Deep Fields and Distant Galaxies

science and strategies

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TMT Science Forum
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Outline

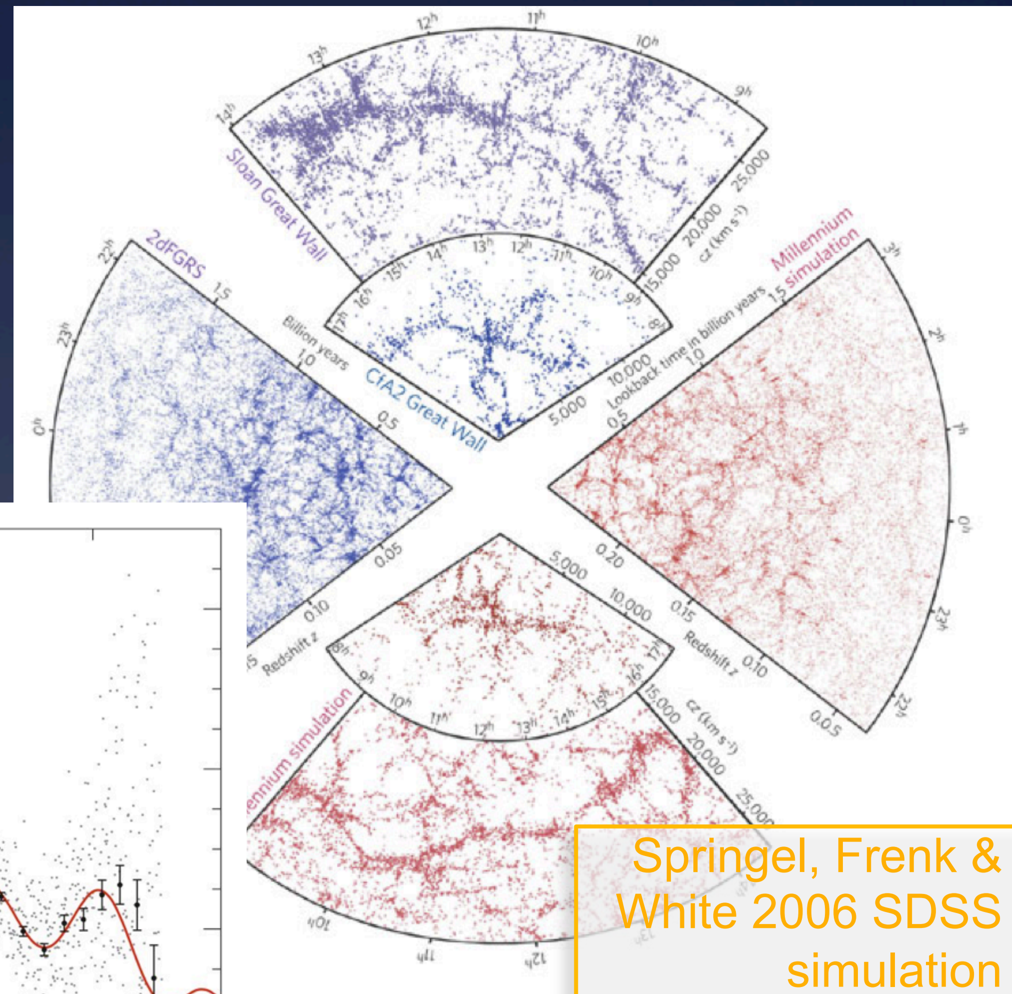
- The role of large multi-purpose surveys
  - Science motivation
  - A few recent science highlights
- Ground/space synergy past and future
- Public vs. proprietary science

Why me?

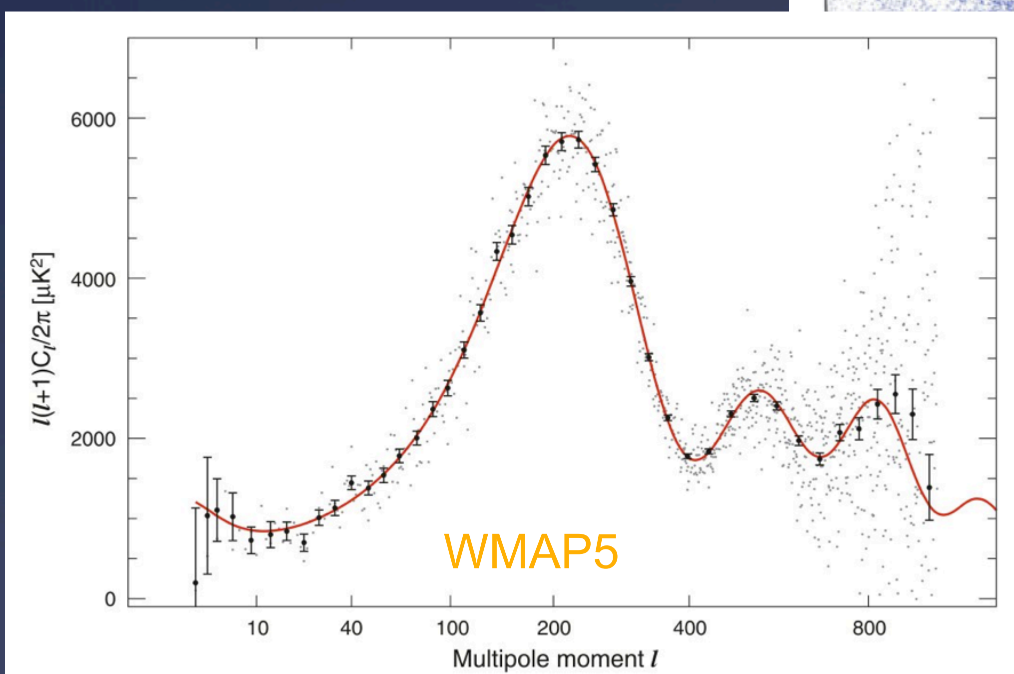
1. Mark Dickinson twisted my arm
2. I have helped engineer many of the large HST surveys: HDF, HDF-S, GOODS, UDF, CANDELS
3. I am fan of archives and public data sets
4. I have had no involvement in TMT, GMT, EELT (blissfully unaware of whom I will offend)

Motivation

- The ΛCDM paradigm is a huge success on large scales



Springel, Frenk & White 2006 SDSS simulation



WMAP5

Galaxy evolution within ΛCDM is complicated!

Galaxy evolution within ΛCDM is complicated!

Dependencies

- Cosmological parameters, properties of dark matter, dark energy
- Chemistry, star-formation, initial-mass function
- Gas instabilities, shocks, critical phenomena
- Black holes, galactic winds, recycling
- Dust, magnetic fields

Illustris

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 the space density as a function of x,y,z,….
  - Not just the mean relations, but the scatter…
  - Need (cross, auto)correlations as a function of x,y,z…

CANDELS

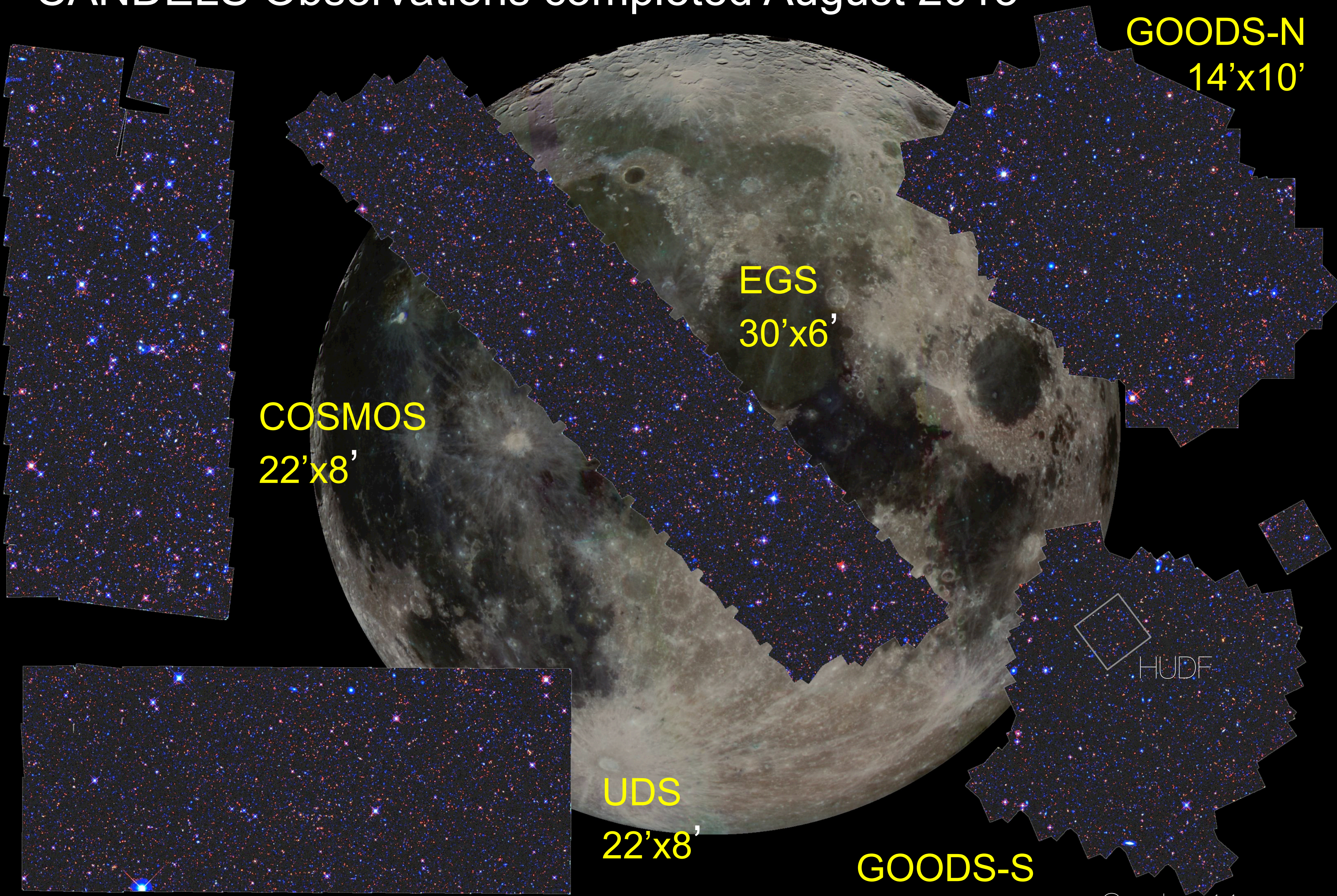
Cosmic Assembly Near-infrared Deep Extragalactic Legacy Survey

~175 team members

~45 institutions

12 countries

CANDELS Observations completed August 2013



Grogin+ 11
Koekemoer+ 11

Same fields covered with WFC3 Grism in AGHAST & 3D-HST

14 SNe at z>1.5

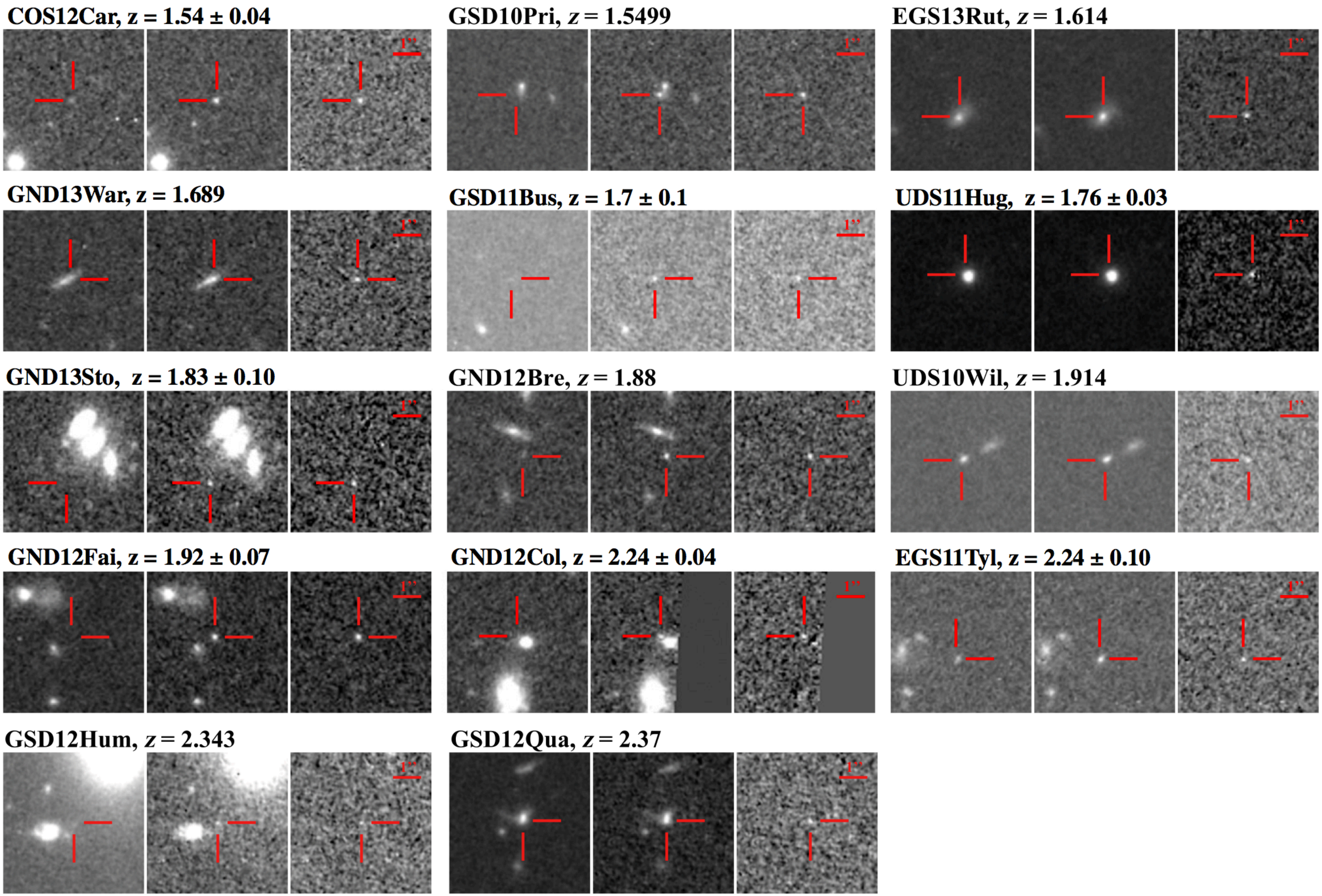
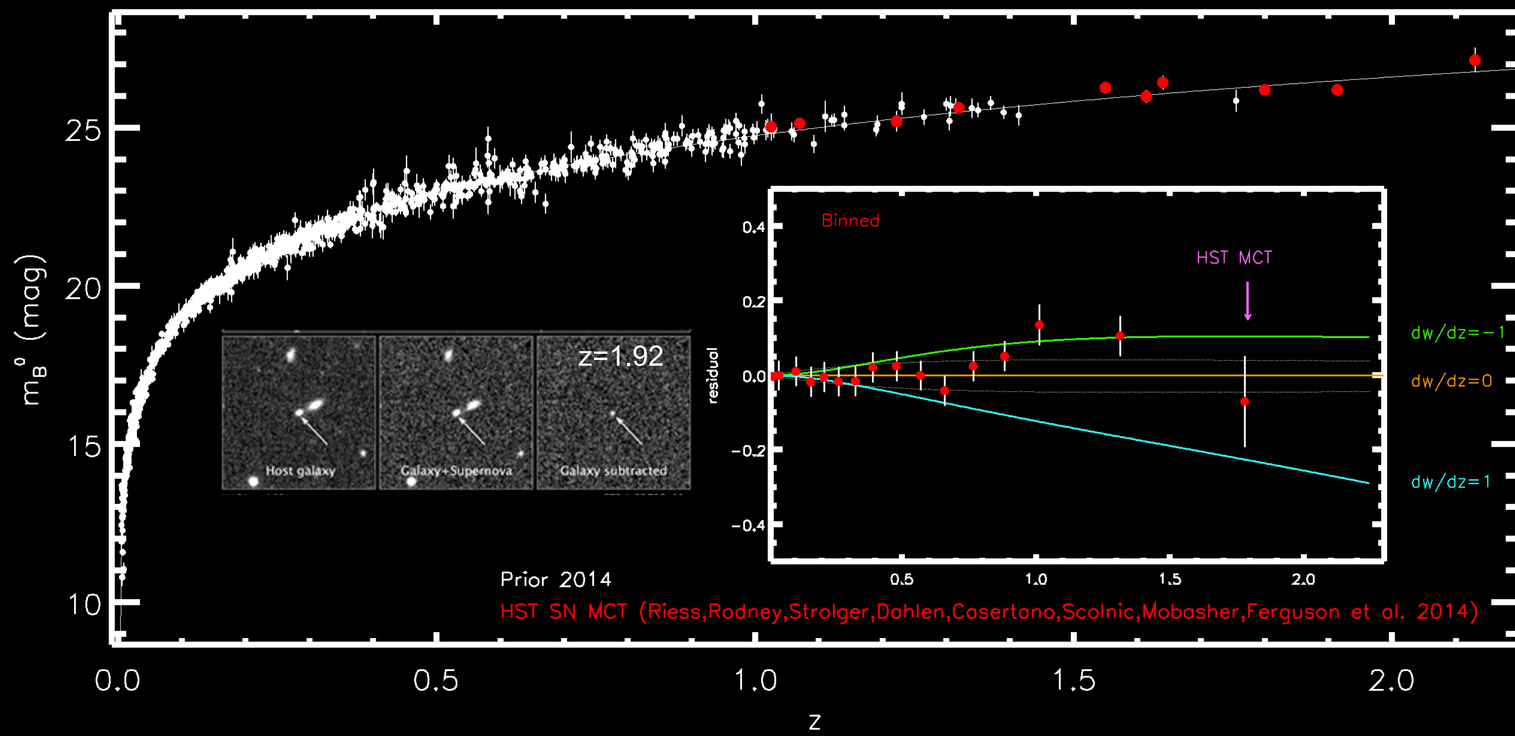


Figure 2. Detection images for 14 SN from the CANDELS fields with redshifts $z > 1.5$. Each image triplet shows H band (F160W) images with the template image on the left, the discovery epoch image in the middle, and the difference image on the right. All images have a width of about 6 arcsec, with north up and east to the left. The position of the SN is marked by (red) crosshairs in every frame. Discovery images for the other 51 SN with $z < 1.5$ are provided in Appendix B.

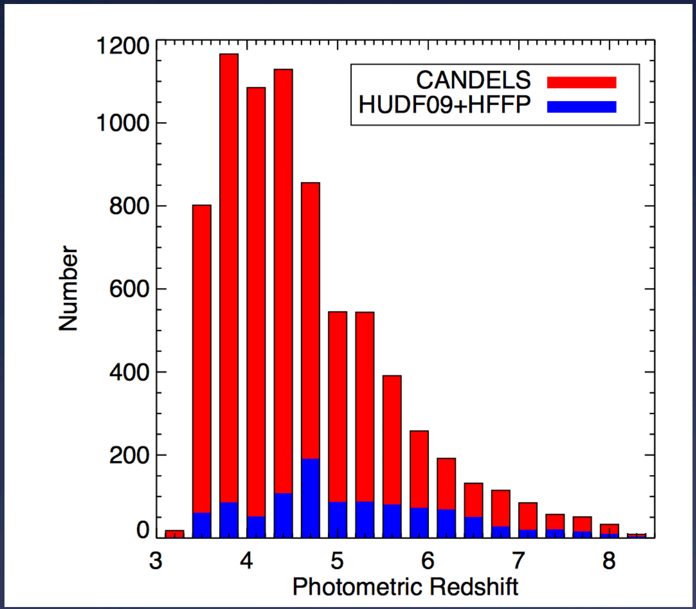
Building the Modern SN Ia Hubble Diagram; to the limit

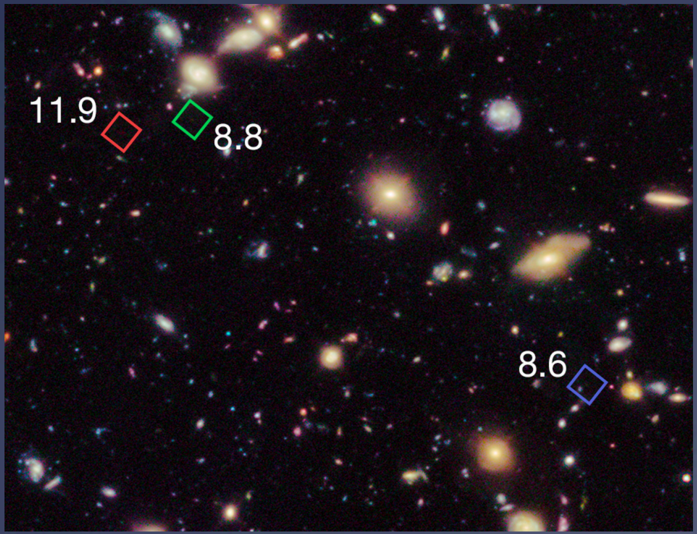
2014: HST SN MCT, searched CANDELS/CLASH w/ WFC3-IR, 1.5<z<2.1

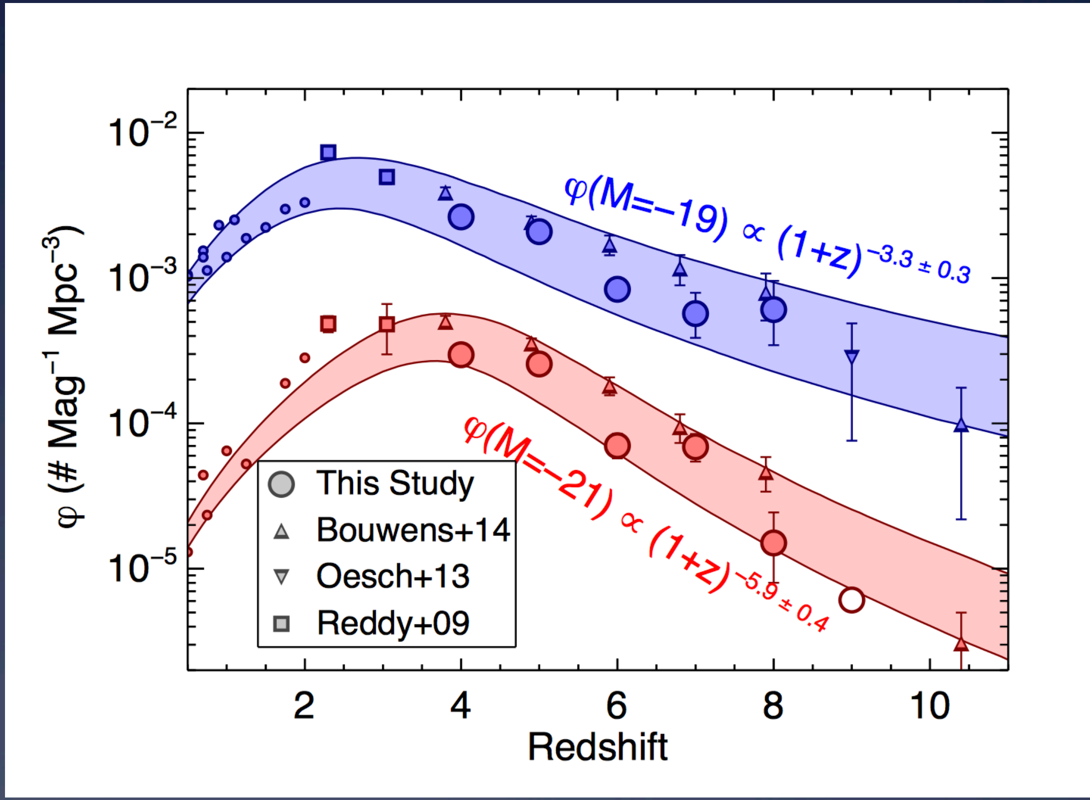


Established: SNe Ia to z=2.1, dw/dz~0 +/-1 still tracking model, but SN Ia at z~2 are rare→long progenitor fuse

Early Universe

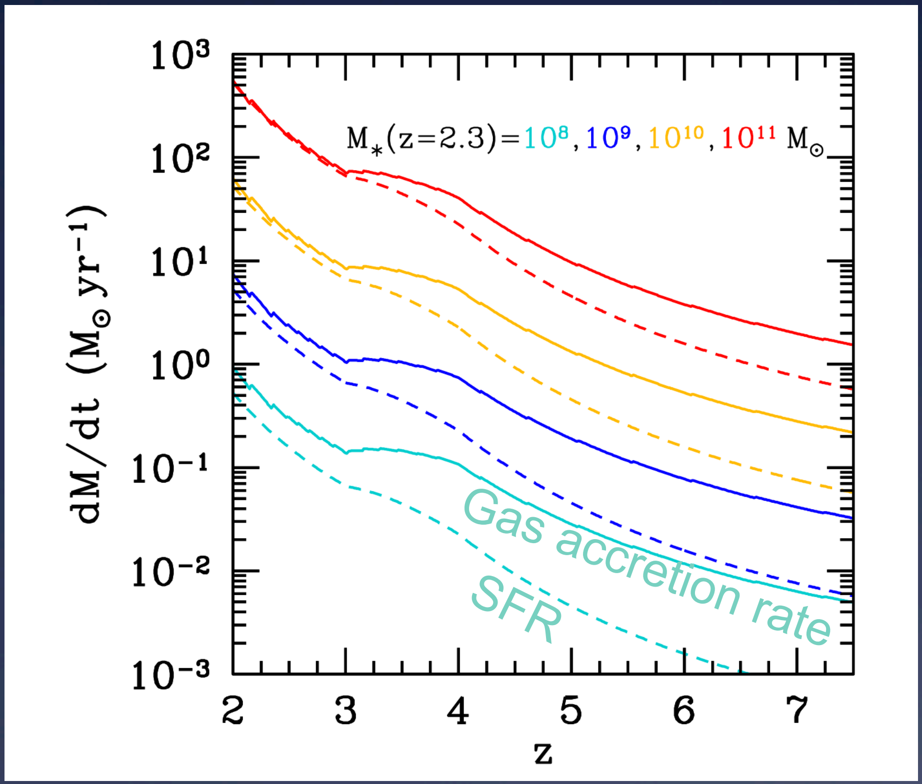




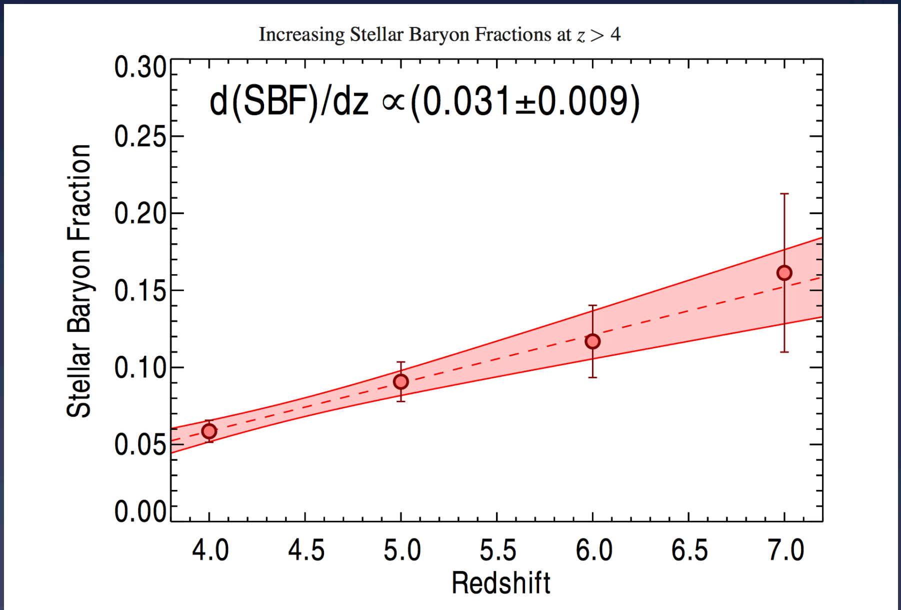


With reasonable extrapolations, galaxies can account for reionization

Star-formation efficiency

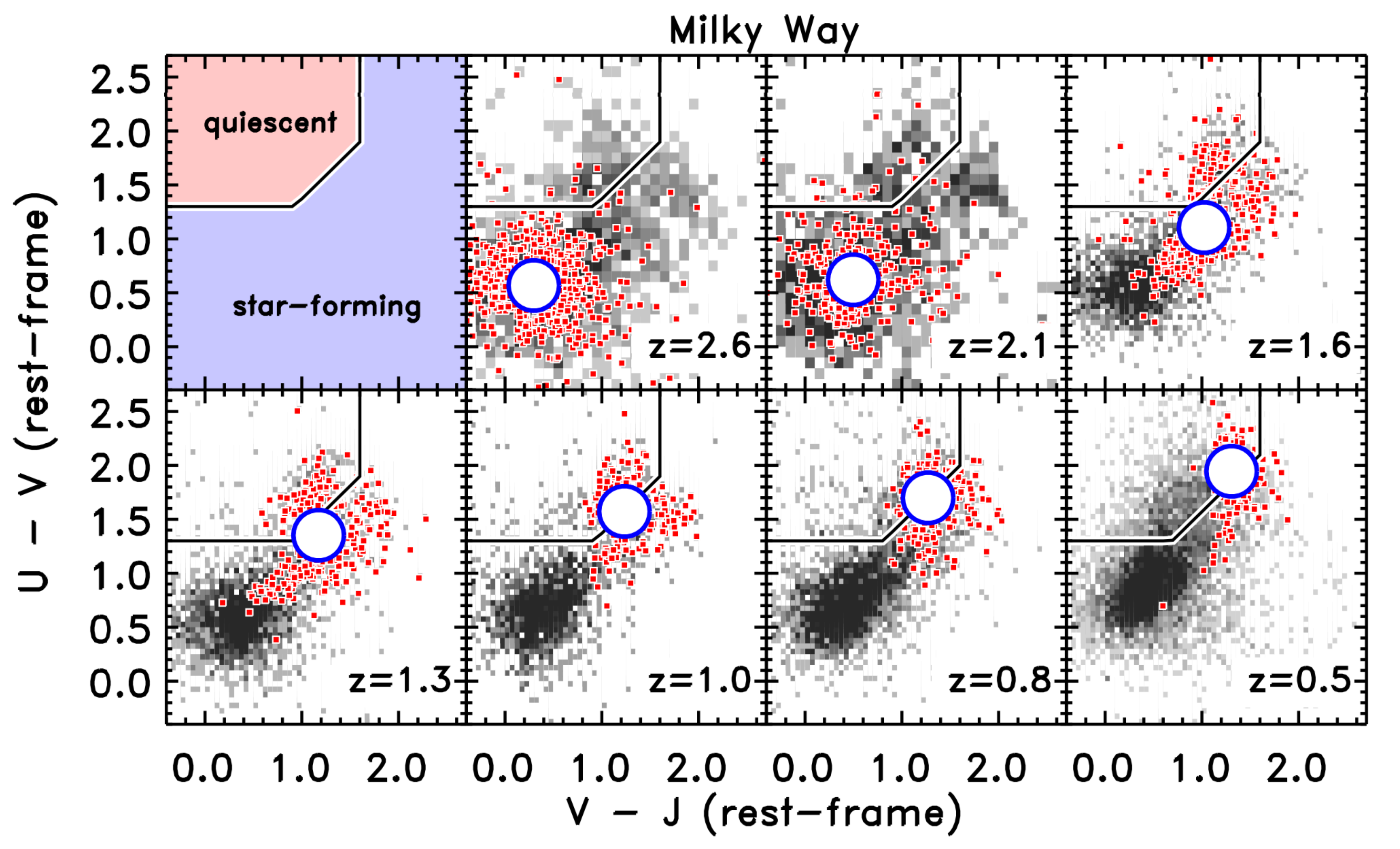


Reddy+12: declining star-formation efficiencies at z>>4 inferred from star-formation histories at z<4



Finkelstein+15: increasing star-formation efficiencies at z>>4 inferred from luminosity functions and halo-abundance matching.

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



Papovich+15 (CANDELS + ZFOURGE)
Also Van Dokkum+ 13 3D-HST

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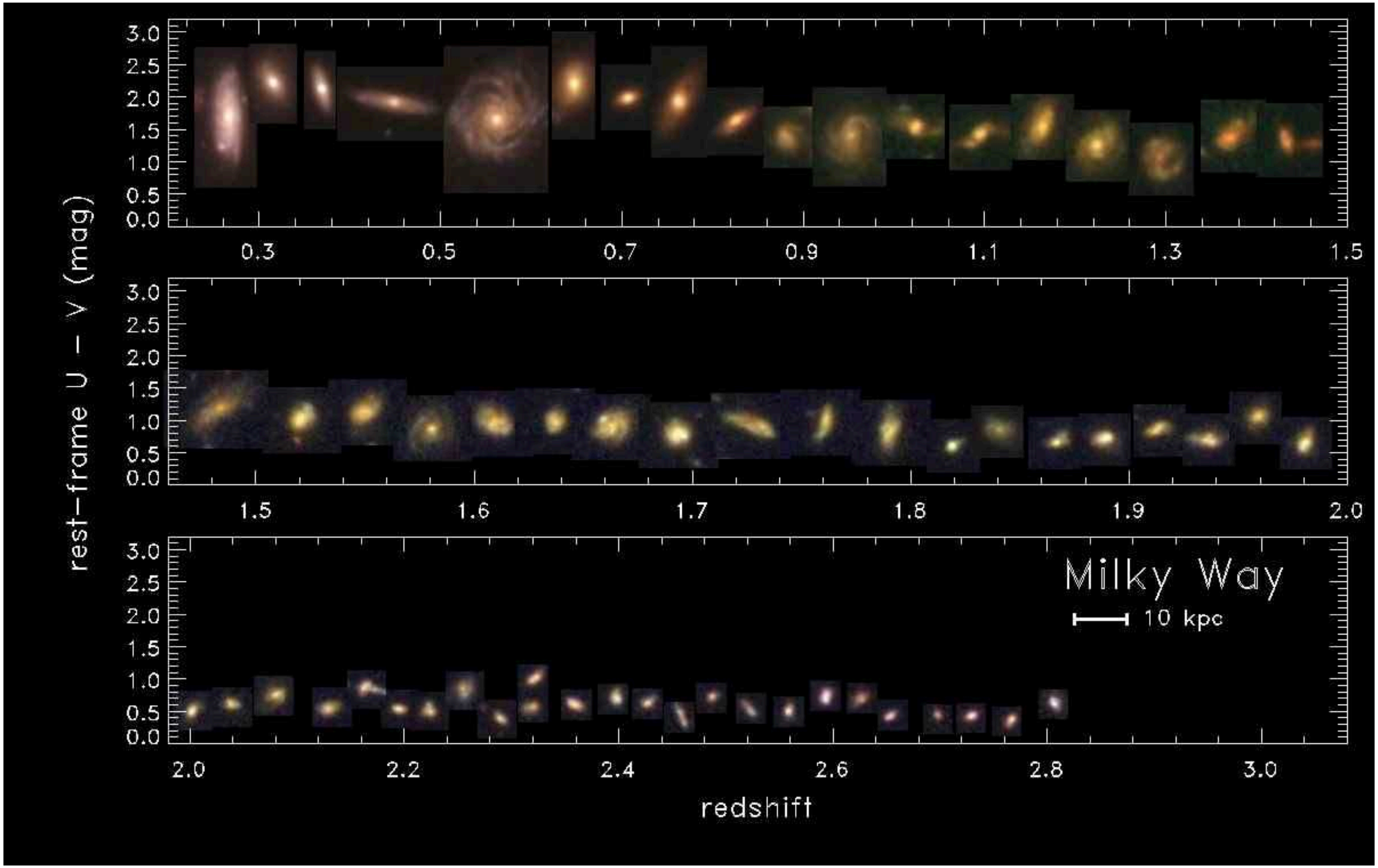

PAPOVICH ET AL.

Carefully-designed surveys serve multiple science goals

Supernovae	Obtain a direct, explosion-model-independent measure of the evolution of Type Ia supernovae as distance indicators at $z > 1.5$, independent of dark energy.
Supernovae	Refine the only constraints we have on the time variation of the cosmic-equation of state parameter *w*, on a path to more than doubling the strength of this crucial test of a cosmological constant by the end of HST's life.
Supernovae	Provide the first measurement of the SN Ia rate at $z \approx 2$ to distinguish between prompt and delayed SN Ia production and their corresponding progenitor models.
Cosmic Dawn	Constrain star-formation rates, ages, metallicities, stellar-masses, and dust content of galaxies at the end of the reionization era $z \sim 6 - 10$.
Cosmic Dawn	Improve the constraints on the bright end of the luminosity function at $z \sim 7$ and 8, and make $z \sim 6$ measurements robust using proper 2-color Lyman break selection.
Cosmic Dawn	Measure fluctuations in the near-IR background light, at sensitivities sufficiently faint and angular scales sufficiently large to constrain reionization models.
Cosmic Dawn	Greatly improve the estimates of the evolution of stellar mass, dust and metallicity at $z = 4 - 8$ by combining WFC3 data with very deep Spitzer IRAC photometry.
Cosmic Dawn	Identify very high-redshift AGN by cross-correlating optical dropouts with deep Chandra observations. Constrain fainter AGN contributions via X-ray stacking.
Cosmic Dawn	Use clustering statistics to estimate the dark-halo masses of high-redshift galaxies with triple the area and double the maximum lag of prior HST surveys.

Carefully-designed surveys serve multiple science goals

Cosmic Noon	Improve by an order of magnitude the census of passively-evolving galaxies at $1.5 < z < 4$. Measure mass functions and size distributions in the rest-frame optical, measure the trend in clustering with luminosity, and quantify evolution with redshift.
Cosmic Noon	Use rest-frame optical observations at $1 < z < 3$ to provide solid estimates of bulge and disk growth, and the evolution spiral arms, bars, and disk instabilities.
Cosmic Noon	Test models for the co-evolution of black holes and bulges via the most detailed HST census of interacting pairs, mergers, AGN, and bulges, aided by the most complete and unbiased census of AGN from Herschel, improved Chandra observations, and optical variability.
Cosmic Noon	Detect individual galaxy subclumps and measure their stellar mass, constraining the timescale for their dynamical-friction migration to the center leading to bulge formation.
Cosmic Noon	Measure the effective radius and Sersic index in the rest-frame optical of passive galaxies up to $z \sim 2$ and beyond and combine with ACS data to quantify envelope growth and UV-optical color (age) gradients.
Cosmic Noon	Determine the rest-frame optical structure of AGN hosts at $z \sim 2$.
Cosmic Noon	Identify Compton-thick, optically obscured AGN at $z \sim 2$ and determine their structure.
UV	Constrain the Lyman-continuum escape-fraction for galaxies at $z \sim 2.5$.
UV	Identify Lyman-break galaxies at $z \sim 2.5$ and compare their properties to higher-z LBG samples.
UV	Estimate the star-formation rate in dwarf galaxies to $z > 1$ to test whether dwarf galaxies are "turning on" as the UV background declines at low redshift.

Ground-based component

- Deep near-IR imaging
- Wider, shallower fields (e.g. for clustering)
- Redshifts
- Metallicities
- Ly-alpha evolution
- Kinematics
- AO morphologies

JWST NIRSpec territory

TMT territory

Thoughts on large surveys

- Statistical studies are severely hampered without large surveys
- Takes ***a lot of effort*** to optimize for multiple science goals
  - Science team & observatory staff
  - Observation phasing, Parallels, slit mask optimization, data-reduction pipelines
- It is worth the effort
  - Ends up saving telescope time relative to uncoordinated smaller GO programs to accomplish the same goals.

Thoughts on large surveys

- ~25% of the time for proposals ~10x larger than average seems like a good balance.
  - Does not have to be "surveys"
  - But "surveys" with broad uses tend to yield more publications than narrower programs
- Complaints that "large programs crowd out small ones" are generally off base
  - If anything, they probably reduce overall proposal pressure, because they often yield public data with multiple uses.

Thoughts on large teams

- Can stimulate better science
  - Multiple techniques, cross-comparisons
- Can be good for young scientists
  - More contacts, interaction
- Can be inefficient
  - More coordination, some redundancy, more time to review papers
- Much depends on the team itself

Thoughts on proprietary data

Dead Sea Scrolls

Thoughts on non-proprietary data

- Science enabling
  - Multiple telescopes & teams invest in common fields because core data are public.
- Speeds the intellectual cycle
  - Faster publication
  - Multiple perspectives on hot topics
  - Fosters collaboration on followup observations

Thoughts on non-proprietary data

- Not a serious problem for the PI team
  - PI team's accomplishments are not greatly diminished by someone else addressing similar scientific goals with the same data
  - Public data in some sense frees you to "do the right thing"
- Extra "protection" for students from proprietary data is a bit of a myth
  - There are generally other facilities and other ways to compete for the same science goals

Thoughts on time allocation

- Possible ways to optimize while preserving "shares" and guaranteed time:
  - One TAC with global rankings; partner shares achieved by going further down the list (while avoiding duplication)
  - Guaranteed time for instrument teams, but priority on targets determined by proposal ranking (Spitzer, later cycles?)
  - Shares allocated proportionally according to proposal team affiliations (PI counts 2x?)

Thoughts on time allocation

- Alternative (experiment):
  - Separate partner TACs for 50%
  - Unrestricted TAC for the other 50%
  - More incentive for NSF to join in this model
- Incentivize making data public
  - Calibration time “free”?
  - Priority in queues?
  - Priority for completion
  - Funding for value-added data products
  - Checkbox on NSF grant applications

Conclusions

- Large, public surveys enhance certain kinds of science
- Consider ways to enable this