MASSIVE QUIESCENT DISKS IN THE EARLY UNIVERSE

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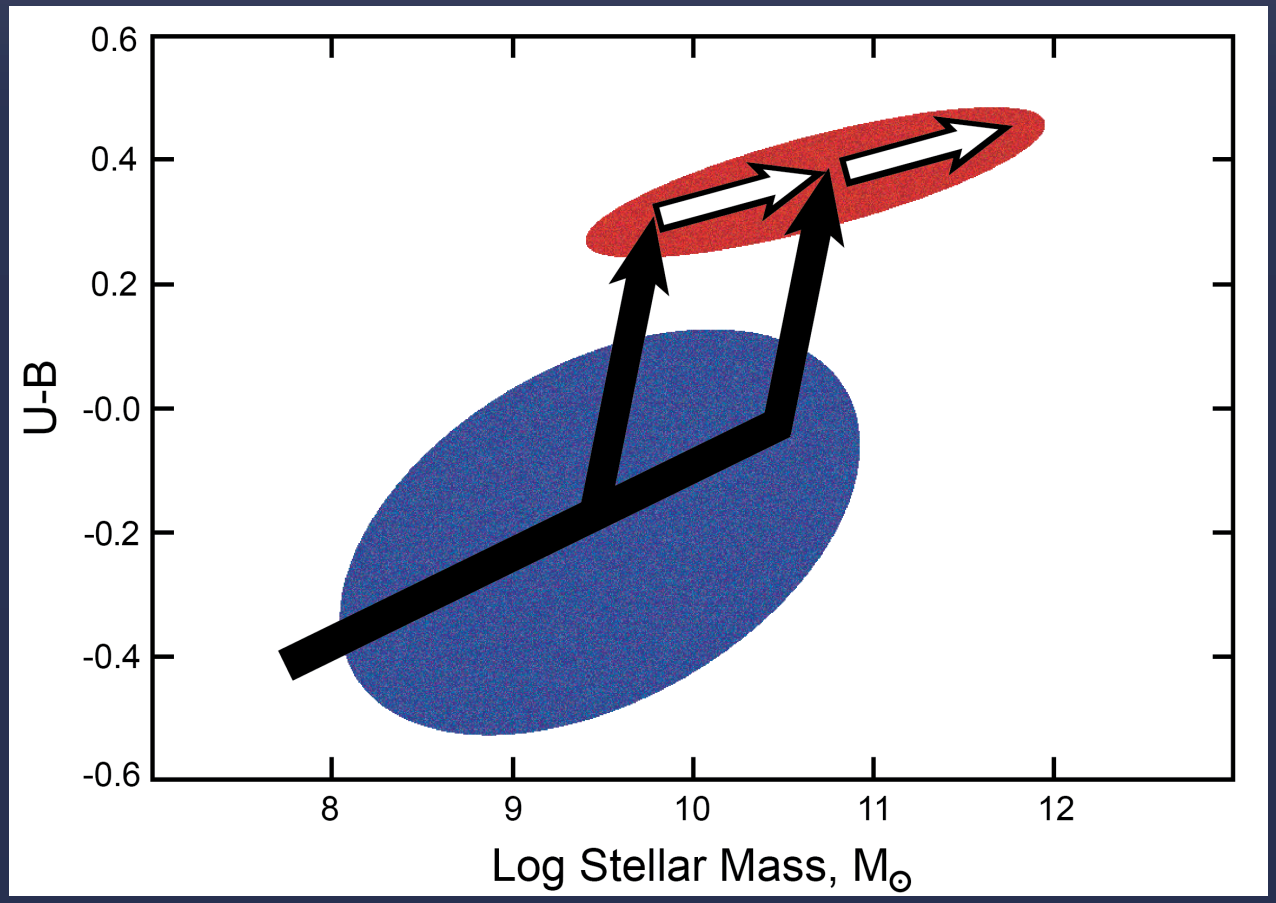
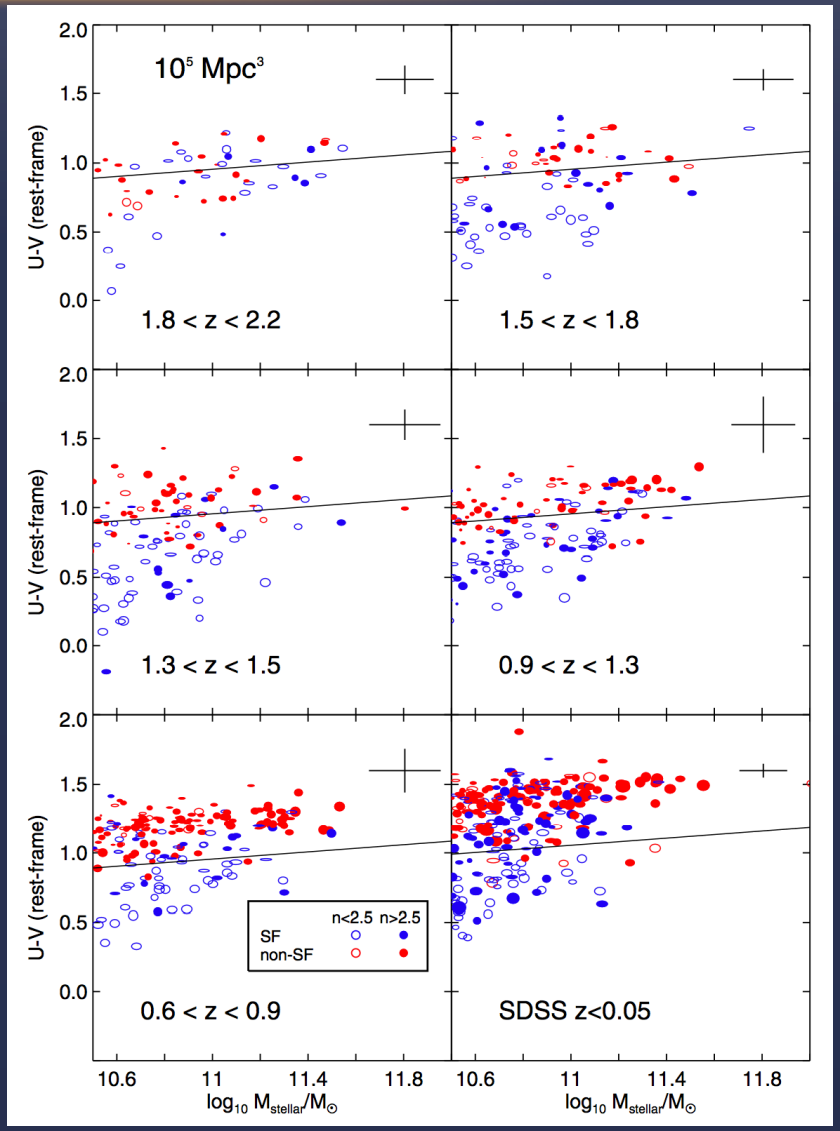
GALAXY BIMODALITY



Faber et al. (2007)

FORMATION OF THE RED SEQUENCE

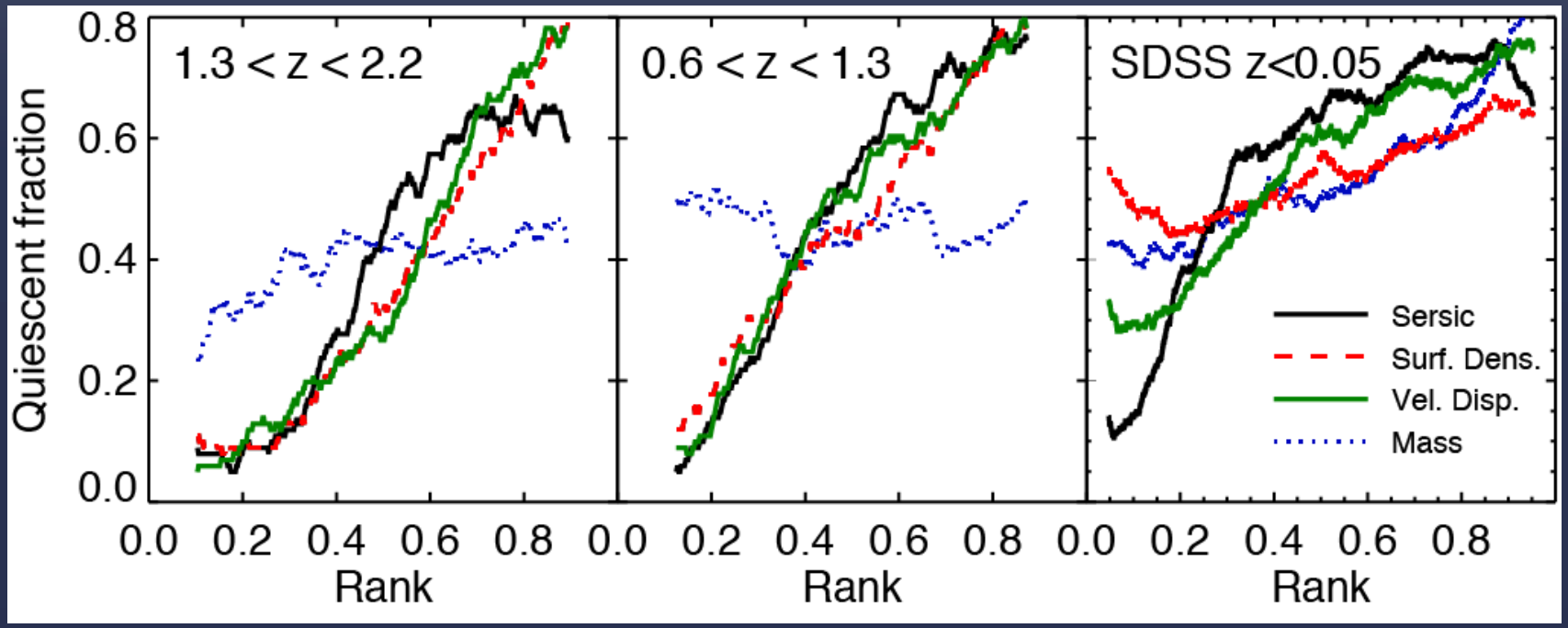
- Red sequence in place at z~2
- Growth in quiescent population (red symbols) is dramatic since z~2
- Galaxies evolve from mostly low Sersic index (open symbols) to higher Sersic (filled symbols)



Bell et al. (2012)

SEARCH FOR A QUENCHING PARAMETER

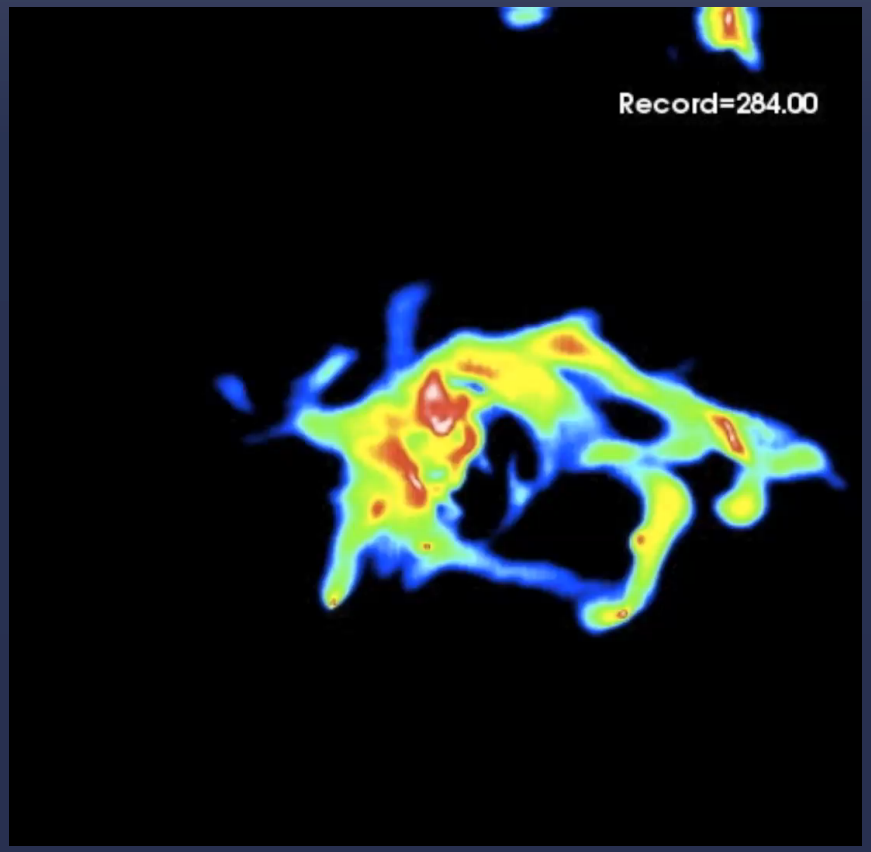
Bell et al. (2012)



- Strongest correlation is between Sersic index and quenched fraction for all redshift ranges.
- High Sersic = bulge dominated (?)
- Consistent with merger formation scenario

COLD STREAMS AND VIOLENT DISK INSTABILITIES

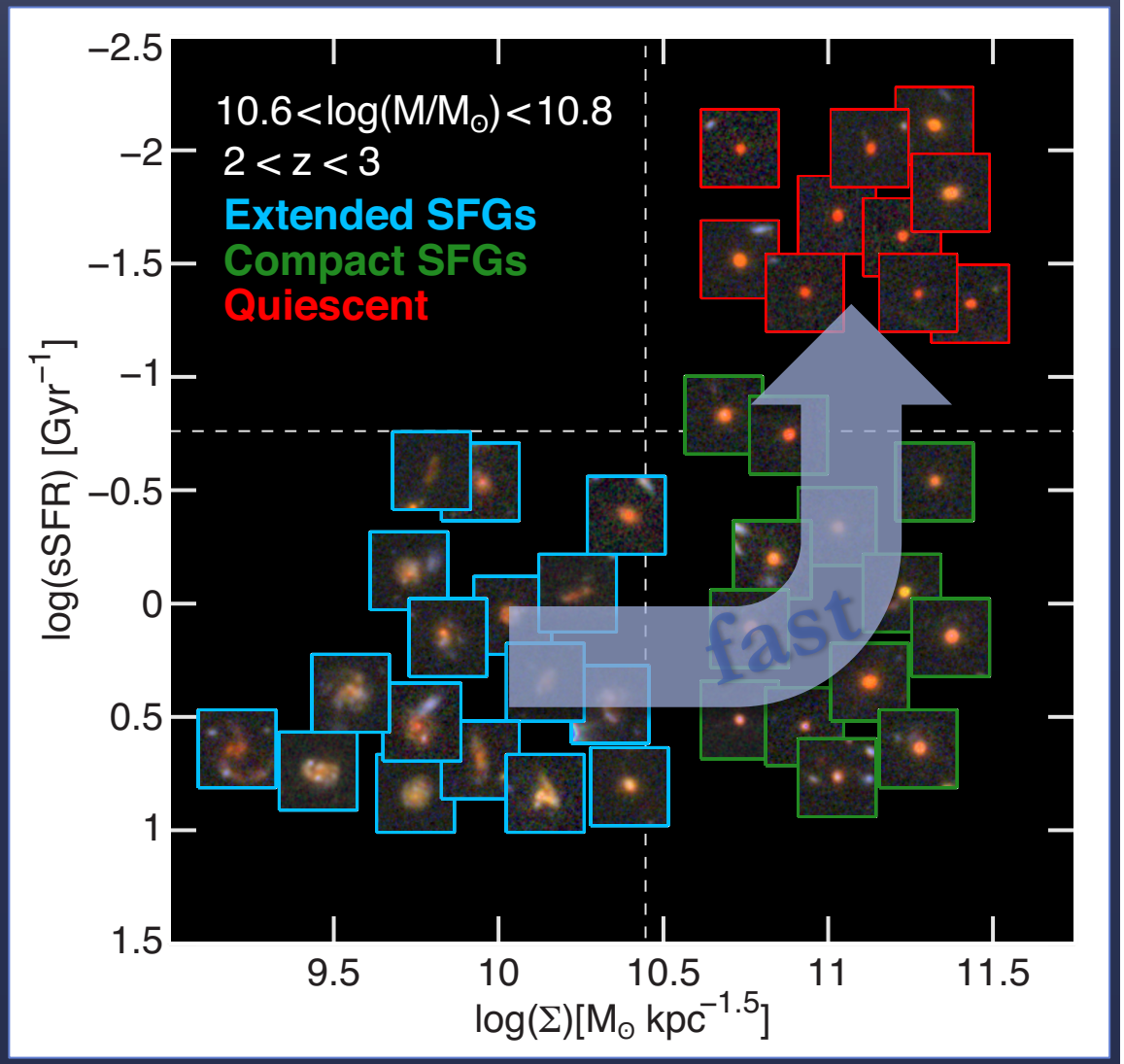
- Narrow, cold streams penetrate to the center of dark matter halo.
- High gas density = disk unstable. Clumps form: violent disk instability (VDI)
- Torques/ Dynamical friction = clumps (and gas) migrate to center.
- VDI can form compact objects easier than galaxy mergers.



Ceverino, Dekel, Bournaud (2010)

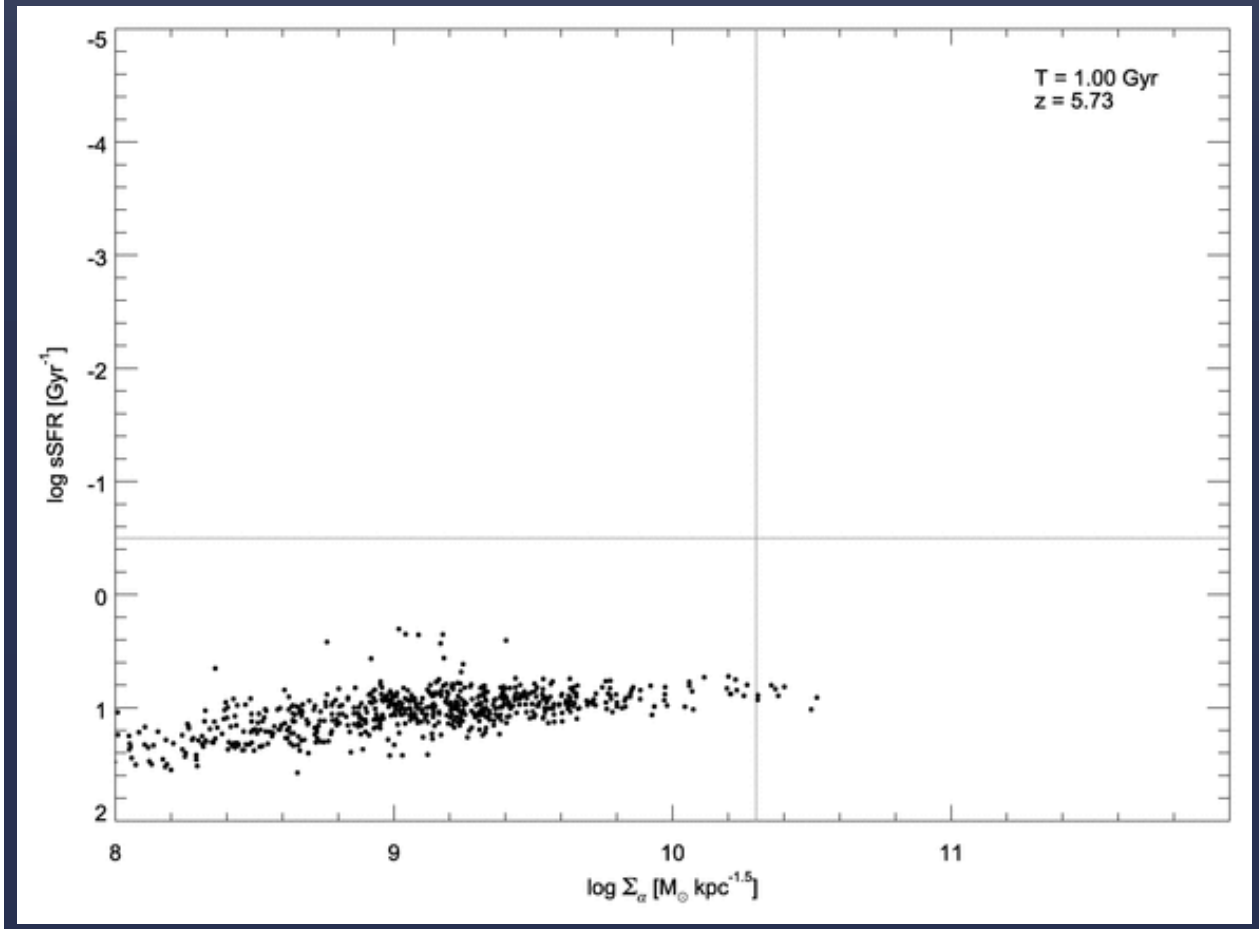
GALAXY EVOLUTION REVEALED BY STRUCTURAL CHANGES

- "Compaction" and quenching



Barro et al. (2014)

RESULTS ON COMPACTION AND QUENCHING FROM SAMS



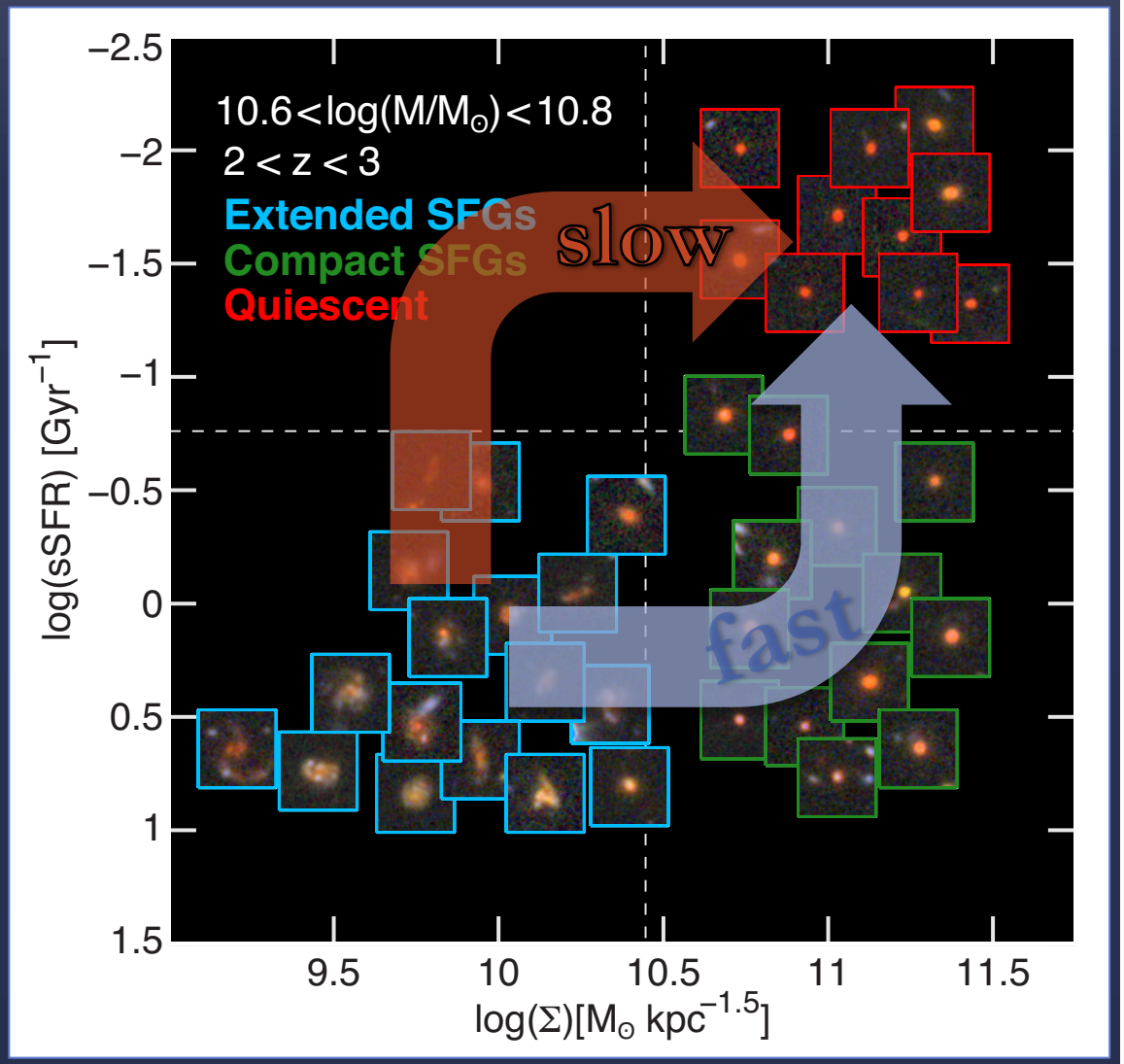
Semi-analytical models from Porter, Somerville+ (2014)

Include:

- Disk instabilities
- Dissipation and star formation in major & minor mergers

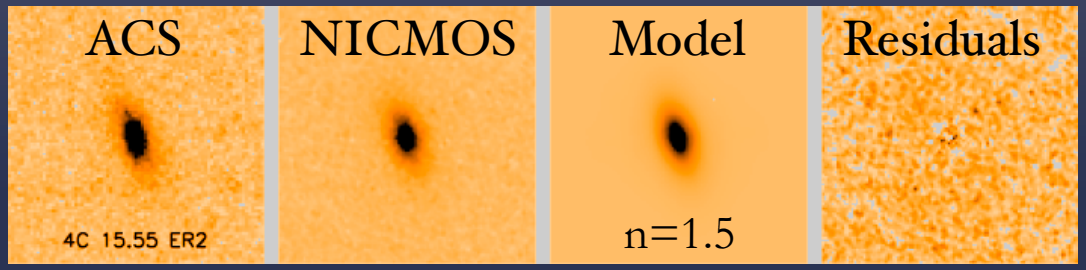
GALAXY EVOLUTION REVEALED BY STRUCTURAL CHANGES

- "Compaction" and quenching
- Extended red galaxies possibly trace a slower quenching pathway.



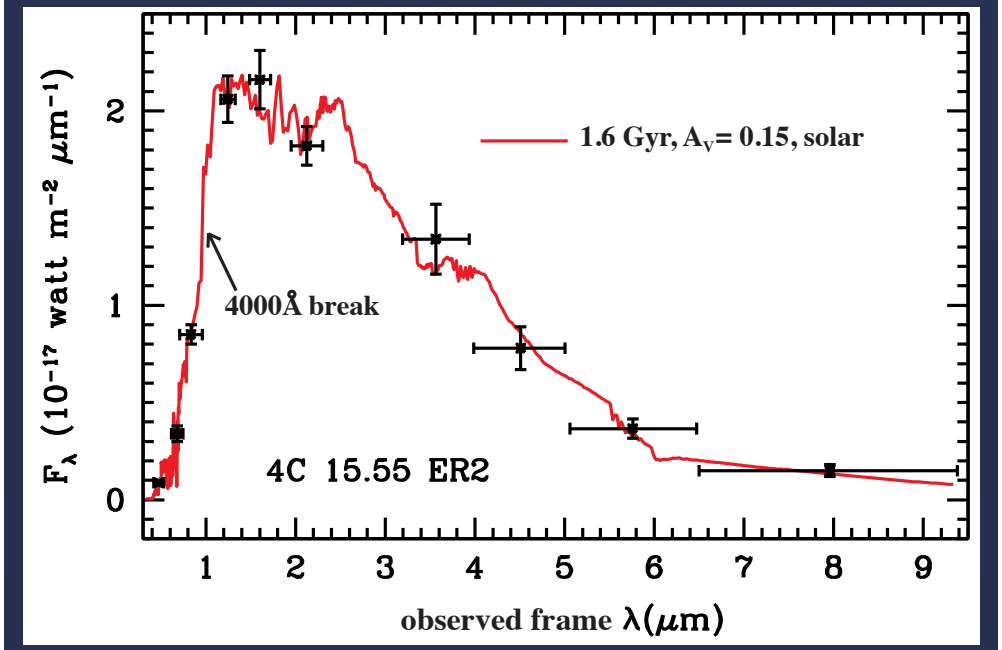
Barro et al. (2014)

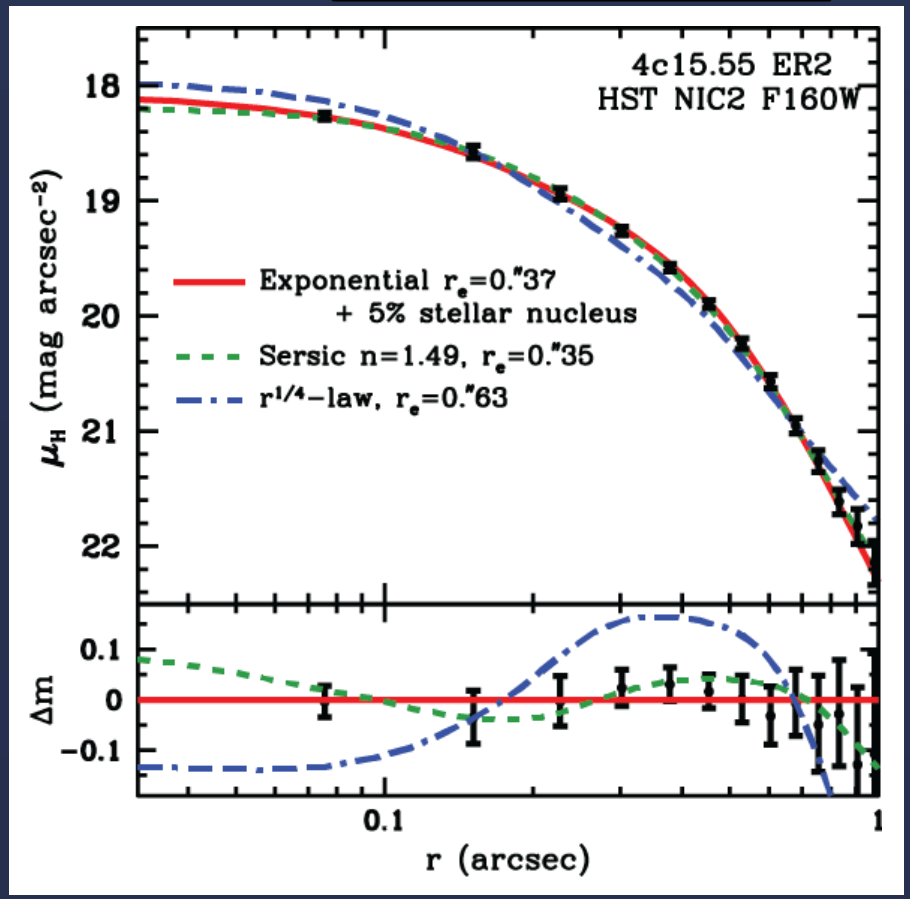
4C15.55 ER2: THE CASE OF A MASSIVE QUIESCENT DISK



$z = 1.4$
$M_* = 2 \times 10^{11}\ M_{sun}$
$n = 1.5$
$R_{eff} = 3.15$ kpc
$B/T = 0.05$

- Some quiescent galaxies are nearly pure exponential disks

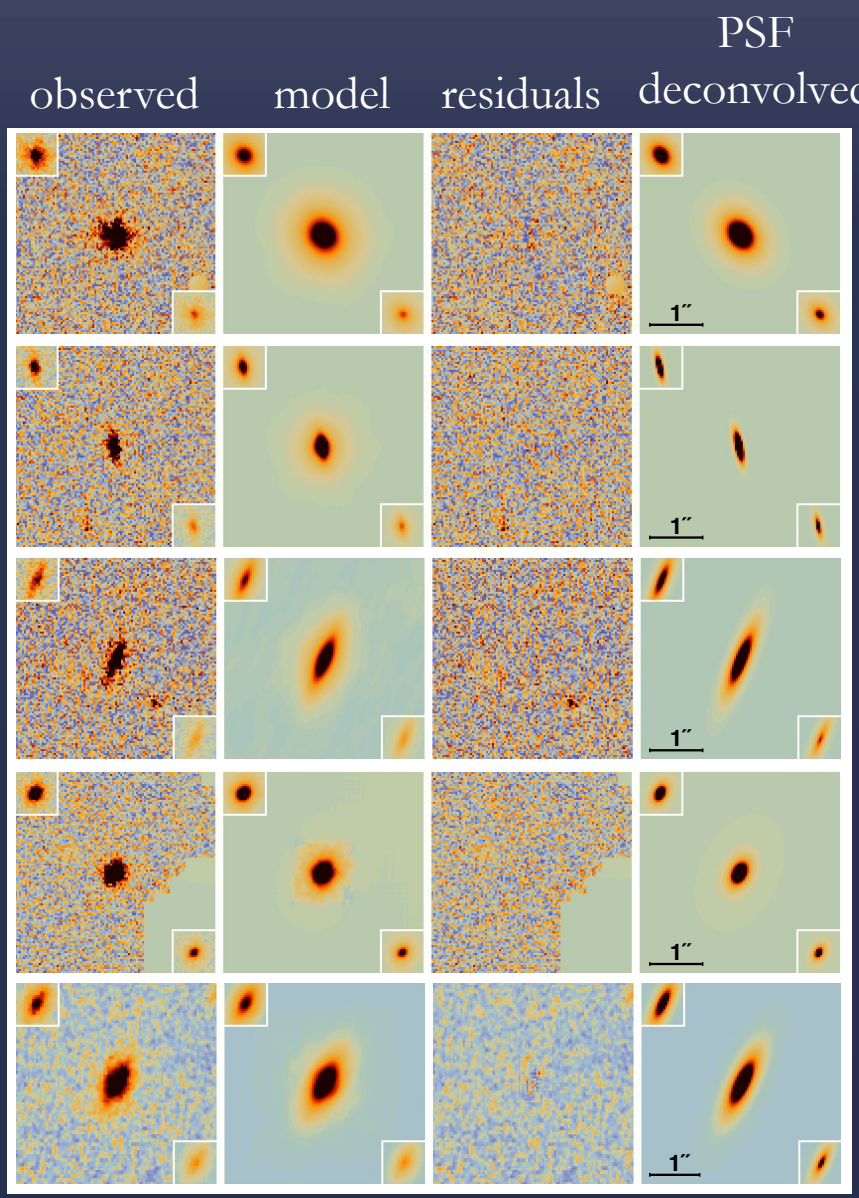




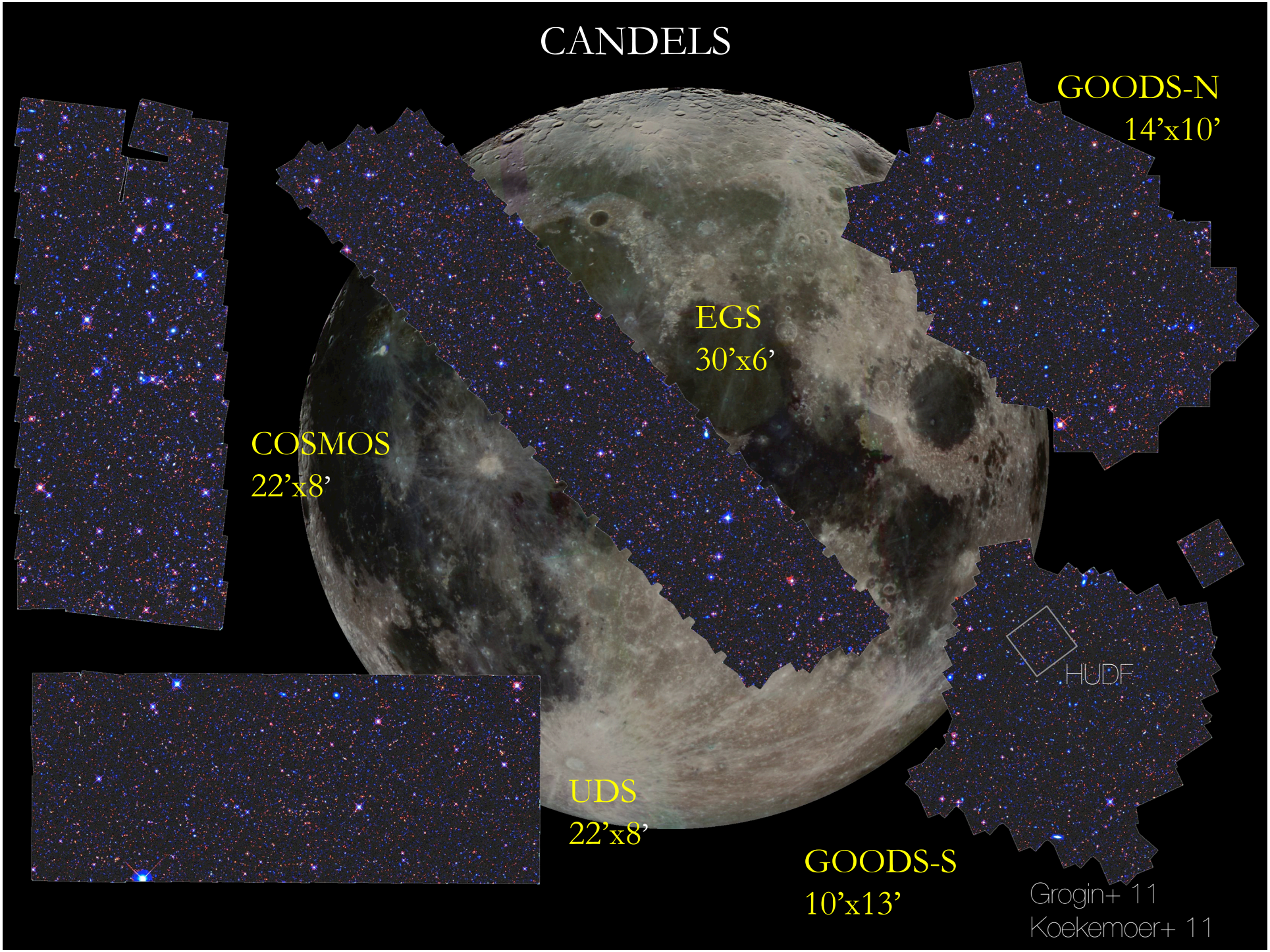
EJM et al. (2007, 2008)

QUIESCENT DISKS

Even more examples at higher redshift (z~2.5):

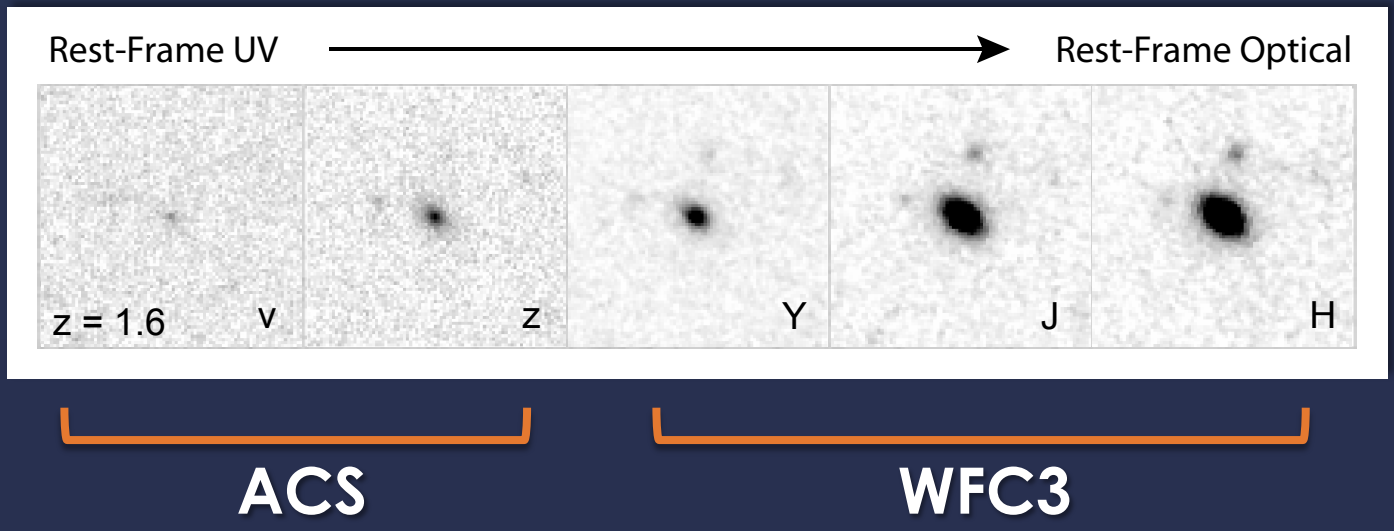


Stockton, EJM, et al. (2008)

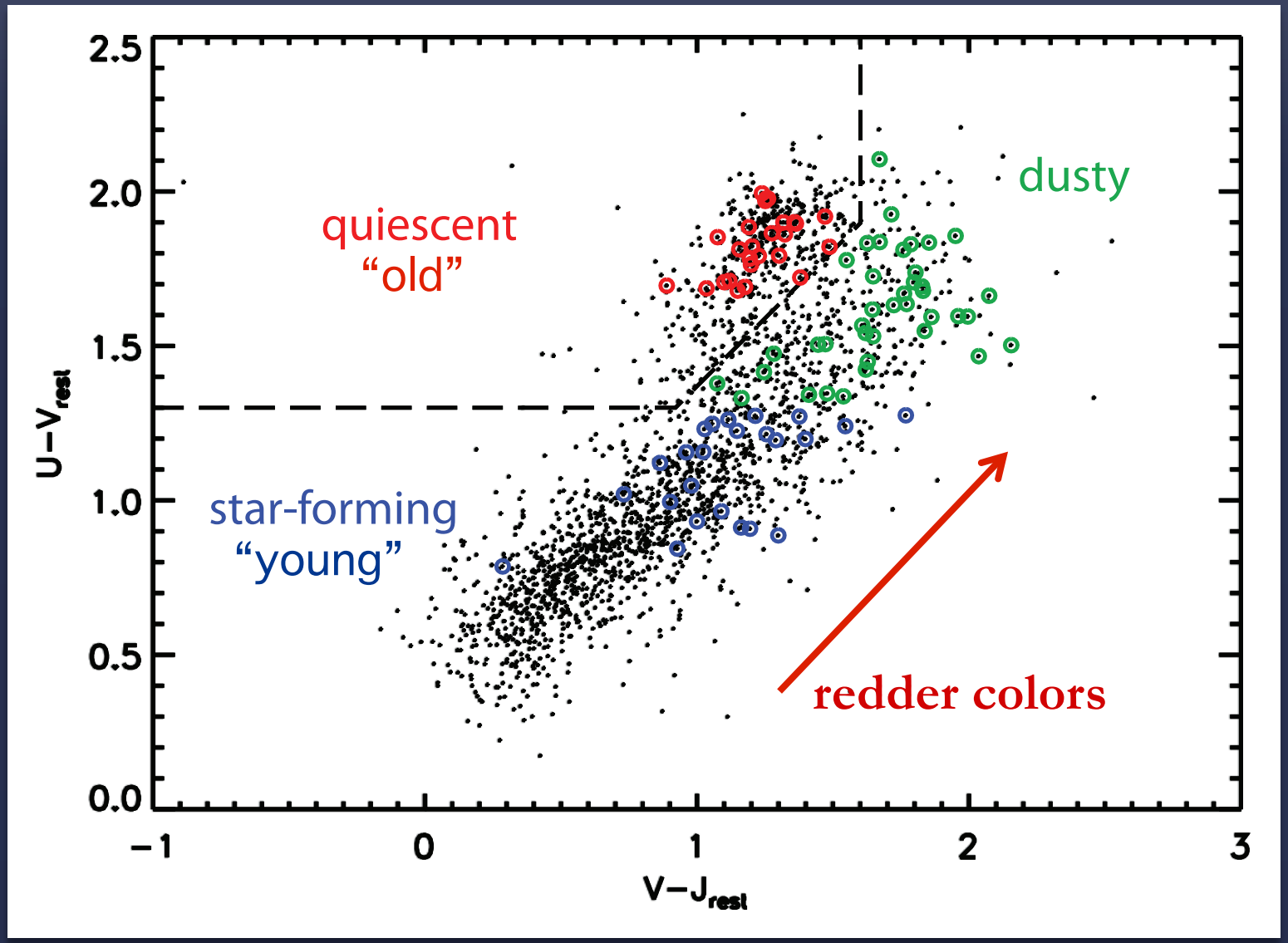

CANDELS
GOODS-N
14'x10'
EGS
30'x6'
COSMOS
22'x8'
HUDF
UDS
22'x8'
GOODS-S
10'x13'
Grogin+ 11
Koekemoer+ 11

CANDELS

- Particularly well-suited to the study of quenched or "passive" galaxies at z~2 that are essentially invisible at shorter, optical wavelengths.



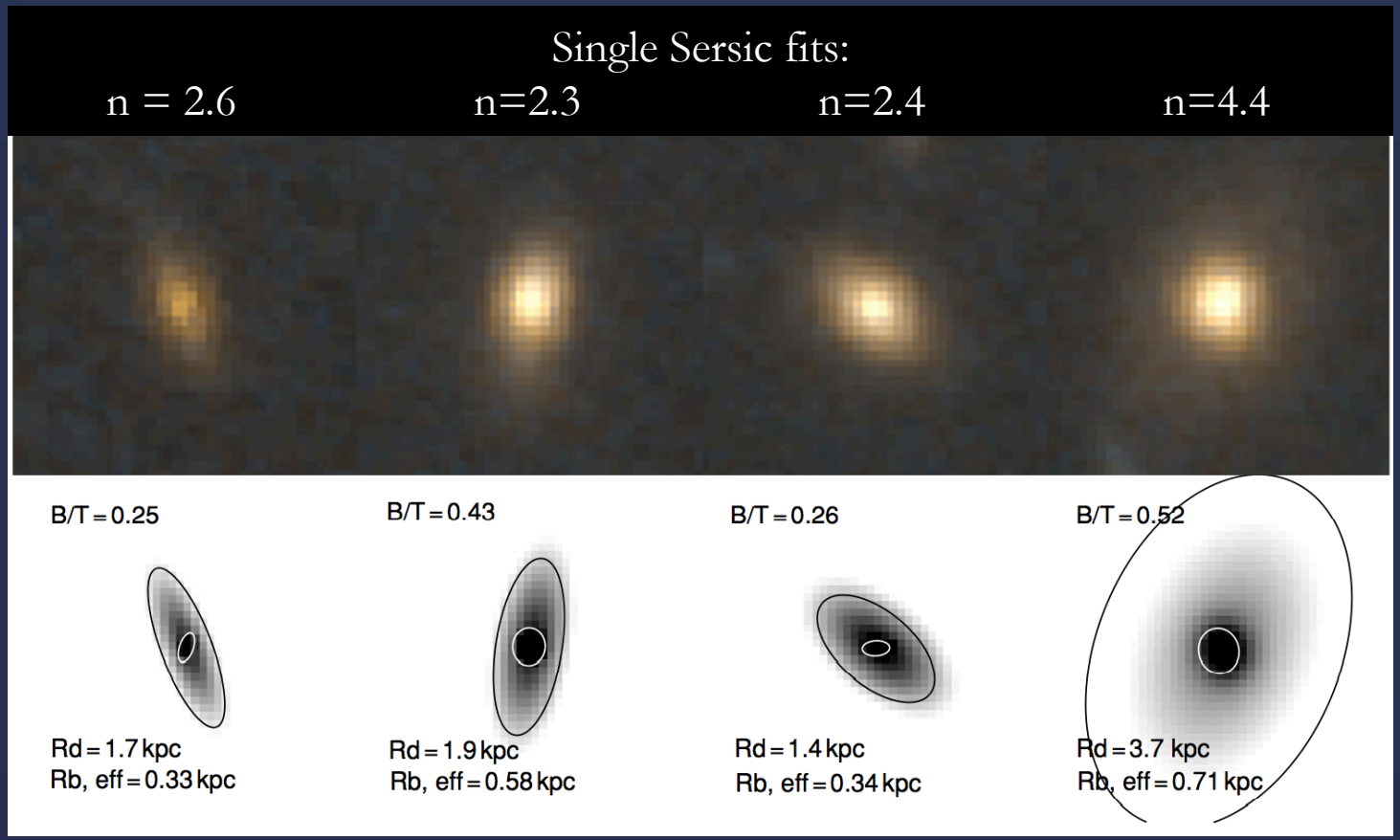
UVJ DIAGRAM: QUIESCENT GALAXY SELECTION



QUIESCENT DISKS

- Closer inspection of "high-Sersic", massive, quiescent galaxies has revealed a number of disk-dominated galaxies.

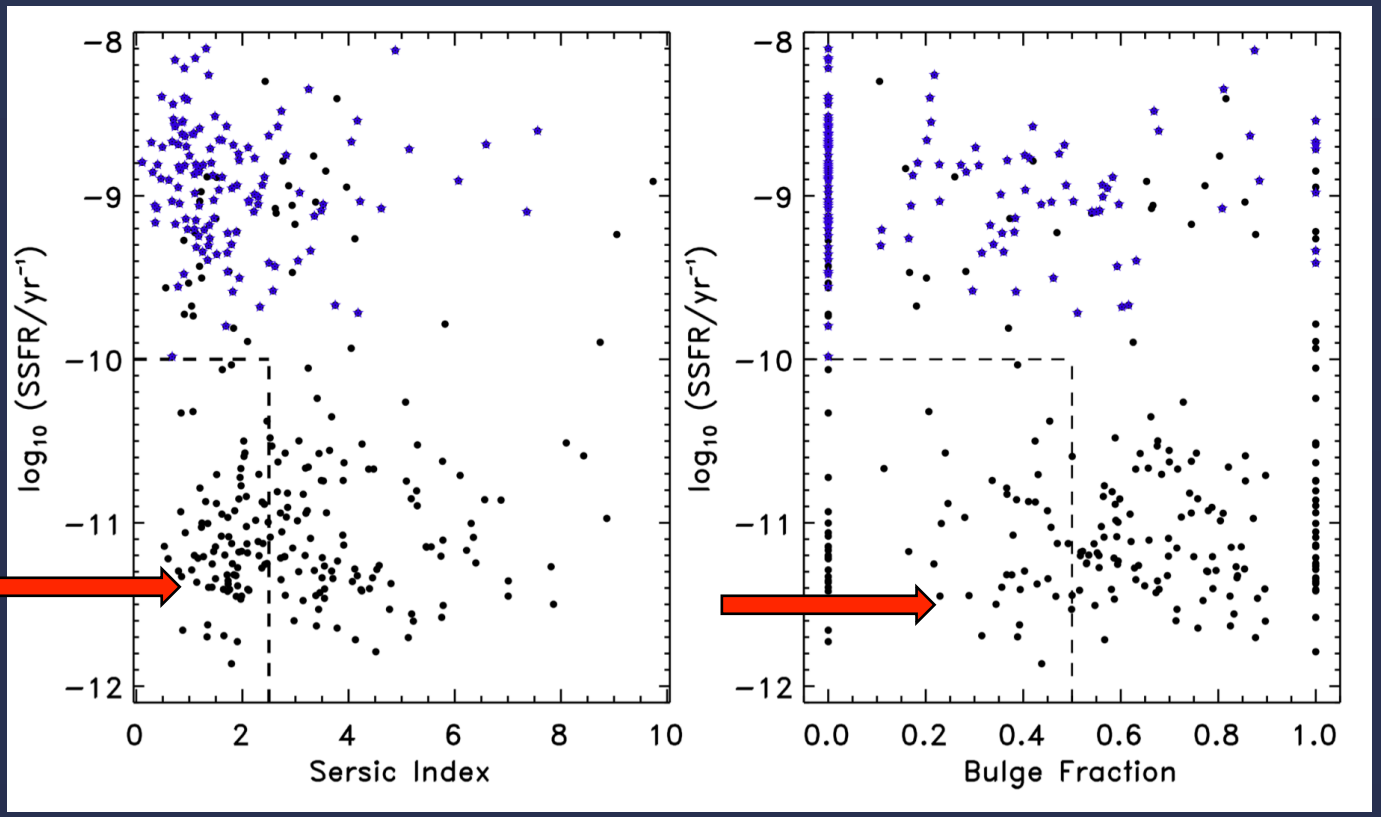
Bulge component < ½ total light



van der Wel+, EJM, et al. (2011)

EXPANDING THE SAMPLE WITH CANDELS

- Using CANDELS, we can now extend previous work to much larger sample sizes
  - Results from UDS & COSMOS fields ($1<z<3$, $M_* > 10^{11}\ M_{sun}$)



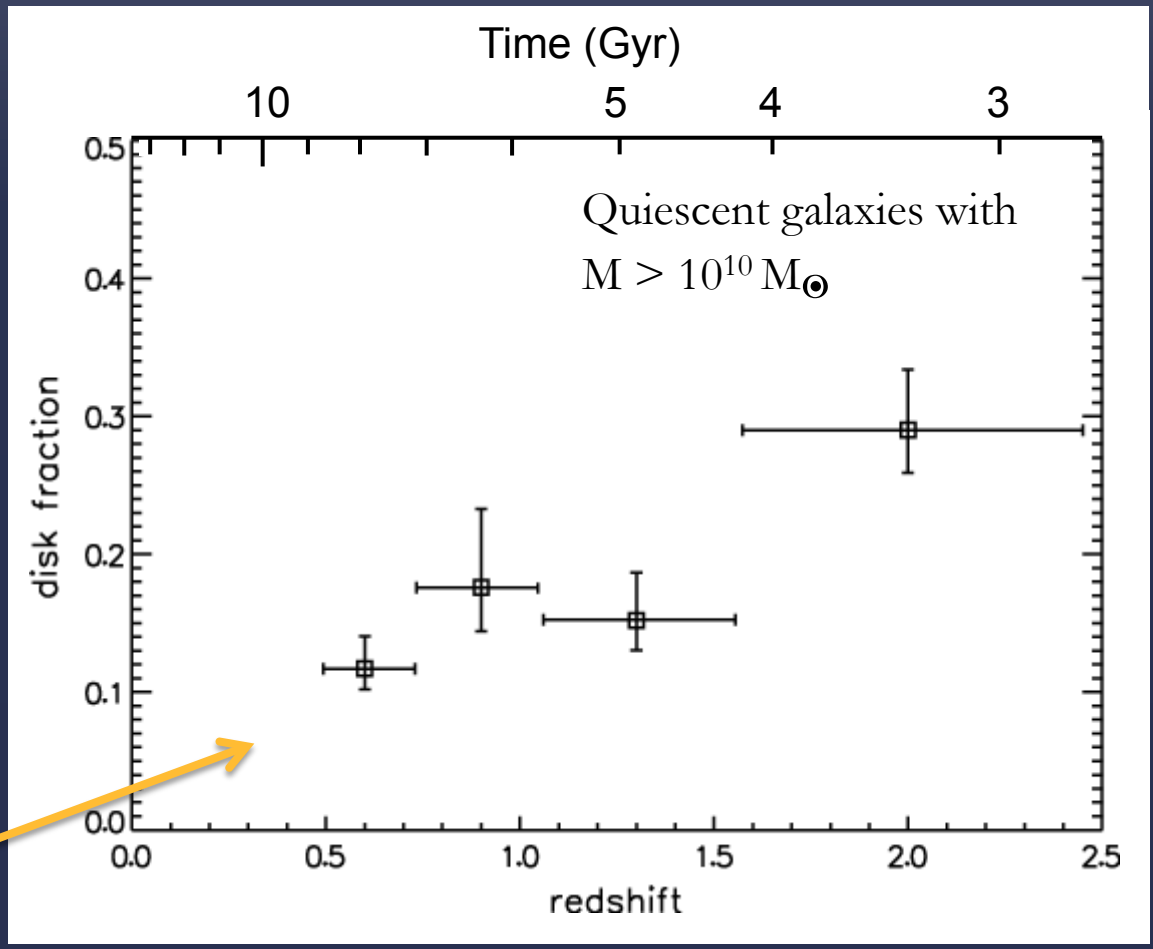
30% of all quiescent galaxies have $n<2.5$

29% of all quiescent galaxies have $B/T < 0.5$

Bruce et al. (2014)

HOW COMMON ARE QUIESCENT DISKS?

- Expanding the sample with CANDELS GOODS-S:
  - Defined to be disks if B/T < 0.5

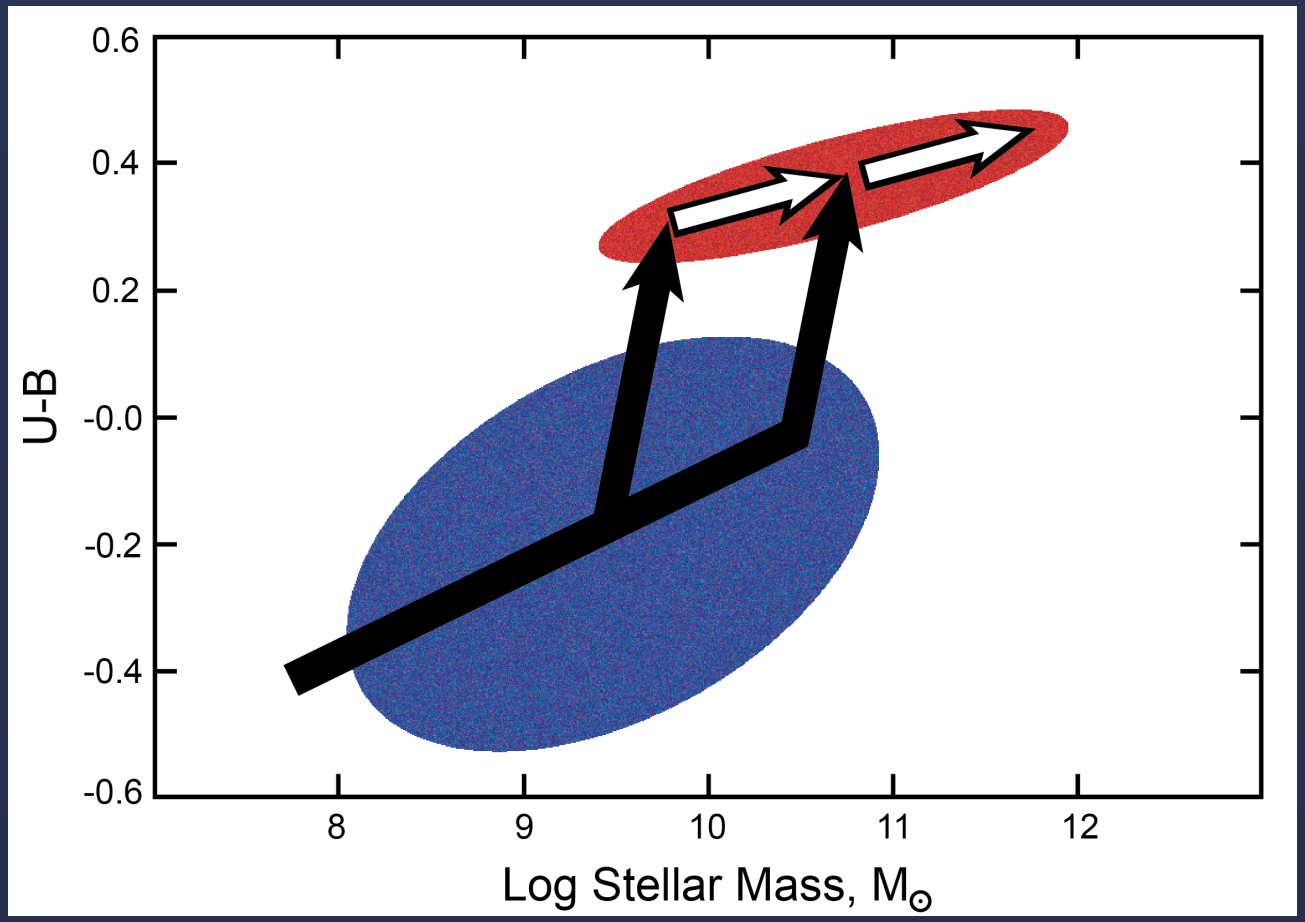


30% are disk-dominated at z~2

EJM, Kesseli, et al. (in prep.)

SEARCH FOR A QUENCHING PARAMETER

- Spheroid formation may not be the (only) trigger that quenches star-formation, but just an end result.



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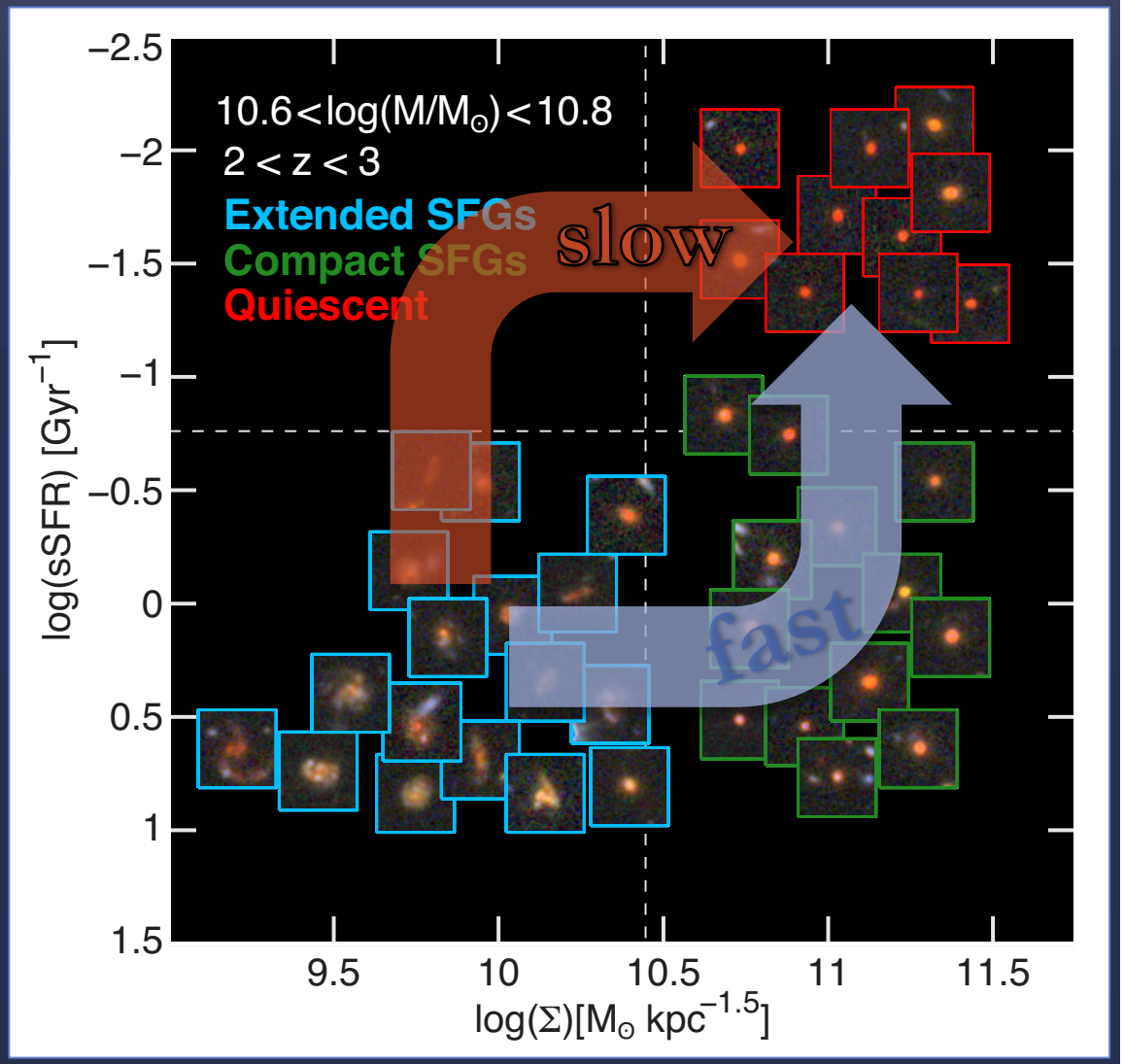

Barro et al. (2014)

SUMMARY

- Massive quiescent disks are common at high-z.
- Mechanism other than major merging is required to build up early massive disks. Cold streams are one likely possibility.
- Need a mechanism to shut down star formation.
  - Violent disk instabilities + AGN feedback? (Can VDI funnel enough gas to the center to feed an AGN without compactifying and/ or building too much bulge?)
  - Possibly slower processes like morphological quenching and halo quenching?
- Mergers important later in "puffing-up" dense galaxies to place them on local size-mass scaling relations and in converting disks to spheroids.