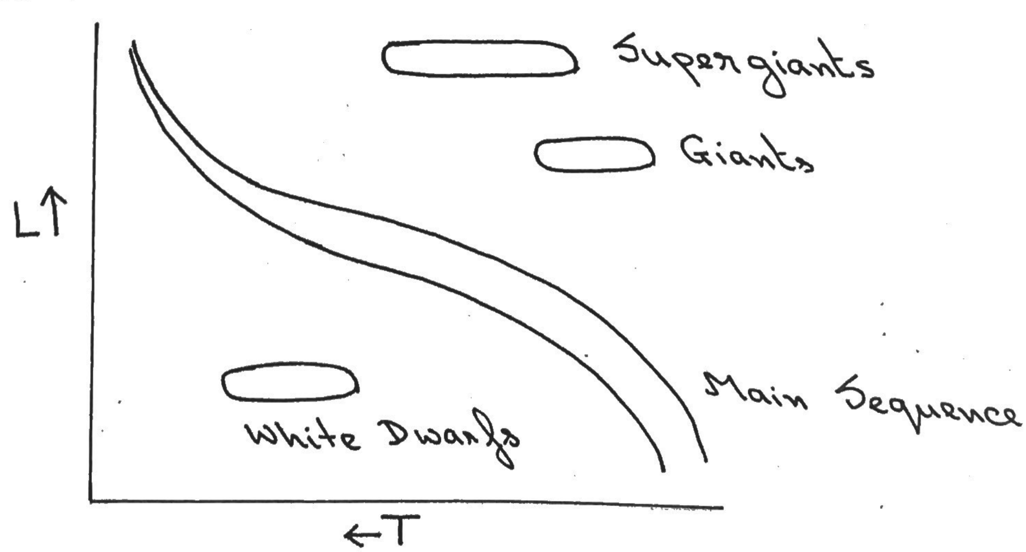
Spectral Classification

- Edward Pickering classified stellar spectra according to the strength of hydrogen lines (from strongest to weakest). He named them A, B, C ...
- Annie J. Cannon rearranged the series according to temperature : O, B, A, F, G, K, M.

Spectral Type	Temp °k	Color	Spectral Lines
O	40,000	Bluest	HeII
B	18,000	Bluish	HeI
A	10,000	Bluish-white	HI
F	7,000	White	HI + ionized metals
G	6,000	Yellowish-white	Ionized metals
K	4,000	Orangish	Neutral metals
M	3,000	Reddest	Molecules + neutral metals

Hertzsprung - Russell (H-R) diagram

Hertzsprung and Russell, independently of each other, plotted the absolute luminosities of stars versus their temperatures. They noticed that about 90% of the stars fall along a diagonal on their plot. The band of stars is called the main-sequence and the plot is called the H-R diagram. There are two other prominent groups of stars on this diagram. One of the groups has high luminosity and low temperature and these stars are called red giants. The other group has low luminosity and high temperature and these stars are called white dwarfs.



- Spectral class ≡ temperature class
The spectral class can be divided more finely.
O5....O9 B0....B9 A0....A9 F0....F9 G0....G9 K0....K9 M0....M9

- The Luminosity class is denoted by roman numerals
I : supergiants [Ia - most luminous; Ib - less luminous]
II : extreme giants
III : giants
IV : stars just above the main-sequence (sub-giants)
V : main-sequence stars (or dwarfs)
VI : sub-dwarfs (just below the main-sequence
VII : white dwarfs

- The spectral classification is made from a study of the relative strengths of spectral lines which are sensitive to temperature.

- For a given spectral type the luminosity classification is obtained by a comparison of the relative strengths of spectral lines which are sensitive to absolute luminosity. In reality the luminosity classification is made from lines which are sensitive to atmospheric pressure or surface gravity of the star.
Giants have low atmospheric pressure → narrow spectral lines
Dwarfs have high atmospheric pressure → broad spectral lines

Main - Sequence

1) The main sequence is a temperature sequence where the temperature increases from M stars to O stars.
2) The main sequence is also a mass sequence. In fact, the position occupied by a star on the main sequence is determined by the star's mass. Mass increases from M stars to O stars. The radius increases only slightly

from M stars to O stars. Most stars, however, have approximately the same density. There is a Mass-Luminosity relation for main sequence stars.

a) Low mass stars : $L \propto M^3$

b) High mass stars : $L \propto M^4$

On the average : $L \propto M^{3.5}$

Range in mass of stars : 0.08 to 100 $M_\odot$

Range in luminosity : 10^{-6} to 10^6 $L_\odot$

The minimum mass that a star could have is 0.08 $M_\odot$. You need a minimum mass for the pressure and temperature to be high enough in the core for nuclear fusion. There is no upper limit to the mass of a star. But very few stars have been observed with masses greater than 60 $M_\odot$.

Stellar Structure

- Characteristics of main sequence stars

1) Main sequence stars are in hydrostatic equilibrium.

Force (inwards) due to gravity = Force (outwards) due to pressure

pressure ≡ gas pressure + radiation pressure

Hydrostatic equilibrium is maintained at all points within the star.

2) Main sequence stars are in thermal equilibrium.

Energy flowing into a layer (inside the star) = energy flowing out of the layer

Thermal equilibrium need not be maintained at all points inside the star.

3) There is nuclear fusion of hydrogen into helium in the <u>core</u> of the star.

Low mass star (<1.5 $M_\odot$) the fusion process is the p-p chain.

High mass star (>1.5$M_\odot$) the fusion process is the C-N-O cycle.

4) Energy Transport : The energy produced in the core of the star is transported to the surface by two means - convection and radiation. In the convective mode of energy transport heat is conveyed physically from a region of higher temperature to a region of lower temperature by means of convective cells or bubbles. In the radiative mode of energy transport heat is conveyed by means of photons from regions of higher to regions of lower temperature. In the radiative transport of heat high frequency, short wavelength photons degrades to low frequency, long wavelength photons due to absorption and re-emission by the atoms inside the star.

Low mass stars have radiative cores and convective envelopes.

High mass stars have convective cores and radiative envelopes.

5) Stellar Lifetime τ on the main sequence

τ = Fuel a star has / Rate of consumption of fuel

$\tau = M / L = M / M^{3.5} = 1 / M^{2.5}$

More massive stars have shorter lifetimes! If the mass is expressed in units of the sun's mass then the main sequence life time is in units of the sun's main sequence life time, i.e 10 billion years.

- To study stellar structure we assume Russell-Vogt theorem : The equilibrium structure of a star is determined uniquely by its mass and chemical composition.
- We divide the star into a large number of concentric shells. We then solve a set of four equations connecting pressure P, mass M, luminosity L, and temperature T with radius R for each shell. A stellar model would consist of a table of values giving the pressure, mass, luminosity, temperature, and chemical composition as a function of radius from the center of the star.

- An example of the solar structure is illustrated in the table below

Central values in the sun

Temperature $T_c = 15 \times 10^6$°k

Density $\rho_c = 160$ gm / cm^3

Pressure $P_c = 3.4 \times 10^{17}$ dyn / cm^2

T = temperature, ρ = density, P = pressure, M_r = mass within radius r, L_r = energy generation (luminosity) within radius r. R⊙, M⊙, L⊙ = mass, radius, energy generation (luminosity) of the whole sun

	r	T	ρ	M_r	L_r	logP
R⊙	10^3km	10^6°k	gm/cm^3	M⊙	L⊙	dyn/cm^2
0.00	0	15.5	160	0.000	0.00	17.53
0.04	28	15.0	141	0.008	0.08	17.46
0.1	70	13.0	89	0.07	0.42	17.20
0.2	139	9.5	41	0.35	0.94	16.72
0.3	209	6.7	13.3	0.64	0.998	16.08
0.4	278	4.8	3.6	0.85	1.00	15.37
0.5	348	3.4	1.00	0.94	1.000	14.67
0.6	418	2.2	0.35	0.982	1.000	14.01
0.7	487	1.2	0.08	0.994	1.000	13.08
0.8	557	0.7	0.018	0.999	1.000	12.18
0.9	627	0.31	0.0020	1.000	1.000	10.94
0.95	661	0.16	4×10^{-4}	1.000	1.000	9.82
0.99	689	0.052	5×10^{-5}	1.000	1.000	8.32
0.995	692.5	0.031	2×10^{-5}	1.000	1.000	7.68
0.999	695.3	0.014	1×10^{-7}	1.000	1.000	6.15
1.000	696.0	0.006	0.0	1.000	1.000	-