Astronomy 401/Physics 903
Lecture 12
Galaxy Spectra II

## 1 Emission and absorption spectra

Now that we understand the production of spectral lines by the transition of an electron between energy levels in an atom (higher to lower energy levels $\rightarrow$ emission of a photon, lower to higher energy levels $\rightarrow$ absorption of a photon), we can understand the production of spectra from hot sources, clouds, and hot sources seen through clouds.

1. A hot dense gas or a hot solid object produces a **continuous spectrum** with no spectral lines. This is blackbody radiation, and the spectrum is determined by the temperature of the object.

2. A hot, diffuse gas produces bright **emission lines**, when electrons make downward transitions from higher to lower orbits. If the cloud is near a strong source of radiation, the electrons will be continually excited by photons, and emit photons as they then fall back to lower orbits. These are called **recombination lines**.

3. If diffuse gas is seen in front of the source of radiation, it will produce **absorption lines** in the continuous spectrum of the hot object. These occur when the atom absorbs a photon and the electron makes a transition from a lower to a higher energy level. This is the case with a star: diffuse gas in the stellar atmosphere produces an absorption line spectrum against the continuous blackbody spectrum of the star itself.

(These are Kirchoff's laws.)

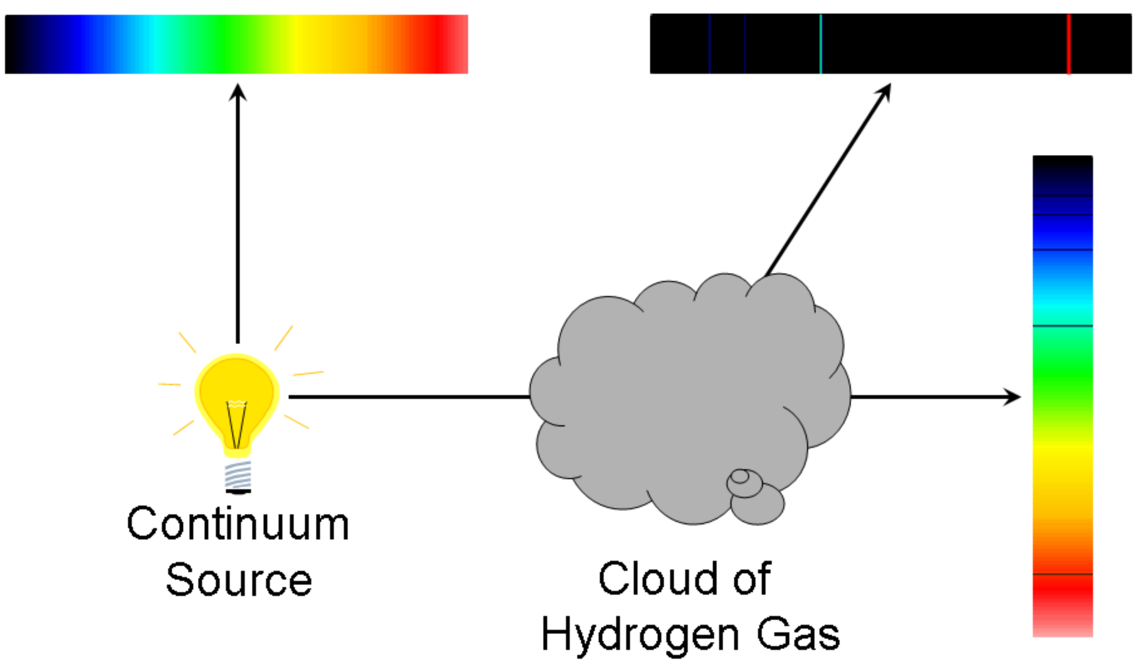


Figure 1: Kirchoff's law: continuum, emission and absorption lines.

## 2 The real world — applications to galaxies

Spectra of galaxies look like spectra of stars and gas. We'll look at some examples.

Spectra of elliptical galaxies have strong absorption lines, due mostly to metals in the atmospheres of cool, low mass, low luminosity stars; see Figure 2, and compare these to the spectrum of a low mass star in Figure 3. Elliptical galaxies have weak or no emission lines, because they don't have much gas.

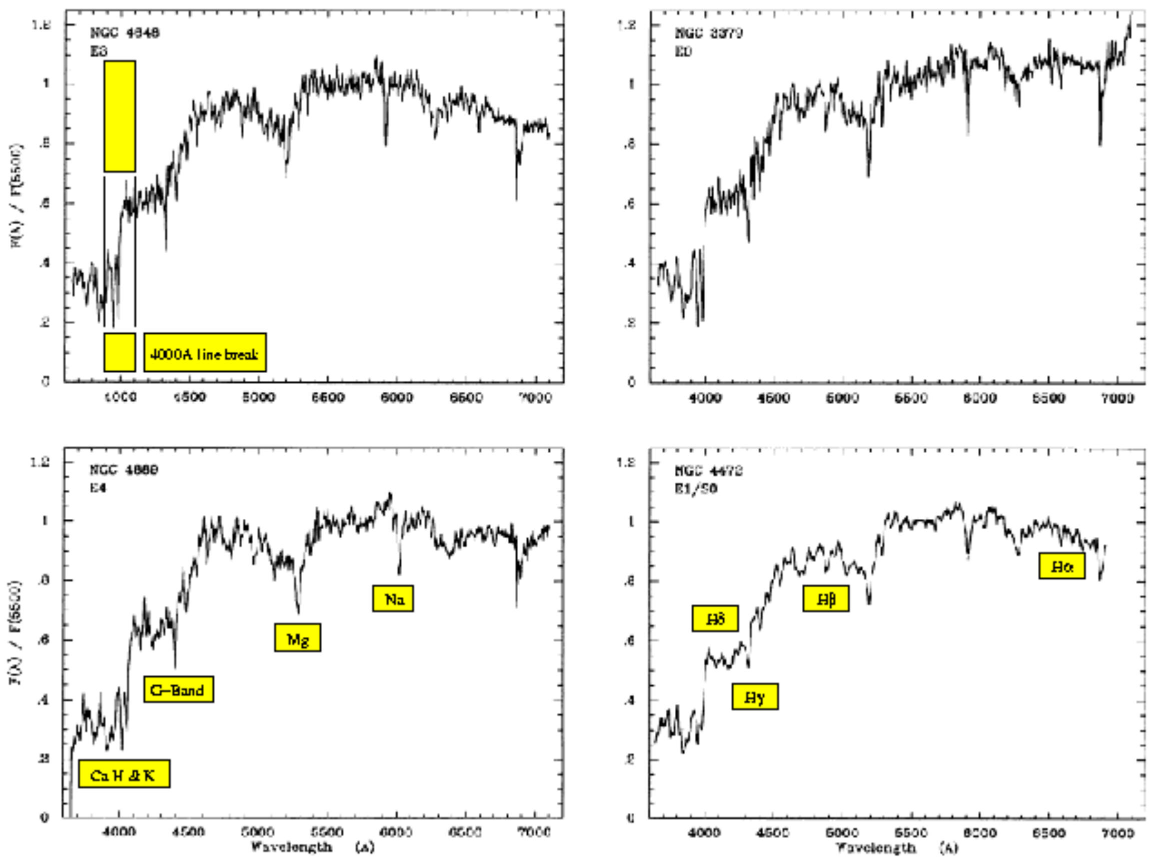


Figure 2: Spectra of elliptical galaxies

Spectra of star-forming galaxies (spiral, irregular) look different. They have emission lines from gas ionized by hot young stars, blue light from those young stars, and red light and absorption features from the underlying older stellar population. Spectra of gas-rich galaxies with high star formation rates are dominated by emission lines. Examples of spiral galaxy spectra are shown in Figure 4, and irregular galaxy spectra are shown in Figure 5.

## 3 Measuring star formation rates

Spectral lines provide a great deal of information about the galaxy. We can use them to measure the star formation rate, metallicities of stars and gas, and the internal dynamics of the galaxy, among other things. Here we will consider the star formation rate.

How hot is a star that produces lots of photons with energy of at least 13.6 eV? A photon with 13.6 eV has

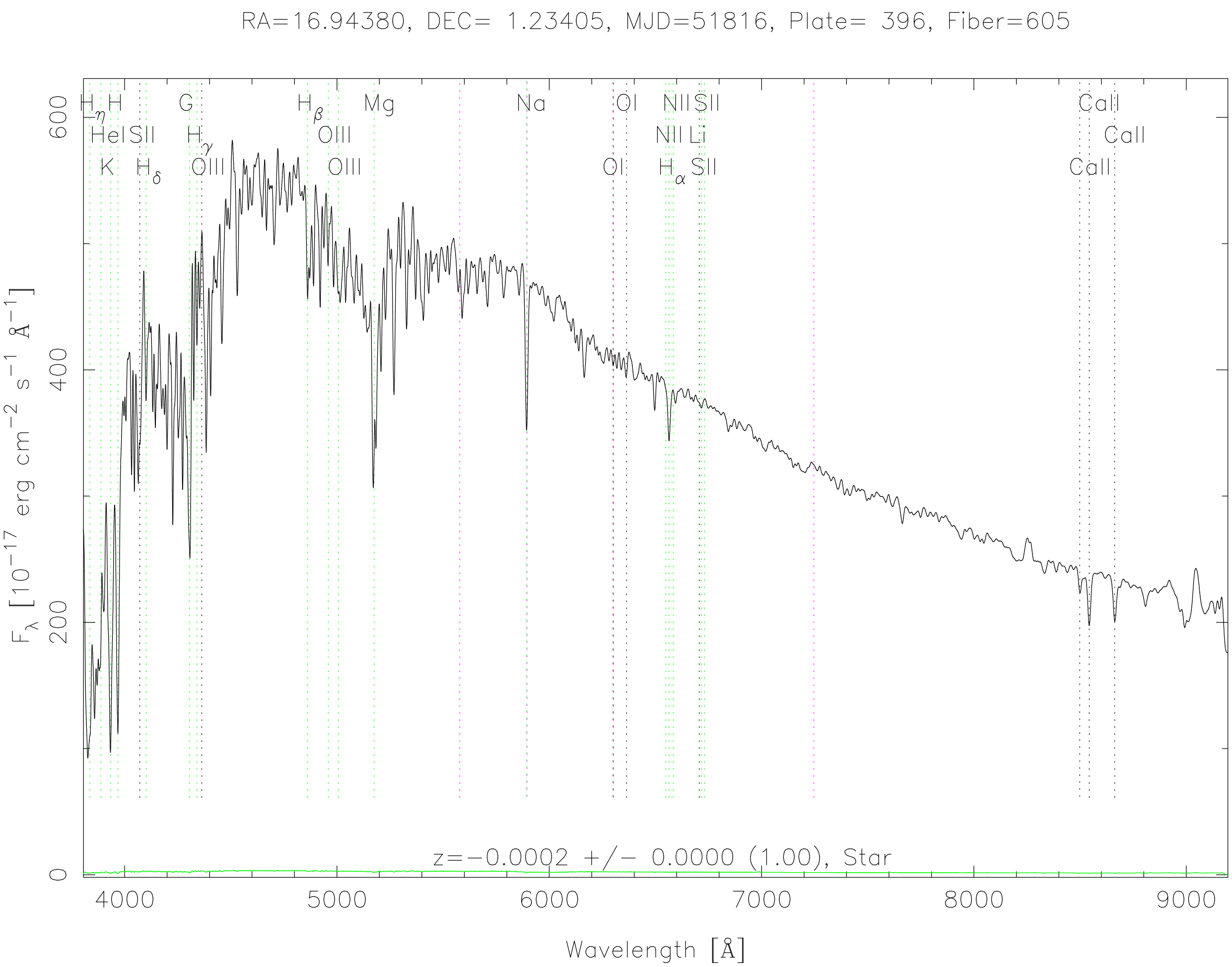


Figure 3: Spectrum of a K star

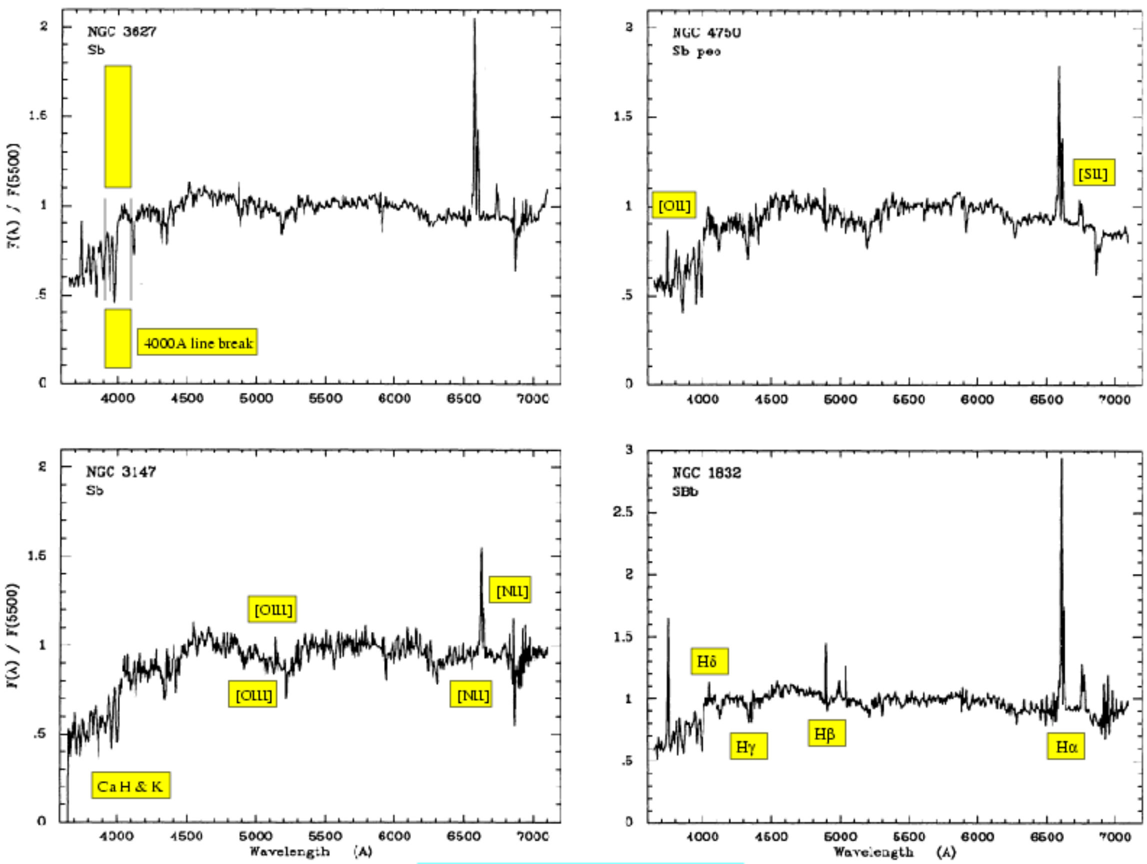


Figure 4: Spectra of spiral galaxies

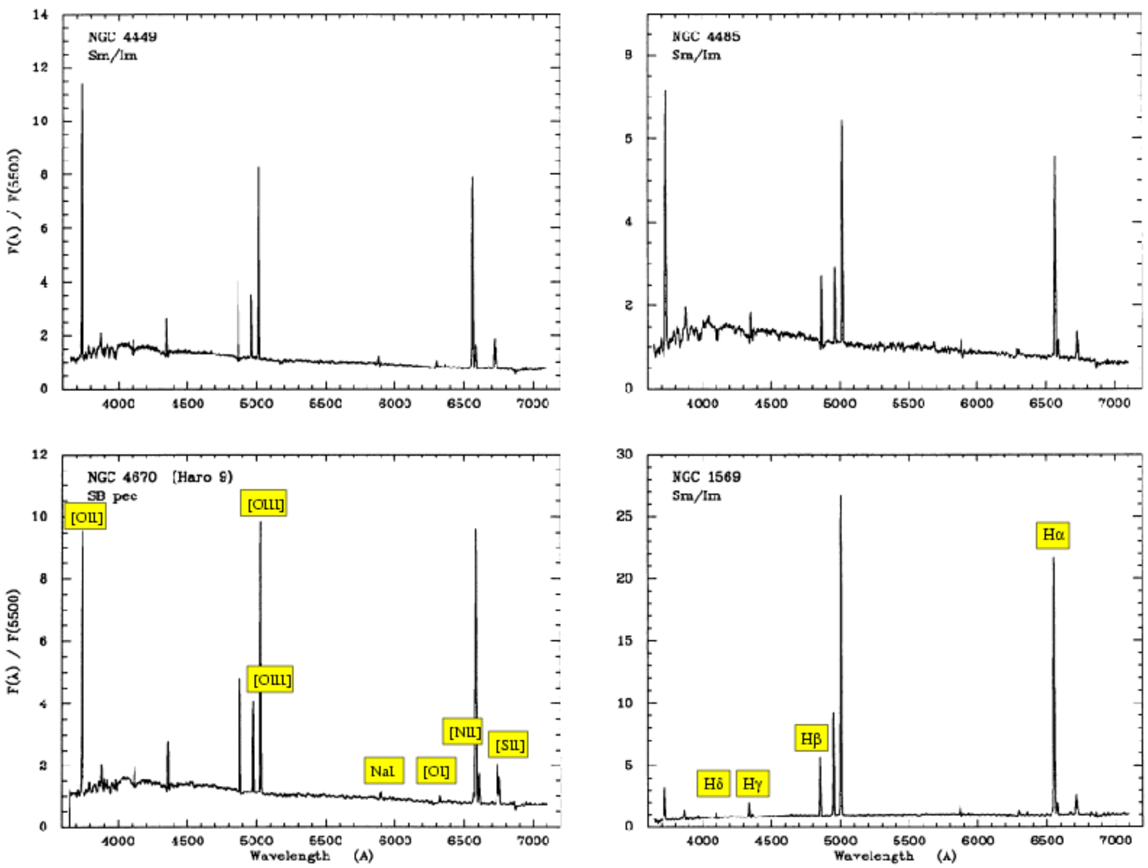


Figure 5: Spectra of irregular galaxies

a wavelength

$$\lambda = \frac{hc}{E} = 912 \text{ Å}, \tag{1}$$

and we will use Wien's law to figure out the temperature of the star this corresponds to:

$$T = \frac{0.0029 \text{ m}}{\lambda} \text{ K} = 32,000 \text{ K}. \tag{2}$$

This is somewhere between an O8 and B0 star, with a lifetime of $\sim 5$ Myr. This is effectively instantaneous, considering the lifetime of a galaxy. This means that *the presence of emission lines from ionized hydrogen indicates current star formation* (unless they're from shocks or an AGN, but we can usually tell that by looking at line ratios and line widths).

This is very useful. The number of hydrogen ionizing photons is directly proportional to the number of massive stars, which means that if we can measure how much radiation there is from ionized gas, via the H$\alpha$ emission line for example, we can measure the **current star formation rate** of the galaxy. This is one of the mostly widely used measurements of the star formation rate.

Another popular method is to measure the continuum luminosity in the UV, since this is also produced by massive stars; this tells us about star formation on a slightly longer timescale ($\sim$ 100 Myr), since stars of slightly lower masses also contribute to the UV continuum light.

The major difficulty with both of these methods, especially the UV continuum, is **dust**. Interstellar dust absorbs and reprocesses approximately half of the starlight in the Universe, which means that if we don't correct for dust absorption we will generally significantly underestimate the SFR. So nearly all star formation rate determinations include an *extinction correction*.

The extinction correction can be measured from the observed ratio of two emission lines such as H$\alpha$ and H$\beta$. The intrinsic ratio of these lines is given by atomic physics, H$\alpha$/H$\beta$= 2.86. Because H$\beta$ is at a bluer wavelength that H$\alpha$ and because blue light is more affected by dust than red light, the observed H$\alpha$/H$\beta$ ratio is almost always greater than the intrinsic ratio, and it increases as the amount of dust increases. This ratio therefore allows us to estimate the extinction in the galaxy. The extinction can also be estimated by measuring the slope of the UV continuum. Again because blue light is more affected by dust than red light, the slope will be redder for dustier galaxies.

If a galaxy is very dusty (and dusty galaxies often have the highest star formation rates), however, then both of these methods will miss most of the star formation. Then what? We can also measure the thermal emission from dust in the IR. Dust absorbs light from massive stars and is heated, so by measuring thermal radiation in the infrared we can measure star formation from the stellar light that has been reprocessed by dust. The best method is often to combine multiple indicators.

Note that all of these methods tell us about the number of massive stars only — to get the overall star formation rate from this, we have to assume an initial mass function. This is an important systematic uncertainty.