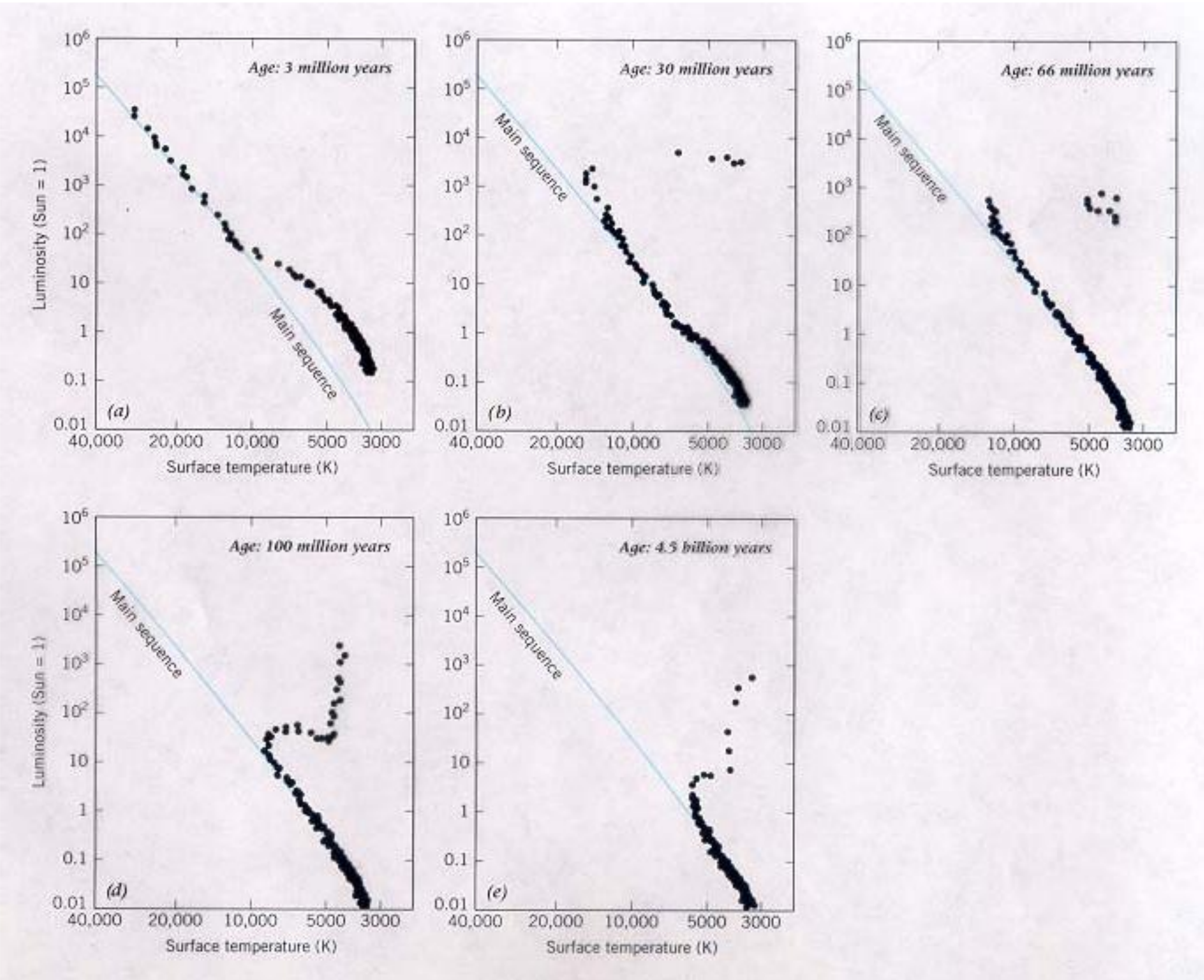
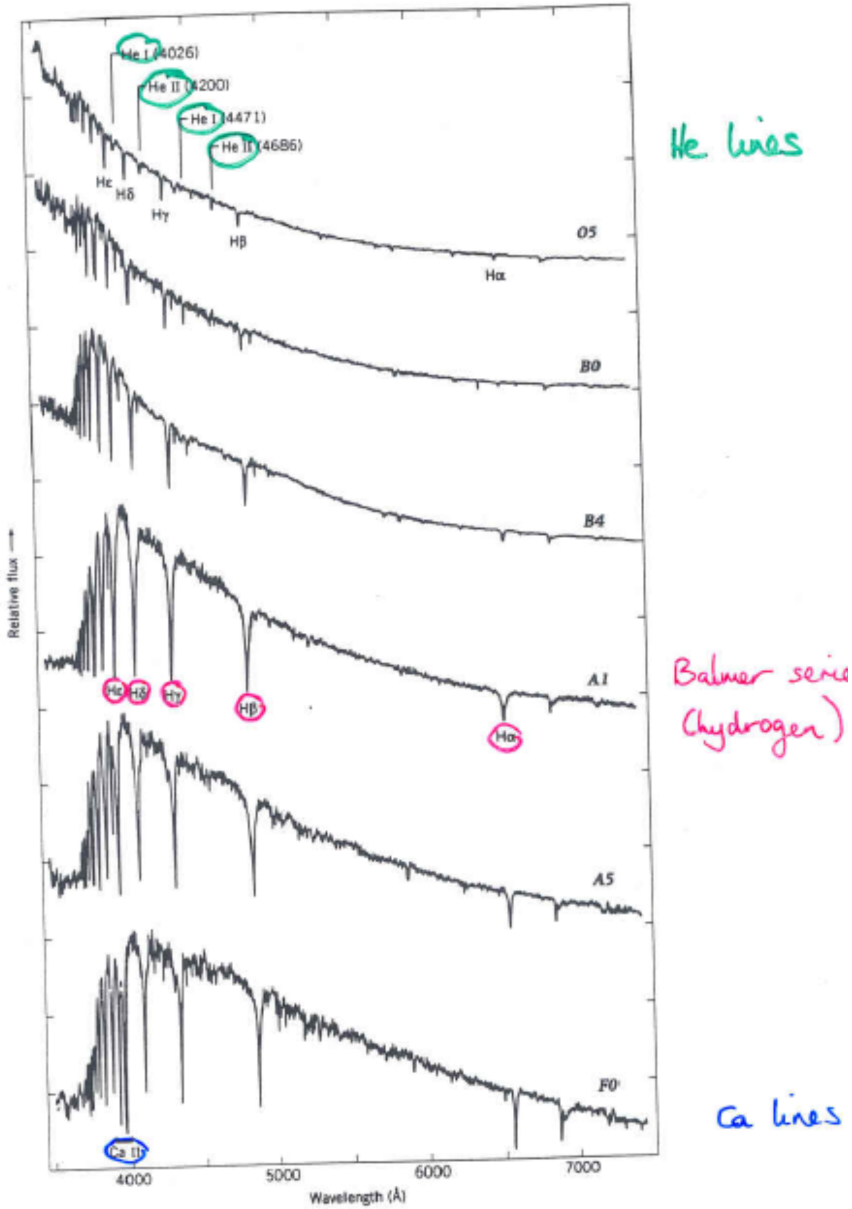
Studying galaxies via integrated light

- Almost all star clusters have, to a good approximation, a single age and metallicity
- Galaxies, by contrast, have a range of ages and metallicities in their stars
- Integrated light studies seek to disentangle the history of star formation and chemical evolution from the integrated light of galaxies via photometry (thru various filters) or spectra

Integrated light of star clusters

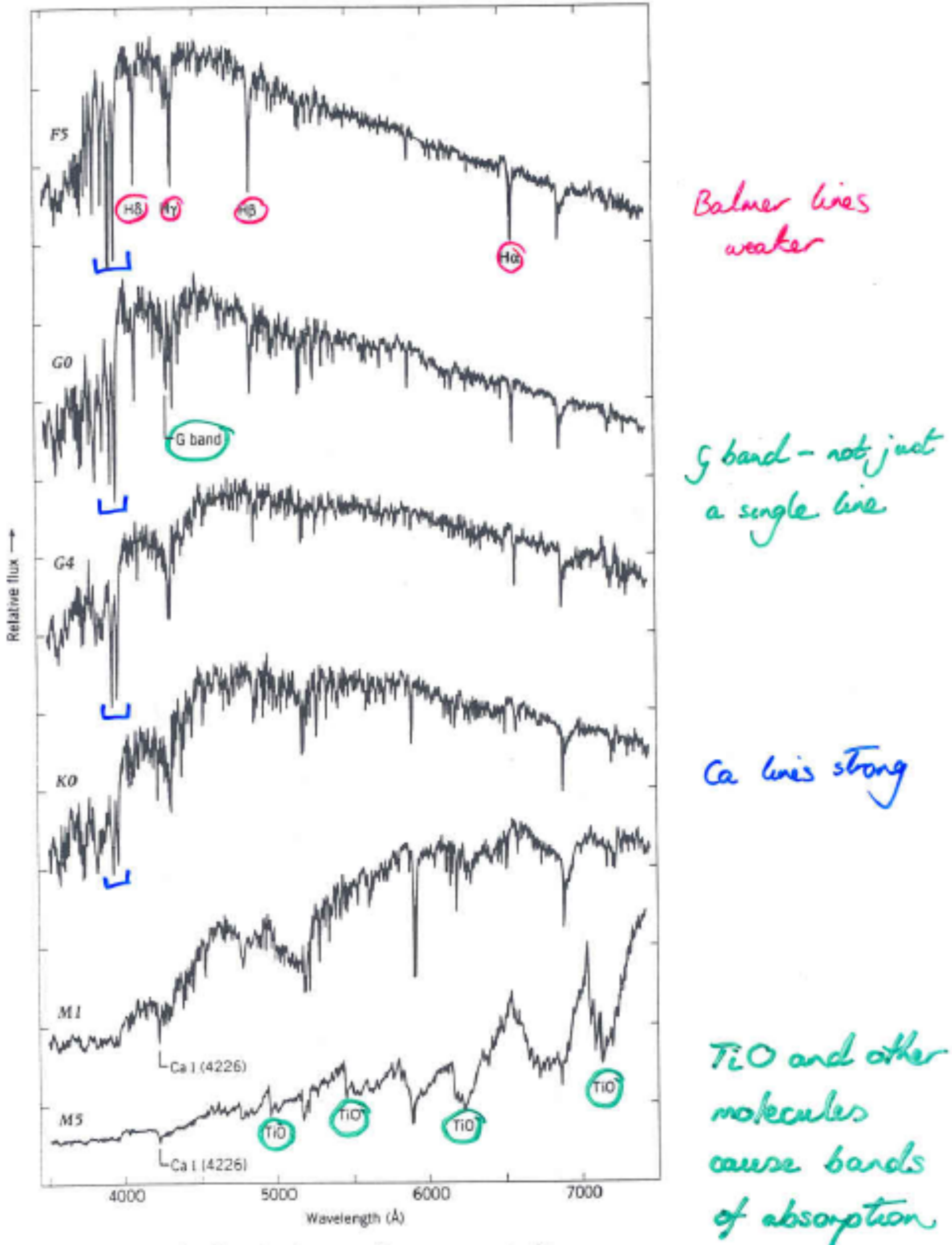


- Here we have an illustration of the CMD of a star cluster as it ages
- Q: How would you infer the spectrum of the star cluster at each age?



Stellar spectra: warm stars

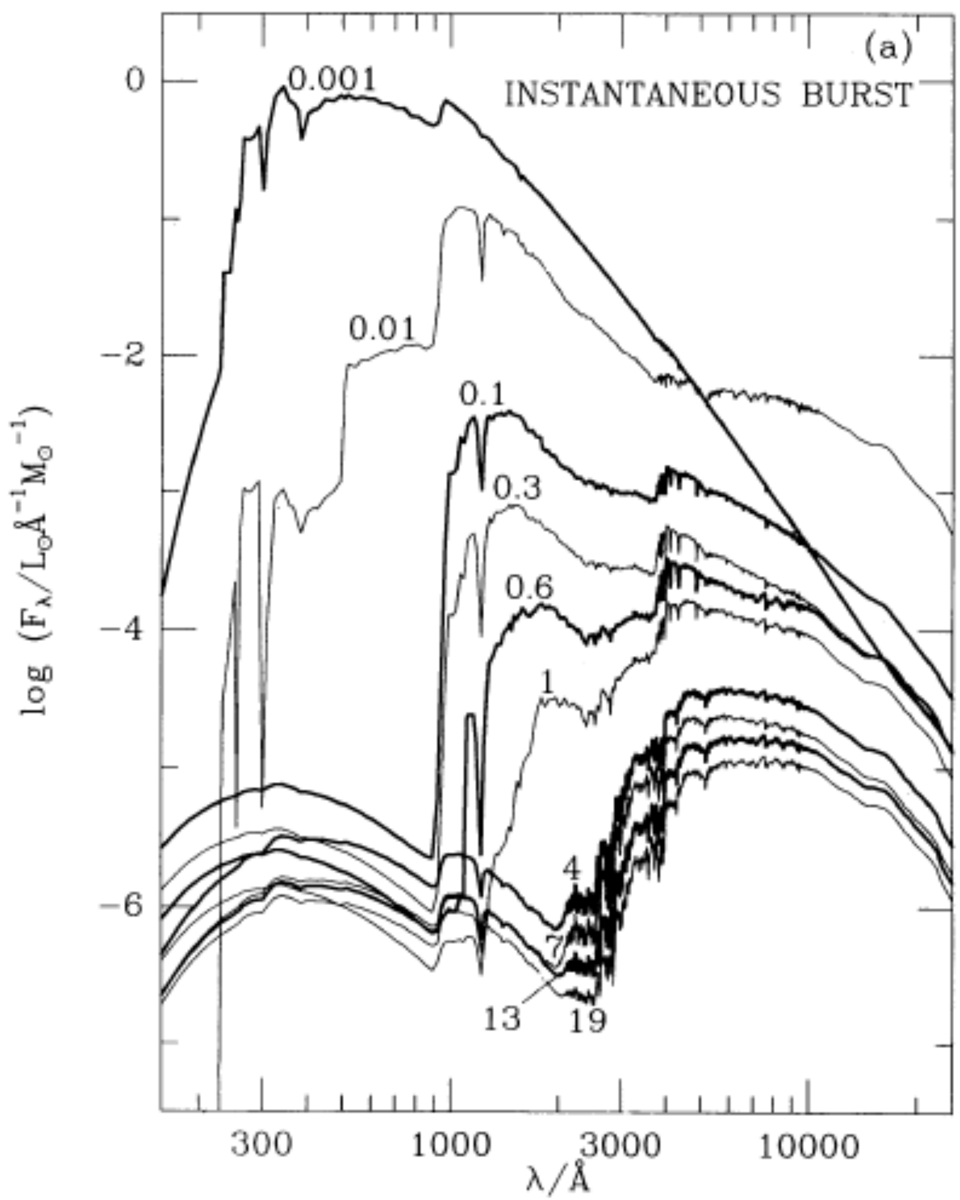
- Q: which age cluster will have its spectrum dominated by O and B stars? Why?



Stellar spectra: cool stars

- Q: which cluster will have its spectrum dominated by G stars?
- K stars?
- Why?

Spectral changes with age

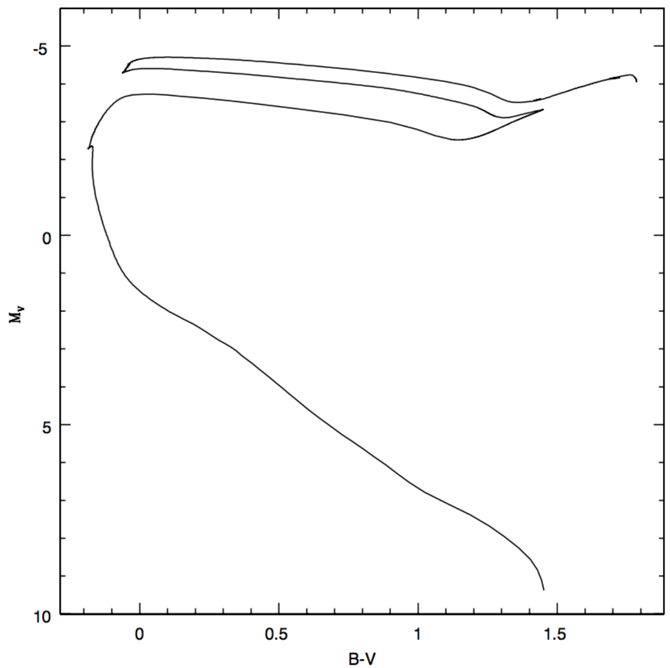


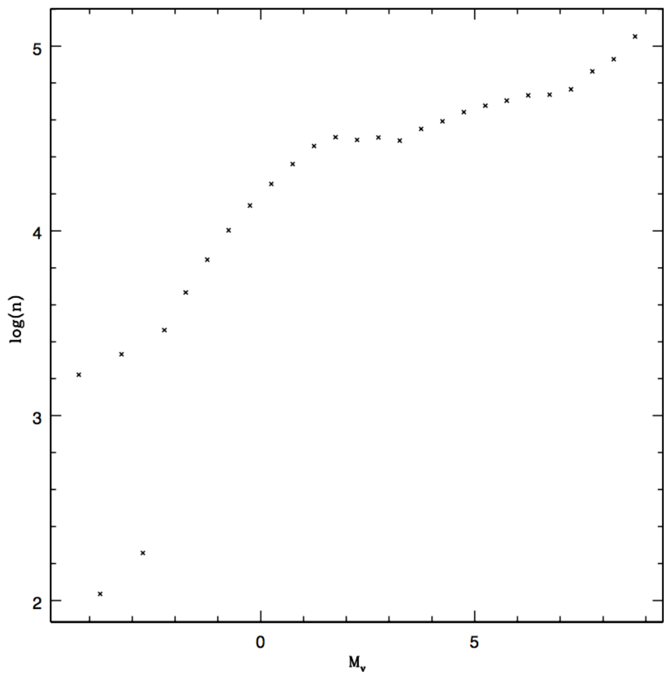
- From Bruzual and Charlot (1993): widely used models for spectral synthesis (also BC03)
- Note spectral coverage: vacuum UV (300 A) to near IR (2 microns)
- These BC93 models use real spectra of different metallicity and then add them in the correct proportion using stellar evolution models and luminosity functions
- This plot shows the aging of a single starbust
- Note that older populations are harder to distinguish

Which wins, luminosity or numbers?

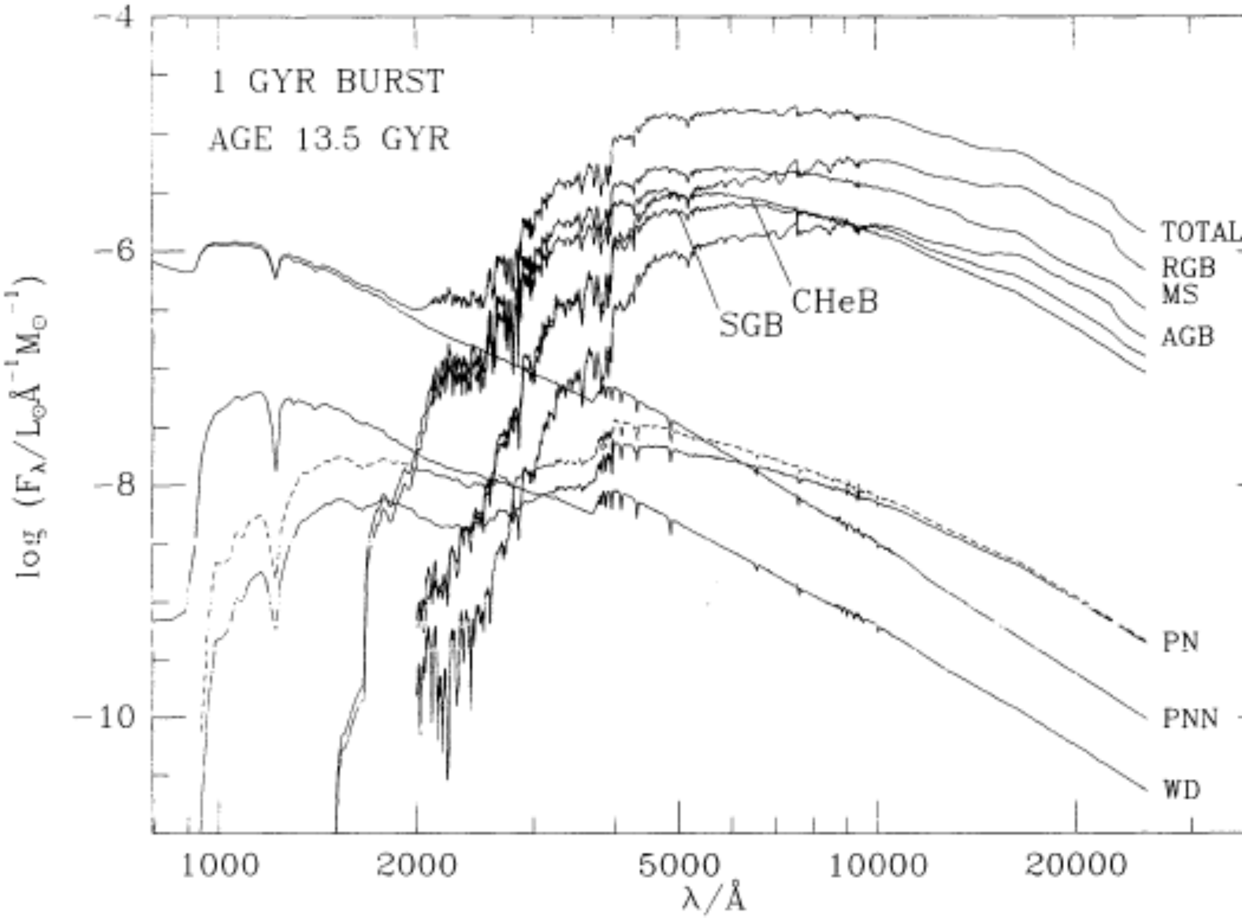
Basti isochrones for 40 Myr population, solar abundance.

Q1: What is the range of luminosity associated with 15 magnitudes?
Q2: which wins, the more luminous rare supergiant stars at Mv=-5, or the much more common M dwarf stars at Mv=10?

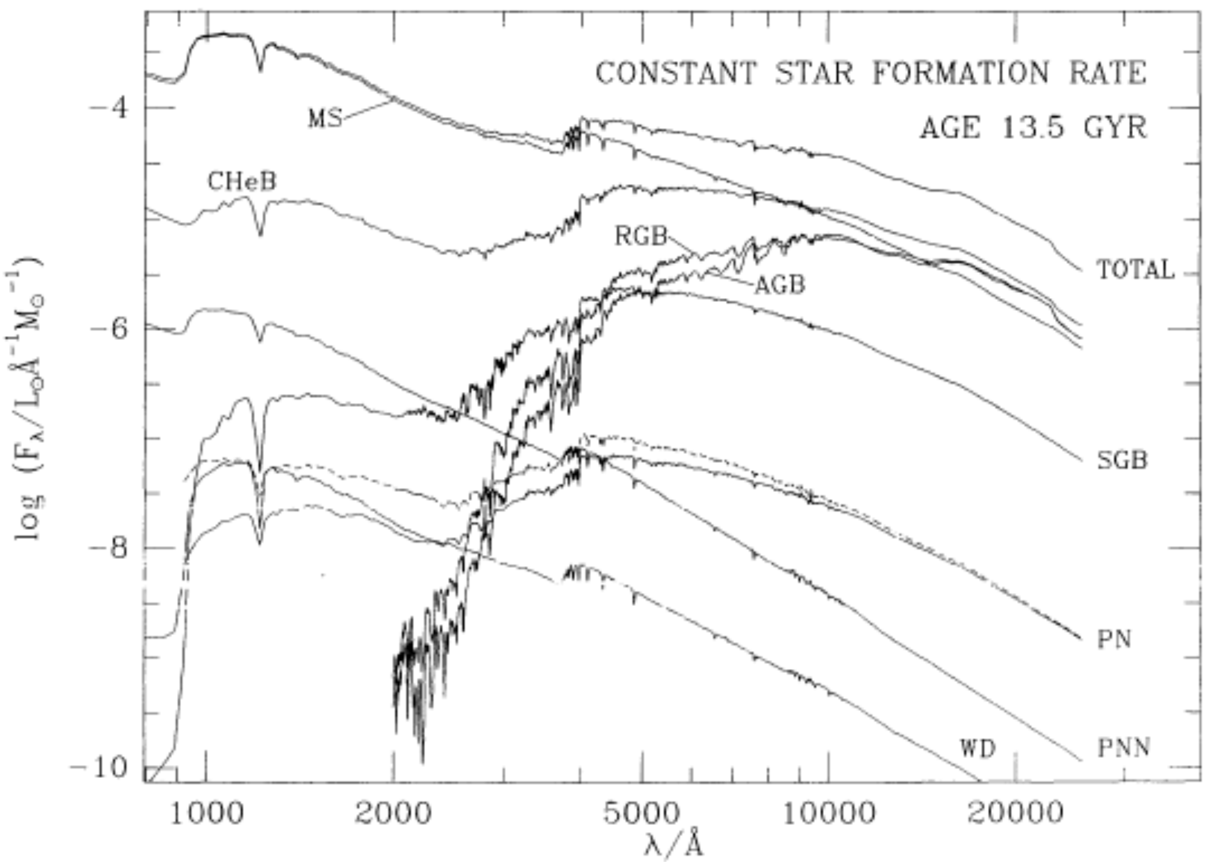




Contribution of different evolutionary states in old population like an elliptical galaxy



Now for a population with a constant star formation rate: like a disk galaxy



The effect of metallicity on optical spectra

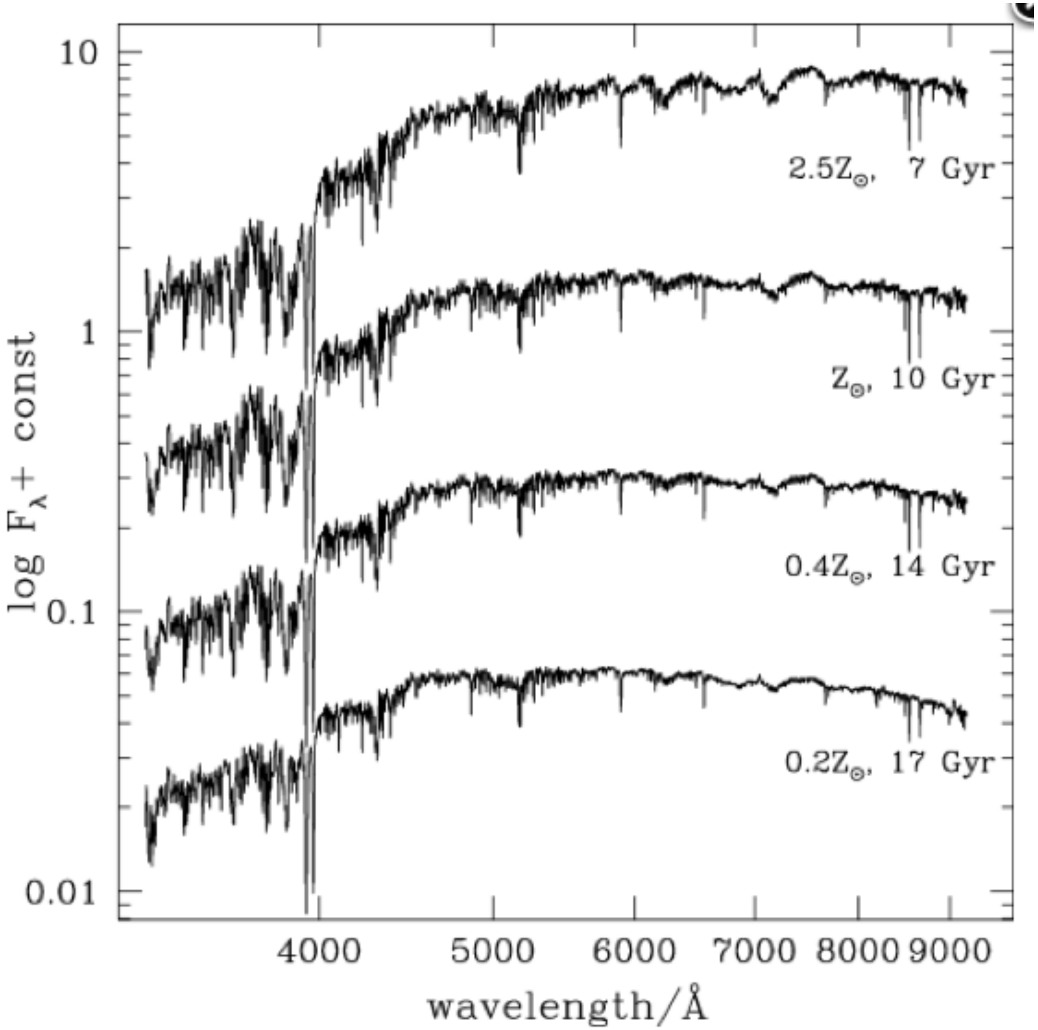
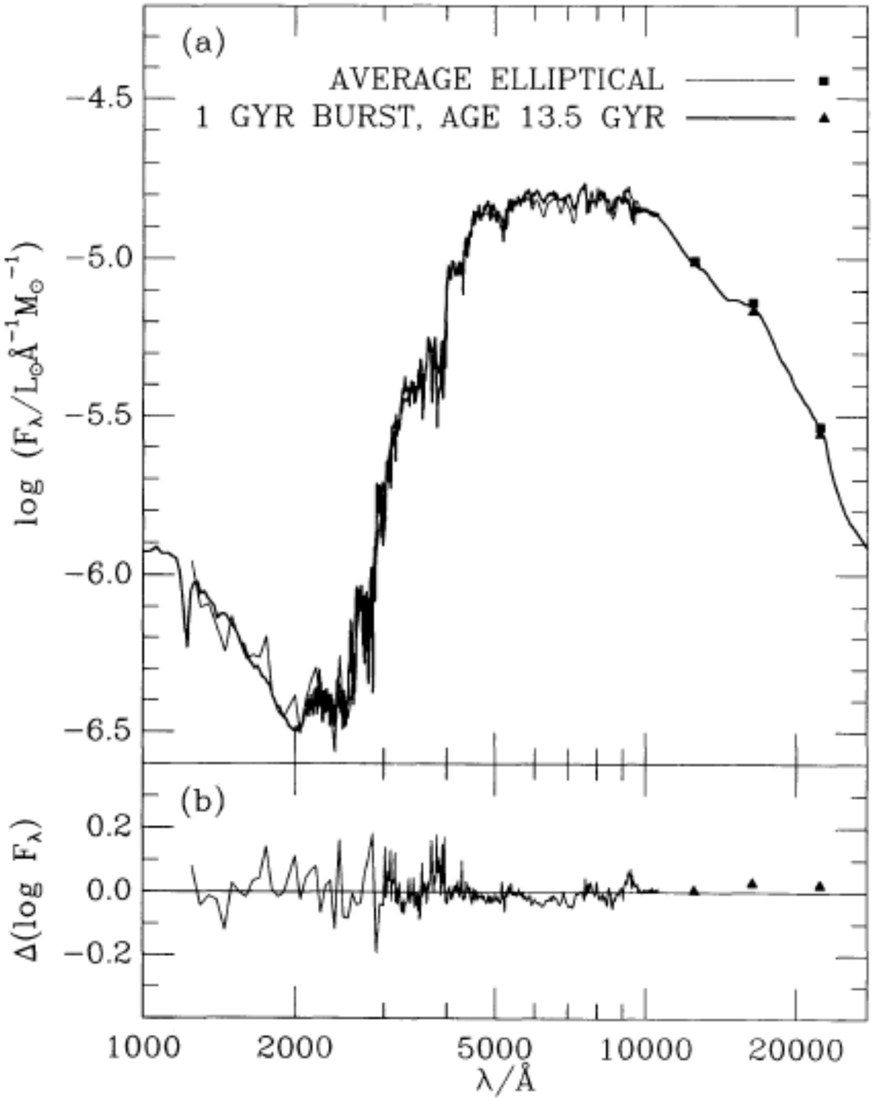


Figure 10. Spectra of the standard SSP model of Section 3 at different ages for different metallicities, as indicated. The prominent metallic features show a clear strengthening from the most metal-poor to the most metal-rich models, even though the shape of the spectral continuum is roughly similar in all models.

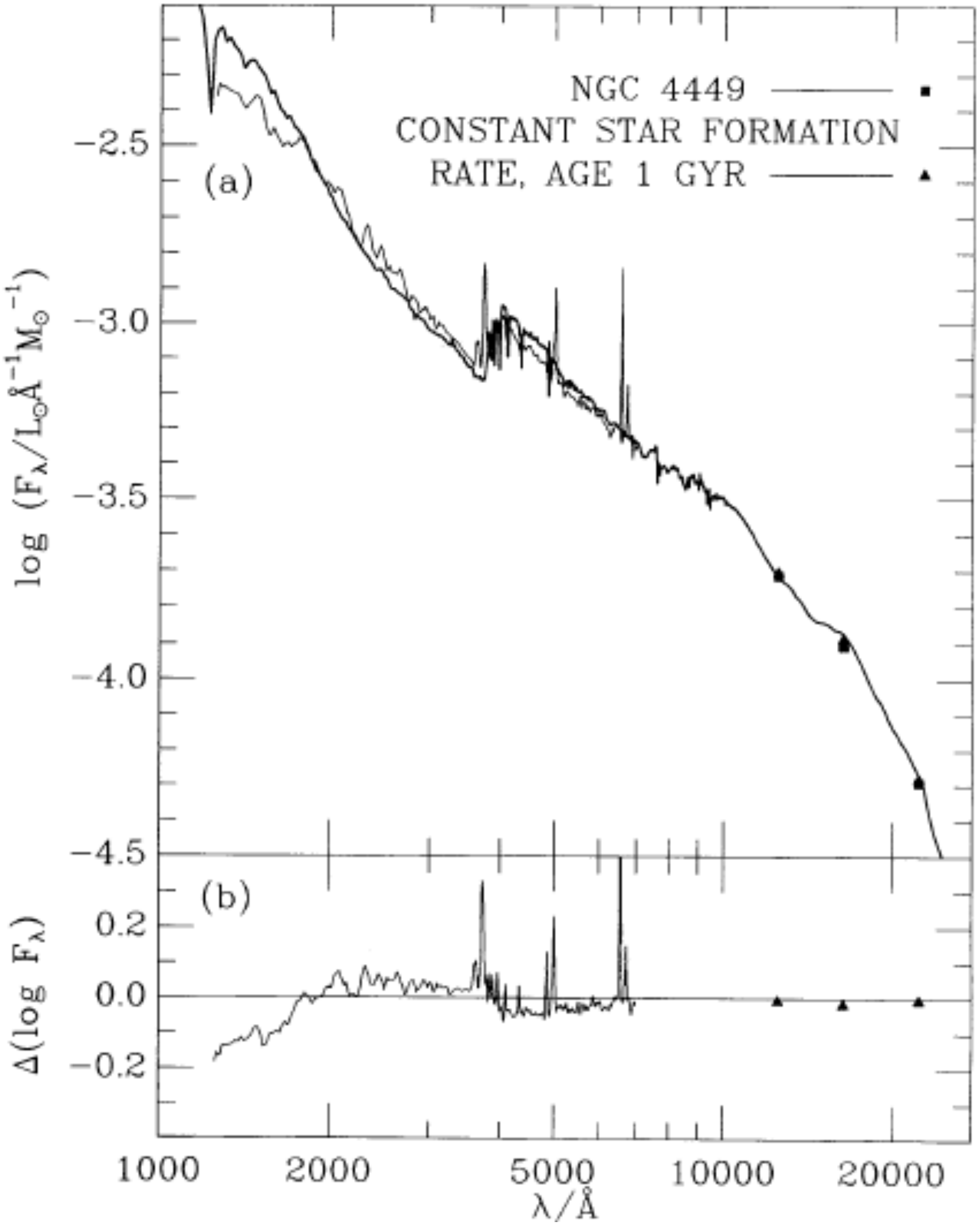
See the line blanketing increase in the blue as the metallicity increases

Real galaxy spectrum with derived SFR and age



- Star formation starts 13.5 Gyr ago and continues for one Gyr
- Note infrared passbands J,H and K

dwarf Irregular NGC 4449



Q: do you think there are any old stars (~10 Gyr) in this galaxy?

Q: what affects the strength of a spectral line in absorption or emission?

Absorption: temperature of star

amount of the element or molecule

energy levels populated

pressure, density

Emission: also need to think about source of photons to excite photons in gas, and emission process (eg collisional de-excitation)

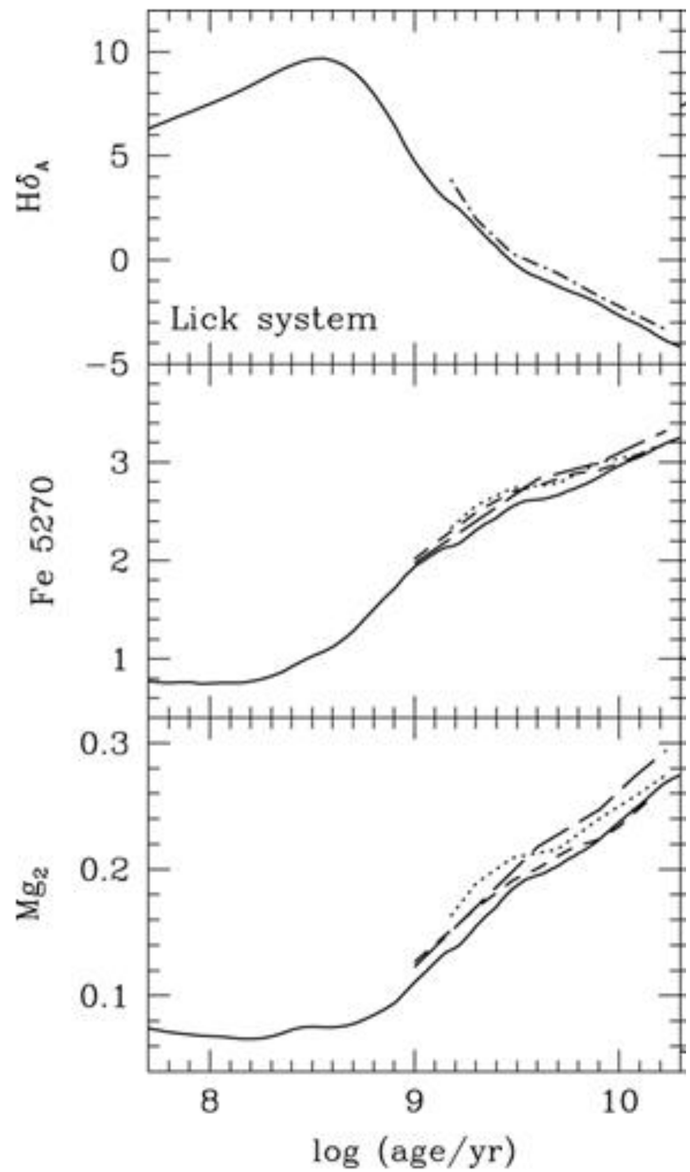
- While it is possible to compare model spectra with real spectra by eye, it is simpler to identify regions of the spectrum which carry information about age or metallicity and measure these spectral features directly
- Examples are Balmer lines, 4000A break, Mg lines, etc.

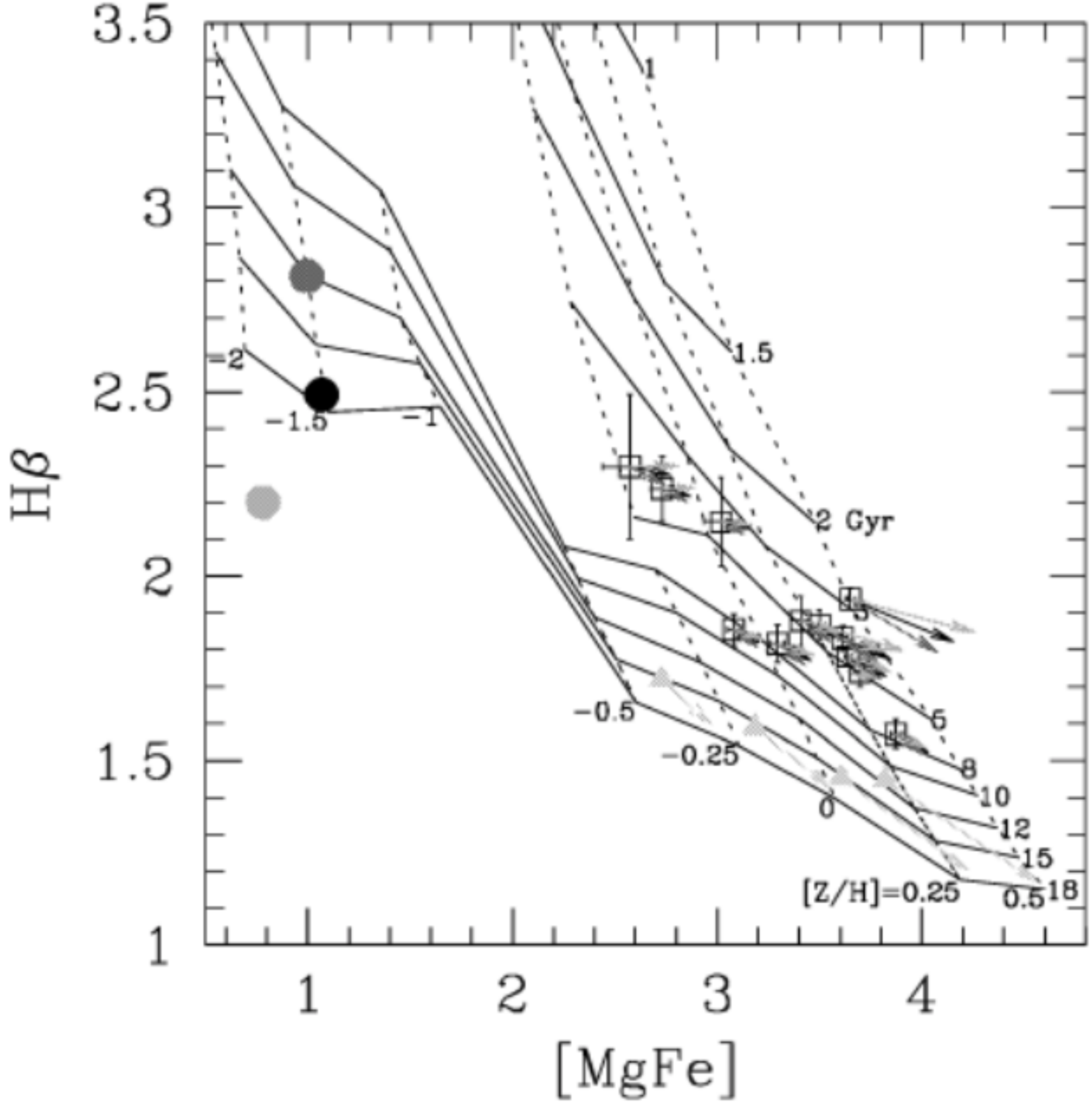
Q: How might you go about measuring the strength of a spectral line? What issues will you need to deal with?

- Continuum placement can be a challenge

- One way around this is to designate ‘clean’ regions of the spectrum as continuum regions, and then just average their flux to get the average continuum over the line region of interest

- Q: why would the strength of Balmer lines in a galaxy spectrum be a good indicator of the overall age of the population?
- How about metal lines?

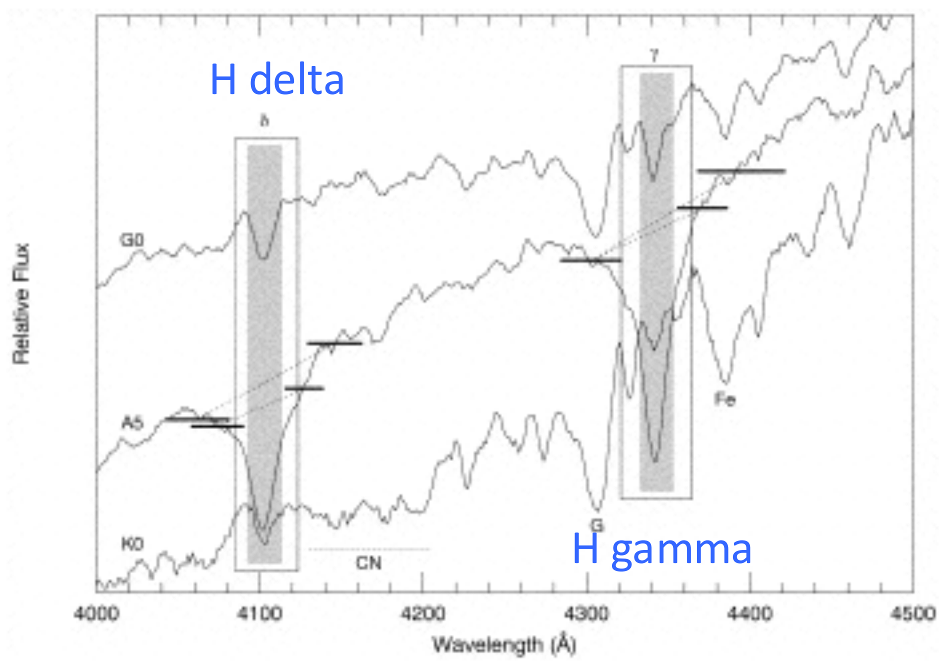




Trager et al 2005

Quantifying agreement with models

- The spectral synthesis codes provide the synthetic spectra themselves and colors in various passbands
- Comparison of measured colors with predictions are straightforward (see Homework 3) but spectral comparisons are more difficult



Worthey and Ottaviani 1997

Pseudo equivalent widths are a common way of measuring the strength of important spectral features

How age and metallicity are measured in SDSS spectra

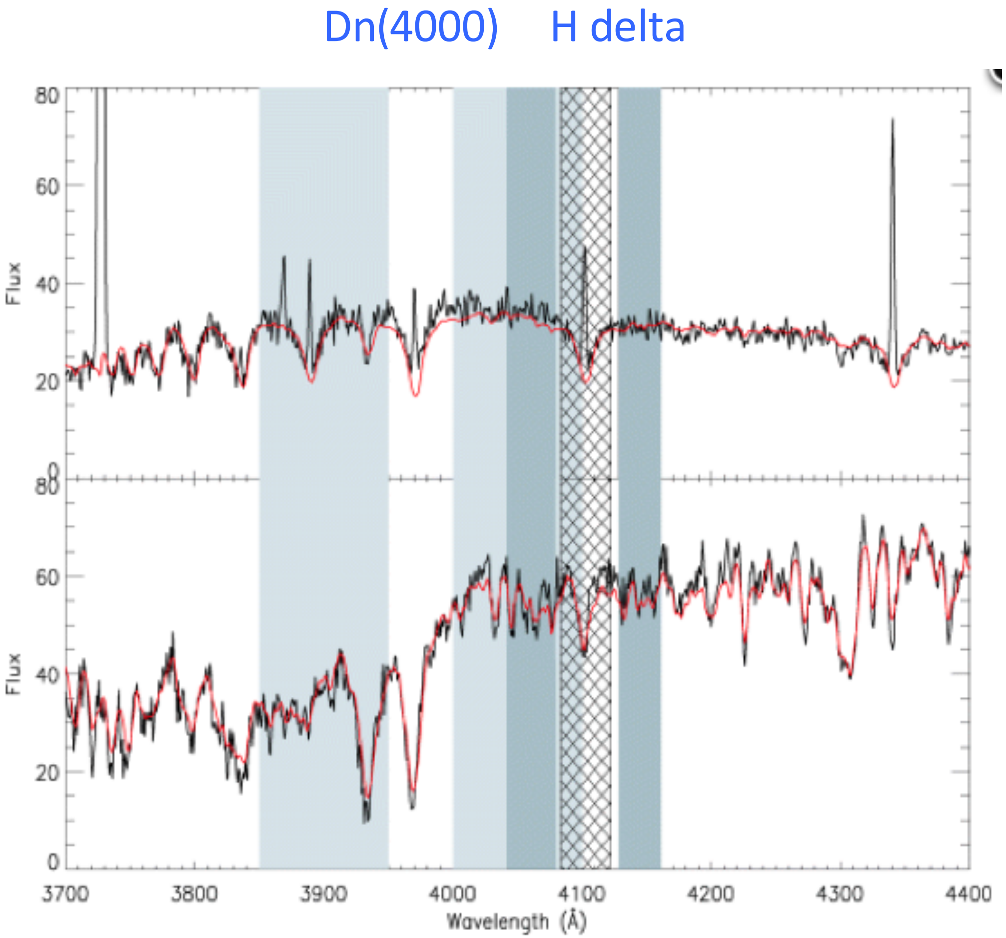


Figure 1. SDSS spectra of a late-type galaxy (top) and an early-type galaxy (bottom) are plotted over the interval 3700–4400 Å in the restframe. The red line shows our best-fitting BC2003 model spectrum. The light grey-shaded regions indicate the bandpasses over which the $D_n(4000)$ index is measured. The dark grey regions show the pseudocontinua for the $H\delta_A$ index, while the hatched region shows the $H\delta_A$ bandpass.

Kauffmann et al 2003

- Remove emission line from H delta absorption
- Measure Dn(4000), which quantifies the 4000 A break using the ratio of continuum flux above and below 4000A
- Measure the H delta index, using continuum bands shown in the diagram

Q: what will affect the 4000A break? Age? Metallicity?

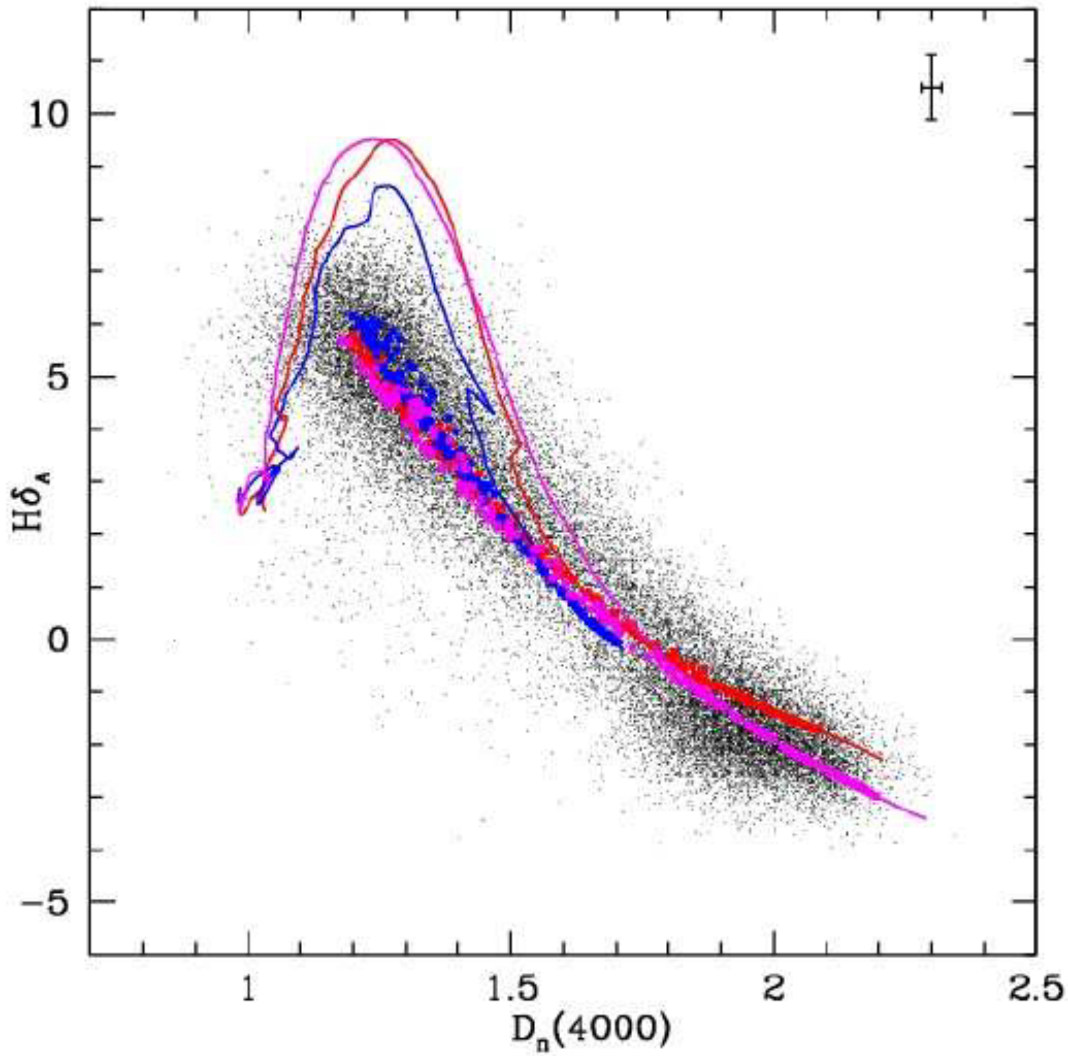


Figure 3: $H\delta_A$ is plotted as a function of $D_n(4000)$ for 20% solar, solar and 2.5 times solar metallicity bursts (blue, red and magenta lines), and for 20% solar, solar and 2.5 solar continuous star formation histories (blue, red and magenta symbols). A subset of the SDSS data points with small errors are plotted as black dots. The typical error bar on the observed indices is shown in the top right-hand corner of the plot.

120,000 spectra from SDSS galaxies

Q1: where are the oldest (E) galaxies?

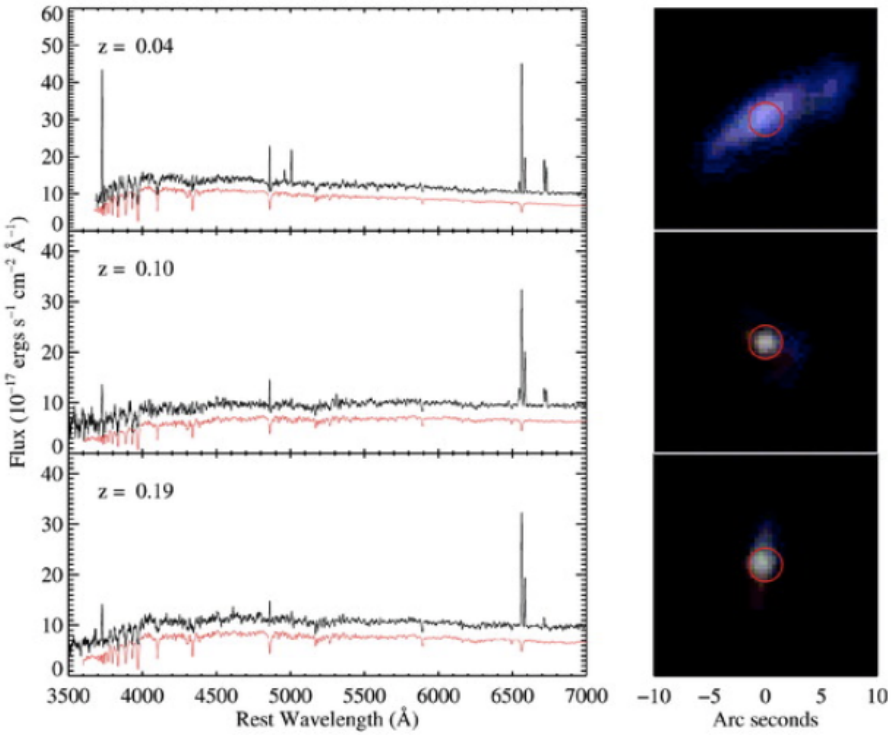
Q2: do the data prefer a single burst or continuous star formation?

Kauffmann et al 2003

Luminosity/mass metallicity relation

Q: the lowest luminosity galaxies we know (satellites of the Milky Way called ultra-faints) have absolute magnitudes comparable to a single giant star and metallicities lower than -2.0. By contrast, giant ellipticals have absolute magnitudes of $M_V \sim -24$ and metallicities above solar. The luminosity/metallicity relation connects these two extremes

What might cause this relationship?

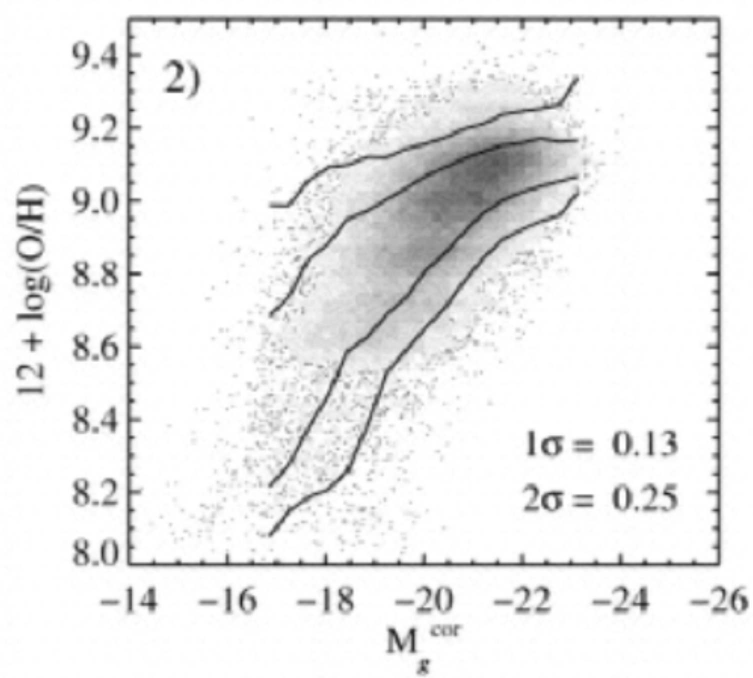


Tremonti et al (04) studied 50,000 galaxies with SDSS, using their emission line strengths to measure the metallicity of each galaxy

Q: how would they obtain the galaxy luminosity?

A: redshift plus magnitude gives absolute mag

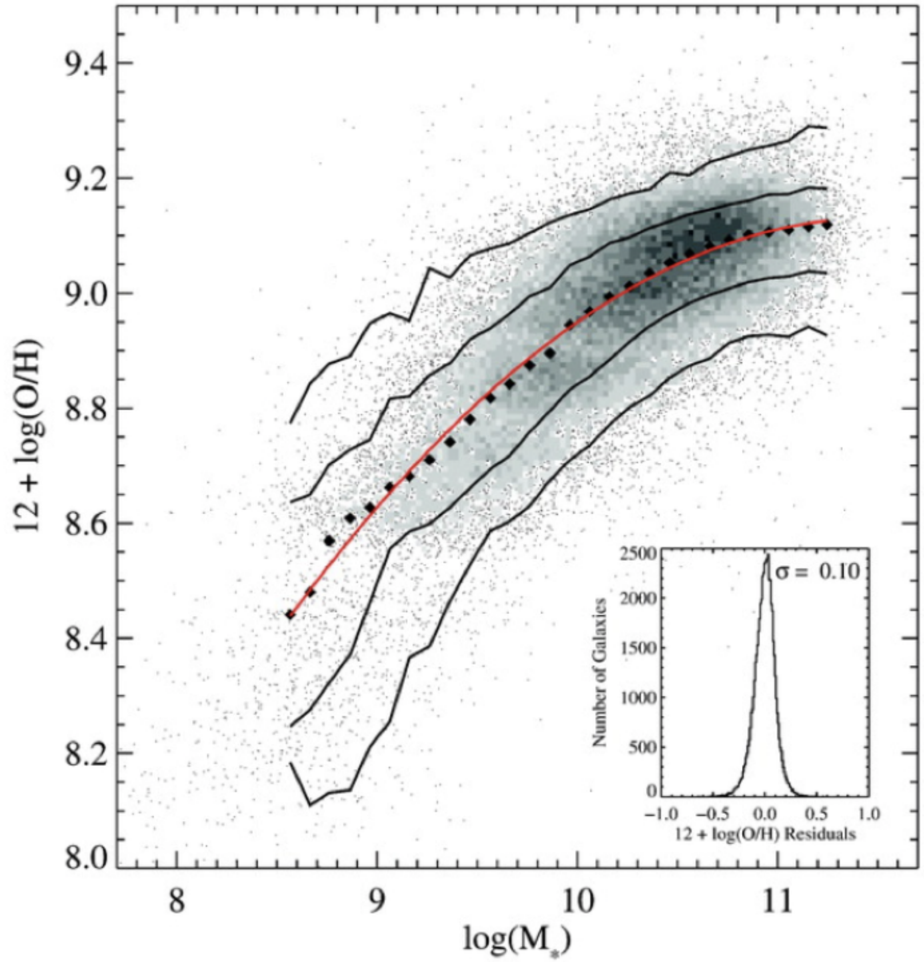
Luminosity (M_g) vs metallicity for the SDSS galaxies



Tremonti et al 2004

Q: how do we go from luminosity to stellar mass for the galaxy, using the spectrum?

A: we know how many stars of each type we have from absmag and spectrum; can then work out how many stars of each mass – population synthesis models can help



Mass-metallicity relation from Tremonti et al 2004

Q: if the calibration from luminosity to mass was erroneous or even random, why would it decrease the scatter?