Galaxy evolution with LSST

Vivienne Wild

(with thanks to Sugata Kaviraj, Milena Pawlik, Garreth Martin, Harry Ferguson, the LSST Galaxy SC Roadmap & webpages)

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z = 20.0

50 Mpc/h

Our cosmological model is very successful!

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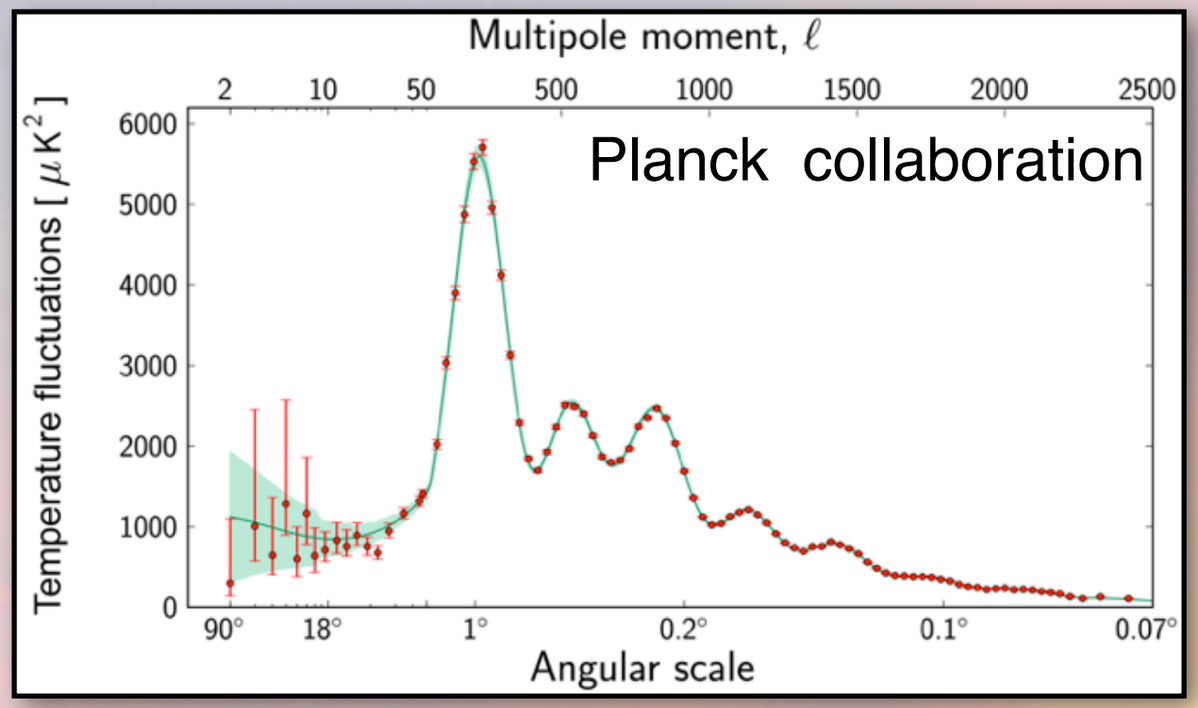
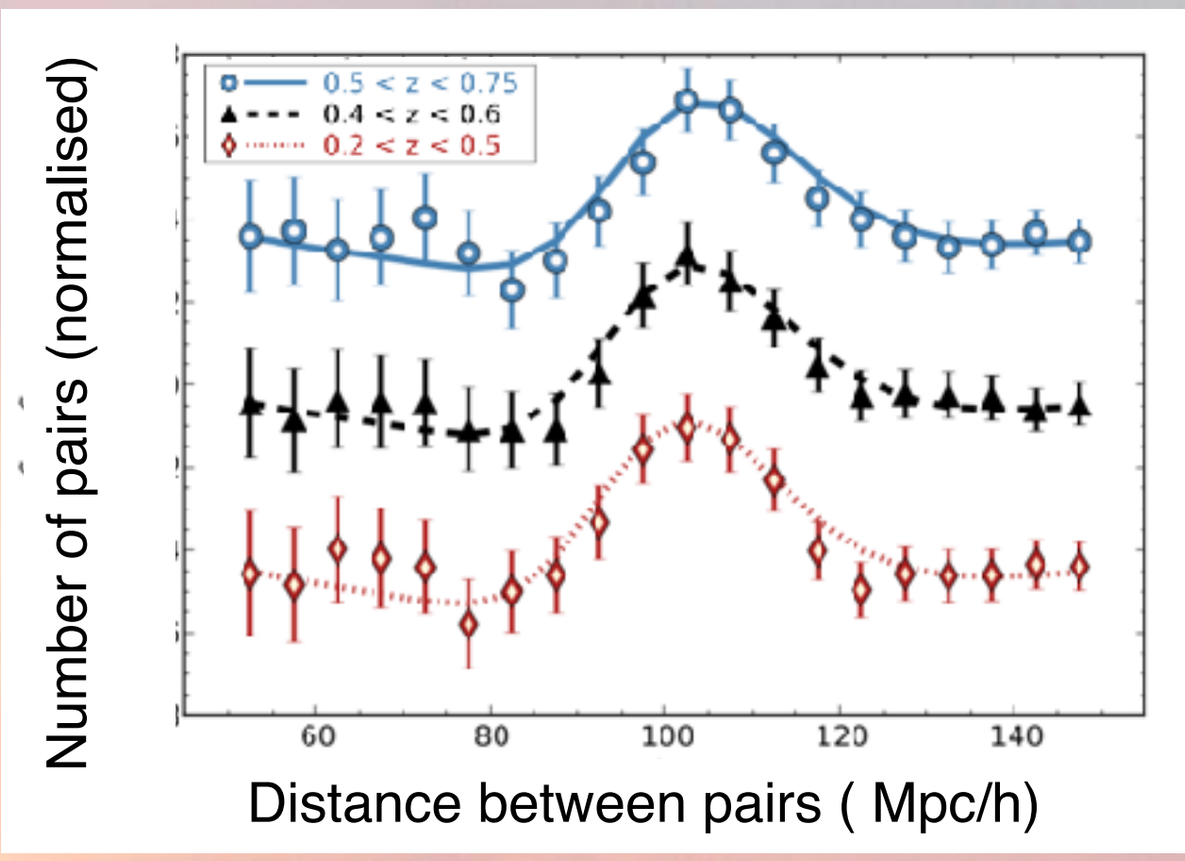
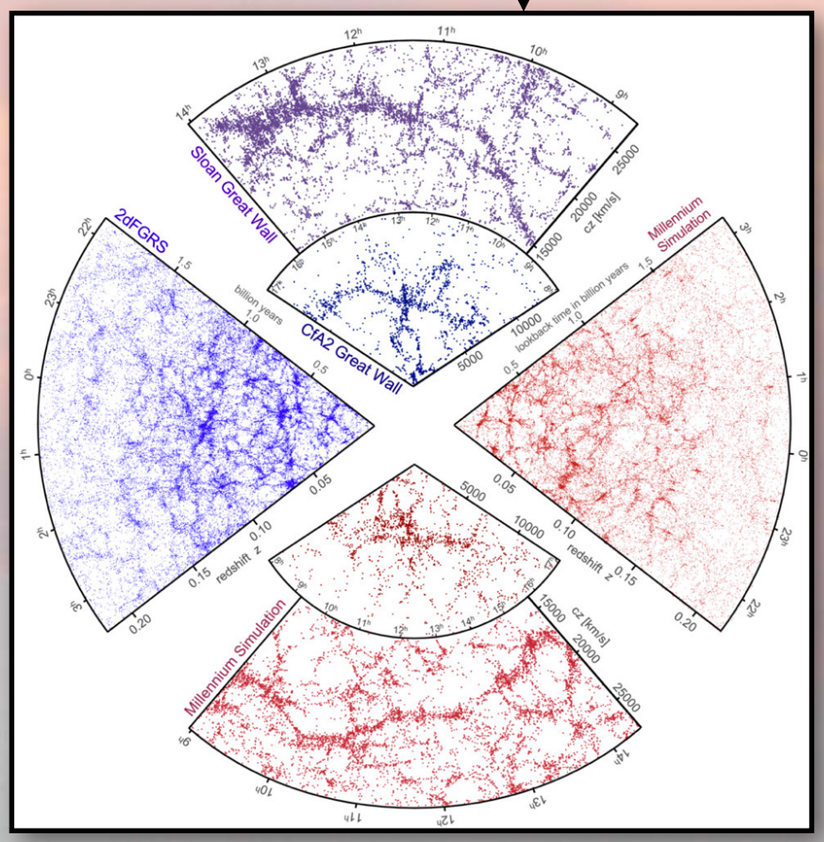




Alam et al. 2017: BOSS BAO



From observations of the CMB we can predict where (massive) galaxies live

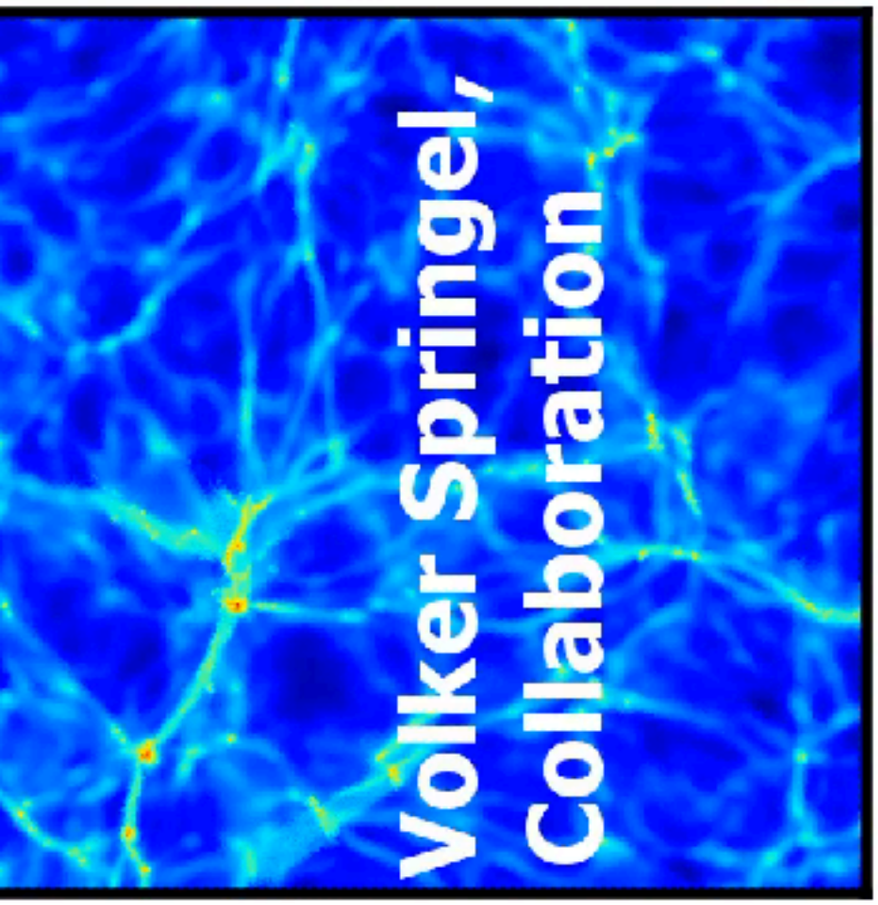
Springel et al. 2006 Millennium simulation

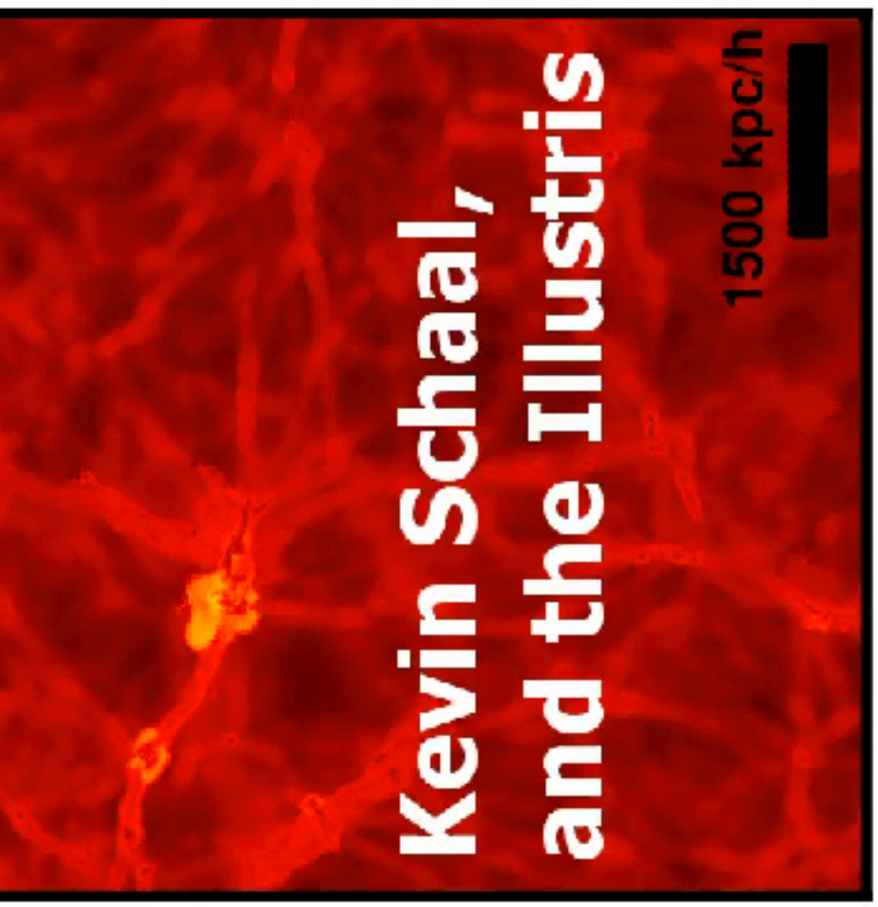
Baryonic Overdensity $\delta_b + 1$

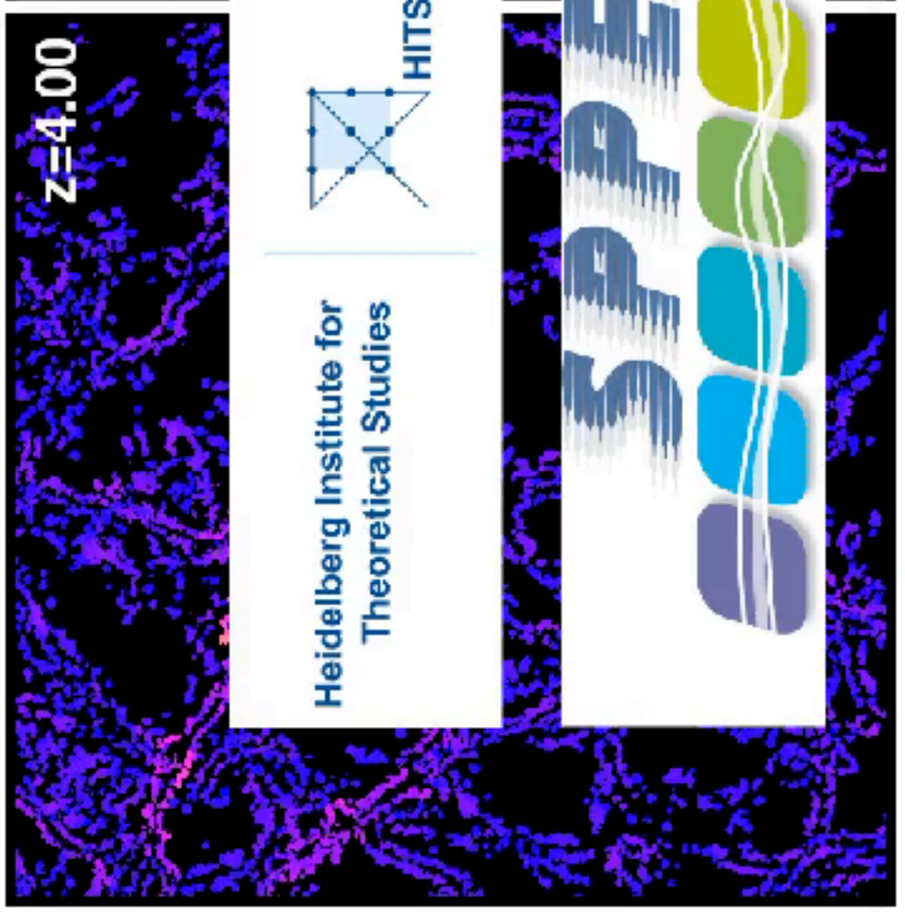
10^4 10^3 10^2 10^1 10^0 10^{-1}

Dissipated Energy [erg/s/kpc^3]

10^{38} 10^{37} 10^{36} 10^{35} 10^{34} 10^{33} 10^{32} 10^{31} 10^{30}







Temperature [K]

10^8 10^7 10^6 10^5 10^4 10^3

Mach Number

10^2 10^1 10^0

Baryonic physics is messy….

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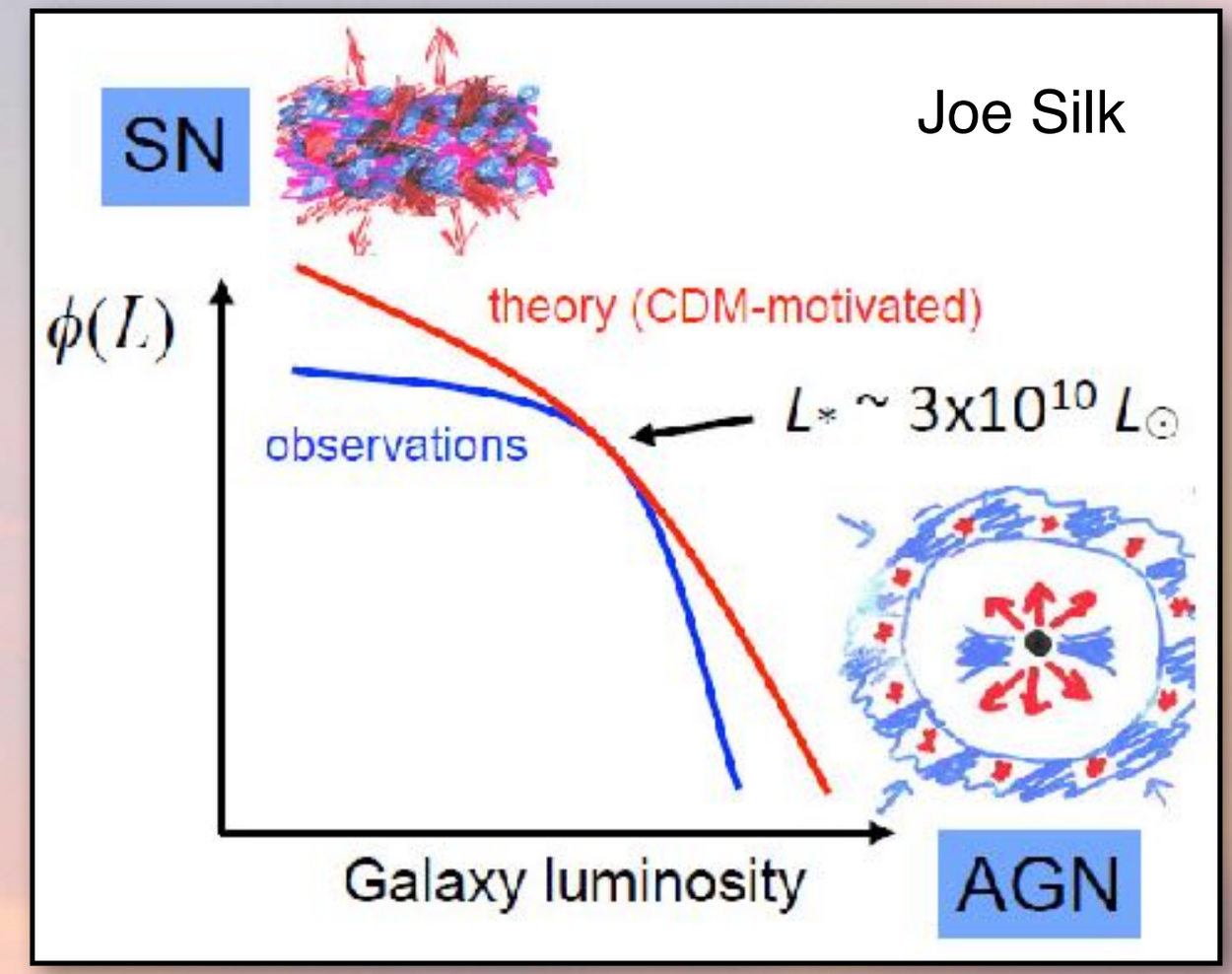

http://ned.ipac.caltech.edu/level5/March12/Silk/Silk2.html

- ★ Star formation
- ★ Inflows and outflows of gas
- ★ Shocks
- ★ Dust
- ★ Magnetic fields
- ★ Black holes

From first principles we can't predict the mass of galaxy that a dark matter halo will contain, nor other basic properties such as morphology.

Some key topics in galaxy evolution in 2018

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★ Stellar mass assembly

- External vs. internal
- Gas vs. stellar accretion
- As a function of mass and redshift

★ The role of environment

- Assembly bias and galaxy conformity

★ Development of galaxy bimodality

- Spectral (quiescent vs. star-forming)
- Morphological (spheroid vs. disk)

★ The low mass / low surface brightness regime

- Dwarfs (low mass end of mass function)
- Ultra diffuse galaxies

Stellar mass assembly history

How do galaxies grow?

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Building mass through mergers

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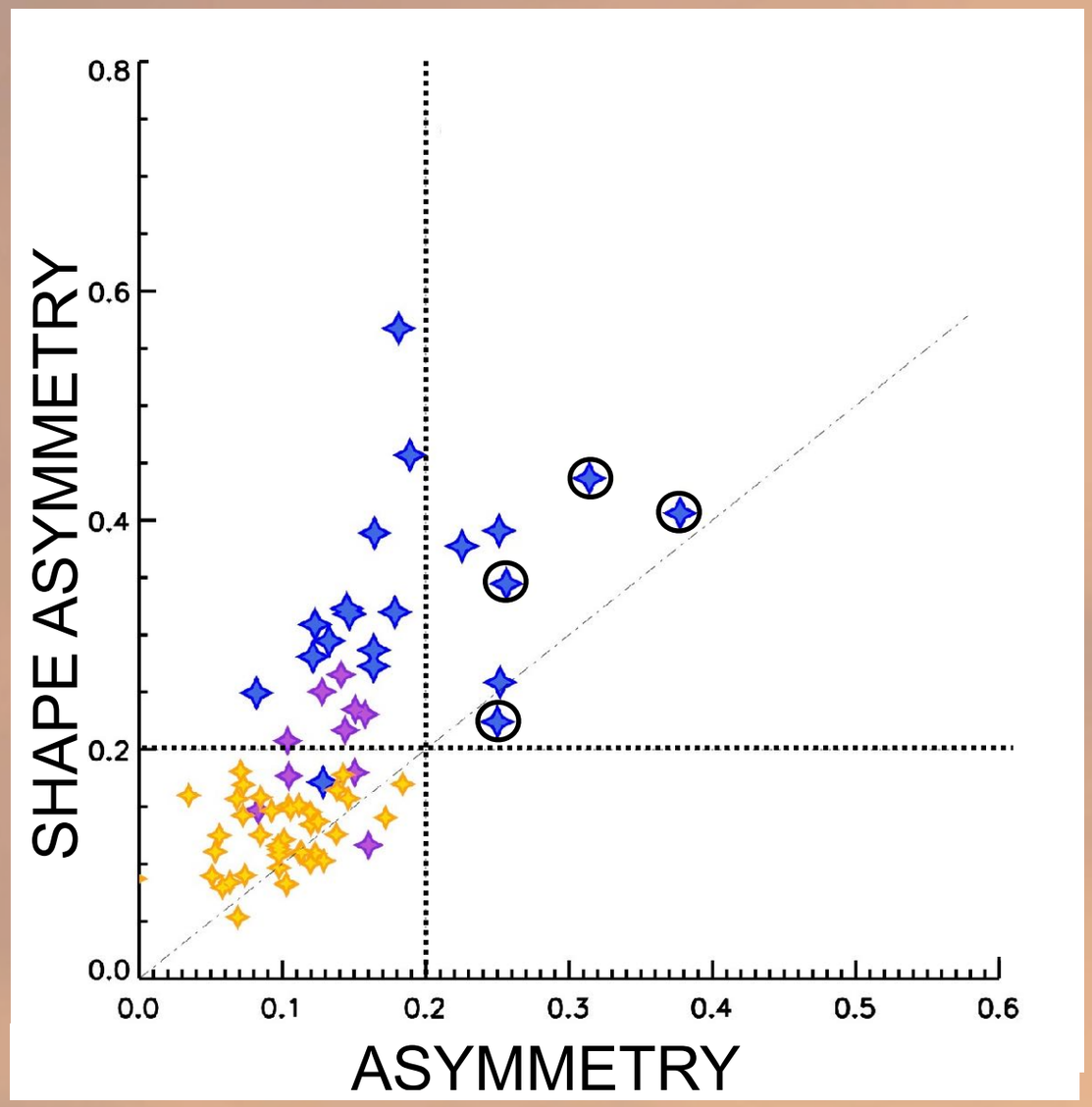
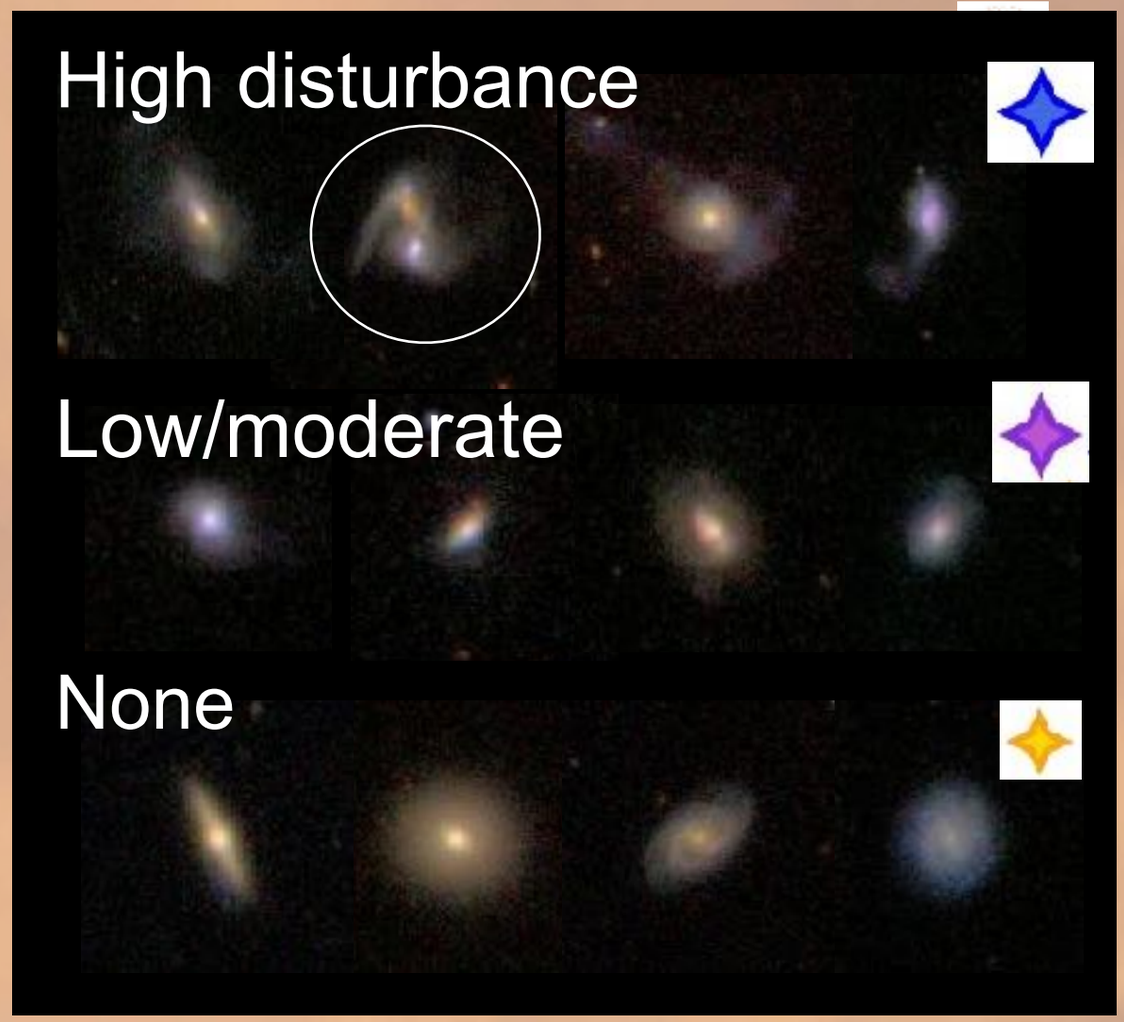
★ Tidal features are critical for identifying past mergers

- Constrain merger history on galaxy-by-galaxy basis
- Not well identified by “traditional” non-parametric measures
- Faint and decay rapidly e.g. in SDSS ~250Myr after (major) merger



Pawlik, VW et al. 2016: SDSS 0.01 < z < 0.07 post-starburst galaxies



Shape asymmetry (A_s)

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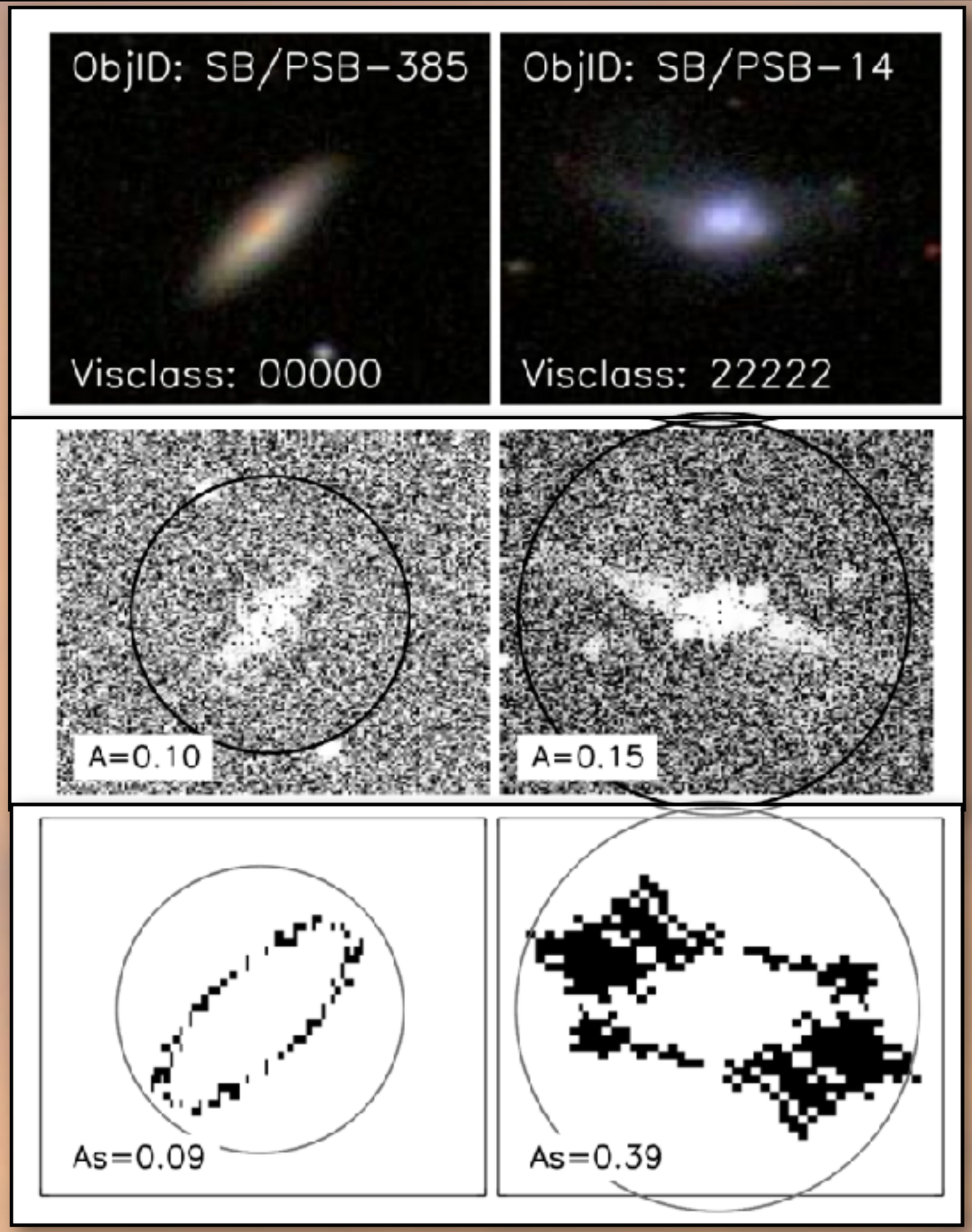
- ★ Shape asymmetry removes the flux weighting to identify faint tidal features
- ★ Asymmetry of a **binary detection mask**, computed with an 8-connected structure detection algorithm to identify **connected** features.



Pawlik, VW et al. 2016:
SDSS $0.01 < z < 0.07$

Merger remnant features vanish rapidly

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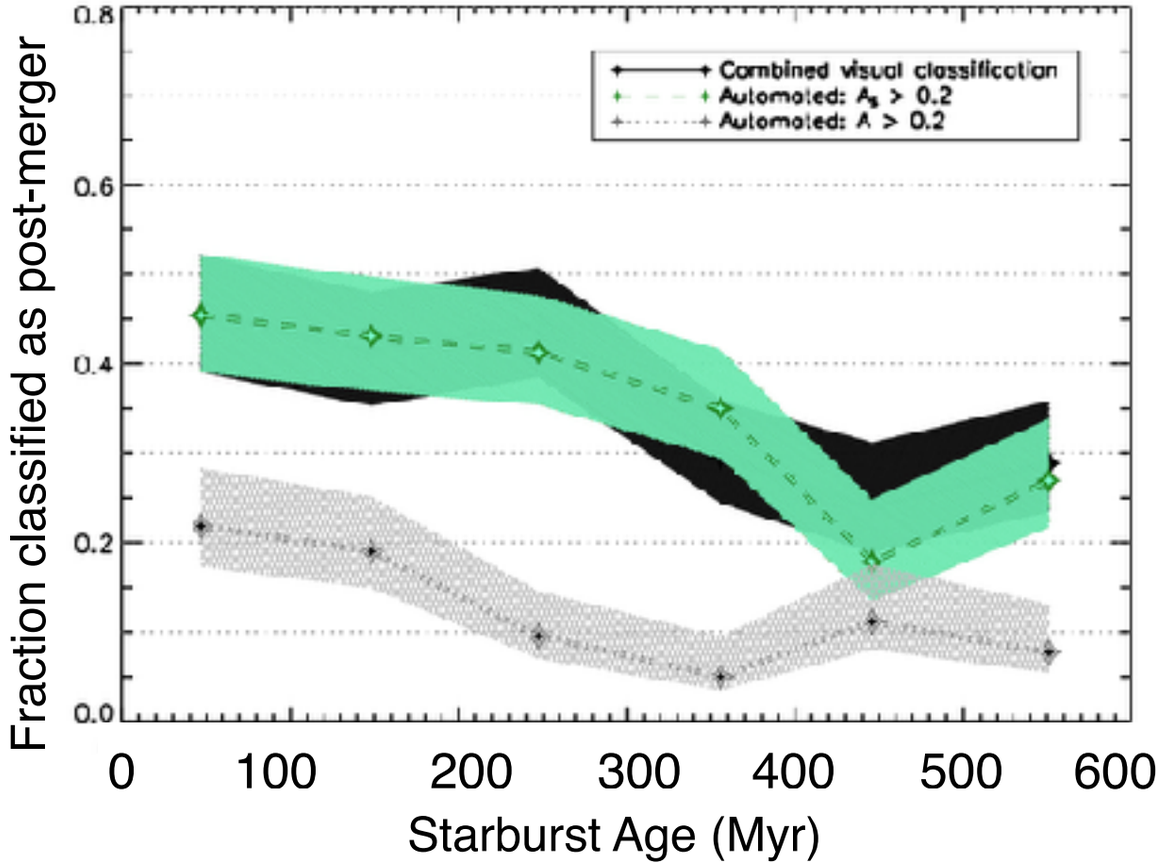

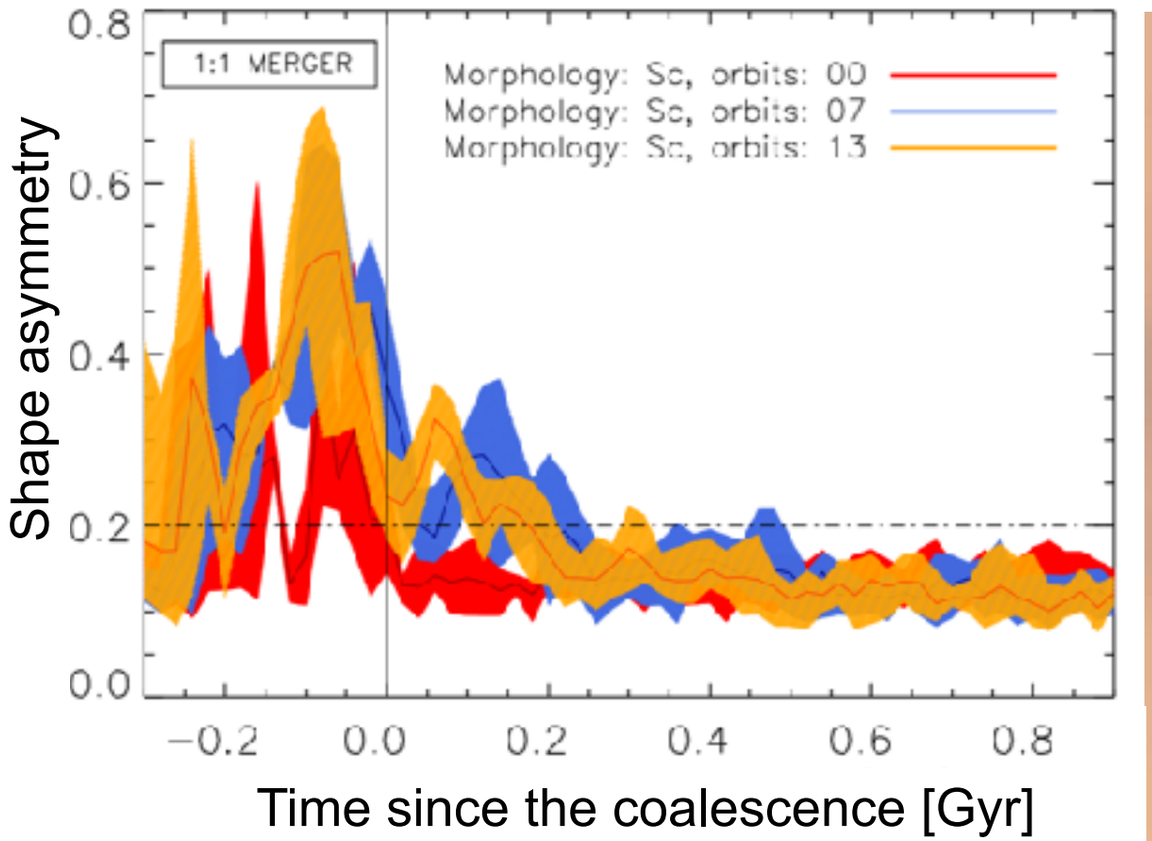

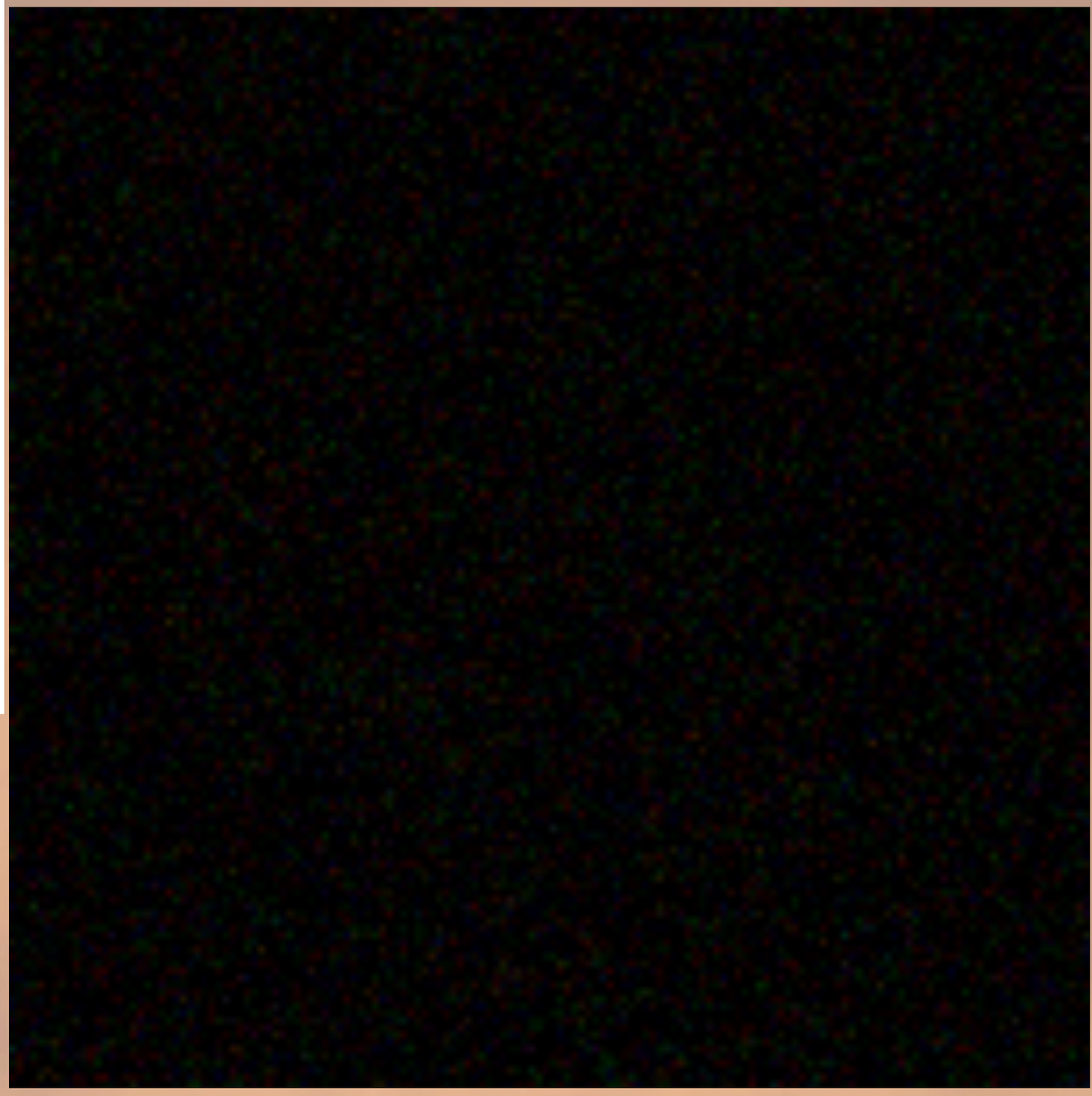

Pawlik et al. 2018: SDSS 0.01 < z < 0.07

Movie credit: Peter Johansson, VW

How might LSST help?

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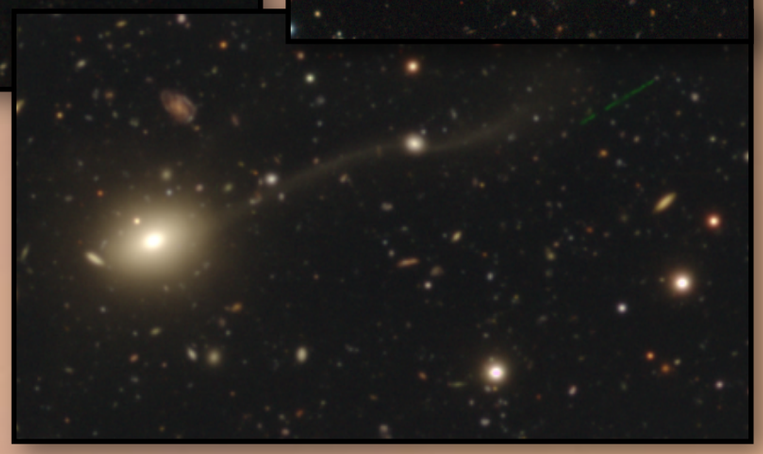

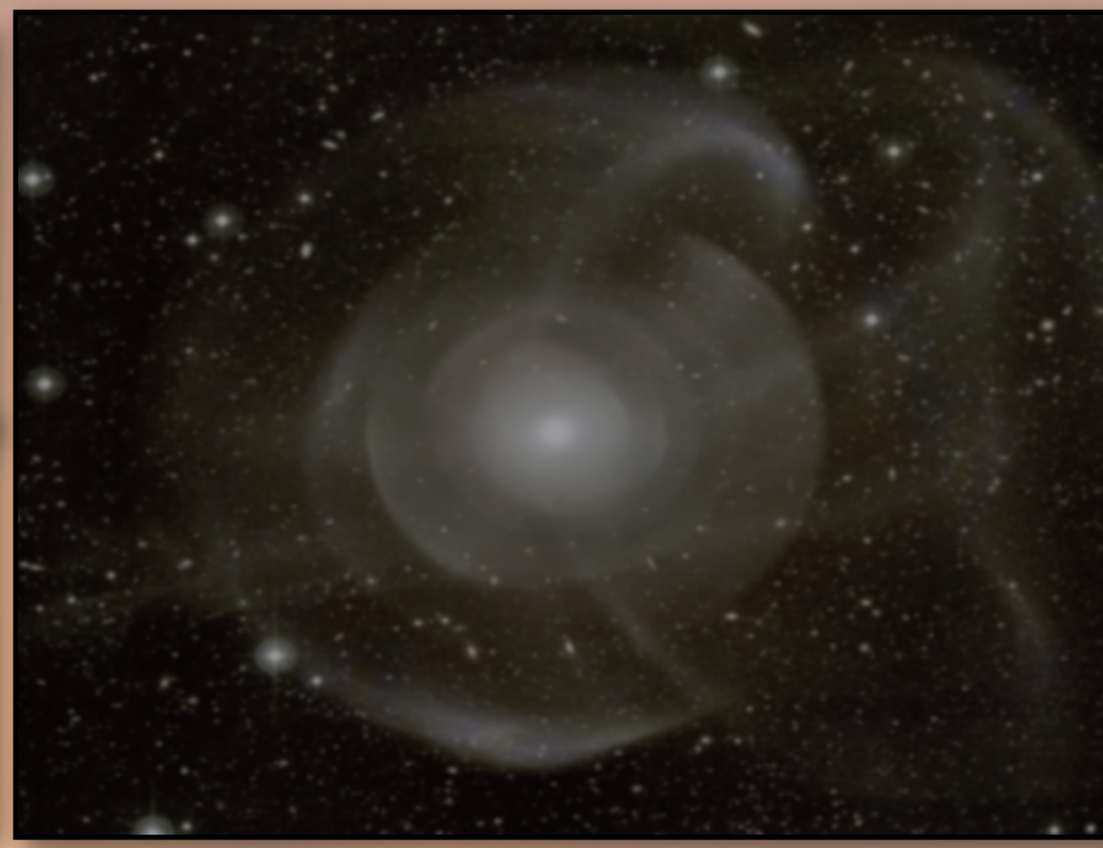

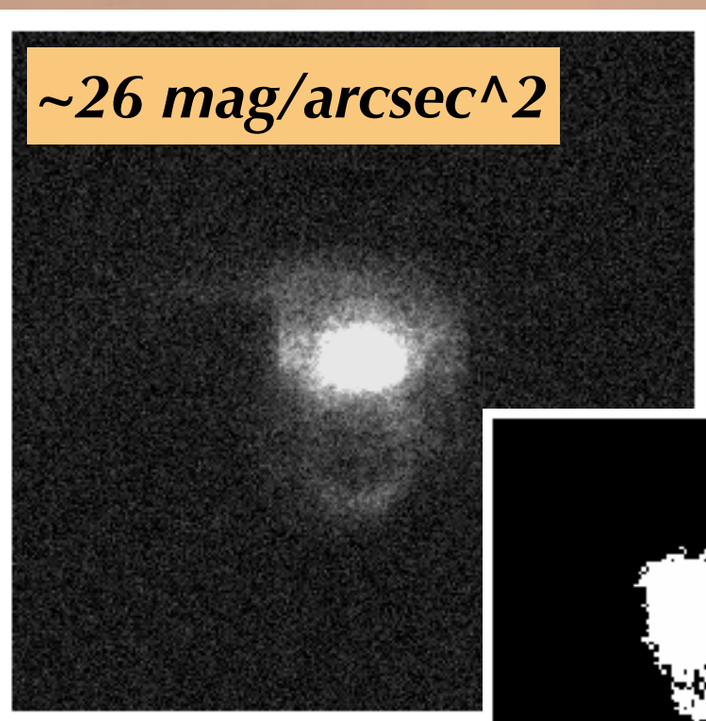

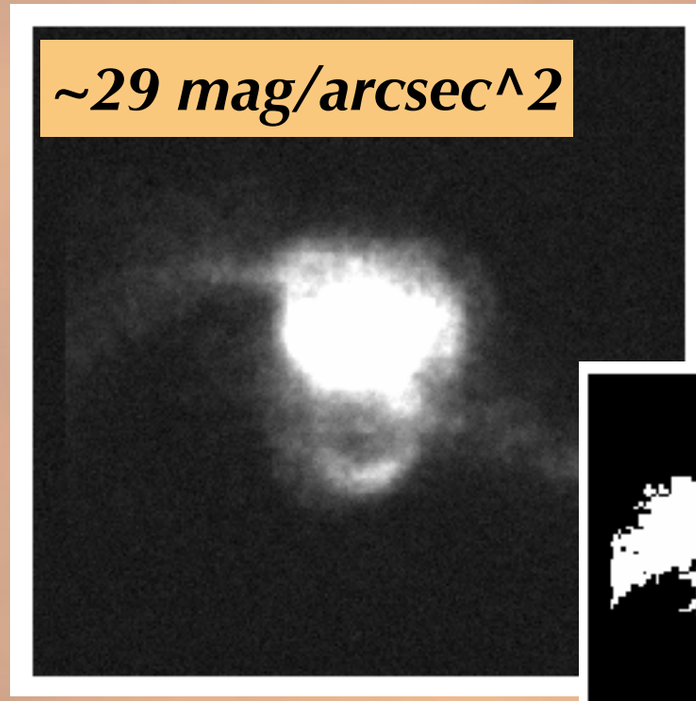

Courtesy M. Pawlik

See talks by Lee Kelvin and Sugata Kaviraj

Environment

Does it matter where galaxies live?

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To 1st order, more massive halo = more massive galaxy

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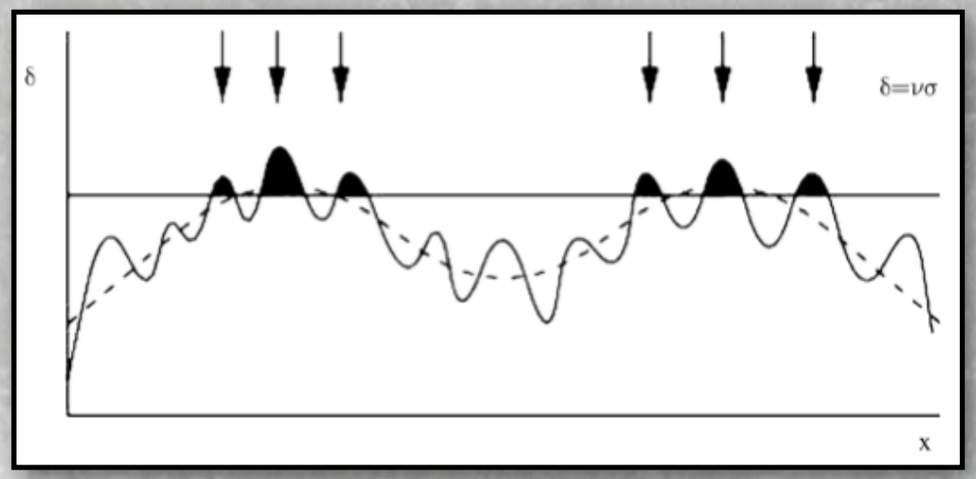
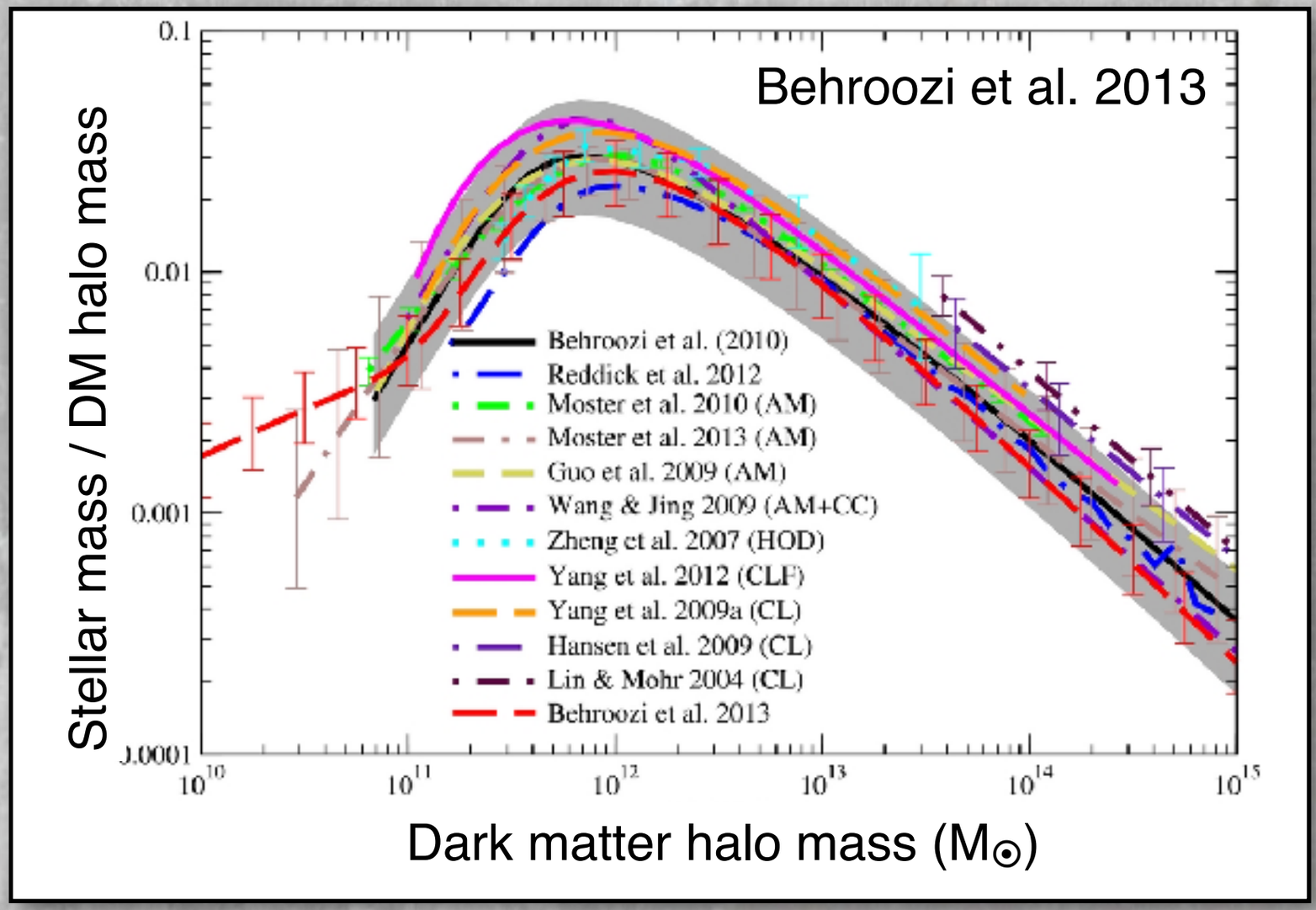


Courtesy P. Schneider

- ★ There isn't a 1:1 correspondence between halo mass and stellar mass
- ★ But if we line up all the galaxies and DM halos by mass, and match them, we get models that work incredibly well.



But is dark matter halo mass the whole story?

Galaxy assembly bias / galaxy conformity

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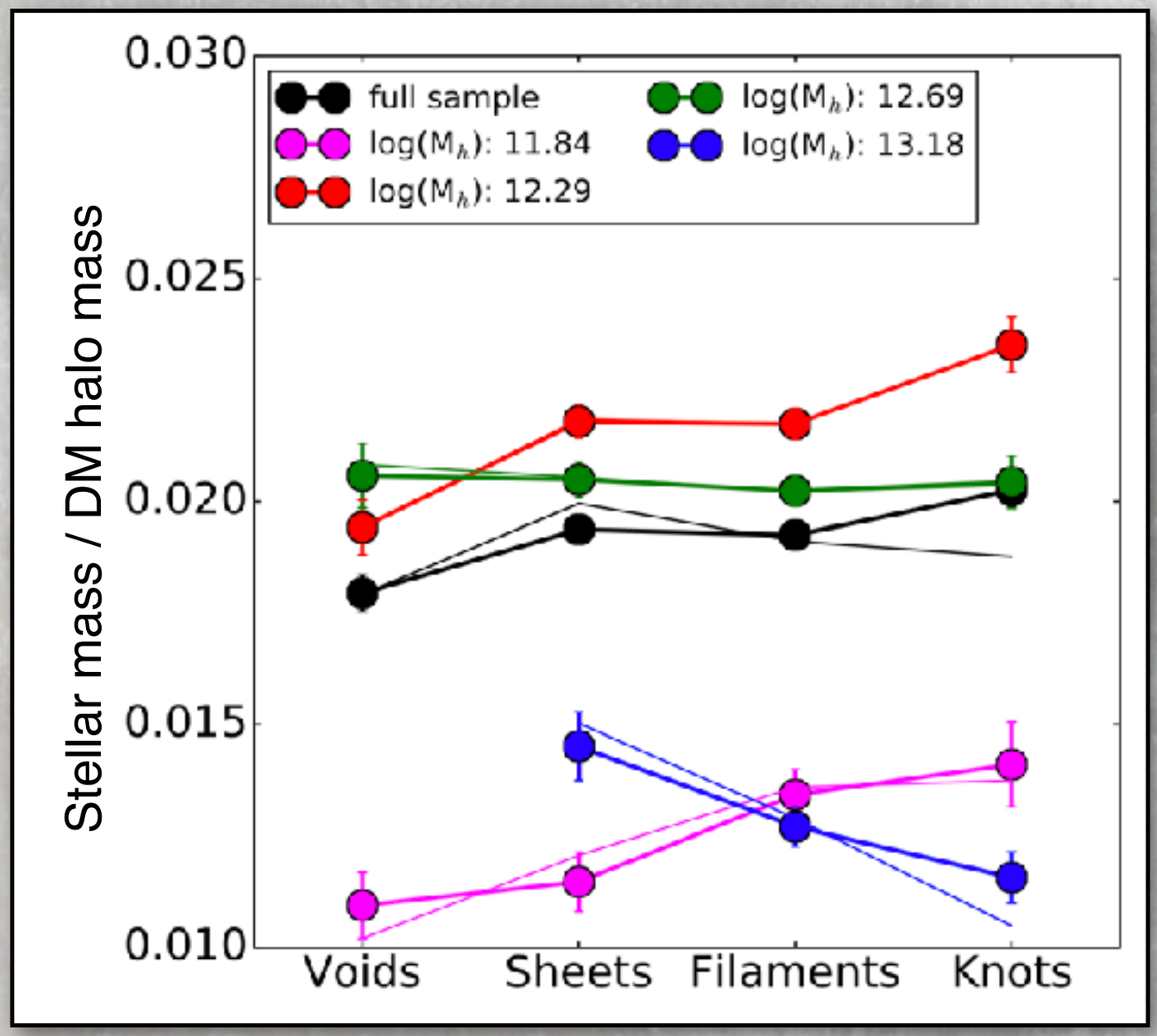

Tojeiro et al. 2017
(see also Hearin et al. 2015)

- ★ Low mass halos may “stall” if they live in regions with strong tidal forces, causing gas to flow away from them.
- ★ Densest regions are expected to start forming their stellar mass earlier.
- ★ Link to “Galaxy conformity” i.e. passive satellites are more likely to share a halo with passive centrals.

Galaxy properties depend on environment, not just dark matter halo mass.

Environment with photometric redshifts

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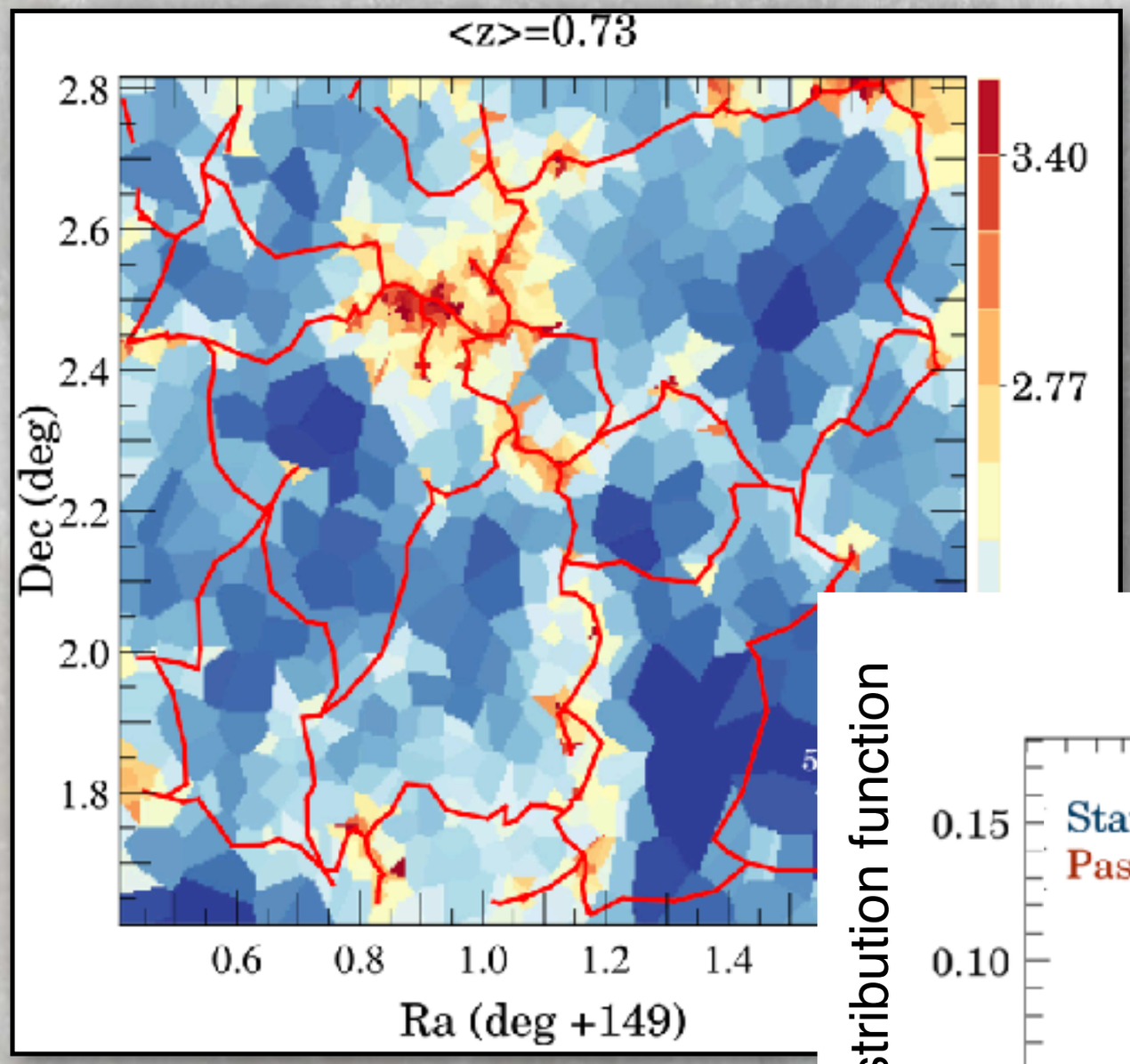
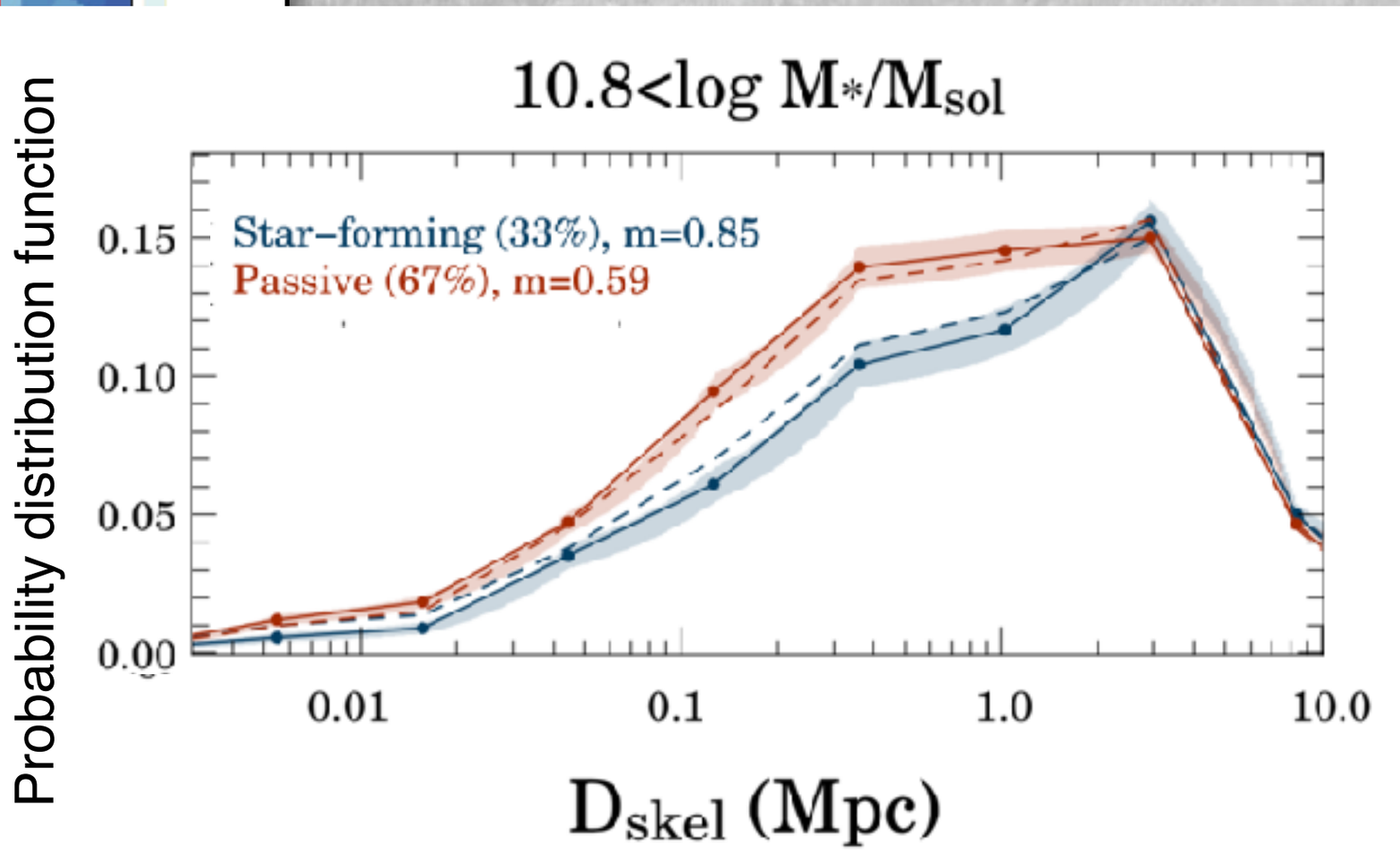
Laigle et al. 2018 using the DiSPERSE algorithm on COSMOS



- ★ Passive galaxies are found closer to their filament than star-forming galaxies (at fixed M*)
- ★ Tidal forces of large-scale-structure affect how galaxies grow



Morphology

The emergence of galaxy bimodality:

quiescent, ellipticals + star-forming spirals

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How are elliptical galaxies formed?

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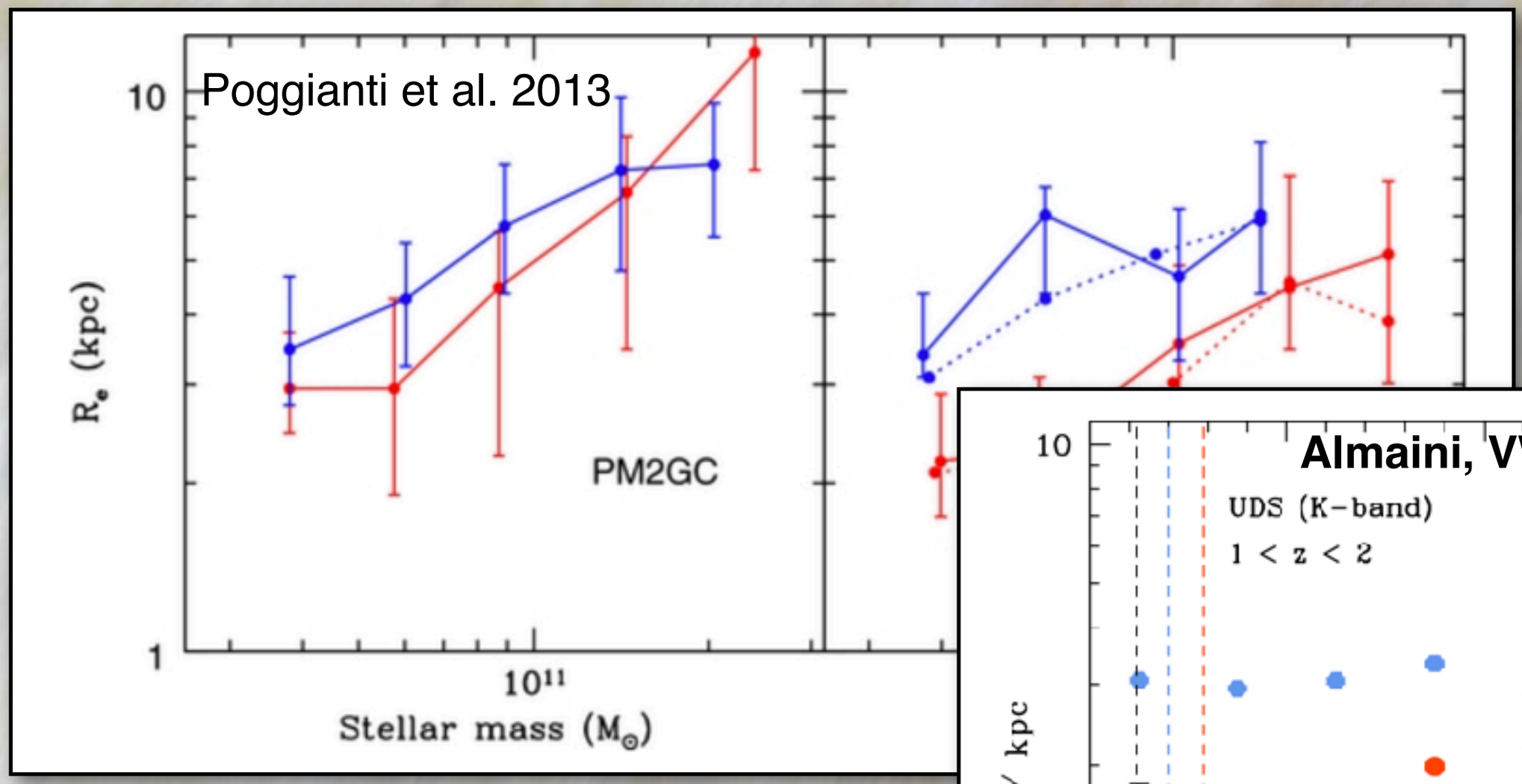

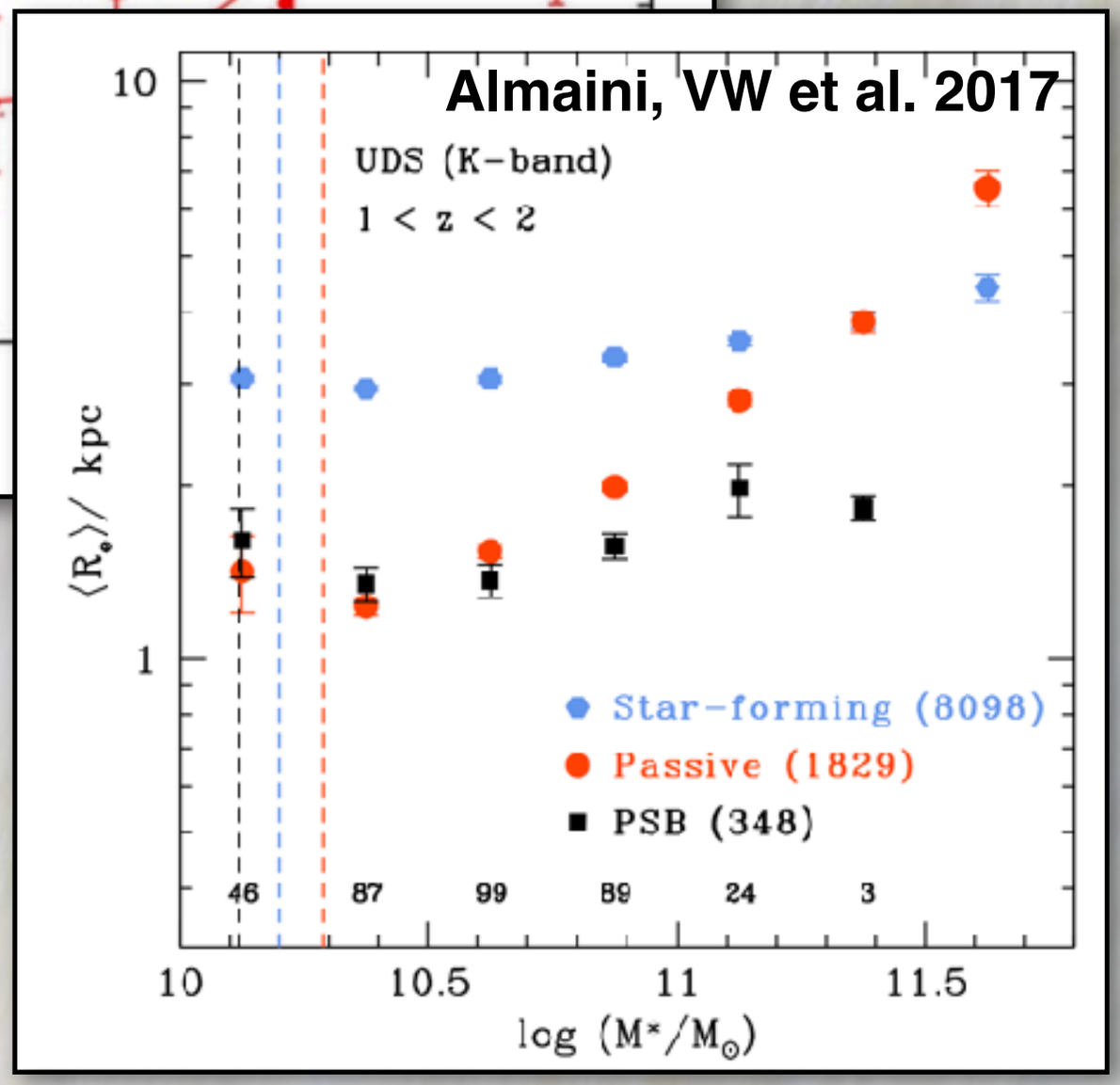

Automatic (unsupervised) classification

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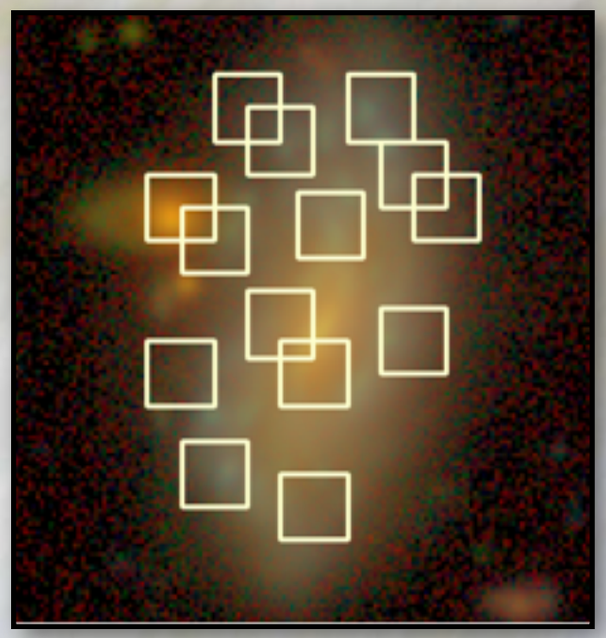
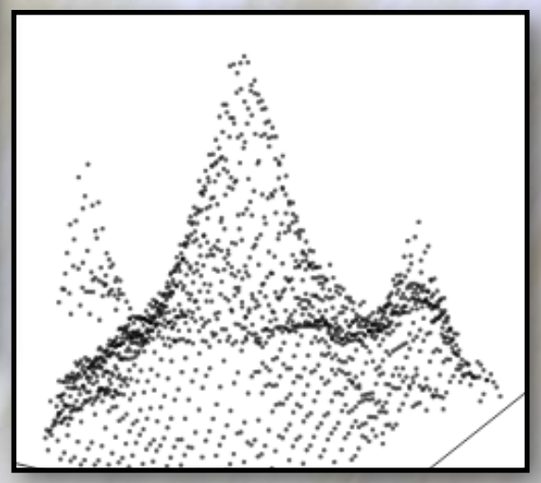
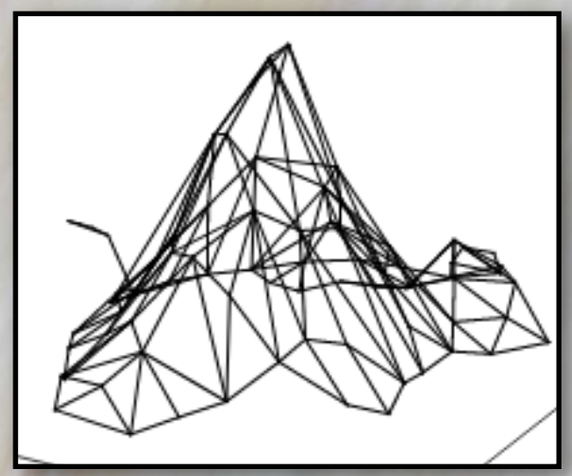


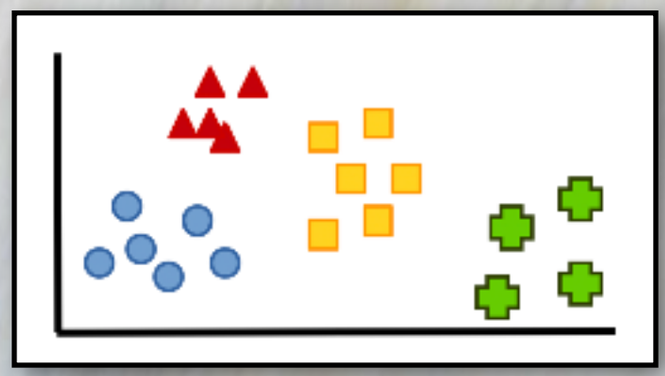
1) Extract image patches at each non-zero flux spaxel. FT to remove position angle.



2) Use “Growing Neural Gas” to create topological map. Sample vectors represent groups of similar patches.



3) Further group similar ‘types’ of patches with hierarchical clustering



4) Identify objects using “connected component labelling”. Each object is represented by a histogram of different types of patches they are formed from.

Hocking et al. 2018

Automatic classification of HSC images

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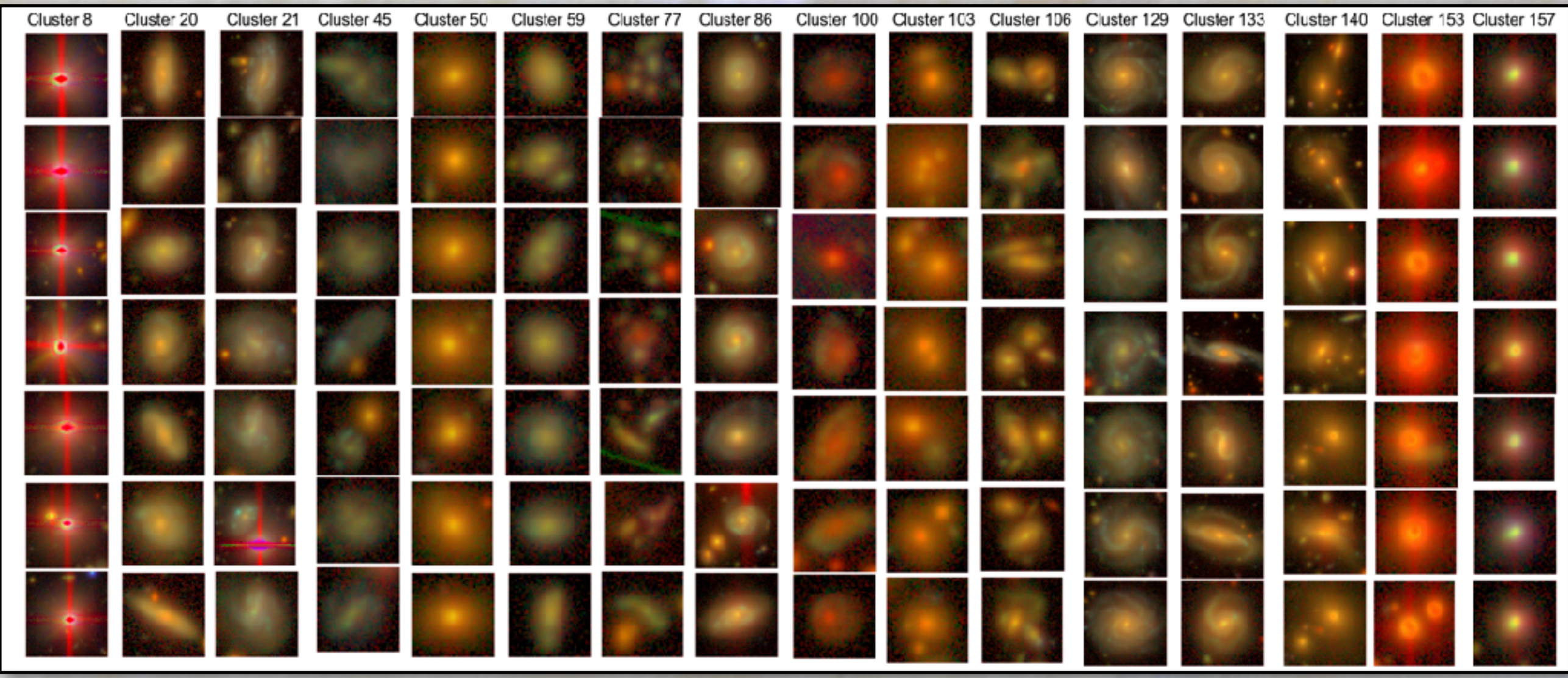
G. Martin + in prep



Stellar populations

Star formation rates, stellar masses,
metallicities, star formation histories

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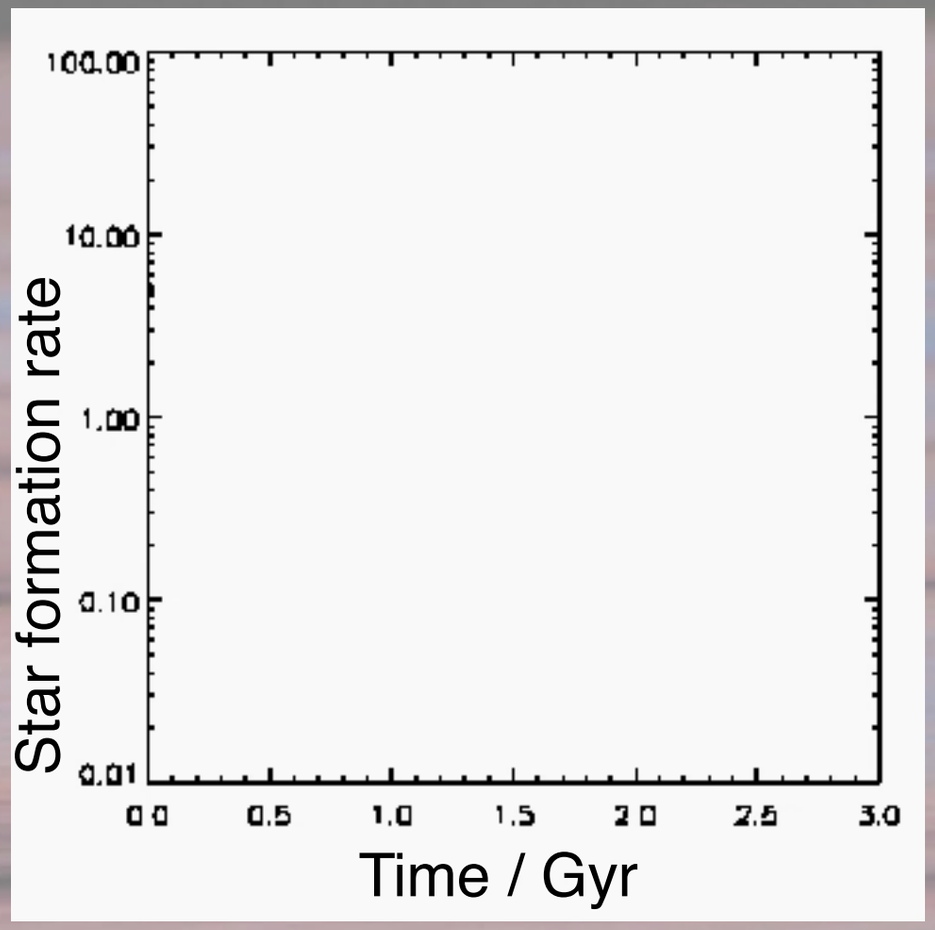

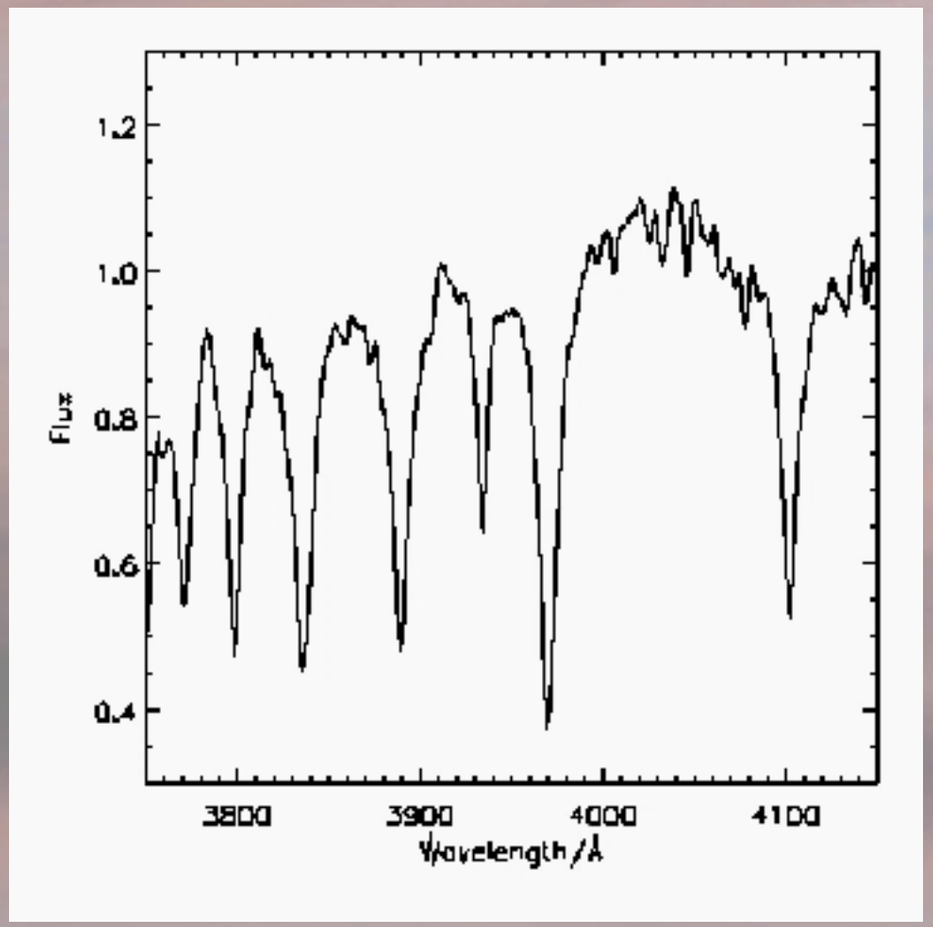

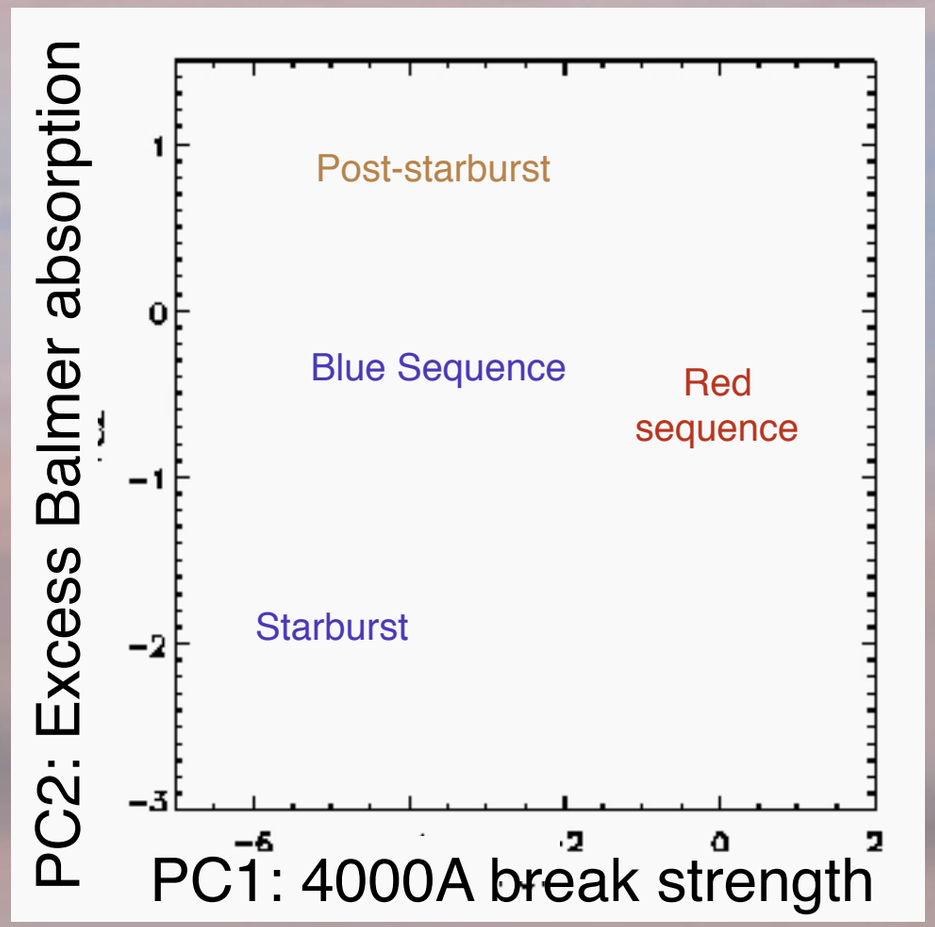

Wild, Walcher, Johansson et al. 2009

Classifying galaxies with PCA "super-colours"

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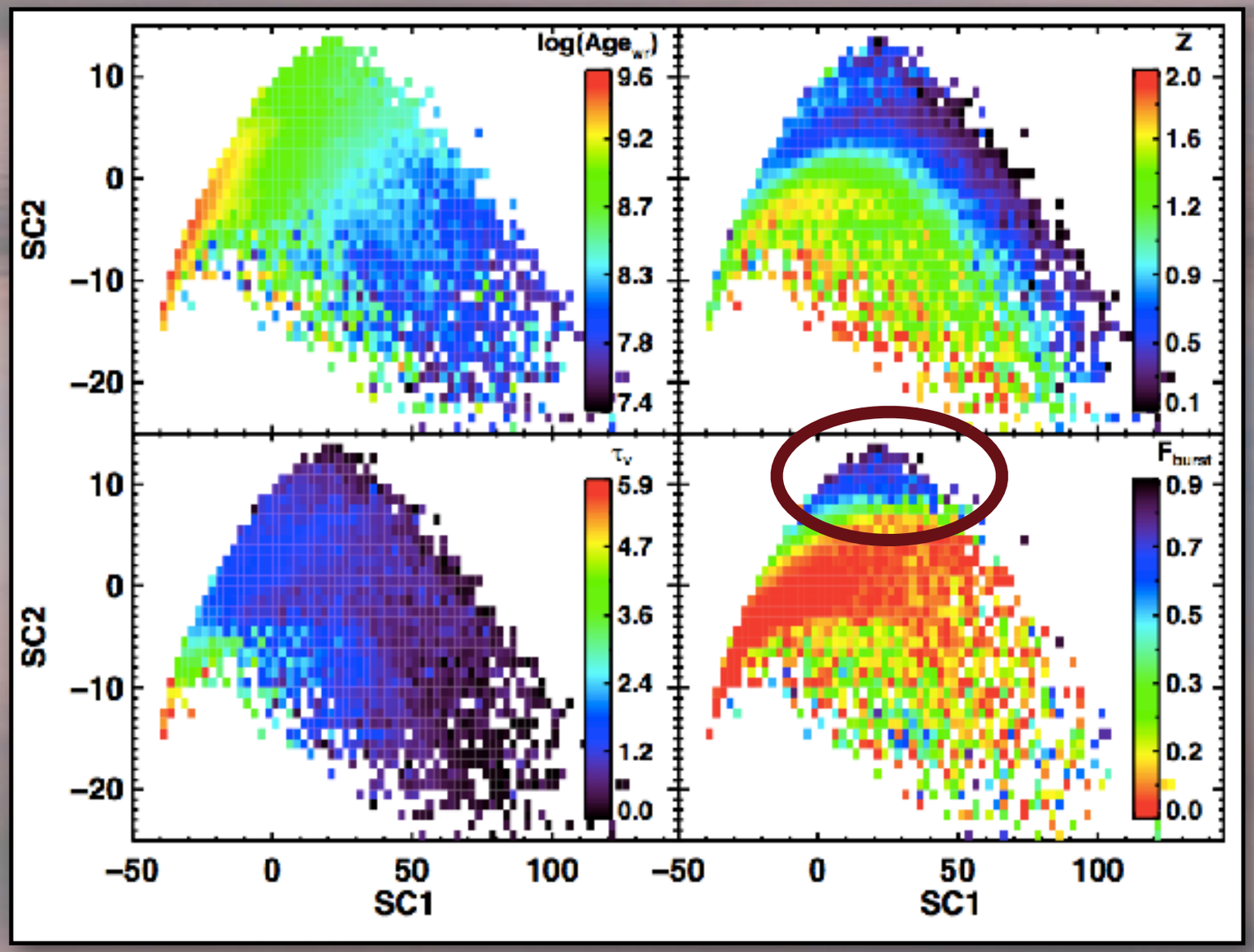
- 6/7-band UDS photometry
- Super-colour = semi-optimal weighted linear combination of observed bands
- No SED fitting: colours free to vary from model basis
- Principal Component analysis performed on massively sparse data matrix



$$\frac{f_\lambda}{n} = m_\lambda + \sum_{i=1}^{p} a_i e_{i\lambda}$$

Wild et al. 2014

Identifying post-starburst galaxies at high-z

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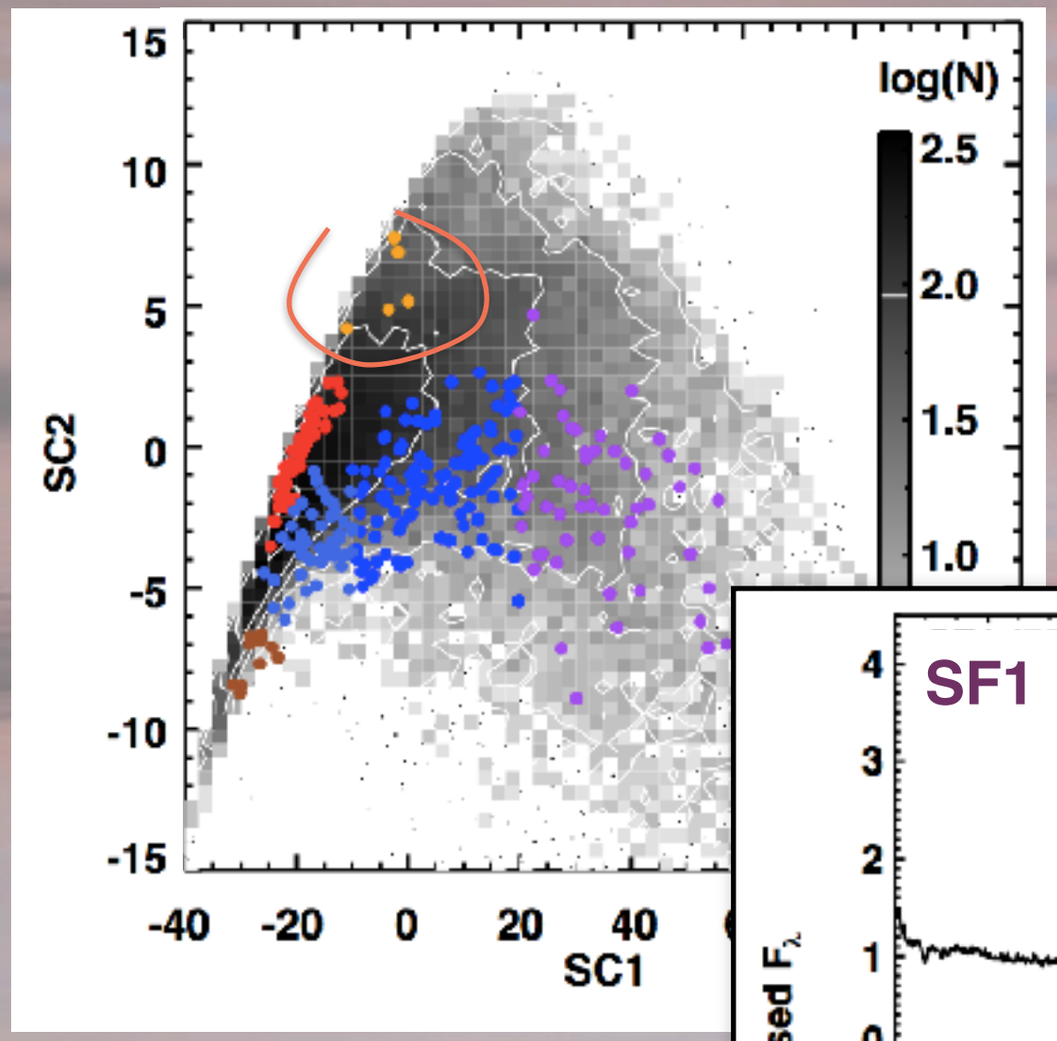
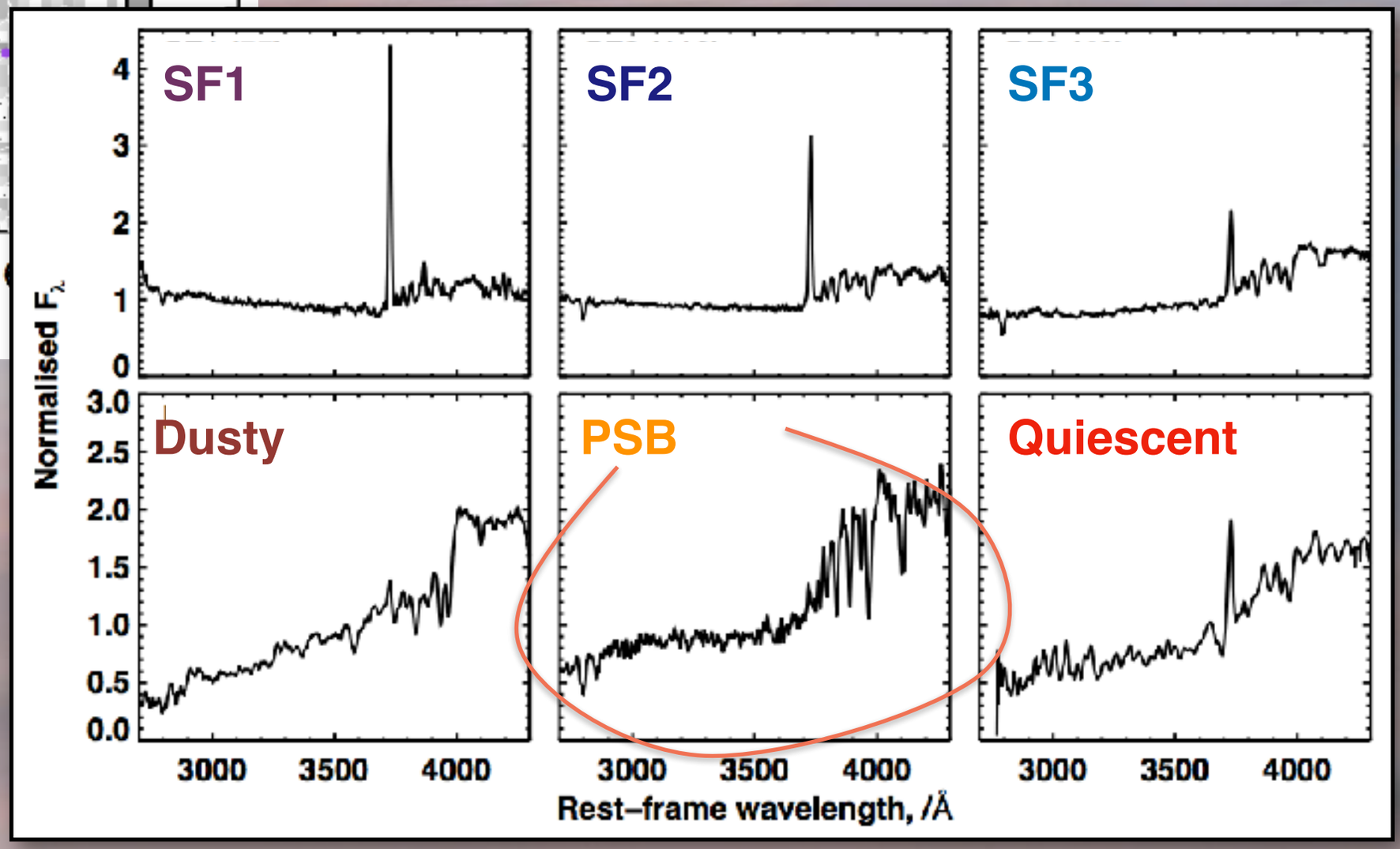


900 candidate PSBs
0.5<z<2 in UDS

Stacked UDSz spectra: 0.9 < z < 1.2



Wild et al. 2014

Classifying galaxy SEDs

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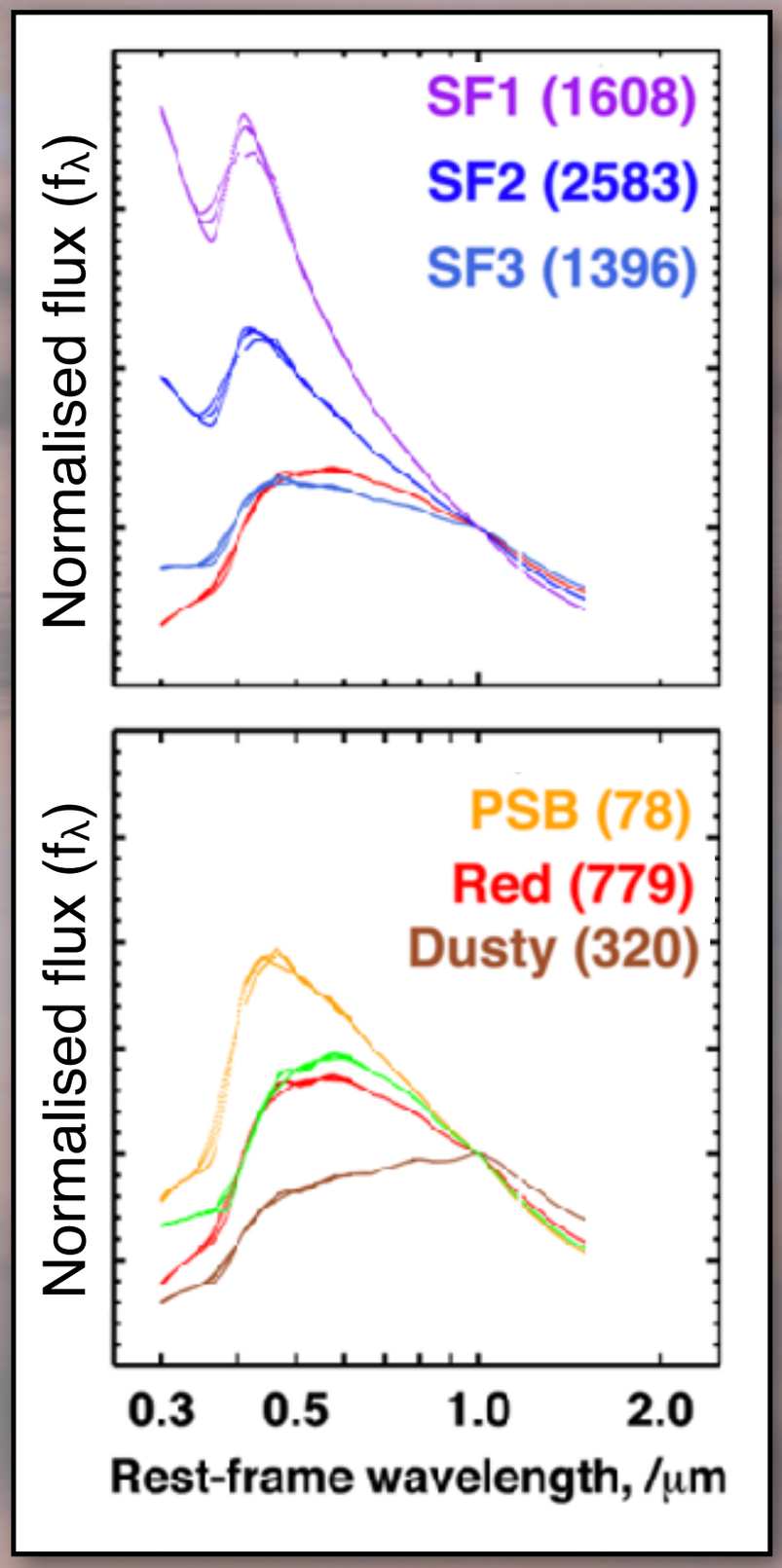
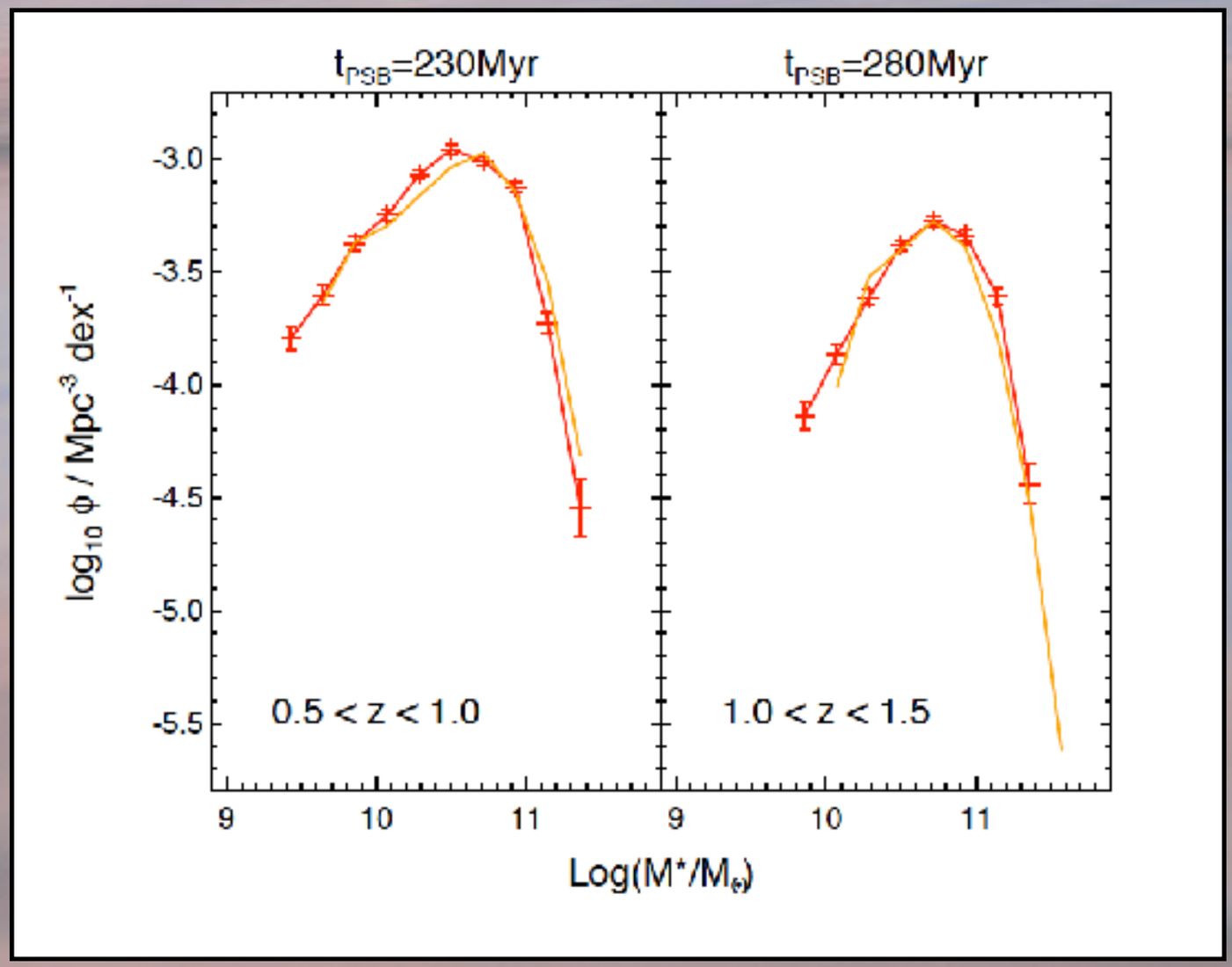


Wild et al. 2016, 2018

★ 6-band photometry (including rest-frame NIR) is sufficient to find rare populations of galaxies that are interesting and relevant for understanding how galaxies form and evolve



Morphology

- (Unsupervised) classification
- Optimising non-parametric parameters (CAS, As)
- Optimising decomposition codes

Environments

- Photo-z accuracy

LSST Galaxies: thinking list

Mass assembly via low surface brightness

- Sky subtraction
- Deblending
- Finding low SB features

Stellar populations

- Photometric accuracy
- Photo-z accuracy
- Combination with NIR surveys
- Fitting populations