

The Life and Death of Stars

Stellar Physics and Evolution

Session by

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PRAVEGA Astrophysics Workshop

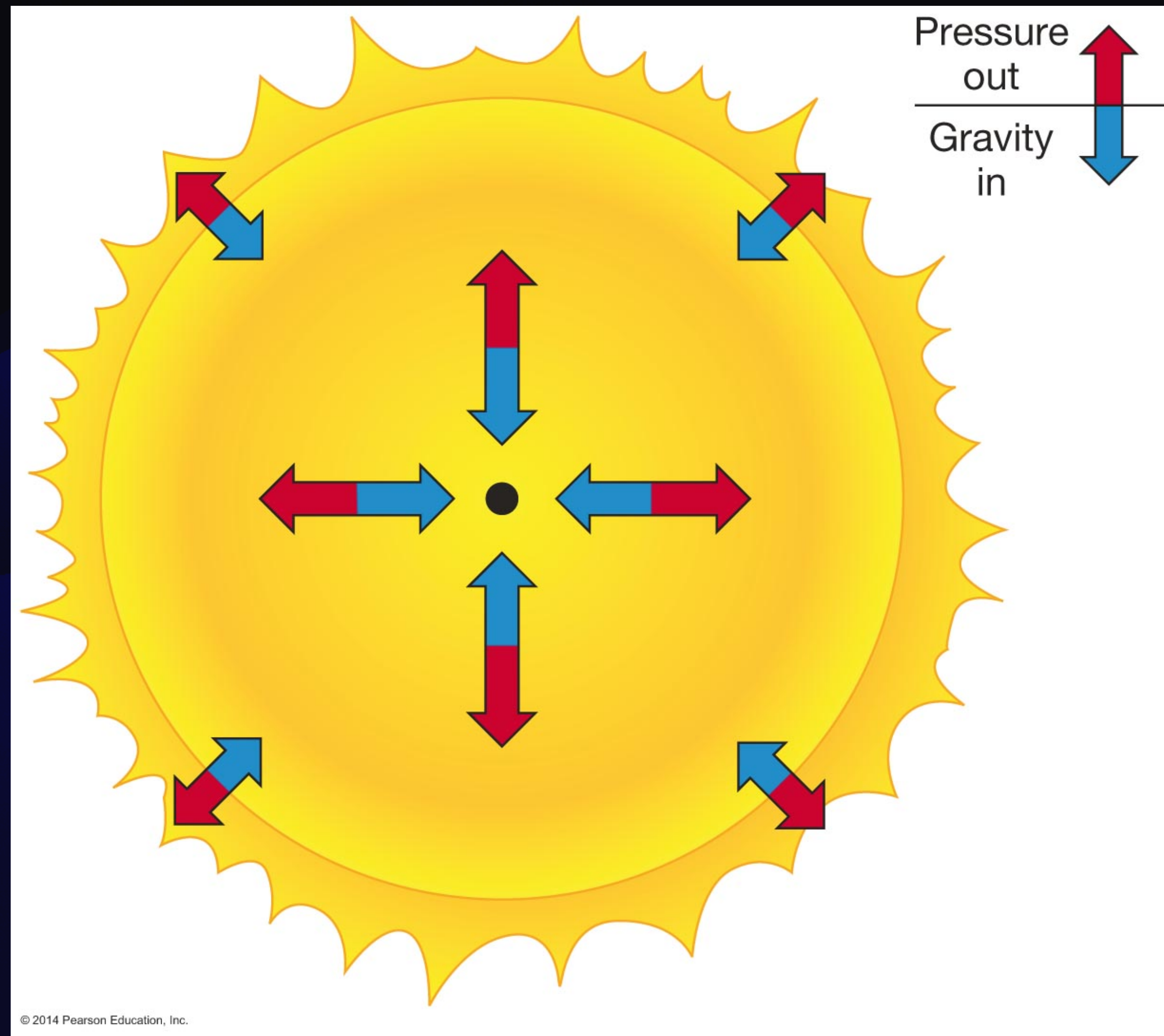
09/05/2026



Agenda

- Birth, life and death of stars
- Nuclear fusion and energy generation
- Star classification (Hertzsprung-Russell Diagram)
- *Aside*: Introducing white dwarfs and the Chandrasekhar limit
- Supernovae and Pulsars

**Why doesn't the Sun collapse
under gravity?**



The most basic concept:
**HYDROSTATIC
EQUILIBRIUM**

Pressure balances gravity!

Source: https://pages.uoregon.edu/jimbrau/BraulmNew/Chap16/FG16_06.jpg

Some interesting questions

Credit: Anwesh Mazumdar (HBCSE-TIFR)

- If there were no pressure, how long would it take for the Sun to collapse onto itself?
- If the source of the Sun's energy were its store of gravitational potential energy, how long could the Sun live?
- If the source of the Sun's energy were nuclear reactions, how long could the Sun live?

Let's calculate some timescales!
The characteristic timescale of a process is

$$t_{char} = \frac{\phi}{\dot{\phi}}$$

→ Changed quantity

→ Rate of change

Dynamical timescale

- How quickly would layers in a star move if hydrostatic balance is disturbed?
- In this case the characteristic length (ϕ) is $\sim R$
- Since the binding force is gravity, the typical velocity ($\dot{\phi}$) would be the characteristic velocity in a gravitational field, i.e. the escape velocity

$$v_{esc} = \sqrt{2GM/R}$$

- Then

$$t_{dyn} \sim \frac{R}{v_{esc}} \sim \sqrt{\frac{R^3}{GM}} \sim \frac{1}{\sqrt{G\rho}}$$

neglecting factors of the order of unity.

Credit: Anwesh Mazumdar (HBCSE-TIFR)

If you substitute values of $R_{\odot}$ and $M_{\odot} \rightarrow t_{dyn} \sim 15$ min

Thermal timescale

- The time required to radiate away the thermal energy of a star is called the thermal timescale.
- Here $\phi = U$ and $\dot{\phi} = L$. So

$$t_{\text{th}} \sim \frac{U}{L}$$

- The Virial Theorem connects the thermal energy U to the gravitational energy (Ω) of the star: $U = -\frac{\Omega}{2} = \frac{GM^2}{R}$. So

$$t_{\text{th}} \sim \frac{GM^2}{RL}$$

neglecting factors of the order of unity.

If you substitute values of
 $R_{\odot}, L_{\odot}$ and $M_{\odot}$
 $\rightarrow t_{\text{th}} \sim 30 \times 10^6$ years

Kelvin -Helmholtz hypothesis
 $\rightarrow$ Sun is supported purely by
thermal energy of contraction

**TIMESCALE IS TOO SHORT.
HYPOTHESIS PROVED FALSE!**

Nuclear timescale

- Timescale on which a star will exhaust its supply of nuclear fuel,

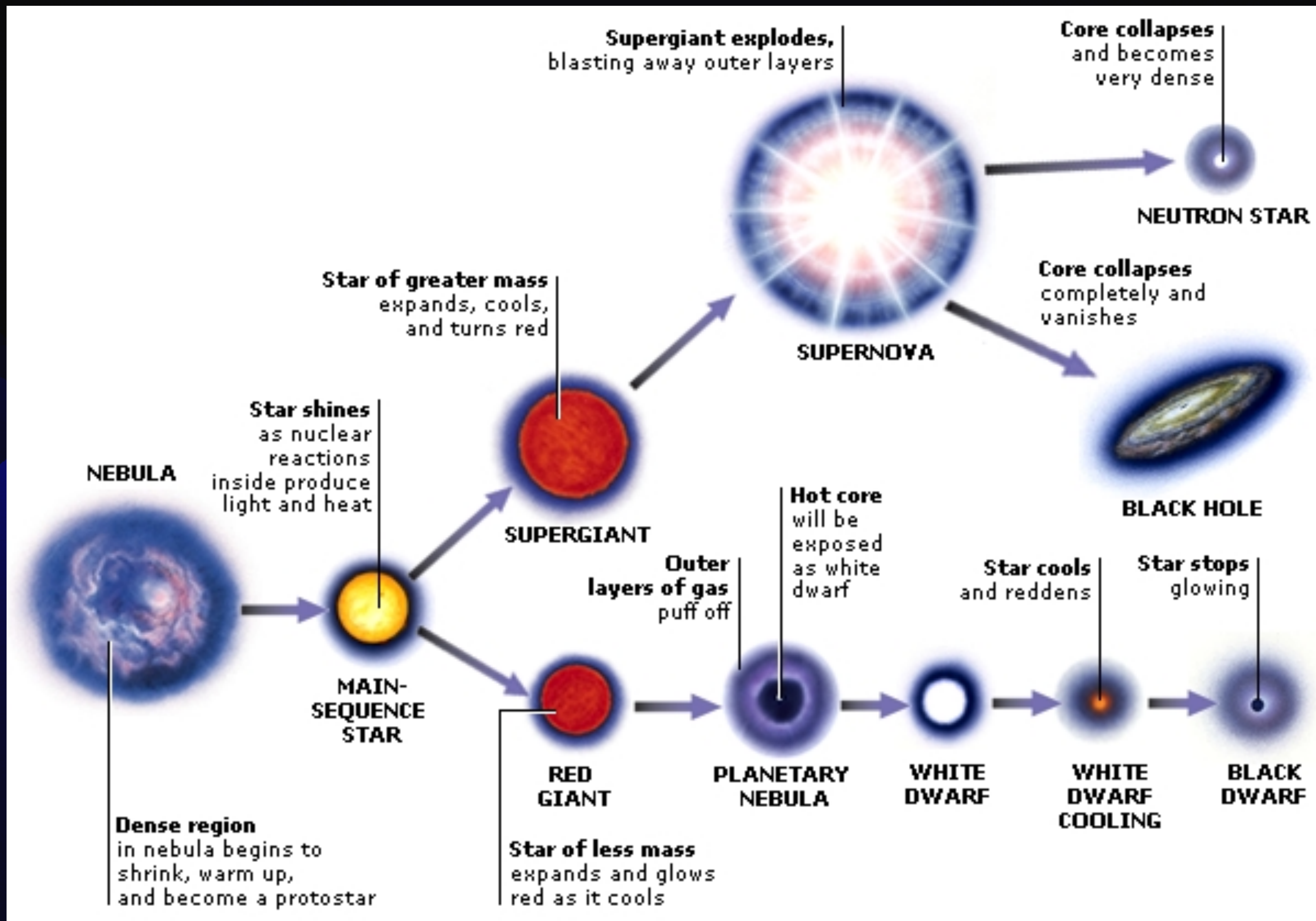
$$t_{\text{nuc}} \sim \frac{\epsilon Mc^2}{L}$$

ϵ is a factor encompassing

- 1 the mass defect
 - 2 fraction of the mass available for nuclear fusion
 - 3 the mass abundance of the fuel (primarily hydrogen).
- For a typical star, $\epsilon \approx 0.007 \times 0.2 \times 0.7 \approx 0.001$
 - For the Sun, $(t_{\text{nuc}})_{\odot} \sim 10^{10}$ years which is consistent with its present age.

Verification of our Sun being supported by nuclear reactions!

The life cycle of a star



Star birth and brown dwarfs

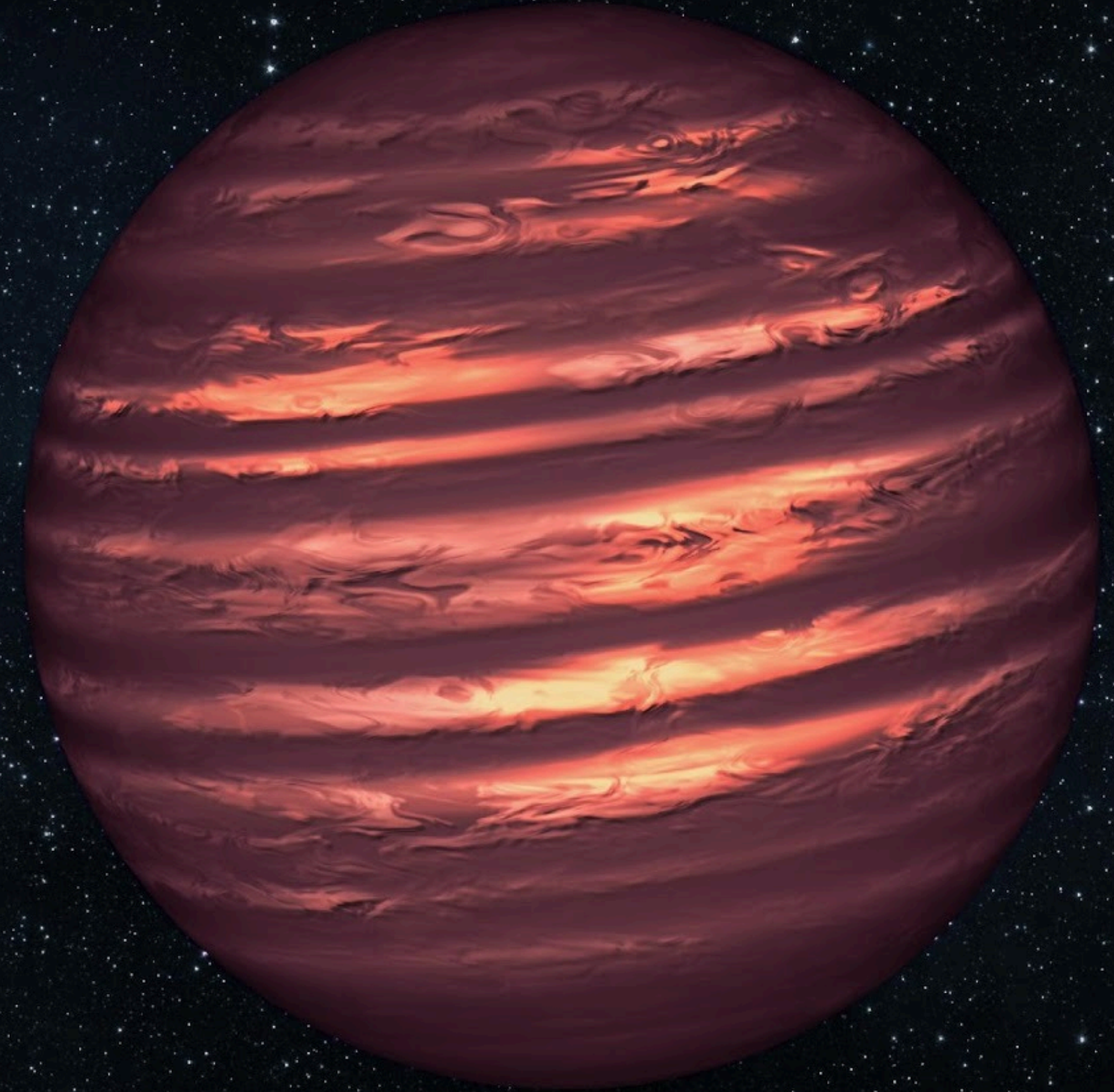
Stars form in large clouds of gas and dust called molecular clouds.

Molecular clouds full of stellar clusters are called stellar nurseries.



Pillars of creation, credit: JWST

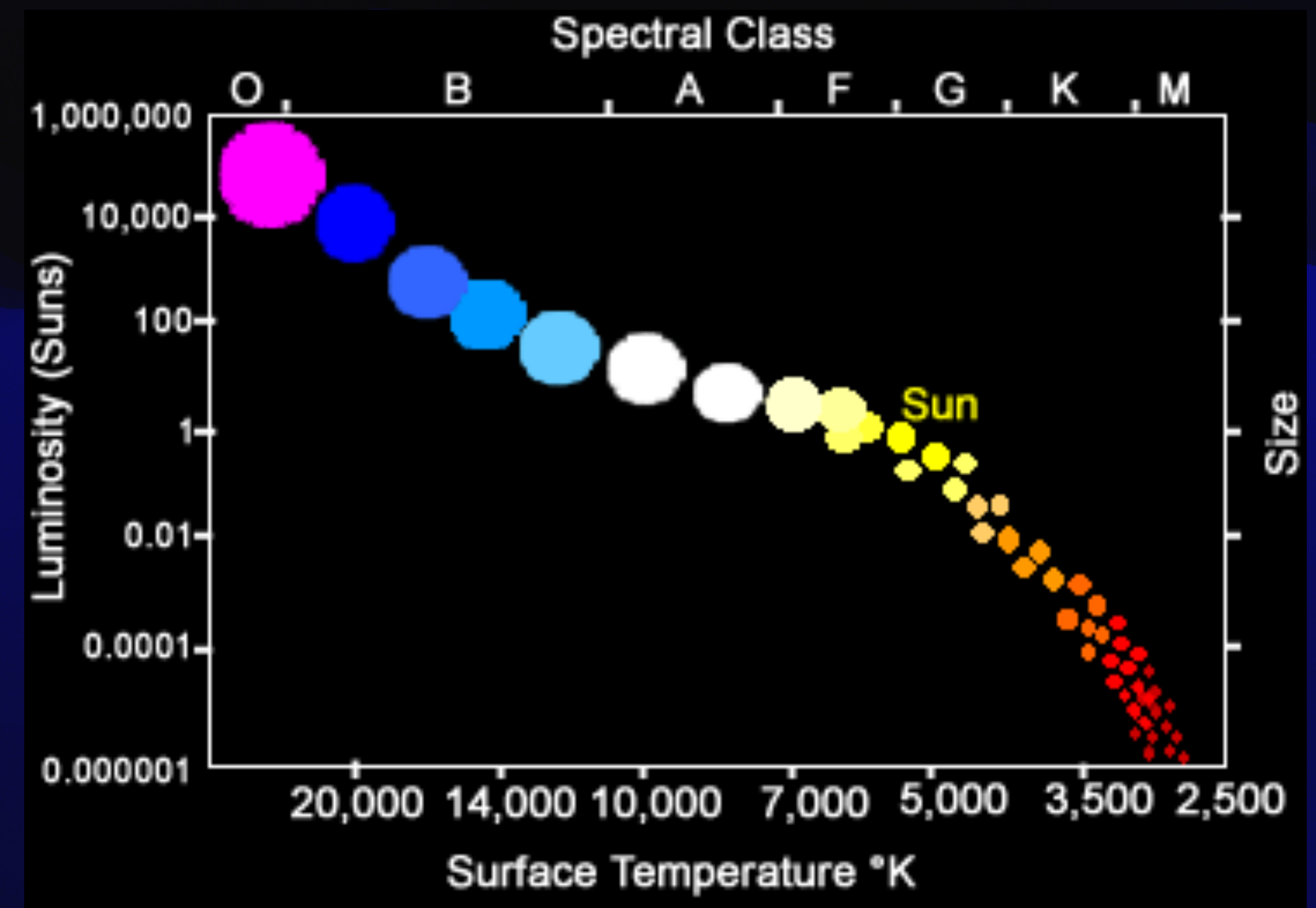
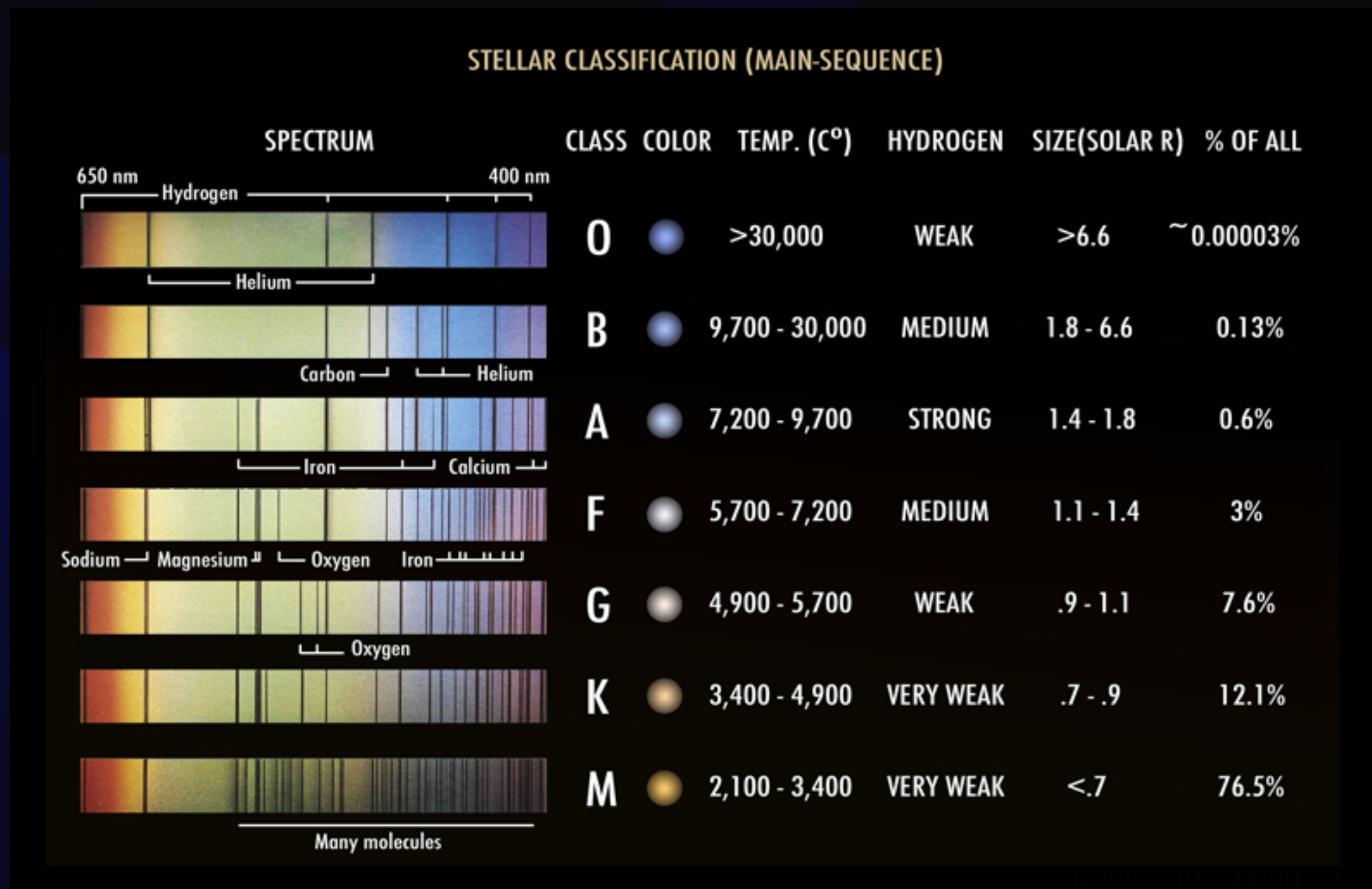
Brown dwarf: a FAILED star.



Check : Is Jupiter a BROWN DWARF?

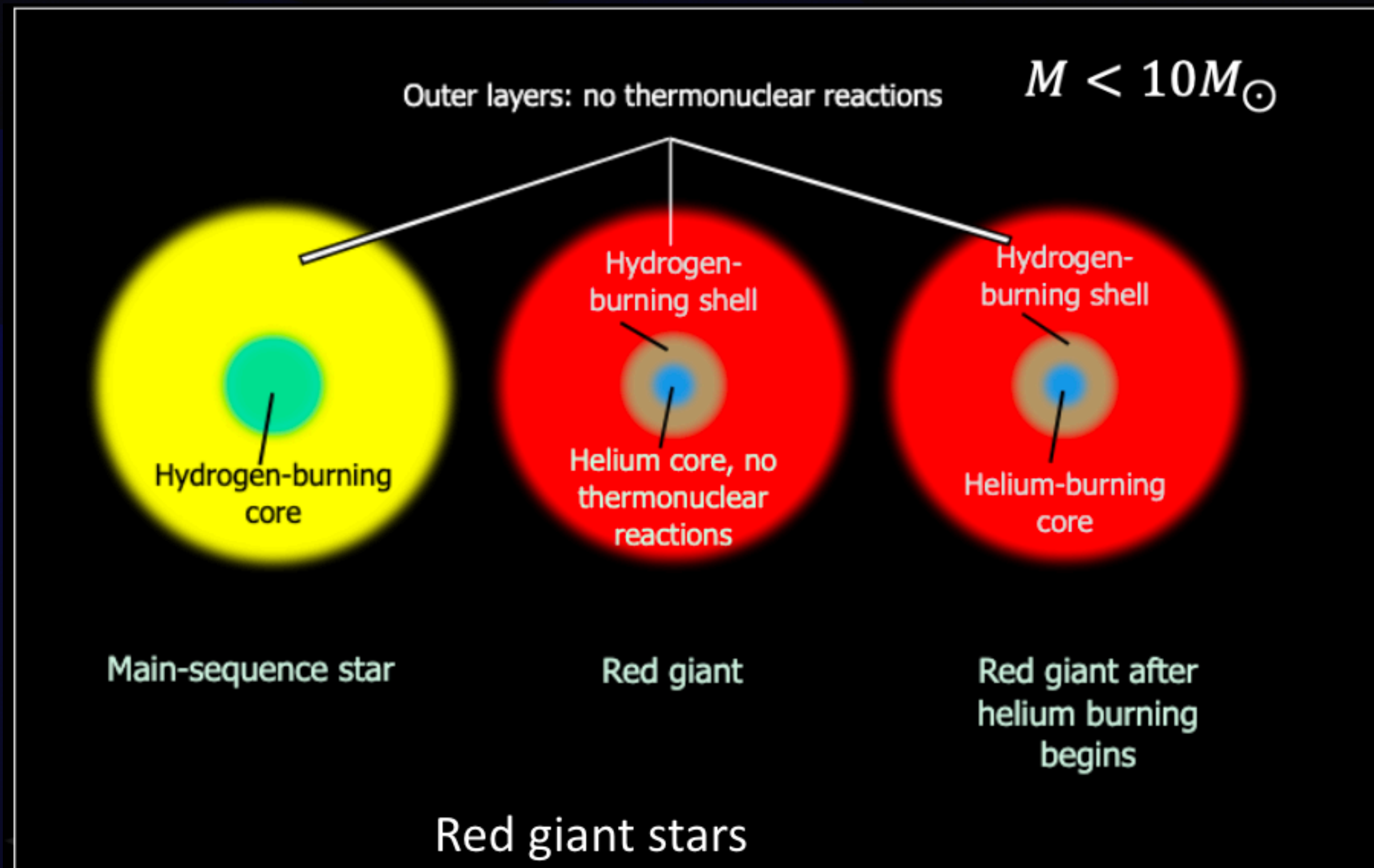
Stars living and dying...

Main sequence and nuclear burning



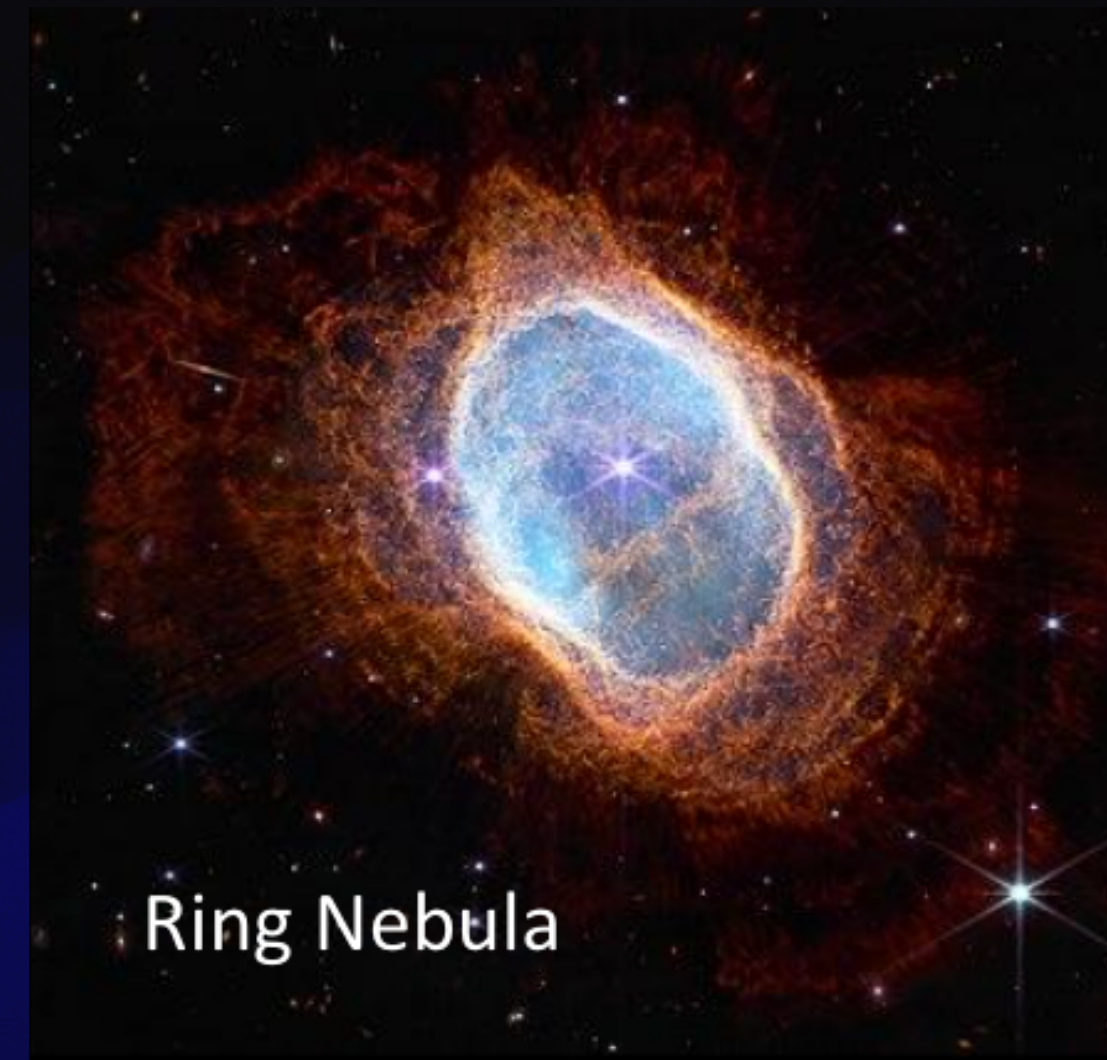
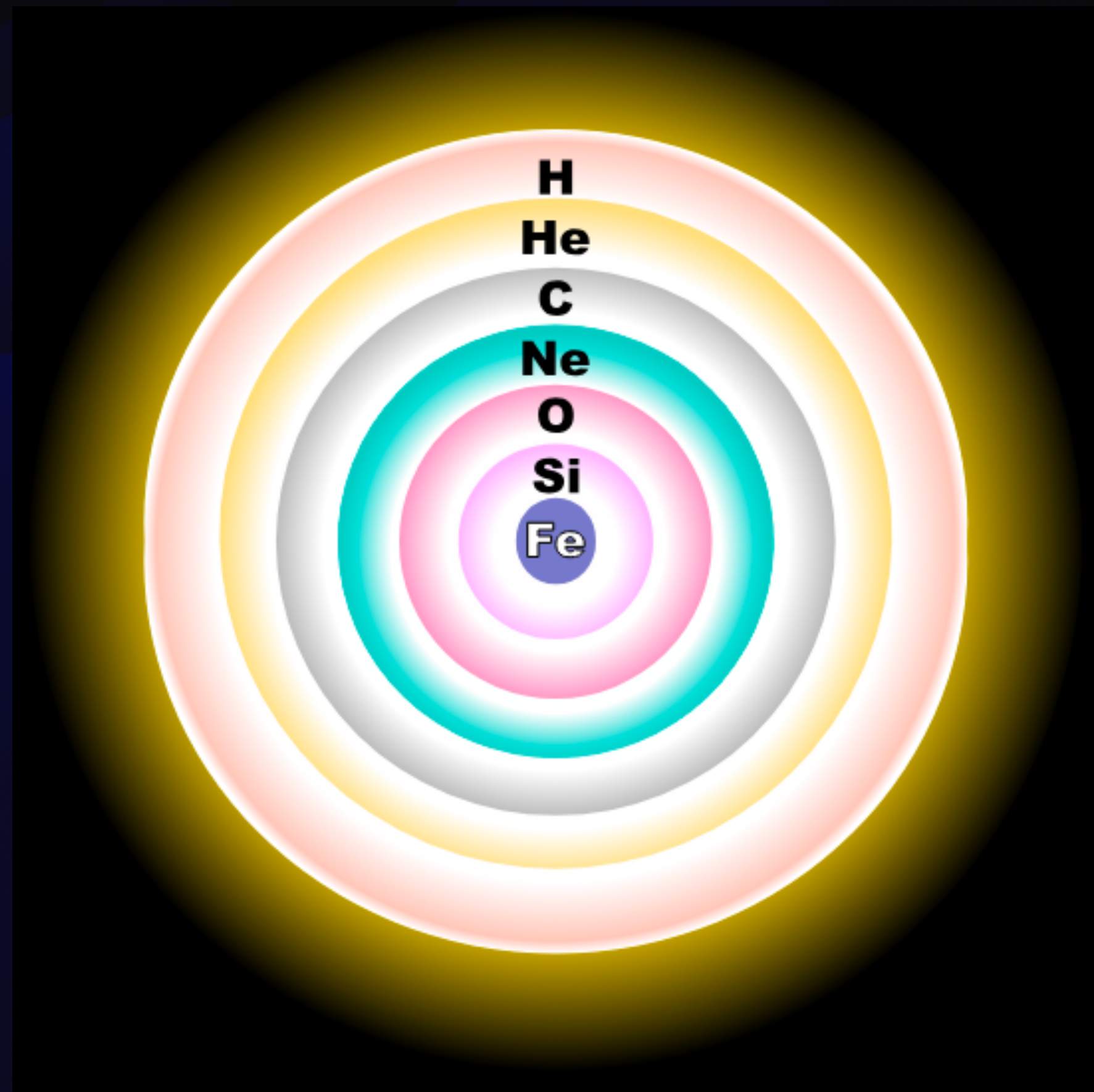
Stars living and dying...

Giants



Stars living and dying...

Planetary nebulae and supernovae



Note: Planetary is
a MISNOMER
→ Nothing to do
with planets!

Heavy stars vs
Lighter stars

Type I and Type II
supernovae



Big stars are like
ogres...

fusion of **hydrogen**
(millions of years)

fusion of **helium**
(100,000's of years)

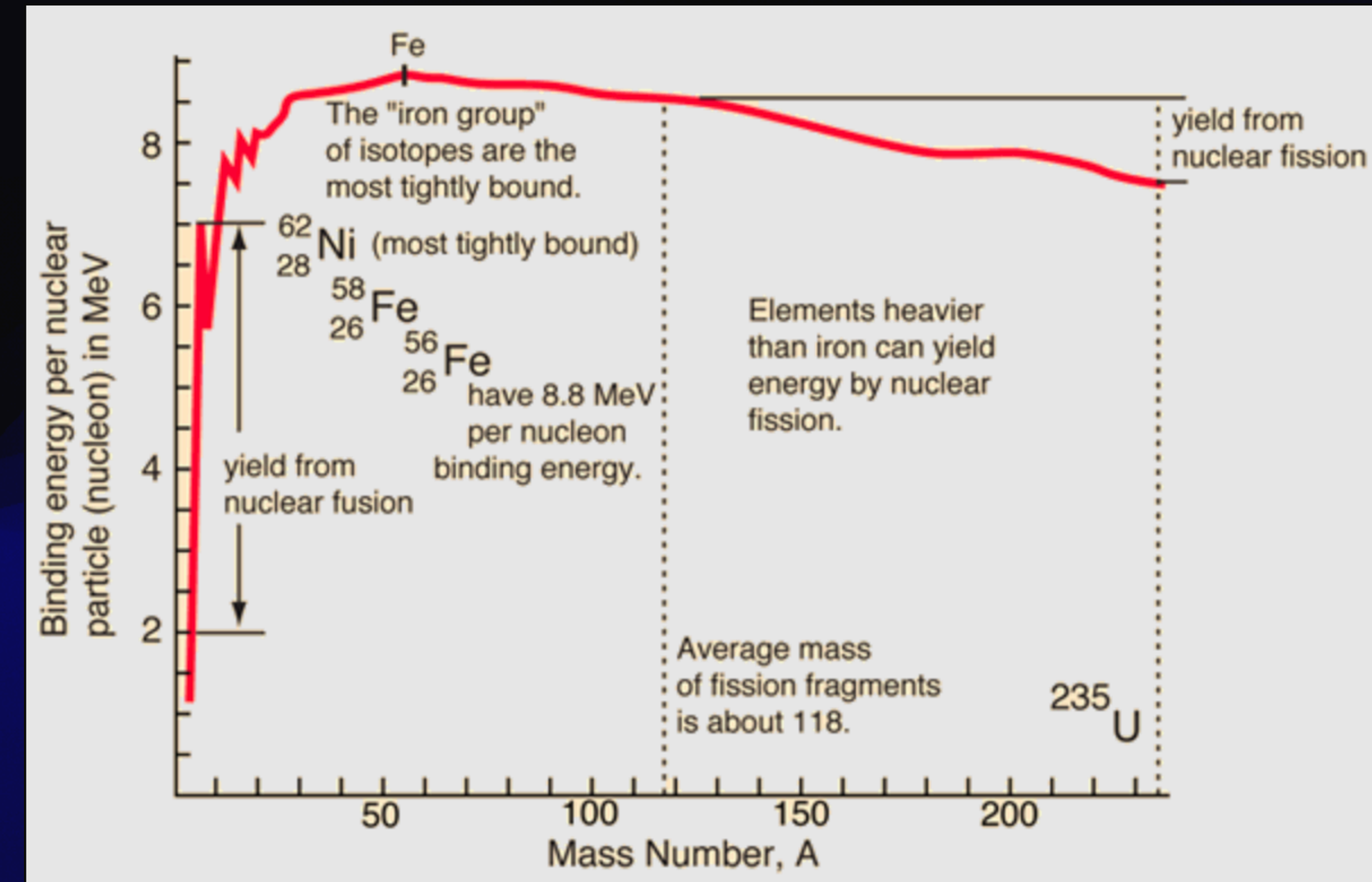
fusion of **carbon**
(hundreds of years)

fusion of **nitrogen & oxygen**
(years/months)

fusion of **silicon**
(weeks/days)

fusion of **iron**
(run!)

adapted from the figure:
<http://www.dangthatscool.com/wp-content/uploads/2009/07/stardigram3.jpg>



Stars living and dying...

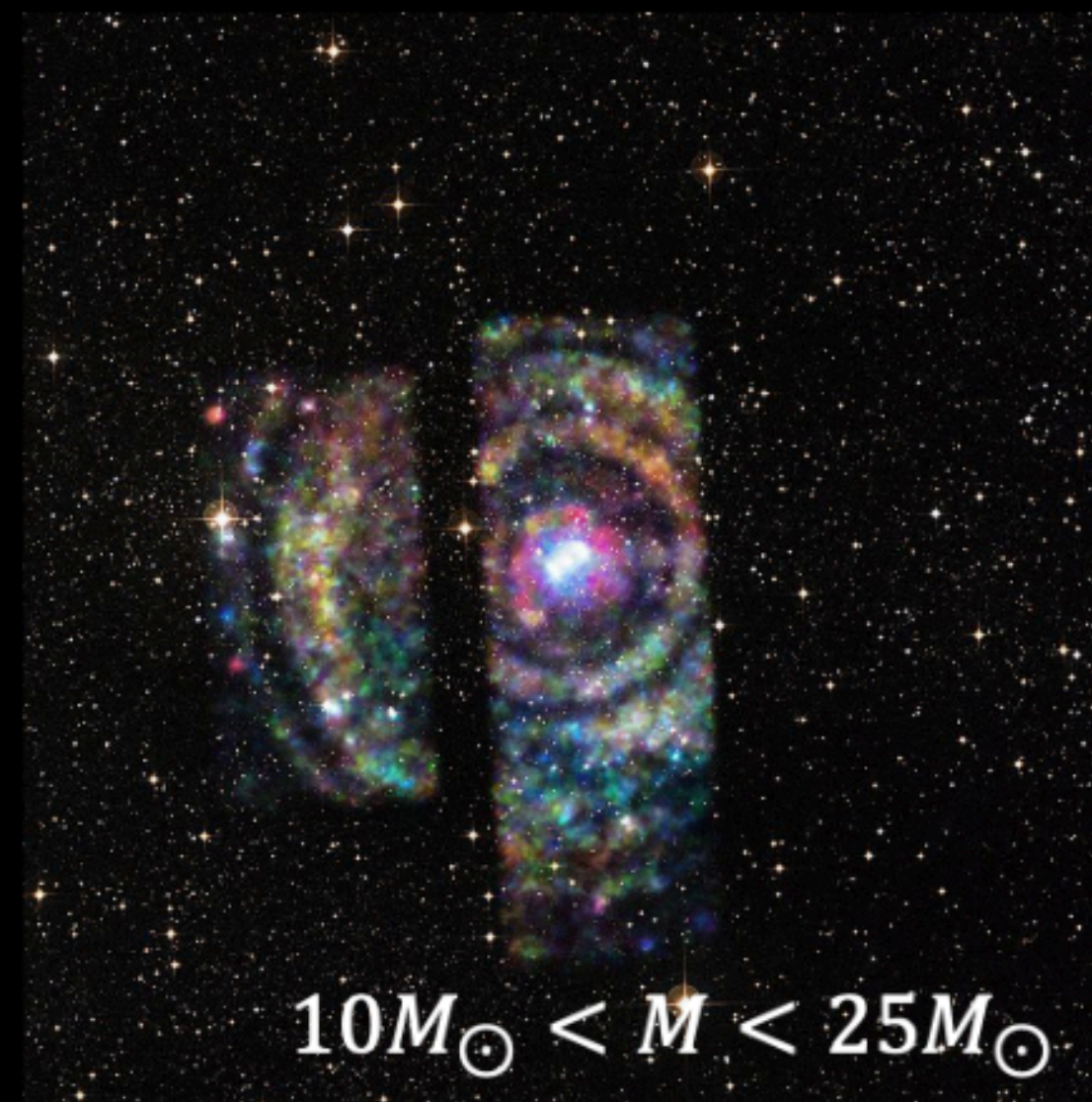
Compact stars

Final stages of stellar evolution: white dwarfs, neutron stars and black holes.



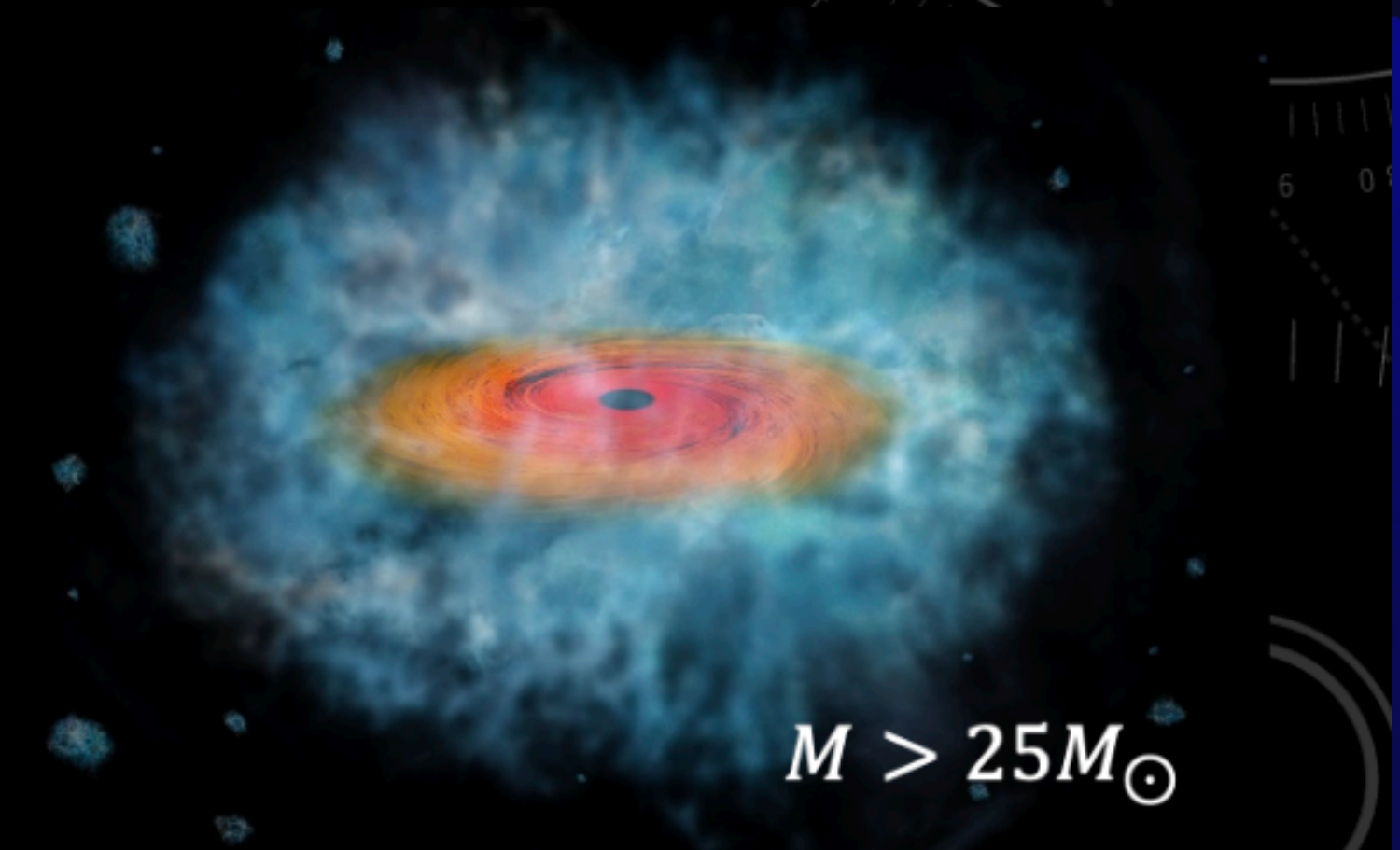
$M < 10M_{\odot}$

Illustration of rocky debris around a white dwarf
Source: [NOIRLab/NSF/AURA/J. da Silva](#) Image processing:
[M. Zamani](#) and [M. Kosari](#) (NSF's [NOIRLab](#))



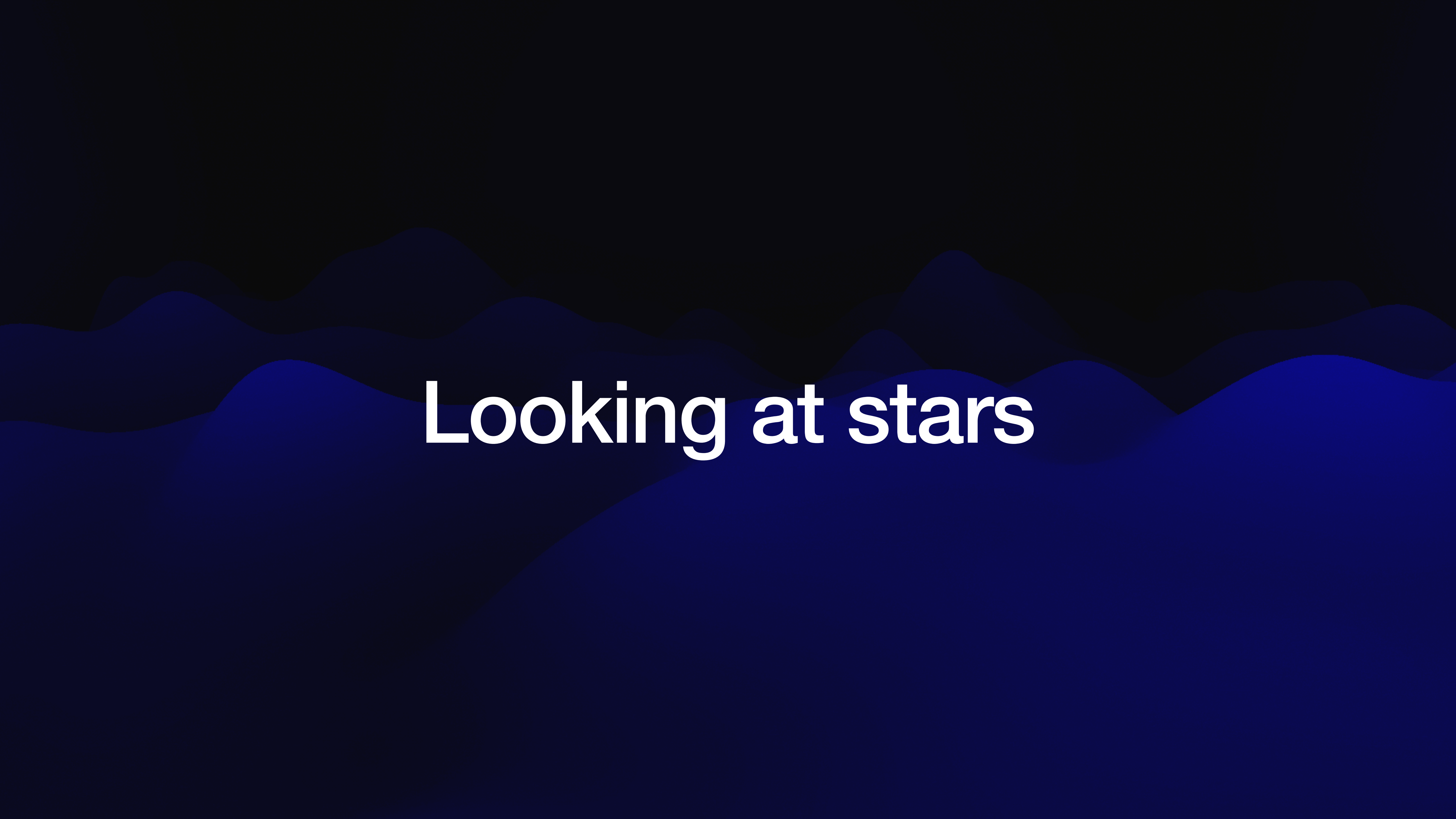
$10M_{\odot} < M < 25M_{\odot}$

X-ray light rings from a binary neutron star
Source: [NASA/CXC/Univ. of Wisconsin-Madison/S. Heinz, et al.](#);
Optical: [DSS](#)



$M > 25M_{\odot}$

Artist's impression of supermassive black hole seed
Source: [ESA/Hubble](#)

The background features a series of overlapping, wavy, mountain-like shapes in various shades of dark blue and black, creating a layered, atmospheric effect. The text is centered over this background.

Looking at stars

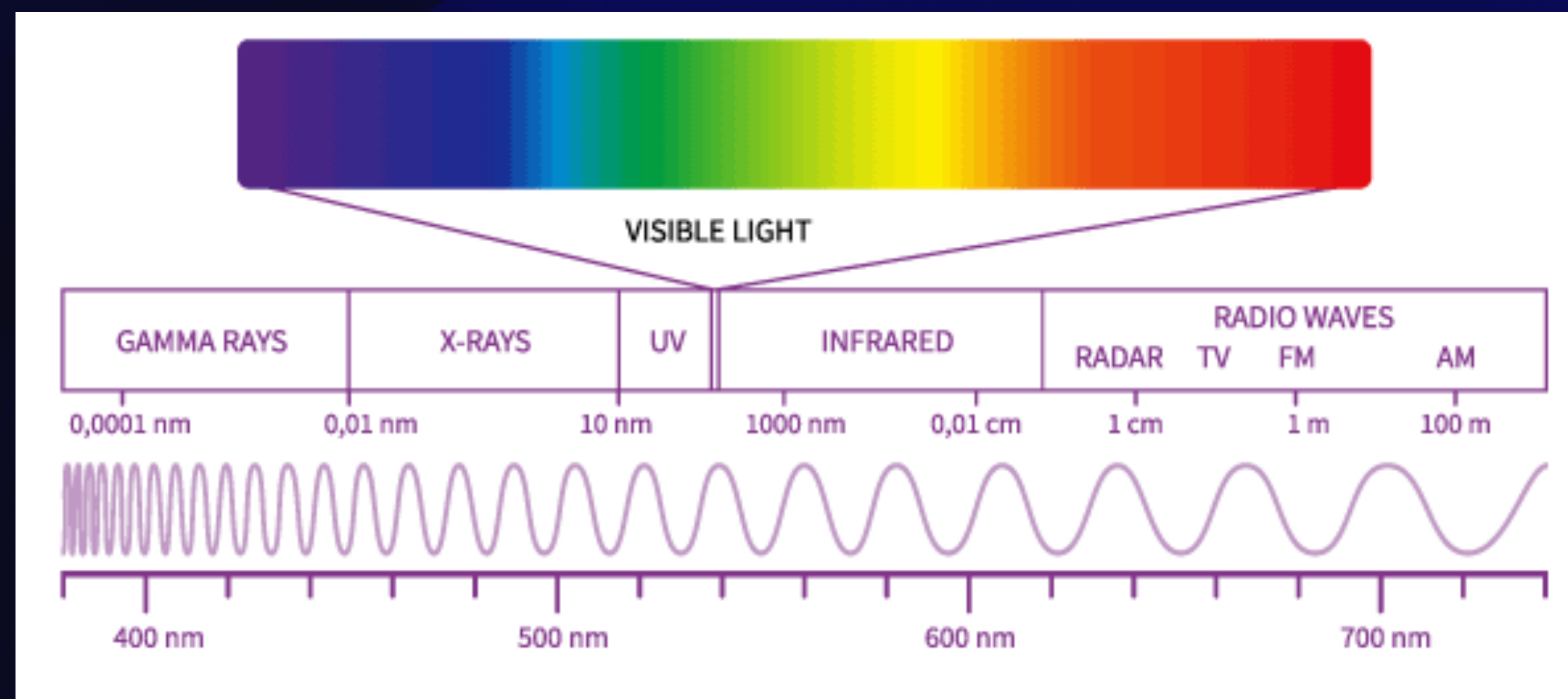
What is light?

Light is a form of energy that lets us see the world around us.

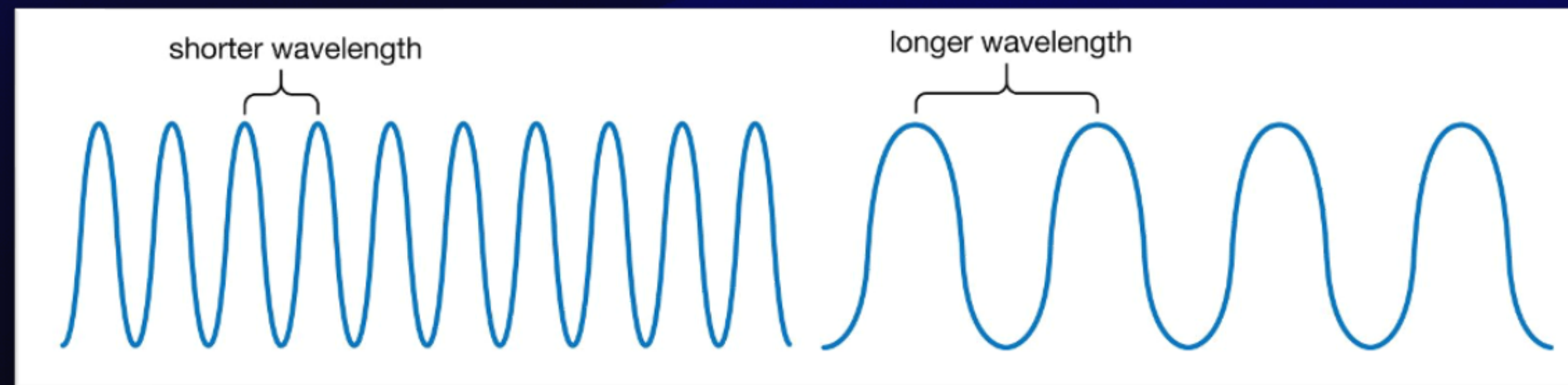
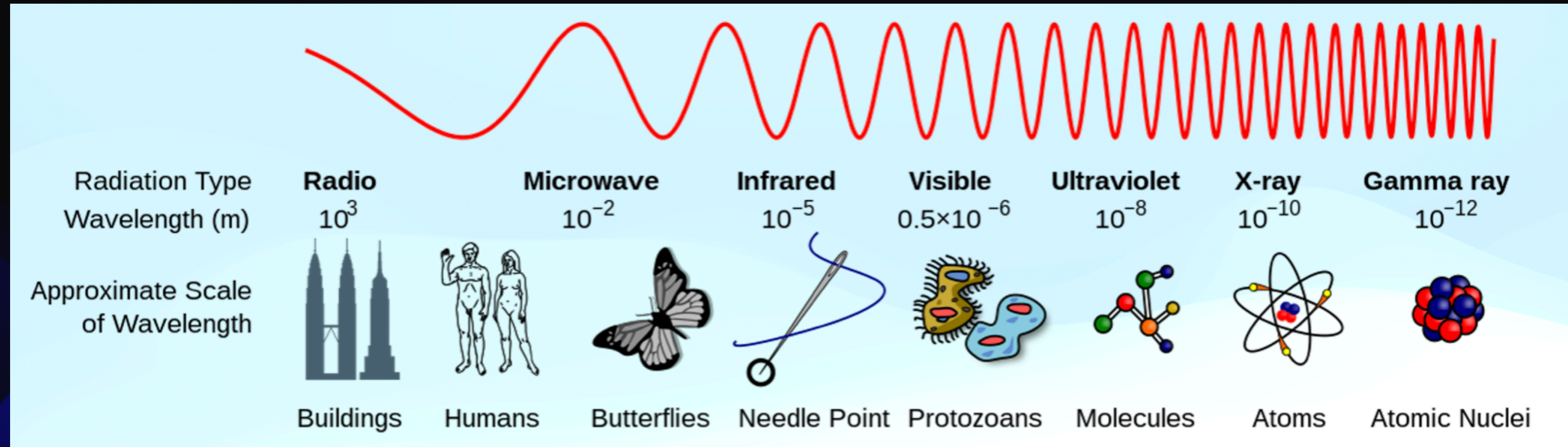
Light can be thought of as **waves** of radiation, and different **wavelengths** have different **energies**. Light travels through space in these waves, like ripples travel in water.

This energy can also be linked to **temperature**. Hotter objects have **more energy** and cooler objects have **less energy**.

Our eyes are sensitive to **visible light**
... but there are also other kind of light with different wavelengths!!

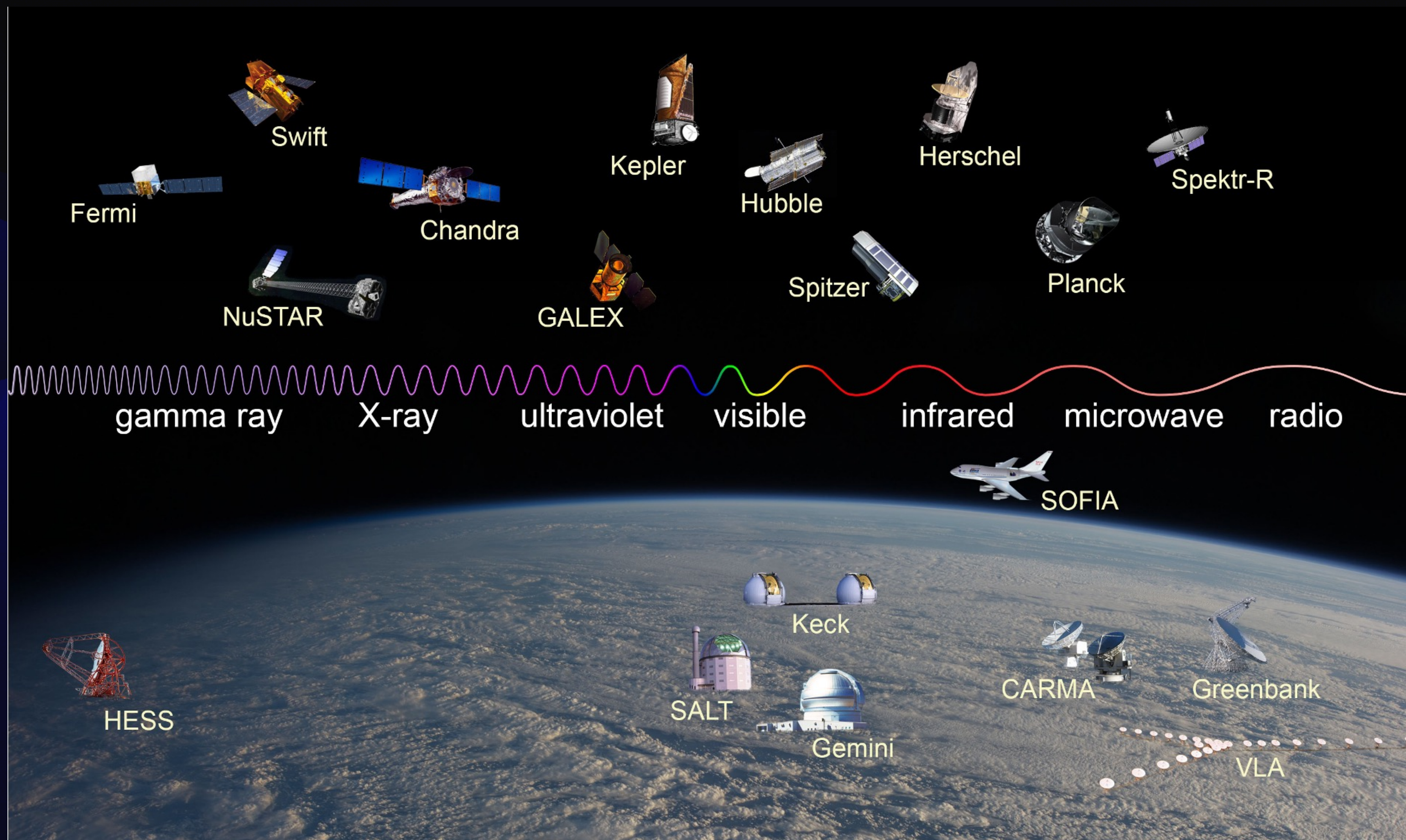


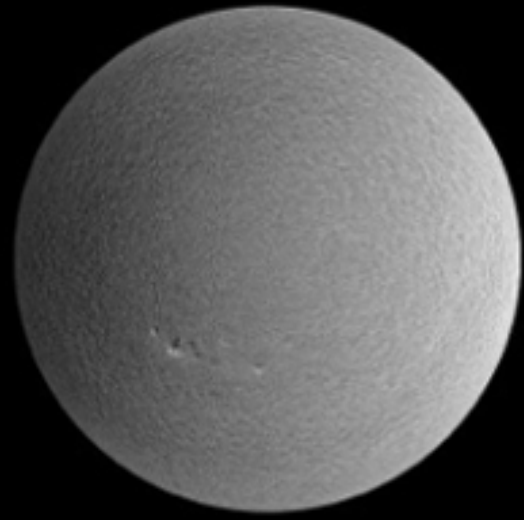
Different kinds of "light"



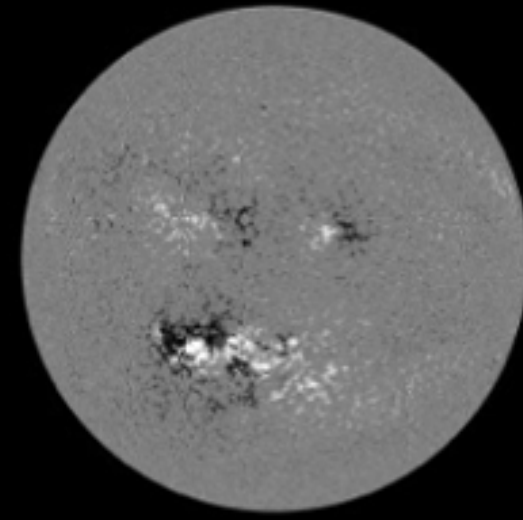
Shorter wavelengths have MORE ENERGY!

Space is full of different kinds of light.
Different telescopes help us to see different types of light!

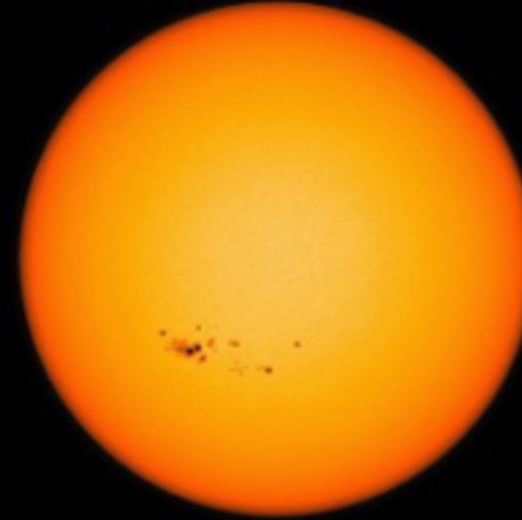




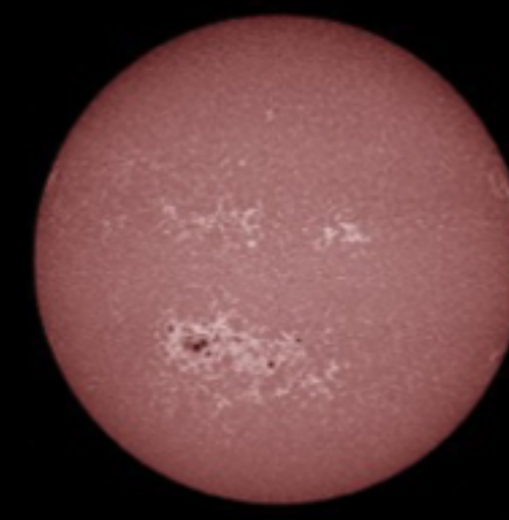
HMI Dopplergram
Surface movement
Photosphere



HMI Magnetogram
Magnetic field polarity
Photosphere



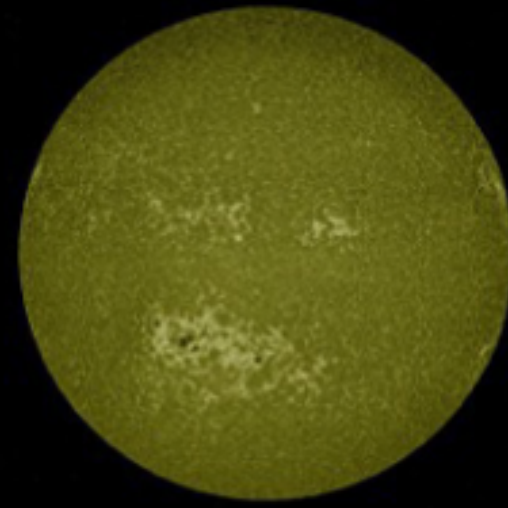
HMI Continuum
Matches visible light
Photosphere



AIA 1700 Å
4500 Kelvin
Photosphere



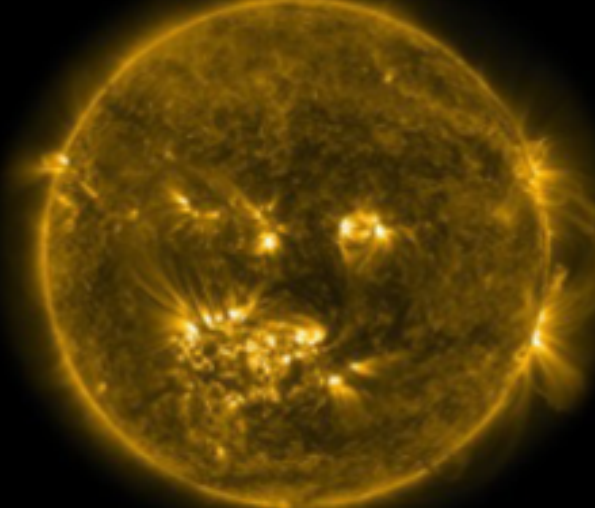
AIA 4500 Å
6000 Kelvin
Photosphere



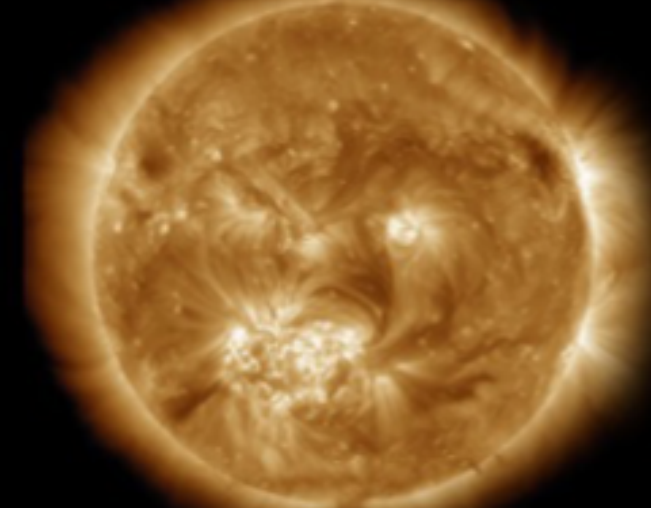
AIA 1600 Å
10,000 Kelvin
Upper photosphere/
Transition region



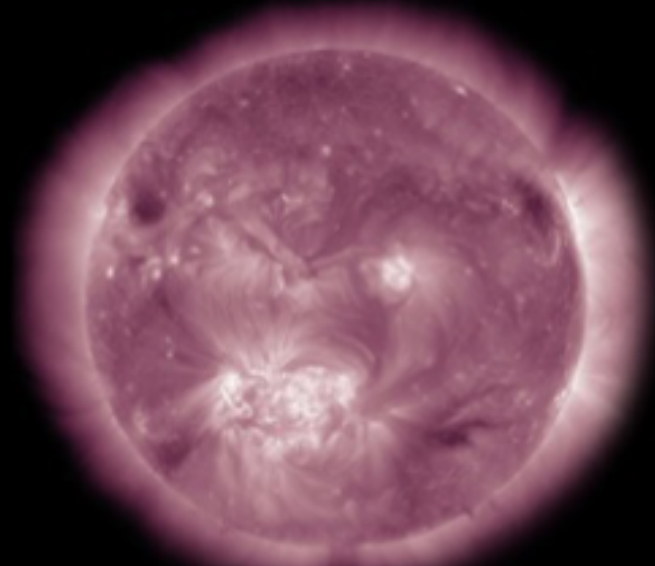
AIA 304 Å
50,000 Kelvin
Transition region/
Chromosphere



AIA 171 Å
600,000 Kelvin
Upper transition
Region/quiet corona



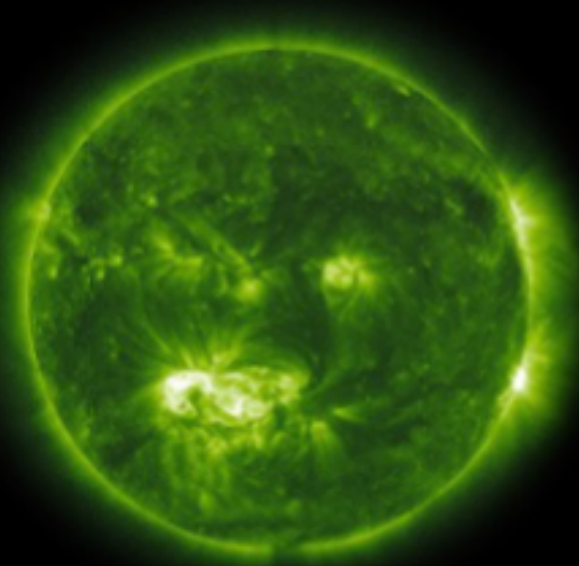
AIA 193 Å
1 million Kelvin
Corona/flare plasma



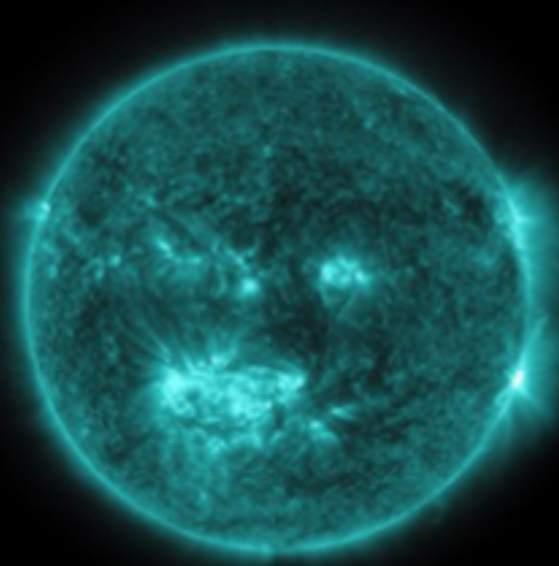
AIA 211 Å
2 million Kelvin
Active regions



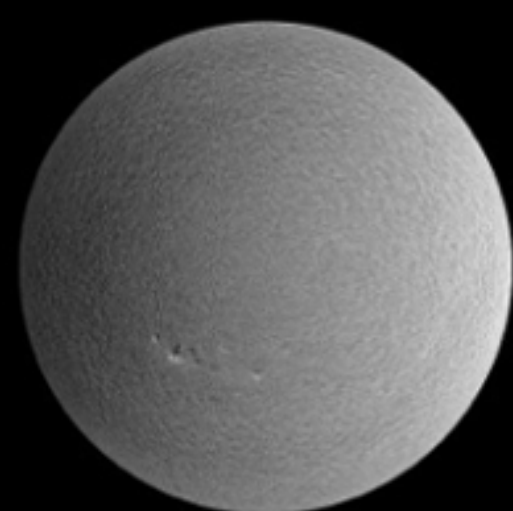
AIA 335 Å
2.5 million Kelvin
Active regions



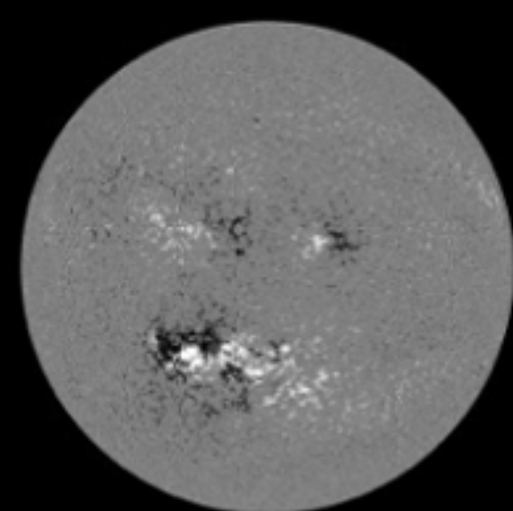
AIA 094 Å
6 million Kelvin
Flaring regions



AIA 131 Å
10 million Kelvin
Flaring regions



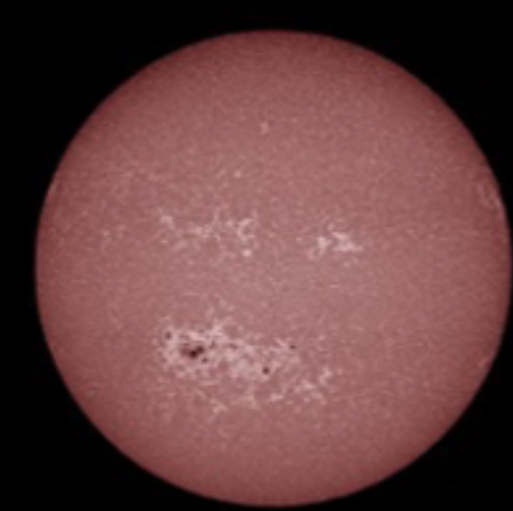
HMI Dopplergram
Surface movement
Photosphere



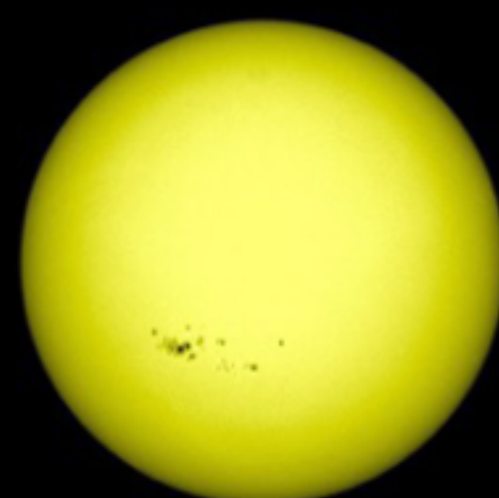
HMI Magnetogram
Magnetic field polarity
Photosphere



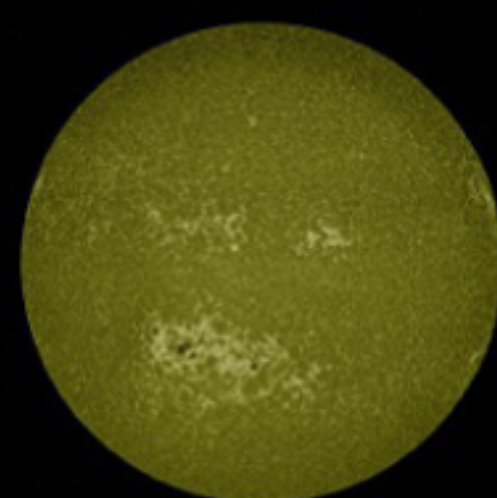
HMI Continuum
Matches visible light
Photosphere



AIA 1700 Å
4500 Kelvin
Photosphere



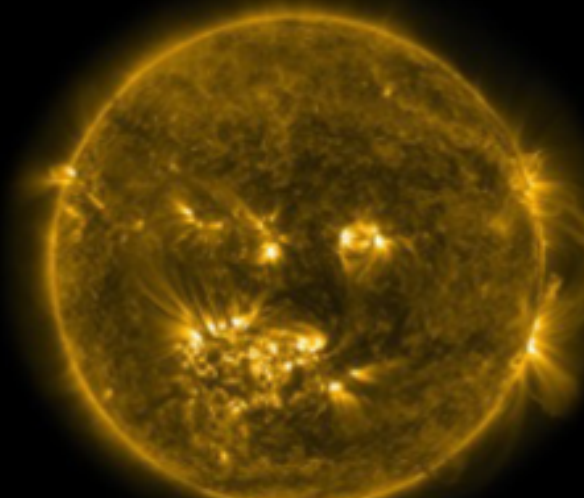
AIA 4500 Å
6000 Kelvin
Photosphere



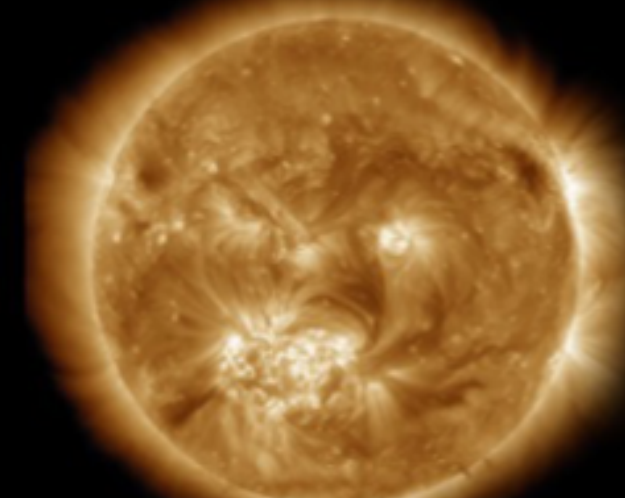
AIA 1600 Å
10,000 Kelvin
Upper photosphere/
Transition region



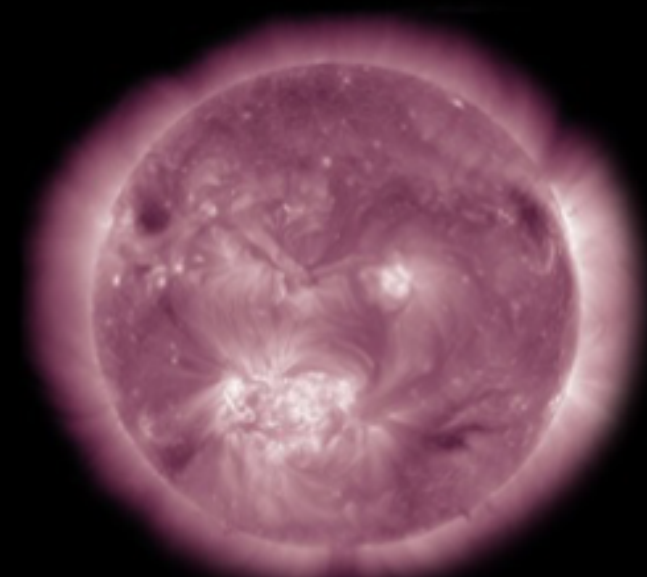
AIA 304 Å
50,000 Kelvin
Transition region/
Chromosphere



AIA 171 Å
600,000 Kelvin
Upper transition
Region/quiet corona



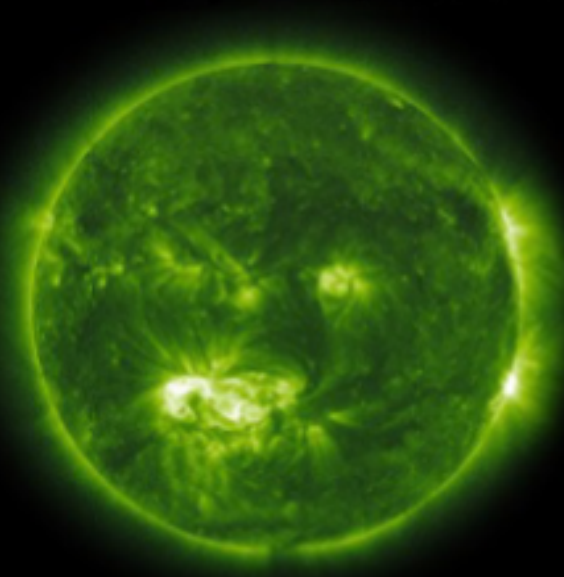
AIA 193 Å
1 million Kelvin
Corona/flare plasma



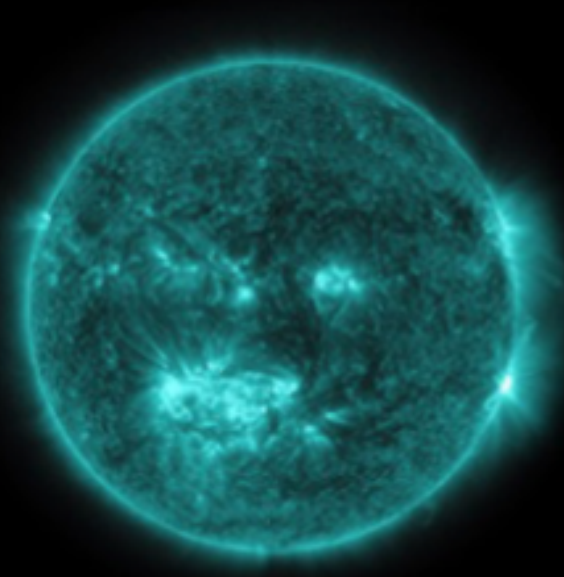
AIA 211 Å
2 million Kelvin
Active regions



AIA 335 Å
2.5 million Kelvin
Active regions



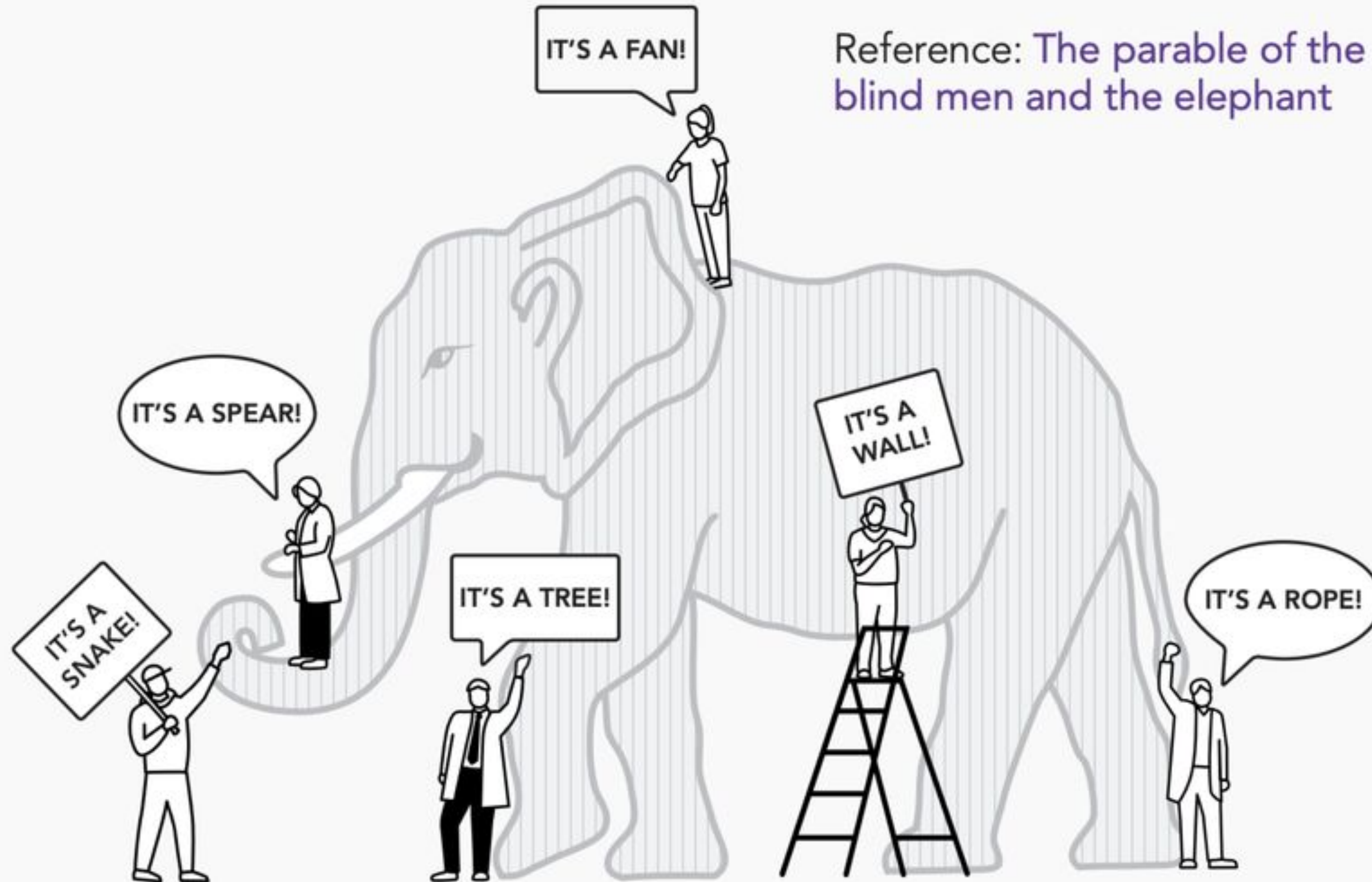
AIA 094 Å
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Flaring regions



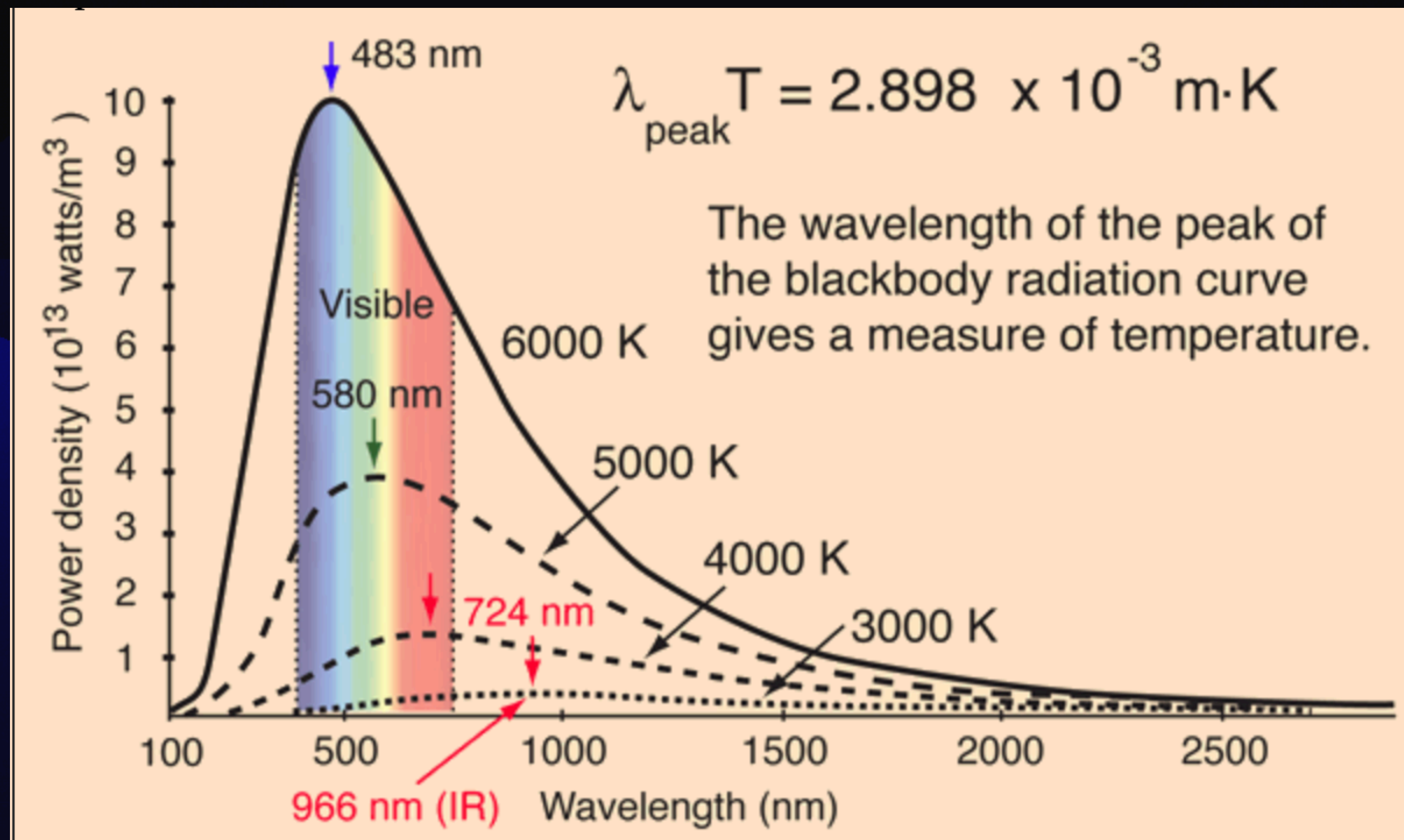
AIA 131 Å
10 million Kelvin
Flaring regions

**Our Sun
viewed in
different
wavelengths!**

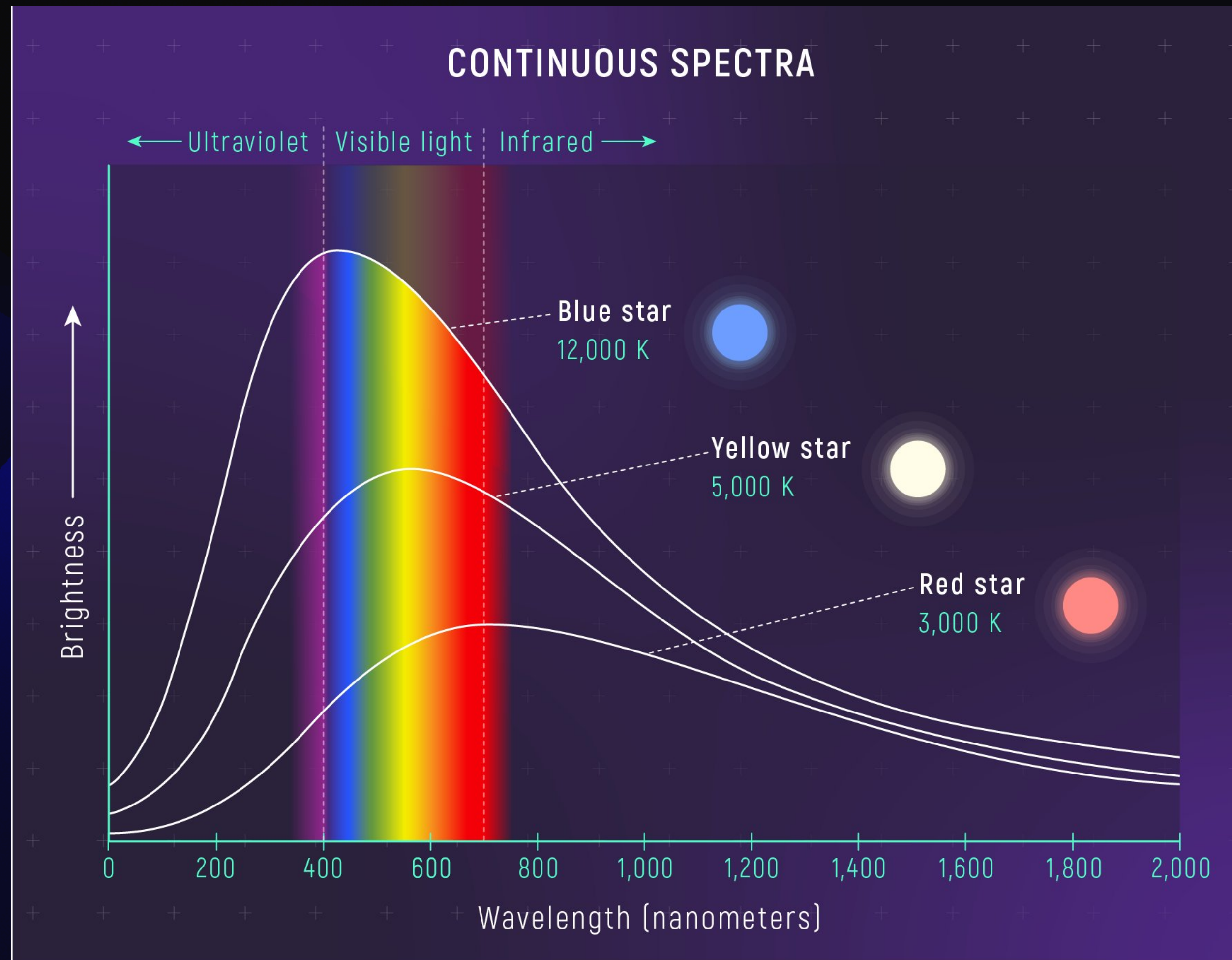
Reference: The parable of the
blind men and the elephant



Astronomers consider stars to be approximate black bodies that are capable of absorbing light at every wavelength without any reflection.



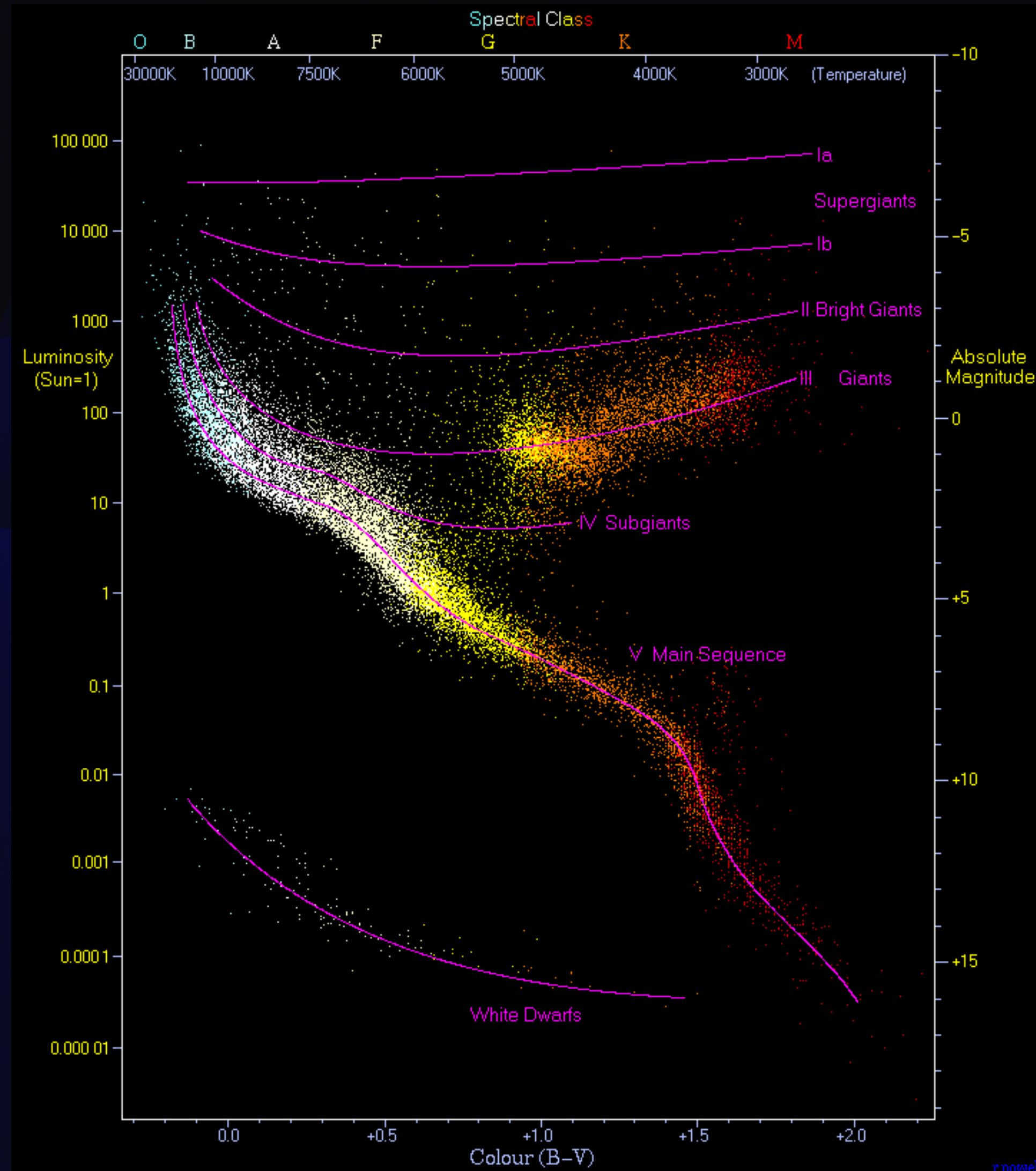
We can use Wein's displacement law to calculate the surface temperature of stars.



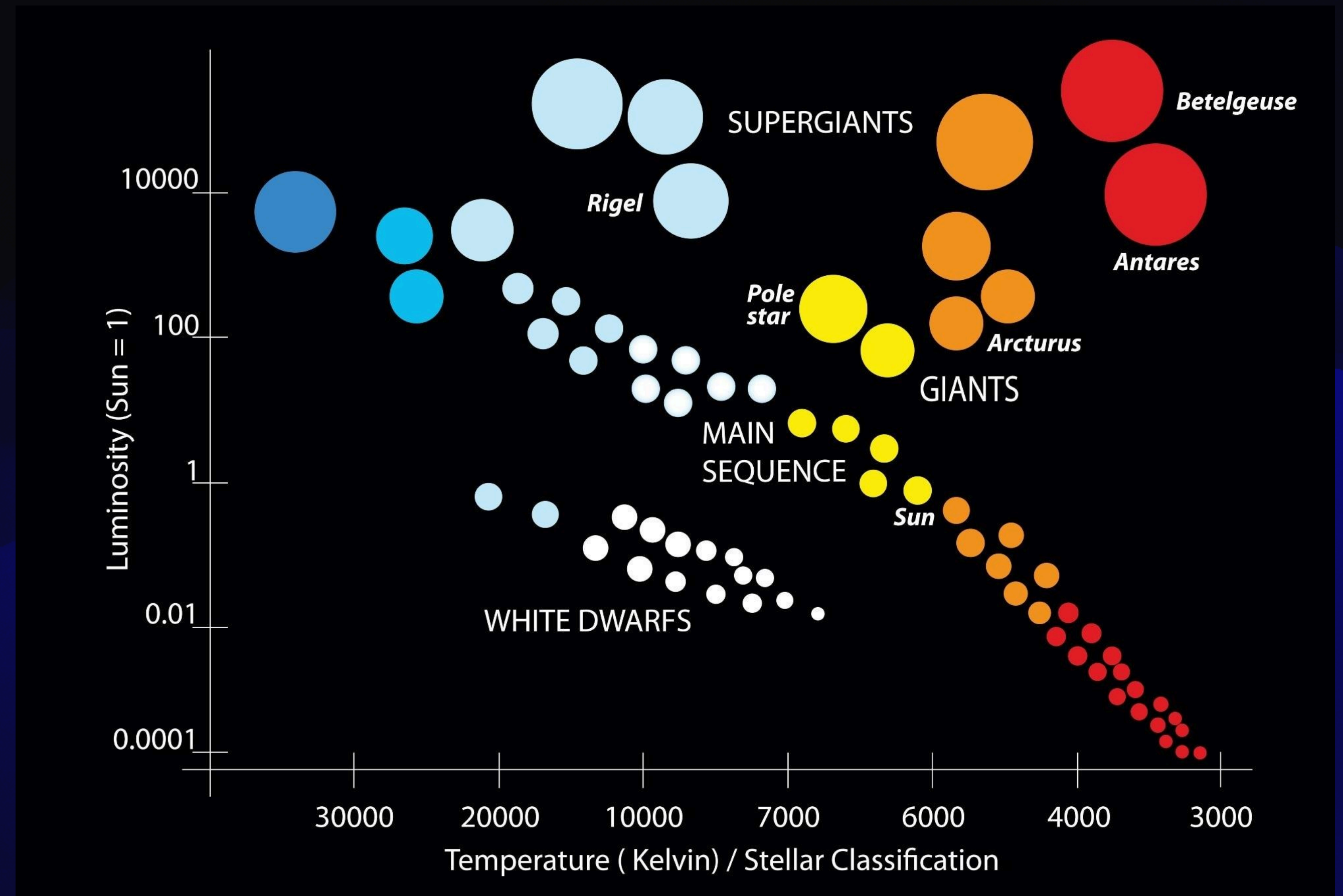
**Blue stars
are hotter
than red
stars!**

The Physics of Stellar Evolution

Hertzsprung-Russell diagram



Source: Wikipedia



<https://www.azoquantum.com/Article.aspx?ArticleID=436>

Equations of Stellar Structure

FUNDAMENTAL STELLAR STRUCTURE EQUATIONS (FSSE)
IN TIME-INDEPENDENT (STATIC) FORM

$$\frac{dP}{dr} = -G \frac{M_r \rho}{r^2} \quad \text{HYDROSTATIC EQUILIBRIUM}$$

$$\frac{dM_r}{dr} = 4\pi r^2 \rho \quad \text{MASS CONSERVATION}$$

$$\frac{dL_r}{dr} = 4\pi r^2 \rho \epsilon \quad \text{ENERGY EQUATION}$$

$$\left. \frac{dT}{dr} \right|_{rad} = - \frac{3}{4} \frac{\bar{\kappa} \rho}{ac T^3} \frac{L_r}{4\pi r^2} \quad \text{RADIATIVE TRANSPORT}$$

$$\left. \frac{dT}{dr} \right|_{ad} = - \left(1 - \frac{1}{\gamma} \right) \frac{\mu m_H}{k} \frac{GM_r}{r^2} \quad \text{ADIABATIC CONVECTION}$$

Fundamental Forces of Nature in a Stellar Nursery

This infrared image shows the heat released throughout a nebula as the fundamental forces combine to form new stars from massive clouds of interstellar matter.

Gravity

Dense hot clouds collapse as gravity starts the star formation process.

Strong & Weak Nuclear

These forces work on the nuclear level fueling the core of new stars.

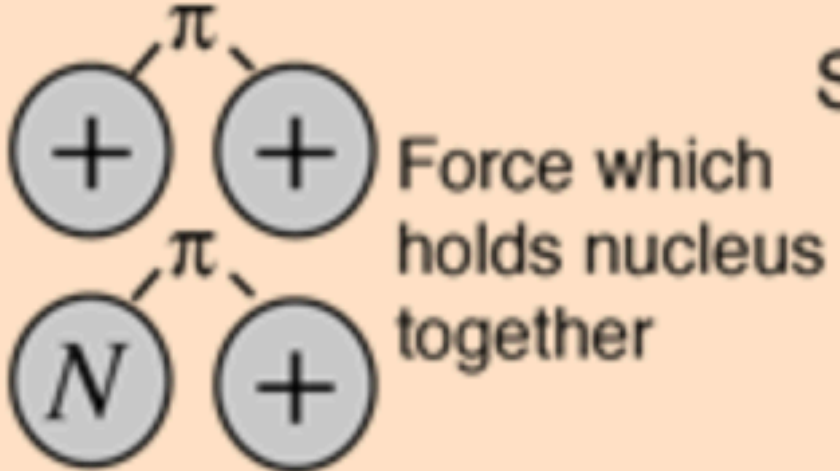
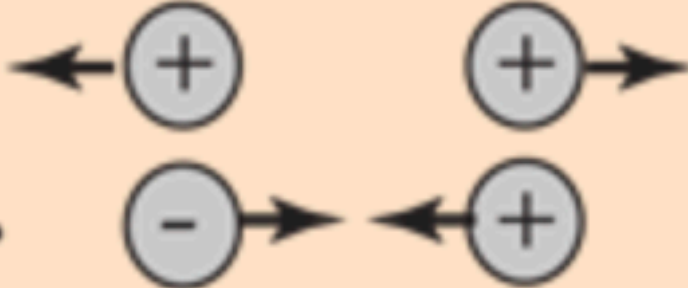
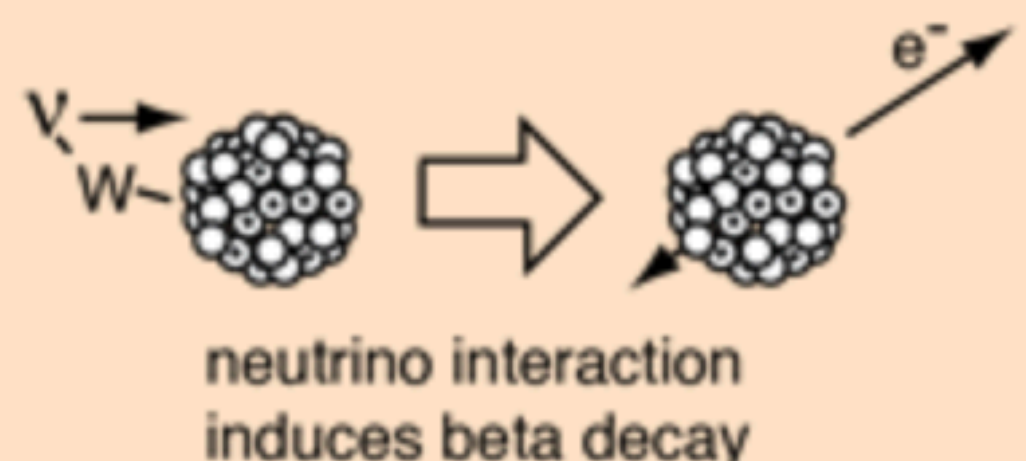
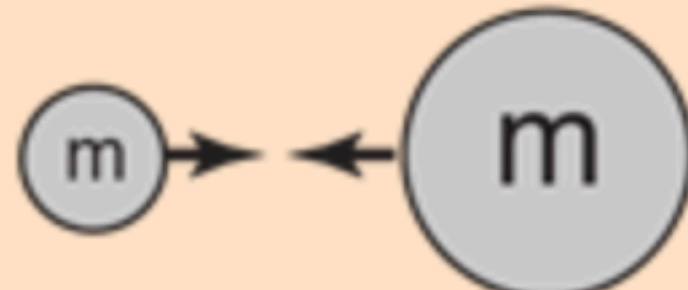
Electromagnetic Force

This force also works at the atomic level enabling stars to shine.

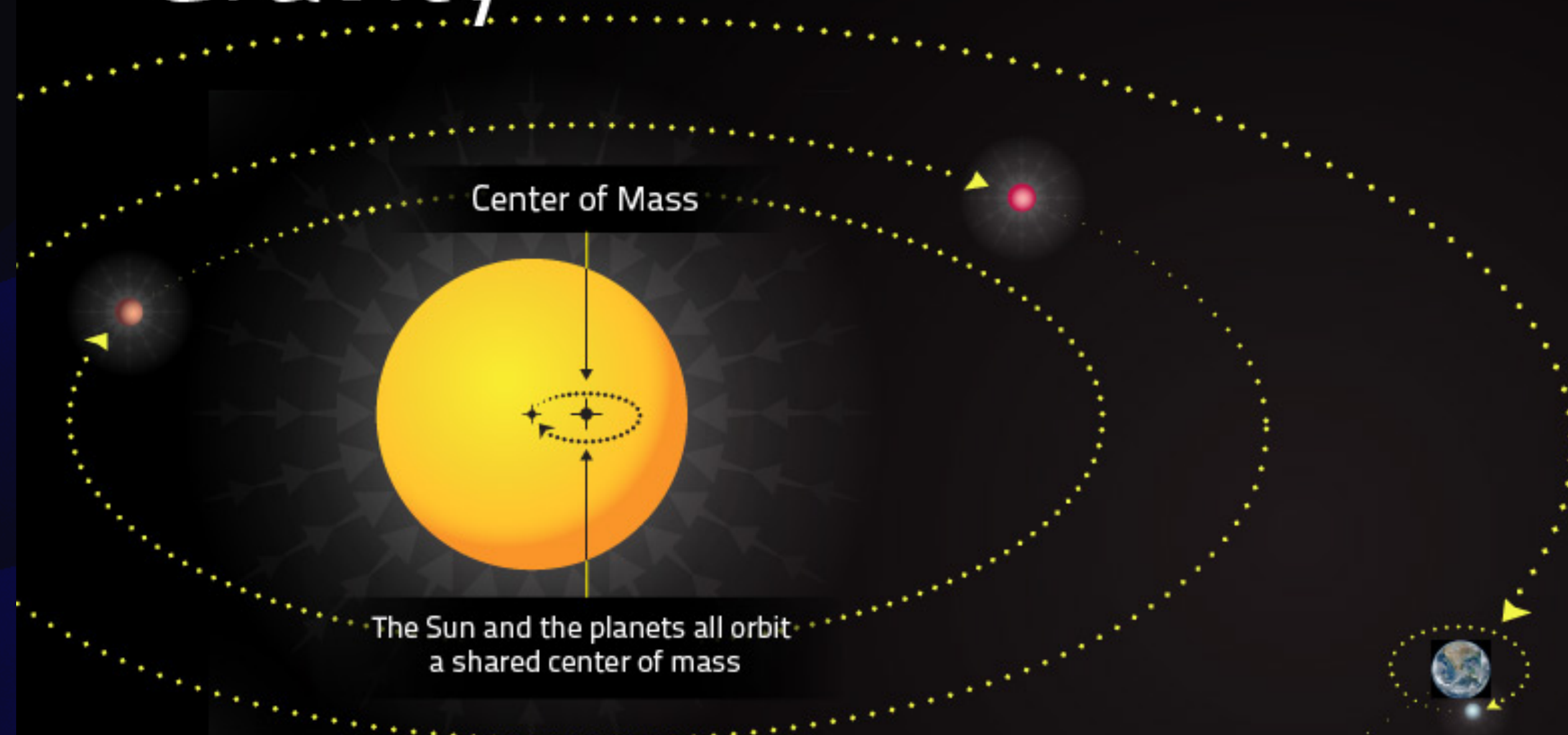
Infrared view of Wizard Nebula — WISE, the Wide-field Infrared Survey Explorer mission

NASA/JPL-Caltech/UCLA

Fundamental Forces

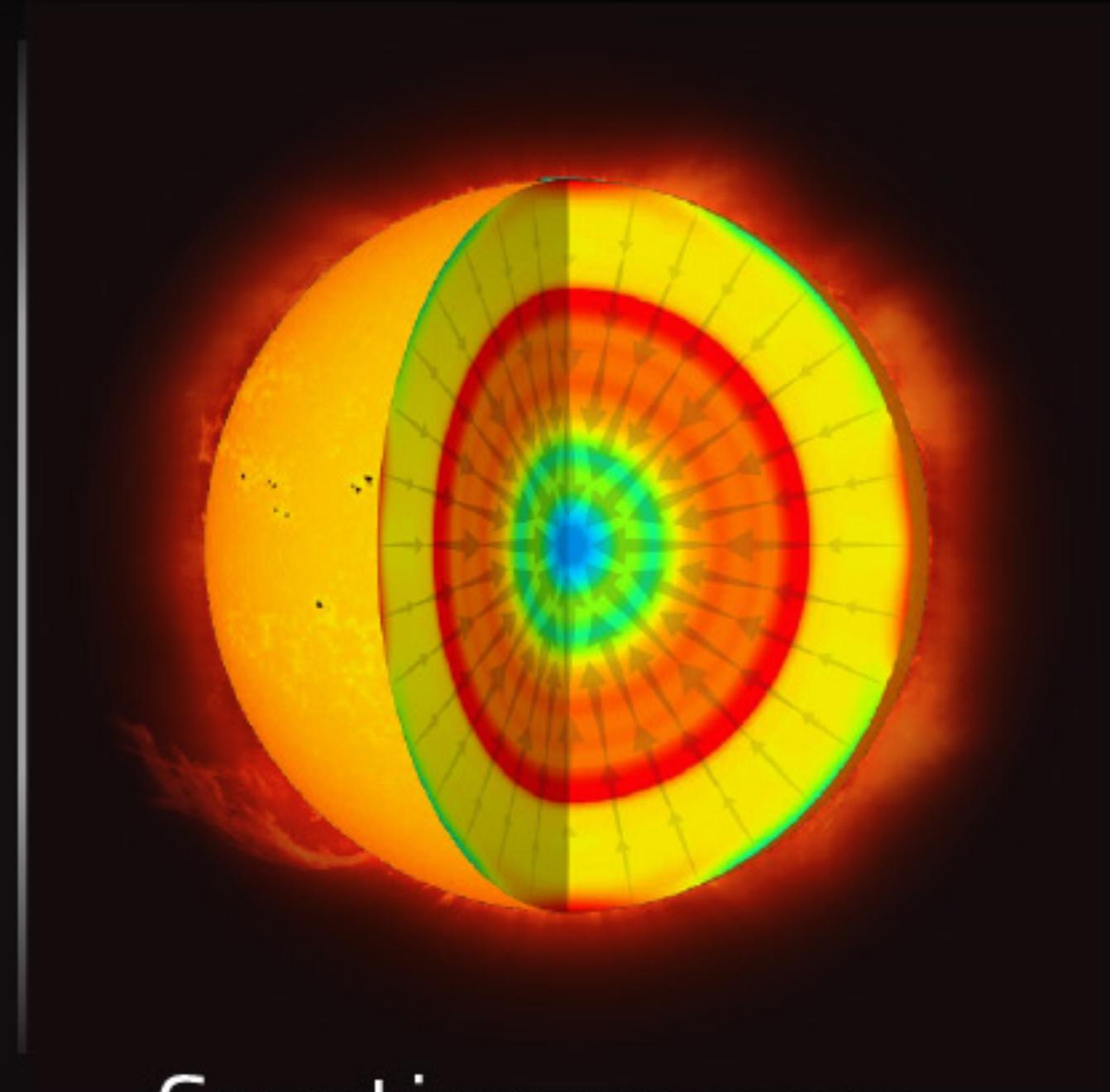
<i>Strong</i>		Strength 1	Range (m) 10^{-15} (diameter of a medium sized nucleus)	Particle gluons, π (nucleons)
<i>Electro-magnetic</i>		Strength $\frac{1}{137}$	Range (m) Infinite	Particle photon mass = 0 spin = 1
<i>Weak</i>		Strength 10^{-6}	Range (m) 10^{-18} (0.1% of the diameter of a proton)	Particle Intermediate vector bosons W^+ , W^- , Z_0 , mass > 80 GeV spin = 1
<i>Gravity</i>		Strength 6×10^{-39}	Range (m) Infinite	Particle graviton ? mass = 0 spin = 2

Gravity



Adding motion to the Universe

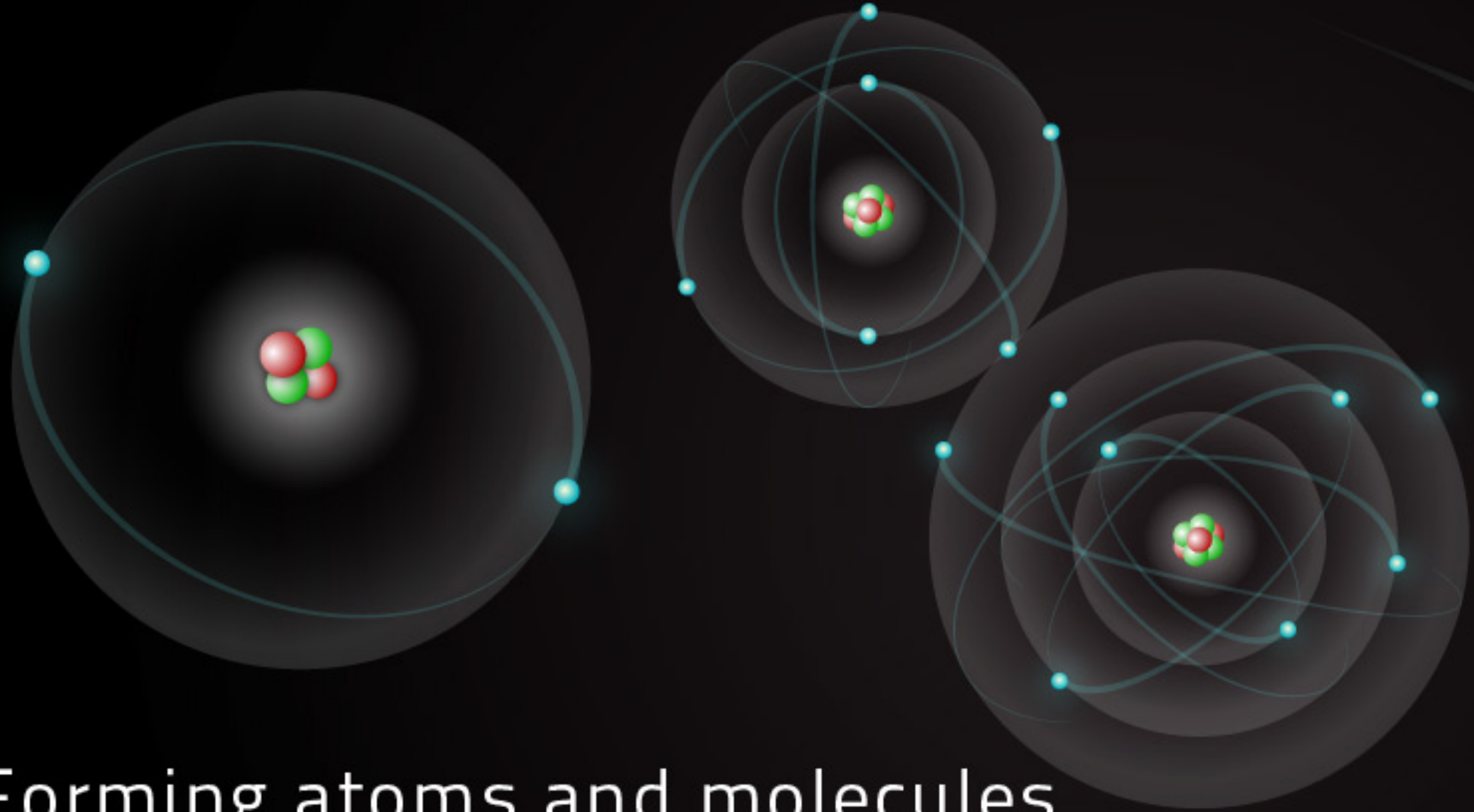
Gravity forms stars, planets, and moons, and forces these objects to spin on an axis and move along an orbital path. The planets appear to be orbiting the center of the Sun, but the Sun and planets all orbit a shared center of mass. Planets with enough mass can develop orbiting moons or rings of debris.



Creating energy

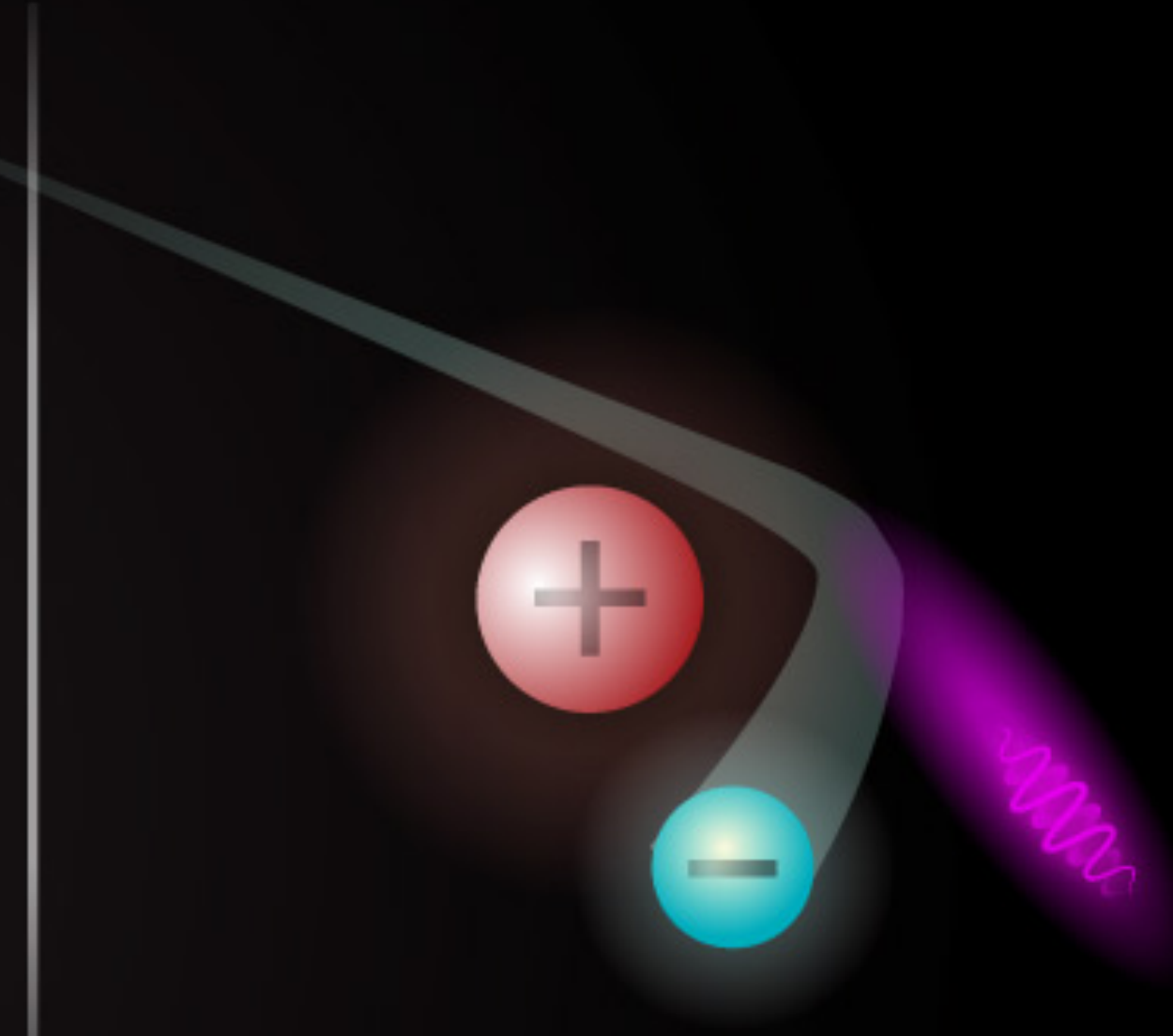
Gravity is the force that creates pressure and fusion energy in the core of stars allowing them to burn for millions of years.

Electromagnetic Force



Forming atoms and molecules

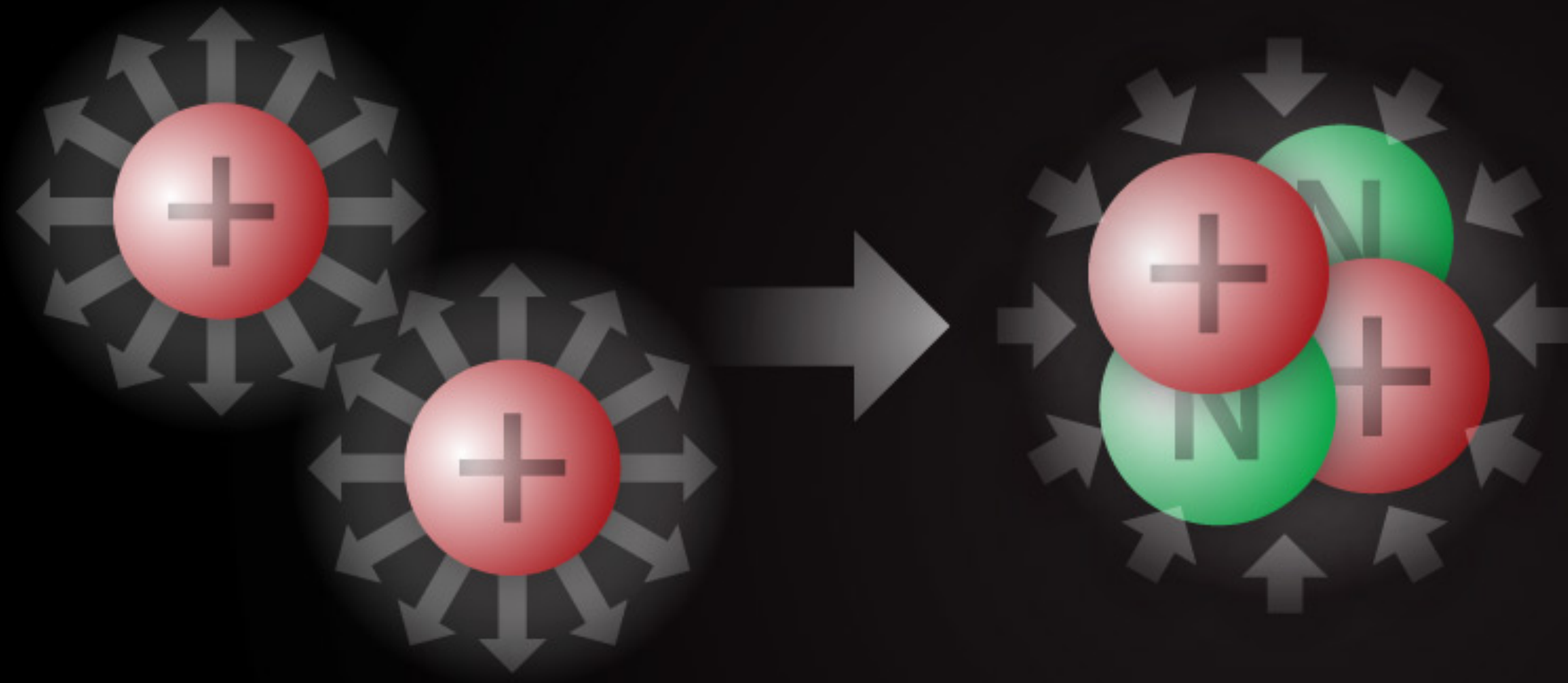
The electromagnetic force pulls negatively charged electrons into bound orbits around positively charged nuclei to form atoms and molecules. As a gas cools, electrons will find their way into the presence of atomic nuclei. Larger nuclei with a greater positive charge pull in more electrons until atoms and molecules have a balance of charges.



Generating light

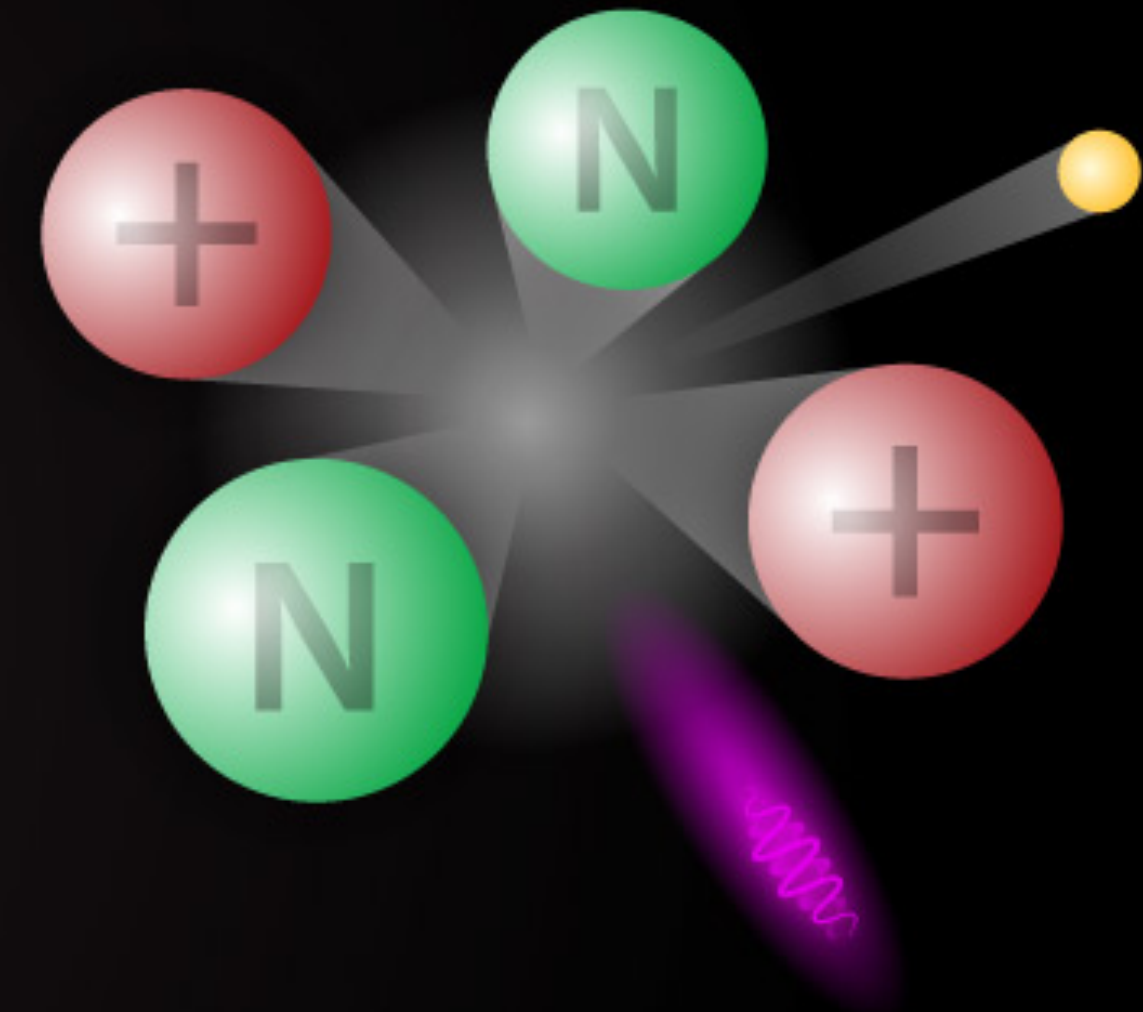
When a negative electron interacts with a positive proton, the electromagnetic force adds energy to the electron generating a photon.

Strong Nuclear Force



Binding protons in atomic nuclei

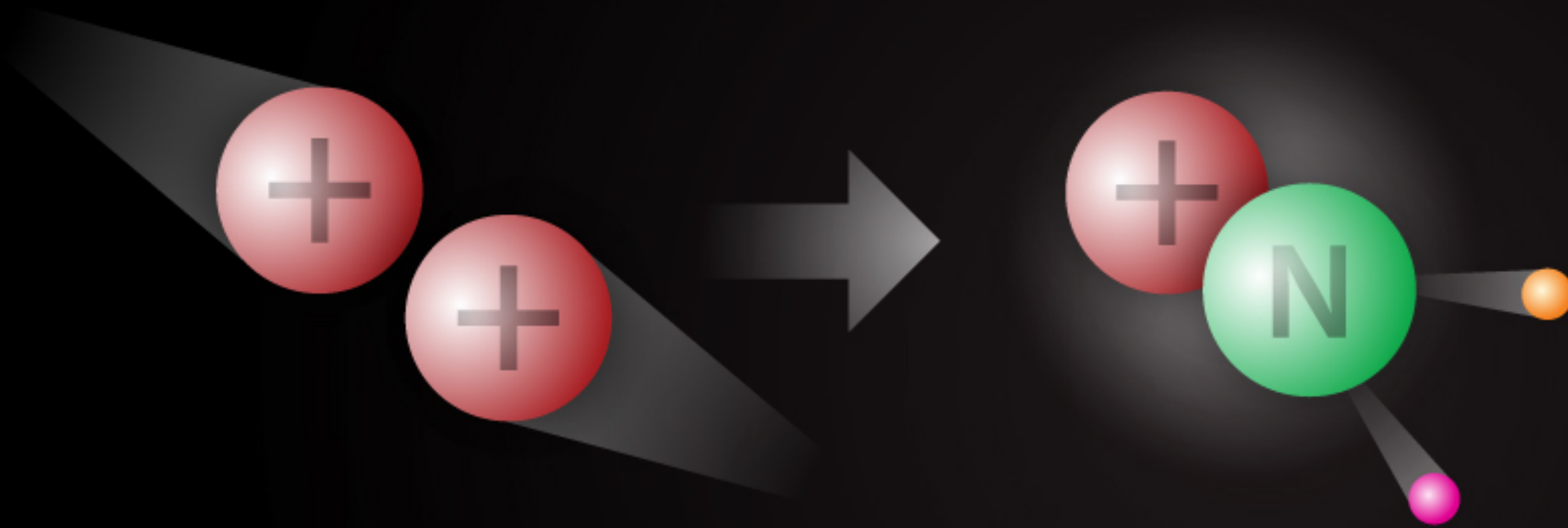
Positively charged particles naturally repel each other, it takes an extreme amount of force to hold protons together. The strong nuclear force overcomes the repulsion between protons to hold together atomic nuclei. Without the strong nuclear force, complex nuclei cannot form.



Breaking the bond

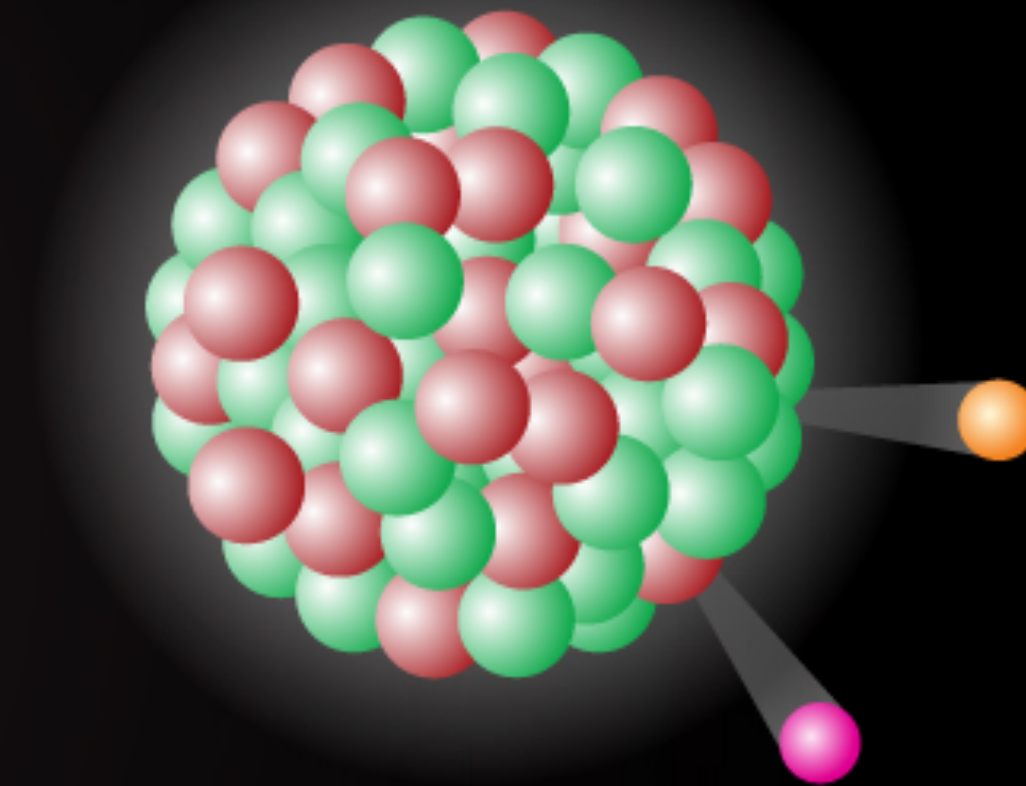
Enormous energy is released as gamma rays and neutrinos when the strong nuclear force is broken between protons and neutrons.

Weak Nuclear Force



Converting protons into neutrons

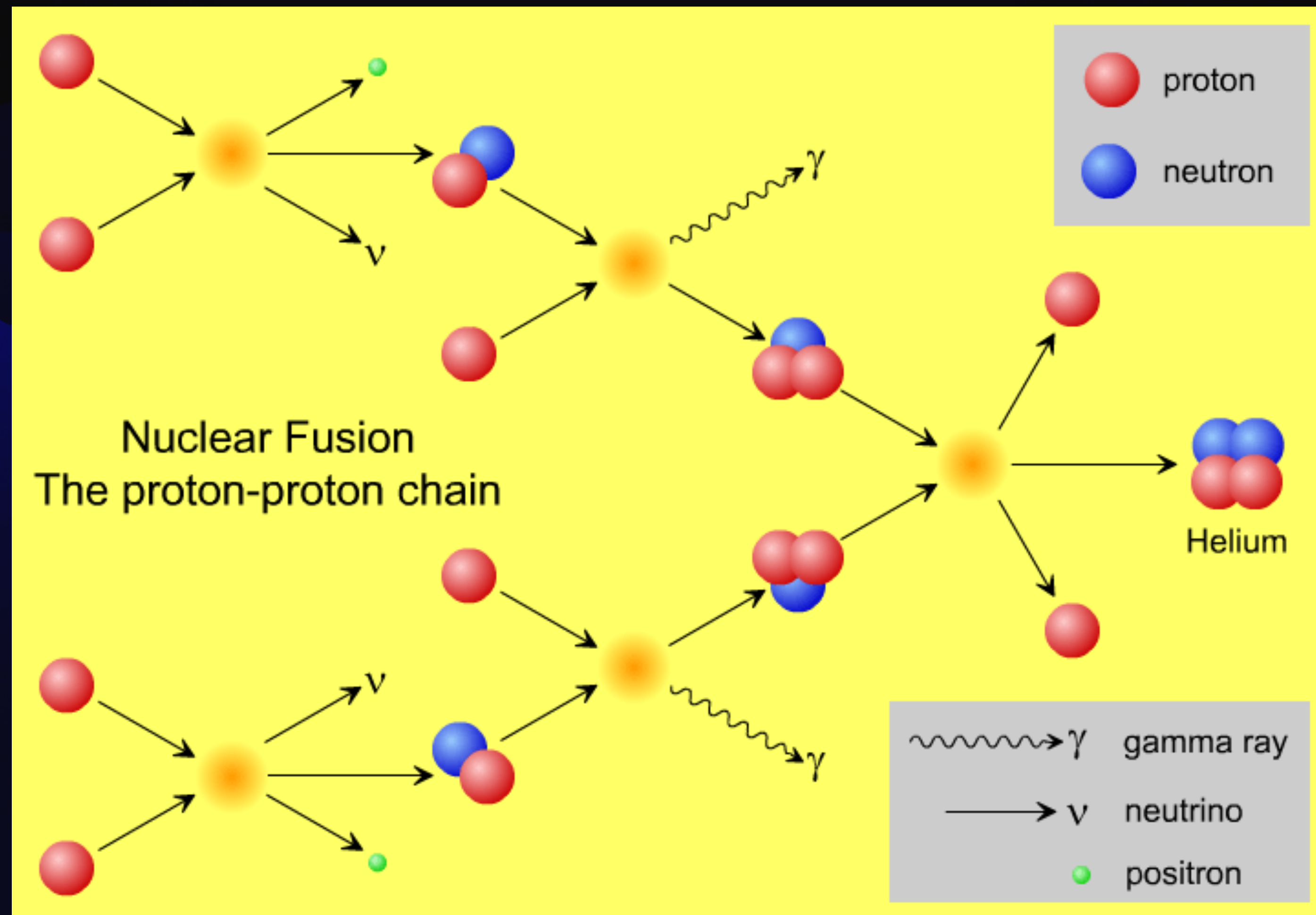
When two protons collide and fuse, a disruption in the weak nuclear force emits a positron and neutrino, which converts one of the positively charged proton to a neutrally charged Neutron. Without the weak nuclear force converting protons into neutrons, certain complex nuclei cannot form.



Releasing radiation

Heavy atoms have an imbalance of protons and neutrons, so the weak nuclear force converts protons to neutrons releasing radiation.

Nuclear Fusion in the Sun



Nuclear Fusion in the Sun

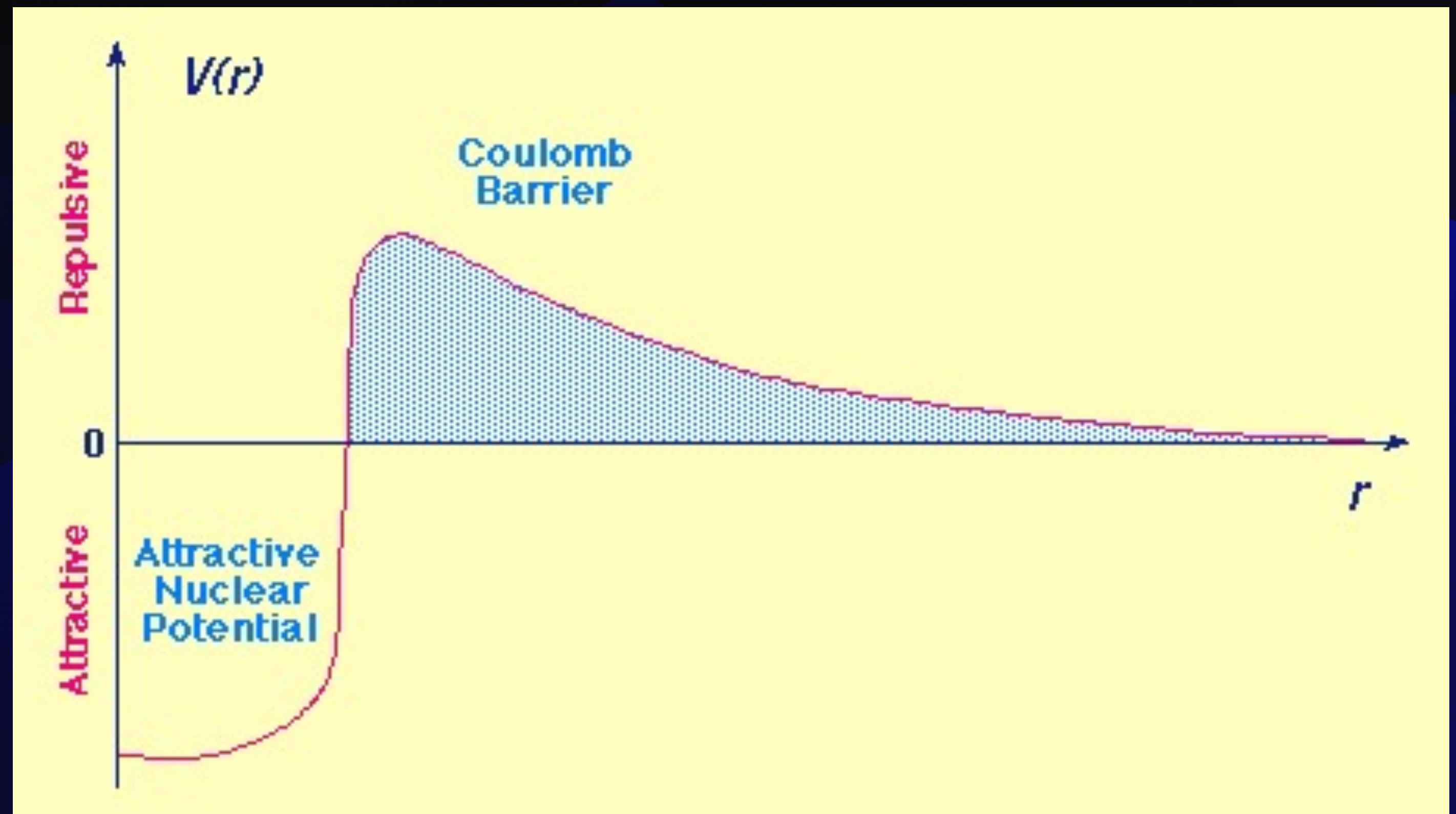
$$V_C(r) = \frac{Z_1 Z_2 e^2}{r}$$

Here, $e^2 = 1.44 \times 10^{-10} \text{ keV cm}$

To overcome Coulomb barrier, we need very high temperature?

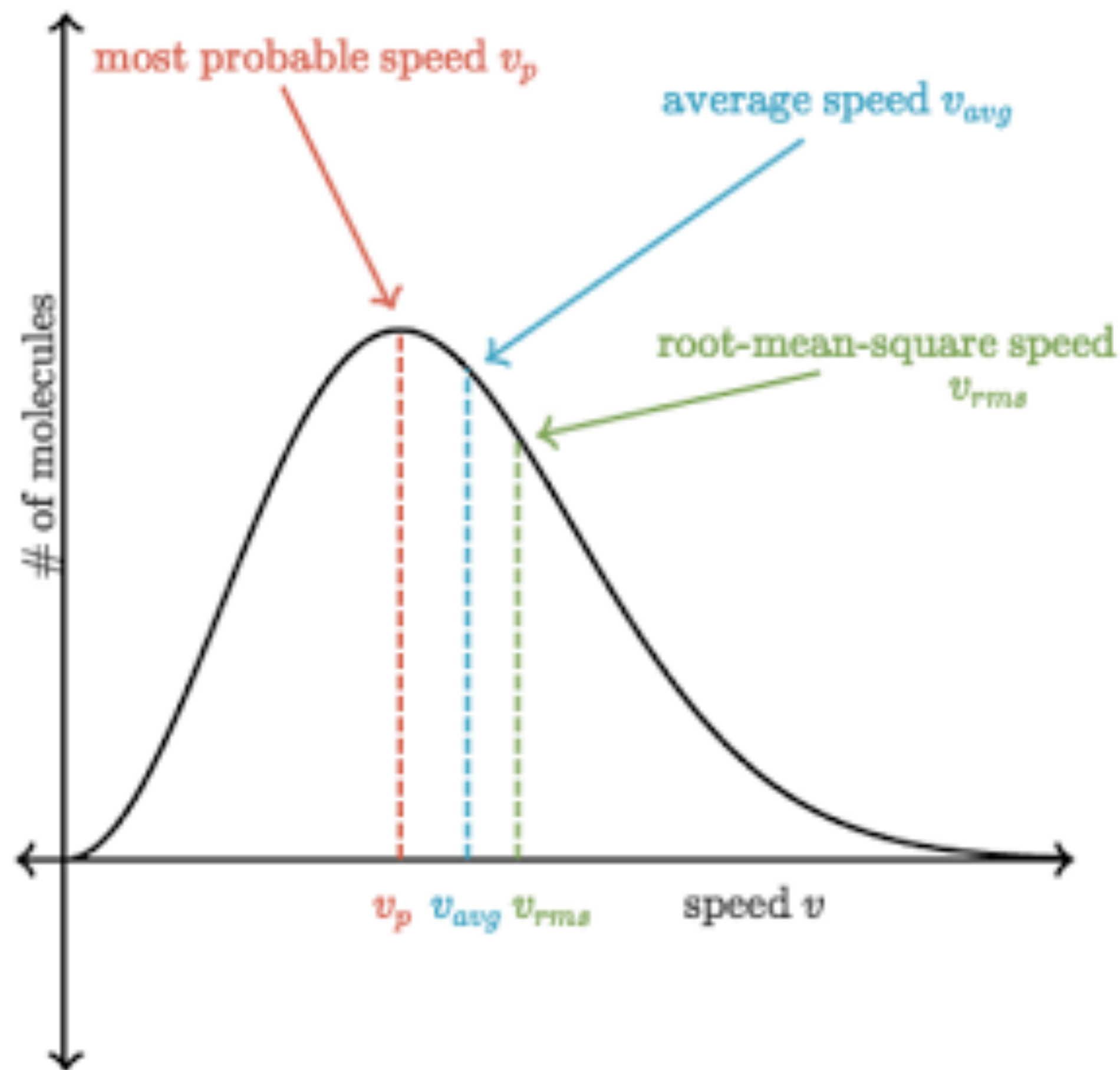
For p-p : Coulomb barrier = 550 keV
 $\rightarrow 6.4 \times 10^9 \text{ K}$

**Sun's energy has around 10^7 K
 $\rightarrow$ HOW IS FUSION HAPPENING?**



Nuclear Fusion in the Sun

If we rely on temperature alone, there is a close to zero chance for the fusion reaction to happen?



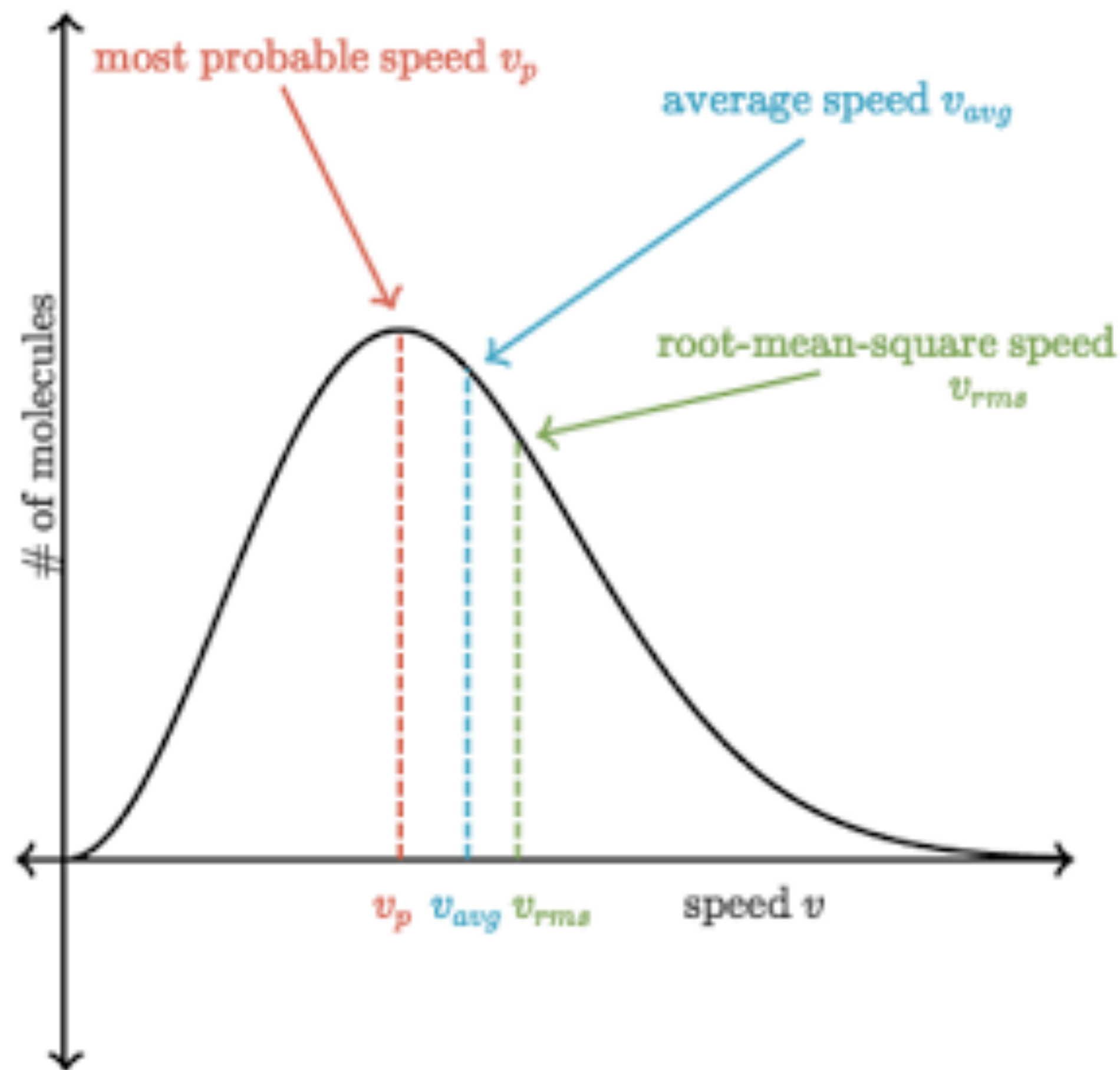
$$10^7 K \rightarrow 0.86 \text{ keV}$$

$$P(v) = 4\pi v^2 (m/(2\pi kT))^{\frac{3}{2}} \exp\left(-\frac{mv^2}{2kT}\right)$$

$$\frac{P(550)}{P(0.86)} = 10^{-275}$$

Nuclear Fusion in the Sun

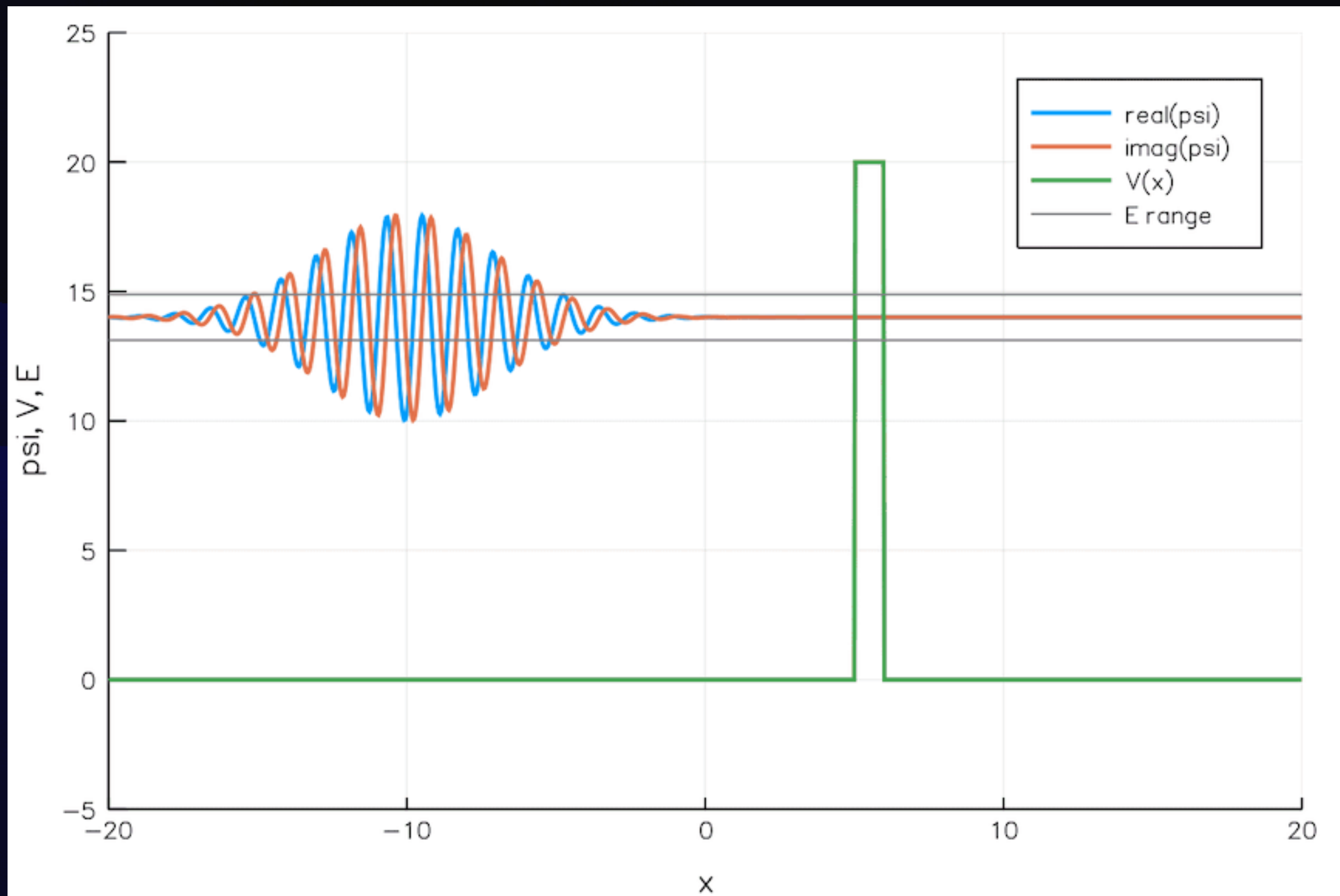
If we rely on temperature alone, there is a close to zero chance for the fusion reaction to happen?



$$10^7 K \rightarrow 0.86 \text{ keV}$$

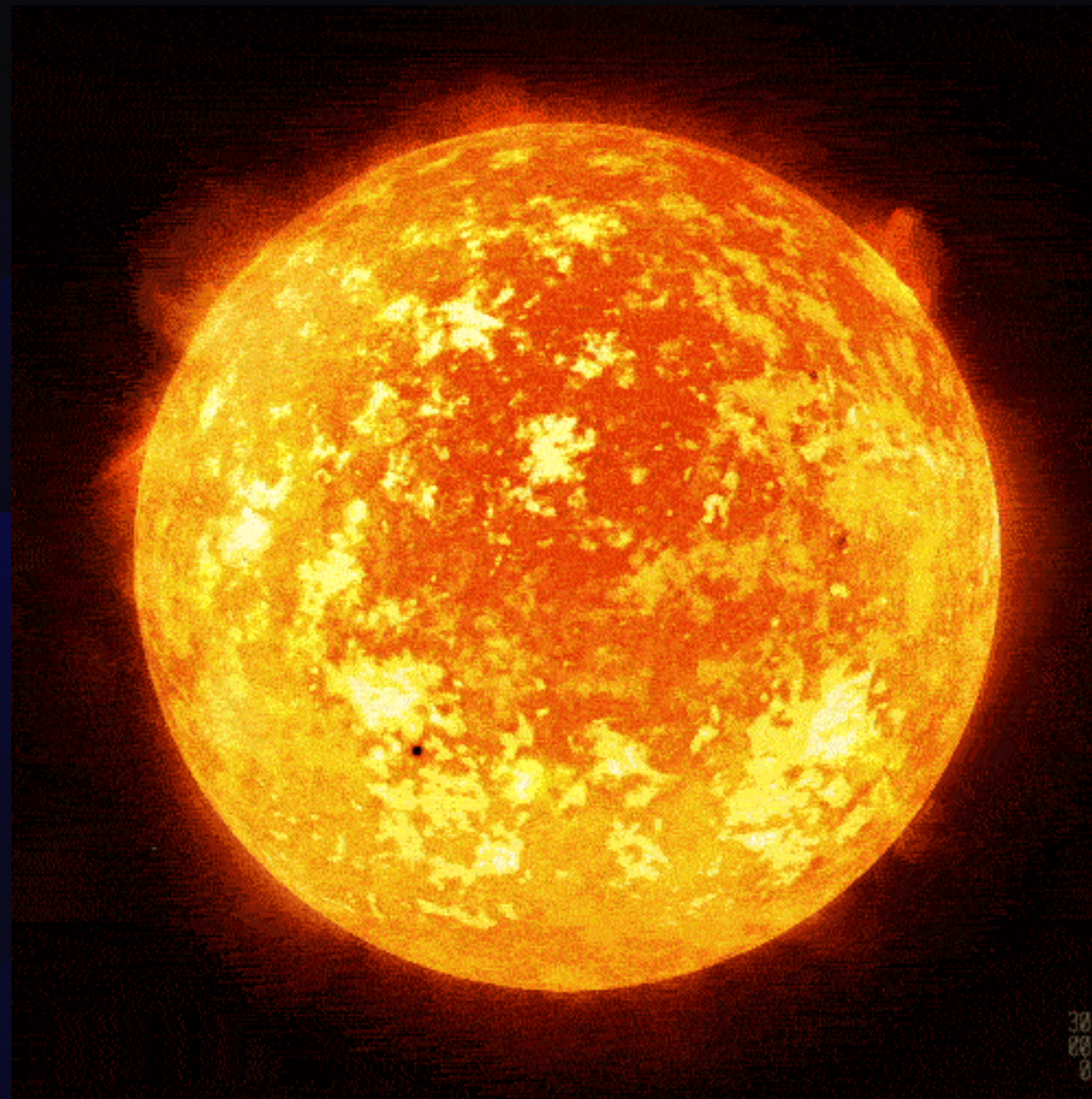
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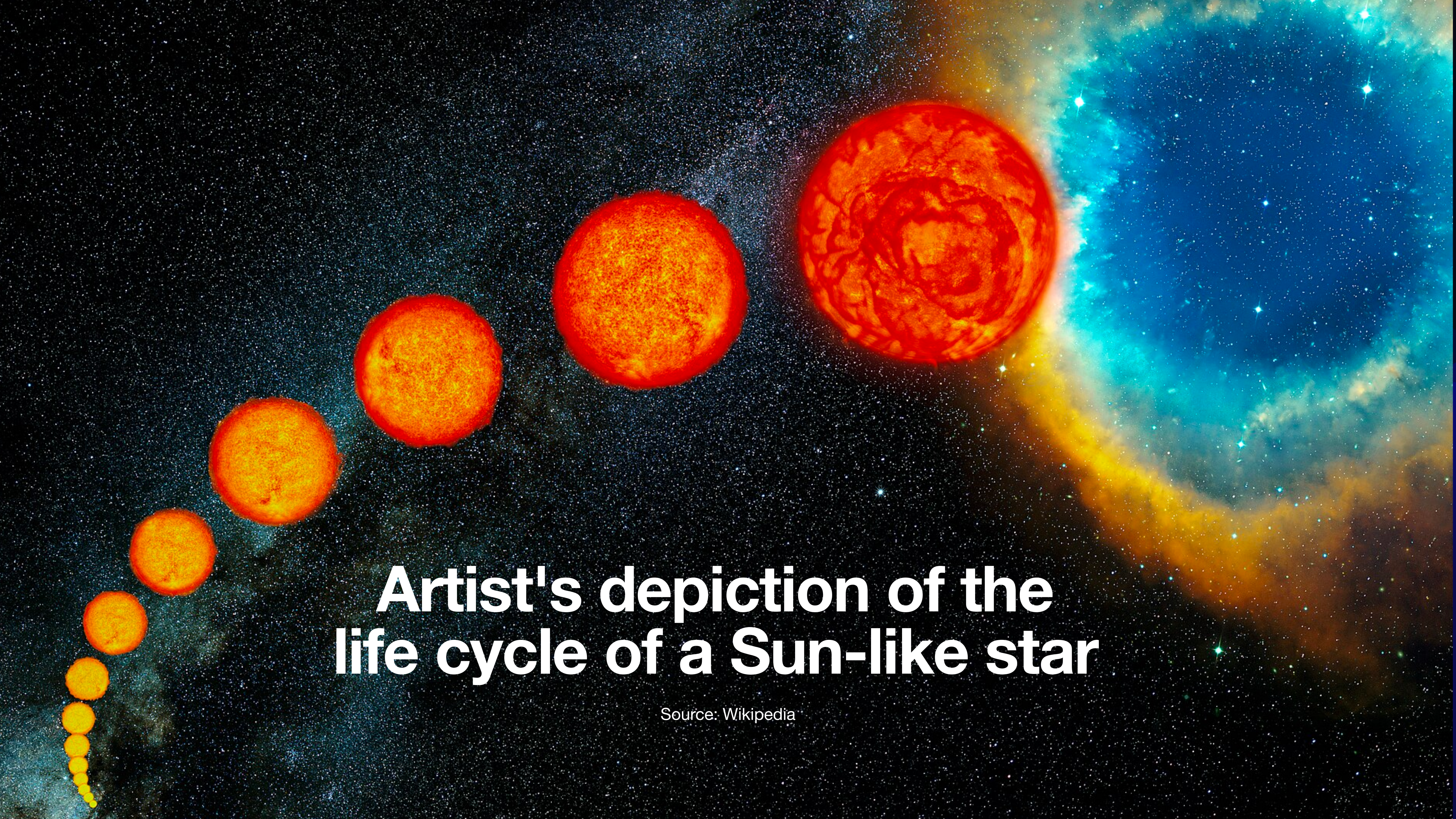


Ans:
QUANTUM
TUNNELLING!

Let's go to the future..



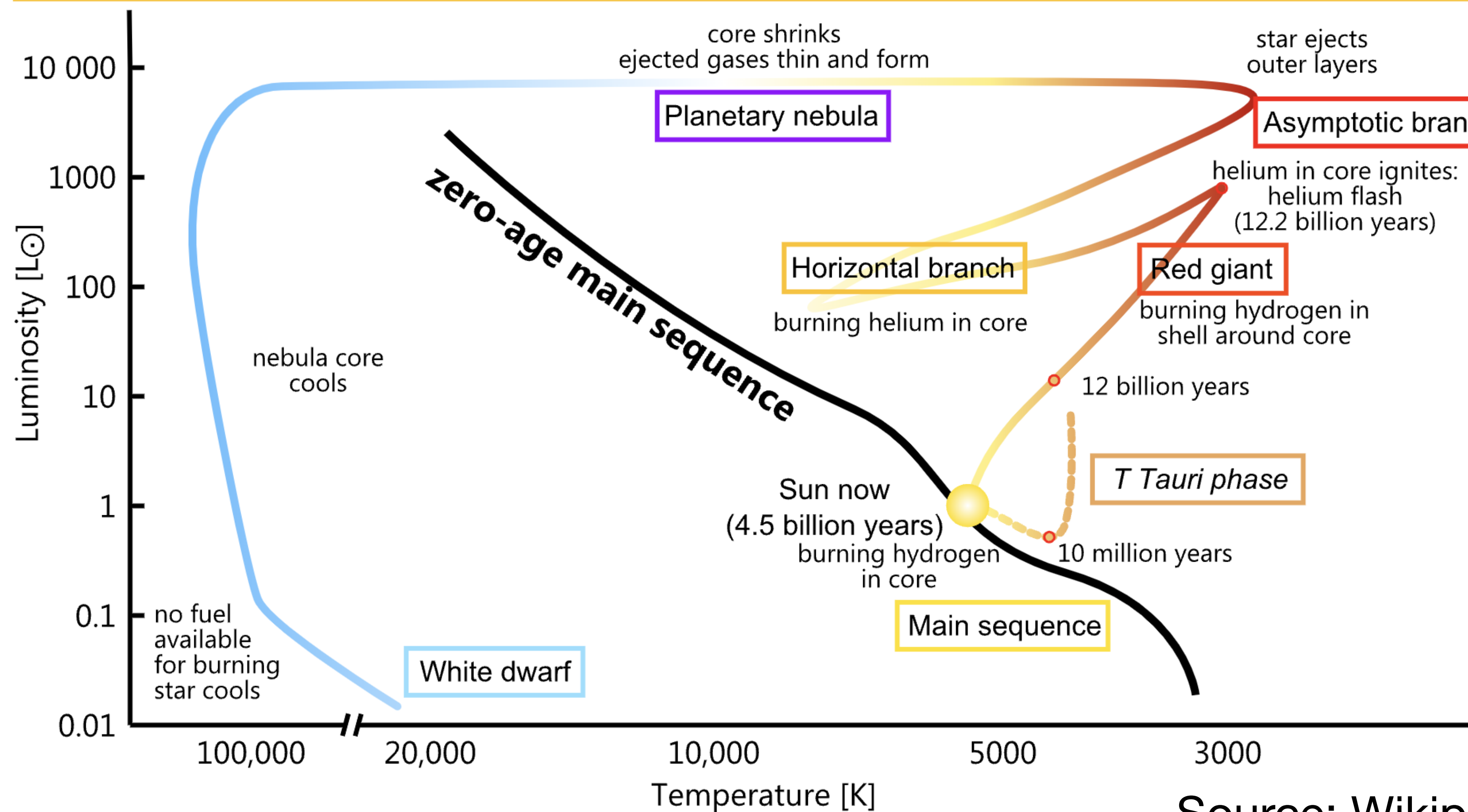
...of our SUN..!

An artistic representation of the stellar life cycle of a Sun-like star. The sequence begins in the bottom left with a series of small, yellowish-orange spheres representing protostars. These spheres increase in size and brightness as they move diagonally upwards and to the right. The final stage on the right is a large, bright red star with a complex, swirling surface pattern, representing a red giant or supergiant. A vibrant blue and yellow nebula is visible in the upper right corner, suggesting the end of the star's life cycle. The background is a deep black space filled with numerous small, distant stars.

Artist's depiction of the life cycle of a Sun-like star

Source: Wikipedia

	~9 Ga	~1 Ga	~100 Ma	~10 000 a	
Stage:	Main sequence	> Red giant	> Horizontal branch	> Planetary nebula	> White dwarf
Sun's age:	4.5 Ga (now)	12.2 Ga	12.3 Ga	12.3305 Ga	12.3306 Ga

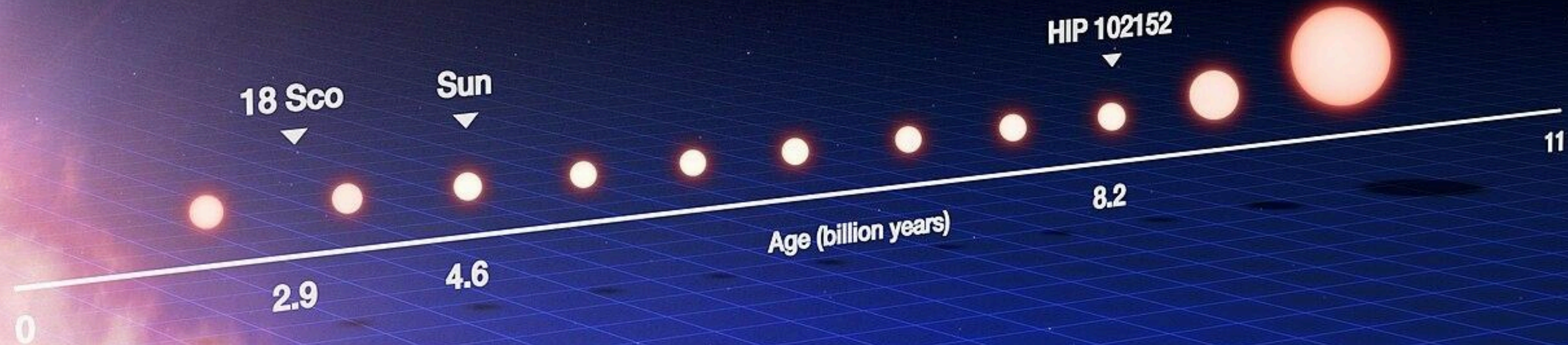


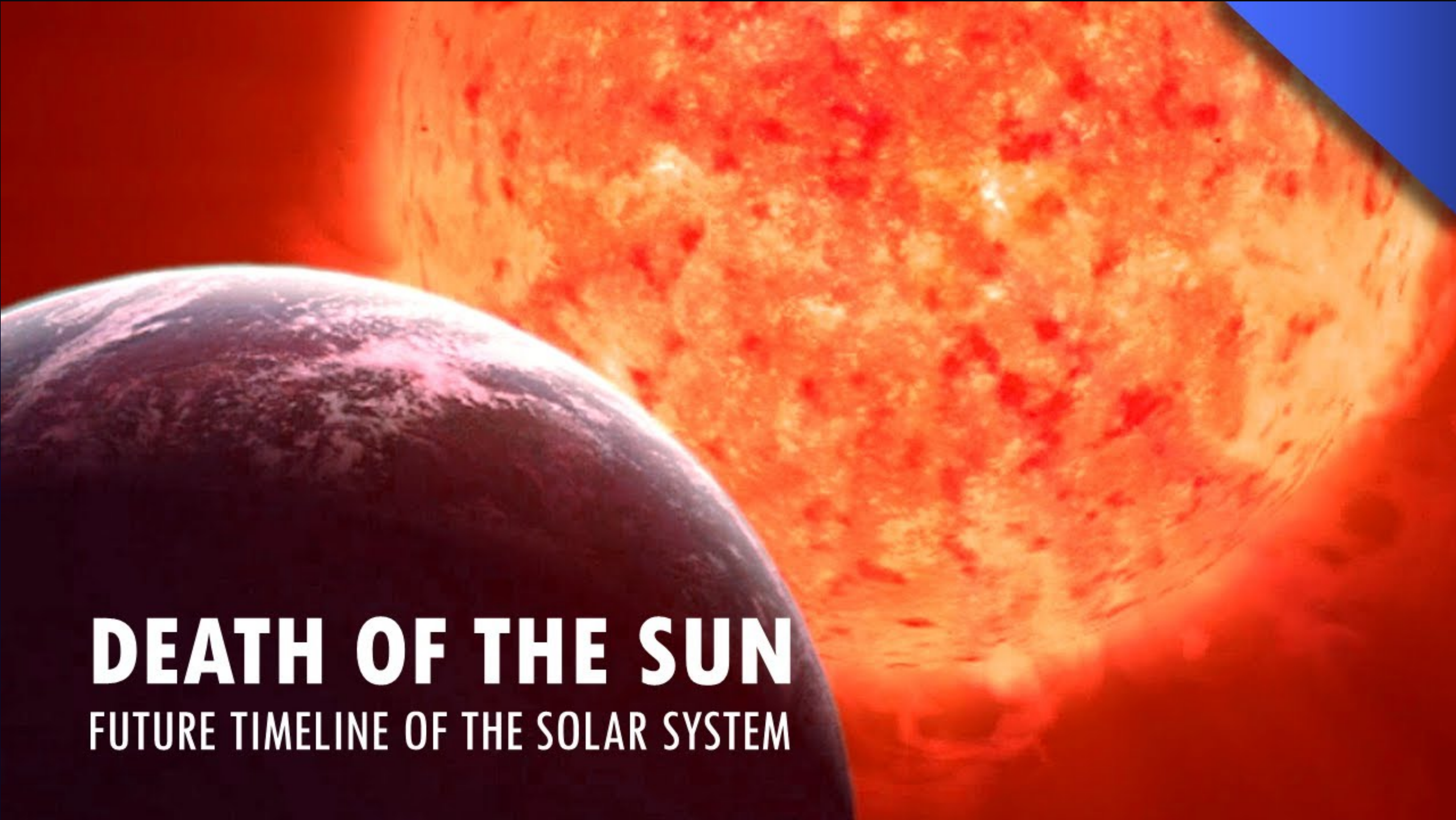
Source: Wikipedia

Evolution of our Sun on the HR diagram

Evolution of sun-like star in size

Source: Wikipedia

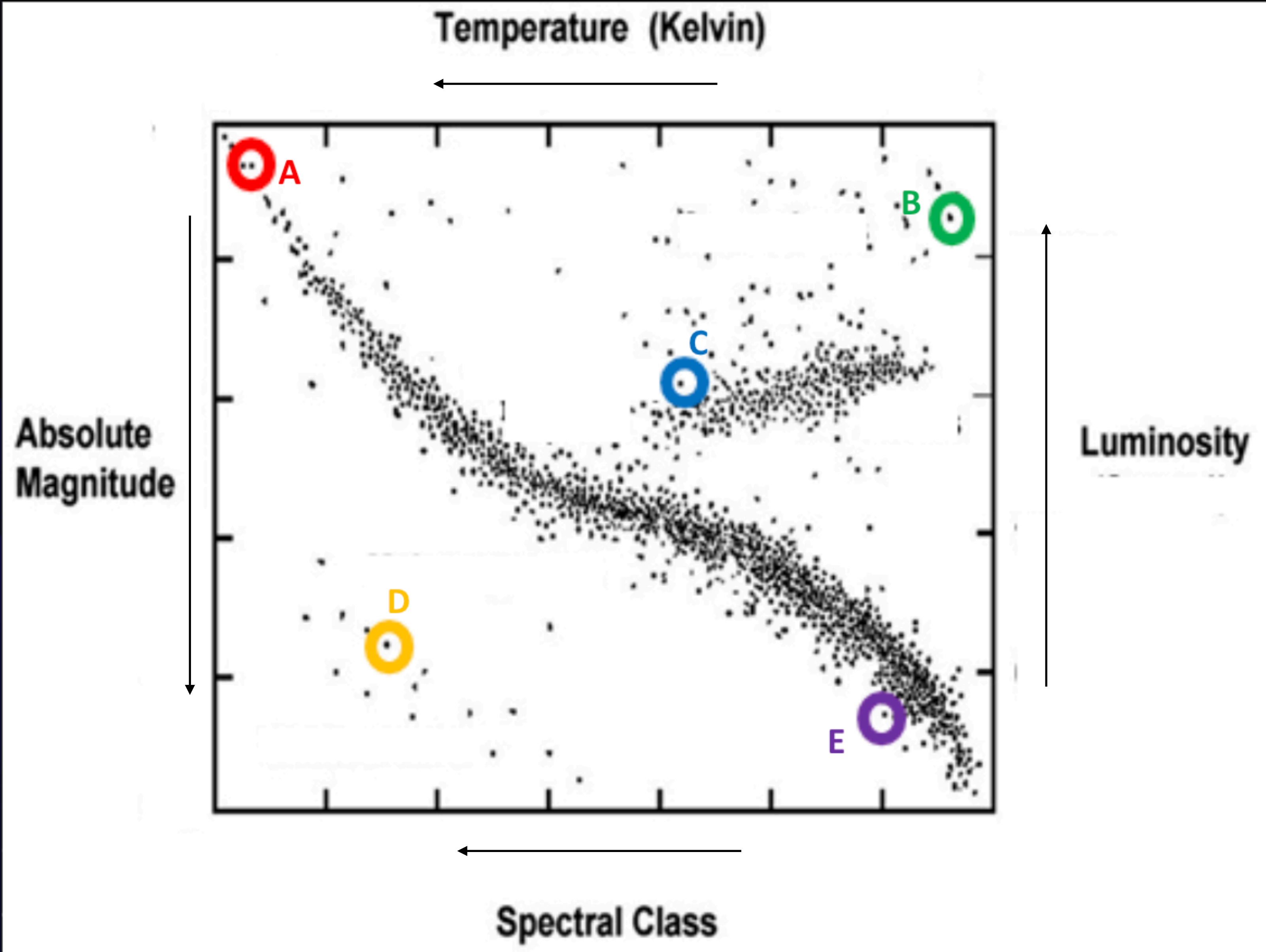




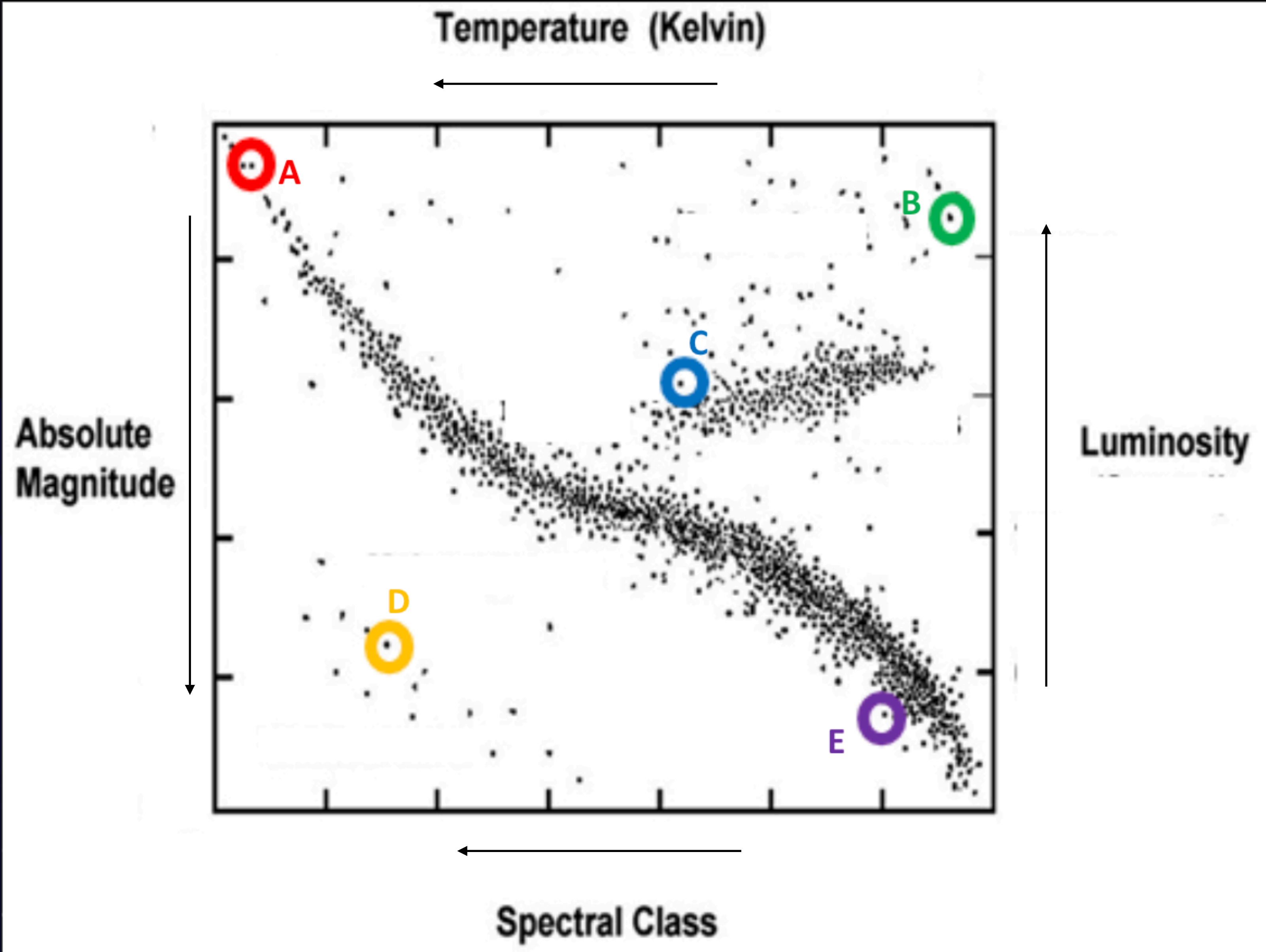
DEATH OF THE SUN

FUTURE TIMELINE OF THE SOLAR SYSTEM

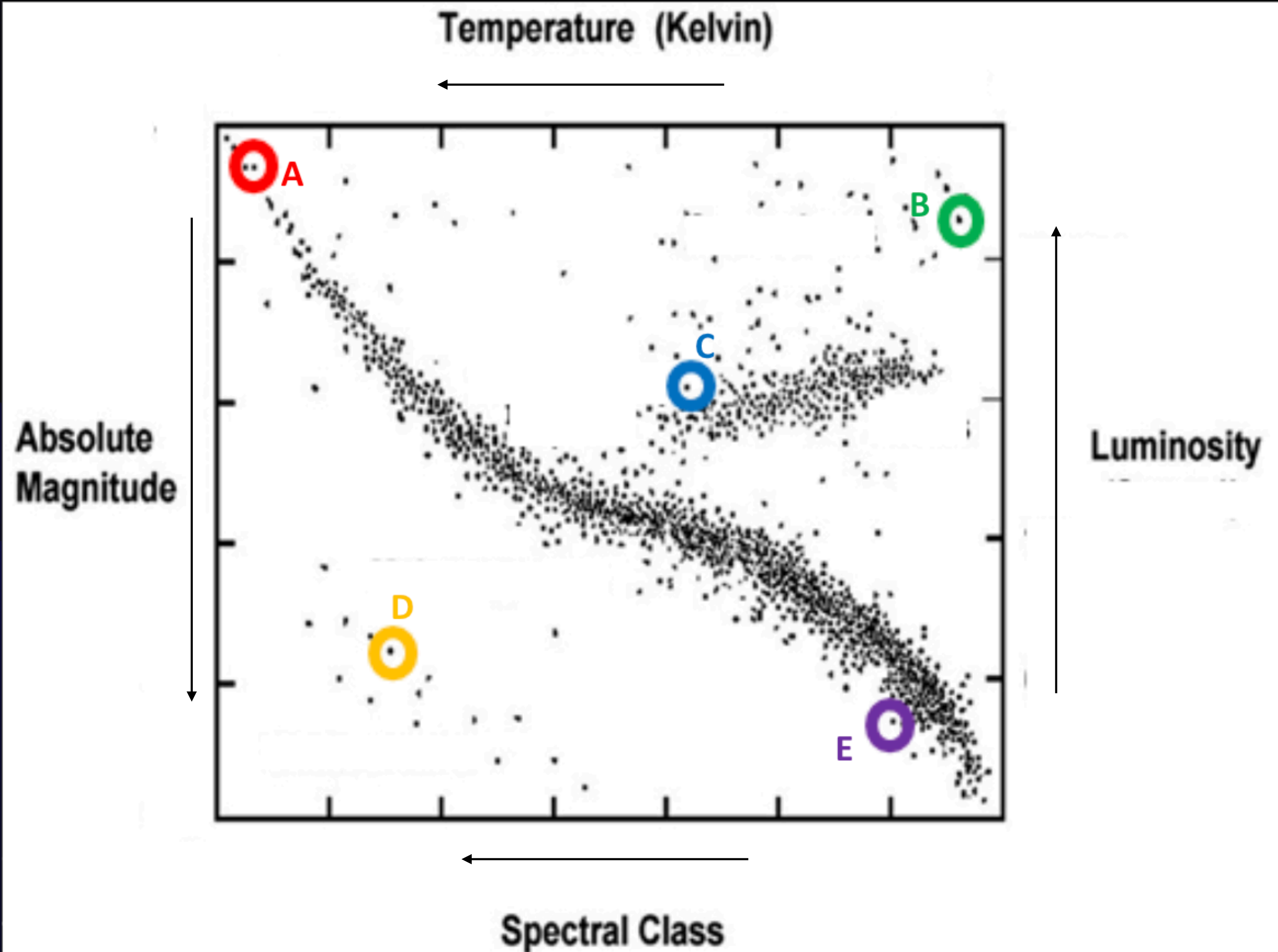
<https://youtu.be/dl7fGSGvX08>



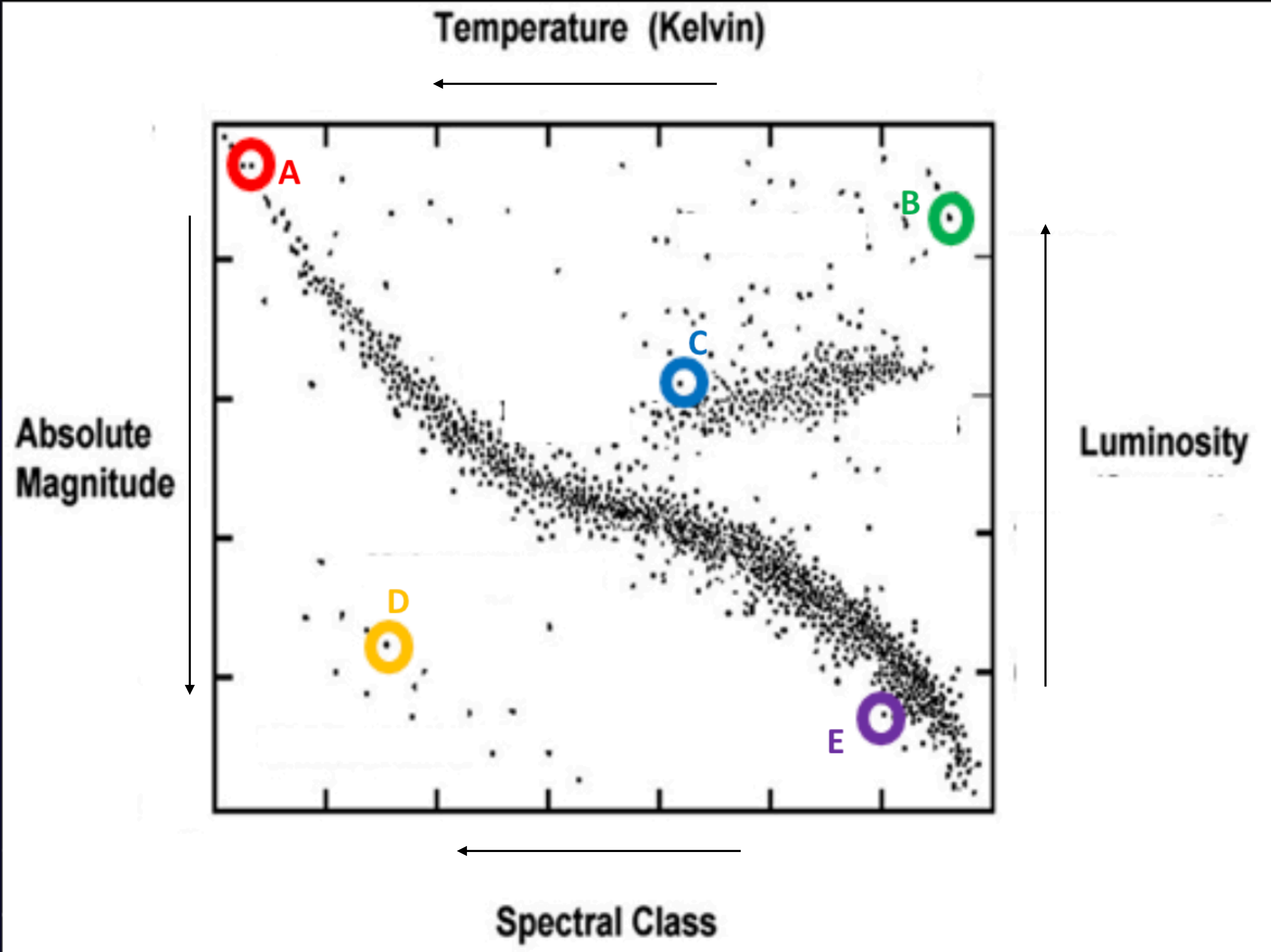
**Let's look at
some HR
diagram
trends!**



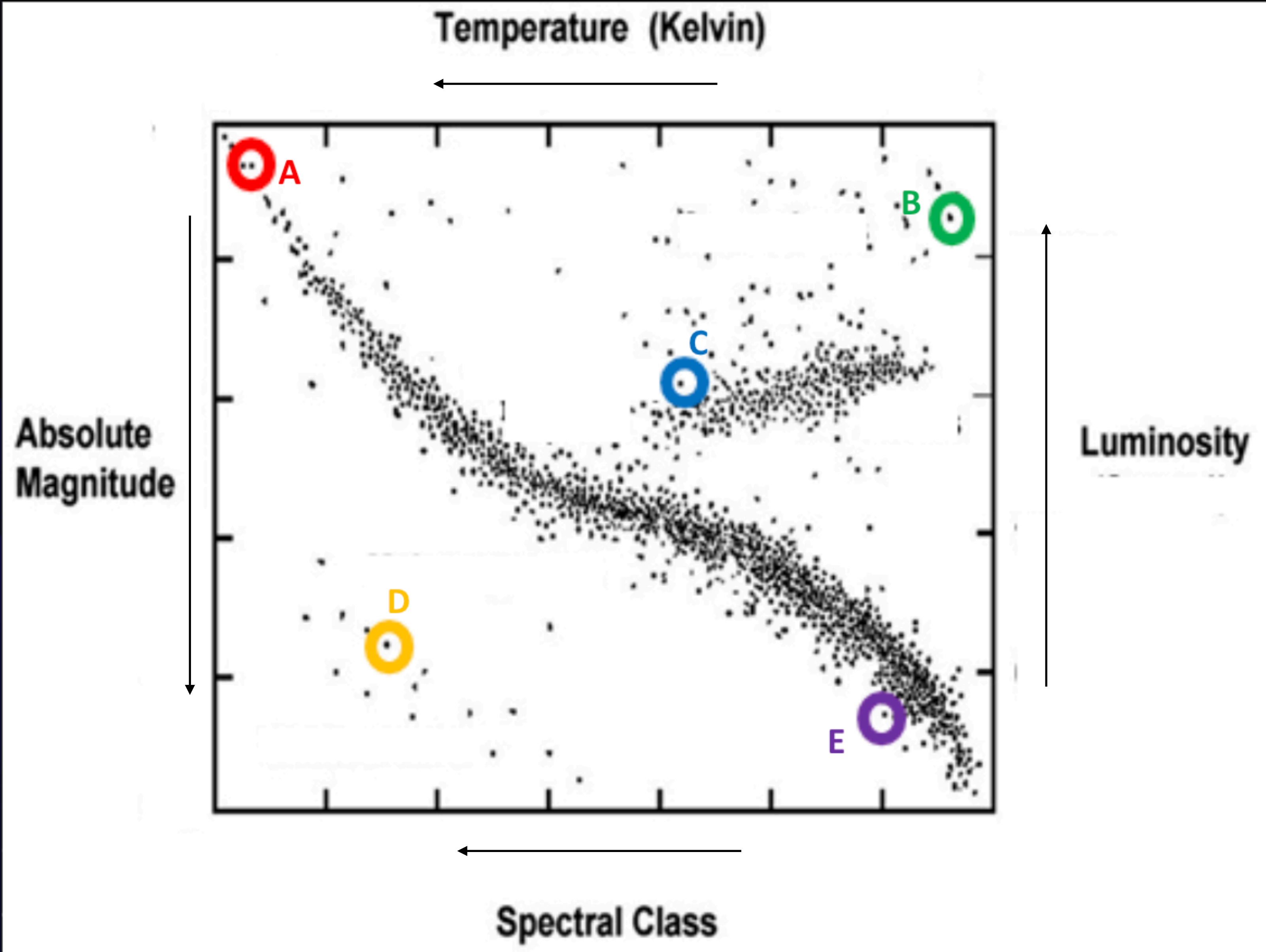
Q1. Which one in the group is a white dwarf?



Q1. Which one in the group is a white dwarf?
Ans: **D**

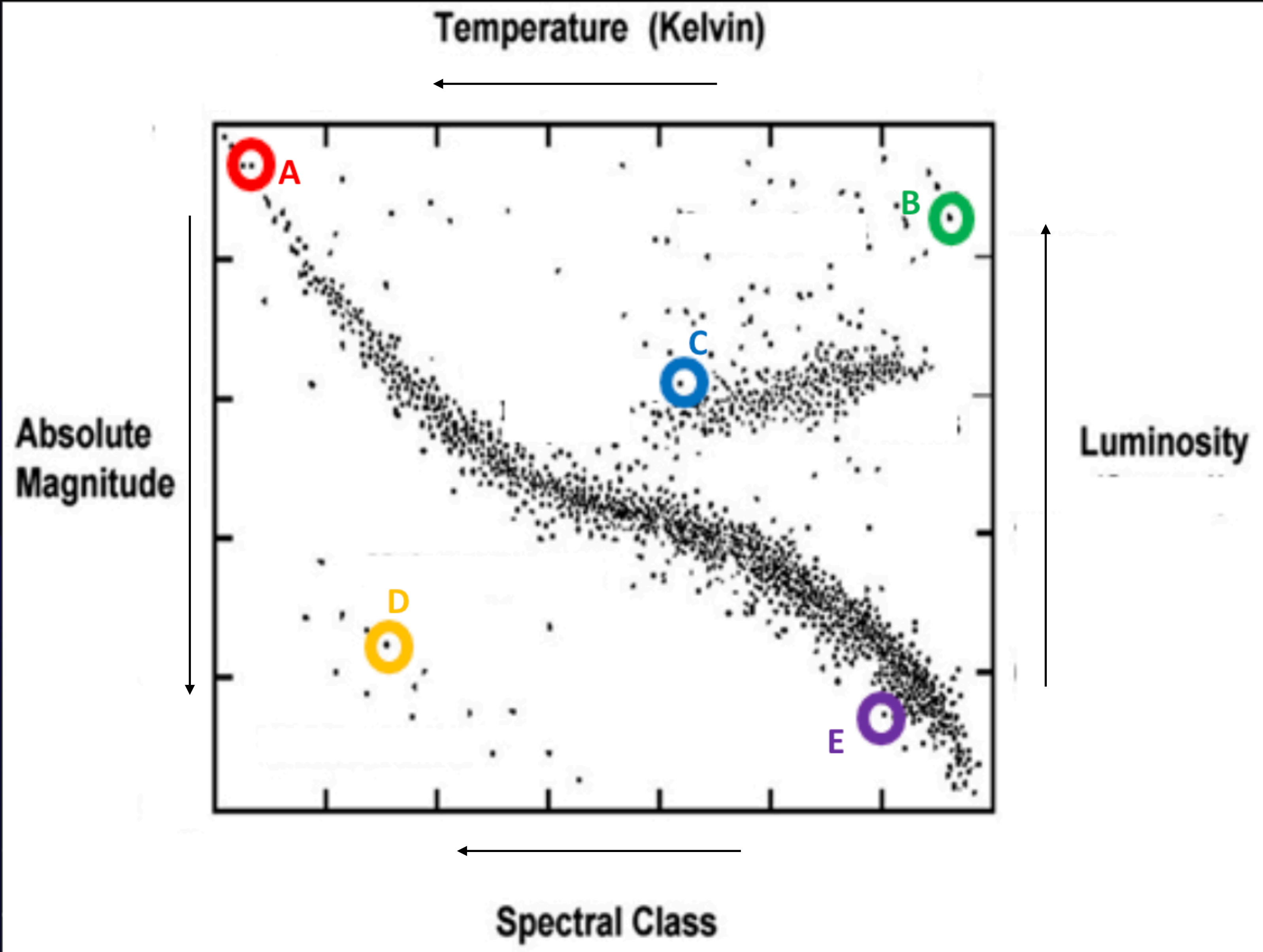


Q2. Which one in the group is the coolest star?

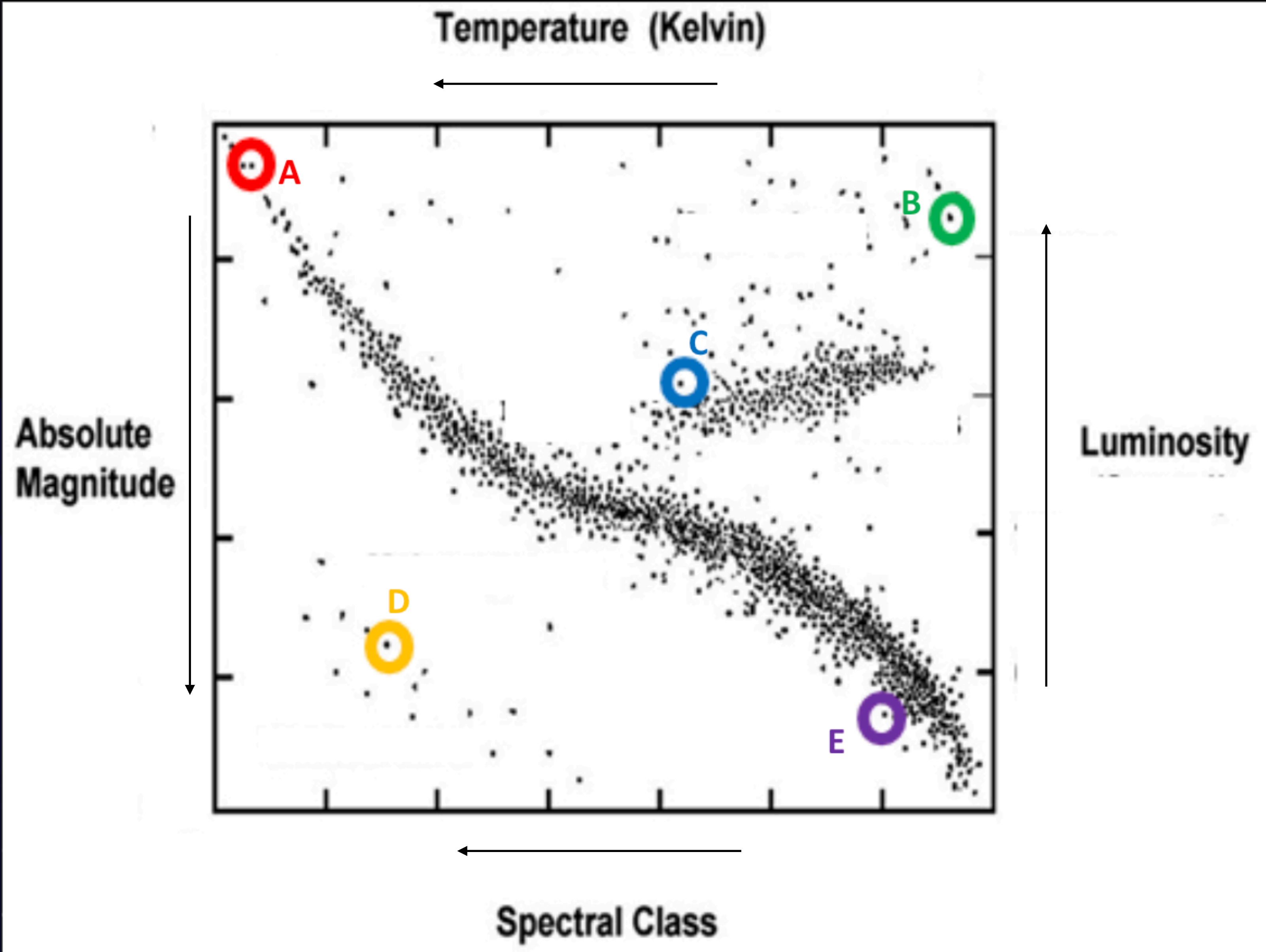


Q2. Which one in the group is the coolest star?

Ans: **B**

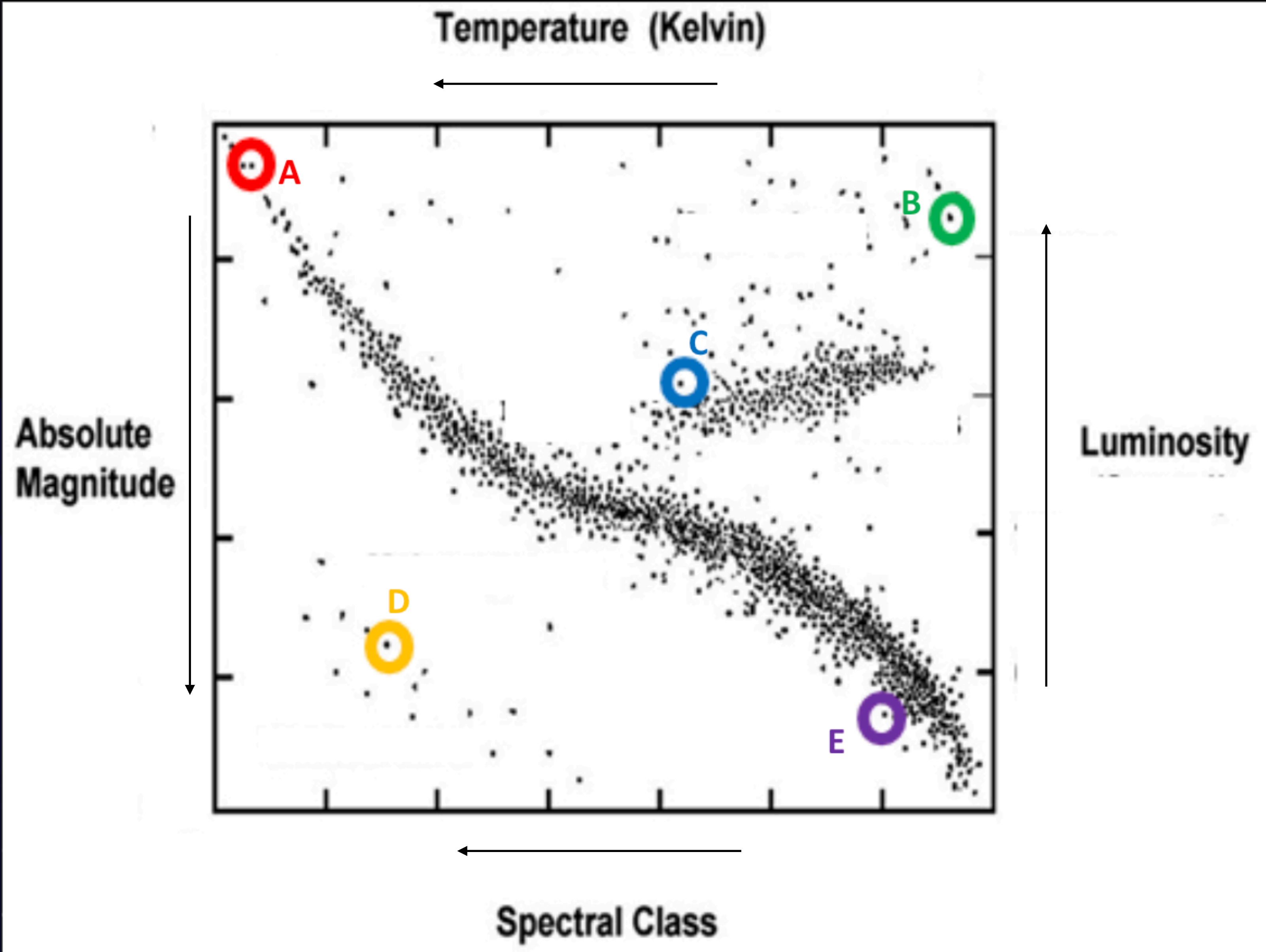


Q3. Which one in the group is the most reddish main sequence star?

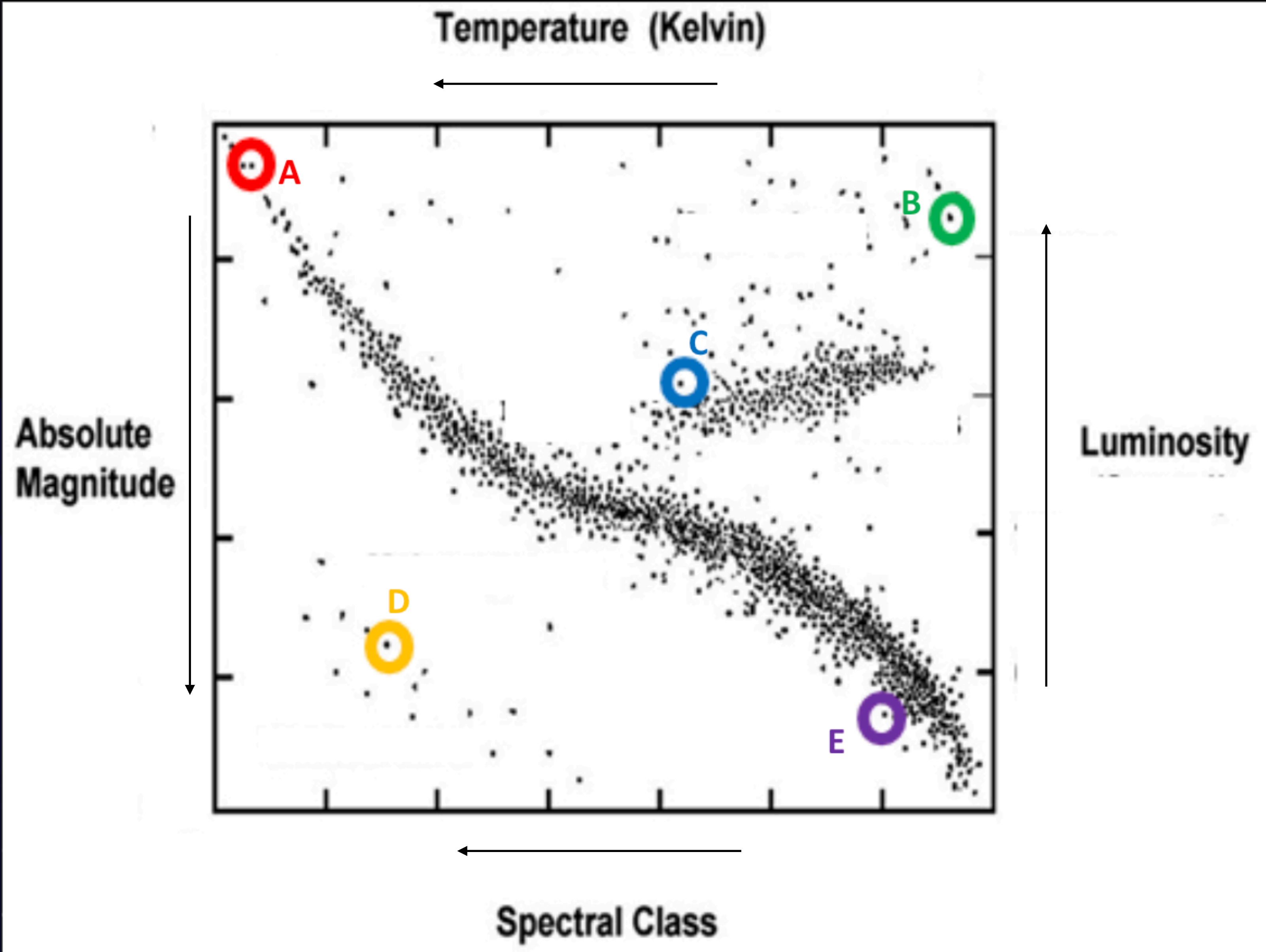


Q3. Which one in the group is the most reddish main sequence star?

Ans: E

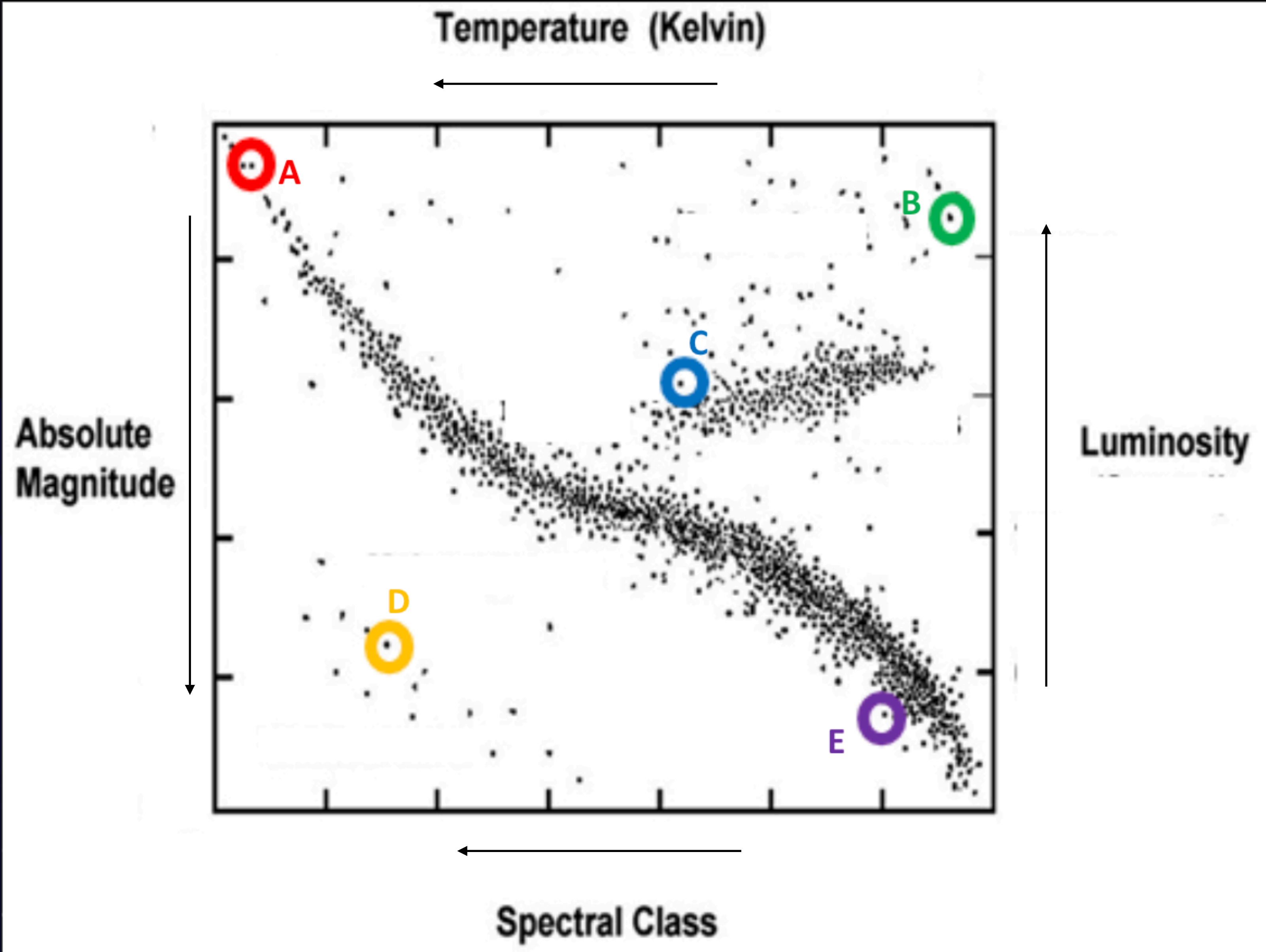


Q4. Which one in the group is the brightest star?

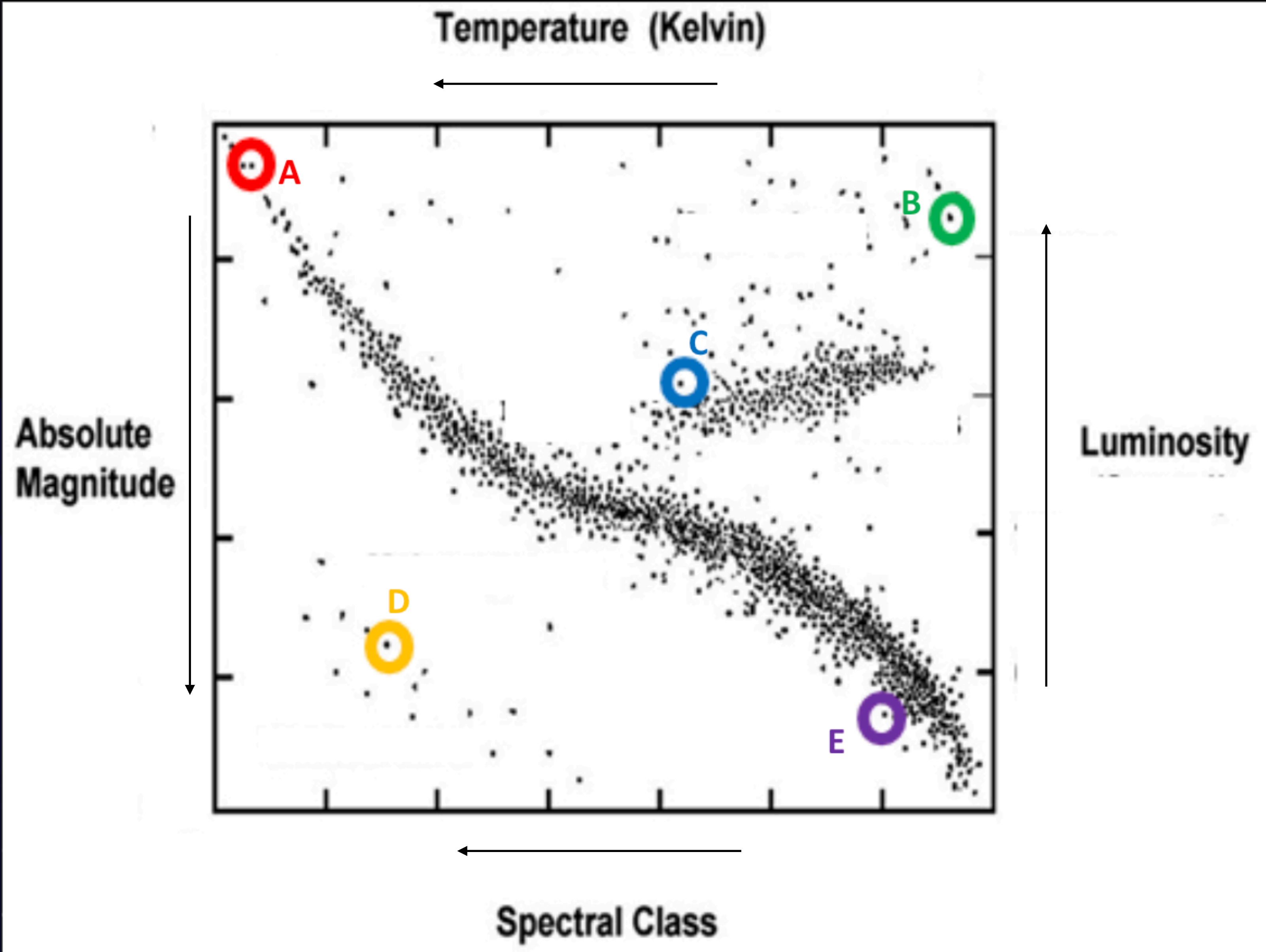


Q4. Which one in the group is the brightest star?

Ans: **A**



Q5. Which one in the group has the highest radius?

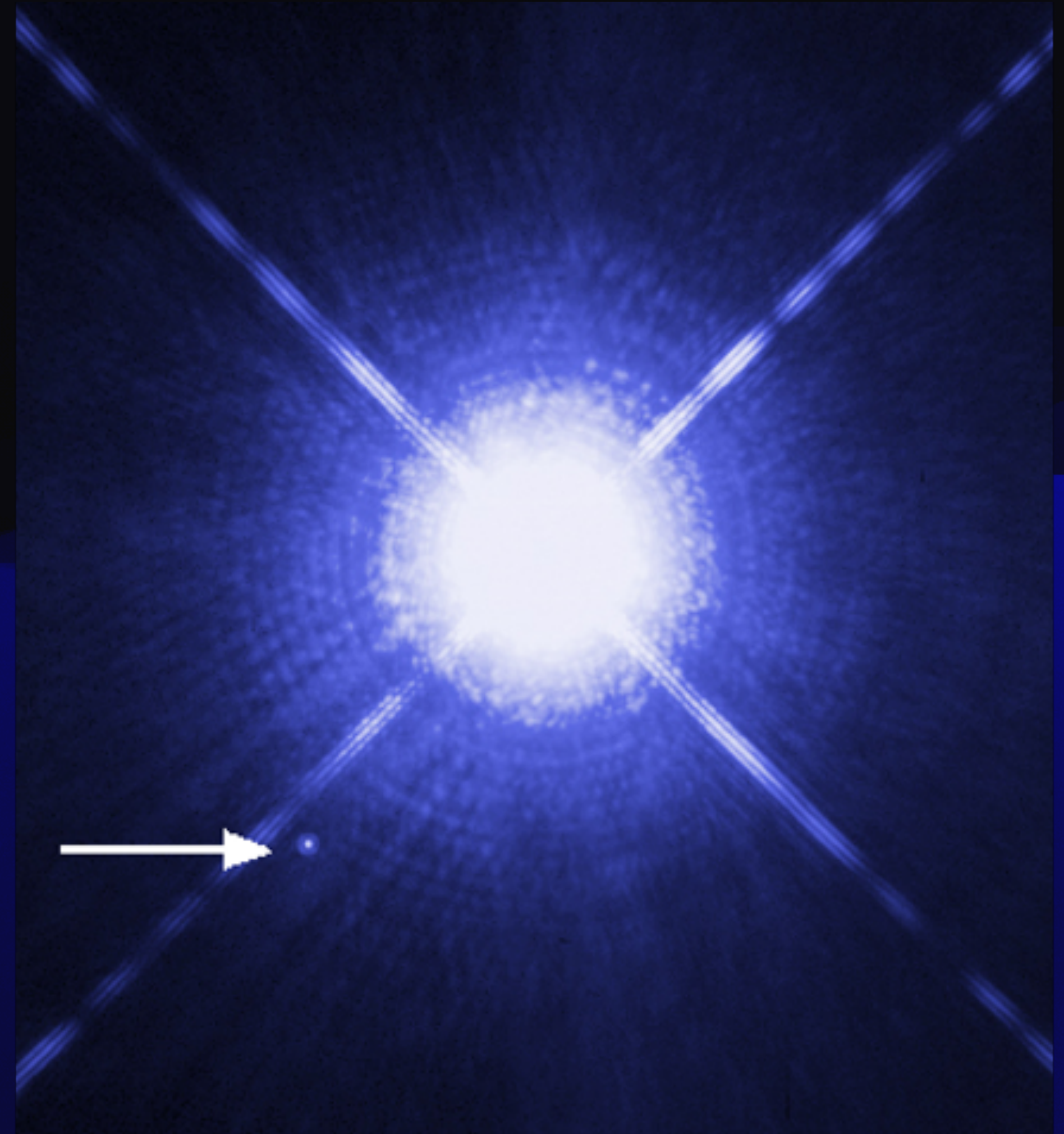


Q5. Which one in the group has the highest radius?
Ans: **B**

White dwarfs and the Chandrasekhar limit

White Dwarfs

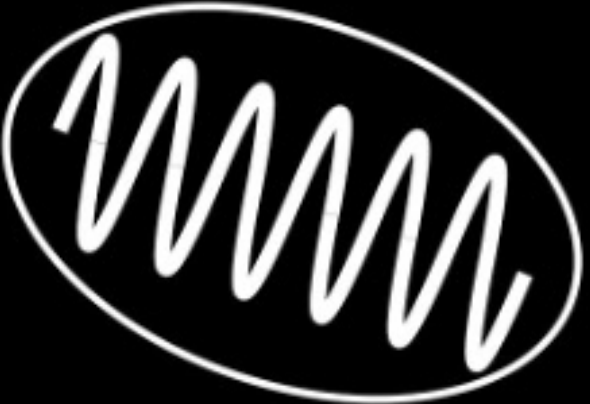
- Formed towards the end of those stars' life with $M \lesssim 10M_{\odot}$.
- Supported against gravitational collapse by the degeneracy pressure of their constituent electrons.
- Non-magnetized, non-rotating white dwarfs all obey the Chandrasekhar limit.



Hubble image of Sirius A and Sirius B

How are white dwarfs held together?

The answer lies in **quantum statistical mechanics**.

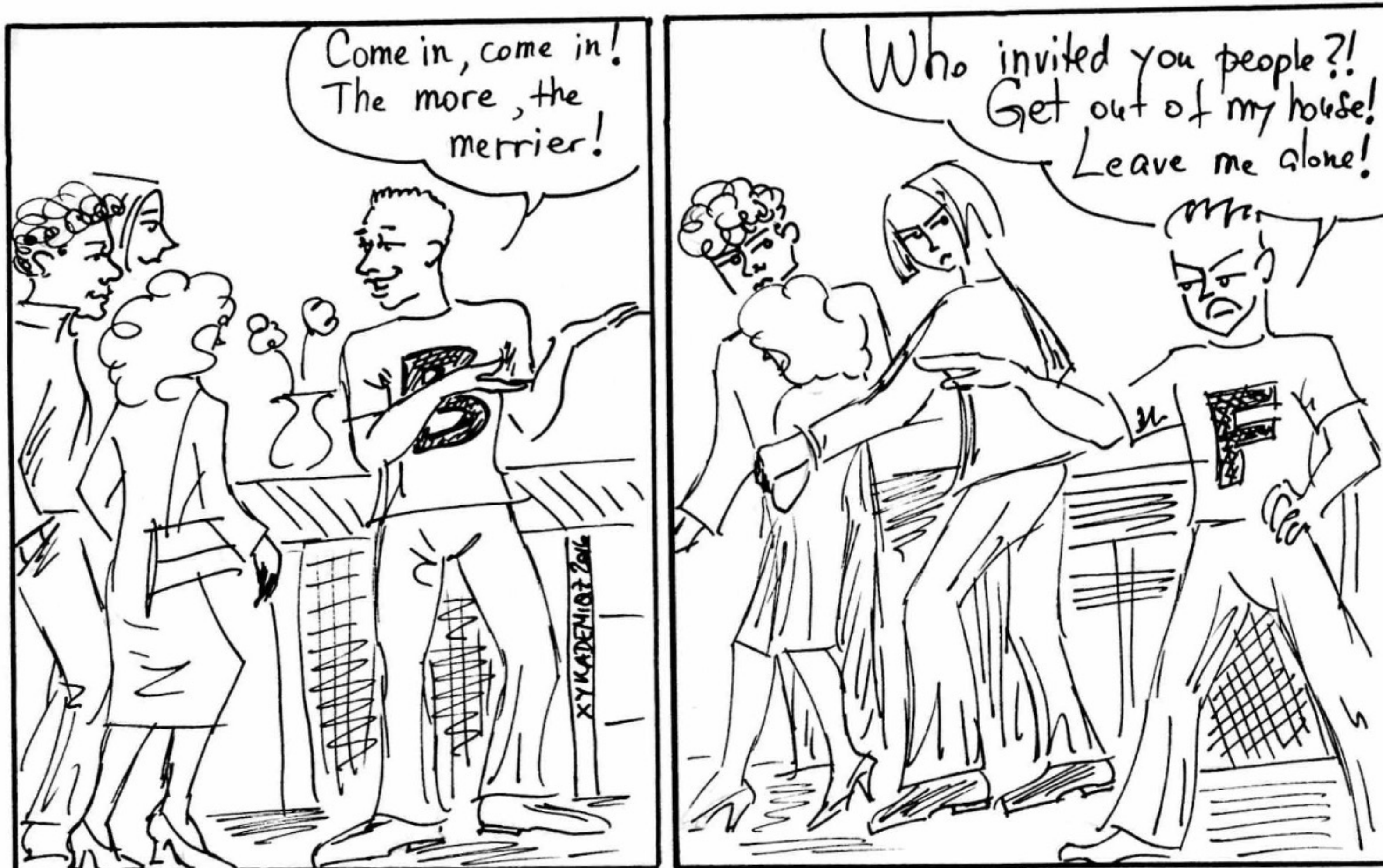
$$\lambda = \frac{h}{p}$$


If packing atoms so close that their wave nature is important

→ Maxwell-Boltzmann distribution no longer correct

Similar to classical mechanics → quantum mechanics

Classical statistical mechanics → Quantum statistical mechanics

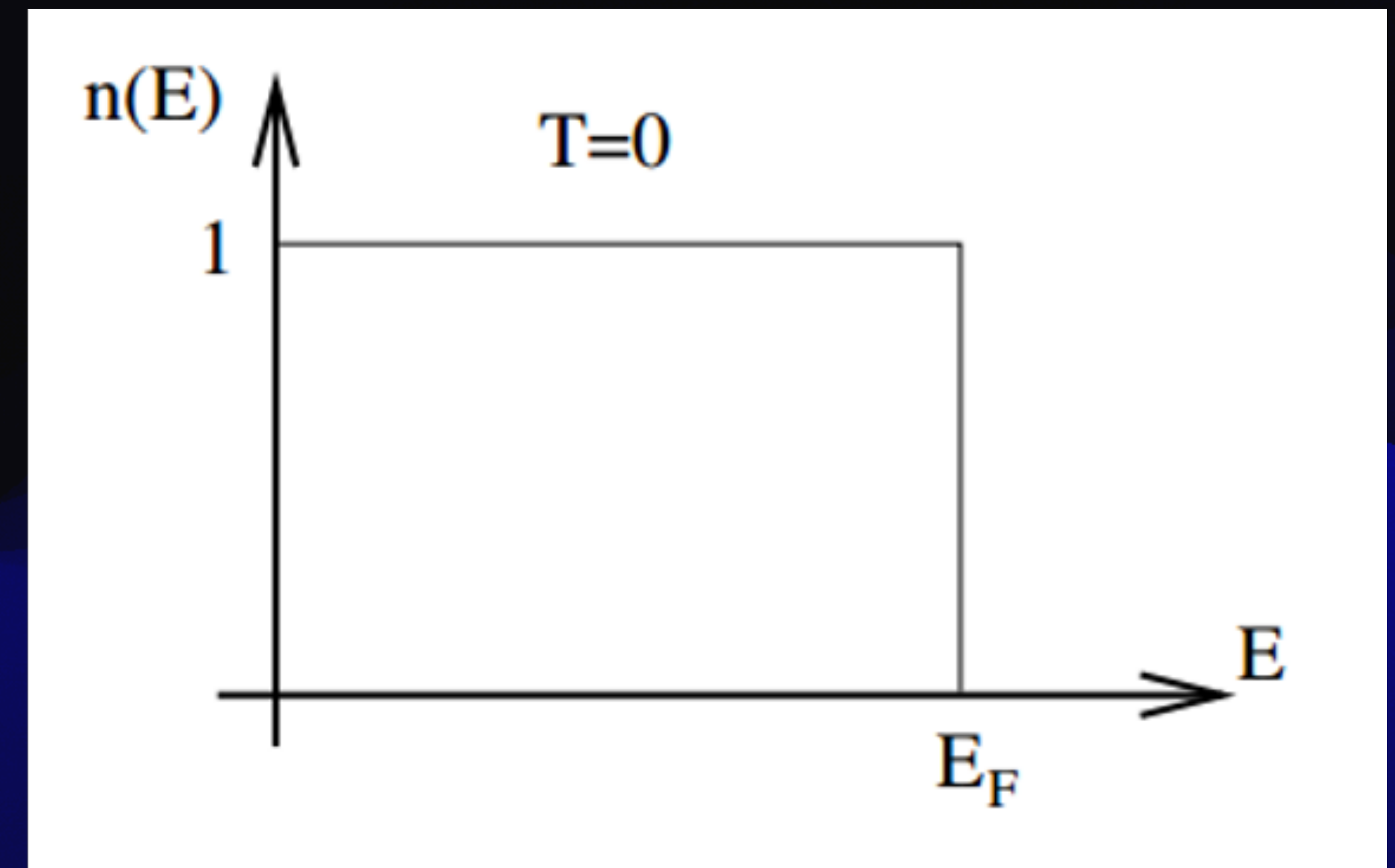


BOSON VS. FERMION

Fermions are particles of half-integral spin. They obey the Pauli Exclusion Principle.

At $T = 0$ K, the fermi gas becomes completely degenerate.

Even at zero temperature, the gas has non-zero pressure, called degeneracy pressure, or fermi pressure.



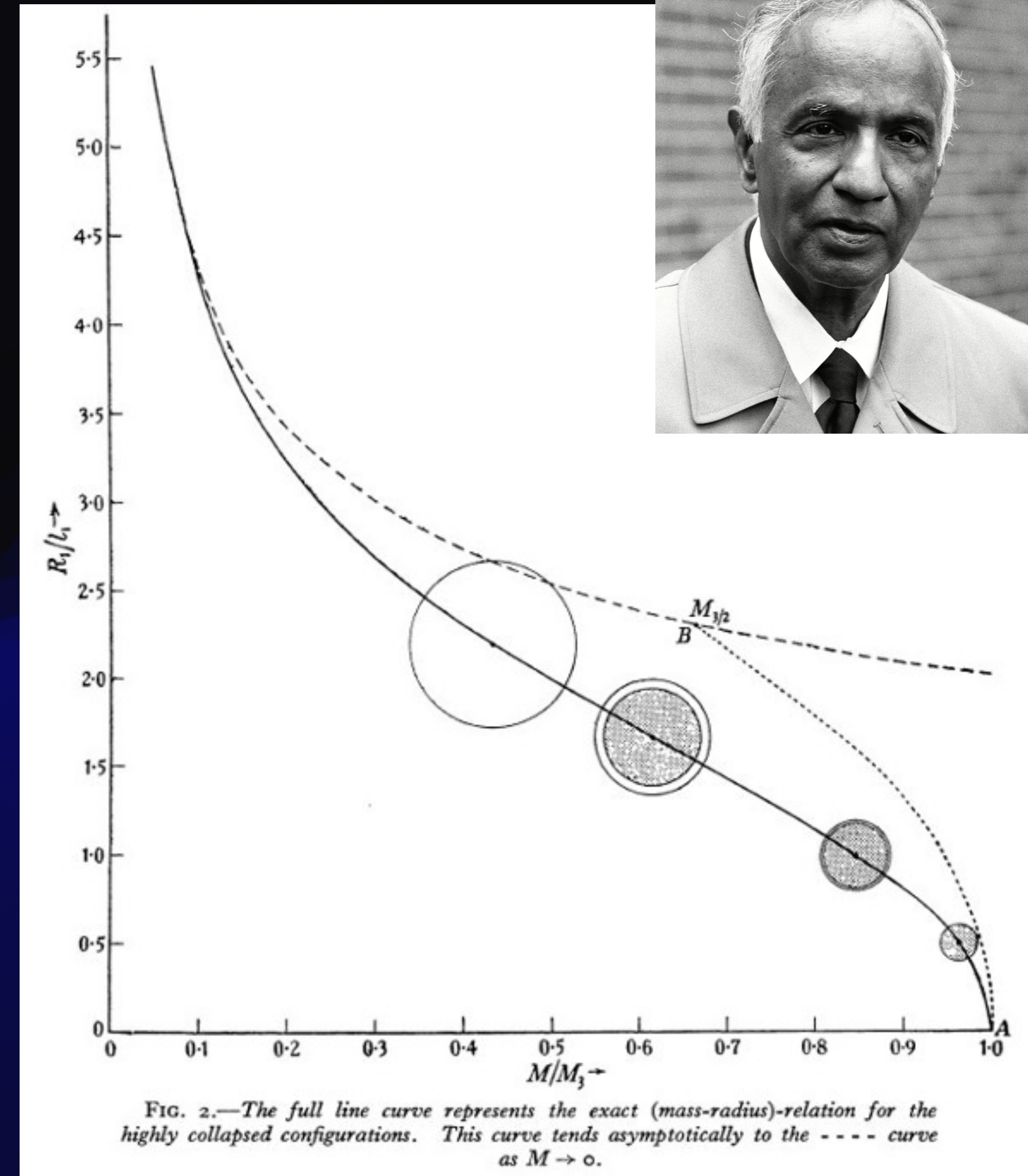
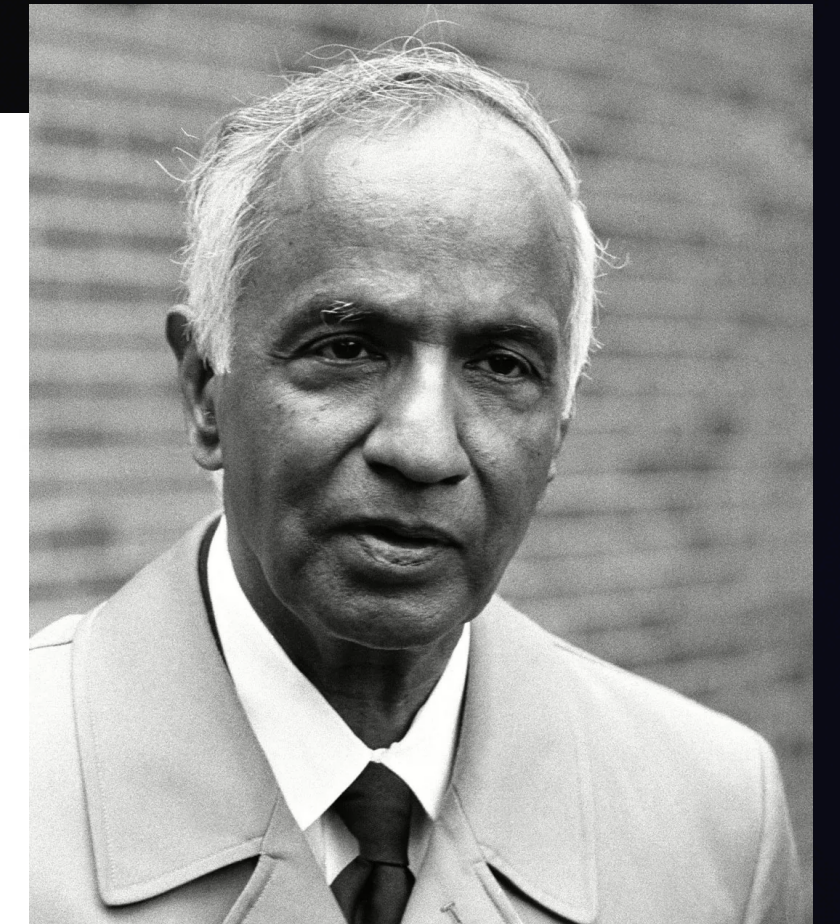
In white dwarfs, it is this degeneracy pressure of the constituent electrons that stabilises the star against gravitational collapse.

Stabilization against gravity due to degeneracy pressure of electrons
 → continues till particles fermi velocity reaches speed of light
 → **Chandrasekhar limit!**

$$M_{Ch} \sim \frac{M_{pl}}{m_n^2}$$

“...the presence of the Planck scale in the Chandra limit is telling us that both **quantum effects and gravitational effects** are needed to understand white dwarf stars: **the matter is quantum; the gravity is classical.**”

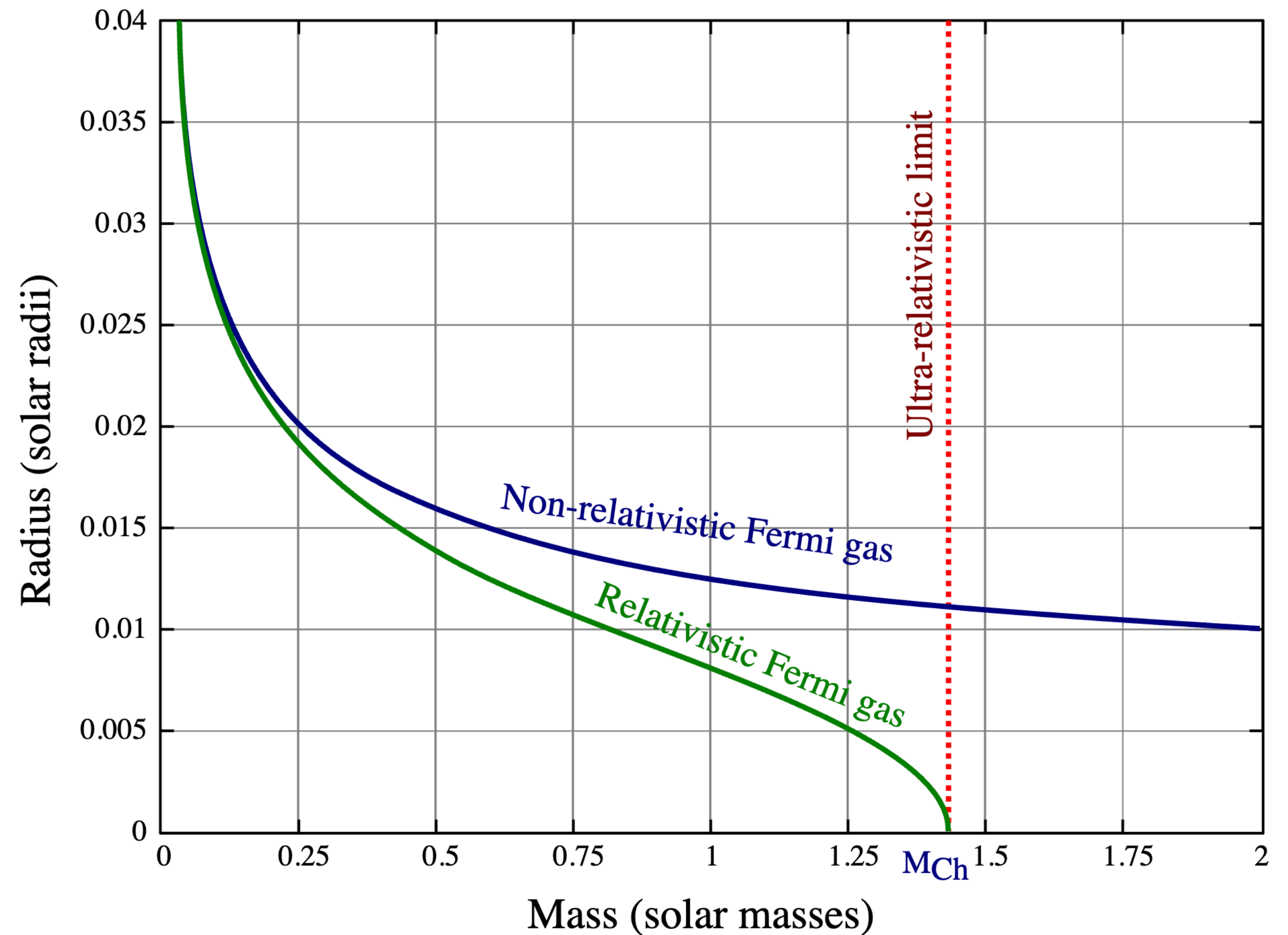
- David Tong, Notes on Statistical Physics



Chandrasekhar, MNRAS (1935)

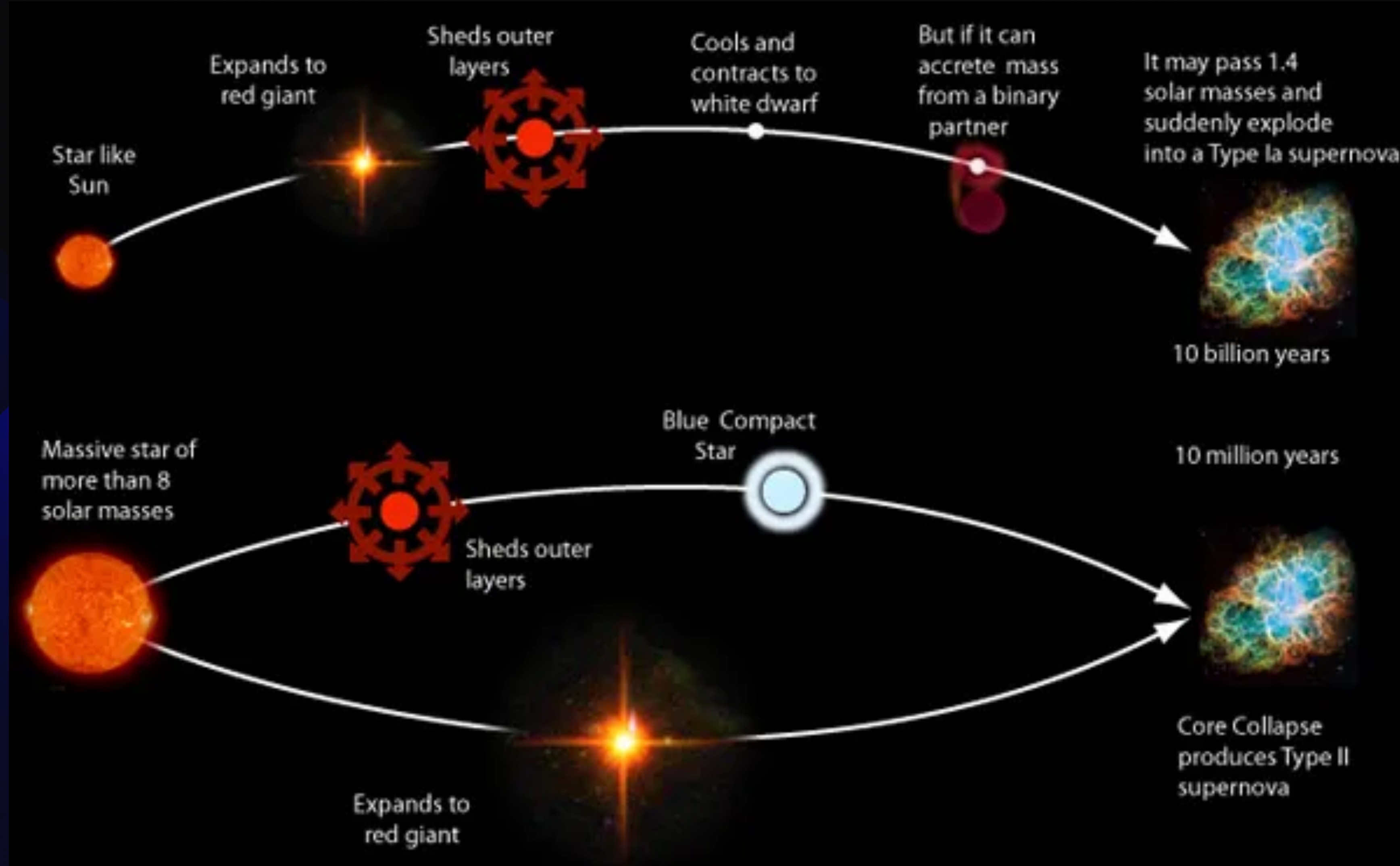
You can use the **Lane-Emden equation** as a way to derive the Chandrasekhar equation under certain assumptions.

Warning: requires some knowledge of ideal fermi gases



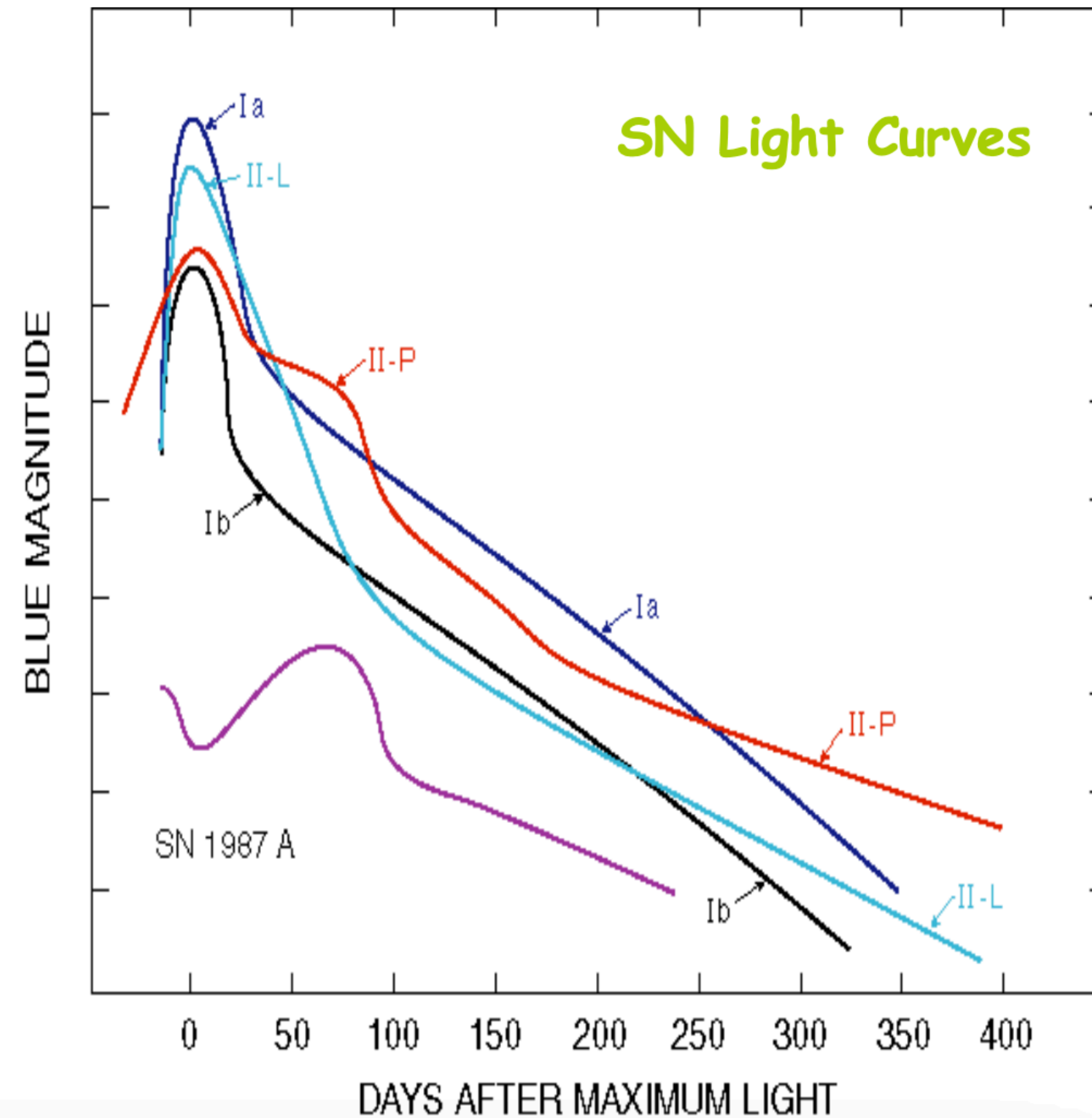
Source: Wikimedia commons

Supernovae and Pulsars



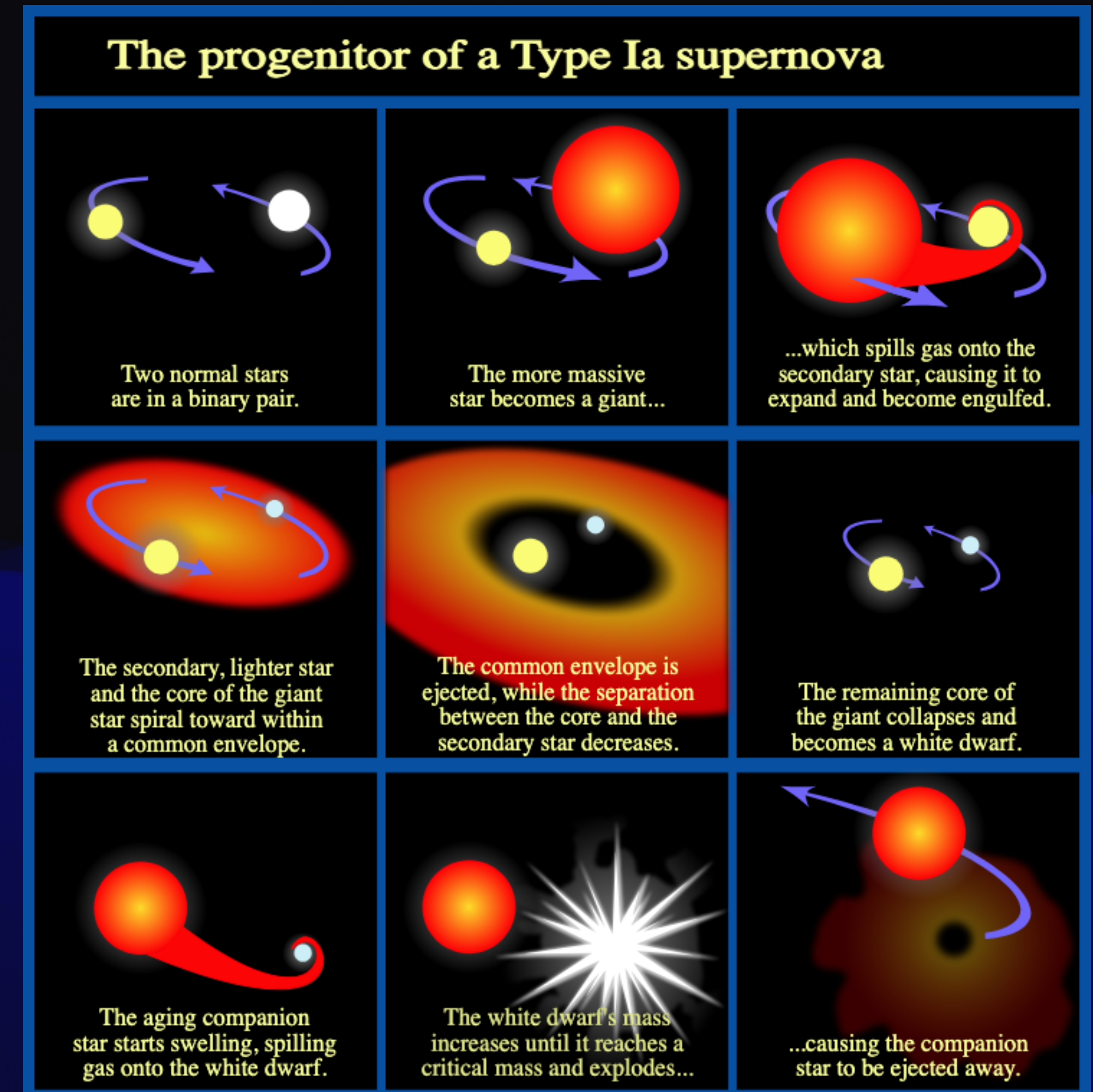
Supernovae

- Explosion of a Star
 - Explosive Nucleosynthesis -> Radioactive Energy
- Energy Release
 - Radioactive Heating
 - Progressive Transparency of Exploding Star
 - Recombination Radiation (stored ionizing energy of explosion)
- Types
 - Thermonuclear Supernovae (Type Ia)
 - Gravitational Collapse Supernovae (Types II, Ib/c)



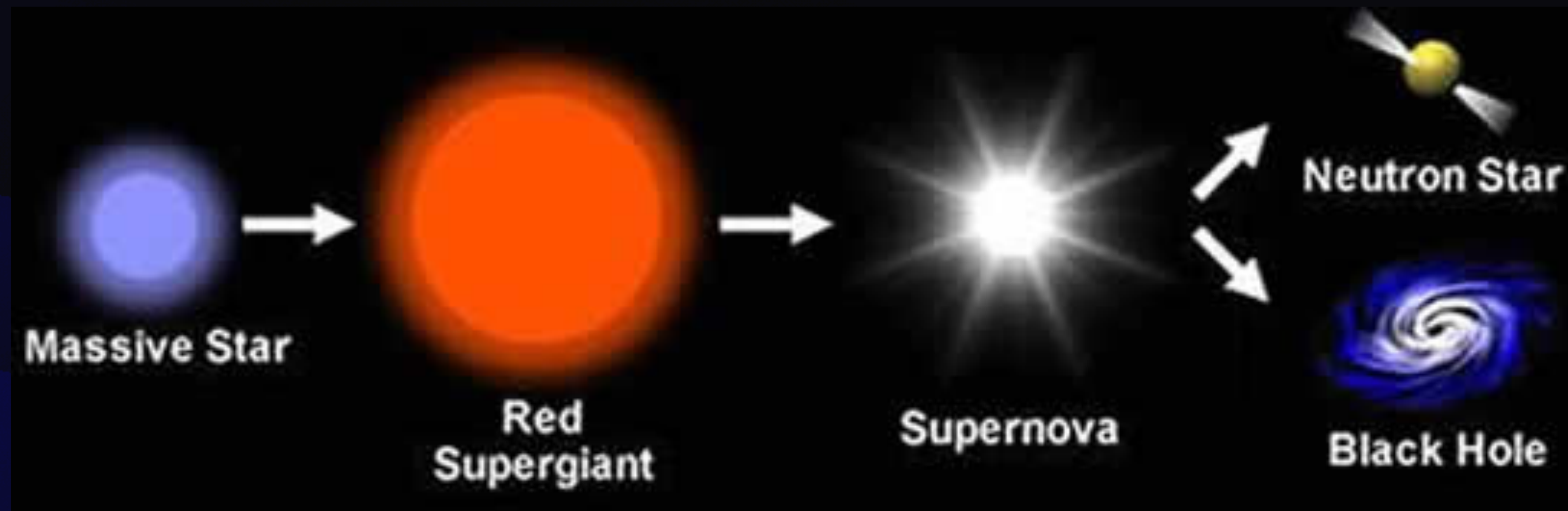
Type Ia supernova

- Formed by the thermonuclear explosion of a white dwarf which has accreted (gained mass) beyond the Chandrasekhar limit ($\sim 1.4M_{\odot}$).
- Produces a consistent peak luminosity.
- Allows these events to be used as standard candles to measure the **distance to their host galaxies**.

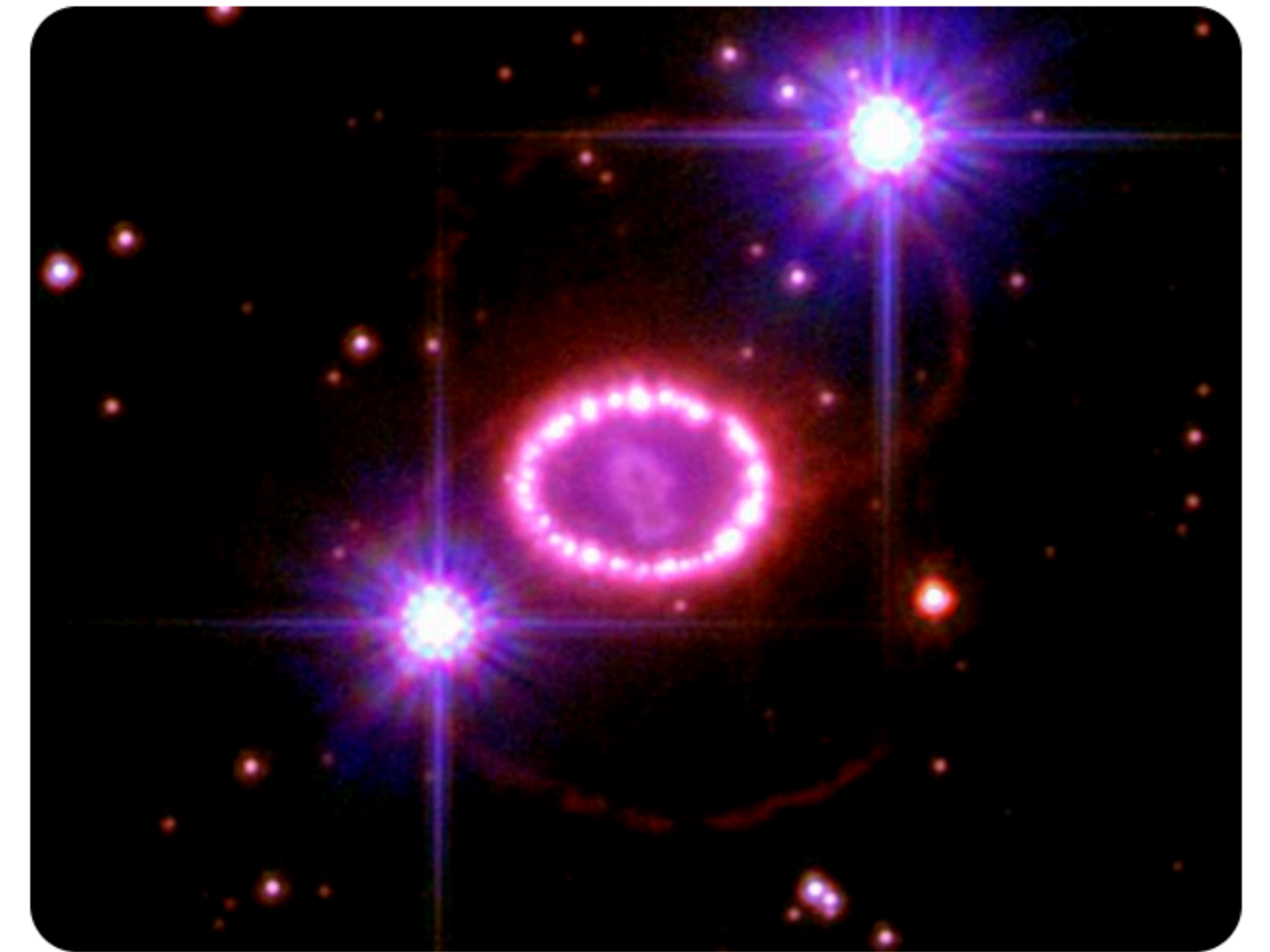


Source: Wikimedia

Type II supernovae



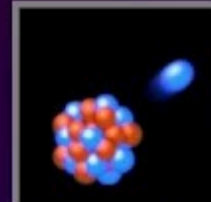
Lifecycle of a massive ($M > 8M_{\odot}$) star.



The expanding remnant of SN 1987A, a peculiar Type II supernova in the Large Magellanic Cloud.
NASA image.



ORIGINS OF THE ELEMENTS

H1 Hydrogen	 The big bang  Dying low-mass stars  White dwarf supernovae  Radioactive decay																He2 Helium															
Li3 Lithium	Be4 Beryllium																	B5 Boron	C6 Carbon	N7 Nitrogen	O8 Oxygen	F9 Fluorine	Ne10 Neon									
Na11 Sodium	Mg12 Magnesium																	Al13 Aluminum	Si14 Silicon	P15 Phosphorus	S16 Sulfur	Cl17 Chlorine	Ar18 Argon									
K19 Potassium	Ca20 Calcium	Sc21 Scandium	Ti22 Titanium	V23 Vanadium	Cr24 Chromium	Mn25 Manganese	Fe26 Iron	Co27 Cobalt	Ni28 Nickel	Cu29 Copper	Zn30 Zinc	Ga31 Gallium	Ge32 Germanium	As33 Arsenic	Se34 Selenium	Br35 Bromine	Kr36 Krypton															
Rb37 Rubidium	Sr38 Strontium	Y39 Yttrium	Zr40 Zirconium	Nb41 Niobium	Mo42 Molybdenum	Tc43 Technetium	Ru44 Ruthenium	Rh45 Rhodium	Pd46 Palladium	Ag47 Silver	Cd48 Cadmium	In49 Indium	Sn50 Tin	Sb51 Antimony	Te52 Tellurium	I53 Iodine	Xe54 Xenon															
Cs55 Cesium	Ba56 Barium																	Hf72 Hafnium	Ta73 Tantalum	W74 Tungsten	Re75 Rhenium	Os76 Osmium	Ir77 Iridium	Pt78 Platinum	Au79 Gold	Hg80 Mercury	Tl81 Thallium	Pb82 Lead	Bi83 Bismuth	Po84 Polonium	At85 Astatine	Rn86 Radon
Fr87 Francium	Ra88 Radium																	Rf104 Rutherfordium	Db105 Dubnium	Sg106 Seaborgium	Bh107 Bohrium	Hs108 Hassium	Mt109 Meitnerium	Ds110 Darmstadtium	Rg111 Roentgenium	Cn112 Copernicium	Nh113 Nihonium	Fl114 Flerovium	Mc115 Moscovium	Lv116 Livermorium	Ts117 Tennessine	Og118 Oganesson
																		La57 Lanthanum	Ce58 Cerium	Pr59 Praseodymium	Nd60 Neodymium	Pm61 Promethium	Sm62 Samarium	Eu63 Europium	Gd64 Gadolinium	Tb65 Terbium	Dy66 Dysprosium	Ho67 Holmium	Er68 Erbium	Tm69 Thulium	Yb70 Ytterbium	Lu71 Lutetium
																		Ac89 Actinium	Th90 Thorium	Pa91 Protactinium	U92 Uranium	Np93 Neptunium	Pu94 Plutonium	Am95 Americium	Cm96 Curium	Bk97 Berkelium	Cf98 Californium	Es99 Einsteinium	Fm100 Fermium	Md101 Mendelevium	No102 Nobelium	Lr103 Lawrencium

This periodic table depicts the primary source on Earth for each element. In cases where two sources contribute fairly equally, both appear.

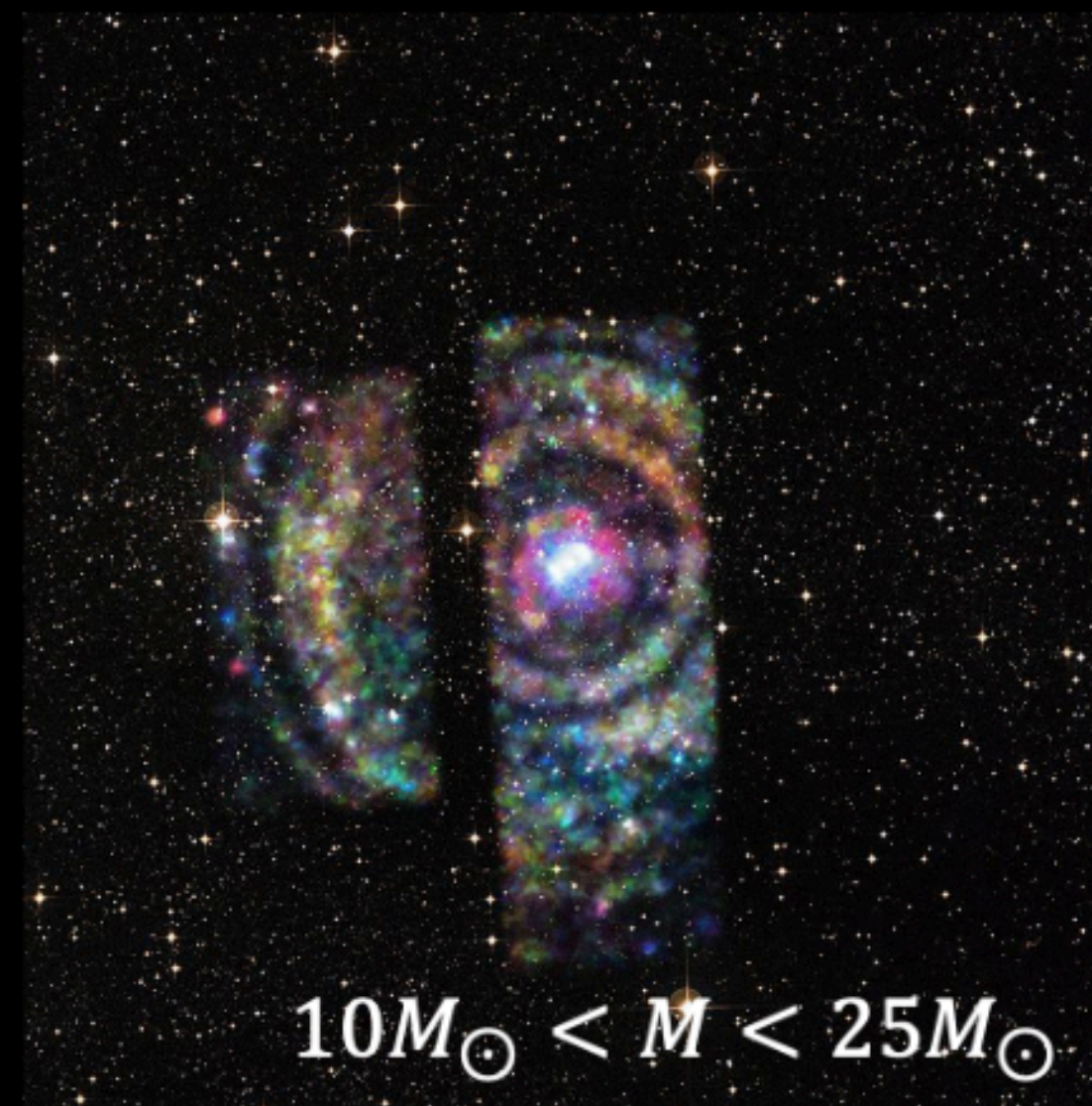
Stars living and dying...

Compact stars

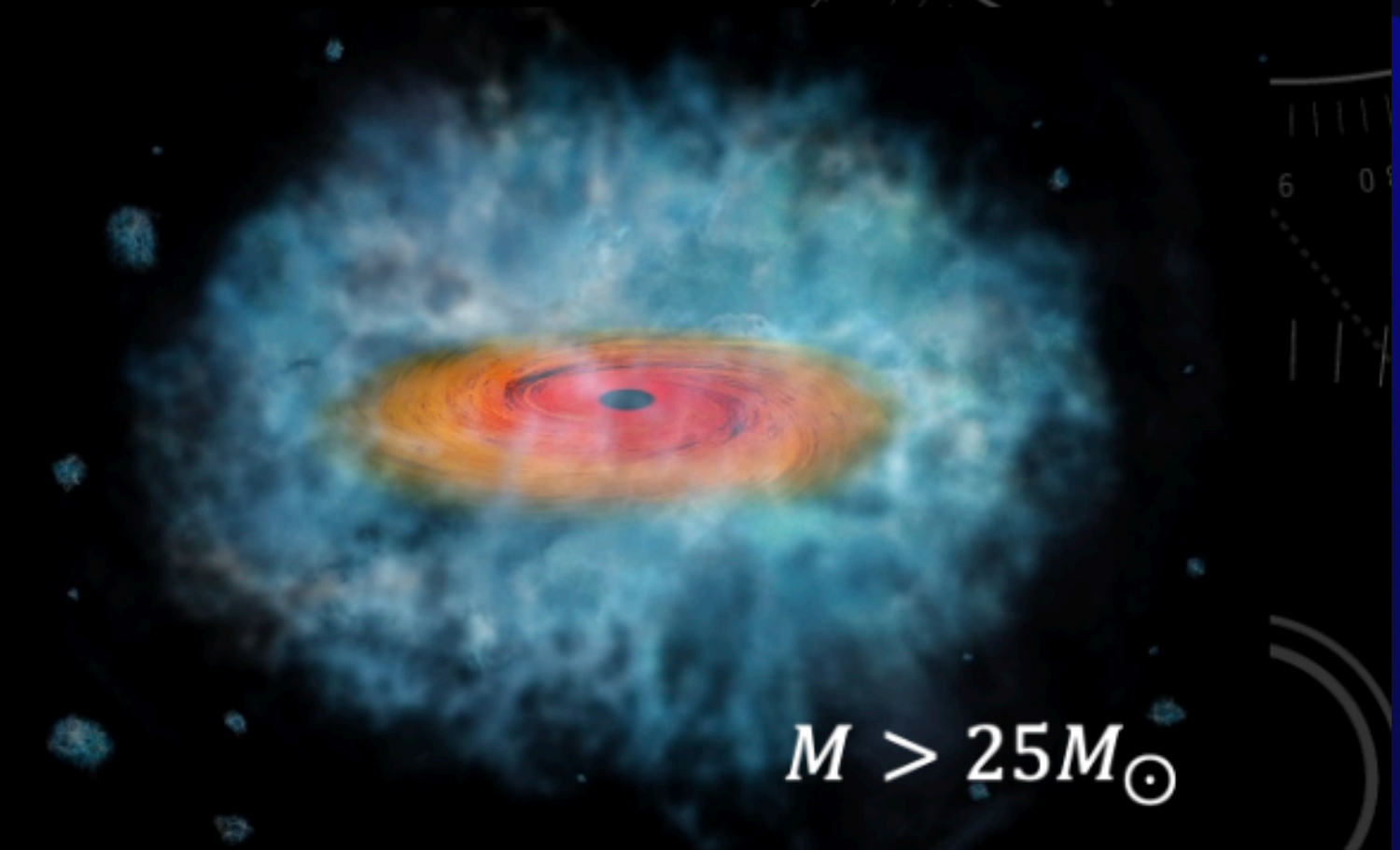
Final stages of stellar evolution: white dwarfs, neutron stars and black holes.



Illustration of rocky debris around a white dwarf
Source: NOIRLab/NSF/AURA/J. da Silva Image processing:
M. Zamani and M. Kosari (NSF's NOIRLab)



X-ray light rings from a binary neutron star
Source: NASA/CXC/Univ. of Wisconsin-Madison/S. Heinz, et al.;
Optical: DSS

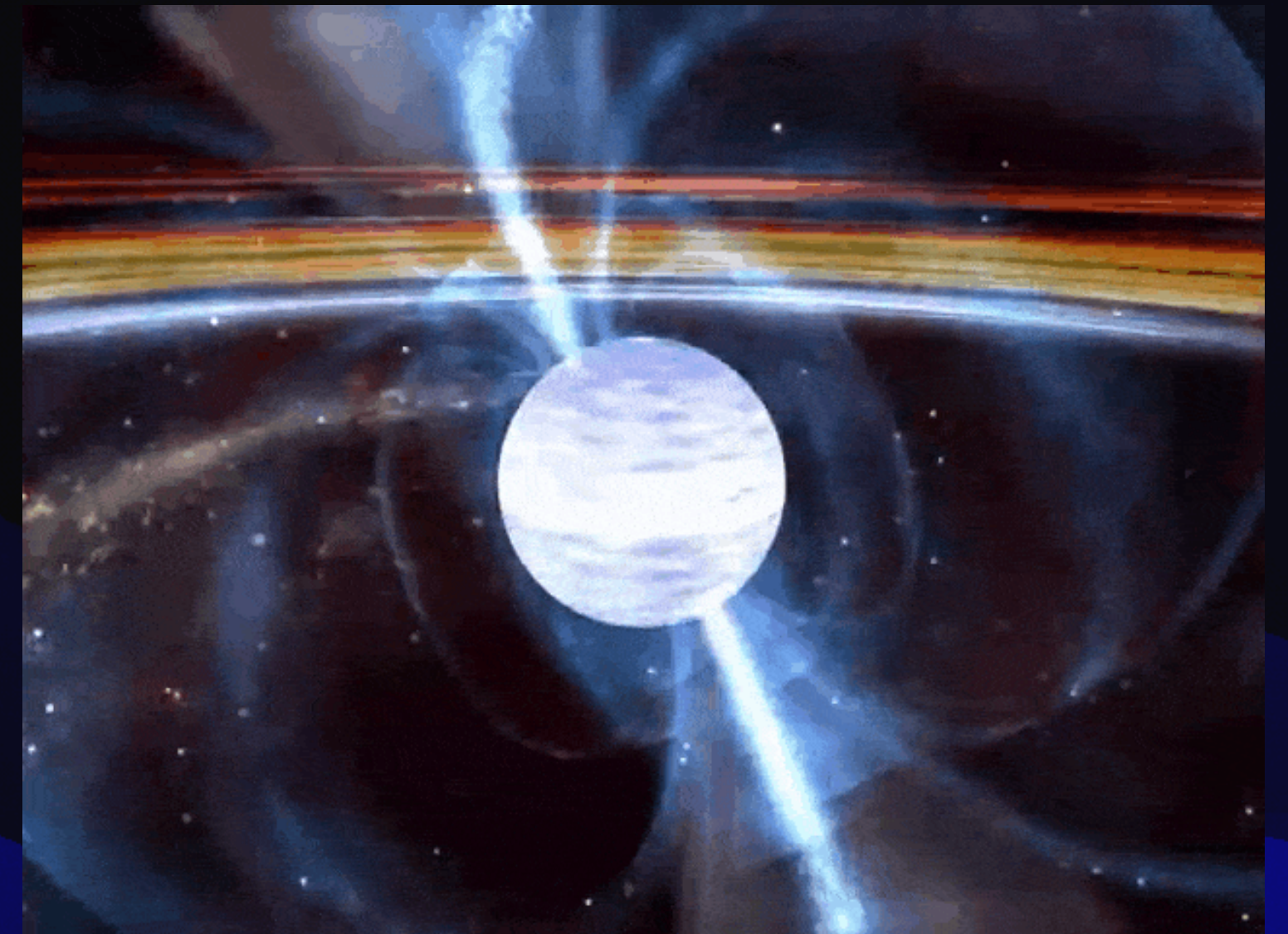


Artist's impression of supermassive black hole seed
Source: ESA/Hubble

Pulsars

Pulsars are neutron stars that spin very quickly, with the fastest of them spinning 100s of times in a second. They are very stable, cosmic clocks.

- Discovered by then graduate student Jocelyn Bell Burnell in 1967
- She detected a periodic radio signal. Initially dubbed "LGM" for "Little Green Men" using a large radio telescope
- Further analysis revealed it was a rapidly rotating pulsar, a new category of star!

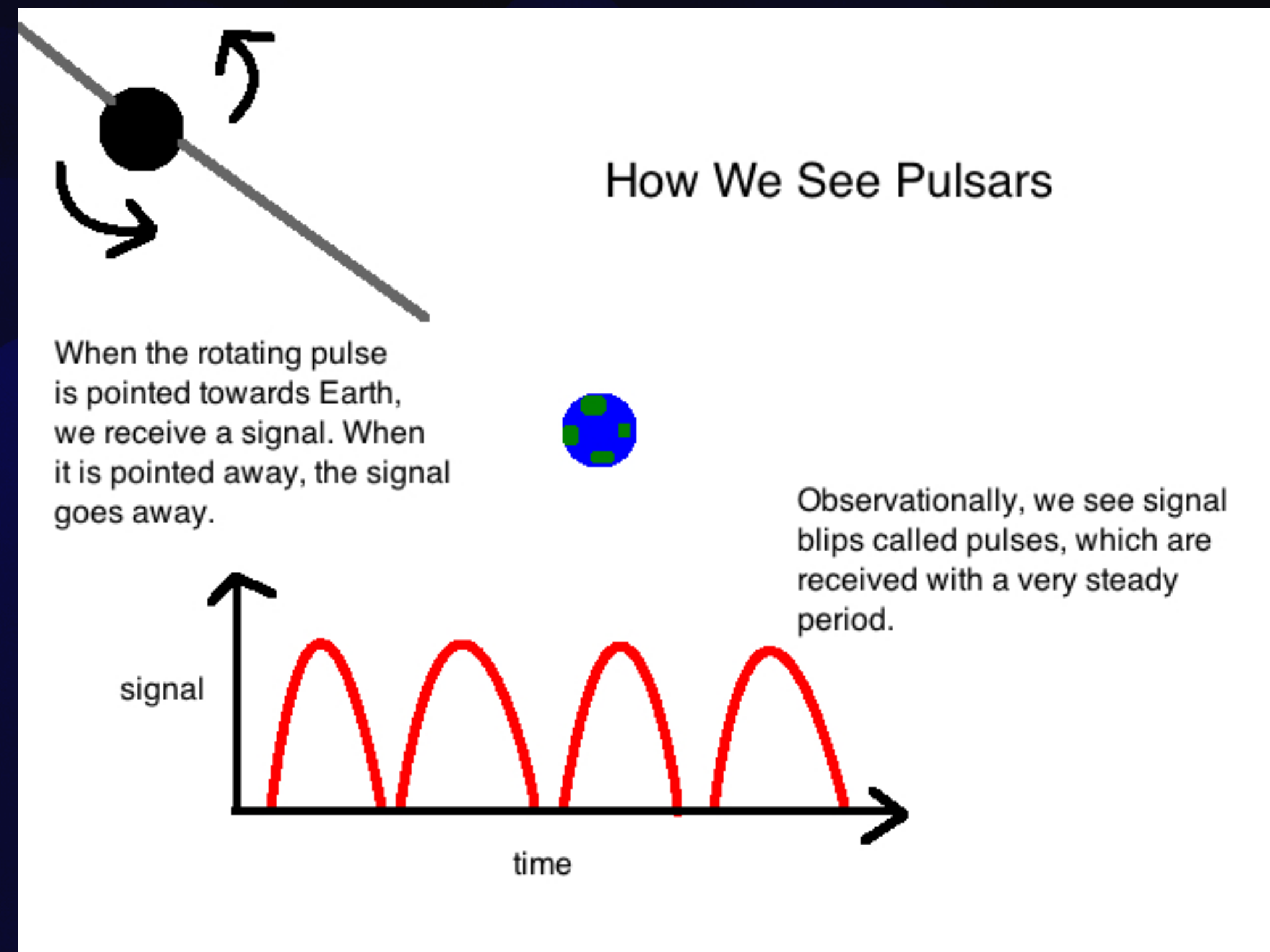
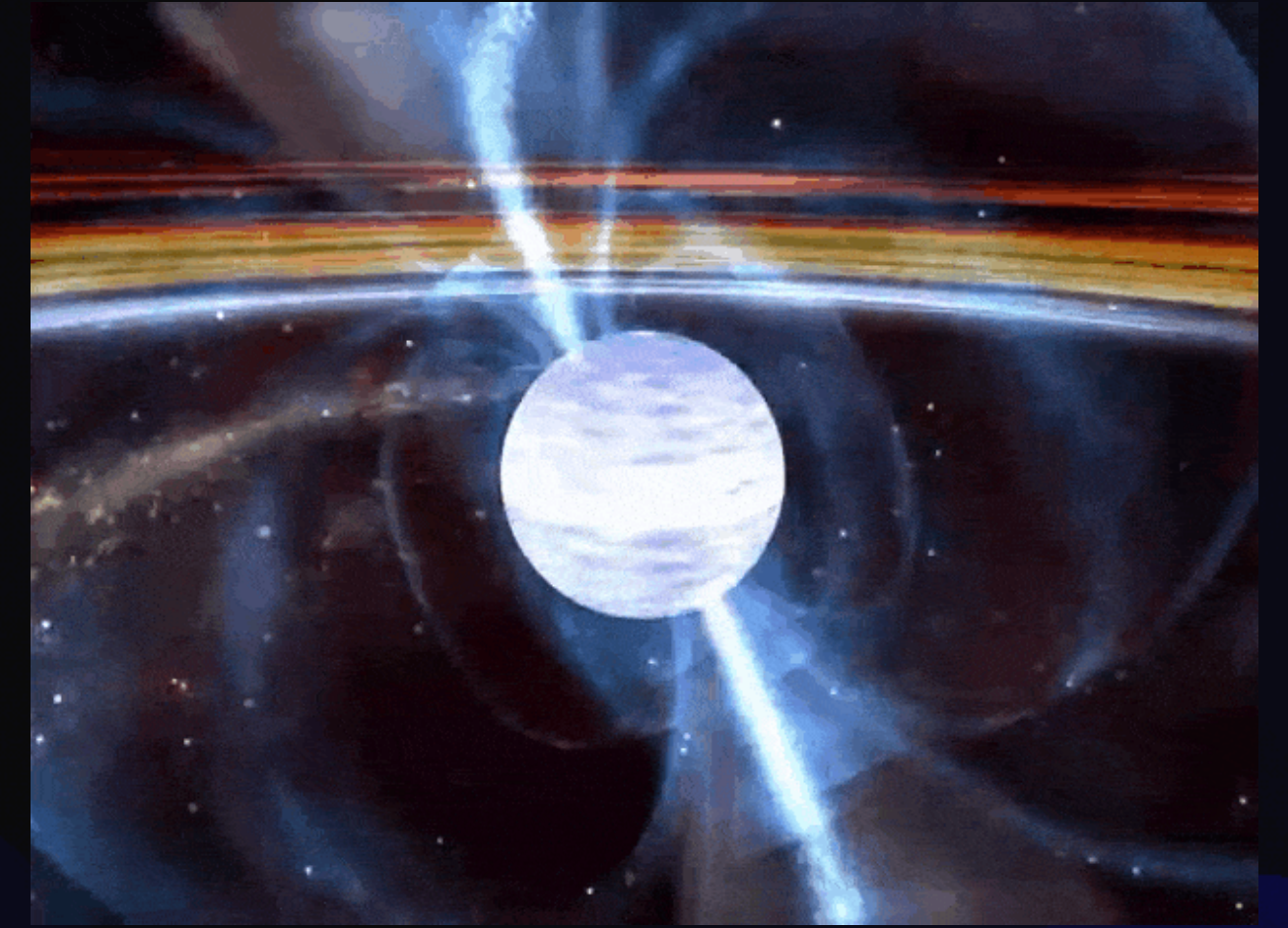


Jocelyn Bell

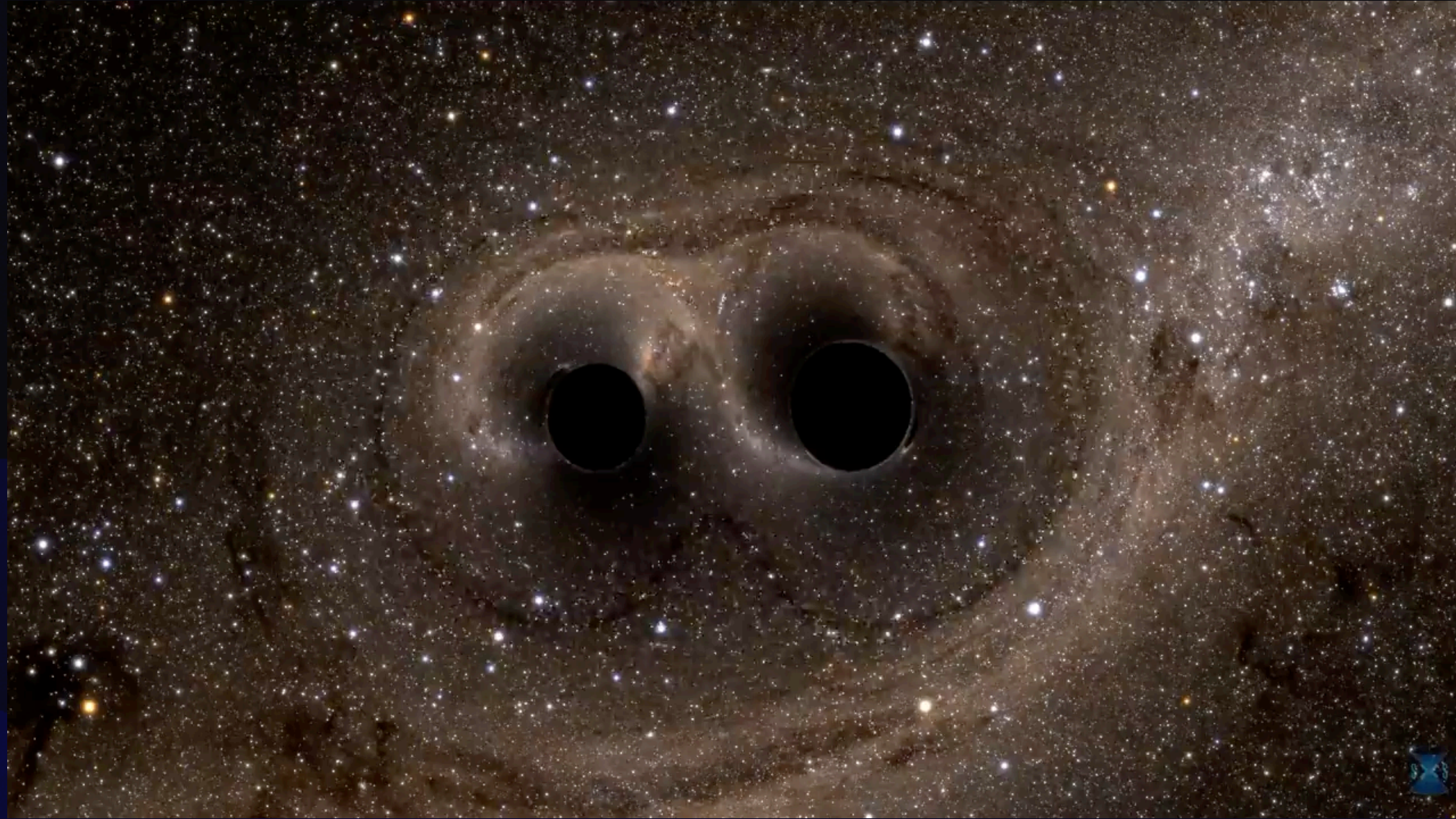
Pulsar Timing Arrays

Pulsar Timing Arrays continuously monitor a population of galactic pulsars using radio telescopes.

Energetic events (like the mergers of 2 supermassive black holes) happening in the Universe result in deviations from pulse arrival times - and these are signs of exciting astrophysics!



Gravitational waves



Light waves are not the only kinds of waves in space!

Gravitational waves stretch and squeeze space-time, an effect first predicted by Einstein 100 years ago.



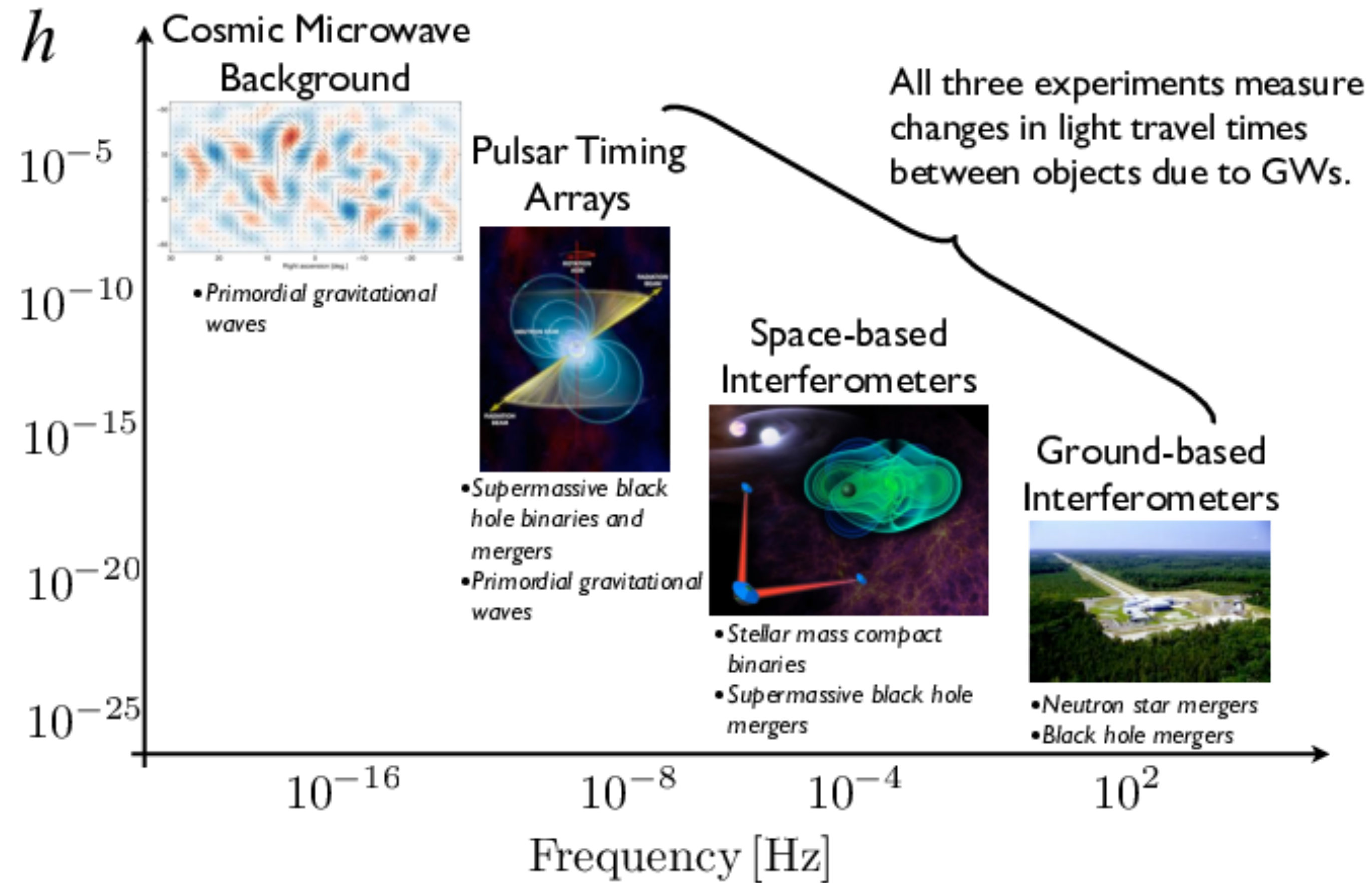
LIGO

Gravitational waves were first detected in 2015 by LIGO, and we have observed many such events since!



PTA

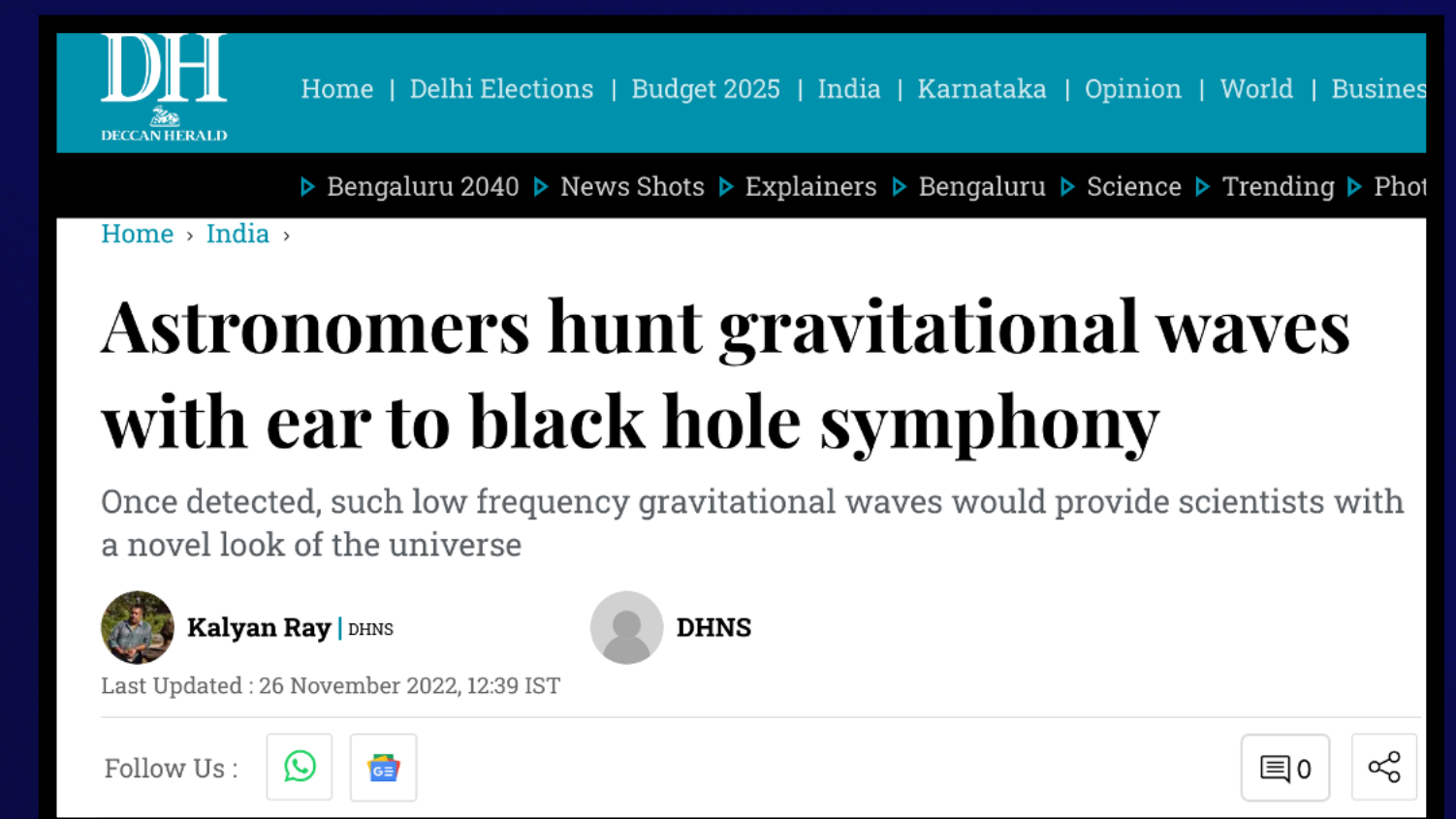
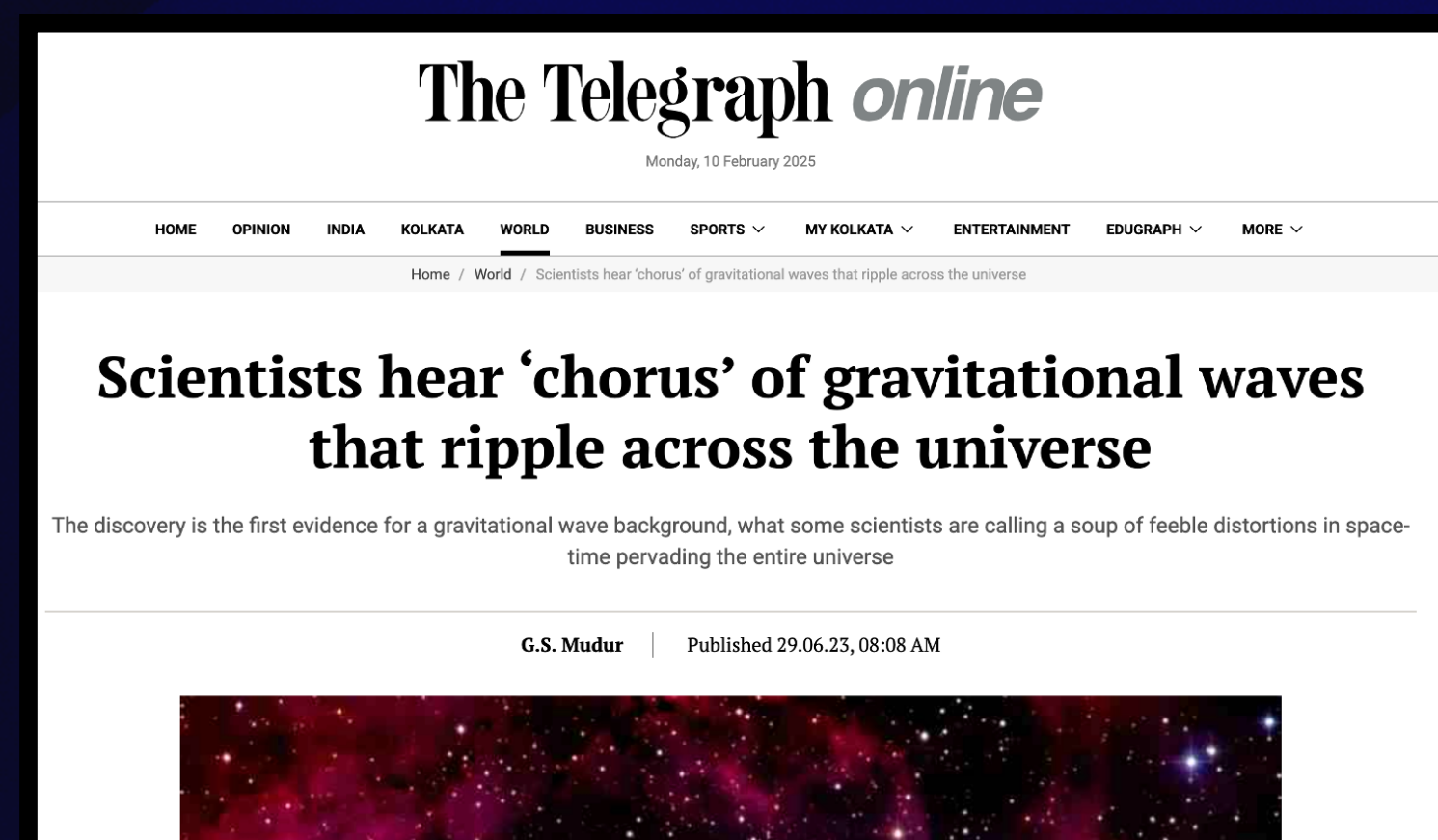
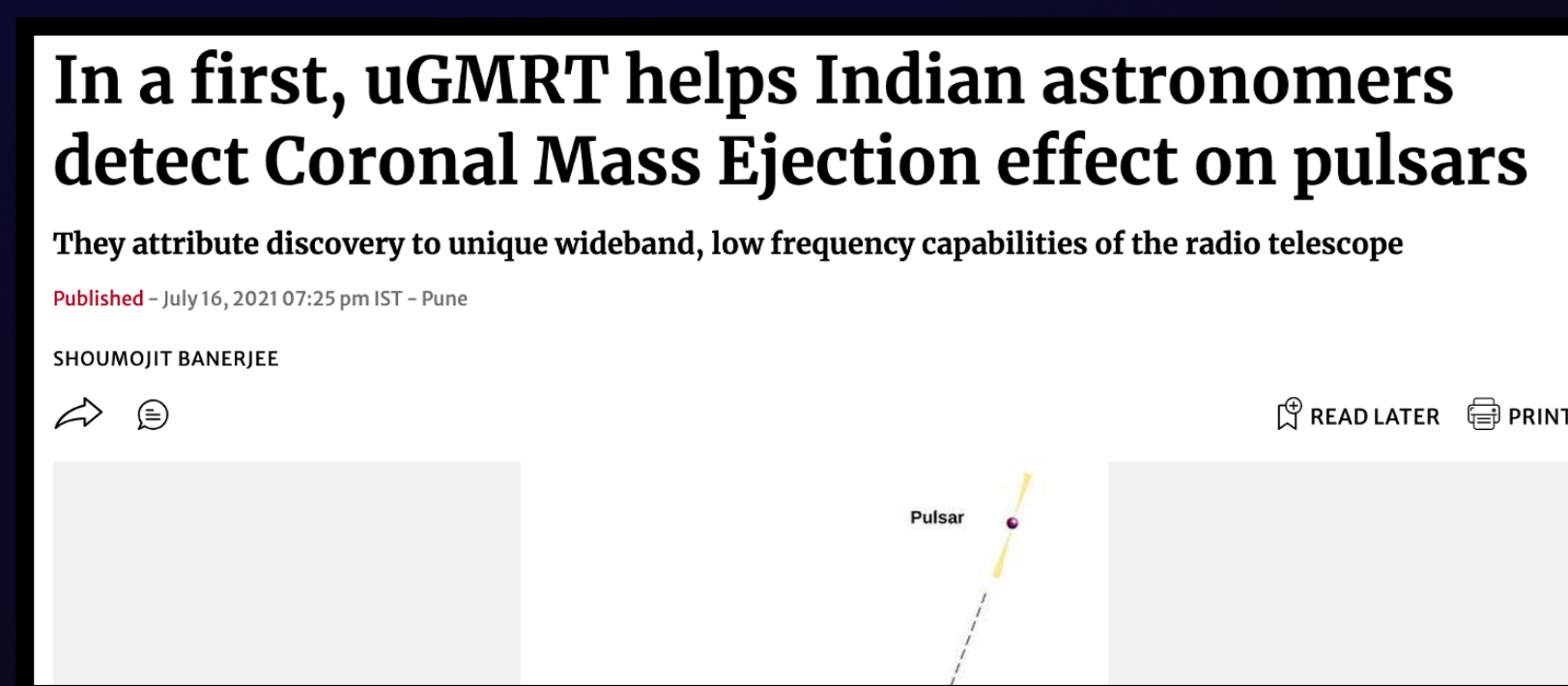
The spectrum of gravitational wave astronomy



The Indian Pulsar Timing Array

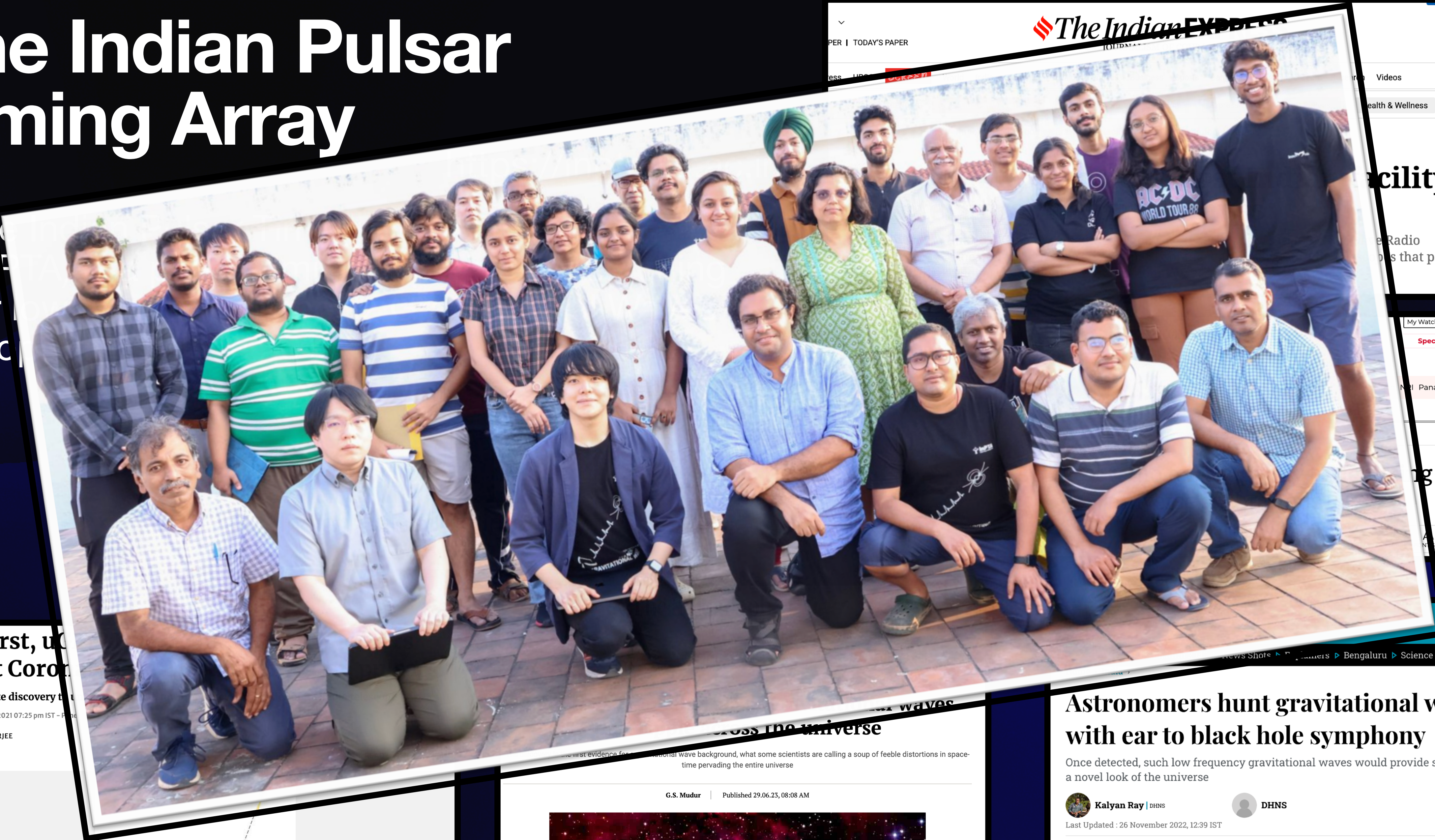
<https://inpta.iitr.ac.in/>

The Indian Pulsar Timing Array Experiment (InPTA) is a pulsar timing experiment searching for low frequency nanoHz Gravitational Waves in operation since 2016.



The Indian Pulsar Timing Array

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In a first, we detect Coronal

They attribute discovery to
Published - July 16, 2021 07:25 pm IST -
SHOUMAJIT BANERJEE

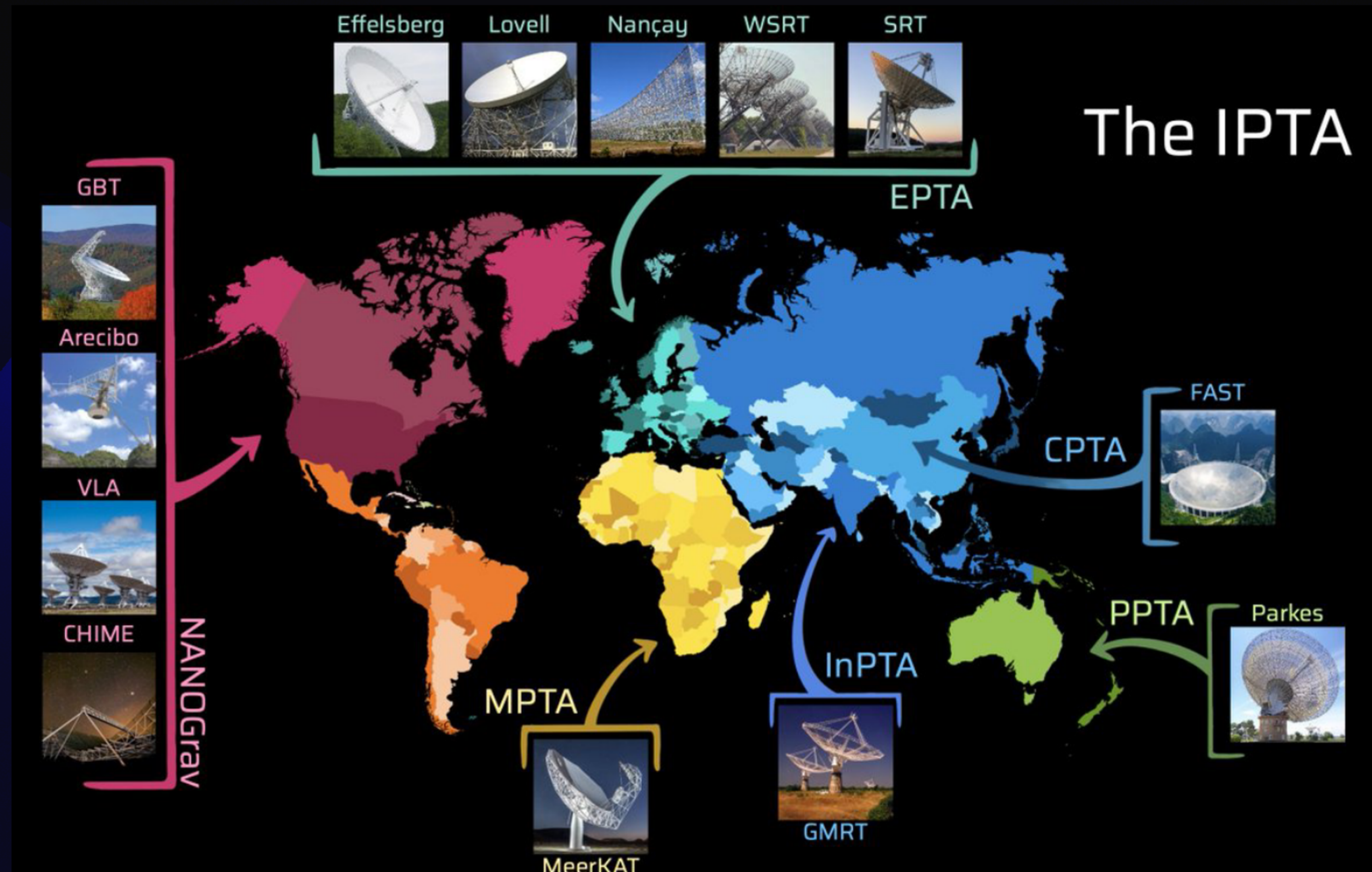
Astronomers hunt gravitational waves with ear to black hole symphony

Once detected, such low frequency gravitational waves would provide scientists with
a novel look of the universe

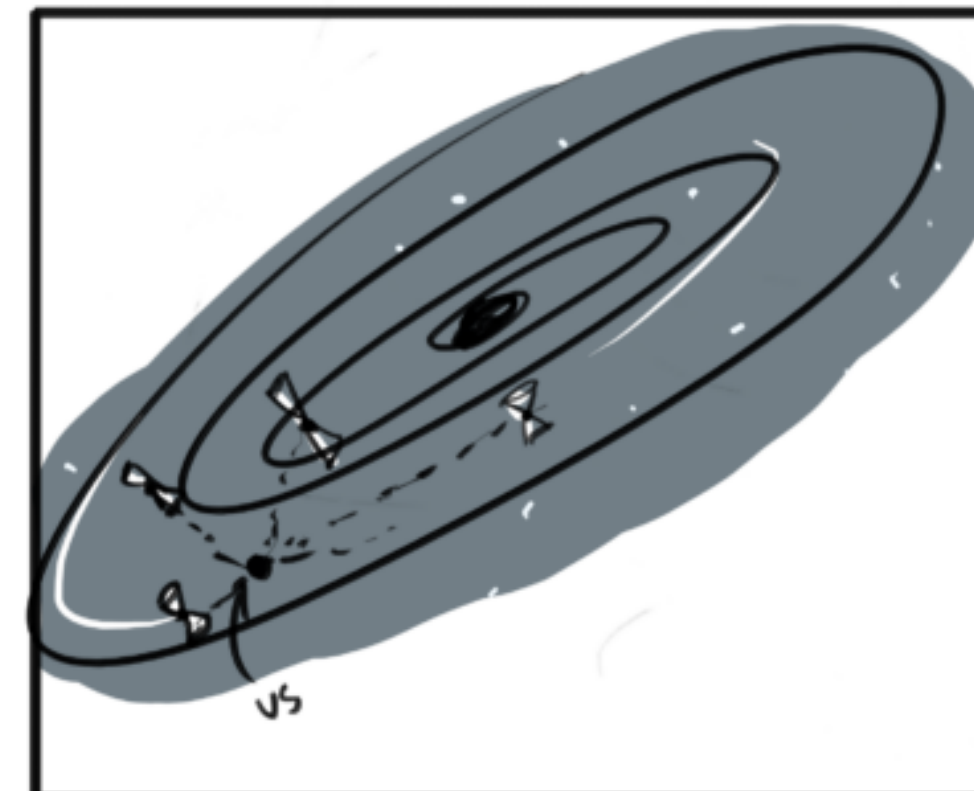
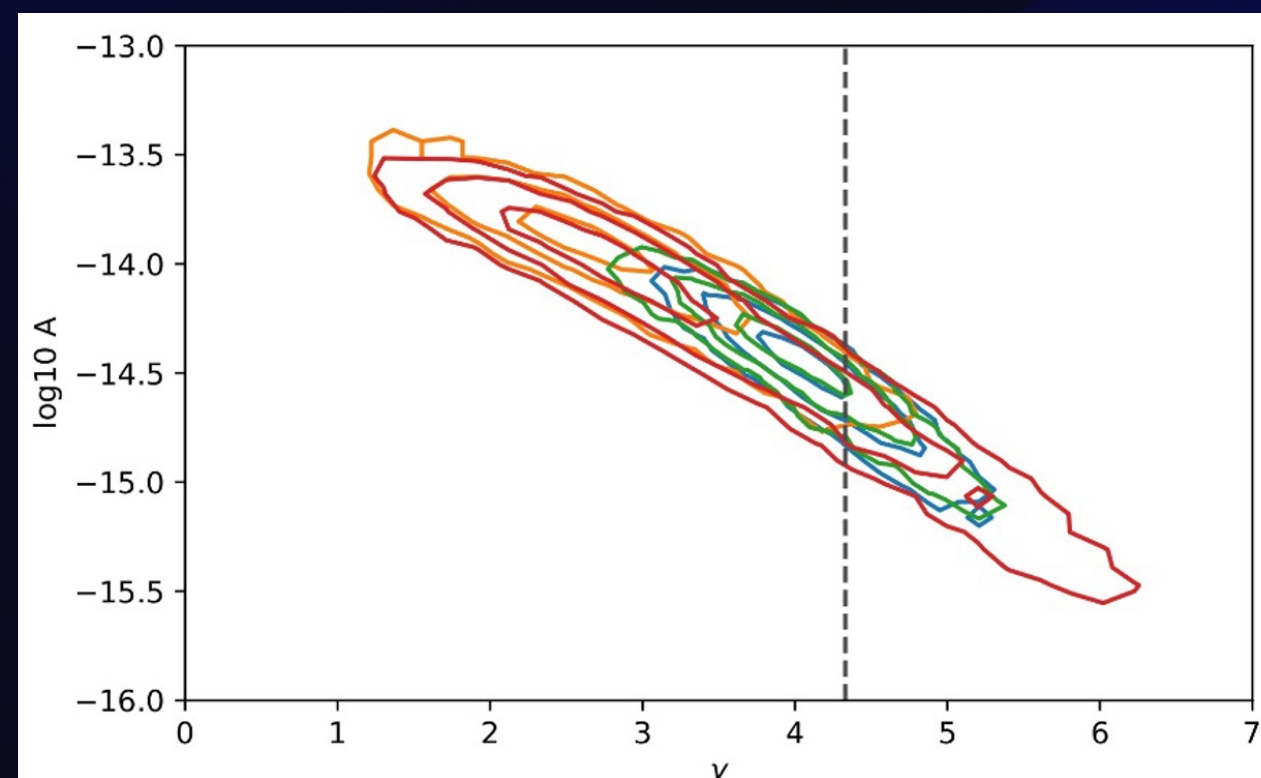
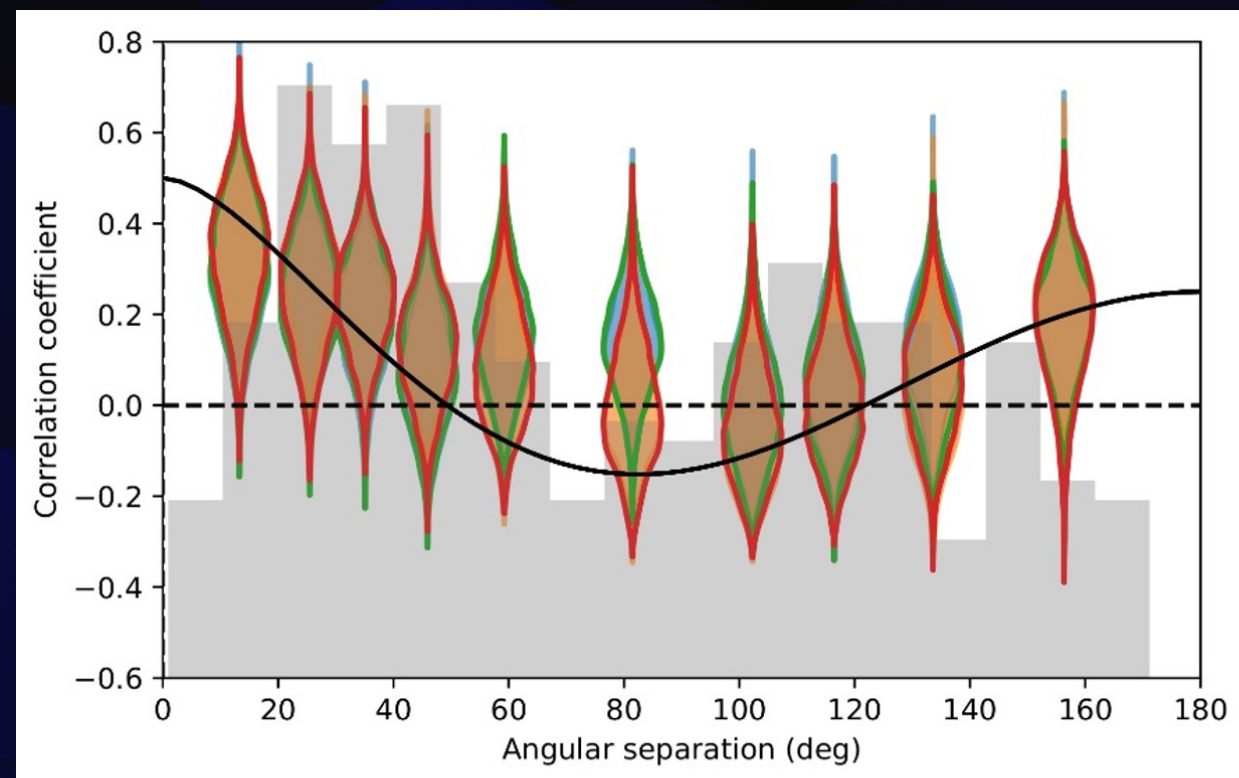
 **Kalyan Ray** | DHNS
Last Updated : 26 November 2022, 12:39 IST

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InPTA is a member of International Pulsar Timing Array collaboration (IPTA)

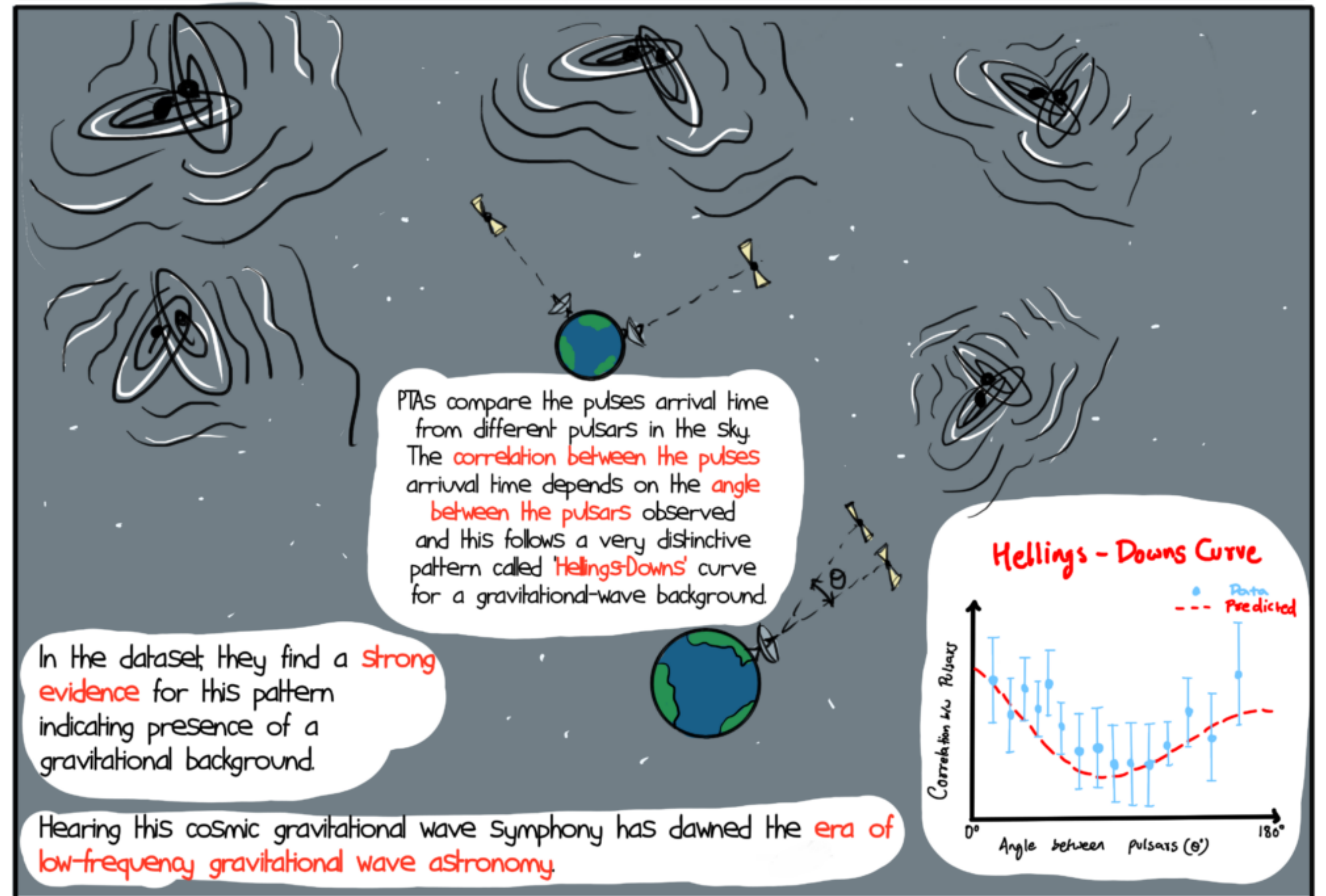


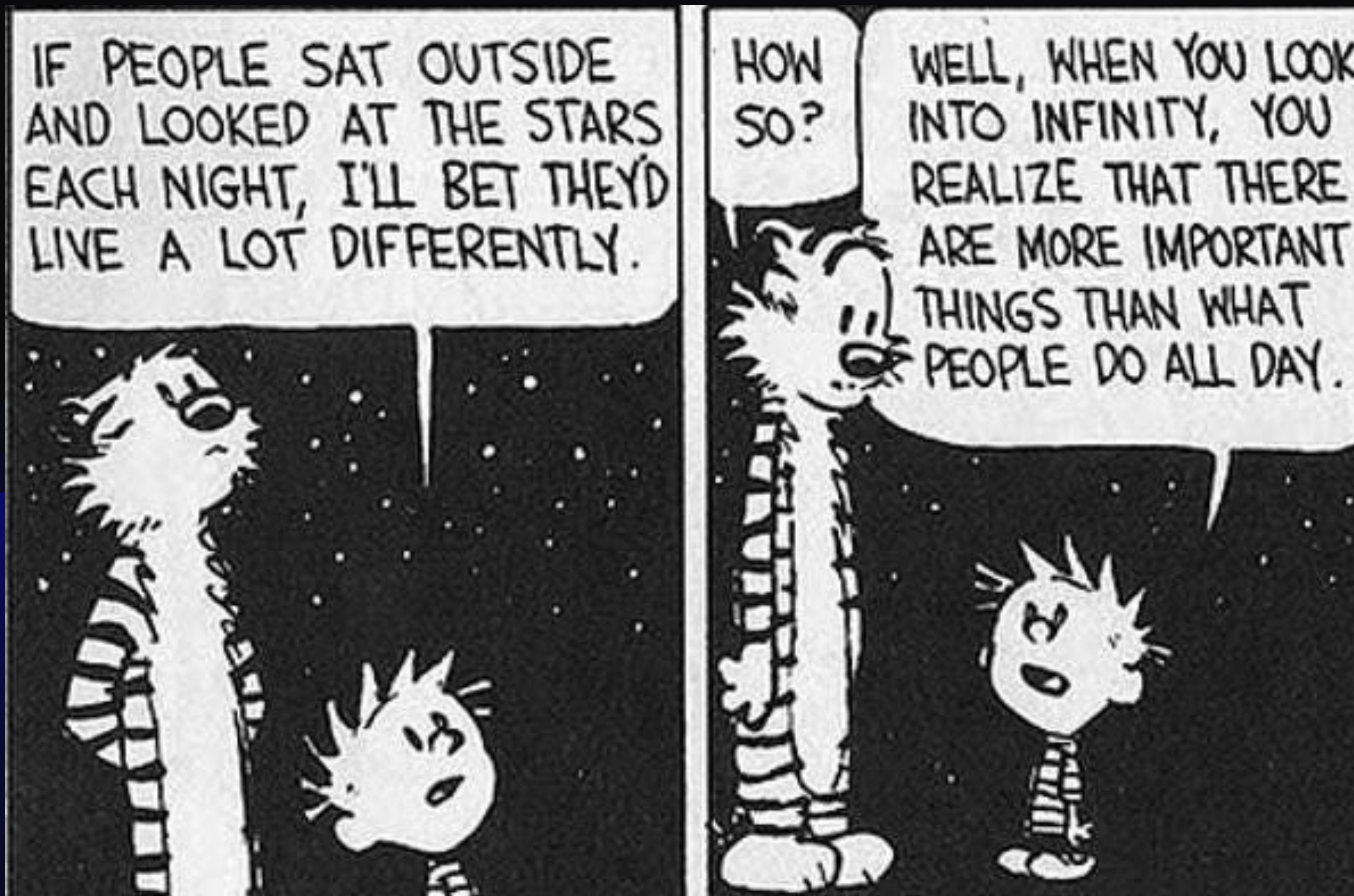
In June 2023, InPTA combined its data with the EPTA dataset and detected strong HD correlation, which provides **strong evidence of stochastic GW Background**.



The pulsar timing array creates a gravitational wave detector of **the size of a galaxy**. The size enables us to observe **long wavelength** or **low-frequency** (Specifically in **nanoherz**) gravitational waves.

PTAs have recently announced that they've found **evidence** for a **gravitational wave background** most likely consisting of gravitational waves from **several supermassive black holes**.





Thank you!