Hubble's Survey of the Ultraviolet universe: Panchromatic Extragalactic Research ("SUPER")

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221st AAS meeting, Session 228 "High Resolution Ultraviolet Imaging with the HST — II [high redshift]".

Tuesday January 8, 2013, 2:00 pm, Room 202A, Long Beach Convention Center, Long Beach, CA.

Outline and 4 Science Goals

- Deep wide-field HST WFC3 UV imaging is critical NOW to prepare for JWST ($\lambda \gtrsim 0.7 \mu$m), and to define a $\gtrsim$8-meter UV-optical sequel to HST:

- (1) The physics and evolution of SF in low-mass galaxies over the LAST 9 Gyrs: Critical benchmark to understand cosmic reionization at z$\gtrsim$6;

- (2) Evolution of the star/dust/gas mixture in SF regions, and the influence of supernovae and AGN feedback;

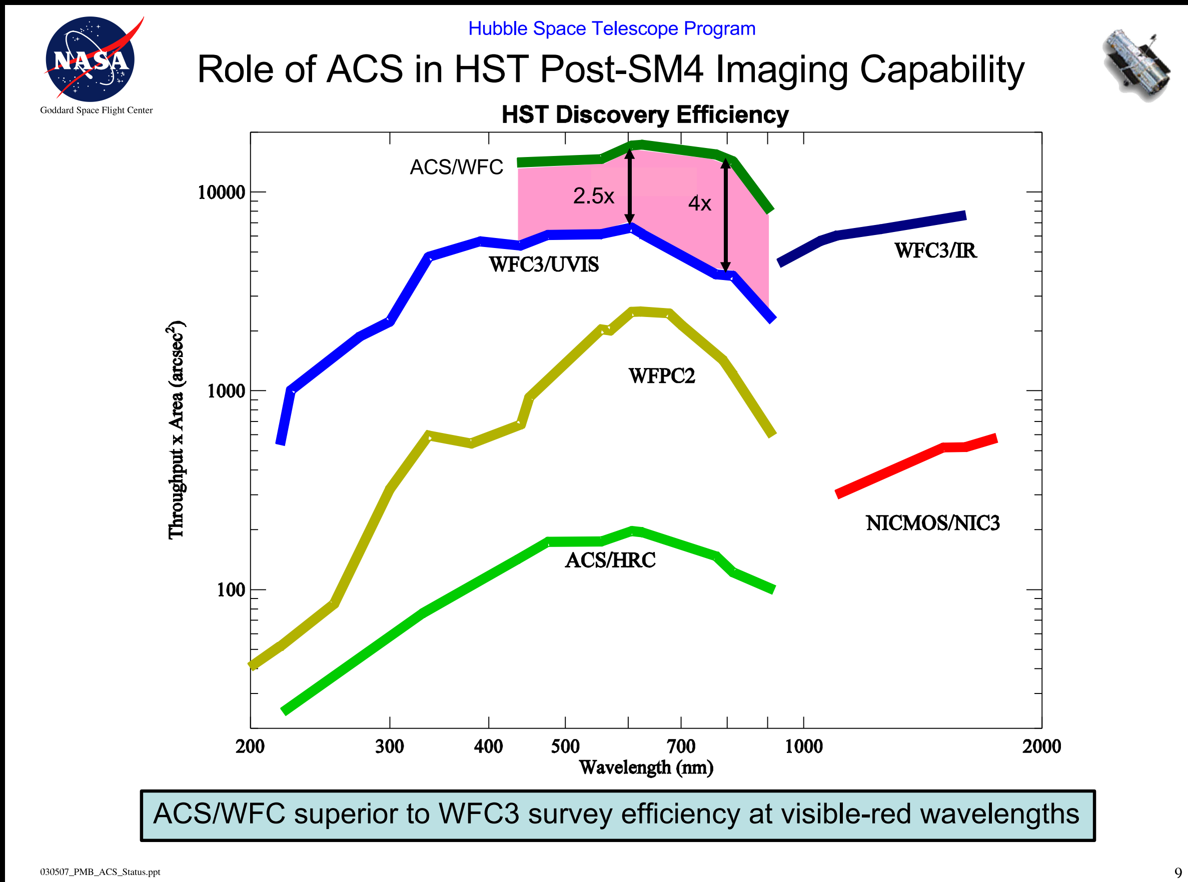
- (3) Evolution of young, star-forming sub-galactic clumps induced by mergers or gas accretion, and the growth of stable galaxy disks;

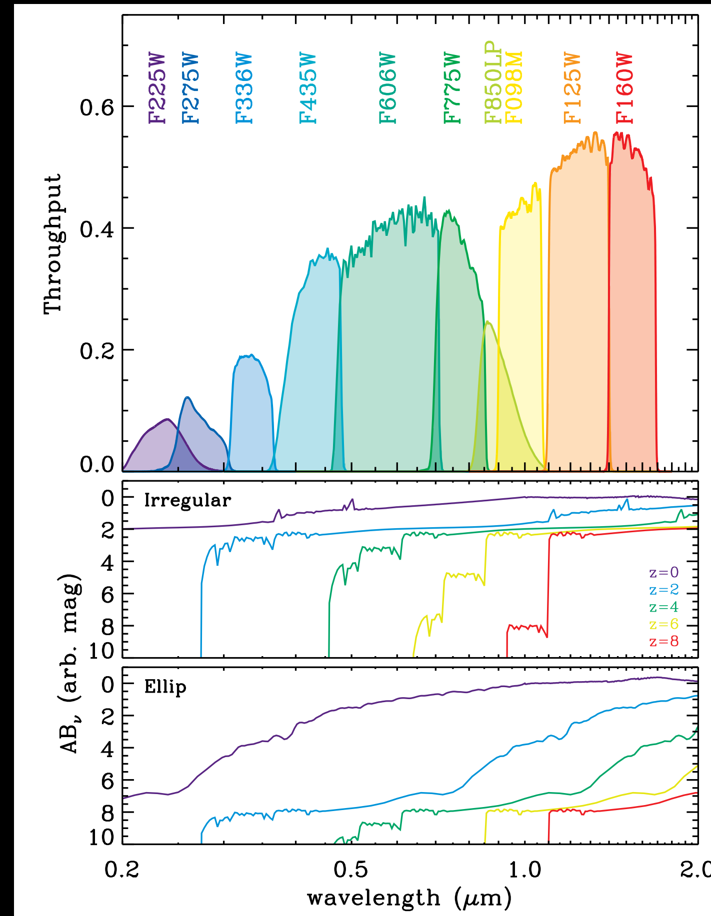
- (4) Late-epoch SF & structural evolution in massive early-type galaxies.

(5) Summary and Conclusions.

Sponsored by NASA/HST WFC3 & JWST

ASU Arizona State University

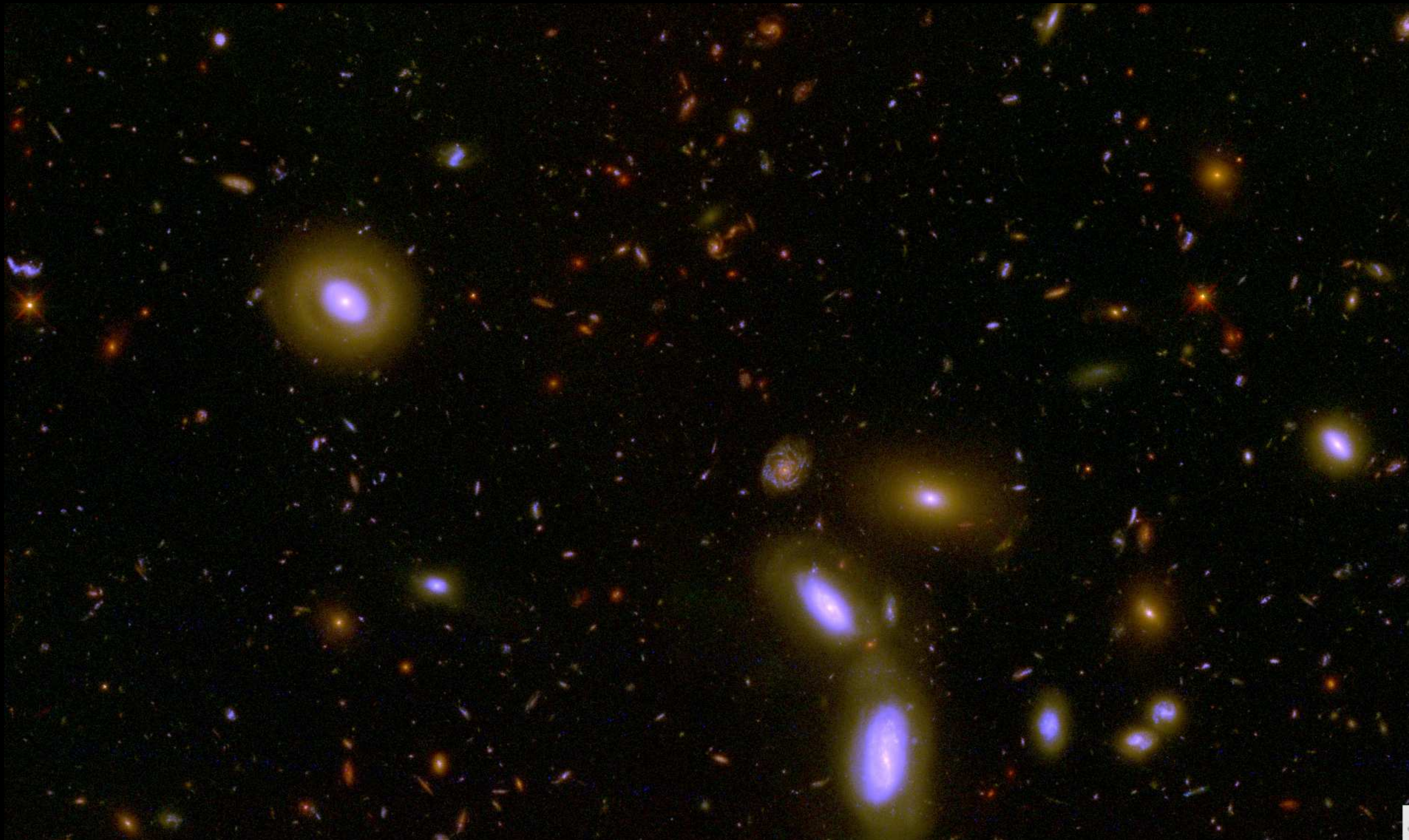




WFC3/UVIS channel unprecedented UV–blue throughput & areal coverage:
QE$\gtrsim$70%, 4k$\times$4k array of $0\farcs04$ pixel, FOV $\simeq$ $2\farcm67 \times 2\farcm67$.

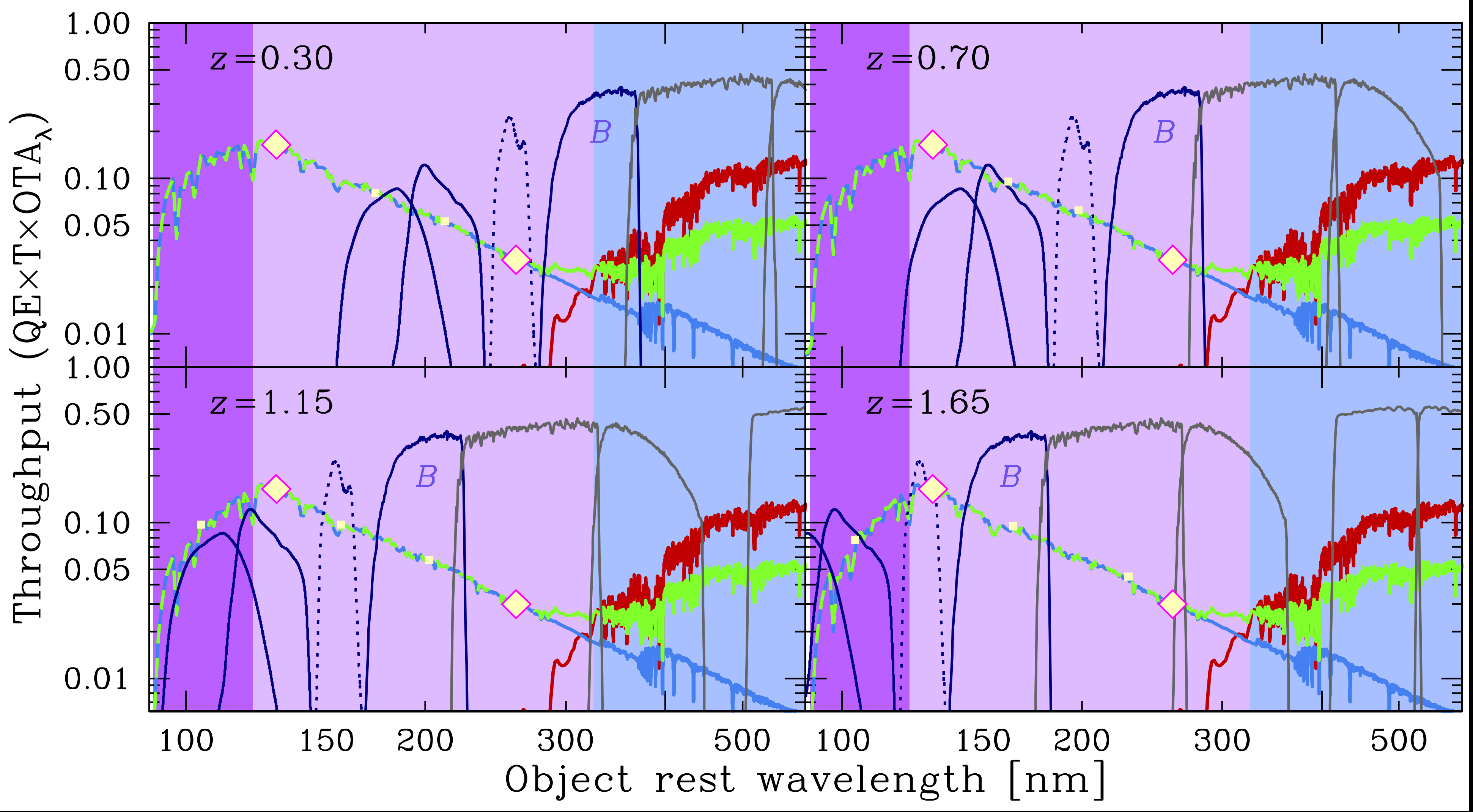
WFC3/IR channel unprecedented near–IR throughput & areal coverage:
QE$\gtrsim$70%, 1k$\times$1k array of $0\farcs13$ pixel, FOV $\simeq$ $2\farcm25 \times 2\farcm25$.

- WFC3 filters designed for star-formation and galaxy assembly at z$\simeq$0–8.
- HST WFC3 and its UVIS channel a critical pathfinder for JWST science.



10 filters with HST/WFC3 & ACS reaching AB=26.5-27.0 mag (10-σ) over 40 arcmin^2 at 0.07–0.15" FWHM from 0.2–1.7μm (UVUBVizYJH).

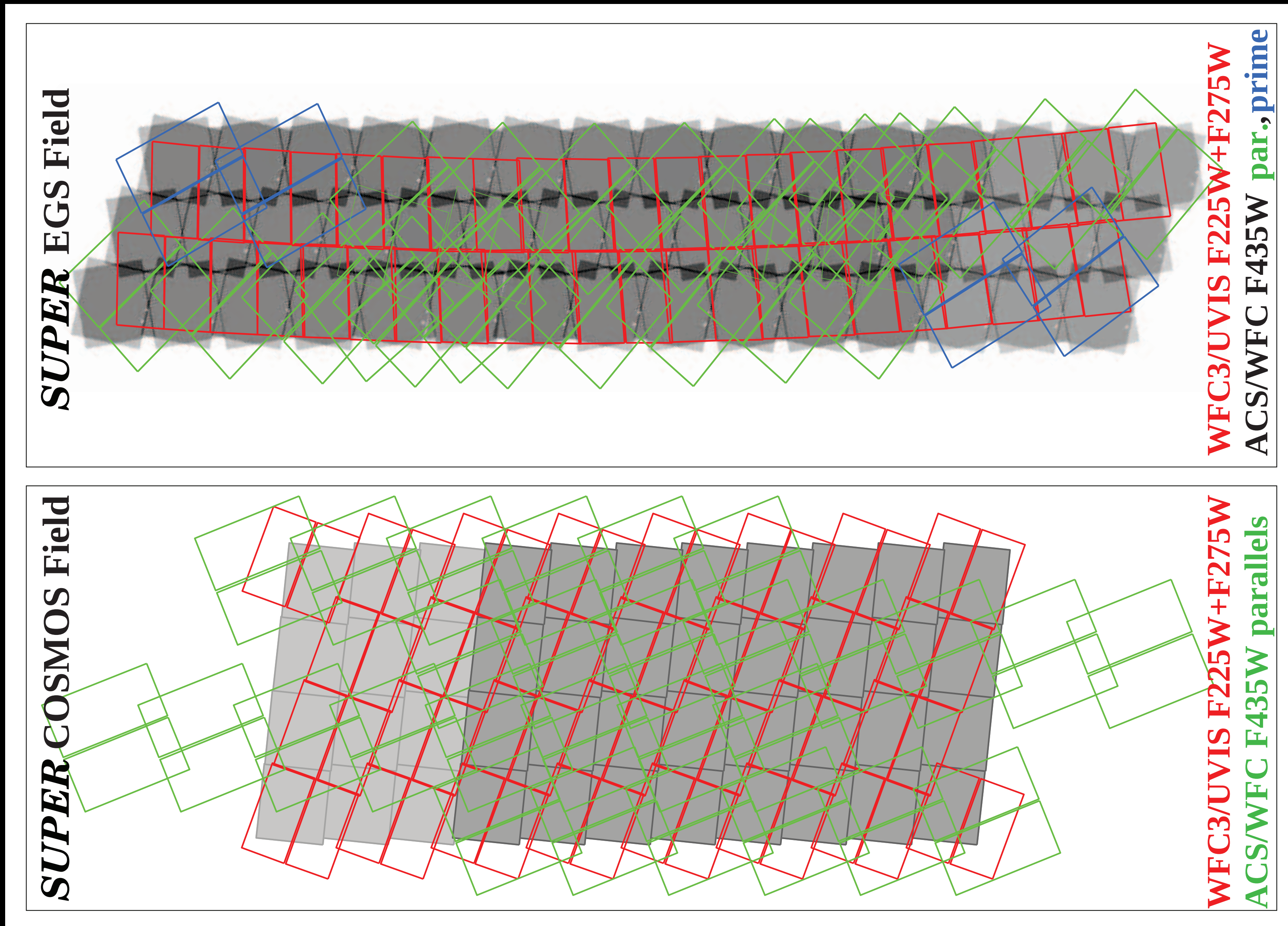
- ERS in GOODS-S v2: using WFC3 for what it was designed to do.
- JWST adds 0.05–0.2" FWHM imaging to AB$\simeq$31.5 mag at 0.7–5μm, and 0.2–1.2" FWHM at 5–29μm, tracing young+old SEDs & dust.



- *Rest-frame* SEDs of objects with young, mixed, and old stellar populations with WFC3 UV, ACS B & CANDELS VIJH filters.

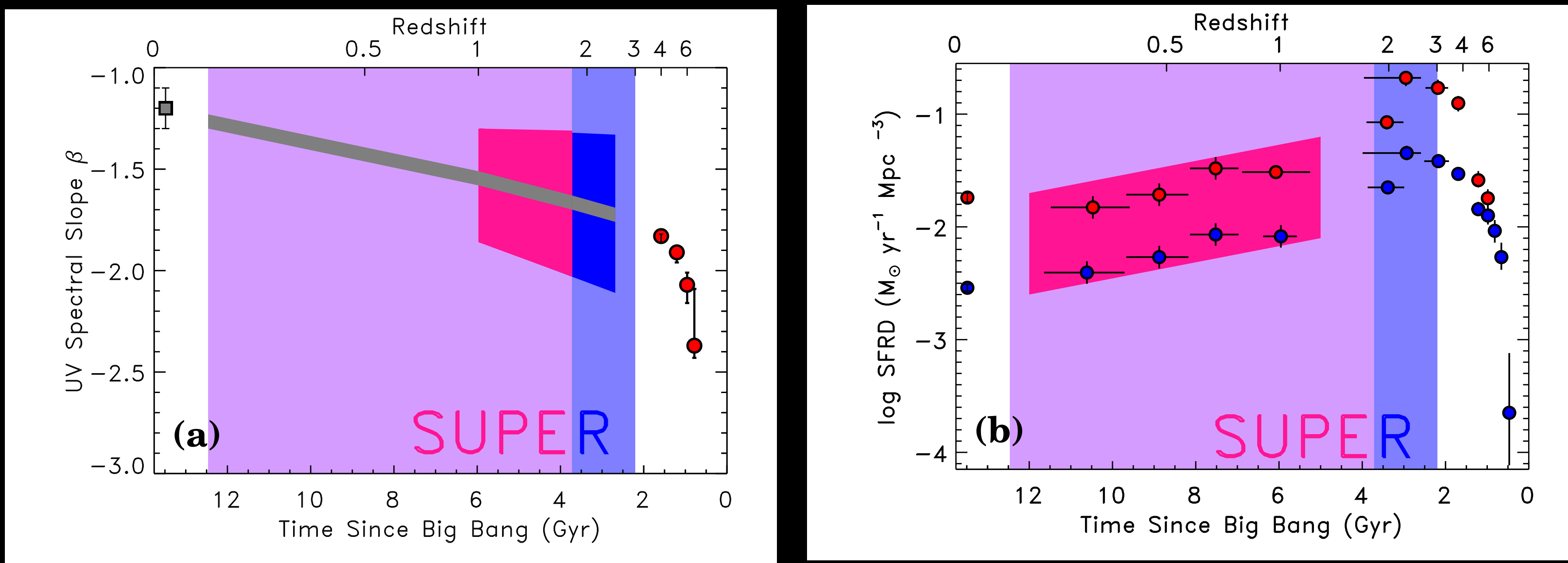
- Diamonds: Rest-frame 1300Å and 2600Å to measure UV β-slope.

- For $0.2 \lesssim z \lesssim 2.0$ WFC3 UV, ACS F435W & CANDELS (F606W, F814W) filters sample the β-slope for SF objects in $\gtrsim$2 filters at $\lesssim$0.″1 FWHM.



- Viable APT solutions to cover CANDELS fields (split over 2 ORIENTs ∼180 days apart to aid scheduling).
- WFC3/UVIS tiles in red, ACS/F435W tiles in green (parallels), or blue (primary); CANDELS WFC3/IR F125W, F160W tiles in grey.

(1) Physics and evolution of SF in low-mass galaxies over the LAST 9 Gyrs:

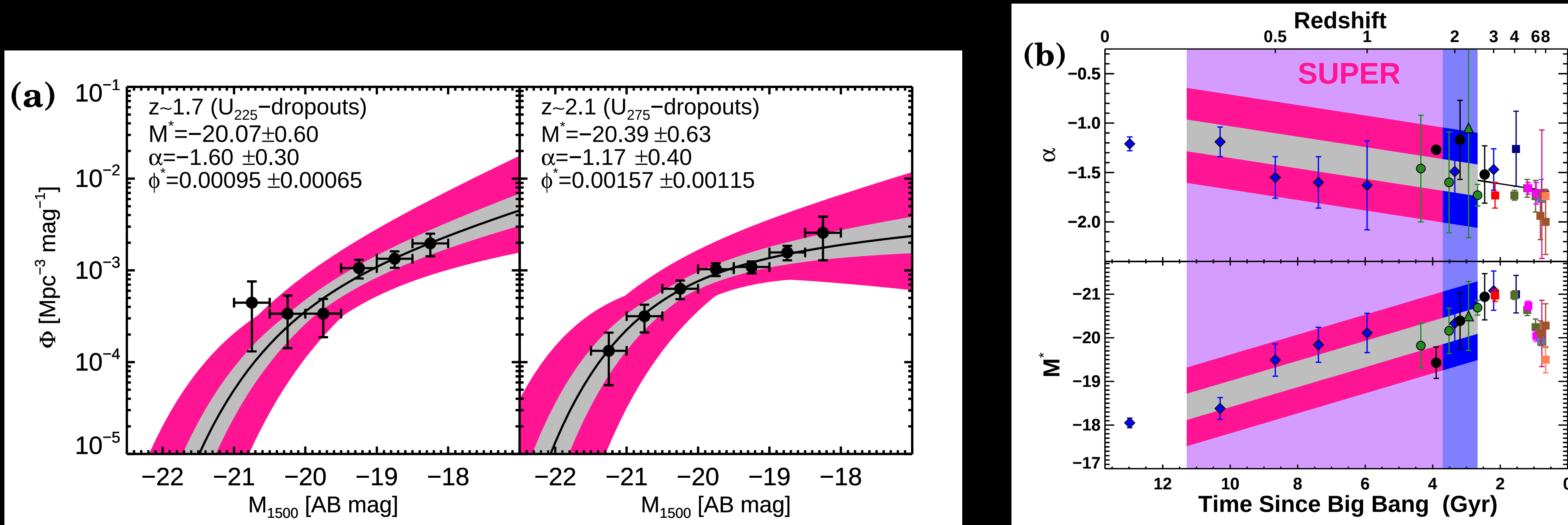


[LEFT] Evolution of the UV spectral slope β (Finkelstein et al. 2011). Dark pink/dark blue region is WFC3 ERS β-range (Hathi et al. 2012).

- Deep wide-field WFC3 UV traces β-evolution for 16,000 SF clumps at $0.2 \lesssim z \lesssim 2$ (grey strip) $\Rightarrow$ dust A_V in SF knots of sub-L^* galaxies.

[RIGHT] Evolution of the cosmic SF-rate density ("SFRD"; Bouwens et al. 2011). Blue dots are before and red dots after dust-correction.

- Deep wide-field WFC3 UV will yield SFRD in low-mass galaxies at $z \lesssim 2$.
- Essential synergy with Herschel FIR $\Rightarrow$ relation between β and dust attenuation, providing the most robust estimate of the SFRD at $z \lesssim 2$.



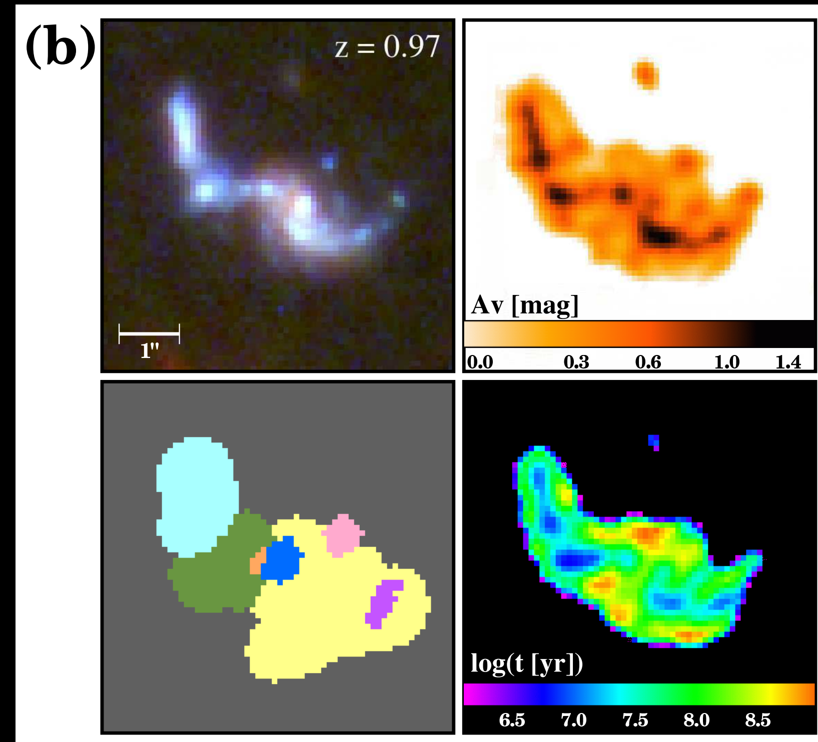
[LEFT panels] Rest-frame UV Luminosity Functions (LFs) based on UV-dropouts (Hathi et al. 2010, 2012).

[RIGHT] • (top) Evolution of the faint-end Schechter slope α and M^* ($e.g.$, Hathi et al. 2010, Oesch et al. 2010b).

• (Bottom) M^* vs. z behavior resembles the cosmic SF history (Madau et al. 1996), and reflects the process of galaxy assembly and downsizing.

• Dark pink indicates current WFC ERS + CANDELS uncertainties.

• Grey wedge shows the significant improvement from deep wide-field WFC3 UV imaging for $0.2 \lesssim z \lesssim 2.5$.



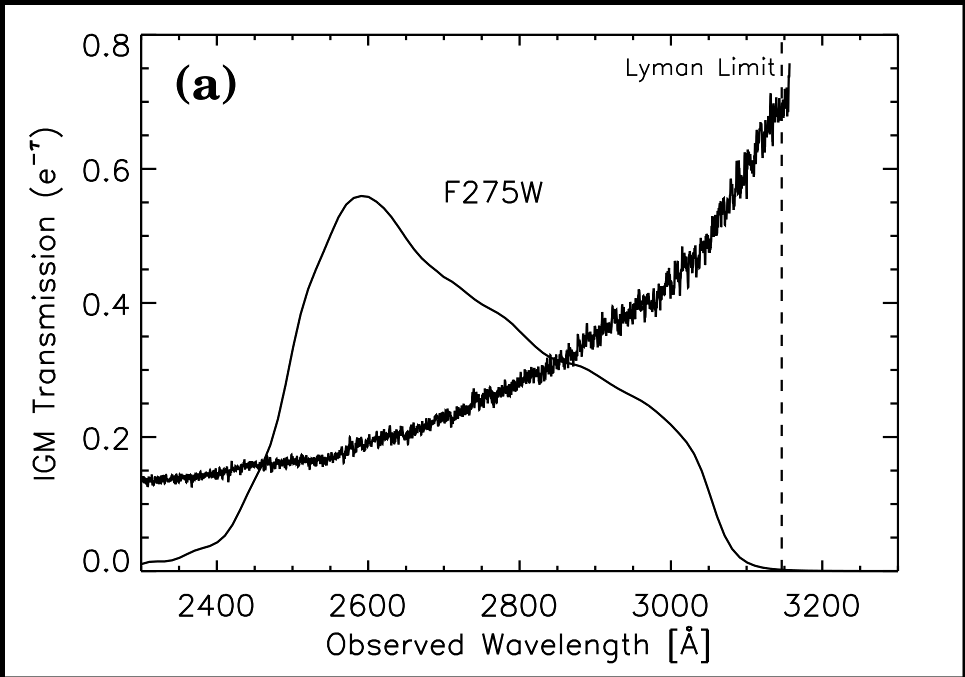
[LEFT panels] WFC3 ERS color images of galaxies at z$\simeq$0.75 shown in the 7 WFC3 UV+B & CANDELS filters. All show measurable UV flux.

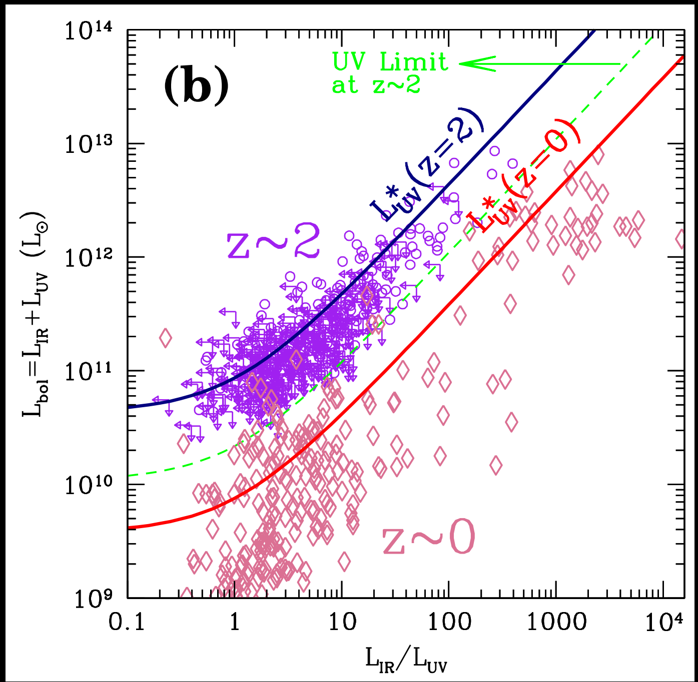
[RIGHT] z$\simeq$1 galaxy in same filters (upper left). WFC3 UV priors can dissect deep ground-based U_{360}-images ($0''.9$ FWHM; Grazian et al. 2006), recovering fluxes for $\gtrsim$65% of HST's SF-clumps (lower left).

- Right panels show pixel-to-pixel dust (A_V) & SF-age (log t/yr) maps.

- Deep wide-field WFC3 UV will yield pixel-to-pixel mass, age, A_V and dust-maps for $\sim$2000 galaxies at $0.2 \lesssim z \lesssim 2$.

(2) Evolution of star/dust/gas mix in SF regions, and SNe/AGN feedback:





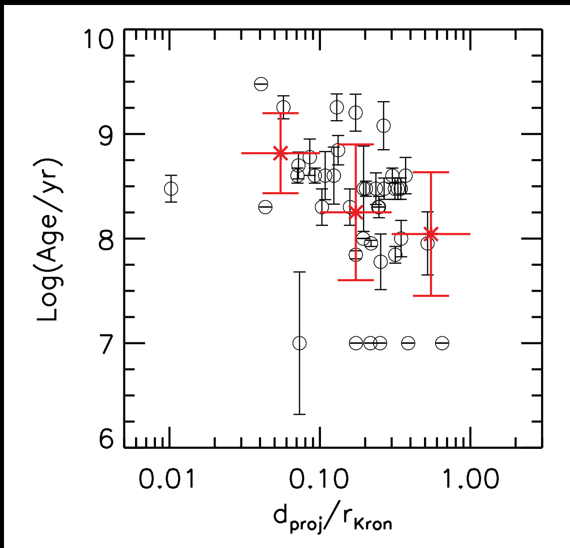
[LEFT] Average IGM transmission vs. wavelength. WFC3 F275W samples Lyman-continuum escape fraction f_{esc} at z$\simeq$2.45, where average transmission is $e^{-\tau}\simeq$0.250 (Siana et al. 2012).

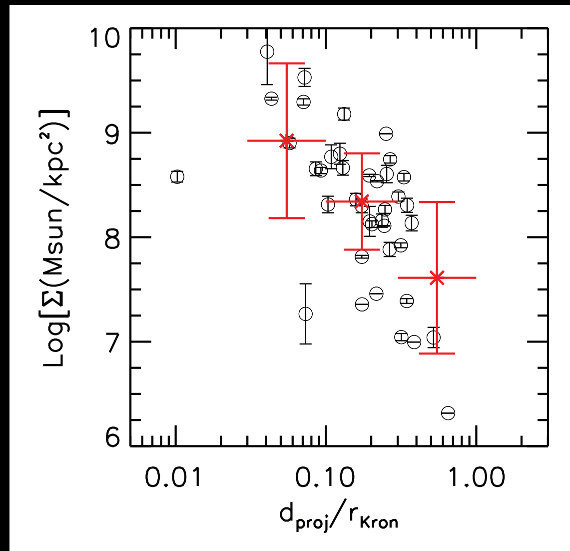
- Deep wide-field WFC3 UV will yield f_{esc} for $\sim$800 galaxies at z$\simeq$2.45, and relate it to physical galaxy properties (mass, type, A_V, V_{rot}/σ_g).

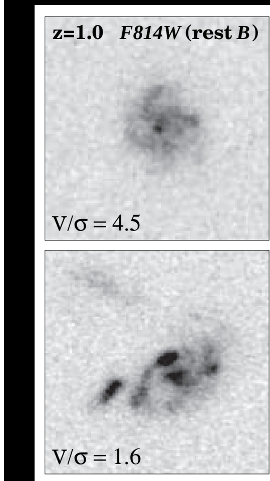
[RIGHT] Bolometric luminosity vs. dust attenuation (L_{IR} / L_{UV}) for z$\simeq$2 compared to local galaxies (Reddy et al. 2010), suggesting evolution of the net extinction in SF galaxies with time.

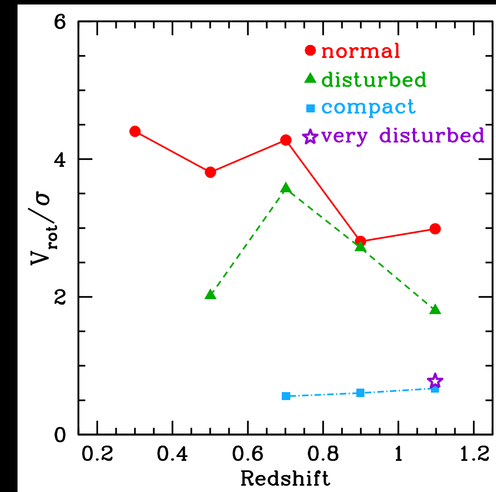
- Deep wide-field WFC3 UV: +800 dusty LBGs in redshift gap 0.2$\lesssim$z$\lesssim$2.

(3) Evolution of SF clumps and the growth of stable galaxy disks:









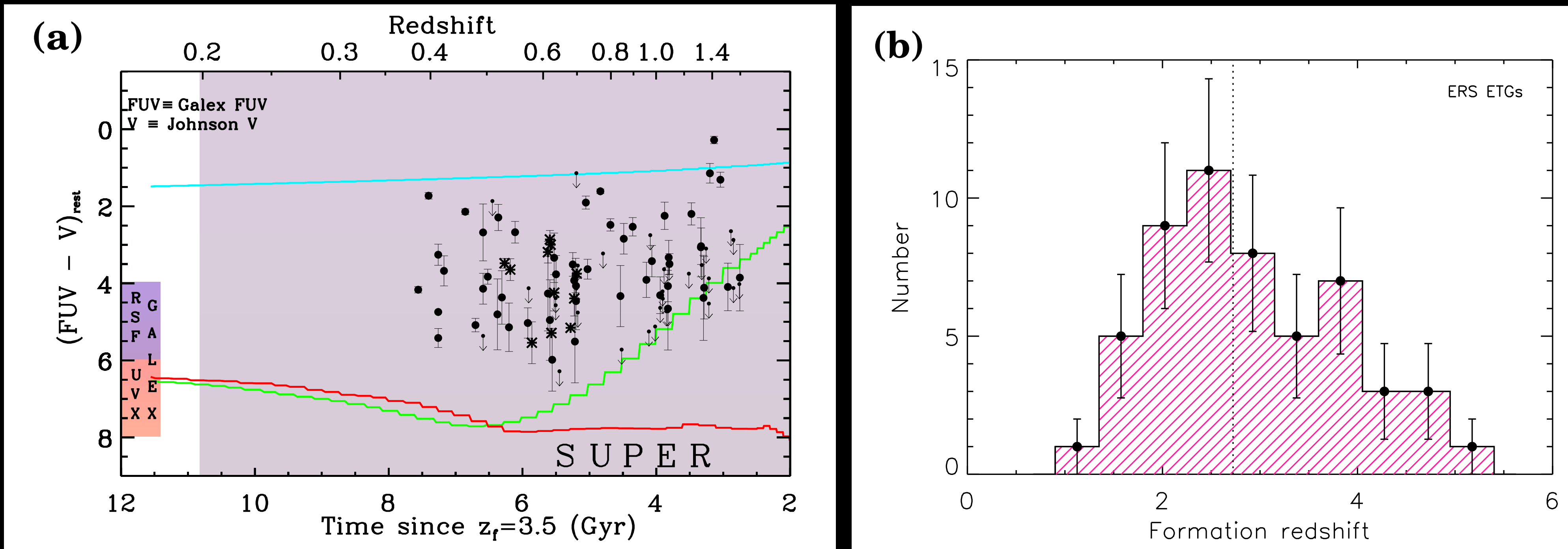
[LEFT 2 panels] Radial variation of age and mass surface-density of sub-galactic clumps at z$\simeq$2 vs. galacto-centric distance (Guo et al. 2011, 2012).

[MIDDLE 2] Ordered rotation ($\boldsymbol{V_{rot}}$) & disturbed motions ($\boldsymbol{\sigma_g}$) shows strong correlation with rest-frame blue morphology (Kassin^{+} 2007).

[RIGHT] Ratio of ordered/disordered motions ($\boldsymbol{V_{rot}/\sigma_g}$) correlated with HST rest-frame $\boldsymbol{B}$-band morphology: the most disturbed galaxies have the lowest $\boldsymbol{V_{rot}/\sigma_g}$ ratio (Kassin et al. 2007, 2012).

- Deep wide-Field WFC3 UV will yield $\lesssim$2000 UV objects, showing how galaxies disks have grown and stabilized for 0.2$\lesssim$z$\lesssim$2.

(4) Late-epoch SF and structural evolution in massive early-type galaxies.



• 10-band WFC3 ERS data measured rest-frame UV-light in nearly all early-type galaxies at $0.3 \lesssim z \lesssim 1.5$ (Rutkowski et al. 2012, ApJS, 199, 4).

$\Longrightarrow$ Most ETGs have continued residual star-formation after they form.

• Can determine their $N(z_{form})$, which resembles the cosmic SFH diagram (Madau et al. 1996), directly constraining the process of galaxy assembly & down-sizing (Kaviraj et al. 2012, MNRAS).

• Deep wide-field WFC3 UV increases sample 10-fold, providing critical UV data to delineate the range in z_{form} for ETGs as function of mass.

(5) Conclusions

For as long as we still have HST, deep wide-field WFC3 UV surveys must be done to address the following critical science questions:

These are critical and unique data in preparation for JWST ($\boldsymbol{\lambda}\gtrsim$0.7$\boldsymbol{\mu}$m), and to define a $\gtrsim$8-meter UV-optical sequel to HST:

- (1) The physics and evolution of SF in low-mass galaxies over the LAST 9 Gyrs: critical benchmark to understand cosmic reionization at z$\gtrsim$6;

- (2) Evolution of the star/dust/gas mixture in SF regions, and the influence of supernovae and AGN feedback;

- (3) Evolution of young, star-forming sub-galactic clumps induced by mergers or gas accretion, and the growth of stable galaxy disks;

- (4) Late-epoch SF and structural evolution in massive early-type galaxies.

SPARE CHARTS

- References and other sources of material shown:

http://www.asu.edu/clas/hst/www/jwst/ [Talk, Movie, Java-tool]

http://www.jwst.nasa.gov/ & http://www.stsci.edu/jwst/

Bouwens, R. et al. 2010, ApJ, 709, L133

Bouwens, R. et al. 2011, ApJ, 737, 90

Finkelstein, S. et al. 2012, ApJ, 428, 925

Grazian, A., et al. 2006, A&A, 449, 951

Gardner, J. P., et al. 2006, Space Science Reviews, 123, 485

Guo, et al. 2011, ApJ, 735, 18

Hathi, N., et al. 2010, ApJ, 720, 1708 & AAS 221, 228.06

Kassin, S., et al. 2007, ApJ, 660, L35 & AAS 221, 210.04

Kaviraj, et al. 2012, MNRAS, 428, 925

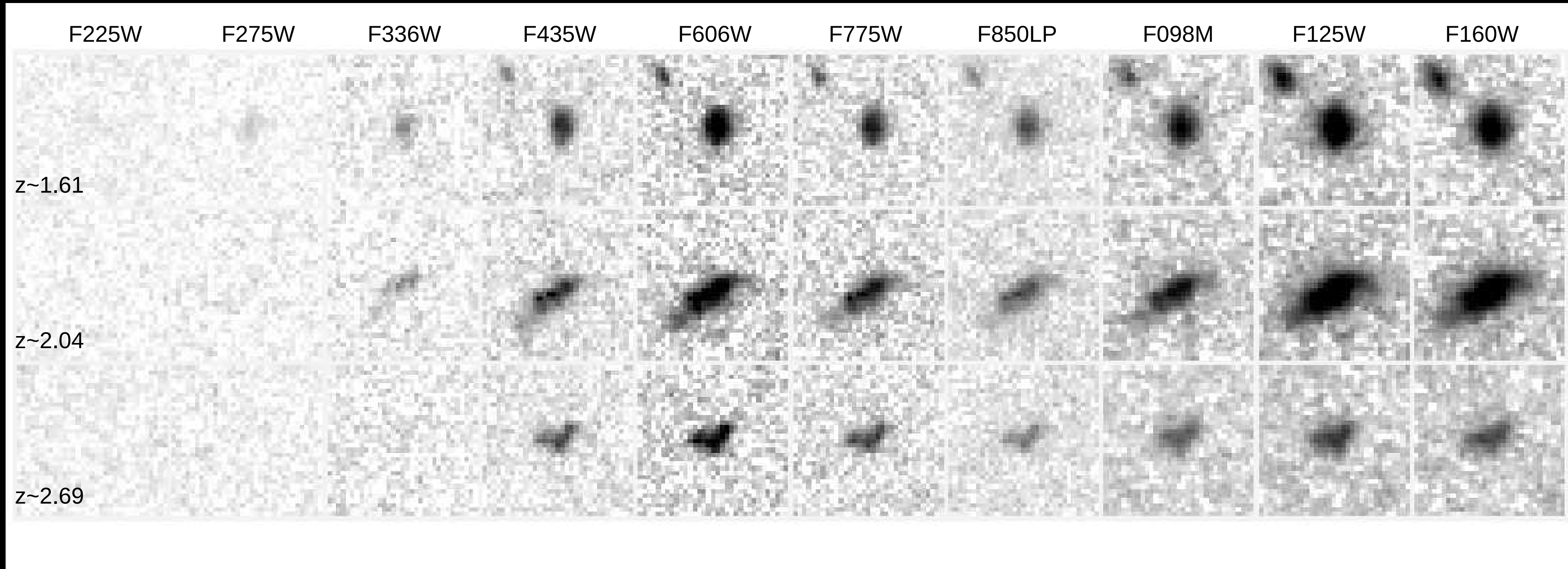
Reddy, N., et al. 2010, ApJ, 712, 1070

Rutkowski, et al. 2012, ApJS, 199, 4

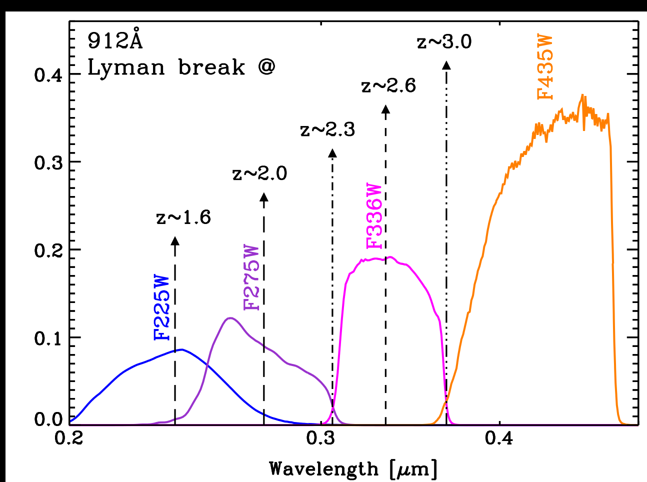
Ryan, R., et al. 2012, ApJ, 749, 53

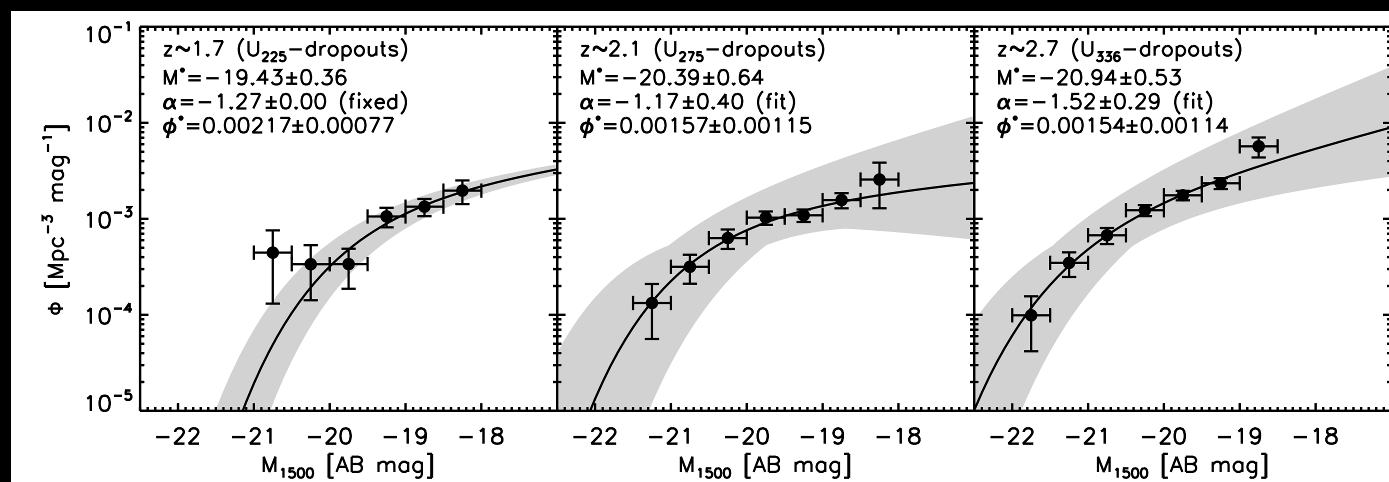
Siana, B., et al. 2010, ApJ, 723, 241 & AAS 221, 228.05

Windhorst, R., et al., 2011, ApJS, 193, 27

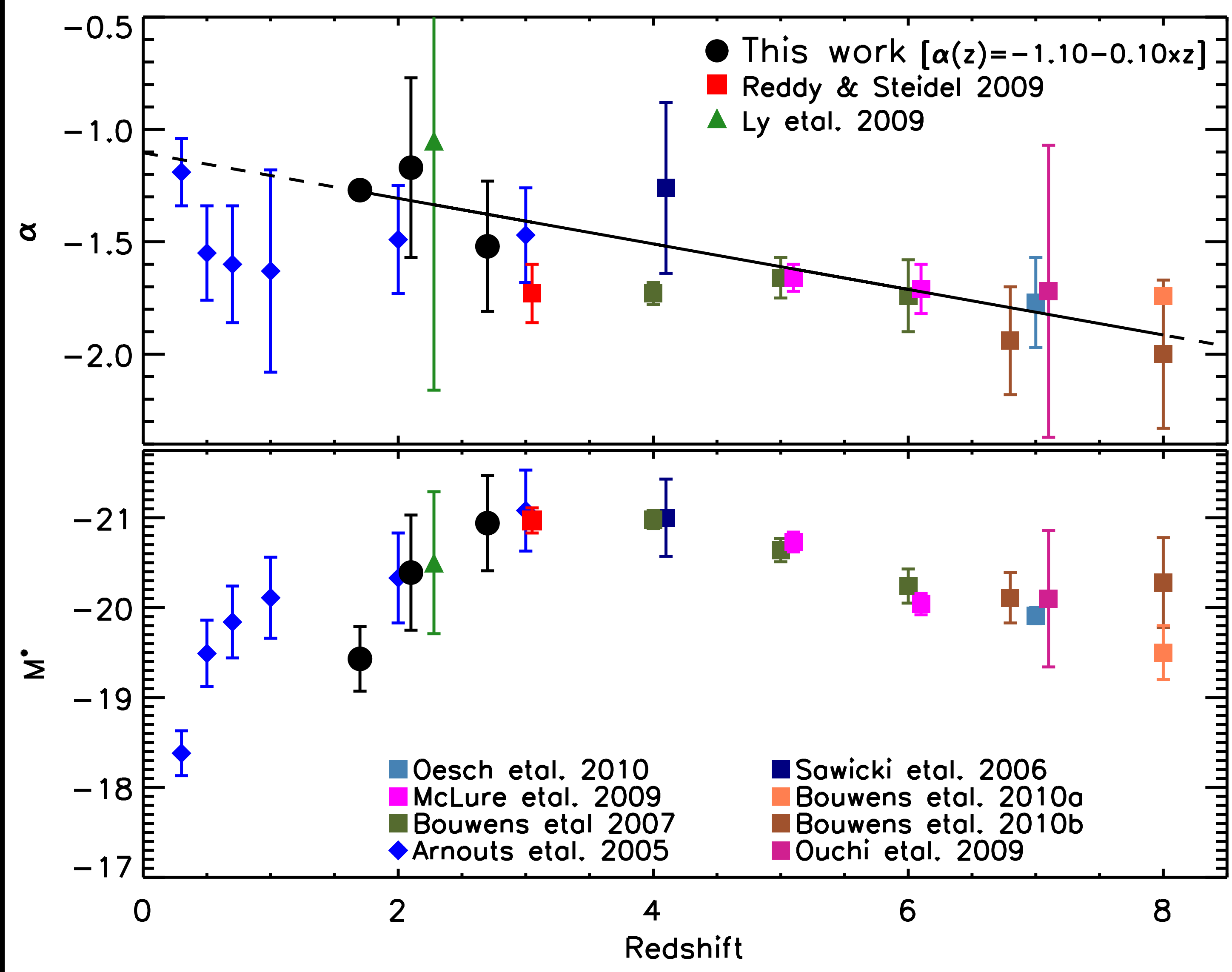


Lyman break galaxies at the peak of cosmic SF (z≃1-3; Hathi ea. 2010)



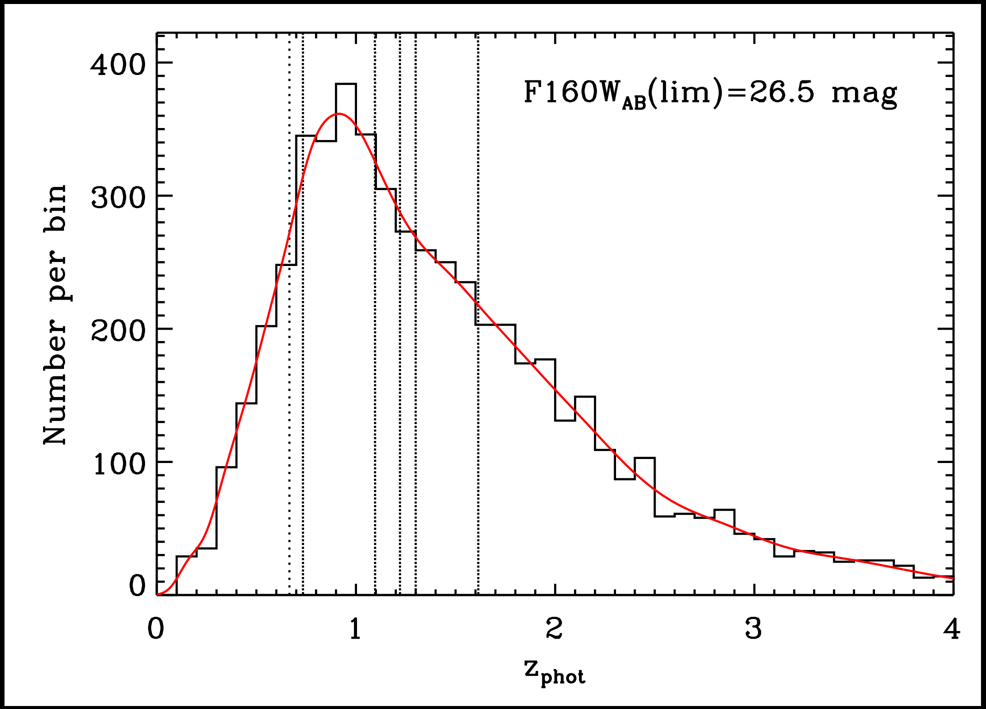


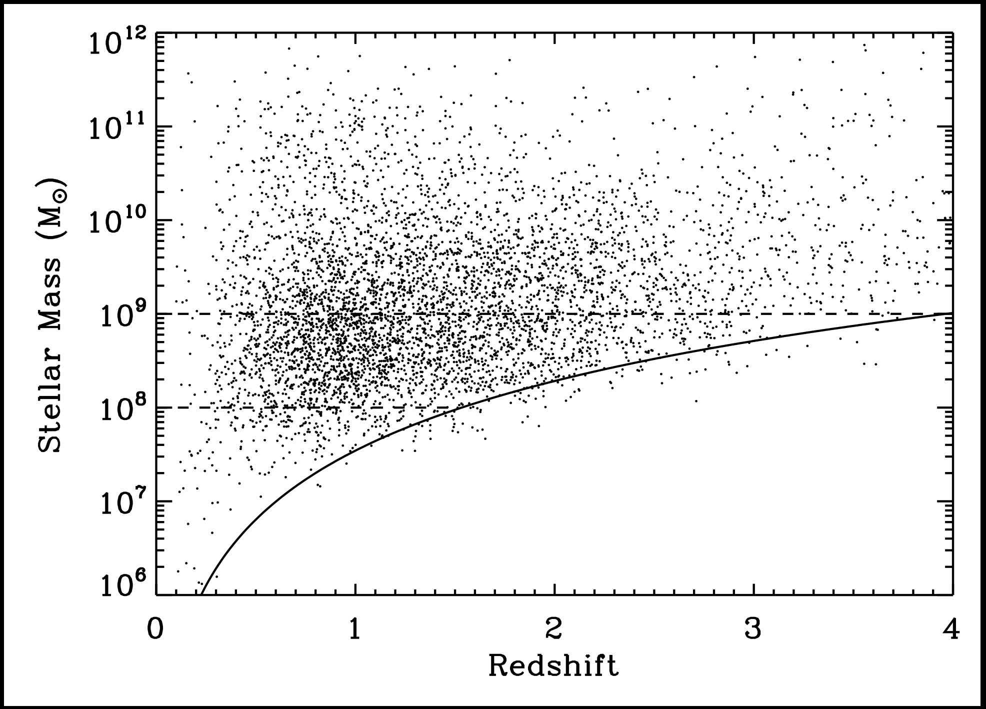
- Limited flux-range as yet, which limits the M^* , ϕ^* , α-accuracy.
- Deep wide-field WFC3 UV: UV LF's in z-range hard to do from ground.
- Deep wide-field WFC3 UV: significantly improves bright-end, M^* & ϕ^* .



Measured faint-end LF slope evolution (α; top) and characteristic luminosity evolution (M^* ; bottom) from Hathi et al. 2010 (ApJ, 720, 1708).

- Still poorly determined LF parameters at $1 \lesssim z \lesssim 3$, when most stars born:
- Deep wide-field WFC3 UV imaging will vastly improve on this.





WFC3 ERS 10-band redshift estimates accurate to $\lesssim$4% with small systematic errors (Hathi et al. 2010, 2012), resulting in a reliable N(z):

• Measure masses of faint galaxies to AB=26.5 mag, tracing the process of galaxy assembly: downsizing, merging, (& weak AGN growth?).

ERS shows WFC3's new panchromatic capabilities on galaxies at z$\simeq$0–8:

• Deep wide-field WFC3 UV will significantly improve SED-fits & photo-z's, both in rms and catastrophic failures (Cohen et al. 2012).