



Extraterrestrial Life

This class (Lecture 7):

Burning Stars

Next Class:

Death of Stars

THE DRAKE EQUATION

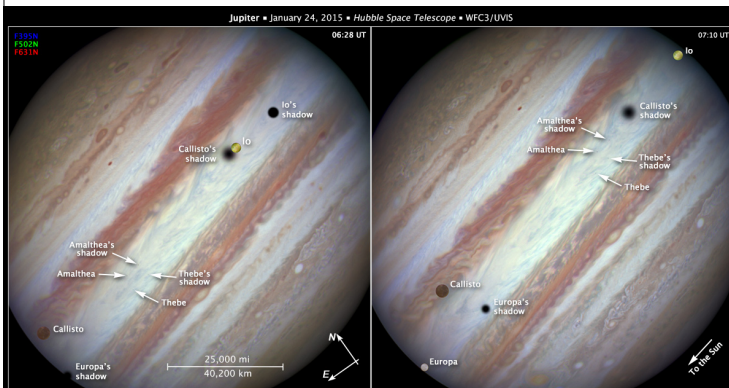
$$N = R^* f_p n_e f_i f_c L_B$$

NUMBER OF COMMUNICATING CIVILIZATIONS IN OUR GALAXY
 PROBABILITY THAT LIFE ON A PLANET BECOMES INTELLIGENT
 NUMBER OF LIFE-SUPPORTING PLANETS PER SOLAR SYSTEM
 AMOUNT OF BULLSHIT YOU'RE WILLING TO BUY FROM FRANK DRAKE

HW #2 due Sunday night.

Music: *Sonne*—Rammstein

The Jupiter Transit



Death Story

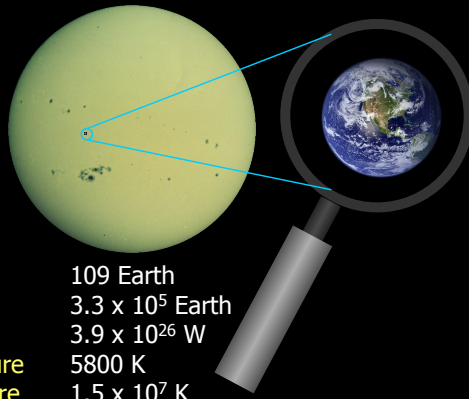


In small groups, write a few sentence explanation about the fate of the Universe for a non-science major friend.

State some of the important facts.

Earth-Sun Comparison

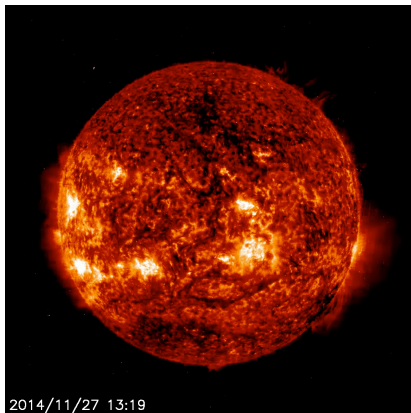
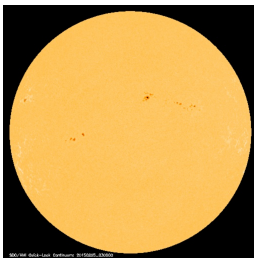
In general, a very typical star. Keep in mind that it is really a ball of gas/plasma.



Visual radius	109 Earth
Mass	3.3×10^5 Earth
Luminosity	3.9×10^{26} W
Surface temperature	5800 K
Central temperature	1.5×10^7 K
Rotation period	25 days

LIVE from the Sun

<http://sohowww.nascom.nasa.gov/data/realtime/mpeg/>



Sun's Luminosity



3.85×10^{26} Watts, but how much is that?

A 100W light bulb...

...the Sun could supply 4×10^{24} light bulbs!



U.S. electricity production in 2009: 4.1 trillion kWh...



... Sun = 3×10^7 times this every second

World's nuclear weapons: 3×10^4 megatons...

... Sun = 4 million times this every second

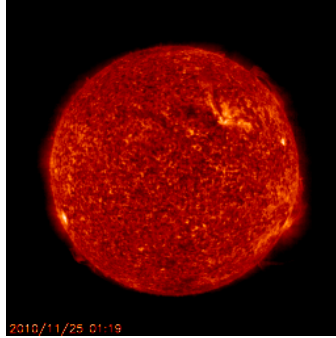


This is a lot of energy!

Question of Stability



- The Sun's size is constant.
- No weatherman says it will be especially hot tomorrow as the Sun's size will be increasing.
- Not expanding or collapsing.
- The Sun is stable! Why?



Not trivial, could have gone the other way

Think: Sun is made of gas, yet not like a cloud, for example, which is made of gas but size, shape changes all of the time

Not a coincidence: really good reason

http://www.londonstimes.us/toons/index_medical.html

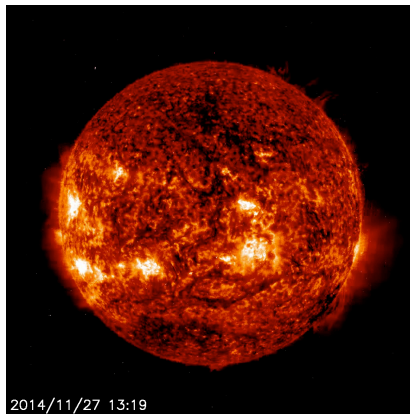
http://sohowww.nascom.nasa.gov/data/realtime/eit_304/512/

Why is the Sun Stable?



What keeps gravity from collapsing the Sun?

What keeps the Sun from exploding?



Pressure

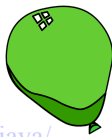


- What is pressure?

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

- Explain blowing up a balloon?

Pressure of Earth's atmosphere is 14.7 pounds per square inch

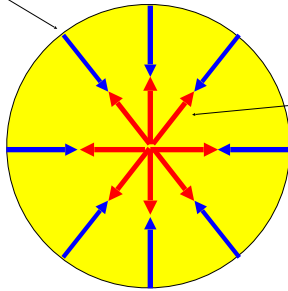


- <http://www.phys.hawaii.edu/~teb/java/ntnujava/idealGas/idealGas.html>

The Battle between Gravity and Pressure



Gravity pushes in



The heat pressure must push out.

Hydrostatic equilibrium: Balanced forces

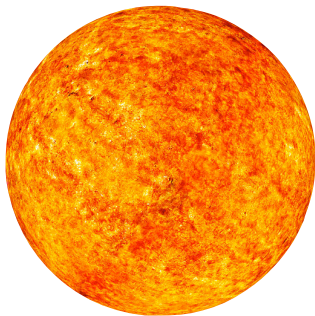
Question



A star is in hydrostatic equilibrium. What does that mean?

- a) Keeps the Sun burning H into He.
- b) Keeps the Sun from turning into a big cloud in the shape of a bunny.
- c) Keeps the Sun a flattened disk.
- d) Keeps the Sun a constant size.
- e) Keeps the Sun unstable.

Becoming a Star



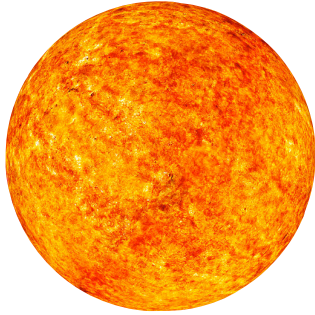
Where does the Heat Pressure come from?



Why doesn't Sun cool down?

The Sun does not collapse nor even change its radius.
Gravity pushes in, but what pushes out?
Okay, heat, but what makes the heat?

Becoming a Star



Darwin: Evolution $> 10^8$ years

Lyell: Geological $> 10^8$ years

Without new energy, Sun will cool down and contract.

Power source > 4.5 billion years

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Question



What is not physical evidence for an extremely old Sun?

- a) Evolution requires hundreds of millions of years.
- b) Meteorites are dated to billions of years.
- c) Geological process require hundreds of millions of years.
- d) Lack of alien contact.
- e) The Sun is stable in size.

iClicker

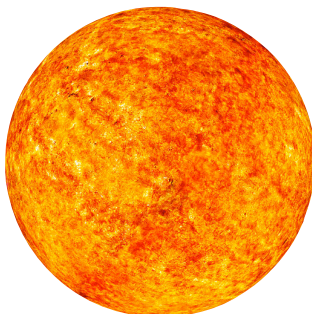
x

D

So, What Powers the Sun?



Discuss with neighbors possible heating options. List at least 2 possibilities, even if you know the correct one. List all feasible ideas.



Gravity:

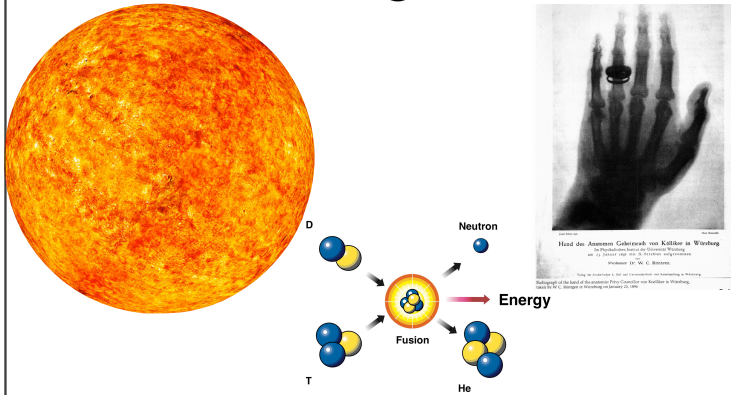
- Seems like a good idea. Remember Jupiter gives off heat from gravity collapse still.
- A contracting Sun releases gravitational energy.
- But only enough for 20 million years

Chemical:

- If the Sun was made from TNT, something that burns very well, then it would still last for only 20,000 years

Need something more powerful!

Becoming a Star



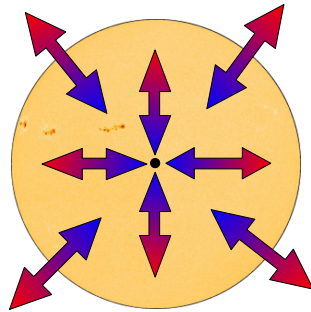
20th century Physics provides the answer!

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Eyes began to turn to the nuclear processes of the Atoms

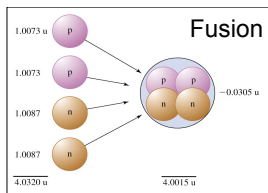
Life as a Main Sequence Star

- Main sequence stars generate energy by hydrogen fusion
- Long, stable part of a star's life
- Energy generated keeps their interiors hot
- Resulting pressure balances gravity and prevents the star from collapsing



In a main sequence star, gravity and pressure are in balance

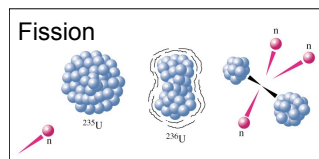
Nuclear Processes



Fuse Together

Hydrogen Bomb

Stars



Break Apart

Atomic Bomb

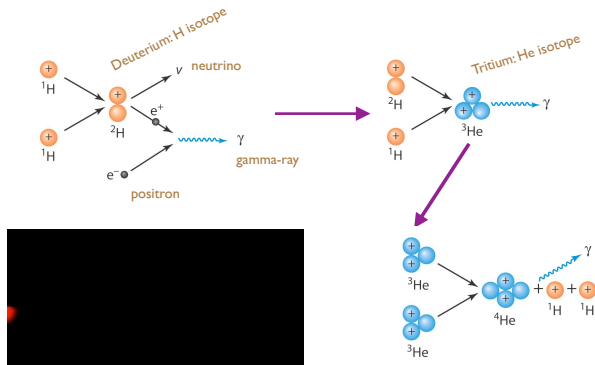
Nuclear Reactors

Light nuclei: fusion
Fuse together light atoms to make heavier ones
Happens in the Sun
H-Bomb

Heavy nuclei: fission
Break apart heavier atoms into lighter ones
Used in power plants
A-Bomb

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Stellar Fusion



The Proton-Proton (p-p) Chain

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Proton-Proton Chain

4 hydrogen atoms fuse to make 1 helium atom

Requires very high density and temperature (at least 7 million K)

Note the production of neutrinos and antimatter

Discovery of Deuterium in lab: Nobel Prize— about 0.01% of all H on earth is deuterium including in your body: you contain about 10 kilos (20 lbs) of H, and about 2 grams of D, Water (normally H₂O) with D is D₂O : “heavy water”

Discovery of neutrino in lab: Nobel Prize. 10 billion from Sun go through hand every sec. Reach out! Go through your body, Earth, but almost never interact

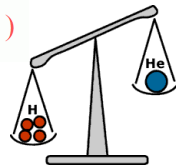
Discovery of positron in lab: Nobel Prize. Because of this reaction the Sun contains a small amount of antimatter!

Why does fusion release energy?



Fusion: $4p \rightarrow {}^4\text{He} \quad (2p, 2n)$

Fact: $4m(p) > m({}^4\text{He})$!
mass of whole < mass of parts!

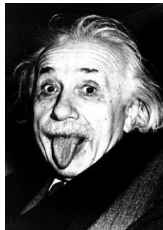


Einstein says $E = mc^2$:

- Mass is a form of energy!
- Each ${}^4\text{He}$ liberates energy:

$$E_{\text{fusion}} = m_{\text{lost}} c^2 = 4m(p)c^2 - m({}^4\text{He})c^2 > 0!$$

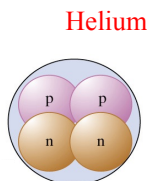
0.7% of mass converted to energy



The Nucleus

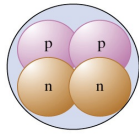


- **Something is odd here!**
- **What is it?**
- **Discuss with neighbor.**



Okay, so we know that the nucleus can have numerous protons (+’s) very close.

The Nucleus



Helium

Why doesn't the nucleus of the atom fly apart?

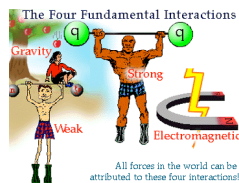
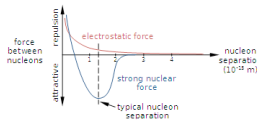
What binds the Nucleus?



Fundamental Forces			
Strong		Strength Force which holds nucleus together 1	Range (m) 10^{-15} (diameter of a medium sized nucleus) Particle gluons, π (nucleons)
Electro-magnetic		Strength $\frac{1}{137}$	Range (m) Infinite Particle photon mass = 0 spin = 1
Weak		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
Gravity		Strength 6×10^{-39}	Range (m) Infinite Particle graviton? mass = 0 spin = 2

Does not depend on charge.

Not an inverse square law



Strong Nuclear

The strongest of the 4 forces

The force which holds an atom's nucleus together, in spite of the repulsion between the protons.

Does not depend on charge

Not an inverse square law- very short range.

Question



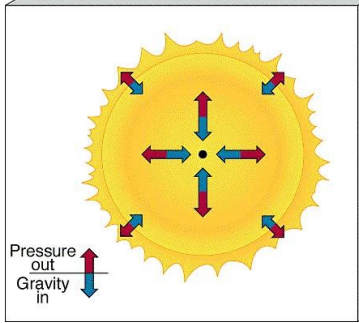
Why does the Sun shine?

- Nuclear burning.
- Nuclear burning of helium to carbon.
- Nuclear burning of dreams to pure energy.
- Nuclear burning of hydrogen to helium.
- Nuclear burning of carbon to helium.

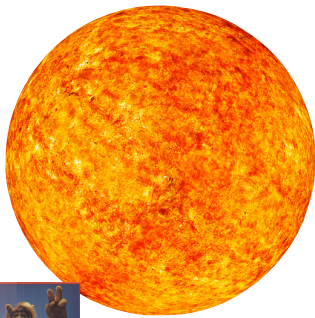
Why Doesn't The Sun Shrink?



- Sun is currently stable
- Pressure from the radiation created by fusion balances the force of gravity.
- Gravity is balanced by pressure from fusion!



Hydrostatic Equilibrium



- Fairly constant size
- Fairly constant luminosity
- Fairly constant density

Billions of years!

Relevant for Life?



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UV constancy?

They Might Be Giants Why Does The Sun Shine



The Sun is largest fifth and second row, a million Earth's would fit inside

Arguably the best of all possible stars

Where hydrogen is built into helium

At a temperature of millions of degrees

The Sun is far away... About 93,000,000 miles away

And that's why it looks so small

A place where we could live

But here on Earth there'd be no life

Without the light and day

We need its heat, we need its light

We need its light, we need its heat

The Sun light comes from our own sun's atomic energy

The Sun light comes from our own sun's atomic energy

Scientists have found that the Sun is a huge atom smashing machine

The heat and light of the sun are caused by nuclear reactions between Hydrogen, Nitrogen, Carbon, and

A gigantic nuclear furnace

Where hydrogen is built into helium

At a temperature of millions of degrees

The Sun is a mass of incandescent gas

A gigantic nuclear furnace

Where hydrogen is built into Helium

The Sun is not made of anything but a gas: Aluminum, Copper, Iron, and many others

The Sun is a mass of incandescent gas

A gigantic nuclear furnace

Where hydrogen is built into helium

At a temperature of millions of degrees

The Sun is hot, the Sun is not

A place where we could live

But here on Earth there'd be no life

Without the light it gives

We need its light

We need its heat

The Sun light that we seek

The Sun light comes from our own Sun's atomic energy

The Sun is a mass of incandescent gas

A gigantic nuclear furnace

Where hydrogen is built into helium

Homemade Fusion?



High Temperature $> 10^6 \text{ K}$

High Density



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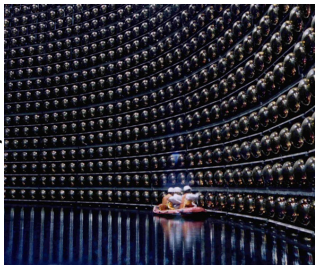
Sun (Neutrino Goggles)



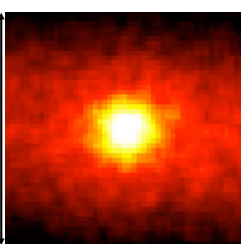
The Sun's nuclear fusion produces a particle called a neutrino. Matter is almost transparent to neutrinos. On average, it would take a block of lead over a quarter of a light-year long to stop one. Roughly 1 billion pass through every square centimeter of you every second!

But we can detect them. Every once in a while they interact with a proton and create light. We have detected the Sun in neutrinos. Confirmation that nuclear fusion is happening in the Sun's core. 500 days of data! As neutrinos can only be produced by nuclear processes, our energy source concept must be fundamental. Proves nuclear burning!

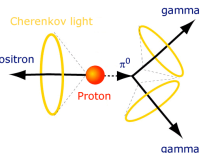
50 Tons Extremely Pure Water



90 degrees



Super-Kamiokande

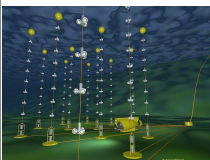


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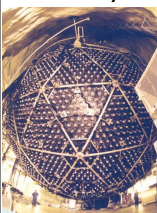
Neutrino Detection



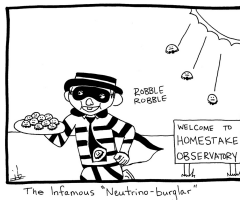
Antares



Sudbury



Homestake



The Infamous "Neutrino-buglar"



Daya Bay

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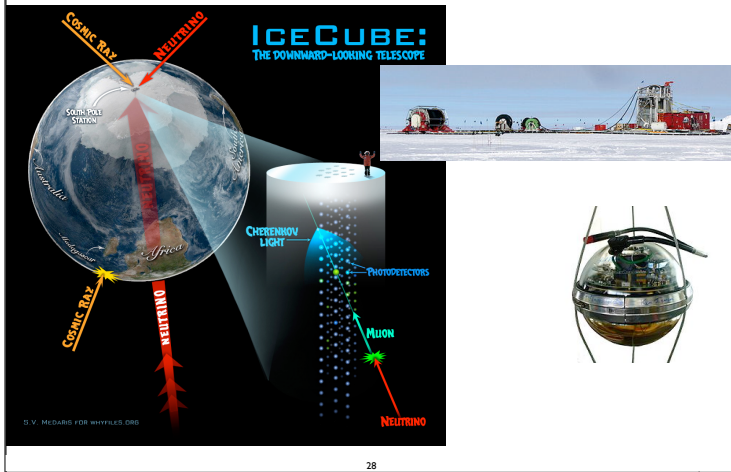
The [Sudbury Neutrino Observatory](#), a 12-meter sphere filled with heavy water surrounded by light detectors located 2000 meters below the ground in Sudbury, Ontario, Canada.

Located about 2.5 km under the [Mediterranean Sea](#), the [ANTARES](#) (*Astronomy with a Neutrino Telescope and Abyss environmental REsearch*) has been fully operational since May 30, 2008.

Consisting of an array of twelve separate 350 meter long vertical strings 70 meters apart from each other with 75 photomultiplier optical modules, this detector uses the sea water as the detector mass.

An older neutrino spotter lies beneath a mountain in Japan. Its giant, spherical tank holds about 50 million liters (13 million gallons) of water, enough to fill 20 Olympic-size swimming pools. The inside of the tank is lined with thousands of beach-ball-sized detectors that can pick up even the faintest flash of blue light.

Neutrino Detection



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Cosmic Gall



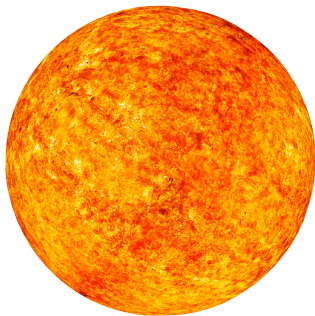
NEUTRINOS, they are very small.
 They have no charge and have ~~n~~ mass
 And do ~~not~~ interact at all.
 The earth is just a silly ball
 To them, through which they simply pass,
 Like dustmaids down a drafty hall
 Or photons through a sheet of glass.
 They snub the most exquisite gas,
 Ignore the most substantial wall,
 Cold shoulder steel and sounding brass,
 Insult the stallion in his stall,
 And scorning barriers of class,
 Infiltrate you and me! Like tall
 and painless guillotines, they fall
 Down through our heads into the grass.
 At night, they enter at Nepal
 and pierce the lover and his lass
 From underneath the bed-you call
 It wonderful; I call it crass.

very little

hardly

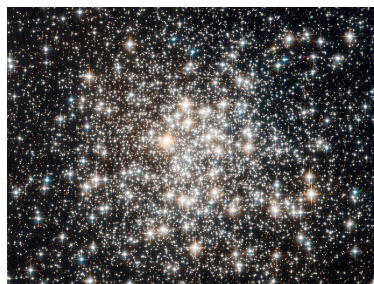
- Telephone Poles and Other Poems, John Updike, Knopf, 1960

Main Sequence Star



Fusion of H into He = MS

Stars are nuclear reactors



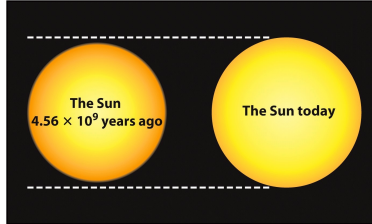
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The Sun is a nuclear reactor, but I'm saying much more than that:
 Sun is a typical star
 So all stars are run by thermonuclear fusion
 Night sky, Universe lit up ultimately by dense nuclear furnaces
 scattered everywhere with life snuggled up close

Life of a Low Mass (Sun-like) Star



- Happy pursuit of burning $H \Rightarrow He$
- Luminosity and temperature increases as Sun evolves
- Today 40% brighter and 6% larger than zero age MS.



http://wings.avkids.com/Book/Myth/Images/ocean_sun.gif

Main sequence stars are by definition burning H into He in the core, but the star will get hotter and brighter as it ages

Life of Our Sun



- As Sun ages, Earth is affected
- Hotter means lighter elements (e.g. water) can escape atmosphere
- In 1.1 billion years, the continents will be deserts and the oceans will start to evaporate.



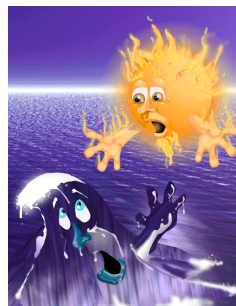
<http://www.esquire.com/cm/esquire/images/Gd/desert-1108-1g.jpg>

Increased temperature means that the lighter elements, like water molecules in the air, will have enough speed to escape Earth completely.

Life of Our Sun



- Sun increases 40% in brightness in next 3.5 billion years.
 - All oceans gone!
- The baking sediments at the bottom of the oceans, release CO₂
- Earth becomes Venus-like!
- The Earth will be a barren rock in about 4 billion years!



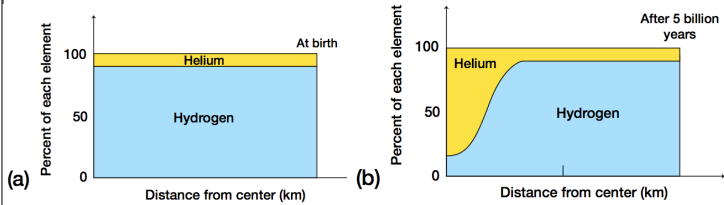
http://wings.avkids.com/Book/Myth/Images/ocean_sun.gif

Then the heat makes even those heavier molecules leave the Earth.

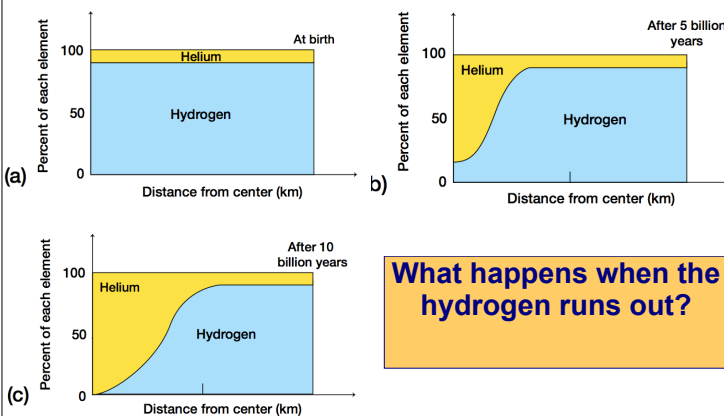
Sun's Lifetime



While on the MS, Sun is stable.
But for how much longer?



The Sun has used up about half its initial hydrogen supply

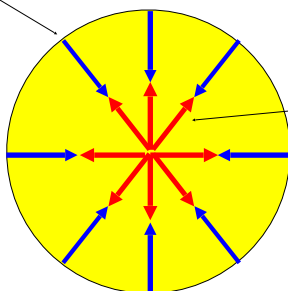


What happens when the hydrogen runs out?

The Battle between Gravity and Pressure



Gravity pushes in



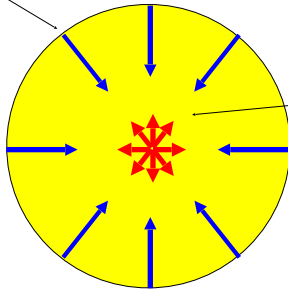
Heat pressure from $H \rightarrow He$ fusion pushes out.

Hydrostatic equilibrium: Balanced forces

The Battle between Gravity and Pressure



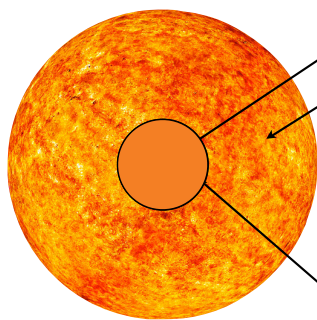
Gravity pushes in



With end of H fusion, gravity thinks it's winning

Unbalanced forces

After the Main Sequence



Inert He Core

Cool, extended envelope

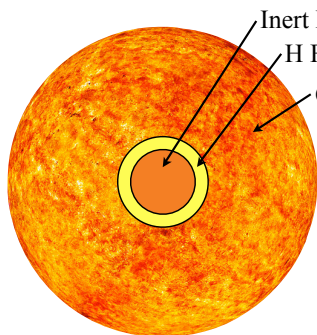
Unbalanced forces leads to

Core contraction, which leads to

H Fusing in shell

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Red Giant Stage

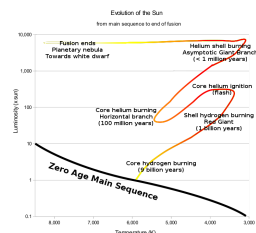


Inert He Core

H Fusing in shell - **Energy released!**

Cool, extended envelope:
Expands and Cools!

Expansion takes 100 million years



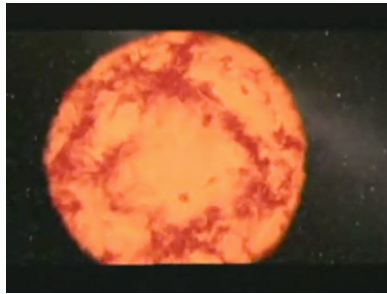
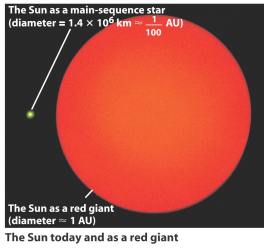
When the hydrogen is gone in the core, fusion stops. Equilibrium is shot. Core starts to contract under its own gravity. This contracting heats the core, and hydrogen fusion starts in a shell around the core. Energy is released, expands envelope \Rightarrow Lum increases!

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Red Giant Stage



As the envelope expands, it cools – so it becomes a red giant.
This process takes 50–100 million years.



Radii grows **100-250x** larger

Same Mass

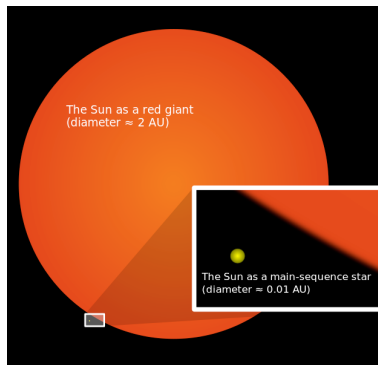
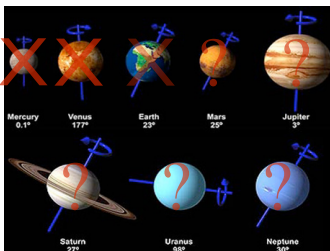


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Solar System Effects



Mars?
For sure too hot.
Jupiter's Moons?
Still too hot
Europa's water vaporizes
Even the moons of Uranus and Neptune may be too hot.



Earth: Gone or just
barren wasteland?

Too hot for life on Mars, Jupiter, or moons of outer gas planets.

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