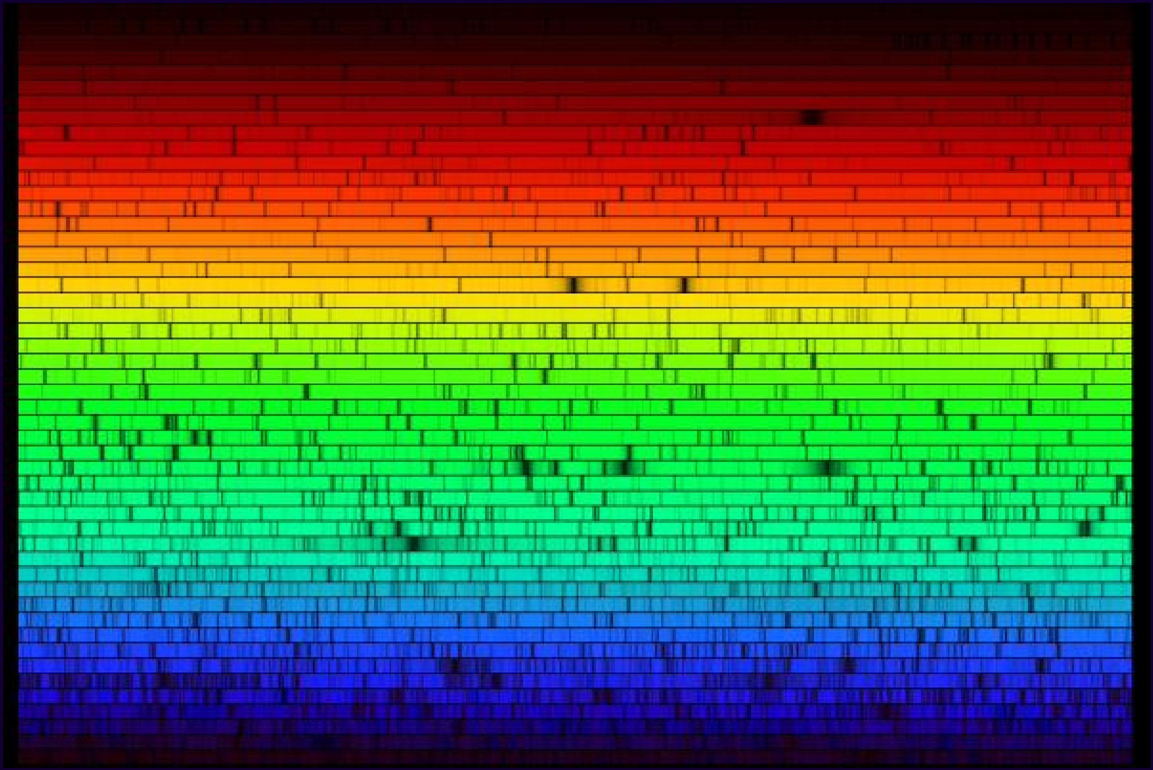
The Sun

Astronomy 101
Syracuse University, Fall 2019
Walter Freeman

November 5, 2019



Announcements

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- Exam 3 next Tuesday

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- Exam 3 next Tuesday
- Study guide and last year's exam posted, as usual
- Solutions to last year's exam will be posted on Friday
- Extra study sessions (priority for groups):
  - Wednesday 2-4pm, Physics 215
  - Friday 9:30am-noon, Physics 215
  - Sunday 1-4pm, Physics Clinic

Last year's Exam 3

Last year's exam has some questions on it that you may not know how to do yet, or that may not be part of Unit 3 this year:

- Questions 4 and 9 cover neutrino astronomy, which was on Unit 2 this year
- Question 29 covers conservation of angular momentum, which will be on Unit 4 this year
- Questions 23 and 24 cover what will be next week's lab, which will be on Unit 4 this year

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- Questions 8, 11, 13, 19, 25, 26, and 30 touch on an idea we'll review now

Benchmarks: thermal radiation

You should know, roughly, what sort of light objects at different temperatures emit.

Keep in mind that an object may *mostly* emit light outside our visible range...

	T (Kelvin)	Peak wavelength	Visible light?
Deep space	3	Microwave	None
Freezing ice	273	Infrared	None
People	300	Infrared	None
Boiling water	373	Infrared	None
Hot stove, candle, etc.	1500	Near infrared	A little red
Incandescent light	2400-2800	Near infrared	Mostly red/orange
The Sun	5700	Visible	Mix of all colors (looks white)
Hot stars	10000+	UV	Mostly blue

Light bulbs

Why is one of these light bulbs so much easier to operate than the other?

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.

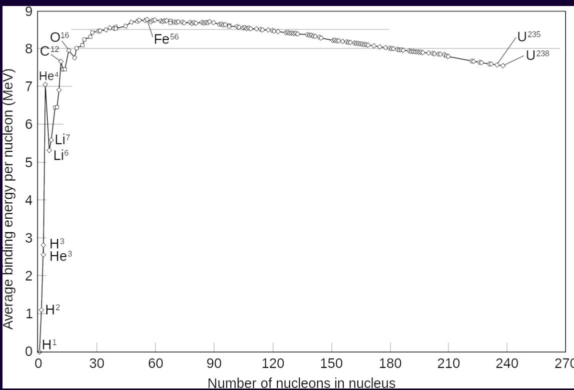
$$(P) + (P) + (P) + (P) \rightarrow (NNPP) + 2e^{+} + 2\nu$$

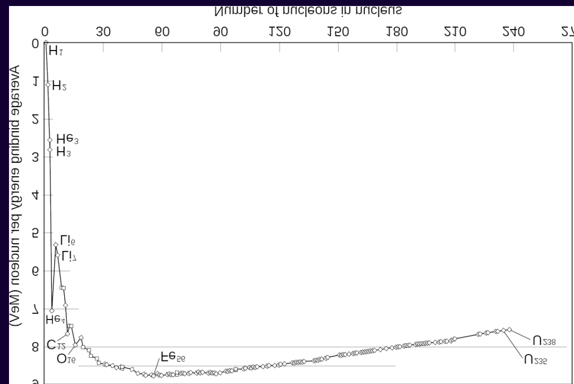
How much energy? We can calculate it...

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.



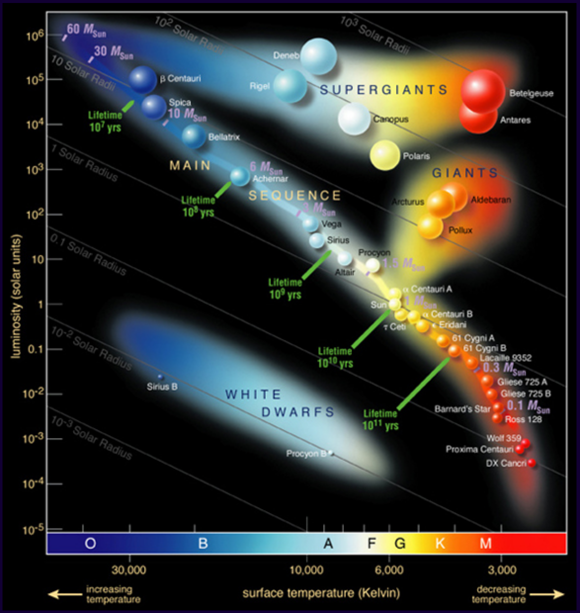


A star's life

- 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
Helium to carbon	2 years	100 million
Carbon to neon	1 year	500 million
Neon to oxygen	5 days	1 billion
Oxygen to silicon	1.5 years	2 billion
Silicon to iron	10 months	3 billion
Uranium to fission products	3.6 years	
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.

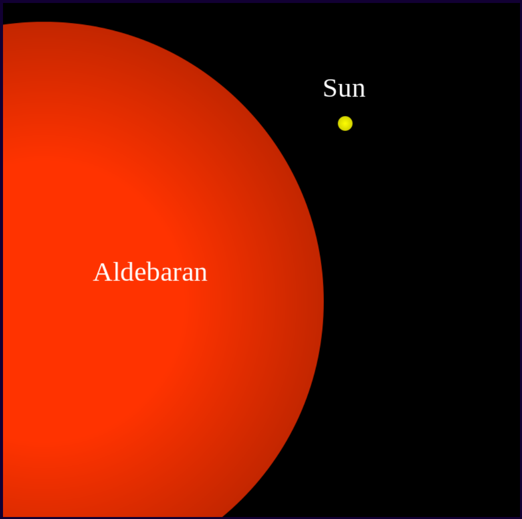
They are too faint for us to see without telescopes, but they contribute to the Milky Way glow. (Our nearest star is a red dwarf.)

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.

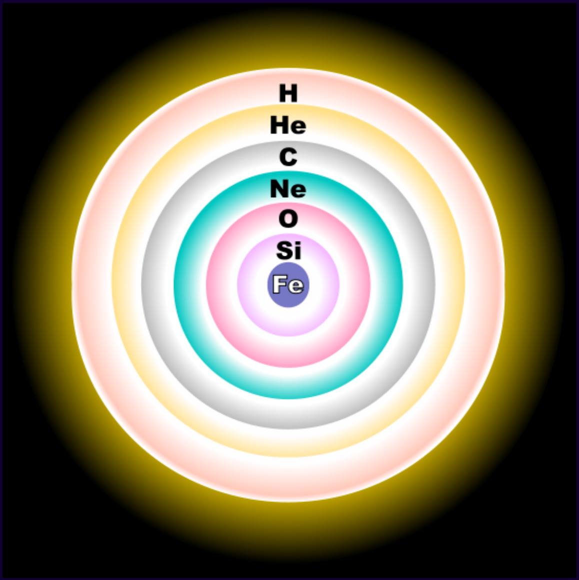
The Sun's fate

- 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.

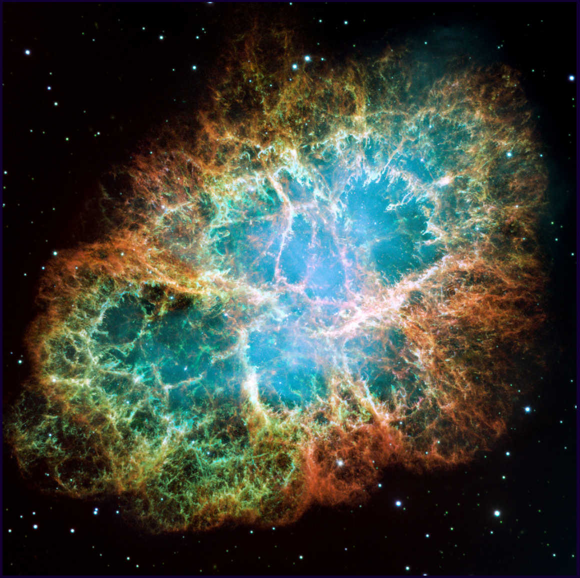
This process releases less energy than even helium fusion, so it doesn't last as long.

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!