2.7 GLOBAL PROPERTIES OF GALAXIES

OVERVIEW

- Morphological properties of galaxies (interactive discussion)
- Galaxy mass function

MASS FUNCTION - DEFINITION

- Mass (luminosity) function = number density of galaxies per unit mass (luminosity) per unit co-moving volume:

$$\Phi(M) = N_{GALAXIES}\,(M)\;/\;\text{Volume}\;/dM$$

or, more formally:

$$\Phi(M) = N_{GALAXIES}\,(M)\;/\;\text{Mpc}^3\;/\;\text{dex}$$

NOTE: "dex" is the mass interval dM expressed in logarithmic units

→ $\Phi(M)dM$ = number of galaxies per Mpc^3 with mass within $M \pm dM$

CONVERTING L → M

- We usually derive stellar mass M from a galaxy luminosity L
  → we need to assume a *mass-to-light ratio* (M/L)

- M/L for a galaxy can be derived from simulations:
  (see e.g. Bell 2003ApJS..149..289B)
  - create a grid of stellar populations of different metallicity/SF histories
  - compute color in filter of interest (e.g. K-band) for all the grid
  - compare observed with simulated colors, find best-fit
    NOTE: if galaxies are at $z > 0$, must blue-shift simulated colors
  - record the M corresponding to the simulated galaxy with best-fit color
  - calculate M_{SIM}/L_{SIM}

NOTE: the color is used as a "proxy" for spectral shape of the galaxy

BUILDING A MASS FUNCTION

- We will adopt the V_{MAX} technique

  (Schmidt 1968 ApJ, 151, 393)

- References for studying:

  - Chapter 5 in:

  http://users.physics.uoc.gr/~paolo/public_data/PhD_thesis/Paolo_Bonfini_PhD_thesis.pdf

  - Johnston 2011, A&ARv, 19, 41

  - Felten 1977, AJ, 82, 861

- Procedure:

  1 - estimate the volume density represented by each galaxy ($1/V_{MAX}$)

  2 - sum the volume density within a mass bin dM

  3 - correct for selection effects (completeness-correction)

BUILDING A MASS FUNCTION - V_{MAX}

- For each sample galaxy with luminosity L (↔ M), how many objects does it represent per Mpc^3 ?

  or, similarly:

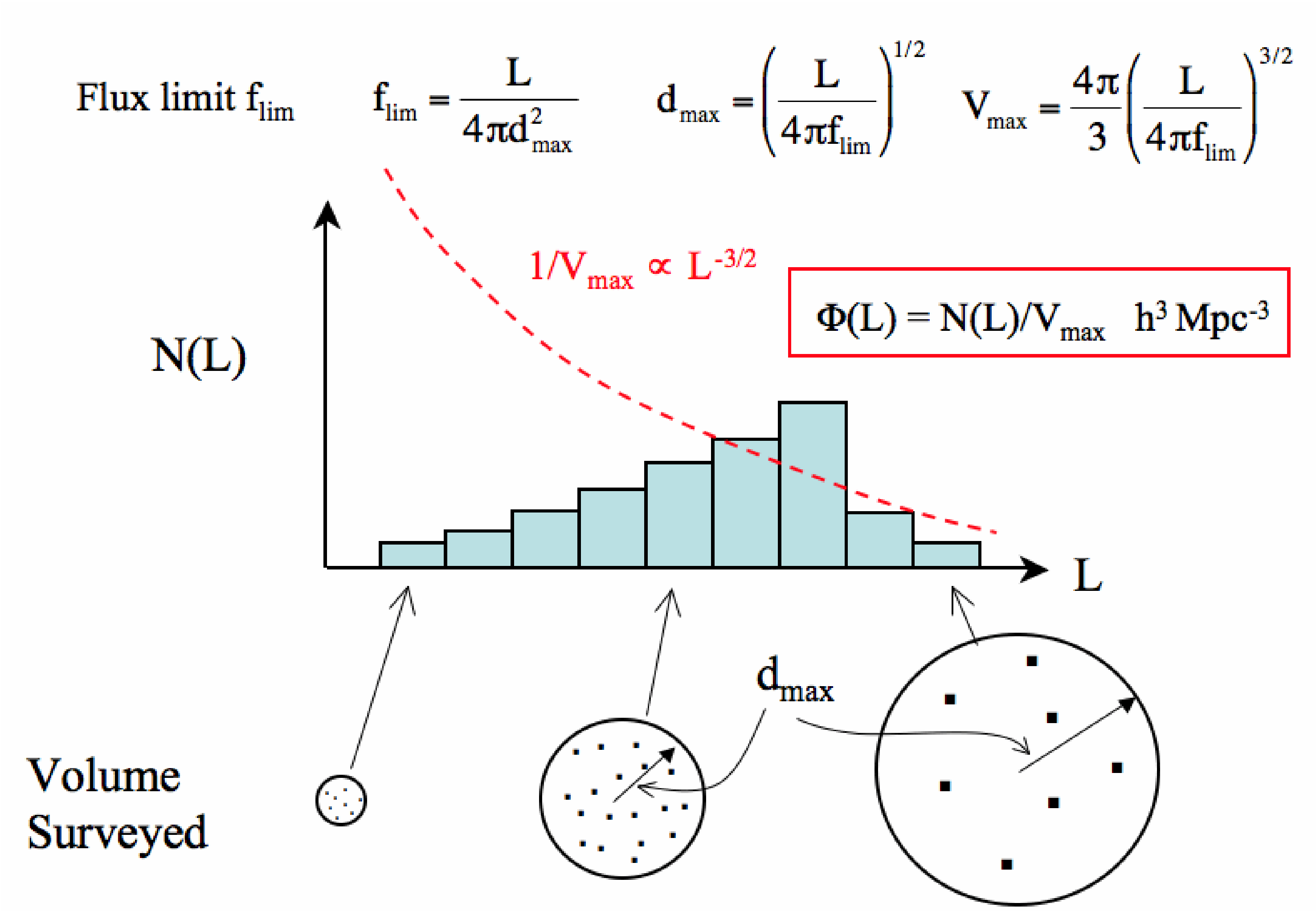
  which volume V does that galaxy represent?

  NOTE: bright objects can be detected at larger volumes ("Malmquist bias")

- V_{MAX} represents the MAX volume up to which a source of luminosity L can be observed given the sample limiting flux F_{lim}

$$V_{MAX}(L) = \frac{4\pi}{3}(\frac{L}{4\pi F_{lim}})^{3/2}$$

BUILDING A MASS FUNCTION - MALMQUIST BIAS & V_{MAX}



BUILDING A MASS FUNCTION - SUMMING VOLUME DENSITIES

- The density of sources with that L (↔ M) is therefore:

  $1/V_{MAX}(L)$ $[1/\mathrm{Mpc}^3]$

- If we select a bin dL (↔ dM), we will have N^{bin} sources

  → N^{bin} different V_{MAX}

- So how many sources per Mpc^3 does the dL bin represent?

  → source 1 contributes $1/V_{MAX1}(L_1)$ sources per Mpc^3

  → source 2 contributes $1/V_{MAX2}(L_2)$ sources per Mpc^3

  → ...

  → source N^{bin} contributes $1/V_{MAXN^{bin}}(L_N)$ sources per Mpc^3

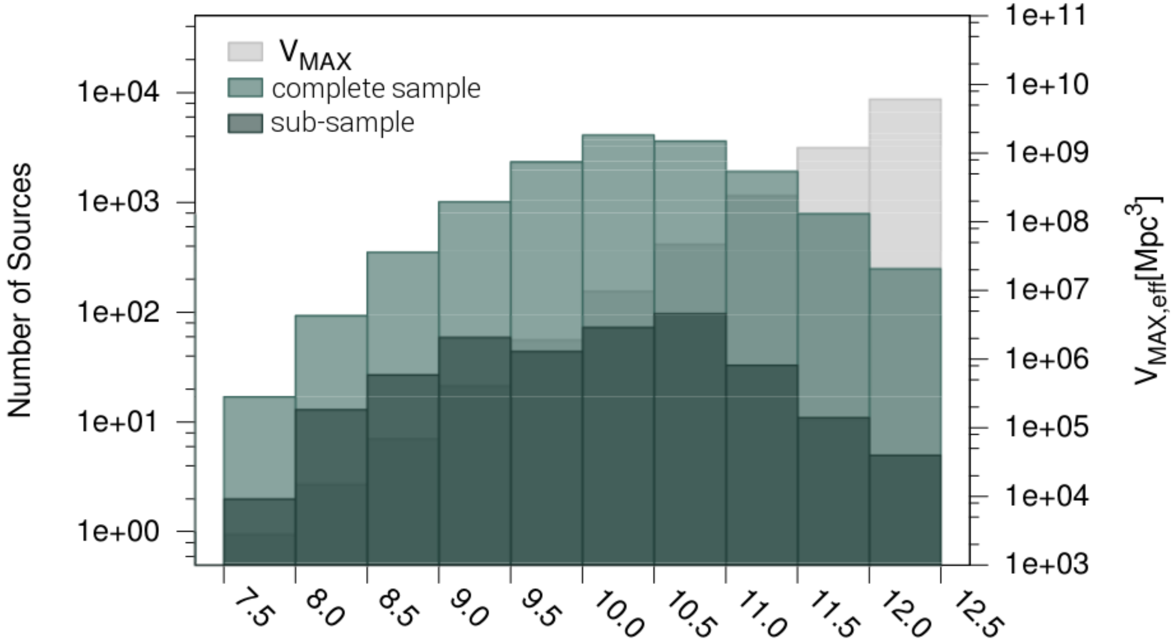
  → total:

$$\frac{dN^{bin}}{dV} = \sum_{i=0}^{N^{bin}} \frac{1}{V_{MAX}(L_i)}$$

BUILDING A MASS FUNCTION - COMPLETENESS CORRECTION

- Assuming we *know* the selection function → correct bin counts

  e.g. . we selected a sub-sample from a volume-complete sample



[Bonfini 2017]

- The correction factor is:

  $C^{bin} = N^{bin}_{COMPLETE} / N^{bin}_{SAMPLE}$

- Then, assuming an average V_{MAX} for the bin (V^{bin}_{MAX}):

$$\frac{dN^{bin}}{dV} = \frac{N^{bin} \times C^{bin}}{V^{bin}_{MAX}}$$

BUILDING A MASS FUNCTION - FINAL NOTE

- The mass function depends on the choice of cosmology

Steps which depend on the distance (hence H_0):

- converting fluxes into L

- calculating V_{MAX}

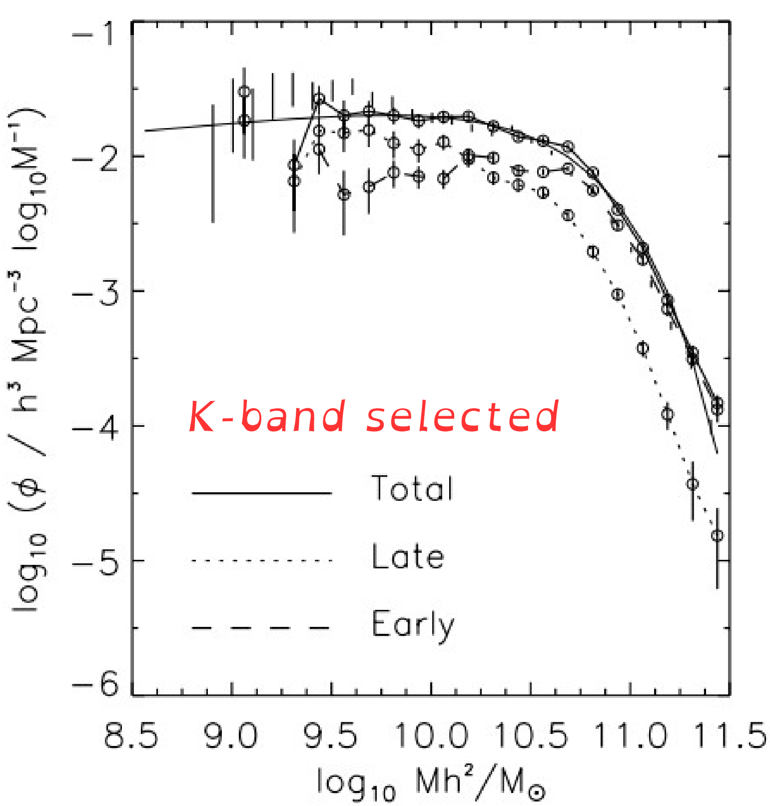
→ it is expressed in terms of:

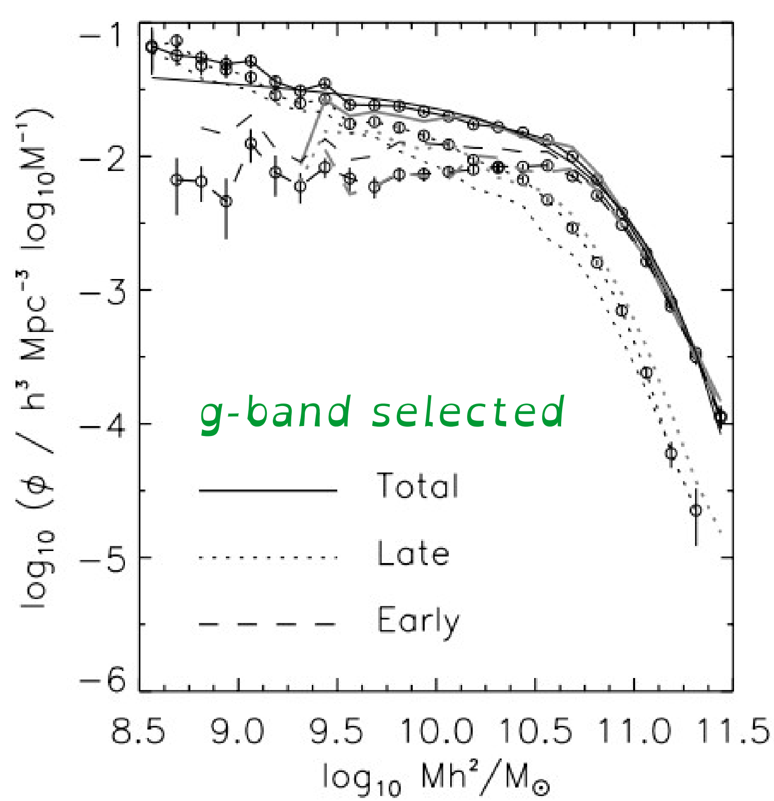
$$h = H_0 / 100$$

OBSERVED MASS FUNCTIONS - WAVELENGTH BIAS

- We can finally plot the mass function!

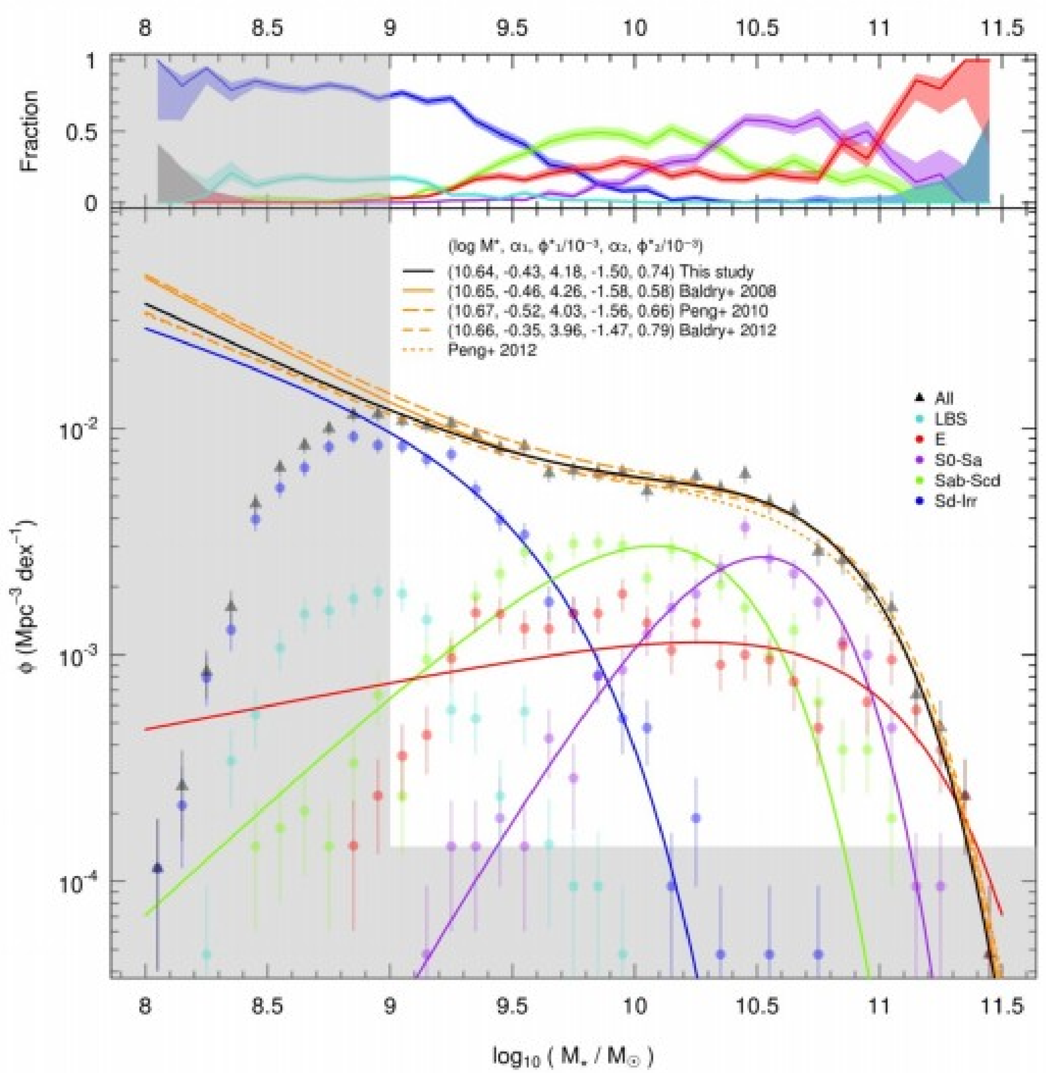
NOTE: it will vary with sample selection (e.g. F_{lim} in different bands)





[Bell 2003, Apj, 149, 289]

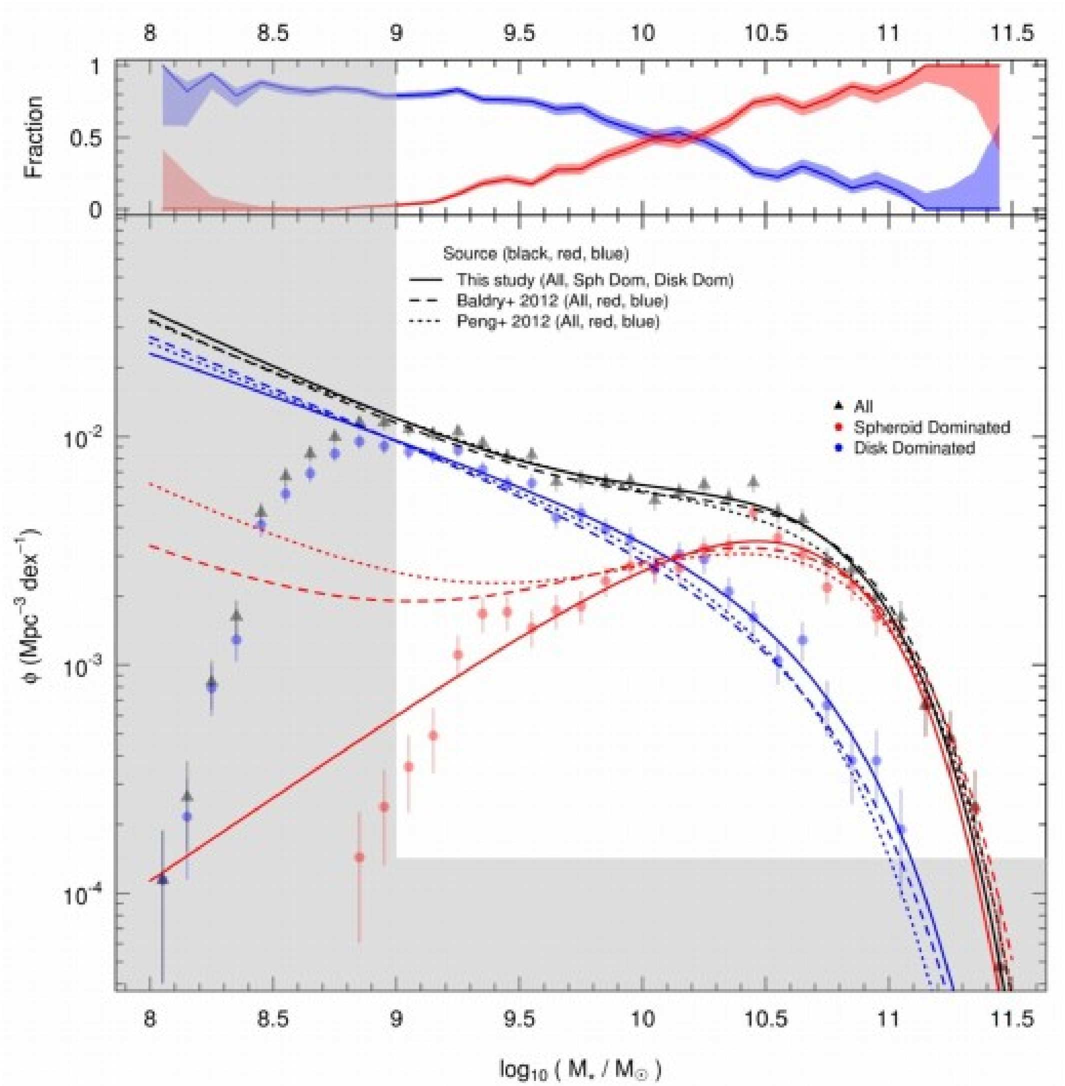
OBSERVED MASS FUNCTIONS PER HUBBLE TYPE



[GAMA Survey - Kelvin 2014 arXiv:1407.7555v1]

- Dominated by different types at different M:
  - early-types (E, S0) ↔ high M
  - late-types (Sab to Irr) ↔ low M

OBSERVED MASS FUNCTIONS PER HUBBLE TYPE

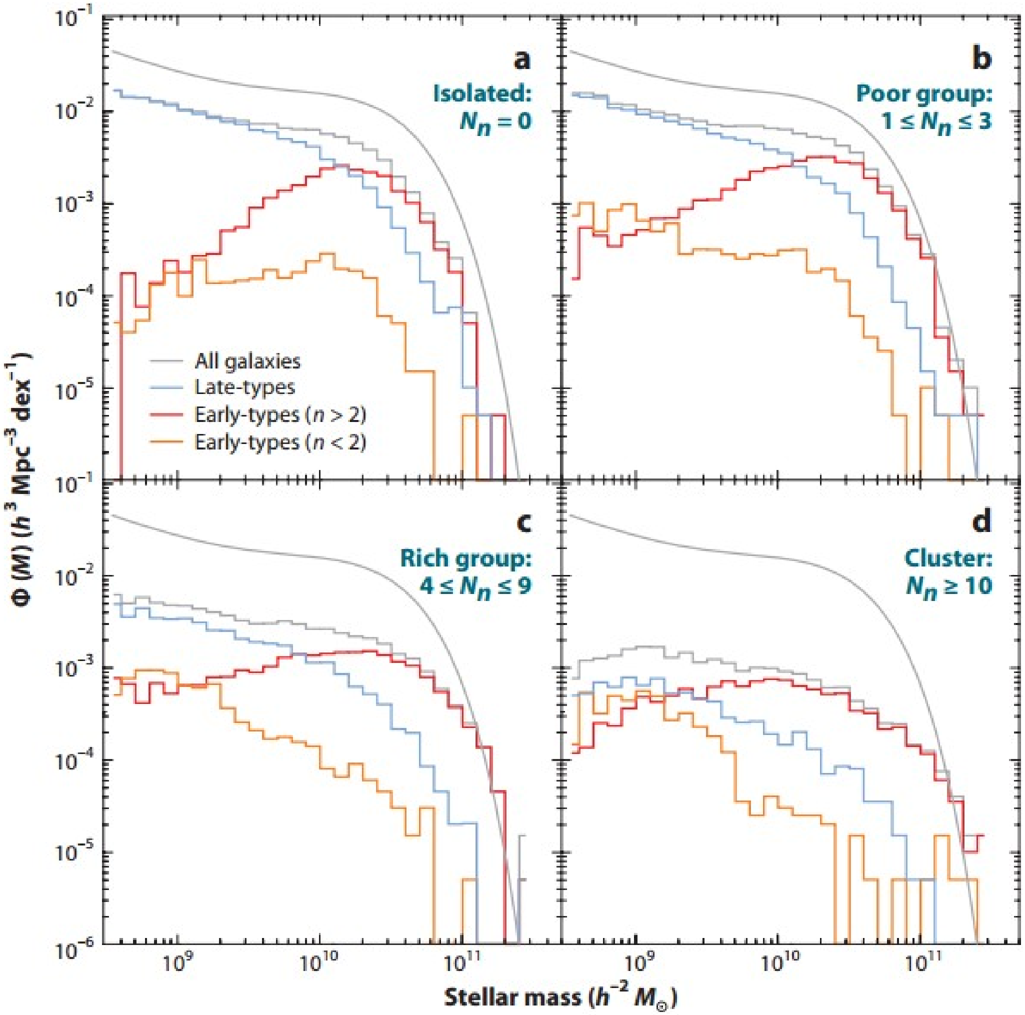


[GAMA Survey - Kelvin 2014 arXiv:1407.7555v1]

- Simplified version:
  - bulge-dominated ↔ high M
  - disk-dominated ↔ low M
- M ~ $10^{10.5}$ $M_\odot$
  → mass of “inversion”

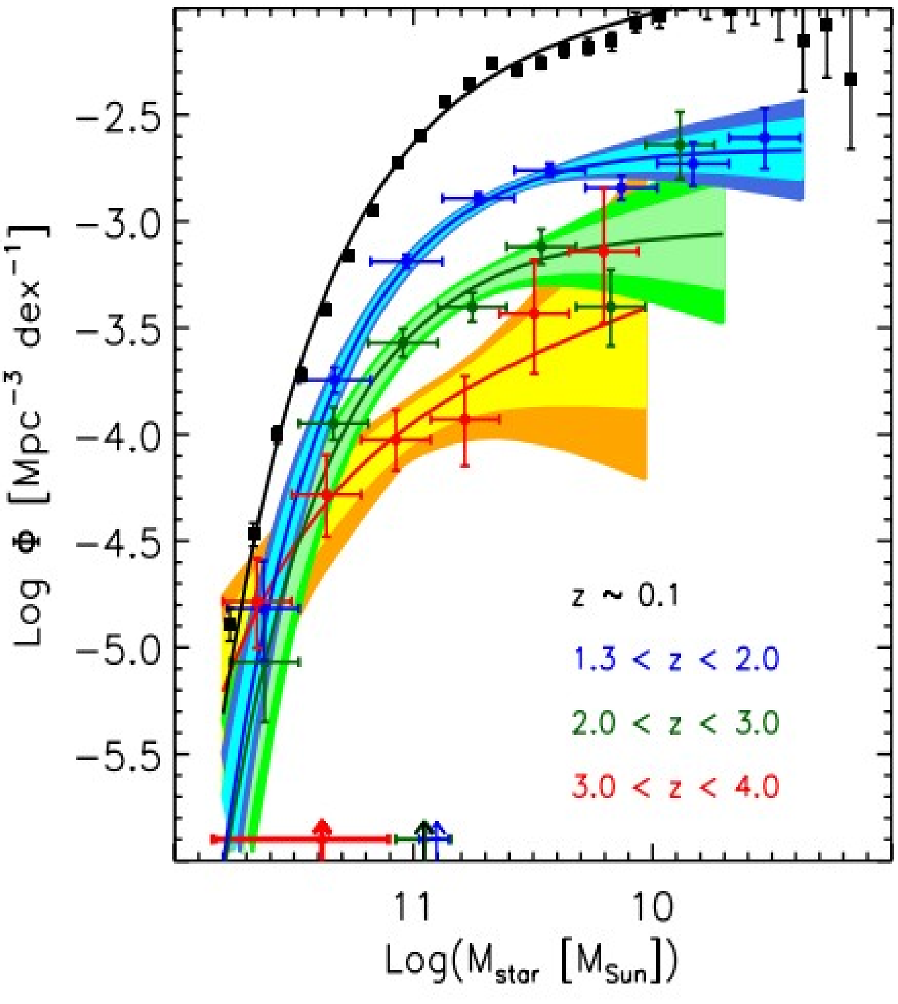
MASS FUNCTION - ENVIRONMENT

- Massive early-type galaxies relatively more abundant in denser environments
- Small late-type galaxies totally dominate the “field”
- The question: “Are there more spirals or ellipticals?” Depends on *where*.



[SDSS – Blanton 2009, ARA&A, 47, 159]

MASS FUNCTION EVOLUTION



[Marchesini 2009, ApJ, 701, 1765]

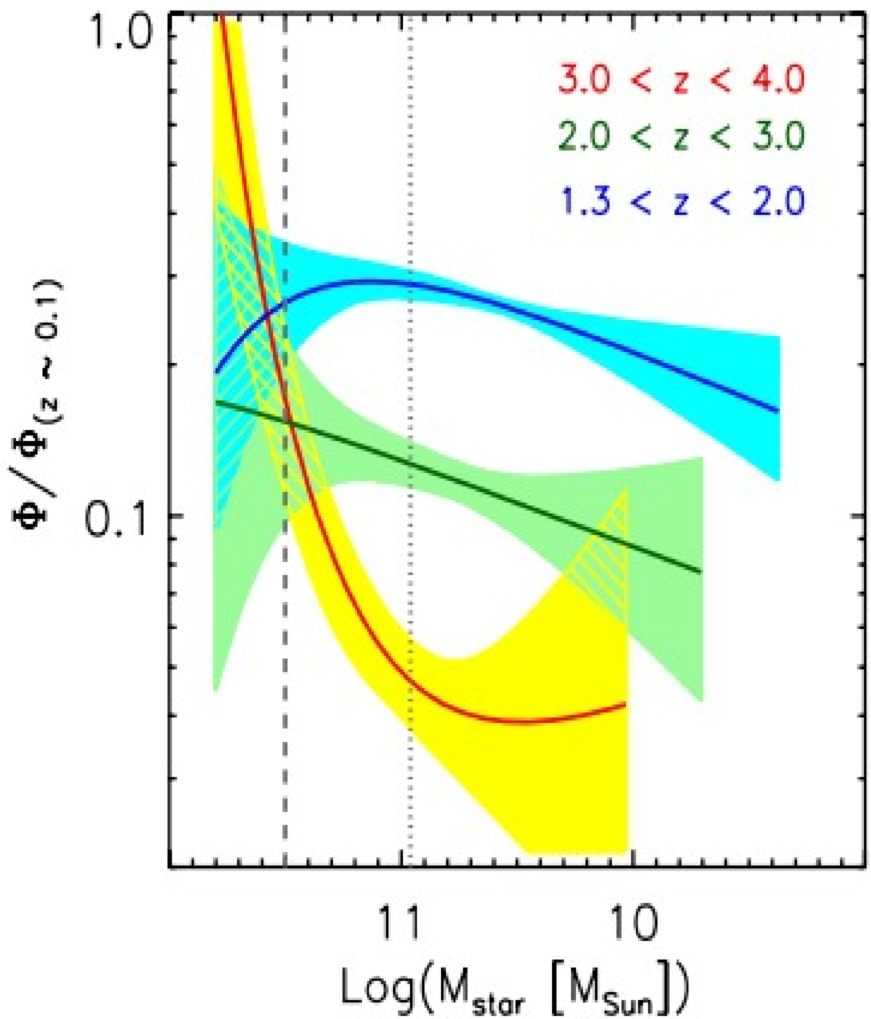
- Normalization evolves dramatically
  → especially between z~0 and z~1

- Shape stays roughly the same

- Indication for lack of creation of new massive galaxies (since at least z~2)

→ let's see this in an other way

MASS FUNCTION EVOLUTION



[Marchesini 2009, ApJ, 701, 1765]

← *Ratio between mass function at z and mass function at z~0*

- Massive galaxies were relatively more abundant in the past

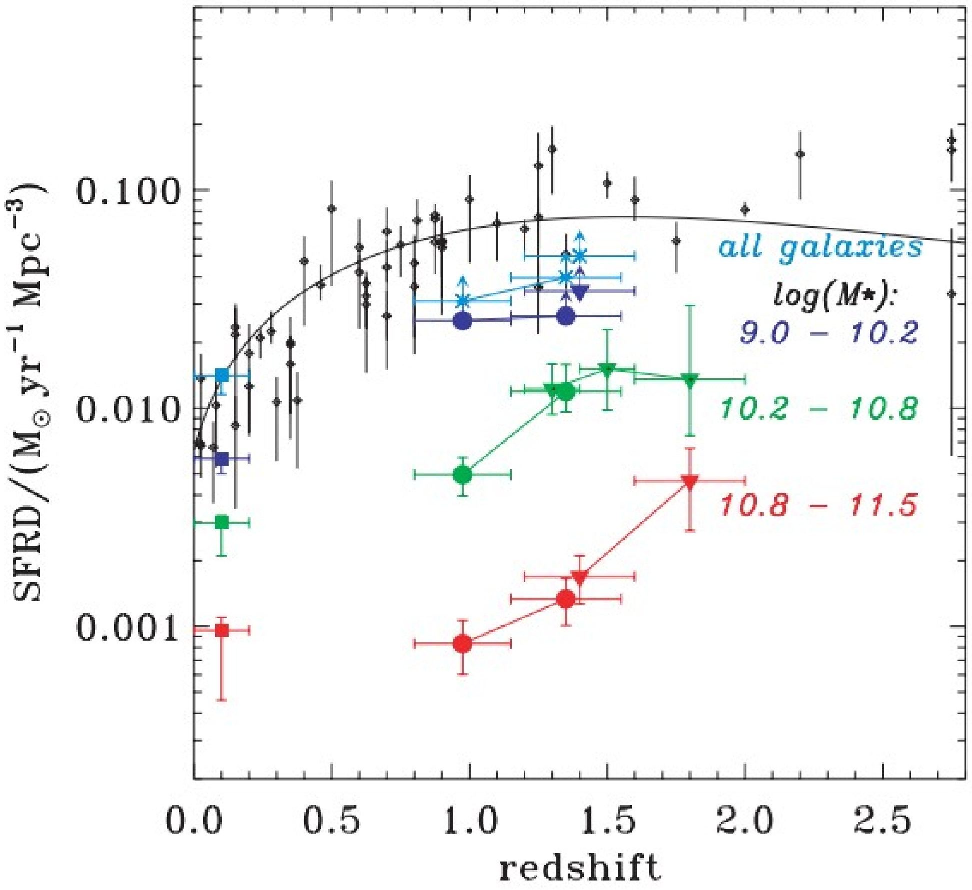
STAR FORMATION RATE DENSITY FUNCTION

- One more way to see it → star formation rate density function

- Massive galaxies ceased star-formation at z~2

- Lower mass galaxies keep being active

- This is known as "downsizing":
  - early assembly of massive gal.?
  - SF quenching mechanisms? (e.g. AGN/shock feedbacks)



[Juneau 2005, ApJ, 619, 135]

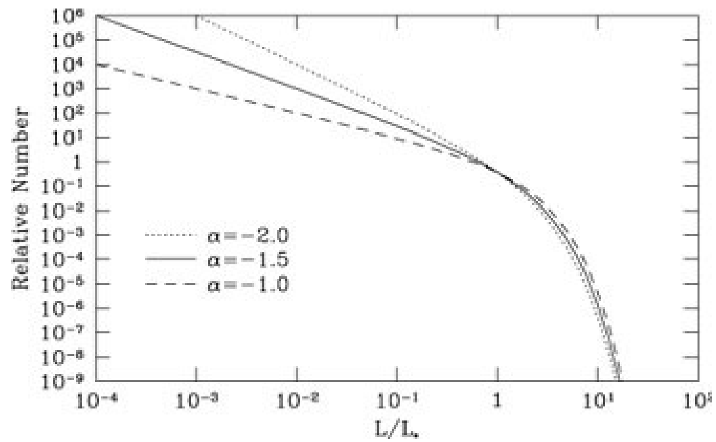
MASS FUNCTION –

FUNCTIONAL FORM

- Schechter (1976, ApJ, 203, 297) provided the first analytic form:

$$\phi(L)\, dL = N_* \left(\frac{L}{L^*}\right)^{\alpha} exp\left(-\frac{L}{L^*}\right) d\left(\frac{L}{L^*}\right)$$

$$\phi(M)\, dM = \phi^* \left(\frac{M}{M^*}\right)^{\alpha} \exp\left(-\frac{M}{M^*}\right) \frac{dM}{M^*}$$



where:

- Φ_* is the normalization (sometimes written as N_*)

- for M << → Φ(M) ~ power law (of index α)

- for M >> → Φ(M) ~ exponential

- M* → power law/exponential transition point

- integral diverges for α < -1 → real functions are truncated at low M

NOTE: This is an empirical function

MASS FUNCTION – PRACTICAL FORM

- Using real data, dM cannot be infinitesimal

  → convenient to plot $\Phi(M)dM$ vs. $d(\log_{10}(M))$ (re-writing $d(M/M^*)$)

$$M = 10^{(\log 10(M))}$$

$$dM = 10^{(\log 10(M))} \ln(10)\, d(\log_{10}(M))$$

$$d(M/M^*) = 10^{(\log 10(M))} \ln(10)\, d(\log_{10}(M)) \,/\, M^*$$

- Then, we can write:

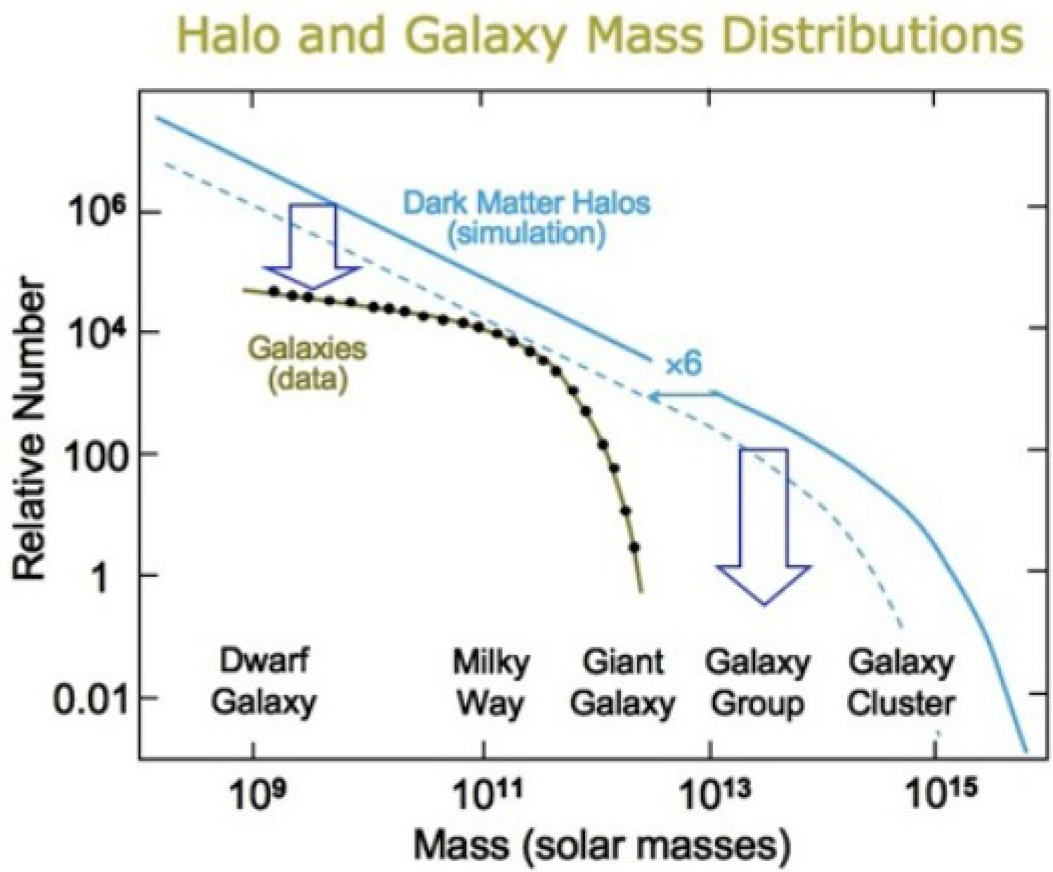
$$\Phi(M)dM = \Phi_* \,(M/M^*)^{\alpha} \exp(-M/M^*)\, d(M/M^*)$$

$$\Phi(M)dM = \Phi_* \,(M/M^*)^{\alpha} \exp(-M/M^*) \,[\, 10^{(\log 10(M))} \ln(10)\, d(\log_{10}(M)) \,/\, M^* \,]$$

$$\Phi(M)dM = \Phi_*/M^* \,(M/M^*)^{\alpha} \exp(-M/M^*)\, M \ln(10)\, d(\log_{10}(M))$$

MASS FUNCTION –
DARK MATTER vs BARYONS

- DM mass function expected to be power law at almost all scales



http://www.astro.princeton.edu/~jgreene/AST542/Alex2013.pdf

MASS FUNCTION –

DARK MATTER vs BARYONS

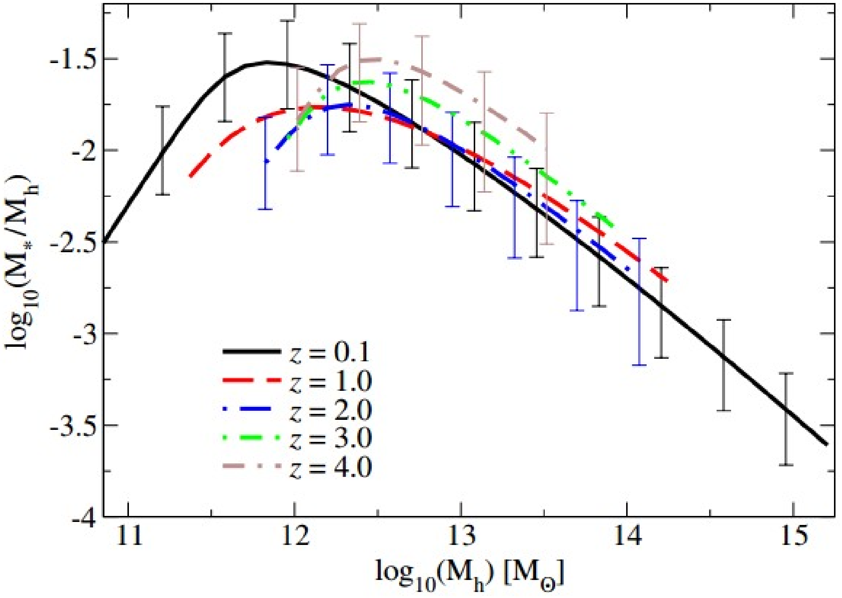
- The ratio between baryon and DM densities gives the "efficiency" of star-formation per *total* mass

  NOTE: requires "abundance matching technique"

  (see https://ned.ipac.caltech.edu/level5/Sept13/Silk/Silk11.html)

- The peak of "efficiency" at z~0 is just about the mass of MW!

- With time, the peak moves to lower masses (*downsizing*)



[Behroozi 2010, ApJ, 717, 379]