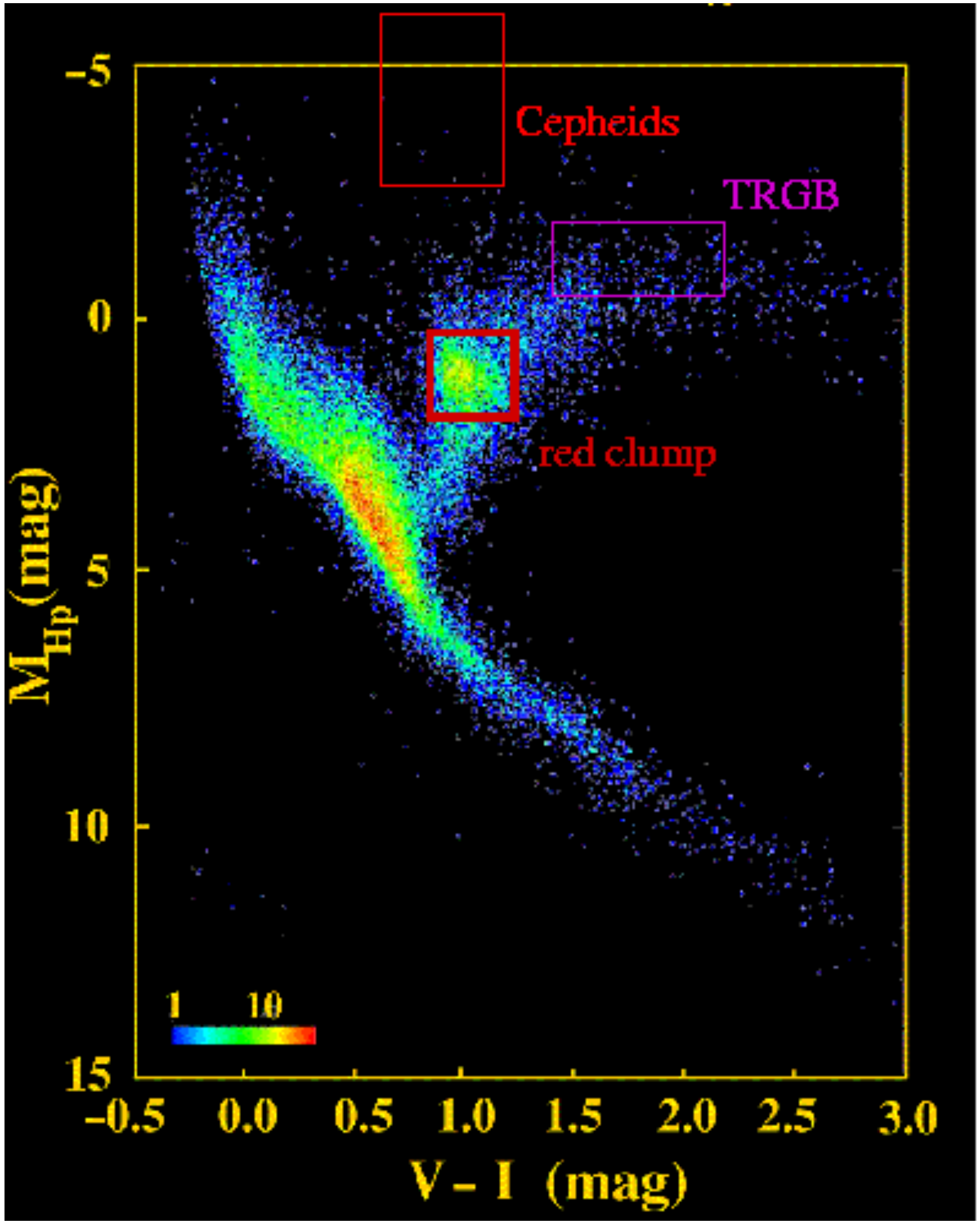
The nearest stars

The stars in the solar neighborhood are almost all disk stars, so we can get a good sample of the disk

Q What can we learn about the local stars from the Hipparcos color-magnitude diagram ?



Cepheids
TRGB
red clump
M_{Hp} (mag)
V - I (mag)
-5
0
5
10
15
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
1
10

Q What can we learn about the local stars from the Hipparcos color-magnitude diagram?

- age range
- metallicity distribution
- luminosity and mass distribution

The distribution of luminosity & mass in local stars are important tools when we study more distant populations of stars

luminosity function $\phi(M_V)$:

no of stars of each M_V in $1\,pc^3$

$$\phi(x) = \frac{\#\text{ of stars} \in (M_V - \tfrac{1}{2},\, M_V + \tfrac{1}{2})}{\text{volume over which stars seen}}$$

Stellar luminosity function

An important ingredient of galaxy models, etc

Q: How would you go about measuring the luminosity function for stars in the solar neighborhood?

Stellar luminosity function

An important ingredient of galaxy models

Q: How would you go about measuring the luminosity function for stars in the solar neighborhood?

1) Use Hipparcos sample where it is close to complete
2) Use a smaller volume (5 pc radius?) for very low mass stars …. These will be found originally from proper motion surveys (why?)

3) Use young star clusters plus a large volume to give the normalization for the most massive stars

HOWEVER:

Star clusters are special places: they experience mass segregation. Equipartition of energy gives low mass stars higher velocities, so massive stars are more centrally concentrated, and this happens quite rapidly for open clusters since relaxation time goes as N/ln(N) for N members

Q: why might this be a problem for studying stars in clusters? Why does it matter whether a star is centrally concentrated or not?

Q: what is another problem with low mass stars and young clusters?

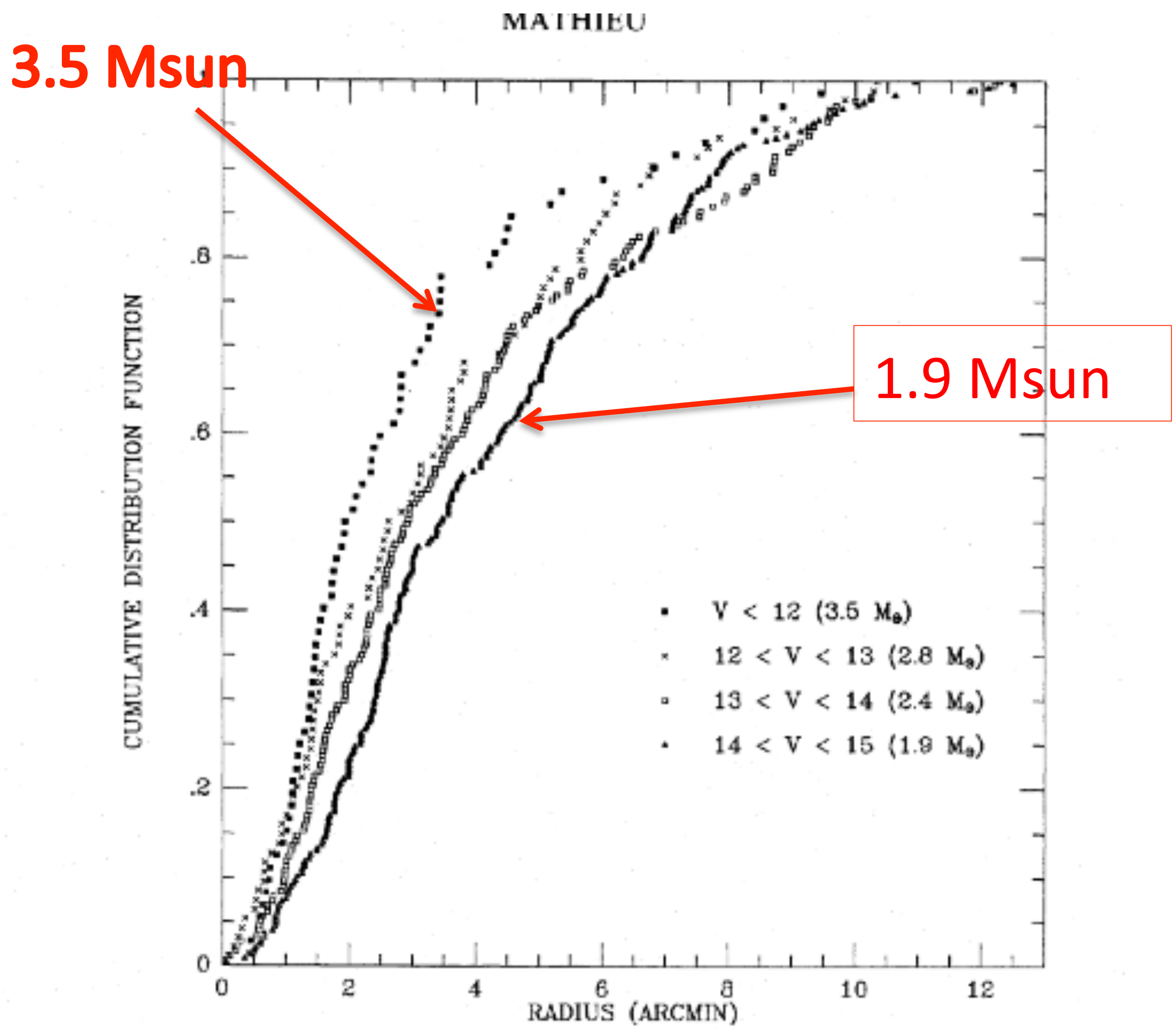
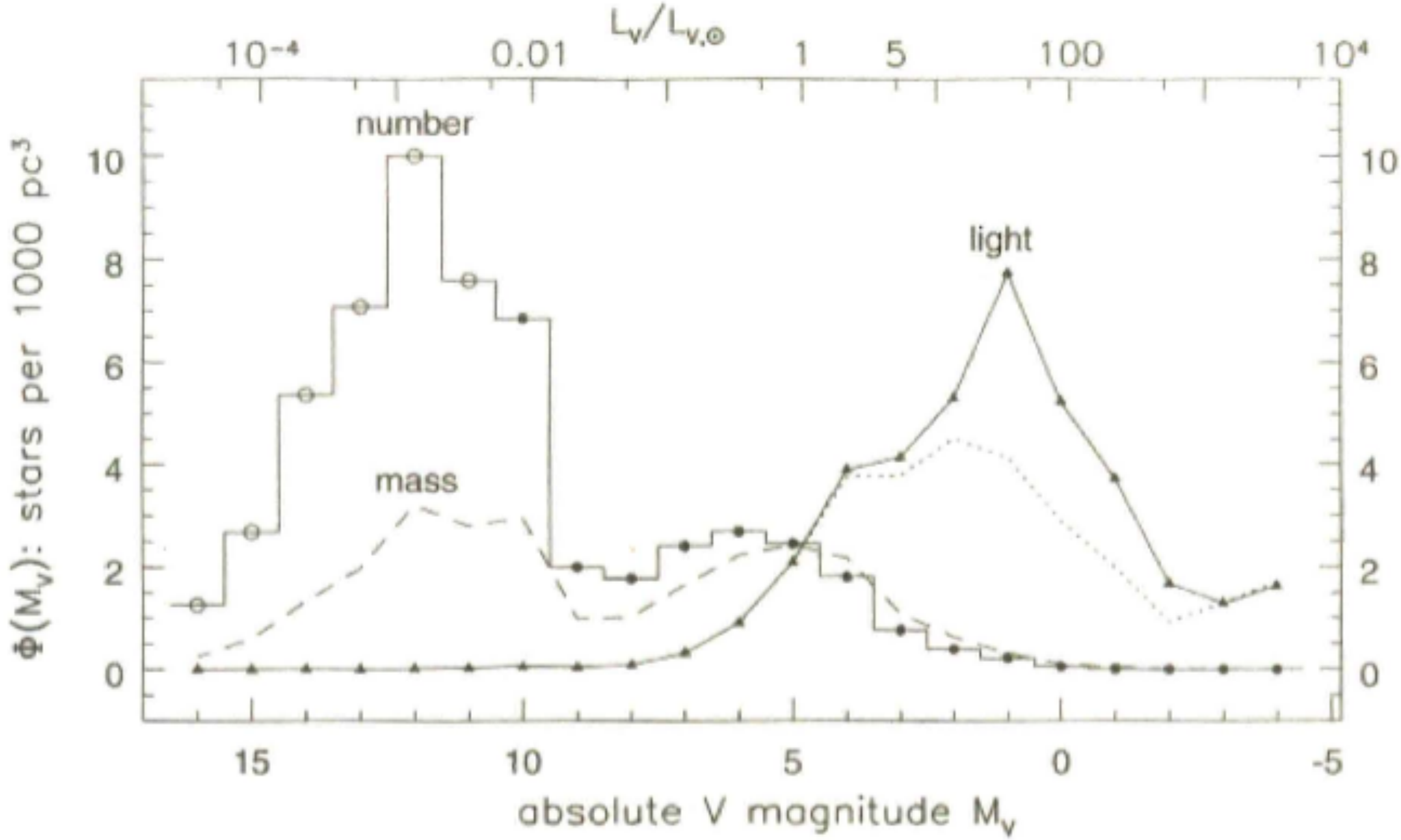
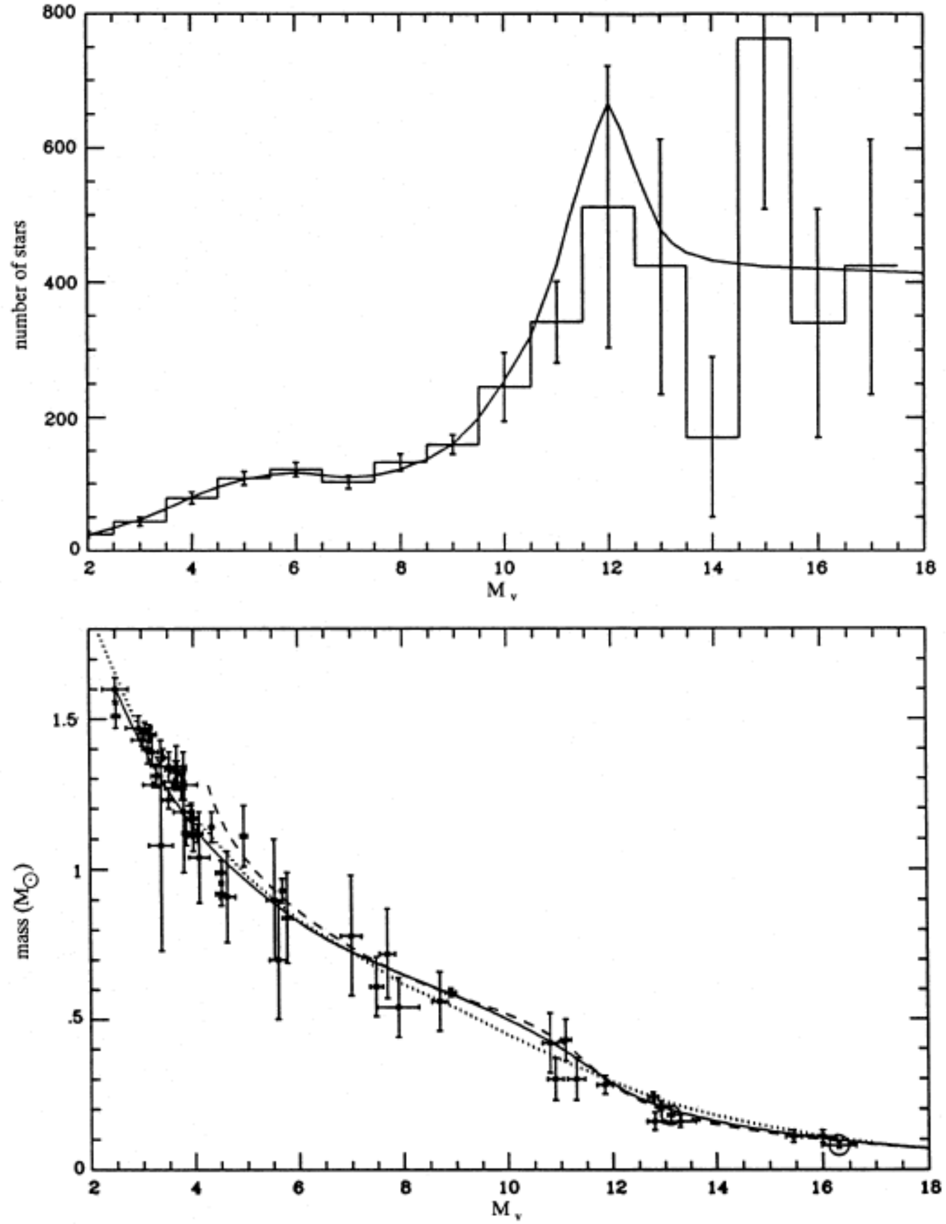


FIG. 9.—Cumulative radial distributions of the upper four luminosity groups in Fig. 8

Mass segregation in open cluster M11, from Mathieu 1984



2.3 Luminosity function $\Phi(M_V)$ for nearby stars: solid dots are from the stars of 2.2; open circles are from *photometric parallax*. The solid line and triangles show M_V), light from stars in each magnitude bin; the dotted curve shows the light of main-ıce stars alone. The dashed curve gives $\mathcal{M}\Phi_{MS}(M_V)$, the mass in main-sequence units are $L_\odot$ or $\mathcal{M}_\odot$ per 10 pc cube.

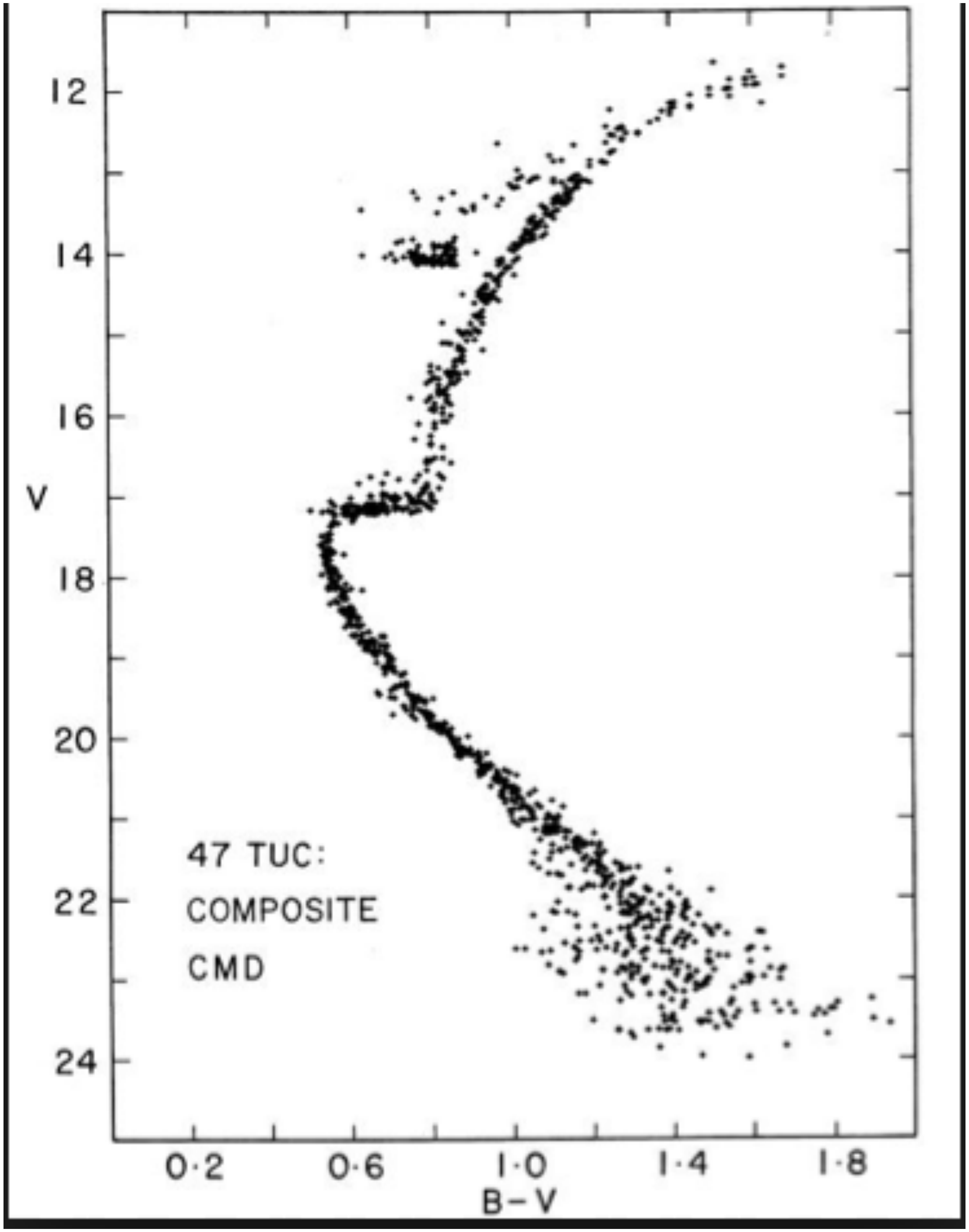


Luminosity function (top) and mass-luminosity relation (bottom) from Kroupa et al 1993; dotted curve shows metal-weak star relation

Current day to initial mass function

Q Globular and open clusters are thought to have been formed in a single burst of star formation.

How does the current CMD of 47 Tuc (a relatively metal-rich globular) differ from its CMD soon after it formed?



Hesser et al 1987

Star formation rate and IMF are intertwined

Because many of the massive stars have now become stellar remnants (and we don't have a good census of these – why?) we need both an estimate of

(a) the star formation rate and

(b) the present-day mass function

to infer the initial mass function

We think that the SFR has been roughly constant in the Milky Way disk for about 10 Gyr

Formulas for the initial mass function

IMF near Sun roughly

$$\xi(m) = \xi_0 \, m^{-2.35}$$

— Salpeter IMF

Salpeter first suggested a power-law form for the IMF in 1955 (note Basti LF uses this as default)

More recently, different functions have been suggested: either lognormal or power law with different exponents in different mass ranges

Chabrier (lognormal) form of IMF

Note also that some authors use log m bins for the IMF, others linear mass bins --- power law exponent changes.

$$\phi(m) \sim e^{-\frac{(\log m - \log m_c)^2}{2\sigma^2}}.$$

•

Lognormal form justified

Justification of the normal (Gaussian) shape comes from the statistical Central Limit Theorem, which states that the sum of a large number of independent probability distributions will approach a normal distribution

Star formation is a complex process, and if stellar mass is determined by the product of a number of different variables, log mass will be the sum, so the Central Limit theorem applies!

Canonical IMF (Kroupa et al 2013)

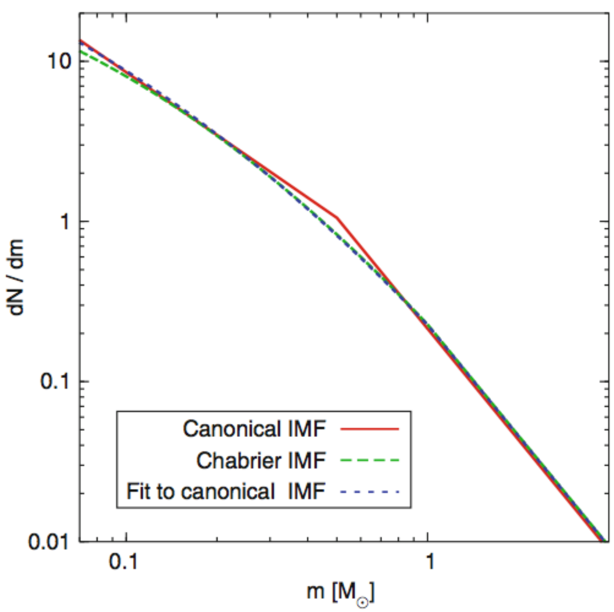
$lm_c \equiv \log_{10} m_c / M_\odot$;

$$\xi_{\rm star}(m) = k \begin{cases} \frac{1}{m} \exp\left[-\frac{(lm - lm_c)^2}{2\,\sigma_{lm}^2} \right] & , \quad 0.07 < m \le 1.0, \\ A \left(\frac{m}{1.0} \right)^{-2.3 \pm 0.36} & , \quad 1.0 < m \le 150. \end{cases}$$

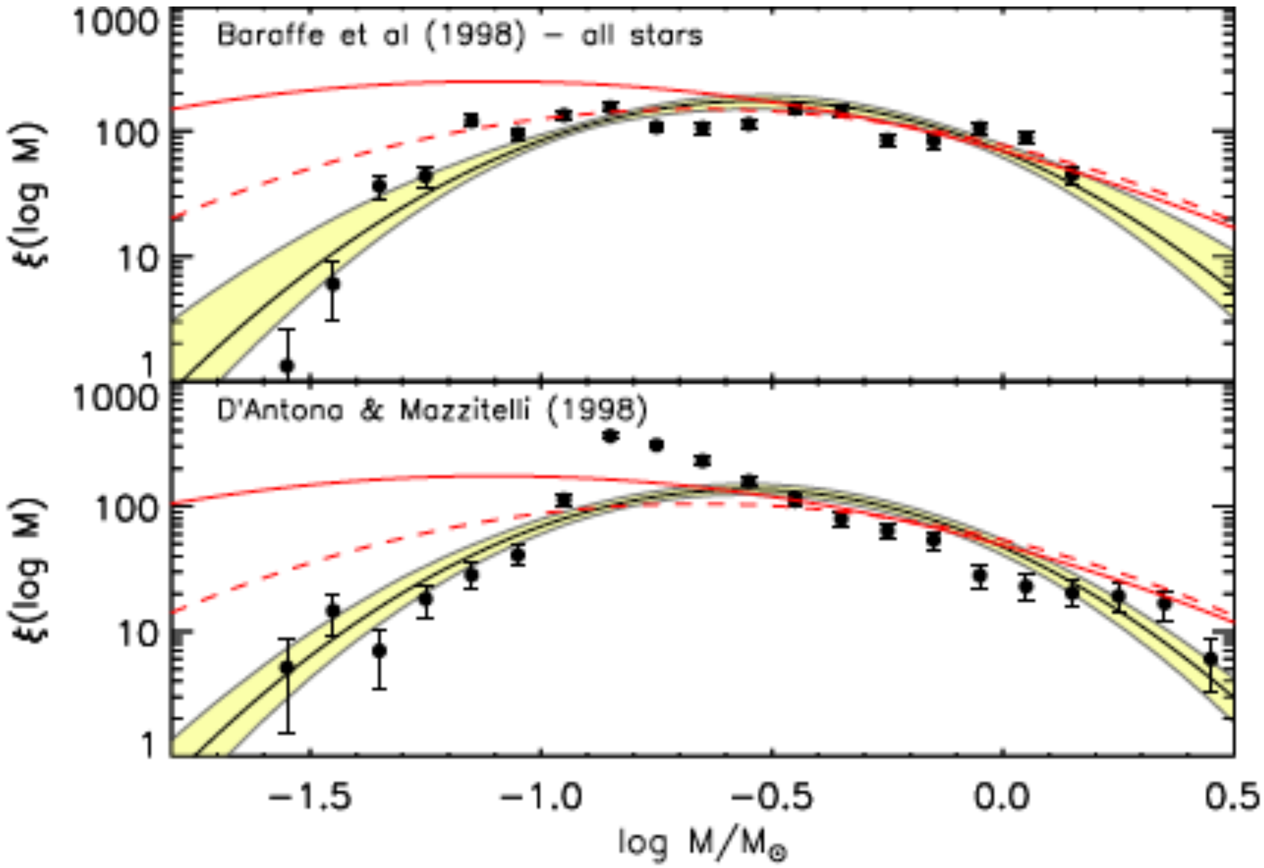
(close to Salpeter)

or

$$\xi_{\rm star}(m) = k \begin{cases} \left(\frac{m}{0.07} \right)^{-1.3 \pm 0.3} & , \quad 0.07 < m \le 0.5, \\ \left[\left(\frac{0.5}{0.07} \right)^{-1.3 \pm 0.3} \right] \left(\frac{m}{0.5} \right)^{-2.3 \pm 0.36} & , \quad 0.5 < m \le 150. \end{cases}$$



m in units of solar masses
The two formulae are
very similar in practice



Comparison (from Krumholz 2014) of IMF for the young Orion nebula cluster. The same data in both panels, but different transformations between colors/magnitudes and masses. Red is lognormal IMF with and without binaries

Q: why is there such disagreement at the low mass end?

Discussion: stellar masses for galaxies

- We discussed in class how to infer the mass of a galaxy using spectroscopy and photometry to derive its stellar M/L ratio and redshift for its distance and so luminosity

Q: What are the steps that are needed to make this inference? How many of them are currently not agreed on by all researchers?

Inside the Basti Black Box

Stellar interiors:

How does the light get out?

-- Radiation? (opacities)

-- Convection? (Mixing length approx vs 3D models)

Equation of state P=P(T,rho,abundance); ionization

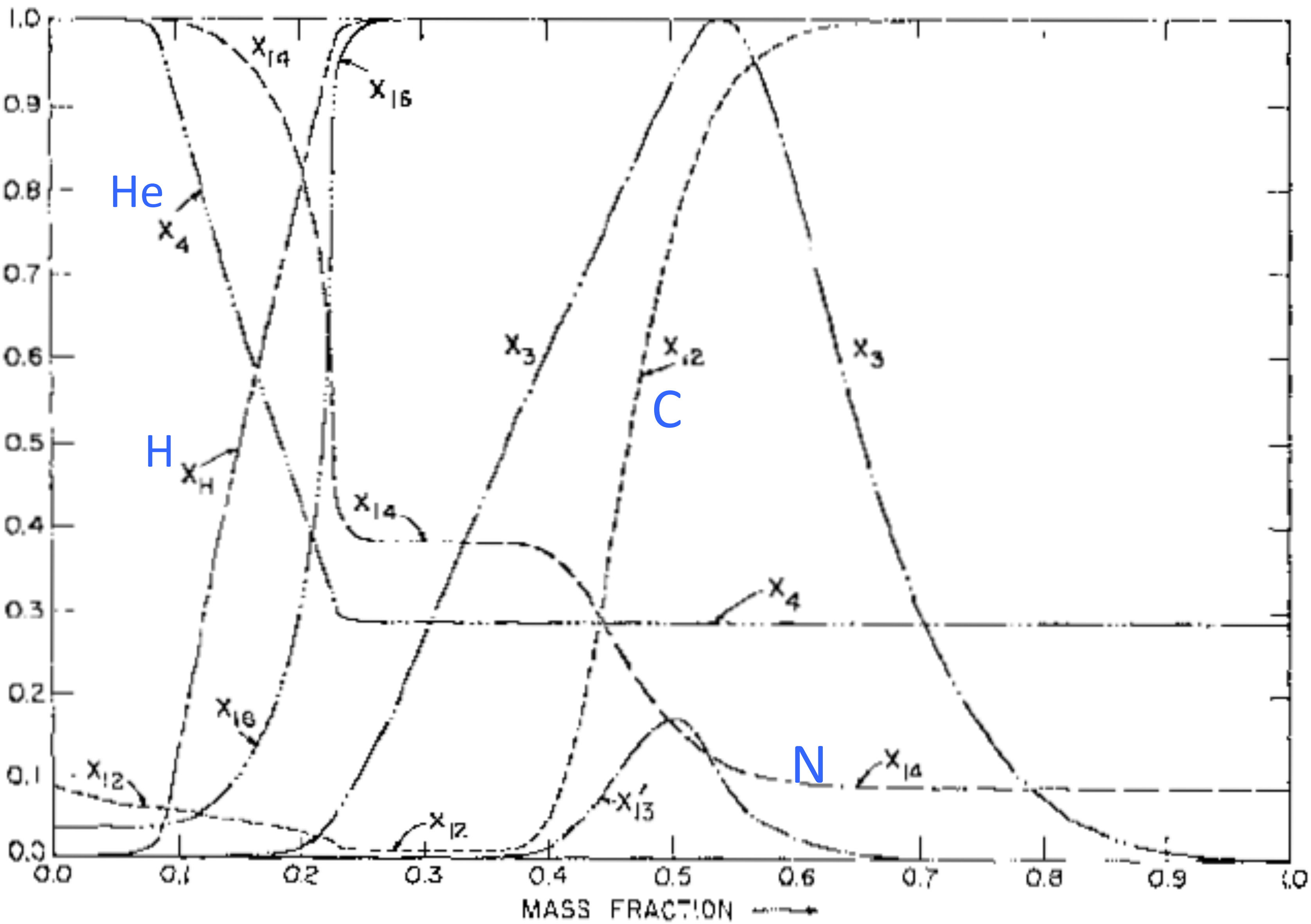
Abundance changes with radius

Reaction rates

Observational checks:

Helio and asteroseismology

Solar neutrinos



Iben ARAA 1967 5 Msun star; note these are fractions of total amt of that element in star

Basti's Black Box

Model atmospheres:

-- Radiative transfer and line formation

-- Optical depth, opacities, gf values

-- Broadening of spectral lines

Stellar evolution

Transformation from L,T to absolute mag and color

Observational constraints:

-- cluster CMDs, stellar and solar spectra and photometry

-- NOTE that there is currently a disagreement between helioseismology and 3d model atmospheres about light element abundances in Sun of ~0.2 dex

Integrated stellar populations

Uncertainties here come from

-- choice of IMF and problems determining it

-- different treatment of AGB by different groups

-- different transformations from L, T to mag and color

-- k-corrections (transformation of galaxy color to redshift zero)

-- mismatches between isochrones and reality