Science with synthetic images from cosmological simulations

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STScI

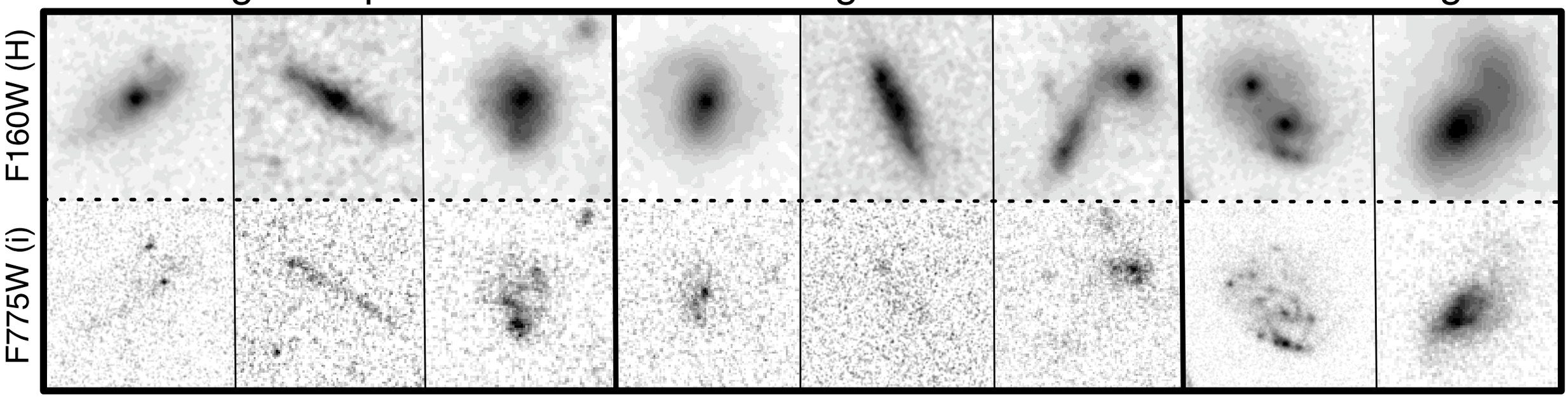
UCSC Aug 15, 2014

Jennifer Lotz, Mike Peth, Paul Torrey, Chris Moody, Joel Primack, Daniel Ceverino, Mark Vogelsberger, Shy Genel, Lars Hernquist, …

Grogin et al. 2011

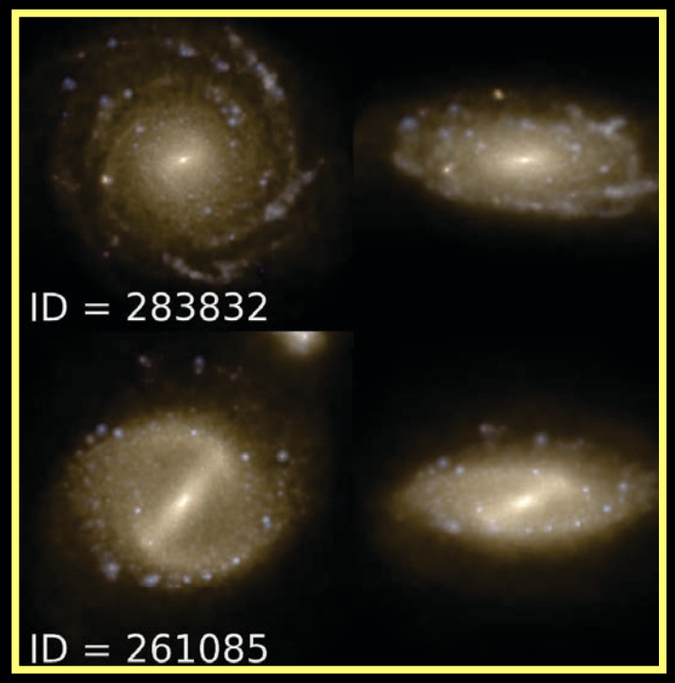
CANDELS Multi-Cycle Treasury Program

z~2



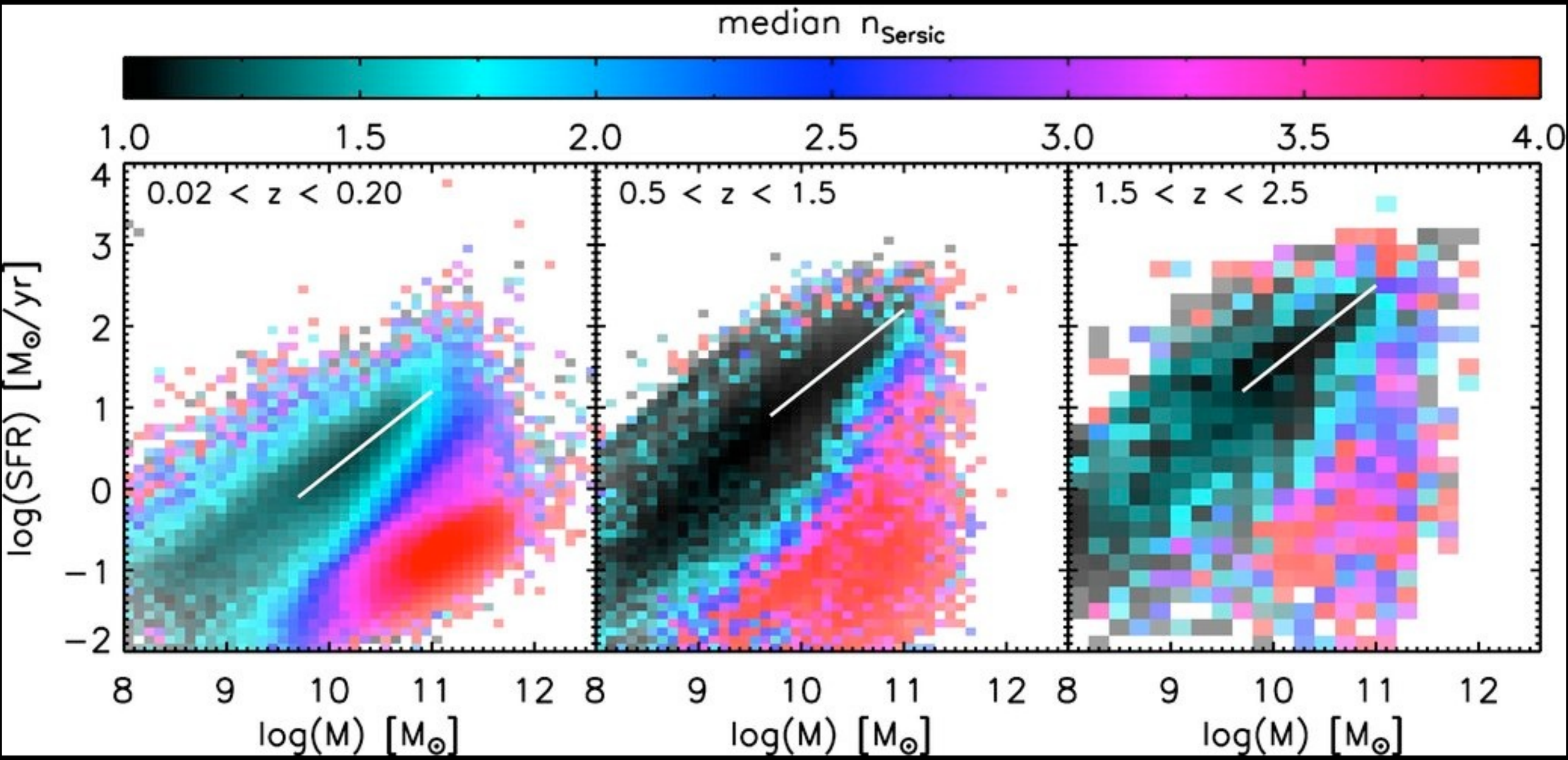
- Current diagnostics do not:
  - exploit all information in observations
  - accurately classify rare but important stages
  - necessarily give ‘plausible life stories’

1. Illustris Simulation Observatory: sub-kpc resolved mock images of ~10,000 galaxies in $(100\ \mathrm{Mpc})^3$



2. Hydro-ART mock HST images: very high time (30 Myr) and space (~25pc) resolution

e.g., Moody et al. 2014
McGrath et al. talk



Wuyts et al. 2011

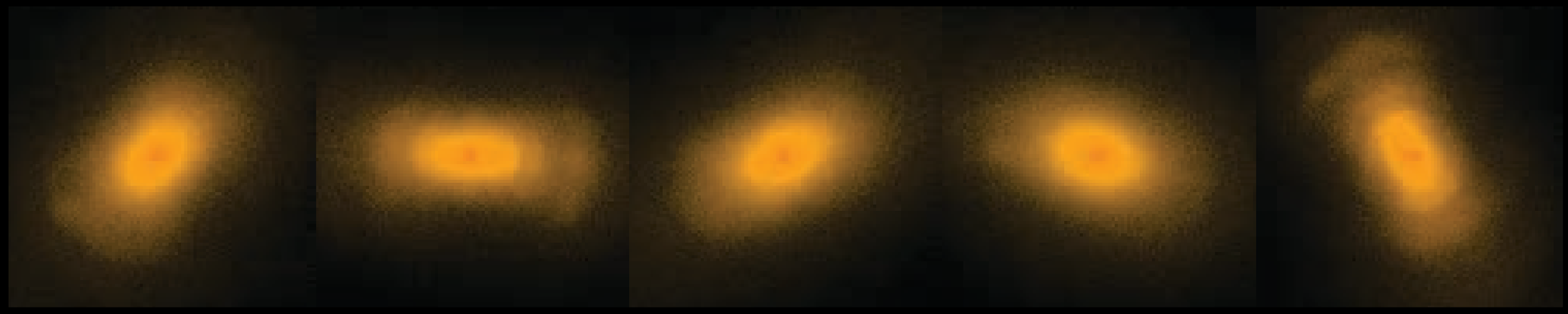
Illustris Project

Vogelsberger et al. 2014ab
Genel et al. 2014

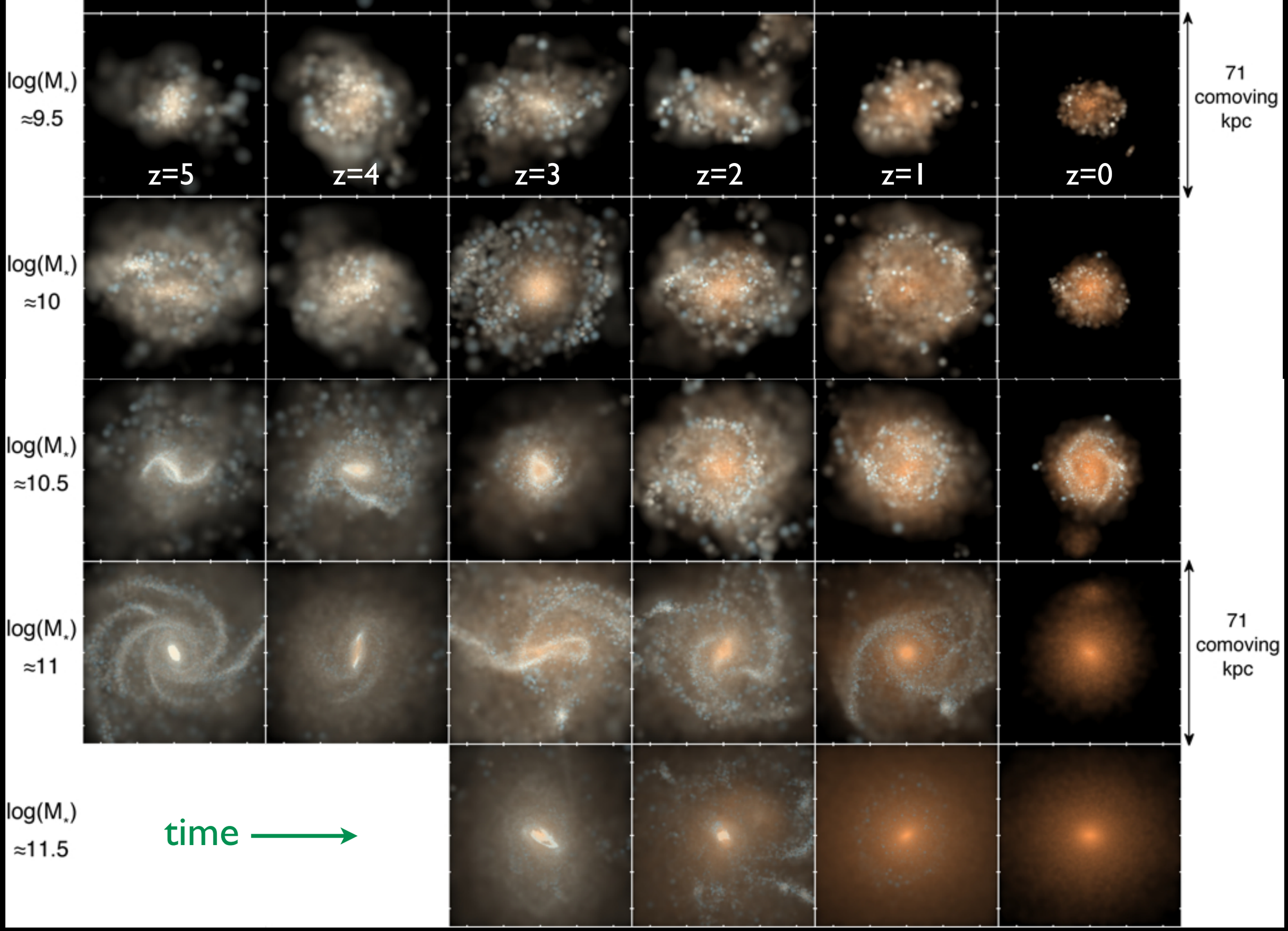
- Goal: simulate a galaxy population
- Volume: $(\sim 100\ \mathrm{Mpc})^3$
- Scales: ~ 1 ckpc
- Physics: sub-grid feedback from SNe and SMBHs
- ~10,000 galaxies, $M_* > 10^{9.5}\ M_{sun}$

Illustris Simulation Observatory

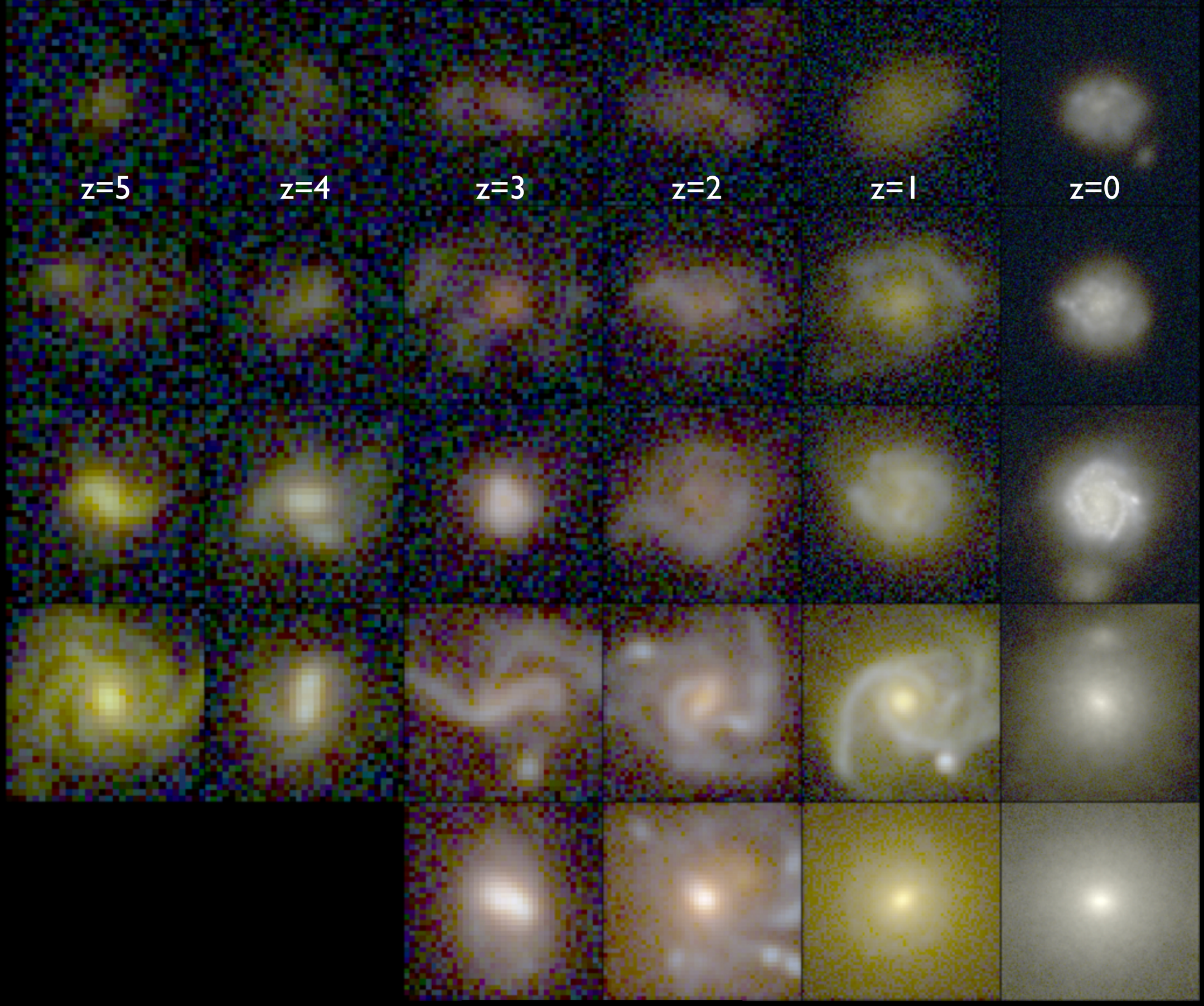
Torrey, GFS et al. (**submitted**) ; GFS et al. (in prep)



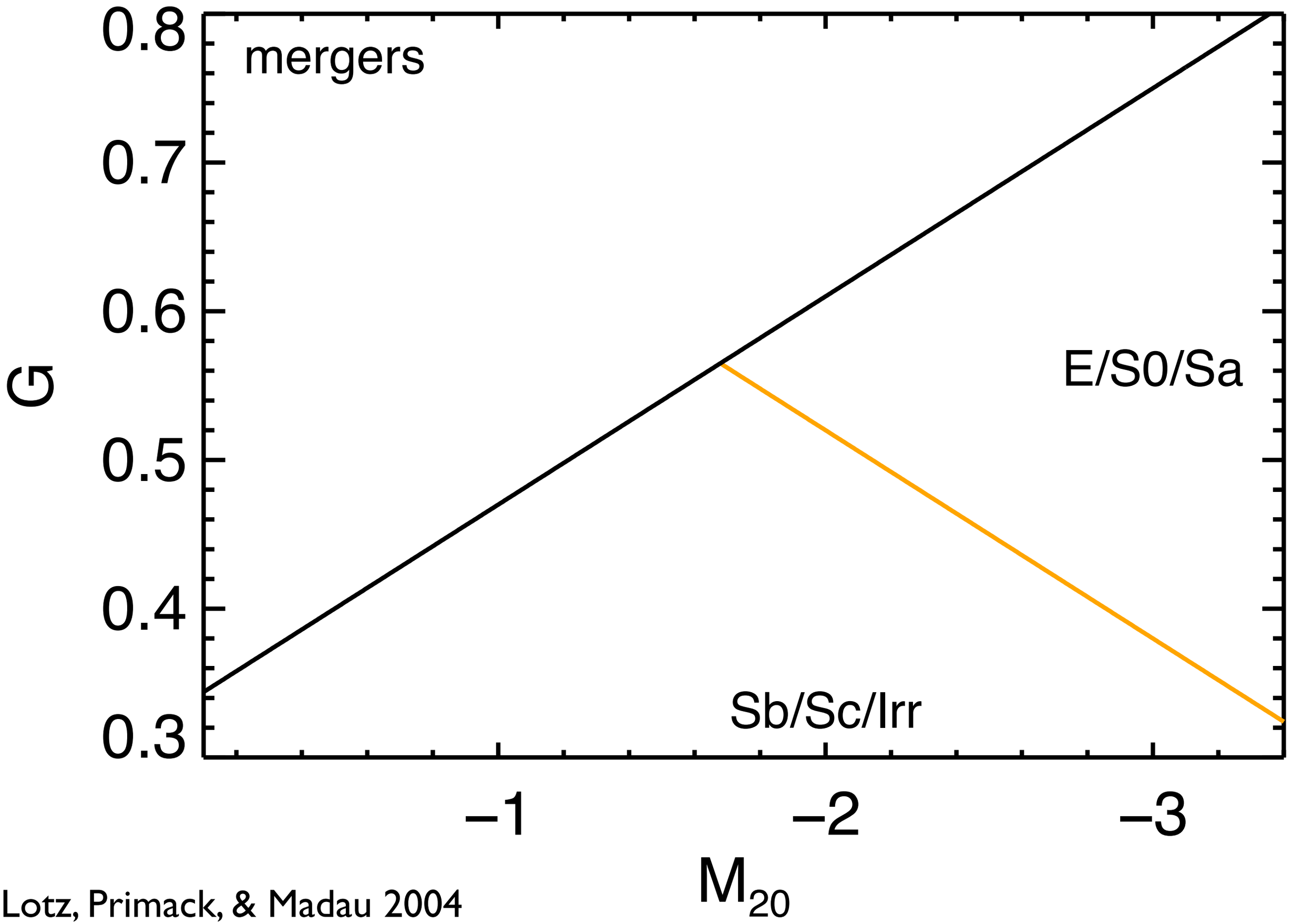
- ~100 timesteps
- ~10,000 objects of interest
  - ~4 viewing directions
  - ~25 filters
- ~100,000,000 synthetic images



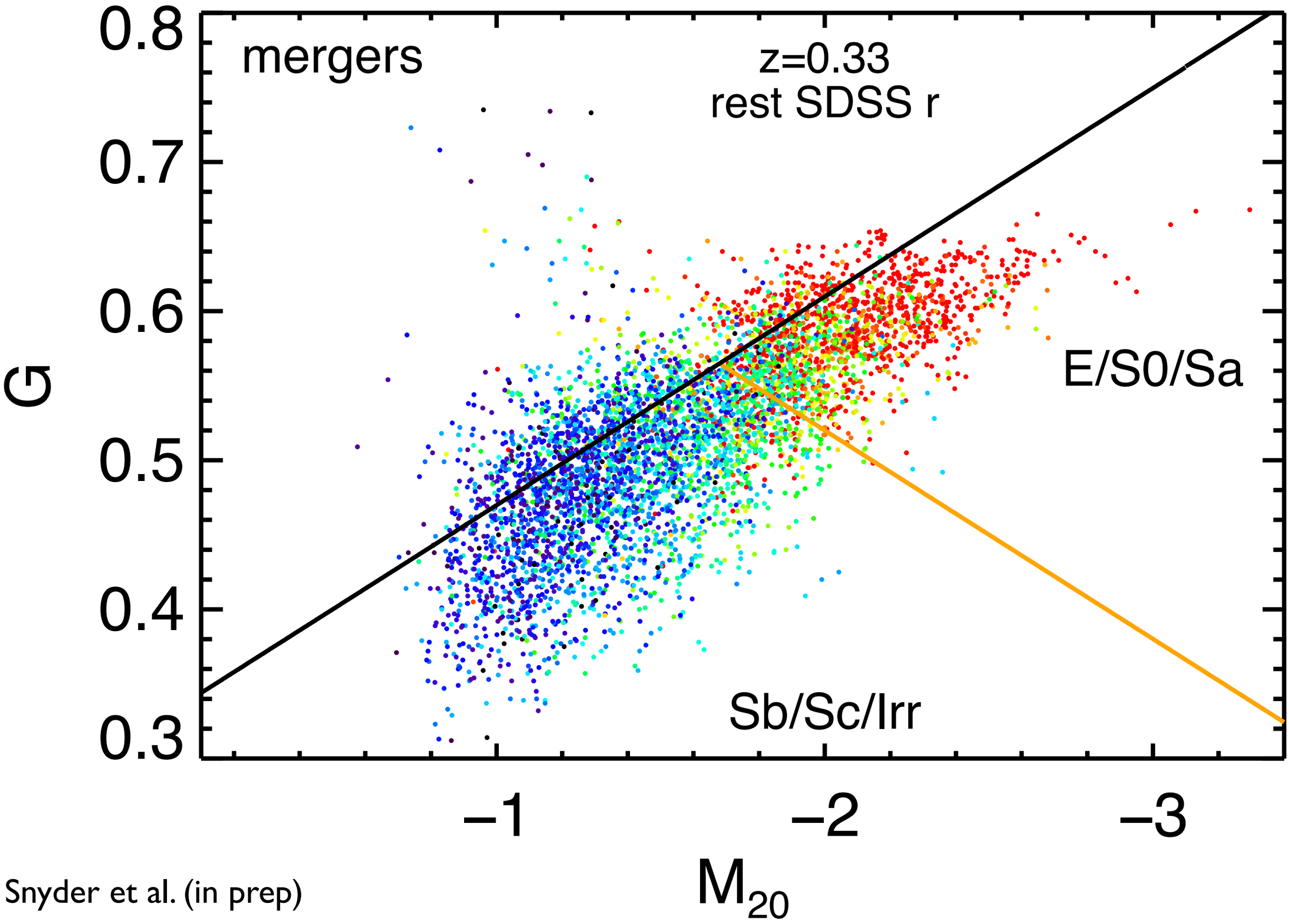
Genel et al. 2014



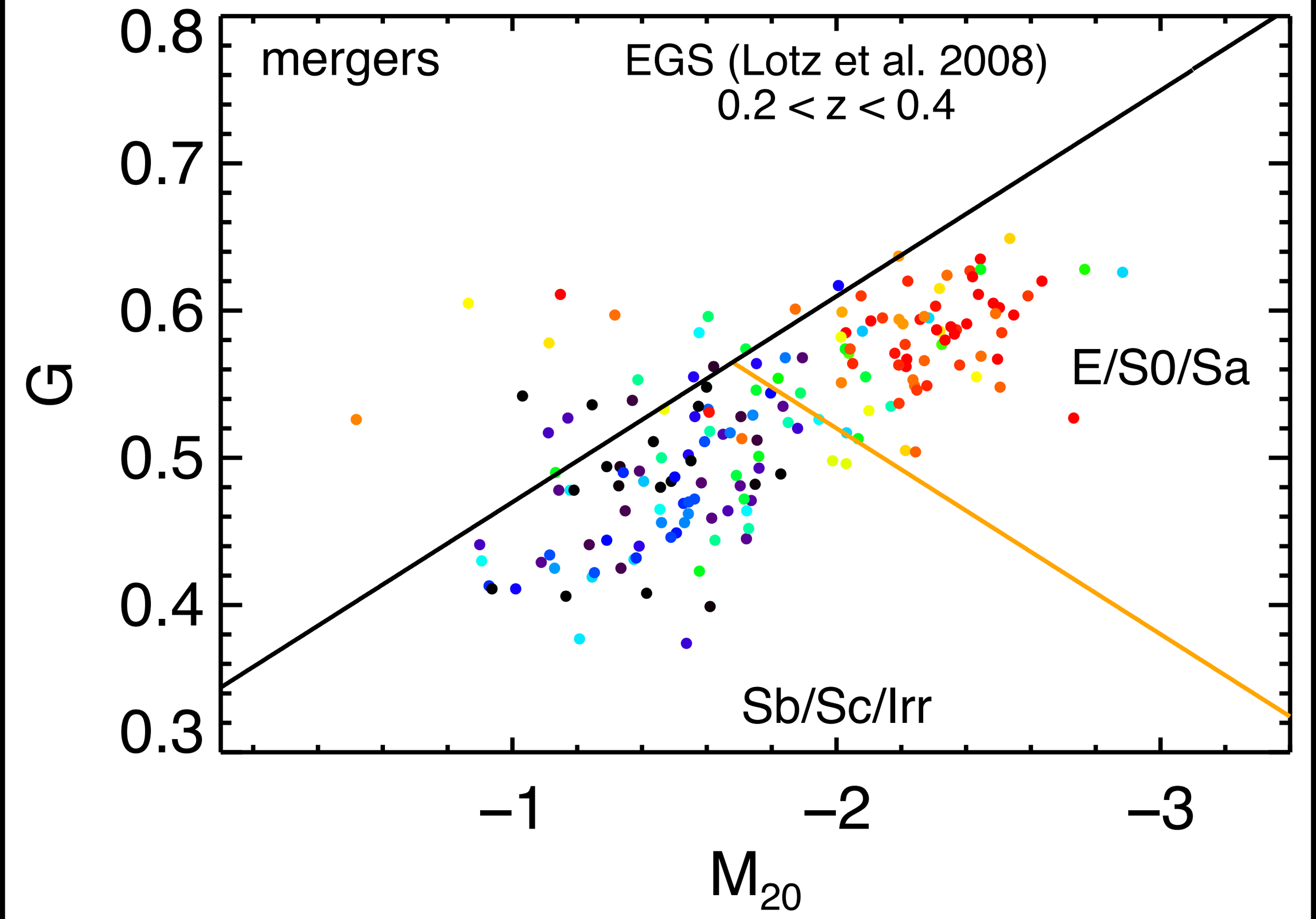
Genel et al. 2014

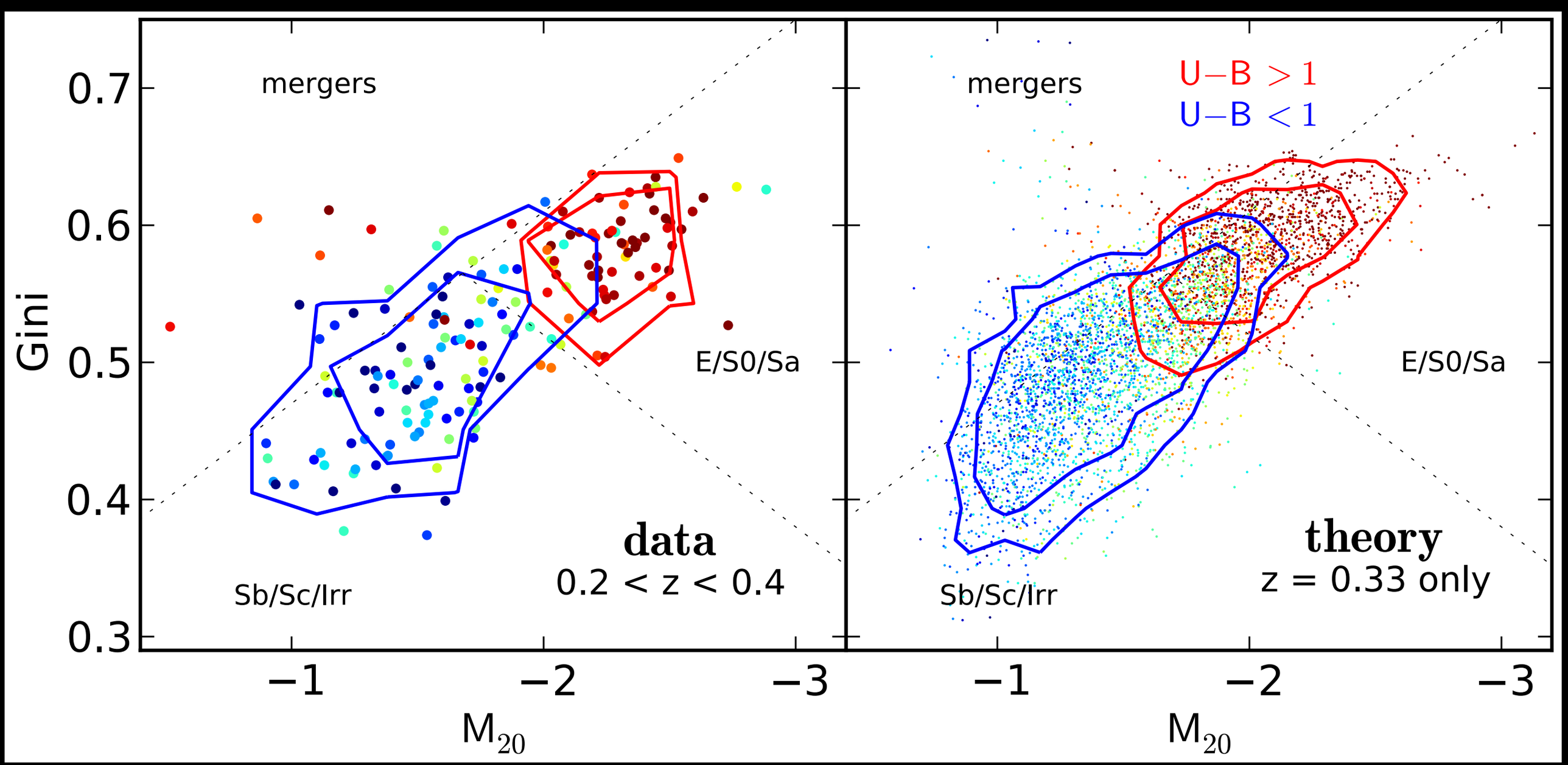


Lotz, Primack, & Madau 2004



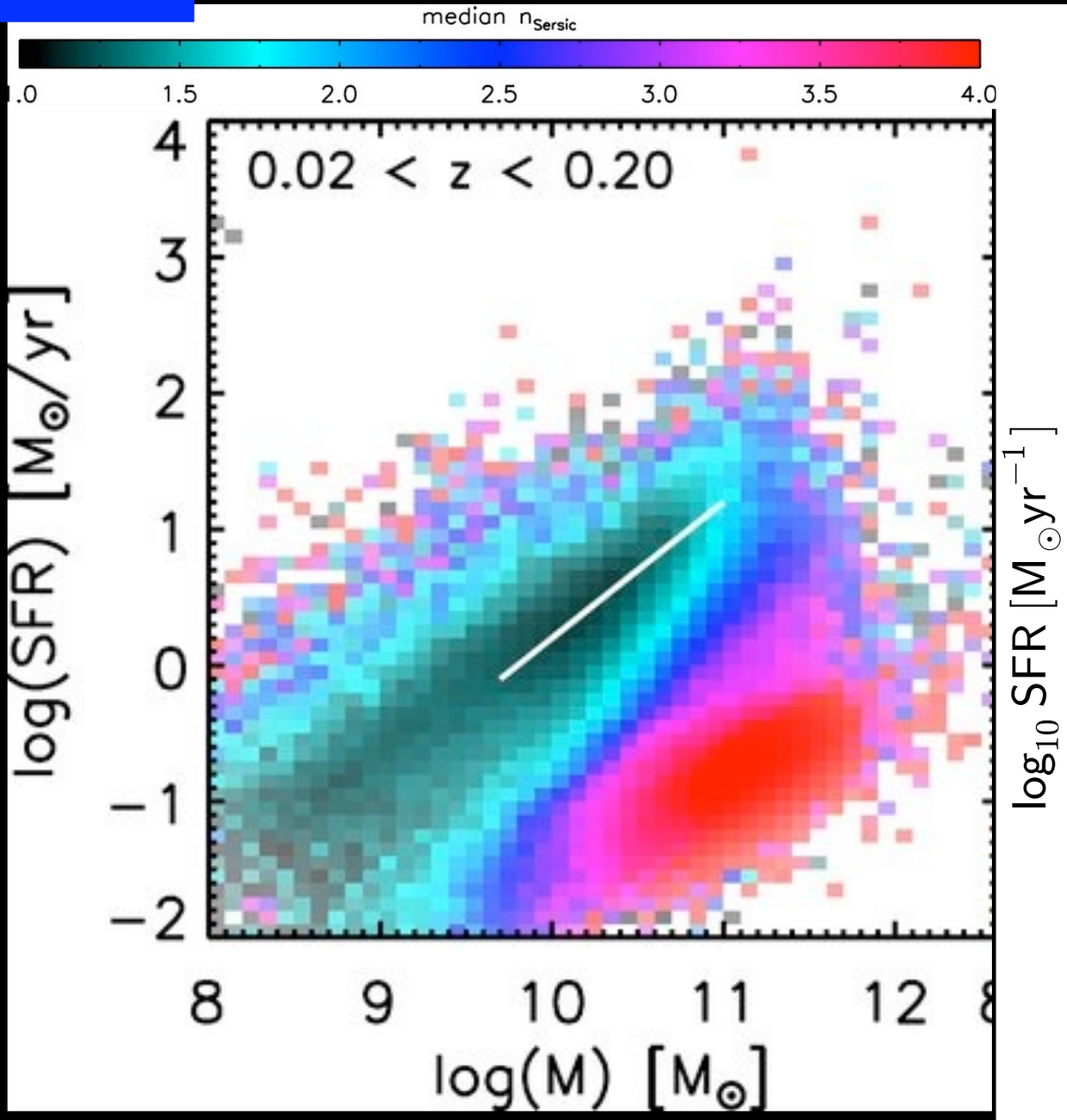
Snyder et al. (in prep)


mergers
EGS (Lotz et al. 2008)
0.2 < z < 0.4
E/S0/Sa
Sb/Sc/Irr
G
M20
0.8
0.7
0.6
0.5
0.4
0.3
−1
−2
−3



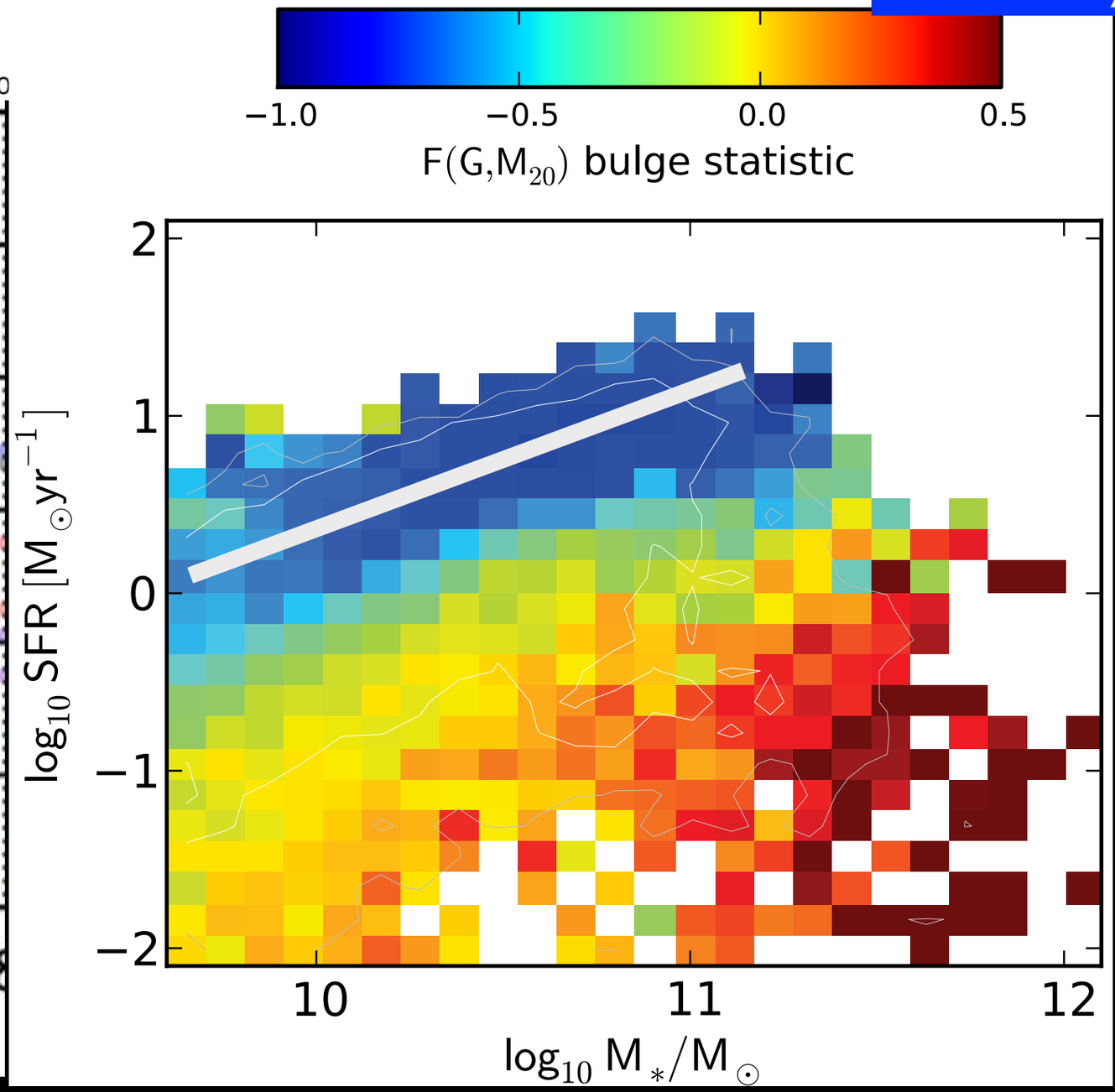
Snyder et al. (in prep.)

Data



Wuyts et al. 2011

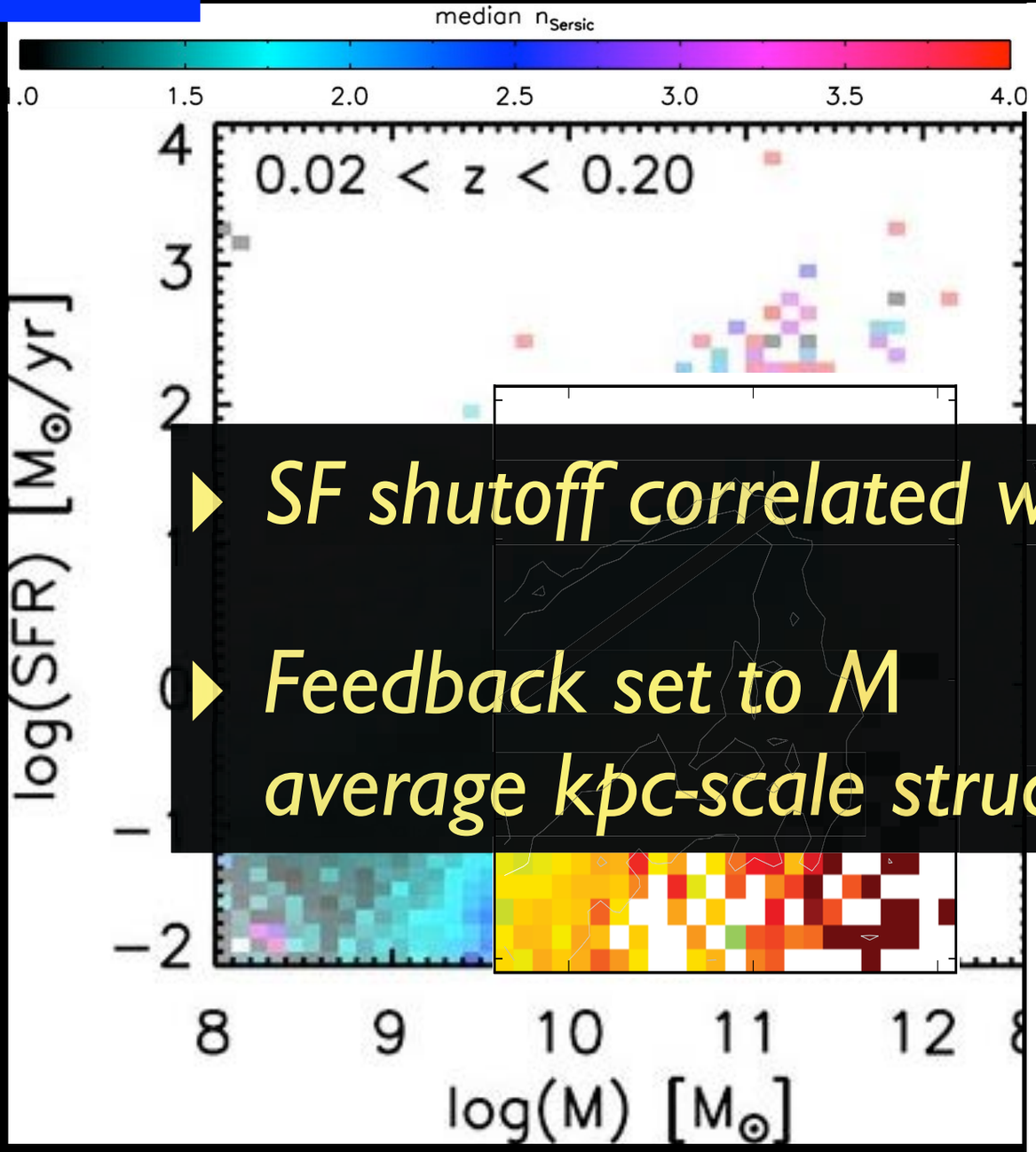
Theory



Snyder et al. (in prep.)

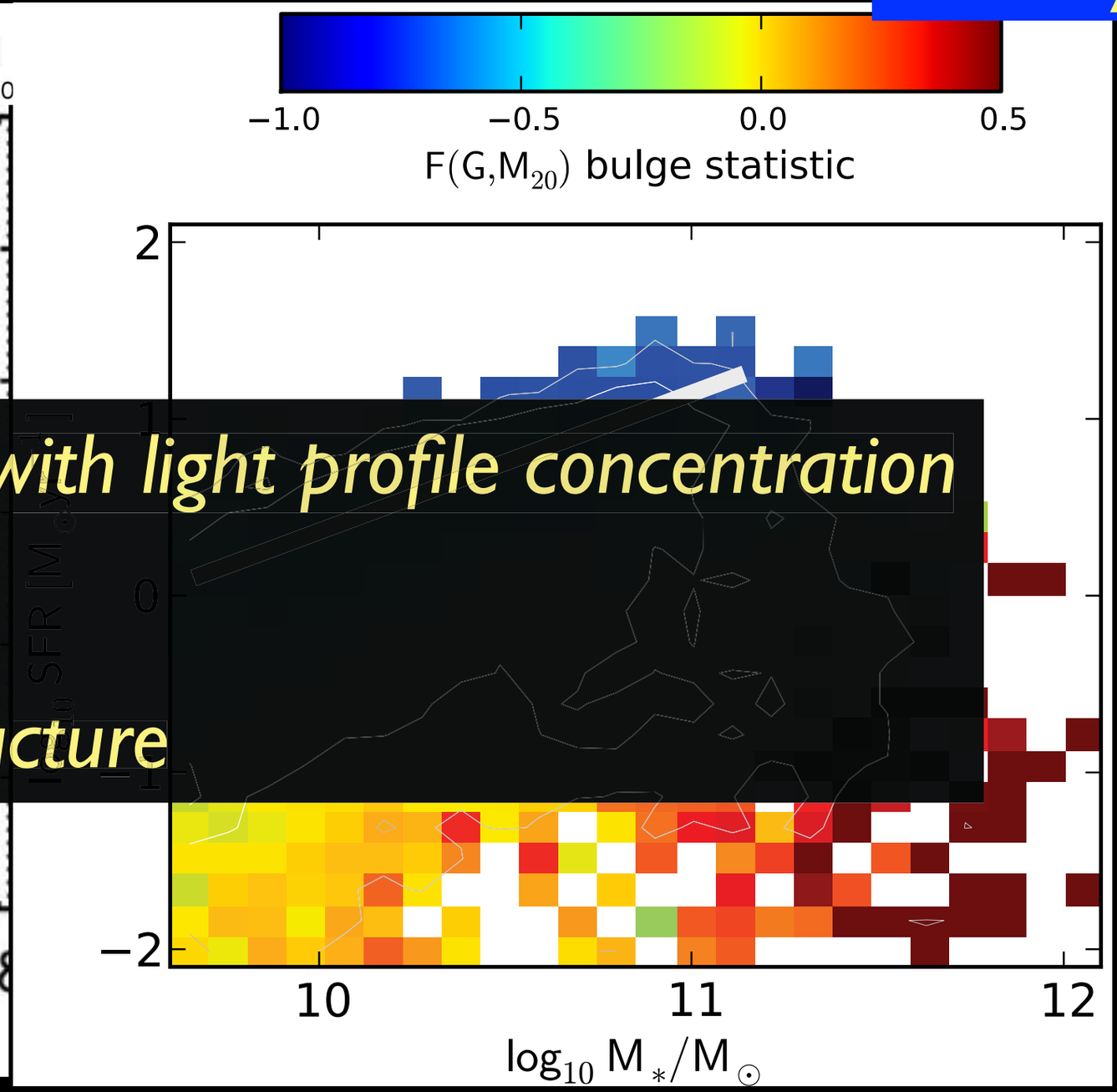
Data

Theory



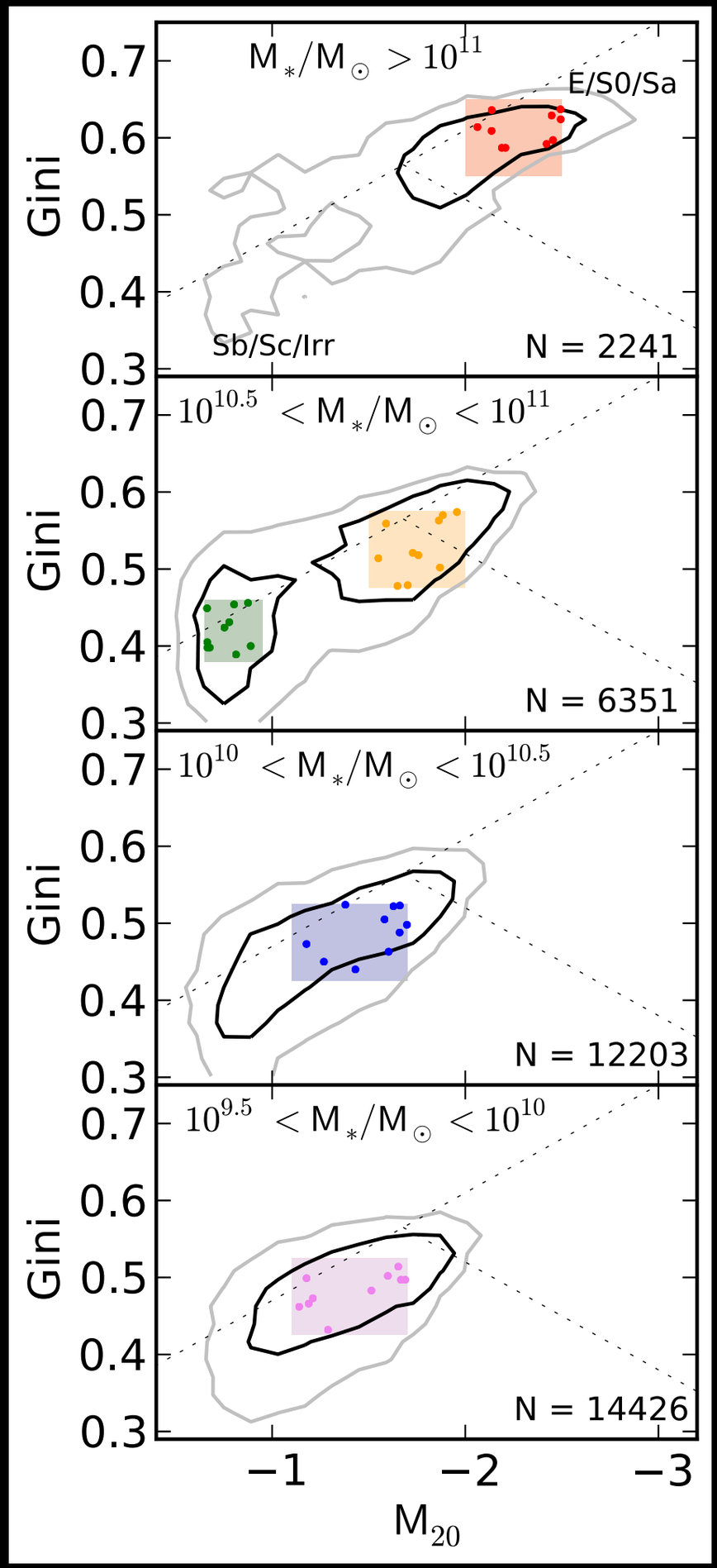
- *SF shutoff correlated with light profile concentration*
- *Feedback set to M average kpc-scale structure*

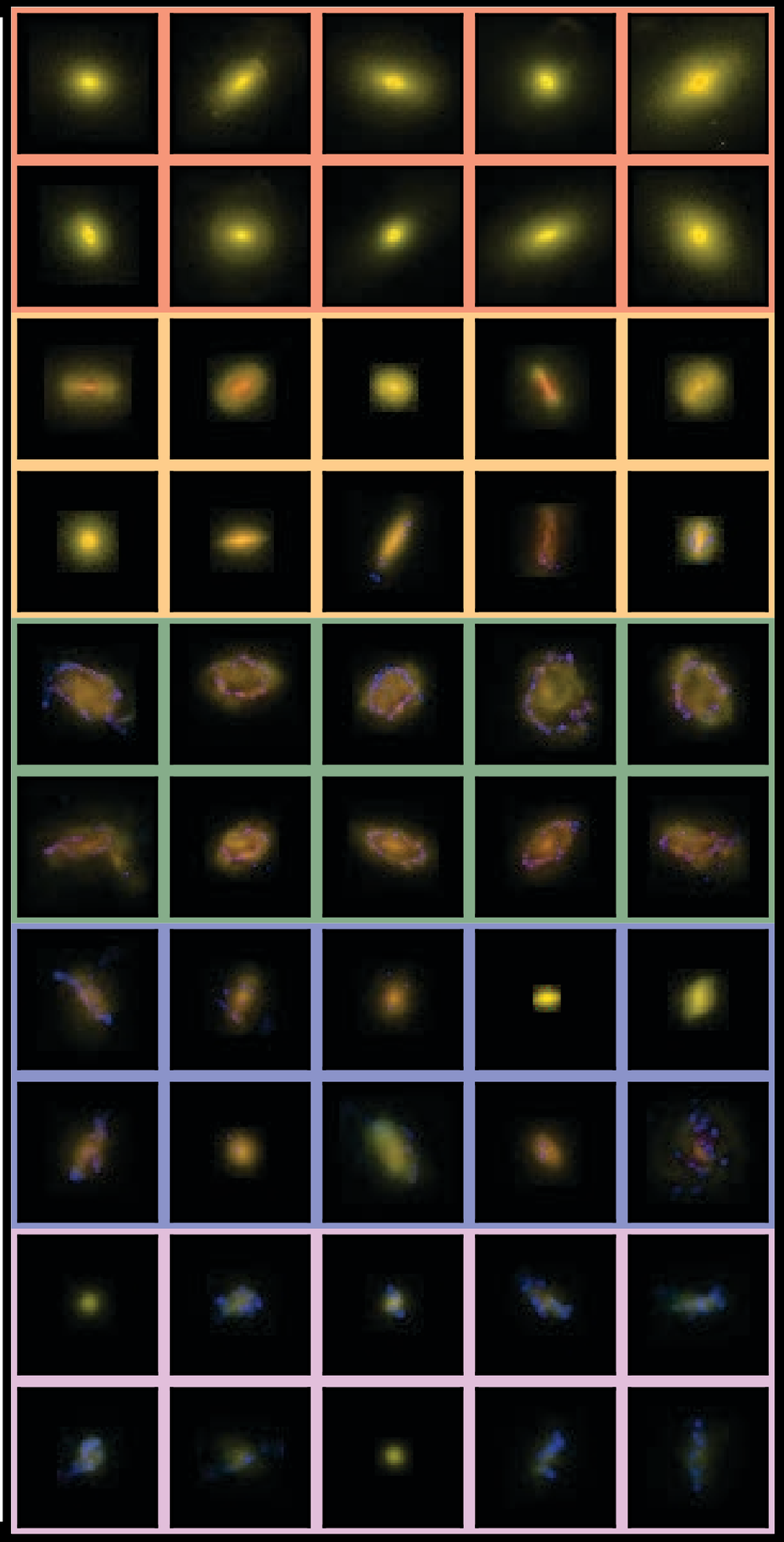
Wuyts et al. 2011



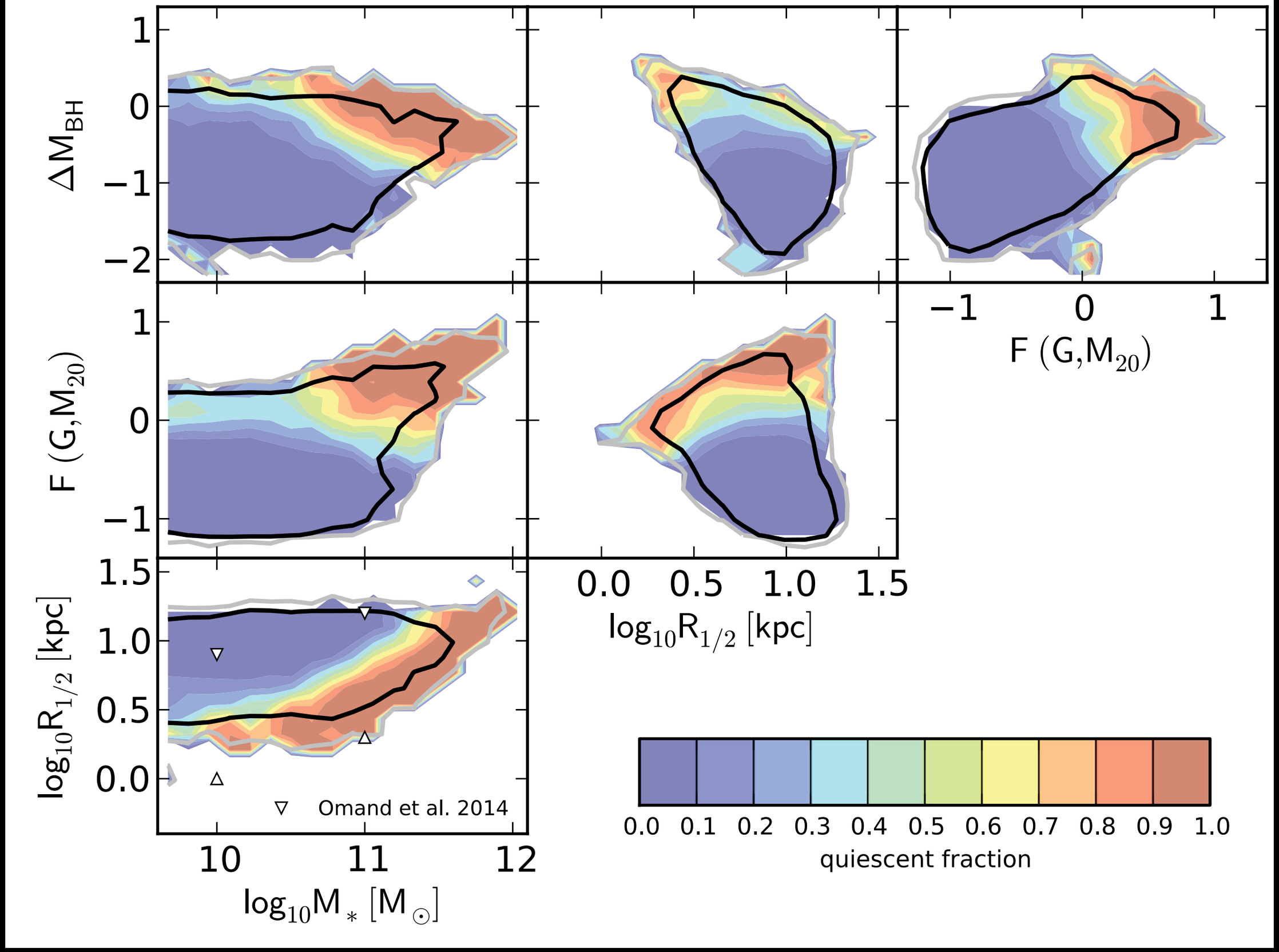
Snyder et al. (in prep.)

Physics model imprints a signature on quantitative structures.

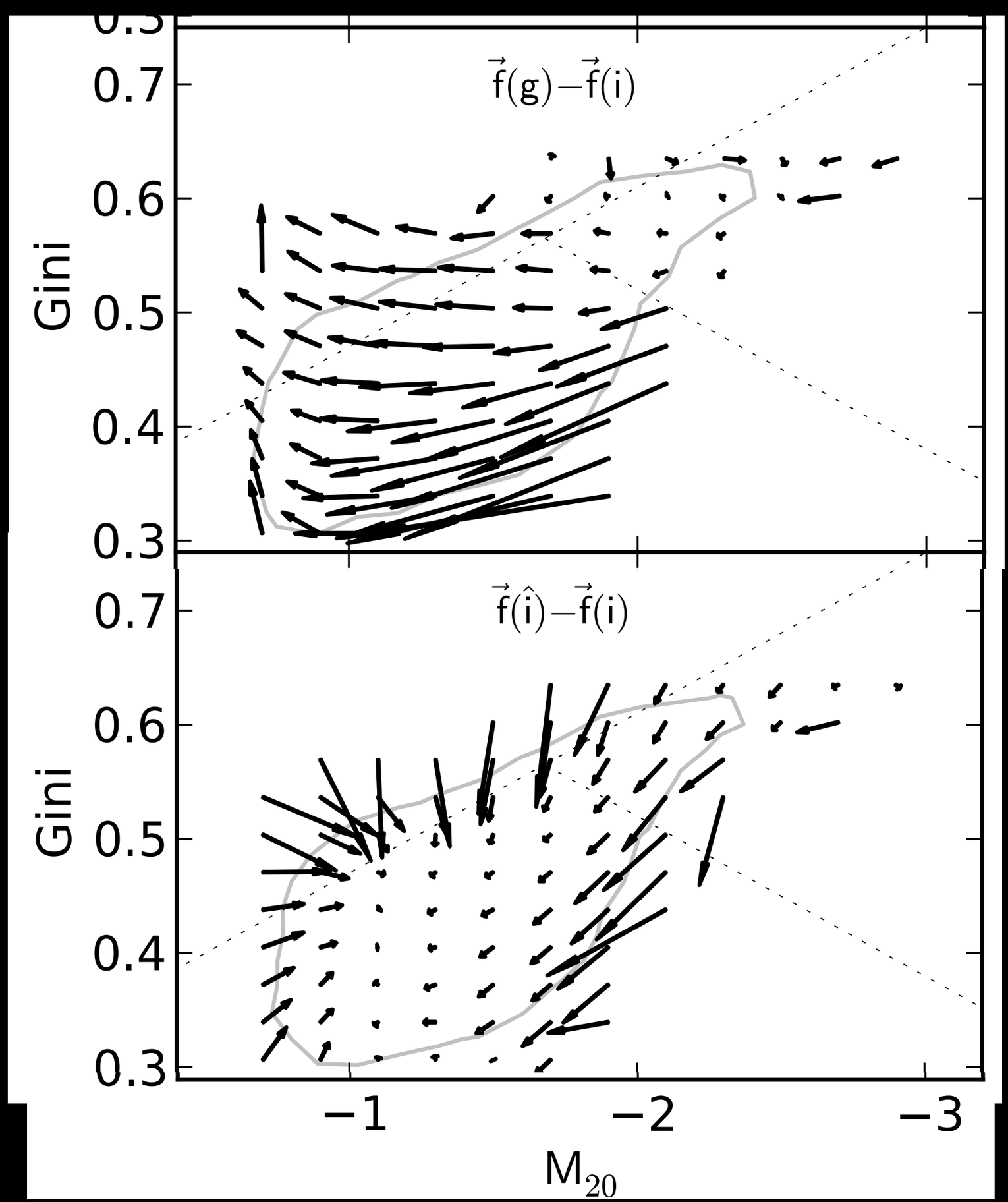




Snyder et al.
(in prep)



Snyder et al.
(in prep)



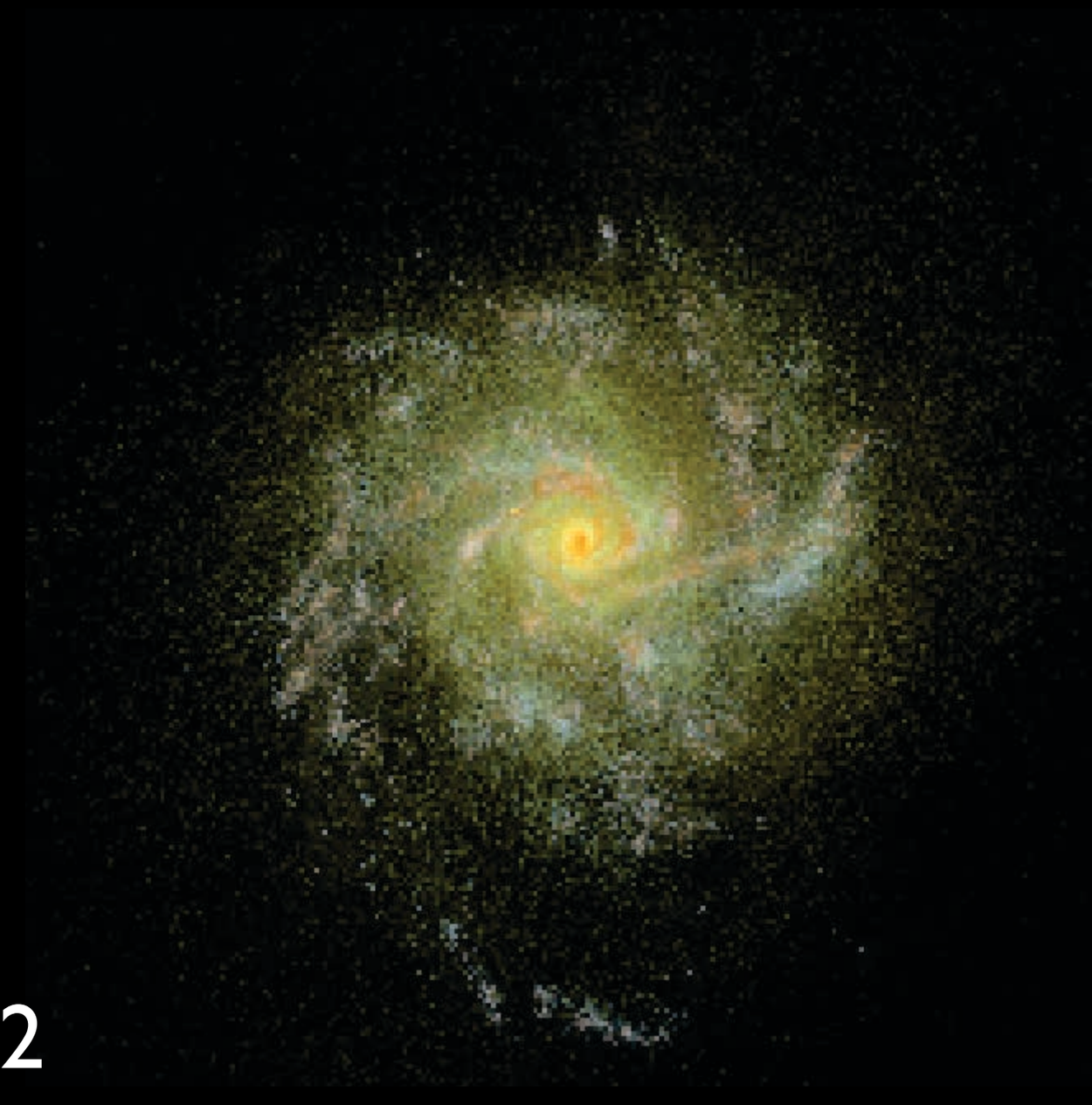
k-correction

dust

Snyder et al.
(in prep)

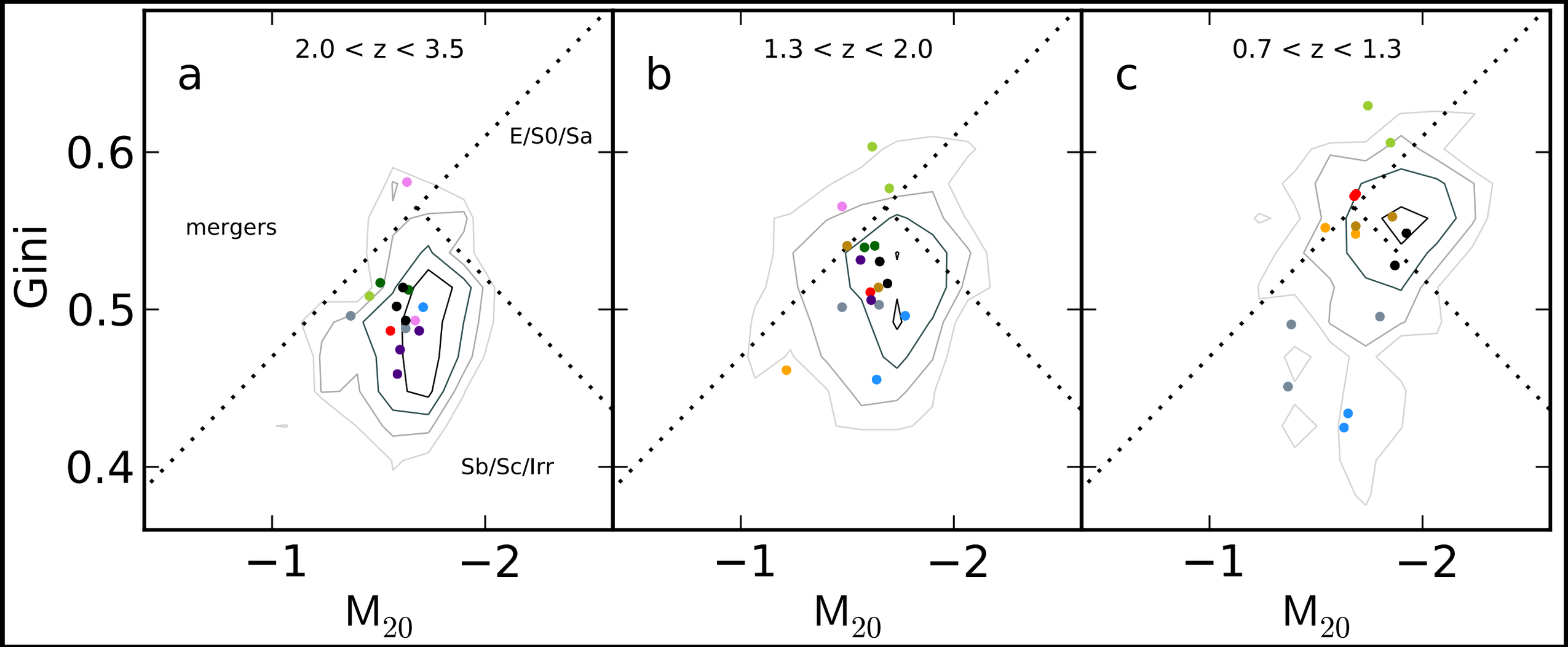
Zoom simulations

z~2



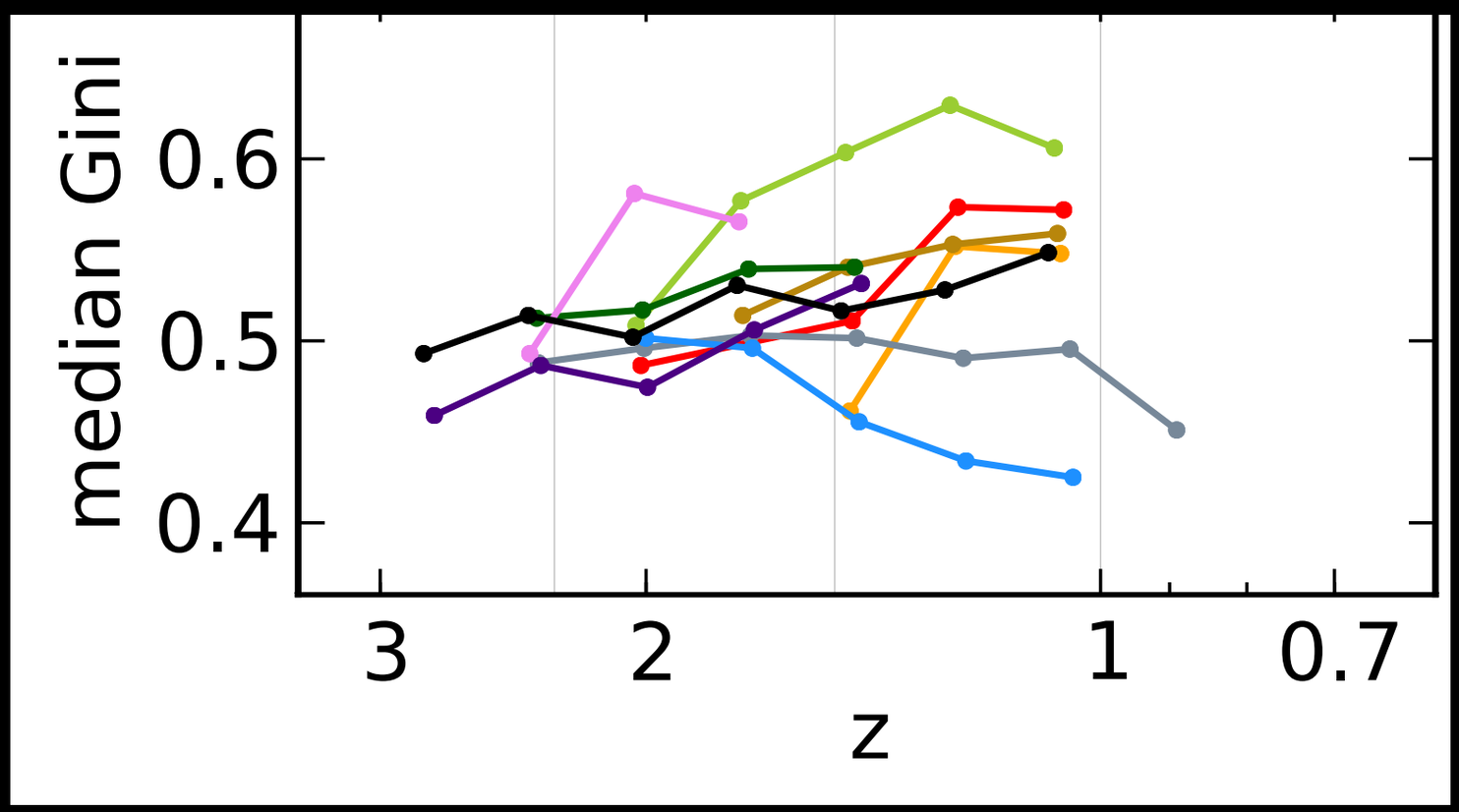
Joel Primack, Jen Lotz, Daniel Ceverino, Mike Peth, Chris Moody, Liz McGrath, Avishai Dekel, Peter Freeman

time ⟶

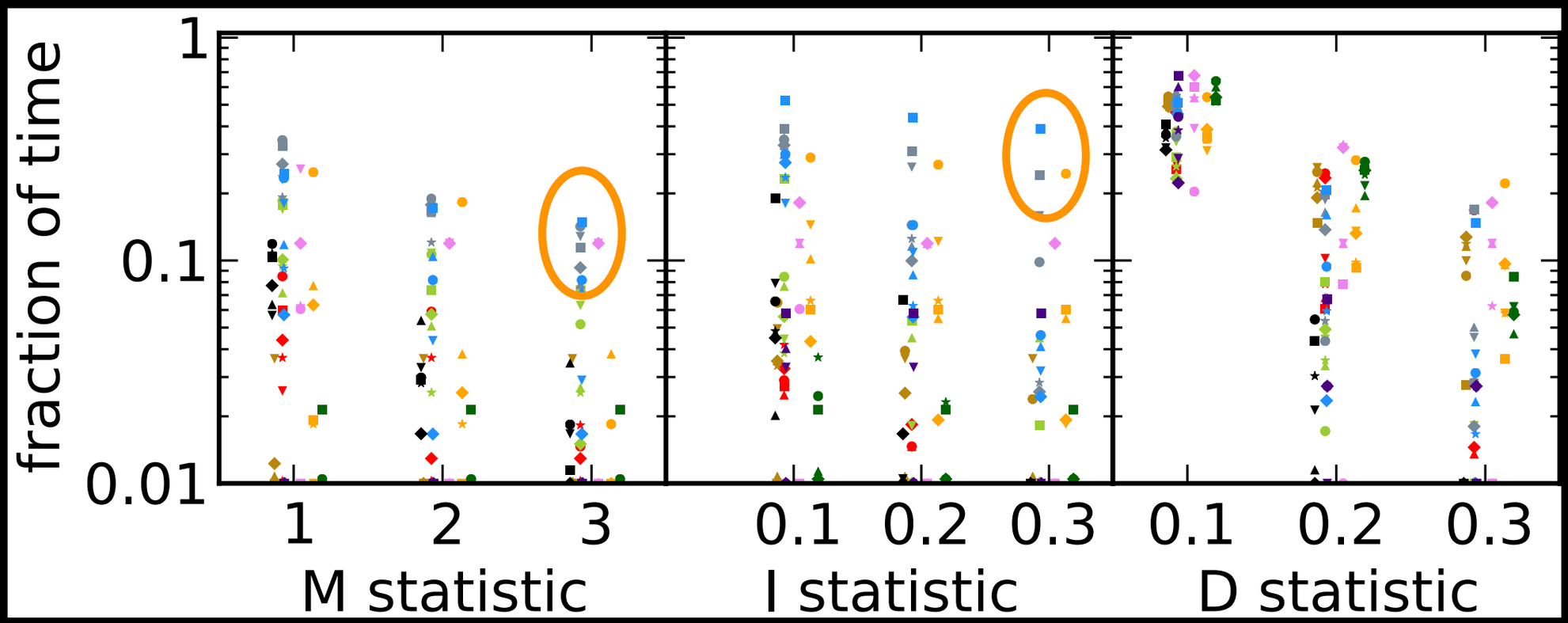


- Typically more bulge-dominated with time, but some outliers
- SF and mass correlated with structure in expected ways (not shown)

Snyder et al.
(in prep.)



Some outliers in structural evolution are *also* outliers in merger diagnostics



Snyder et al.
(in prep.)

time ⟶

5

4

3

2

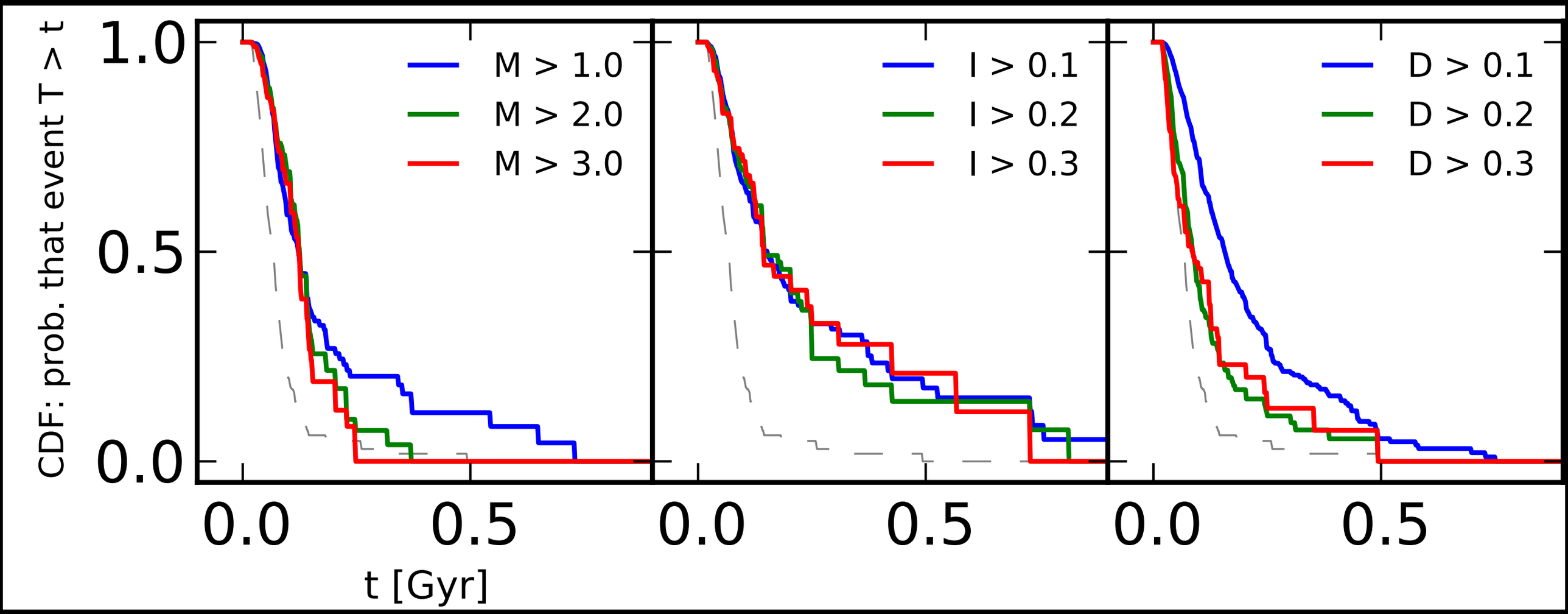
1

VELA15

merger-triggered disk growth

e.g., earlier talks

Snyder et al.
(in prep.)



In images, many merger-like “events” are short and noisy.

Snyder et al.
(in prep.)

Summary

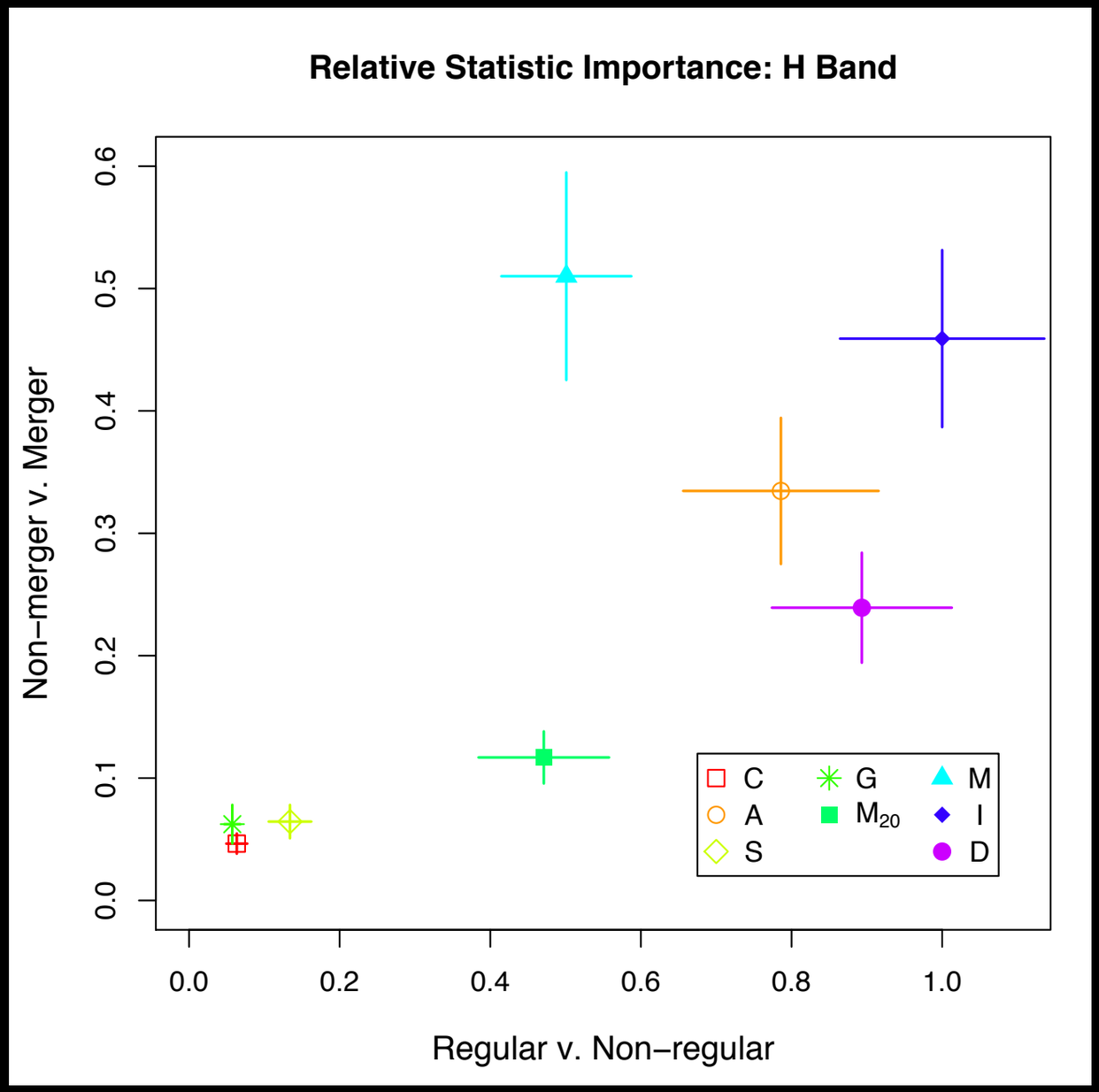
- Galaxy physics tuned to mass & SFR also reproduces coarse morphology, on average

- Actual paths taken are diverse at $z > 1$: interactions can trigger bulge or disk growth

- Merger diagnostics are triggered *briefly* by both minor mergers and clumpy star formation

What is the best diagnostic for X ?

- Often, X = *empirical*
- Hydro sims + synthetic data, X → *explicit*



e.g., Freeman et al. 2013

Zoom simulations

z~2

Joel Primack, Jen Lotz, Daniel Ceverino, Mike Peth,
Chris Moody, Avishai Dekel, Peter Freeman

Zoom simulations

z~2

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i z J

z J H

z= 1.0

z= 1.1

z= 1.2

z= 1.3

z= 1.4

z= 1.5

z= 1.5

z= 1.7

z= 1.7

z= 1.8

z= 1.9

z= 1.8

z= 2.0

z= 2.1

z= 2.0

z= 2.3

z= 2.3

z= 2.2

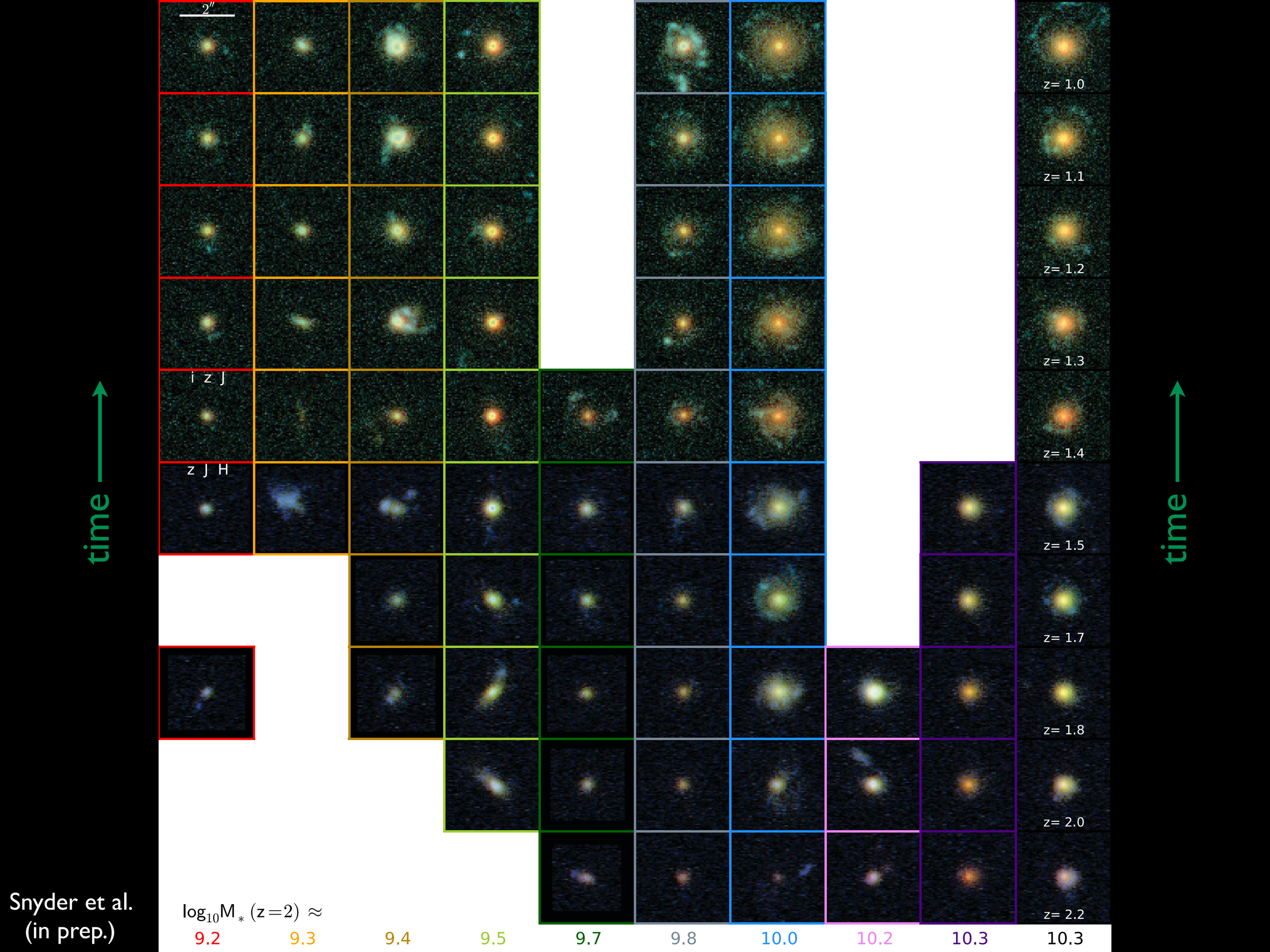
time

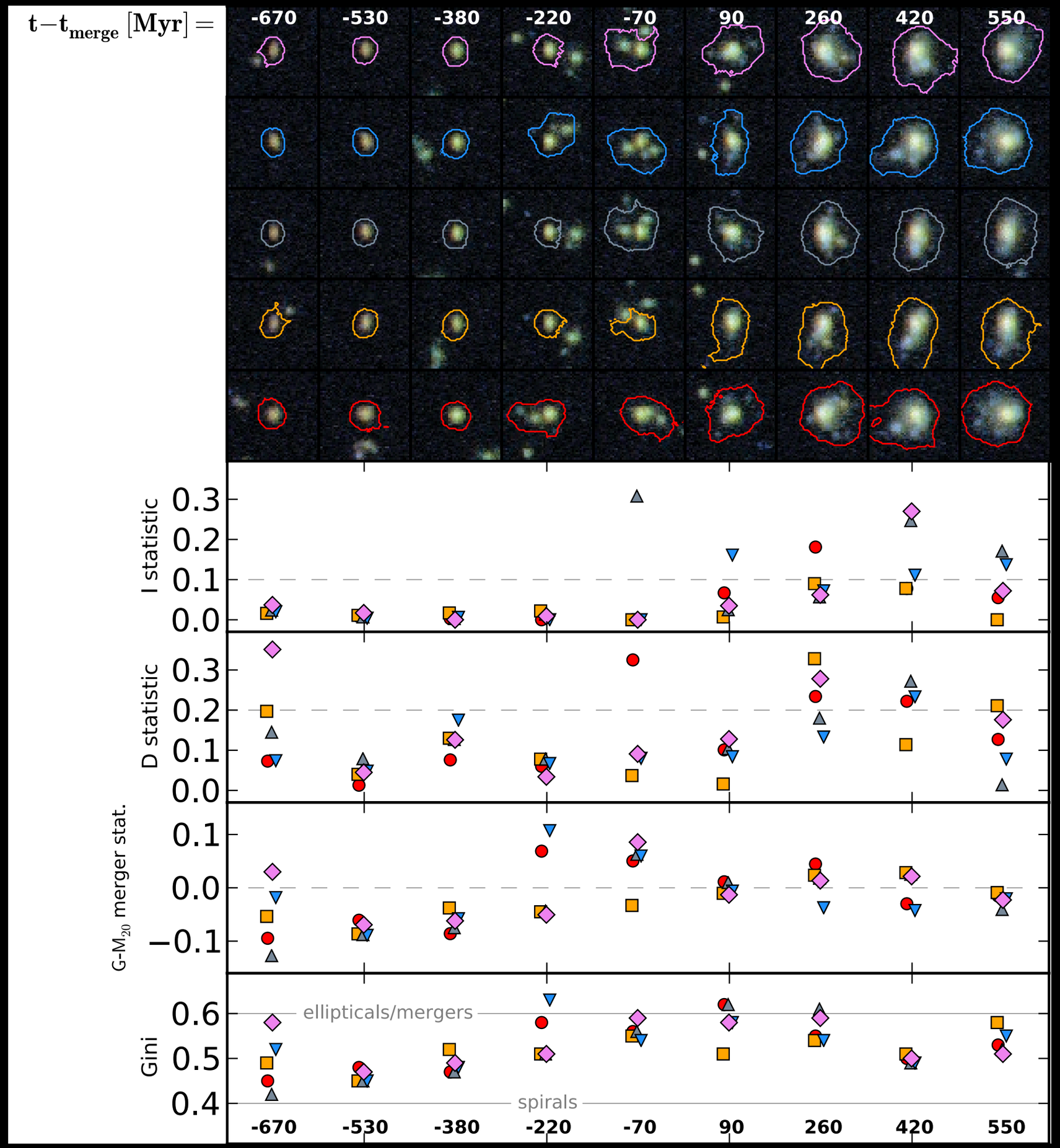
time

Snyder et al.
(in prep.)

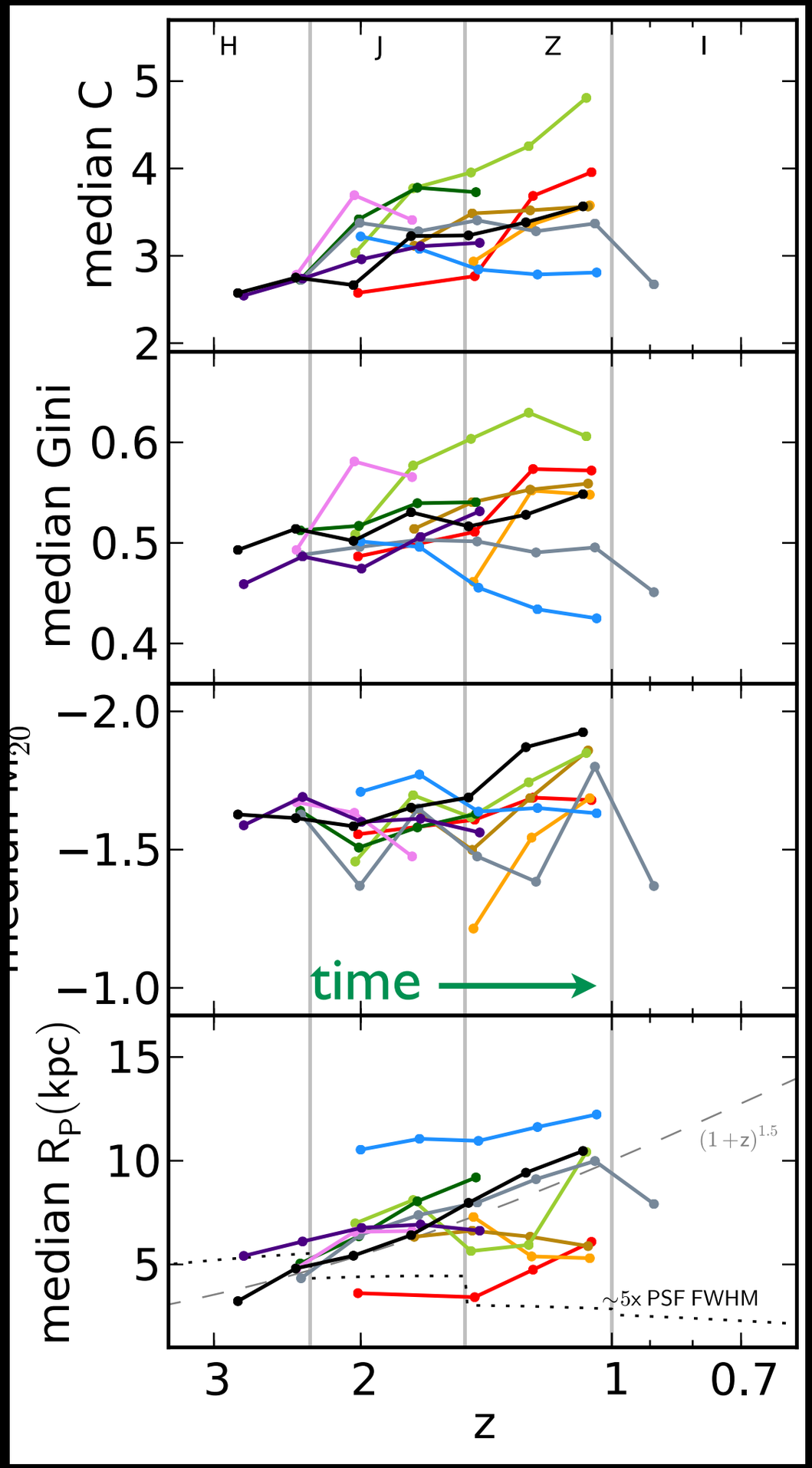
$\log_{10} M_* \, (z=2) \approx$

9.2	9.3	9.4	9.5	9.7	9.8	10.0	10.2	10.3	10.3

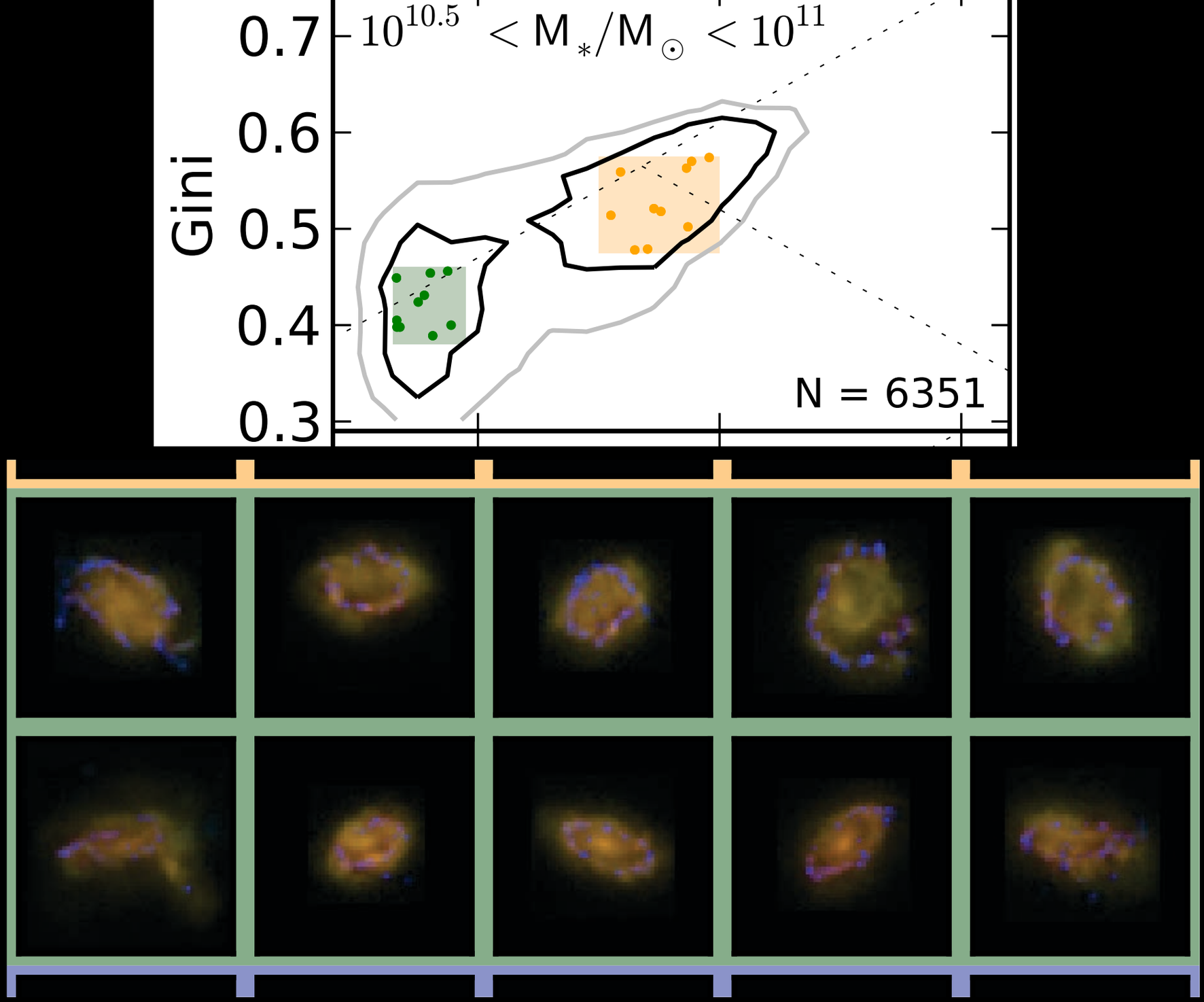

2″
i z J
z J H
z= 1.0
z= 1.1
z= 1.2
z= 1.3
z= 1.4
z= 1.5
z= 1.7
z= 1.8
z= 2.0
z= 2.2
time →
time →
log10M* (z=2) ≈
9.2
9.3
9.4
9.5
9.7
9.8
10.0
10.2
10.3
10.3
Snyder et al.
(in prep.)



Snyder et al.
(in prep.)



Snyder et al.
(in prep.)

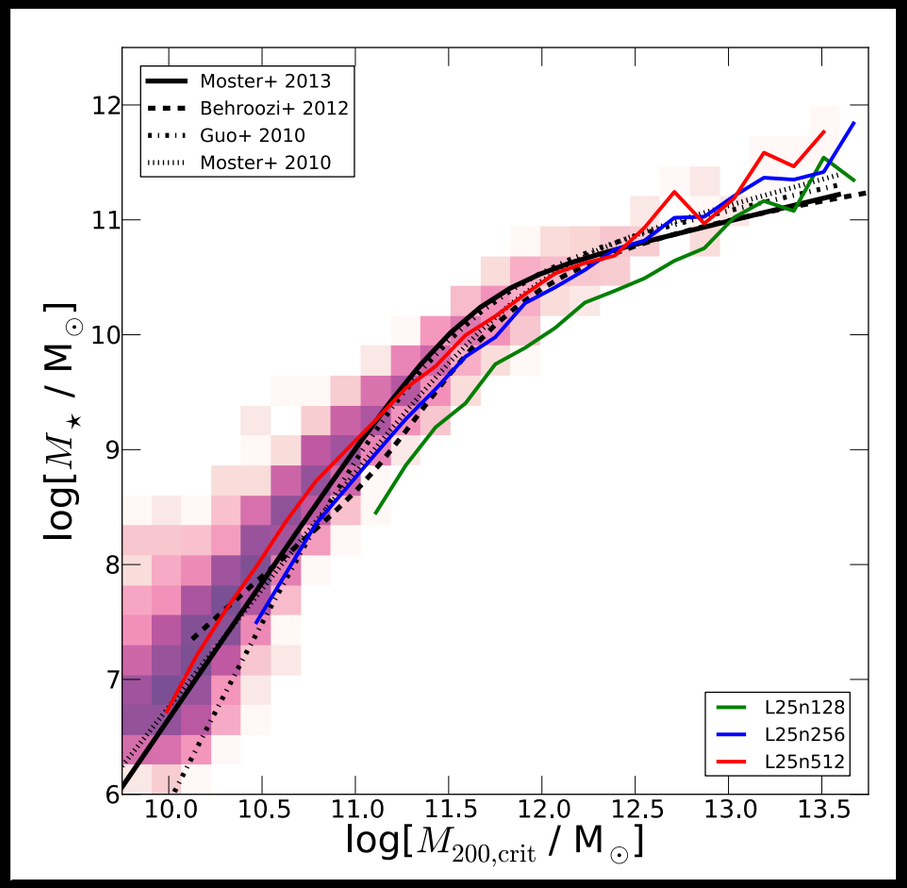


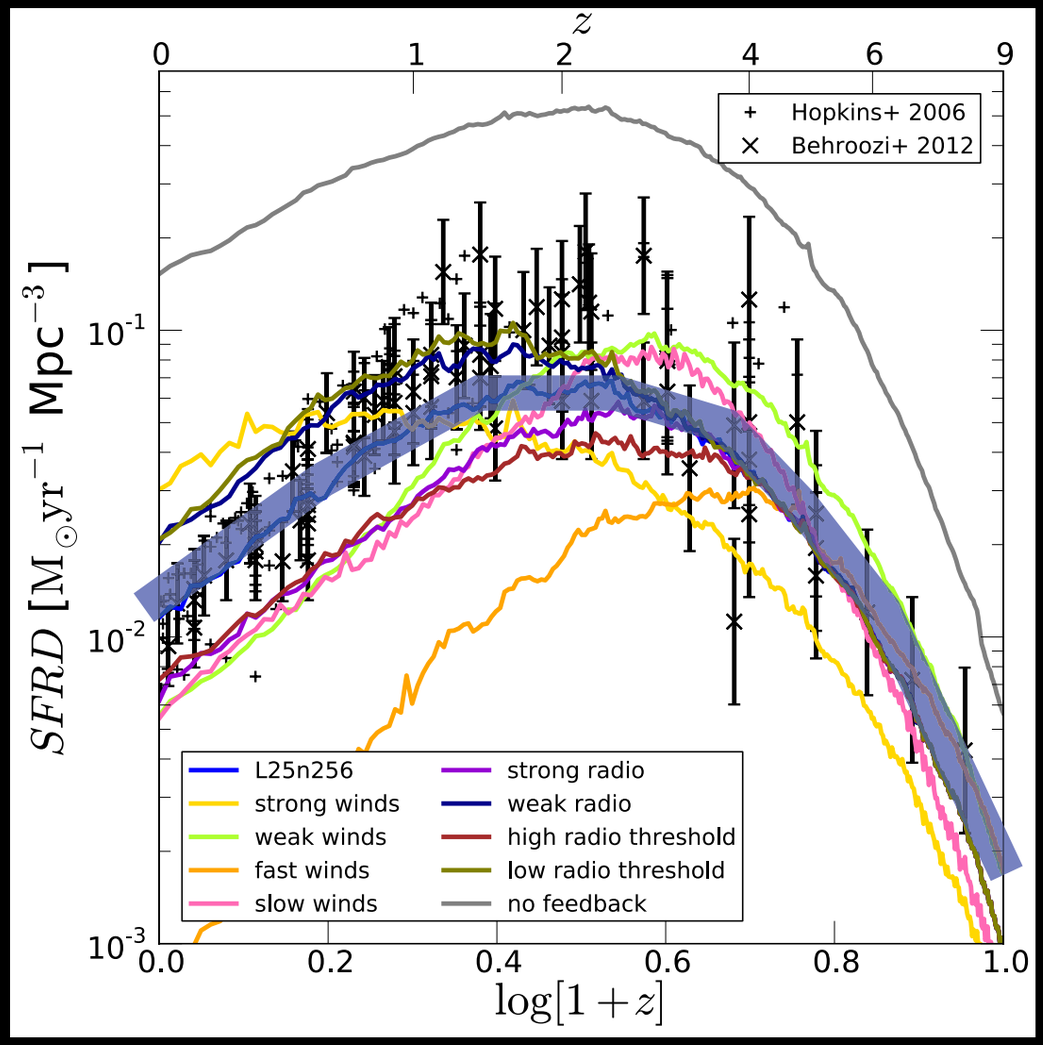
Galaxy physics model imprints a signature on quantitative structures.

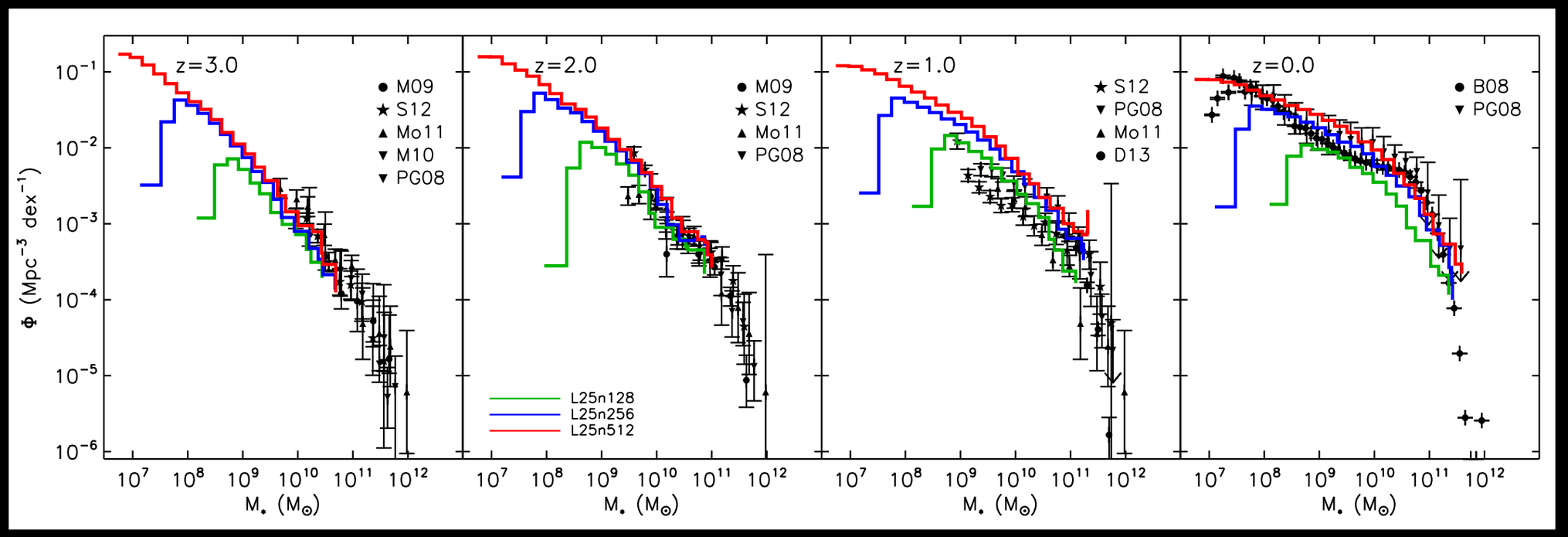
Snyder et al.
(in prep)

Physics and first results: approaching realistic populations

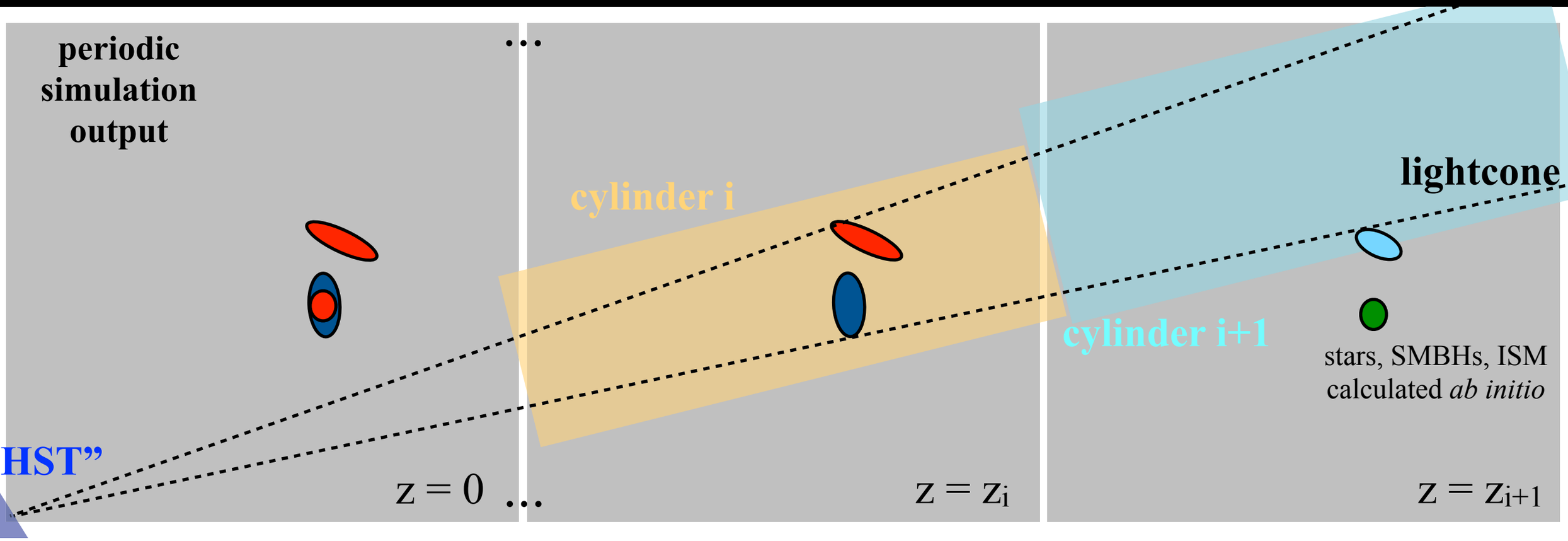
Vogelsberger et al. 2013 ; Torrey et al. 2013 ;
1/30 volume tests







“Hydro Mock Observatory”



following Kitzbichler & White ’07, Overzier ’13, etc

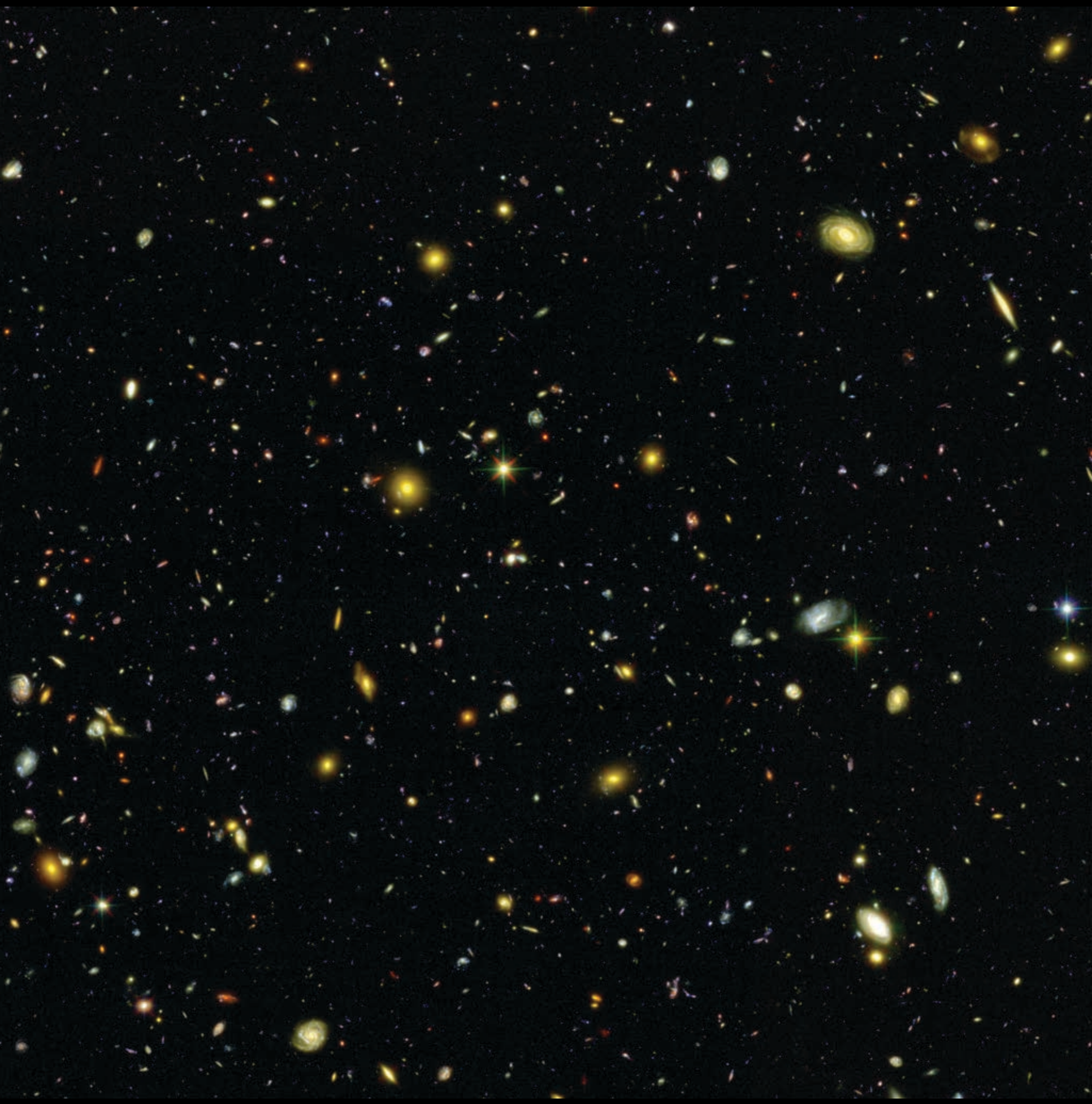
Snyder et al. (in prep)

Vogelsberger et al. (incl. GFS, 2014)

Illustris Simulation

F435W F850LP F160W

XDF (Illingworth+ ’13)

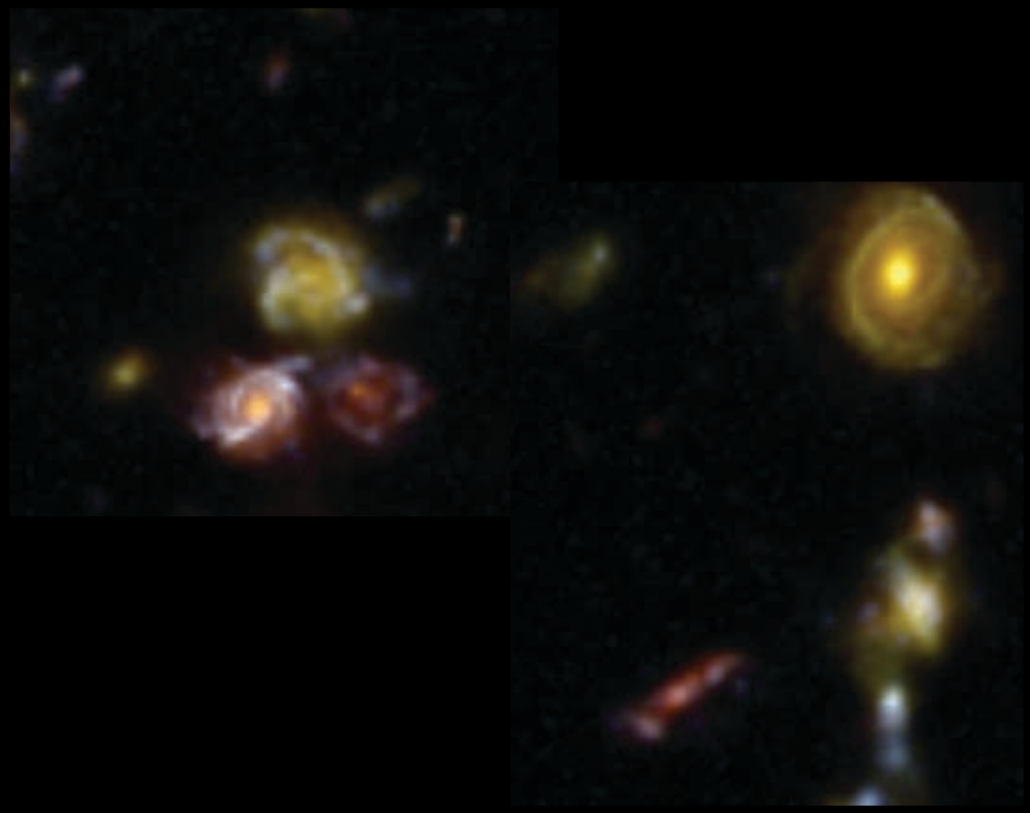


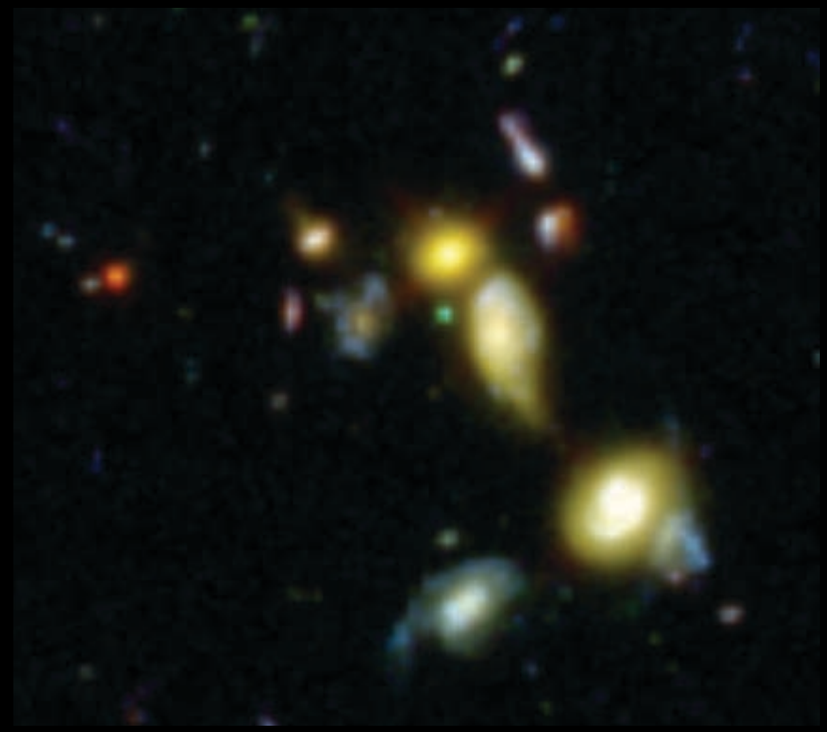
F435W F850LP F160W

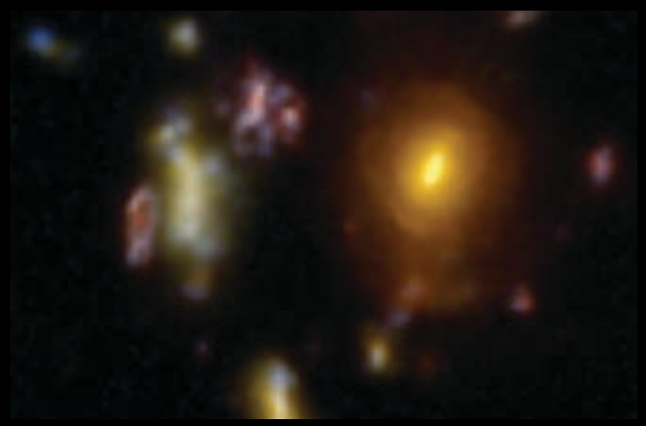
Theory

Data

Vogelsberger et al. (incl. GFS, 2014)





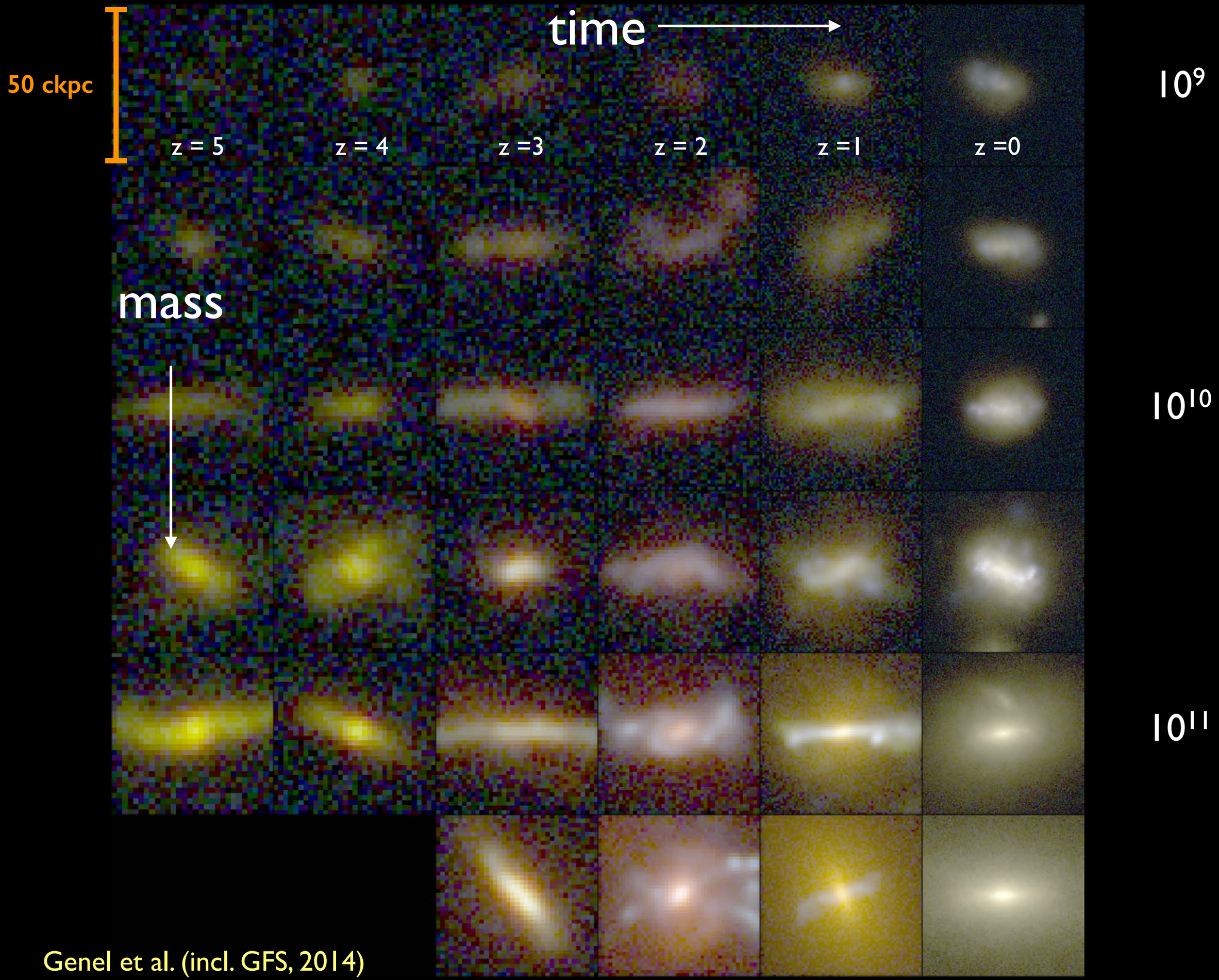


Theory

Data

Snyder et al. (in prep)

Vogelsberger et al. (incl. GFS, 2014)



Genel et al. (incl. GFS, 2014)

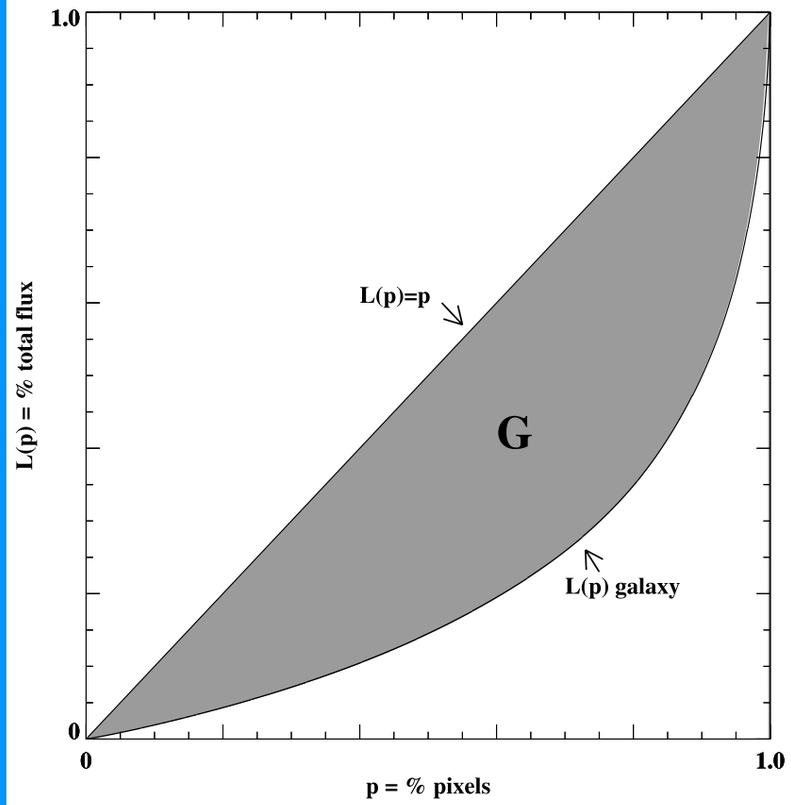


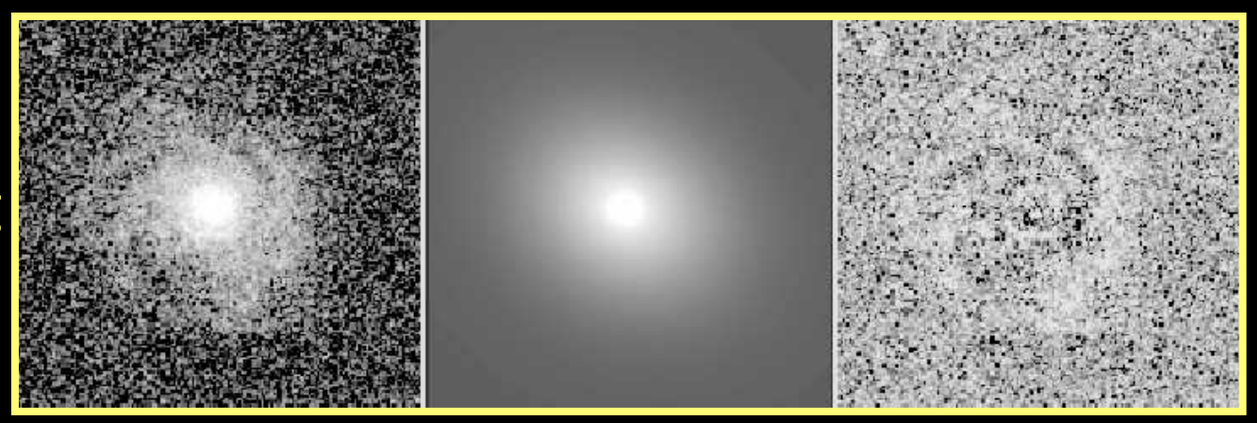
FIG. 1.—Lorenz curve: the Gini coefficient is the area between the Lorenz curve of the galaxy's pixels and that of equitable distribution (*shaded region*). The given curve is for S0 NGC 4526, $G = 0.59$.

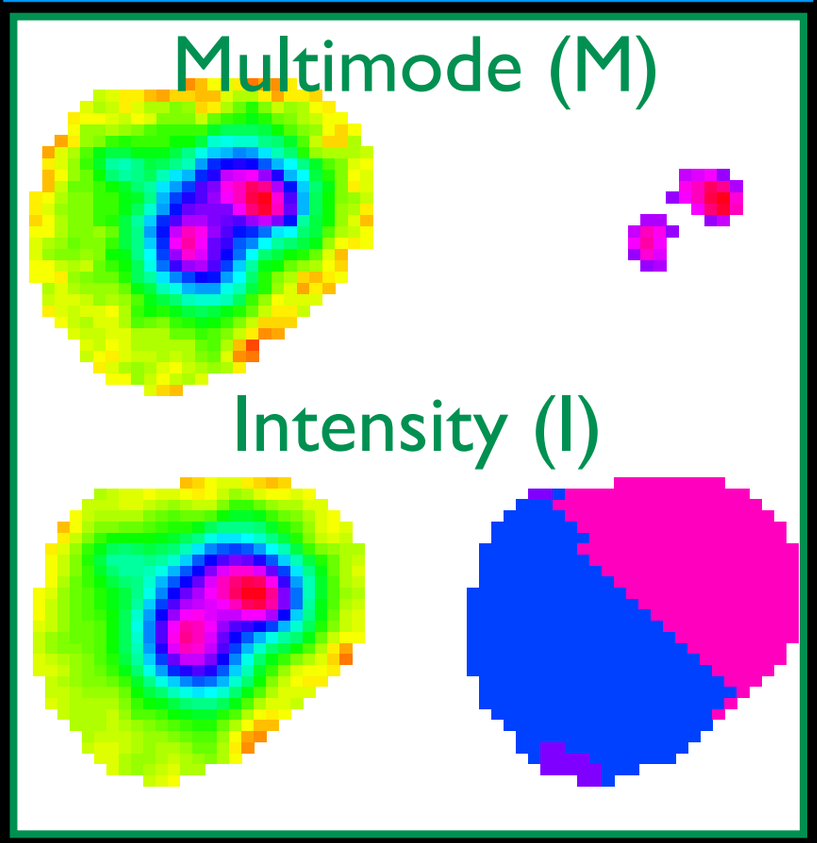
e.g., Lotz, Primack & Madau 2004, Conselice 2003, etc

$$M_{20} \equiv \log10\left(\frac{\sum_i M_i}{M_{\rm tot}}\right), \text{ while } \sum_i f_i < 0.2 f_{\rm tot}. \qquad (8)$$

Automated Methods

model fitting
(e.g., GalFit)

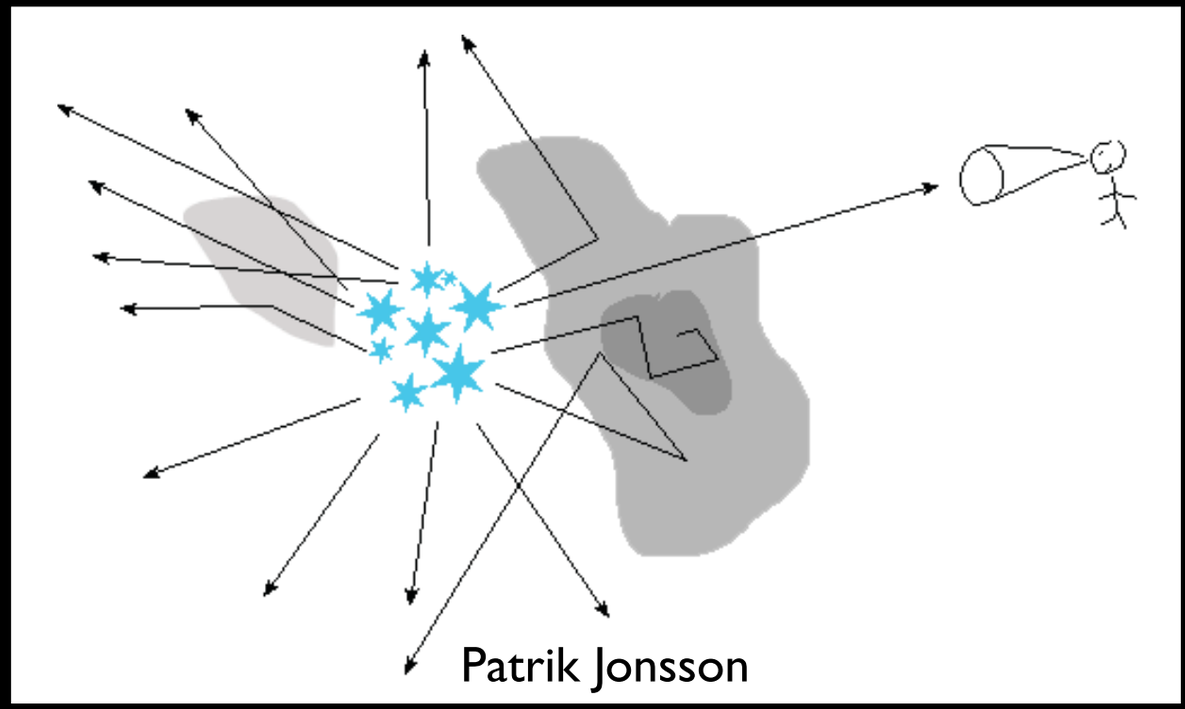




e.g., Freeman et al. 2013

Modeling Tools

isolated or merging galaxies, e.g., Jonsson '06, Lotz+ '08, Younger+ '09, Wuyts+ '10, Bush+ '10, Narayanan+ '10, Jonsson+ '10, Hayward+ '11,12ab, Snyder+ '11, Snyder+ '13



- [e.g.,] Gadget (Springel 05)
  - SPH+N-body simulations
  - ISM model with star formation, SN feedback, & metal enrichment
  - Supermassive black hole accretion and thermal feedback
- [e.g.,] Sunrise (Jonsson 06, Jonsson et al. 2010a,b)
  - Assigns input stellar, AGN SEDs, and dust opacities
  - 3D dust radiative transfer: absorption, scattering, (emission)
  - Pan-chromatic SED from arbitrary viewing angles and positions