# Introduction to Astronomy Lecture 6: An Astronomical Miscellany

*– binaries, clusters and variables*

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THE UNIVERSITY OF SYDNEY

# In tonight's lecture

- Binary stars
- Variable stars
  - Irregular variables *– stars that go bang*
  - Regular variables *– stars that pulsate*
- Clusters
  - Open clusters
  - Globular clusters
  - The binary connection


Binary stars

# Binary stars

Perhaps 80% of all the stars in the Galaxy are in some kind of double- or multiple-star system. Of the stars we can see, at least 50% are in fact multiple star systems. Somewhere between 5% and 15% are in systems of three or more stars.

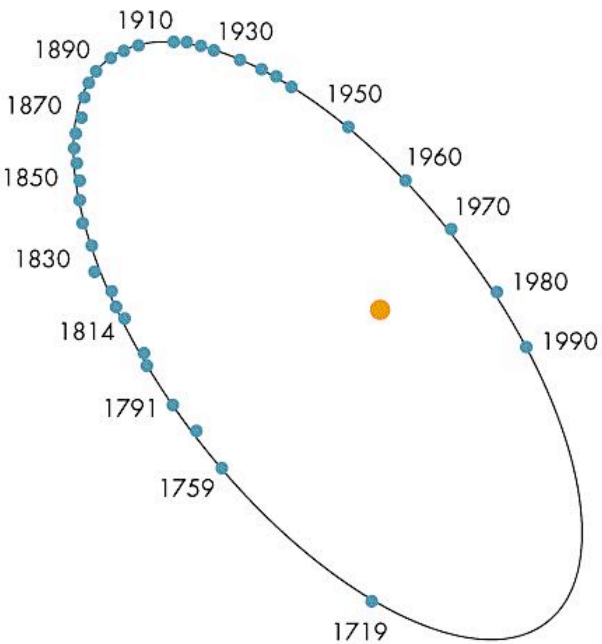
*"Three out of every two stars are in a binary system."*

*– Cecilia Payne-Gaposhkin*

Their orbital separations range from many times the size of our Solar System, like Proxima Centauri, which orbits the inner binary of $\alpha$ Cen A and $\alpha$ Cen B at a distance of 13,000 AU, to distances so close that the two stars actually share a common atmosphere.

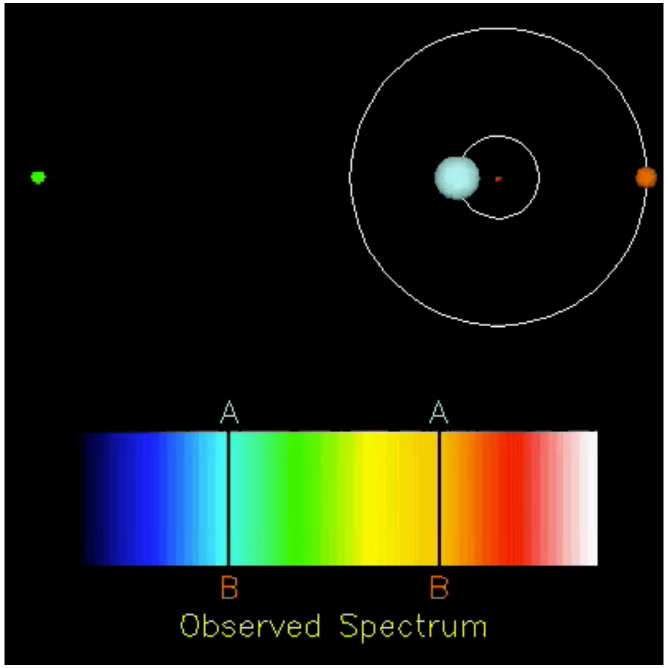

*Artist's impression of the view from a planet orbiting a contact binary. Painting by Don Dixon.*

Some binaries (the *visual binaries*) can actually be seen directly. The two stars are separately visible in a telescope, and we can actually see them moving around one another.

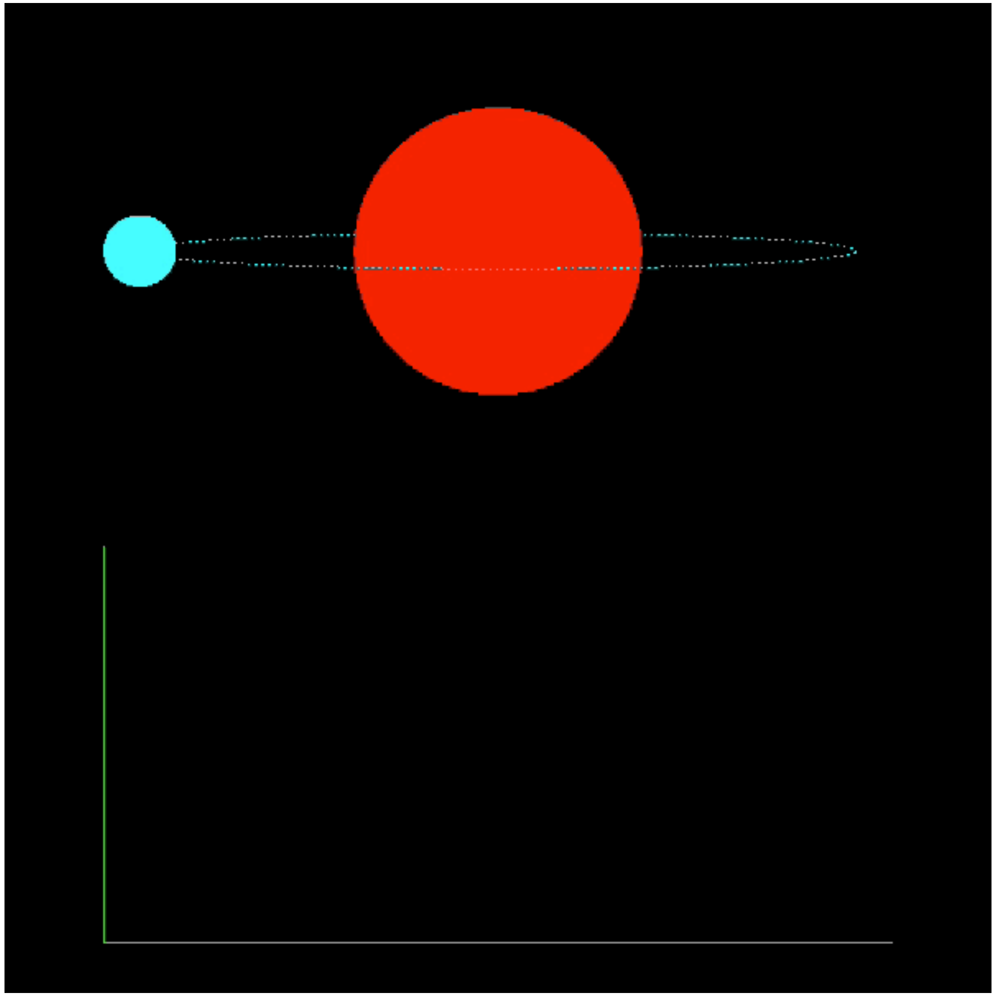

*Castor (α Geminorum) is a visual binary with a separation of a couple of seconds of arc. The binary has not yet completed one 467-year orbit since the first observations were made in 1719*

In all other cases, we have to deduce the presence of a binary. In *spectroscopic binaries*, the two stars appear as a single point of light, but we see the Doppler shifts of the two stars as they move around each other.

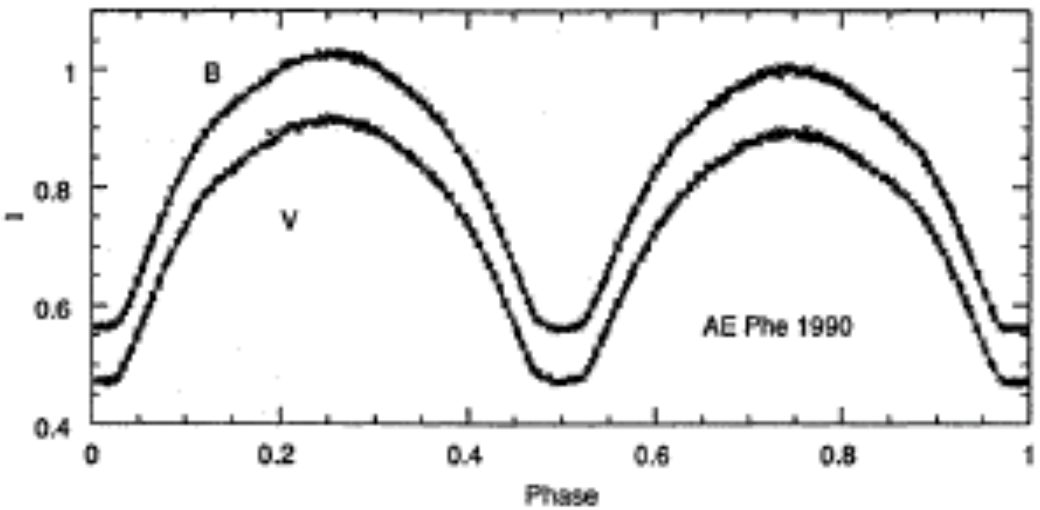


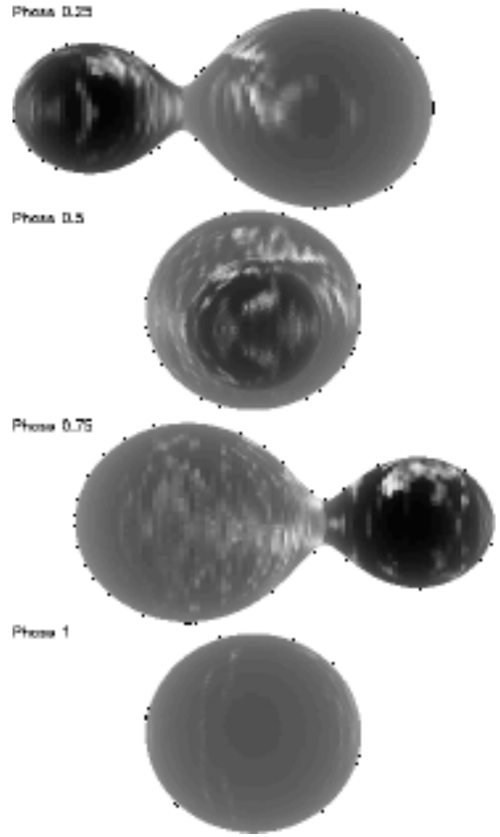
In *eclipsing binaries*, we can see the light from the stars change when one star moves in front of the other.

This only works if the plane of the binary is (almost) edge-on to us.



Sometimes the two stars are so close that their outer atmospheres actually merge: these are known as *contact binaries*. While we can't resolve such a binary as an image, we can infer its existence from the study of the light curve.



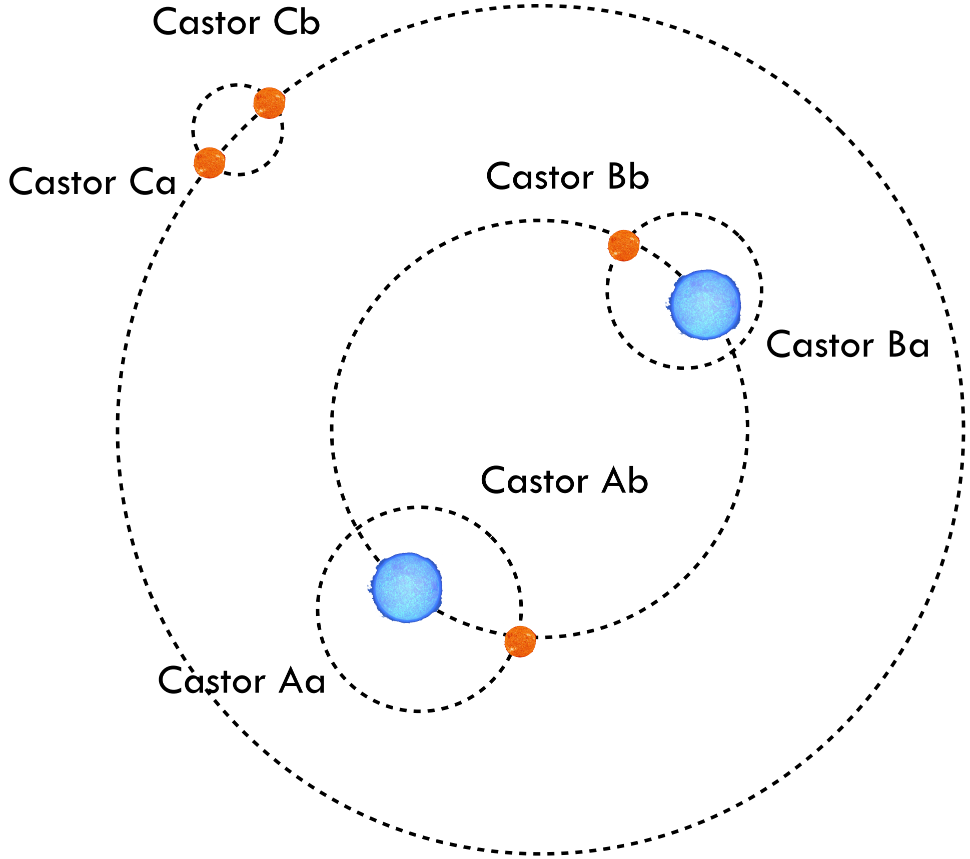




*The light curve of the contact binary AE Phoenicis, and the model for the system deduced from Doppler images of the system. The fact that there is no part of the orbit where the light-curve is flat shows that the stars are never separate: they are actually in contact.*

Each method is biased towards finding different types of binaries.

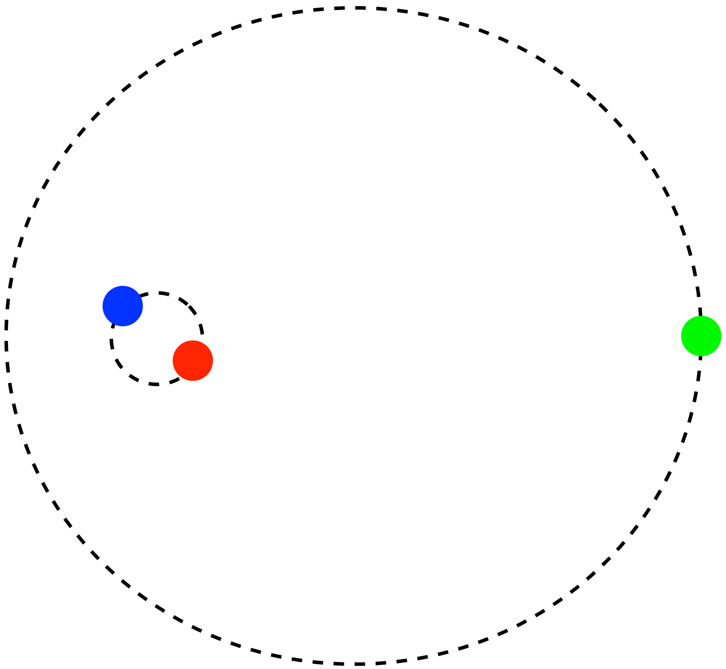
- *Visual binaries* tend to be widely separated (so they can be resolved) and of similar brightness (or the fainter one is swamped)
- *Spectroscopic binaries* tend to be closely spaced (so the velocities are high) and not too different in mass
- *Eclipsing binaries* must be edge-on, and tend to be closely spaced (so the chances of eclipse are higher) and similar in size (so the change in light is greater)

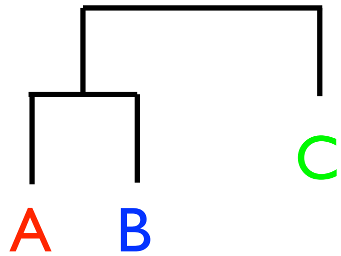
Multiple star systems are also common, containing three or even more stars. For example, Castor (α Geminorum), is in fact a *sextuple* star system, consisting of an inner pair of binaries, with a *third* binary orbiting around the inner pair of binaries.



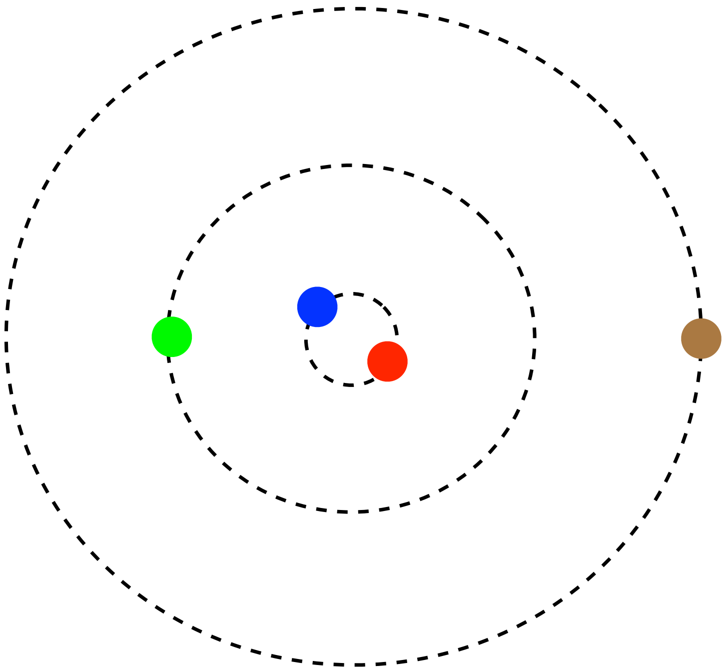

*(orbits not to scale)*

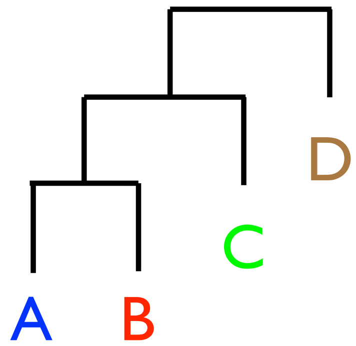
Multiple star systems are always *hierarchical* systems, which can be decomposed into binaries (whose components may themselves be binaries); non-hierarchical systems are dynamically unstable.

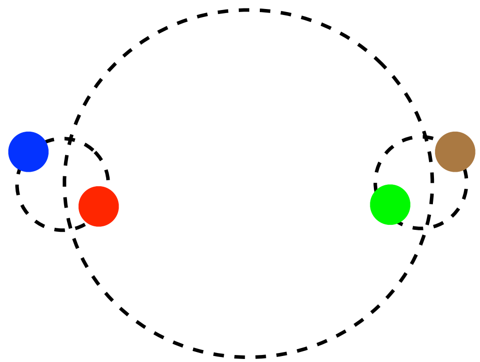


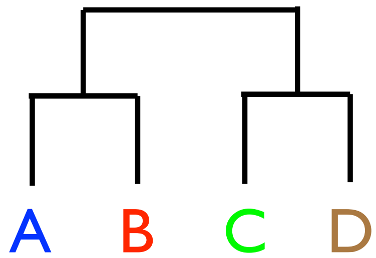


## *Quadruple systems:*

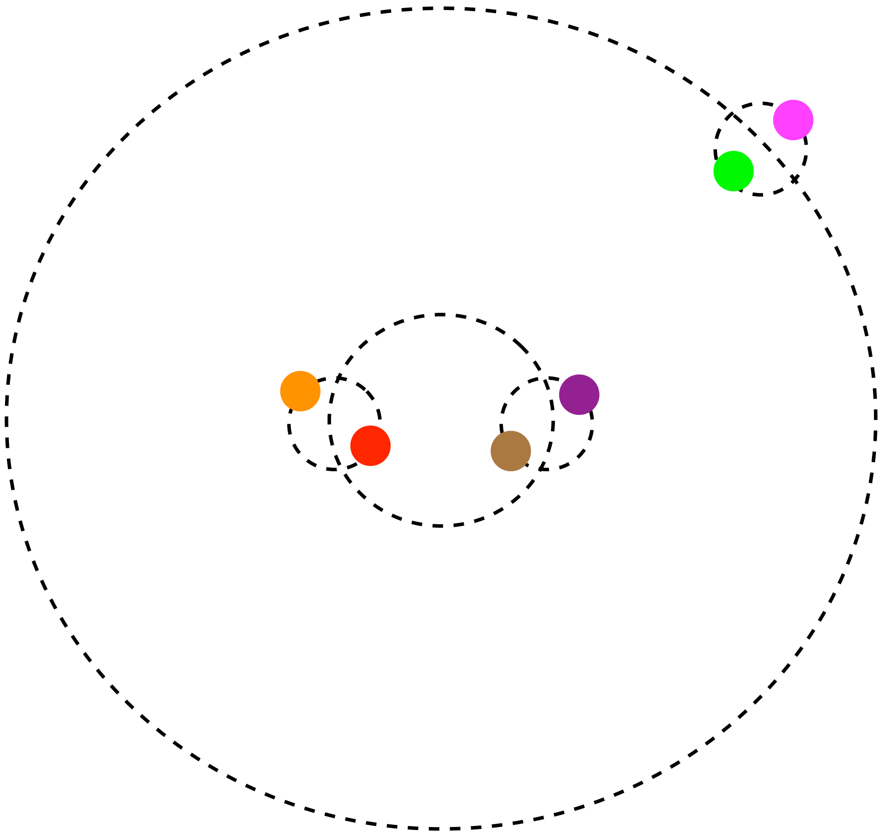


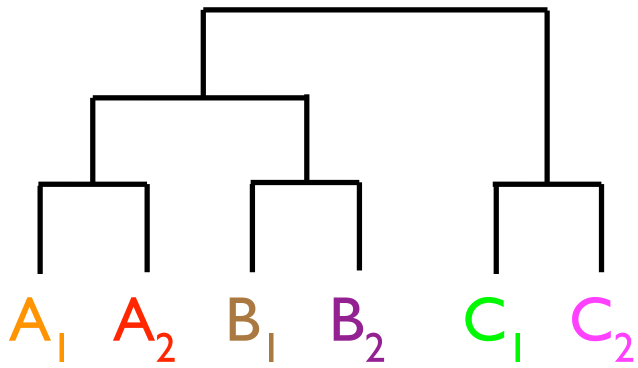


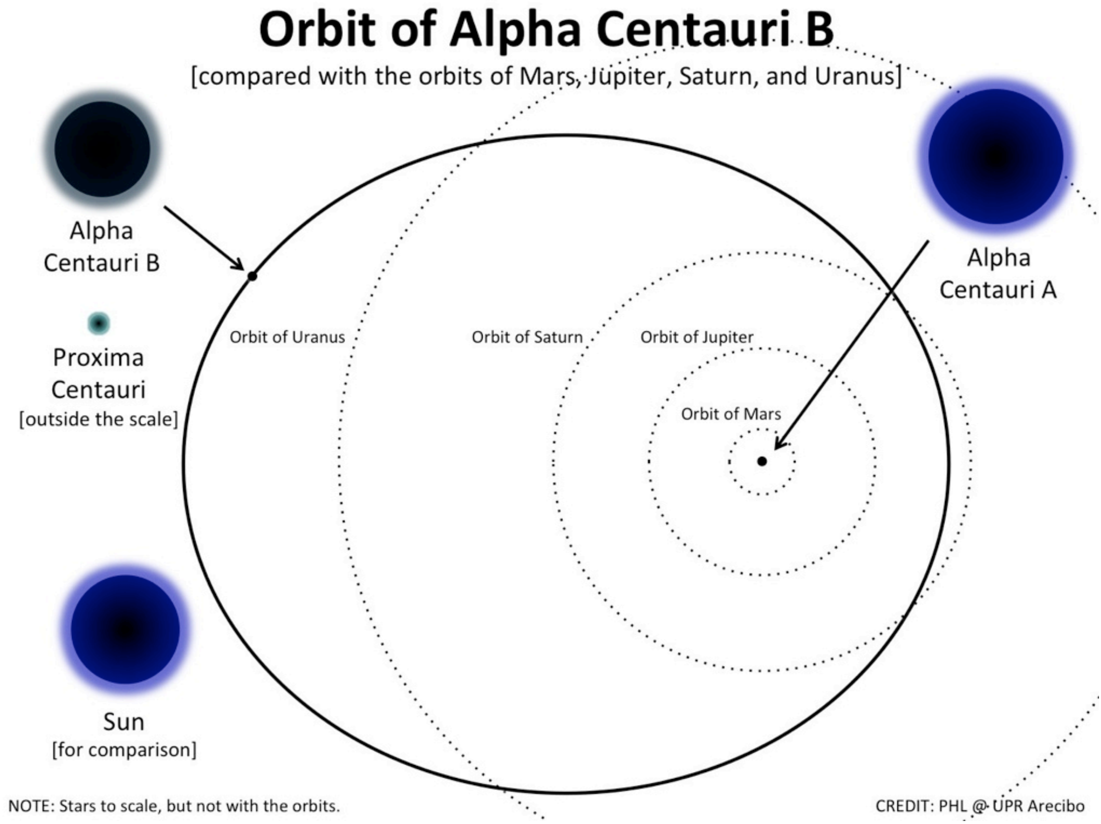


# The Castor system:



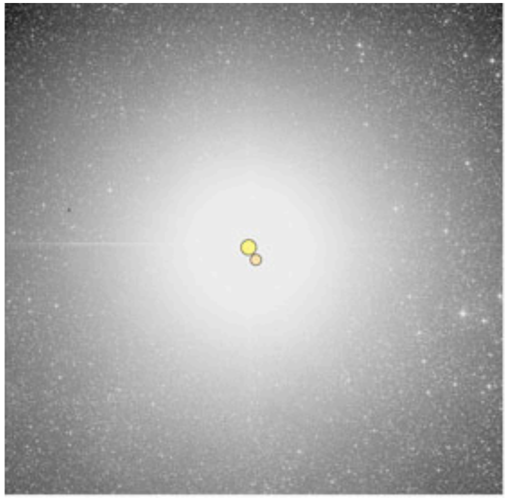


α *Centauri* – the brightest of the two Pointers – is a binary, with two stars separated by 18”, so appear as a single star to the naked eye, though through a small telescope you can see it is double. α Cen A is slightly brighter and more massive than the Sun, α Cen B slightly fainter and less massive. They orbit each other in an 80-year elliptical orbit.

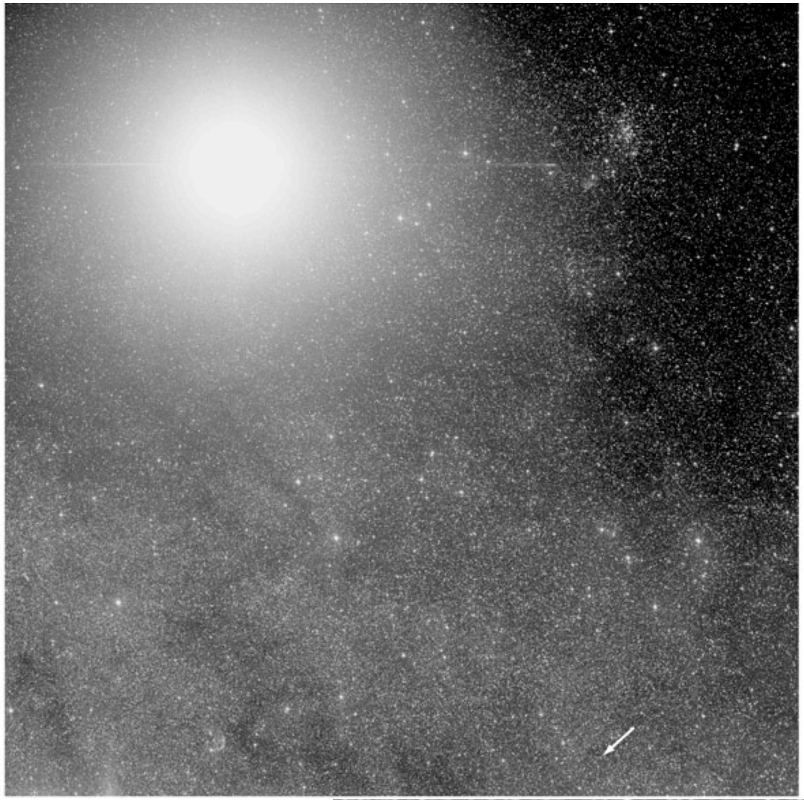


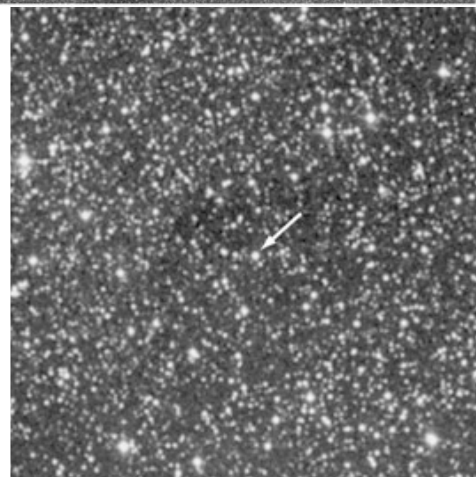
*Proxima Centauri* (α Cen C) is probably a third member of of the α Cen system. Despite being at the same distance, it is 11 magnitudes fainter than the brightest star, α Cen A.

Its distance from the inner binary is 15,000 AU (0.21 ly), and it is probably bound, with an orbital period of about 500,000 years.



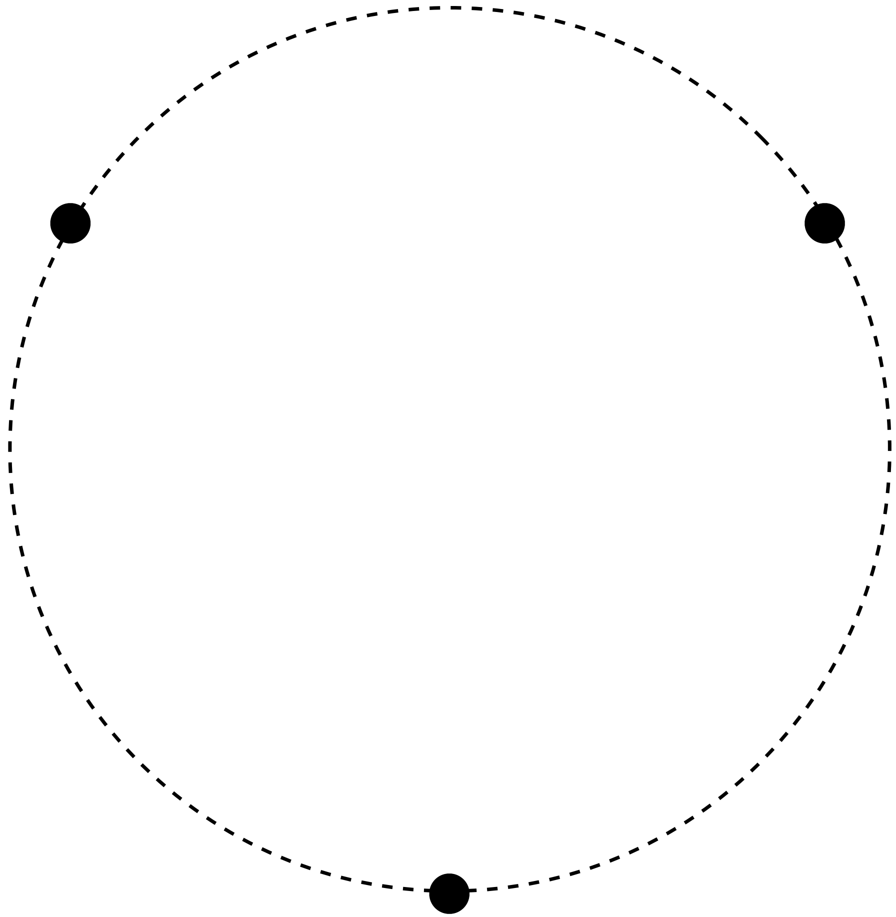
α Cen A & B



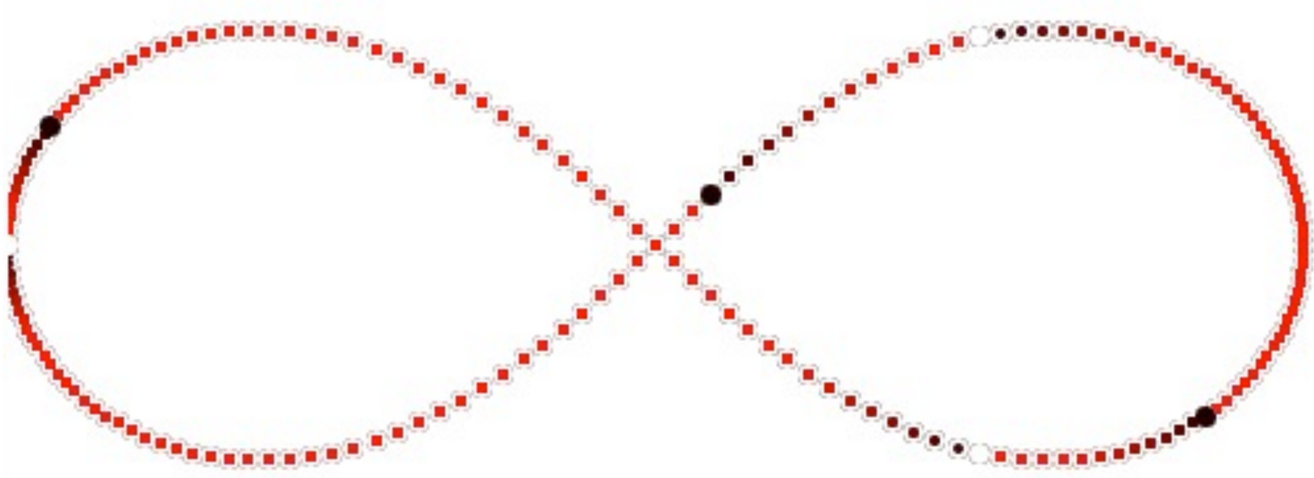


*α Cen A and B are both hidden in the glare; Proxima is arrowed at the lower right.*

Other orbits are theoretically possible, e.g. the Lagrange configuration, with three objects orbiting in an equilateral triangle



Recently even more bizarre orbits have been found to be stable.



However, it's hard to see how they could form!

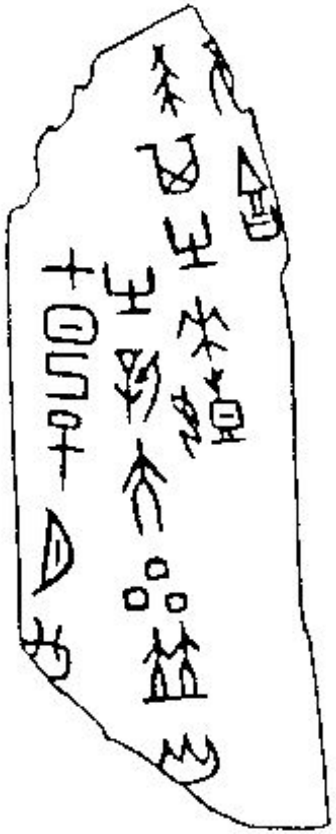
# Variable stars

# Stars that go bang

Although the Greeks considered the heavens to be eternal and unchanging, careful observers have known for a long time that this is not in fact the case.

Hipparchus observed a new star in Scorpius in 134 BC, and was inspired to make a catalogue of stars – the first stellar catalogue – so that new stars could more easily be recognised in the future.

Chinese astronomers have been observing new stars for even longer. A tortoise-shell inscription from 1400 BC reads:



*"On the Jisi day, the 7th day of the month, a big new star appeared in the company of the Ho star."*

*"On the Xinwei day the new star dwindled."*

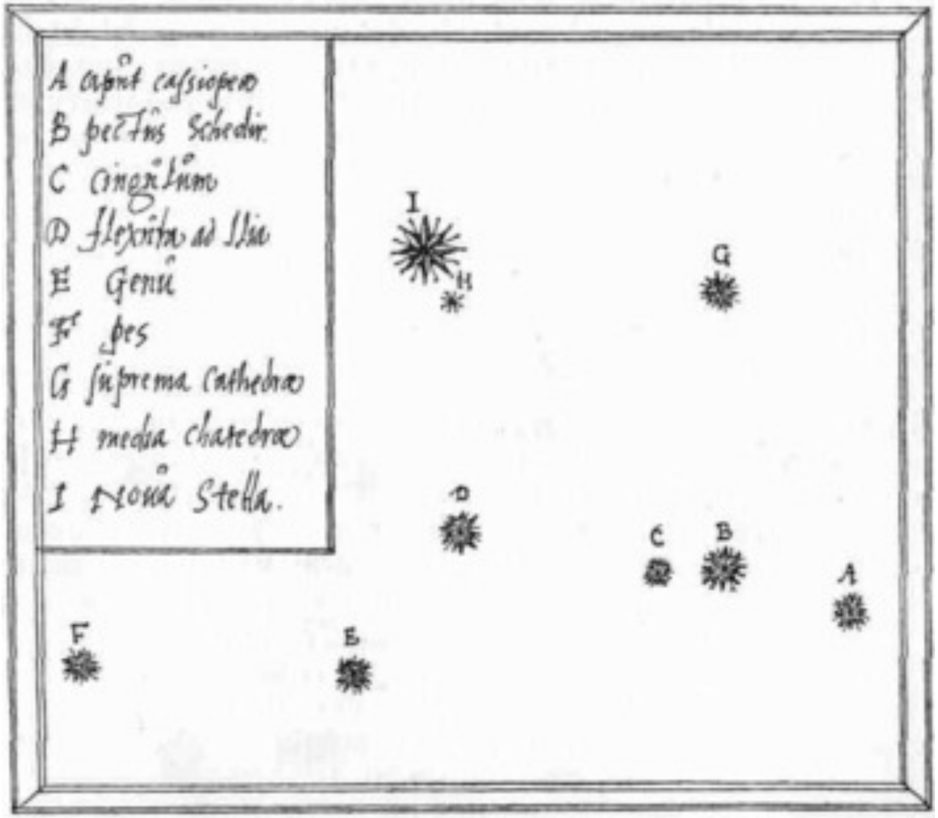
The brightest supernova in history was probably SN 1006. The Egyptian astrologer Ali bin Ridwan wrote

*"I will now describe for you a spectacle that I saw at the beginning of my education. This spectacle appeared in the zodiacal sign Scorpio... It was a large nayzak [spectacle], round in shape, and its size 2½ or 3 times the magnitude of Venus. Its light illuminated the horizon and it twinkled very much. The magnitude of its brightness was a little more than a quarter of the brightness of the moon."*

The star reached magnitude about –7.5, and was visible during daylight for some time. The star remained visible for more than a year.

*The supernova remnant from SN 1006 seen by Chandra; the remnant is now 70 light years across.*

The first such star recorded in the West was by Tycho Brahe in 1572, who wrote a book about it called *De Nova Stella* (On the new star). The star reached magnitude –4, and could be seen in daylight for two weeks.




*"I was led into such perplexity by the unbelievability of the thing that I began to doubt the faith of my own eyes."*
*– Tycho Brahe, De Nova Stella (On the New Star)*

# Recorded explosions visible to the naked eye.

| Year | Where observed | Brightness |
|---|---|---|
| 185 | China | Brighter than Venus |
| 369 | China | Brighter than Mars or Jupiter |
| 1006 | China, Japan, Korea, Europe, Arabia | Brighter than Venus |
| 1054 | China, SW India, Arabia<br>➔ Crab Nebula | Brighter than Venus |
| 1572 | Tycho | Nearly as bright as Venus |
| 1604 | Kepler | Brighter than Jupiter |
| 1987 | Ian Shelton (Chile) | - |

Nowadays, we distinguish between a *supernova explosion*, which is a catastrophic event (involving the destruction of the star), and a *nova explosion*, which is a cataclysmic event (non-destructive but still violent event).

We now believe the historical new stars were all supernovae.

# Cataclysmic variables

There is a class of “new stars” (*novae*) which are not as violent or impressive as supernova explosions. They involve the sudden appearance of a “new” (previously unknown) star, or the sudden brightening of an already known star.

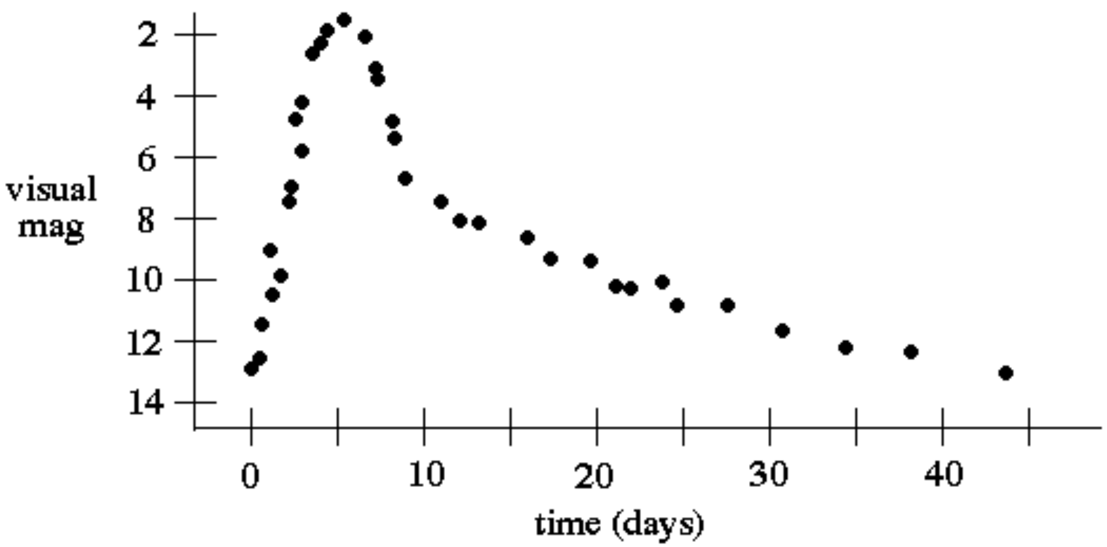
By locating and studying the star after it has faded back to normal, we can find out how these stars work.

Novae turn out to be related to binary stars.

*Classical novae* brighten by 6–10 mag, with a rapid rise and slow decline: this makes it look as though a new star has suddenly appeared.

There have been seven novae in the past century which reached magnitude 2 or brighter (making them among the 100 brightest stars in the sky), nearly all of them discovered by amateurs.

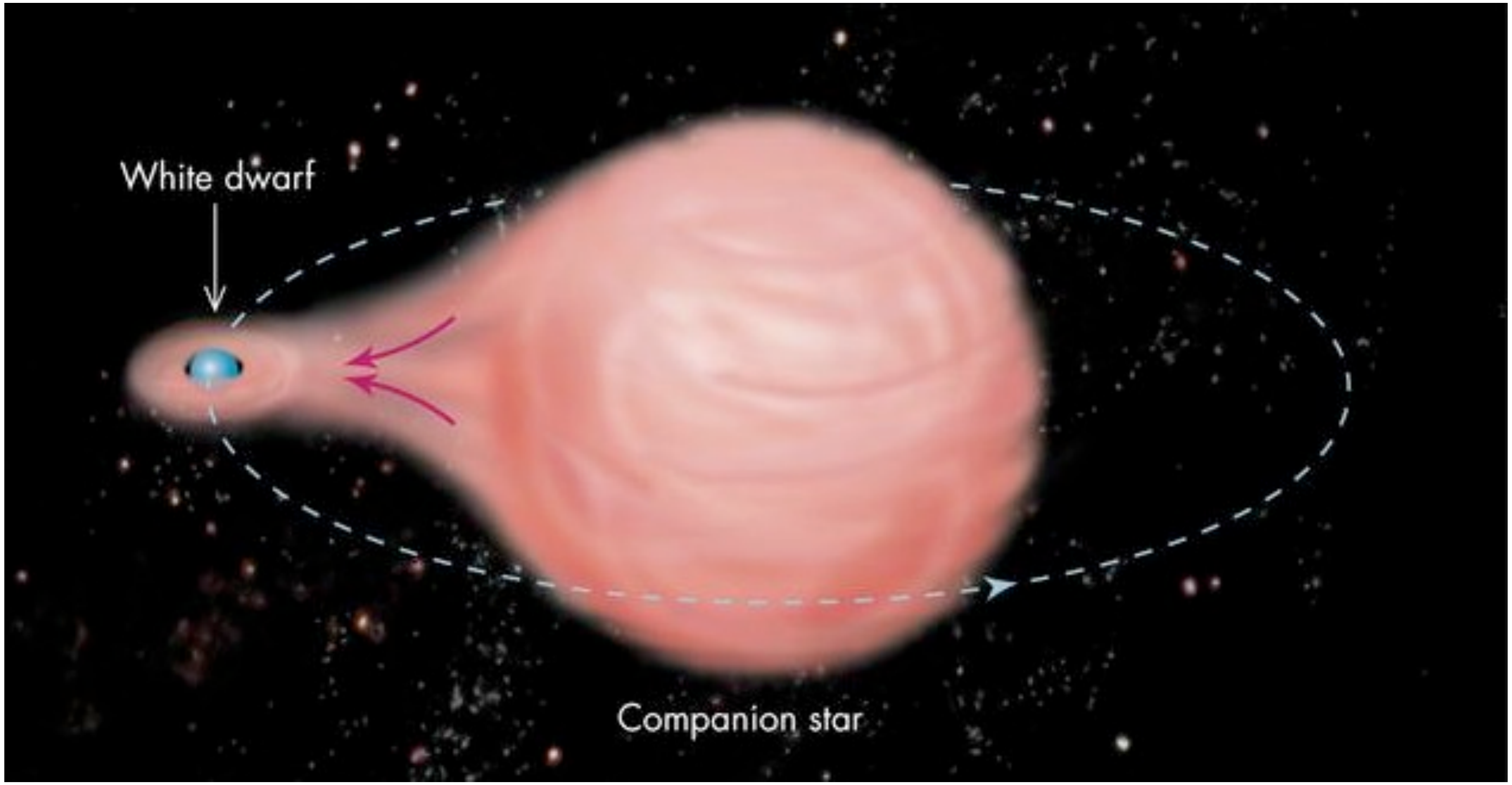
Nova Light Curve




Novae typically brighten in a couple of days, then fade more slowly over a month or more.

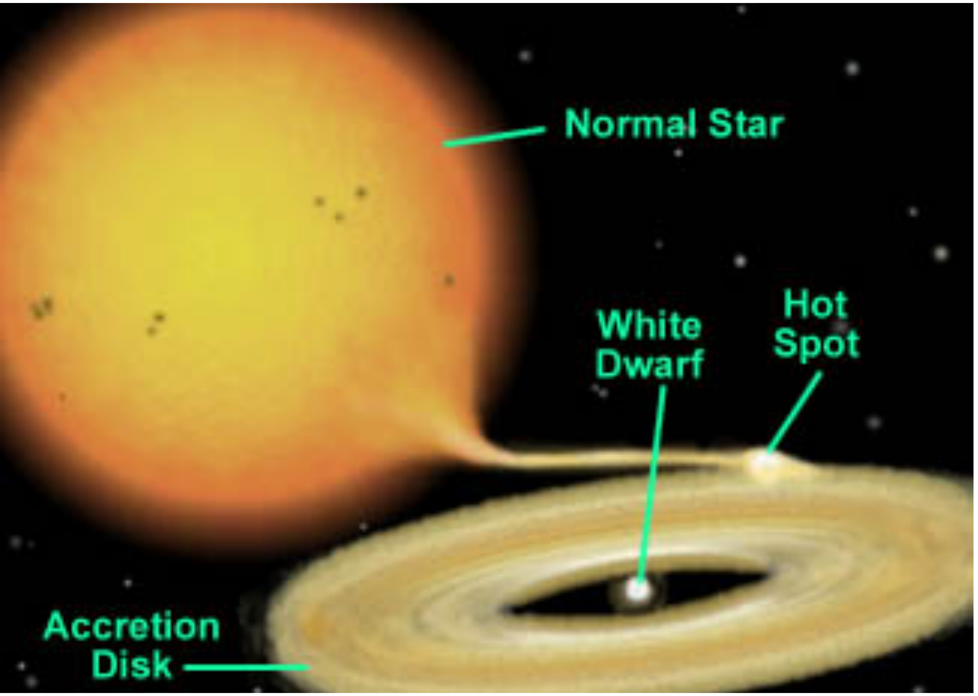

In December 2013, Nova Centauri 2013 was visible to the naked eye.
Nova Cen 2013
Beta Cen
Alpha Cen
Centaurus

Novae are one of several types of *cataclysmic variable* stars. We now know that all cataclysmic variables occur in binary systems. A white dwarf accretes matter from a companion star.



# How cataclysmic variables work

Cataclysmic variables are all very short period binary systems, consisting of a white dwarf with a main sequence companion. The orbital period of the binary is between 1.5 and 14 hours, and the distance between the two stars is only a few times the radius of the Sun.

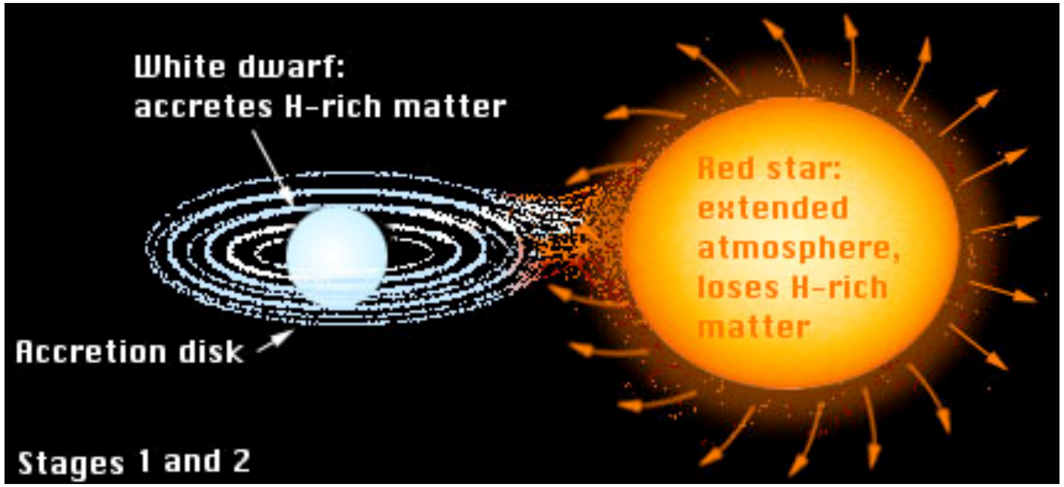


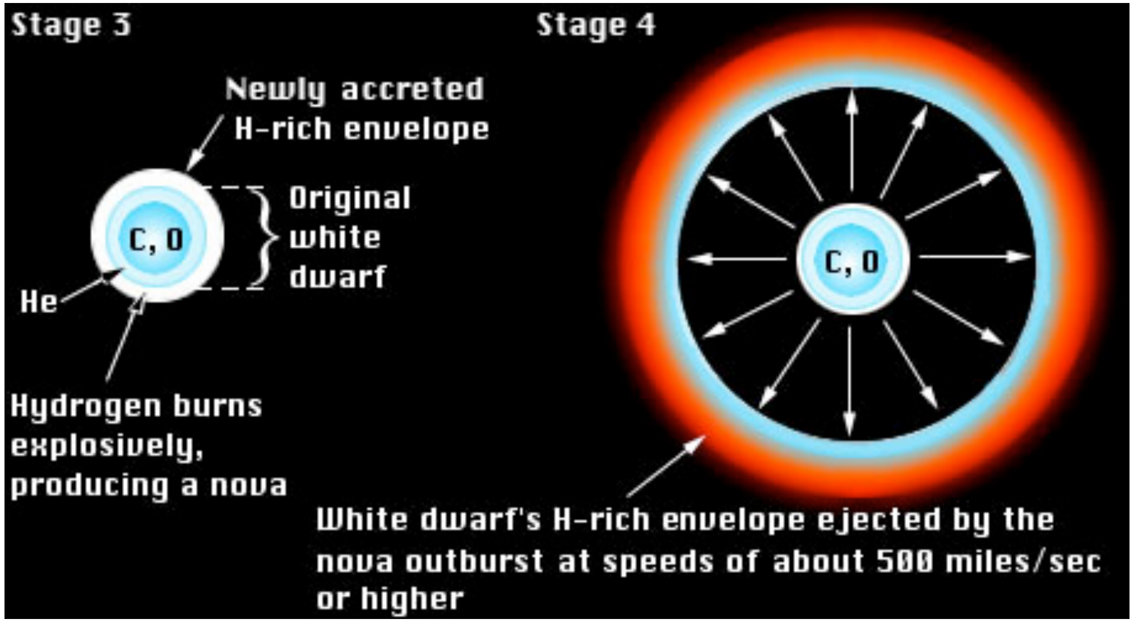

They are similar to the X-ray binaries we discussed last week, except that the star that is accreting matter is a white dwarf instead of a neutron star.

# Nova outbursts

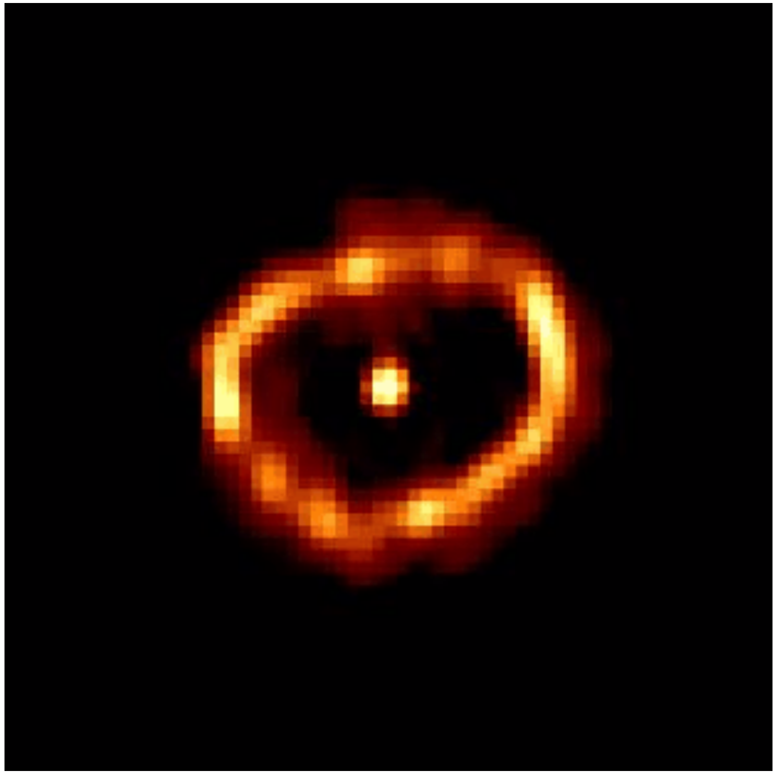
Hydrogen transferred from the secondary accumulates on the surface of the white dwarf.

When the base of this layer reaches a critical temperature, the whole layer explodes.



The ejected matter forms a shell, which can be seen years later.



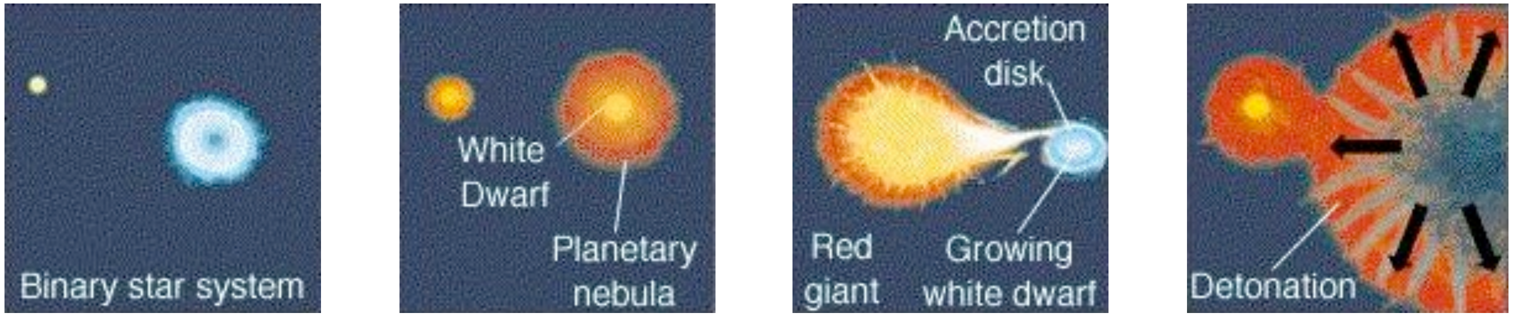
*The shell from Nova Cygni 1992, photographed by HST two years after the outburst.*

# A bigger bang

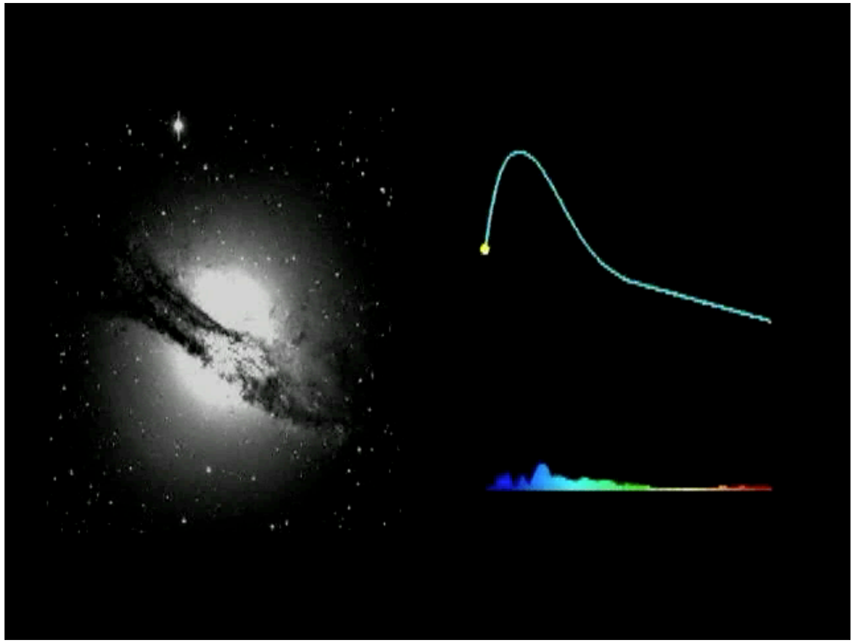
Remember that white dwarfs have a maximum mass – the Chandrasekhar mass – above which they can no longer resist the pull of gravity.

If a white dwarf accretes enough matter to push it over the Chandrasekhar limit, it will collapse.

Most of the time, the white dwarf is totally destroyed in the resulting explosion.



These supernovae – *thermonuclear* or *Type Ia supernovae* – have no hydrogen in their spectra at all. They are 1.5–3 magnitudes brighter than core-collapse supernovae.



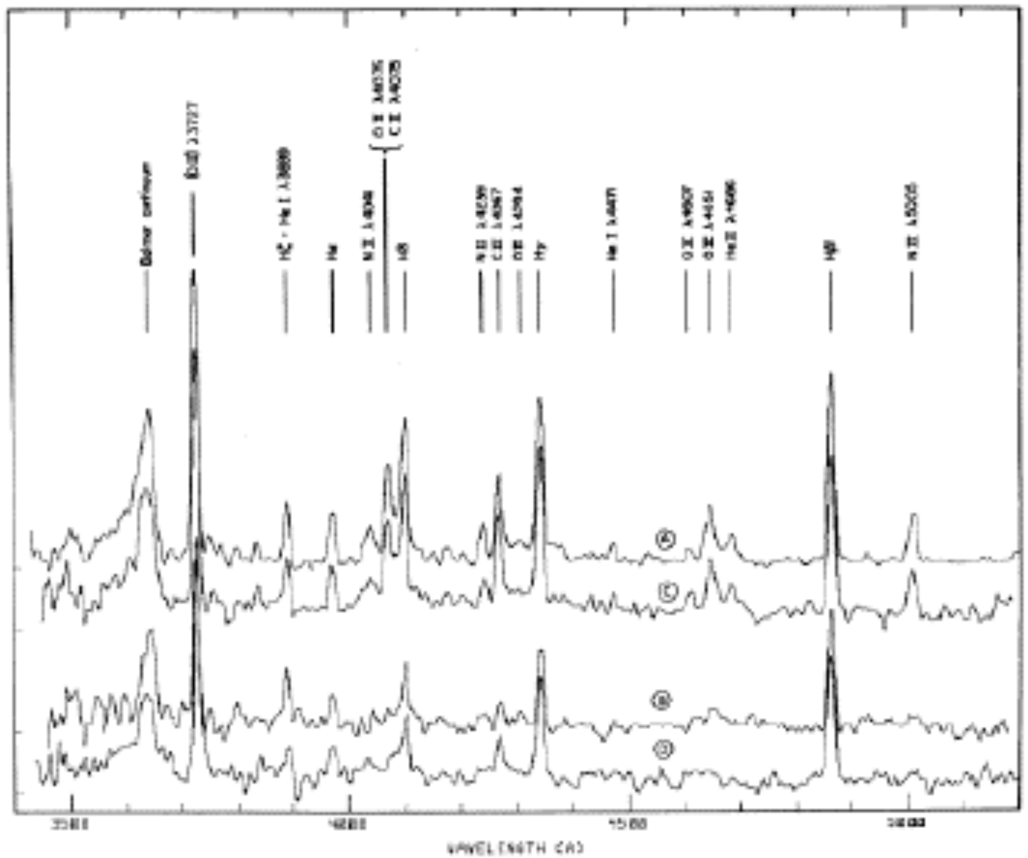
Thermonuclear supernovae are so luminous that we can see them more than halfway across the universe. Because they all have very similar brightness, they are very important beacons for measuring the distances to very distant galaxies.

(Later, we will see that it was thermonuclear supernovae that led to the discovery of dark energy.)


*Supernova 1994D, visible as the bright spot on the lower left, in the outskirts of disk galaxy NGC 4526.*

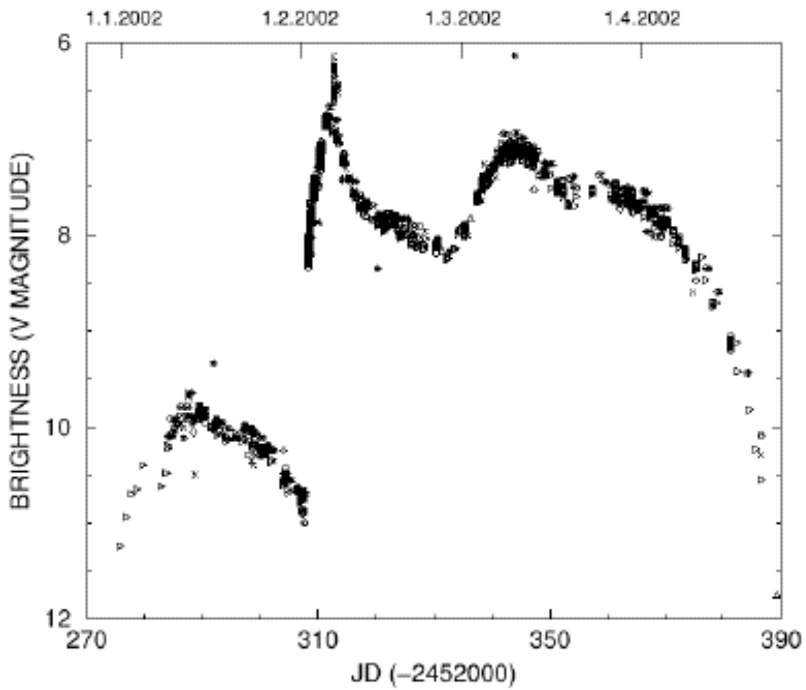
*Major problem*: how do you get a white dwarf near the Chandrasekhar mass? Why isn't the material consumed in repeated nova explosions instead?

In ordinary nova explosions, the white dwarf loses a little mass each time: so how does it grow large enough to reach the Chandrasekhar mass?

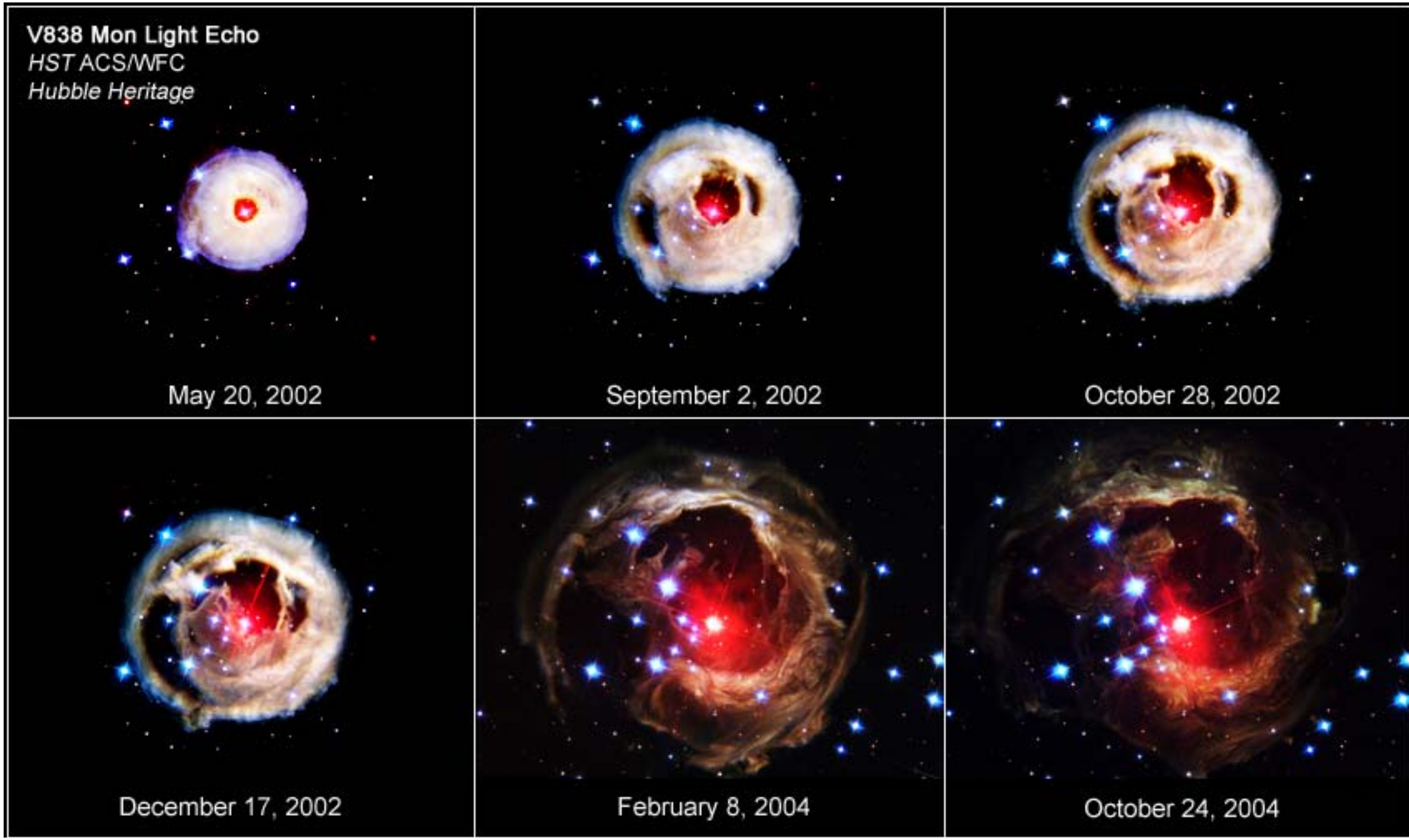


*Spectrum of the shell of DQ Her, showing enhanced heavy elements*

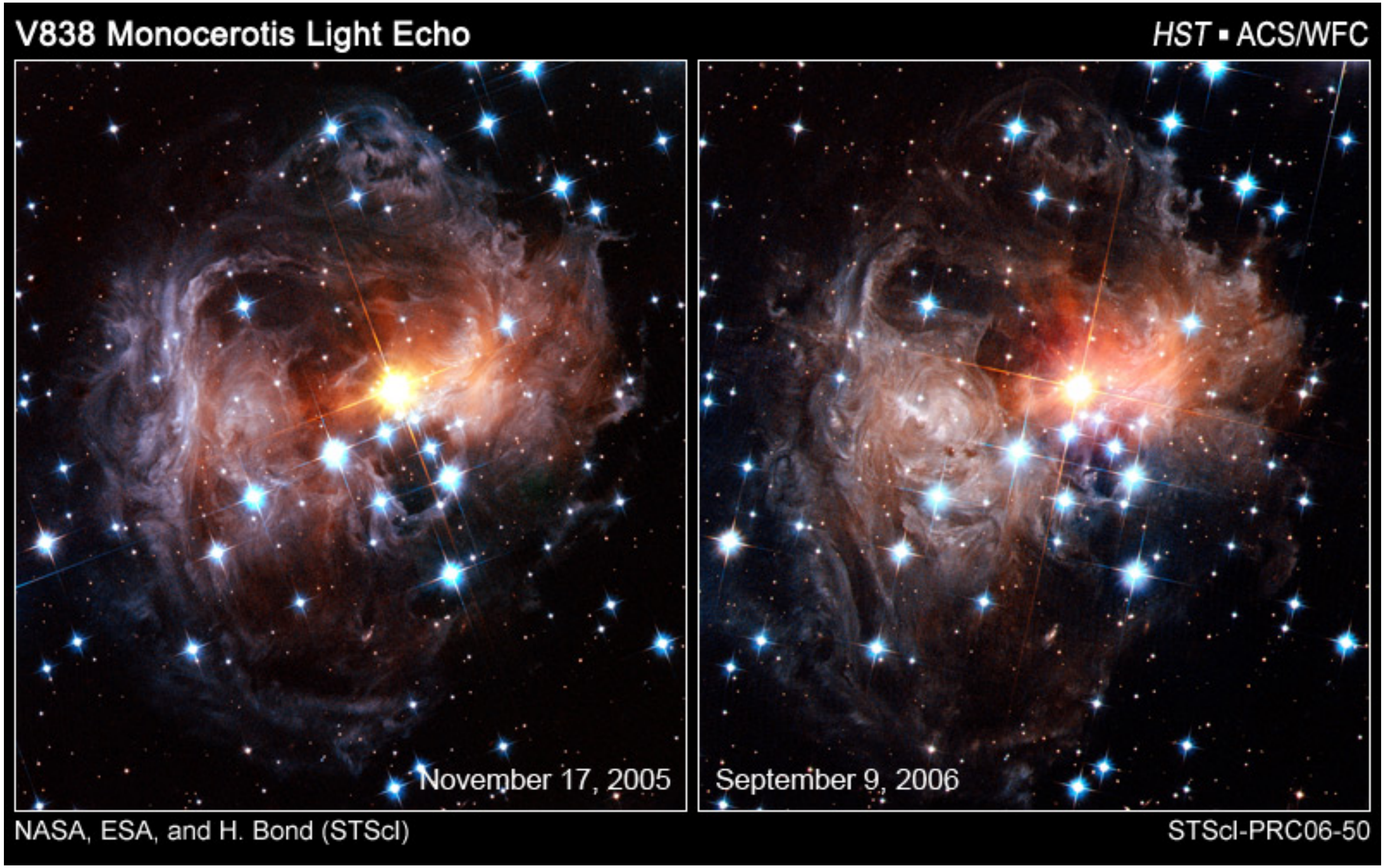
There are actually many variable stars whose nature we don't understand at all. *V838 Monocerotis* was discovered by an Australian amateur in January 2002, but it turned out to be very bizarre. Instead of fading like normal novae, it had three peaks in its light-curve!



HST found spectacular reflections from dust shells surrounding V838 Mon. The star in the centre is red, not a white dwarf at all!



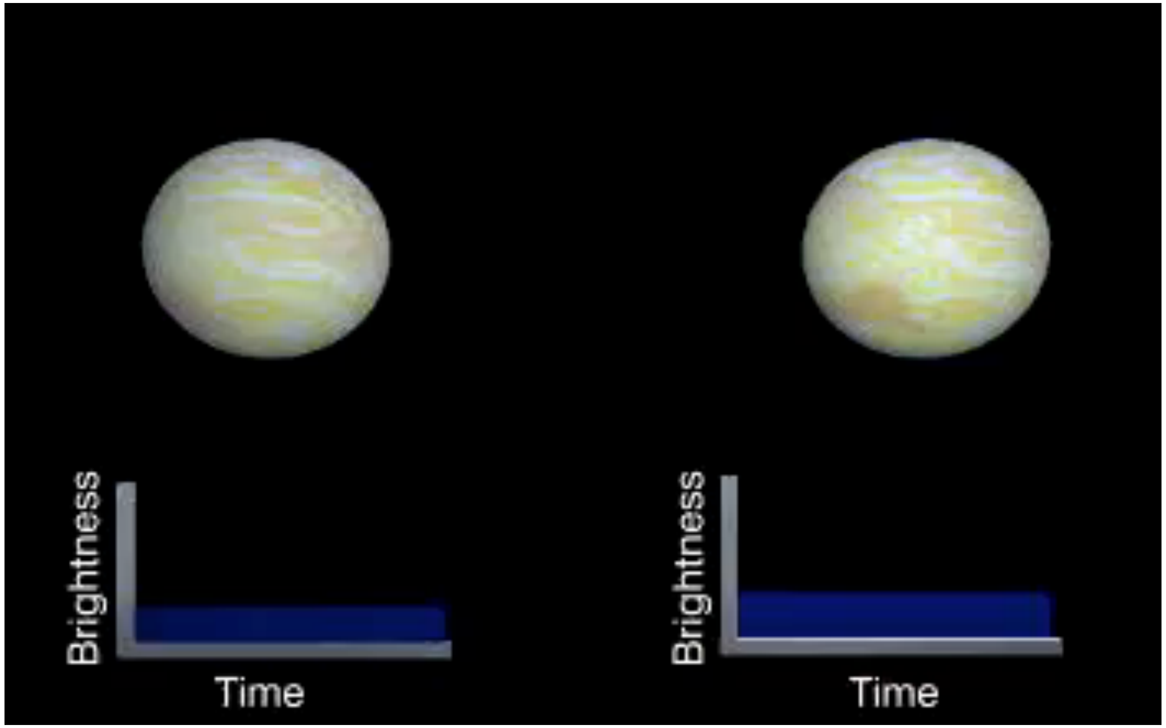

*Light echoes reflecting off shells of dust expelled earlier in the star's life*



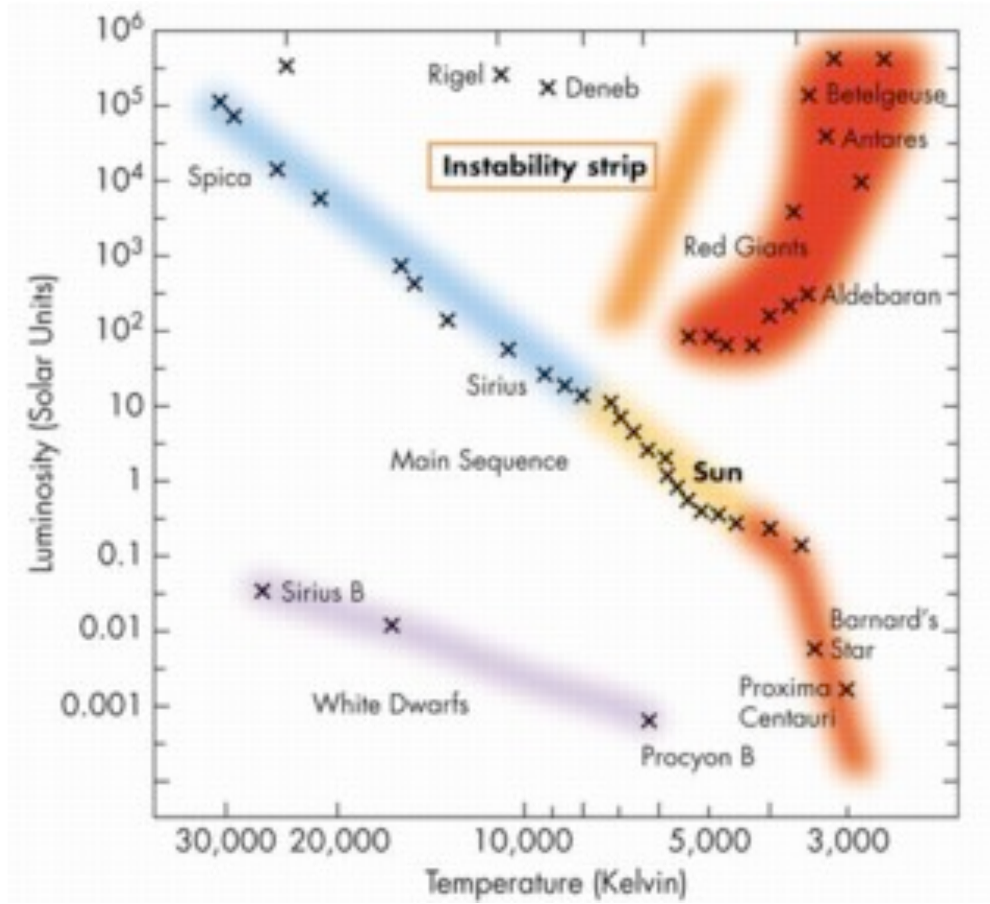

*The shell observed in 2005 and 2006*

# Pulsating stars

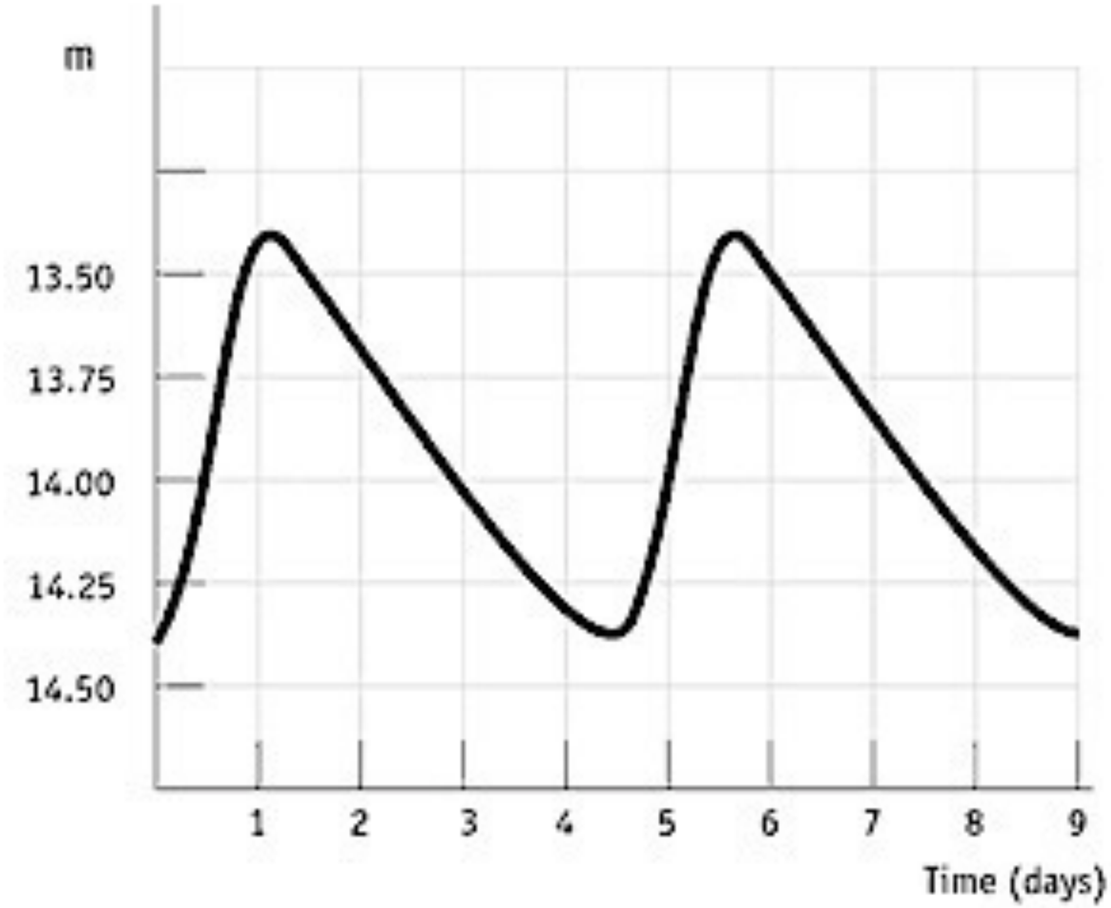
There is a group of stars which change their brightness in a regular manner.



These stars are all giants. In a certain region of the Hertzsprung-Russell diagram, the pressure-gravity balance becomes unstable. These stars are named *Cepheid variables* or *Cepheids*, after the prototype star, delta Cephei.



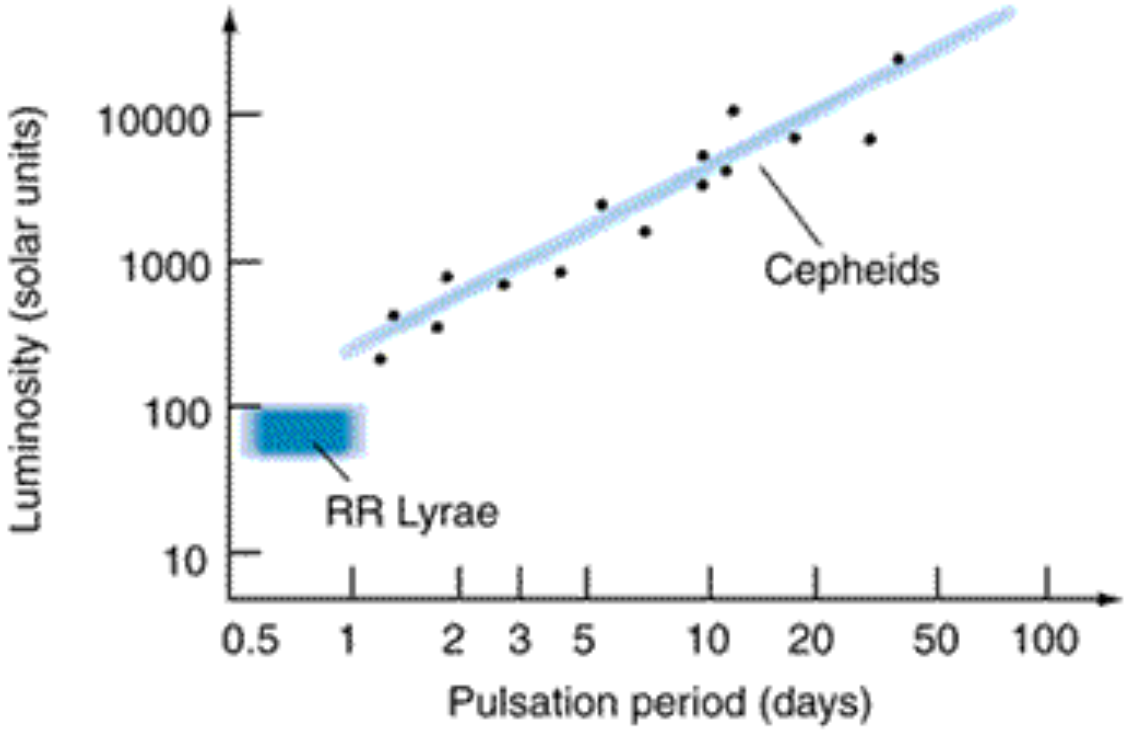
Cepheids have distinctive light curves, with a rapid rise in brightness followed by a more gradual decline, shaped like a shark fin. They change in magnitude by 0.5 to 2 magnitudes, with periods of between 1 and 70 days.



Henrietta Leavitt discovered that there was a relationship between the period of these variables and their brightness: the brighter the star, the longer the period.

This meant that, if you measure how long the period is and how bright the star appears, you know *how far away* the star is.

Cepheids are one of the most important tools for measuring the distances to galaxies.



# Star clusters

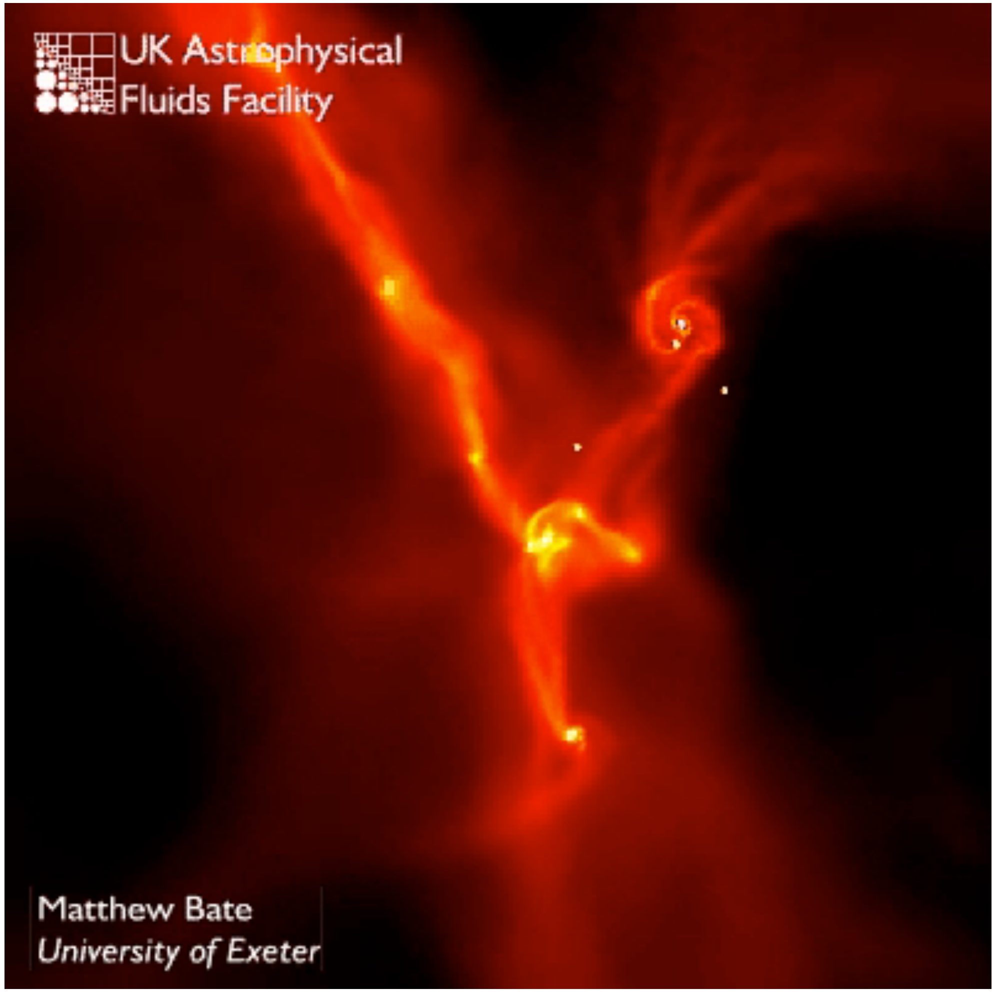
# Clusters

Many stars occur in associations called *star clusters*. Clusters are ubiquitous in the galaxy, and come in all sizes.

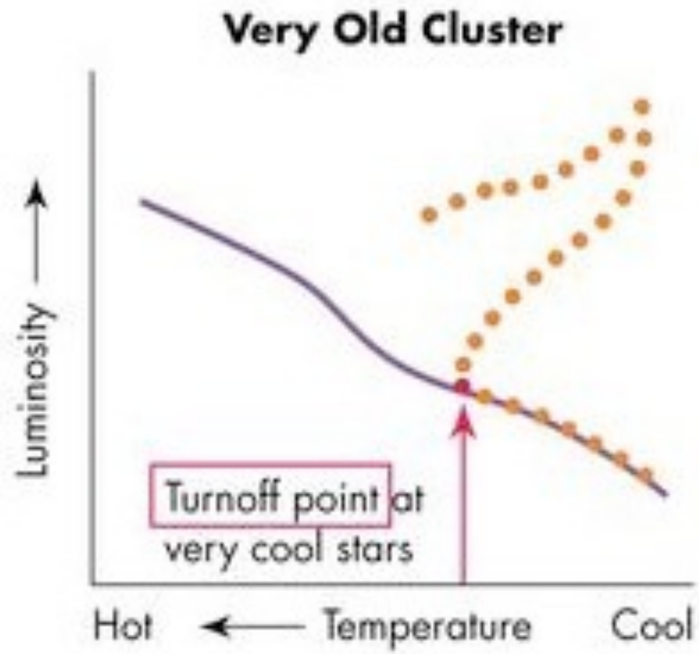
*Open clusters* are small groups of stars, containing 100–1000 stars, which were all born from the same molecular cloud.


*The Pleiades*

(Recall the simulation of stars being born from a gas cloud that we saw in lecture 3).



Since all the stars in a cluster formed at the same time, they are all the same age. This gives their H-R diagram a very notable appearance. Like a candle, the main sequence burns from the top, as the most massive stars age and die first.



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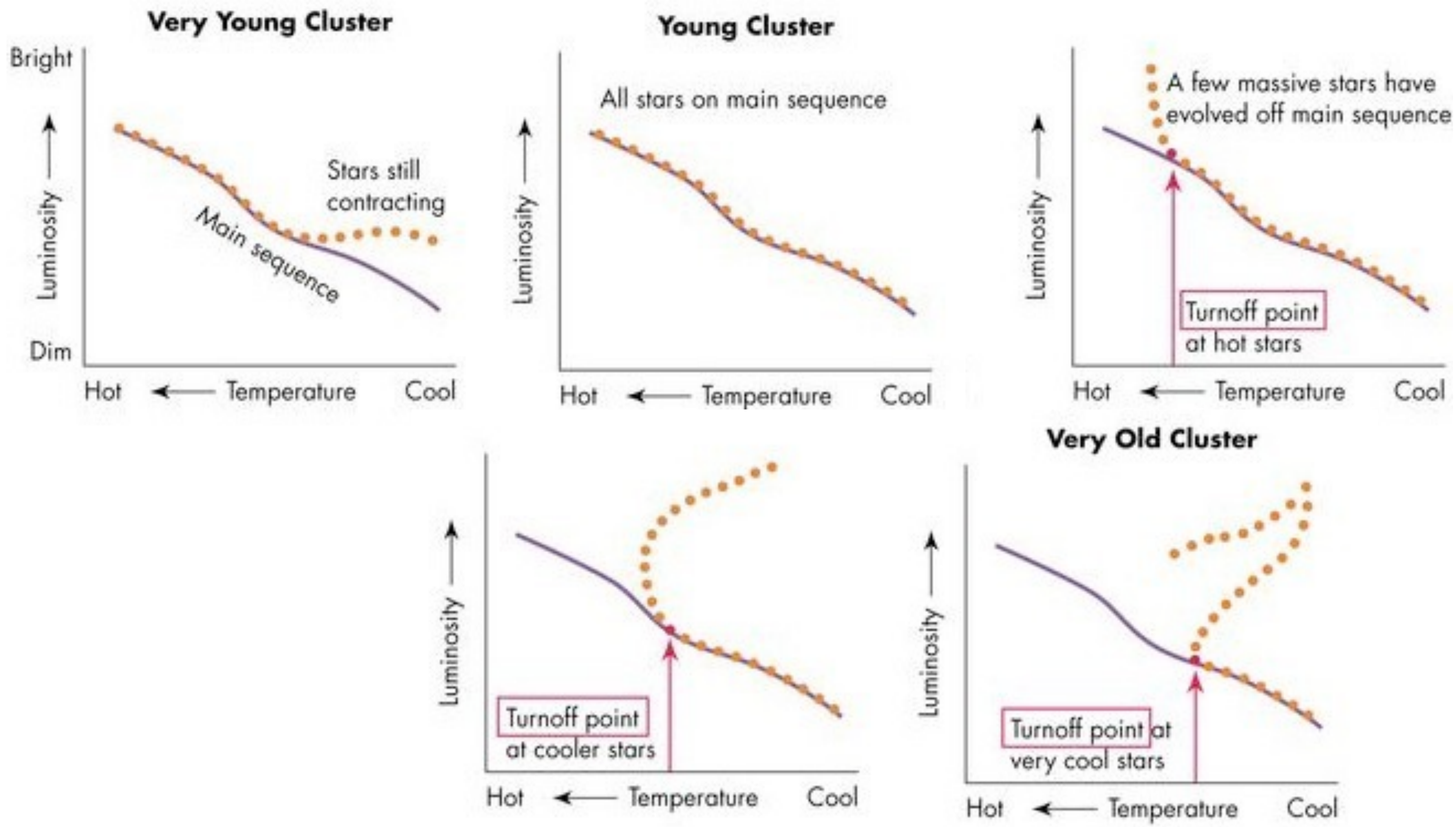
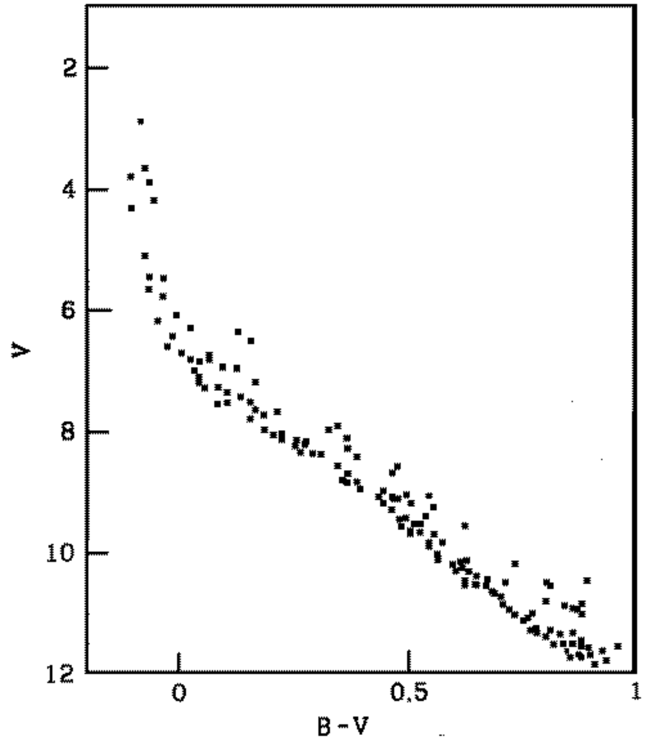


Here is the observed Hertzsprung-Russell diagram of the Pleiades, a young open cluster. There are no red giant stars at all, just a straight main sequence, with the very brightest stars beginning to curve away.

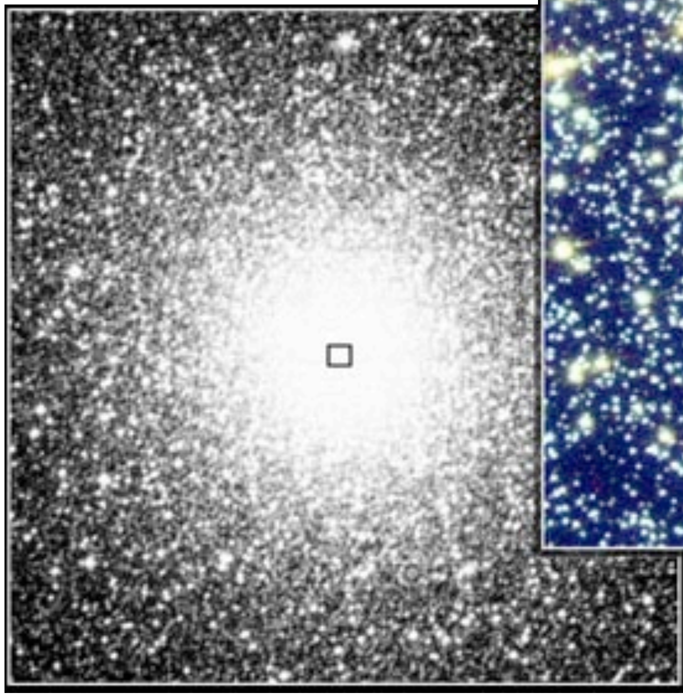


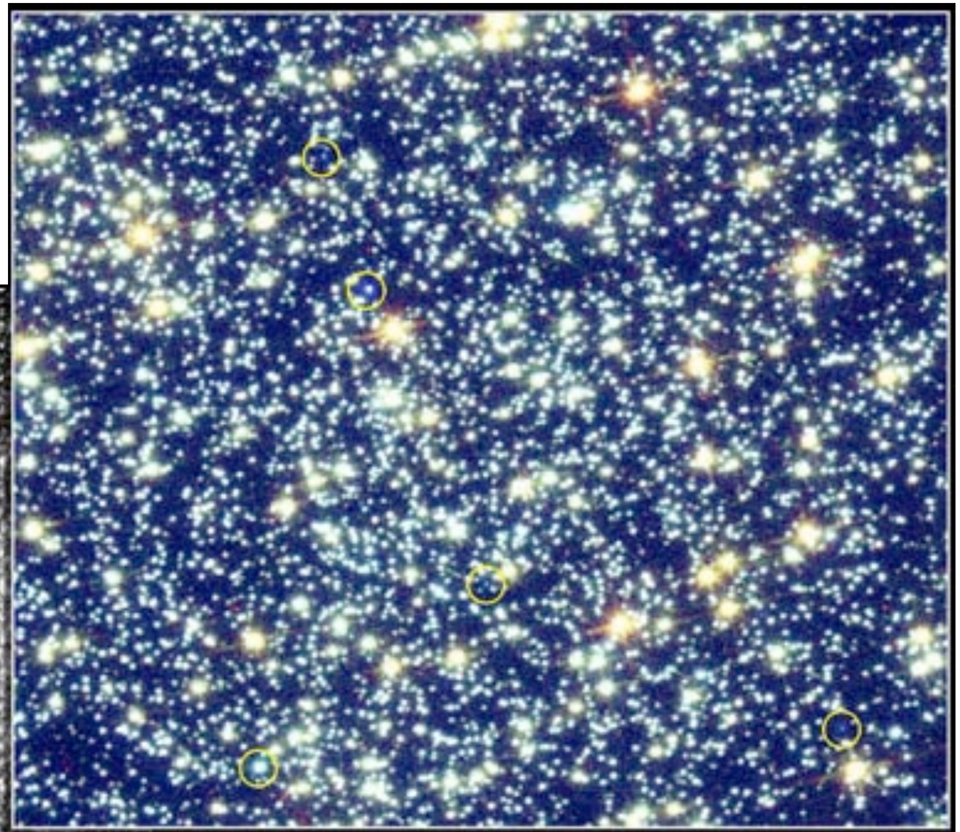
# Globular clusters

Early in the formation of our Galaxy, very large *globular clusters* formed from giant molecular clouds.
Each contained over 10,000 members, the largest a million stars.

*The globular cluster omega Centauri, one of the largest in the Galaxy.*

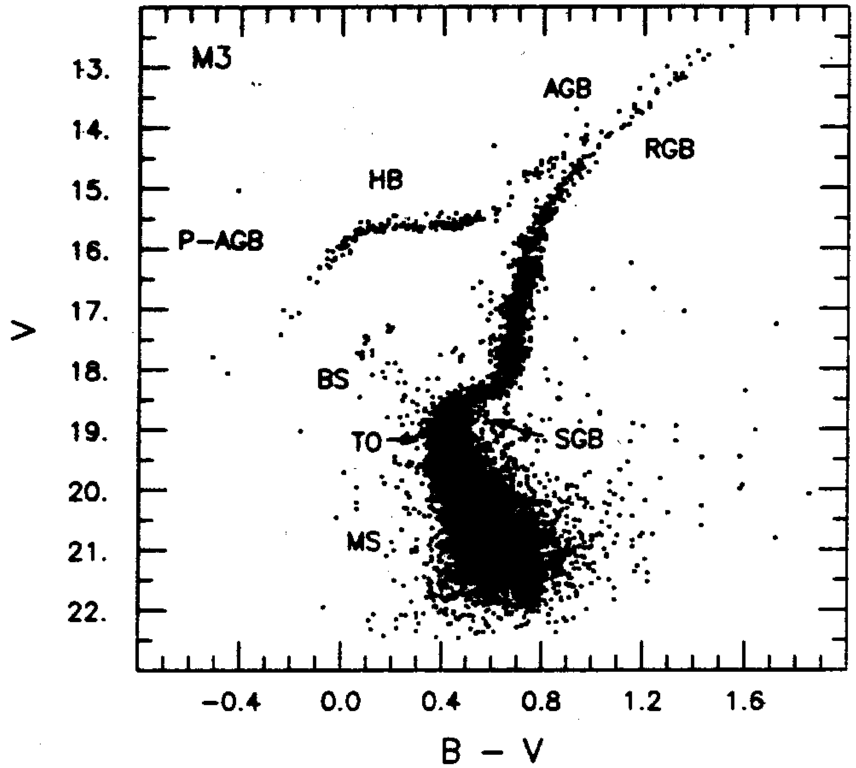
Globular clusters are up to a few parsecs in size, and are densest in the centre, where there may be as many as 1,000,000 stars per cubic parsec.





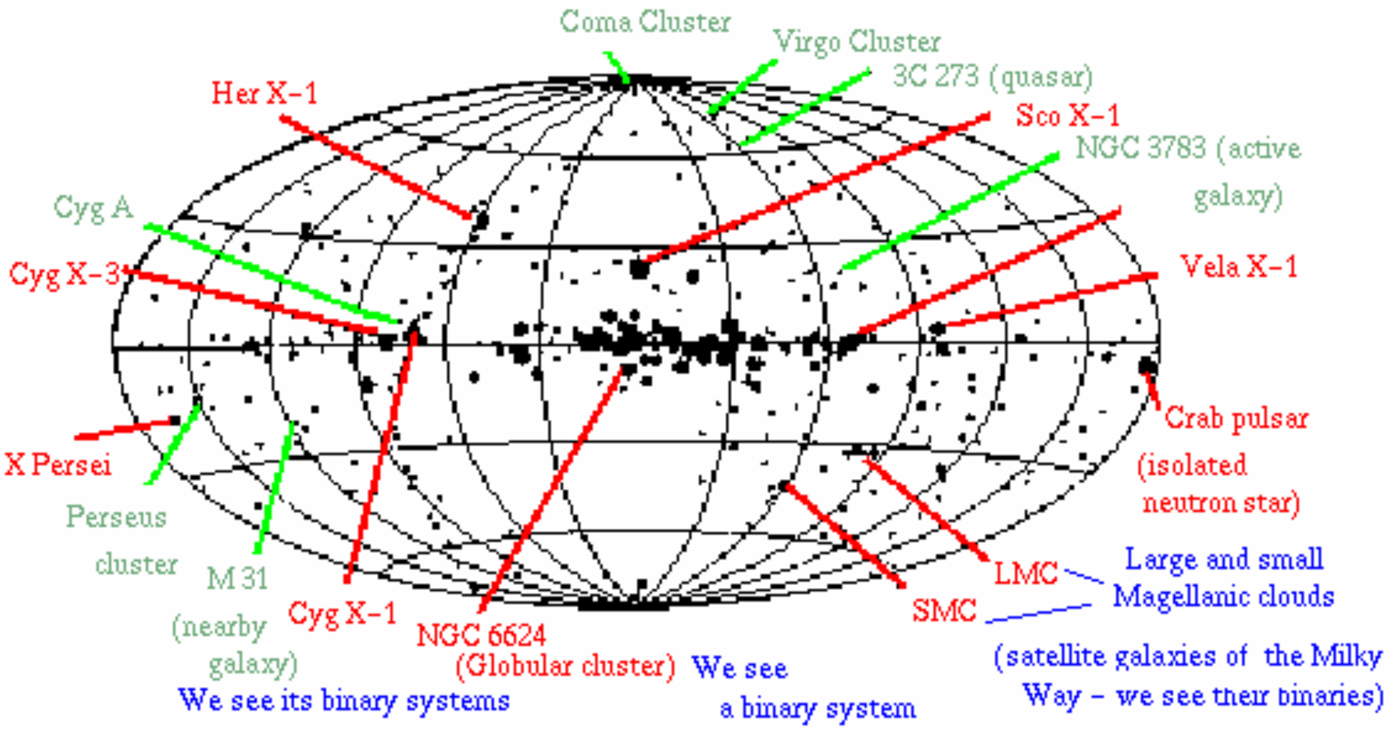
*47 Tuc from the ground and from space*

The observed Hertzsprung-Russell diagram of M3, an old globular cluster. There are no main sequence stars heavier than the Sun.



# X-rays from clusters

In the early 1970s, the Uhuru X-ray satellite found six X-ray sources in globular clusters.



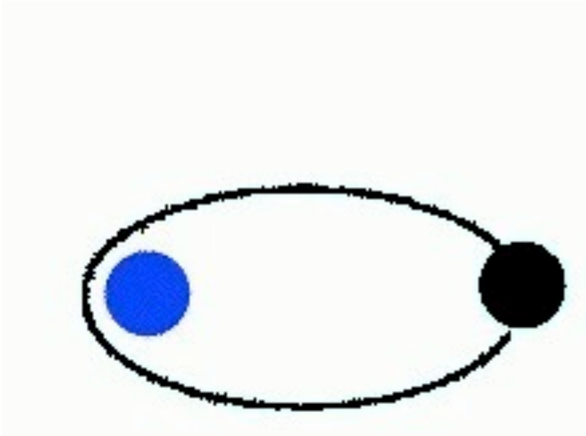
The sources looked just like X-ray binaries in the Galaxy, but are much more common: globular clusters contain

~ 0.1% of the stars in the galaxy

~ 10% of X-ray binaries in galaxy

Why would binaries be more common in globular clusters?

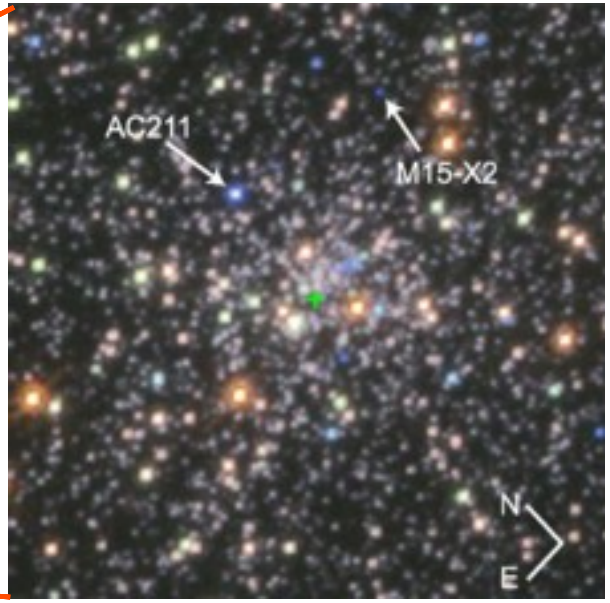
Binaries must be *formed* in globular clusters. They do this by *tidal capture*.

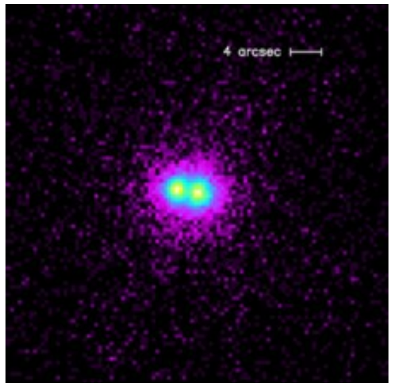


For two stars to stay in orbit around each other after the encounter, they need to pass very close to each other at closest approach (about 3 stellar radii).

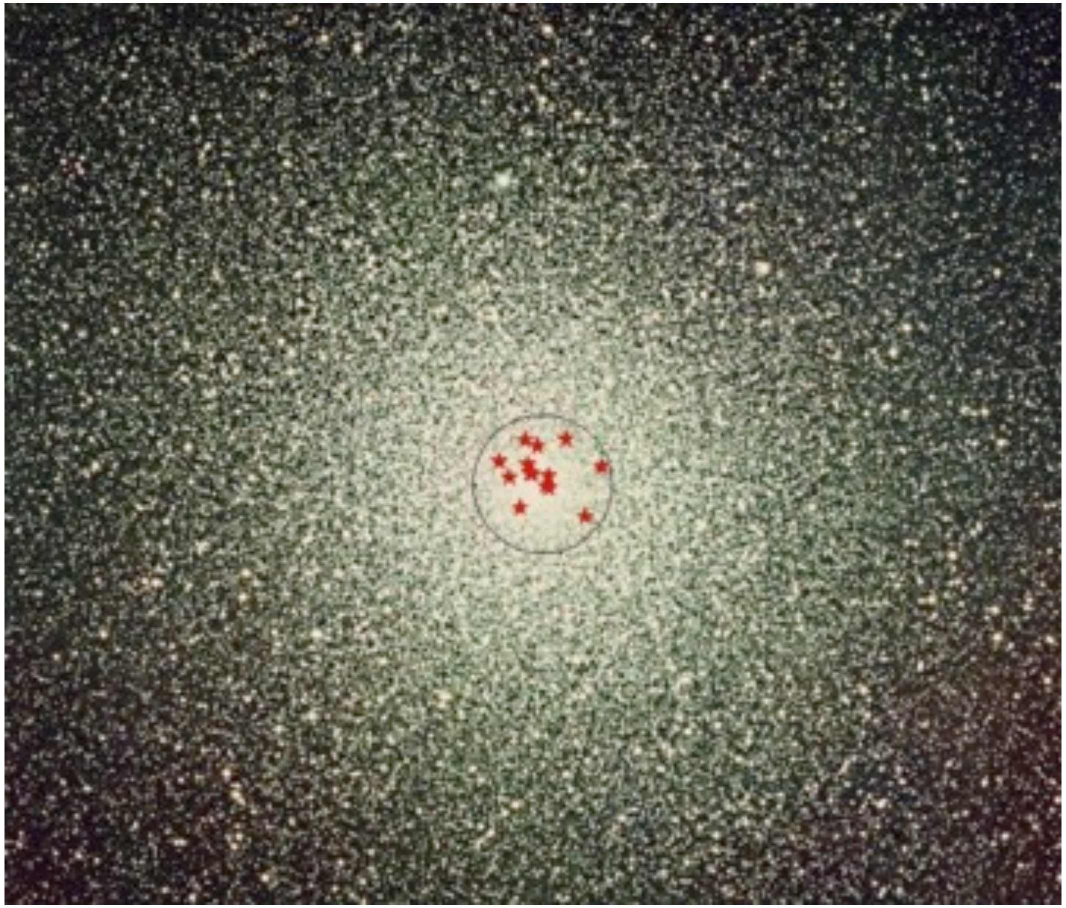
Only in the cores of the densest globular clusters are stars close enough together for this to be likely to happen in the lifetime of the universe.

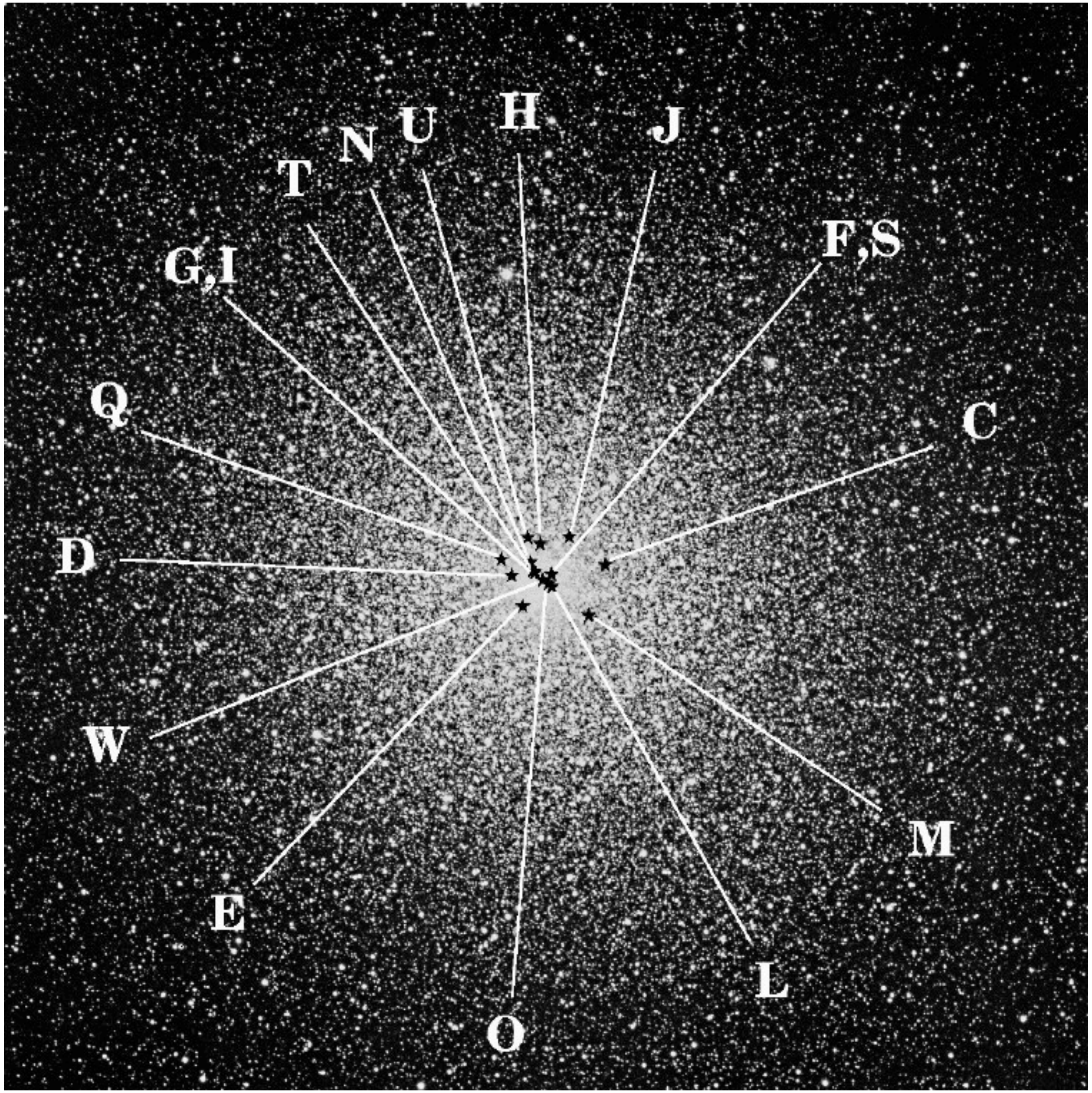
X-ray binaries are found only in the densest clusters, like M15, just as predicted if they were formed by tidal capture.



But... In 1987, astronomers began finding pulsars in globular clusters. There are now 144 known, with 23 in one cluster (47 Tucanae) and 34 in another (Terzan 5).

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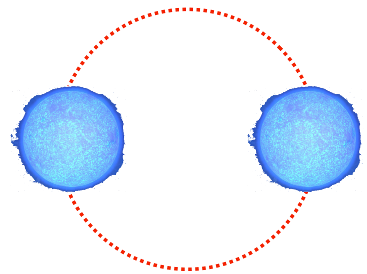
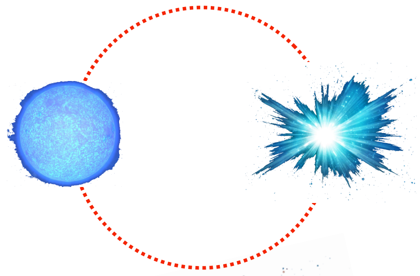
## Recall where millisecond pulsars come from:

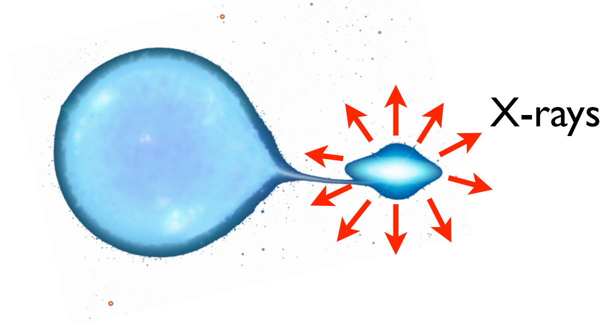
Born in a binary system,



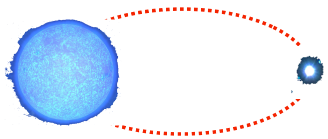
one star goes supernova, then the other evolves and leaves a neutron star.



The second star starts spilling matter onto the neutron star, which accretes matter and angular momentum, which spins it up: an *X-ray binary*.




When accretion stops, we have a very fast pulsar in orbit with a neutron star or white dwarf.



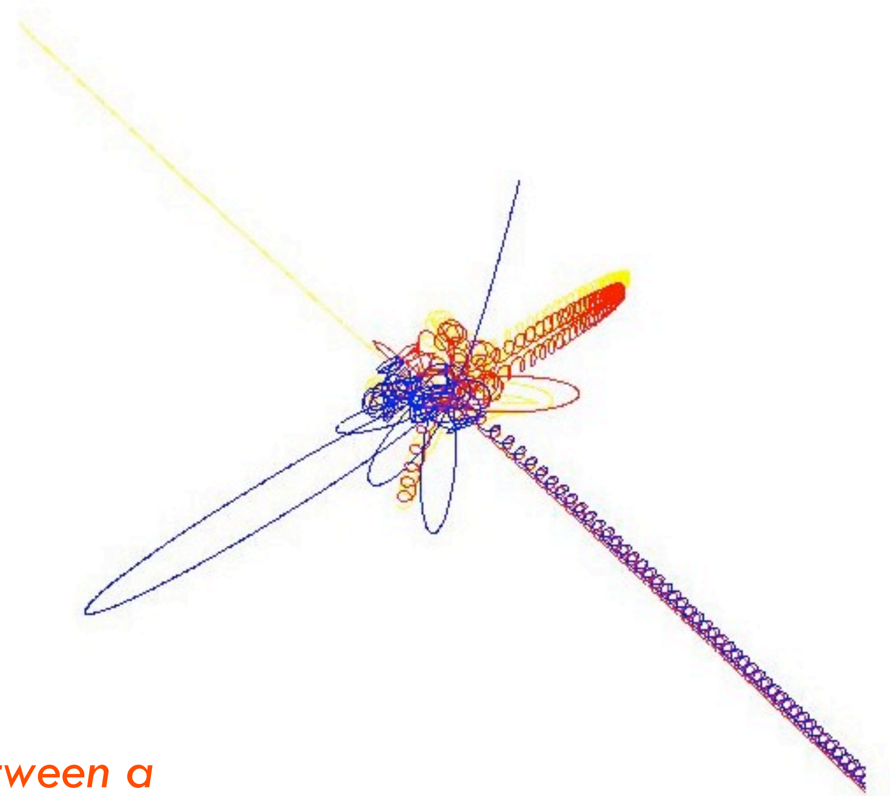
The problem is: there are too many pulsars! And in the wrong clusters (not dense enough).

They must be formed in interactions between a neutron star and a binary.

There are several possible outcomes:

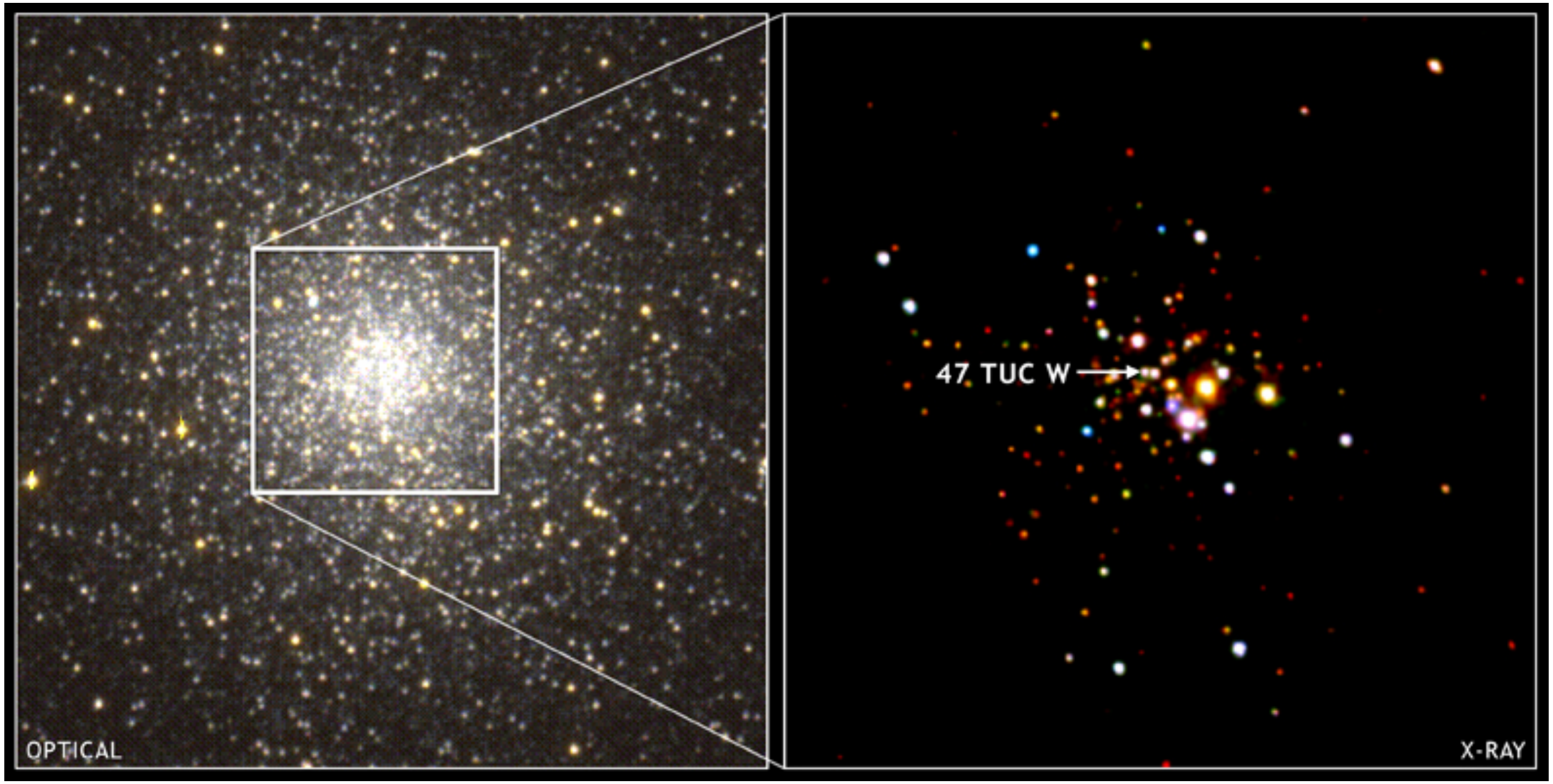
- a *fly-by* (nothing happens)
- a *merger* (two stars collide)
- an *exchange* (stars change places).

The encounters are very hard to follow!

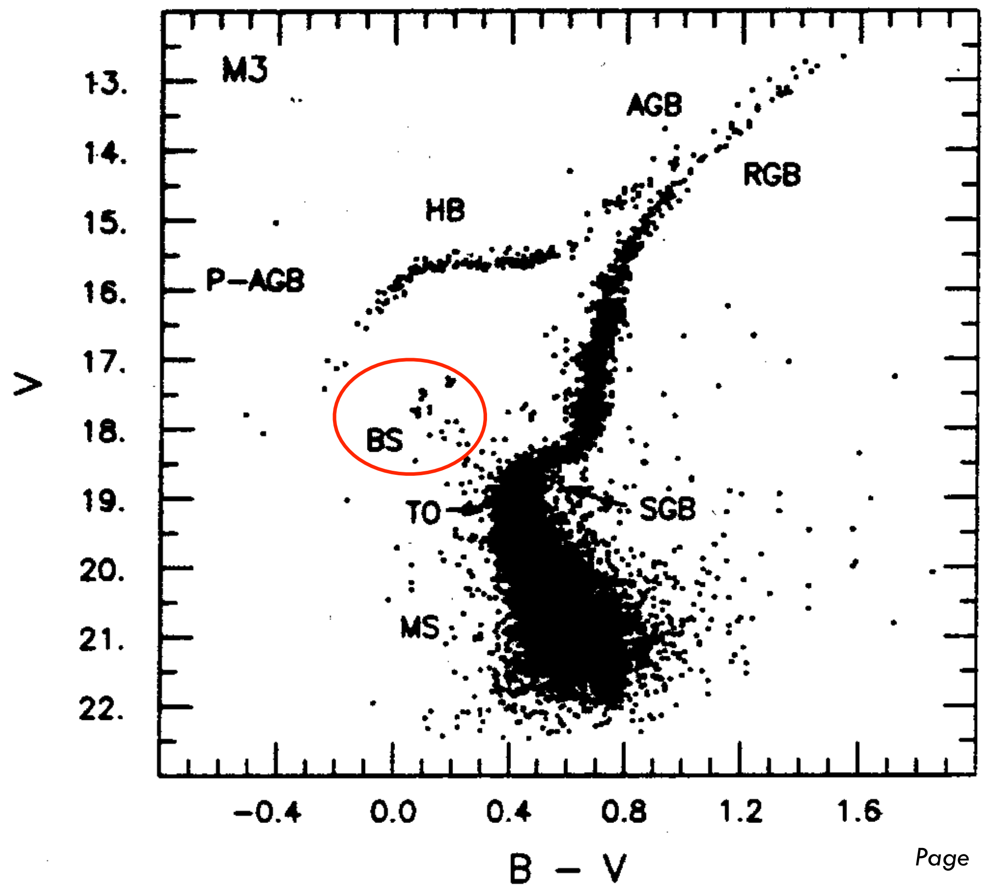


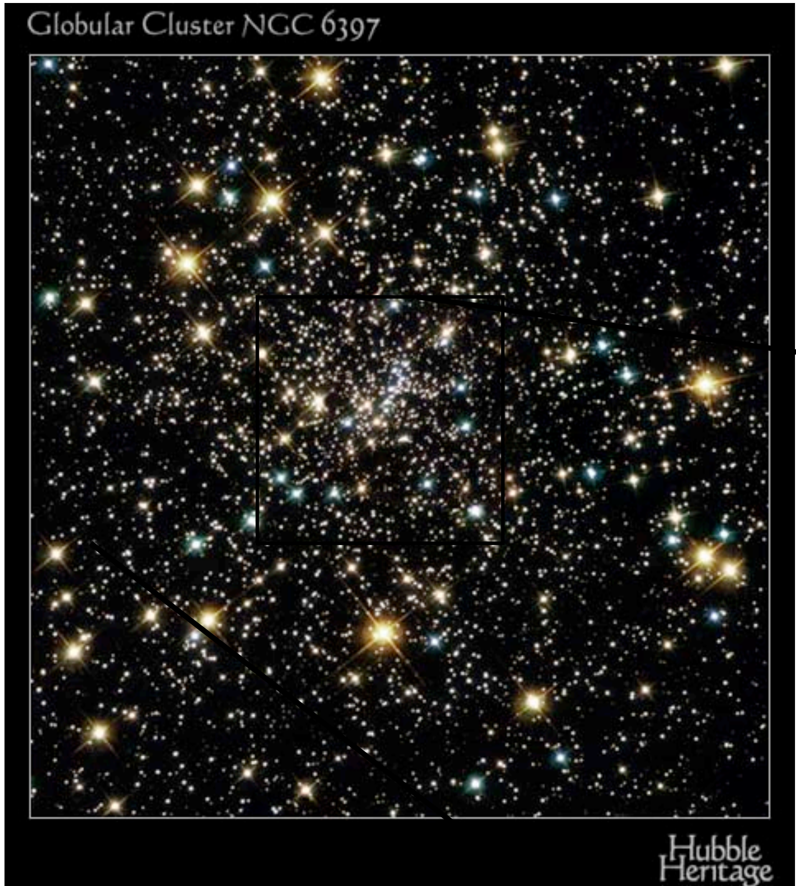
*Simulation of an encounter between a single star and a binary*

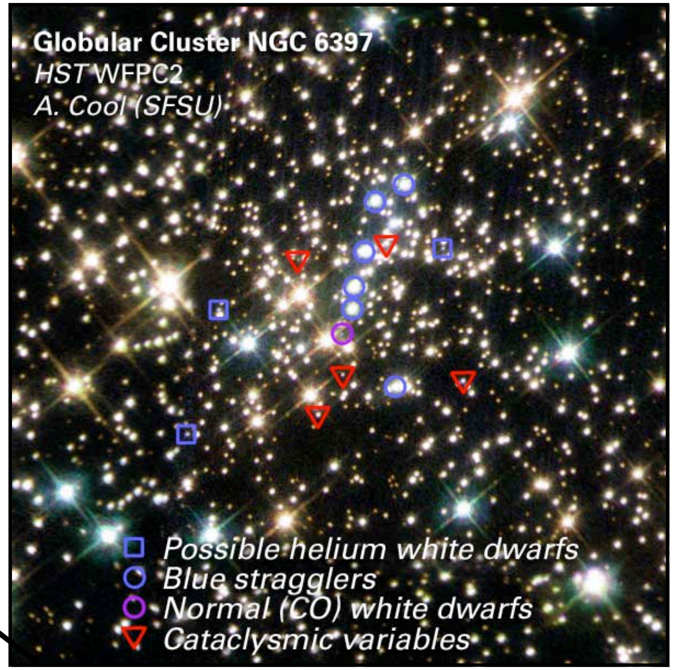
X-ray images from *Chandra* show large numbers of X-ray sources, most of which are binaries formed in this manner.



Encounters between stars probably also explain the *blue stragglers* in globular clusters: stars which look like main sequence stars younger than the turn-off mass.

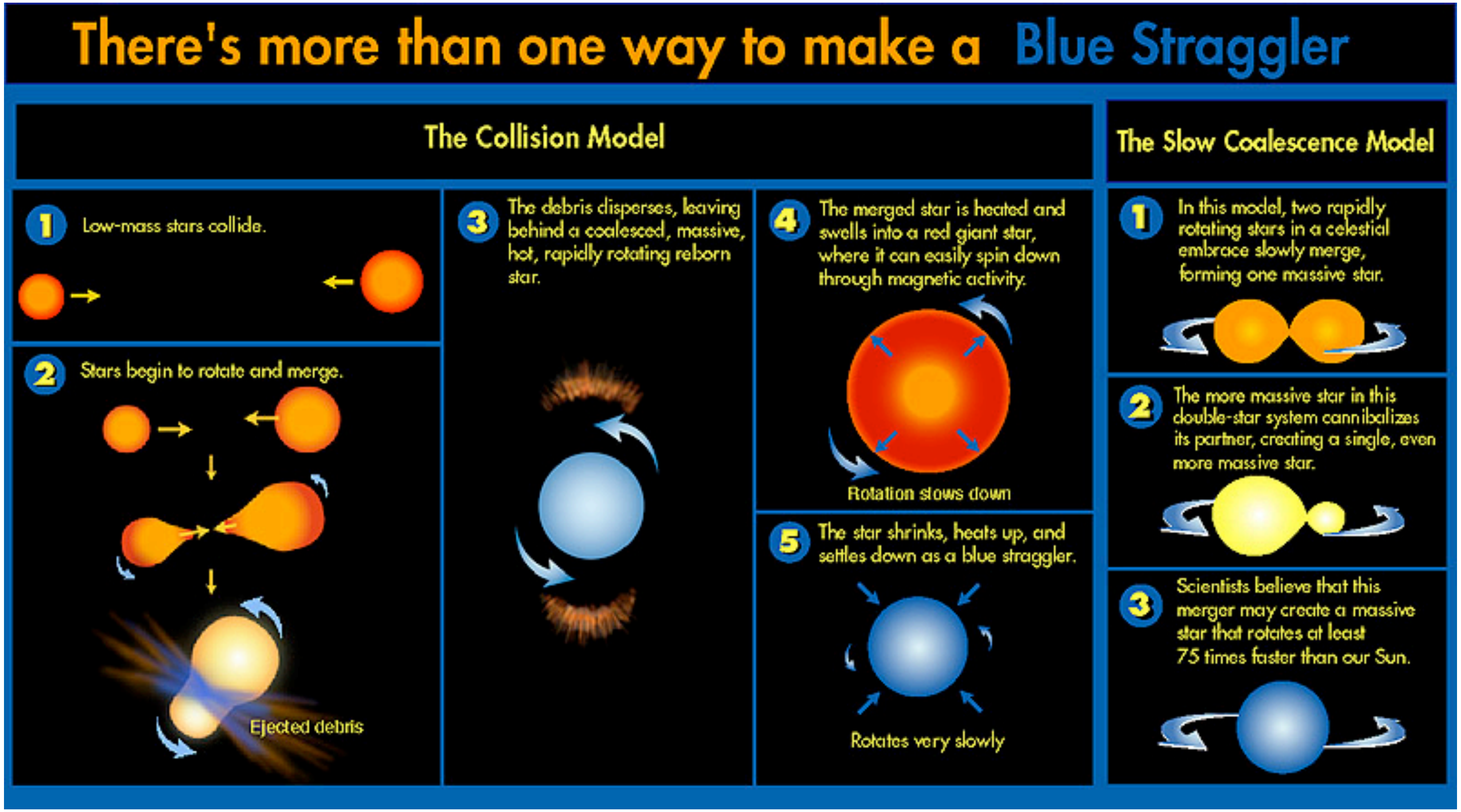




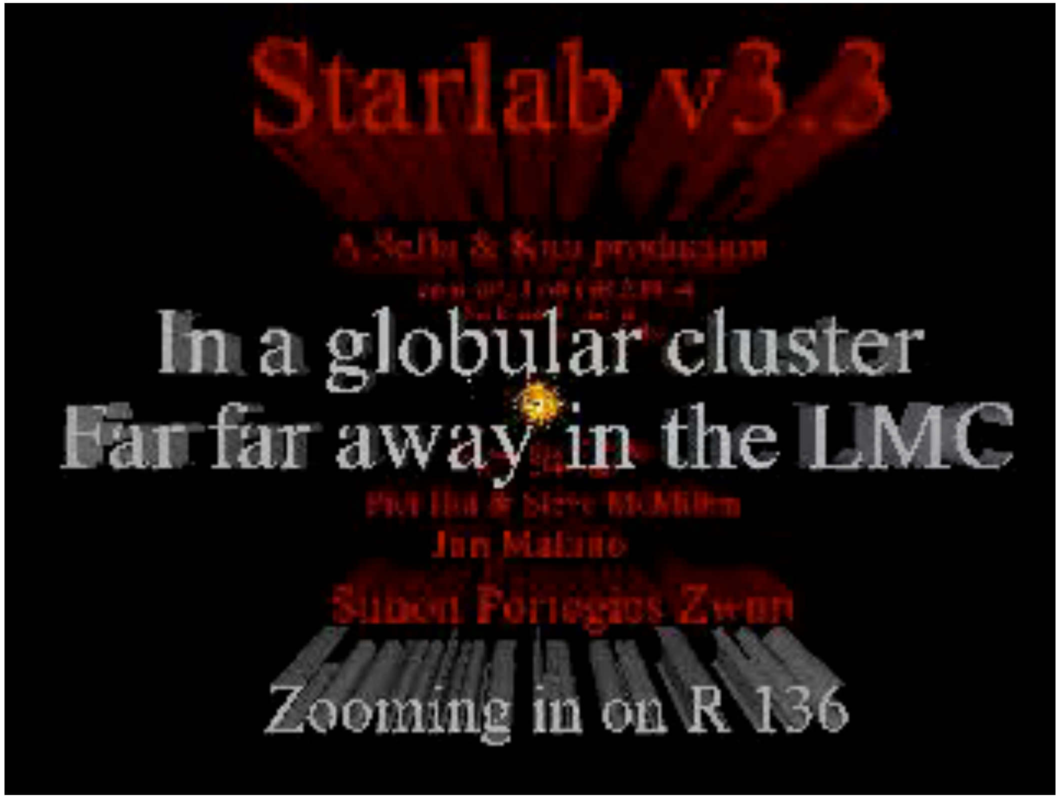




# *Blue stragglers in NGC 6397*

These stars must form from the merger of two stars, which leaves a more massive star, hotter and therefore bluer. There are probably several ways to merge stars in a cluster.



These binary interactions are helping to prevent the collapse of globular clusters into a black hole.



# Next week

… we'll go back to the proper sequence, and look other galaxies, and the way they live and evolve.

# Further reading

- The site "Astronomy 162 Digital Movie Gallery" by Richard Pogge, http://www-astronomy.mps.ohio-state.edu/~pogge/Ast162/Movies/ has a nice collection of simulations of various types of binaries.
- There's an article about the discovery of the new stable orbits in "**Strange Orbits**" by Ivars Peterson, http://www.maa.org/mathland/mathtrek_4_9_01.html. The java applet showing some of the incredibly weird orbits which have been found is at http://www.cse.ucsc.edu/~charlie/3body/
- Isaac Asimov wrote an essay called "The tragedy of the Moon", in which he speculates how the history of science may have been different if our Sun had a binary companion.
- Brian Schmidt at ANU, who in 2011 won the Nobel Prize, has a very good page about Type Ia Supernovae and using them to measure the expansion of the universe, at "**The Accelerating Universe: an explanation for the interested non-scientist**", http://msowww.anu.edu.au/~brian/PUBLIC/public.html
- Paul Freire keeps an up-to-date listing of pulsars in globular clusters at http://www.naic.edu/~pfreire/GCpsr.html
- There's a recent biography of Henrietta Leavitt, the discoverer of the Cepheid period-luminosity relation: "**Miss Leavitt's Stars**: The untold story of the woman who discovered how to measured the universe" by George Johnson (Atlas Books, 2005), which mostly goes to show how little we know of her.

- If you'd like to get involved in networks of amateur astronomers, your best starting point is your local amateur astronomy organisation (list available on the Astronomical Society of Australia pages, http://astronomy.org.au/amateur/amateur-societies/australia/). A couple of sites of the web, where you can find out about what amateurs do for variable star research, are:
  - The Center for Backyard Astrophysics, http://cbastro.org/
  - The American Association of Variable Star Observers is at http://www.aavso.org.

## Sources for images used:

- Binary stars: from “How To Find A Binary System's Habitable Zone” http://www.iflscience.com/space/how-find-binary-stars-habitable-zone
- Wide binary: image by Karen Teramura, from “Wide Binary Stars: Long-Distance Stellar Relationships” http://www.ifa.hawaii.edu/info/press-releases/WideBinaryStars/
- Contact binary: painting by Don Dixon, from http://www.scifi-az.com/dixon/ddbetalyrae.htm
- Light curve of AE Phe: from Maceroni et al. 1994, “Surface imaging of late-type contact binaries I: AE Phoenicis and YY Eridani”, A&A 288, 529; Doppler image from Barnes et al. 2004, “High-resolution Doppler images of the spotted contact binary AE Phe”, MNRAS 348, 1321
- Orbit of Castor: from “Astronomy: Journey to the Cosmic Frontier” by John Fix, Fig. 21.1 http://www.mhhe.com/physsci/astronomy/fix/student/chapter21/21f01.html
- Hierarchical doubles: redrawn from “Multiple Stellar Systems: Types and Stability” by Peter Leonard, Encyclopedia of Astronomy and Astrophysics, ed. Paul Murdin, article 1854. (IPP 2001)
- Image of Castor: from “Double Stars” by Jack Schmidling, http://schmidling.netfirms.com/doubst.htm
- Spectroscopic binary animation: from “Astronomy 162 Digital Movie Gallery” by Richard Pogge, http://www-astronomy.mps.ohio-state.edu/~pogge/Ast162/Movies/ . Used with permission
- Castor: from Jodrell Bank Constellations, http://www.jb.man.ac.uk/public/AList/Gemini.html
- α Cen orbit: from http://phl.upr.edu/press-releases/aplanetarysystemaroundourneareststarisemerging. Image: from APOD 2011 July 3 http://apod.nasa.gov/apod/ap110703.html
- Figure 8 orbit: from Charlie McDowell, http://www.cse.ucsc.edu/~charlie/3body/
- V838 Mon shell: from http://hubblesite.org/newscenter/archive/releases/2006/50/
- Chinese records of supernova: from “Historical Supernovae” by B. Aschenbach, G. Boerner & Q. B. Li http://www.mpa-garching.mpg.de/HIGHLIGHT/2000/highlight0005_e.html
- SN 1006: imagined image by Tunc Tezel from APOD 2006 April 30 http://antwrp.gsfc.nasa.gov/apod/ap060430.html; Chandra image from APOD 2005 December 26 http://antwrp.gsfc.nasa.gov/apod/ap051226.html
- Tycho’s supernova: from “Astronomen Tycho Brahe”, http://www.landskrona.se/kultur/tychobrahe/sv_tychobrahe/index.html
- Brightness of the historical supernovae: from “Astronomy 122: Birth and Death of Stars” by Jim Brau: Stellar Explosions, http://blueox.uoregon.edu/~jimbrau/astr122
- Cataclysmic variable: from “Explorations: An Introduction to Astronomy” by Thomas Arny, Fig. 14.3 http://www.mhhe.com/physsci/astronomy/arny/instructor/graphics/ch14/1403.html
- Classical nova light curve: from “Birth and Death of Stars” by Jim Schombert, http://abyss.uoregon.edu/~js/ast222/lectures/lec14.html
- Nova Centauri 2013: from APOD 2013 December 7 http://apod.nasa.gov/apod/ap131207.html
- Cataclysmic variable: from “Cataclysmic Variables”, http://heasarc.gsfc.nasa.gov/docs/objects/cvs/cvs.html
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- Nova Cygni shell: from Astronomy Picture of the Day, 1995 December 27 http://antwrp.gsfc.nasa.gov/apod/ap951227.html

- Type Ia supernova: from “Astronomy 122: Birth and Death of Stars” by Jim Brau: Stellar Explosions http://blueox.uoregon.edu/~jimbrau/astr122
- Simulation of a supernova in Centaurus A: from The Supernova Cosmology Project: What we can “See” in a Supernova, http://www-supernova.lbl.gov/public/figures/snvidea.html
- Supernova 1994D in the galaxy NGC 4526: from APOD 2015 May 31 http://apod.nasa.gov/apod/ap150531.html
- Spectrum of the shell of DQ Her, taken in 1978, 44 years after the nova outburst: from the original paper by Williams et al. 1978, ApJ 224, 171
- Light curve of V838 Mon: from paper by Retter & Marom, 2003, MNRAS 345 L25 http://adsabs.harvard.edu/abs/2003MNRAS.345L..25R
- Cepheid period-luminosity relation: from “Stars and Galaxies” by Richard McCray, http://cosmos.colorado.edu/cw2/courses/astro1120/text/chapter8/lesson8.html
- Nova outbursts: from NASA’s Observatorium: Stellar Evolution and Death http://observe.arc.nasa.gov/nasa/space/stellardeath/stellardeath_4b2.html
- HST shells from V838 Mon: from Hubble Heritage Project, http://heritage.stsci.edu/2005/02/index.html; 2006 images, from Hubblesite http://hubblesite.org/newscenter/archive/releases/2006/50/
- M5 from HST: from 2015 June 20 http://apod.nasa.gov/apod/ap150620.html
- Jewel Box cluster, NGC 4755: picture by Mike Bessell, from Astronomy Picture of the Day2001 June 18 http://antwrp.gsfc.nasa.gov/apod/ap010618.html
- Sizes of clusters: after Figure 1 from M. Davies 2002, “Stellar Exotica produced from Stellar Encounters”, in “Omega Centauri”, ASP Conf. Proc. Vol. 265 ed. van Leeuwen, Hughes & Piotto (ASP), p. 215
- Hertzsprung-Russell diagrams of clusters: from “Explorations: An Introduction to Astronomy” by Thomas Arny, Fig. 13.24 http://www.mhhe.com/physsci/astronomy/arny/instructor/graphics/ch13/1324.html
- The Pleiades: from “Stars and Galaxies” by Richard McCray, http://cosmos.colorado.edu/cw2/courses/astro1120/text/chapter5/lesson5.html
- Simulation of molecular cloud collapse: from Matthew Bate’s Animations, http://www.astro.ex.ac.uk/people/mbate/animations.html
- Pleaides: image by Marco Lorenzi, from APOD 2015 Jun 17 http://apod.nasa.gov/apod/ap130501.html
- The globular cluster Omega Centauri: image by Joaquin Polleri & Ezequiel Etcheverry, from APOD 2013 May 1 http://apod.nasa.gov/apod/ap130501.html
- 47 Tucanae: ground and space-based images, from Astronomy Picture of the Day 1997 November 4 http://antwrp.gsfc.nasa.gov/apod/ap971104.html
- The globular cluster M3: image by Karel Teuwen, from APOD 2007 June 9 http://apod.nasa.gov/apod/ap070609.html; H-R diagram from “Stars and Galaxies” by Richard McCray, http://cosmos.colorado.edu/cw2/courses/astro1120/text/chapter5/lesson5.html
- X-ray sources in M15: wide field image, from Hubble Heritage Project, http://heritage.stsci.edu/2000/25/. Optical and X-ray images of core, from Chandra Photo Album: More Images of M15 http://chandra.harvard.edu/photo/cycle1/m15/more.html
- Pulsars in 47 Tuc: from Jodrell Bank Observatory: Discover helps to solve mystery in globular clusters http://www.jb.man.ac.uk/news/47Tuc/ ; 2D positions from “The 47 Tucanae Pulsars home page” http://www2.naic.edu/~pfreire/47Tuc/
- Encounters with binaries: after Figure 2 from M. Davies 2002, “Stellar Exotica produced from Stellar Encounters”, in “Omega Centauri”, ASP Conf. Proc. Vol. 265 ed. van Leeuwen, Hughes & Piotto (ASP), p. 215
- Binary/single star encounters: from Steinn Sigurdsson http://www.astro.psu.edu/users/steinn/research/pretty.html
- Blue stragglers in NGC 6397: from Hubble Heritage http://heritage.stsci.edu/2003/21/index.html
- Ways to make a blue straggler: from Hubblesite http://hubblesite.org/newscenter/archive/releases/1997/35/
- Cluster simulation: by Simon Portegies Zwart http://staff.science.uva.nl/~spz/index.html