MACARTHUR ASTRONOMICAL SOCIETY Inc.

Journal

PRIME FOCUS

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President' Report

Greetings to all members and guests. Tonight it gives us great pleasure in announcing as our special guest speaker Ken Freeman. Ken comes to us from the research school of Astronomy and Astrophysics, Australian National University in Canberra. His subject for tonight will be on the formation of our galaxy. On behalf of the society I thank Ken for taking the time to visit us here tonight.

Melissa Hulbert, Bachelor of Science (Honours) in Physics/Astrophysics and a member of Sutherland Astronomical Society was our guest speaker last month. Melissa spoke to us about the various technologies involved in imaging the night sky, everything from a box brownie to the latest in digital cameras, even web cams can now take extraordinary pictures. Melissa's presentation was well received by everyone and I know that our very keen astro-photographers got a lot out of the night. Thanks Melissa.

Melissa Hulbert

The next couple of months should be a really exciting and busy period for our club, weather permitting of course. It would be great to see as many members as possible at the public and field nights that are on the schedule below. I can "Shiver Me Timbers" to the fact that it has been very cold lately with the coldest June since 1984 and apparently the 2nd coldest on record. So if you are coming along please bring along extra warm clothing, especially the members trekking down to the Magellan Observatory weekend.

The Dates

22/07/06 Magellan Observatory
29/07/06 Stargard Field
05/08/06 International House Students night The Forest, (now confirmed)
18/08/06 Science Week night at Macarthur Anglican High School, (now confirmed)
19/08/06 Stargard Field
21/08/06 Monthly Meeting
26/08/06 The Forest
02/09/06 Macastro Star night, Stargard field
16/09/06 Stargard Field
18/09/06 Monthly Meeting
23/09/06 The Forest
14/10/06 Macastro Star night, Stargard field
16/10/06 Monthly Meeting
21/10/06 The Forest
18/11/06 The Forest
20/11/06 Monthly Meeting
25/11/06 Stargard Field

Space Cadets

The Cadets will be meeting this Thursday the 20th of July. The meetings are primarily aimed at young adults and children, however for our newer members just starting out the Cadets could prove a valuable way to gain more fundamental knowledge about astronomy, so please come along. Meetings are held at the Campbelltown Library every 3rd Thursday of the month at 5.30pm to 6.30pm.

Further details can be found on the MAS website, **www.macastro.org.au**
Just follow the link to "Space Cadets" which is on the home page. We have some basic info on that link, however, so when you attend the meetings you will be issued a special password that will allow you to explore further.

The Stargard Field

Again another disappointing night courtesy of some very thick cloud cover. We just cannot take a trick at the moment! It was a real shame because we had a great turnout of members. I took along the great white beastie and tried to tame it a bit. I did manage to grab some really pleasing views of the Moon and for the first time I actually saw the Great Red Spot of Jupiter, although a whiter shade of pale would best describe the spot. For a while I was in awe as I could imagine our planet Earth fitting right into the great spot.

I like to sometimes think about the scale of things in this great Universe of ours. Recently John sent out an email that contained an image about a giant solar flare that in comparison made the Earth look very insignificant indeed. Also I always look up at Alpha Centauri and relate to it as being only 39 trillion clicks away, or thereabouts. Recently we had a close fly-by of a large piece of rock and I heard that sometime in the next decade another visitor could pass very close, this one being inside the orbit of our Moon. Now the grand scale of things seems to be getting a tad bit smaller.

Well that about all from me, good luck to all the guys heading down to Magellan, drive safely and stay warm!

Kind Regards Noel Sharpe ■

A Forest Report

G'Day to all. Just a quick report from our observing night at The Forest on 24th June.

Ned & Lloyd made the trip down on Friday and enjoyed the serene surroundings, but unfortunately for astronomy, the night produced only the sound of rain on the tin roof.
Saturday dawned partly cloudy, but as the day went on the clouds cleared and promised great viewing. Martin, Dick, Bruce, Noel and I, joined Ned & Lloyd on the field in the late afternoon.

This was first light at this site both for Noel's and my 12" Dobs. We were not disappointed. Martin continued his very successful imaging, the most challenging was a **70 minute exposure of the Helix Nebula**. He sat at the scope keeping a watchful eye on the guiding to what we hope will be a spectacular result. We couldn't even tempt him into the cabin for a quick port! Now that's commitment!!!! I think he was frozen to the chair.

Ned & Bruce were tinkering with their new Meade D.S./L.P. Imagers with mixed results. Electronic imaging is a steep learning curve but ultimately a rewarding one - watch this space! Unfortunately Lloyd's 10" Dob succumbed to the dew factor, so he was knocked out early. An addition of a primary fan and dew shield will fix this. Lloyd was able to enjoy the views through the other scopes on the field at least.

Dick was our fountain of knowledge and challenge. After trying and failing to find Shapely 1 (again) at Lloyd's and Dick's request, I turned my attention to the Helix Nebula. It's as big as a half full Moon, but low on the horizon and I couldn't see it. Dick saw it easily (must be all the carrots Dick) I had to wait until it was 20° further up, when I could make it out naked eye.

Noel had his newly painted (Classic White) 12" Dob on a EQ6 mount, move over Keck!!!. A huge kit that dwarfed Noel. After a world wide search Noel was able to find a supplier to build the tube rings to mount the monster - a job well done. This is one serious set-up that is heading for good things.

Ned paid me a visit during the wee hours and we headed off to find NGC 55, NGC 300, NGC 247 and NGC 253 all galaxies at different angles and spectacular sights.

As I mentioned before the dew was prominent, it then changed character - **ICE!!!** All the scopes were covered with ice (about 7mm thick) my shroud was frozen stiff like a board.

During the early to mid hours of the morning astronomers peeled off to the siren like lure of a warm bed. I hit the sack at 3am and left Martin to pack up. He mentioned that as he was about hit the hay at 4am the cloud rolled in. We were all lucky to have such a great night.

Last thing, I was up at 6.30am and greeted by a winter wonderland. The field was white with a very thick frost. Martin took some pictures of this and may place them on the website. So there you are. That's the fun that you missed if you didn't join us at the Forest.

Cheers, John Rombi ■

Observations from Orange

The truly glorious viewing nights are upon us, especially in Spring Hill, which is, located 20kms east of Orange at 885 m above sea level. Loaded up with deck chair, blankets, and thermals, my trusty binoculars and a thermos flask so I didn't have to come inside and ruin my night vision, I settled in my back yard for a wonderful night's viewing. I quickly became intoxicated with the familiar and now not so familiar objects in the night sky.

For those of you in MAS who have observed dark sky, Spring Hill is as good as most of these, with very few street lights, and the ones we have are Orange and away from the house. My viewing could be almost compared with The Oaks, or even possibly Belanglo State Forest. I am certain most of the diehard observers can understand how great the night sky at Spring Hill is to observe even with my trusty 7 by 40 binoculars. When twilight goes and the dark sky arrives around 10-11pm I just peer up and see a plethora of stars and I am in another world and can become lost with all the darkness and deep sky objects I can see just with the naked eye.

Some of the objects I observed in June this year were the jewel of the night, Saturn at magnitude 0.2 in the early evening twilight of June 9th-11th, and just down right of this magnificent object is a thin crescent Moon. Then I saw a small fuzzy object just below the Y in the constellation of Cancer, which was an open cluster known as the Beehive Cluster or M44.

I have found naked eye astronomy most rewarding, but armed with a small set of binoculars the view is magnified and objects which are just small starlike objects take on some personality and shape (be it small).

Later in June I was treated to a Full Moon between 20th-23rd and although stunning, it was so bright it stuffed up any night vision I could hope to see any other objects with any clarity for the remainder of the evening. This however was a blessing in disguise as I stated I went out for the next three night and studied the features easily seen with the naked eye and brilliantly enhanced by my binoculars.

Becoming frustrated at my lack of geographical knowledge of the Moon I decided the following night to down load and print out a basic map of the Moon from the net. My excitement grew and grew as I started recognising certain features such as Copernicus 92 kms wide. This is a crater formed over 800 million years ago. I then spied Mare Tranquillitatis or in simple terms the Sea of Tranquillity where man first walked on the Luna surface back in 1969. This land mass has been covered by lava and was an easier site for the first Moon landing. The feature of the evening viewings was mare Crisium, a huge crater over 550 kms wide and located right in the area known as the right eye of the Man in the Moon.

Despite almost 40 years of observing, I never tire of the beautiful sky above, be it planetary (my favourite), deep sky fuzzy objects or our closest neighbour The Moon. I endeavour to make Astronomy simple and fun, and believe in just going out with a cheap star wheel, binoculars and now Bob's Binocular book and try to recognise my friends up there in the sky and try to find new ones.

Phillip Ainsworth ■

That's a Strange Hobby

I mean, why pick a hobby like astronomy? After all, what do I know about stars? The only stars I've ever watched have been the Hollywood variety – not that there aren't a few 'super novas' amongst them!

I guess it comes down to a life-long yearning to explore something that extends beyond my puny imagination. As a teenager, I would gaze wonderingly at the northern skies. The idea of looking back hundreds, if not thousands, of years into history was a mind-blowing concept. The constellation names then were as familiar as were the English flora and fauna.

Then life got in the way and the skies took a back seat.
In my twenties I went to sea, sailing around the globe for six years. The night sky at sea is itself a wonder, matched only by the phosphorescent wake sparkling against the velvet black night sea.

I soon discovered the night sky is more wondrous in certain latitudes than others.
I recall my first trip Far East, staring at a night sky that was unbelievably memorable compared to the pervasive northern night haze.

The only drawback - the sky was not as familiar as the night sky I had grown up with. In my forties we emigrated Down Under and moved for a while to Orange, where, away from the city, the night skies are breathtaking. Again I noticed that as magnificent the night sky might be, its unfamiliarity left me feeling just a little homesick. Apart from the Southern Cross, there wasn't much I could point to with any certainty.

Never mind; life got in the way again and there were too many earthly things to worry about. Like a lot of folks, through my fifties and into my sixties my health began to suffer, until at last I decided it might be time to stop and smell the roses.

Then it occurred to me – why stop at roses? Why not learn about the sparkling southern night sky, making it as familiar as the night sky of my youth? One friend commented that perhaps it was just a desire to look more deeply into the heavens to check out the next life! I reassured him this was not so; rather, it is more a case of recapturing something of my youth. To gaze with wonder yet again and to know exactly in which direction and what it is I am looking at.
Thanks for welcoming me to your group at MAS. I look forward to what promises to be a most informative and rewarding hobby.

Regards – Davy Jones

[Davy – All of us at MAS will do everything we can to help you achieve your aims. And I couldn't help but get a little 'Twilight Zone' feeling when you mentioned your experience of the sky at Orange, as I had just finished inserting Phil's article where he talks about that very thing. Spooky! Ed.]

To Collimate or Note Collimate... That is The Question

Hello Fellow Astronomers, I would like to talk to you about my experience with Dobsonian Telescopes. First of all I love the Dob. (I am not the only one lately, am I gentlemen?) I have been very slack over the years in learning about collimation. That is a big mistake. You must learn how to collimate your scope and your secondary mirror.

"Why?" I hear you say. Well the reason being is if you don't, you won't see the wonders of the universe. (Well you will, but the views will be absolutely awful and you will feel like going home). Stopppppp, don't do that? All is not lost. If your scope is not collimated properly, Stars will have long tails (not that you want to look at stars). However doubles you will? (That will make Ian Cooke happy.) You won't be able to see fine sharp details on.... planets... nebula.... globular clusters... double stars. Everything in other words.
I have never had to collimate the secondary mirror, because I never took it out. I only had to collimate the Primary mirror. That's the way I like it, easy and simple, just like me. (No smart remarks please?) Doing the primary is pretty simple, (even for me). When it comes to the secondary it's a little more complicated.

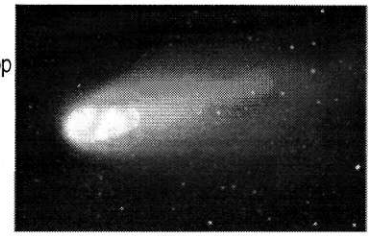
However there is hope, thanks to Mr John Rombi esquire. John has recently sent myself and others a site on Collimation. The site is: www.andysshotglass.com/collimating.html. This site is an excellent site to learn how to collimate your telescope. I would also like to thank Mr Dick Everett for helping me about 1000 times on collimation. (I wonder why Dick is trying to avoid me lately?) mmmmm I can feel 1001 coming up? Just joking Dick.
All the best. Lloyd Wright ■

Comet Pot Pourri

I gave a talk last week to the Campbelltown Philately Club – the chosen topic was "Comets and World Stamps". Some tit bits of comet trivia I researched are worth repeating here: Did you know...?

- The word 'comet' comes from the Greek 'kometes' meaning 'flowing hair'.
- Halley's comet is next due to return in 2062.
- Halley's and Encke's comets weren't named after their discoverers but the people who calculated their periodicity. i.e. return dates.
- The 1973 Comet Kohoutek is due to return in about 75,000 years.
- There is an estimated 100 trillion comets in the Oort Cloud but the average distance between two of them is 20 AUs (distance of Sun to Uranus).
- Historical documents can trace every passage of Halley's Comet back as far as 240BC.
- If I had been the co-discoverer of that 1997 comet with Thomas Bopp, people would have admired the beautiful sight and exclaimed "Bee-Bopp's a Lulu".
- Comet Hale-Bopp will return ca 6400AD.
- In my Chronicle column as start of the year, I made a rash prediction that there would be a major comet seen this year. With 5 months to go, what are my chances? RB

Comet Hale-Bopp 1997



FINDING THE AGE OF THE UNIVERSE

Frank Kish Feb. 2006. PART I

[This is the first part of a 3 Part Article by our Frank Kish.
I would suggest it is recommended reading for those of us who want to understand those heavy cosmological articles in magazines like Sky and Telecope. I would describe this article as 'Cosmology 101'. Ed.]

PREAMBLE

This article is not intended to question or verify the scientific facts surrounding the **13.7 Gy,** the most recently established age of the Universe, but only to provide a summary of the various *measurement methods* used by astronomers up until now, for determining the ages of the galaxies and the Universe. Although these *methods* may well be known to all of us, a *summary* of these for some people might still be of interest.

...a more accurate and up-to-date age of 13.7 Gy for the Universe has been confirmed recently...

ACKNOWLEDGEMENTS

The following sources of information used for the basis of this article:
- The World Treasury of Physics, Astronomy and Mathematics, Edited by Timothy Ferris (1991).
- Free publication from the National Academy of Scientific Paper, by J. W. Truran and D.N. Schramm, Dep't of Astronomy, University of Chicago. USA.
- Cosmic Enigmas, by J. Silk, Prof. of Theoretical Physics, Uni. of California.USA.
- The Extravagant Universe, by R. P. Kirshner, Prof. of Science, Harvard Uni. USA.
- The Physical Universe, by Frank Shu, Prof. of Astronomy, Uni. of California. USA.
- H.R.- Diagram modified by ffk..; Courtesy of D. Eicher, Editor of Astronomy Mag.

INTRODUCTION

Up until recently, scientists, astronomers and cosmologists used several measuring methods of astrophysical objects and events, in order to determine their distances from us, which enabled them to calculate the ages of stars, galaxies, and ultimately the age of the Universe.
Although the distance measurements may be similar in these methods, the objects and events selected will differ. The following are these methods:-

a) Measurements of **redshift** of the light from galaxies. From this a **cosmic expansion** postulated and with the aid of the **Hubble Constant** the age of the Universe calculated.
b) Measurements of the **rate of decay** of the radioactive nuclei of elements, using the technique of **nucleocosmochronology** of the **Type II Supernovae** (>8 M_{Solar}).
c) Measurements of the **recession of galaxies**, using the **Type Ia Supernovae** (<4 M_{Solar}).
d) Measurements of the **age of our Galaxy**, using the **spectral analysis** of stars in the **Globular Clusters**.
e) Measurements of the **Oldest White Dwarfs,** the end-state of main sequence stars of <4$_{Solar}$, (like the future of our Sun), after their planetary nebula stage.

Note: Since the above methods of measurements, a more accurate and up-to-date age of **13.7 Gy.** for the Universe has been confirmed recently, through the

Beryllium analysis of the Globular Clusters. See: www.eso.org/outreach/press-rel/pr- "How Old is the Milky Way? (ESO Press Release 20-04).

The description of this latest method of measurement is **excluded** from this article.

CONTENTS

The following items are described in this article:-

1) The Hertzsprung-Russell Diagram, (HR-D).
2) The Cosmic Expansion;
   Including: The Cosmological Redshift and the Hubble Constant.
3) The Nucleo-cosmochronology, using the **Type II** Supernovae.
4) The Recession of galaxies, using the **Type Ia** Supernovae.
5) The spectral analysis of stars in the Globular Clusters.
6) The temperature measurements of the Oldest White Dwarfs.

...after a star exhausts its primary fuel of core hydrogen, it begins to leave the main sequence...

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1) THE HERZSPRUNG-RUSSELL – DIAGRAM. (HR-D)

Stars play a principal role in all manner of measurements for determining the age of the galaxies and from that the Universe. Therefore, it may be proper to highlight some aspects of the HR-D that represents these procedures in a visual form.

The HR-D is widely used in astronomy, engineering and in statistical work. Astronomers use two types of diagrams, the Theoretical and Observational HR-D.

a) The Theoretical HR-D.

There are various ways by which the properties of stars can be represented on the theoretical HR-D; however, the simplest and the most common way of presentation is by their "Luminosity and the Effective Surface Temperature", which relationship determines their colour. The diagram shows a diagonally located "main-sequence" band of chemically homogeneous, core-hydrogen burning stars, having similar mass, and shining steadily throughout their life, like our Sun.
This article is concerned mainly with the Theoretical HR-D.

The Peculiarities of the Theoretical HR-D.

- Virtually all stars begin their life-cycle on the diagonal "main sequence" band, by converting through fusion reaction their core hydrogen into helium.
- All stars are represented by their mass, with reference to the M_{Solar}, and their mass determines their relative position. Thus, the heavier a star the higher position it occupies on the main sequence.
- The main sequence stars have on average the lowest mass, hence they are called dwarfs, (our Sun included).
- After a star exhausts its primary fuel of core hydrogen, it begins to leave the main sequence.
- The older a star the earlier it begins to drift to the right, where astronomers can estimate from its turn-off point the age of a star.
- After a star leaves the main sequence, its subsequent event depends on its mass. Most single stars will turn into giants, supergiants, planetary nebulae and end up as white dwarfs, just like our Sun will, (incl. all those having originally $<4M_{Solar}$).
- Binary stars, however, after their first explosion into planetary nebulae and

reaching white dwarf stage, will accrete enough energy to explode once again into Type Ia Supernovae, and end up as planetary nebulae with a white dwarf end stage.
- Stars between >4 M_{Solar} and <8M_{Solar} could all become supernovae as well.
- Stars >8M_{Solar}, after their supergiant stage, will turn into Type II Supernovae, and end up as neutron stars, pulsars or sometimes even black holes.
- Irrespective of the age of the Universe, all cosmic events remain in their general sequence as shown in the HR-D.

A copy of this Theoretical **HR-D** modified by the author, is attached to this article.

b) The Observational HR-D.
In order to compare the results of the theoretical calculations with observed stars and star clusters, astronomers first have to prepare observational counterpart of the Theoretical HR-D. These observations require the **Luminosity** of a star from its apparent brightness and the **Distance** to the star.

The other requirement is to determine the **Effective temperature** of a star.
Note by F. Shu: "Because of our observations into the far distances of space, we appear to see only the large galaxies, as the small ones become invisible, and during such times, much evolution of the stellar populations may have taken place, thus they become incomparable with local examples. This incompatibility represents a fundamental and unresolved obstacle for observational cosmology."

2) THE COSMIC EXPANSION

Before we begin describing the Cosmic Expansion, that is the earliest method used for determining the age of the Universe, it may help to recapitulate the two important theories that are associated intimately with this measuring method, namely:-
- The Cosmological Red shift, and
- The Hubble Constant.

a) The Cosmological Redshift
We were able to make distance measurements for a long time within our Galaxy with great ease, and even distances of nearby bright spiral galaxies. In the case of far more distances, however, in addition to further difficulties there is also another problem, i.e. as we look to more and more distant clusters of galaxies, we are examining them as they appeared in their earlier past. In such a case the light from the furthest recognizable galaxy began its journey to us say, 500 million years ago.

It is important to emphasise that galaxies *redshift* because of space-time curvature...

This represents a difficulty in our observations in so far as those distant objects underwent already a considerable evolutionary phase, thus lacking a valid basis of comparison with nearby examples obtained from younger age galaxies. (See the Note on the Observational HR-D. above).

Consequently, "...just at distances where the effects of cosmology (the subtle changes in brightness) begin to be important, the uncertainties in the measurements (of redshift) begin to grow large." (Kirshner).

It is important to emphasise that galaxies *redshift* because of space-time curvature, and not because they have velocities along the radial line of sight or in any other observed direction. Hence the recession "velocity" is a misnomer. And since we have no velocity in its true sense, then we cannot think of the redshift as a *Doppler shift* either.

The concept of the cosmological redshift is a product of the Einstein-relativistic theory, as interpreted by Friedmann-Lemaitre for the radius of curvature for a matter-dominated, *closed* Universe. One may symbolise this concept by the wavelength of light, be it from radio waves to gamma rays that we receive through space-time, and irrespective of whether it represents waveform or radiant energy, it will grow in direct proportion to an *expansion factor*, which is the meaning of redshift.

Astronomers often use the redshift *z* as a synonymous indicator of both distance and elapsed time...

In other words, the cosmic expansion stretches out the wavelength of every photon or any other massless particle in direct proportion to the expansion factor during an elapsed time.

Therefore, formally, the redshift is just a number, whose symbol of:
z* = *(Wavelength* Observed / *Wavelength Emitted.) -1

For small redshifts, the speed of light (***c***) times the redshift (***z***) gives a "velocity". As we know already from the above, the redshift does not tell us how fast the galaxies are moving away from us, and/or from one another, but it measures the expansion of space itself that has taken place while the light from a galaxy is approaching towards us.

Astronomers often use the redshift ***z*** as a synonymous indicator of both distance and elapsed time:-

a) Thus, the statement that **an object** lies at ***z* = *x*** means: an object lies at a distance associated with redshift ***x;*** and
b) When **an event** occurred at redshift ***z* = *y*** means: an event occurred a time ago associated with redshift ***y.***

b) The Hubble Constant

Many fundamental questions, such as in our case, the finding the age of the Universe, are closely associated with the need for a more precise cosmic-distance scale, such as the Hubble Constant. It is also known as the Hubble Law, although it is neither a law nor a constant as it varies very slowly over time. In this article we may still call it a "constant". The Hubble **constant** was built around Einstein's theory of relativity, and it has three important aspects, namely:-
-The velocity of light is constant;
- There is no absolute system of reference in existence;
- The remnants of the Big Bang are accelerating in a curved space, away from a centre of the observer.

Hubble measured initially some 40 galaxies as moving away at a speed proportional to their distance from the observer. This became known as the Hubble constant of: $V = H_0 \times D$, where ***V*** is the galaxy's radial outward velocity, ***D*** is the galaxy's distance from Earth and H_0 is the current value of the Hubble constant. From this equation the inverse of $1/H_0$ = the Age of the Universe.

The Hubble **constant** is determined first, by spectroscopic observations of several, distant galaxies' **redshift,** i.e. their radial velocities, coupled with the precise **distance** measurement of those galaxies from Earth. Through the averaging out many such readings was the present-day value of H_0 determined.

The units of Hubble Constant are: **km/sec. Mpc.** We can, however, calculate the age of the Universe more easily by using the alternative numerical values for the Hubble Constant proposed by F. Shu as being 20 km/sec.million light years.
Thus, one million **ly**. = $3x10^5$ km/sec. x 10^6 yr.
Therefore, H_0^{-1} = $3x\ 10^{11}$ km sec^{-1}. yr / 20 km sec^{-1} = 15×10^{10} yr;
i.e.: **The age of the Universe = 15 Gy.** approximately.

Herzprung-Russel (HR) theoretical Diagram

The basic Herzprung-Russel (HR) theoretical Diagram (as shown on the next page) indicates the relative location and mass of the stars. It also shows the evolutionary paths of our Sun, compared with a mass > $8M_{solar}$ of a young massive star, which develops into a Type II Supernova/Planetary Nebula.

The Type II supernova, where most heavy elements from carbon to iron formed, is the subject of the article "Finding the Age of the Universe". Using these elements as nuclear chronometers for dating, it can establish not only the age of a supernova but also the age of our galaxy and the age of the Universe.

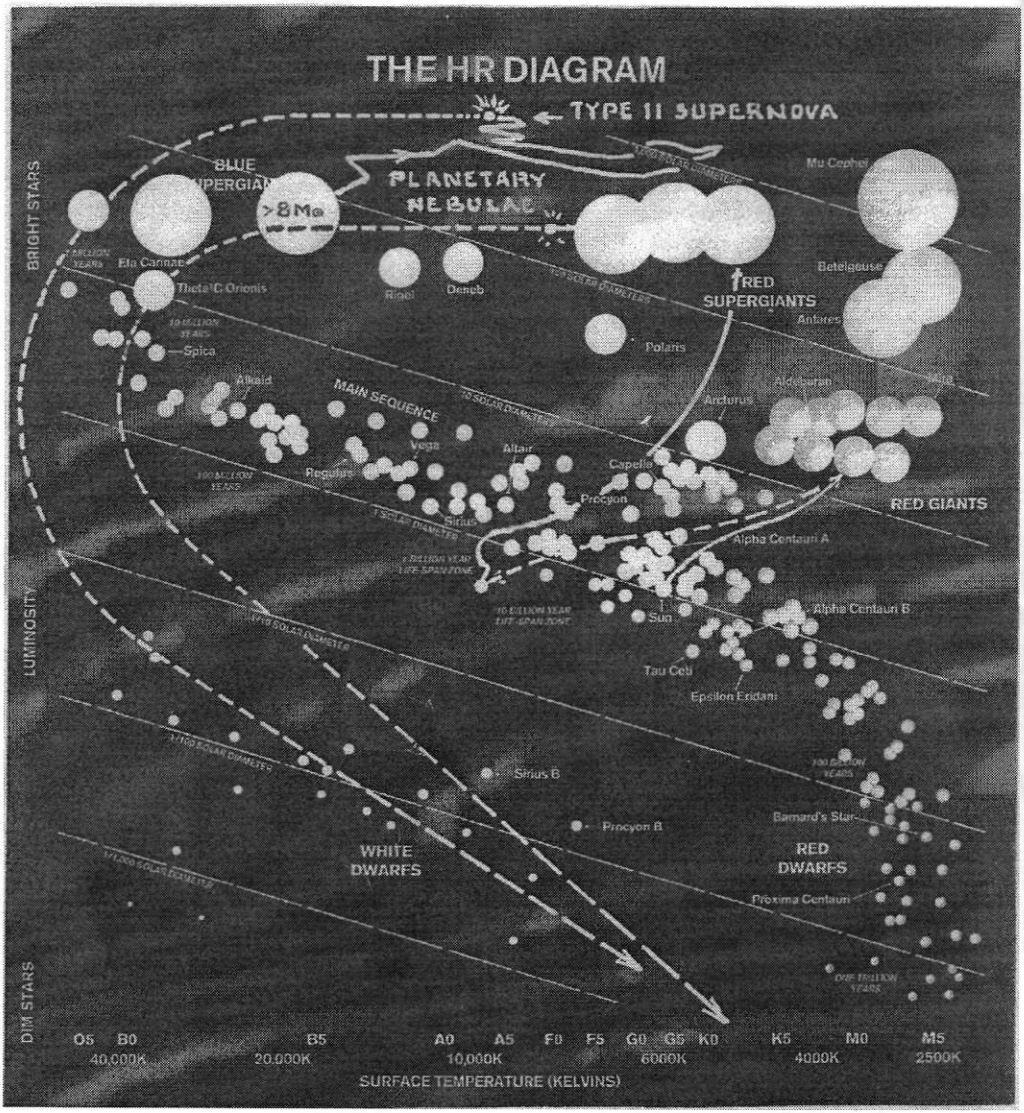
The main sequence, low mass stars (dwarfs), called the Population I Stars, like our Sun, have chemically homogeneous mass, relatively rich in heavy elements, burning hydrogen into helium in their core. The stars generally above $6M_{solar}$ (called high-mass stars) leave the main sequence band earlier than the low-mass stars.

After the main sequence stars used up their core hydrogen, the issue common to all is how to maintain equilibrium between the pull of self-gravity and the loss of heat energy to the outside. High-mass stars begin as low-mass stars begin this process in the same manner as low-mass stars, but then they continue to burn helium, then carbon-oxygen, due to successively alternating core exhaustion/ ignition cycles of the previous layers of ash, which turned into new fuel.

This energy cycling accounts for the almost horizontal zig-zagging shown on the HR Diagram, without any change in luminosity. In its final phase, labelled "the iron catastrophe", a high-mass star will have reached a point where its core becomes iron, beyond which phase there is no further nuclear extraction, but heat loss; it contracts and suffers a catastrophic implosion, then a supernova is born. Supernovae become neutron stars (pulsars), stars become white dwarfs.

Edited by permission from Nov. 2000 Issue of Astronomy Magazine.

[Frank's article will continue in the next issue]


THE HR DIAGRAM
TYPE II SUPERNOVA
BLUE SUPERGIANTS
>8M⊙
PLANETARY NEBULAE
Mu Cephei
Betelgeuse
Ela Cannae
Theta¹ C Orionis
Rigel
Deneb
RED SUPERGIANTS
Antares
Polaris
Spica
Alkaid
MAIN SEQUENCE
Arcturus
Aldebaran
Vega
Altair
Regulus
Capella
Procyon
RED GIANTS
Sirius
Alpha Centauri A
Sun
Alpha Centauri B
Tau Ceti
Epsilon Eridani
Sirius B
Procyon B
Barnard's Star
WHITE DWARFS
RED DWARFS
Proxima Centauri
BRIGHT STARS
LUMINOSITY
DIM STARS
O5 B0 B5 A0 A5 F0 F5 G0 G5 K0 K5 M0 M5
40,000K 20,000K 10,000K 6000K 4000K 2500K
SURFACE TEMPERATURE (KELVINS)