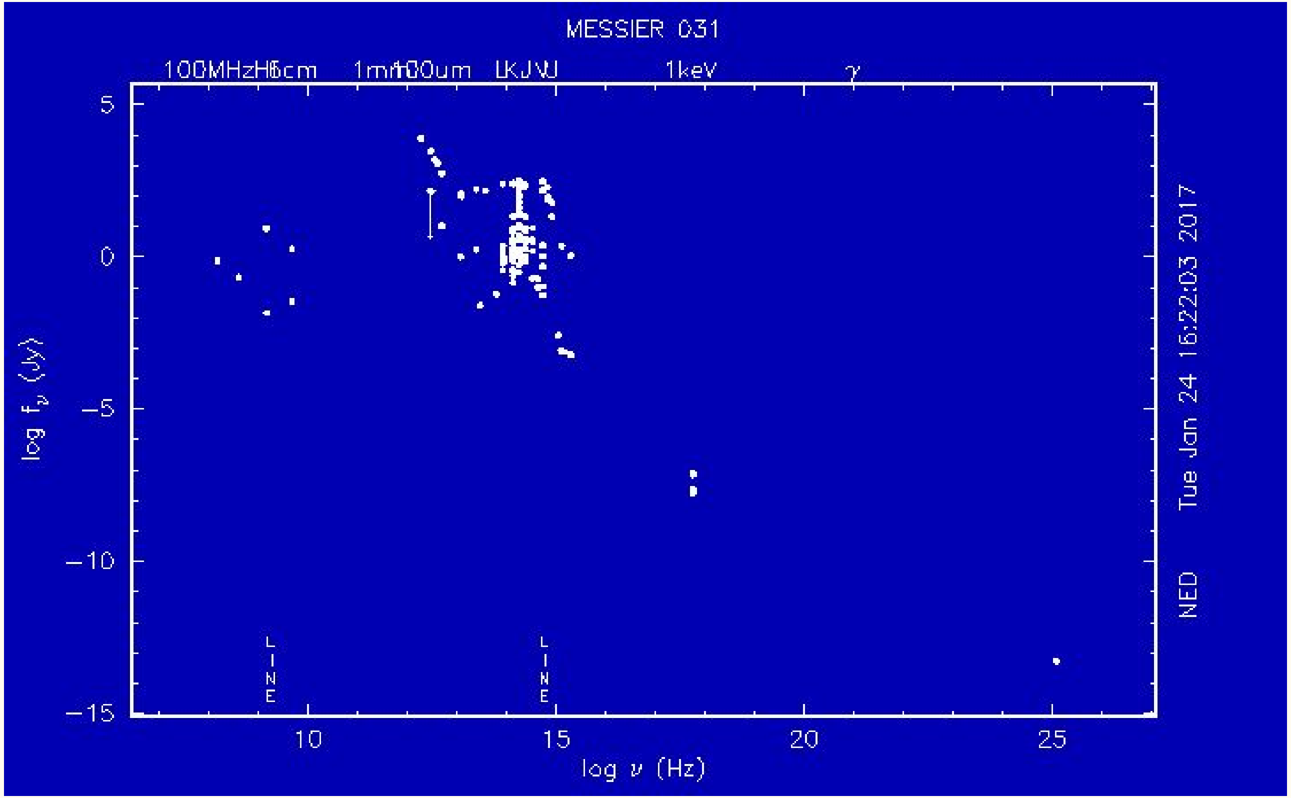
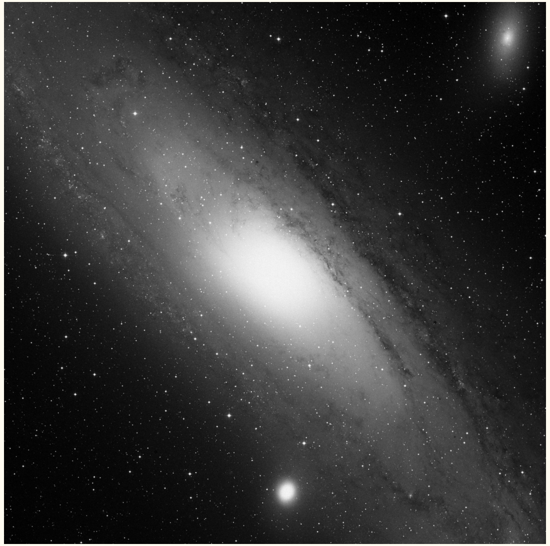
Luminosity Function for Galaxies

First speaker: Christie Balanduk
Second speaker: Robert Gleisinger

Contents

Spectral Energy Distribution   M31





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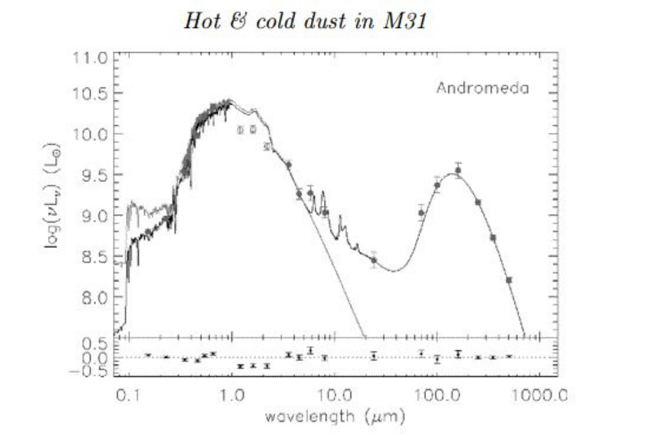
Spectral Energy Distribution
Andromeda

- ❑ SEDs will demonstrate absorption lines if the light passes through a gas before it arrives at Earth.
- ❑ This light in the form of an SED can then tell us what kind of gas the light passed through and the temperature of the gas.



Groves B, Krause O, et al. (2012)

Spectral Energy Distribution
Andromeda

- Some information collected about Andromedan was that over the majority of the disk, the dust is heated by optical photons that come from stars that are older than 1Gyr
- Astronomers have found that Andromeda is a dust-poor galaxy with relatively cool gas.

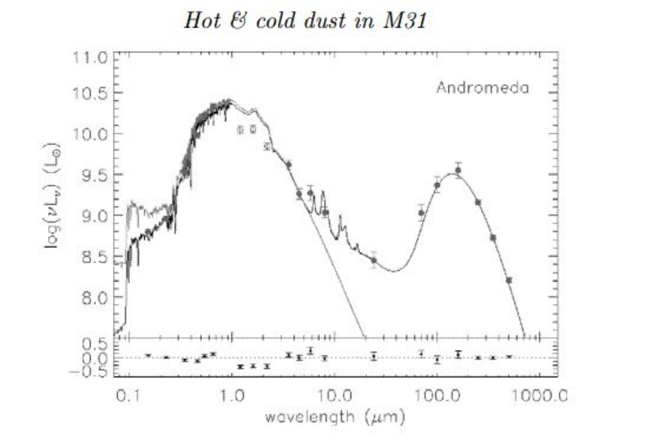
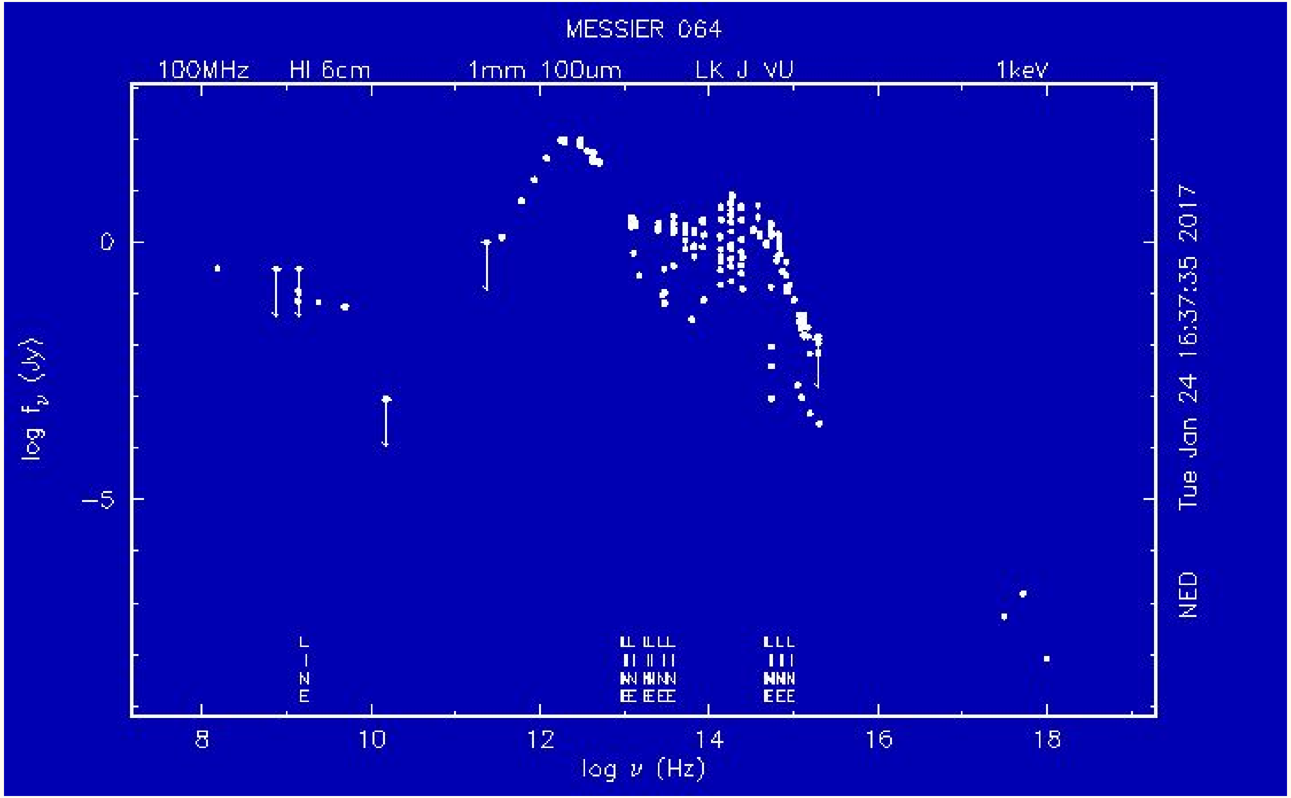
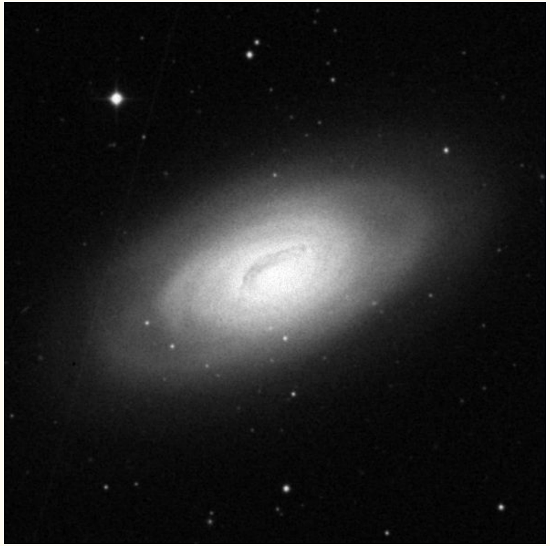


Figure 1, Groves B, Krause O, et al. (2012)

Groves B, Krause O, et al. (2012)

Spectral Energy Distribution M64





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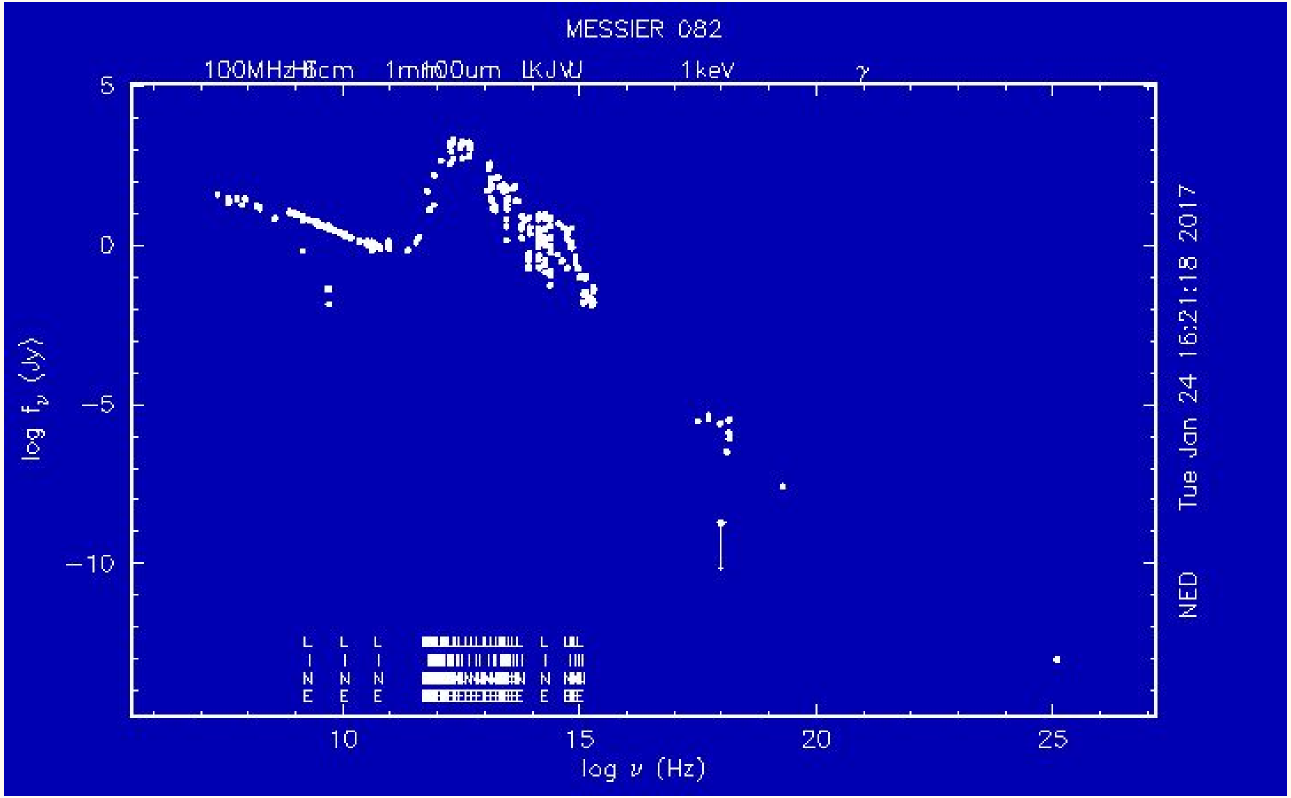
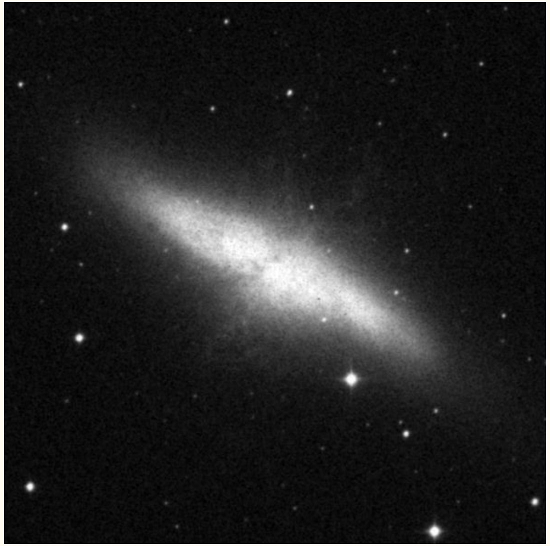
Spectral Energy Distribution M82





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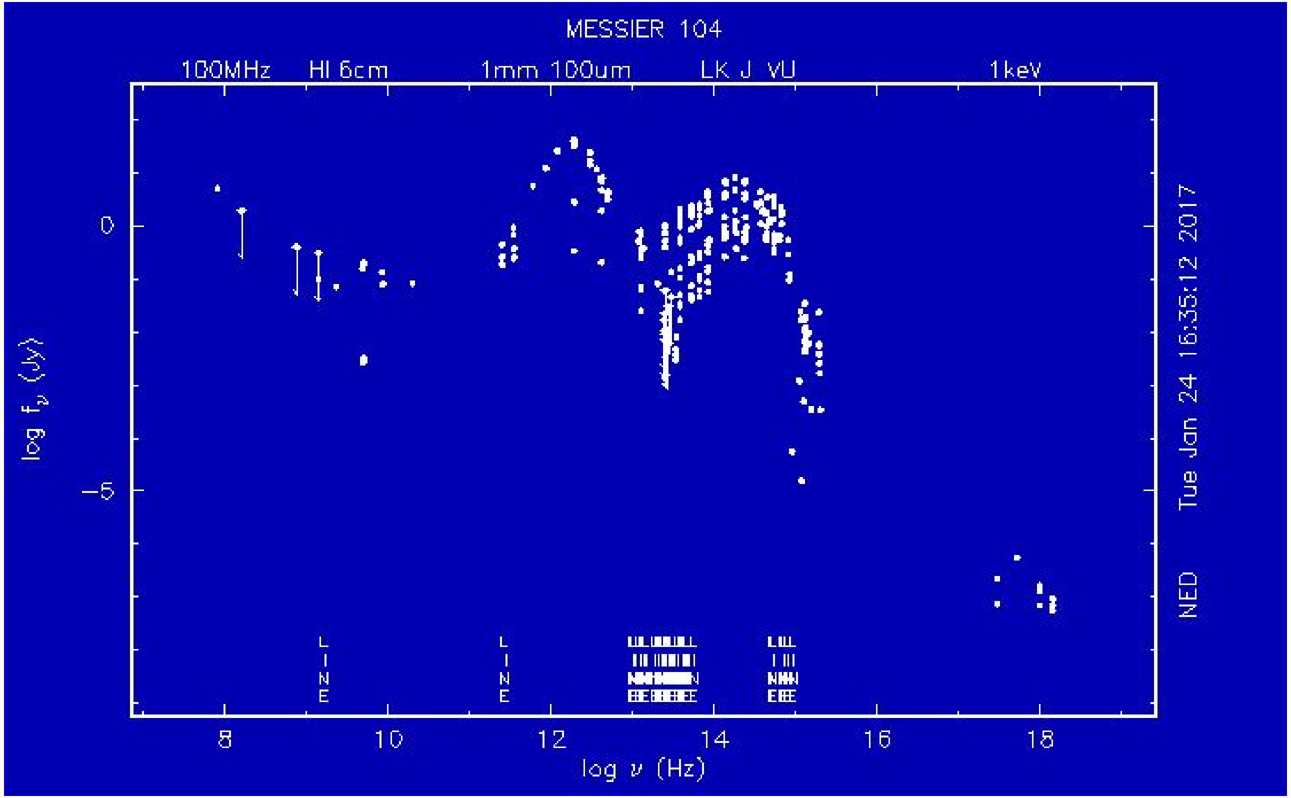
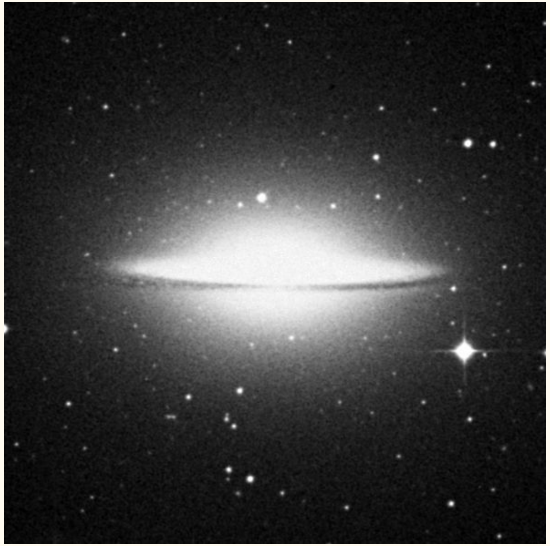
Spectral Energy Distribution
M82

- ❑ The bump in the the SED of M82 that shows up in the sub-millimeter and far infrared wavelengths is characteristic of starburst galaxies.
- ❑ This highlights the large amount of star formation that has recently occured in this galaxy

esa/planck collaboration (2011)

Spectral Energy Distribution M104





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Stellar Mass-to-Light Ratio

- ❑ The brightness of an object is often found by calculating how many of Earth suns would have to be placed at the distance of that object on order for us to receive the same flux
- ❑ If we know the object's mass we can then calculate the mass-to-light ratio in comparison to the sun
- ❑ Should the object have an identical spectral energy distribution to that of our sun then the mass-to-light ratio will be the same at all wavebands X.

Binney & Merrifield (1998, p. 60)

Stellar Mass-to-Light Ratio Limits

- If an object does not have a similar spectral energy distribution to our Sun then we have to use the bolometric luminosity. Unfortunately this is rarely available and assumptions have to be made about the objects full spectrum which can be very uncertain.

Binney & Merrifield (1998, p. 60)

Surface Brightness

- The surface brightness (I(x)) of a galaxy is the amount of light per square arcsecond on the sky at a particular point.
  - $I(x) = F/\boldsymbol{\alpha} = (L/4\pi d^2)/(D^2/d^2) = L/(4\pi D^2)$ (1.23)
- Units: mag arcsec^{-2} (the apparent magnitude of a star that appears as bright as one square arcsecond of the galaxy's image) or $L_\odot\ \text{pc}^{-2}$
- The surface brightness at any point does not depend on distance d unless a galaxy is so far away that the expansion of the Universe reduces I(x).

Sparke & Gallagher (2007, p. 42)

Surface Brightness

- Surface brightness is usually measured in a fixed wavelength band for galaxies just as we've already seen for stars.
- The disks of galaxies are much fainter than the centers; the centers can reach $I(B) \approx 18$ mag arcsec^{-2} or $I(R) \approx 16$ mag arcsec^{-2}
- Since galaxies do not have sharp edges we can measure their size using fixed isophotes.
  - Popular choices being the 25th-magnitude isophote in the B-band (R_{25}) and the Holmberg radius at $I(B)(x) = 26.5$ mag arcsec^{-2}
- To calculate the luminosity for a galaxy we measure how the amount of light from a given radius increases as we increase the radius, then extrapolate out for the total luminosity.

Sparke & Gallagher (2007, p. 42-43)

Surface Brightness

- Galaxies are usually very dim in comparison with the night sky, moonlight alone can make the sky brighter than a galaxy, therefore observing a galaxy from a ground based observatory requires certain procedures.
  - We can use certain filters in order to cut out some of the emission
  - Measure the brightness of the blank sky as it changes through the night while measuring the brightness of the galaxy just as carefully.
  - We can also observe in near-ultraviolet because the sky brightness is lower in this range.

Sparke & Gallagher (2007, p. 43)

Table 1.9 Average sky brightness in ultraviolet, optical, and infrared wavebands

Band	*Wavelength*	*Full moon* (mag arcsec^{-2})	*Dark sky* (mag arcsec^{-2})	*From space* (mag arcsec^{-2})	*From space* (μJy arcsec^{-2})	*South Pole* (μJy arcsec^{-2})
	1500 Å			25.0		
	2000 Å			26.0		
	2500 Å			25.6		
U	3700 Å		22.0	23.2		
B	4400 Å	19.4	22.7	23.4	1.8	
V	5500 Å	19.7	21.8	22.7		
R	6400 Å	19.9	20.9	22.2		
I	8000 Å	19.2	19.9	22.2	3.2	
J	1.2 μm	15.0	15.0	20.7	2.4	300–600
H	1.6 μm	13.7	13.7	20.9	4.4	800–2 000
K	2.2 μm	12.5	12.5	21.3	1.9	300–700
K′	2.2 μm	13.7	13.7	21.3	1.9	500
L	3.3 μm				1.1	10^5
M	4.9 μm				8.0	10^6
N	10.6 μm				220	4×10^7
Q	19 μm				400	3×10^8

Sparke & Gallagher (2007, p. 44)

- There seem to exist many more small, dim galaxies than large bright ones.
- Most of the very bright galaxies are red
  - Elliptical and S0 galaxies
- Most of the dim galaxies are spirals of irregulars, which are blue as a result of recent massive star birth.
- Despite the fact that there are dramatically more irregular and spiral galaxies, elliptical galaxies actually contain roughly half of the total mass of stars.

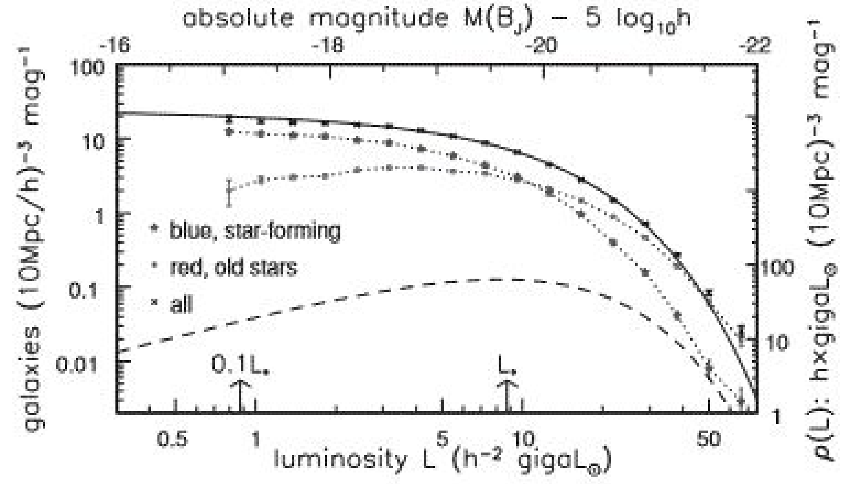


Fig. 1.16. Number of galaxies per 10 Mpc cube between absolute magnitude $M(B_J)$ and $M(B_J) + 1$ (crosses). Dotted lines show numbers of blue (stars) and red (filled dots) galaxies making up this total; vertical bars indicate errors. The solid line shows the luminosity function of Equation 1.24; the dashed line gives $\Phi(M) \times L/L_*$, the light from galaxies in each interval of absolute magnitude. The blue bandpass B_J is matched to the photographic plates used to select the galaxies – 2dF survey, D. Croton.

Sparke & Gallagher (2007, p. 45)

The Luminosity Function

- Just as we have learned about stars through the stellar luminosity function, we hope to learn about the evolution of galaxies through studying the distribution of galaxy luminosities.
- The luminosity function for galaxies is represented by ($\phi(M)$) where M represents the absolute magnitude of a galaxy.
- $\phi(M)dM$ is proportional to the number of galaxies with absolute magnitudes within the range$(M, M+dM)$ and represents the number density of galaxies within that magnitude range.
- If we integrate $\phi(M)dM$ from negative infinity to infinity then we get a normalization value for the function which is equal to the total number of galaxies per unit volume.

Binney & Merrifield (1998, p.162-163)

The Luminosity Function

- The following is the procedure for estimating the luminosity function:
  - Measure the apparent brightness for the galaxies in the volume sample
  - Convert the apparent magnitude to absolute magnitude using the distance
    - Often we will use the hubble law to account for the redshift
    - If the redshift is too substantial, we can do a k-band correction
  - Divide the number of galaxies within a magnitude range by the volume of space surveyed
- This classical method for estimating the luminosity function however, is flawed:
  - This method assumes that galaxies are evenly distributed in the Universe, however galaxies tend to clump together creating areas which are very dense along with voids.
  - We need a better way to describe the luminosity function.

Binney & Merrifield (1998, p.162-163)

The Luminosity Function

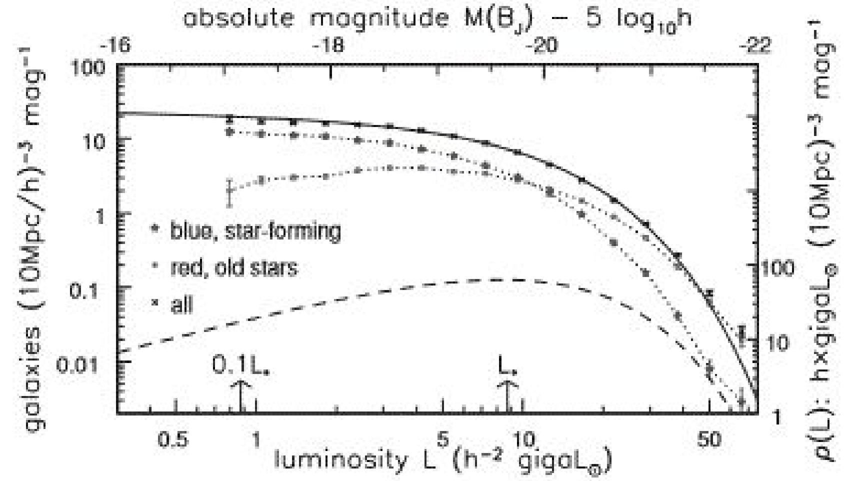
Schechter Function

- The schechter function is a parameterization of the luminosity function that accurately describes most galaxies for average luminosities, the function becoming less accurate at the higher and lower ends of the observed luminosity ranges.
- The schechter function can be represented both in terms of absolute magnitude and luminosity, leading us to define terms L^* and M^*
- The number of galaxies with luminosities brighter than L^* drops off sharply
- Alpha sets the slope of the luminosity function at the dim end.
- $L \geq 0.1L^*$ is the criterion used for defining a bright or giant galaxy instead of a dwarf galaxy.

Sparke & Gallagher (2007, p.45)
Binney & Merrifield (1998, p.162-169)

The Schechter Function

- The Schechter function overestimates the density of very faint galaxies, however most of the light comes from galaxies close to L*.



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Sparke & Gallagher (2007, p. 45)

Limits in the Luminosity Function

- The extreme ends are difficult to determine
  - The faint galaxies are hard to see
  - There are not many extremely bright galaxies created therefore we would have to observe in a larger volume of space, which would give a lower galaxy density.

Sparke & Gallagher (2007, p.63-64)

The Malmquist Bias

- When we observe a luminosity function a limiting magnitude is always present from the instruments used or from the conditions of the night sky
- As a result of this limiting magnitude, the mean absolute magnitude observed within a volume sample will be brighter than the mean absolute magnitude of a population as a whole.

Binney & Merrifield (1998, p. 111)

Citations

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The STScI Digitized Sky Survey
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