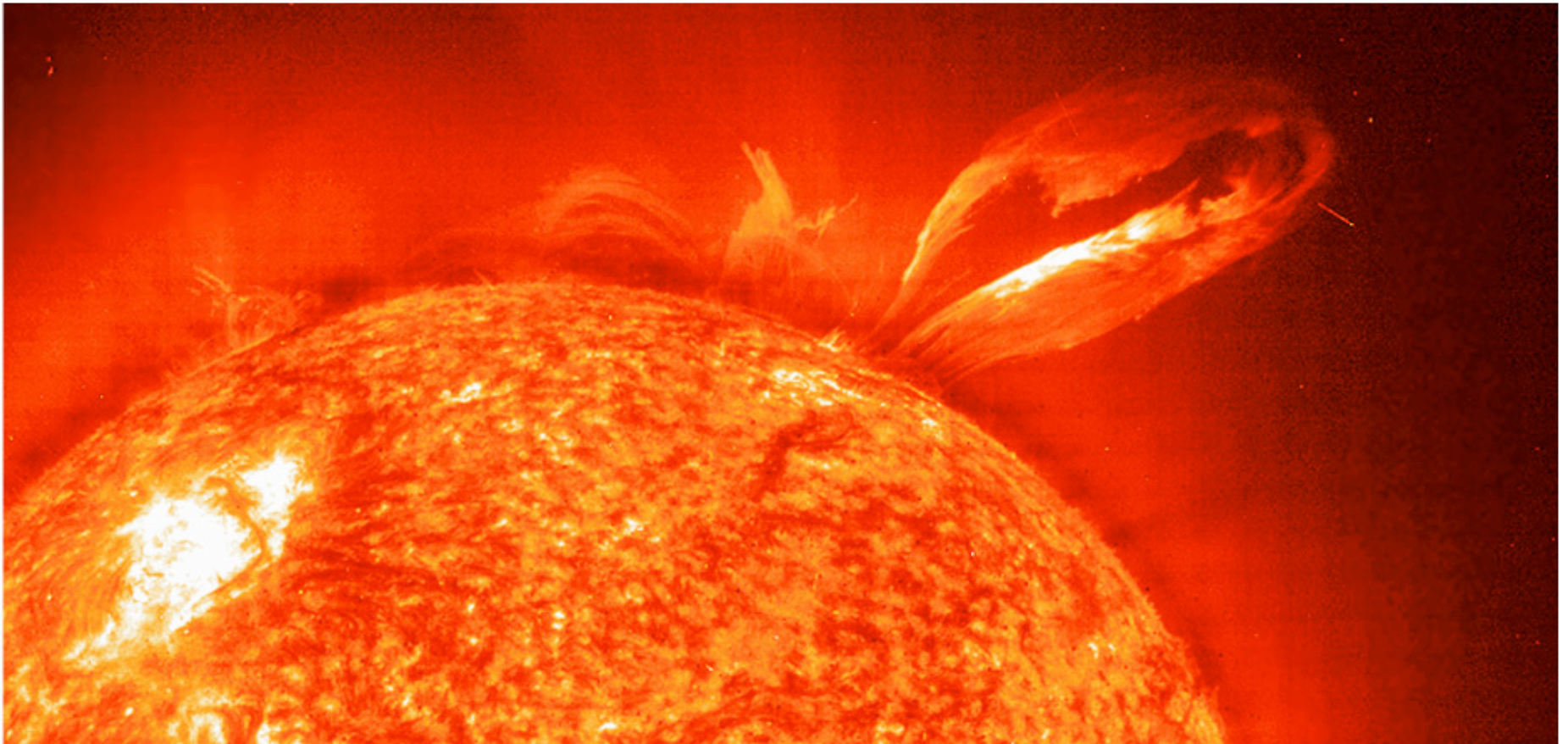
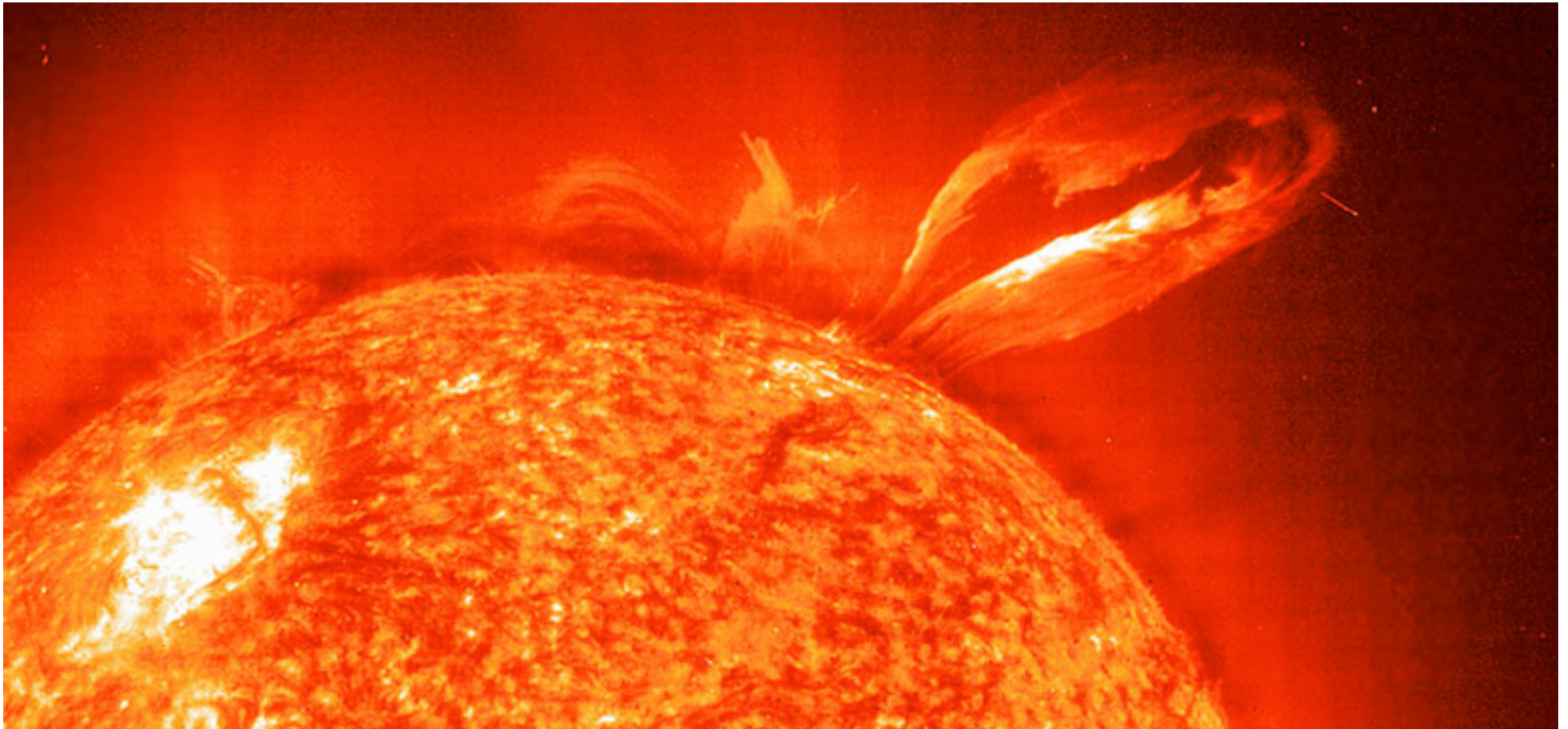


Why does the Sun shine?



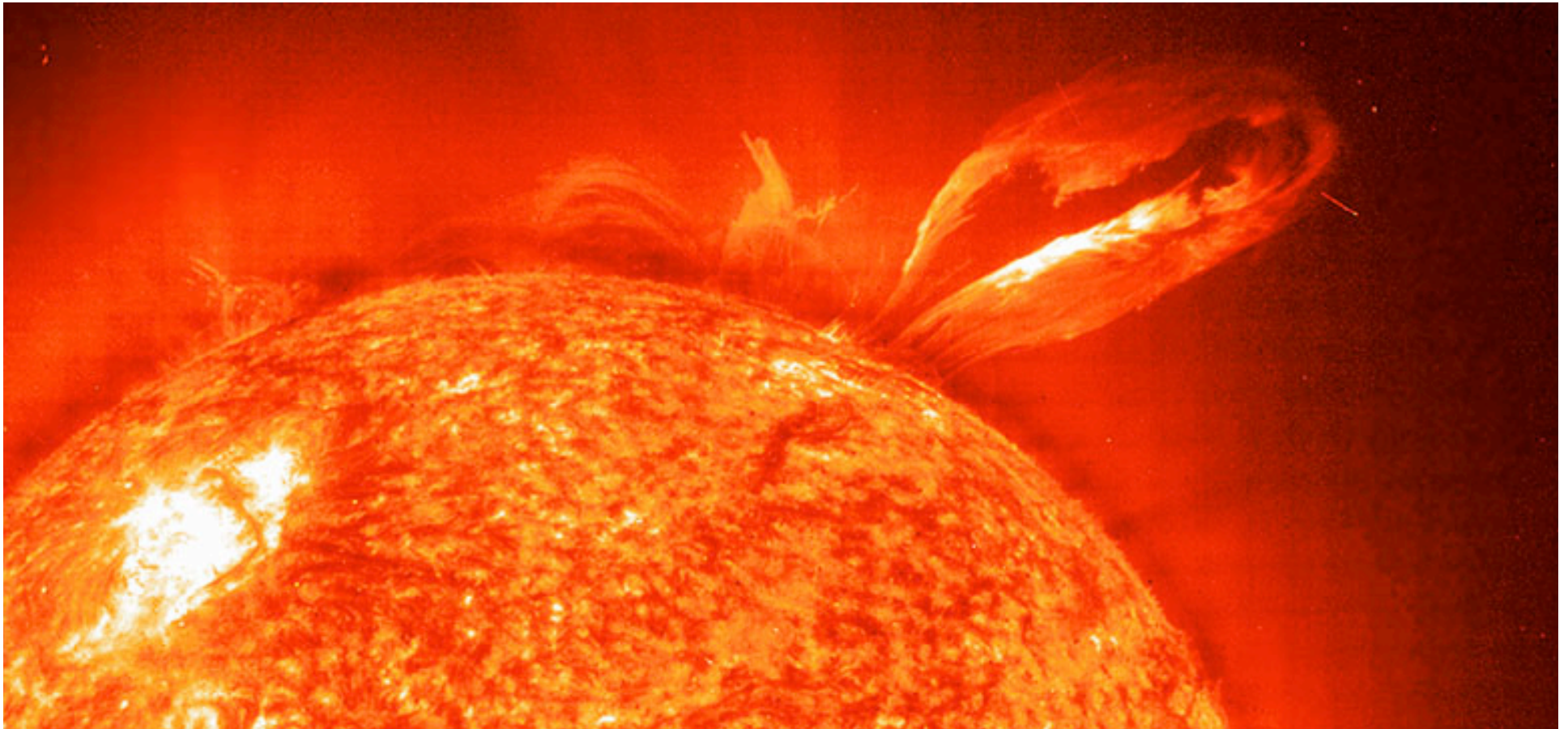


Is it on FIRE?

Chemical Energy Content

Luminosity

~ 10,000 years



Is it CONTRACTING? ... NO!

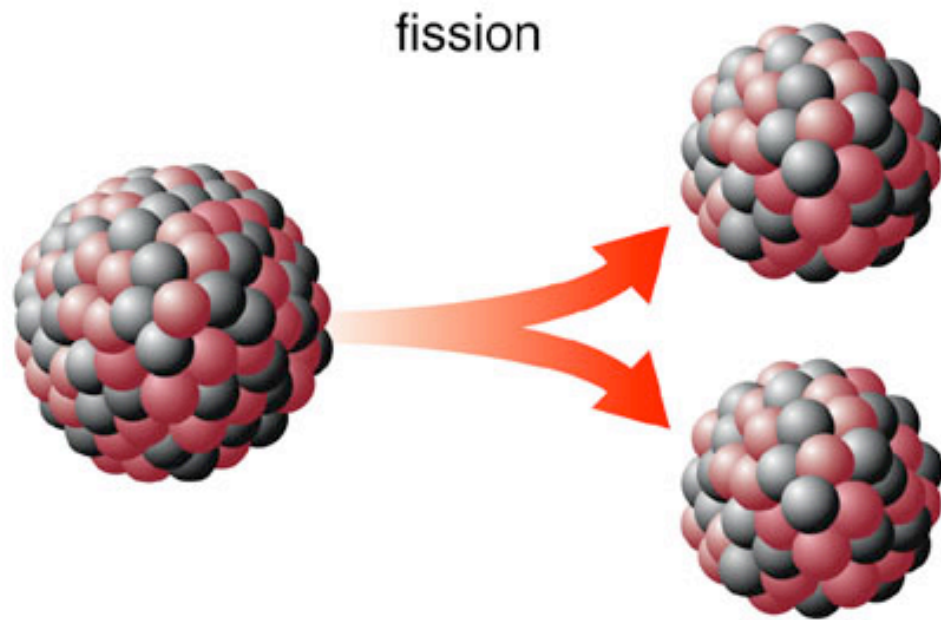
$$\frac{\text{Gravitational Potential Energy}}{\text{Luminosity}} \sim 25 \text{ million years}$$


$$E = mc^2$$

- Einstein, 1905

It can be powered by NUCLEAR ENERGY!

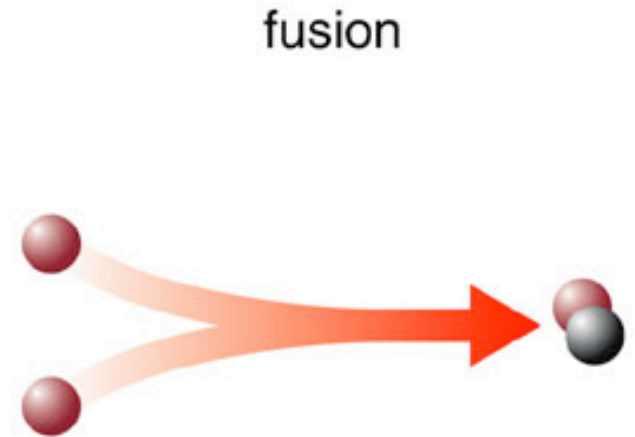
$$\frac{\text{Nuclear Potential Energy (core)}}{\text{Luminosity}} \sim 10 \text{ billion years}$$



Fission

Big nucleus splits into smaller pieces

(Nuclear power plants; “Atom Bomb”)

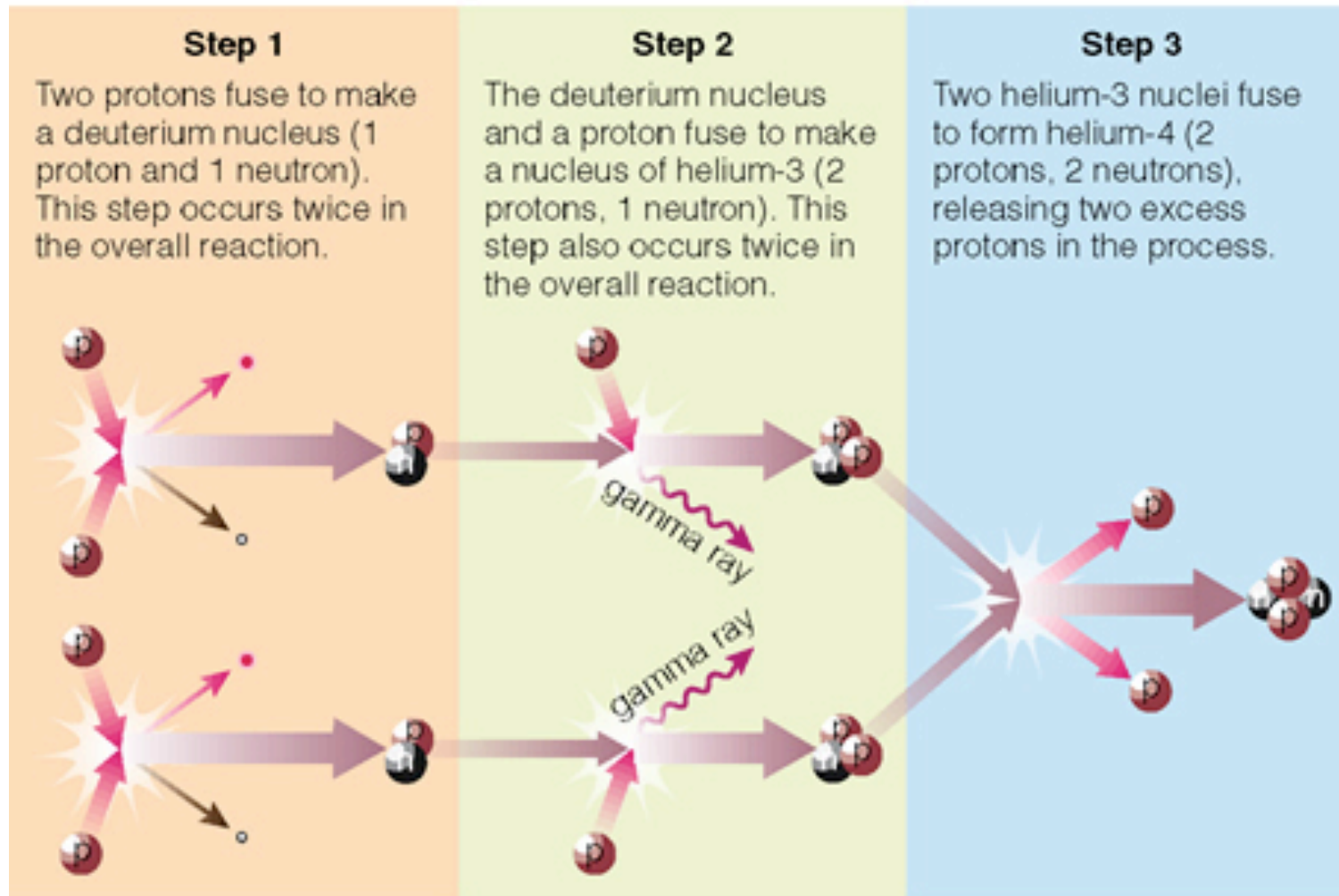


Fusion

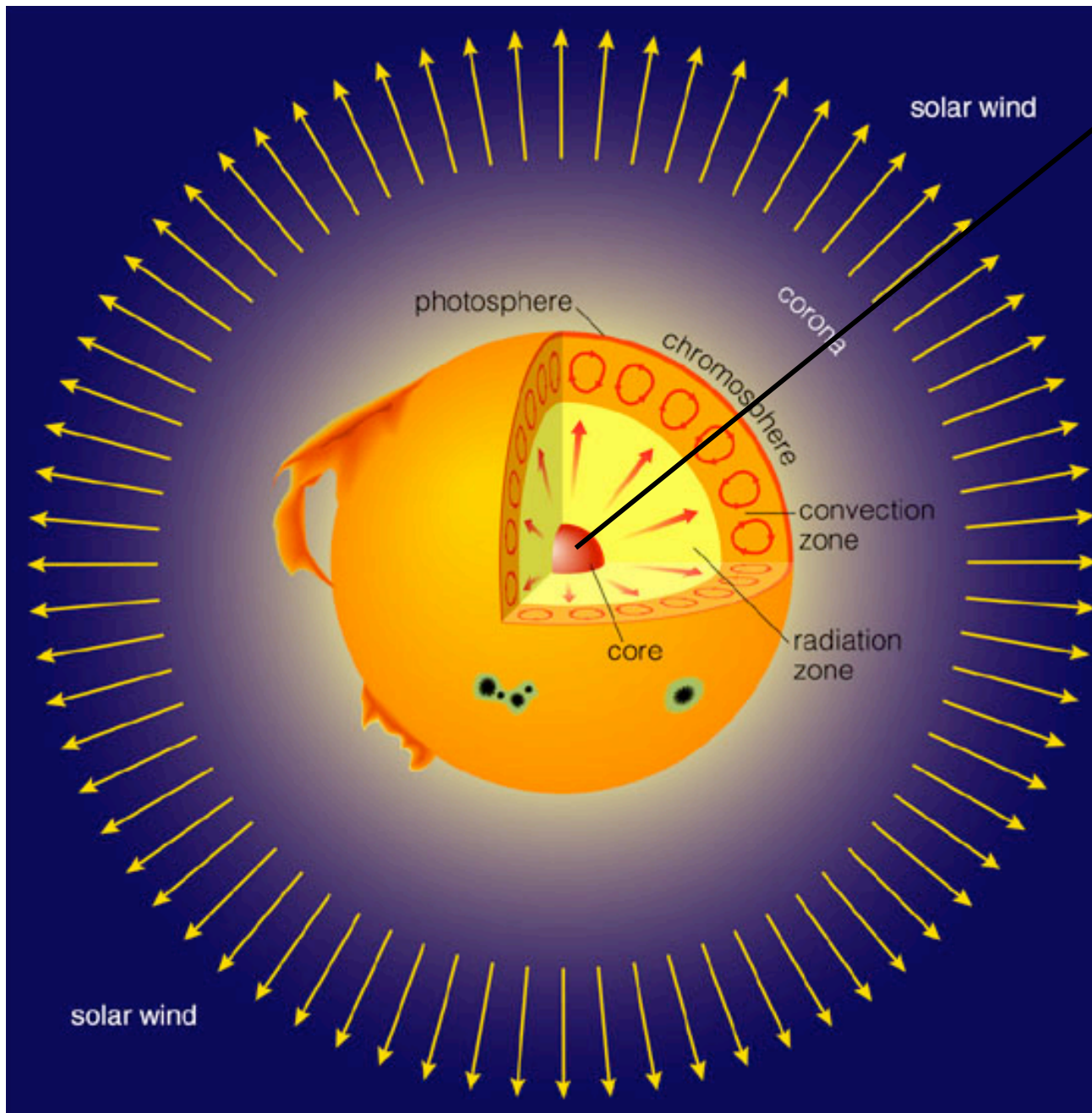
Small nuclei stick together to make a bigger one

(Sun, stars; Hydrogen Bomb)

Hydrogen Fusion by the Proton-Proton Chain



Proton-proton chain is how hydrogen fuses into helium in Sun



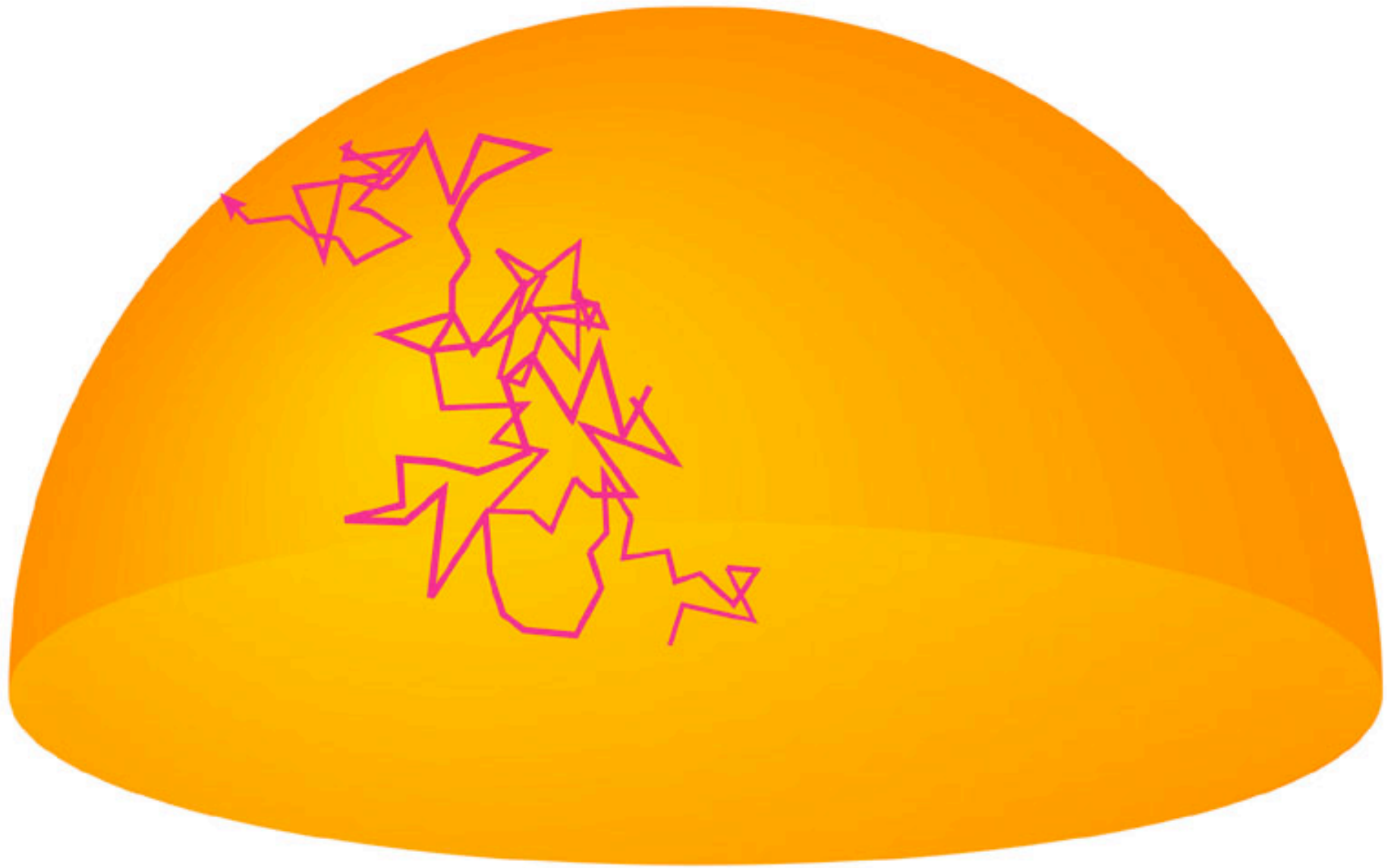
Core:

Energy generated
by nuclear fusion

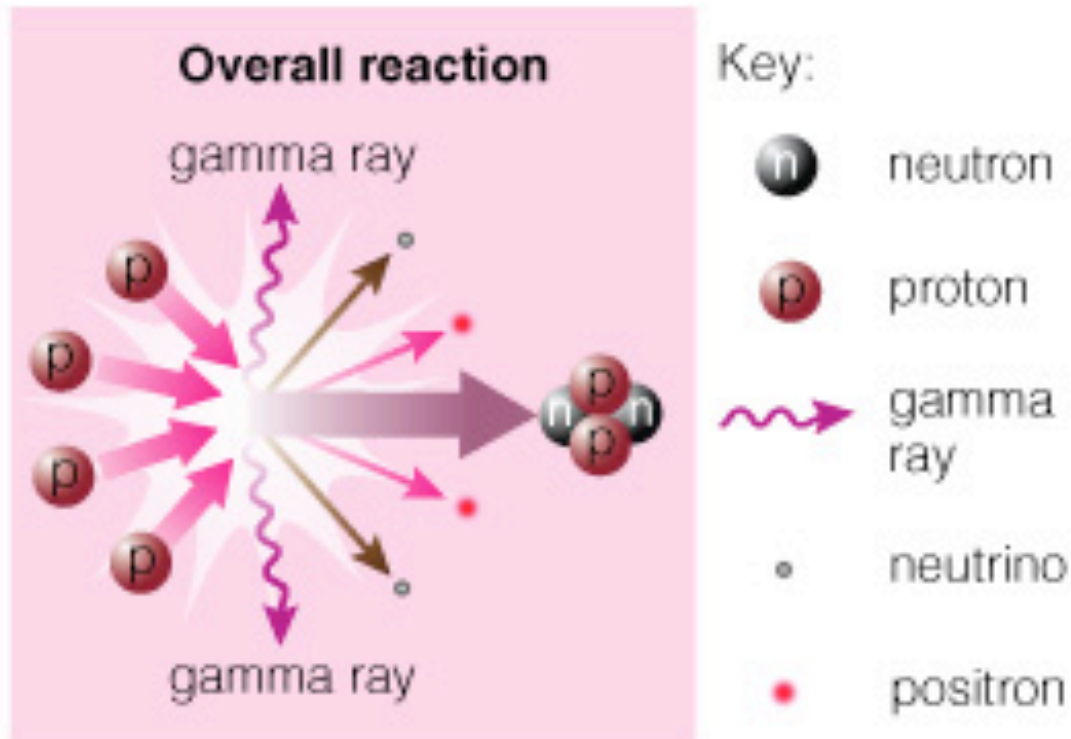
$T \sim 15$ million K

Density ~ 150 g/cm³
(10x density of lead)

Core is fully ionized -
a *Plasma*



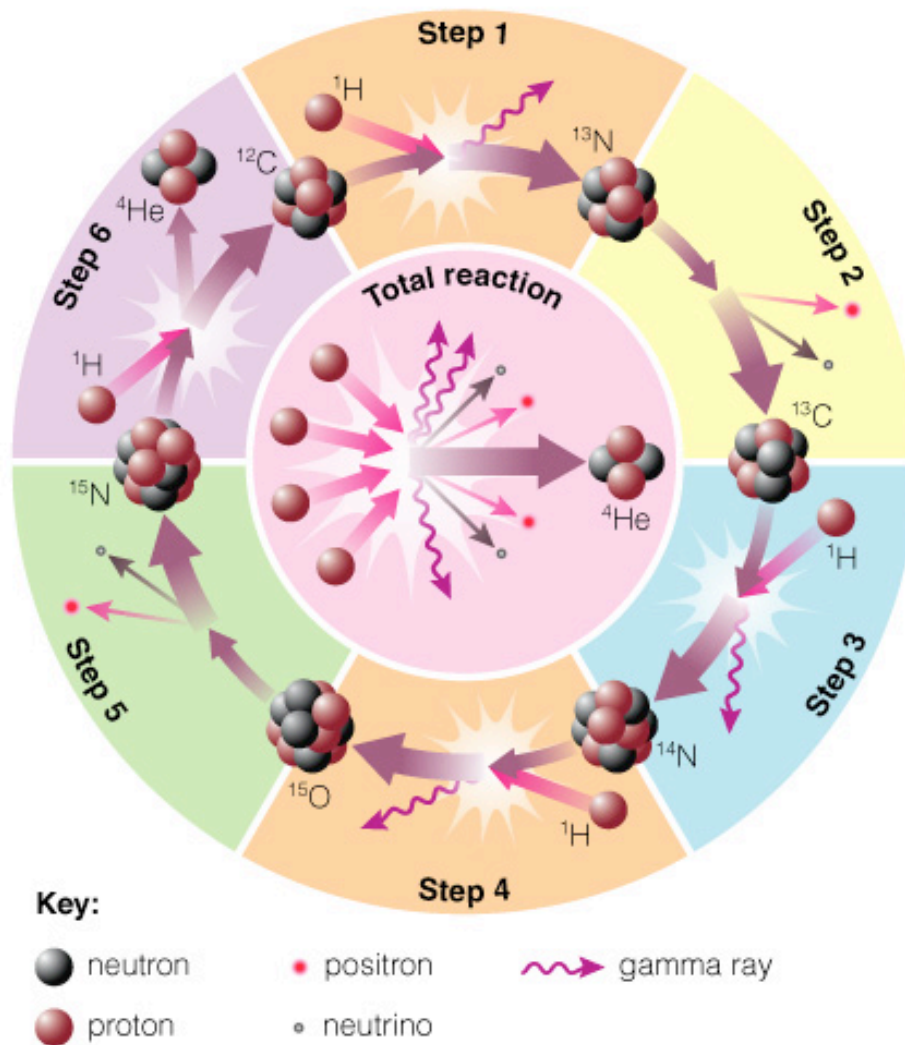
Energy gradually leaks out of radiation zone in form of randomly bouncing photons; gamma-rays created in nuclear reactions are gradually degraded into optical photons at the surface - taking about a million yrs



Neutrinos created during fusion fly directly through the Sun

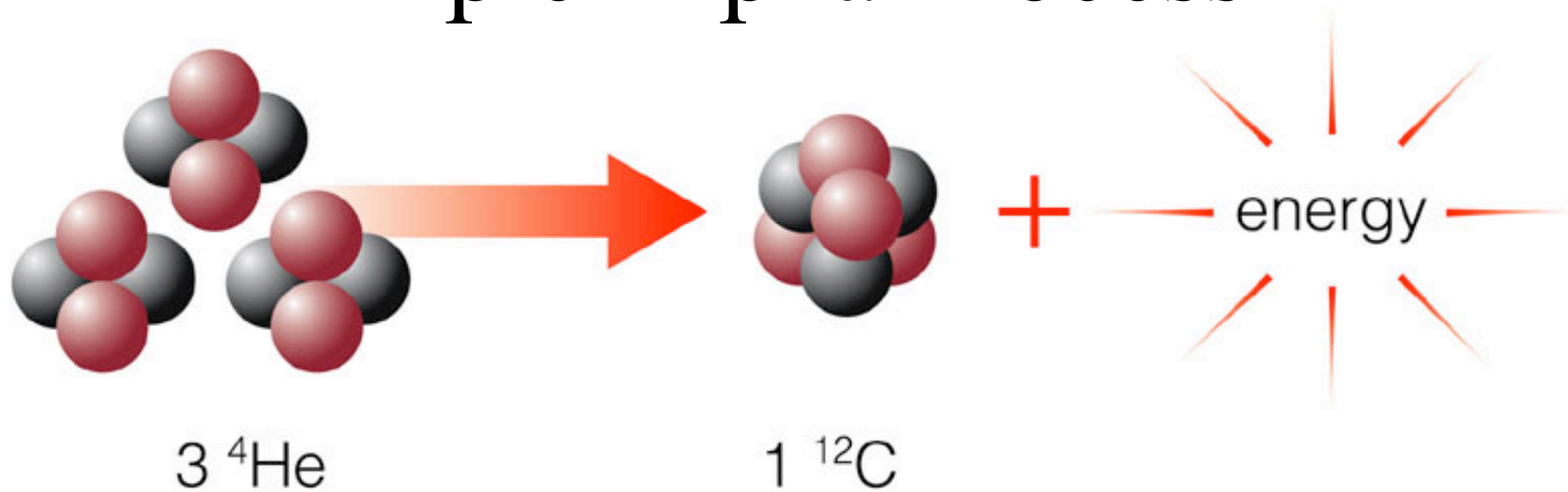
Observations of these solar neutrinos can tell us what's happening in core

CNO Cycle



- High-mass main sequence stars fuse H to He at a higher rate using carbon, nitrogen, and oxygen as catalysts
- Greater core temperature enables H nuclei to overcome greater repulsion

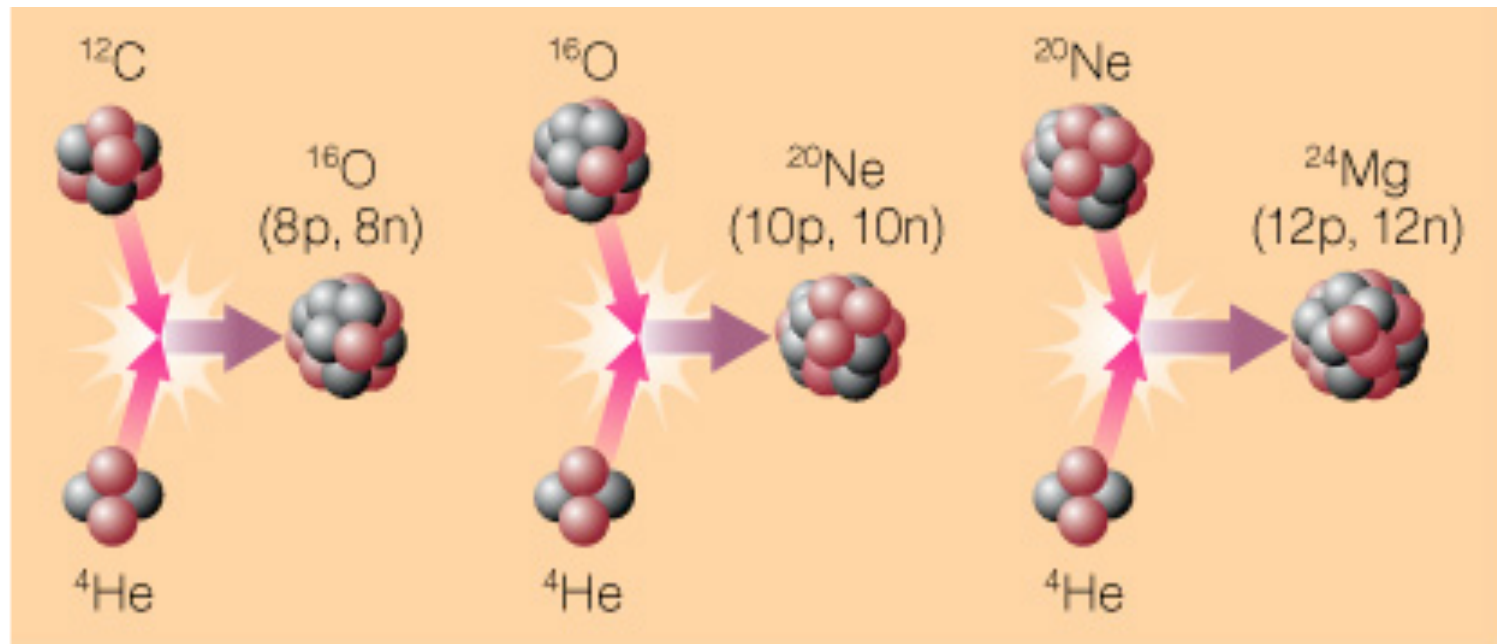
Triple Alpha Process



Helium fusion does not begin right away because it requires higher temperatures than hydrogen fusion—larger charge leads to greater repulsion

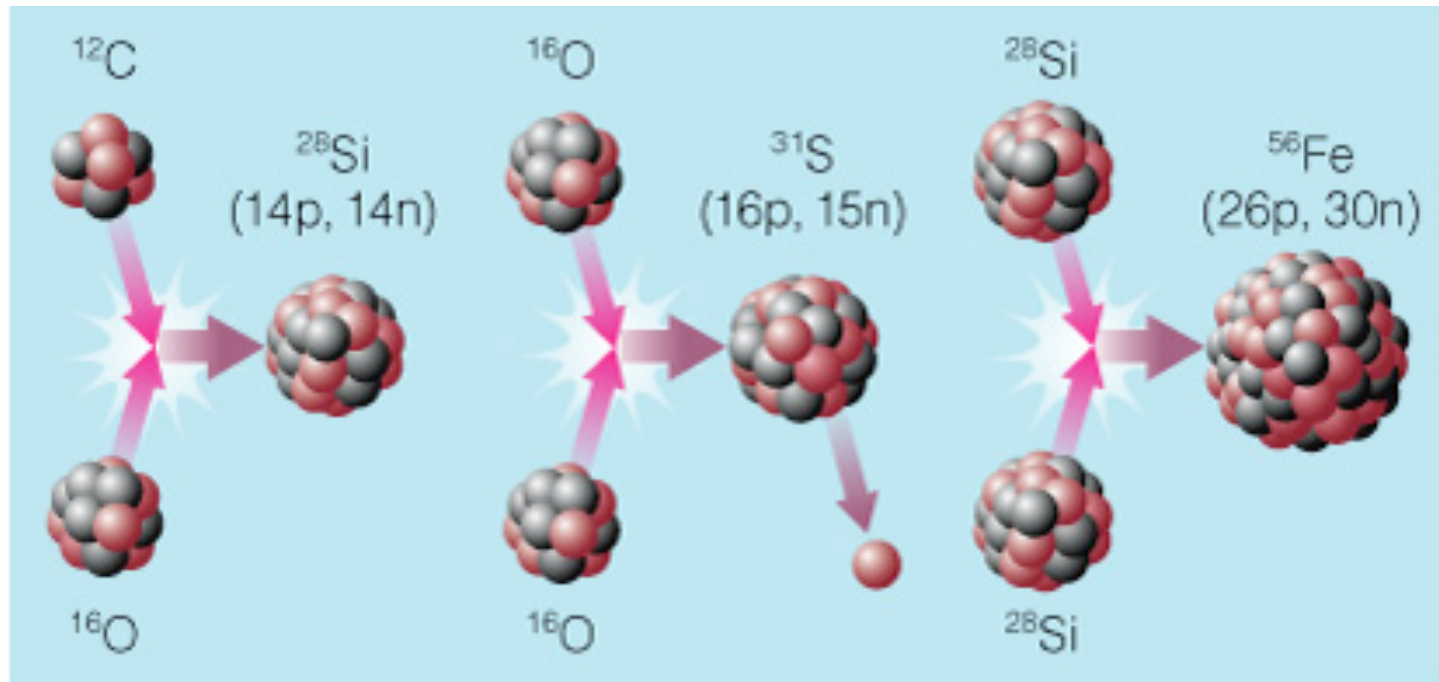
Fusion of two helium nuclei doesn't work, so helium fusion must combine three He nuclei to make carbon

Helium Capture

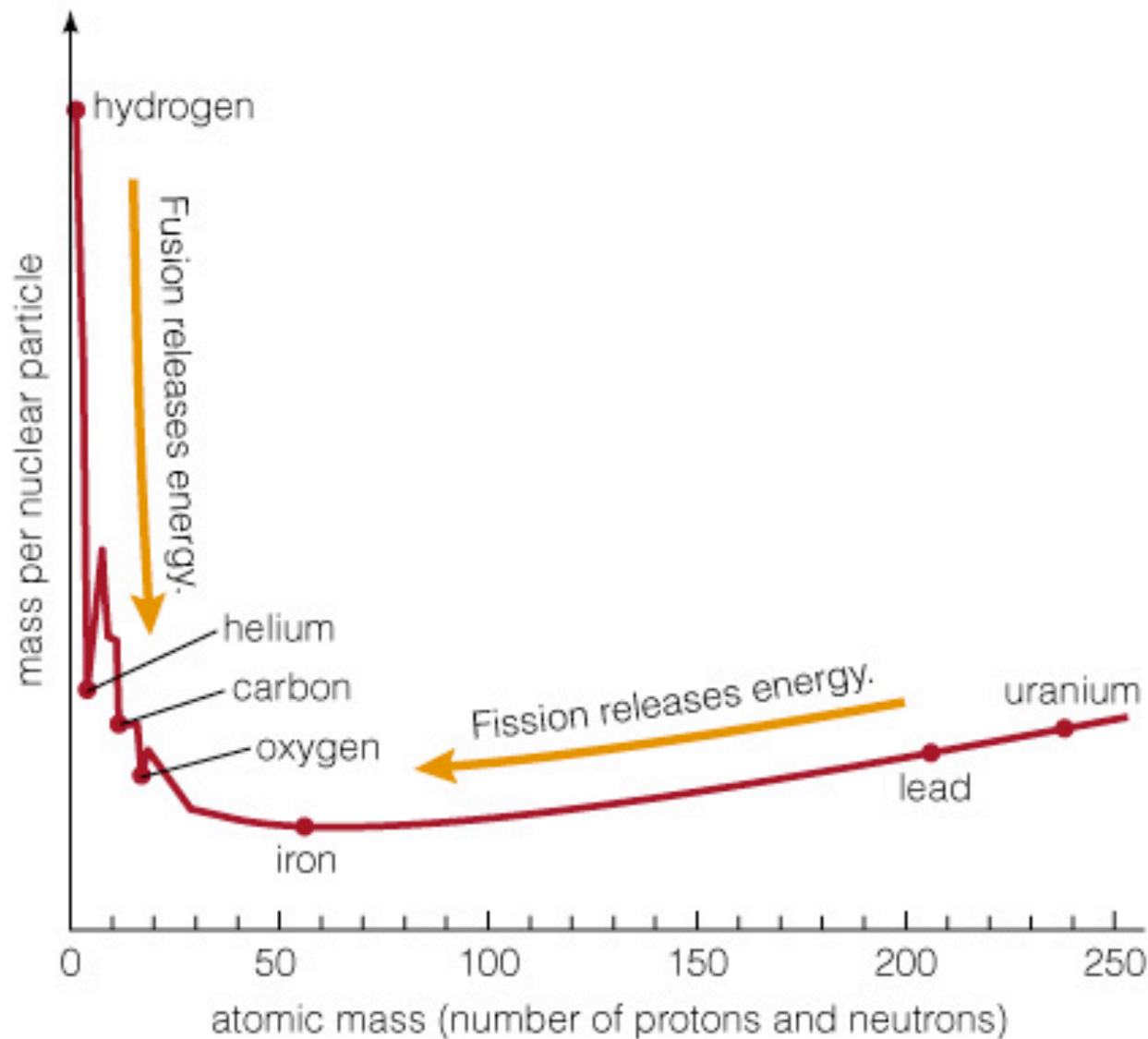


- High core temperatures allow helium to fuse with heavier elements

Advanced Nuclear Burning



- Core temperatures in stars with $>8M_{\text{Sun}}$ allow fusion of elements as heavy as iron

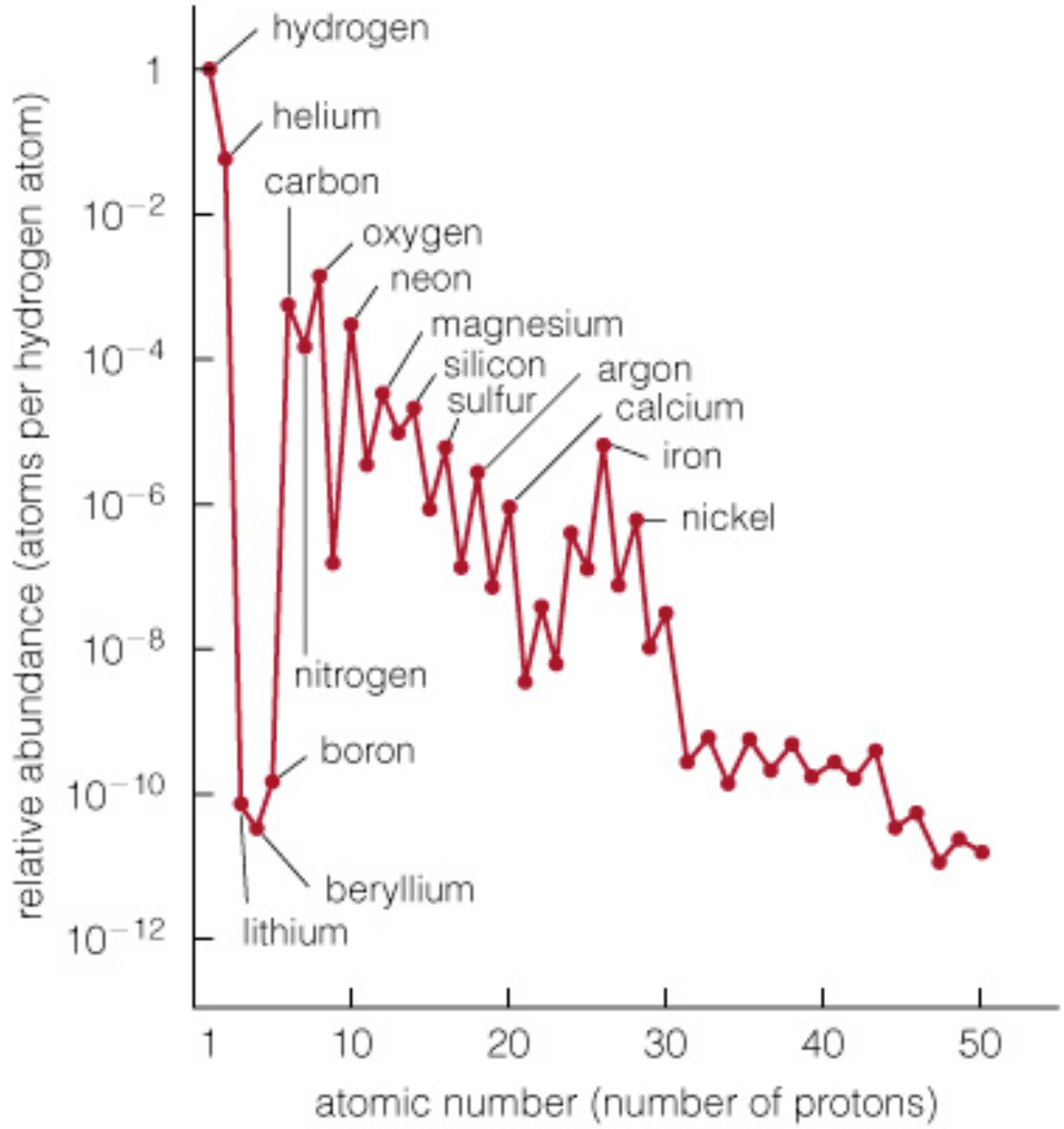


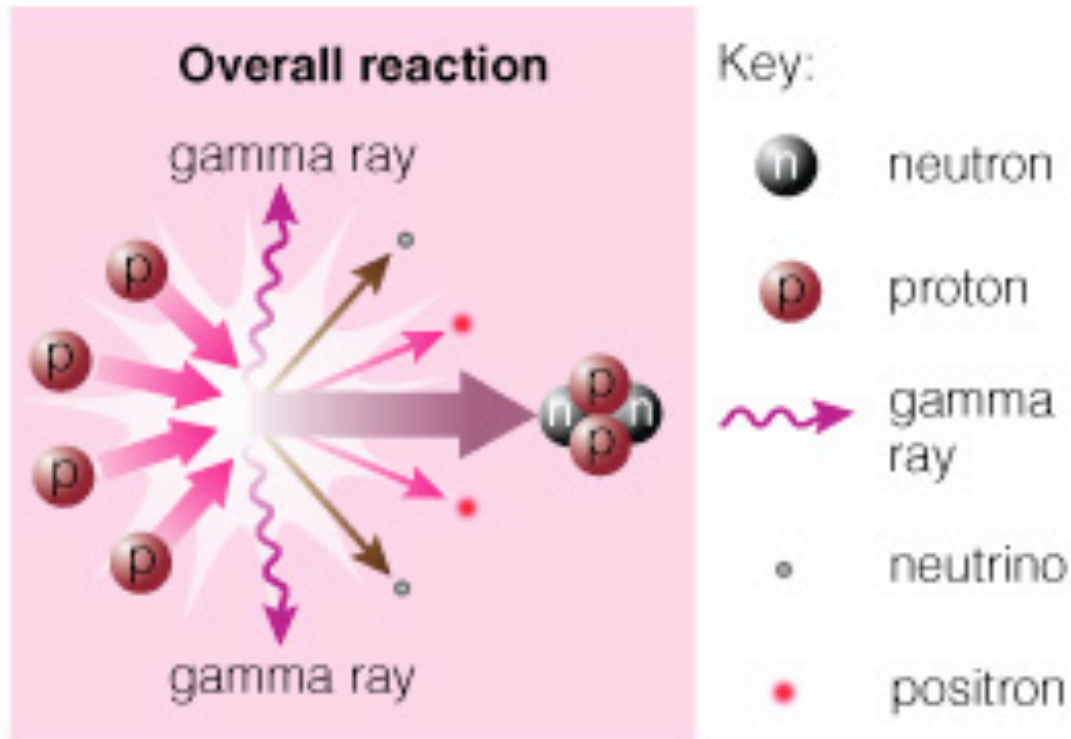
Iron is dead end for fusion because nuclear reactions involving iron do not release energy

(Fe has lowest mass per nuclear particle)

Evidence for
helium
capture:

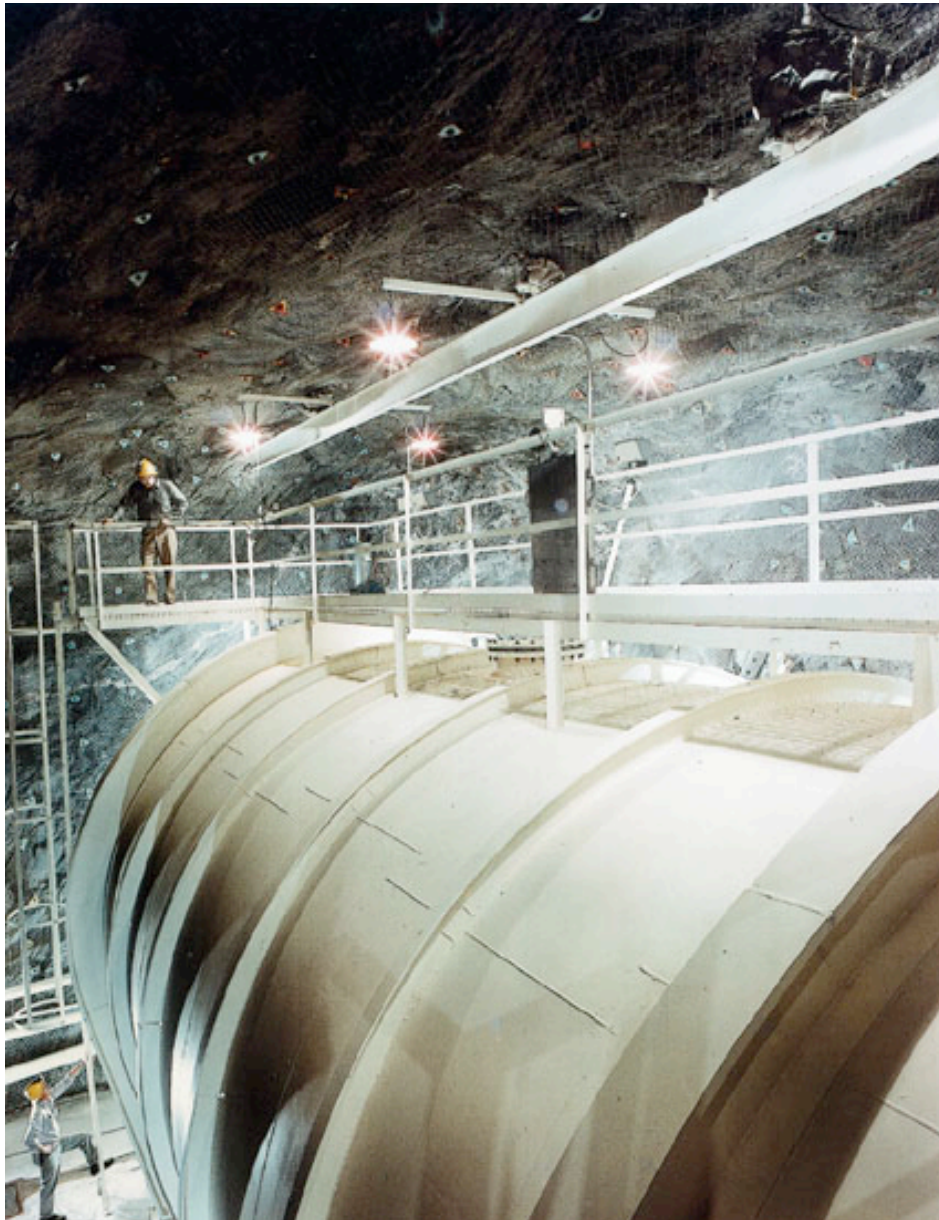
Higher
abundances of
elements with
even numbers
of protons





Neutrinos created during fusion fly directly through the Sun

Observations of these solar neutrinos can tell us what's happening in core



Solar neutrino problem:

Early searches for solar neutrinos failed to find the predicted number

Cosmic Gall

-John Updike -

*Neutrinos, they are very small.
They have no charge and have no mass
And do not interact at all.
The earth is just a silly ball
To them, through which they simply pass,
Like dustmaids through 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.*