Astr 8100 Stellar Structure & Evolution

Introduction: H-R diagram

Spectral classes
Luminosity classes
Mass-luminosity relation

Three Sortings:

First: by evolutionary phase

1) Pre M-S : first in dynamical collapse, then quasi-hydrostatic equilibrium
Strong IR source, dust reprocessing.
Variable, strong winds: T Tauri,
FU Orionis, jets: Herbig Haro

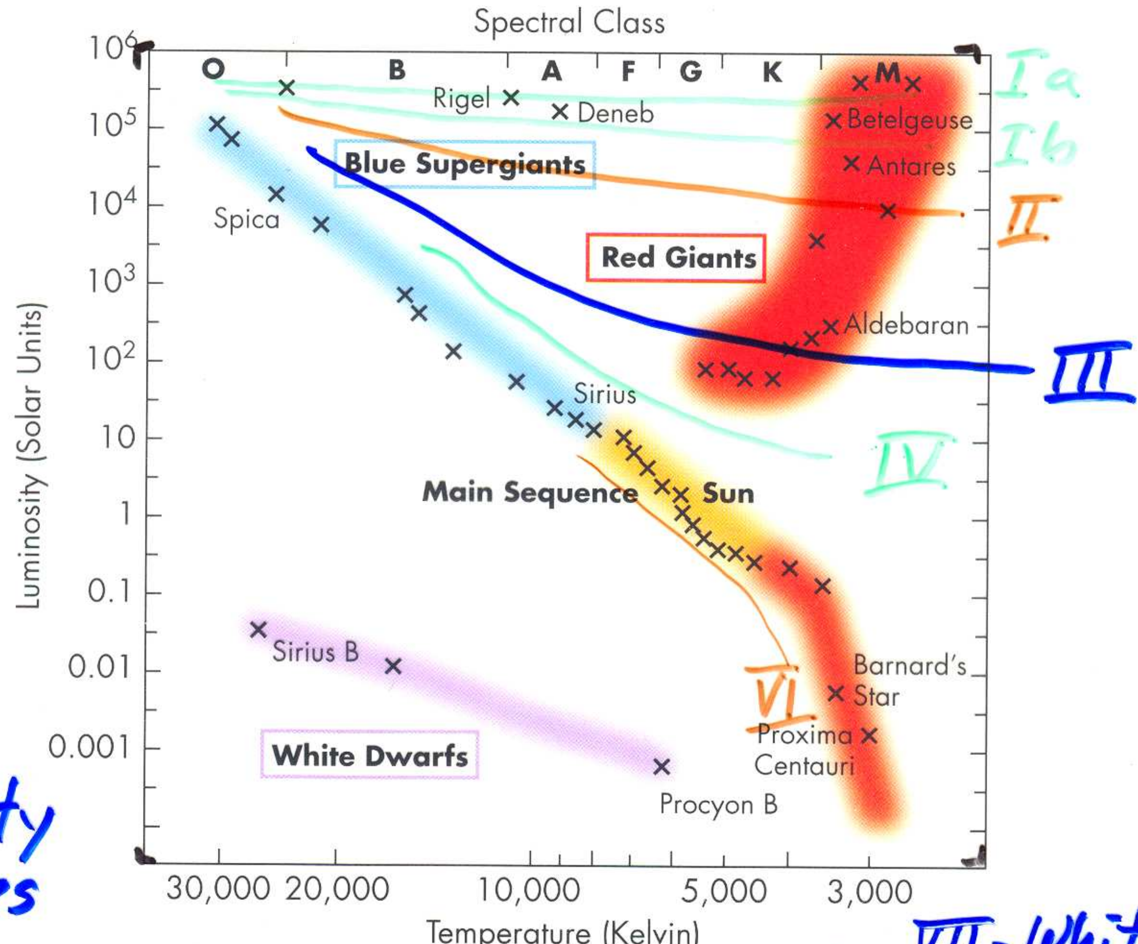
2) MS : H core burning – longest phase of ★s life ⇒ most populated part of H-R diagram.

3) Advanced phases – Red Giants:
H shell + He core burning – quiet mass ejection
Mira + Cepheid Variables

4) Late phases: C flash or core collapse leading to Supernovae – Dynamical Evol.

5) Final phases: WDs, N★s, BHs

11a



Luminosity Classes

I - Supergiants

II - Bright giants

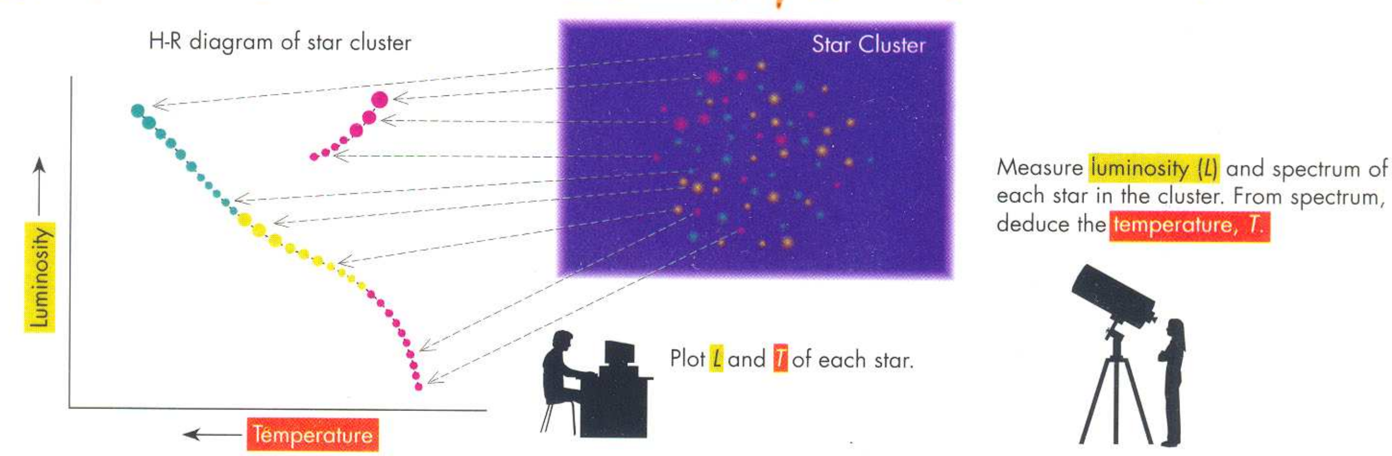
III - Giants

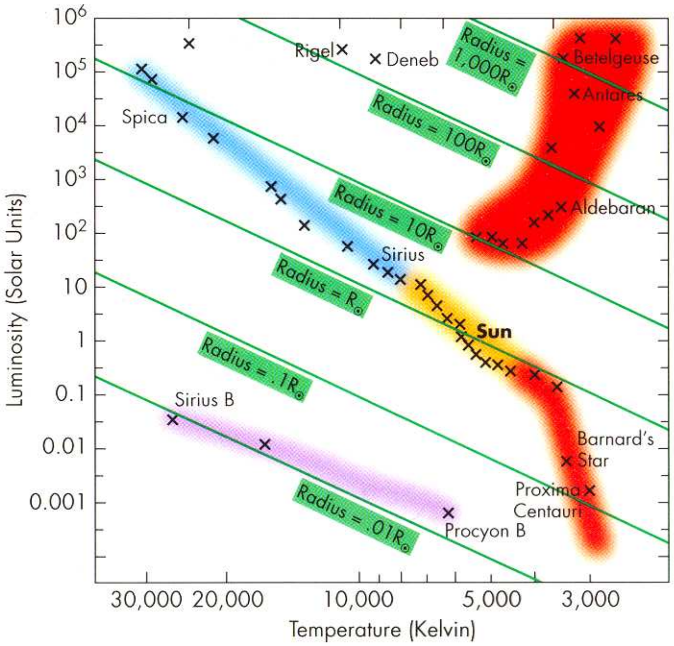
IV. Sub-giants

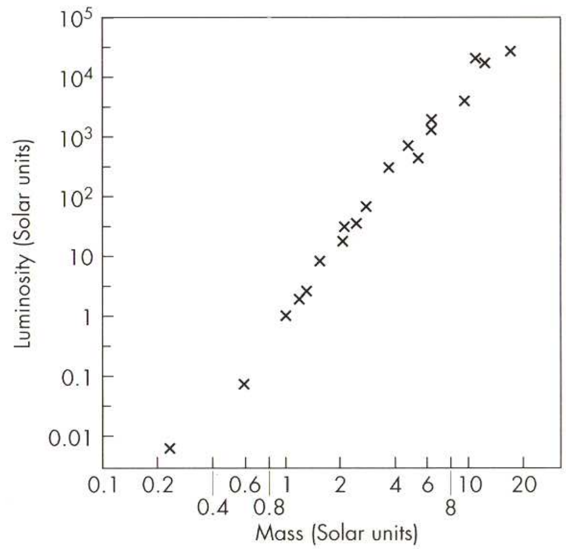
V - Main-sequence (dwarfs)

VI - Pop II - subdwarfs

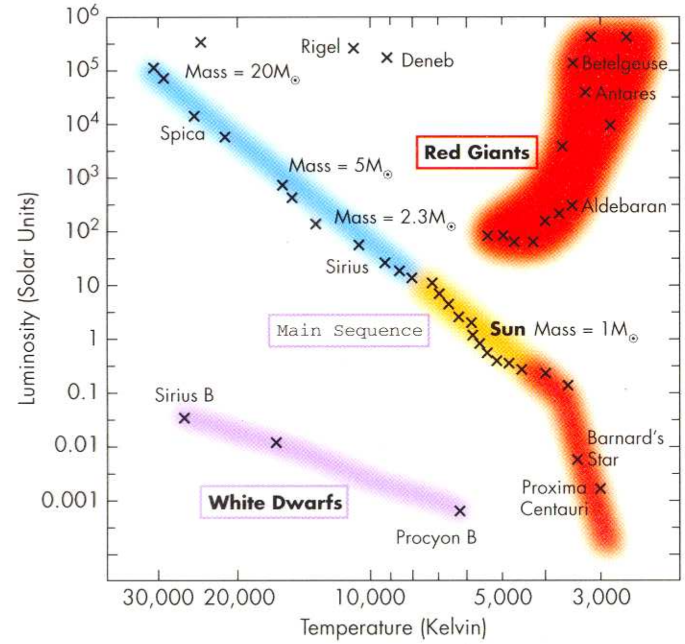
VII - White dwarfs







A



B

92 Constant radii lines, and mass-luminosity relation Figures 12.19 and 12.20

1c

Second sorting: by mass

1) Featherweight: too light to fuse H: P can stop grav. indep of T. – degenerate or solid state forces: $M \lesssim 0.075 M_\odot$ Brown dwarfs (Planets if $< 0.013 M_\odot \simeq 13 M_J$)

2) Lightweight: burn H (up to $\sim 0.3 M_\odot$) or both H + He (up to 6 or 7 $M_\odot$) Leave behind white dwarfs.

3) Middleweight: can burn C but probably degenerate ∴ C flash probable – could ⇒ fully disrupted SN or could leave N★ + type I SN

$$(6\text{-}7) M_\odot < M < (8.5\text{-}9) M_\odot$$

4) Heavyweight: C burns non-degenerately – many heavy elements produced. Likely that many ⇒ Type II SN & N★ remnant

$$(8.5\text{-}9) M_\odot < M < (\sim 30\text{-}40) M_\odot$$

5) Superheavyweight: $(\sim 30\text{-}40) M_\odot < M < (80\text{-}120) M_\odot$ Again C burns & onwards to Fe. Should ⇒ BH

Upper limit – rad'n pressure, pulsational instabilities, electron-positron pair instabilities

$L_{Edd} \simeq 1.3 \times 10^{38}\ \text{erg s}^{-1}/M_\odot$ while $L_\star \propto M_\star^{3.5}$. Theory says UML $\lesssim 80 M_\odot$ but some ★s (e.g. η Carina) $\gtrsim 100 M_\odot$

$$\text{Flux}_{rad} = \frac{L}{4\pi r^2 c} \qquad \text{Force}_{rad} = \frac{L\,\sigma_T}{4\pi r^2 c} \qquad \sigma_T \sim \frac{8\pi}{3}\left(\frac{e^2}{m_e c^2}\right)^2 = 6.7\times10^{-25}\ \text{cm}^2$$

$$\text{Force}_{grav} = \frac{m_H M G}{r^2} \qquad \therefore L_{Edd} = \frac{4\pi c\, m_H G M}{\sigma_T}$$

Third sorting: Chemical Composition (Populations)

1) Extreme Pop I - O, B $z \simeq 0.025$
2) Intermediate Pop I - $\sim 10^8$ y, Pleides $z \simeq 0.022$
3) Disk Population (I) - 10^9-10^{10} y, most ☆s $z \simeq 0.020$
4) Intermediate Pop II ($\lesssim 10^{10}$ y, High v ☆'s) $z \simeq 0.002$
5) Extreme Pop II $\gtrsim 10^{10}$ y, very hi v ☆s ($\gtrsim 100$ km/s) $z \simeq 0.0003$
6) Pop III - postulated 1st generation $z \sim 10^{-9}$

These are only averages for Pop I + Disk
∃ variations by ∼2 depending on position
in galaxy, with composition gradient ∋
higher z towards center.

Models must feed individual stellar evolution into galactic structure & evolution.

Since lightweight ☆s dominate the mass (most numerous) but not necessarily the light M/L ratios require calibration: this is particularly true.
In some spiral galaxies
In most S & all E galaxies the bulk of light comes from red (K) ☆'s - both RGs + MS so M/L comes from two classes.

Timescales

1) Free-fall or dynamical: dimensional analysis shows: $t_{ff} \sim \left(\frac{R^3}{GM}\right)^{1/2}$

Crudely: $\frac{d^2r}{dt^2} = -\frac{GM}{r^2}$ ∴ over average time of collapse

$\frac{d^2r}{dt^2} \simeq -\frac{R}{t^2} = \frac{-MG}{R^2}$, again $\Rightarrow t_{ff} = \left(\frac{R^3}{GM}\right)^{1/2}$

For the $\odot$ $t_{ff} = 1.6\times10^3\left(\frac{M}{M_\odot}\right)^{-1/2}\left(\frac{R}{R_\odot}\right)^{3/2}$ s

$= 26.6$ min as $M_\odot = 1.989\times10^{33}$ g

$R_\odot = 6.96\times10^{10}$ cm

N.B.: Pulsational periods of g-modes have similar periods $\Rightarrow P\bar{\rho}^{1/2} = G^{-1/2}$

2) Kelvin-Helmholtz – extraction of gravitational energy: $W = -\frac{Gmm'}{r}$, integrate: $W \simeq -\frac{M^2G}{R}$

$\simeq 4\times10^{48}$ erg

Now $L_\odot = 3.86\times10^{33}$ erg s^{-1} so,

$t_K = \frac{W}{L_\odot} \simeq 10^{15}$ s $\sim 3\times10^7$ yr – lifetime of $\odot$ on stored energy $\Rightarrow$ Not chemical or stored energy.

3) Fusion, w/ $\Delta E \sim 1$ MeV $\sim 10^{-6}$ erg $\Rightarrow t_{ev} \simeq 10^{10}$ y

Total energy, $E = M_\odot c^2 = 1.79\times10^{54}$ erg, but efficiency $\simeq 0.007$. But only the inner 10% by mass typically can fuse.

Binary Systems

~60% of ★s in binaries

⇒ Fundamental quantities : M, L, R !

Visual : real doubles, large separations ("Optical" are false superpositions)

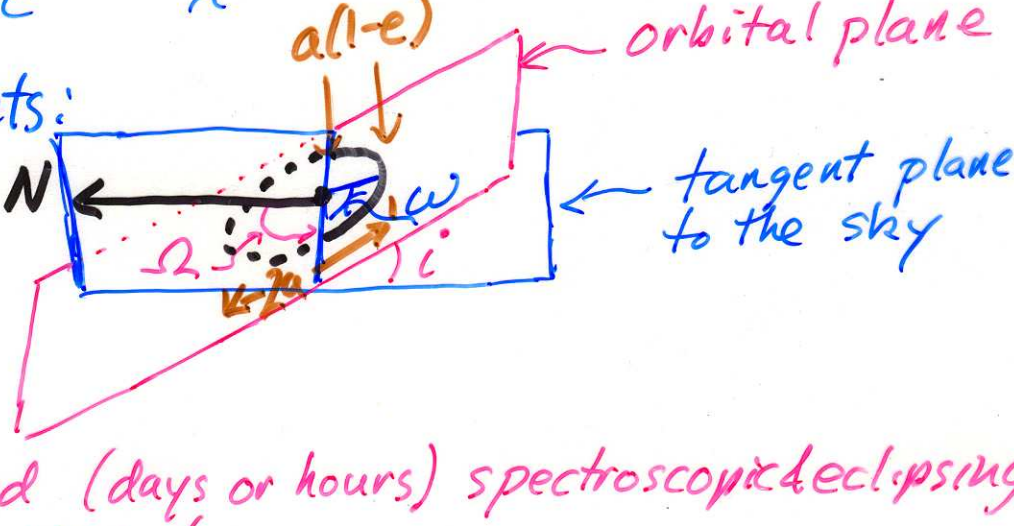
Speckle : closer separations

Eclipsing : large enough inclination & close enough so one ★ blocks another ⇒ light curves

Spectrum : see two superposed spectra ∴ comparable magnitudes but no visible orbital motion

Spectroscopic : shifts in lines due to l-o-s motion $\frac{v_{rel}}{c} = \frac{\Delta\lambda}{\lambda}$ single- or double-line

Orbital elements:



P = orbital period (days or hours) spectroscopic & eclipsing
(years) visual

i = inclination of orbital plane to tangent plane of Celestial Sphere

a = semi-major axis

e = eccentricity

T = time of periastron

Ω = ∡ of nodes: position ∡ of line of nodes (intersection of orbital & tangent planes) measured in tangent plane from N through E

ω = angle bet. direction of ascending node (when ★ crosses tangent plane while receding) and point of closest approach of ★'s (periastron).

Visual: ω of secondary; Spectroeclipsing: ω of primary so $\omega_s = \omega_p + \pi$

Absolute orbit: each ★ about CM of system, ellipses

Relative orbit (or true orbit): primary @ one focus

Apparent orbit: projected on plane of sky — also elliptical but primary no longer @ the focus.

Kepler's 3rd Law: $M_1 + M_2 = \frac{a^3}{P^2}$ with P in y, a of true orbit in AU & M's in $M_\odot$

Since most visual & spectroscopic binaries are close to ⊕ their parallaxes can be found $\Rightarrow d$ (in pc) so $a'' \to a$

$(a_\oplus = 1\,AU = 1.496 \times 10^{13}$ cm)

$$P = \frac{365.25\,(a/a_\oplus)^{3/2}}{(M/M_\odot)^{1/2}} = \frac{0.116\,(a/R_\odot)^{3/2}}{(M/M_\odot)^{1/2}} \text{ days}$$

Circular orbit: $V = \left(\frac{GM}{a}\right)^{1/2} = 437 \frac{(M/M_\odot)^{1/2}}{(a/R_\odot)^{1/2}}$ km s^{-1}

Elliptical case: $r = \frac{a(1-e^2)}{1+e\cos\theta}$

for a single-line system, best is the mass function:

$$f(M_1, M_2, i) = \left(\frac{M_2}{M_1+M_2}\right)^2 M_2 \sin^3 i = \frac{4\pi^2}{G}\frac{(a_1 \sin i)^3}{P^2}$$

If $a = a_1 + a_2$ is known $\Rightarrow M_1 + M_2$ known $\Rightarrow$ rel. bet. M_2 & i & limit on $i \Rightarrow$ bound on M_2

Information Obtainable from Binary Systems

Quanity	Visual	Spectroscopic Single	Spectroscopic Double	Eclipsin
P	✓	✓	✓	✓
a	apparent a''	$a_1 \sin i$	$a \sin i \left[\begin{array}{l} a_1 \sin i \\ a_2 \sin i \end{array}\right.$	no
e	✓	✓	✓	✓
ω	✓	✓	✓	✓
T	✓	✓	✓	✓
i	✓	no	no	✓
Ω	✓ Ambiguous w/o radial vel. measurements	no	no	no
M_1, M_2	$\left\{ \Sigma \text{ if parallax is known} \right\}$	$f(m)$	$M_1 \sin^3 i$, $M_2 \sin^3 i$	no, no
R_1	no	Estimated from knowledge of spectrum & luminosity		$r_1 = R_1/a$
Fractional uminosity $\left(\begin{array}{c} L_1 \\ L_2 \end{array}\right)$	✓	Estimated from spectrum		✓
Spectral types	✓	✓	✓	If several color available
imb darkening u_1, u_2	no, no	no, no	no, no	In principle – but only small piece of light curve is affecte
llipticity	no	no	no	In principle – in close binaries since distorted star displays more area at quadrature than conjuncti

For spect. binaries we measure:

V_0 = radial vel. of CM of system

K_1, K_2 = half-total range of radial-vel variations of brighter (fainter) ☆ [as long as fainter's spectrum is visible]