Stellar Populations

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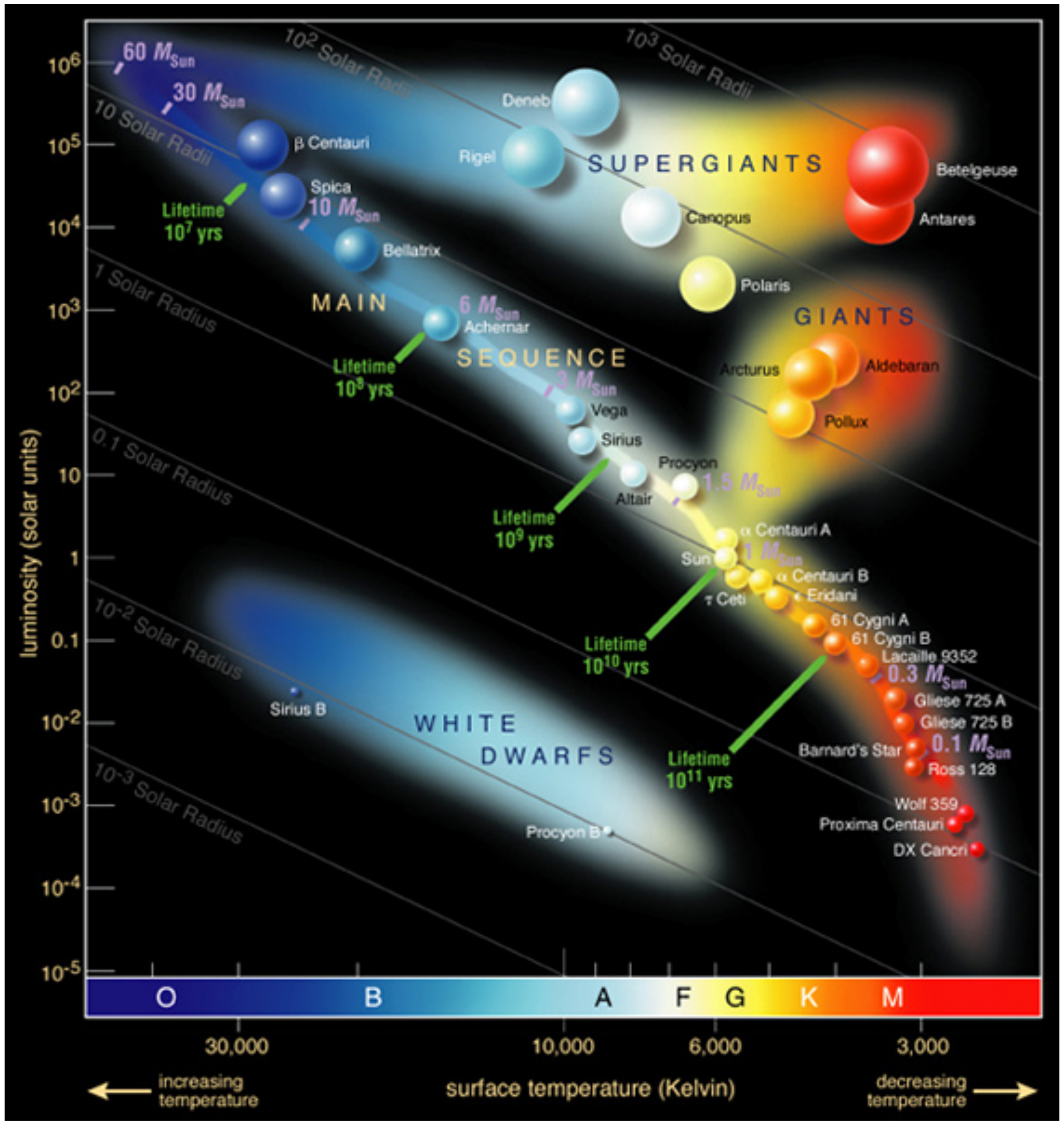
Stellar evolution as key for galaxy evolution

Galaxy evolution is the integrated consequence of stellar evolution



For a single star, the evolution depends on its initial mass

The evolution of a galaxy depends on the initial mass distribution of all its stars

initial mass function (IMF)

Picture credit: ESO

Stellar properties

Three main physical properties define a star:

$$R \sim R_\odot \left(\frac{\mathcal{M}}{\mathcal{M}_\odot}\right)^{0.7}$$

- <u>Effective Temperature</u> T_{eff} $$L \equiv 4\pi R^2 \sigma T_{\mathrm{eff}}^4$$

  The continuum of a star is a black-body curve, with $T \sim T_{eff}$

$$\lambda_{\max} = [2.9/T\,(\mathrm{K})]\,\mathrm{mm}$$

- <u>Surface Gravity</u> log g pressure of stellar photosphere $$g = G\,M\,/\,R^2$$

  ionisation balance, pressure broadening, molecular abundance

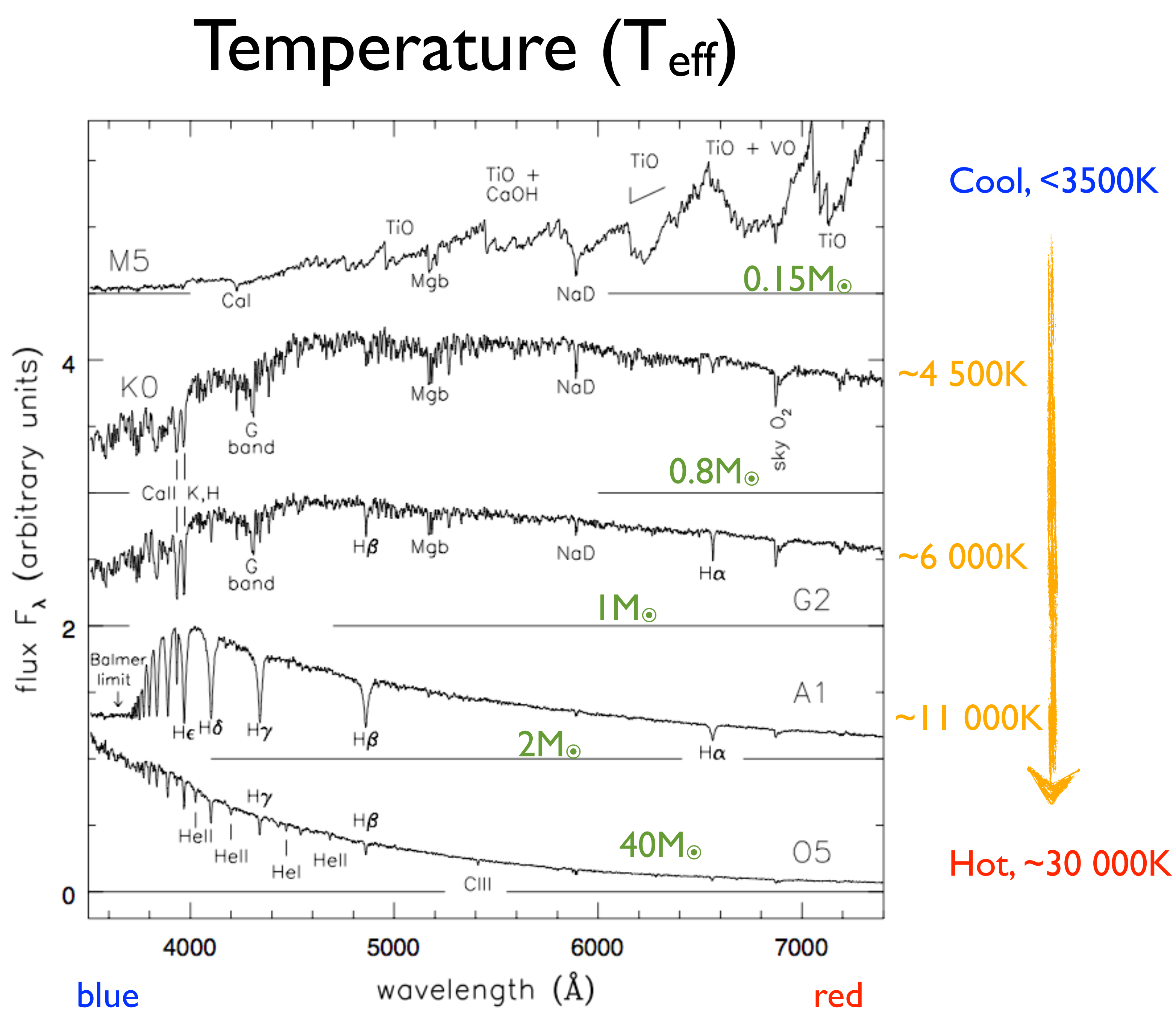
- <u>Metallicity</u> Z or [Fe/H] or chemical composition, elements heavier than He

$$[A/B] \equiv \log_{10}\left\{\frac{(\text{number of A atoms}/\text{number of B atoms})_\star}{(\text{number of A atoms}/\text{number of B atoms})_\odot}\right\}$$

individual elements cause absorption lines where atoms intercept light from the centre of the star

a star with [Fe/H] = -2 has 1% as much Fe as the Sun

Spectral variation versus Teff



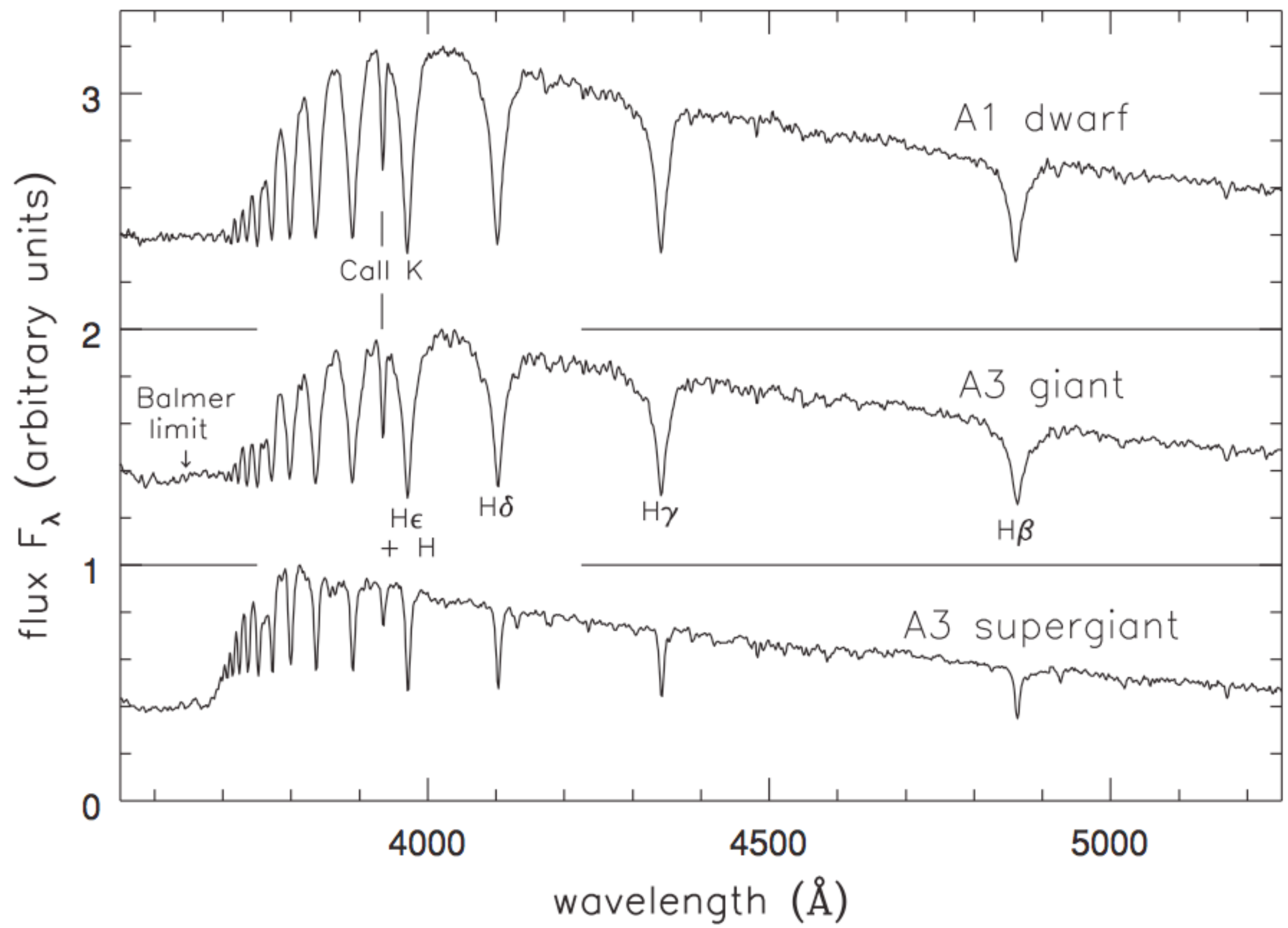
Strength of spectral line depends on T_{eff} of star & also abundance of that element

Stars like the Sun are ~72% H; 26% He and 2% "metals"

Spectral variation versus surface gravity

Surface Gravity (log g)

A-stars



log g ~ 4

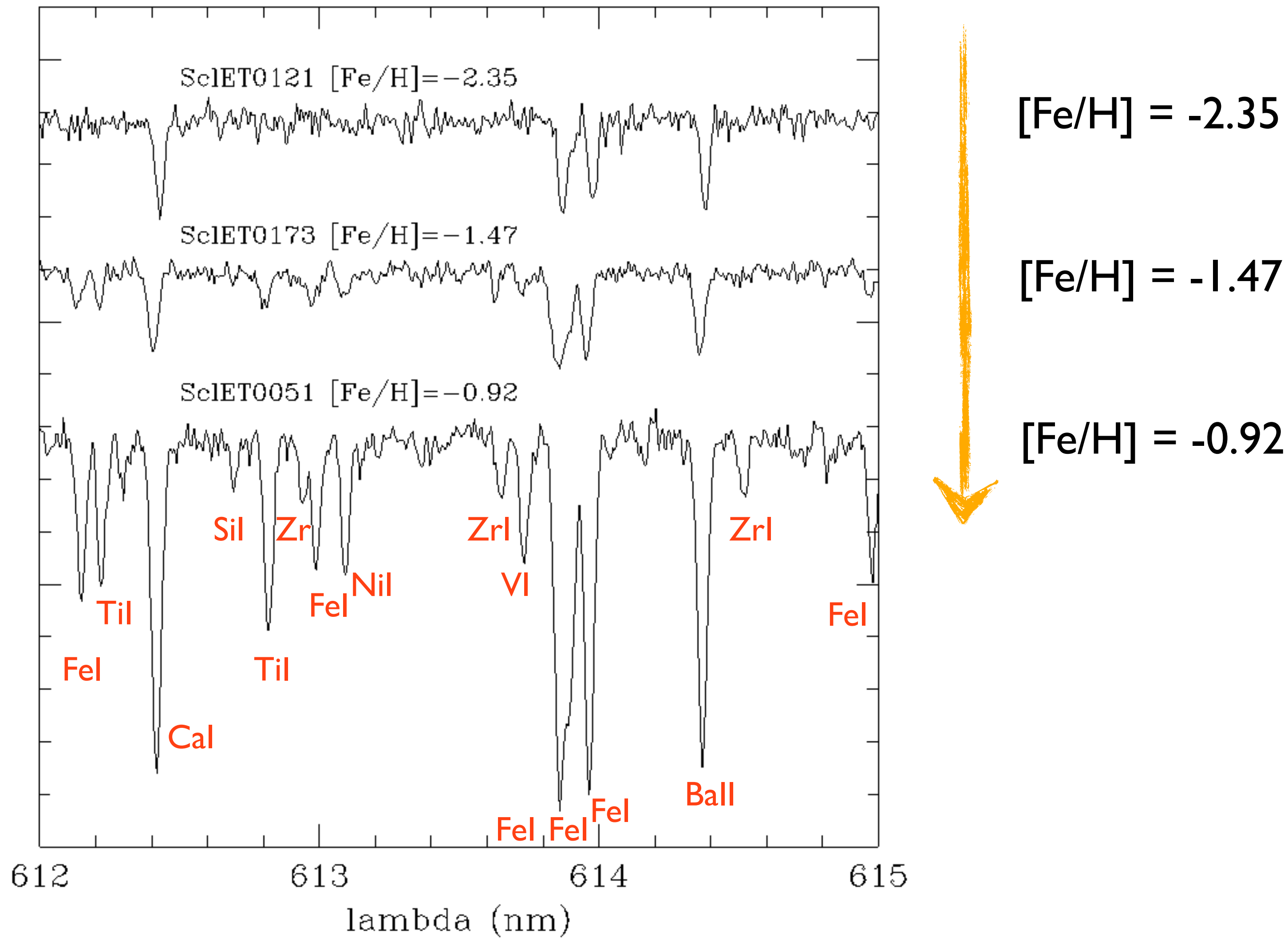
log g ~ 2

log g ~ 0

Spectral variation versus metallicity

Metallicity (Z or [Fe/H])

K-giant stars



GIRAFFE, R ~ 20k

Stellar classification according to spectra

Standard spectral classification: ***OBAFGKM***

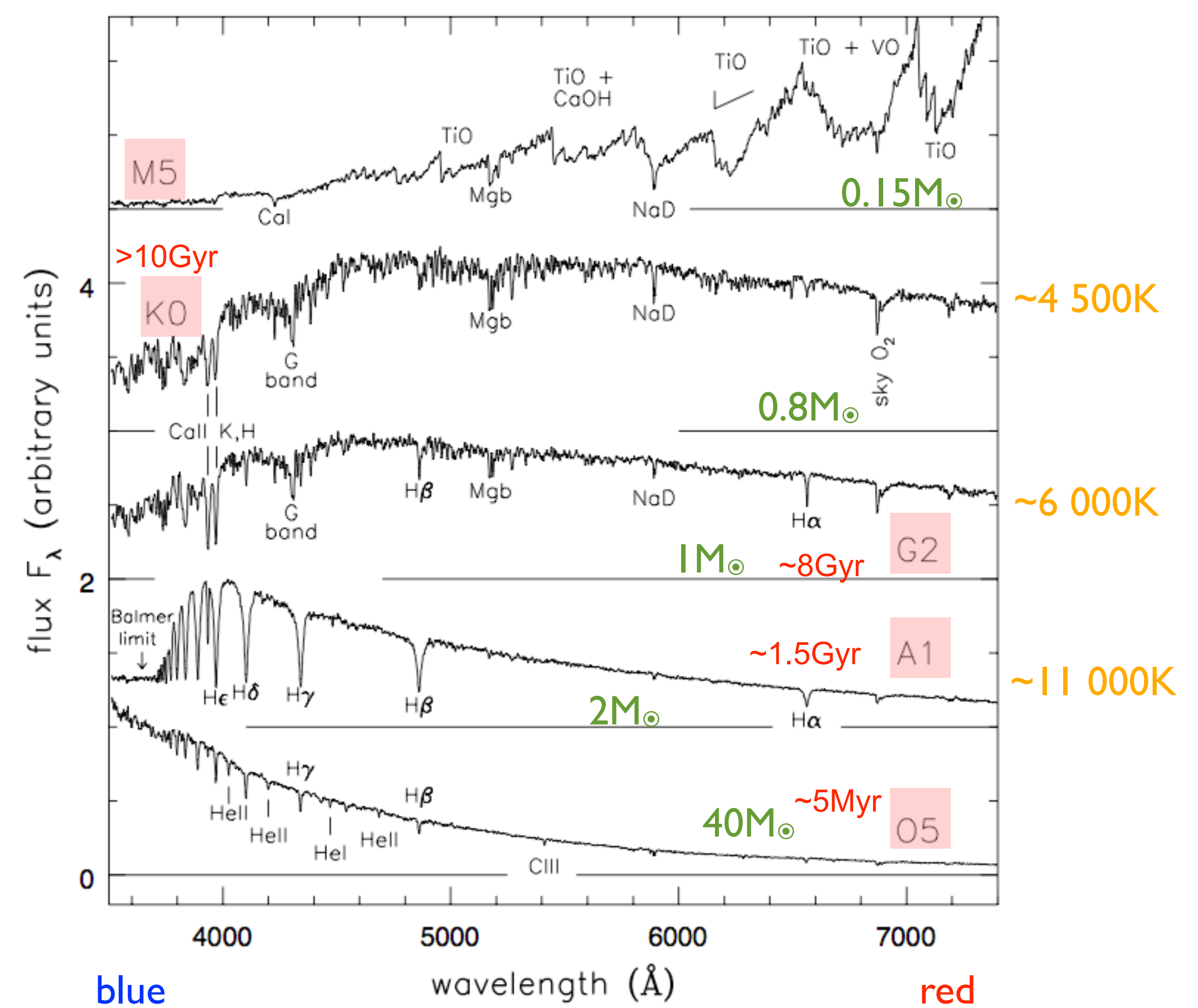
Decreasing T_{eff} sequence

Numbers 1-9 - temperature sub-classes (hot-cool)

Numbers I-V - luminosity sub-classes (decreasing log g)

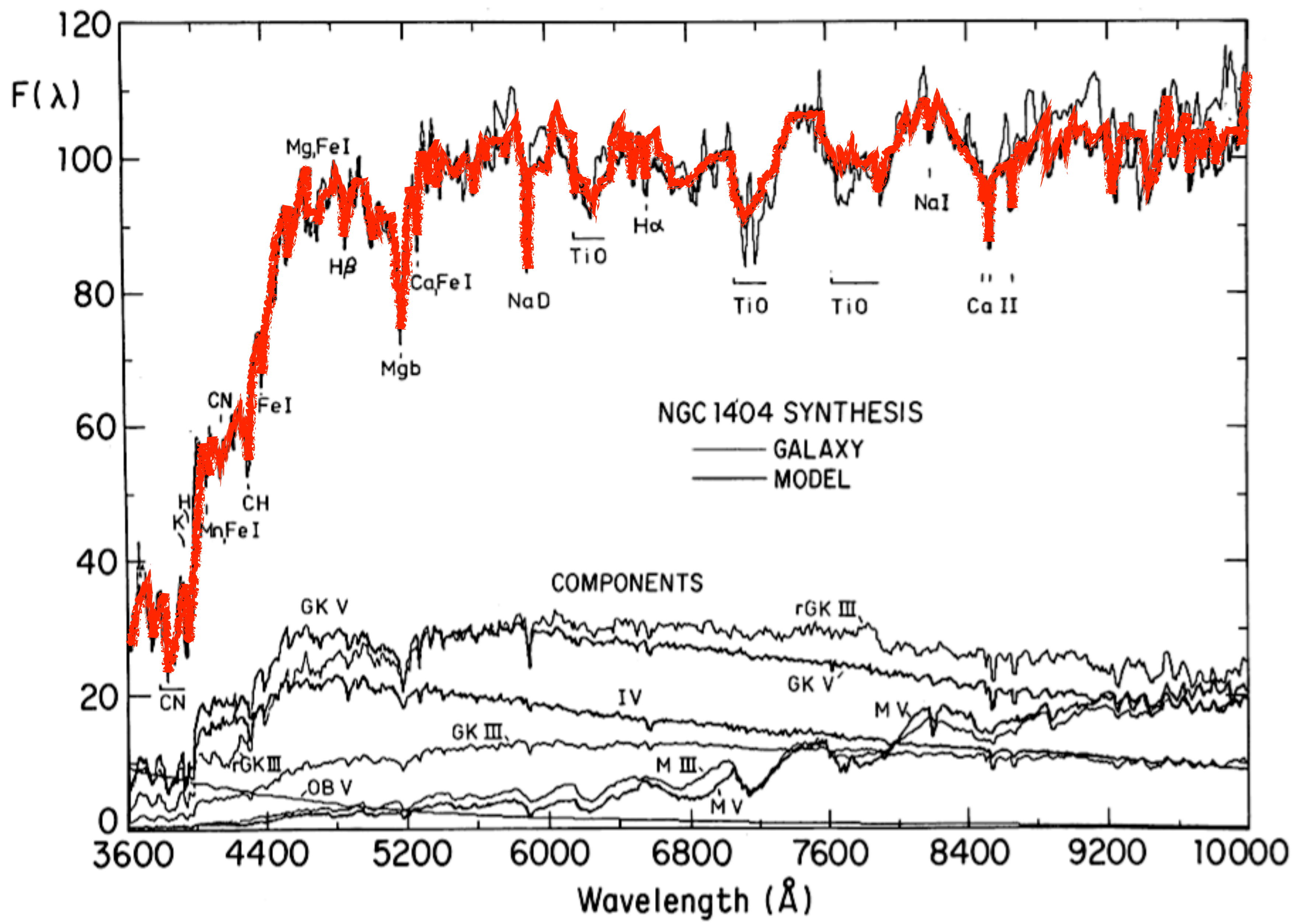
The Sun is a G2V star

Stellar Types & Ages



OBAFGKM...

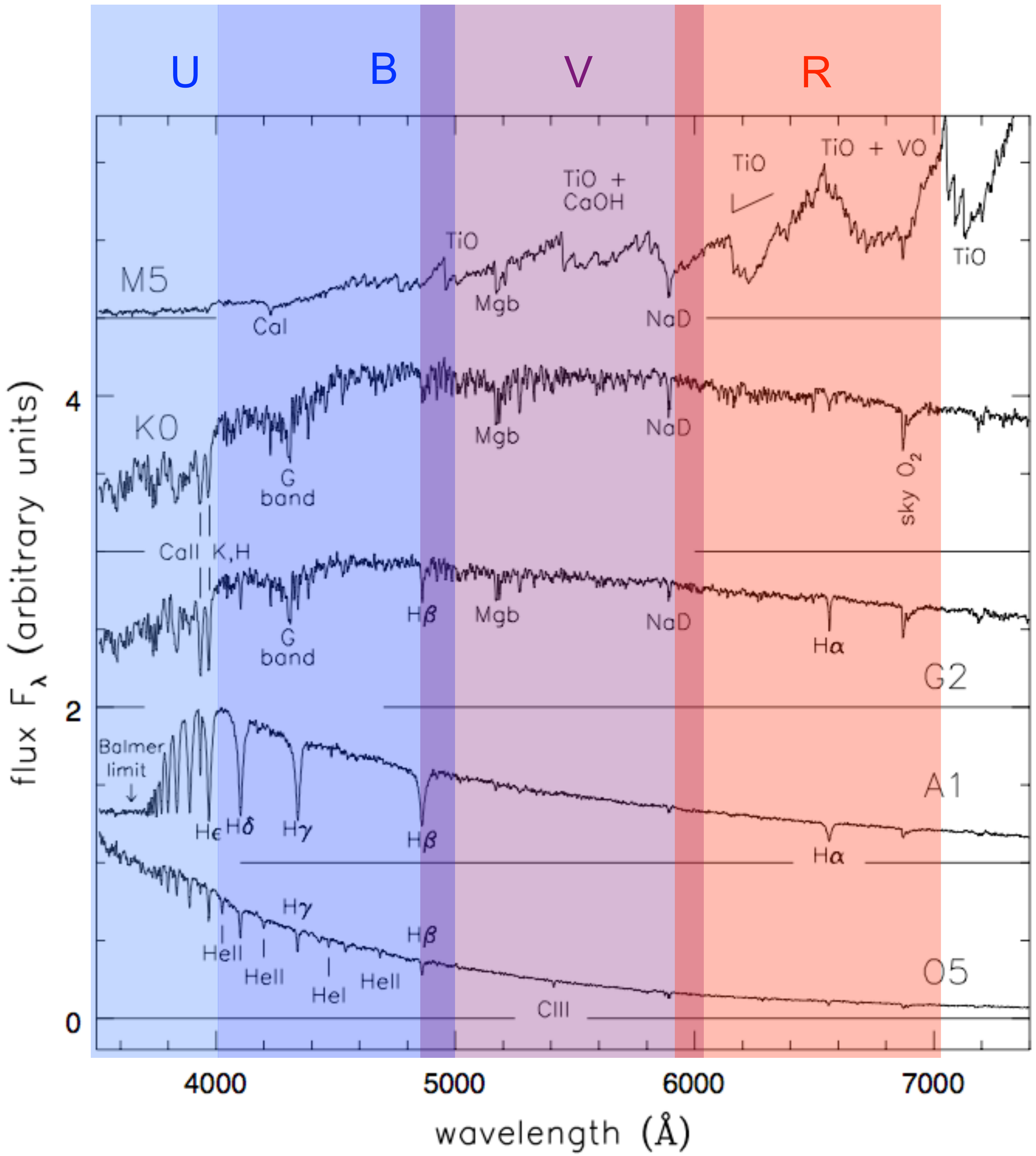
Galaxy = integrated stellar populations



Elliptical Galaxy

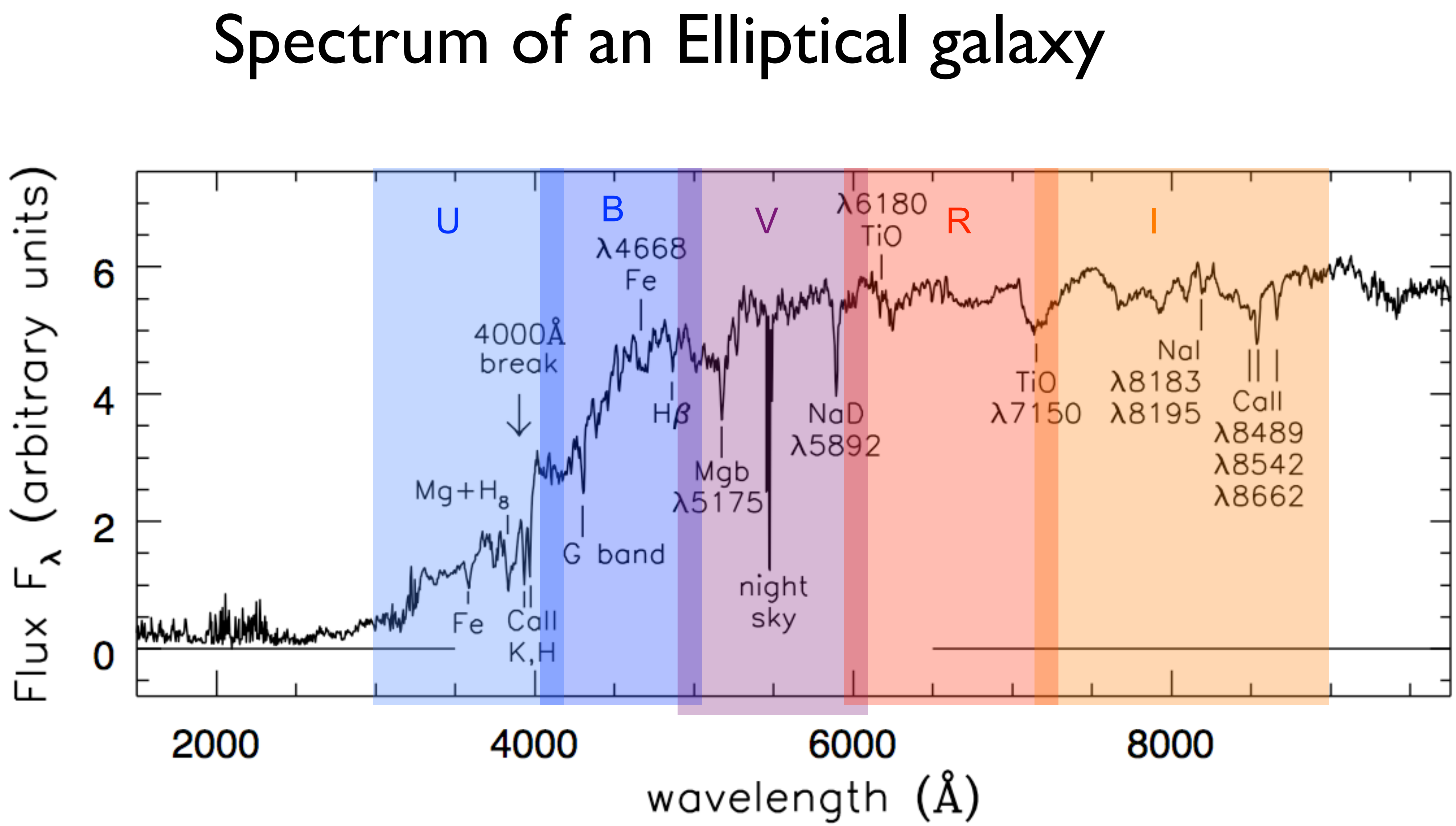
O'Connell 1986 PASP, 98, 163

Stellar spectra in different broad-band filters



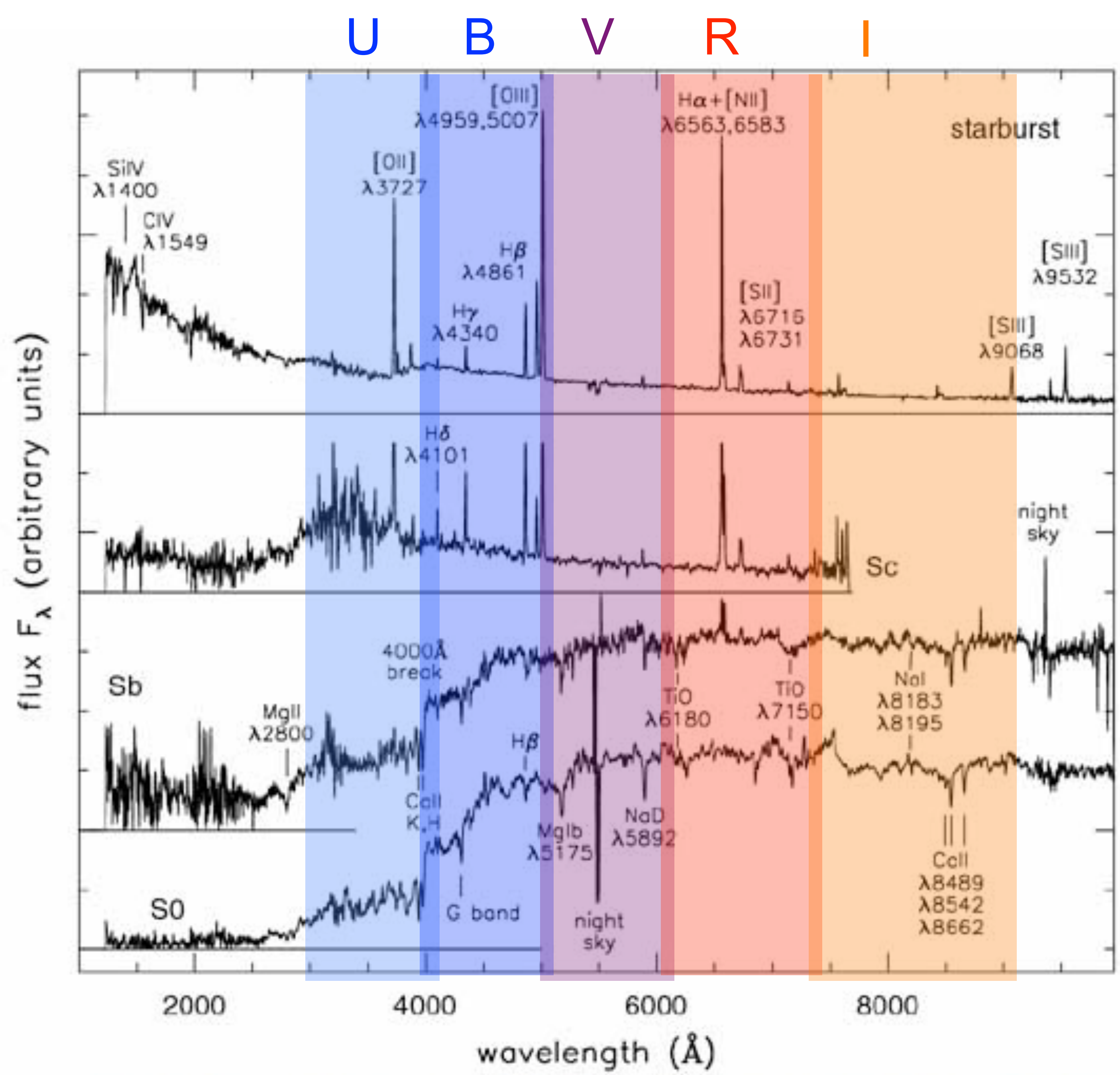
Notice that stars of different temperatures have very different spectra, so they have different fluxes through the filters and therefore they have different colors.

Spectrum of a typical elliptical galaxy

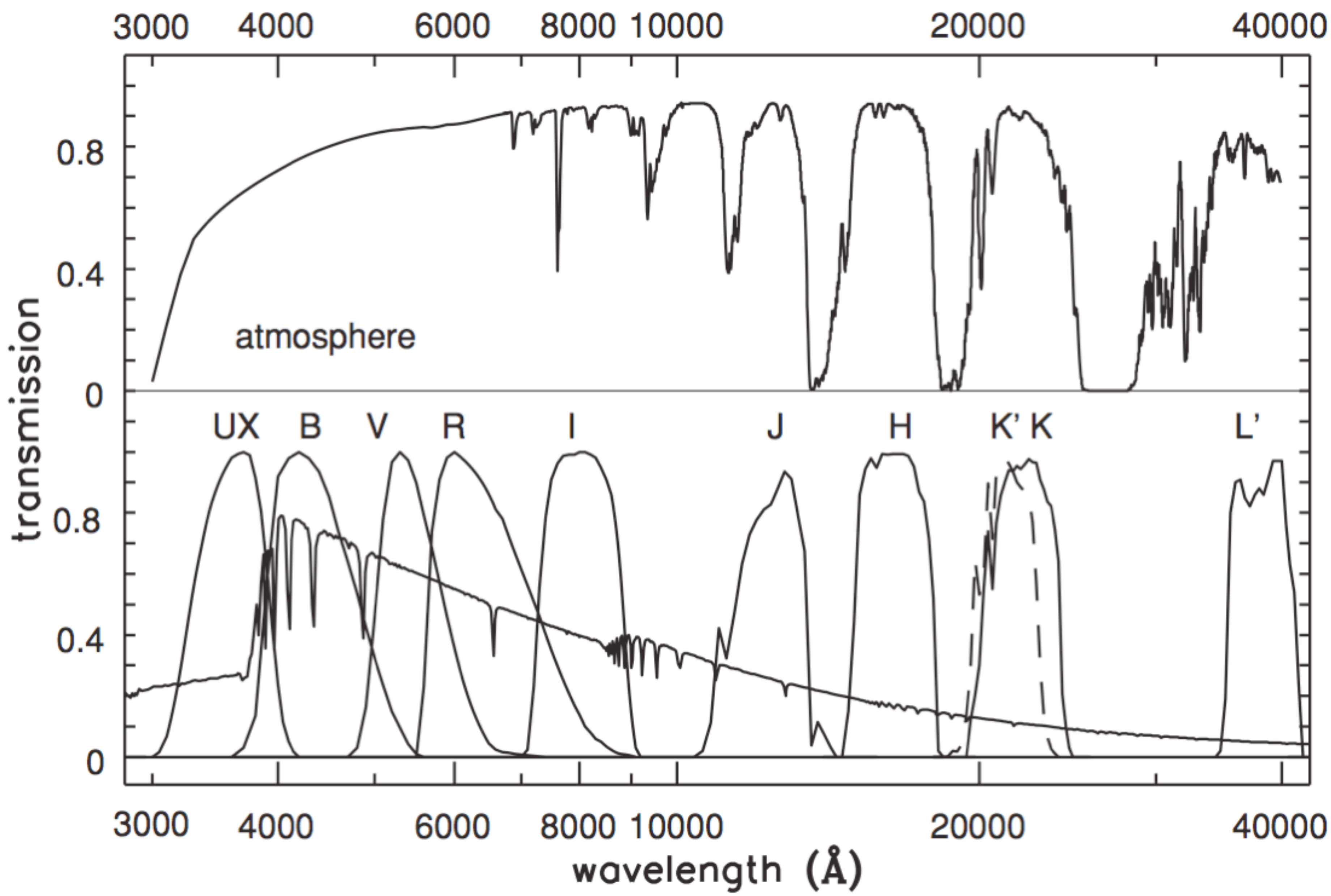


Spectrum of a typical star-forming galaxy

Spectra of late-type galaxies



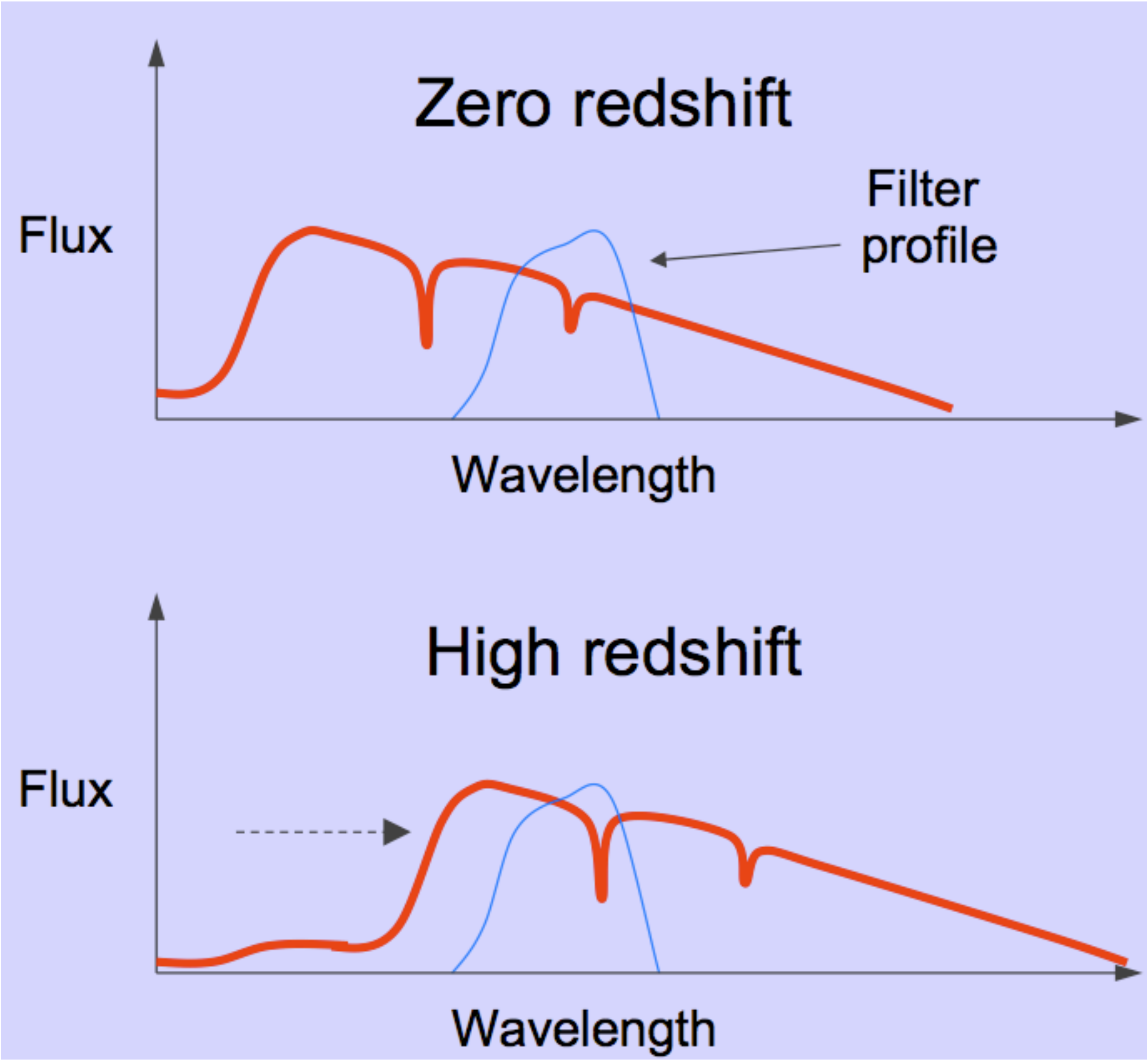
Atmospheric transmission



Photometric calibration is defined to correct for all effects and determine true magnitude of a star in a perfect telescope above the Earth's atmosphere.

The k-correction

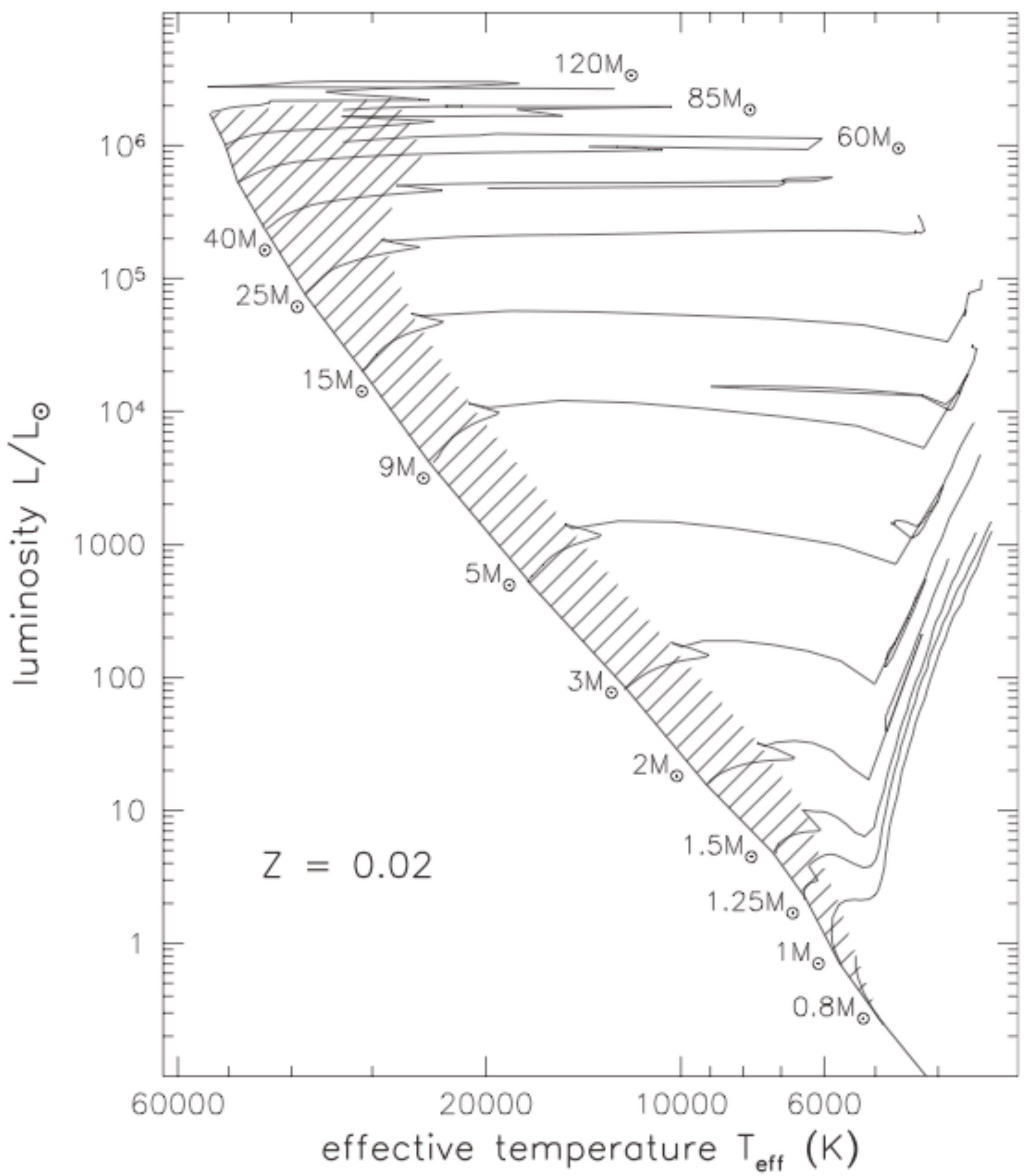
Correcting for red-shifting of light out of wavelength region



This is most important for high-redshift galaxies. If it is not taken into account conclusions can easily be in error.

Stellar Evolution models in HR diagram

A set of stellar models all with the same composition

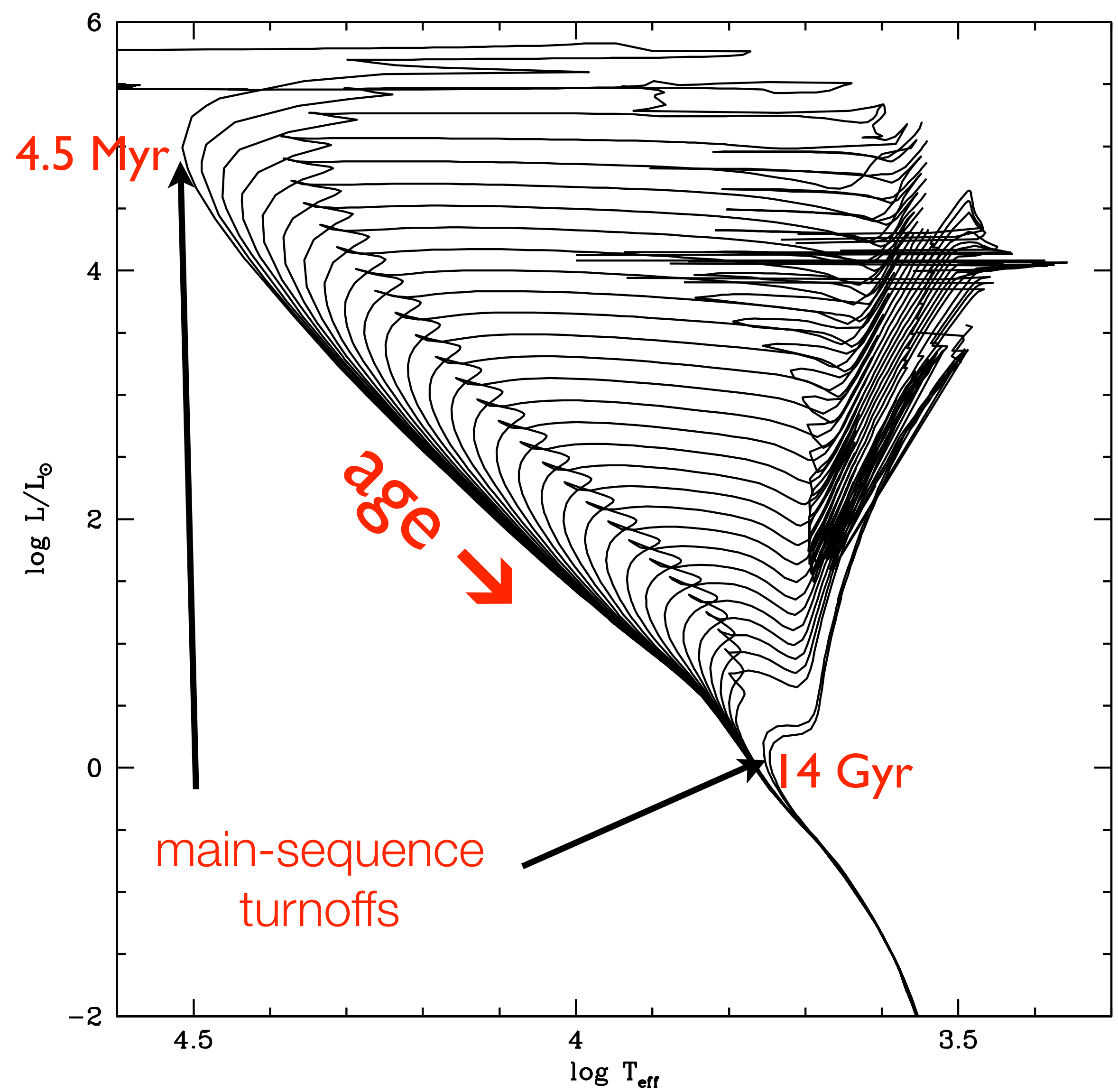


Isochrones in HR diagram

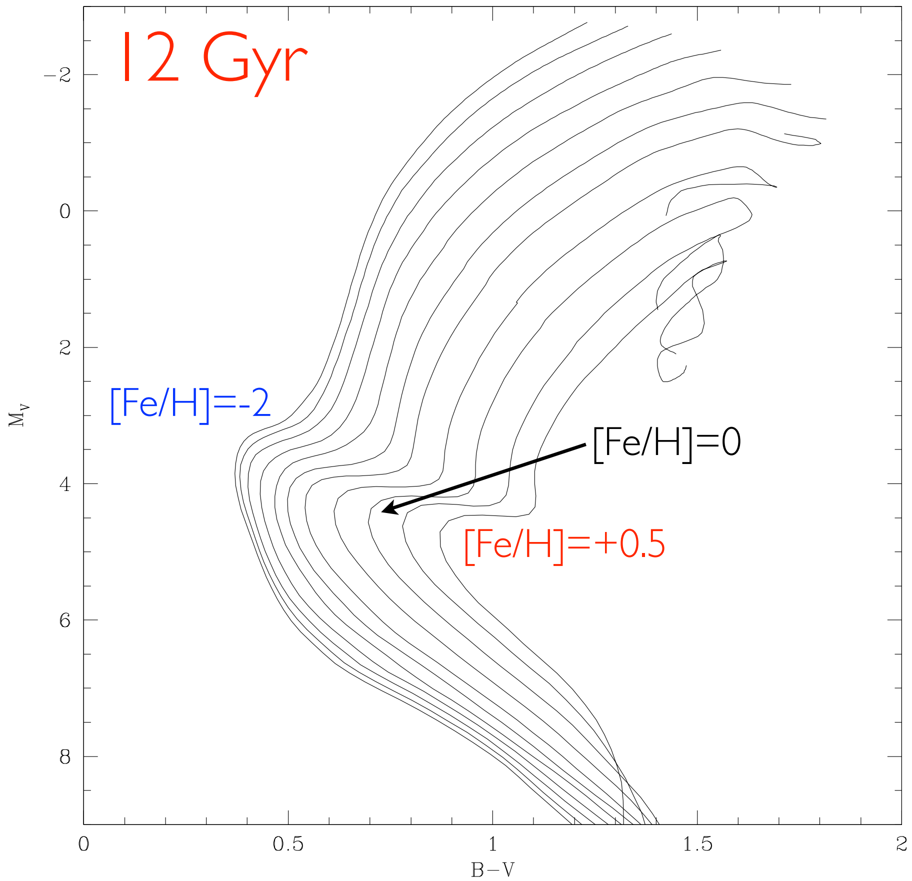
Isochrones - single age stellar populations

A set of stellar models all with the same age and same composition

The resulting track in an HR diagram or a CMD is called an isochrone



The effect of metallicity

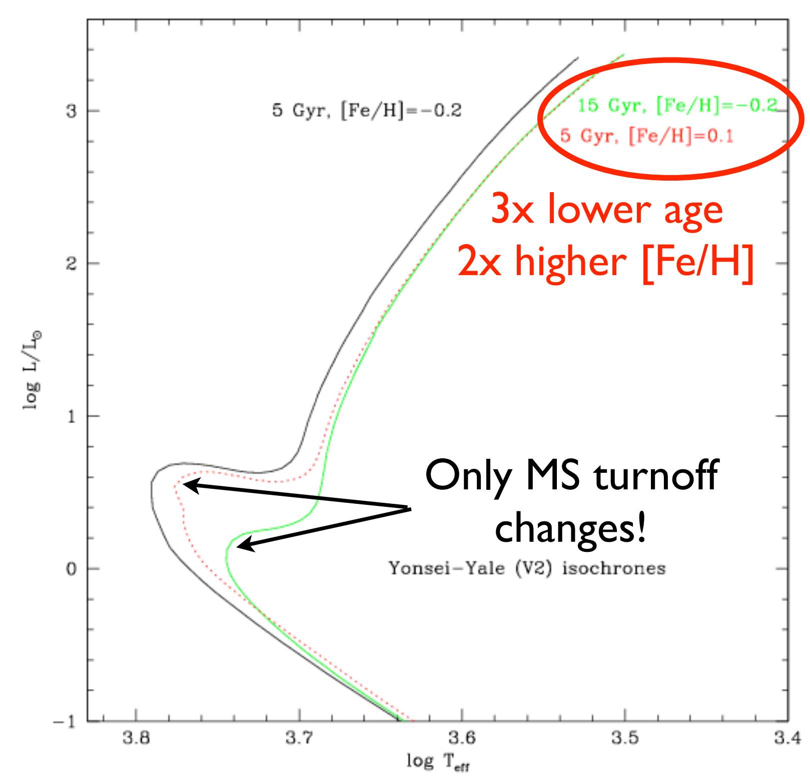


Stellar temperatures and luminosities also depend on composition.

This is an opacity effect: more metals mean more absorption, especially in the blue (it's reradiated into the IR), so stars become cooler (redder) and dimmer

age-metallicity degeneracy

Both age and metallicity affect isochrones, and so MS turnoff required to separate their effects on stellar populations.



Statistical Properties

The stellar luminosity function (LF)

The stellar luminosity function is a measure of the number density of stars per unit of volume and per unit of luminosity (or absolute magnitude)

$$dN = \Phi(M, V)\, dM\, dV$$

***If the distribution** of stars of different luminosities **is homogeneous** in space:*

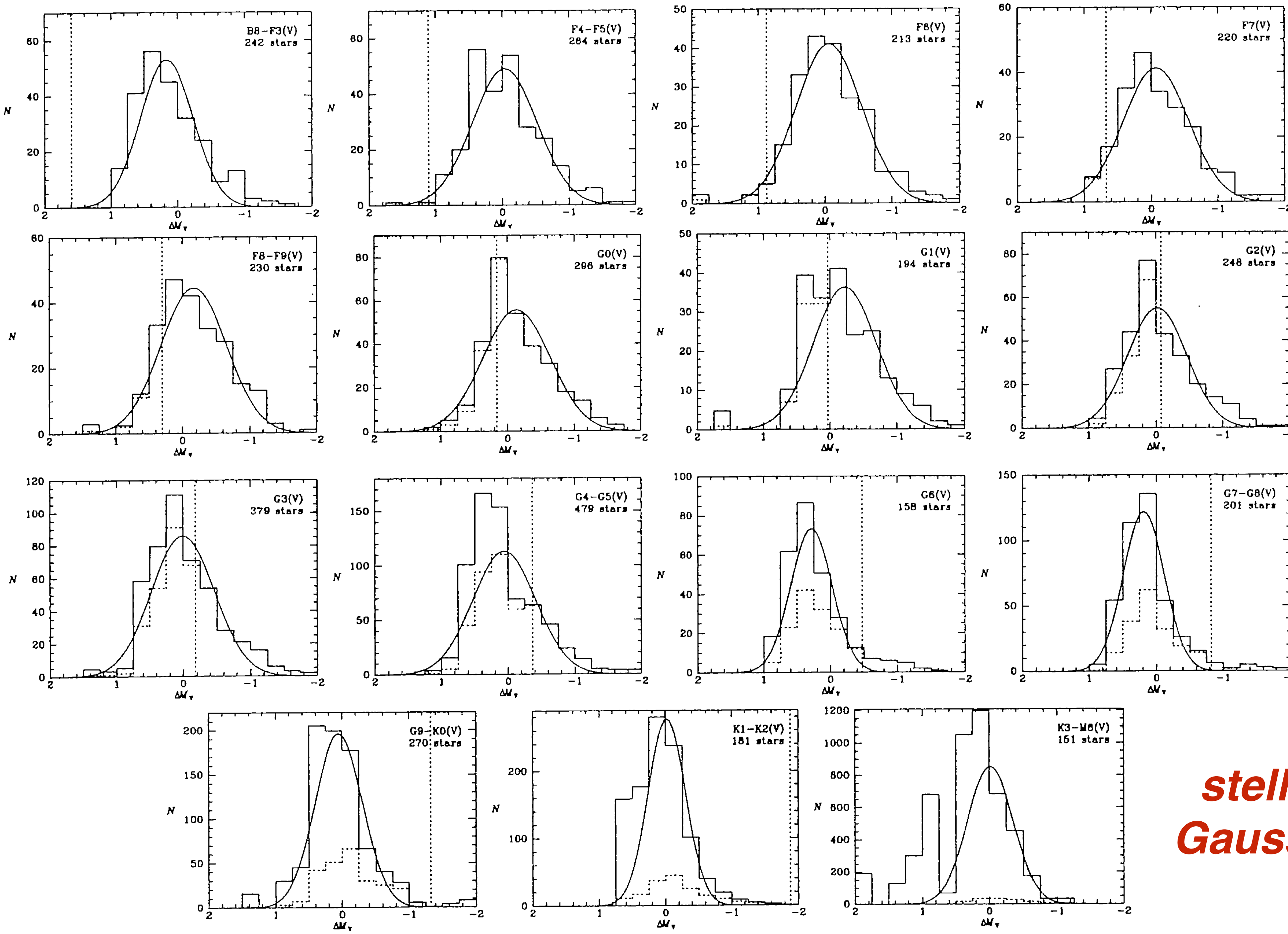
$$dN = [\Phi(M)\, dM][\nu(V)\, dV]$$

*Generally, source surveys are apparent-magnitude limited, so the resulting LF is affected by **Malmquist bias***

*This means that the mean absolute magnitude of the **observed** sample is brighter than the mean absolute magnitude of the **total** stellar population*

In practice this means that the effective volume in which we see brighter objects is LARGER than the effective volume in which we see fainter objects.

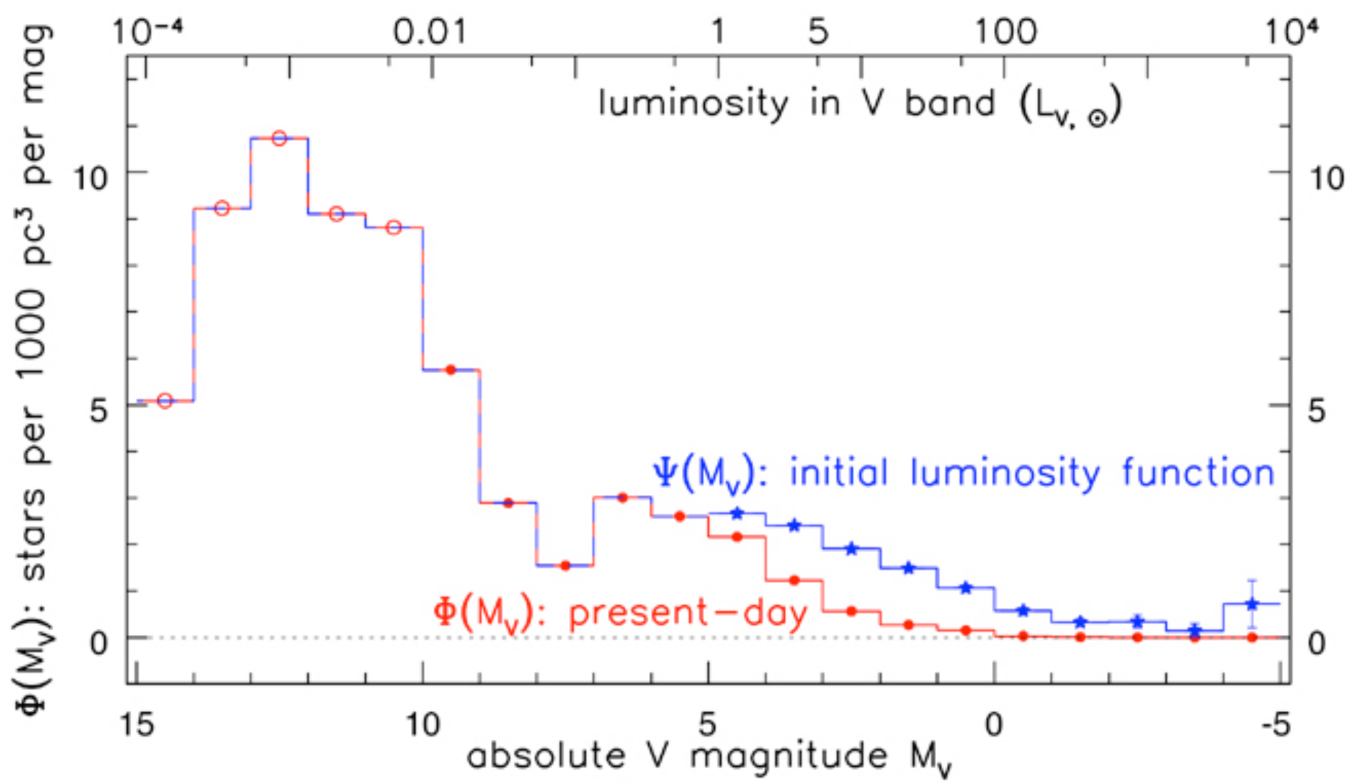
LF for different spectral-type stars



stellar LF has Gaussian shape

Houk et al. (1997)

The initial mass function (IMF)



To determine $\Psi(M_V)$, we need to determine dN immediately after a star-formation event to get the initial luminosity function Φ_0

$$dN = \Phi(M)\, dM$$

If the system has been forming stars at a constant rate (roughly true for the MW disk) since time t, then

$$\Phi_0(M) = \Phi(M) \times \begin{cases} t/\tau_{\rm MS} & \text{for } \tau_{\rm MS}(M) < t \\ 1 & \text{otherwise} \end{cases}$$

t/τ_{ms} corrects that we only see stars of magnitude M that formed in the last fraction t/τ_{ms} of the population's life

Now we can determine:

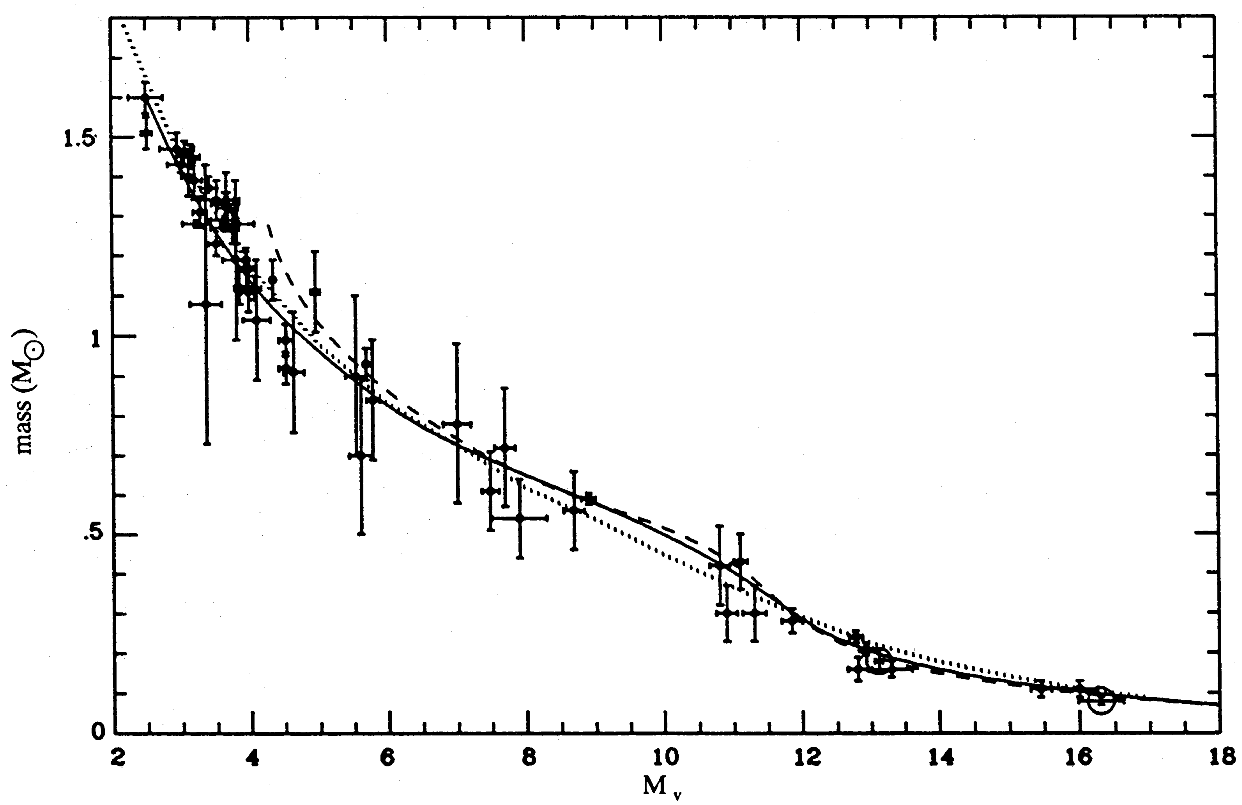
$$\Psi(\mathcal{M}) = \frac{\mathrm{dM}}{\mathrm{d}\mathcal{M}} \Phi_0 [\mathrm{M}(\mathcal{M})]$$

specifies the relation between stellar mass and absolute magnitude

Mass-to-light relation

$M(\mathcal{M})$ can be determined from theory or observation…

theory doesn't work very well…



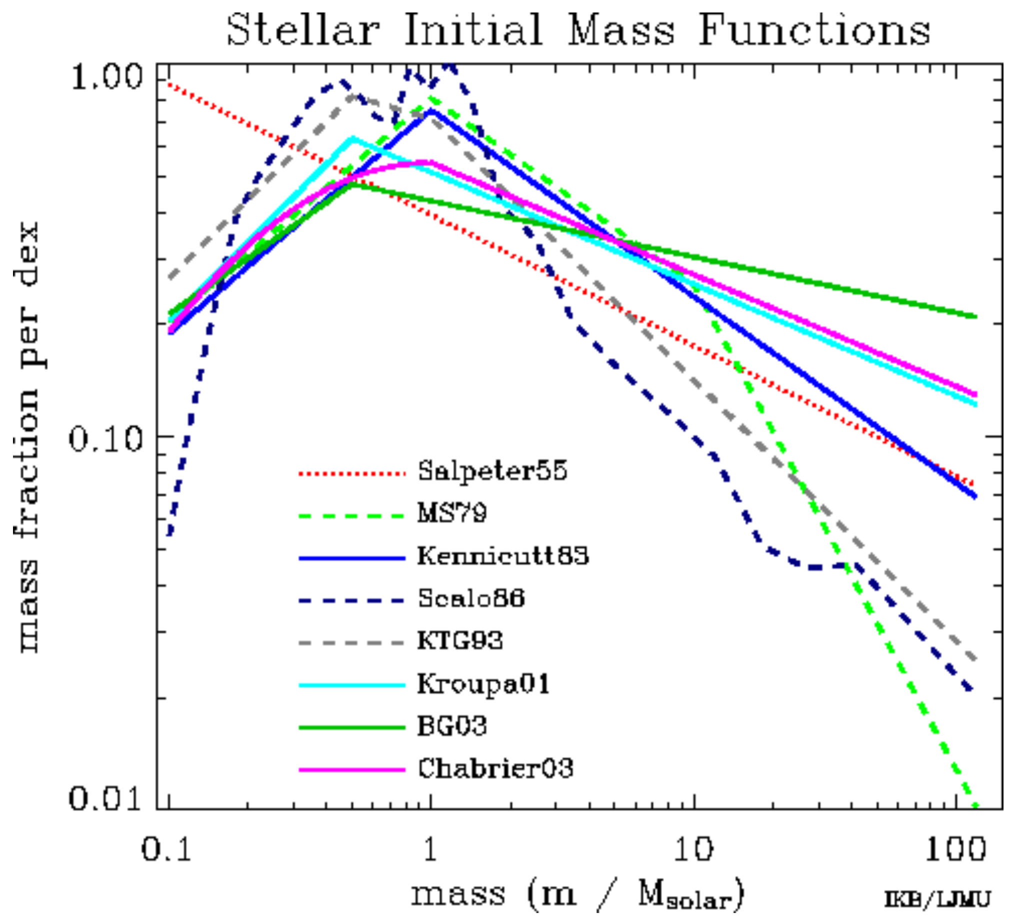
assume a simple function

The simplest IMF is that inferred by Salpeter (1955), which is a power-law

$$\Psi(\mathcal{M}) \propto \mathcal{M}^{-2.35}$$

Possible IMFs

There are a number of different IMFs.



Most evidence suggests that the stellar IMF is universal, meaning it always have the same form. But this is hard to test.

Independently of the IMF, the only stars that will live for > 2.5 Gyr are those with masses < 1.5 Msun

Star Clusters

Globular clusters

very compact objects: Re ~ 5-10 pc

Typically have between 1,000 and 1,000,000 stars

contain some of the oldest stars of the host galaxy
tight sequence in CMD

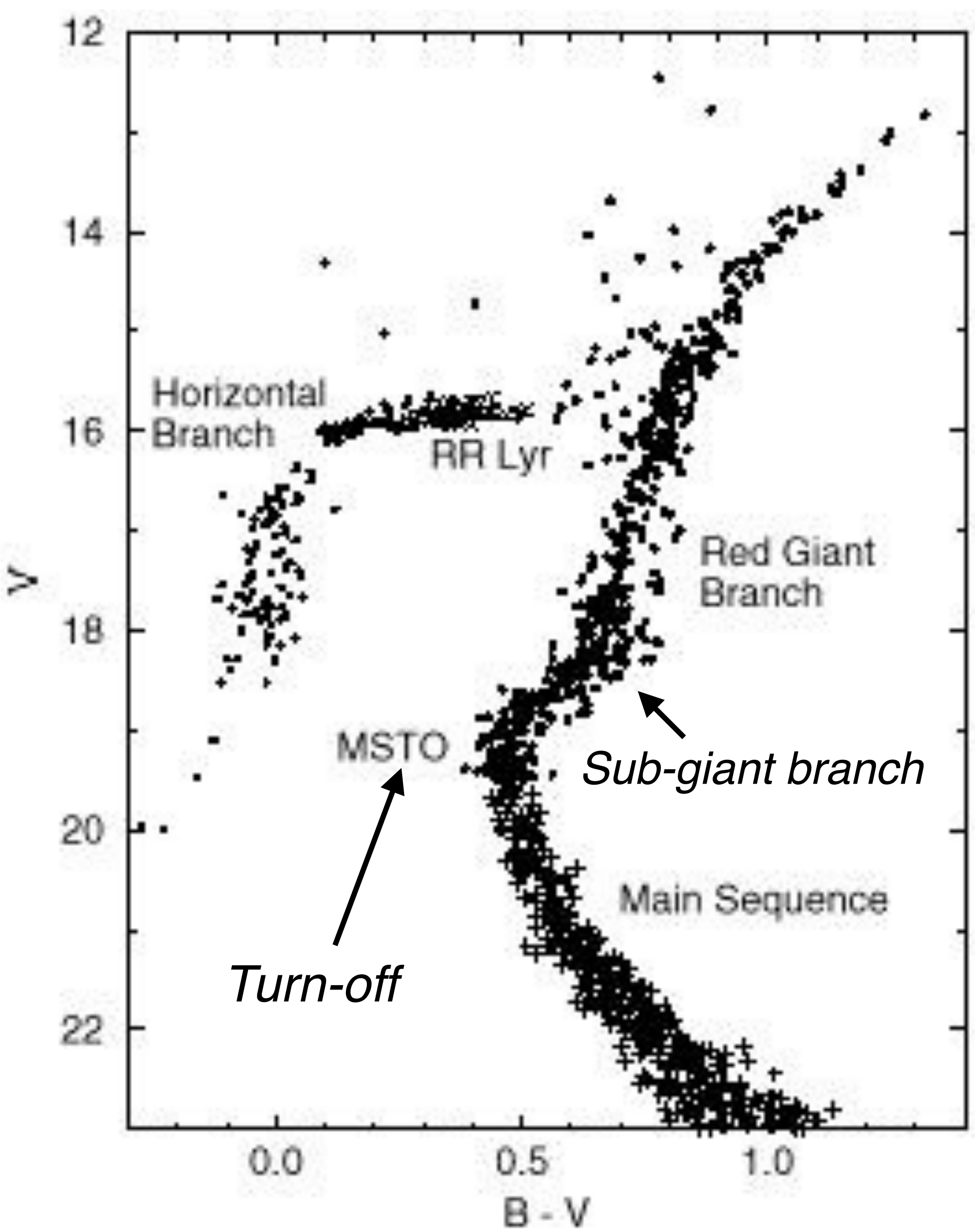
in local galaxies: GC are bluer than host galaxies, suggesting lower metallicities

Picture credit: J.-C. Cuillandre

GC set a minimum age for the host galaxy and have been used to constrain the age of the Universe

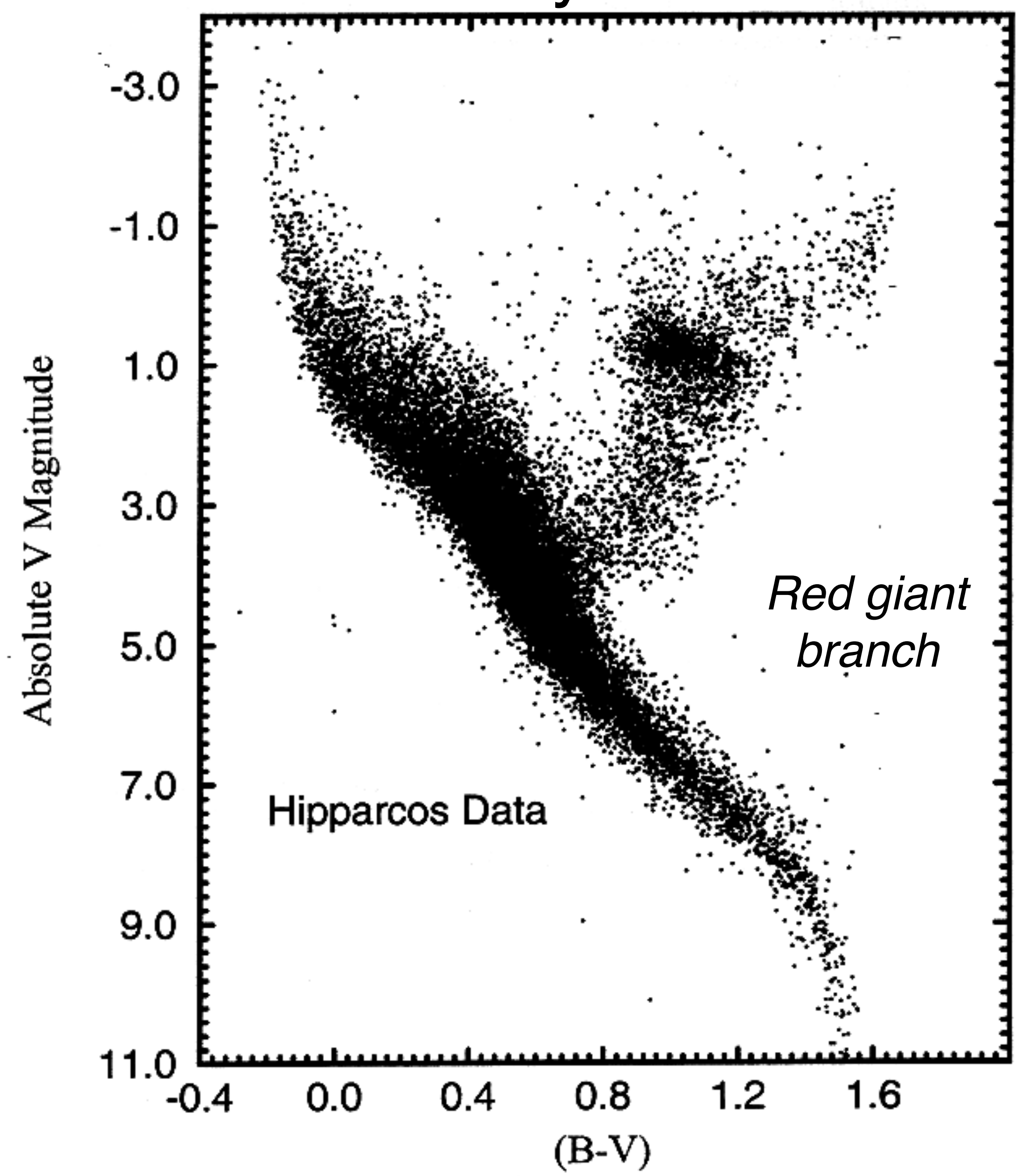
Globular clusters - CM diagrams

GC M15



Picture credit: NED notes - Krauss

nearby stars



In GCs the MS is truncated: **lack of young stars**

In GCs the SGB is very well defined - indicates that **most stars probably have same age**

Prominent Horizontal Branch indicates many stars with **low metallicities**

See Binney & Merrifield - ch.6

Open clusters

Low mass - Re ~ 10 pc

Typically have < 1,000 stars

most of them are young and do not last long - they live in MW disk, so suffer strong tides and shearing motions

*Member stars are **coeval and have the same composition***

The Pleiades cluster is a good example of an open cluster.
The "fuzziness" is starlight reflected from interstellar dust