Galaxy Formation and Evolution
Lecture 4:
Spectral synthesis and star formation indicators

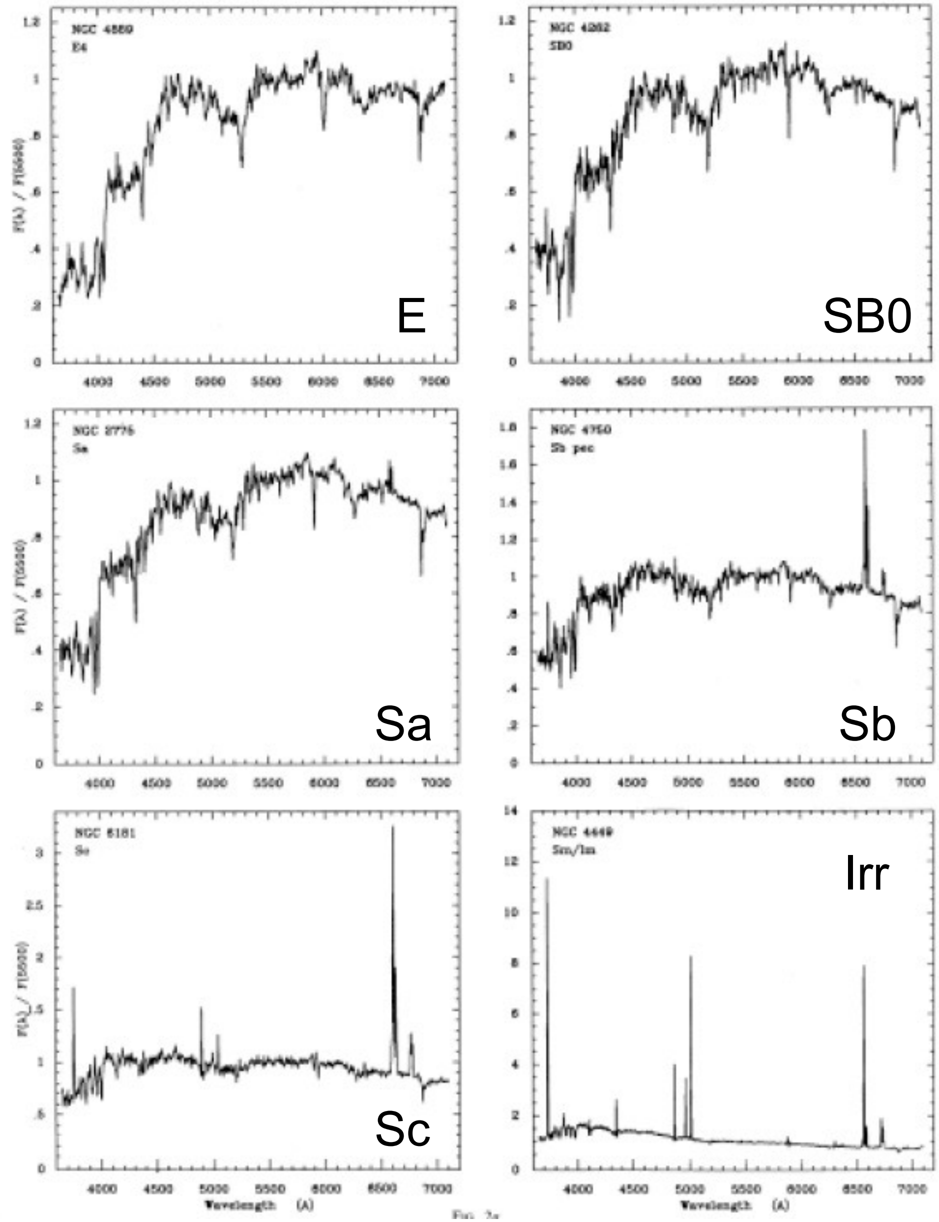
Course contents

Key learning objectives

- Have an appreciation of the importance of measuring galaxy properties.
- Understanding of how spectral synthesis modelling can be used to determine the masses, SF histories and metallicities of galaxies
- Knowledge of how the spectrum of an instantaneous starburst changes with age
- Understanding of the main ingredients and uncertainties in spectral synthesis modelling
- Appreciation of the main techniques used to determine the integrated SFR of galaxies and their pros and cons

Measuring galaxy properties

How do we determine the masses, star formation histories, and metallicities of galaxies from their integrated photometry and spectra?



Interpreting galaxy spectra: spectral synthesis models

- Spectral synthesis models are crucial for interpreting the spectra of galaxies

- In principle they can be used to determine the star formation histories, metallicities and stellar masses by fitting models to the observed spectra or photometry.

- They involve a detailed understanding of stellar evolution and knowledge of the spectra of stars at different positions on HR diagram (both dependent on metallicity).

Spectral synthesis: the ingredients

Spectral synthesis involves a number of steps, each requiring different ingredients…

- Initial stellar mass function (IMF e.g. Salpeter, Chabrier or Kroupa), with mass limits
- Stellar evolutionary tracks,
- Spectra of stars at different locations across the HR diagram (synthetic or observed),
- Metallicity (affects both stellar evolution and stellar spectra),
- Star formation history (e.g. instantaneous burst, continuous, exponentially declining etc.).

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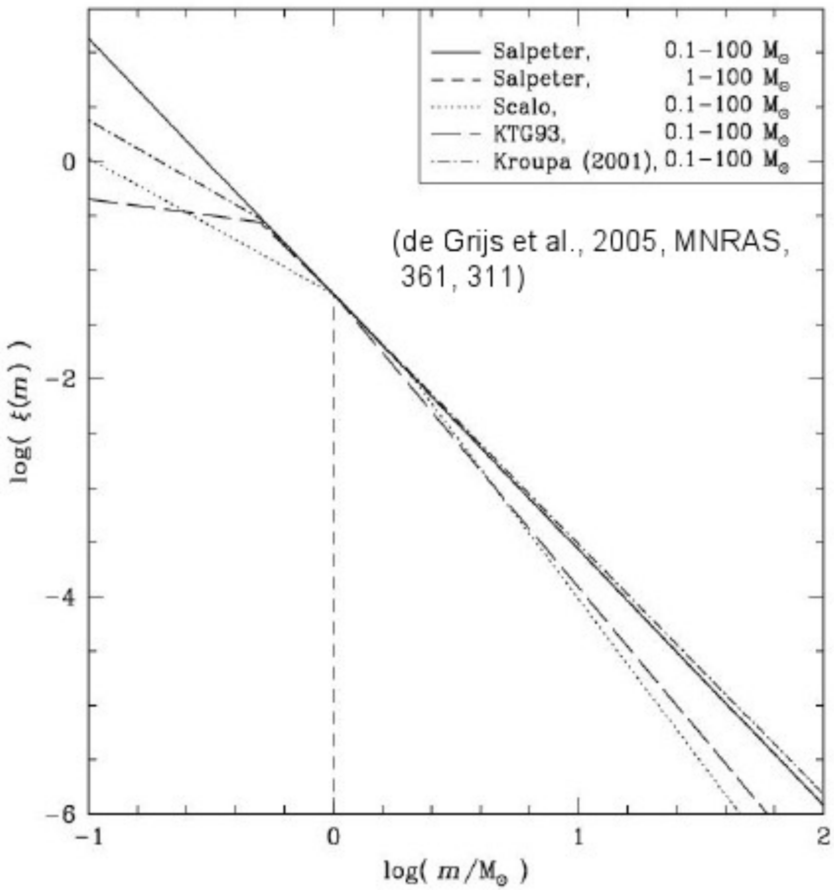
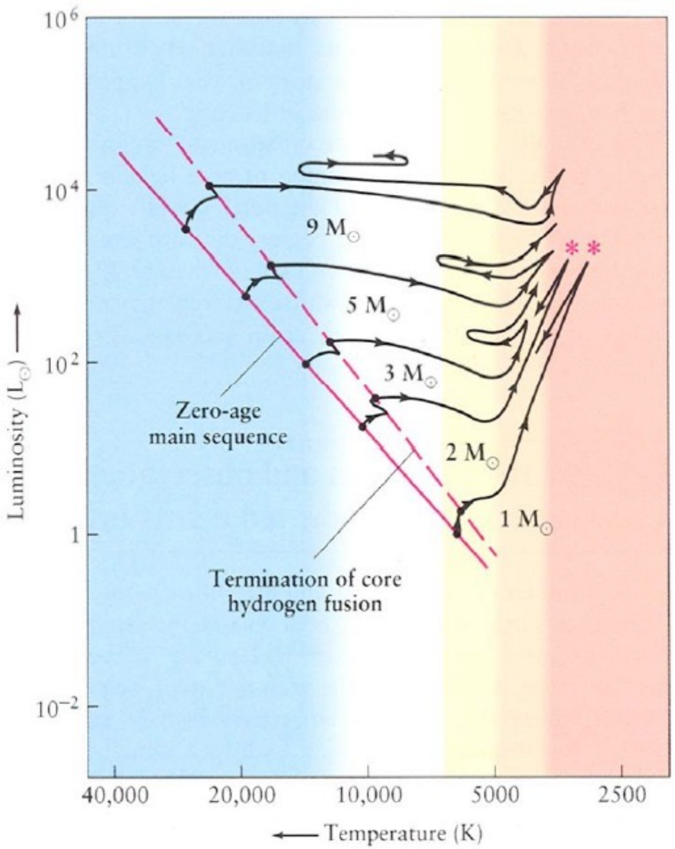
- Repeat the process for stellar populations with different metallicities.

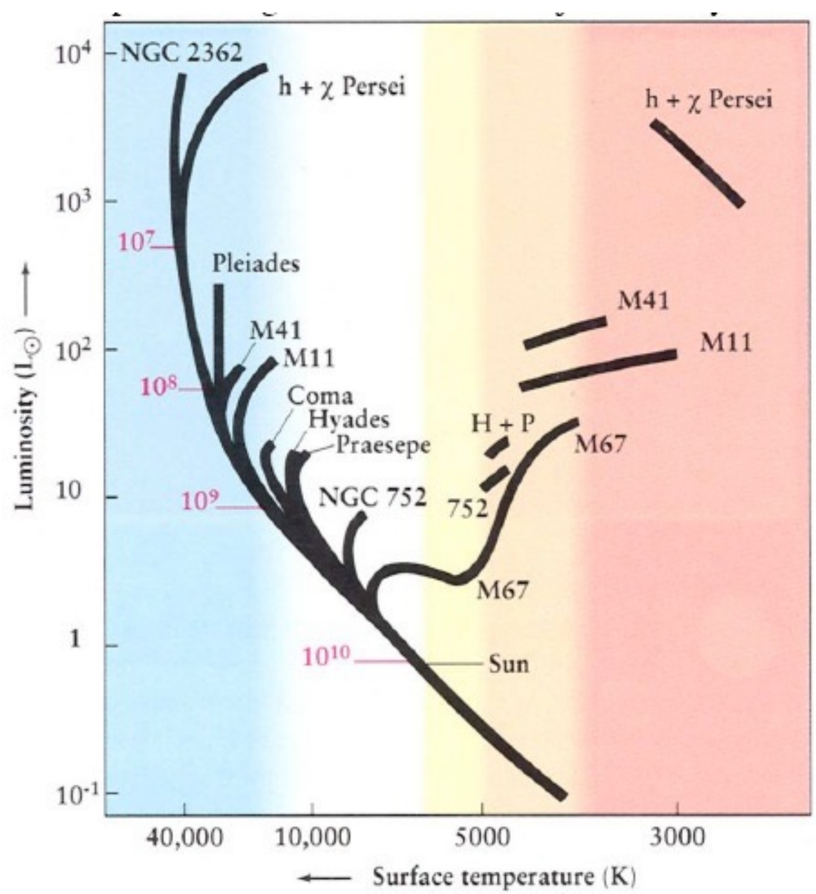
Start with an IMF



The Initial Mass Function tells us the distribution of stellar masses right at the start of the life of a population of stars.

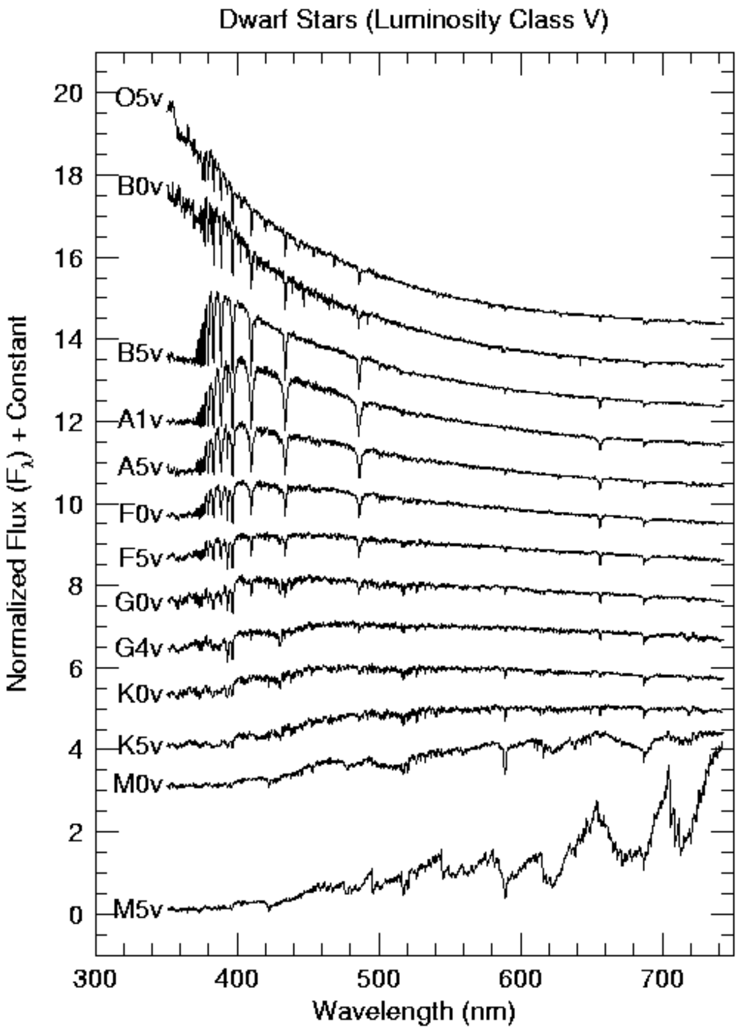
HR diagram and evolutionary tracks





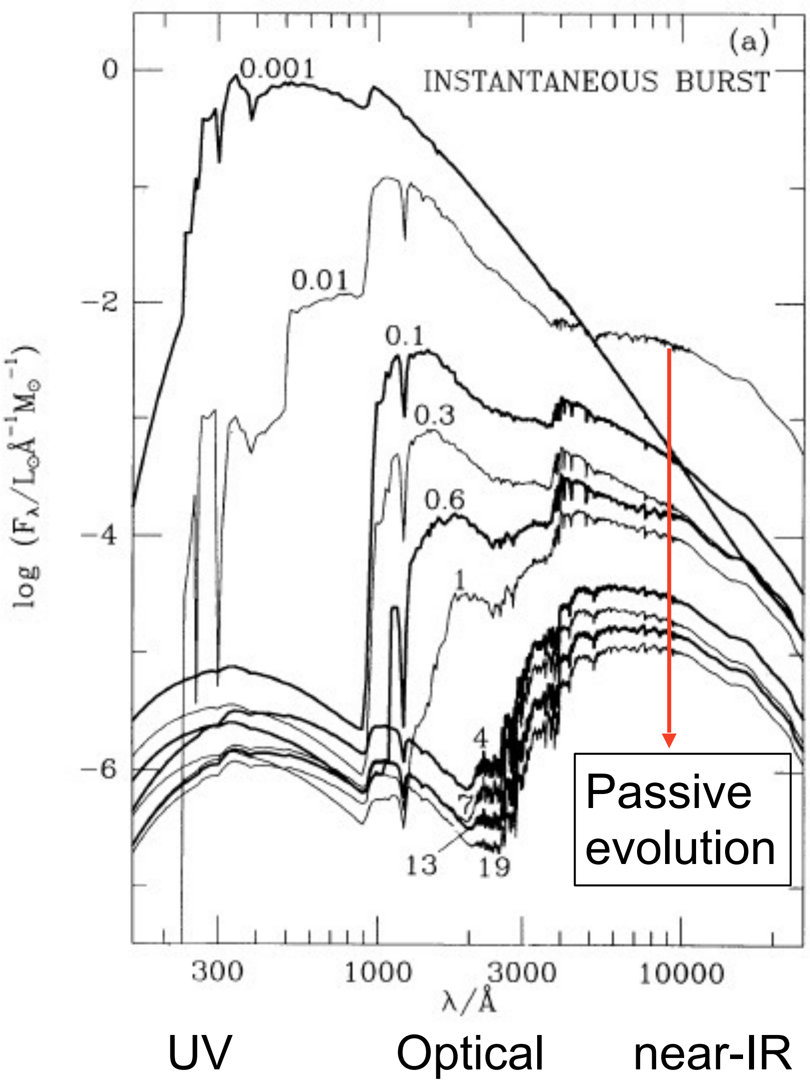
Stellar evolutionary tracks are used to determine how a star of given mass evolves with time. The combination of IMF and stellar evolutionary tracks gives the total number of stars in each part of the HR diagram at any given time after the burst of star formation.

Libraries of stellar spectra



Allocate each star a spectrum according to its position on the HR diagram

Spectral synthesis results I - Instantaneous burst models

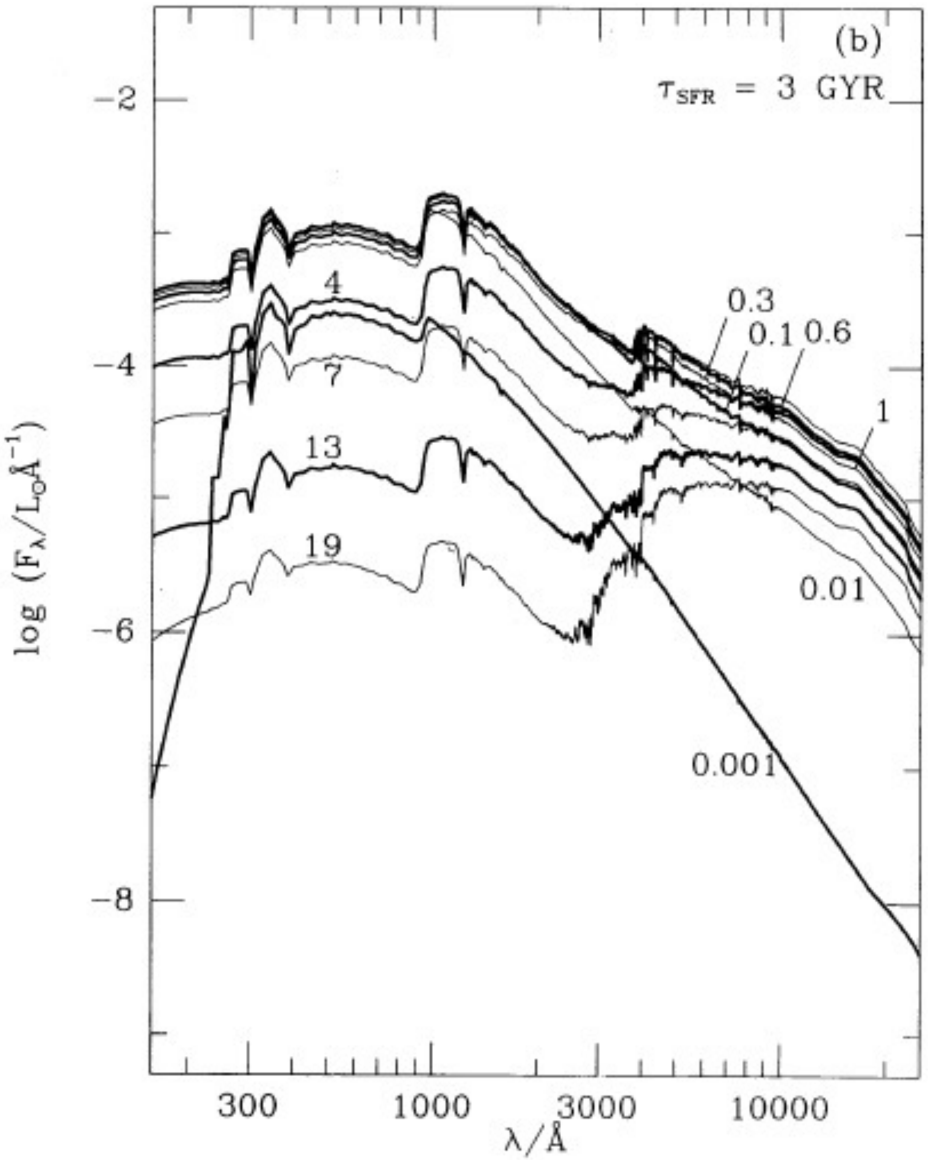


Plot shows the predicted UV/optical spectra for instantaneous-burst stellar populations of various ages (in Gyr).

The trends towards redder spectra with increasing age largely reflects the main sequence turn-off moving towards later spectral types/cooler stars, as the stars evolve off the main sequence.

Bruzual & Charlot (2003)

Spectral synthesis results II. Long, exponential burst model

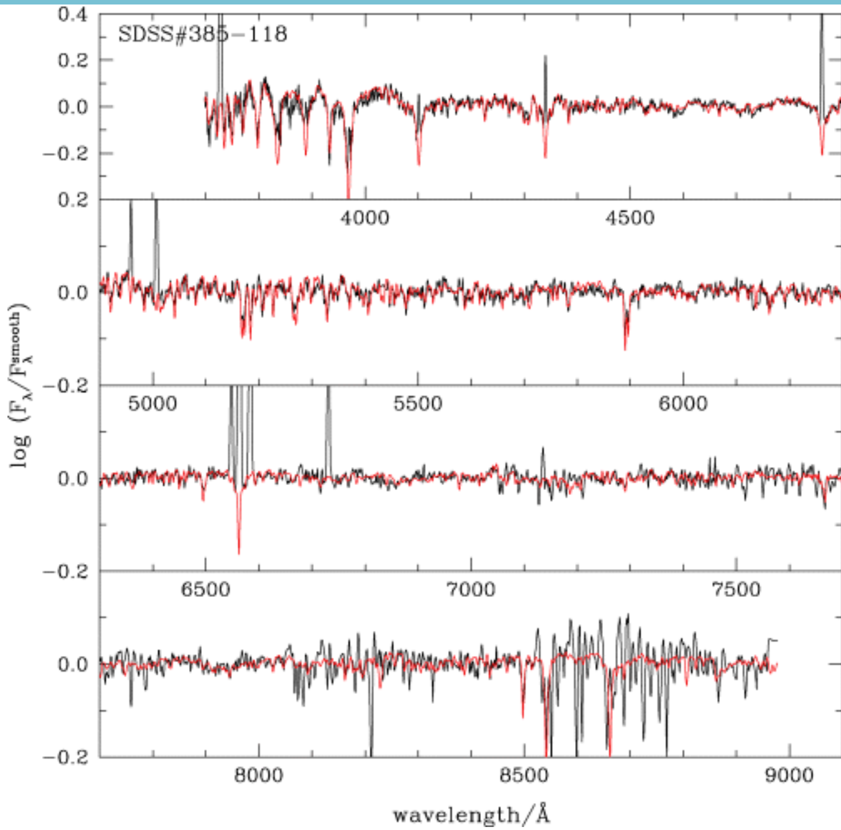


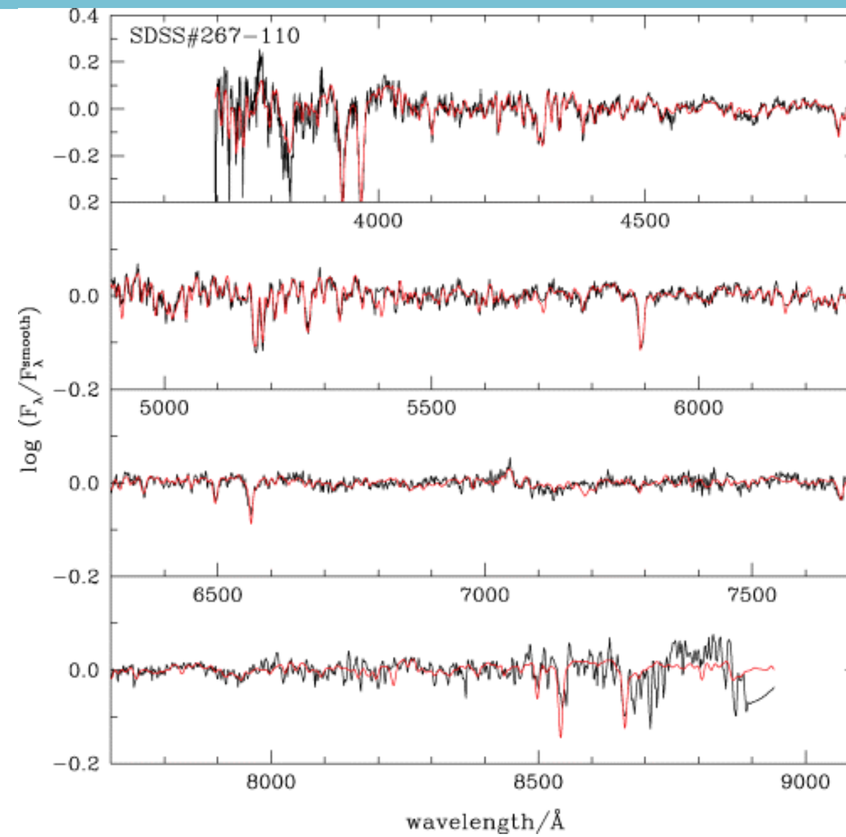
Spectral synthesis models for exponentially declining starburst of characteristic (e-folding) timescale of 3 Gyr.

The results are shown for various times (in Gyr) after the the start of the starburst.

In this case, the spectrum stays blue for much longer than in the instantaneous burst models because young, massive stars continue to be born for considerable period after the start of the burst.

Synthetic spectra





Stellar mass 10^9 M_o	Stellar Mass 10^{10} M_o
90% >2.5Gyr; 10% ~1Gyr	50% >5 Gyr; 50% 2.5-5 Gyr
LMC composition	Solar composition

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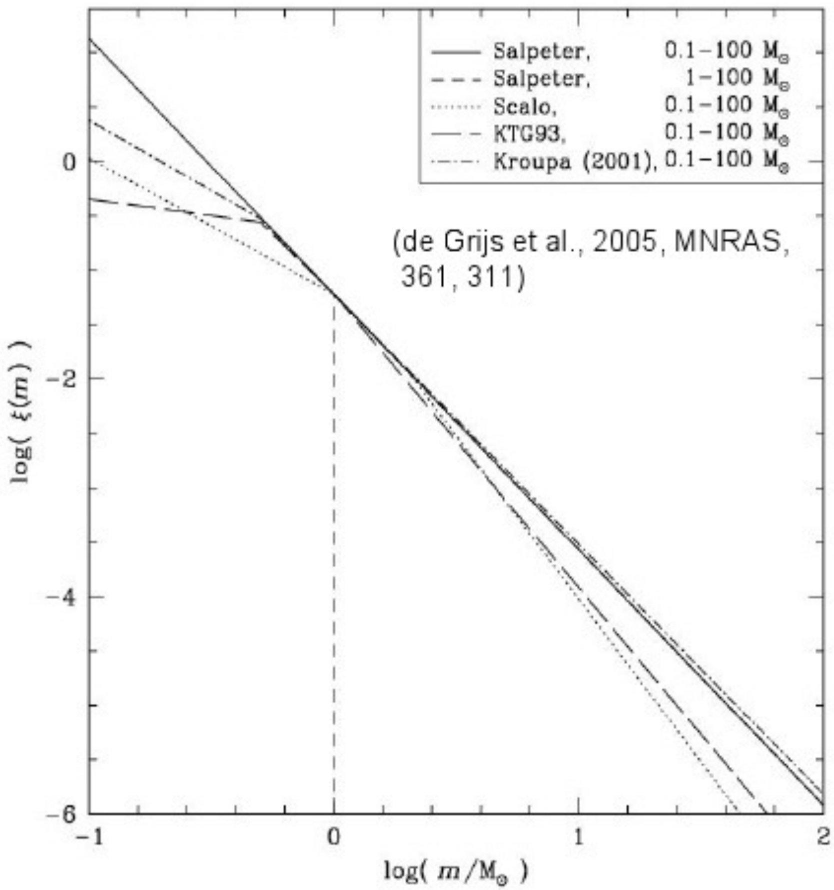
- It can be difficult to obtain a unique fit to spectra if there are several stellar components of different age, metallicity, reddening etc.

The uncertain IMF

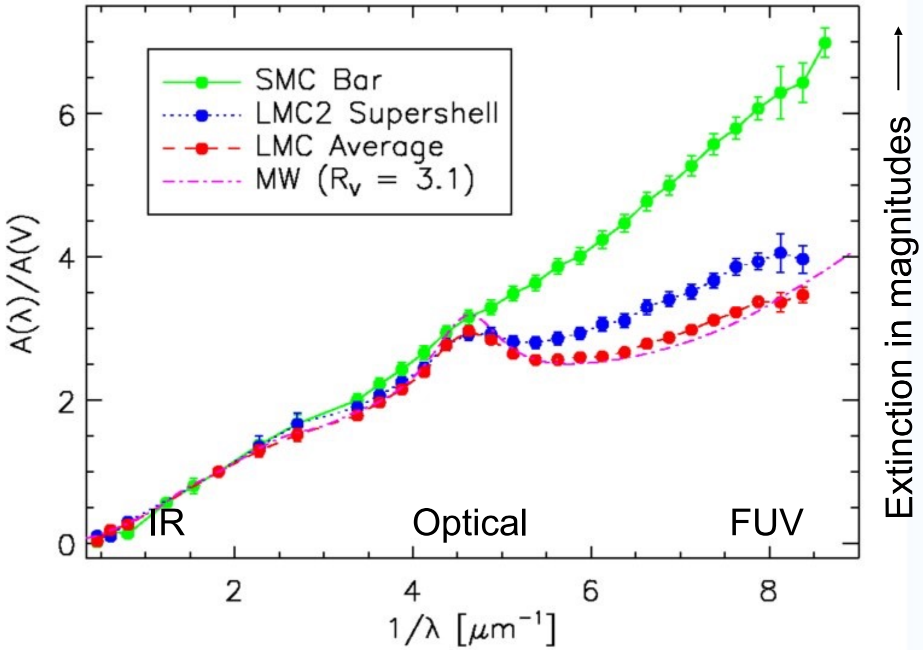


Uncertainties in the form assumed for the IMF can lead to large uncertainties in the derived total masses for the stellar populations, especially when using UV observations which sample the young, massive stars.

Interstellar extinction/reddening

The reddened starburst in Arp220

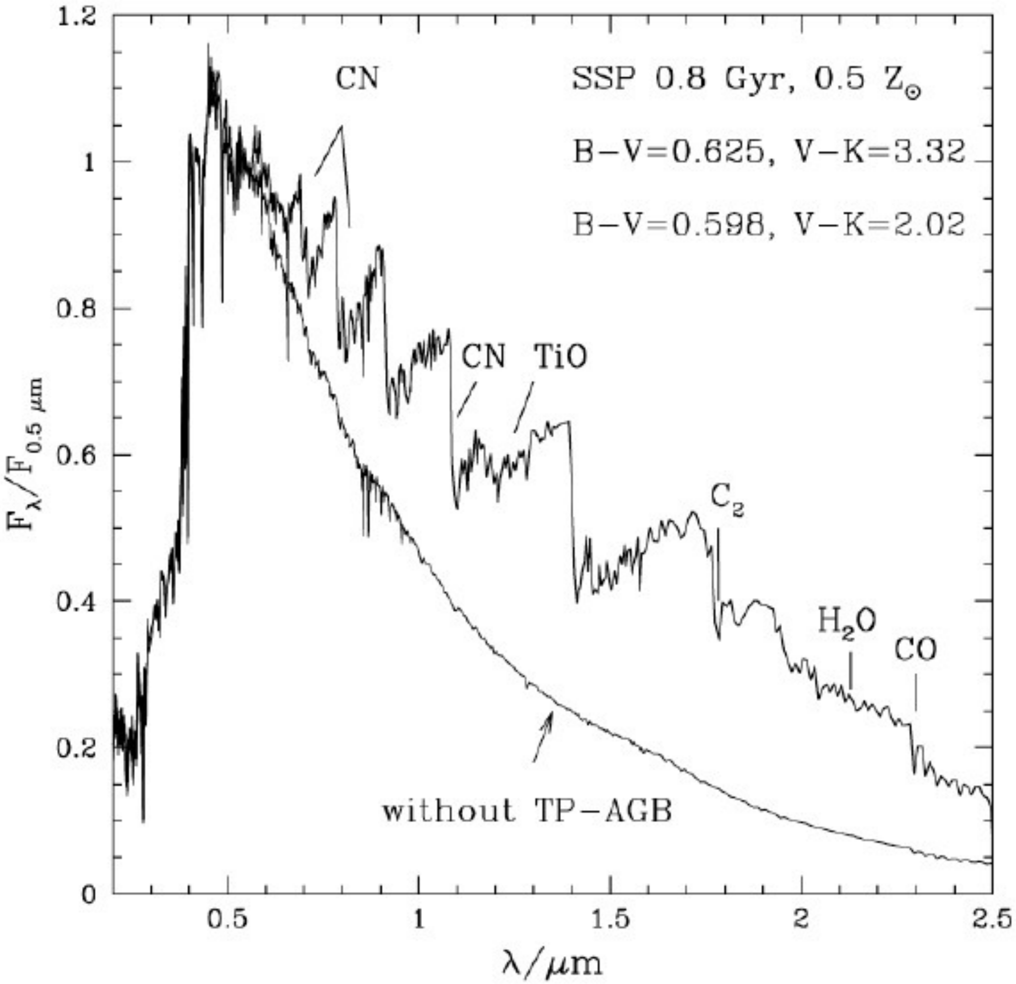
Extinction curves for different galaxies



- Interstellar dust absorbs and scatters the light of the stars in galaxies, causing line of sight *extinction*. Since the scattering and absorption tends to increase to shorter wavelengths, this leads to *reddening* of the starlight.

- The wavelength dependence of the extinction (the reddening curve) varies between galaxies (especially at UV wavelengths).

Uncertainties in the late stages of stellar evolution



Inclusion of TP AGB phase has a large impact on the red/IR spectra of intermediate-age galaxies (~1Gyr). This will affect mass determinations based on IR fluxes (by a factor x2).

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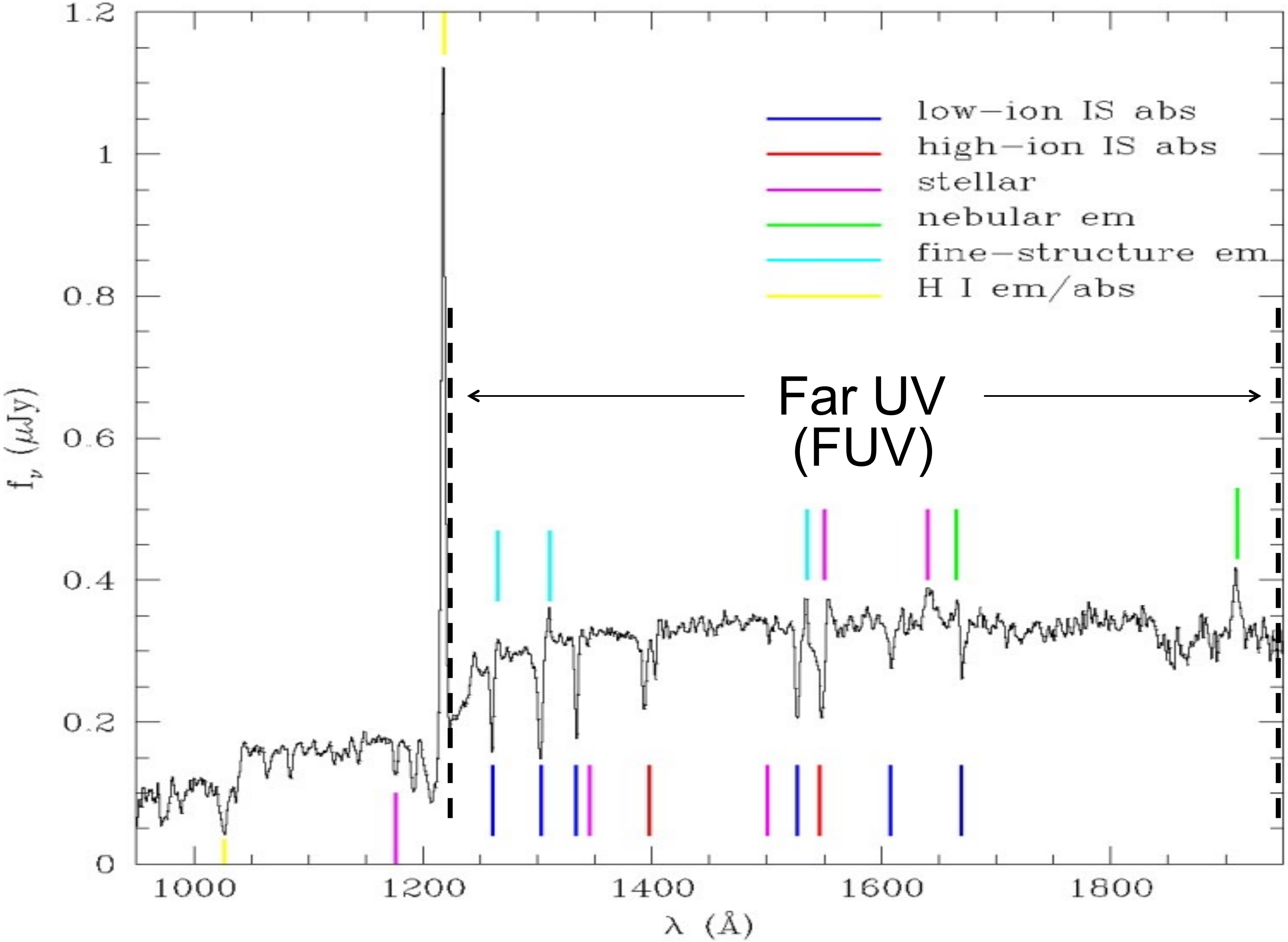
- This is, effectively, the SFR of the galaxy.

The far-UV as a measure of SFR

The UV spectrum of a galaxy:



Measuring SFRs from the UV continuum

- The FUV continuum (125 – 250 nm) is dominated by the light of young (<100 Myr) massive (≥ 5 $M_\odot$) stars

- It is uncontaminated by the light of older stellar populations.
- The FUV continuum luminosity therefore gives a direct indication of the current star formation rate:

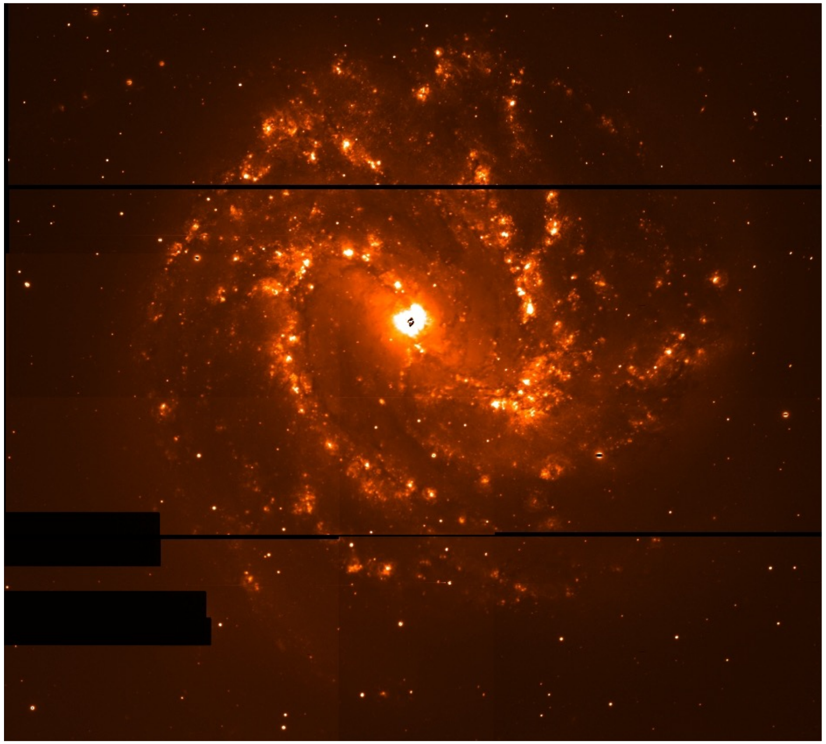
$$\mathbf{SFR(M_o\ yr^{-1}) = 4x10^{-41}\ L(FUV)\ (erg/s/A)}$$

But:

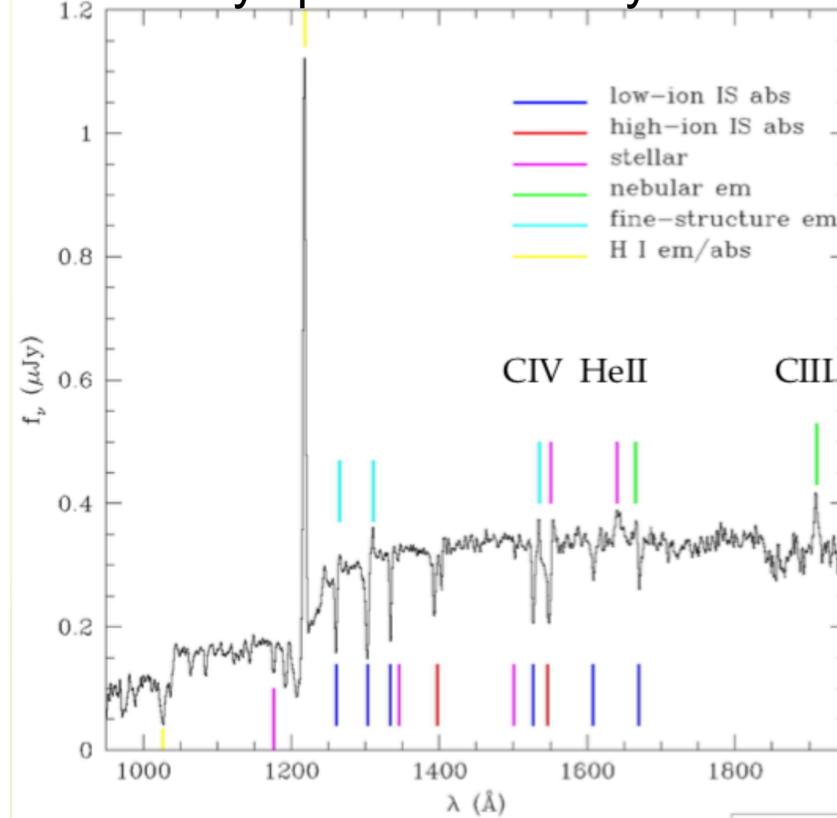
- The FUV is highly sensitive to dust reddening and extinction.
- The SFR vs L(FUV) relation depends strongly on the assumed IMF, metallicity and star formation history

Measuring SFRs from emission lines

Image of a galaxy in Lyα



Galaxy spectrum with Lyα at 1216A



High mass stars, capable of producing HII regions are uniquely young (<10^7yr). The presence of nebular emission (especially Lyα or Hα) provides a signature of current star formation.

Nebular SFR diagnostics

- Only most massive (>10 $M_\odot$) stars are hot enough

  (i.e., T > $2.5x10^7$ K) to produce significant ionizing photons (i.e., $h\nu$ > 13.6 eV)
- Resultant HII regions emit strong nebular emission lines (e.g. Hα) ➔ the luminosities of the nebular lines provide an estimate of the numbers of massive stars, hence SFR.
- For a standard Salpeter initial mass function:

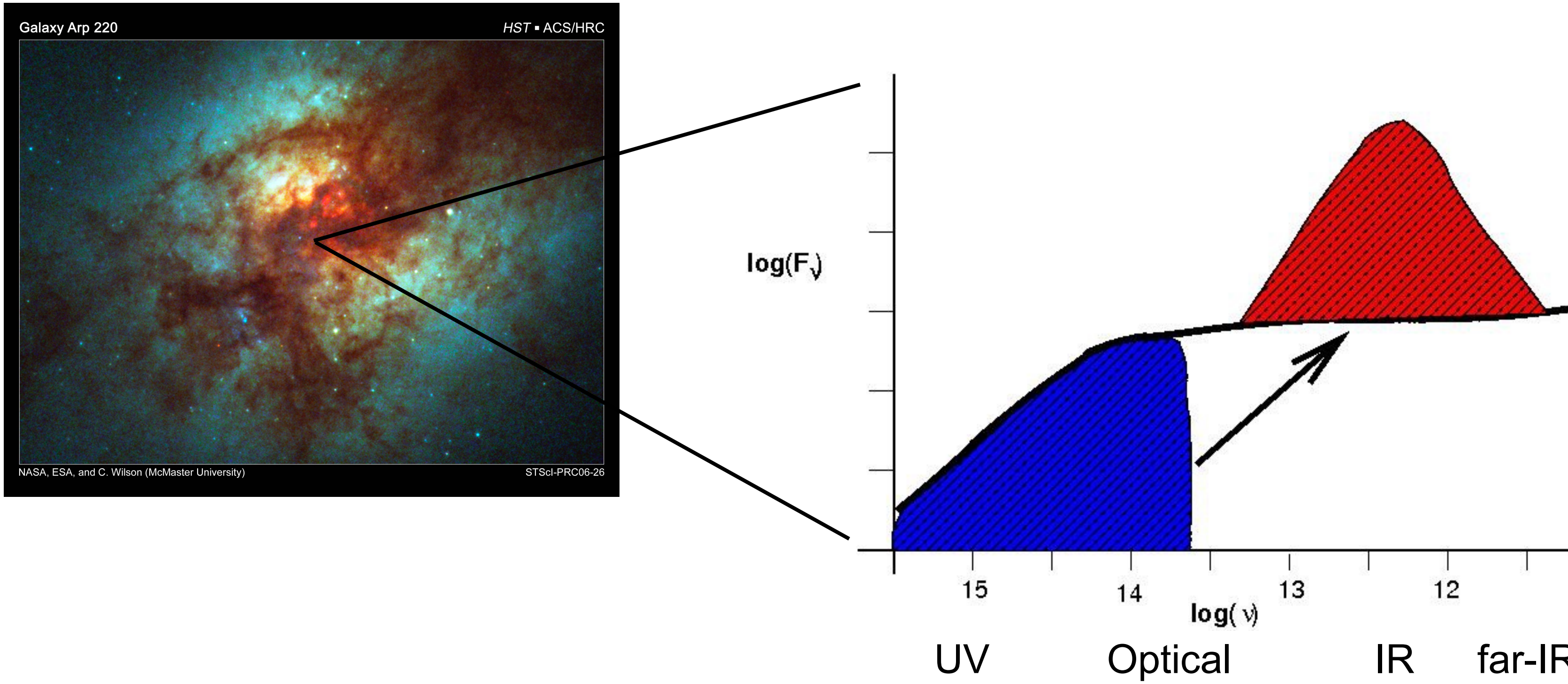
$$\mathbf{SFR(M_o\ yr^{-1}) = 7.9x10^{-42}\ L(H\alpha)\ (erg/s)}$$

$$\mathbf{= 1.1x10^{-53}\ Q_0\ (s^{-1})}$$

But:

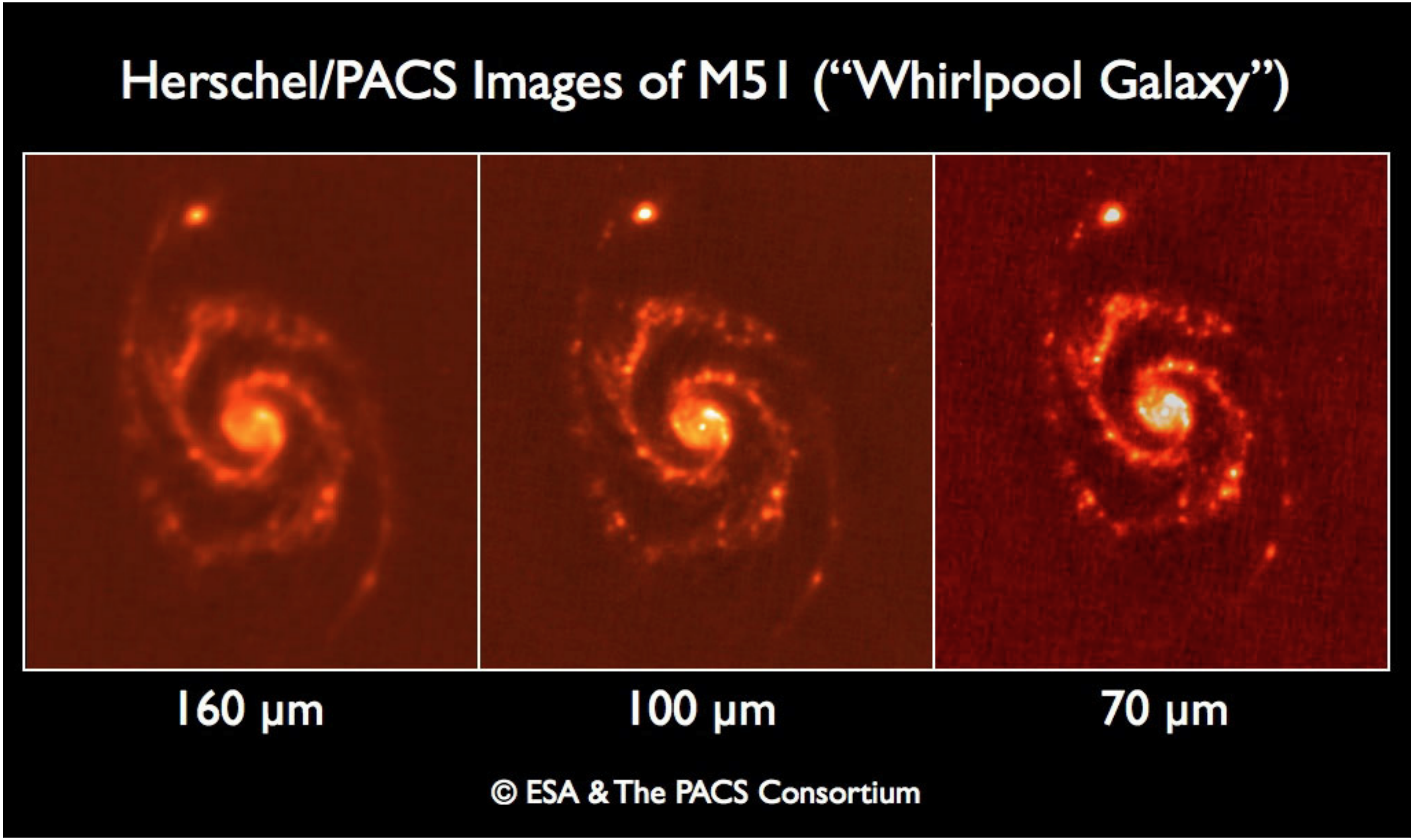
- Depends on assumed IMF, metallicity, SF history etc.
- Optical emission lines (e.g. Hα) are affected by reddening/ extinction
- Some ionizing photons may escape the nebula

Dust reprocessing of light from a starburst



The Optical/UV light emitted by stars in circum-starbursts is absorbed by dust, heating it to T_{dust}~20-100K. The energy is re-radiated at far-IR and sub-mm wavelengths (>10μm) as thermal (~black body) radiation. Thus, the far-IR luminosity can be used to measure the star formation rate.

The infrared view of star-formation



SFR from far-infrared (FIR)

- Massive, hot stars heat the surrounding dust strongly; dust absorption particularly efficient at FUV and shorter wavelengths, where the massive stars emit most light
- Dust is heated to relatively cool temperatures and radiates at FIR wavelengths (8 – 1000μm) ➔ integrated IR luminosity can be used to estimate SFR:

$$\mathbf{SFR(M_o\ yr^{-1}) = 1.8x10^{-44}\ L(FIR)\ (erg/s)}$$

- Dust obscuration not significant at FIR wavelengths

But:

- Depends on assumed IMF, SF history etc.
- Requires satellite observations (e.g. Spitzer, Herschel)
- Assumes that dust heated by young, massive stars, but old stars may also contribute to dust heating

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