MASSIVE QUIESCENT DISKS AT HIGH-REDSHIFT

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With the CANDELS team, including:

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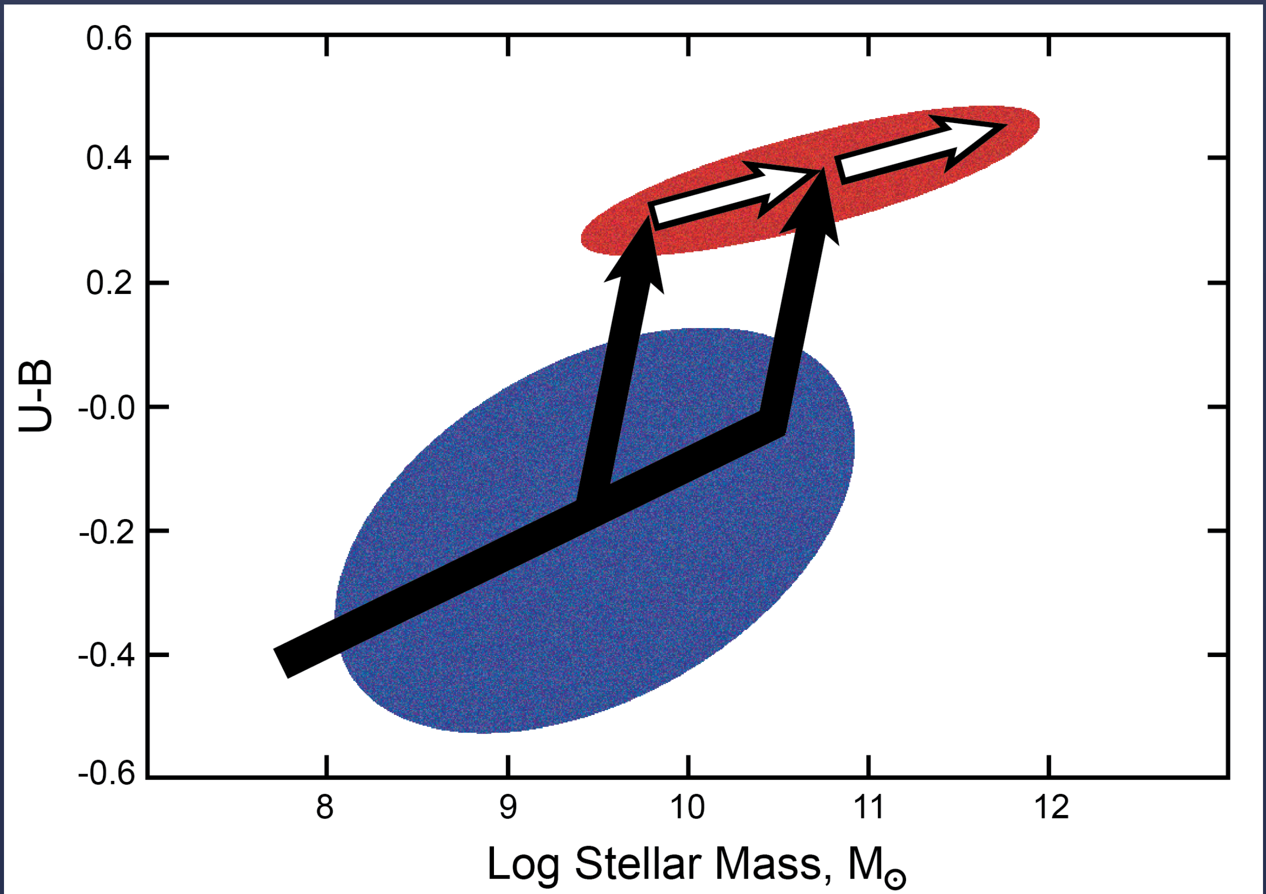
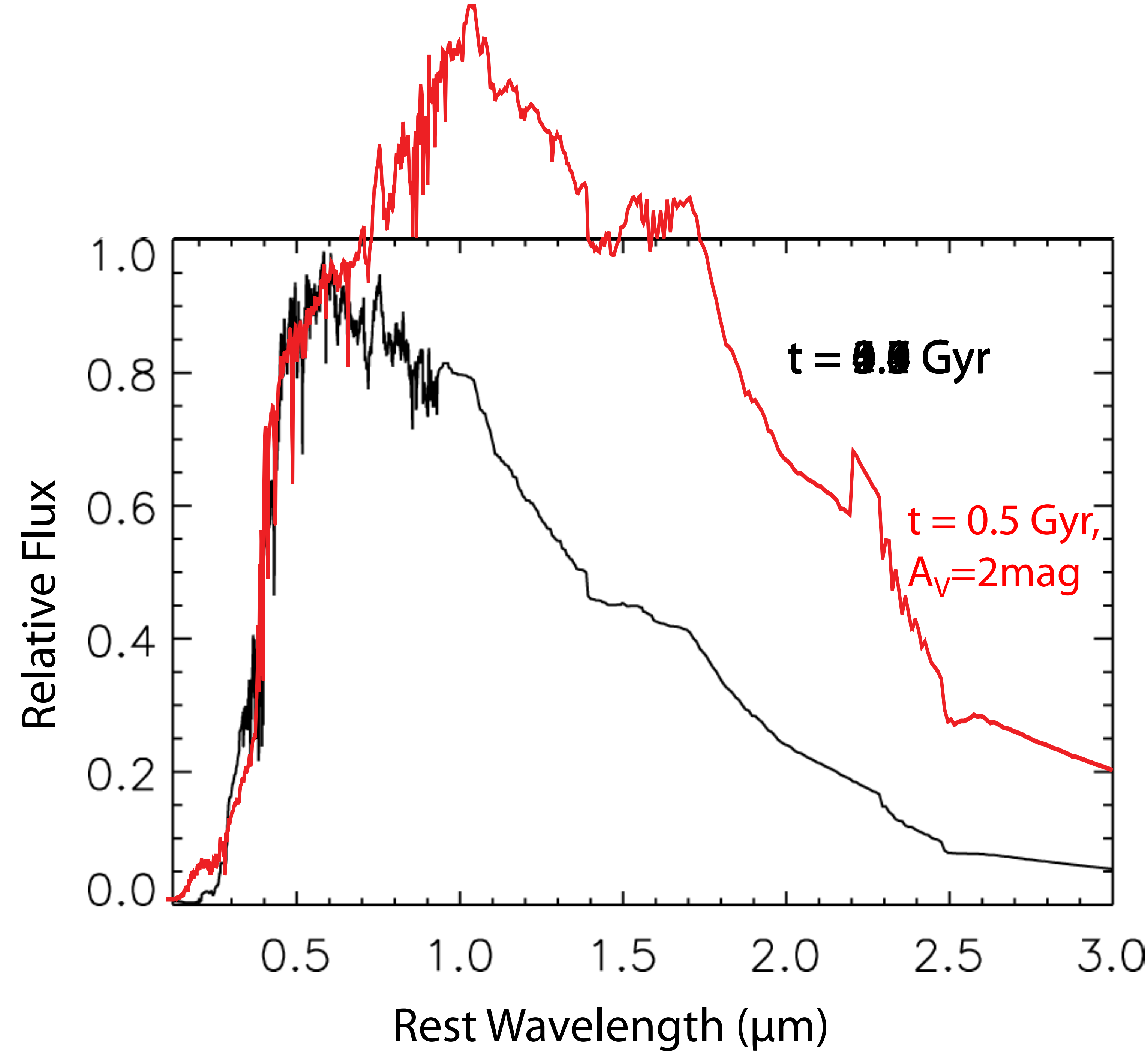
Exponential Disks Workshop 2014, Lowell Observatory

GALAXY BIMODALITY

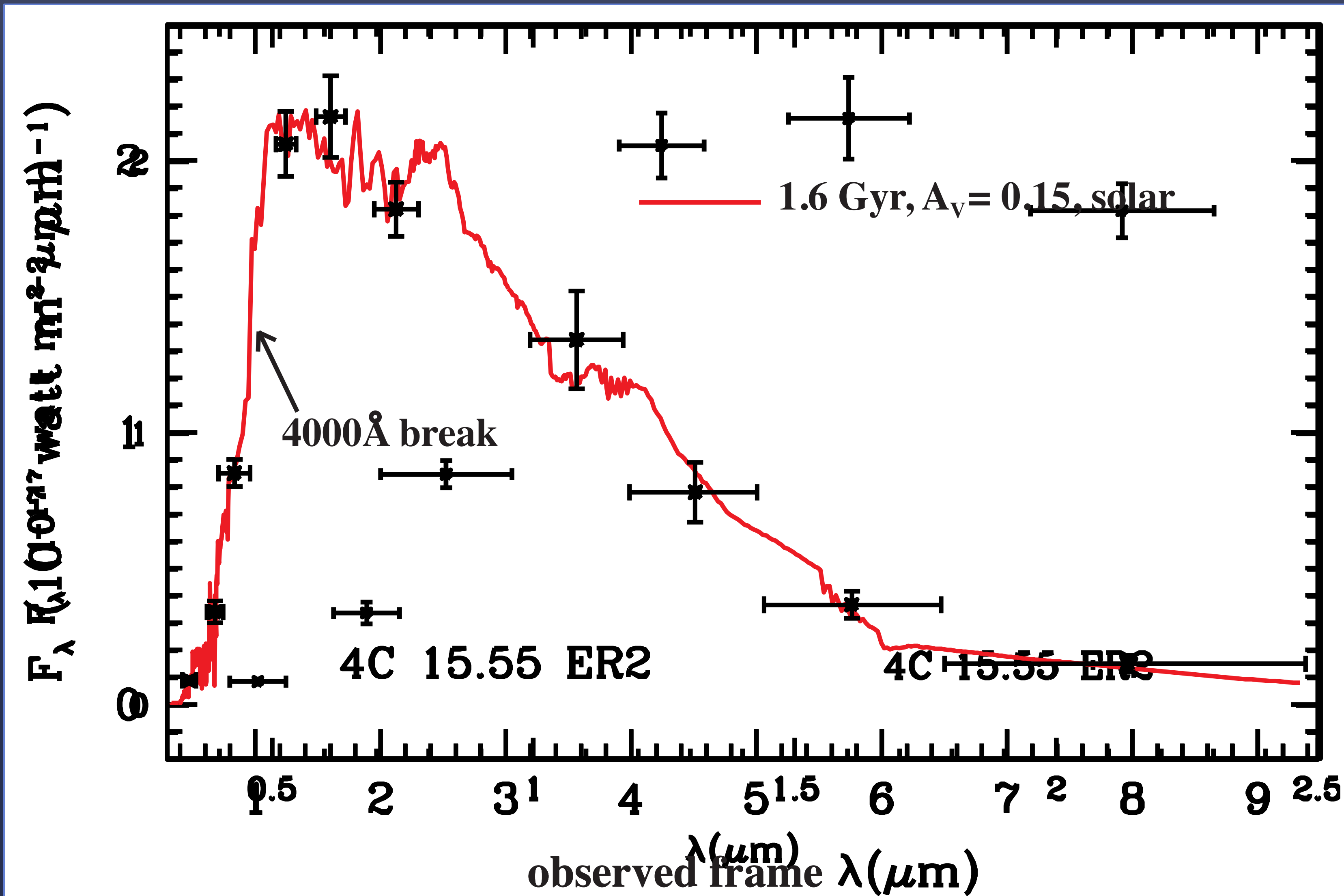


Faber et al. (2007)



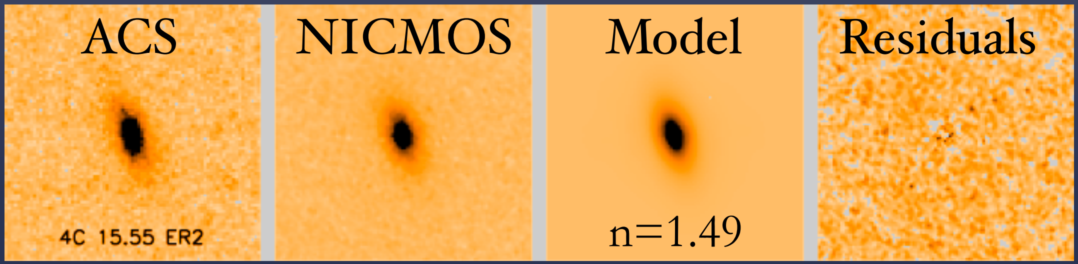
Relative Flux
1.0
0.8
0.6
0.4
0.2
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Rest Wavelength (μm)
t = 0.5 Gyr,
A_V=2mag

SED-FITTING OF ACTUAL HIGH-Z QUENCHED GALAXIES

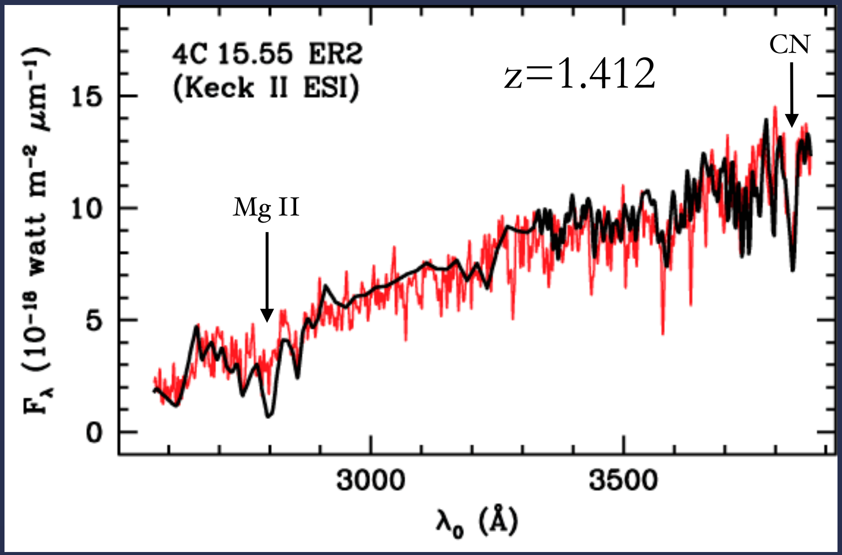


EJM, et al. (2007)

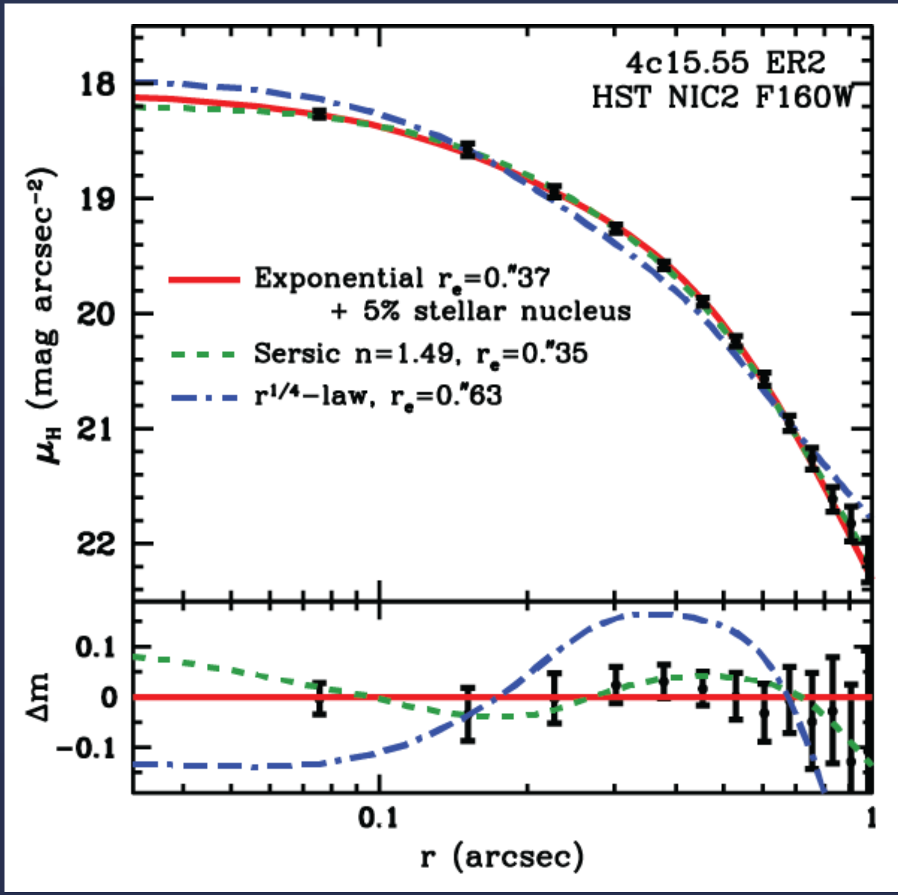
4C15.55 ER2: THE CASE OF A MASSIVE QUIESCENT DISK



- Some quiescent galaxies are nearly pure exponential disks

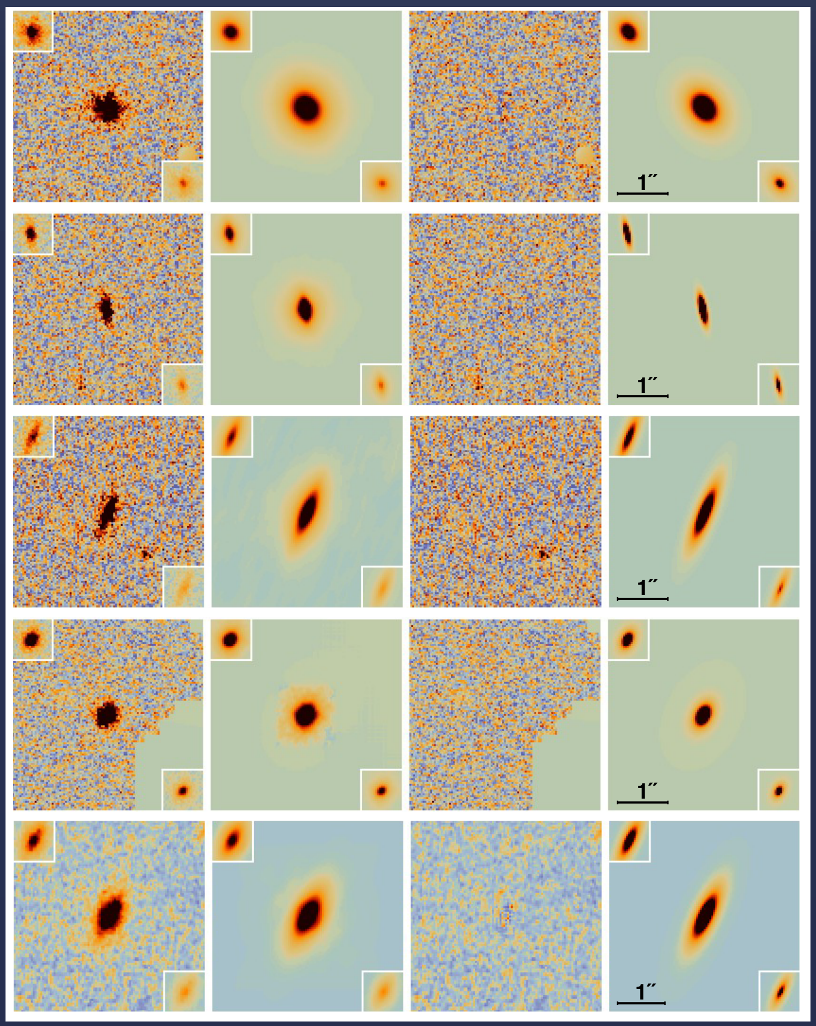


EJM et al. (2007, 2008)



QUIESCENT DISKS

Even more examples at higher redshift ($z\sim2.5$):



Stockton, EJM, et al. (2008)

THE PROBLEM OF QUIESCENT DISKS

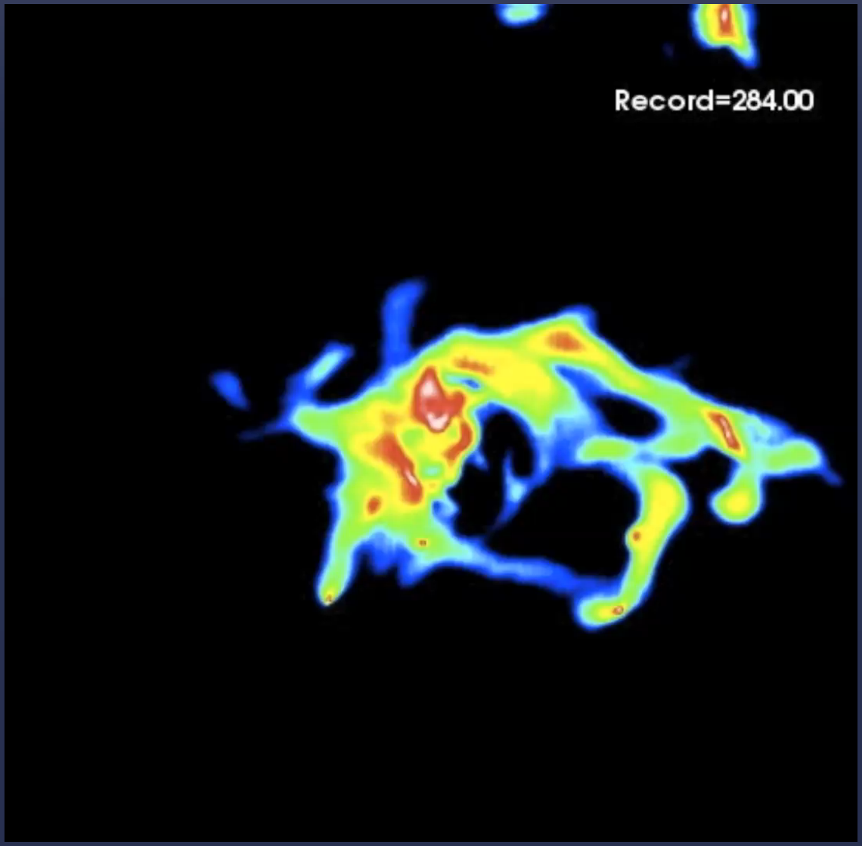
- Formation through Major Mergers?
  - Requires extremely gas-rich progenitors, and even then, difficult to form low bulge fraction disks.

- Formation through cold streams?
  - Streams build-up angular momentum of disk.
  - Can be clumpy or smooth.

Dekel et al. (2009)

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.



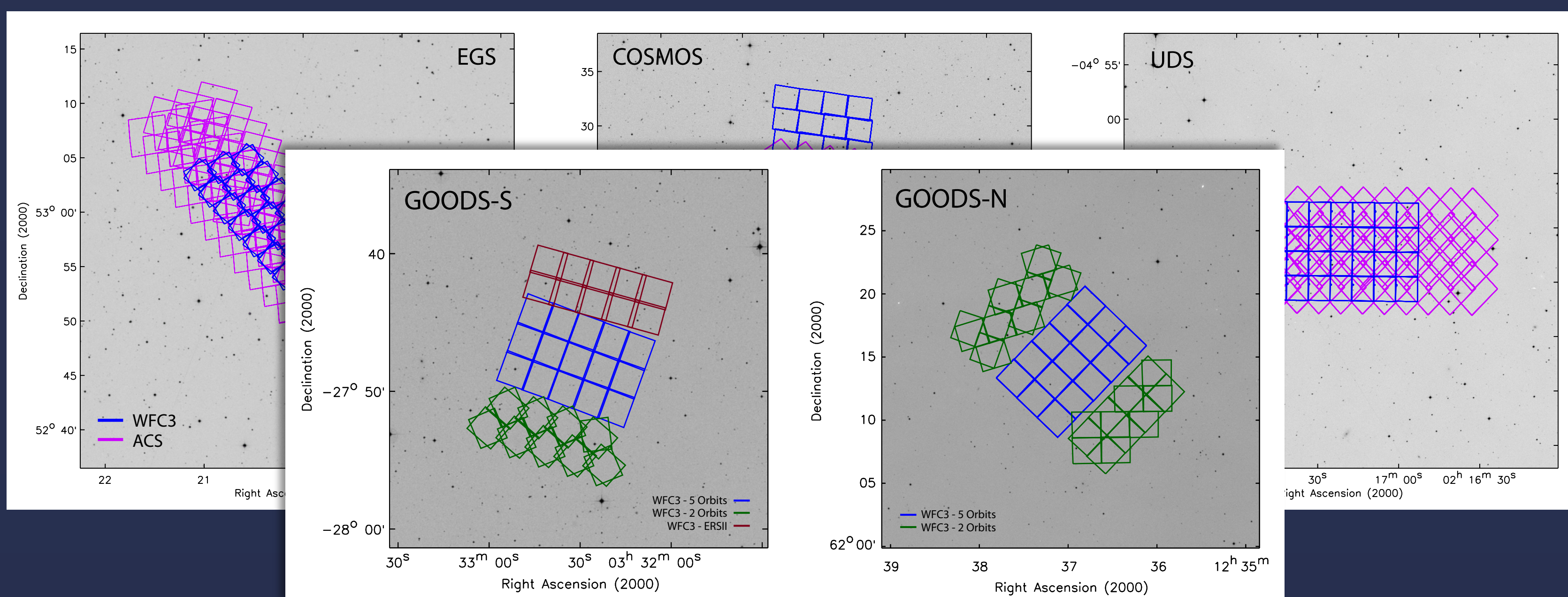
Ceverino, Dekel, Bournaud (2010)

WHAT CAN WE LEARN FROM QUIESCENT DISKS?

- Until recently, sample sizes of high-z quiescent galaxies with high-res imaging have been small.
  - How common are they?
  - How much of the mass is within a typical bulge vs. amount in the disk?

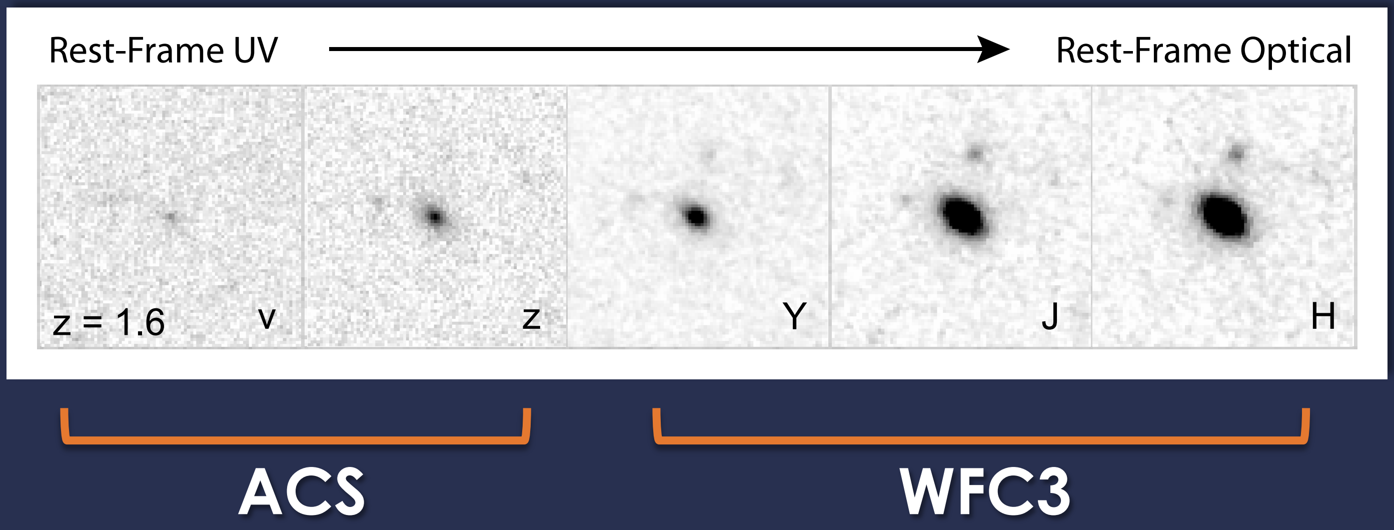
THE POWER OF CANDELS

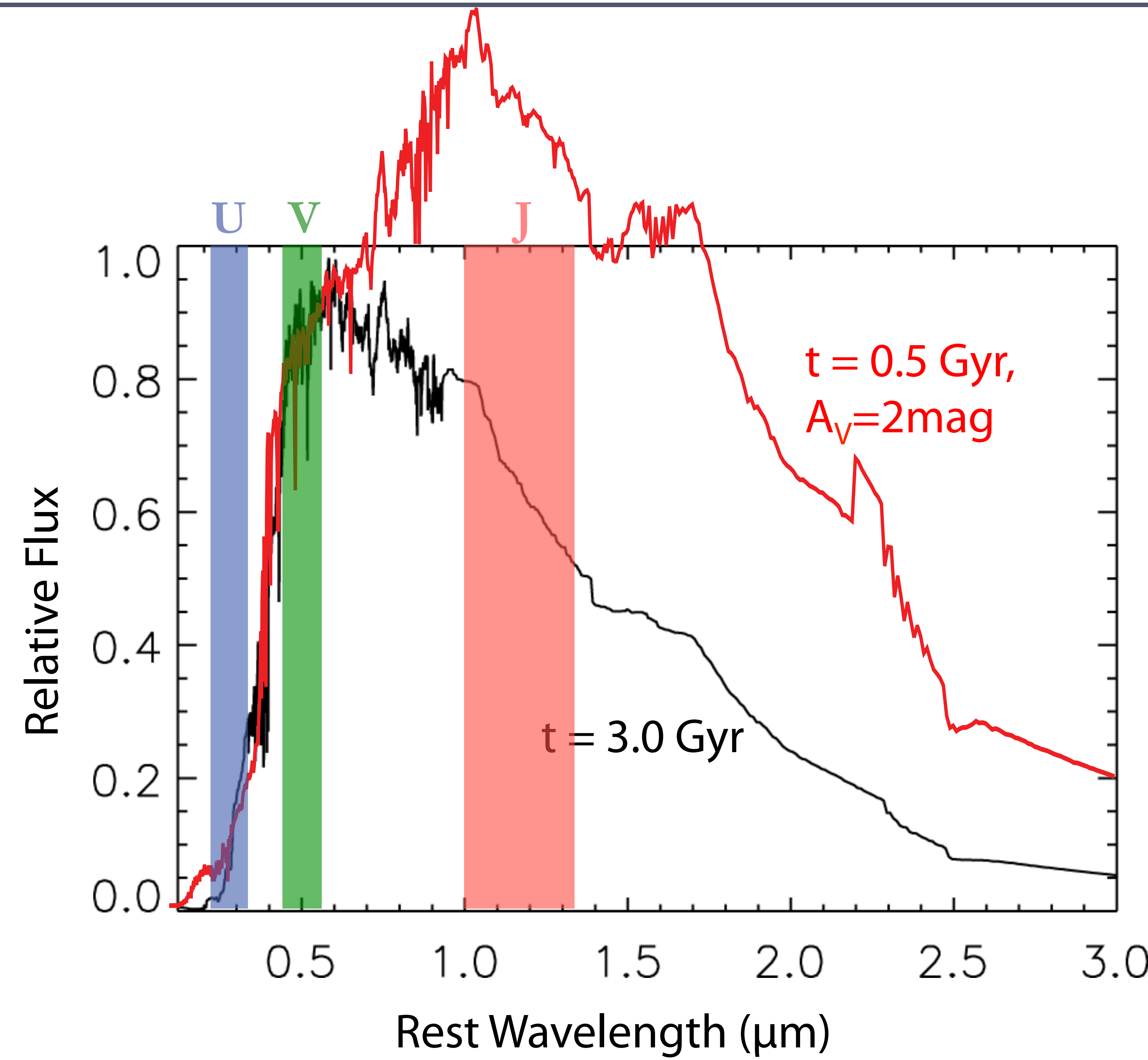
- **Wide** Program: 2 orbit depth, ~0.2 sq. deg.
  - EGS, COSMOS, & UKIDSS/UDS
- **Deep** Program: 12 orbit depth, ~0.04 sq. deg.
  - GOODS-S, GOODS-N



THE CANDELS PROJECT

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




U
V
J
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0.8
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Relative Flux
0.5
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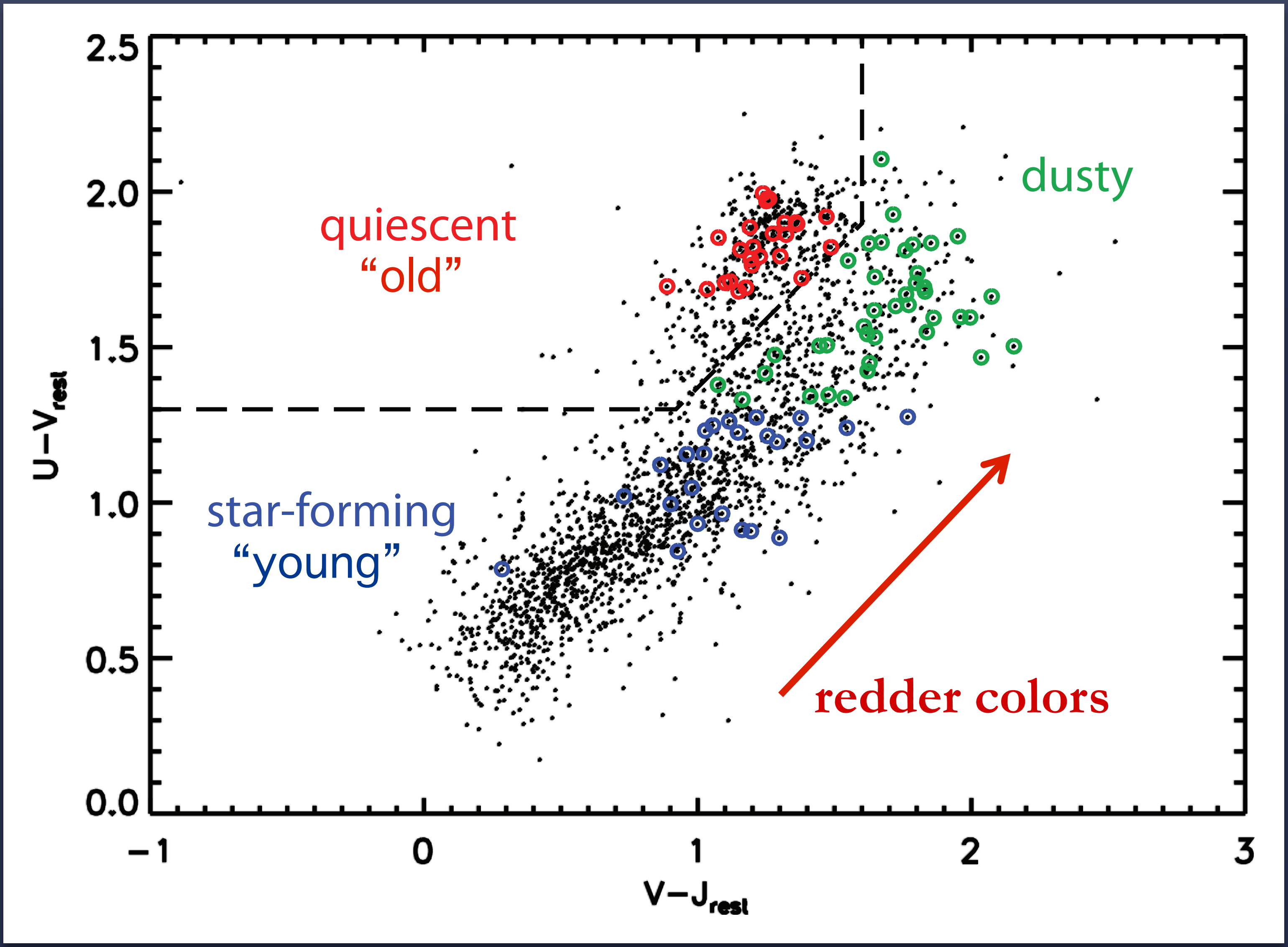
3.0
Rest Wavelength (µm)
t = 0.5 Gyr,
A$_V$=2mag
t = 3.0 Gyr

UVJ DIAGRAM: QUIESCENT GALAXY SELECTION



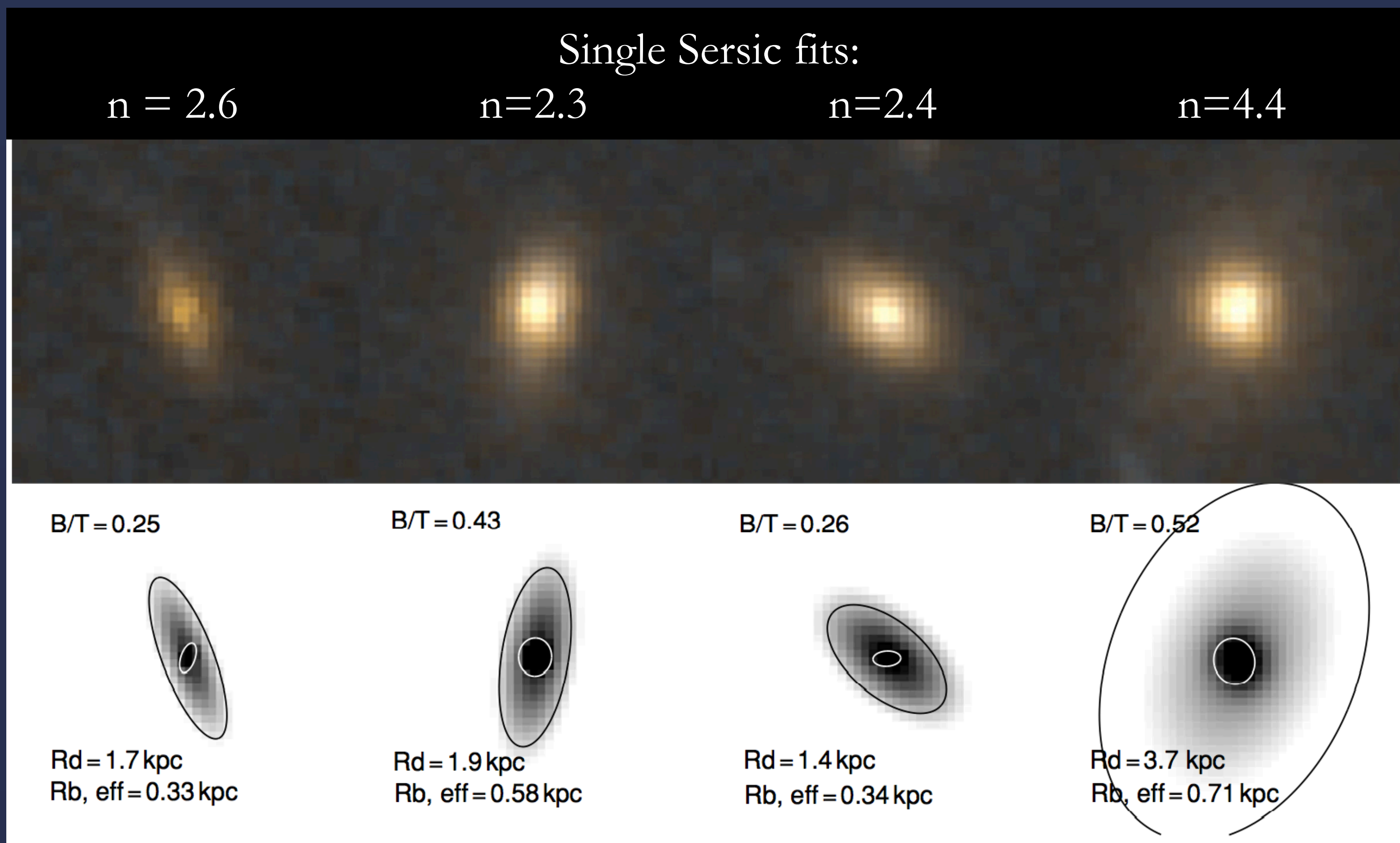
DETAILED MORPHOLOGY STUDIES

- Real galaxies aren't as simple as pure disks or pure ellipticals.
- By convention, Sersic
  $n<2.5$ = disk-like
  $n>2.5$ = spheroidal
- With good data we can decompose an image of a galaxy into its subcomponents

QUIESCENT DISKS

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

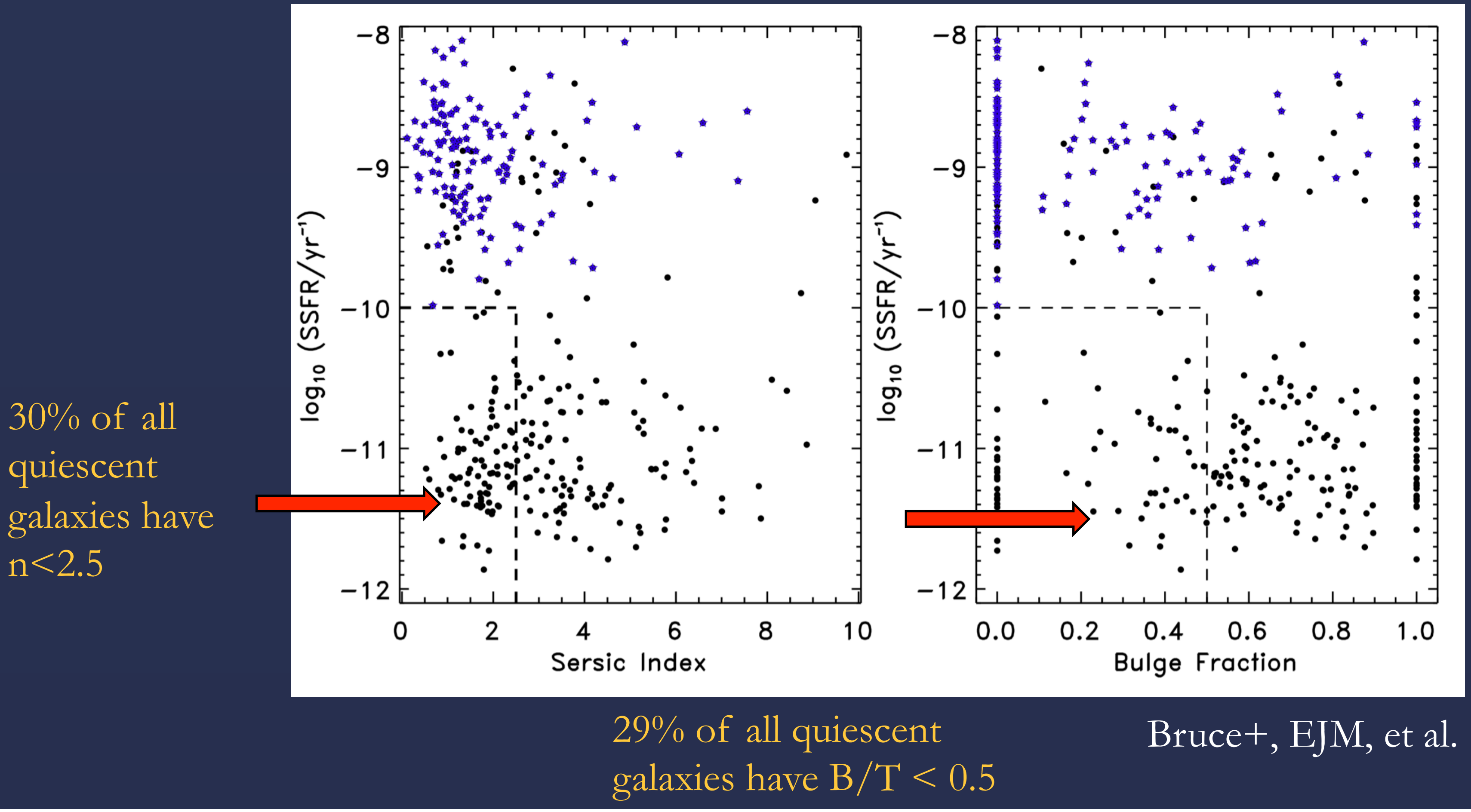
Bulge component < ½ total light



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

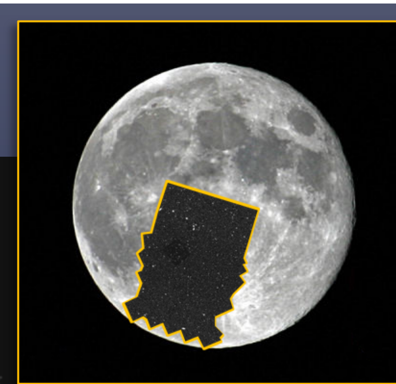
EXPANDING THE SAMPLE WITH CANDELS

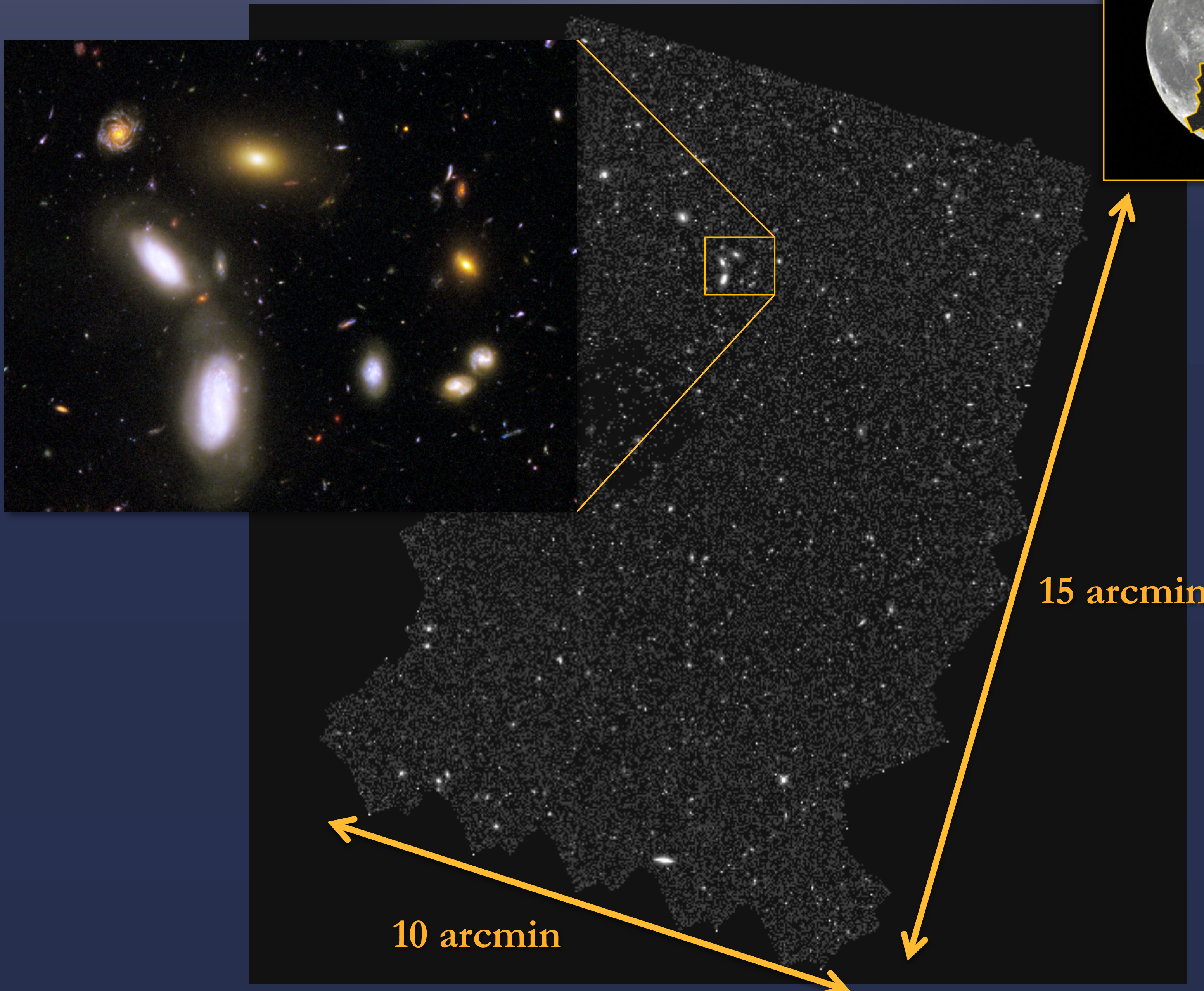
- Using CANDELS, we can now extend previous work to much larger sample sizes
  - Results from UDS & COSMOS fields ($1<z<3$, $M_*>10^{11}$ M_{sun})



Bruce+, EJM, et al. (2014)

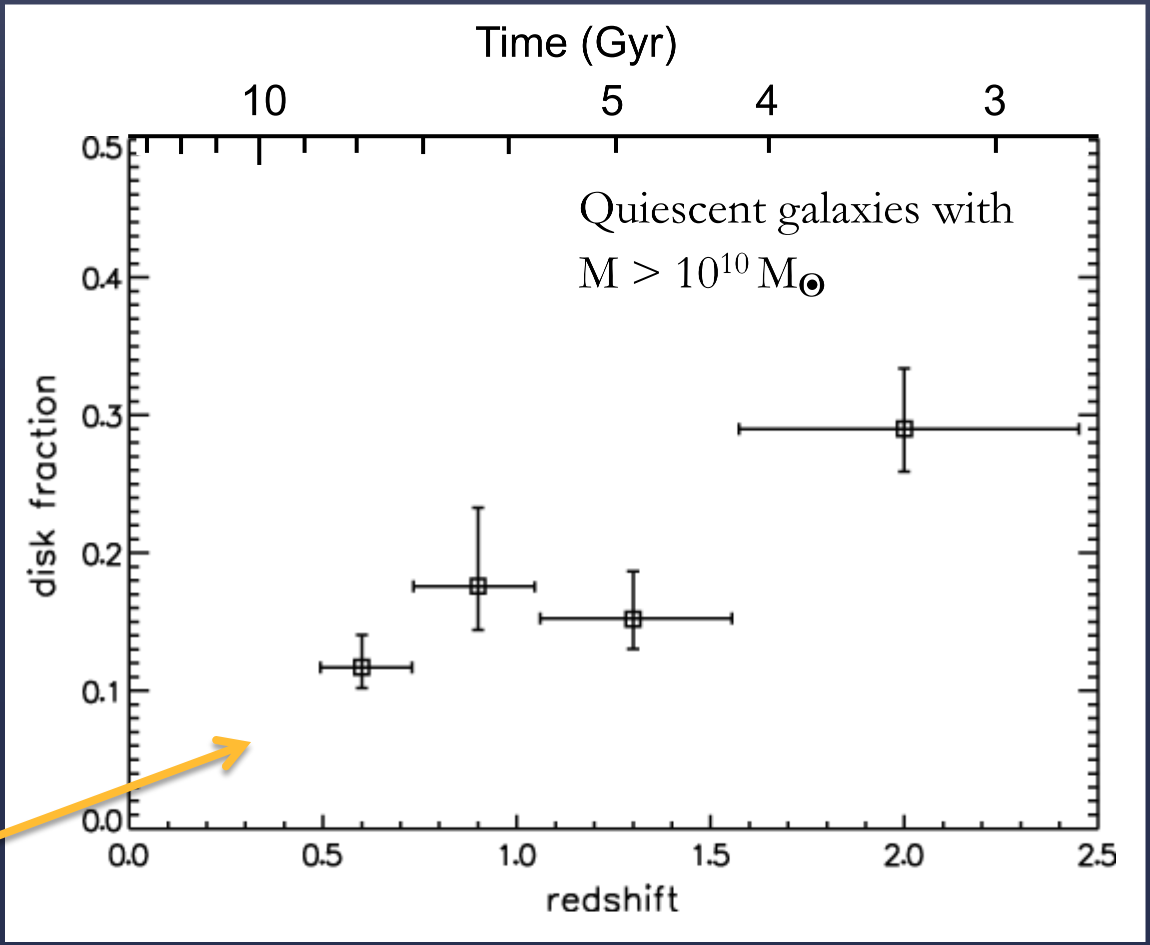
THE GOODS-S FIELD





HOW COMMON ARE QUIESCENT DISKS?

- Expanding the sample with CANDELS GOODS-S:
  - Defined to be disks if B/T < 0.5
  - Redshift bins spaced equally in time.

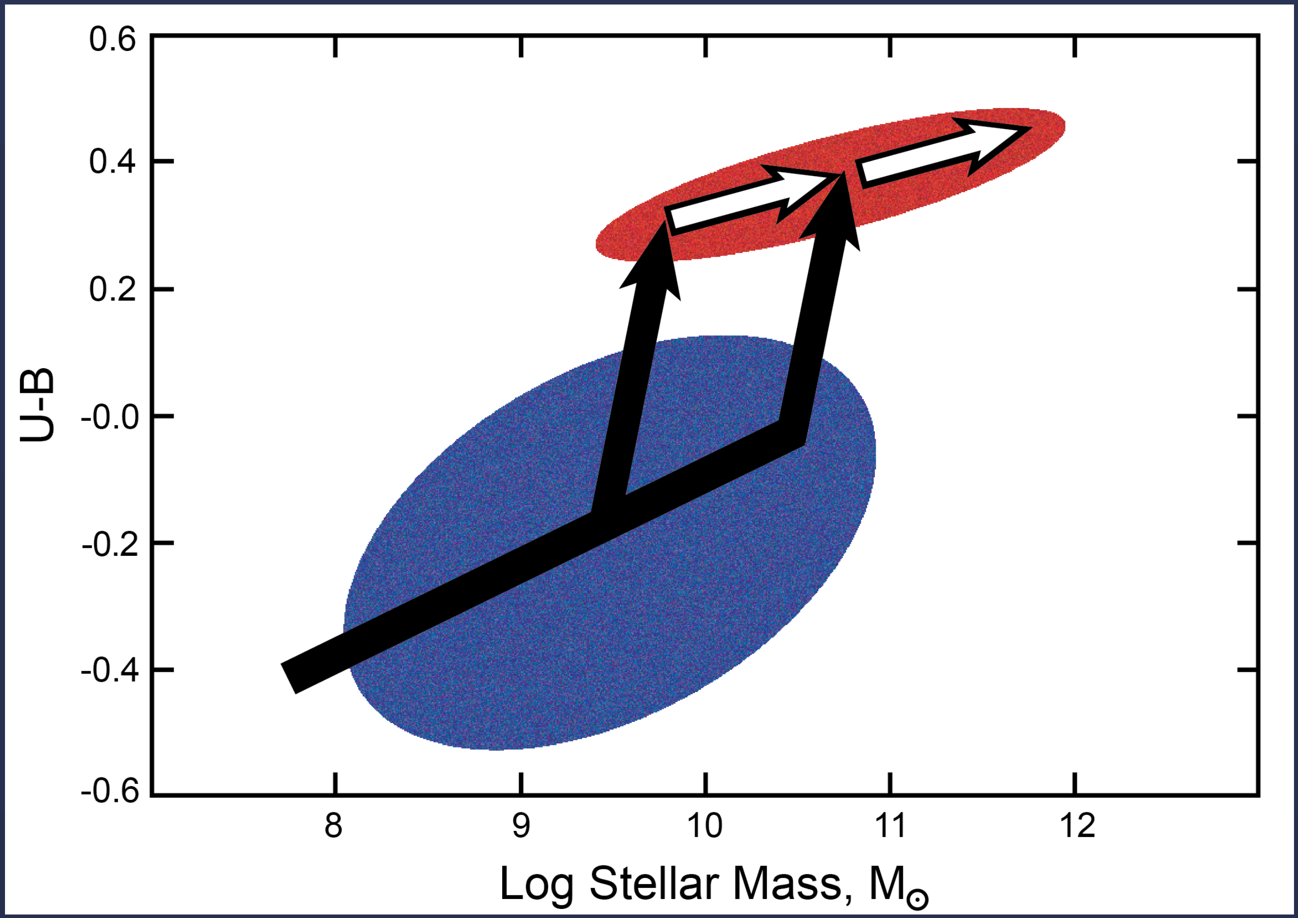


30% are disk-dominated at z~2

EJM, Kesseli, et al.(2014)

SEARCH FOR A QUENCHING PARAMETER

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



THE PROBLEM OF QUIESCENT DISKS

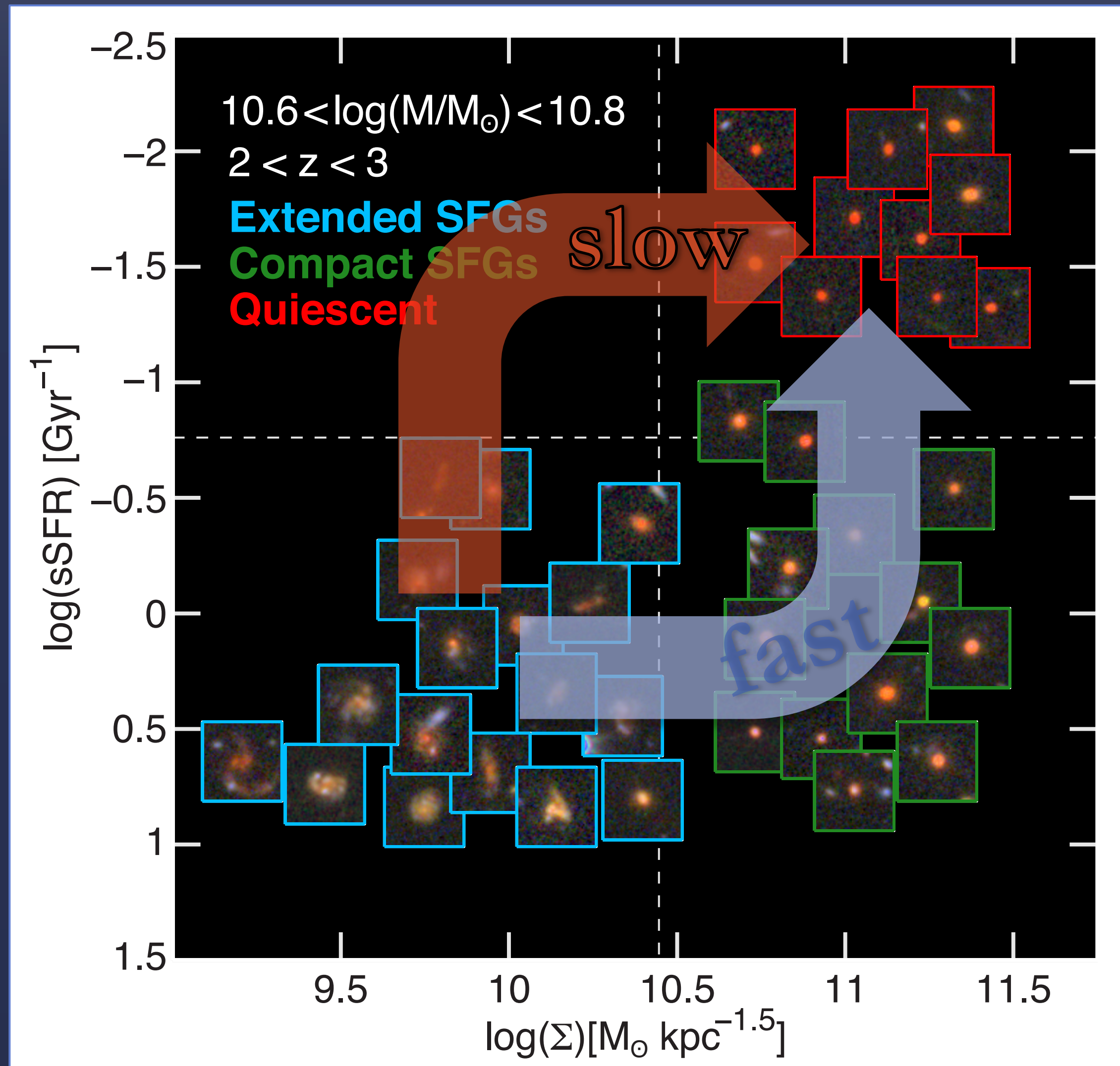
- What quenches the star-formation after disk is assembled?
  - Leading theories:

fast ↓ slow

1. AGN feedback (internal process)
   - Hydrodynamic & Radiative processes expel and heat gas
   - To fuel black hole, need to funnel gas to the center of the galaxy (e.g., mergers, violent disk instabilities?, bar instability?)
2. Morphological Quenching (internal process)
   - Growth of bulge stabilizes disk against gravitational instabilities
3. Halo quenching (external process)
   - Dark matter halo becomes massive enough that it shock-heats gas, preventing further collapse.

GALAXY EVOLUTION REVEALED BY STRUCTURAL CHANGES

- Compact blue nuggets as progenitors to massive red nuggets
- “Fast track” vs. “Slow track”



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. Possibly AGN, but how to feed the black hole without mergers?
  - Violent disk instabilities? (Can VDI funnel enough gas to the center without compactifying galaxy too much?)
  - 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.