



The Heliophysics Big Year

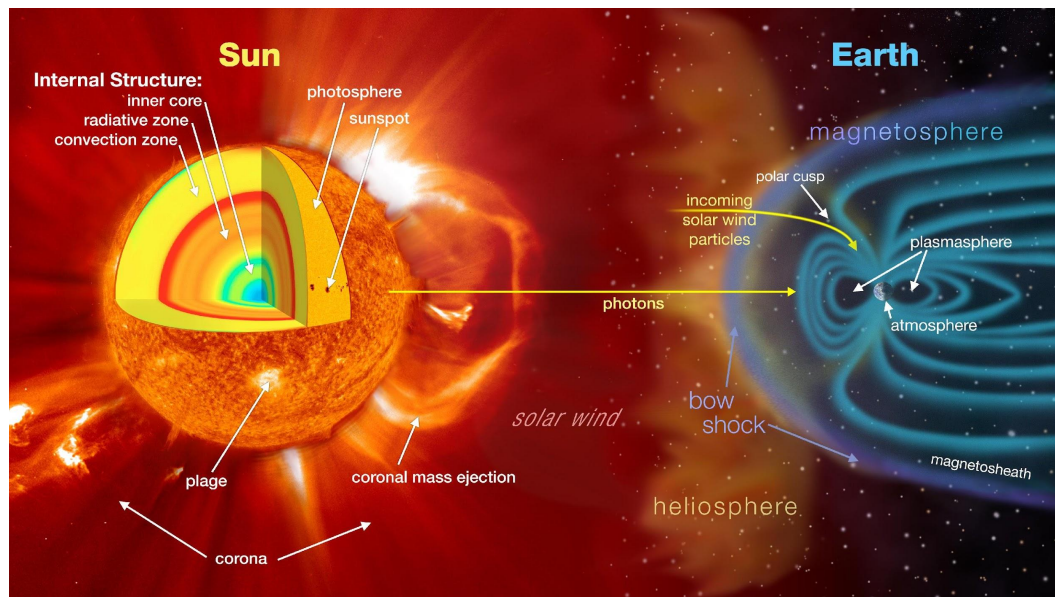
Dr. Sten Odenwald, Astronomer



August 2024: What is Heliophysics?

Heliophysics is the discipline in space science that deals with the matter and energy of our Sun and its effects on the solar system.

It also studies how the Sun varies over time and how those changes can sometimes pose a hazard to humans on Earth and in space.



Heliophysics Big Year Timeline

Annular Eclipse

October 14, 2023



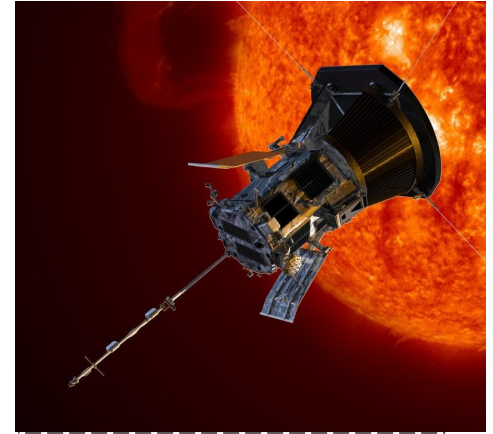
Total Eclipse

April 8, 2024



**Solar Parker
Probe Perihelion**

December 24, 2024



Heliophysics Big Year Themes

2023

- ✓ **October**- Annular Solar Eclipse
- ✓ **November**- Mission Fleet
- ✓ **December**- Citizen Science

2024

- ✓ **January**- The Sun Touches Everything
- ✓ **February**- Fashion
- ✓ **March**- Experiencing the Sun
- ✓ **April**- Total Solar Eclipse
- ✓ **May**- Visual Art
- ✓ **June**- Performance Art
- ✓ **July**- Physical and Mental Health
- August**- Back to School
- September**- Environment / Sustainability
- November**- Bonus Science
- December**- Parker's Perihelion

<https://www.nasa.gov/science-research/heliophysics/nasa-announces-monthly-themes-to-celebrate-the-heliophysics-big-year/>

August 2024 : NASA's Big Questions

1. What causes the Sun to vary?
2. How do the Earth and the heliosphere respond?
3. What are the impacts on humanity?

These Big Questions form the basis for the

Framework for Heliophysics Education

<https://science.nasa.gov/learn/heat/big-ideas/>



How to Teach Heliophysics

Framework for Heliophysics Education

3 Heliophysics
Investigatory Questions



3 NGSS-aligned
Big Ideas per Question



3 Guiding Questions per
Idea
-1 Question per Level-



Heliophysics
Resource Database

1. What causes the Sun to vary?

1.1 The Sun is really big and its gravity influences all objects in the solar system. (PS2, ESS1)

1.2 The Sun is active and can impact technology on Earth via space weather. (PS1, PS2, PS4, ESS2, ESS3)

1.3 The Sun's energy drives Earth's climate, but the climate is in a delicate balance and is changing due to human activity. (PS1, PS2, PS3, LS4, ESS2, ESS3)

1. How do Earth, the solar system, and the heliosphere respond to changes on the Sun?

2.1 Life on Earth has evolved with complex diversity because of our location near the Sun. It is just right! (PS3, PS4, LS1, LS2, ESS2)

2.2 The Sun defines the space around it, which is different from interstellar space. (PS2, ESS1, ESS2)

2.3 The Sun is the primary source of light in the solar system. (PS1, PS2, PS3, PS4, ESS1)

1. What are the impacts of changes on the Sun on humans?

3.1 The Sun is made of churning plasma, causing the surface to be made of complex, tangled magnetic fields. (PS1, PS2, ESS1, ESS2)

3.2 Energy from the Sun is created in the core and travels outward through the Sun and into the heliosphere. (PS1, PS3, PS4, ESS1, ESS2, ESS3)

3.3 Our Sun, like all stars, has a life cycle. (PS1, LS1, ESS1)

August 2024: Back to School

Many things are controlled by cycles, such as the way that every September we start a new school year.

There is also the 'Cycle of Life' that begins at birth and ends at death.

This month we will explore how stars are formed and how they 'die' and in some cases become black holes.



<https://sciencephotogallery.com/featured/life-cycle-of-the-sun-mark-garlickscience-photo-library.html>

August 2024: Back to School

Stars form from collapsing clouds of interstellar matter.

This is the cloud called LDN 1622 covering most of the constellation Orion.



Image credit: KPNO/NOIRLab/NSF/AURA/

August 2024: Back to School

As portions of these clouds collapse they form protostars surrounded by circumstellar disks of matter dozens of times larger than our solar system.

At right: HL Tauri

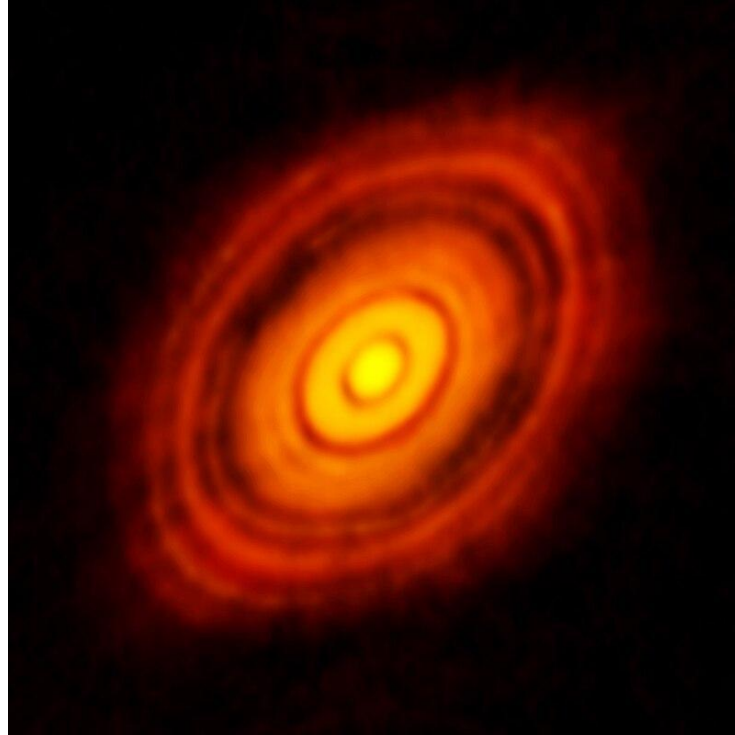


Image credit: Atacama Large Millimeter Array

August 2024: Back to School

Most stars live for billions of years as stable objects supported by thermonuclear fusion of hydrogen into helium.

At right: NGC 3603



Image credit: Hubble Space Telescope

August 2024: Back to School

Stars end their lives by becoming red giants. Low-mass stars then become planetary nebulae and leave behind white dwarfs.

At right: NGC 6302



Image credit: Hubble Space Telescope

August 2024: Back to School

More massive stars
explode as supernovae.

At right: Cassiopeia A



Image credit: NASA/CXC/SAO

August 2024: Back to School

What is left behind
can either be a
neutron star like
this one in the
heart of the Crab
Nebula.

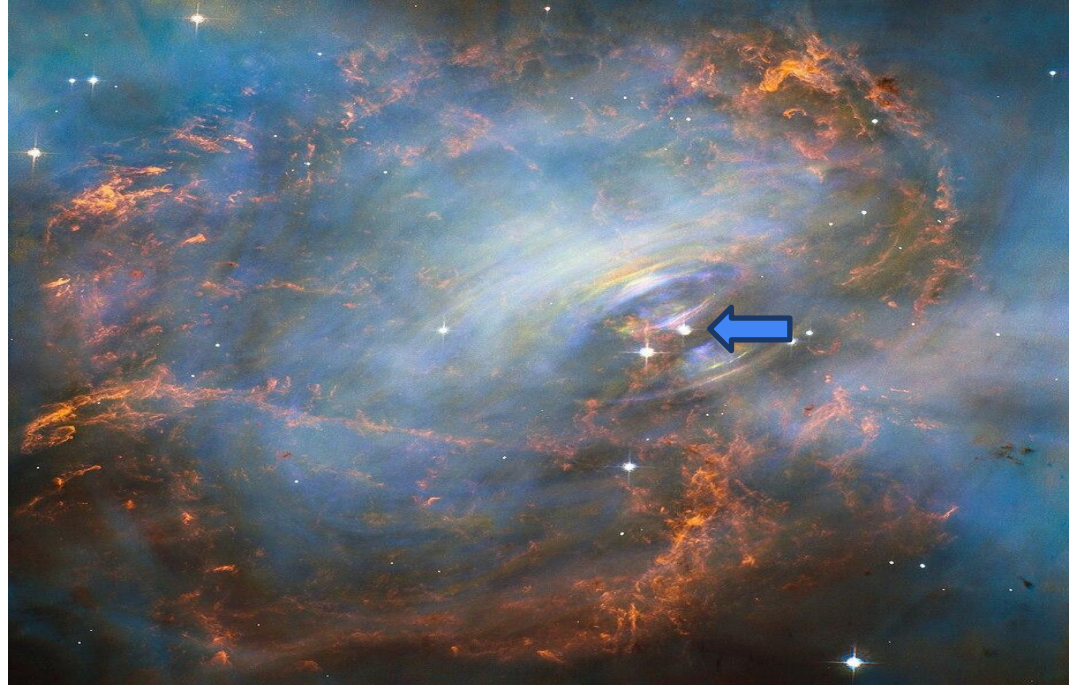


Image credit: NASA/ESA

August 2024: Back to School

..or a black hole.

Let's look at each of these stages in detail with a little math.

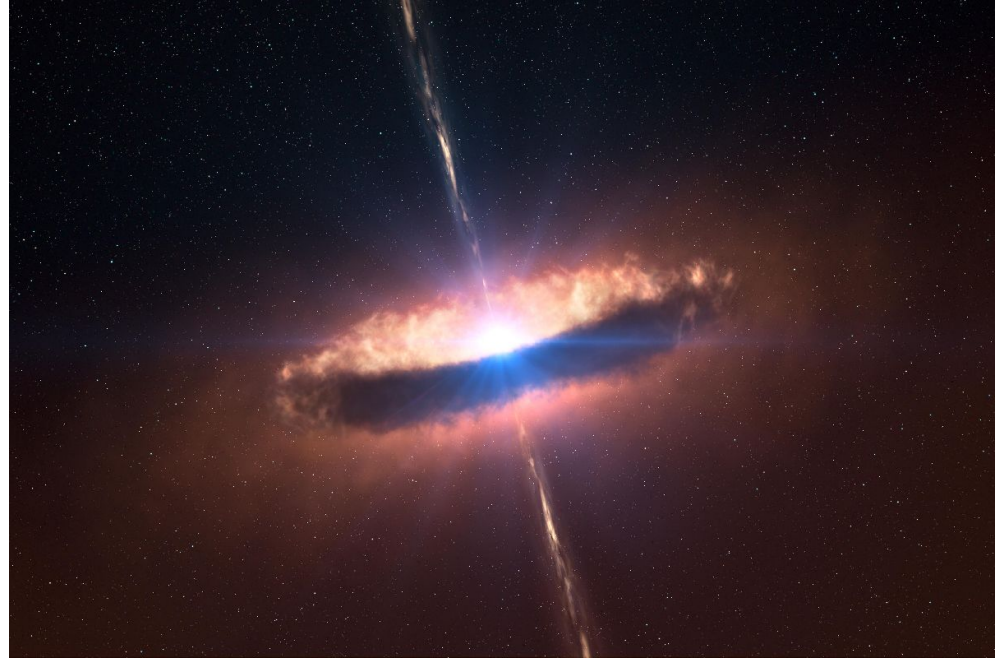


Image credit: *Interstellar* / Wikipedia

August 2024 – Beginning – Cloud Collapse

A proto-stellar nebula has a radius of 1 light year (6 trillion km).

If the infall speed is 0.5 km/sec, about how long will it take for the star to form?



<https://keystagewiki.com/index.php/File:Protostar.png#mw-jump-to-license>

August 2024 – Beginning – Cloud Collapse

Distance = 1 light year

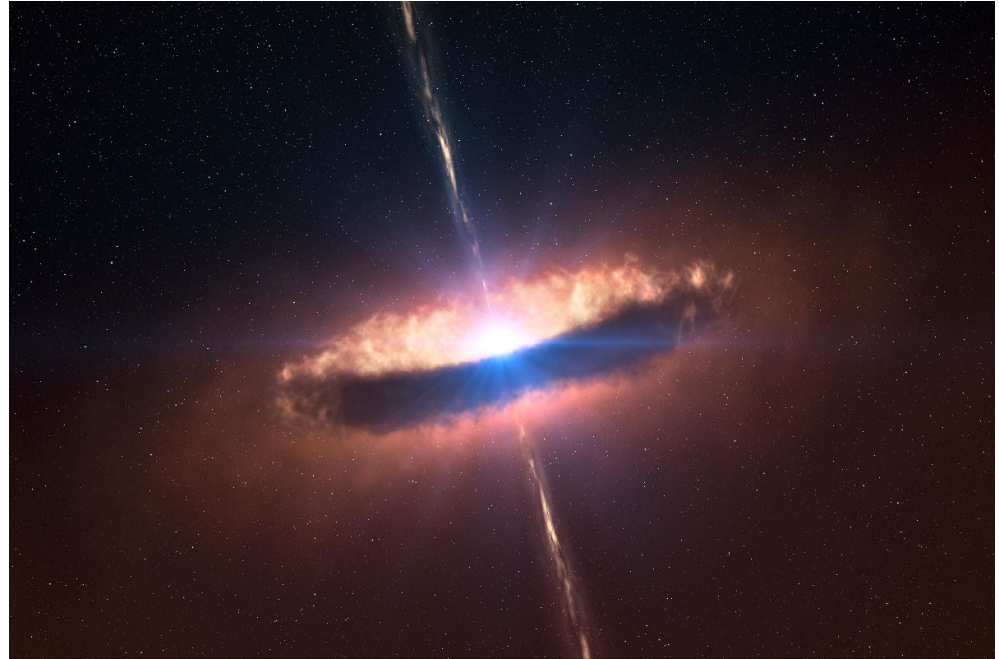
Speed = 0.5 km/s

Time = Distance/speed

Time = 6×10^{12} km/(0.5 km/s)

Time = 1.2×10^{13} seconds

Time = 400,000 years.

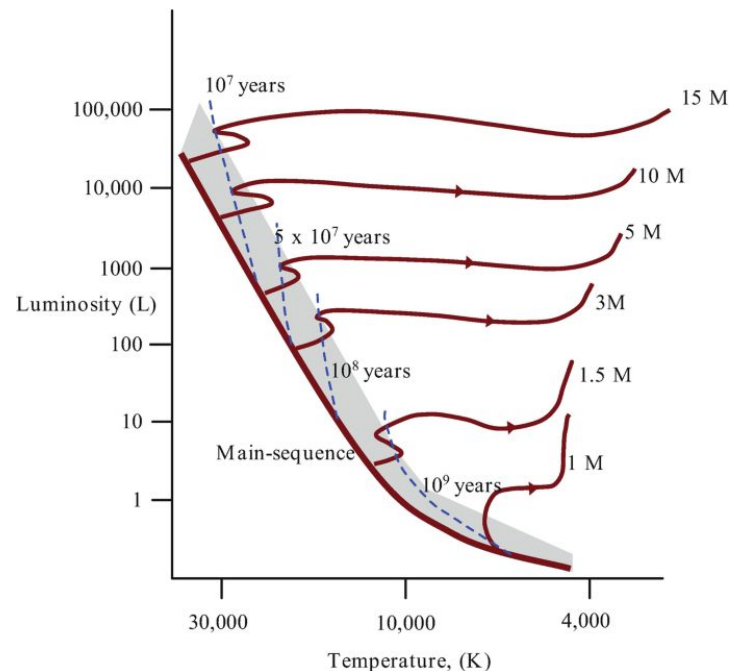


<https://keystagewiki.com/index.php/File:Protostar.png#mw-jump-to-license>

August 2024 – Intermediate – The Main Sequence

The star is now stable and is fusing hydrogen into helium to maintain internal pressure and prevent further collapse. This is the longest phase of a star's life cycle. The duration of this phase is given by the simple formula

$$T = 10 \text{ billion years} \times \frac{1}{\text{Mass}^{2.5}}$$



Graph showing stellar evolution for different masses

August 2024 – Intermediate – The Main Sequence

Compare the lifetimes of three stars:

Proxima Centauri $M = 0.1 \text{ msun}$ Red Dwarf

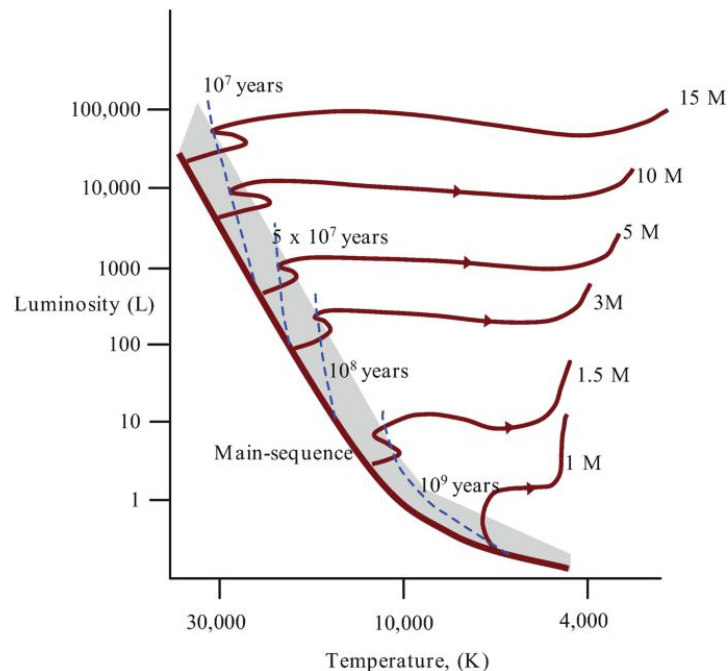
The Sun $M = 1.0 \text{ msun}$ Main Sequence

Betelgeuse $M = 20 \text{ msun}$ Red Supergiant

Which star is the most likely to vanish tomorrow?

1

$$T = 10 \text{ billion years} \times \frac{1}{\text{Mass}^{2.5}}$$



Graph showing stellar evolution for different masses



August 2024 – Intermediate – The Main Sequence

Proxima Centauri $M = 0.1 \text{ msun}$

$T = 10 \text{ billion} / (0.1)^{2.5} = 3 \text{ trillion years.}$

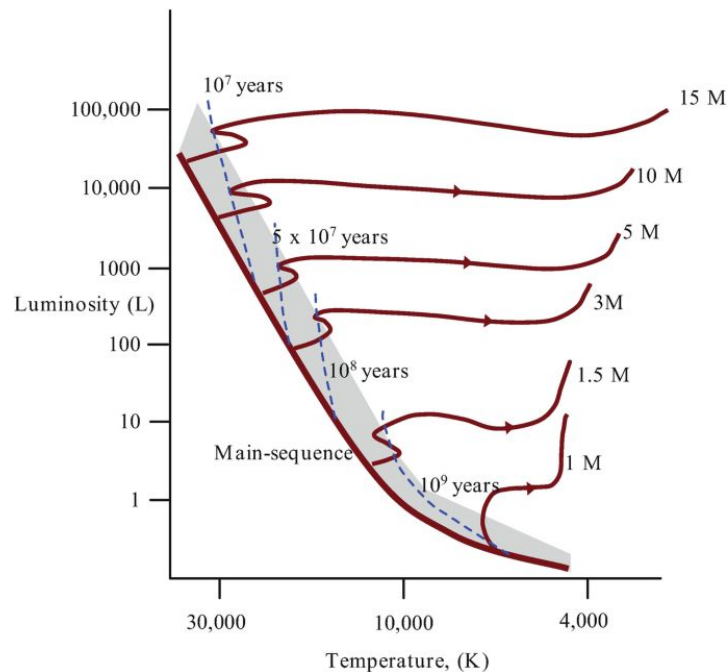
The Sun $M = 1.0 \text{ msun}$

$T = 10 \text{ billion} / (1)^{2.5} = 10 \text{ billion years}$

Betelgeuse $M = 20 \text{ msun}$

$T = 10 \text{ billion} / (20)^{2.5} = 5.6 \text{ million years}$

Which star is the most likely to vanish tomorrow? **Probably Betelgeuse.**



Graph showing stellar evolution for different masses

August 2024 – Advanced – Stellar Remnants

What is left behind after a star 'dies' depends on its mass.

Stars like our sun:

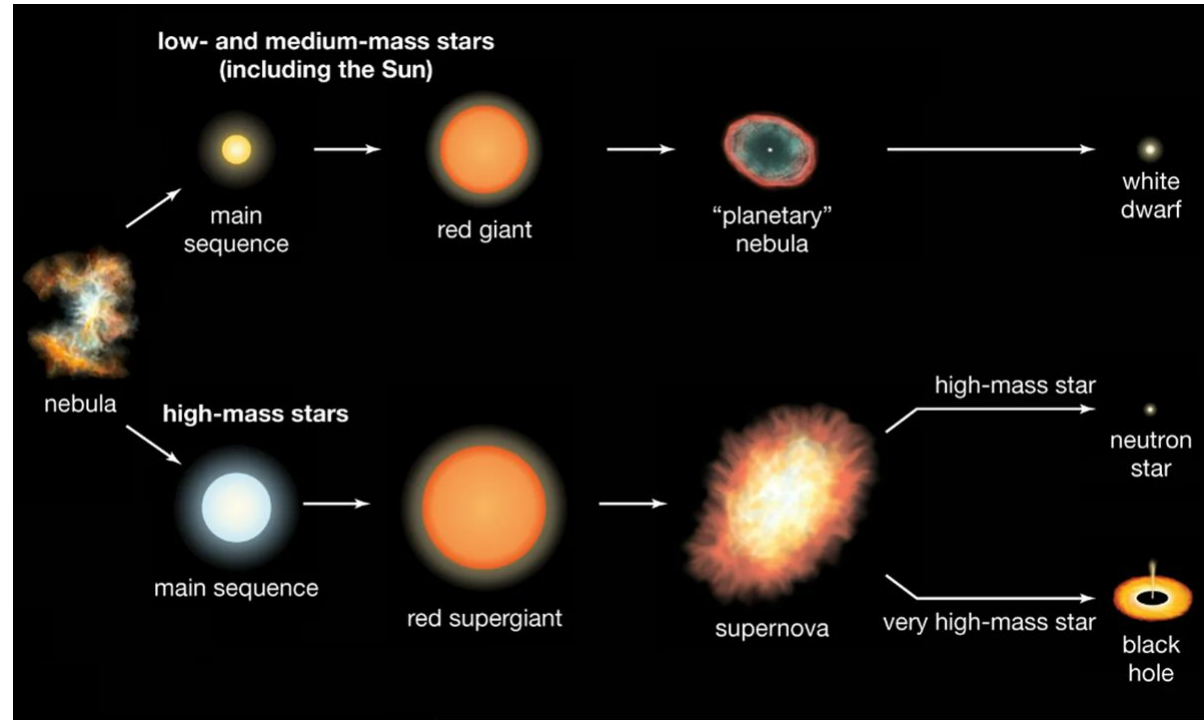
0.1 to 5 suns = **White Dwarfs**

Stars with intermediate masses:

6-20 suns = **Neutron Stars**

Stars with high masses:

> 20 suns = **Black Holes**.



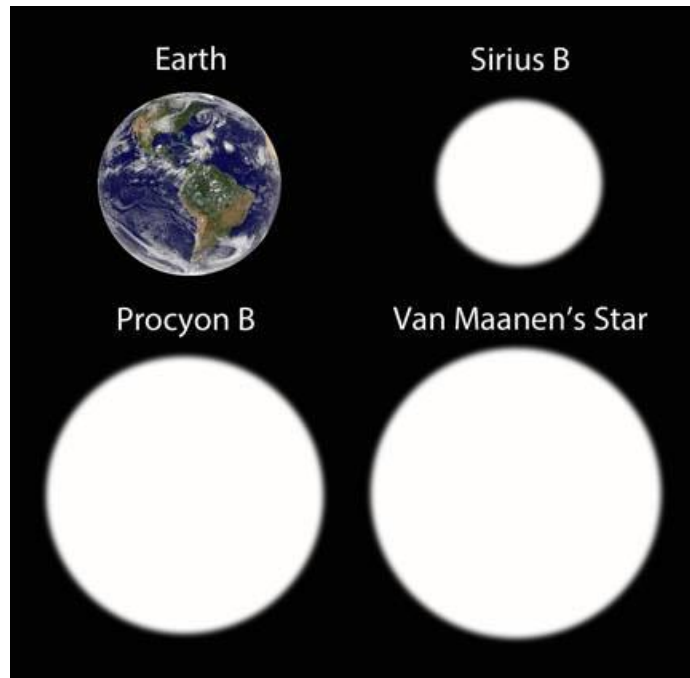
<https://explainingscience.org/2023/05/07/the-end-of-the-universe/>

August 2024 – Advanced – Stellar Remnants

A **white dwarf** has a size comparable to Earth (radius: 6000km) with a mass equal to our sun (2×10^{30} kg).

What is its density?

How much would a 1cm sugar cube weigh in tons?



White dwarf sizes compared to Earth. (Bob King/NASA)

August 2024 – Advanced – Stellar Remnants

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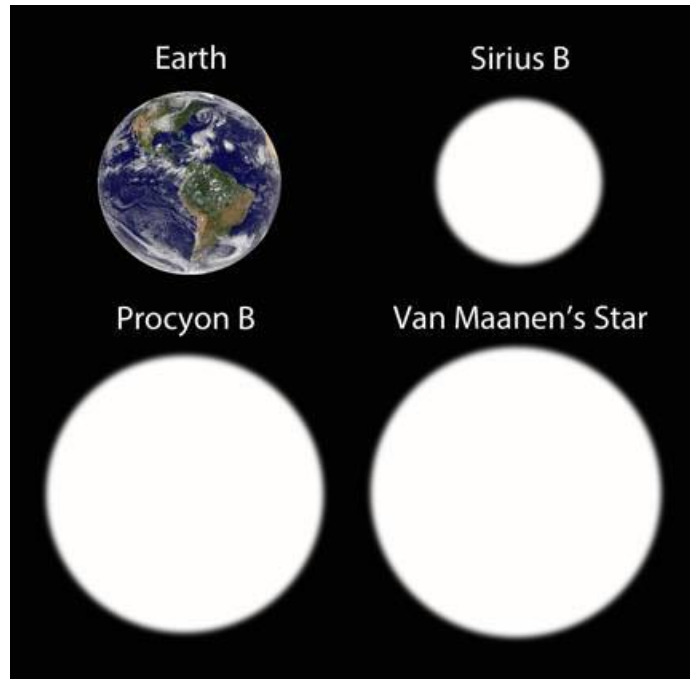
What is its density?

$$\begin{aligned}\text{Spherical volume} &= \frac{4}{3}\pi (6 \times 10^8 \text{ cm})^3 \\ &= 9 \times 10^{26} \text{ cm}^3.\end{aligned}$$

$$\begin{aligned}\text{Density} &= 2 \times 10^{33} \text{ gm} / 9 \times 10^{26} \text{ cm}^3 \\ &= 2.2 \times 10^6 \text{ gm/cm}^3\end{aligned}$$

How much would a 1cm sugar cube weigh in tons?

$$\text{density} \times \text{volume} = 2.2 \text{ tons}$$



White dwarf sizes compared to Earth. (Bob King/NASA)

August 2024 – Advanced – Stellar Remnants

A **Neutron Star** has a radius of 12 km with a mass equal to our sun (2×10^{30} kg).

What is its density?

How much would a 1cm sugar cube weigh in tons?



Size of a neutron star compared to Manhattan, NY
(Credit: NASA)

August 2024 – Advanced – Stellar Remnants

A **Neutron Star** has a size of 12 km with a mass equal to our sun (2×10^{30} kg).

$$\text{Volume} = \frac{4}{3}\pi (12000)^3 = 7 \times 10^{12} \text{ m}^3$$

$$\begin{aligned}\text{Density} &= \text{Mass/Volume} \\ &= 2 \times 10^{30} \text{ kg} / 7 \times 10^{12} \text{ m}^3 \\ &= 3 \times 10^{17} \text{ kg/m}^3 \\ &= \text{300,000 trillion tons/m}^3\end{aligned}$$

What is its density?

How much would a 1cm sugar cube weigh in tons?

$$\text{Volume} = (1\text{cm}/100\text{cm})^3 = 10^{-6} \text{ m}^3.$$

Density of an atomic nucleus is
 $2 \times 10^{17} \text{ kg/m}^3$.

$$\begin{aligned}\text{Mass} &= 3 \times 10^{17} \text{ tons/m}^3 \times 10^{-6} \text{ m}^3 \\ &= \text{300 billion tons.}\end{aligned}$$

August 2024 – Advanced – Stellar Remnants

A **Black Hole** has a size that depends on its mass in multiples of the mass of our sun.

This size is defined by its Event Horizon.

$$\text{Radius (km)} = 2.8 \times \text{Mass}$$

What is the Event Horizon radius for a 20-solar mass black hole?



Image of accretion disk warped by the gravity of a black hole.
(Credit: [Interstellar.wiki/CC BY-NC](https://www.interstellar.wiki/))

August 2024 – Advanced – Stellar Remnants

$$\text{Radius (km)} = 2.8 \times \text{Mass}$$

What is the Event Horizon radius for a 20-solar mass black hole?

$$\text{Radius} = 2.8 \times 20 = \mathbf{56 \text{ km}}$$



Image of accretion disk warped by the gravity of a black hole.
(Credit: Interstellar.wiki/CC BY-NC)

August 2024 – Advanced – Stellar Remnants

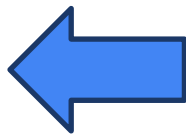
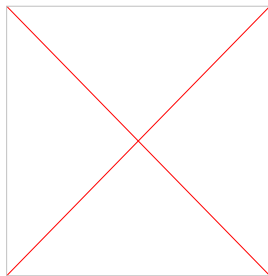
If Earth became a black hole, what would be its radius?

$$M = 3 \times 10^{-6} \text{ Msun}$$

$$\text{Radius (km)} = 2.8 \times (3 \times 10^{-6})$$

$$= 8.4 \times 10^{-6} \text{ km}$$

$$= \mathbf{8.4 \text{ millimeters}}$$



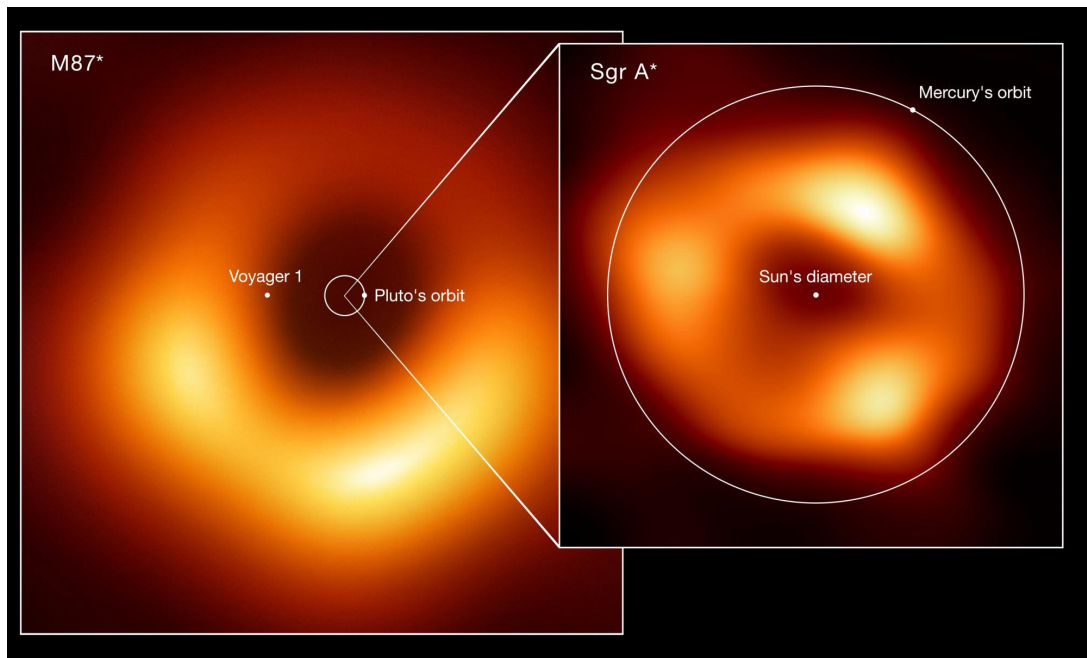
August 2024 – Advanced – Supermassive Remnants

What is the radius of a **supermassive black hole** with a mass of 10 billion suns, like the one in the core of the galaxy Messier 87?

$R = 2.8 \times 10 \text{ billion} = 28 \text{ billion km}$

Orbit of Pluto: 5.2 billion km.

M87 would easily swallow our entire solar system.



Comparison of two supermassive black holes with solar system.
Credit: EHT collaboration / Lia Medeiros, <https://xkcd.com/2135/>

August 2024 – ChatGPT – Black Hole Growth

Black holes can only grow in mass by consuming matter nearby them.

Astronomers can detect the merging of pairs of black holes and neutron stars by the gravitational radiation they produce.

The LIGO Observatory detects several of these mergers across the visible universe every month.



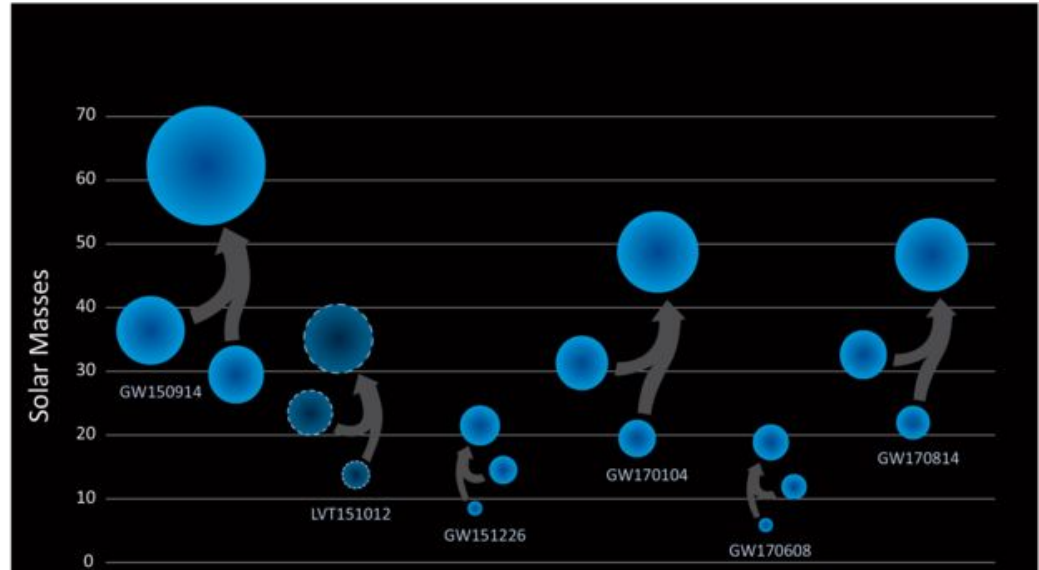
The Virgo/LIGO observatory. Credit: The Virgo Collaboration

August 2024 – ChatGPT – Black Hole Growth

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Black hole mergers. Credit: The Virgo Collaboration

August 2024 – ChatGPT – Black Hole Mergers

ChatGPT query: Suppose that an object grows by binary fusion of pairs of equal-mass objects. Starting from a mass of 1.0 units, how long will it take to grow an object with a mass of 1 billion units if each merger takes 10 million years? Show your work.

Correct answer:

**1 billion = 2^{30} so 30 x 10 million
= 300 million years.**

$$2^n \geq 1,000,000,000$$

Taking the logarithm base 2 of both sides gives:

$$n \geq \log_2(1,000,000,000)$$

Calculate $\log_2(1,000,000,000)$:

$$\log_2(1,000,000,000) = \log_2(10^9) = 9$$

So, $n \geq 30$.

Therefore, at least 30 mergers are needed for the object to reach a mass of 1 billion units

Now, calculate the total time required:

$$\text{Total time} = n \times \text{Time per merger}$$

$$\text{Total time} = 30 \times 10 \text{ million years}$$

$$\text{Total time} = 300 \text{ million years}$$

Thus, it will take 300 million years for the object to grow to a mass of 1 billion units :



September 2024 – Environment and Sustainability

Next Time!

The Sun is a powerful source of energy. In modern times, we rely on the Sun to help produce the electricity we use every day.

To make this work, we use solar panels to convert sunlight into electricity.



Slides and Recordings

Slides: <https://rb.gy/qsgmbr>

Previous webinar recordings

https://www.youtube.com/watch?v=lwf8Y_fOOIs&list=PL5mpEj48YwXntxhPvZBgJn0ZG5MRm4UIS