Luminosity and Mass Functions of Galaxies

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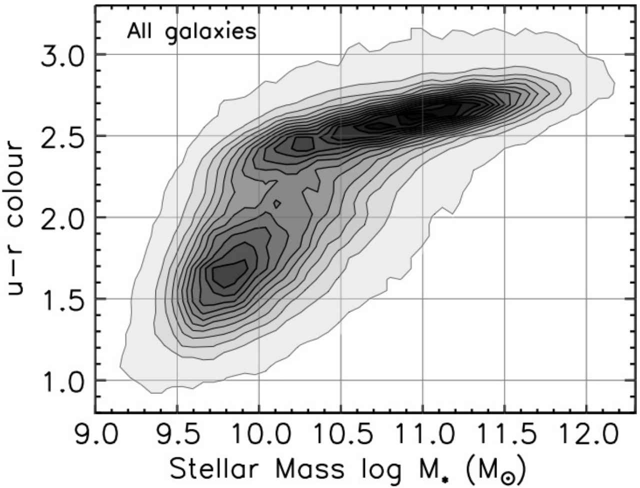
Outline

- Overview of galaxy types
- Definitions and origin of luminosity and mass functions
- Systematics
- Properties of luminosity and mass functions
- Mass-to-light ratios
- Effect of environment
- Group luminosity and mass functions


All galaxies
3.0
2.5
2.0
1.5
1.0
u−r colour
9.0
9.5
10.0
10.5
11.0
11.5
12.0
Stellar Mass log M* (M⊙)

Keel (2009).

Red and Blue Galaxies

- Blue galaxies are late types, mostly spirals and irregulars.
- Red galaxies are early types, mostly ellipticals and lenticulars.
- Early type (red) galaxies may be divided into two groups by Sérsic index.
- $n > 2$ are concentrated early types, including traditional de Vaucouleurs profile.
- $n < 2$ are diffuse early types, strongly biased toward dwarf galaxies.

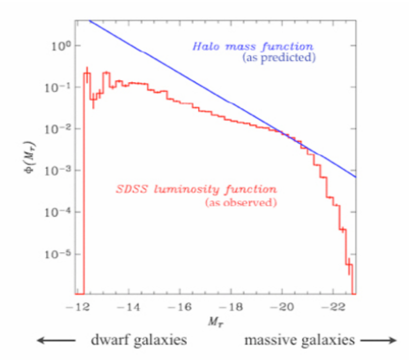
Luminosity and Mass Functions

Number density of galaxies as a function of some property of interest. May be luminosity at particular wavelengths or mass of particular components.

$$\Phi(M_\lambda) = \text{Galaxies Mpc}^{-3}\ \text{mag}^{-1} \tag{1}$$

$$\Phi(M) = \text{Galaxies Mpc}^{-3}\ \text{dex}^{-1} \tag{2}$$

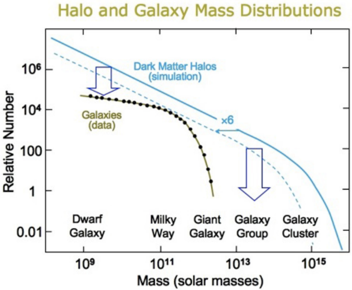
(Definitions from Blanton & Moustakas (2009)–alternative differential forms may be used.)



J. Greene, personal correspondence.

- Halo mass function is predicted to be a power law.
- Luminosity function is close to a different power law with a sharp upper limit.
- Total mass-to-light ratio is a function of luminosity.

Halo and Stellar Mass Functions



J. Greene, personal correspondence.

- Dashed line: baryonic mass function if baryons follow dark matter perfectly.
- Halo mass function extends to cluster scales.
- Star formation most efficient where curves are closest–near $L_\star$.

Physical Origins of Luminosity Function

- Near $L_\star$, star formation is efficient and LF matches expectations.
- Star formation is suppressed at higher masses:
  - virial heating in cluster-sized halos;
  - AGN feedback in most massive galaxies.
- Star formation is suppressed at lower masses (missing satellite problem):
  - gas ejected from small halos by supernova winds;
  - gas pressure suppresses collapse in small halos.
- J. Greene, personal correspondence.

Systematics

- Malmquist Bias: brighter galaxies are easier to detect and are detectable at greater distances.
- Weight galaxies by $1/V_{\max}$, the maximum volume over which they can be detected.
- $\Phi = \Sigma_i 1/V_{\max,i}$
- Accounts for many selection effects: luminosity, redshift, etc.
- Agrees well with fancier methods.
- Not strongly affected by redshift-large scale structure correlations.
- Blanton & Moustakas (2009).

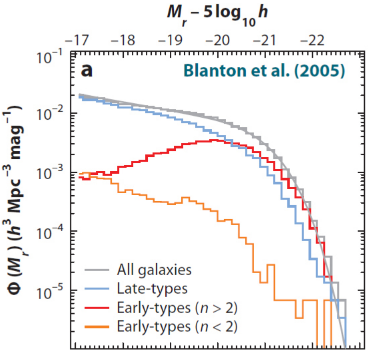
Systematics

- Oversubtraction in SDSS: largest galaxies ($\gtrsim 20''$) have backgrounds oversubtracted by $\gtrsim 20\%$ due to catching halo stars in background fluxes.
- Mostly affects nearest galaxies.
- Small effect on luminosity function, especially at high luminosities because brightest galaxies are far away.
- Blanton & Moustakas (2009).

Systematics

- Low surface-brightness galaxies: selected against due to background selection statistics.
- Estimated at $\sim$10% at $M_r - 5\log_{10} h = -17$.
- Spectroscopic surveys incomplete at lower luminosities.
- Effect on mass function is uncertain.
- O'Neil et al. (2004) suggest low surface-brightness galaxies with high HI masses $> 10^{10} M_\odot$.
- Some such galaxies are known, but their abundance is not.
- Blanton & Moustakas (2009).

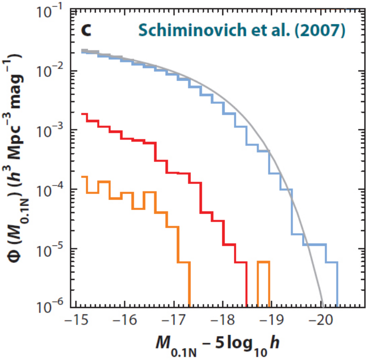
r-Band Luminosity Functions



Blanton & Moustakas (2009), Fig. 3a.

- r-band luminosity function of all (gray), late-type (blue), early type (red), and diffuse early type (orange) galaxies.
- "Early" types include most S0's and many Sa's.
- Late types most common at low luminosity.
- Early types most common at high luminosity.
- Diffuse early types follow late types.
- Converge at highest luminosities.

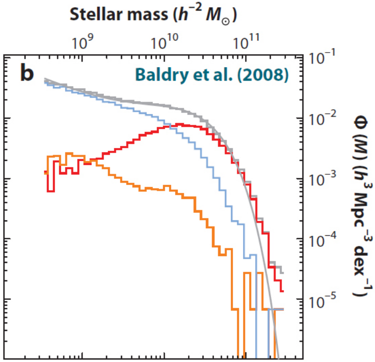
NUV Luminosity Functions



Blanton & Moustakas (2009), Fig. 3c.

- Near-UV luminosity functions derived from GALEX GR3
- 175-280 nm observations, K-corrected for $z = 0.1$.
- Indicator of star formation.
- Late types overwhelmingly dominant.
- Diffuse much lower than concentrated early types.

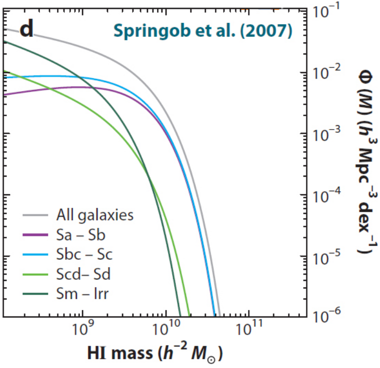
Stellar Mass Functions



Blanton & Moustakas (2009), Fig. 3b.

- Mass functions very similar to luminosity functions.
- Relatively higher for all early-types.
- Suggests difference in mass-to-light ratios.

HI Mass Functions



Blanton & Moustakas (2009), Fig. 3d.

- Mass function of HI gas–an indicator for star formation.
- Early-type HI mass function is negligible.
- Higher mass cutoff for Sa-Sc.
- More small Scd-Irr galaxies.

Mass-to-Light Ratios

- Need *stellar* mass-to-light ratios to convert luminosity function to mass function.
- (Total mass can be found dynamically.)
- Bell et al. (2003) develop conversion from luminosity and color to M/L.
- Create a grid of stellar populations with range of metalicities and star-formation histories.
- Compute colors at both observed redshift and $z = 0$ for each galaxy and fit to observations.

Systematics and Corrections

- Must assume an IMF–Bell et al. (2003) use a "diet" Salpeter IMF with fewer low-mass stars.
- K-corrections.
- Evolution corrections.
- Systematic effects of dust remain, but are mostly degenerate with stellar population.
- Galaxy age can change M/L at fixed color.
- Bursts of star formation can cause overestimate of M/L by $\sim 10\%$ when interpreted as smooth SFHs.

Mass-to-Light Ratios

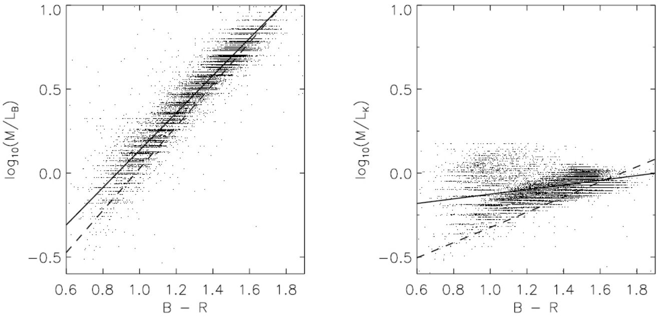


FIG. 20.—Comparison of estimated *B*-band and *K*-band stellar M/L ratios as a function of $B-R$ color for galaxies in this paper (*dots*). In both panels we show a "robust" bi-square weighted line fit (*solid line*), and the galaxy model color–M/L ratio correlations (*dashed line*) from Bell & de Jong (2001).

B-band (left) and K-band (right) mass-to-light ratios based on B-R color. Solid lines: least-squares fit.
Bell et al. (2003), Fig. 20.

Color to M/L Conversion Table

STELLAR MASS-TO-LIGHT RATIO AS A FUNCTION OF COLOR

Color	a_g	b_g	a_r	b_r	a_i	b_i	a_z	b_z	a_J	b_J	a_H	b_H	a_K	b_K
$u-g$	−0.221	0.485	−0.099	0.345	−0.053	0.268	−0.105	0.226	−0.128	0.169	−0.209	0.133	−0.260	0.123
$u-r$	−0.390	0.417	−0.223	0.299	−0.151	0.233	−0.178	0.192	−0.172	0.138	−0.237	0.104	−0.273	0.091
$u-i$	−0.375	0.359	−0.212	0.257	−0.144	0.201	−0.171	0.165	−0.169	0.119	−0.233	0.090	−0.267	0.077
$u-z$	−0.400	0.332	−0.232	0.239	−0.161	0.187	−0.179	0.151	−0.163	0.105	−0.205	0.071	−0.232	0.056
$g-r$	−0.499	1.519	−0.306	1.097	−0.222	0.864	−0.223	0.689	−0.172	0.444	−0.189	0.266	−0.209	0.197
$g-i$	−0.379	0.914	−0.220	0.661	−0.152	0.518	−0.175	0.421	−0.153	0.283	−0.186	0.179	−0.211	0.137
$g-z$	−0.367	0.698	−0.215	0.508	−0.153	0.402	−0.171	0.322	−0.097	0.175	−0.117	0.083	−0.138	0.047
$r-i$	−0.106	1.982	−0.022	1.431	0.006	1.114	−0.052	0.923	−0.079	0.650	−0.148	0.437	−0.186	0.349
$r-z$	−0.124	1.067	−0.041	0.780	−0.018	0.623	−0.041	0.463	−0.011	0.224	−0.059	0.076	−0.092	0.019

Color	a_B	b_B	a_V	b_V	a_R	b_R	a_I	b_I	a_J	b_J	a_H	b_H	a_K	b_K
$B-V$	−0.942	1.737	−0.628	1.305	−0.520	1.094	−0.399	0.824	−0.261	0.433	−0.209	0.210	−0.206	0.135
$B-R$	−0.976	1.111	−0.633	0.816	−0.523	0.683	−0.405	0.518	−0.289	0.297	−0.262	0.180	−0.264	0.138

NOTES.—Stellar M/L ratios are given by $\log_{10}(M/L) = a_\lambda + (b_\lambda \times \text{color})$, where the M/L ratio is in solar units. If *all* galaxies are submaximal, then the above zero points (a_λ) should be modified by subtracting an IMF dependent constant as follows: 0.15 dex for a Kennicutt or Kroupa IMF, and 0.4 dex for a Bottema IMF. Scatter in the above correlations is ~0.1 dex for all optical M/L ratios, and 0.1–0.2 dex for NIR M/L ratios (larger for galaxies with blue optical colors). SDSS filters are in *AB* magnitudes; Johnson *BVR* and *JHK* are in Vega magnitudes.

Bell et al. (2003), Tab. 7.

Mass-to-Light Ratio Functions

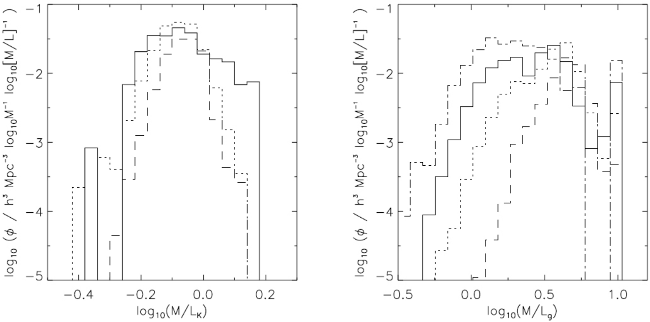
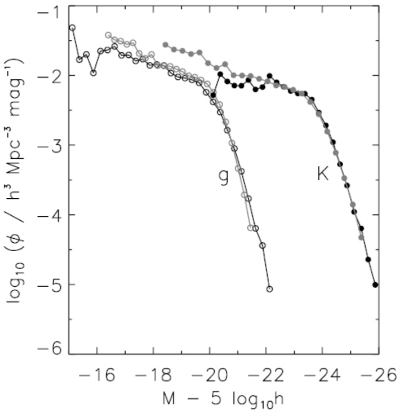


FIG. 18.—Distributions of stellar M/L ratio estimated from galaxy colors in K-band (*left*) and g-band (*right*). We show four different galaxy stellar mass bins in units of solar mass ($M_\odot$): $9 < \log_{10} Mh^2 \leq 9.5$ (*dot-dashed line*), $9.5 < \log_{10} Mh^2 \leq 10$ (*solid line*), $10 < \log_{10} Mh^2 \leq 10.5$ (*dotted line*), and $10.5 < \log_{10} Mh^2 \leq 11$ (*dashed line*). The K-band $9 < \log_{10} Mh^2 \leq 9.5$ bin is missing owing to poor number statistics.

K-band (left) and g-band (right) functions of stellar mass-to-light ratios (higher means more low-mass stars) for different total stellar masses.

Bell et al. (2003), Fig. 18.

Modeling Luminosity Functions



Bell et al. (2003), Fig. 19.

- Measured (black) and predicted (gray) g-band and K-band luminosity functions.
- Predictions from stellar mass functions from galaxy formation models divided by average stellar M/L.
- Only K-band predictions considered accurate.

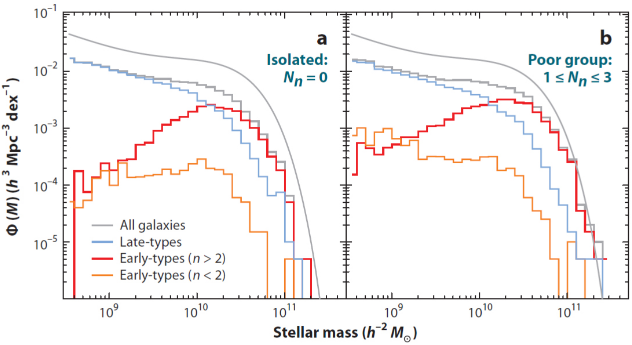
Environment

- Galaxies may be in clusters, groups, or voids, and properties correlate with environment.
- Dense environments have serious effects on galaxies: tidal interactions, mergers, ram-pressure stripping, etc.
- Estimate environment by counting number of neighbors N_n with $M_r - 5\log_{10} h < -18.5$ ($\approx L_{LMC}$).
- Neighbors counted within projected 500 h^{-1} kpc and 600 km s^{-1} (Blanton & Moustakas, 2009).

Other Measures of Environment

- Membership in a group/size of group.
- Distance to nearest neighbor.
- Kernel density smoothing.
- All measures produce similar results (Blanton & Moustakas, 2009).

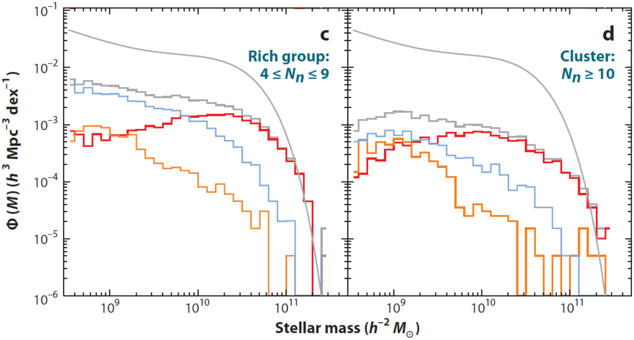
Mass Functions in Sparse Regions



Blanton & Moustakas (2009), Figs. 4a,b.

- Right panel comparable to Local Group.
- Gray curve shows model for total for all galaxies.
- Early types most common at high masses, even for isolated galaxies.
- Early types have a characteristic mass.

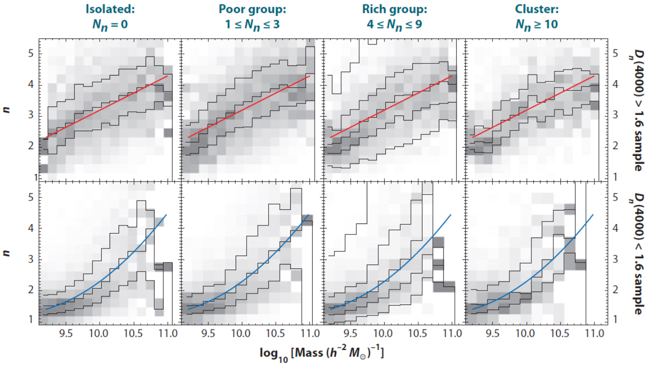
Mass Functions in Dense Regions



Blanton & Moustakas (2009), Figs. 4c,d.

- Most galaxies not in rich groups or clusters.
- But more massive galaxies and relatively more early types.
- Weaker characteristic mass for early types.
- Late types most common at low masses, even in clusters.

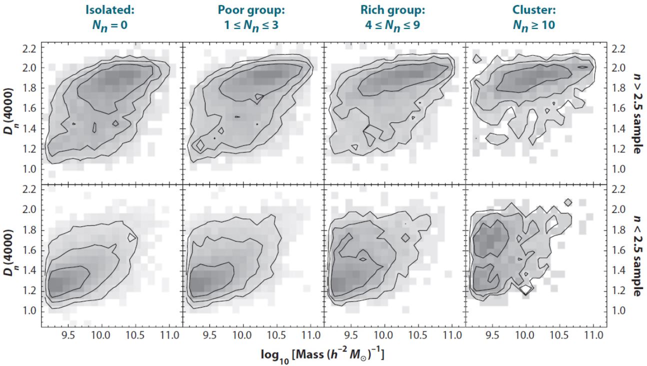
Trends with Environment



Blanton & Moustakas (2009), Figs. 6 top half.

- Trends in Sérsic indices across age and density.
- Lower for young galaxies (mostly late-type).
- Little variation with density.

Trends with Environment



Blanton & Moustakas (2009), Figs. 6, bottom half.

- Trends in $D_n(4000)$ (proxy for age) across Sérsic indices and densities.
- Higher (redder) for high Sérsic indices (mostly-early type).
- Little variation with density.

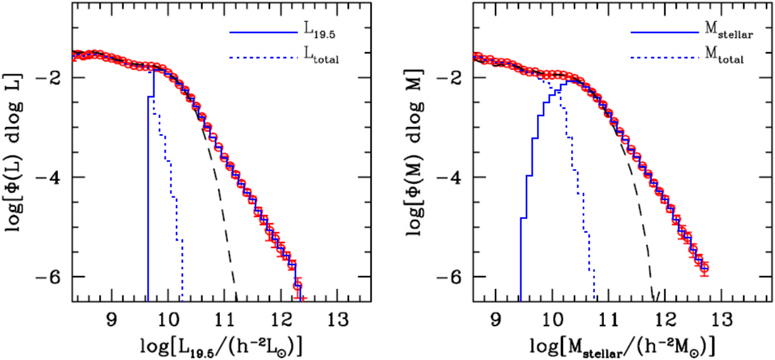
Effects of Environment

- Environment correlates stongly with proxies for star-formation history (e.g. $D_n(4000)$ or Sérsic index).
- When galaxies are classified by star-formation history, other parameters (e.g. $D_n(4000)$, Sérsic index, Hubble type, quantitative morphology parameters) are nearly uncorrelated with environment.
- Significant differences between $N_n = 0$ and $N_n = 1$.
- Degeneracy between center of small group and edge of large cluster, but Blanton & Berlind (2007) show this does not strongly affect galaxy properties.
- Only local density is important.

Effects of Environment

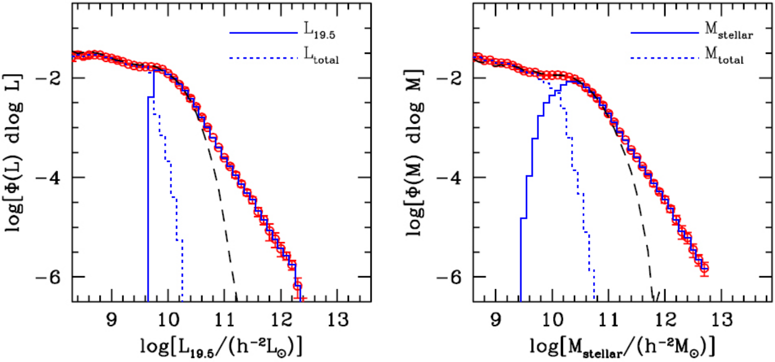
- Very close pairs of galaxies (within ~ 1 virial radius) more likely to be red and more likely to have the same morphology.
- Not clear if this is related to star formation.
- Central galaxies of clusters are larger and more diffuse than other ellipticals, and more affected by large-scale density.
- Blanton & Moustakas (2009).

Group Luminosity and Mass Functions



Yang et al. (2009), Fig. 7, top half.
Luminosity functions (left) and stellar mass functions (right) for galaxy groups.

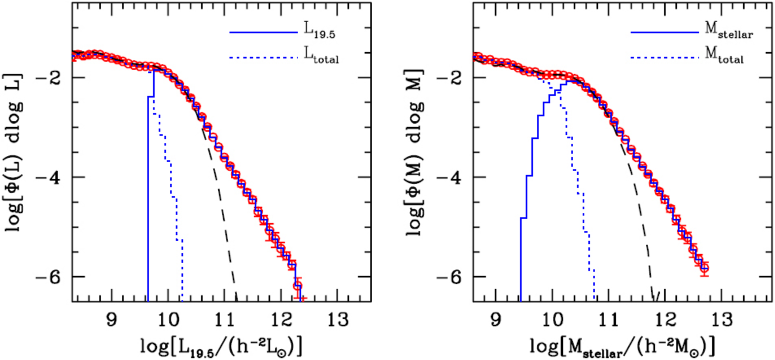
Group Luminosity and Mass Functions



Solid blue: summed luminosities and stellar masses of galaxies with $M_r \leq -19.5$.

Dotted blue: summed luminosities and stellar masses of all galaxes in clusters with no bright galaxies.

Group Luminosity and Mass Functions



Red points: sum of all groups.
Dashed black: luminosities and stellar masses of central galaxies of groups.

Summary

- Luminosity and mass functions have characteristic shapes that mostly depend on star-formation history.
- This manifests as differences between galaxy types (early vs. late) and environments.
- It is possible to reliably convert from luminosity and color to stellar mass.
- The group luminosity function more closely follows the halo mass function.

References

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