Developing a Detailed Picture of Galaxy and Dark Matter Evolution with WFIRST

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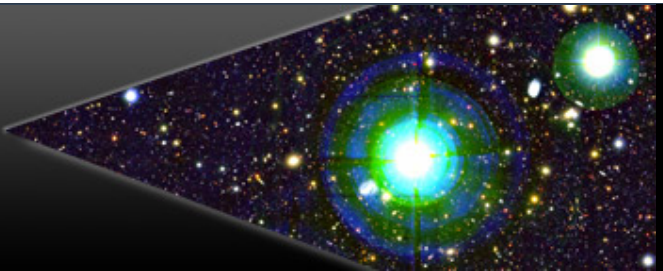

Barisic, Ivana
Casey, C.
Carilli, Chris
Carollo, Marcella
Davidzon, Iary
Dunlop, James
Faisst, A.
Hashimoto, Yasuhiro
Hildebrandt, Hendrick
Hsieh, Bau-Ching
Ilbert, Olivier
Jones, Gareth
Karim, Alex
Laigle, Clotilde
Le Fevre, Olivier
Le Floc'h, Emeric
Lee, Nicholas
Lilly, Simon
Lin, Lihwai
Lin, Yen-Ting
Masters, Dan
McCracken, Henry
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Ouchi, Massami
Reichers, D.
Salvato, Mara
Sanders, Dave
Scoville, Nick
Sheth, Kartik
Silverman, John D.
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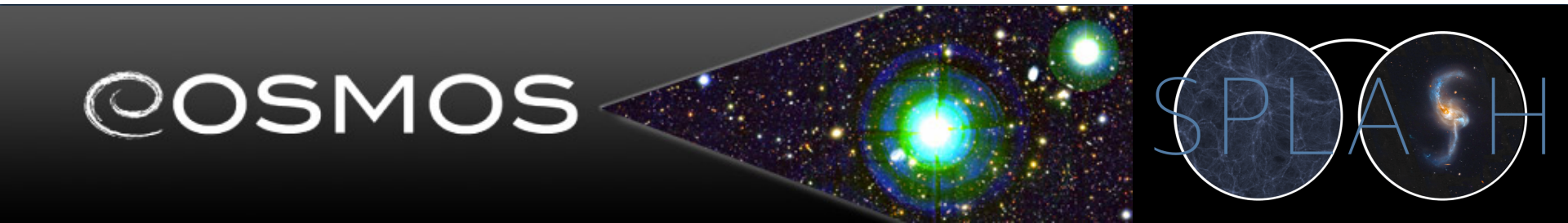
Speagle, Josh S.
Steinhardt, Charles L.
Strauss, Michael A.
Taniguchi, Yoshiaki
Yan, L.

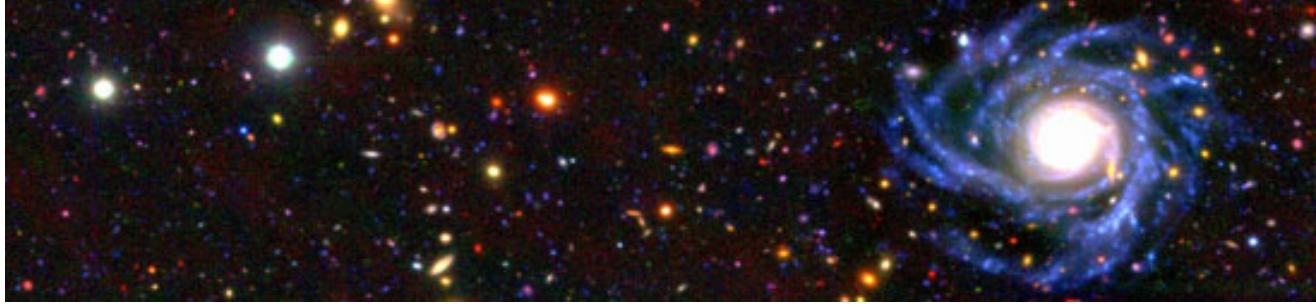


Overview

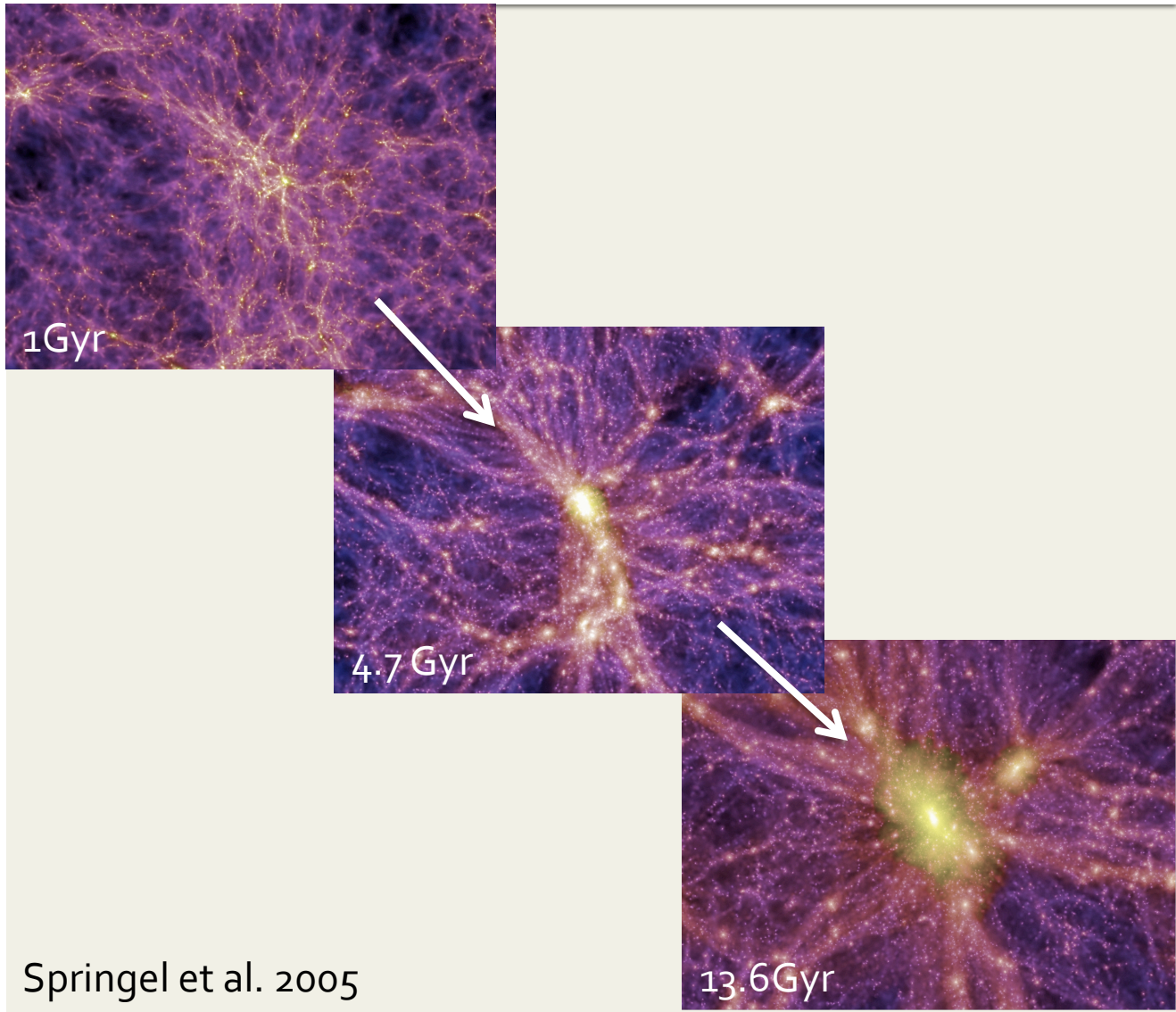
- Large survey astronomy will change how we do galaxy evolution in the 2020s
  - We will form a continuous and granular picture of galaxy evolution
- But this makes detailed studies of individual objects even more important
  - Correlations are only interesting if you understand the physics behind them

2020s

2020s



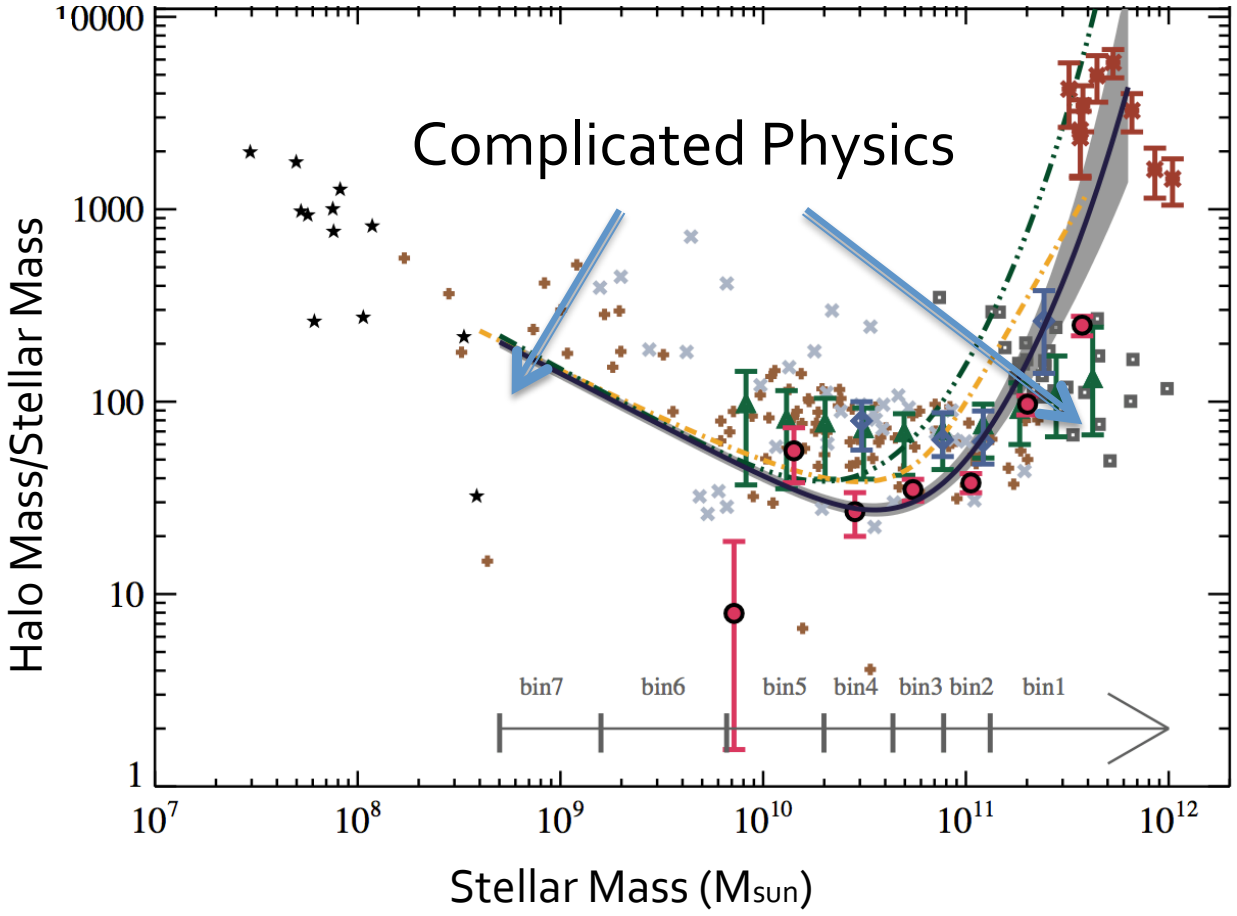
- Matter makes up ~30% of the universe, the rest is some form of energy
- >90% of matter in the universe is in a dark collisionless form
- Dark Matter (DM) Halos Grow with time
- Evolution determined by gravity



Springel et al. 2005

2020s

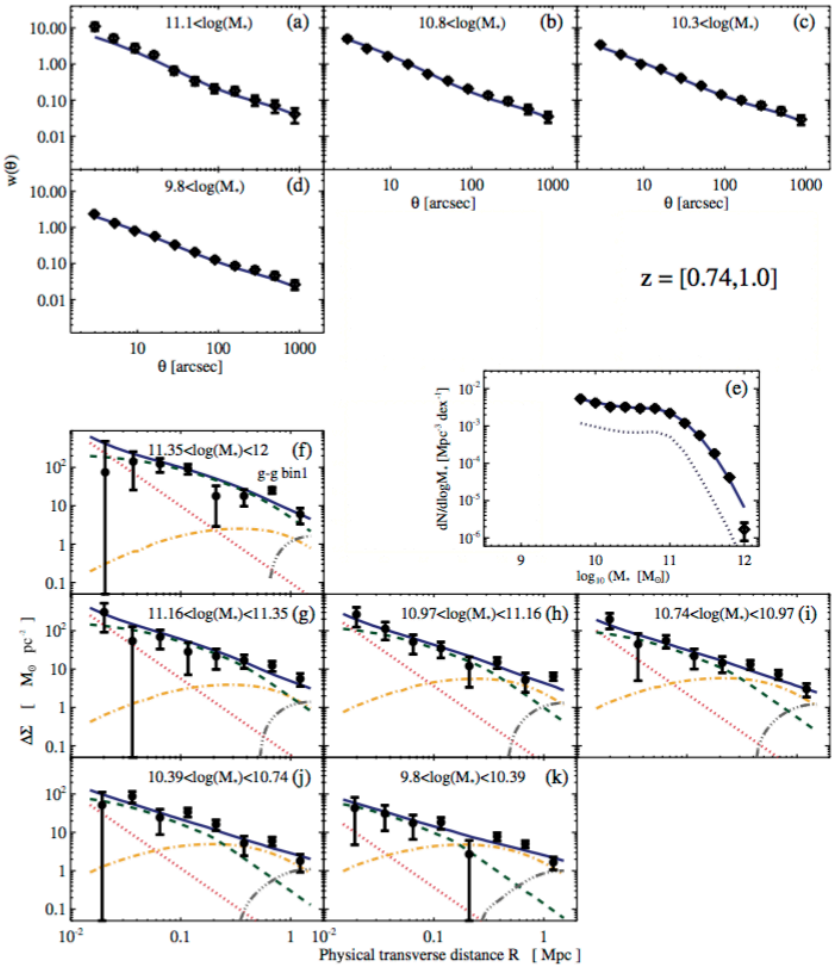
- Evolution of the DM mass ≠ evolution of stellar mass
- Gas accretion /Star formation suppressed at high and low masses
- Best way to link dark matter and galaxy evolution is via statistics
  - Clustering
  - Lensing shear
  - Lensing magnification
  - Redshift Space Distortions
  - Dynamics
  - Abundance Matching



Massey et al. 2007a, 2007b, Leauthaud et al. 2012

2020S

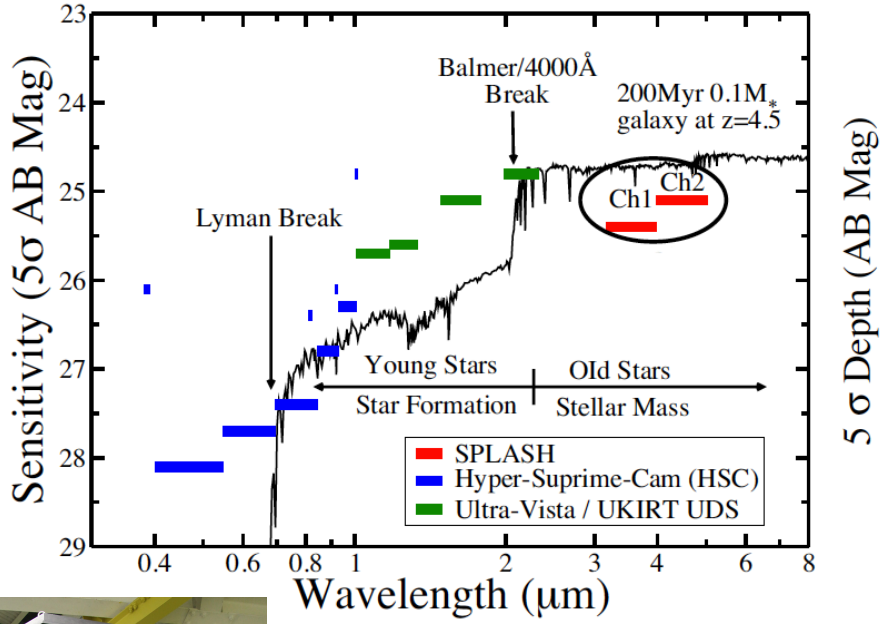
- Same data that measures dark energy measures galaxies
- Can access the dark matter halo properties for samples of galaxies
- Need to define those samples

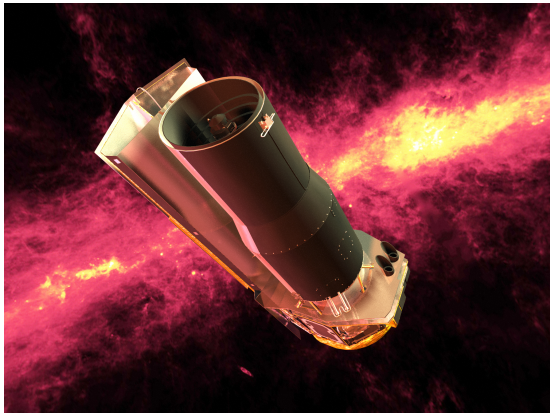


Leauthaud et al. 2012

SPLASH

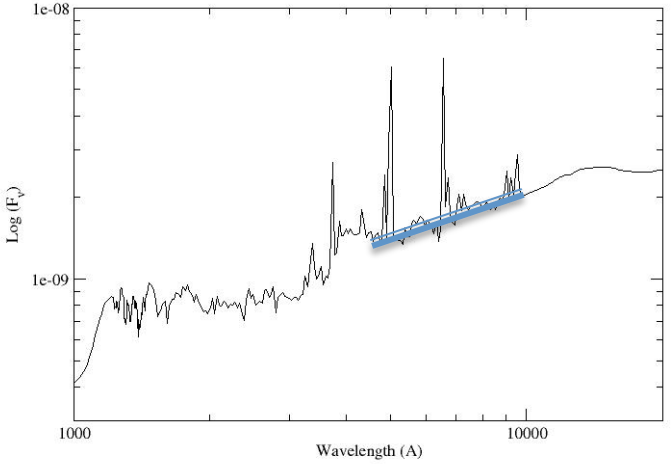
- Survey with Spitzer and Hyper-Suprime-Cam (SPLASH)
- Builds on COSMOS and SXDS/UDS, total of 3.6 sq degrees
- Designed to link visible and dark matter at 3<z<7
  - Deep enough to reach ~0.1 M* at z~7 (ch1~25.5)
  - Wide enough to probe large scale structure at z>3 (3.6 square degrees)
  - Enough objects to enable statistical studies
  - Taken in 18-24 epochs to enable variability studies
- Spitzer is done
- HSC started in 2014
  - Ongoing until 2020

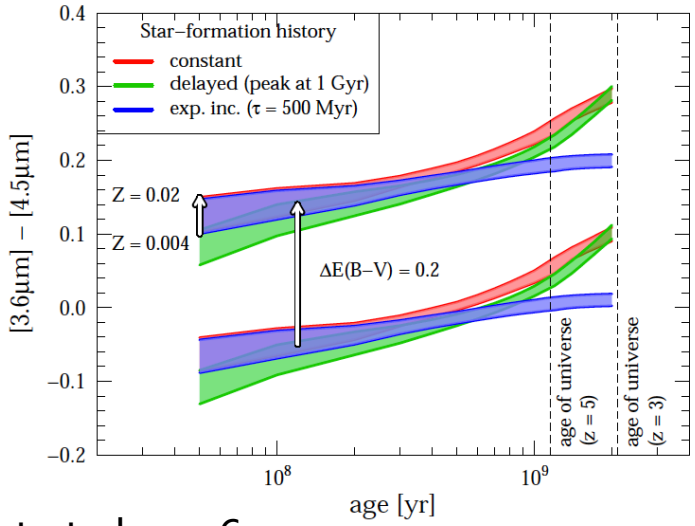




Properties of z>4 galaxies

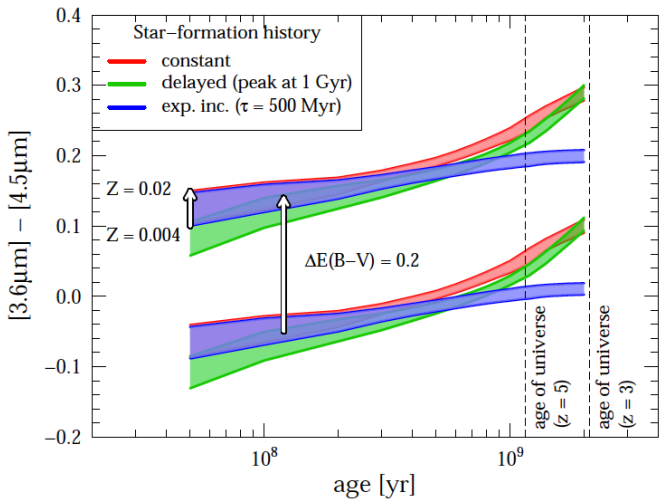
- Star-formation-Mass relation (Main Sequence) untested at z>4
- Heavily reliant on SED fitting
  - Lots of assumptions
- Specific Star Formation Rate (sSFR) can be measured without any SED fitting
  - Hα line luminosity is proportional to prompt star formation
  - Continuum at 0.5-1μm is proportional to accumulated stellar mass
  - So Hα equivalent width is proportional to sSFR

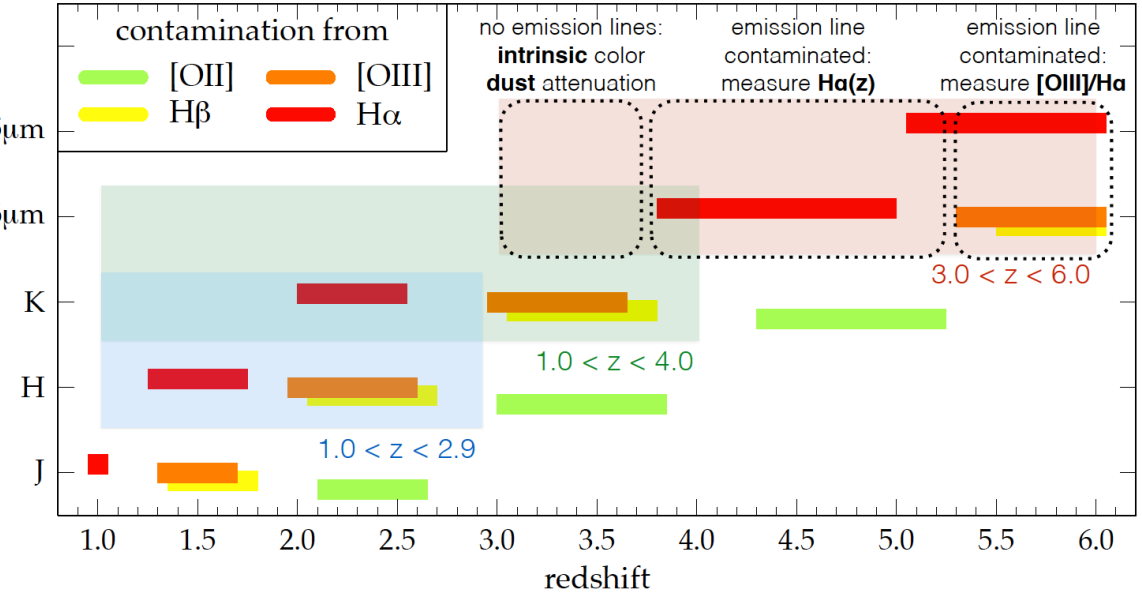




Faisst et al. 2016

Properties of z>4 galaxies



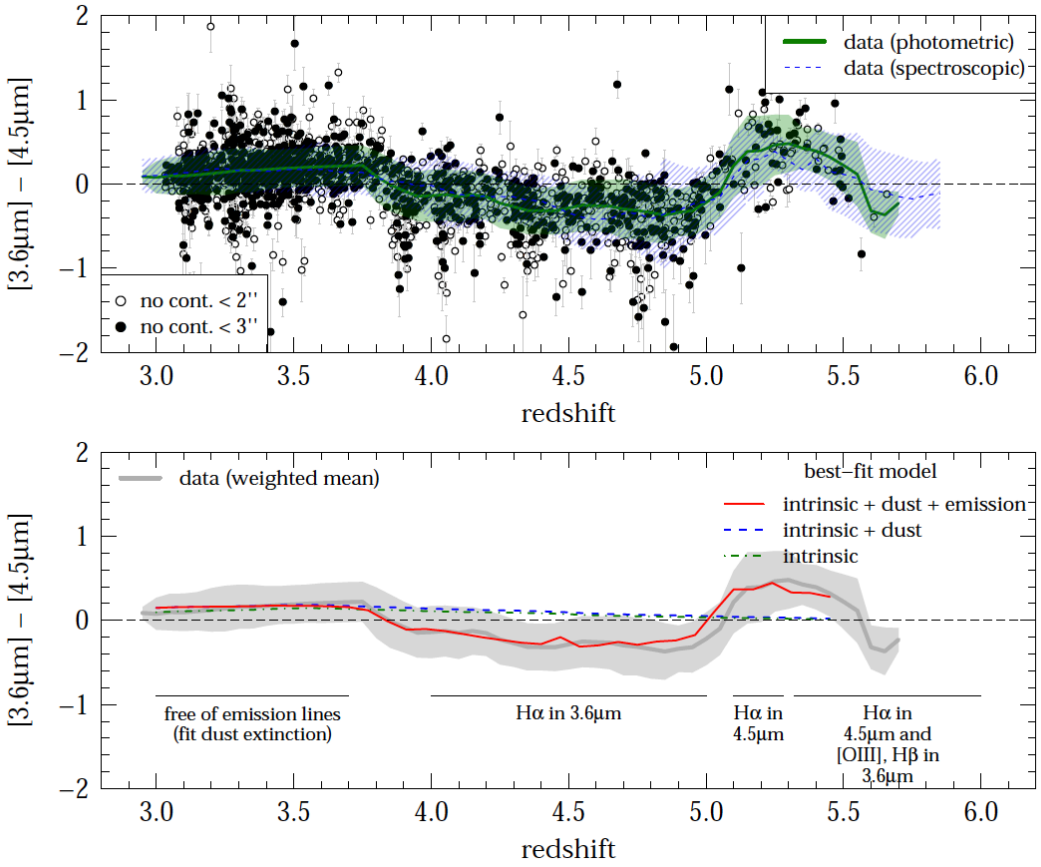


- Can measure Hα EW (and other lines) from photometry if redshift is known
  - Need to estimate continuum under line
  - Insensitive to most parameters except extinction
- Need to identify line-free continuum to estimate continuum distribution
- Create a forward model of the galaxy population
  - Age distribution of population, e(B-V) of continuum, e(B-V) of lines, line strengths
  - Smooth evolution in all properties with redshift

Faisst et al. 2016

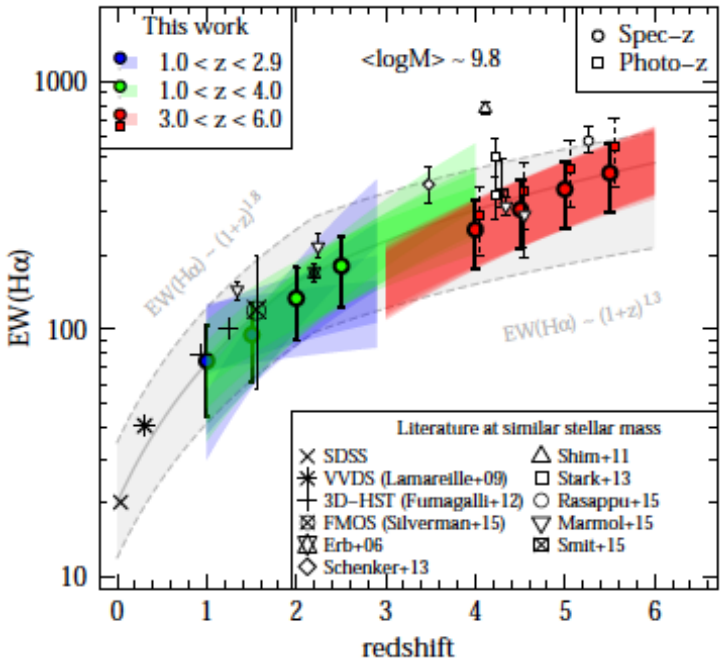
Properties of z>4 galaxies

- Can clearly see signatures in raw photometry
- Both in spec-z and photo-z sample
- Fit our forward model to the data to extract line EW

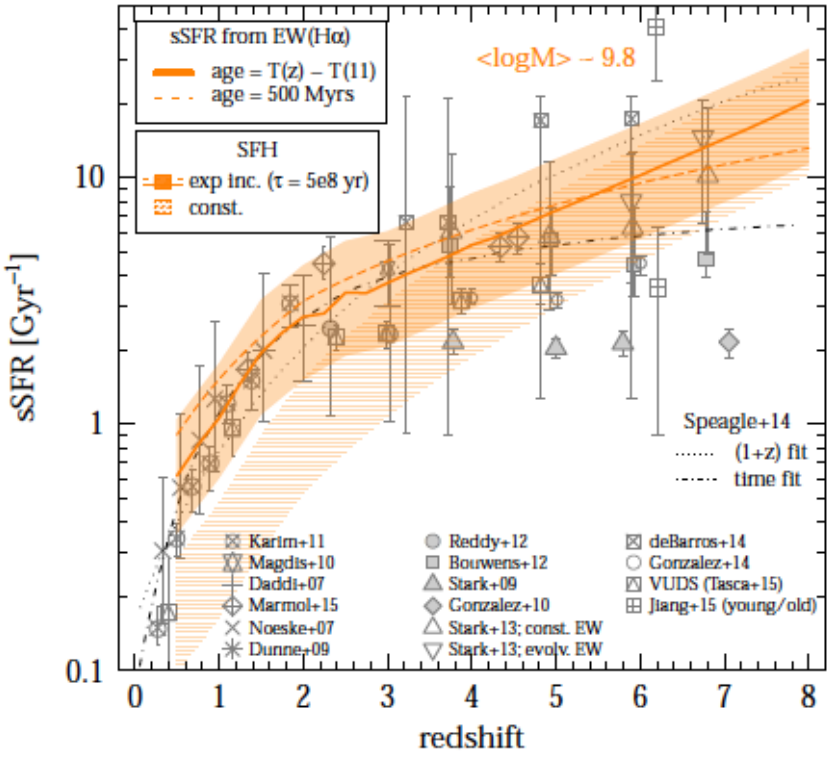


Faisst et al. in prep

Properties of z>4 galaxies



- Estimate Hα EW distribution agrees with direct measurements at lower-z
- Evolution at high-z is lower than but consistent with SED fitting results

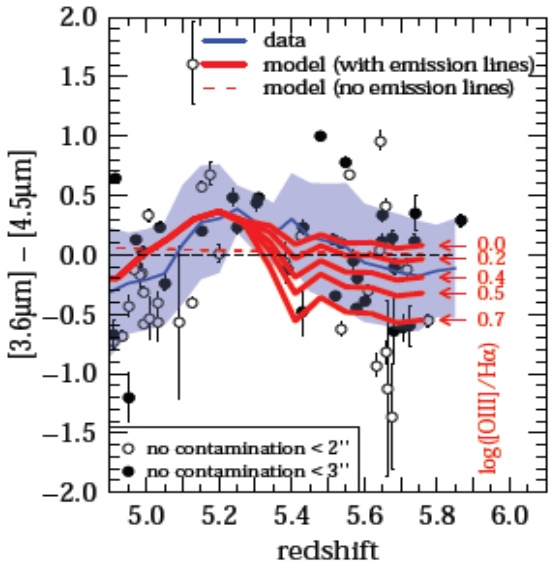


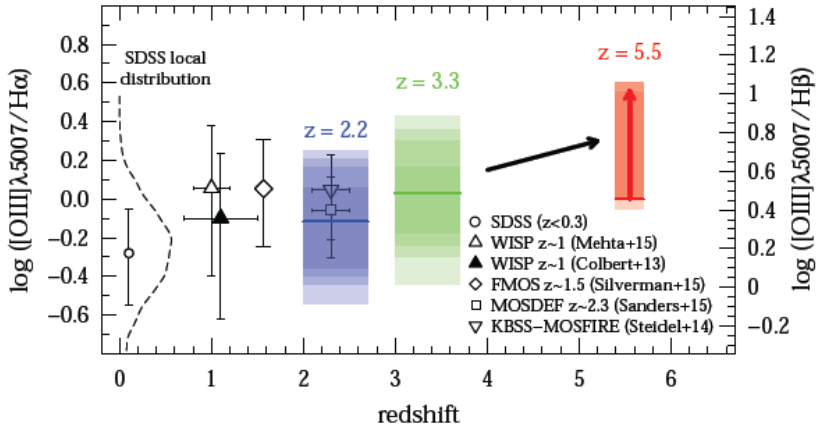
- sSFR also agrees
- Implies continued increase in sSFR to higher redshift

Faisst et al. 2016

Properties of z>4 galaxies

- O[III]/Hα is also measured by our forward model
- Currently just a lower limit
  - Need deeper HSC data to get full distribution at z>5.6





Faisst et al. 2016

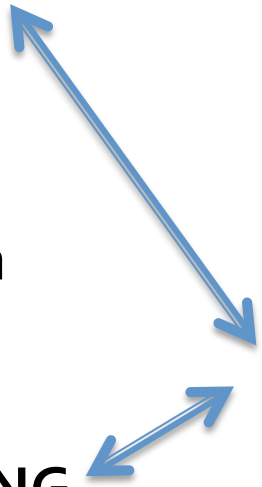
Oceans of Data

ANALYTIC MODELS

- Fundamental understanding of underlying problem

SUPERVISED LEARNING

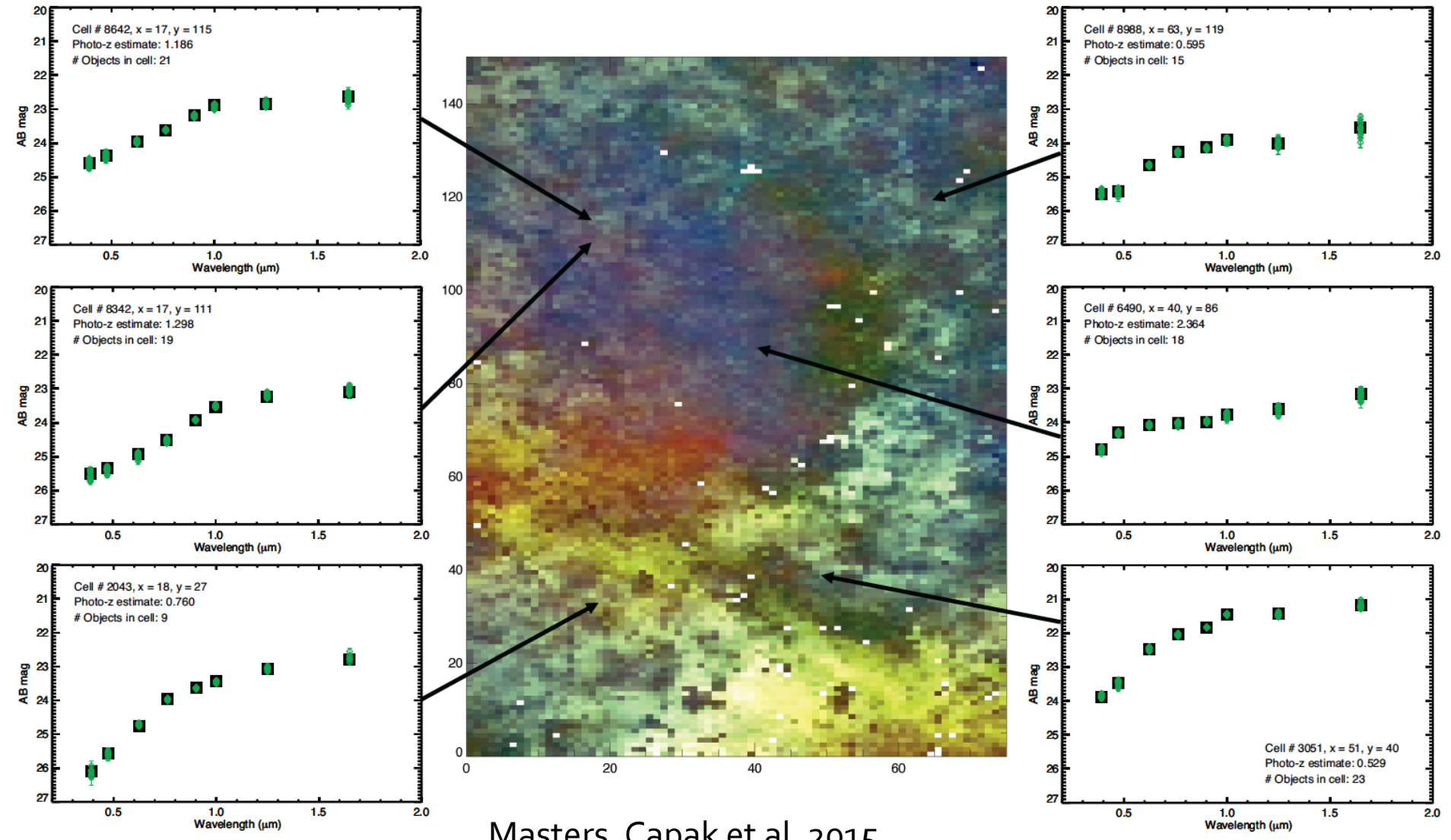
- Create an empirical model of complex systems based on data
- Reproduce human vision/ intuition on large data sets



UNSUPERVISED LEARNING

- Discover correlations you didn't know existed
- Visually explore high-dimensional data sets
- Compare analytic models and complex data to look for discrepancies

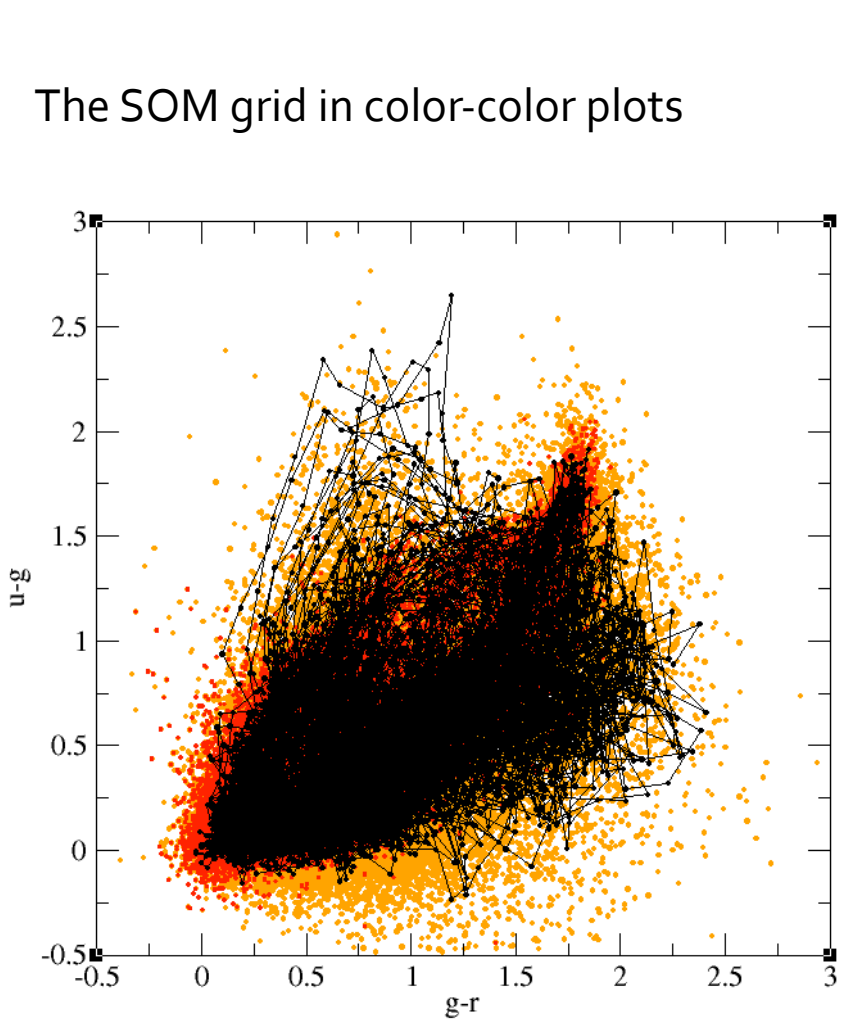
Oceans of Data

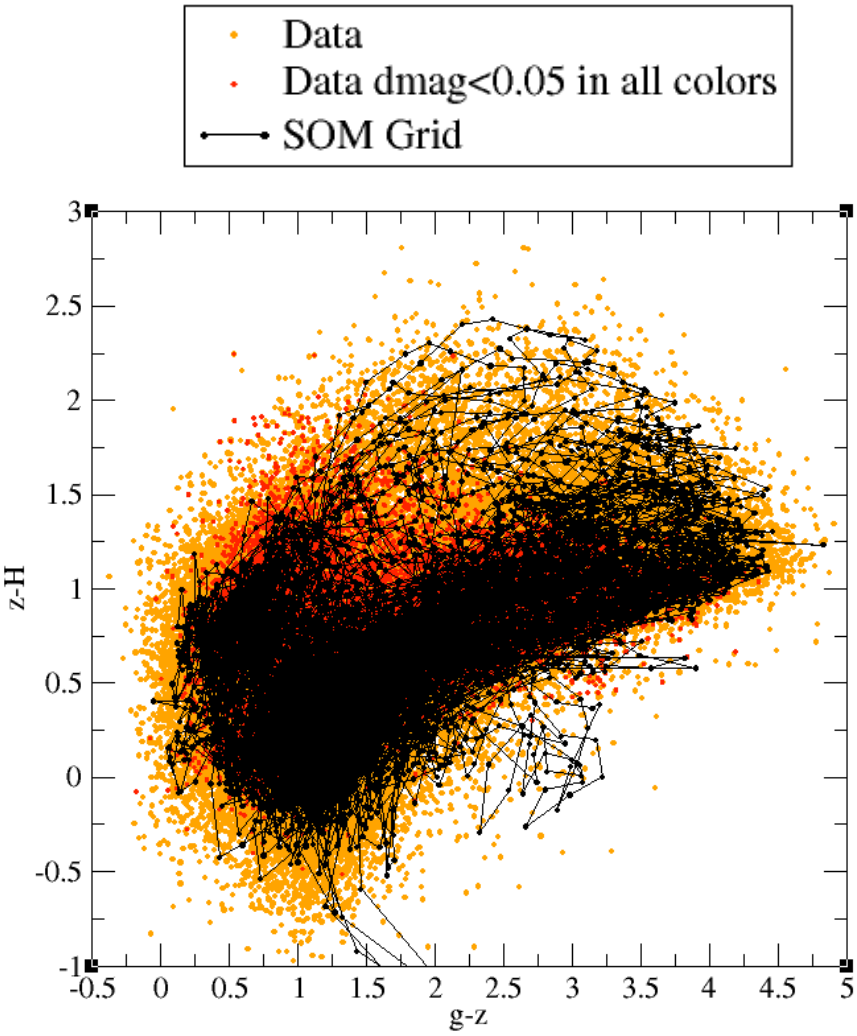


Masters, Capak et al. 2015

Oceans of Data

The SOM grid in color-color plots

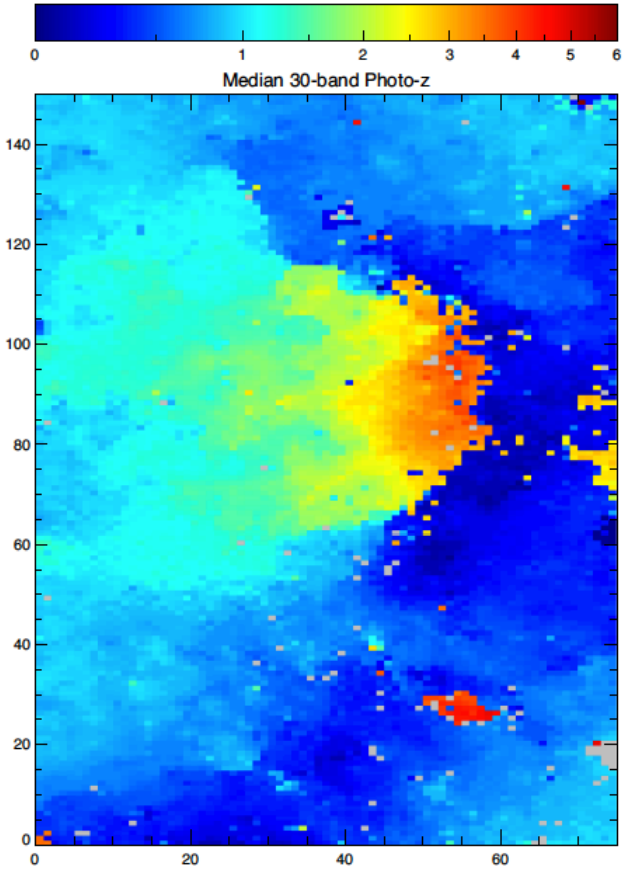




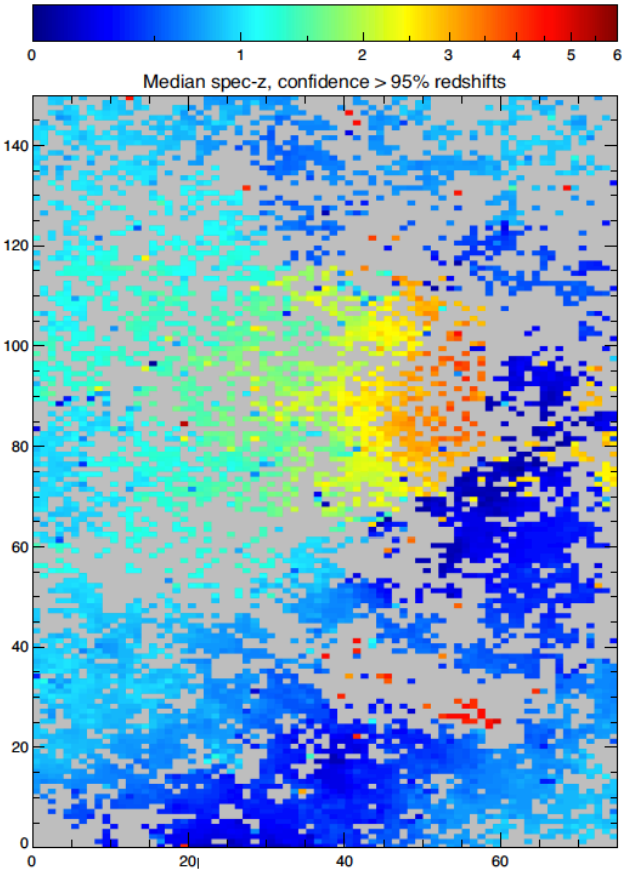
Oceans of Data

- Photo-z distribution is very smooth over most of color space
- Spec-z are not representative of data
  - Lots of missing area
- Can use SOM to select optimal spectroscopic sample
  - Masters, Capak et al. 2015

Mean photo-z of cell from COSMOS 30-band data



Mean spec-z of cell from COSMOS

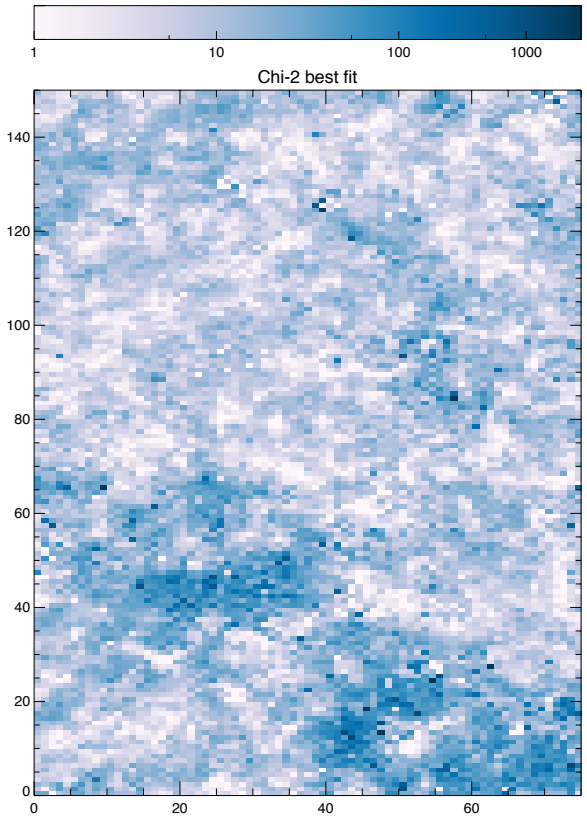


Oceans of Data

Explore how well our SED models represent the data

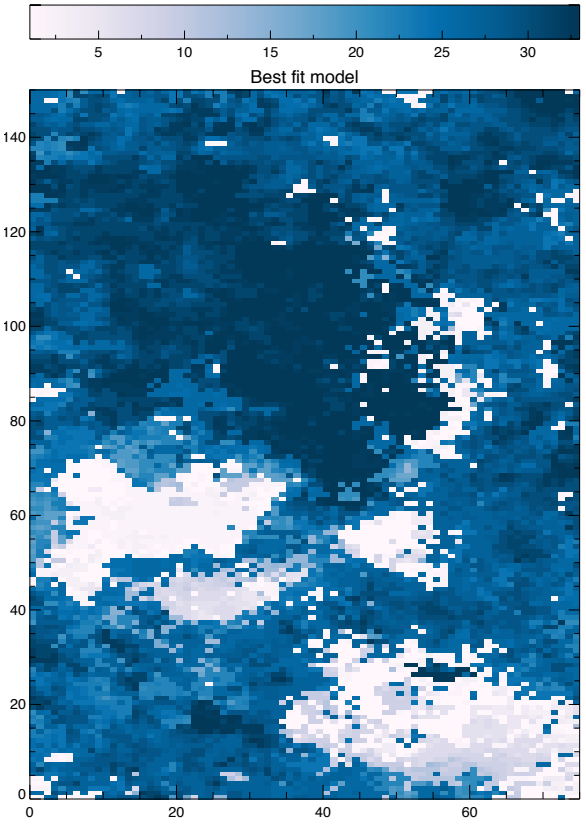
Goodness of fit

Good Bad



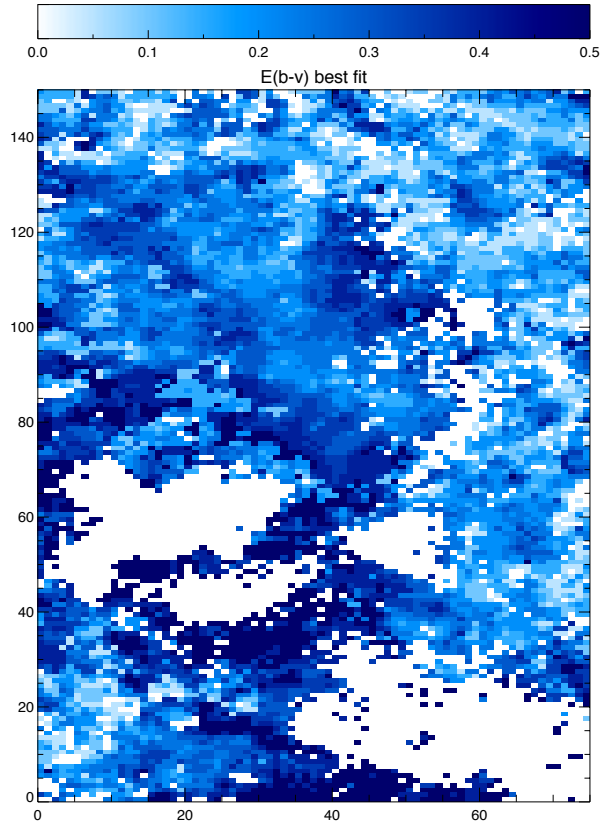
Model

Red Blue



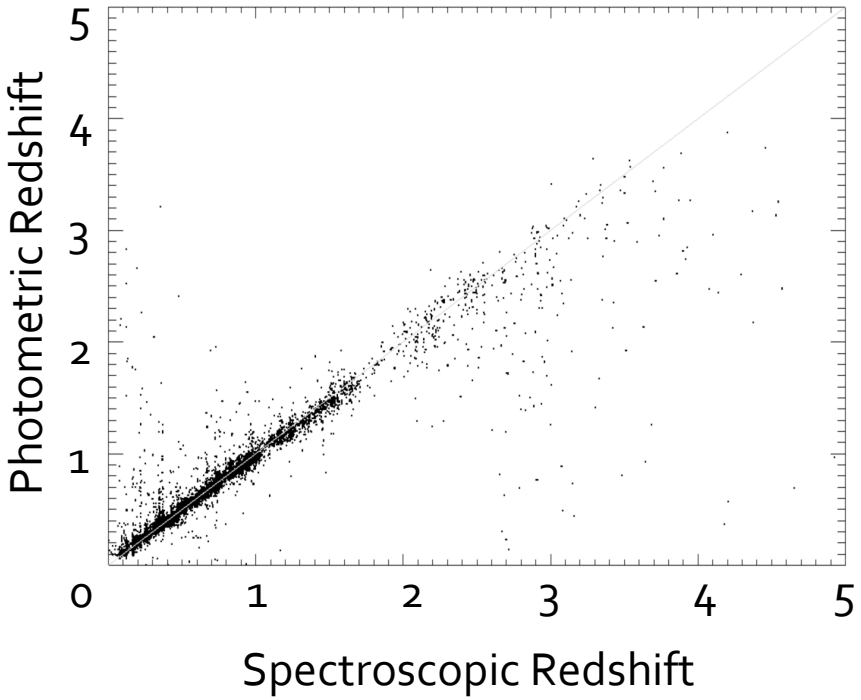
Dust Obscuration

Blue Red



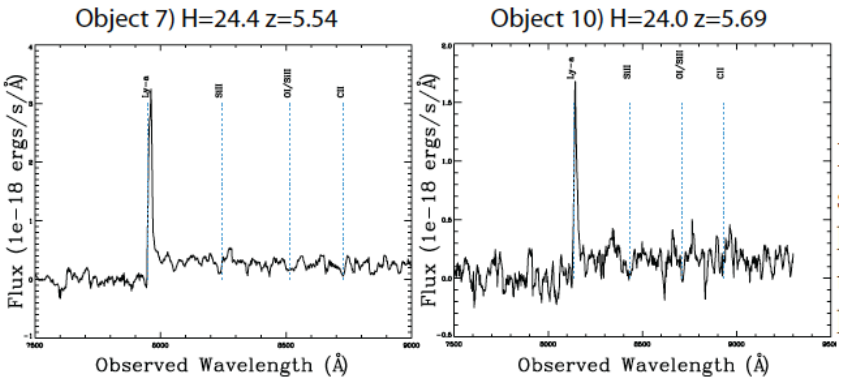
Oceans of Data

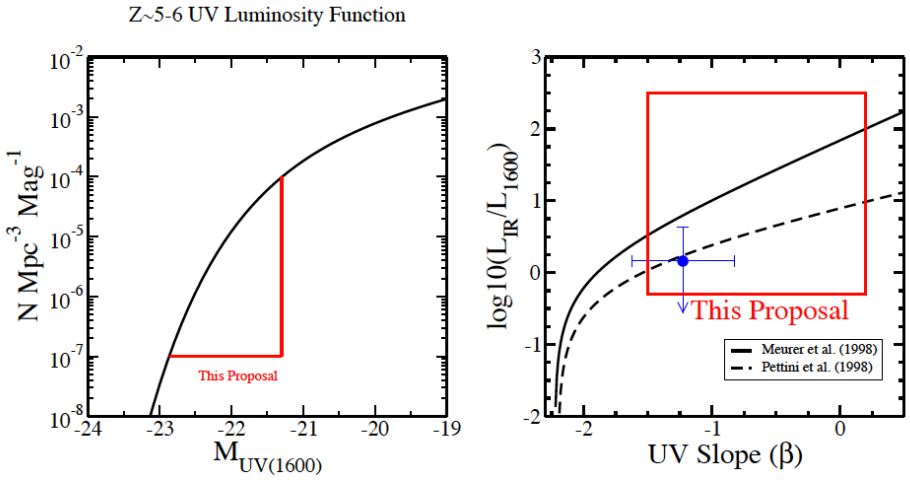
- Preliminary test of photo-z improvement
  - Weight photo-z by likely-hood of model occurring in the data
  - Based on the **photometry and template fitting**, no spectra
  - Using only u,g,r,I,z,Y,J,H photometry
- Significantly improve over raw template fitting
  - Outlier fraction 10.2 -> 1.5%
  - Sigma_NMAD=0.03 -> 0.02
  - Bias = 0.004
- Very preliminary



Rosetta Stones

- Are the SFR and Mass estimates correct at z>5?
- Are changes in the ISM driving the main sequence and early galaxy formation?
- Lets check with ALMA!
- Selected 9 "Normal" objects and 1 quasar between 5.2<z<6
- Observed [CII] and continuum
- Set exposure times to un-obscured SFR and $L_{CII}=10^{-3}L_{IR}$

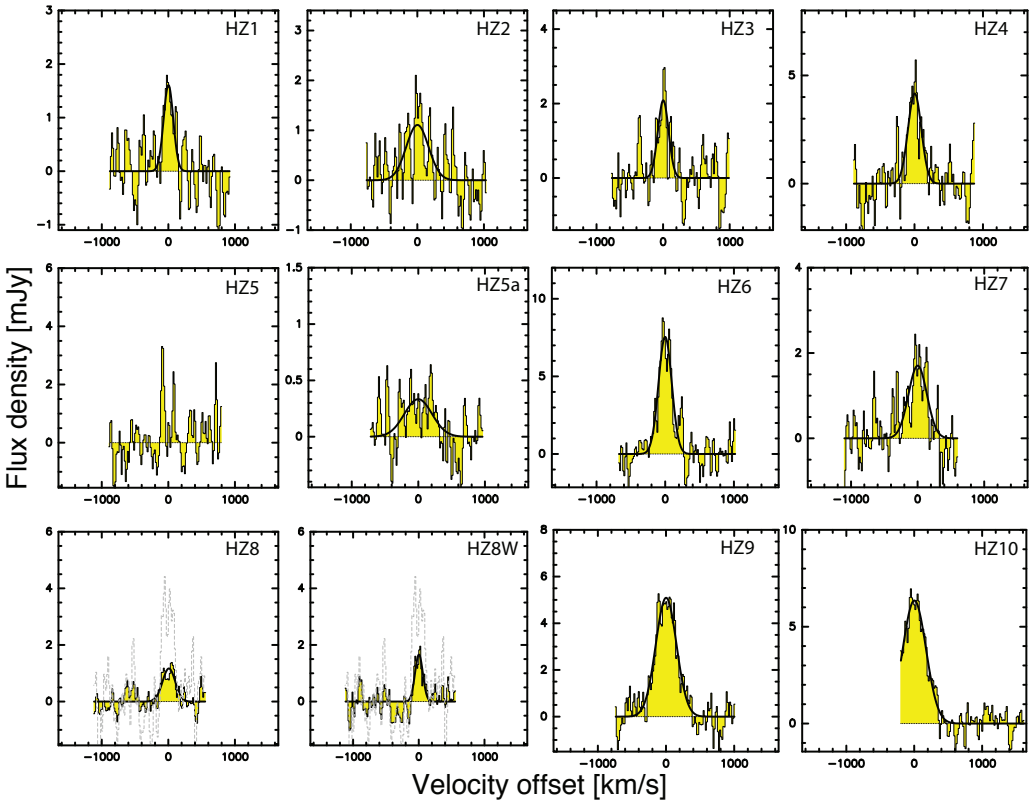




Capak et al. 2015

Rosetta Stones

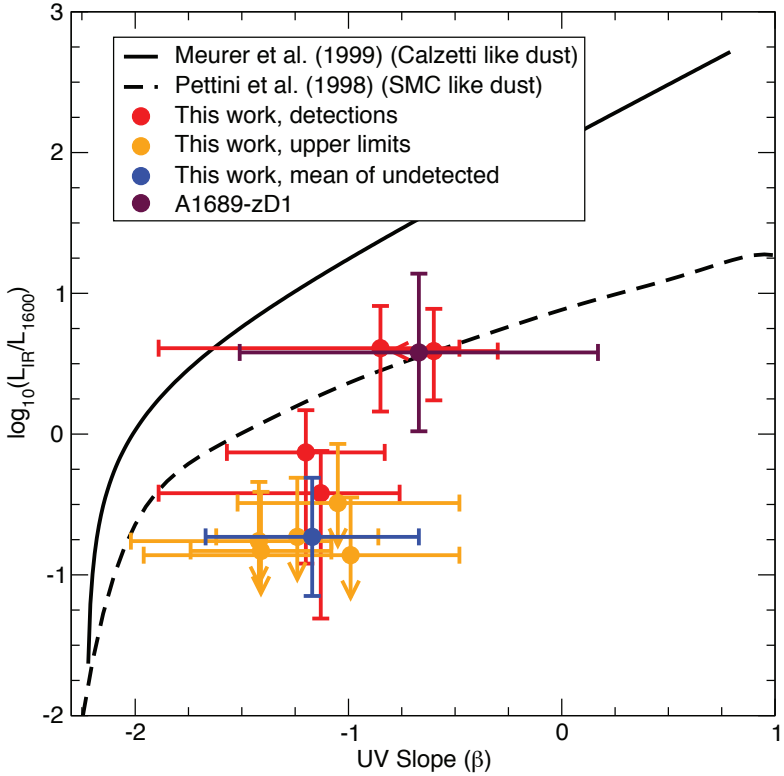
- All detected in [CII]
- Only three objects detected in continuum



Capak et al. (2015)

Rosetta Stones

- Continuum is much fainter than expected
  - Z~6 L* galaxies is 30μJy
- Z~5.5 galaxies are significantly less obscured than similar z~3 systems
  - Factor of ~>12 , average >40
- Dust is like that found in low-metallicity systems
- New HST data pushed Beta's blue-ward by ~0.5dex
  - Consistent with expected systematic error
  - Probably due to Mamquest bias in Ultra-Vista photometry



Capak et al. (2015)

Conclusions

- In the 2020s large surveys will change how we do astronomy
  - Large statistical analysis to define "normal" and unique objects
  - Links to dark matter
  - All of galaxy evolution is encoded in these statistical distributions
    - Can form a very granular picture of galaxy evolution
- We need to think about what tools we need for this
  - New types of statistics and tools
- We are starting to do this now
  - SPLASH is a pathfinder/precursor to WFIRST surveys
  - Starting to characterize the high-z galaxy population
  - Finding representative and "Rosetta stone" objects to study in detail