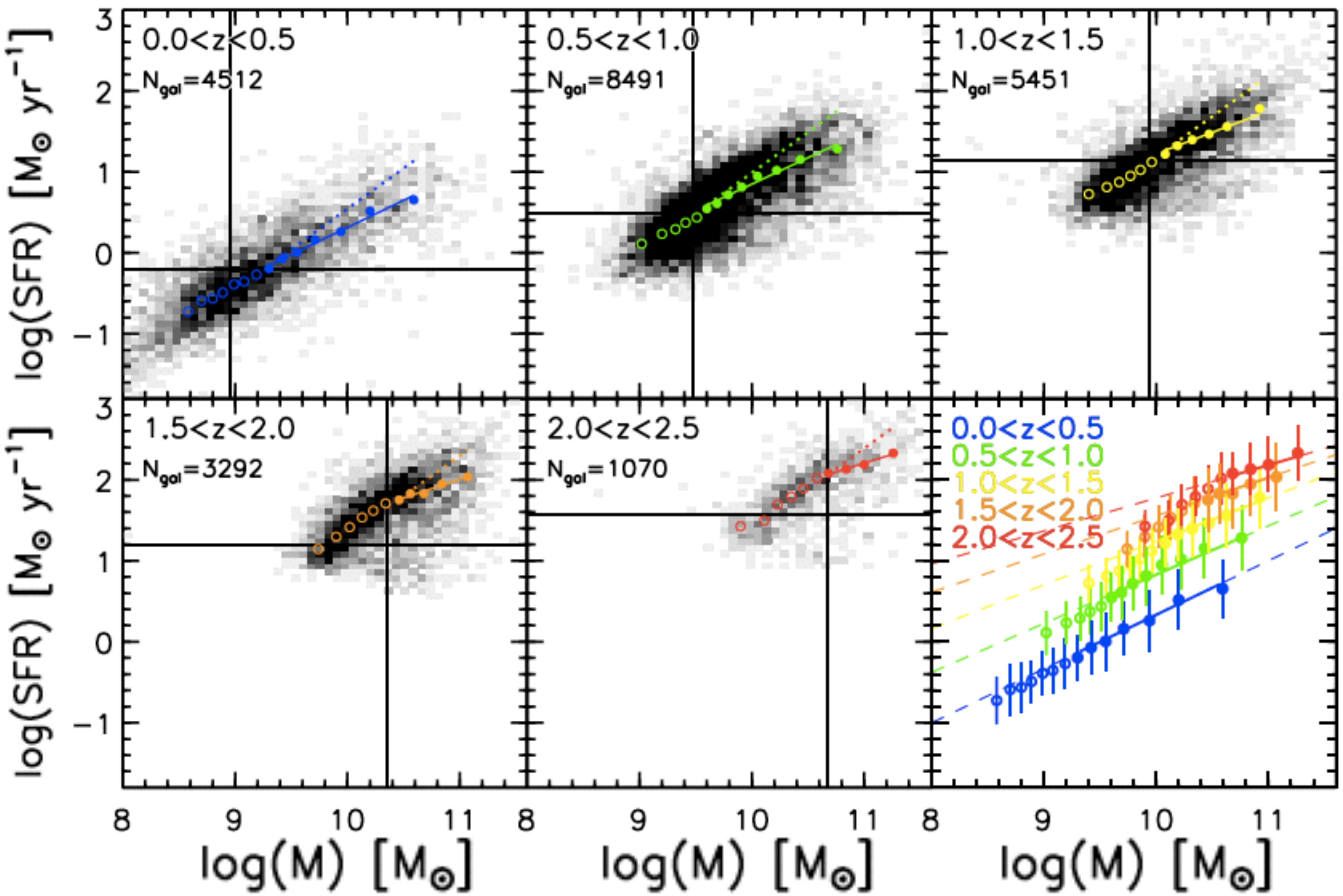
Galaxy evolution workshop, Ehime University - June 6th, 2018

Outlines

- Introduction
- Methodology
- Results & discussions
  - Spatially resolved SFMS at z~0
  - Spatially resolved SFMS at z~1
  - Connecting z~0 and z~1 samples: stellar mass buildup and quenching in massive disk galaxies
- Summary

Global Star formation main sequence (SFMS)

- Tight (~0.3 dex) relation in logarithmic scale between SFR and stellar mass
- Hold up to high z and show evolution in term of slope and normalization
- ~90% cosmic SFR occurs on the SFMS



$$\log(\mathrm{SFR}) = \alpha(z)(\log M_\star - 10.5) + \beta(z).$$

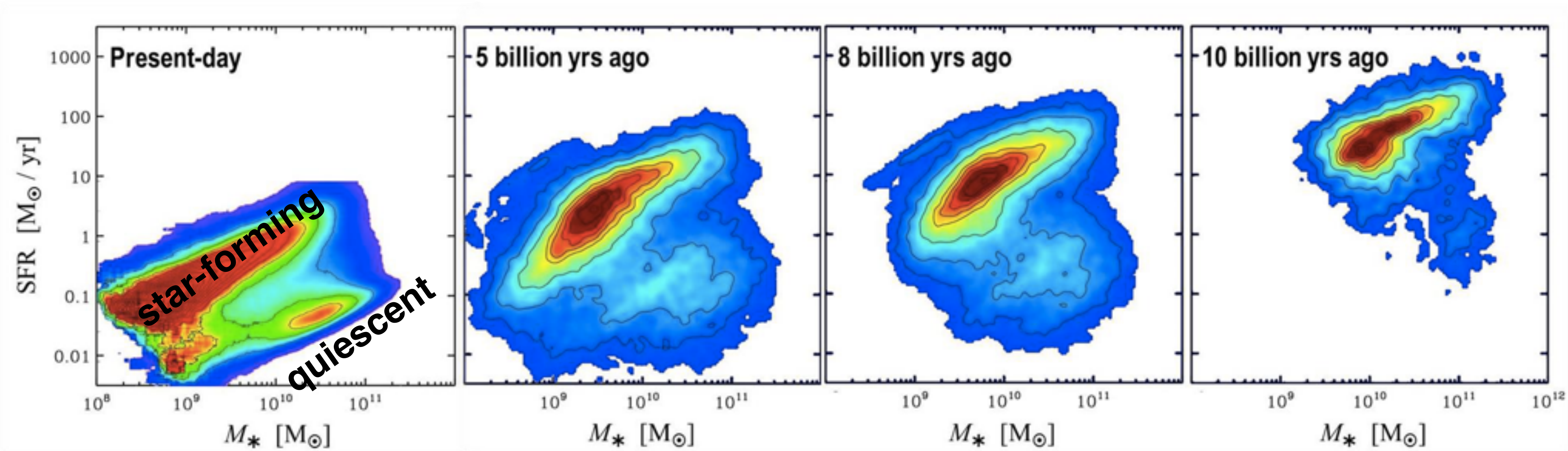
$$\beta(z) = 0.38 + 1.14z - 0.19z^2$$

$$\alpha(z) = 0.70 - 0.13z$$

Whitaker et al. (2012)

Growing number of quiescent galaxies with cosmic time

- Number of quiescent galaxies is growing with time
- Normalisation of the SFMS is decreasing with time
- How galaxies quench and what mechanism make them to quench, is not yet understood

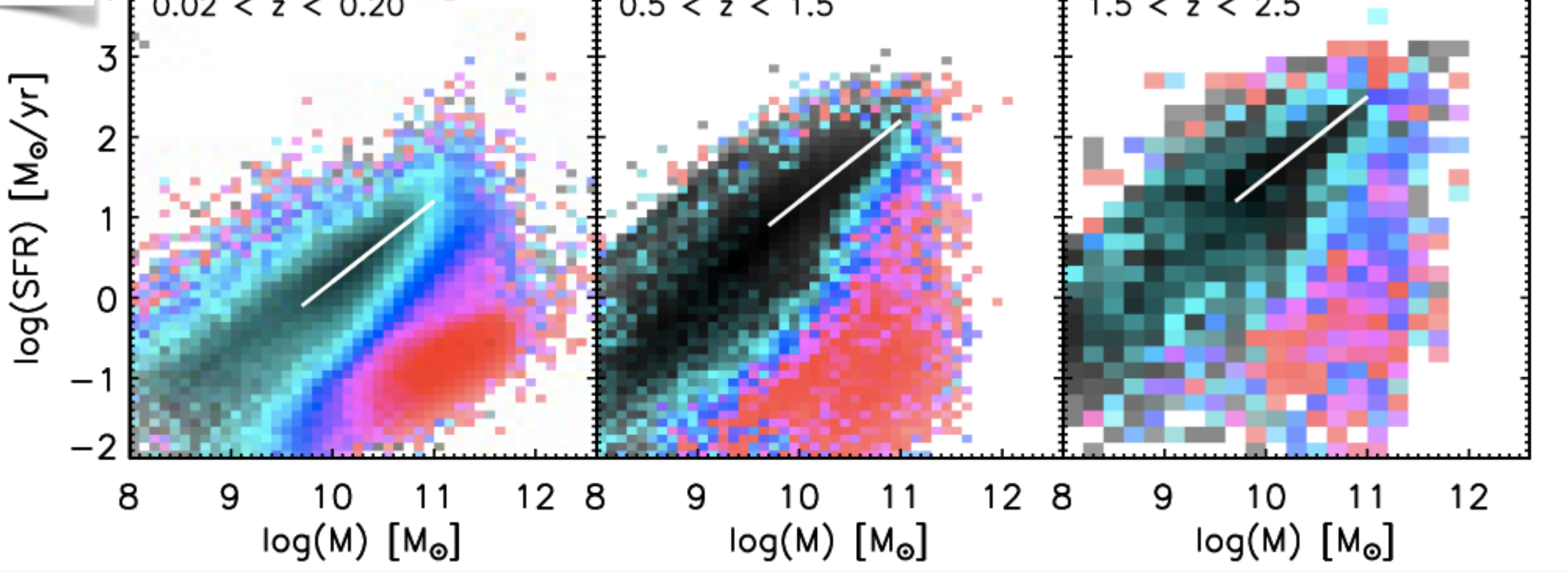


Renzini & Peng (2015)

Image credit: Forster-Schreiber

Hubble sequence is already in place at z~2.5

- Hubble sequence is already in place at z~2.5
- Star-forming galaxies are disk-dominated and quiescent galaxies are bulge-dominated



- How galaxies built heir structure from disk-dominated to bulge-dominated system as they evolve?

Wuyts et al. (2011)

Motivation: How galaxies growth and quench?

- Study the spatially resolved **stellar mass buildup and quenching process** in massive disk galaxies from z~1 to z~0
- There is **lack of study which directly connect between evolution of the spatially-resolved star formation activity and stellar mass growth** in the galaxies over wide redshift range

Previous studies by other researchers:

at z~1

connecting them need additional efforts (e.g. calibration)

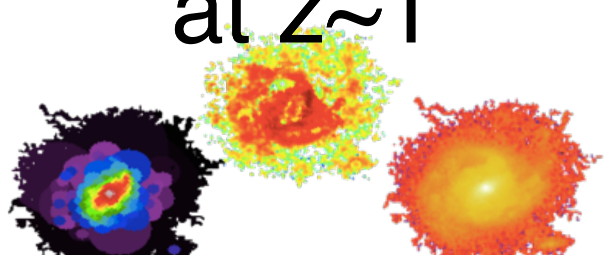
?

at z~0

X

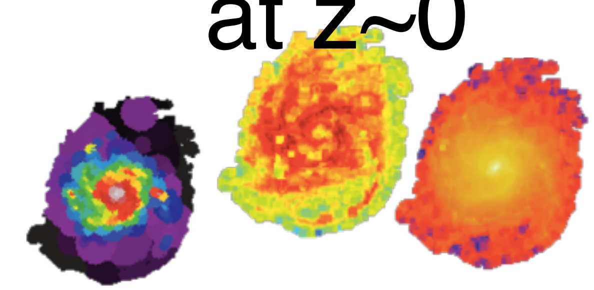
Our approach: single method applied to z~1 and z~0 galaxies

at z~1



Spatially resolved SED fitting

at z~0

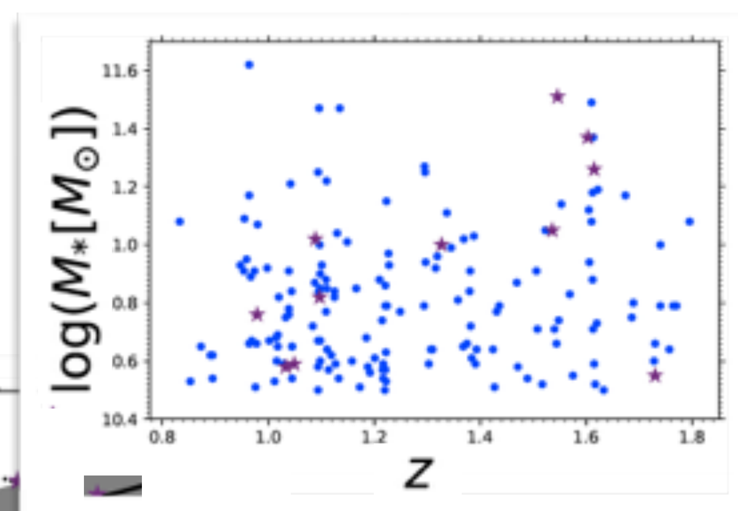


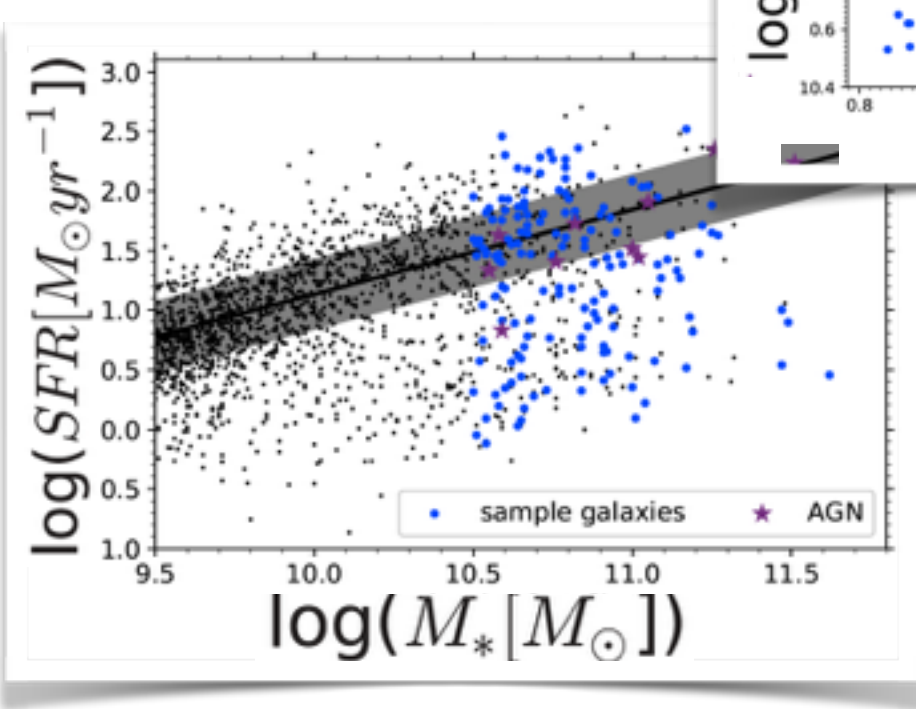
Sample galaxies

z~1 sample

- 152 galaxies
- **Massive** (log(M*)≥10.5)
- **Face-on** (e<0.6), **disc** (n<2.6)
- **Redshift**: 0.8 ≤ z ≤ 1.8
- 8 bands imaging data from **CANDELS and 3D-HST**
- FWHM=0.19” (~1.4-1.6 kpc) and pixel-sampling=0.06”

3D-HST imaging





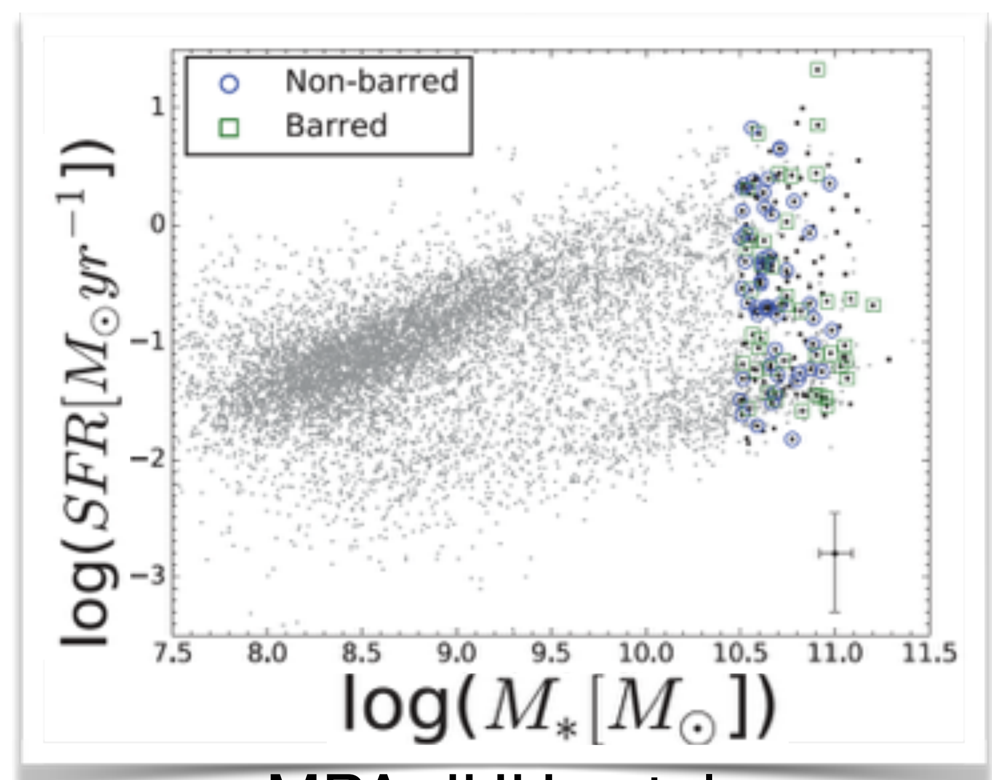
- 3D-HST catalog

z~0 sample

- 93 galaxies
- **Massive** (log(M*)≥10.5)
- **Face-on** (e<0.6), **spiral galaxies**
- **Redshift:** 0.01≤ z ≤ 0.02
- 7 bands imaging data from **GALEX and SDSS**
- FWHM=5.3” (~1-2 kpc) and pixel-sampling=1.5”

GALEX

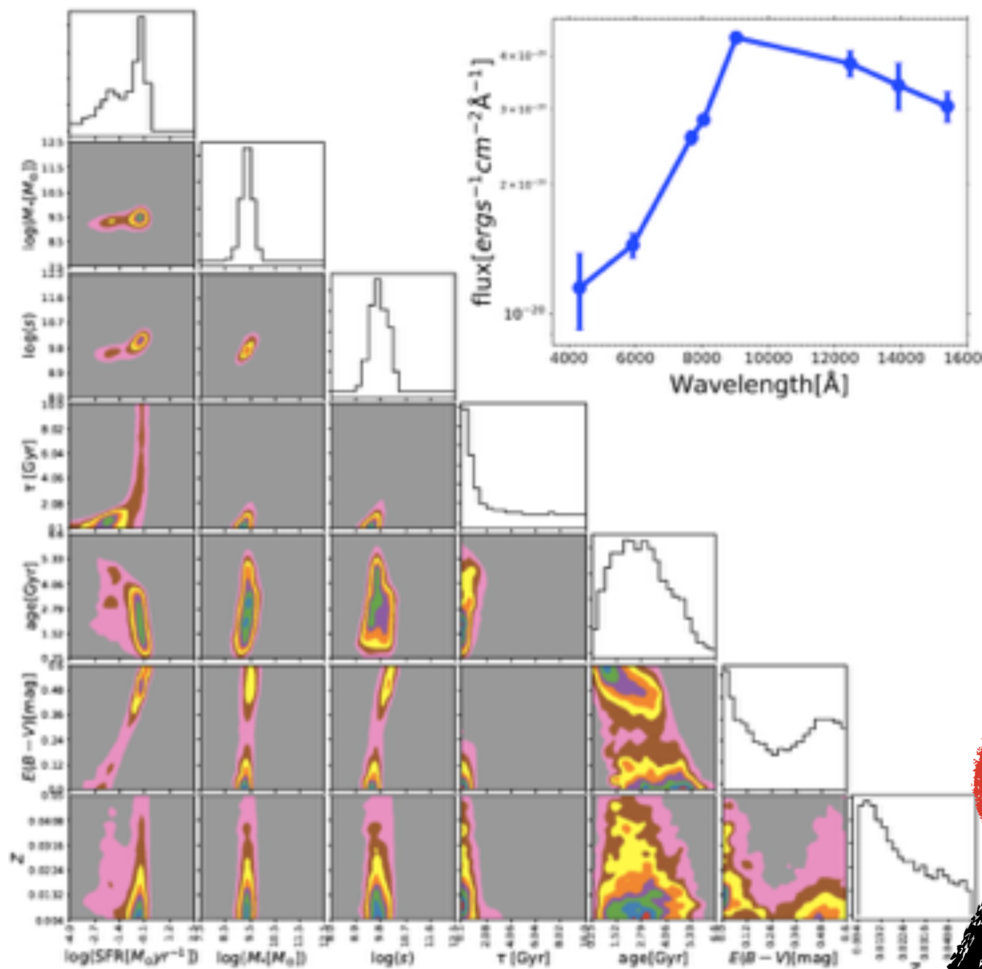
+ SDSS

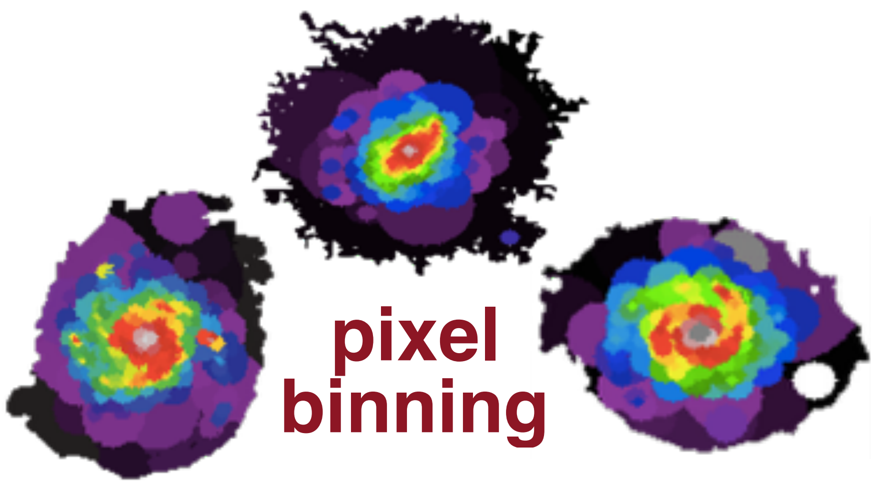


- MPA-JHU catalog

Methodology: pixel-to-pixel SED fitting

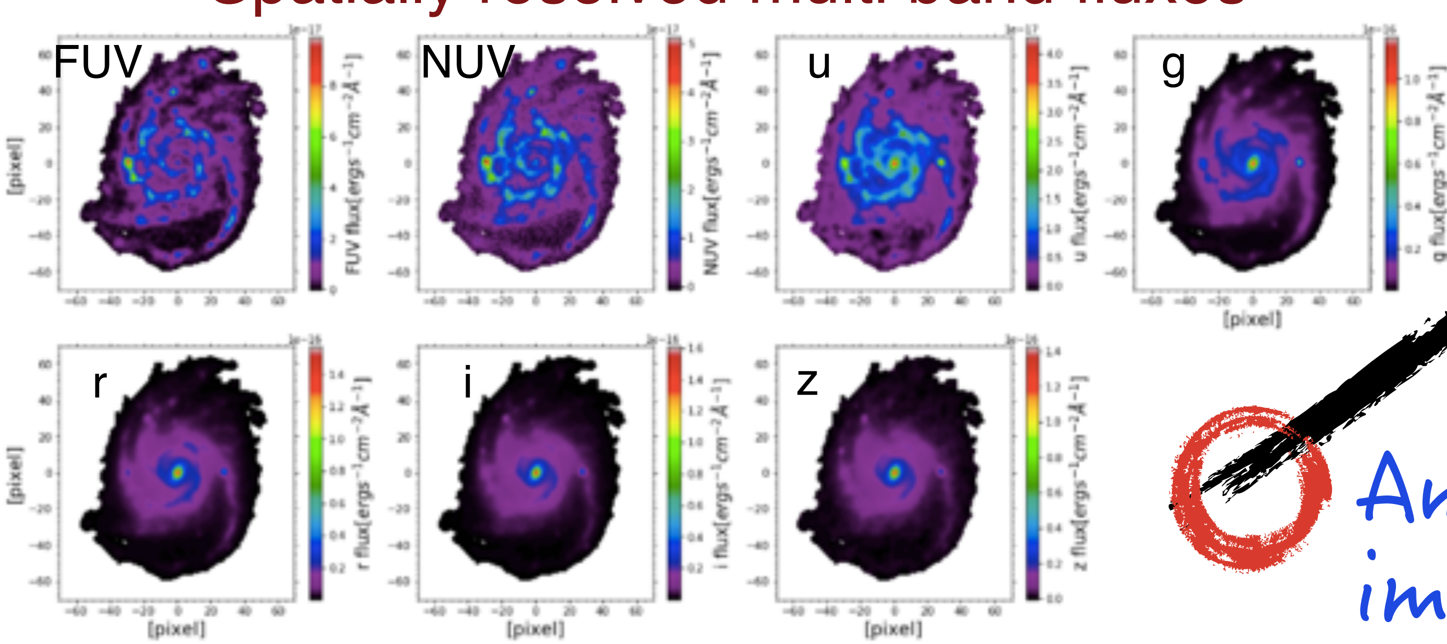
- SED fitting for each bin SED using Bayesian statistics





pixel binning

Spatially resolved multi band fluxes



SED Fitting with Bayesian statistics

Construction of model SEDs

- 300000 random model SEDs
- Random parameters: Z, tau (exp. SFH), E(B-V), and age

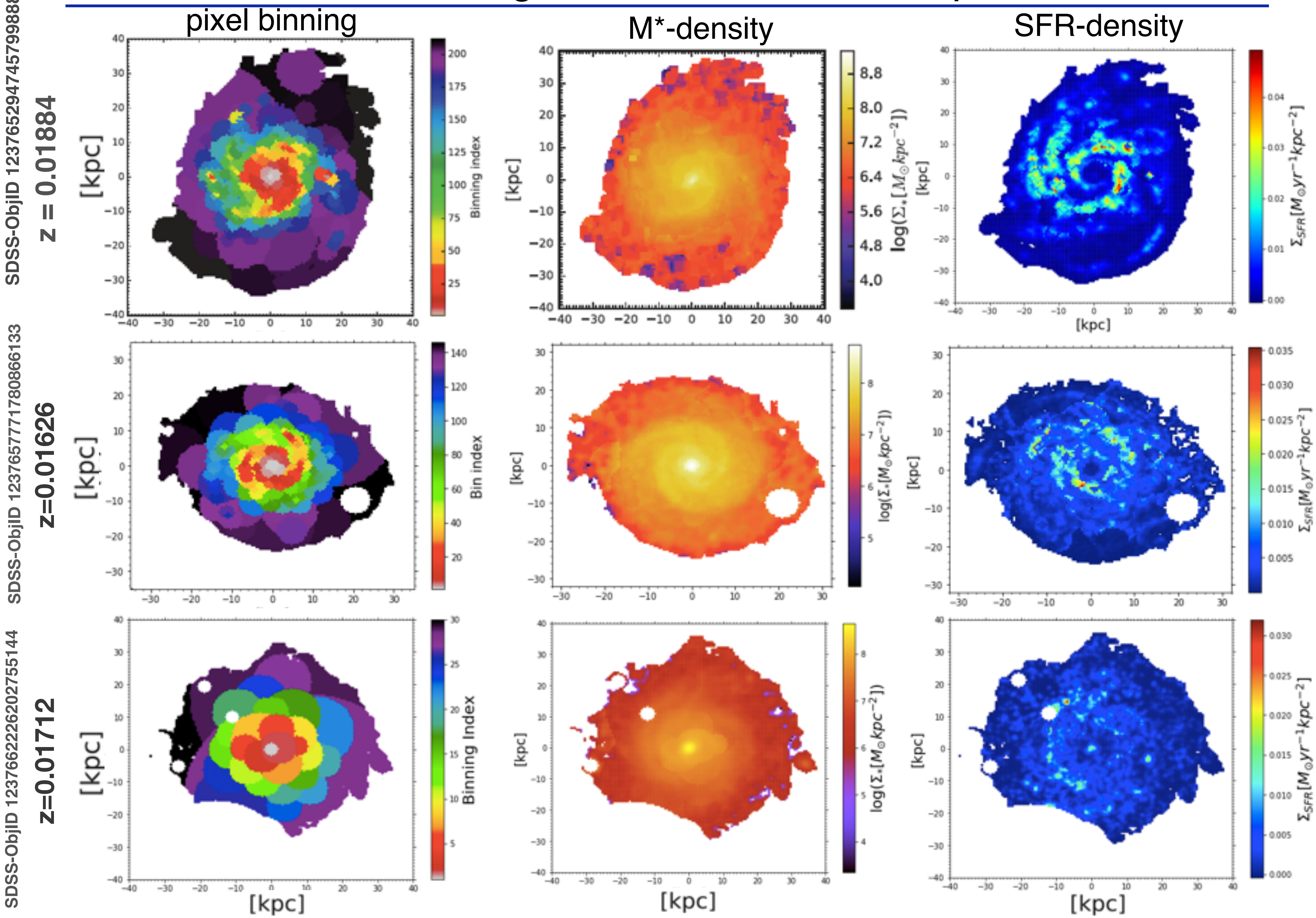
Pixel binning

Analysis of imaging data → Spatially resolved multi band fluxes

Methodology

Examples of pixel-to-pixel SED fitting result

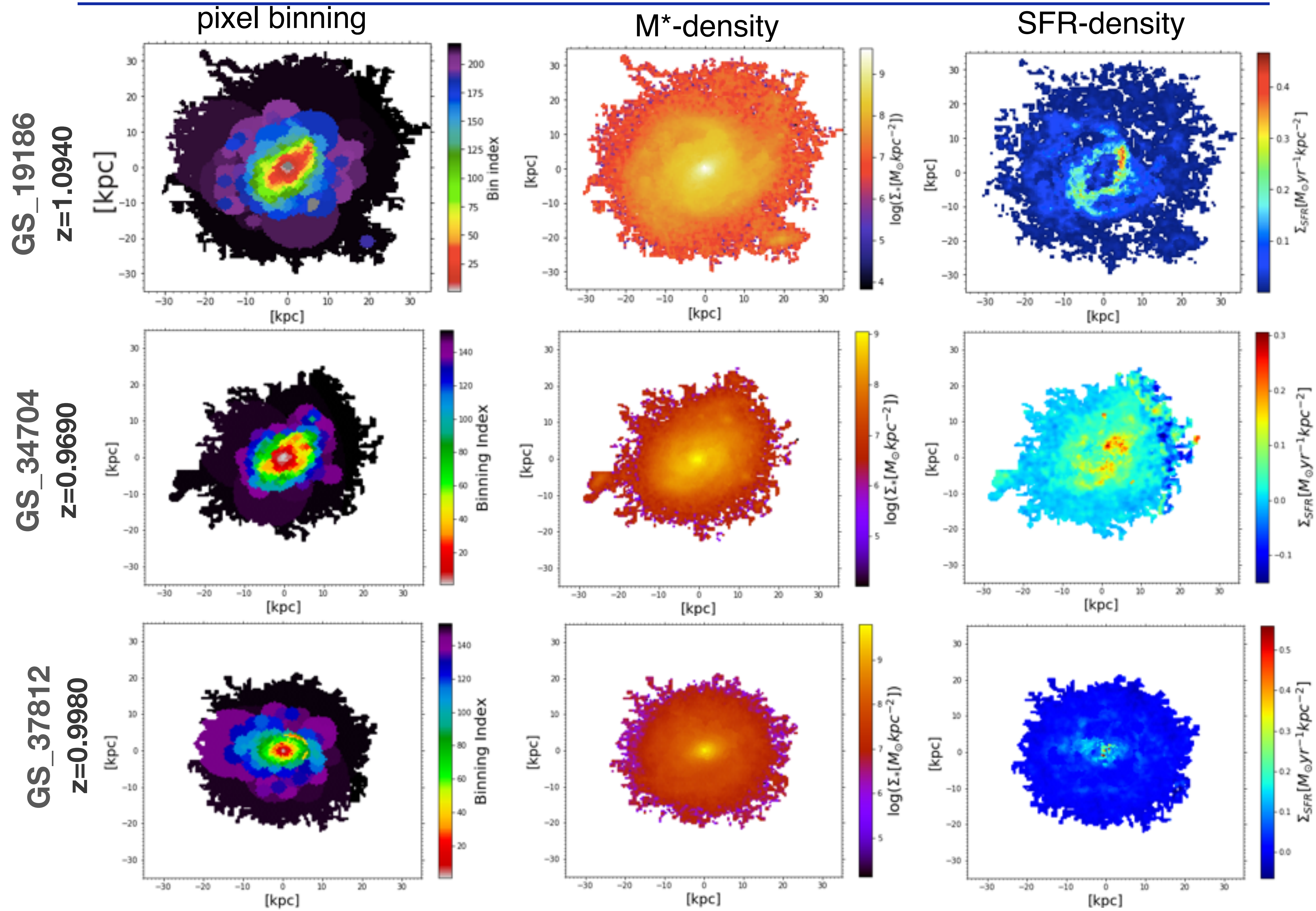
Some galaxies in the z~0 sample



Methodology

Examples of pixel-to-pixel SED fitting result

Some galaxies in the z~1 sample



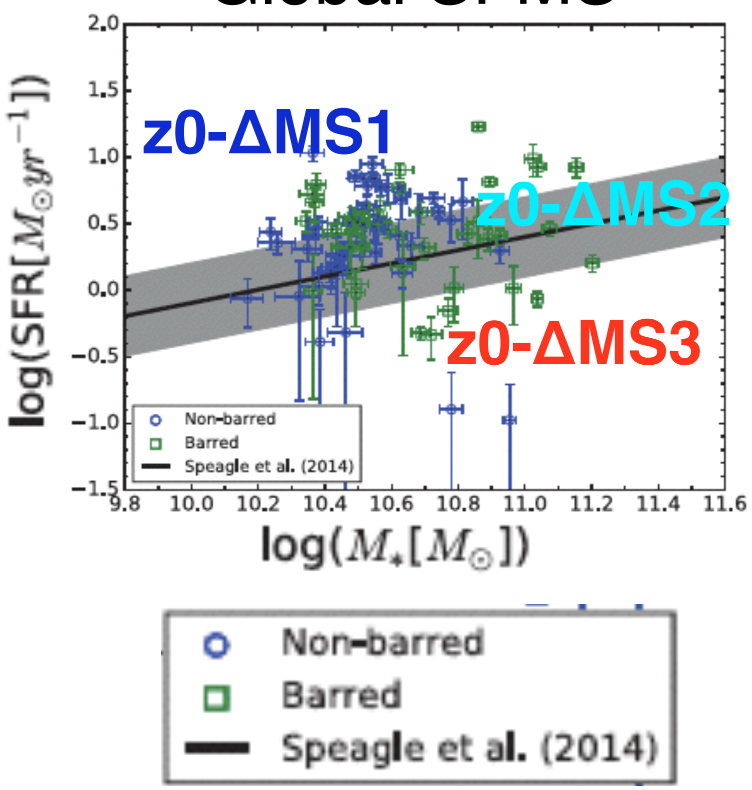
RESULTS
&
DISCUSSION

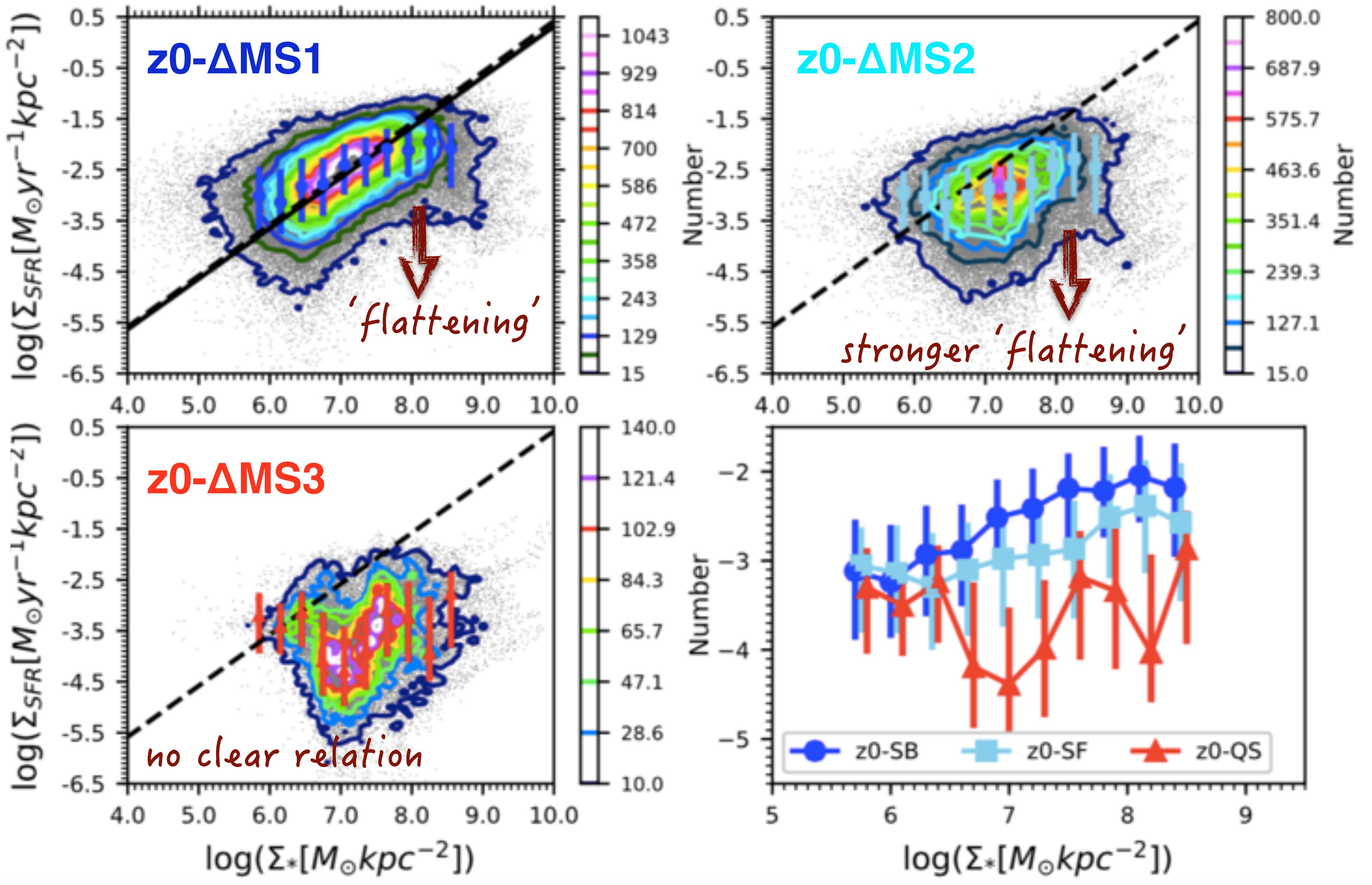
Spatially resolved SFMS at z~0

- Tight spatially resolved star formation main sequence (SFMS) in z0-ΔMS1 with linear form at low Σ_* and '**flattened**' at high Σ_*
- stronger '**flattening**' at high Σ_* in z0-ΔMS2
- No clear relation is hold in z0-ΔMS3

Each point in the plot represent a pixel (~1kpc scale)

Global SFMS





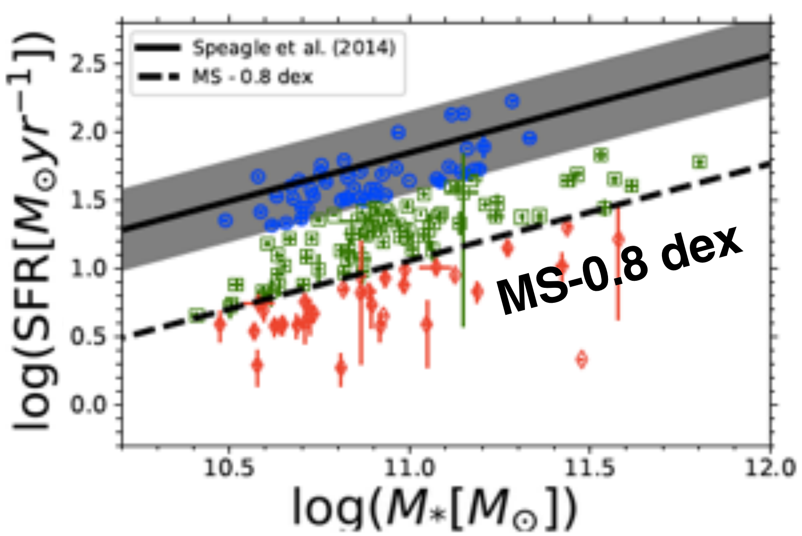
Abdurro'uf & Akiyama (2017)

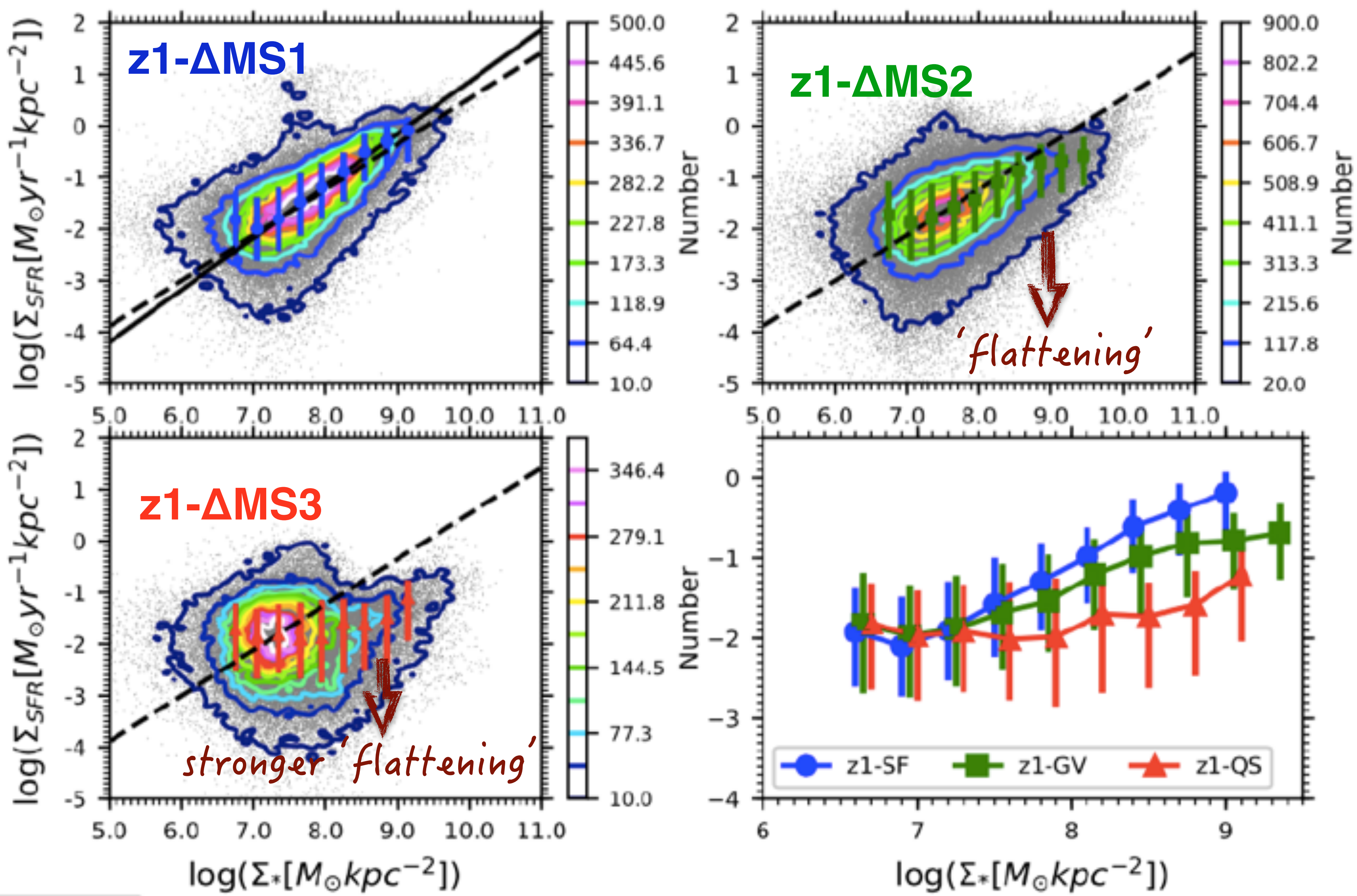
Spatially resolved SFMS at z~1

- Tight linear spatially resolved SFMS in z1-ΔMS1 without **'flattening'** at high Σ_*
- **'flattening'** at high Σ_* start to appear in spatially resolved SFMS in z1-ΔMS2
- Stronger 'flattening' in z1-ΔMS3

Each point in the plot represent a pixel (~1kpc scale)

Global SFMS



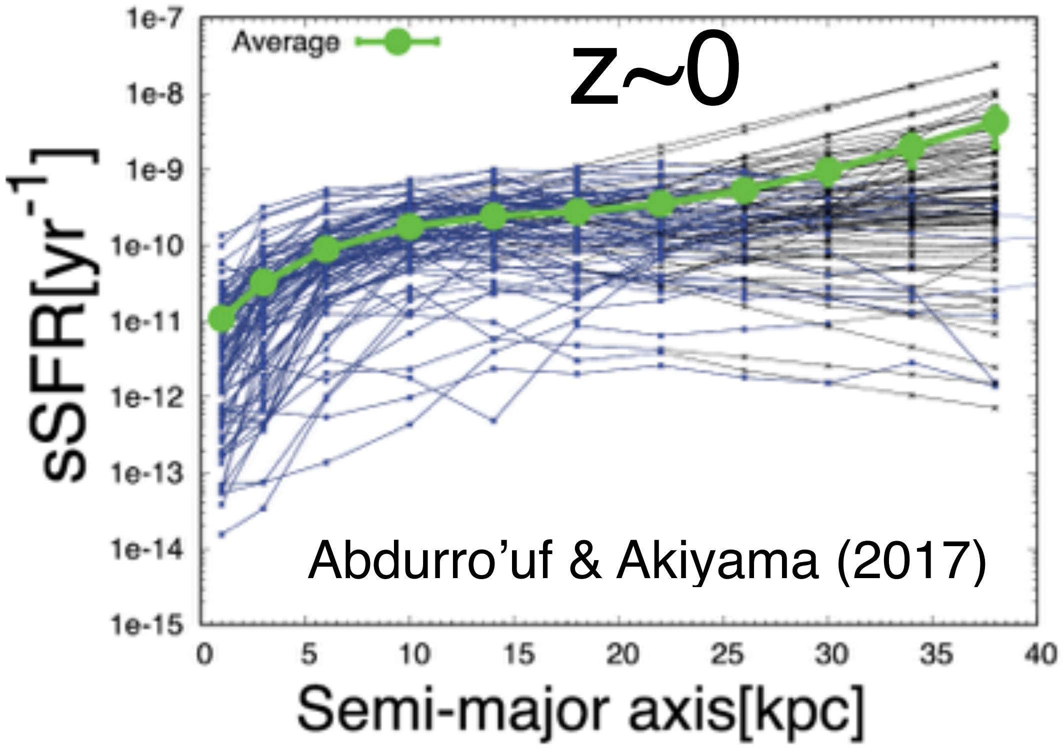


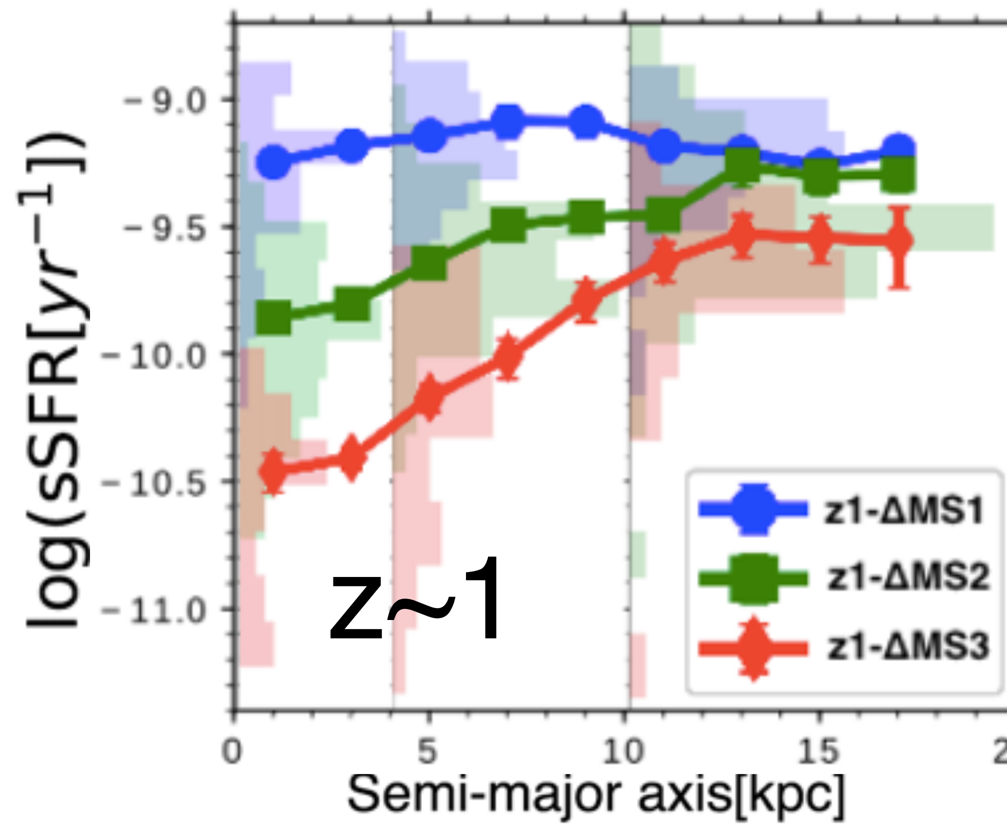
z1-ΔMS1 z1-ΔMS2 z1-ΔMS3

Abdurro'uf & Akiyama (2018)

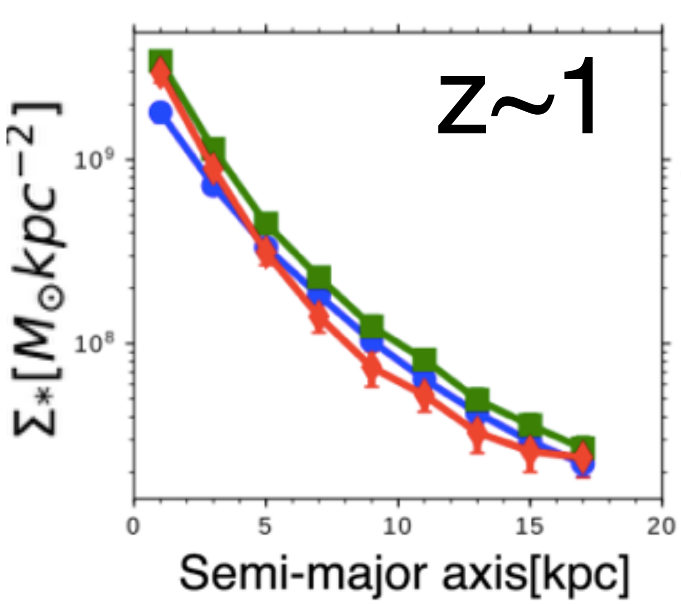
Radial profiles of SFR, M*, and sSFR at z~1 and z~0

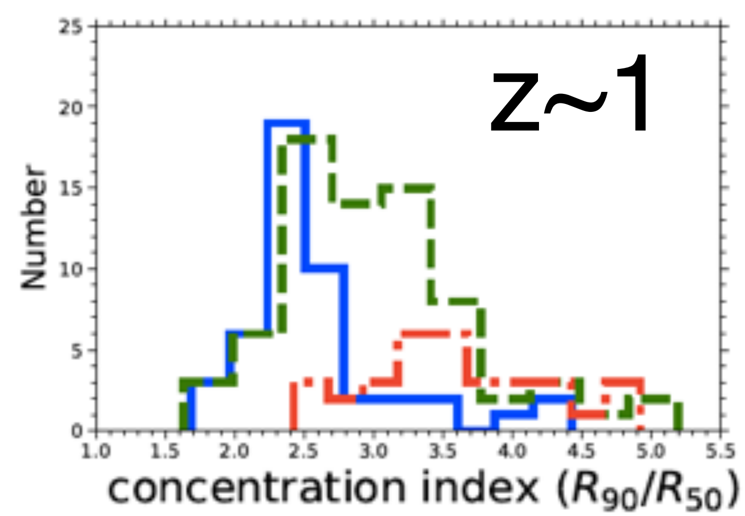
- Massive star-forming galaxies at z~1 have on average flat sSFR radial profile
- As galaxies evolved their central sSFR were suppressed first, then followed by sSFR in outskirt region —> **inside-out quenching**

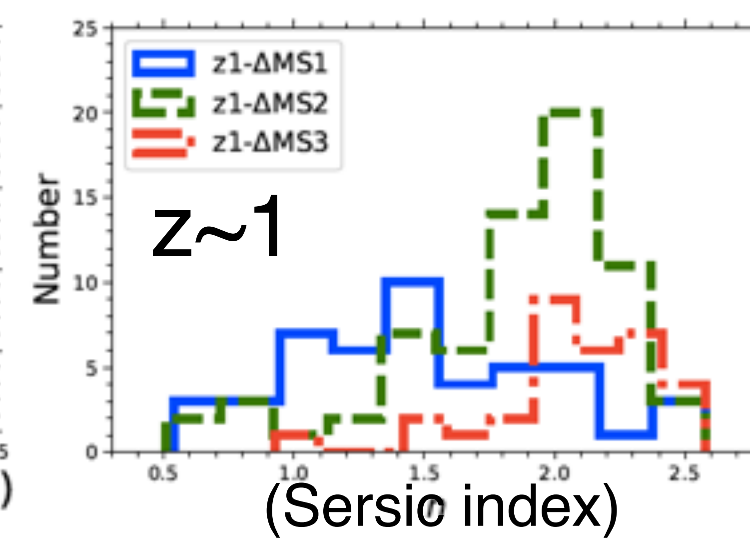




Abdurro'uf & Akiyama (2018)



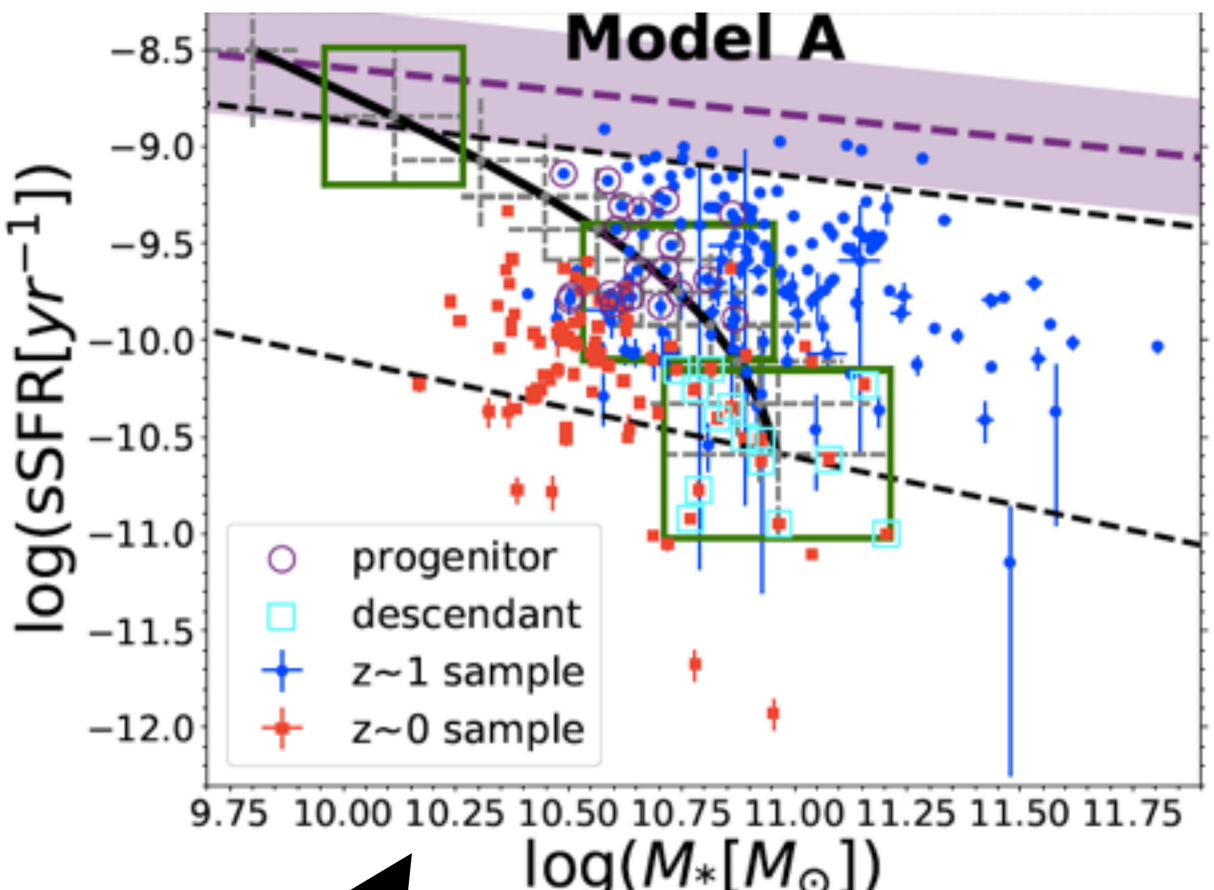




star-forming —> disky   quiescent —> bulgy

Connecting z~1 and z~0 samples

Find possible pairs of progenitors and descendants



- Assuming exponentially declining SFH:

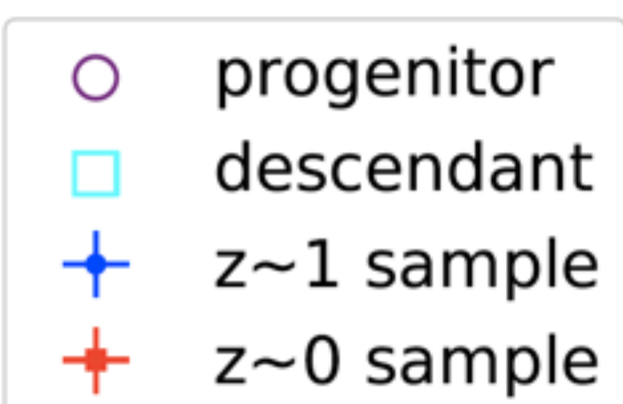
$$\mathrm{SFR}(t) = \mathrm{SFR}(t_0)e^{-\Delta t/\tau}$$

$$M_*(t) = M_*(t_0) + \tau\mathrm{SFR}(t_0)\left(1 - e^{-\Delta t/\tau}\right)$$

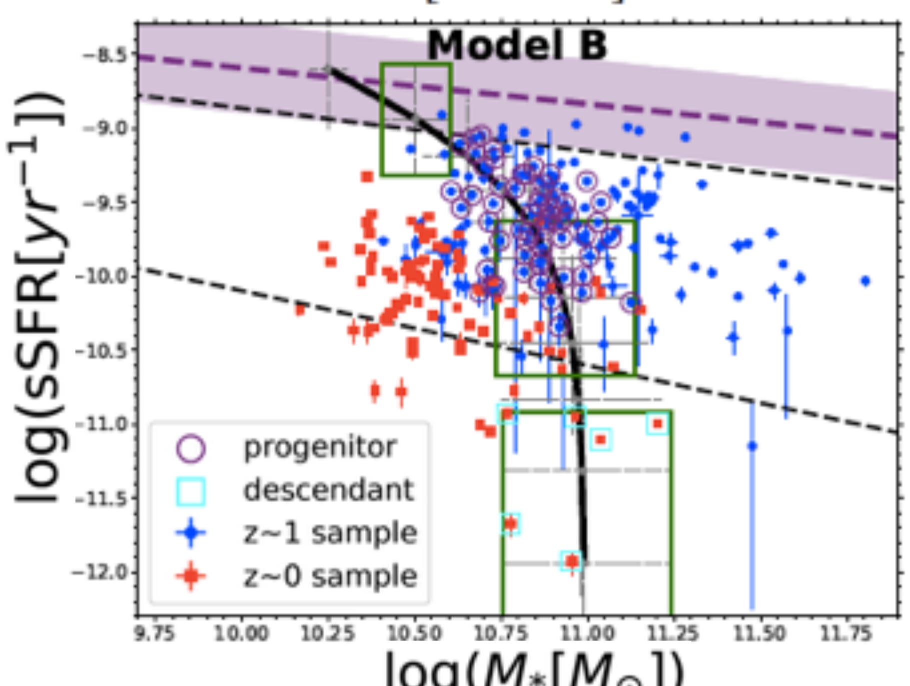
$$\mathrm{sSFR}(t) = \frac{e^{-\Delta t/\tau}}{\mathrm{sSFR}^{-1}(t_0) + \tau\left(1 - e^{-\Delta t/\tau}\right)}$$

- Model track started from z=2
- Free parameters: log(M*(z=2)),log(sSFR(z=2)),τ

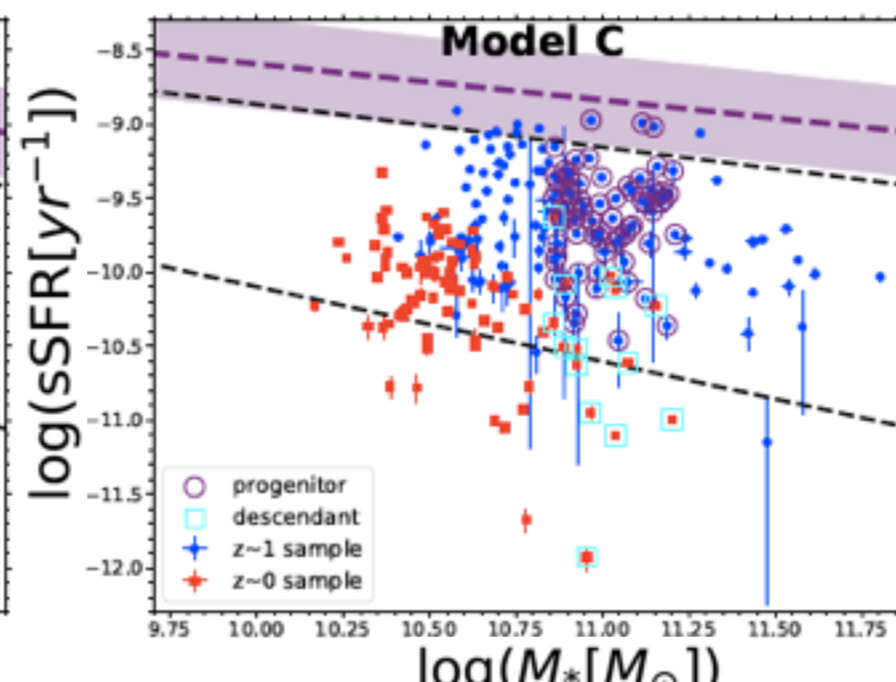
$\log(M_*(t_0)) = [9.7 : 9.9]$
$\log(\mathrm{sSFR}(t_0)) = [-8.6 : -8.4]$
$\tau = [4.0 : 6.0]$



$\log(M_*(t_0)) = [10.2 : 10.3]$
$\log(\mathrm{sSFR}(t_0)) = [-8.7 : -8.5]$
$\tau = [1.3 : 2.5]$



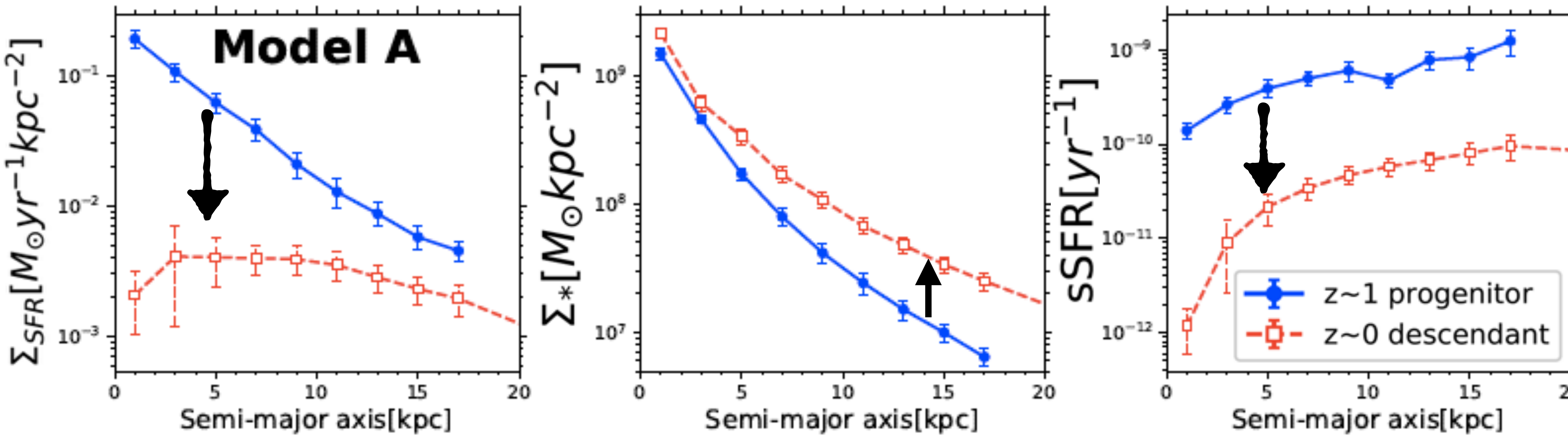
(no assumed SFH)
$10.85 \leqslant \log(M_*/M_\odot) \leqslant 11.2$



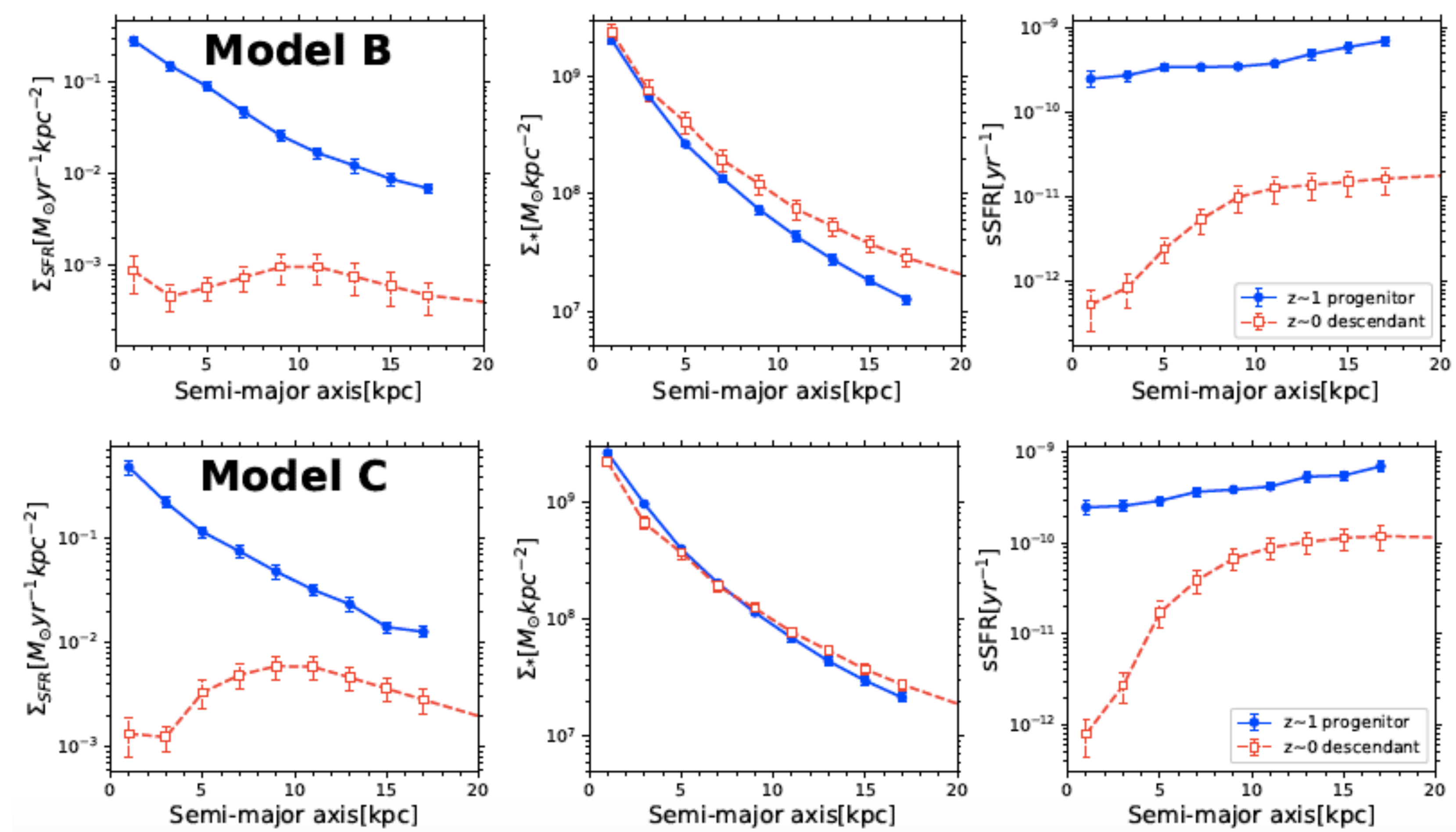
Abdurro'uf & Akiyama (2018)

Result: evolutionary empirical model

Average radial profiles of the progenitors and descendants

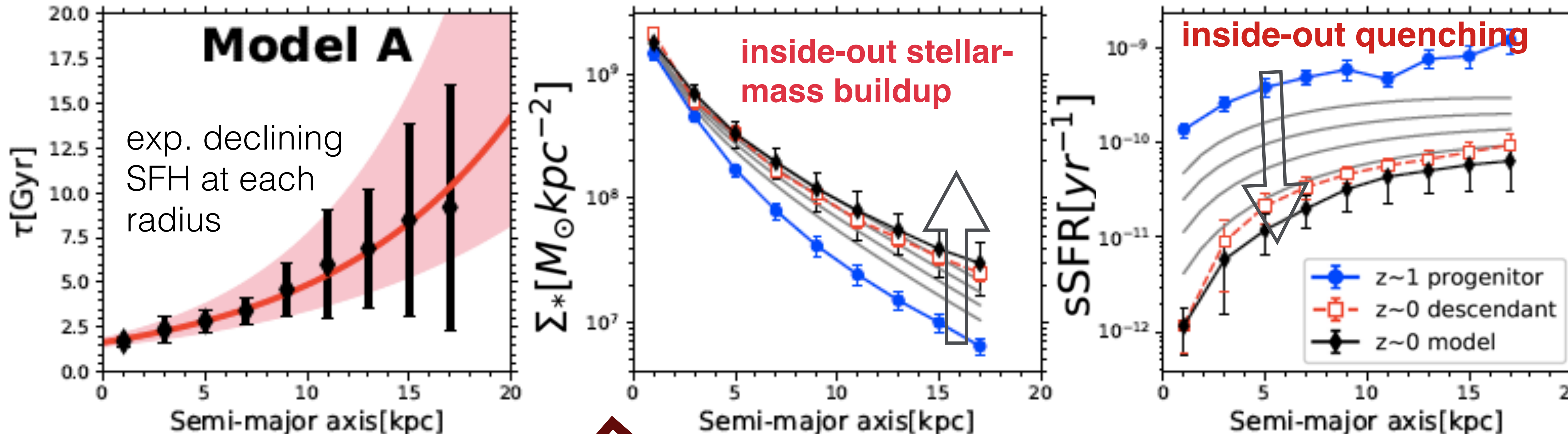


- Larger decrease of SFR in the central region compared to that in outskirt
- Radial stellar mass growth in model A and B
- No radial stellar mass growth in model C



Abdurro'uf & Akiyama (2018)

Empirical model for the evolution of surface density radial profiles



- SFR and M* surface densities radial profiles at z=1

$$\Sigma_*(r,t_0) = (8.43\times10^9 \pm 4.43\times10^8)e^{-\left(\frac{r}{0.35\pm0.02}\right)^{\left(\frac{1}{1.96\pm0.03}\right)}}$$

$$\Sigma_{\rm SFR}(r,t_0) = (0.21\pm0.03)e^{-r/(4.18\pm0.24)}$$

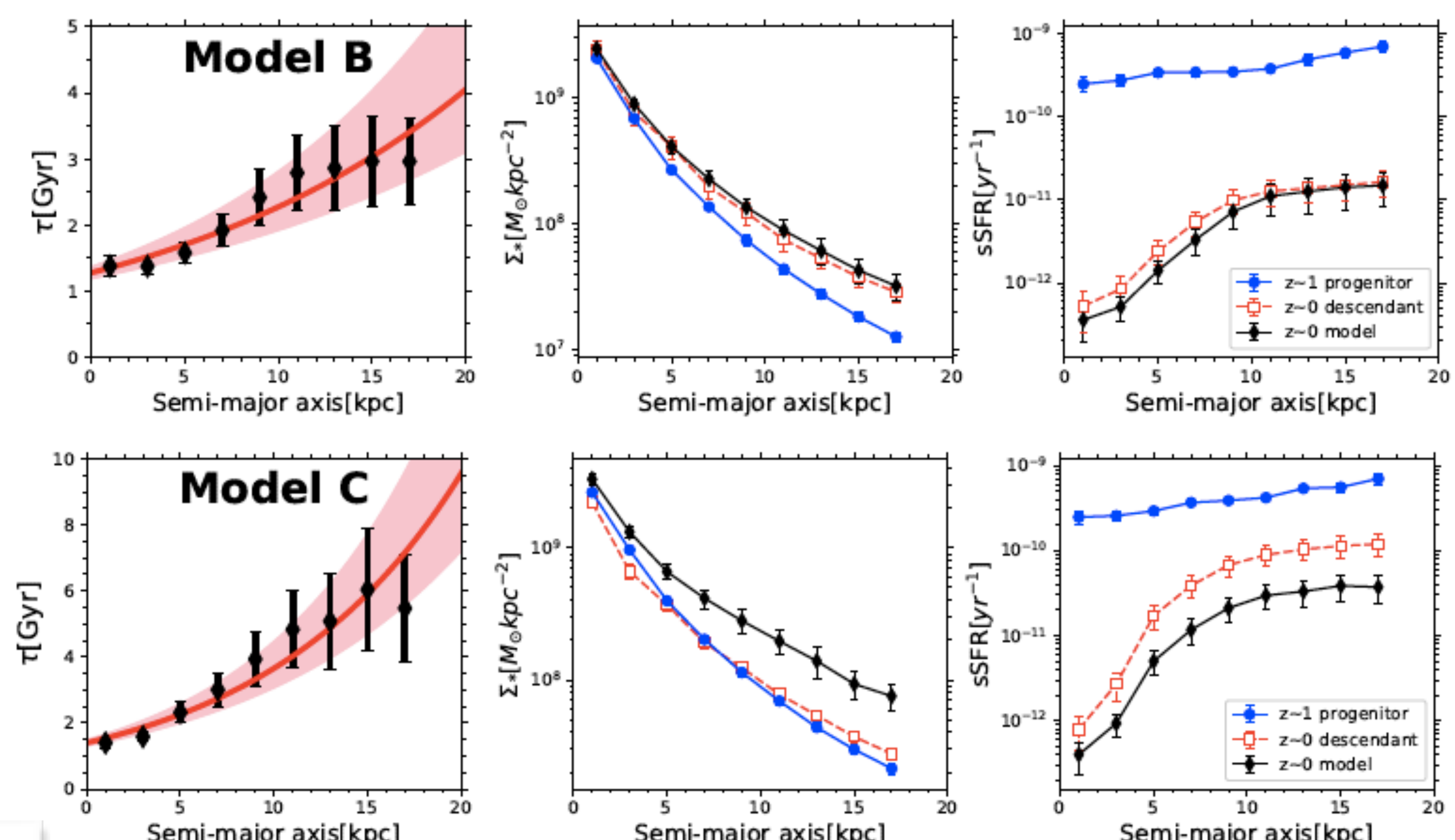
- SFR decaying time-scale as a function of radius

$$\tau(r) = (1.66\pm0.22)e^{r/(9.32\pm2.21)}$$

- Evolution of SFR and M* density profiles

$$\Sigma_{\rm SFR}(r,t) = \Sigma_{\rm SFR}(r,t_0)e^{-(t-t_0)/\tau(r)}$$

$$\Sigma_*(r,t) = \Sigma_*(r,t_0) + \tau(r)\Sigma_{\rm SFR}(r,t_0)\left(1 - e^{-(t-t_0)/\tau(r)}\right)$$

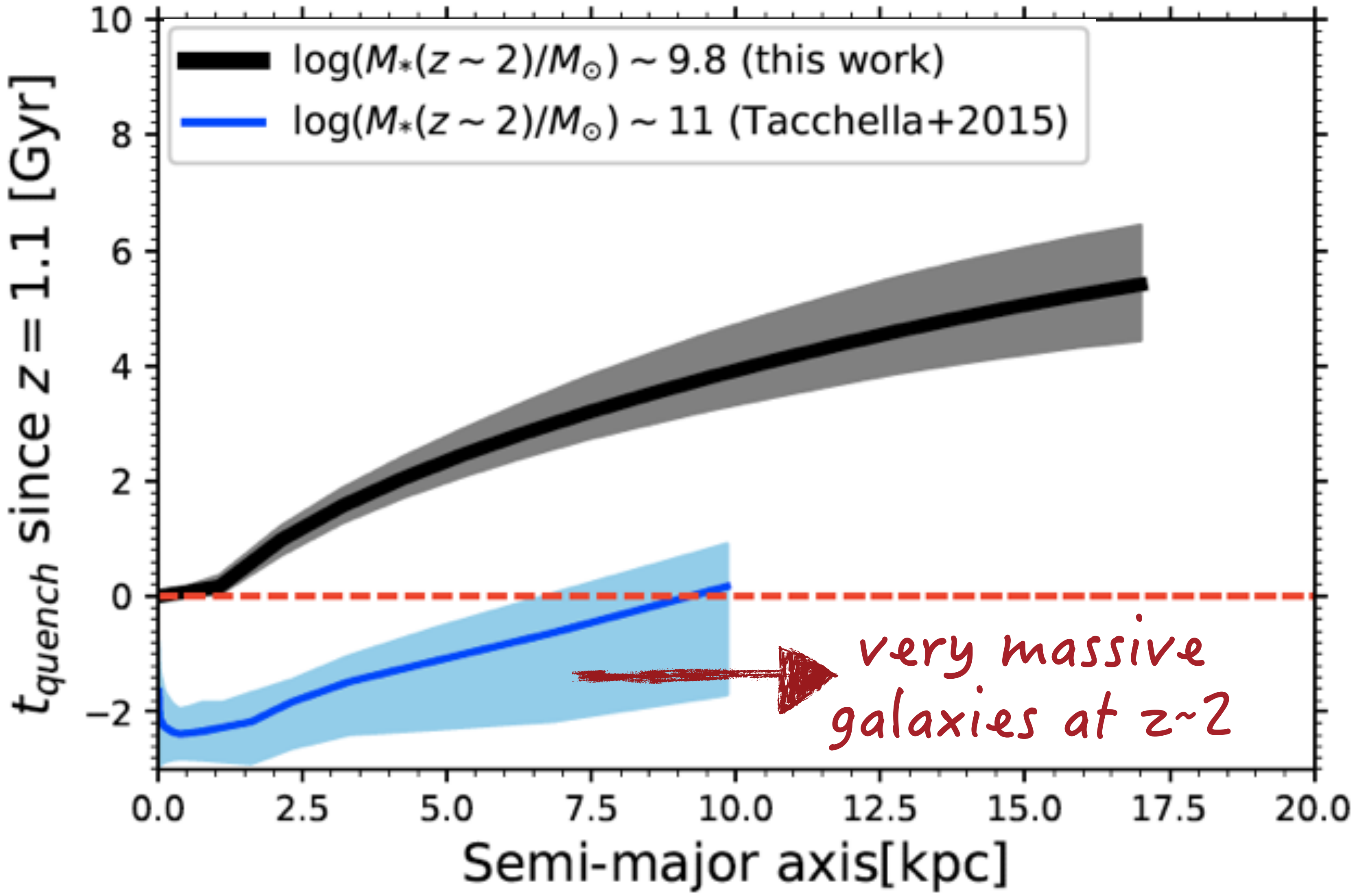


Abdurro'uf & Akiyama (2018)

Radial profile of quenching time-scale

- Derived using the evolutionary empirical model by estimating **time needed for each radius to reach log(sSFR[yr⁻¹])=-10**
- **central region (r ~ 1 kpc) will quench by 0.2 Gyr, while outskirt region (r ~ 15 kpc) will quench by 5.2 Gyr after z=1.1**
- Comparison with the radial quenching time-scale of massive galaxies at z~2, indicates **a preservation of the "downsizing" signal in spatial scale**

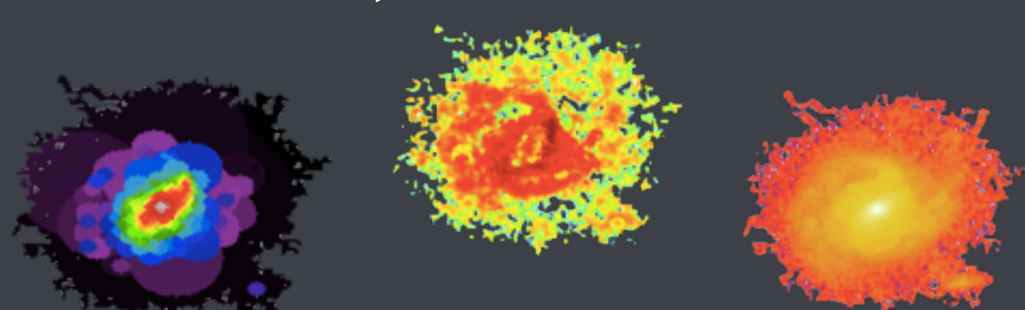
Inside-out quenching and spatially-resolved downsizing

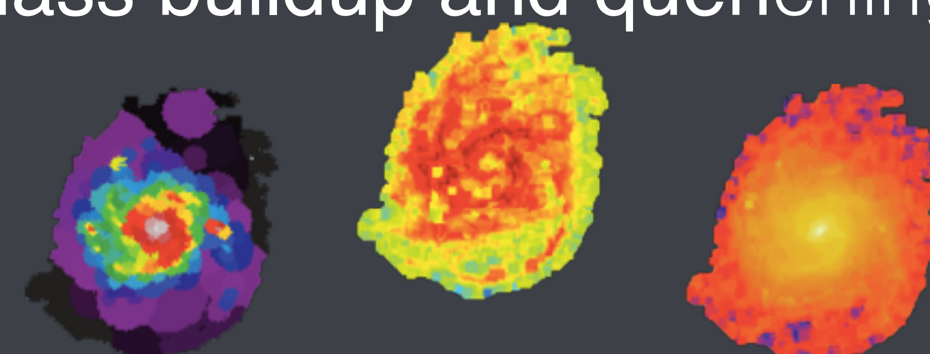


Abdurro'uf & Akiyama (2018)

Summary

- **Star formation main sequence is preserved in kpc scale across cosmic time** (at least up to z~1) —> indicates universal star formation process at various scales
- Spatially resolved SFMS evolved by decreasing sSFR (i.e. normalization) in entire mass density range and becoming flattened and flattened with time
- Evolution of the sSFR(r) radial profile shows inside-out quenching process with indication of bulge formation and growth
- During z~0-1, massive disk galaxies were building their stellar mass and quench their star formation in “inside-to-outside” manner, i.e. inside-out stellar mass buildup and quenching





Thank you very much
for your attention!