Thursday, 12 November, 2009

PHYS-1060 (2)

Fall 2009

3:30-4:45pm Tu Th 1104 Rood

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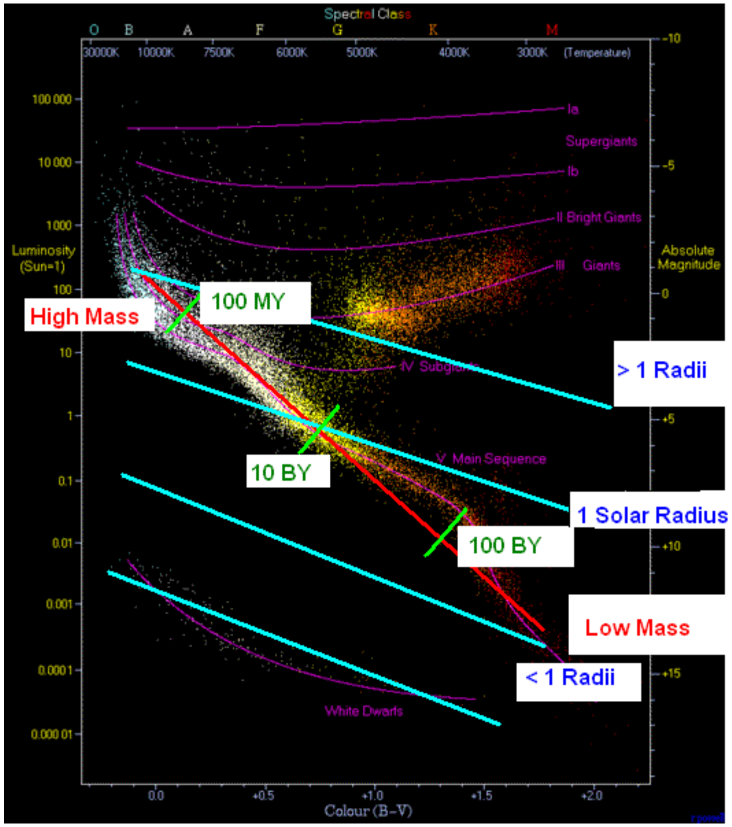
Unit 3

Things We Can Learn From The H-R Diagram:

Main Sequence Distribution
and
Those bands NOT Main Sequence



Star Clusters

Open and "Closed" Globular Clusters

Star clusters are Localized:
The stars are all about the same distance from Earth and all about the same age.

Open clusters in the flat plane of the galaxy, where the dust and gasses are.

Up to a few thousand stars,
loosely held together by gravity.

Globular clusters are in the "halo" or sphere around the galaxy – and are very old.

Up to a hundred thousand stars,
tightly bound by gravity.
No dust or gas. Low metal stars.

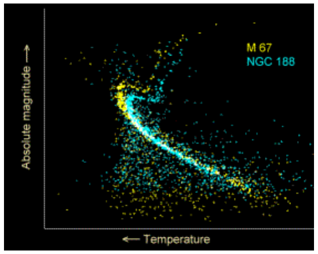
Stellar nurseries

The H-R Diagram for an Open Cluster is cut off at the high mass end (O B A), and though it has a strong Main Sequence line, there is some spread outward.

Age of Star Clusters

The Main Sequence Turn-Off… occurs because the stars in a cluster are roughly of the same age and the high mass stars have shorter lifetimes. So as the star cluster ages, any high mass stars will end their hydrogen burning life and leave the Main Sequence.

H-R Diagram for two clusters (M67 and NGC 188):



Recall that the Main Sequence stars have age estimates based on their mass…

So NGC 188 is older than M67.

H-R Diagrams

- All Stars
- Stars From A Particular Population

Quiz 7 – Our Neighborhood

Plotting the H-R Diagram of:

- Nearest Stars
- Brightest Stars

Our Sun is:

Spectral Type G2
Luminosity Class V
(G2 V)

Why aren't we plotting Luminosity Class?

Stellar Lives

Cloud –
Protostar – collapsed down to a spinning object, but not enough yet for thermonuclear ignition in the core.

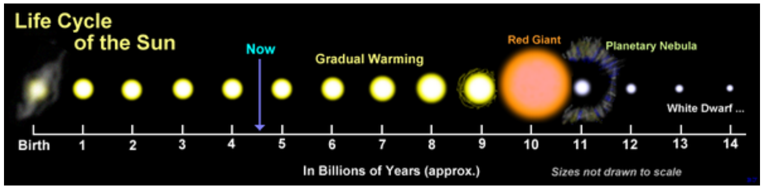
When the core reaches 10,000,000K – hydrogen fusion gets efficient enough for the star to ignite.
Stabilization takes time:
O star, maybe 1,000,000 years
G2 star, maybe 30,000,000 years

Perhaps not so strange when you consider that for our G2 star, it takes several million years for light to get out to the surface from the core.

Main Sequence

high end, about 150 solar masses (but this number is under debate)
low end for mass, 0.08 solar masses or about 80 Jupiters

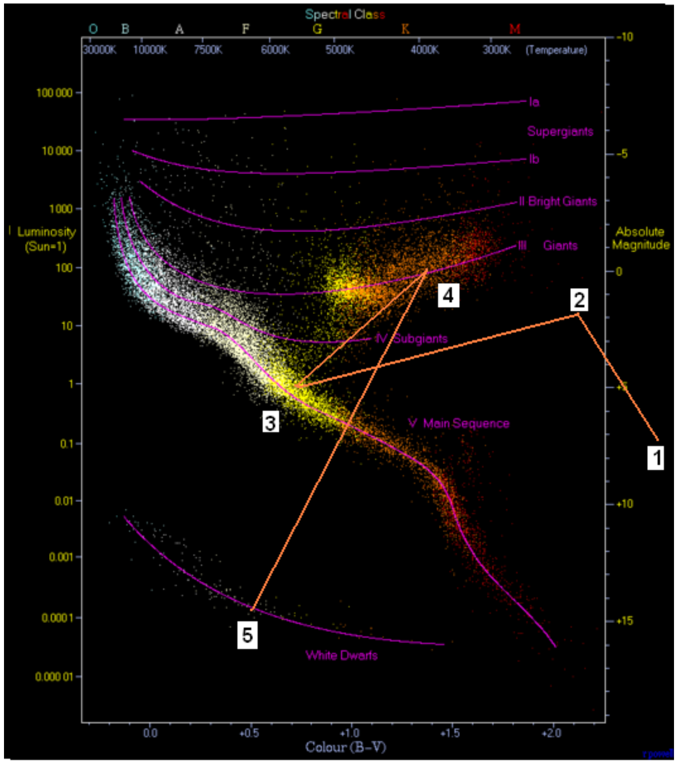
The Sun's Life



Hydrogen ignition – 10,000,000 K

Helium ignition – 100,000,000 K
requires 0.5 solar masses and up
(requires mass, pressure, gravity to reach that temp!)

Our Sun's Life (estimated)



1 – condensing phase, 2 – protostar,
3 – Main Sequence, 4 – Red Giant,
5 – White Dwarf

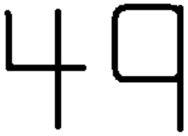
Exam 2 Scores

X2rraw (50), X2raw (150), X2curved (150)

	X2rraw	X2 raw	X2curve
	43	129	150
	42	126	147
	41	123	144
	40	120	141
	39	117	138
	38	114	135
	37	111	132
	36	108	129
	35	105	126
	34	102	123
	33	99	120
	32	96	117
	31	93	114
	30	90	111
mean/median	29	87	108
	28	84	105
	27	81	102
	26	78	99
	25	75	96
	24	72	93
	23	69	90
	22	66	87
	21	63	84
	20	60	81
	19	57	78
	18	54	75
	17	51	72
	16	48	69
n	119	119	119
hi	43	129	150
lo	16	48	69
ave	29.36	88.08	109.1
s.d.	6.21	18.63	18.63

To get Percent Grade, find “X1curved” ÷ 1.5

NOTE: The Printed Scores T24 and T29 look similar,
but the “4” has a cross-piece and the “9” does not:



NOTE: Mid-Term Grades are still estimated – missing X2’s are bad.

What is so surprising about stars…

Is the link between these large objects
and
Quantum Mechanics – the study of the very smallest of things inside the atom.

Recall:

Electron orbitals determine the absorption and emission spectral lines.

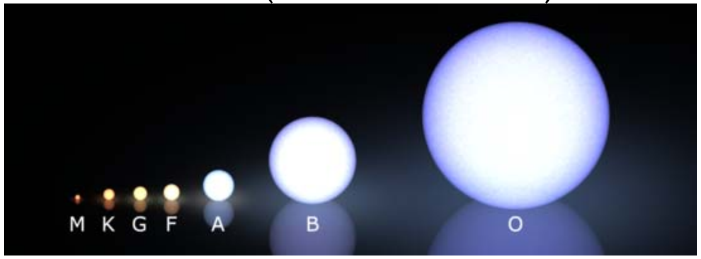
Z = Proton Number (determines the element)

N = Neutron Number (determines the isotope)

A = Z + N (isotope number and “mass”)

${}^{1}_{1}H$ or H^{1}	Hydrogen-1
${}^{2}_{1}H$ or H^{2}	Hydrogren-2 (Deuterium)
${}^{3}_{1}H$ or H^{3}	Hydrogen-3 (Tritium)
${}^{3}_{2}He$ or He^{3}	Helium-3
${}^{4}_{2}He$ or He^{4}	Helium-4

A Comparison of Main Sequence Stars (color and size)



Note the puny little yellow G star towards the left.

Why Aren't All G2 stars the same?

There is tremendous variety in star classifications, because each star has its own composition and age.

A young G star is different than an older G star.
Some stars are Variable stars.
Giant stars build up carbon and other elements.

Wolf-Rayet stars (W or WR) – Helium rich…
or are they late stage supergiants which have blown away their hydrogen shell, exposing their helium cores?

Brown dwarfs
(L 1300-2000 K, T 700-1300K, Y < 700K ?)

Size Matters

Not only does mass determine stellar type and temperature on the Main Sequence,
Mass determines what happens when
a star collapses.

Internal Pressure versus Gravity

With Stars, we get a balance between
gravity pulling the mass IN and
thermal pressure pushing OUT.

The Pressure comes from the heat and radiation from the core.

But what about Brown Dwarfs?

As failed stars, they do not generate enough
temperature at the core to
support hydrogen ignition
Therefore not enough thermal pressure.
So what keeps them from collapsing
due to gravity?

Electron Degeneracy

Recall our discussion of electron orbitals.
Electrons are fermions
– they cannot occupy the same orbitals.
Think of the seats in this lecture hall:
One to a customer at most.

So gravity wants to squeeze the brown dwarf smaller and smaller.

But the electrons cannot be squeezed. At best, all the “seats” closest to the nucleus of all the atoms are occupied.

Degeneracy Pressure keeps brown dwarf from collapsing.

Over time the brown dwarf simply loses its thermal energy and cools.
But it cannot collapse any further.

White Dwarfs

and Degeneracy Pressure

White Dwarfs are the exposed cores of a star after it has shed its outer layers in a Planetary Nebula.
No more fusion in core,
gravity should crush the White Dwarf.
Electron Degeneracy Pressure opposes this.

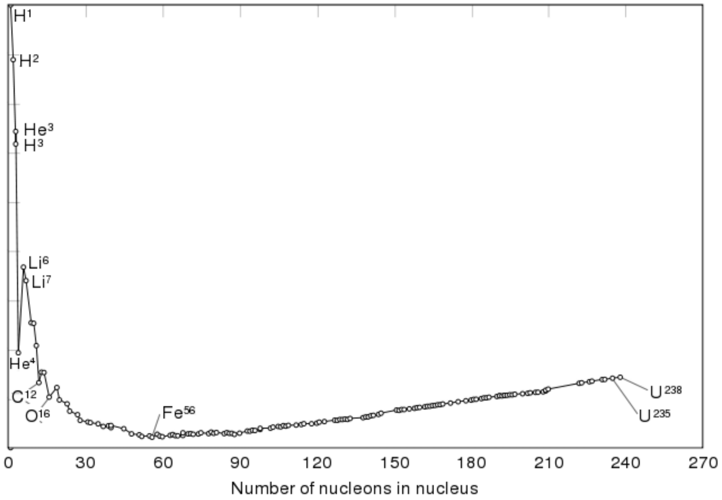
Neutron Stars

Neutron Stars are the collapsed iron cores of very large stars after it has shed the rest of a star in a supernova explosion.
No more fusion in core,
gravity should crush the Neutron Star.
This time gravity is SO strong, it does crush through the Electron Degeneracy.
(Electrons smashed into protons = neutrons)
This time it is Neutron Degeneracy Pressure that keeps the Neutron Star from being crushed further.

Black Holes

If you have enough mass and there is no more fusion, then gravity wins.

~Fig 12-17 (p. 349)



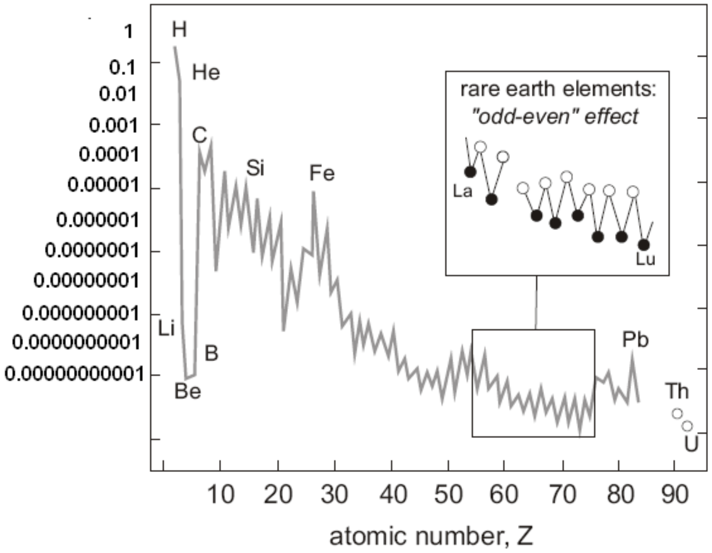
Mass per nucleon.
The Iron Minimum.

Isotopes on the left can use fusion to reach Iron-56 and release energy.
Isotopes on the right can use fission to reach Iron-56 and release energy.

During the death of a massive star, the energy of the collapse can drive the fusion reactions past Iron-56, but cannot sustain the energy.

~Fig. 12-18 (p. 350)

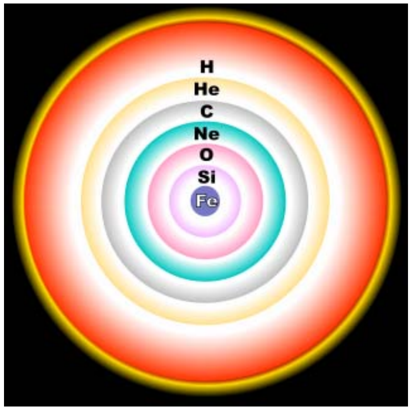
COSMIC ABUNDANCES of the elements



For every 1 Hydrogen atom, there is a tenth of a Helium. Other elements are even more rare.

This is a log plot – the vertical axis is not evenly spaced, but each division is 10 times smaller going down

Note that Carbon is MUCH more plentiful than Beryllium. Be is made from 2 He, while C is made from 3 He.



Shells of Fusion Layers Prior to Stellar Collapse of Large Stars $M > 8\ M_{Sun}$

Why Iron (Fe) at the center?

As new elements begin fusion, the supergiant star may zig-zag along the H-R diagram, alternating in color. (Fig.12-14)

Mass to Energy Conversion
$E = mc^2$

$$\boxed{4\left({}_1^1H\right) \rightarrow {}_2^4He + 2\,neutrinos + energy}$$

If core T exceeds 10,000,000 K (10^7 K):

4 Hydrogen nuclei fuse into
1 Helium nucleus + energy (gamma-rays)
+ 2 neutrinos
at a rate sufficient to balance off the loss of energy in the form of light at the star's surface (i.e., it's luminosity).

In our Sun, the central temperature is at present about 15.7 million K, and 613.8 million metric tons of H are fused into 609.5 million metric tons of He each second.

By the way, what happens to the other 4.3 million tons of matter processed per second?

Fun with Fusion (Preface to Quiz 8)

Z = # of protons
N = # of neutrons
A = Z+N = # of nucleons
(neutrons & protons)

If we fuse two nuclei together, our nuclear reaction looks something like:

$$ {}^{A}_{Z}X + {}^{a}_{z}Y \rightarrow {}^{(A+a)}_{(Z+z)}Z + Energy + Etc. $$

Carbon-12 (${}^{12}_{6}C$) has 6 protons and 6 neutrons, and a mass of 12.000 amu.

But each proton by itself has a mass of 1.007825 amu and each neutron has a mass of 1.008665 amu. So, is the whole greater than the sum of its parts? Well, as you can see, 6 p's and 6 n's have more mass than that of the Carbon-12 nucleus. Since you can't just "hide" mass, forming the Carbon-12 nucleus must have some freed that excess mass as the *binding energy* for the nucleus, or the energy that holds it together.

6 protons × 1.007825 amu/proton	=	6.046950 amu
6 neutrons × 1.008665 amu/neutron	=	6.051990 amu
Total mass of 6 p + 6 n	=	12.098940 amu
Carbon-12 (made of 6 p and 6 n)	=	12.000000 amu
Excess mass of pieces	=	0.098940 amu

The Pressure-Gravity Balance in Larger Stars

Higher Core Temperatures
Larger Size and More Mass

But… Lower Density (mass-to-volume ratio)

If all Main Sequence stars had the *same* density, then $R \sim M^{1/3}$

$$ \left(\boxed{\rho = \frac{M}{V} = \frac{M}{\frac{4}{3}\pi R^3}} \right) $$

But it is more like $R \sim M^{0.6}$
And the Luminosity goes as
$L_* \sim R^2 T^4_{surface}$

So the larger, hotter stars are also more luminous.

To be more luminous, requires more fusion at the core, burning through the hydrogen fuel at a much faster rate…

Figure 12.22 (pp. 354-355)

Protostar (25 M_{sun})
Blue Main-Sequence star
CNO cycle
Red Supergiant
Helium-burning Supergiant
core expands
hydrogen-burning shell shrinks
Multiple-Burning Supergiant
Supernova
Neutron Star or Black Hole

Protostar (1 M_{sun})
Yellow Main-Sequence star
proton-proton chain
Red Giant
hydrogen burning around
inert helium core
Helium-burning star
Double-shell burning
inert carbon core
Planetary Nebula
White Dwarf

Quiz 8 – You're Probably Making It Too Hard

Sum of the Mass of the Pieces
Minus The Mass of the Result
Equals The Mass Difference

Part (c)

Remember Mass of Carbon-12 is exactly 12.000000
(mass is defined this way)

We expect the mass difference you find in (c) to be LESS that the one we found in class from 6 protons plus 6 neutrons. Why?

Total mass of 6 p + 6 n = 12.098940 amu
Carbon-12 (made of 6 p and 6 n) = 12.000000 amu

Excess mass of pieces = 0.098940 amu

Nova and Supernova

A **Nova** is a potentially recurring explosion in a star, typically caused when hydrogen from a companion star is pulled into the strong gravity of a white dwarf and ignites.

Supernovas are massive explosions as when a large mass supergiant reaches the iron minimum and is unable to continue multiple shell burning in the usual way

or when hydrogen from a companion star falls into a white dwarf and sufficiently raises the temperature for the inert carbon core of the white dwarf to suddenly begin fusion.

Neutron Star

Degenerate matter remnant from a supernova explosion of a supergiant star. The gravitational force is sufficiently large to crush the neutrons, protons and electrons of the atoms into a large ~~planet-sized~~ block of neutrons (“neutronium”).

Black Hole

Supernova remnant with enough gravity to prevent light from escaping. Hence, it “looks black”, like a “hole in space.”

Where It Gets Weird

White Dwarfs and Black Holes Do Not Have To Be Static

Things can fall into them, which might reignite a White Dwarf or cause Black Holes to grow.

Tidal Forces

The intense gravity near these stellar remnants means that you get a strong difference in gravitational strength from a near side and a far side, resulting in tidal forces.

These can pull an object apart – be it a planet, ship or person.

Two Important Effects

Gravity

It’s not that the gravity of a white dwarf, neutron star or black hole is any different at normal large distances…

It’s that their smaller size means that their surface is <u>much closer to the center</u>, so you can get much closer and <u>get much higher gravity</u> without being inside the star.

“Dark Matter”

Even before we get to a modern discussion of dark matter, realize that White Dwarfs, Red Dwarfs, Brown Dwarfs, Neutron Stars, Black Holes and many gas and dust clouds are too dim in Apparent Magnitude to be visible without a telescope.

In other words, much of the mass of the Universe can NOT be seen with the naked eye to begin with!