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, metallicity, 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:

\[ I_{\nu}(\lambda, \alpha, \delta, t, p) \]

- \( I_{\nu} \) - energy (or number of photons) / time / Hz / solid angle

- \( \lambda \) - \( \gamma \)-ray to radio, depending on resolution: spectroscopy, narrow-band photometry, broad-band photometry

- \( \alpha, \delta \) - 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):**

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

(1)

**SDSS:** \( T = 54.1 \text{ sec}, \theta \sim 1.5 \text{ arcsec}, \text{ filter width} \sim 1000 \text{ Å} \)

**Spectroscopy:**

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

(2)

**SDSS:** \( T = 45 \text{ min}, A: 3 \text{ arcsec fibers (} \sim 6 \text{ kpc at the redshift of 0.1)}, R\sim 2 \text{ Å (} \sim 70 \text{ km/s) } \)
Calibrated flux and magnitudes

• Traditionally, the astronomical flux is reported on a magnitude scale

\[
m_b = -2.5 \log_{10}\left(\frac{F_b}{F_{AB}}\right).
\]  

where \(F_{AB} = 3631 \text{ Jy (1 Jansky} = 10^{-26} \text{ W Hz}^{-1} \text{ m}^{-2} = 10^{-23} \text{ erg s}^{-1} \text{ Hz}^{-1} \text{ cm}^{-2}\) 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

$$F_b = \int_0^\infty F_\nu(\lambda) \phi_b(\lambda) d\lambda,$$

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

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

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

$$S_b(\lambda) = S^{atm}(\lambda) \times S^{sys}_b(\lambda).$$
LSST throughput

Throughput Components

Throughput Probability

Wavelength (nm)

- detector
- optics
- atmos
- u
- g
- r
- i
- z
- y2
- y3
- y4
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
- \( L = \text{Area} \times \text{Flux} = 4\pi R^2 \sigma T^4 \)
- 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 $T_{\text{eff}}$, $\log(g)$ and $[Fe/H]$. 
Population Synthesis: modeling SEDs of galaxies

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
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 recent star formation have a large fraction of young main sequence stars.

Galaxies with no recent stars have red giants as their brightest stars.