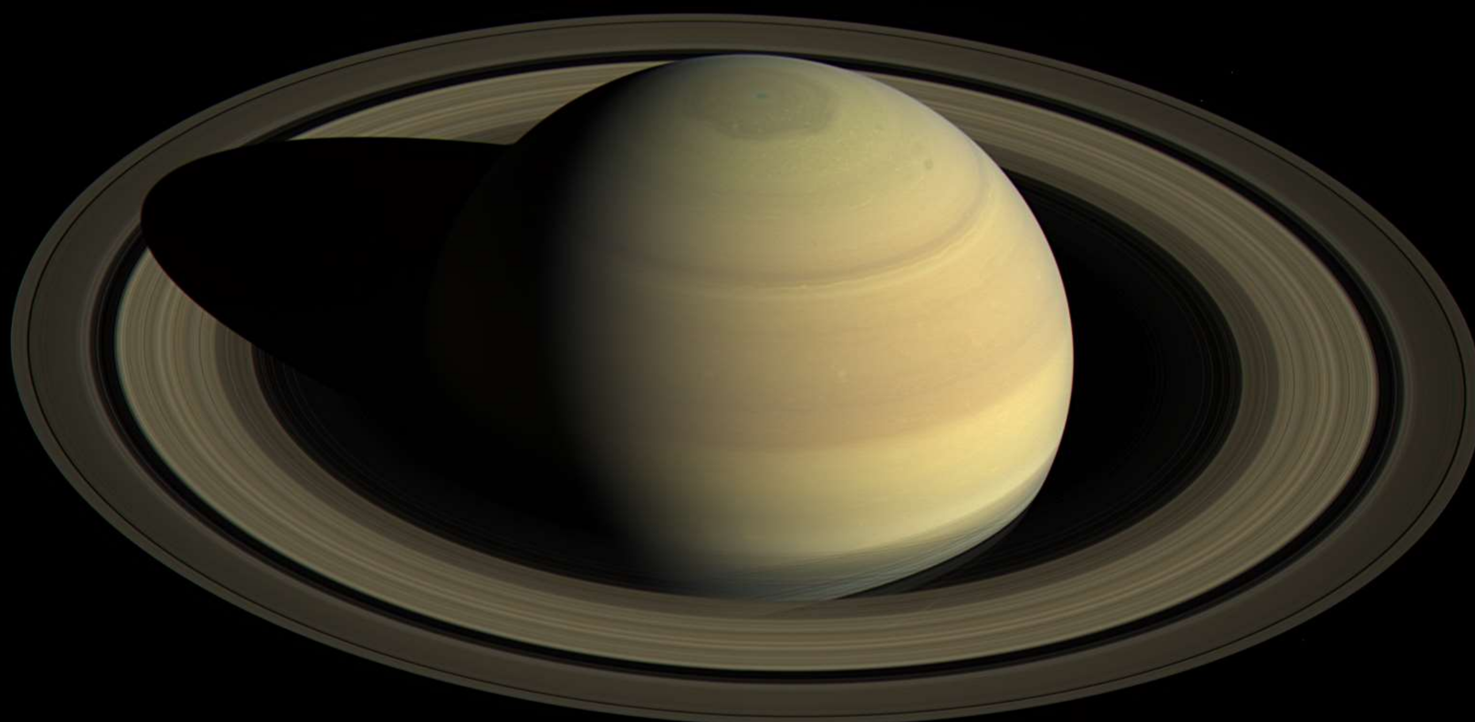
AST 2002
Introduction to Astronomy



A Few Quick Things…

E-mailing me: Must have AST2002 in the subject

Mary Hinkle, Graduate Teaching Assistant:

Office Hours: Mon 1:30-3:00pm. PSB 316

My office hours: Mon 3:00-4:00pm. PSB 308

Tue 3-4 pm. PSB 308

Last day to Drop Classes is Wednesday 21st March… Today

Curved Exam Grades have been Uploaded to Webcourses… this should give a reasonable idea how you are doing in the class…

Next Knights Under the Stars Event – Thu 22nd Mar 8:30-10:00pm - tomorrow

Opportunity to make up the 1% extra credit that was offered (if you haven't been yet, worth 2%)

What have we covered so far?

Chapter 10: Other Planetary Systems: The New Science of Distant Worlds

10.1. Detecting Planets Around Other Stars

- How do we detect planets around other stars?

10.2. The Nature of Planets Around Other Stars

- What properties of extrasolar planets can we measure?
- How do extrasolar planets compare with planets in our Solar System?

10.3. The Formation of Other Planetary Systems

- Do we need to modify our theory of Solar System formation?
- Are planetary systems like ours common?

Categories of Planet Detection Methods…

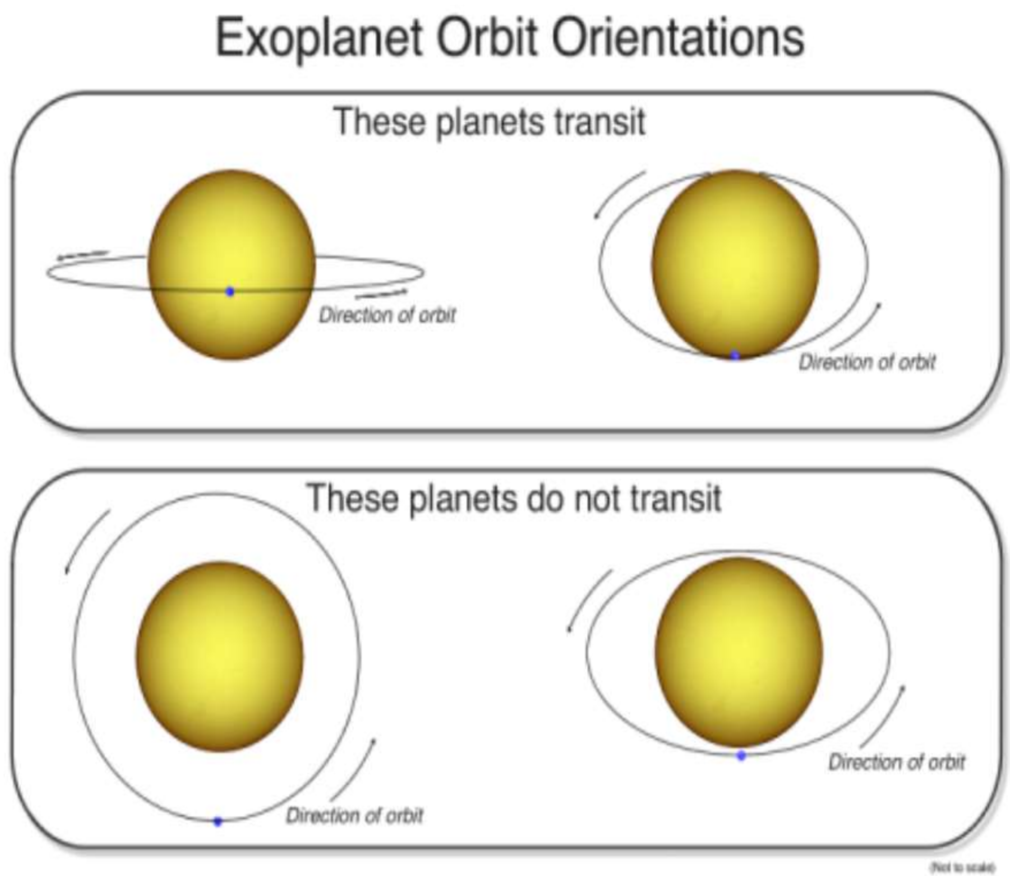
Direct:

- Pictures (or spectra) of the planets themselves

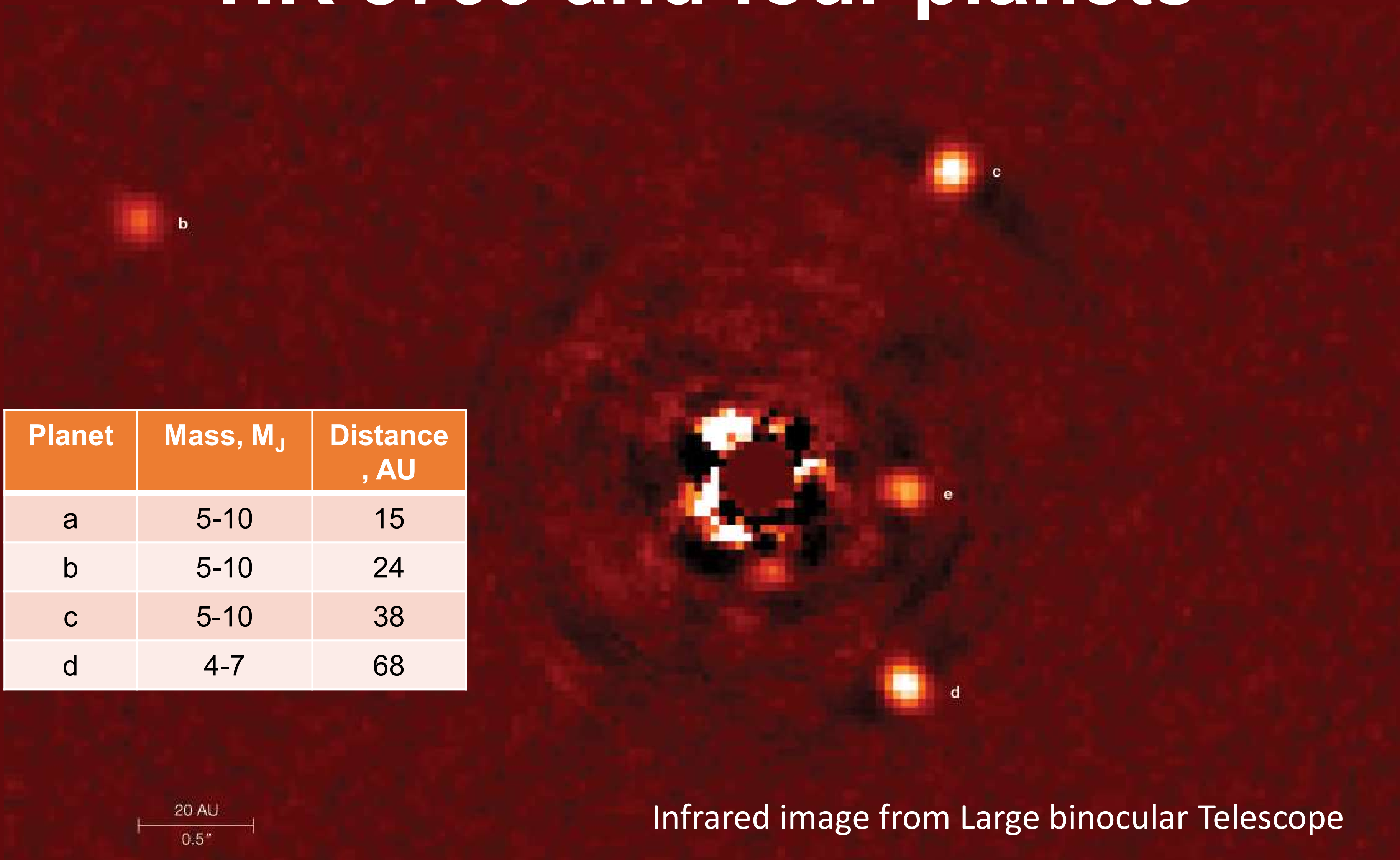
Indirect:

- Measurements of stellar properties revealing the effects of orbiting planets

Orientation of the planetary system relative to the star matters for both



Example of Direct Imaging: star HR 8799 and four planets



Planet	Mass, M_J	Distance, AU
a	5-10	15
b	5-10	24
c	5-10	38
d	4-7	68

Infrared image from Large binocular Telescope

The Astrometric Technique
(An Indirect method)

The Detection of planets by measuring the stars *'Wobble'* in the sky caused by the gravitational effects of the planetary system.

These effects are small (~ 0.001 arcsecond, or 1 milliarcseconds and since orbital periods are long requires extended observations

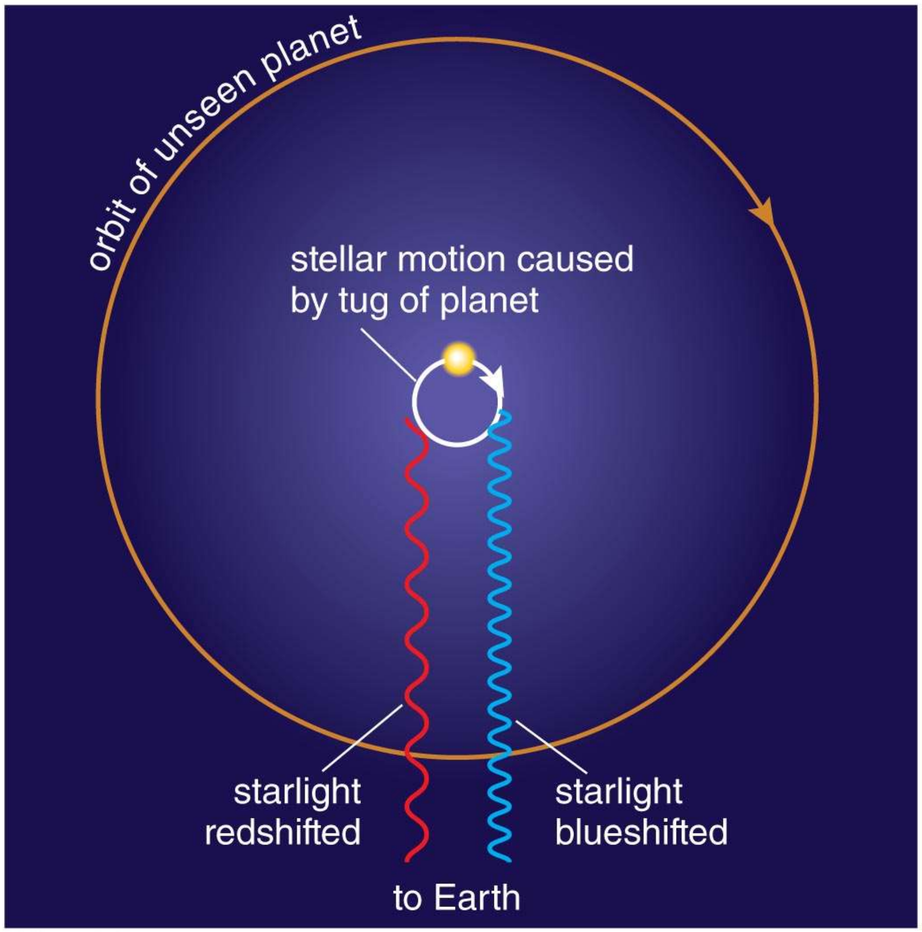
What can it (help) inform you of?

- Orbital period, distance and eccentricity
- Planetary mass

The GAIA Spacecraft (ESA) has been obtaining astrometric observations of a billion stars since 2013 (may last to 2022).

Has an accuracy down to 10 microarcseconds (0.000010)

The Doppler Method
(An Indirect Technique)



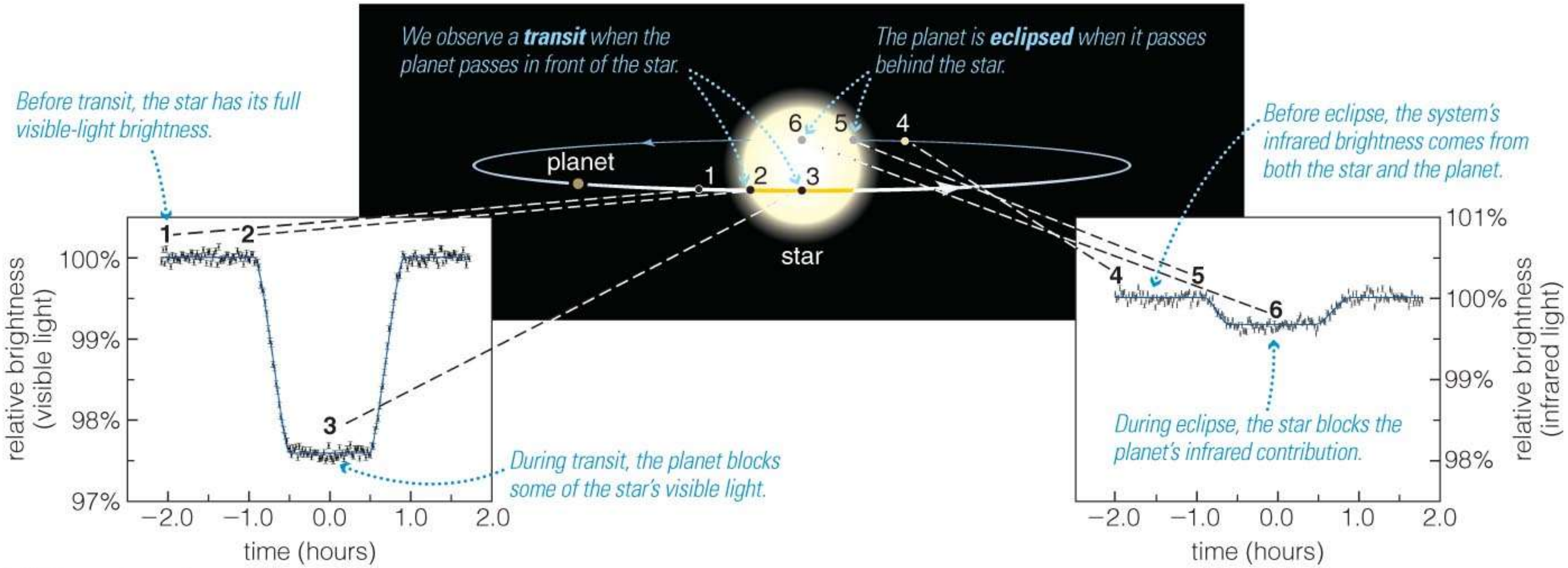
Requires the planetary system to be sufficiently 'edge-on'

- Measuring a star's Doppler shift can tell us its motion toward and away from us.
- Current techniques can measure motions as small as 1 m/s (walking speed!).

What can it (help) inform you of?

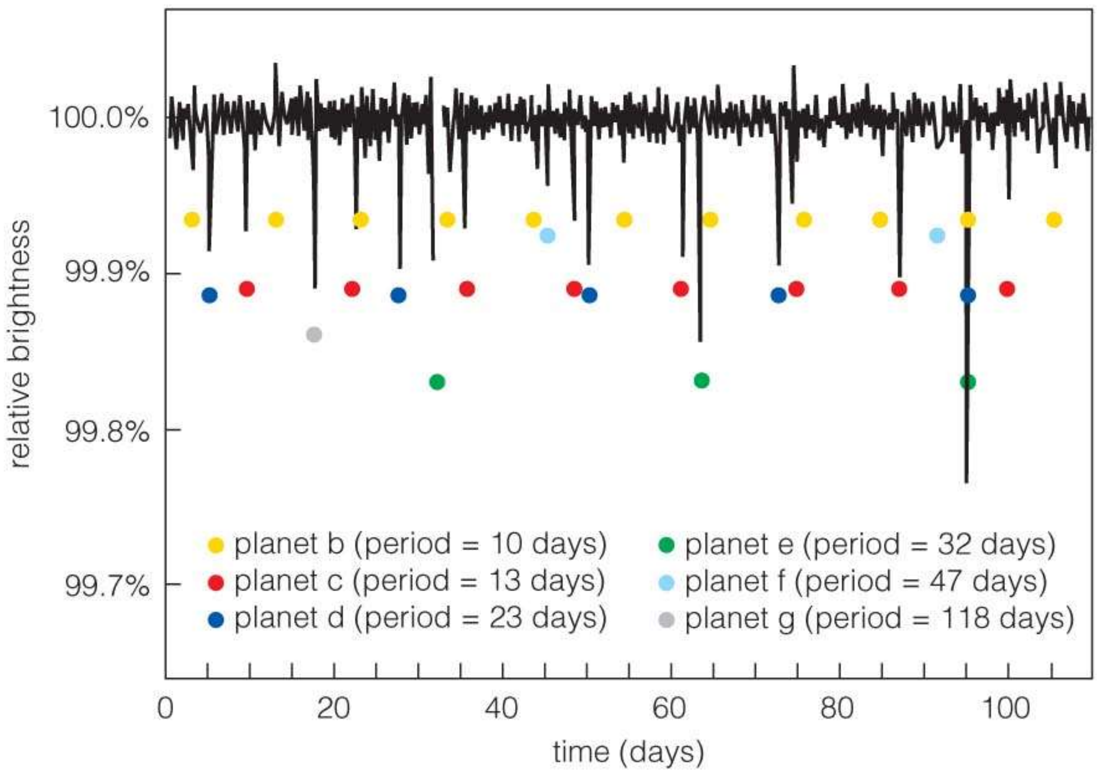
- Orbital period, distance and eccentricity
- Planetary mass (minimum, max is factor of ~two larger)

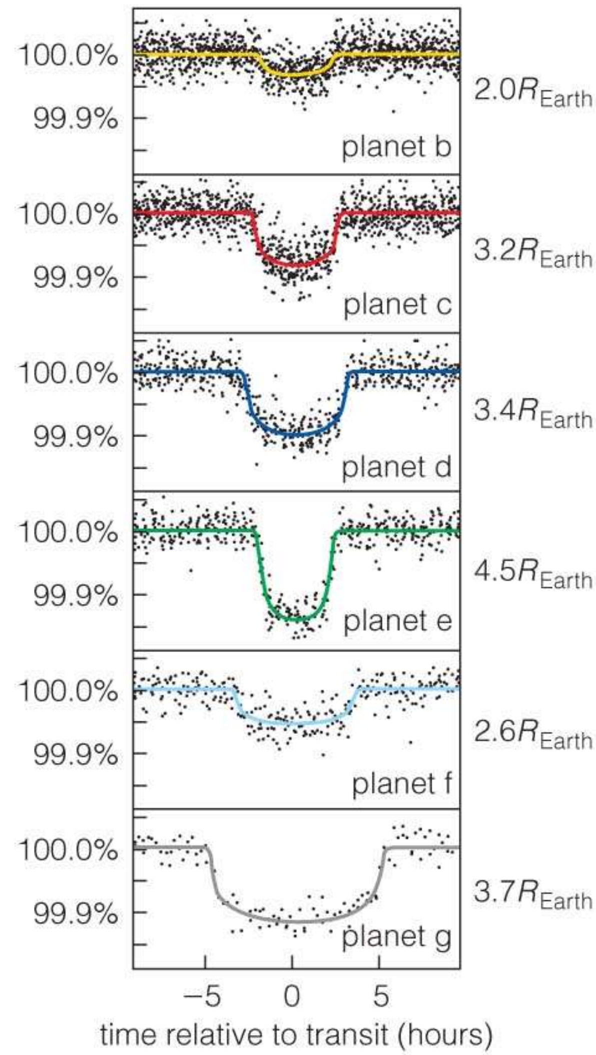
The Transit Method
(indirect technique)



- A **transit** is when a planet crosses in front of a star.
- This reduces the star's apparent brightness and tells us planet's radius.
- Sometimes an **eclipse** – the planet passing behind the star, can also be detected. *(Contributions of exoplanet atmosphere are **now** hidden)*

Transit Example: The Kepler 11 system





The periods and sizes of Kepler 11's 6 known planets can be determined using transit data.

Measurable Properties

Planetary Property	Method(s) Used	Explanation
period	Doppler, astrometric, or transit	We directly measure orbital period.
distance	Doppler, astrometric, or transit	We calculate orbital distance from orbital period using Newton's version of Kepler's third law.
eccentricity	Doppler or astrometric	Velocity curves and astrometric star positions reveal eccentricity.
mass	Doppler or astrometric	We calculate mass based on the amount of stellar motion caused by a planet's gravitational tug.
size (radius)	transit	We calculate size based on the amount of dip in a star's brightness during a transit.
density	transit plus Doppler	We calculate density by dividing the mass by the volume (using the size from the transit method).
atmospheric composition, temperature	transit or direct detection	Transits and eclipses provide data on atmospheric composition and temperature.

Planet mass and orbital tilt:

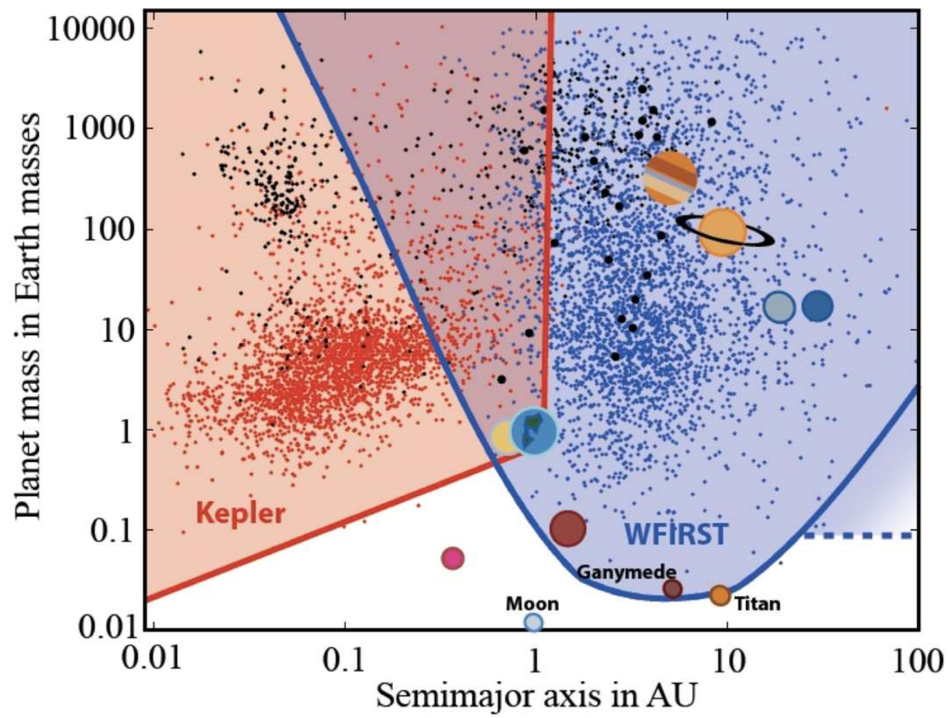
- We cannot measure an exact mass for a planet without knowing the tilt of its orbit using the doppler technique since it only forms us of the velocity towards/away from us
- Doppler will only provide lower limit on masses, but can provide excellent complimentary information for planets detected by the transit method, which must be edge-on.

Gravitational microlensing:

Surprisingly good at detecting 'Earth-like planets'

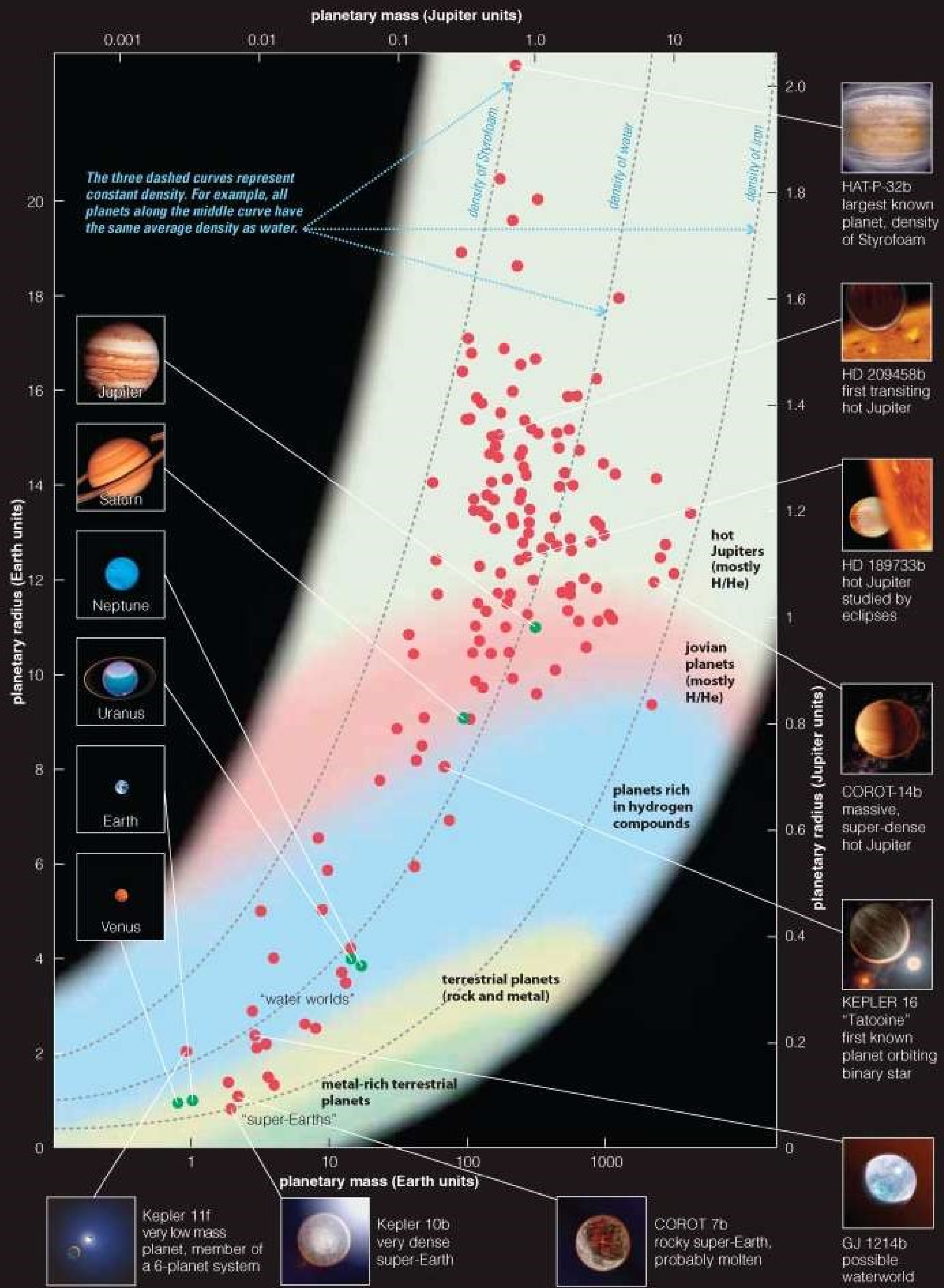
Wide **F**ield **I**nfra**r**ed **S**urvey **T**elescope (WFIRST) (NASA)

- Mid 2020s launch
- Would provide both direct imaging as well as be able to use microlensing to detect planets
- Can detect objects down to almost as small as our moon



But only get a snapshot of the system…
…. Mass & orbital distance estimates.

Exoplanets Properties Compared



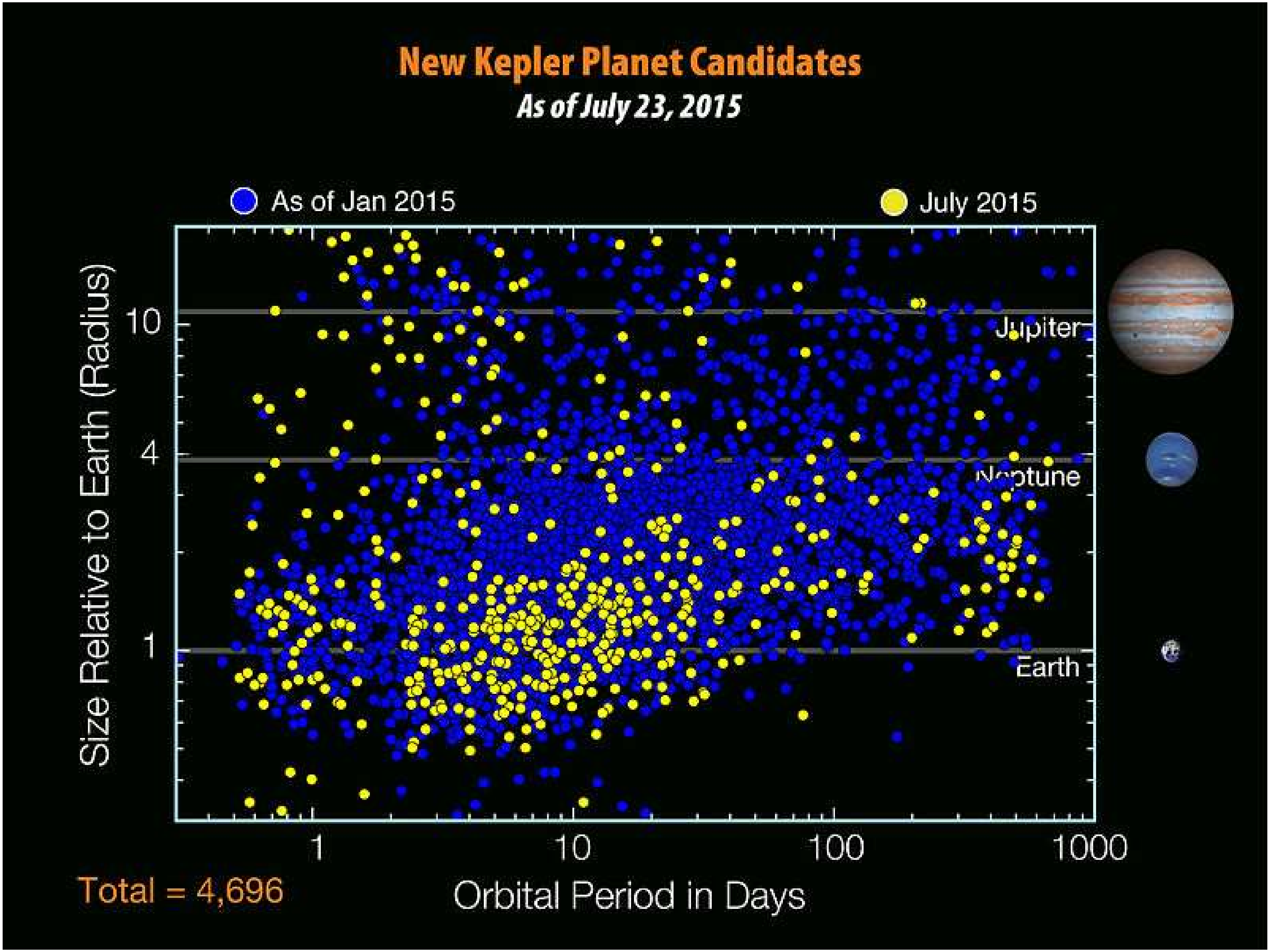
- Much wider array of physical properties compared to the planets in our Solar System
- Some have the density of Styrofoam
- Some have the density of Iron
- Some planets have highly elliptic orbits
- Massive planets (hot Jupiters) are found close to their host stars…

Revisiting the Nebula Theory

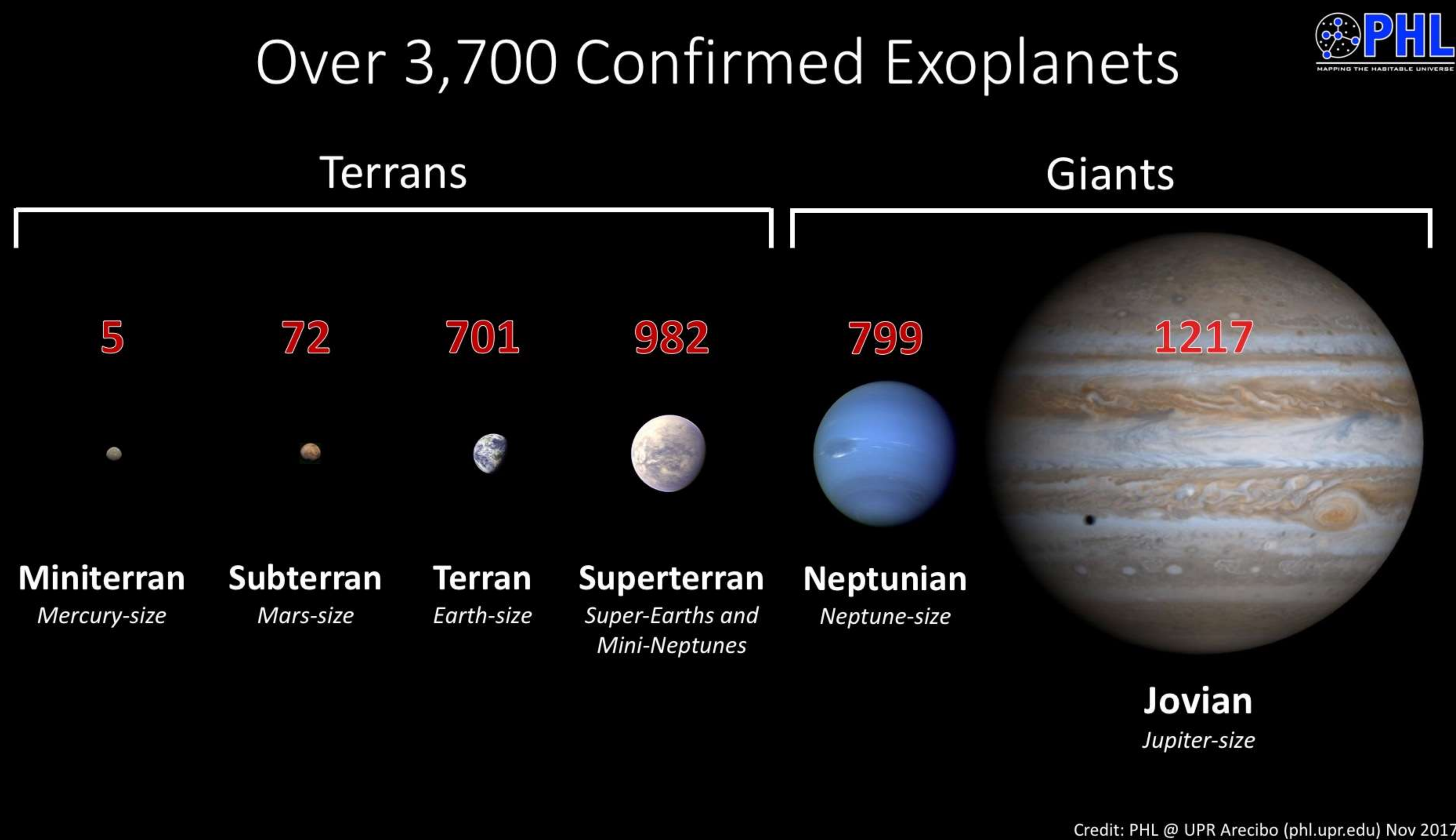
- The nebular theory predicts that massive Jupiter-like planets should not form inside the frost line (at << 5 AU).
- The discovery of hot Jupiters must force a reexamination of nebular theory.

Solution: ***Planetary Migration…***

- Close gravitational encounters between two massive planets can eject one planet while flinging the other into a highly elliptical orbit.
- Multiple close encounters with smaller planetesimals can also cause inward migration.


New Kepler Planet Candidates
As of July 23, 2015
As of Jan 2015
July 2015
Size Relative to Earth (Radius)
10
4
1
Jupiter
Neptune
Earth
1
10
100
1000
Orbital Period in Days
Total = 4,696

Summary of Detections to Date



Extrasolar Planets Summary

Based on extrapolations from data collected so far:

- There is >1 planet per star, on average per star
- At least 1 in 5 Sun-like stars have an Earth-sized planet within the habitable zone
- Estimated 11-40 billion Earth-sized exoplanets estimated within the Milky Way Galaxy Alone

iClicker Question

Jupiter is about one tenth the diameter of the Sun. If Jupiter transited the Sun, how much of the Sun’s light would be blocked?

A. About 10% (it would be 90% of its regular brightness)

B. About 1% (it would be about 99% its regular brightness)

C. About 30% (it would be about 70% of its regular brightness)

D. About 50% (it would be about half its regular brightness)

E. Less than 0.0001% (its brightness would not change a noticeable amount)

iClicker Question

Jupiter is about one tenth the diameter of the Sun. If Jupiter transited the Sun, how much of the Sun's light would be blocked?

A. About 10% (it would be 90% of its regular brightness)

B. About 1% (it would be about 99% its regular brightness)

C. About 30% (it would be about 70% of its regular brightness)

D. About 50% (it would be about half its regular brightness)

E. Less than 0.0001% (its brightness would not change a noticeable amount)

What's Next?

Chapter 11: Our Star

11.1. A Closer Look at the Sun

- Why does the Sun Shine?
- What is the Sun's Structure?

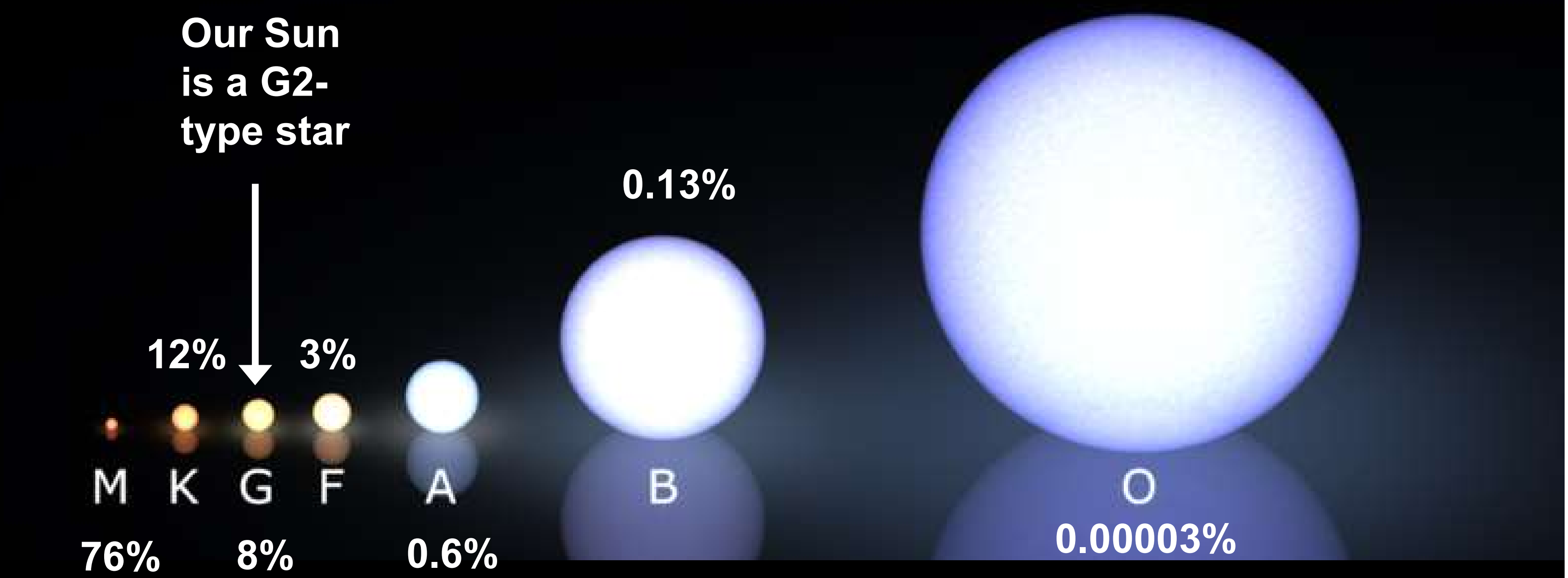
11.2. Nuclear Fusion in the Sun

- How does nuclear fusion occur in the Sun?
- How does the energy from fusion get out of the Sun?
- How do we know what is happening inside the Sun?

11.3. The Sun-Earth Connection

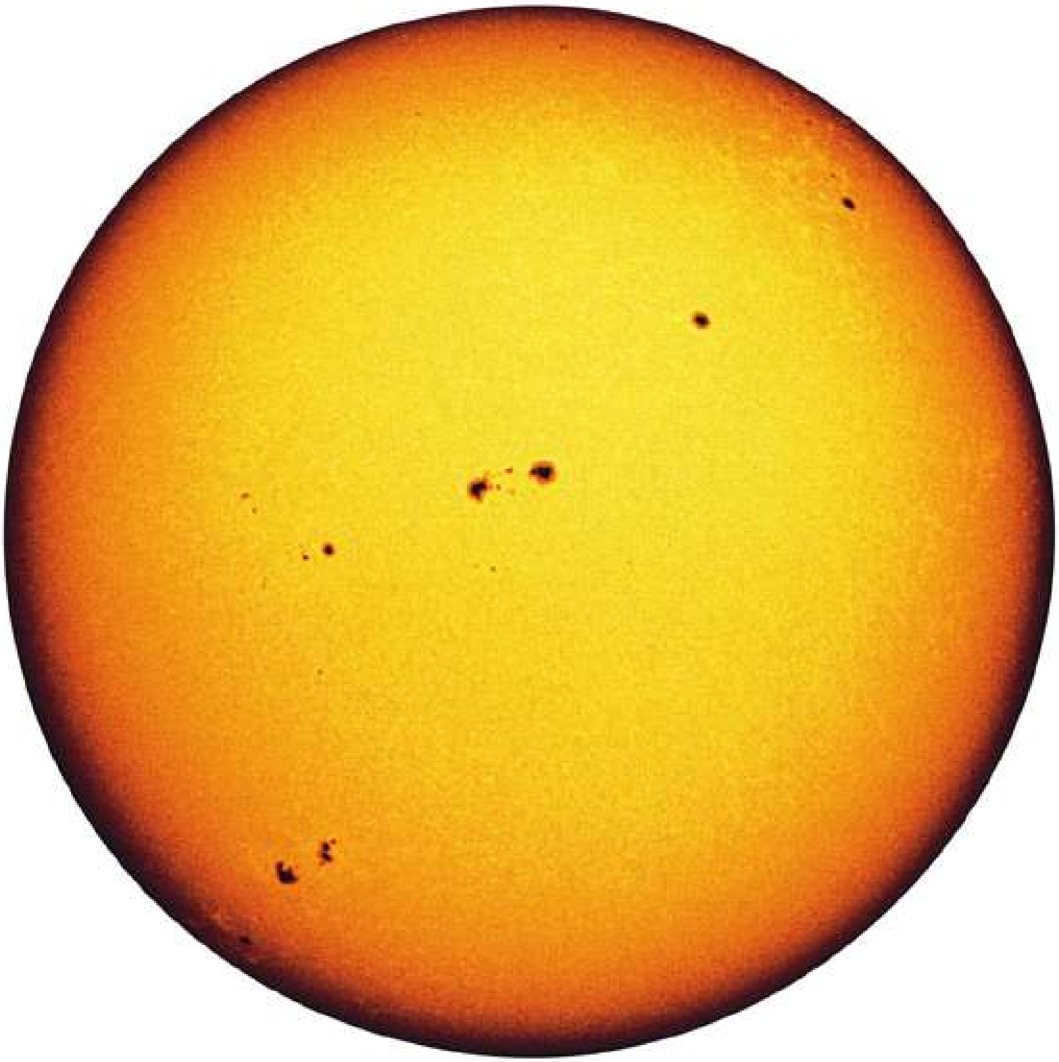
- What causes Solar activity?
- How does solar activity vary with time?

Our Sun is a Fairly Average Star



% indicate Fraction of all main-sequence stars of this spectral type

The Sun: A Few Quick Facts



Radius:

6.9×10^5 km

(109 times Earth)

Mass:

2×10^{30} kg

(300,000 Earths)

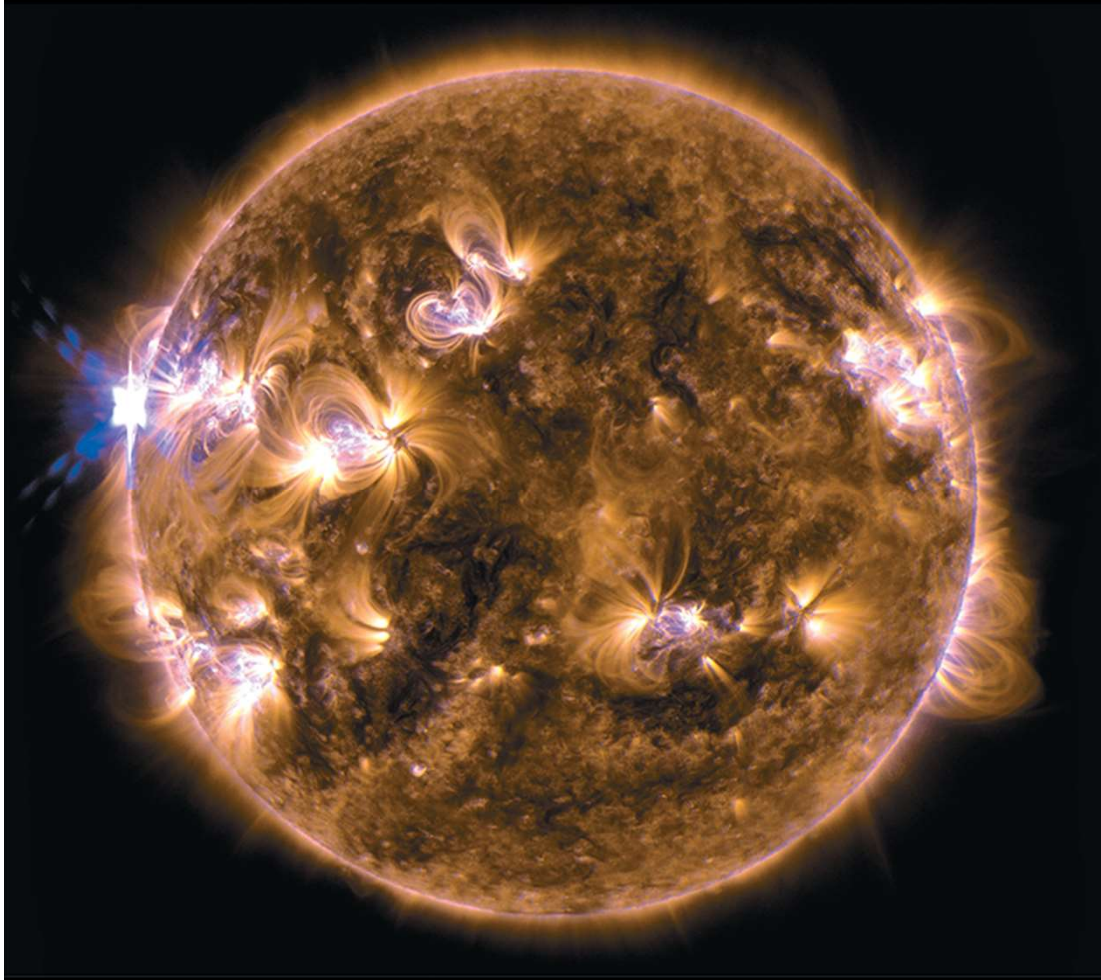
Luminosity: (Energy Output)

3.8×10^{26} watts

1 watt = 1 Joule / second

Typical lightbulb = 100 watts

Why does the Sun shine?



Is it a fire in the Sky?

- No. Chemical burning could not account for the Sun's huge energy output… ~ 10,000 years

Kelvin-Helmholtz contraction? (the process whereby slow gravitational contraction could provide sufficient energy)

- No, The best estimates indicate that this could have kept the Sun shining for approximately 25 million years

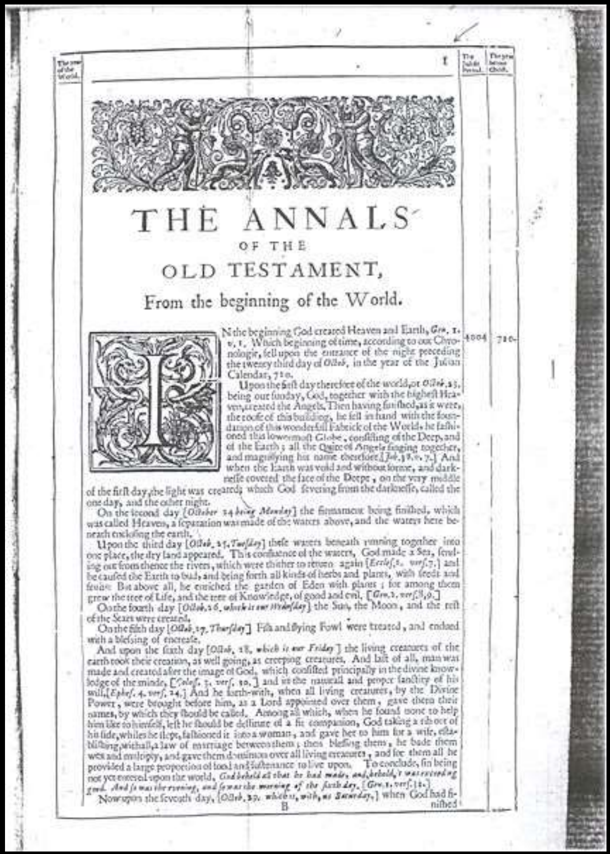
Why does that matter?

How Old is the Earth?

Part I – The Biblical Interpretation

"one day is with the Lord as a thousand years, and a thousand years as one day" (2 Peter 3:8) *(to be taken literally??)*

- If each of the six days is a thousand years, then the Earth is ~ 6,000 years old.
- Bishop James Usshher (Archbishop of Armagh) calculated the beginning of creation occurred on Sunday October 23rd, 4004 BC (published in 1654)
- Consistent predictions were numerous…
  - 3896 BC - Jose Ben Halafta (2nd century)
  - 3992 BC – Johannes Kepler (17th century)
  - 4000 BC – Sir Isaac Newton (17th century)



THE ANNALS OF THE OLD TESTAMENT, From the beginning of the World.

IN the beginning God created Heaven and Earth, *Gen. 1. v. 1.* Which beginning of time, according to our Chronologie, fell upon the entrance of the night preceding the twenty third day of *Octob.* in the year of the Julian Calendar, 710. 4004 710

Upon the first day therefore of the world, or *Octob. 23.* being our sunday, God, together with the highest Heaven, created the Angels. Then having finished, as it were, the roofe of this building, he fell in hand with the foundation of this wonderfull Fabrick of the World, he fashioned this lowermost Globe, consisting of the Deep, and of the Earth; all the Quire of Angels singing together, and magnifying his name therefore [*Job. 38. 6, 7.*] And when the Earth was void and without forme, and darknesse covered the face of the Deepe, on the very middle of the first day, the light was created; which God severing from the darknesse, called the one day, and the other night.

On the second day [*October 24 being Monday*] the firmament being finished, which was called Heaven, a separation was made of the waters above, and the waters here beneath enclosing the earth.

Upon the third day [*Octob. 25. Tuesday*] these waters beneath running together into one place, the dry land appeared. This confluence of the waters, God made a Sea, sending out from thence the rivers, which were thither to return again [*Eccles. 1. vers. 7.*] and he caused the Earth to bud, and bring forth all kinds of herbs and plants, with seeds and fruits. But above all, he enriched the garden of Eden with plants; for among them grew the tree of Life, and the tree of Knowledge, of good and evil. [*Gen. 2. vers. 8, 9.*]

On the fourth day [*Octob. 26. which is our Wednesday*] the Sun, the Moon, and the rest of the Stars were created.

On the fifth day [*Octob. 27. Thursday*] Fish and flying Fowl were created, and endued with a blessing of encrease.

And upon the sixth day [*Octob. 28. which is our Friday*] the living creatures of the earth took their creation, as well going, as creeping creatures. And last of all, man was made and created after the image of God, which consisted principally in the divine knowledge of the minde, [*Colos. 3. vers. 10.*] and in the naturall and proper sanctity of his will, [*Ephes. 4. vers. 24.*] And he forth-with, when all living creatures, by the Divine Power, were brought before him, as a Lord appointed over them, gave them their names, by which they should be called. Among all which, when he found none to help him like to himself, lest he should be destitute of a fit companion, God taking a rib out of his side, whiles he slept, fashioned it into a woman, and gave her to him for a wife, establishing withall, a law of marriage between them; then blessing them, he bade them encrease and multiply, and gave them dominion over all living creatures, and for them all he provided a large proportion of food and sustenance to live upon. To conclude, sin being not yet entered upon the world, *God beheld all that he had made, and, behold, it was exceeding good. And so was the evening, and so was the morning of the sixth day.* [*Gen. 1. vers. 31.*]

Now upon the seventh day, [*Octob. 29. which is, with us Saturday,*] when God had finished

B

How Old is the Earth?

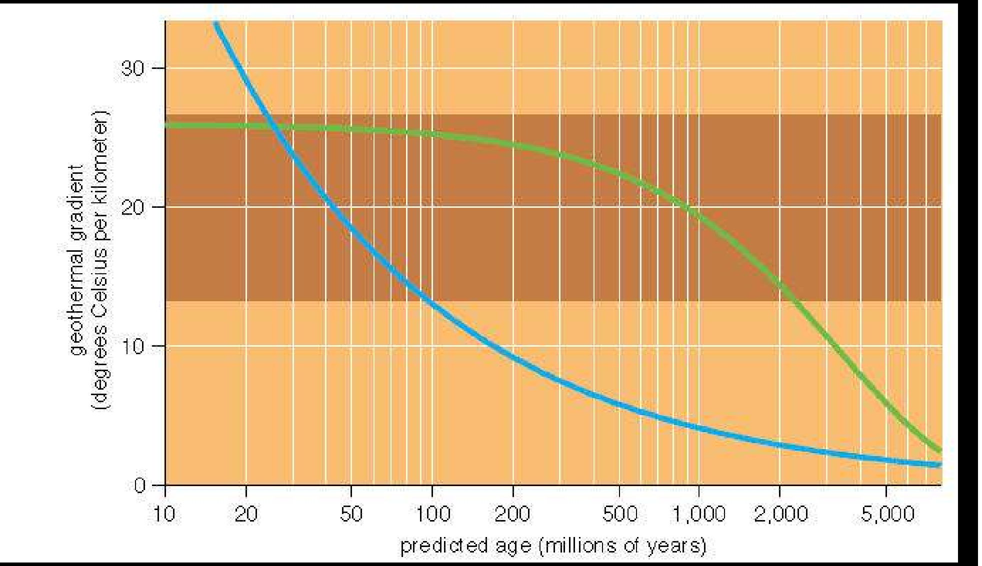
Part II – Mounting Geological Evidence

← Sedimentary layers take a long time to deposit. From the time taken to form and the number of layers, lower limits of ~100 Myrs

↓ Lord Kelvin & John Perry had conflicting ideas about how the diffusion of heat through the Earth and the rate Earth cools could be used to estimate the age of the Earth. (end of 19th Cent)

- Kelvin's conduction model predicted 34-400 million years.
- Perry's conduction/convection model indicated a 2-3 billion yr old Earth

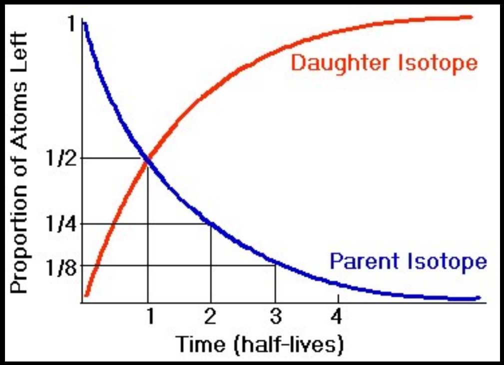
However, additional heat sources such as radioactive decay increase this age



How Old is the Earth?
Part III – Radiometric Dating

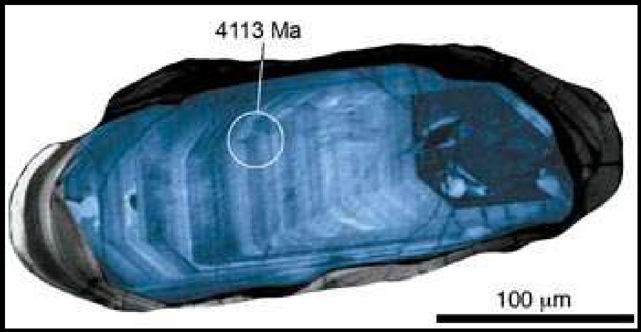
By the turn of the 20th century, Marie Curie's work on Radioactivity was well-known

In 1904, Rutherford suggested that helium particles (the daughter isotope from radium decay) could be used to age rocks, which worked reasonably well.

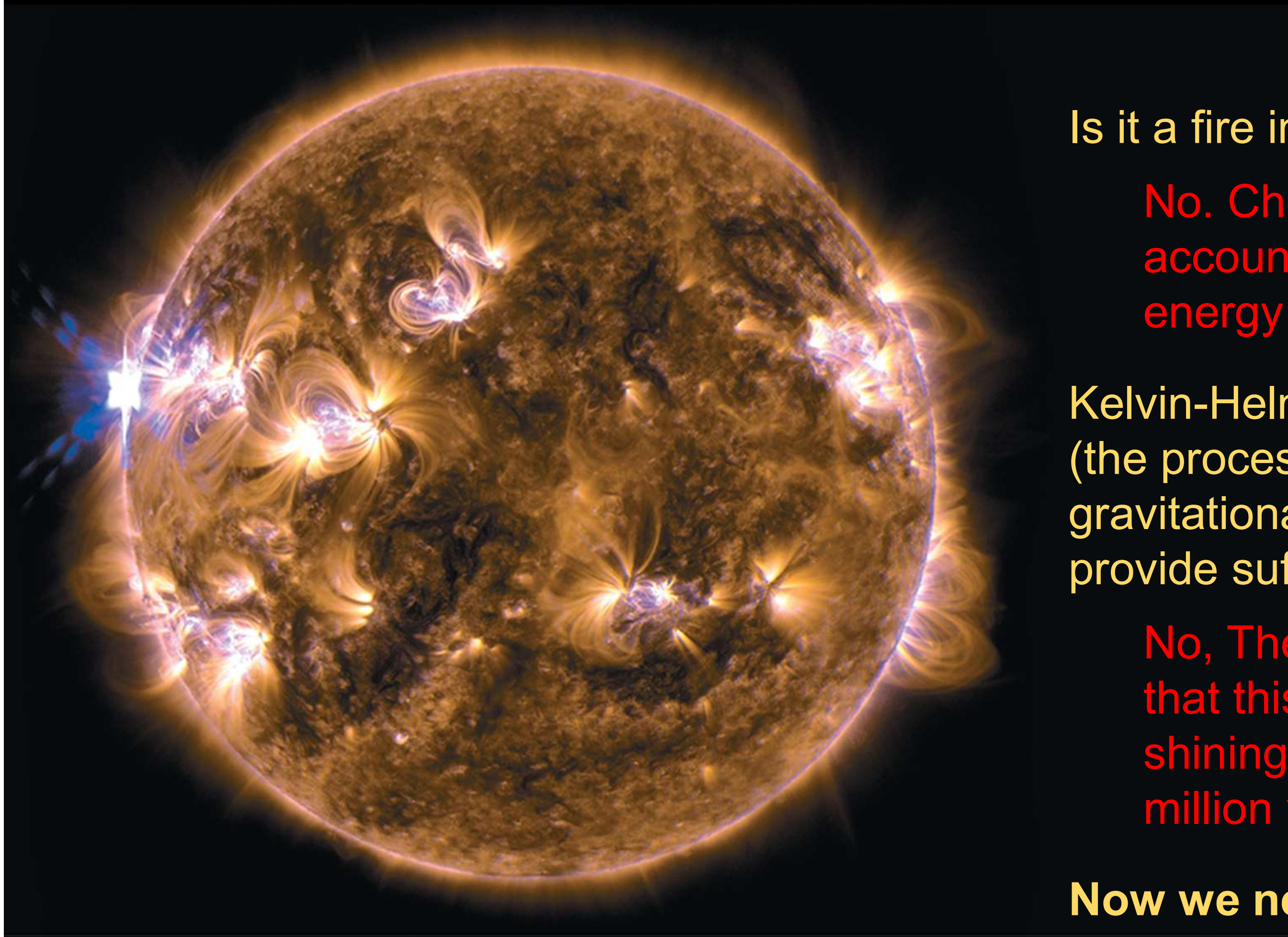


Today….

- Oldest rocks in America are ~3.6 Ga (Billion years)
- Oldest rocks on Earth are ~3.96 Ga (Byr).
- Some zoned-Zircon minerals identified at 4.1-4.3 Ga (Jack Hills, Australia, *and these require liquid water to form*). Based on Pb-isotopes.
- Based on the age of lunar rocks and meteorites, the Earth (and Solar System) is thought to be **~4.57 Billion years old**. *Multiple isotopes used.*



Why does the Sun shine?



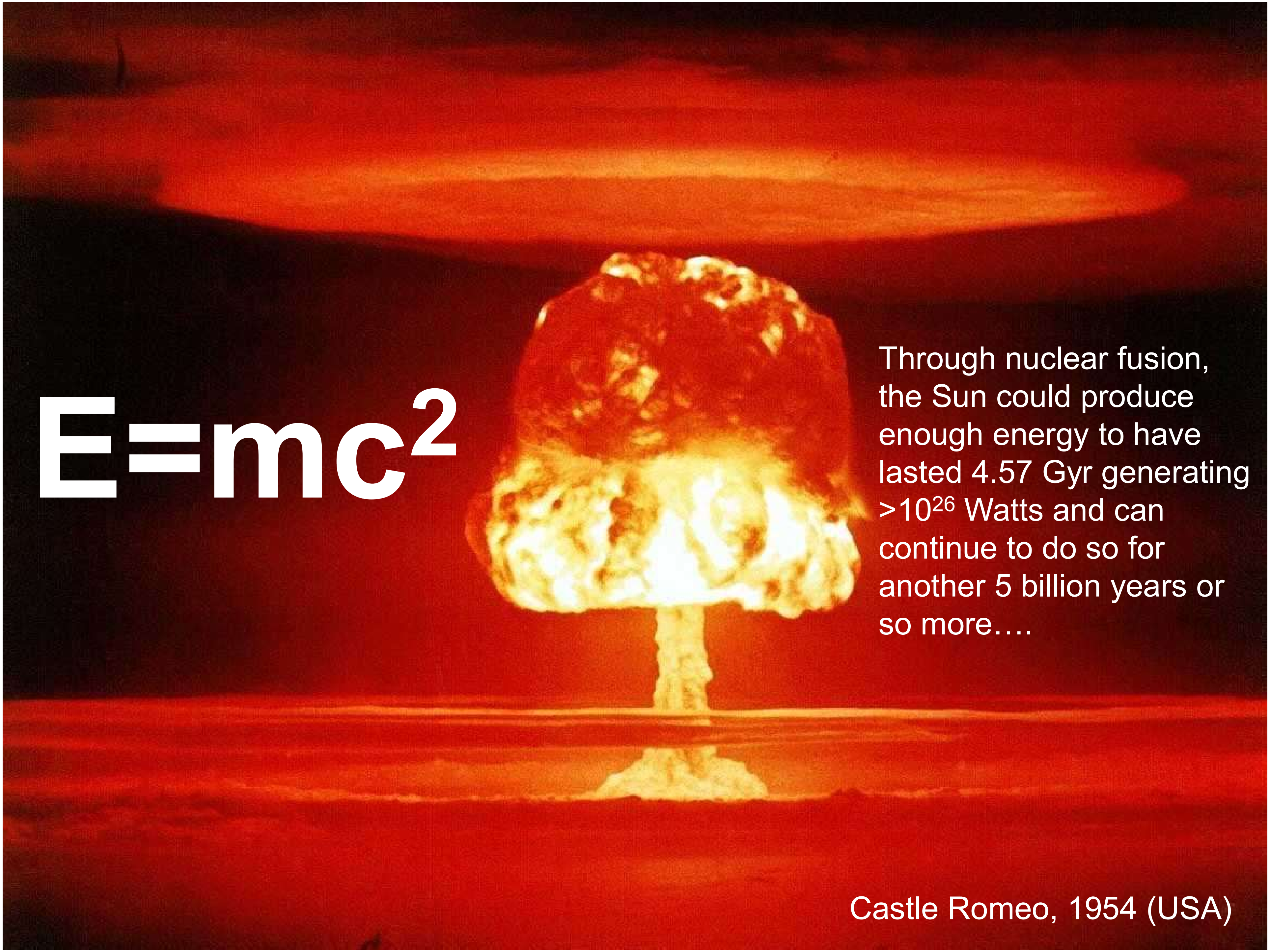
Is it a fire in the Sky?

No. Chemical burning could not account for the Sun's huge energy output… ~ 10,000 years

Kelvin-Helmholtz contraction? (the process whereby slow gravitational contraction could provide sufficient energy)

No, The best estimates indicate that this could have kept the Sun shining for approximately 25 million years

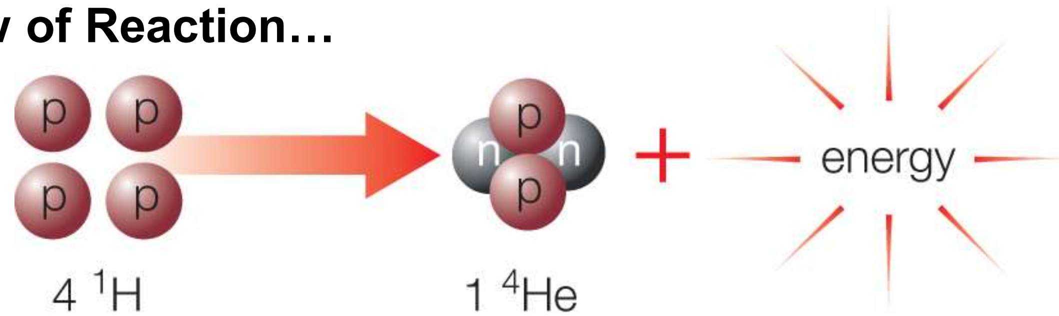
Now we need an energy source that can output >10^{26} Watts for 4.57 Billion years??


E=mc2
Through nuclear fusion, the Sun could produce enough energy to have lasted 4.57 Gyr generating >1026 Watts and can continue to do so for another 5 billion years or so more….
Castle Romeo, 1954 (USA)

Hydrogen Fusion in the Sun

The Proton-Proton Chain (P-P chain)

Overview of Reaction…



Exact masses (in atomic mass units; 1 mole of ^{12}C = 12 g exactly):

H = 1.007825

(4) H = 4.0313

He = 4.002603

Mass difference = 0.028697

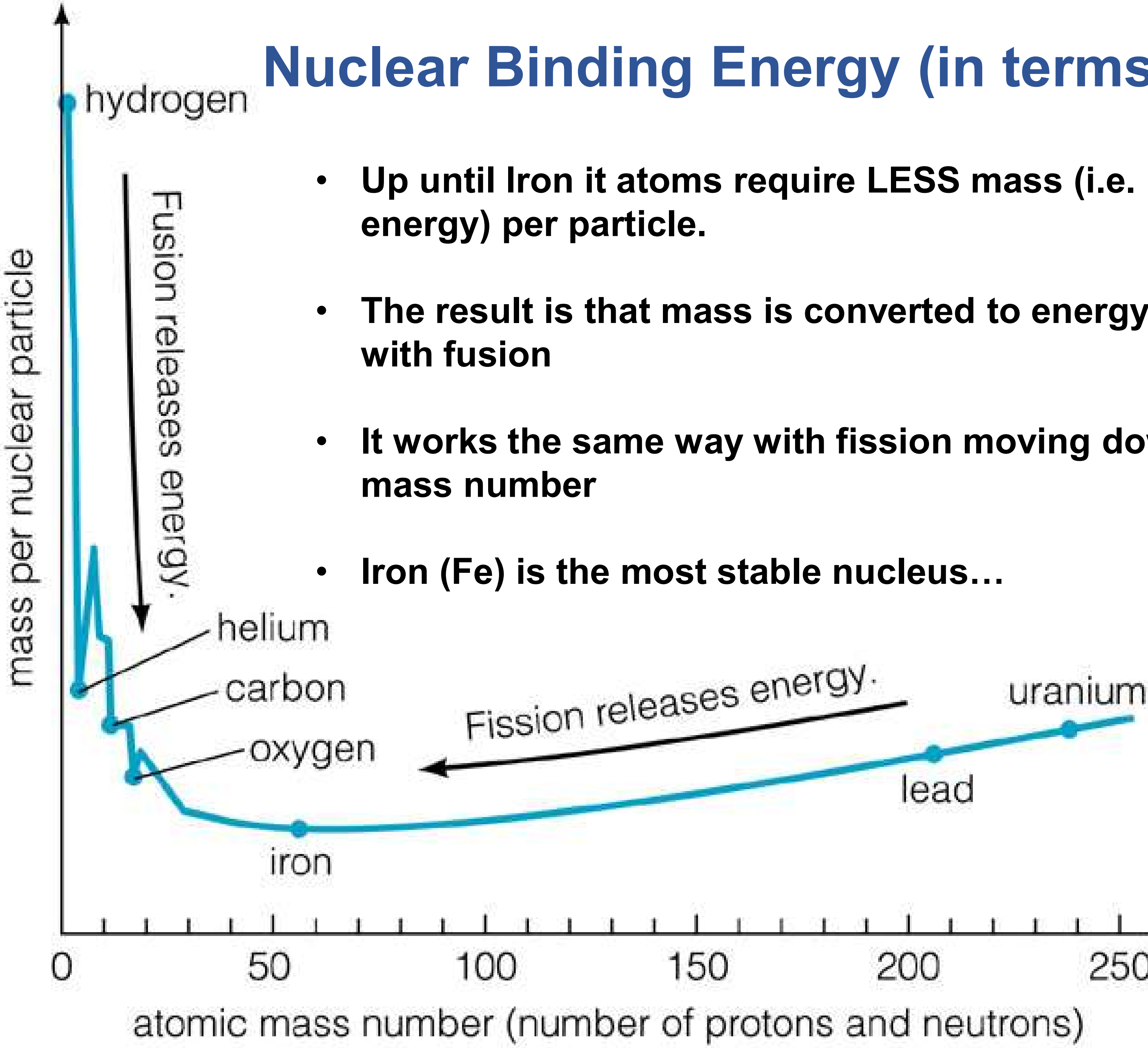
Total mass of the products is *lower* than that of the reactants… where did the mass go?

$E=mc^2$ (where c is the speed of light, 3×10^8 meters/second)

- Every second, the Sun converts 600 million tons of H into 596 million tons of He
- 4 million tons each second is converted to energy.

Nuclear Binding Energy (in terms of mass)

- **Up until Iron it atoms require LESS mass (i.e. binding energy) per particle.**
- **The result is that mass is converted to energy and released with fusion**
- **It works the same way with fission moving down the atomic mass number**
- **Iron (Fe) is the most stable nucleus…**



What is an Electron-Volt (eV?)

From Wikipedia:

- By definition, *"it is the amount of energy gained (or lost) by the charge of a single electron moving across an electric potential difference of one volt".*
- Thus it is 1 volt (1 joule per coulomb, 1 J/C) multiplied by the elementary charge (e, or $1.6021766208(98)\times10^{-19}$ C).
- Therefore, one electronvolt (eV) is equal to $1.6021766208(98)\times10^{-19}$ J.

As a scale of energy:

- A typical chemical bond is around 4.5 eV (strongest ~ 10 eV)
- The amount of energy to ionize atoms/molecules ranges from 6 to ~20 eV

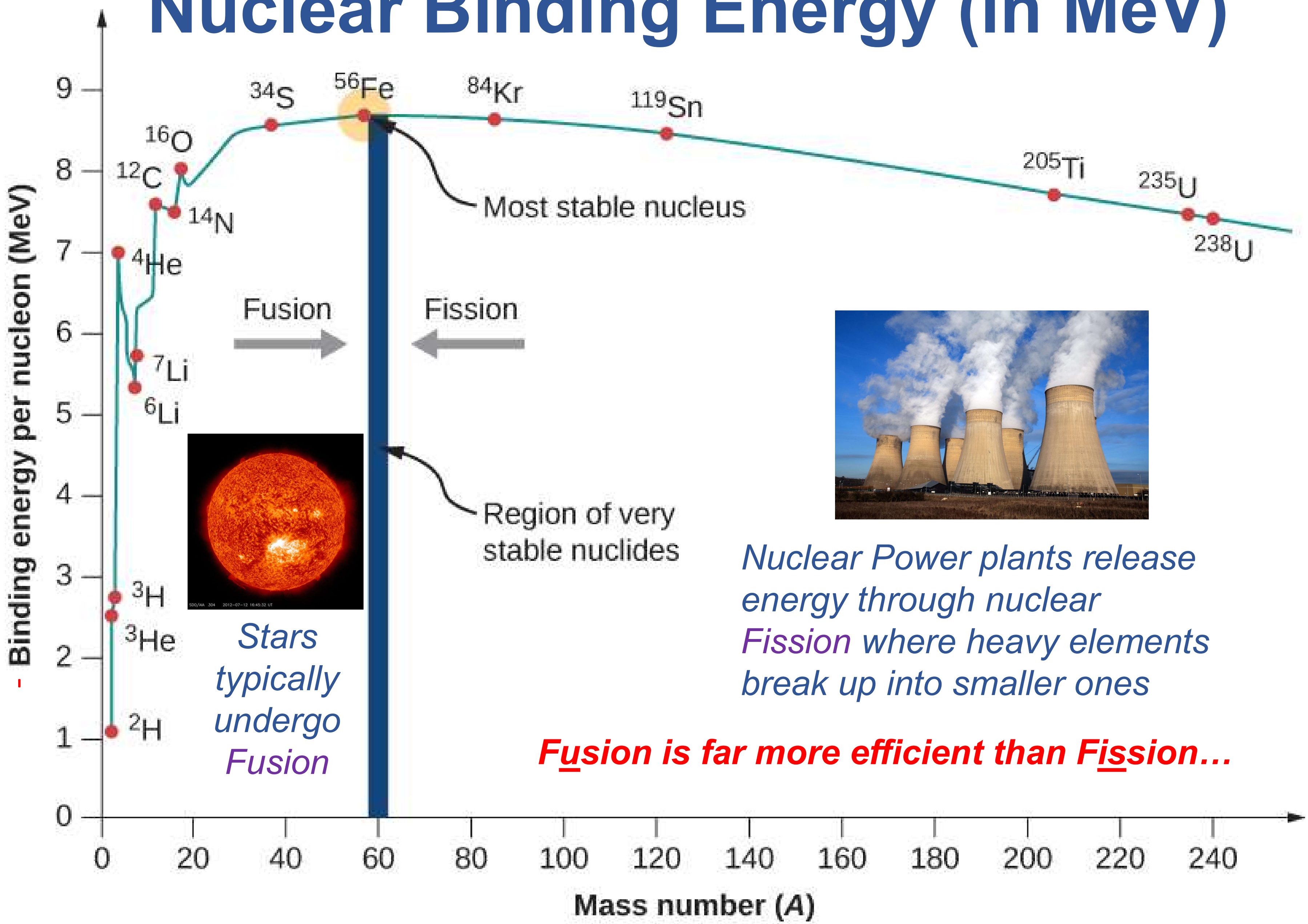
As Temperature:

- 1 eV ~ 10,000 K (at 300 K, most atoms/molecules have around 0.025 eV)

As Mass:

- 1 eV = 1.782662×10^{-36} kg (can use this to convert mass to energy)

Nuclear Binding Energy (in MeV)



Stars typically undergo Fusion

Nuclear Power plants release energy through nuclear Fission where heavy elements break up into smaller ones

Fusion is far more efficient than Fission…

A Few Elementary Particles

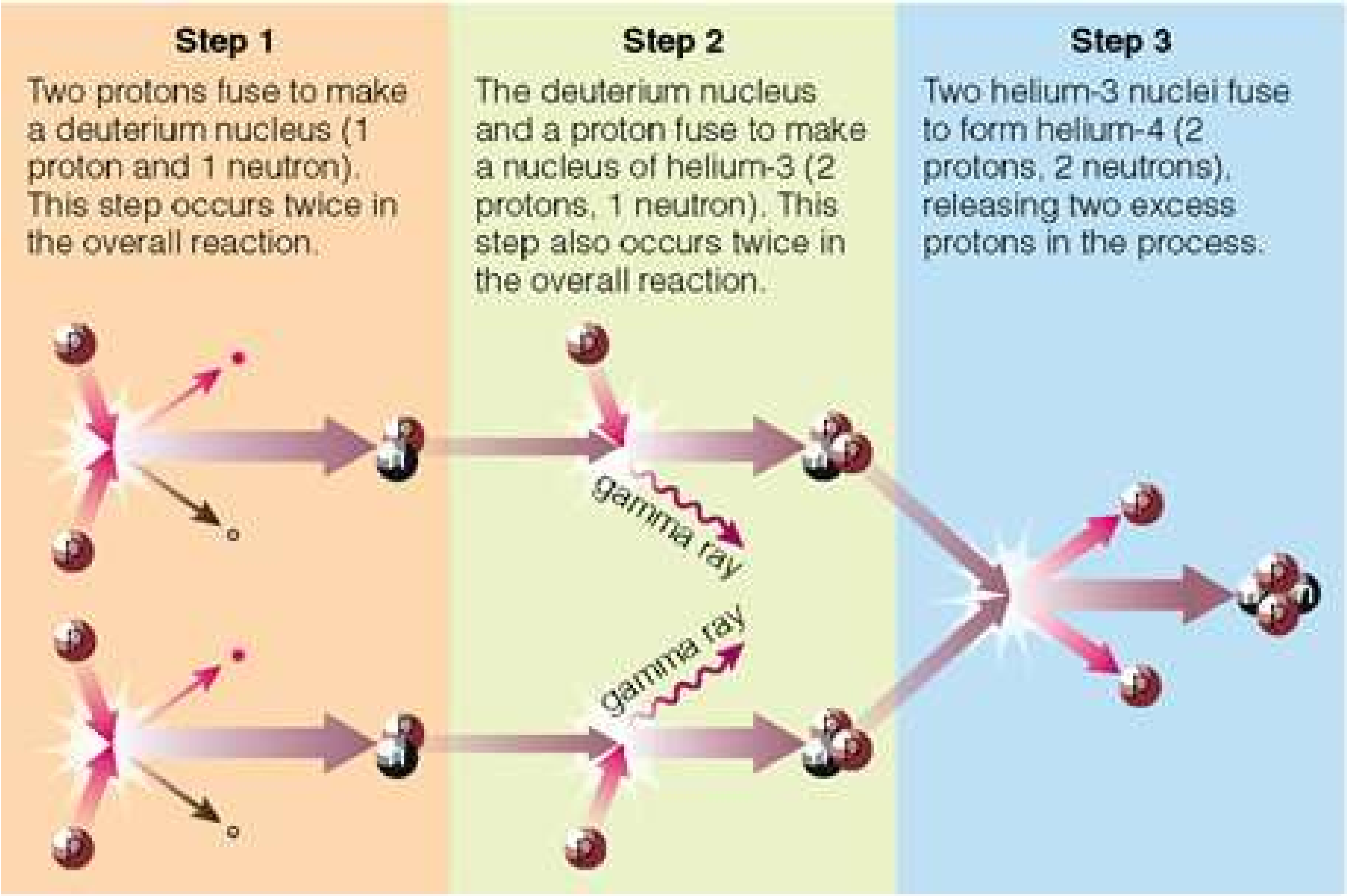
Particle Name	Mass (MeV/c^2)	Charge (e)
Proton	938.272	+1
Neutron	939.565	0
Electron	0.511	-1
Positron	0.511	+1
Neutrino	$<10^{-6}$	~0
Photon	0	0

These particles all play a vital role in how the Sun generates energy:

- Protons and Neutrons make up atomic nuclei
- Electrons orbit the nuclei of atoms* *(* - if temperature is low enough)*
- Positrons are anti-matter and are generated by the Sun
- Photons and Neutrinos are also emitted by the Sun

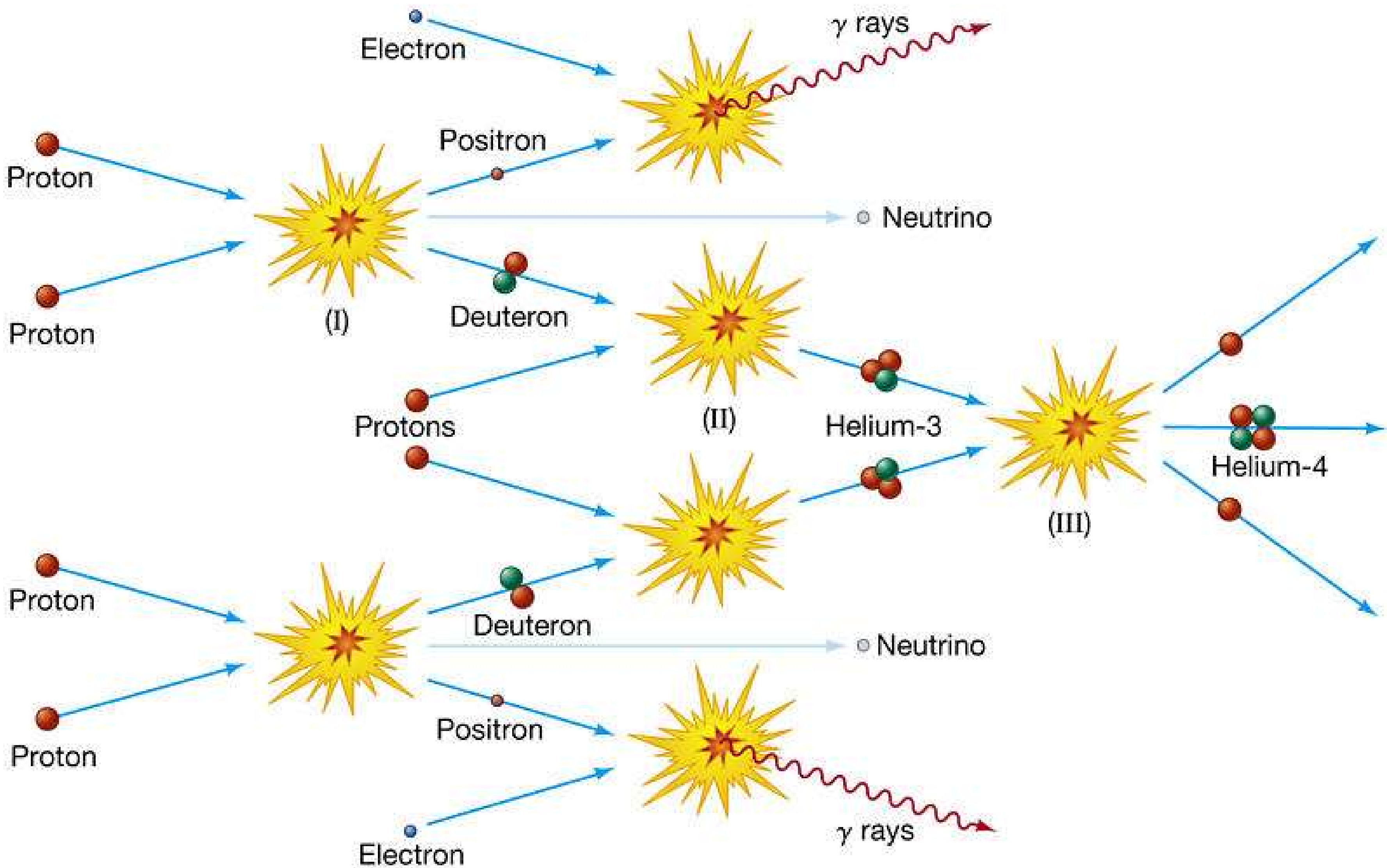
The Proton-Proton Chain Sequence

The first important thing to know is that it is a <u>sequence</u> of events.



You can't have 4 protons colliding at the same time to give you helium.

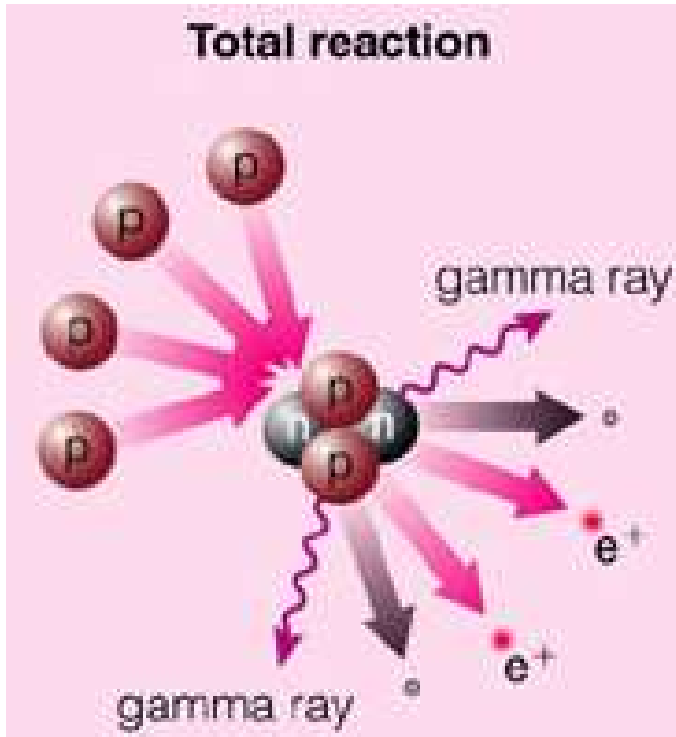
The Full Proton-Proton Chain



Summary of P-P Reaction Chain

In:

- **4 protons**



Out:

- **1 Helium Nucleus**
- **2 positrons**
- **2 neutrinos**
- **>2 gamma rays***

*** - The positrons recombine with electrons to annihilate one-another generating 2 more 0.511 MeV gamma rays each**

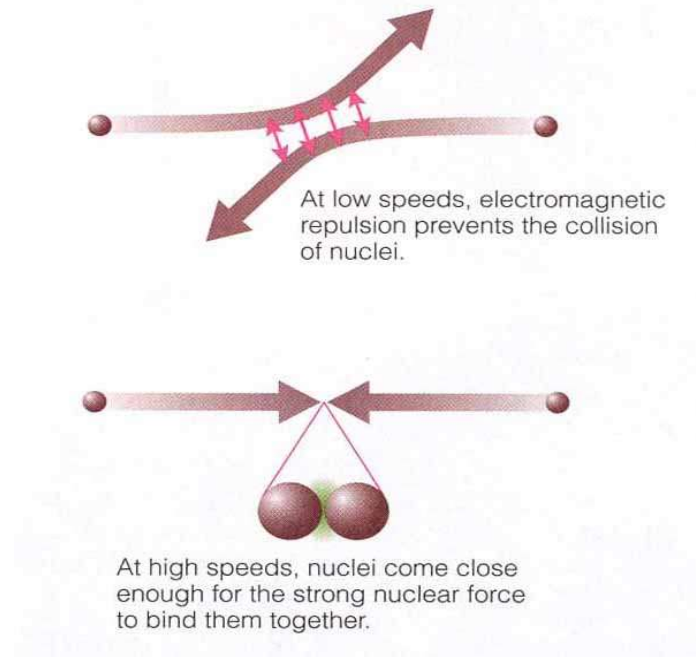
How Does Fusion Occur in the Sun's Core ?

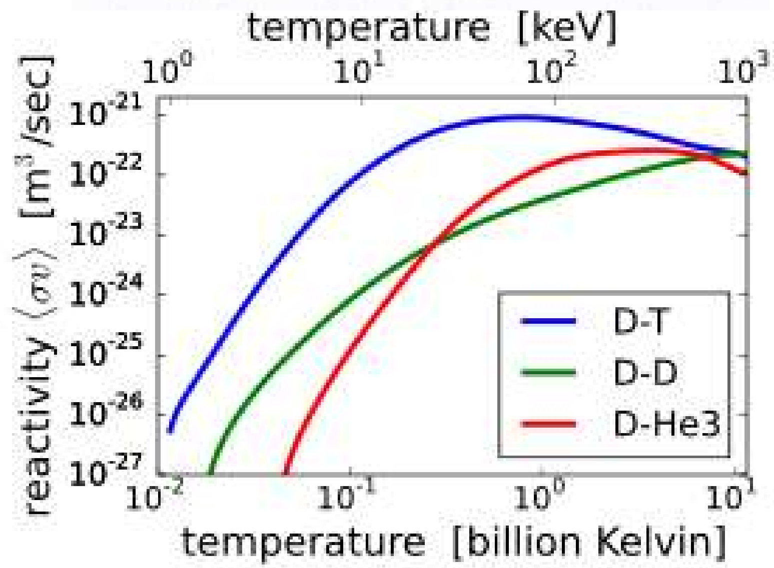
Nuclear fusion

- **a reaction where heavier nuclei are created by combining (*fusing*) lighter nuclei.**
- **all nuclei are positively charged**

→ Electromagnetic force causes nuclei to repel each other.

- **Remember the nucleus is full of protons! Like charges repel!**
- **for fusion to occur, nuclei must be moving fast enough to overcome E-M repulsion**
- **To be efficient, this requires VERY high temperatures & pressures!**

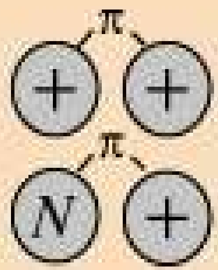




When nuclei touch, the strong nuclear binding force binds them together (acts over very short distances)

Fundamental Forces

Strong



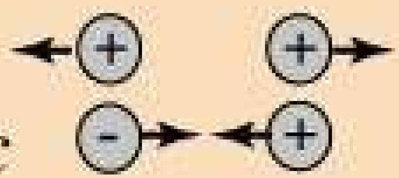
Force which holds nucleus togeher

Strength: 1

Range (m): 10^{-15} (diameter of a medium sized nucleus)

Particle: gluons, π(nucleons)

Electro-magnetic

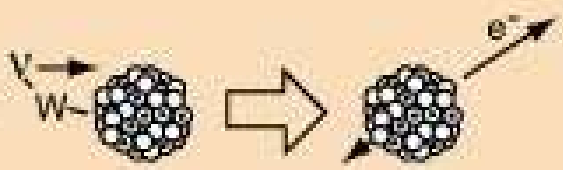


Strength: $\frac{1}{137}$

Range (m): Infinite

Particle: photon, mass = 0, spin = 1

Weak



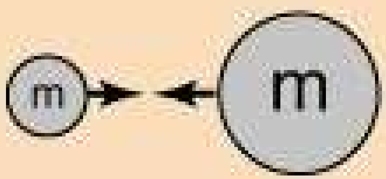
neutrino interaction induces beta decay

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

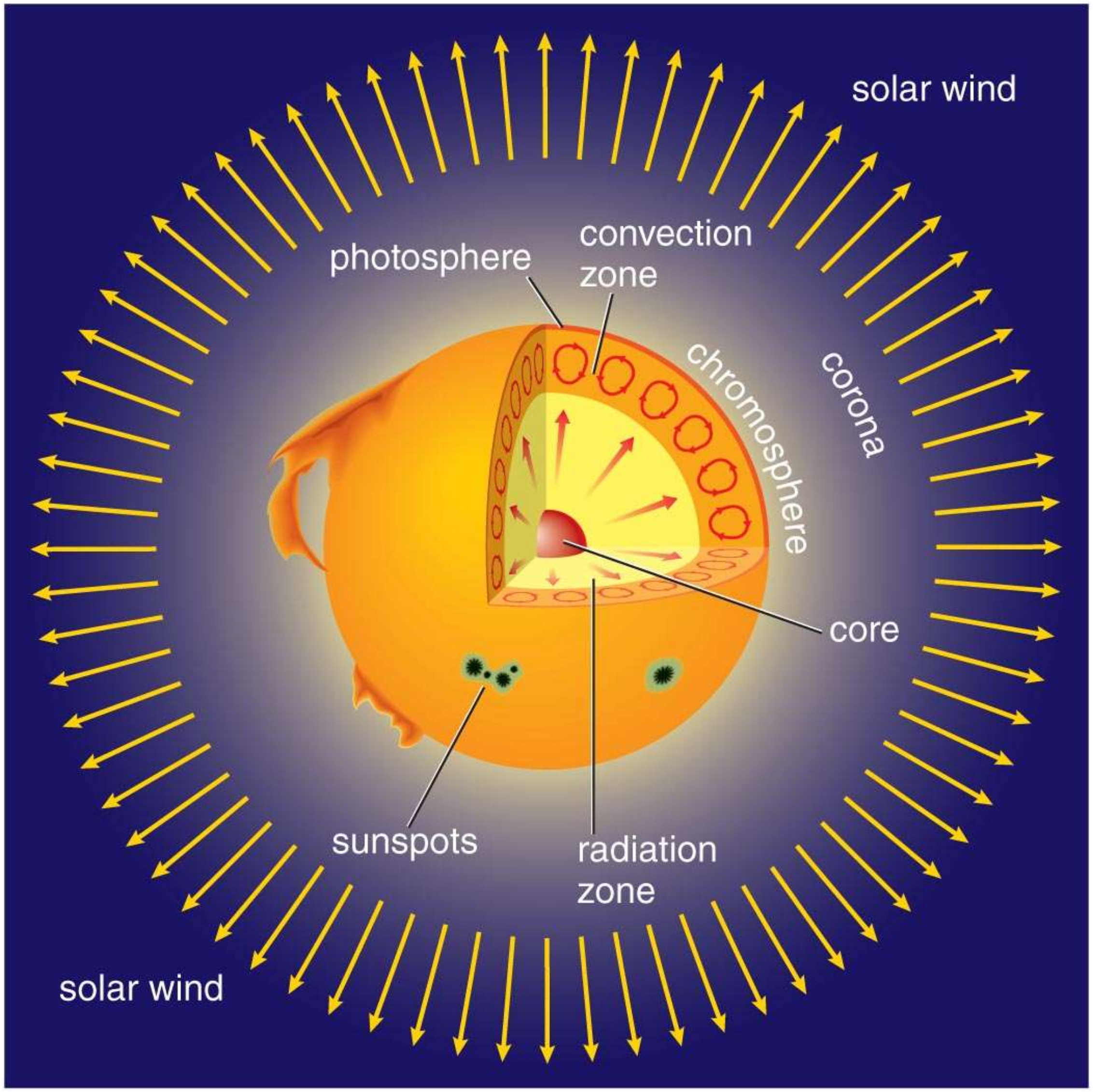


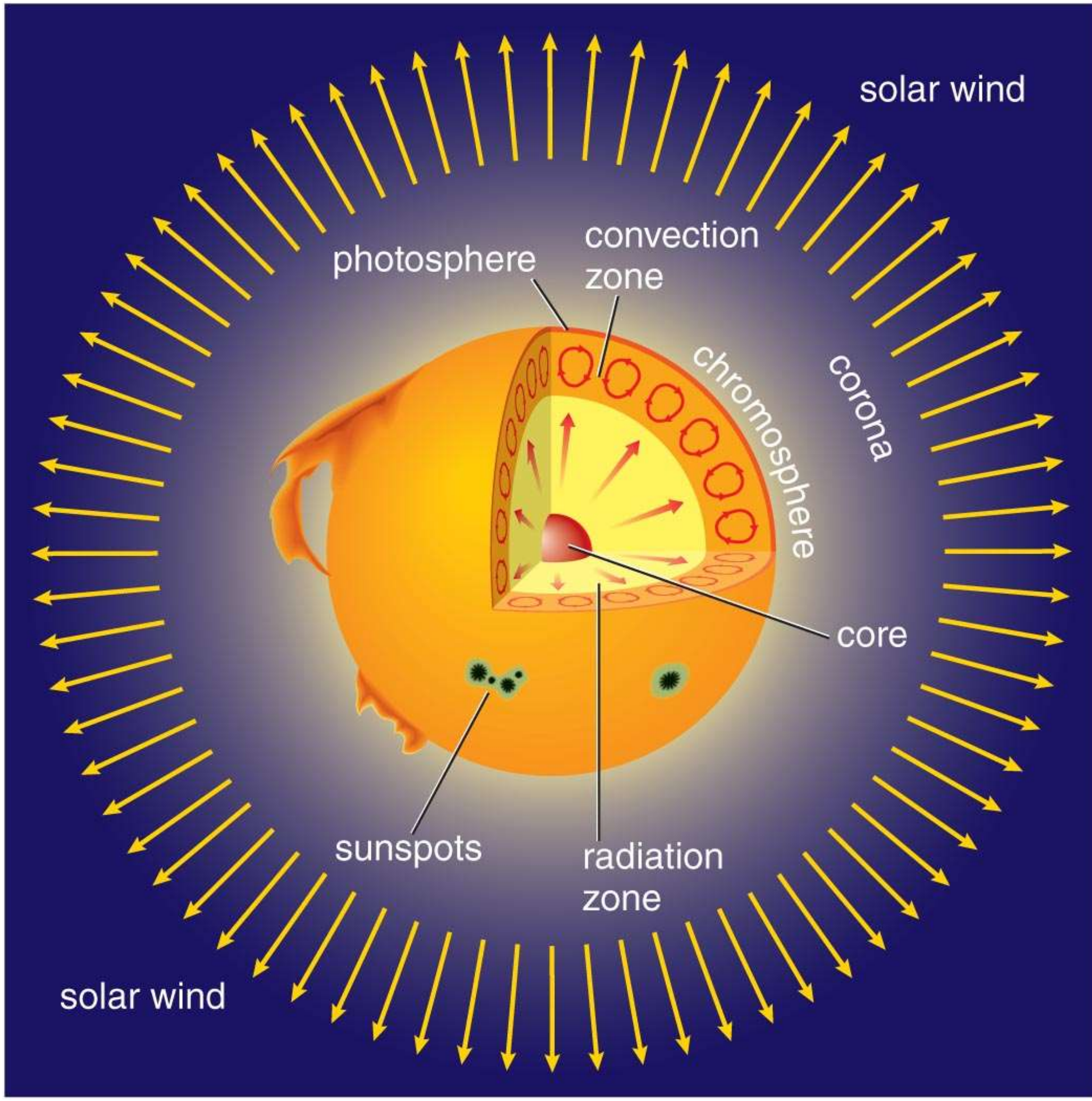
Strength: 6×10^{-39}

Range (m): Infinite

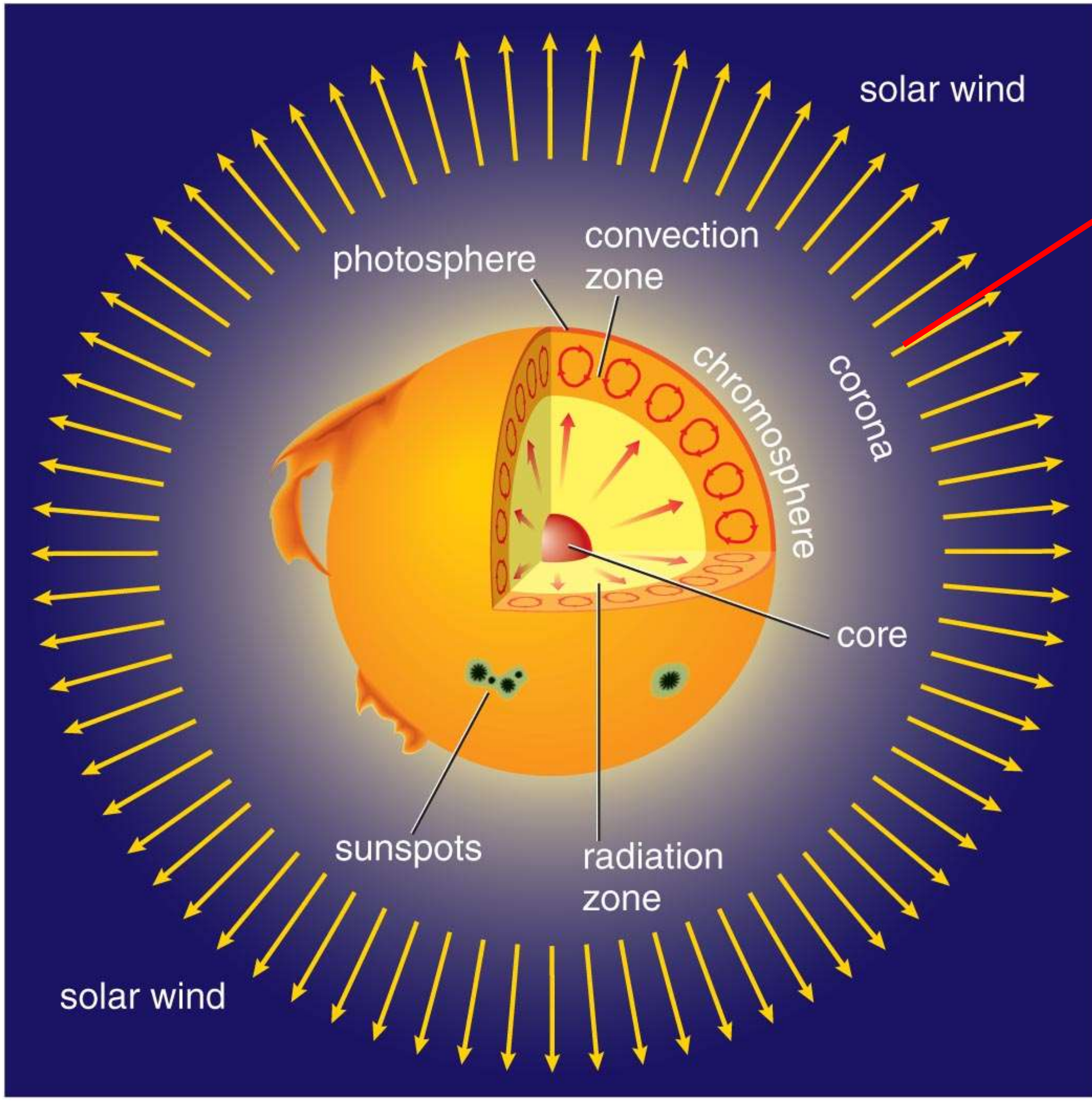
Particle: graviton ?, mass = 0, spin = 2

What is the Sun's structure?

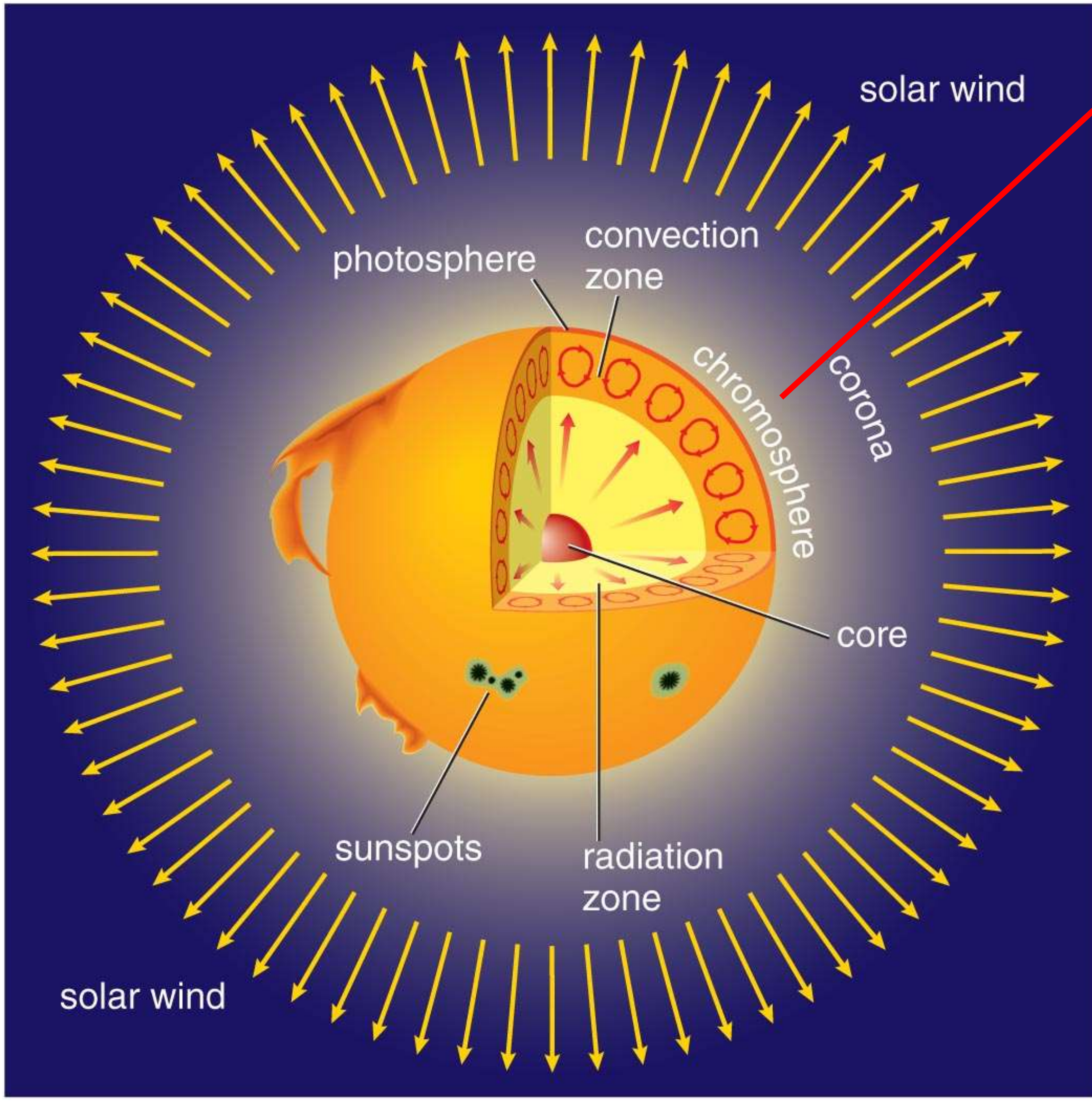




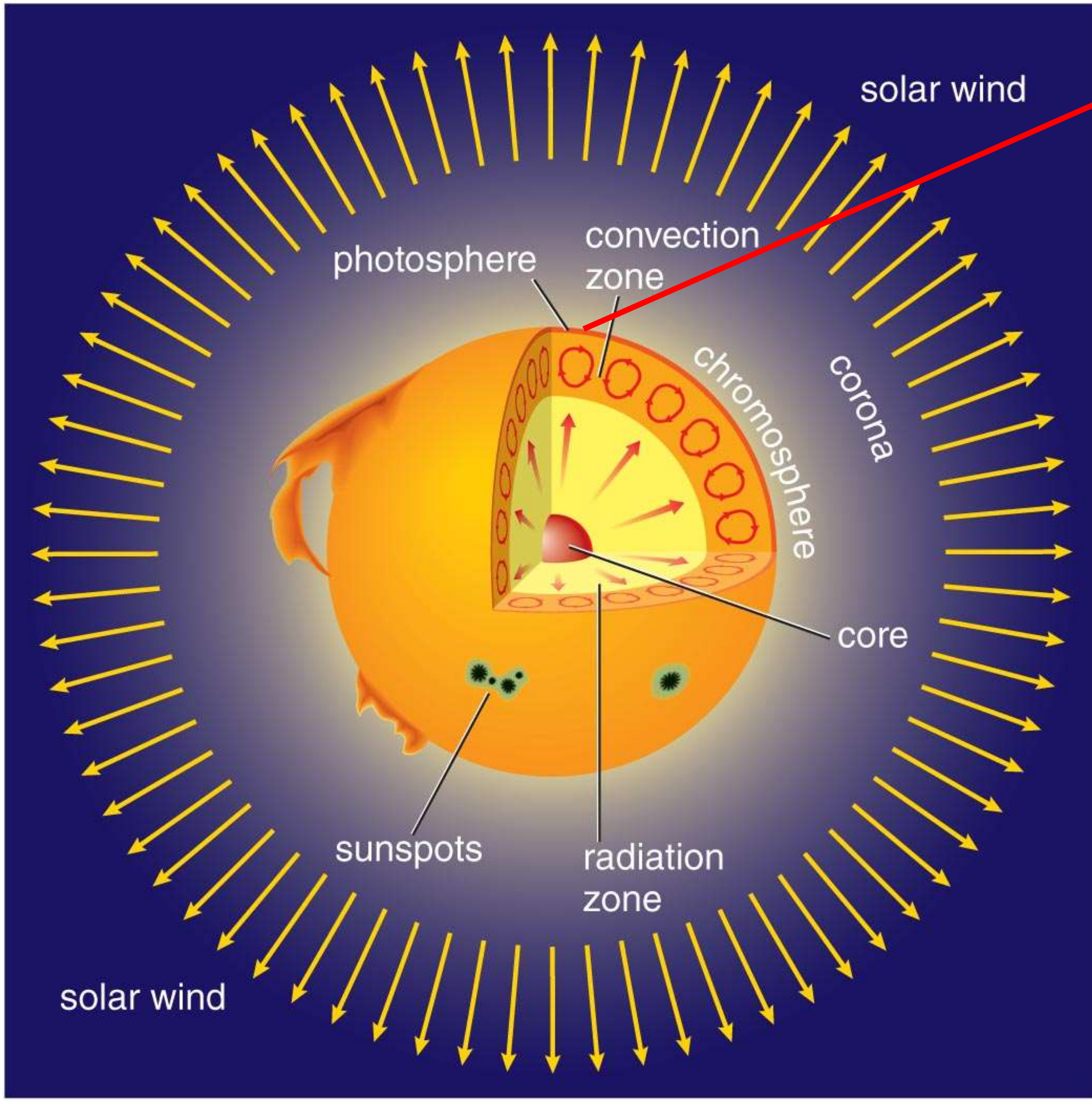
Solar wind:
A flow of charged particles from the surface of the Sun



Corona:
Outermost layer of solar atmosphere
~ 1 million K



Chromosphere:
Middle layer of solar atmosphere
~ 10^4–10^5 K



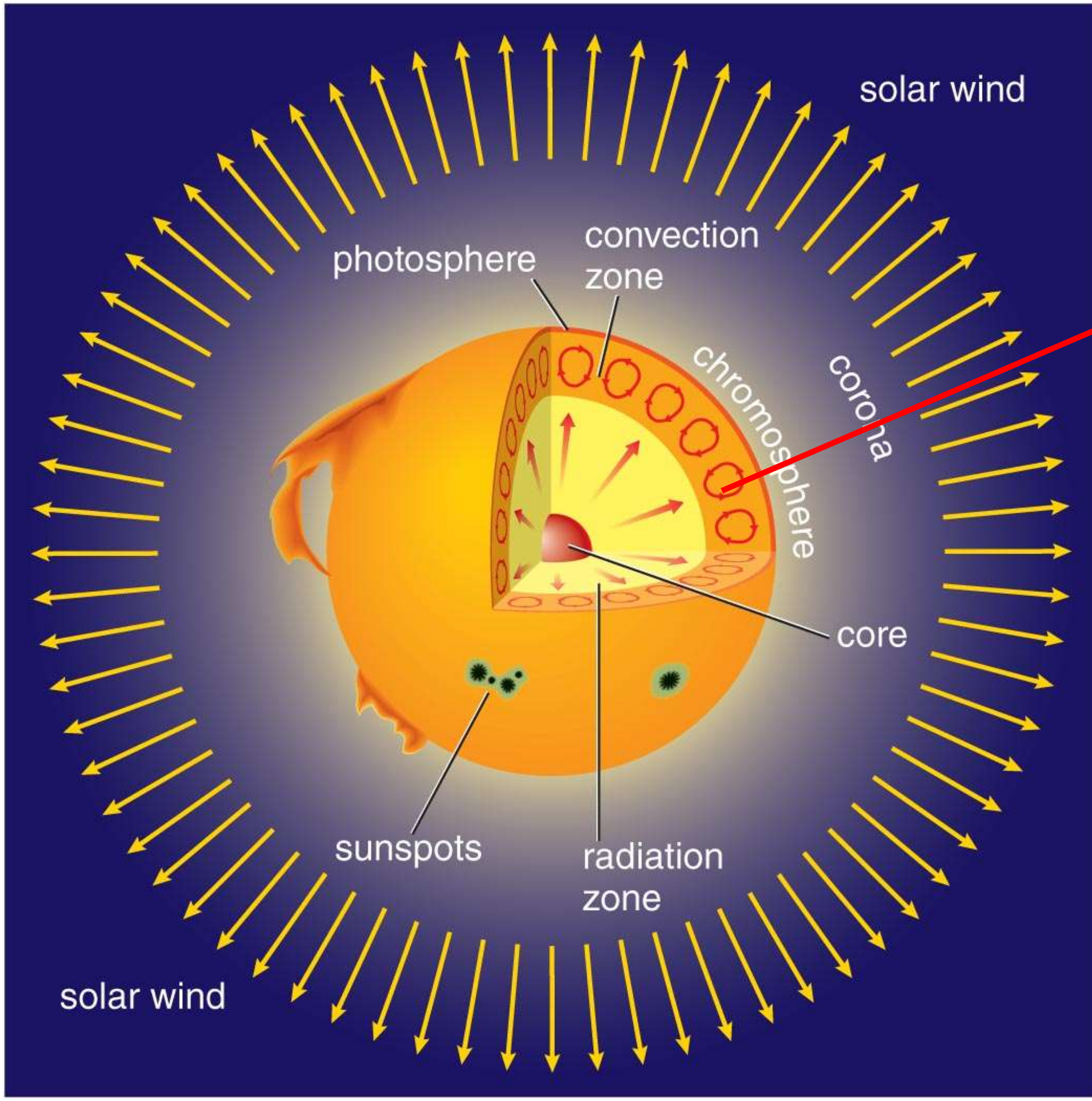
Photosphere:

Visible surface of the Sun

~ 5800 K

~ 5500 ° C

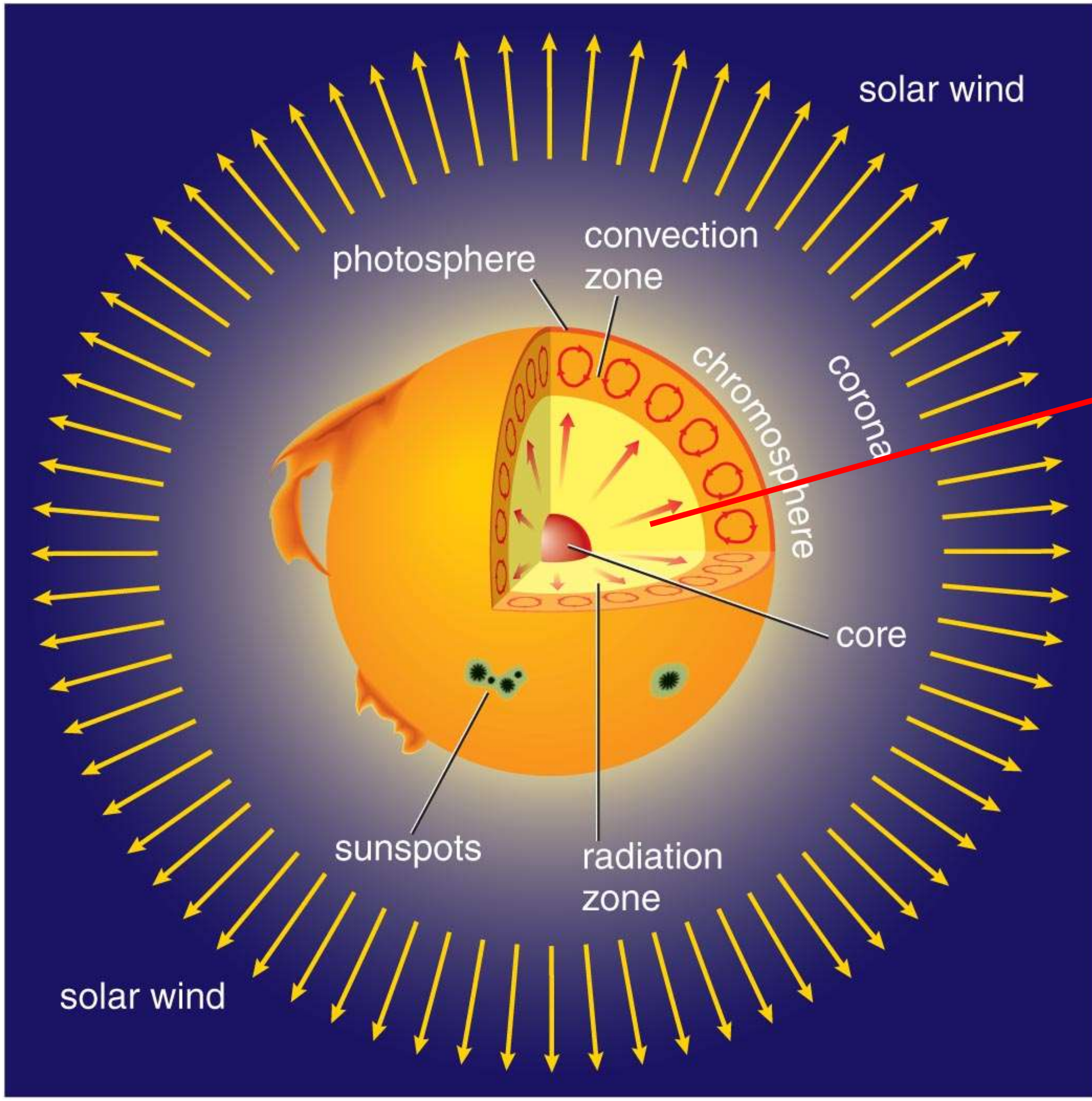
(this is typically what we view as the surface)



Convection zone:
Energy transported upward by rising hot gas

Hotter gas rises

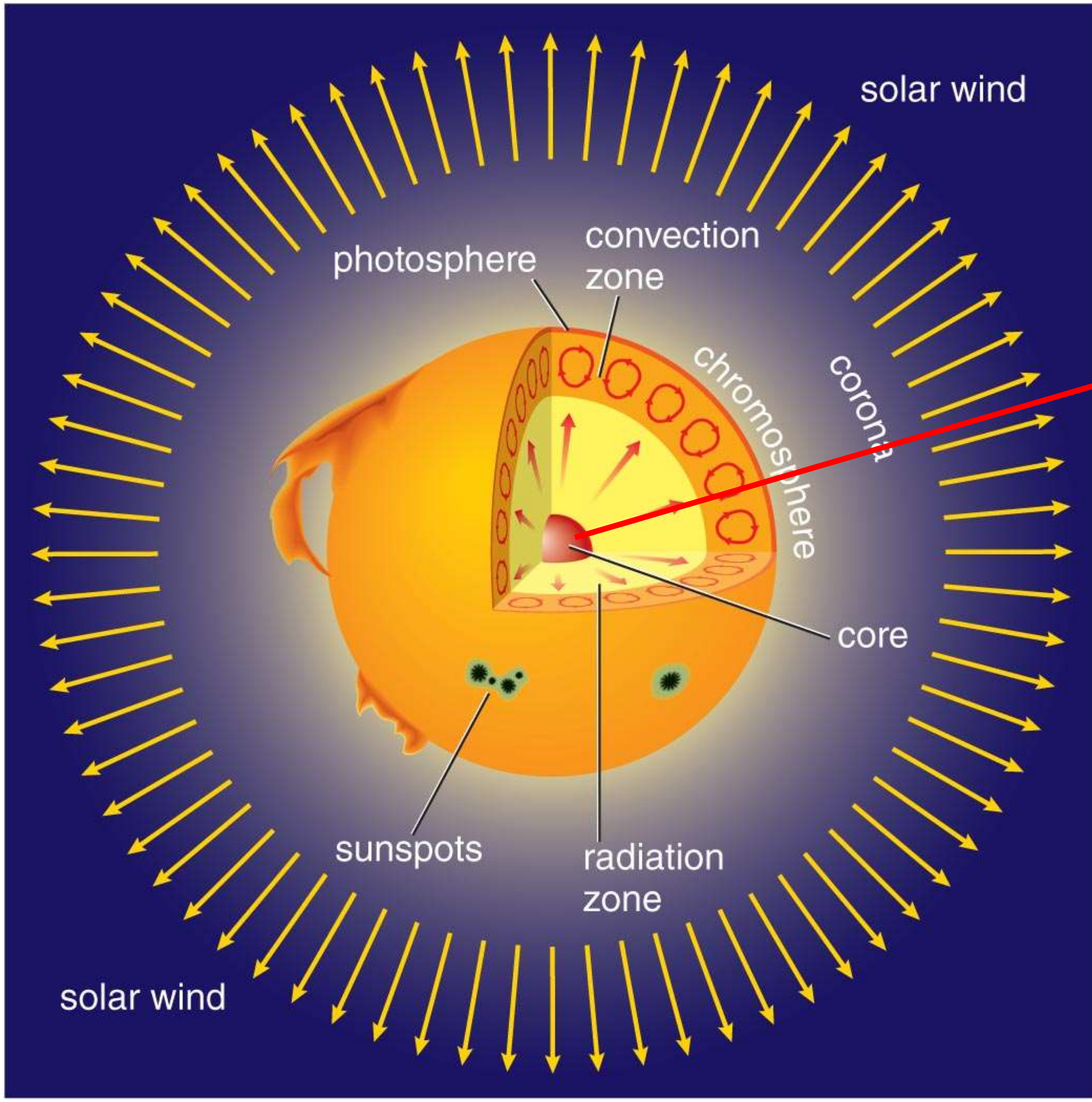
Cooler gas falls



Radiation zone:

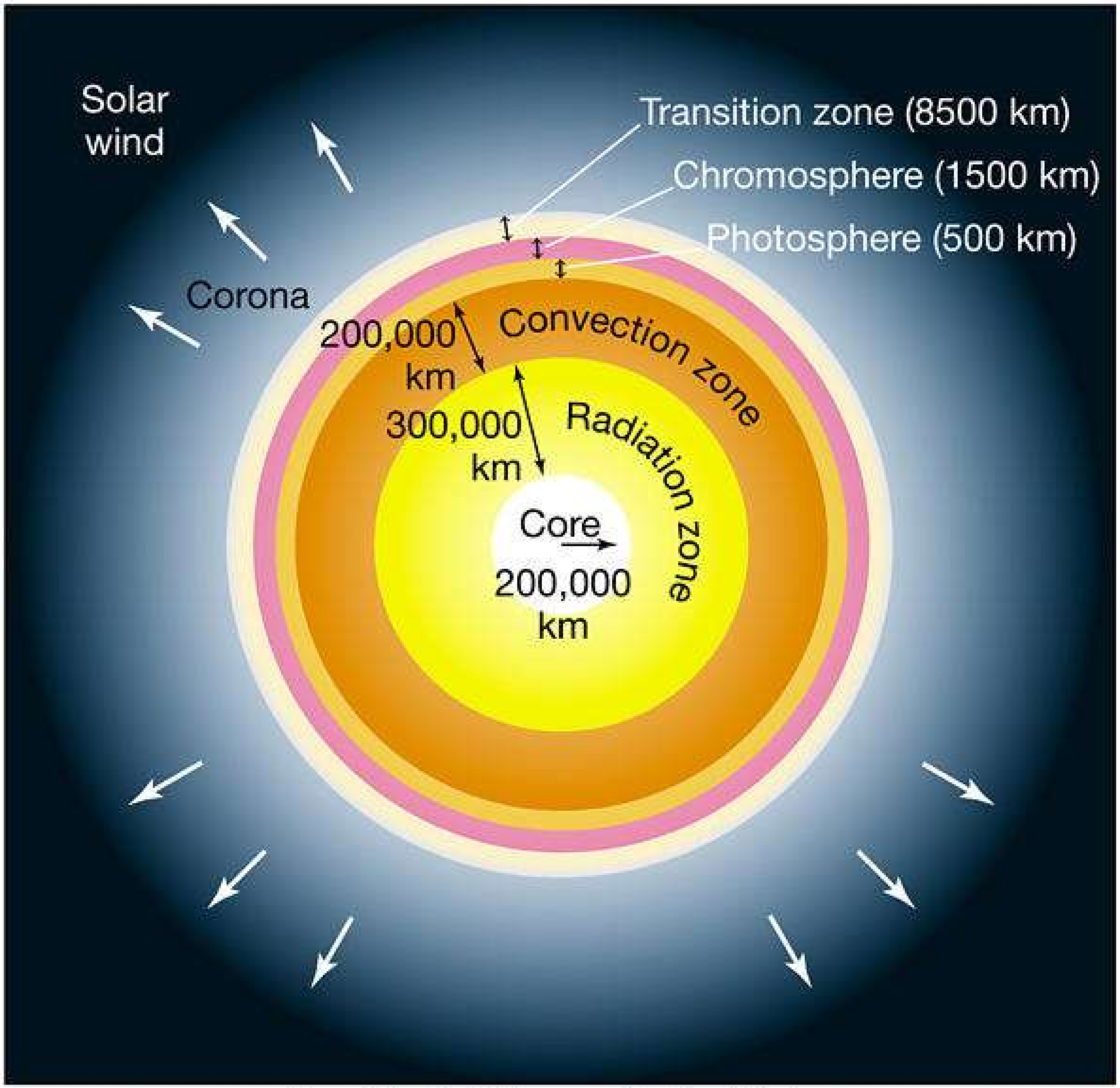
Energy transported upward by photons

(takes a long time)

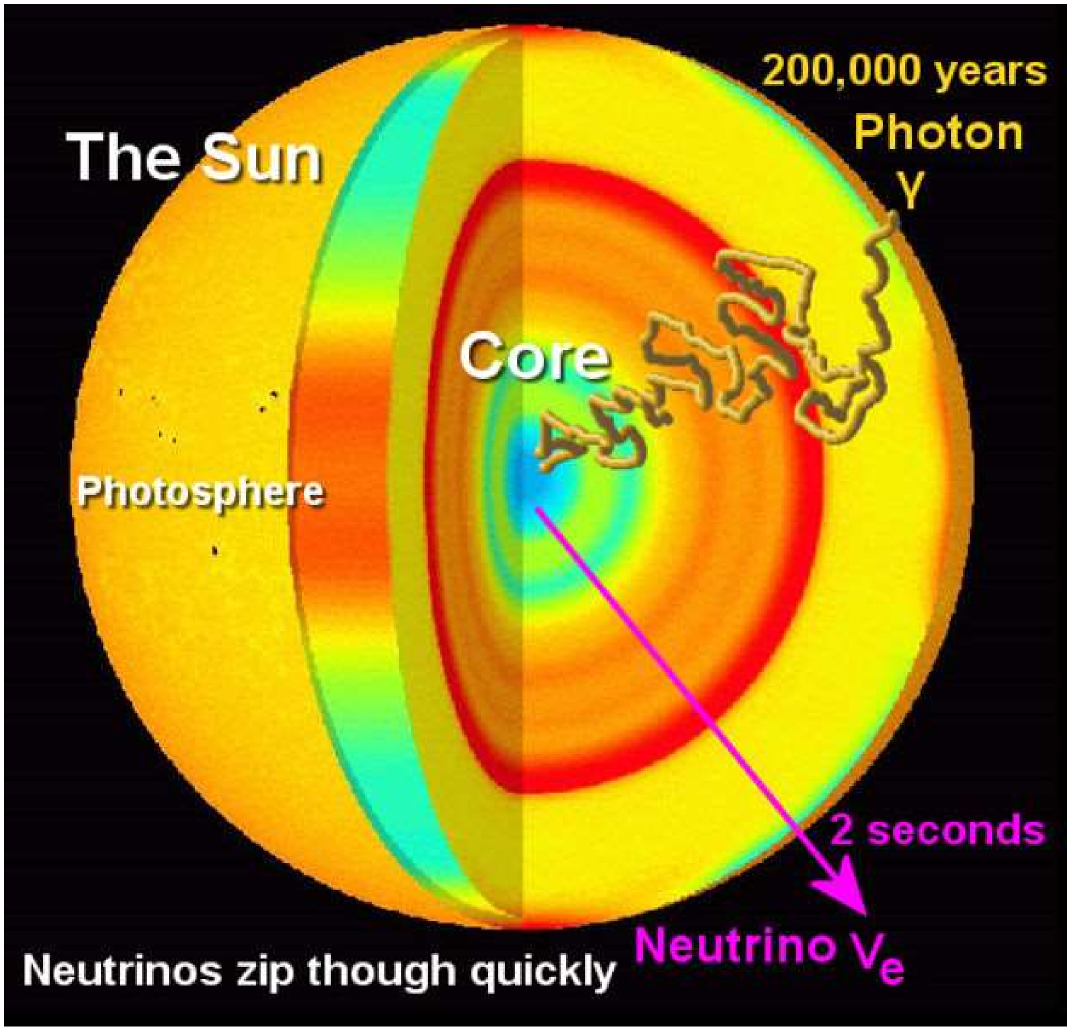


Core:
Energy generated by nuclear fusion
~ 15 million K

What is the Sun's structure?



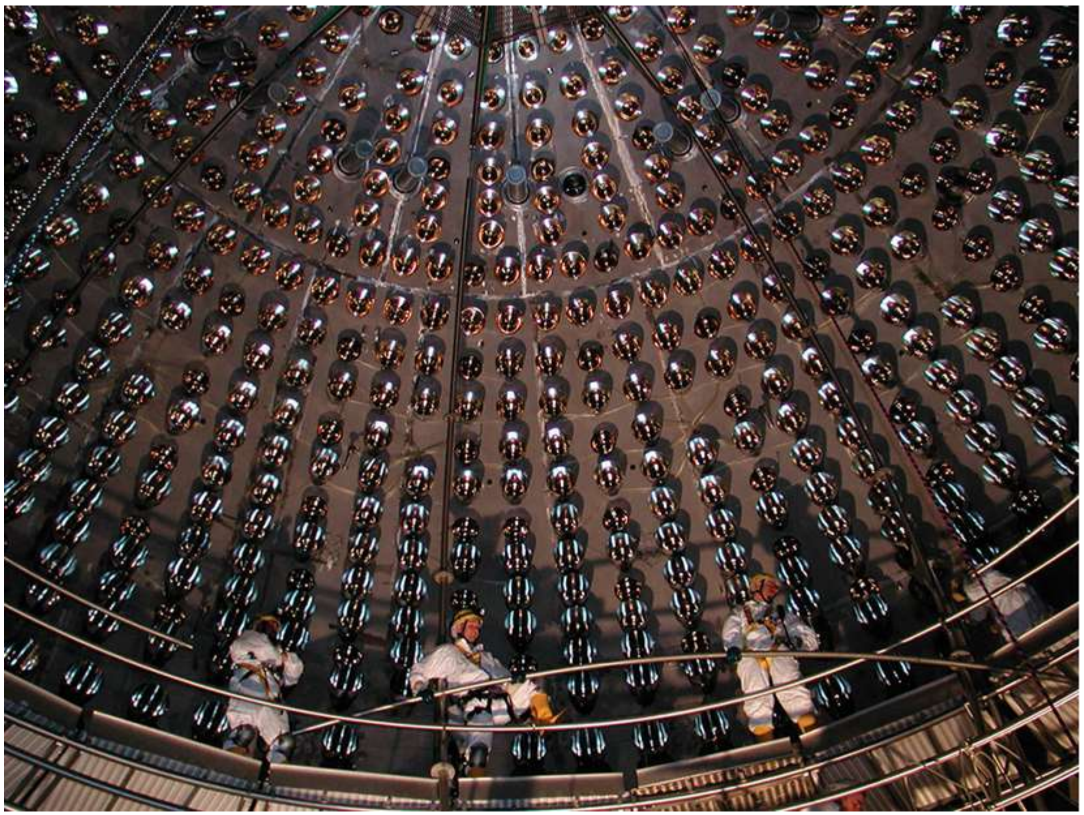
Solar Neutrinos



- Neutrinos created during fusion fly directly through the Sun.
- Observations of these solar neutrinos can tell us what's happening in the core.

The Solar Neutrino Problem

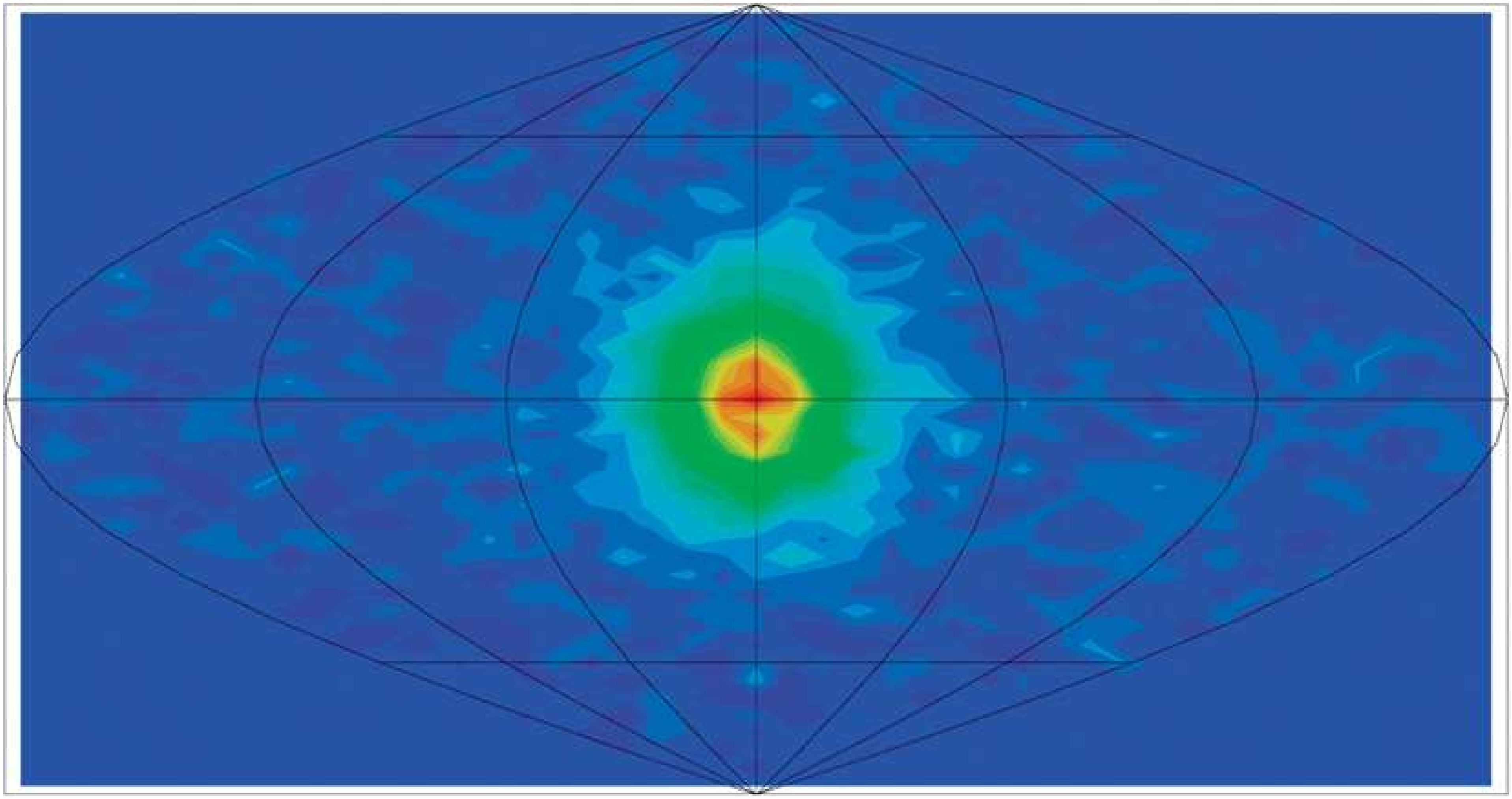
Detecting Neutrinos is VERY HARD. Requires very large detectors. Neutrinos have a non-zero probability of reacting with a proton within a nucleus to generate a positron and a neutron. The positron gets annihilated, generating two 0.511 MeV which if detected simultaneously yield a positive detection.



Early searches for solar neutrinos failed to find the predicted number (~ 1/3).

More recent observations find the right number of neutrinos, but some have changed form (often termed, different flavors)

Solar Neutrino Maps of the Sun



A full-sky neutrino map, centered on the Sun, produced by the Super-Kamiokande neutrino observatory in Japan.

End of Todays Lecture