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

- Wide-field HST WFC3 UV imaging is critical to do 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;

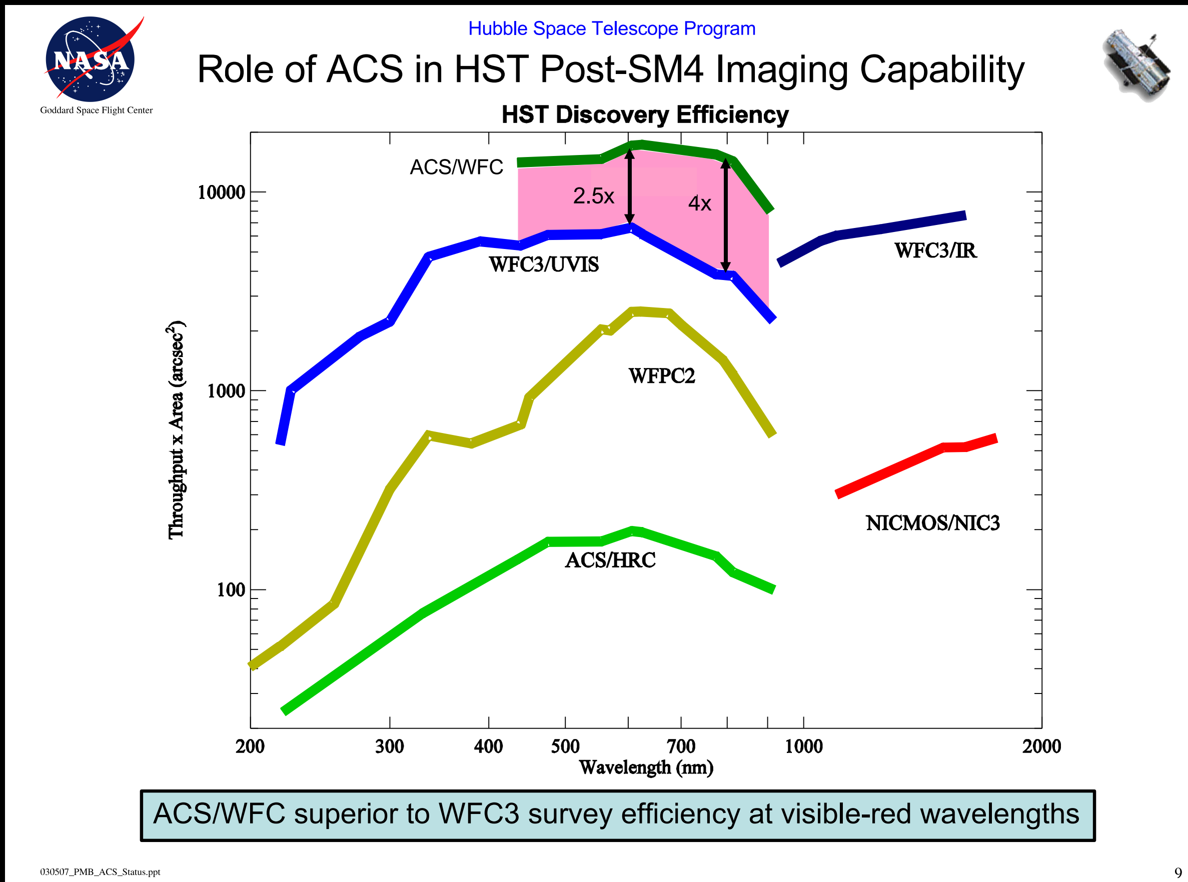
- (3) Evolution of young, star-forming sub-galactic clumps induced by mergers or gas accretion, and the growth of stable galaxy disks;

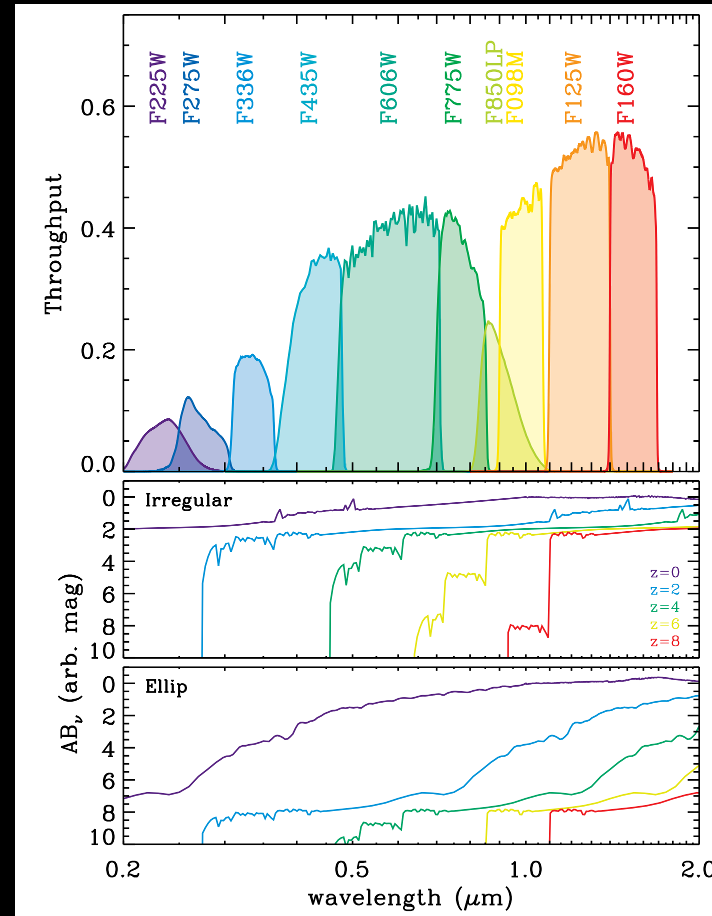
- (4) Late-epoch SF & structural evolution in massive early-type galaxies.

(5) Summary and Conclusions.

Sponsored by NASA/HST WFC3 & JWST

Arizona State University





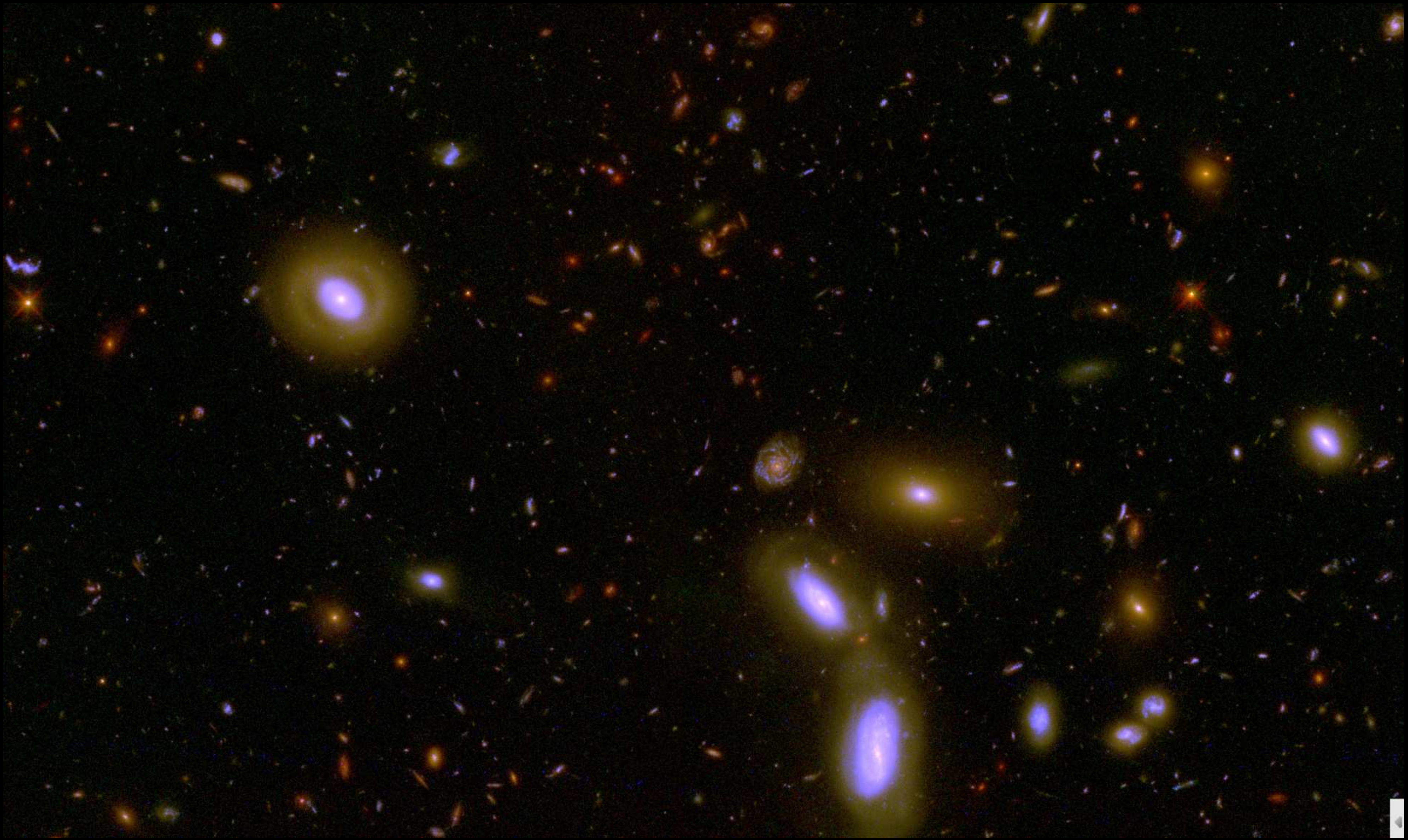
WFC3/UVIS channel unprecedented UV–blue throughput & areal coverage:

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:

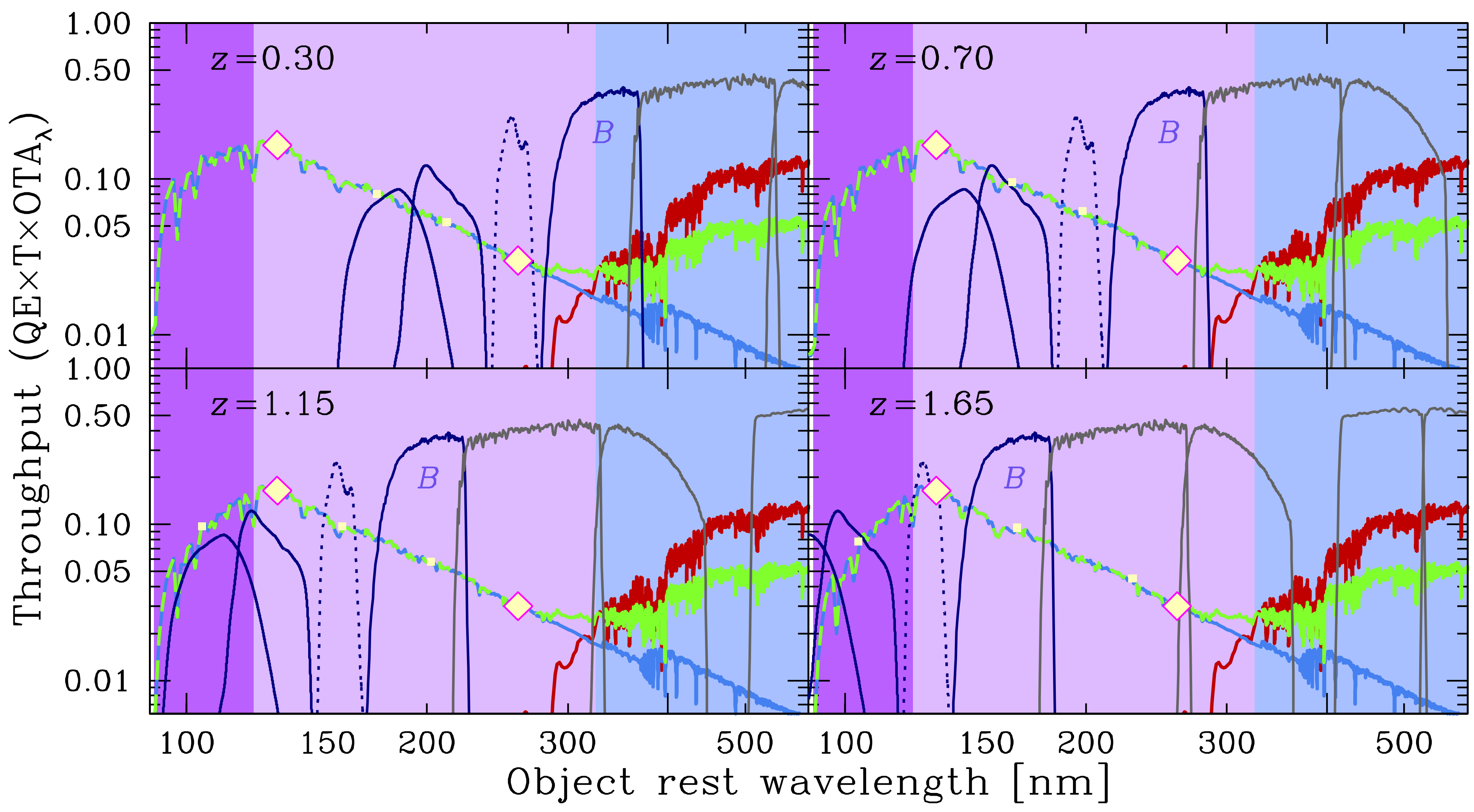
QE$\gtrsim$70%, 1k$\times$1k array of $0\farcs13$ pixel, FOV $\simeq$ $2\farcm25 \times 2\farcm25$.

- 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).

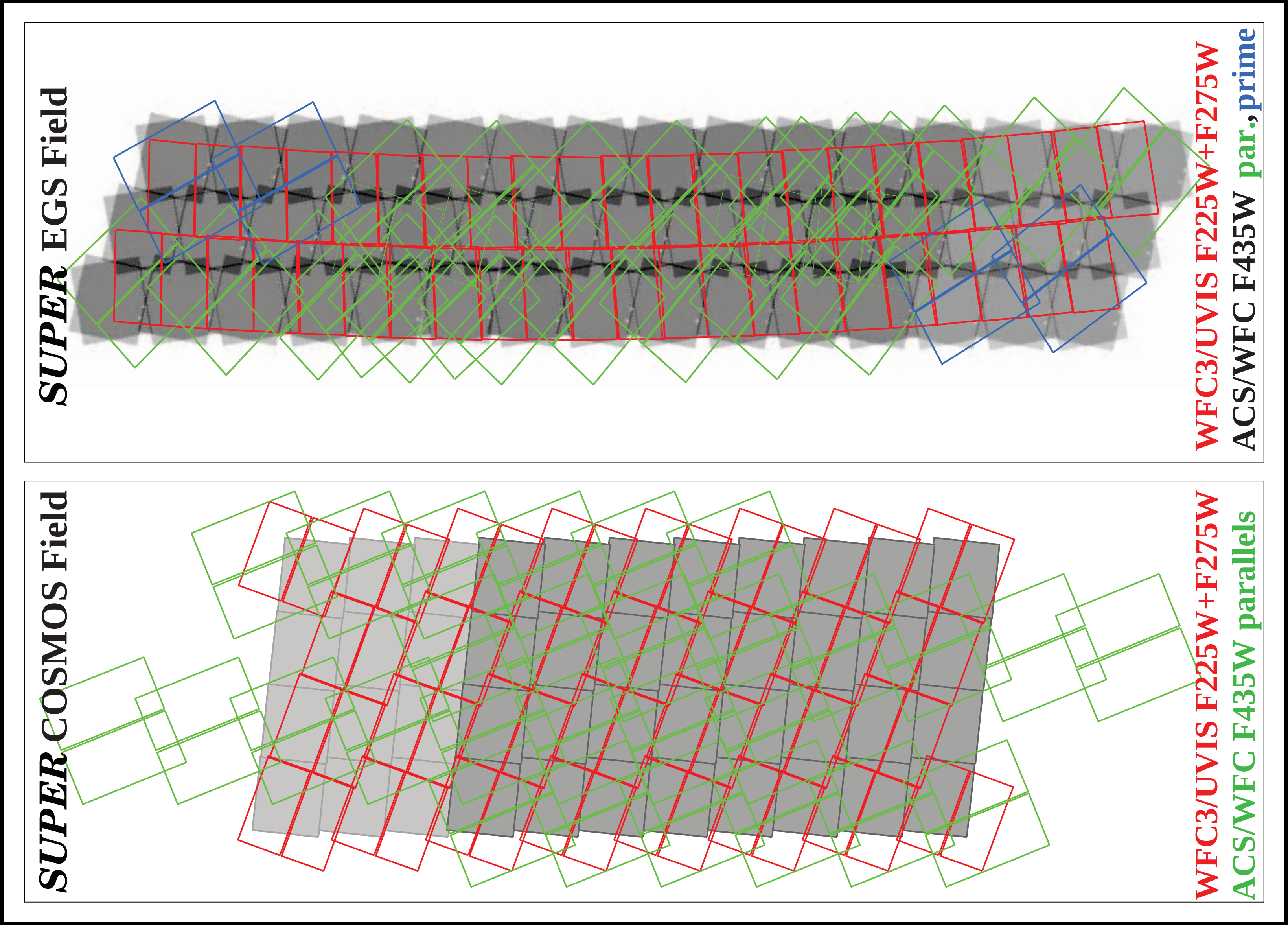
- ERS in GOODS-S v2: using WFC3 for what it was designed to do.
- JWST adds 0.05–0.2" FWHM imaging to AB$\simeq$31.5 mag at 0.7–5μm, and 0.2–1.2" FWHM at 5–29μm, tracing young+old SEDs & dust.



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

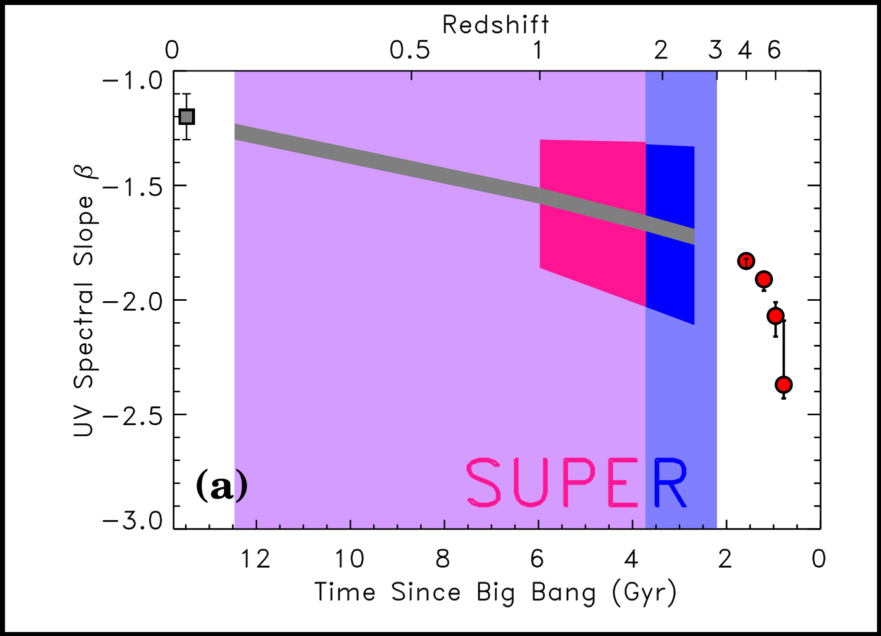
• Diamonds: Rest-frame 1300Å and 2600Å to measure UV β-slope.

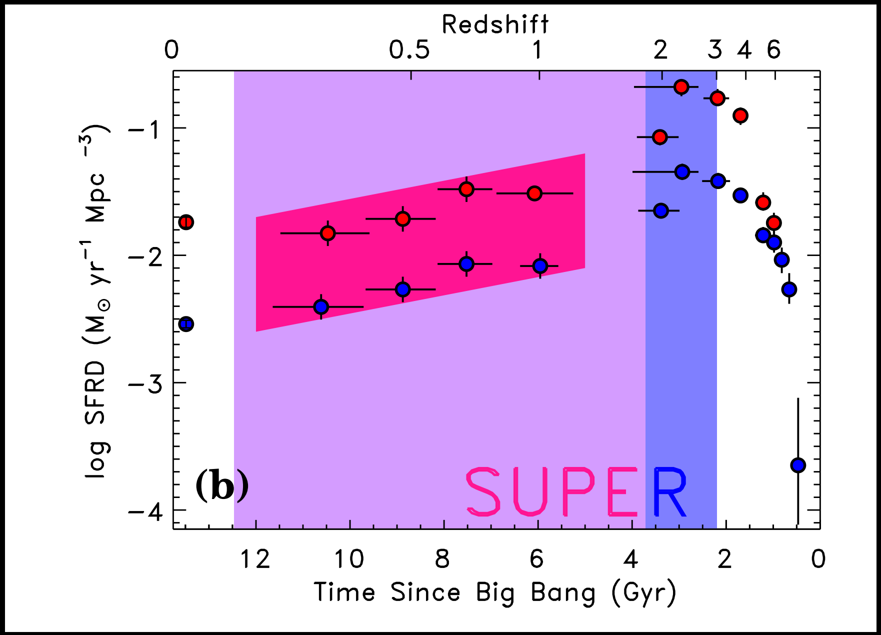
• For $0.2 \lesssim z \lesssim 2.0$ WFC3 UV, ACS F435W & CANDELS (F606W, F814W) filters sample the β-slope for SF objects in $\gtrsim$2 filters at $\lesssim$0.″1 FWHM.



- 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:



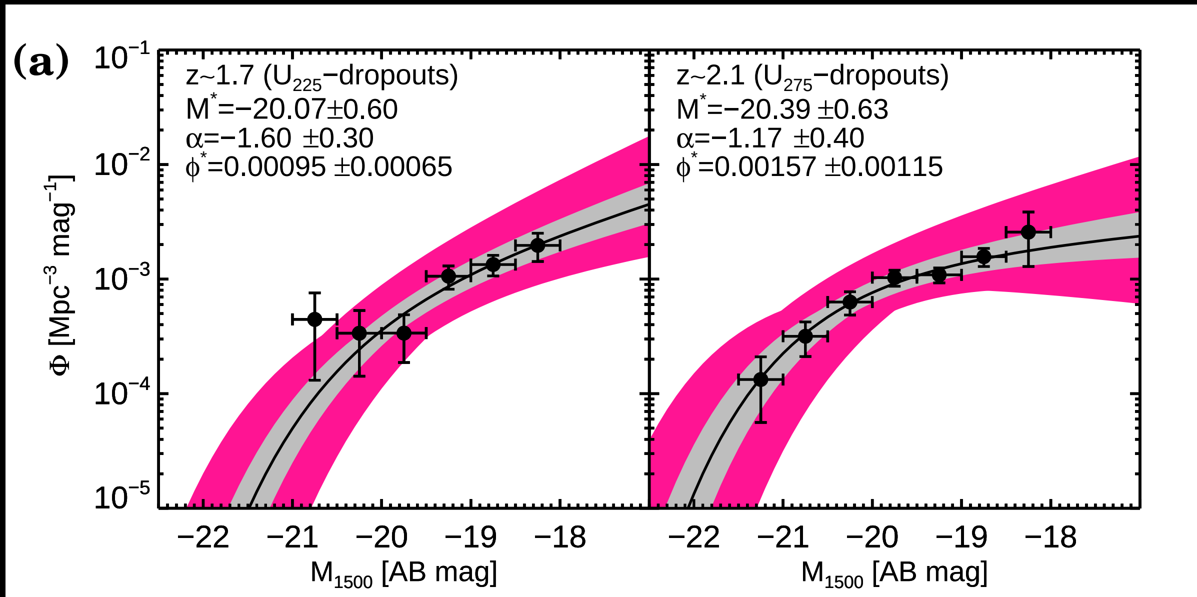


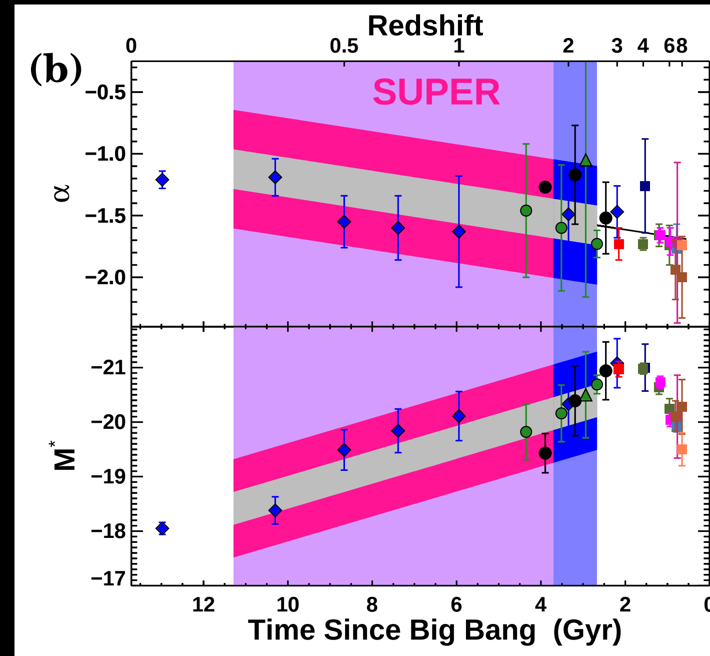
[LEFT] Evolution of the UV spectral slope β (Finkelstein et al. 2011). Dark pink/dark blue region is WFC3 ERS β-range (Hathi et al. 2012).

- Wide-field WFC3 UV traces β-evolution from 16,000 SF clumps for $0.2 \lesssim z \lesssim 2$ (grey strip) $\Longrightarrow$ dust attenuation in SF knots in 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.

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





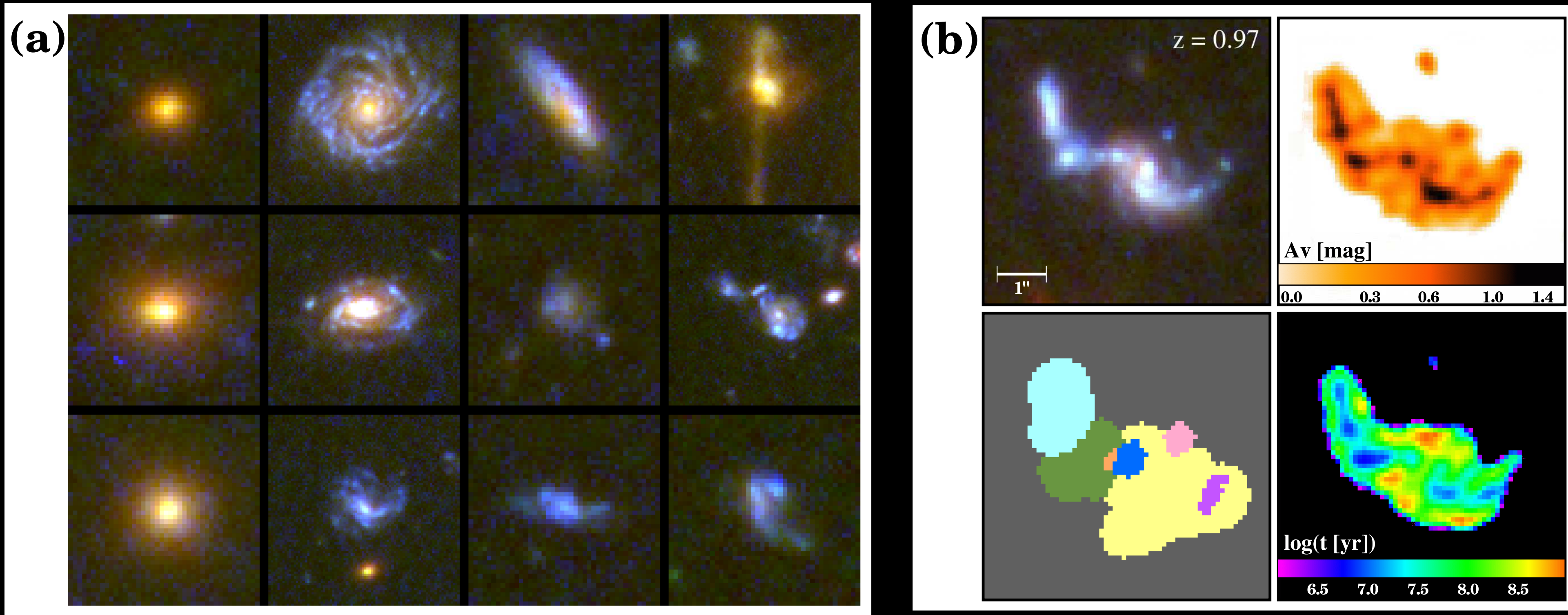
[LEFT panels] Rest-frame UV Luminosity Functions (LFs) based on UV-dropouts (Hathi et al. 2010, 2012).

[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 $0.2 \lesssim z \lesssim 2.5$.

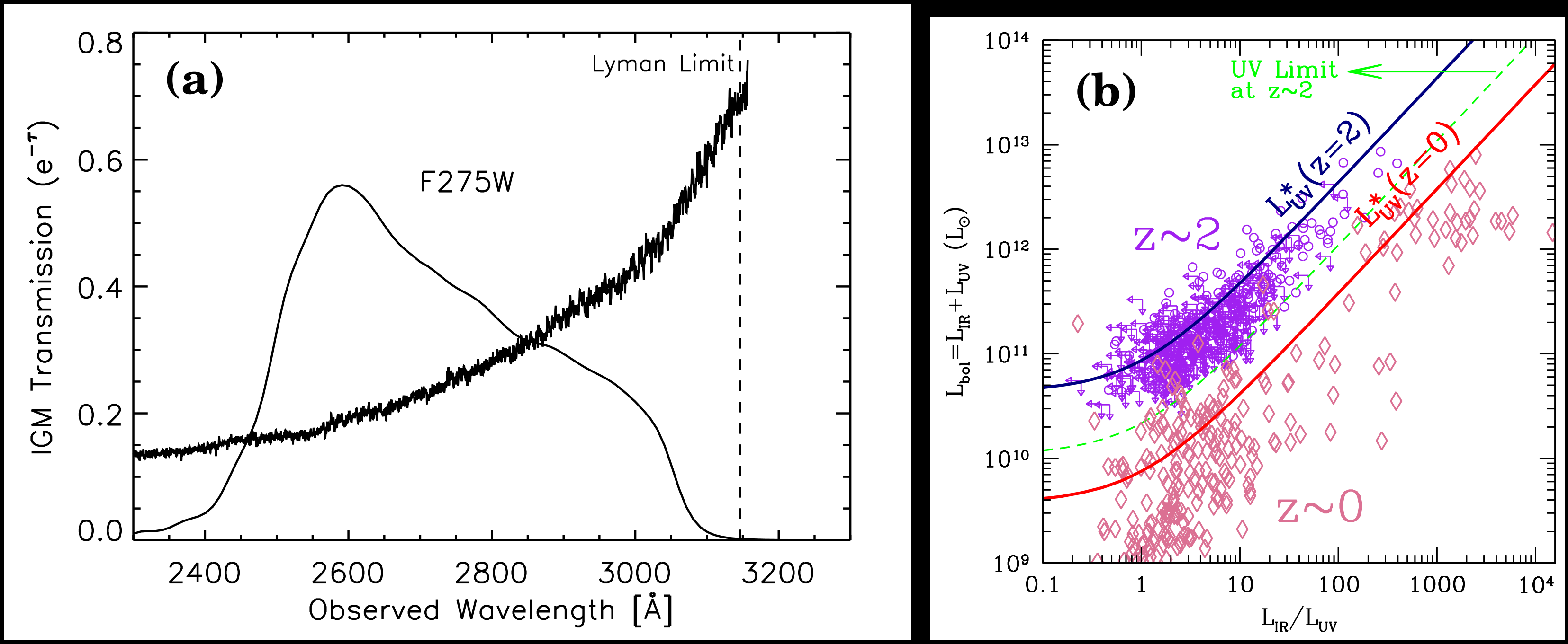


[LEFT panels] WFC3 ERS color images of galaxies at z$\simeq$0.75 shown in the 7 WFC3 UV+B & CANDELS filters. All show measurable UV flux.

[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.
- 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:



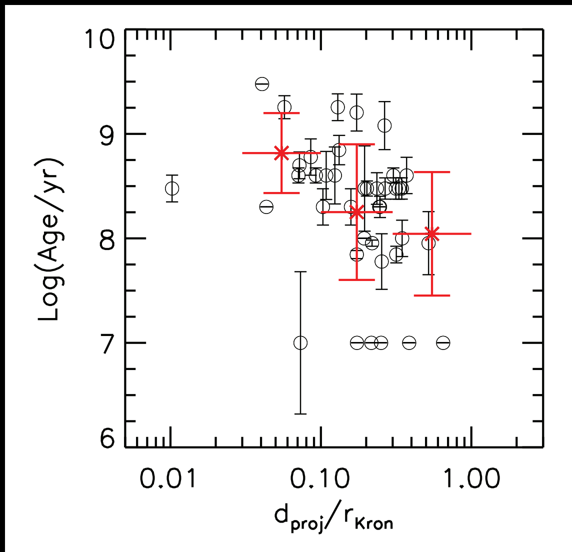
[LEFT] Average IGM transmission vs. wavelength. WFC3 F275W samples Lyman-continuum escape fraction f_{esc} at z≃2.45, where average transmission is $e^{-\tau}$≃0.250 (Siana et al. 2012).

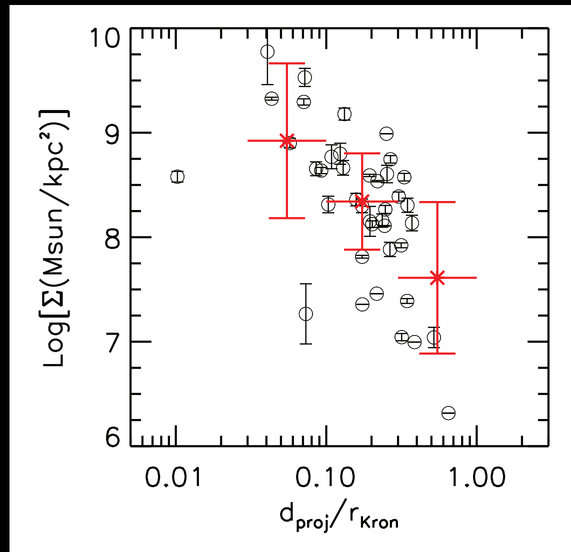
- Wide-field WFC3 UV will yield f_{esc} for ∼800 galaxies at z≃2.45±0.2, and relate it to physical galaxy properties (mass, type, A_V, V_{rot}/σ_g).

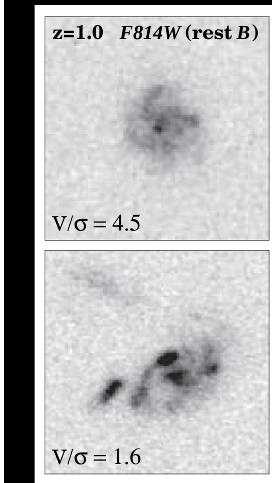
[RIGHT] Bolometric luminosity vs. dust attenuation (L_{IR} / L_{UV}) for z≃2 compared to local galaxies (Reddy et al. 2010), suggesting evolution of the net extinction in SF galaxies with time.

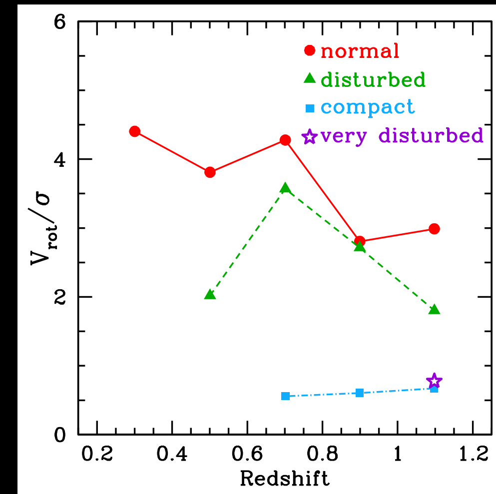
- Wide-field WFC3 UV adds ∼800 dusty LBGs in redshift gap 0.2≲z≲2.

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









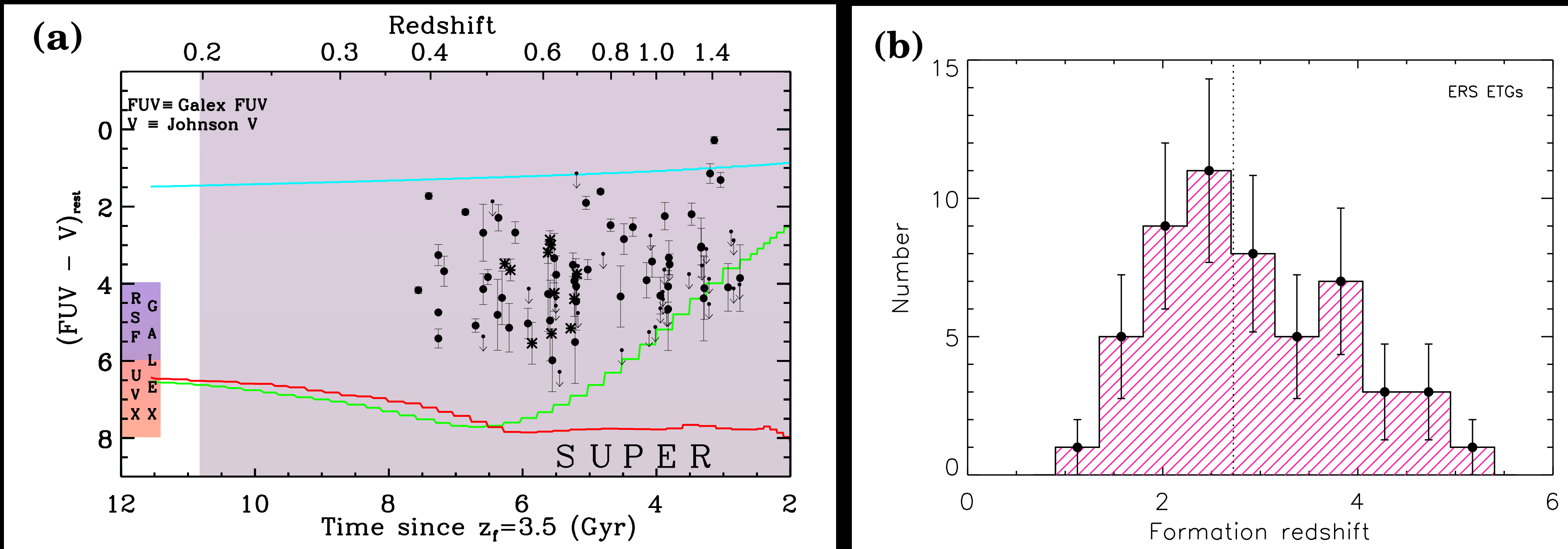
[LEFT 2 panels] Radial variation of age and mass surface-density of sub-galactic clumps at z≃2 vs. galacto-centric distance (Guo et al. 2011, 2012).

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

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

- Wide-Field WFC3 UV will do this for $\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;

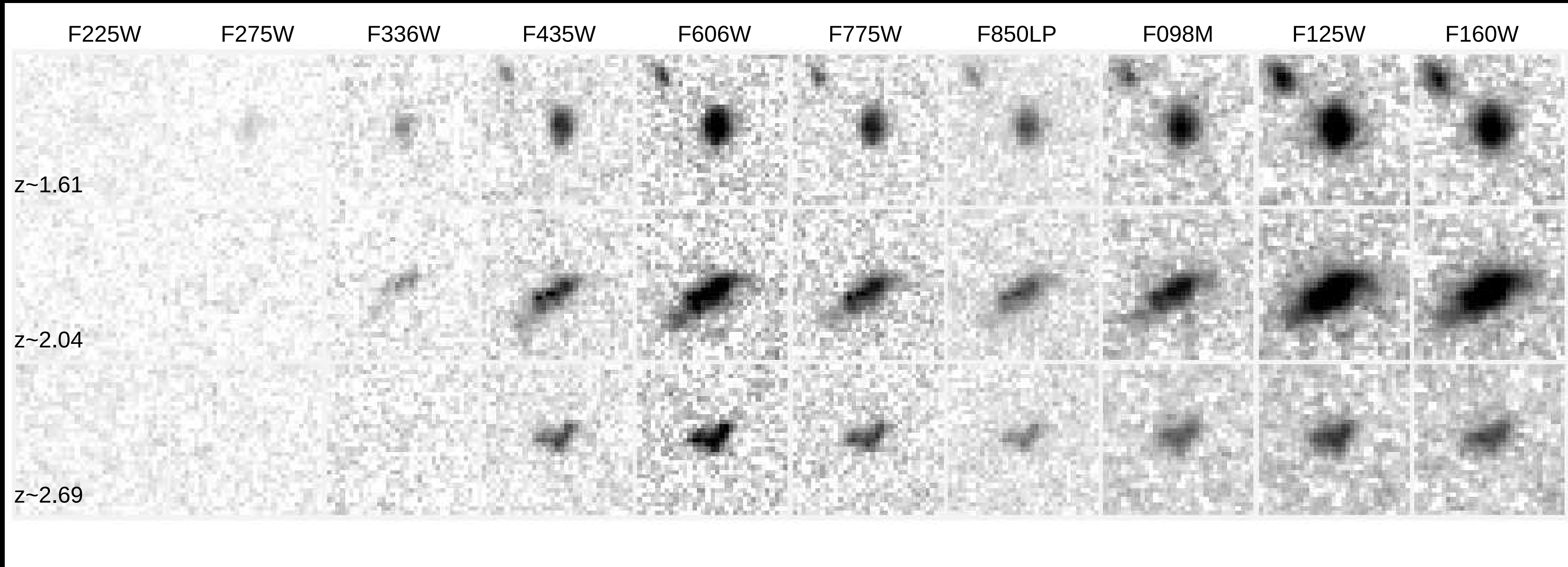
- (4) Late-epoch SF and structural evolution in massive early-type galaxies.

SPARE CHARTS

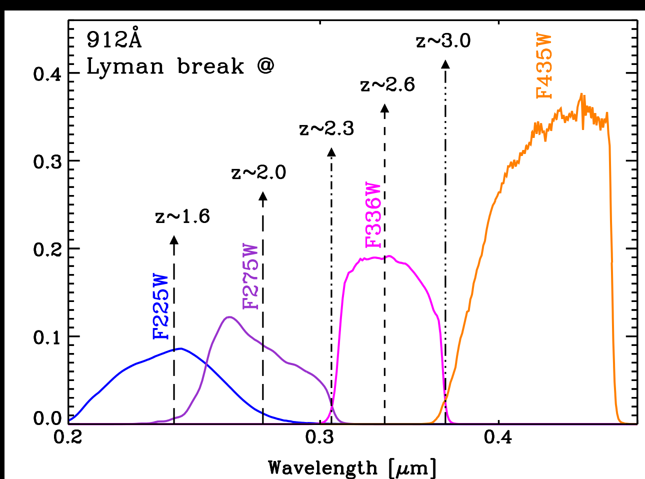
- References and other sources of material shown:

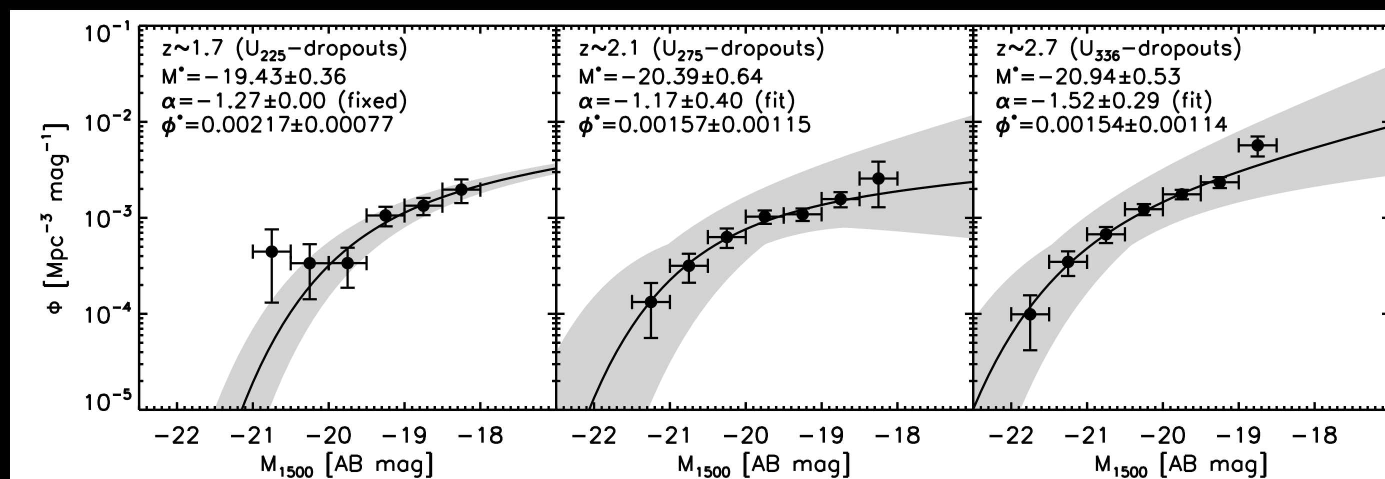
http://www.asu.edu/clas/hst/www/jwst/ [Talk, Movie, Java-tool]
http://www.jwst.nasa.gov/ & http://www.stsci.edu/jwst/

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
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

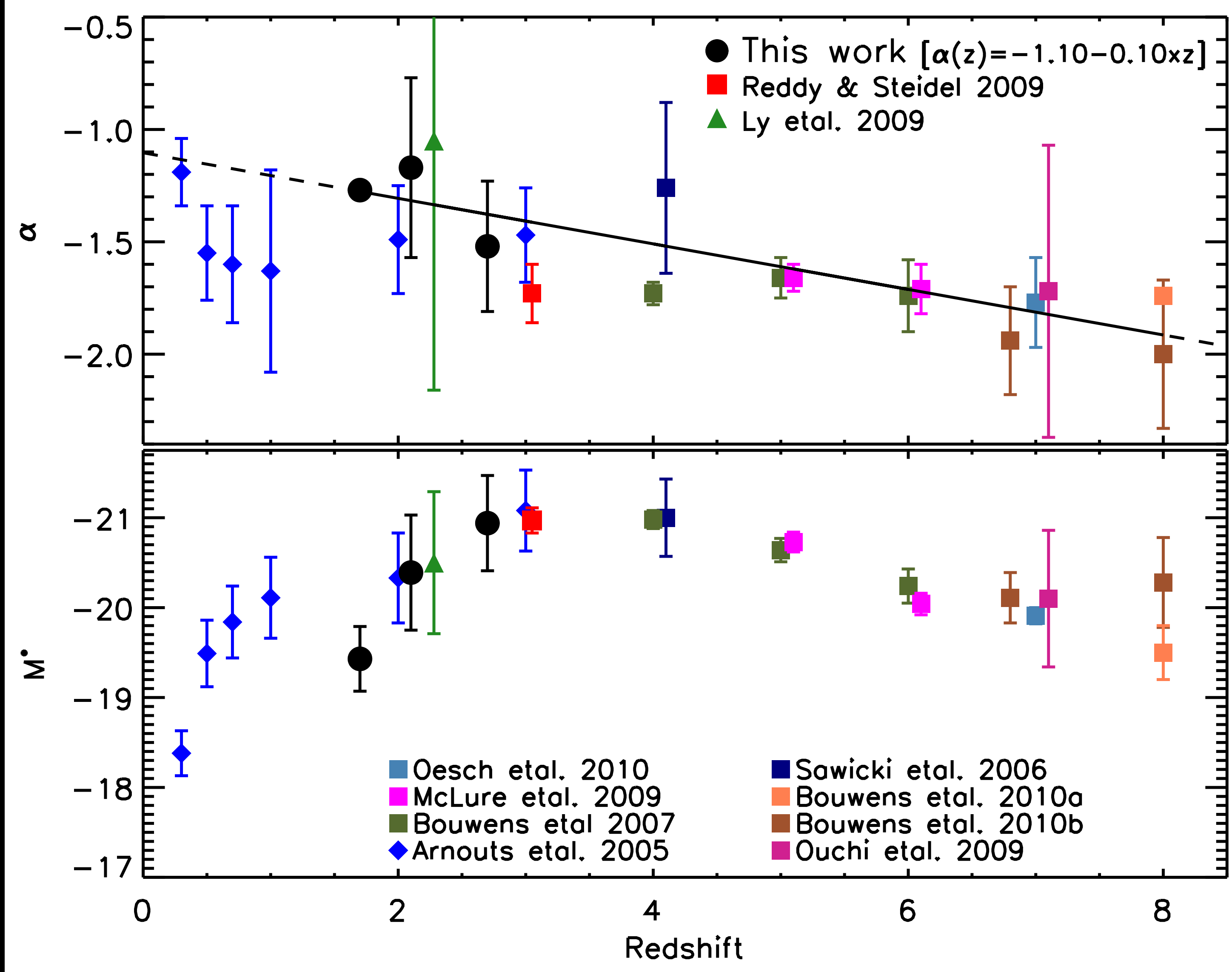


Lyman break galaxies at the peak of cosmic SF (z≃1-3; Hathi ea. 2010)



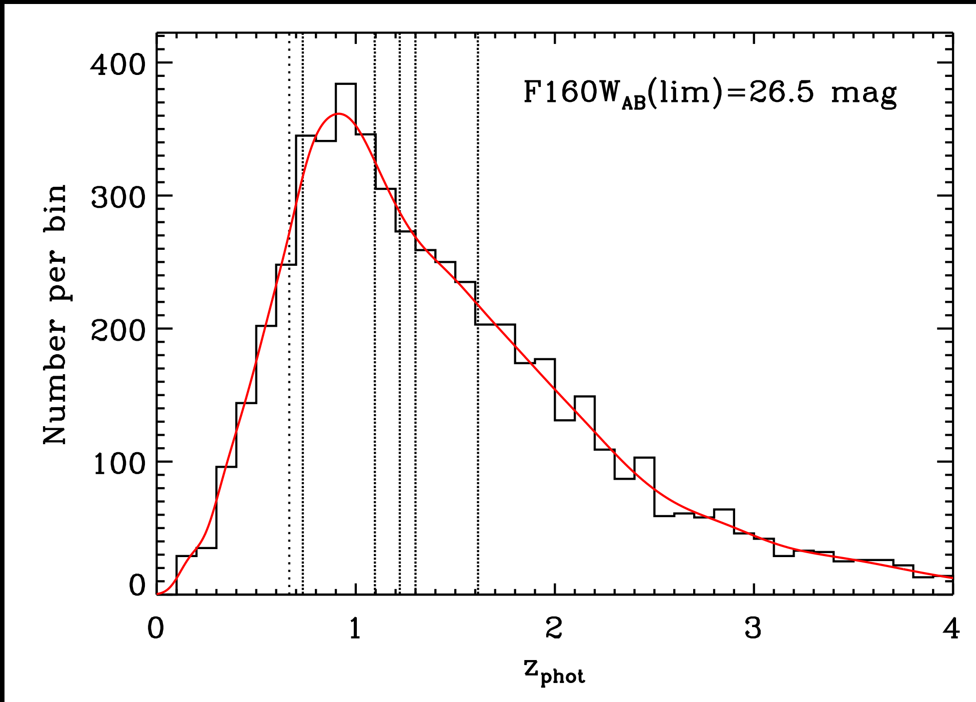


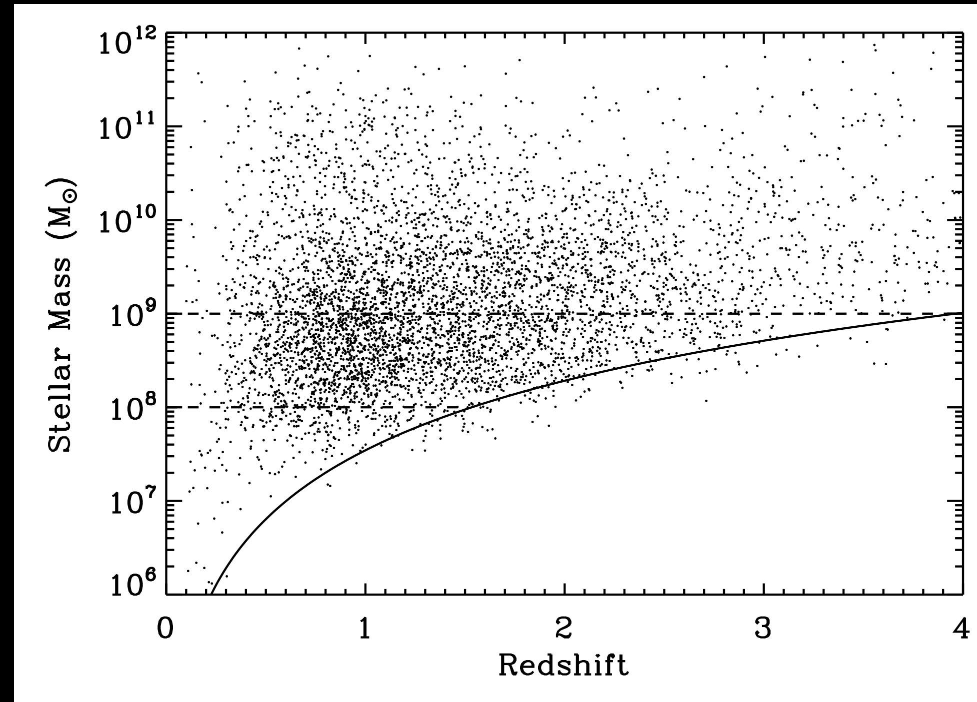
- Limited flux-range as yet, which limits the M^* , ϕ^* , α-accuracy.
- Wide-field WFC3 UV: UV LF's over z-range that is hard from ground.
- Wide-field WFC3 UV: will significantly improve on bright-end, M^* & ϕ^* .



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).