The Births, Lives, and Bizarre Deaths of Stars

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The Births, Lives, and Bizarre Deaths of Stars: What This Lecture Is NOT About

Why Care?

The atoms in your body are created by starlife and stardeath. You are starstuff!

The sun is essential for life, and its evolution will have a profound effect on Earth's future

Stellar corpses – particularly neutron stars and black holes – push the boundaries of the laws of physics

The topic is interesting!

A Crowd of People

Each is unique; each has a life cycle, from birth to death

6000 people watched the transit of Venus on June 5, 2012 from Varsity Stadium in Toronto,

Source: Dunlap Institute

A Crowd of 300 Billion Stars

Each is unique, each has a life cycle, from birth to death

NASA

"They all look the same to me....."

What is a **Star?**
Stars are Distant Suns!

NASA

- Huge massive balls of hydrogen and helium gas, producing energy by thermonuclear fusion in their cores, where the temperature is 15,000,000 degrees, and the density is 100 times that of water!

The stars are born in **nebulas**: clouds of gas and dust in space

NASA

- Nebulas, like the Orion Nebula which you can see with binoculars, are huge clouds of hydrogen and helium, and dust
- … which come from the birth of the universe, and also from dying stars

How We Know

By observing and studying stars with telescopes and instruments on the ground and in space

University of Hawaii

Canada shares telescopes on this mountain -- Mauna Kea

How We Know

by observing and studying stars with telescopes and instruments on the ground and in space

NASA/ESA/HST

How We Know

by using the laws of physics and computer simulations

$$\frac{dP}{dR} = -g\rho,$$

$$\frac{dM}{dR} = 4\pi R^2\rho,$$

$$\frac{dT}{dR} = \frac{-\nabla G M \rho T}{R^2 P}$$

The laws of physics

Starlife in 5 Easy Lessons

- **Stars --- like the sun -- shine by producing energy**
- Inward pull of gravity must be balanced by outward force – pressure of hot gas
- Inside of star is hotter than outside; energy flows from hot to less hot
- Unless the outflowing energy was replaced, the star would cool and contract
- Energy is produced in the core of the star by thermonuclear fusion of hydrogen into helium, helium into carbon etc.

Starlife in 5 Easy Lessons

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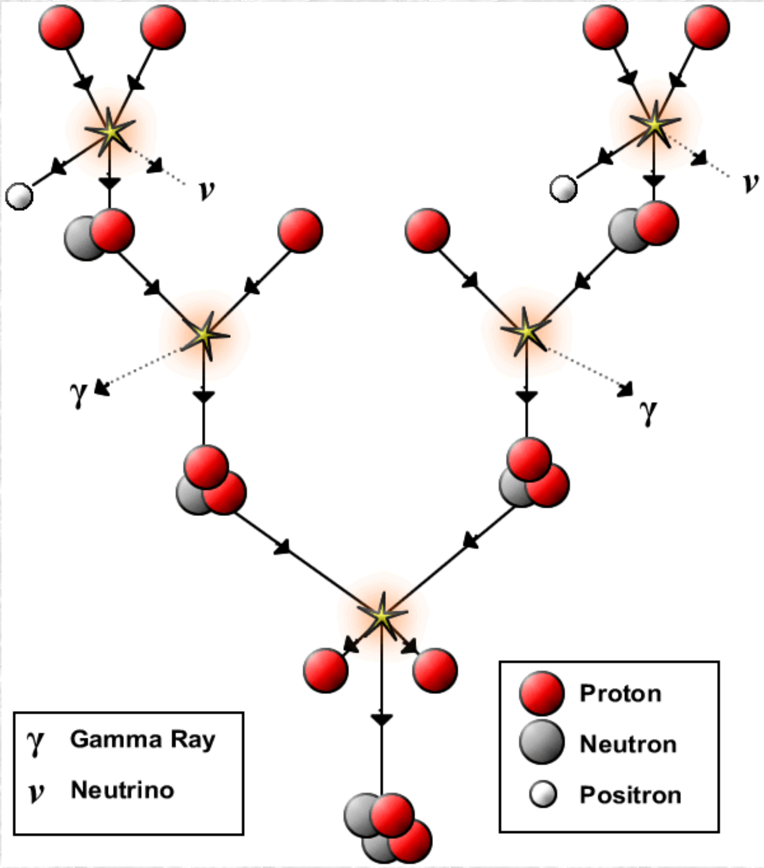
The stars make energy by nuclear fusion of hydrogen into helium

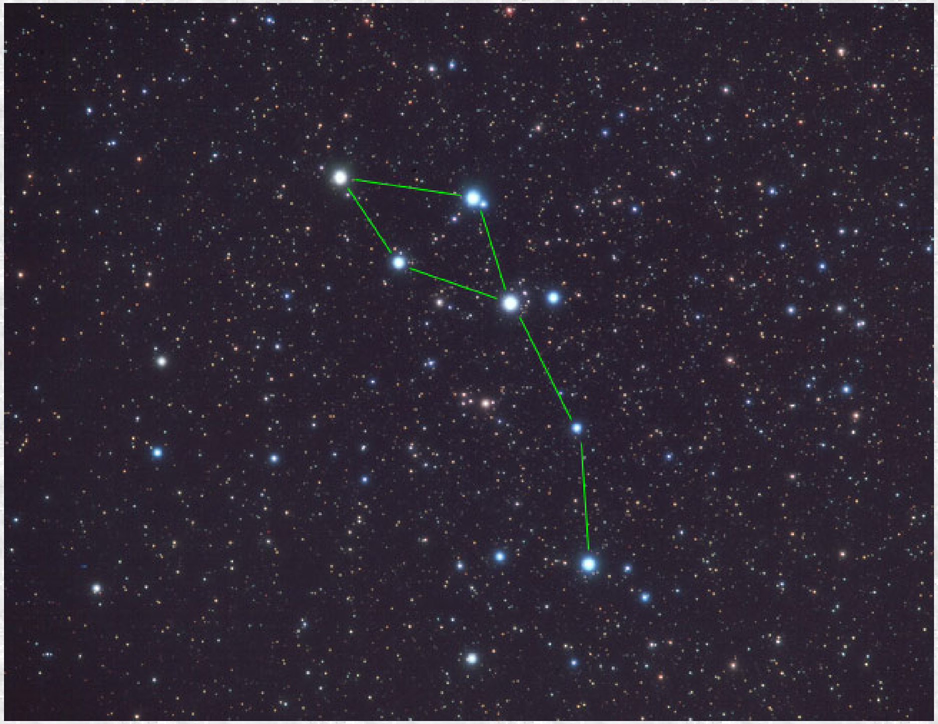


wikipedia.org

- Stars are ¾ hydrogen and ¼ helium
- In their hot, dense cores, hydrogen nuclei (protons) fuse into helium nuclei: "thermonuclear fusion"
- A small amount of mass is converted into energy: $E = mc^2$
- The energy slowly makes its way to the surface, and into space

Canada's Art Macdonald won the 2015 Nobel Prize for verifying this

Constellations – Star Patterns

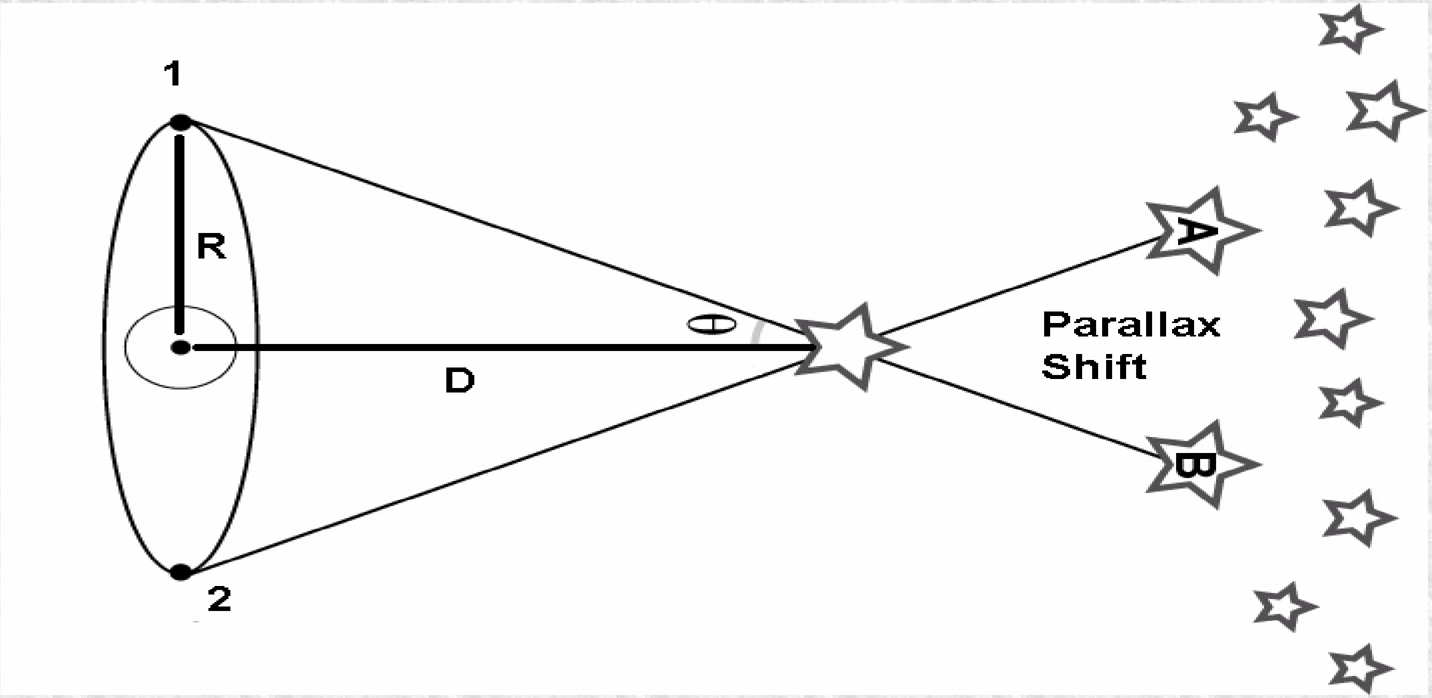


Delphinus, the dolphin

- Constellations are random star patterns on the sky
- Different cultures have different constellation patterns
- Ours are not "special"

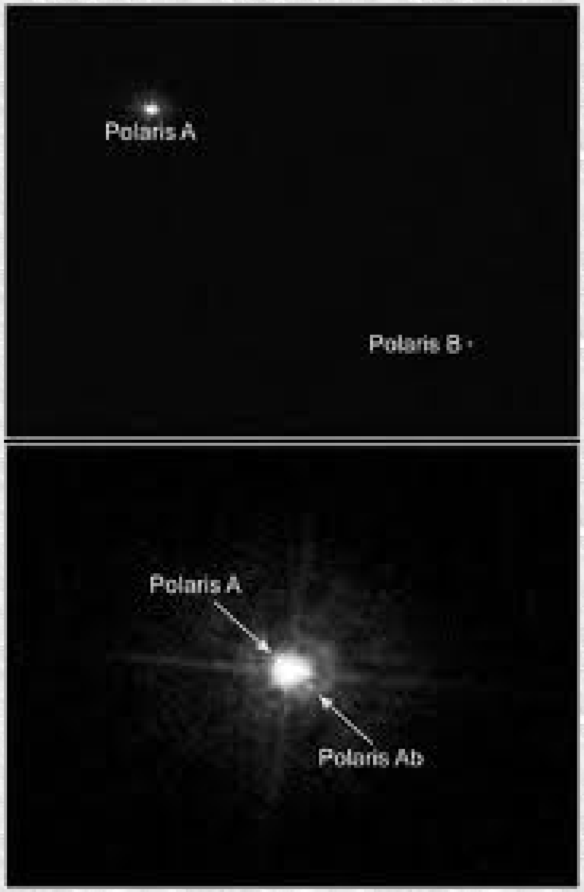
How Distant?

Star distances are measured by parallax – the apparent shift in their position as the earth orbits the sun. The nearest other star is about 5 light years distant.

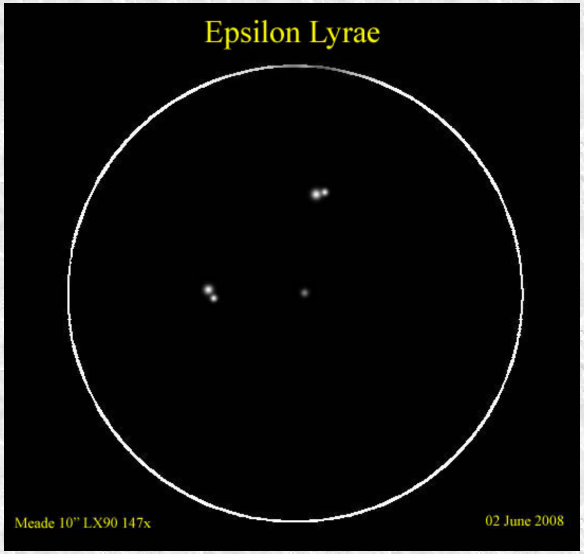


Many Stars Are Double/Multiple

Albireo, in Cygnus



Polaris, the North Star



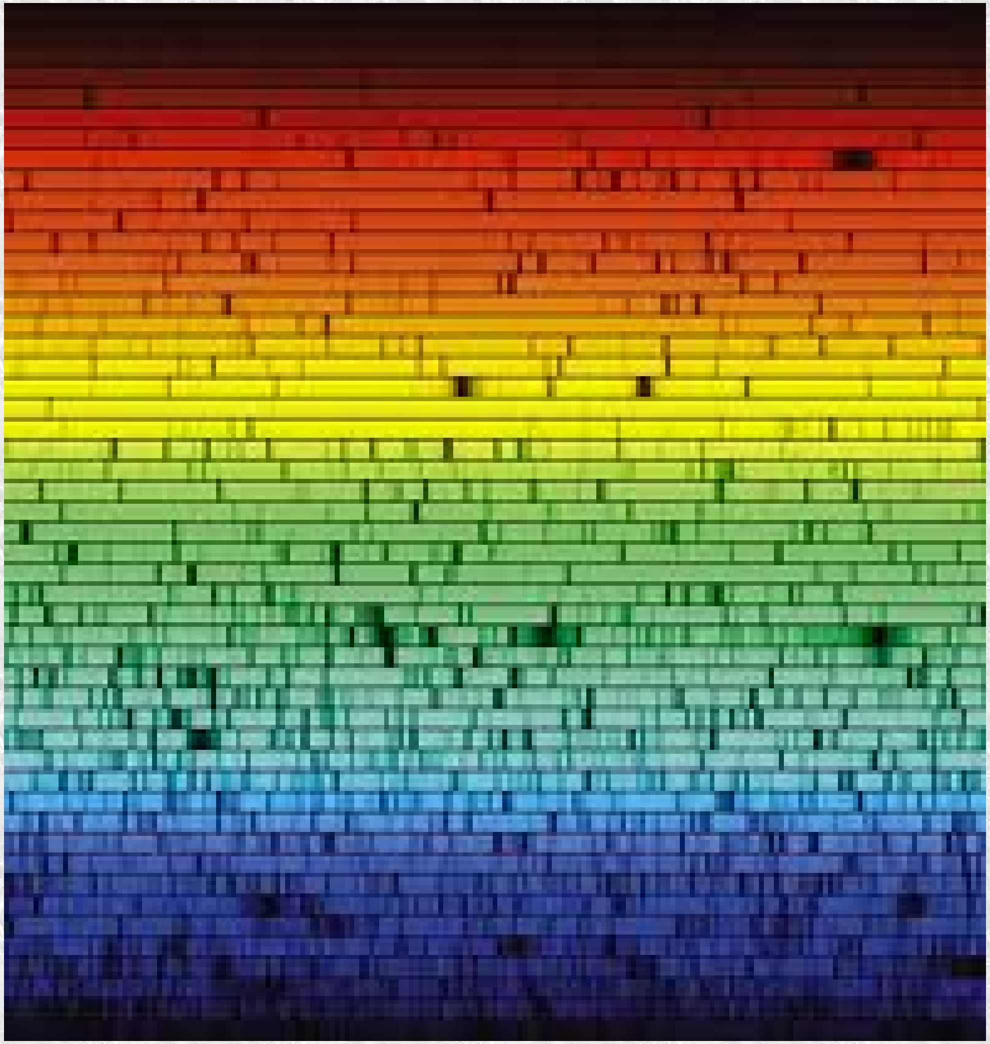
Epsilon Lyrae, in Lyra, the **double double**

Stars, Hot and Cool

Betelgeuse (upper left) and Rigel (lower right) in Orion

- Hot stars appear bluish
- Cool stars appear reddish
- Opposite to the taps in your bathroom

The Message of Starlight



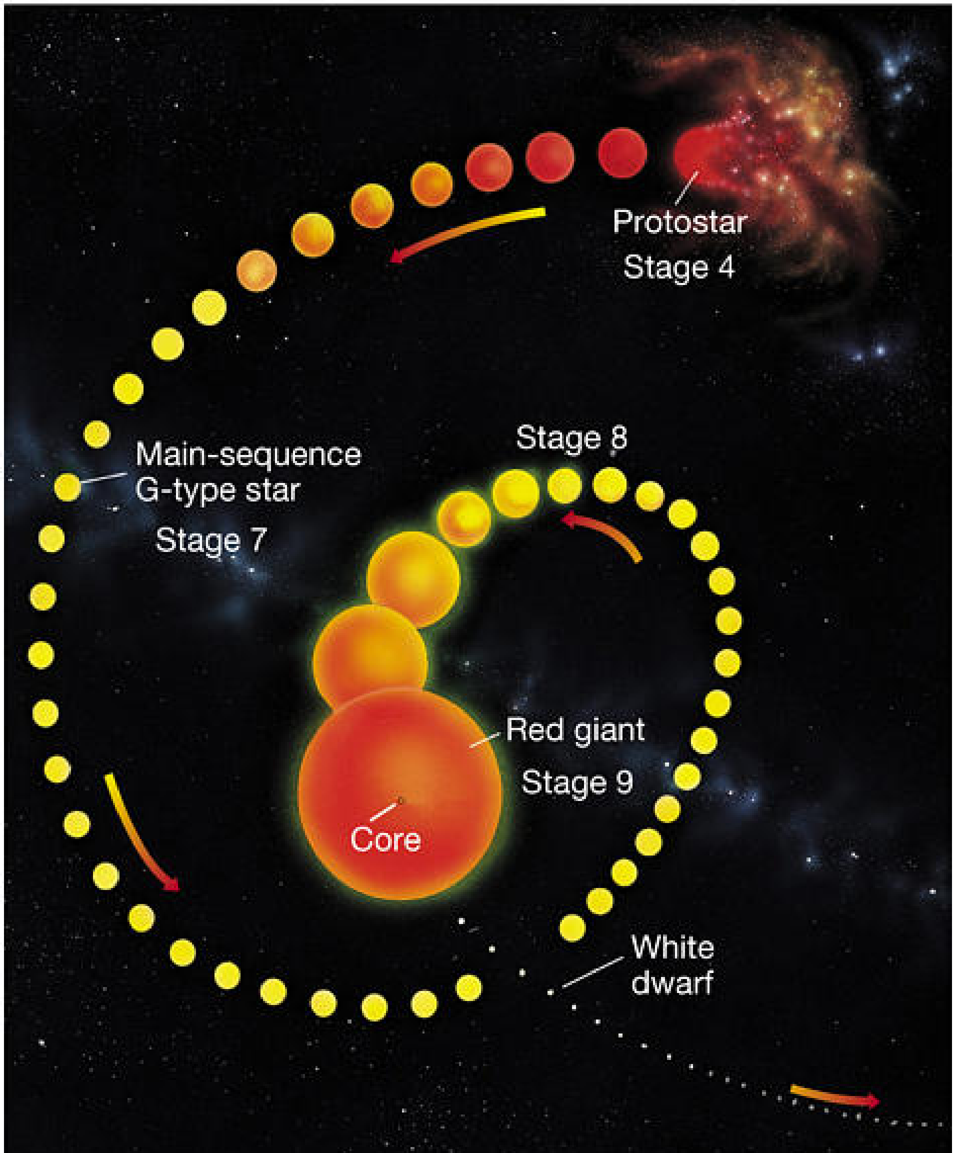
The light of the sun, dispersed rainbow-style

The sun is not an average star!

NASA

- It's not average; it's bigger and more powerful than 90% of other stars
- Most stars are red dwarfs, like the “low mass” star at left – and have planets!!
- Massive stars are very rare!

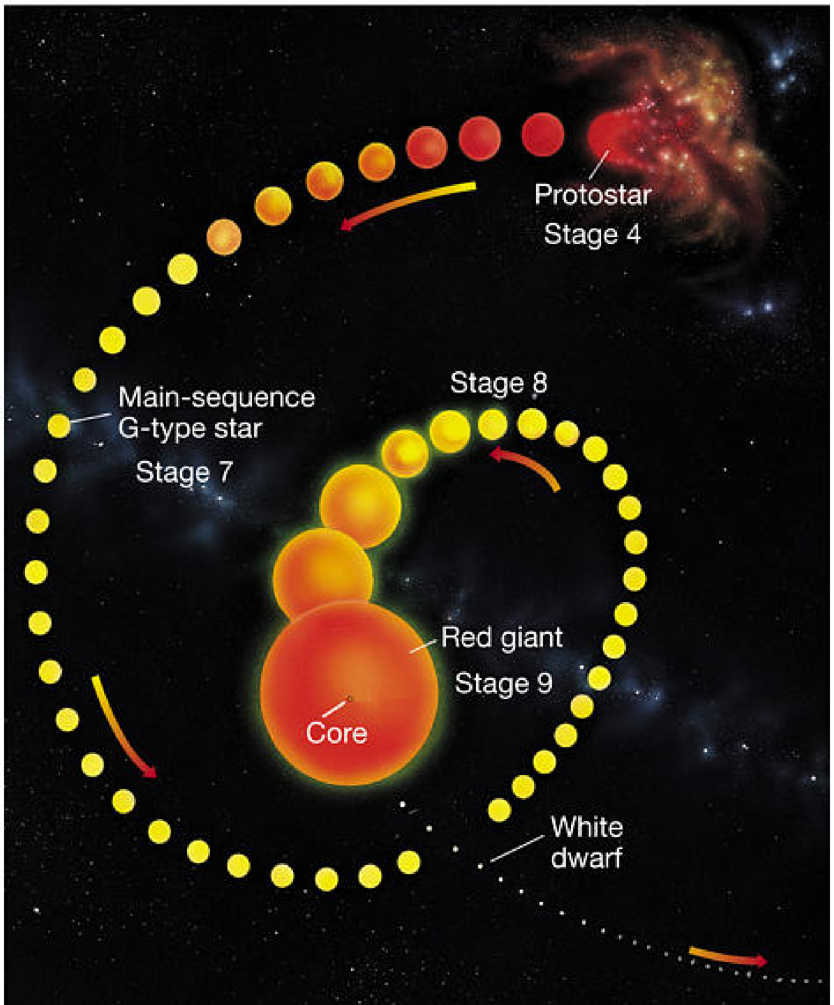
Stars have long lifetimes!



- The sun's power is 400 trillion, trillion Watts
- Yet, it has enough fuel to last for 10 billion years
- Most stars have even longer lifetimes – trillions of years
- Only rare, more massive stars have shorter lifetimes – millions of years

Stellar Evolution: How We Know

Computer “modelling” = simulation



$$\frac{dR}{dM_r} = \frac{1}{4\pi R^2 \rho},$$

$$\frac{dL_r}{dM_r} = \epsilon - T\frac{dS}{dt},$$

$$\frac{dP}{dM_r} = -\frac{GM_r}{4\pi R^4},$$

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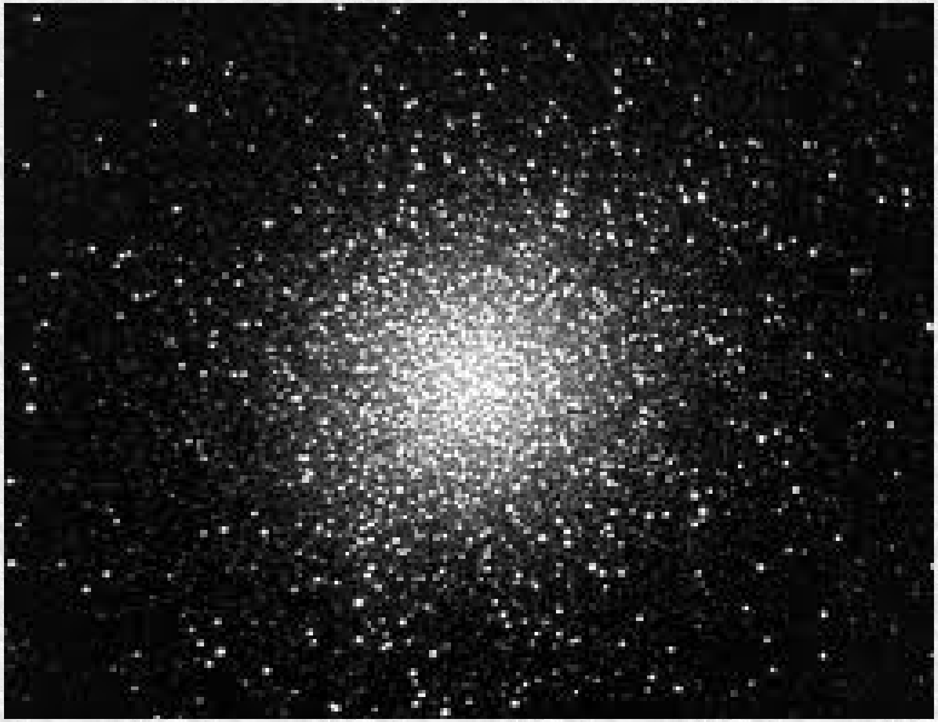
The laws of physics

Stellar Evolution: How We Know

Star Clusters: “nature's experiments”: stars of different masses, formed at the same time, from the same material

Pleiades: a young “open cluster”



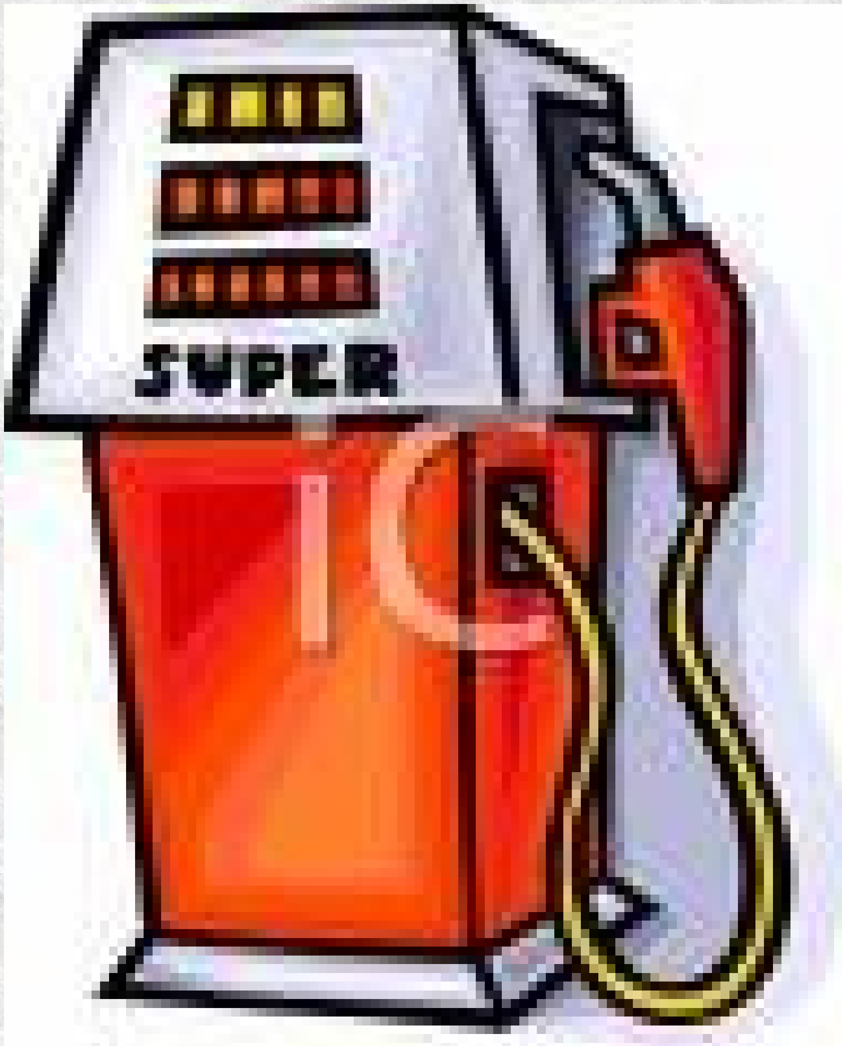
M13: an ancient “globular cluster”

Most Stars Live Forever (Almost)

Gliese 581g; stocktrek images

- Most stars in our Milky Way galaxy are red dwarfs, with low mass, and VERY low power
- If the sun was a red dwarf, the earth would be very dark and cold!
- Red dwarfs have lifetimes of trillions of years – longer than the age of the universe!

But the stars eventually run out of fuel



- Every energy supply runs out eventually
- The stars run out of energy when all of the hydrogen in their hot core is changed into helium
- The core shrinks, to squeeze some energy out of the helium; this lasts for a short time only
- The rest of the star swells into a red giant

Stardeath in 5 Easy Lessons

- **Stars --- like the sun -- shine by producing energy**
- Stars' energy supplies eventually run out, after billions of years; they run out of fuel
- As this happens, the stars swell up into a red giant or supergiant as their core shrinks, and may eject their outer layers into space
- Gravity – which always attracts things – compresses the dead star into a white dwarf, neutron star, or black hole
- The collapse to a neutron star or black hole may explode the star as a supernova

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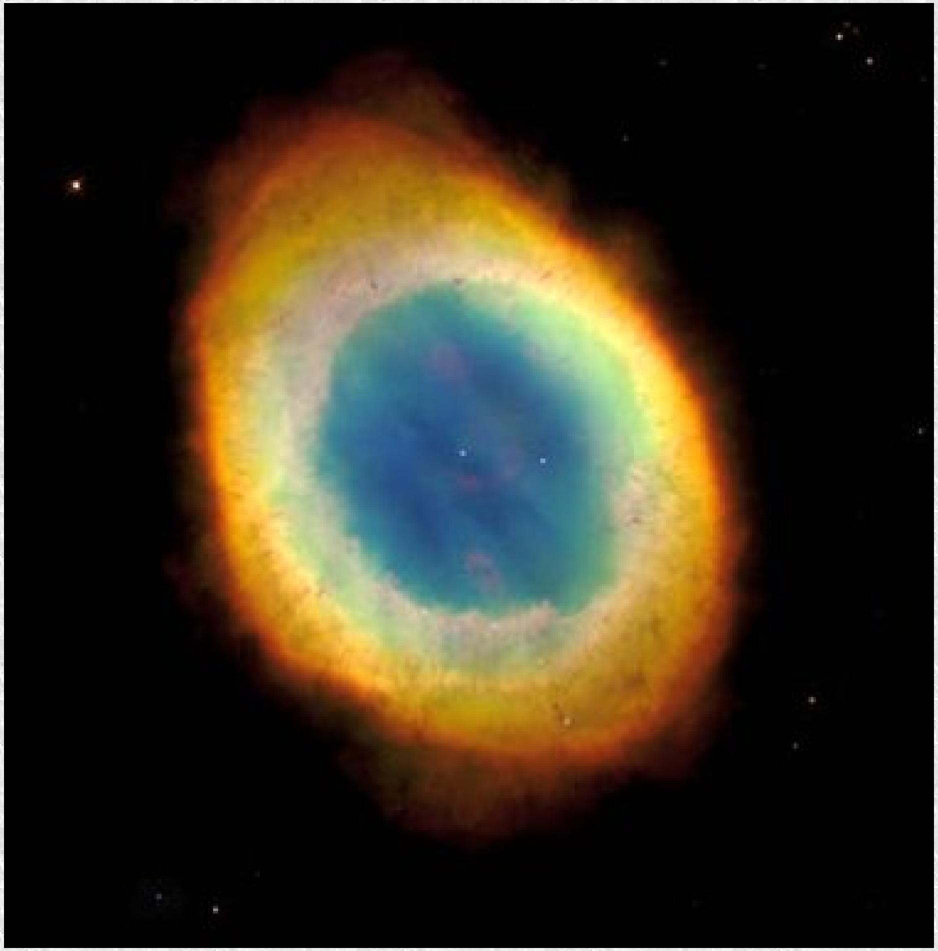
The Star Swells, then Throbs

Penn State University

- The star swells, cools and brightens into a red giant, swallowing the inner planets
- The outer layers of the star become unstable
- They begin to pulse, or throb gently at first, but then more powerfully
- This is what I and my students study

The Death of a Sun-like Star

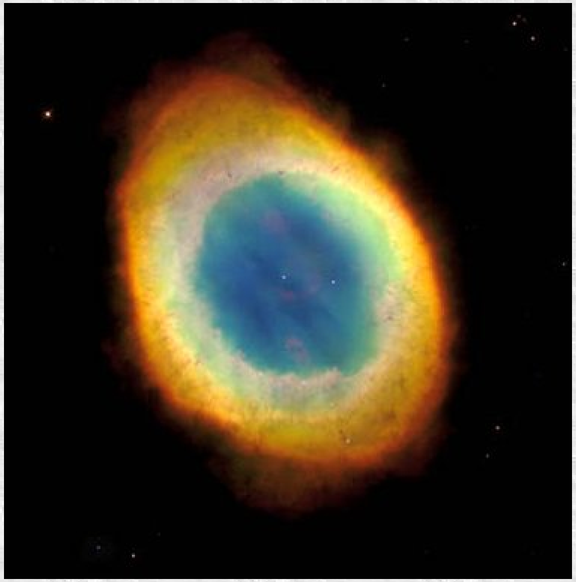


NASA

- The pulsation drives the outer layers of the star into space, producing a beautiful planetary nebula (so called because of its shape)
- The dead core of the star is exposed; it is a white dwarf star

Dying Suns – **Planetary Nebulas**

Images from the Hubble Space Telescope: NASA/ESA



White Dwarfs – Dead Stars

the most common stellar corpses

BBC

- A white dwarf is the shrunken remains of a normal star like the sun
- It has the mass of a star, in the volume of earth
- Its density is a million times that of water
- It has no energy; it cools like an ember in a fire
- There are dozens in the sun's neighbourhood

Sirius B: A Nearby White Dwarf

NASA

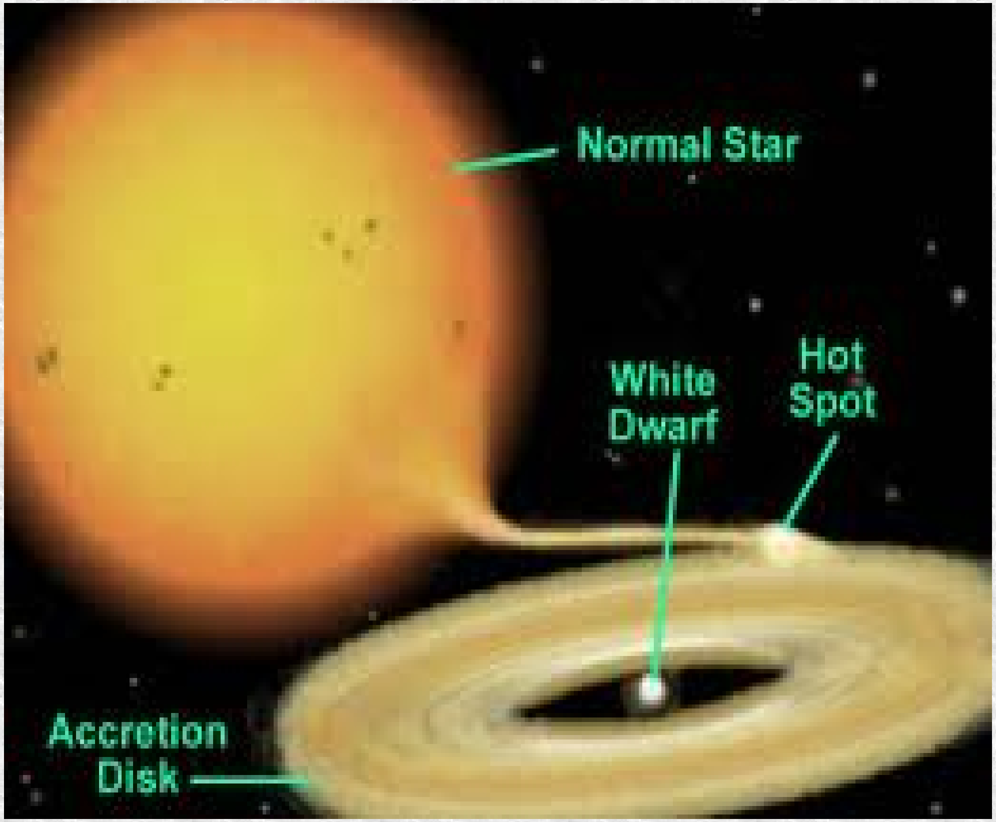
- Sirius is the brightest star in the night sky, and quite near by
- It is actually a *pair* of stars, orbiting each other
- One (Sirius A) is a normal star; the other (Sirius B) is a white dwarf
- It is the remains of a more massive star that has lived and died

Subrahmanyan Chandrasekhar

S. Chandrasekhar

- A student who, while travelling from India to the UK, used the new theories of quantum mechanics and relativity to understand the nature of white dwarfs
- But if their masses were greater than 1.44 suns, they would collapse!
- Nobel Prize in Physics in 1983

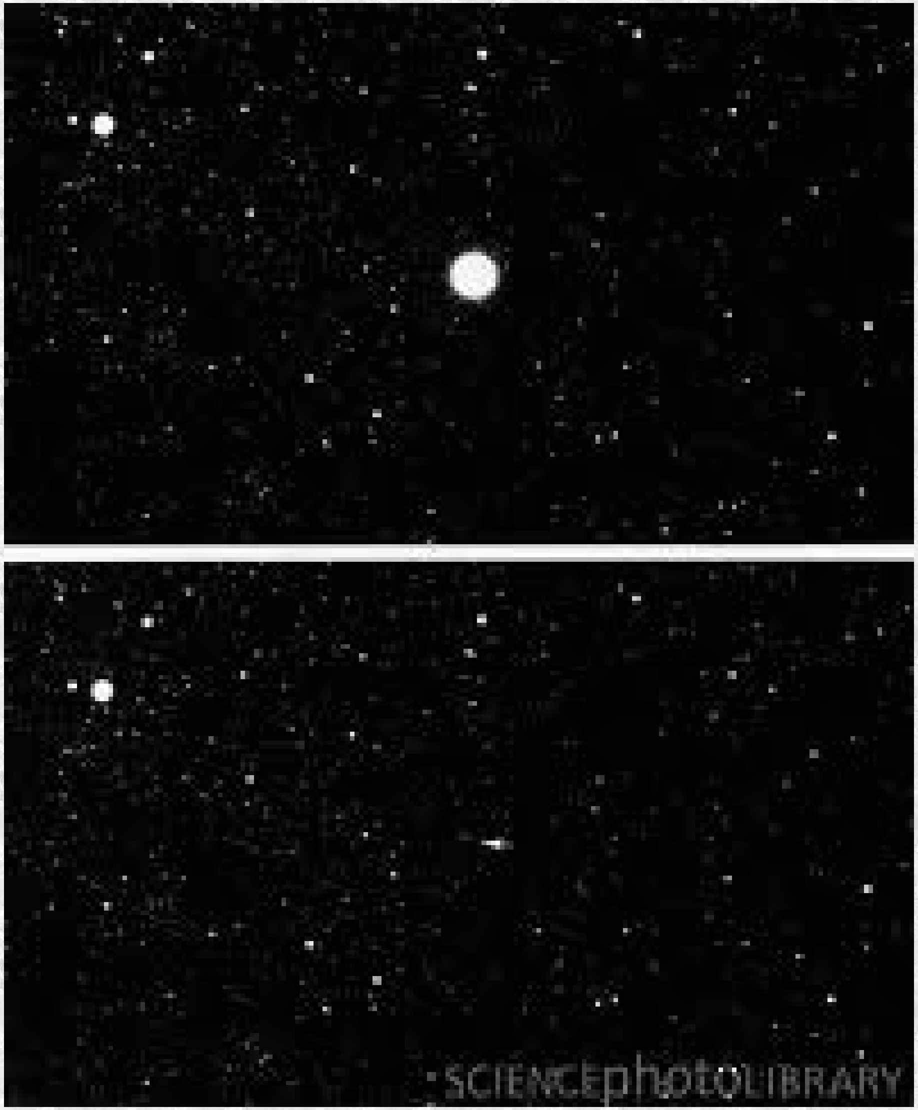
Rare, Born-Again Stars: Cataclysmic Variable Stars



NASA

- Cataclysmic variable stars are close binaries
- The more massive star in a binary dies first, and become a white dwarf
- The less massive star begins to run out of fuel, and swell up
- As the stars orbit, gas swirls into an accretion disc, and interesting things happen!

Nova -- “New Star”



Top: Nova Cygni 1975: Lick Observatory

- Hydrogen-rich gas falls on the white dwarf
- It gets hotter and hotter
- Finally, there is a runaway thermonuclear explosion
- The outer layers of the star expand and explode
- The star becomes thousands of times brighter for a few weeks

When MASSIVE stars run out of fuel

NASA

- Rare, massive stars fuse hydrogen into helium, carbon, oxygen, and elements as heavy as iron which has nonuclear energy
- When they run out of fuel, their cores collapse violently under their own weight
- The gravitational energy release explodes the star: a supernova

Brightest Supernova in 400 Years!

This supernova was discovered by University of Toronto astronomer Ian Shelton on February 23-24, 1987.

Richmond Hill Naturalists

Large Magellanic Cloud – after and before

Supernova remnants

NASA

- The supernova remnant is blasted into space at thousands of km/sec!
- This material has been enriched in the elements created in the star by thermonuclear fusion
- The material forms new nebulas from which new stars and planets and life are made
- You are starstuff!

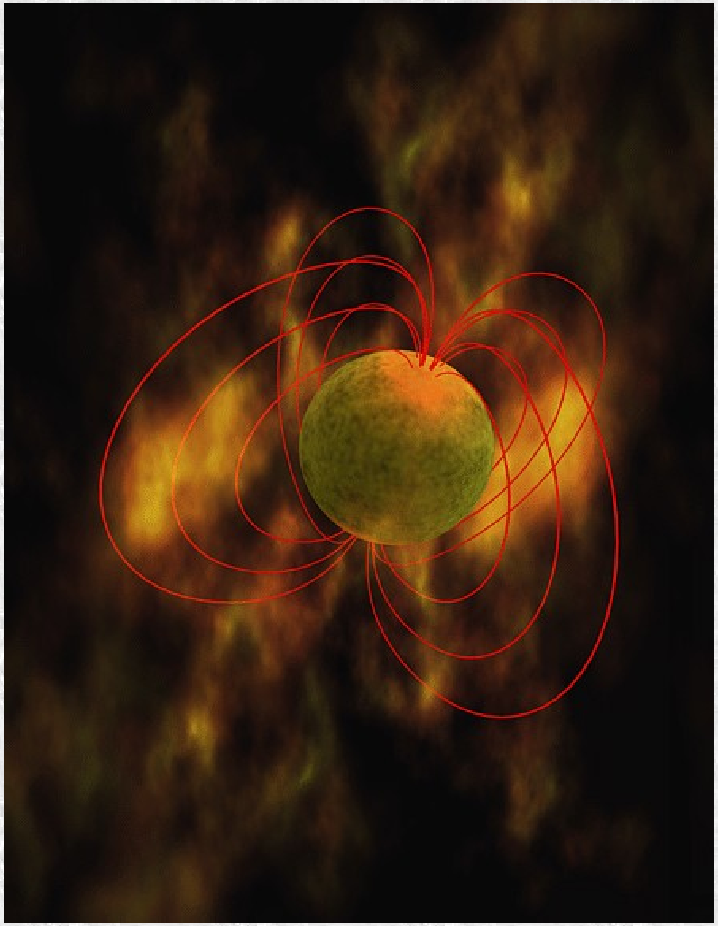
Neutron Stars!

NASA/ESA/HST

- The core of a rare, massive star collapses under its own weight until it is a ball of neutrons – a neutron star
- Its density is a million tonnes per cm^3
- It can spin faster than a kitchen blender!
- It emits pulses of radiation as it spins; it is a pulsar

Magnetars

Neutron stars with magnetic fields which are quadrillions of times stronger than Earth’s; studied and named by U of T astronomer Chris Thompson



Dame Jocelyn Bell Burnell

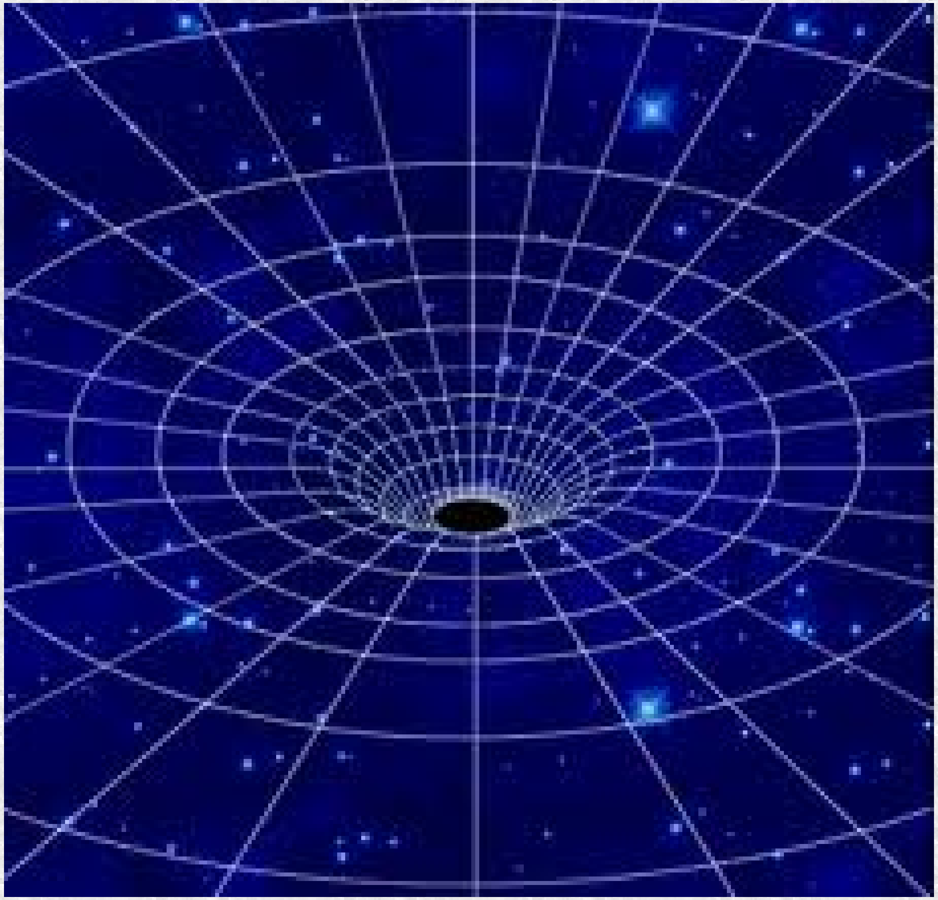
Robin Scagell; sciencephoto.com

- While a graduate student at Cambridge, she used a radio telescope, built by her supervisor, to study rapidly-varying radio sources
- She found pulsars, pulsing regularly every second or two
- Her supervisor won the Nobel Prize in Physics
- Jocelyn went on to a varied and illustrious career

When a *very* massive star runs out of fuel

- One star in a billion is so massive that, when it runs out of fuel, and collapses under its own weight, its core becomes a black hole
- Its density is so great that its gravity is so strong that nothing can escape from it – not even light

Black Holes



Keck Observatory

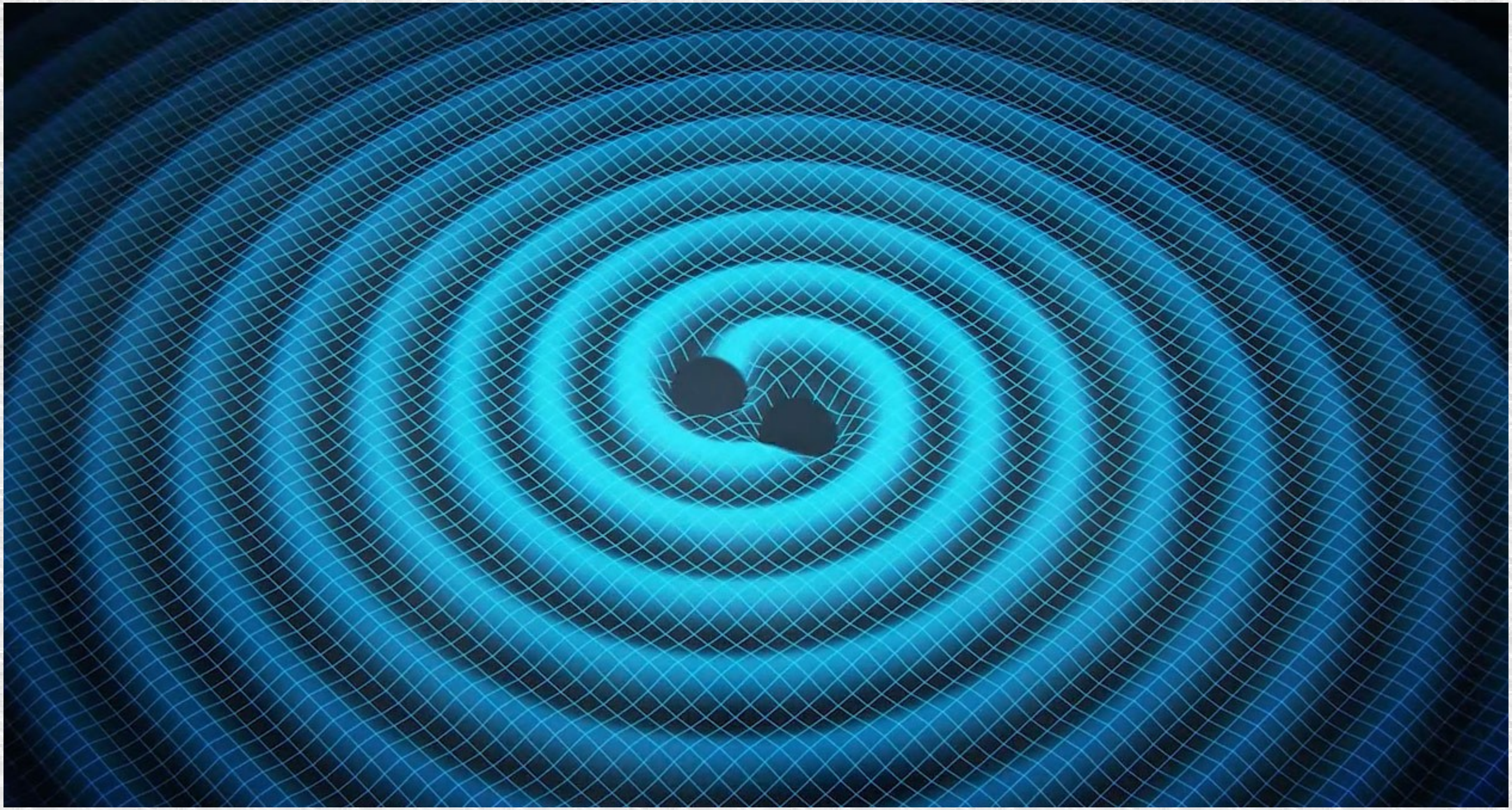
- According to the General Theory of Relativity, mass curves space and time
- A black hole makes a hole in space-time, from which nothing can escape
- Material can fall into a black hole
- But it can't get out!

How the First Black Hole was Discovered

- X-ray source Cygnus X-1
- By University of Toronto astronomer Tom Bolton at the Dunlap Observatory in Richmond Hill ON
- By observing the black hole's pull and effect on a normal star going around it
- And from X-rays produced as gas falls into the black hole

This Star System's Eventual Fate?

A pair of black holes which eventually merge, and produce a burst of gravitational waves

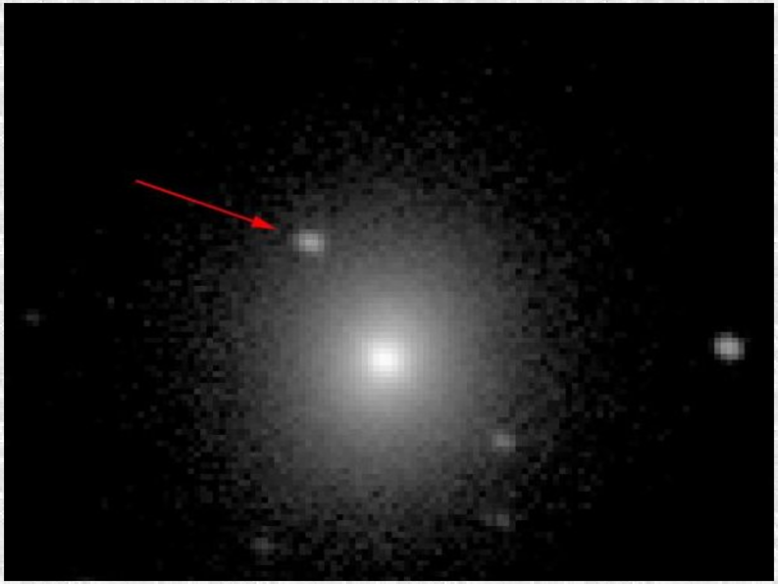


Canadian astronomers were part of the team that first observed gravitational radiation

Two Neutron Stars in Mortal Embrace

Two neutron stars orbit, inspiral, merge, explode, releasing both light and gravitational waves, and creating the heavy elements

The latter was first detected by UToronto astronomer Maria Drout's team



Maria Drout
Remember this name!

Myths about black holes

- **You can see a black hole. No, light can't escape.**
- The gravity of a black hole is different from normal gravity. No, same gravity.
- The sun – and all other stars – will turn into a black hole. No, just very rare, massive stars.
- Black holes are giant cosmic vacuum cleaners that swallow everything around them. No, only things very nearby, such as gas from a star which is orbiting them.
- Matter (such as you) that falls into a black hole will appear somewhere else in the universe. No, it stays right there.

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Mysteries Remain: FRBs

- Fast Radio Bursts are brief bursts of radio radiation from ?? in distant galaxies
- Are they from magnetars? Other neutron stars? Black holes?
- Canada’s CHIME radio telescope is leading the way!

Let's get back to “the beginning”!

The stars are born in nebulas: clouds of gas and dust in space

NASA

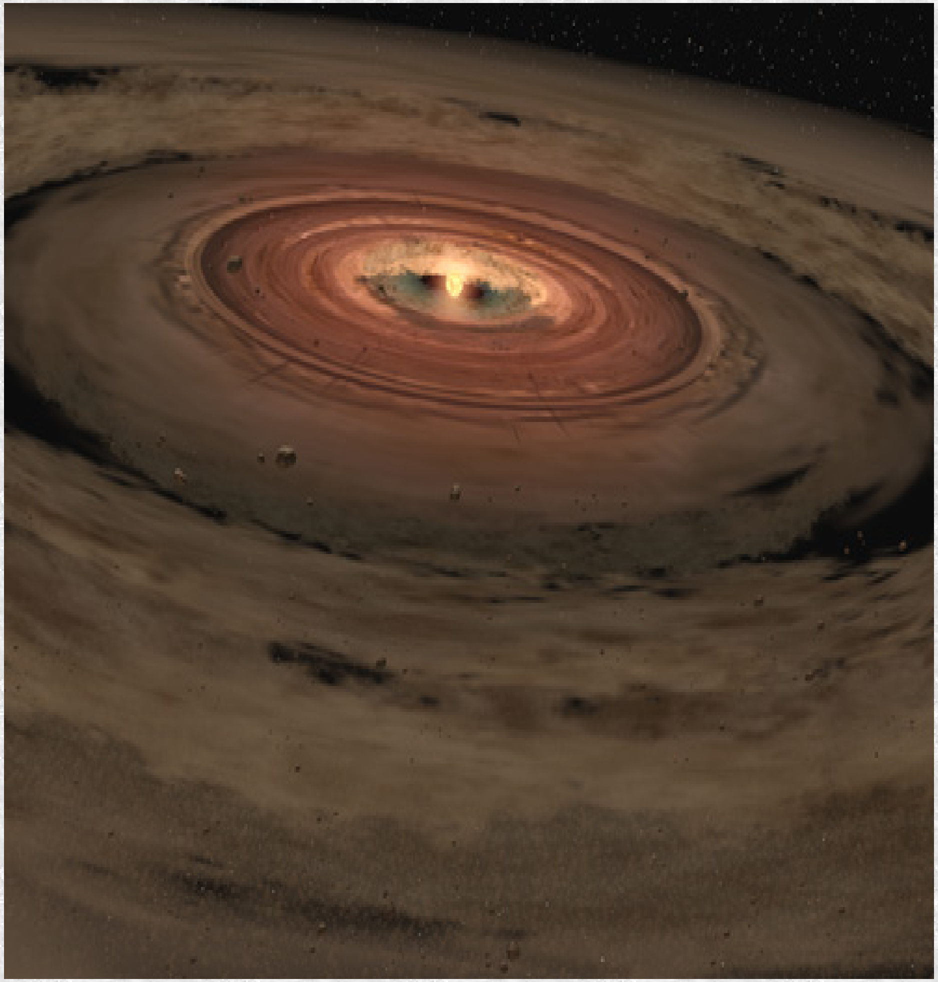
- Nebulas, like the Orion Nebula which you can see with binoculars, are clouds of gas and dust in space
- The gas and dust comes from the birth of the universe, and also from dying stars

Stars Are Formed in Families: **Clusters**

The Rosette Nebula

The Pleiades

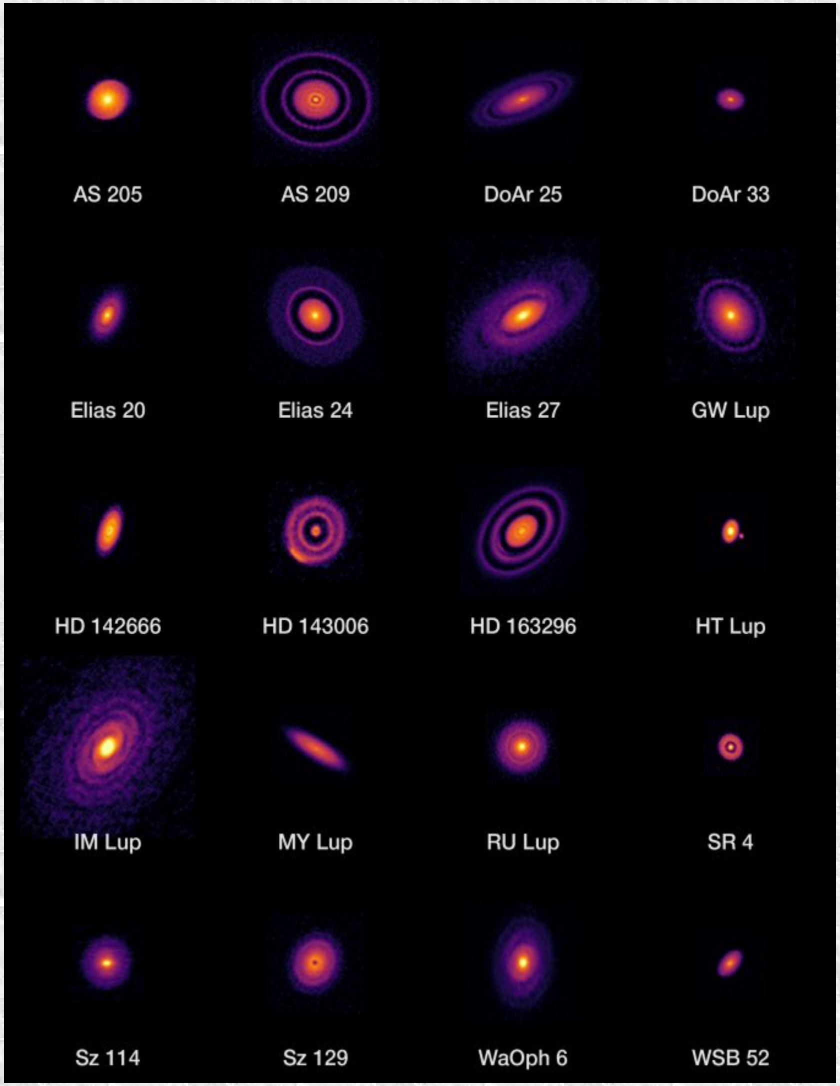
Star and Planet Formation



- A portion of the nebula begins to contract, due to gravity
- It spins faster, because of “the figure skater effect” and forms a disc
- The star forms at the dense centre; the planets form in the disc

Protoplanetary Discs

in which planets are currently forming



Discs surrounding 20 young stars

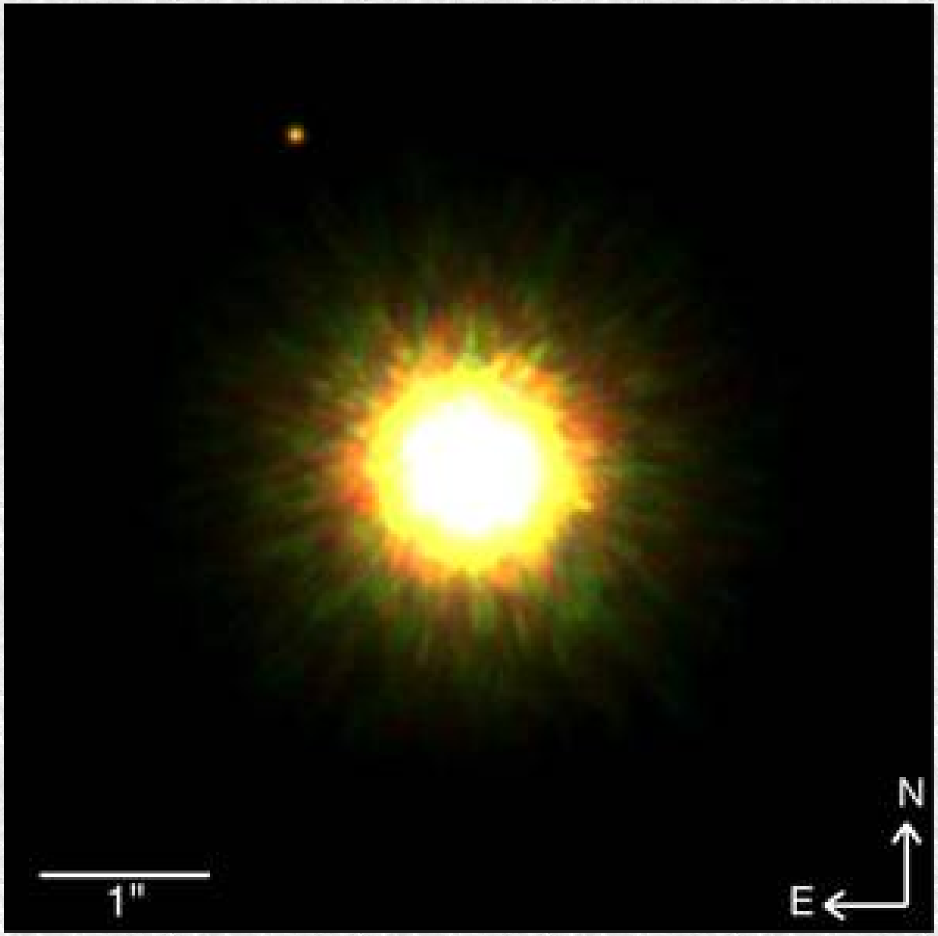
Atacama Large Millimetre Array; Canada is a partner in this facility

Brown Dwarfs: “Failed Stars”

Artist’s conception: wikipedia

- If the forming star is not sufficiently massive, it is not hot and dense enough to fuse hydrogen in its core
- It slowly cools, over billions of years

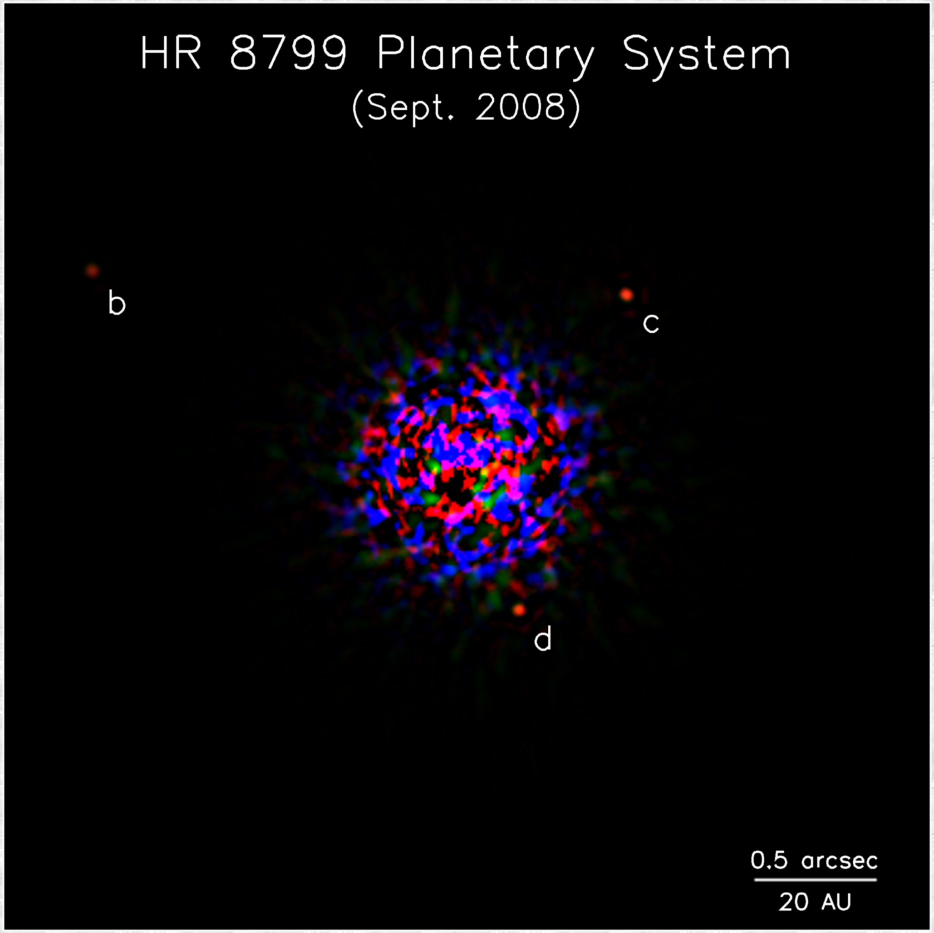
Exoplanets: Planets around other Stars



- Our theory of star formation suggests that other stars should have planets
- These are being detected in large numbers, originally by a method developed by Canadian astronomers
- But earth-sized planets are hard to detect

Canadian astronomers
are leaders in exoplanet research

Exoplanetary Systems

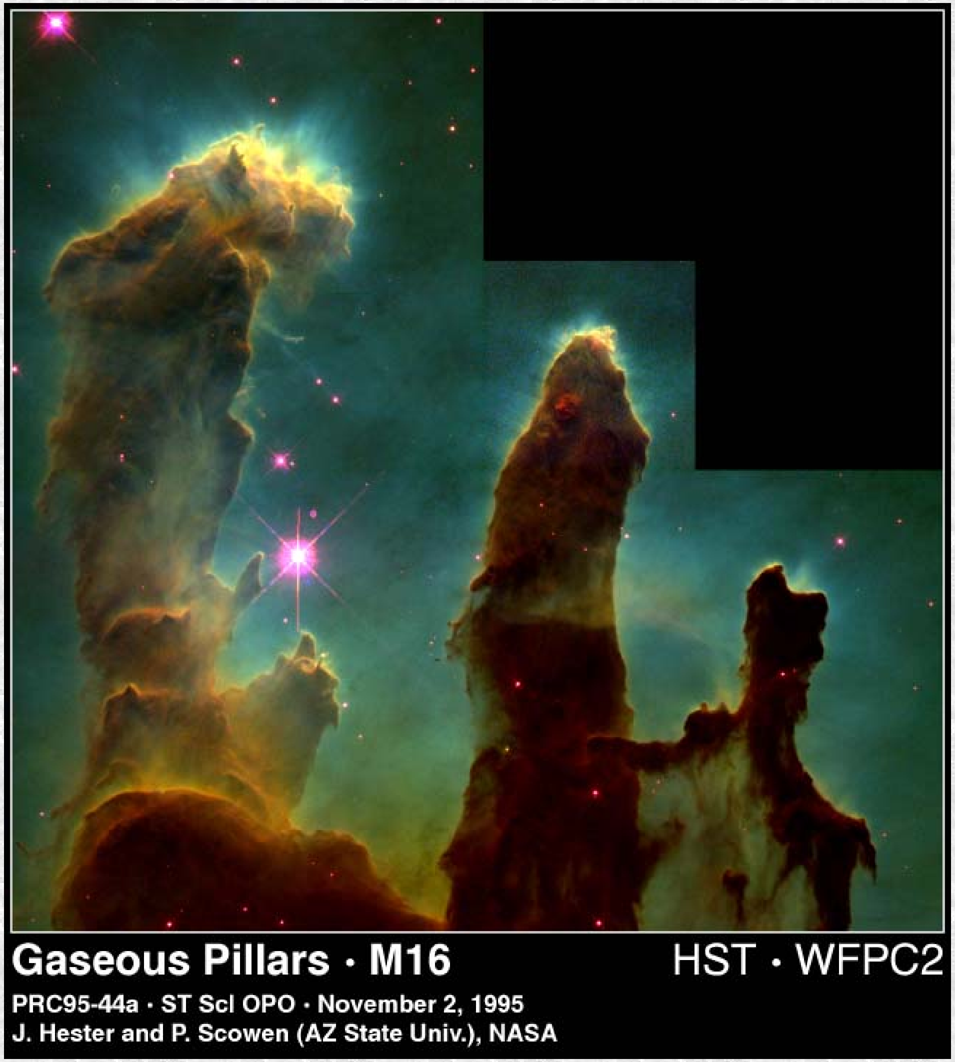


- ... and there are stars with systems of many planets
- Many are in the “habitable zone” around their star
- We are now getting our first information about the atmospheres of exoplanets

Image from National Research Council of Canada

The nearest star to the sun – Proxima Centauri -- has an earth-like planet!

Cosmic Recycling



- Gas and dust from dying stars, enriched by nuclear fusion, is ejected into space – gently or explosively
- It mixes with other gas and dust to form nebula, where new stars, planets – and perhaps life – is formed
- You are starstuff!

NASA

“Gravity is the midwife and the undertaker of the stars”

Professor Roy Bishop, Acadia University

Good News!

- The sun will not die for 5 billion years
- The sun will not explode
- A black hole will not swallow the earth
- A solar “flare” will not destroy the earth
- So enjoy the sky and the universe! And take care of the earth!

Resources

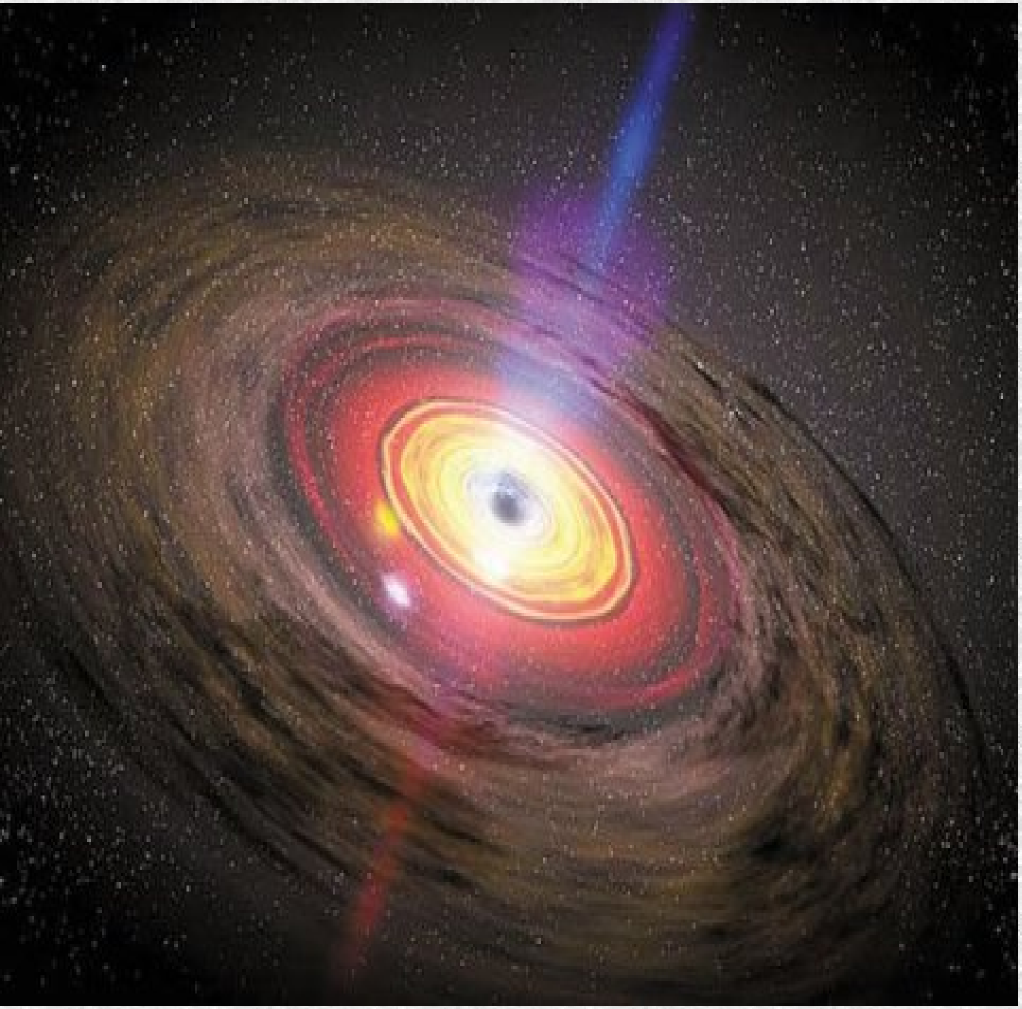
This presentation: www.astro.utoronto.ca/~percy/starlife.pdf

My website: www.astro.utoronto.ca/~percy/EPOindex.htm

Astro events:
rascto.ca/events

U of T astronomy outreach:
universe.utoronto.ca

Supermassive Black Holes



- Supermassive black holes, millions of times more massive than the sun, are formed – somehow??? -- at the centre of galaxies such as our Milky Way

NASA

Stellar Evolution: How We Know

1. **Computer simulations of the behaviour of stars of various masses, over time, based on the known laws of physics**

2. Observations of star clusters of various ages: samples of stars of the same age but different masses

3. Change in the “ticking” rate of pulsating stars – my favourite kind

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