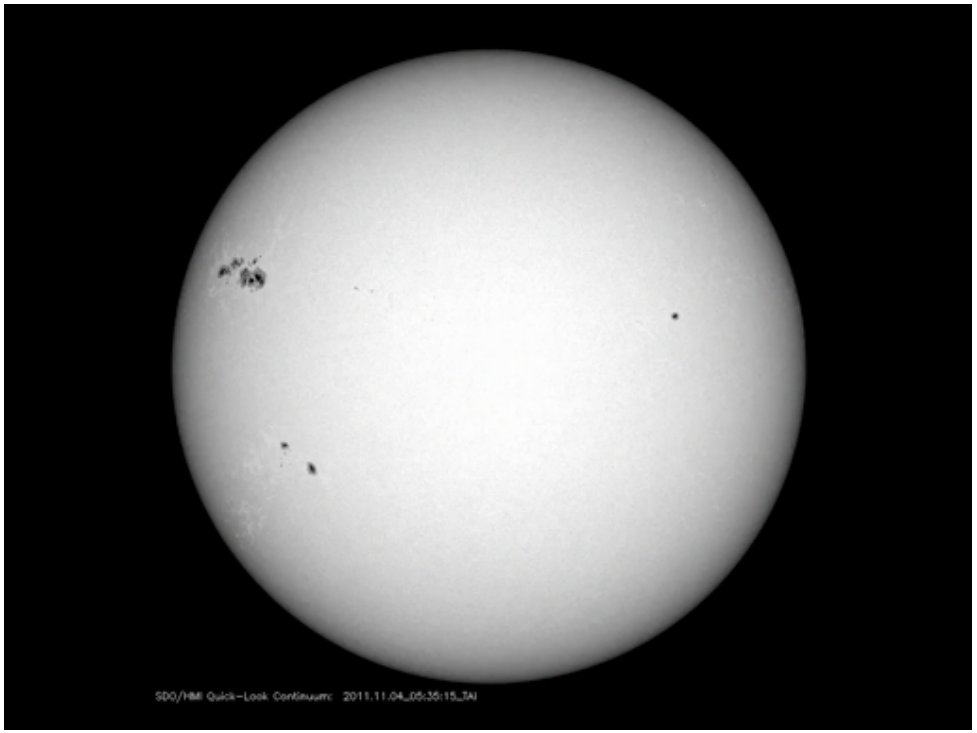
Reading: Chap. 15; Sect. 15.1-15.3; skim Chap. 16; Chap. 21, Sect. 21.1, 21.3-21.6
Exam 3 - Wednesday, Dec 18, 4:30-6:30PM
No Recitations Tomorrow or Monday after break
HW 10: Next assignment due in recitation Dec. 6 / 9

## Last time: Astrology

- Fundamental Thesis of Astrology
- no correspondence with any known physical effect
- Sun sign test
- Double-blind study (1985)
- nagging questions, and Science vs. pseudoscience
- a prediction…

## Today: Our Sun

- The SUN:
  - statistics
  - photosphere, chromosphere, corona
  - the solar magnetic cycle
- Source of the Sun's energy:
- Hydrogen Fusion
  - energy source for 10 billion years





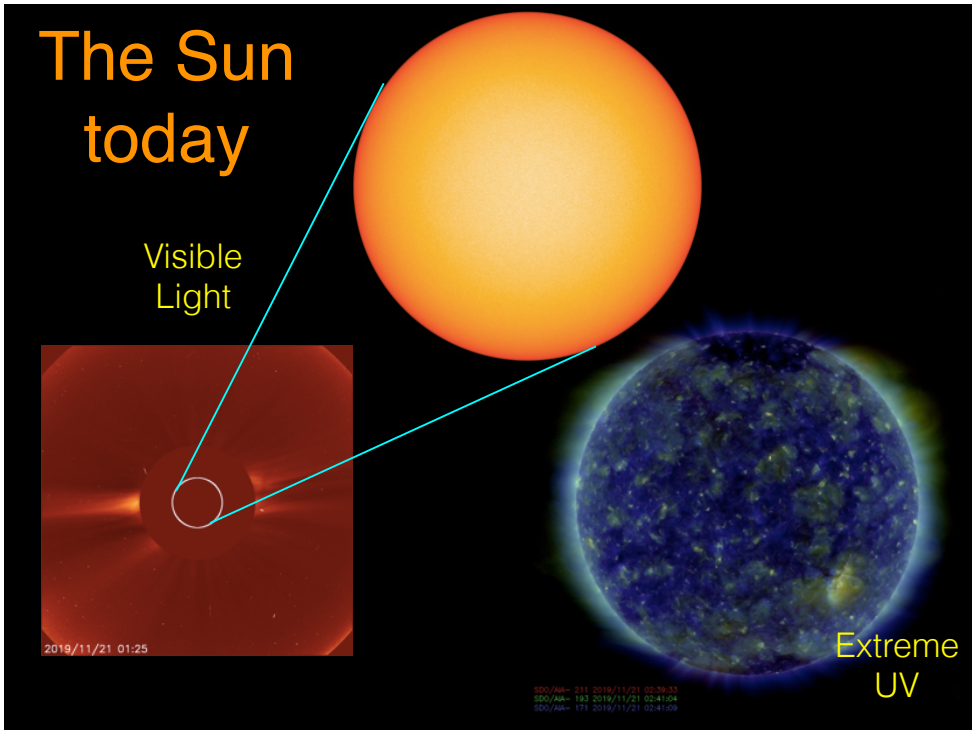

# The Vital Statistics of the Sun

| | | |
|---|---|---|
| Distance: | $1.5\times10^{8}$ km | Kepler's 3rd law |
| Mass: | $2\times10^{33}$ grams | Kepler's 3rd law |
| Radius: | $7\times10^{5}$ km | angular size & distance |
| Luminosity: | $4\times10^{33}$ erg/s | solar constant & distance |
| Temperature: | 5800K (10,000$^{o}$ F) | Thermal Balance |
| Composition: | | spectroscopy |

| | | |
|---|---|---|
| **Hydrogen** | **73.4%** | by mass |
| Helium | 24.8% | " " |
| Oxygen | 0.8% | " " |
| Carbon | 0.4% | " " |
| *everything else* | 0.6% | " " |

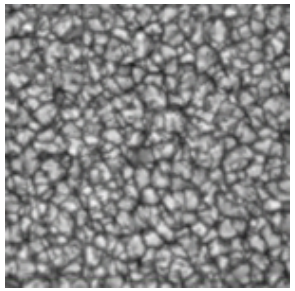
**i.e. Silver ~ 0.00000066% (still, that's $5\times10^{20}$ tons of silver in the Sun!)**

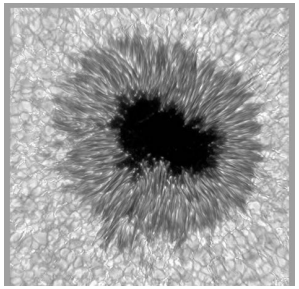
**1868: Lockyer & Jansen find spectral lines in Sun never seen on Earth –> Helium proposed as a new element**
**1891: Helium finally discovered on Earth**



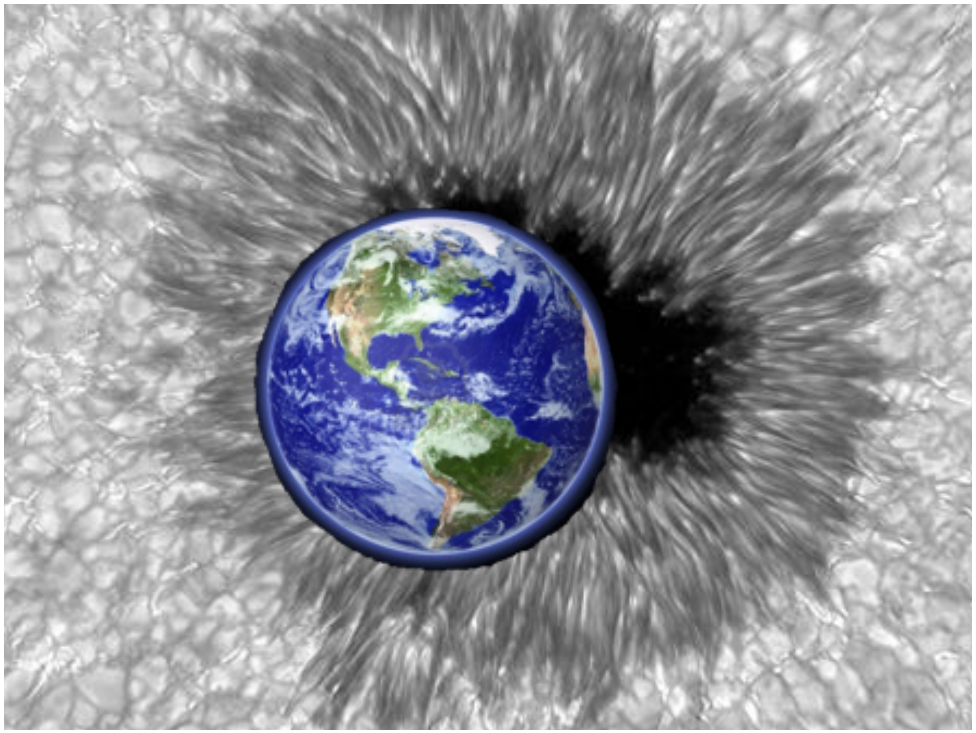
# The 'surface' of the Sun:

## the **Photosphere**

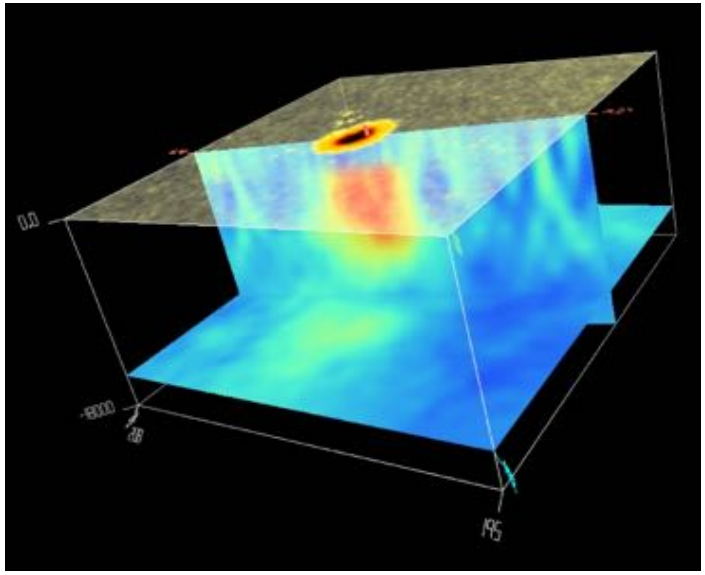




- T ~ 5800K
- Granulation
  - cells of rising gases (~1000 km across)
  - give mottled appearance to photosphere
- Sunspots
  - relatively cooler than photosphere (T ~ 4500K)
  - site of strong magnetic fields





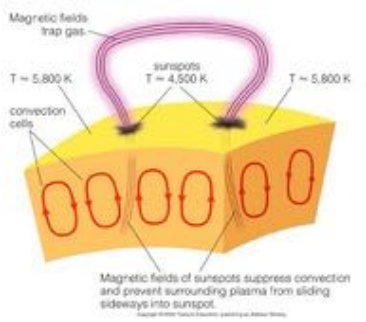


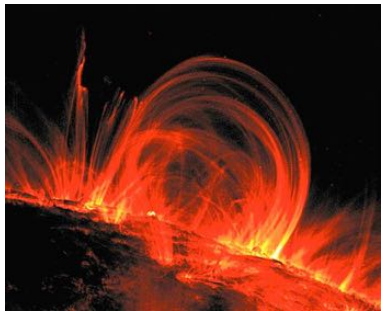
SOHO satellite image of a sunspot at and below the solar photosphere (using helioseismology)

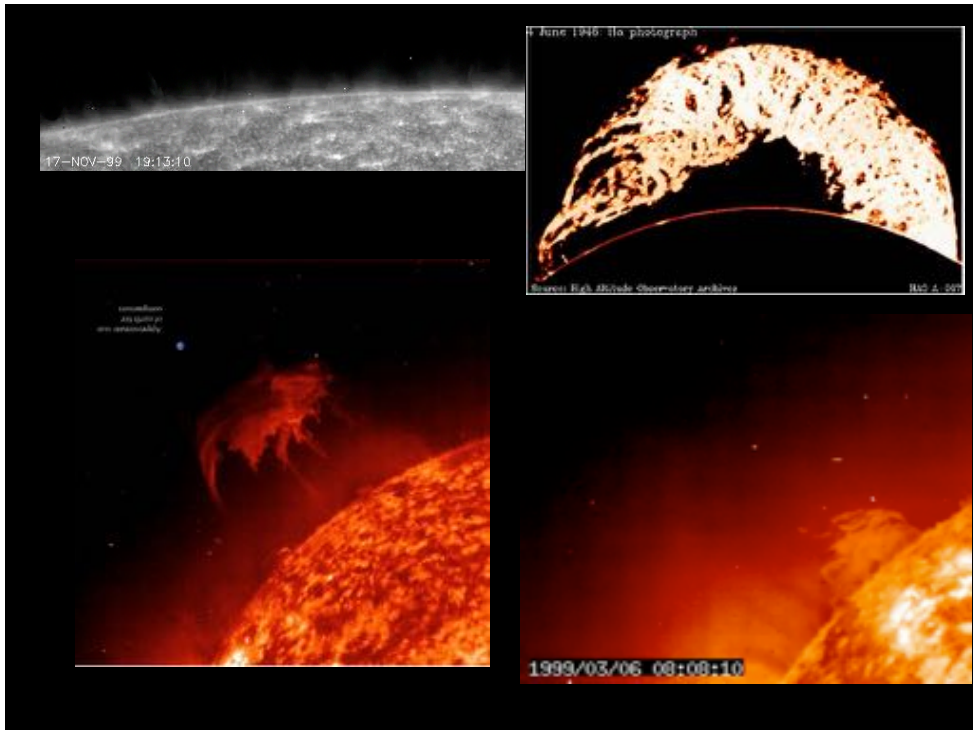


# The Chromosphere

- cooler (and hotter) layer above photosphere
- dominated by light of hydrogen emission
- Prominences
  - material suspended above photosphere
- Flares
  - giant eruptions



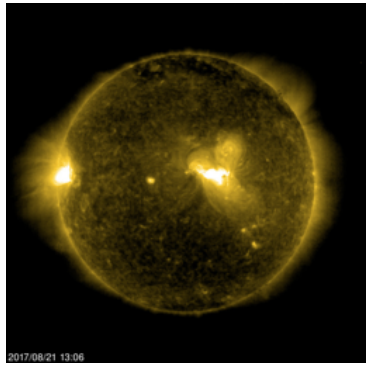





# The Solar Corona

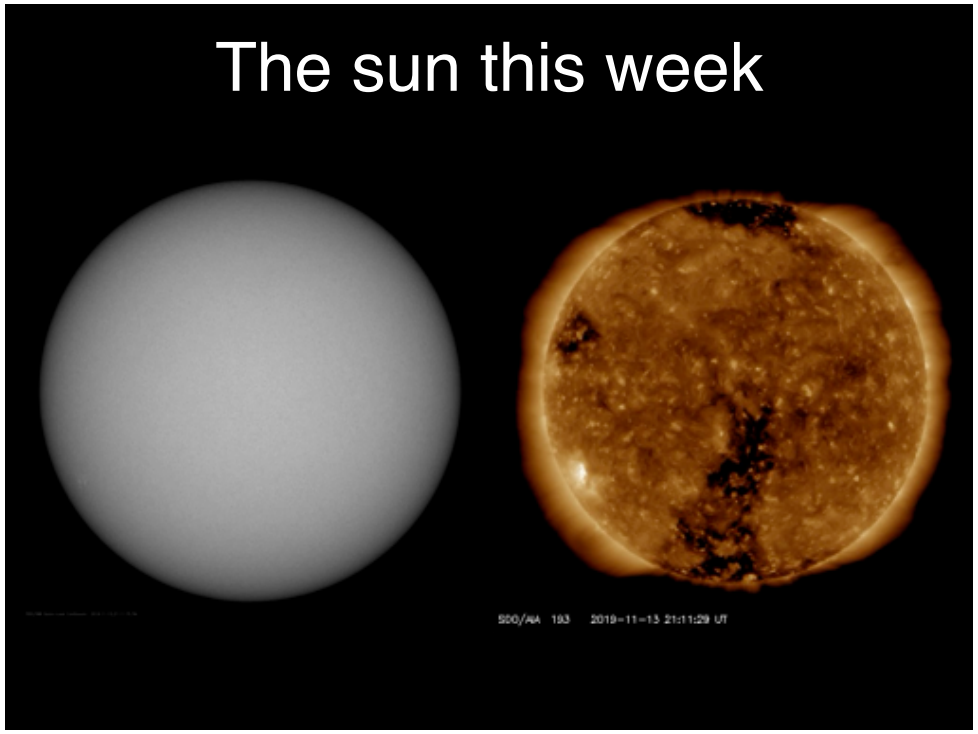
- rarefied outer solar atmosphere
  - visible during eclipses or from space
- strange emission lines
  - identified as highly ionized heavy elements
  - T ~ 2,000,000K

Optical image (eclipse)




Extreme UV (space)

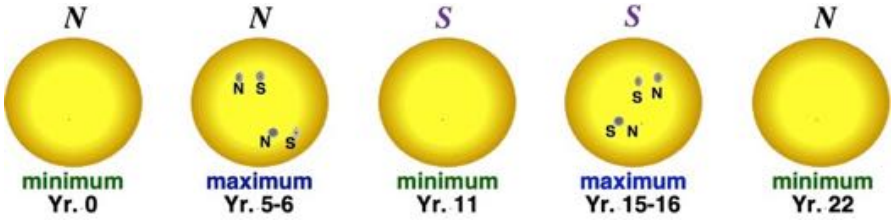
# The sun this week



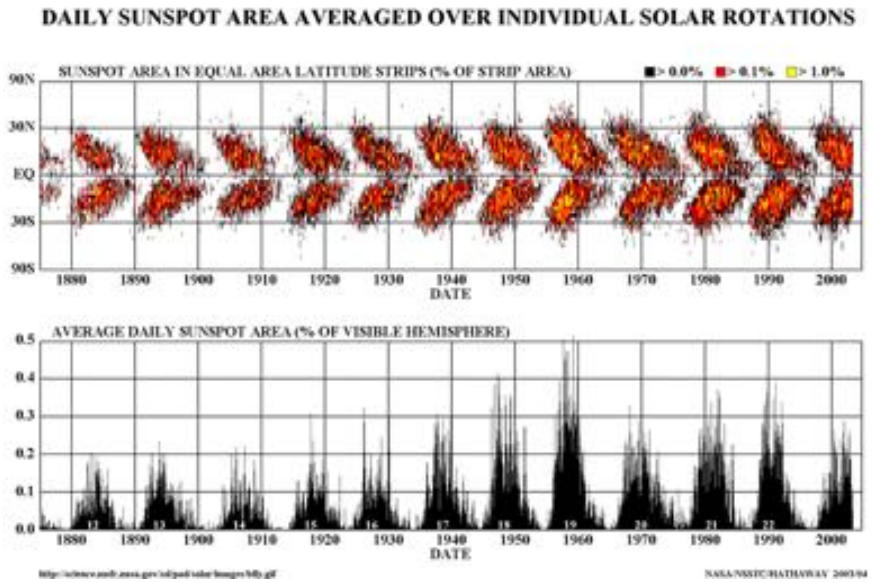


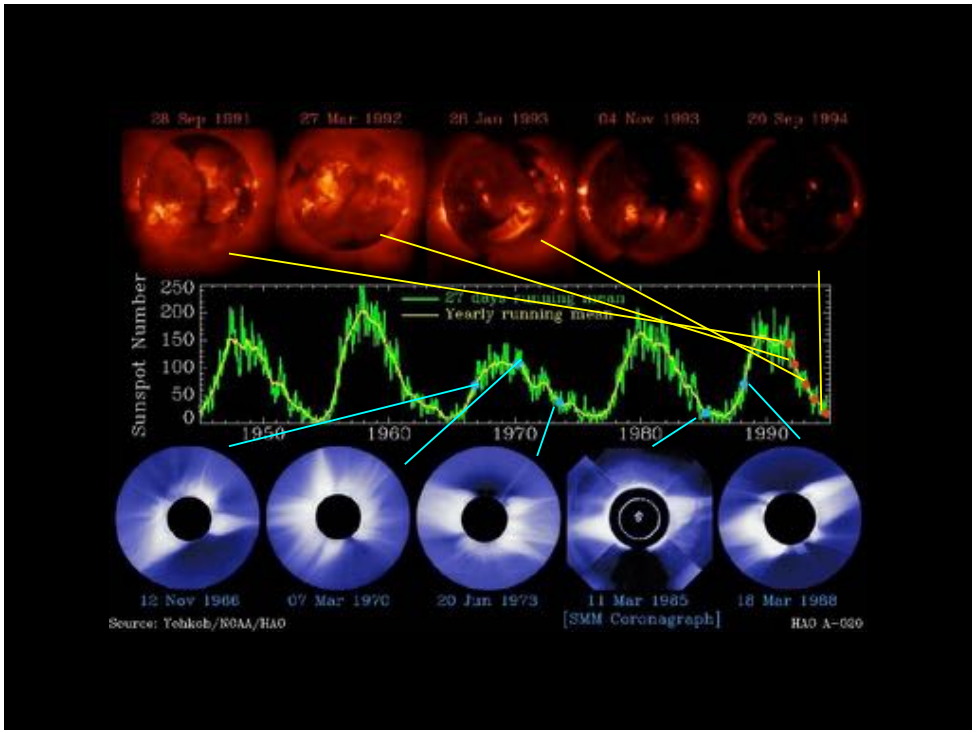

# The Solar Cycle

- number of spots changes over 11 year cycle
- magnetic polarity (N/S) of spots flips every 11 years
- —> whole pattern repeats every 22 years



# The Butterfly Diagram







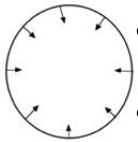
inside the sun



# Energy Source for the Sun

- **Combustion?**
  - 1 kg of coal per square meter per second!
  - whole Sun consumed in 10,000 years! . . .nope
- **Gravitational Contraction?**

  Kelvin and Helmholtz, 1871



  - falling objects acquire energy that can be converted to heat
  - slow contraction can provide heat energy to keep the Sun shining
  - contraction by 20 meters each year can keep the Sun shining
  - K-H contraction can provide energy for

    100 million years!

*BUT*

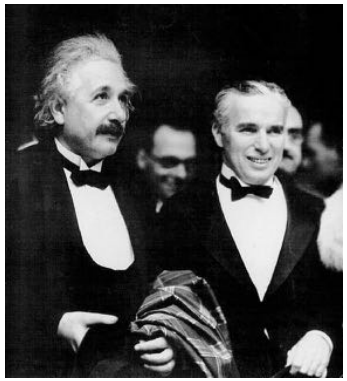
**various evidence shows that the Sun has been shining for at least**

4.6 billion years!

***Where does this energy come from?***

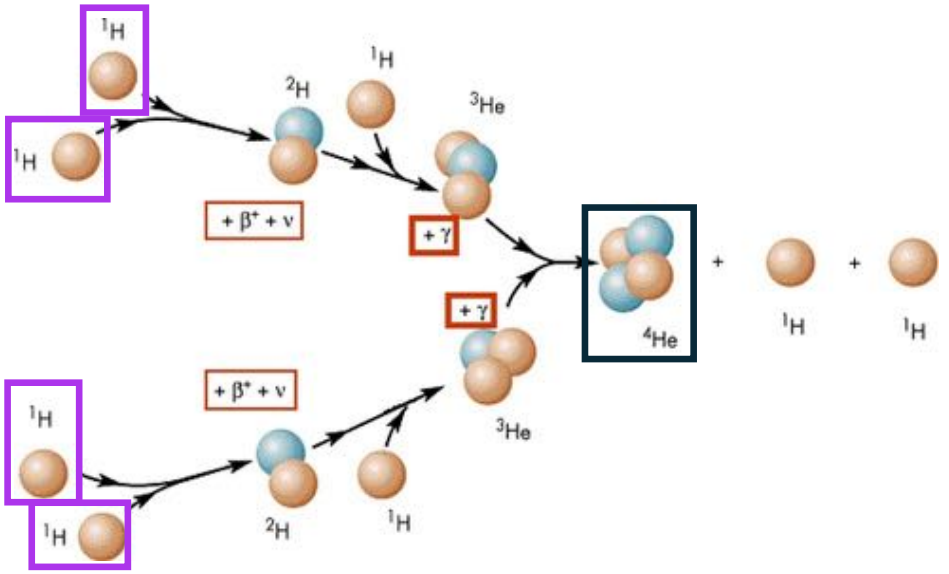
**(a hint: E= m $c^2$)**

**Answer: NUCLEAR FUSION**



"They cheer for me because they all understand me and they cheer for you because nobody understands you."






**4 $H^1$ --> $He^4$ + photons + *neutrinos***



**4 $H^1$ --> $He^4$ + photons + *neutrinos***

- mass of $H^1$ = 1.0078 AM
- mass of 4 x $H^1$ = 4.0312 AMU
- BUT: mass of $He^4$ = 4.0026 AMU . . .
  0.0286 AMU
  disappears in p-p chain!
  - **converted into energy via $E=mc^2$**
- **0.7% of H is converted into energy**
- **E = 0.007 x $c^2$ ergs per gram of H-> He**
- **E = 6 x $10^{18}$ ergs per gram of H -> He**

Hans Bethe - Nobel Prize in Physics
for work published in 1939



**To supply the solar luminosity ($4\times10^{33}$ ergs/second) the Sun must consume**

**$6.4\times10^{14}$ grams of hydrogen every second!**

## How long can this go on?

$M_{sun} = 2\times10^{33}$ grams

rate of consumption = $6.4\times10^{14}$ grams/second

$$\text{lifetime} = \frac{2\times10^{33}\ \text{grams}}{6.4\times10^{14}\ \text{grams/second}} \times 0.1$$

$$= 3.1\times10^{17}\ \text{seconds}$$

**= 10 billion years!**