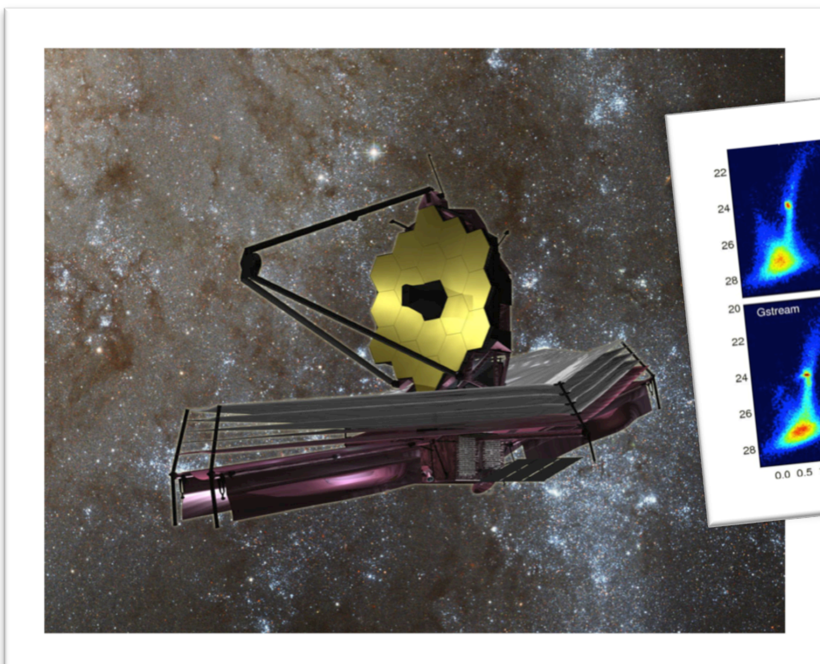
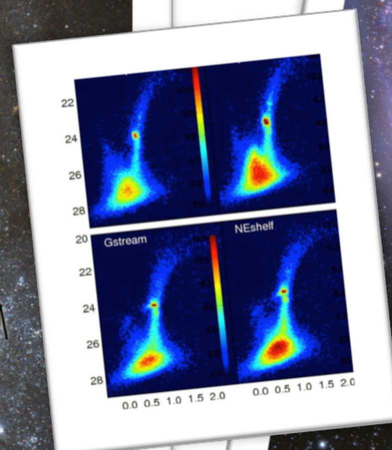
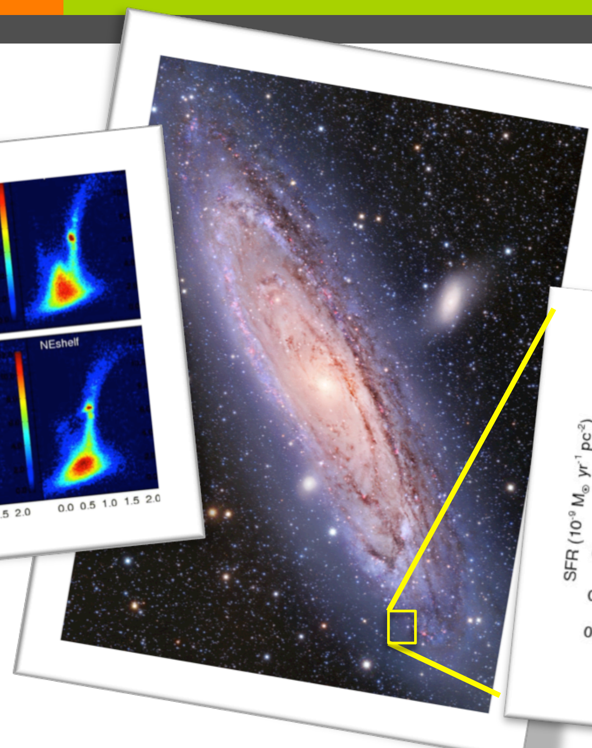
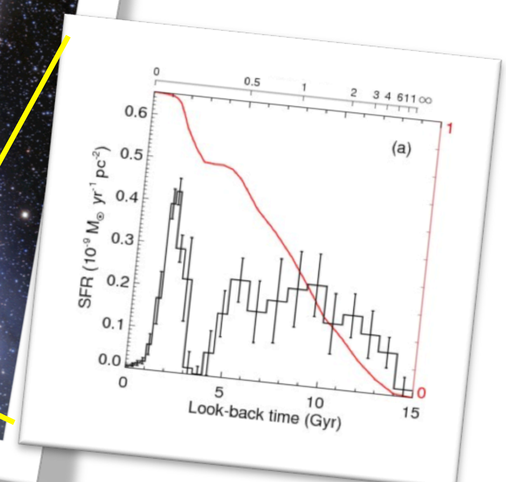
Exploring Resolved Stellar Populations in Local Volume Galaxies with JWST

Annette Ferguson, IfA Edinburgh









Institute for Astronomy

*** Plus see posters by Martha Boyer (S&P 2) and Chris Evans (GA9)!!!

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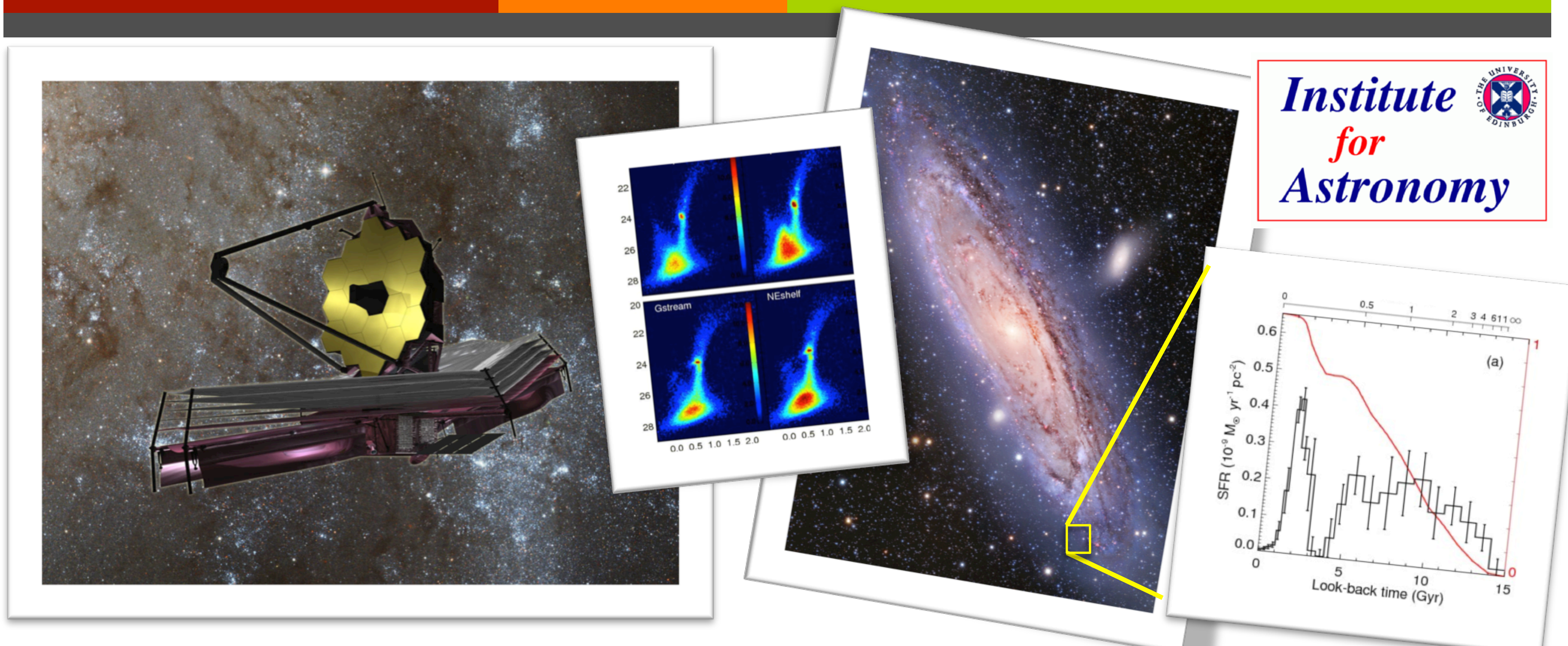


*** Plus see posters by Martha Boyer (S&P 2) and Chris Evans (GA9)!!!

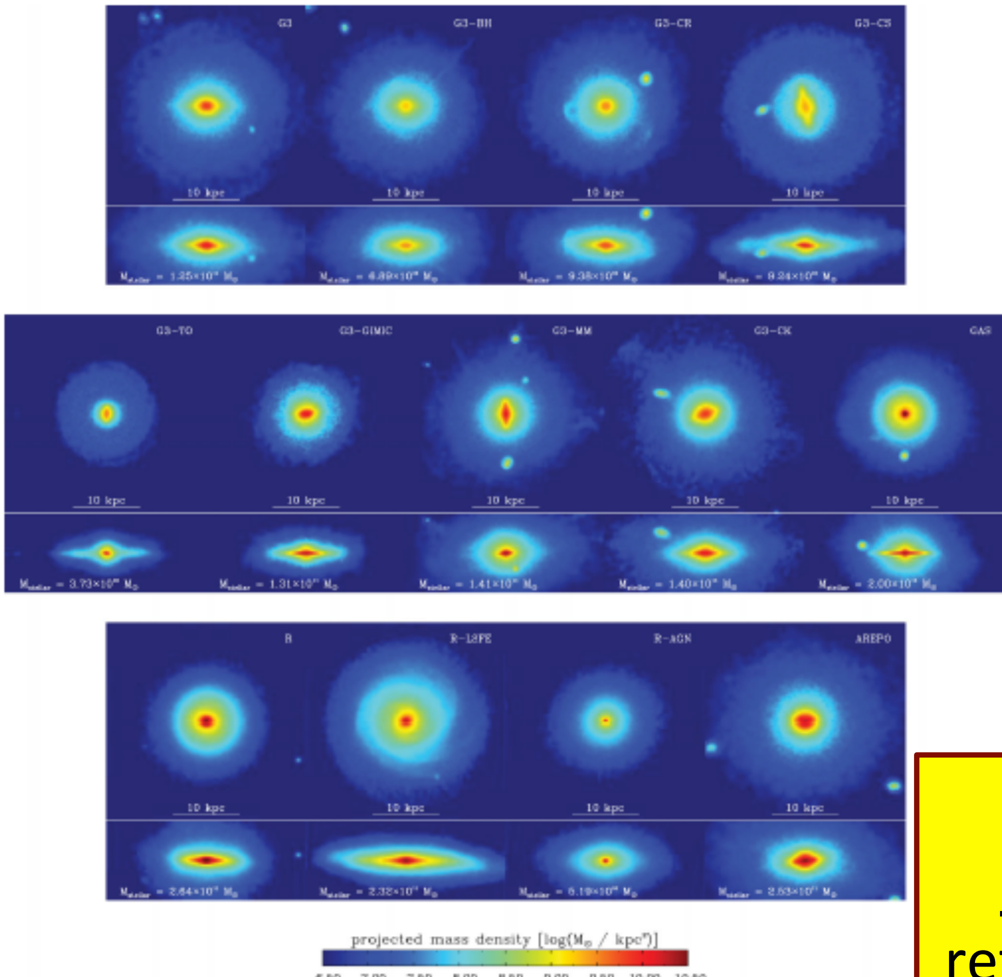
Understanding Galaxy Assembly

- Ultimate goal: build a coherent picture of how galaxies form and evolve starting within few 100 Myr of the Big Bang through to the present-day.
  - How did mass grow within individual galaxies/populations?
  - What triggered and quenched star formation?
  - How important was in situ SF vs accretions/mergers?
  - How did galactic sub-components form and evolve?
  - Is the Milky Way and its satellite system representative?

- HST has given us a glimpse of the fantastic complementarity between near-field and far-field approaches to studying galaxy assembly → JWST will make this a reality!

Understanding Galaxy Assembly

Scannapieco et al 2012, Aquila Comparison



Cosmological hydro simulations can now produce realistic disc galaxies at z=0.

But internal content and structure depends crucially on adopted baryonic physics…

<u>Precision observational constraints are crucial to refine understanding on sub-galactic scales!</u>

Contrasting Far- and Near-Field Studies

<u>The far-field approach offers:</u>

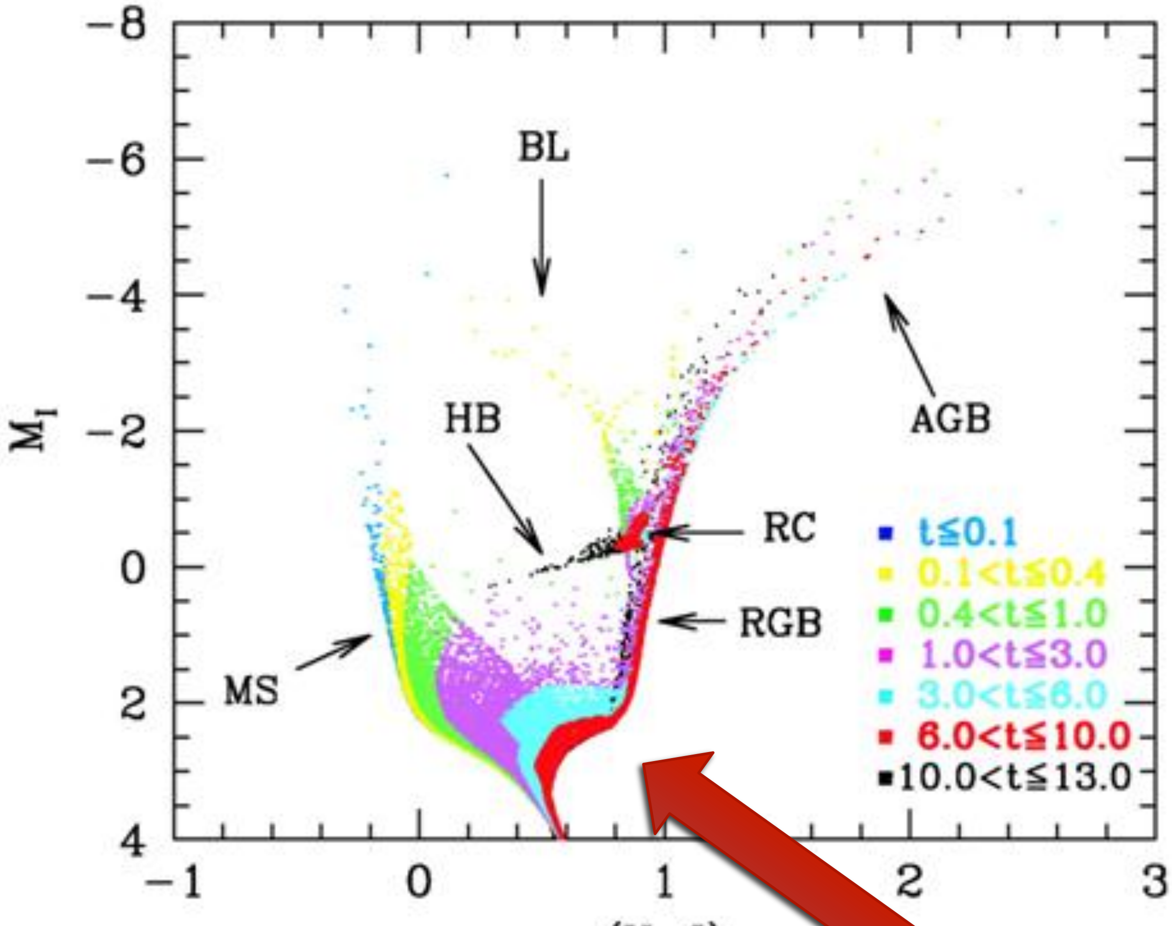
- ✓ Snapshots of the states of galaxies at given times
- ✓ Large samples hence representative properties can be derived at a given epoch
- x But what happened to an individual galaxy before/after epoch of observation is less clear..
- x Usually only crude spatial resolution possible, and often only global properties known with moderate uncertainty
- x Only the brightest components of galaxies can be studied

Contrasting Far- and Near-Field Studies

<u>The near-field (resolved star) approach offers:</u>

- ✓ Entire history of an individual galaxy can be recovered via the fossil record
- ✓ Precision measurements of ages, metallicities/abundances, star formation histories, chemical enrichment and kinematics; all with exquisite spatial resolution
- ✓ Only way to currently study extremely low mass/luminosity galaxies, and very low surface brightness components
- x Current studies are limited to low crowding regions and small areas, not where the bulk of the stellar mass resides
- x Samples are tiny and highly incomplete → likely very biased

The Near-Field Tool: CMD Analysis



Gallart et al. 2008

Resolved stars populate regions of a colour-magnitude diagram according to their masses, ages and metallicities.

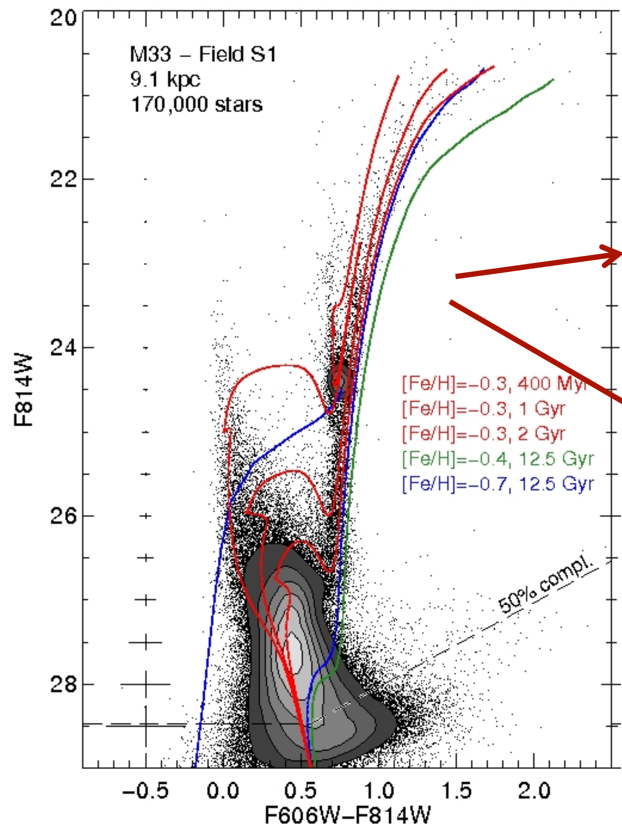
Even the "by-eye" morphology of a CMD gives a clue about the SFH.

<u>The main sequence turn-off (MSTO)</u> is the key diagnostic, but for old populations this is faint!

Calculating Star Formation Histories

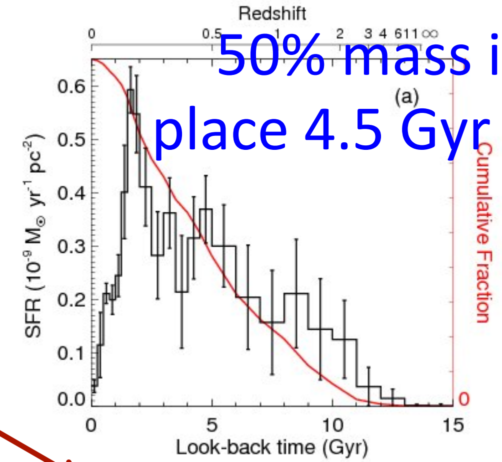
SFR and metallicity have profound effect on CMD morphology

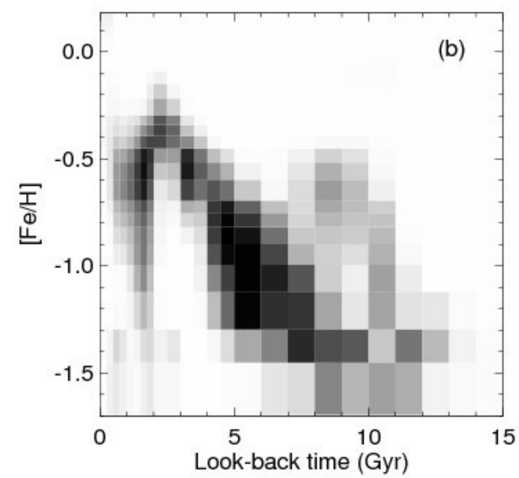
Model CMD using synthetic libraries with range in age and metallicity to extract SFR and [Fe/H] evolution.



Barker, Ferguson et al. 2011
12 orbits HST/ACS

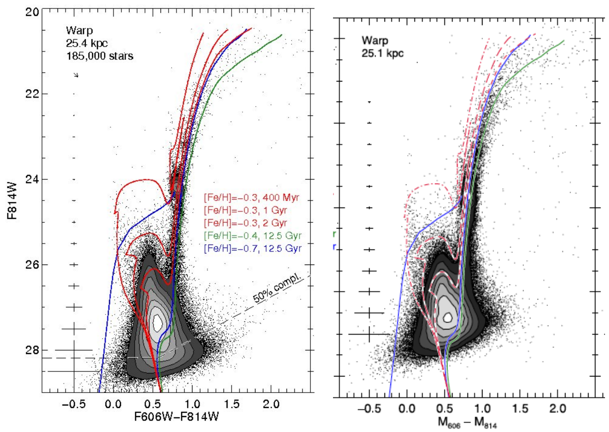
50% mass in place 4.5 Gyr ago



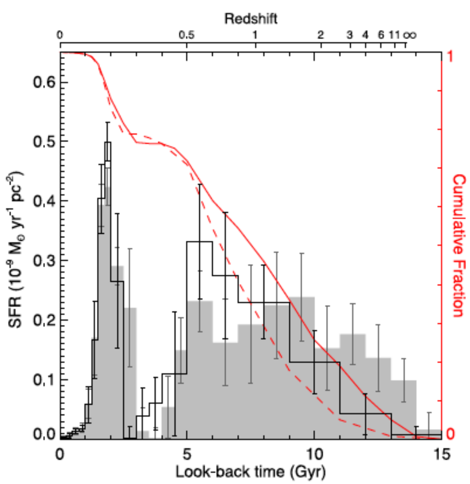


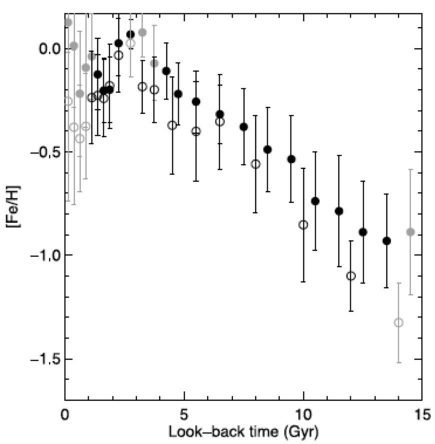
How Deep? Depends on Science Goal!

Bernard, Ferguson et al. 2012, 2015a
See also Weisz et al. 2014



Comparison of SFHs and age-metallicity relations recovered for a field in M31 using CMDs constructed from 3 and 10 orbits → overall agreement is very encouraging.





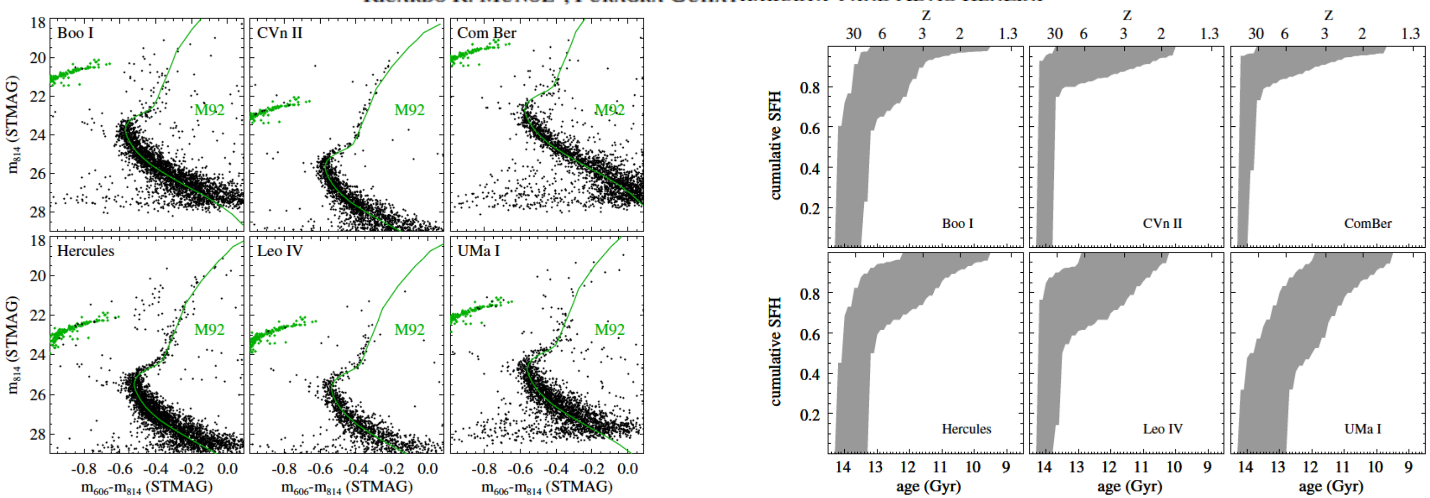
If you can live with mean age ±1.5 Gyr and don't care about precision at the earliest epochs, observations become less expensive.....

The SFHs of the Faintest Galaxies

The Astrophysical Journal, 796:91 (13pp), 2014 December 1
doi:10.1088/0004-637X/796/2/91

THE QUENCHING OF THE ULTRA-FAINT DWARF GALAXIES IN THE REIONIZATION ERA*

Thomas M. Brown[1], Jason Tumlinson[1], Marla Geha[2], Joshua D. Simon[3], Luis C. Vargas[2], Don A. VandenBerg[4], Evan N. Kirby[5], Jason S. Kalirai[1,6], Roberto J. Avila[1], Mario Gennaro[1], Henry C. Ferguson[1], Ricardo R. Muñoz[7], Puragra Guhathakurta[8], and Alvio Renzini[9]



<u>"Ultra-faint dwarfs": M_V>-8, sizes ~50-300pc, M/L_V>100:</u>

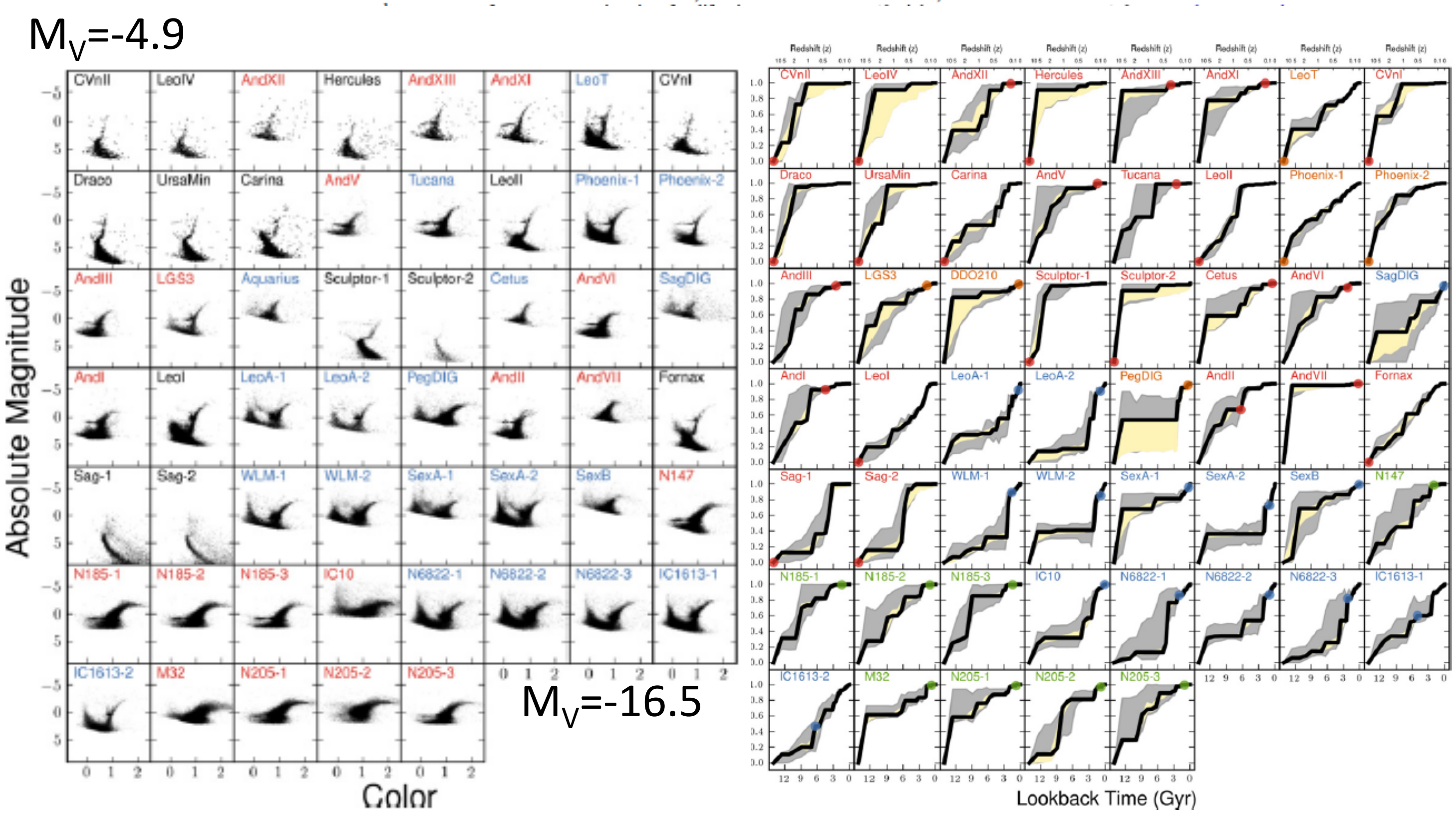
→ Within a (small) sample, 75% of the stars in these systems formed by z~10, and 80% by z~6. Evidence for suppression by reionization?

The Diverse Histories of Dwarfs

The Astrophysical Journal, 789:147 (23pp), 2014 July 10 doi:10.1088/0004-637X/789/2/147

THE STAR FORMATION HISTORIES OF LOCAL GROUP DWARF GALAXIES. I. *HUBBLE SPACE TELESCOPE*/WIDE FIELD PLANETARY CAMERA 2 OBSERVATIONS*

Daniel R. Weisz[1,2,7], Andrew E. Dolphin[3], Evan D. Skillman[4], Jon Holtzman[5],
Karoline M. Gilbert[2,6], Julianne J. Dalcanton[2], and Benjamin F. Williams[2]



Lower mass dwarfs build up their present-day mass more quickly than high mass dwarfs.

The Cosmological Significance of Dwarfs

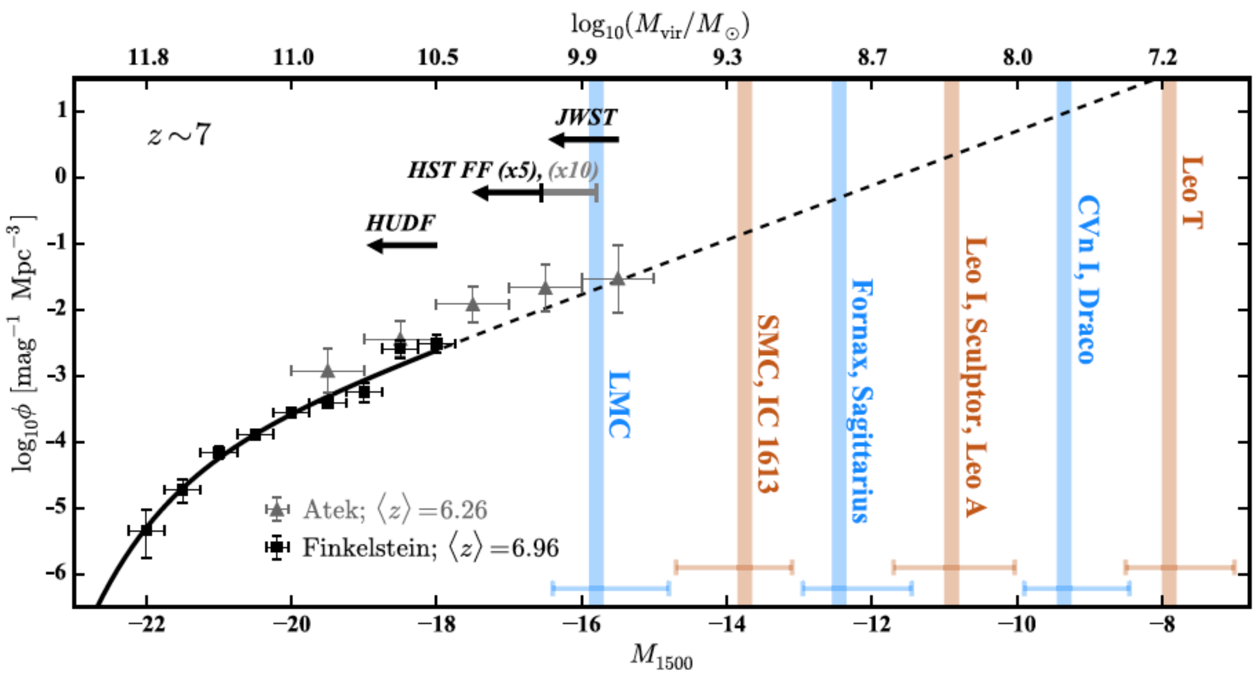
The SFHs of MW dwarf satellites can be "rewound" to predict their appearance at the early epochs.

Caveat: current uncertainties are very large!

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
MNRAS 453, 1503–1512 (2015) doi:10.1093/mnras/stv1736

The Local Group as a time machine: studying the high-redshift Universe with nearby galaxies

Michael Boylan-Kolchin,[1⋆] Daniel R. Weisz,[2†] Benjamin D. Johnson,[3]
James S. Bullock,[4] Charlie Conroy[3] and Alex Fitts[1]



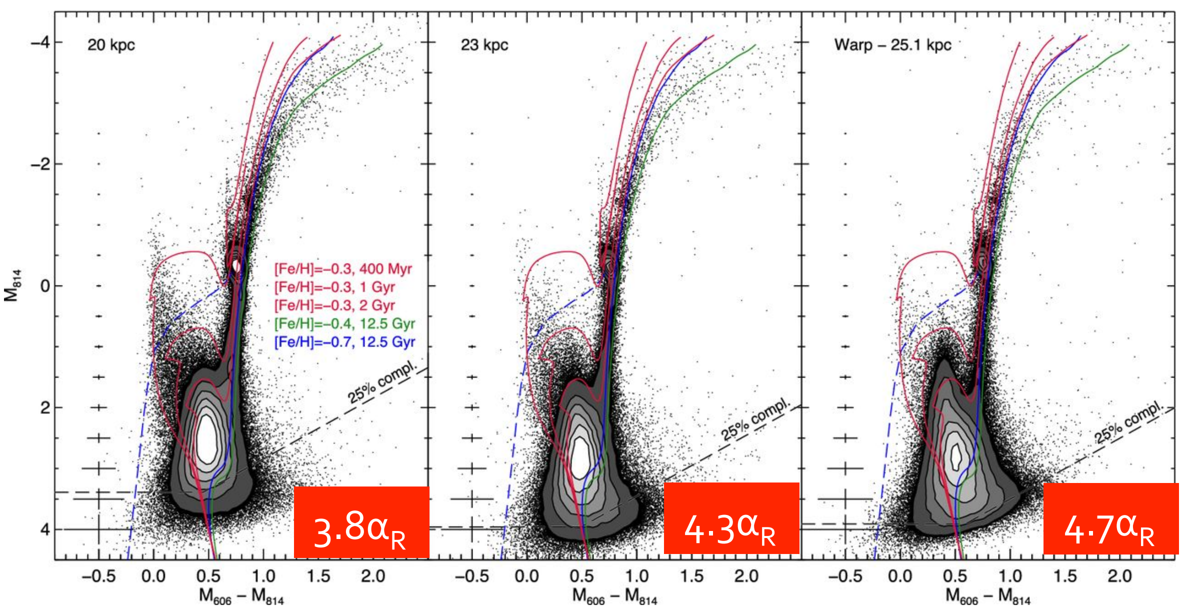
The Radial Growth of a Large Disc Galaxy

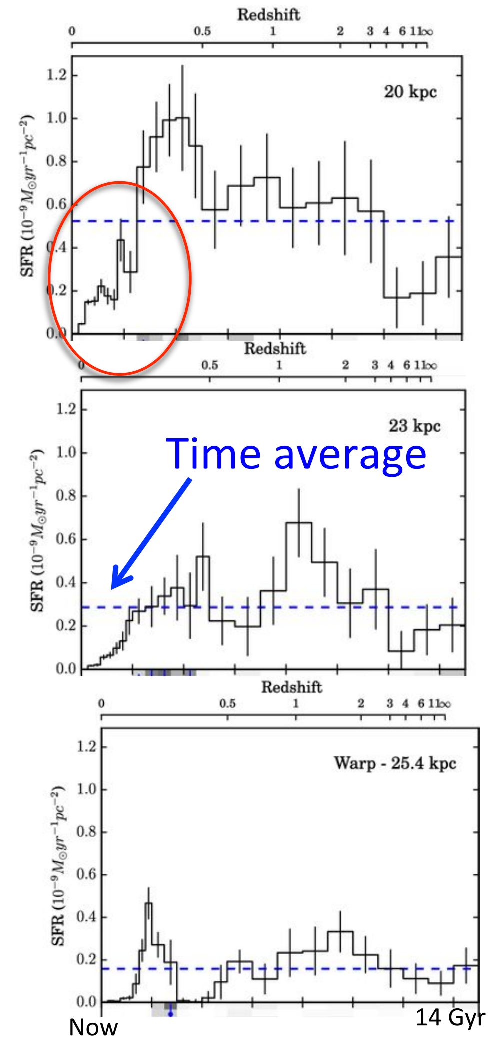
Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

MNRAS 453, L113–L117 (2015) doi:10.1093/mnrasl/slv116

The spatially-resolved star formation history of the M31 outer disc

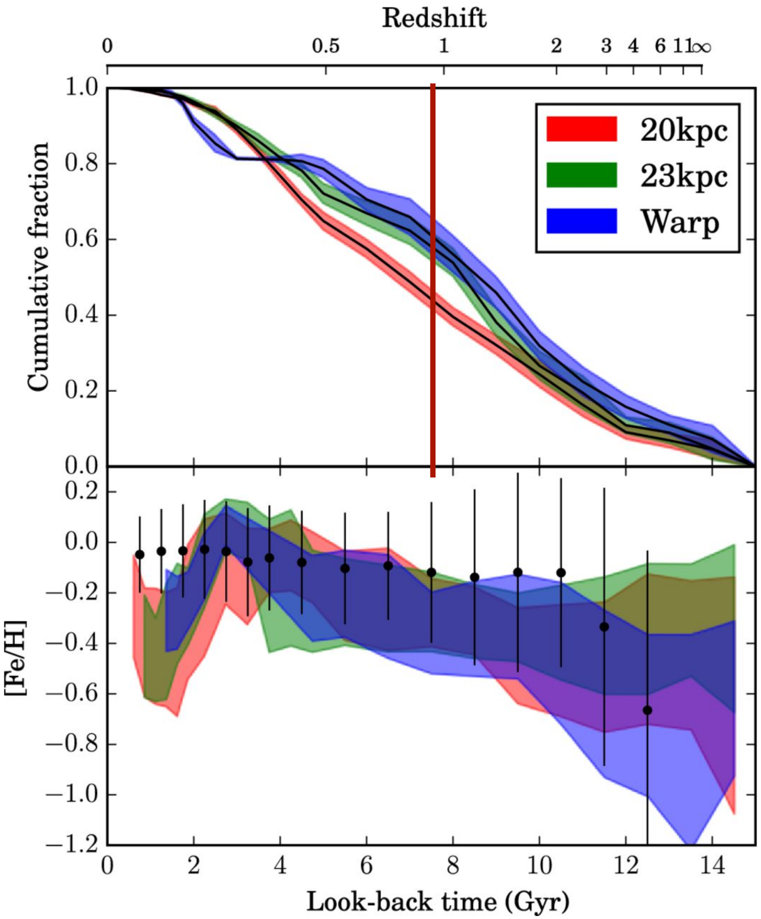
Edouard J. Bernard,[1★] Annette M. N. Ferguson,[1] Scott C. Chapman,[2] Rodrigo A. Ibata,[3] Mike J. Irwin,[4] Geraint F. Lewis[5] and Alan W. McConnachie[6]



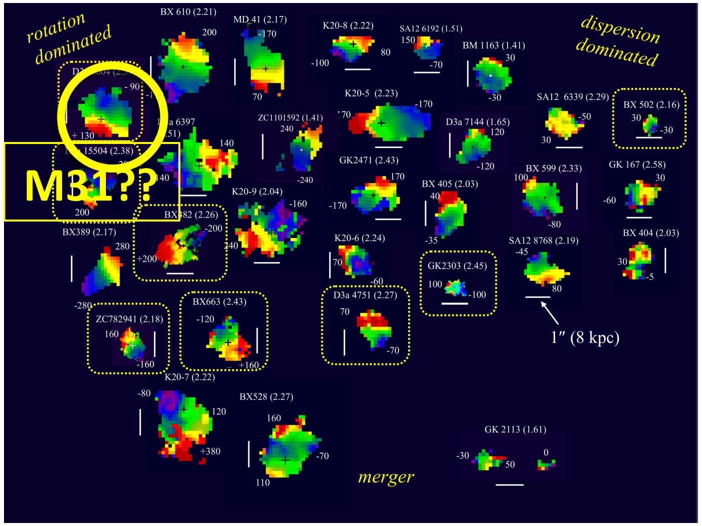


The Radial Growth of a Large Disc Galaxy

Bernard, Ferguson et al 2015b



- Median age of stars in all fields is 7.5 Gyr: M31 was already a large disc at z~2!
- No evidence strong outside-in formation (caveat: only one scalelength spanned!)

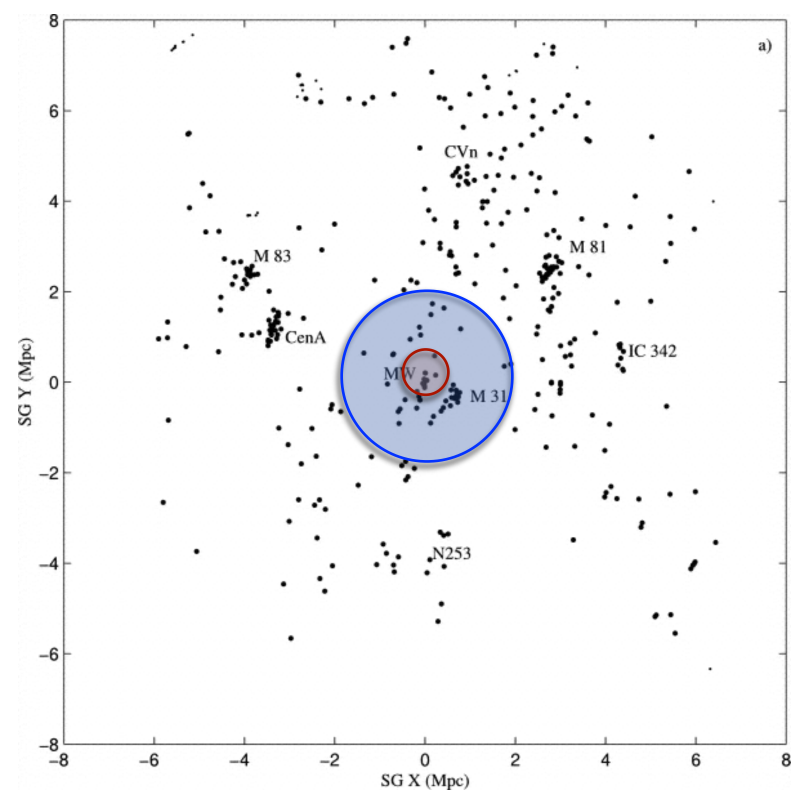


SiNS Survey, Foerster-Schreiber, Genzel et al.

The Promise of JWST

The main issues right now are the small galaxy samples, the small volumes probed and the expensive nature of the observations.

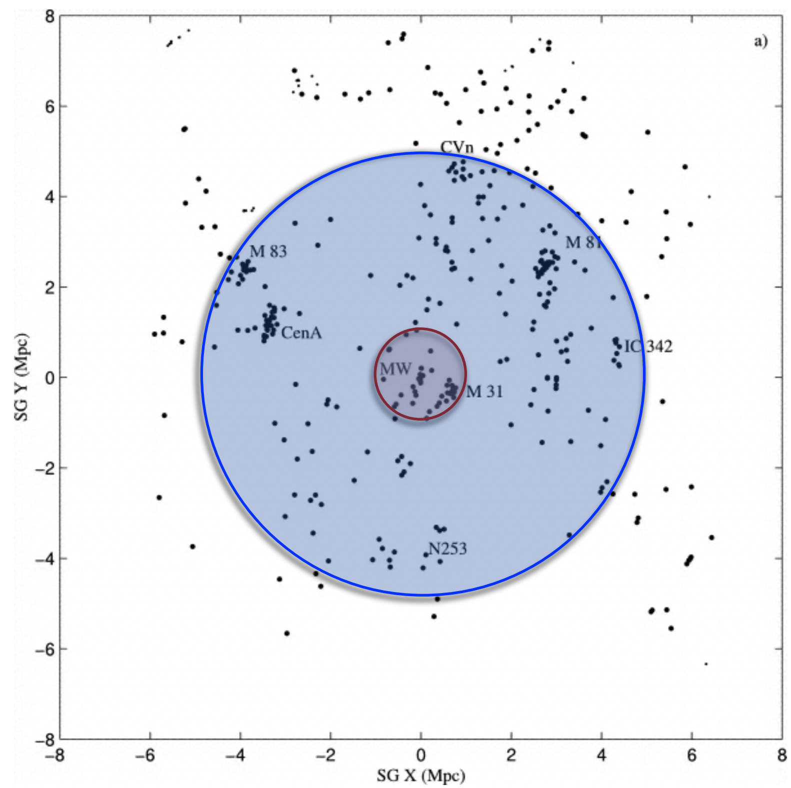
1. JWST/NIRCam will enable CMDs reaching 0.5-1 mag below the oldest MSTO with high S/N to distances of ~2 Mpc → high precision SFHs back to the earliest epochs (z>3) for galaxies spanning a range of luminosities/masses, morphologies, environments. A few hundred (primarily dwarf) galaxies fall within this volume.



The Promise of JWST

The main issues right now are the small galaxy samples, the small volumes probed and the expensive nature of the observations.

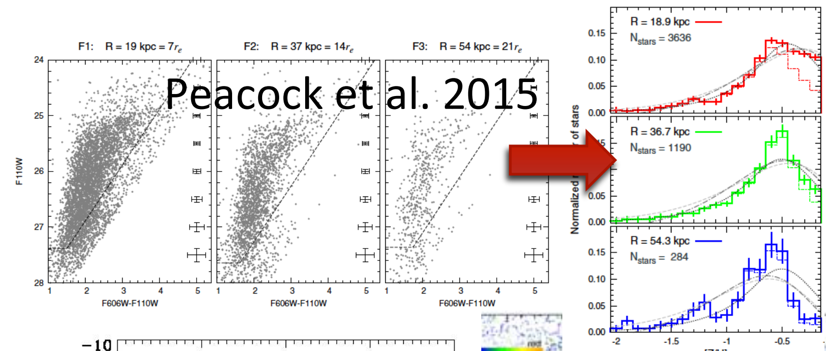
2. "Cosmologically interesting" SFHs (i.e. well-resolved and accurate to z~2) for systems within ~5 Mpc through obtaining CMDs reaching to the ~10 Gyr MSTO → track the (spatially-resolved) histories in a much broader range of galaxy types. A few thousand objects fall within this volume (although very few gEs).



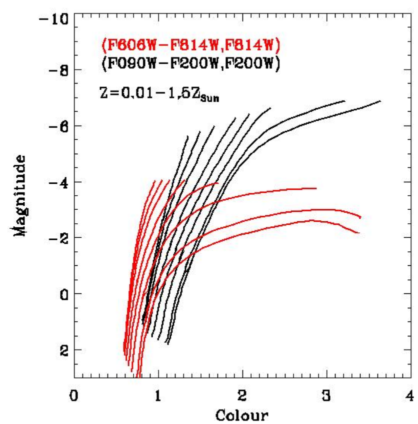
The Promise of JWST

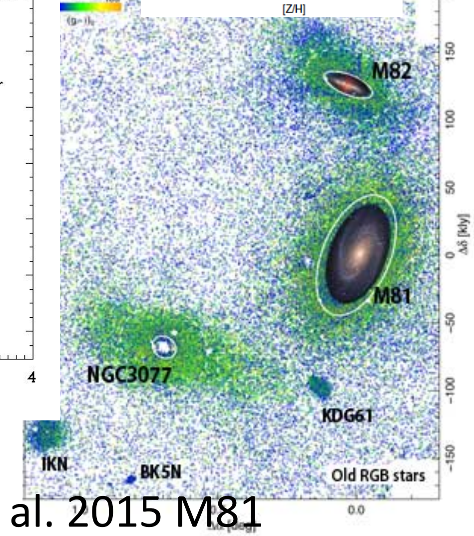
The main issues right now are the small galaxy samples, the small volumes probed and the expensive nature of the observations.

3. The upper ~2-4 magnitudes of the RGB is accessible in galaxies out to ~40 Mpc. While this feature is insensitive to age, it provides excellent constraints on the stellar metallicity distribution. Within this volume, many gEs, several galaxy clusters (including their ICL) and other exotic galaxies (e.g. UDGs, UCDs) can be reached.



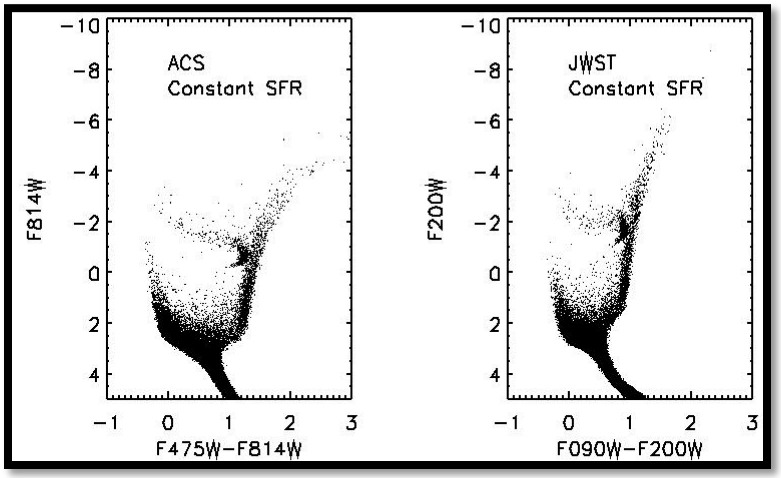
Peacock et al. 2015

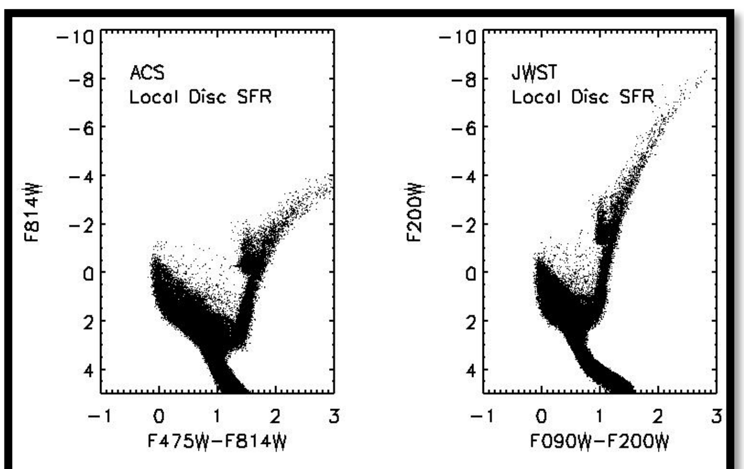


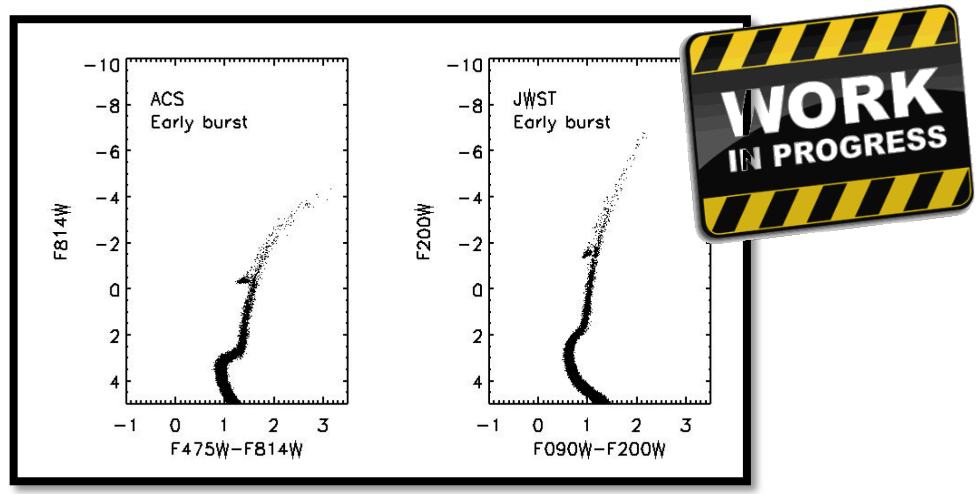


Okamoto et al. 2015 M81

What will NIRCam CMDs Look Like?







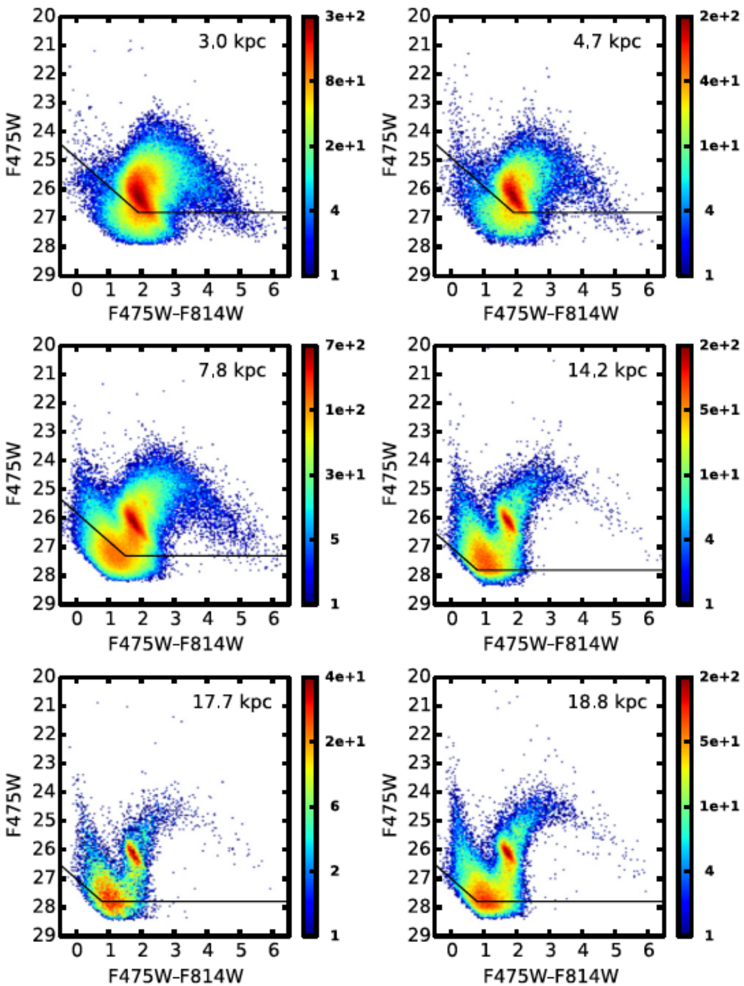
Simulating NIRCam CMDS for a variety of SFHs and [Fe/H] evolution using BASTI stellar models (with Santi Cassisi (Teramo))

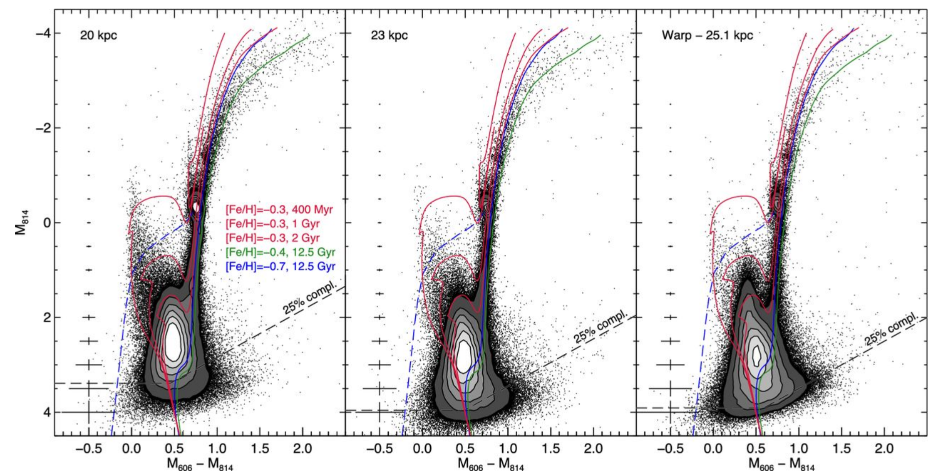
- Observational effects to be added
  - Test SFH recovery

Summary

- HST has given us a taste of the synergy between near and far-field studies of galaxy assembly but the power of the approach has not been fully realised due to small and biased samples and the expensive nature of obtaining deep MSTO data.
- JWST will provide exquisite depth CMDs for 100s-1000s of galaxies→ will enable us to directly compare inferences from near and far-field stellar mass assembly histories, and through comparison to simulation data constrain baryonic physics.
- There are many possibilities for designing medium and large-scale programs (50-500h) to tackle focused questions, e.g. radial growth of disks, histories of the faintest galaxies, stellar envelopes of gEs, stellar halo properties as a function of mass,…

PHAT vs Deep CMDs in M31





- PHAT CMDs are much shallower, due both to exposure time and crowding in the inner regions of the disc
- PHAT CMDs also suffer significant differential extinction
- Aside from bright MS stars, PHAT CMDs sample only the evolved stars (e.g. RC, RGB) where there is little age sensitivity and/or models are highly uncertain.