Introduction to Astronomy and Astrophysics I

Lecture 13

Yogesh Wadadekar

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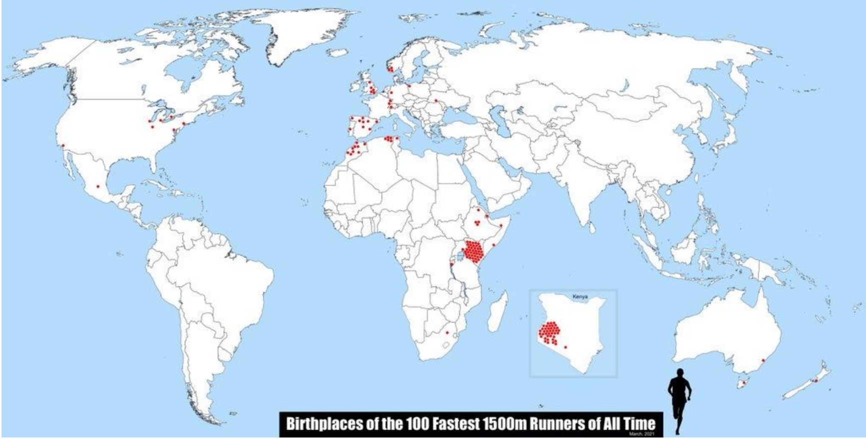
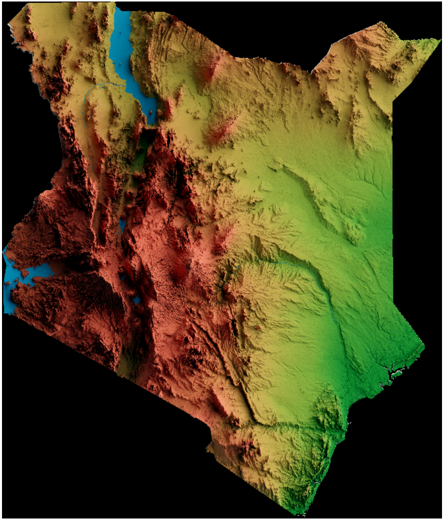
Fastest runners



Kenya Geography



Question

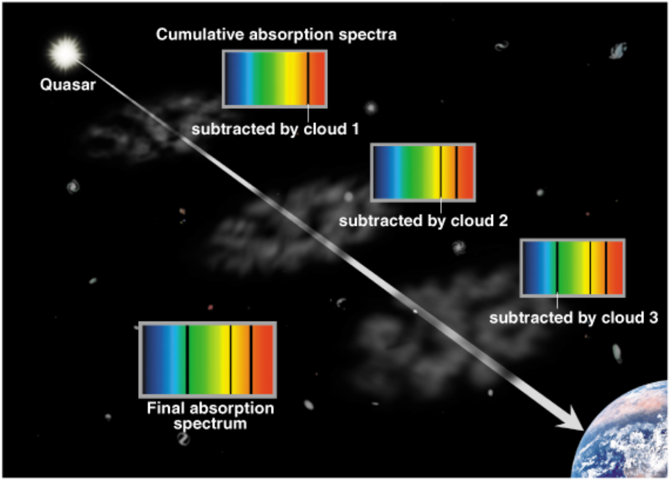
There is one major component of the baryonic large scale structure that we have ignored so far

Intergalactic medium (IGM) - baryons between galaxies

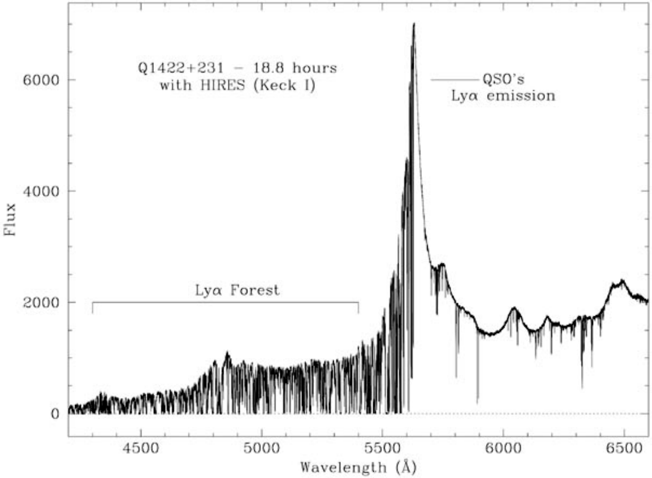
- Its density evolution follows the LSS formation, and the potential wells defined by the DM, forming a web of filaments, the "Cosmic Web"
- An important distinction is that this gas unaffiliated with galaxies samples the low-density regions, which are still in a linear regime
- Gas falls into galaxies, where it serves as a replenishment fuel for star formation. Likewise, enriched gas is driven from galaxies through the radiatively and SN powered galactic winds, which chemically enriches the IGM
- Chemical evolution of galaxies and IGM thus track each other

How to observationally detect the IGM?

Absorption line systems



Quasar spectrum



Luminosity functions

The Luminosity Function specifies the relative number of galaxies at each luminosity.
The Luminosity function is a convolution of many effects:

- primordial density fluctuations
- processes that destroy/create galaxies
- processes that change one type of galaxy into another (eg mergers, stripping)
- processes that transform mass into light

Observed LFs are fundamental observational quantities. Successful theories of galaxy formation/evolution must reproduce them.

The luminosity function

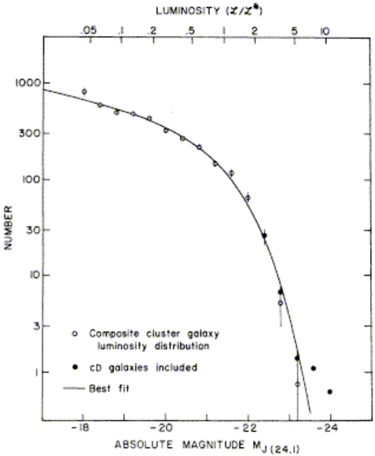


FIG. 2.—Best fit of analytic expression to observed composite cluster galaxy luminosity distribution. Filled circles show the effect of including cD galaxies in composite.

Schecter Luminosity Function

In 1974 Press and Schechter calculated the mass distribution of clumps emerging from the young universe, and in 1976 Paul Schechter applied this function to fit the luminosity distribution of galaxies in Abell clusters.

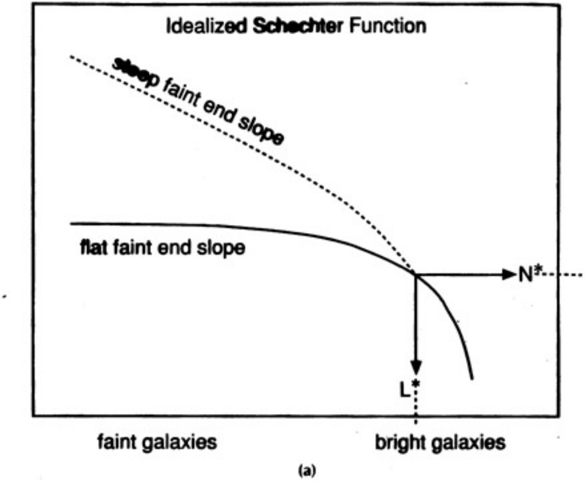
$$\phi(L)dL = n_* \left(\frac{L}{L_*}\right)^{\alpha} exp\left(-\frac{L}{L_*}\right) d\left(\frac{L}{L_*}\right) \tag{1}$$

Function has two parts and three parameters.

Schecter Luminosity function

- L_* : luminosity that separates the low and high luminosity parts; $L_* \sim 10^{10} L_{B\odot} h^{-2}$, or $M_{B,*} \sim -19.7 + 5\log(h)$
- At low luminosity, ($L < L_*$): We have a power law with $\alpha \sim -0.8$ to -1.3 ("flat" to "steep") lower luminosity galaxies are more common.
- At high luminosity, ($L > L_*$): We have an exponential cutoff, very luminous galaxies are very rare
- n_* : is a normalization, set at L_* $n_* \sim 0.02h^3$ Mpc^{-3} for the total galaxy population. Depending on context, n_* can be a number; a number per unit volume; or a probability. Note the implicit dependence on Hubble constant, via h^3.

What each parameter does



Different equivalent forms of the luminosity function

$\phi(L)$ per dL, (which is usually plotted $\log(\phi)$ vs $\log L$). $\phi(M)$ per dM where M is absolute magnitude, so this is effectively $d(\log L)$. Sometimes the cumulative LF is given: $N > L$ or $N < M$. So please check the axes on your plots.Observationally, it is also important to specify:

- whether the LF is for specific Hubble Types, or integrated over all Types
- whether the LF is for Field galaxies or Cluster galaxies (or whatever the environment is)
- the value of H_0, since ϕ varies as h^3 while L or M vary as h^{-2}

How to measure the luminosity function? in Clusters

All cluster galaxies are at the same distance.

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All cluster galaxies are at the same distance.

1. bin galaxies by apparent magnitude, down to some limit, to get $\phi(m)$
2. use cluster redshift (distance) to get $\phi(M)$
3. Fit a Schechter function to $\phi(M)$ by minimizing χ^2 to obtain M_* and α.

Complications arise principally from trying to eliminate fore/back-ground field galaxy contamination: here galaxy velocities are useful. Also dwarfs are often too faint to measure (except BCDs) because they have low SB. We need to apply statistical corrections to $N(m)$ using field samples.

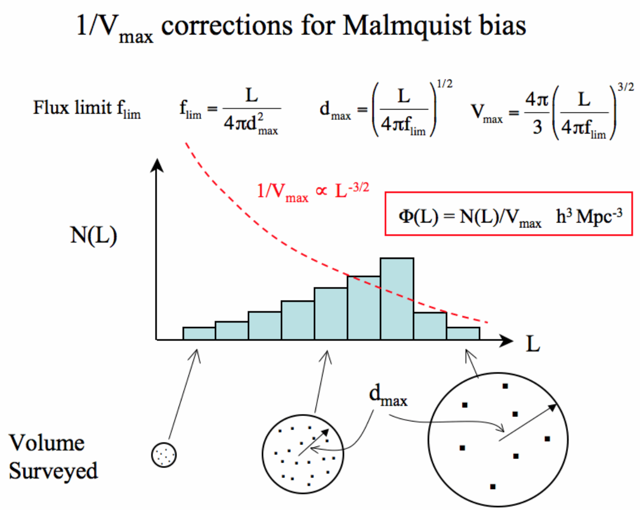
Measuring the LF in the field

Obtain a **flux limited** sample: all galaxies brighter than given apparent magnitude limit. Use distances to calculate luminosity of each galaxy. Form a histogram of luminosity: $N(L)$.

However, each luminosity bin comes from a different survey volume (Malmquist bias) i.e. surveyed volume, $V_{max}(L)$, is small (large) for low (high) luminosity objects. So divide $N(L)$ by $V_{max}(L)$ to create $\phi(L)$ the density of objects at each luminosity. This now corrects the Malmquist bias and each luminosity samples the same effective volume.

Unfortunately, this method assumes a constant space density. When will this assumption be especially problematic?

Correcting Malmquist bias



Maximum likelihood method

See: Blanton et al. 2003, ApJ, 592, 819
This is the method most commonly used today.

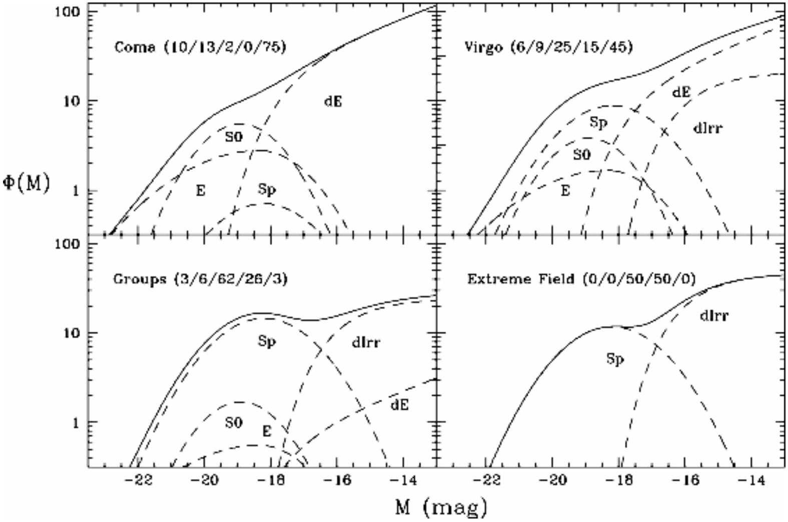
Schecter LF

Early work showed that the Schechter function is a good fit to many galaxy samples, but the parameters (L_*,α) can vary depending on: sample depth, cluster or field, cluster type, morphological type. **Which one is more important?**
In general, cluster LFs are well fit by a Schechter function have similar L*, α is often steeper than in the field ($\sim$ -1.3), there can be a dip/drop near $M_B \sim -16 + 5\log(h)$, there can be an excess at higher luminosities for cD galaxies ($\sim 10L_*$).

Understanding the cluster LF

Recent research shows that different LFs usually arise from **different proportions** of Sp, S0, E, dE, and dIrr specifically, more E, S0, dEs are in clusters, while more Spirals and dIrr are in the field. This is evidence for a morphological dependence on galaxy density - the **morphology density relation** (Dressler 1980). The dip at $M_B \sim -16$ occurs at the changeover from “normal” to “dwarf” galaxies. cD galaxies have clearly had a different history, probably growing by accretion in dense galactic environments.

Decomposing LF by morphology



Abell 1689 - cD galaxy more luminous than LF predicts

This was already discovered by Schecter (1976)!

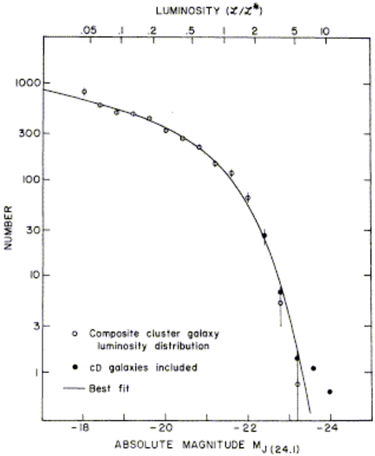


FIG. 2.—Best fit of analytic expression to observed composite cluster galaxy luminosity distribution. Filled circles show the effect of including cD galaxies in composite.

Physical origin of the LF

Making galaxies involves at least two steps.

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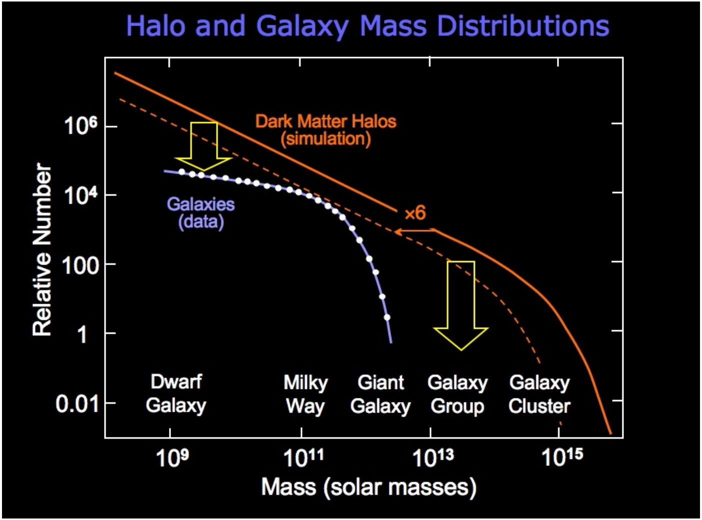
Making galaxies involves at least two steps.

1. dark matter halos must form (relatively straightforward and well understood)
2. baryons must fall in and make stars (complex physics)

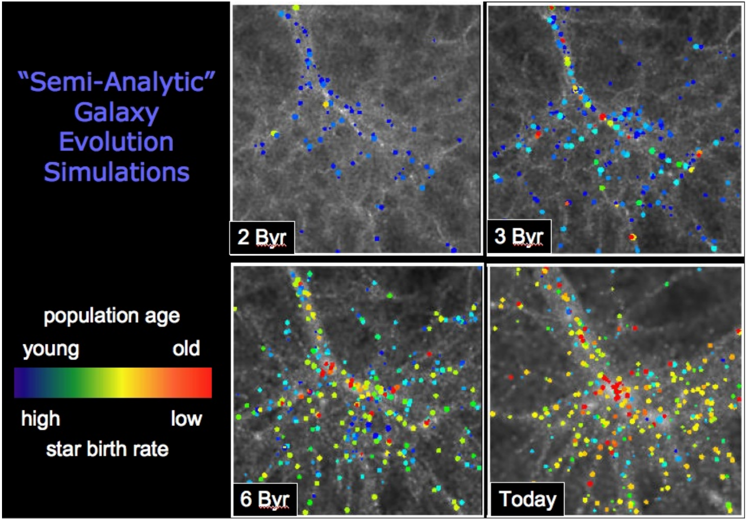
Cosmological simulations follow cold dark matter from initial slight perturbations to make many halos by hierarchical assembly. The mass distribution of these halos follows the Schechter form (Press & Schecter 1974). Hence one might expect a Schechter function for the galaxy mass distribution. Under what assumption?
The **observed** galaxy mass function has completely different upper cutoff and lower slope. Specifically, there are too many huge and dwarf halos (in simulations) without huge and dwarf galaxies (in the real universe).

Too many haloes too few galaxies

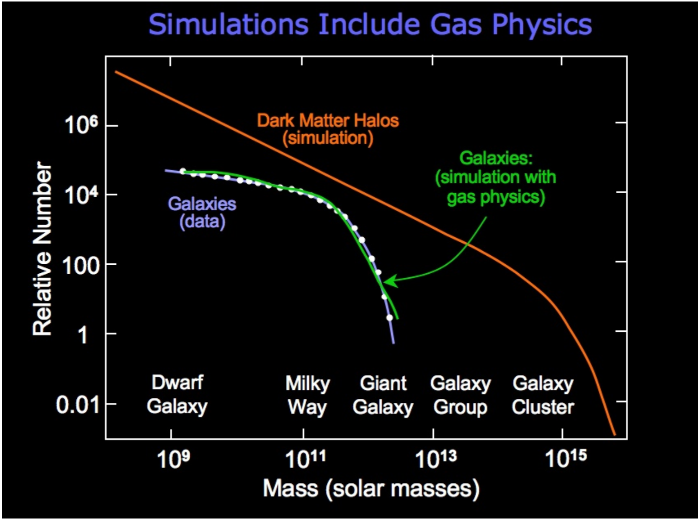


See: http://www.illustris-project.org/

Semi analytic models



Semi analytic models reproduce the observed LF well



Measuring dynamical mass via virial theorem

The virial theorem can be applied to any system of stars that is in a steady state such as:

- elliptical galaxies
- evolved star clusters, e.g. globular clusters
- evolved clusters of galaxies (with the galaxies acting as the particles, not the individual stars)

It obviously cannot be used for:

- merging galaxies
- newly formed star clusters
- clusters of galaxies that are still forming/still have infalling galaxies

Can it be applied in the solar system today?

Measuring dynamical mass via virial theorem

Consider a spherical elliptical galaxy of radius R that has uniform density and which consists of N stars each of mass m having typical velocities v. Can we measure typical velocity of stars in an elliptical galaxy?

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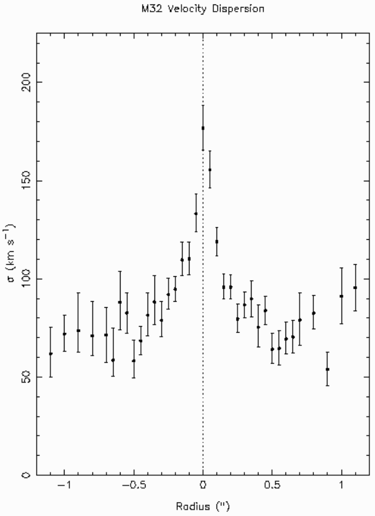
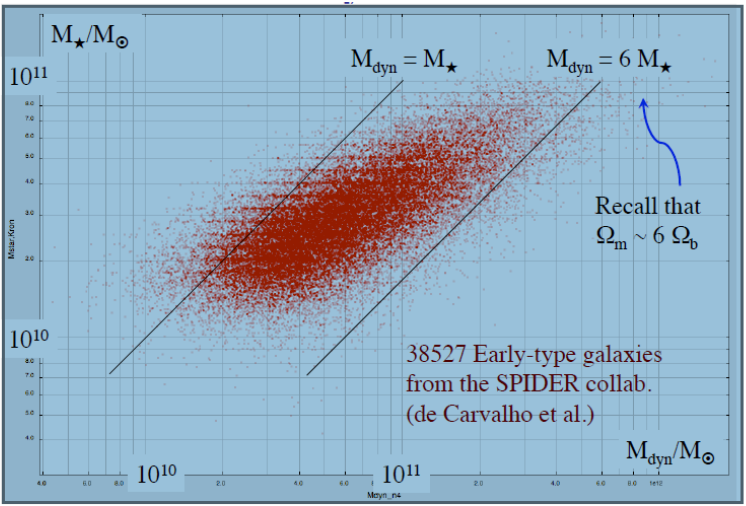
$$2T + U = 2\left(\frac{1}{2}Nm\sigma^2\right) - \frac{3}{5}\frac{GM^2}{r} = 0$$

where the gravitational PE is for uniform sphere of mass M and radius R. This implies: $M \simeq \frac{\sigma^2 R}{G}$ Can we measure the mass of supermassive black holes using this?

Even black holes in small galaxies can be measured!



Baryonic mass versus dynamical mass



Question

How would you use the Virial Theorem to estimate the mass of a virialised cluster? Before that, how will you determine if a cluster is virialised or not?

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Cluster: Virialised or not?