The evolution of quiescent galaxies over 11 Gyr

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Ivo Labbé, Mariska Kriek, Sune Toft

Galaxies at z~0

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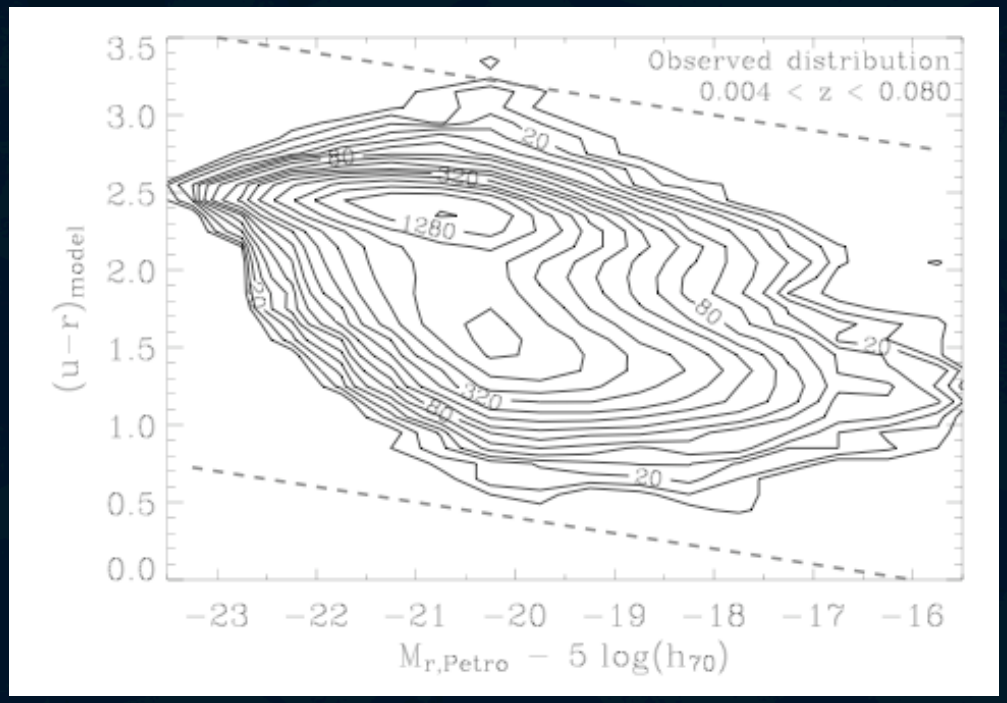
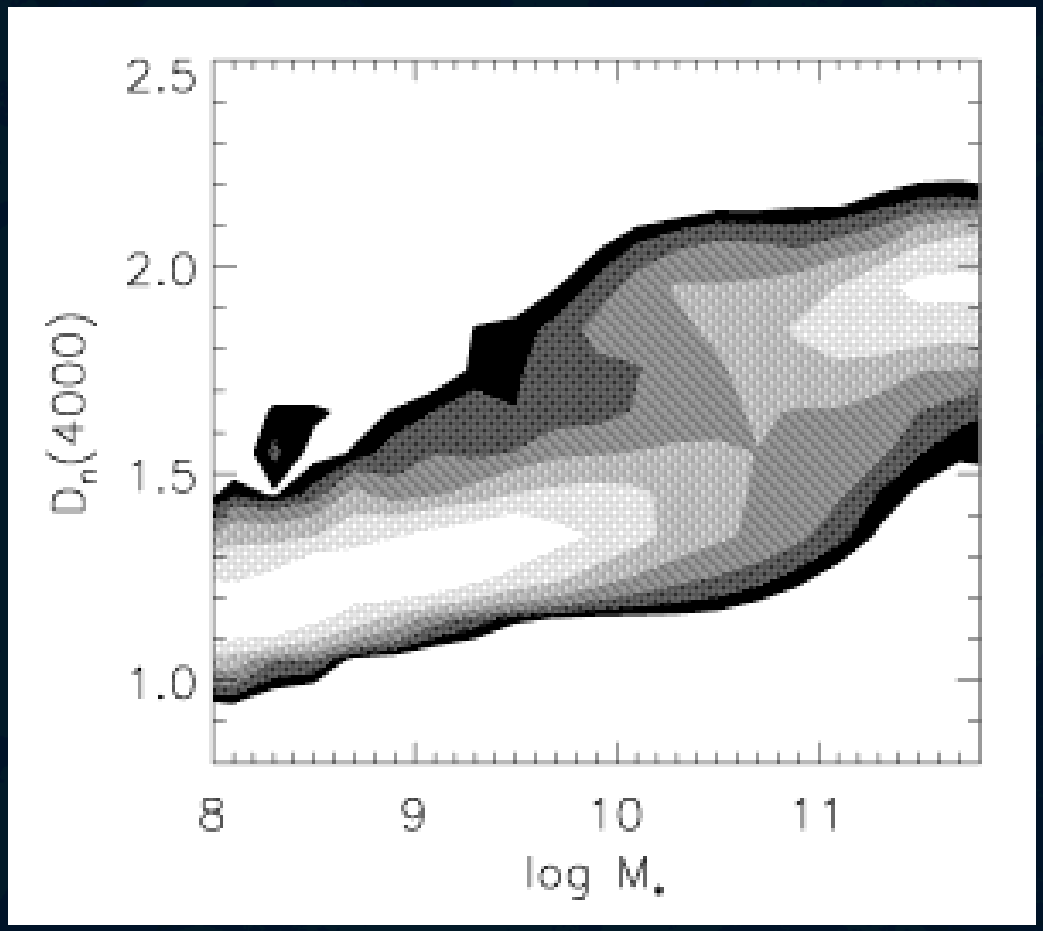
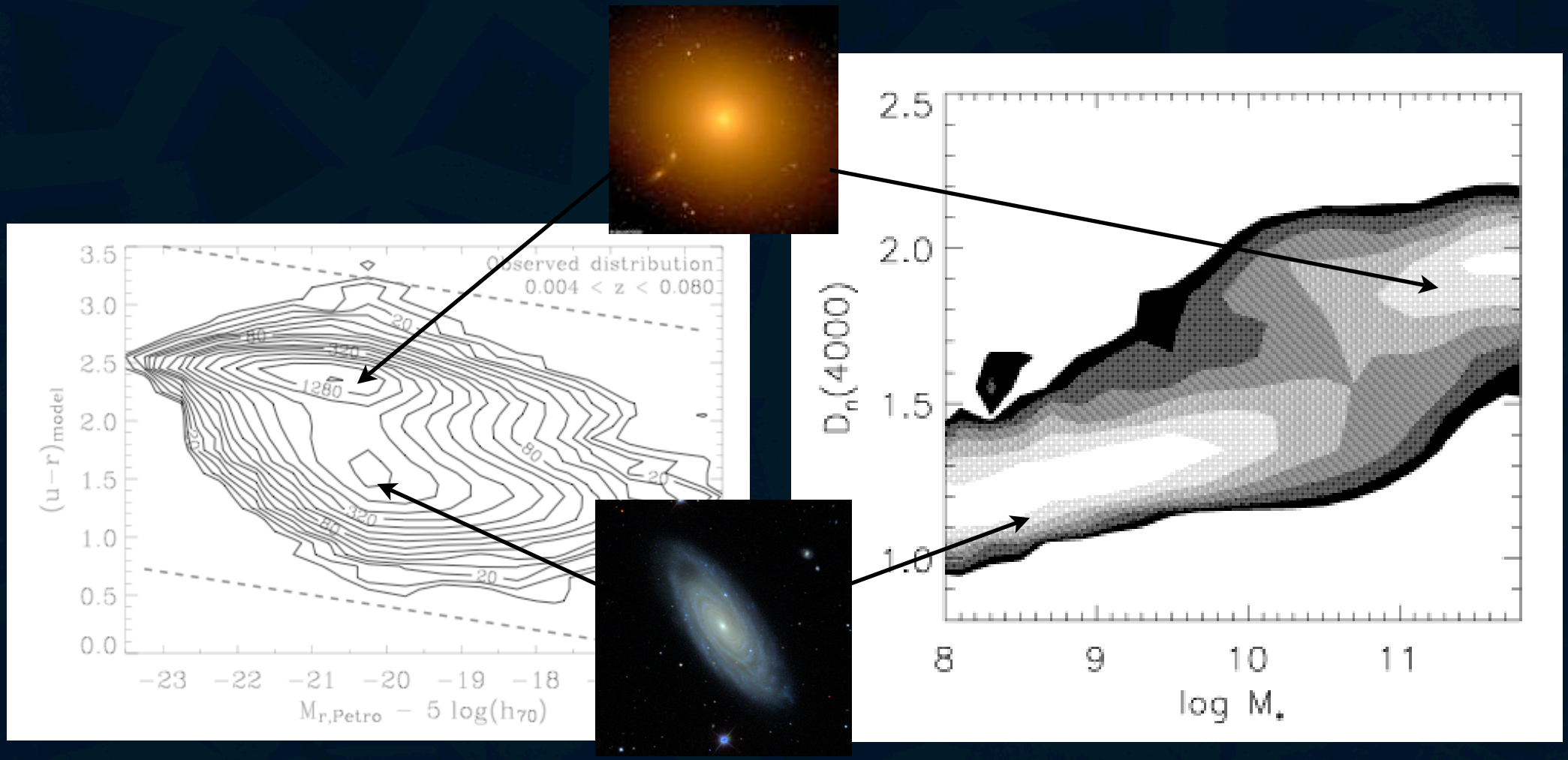


Baldry et al. (2004)



Kauffmann et al. (2003)

Galaxies at z~0



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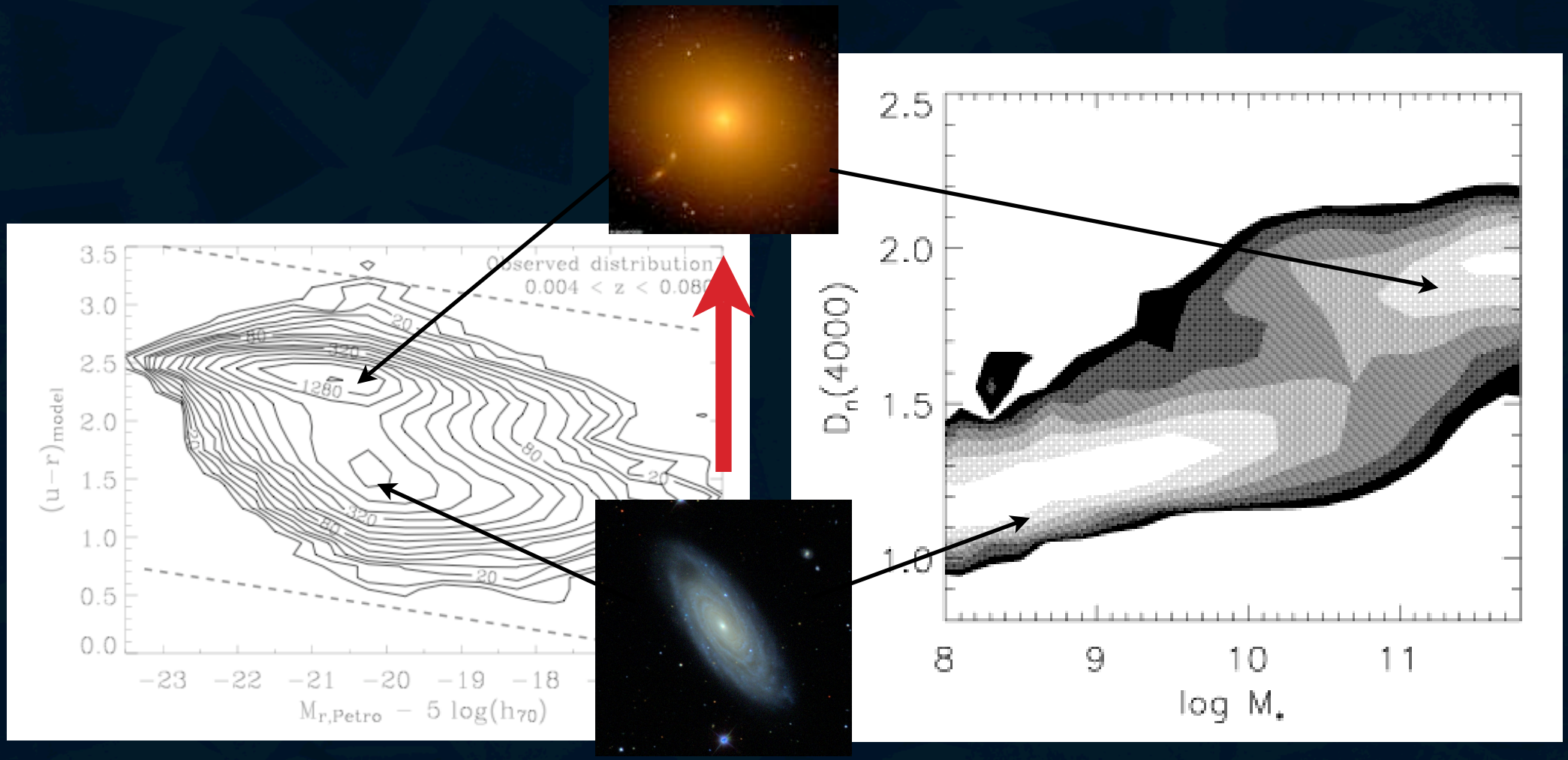
Galaxies at z~0



Baldry et al. (2004)

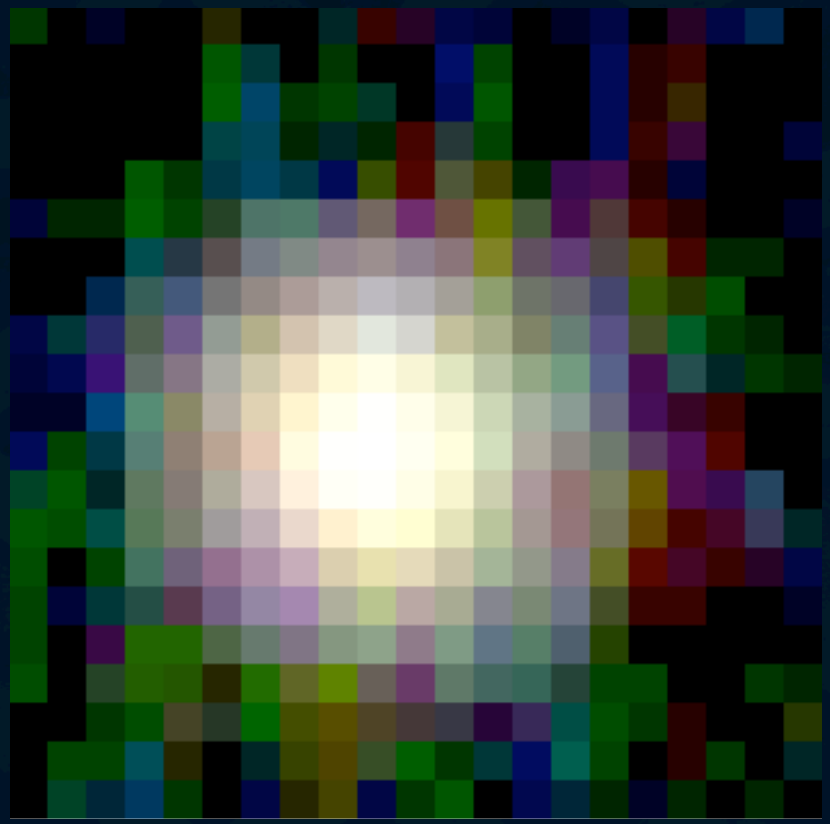
Kauffmann et al. (2003)

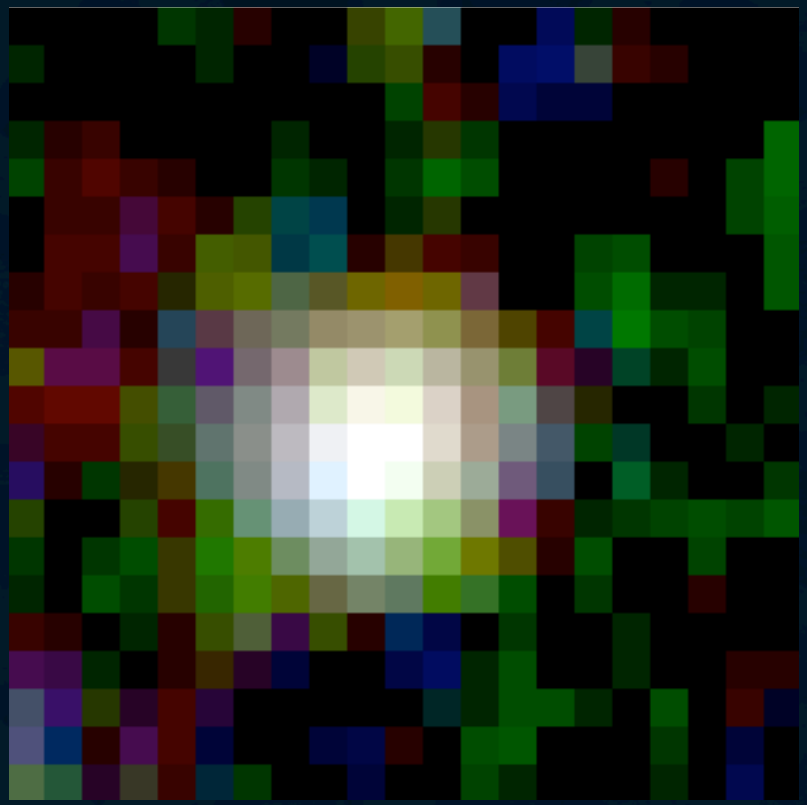
- When does the quiescent population emerge?
- What "kills" star formation?
- How do the quiescent galaxies (and bimodality) evolve with redshift?

- **Many galaxies over a wide redshift range are needed**

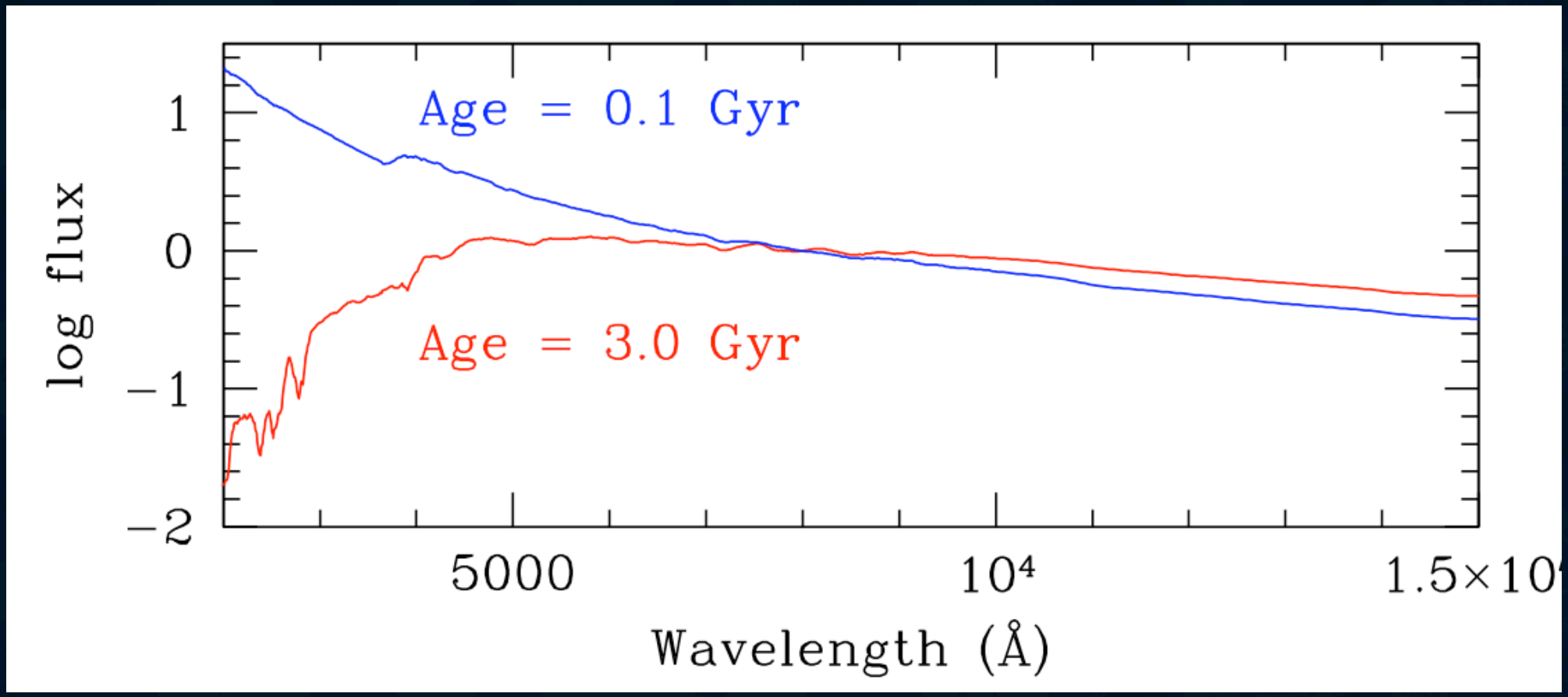
Galaxies at z~0

Galaxies at z~2, seen from z=0





Spectroscopy



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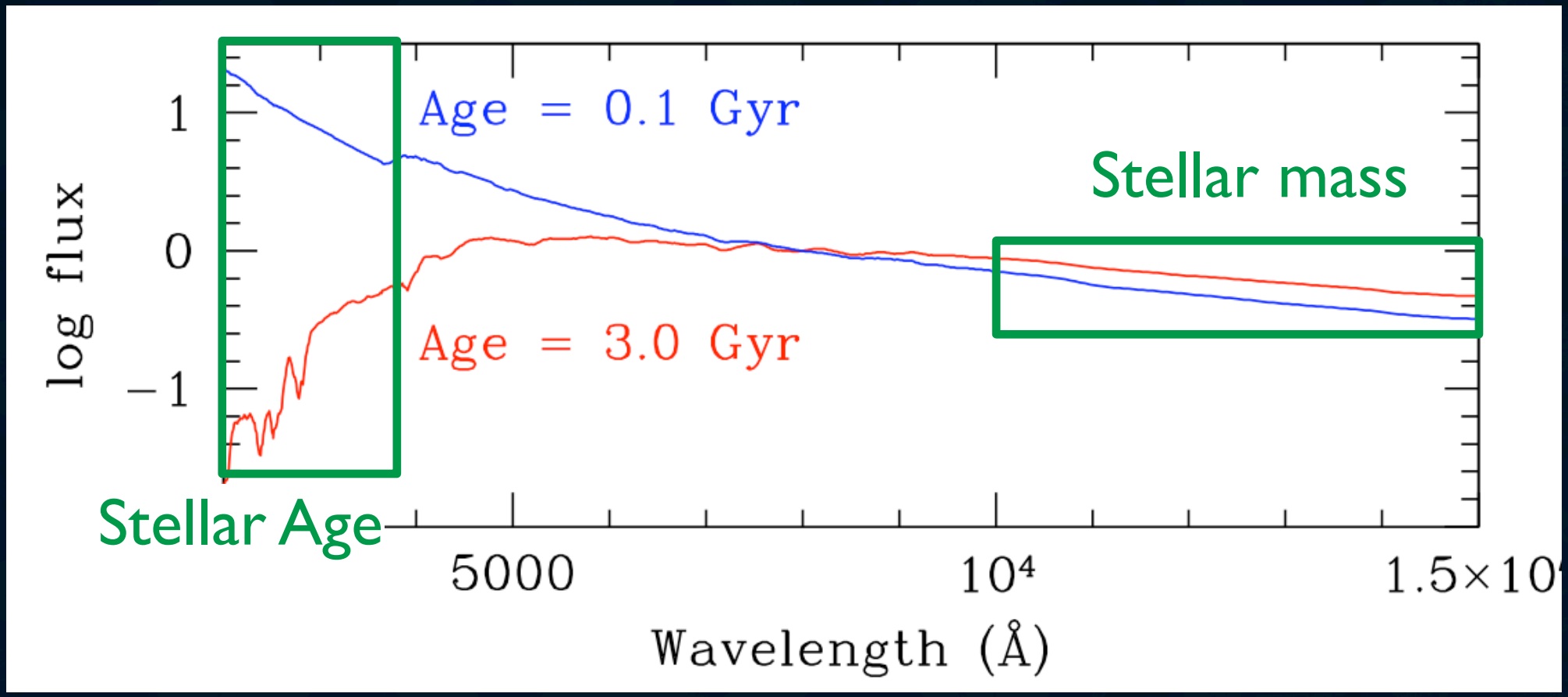
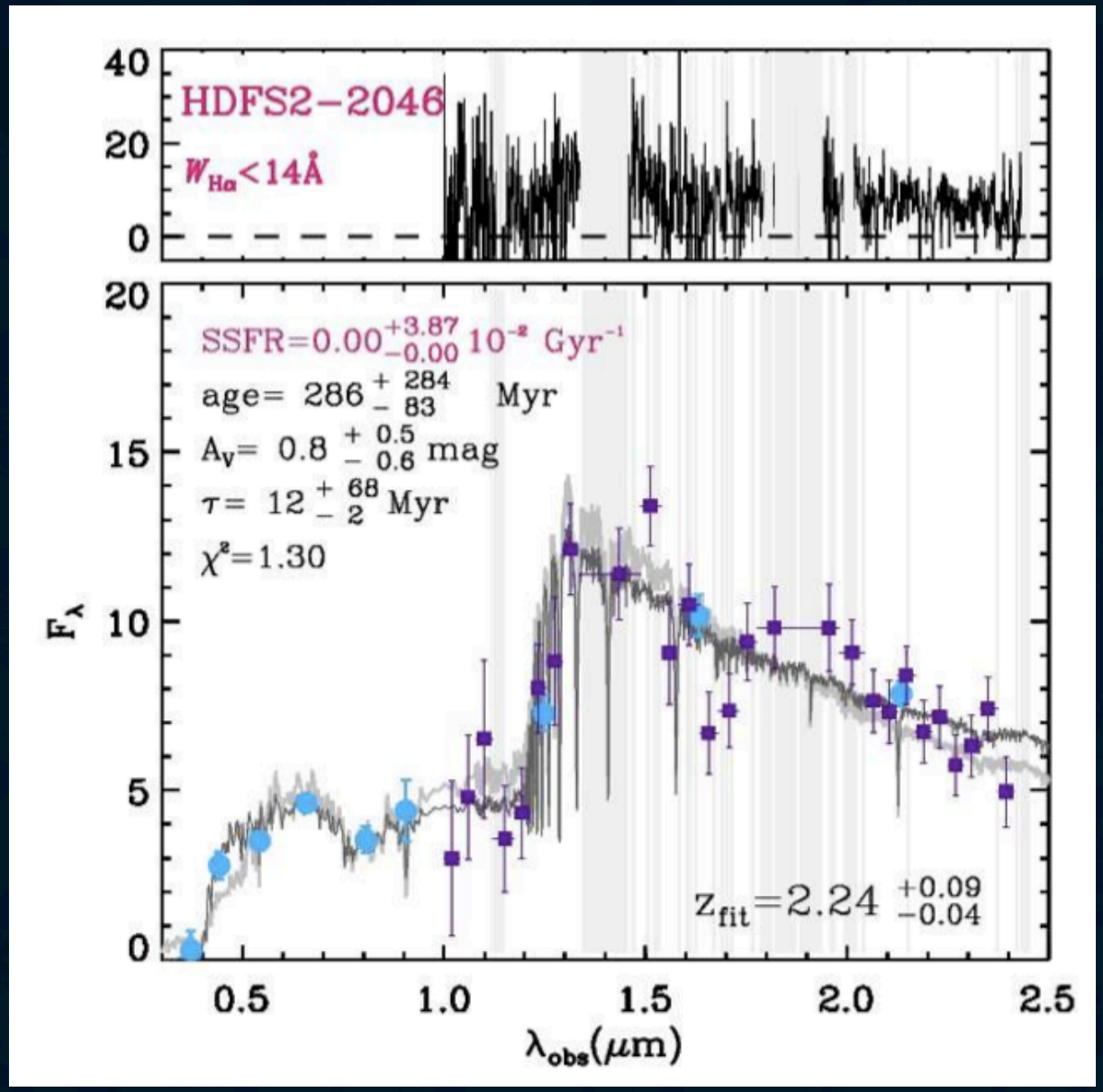
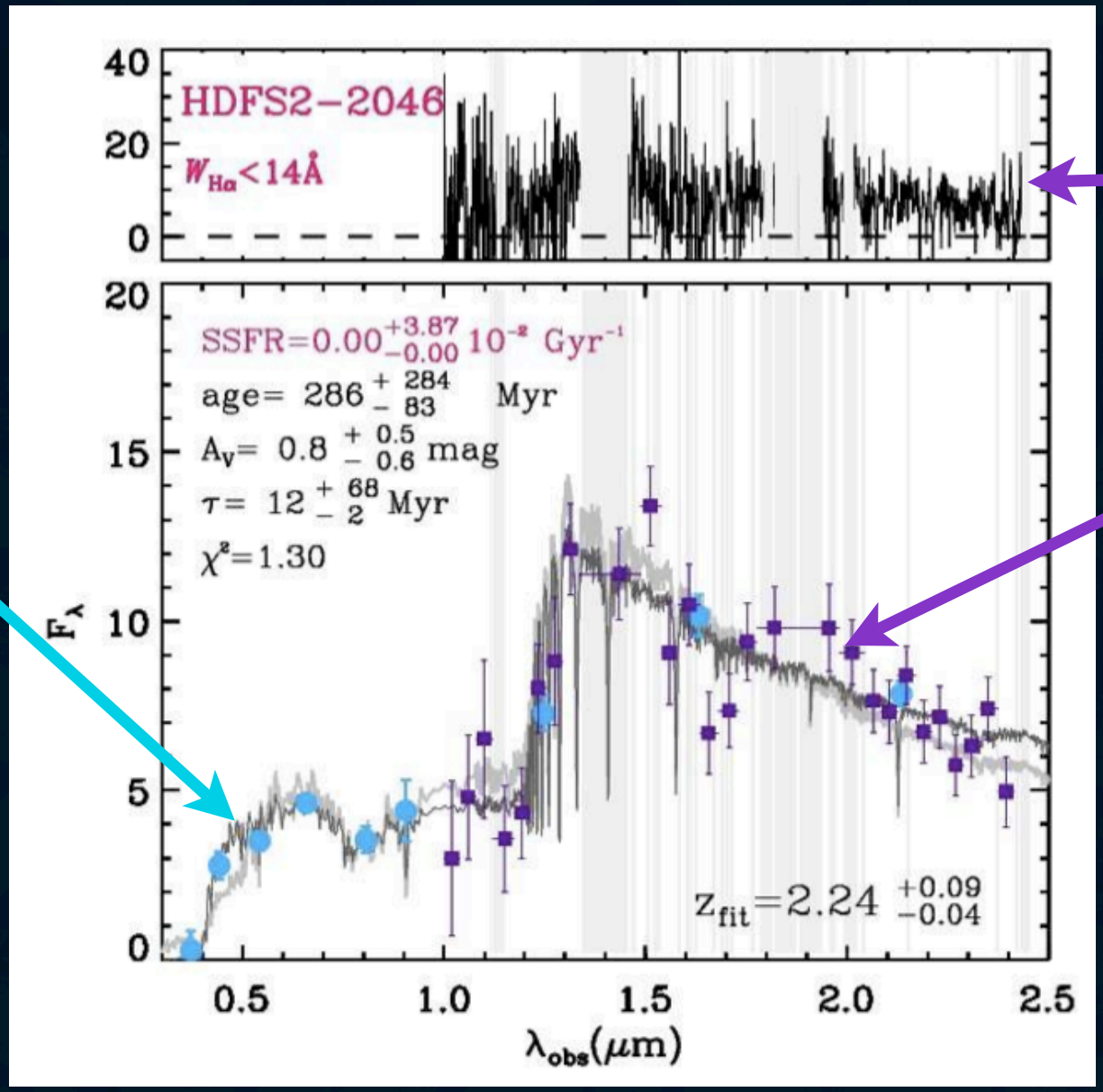


Spectroscopy at z~2.3



Kriek et al. (2006)

Spectroscopy at z~2.3



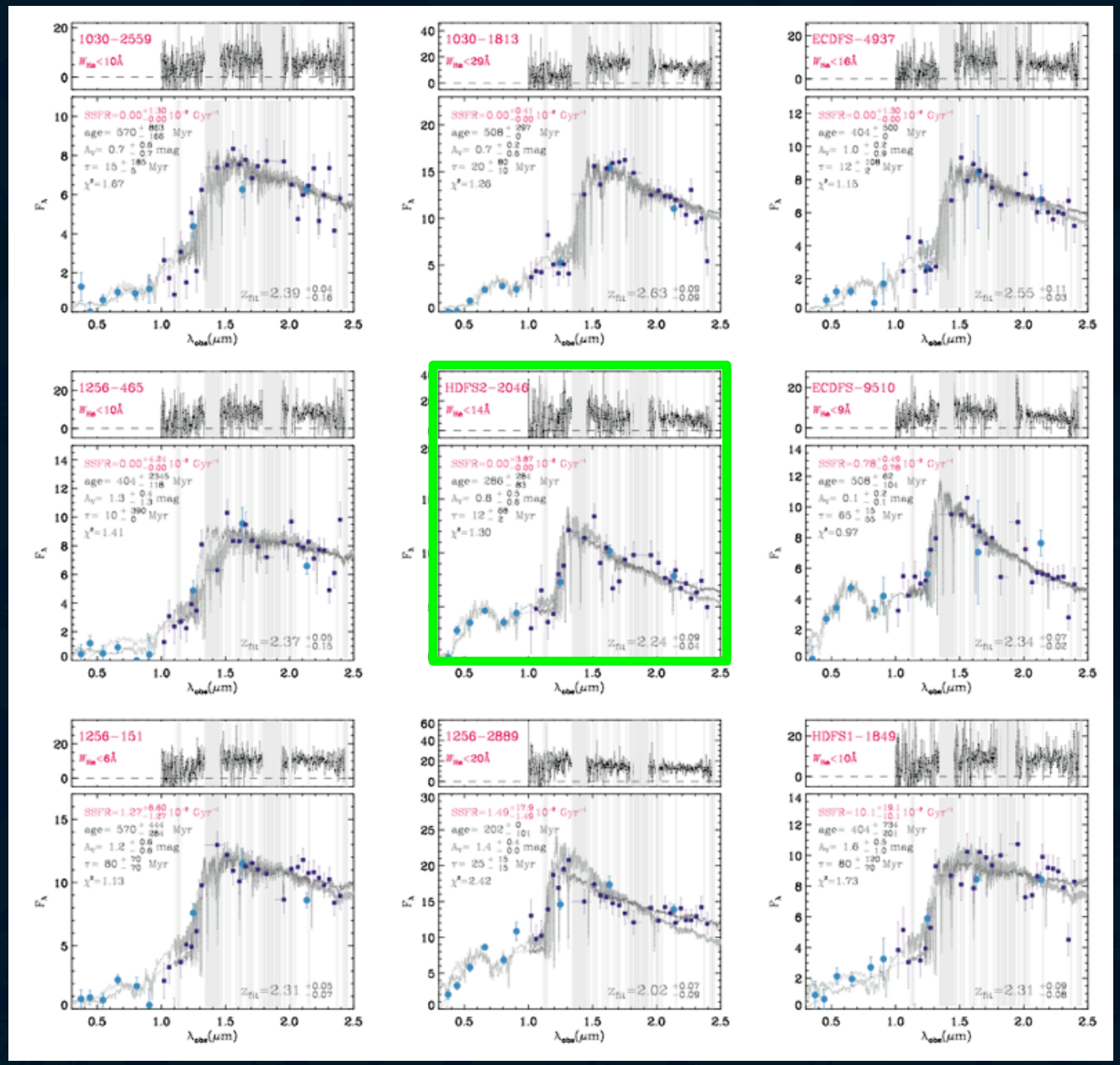
Raw IR Spectrum

Binned IR Spectrum

Broadband Filters

Kriek et al. (2006)

Spectroscopy at z~2.3



9/20 quiescent

Kriek et al. (2006)

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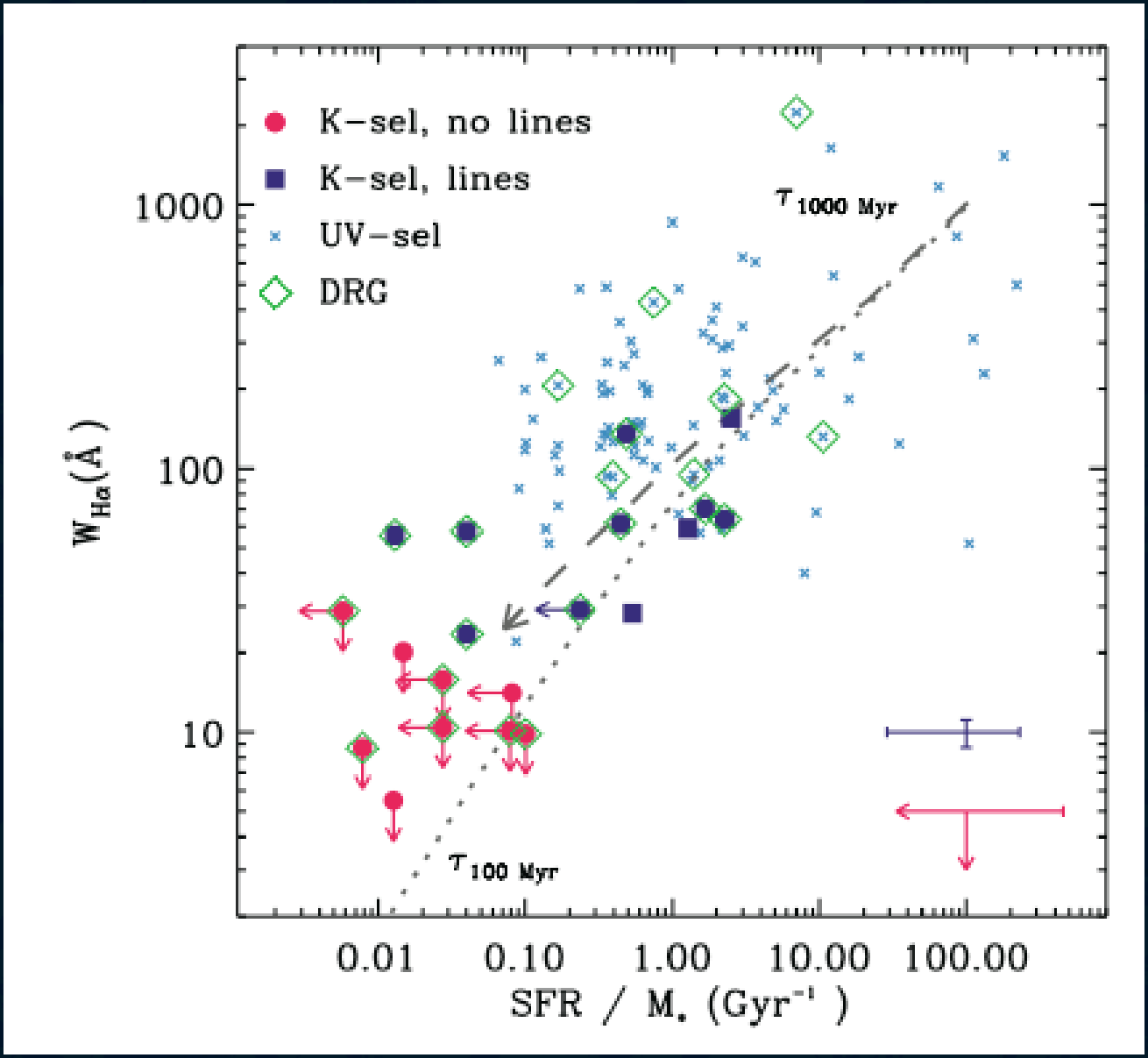

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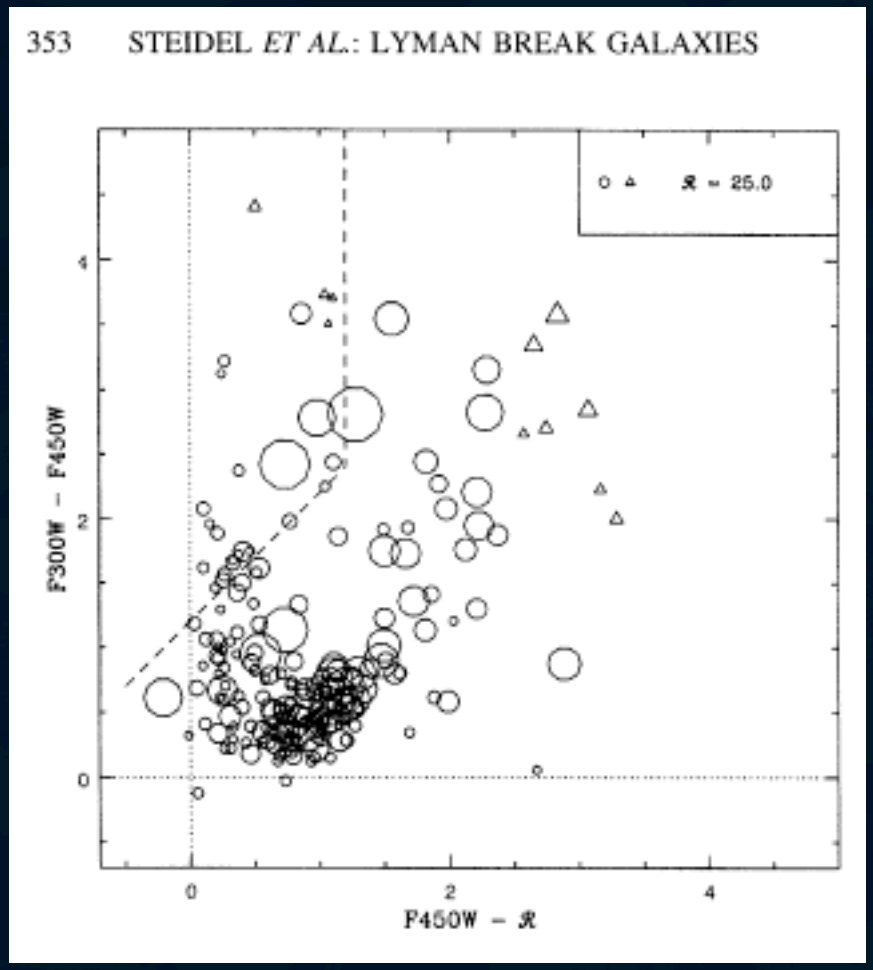
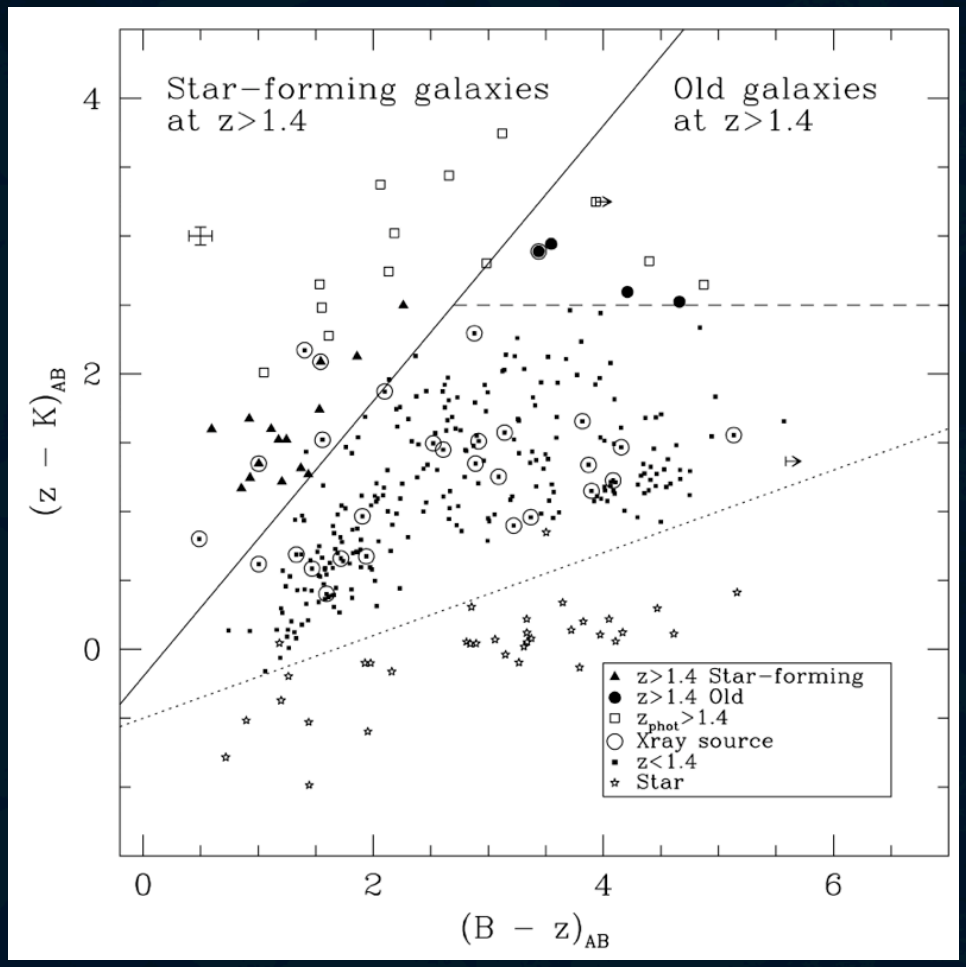
Candidates from observed colors



LBGs, Steidel et al. 1996



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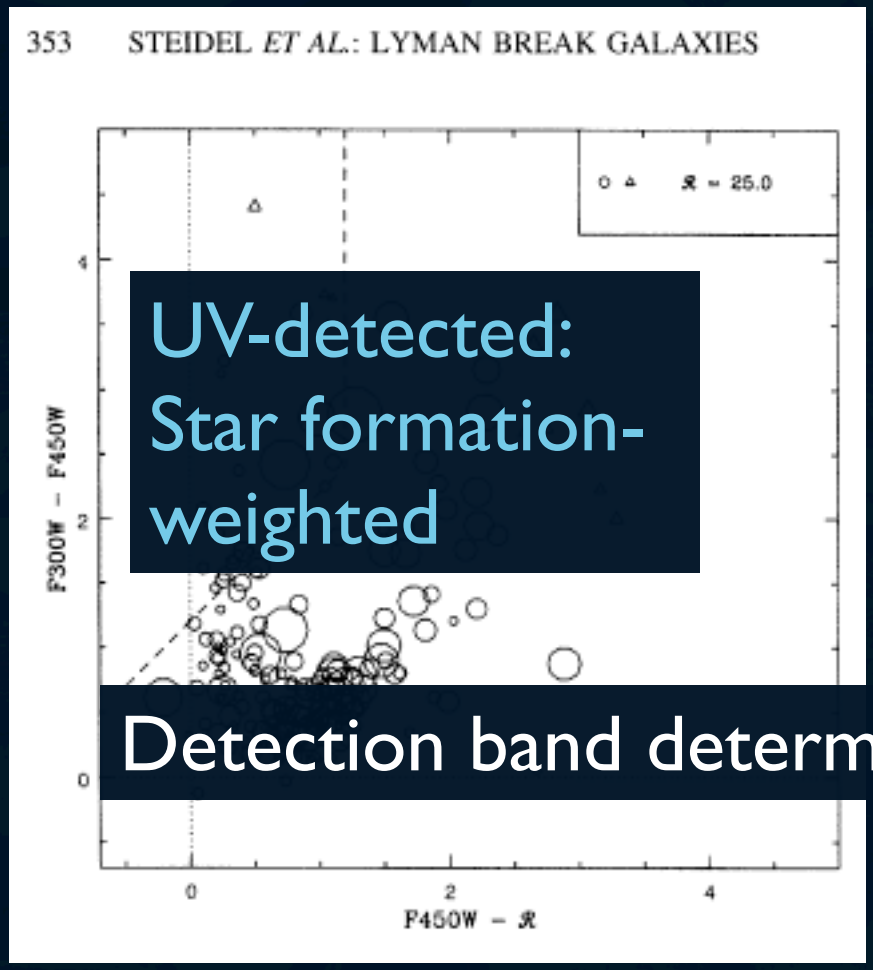
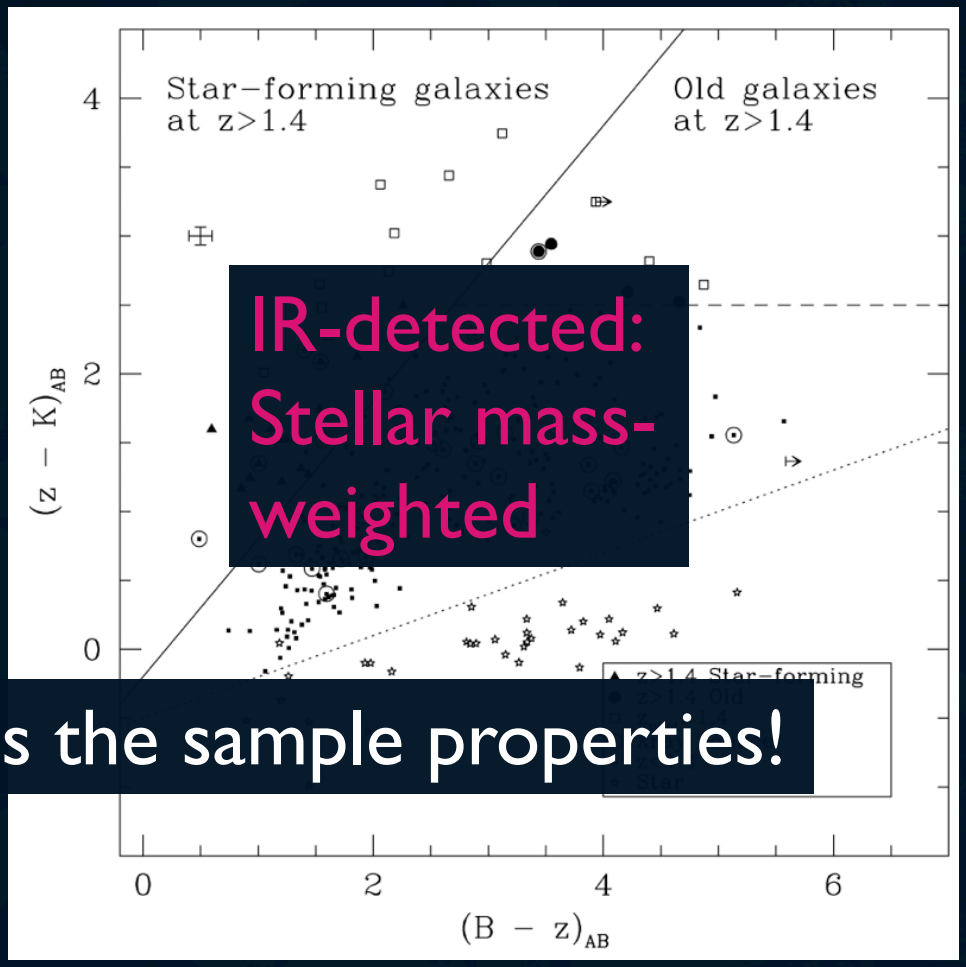


UV-detected:
Star formation-weighted



IR-detected:
Stellar mass-weighted

Detection band determines the sample properties!

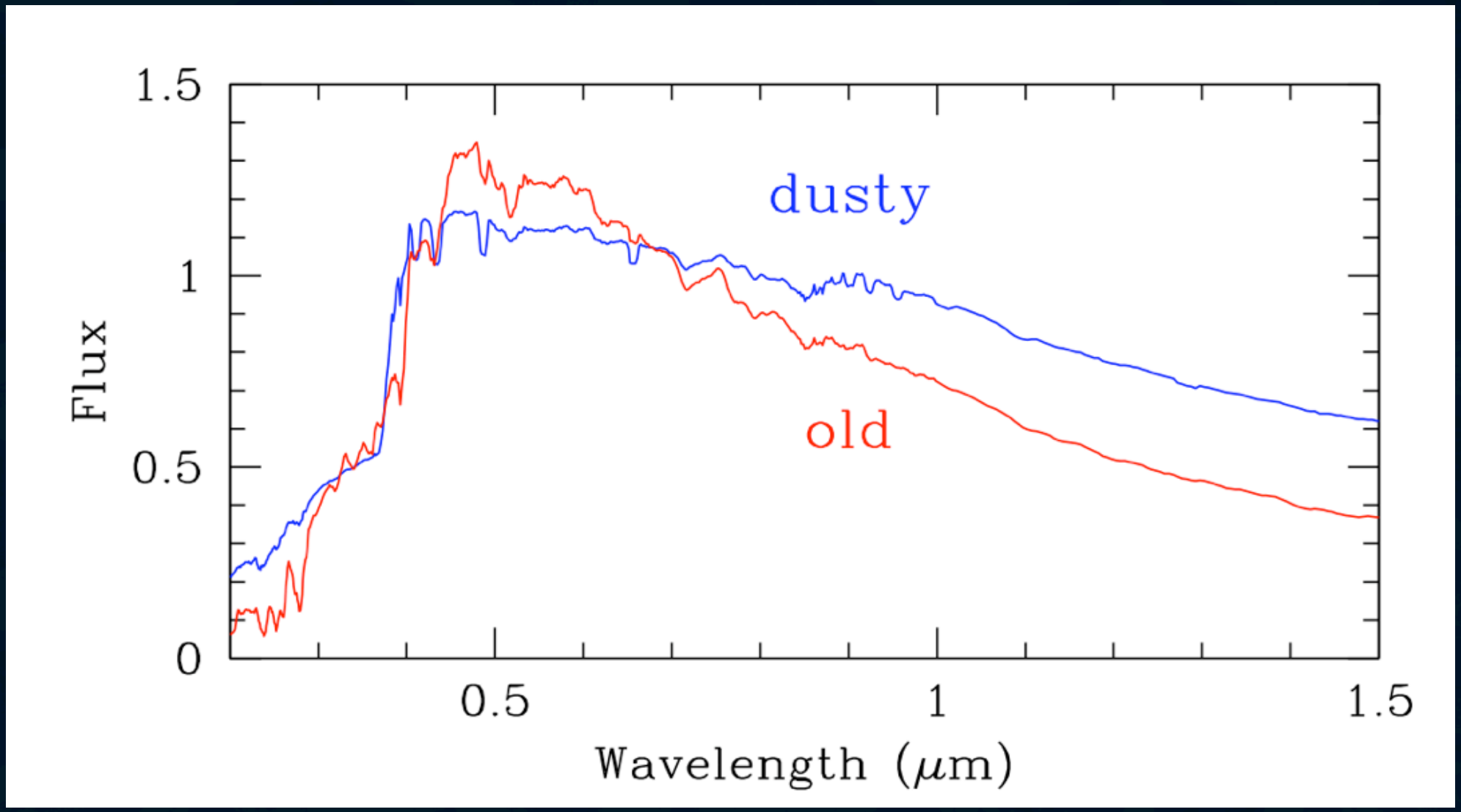
LBGs, Steidel et al. 1996

BzK, Daddi et al. (2004)

Is there a generalized way to characterize star formation in massive galaxies using only photometric data?

Could look at blue vs. red IR-selected galaxies, except...

Red galaxies in the rest frame



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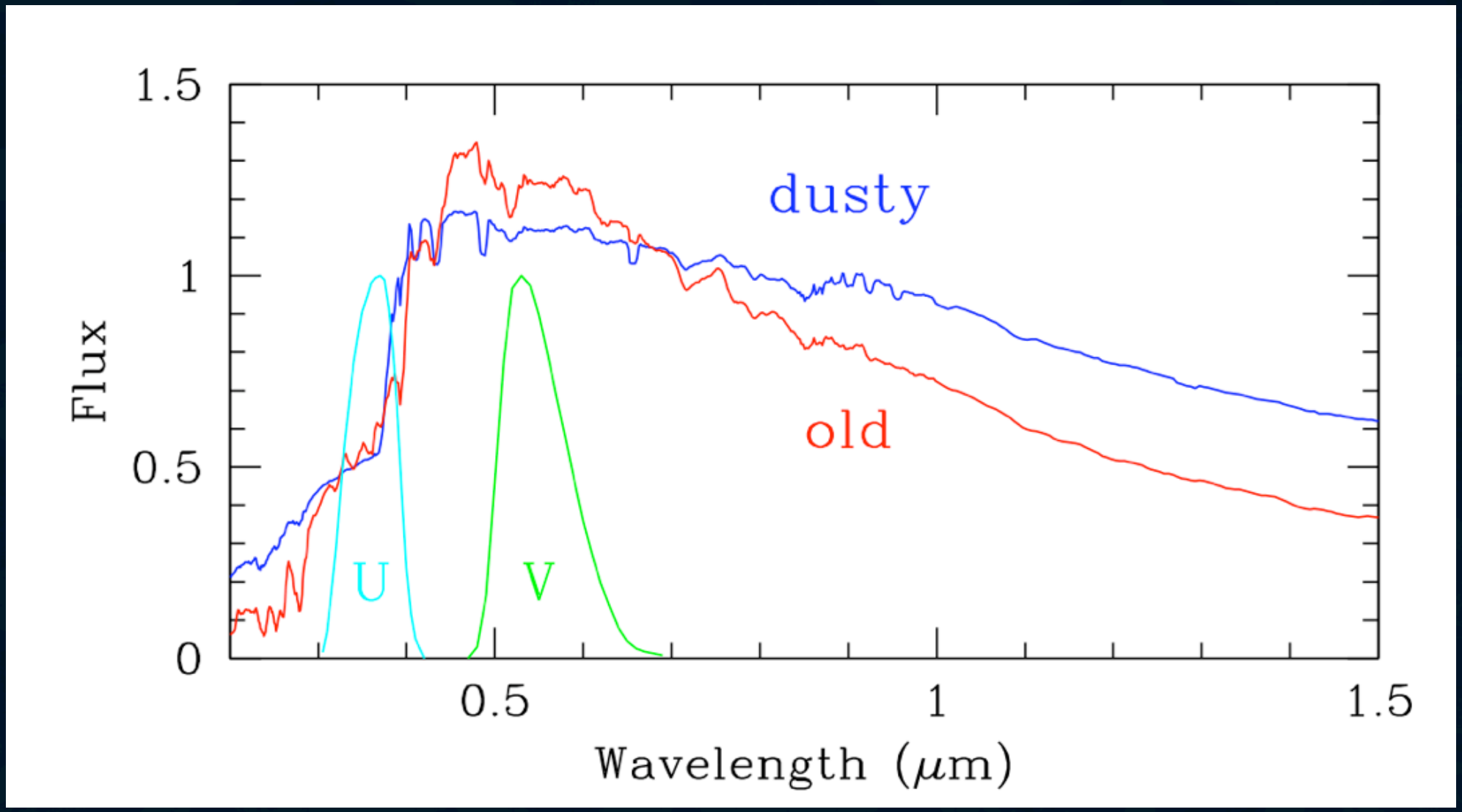

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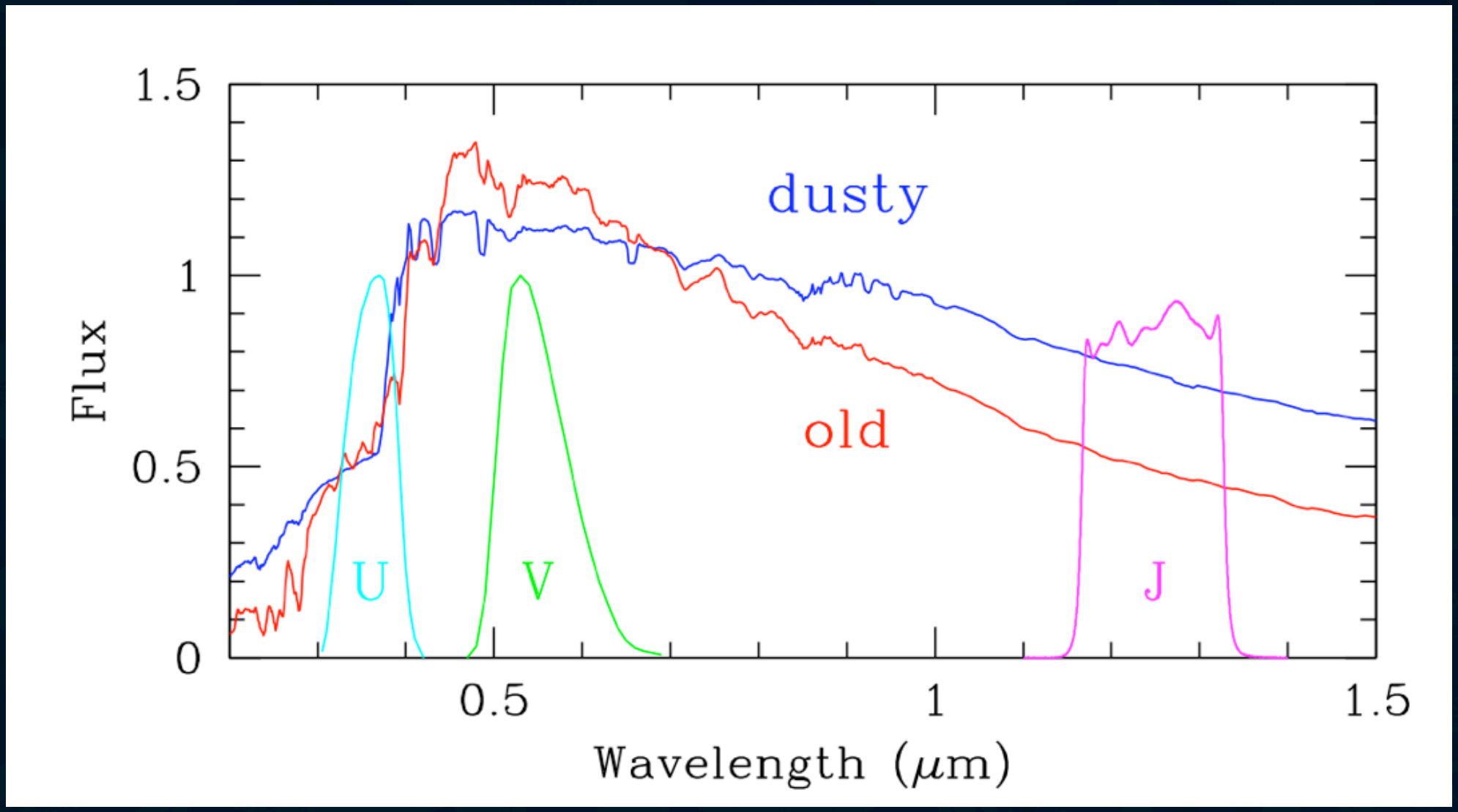
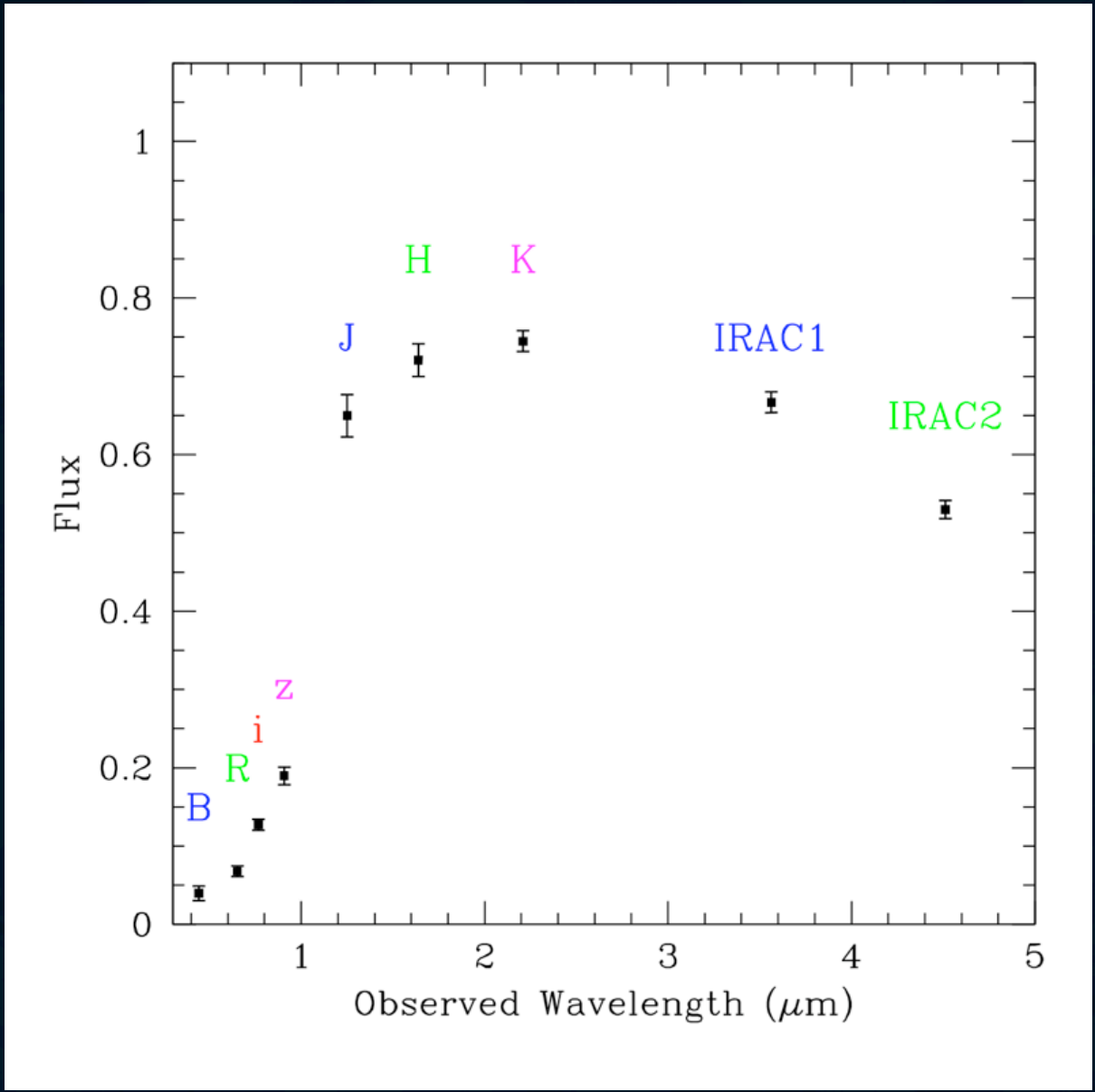


Near-IR breaks the dust-age degeneracy

Computing z_{phot} and U/V/J



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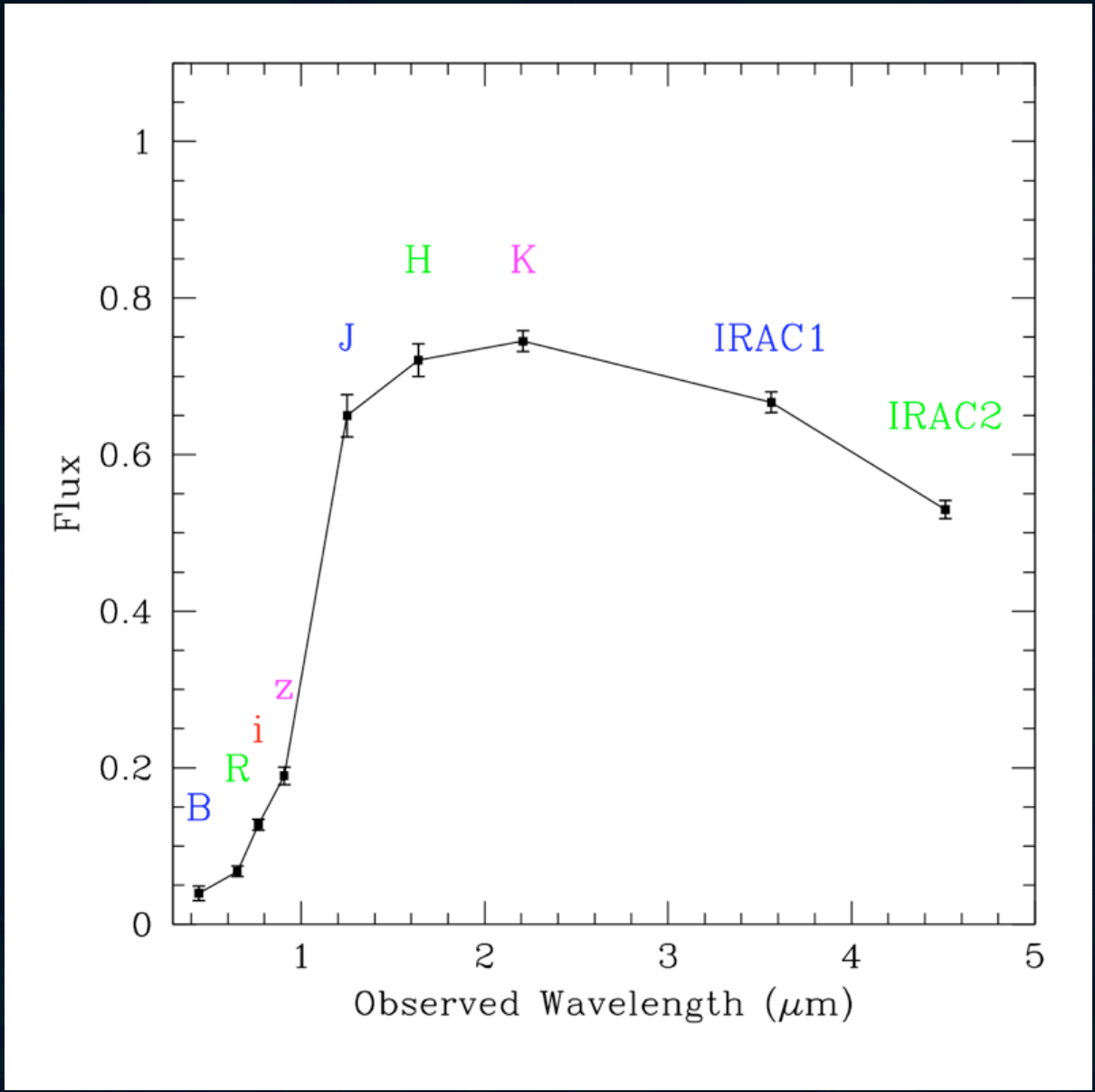

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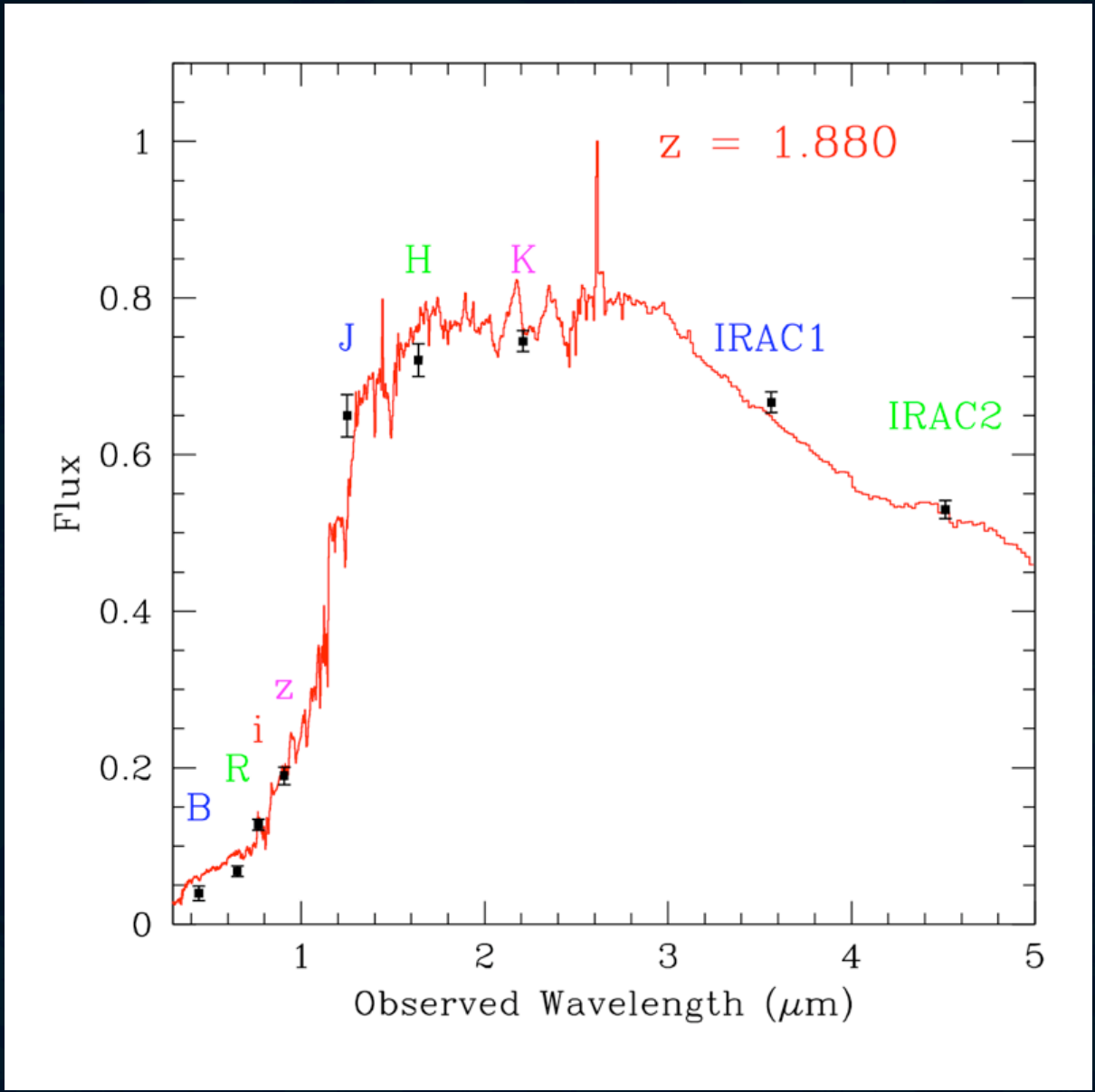

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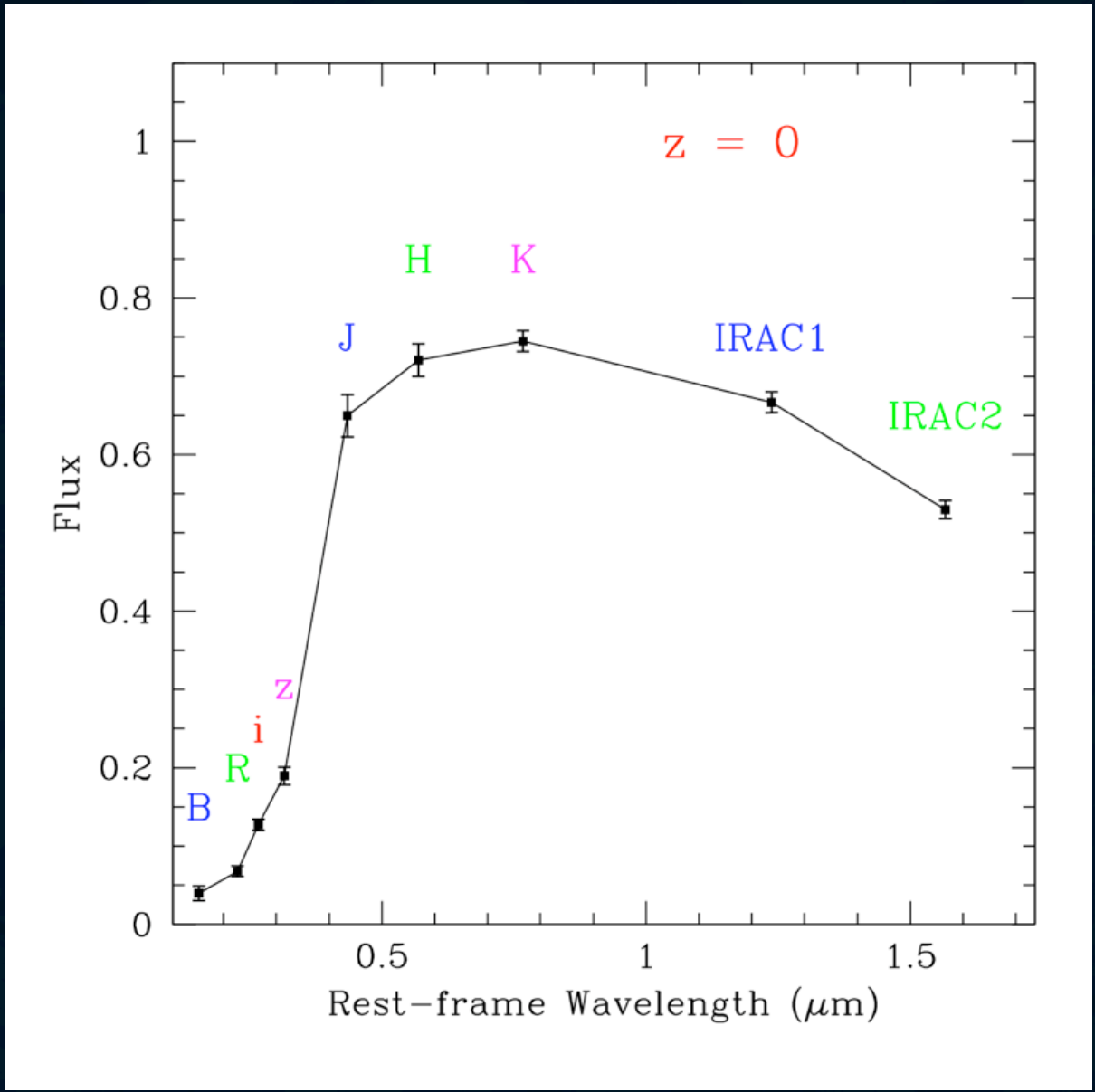

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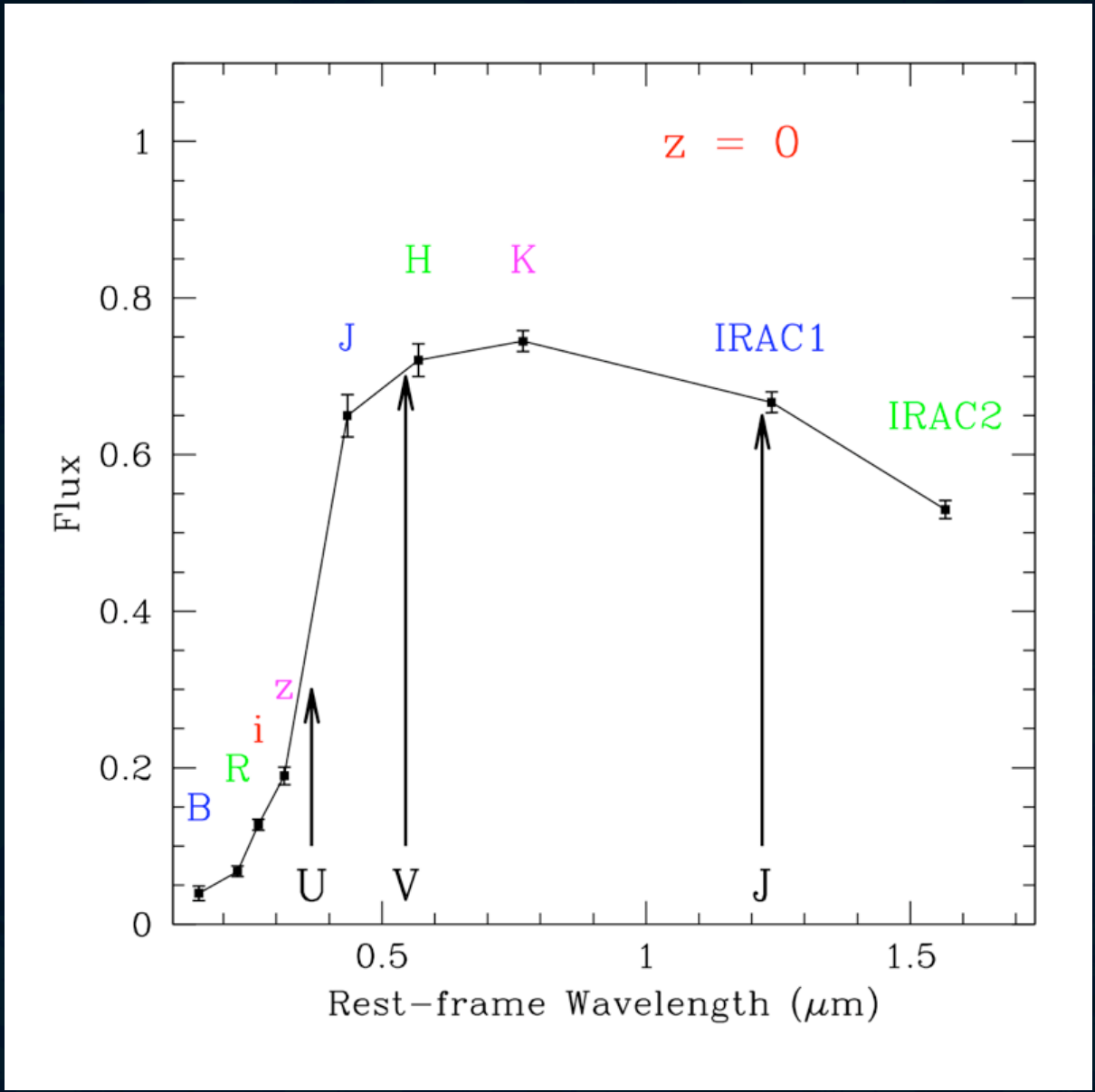

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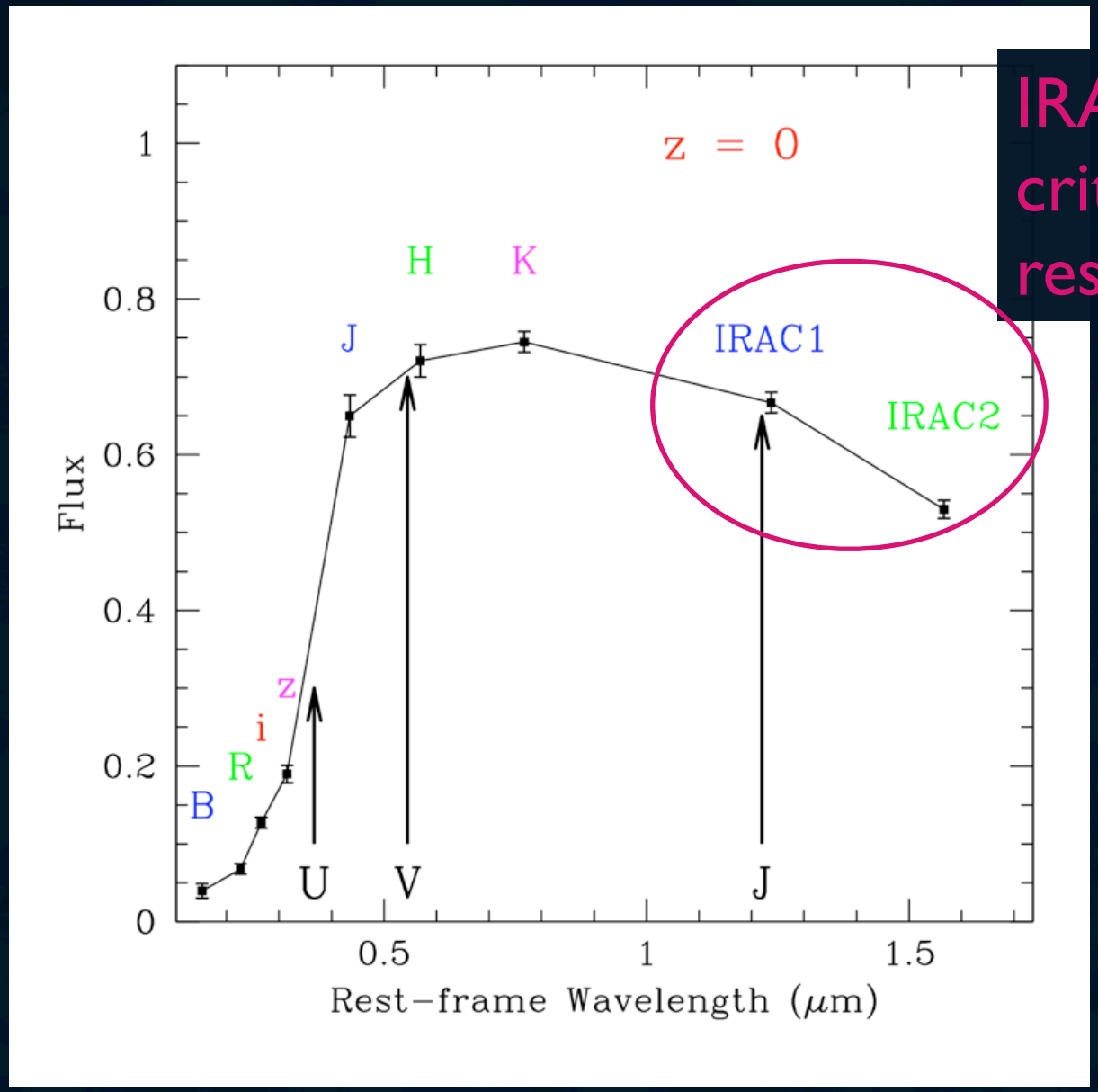
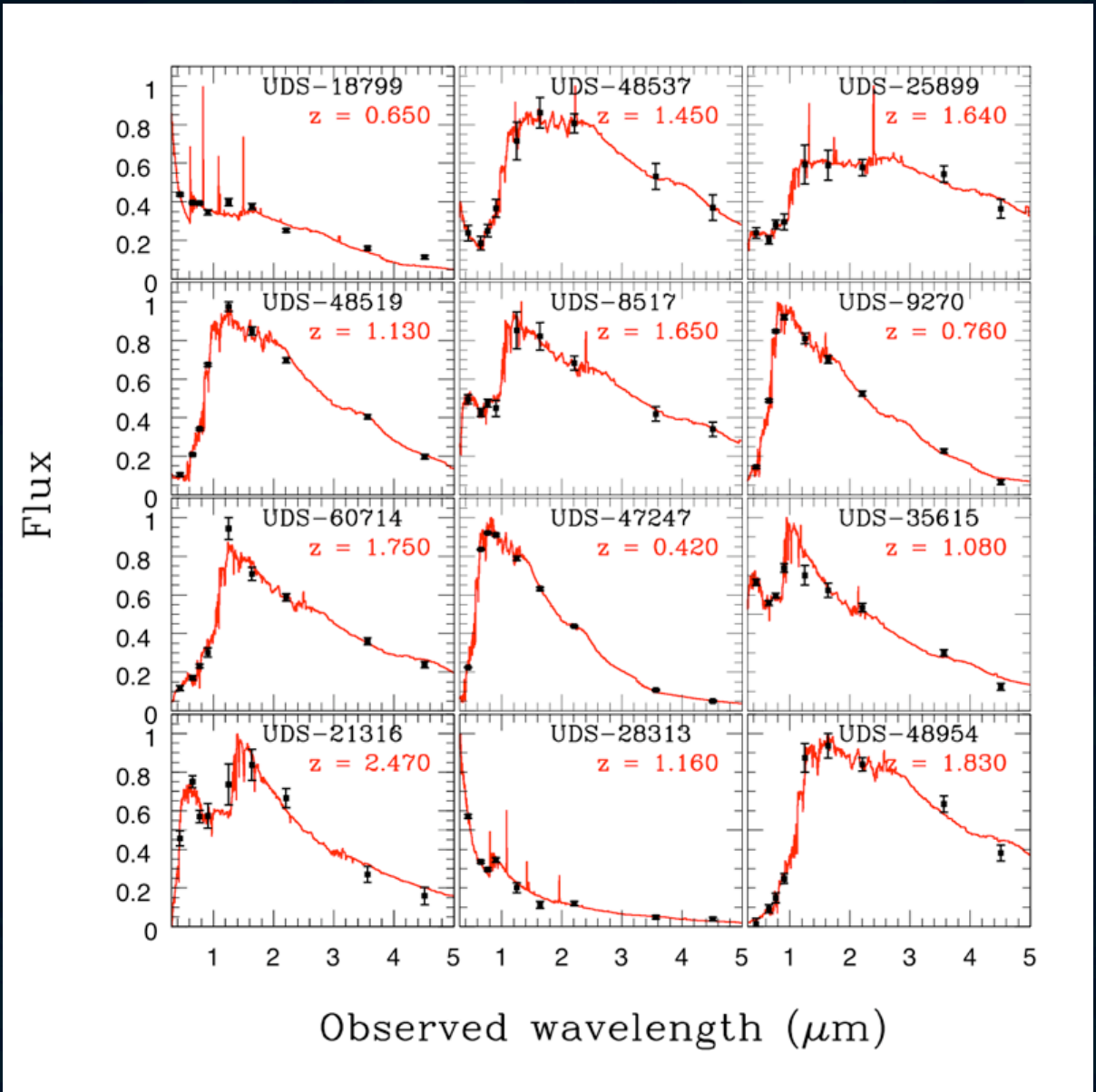
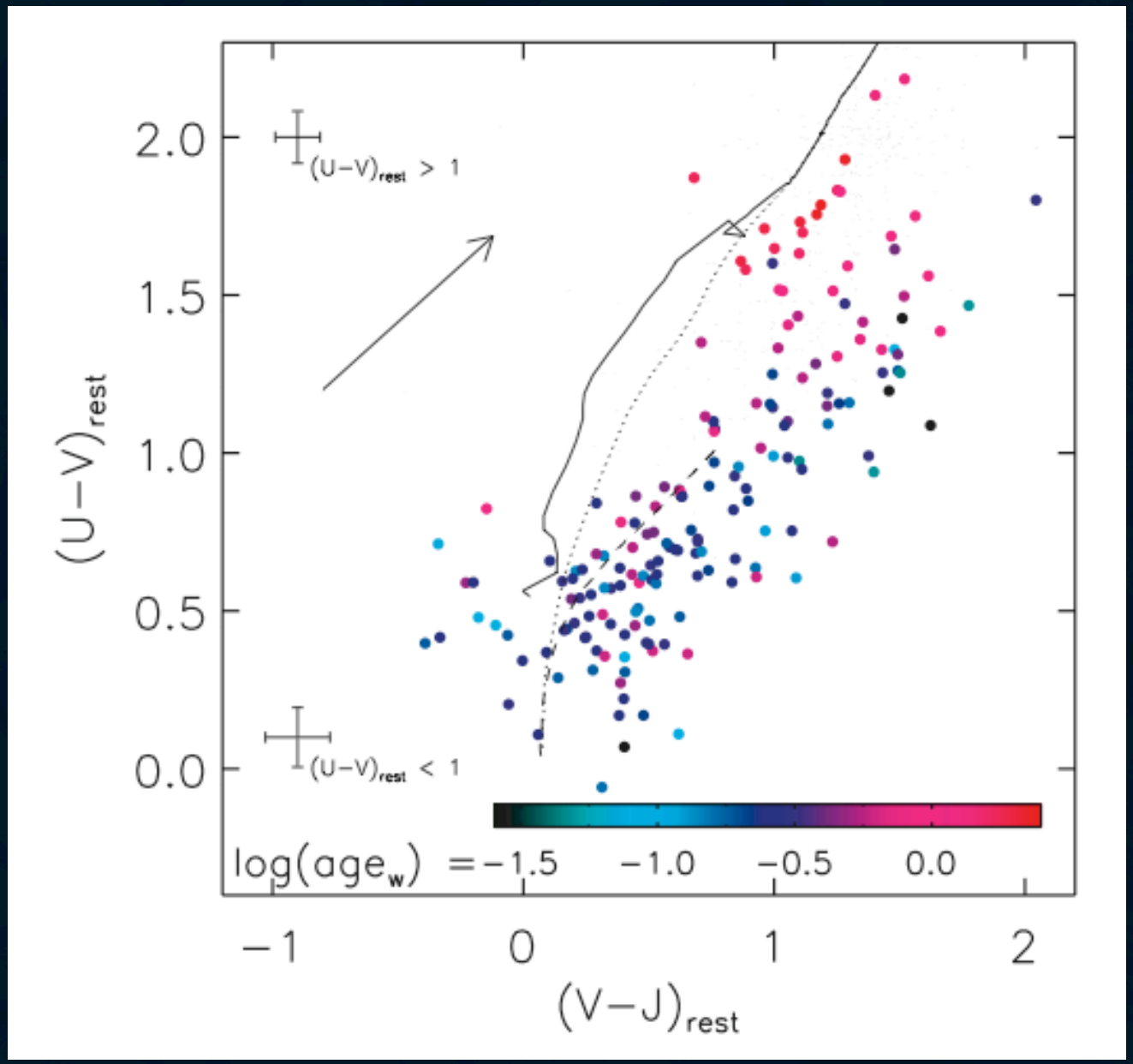


IRAC data critical for rest-frame J!

Repeat 10^2-10^5 times...



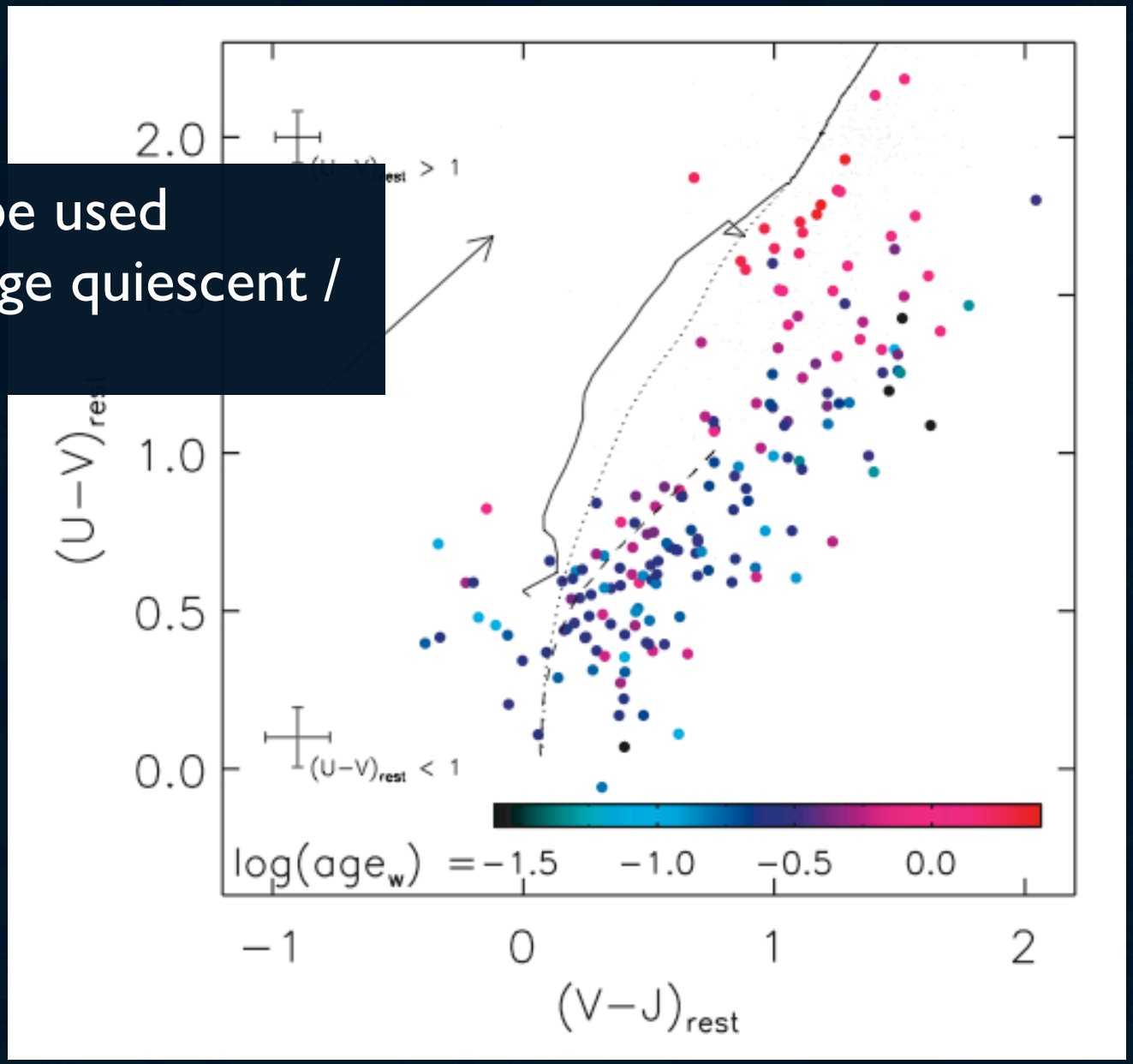
UVJ Colors



HDF-S, Wuyts et al. (2007)

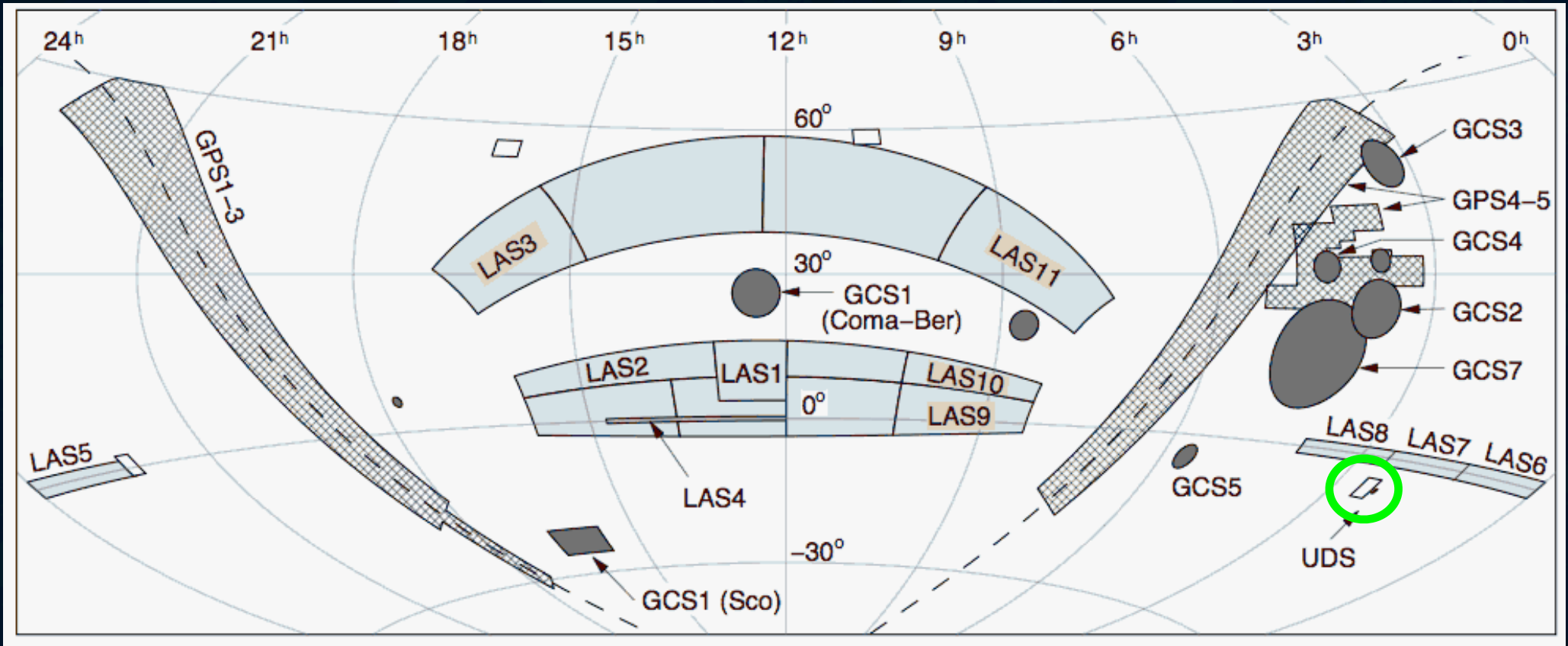
UVJ Colors

Can this diagram be used to characterize large quiescent / SF galaxy samples?



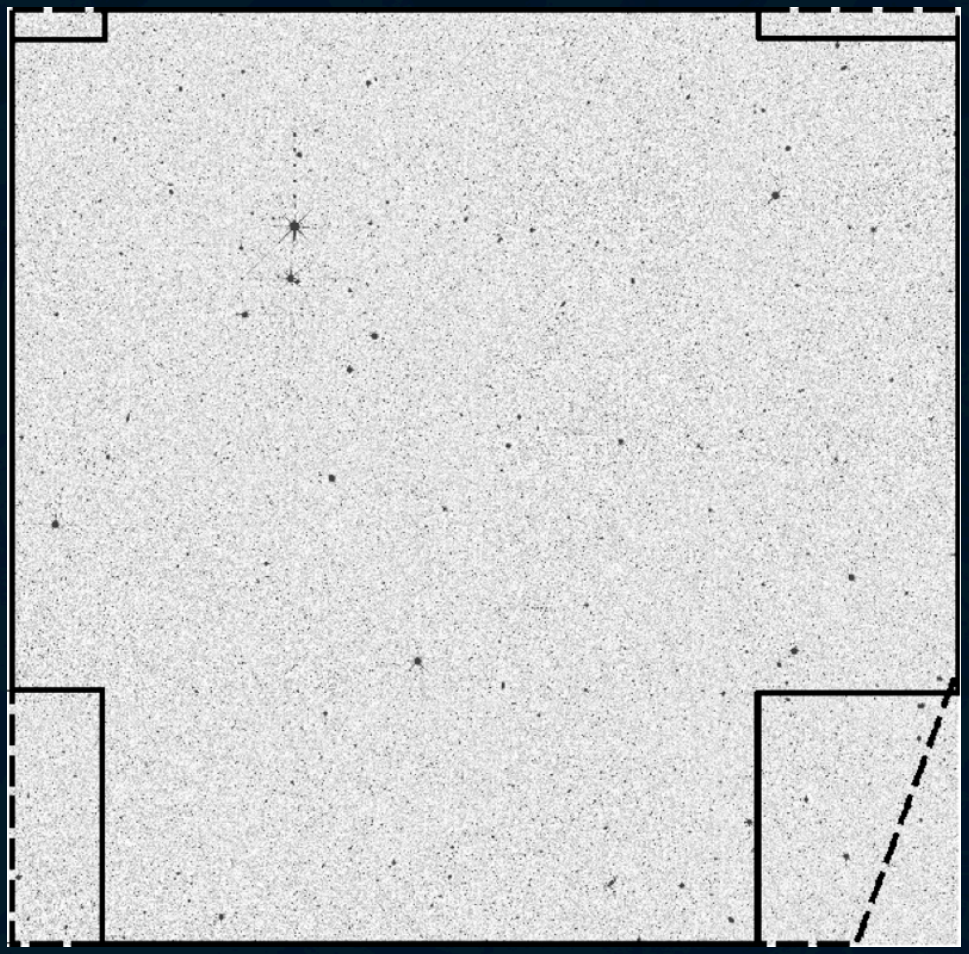
HDF-S, Wuyts et al. (2007)

UKIRT Infrared Deep Sky Survey



UKIDSS UDS

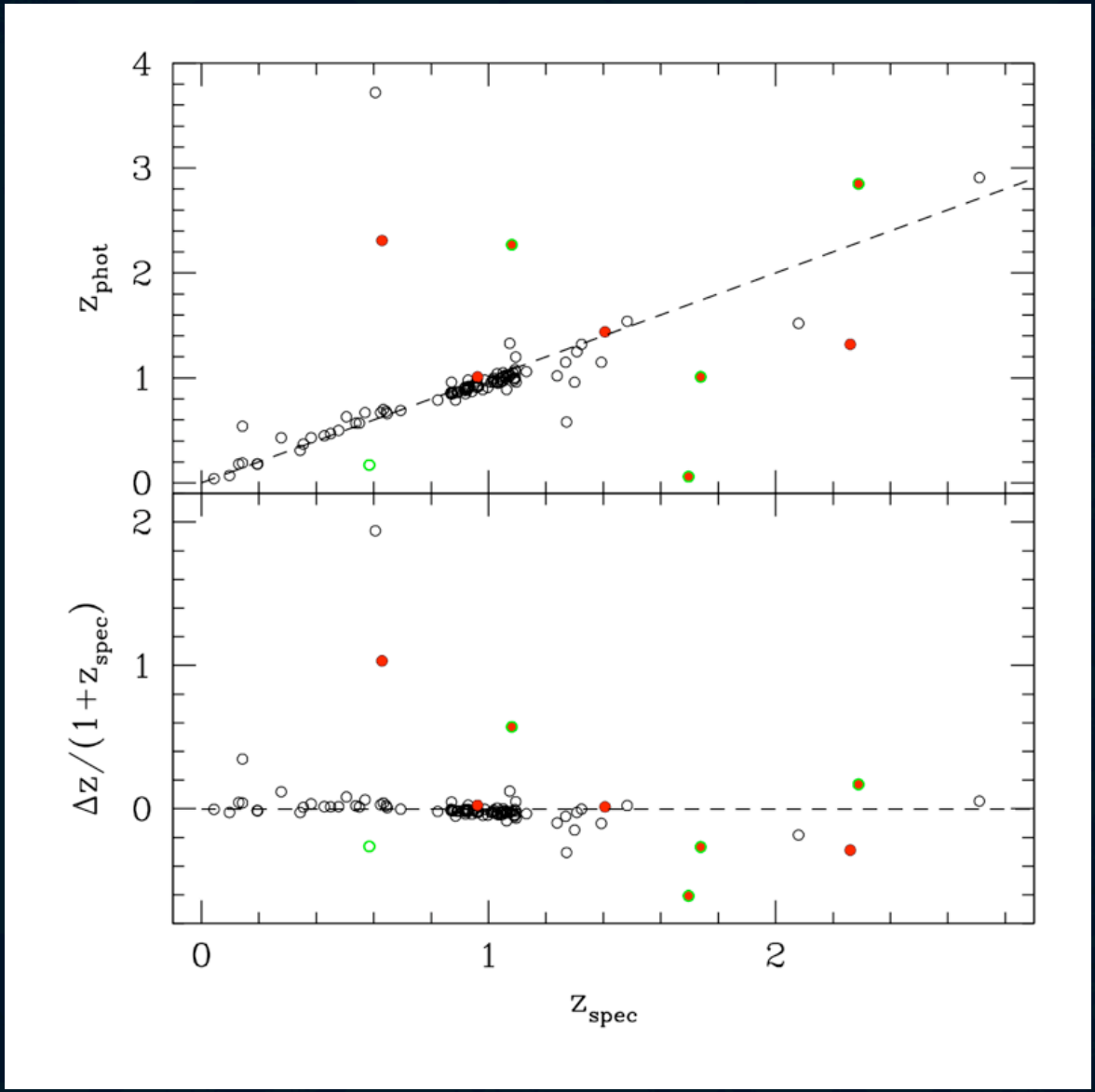
- 0.7 deg^2
- Deep BRizJK plus SWIRE IRAC 3.6/4.5um
- K<21.7 (Vega)
- 10^5 K-detected objects (60% with K<21)
- coming soon: V, H, deep IRAC+MIPS...



Catalogs at:
www.strw.leidenuniv.nl/galaxyevolution/UDS/

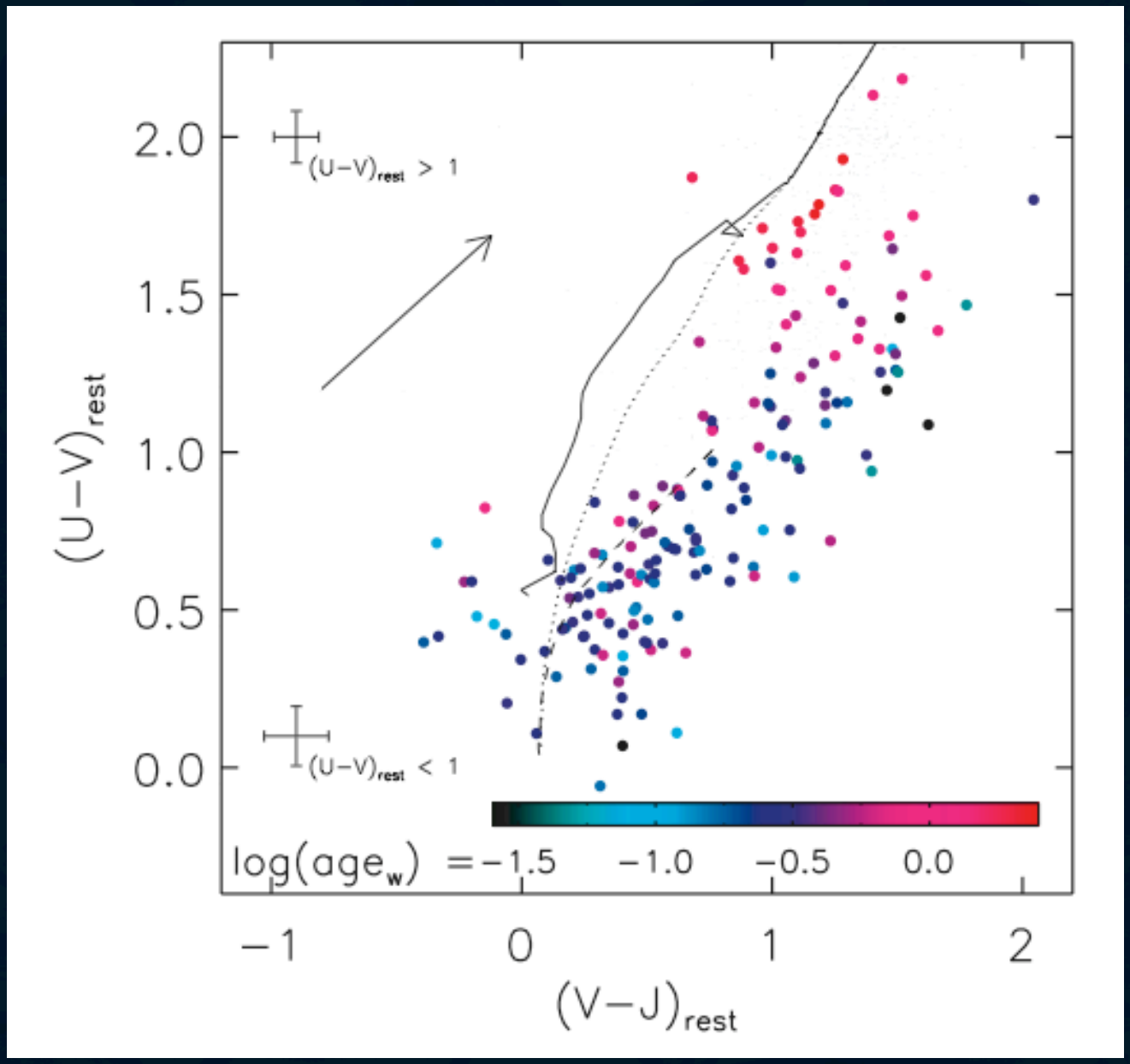
Photometric Redshifts

- z_{phot}s calculated with EAZY (Brammer et al. 2008)
- Compared with 119 public spec-z's in this field
- Deviation of |dz|/(1+z)=0.033 dz/(1+z)=-0.01
- Only 2 non-AGN at z>1.5!



Williams et al., arXiv:0806.0625

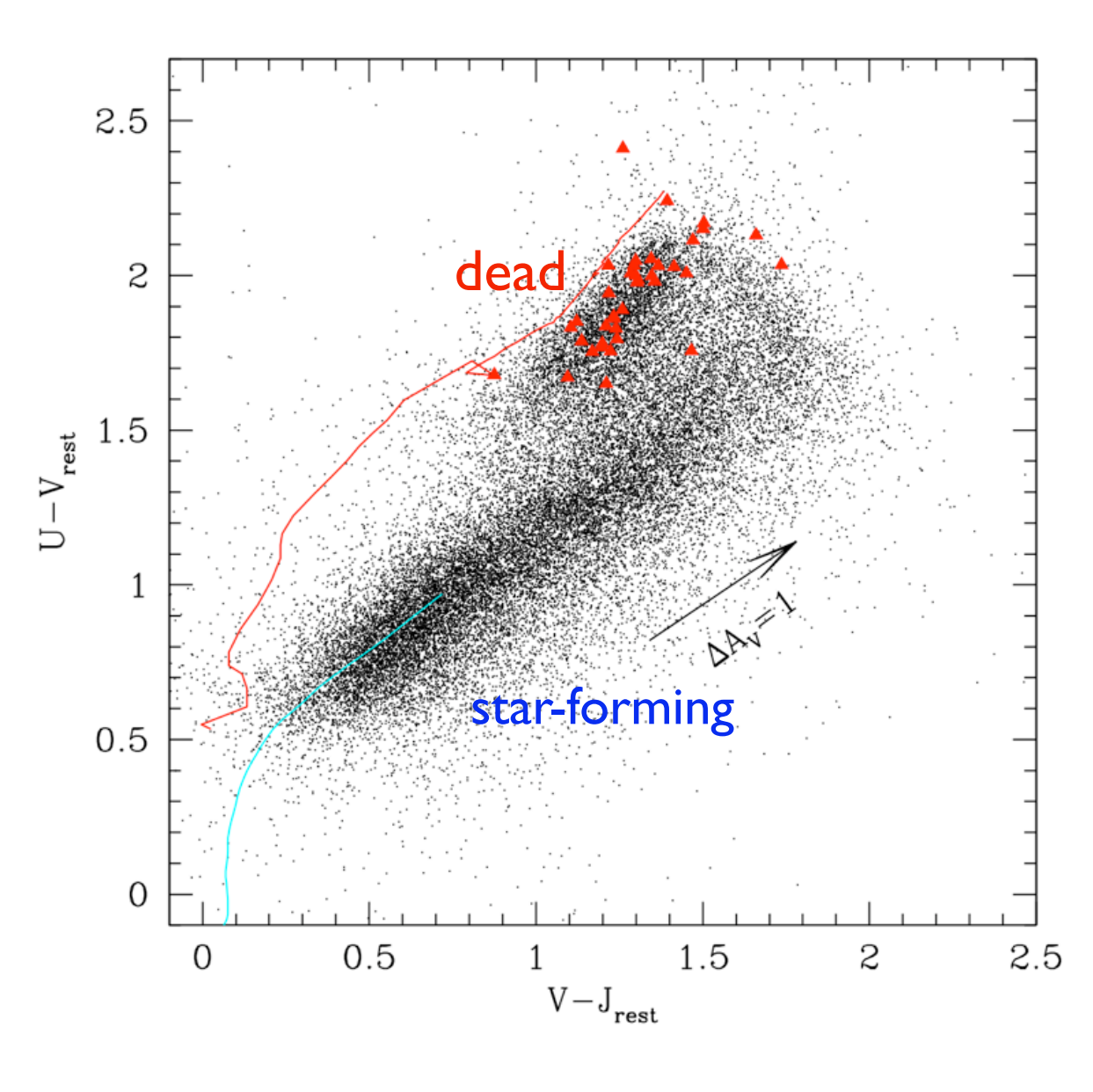
UVJ Colors



HDF-S, Wuyts et al. (2007)

UVJ Colors

- 29398 galaxies between 0<z<2.5
- Red points: confirmed z~1 dead galaxies



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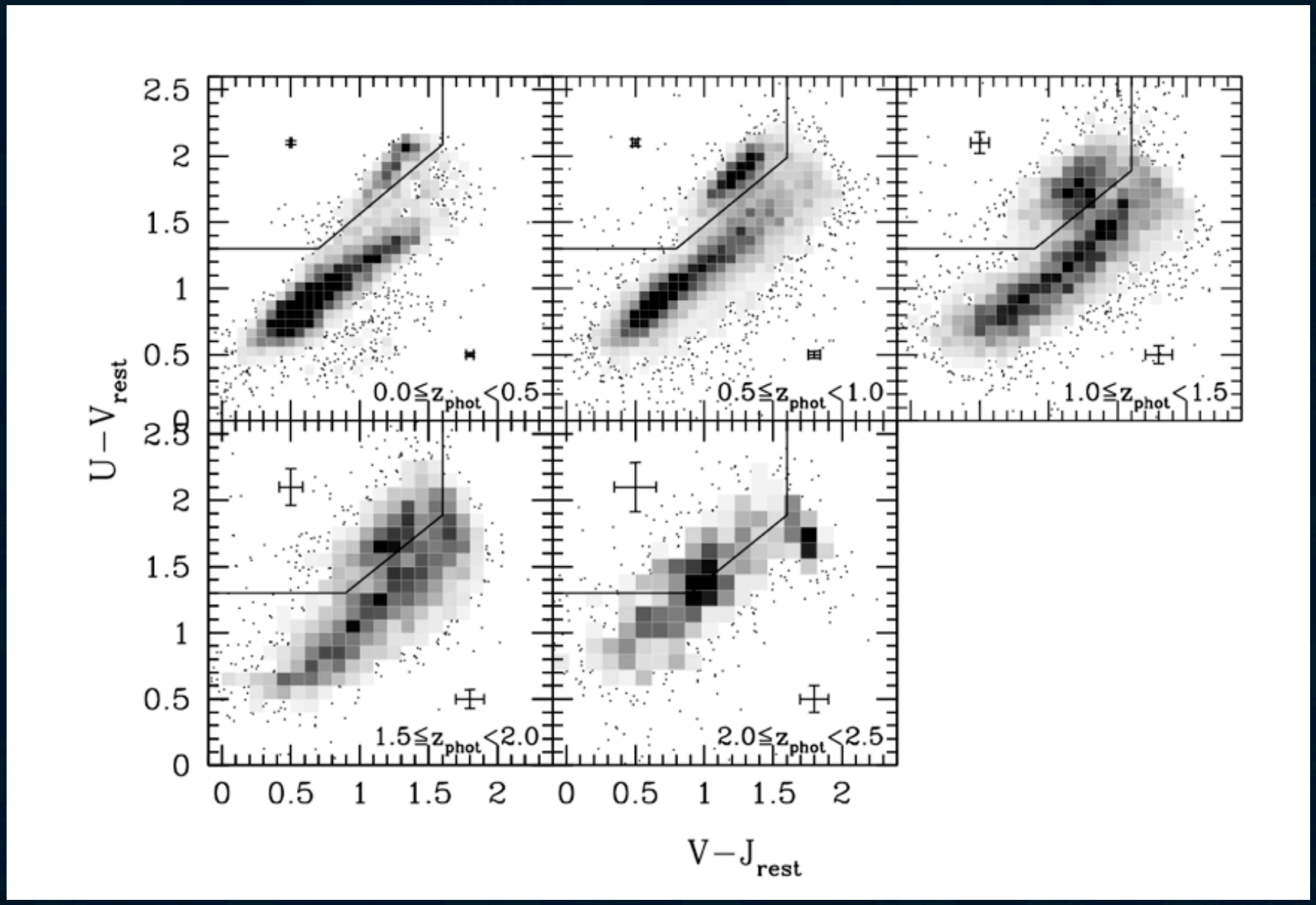
Bimodal up to z~2



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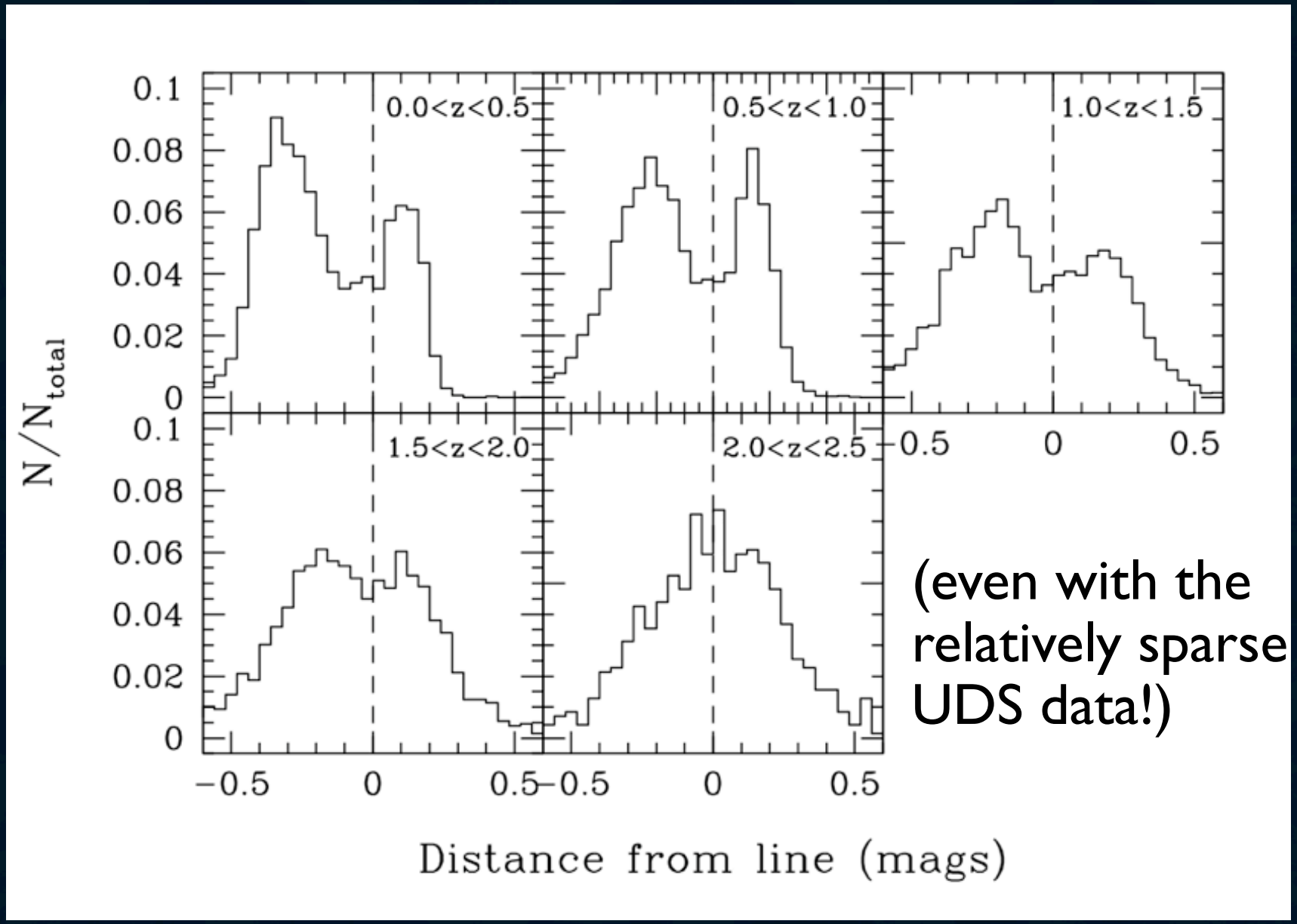


(even with the relatively sparse UDS data!)

Williams et al., arXiv:0806.0625

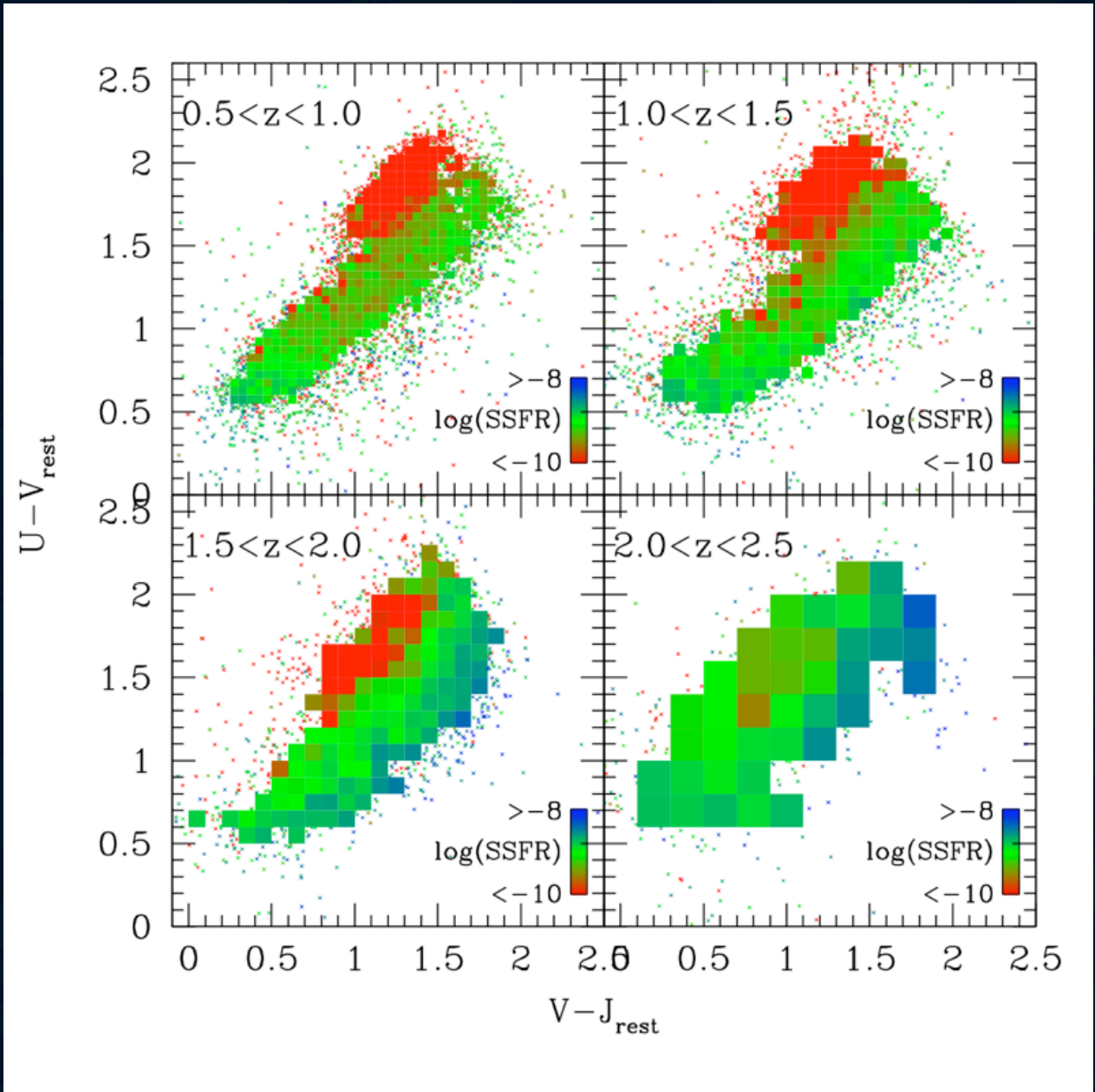
UVJ colors...

- Allow studies of much larger samples than spectroscopy (all galaxies detected in a deep field)

- Provide consistent diagnostics over (in principle) any redshift range

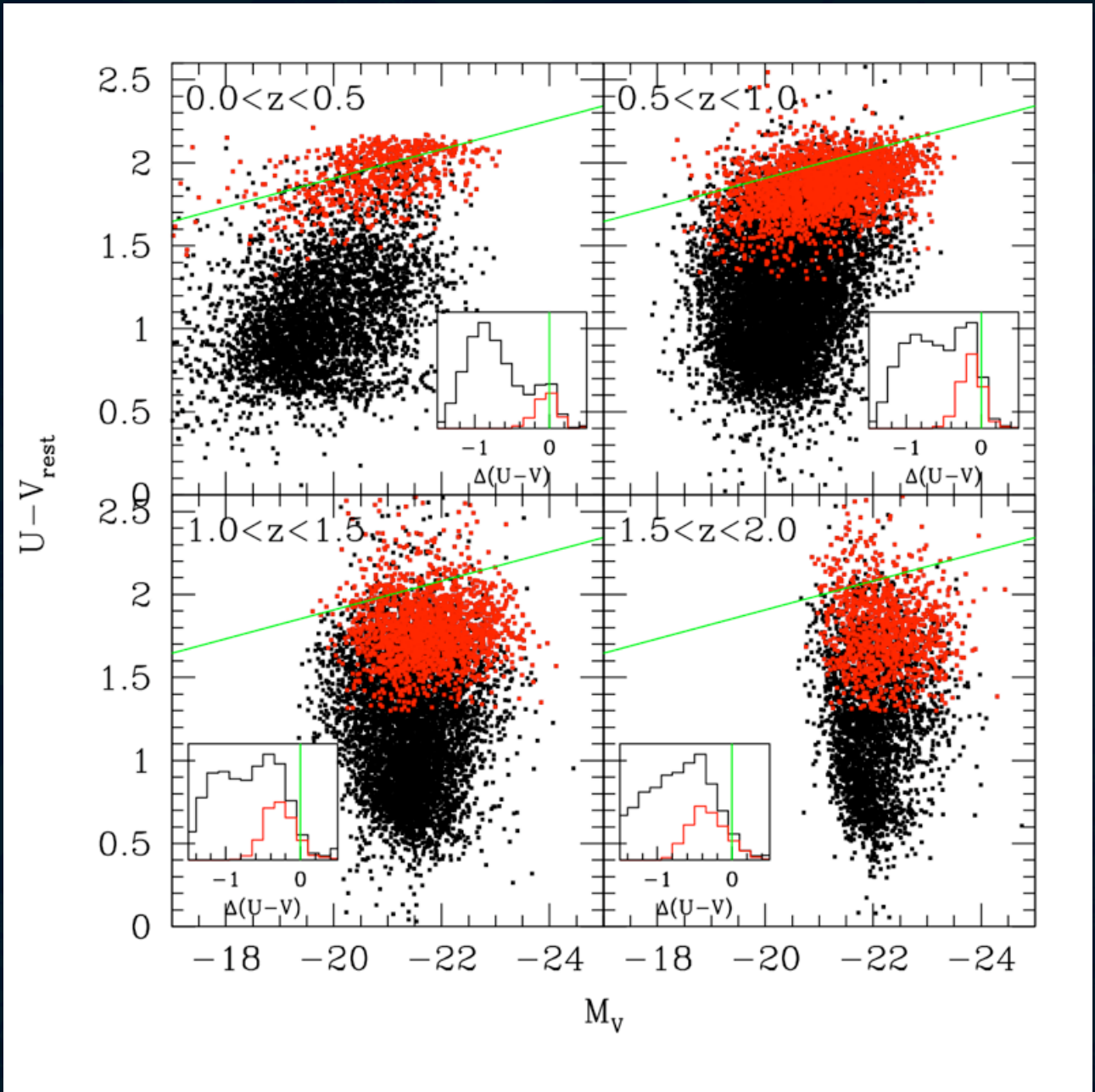
- Successfully distinguish "red and dead" from "red and dusty"

Specific star-formation rates



Williams et al., arXiv:0806.0625

One-color red sequence



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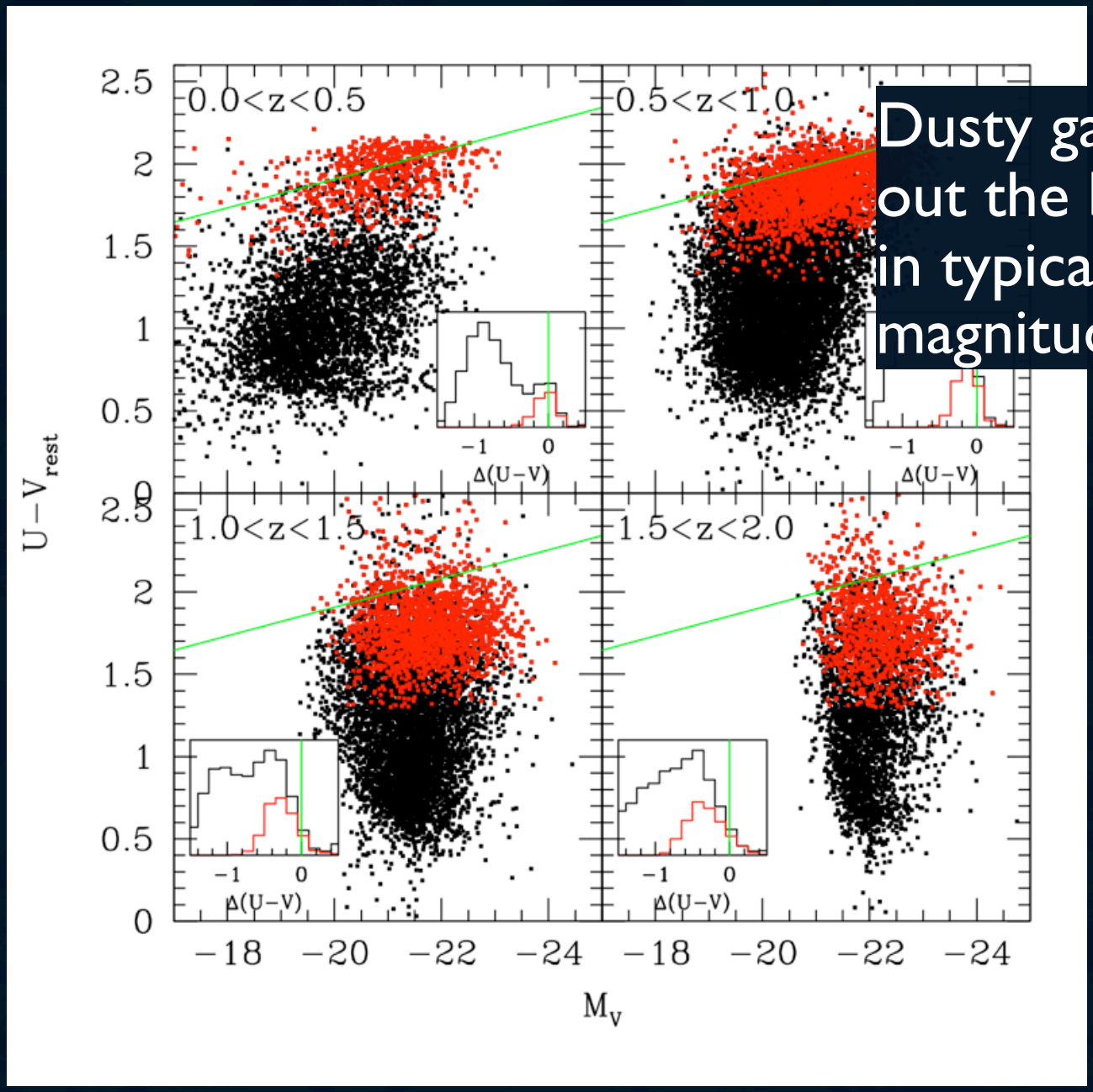

Dusty galaxies wash out the bimodality in typical color-magnitude diagrams

Williams et al., arXiv:0806.0625

Clustering

- More massive dark matter halos are rarer, thus more strongly clustered
  - Clustering strength reflects average halo mass of a population

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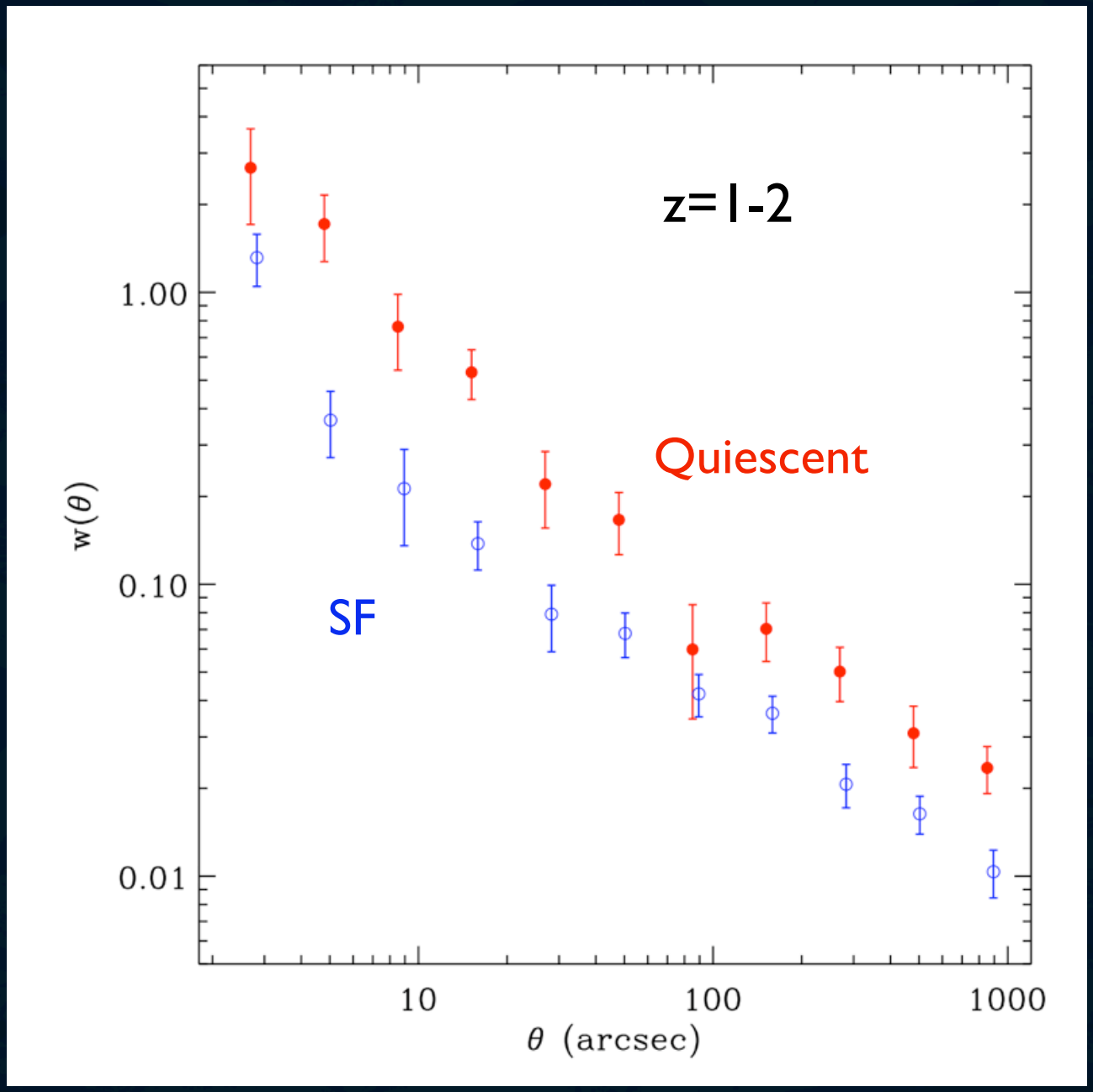
- Measure angular correlation function
- Deproject using z distribution to get physical correlation length

Clustering



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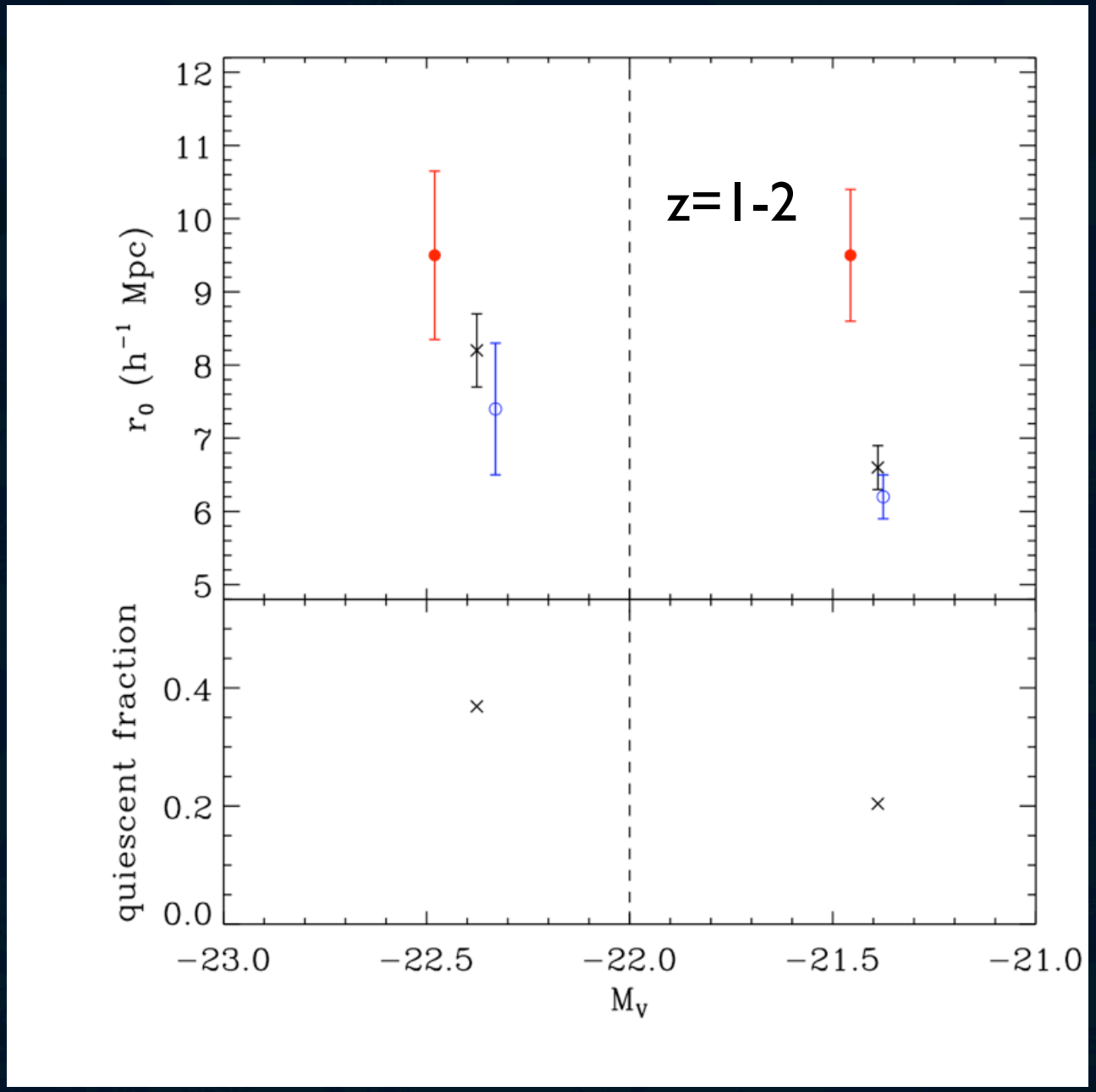
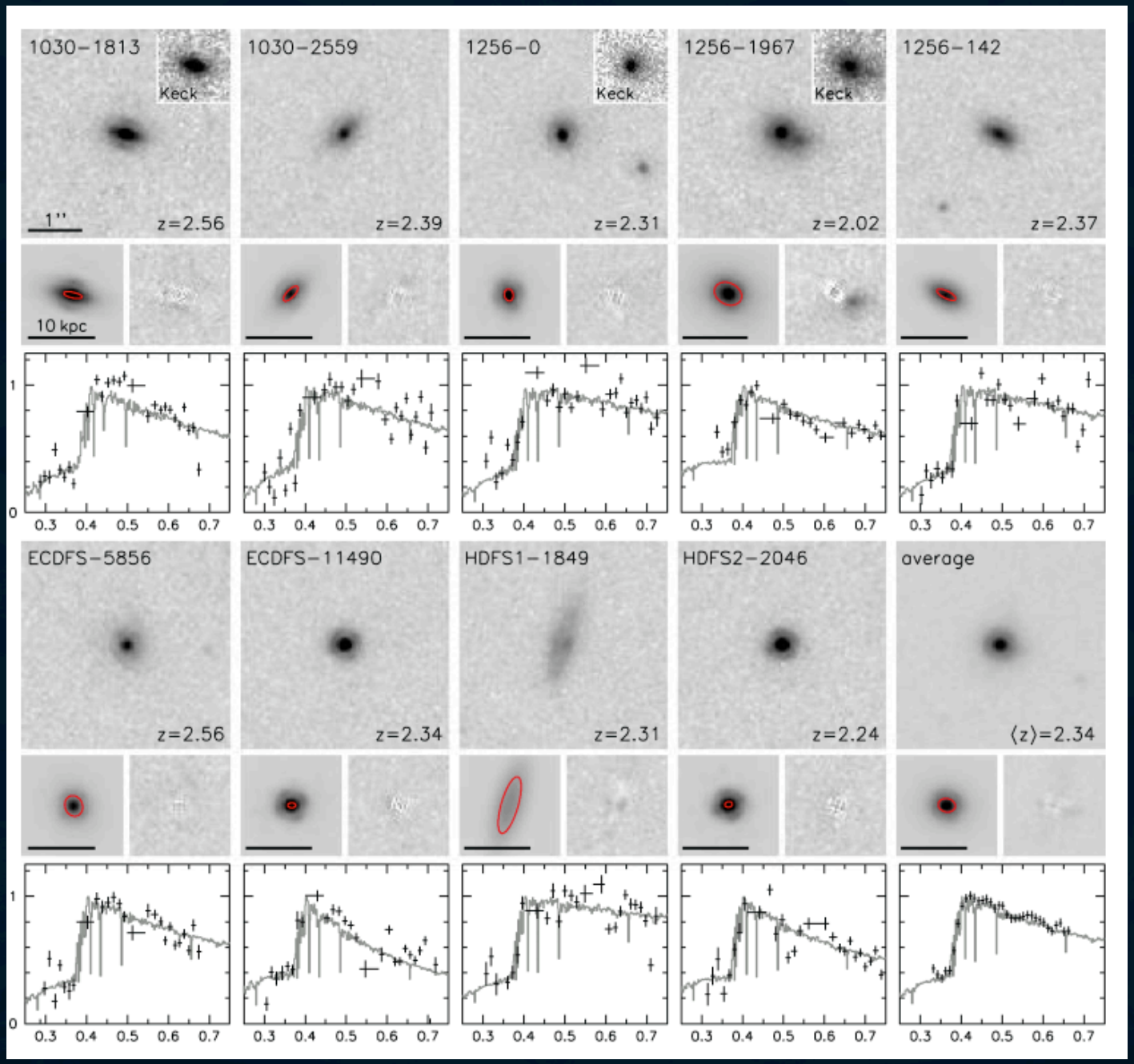


Williams et al., arXiv:0806.0625

- Quiescent galaxies inhabit more massive halos than star-forming galaxies (regardless of luminosity)

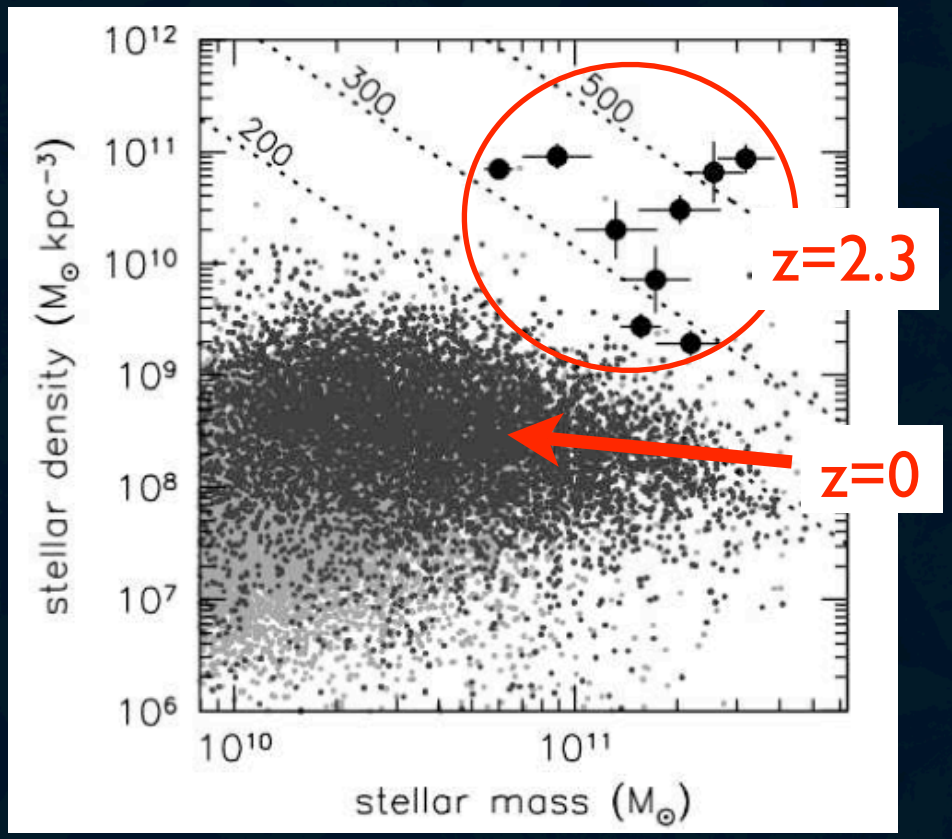
- Halo mass may be the culprit in the death of star formation!
  - Radio-mode AGN feedback (Croton+06, Bower+06)
  - Hot accretion/shocks (Keres+05, Birnboim+07)

Compact dead galaxies



van Dokkum et al. 2008, ApJL, 677, 5

Compact dead galaxies



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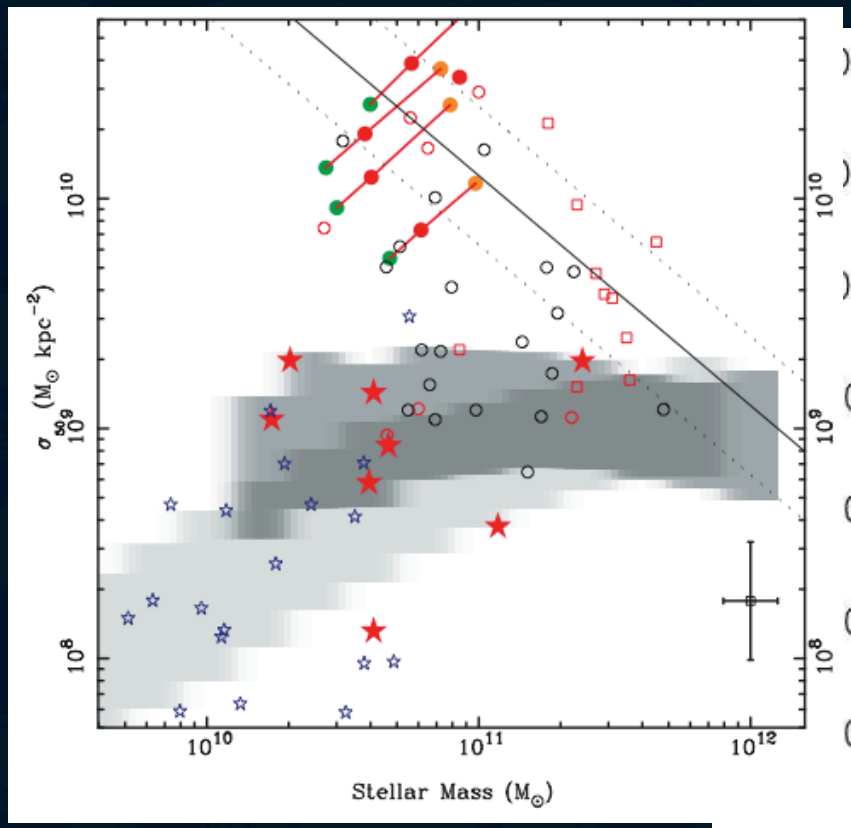
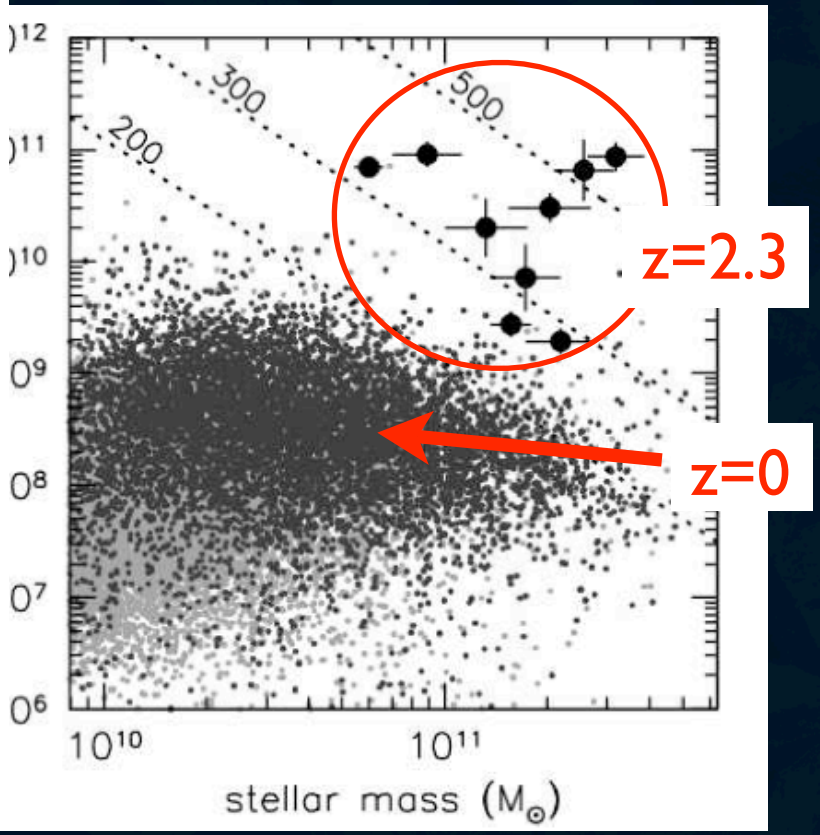
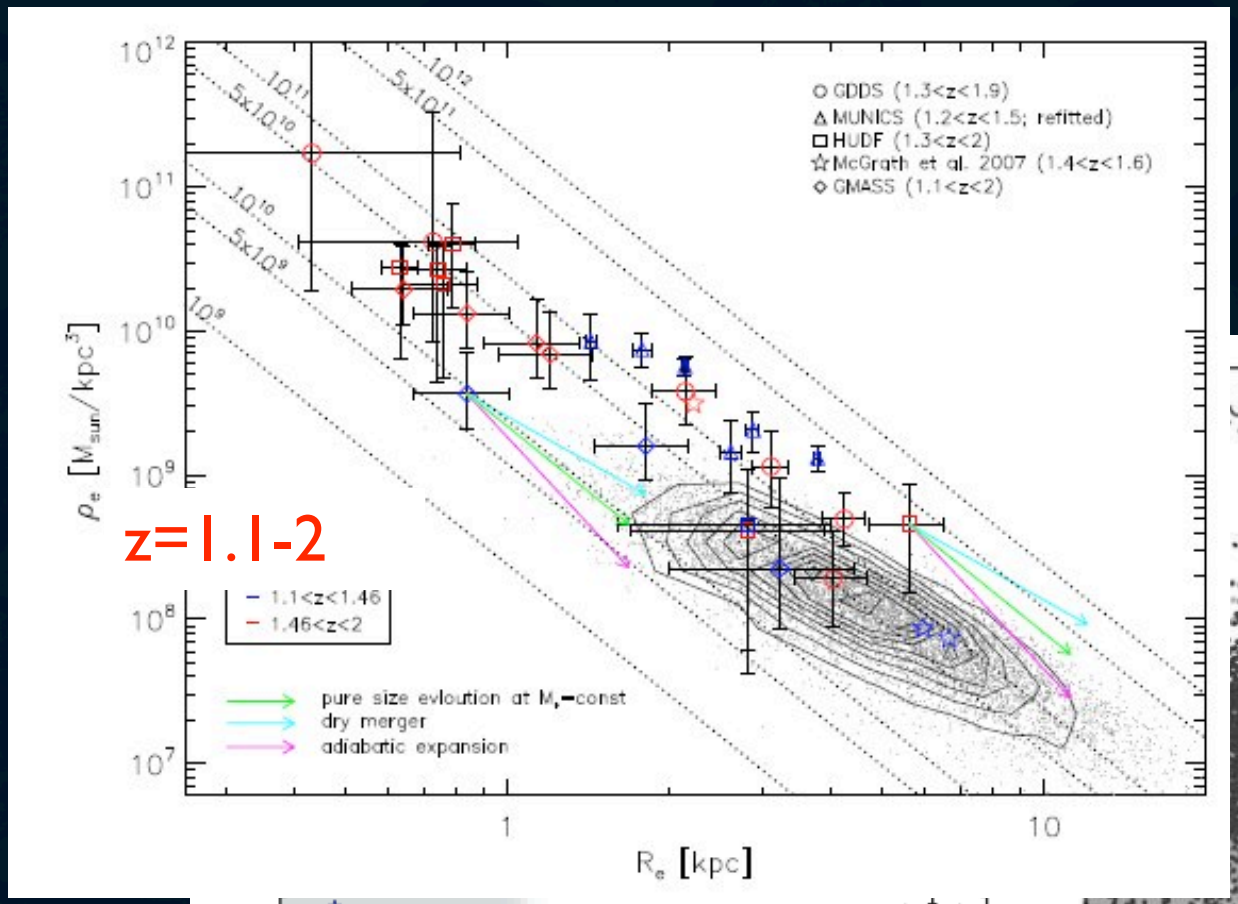


Zirm et al. 2007, ApJ, 656, 66

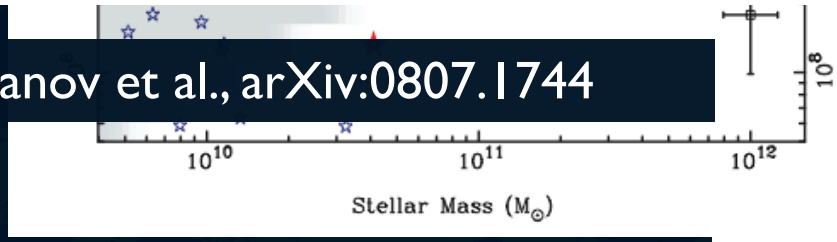


van Dokkum et al., 2008, ApJL, 677, 5

Compact dead galaxies



Damjanov et al., arXiv:0807.1744



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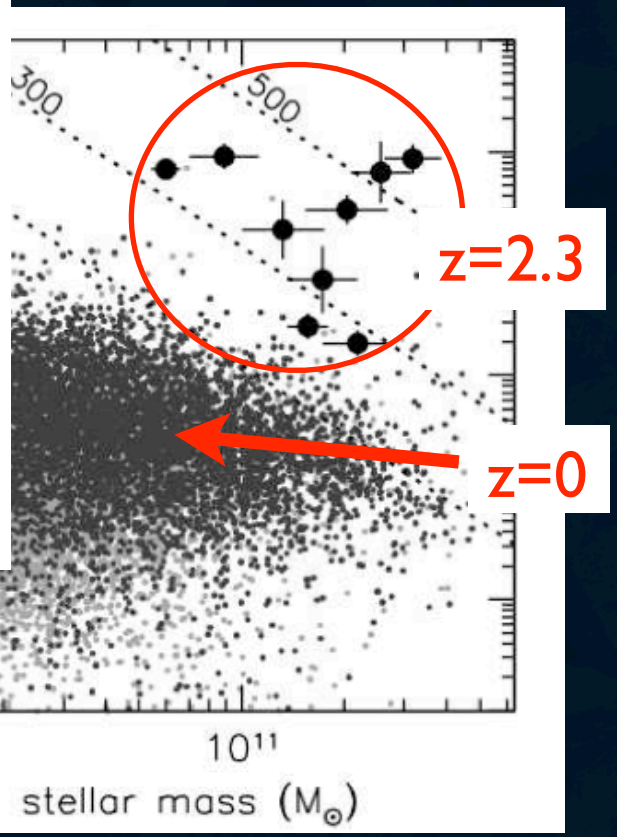

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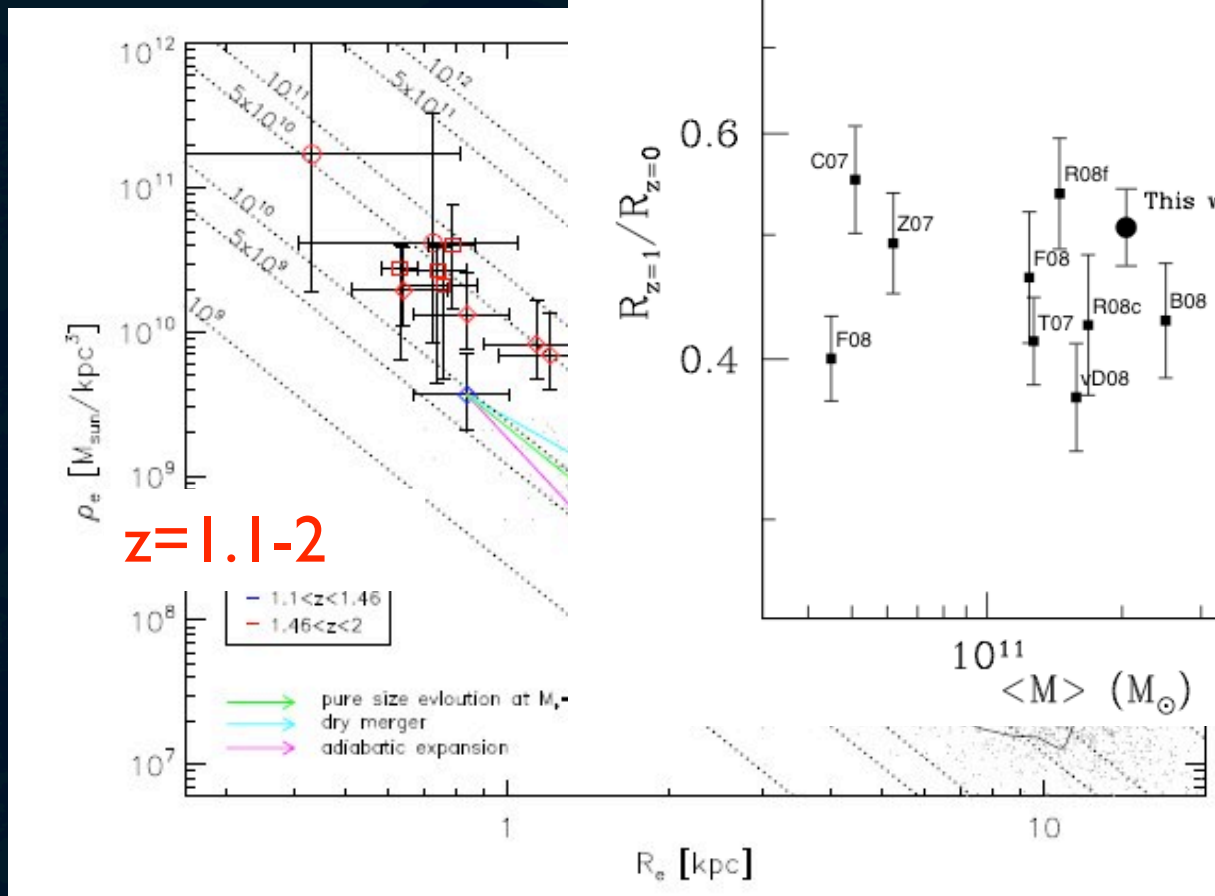
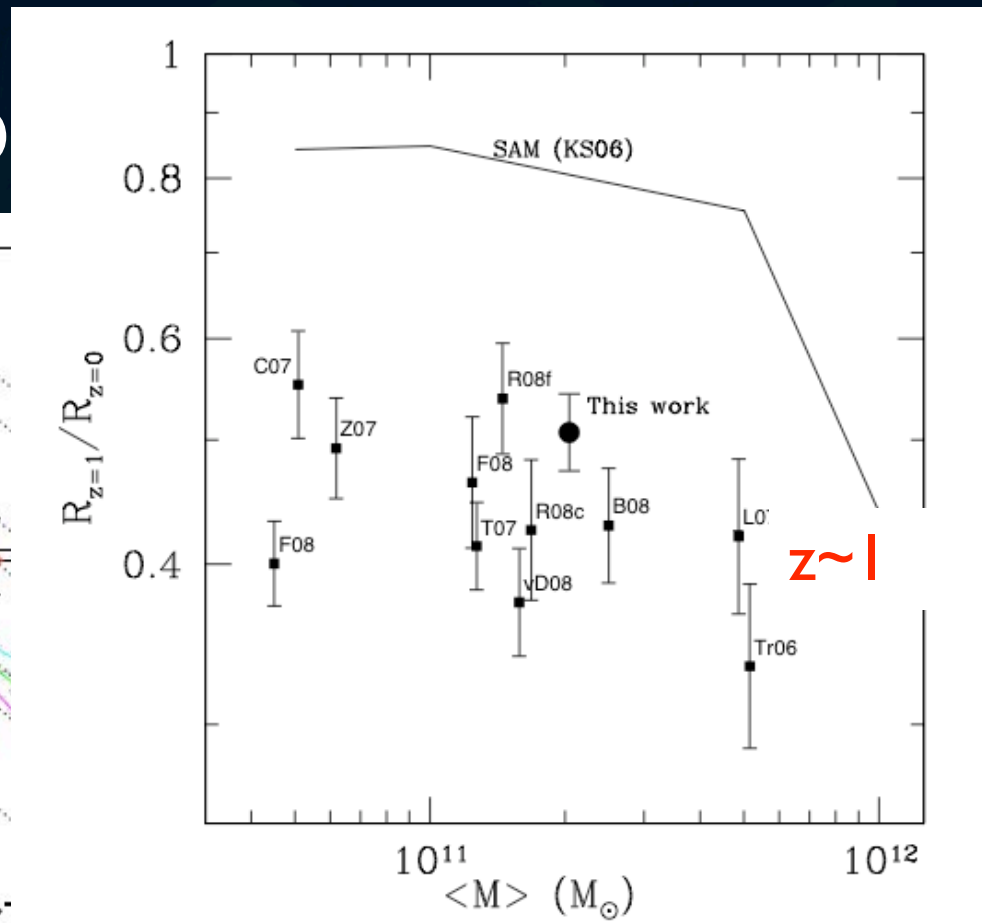
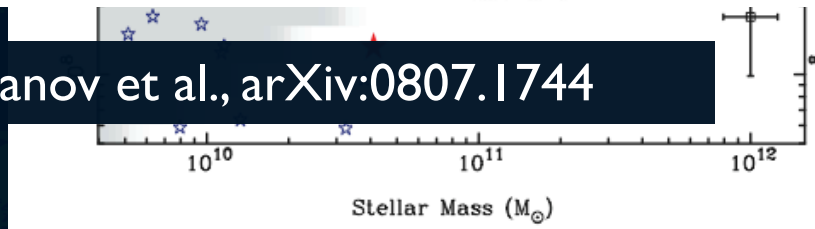




van der Wel et al., arXiv:0808.0077



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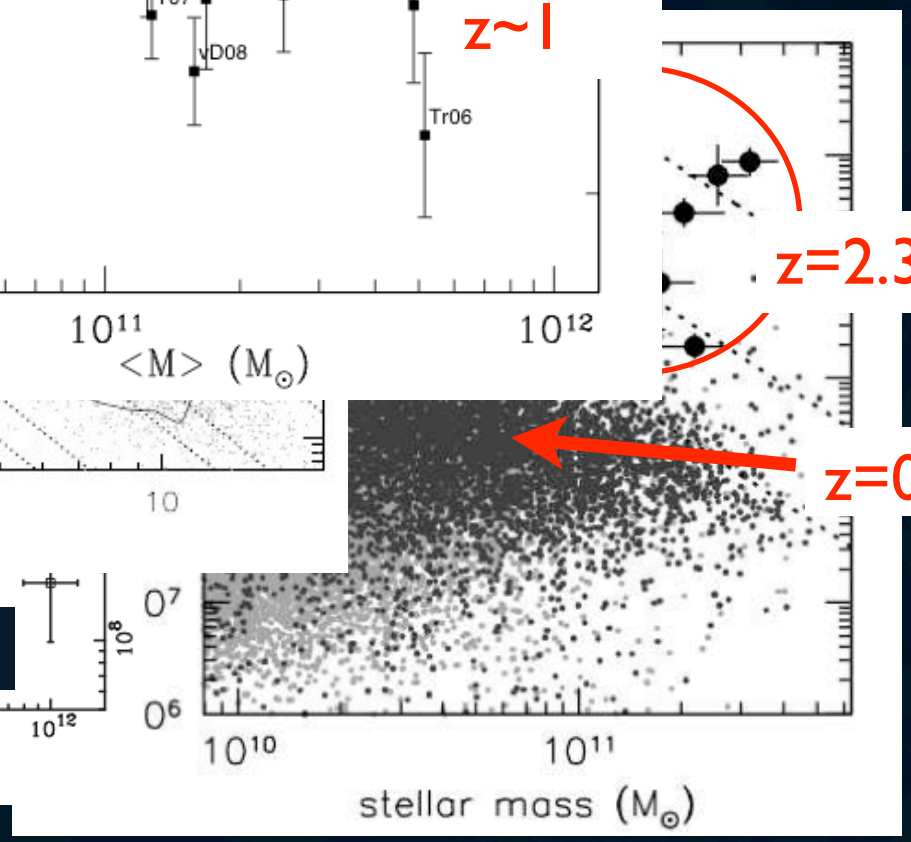
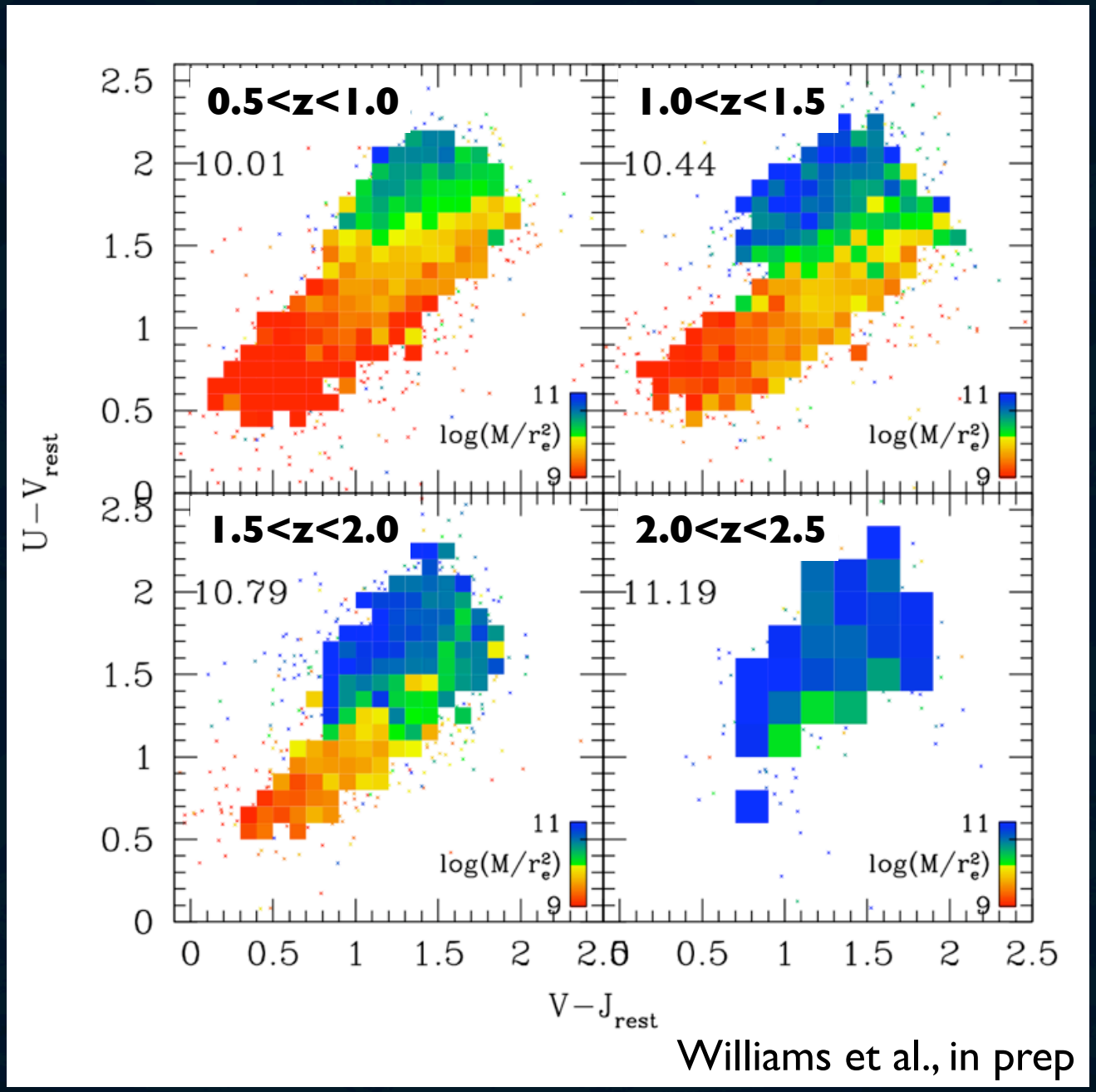


van Dokkum et al., 2008, ApJL, 677, 5

Compact dead galaxies in UDS



Williams et al., in prep

Compact dead galaxies in UDS

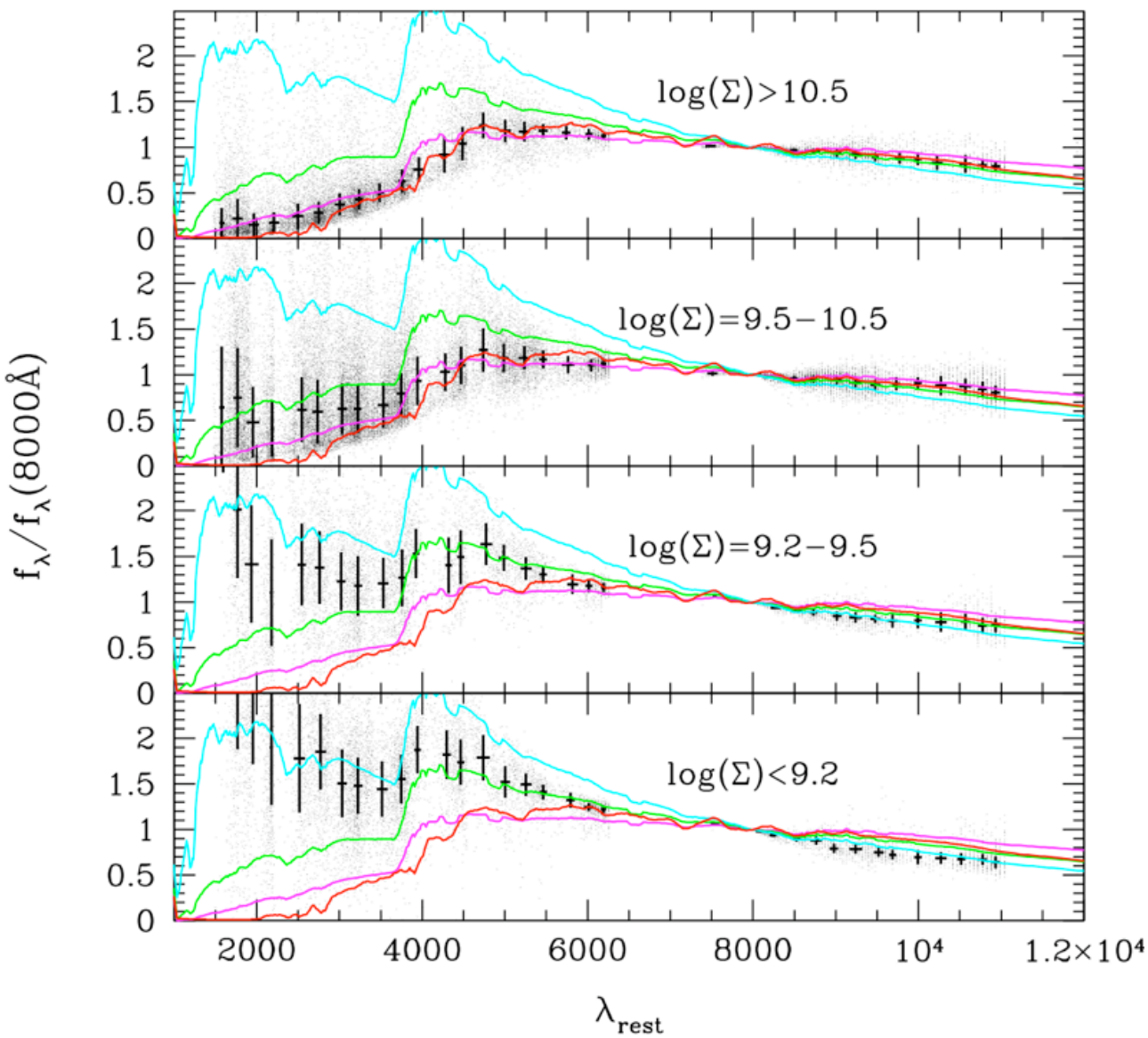
BC03 models:

Av=1

Av=2

Av=3

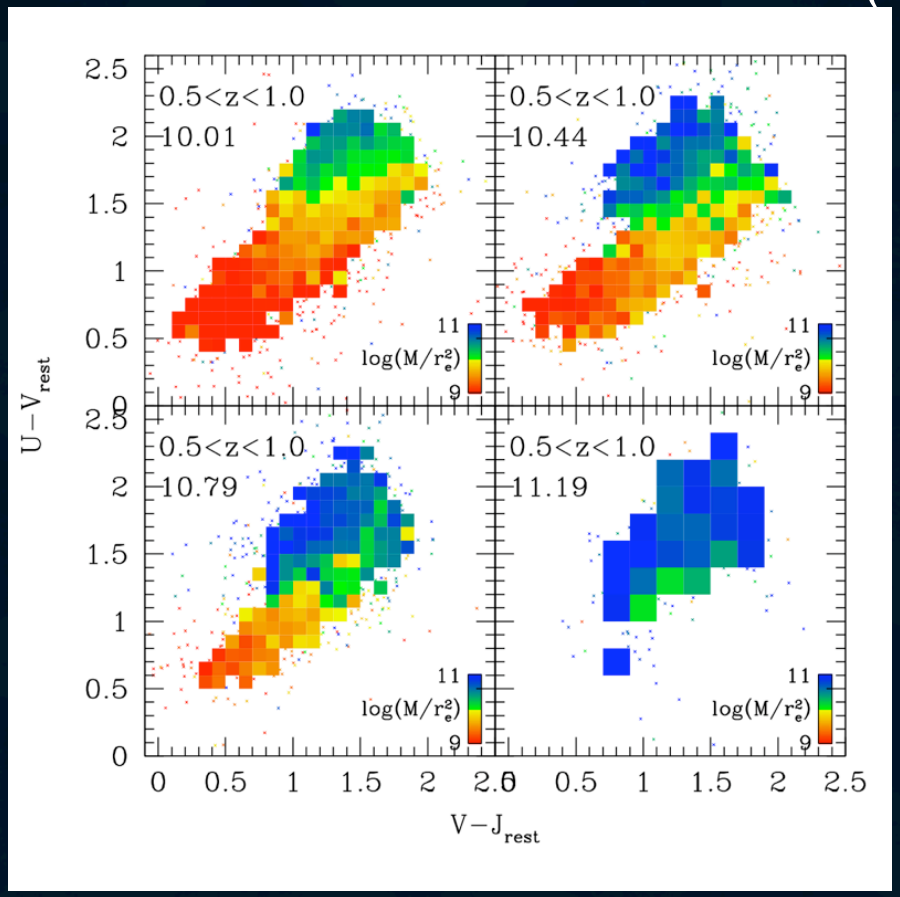
Quiescent

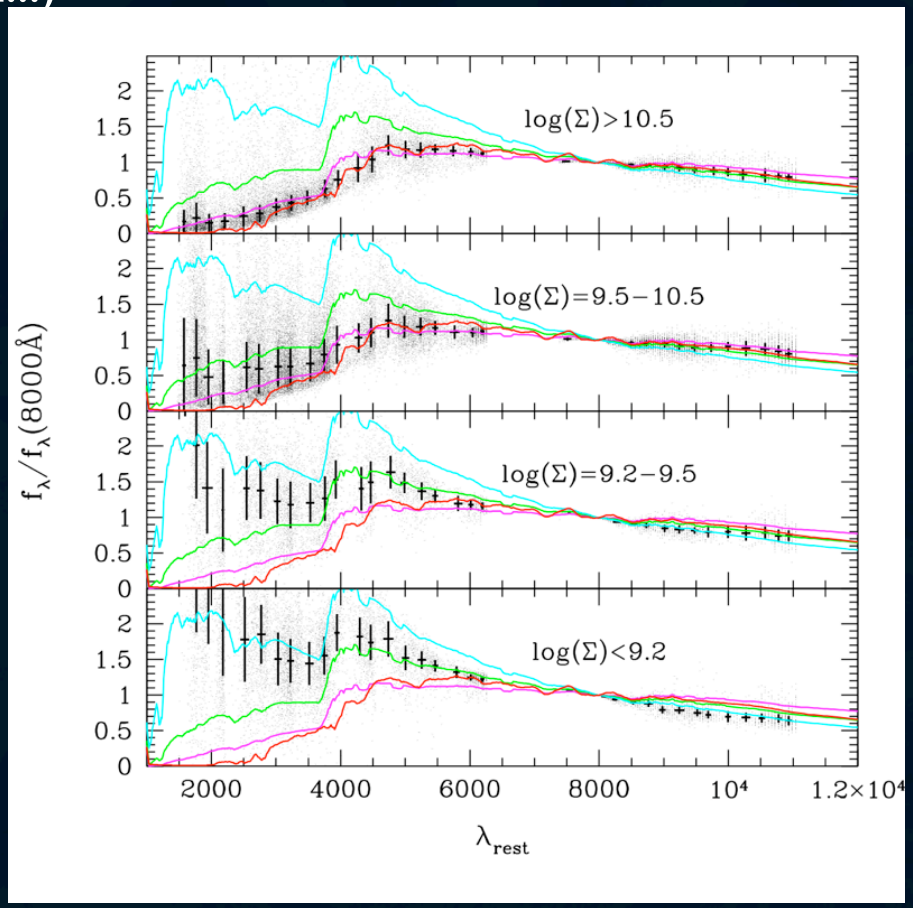


Williams et al., in prep

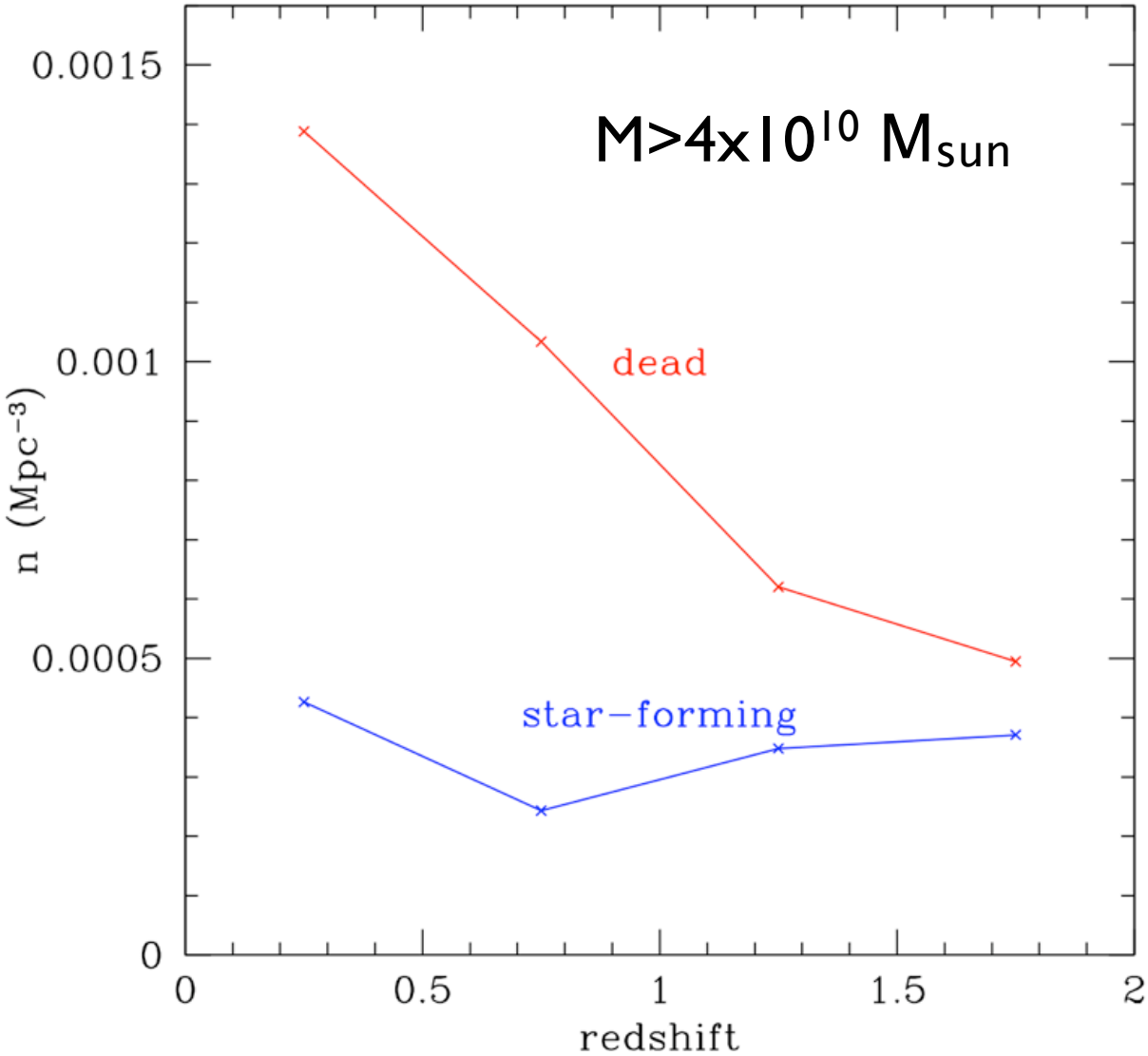
Dead galaxies were compact, compact galaxies were dead

(at z~1-2...)





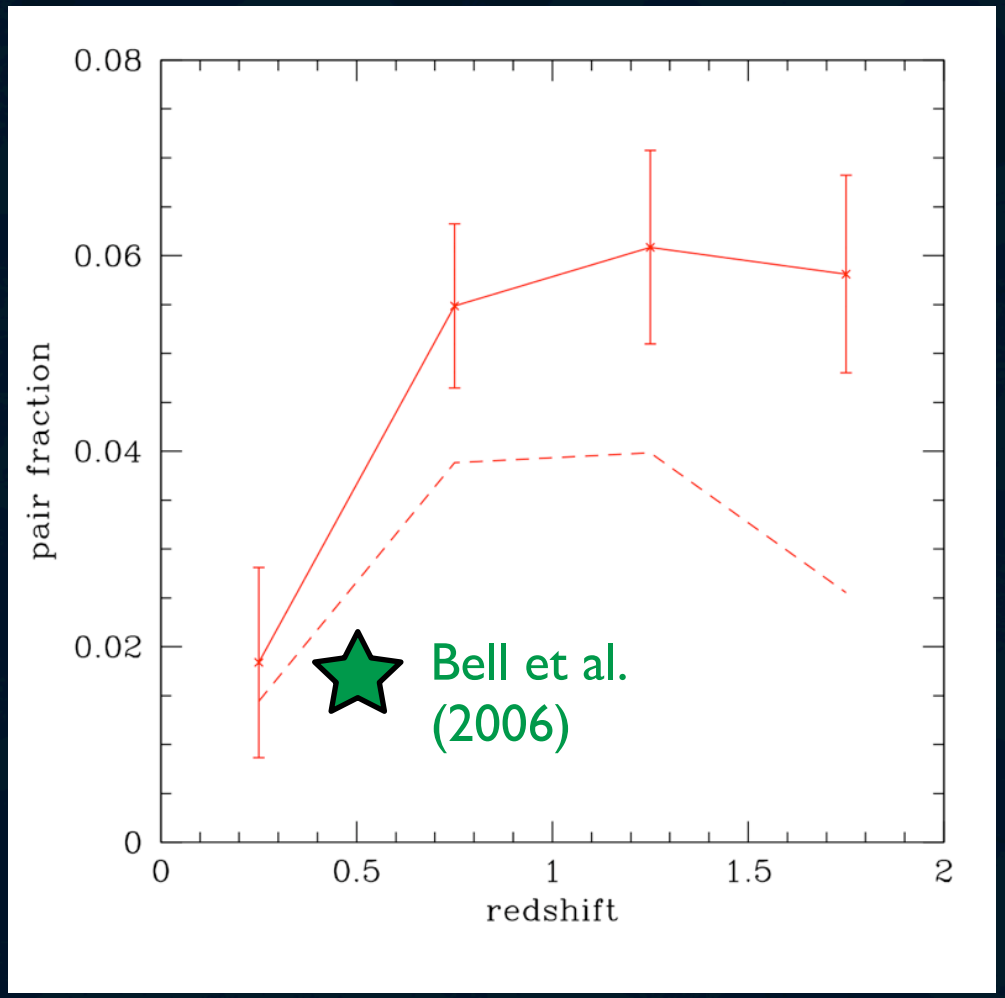
Galaxy number densities



What caused the evolution?

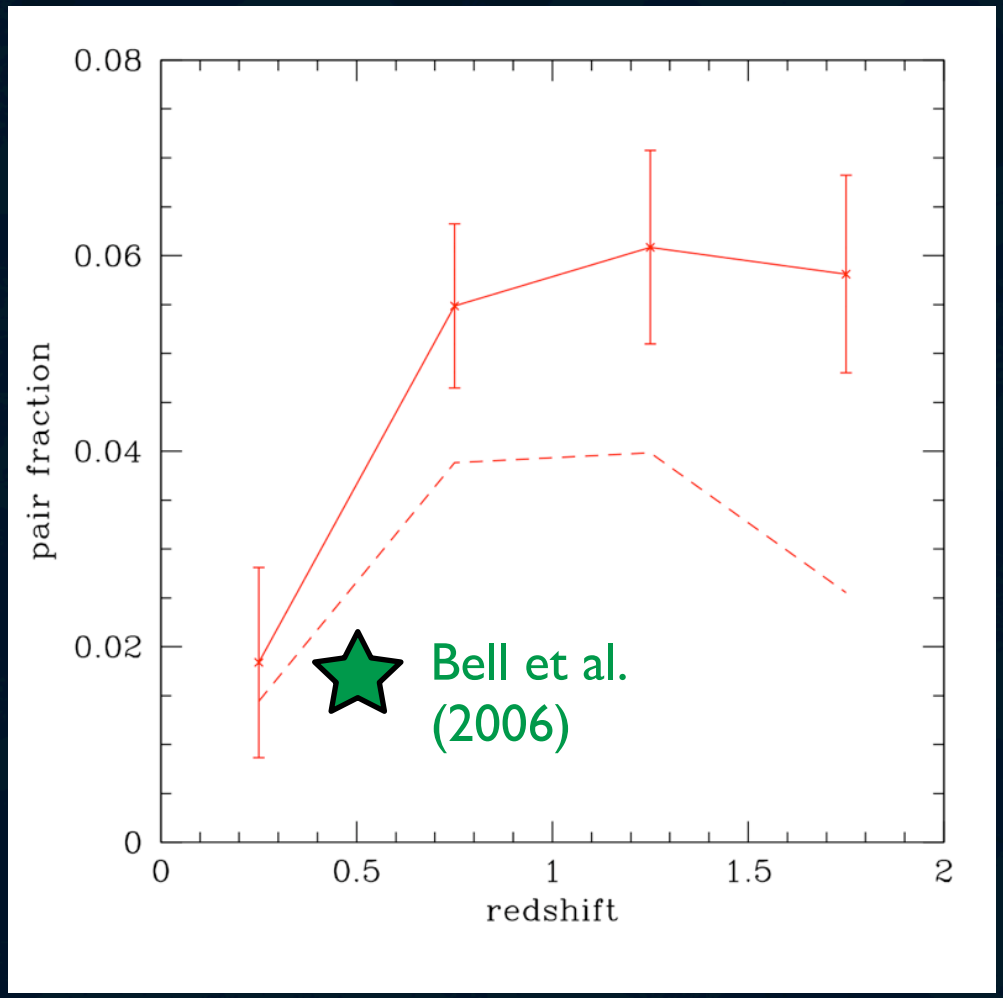
Mergers?

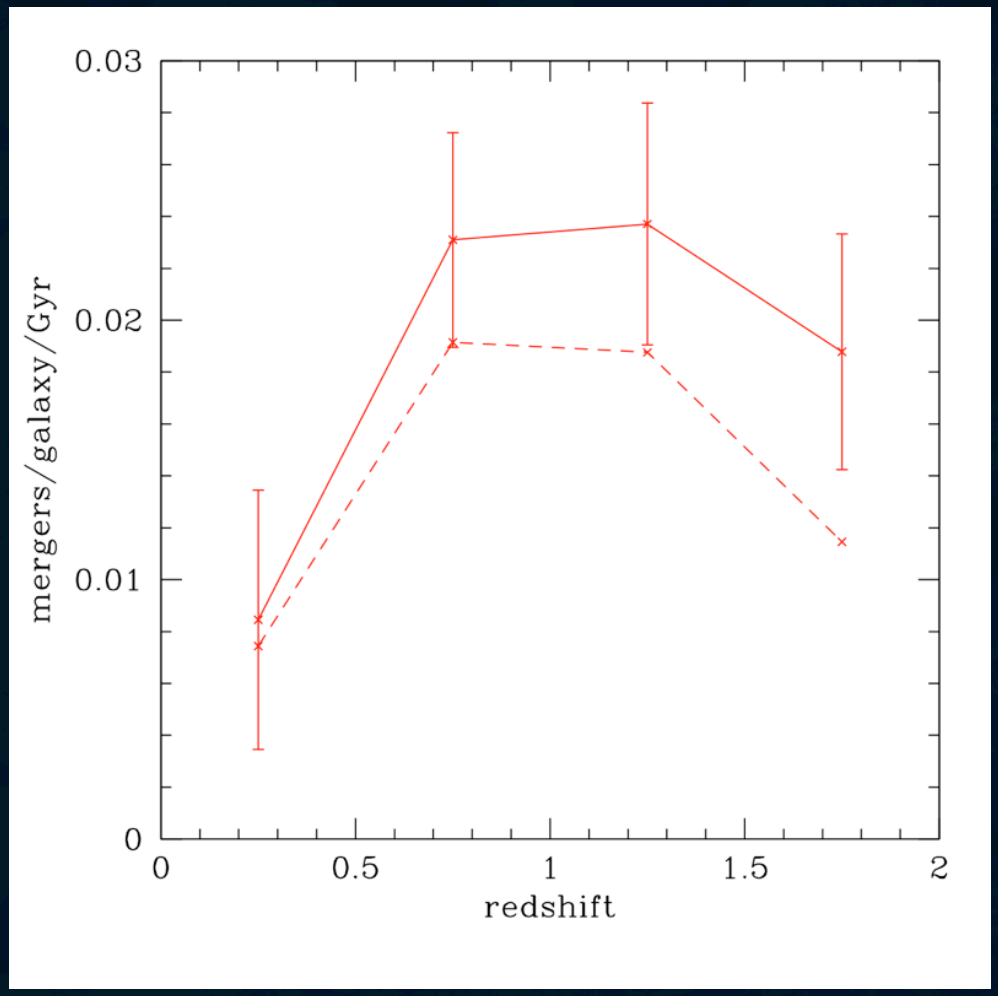
Can major mergers do it?



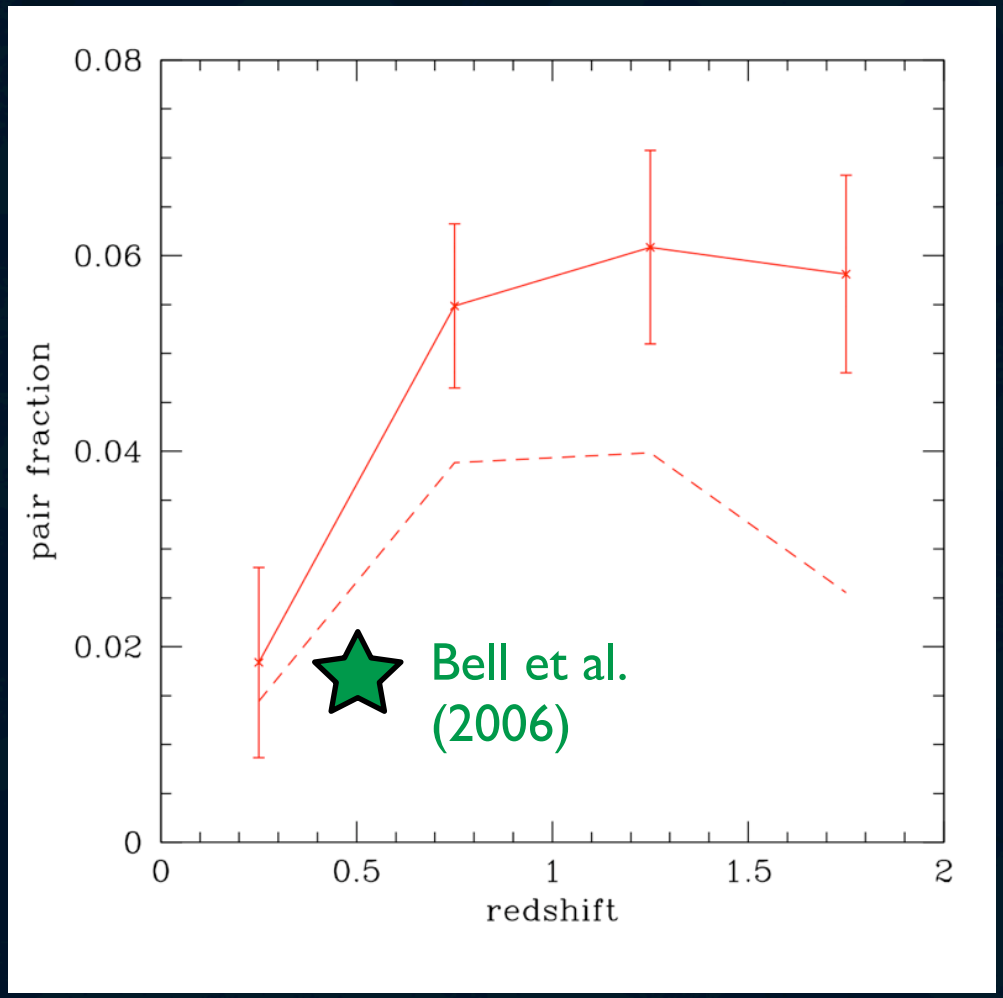
- Count pairs within $30h^{-1}$ kpc, log(M)>10.6, mass ratio <3:1
- Convert to merger rate with Kitzbichler & White (2008) : typical timescale of ~2 Gyr

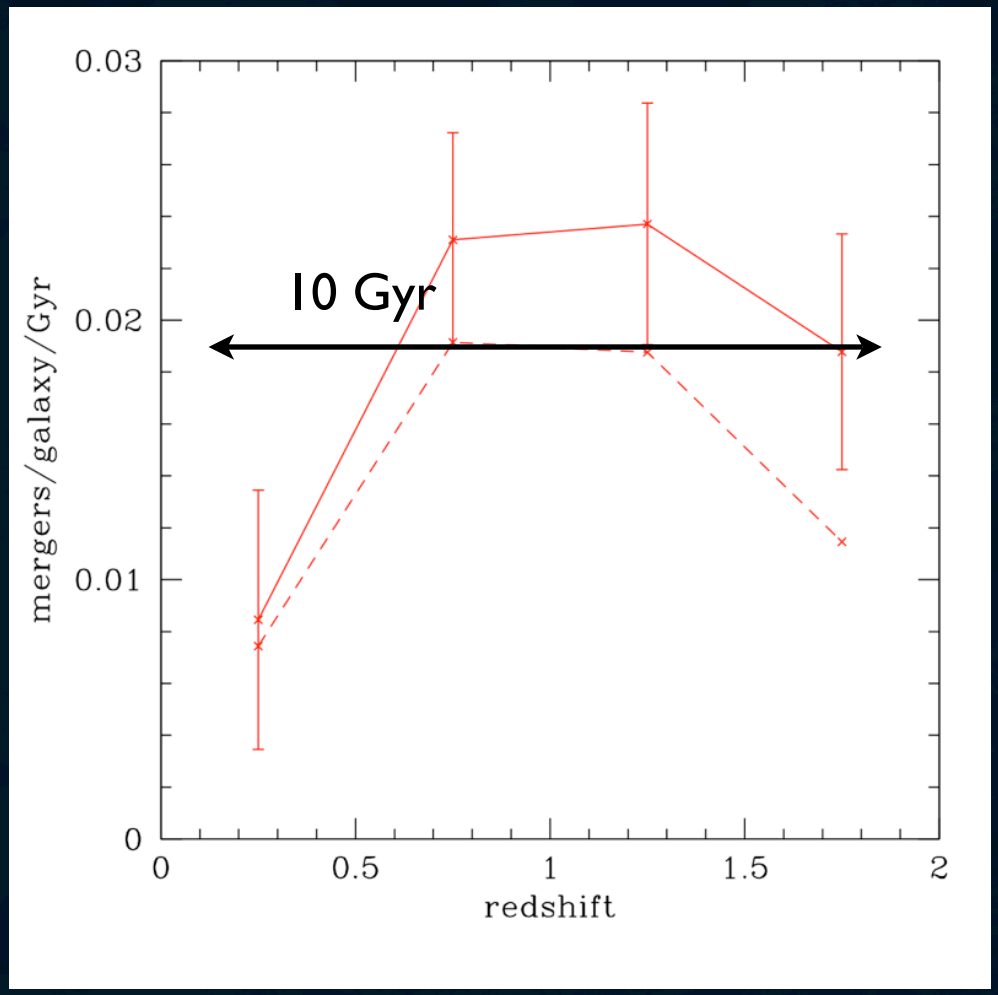
Can major mergers do it?





Can major mergers do it?





Only ~1/5 of massive ellipticals undergo a major merger at z<2

Conclusions

- Rest-frame UVJ colors are useful for star-formation diagnostics at high redshift
- Population is bimodal to at least z~2
- Quenching and halo mass appear to be related
- Quiescent galaxies at z~1-2 had higher surface densities than those seen at z=0
- Major dry mergers were too rare to account for present-day elliptical sizes; perhaps it's minor mergers/accretion?

Future work

- X-ray/radio properties as a function of UVJ
- Progenitors of the compact quiescent galaxies: compact, dusty starbursts at z=2.5-3?
- Better constraints on masses/SFR via spectroscopy
  - Flood of new near-IR survey data on the way (future UDS releases; Ultra-VISTA)
  - Near-IR wideband and multi-object spectrographs (X-Shooter, MOSFIRE, NIRSPEC...)