Lecture 20
Elliptical galaxies - stars and gas

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(Notes by Paul Hickson)
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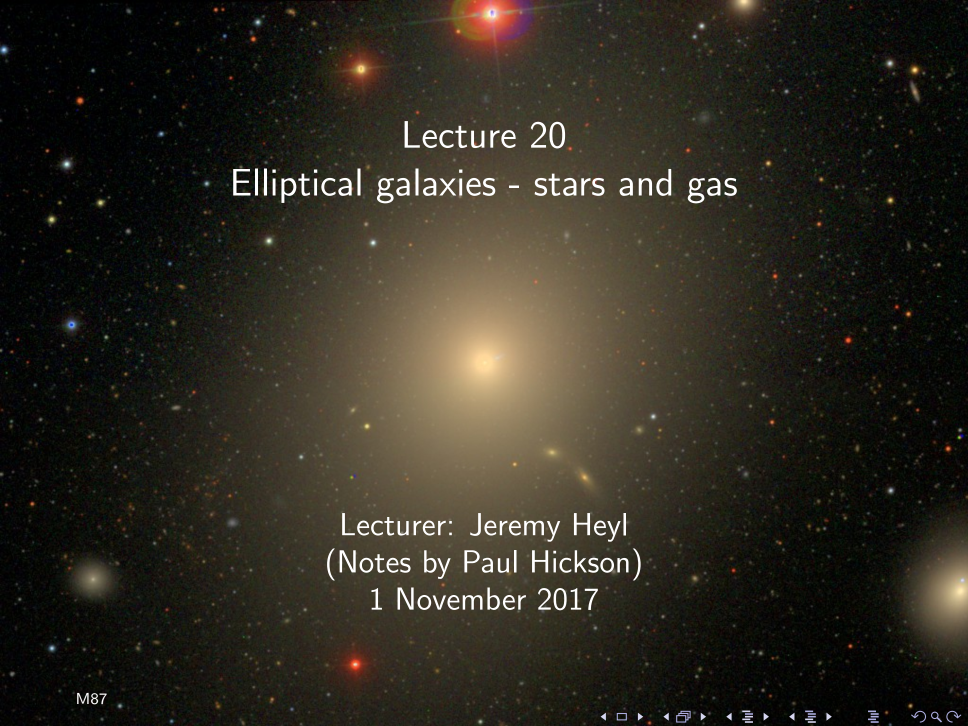

M87

Stars

Most of the light emitted by elliptical galaxies is produced by red giant and AGB stars. There are few if any luminous blue stars.

Unlike the stars in globular clusters, stars in elliptical galaxies are metal rich, with metallicity comparable to that of the Sun.

Spectra show a prominent break at 4000 Å . This is a combination of the Balmer continuum break at 3647A and deep lines of CaII (the Fraunhofer H and K lines) and Mg.

The absence of light shortward of 3500 Å indicates that there has been virtually no star formation within the past 1-2 Gyr.

More-luminous galaxies tend to be redder. Low-luminosity galaxies are bluer and therefore contain either younger or more metal-poor stars.

Stars in the centre are more metal-rich than those in the outer regions.

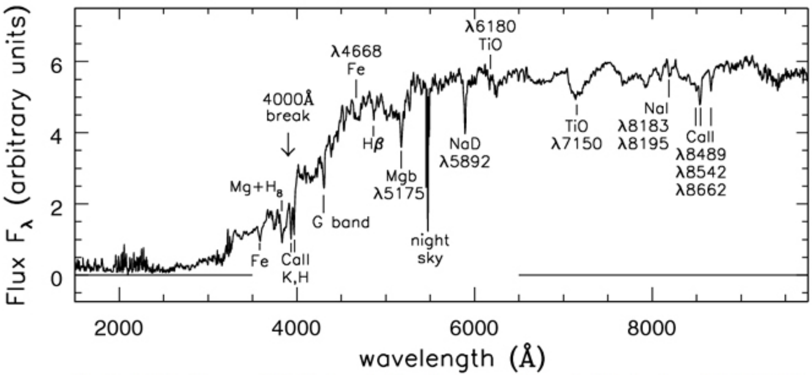

Fig 6.17 (A. Kinney) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

Spectrum of an elliptical galaxy.

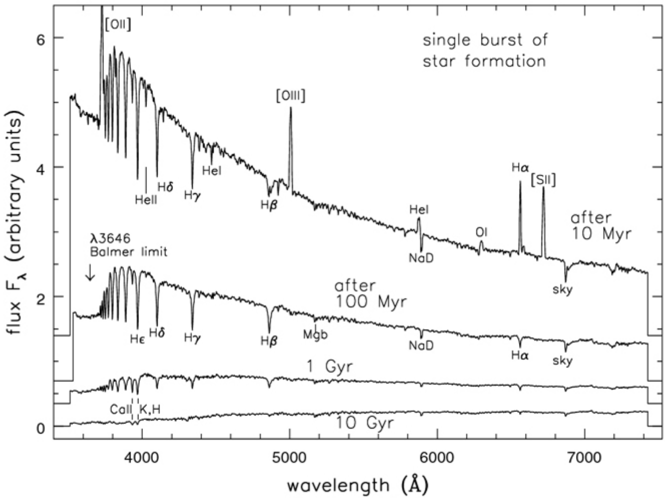

Fig 6.18 (B. Poggianti) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

Spectra for a 'galaxy' that makes its stars in a 10^8-yr burst, all plotted to the same vertical scale. Emission lines of ionized gas are strong 10 Myr after the burst ends; after 100 Myr, the galaxy has faded and reddened, and deep hydrogen lines of A stars are prominent. Beyond 1 Gyr, the light dims and becomes slightly redder, but changes are much slower.

Stars

In elliptical galaxies, light elements such as oxygen, sodium and magnesium are enhanced with respect to iron, compared to the Sun.

This suggests that star formation likely proceeded rapidly, with the bulk of the stars forming in ~ 1 Gyr or less.

Alternatively, the stars were formed in lower-mass systems where the iron produced by type Ia supernovae was more easily able to escape. (The ejecta of type II supernovae moves more slowly.)

If elliptical galaxies were built by mergers of smaller galaxies, one might expect that their stellar content would be similar to that of the progenitor galaxies.

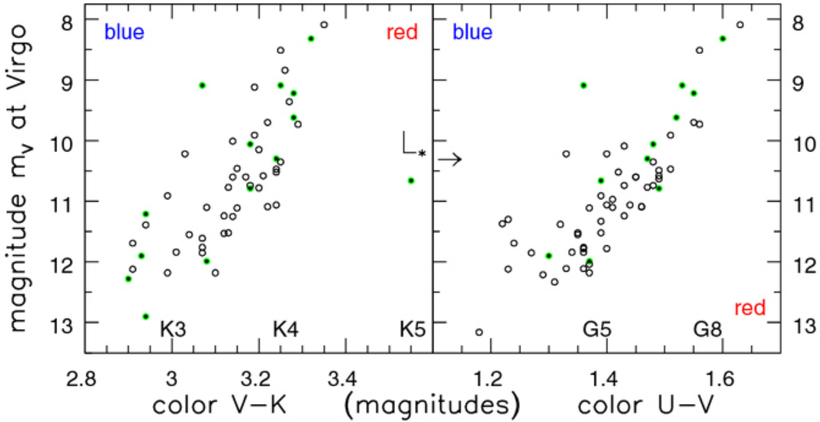

Fig 6.19 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

For elliptical galaxies in the Virgo (open symbols) and Coma (closed symbols) clusters, the U – V and V – K colours are plotted against apparent magnitude. Colours of giant stars. Coma galaxies are shown 3.6 magnitudes brighter, as they would appear at the distance of Virgo.

Gas

There is very little cool gas in elliptical galaxies, and consequently, little if any star formation.

Only 5-10% of ellipticals have any detectable cool atomic or molecular gas. For those that do the measured amounts are one to two orders of magnitude lower than a large Sc galaxy would have.

There are a few exceptions, but in these the gas typically is found in a ring that is not aligned with the axes of the galaxy. This is presumably gas captured by ingesting a small gas-rich galaxy.

However, there is abundant *hot* gas, which can be detected by its X-ray emission (bremsstrahlung).

Such gas is ejected from stars in stellar winds and supernovae explosions.

There are also X-rays numerous point sources (X-ray binary stars) and possibly an active nucleus.

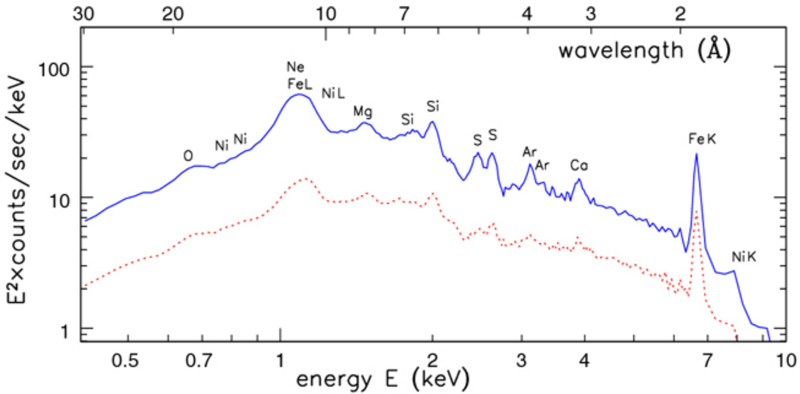

Fig 6.21 (K. Matsushita) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

The X-ray spectrum of hot gas at $T \sim 2 \times 10^7$ K around the luminous elliptical M87. The solid line shows emission from gas within 4 arcmin (5 kpc) of the center; the broken line is for gas between 4 arcmin and 8 arcmin radius. All lines except iron L and nickel L are emitted as electrons drop to the lowest-energy orbits, in the K shell.

Dark matter

In nearby elliptical galaxyes, dark matter can be inferred from the motion of the globular clusters that surround them.

Within 50 kpc of the centre, one finds a typical mass-to-light ratio of $M/L_V \sim 50$.

Measurements of rotation velocities in the few elliptical galaxies that have some cold gas also gives high mass-to-light ratios, typically on the order of 10-20.

Like spiral galaxies, dark matter dominates the mass density in the outer regions of the galaxy. The total mass of dark matter is typically an order of magnitude greater than the total mass of stars.

Central black holes

In elliptical galaxies, central black holes can be detected by a rise in the velocity dispersion as one approaches the centre.

The **region of influence** of a black hole is contained within a radius

$$r_{\mathrm{BH}} \simeq 45\mathrm{pc}\left(\frac{M_{\mathrm{BH}}}{10^8 M_\odot}\right)\left(\frac{\sigma_c^2}{100\ \mathrm{km\ s^{-1}}}\right)^{-2}$$

where the rotation velocity of a star orbiting the black hole would be larger than the central velocity dispersion σ_c of the galaxy.

One finds that the mass of the central black hole correlates with the velocity dispersion of the galaxy,

$$M_{\mathrm{BH}} \simeq 2 \times 10^8 M_\odot \times \left(\frac{\sigma_c^2}{200\ \mathrm{km\ s^{-1}}}\right)^{-4.86}$$

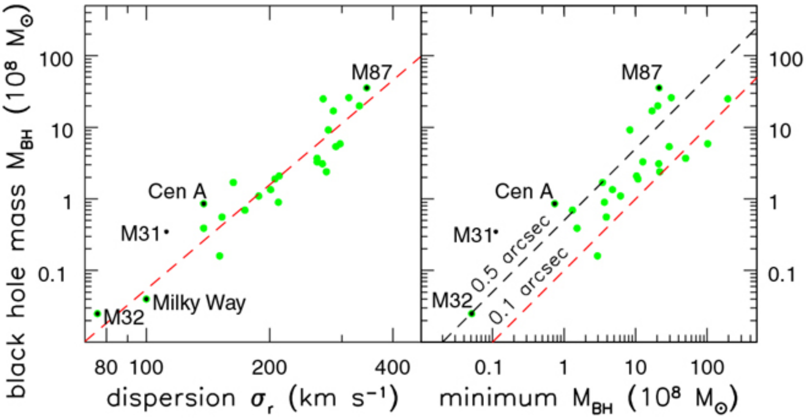

Fig 6.23 (L. Ferrarese) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

Left, the central compact mass, probably a black hole, grows with velocity dispersion σ_c of the galaxys central region. Right, the inferred masses are close to the minimum that could be detected: dashed lines show where $r_{\rm BH} = 0.5$ arcsec and 0.1 arcsec.

M87

One of the closest elliptical galaxies is Messier 87, the brightest galaxy in the Virgo cluster, at a distance of about 16.5 Mpc.

M87 has a small amount of gas in its nucleus, for which HST observations indicate an orbital speed of about 1000 km s^{-1} 0.1 arcsec from the centre. This corresponds to a radius of $R = 0.1 \times 5 \times 10^{-6} \times 16.5 \times 10^{6} = 8.3$ pc.

The mass of the central object is therefore

$$M = \frac{V^2 R}{G} = \frac{1,000,000^2 \times 8.3 \times 3.09 \times 10^{16}}{6.67 \times 10^{11}} = 1.9 \times 10^9 M_\odot.$$

This is nearly a thousand times more massive than the black hole at the centre of the Milky Way!

Most elliptical galaxies show compact nuclear radio sources, suggesting that they also harbour black holes with masses of at least $10^6 M_\odot$.