Extragalactic Science with DECam
Galaxy Evolution at z<1

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• what do we know about z<1 universe?
• unsolved problems
• DECam advantage
• the low surface brightness universe
What have we learned at $z<1$?

- blue disks (red spheroids) were more (less) common in past
- most $z<1$ star-formation occurs in disk galaxies
- galaxy merger rate evolves modestly
- typical AGN are in massive, bulge-dominated galaxies
Morphology

Assembly History

Star-formation History

SAURON, ATLAS3d

Hogg et al. 2004
Evolution in SFR density

Bouwens et al. 2009

t (Gyr)

redshift

Bouwens et al. 2009
and our results are tabulated in Table 3. Note that we have used the rest-frame $B$-band primarily as an accounting device here, calculating $M = L_B$ and using a Schechter fit to the luminosity function to correct for sample incompleteness at the faint end. Our stellar masses are actually derived using NICMOS and ground-based near-IR observations that reach significantly redder rest-frame wavelengths ($0.54–1.4\,\lambda_{\text{rest}}$) over the entire redshift range being considered here.

Regardless of the model adopted for the mass estimates, there is good evidence that the global stellar mass density increased with cosmic time. For example, for galaxies brighter than present-day $L/C3_{\text{B}}$, which are abundant in the HDF-N at all redshifts $z < 3$, the minimum estimate for $M/C2_{\text{B}}$ at $z/C2_{\text{B}} = 1$ is 7 times larger than that from the maximum-$M = L_B$ models at $z/C2_{\text{B}} = 2$.

Figure 7 places the HDF-N mass density estimates into a global context, comparing them with other data at various redshifts.
Evolution in the Galaxy Merger Rate

- Major Mergers
  - Merger rate evolves modestly
  - 0.5-1 major merger per L* galaxy since z~1

- Major+Minor Mergers
  - 1-3 minor mergers per L* galaxy since z~1

Lotz et al. 2011
How Do Galaxies Assemble?

galaxy mergers vs. gas accretion

Lacey & Cole 1993

Ceverino et al. 2009
theory: mergers v. gas accretion

Keres et al. 2009

mass accretion rate per co-moving volume

redshift

Keres et al. 2009
Unsolved problems in galaxy evolution

- inside-out growth of disks and spheroids: gas accretion and minor mergers
- quenching + spheroid formation
- assembly of the most massive galaxies
- survival of the smallest galaxies
A key to testing our understanding of galaxy formation and evolution will be to examine the full multidimensional distributions of galaxy properties. Tools in use today include the luminosity function of galaxies, the color-luminosity relations, size-luminosity relations, quantitative morphology, and the variation of these distributions with environment or local density or halo mass. As data sets and techniques evolve, models will be tested not just by their ability to reproduce the mean trends but by their ability to reproduce the full distribution in multiple dimensions. Studies of the tails of these distributions—e.g., galaxies of unusual surface brightness or morphology—give us the leverage to understand short-lived phases of galaxy evolution and to probe star formation in a wide range of environments.
Deep/Wide Extragalactic Surveys

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Figure 9 provides indications of the grasp of LSST relative to other existing or planned surveys. The height of the bar shows the solid angle covered by the survey. The color of the bar is set to indicate a combination of resolution area and depth with rgb values set to $r = \frac{V}{V_{lim}}$, $g = d_{lim} - m/n$, and $b = \theta/\theta_{lim}$, where $V$ is the volume within which the survey can detect a typical $L^*$ galaxy with a Lyman-break spectrum in the r band, $m_{lim}$ is the limiting magnitude, and $\theta$ is the resolution in arcseconds. The surveys compared in the figure are as follows: SDSS, Sloan Digital Sky Survey; MGC, Millennium Galaxy Catalog; EIS, Isaac Newton Telescope; PS1, PanSTARRS in wide survey starting in 2017 in Hawaii; DES, Dark Energy Survey; NOAO, Blanco telescope starting in 2017; ESO Imaging Survey; CADIS, Calar Alto Deep Imaging Survey; CFHTLS, Canada France Hawaii Telescope Legacy Survey; NOAO, Deep Wide Survey; COSMOS, HST o deg survey with support from many other facilities; PS1MD, PanSTARRS in Medium Deep Survey covering 5 deg$^2$; GOODS, Great Observatories Origins Deep Survey; WHTDF, William Herschel Telescope Deep Field; HDF, Hubble Deep Field and Ultra Deep Field.

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Limiting AB Magnitude

Solid angle (sq. degrees)

22 23 24 25 26 27 28 29 30

DES SNe

LSST

SDSS
SkyMapper

PS1

MCG

DES

NOAO

HTLS

CADIS

CFHTLS

GOODS

WHTDF

HDF

HUDF

HUDF

DES

PS1MD

HDF

HUDF

DES SNe

LSST

SDSS
SkyMapper

PS1

MCG

DES

NOAO

HTLS

CADIS

CFHTLS

GOODS

WHTDF

HDF

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HDF

HUDF

LSST
DECam advantages

field of view: statistics, large objects

depth: distant objects, low-surface brightness

y-band: better photz, stellar masses

what DES will not do:

• very deep fields (except for SNe fields but no y)
• special places (local galaxies, nearby clusters)
• special filters (u, narrow-band)
Unsolved problems in galaxy evolution

- inside-out growth of disks and spheroids: gas accretion and minor mergers
- quenching + spheroid formation
- assembly of the most massive galaxies
- formation + survival of the smallest galaxies

⇒ low-surface brightness universe

μ ∼ 27-29 mag per sq arcsec
Ly-alpha halos: scattering or accretion?

Stack of 92 z~3 LBGs
LRIS NB over 0.04 sq degrees
~3 fields x 10 hr exptime on Keck
need to go 10x deeper to see fluorescence?

DECam (+u, NB) for 4 sq degrees,
100x more objects in stack?

Steidel et al. 2011
Outer halos of local disk galaxies

Figure 1. Luminance filter images of nearby galaxies from our pilot survey (see Section 3 for discussion) showing large, diffuse light substructures in their outskirts: (a) a possible Sgr-like stream in Messier 63; (b) giant plumes around NGC 1084; (c) partial tidally disrupted satellites in NGC 4216; (d) an umbrella-shaped tidal debris structure in NGC 4651; (e) an enormous stellar cloud in NGC 7531; (f) diffuse, large-scale and more coherent features around NGC 3521; (g) a prominent spike and giant wedge-shaped structure seen emanating from NGC 5866 (BBO 0.5 m); (h) a strange inner halo in NGC 1055, sprinkled with several spikes of debris (RdS 0.5 m). Each panel displays a (linear) super-stretched contrast version of the total image. A color inset of the disk of each galaxy (obtained from data from the same telescope as the luminance images) has been over plotted for reference purposes. In addition, some of the original images were also cropped to better show the most interesting regions around each target.

Photometric calibration of the luminance filter (L) images is not currently available. So, to assess their depth and typical quality in terms of background and flat-fielding, we relied on images of six of our galaxies—NGC 1055, NGC 1084, NGC 3521, NGC 4216, NGC 4651, and NGC 5866—obtained by the Sloan Digital Sky Survey (SDSS; York et al. 2000; Data Release 7; Abazajian et al. 2009). Based on SDSS photometry, we derived photometric equations to convert the L-band counts into g-band magnitudes.
Outer halos of local disk galaxies

Figure 2. Way-like galaxies (see Section 4). The three central panels provide an external perspective realized through a simulation (from left to right, halo models numbered 9, 10, and 11 from Johnston et al. 2008). The tidal features labeled in the snapshots identify structures similar to those observed in our data:

- A, great circles features (Messier 63);
- SP, umbrella-shaped structures (NGC 4651);
- PD, partially disrupted satellites (NGC 4216);
- GP, giant plumes (NGC 1084);
- A, possibly mixed-type streams (NGC 1055).

(c) (A color version of this figure is available in the online journal.)
Quenching - environment, mass, AGN

Faber et al. 2007

Peng et al. 2010
Quenching - environment, mass, AGN

Faber et al. 2007

Peng et al. 2010

Heckman et al. 2004
AGN variability is detectable for $i < 24$ objects in 2-epoch, $dt = 30$ days.

What is the correlation of AGN with stellar mass, environment, color?
Spheroid galaxy assembly

Spheroidal galaxies grow outer envelopes from z~2 via ‘dry’ or minor mergers?

van Dokkum 2005, 2010; LSST Science Book
Distant major mergers

CFHTLS Deep
i-band exptime ~ 30 hours
μ_i ~ 29 mag/sq arcsec

~1500 interactions to z~1
found in 2 sq degrees
Bridge et al. 2010
Brightest Cluster Galaxy Formation

de Lucia & Blaziot 2007

Brown et al. 2007

why don’t very massive galaxies grow at z<0.7?
IntraCluster Light in Virgo

~2 degrees
μν ~ 25–26  μν ~ 26–27
μν ~ 27–28  μν ~ 28-29

Mihos et al. 2005
Ultra-faint dwarf galaxy detection

Ursa Major I dwarf satellite, $M_v = -5.5$, $d = 100$ kpc

$\mu_v \sim 27.5$

Tollerud et al. 2008 / Willman et al 2009/ LSST Science Book
Ultra-faint dwarf galaxy detection

Ursa Major I dwarf satellite, $M_V = -5.5$, $d = 100$ kpc

search for ultra-faint dwarfs in southern sky

Tollerud et al. 2008 / Willman et al 2009/ LSST Science Book
Summary

‘sweet spot’ for low-surface brightness universe
\( \mu \sim 27-28 \) mag per sq arcsec (\( \sim 10-20 \) hours of exptime)

distant galaxies -- stacking to examine outer halos

nearby galaxies/clusters -- deep, targeted observations

ultra-faint dwarfs -- blind search, deep follow-up