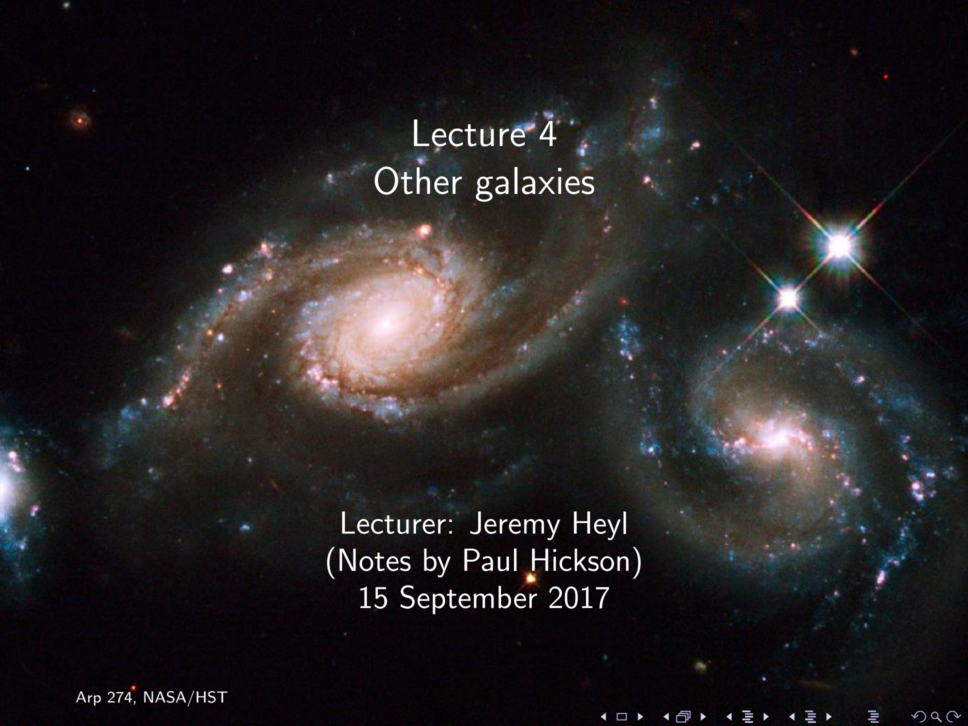

Lecture 4
Other galaxies

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(Notes by Paul Hickson)
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Arp 274, NASA/HST

1.3 Other Galaxies

Galaxies are found in a variety of shapes and sizes. A first is to study their morphology.

NASA/ESA HST J. Lotz

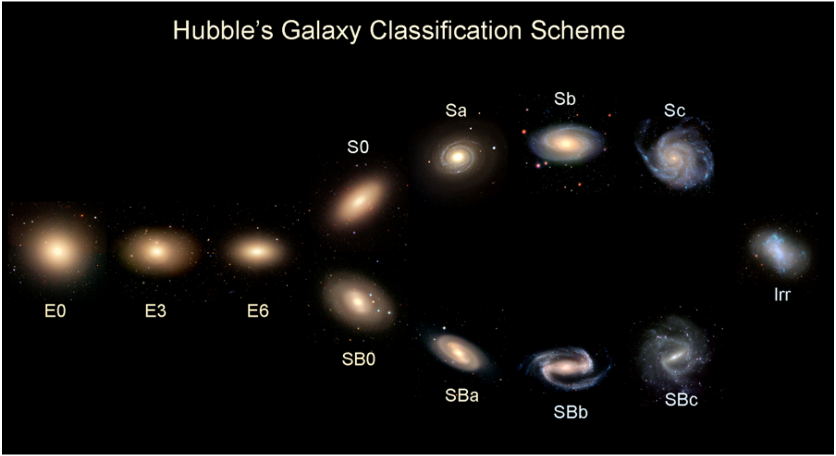
Hubble classification

A useful classification scheme was first proposed by Hubble (1926). He identified four main categories:

- **elliptical** (E) - elliptical shape with a smooth distribution of stars. Degree of flattening is indicated by a number $(0-7)$.
- **spiral** (S, SB) - galaxy with a stellar disk and spiral arms. Types a, b and c denote decreasing central concentration and wider more irregular spiral structure. The letter B denotes a central bar-like structure.
- **lenticular** (S0, SB0) - a smooth disk galaxy with no spiral structure.
- **irregular** (Irr) - Hubble identified two types. Irr I are small low-luminosity gas-rich galaxies with no clear spiral structure. Irr II are peculiar galaxies.

Hubble called E and S0 **early** types and S, SB and Irr **I late types**, because he thought that the former evolved into the later. They don't, but the names are still used.

Hubble classification

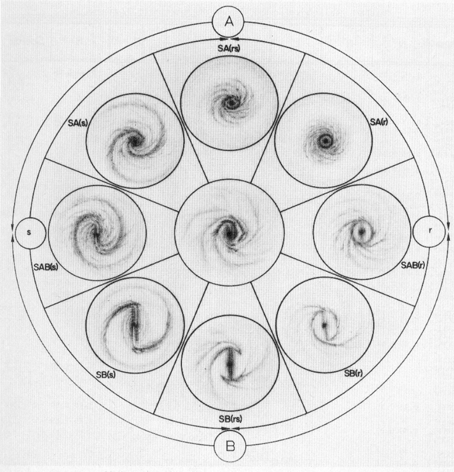


blog.galaxyzoo.com

de Vaucouleurs classification

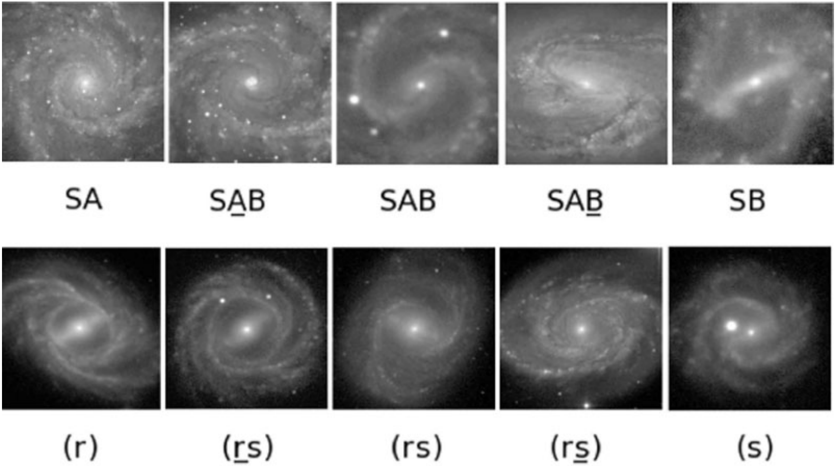
de Vaucouleurs made many changes and additions:

- He added types d and m to denote 'later' spirals
- He introduced a new type Im, which is the same as Hubble's Irr I.
- He added the notation (r) or (s) to indicate a ring or s-shaped structure.
- He called unbarred spirals SA instead of S.



bama.az.edu

de Vaucouleurs extensions



ned.ipac.caltech.edu

Other classes

- D - a giant elliptical galaxy
- cD - a supergiant elliptical galaxies found at the centres of rich clusters.
- dE - a dwarf elliptical galaxy
- dSph - a dwarf spheroidal galaxy
- dIrr - a dwarf irregular galaxy

NGC 6166 cD galaxy, NASA/JPL-Caltech/SSC

IC 1613 dwarf irregular, NASA/JPL-Caltech/SSC

Leo 1, a dwarf spheroidal galaxy

SDSS

Catalogues

- *Messier Catalogue* (Messier 1784) - lists 109 nonstellar objects. Many are not galaxies (eg. M1, M42, etc)
- *New General Catalogue* (Dreyer 1888) - over 7000 nonstellar objects. NGC 224 = M31 = Andromeda galaxy.
- *Third Reference Catalog of Bright Galaxies* (RC3, de Vaucouleurs et al. 1991)
- *Revised Shapley-Ames Catalog of Bright Galaxies* (RSA, Sandage & Tamman 1981).
- *Uppsalla General Catalogue of Galaxies* (Nilson 1973) - Also has a southern extension, the *ESO/Uppsala Survey of the ESO (B) Atlas* (Lauberts 1982).

Many catalogues are available on-line at **cdsweb.u-strasbg.fr** and/or **ned.ipac.caltech.edu**

Galaxy photometry

In the local Universe, intensity is essentially independent of distance. To see this consider the flux received from a small region of a galaxy having angular dimensions $\alpha \times \alpha$. The intensity is

$$I = \frac{F}{\alpha^2} = \frac{L}{4\pi d^2 \alpha^2} = \frac{L}{4\pi l^2}$$

where $l = \alpha d$ is the linear size of the region. This depends only on the amount of luminosity emitted per unit area of the galaxy, and not on its distance d.

In fact, the intensity decreases at very large distances because it is affected by redshift z due to the expansion of the Universe. One can show that

$$I \propto (1 + z)^{-4}$$

which is called the **surface brightness dimming** law.

Isophotes

One can map the brightness distribution of light from a galaxy by drawing lines of constant intensity. These are called **isophotes**.

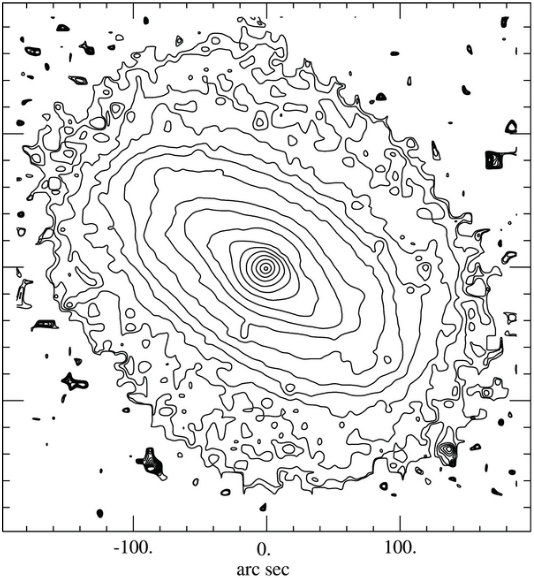
Usually the isophotes are labelled with *surface brightness*, in some waveength band.

This typically ranges from about $\mu_B \sim 18$ in the centre to ~ 28 in the faint outer regions.

The **Holmberg radius** is defined as the radius of the $\mu_B = 26.5$ isophote.

Warning: the text uses the symbol I to denote surface brightness. We shall distinguish between intensity I, which has units of W m^{-2} sr^{-1}, and surface brightness μ which is a dimensionless logarithmic quantity.

Isophotal photometry



Gutiérrez et al 2011

Luminosity function

The *luminosity function* $\Phi(L)$ provides a census of the luminosities of the various galaxies in some large volume of space.

Specifically, $\Phi(L)\Delta L$ denotes the number of galaxies per Mpc^3 having luminosity between L and $L + \Delta L$.

One finds that there are more low luminosity galaxies than high-luminosity. A convenient empirical fitting formula is the **Schechter function**,

$$\Phi(L) = \frac{n_*}{L_*}\left(\frac{L}{L_*}\right)^{\alpha} \exp\left(-\frac{L}{L_*}\right).$$

Here n_*, L_* and α are constants determined from the data.

Surveys conducted in blue light indicate that $n_* \simeq 0.007\ \mathrm{Mpc}^{-3}$, $L_* \simeq 2 \times 10^{10} L_\odot$ and $\alpha \simeq -0.5$.

Luminosity function

Often, astronomers use $\Phi(M)$, defined as the number of galaxies per Mpc^3 per interval of absolute magnitude.

To find the relationship between $\Phi(L)$ and $\Phi(M)$, we note that the number of galaxies in the luminosity interval dL is then same as the number in the corresponding magnitude interval dM, therefore

$$\Phi(M)|dM| = \Phi(L)|dL|.$$

Now, magnitude and luminosity are related by

$$M = -2.5 \log L + const,$$

therefore,

$$dM = -\frac{2.5}{\ln 10}\frac{dL}{L}$$

So we find that

$$\Phi(M) = \left|\frac{dM}{dL}\right|^{-1} \Phi(L) = 0.92 L \Phi(L).$$

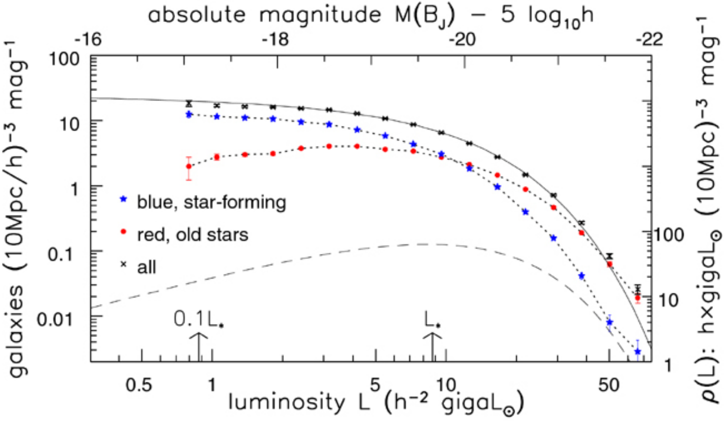


Fig 1.16 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

Number of galaxies per 10 Mpc cube between absolute magnitude M_B and $M_B + 1$ (crosses). The solid line shows the Schechter function and the dashed line gives $\rho(L) = \Phi(M) \times L/L_*$, the luminosity density per magnitude - 2dF survey, D. Croton.

Number density

The total number of galaxies, per Mpc^3 can be found by integrating the luminosity function,

$$n = \int_0^\infty \Phi(L)dL = n_* L_* \int_0^\infty x^\alpha e^{-x} dx$$
$$= n_* \Gamma(\alpha + 1) \quad (1)$$

where we have put $x = L/L_*$, and Γ is the gamma function. $\Gamma(j+1) = j!$ if j is an integer.

Observations indicate that $n \simeq 0.02$ Mpc^{-3}, which is one galaxy about every 50 Mpc^3.

Luminosity density

The total luminosity emitted by all galaxies, per Mpc^3 can be found by integrating the luminosity function, weighted by the luminosity,

$$\rho_L = \int_0^\infty \Phi(L) L dL = n_* L_* \int_0^\infty x^{\alpha+1} e^{-x} dx$$
$$= n_* L_* \Gamma(\alpha + 2) \quad (2)$$

Including infrared emission, one finds $\rho_L \simeq 5 \times 10^8 L_\odot$ Mpc^{-3}. This is roughly equivalent to an L_* galaxy every 100 Mpc^3.