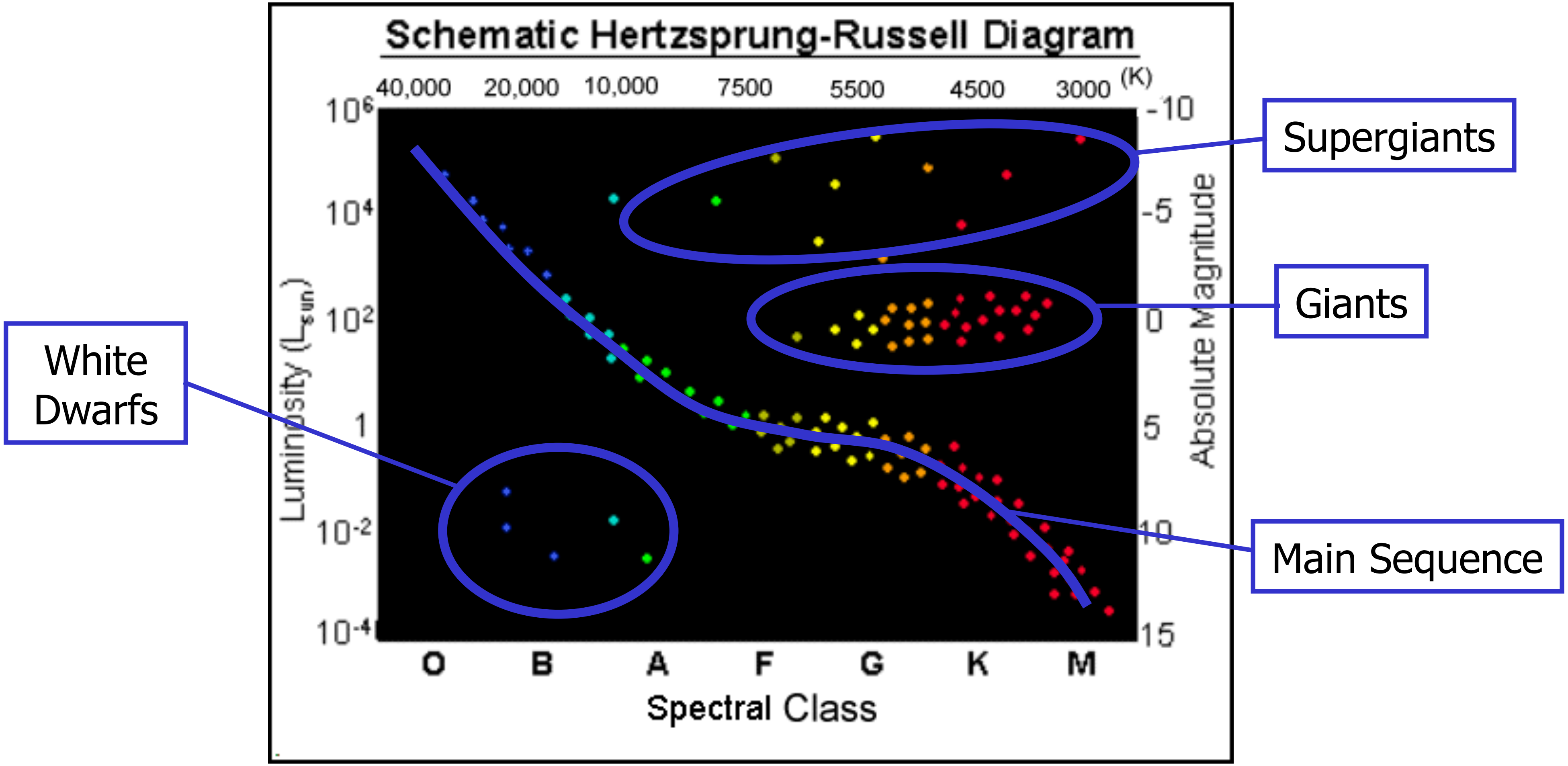
Stellar spectra & spectral types

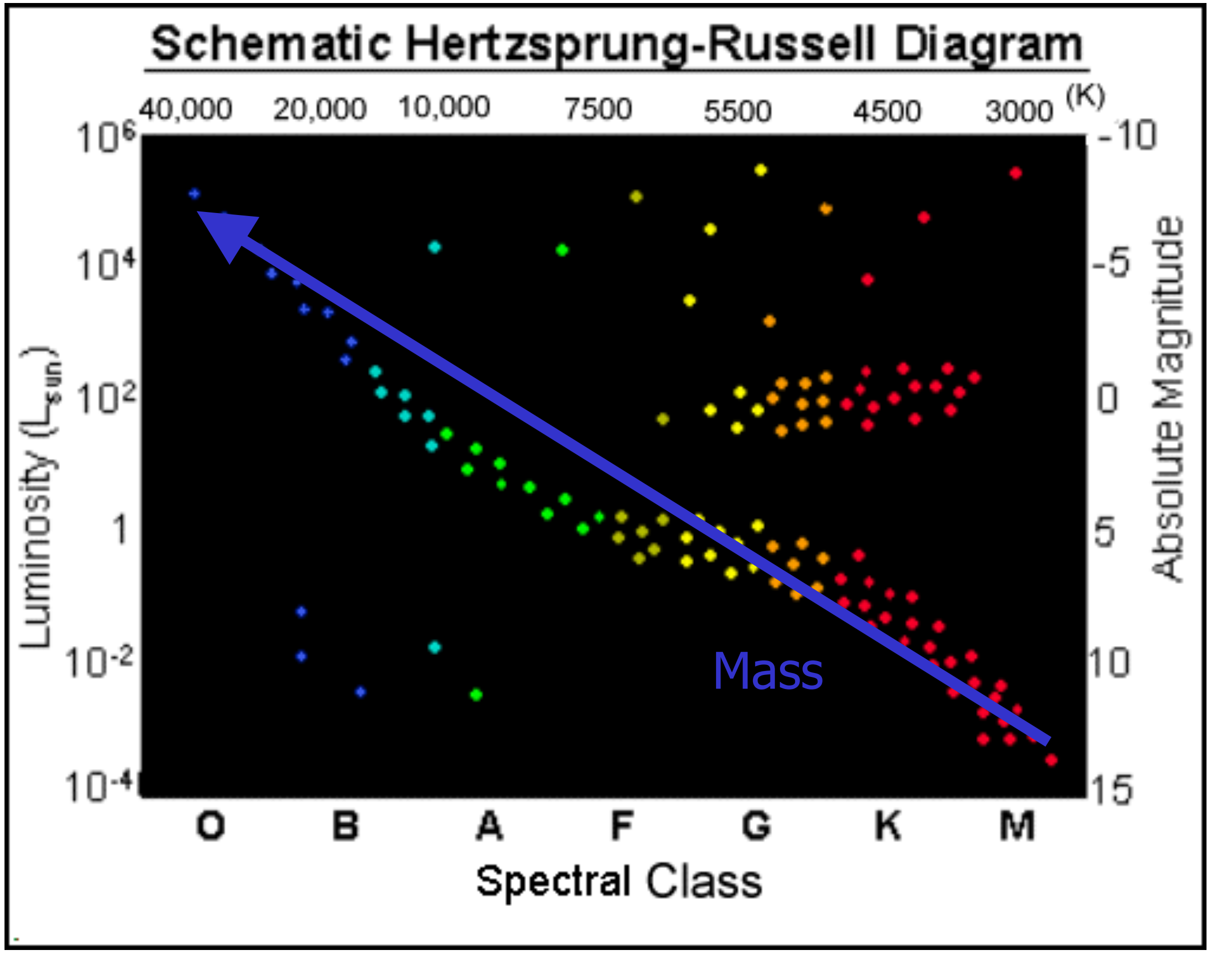
Spectral Type	Principal Characteristics	Spectral Criteria
O	Hottest bluish-white stars; relatively few lines; He II dominates	Strong He II lines in absorption, sometimes emission; He I lines weak but increasing in strength from O5 to O9; hydrogen Balmer lines prominent but weak relative to later types; lines of Si IV, O III, N III and C III
B	Hot bluish-white stars; more lines; He I dominates	He I lines dominate. With max strength at B2; He II lines virtually absent; hydrogen lines strengthening from B0 to B9; Mg II and Si II lines
A	White stars; ionised metal lines; hydrogen Balmer lines dominate	Hydrogen lines reach max strength at A0; lines of ionised metals (Fe II, Si II, Mg II) at max strength near A5; Ca II lines strengthening; weak lines of neutral metals appear
F	White stars; hydrogen lines declining; neutral metal lines increasing	Hydrogen lines weakening rapidly while H and K lines of Ca II strengthen; neutral metal (Fe I and Cr I) lines gaining on ionised metal lines by late F.
G	Yellowish stars; many metal lines; Ca II lines dominate	Hydrogen lines very weak; Ca II H and K lines reach max strength near G2; neutral metal lines (Fe I, Mn I, Ca I) lines strengthening while ionised metal lines diminish; molecular band of CH becomes strong
K	Reddish stars; molecular bands appear; neutral metal lines dominate	Hydrogen lines almost gone; Ca lines strong; neutral metal lines very prominent; moleular bands of TiO beging to appear by late K
M	Coolest reddish stars (late M can be brown dwarfs); neutral metal lines strong; molecular band dominate	Neutral metal lines very strong; molecular bands prominent, with TiO bands dominating by M5; vanadium oxide bands appear
L	Cool star/brown dwarf with T ~2000 K and dusty atmospheres	TiO/VO bands disappearing, Na I/K I lines increase in strength, as do hydride lines.
T	Cool substellar brown dwarfs with T ~ 500-1000 K, clear atmospheres	Hydride lines reduce in strength, absorption from H2O and CH4 becomes more important

Decomposing the H-R diagram



Stars appear in discrete groups in the H-R diagram (cf the comparative planetology in the solar system lecture)

Mass-luminosity law & the Main Sequence



The mass-luminosity law applies to the *main-sequence* & this means that the main sequence is ordered by mass.

Low-mass low-luminosity stars at the bottom and high-mass high luminosity stars at the top.

Main sequence runs from ~ 0.08 – 100 $M_\odot$)

For stars with $M < 0.43\ M_\odot$: $L = 0.23 \times M^{2.3}$

For stars with $M > 0.43\ M_\odot$: $L = M^{4.0}$

Average relation (all stars): $L = M^{3.3}$

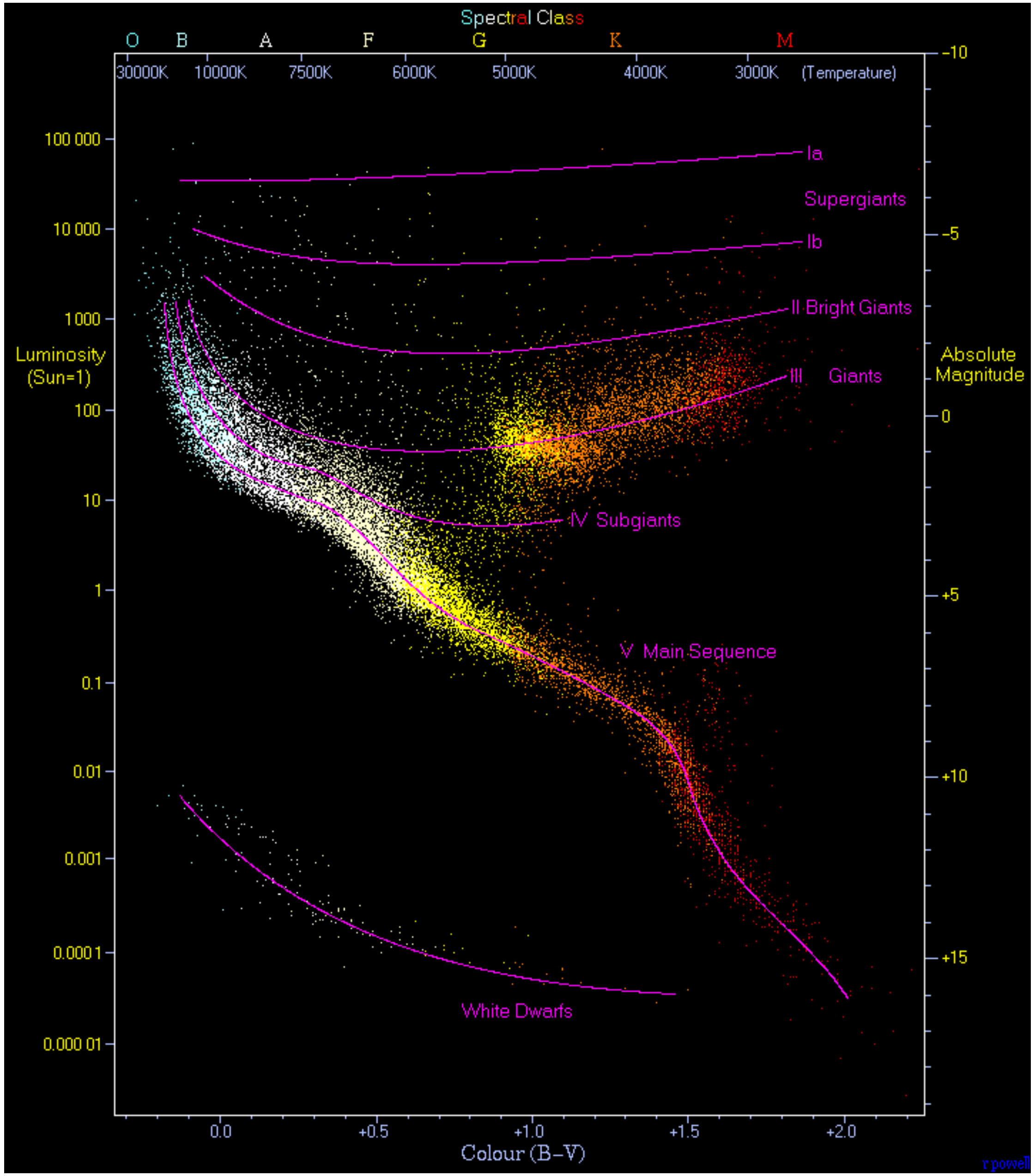
(L in $L_\odot$, M in $M_\odot$)

The H-R diagram in practice: stellar distances

If we know the T_{eff} of the star from the spectral class and the radius from the width of the lines, then using Eqn. (1) we can work out the luminosity of the star.

In 1937 Morgan & Keenan refined the Harvard classification system to include *luminosity classes.* The M-K system has 5 classes ranging from Ia/b (supergiants) to V (main sequence).

The Sun is a G2 V star.



The H-R diagram in practice: stellar distances

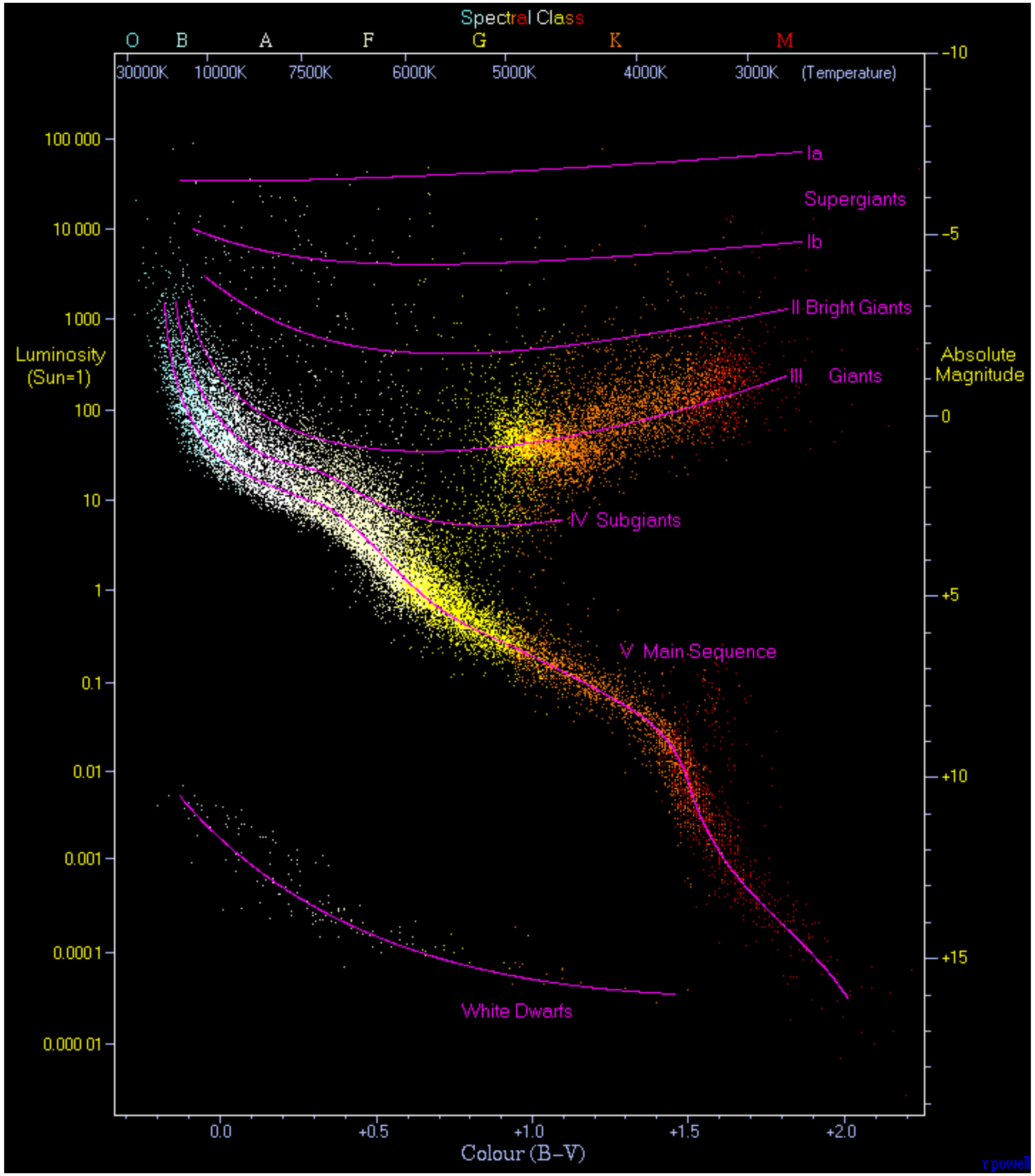
So how does this work for stellar distances?

Armed with the M-K class of a star (identified from its spectrum), we can look at the H-R diagram to find out what the *absolute magnitude* of the star should be.

Then we compare the absolute magnitude (M) from the H-R diagram to the apparent magnitude (m) of the star measured at the telescope.

$m - M = 5\log(d) - 5$,

So from this we can evaluate the distance *d.*



An example

Take the star Altair as an example. Altair is an A7 V star with an apparent V magnitude of m=0.77 (according to the SIMBAD database).

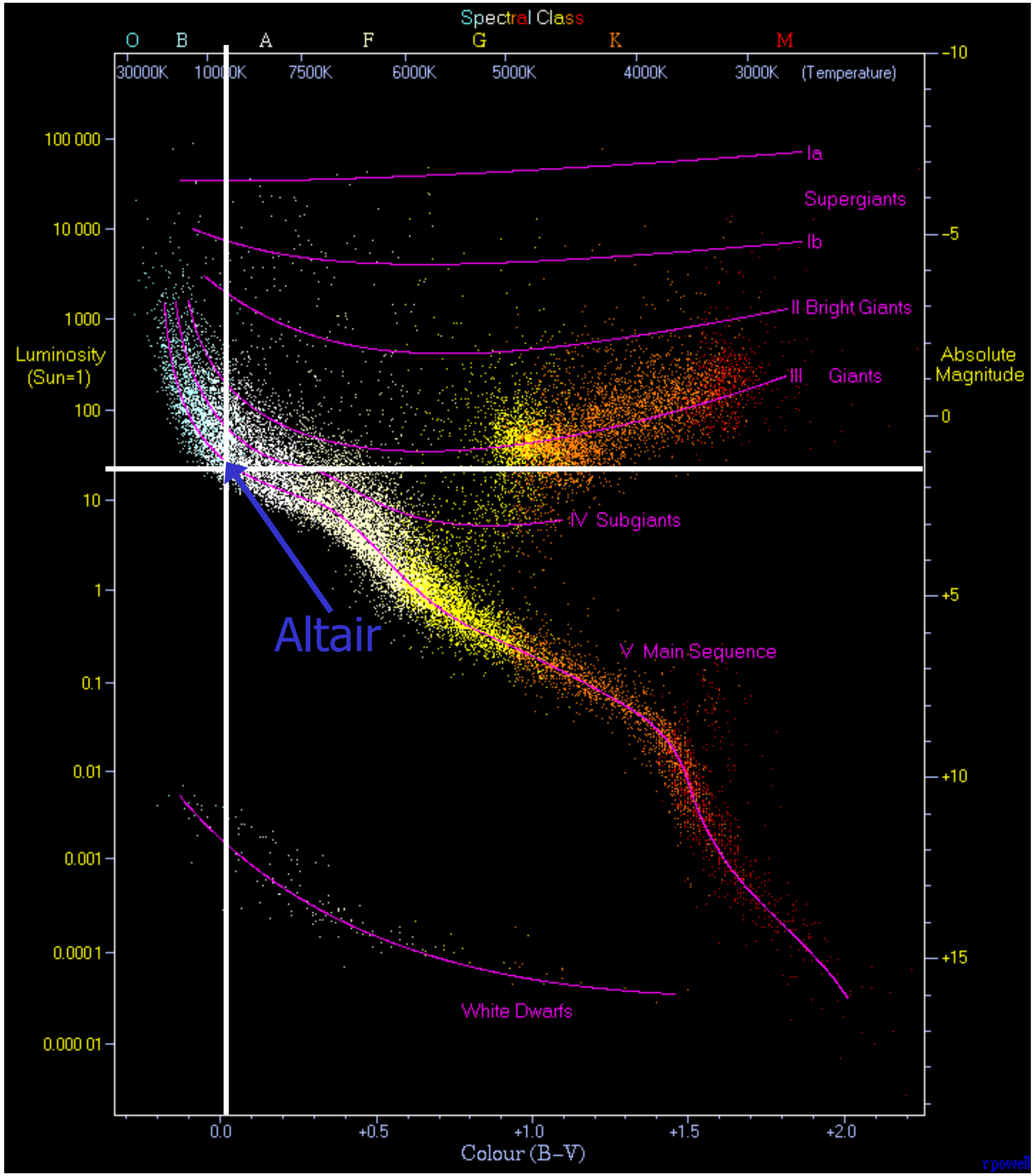
From the H-R diag, M=+1.5, so 0.77-1.5 = 5 log(d) – 5

log(d) = 0.754 → d = 7.1 pc

From stellar parallaxes we know that the true distance to Altair is 5.1 pc.

Due to scatter in H-R diagram distances are only accurate to ~ 50%.

This method is known as *spectroscopic parallax*.



The H-R diagram in practice: stellar evolution

We know that the main sequence lifetime $t_* = M_*^{-2.3}$, so stars don't stay on the main sequence forever. Apart from M stars whose main-sequence lifetime is longer than the age of the universe…

What happens to a star when it leaves the main sequence?

This ultimately depends upon the mass of the star which impacts its capacity to burn elements beyond Carbon in its core.

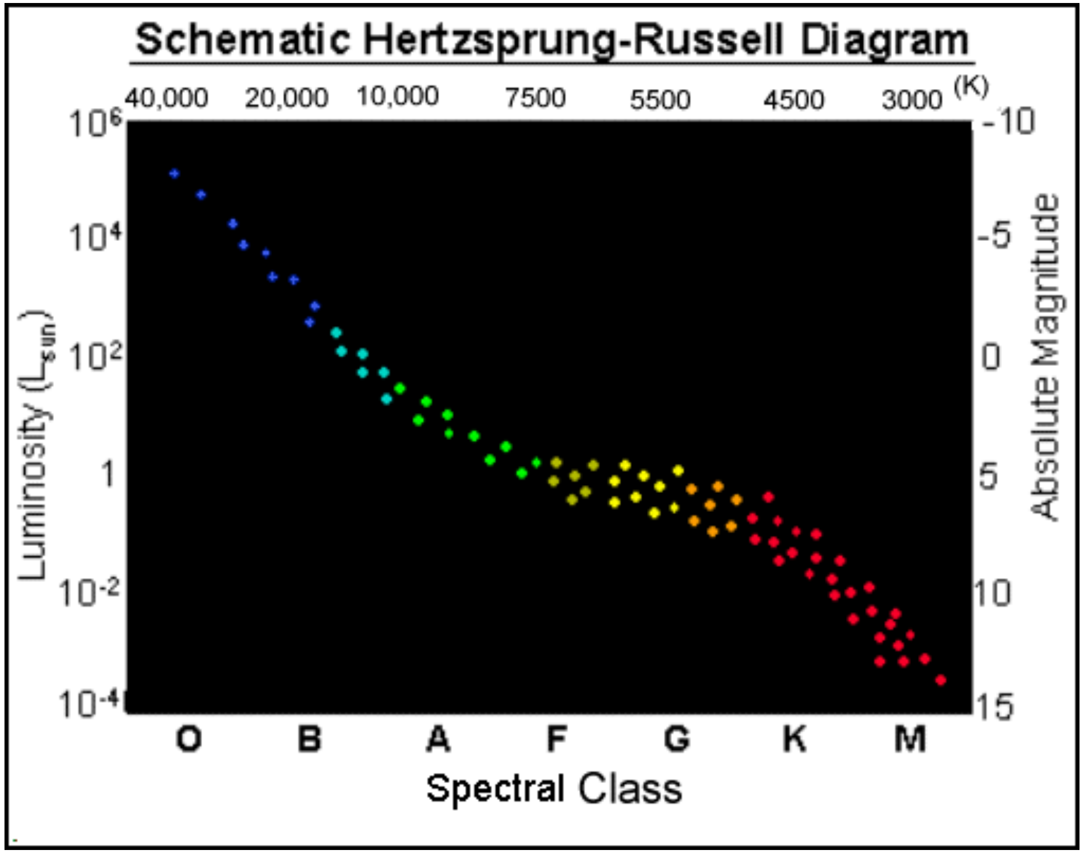
- High-mass stars become giants/supergiants and then explode as supernovae
- Low-mass stars become giants and then white dwarfs.

High-mass is $\geq 10\ M_\odot$ and low-mass is $\leq 5\text{-}10\ M_\odot$

The important point is that the position of a star on the H-R diagram *changes* as the star evolves.

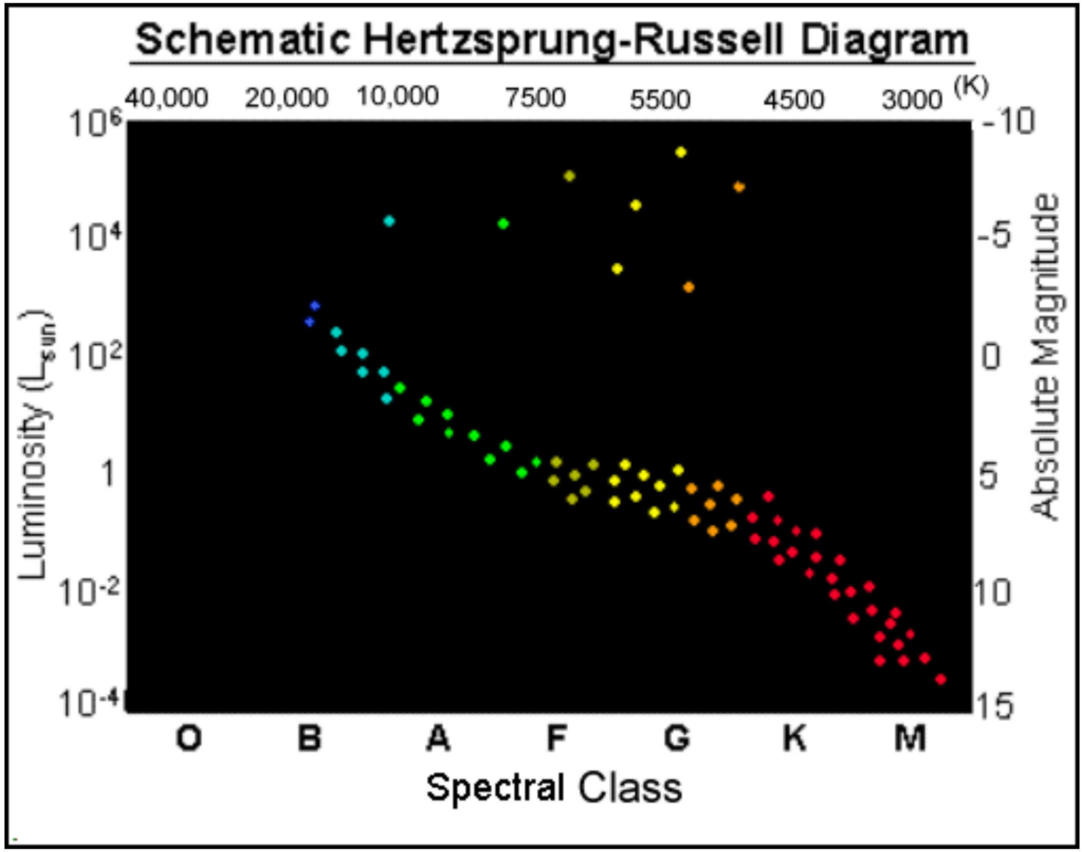
Stellar evolution & cluster ages

Consider observing a cluster of stars that all formed at the same time. What would the corresponding H-R diagram look like?



Initially, we would just see main sequence stars as none of the stars have become giants yet.

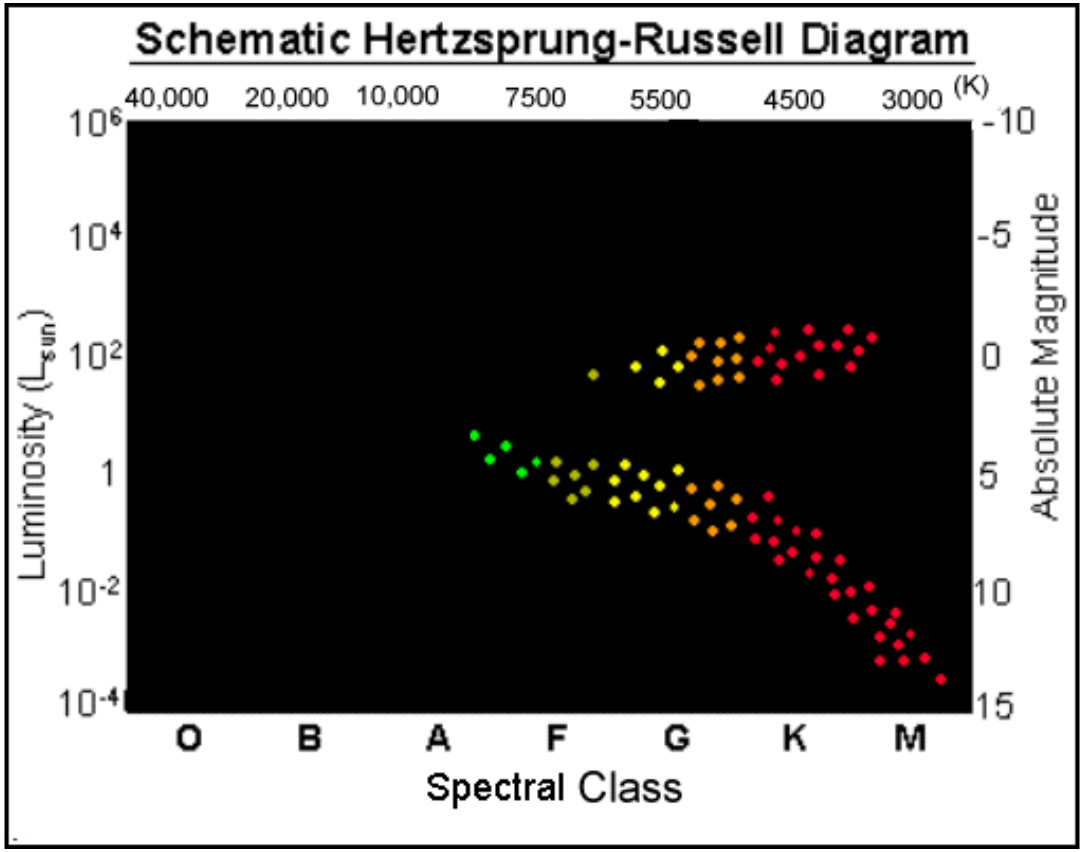
Stellar evolution & cluster ages



After about 10^7 years all the OB stars have begun to move off the main sequence to become supergiant or giant stars.

Lower mass stars are still on the main sequence.

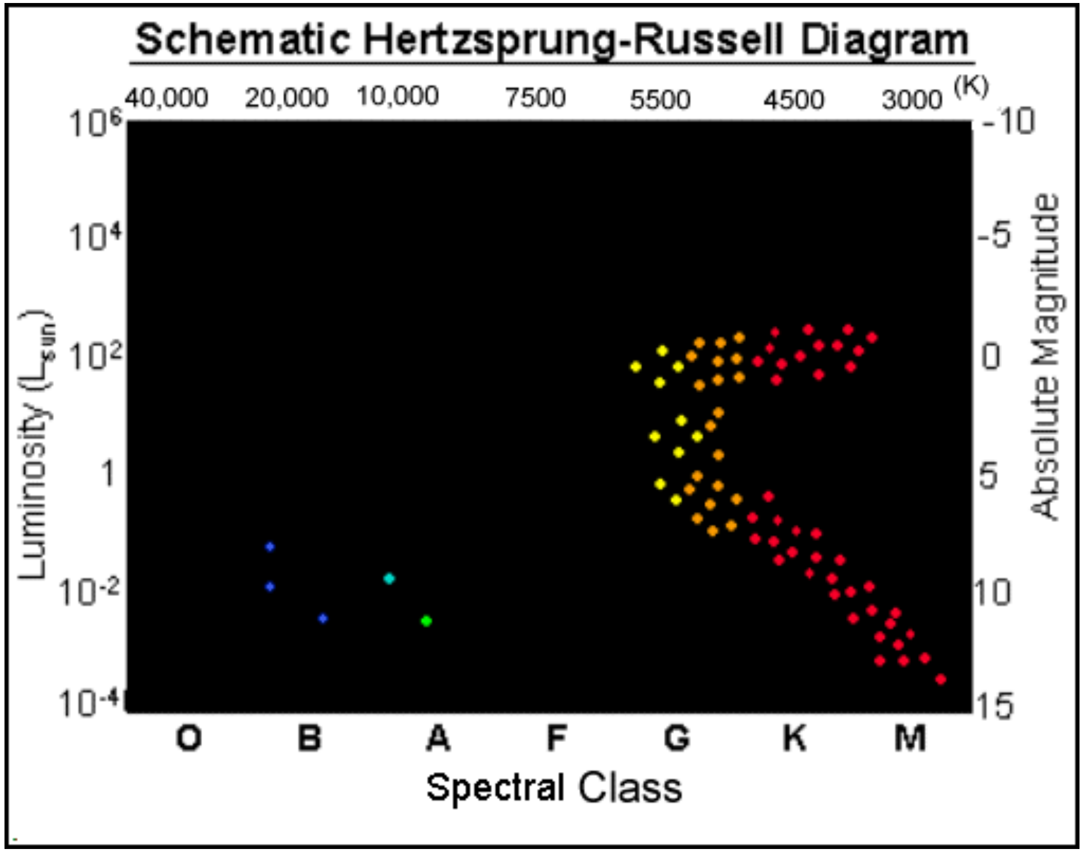
Stellar evolution & cluster ages



After about 10^8 years all of the OB stars have evolved through the giant stage and exploded as supernovae.

Some of the A stars are in the process of reaching the giant stage.

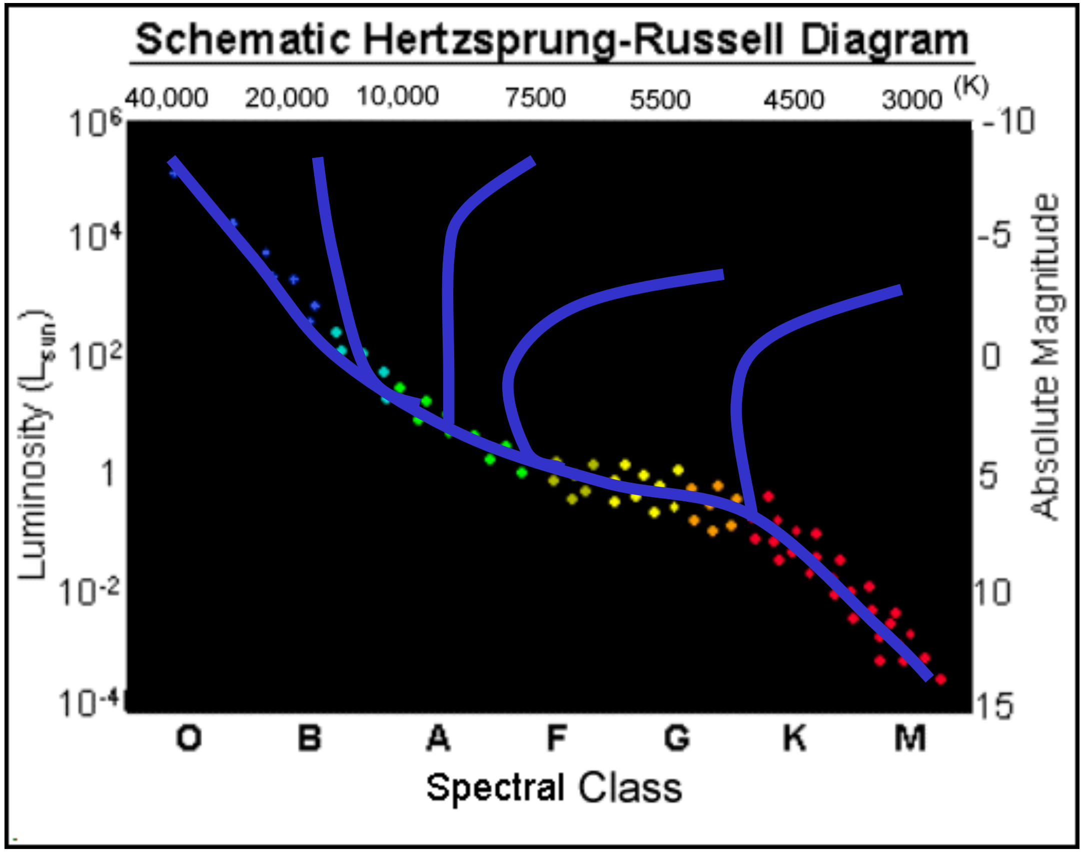
Stellar evolution & cluster ages



After about 10^9 – 10^{10} years the F and G stars are beginning to reach the giant stage.

The F and A stars have been through the giant phase, have run out of hydrogen or helium to fuel their nuclear fusion and have collapsed to become white dwarfs

Isochrones on the H-R diagram



We can fit lines to an H-R diagram of a cluster for constant ages – these lines are known as isochrones.

By measuring the “turnoff” point where main sequence stars of a particular spectral type have become giants it is possible to determine an age for the cluster.