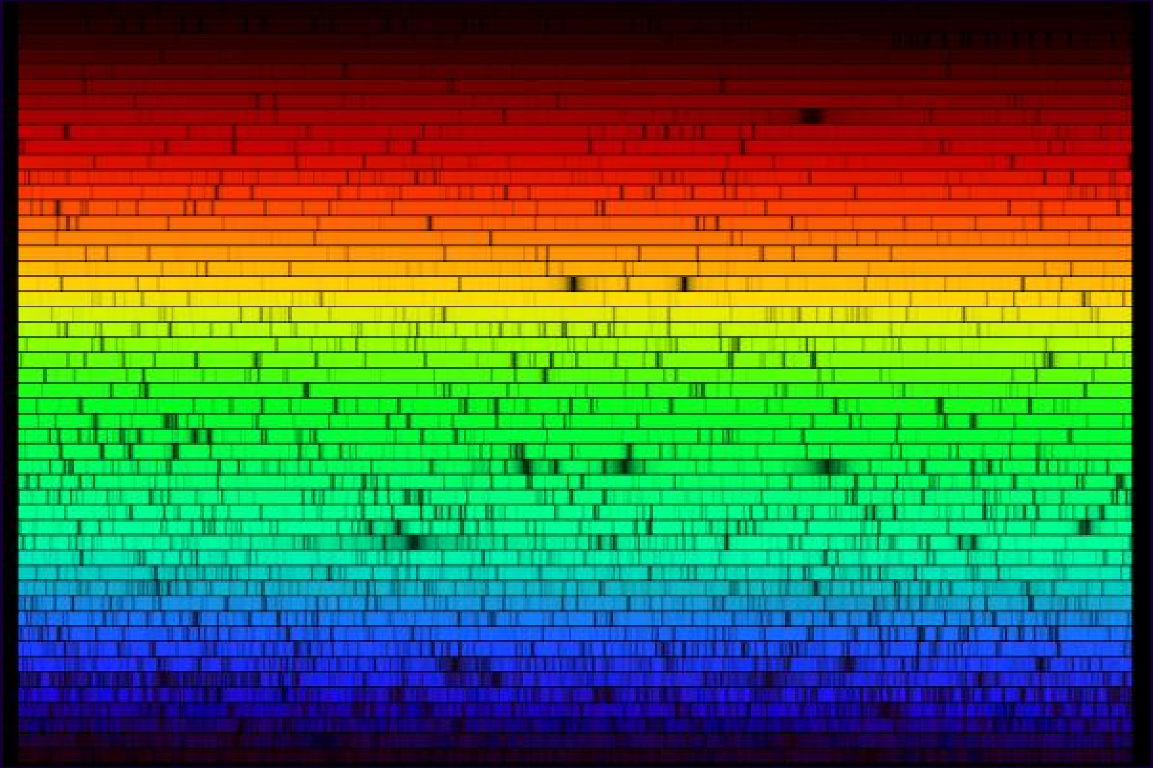
The Sun

Astronomy 101
Syracuse University, Fall 2021
Walter Freeman

November 9, 2021



If you did not get the tutorial last Thursday, come pick one up https://www.reddit.com/r/space/comments/qj641r/cameraman_focused_on_jupiter_and_its_moons_during/

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- Quiz 5 Retake + Quiz 6 on Thursday **at the end of class**

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  - We have called in "reinforcements" to get your papers graded faster
- If you haven't yet, turn in your printed copy of Paper 2 to your TA's mailbox
- Also email a copy to `suast101projects@gmail.com`
- Final project description posted; discussion coming Thursday

Take 10 minutes to finish
the tutorial from last week.

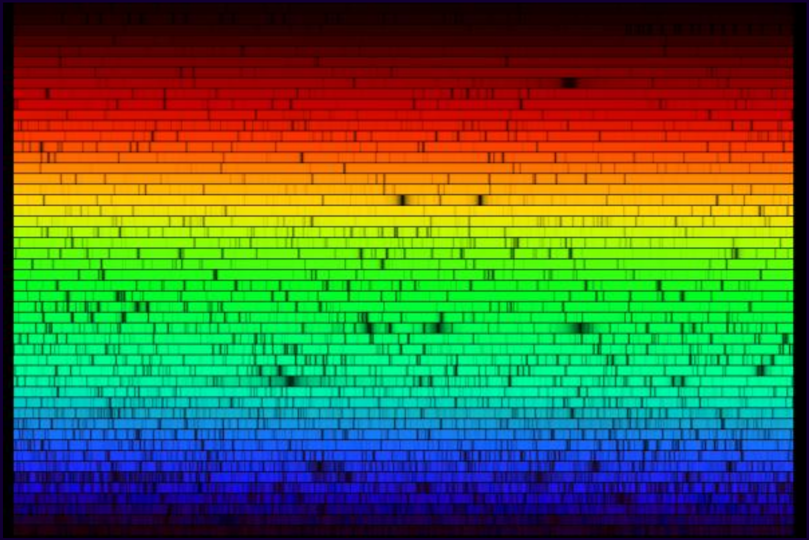
Suppose I put a 5000 K object behind a cloud of gas with energy levels at 0, 3, and 5 eV, and then separate its light by color. (Assume that I am a bird and can see ultraviolet light.) What would I see?

A: Only two bright lines

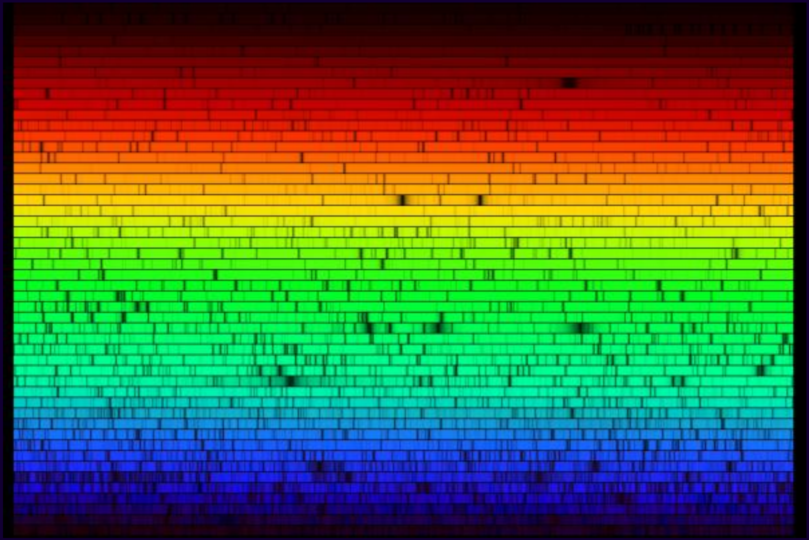
B: Only three bright lines

C: A solid band of color, but with two dark lines

D: A solid band of color, but with three dark lines



- The hot core of the Sun emits light of all wavelengths (thermal radiation)



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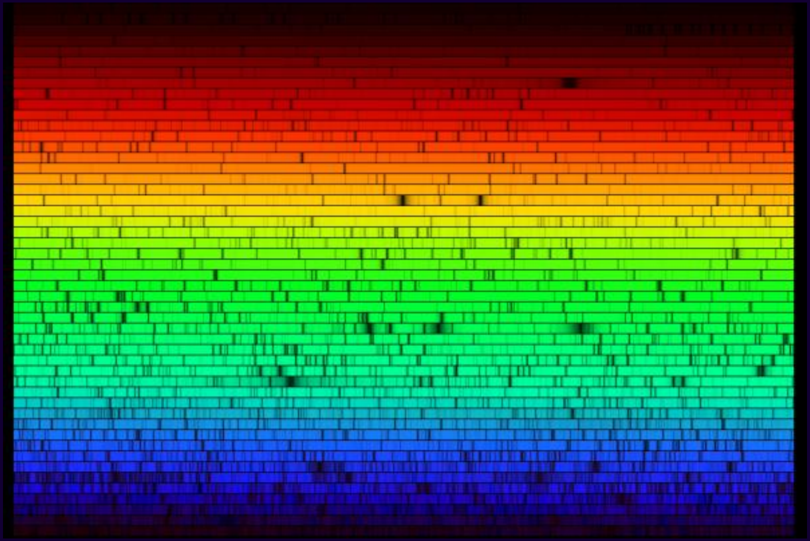

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This picture tells us what's in the Sun!

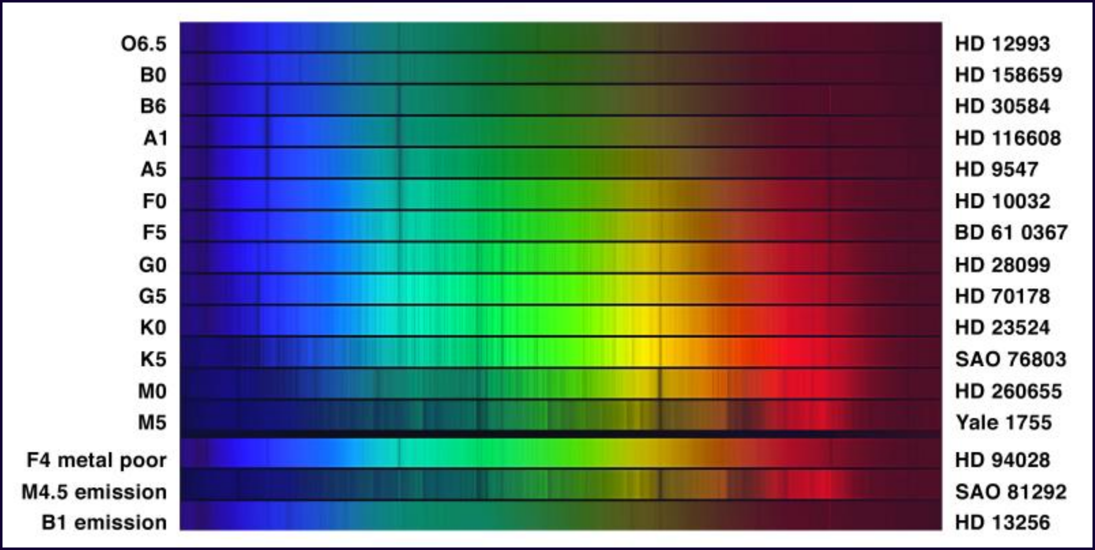
You discover lines in the solar spectrum that don't correspond to any known element. What do you conclude?

A: Something about quantum mechanics is different in the Sun

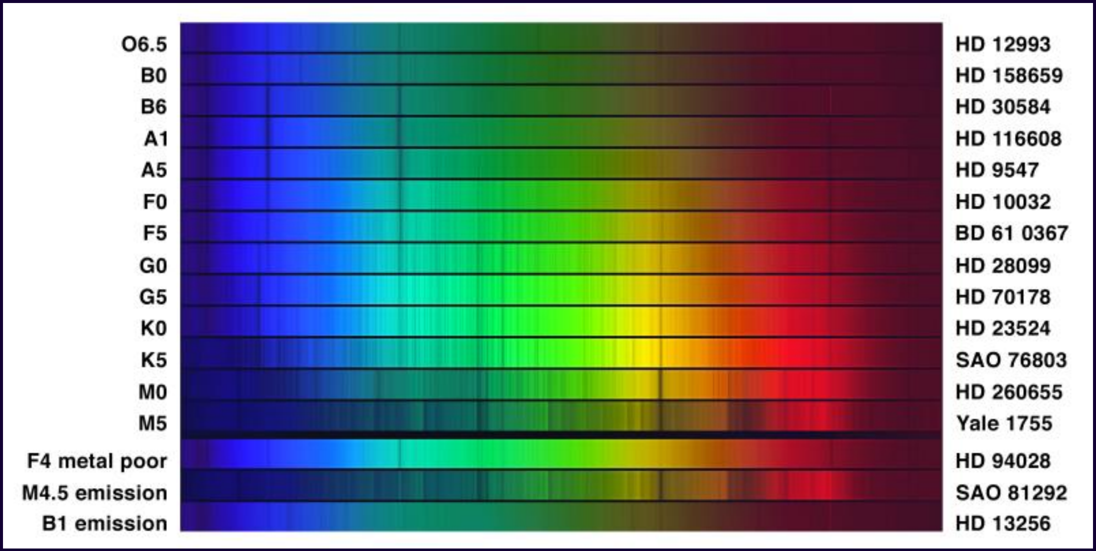
B: Something about light is different in the Sun

C: There's an element in the Sun that's not on Earth – call it **sunium**

D: The extreme temperature of the Sun causes new lines to appear in its gas



All the stars are made of the same stuff – the same stuff as we are.



All the stars are made of the same stuff – the same stuff as we are.

"The cosmos is also within us. We are made of star-stuff. We are a way for the universe to know itself."

–Carl Sagan, *Cosmos*

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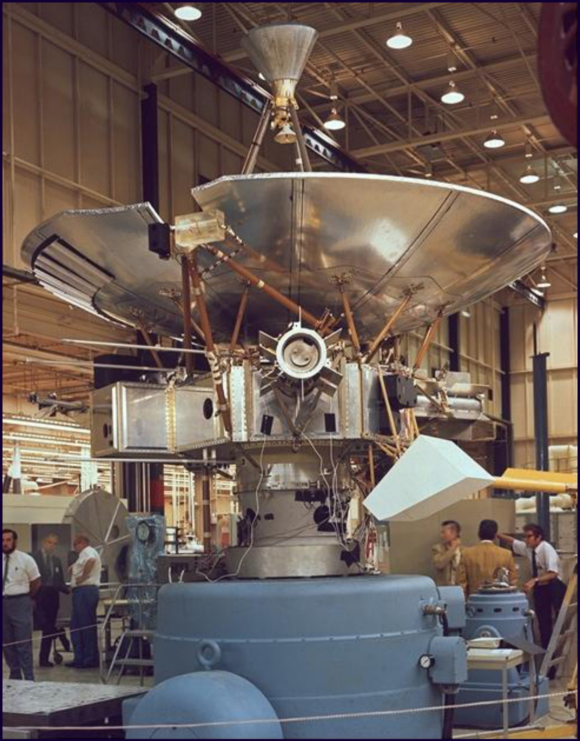
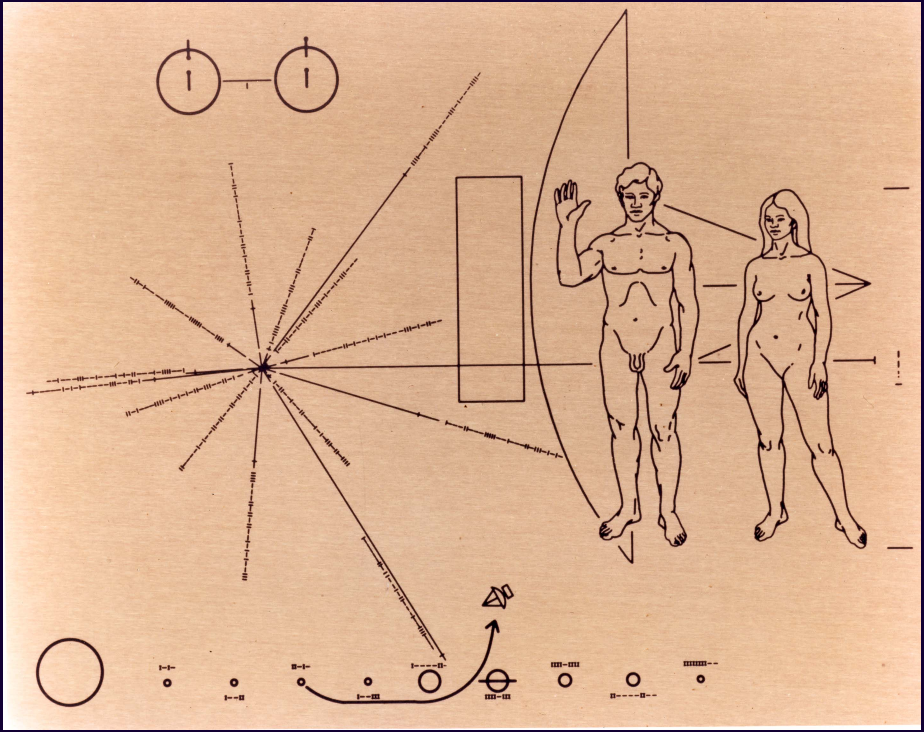
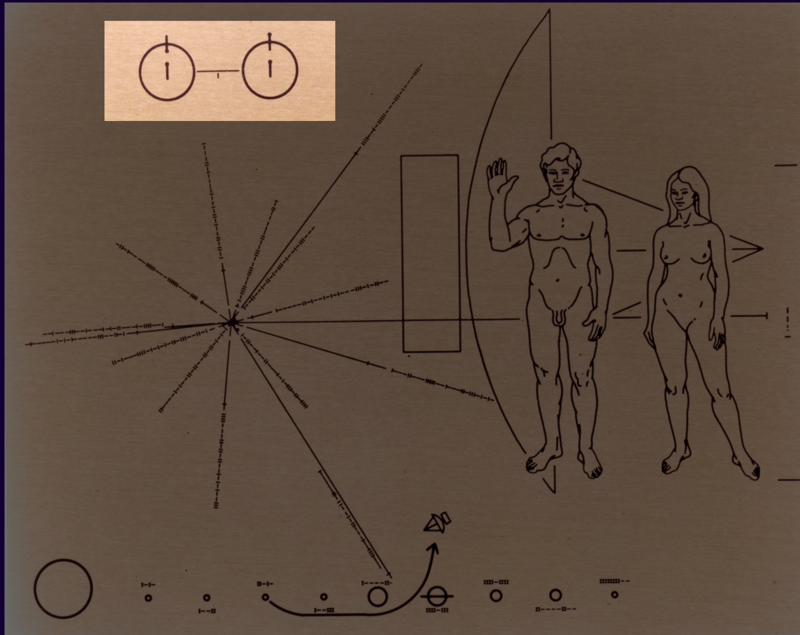
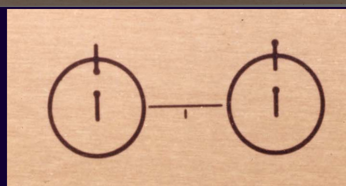
- Molecular vibrations: infrared
- Molecular *rotations*: microwave
- "Hyperfine structure" energy levels in hydrogen: 21 cm radio waves

This last is particularly interesting: it is a very particular frequency, echoing out from all corners of the Universe, that says: hydrogen is here. (Hydrogen is 75% of the universe.)









The Sun's history and the source of its power

(Hubble Space Telescope image: NASA + ESA / Judy Schmidt)

Clouds of gas – mostly hydrogen but with a few heavier elements – collapse under their own gravity to form stars.

The Sun's history and the source of its power

If you smash hydrogen nuclei together hard enough, they fuse to make helium – plus two neutrinos – plus a *lot* of energy.

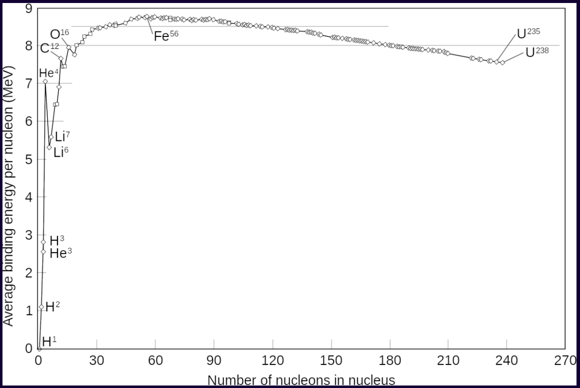
$$(P) + (P) + (P) + (P) \rightarrow (NNPP) + 2e^{+} + 2\nu$$

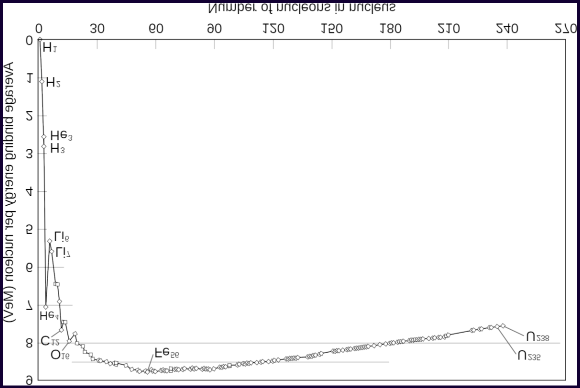
How much energy? We can calculate it...

Nuclear potential energy

There is potential energy associated with the *arrangement of protons and neutrons in nuclei.*

We can calculate how much energy is associated with nuclear fusion by looking at how much potential energy there is.



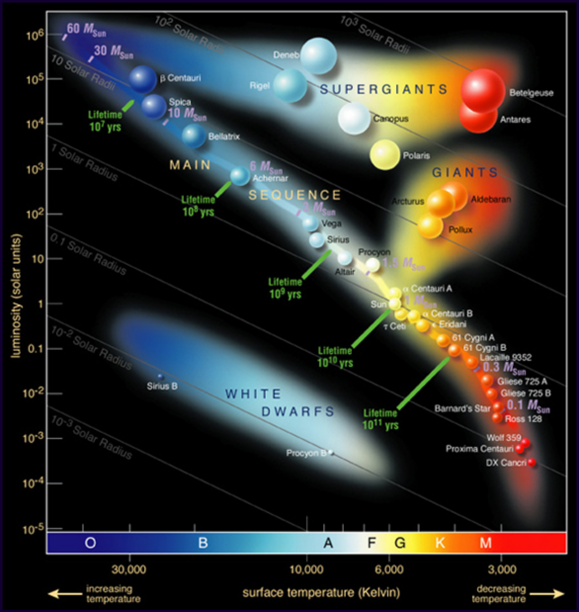


A star's life

- Gravity compresses a star's core, heating it up
- Nuclear fusion starts, pushing back against gravity
- Once the nuclear fuel is depleted, gravity takes back over
- Once it reaches even higher temperatures, the next stage of fusion starts

	Energy produced (power plant time per ton)	Temperature required (Kelvin)
Hydrogen to helium	20 years	10 million K
Helium to carbon	2 years	100 million K
Carbon to neon	1 year	500 million K
Neon to oxygen	5 days	1 billion K
Oxygen to silicon	1.5 years	2 billion K
Silicon to iron	10 months	3 billion K
Uranium to fission products (nuclear power plant)	3 years (ideal) 2 months (actual)	600 K (!)
Coal	20 seconds	
Natural gas	45 seconds	

The life of the Sun



(European Southern Observatory)

Most stars are less massive than the Sun.

These "red dwarfs" lead long, cool, boring lives, slowly fusing hydrogen to helium, emitting red and infrared light.

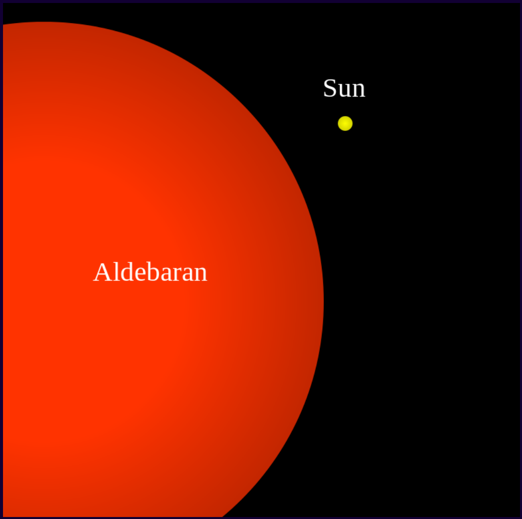
They are too faint for us to see without telescopes, but they contribute to the Milky Way glow. (Our nearest star is a red dwarf.)

They will live 10-100 times as long as the present age of the universe – a trillion years.

They will burn their hydrogen until it is all gone, then slowly fade away as brown dwarfs made of helium.

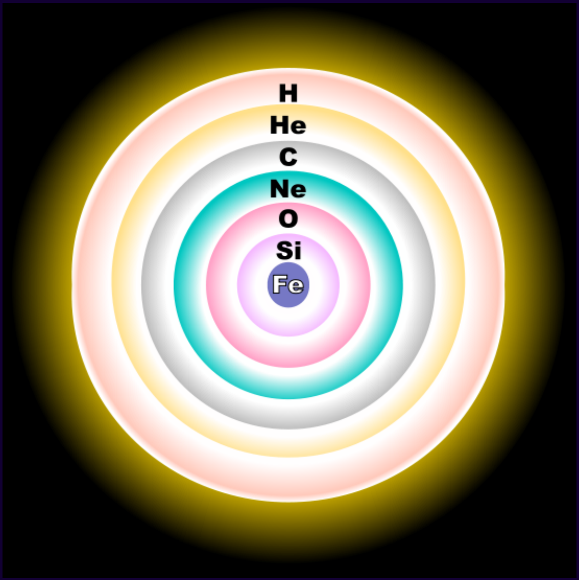
The Sun's fate

- When the Sun runs out of hydrogen in its core, the core contracts, while the outer layers puff up: it becomes a red giant. (5 billion years in the future, lasting for 1 billion years)
- Eventually the core gets hot enough to fuse helium into carbon, and the core ignites in a "helium flash".
- When the helium is depleted, that's it: the Sun isn't heavy enough to fuse carbon.
- The carbon core will be left behind as a white dwarf, slowly cooling – a dying ember in the sky, called a brown/black dwarf.
- Its outer layers will be blown out into interstellar space, briefly forming a nebula.



(Wikimedia Commons)

Other stars



Wikimedia Commons / R. J. Hall.
Image not to scale.

More massive stars have enough weight to compress their carbon cores and fuse it to (mostly) Ne, Na, Mg, and O.

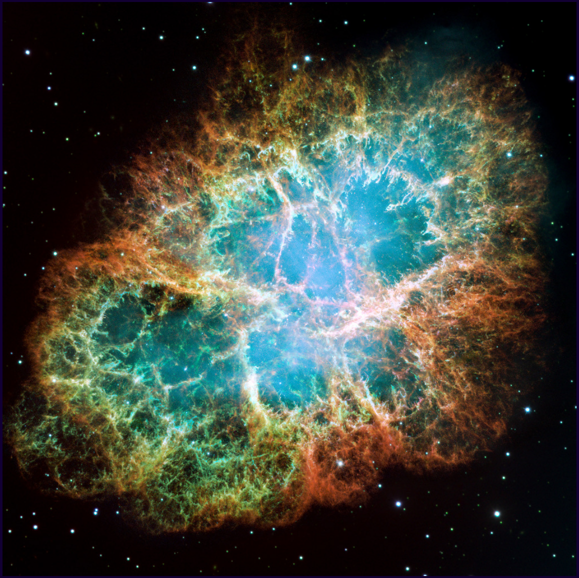
This process releases less energy than even helium fusion, so it doesn't last as long.

Elements fuse into heavier and heavier elements, releasing less energy each time, until they reach iron in the heaviest stars.

Iron is "stellar ash" – it can't release any more energy by fusion.

In some of these heaviest stars, once their iron cores grow too much, gravity crushes them into one enormous atomic nucleus – a neutron star.

Supernovae



(Hubble Space Telescope/NASA)

The resulting explosion destroys the rest of the star.

It causes a flurry of nuclear reactions, forging elements heavier than iron.

It also scatters the heavy-element-rich contents of the star out to space. This is why the Earth has so much iron in it – and where our heavy elements come from.

It releases massive amounts of energy, forming a bright flash in the sky.

This is the Crab Nebula, the remnant of the 1054 supernova.

It was hundreds of times further away than most visible stars, but could be seen even during the day!