Lecture 4 : Galaxy Evolution

I. Mesure of galactic distances.

Measuring distances is a difficult issue in Astronomy. The sky is seen in 2-dimensions, the third one is not accessible directly. Only projected distances are measured.
Distances of galaxies are essentially measured thanks to their general move due to the universe expansion. In the nearby universe on must correct for local attractions between galaxies, especially within groups or clusters (or towards groups and clusters). At large distance the velocities due to the Hubble flow dominate, and no correction needs to be applied.
The spectral redshift is the way to measure galaxy distance. Galaxies with strong emission lines are the best candidates for these measures. Absorption lines can also be used but a signal to noise ratio is needed.

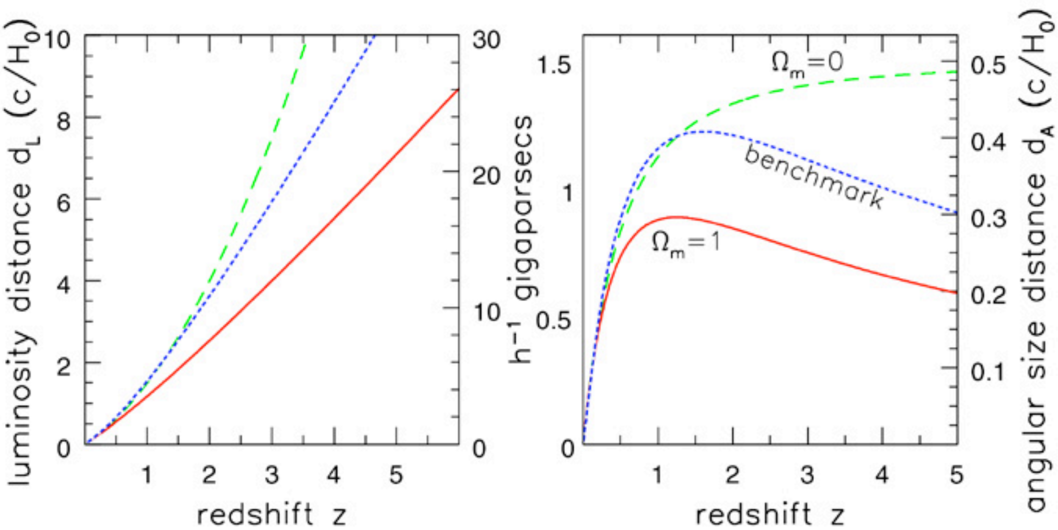
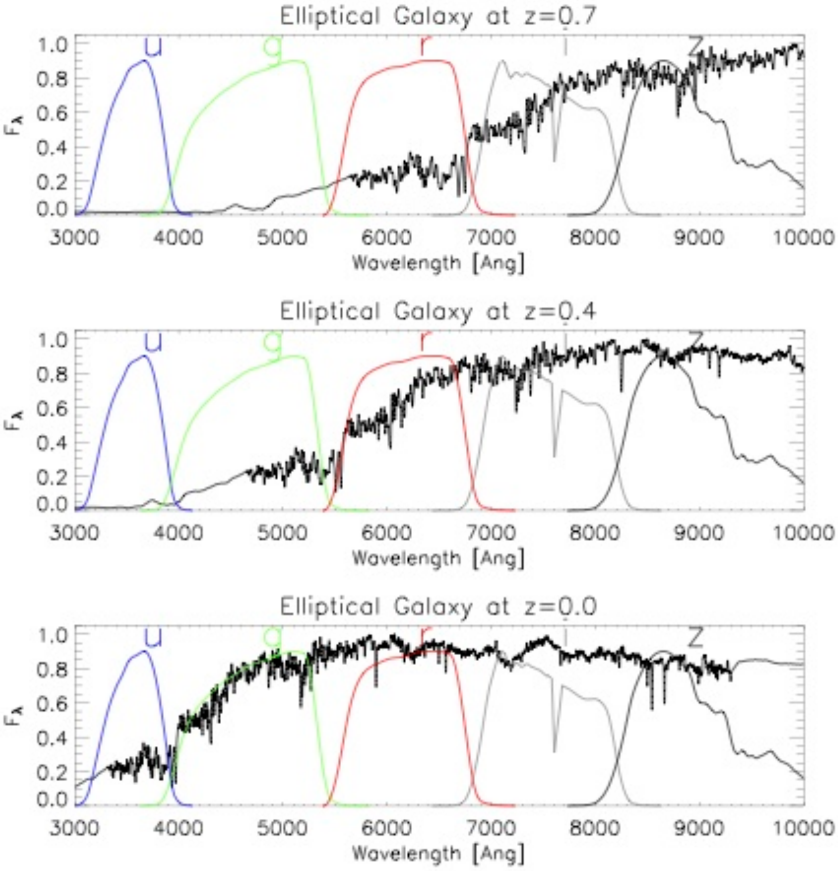


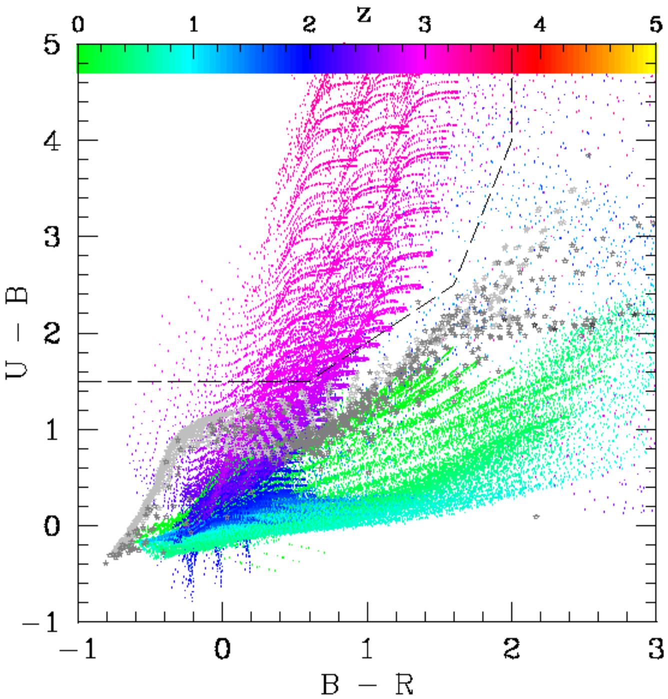
Fig 8.11 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

Spectroscopy is not available for all the galaxies observed in photometric surveys. A very popular method to have an estimate of the redshift is to use photometric data only. The general shape of the SED is compared to models and the best redshift is deduced. The method is robust when well defined features like breaks or bumps are present in the SED built with photometric data. It is illustrated below.



Question : What is the spectral signature which helps to measure the redshift in the above figure?

When people want to select galaxies in a large redshift interval (with no need of precise redshift), they can use few photometric bands and compare colours to the ones predicted by models, once again it is useful when strong features are present in the bands.



Question : which spectral signature is highlighted here?

II. Galaxies in the local universe

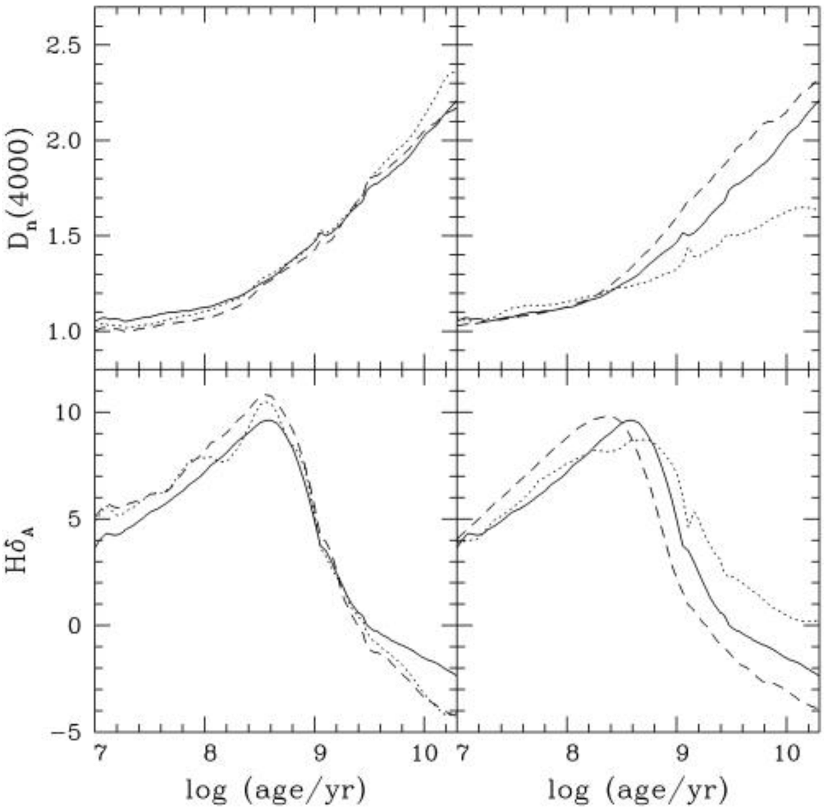
The local universe is the best laboratory to study galaxies in details and understand the main processes and measure the physical conditions.

The Sloan Digital Sky Survey collected data over half the sky (20000 sq.deg.) in several photometric bands. A large fraction of the fields were also observed spectroscopically. Several publications described the main results drawn from this survey.

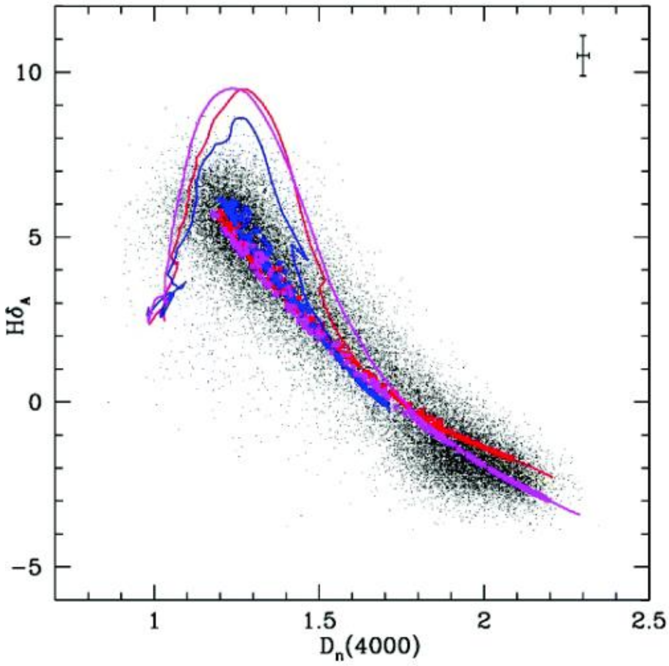
The star formation history was studied by comparing the D4000 feature to the Hδ absorption line (Kauffmann et al. 2003, MNRAS, 341, 33)

D4000 and the Balmer absorption lines were described before: why are they chosen to measure the star formation histories?

Models are needed to interpret these spectral signatures. The first illustration is obtained with a population synthesis model assuming an instantaneous starburst. The various lines in the left diagrams correspond to different stellar libraries. The lines in the right diagrams are drawn with different metallicities. One can see the very different evolution of both quantities with age.

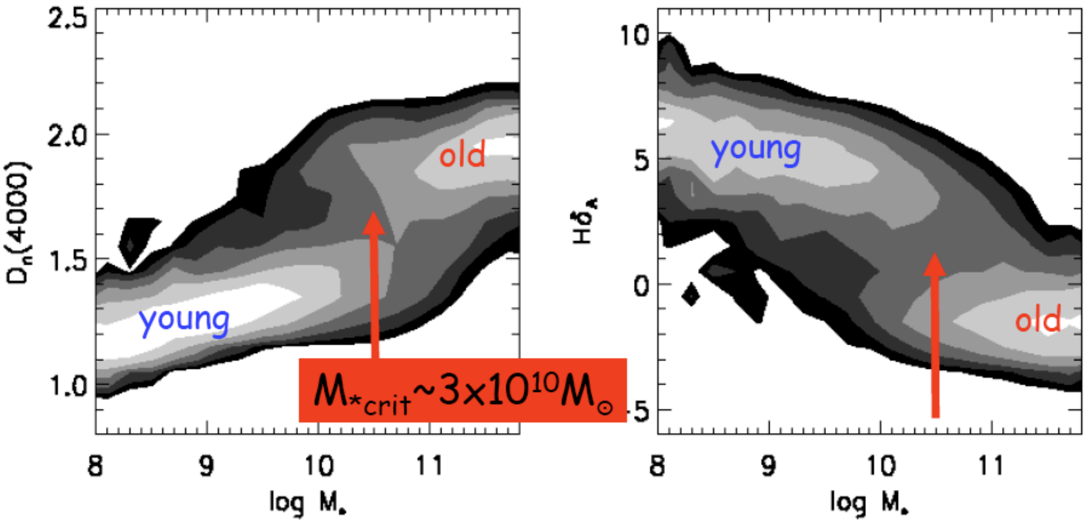


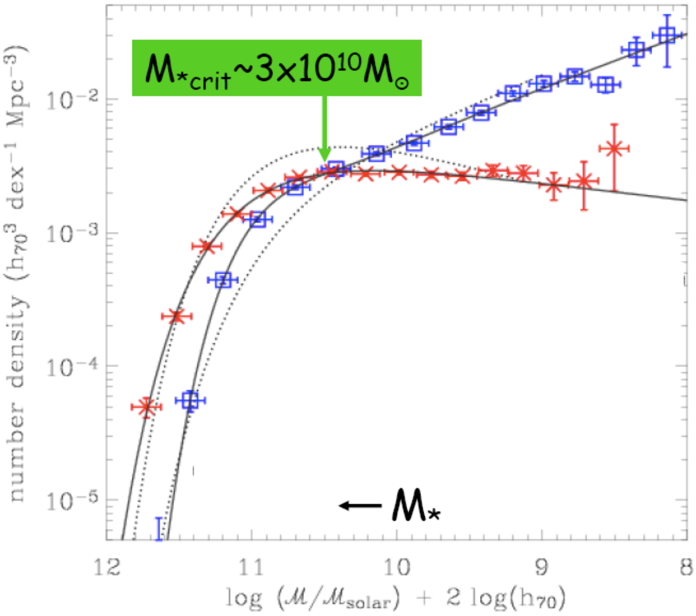
The second figure combines Hδ and D(4000)) for different metallicities (blue: 20% solar, red: solar, magenta: 2.5 times solar) . The lines are for an instantaneous burst (age increasing with D(4000)). Symbols are for a constant star formation. Black points are observed data from the SDSS.
One can conclude that a constant SFR is a good model for the mean behavior of the local galaxies.



Another very important result from the SDSS is the bimodal distribution of D(4000) and Hδ with a population of blue late-type galaxies and a population of red early-type ones (Baldry et al. 2004)

Can you comment about the wording “red, early-type” and “blue, late-type”

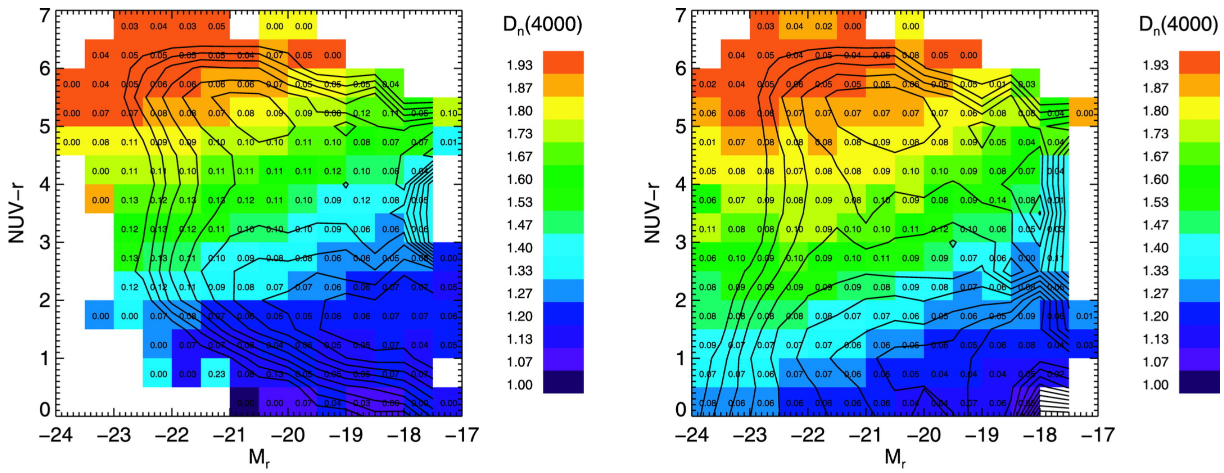




Baldry et al. 2004 also subdivide the population as a function of u-r (very sensitive to the current star formation) to build the mass functions of blue (gaussian distribution with <u-r> = 1.5) and red (the same with <u-r>=2.3).

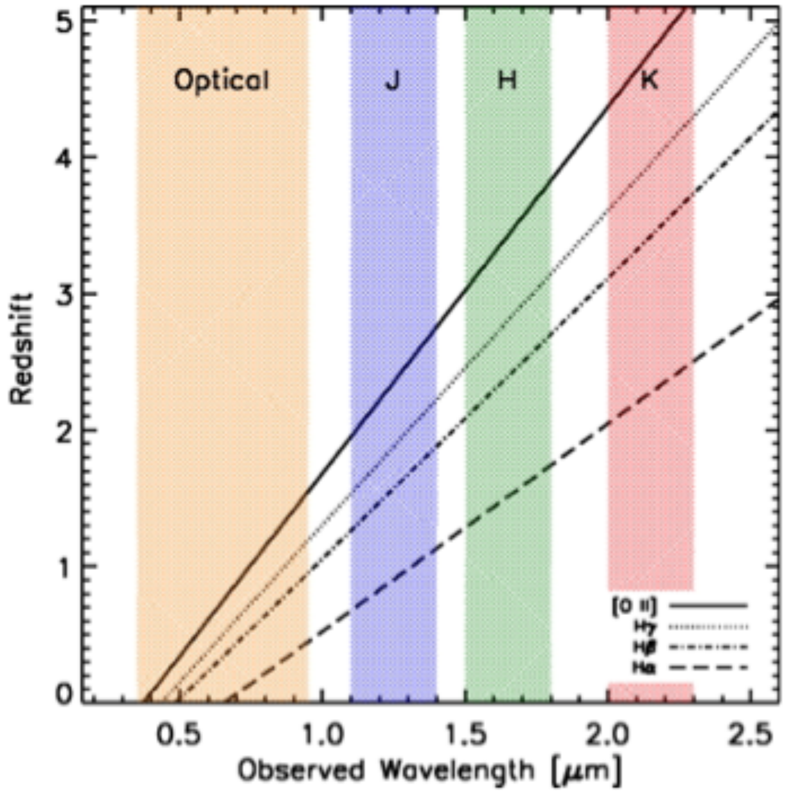
The mass with equal quantities of both galaxies is around 3 10^{10} M_{sun}

Note that we do not always have D(4000) and Hδ measures. Photometric colours (as u-r above) are also used to separate the populations in red and blue ones. The relatively small number of galaxies between the red and blue distributions is called the green valley.

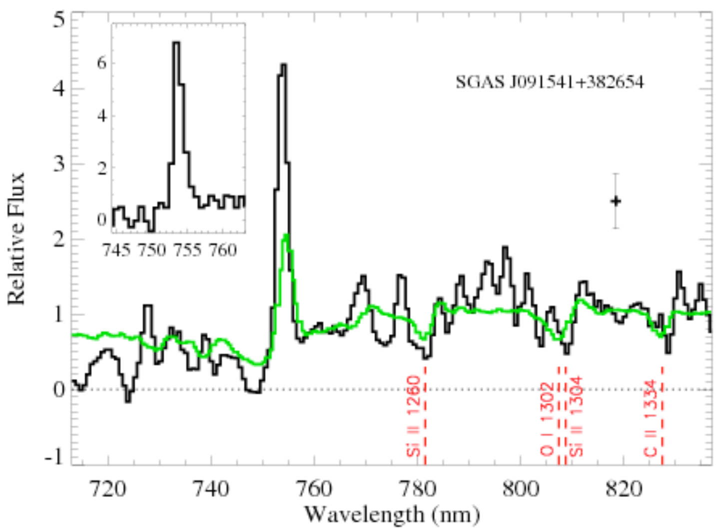


III High redshift galaxies

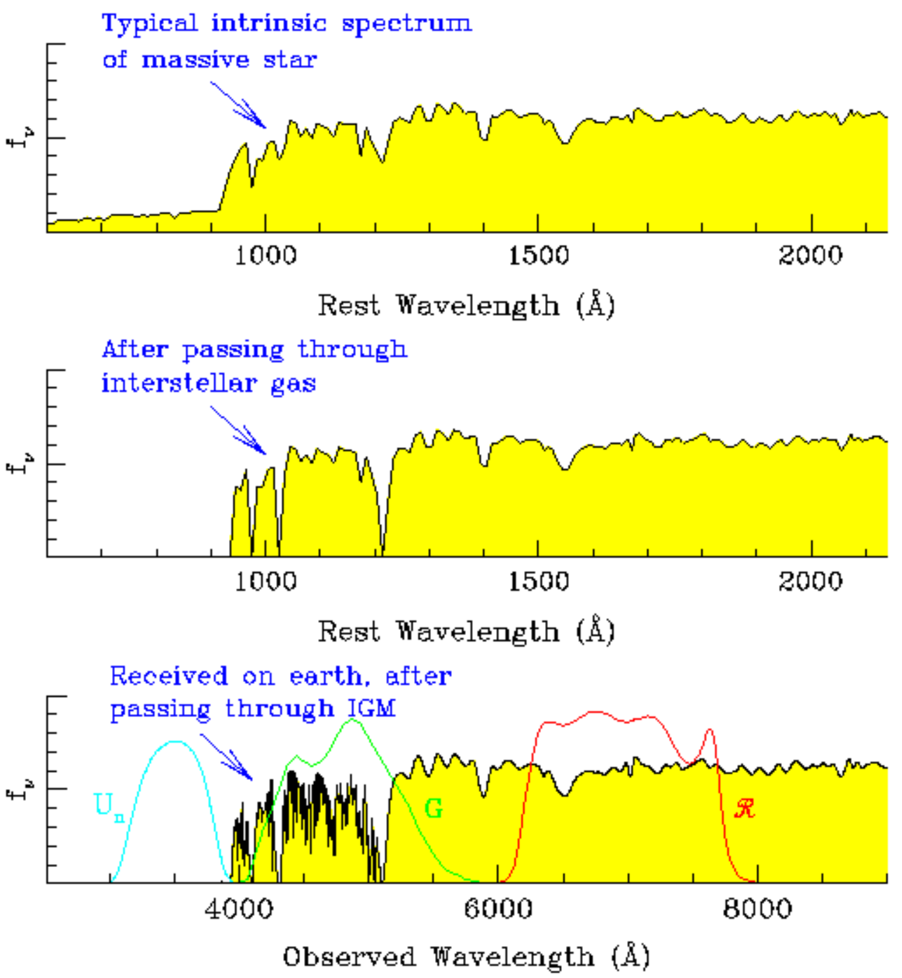
We now go to the very distant universe (redshift much larger than 1). With the increase of collecting areas of telescopes both in the ground and space these distant objects become accessible but very difficult to identify.
Their detection is based on the search of the main features found in the well known closer objects:
-Emission lines: it is the most obvious signature of distance. As shown before the lines seen in the nearby universe are no longer observed in the visible when z increases.



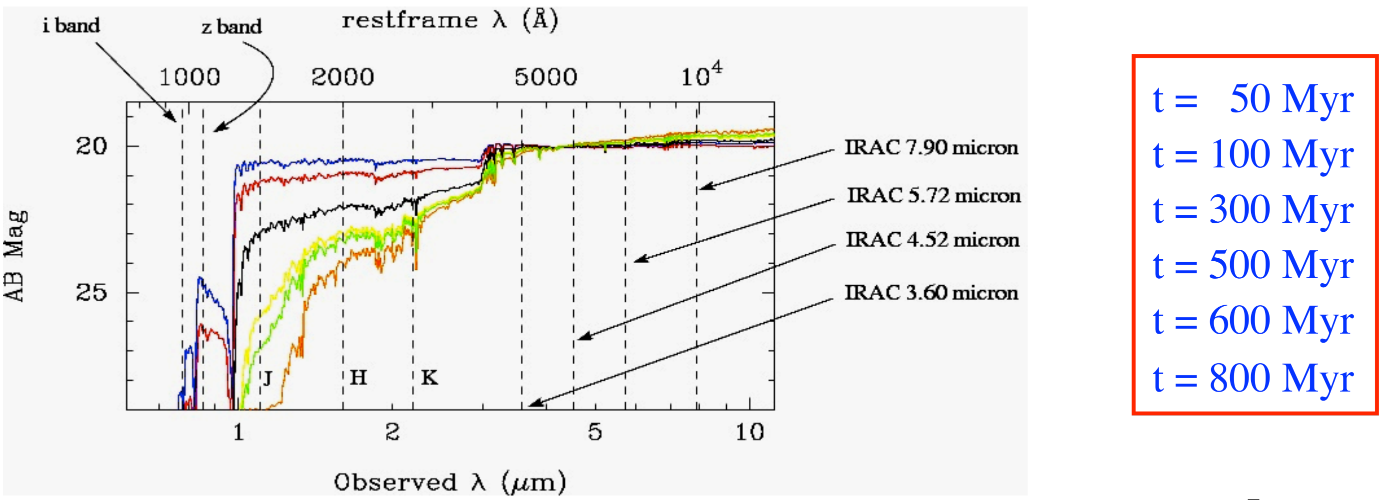
There is two ways to solve the issue: either change the line or go to the near-infared. Both are explored. Lyman alpha emitters are searched for at very high redshift, but as we saw before the resonant scattering makes the line difficult to interpret



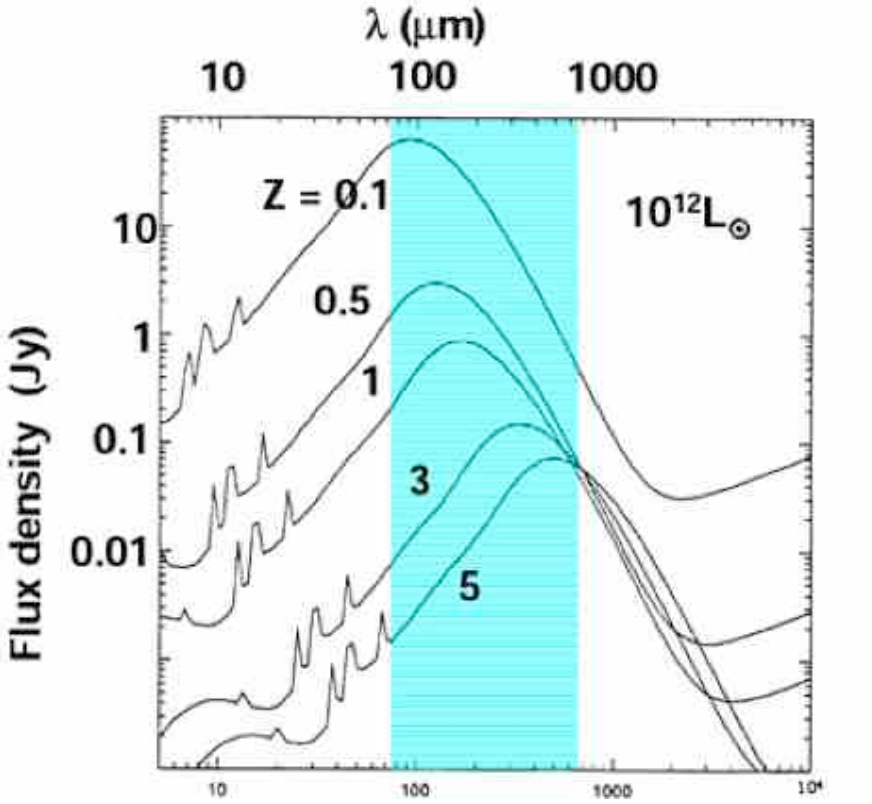
Lyman Break galaxies were already presented. At high redshift, the intergalactic medium (HI neutral gas) adds an absorption below the Lyman alpha line and modifies the break due to the stars inside galaxies. It is illustrated below.



Balmer breaks are also searched for, they are more difficult to detect than the Lyman break since their amplitudes are lower. Balmer lines being a signature of B stars, the galaxies harbouring a Balmer break are several hundred Myr old, which is not very young at high redshift!



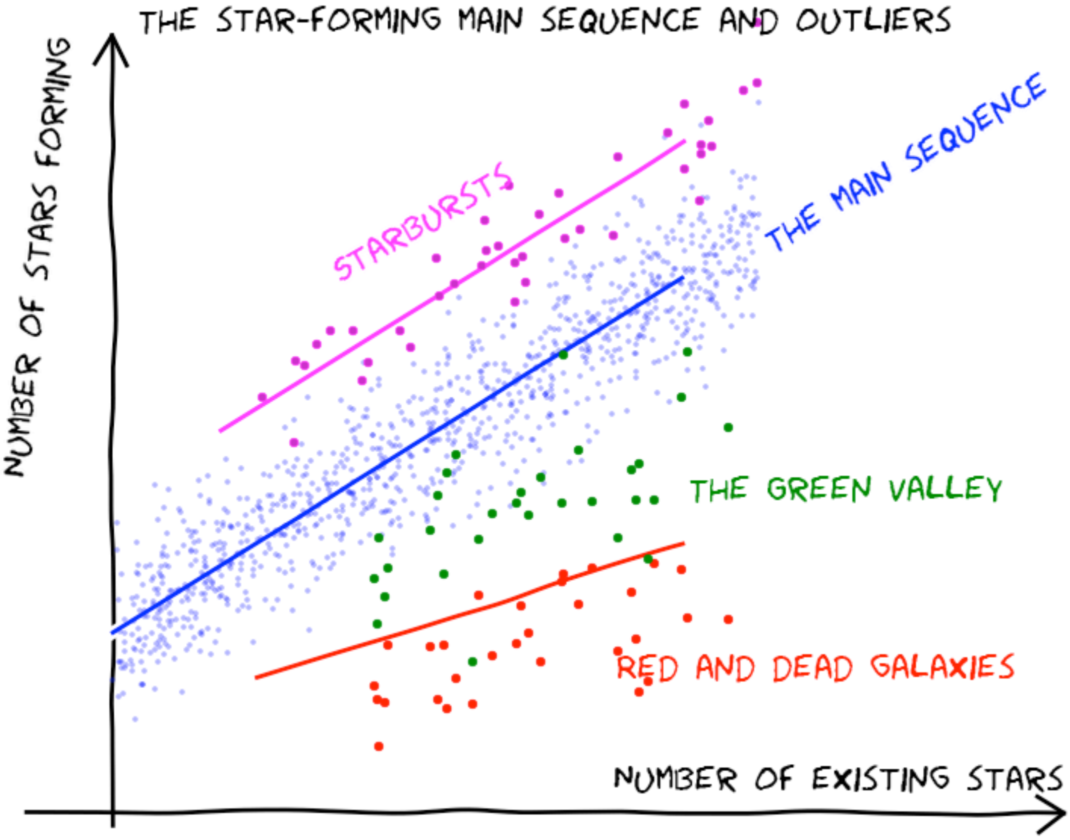
Another way to detect high redshift galaxies is to search for **their dust emission**, so going to the submm. This method takes advantage of the positive K correction. The K correction is the dimming due to the (1+z) shifting of the wavelength band, and one also must account for the increase of the luminosity distance. The positive K correction refers to the dust black body spectrum, in the Rayleigh-Jeans regime, the galaxies get brighter when they are redshifted at very high redshift. The main limitation of the method is that submm instruments are not very sensitive and only intrinsic luminous objects can be detected at any redshift.



IV Evolution of the star formation with time

a. Star formation rate and stellar masses.

For several years astronomers have searched for a link between the stellar mass and star formation rates of galaxies at different redshift and found that both quantities correlate. They define the relation as the 'main sequence of galaxies" (e.g. Noeske et al. 2007, Rodighiero et al. 2011).
All large surveys at low and high redshift have studied and found more or less dispersed relations.



It is a very schematic representation of the main sequence, outliers are found, above the Main Sequence (MS) as objects very active in star formation and called starbursts, the quiescent galaxies (related to the red cloud defined above) are below the main sequence, and the green valley between these red objects and the blue, active and starburst galaxies.

The slope of this relation is important and defined as the specific star formation rate

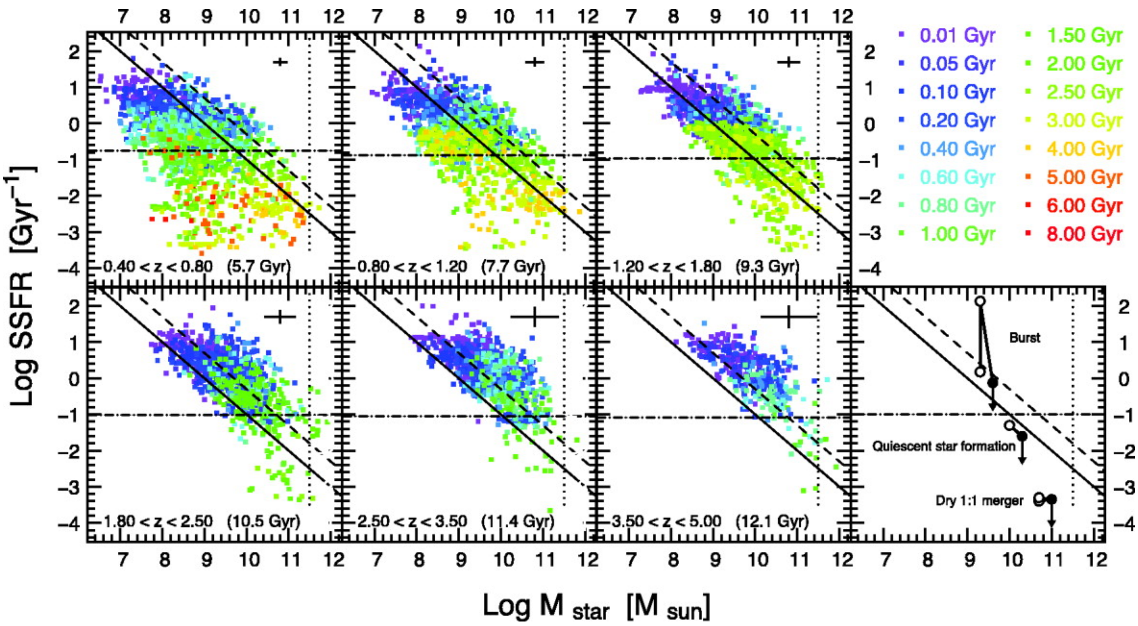
$$sSFR= SFR/M^*$$

The stellar mass represents the past star formation since we can write
$M^* = \langle SFR \rangle * T*(1-R)$ accounting for the recycling R, T is the age of the stellar population.
sSFR compared the current star formation to the averaged past one.

If we assume a constant SFR with time, sSFR scales as the inverse of the age of the galaxy.

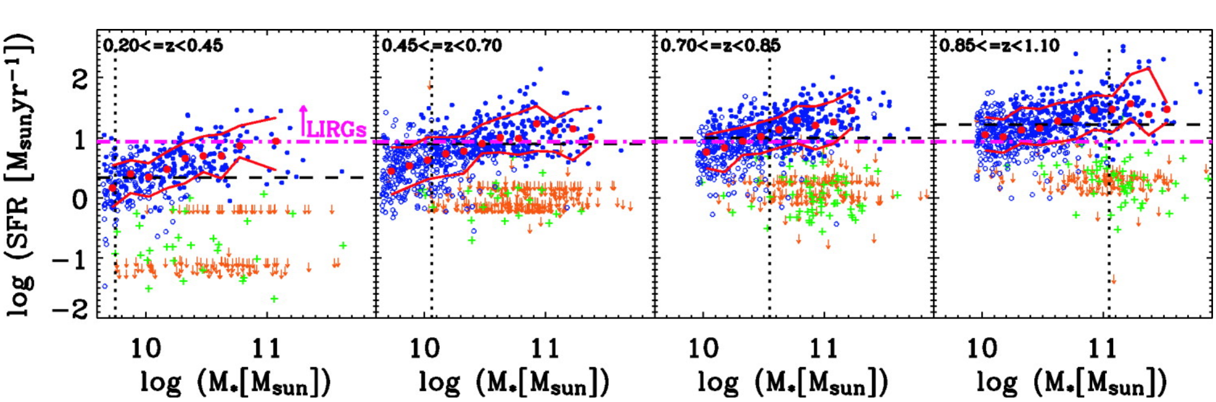
In the nearby universe the sSFR decreases when stellar mass increases, massive galaxies formed their stars in the past whereas less massive ones are still quite active in star formation, or equivalently, the mean age of the stellar populations of massive galaxies is higher than that of low mass galaxies

This behaviour is also observed at higher redshift pushing the formation of the stellar population of massive galaxies at very high redshift. It is known as the downsizing formation of galaxies.



Feulner et al. 2005, among numerous studies

In numerous studies, people make a distinction between active and passive galaxies. In this case the main sequence appear to have a slope close to 1 (constant sSFR).



(Noeske et al 2007)

b. Variation of the star formation rate density in the universe

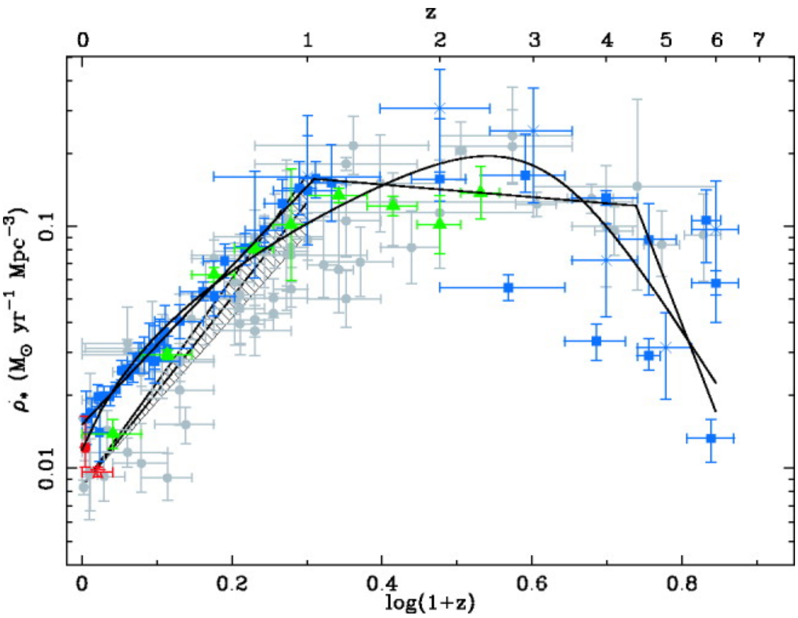
One of the most popular plots is the evolution of the star formation rate density (SFRD) with redshift. This density is expressed in $M_{sun}\ yr^{-1}\ Mpc^{-3}$ and traces the global evolution of stellar formation per unit volume with time. All the information on individual galaxies is lost.

Practically we start with the luminosity funtions of emissions linked to the star formation (UV, IR recombination lines).
The luminosity function is integrated

$$\int_0^\infty L\,\Phi(L)\,dL = \mathcal{L}$$

If it is a Schechter function $\mathcal{L} = \Phi^* L^* \Gamma(2+\alpha)$

Otherwise a specific calculation must be performed numerically
This luminosity density is then translated in SFR as discussed in the previous lecture



The exact shape is still under discussion, especially at high z. From z=0 à z=1 The SFRD increases by a factor ~10 du SFRD. Above z=1 it remains uncertain with perhaps a plateau between 1 and 2 and then a decrease. The main factor of uncertainty comes from the correction for dust attenuation since only UV indicators are observable at very high redshift.

The models of galaxy formation must reproduce this trend. The role of mergers versus secular evolution with inflow is discussed with no real consensus. Today the role of mergers seem not to be predominant, in agreement with the main sequence of galaxies.