Astr 511: Galaxies as galaxies

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Lecture 4:

Luminosity and mass functions of galaxies: I

Outline

- Luminosity function: basic concepts
- Stellar mass function in the Milky Way
- Methods for estimating LF from data (Lecture 5)

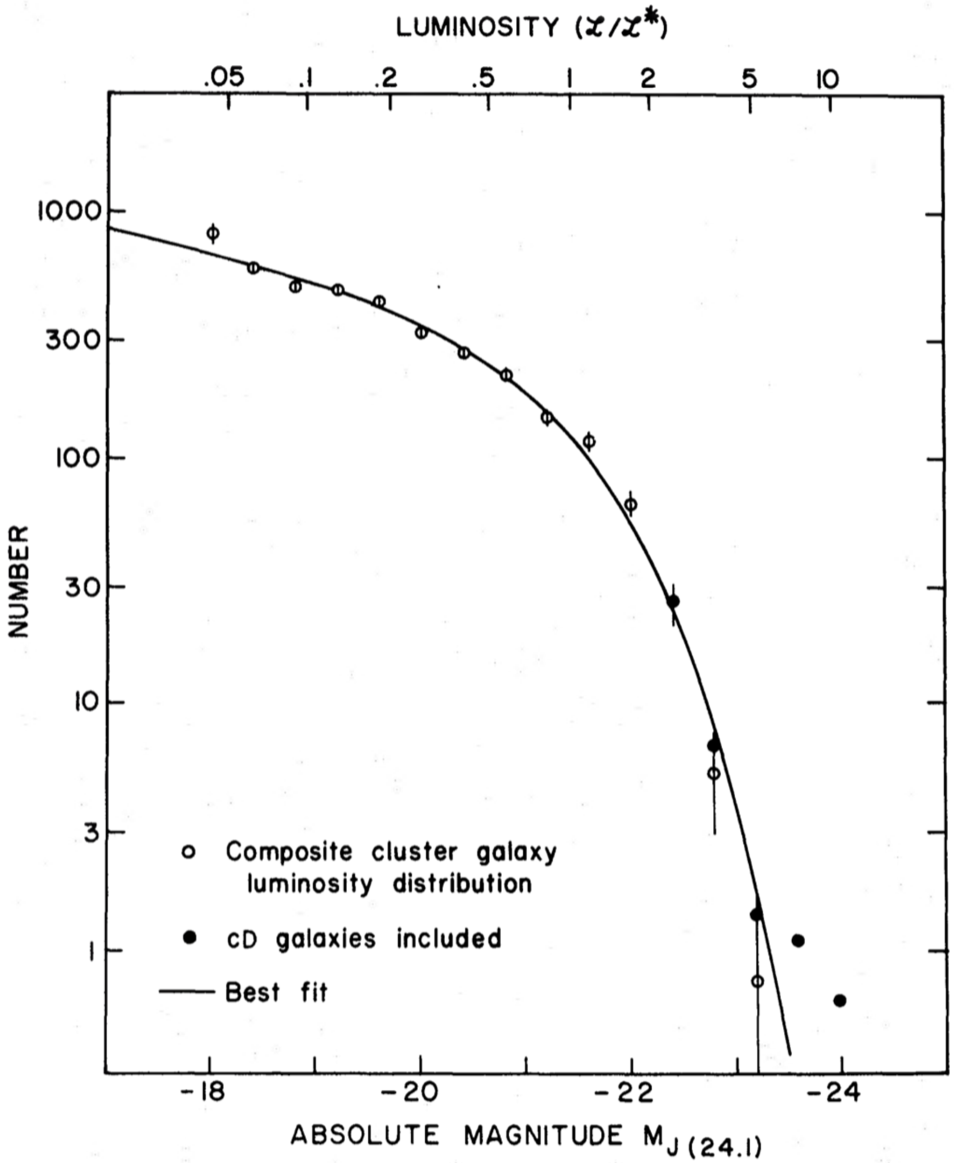


FIG. 2.—Best fit of analytic expression to observed composite cluster galaxy luminosity distribution. Filled circles show the effect of including cD galaxies in composite.

Luminosity Function

- The Luminosity Function gives the expected number of galaxies in some volume of space, per luminosity (or magnitude) interval.
- Left: a figure from the paper that introduced the so-called Schechter function (Schechter, 1976, ApJ, 203, 297)

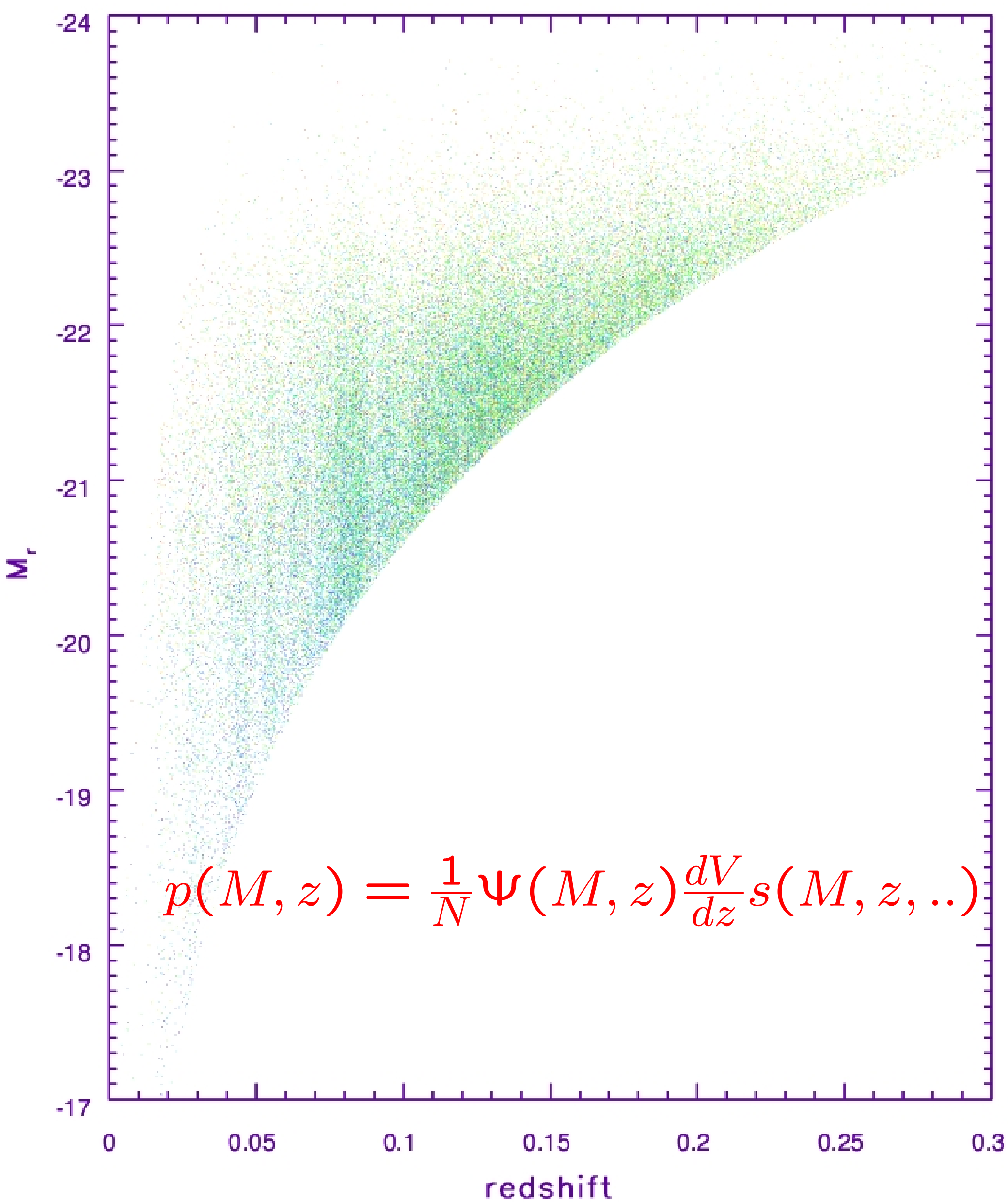
Luminosity Function

- Often, this is a separable function: $\Psi(M, z) = \Phi(M)\, n(z)$, where $\Phi(M)$ is the absolute magnitude (i.e. luminosity) distribution, and $n(z)$ is the number volume density.

- Luminosity is a product of flux and distance squared (ignore cosmological effects for simplicity): $L = 4\pi D^2 F$

- Note that the samples are usually *flux-limited* (meaning: all sources brighter than some flux limit are detected) – the minimum detectable luminosity depends on distance: $L > 4\pi D^2 F_{min}$, or for absolute magnitude $M < M_{max}(D)$ (c.f. the first plot). This introduces a bias which needs to be corrected (e.g., using Lynden-Bells C^- technique)

Luminosity Function



- More generally, the Luminosity Function is the distribution in the luminosity–distance plane; how many galaxies per unit interval in luminosity and unit volume (or redshift): $\Psi(M,z)$
- Imagine a tiny area with the widths ΔM_r and Δz centered at some M_r and z in the plot to the left: count the number of galaxies, divide by $\Delta M_r \Delta z$, correct for the fraction of sky covered by your survey, and for the selection probability (a function of M_r, z, and possibly many other parameters): this gives you $\Psi(M,z)$.

Schechter Function

Observationally, we find that galaxy luminosity distribution resembles a power-law, with an exponential cutoff.

This distribution is usually modeled by Schechter function:

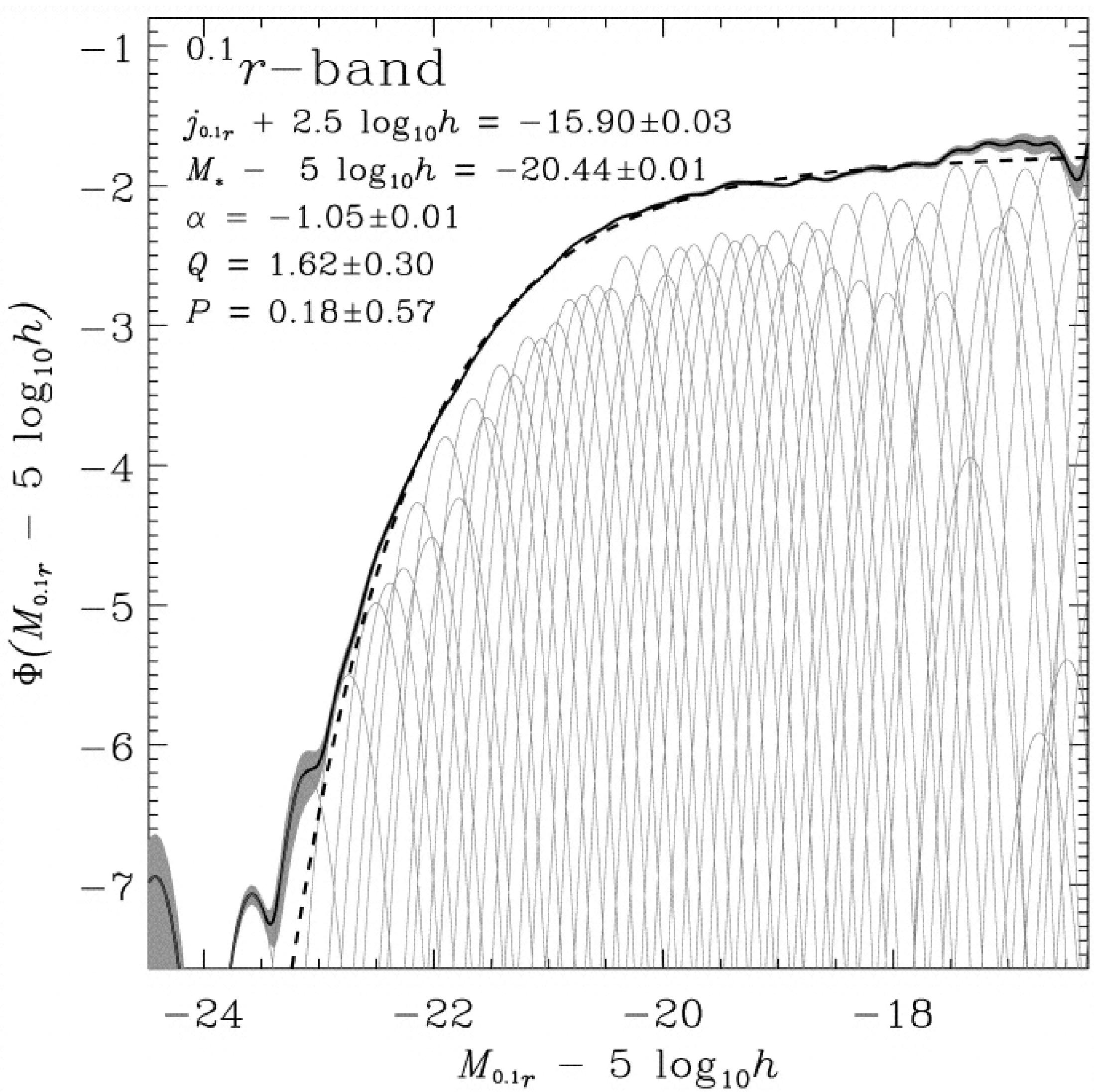
$$\Phi(L) = \Phi^* \left(\frac{L}{L_*}\right)^{\alpha} \mathrm{e}^{-L/L_*} \tag{1}$$

named after Schechter, who first proposed it (Schechter 1976).

Or using absolute magnitudes:

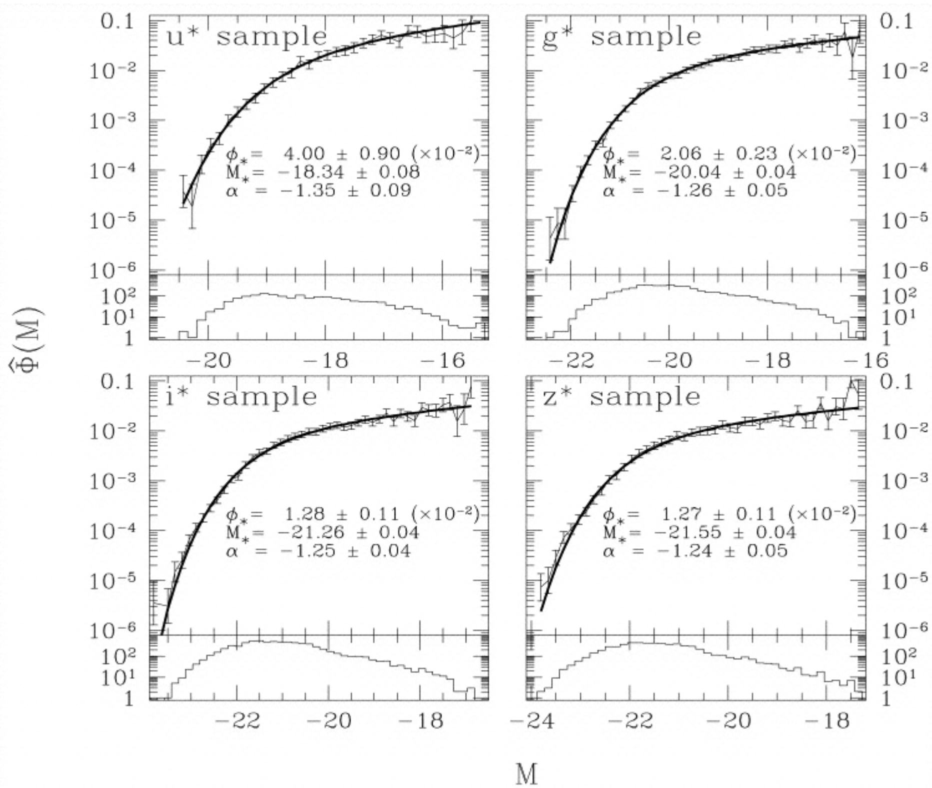
$$\Phi(Mr) = 0.4\Phi^* \, \mathrm{e}^{-0.4(\alpha+1)(Mr-M^*)} \, \mathrm{e}^{-\mathrm{e}^{-0.4(Mr-M^*)}} \tag{2}$$

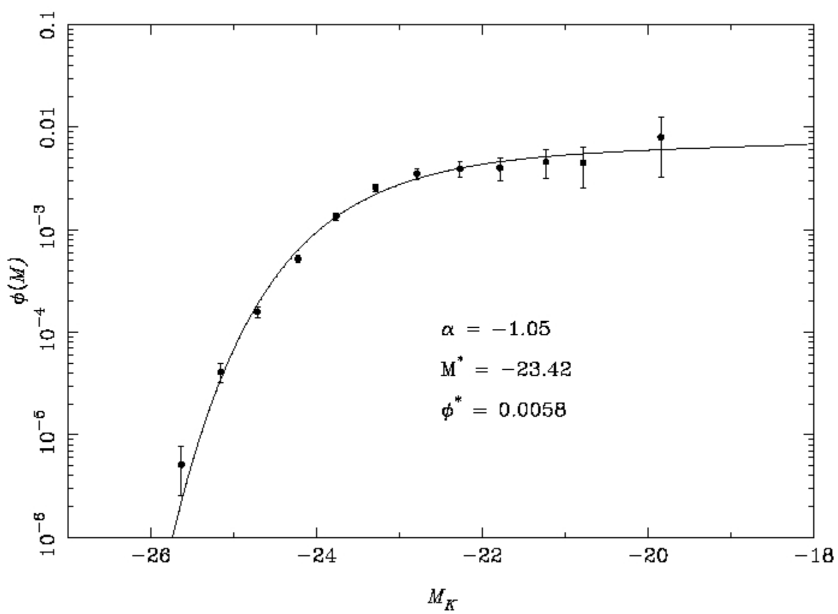
Example: The LF in the SDSS r band



Note: this LF cannot be expressed as $\Phi(M, z) = f(M)\, g(z)$ – not separable!

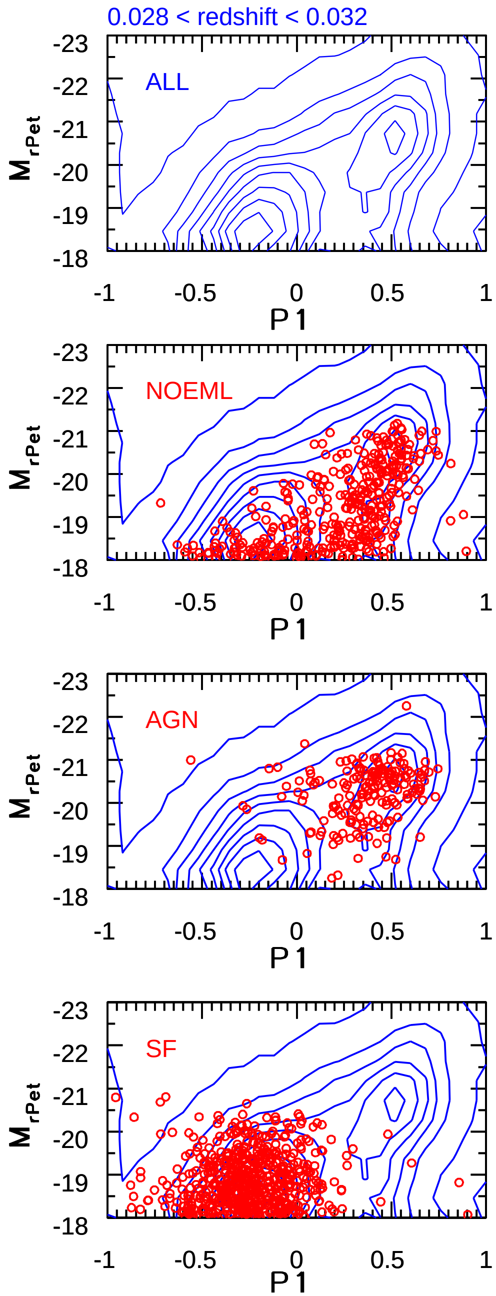
- The thick solid line is the measured SDSS r band luminosity function (the gray band is its uncertainty).
- The dashed line is a Schechter-like fit that also includes the effects of changing luminosity and the number density with time (i.e. distance, or redshift). $Q > 0$ indicates that galaxies were more luminous in the past, and $P > 0$ that galaxies were more numerous in the past. For detailed discussion, see Blanton et al. 2003 (Astronomical Journal, 592, 819-838)





The dependence of LF on wavelength

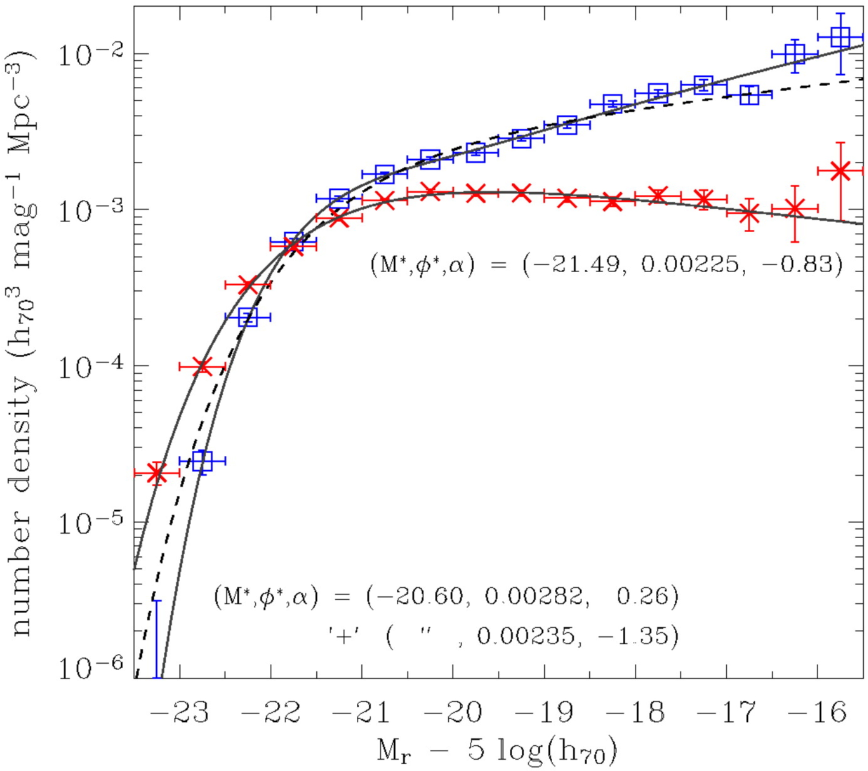
- Top: SDSS ugiz bands
- Bottom: 2MASS K band
- The Schechter function is still a good fit, but best-fit parameters vary.



The dependence of LF on galaxy type

- The top panel shows the distribution of SDSS galaxies in the absolute magnitude – color plane (in a narrow redshift range)
- In the bottom three panels, the same distribution is compared to the distributions for subsamples selected by their emission line properties
- Note that the most luminous galaxies ($M_r < -20$) are predominantly red ($P1 > 0.2$), while faint galaxies ($M_r > -19$) are blue ($P1 < 0.2$)

The dependence of LF on galaxy type



- The comparison of LFs for blue and red galaxies (from Baldry et al. 2004, ApJ, 600, 681-694)
- The red distribution has a more luminous characteristic magnitude and a shallower faint-end slope, compared to the blue distribution
- The transition between the two types corresponds to stellar mass of $\sim 3 \times 10^{10}$ $M_\odot$
- The differences between the two LFs are consistent with the red distribution being formed from major galaxy mergers.

Stellar Mass Function

- Analogously to luminosity function, the mass function is the distribution of mass of stars, galaxies, etc.

- The term *Stellar mass function* can refer to the distribution of galaxies with respect to their stellar mass (mass of all their stars), or to the distribution of mass of stars in the Milky Way.

- The distribution of mass of stars in the Milky Way is often parametrized by a power law, $dN/dM \propto M^{-\alpha}$, with $\alpha = 2.35$ (called Salpeter function in this context; FYI: power law is called the Pareto distribution in statistics...)

- Kroupa, Tout & Gilmore (1993, MNRAS 262, 545) proposed a three-part power law

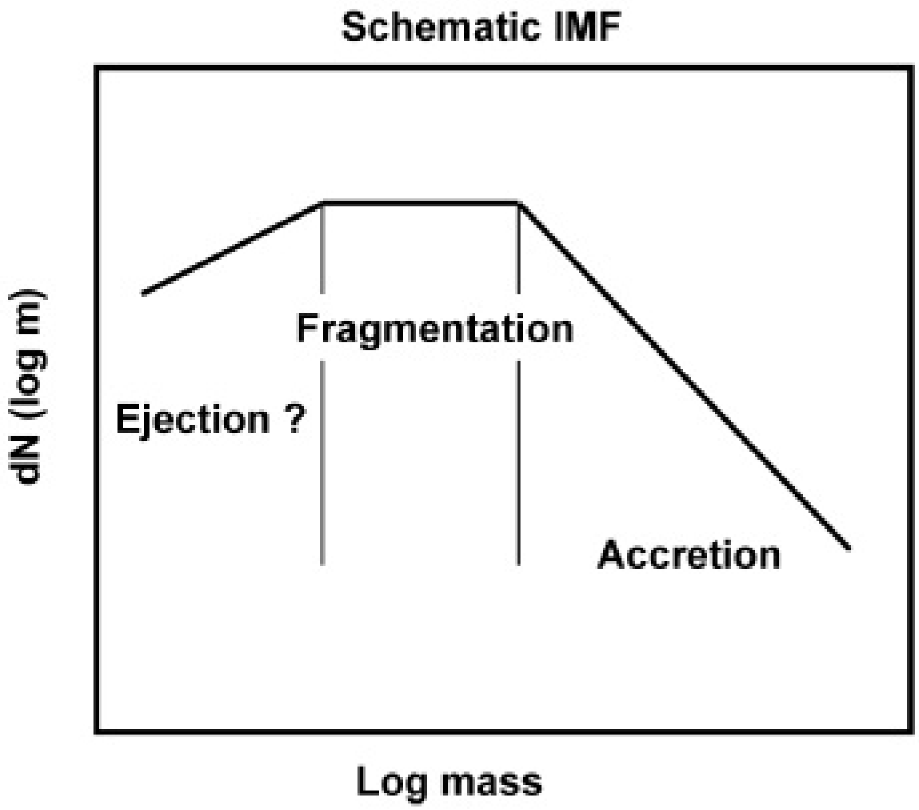


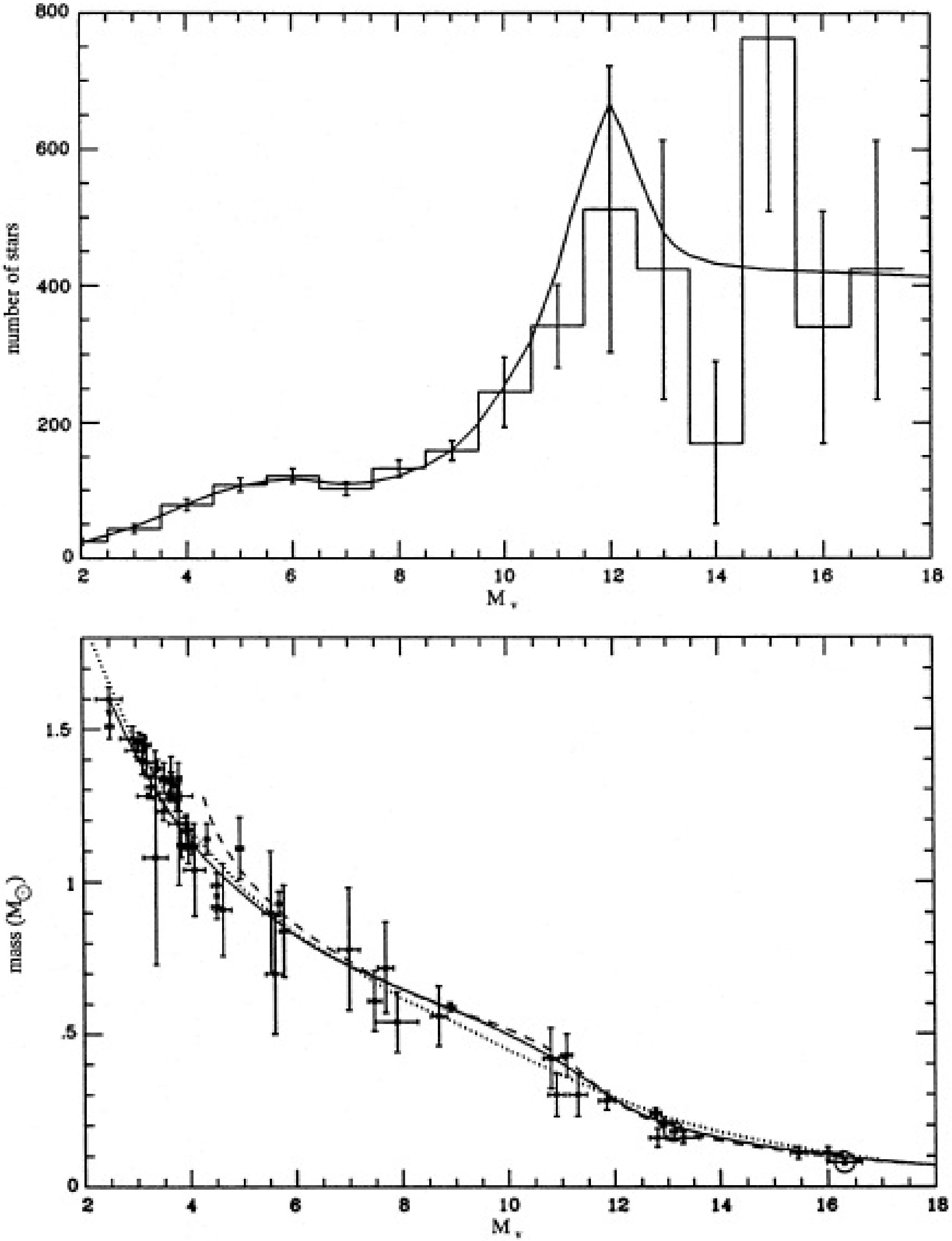
Fig. 11.— A schematic IMF showing the regions that are expected to be due to the individual processes. The peak of the IMF and the characteristic stellar mass are believed to be due to gravitational fragmentation, while lower mass stars are best understood as being due to fragmentation plus ejection or truncated accretion while higher-mass stars are understood as being due to accretion.

From W. Chen

Initial Mass Function

- An approximate understanding of the origin of different slopes.
- A hard problem to solve! (e.g. turbulence, magnetic fields...)

Mass Function of Disk stars



- Determination of a three-part power law mass function by Kroupa, Tout & Gilmore (1993)
- Top: the measured number of stars per M_V bin
- Bottom: the mass-luminosity relation adopted in deriving the mass function

Low-mass stars in the Galactic disc 575

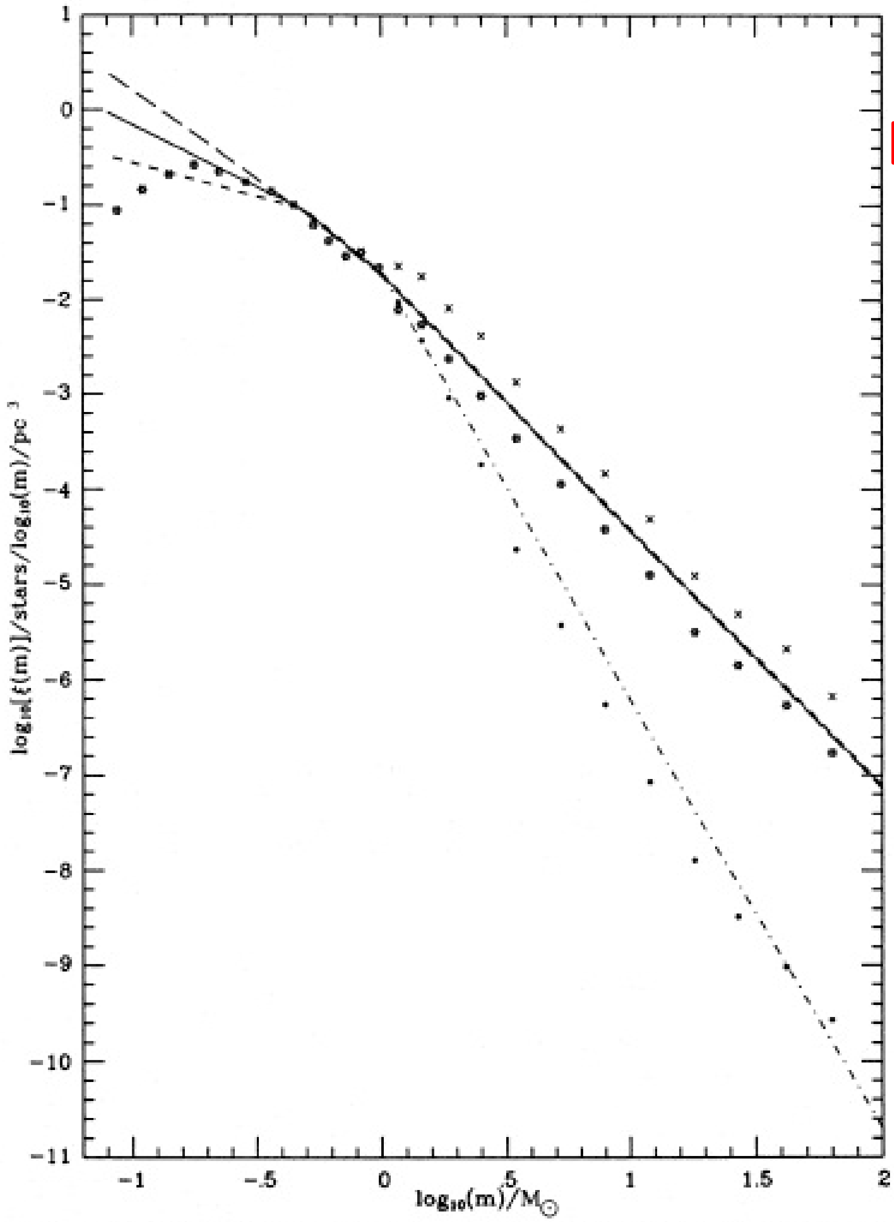


Figure 22. The stellar initial mass function (IMF) and present-day mass function (PDMF). The solid line represents the IMF given by equation (13), and the long- and short-dashed lines are for the cases $\alpha_1 = 1.85$ and 0.70, respectively. The PDMF ($\alpha_3 = 4.5$, Section 2) is indicated by the dot–dashed line. At masses below about 1 $M_\odot$ the PDMF equals the IMF. As a comparison, we show the PDMF derived by Scalo (1986) by solid dots. He corrects for stellar evolution; for a Galactic disc age of $T_0 = 9$ Gyr the IMF is indicated by stars, and for $T_0 = 12$ Gyr by crosses.

Mass Function of Disk stars

- Determination of a three-part power law mass function by Kroupa, Tout & Gilmore (1993)
- Present-day mass function (PDMF): dot-dashed line
- Initial mass function (IMF): solid line
- Note that the PDMF and IMF are equal below about 1 solar mass.

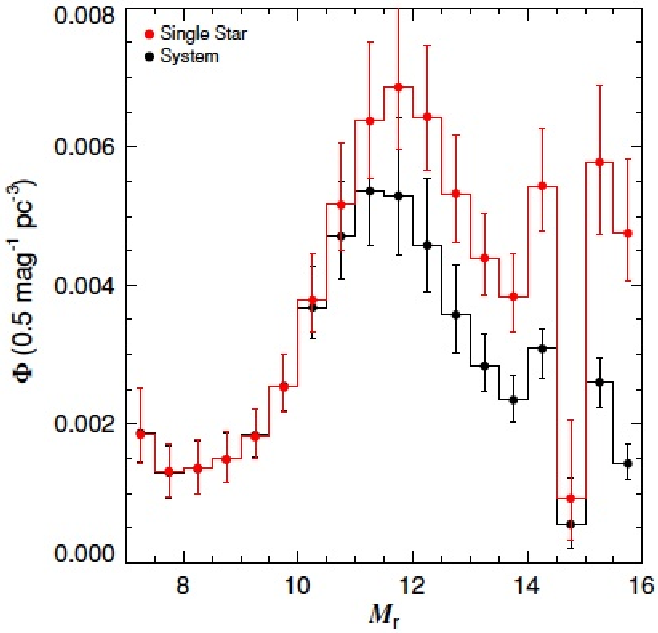


Figure 21. Single-star (red filled circles) and system (black filled circles) LFs. Note that the major differences between our system and single-star LFs occur at low luminosities, since low-mass stars can be companions to stars of any higher mass, including masses above those sampled here.

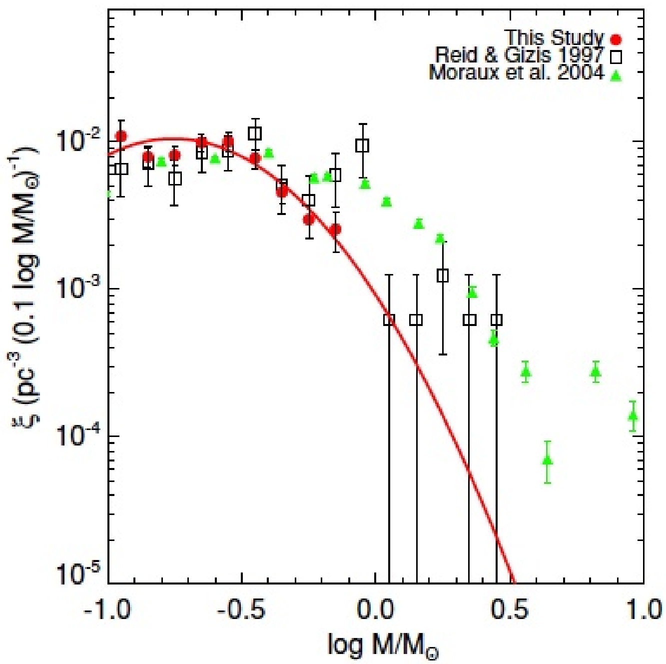
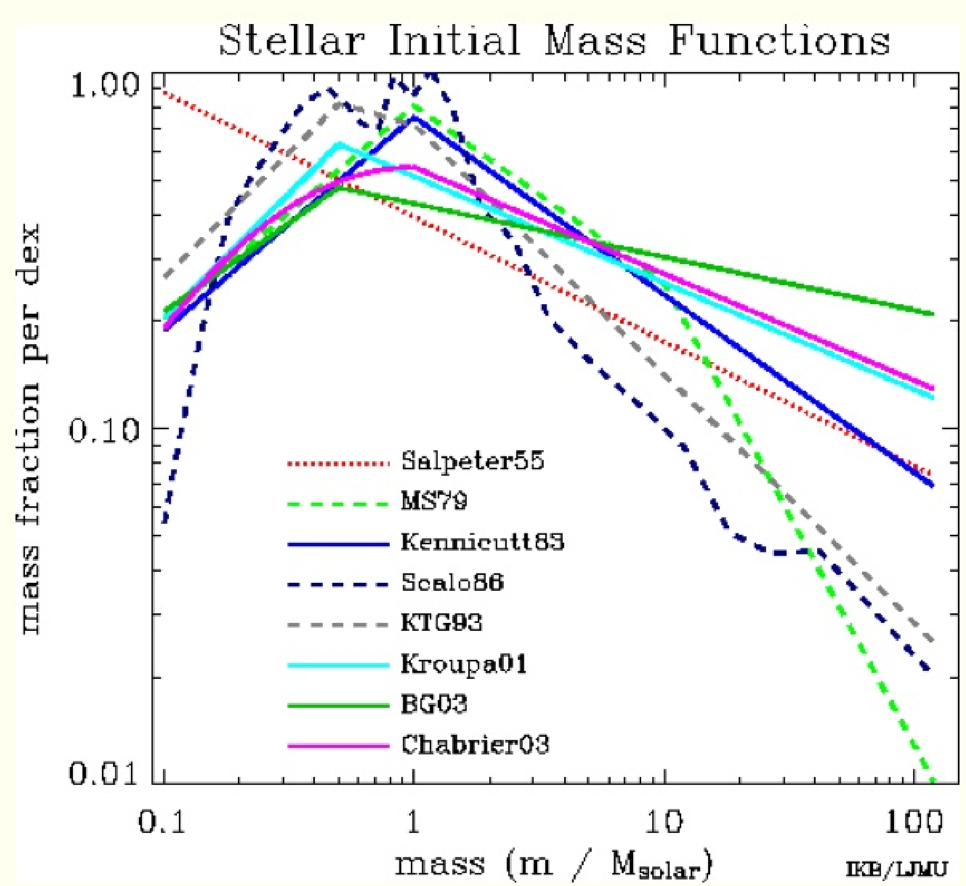


Figure 27. Shown are the single-star MF and best lognormal fit from this study (red filled circles and solid line), the Reid & Gizis (1997, open squares), MF (open squares), and the Pleiades MF Moraux et al. (2004, green triangles). The best fit extrapolated from our study systematically under-predicts the density at masses outside the bounds of our data.

Luminosity and Mass Function of Low-mass stars

- Bochanski et al. (2010, AJ 139, 2679)
- Based on SDSS data for 15 million low-mass stars!
- The mass range: 0.1–0.8 solar masses (corresponding to $7 < M_r < 16$)
- The turn-over and a local maximum well detected!
- Data well described by a log-normal distribution (over the probed mass range).



Initial Mass Function

- The stellar initial mass function (IMF) is used for computing stellar masses and colors of galaxies in cosmology.
- There is substantial variation between different estimates (left).
- Kroupa (2001) claimed a variable IMF (MNRAS 322, 231).

From Ivan Baldry:

`http://www.astro.ljmu.ac.uk/~ikb/research/imf-use-in-cosmology.html`