Lecture 15
Spiral galaxies

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(Notes by Paul Hickson)
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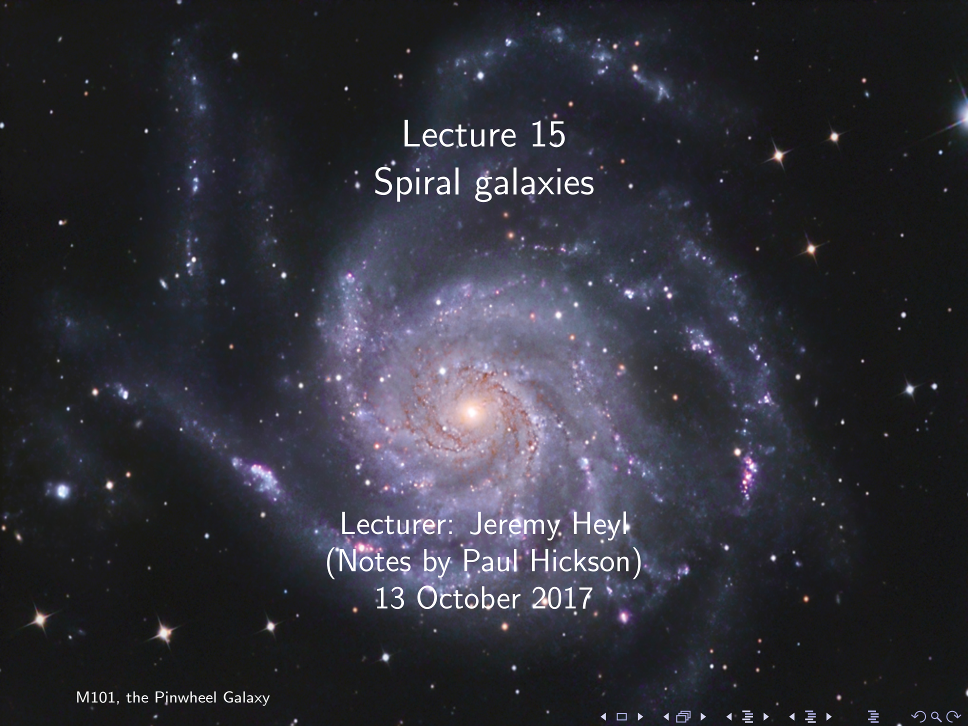

M101, the Pinwheel Galaxy

Structure

Spirals are the most common of the large galaxies (about 80% are spiral).

Spiral and S0 galaxies both have prominent disks. The difference is that S0 galaxies have no spiral arms and appear to have no cool gas.

Both have halos, bulges and nuclei.

Along the sequence Sa ... Sm the galaxies become less luminous and bluer. The bulge becomes less prominent and the spiral arms become more open and patchy.

Both may contain bars. One has a parallel sequence SBa ... SBm for barred spirals.

M101, an Sc galaxy.

M102, an S0 galaxy.

Magnitudes and colours of galaxies in the Ursa Major group.

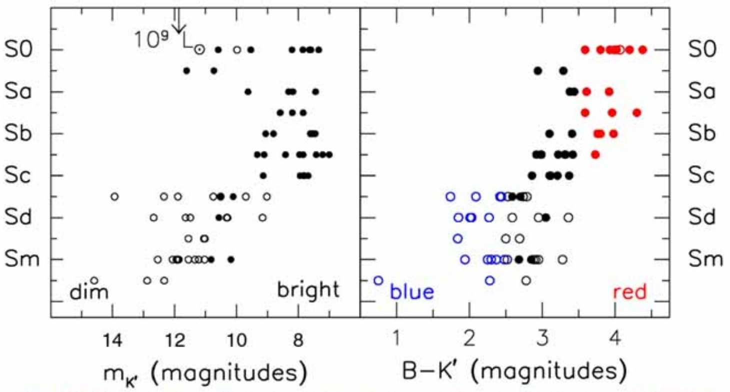

Fig 5.6 (M. Verheijen) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

Apparent magnitude m K' and B – K' color of galaxies in the Ursa Major group, plotted by galaxy type. Galaxies to the right of the arrow have $L > 10^9 L_\odot$ at the group's distance of 15.5 Mpc. Open circles show galaxies for which the disk has lower central brightness: $I_{K'}(0) > 19.5$. On average, S0 galaxies are luminous and red, while the Sd and Sm systems are fainter and bluer.

Surface photometry

Images taken using electronic detectors such as CCDs (charge-coupled devices) provide a signal that is proportional to the number of photons absorbed by each pixel of the detector.

With careful calibration, a map of the intensity I, integrated over the bandpass of the detector/filter combination, can be determined.

From this one can construct contours and study the distribution of intensity (surface brightness). Or one can integrate the intensity to get the total flux (magnitude) of the galaxy.

A correction is needed if the galaxy is inclined to the line of sight (not seen face on). For a uniform disk, the intensity is increased by a factor $\sim \cos i$, where i is the angle between the symmetry axis and the line of sight.

NGC 7331

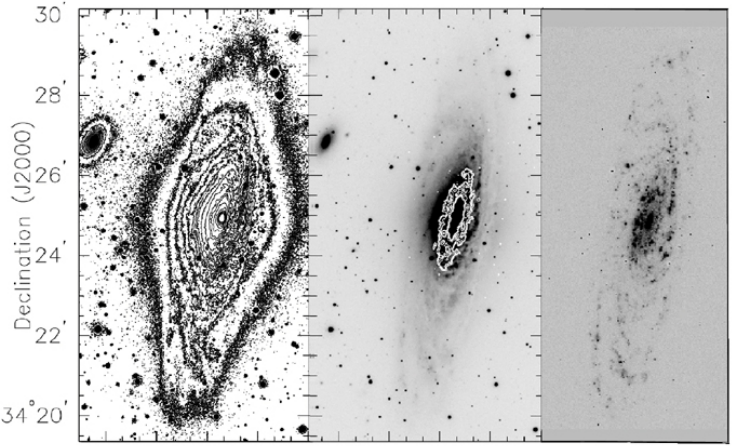

Fig 5.3 (Ferguson, Thornley) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

Sb galaxy NGC 7331. Left, isophotes in the R band; Center, negative image in the R band, with contours of CO emission overlaid. Right, negative image in H_α, showing HII regions in the spiral arms.

Surface photometry

A plot of intensity vs effective radius is called an **intensity profile**.

The radial profiles of the disks of spiral galaxies are generally well-fit by an exponential law.

$$I(R) = I(0)\exp(-R/h_R)$$

where $I(0)$ is the central intensity and h_R is the scale length.

Typically, $1 < h_R < 10$ kpc. It is slightly smaller in B than R as disks tend to become redder towards the centre.

Near the centre, one needs to also account for light from the bulge. The (extrapolated) central surface brightness of disks typically range from ~ 22 mag/arcsec^2 in B to ~ 18 mag/arcsec^2 in the K band.

Some **low-surface-brightness** (LSB) galaxies may be as much as 25 times fainter.

NGC 7331 intensity profile

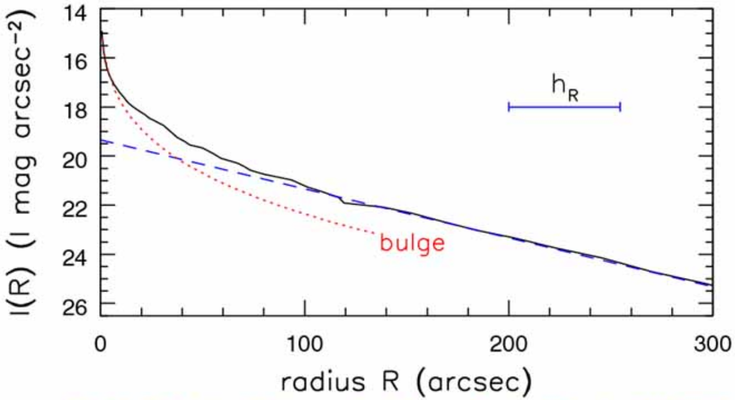

Fig 5.4 (R. Peletier) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

NGC7331: the solid line shows surface brightness in the I band, near 8000Å. The dashed line is an exponential with scale height $h_R = 55$ arcsec; the dotted line represents additional light from the bulge.

Surface photometry

In galaxies that are seen edge on, one can measure the distribution of light perpendicular to the disk. In general, an exponential law fits well,

$$I(R, z) = I(R) \exp(-|z|/h_z)$$

where $I(0)$ is the central intensity and h_z is the scale height.

Typically, $h_z \simeq 0.1 h_R$. A few late-type spirals have very thin disks. Others, like the Milky Way, have a thick-disk component.

The appearance of a galaxy depends on the wavelength that one observes. In the UV, only the hottest stars are visible. In the near infrared (1 - 2.5 um), one sees primarily the old stellar population. In the mid infrared (3 - 100 um) we see thermal emission from the dust.

M95 in UV and visible light

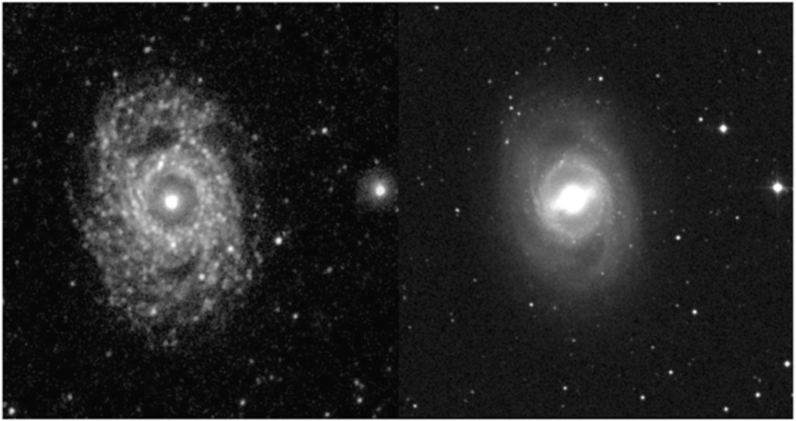

Fig 5.10 (Galex) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

SBb barred spiral galaxy NGC 3351(M95). The left image combines ultraviolet light at 1530Åand 2300Å. We do not see the bar, since it lacks young blue stars; star- forming knots give the spiral arms a fragmented appearance. Right, in visible light we see a strong central bar, surrounded by a ring and smooth spiral arms.

Cool gas

The cool gas in these galaxies is mostly confined to the disk. It can be mapped using the 21 cm hydrogen line.

The 21cm line is generally optically thin, so the gas mass is just proportional to the flux F_ν. By observing over a range of radio frequencies, we can determine the mass of gas as a function of radial velocity for each line of sight.

The total mass can be found by integrating over frequency,

$$M_{\mathsf{HI}} = 2.36 \times 10^5 M_\odot \times d^2 \int F_\nu \left[1421 \text{ MHz} \times (1 - V_r/c)\right] dV_r,$$

where d is the distance to the galaxy in Mpc, F_ν is the flux density in Jy, and V_r is the radial velocity in km/s.

One finds that the HI extends to larger radius than the visible light.

NGC 7576

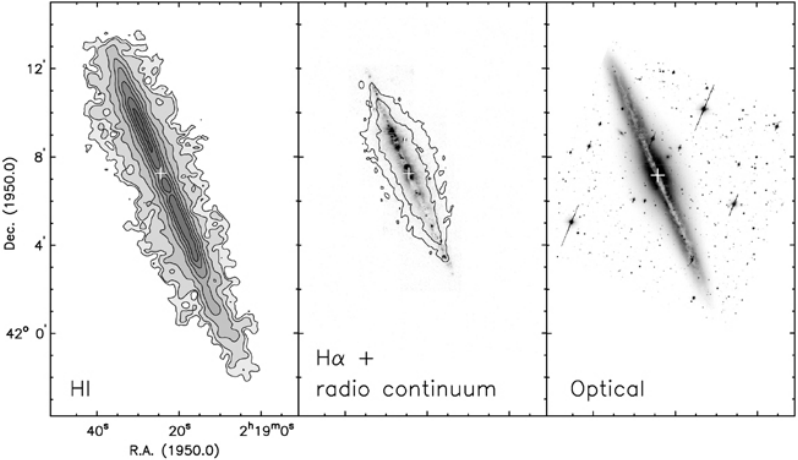

Fig 5.16 (Swaters & Rand) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

Stars and interstellar gas in the edge-on Sc galaxy NGC 891. Left, surface density of HI gas; centre, an image in H_α, with contours showing radio emission in the 20-cm continuum; right, R-band optical image.

NGC 7331 21-cm map

HI gas in NGC 7331, observed with the VLA. Left, gas surface density; at $d = 14$ Mpc, we see $11.3 \times 10^9 M_\odot$ of HI, and 1 arcmin $= 4$ kpc.

The outer contour shows diffuse gas, at $N_H = 2.8 \times 10^{19}$ cm^{-2} ; higher levels are at 1.2, 3.3, 6.4, and 9.5×10^{20} cm^{-2}.

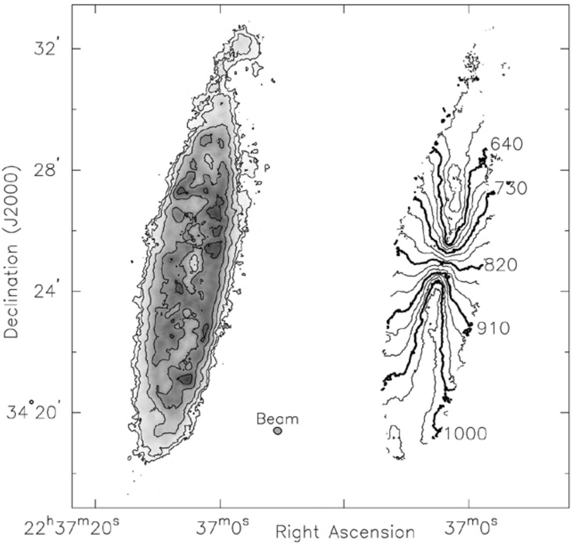

Fig 5.13 (Thornley & Bambic) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

Right, contours of gas velocity V_r, spaced 30 km/s apart.

NGC 7331 HI surface density

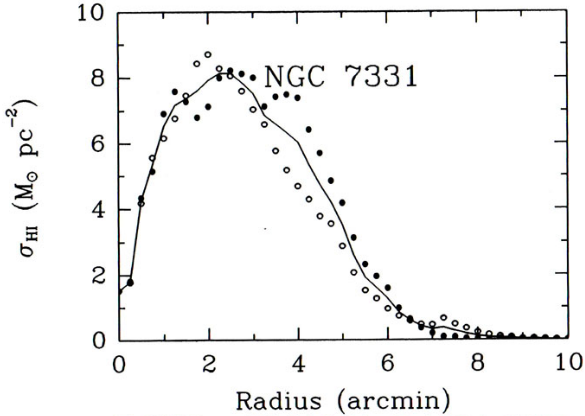

Fig 5.14 (K. Begeman) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

In NGC 7331, the average surface density of HI gas at each radius, calculated separately for northern (filled dots) and southern (open circles) halves of the galaxy; the solid curve shows the average.

HI mass vs galaxy diameter

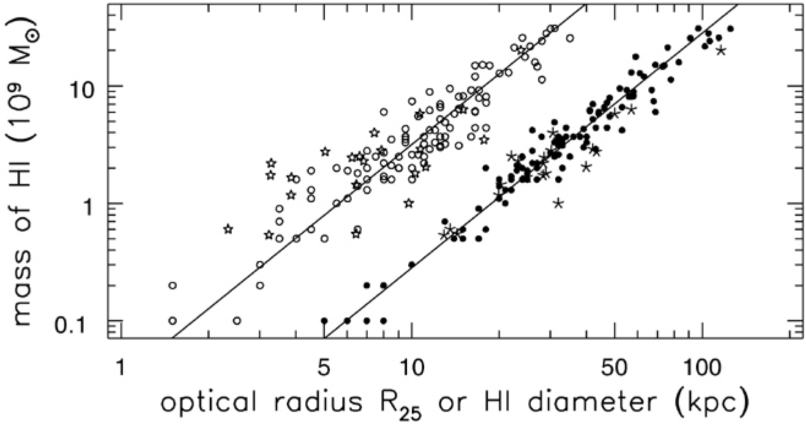

Fig 5.15 (Broeils & de Blok) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

The mass of HI gas in disk galaxies increases as the square of the optical radius R_{25} (open symbols) and the diameter at which the surface density of HI drops to $1 M_\odot$ pc^{-2} (filled symbols): sloping lines show $10 M_\odot$ pc^{-2} of HI within R_{25} and $3.6 M_\odot$ pc^{-2} within the HI diameter. Five-pointed symbols represent low-surface-brightness galaxies.

Molecular gas

Molecular hydrogen is difficult to detect as the molecule has no dipole moment. Usually, one looks for CO and other molecules, in the mm and sub-mm regions of the spectrum, and assumes a constant ratio of CO/H_2.

The mass of molecular gas is generally comparable to the atomic gas in spiral galaxies. However, the ratio of CO to H_2 is typically $\sim 10^{-4}$. So observations of molecular gas are less sensitive than those of HI.

Molecular gas is generally not detected beyond the visible extent of the galaxy.

Gas in S0 galaxies

Most S0 galaxies have little if any cool gas. It has either been converted entirely to stars, or removed from the galaxy.

There are some exceptions however. A few S0 galaxies have as much as $10^{10} M_{\odot}$ of HI. In these galaxies, the gas is often not in the disk of the galaxy, but in a tilted ring. And it often rotates in the opposite direction (**retrograde**).

It seems likely that this gas has been accreted, perhaps by the capture of a smaller gas-rich companion galaxy.
In a few (less than 1%) galaxies, such as NGC 4550, one finds a significant number of stars in retrograde orbits. These presumably formed from retrograde gas.

NGC 7576

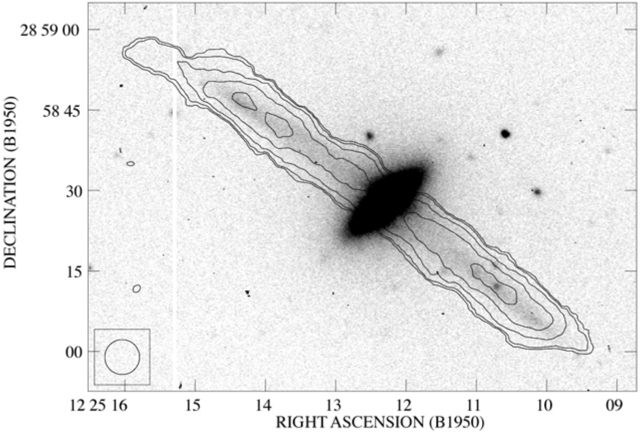

Fig 5.17 (A. Cox) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

A negative image of the S0 galaxy UGC 7576 in the V band: a thin ring of dust, gas, and stars orbits over the galaxys pole. Contours show $5 \times 10^9 M_\odot$ of HI gas in the polar ring; the disk of the S0 galaxy has hardly any cool gas.