Revealing the nature of galaxies at z~1

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Harry Teplitz (SSC/Caltech)
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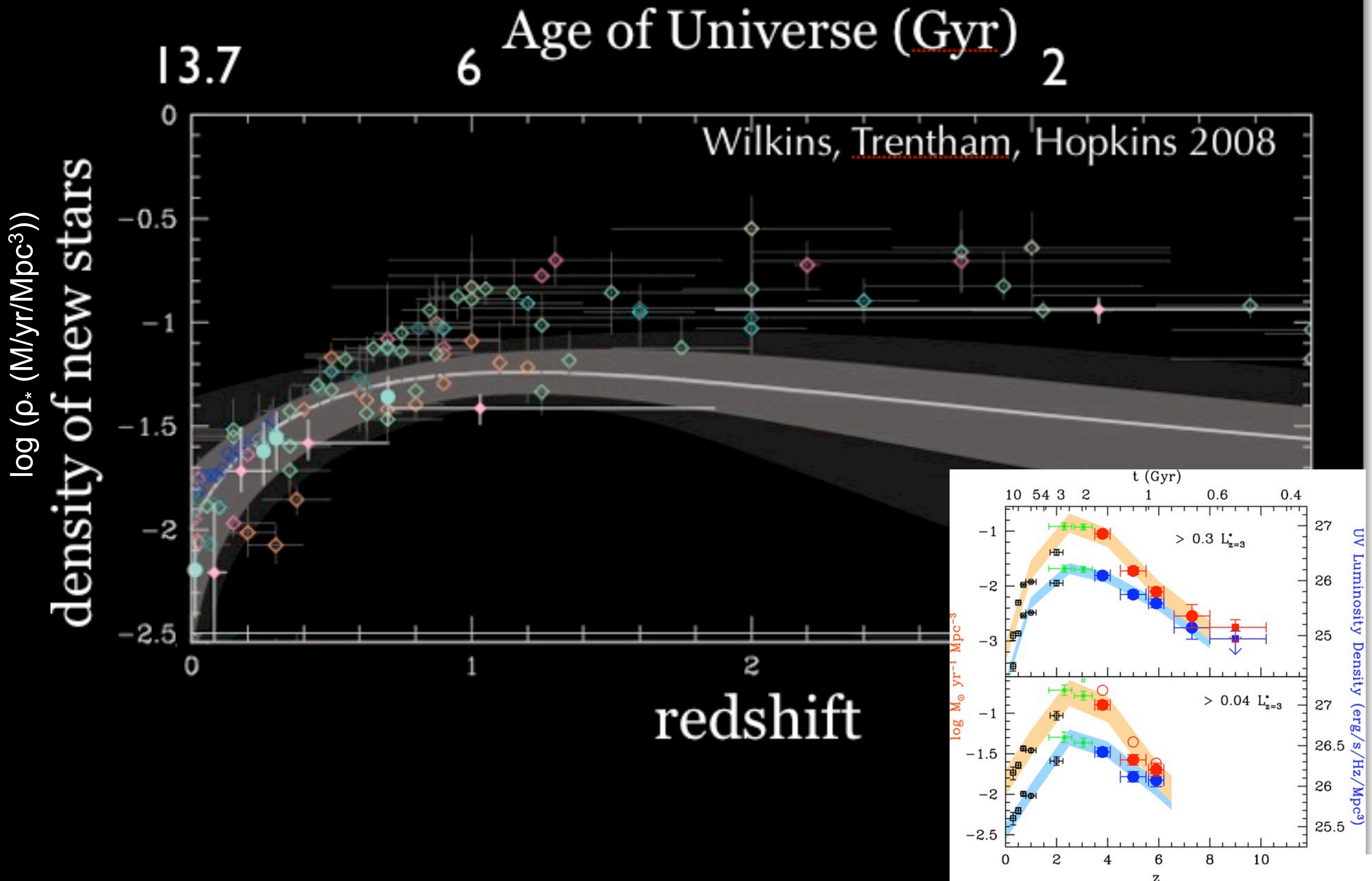
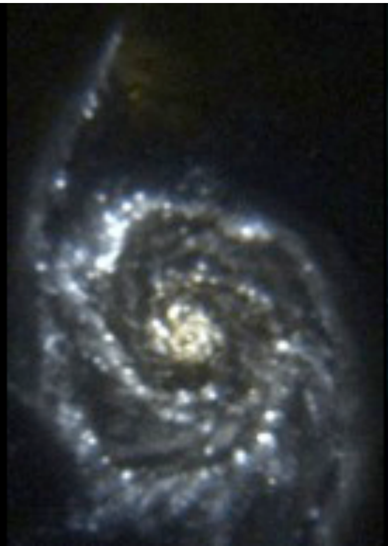
Why redshift 1 ?



Is the UV the right wavelength?



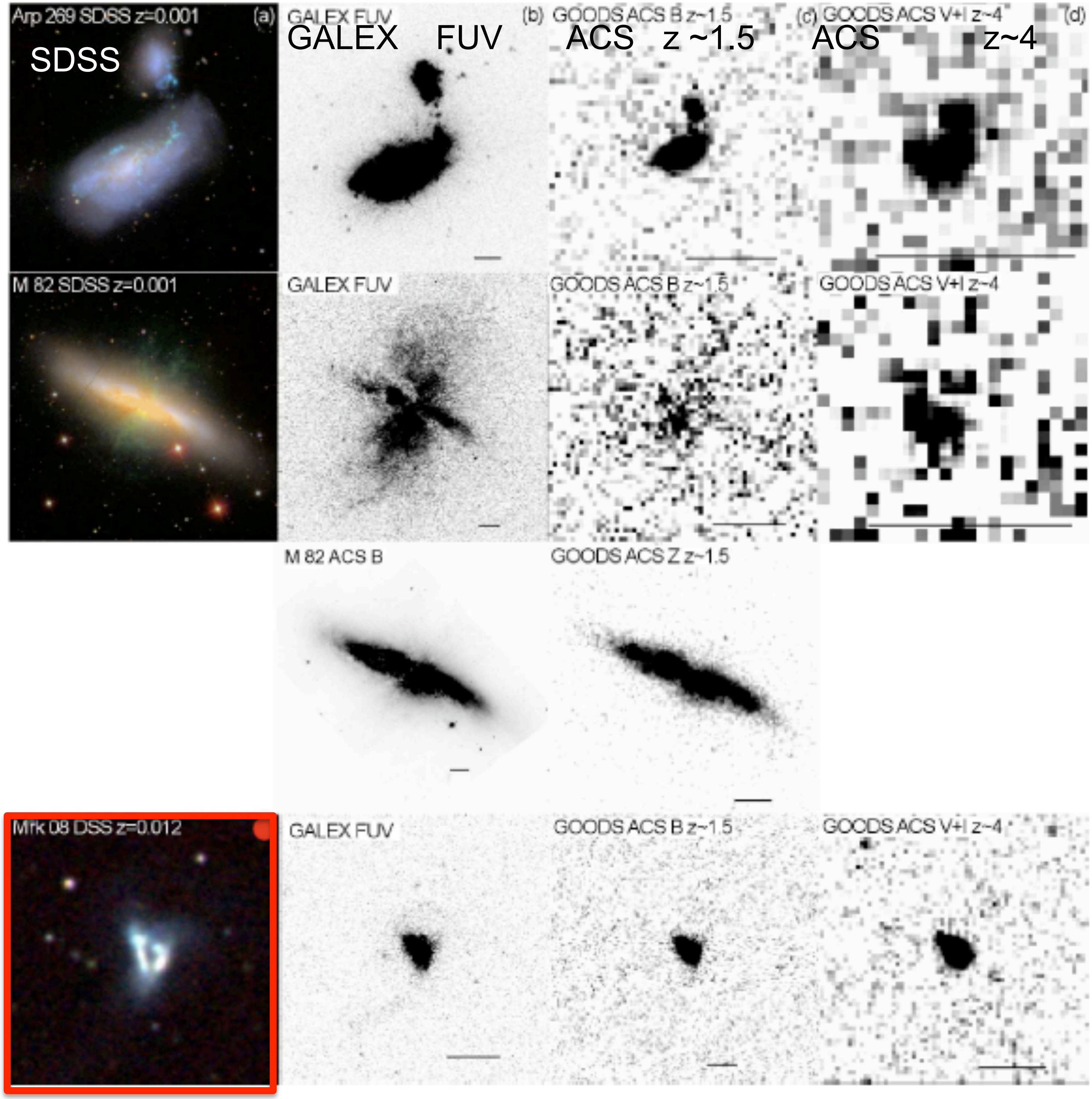
Is the UV the right wavelength?

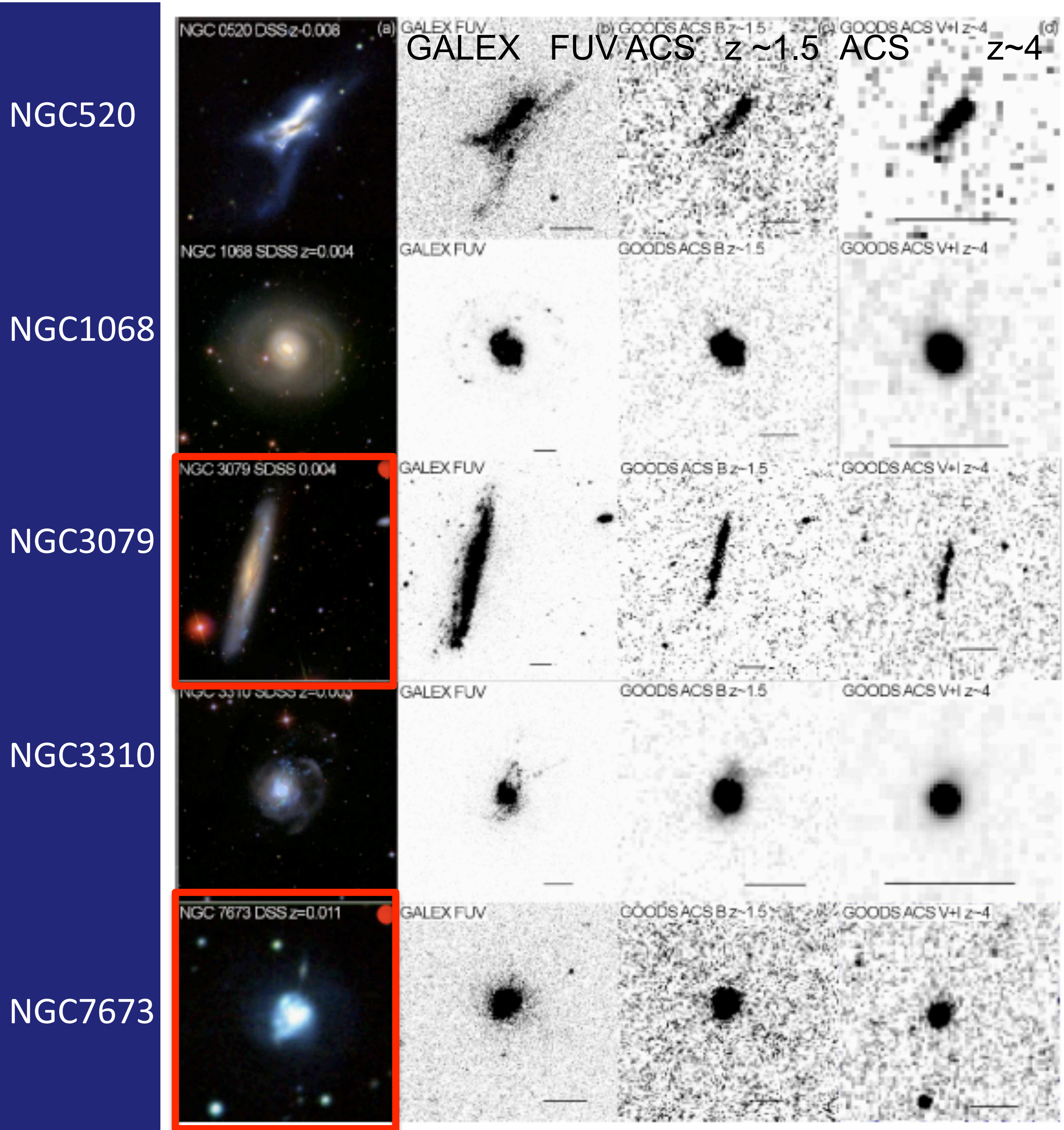
Arp 269

M82

Mrk8

Petty
et al. 09




NGC520
NGC1068
NGC3079
NGC3310
NGC7673
GALEX FUV
ACS z~1.5
ACS z~4
NGC 0520 DSS z-0.008
(a)
(b)
(c)
(d)
NGC 1068 SDSS z=0.004
NGC 3079 SDSS 0.004
NGC 7673 DSS z=0.011
GALEX FUV
GOODS ACS B z~1.5
GOODS ACS V+I z~4

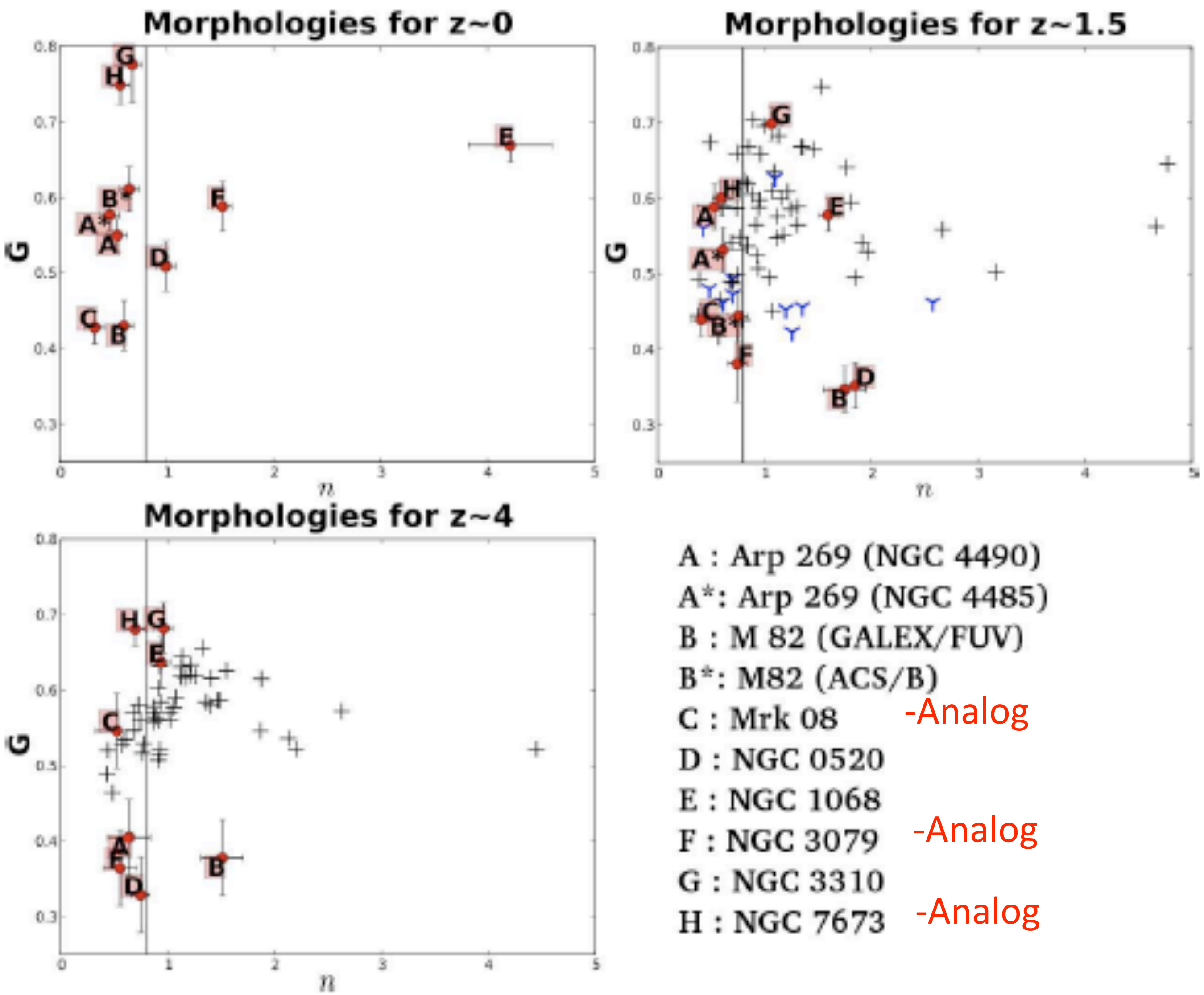


Figure 2.7 Morphologies using G and Sérsic. I plot G and n, Sérsic index, to determine high redshift star-forming galaxy analogs (see §2.5.6). The symbols are the same as for Figure 2.5. The vertical line marks $n = 0.8$, which helps distinguish whether the object, if to the left of the line, has a merger profile.

Is the UV The Right Wavelength?

- ✧ It depends, but always compare rest-frame wavelength
- ✧ Careful when using UV, it does not show the whole story, only the massive stars.
- ✧ Dusty objects will not radiate UV, but IR
- ✧ The morphology of rest-frame UV at high-z are similar to Mrk08, NCG3079, NGC7673 (not M82), i.e. peculiar and compact (Petty et al. 2009).

HST U-band Observations of the UDF

- Observations made with WFPC2 through F300W filter (λ_{max} = 2987Å, $\Delta\lambda$=740Å) 12 orbits

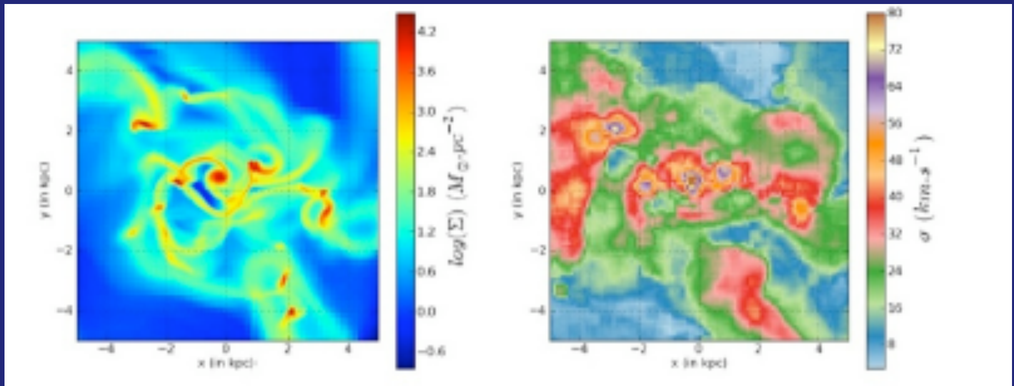
Source catalog: Voyer et al. (2009)

Rest-frame UV Clumpy Galaxies at Intermediate-z

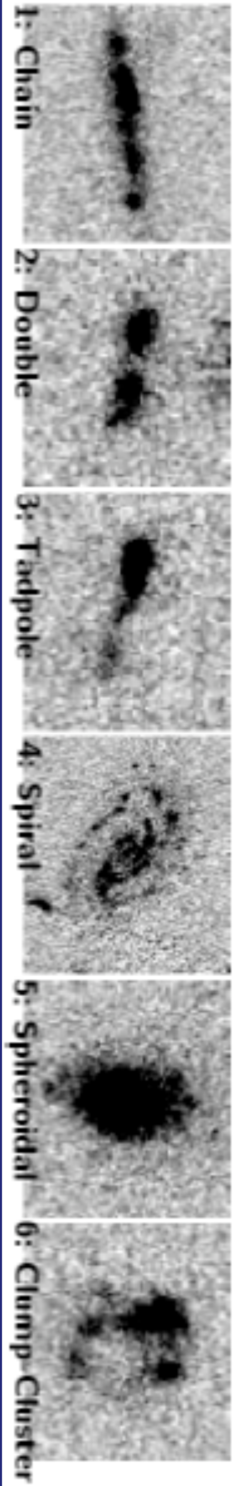
Motivation:

- Sizes of 10 clump-cluster rest-frame high-z UV sources (1.6 < z < 3) in the UDF measured by Elmegreen & Elmegreen (2005)
  - Range 1-2 Kpc in diameter
  - 5-10 giant clumps per galaxy
- Recent simulations suggest high-z clumps could both dissipate to form disks and coalesce to form bulges (e.g., Bournaud et al 2011; Krumholz et al. 2010; Agertz et al. 2009; Elmegreen 2008) – potential building block of local spirals

Bournaud et al. 11



ELMEGREENS 05



HST U-band Observations of the HUDF

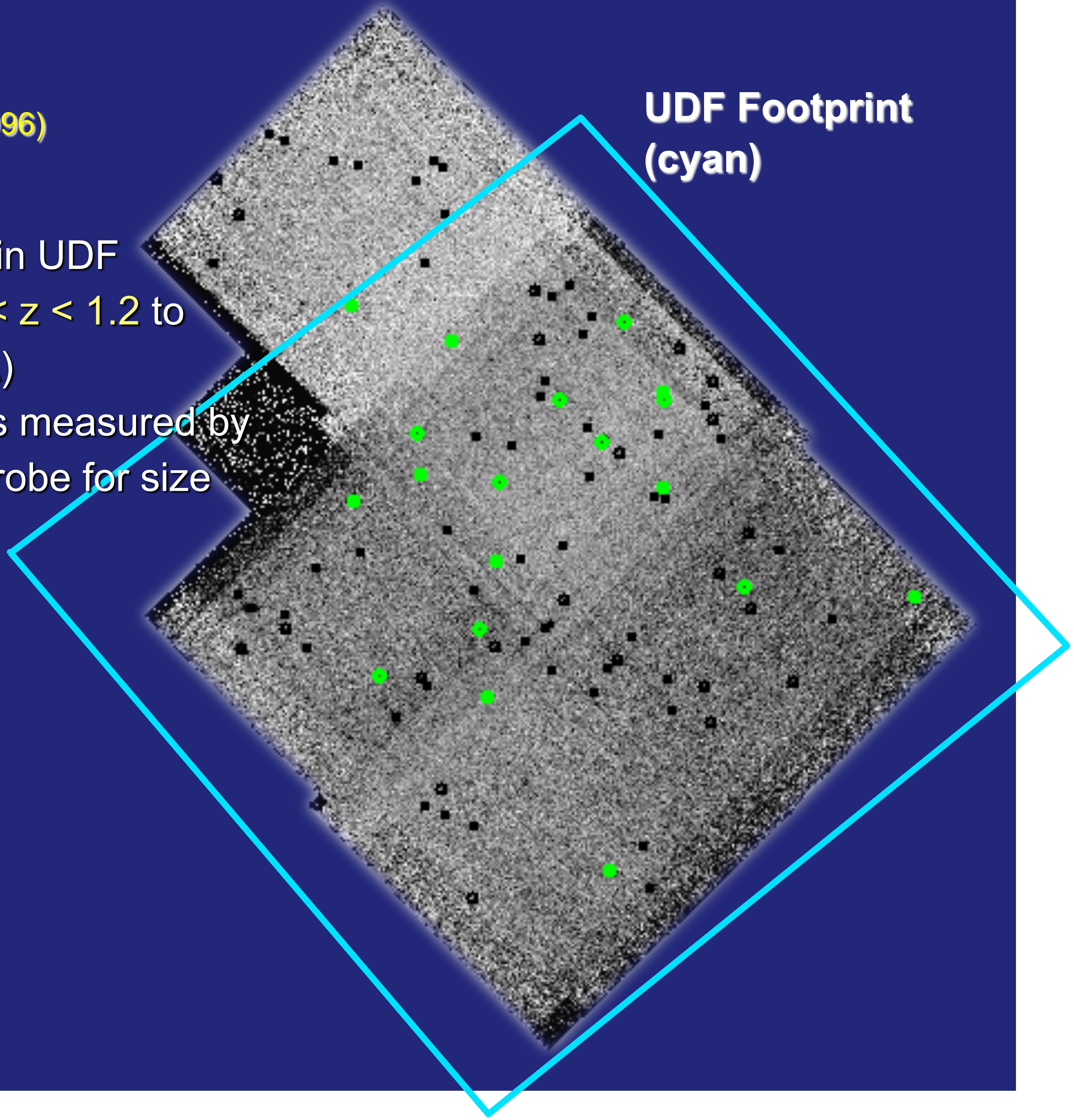
- Observations made with WFPC2 through F300W filter (λ_{max} = 2987Å, $\Delta\lambda$=740Å)

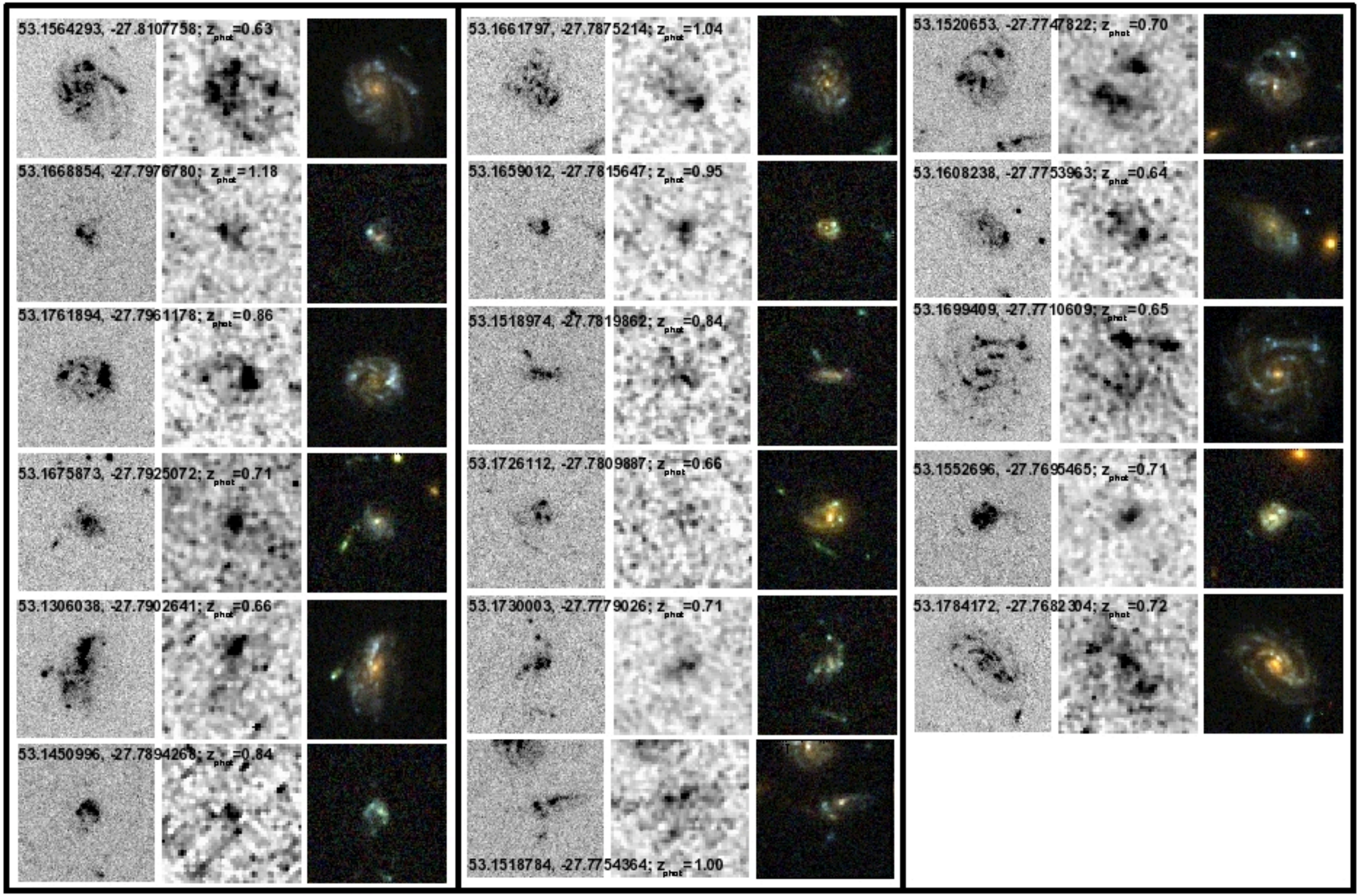
Source catalog: Voyer et al. (2009)

Made with Source Extractor (Bertin & Arnouts 1996)

96 detected rest-frame ultraviolet sources
18 selected clumpy sources

- **This Work:** select clumpy sources in UDF WFPC2 U-band data between 0.63 < z < 1.2 to target *rest-frame* UV (1200 - 1800 Å)
  - Compare to z ~ 2-3 UDF sources measured by Elmegreen & Elmegreen (2005) to probe for size evolution



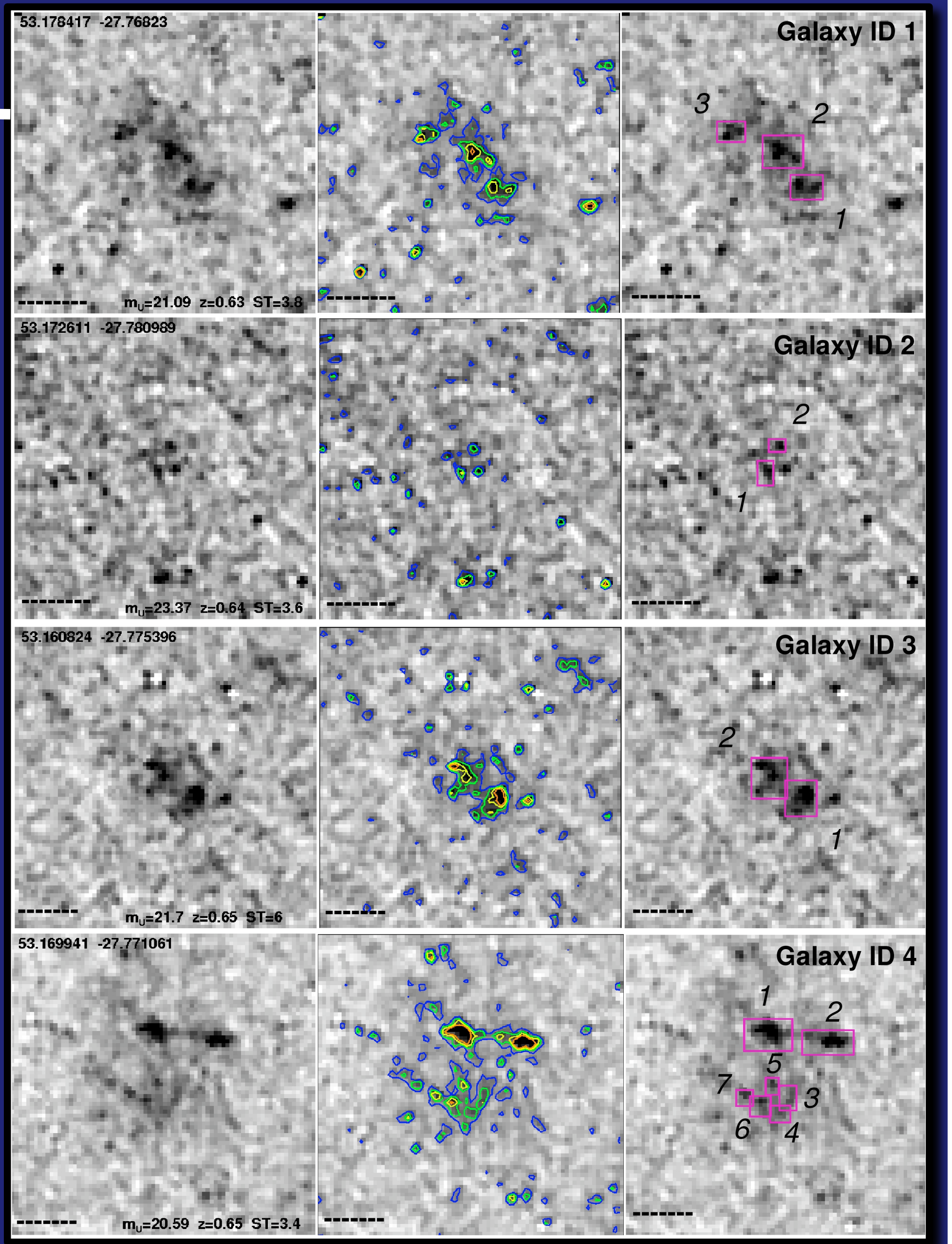


Voyer et al. 2009

UV Clump Detection & Size Measurement

- WFPC2 F300W (cutouts 7"x7")
  ----- are 10 kpc @z

- Used contours between 2-5σ above background (blue to orange)



Voyer et al 2011 in prep

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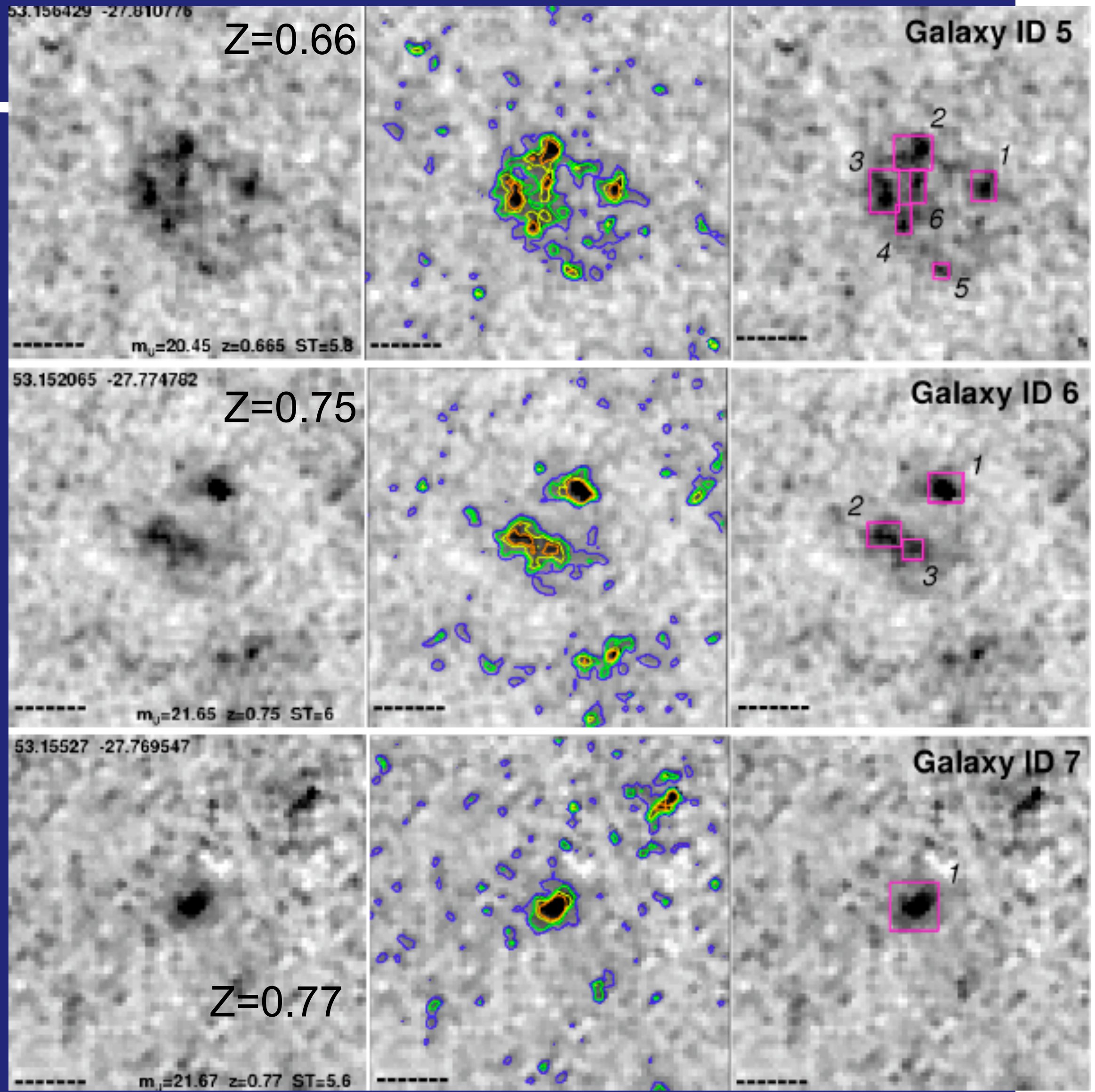

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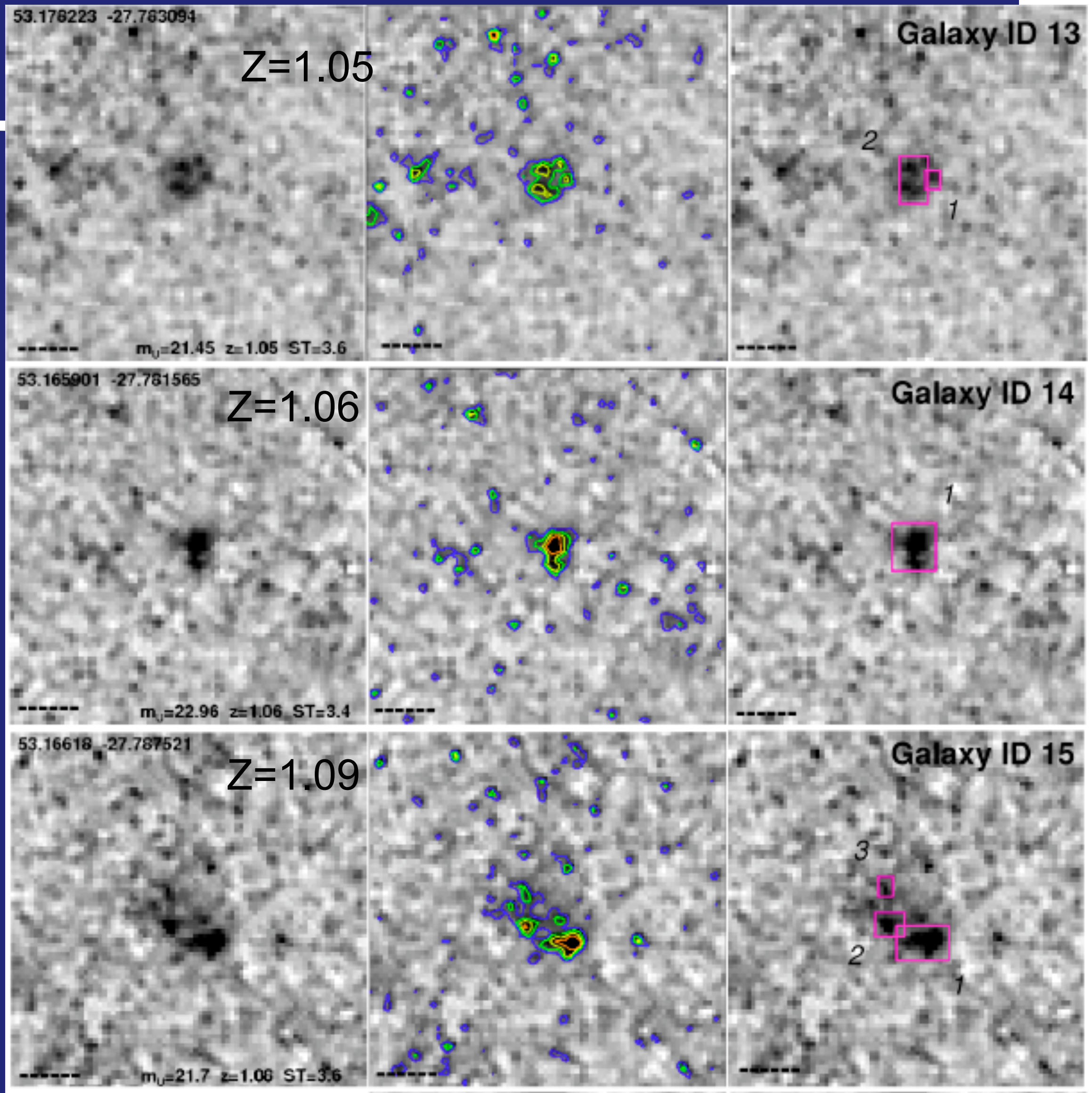
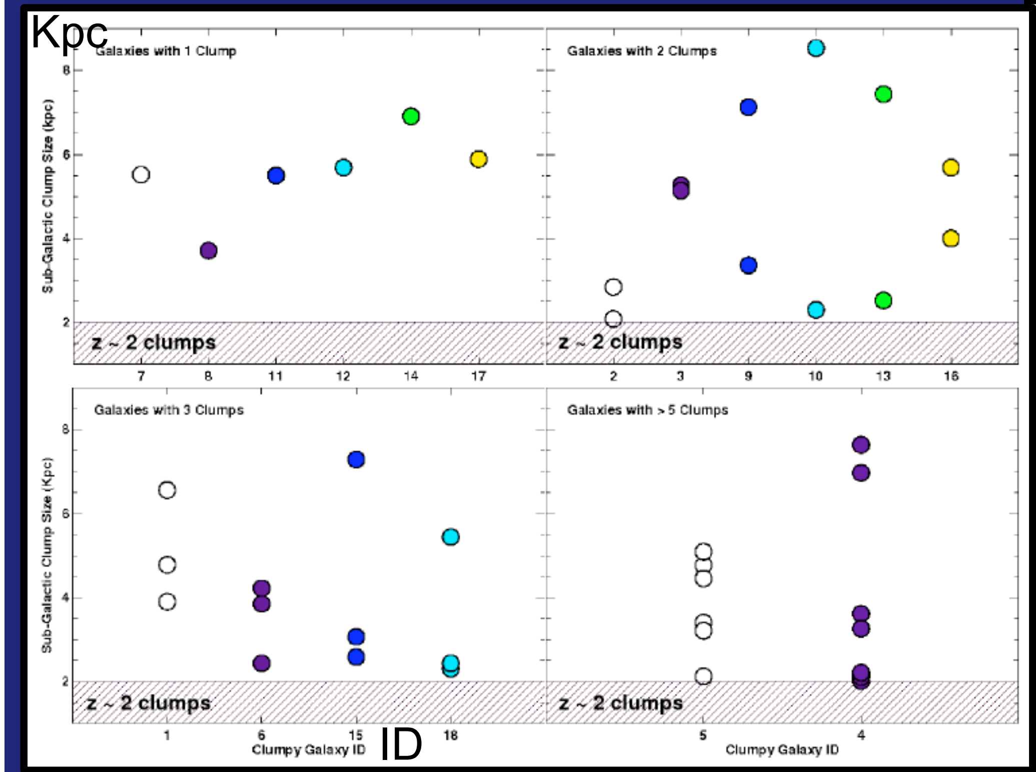
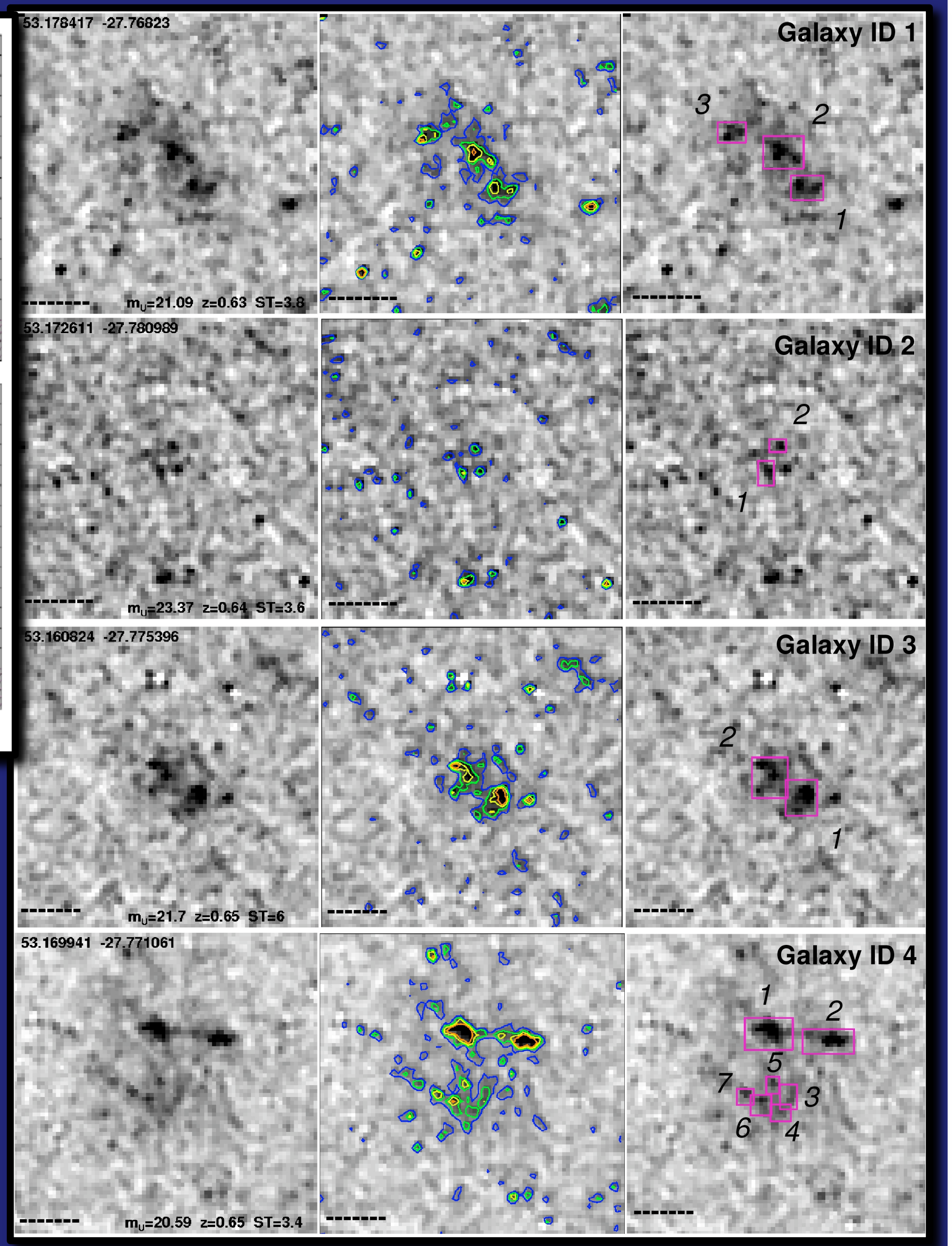


UV Clump Detection & Size Measurement





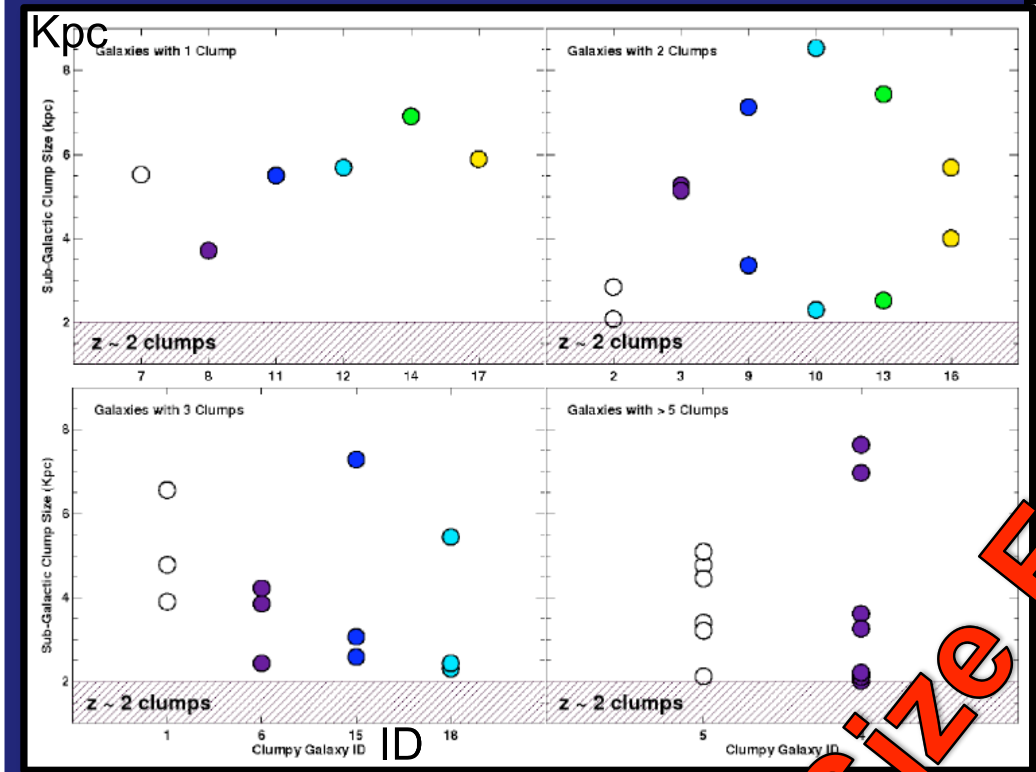
Sizes of individual sub galactic Clumps (kpc)

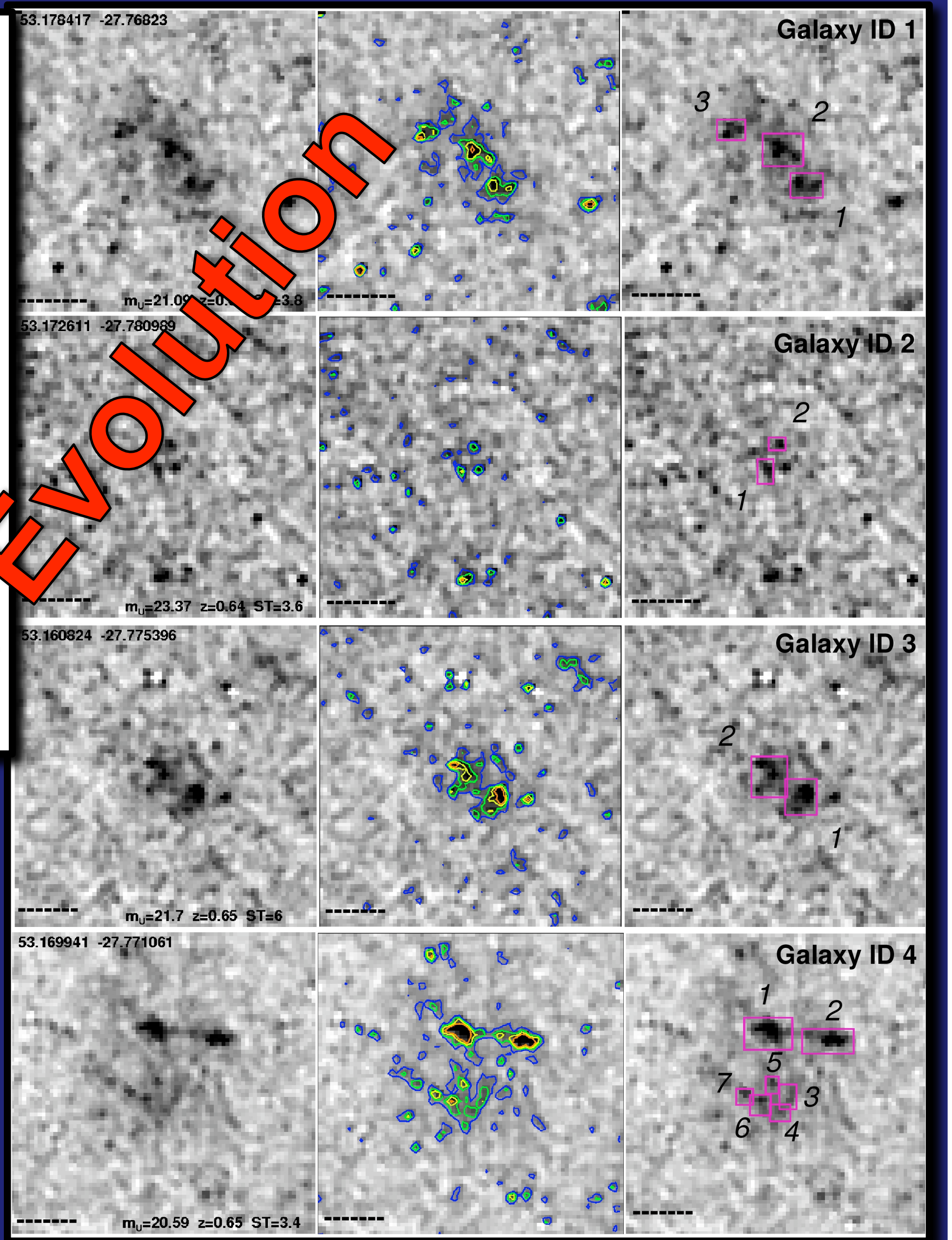
Plots divided by number of clumps per Individual galaxy

Clumps are on average larger at z <1 than at higher z. (18 objects):

SIZE EVOLUTION

UV Clump Detection & Size Measurement





Sizes of individual sub galactic Clumps (kpc)

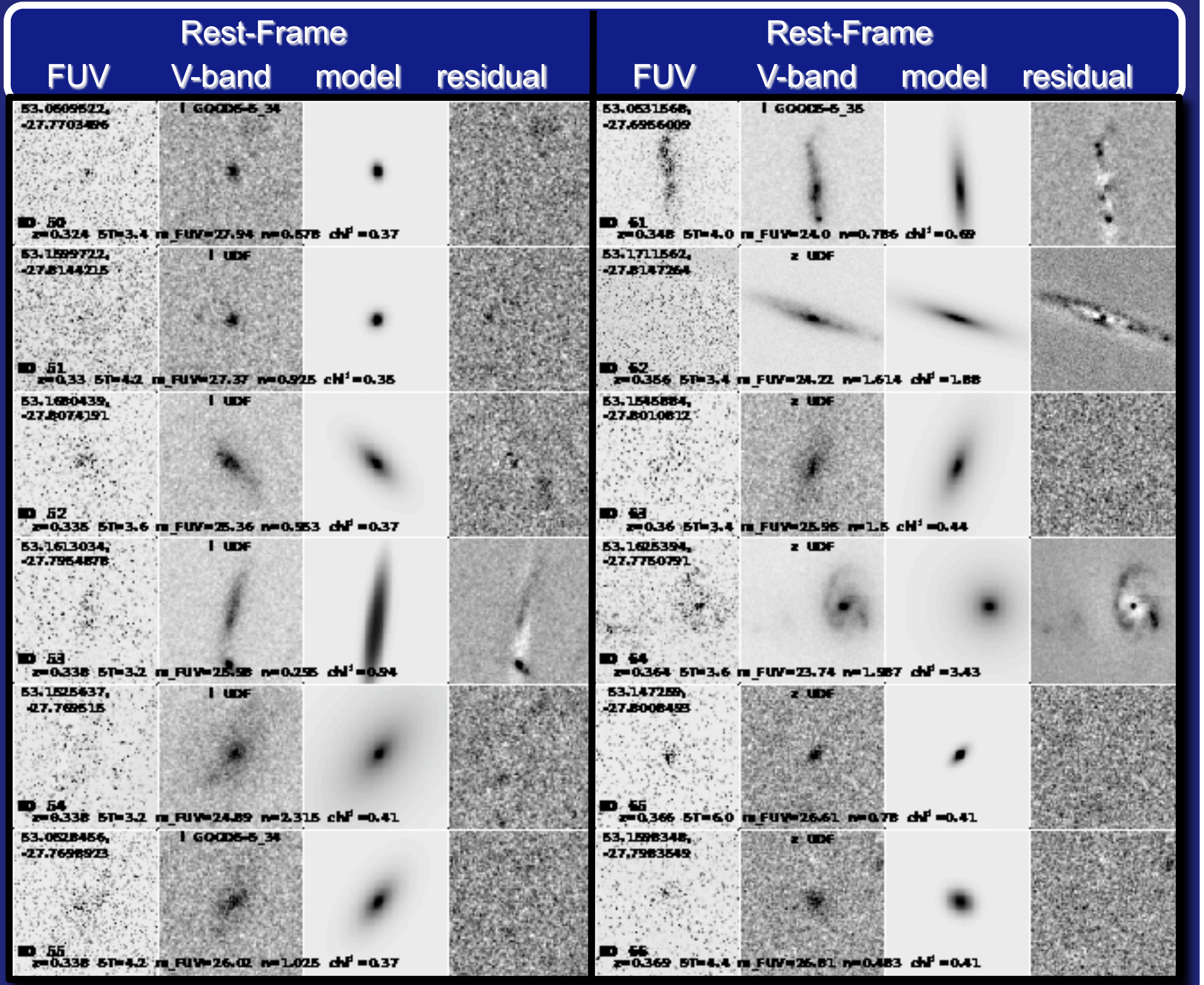
Plots divided by number of clumps per Individual galaxy

Clumps are on average larger at z <1 than at higher z. (18 objects): SIZE EVOLUTION

Optical Morphologies of FUV Detected Galaxies

- Choose FUV galaxies with measured z < 1.2 (212 sources)

- Measure rest-frame GOODS V-band optical quantitative morphologies (5000Å < λ < 7000Å)



de Vaucouleurs (1959)

n = 4 → elliptical steep profile

Shen et al. (2003), Ravindranath et al. (2004), Petty et al. (2009):

n < 0.8 → clumpy/merger/tidal morph.

0.8 < n < 2.5 → exponential disk morph.

2.5 < n < 4 → spheroid-like morph.

Spectral Types

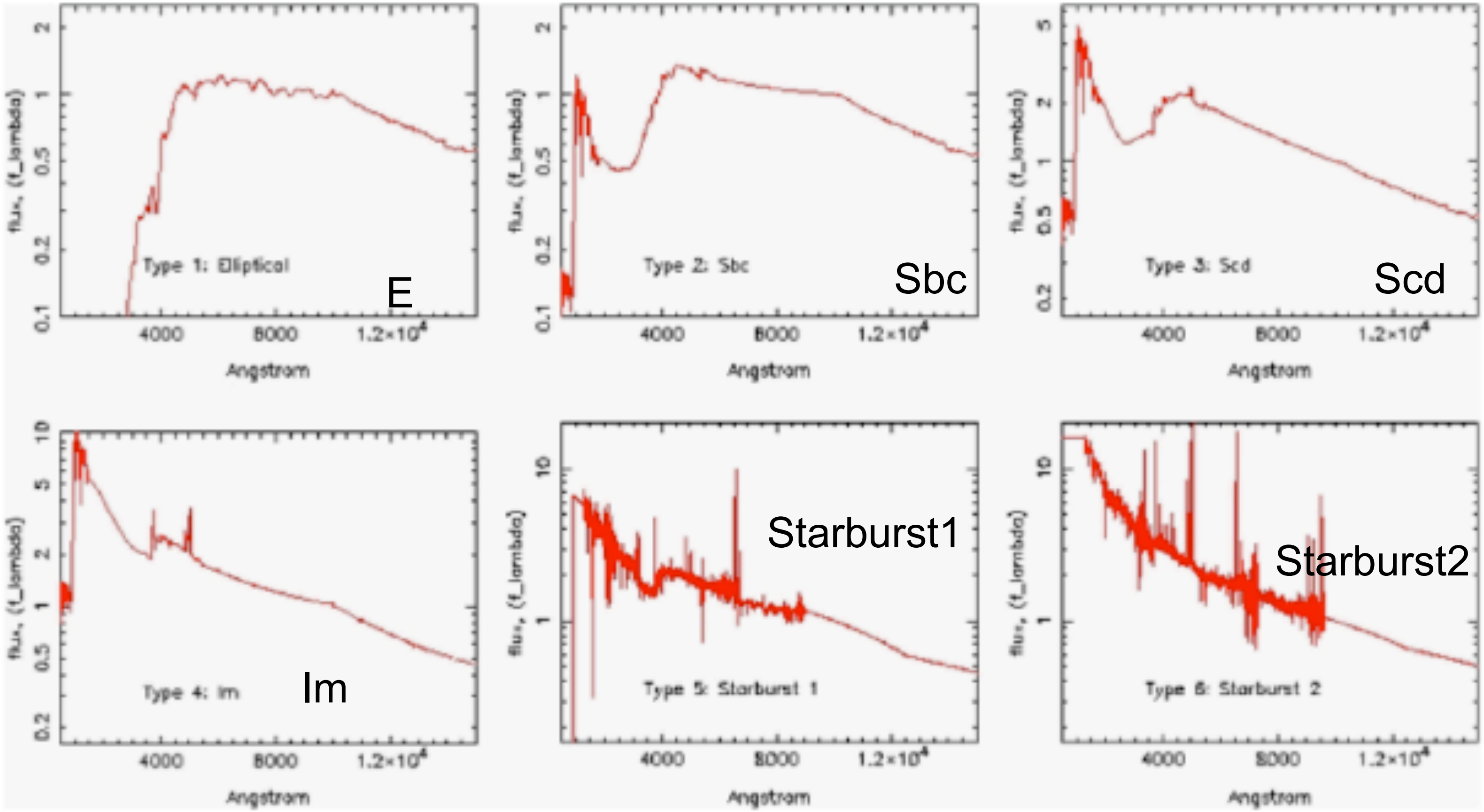
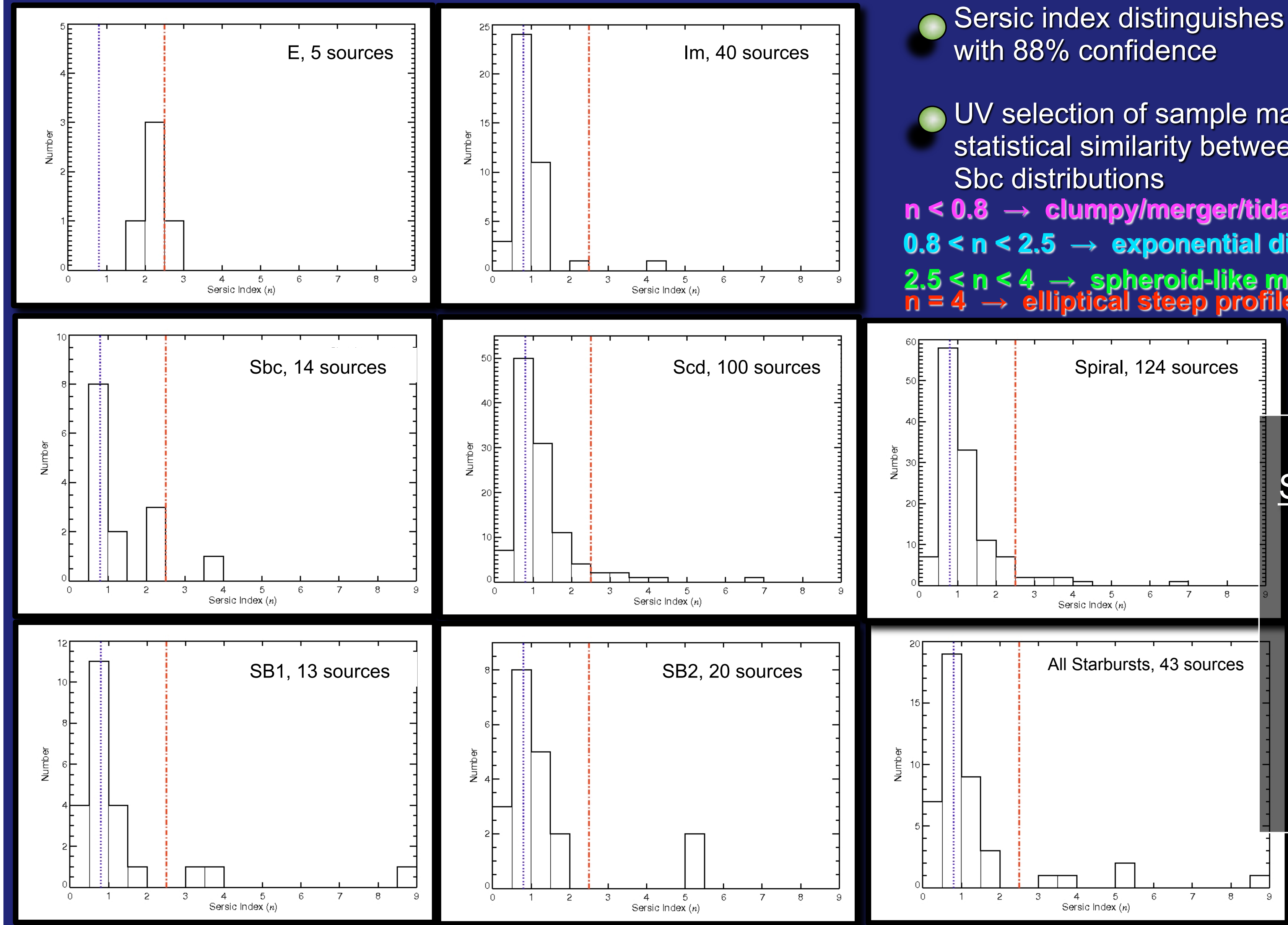


Figure 2.7 Spectral energy distributions from Coleman et al. (1980) (E, Sbc, Scd, Im) and Kinney et al. (1996) (SB1, SB2) that are the basis for galaxy the spectral types (STs) used throughout this thesis derived by Dahlen et al. (2010) for galaxies in the GOODS-S field.

Morph. Distributions
For each Spectral Type



Sersic Index

- Starbursts not distinguished from other spectral types by Sersic index
- Sersic index distinguishes Im and Scd with 88% confidence
- UV selection of sample may cause statistical similarity between Im and Sbc distributions

n < 0.8 → clumpy/merger/tidal morph.

0.8 < n < 2.5 → exponential disk morph.

2.5 < n < 4 → spheroid-like morph.

n = 4 → elliptical steep profile

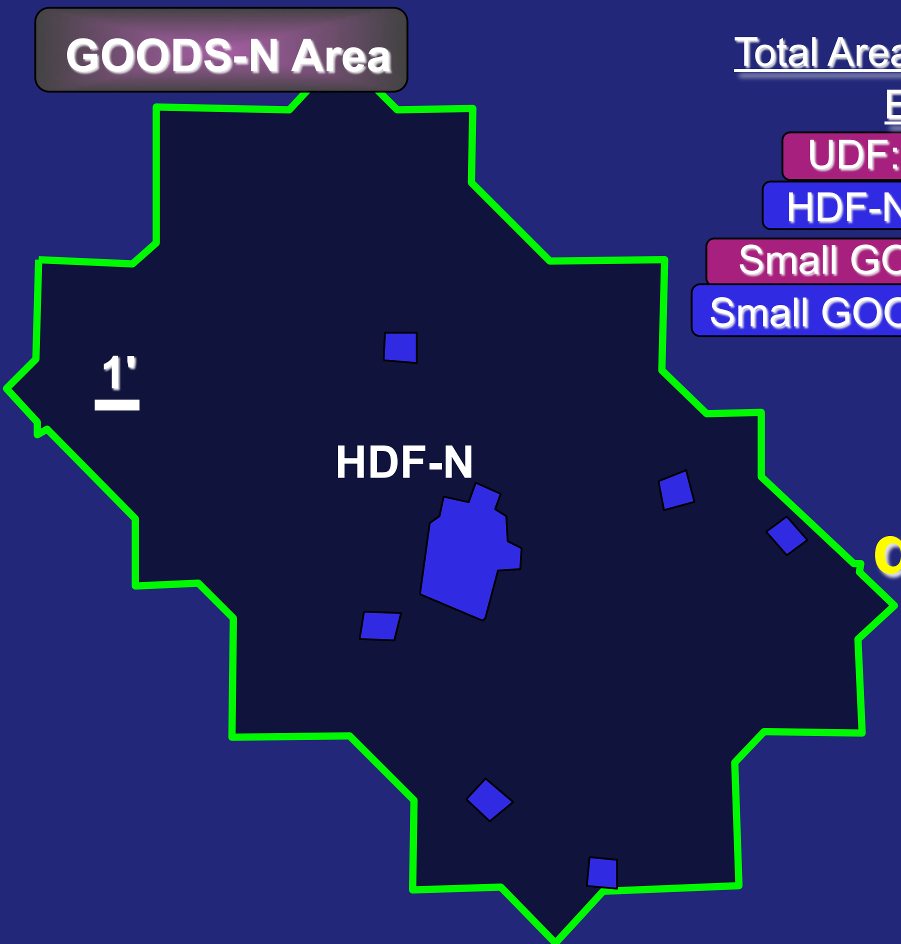
SED Based Spectral Types

1 = E, S0, Sa
2 = Sbc
3 = Scd
4 = Im
5 = SB1
6 = SB2

FUV Observations

- HST Advanced Camera for Survey's (ACS) Solar Blind Channel Detector
  - Multi-anode Microchannel Array (MAMA)
  - ***Filter:*** *F150 long pass*

3 observation sets: UDF, HDF-N, and 15 smaller (1 arcmin^2 <) fields in GOODS-N & -S



Total Area Covered: 15.9 arcmin^2

Exposure Times

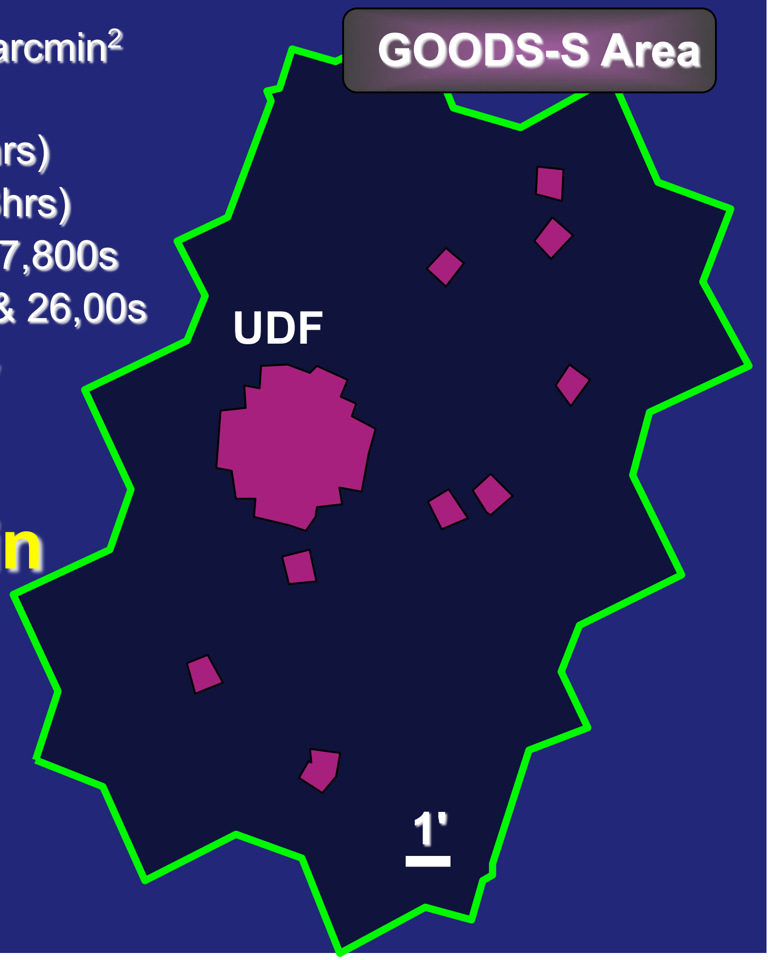
UDF: 132,500s (36.8hrs)

HDF-N: 143,360s (39.8hrs)

Small GOODS-S: 7,560-37,800s

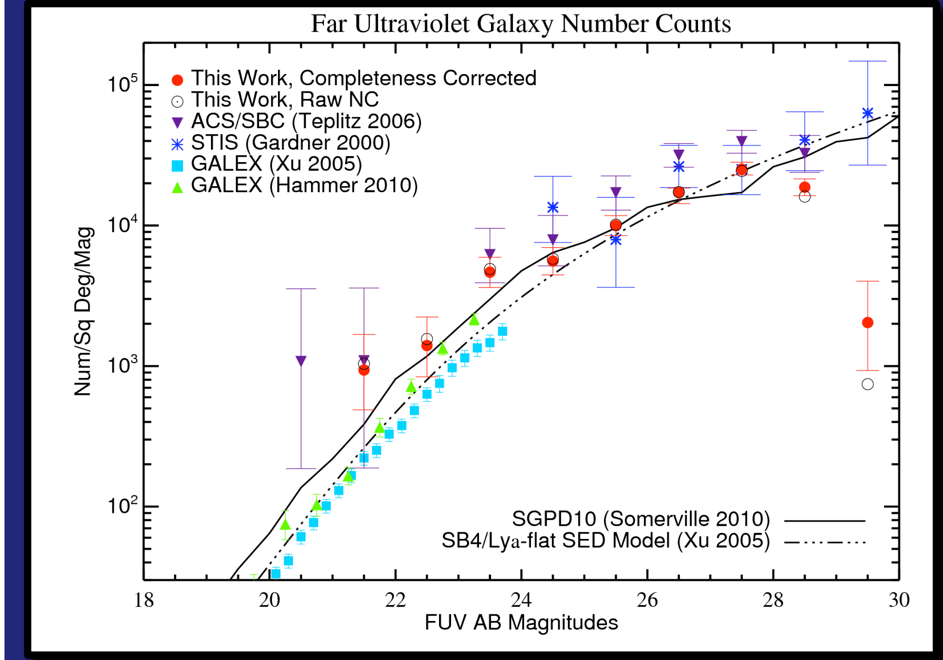
Small GOODS-N: 13,000s & 26,00s

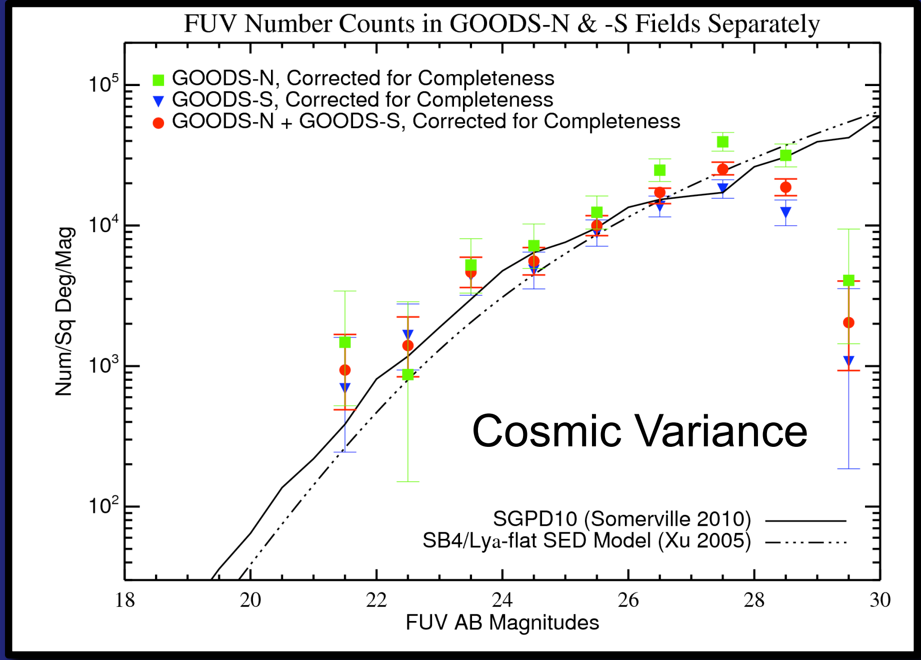
333 FUV sources detected in total



Measured FUV Number Counts

Authors	Field	Instrument	Mag Range (FUV_{AB})	Area Covered ($arcmin^2$)	Observed λ (Å)
Xu et al. (2005)	36 MIS, 3 DIS	GALEX	14.0 - 23.8	7,2000 (~20 deg^2)	1530
Hammer et al. (2010)	Coma Field	GALEX	16.75-23.5	~4,068 (~1.13 deg^2)	1530
Gardner et al. (2000)	HDF-N	ACS/STIS	24.5-29.5	1.54	1595
Teplitz et al. (2006)	HDF-N	ACS/SBC	20.5-28.5	3.77	1610
Voyer et al. (2011)	HDF-N + UDF + Smaller Fields in GOODS-N & -S	ACS/SBC	21.5-28.5 (29.5?)	15.9	1610

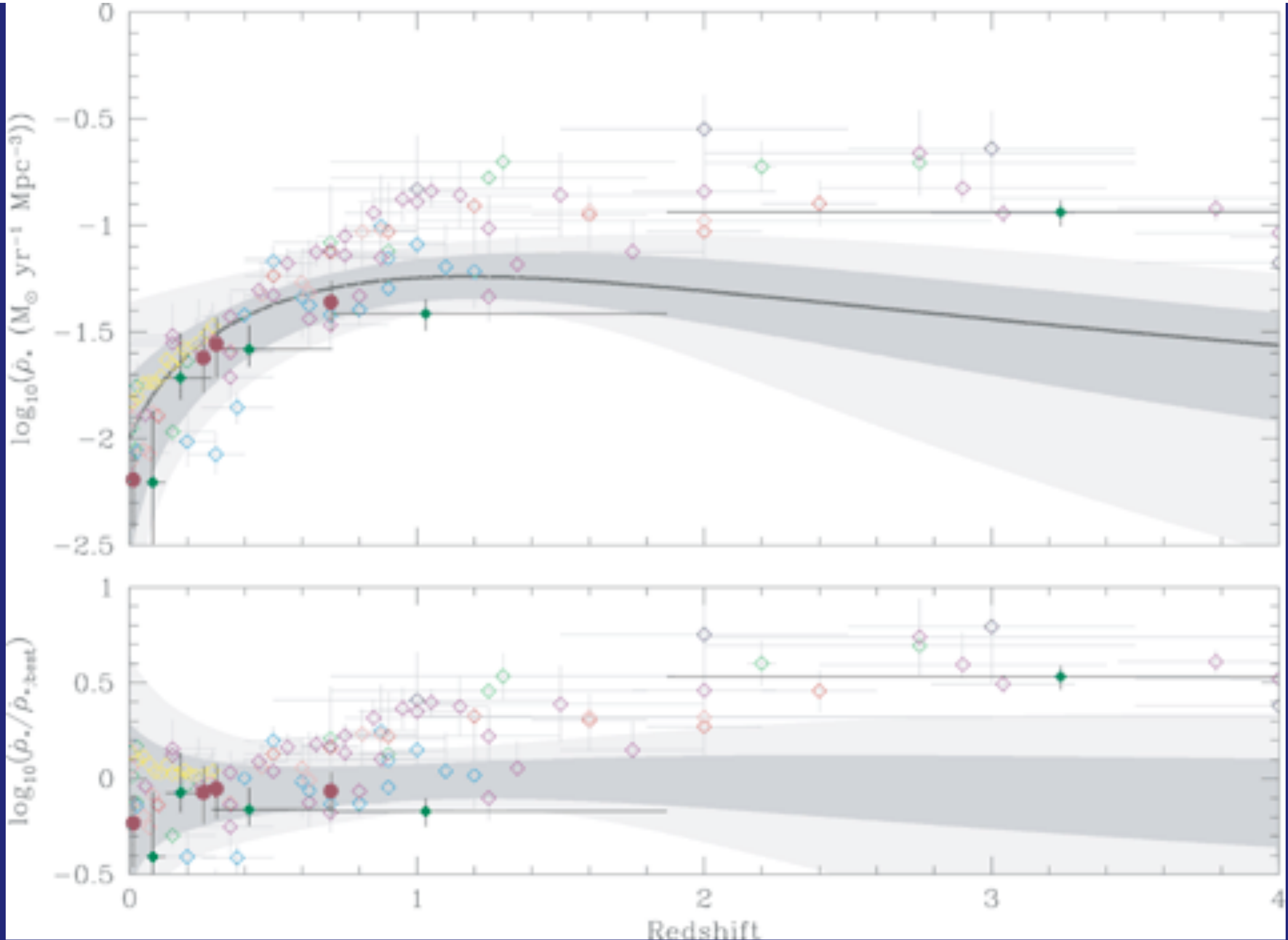




Voyer et al. 2011 SAMs are from Somerville et al. 11

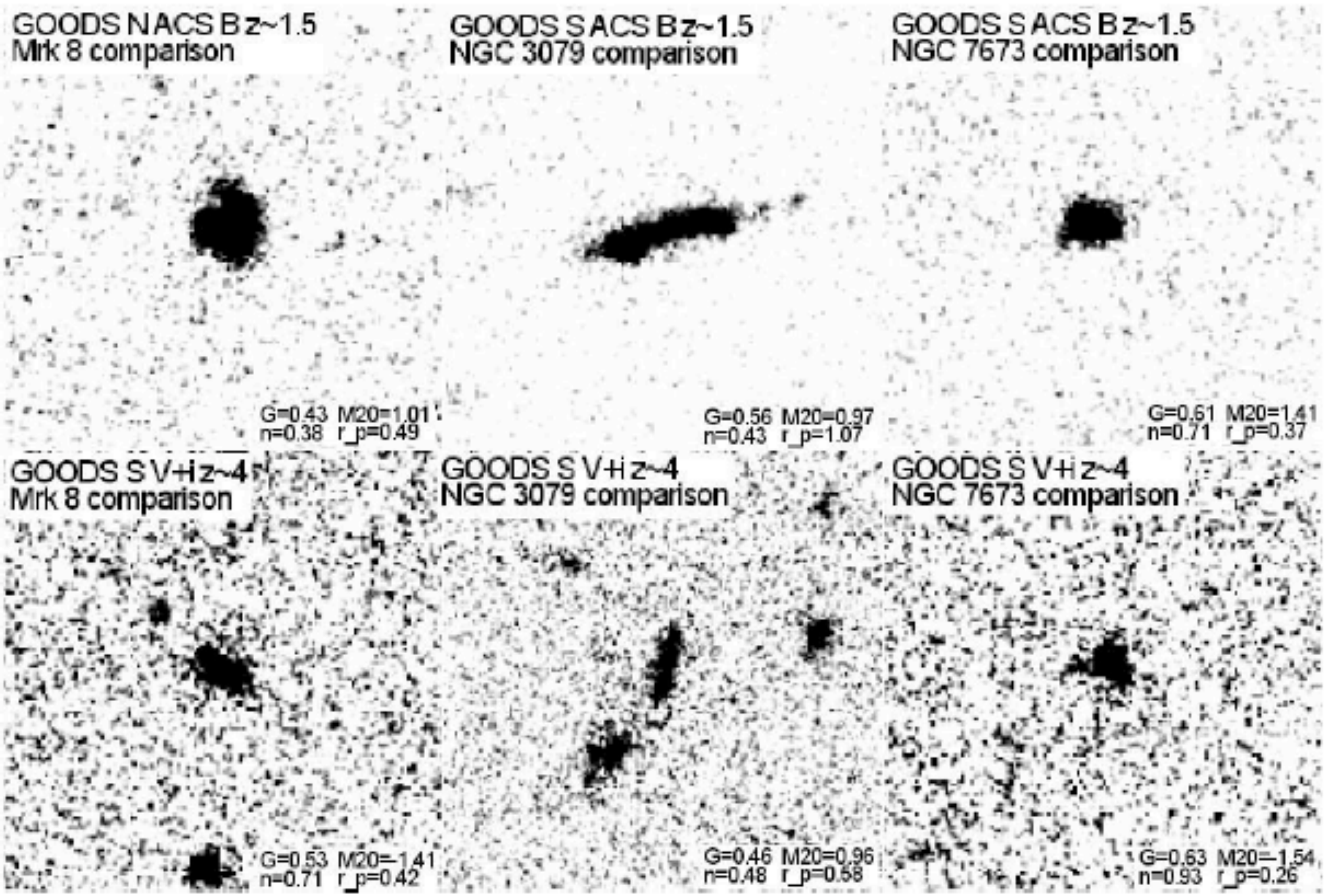
Conclusions

- ✧ Careful when using UV to study overall properties of galaxies
- ✧ Found signatures of size evolution – lower redshift clumps are bigger, but less luminous and less numerous (per galaxy)
- ✧ UV number counts of large areas match well SAMs
- ✧ Sample of galaxies for ALMA in the future



Comparison of the SFH inferred from the SMH compared to other measurements of star formation rates. The SFH inferred from the evolution of stellar mass is shown by the 1 and 3σ uncertainty regions (dark and light grey-shaded areas, respectively). The dark solid line is the parametrized best fit to our SFH discussed in the text. The lower panel displays the ratio of this best-fitting SFH to the other measurements.

Wilkins et al. 2008



GOODS N ACS B z~1.5
Mrk 8 comparison
G=0.43 M20=1.01
n=0.38 r_p=0.49
GOODS S ACS B z~1.5
NGC 3079 comparison
G=0.56 M20=0.97
n=0.43 r_p=1.07
GOODS S ACS B z~1.5
NGC 7673 comparison
G=0.61 M20=1.41
n=0.71 r_p=0.37
GOODS S V+i z~4
Mrk 8 comparison
G=0.53 M20=-1.41
n=0.71 r_p=0.42
GOODS S V+i z~4
NGC 3079 comparison
G=0.46 M20=0.96
n=0.48 r_p=0.58
GOODS S V+i z~4
NGC 7673 comparison
G=0.63 M20=-1.54
n=0.93 r_p=0.26

Rest-frame UV vs optical

- ✧ Rawat, Wadadekar, de Mello (2009) used the deepest U-band (F300W) taken with Hubble (de Mello et al. 2006) probing the rest-frame UV at intermediate-z.

- ✧ Comparison with GOODS F850LP show:
  - twice as many n < 0.5 in the F300W. (n is often used to identify mergers). Star-forming clumps?
  - ~ 3 times higher ellipticity in the F300W than in the rest-frame optical image. Could explain why LBGs seem to have higher ellipticity (Ravindranath et al. 06).

Conclusion: (WARNING) MERGERS AT HIGH-Z (IN THE REST-FRAME UV) MIGHT BE STAR-FORMING REGIONS.