Open book Test 1 Reminder

Test 1: Wednesday Lecture slot : 10:00 am (one Hour test)

3rd March 2021 (7th week) : after one week-term break

Instructions : need you to position your “PC or handphone” cameras on yourselves for the Zoom.

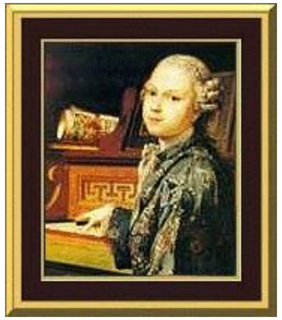
MCQ & short Questions : If you have participated in all the (Zero to where we stop next week) lectures & Tutorials, LumiNUS Forum and read the uploaded Relativity related essays/articles, it should be straightforward. (the pdf readings in LumiNUS should consolidate your learning)

Twinkle, twinkle little stars
How I wonder what you are ?
Up above the world so high
Like a diamond in the sky.
Twinkle, twinkle little star
How I wonder what you are !

Lecture 7

Life Cycle of Stars

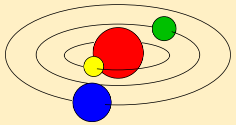
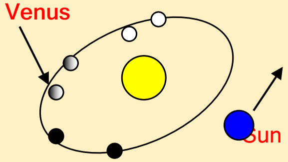
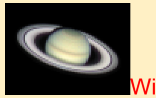
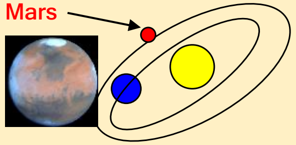
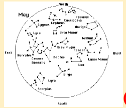
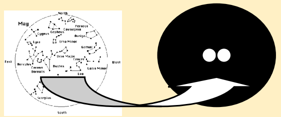
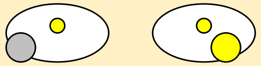
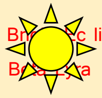
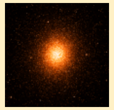
W. A. Mozart (1756-1791)



How Stars become great ?

Seeing Beautiful Stars !
Stars of the Universe
Not Stars of Universal Studios, Hollywood

The Singapore Skies

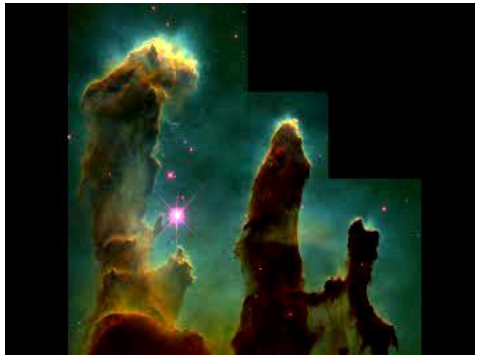
The Singapore Sky Show 	**The Sun**  To observe the sun without a proper filter may damage one's eyes. Can you see the solar spots also?	**The Moon**  Can You see Jack and Jill on the Lunar Surface?	**Venus**  Earth It is sometimes called the morning star or evening star. Venus has phases.
Jupiter  One can easily see 4 Galiilean moons with small telescopes.	**Saturn**  With a small but good resolution telescope, one may be able to see the Cassini ring.	**Mars**  Occasionally the snow cap can been seen with 200-300X telescopes on this red planet.	**Constellations**  On geographic earth we call different land patches countries but in the sky, various patches are called constellations.
Double Stars  Many stars in our skies are binary stars but some are optical double. There is a famous double double in Lyra constellation.	**Variable Stars**  Dark Eclipsing Br c lipsing Algol, Perseus B a  Pulsating Delta Cepheus	**Open Clusters**  A few hundred stars loosely congregating with no definite shape. Pleiades M45	**Globular Clusters**  Several hundred thousands stars "partying" to form a ball of stars. ω Centauri, NGC4755.
Planetary Nebula  A graveyard	**Diffuse Nebulae**  A star hospital	**Galaxies** 	**Messier Objects** 

What is a ‘great’ Star ?

A great gaseous cloud (Nebulae).

Clouds are basically water vapour.

They rapidly diffuse a way.



M16 Eagle Nebula

If stars are made of gaseous cloud, why don’t they behave the same way ?

Why stars can live for billions of years ?

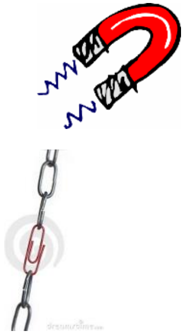
The gravity of the Matter !

Star clouds held together by gravity.

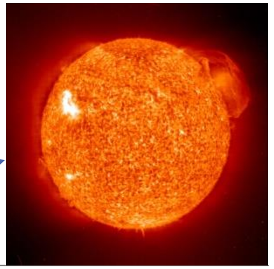
But gravity is very very weak ?

A small magnet can easily pull up a chain of paper clips against gravity. It is hard to imagine that the whole earth under our feet cannot pull this chain down !

Because a star is a very massive ball of stellar gas … hydrogen.



What is the Matter ?



If the star matter is really held together by gravity, then why gravity does not crush the star ?
How come stars have finite radii ?
What prevents the star from collapsing completely ?

Note:
A light year is the distance light travels in one year.
i.e. 9.5×10^{12} km ~ 60,000 AU. Light travels 300,000 km in 1 sec.
Milky Way ~ 100,000 light years or 6,000,000,000 AU
The distance between earth and the sun is 1 AU = 1.5×10^{8} km. From the Sun to Pluto ~ 40 AU. Pluto is not a planet now !

So a "Star" is born ?

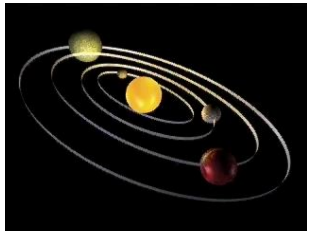
2 competing Forces at work: Gravity vs Outward Pressure (hydrogen gas & radiation) generated by the cosmic cloud.

Healthy stars : in equilibrium

Gravity tries to crush the star while outward pressure tends to distend the star.

But no star will be in equilibrium forever ?

School Chemistry



Recall Secondary School chemistry $$2H_2 + O_2 \rightarrow 2H_2O + energy$$

Hydrogen combines with oxygen to form water vapour, releasing a lot of energy (explosive !)

This reaction occurs because electrons in the outer shells of the atoms like to get readjusted, in the process breaking up some molecules and reattaching to others.

Stellar Chemistry : Burning $E = mc^2$

M42 Orion Nebula

Blobs of hydrogen cloud (Nebula) began to shrink under the action of gravity.

A stage will come when the core of the star becomes so hot as to trigger nuclear reactions.

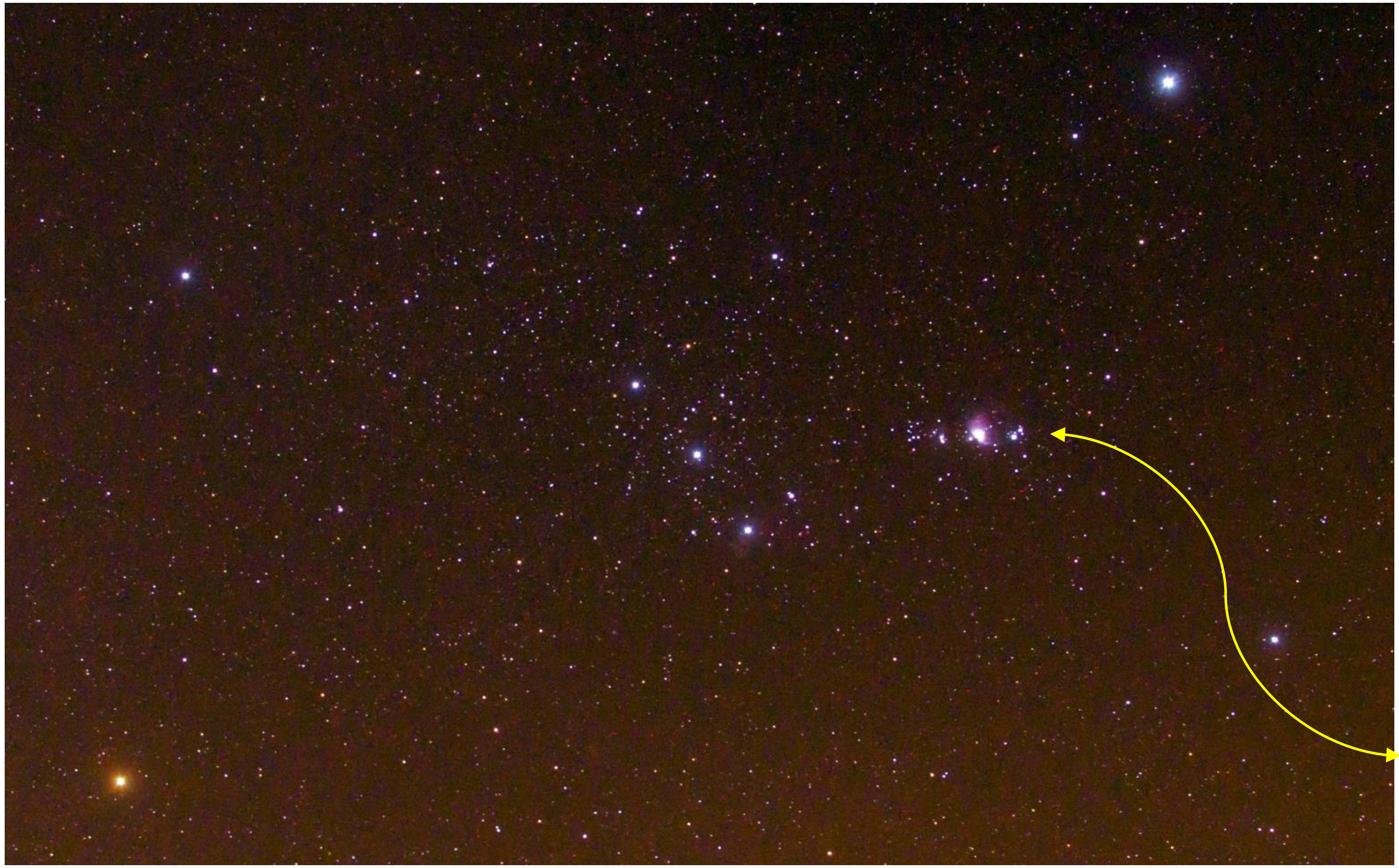
Thermonuclear burning / Stellar Nucleosynthesis

Baby stars : Proto-stars

Non-mature stars: Brown Dwarfs

The burning in the stars is due to nuclear reactions

Orion Nebulae (one weekend)



M42 Orion Nebula

Stage 1: p – p Cycle (proton-proton)

$$H_1^1 + H_1^1 \rightarrow D_1^2 + e^+ + energy$$
$$D_1^2 + H_1^1 \rightarrow He_2^3 + energy$$
$$He_2^3 + He_2^3 \rightarrow He_2^4 + 2H_1^1$$

Also called α particle

Isotopes of Helium

Sometimes called the proton ?

Deuteron (isotope of hydrogen)

Positron (anti – electron ?) need Quantum Physics !

What happens when all the hydrogen has been used up ?

$E = mc^2$

"We do not argue with critics who urge that stars are not hot enough for this process; we tell him to go and find a hotter place"

What was the critics' objection ?
It is difficult to bring 4 H nuclei together to form Helium … they repel.

New force was not discovered yet :
The Strong Nuclear Force, it is stronger than electrostatic force of repulsion.
Hans Bethe completed the study of Stars like our Sun.

Eddington

Hans Bethe

When all the hydrogen is being used up

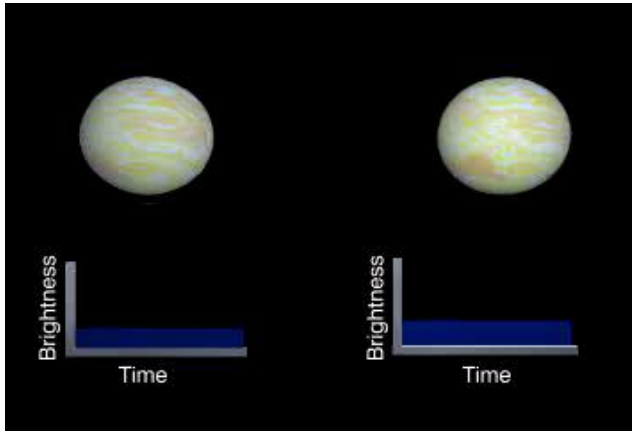
A Comment on the reaction

Gas pressure starts to decrease and star starts to shrink due to gravity.

The shell of hydrogen surrounding the burnt up core starts to heat up.

This shell burns and starts to expand the outer mantle.

In short … the core contracts while the outside shell expands to a huge size making the star appearing as a ‘giant’ e.g. Red Giant star



The ‘Butterfly’ Constellation

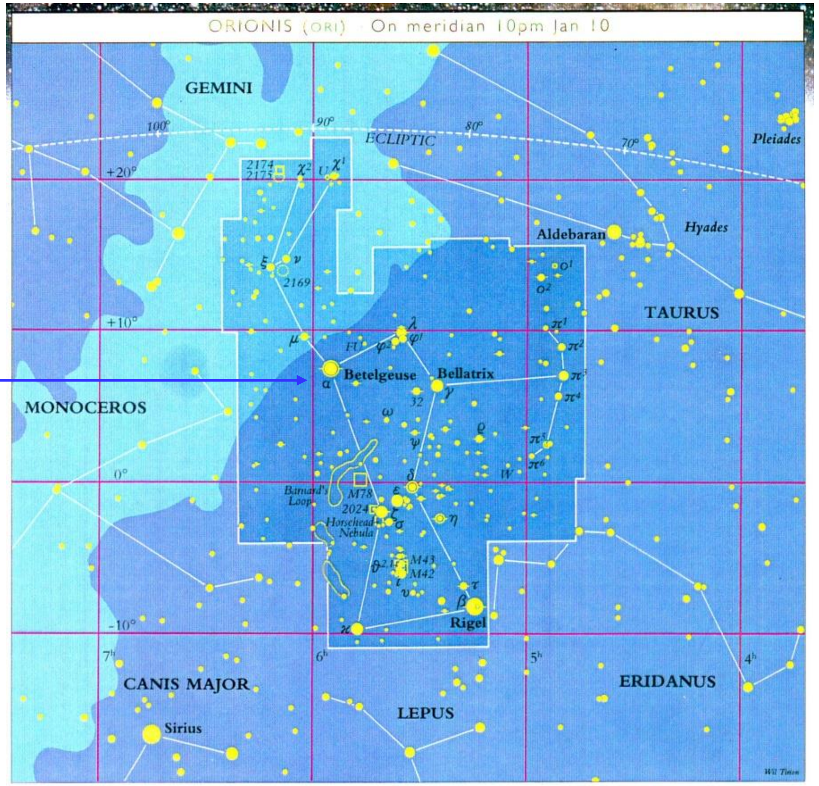
α Orioni

~ called Betelgeuse ~

a Super Red Giant star

i.e. a dying star.

Star Birth

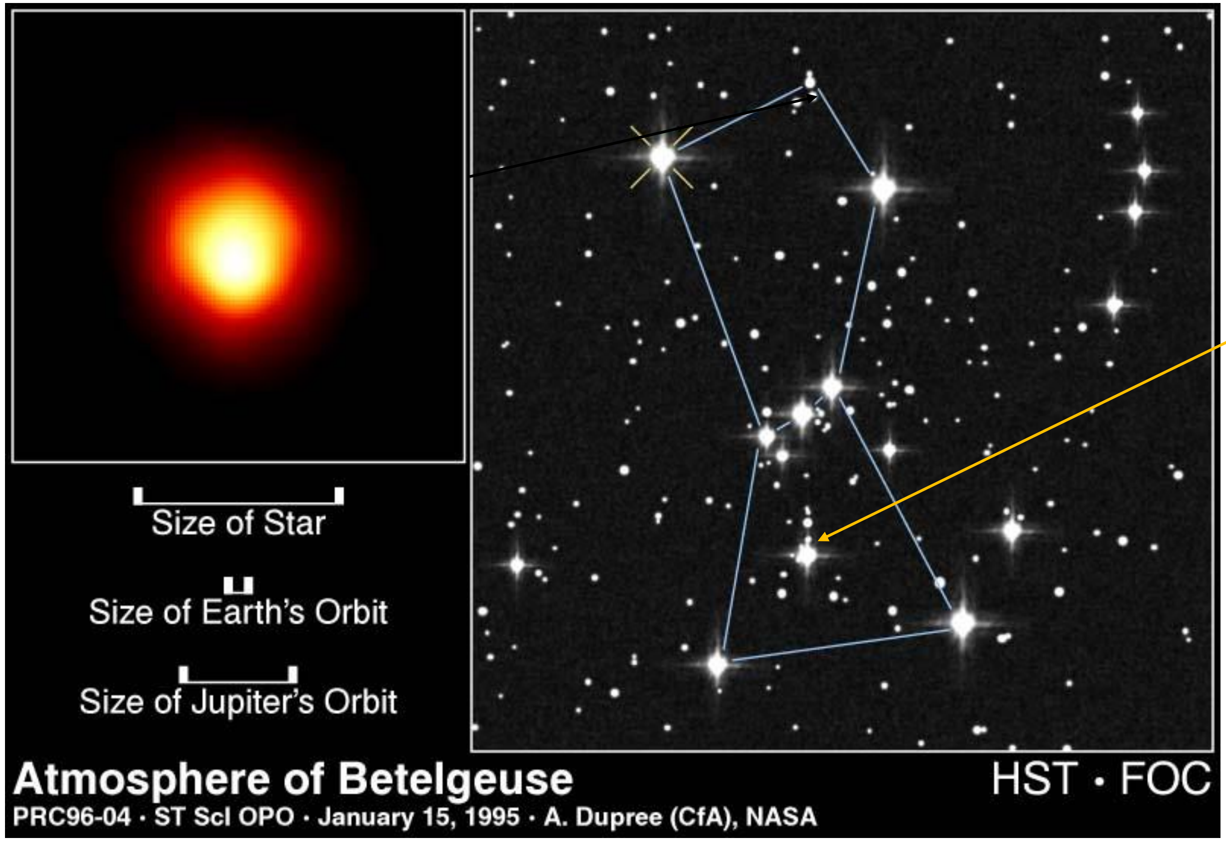


Orion

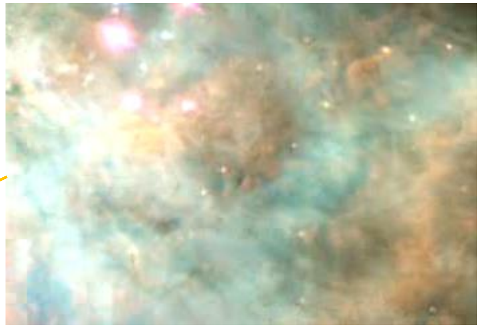
(oh-RYE-un) The Hunter

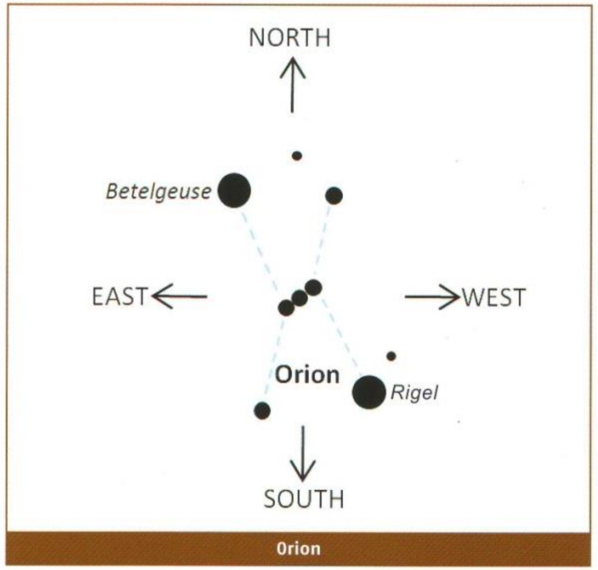
https://www.sciencenews.org/article/betelgeuse-star-dim-supernova-death-what-happened

Super Red Giant



M42





Orion Nebulae (one weekend)

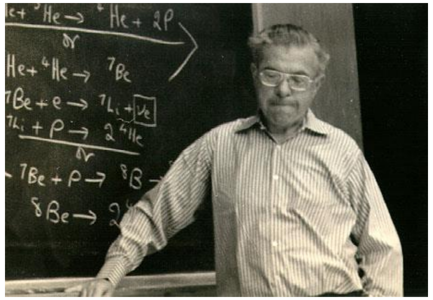
N

Exhausted of all Hydrogen fuel

Can Helium formed at the center be used as fuel to make still heavier nuclei ?

Same problem with hydrogen as before.

3 Helium nuclei form into an excited Carbon nucleus. (energy resonance)



Hoyle

Fowler

Stage 2 : C N O cycle

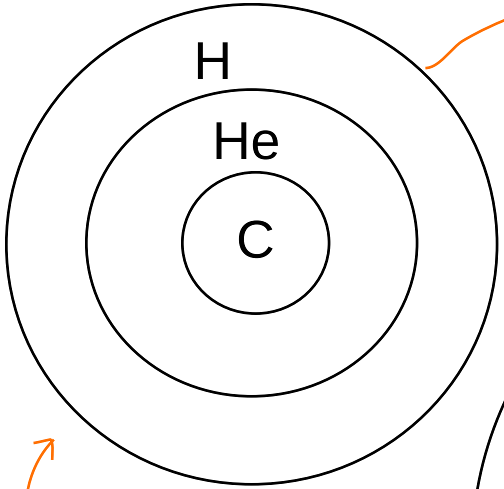
A new thermonuclear cycle starts, this time with Helium.

The production occurs in a star is due to burning of hydrogen, but assisted by carbon, nitrogen and oxygen. i.e. C, N & O play the role of catalysts.

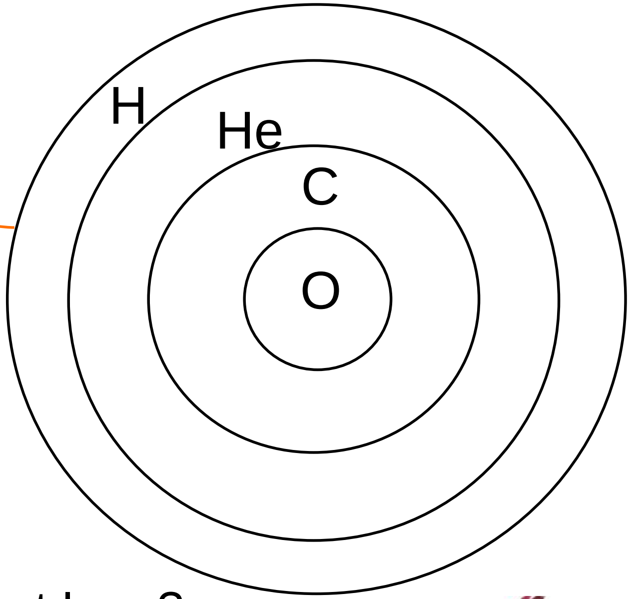
Each burning cycle : leads to conversion of light elements into slightly heavier … nuclear fusion.

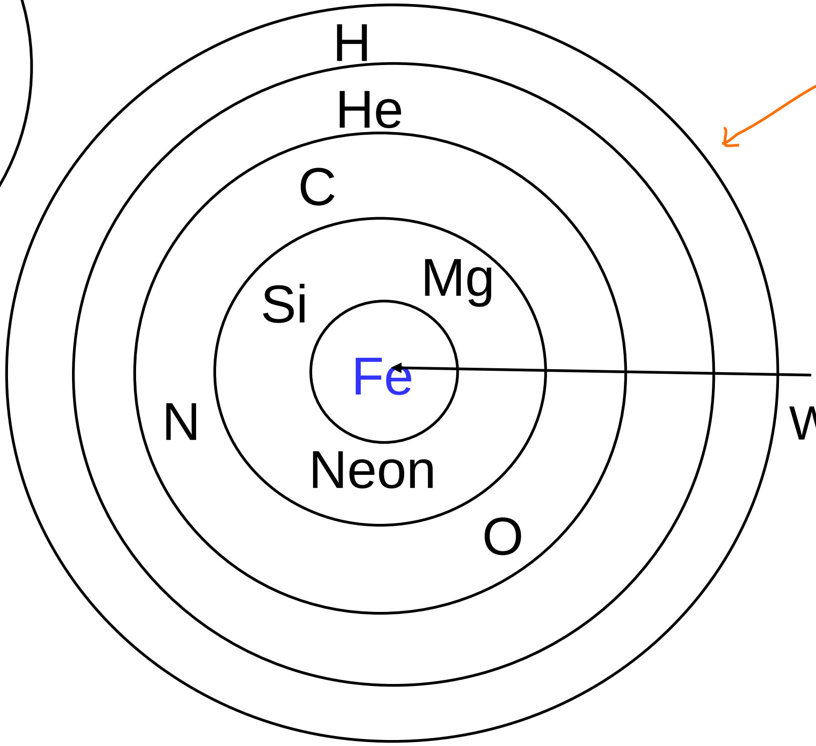
Is there an end ? Yes. Until iron.

Internal Structure of Stars

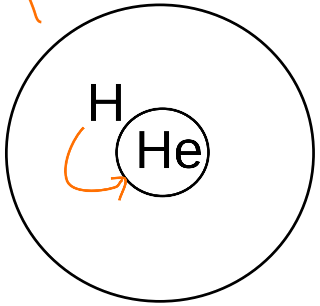


Has undergone varying numbers of thermonuclear burn cycles.





Why stop at Iron ?



Why stop at Iron ?

Once a heavy weight star has exhausted its hydrogen, it has sufficiently high temperatures and pressures to fuse heavier elements. But when it tries to squeeze a core made of iron, all hell break lose … supernova !

He ~ C ~ O ~ ~ Neon ~~ ~~ ~ Fe (Iron)

Nuclear reactions have produced a core made of iron which cannot be used as nuclear fuel. Fusing iron takes in energy rather than giving it out.

The result is internal collapse with the temperature soaring to 50 billion degrees C, the cores emits a flood of tiny energetic particles, called neutrinos (another quantum idea), that rip the star apart.

All that glitters is not gold

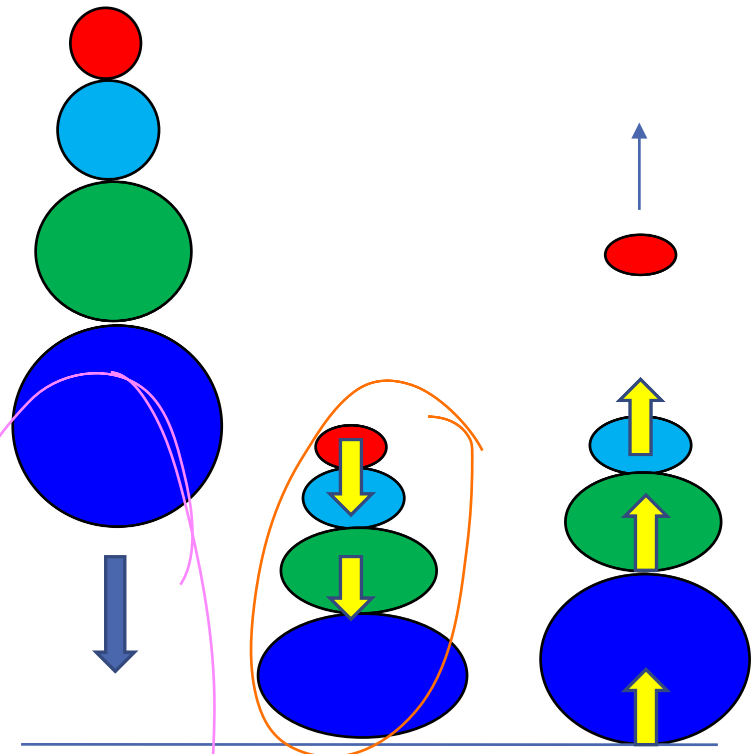
“I am as constant as the North Star” *King Lear* by Shakespeare

The star’s core attempts to fuse iron to supply the energy the star tries to … contract its core. The falling matter bounces off the core and …. Powered by a flood of neutrinos, the star’s outer layers are blasted into space.

The supernova explosion carn spawn some bizarre descendants: a neutron star or even a black hole.

Supernova Example Cassiopeia A 300 years ago

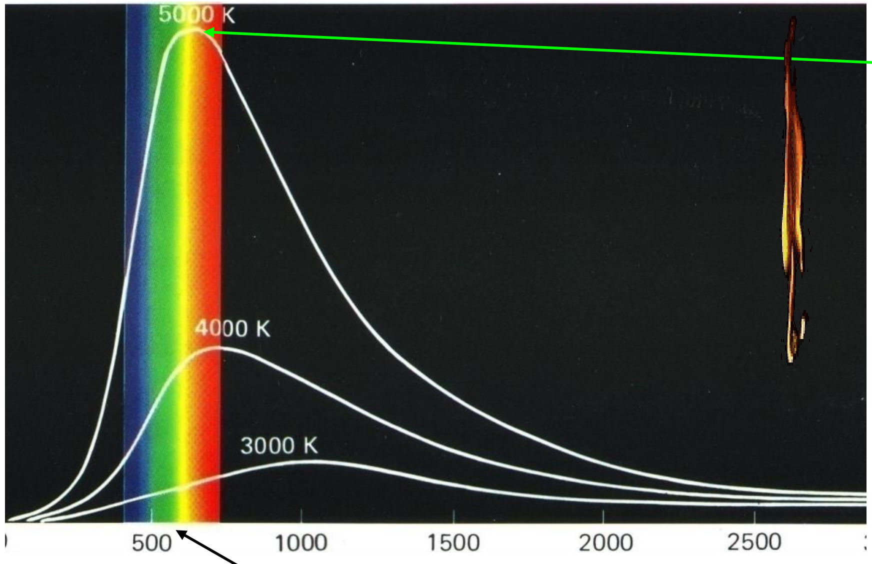
Veil Nebula 20,000 yr ago

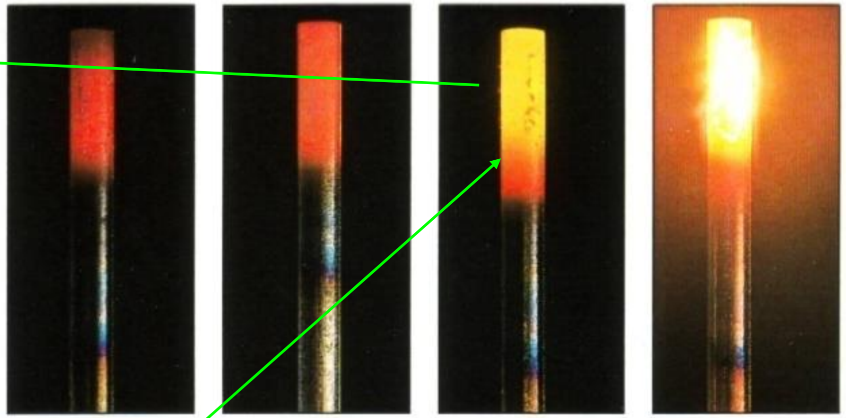


Why Stars shine ?

… why the colours …

Surface Temperature of Stars





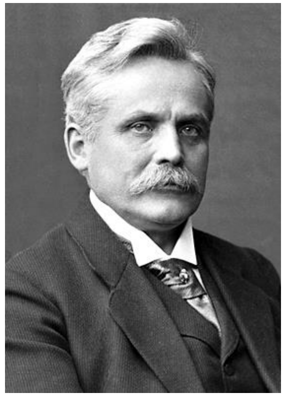
Red light
When the iron bar is heated, it begins to lose its original dark colouring and glow a dull red. The iron atoms emit light as the heat energy makes them vibrate.

Orange light
As the bar continues to be heated, the iron atoms vibrate more quickly. They now emit an even brighter light, which has changed in colour from red to orange.

Yellow light
The metal is now extremely hot and the tip of the iron bar glows a bright yellow in colour. However, the cooler parts of the bar still emit orange and red light.

White light
The bar has now been heated up to its melting point. The heat is so intense that the bar is white hot. If it could survive melting, the bar would shine blue-white.

Planck



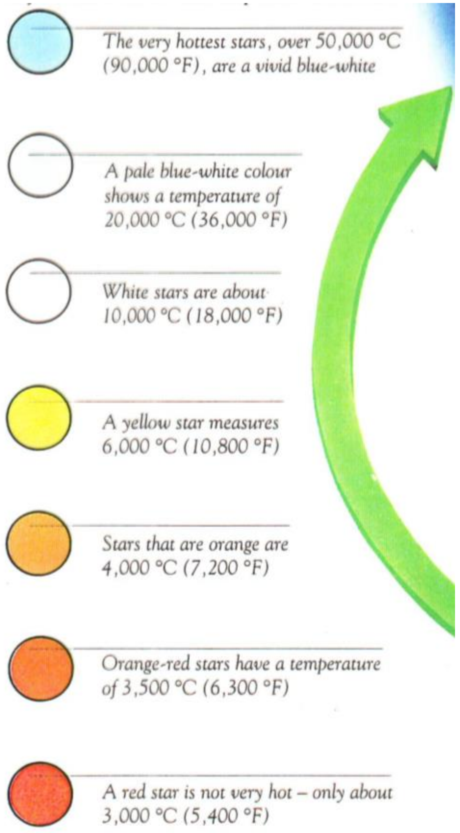
Wien

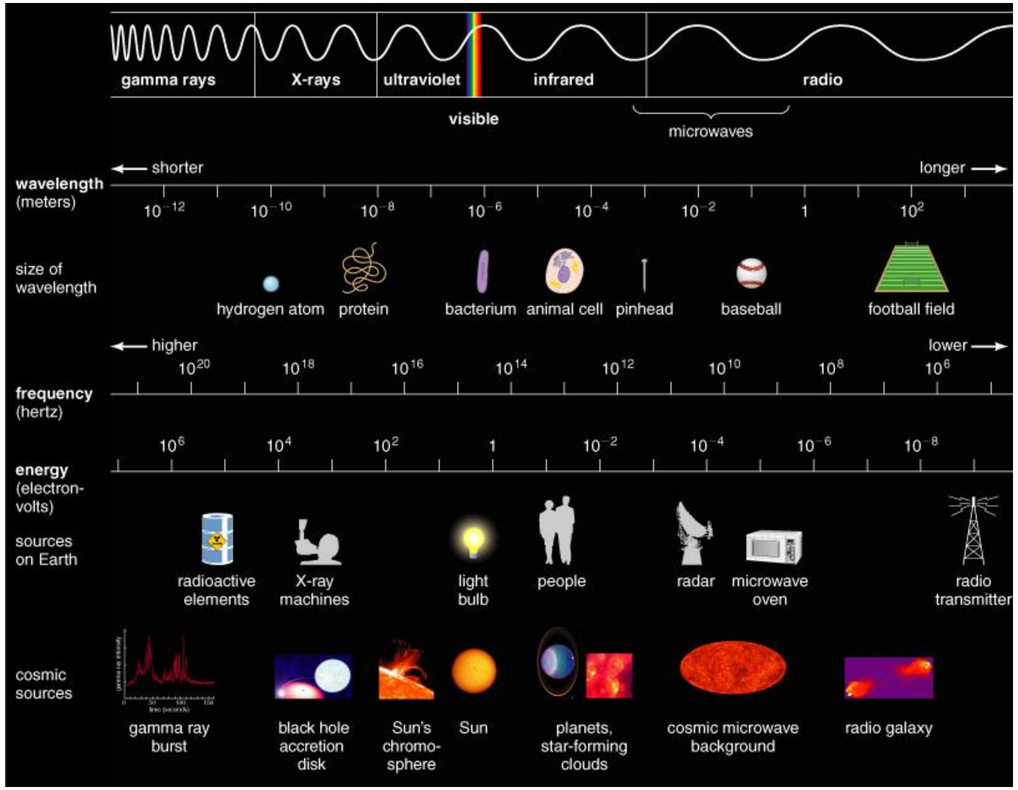
Wien's Law

$$\lambda_m T = 2.90 \times 10^{-3}\, mK$$

$$\lambda_m = \frac{2.90 \times 10^{-3}\, m}{T}$$

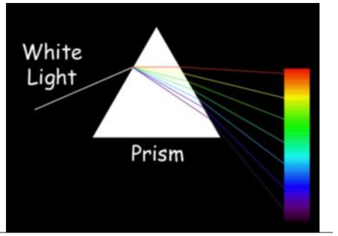
Surface Temperature of Stars





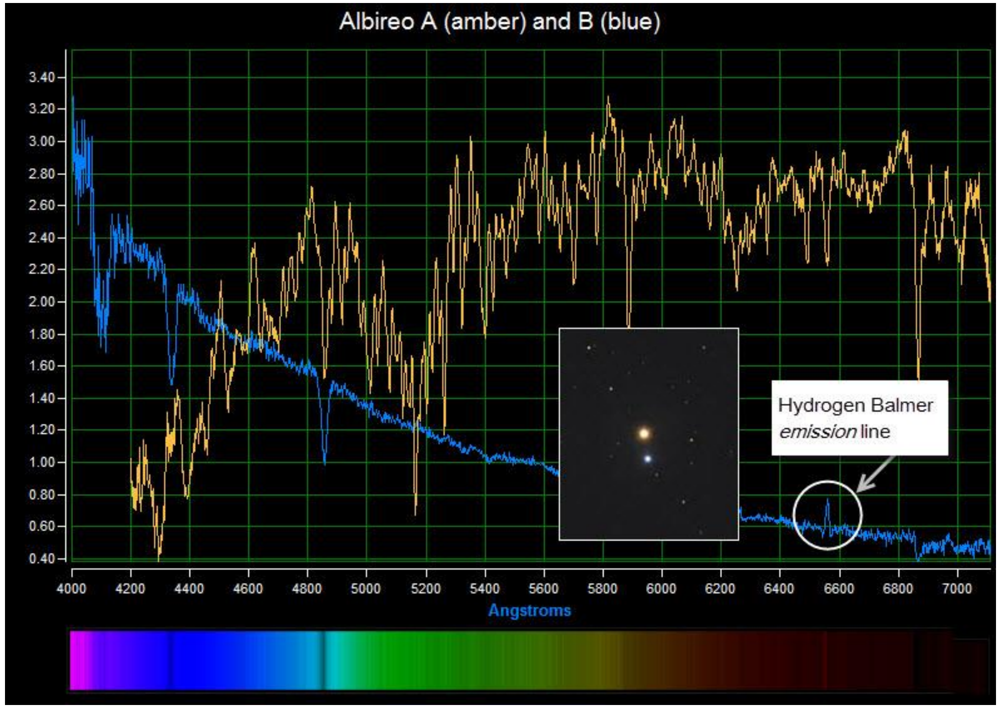
Stars are classified at O, B, A, F, G, K, M, R, N ... L, M

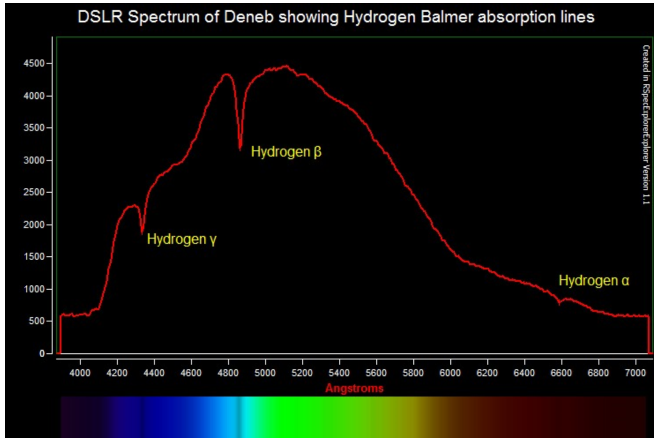
General Knowledge
Star Analyzer



http://www.rspec-astro.com/star-analyser/

General Knowledge
Rspec Software



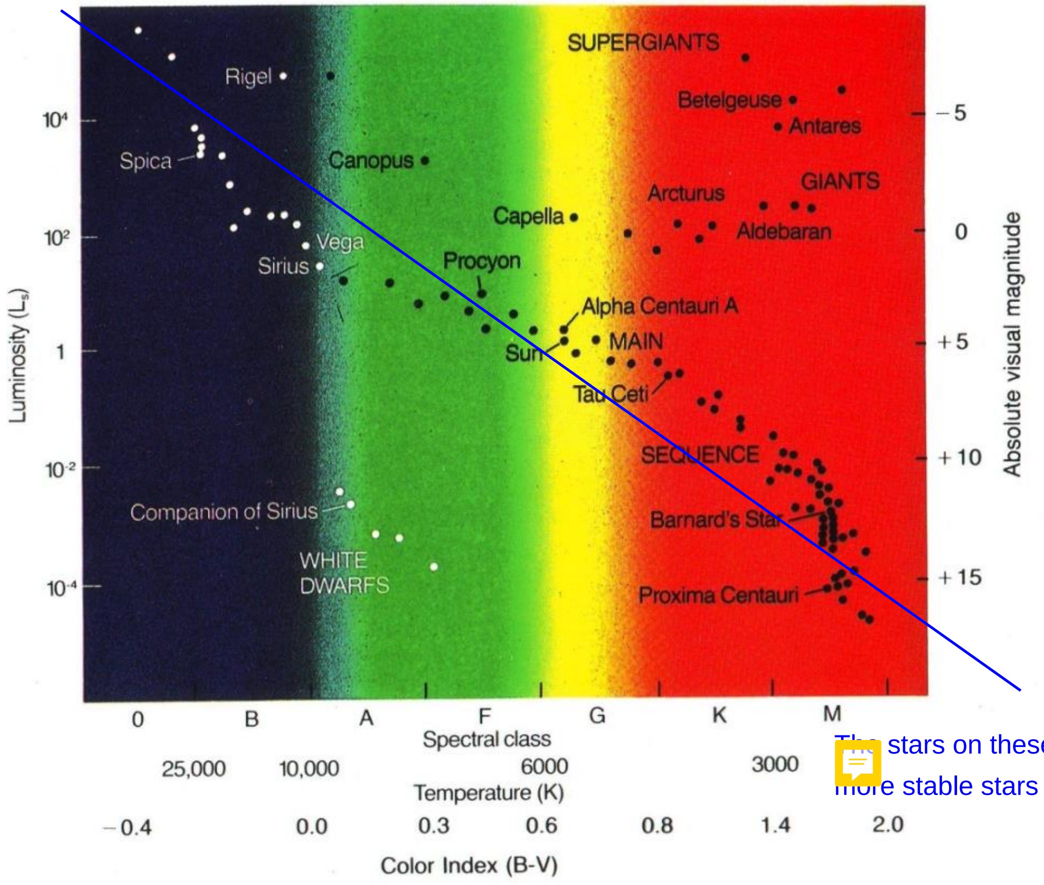


http://www.rspec-astro.com/star-analyser/

What do we do with the spectrum ?

… why the colours …

Hertzsprung-Russell (H-R)



The stars on these line are the more stable stars

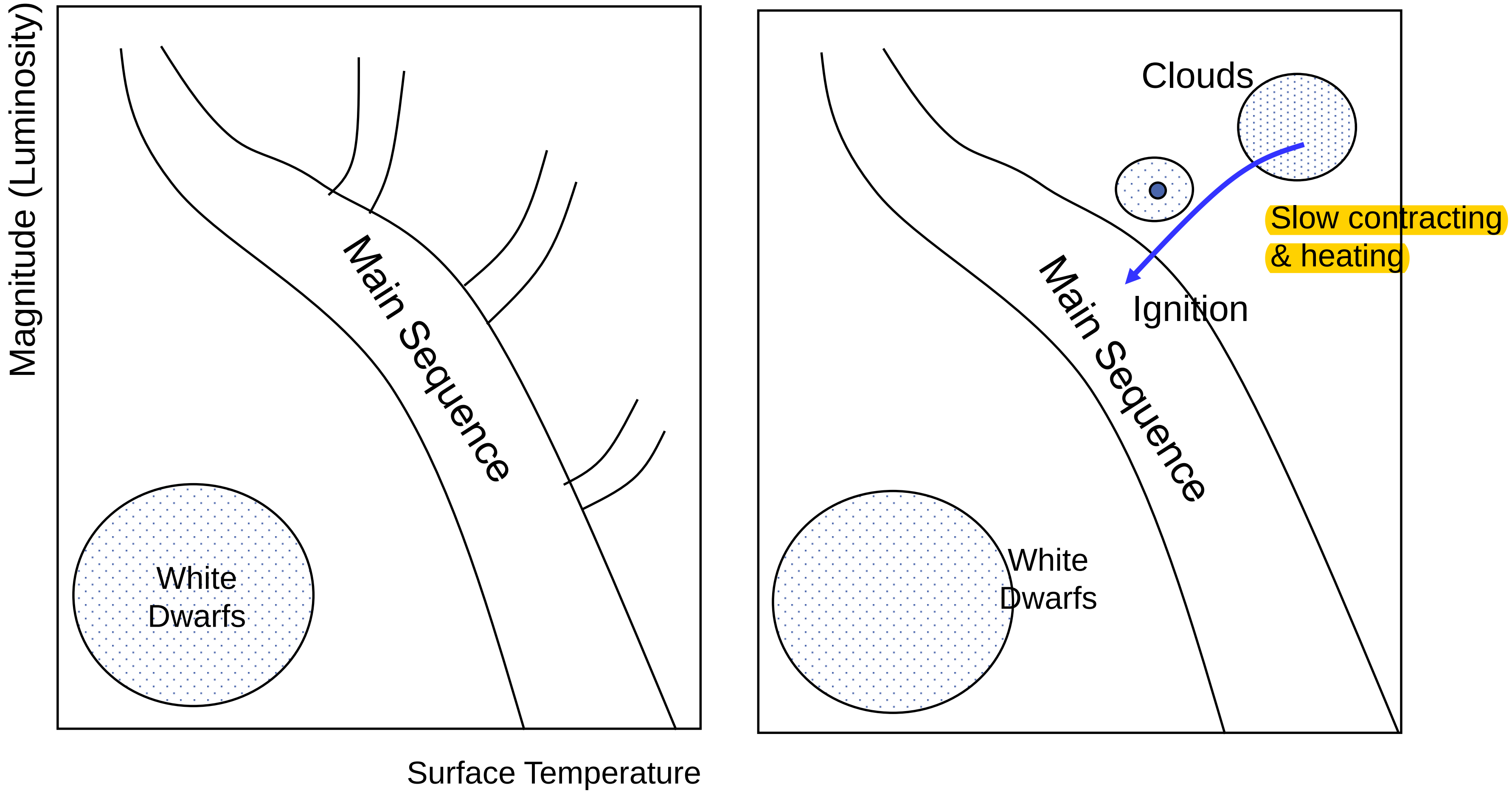
A star luminosity against surface temperature plot.

Luminosity of a star is the total amount of radiation energy it emits from its surface into outer space.

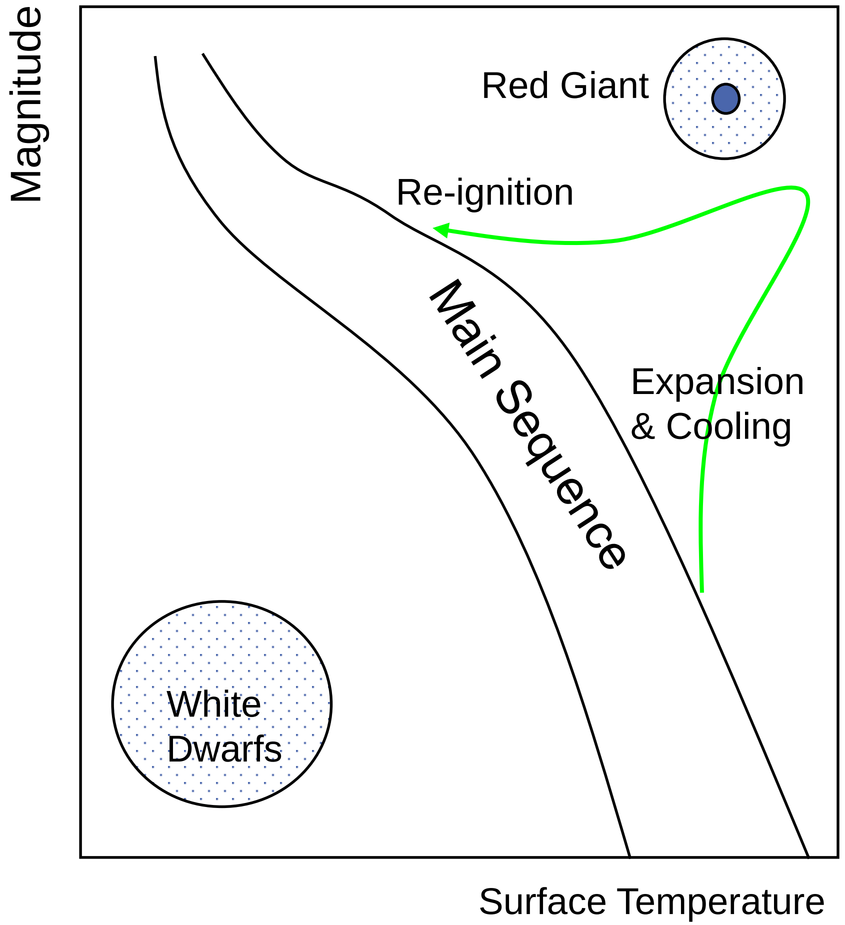
Temperature is related to wavelength of light emitted … colour. Wien's Law

Stellar Sequence (H-R)

Clouds are the birth area, not every bright yet then will move in and out of the main sequence



Main Sequence (H-R)



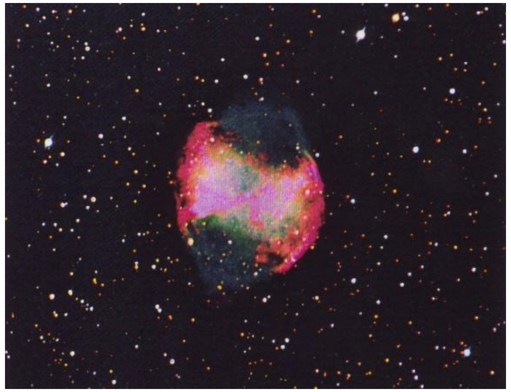
A path taken by a star that has gone through a thermonuclear burn cycle.

The star then cools down & begins the red giant phase.

The path may be quite complex but eventually returns to the main sequence.

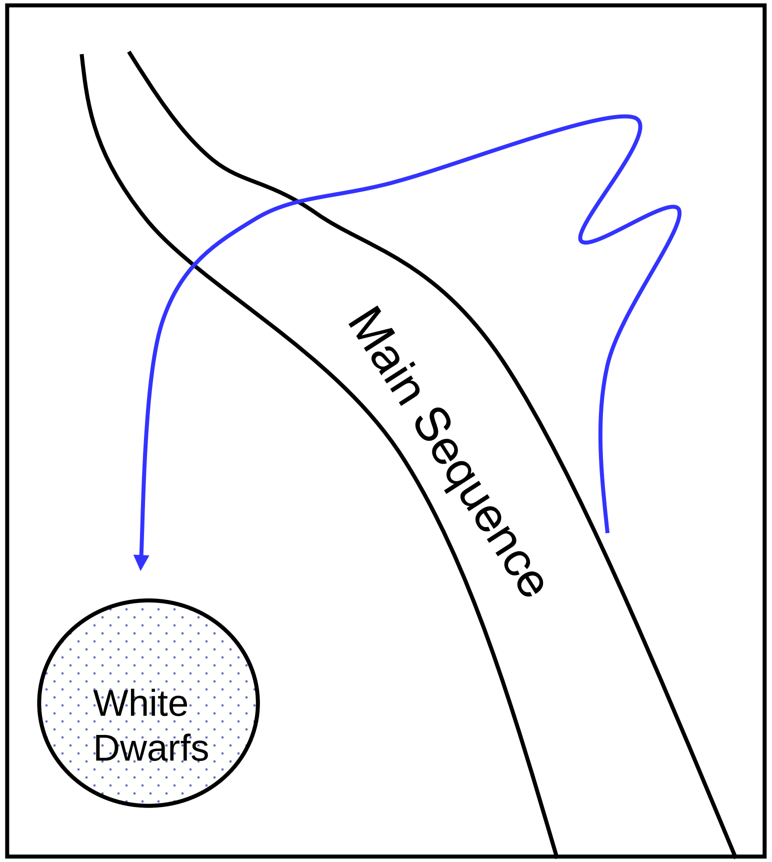
White Dwarf (H-R)

The route taken by a burnt out star will end up as a white dwarf.



Ring Nebula in Lyra Constellation

Dumbbell Nebula in Vulpecular



White Dwarf

Do all stars that begins with p – p cycle and go through all the nuclear cycles ending up finally with an iron core ?

For sure all stars will quit from burning eventually.

A dead star has no option but keep shrinking till it becomes a geometric point !

Aha ! We know this did not happen. So what is preventing the star from collapsing ?

Degeneracy Pressure

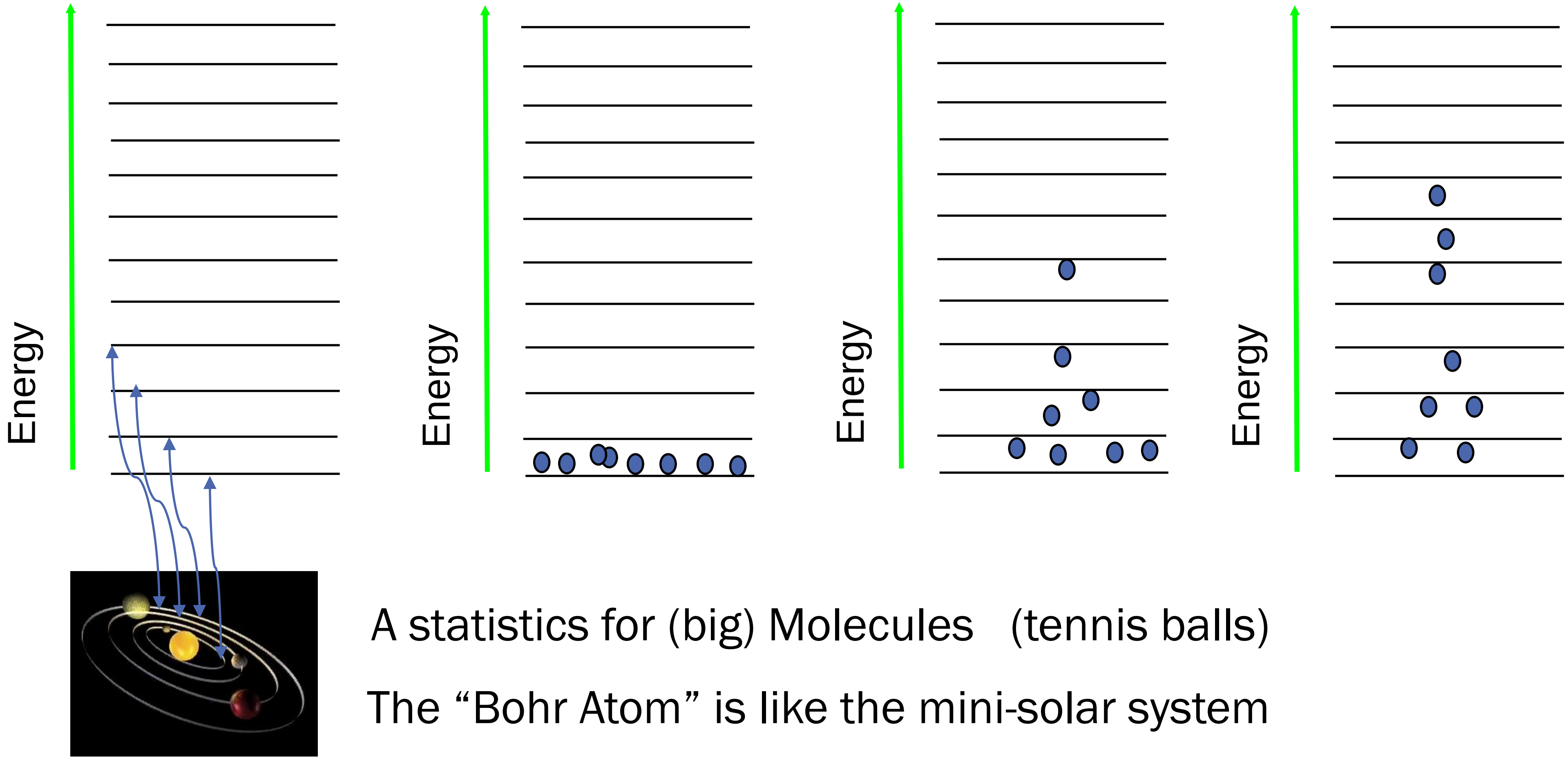
No. Fowler said that dead stars do not shrink endlessly to disappear into a point but the shrinking stops much earlier.

He suggested that a new type of pressure is at work to prevent stars from collapsing.

In short, he applied the newly discovered Quantum Theory to stars.

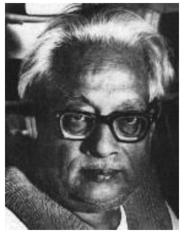
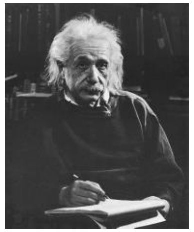
Fowler

Boltzmann  Maxwell  Statistics



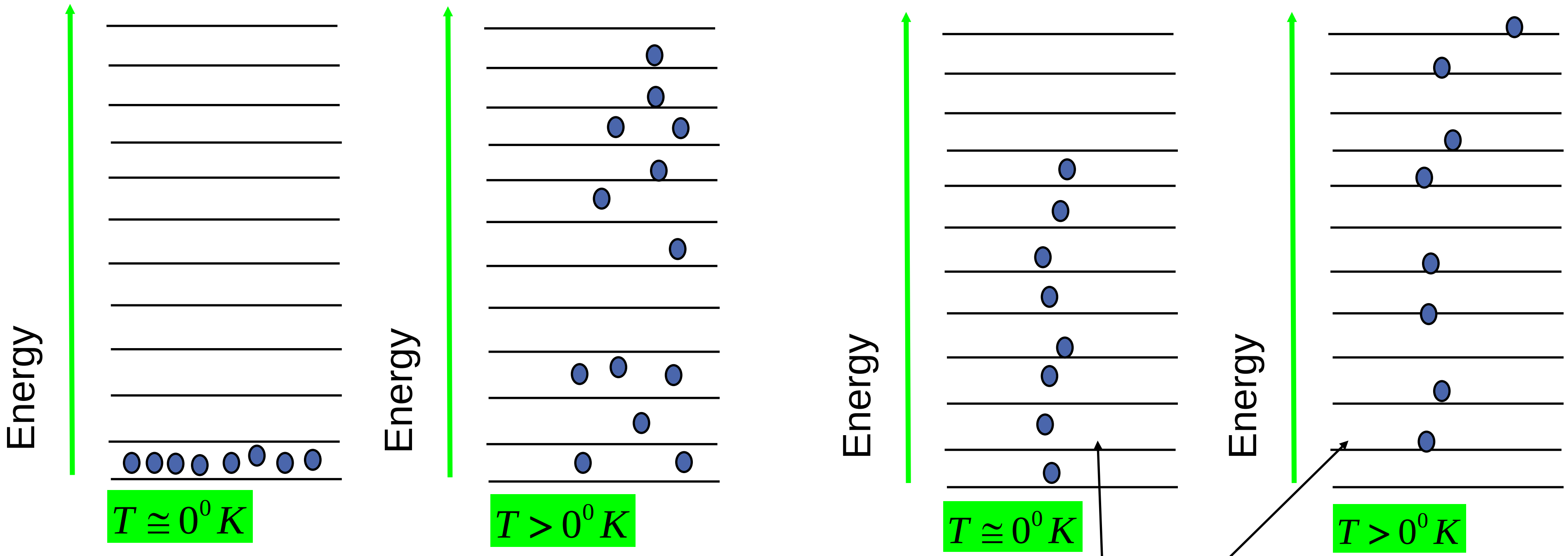
A statistics for (big) Molecules (tennis balls)

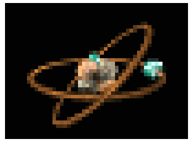
The "Bohr Atom" is like the mini-solar system

Bose  Einstein  Fermion  Dirac 

Quantum Bose-Einstein Statistics

Quantum Fermi-Dirac Statistics



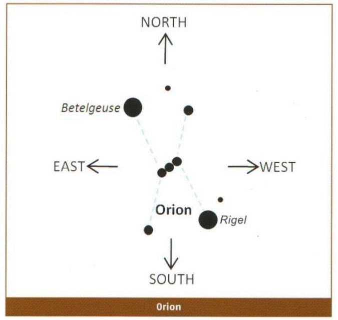


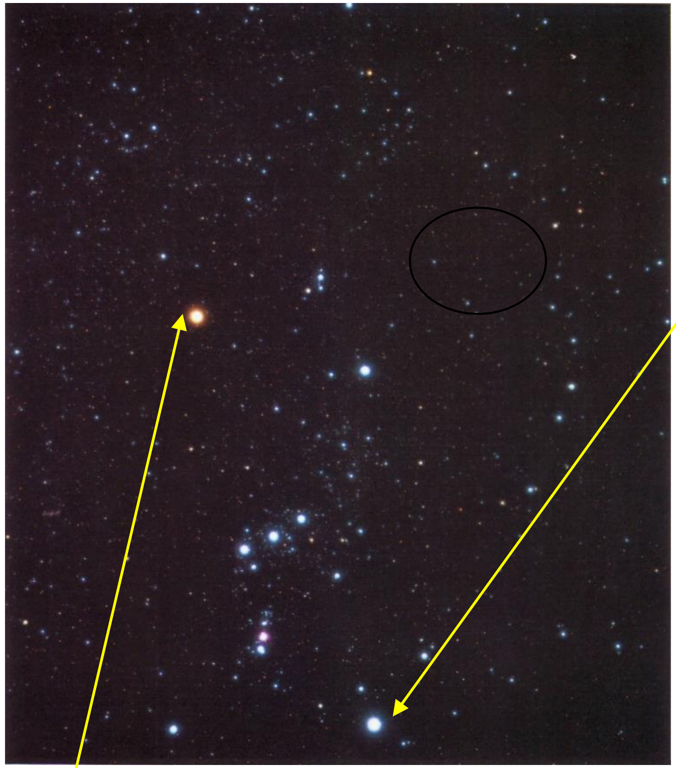
Note : At high temperature Bosons and Fermions behave like Boltzmann particles.

Degeneracy Pressure

Are there such evidences ?

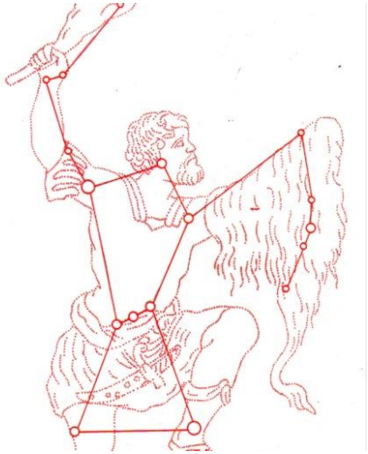
Orion (Star Hopping)

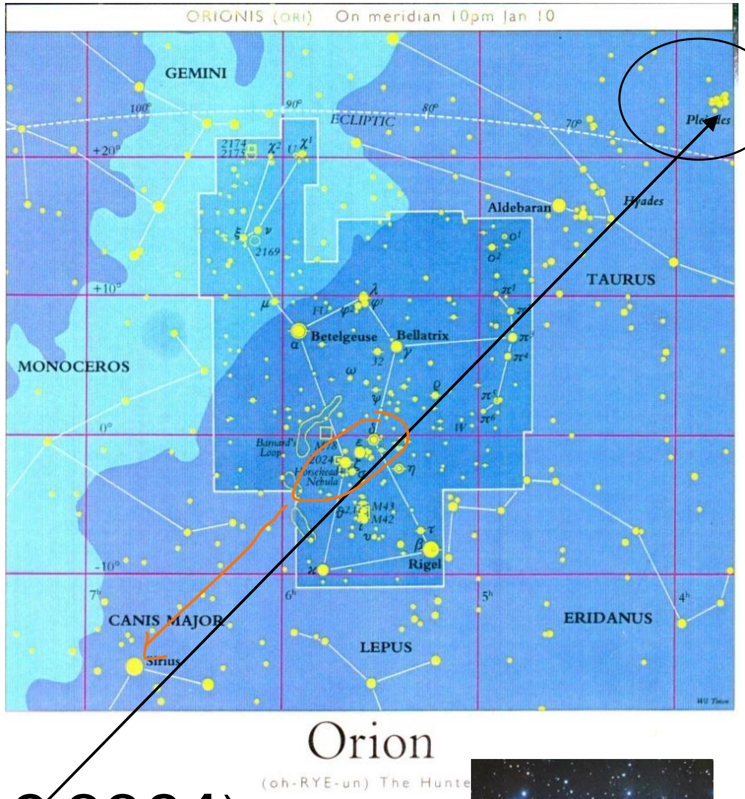




Beta Orioni

Rigel





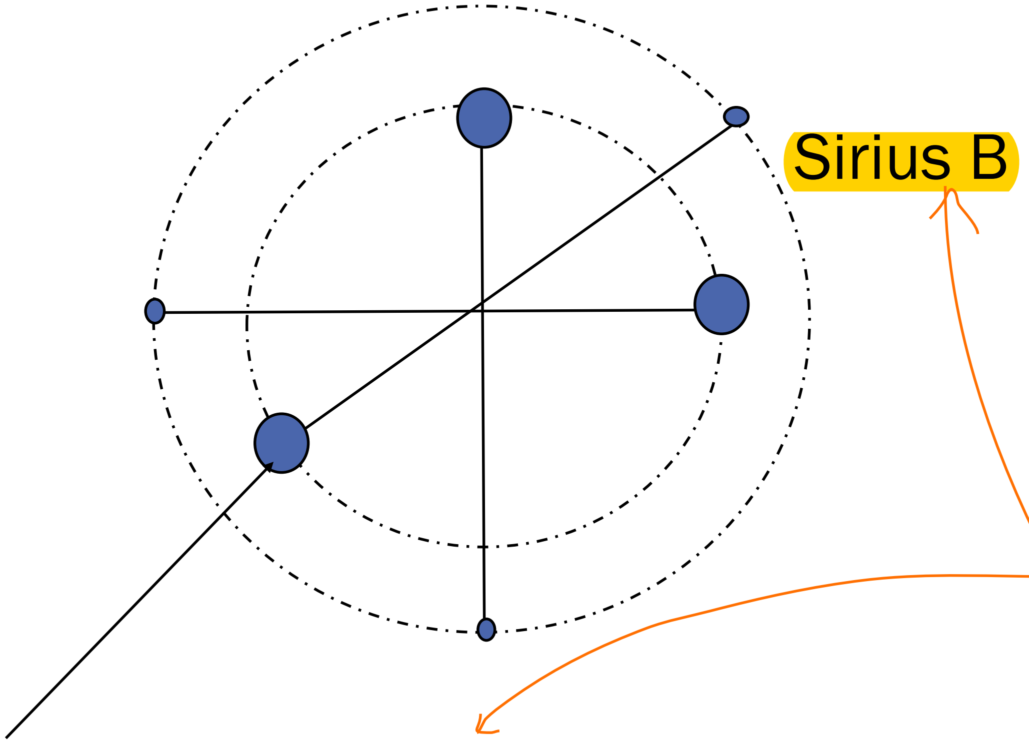
Alpha Orioni

Betelgeuse Super Red Giant

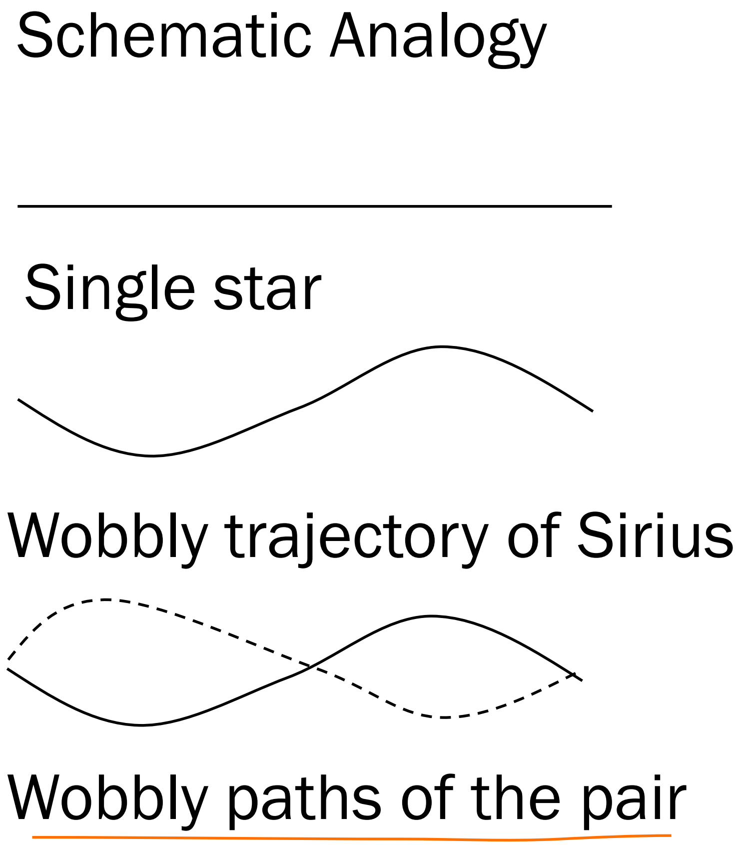
Open Cluster (NGC 2264)

7 Sisters (M45)

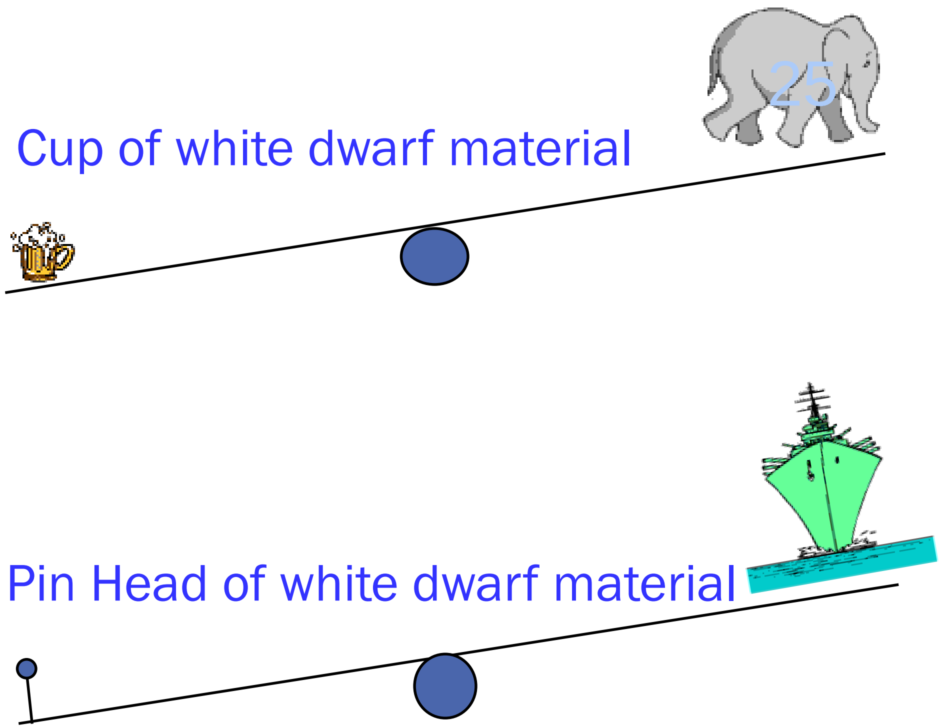
Detection of White Dwarf



Sirius A (the brightest star in the night sky) negative magnitude



So what is Degeneracy Pressure ?

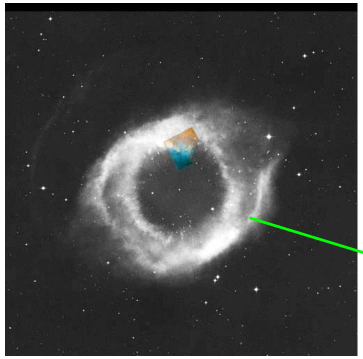


Pauli Exclusion Principle
No two electrons can occupy the same electronic shell.

General Relativity warps space-time around white dwarf material.

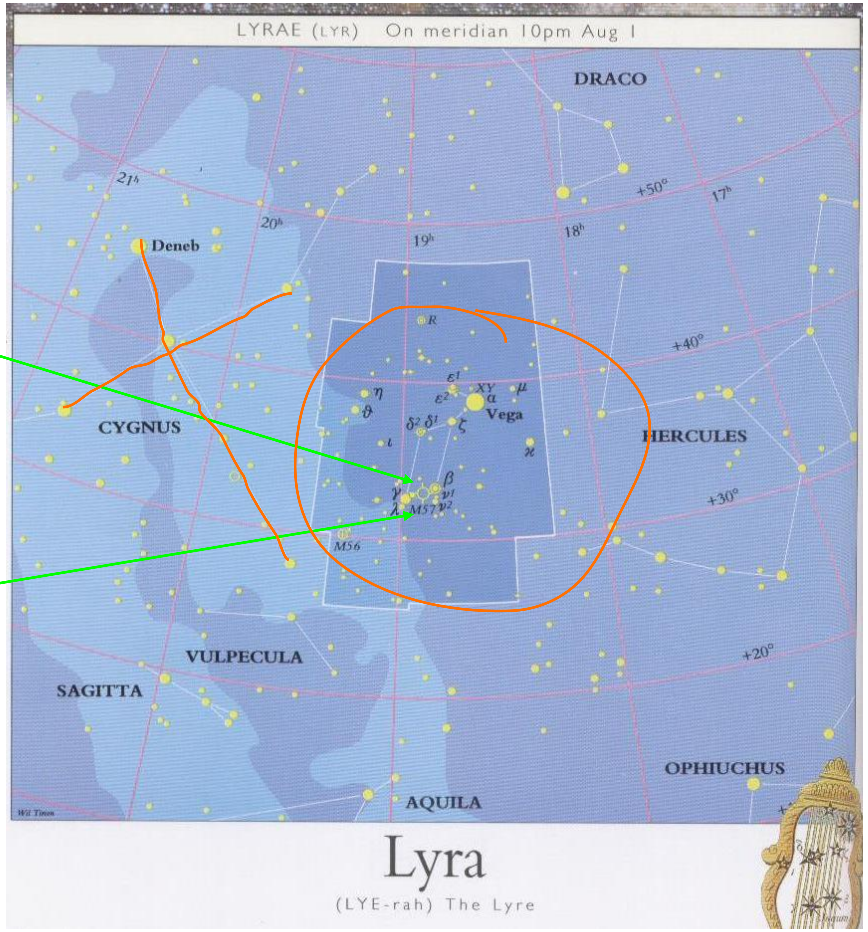
Star Graveyard in Lyra Constellation

explosion



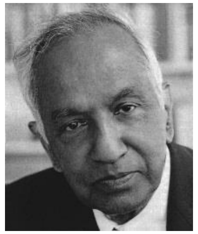
Why is it called a Planetary Nebulae ?

Is there a planet or a white dwarf ?



Is there a theory for Star Graveyards ?

Chandrasekhar's Strategy

	Non-degenerate	Degenerate (Quantum Mechanics)
Non-relativistic	Ordinary Stars by Eddington and Bethe (Boltzman)	White Dwarf solved by Fowler
Relativistic	Ordinary Stars by Eddington and Bethe etc ?	Stars heavier than white dwarf by Chandra

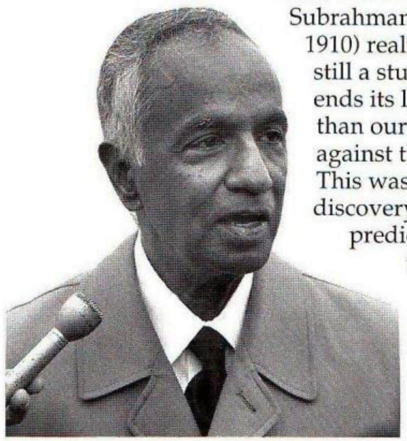
Chandrasekhar‘s White Dwarf

Fowler applied standard non-relativistic quantum statistical mechanics (Fermi-Dirac Statistics)

Chandra questioned that the density would be so high as to make relativistic effects important.

Chandra discovered that even the degeneracy pressure cannot arrest the collapse to a point. This is the source of A Great Quarrel !

Chandrasekhar & Eddington



STAR SCIENTIST
Subrahmanyan Chandrasekhar (born 1910) realized in the 1930s, when still a student, that a star which ends its life with a little more mass than our Sun cannot hold itself up against the pull of its own gravity. This was a key step towards the discovery of black holes predicted by the general theory
Chandrasekhar also helped to explain how stars work, and came back to black hole studies during the 1970s and 1980s.

"I do not know whether I shall escape from this meeting alive but the point of my paper is that there is no such thing as relativistic degeneracy. …

I think there should be a law of Nature to prevent a star from behaving in this absurd way.

Your mathematics may be right but I don't think your physics is correct. "

In 1982, he still uses the Mathematical Theory of relativity.

Chandrasekhar's Limit, 1.4

Scientific ☉

Chinese 日

Stars 1.4 times more mass than our Sun.

The atoms would all have been crushed and there would be nothing but nucleus (& electrons ?)

Results in an unusual material (cloud or gas ?)

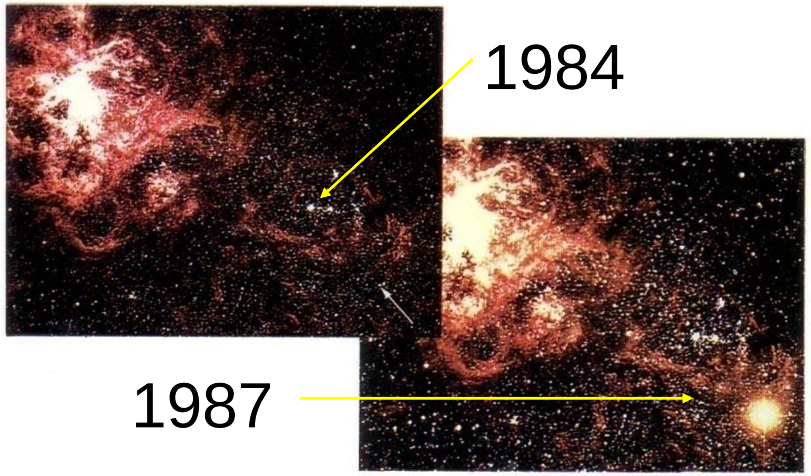
It is mostly Neutrons in the nucleus!

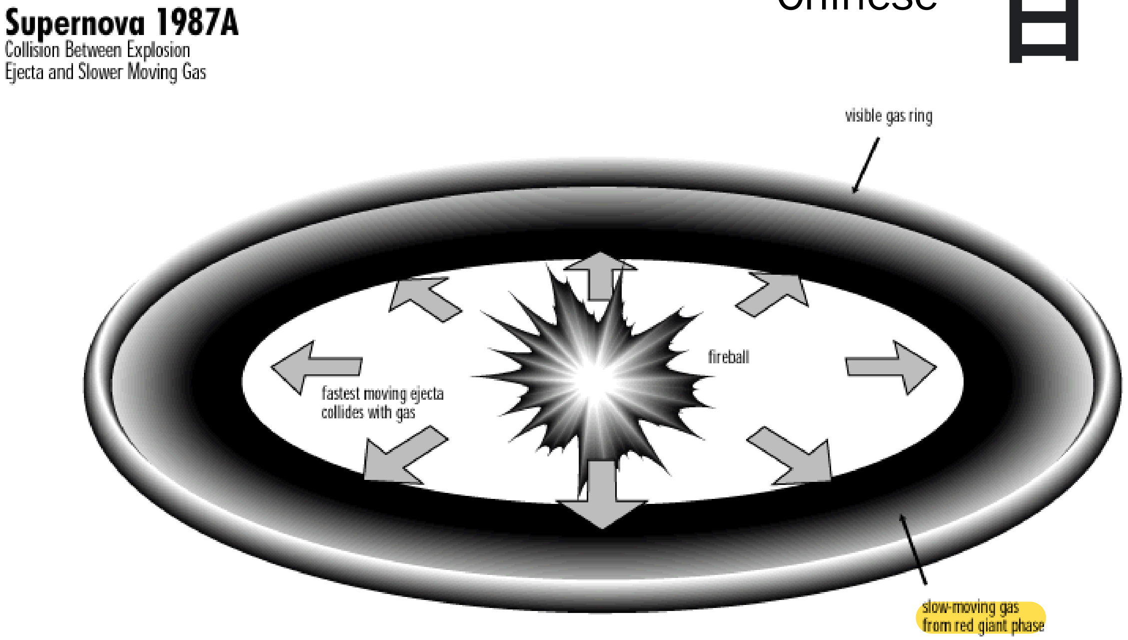
Evidence : Supernova

Scientific $\odot$

Chinese 日

NGC 2070 Tarantula Nebula

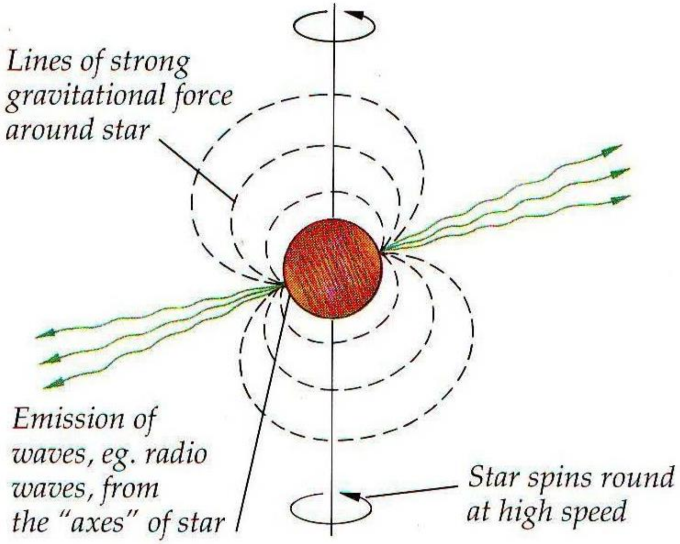




Heavy stars, many x $\odot$ are unstable, somewhere along, the star suddenly explodes, losing a large amount of mass.

The remnant will be stable if it is ~ less than 1.4 x $\odot$

Neutron Stars (Pulsars)



WHAT IS A PULSAR?
The most dense concentrations of matter are neutron stars. A neutron star is little bigger than a mountain, but contains as much mass as the Sun. The star has the density of an atomic nucleus (p. 58). Some neutron stars have strong magnetic fields, and beam out radio waves like a lighthouse. They are called pulsars. Changes in the pulsar spin show up as changes in the lighthouse effect.

Neutrons are radioactive and decay into protons, electrons and also neutrinos.

Why don't neutrons get crushed also ?

Celestial Light House

(LGM 1) Little <u>Green</u> Man !

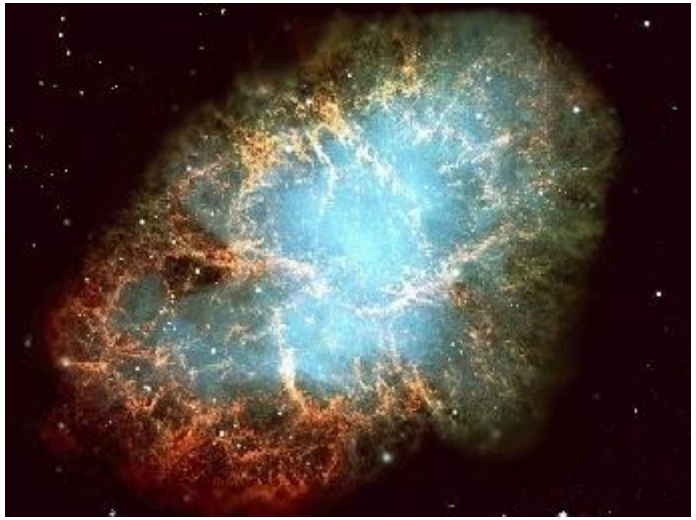
Super-dense Lighthouses

A supernova's core collapses in just a few seconds, often producing a pulsar. These are super-dense rotating neutron stars that beam flashes of radiation – like a lighthouse – as they spin. Most pulsar, which are about the size of Manhattan, spin about once a sec but the record is 642 times a second !
Pulsar only pulse for a million year or so. They lose energy, spin more slowly and turn into non-pulsing neutron stars.
A pulsar is the ultimate in squashed matter. The protons and electrons in the core of the former star have been squeezed to form neutrons – particles with no electrical charge. Standing shoulder to shoulder, the neutrons hold up the pulsar against the force of gravity. The compressed neutron star has a magnetic field about a trillion times more powerful than the earth's. Its magnetic poles squirt dazzling beams of radiation into space.

Crab Pulsar youngest neutron spins 30 times a sec.
Many may not be detected… tilted in the wrong way.

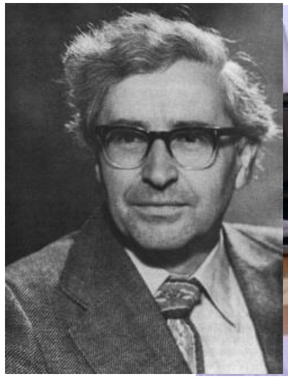
How to detect a Pulsar ?

2 am on July 4 1054 AD by Imperial Chinese astronomers. ‘For 23 days after the event, the supernova remnant glowed so brilliantly that it was visible even during the day time … it kept getting fainter & fainter & after 653 days could not be seen with the naked eye’ Yang Wei-Te, Aug 27 1054



M1, Crab Nebula, NGC1952

Hubble identified it



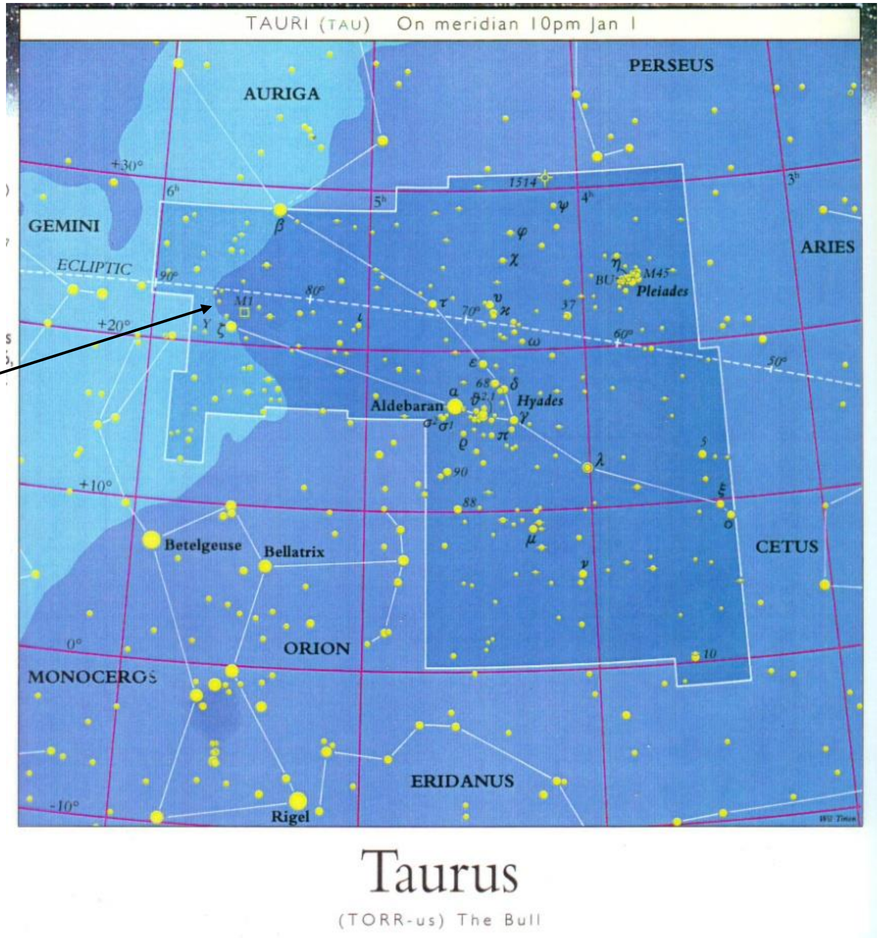
Hewish J. Bell

In this Bull, is Crab !

Normal Pulsar

Medium Vela

Fast Crab



Crab Nebula in Taurus (Bull) Constellation (M1 object)

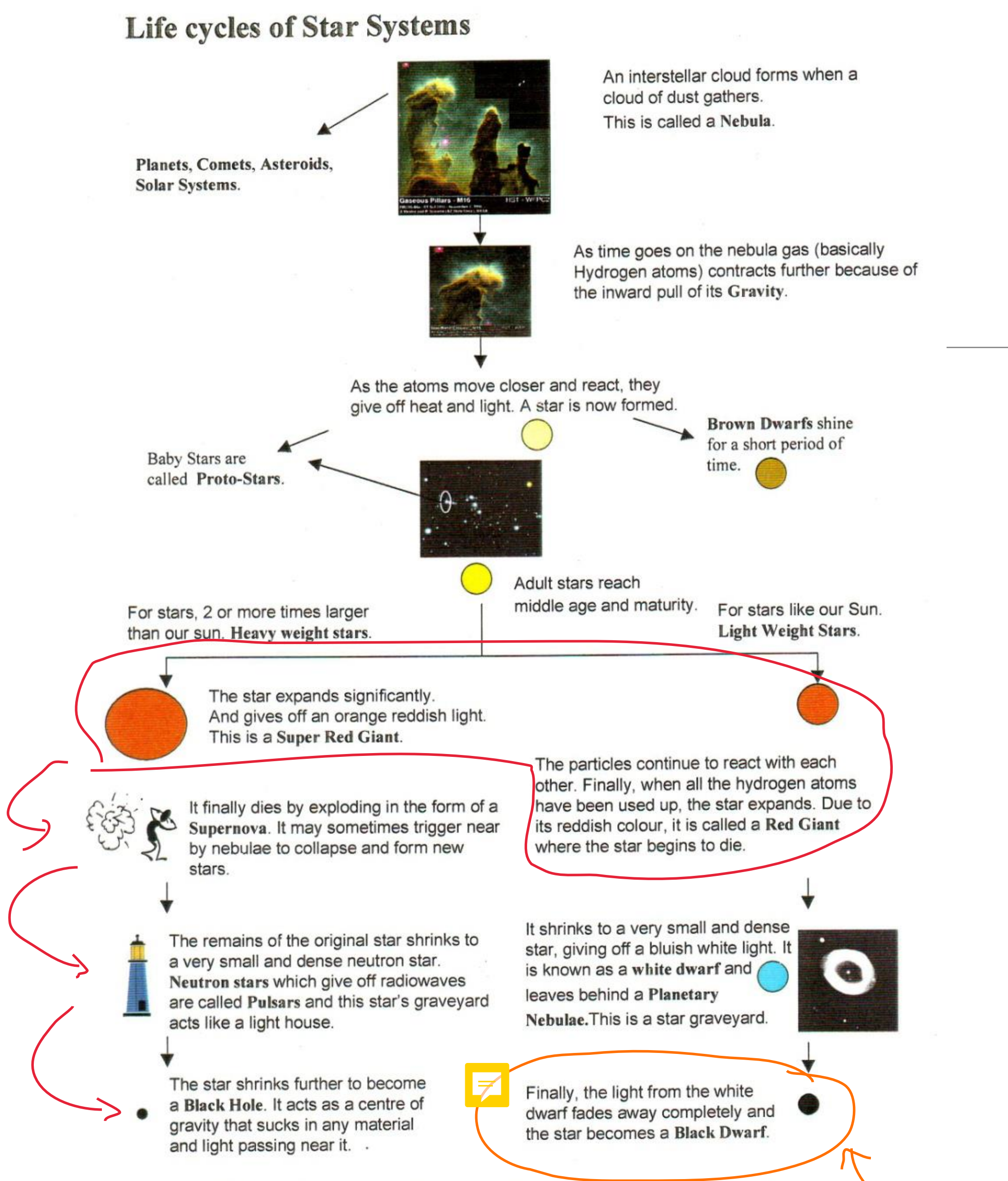


Figure [5] The participants of the *stellar country* and the life cycles of stars **in full glory**. But this is not the ultimate story, we will know more as we piece together more scientific *jig-saw puzzles* when they are available to mankind in future.

Summary

Terminologies

Nebulae

Proto Stars

Brown Dwarfs

White Dwarfs (degeneracy)

Red Giants (Super)

Supernovae

Pulsars (degeneracy)

BlackHoles

Chandra marries Relativity with Quantum Mechanics to get 1.4 limit.

Life Cycles of Stars

Baby stars are called
Proto-stars

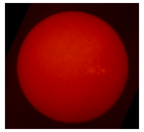
Interstellar clouds form when a cloud of dust gathers.
This is called a Nebula

As time goes on the Nebula gas contracts further because of the inward pull of its Gravity

As the atoms move closer and interact, they give off heat and light. A star may be formed

Adult stars matures and achieve middle age status like our Sun

Premature stars are called
Brown Dwarf



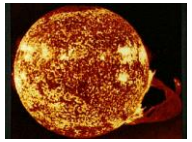
For stars, 3 or more times larger than our sun.
Heavy Weight Stars

Our Beloved Sun

For stars like our Sun
Light Weight Stars

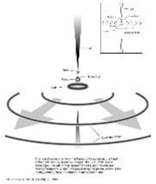
The stars expands significantly.
It gives of an orangy red light
Super Red Giant

The particles continue to react with each other. Finally, when all the hydrogen atoms have been used up, the star expands with a reddish colour
It is now call a Red Giant



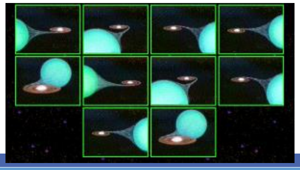
It finally dies by exploding in the form of a Supernova
by nebula to collapse to form
by nebula to collapse to form new stars

As the stars begin to shrink to a very small and dense star giving off a bluish white light. It is known as a white dwarf and it leaves behind a Planetary Nebula, a graveyard



The debris of the original star shrinks to a very small and dense Neutron Star.
Stars that give off radiowaves are also called Pulsars, a graveyard that acts like a lighthouse

Finally the light from the white dwarf fades away gradually and the star becomes a Black Dwarf



When stars are many times our sun, it will further shrinks to become a exotic Black Hole
It gravity force will suck in any material in it's it's vincity, even light cannot escape.