Studying Galaxy
Evolution with WFIRST

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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:

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

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

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

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

- Halo Mass
- Stellar Mass
- Dark Ages
- Re-ionization
- Cosmic High noon
- Blue nuggets
- Red nuggets & bulges
- Dry Merging
- Massive clusters form
- WFIRST M* limits
- JWST M* limit
- LSST
- Radius (arcsec)
- Age (Gyr)
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
The best predictor of a galaxy’s specific star-formation rate at $z \sim 2$ is its morphology.

Wuyts+11
At $z>2$, most galaxies of Milky-Way mass are disk dominated. Below $z\sim2$, central non-star-forming bulges become prominent.

**Bulge fractions**

- Bulges become dominant in massive galaxies at $z\sim2$
- Bulges are smaller at fixed mass at $z\sim2$ than today.
- While most passive galaxies are bulge dominated, a few passive galaxies appear to be pure disks.
- Implications for quenching models?

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

- Era of massive disks at $2<z<3$

Bruce+13
Mortlock+13
What did the Milky Way look like 11 billion years ago?
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
  - 1 sq 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?

～7 million in WFIRST HLS grism survey

Van der Wel+ 11
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
Map diffuse streams, halos, and thick disks with RGB stars for hundreds of nearby galaxies.
Census of dwarfs in the field

Archival science:
- Expect >1500 dwarfs to $M_v = -10$ 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