Astro 210

Lecture 30

November 5, 2010

Announcements

- HW 8 due now
- HW 9 available, due in class next Friday

Solar Observing raindate: Monday, 10am-2pm

  ▷ schedule, report form online

Last time: the source of solar power

Q: how is the Sun different from a cup of coffee?

Q: what is the source of solar power?

Q: what are the inputs, outputs from the sun's burning reactions?

Hydrogen Burning in the Sun

The Sun is a mass of incandescent gas // a gigantic nuclear furnace
Where hydrogen is burned into helium, // at temperatures of millions of degrees

– Lou Singer and Hy Zaret, 1959; cover: They Might Be Giants 1993

"pp" Chain

$p + p \rightarrow {}^2\mathrm{H} + e^+ + \nu$, then $e^- + e^+ \rightarrow \gamma + \gamma$

${}^2\mathrm{H} + p \rightarrow {}^3\mathrm{He} + \gamma$

${}^3\mathrm{He} + {}^3\mathrm{He} \rightarrow {}^4\mathrm{He} + 2p$

where:

- deuterium ${}^2\mathrm{H} = \boxed{np}$ *Q: what's that?*
- e^+ "positron" *Q: what's that?*
- ν "neutrino" *Q: what's that?*

Net effect:

$4p + 2e^- \rightarrow \boxed{2n2p} = {}^4\mathrm{He} + \text{energy} + \ldots$

Fusion Energy

Where does the energy come from? **mass!**

`www: Big Al`

`www: scale cartoon`

Einstein: $\boxed{\varepsilon = mc^2}$

Observed fact: $m(^4\text{He}_{\text{atom}}) < m(4p + 2e)$! whole $<$ parts!

Do the math:

$$\begin{array}{rrll} & m(4p+2e) & = 6.694 \times 10^{-27}\ \text{kg} & (1) \\ - & m(^4\text{He}) & = 6.644 \times 10^{-27}\ \text{kg} & (2) \\ \hline = & \Delta m & = 5 \times 10^{-29}\ \text{kg} & (3) \end{array}$$

- fusion $\rightarrow$ mass reduction!

  $\rightarrow$ rest mass decrease $\rightarrow$ energy release!

in each reaction mass $\rightarrow$ energy (kinetic, photons)

$Q = \Delta\varepsilon = \Delta mc^2 = 4.5 \times 10^{-12}$ Joules

for each $4p \rightarrow$ ^{4}He fusion

Estimate fusion energy supply:

$$E_{\text{fuse}} = \frac{\#\text{ nuclei in Sun}}{4\text{nuclei/fusion}} \times Q \sim 1.3 \times 10^{45} \text{ Joules} \qquad (4)$$

Lasts for

$\tau_{\text{fuse}} = E_{\text{fuse}}/L = 3 \times 10^{18}$ sec $= 100$ billion years!

Vote your conscience!

This is a crude estimate of the solar fusion lifespan–but how?

A this is an *over*estimate of the lifespan

B this is an *under*estimate of the lifespan

Solar Life Expectancy

Overestimated fuel available for fusion:
$\rightarrow$ only fuse at high T, ρ
$\rightarrow$ core of Sun

true lifetime: $\tau \sim 1 \times 10^{10}$ yr $=$ 10 billion yrs
$\rightarrow$ Sun is middle aged
will last another $\sim$ 5 billion yrs

Q: how test that sun is nuke powered?

How Do We Know?

By the 1930's we knew that the Sun is nuclear powered

`www: Nobel Prize: Hans Bethe`

Q: how could we be so sure?

Can we get even more direct confirmation?

Q: is another way to confirms the Sun is a nuclear reactor? A "smoking gun" signature?

The Evidence: Solar Neutrinos

If the Sun takes $4p \rightarrow {}^4\mathrm{He} =$ 2p2n
then it *must* convert $2p \rightarrow 2n$
$\rightarrow$ *must* produce neutrinos!
in fact: most made via $pp \rightarrow de^+\nu$

The Sun radiates neutrinos as well as photons!
...we are bathed in solar "neutrinoshine"

Moreover:

- since ν are weakly interacting
  they come directly from the solar core
  $\rightarrow$ messengers from the center of the Sun!
- but luckily, *weakly* interacting $\neq$ *non*-interacting
  $\Rightarrow$ solar neutrinos are potentially observable!
- clever experiments can try to "catch" them

In Search of Solar Neutrinos

experiments have been built to "see" solar neutrinos
by observing rare cases of ν interations with atoms
all use huge underground detectors
Q: why huge? why underground?

Two types:
1. "radiochemical" – vats of fluid
see element change due to ν
ex: chlorine fluid $\nu + {}^{37}\mathrm{Cl} \rightarrow {}^{37}\mathrm{Ar} + e^-$
collect Ar atoms (radioactive!)
`www: Cl expt`

2. "scattering" – vats of ultrapure water
see light pulses from
high-energy e^- scattered by νs
`www: SNO ball`
`www: Super-K Sun image`

Upshot:

⋆ All experiments detect solar νs!

⋆ Amount (flux) is just as predicted

Q: what fundamental fact(s) is/are confirmed?

Solar Neutrino Results

I. proof that Sun powered by nuke fusion

II. νs give view into solar core

III. these are ν telescopes!

A new window on the Universe:

Nobel Prize 2002!

Poetry reading: John Updike, "Cosmic Gall"

The Stars as Suns

We've proved that that Sun is nuclear reactor
but (we'll see that) the Sun is a typical star
$\Rightarrow$ **all** stars run by thermonuclear fusion

The Night sky, the Universe lit up ultimately by nuclear power

How do we know Sun is typical?
Compare!

`www: big picture cartoon`