Astr 323: Extragalactic Astronomy and Cosmology

Spring Quarter 2014, University of Washington, Željko Ivezić

Lecture 1:

Review of Stellar Astrophysics

Understanding Galaxy Properties and Cosmology

The goals of this class are:

- Understanding the correlations between various galaxy properties using simple physical principles
- Understanding the formation and evolution of galaxies, and their overall distribution in the Universe (a.k.a. large scale structure),
- Understanding the cosmological evolution of the Universe

The Basics of Basics

Assumed that you are all familiar with these terms:

- general: distance modulus, absolute magnitude, bolometric luminosity, the Planck function, colors
- types of stars: white dwarfs, horizontal branch, red giants, supergiants, subgiants, subdwarfs, etc.
- stellar properties: effective temperature, spectral class, metalicity, mass, age

If not, please review Chapters 13-18 in Ryden & Peterson.

Outline

- What do we measure: a summary of radiation intensity
- Hertzsprung-Russell Diagram: a summary of gas ball physics
- Stellar parameters: (mass, age, chemical composition) vs. (temperature, surface gravity, metalicity)
- Population Synthesis: cooking up a galaxy

What do we measure? Radiation Intensity:

$$I_\nu(\lambda, \alpha, \delta, t, \mathbf{p})$$

- I_ν - energy (or number of photons) / time / Hz/ solid angle
- λ - γ-ray to radio, depending on resolution: spectroscopy, narrow-band photometry, broad-band photometry
- α, δ - direction (position on the sky); the resolution around that direction splits sources into unresolved (point) and resolved; interferometry, adaptive optics,...
- t - static vs. variable universe, sampling rate,...
- **p** polarization

Examples:

Imaging (photometry):

$$I_\nu^{band}(<\alpha>,<\delta>,<t>) = \int_0^\infty S(\lambda) d\lambda \int_0^T dt \int_\theta d\Omega \, I_\nu(\lambda, \alpha, \delta, t, \mathbf{p}) \tag{1}$$

SDSS: T = 54.1 sec, θ ~1.5 arcsec, filter width ~1000 Å

Spectroscopy:

$$F_\nu^{object}(\lambda, <t>) = \int_0^\infty R(\lambda) d\lambda \int_0^T dt \int_A d\Omega \, I_\nu(\lambda, \alpha_0, \delta_0, t, \mathbf{p}) \tag{2}$$

SDSS: T = 45 min, A: 3 arcsec fibers (~6 kpc at the redshift of 0.1), R~2 Å (~70 km/s)

Calibrated flux and magnitudes

- Traditionally, the astronomical flux is reported on a magnitude scale
$$m_b = -2.5 \log_{10} \left(\frac{F_b}{F_{AB}} \right) . \tag{3}$$
where $F_{AB} = 3631$ Jy (1 Jansky $= 10^{-26}$ W Hz^{-1} m^{-2} $=$ 10^{-23} erg s^{-1} Hz^{-1} cm^{-2}) is the flux normalization for AB magnitudes (Oke & Gunn 1983).

- These magnitudes are also called “flat” because for a source with “flat” spectral energy distribution (SED) $F_\nu(\lambda) = F_0$, $F_b = F_0$.

- A more traditional approach is to use Vega fluxes instead of constant F_0.

Calibrated flux and magnitudes

- Given a specific flux of an object *at the top* of the atmosphere, $F_\nu(\lambda)$, a broad-band photometric system measures the in-band flux

$$F_b = \int_0^\infty F_\nu(\lambda)\phi_b(\lambda)d\lambda, \tag{4}$$

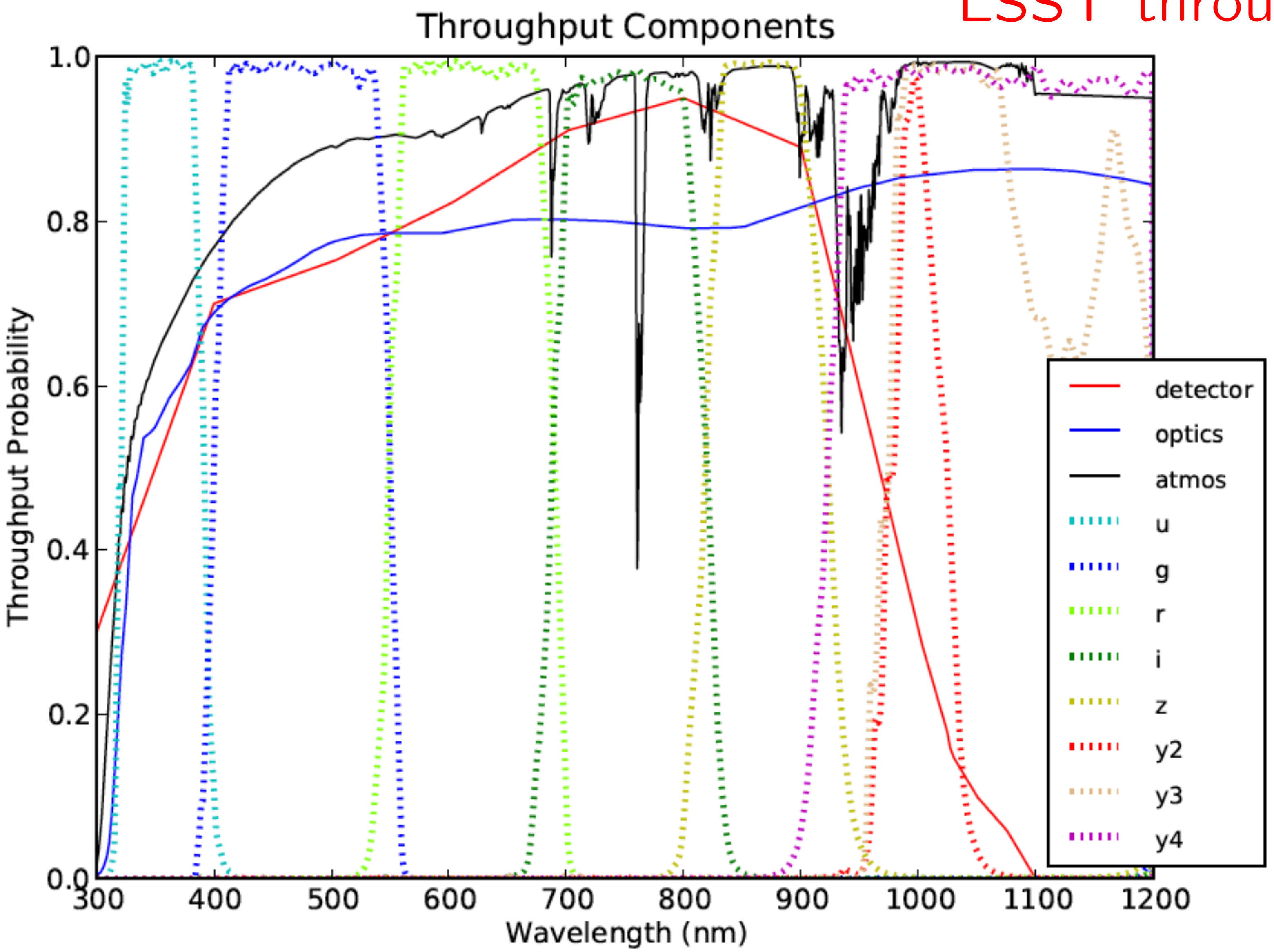
where $\phi_b(\lambda)$ is the normalized system response for a given band (e.g. for SDSS $b = ugriz$)

$$\phi_b(\lambda) = \frac{\lambda^{-1}S_b(\lambda)}{\int_0^\infty \lambda^{-1}S_b(\lambda)d\lambda}. \tag{5}$$

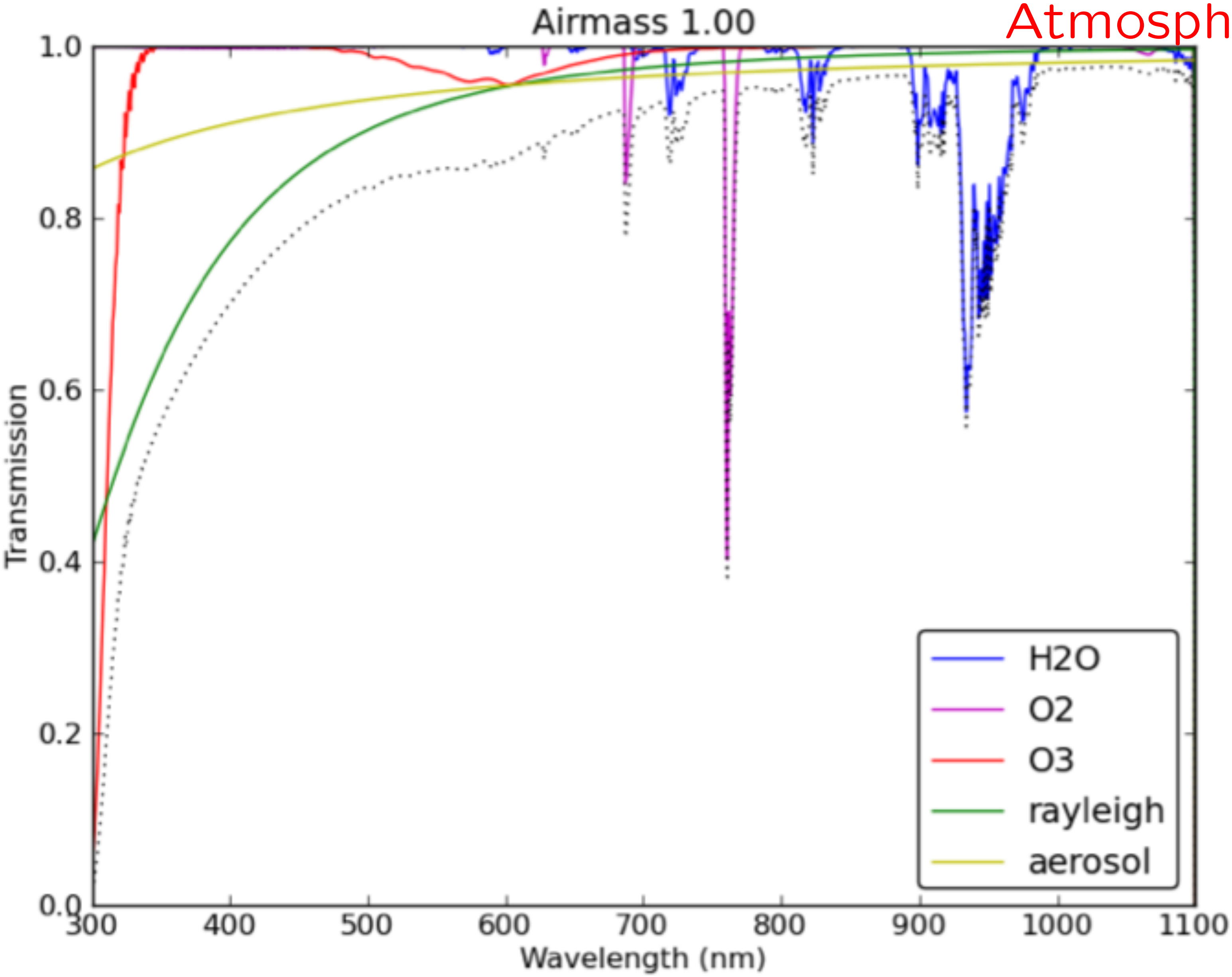
- The overall atmosphere + system throughput, $S_b(\lambda)$, is obtained from

$$S_b(\lambda) = S^{atm}(\lambda) \times S_b^{sys}(\lambda). \tag{6}$$

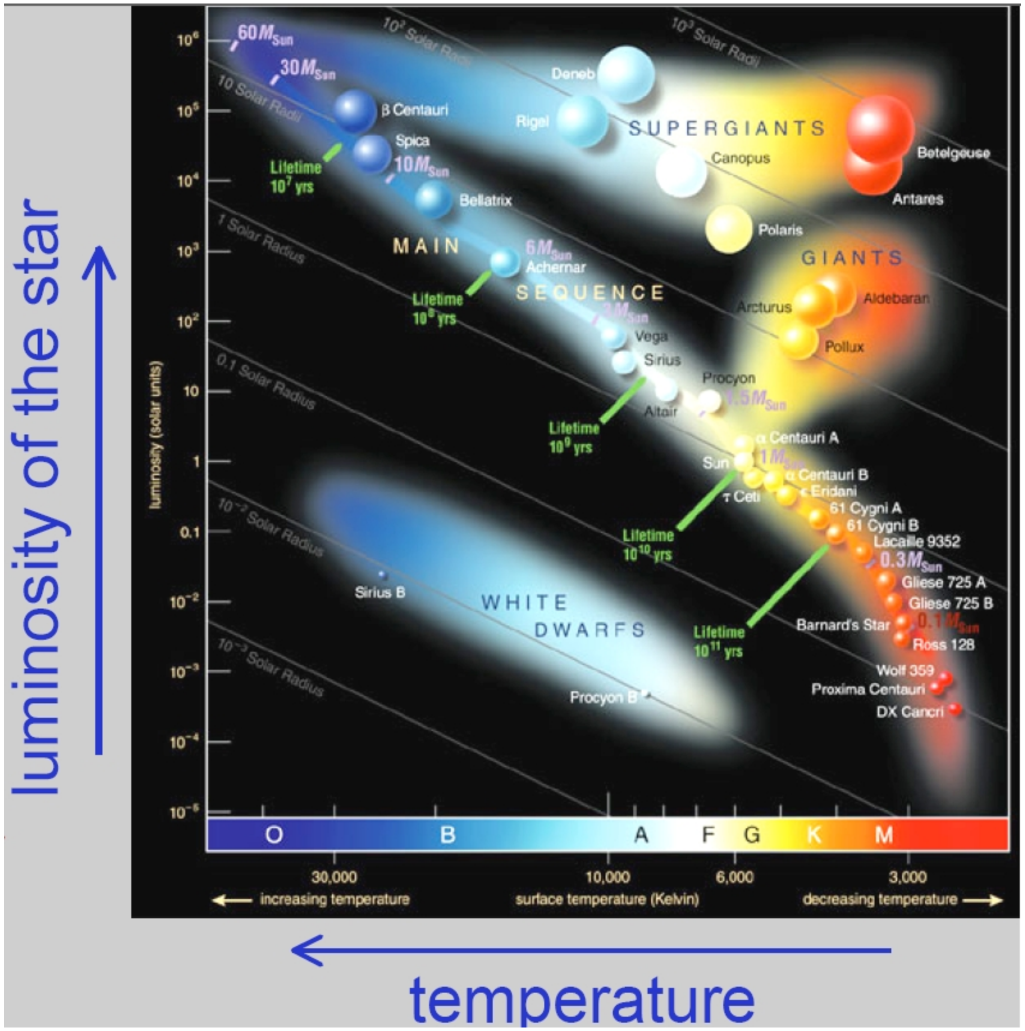
LSST throughput



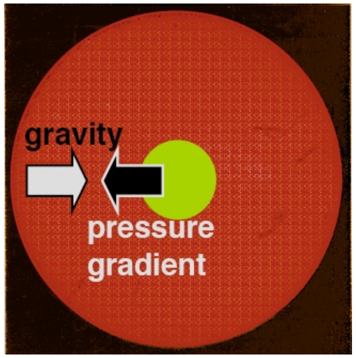
Atmosphere

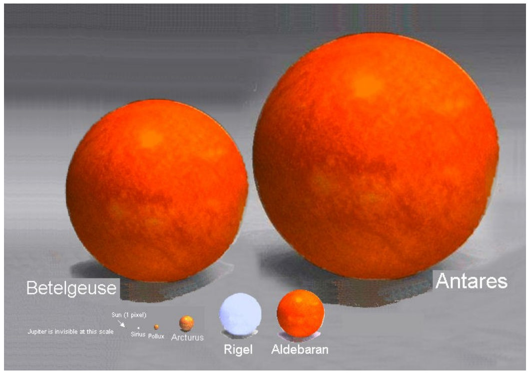

Airmass 1.00
Transmission
Wavelength (nm)
0.0
0.2
0.4
0.6
0.8
1.0
300
400
500
600
700
800
900
1000
1100
H2O
O2
O3
rayleigh
aerosol

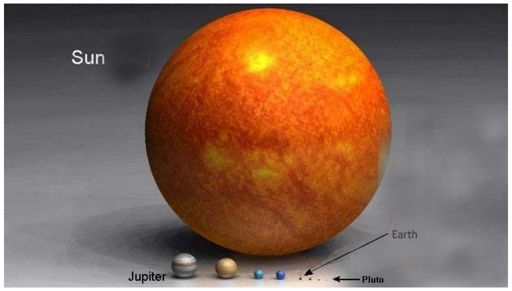
Hertzsprung-Russell Diagram



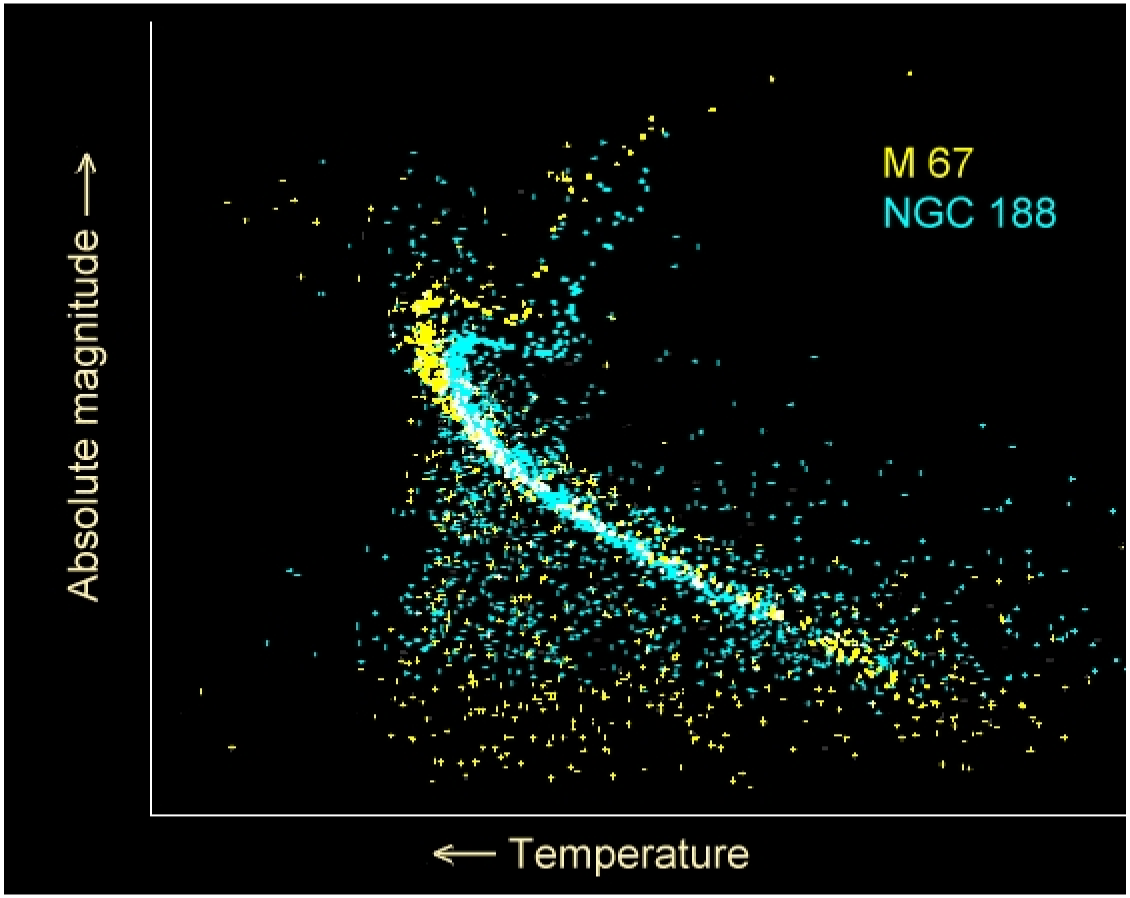
- Stars are balls of hot gas in hydrodynamical and thermodynamical equilibrium
- Equilibrium based on two forces, gravity: inward, radiation pressure: outward
- Temperature and size cannot take arbitrary values: the allowed ones are summarized in Hertzsprung-Russell diagram
- $L = \text{Area x Flux} = 4\pi R^2 \sigma T^4$
- Luminosity and size span a **huge** dynamic range!

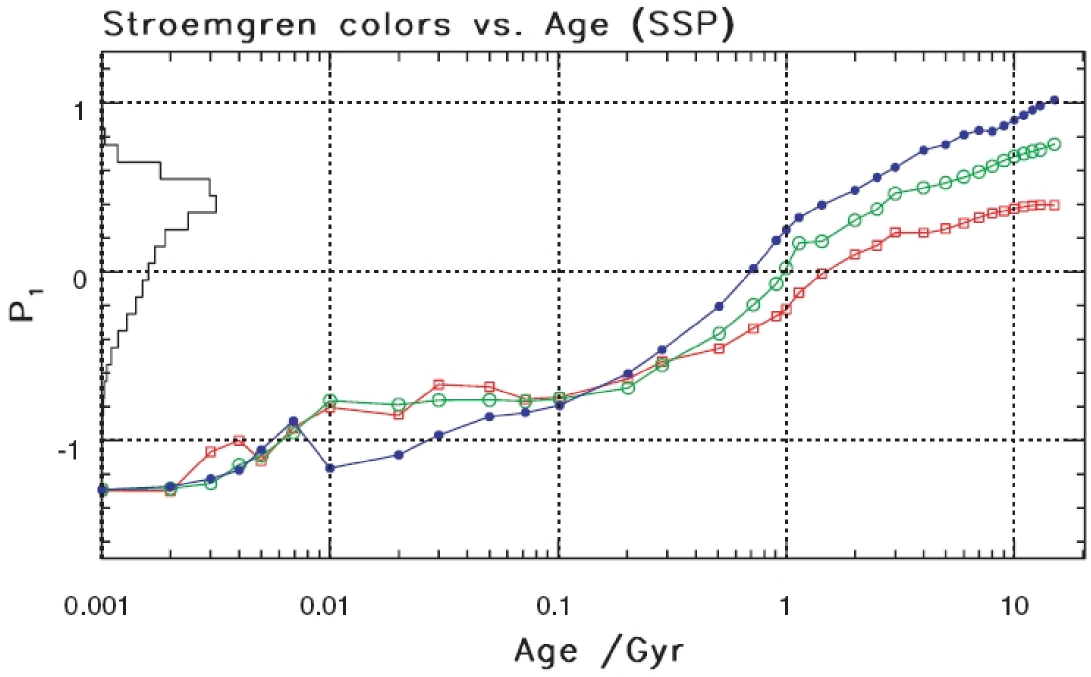






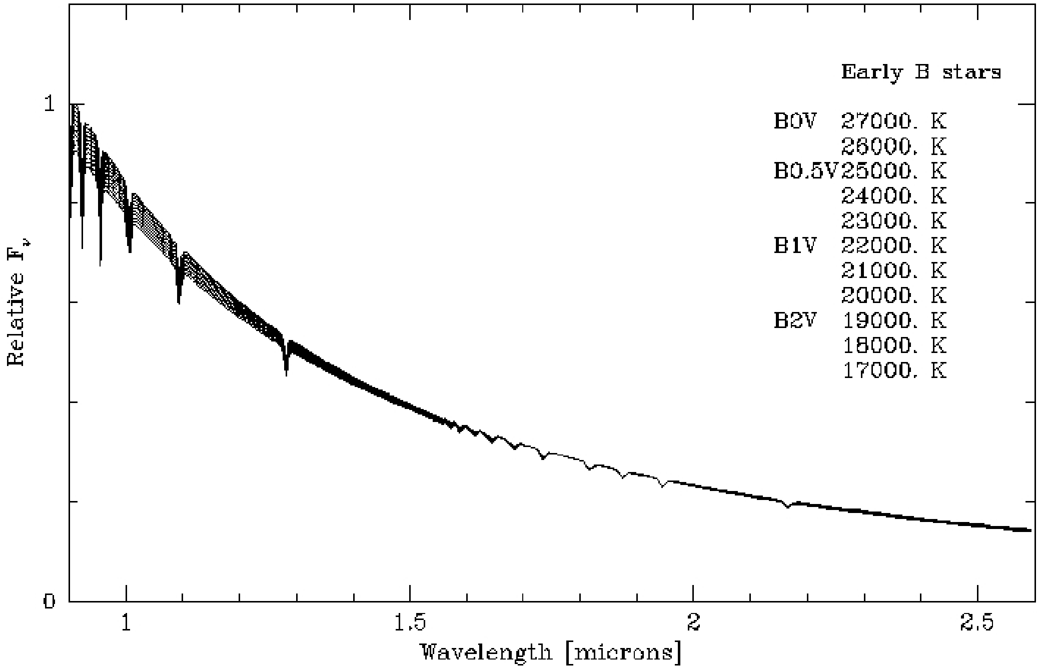
Check out HR simulator at ~
http://www.astro.ubc.ca/~scharein/a311/Sim/hr/HRdiagram.html

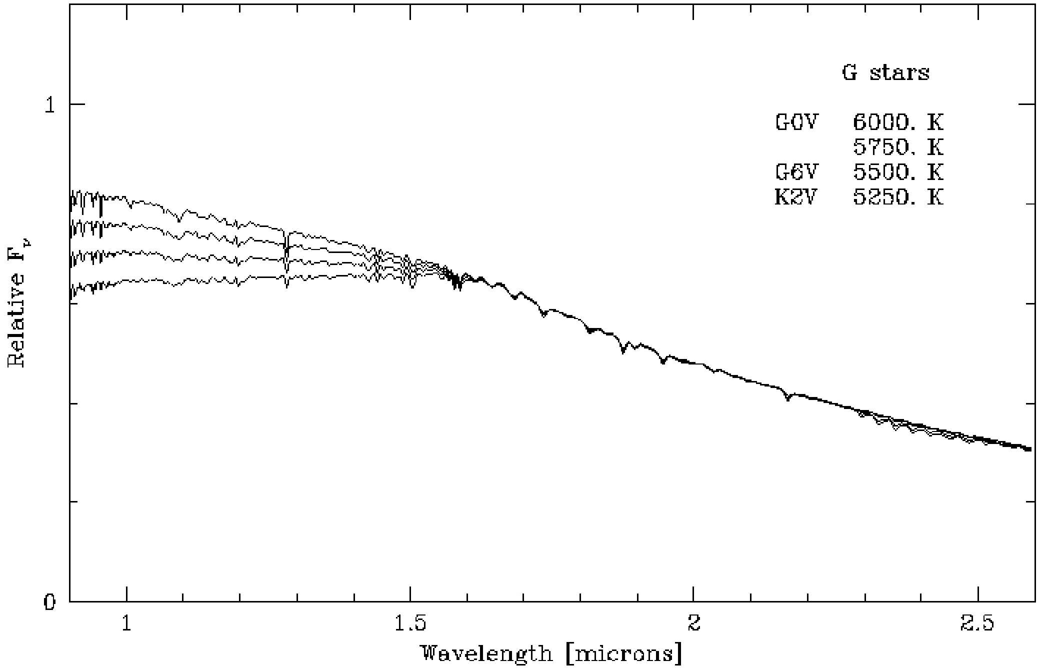




HR Diagram: Stellar Age

- The main sequence is where most of lifetime is spent.
- The position on the main sequence is determined by mass!
- The lifetime depends on mass: massive (hot and blue) stars have **much** shorter lifetimes than red stars
- After a burst of star formation, blue stars disappear **very quickly**, 10^8 years or so
- Galaxies are made of stars: if there is no ongoing star formation, they are red; if blue, there **must** be actively making stars!

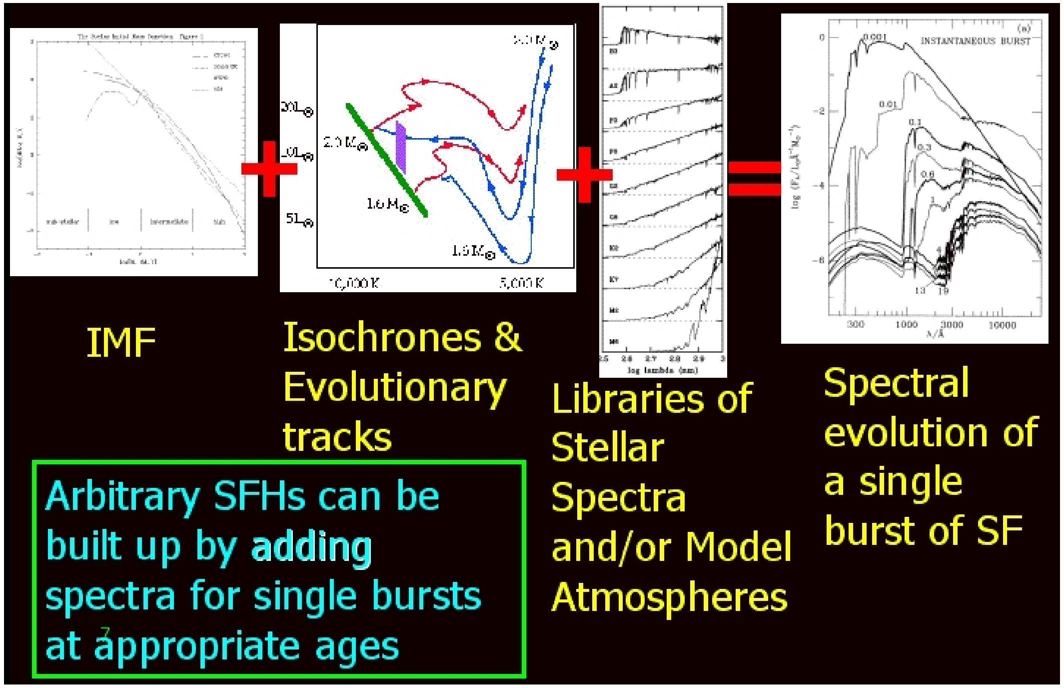




Stellar Parameters

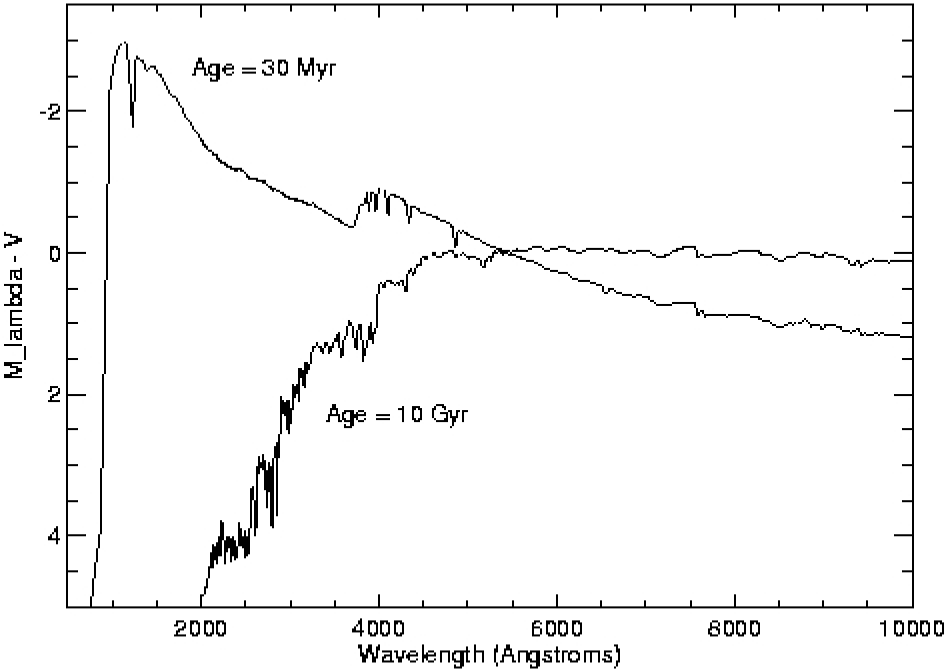
- The stellar spectral energy distribution is a function of mass, chemical composition and age, a theorist would say
- The stellar spectral energy distribution is a function of effective temperature, surface gravity and metallicity (at the accuracy level of 1%); the first two simply describe the position in the HR diagram
- Kurucz models (1979) describe SEDs of (not too cold) main sequence stars, as a function of $T_{\rm eff}$, $log(g)$ and $[Fe/H]$

Population Synthesis: modeling SEDs of galaxies

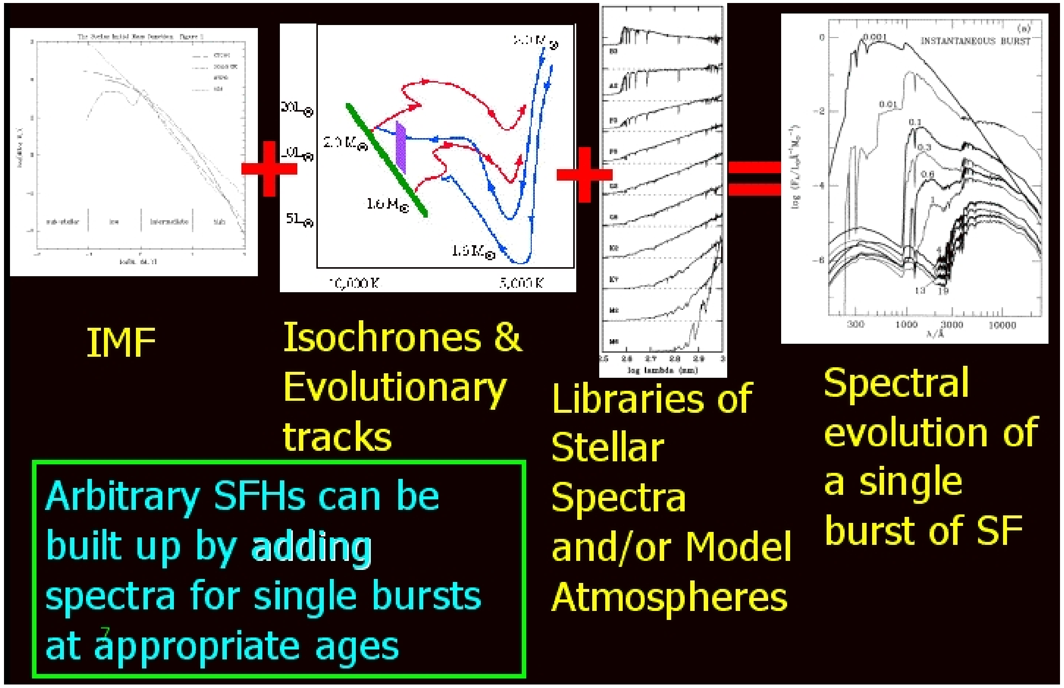


IMF + Isochrones & Evolutionary tracks + Libraries of Stellar Spectra and/or Model Atmospheres = Spectral evolution of a single burst of SF

Arbitrary SFHs can be built up by **adding** spectra for single bursts at appropriate ages



1. A burst of star formation: a bunch of stars (i.e. our galaxy) was formed some time ago: **age**
2. The mass distribution of these stars is given by a function called **initial mass function, IMF**, roughly a power-law $n(M) \propto M^{-3}$
3. The stellar distribution in the HR diagram is given by the adopted age and IMF; equivalently, can adopt a CMD for a globular or open cluster; assume **metallicity** and get a model (i.e. stellar SED, e.g. from Kurucz) for each star and add them up



IMF

Isochrones & Evolutionary tracks

Libraries of Stellar Spectra and/or Model Atmospheres

Spectral evolution of a single burst of SF

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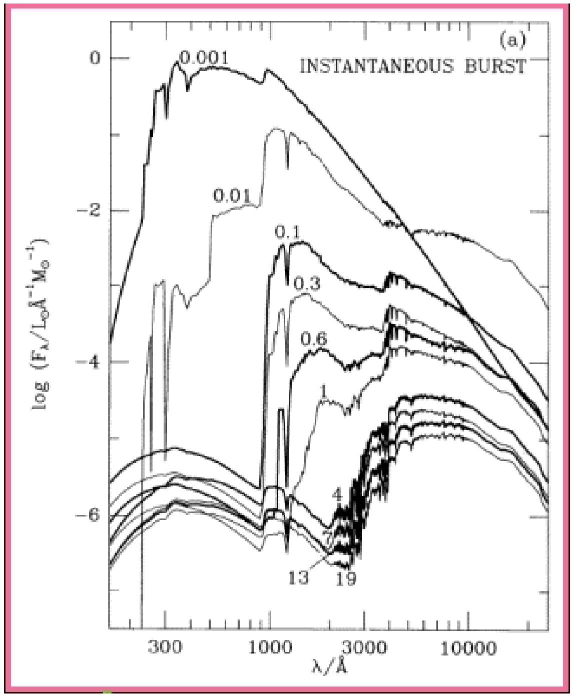

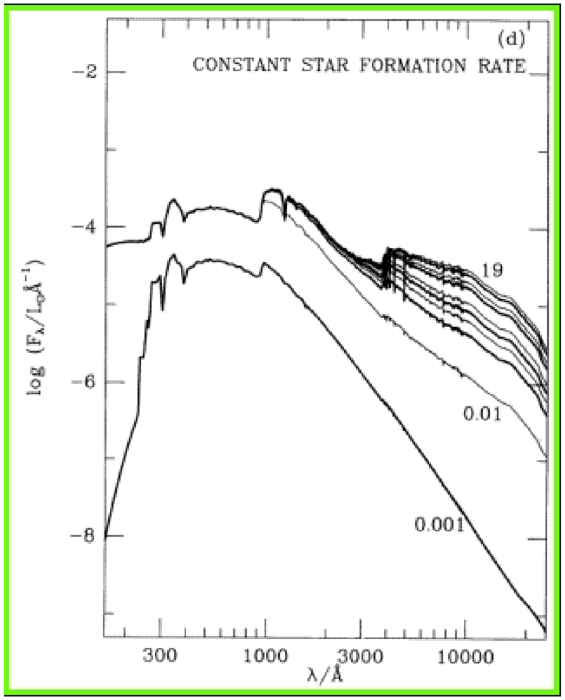

Population Synthesis: modeling SED of galaxies

1. A burst of star formation: **age**
2. The initial mass function, IMF
3. The stellar distribution in the HR diagram and metallicity: **add SEDs for all stars**, the result is
4. Simple stellar population as a function of **age** and **metallicity**
5. Star-formation history, or the distribution of stellar ages, tells us how to combine such simple stellar populations to get SED of a realistic galaxy

Galaxies with more <u>recent star formation</u> have a large fraction of young main sequence stars.

Galaxies with <u>no recent stars</u> have red giants as their brightest stars.