Tracing galaxy formation with deep spectroscopic survey

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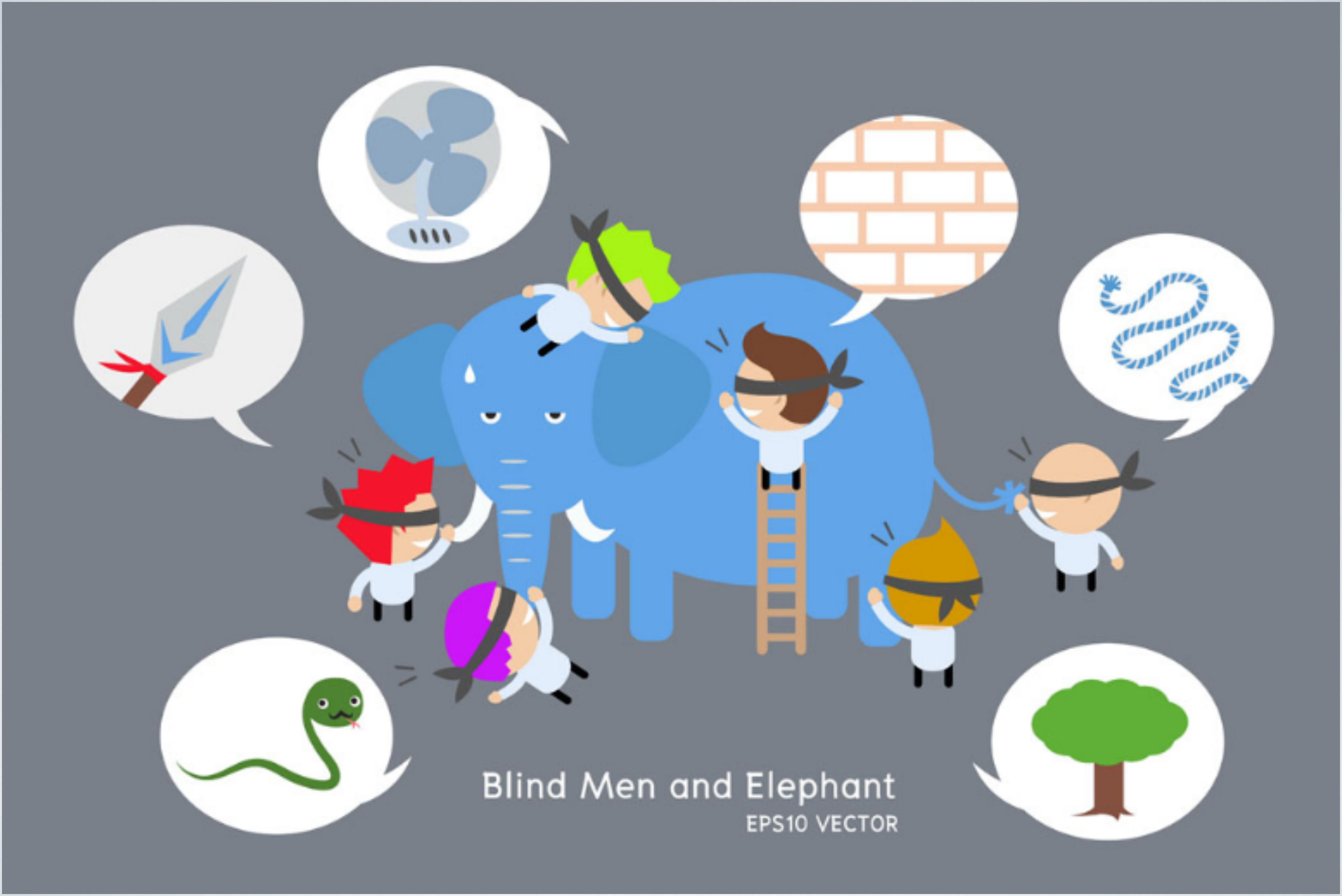
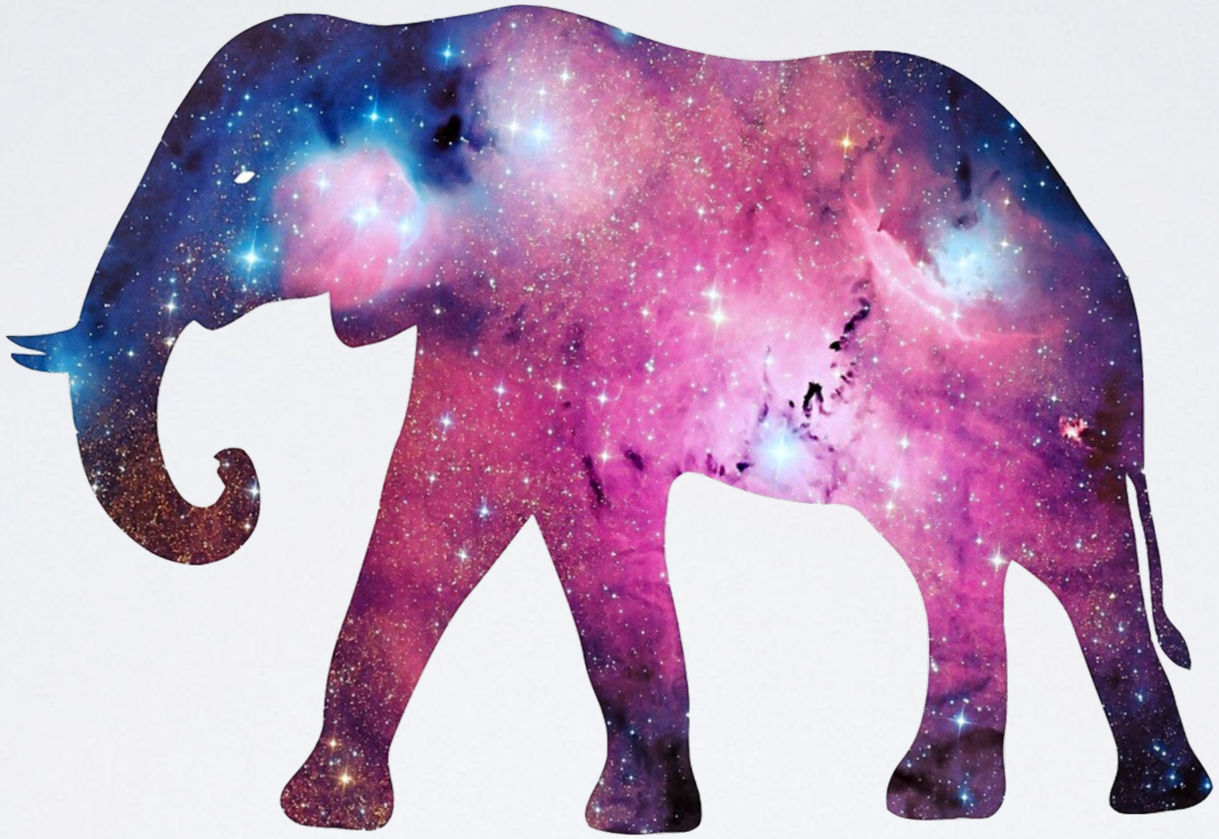
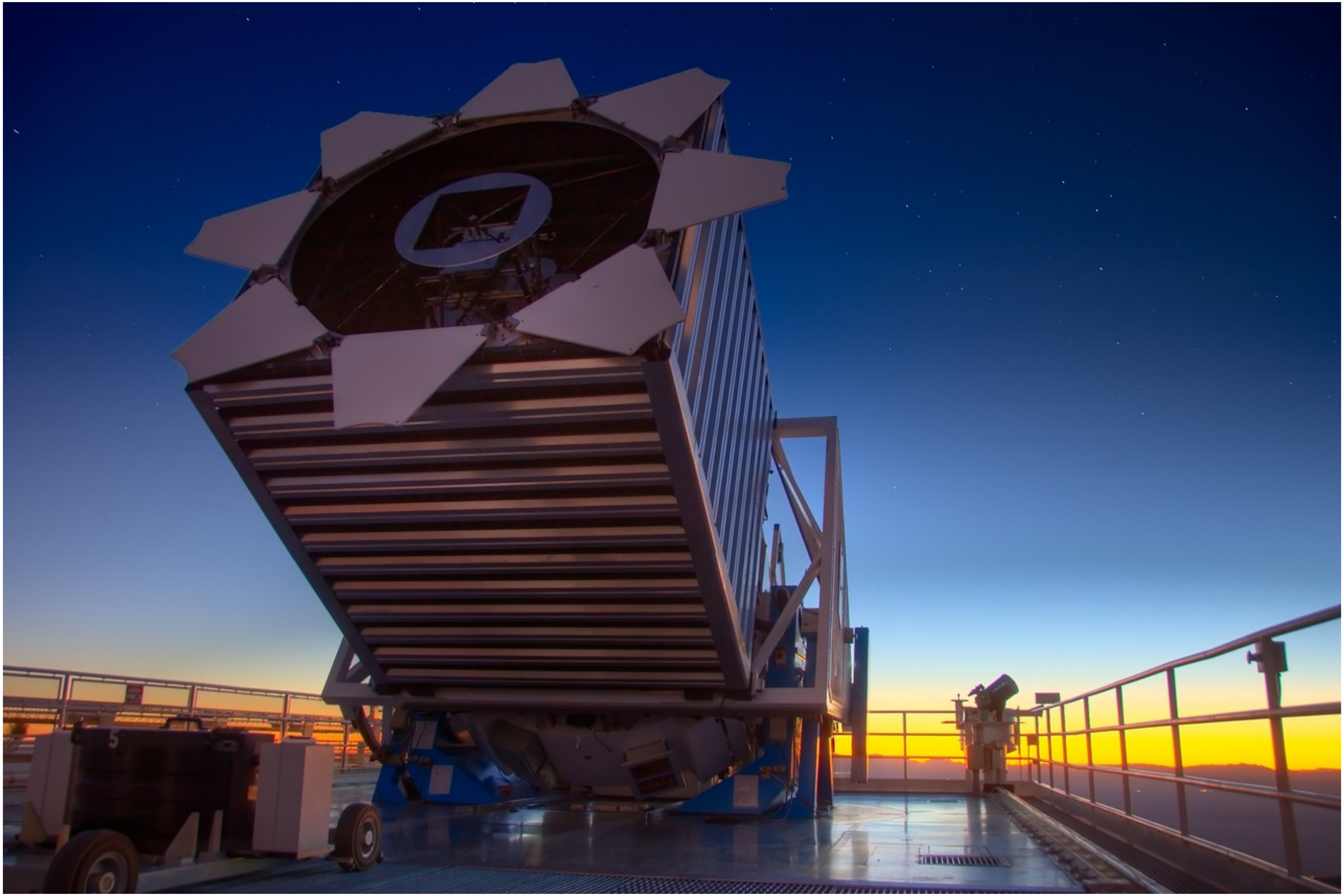
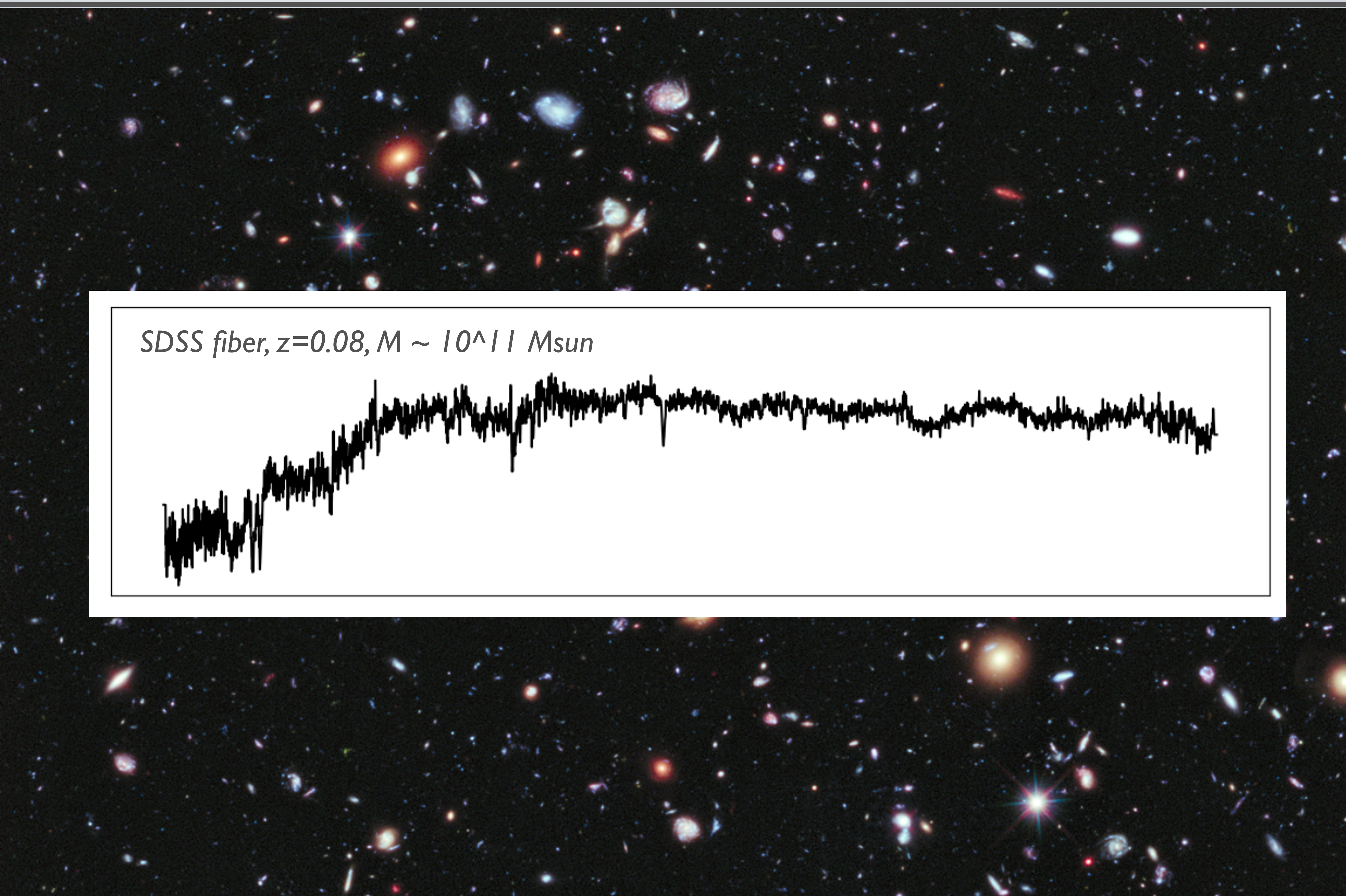

Blind Men and Elephant
EPS10 VECTOR



The SDSS — (mainly) low-z survey



Surveys at high-z



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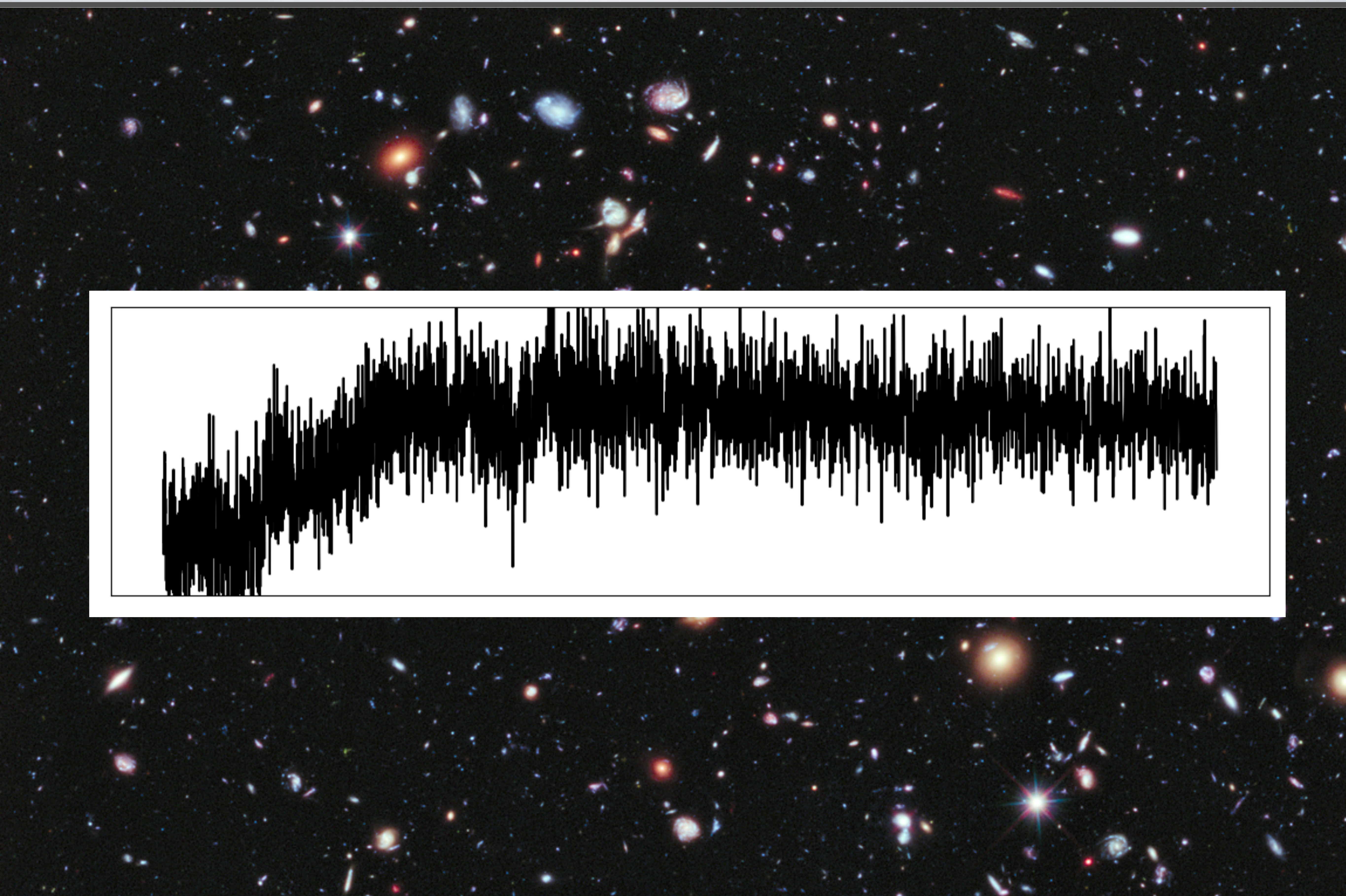
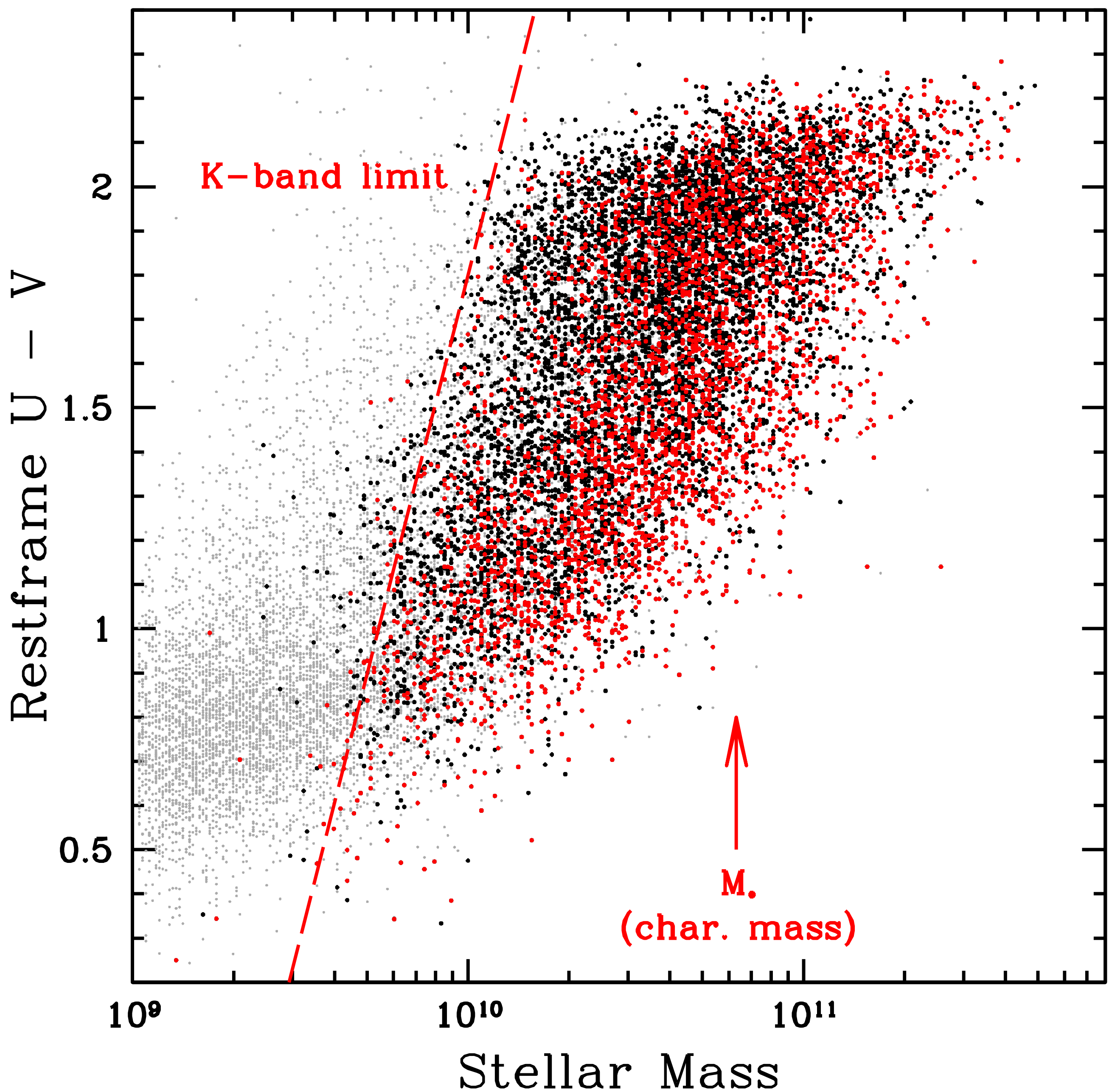


LEGA-C: deep spectroscopic survey @ z~1

Large **E**arly **G**alaxy **A**strophysics **C**ensus (*van der Wel et al. 2016*)

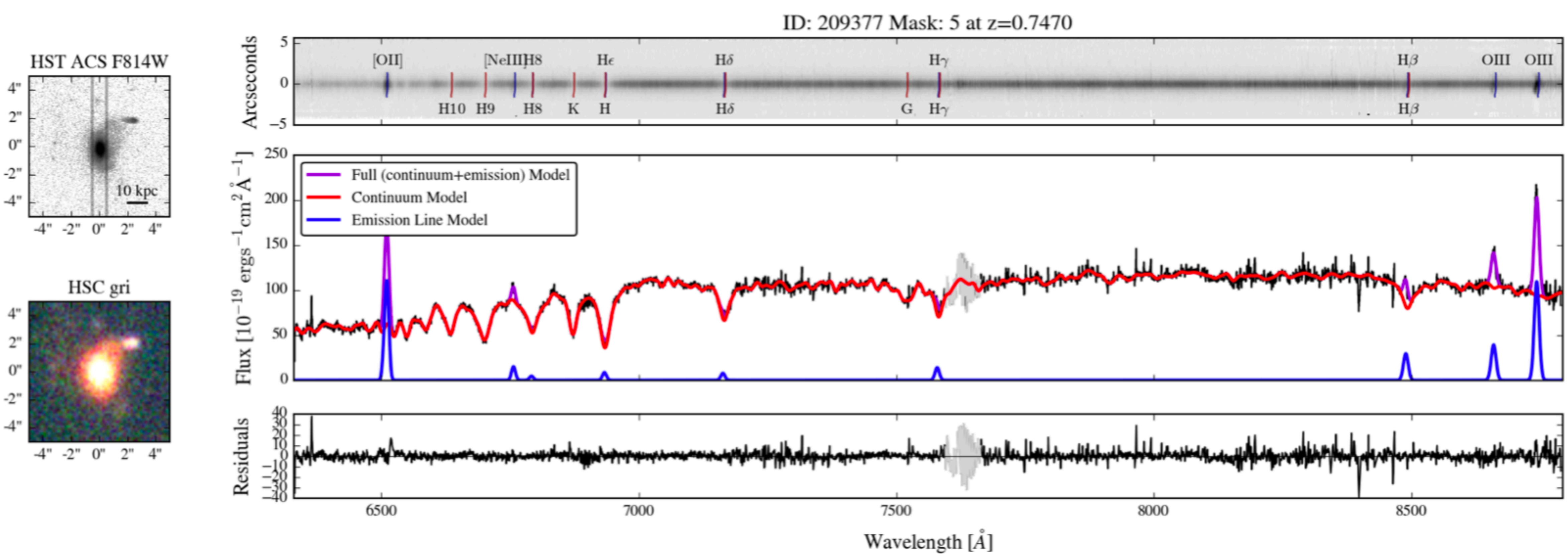
- **>3000** galaxies at 0.6 < z < 1.0
- SDSS-like spectra @ z=0.8
- Simple selection: K mag, redshift
- R ~ 3000, S/N ~ 15/AA
- 20h integrations, VLT / VIMOS
- DR2, half of the sample
    - 1-D spectra, catalog
- Final DR: Year 2020

COSMOS/Ultra-VISTA field



LEGA-C: deep spectroscopic survey @ z~1

Large **E**arly **G**alaxy **A**strophysics **C**ensus (*van der Wel et al. 2016*)



Answers through high-quality spectroscopy of many distant galaxies:

— Stellar populations

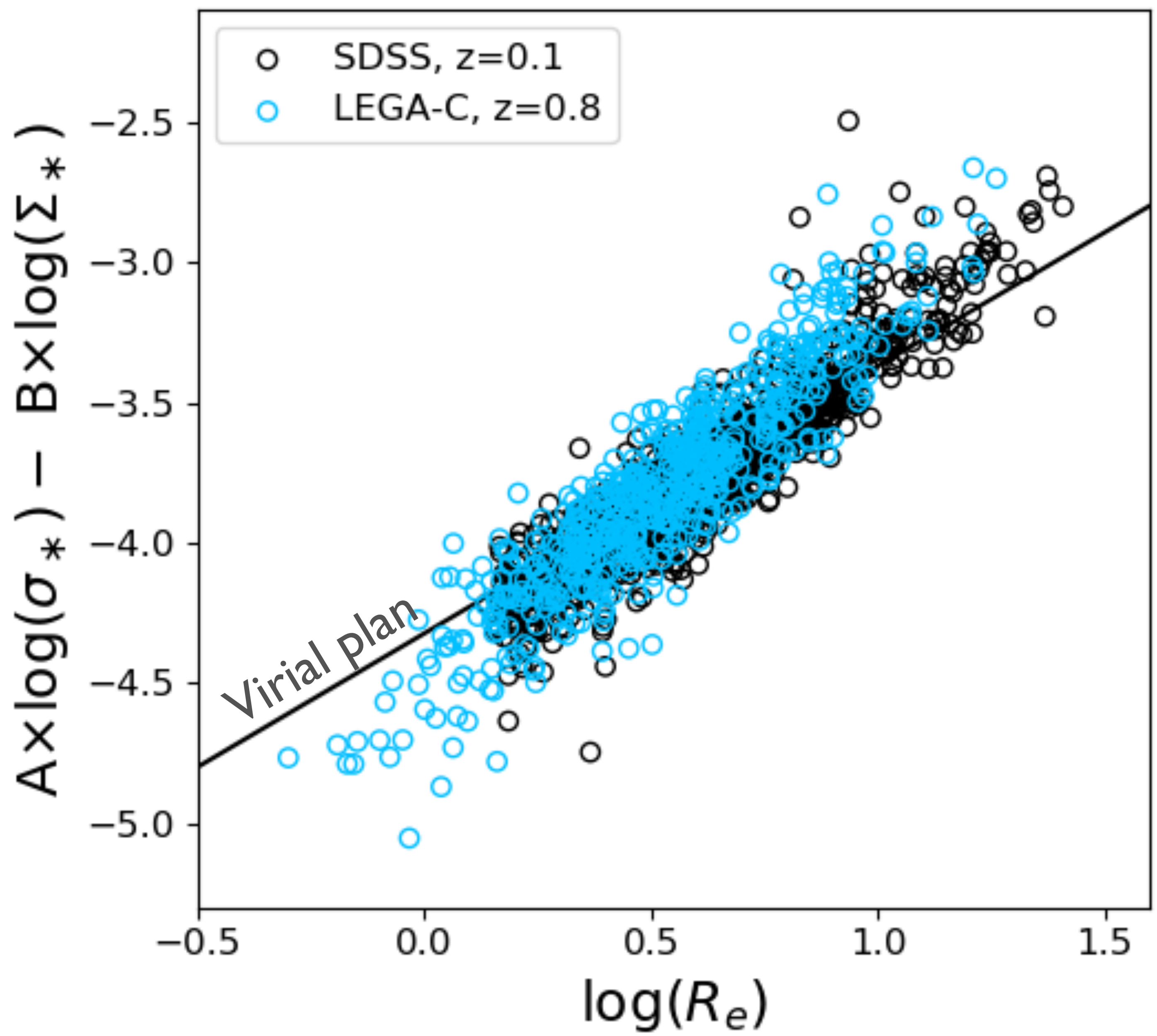
— Stellar kinematics

LEGA-C: deep spectroscopic survey @ z~1

- **Outline**
  - Stellar kinematics
  - Stellar ages
  - The end of star-formation
  - Star-formation histories

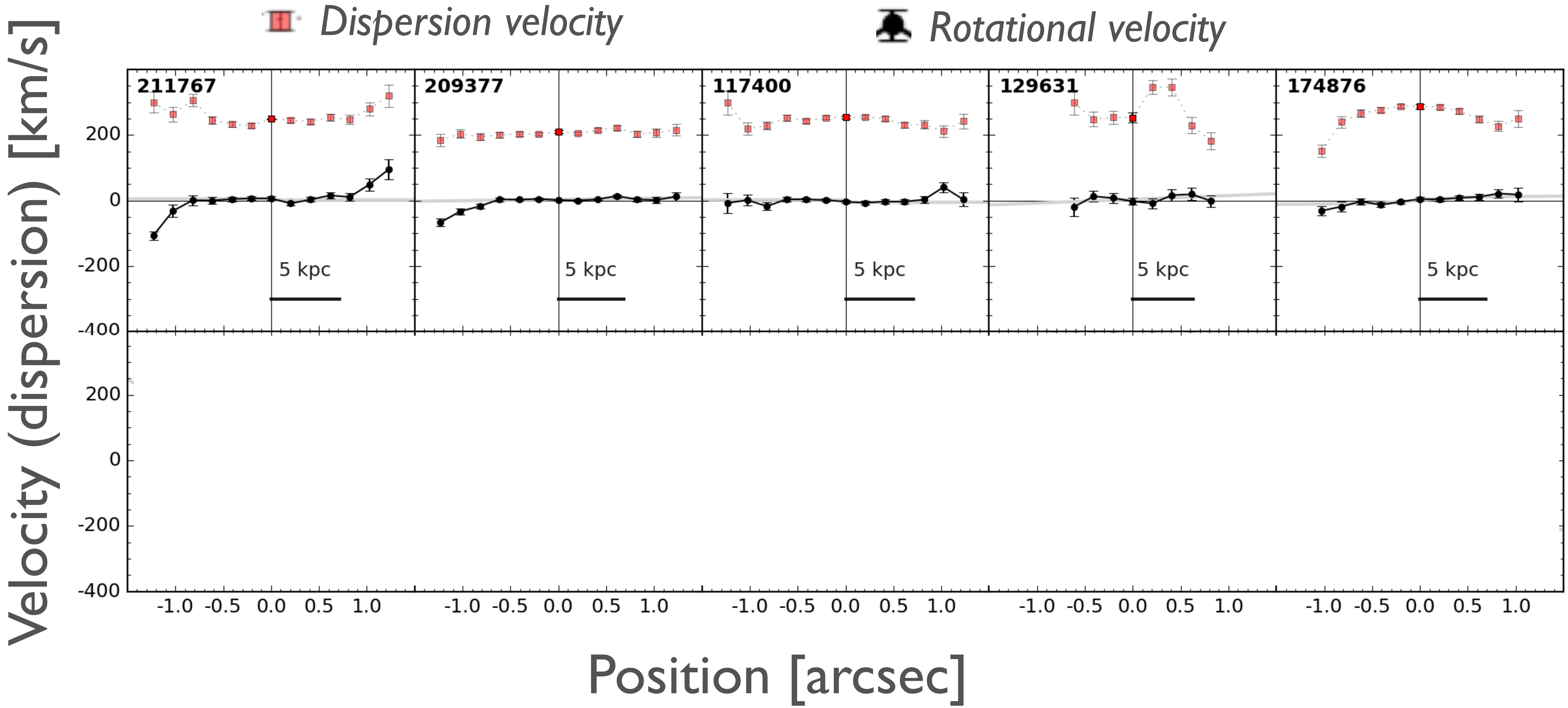
Stellar kinematics

The (stellar mass) Fundamental Plane at z~0.8



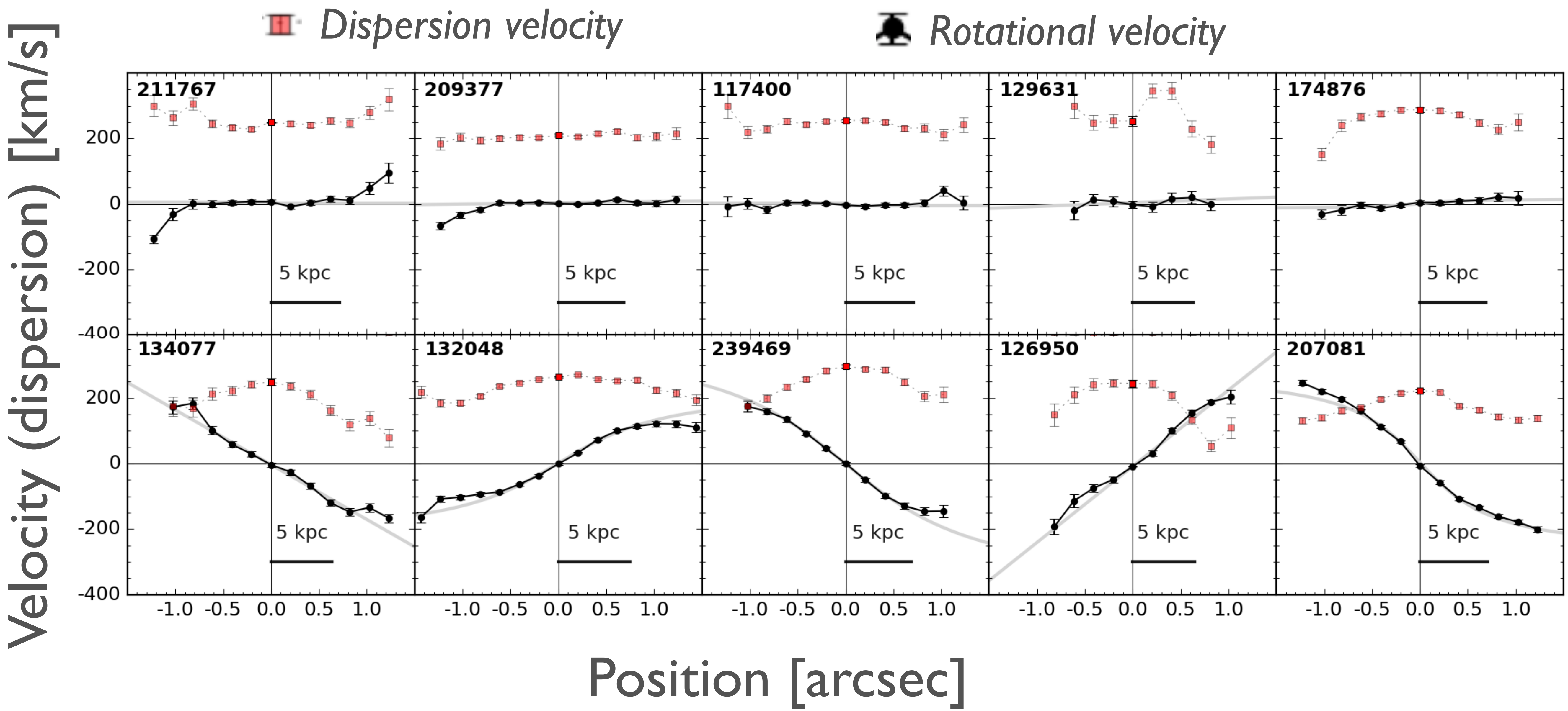
For the first time we can measure the tilt of the FP at large look-back time

Stellar rotation in massive, quiescent galaxies



Bezanson et al. (2018)

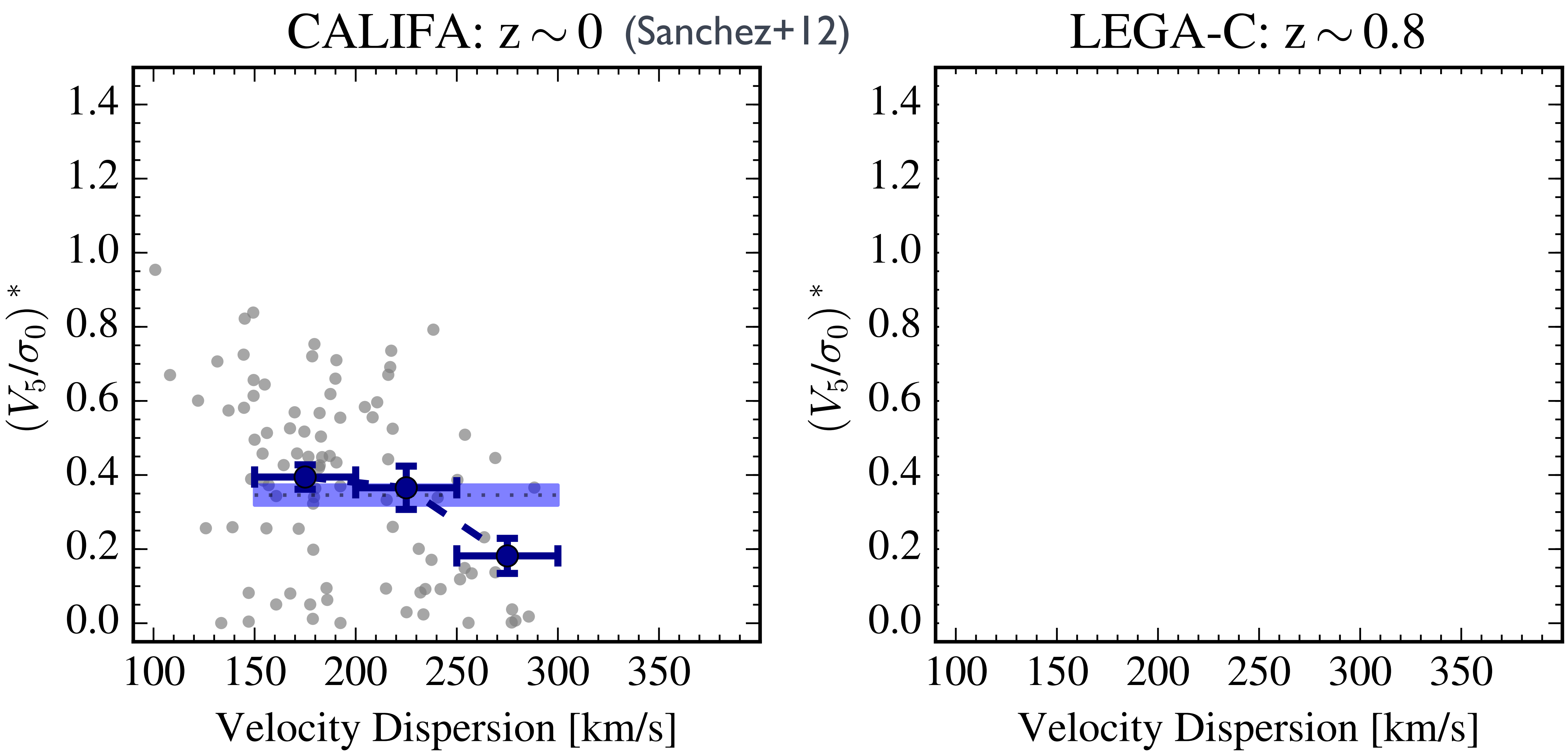
Stellar rotation in massive, quiescent galaxies



Quiescent galaxies rotate

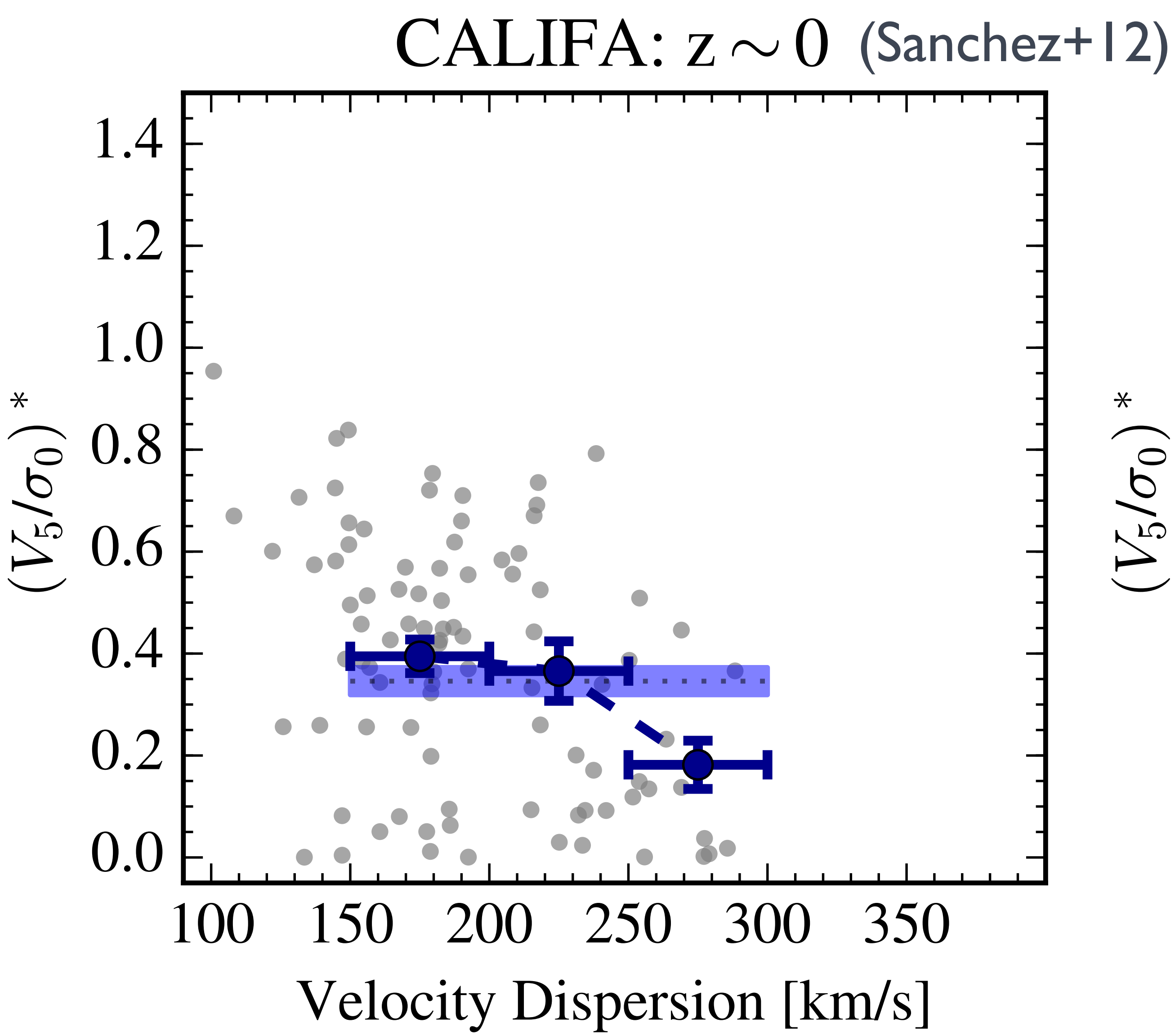
Bezanson et al. (2018)

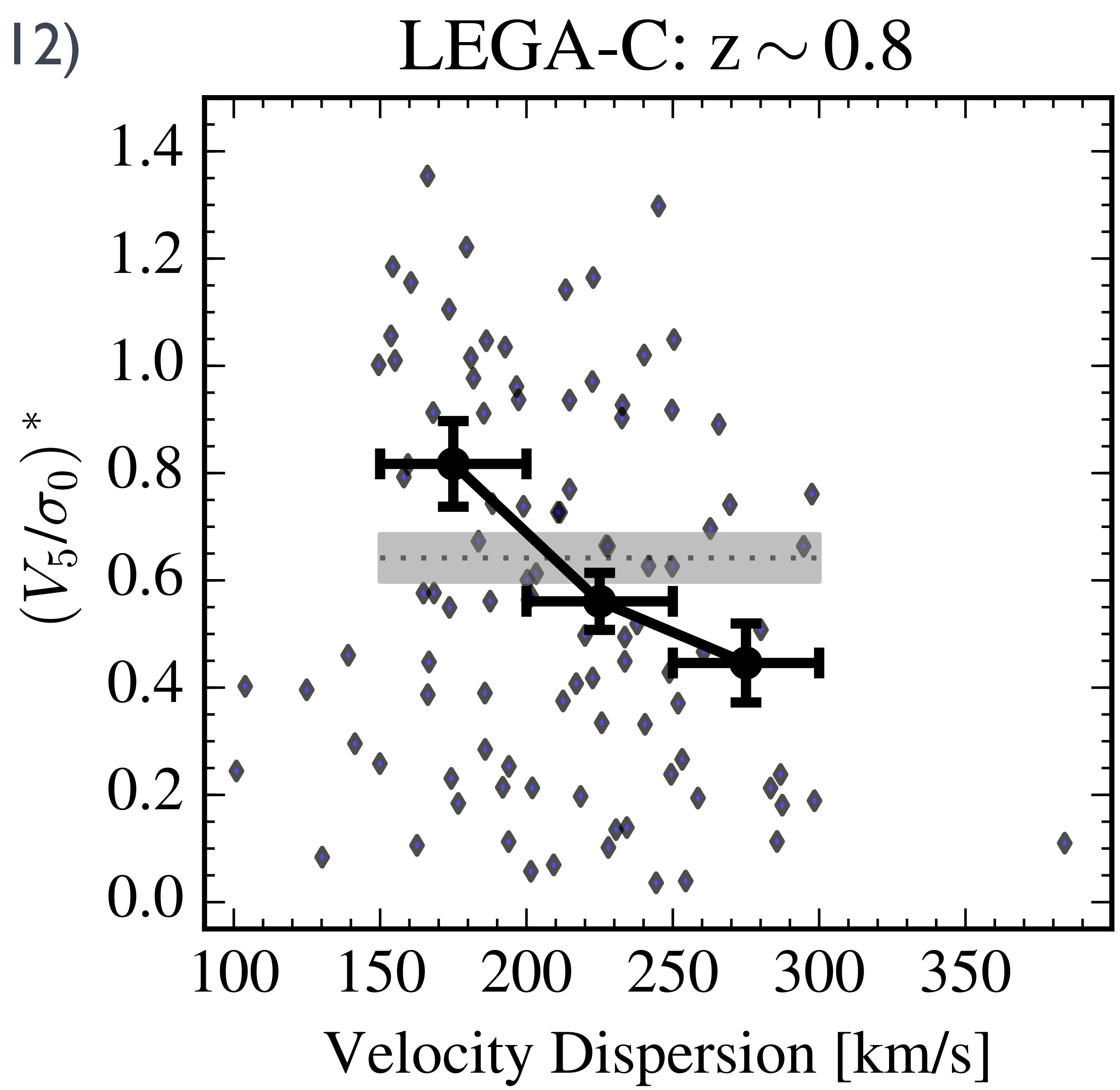
Stellar rotation in passive galaxies



Bezanson et al. (2018)

Stellar rotation in passive galaxies



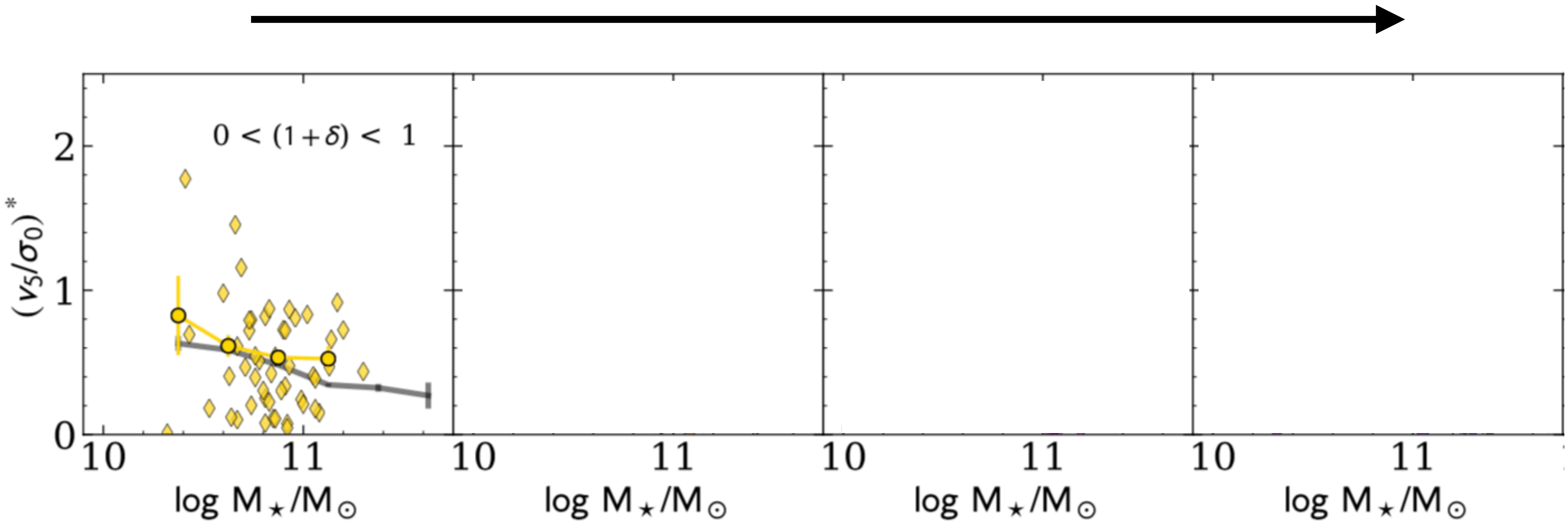


The decrease in rotational support implies significant merging activity

Bezanson et al. (2018)

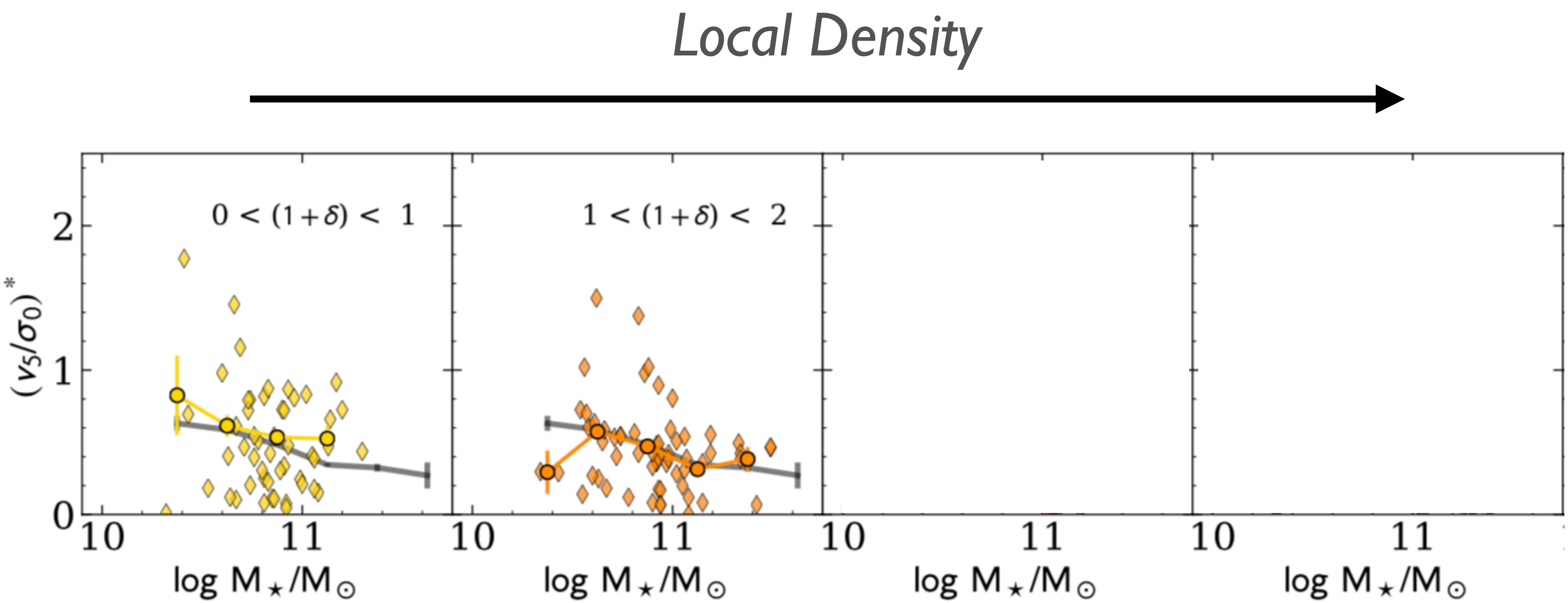
Stellar rotation in passive galaxies

Local Density



Cole et al. 2020 (arXiv 2001.02695)

Stellar rotation in passive galaxies



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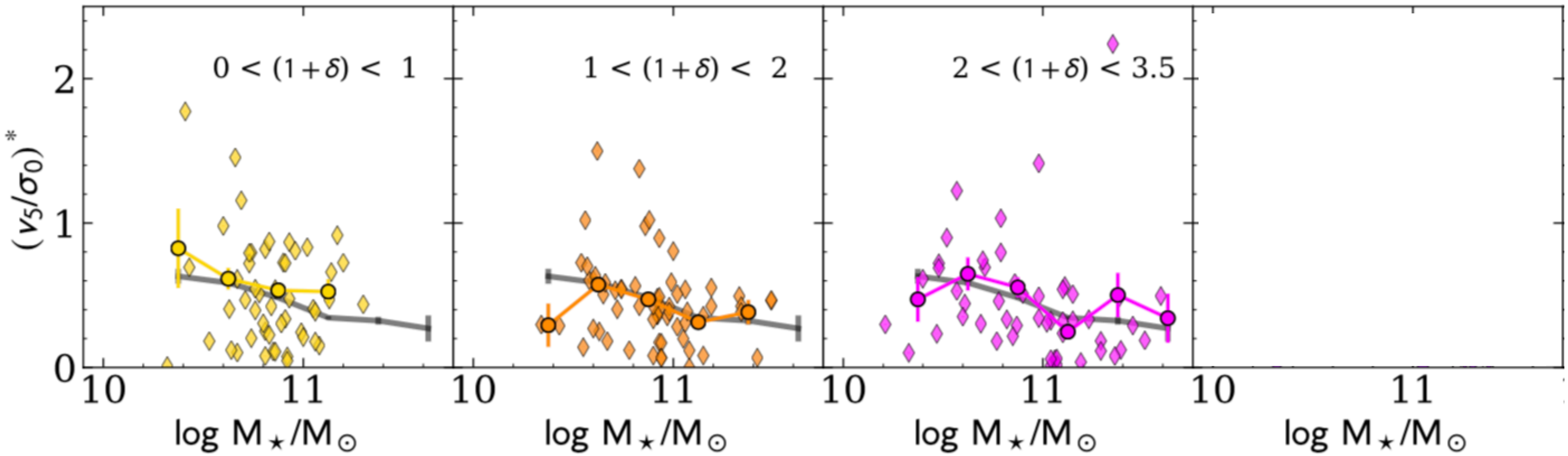
Stellar rotation in passive galaxies

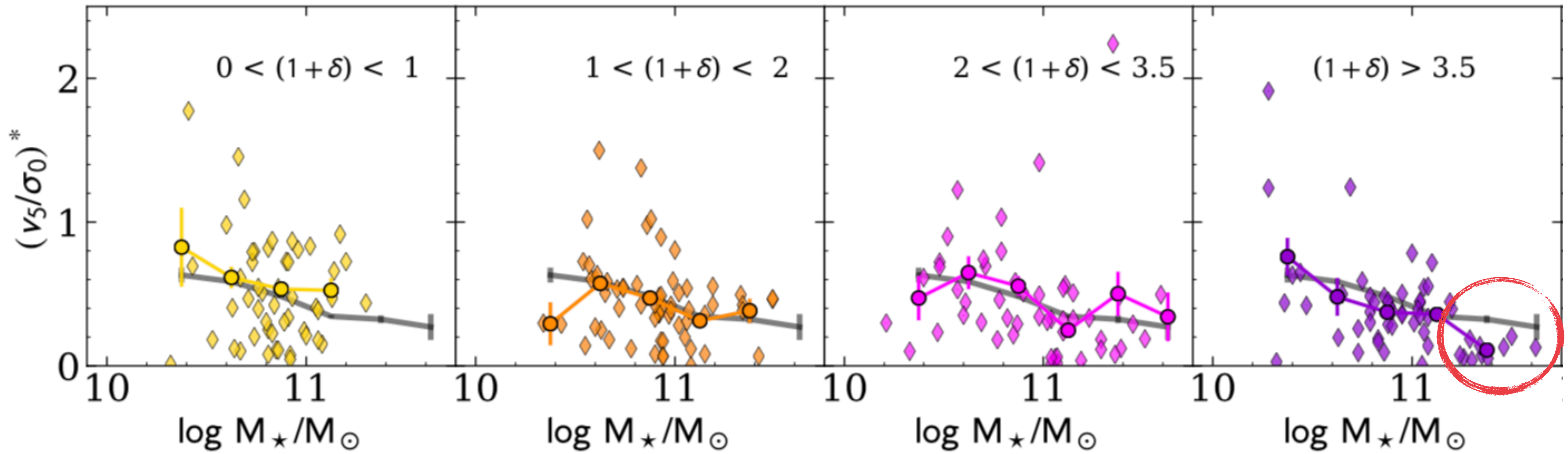
Local Density



Cole et al. 2020 (arXiv 2001.02695)

Stellar rotation in passive galaxies

Local Density



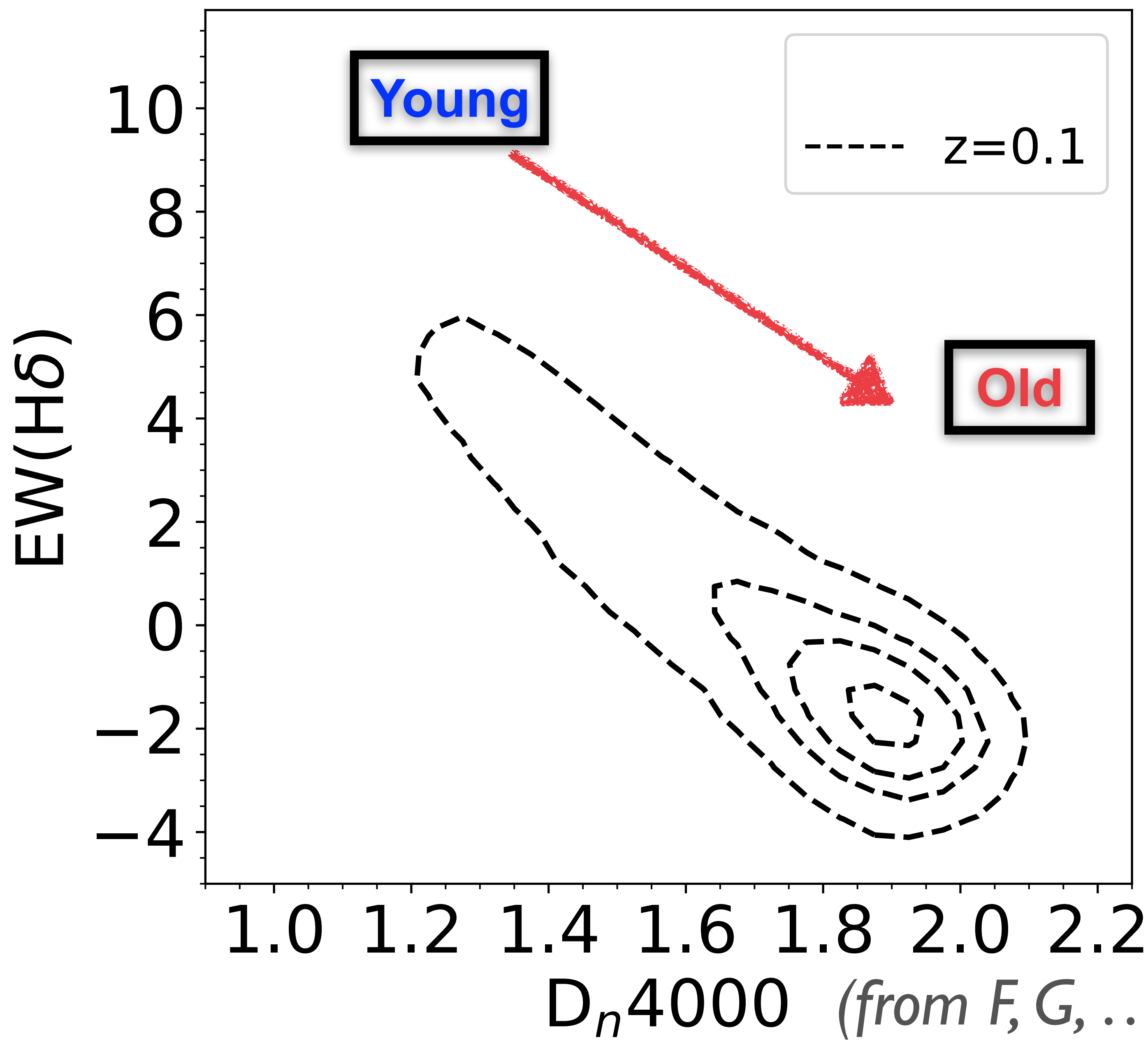
The effect of merger starts to show up at z~0.8

Cole et al. 2020 (arXiv 2001.02695)

Stellar ages

Stellar ages of massive galaxies at z~0.8

M > 2 x 10^{10} Msun

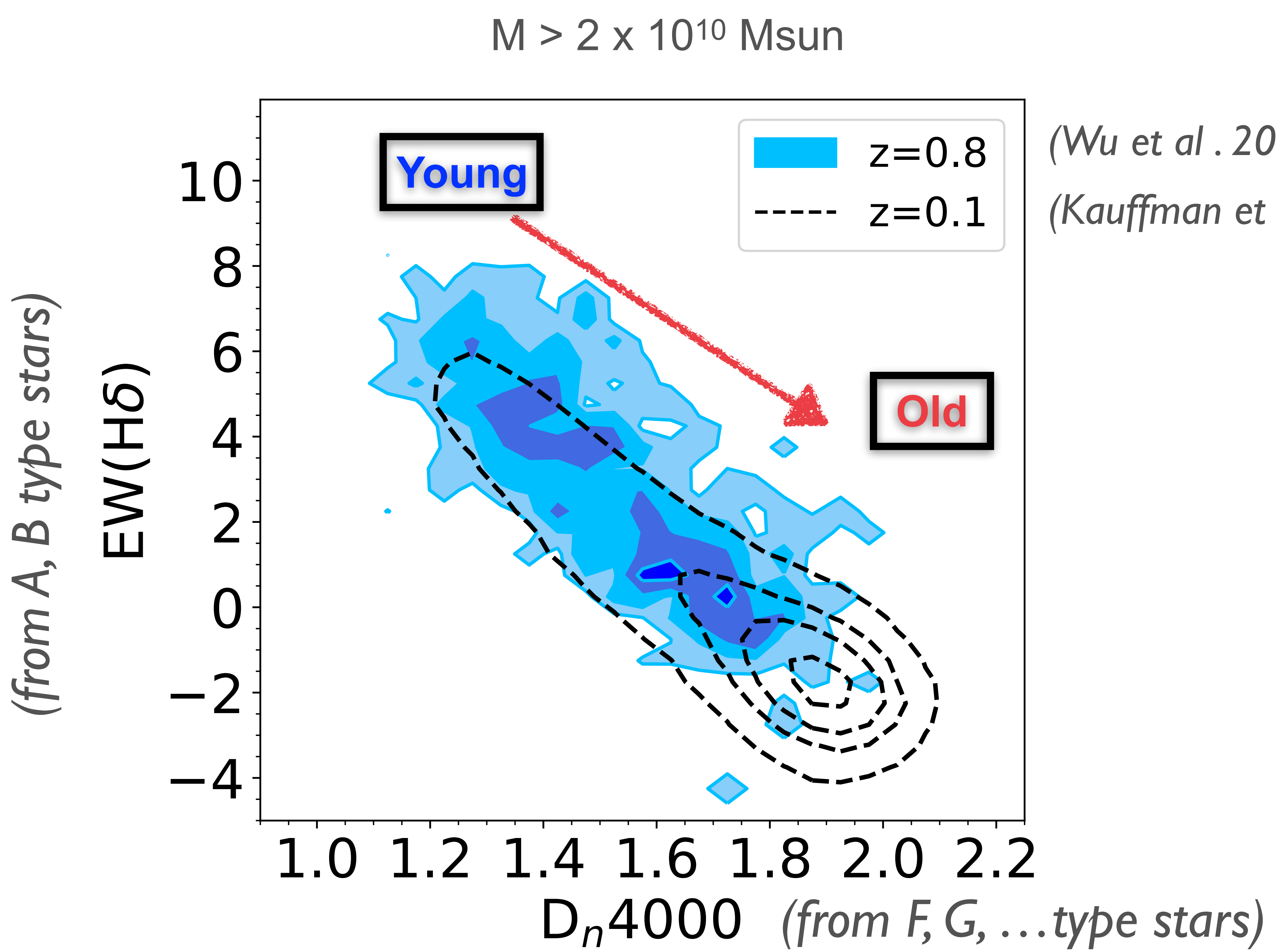


(Kauffman et al . 2003)

(from A, B type stars)

(from F, G, …type stars)

Stellar ages of massive galaxies at z~0.8

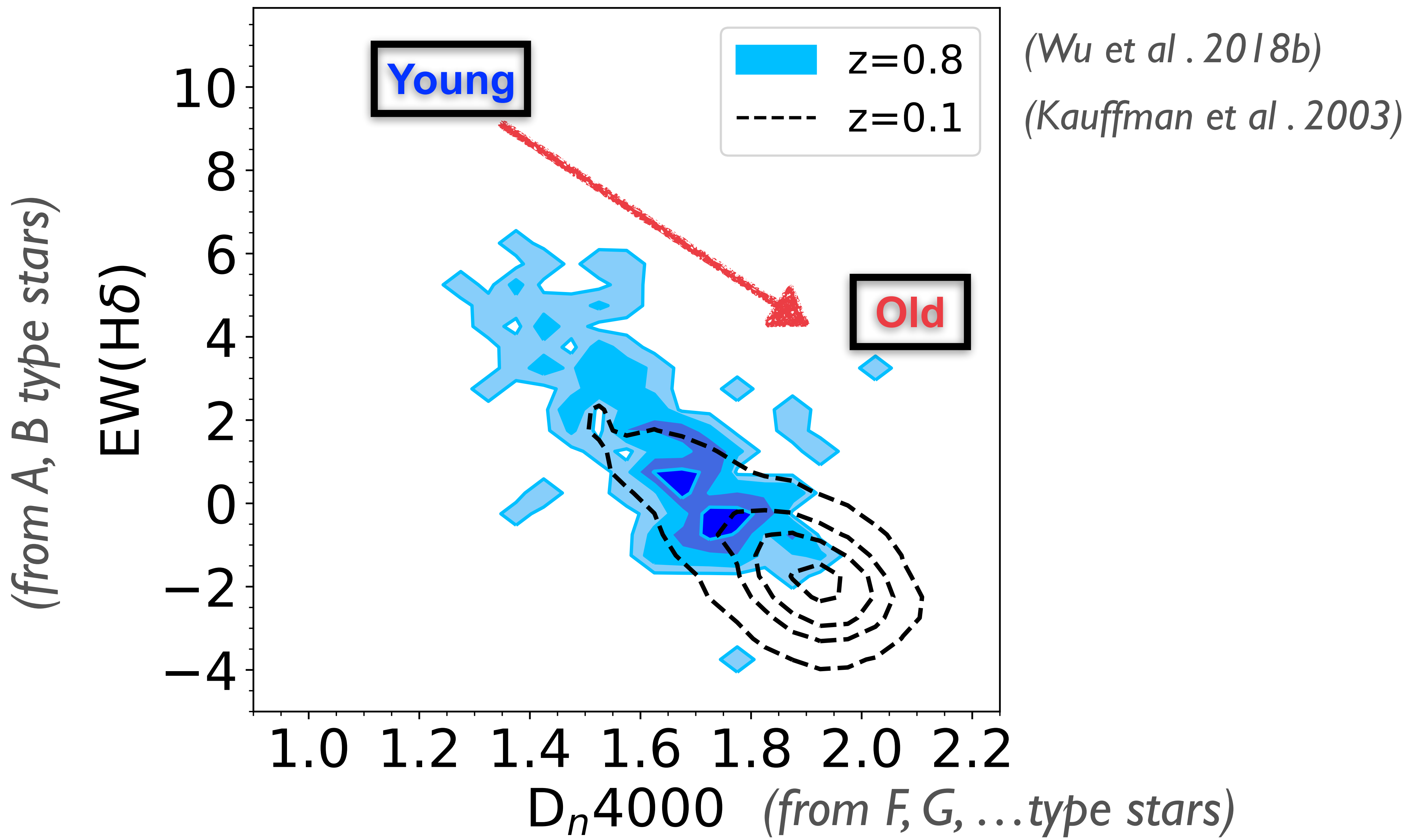


(Wu et al . 2018b)

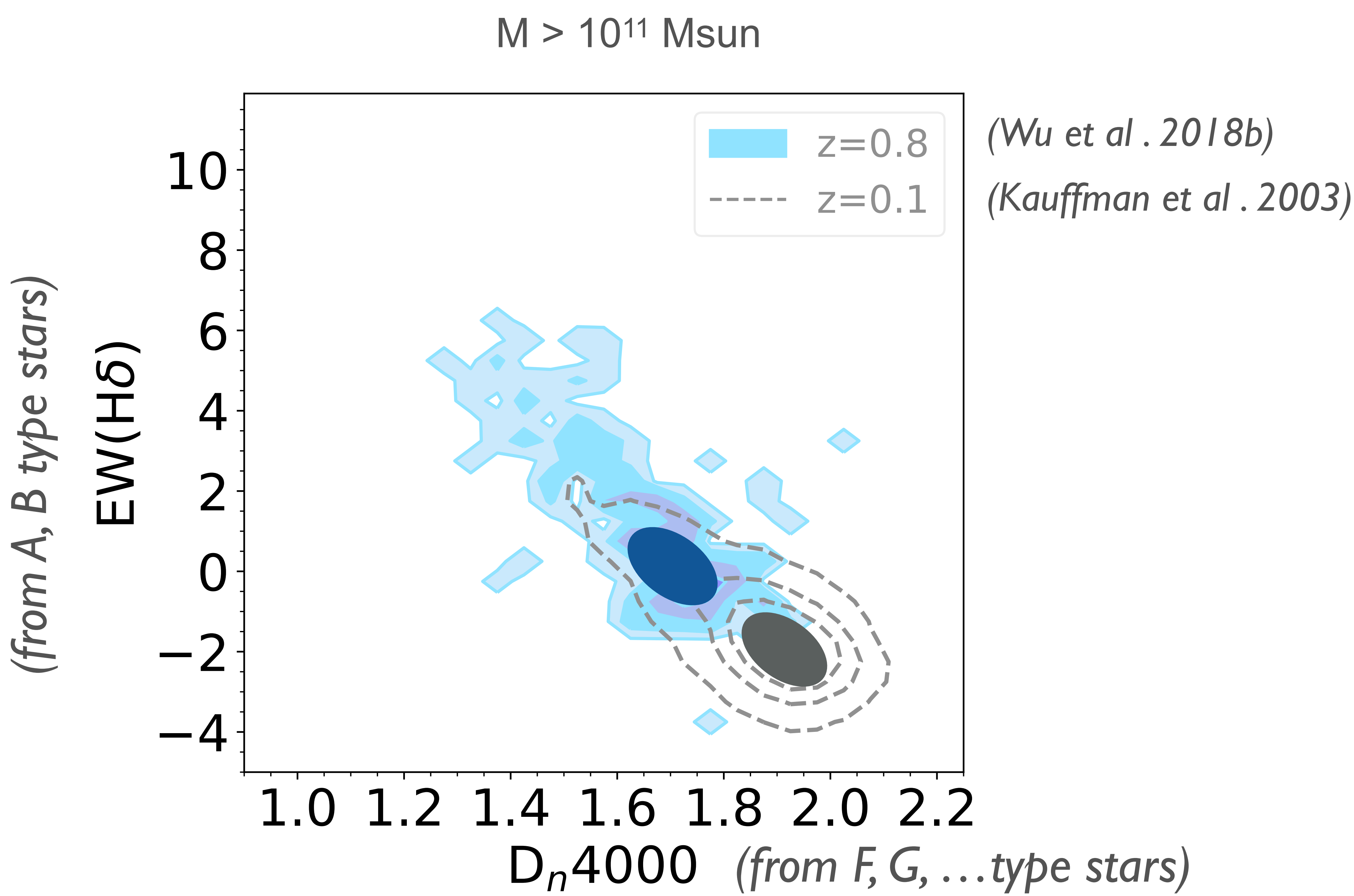
(Kauffman et al . 2003)

Stellar ages of massive galaxies at z~0.8

M > 10^11 Msun

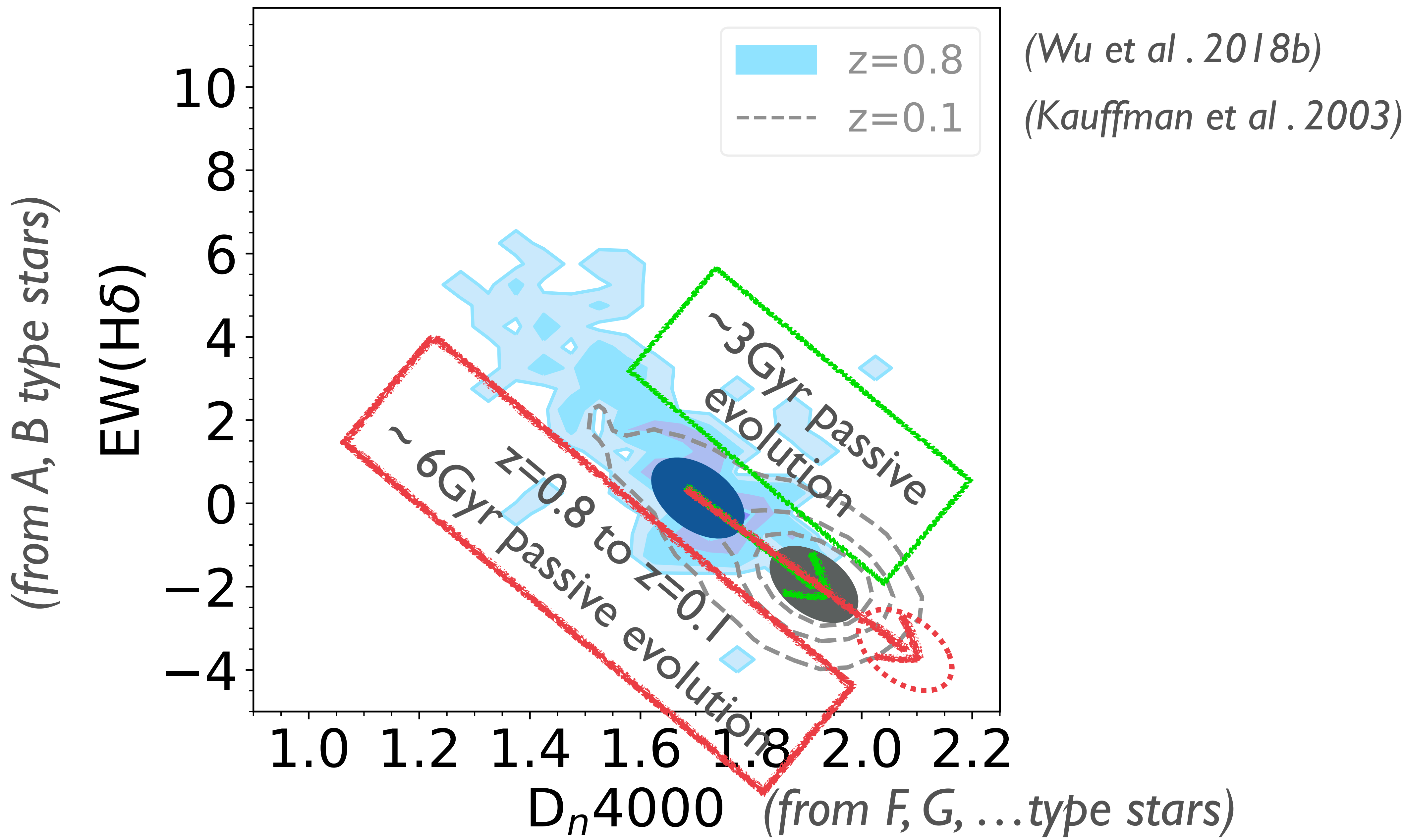


Stellar ages at z~0.8



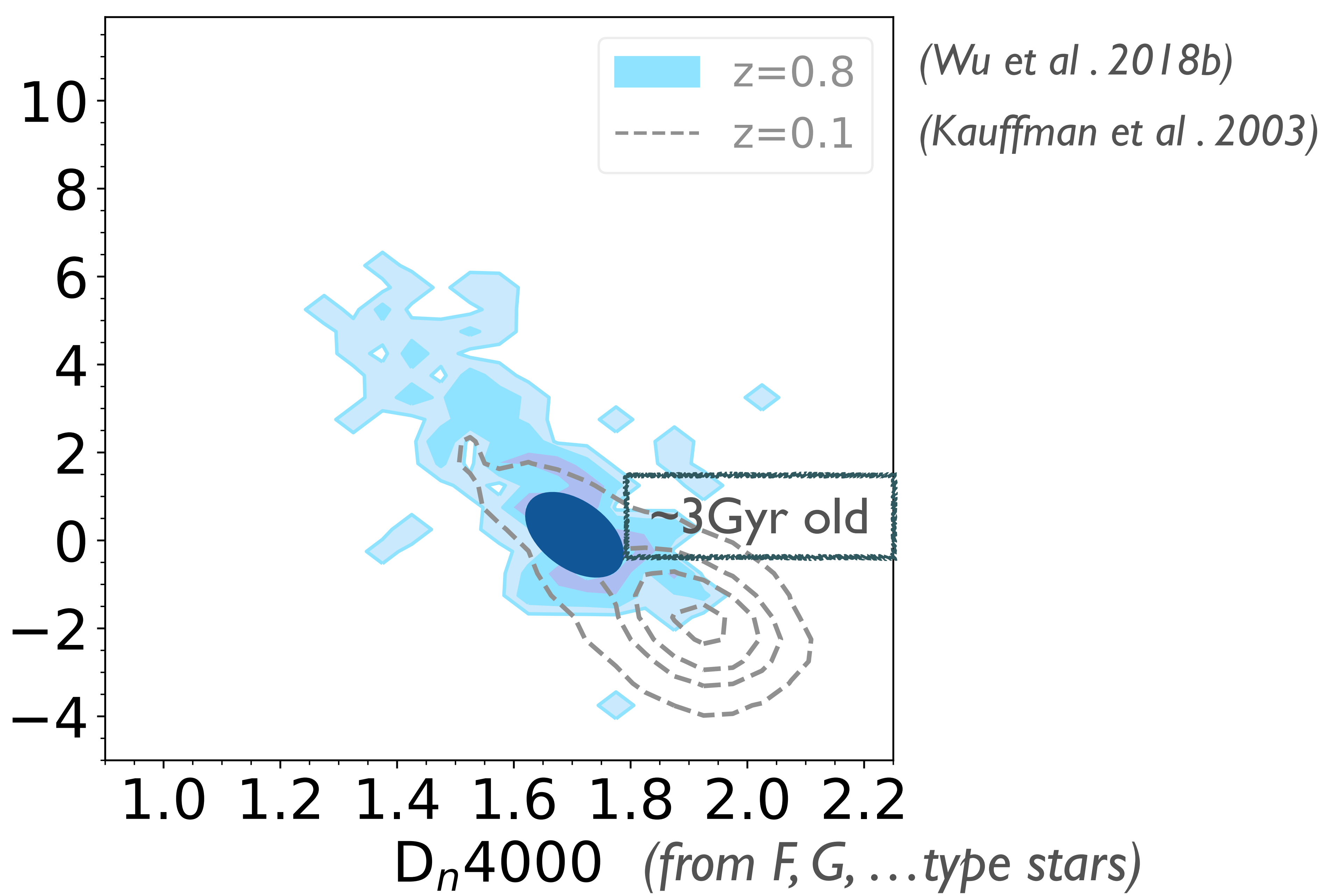
Stellar ages at z~0.8

Massive Quiescent galaxies did not evolve passively, new stars added between z=0.8 and z=0



Stellar ages at z~0.8

M > 10^{11} Msun



Stellar ages at z~0.8

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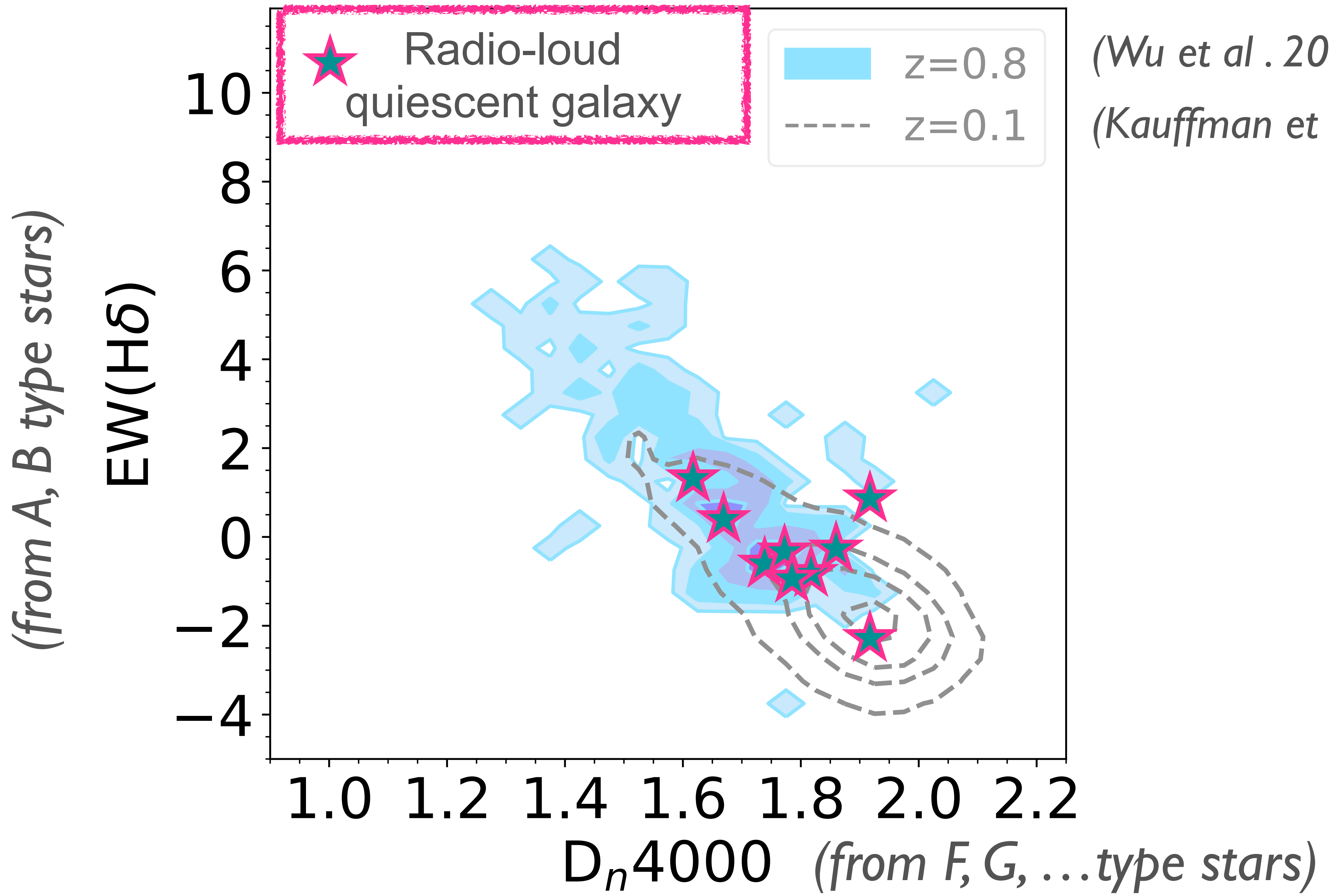
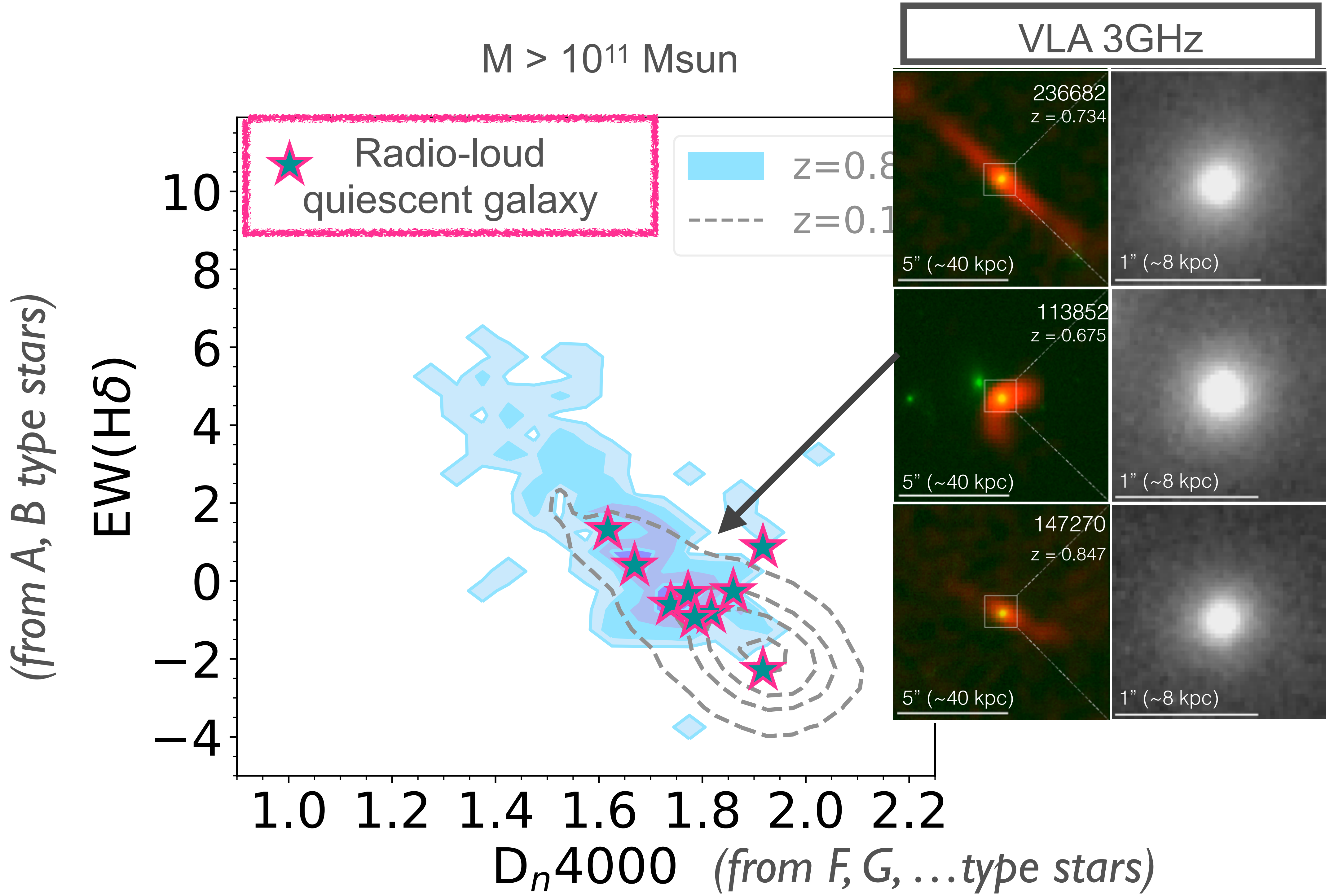


(Wu et al . 2018b)

(Kauffman et al . 2003)

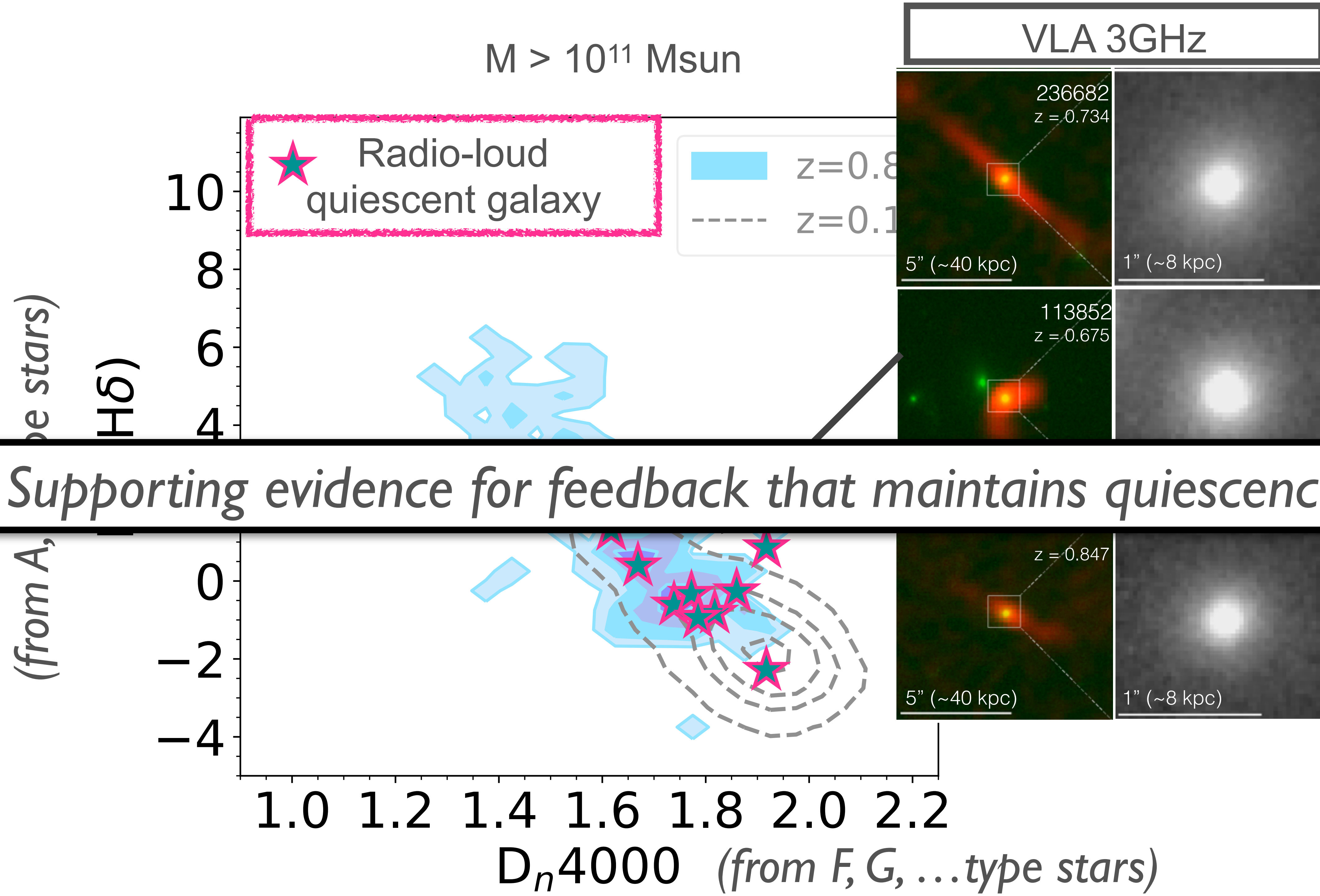
(Barisic et al. 2017)

Stellar ages at z~0.8



(Barisic et al. 2017)

Stellar ages at z~0.8



Supporting evidence for feedback that maintains quiescence

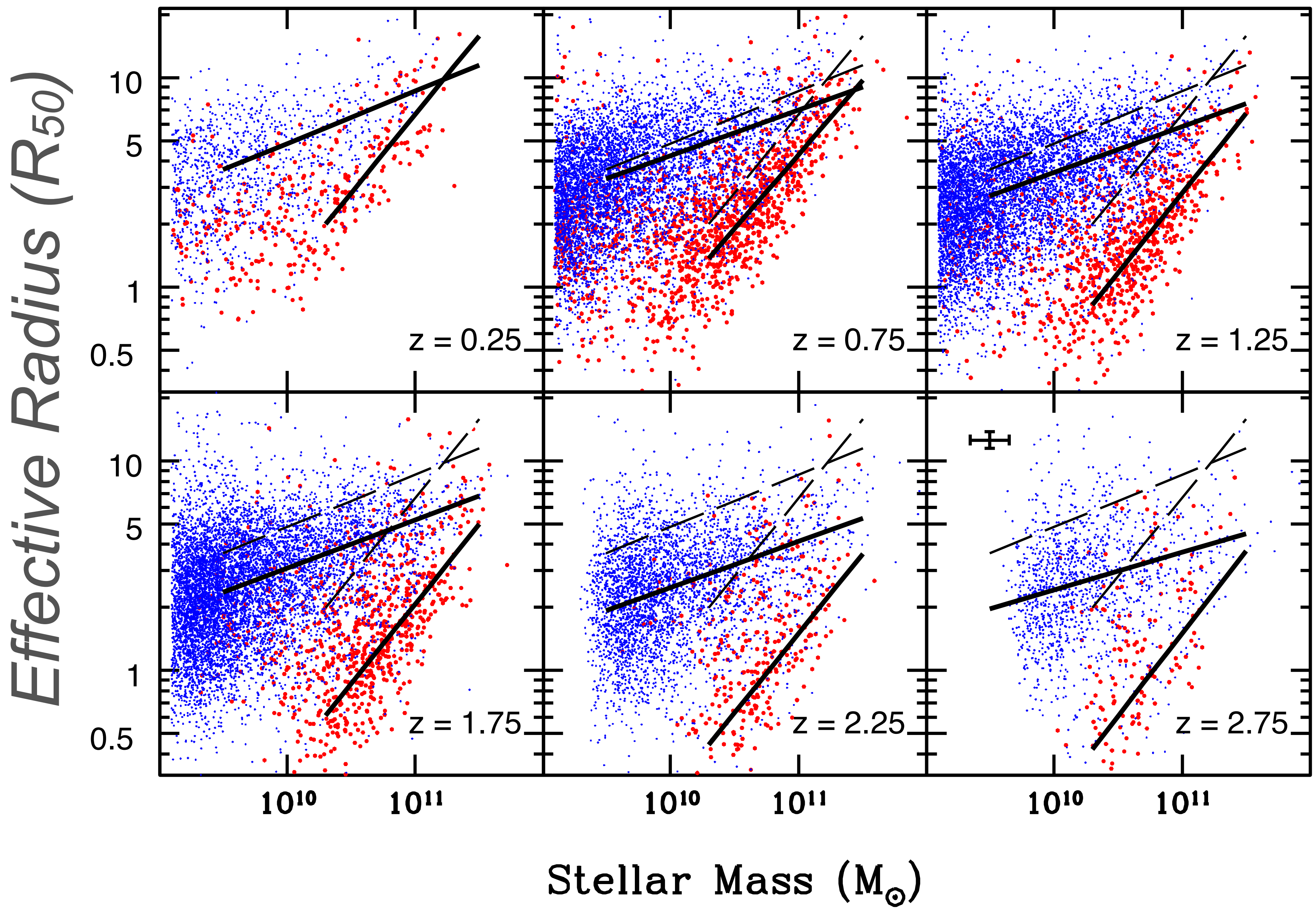
(Barisic et al. 2017)

The end of star-formation

The cessation of star formation

v.s.

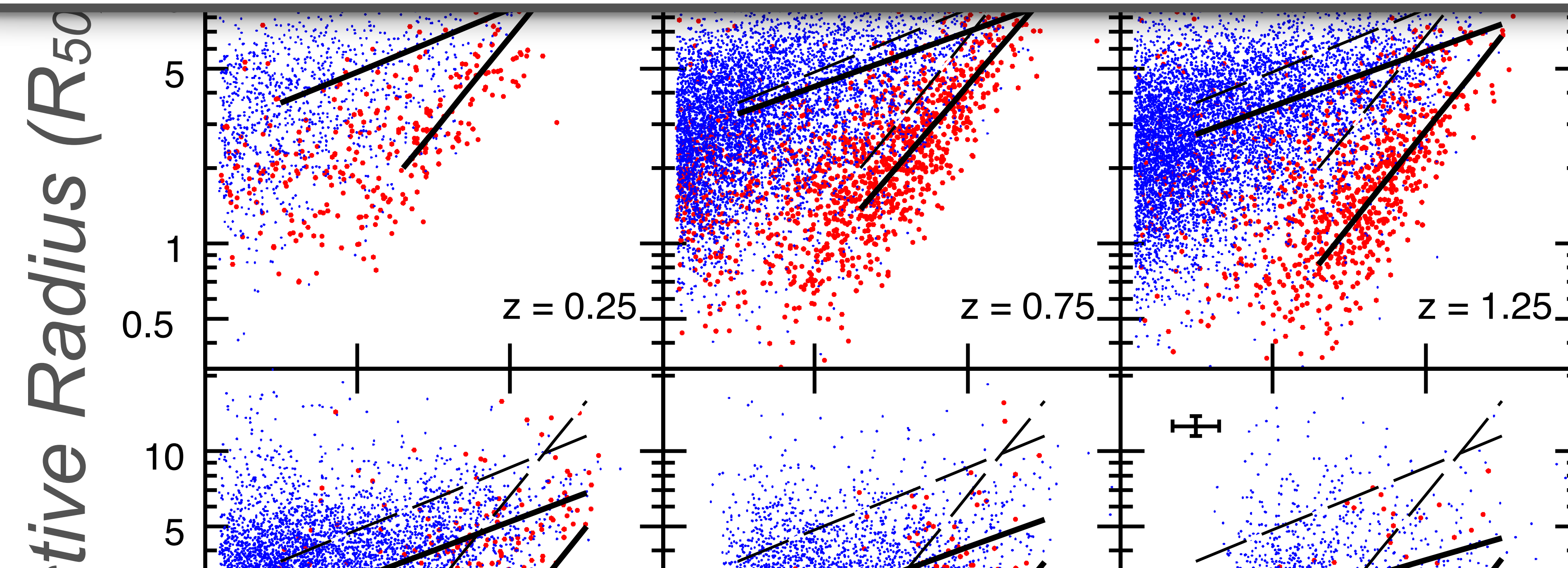
Mass-size relation



(van der Wel et al. 2014)

Mass-size relation

Scenario 1: SFR and size decrease at the same time

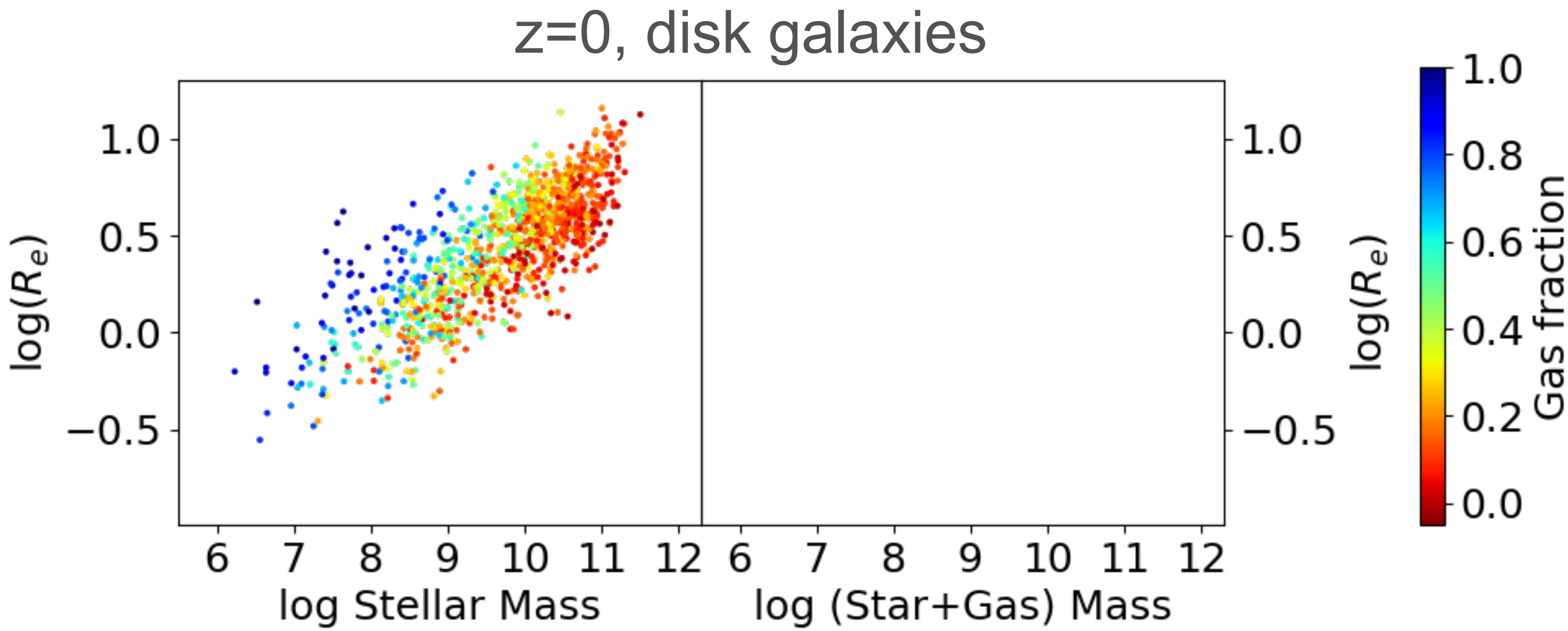


Scenario 2: Smaller galaxies evolve faster

Stellar Mass ($M_\odot$)

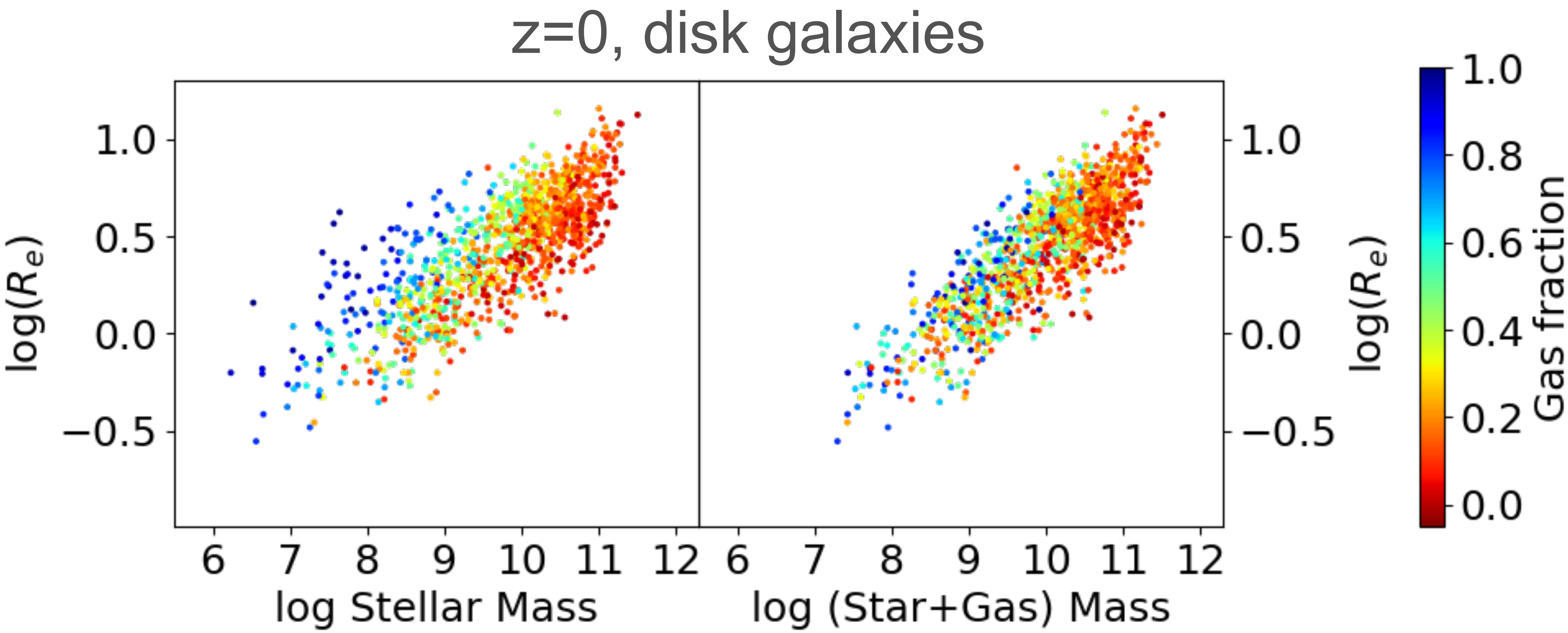
(van der Wel et al. 2014)

(Baryonic) Mass- (stellar) size relation



(Wu 2018a)

(Baryonic) Mass- (stellar) size relation

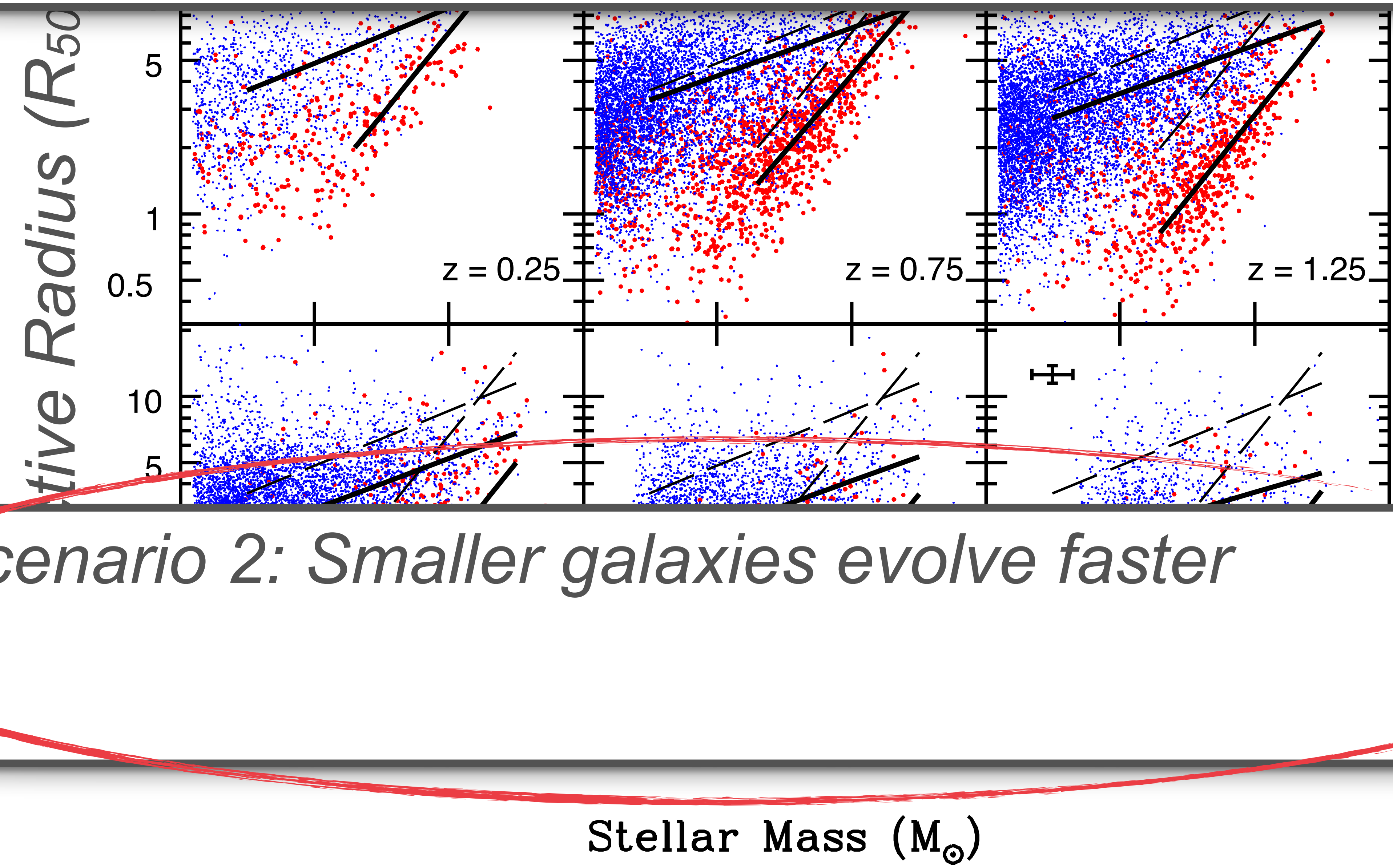


Large galaxies are inefficient at turning gas into stars

(Wu 2018a)

Mass-size relation

Scenario 1: SFR and size decrease at the same time

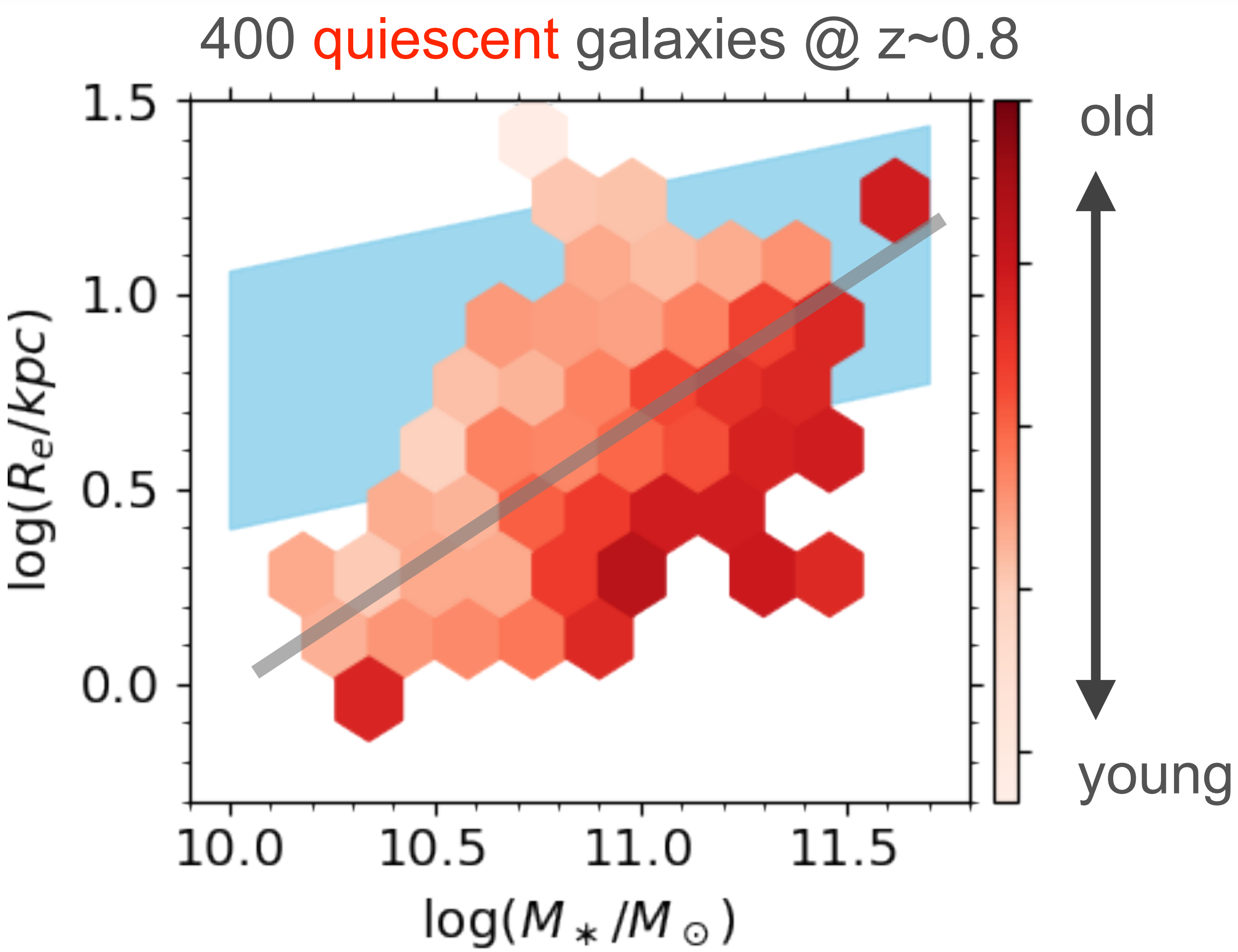


Scenario 2: Smaller galaxies evolve faster

(van der Wel et al. 2014)

Stellar ages of quiescent galaxies

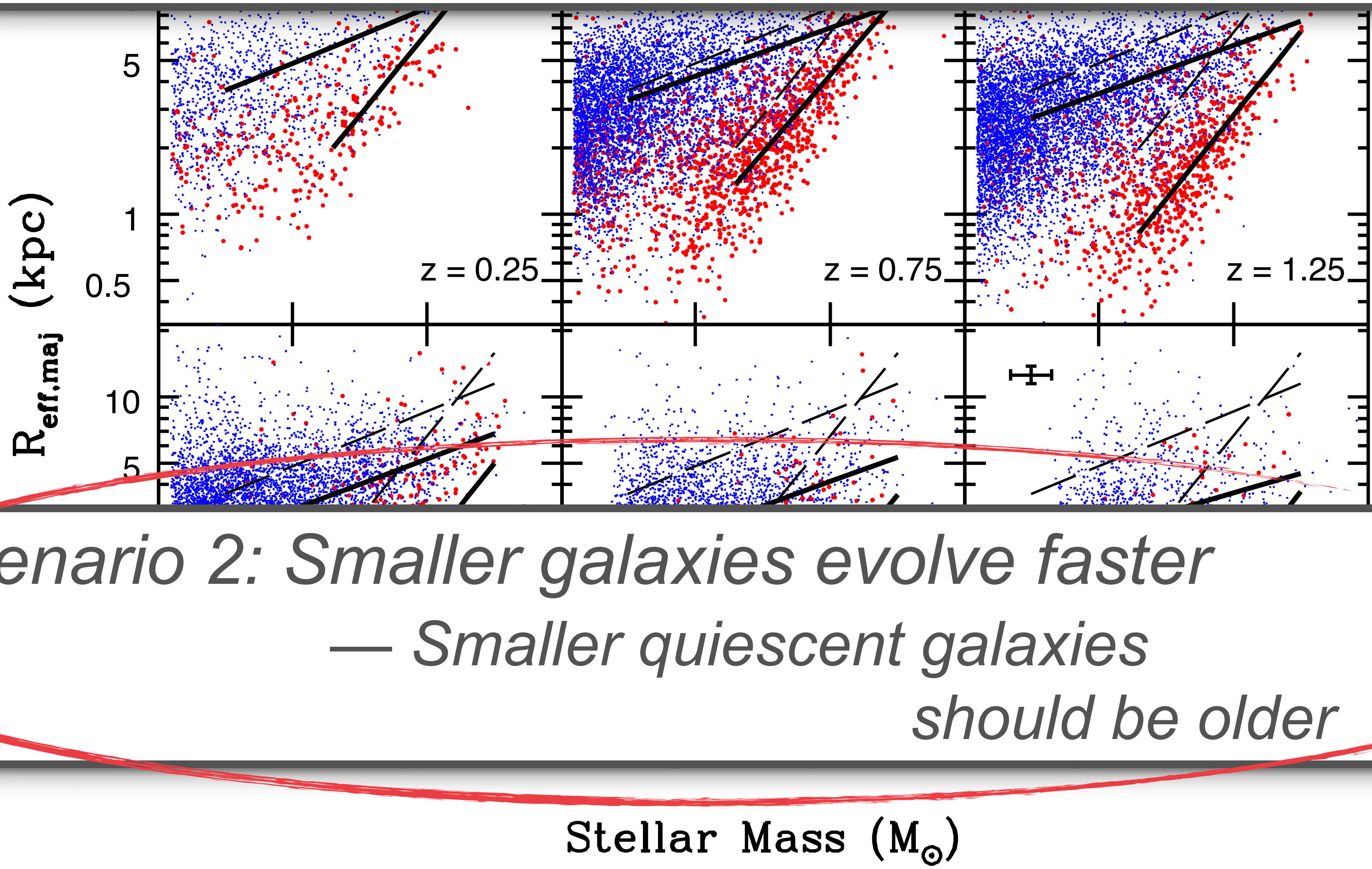
Small quiescent galaxies are on average older



(Wu et al. 2018c)

Mass-size relation

Scenario 1: SFR and size decrease at the same time



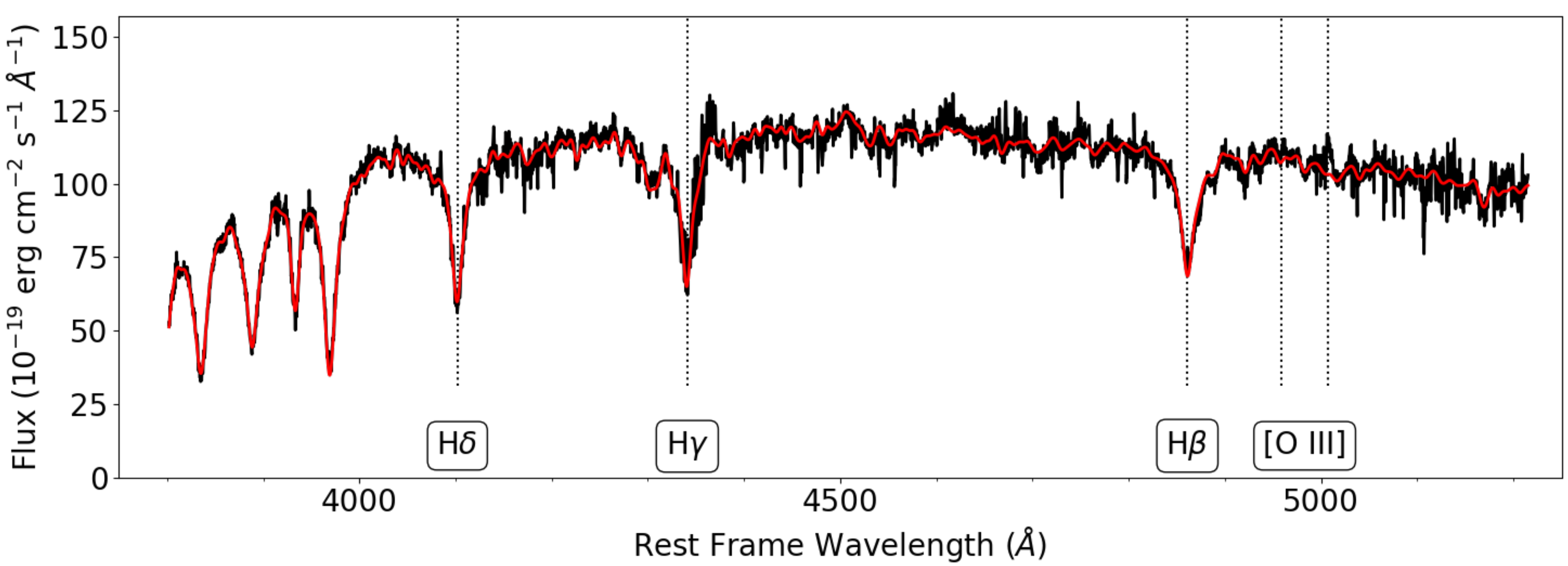
Scenario 2: Smaller galaxies evolve faster

— Smaller quiescent galaxies should be older

A different view from *"Young" galaxies*

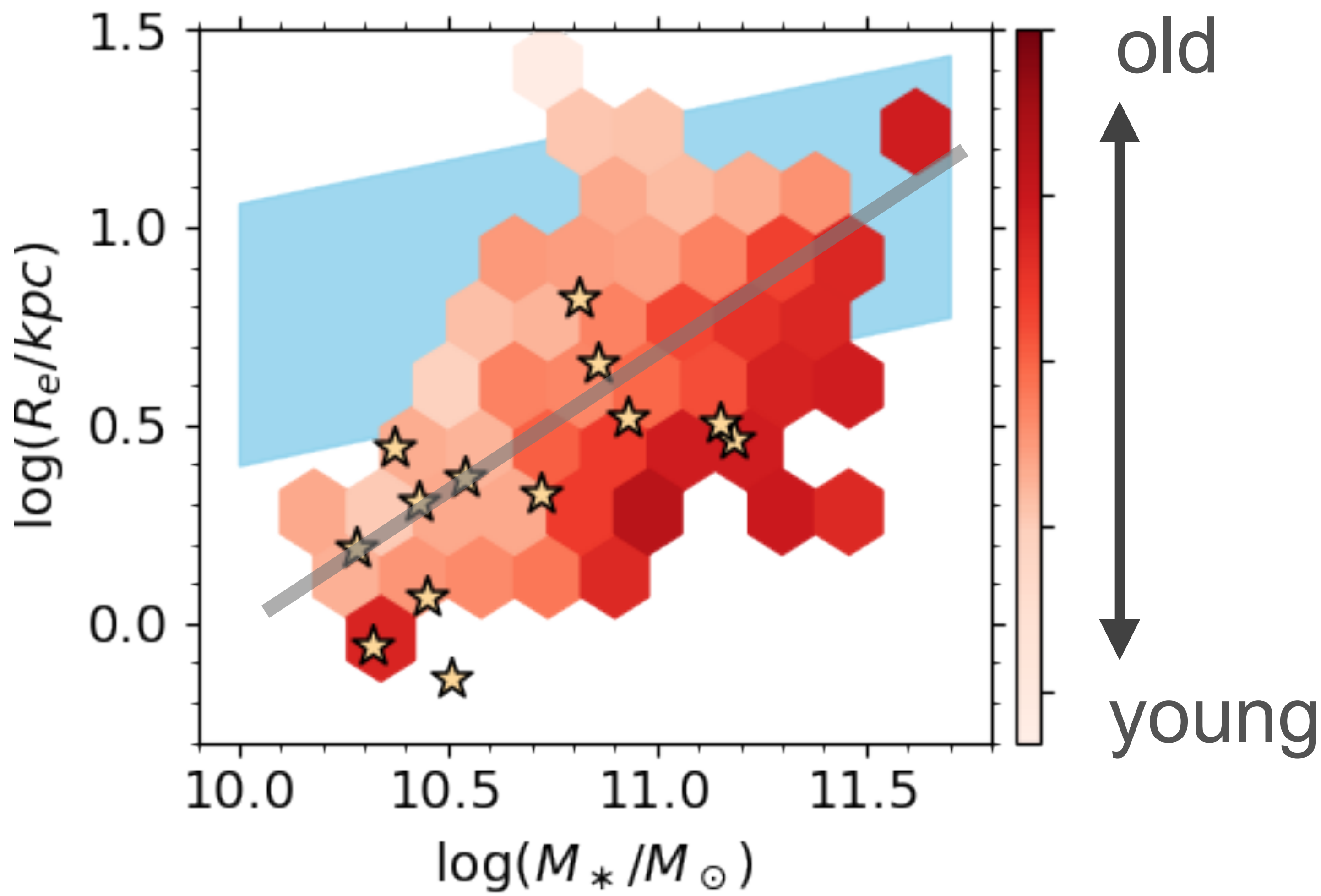
- Quiescent galaxies + Balmer absorption: **A-type stars**
- Star-formation declines rapidly in ~ a few x 100 Myrs
- "***post-starburst galaxies***"

Are these "A-type" galaxies larger?



Size of *"A-type" galaxies*

***No!** "A-type" galaxies are not large*
& much smaller than average SF galaxies



(Wu et al. 2018c)

Mass-size relation

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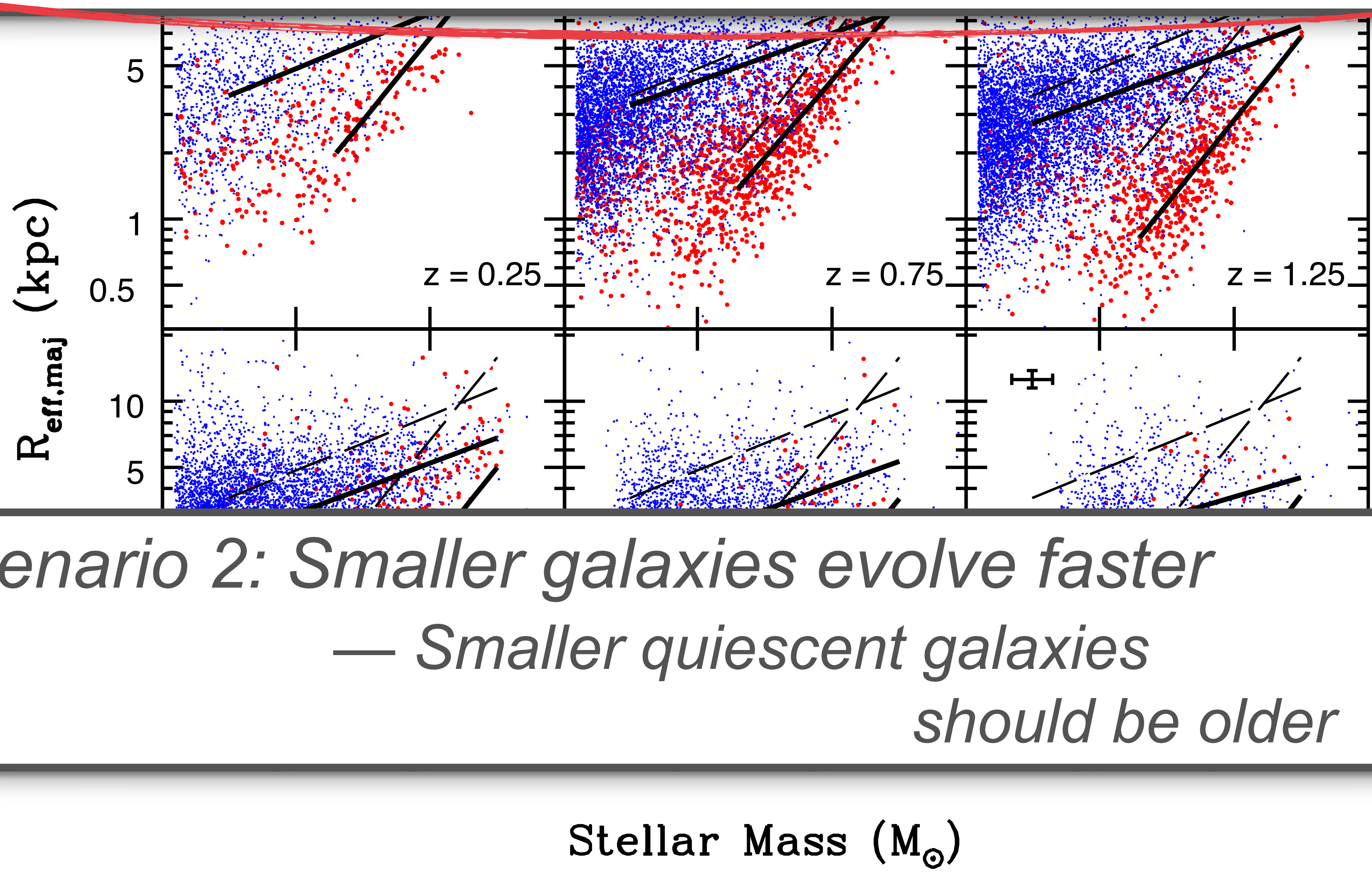
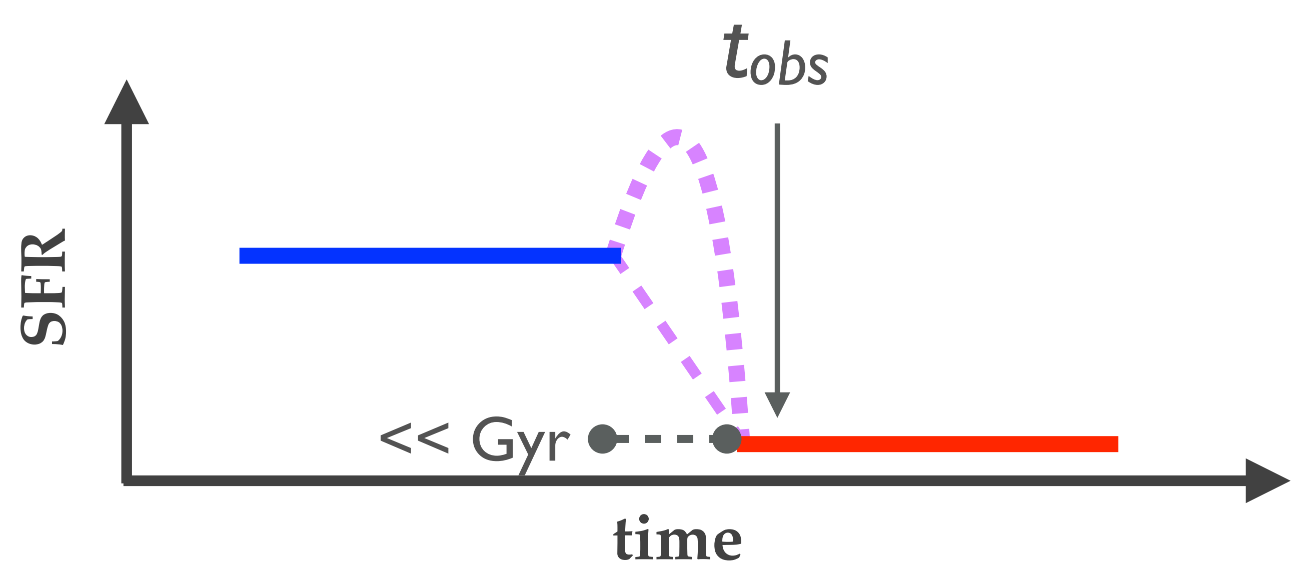


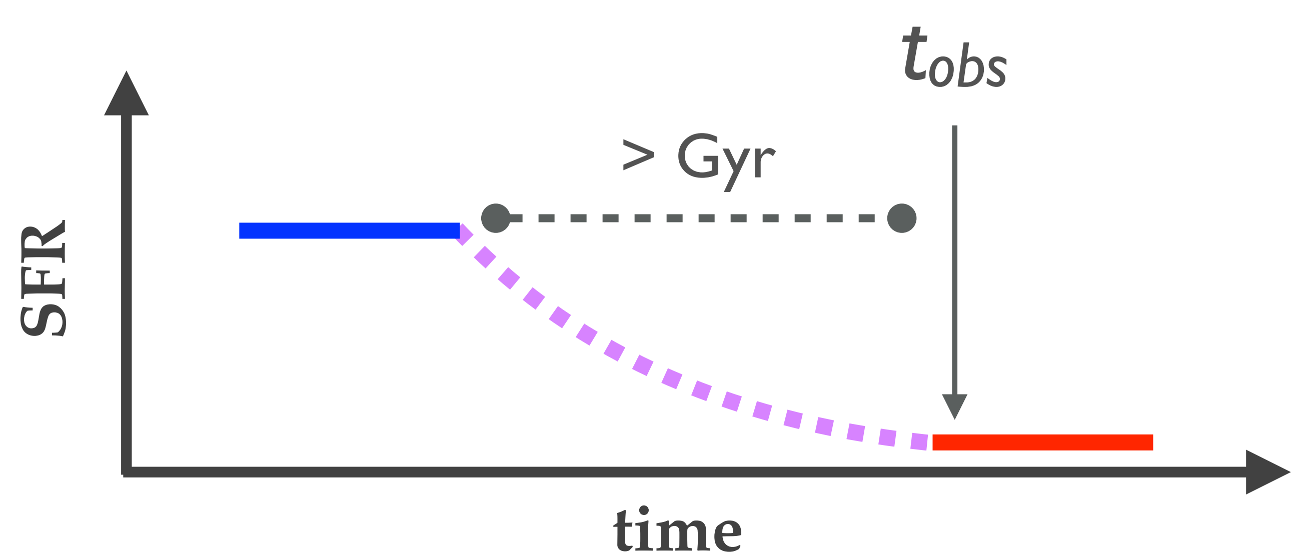
Scenario 2: Smaller galaxies evolve faster

— Smaller quiescent galaxies

should be older

Multiple ways to quiescence

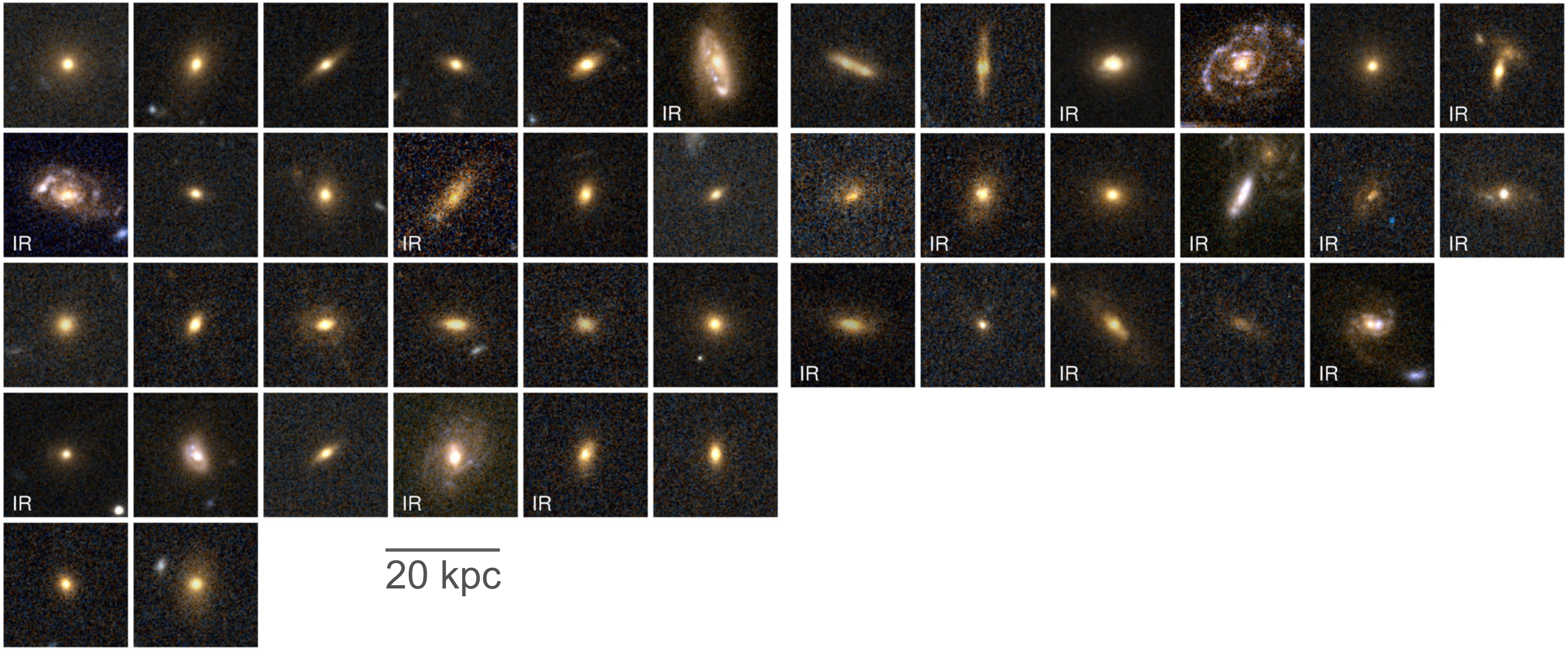




(Wu et al. 2018c)

Gallery of “A-type” Galaxies

“A-type” Galaxies @ z=1, ***HST V + I***



(Wu et al. 2014)

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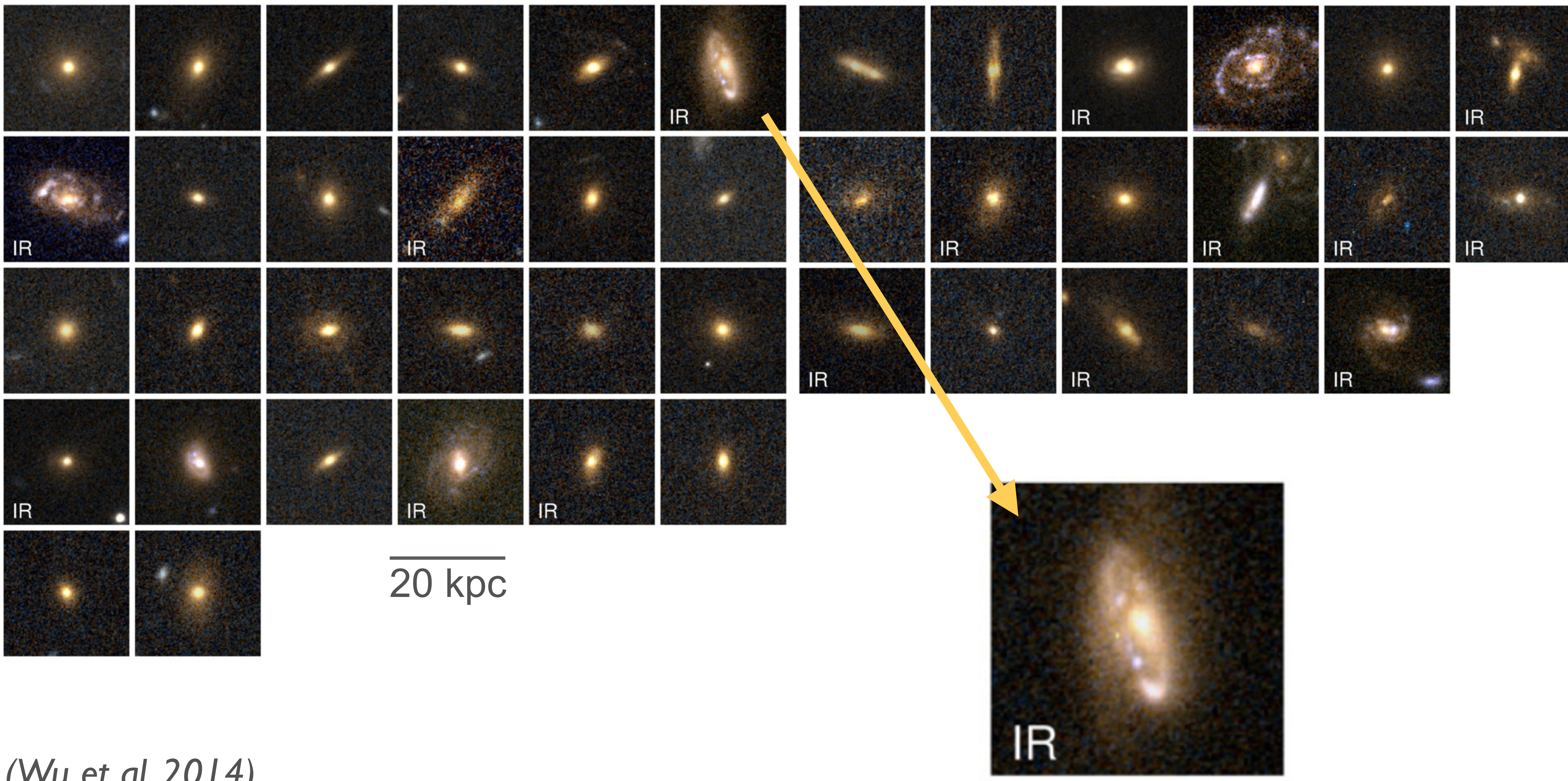

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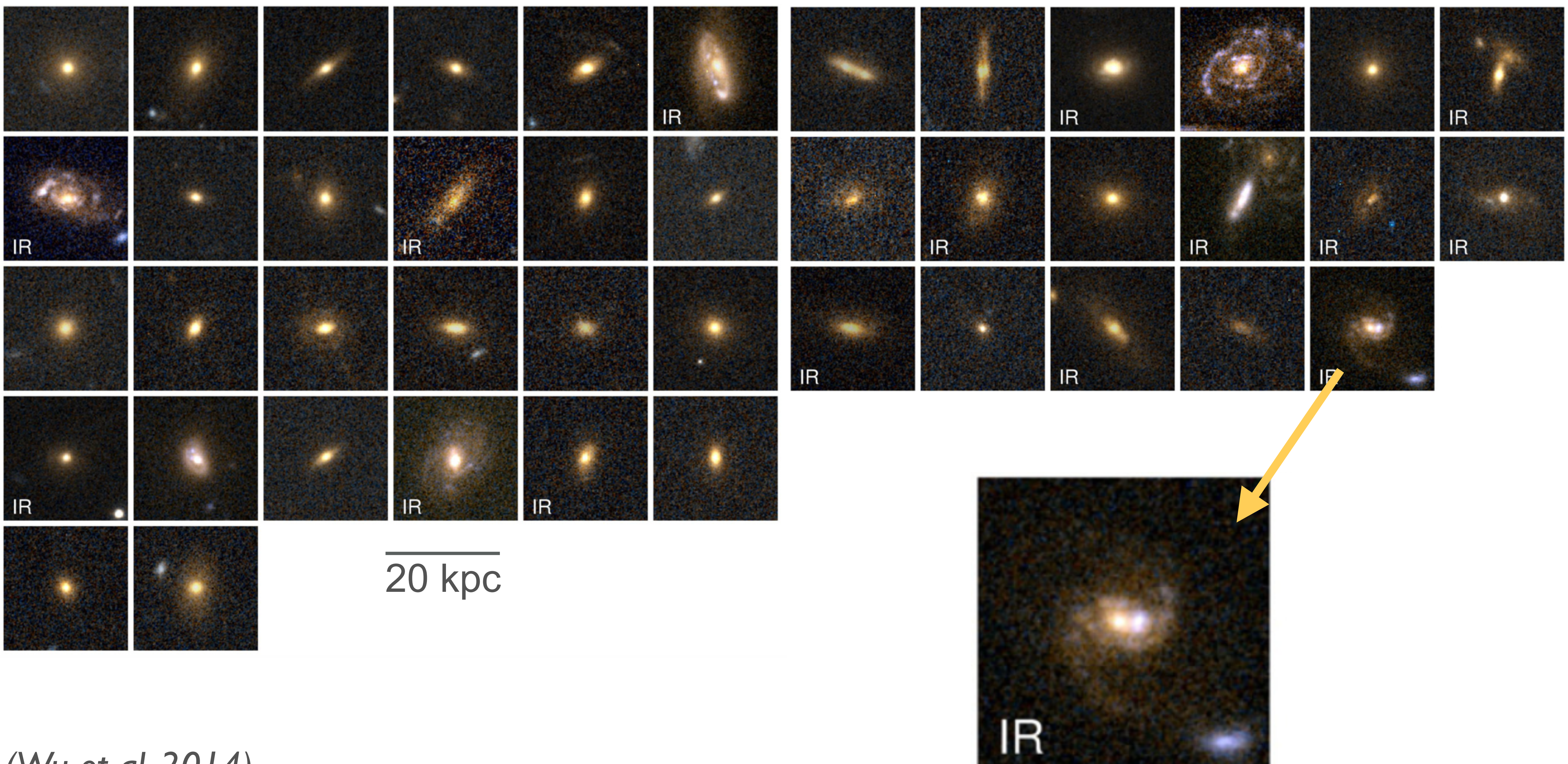

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Gallery of “A-type” Galaxies

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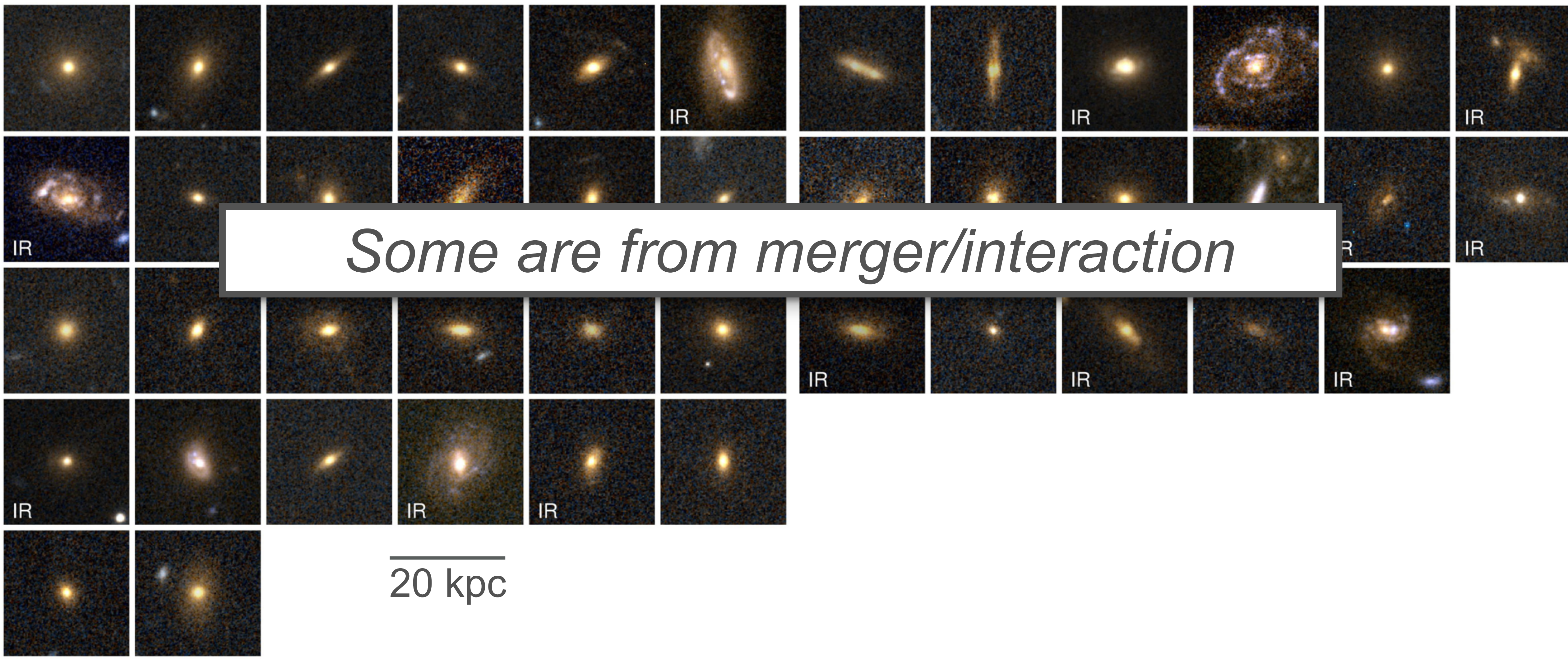

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Gallery of “A-type” Galaxies

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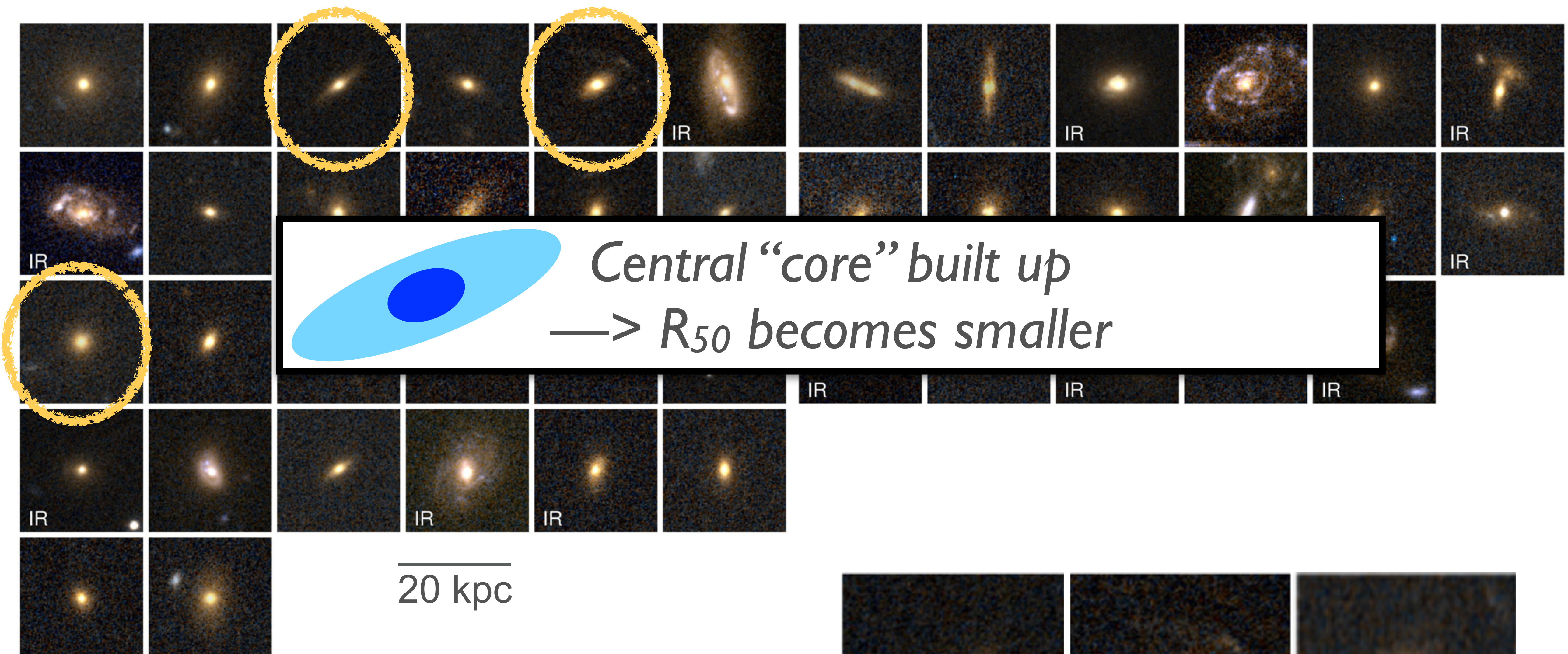
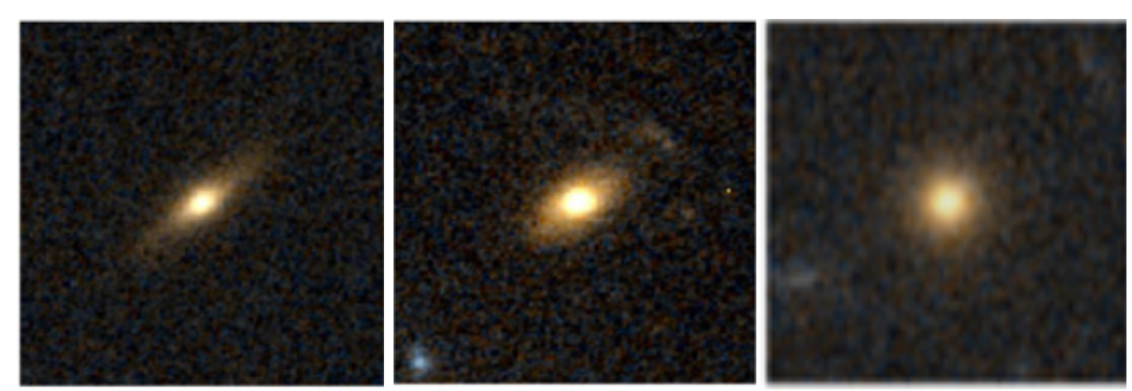
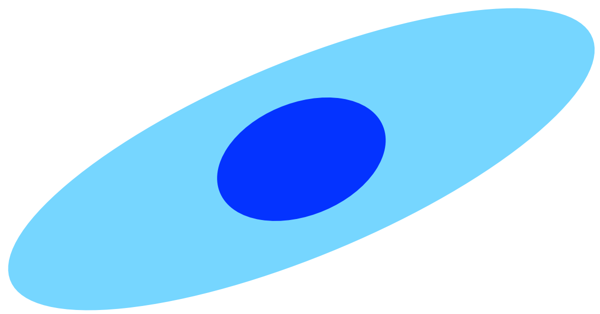




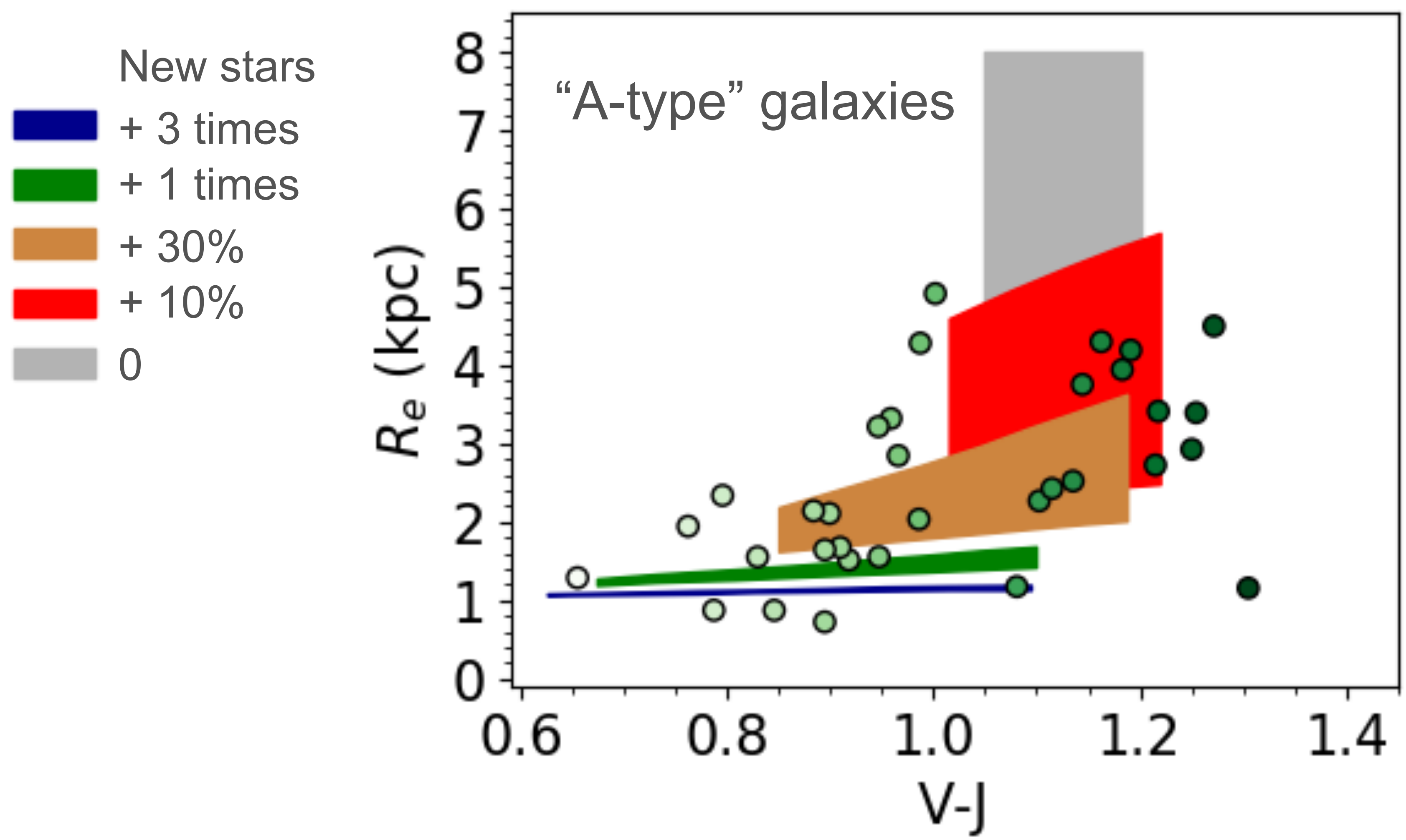
(Wu et al. 2014)

Correlation between colors and sizes



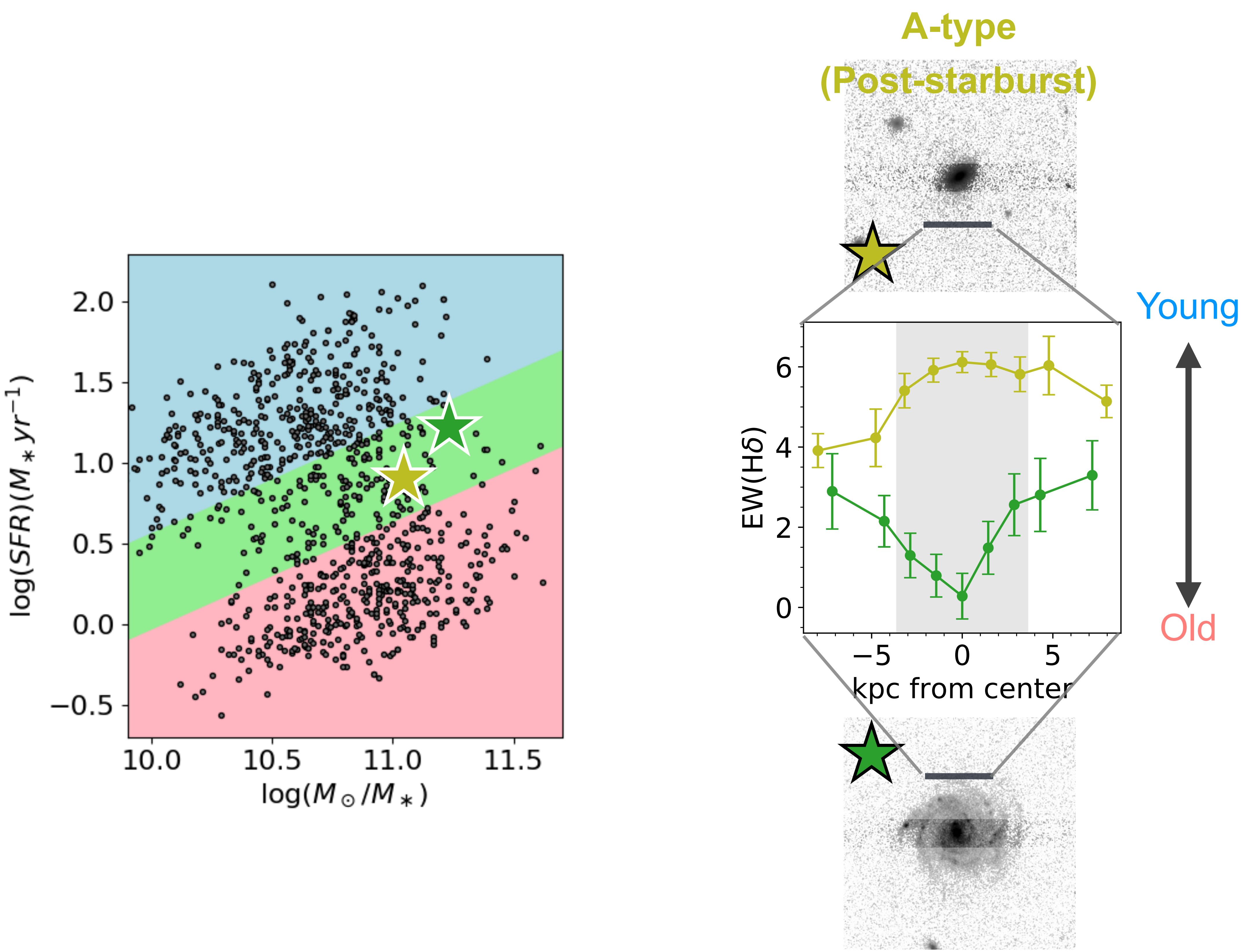
More new stars in the center ->

1. Smaller R_{50}
2. Bluer color



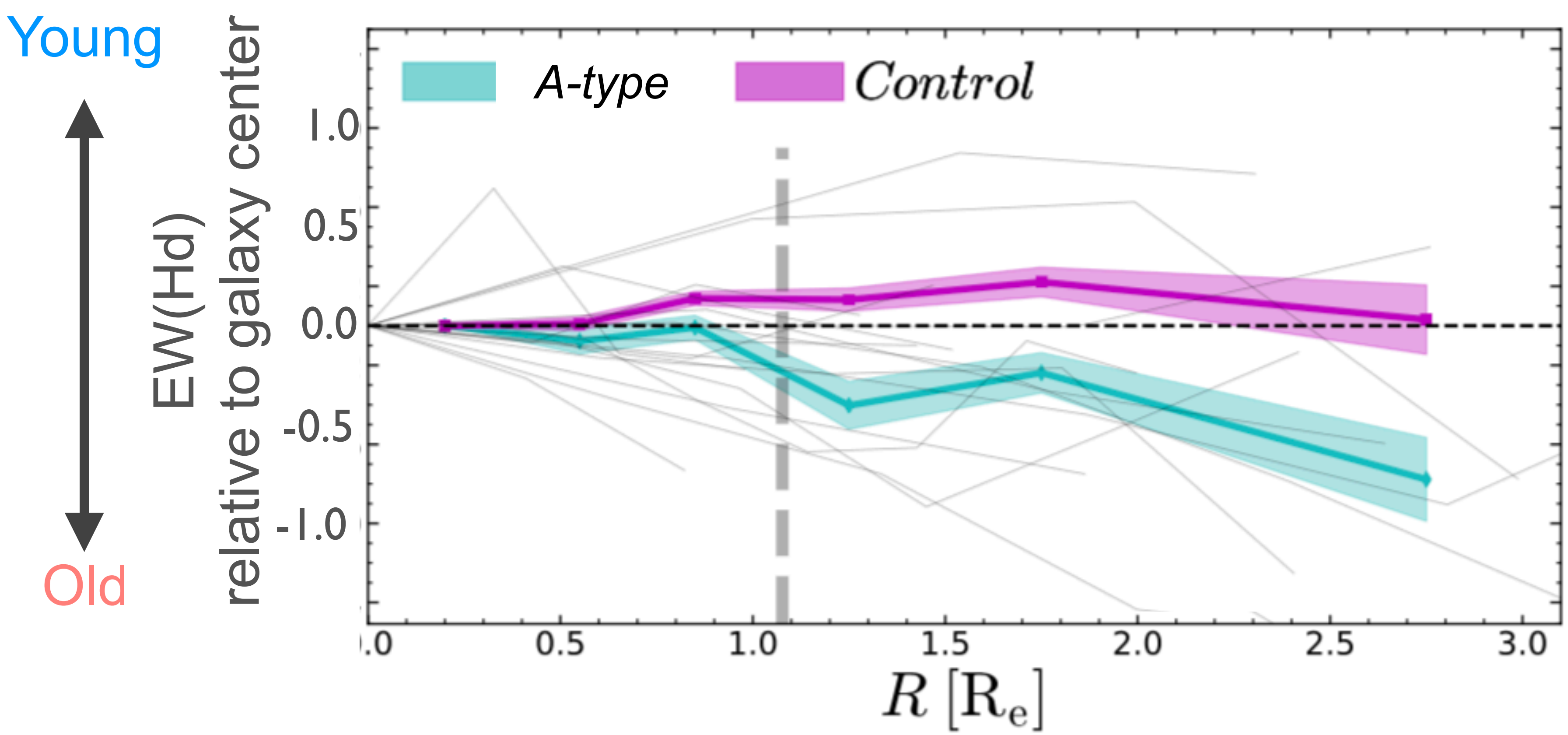
(Wu et al. 2020)

Age gradient



Age gradient

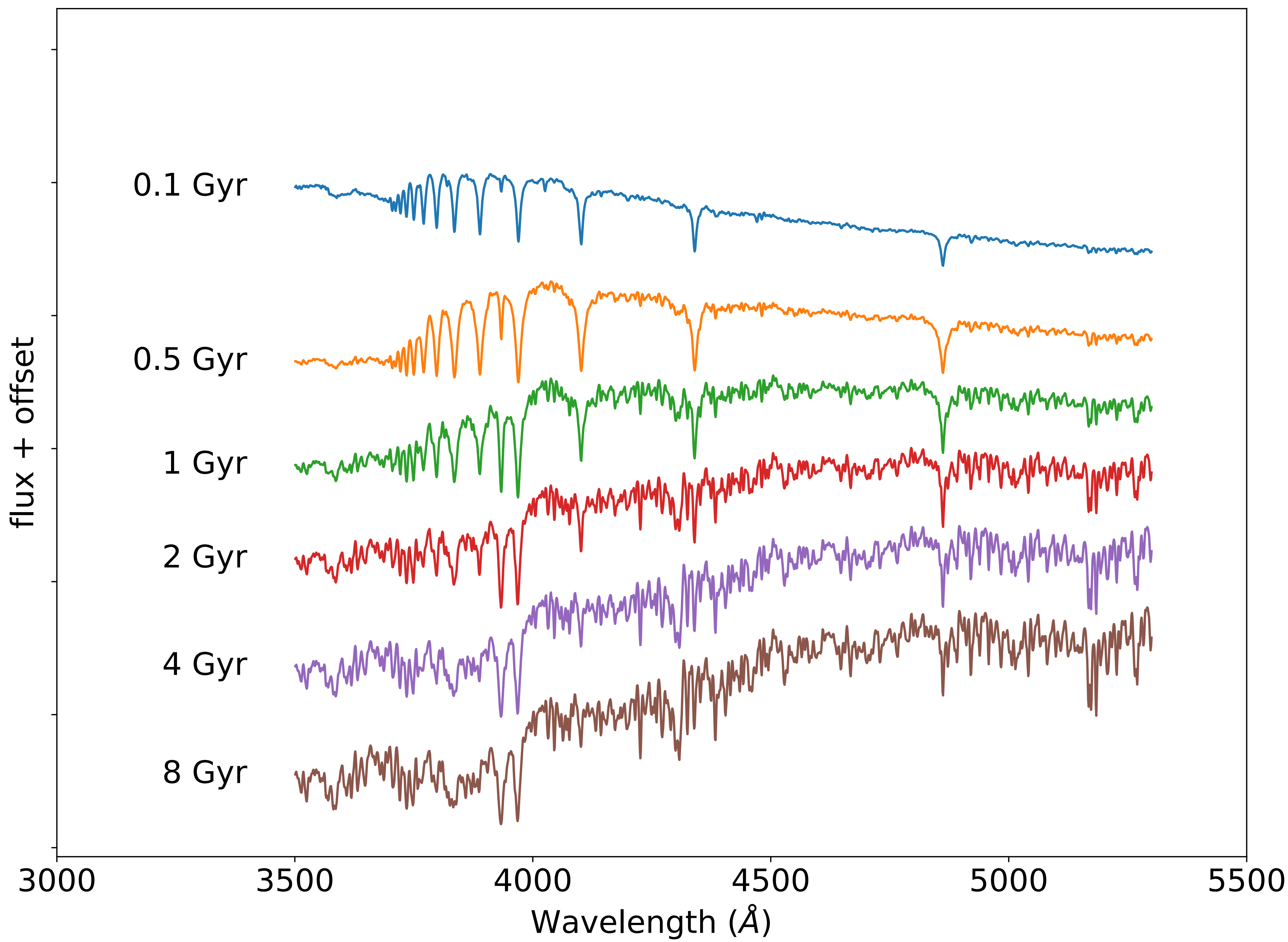
“A-type” galaxies have younger center
—> Not “inside-out”



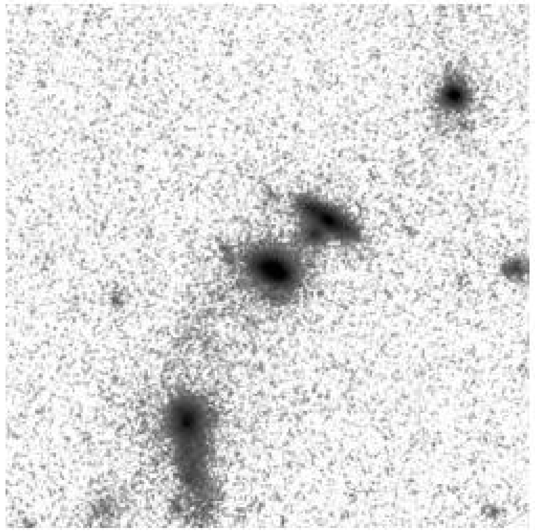
(D’ Eugenio et al., in prep)

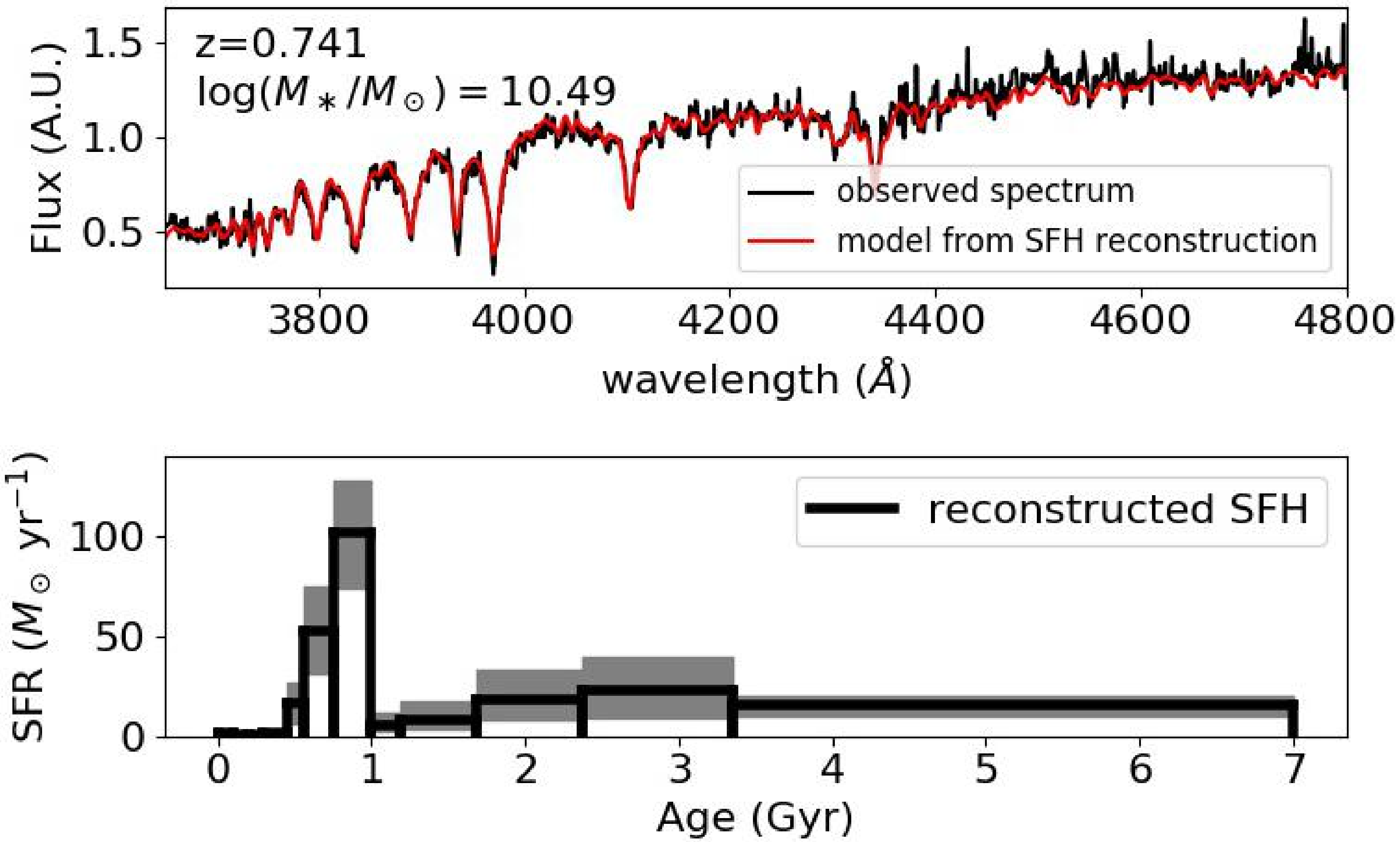
Star formation histories

Star-formation histories



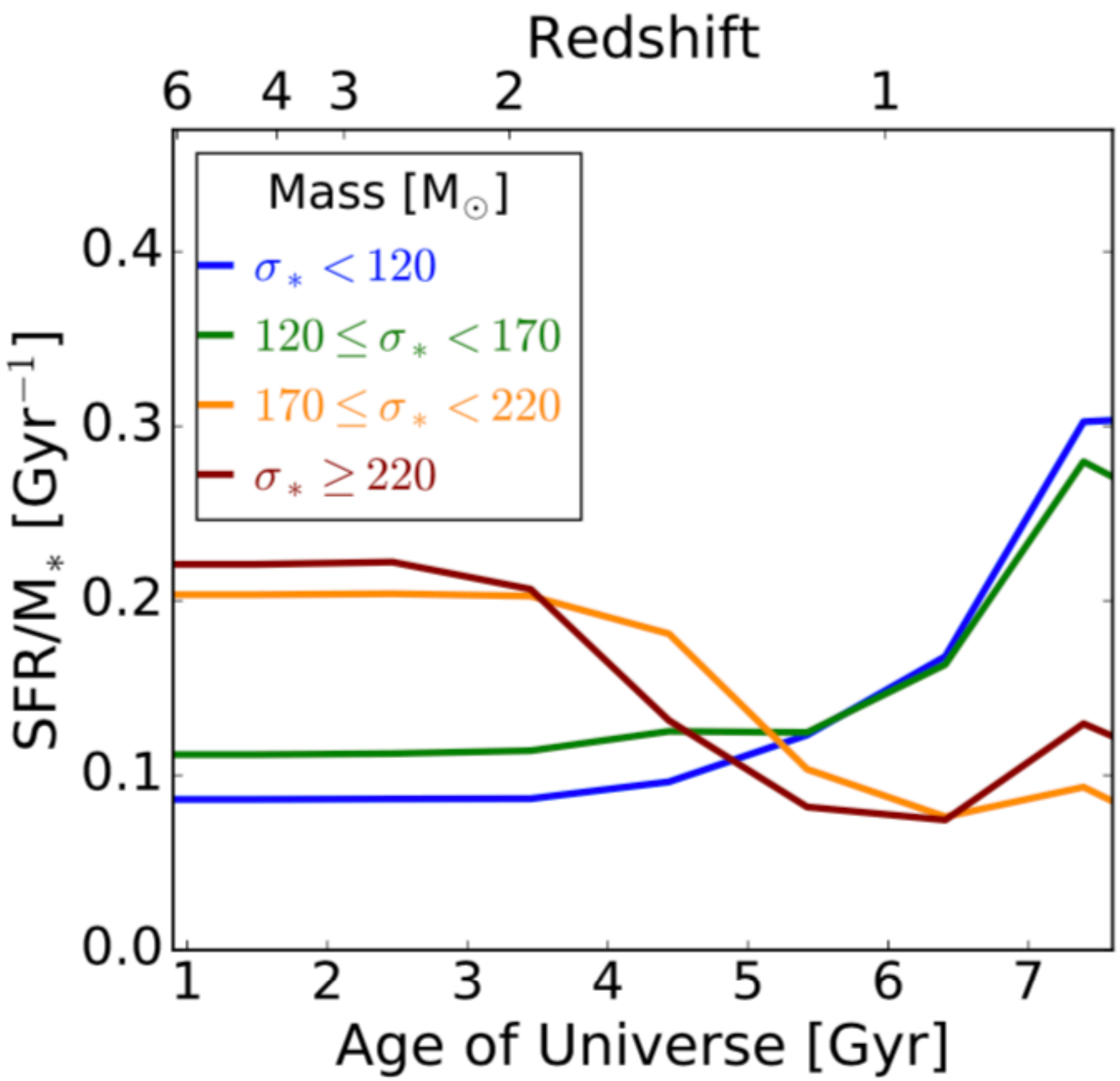
Non-parametric star-formation histories





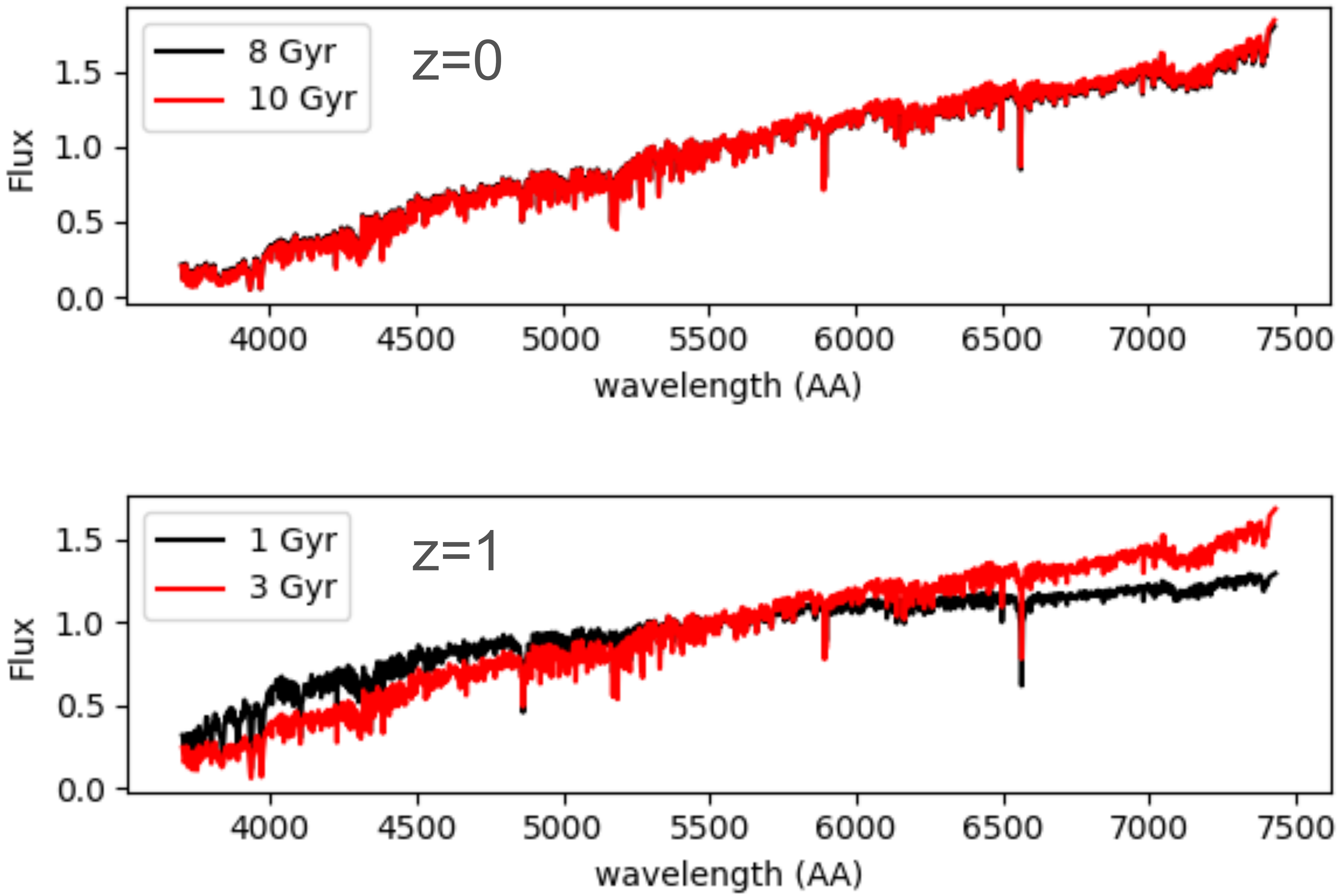
(Chauke et al. 2018)

Average star-formation histories



(Chauke et al. 2018)

Go higher z



8 Gyr
10 Gyr
z=0
Flux
1.5
1.0
0.5
0.0
4000
4500
5000
5500
6000
6500
7000
7500
wavelength (AA)
1 Gyr
3 Gyr
z=1
Flux
1.5
1.0
0.5
0.0
4000
4500
5000
5500
6000
6500
7000
7500
wavelength (AA)

Conclusion

What we have now

- **The LEGA-C**
  - ~3000 galaxies @ 0.6 < z < 1.0
  - DR2, ~1500 galaxies
  - Census of stellar kinematics and stellar population
- **Future with PFS?**
  - Fast, 2400 v.s. 130 (VLT/VIMOS)
  - Wider spectra coverage
    - LEGA-C: 6500 ~ 9000 AA
  - J-band coverage
    - Restframe 4000 AA @ z>1.5