Astronomy 401/Physics 903
Lecture 10
The Stellar Populations of Galaxies

How do we understand the *integrated* light of galaxies? The colors and spectra of galaxies vary from galaxy to galaxy—how and why?

Galaxy light comes from stars, so we can understand the evolution of galaxies by understanding the evolution of stars.

The **stellar population** of a galaxy refers to the different types of stars which make up its light.

Consider the evolution of a single burst of star formation:

1. A bunch of stars are born simultaneously, with a range of masses—lots of low mass stars, few high mass stars
2. When these stars are born, they occupy the zero-age main sequence (ZAMS)
3. As time progresses, high mass stars use up their fuel and evolve off the main sequence. They climb the red giant branch (RGB) and asymptotic giant branch (AGB), before either blowing up as a supernova or fading to a white dwarf.
4. As more time passes, progressively lower mass stars will evolve off the MS

Steps 3 and 4 change the proportions of red and blue stars. An observer looking at all the stars at once will see the colors change with time.

1 The initial mass function

The distribution of stellar masses in a population of newly-formed stars is called the **initial mass function (IMF)**, $\phi(M)$.

$$\phi(M)\,dM = \text{fraction of stars with masses between } M \text{ and } M + dM \tag{1}$$

where the distribution of masses is usually normalized such that

$$\int_{M_L}^{M_U} M\phi(M)\,dM = 1\ \mathrm{M}_\odot. \tag{2}$$

The upper and lower mass limits for the integration (M_U and M_L) are not well-defined. The lower limit is typically $M_L = 0.1$ M$_\odot$ because stars less massive than this are unable to fuse hydrogen; a typical value for the upper limit is $M_U \sim 100$ M$_\odot$, based on the most massive stars that have been observed, but M_U commonly ranges from ~ 60 to ~ 120 M$_\odot$. The mass of the most massive stars is not well-known, however; such stars are expected to be both rare (a very small fraction of the total number of stars that form) and short-lived, making them very difficult to observe. Stars much more massive than this are not likely to exist because they would be unstable due to intense radiation pressure. Stars with masses of up to ~ 200 M$_\odot$ have been reported.

The shape of the IMF is also not well-known, but it is usually written as a power law:

$$\phi(M) \propto M^{-(1+x)}, \tag{3}$$

where x may be a single value or take different values for different mass ranges. One of the most commonly-used values is $x = 1.35$, or $\phi(M) \propto M^{-2.35}$; this is the *Salpeter IMF*, and it seems to be a good description for many populations of stars in many galaxies. There is some evidence that it over-predicts the number of low-mass stars, however, so many other popular parameterizations of the IMF use a shallower slope at lower masses.

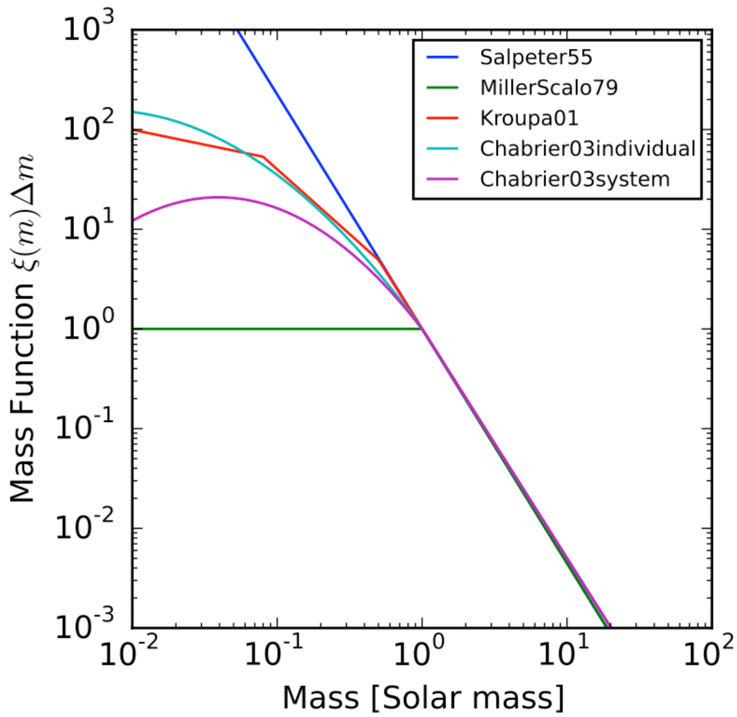

Figure 1: Several parameterizations of the initial mass function (IMF). The Salpeter IMF with a single slope at all masses is shown by the blue line, and the other IMFs shown have a shallower slope at low masses to correct for the Salpeter IMF's apparent over-prediction of low mass stars.

The initial mass function is very difficult to measure, since low mass stars are difficult to see and high mass stars are rare and short-lived. It's often assumed to be universal — the same for all bursts of star formation in all environments and at all times. There is evidence both for and against this; the IMF may be (nearly) universal, or it may depend on galaxy mass, metallicity or other parameters. This is very much an open question.

However, it is clear that low mass stars are much more common than high mass stars, and most of the mass is in low mass stars.

2 Stellar evolution and the color magnitude diagram

How do we interpret the colors and luminosities of a collection of stars? We start by analyzing the **color-magnitude** diagram for a **single stellar population** — a bunch of stars that all formed at the same time, for example in a globular cluster.

The color-magnitude diagram is a plot of the color (e.g. $B-V$) vs magnitude of a large number of stars. This is effectively the H-R diagram, since color is directly related to temperature and magnitude is a measure of luminosity (we'd like to plot absolute magnitude, but if the stars are all at the same distance, as in a cluster, we can use apparent magnitude instead). An example of a color-magnitude diagram for a globular cluster is shown in Figure 2.

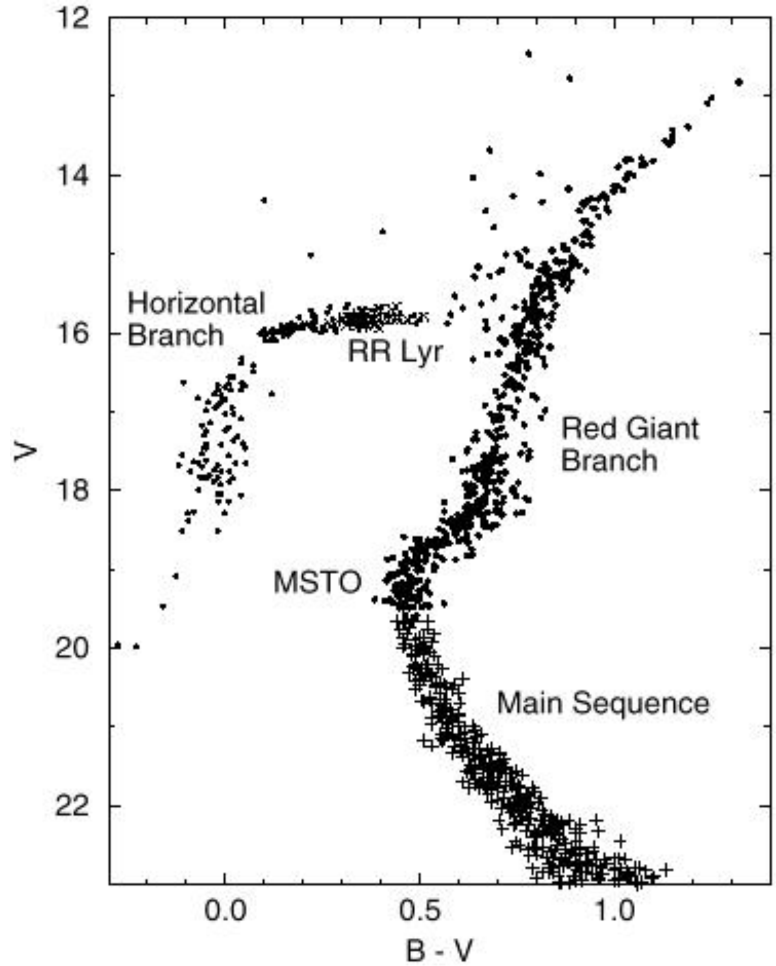

Figure 2: The color-magnitude diagram for the globular cluster M15.

We analyze evolving stellar populations through the use of **isochrones**. An isochrone is the locus in the color-magnitude diagram of a single stellar population at a single point in time (*iso*=same, *chronos*=time). By considering isochrones of different ages we can see that **as a stellar population ages it gets redder**. This is shown in Figure 3, which plots isochrones of varying ages on the color-magnitude diagram.

3 Stellar populations in galaxies

Galaxies have more complex star formation histories—they have had more than one burst of star formation in the past. We think of these as **sums of different single stellar populations with different ages**. The relative amounts of older and more recent star formation affect the colors of the galaxy (see Figure 4):

More star formation long ago $\Rightarrow$ redder, fainter (higher M/L)

More star formation recently $\Rightarrow$ bluer, brighter (lower M/L)

The past star formation rate as a function of time in a galaxy is called the **star formation history**, and it can be modeled in many ways. We will write the star formation rate as $\psi(t)$; popular models of the star

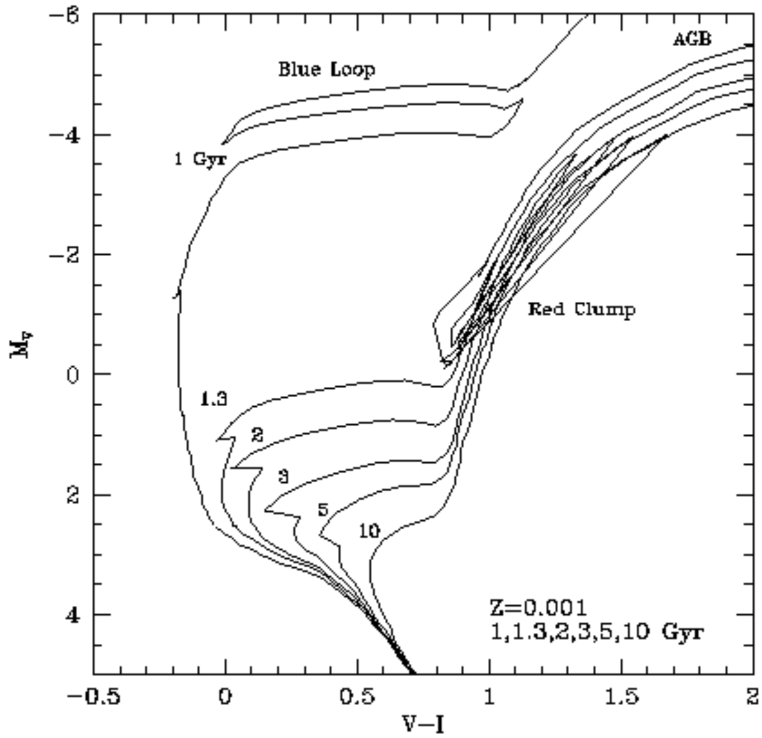

Figure 3: Isochrones of varying ages.

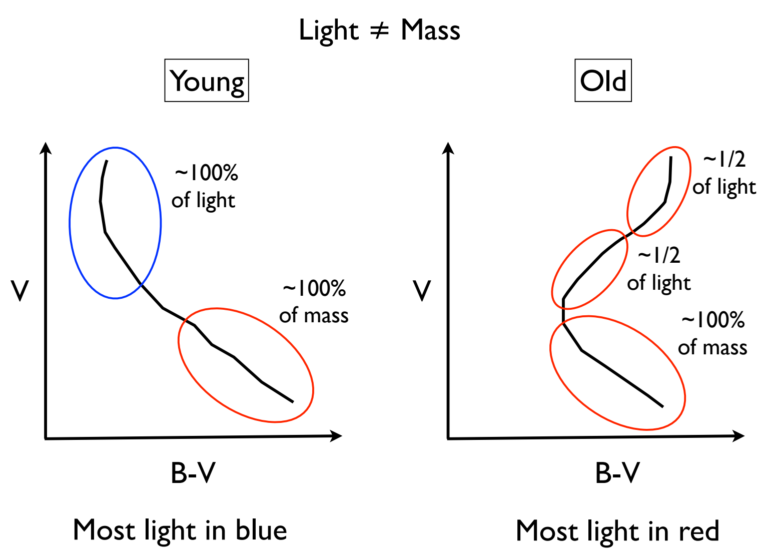

Figure 4: An older stellar population is redder.

formation history in galaxies include exponentially declining SFRs, $\psi(t) \propto e^{-t/\tau}$, where the constant τ determines the rate of decline, or a constant star formation history, $\psi(t) \propto$ constant. Different types of galaxies have different characteristic star formation histories, as shown schematically in Figure 5.

Any star formation history can be represented as the sum of single stellar populations of different ages. Combining these sums of model stellar populations and comparing them with the observed colors of a galaxy (in as many different bands as possible) is called **population synthesis modeling**, and is one of the major ways that we estimate the ages of galaxies and the total mass in stars they contain.

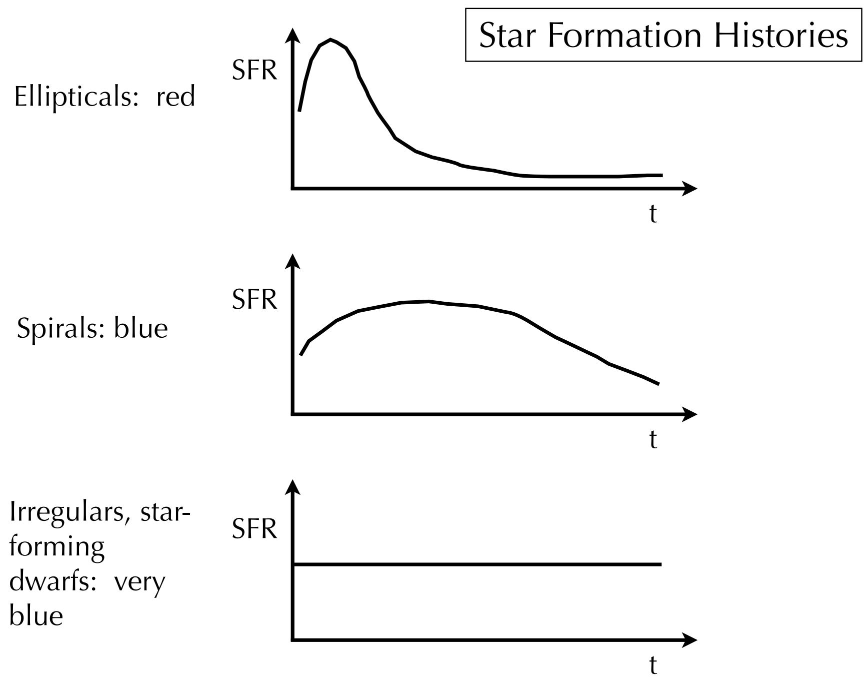

Figure 5: Star formation histories of different types of galaxies.

It is important to note that other things also change the colors of galaxies!

Dust preferentially scatters and absorbs blue light, and therefore dusty galaxies look redder. This effect must be included in population synthesis, since almost all galaxies have some dust.

Metallicity: Higher metallicity stars are also redder. (The opacity is higher if there are more metals, so photons take longer to reach the surface and the star puffs up and gets redder.)

These things, especially dust, need to be included when attempting to match the colors of galaxies with models.