Studying Galaxy Evolution with WFIRST

Henry Ferguson (STScI)
17 November 2014

Outline

- Recent progress and open questions
- Archival science with the WFIRST surveys
- WFIRST pointed observations

The need for large surveys

- Galaxy formation/evolution is inherently statistical
- Making the link between galaxy-scale physics and cosmology is all about measuring distributions:
  - Need to know what kinds of galaxies are common and what kinds are rare.
  - Need to measure correlations between the structure of galaxies and their stellar content.
  - Need to measure correlations between galaxy properties and their environment.
  - Not just the mean relations, but also the scatter

Multivariate Distributions

Tools in use today include:

$P(N|M)$ Multiplicity function vs. cluster or halo mass

$P(L|M)$ Luminosity function vs. cluster or halo mass

With several orders of magnitude larger samples => full multi-variate distributions of a large set of measurable (or inferred) galaxy properties vs. environment:

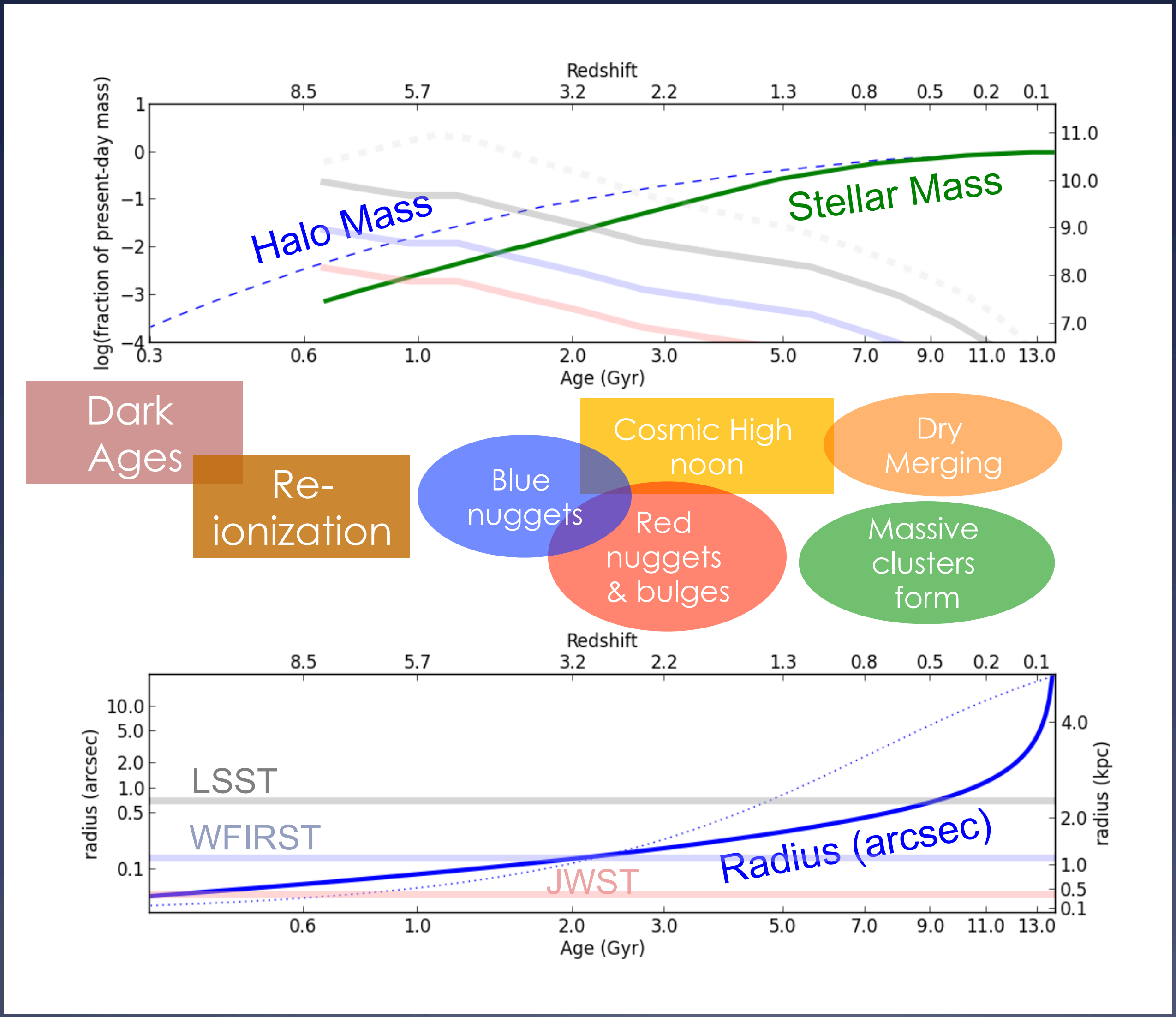
$$P(N, L, r_e, n, E(B-V), B/T, Z, \mathrm{color}, \mathrm{age}, \mathrm{sfr}|M)$$

Stack clusters or groups not just by mass but by other properties, leading to still more general distribution functions:

$$P(N, L, r_e, n, E(B-V), B/T, Z, \mathrm{color}, \mathrm{age}, \mathrm{sfr}|M, a, b, c..)$$

Where *a,b,c* are properties of the environment (cluster or group) such as concentration or ellipticity, inferred, for example, from gravitational lensing.

Milky-Way-like galaxy timeline

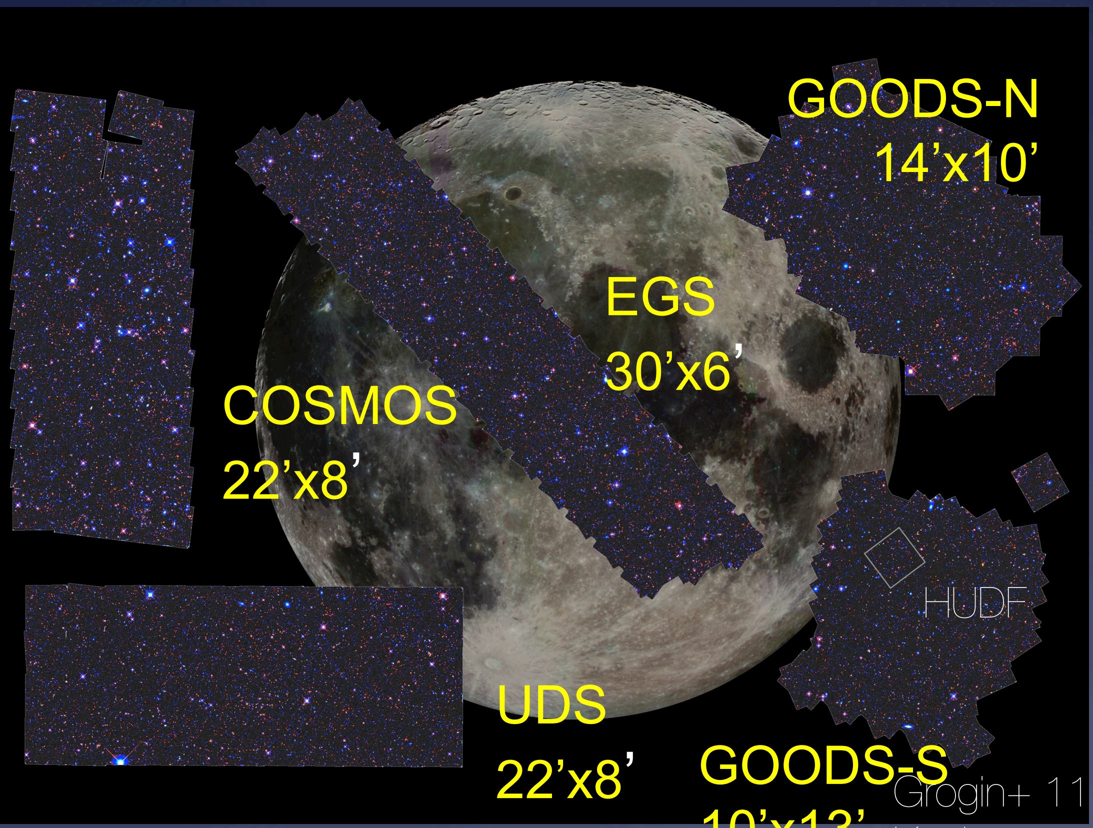


WFIRST M* limits
High-latitude
Deep

JWST M* limit

We are making progress…

- Deep multi-wavelength observations



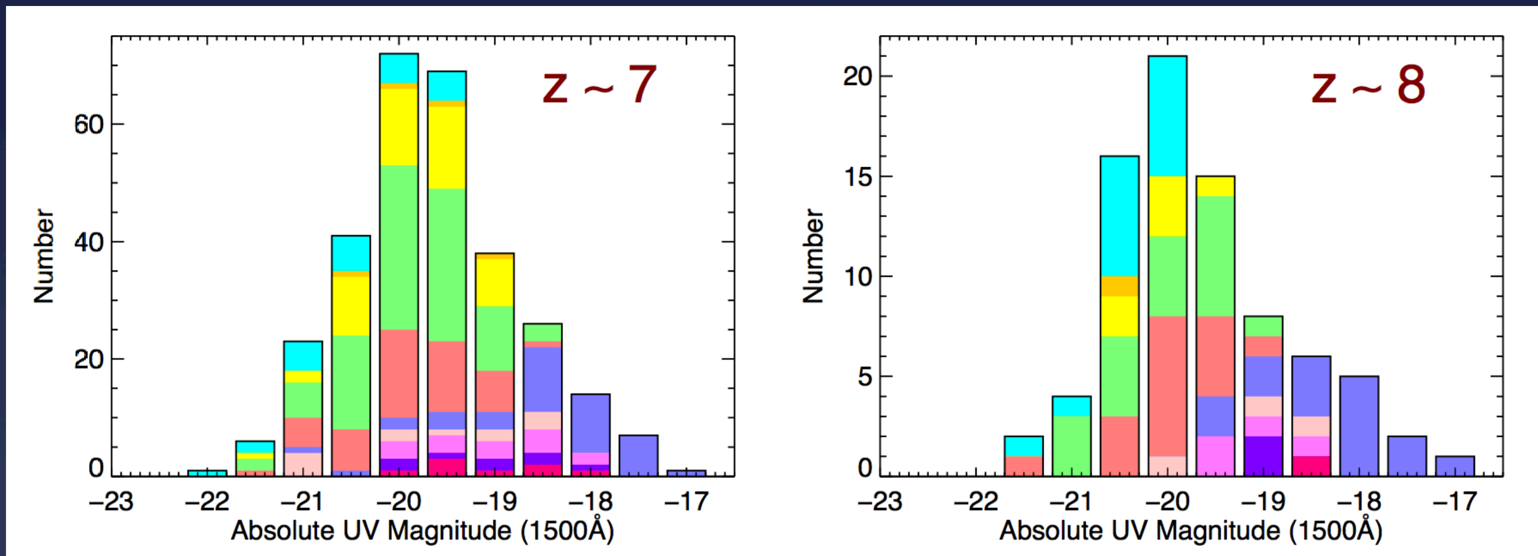
CANDELS:

- 10% of HST over 3 years
- Could be done in 6 hours with WFIRST

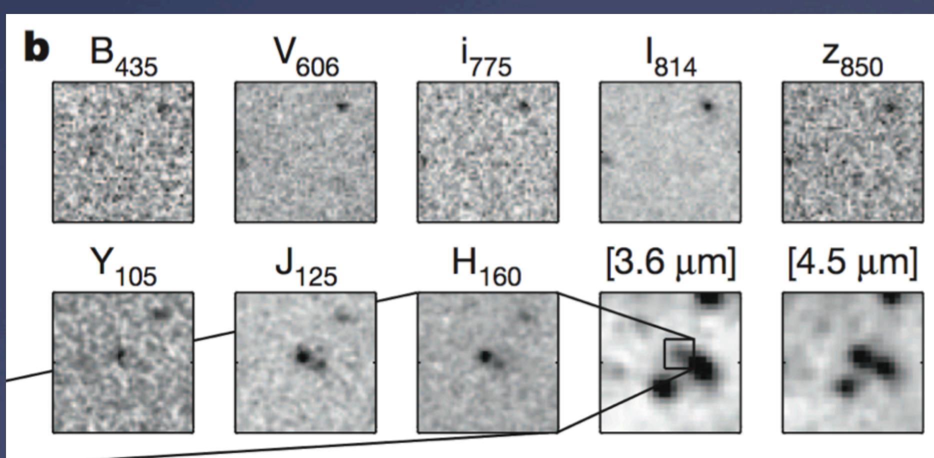
HUDF

- 702ks with HST
- 8 days with WFIRST:
  - Same depth,
  - 70x the area

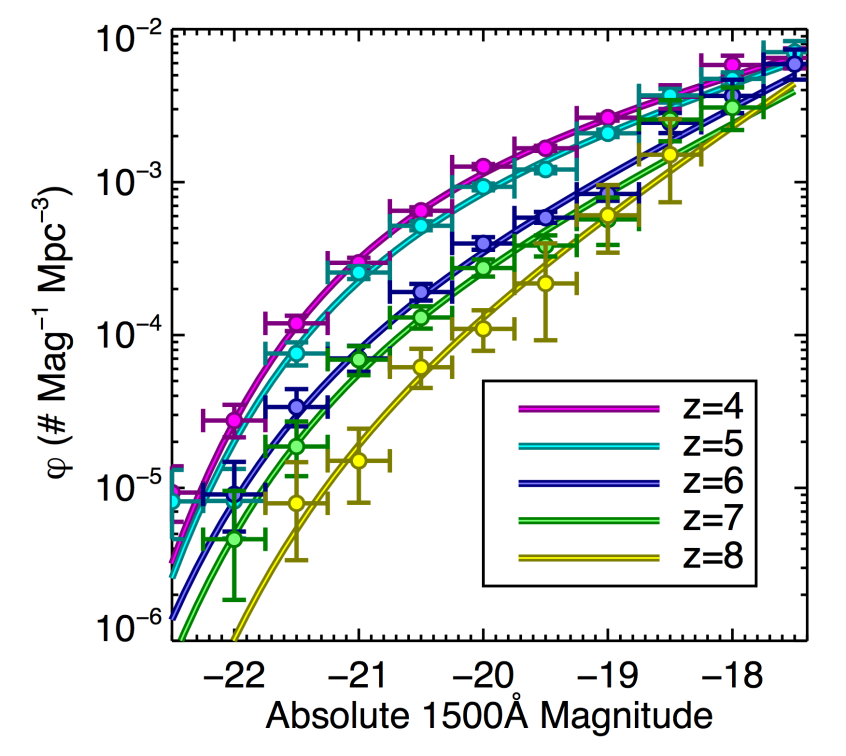
Cosmic Dawn



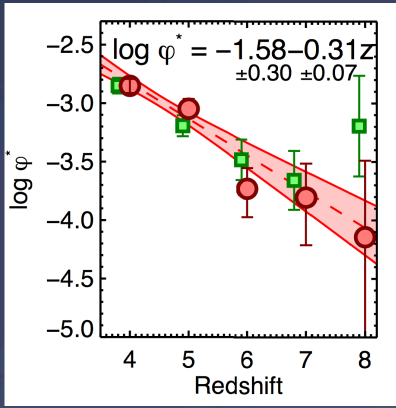
- 7500 galaxies z>3.5

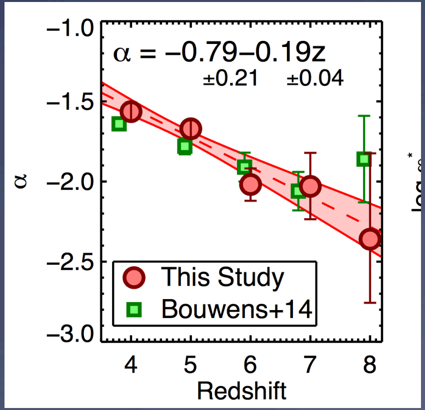


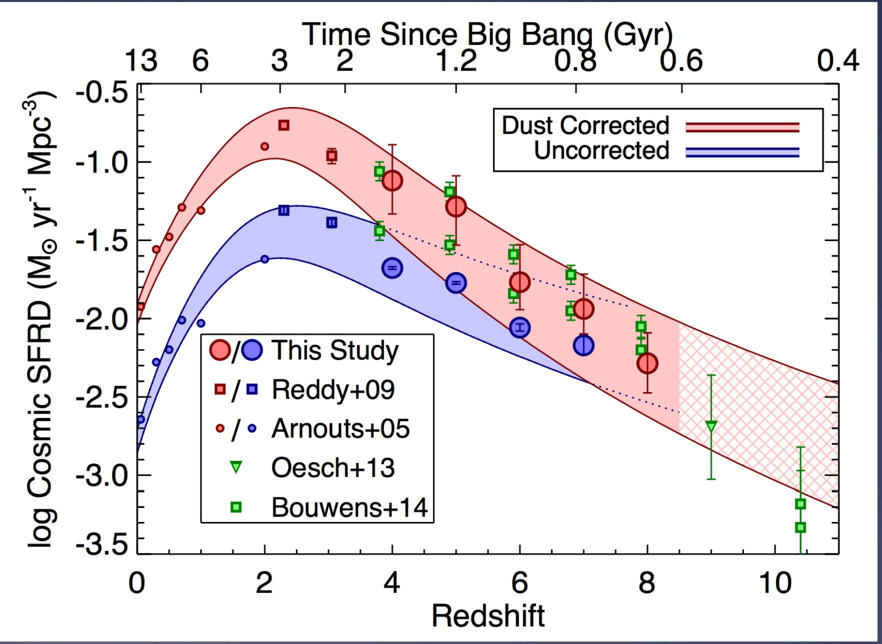
Cosmic Dawn



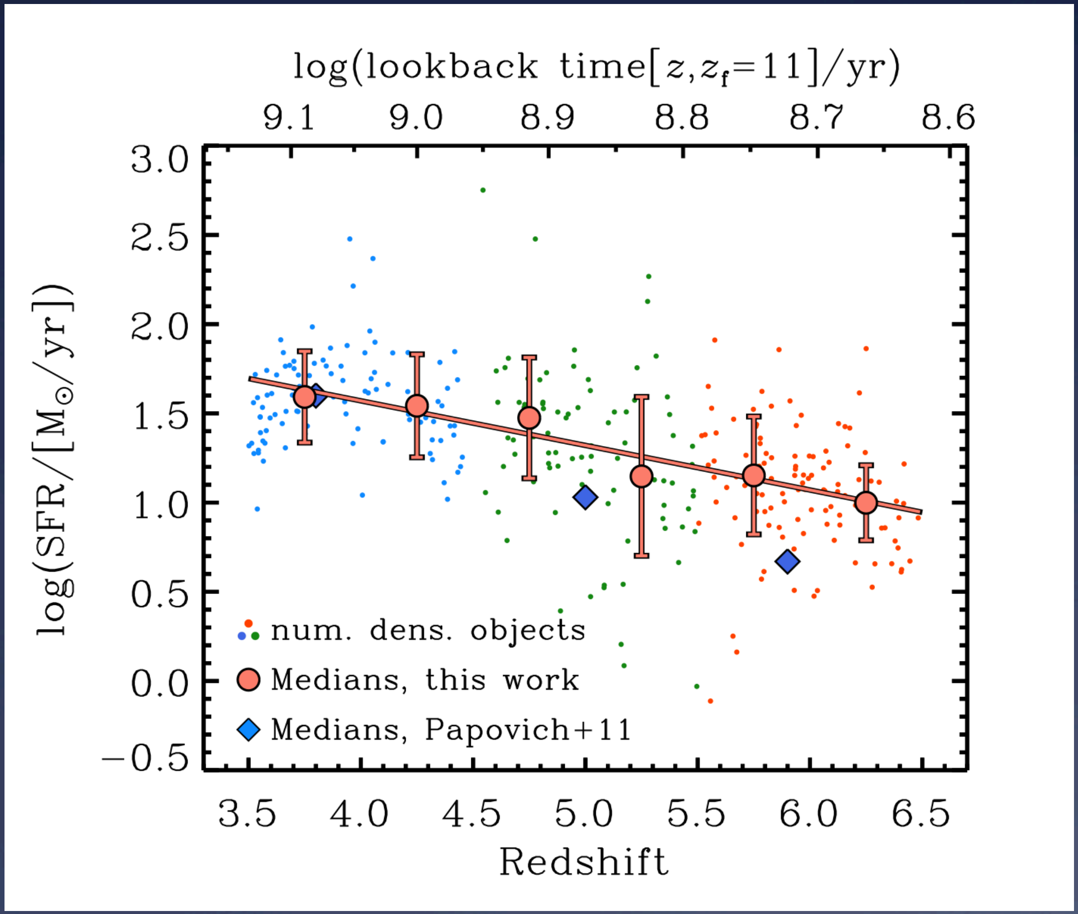
UV Luminosity Function
- Slope evolves
- Density evolves
- Maintains IGM ionization if $C/f_{esc} \sim 30$







Rising star-formation histories



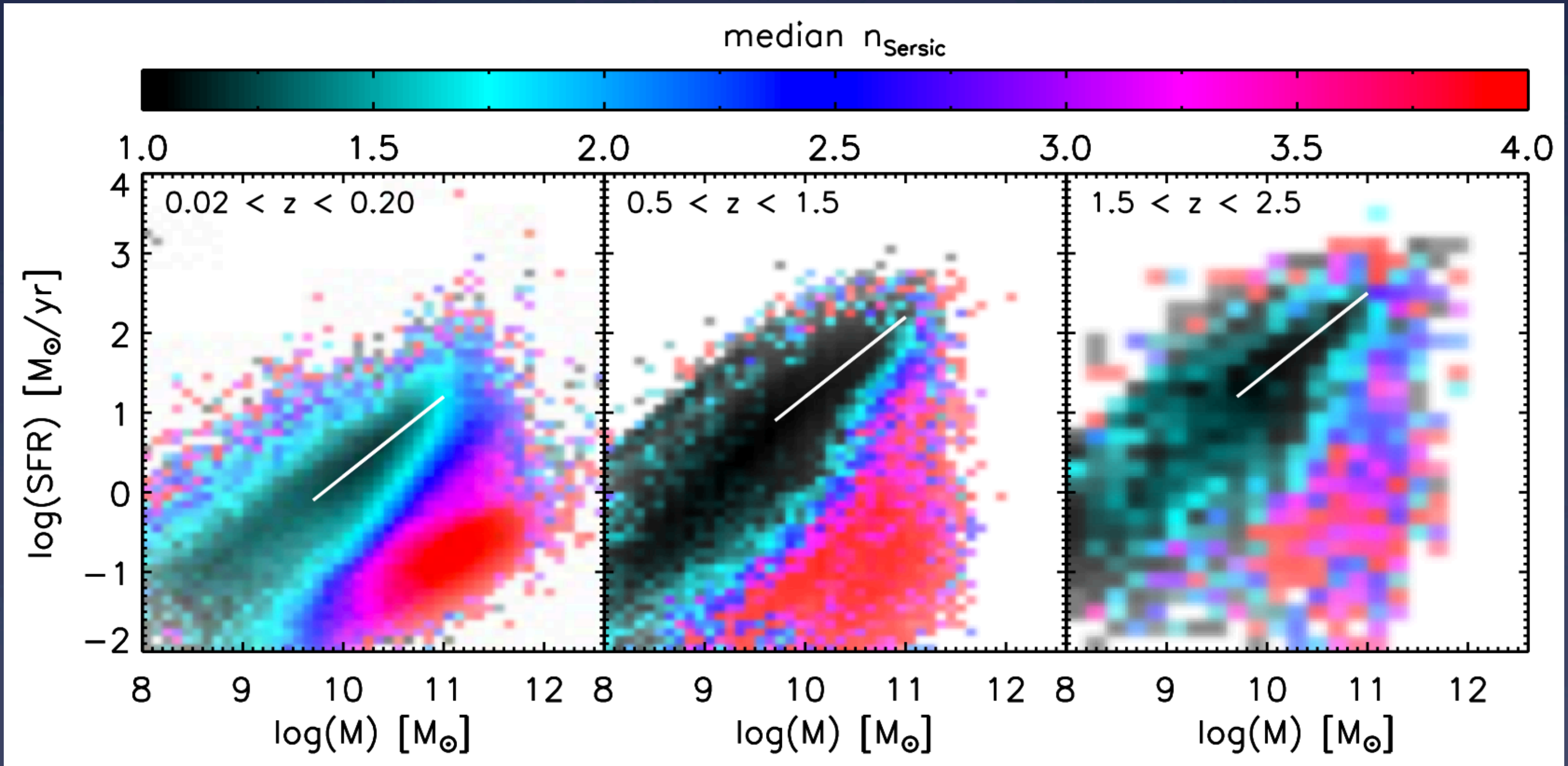
Selecting galaxies at constant number density:

- Star-formation rates increase as $\Psi(t) \sim t^{1.5}$

Salmon+14 submitted

Cosmic High Noon

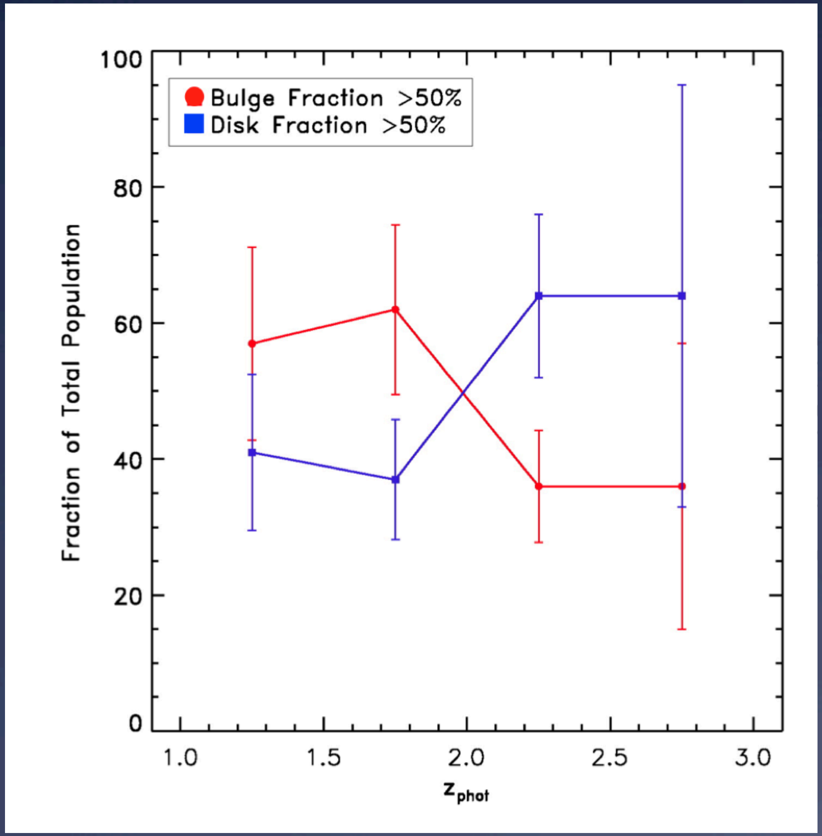
The best predictor of a galaxy's specific star-formation rate at z~2 is its morphology.



Wuyts+11

At z>2, most galaxies of Milky-Way mass are disk dominated. Below z~2, central non-star-forming bulges become prominent.

Bulge fractions

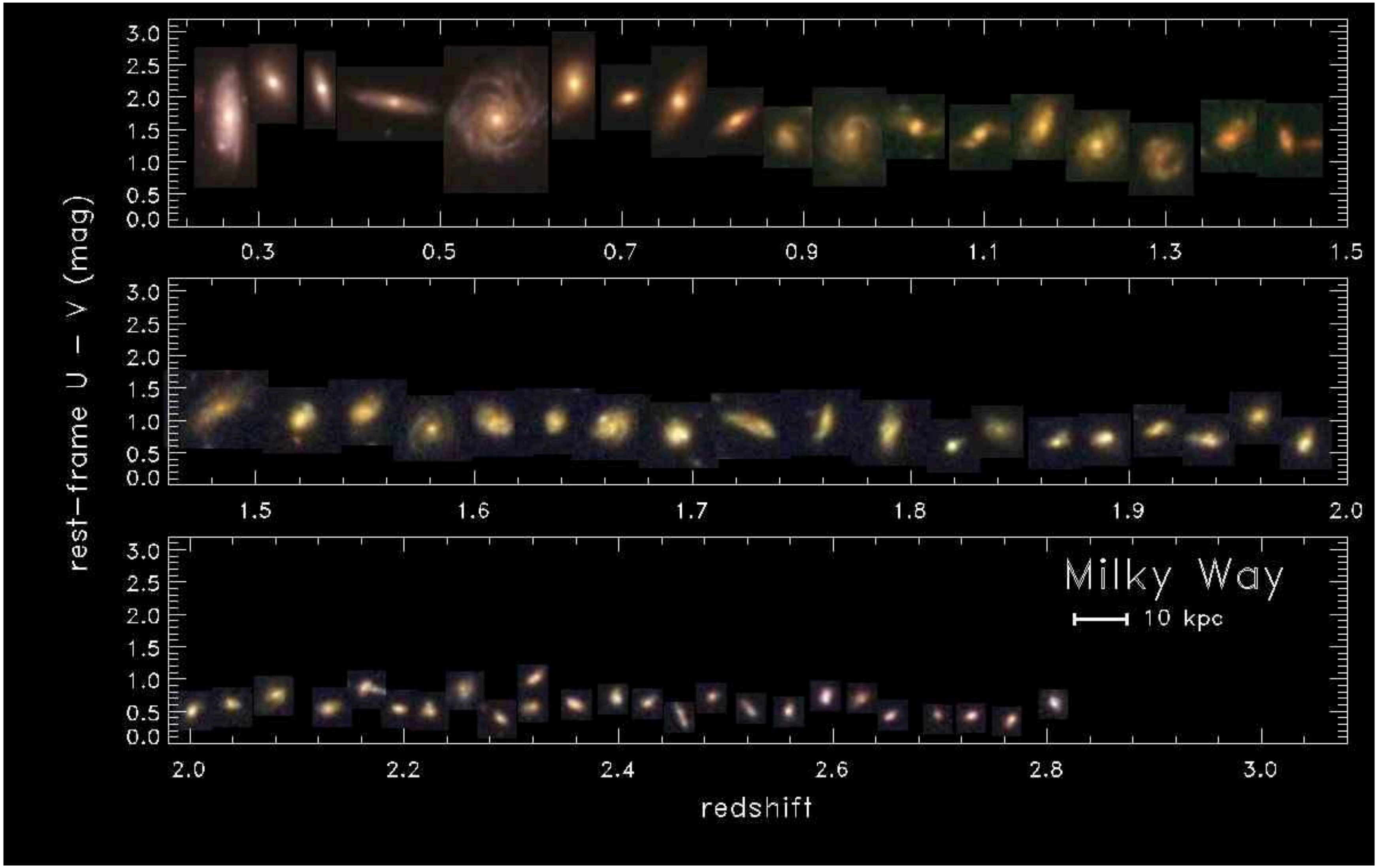


Bruce+13
Mortlock+13

Massive galaxies $M^{*}>10^{11}\ M_{\odot}$

- Bulges become dominant in massive galaxies at z~2
- Bulges are smaller at fixed mass at z~2 than today.
- While most passive galaxies are bulge dominated, a few passive galaxies appear to be pure disks.
  - Implications for quenching models?
- *Era of massive disks* at 2<z<3

What did the Milky Way look like 11 billion years ago?



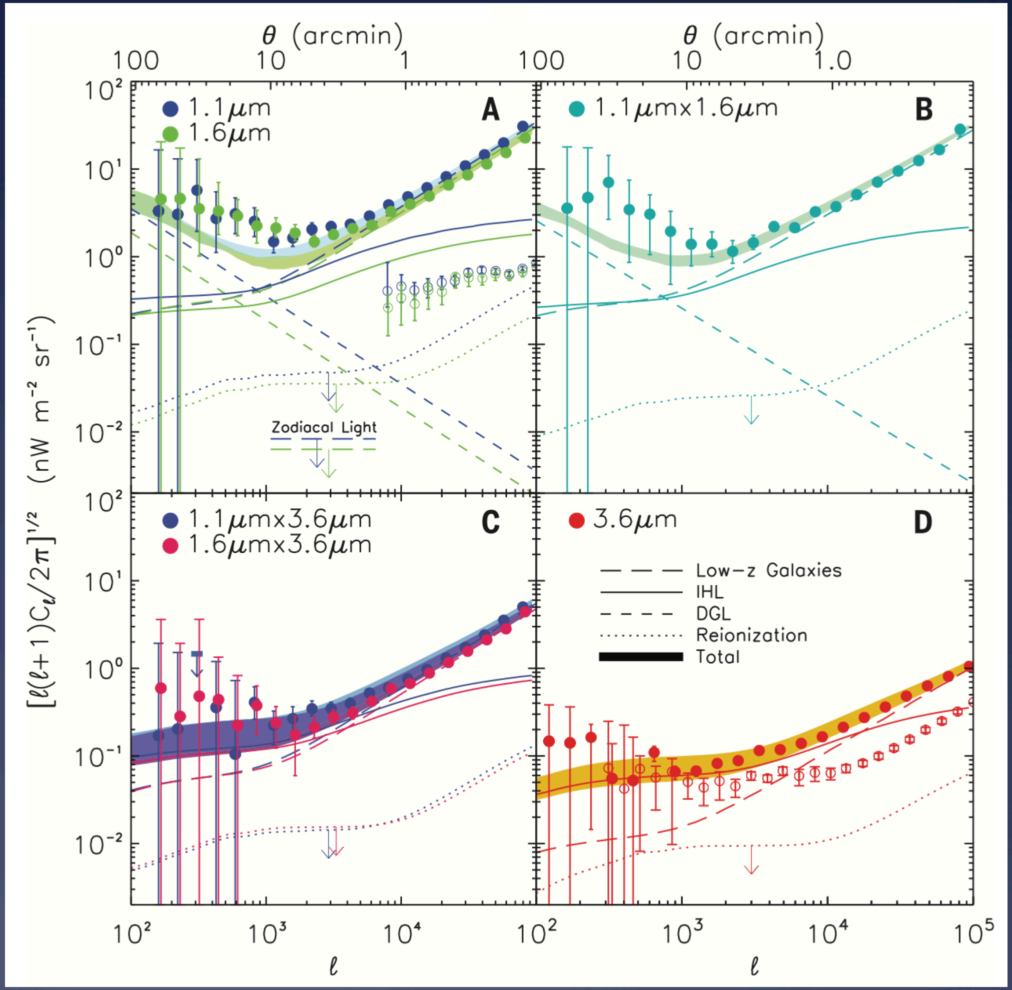
PAPOVICH ET AL.

So, are we done?

- Open questions (examples)
  - Still don't understand feedback
    - AGN connection with quenching tenuous
    - Hard to get the right star-formation histories for dwarfs
    - "too big to fail" problem for dwarf satellites
  - Merging vs. in-situ star-formation
  - Evolutionary status of dusty starbursts
    - Immediate progenitors of massive spheroids?
  - Intra-halo light contribution 50%?

Intra-halo light?

- Background fluctuations
  - best explained by IHL ≈ total light from galaxies.
  - Behroozi+13 also infers large IHL fraction
- WFIRST background fluctuation measurements will settle this



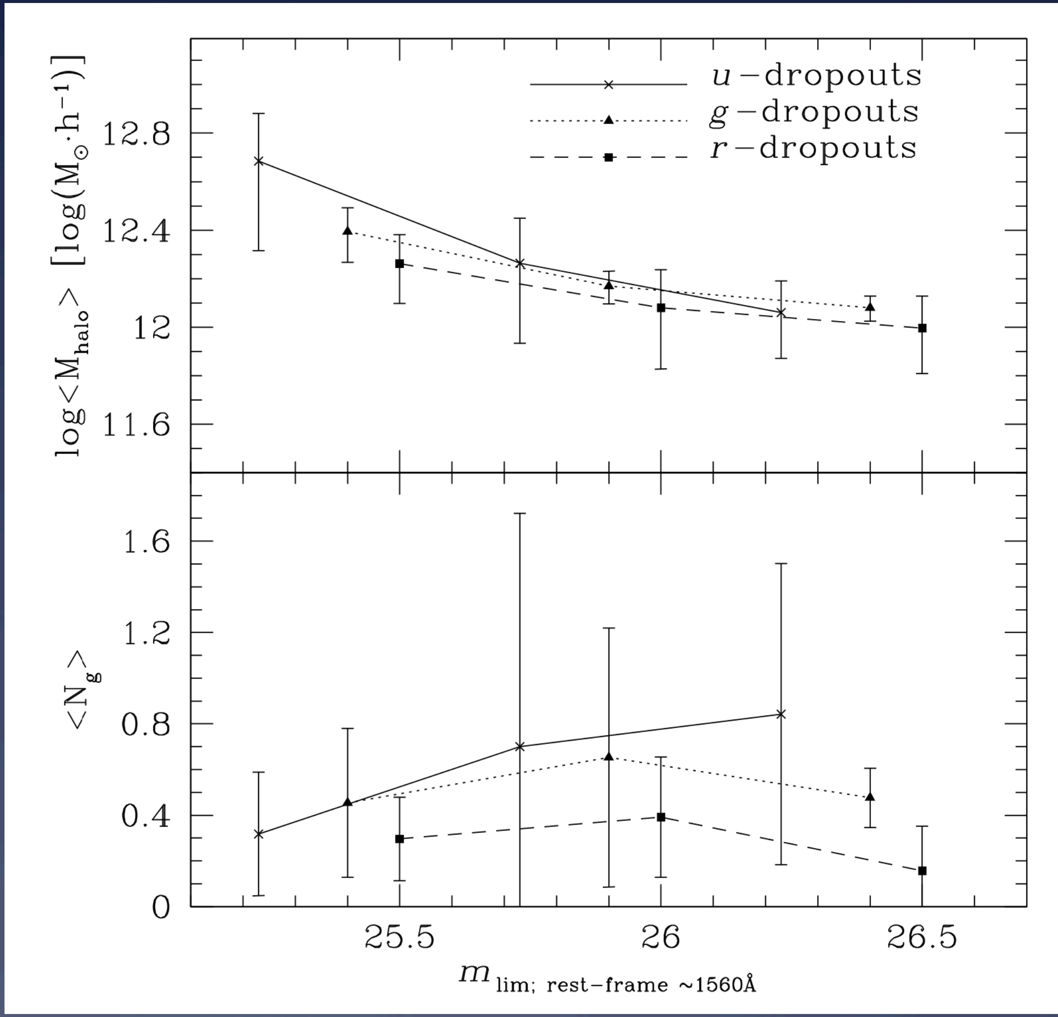
Zemcov+14

WFIRST archival galaxy science

- 500 Million galaxies to AB~27
  - 2000 sq. degrees
  - LSST ugrizy; WFIRST YJH,F184
  - Should yield very good photo-z's
- Luminosity functions by sub-category
- Stellar-mass functions by sub-category
- Clustering by sub-category

Clustering

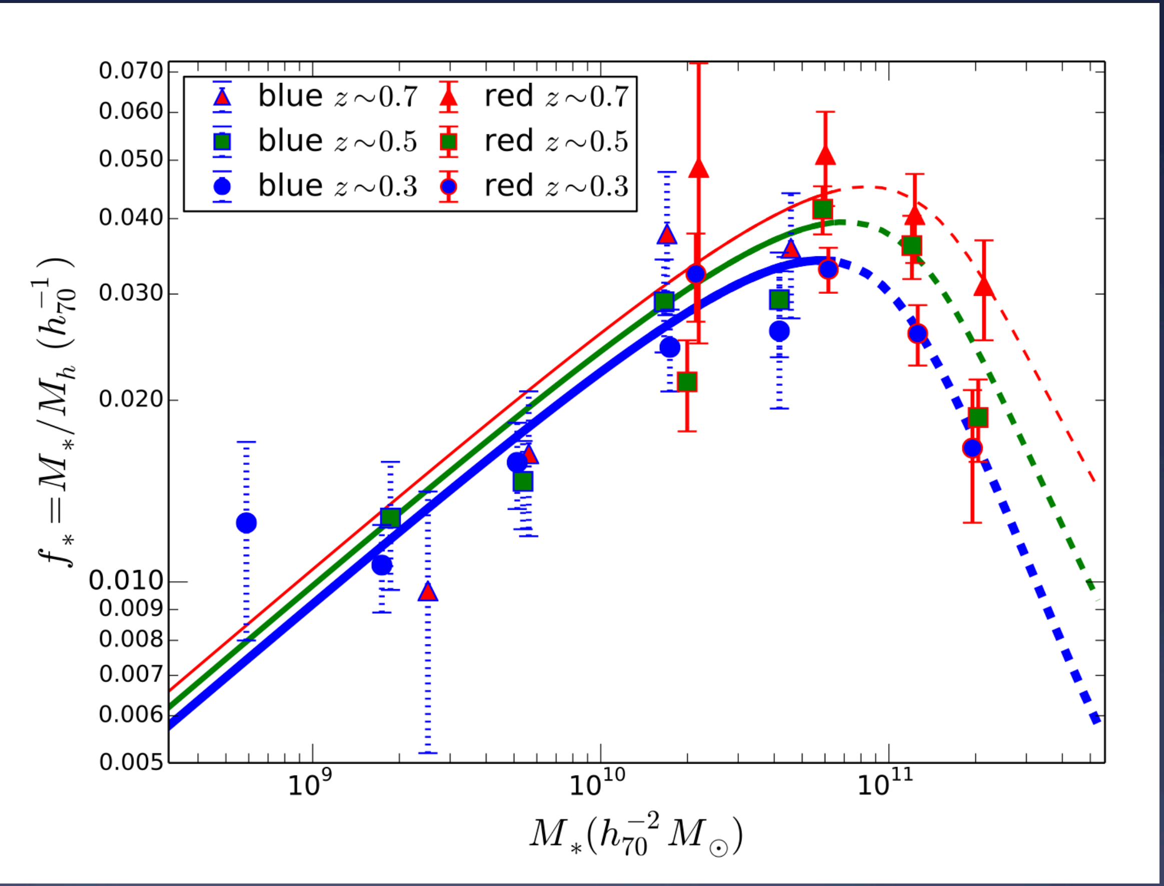
- Current state of the art at z>3:
  - CFHTLS
  - 1sq degree
- Halo mass not evolving?
- Duty cycle < 1?
- WFIRST archive:
  - 2000 times more galaxies; with decent stellar mass estimates



Hildebrandt+09

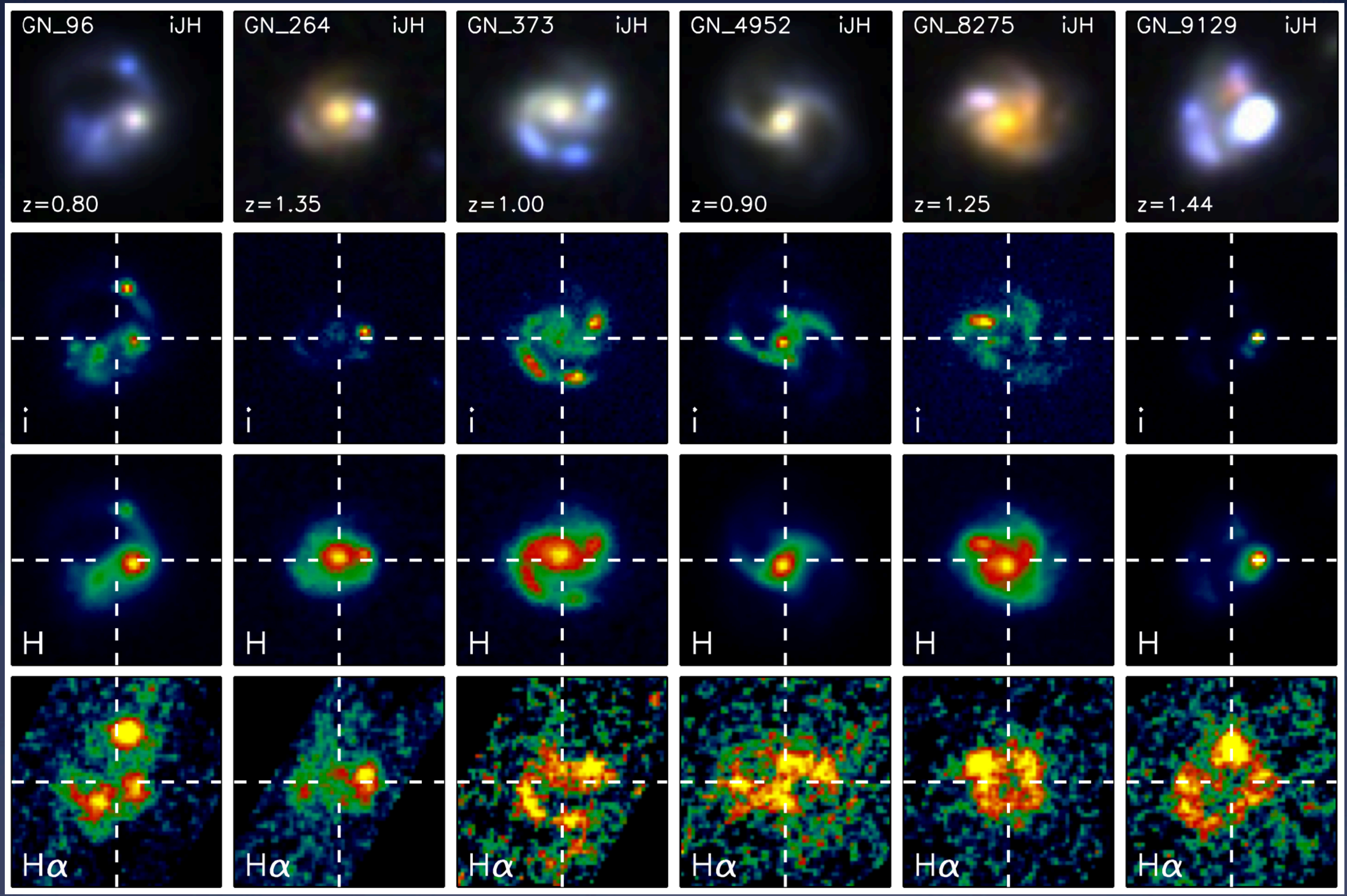
Galaxy—Mass correlation

- Correlating lensing surface mass density with galaxies
- Constrains stellar-mass to halo-mass relation



CFHTLenS
Hudson+13

Grism: Resolved star-formation

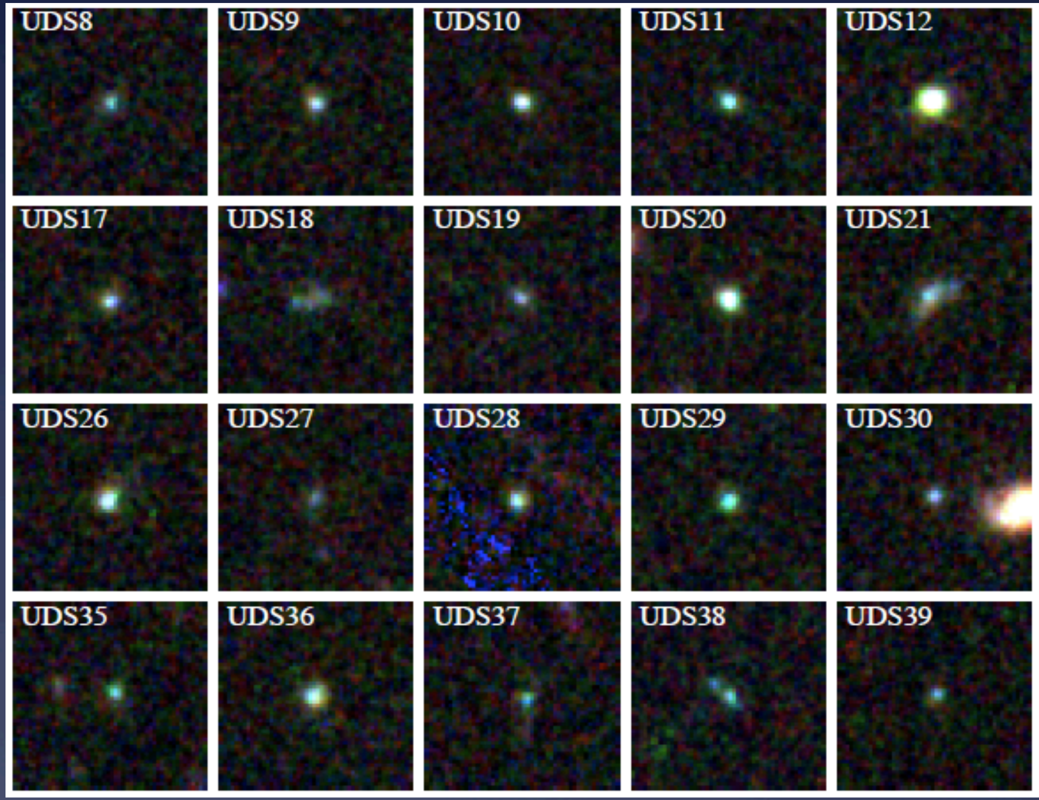


4 million galaxies from WFIRST
(443 to this depth from CANDELS + 3D-HST)

Wuyts+13

Grism: Bursting dwarf galaxies

- Very strong [OIII] emitters
  - EW > 1500 Å
  - ~1 $arcmin^{-2}$ at 1.8<z<2.8
  - Low-Z/Z dwarfs
  - Weak AGN
  - Connection to low-z dwarfs unclear:
    - proto dE galaxies?



Van der Wel+ 11

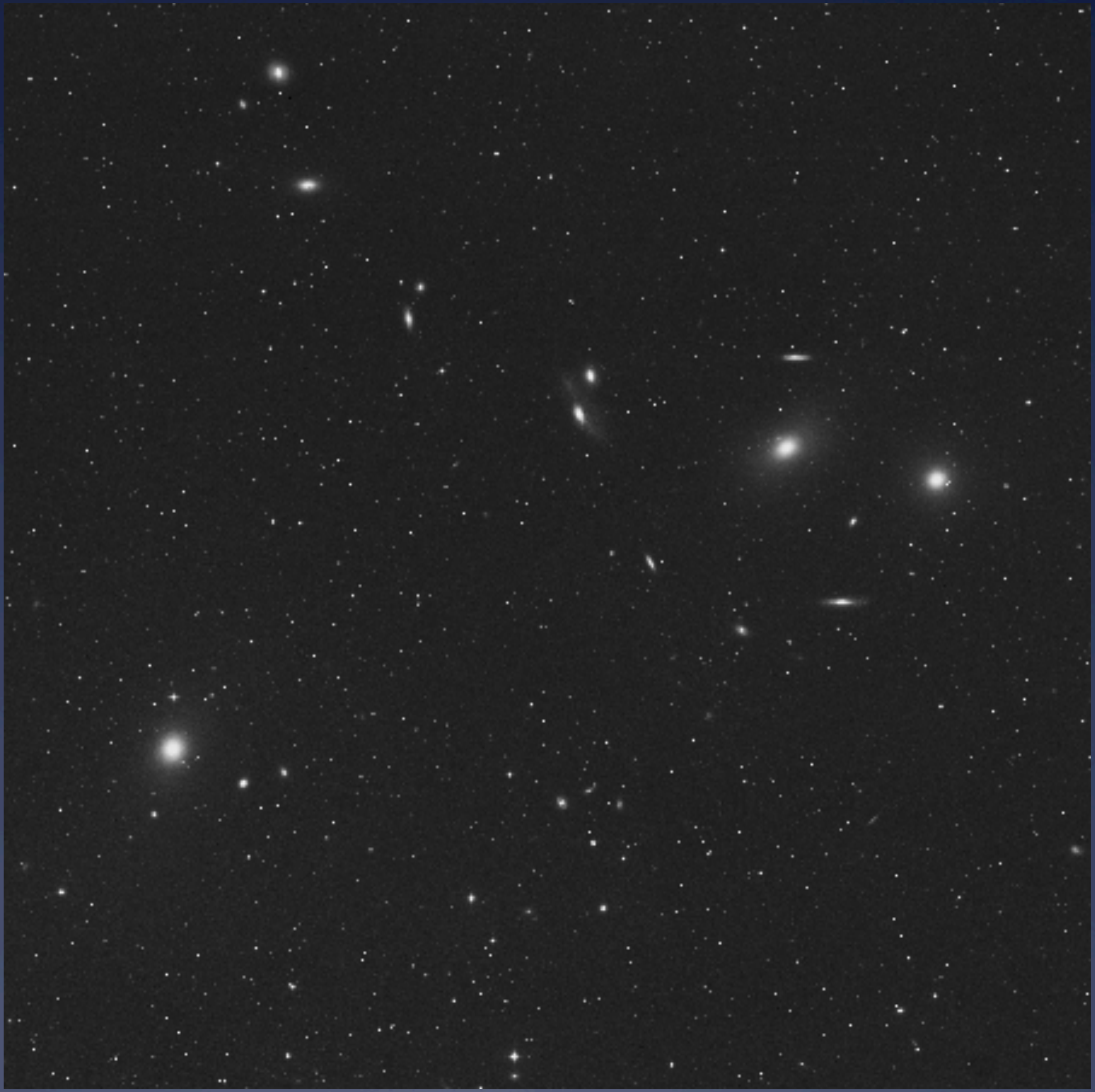
~7 million in WFIRST HLS grism survey

WFIRST Deep Fields

- SNe – 5 sq. degrees to AB~29
  - J, H for SNe
  - Need to supplement with similar depths in the other 3 bands; Need deep optical data
  - Complements JWST – bright reionization sources; clustering
  - JWST:
    - single band at 3.6 microns would take ~200 days to AB~29 (assuming 50% efficiency)
  - Placement of fields where there is deep long-wavelength data is important

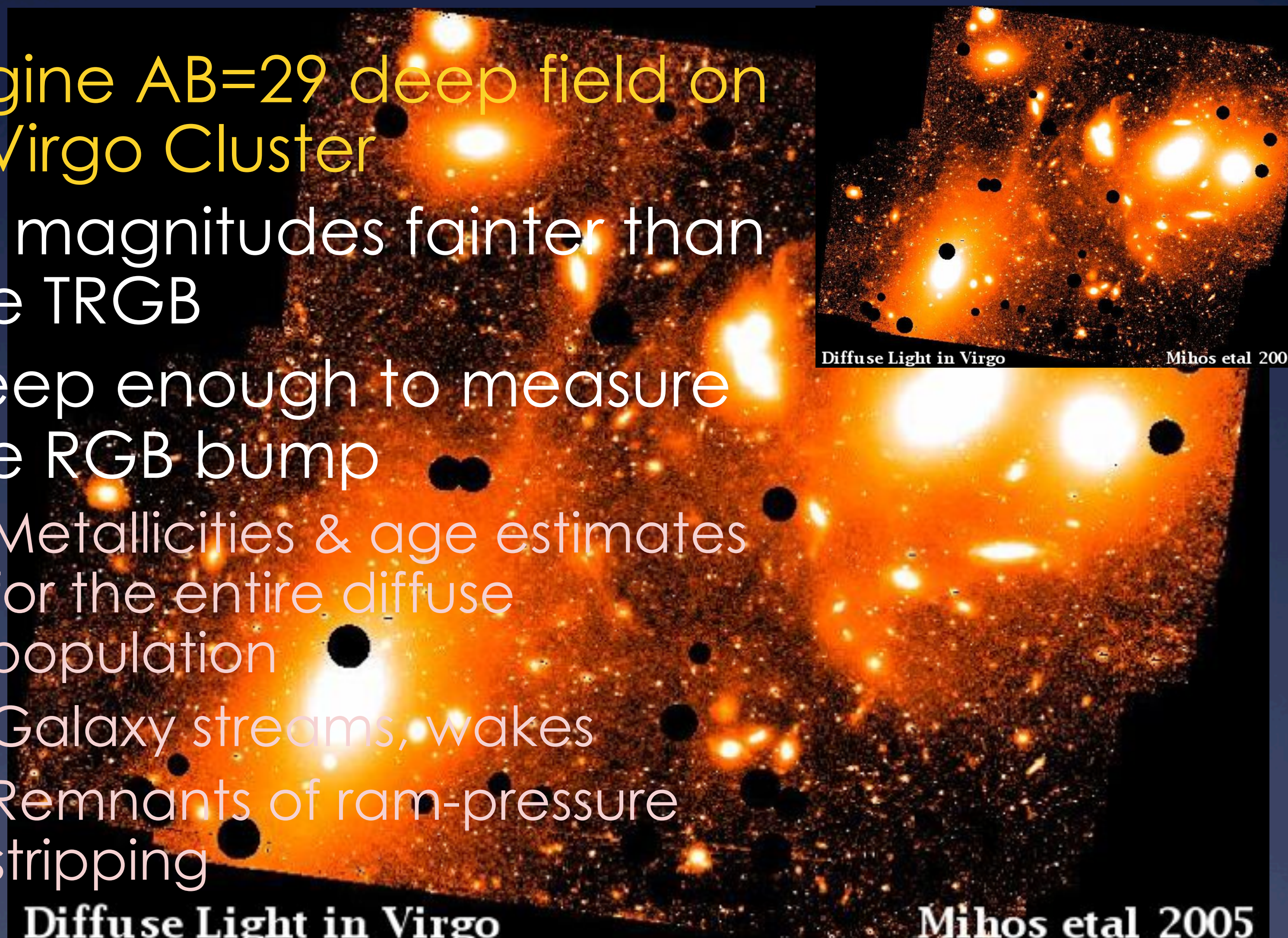
WFIRST Pointed Observations

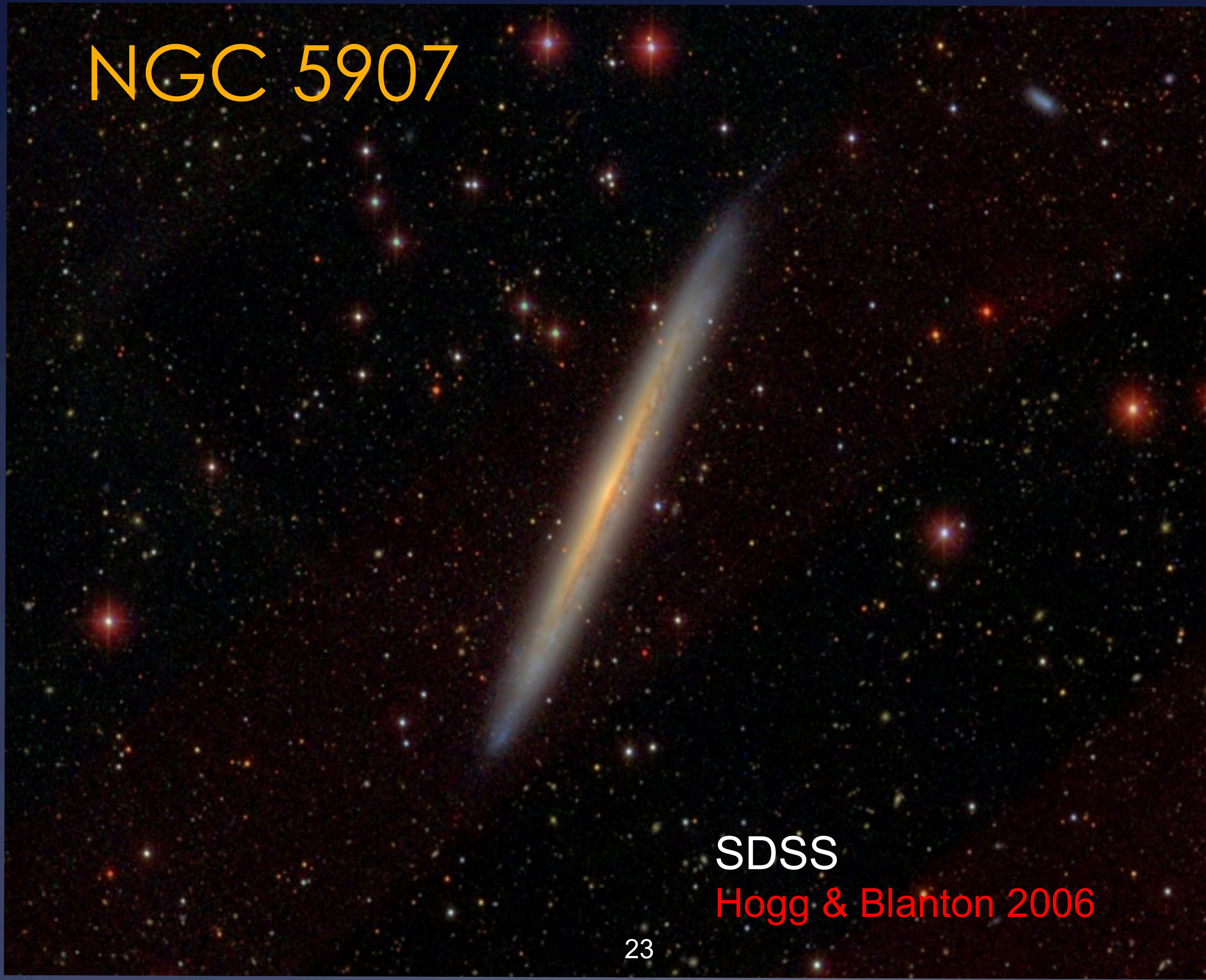
- Nearby Clusters



WFIRST Pointed Observations

- Imagine AB=29 deep field on the Virgo Cluster
  - ~4 magnitudes fainter than the TRGB
  - Deep enough to measure the RGB bump
    - Metallicities & age estimates for the entire diffuse population
    - Galaxy streams, wakes
    - Remnants of ram-pressure stripping




NGC 5907
SDSS
Hogg & Blanton 2006

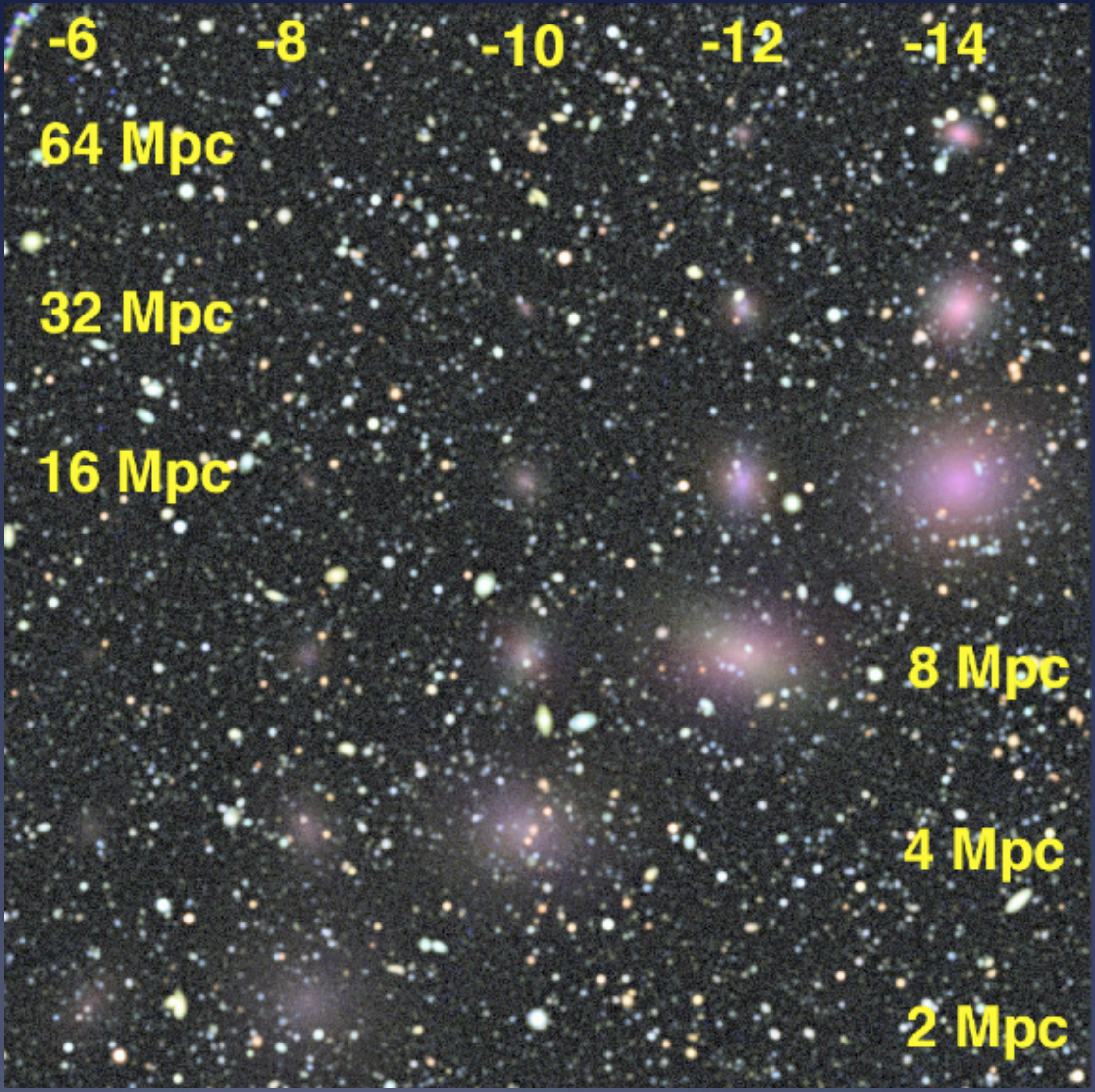
Map diffuse streams, halos, and thick disks with RGB stars for hundreds of nearby galaxies.

Martinez-Delgado+ 08

Census of dwarfs in the field

Archival science:

- Expect >1500 dwarfs to Mv = -10 within 32 Mpc in 2000 sq. deg
- Predictions are uncertain by at least an order of magnitude at this luminosity
- TRGB detectable:
  - instant distance estimates



Conclusions

- WFIRST will be a phenomenal mission for galaxy-evolution science
- A huge amount can piggy-back on the dark-energy surveys
- Pointed observations of nearby targets will be extremely interesting
- Need to ensure that deep fields have maximal wavelength coverage