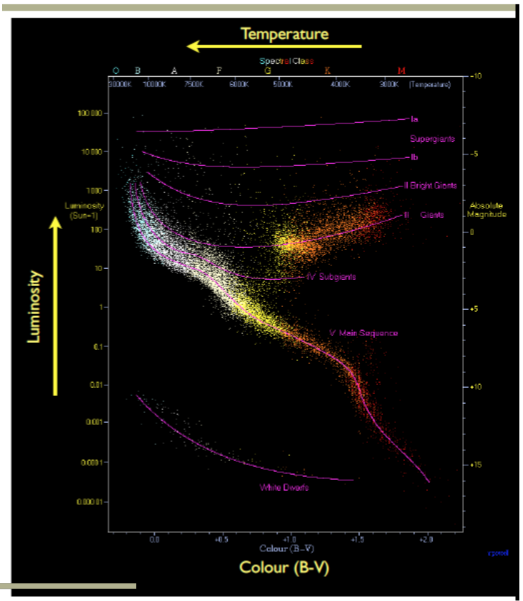
Stellar Populations of Galaxies- **2** Lectures

see MBW10.3- (sec 10.1-10.2 for stellar structure theory- will not cover this) parts of sec 2.2 and 6.3 in S&G and Chs 3 &5 in Binney and Merrifield

Top level summary

- stars with $M<0.9M_{\odot}$ have MS lifetimes $>t_{Hubble}$
- $M>10M_{\odot}$ are short-lived:$<10^8$years ~1t_{orbit}
- Only massive stars are hot enough to produce HI–ionizing radiation
- massive stars dominate the luminosity of a young SSP (simple stellar population)



HERTZSPRUNG-RUSSELL DIAGRAM

Plots luminosity of stars, versus their temperature.

Stars populate distinct regions of this plane, corresponding to particular evolutionary phases.

H-R(CMD) diagram of region near sun

H-R is theoretical

CMD is in observed units (e.g. colors)

HST Image of M31

Some Review Articles in Literature

Extensive Review Articles:

- 'Stellar Populations in the Galaxy Mould 1982 ARA&A..20, 91
- sec 2 of the "Galaxy Mass" review paper by Courteau et al on web arxiv 1309.3276
- Modeling the Panchromatic Spectral Energy Distributions of Galaxies Charlie Conroy ARA&A 2013 51:393–455!

Field is now very active stimulated by planets, stellar seismology and GAIA

Assumptions

- I assume that you all have
  - understood the magnitude system (ch 1 pg 21-24 of S&G)
  - the black body law (not in text, but in Astro 120)
  - coordinate systems (RA and Dec) and galactic coordinates (l,b)
  - a little bit about astronomical spectra (lots of jargon)

Why are **We** Studying Stars???

- The UV-near IR band is one of the prime regions for studying galaxies and most of the light in that band comes from stars.
- The stellar populations of galaxies hold vital clues to their formation histories
- Stellar spectra contain information about
  - age
  - metallicity and abundance patterns (origin of elements)
  - star formation rate history (conversion of gas into stars)
  - dynamics of the system (ability to measure formation processes and dark matter)
- Understanding stellar spectra allows measurement of dust and dust distribution
- One needs to understand stellar spectrum to obtain information about the Initial Mass Function of stars.

Why Study Stars

- We can examine the " fossil evidence" of past star-formation trends in the stellar populations of present-day galaxies
- Study the star-formation activity in galaxies at ever earlier times byobservingt galaxies at ever greater distances
- Set constraints on the history of cosmic star formation by measureing how the average chemical composition of the universe has changed over cosmic time.

Stars S&G Chap 1.1 and 2.2 page 67-89

- Directly produce most of the visible light and galaxies and (indirectly) the infrared light
- Responsible for producing all the elements heavier than boron
- Inject energy into the interstellar medium (winds and supernova)
- Tracers of the dynamics of galaxies (rotation, spiral arms etc)
- Wide range of masses, luminosity, chemical composition and ages.
  - MW has ~10^{11} stars.
  - Distributed as a luminosity function (#/unit luminosity/volume)
  - Distributed as a mass function (#/unit mass/volume)
- Are dynamic entities – born, age and die

(see Bender lecture in web page additional material and https://ned.ipac.caltech.edu/level5/Sept12/Peletier)

Galactic Evolution **(Read the Dunlop article on class site)**

- Stars of different masses have vastly different main-sequence lifetimes
  - massive stars have main-sequence lifetimes much shorter than the age of the Universe
- Thus when we observe a galaxy today we are observing the light from the stars that have evolved to the present time.
  - Main-sequence stars with $M_s \sim M_\odot$ observed today include all stars of such masses that have formed during the pas t~10^{10} yr, While the main-sequence stars with $M_s \sim 10M$ observed today are formed only during the past 10^7 yr.
- Thus, the stellar population observed from a galaxy depends strongly on its <u>star-formation history</u>.

Why are Stars Interesting- Rev 2

- Stellar data allow
  - high precision abundances for multiple elements in stars across the Galaxy, and the distributions of these chemical properties
  - kinematical data constrain dynamical models for the disk, bulge, bar and halo (where and how much matter is there)
  - explore the history of Galaxies by inferring the properties of stars as a function of age
  - From "The Apache Point Observatory Galactic Evolution Experiment (Apogee):Majewski et al 2015

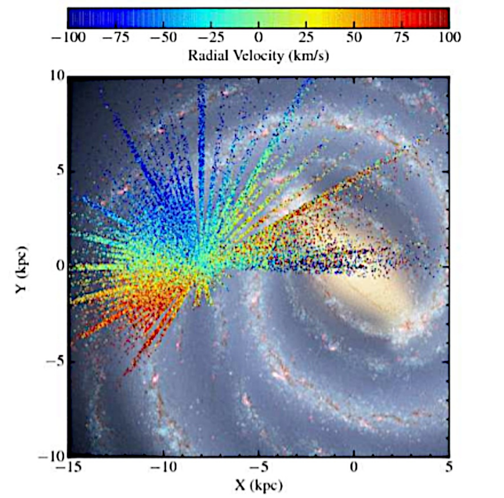


FIG. 24.— Star-by-star APOGEE heliocentric velocities as a function of Galactic X-Y position and projected on an artist's conception image of the Milky Way. The points represent main APOGEE

Velocity field of stars in MW

Use of Stellar Data to Understand Galaxy formation and Evolution

– To quote from Conroy et al 2013

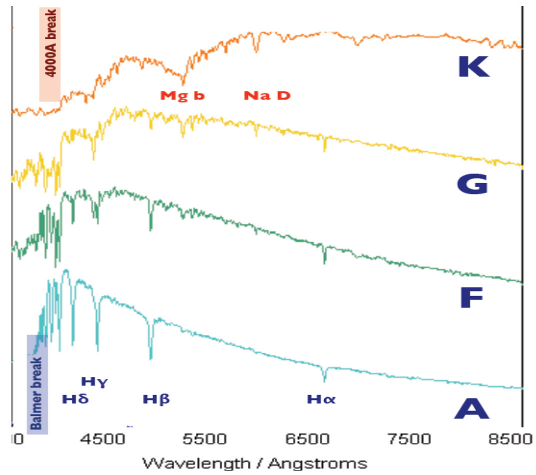
From an empirical point of view, the formation and evolution of galaxies can be probed via two general techniques.

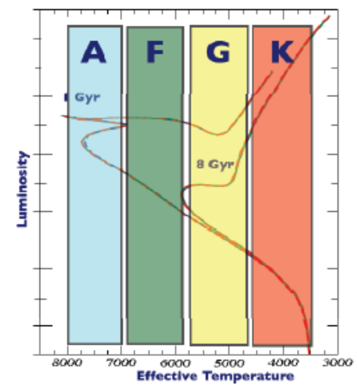
1) look back studies where one observes, statistically, the progenitors of present day galaxies at progressively higher redshifts e.g. observing high redshift galaxies

2) studying the present day properties of galaxies, including their stellar populations, structure, and kinematics, in order to learn about their past evolution.

Spectra of Individual Stars

- Stellar spectra (spectral type (OBAFGKM)_
- effective temperature T_{eff}
- chemical (surface) abundance
  - [Fe/H]+much more e.g [α/Fe]
    - absorption line strengths in stellar spectra depend on T_{eff} and[Fe/H]
- Luminosity class- (giant/dwarf)
- Stellar properties determined by mass, chemical composition, age and spin





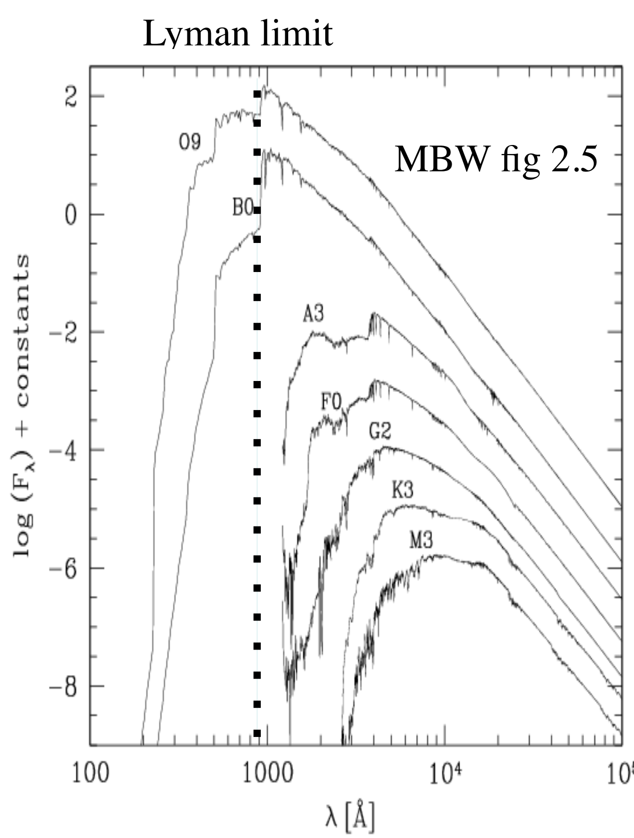
Luminosity

H.Rix

11

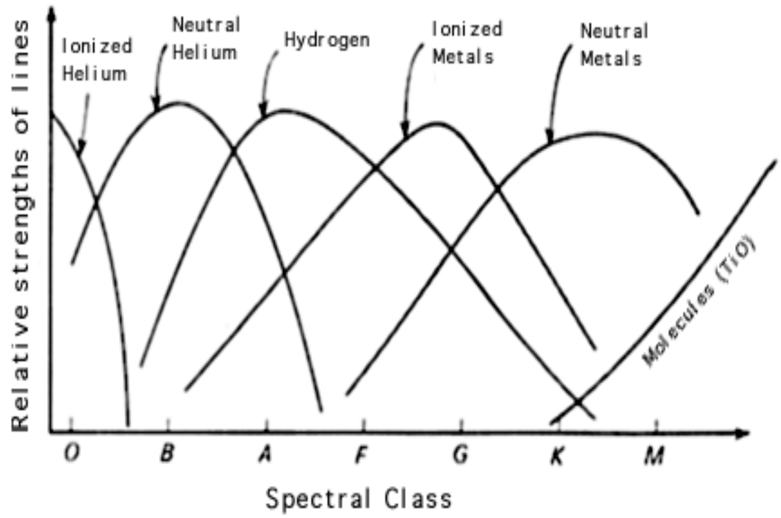
Stellar Spectra by Types

- 0.01-10μ micron spectra of main sequence stars
  - Notice the presence of 'unique' spectral signatures and the vast difference in the UV flux of the stars
- The observed spectrum depends primarily on the bolometric luminosity, M_{bol}, effective temperature , T_{eff}, metallicities, Z, effective gravity and age
  - Lyman limit- below this wavelength the ISM is optically thick-spectra are 'cut-off' from distant objects



Basic Physics of Stellar Classes

- The spectra of stars from each class is dominated by different physical processes in the stars atmosphere-but there is strong overlap between classes



Again- horrible nomenclature eg. GOV, Wolf-Rayet, giants, dwarfs etc etc tables 1.4-1.6 in S+G
Huge (~ 10^9)range in luminosities (table 1.4)

Mass and age are the prime determinant of stars properties

Physical Origin of Range of Stellar Parameters

- For stars above $100M_\odot$ the outer layers are not in stable equilibrium, and the star will begin to shed its mass. Very few stars with masses above 100M are known to exist,
- a mass of about $0.1M_\odot$ is required to produce core temperatures and densities sufficient to provide a significant amount of energy from nuclear processes.
  – range of stellar masses spans a factor of 10^3 in mass.
- Parameters
  – sizes range from $10^{-3}R_\odot<R<10^3R_\odot$, on the main sequence.
- On main sequence,
  – observed mass-radius relation $M \sim R^{4/3}$ (range of 200 in size)
  – luminosity $10^{-4}L_\odot<L<10^6L_\odot$ (10^{10} in L)
- For $M<2\ M_\odot$ stars 'burn' via the p-p chain; the main sequence lifetime of a low mass star consists of a steady energy output from hydrogen burning in an environment of steadily increasing helium.