Stellar Populations of Galaxies- **2** Lectures

some of this material is in S&G sec 1.1

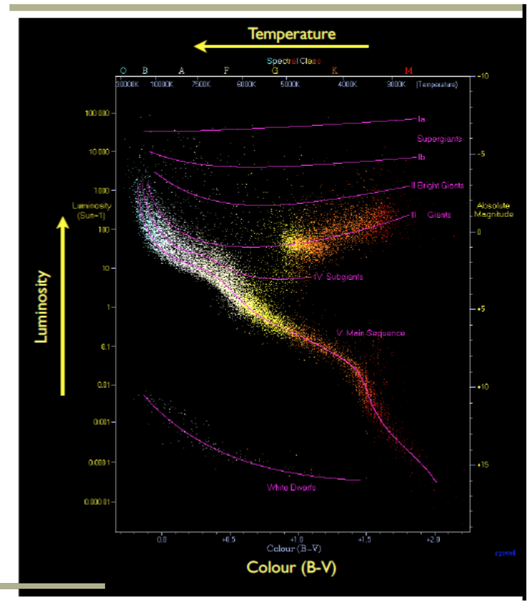
see MBW sec 10.1-10.3 for stellar structure theory- will not cover this

Top level summary

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

see 'Stellar Populations in the Galaxy Mould 1982 ARA&A..20, 91

and sec 2 of the "Galaxy Mass " review paper by Courteau et al arxiv 1309.3276



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

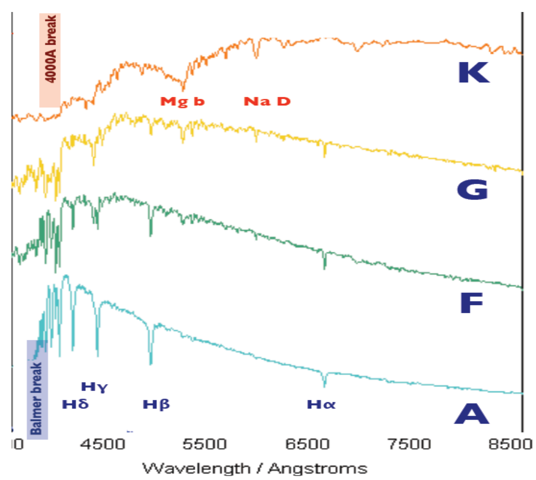
H-R is theoretical

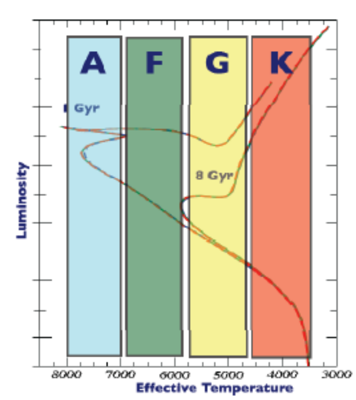
CMD is in observed units (e.g.colors)

Spectra of Individual Stars

- Stellar spectra reflect:

  spectral type (OBAFGKM)
- effective temperature T_{eff}
- chemical (surface)abundance
  - [Fe/H]+much more e.g [α/Fe]
  - absorption line strengths depend on T_{eff} and[Fe/H]
- surface gravity, log g
  - Line width (line broadening)
  - yields:size at a given mass
  - dwarf-giant distinction for GKM stars
- no easy ‘age’ -parameter
  - Except e.g. $t<t_{MS}$
- the structure of a star, in hydrostatic and thermal equilibrium with all energy derived from nuclear reactions, is determined by its mass distribution of chemical elements and spin





Luminosity

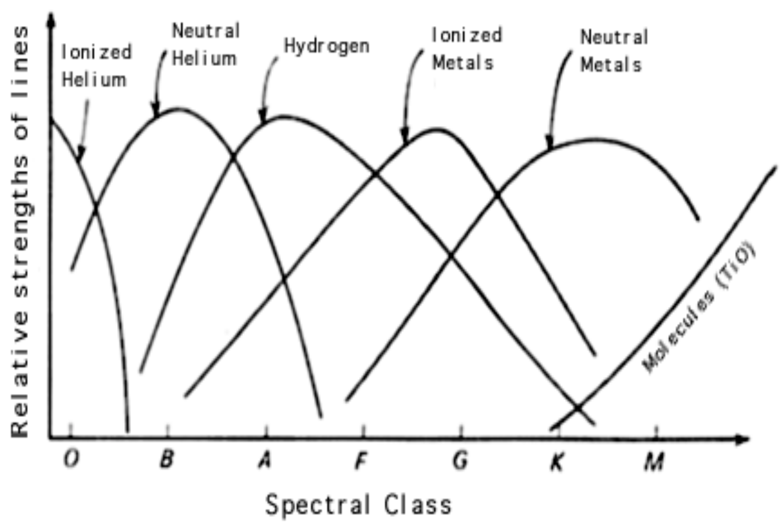
H.Rix

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,
- At the other end of the mass scale, 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.
- Thus, the range of stellar masses spans a factor of 10^3 in mass.
- Observationally sizes range from $10^{-3}R_\odot<R<10^3R_\odot$; on the main sequence. For stars on the main sequence, the observed mass-radius relation is approximately $M\sim R^{4/3}$ and luminosity $10^{-4}L_\odot<L<10^6L_\odot$ - **see S&G eq 1.6, 1.8 and 1.9**
- In Collins (see web page) sec 5.3 there is a detailed discussion of the main sequence physics (e.g. when stars are burning nuclear fuel steadily)
  - 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.

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

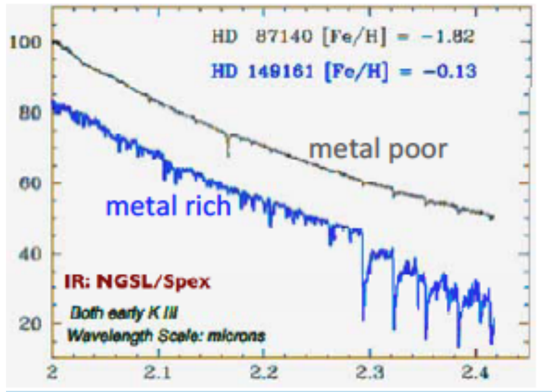
More Details

- If one has spectra of individual stars much can be learned -detailed metallicity, gravity, rotation rate
- BUT for composite stellar systems in real galaxies much harder to obtain this information due to
  - velocity of stars broadens features
  - composite spectra are not unique
- For young populations (<300 Myrs)

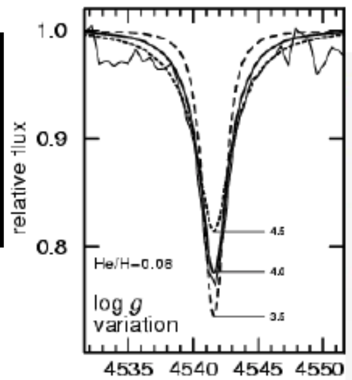
– upper MS stars (massive, young) dominates integrated L_{bol}

- For old populations (>2Gyrs)

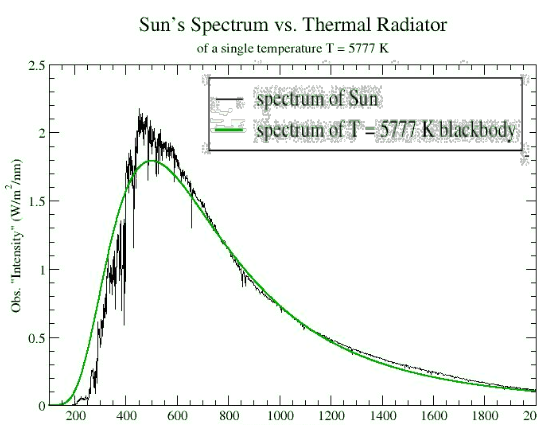
– red giants (moderate mass, wide range of ages) dominate integrated L_{bol}



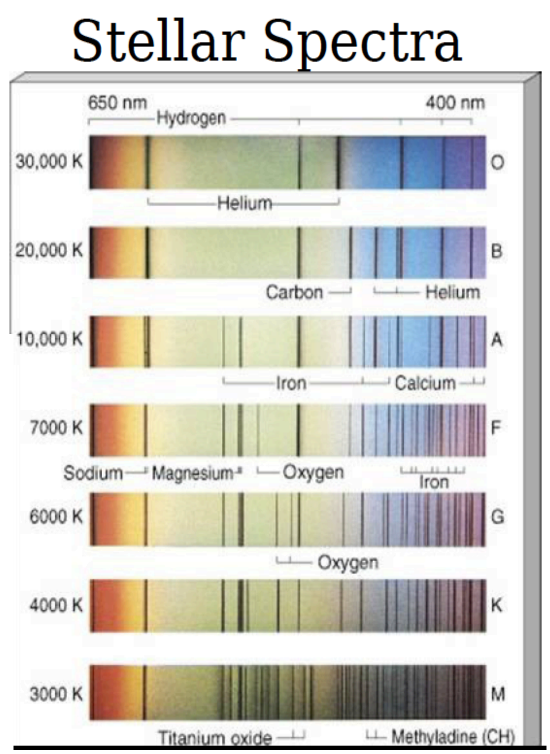
line shape as a function of surface gravity



- To zeroth order stellar spectra can be approximated as black bodies of the appropriate temperature. - If this is true, comparison of flux in 2 well separated bands can determine the temperature



http://homepages.wmich.edu/~korista/sun-images/solar_specbb.jpg



discovery of quantum levels

Simplest Physics of Stellar Spectra

- "hot" opaque bodies emits a continuous spectra.
- "hot" low density gas emits a sequence of emission lines. - a neon sign.

- "cold" low density gas, placed in front of a hot opaque body, produces a continuous spectrum with dark lines on top (absorption lines). - light from the sun.
- Every element (Hydrogen, Oxygen, Nitrogen etc.) produces
  - a unique set of emission and absorption lines
    - contains information on the ionization state of the element , its velocity (and with more discrimination the density of the gas and whether it is in equilibrium)

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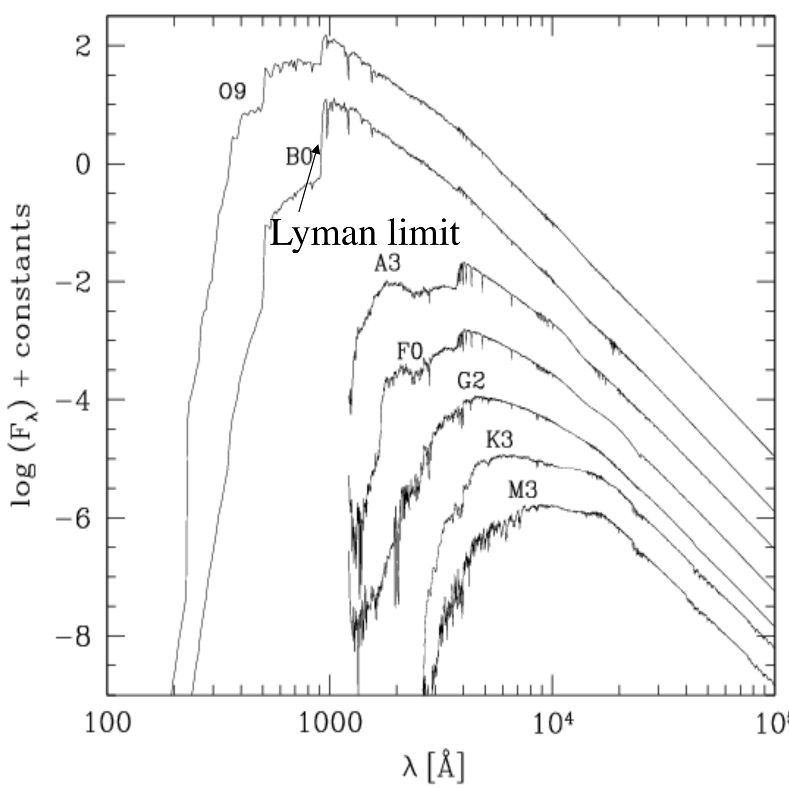
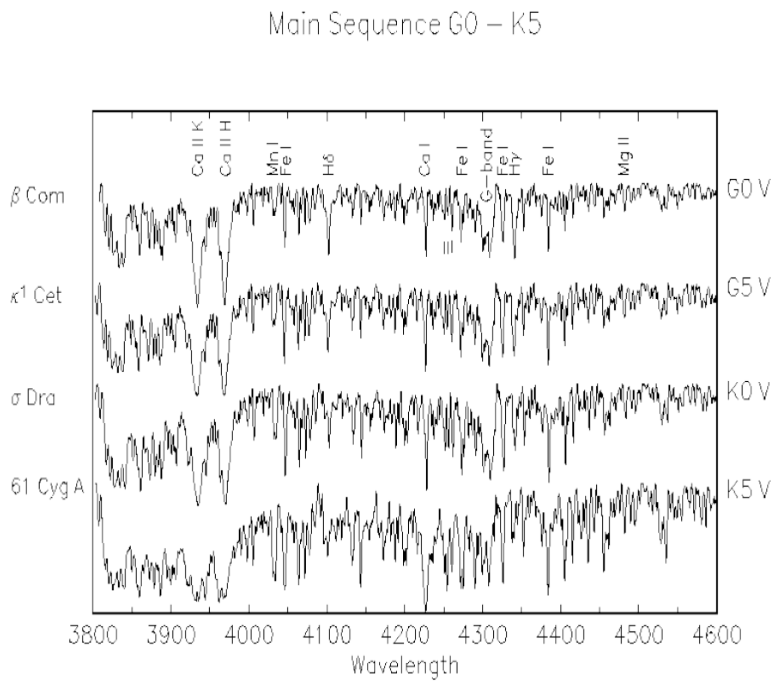
Stellar Spectra by Types

- 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



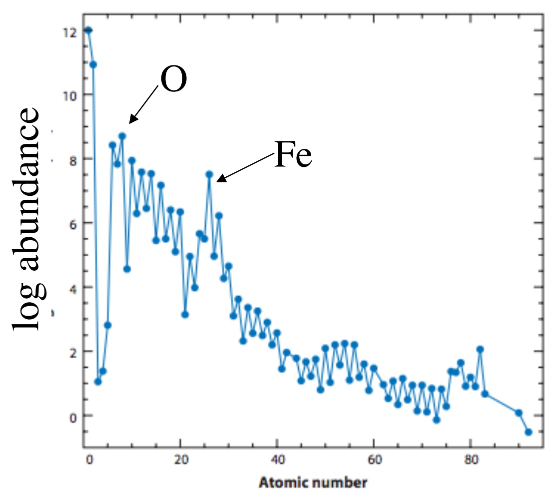
- Detailed spectra of bright stars can reveal their age, metallicity, rotation rate, size and distance.... allowing measurements of detail of MW structure, age, chemical evolution..etc

- Need very high (>30,000) spectral resolution ($\lambda/\delta\lambda$)



Chemical Composition of Stars

- Frequently normalize the chemical composition of an astrophysical system to the sun- The Chemical Composition of the Sun Annual Review of Astronomy and Astrophysics 47: 481-522 Asplund et al
- There are 2 types of variation: total abundance of 'metals' (elements heavier than He) and their relative abundance; total abundance of metals by mass (Z) in sun is ~0.013
- to zeroth order (more later) there are 4 sources of metals
- BBN- Li Be
- Type I SN -Fe, Ni etc
- Type II SN - O, Ne, etc
- Other (stellar winds, planetary nebulae etc) - N, C - still to be understood .



Atomic Number

•in nearby stars, 40-80% of the carbon is due to low- and intermediate-mass stars.

•The stellar origin of carbon is thus uncertain (e.g. Mattsson 2012)

Luminosity Mass Relation

- on the main sequence stars of the same age and metallicity have simple scaling relations (first order) between mass, luminosity and size
  - 2nd order corrections can be important
  - Basic physics of stellar structure eqs (MBW sec 10.1.4 eq 10.61) shows that on the main sequence L~

    $81(M/M_\odot)^{2.14}$; $M>20M_\odot$

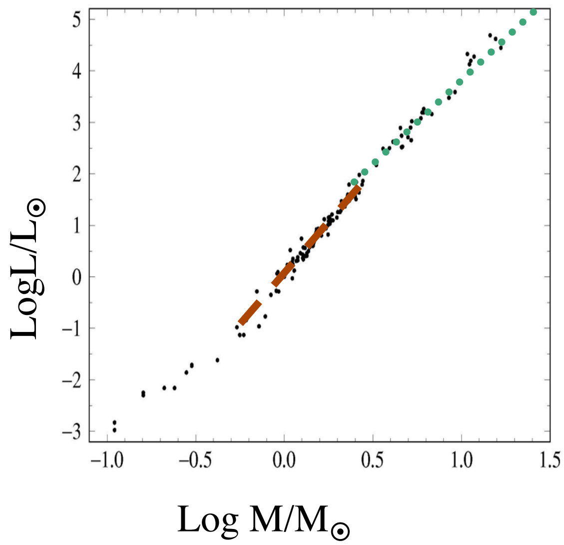
    $1.78(M/M_\odot)^{3.5}$; $2M_\odot<M<20M_\odot$

    $0.75(M/M_\odot)^{4.8}$; $M<2M_\odot$

L~T^b with b~4.1 at low and 8.6 at high mass

Notice the very strong dependences

Lifetime on MS ~M/L~M^{-3}



$$R \propto R_\odot \left(\frac{M}{M_\odot}\right)^\alpha, L \propto L_\odot \left(\frac{M}{M_\odot}\right)^\beta$$

α~0.7, β~5

Estimating Lifetimes - MS

26.7 MeV released every time 4H $\rightarrow$ He + ν + photons

The difference in mass of 4H and He is

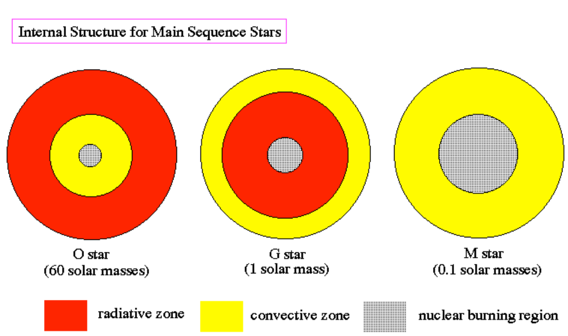
$4m_{proton} - 3.97m_{proton} = 0.0267m_{proton}$

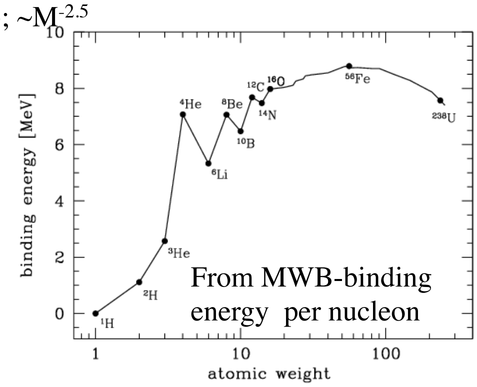
The efficiency of converting mass to energy with p-p process is 0.03 / 4 = 0.007, or 0.7% (some of the energy goes into neutrinos)

- So, $t_{MS} = (0.007\ \alpha M c^2) / L$

α is the total mass of H converted to He while the star is on the main sequence- varies with mass : nuclear burning regions takes up a larger percentage of the stellar interior as one goes to low mass star.

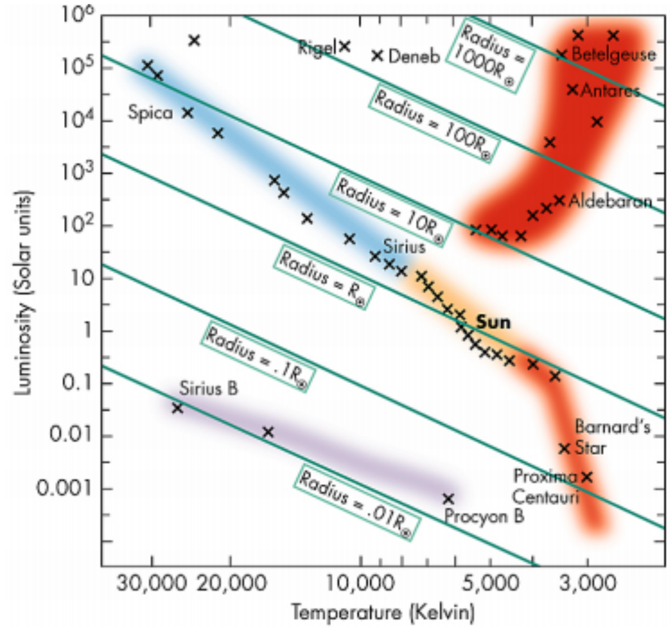
In terms of useful units, $t_{MS} \sim 10^{10}(M/M_{solar})/(L/L_{solar})$; ~$M^{-2.5}$





Stellar Sizes/Luminosity/Temperature

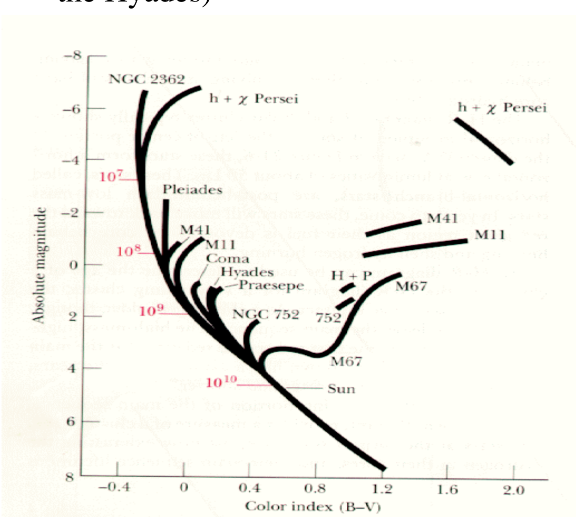
- Stefan-Boltzman law-Lines L~T[4]
- Over a wide range in luminosity stars radiate close to a Black body spectrum in the optical band

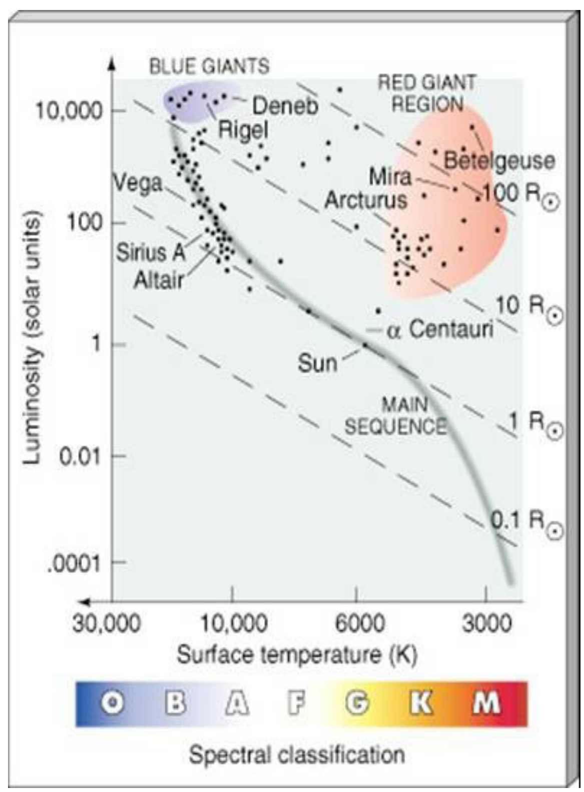


http://www.physics.isu.edu/~hackmart/spectral_class.pdf

H-R Diagram for Visible Stars in MW

- The brightest stars in the visible sky do NOT sample the H-R diagram well -how does one construct an appropriate sample?
- Need to go much fainter, find 'co-eval' populations (e.g. **open clusters** like the Hyades)





Stellar evolution reminder

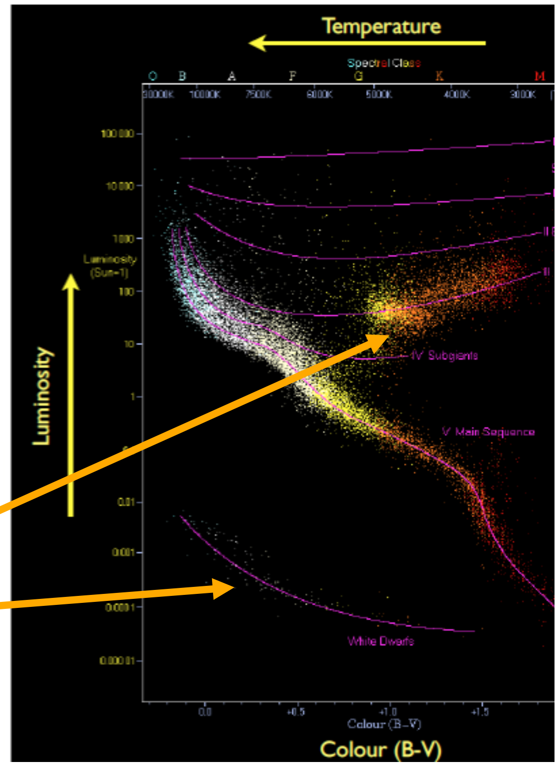
HERTZSPRUNG-RUSSELL DIAGRAM

Russell Smith Durham

Plots luminosity of stars, versus their temperature.

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

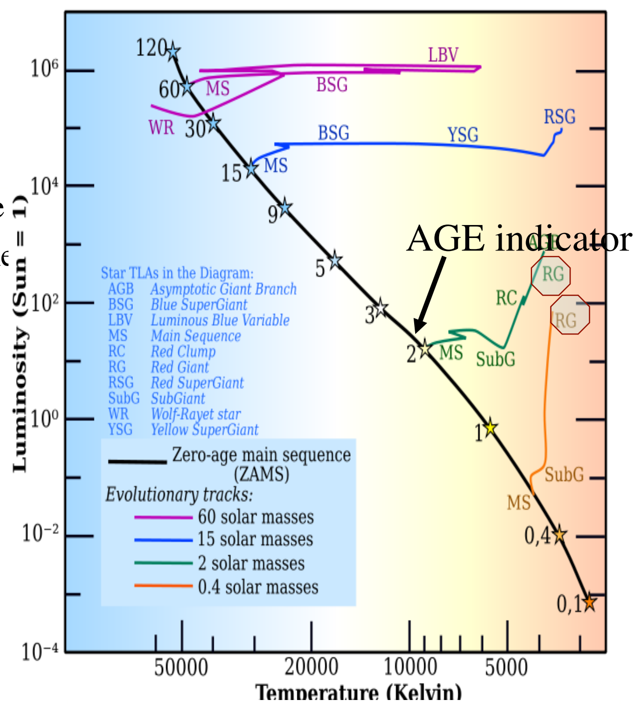
H-R diagram organizes the observed optical properties of stars
Main sequence
white dwarfs
giant branch



TRACKS

"Tracks" are trajectories of individual stars in the H-R

Stellar evolutionary tracks trace the evolution of a given mass star vs time luminosity, temperature plane



as a function of initial mass (and initial chemical composition).

In detail, the tracks are computed from stellar evolution models (Padova, Geneva, BaSTI etc).

Russell J. Smith Durham
http://astro.dur.ac.uk/~rjsmith/stellarpops.html

Isochrones

Theoretical lines in the H-R diagram of a given age for stars of different masses of a 'simple' stellar population

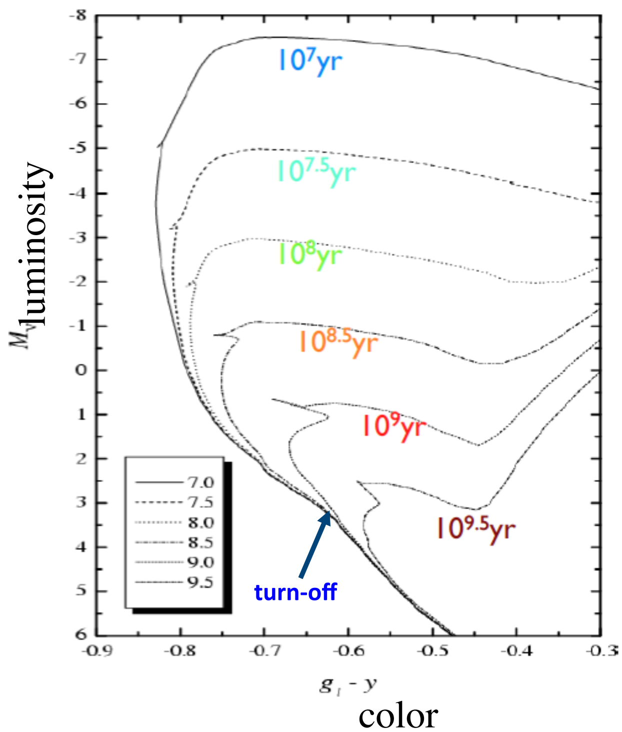
details depend on color used and stellar metallicity

'Simple' stellar population has one age and metallicity

Theoretical models-allow estimate age **from MS turn-off**

metallicity **from** giant branch color

See MBW fig 10.3



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MAIN SEQUENCE (MS)

Core hydrogen burning phase. Longest phase of evolution.

TURN-OFF

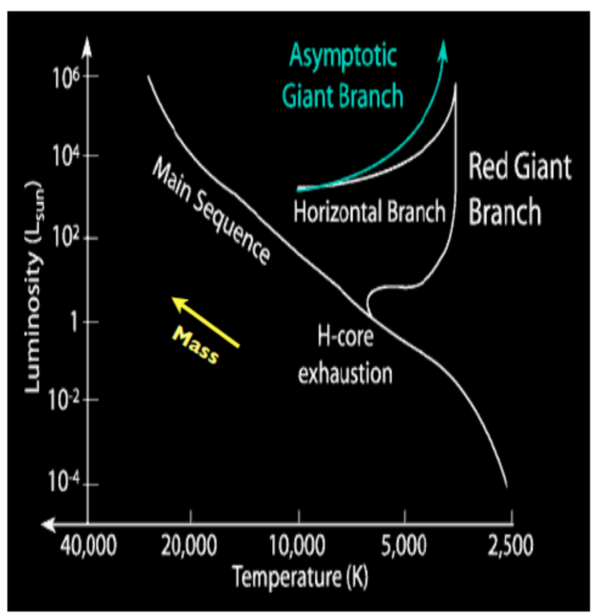
Hydrogen exhausted in core, start of "interesting" evolution.

RED-GIANT BRANCH (RGB)

Hydrogen burning in shell around inert helium core. Growth of He core.

RGB TIP

End of RGB phase: core massive and hot enough to ignite He-burning (the "helium flash")



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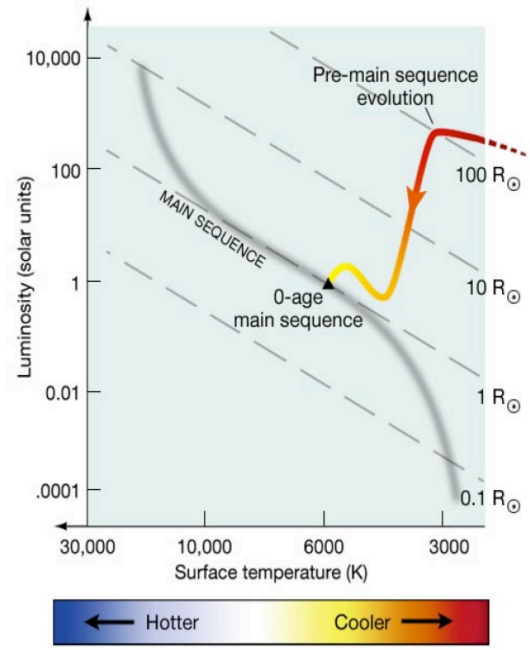
Main Sequence

H-R diagram is for 'zero age'

- 'low' mass stars evolve slowly-'stay' on the M-S for a long time
- On the M-S hydrogen burning' nuclear fusion in the core generates energy, the pressure is balanced by gravity-hydrostatic equilibrium.
- Stars spend ~80% of their lifetime on the M-S fusing hydrogen into helium.
- The position in the HR diagram changes with time, e.g. the Sun will slowly brighten and its color vary over its ~10^{10}year life on the Main Sequence. By the end of its MS lifetime, ~ twice as luminous as now

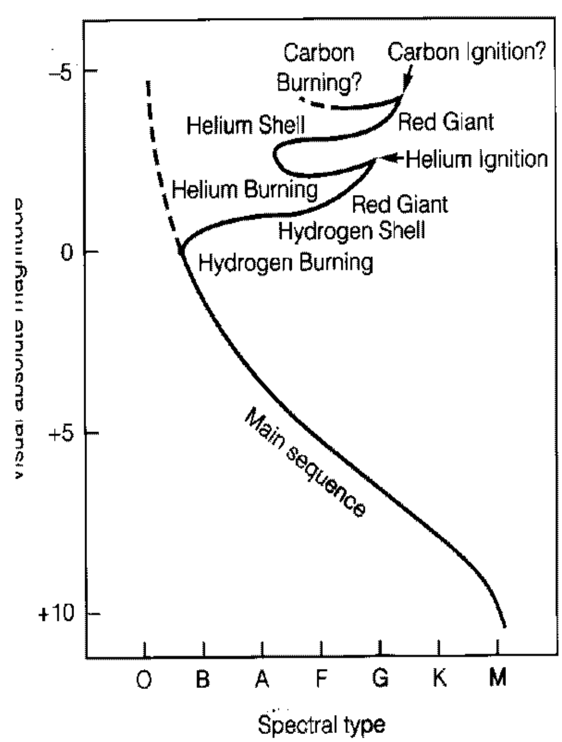


Dr. Christopher Palma PSU

Off the MS

- He burning only releases ~20% of the energy that H burning produces
- Lifetime in the He burning phase is

~ $2x10^9$ yrs for a solar mass star



Detailed Look at Evolution of a 5M star

- The basic nature of the theory of stellar evolution is tested by comparing the location of a collection of stars of differing mass but similar physical age with the H-R diagrams of clusters of stars formed about the same time

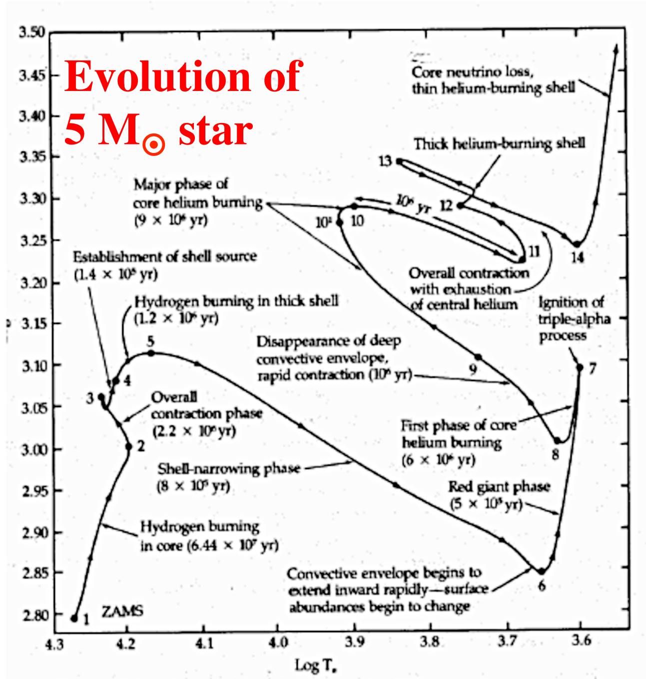


Figure 5.2 delineates the evolution of a 5M$_\odot$ star from its arrival on the main sequence through its demise at the onset on carbon burning[23]. The labeled points are points of interest discussed in the chapter and their duration, place in the stellar lifetime, and the significant physical process taking place are given in Table 5.1.

Collins fig 5.2

A Young SSP

- H-R diagram of the Pleiades (S&G fig 2.12) a nearby young open cluster.
- Notice the thinness of the H-R diagram

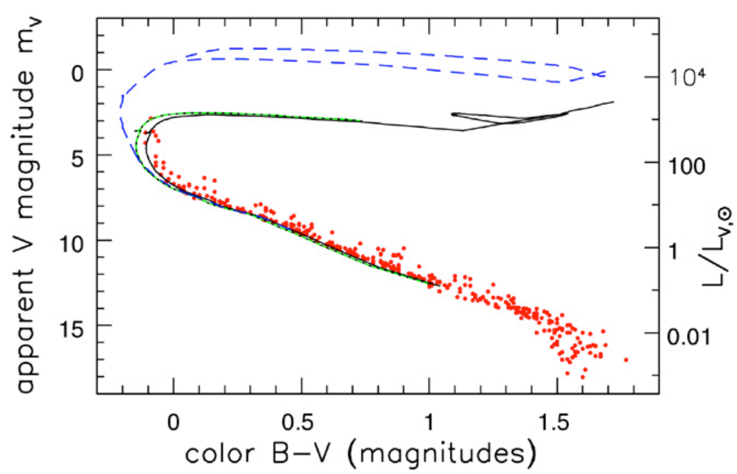
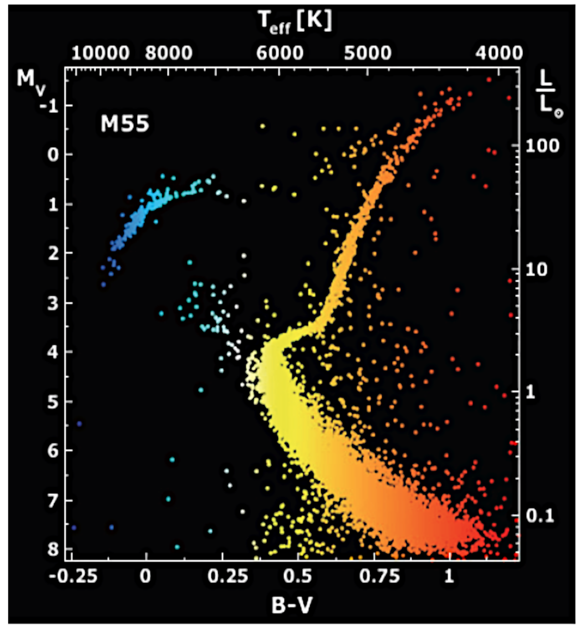


Fig 2.12 (J.-C. Mermilliod) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

A Old SSP

- Color-magnitude (H-R) diagram for stars in the globular cluster M55
- an old population of equal age +metallicity with no recent star formation ; e.g. a SSP
- To first order most Globular clusters are SSPs (some show metallicity variations)



astronomy picture of the day

MASS-DEPENDENT LIFETIMES

Lifetime in each evolutionary phase depends sensitively on initial mass.

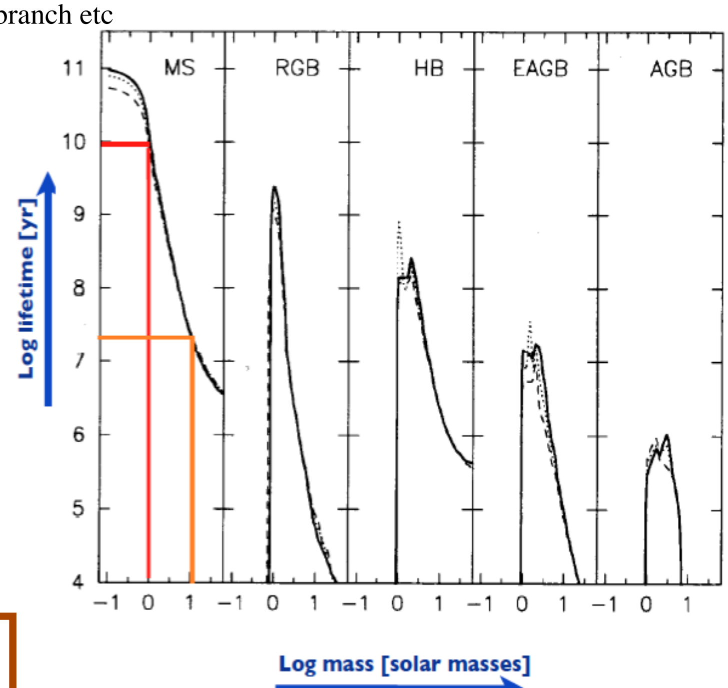
MS lifetime is ~10^{10} $(M/M_{sun})^{-2.5}$ yrs: so 10 Gyr at 1 solar mass, but only ~20 Myr for 10 $M_\odot$

Subsequent phases shorter-lived.

Below ~ 0.9 $M_\odot$, the MS lifetime is longer than age of Universe!

Mass-vs-lifetime relation is one of the crucial tools for age-dating populations.

MS= main sequence, RGB= red giant branch HB= horizontal branch etc



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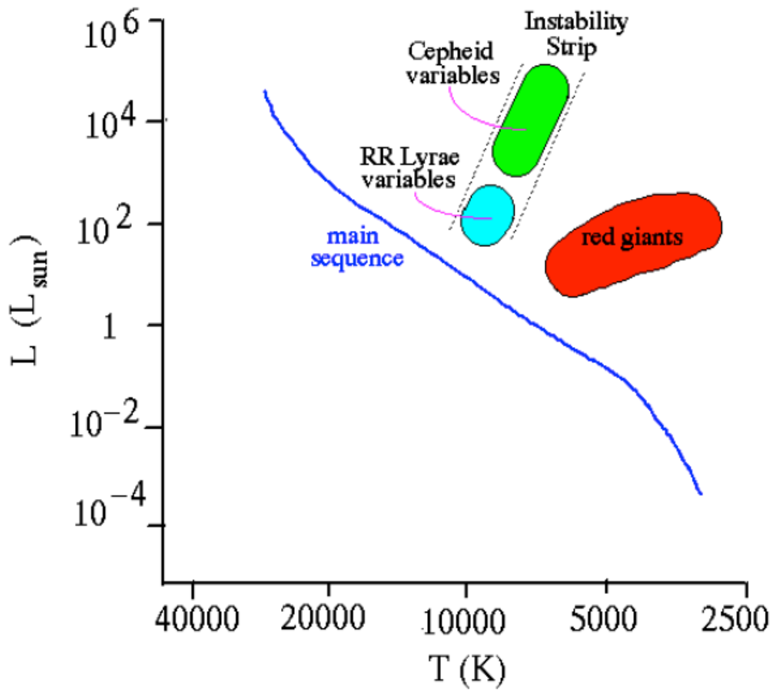
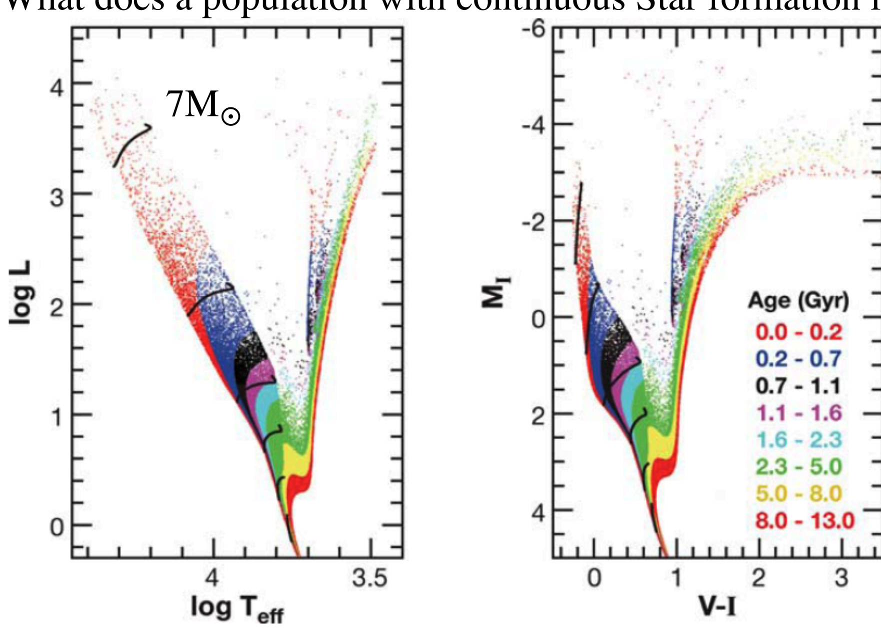
Some Especially Interesting Places in HR Diagram

- Cepheids are used to determine absolute distances
- Red giants are very luminous **with narrow range of parameters**- can be used for distance determinations (called 'tip of red giant branch' TGB)



394 GALLART ■ ZOCCALI ■ APARICIO

What does a population with continuous Star formation look like??



- **Theoretical space (left), observational space (right)**
- **Constant SFR** from 13Gyr ago to the present time, Z =0.0198, IMF slope-2.3
- **stellar evolutionary tracks for stars of masses 7, 3, 1.9, 1.5, 1.2, and1$M_\odot$**

Age Dating a SSP

- Globular clusters can be well approximated by a SSP and are frequently chemically homogenous
- With precision photometry ages can be well estimated by measuring the location of the 'turn-off'- e.g. when the star leaves the main sequence.
  - (because stars at same distance can use observed brightness, V, instead of absolute luminosity)