Practico 3

Ver esta pagina, es un curso completo, muy bueno:

http://lifeng.lamost.org/courses/astr553/Topic04/Lecture_4.html

1 Bingeli 1998

- The *optical* luminosity function (LF) of galaxies is a probability distribution $\varphi_{\mathrm{T}}(M)$ over absolute magnitude M for galaxies of any specified Hubble type T. Summed over all types, it is usually called the *general* LF $\varphi(M)$ (sometimes also labeled the *universal* function)

- The fact that the concept of a general function is now inadequate is not trivial in its consequences. Accurate knowledge of the LF is required for many calculations in cosmology.

  Integrations over space and time must be made to predict various observable distributions. These functions, often at the core of observational cosmology, either test world models or are important in the search for secular evolution in the look-back time. It is here that the LF forms a basic ingredient in *practical* cosmology, in addition, of course, to its deeper significance concerning the physical characteristics of galaxies. In this latter role, the LF holds clues to the formation and evolution of galaxies and of clusters, especially evident from the consequences of the type-density relation [see Dressler (1984) for a review].

- Many uses of the general differential luminosity function (see Section 2 for definitions) are mentioned by Schechter (1976) in the introduction to his influential paper.

  a) the conversion of the observed (projected) angular correlation function to the spatial (three-dimensional) covariance function;

  b) the calculation of the luminosity density averaged over cosmologically interesting volumes;

  c) the determination of selection effects on particular parameter averages in samples chosen by apparent magnitude (Schechter notes only the one example of the mean binding energy of pairs of galaxies, but every calculation of a true distribution, recovered from any particular observed flux-limited sample, is similar);

  d) the estimation of the number of absorbers at different redshifts and different cross sections to produce the "$L\alpha$ forest" in quasi-stellar objects

- History:

  – Following the general recognition of nebulae as galaxies and important early studies by Knut Lundmark, E.J. Öpik, and Edwin Hubble, Hubble initiated an analysis of the velocity-apparent magnitude relationship (the Hubble diagram) for galaxies. His work showed that the scatter in this relation was minimal for the Shapley-Ames galaxies studied by Milton Humason. Assuming a linear velocity-distance relation, Hubble concluded that the spread in absolute magnitude (M) for these galaxies was small and followed a Gaussian distribution with a standard deviation of 0.84 magnitudes. This result was corroborated by independent methods involving the brightest resolved objects, later identified as H II regions.

  – Hubble's initial Gaussian form for the luminosity function (LF) was later challenged by Fritz Zwicky, who argued that selection effects were neglected, and that the true LF was an increasing exponential toward faint dwarf galaxies.

- *Selection effects* refer to biases or limitations in data collection that can skew the interpretation of scientific results, especially in observational studies. These effects arise when the sample being observed or measured is not fully representative of the entire population due to the method or instruments used in the selection process.

- Holmberg's inclusion of faint dwarfs in the Local Group confirmed this by skewing Hubble's symmetrical Gaussian.

- Studies by Abell provided strong evidence that dwarf galaxies follow an exponentially rising LF, unlike spirals and ellipticals, which have bounded LFs.

- Reaves' work on Virgo cluster dwarfs further supported Zwicky's earlier claims. Comprehensive studies by Krupp, Rood, and later Thompson & Gregory in the Coma cluster refined these findings.

- In recent years it has become clear that both Hubble and Zwicky were correct for the types of galaxies each discussed. Hubble's list was almost exclusively high-surface-brightness galaxies, whereas Zwicky's faint rising exponential tail almost entirely contained galaxies of low surface brightness, none of which were in Hubble, Humason, or Mayall's early redshift program.

• Definition:

  - Let $\nu(M,\ x,\ y,\ z)$ denote the number of galaxies lying in volume dV at $(x,\ y,\ z)$ that have absolute magnitudes between M and $M\ +\ dM$. On the assumption that galaxian magnitudes are not correlated with spatial location, one can write:

    $\nu\,(M,x,y,z)\,dMdV=\varphi(M)D(x,y,z)dMdV$

    Condicion de Normalizacion: $\int_{-\infty}^{\infty}\varphi(M)dM=1$

  - $\varphi(M)$ gives the fraction of galaxies per unit magnitude having absolute magnitudes in the interval $(M,\ M\ +\ dM)$ and is called the *luminosity function*.

  - $D(x,\ y,\ z)$ gives the number of galaxies (of all magnitudes) per unit volume at $(x,\ y,\ z)$ and is called the *density function*. φ and D should be viewed as probability densities, which in practice are approached and represented either by (nonparametric) histograms or by (parametric) analytical forms.

  - $\varphi(M)$ can be called the *universal* luminosity function of galaxies. This is clearly an approximation. In reality one expects that φ does somehow depend on the location, i.e. on the environment from which the galaxies are sampled.

  - The "luminosity function" has been given the units of density (number of galaxies per magnitude per cubic megaparsec).

  - The drawback of this definition is the creation of an artificial dichotomy between field and cluster samples.

  - The luminosity function (LF), traditionally created a distinction between field and cluster galaxies due to variations in density (D). Schechter (1976) introduced the term "luminosity distribution" to differentiate between LFs in clusters, where D is not constant, and field galaxies. Later, Sandage et al. (1979) and Kirshner et al. (1979) abandoned the assumption of constant density for field galaxies, acknowledging the inhomogeneity in galaxy distribution. Modern methods focus on separating the LF from the density function. While the mean density remains important in cosmology, it need not be incorporated into the LF itself.

- The normalization of $\varphi(M)$ to unity by integrating over all magnitudes (Equation 9) is difficult in practice because any sample of galaxies is complete, or has good statistical weight, only to a certain limiting magnitude M_{lim}.

- The ideal case, where the faint end of $\varphi(M)$ goes to zero at a magnitude $M' \leq M_{\mathrm{lim}}$ is at present applicable only to certain types of galaxies that are sampled nearby (cf. Section 5). In general, φ not only is nonzero but is growing exponentially at M_{lim}, making such a normalization infeasible; any extrapolation of $\varphi(M)$ to fainter magnitudes by an analytical model will diverge. A way to avoid this divergence would be to go to the luminosity (L) representation of the luminosity function, transforming $\varphi(M)$ into $\varphi(L)$ and setting:

  $\int_0^{\infty}\varphi(L)dL = 1$ which for physical reasons must always converge.

- However, we wish to keep the magnitude representation, since $\varphi(M)$ is closer to the observations than is $\varphi(L)$. An obvious and practicable way to normalize $\varphi(M)$ is to restrict the discussion to galaxies brighter than a certain arbitrary absolute magnitude $\bar{M}$, in which case Equation 9 is replaced by

  $\int_{-\infty}^{\bar{M}}\varphi(M)dM = 1$ where D in $\nu\,(M, x, y, z)\,dMdV = \varphi(M)D(x, y, z)dMdV$

  is then the density of galaxies that are brighter than $\bar{M}$.

- $\bar{M}$ may be different for different samples. Future work will push $\bar{M}$ toward fainter and fainter limits until the ideal normalization of Equation 9 can be realized.

- Magnitudes:

  - It is of the utmost importance to pay attention to the exact definitions of, and the corrections to, the apparent magnitudes used by various authors to derive the LF.

    a) **Passband of magnitudes**: Total blue magnitudes (BT) are commonly used, but approximations or other systems, like Zwicky's magnitudes or infrared fluxes, are also employed.

    b) The Galactic absorption, which must be corrected for.

    c) **Galactic absorption**:The internal absorption, which may or may not be corrected for. The internal absorption of E and S0 galaxies is generally neglected. The exact correction for spirals is not well known. This must be corrected using methods such as specific absorption maps or the RSA approach.

    d) The K-correction for redshift dimming, which must be applied for distant galaxies. For redshifts $z \lesssim 0.02$ the K-correction in optical passbands remains smaller than $0.^{\mathrm{m}}1$ for all galaxy types (Whitford 1971, Wells 1972) and may be neglected for the LF. However, at large redshifts the K-correction not only becomes large but also is sensitive to the galaxy type. For instance, at redshift $Z = 0.5$ the difference in the K-correction may amount to $\sim 1.^{\mathrm{m}}5$ between different types (Pence 1976, Coleman et al. 1980). If such large effects were neglected, comparison of the LFs of nearby and high-redshift galaxy samples could lead to erroneous conclusions on galaxy *evolution*.

- About K-Correction:

  - **K correction** converts measurements of astronomical objects into their respective rest frames. The correction acts on that object's observed magnitude (or equivalently, its flux).

- Because astronomical observations often measure through a single filter or bandpass, observers only measure a fraction of the total spectrum, redshifted into the frame of the observer.

- If one could measure all wavelengths of light from an object (a bolometric flux), a K correction would not be required, nor would it be required if one could measure the light emitted in an emission line.

- ### Key aspects of the K-correction:

  1. **Redshift effect**: As a galaxy moves away from us, its light gets redshifted, meaning the photons we observe are shifted to longer wavelengths. For example, light that originally emitted in the ultraviolet (UV) might appear as visible light or infrared by the time it reaches Earth.

  2. **Passband adjustment**: Because telescopes observe galaxies in specific passbands (ranges of wavelengths), the K-correction accounts for the fact that we are observing light in a different passband than the one in which it was emitted. For example, if a galaxy emits most of its light in the blue region, but due to redshift we observe it in red, we need to correct for this shift to understand the galaxy's intrinsic brightness and spectral energy distribution.

  3. **Magnitude adjustment**: The K-correction modifies the observed magnitude to reflect the galaxy's rest-frame magnitude—how it would appear if redshift effects were absent. Without this correction, distant galaxies might appear dimmer than they actually are, leading to biased estimates of their luminosity.

  4. **Dependence on galaxy type**: The K-correction varies with galaxy type because different types of galaxies emit light with different spectral energy distributions. For example, elliptical galaxies dominated by older stars may require a different K-correction than star-forming spiral galaxies with lots of UV emission.

  ### Example:

  At low redshifts ($z \approx 0.02$), the K-correction can be small and often negligible, but at higher redshifts (e.g., $z > 0.5$), the K-correction becomes significant. If uncorrected, it can lead to incorrect conclusions about the evolution of galaxies across time because distant, high-redshift galaxies would appear fainter due to this redshifted light.

  In summary, the K-correction ensures that astronomers can compare the intrinsic properties of nearby and distant galaxies accurately by accounting for the effects of cosmic redshift.

- Selection of galaxies:

  - The selection of galaxies is fundamental for the LF. Ideally, the galaxies are selected by *total apparent* magnitude. In reality, the galaxies are always drawn from catalogs that are based on *photographic* surveys. The *detection* of a galaxy on a photographic plate does not depend on total magnitude but on surface brightness.

  - Both very compact, high-surface-brightness objects and extended, very low-surface-brightness objects have small isophotal diameters and can go undetected.

  - Reaves (1956) and Arp (1965) were the first to draw attention to this potential selection bias by showing that the normal galaxies detected so far populate a narrow strip in the magnitude-log diameter diagram.

- Galaxies of very low surface brightness may be entirely missed. That such galaxies exist is known from the local dwarf spheroidals (Fornax, Sculptor, et al.), which were detected only because they are sufficiently nearby to be resolved into stars.
- The possible consequences for the LF are clear: The LF derived from any given sample will usually refer only to normal, easily visible galaxies. A population of luminous galaxies of low surface brightness may go unnoticed, although the LF nominally refers to *total* magnitudes.
- Disney (1976) highlighted the "tip-of-the-iceberg" bias, where galaxies of normal surface brightness are preferentially detected, while those with low surface brightness are often missed. Disney & Phillips (1983) quantified this bias and proposed using a "bivariate brightness distribution," which accounts for both total magnitude and surface brightness, instead of the traditional one-dimensional luminosity function (LF).
- The large-scale survey of the Virgo cluster (Binggeli et al., 1985) provided data for exploring this distribution and discovered some very extended, low-surface-brightness galaxies.
- A strong correlation between absolute magnitude and surface brightness was observed for galaxies fainter than MBT $\approx$ -19, suggesting that most low-surface-brightness galaxies are also of low total brightness. Thus, while galaxies are detected based on surface brightness, they are also indirectly selected by their total absolute magnitude.
- Impey et al. (1987) challenged the conventional understanding of galaxy detection by employing Malin's photographic contrast-enhancing technique, revealing many previously undetected objects in the Virgo cluster, particularly those with a central surface brightness below 26 B mag arcsec^{-2}. Their survey also uncovered a distant spiral galaxy with an extremely low surface brightness of 27 B mag arcsec^{-2} and a total magnitude of MBT $\approx$ -22. This discovery raises important questions about how many bright galaxies may be hidden below conventional detection limits, as noted by Disney & Phillips (1987).

• Metodos para determinar la luminosidad de las galaxias.

- Galaxies are usually divided into "cluster galaxies" and "field galaxies."
- A "cluster galaxy" is a member of a (rich) cluster that is representative of the clusters listed in, for example, Abell's (1958) or Zwicky et al.'s (1961-68) catalogs of clusters.
- As "field galaxy," one can then simply declare as such every galaxy that is not lying in a (rich) cluster; groups of galaxies thus become part of the "field."
- The distinction between clusters and field is natural in the context of the luminosity function because the methods used to derive a LF for a cluster and for a field sample are fundamentally different.
- "Cluster" and "field" also denote two basic density environments of galaxies, whose LFs cannot be expected to be the same a priori.
- All methods used to determine the LF discussed here are based on the assumption that the LF does not depend on galaxian position (within the cluster, or in the field). This means that φ and D can be separated, as expressed by Equation 8. This conventional approach is challenged in Section 6, where a general "LF-density relation" is proposed.
- **Cluster Galaxies:**

- Because all cluster galaxies are at the same distance, the apparent magnitudes m, after appropriate binning, are used directly to give $\varphi(m)$ as a histogram.
- Scaling by the distance modulus of the cluster (inferred, for example, from the redshift) transforms $\varphi(m)$ into $\varphi(M)$ and m_{lim} into M_{lim}.
- In nearby clusters like Virgo and Fornax, morphological sampling has been effective in identifying cluster members based on their surface brightness and structural characteristics. Faint cluster members typically have low surface brightness, while bright background galaxies are of high surface brightness. However, early-type giant galaxies (E, S0) and blue compact dwarfs (BCDs) pose challenges in cluster identification due to their high surface brightness and lack of structural detail, requiring velocity data for confirmation. This method is most reliable in isolated clusters, like Virgo, which lie in front of cosmic voids, minimizing background contamination. Nonetheless, a small fraction of cluster members (~10% in Virgo) cannot be definitively identified.
- Once a corrected cluster LF is established, a useful representation is that of Schechter (1976) in the form:

  $\varphi(M)dM \sim 10^{-0.4(\alpha+1)M} e^{-10^{0.4(M^*-M)}} dM$ where α and M^* (or L^*) are free parameters.
- At faint magnitudes, the equation is exponential with slope -0.4(α + 1). On the bright side, it is a double exponential that rapidly approaches zero after a turnover at a characteristic magnitude M^* (corresponding to a characteristic luminosity L^*).
- The best-fit parameters α and M^* for a cluster LF can be found by minimizing χ^2 in fitting Equation 13 to the binned magnitude data (e.g. Dressler 1978). A generalized χ^2 statistic to include the uncertainty in the background correction has been used by Lugger (1986). Alternatively, one can apply a maximum-likelihood method to the unbinned data to obtain α and M^* (Lugger 1986, Oegerle et al. 1986).
- Determining the luminosity function (φ(M)) for field galaxies requires a well-defined, unbiased sample, typically defined by an apparent magnitude cutoff (mlim). However, galaxy catalogs are often incomplete, particularly near this cutoff, due to factors like low surface brightness galaxies and magnitude errors. Completeness can be improved by supplementing catalogs with missing objects or adjusting entries statistically based on a magnitude-dependent incompleteness function. A useful method to test and correct for catalog incompleteness is the V/Vmax technique, which compares the observed sample volume (V) to the maximum volume (Vmax) in which a galaxy can be detected without falling below the cutoff magnitude. A complete sample has an average V/Vmax of 0.5.
- The absolute magnitudes of the sample galaxies must be calculated prior to the derivation of the LF. This requires distance information for every sample galaxy. The distance of field galaxies (except for very nearby ones) must be inferred from the redshift z, since no other precise method is available for all galaxy types.

2 Estimating Galaxy Luminosity Functions - Willmer

- The luminosity function of galaxies is a key tool for studying large-scale structures, as it helps estimate the total amount of luminous matter in galaxies. Several methods have been developed over the years to calculate the luminosity function for both field and cluster galaxies, as well as quasars. Early efforts, like Hubble (1936), used a basic method that counted objects within a given volume (Φ = N/V). However, detailed descriptions of these methods emerged later (e.g., Trumpler & Weaver 1953, Schechter 1976).

- The “classical method,” coined by Felten (1976), assumes a uniform distribution of galaxies in space. An important variation, the 1/Vmax method, introduced by Schmidt (1968) for quasar studies, applies a weight inversely proportional to the object’s luminosity, though it still assumes spatial uniformity. This method was first used on galaxies by Huchra & Sargent (1973) and later extended to combine samples coherently by Avni & Bahcall (1980). Eales (1993) further refined the 1/Vmax method to study the luminosity function as a function of redshift.

- A maximum-likelihood estimator developed by Sandage, Tammann, and Yahil (1979) (STY) was applied to the Revised Shapley-Ames catalog (Sandage & Tammann 1981). This estimator eliminates the influence of the density distribution and allows corrections for incompleteness or other observational effects. Unlike the C^{-}C$-$ method, the STY assumes the luminosity distribution follows an analytic function.

- To visually represent the results and assess the goodness-of-fit, Efstathiou, Ellis, and Peterson (1988) introduced the stepwise maximum likelihood method (SWML), which counts galaxies in magnitude bins without assuming a specific functional form. SWML was further refined by Heyl et al. (1997) to account for redshift dependence, and by Springel & White (1997), who replaced the constant-bin approach with power-law assumptions, producing a smoother luminosity distribution.

- Despite numerous methods for calculating the luminosity function (Binggeli et al. 1988 list 13), no comprehensive comparison between them has been conducted. A notable issue is the discrepancy in normalization values between nearby galaxy surveys ($z \leq 0.1$) and more distant samples. Surveys like those by da Costa et al. (1994) and Marzke et al. (1994) for local galaxies use the STY and SWML methods, while distant surveys (e.g., Lilly et al. 1995) rely on the 1/Vmax estimator. Distant samples typically show higher normalization values, suggesting possible density evolution or “disappearing” galaxies.

- Another potential cause is the poor determination of the faint end of the local luminosity function, as suggested by Gronwall & Koo (1995). Recent studies support this, with da Costa et al. (1997) finding a faint-end slope of $\alpha \sim -1.2$ for the SSRS2 survey, and Sprayberry et al. (1997) reporting an even steeper slope of $\alpha \sim -1.5$ for low surface brightness galaxies.

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3 Blanton - Roweis

- New surveys at low and high redshift have provided us with estimates of galaxy spectral energy distributions (SEDs) for an enormous number of galaxies. When comparing populations of galaxies at different redshifts in these surveys, we need to use comparable measurements of the galaxy SEDs. However, differ- ent surveys use different bandpasses, and the rest-frame wavelengths of these bandpasses necessarily vary with redshift. We need to be able to handle this heterogeneity in order to make sensible comparisons among all of these new surveys.

- **k corr**

- With a model galaxy spectrum, calculating the K-correction is straightforward. The relevant formulas, derived by Hogg et al. (2002), are provided. Typical K-corrections are then presented for the data used in the fitting process.