Surveys at $z \sim 1$

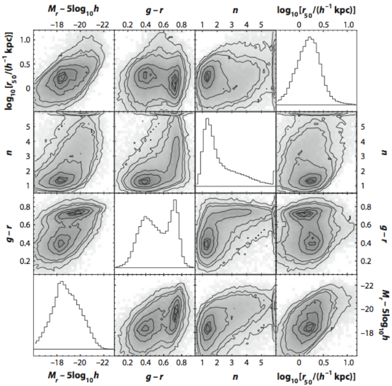
Petchara Pattarakijwanich
20 February 2013

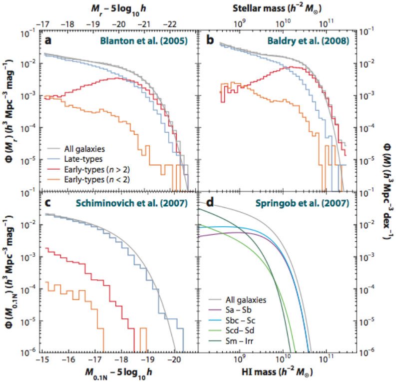
Outline

- Context & Motivation.
- Basics of Galaxy Survey.
  - SDSS
  - COMBO-17
  - DEEP2
  - COSMOS
- Scientific Results and Implications.
  - Properties of $z \sim 1$ galaxies.
  - Evolution of blue galaxies.
  - Evolution of red galaxies.
- Future Surveys.
  - HSC
  - PFS
  - LSST

Motivation

- Munan and Alex talked about local galaxies last week.
- How about the evolution as a function of cosmic time?

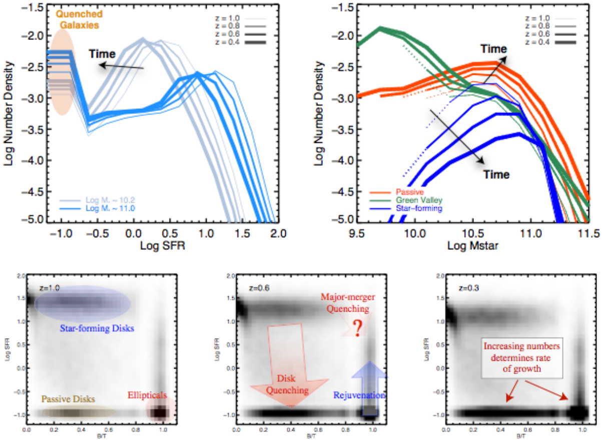




Blanton & Moustakas 2009

How do we study evolution?

- Matching high-z progenitors to local products is non-trivial.
- Need flow diagram in various parameters to constrain models.
- **To do this, need galaxy redshift surveys.**



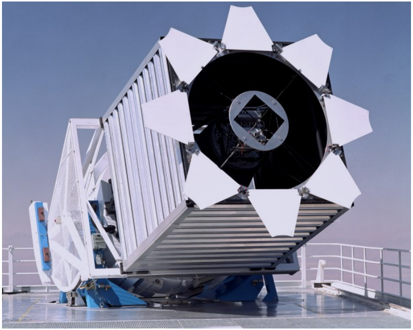
HSC White Paper

Galaxy Survey 101

- Photometric Dataset.
  - Brightness
  - Colors
  - Morphology
  - Photometric Redshift
  - Crude Stellar Population
- Target Selection.
  - Color
  - Morphology
- Spectroscopic Follow-up.
  - Spectroscopic Redshift
  - Emission & Absorption lines
  - Dynamics
  - Metallicity
  - Stellar Population & AGN
  - etc.

Sloan Digital Sky Survey (SDSS)

- Perfect example for redshift survey, but very non-ideal for $z \sim 1$ work.
- SDSS main galaxy sample is very uniform and ideal for studying galaxies but is too local ($z \sim 0.2$).
- BOSS galaxy sample (CMASS) are extremely biased (because it was targeted for BAO science).

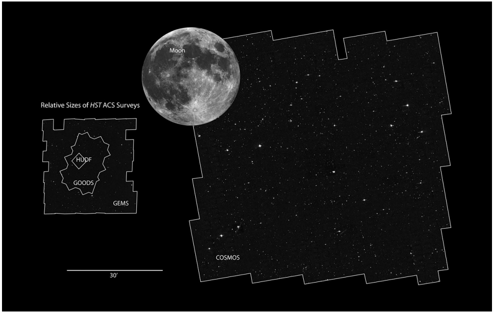


COMBO-17 & DEEP2

- COMBO-17
  - Image 1 deg^2 with 17 broad & medium band filters.
  - To $\mathrm{R}_{\mathrm{Vega}} \sim 26$
  - $\sim$30,000 galaxies with good photometric redshift.
- DEEP2
  - $\sim$ 100 nights survey with Keck DEIMOS.
  - 2.8 deg^2 area down to $\mathrm{R}_{\mathrm{AB}} = 24.1$.
  - Target $\sim$50,000 galaxies at $z > 0.7$ with $\sim$ 40,000 successful redshift.

COSMOS

- HST survey over 2 deg^2.
- Largest HST survey ever taken by area.
- Augmented by data from various observatories from X-ray to Radio.
- Extreme multi-band dataset with HST optical resolution.



www.spacetelescope.org

COSMOS

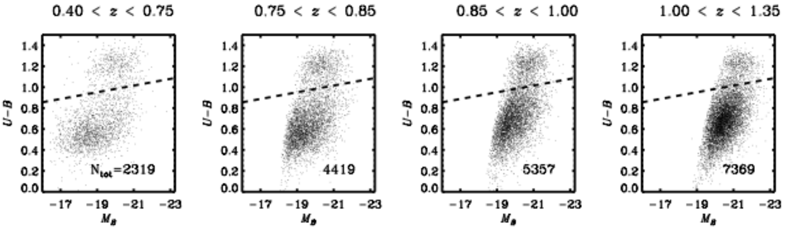
MULTIWAVELENGTH COSMOS DATA

Data	Bands/λ/Res.	Number of Objects	Sensitivity[a]	Investigators	Time
HST ACS	814I		28.8	Scoville et al.	581 orbits
	475g		28.15	Scoville et al.	9 orbits
HST NIC3	160W		25.6 (6% area)	Scoville et al.	590 orbits
HST WFPC2	300W		25.4	Scoville et al.	590 orbits
Subaru SCam	B, V, r', i, z', g'		28–26	Taniguchi et al.	10 n
	10 IB filters		26	Taniguchi, Scoville	11 n
	NB816		25	Taniguchi et al.	8 n
CFHT Megacam	u^*		27	Sanders et al.	24 hr
	u, i^*		26	LeFevre et al.	12 hr
CFHT LS	u–z			Deep LS Survey	
NOAO CTIO	K_s		21	Mobasher et al.	18 n
CFHT UKIRT	J, H, K		24.5–23.5	Sanders et al.	12 n
UH-88	J		21	Sanders et al.	10 n
GALEX	FUV, NUV		26.1, 25.8	Schminovich et al.	200 ks
XMM-Newton EPIC	0.5–10 keV		10^{-15} cgs	Hasinger et al.	1.4 Ms
Chandra	0.5–7 keV			Elvis et al.	Future
VLT VIMOS sp.	$R = 200$	3000	$I < 23$	Kneib et al.	20 hr
	$R = 600$	20000	$I < 22.5$, $0.1 \leq z \geq 1.2$	Lilly et al.	600 hr
	$R = 200$	10000	$B < 25$, $1.4 \leq z \geq 3.0$	Lilly et al.	600 hr
Mag. IMAX sp.	$R = 3000$	2000		Impey, McCarthy, Elvis	12 n
Keck GEMINI sp.	$R = 5000$	4000	$I < 24$	Team Members	
Spitzer MIPS	160, 70, 24 μm		17, 1, 0.15 mJy	Sanders et al.	392 hr
Spitzer IRAC	8, 6, 4.5, 3 μm		11,9,3,2 μJy	Sanders et al.	220 hr
IRAM MAMBO	1.2 mm		1 mJy (20 × 20′)	Bertoldi et al.	90 hr
CSO Bolocam	1.1 mm		3 mJy	Aquirre et al.	40 n
JCMT Aztec	1.1 mm		0.9 mJy (1 σ)	Sanders et al.	5 n
VLA A	20 cm		7 μJy (1 σ)	Schinnerer et al.	60 hr
VLA A/C	20 cm		10 μJy (1 σ)	Schinnerer et al.	275 hr
SZA (full field)	9 mm		S–Z to 2×10^{14} $M_\odot$	Carlstrom et al.	2 mth

Scoville et al (2006)

Properties of $z \sim 1$ galaxies

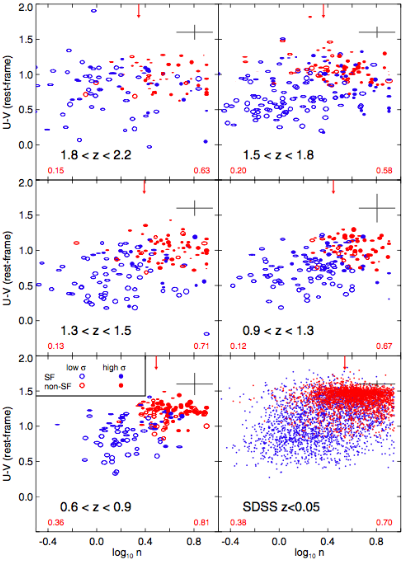
- Clearly two distinct population already in place at $z \sim 1$.



Cooper et al (2006)

Properties of $z \sim 1$ galaxies

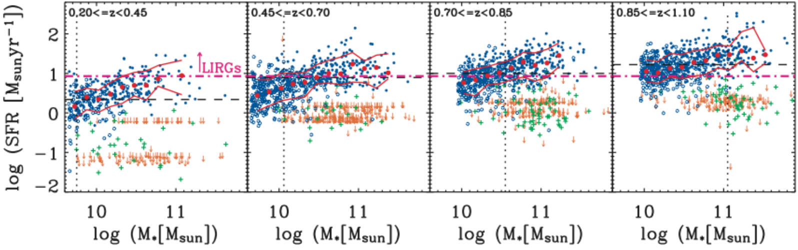
- Red galaxies are bulgy ($n \sim 4$), non star-forming and have large σ (pressure supported).
- Blue galaxies are disky ($n \sim 1$), star-forming and have small σ (rotation supported).
- **All the correlation we see in local galaxy population also holds at $z \sim 1$.**
- Whatever process made these correlations, took place before $z \sim 1$.



Bell et al (2012)

Evolution of Blue Galaxies

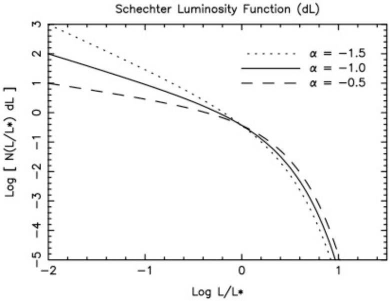
- Star formation rate in blue galaxies decrease with cosmic time in a narrow sequence.
- **The Main Sequence of Star-Forming Galaxies.**
- Narrow sequence supports steady star-formation that gradually declines, rather than bursty star-formation.

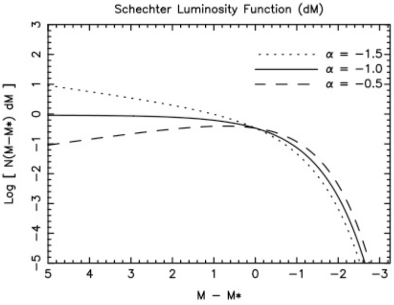


Noeske et al (2007)

Schechter Function

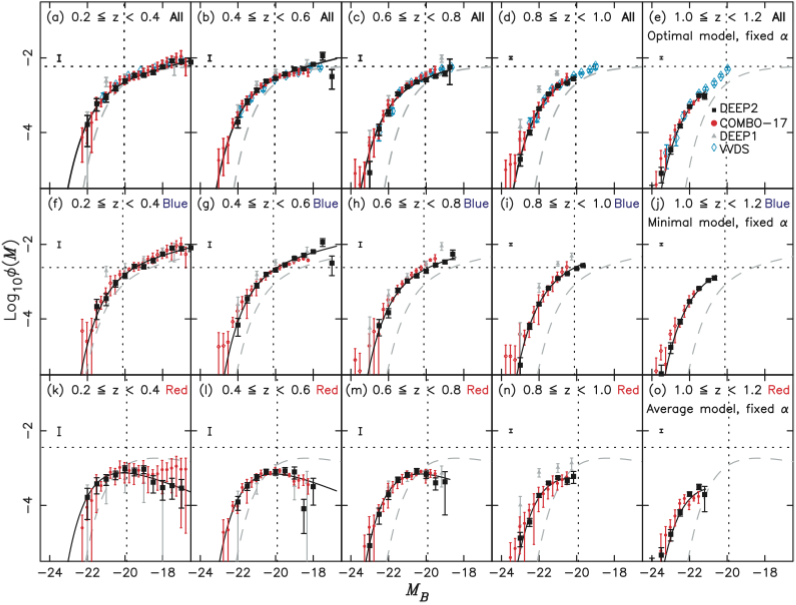
- Functional form commonly used to fit luminosity function
- $\Phi(L) = \frac{\phi^*}{L^*}\left(\frac{L}{L^*}\right)^{\alpha}\exp(-\frac{L}{L^*})$
- $\Phi(M) = \frac{\ln 10}{2.5}\phi^*\, 10^{0.4(\alpha+1)(M-M^*)}\exp(-10^{0.4(M-M^*)})$
- $L_{\text{total}} = \int_0^{\infty} L\phi(L)dL = \phi^* L^* \Gamma(\alpha+2)$





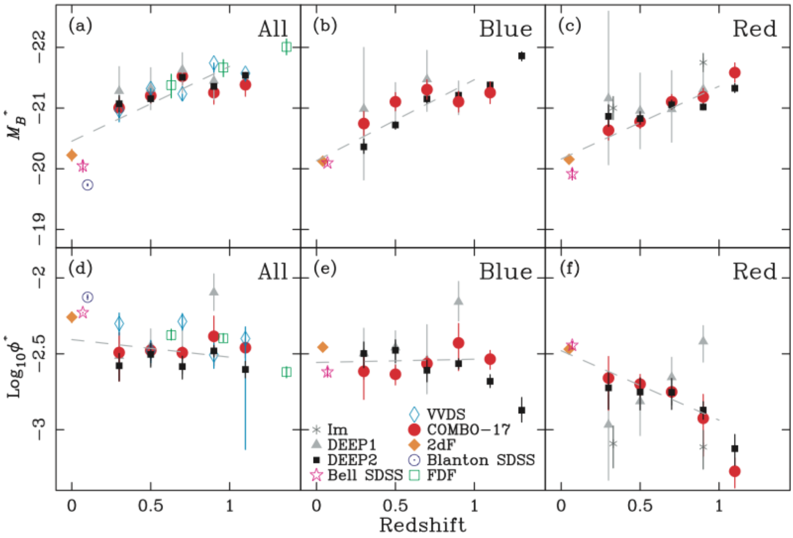
www.astro.virginia.edu/class/whittle/astr553

Evolution of Red Galaxies



Faber et al (2007)

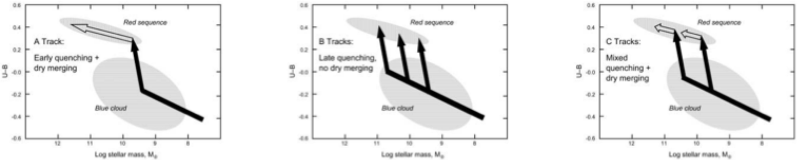
Evolution of Red Galaxies



Faber et al (2007)

Evolution of Red Galaxies

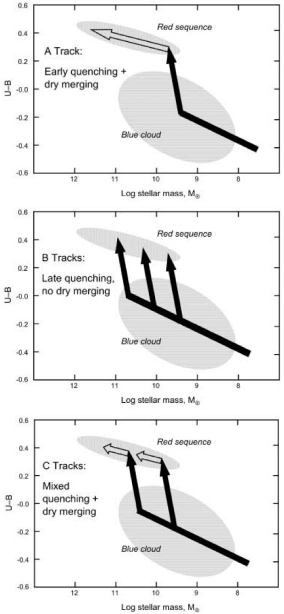
- Number of red galaxies increased by ~ 2 between $z \sim 1 \rightarrow 0$.
- This increase must be due to blue galaxies at $z \sim 1$ turn red.
- Various possible scenarios:
  - Early quenching + Dry mergers (Left)
  - Late quenching + No dry mergers (Middle)
  - "Mixed" scenario (Right)
- Constrain using known properties of local ellipticals.



Faber et al (2007)

Evolution of Red Galaxies

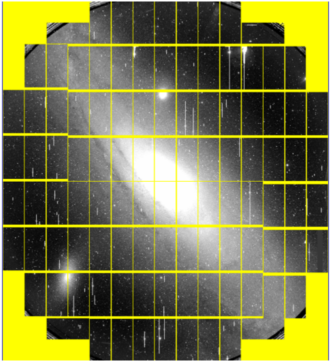
- Early quenching + Dry mergers
  - Predict vast amount of small red galaxies (not observed).
  - Large amount of dry mergers destroys age-metallicity relation.
- Late quenching + No dry mergers
  - Can not turn disk into bulge without any major mergers.
  - No disk galaxy massive enough to make the most massive ellipticals.
- Likely the mixed scenario is correct.
- **Moderate mass assembly in star-forming phase + Quenching + Moderate dry mergers.**

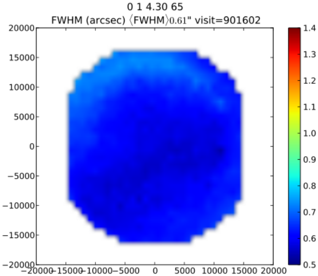


Faber et al (2007)

Hyper Suprime Cam (HSC)

- Imaging survey in 5 bands (grizy).
- 300 Subaru nights.
- 3-layer wedding cake:
  - Wide 2000 deg^2 to $i = 26$.
  - Deep 30 deg^2 to $i = 27$
  - Ultradeep 2 deg^2 to $i = 28$.
- Commissioning observing run very recently. Data looks good.

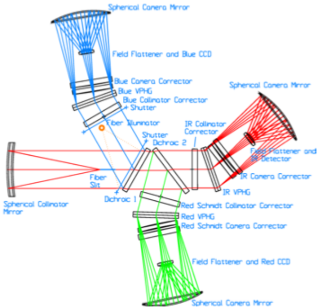


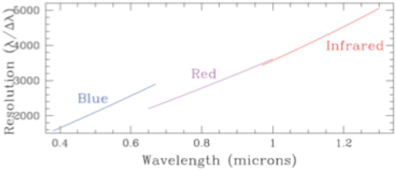


Robert Lupton

Prime Focus Spectrograph (PFS)

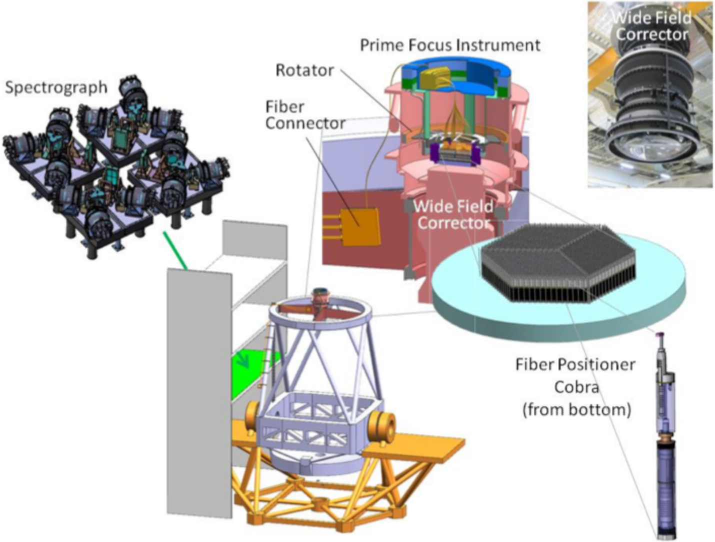
- New multi-object fiber-fed spectrograph on Subaru.
- 3 Channels, taking spectrum simultaneously from 3000Å to 1.3μm.
- 2400 spectra per exposure.
- No more "redshift desert".
- Expected to start in 2018.





Sugai et al (2012)

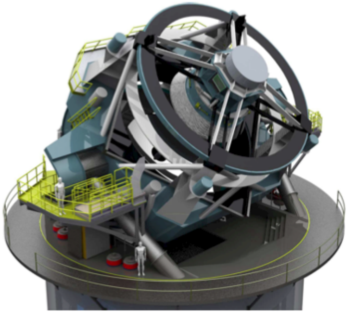
Prime Focus Spectrograph (PFS)

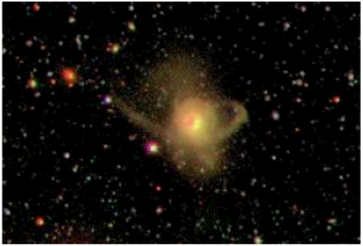


Sugai et al (2012)

Large Synoptic Survey Telescope (LSST)

- 8.4m custom-made telescope for wide-field imaging survey.
- The ultimate lensing+galaxy survey in foreseeable future.
- Expected to start by 2020.





Ivezic et al (2012)

Take-home Points

- **0th order:** Galaxy population at $z \sim 1$ is qualitatively the same as local population.
  - Two distinct groups (red & blue) already in place.
  - Red galaxies are round and has little star-formation.
  - Blue galaxies are disky and star-forming.
- **1st order:** Some evolution between then and now.
  - Star formation rate gradually decline. (Star-formation main sequence).
  - Number of red galaxies increases.
- **Implications:** Combination of wet/dry mergers and star formation quenching turns blue galaxies into red galaxies.
- **Look forward to:** HSC, PFS and LSST

Reference

- Bell et al (2004) "Nearly 5000 Distant Early-Type Galaxies in COMBO-17: A Red Sequence and its Evolution Since $z \sim 1$", 2004ApJ...608..752B
- Faber et al (2007) "Galaxy Luminosity Functions to $z \sim 1$ from DEEP2 and COMBO-17: Implications for Red Galaxy Formation", 2007ApJ...665..265F
- Noeske et al (2007a) "Star Formation in AEGIS Field Galaxies since $z = 1.1$: The Dominance of Gradually Declining Star Formation, and the Main Sequence of Star-forming Galaxies", 2007ApJ...660L..43N
- Noeske et al (2007b) "Star Formation in AEGIS Field Galaxies since z=1.1: Staged Galaxy Formation and a Model of Mass-dependent Gas Exhaustion", 2007ApJ...660L..47N
- Cooper et al (2006) "The DEEP2 Galaxy Redshift Survey: the relationship between galaxy properties and environment at $z \sim 1$" 2006MNRAS.370..198C
- Bell et al (2012) "What Turns Galaxies Off? The Different Morphologies of Star-forming and Quiescent Galaxies since $z \sim 2$ from CANDELS" 2012ApJ...753..167B