Upcoming Astronomy-themed Talks and Events

Thursday, 2/6, 3:45-5:00p Astronomy Colloquium – Phys-Astr A102 – Sally Oey (Michigan) – “Suppressed Superwinds: A New Paradigm for Extreme Massive-Star Feedback”.

Last week we turned our attention to what we can observe from stars – Apparent Brightness, Position and Motion, Colors (in all kinds of light), and Absorption and Emission Lines – and how to use that information to learn other things we want to know about stars like their Luminosity, Distance, Temperature, Radius, Mass, and Age.

How do we go from that first list to the second?

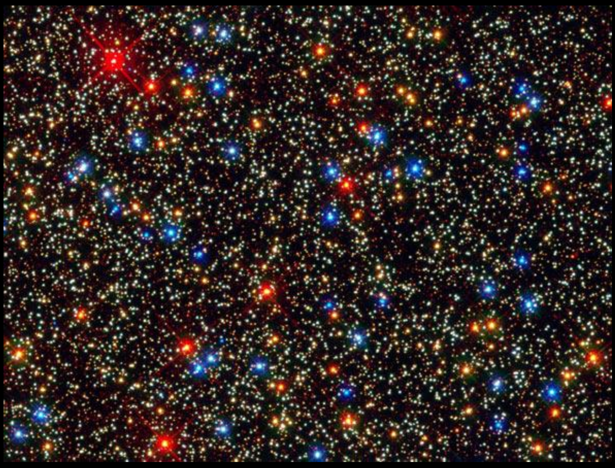
Distance

by measuring the star's *parallax*;
by knowing the luminosity and measuring apparent brightness (*standard candle method*).

Luminosity

by knowing the distance and measuring apparent brightness.

$$\text{App Bright} = L / 4\pi d^2$$



Temperature can be estimated in a relative way by the visual colors of stars. Redder stars have colder atmospheres while bluer stars have hotter atmospheres.

But a far more precise approach is by measuring the *spectral type*.

O B A F G K M (L,T)

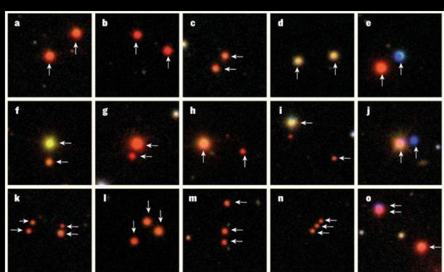
50,000 K ← 3,000 K

Temperature

Sirius
Spectral Type A

Alpha Centauri
Spectral Type G
(so is our Sun!)

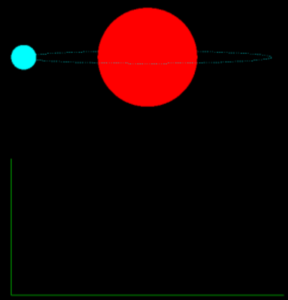
Proxima Centauri
Spectral Type M



Sample of multiple star systems from Stassun, 2012.

Animation of two stars orbiting each other.

Mass is most accurately measured by observing a star moving under gravity, orbiting another star. Fortunately such arrangements tend to be quite common – almost half of all stars like the Sun are in multiple star systems!

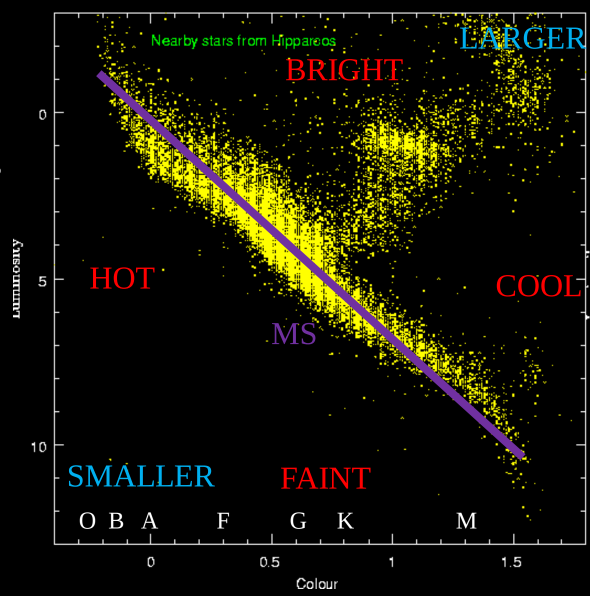


$$L = 4\pi R^2\sigma T^4$$

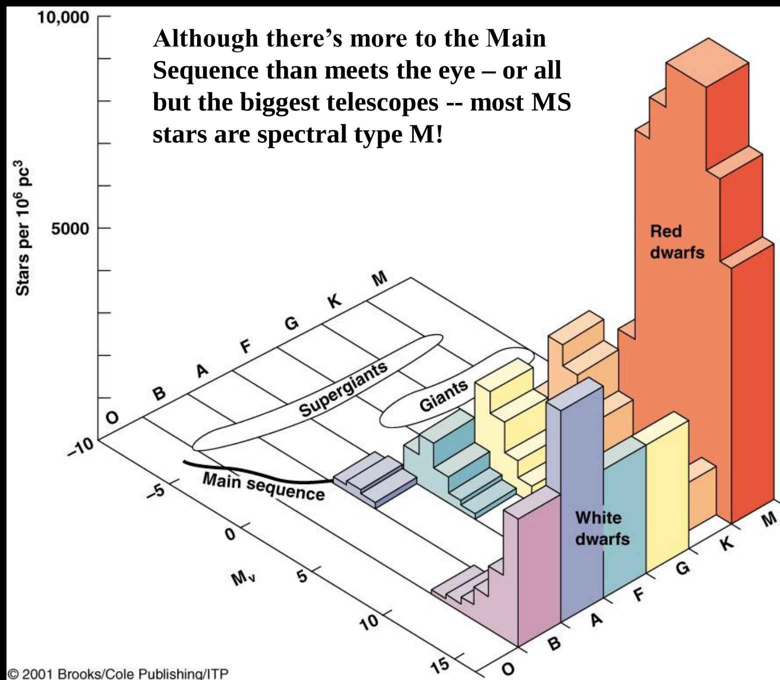
Radius is even more difficult to directly measure – you need binaries that actually *eclipse* each other, as illustrated in the animation on the left.

But if you know a star’s luminosity and temperature, you can use well-known laws of thermal radiation to estimate the star’s size fairly accurately.

The luminosities and temperatures of stars also let you make ***H-R Diagrams***, and we finished last time noting the many patterns in such plots.



Although there’s more to the Main Sequence than meets the eye – or all but the biggest telescopes -- most MS stars are spectral type M!



What’s going on? Why are there so many M dwarfs? Does the star formation process strongly favor the production of such stars? Or is there some other process at work ‘removing’ hotter and more luminous stars from the populations we observe?

The answer requires us to know how stars change over time, and therefore the ***ages*** of different stars – but this is by no means easy. All stars “live” a very long time (billions of years in most cases!), and their observed properties generally do not change significantly on human timescales – so it’s not possible to watch any one star “age” in any meaningful way.

To gain clues as to how stars might be changing over the course of their ‘lives’, we study large *populations* of stars and perform ‘demographic’ studies of those populations. With large enough samples, we can be confident that we’re seeing both younger and older stars – and then look for ways to determine which are which!

Just as in human demographics, this can be simplified by studying unique, isolated populations – which yield insights into both the similarities and differences that can occur in populations.

Fortunately, nature provides such specialized groups to astronomers in the form of **star clusters**.

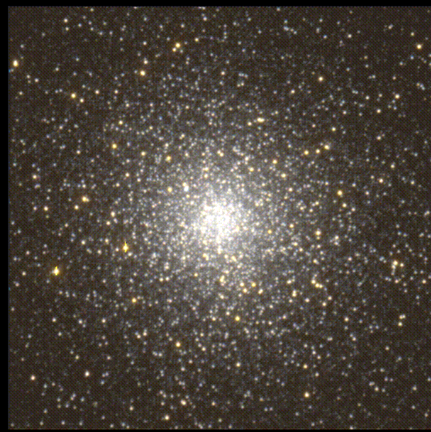
There are two primary categories of these clusters: “Open Clusters”, with irregular, “open” shapes, containing hundreds to thousands of stars, with gas and dust often seen in the space between the stars in the cluster…

Pleaides

…and "Globular Clusters", so-named because of their pronounced spherical ("globe-like") shape. These contain far more stars than open clusters – 10^5 stars or more – and very little gas or dust is seen between those stars.

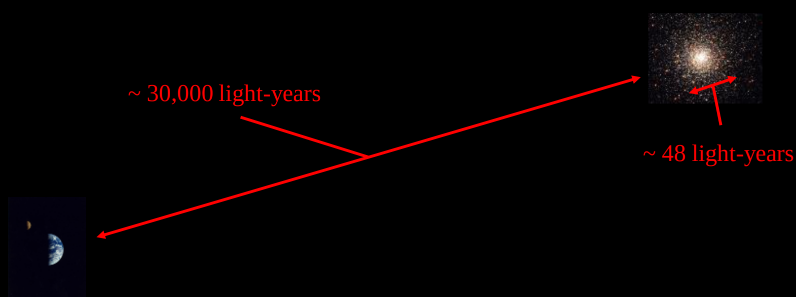
M80

Omega Centauri



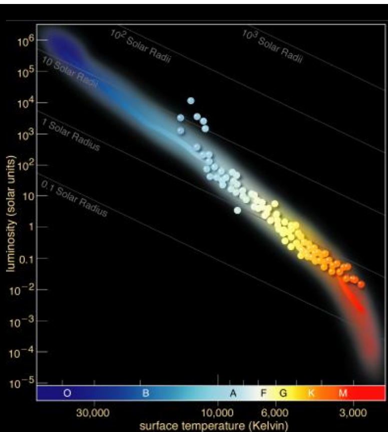
47 Tucanae

Both types of cluster are very useful for studying stellar properties, for two important reasons.

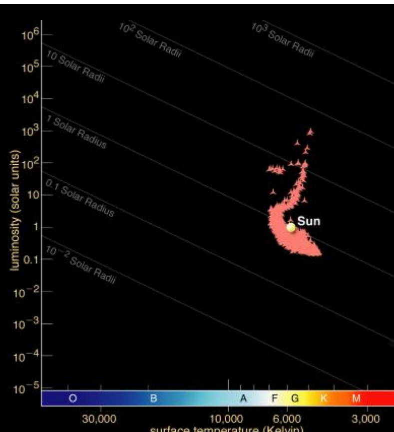


Since all the stars in the cluster are at (roughly) the same distance from us, we can compare their *apparent* brightnesses to each other as though they were *absolute* brightnesses. This allows us to plot a reliable H-R diagram of the cluster, knowing that the brighter stars in the cluster really are ***more luminous***, and not just closer to us!

Further, since all the stars in a cluster form within ~ 100 million years of each other, they are very approximately all the same age, at least in stellar terms. So our H-R diagram of a cluster is a “snapshot” of what a group of stars – all of very nearly the same age – look like.



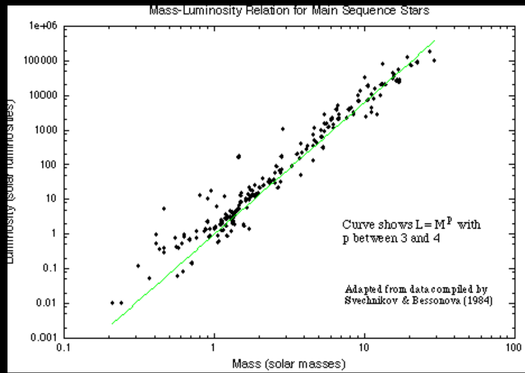
Open Cluster
H-R Diagram – the Pleiades



Globular Cluster
H-R Diagram – Palomar 3

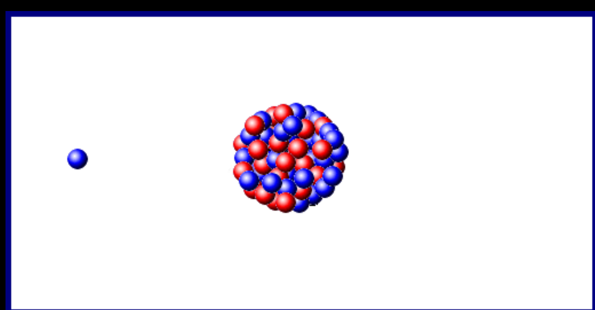
In general, the H-R Diagrams of globular and open clusters are very different from each other – suggesting very different ages. Where are the bright B and A-type main sequence stars in the Globular Cluster on the right?

The key to this age-related difference is found in another trend seen amongst stars in our H-R diagrams – the ***mass-luminosity relationship***. Brighter main sequence stars are much, *much* more massive than the less luminous stars on the main sequence.

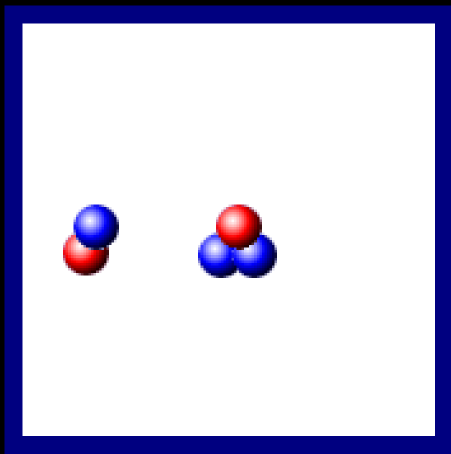


The mass-luminosity relationship for main sequence stars.

The reason behind this relationship between mass and luminosity in stars first began to become clear in the early 20th century, when physicists like Einstein revealed that atoms possess a type of *potential energy* based only on how massive they are. This ***mass energy*** can be changed by altering the atom's mass, via the processes of ***fission*** and ***fusion***.

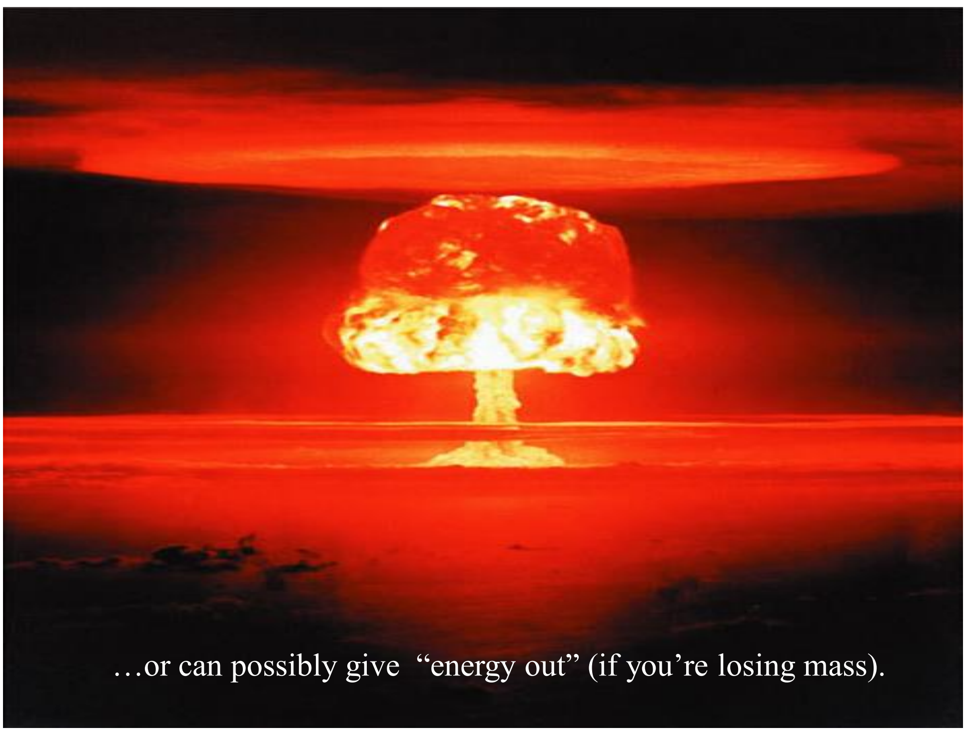


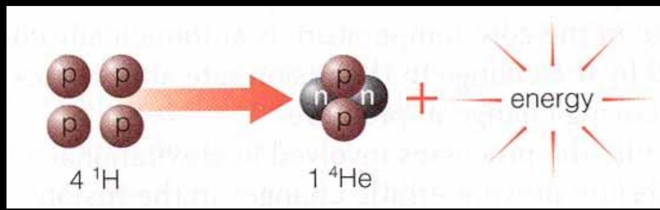
Fission – Heavier element split into multiple lighter elements.



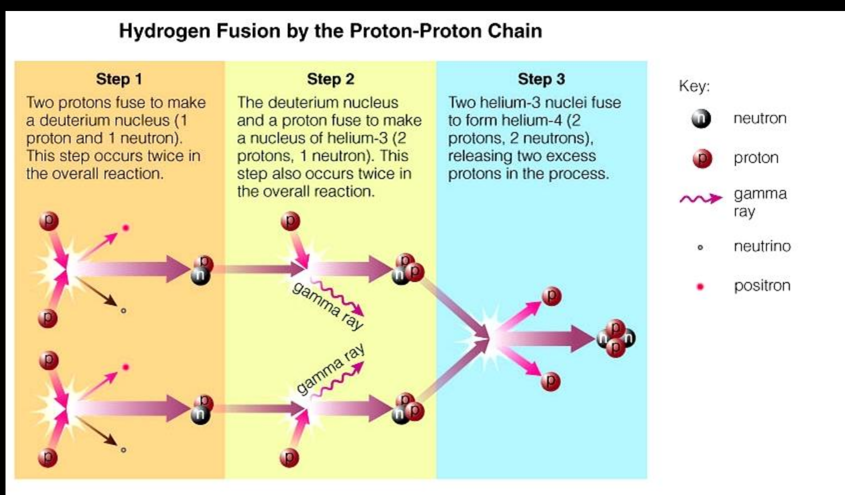
Fusion – Lighter elements merge to form a heavier element.

Note that the atoms that go into either of these reactions ***will not*** have the same overall mass energy as the atoms that come out – depending on which types of atoms go into the process, the new atoms produced can have less mass energy, or more. This means either fusion or fission can require energy to be put in (because you're adding mass)…



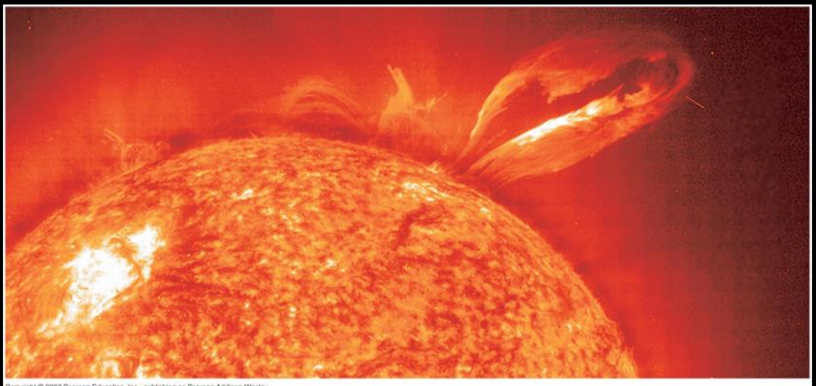


In the early 1920's, it was suggested that deep in a star's core, 4 H nuclei could be forced to fuse into 1 He nucleus via a process called the *proton-proton chain*. This natural process generates energy because the He nucleus has less mass than the 4 H nuclei – that 'lost' mass energy is converted primarily into high-energy photons and tiny particles called neutrinos which stream away from the star's core.

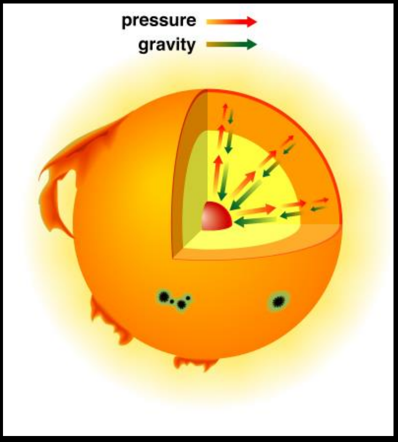


The primary process in a *bit* more gory detail. There are actually many more subtleties to this that are beyond the scope of this course!

Fortunately, only a small amount of mass is transformed into energy – and the Sun is crazy huge! Despite ‘losing’ over 4 million tons of mass per second, ***every second*** for over 5 billion years, the Sun has still only used up less than 0.1% of its total mass.

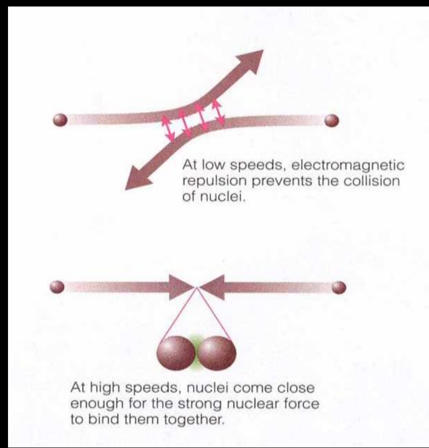


For a star of the Sun’s mass, this process provides enough energy to keep it stable and shining for a total of 10 billion years.



Core fusion generates enormous ***thermal pressure***, kept in check only by the inward force of ***gravity***. Deep inside the Sun’s core the pressure from the heat is strongest, and the forces of gravity – from the mass of the Sun ‘above’ the core – is also strongest. Near the surface, where the gravitational pressure is weakest, the thermal pressure is also weakest. This balance is called **gravitational** (or *hydrostatic*) **equilibrium**, and its details set the Sun’s size.

Fusion itself only occurs in the Sun’s core region. Recall that all nuclei are positively charged – these electromagnetic force causes nuclei to repel each other. For fusion to occur, nuclei must be moving fast enough to overcome this repulsion.
Only the central region of the Sun has sufficiently high temperatures and pressures to bring nuclei close enough to each other for the ***strong nuclear force*** to bind them together.



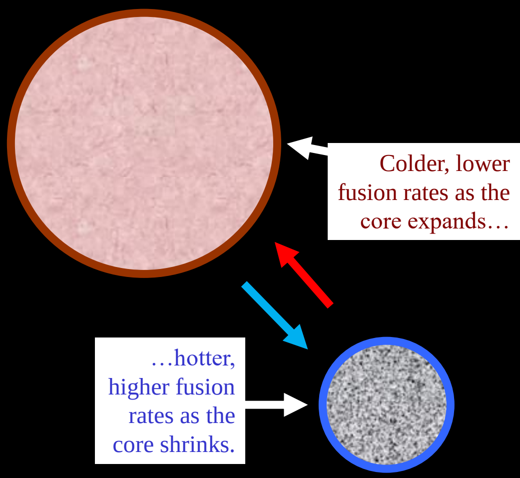
$$Fusion\ Rate\ (G\ spectral\ type, Main\ Sequence)\ \propto T^{4}$$

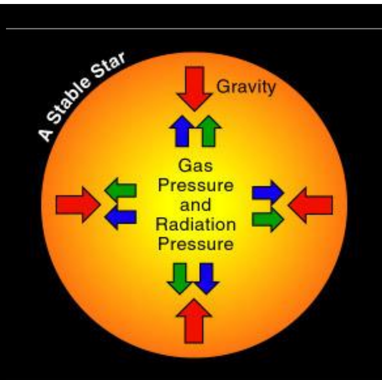
$$Fusion\ Rate\ (A\ spectral\ type, Main\ Sequence)\ \propto T^{20}$$

$$Fusion\ Rate\ (B\ spectral\ type, Supergiant)\ \propto T^{41}$$

Because of this ‘need for speed’, the rate at which fusion reactions occur depends *strongly* on temperature – the higher the temperature, the faster the fusion rate. Faster fusion rates also mean more energy produced, and you might imagine that this situation could run away on itself catastrophically as temperatures and fusion rates spiral upwards together.

However, as energy production in the core varies, regions in the core also naturally expand in response to variations in thermal pressure – and this ***cools*** those areas, causing fusion rates to slow back down! As any regions of the core cool and fusion rates drop, they naturally re-collapse and ***heat*** back up – keeping fusion rates from ever going too low!





Nevertheless, if a star has <u>more</u> mass in general, it means there is always more weight due to gravity from that star’s outer layers that must be supported by pressure from its core – so nuclear fusion rates in more massive stars ***must*** always be higher overall in order to maintain gravitational equilibrium.

This forces higher mass stars to 'burn' through their available fuel more quickly than lower mass stars have to. And even though high mass stars have more fuel (they are more massive, after all!), they burn through it *much* more quickly than their enhanced fuel supply can possibly keep up with.

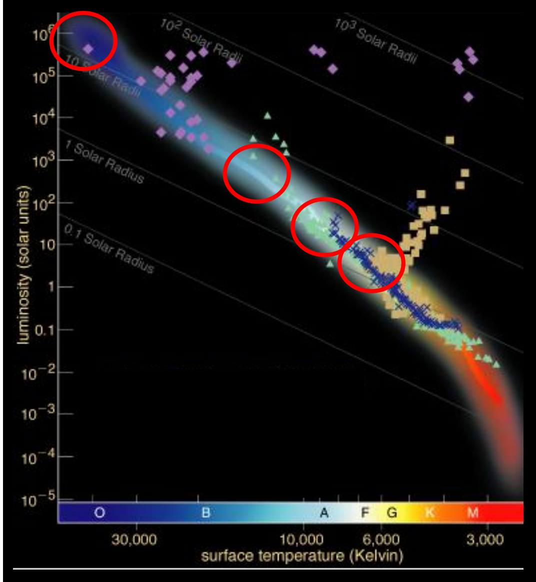
A School Bus has a bigger gas tank, but a smaller car can go farther because it gets better gas mileage! Same with stars!

The end result is a ***mass-lifetime*** relationship among stars:

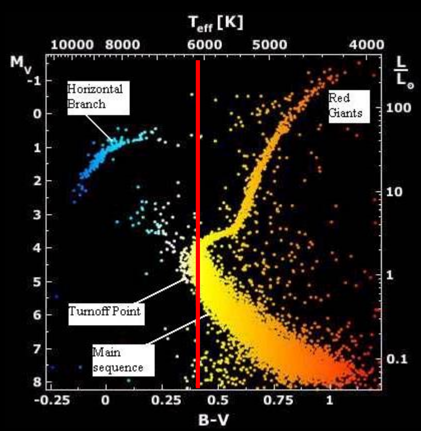
B dwarf* (10 $M_{\odot}$) lasts	32 million yrs.
F dwarf (2 $M_{\odot}$) lasts	1.8 billion yrs.
G dwarf (1.0 $M_{\odot}$) lasts	10 billion yrs.
M dwarf (.5 $M_{\odot}$) lasts	56 billion yrs.

This is the primary reason *why* there are fewer stars on the hot end of the main sequence of those globular clusters – those massive stars 'die' quickly, while very low mass stars have lifetimes that are longer than the current age of the Universe. Every M dwarf that was ever created is *still* on the main sequence!!

*"dwarf" is the common name for a Main Sequence star.



It gets better – we can use this understanding of main sequence 'lifetimes' to measure the *relative ages* of different clusters. The hottest, brightest star still on a cluster's main sequence is at the so-called *main sequence turnoff point* – all stars hotter and more massive have already used up their H fuel and 'turned off'. This point moves to less massive stars as the whole cluster ages.



And note that if you know how long a star of the spectral type *right at* the turnoff 'lives' on the Main Sequence, then you know the age of that star – and ***all the other stars in the cluster as well***, since they were all born around the same time! Can you figure out the age of the main sequence stars this globular cluster, M55?

This lets us work out the lives of stars in detail – by comparing stars in young clusters to stars in older clusters, we can learn how stars ‘age’ over time, without needing to watch any one of them actually change. That’s useful when even the shortest-lived stars are on the main sequence for millions of years!

We’ll pick up the tale there next time, by reviewing the details of how those young stars are born – and exploring in depth how older stars finally and spectacularly die...