Astro 350
Lecture 13
Sept. 26, 2012

Announcements:

- **Hour Exam 1** Friday; info online
  discussion at end of class today
  Office hours: me today at 1pm; TA Thurs 9:30-10:30 am
- *Discussion 4* due today
- *Discussion 5* posted today, due next Wednesday
- *Bonus Participation*: class portrait on Compass
  identify yourself to help me learn your name

Last time: began stars & cosmology
Q: the Sun is made of a huge mass of gas,
which can flow and be compressed,
yet the Sun maintains a spherical shape and constant size–why?

The Lives of Stars

The life of a star is a struggle against its own gravity

- if gravity force balanced by pressure, star is stable
  and to keep pressurized, must stay hot!
- if pressure weaker then gravity, star unstable
  collapses under its own weight

Birth

stars formed when cold gas clouds collapse due to gravity
compression $\rightarrow$ heating, until T at center $\rightarrow 10^7$ K
"birth" when first nuke reactions begin

Youth and Midlife (Main Sequence) – All Stars

in core of star, nuclear reactions convert H $\rightarrow$ He

- energy release $\rightarrow$ heat $\rightarrow$ maintains outward pressure
  $\rightarrow$ balances inward gravity $\rightarrow$ stability! ("hydrostatic equilibrium")

Hydrogen Burning in Stars

interstellar gas is mostly (about 75%) hydrogen
stars formed from this gas $\to$ stars begin as mostly H

nuclear "burning" of hydrogen to helium:

- key reactions occur in "chains"
- first step involves pre-existing solar ingredients
- input for each new step is output from previous step

Dominant reactions: "pp" Chain

$$p + p \to {}^2\text{H} + e^+ + \nu$$

$$e^- + e^+ \to \gamma + \gamma$$

$$^2\text{H} + p \to {}^3\text{He} + \gamma$$

$$^3\text{He} + {}^3\text{He} \to {}^4\text{He} + 2p$$

Net effect:

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

each “p–p reaction” creates:

- ^{2}H=$\boxed{np}$ **“deuterium”**

“heavy hydrogen” nucleus

- e^+ **“positron”**

antimatter: positively charged anti-electron! more later about antimatter

then $e^- + e^+ \rightarrow \gamma + \gamma$ energy!

annihilation

- ν **“neutrino”**

very low-mass ($m_\nu \ll m_e$) particle

only created in nuclear reactions (“weak” decays)

very weakly interacting particle

once born, go thru Sun, Earth, your body

but almost never interact

ν *escape diagram*

The Nuclear Powered Sky

Before 1930's:

- a mystery how the Sun could burn for billions of years
- no known energy source would work

In the 1930's:

nuclei, nuclear reactions, nuclear energy discovered

it was realized that this can power the Sun and all stars

`www: Nobel Prize: Hans Bethe`

> 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

Inner Space and Outer Space

Lesson: a deeper understanding of "inner space"
i.e., the microscopic world
led to a deeper understanding of "outer space"
i.e., the astronomical/cosmological world

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 $4p \rightarrow {}^4\text{He} = \boxed{\text{2p2n}}$
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 interactions 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: Davis chlorine experiment`

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"

Imagine: 100 years ago, you try to explain
that the Sun and all stars create tiny invisible particles
that pass through us all the time in huge numbers
and are essential byproducts of the working of stars

Q: a lesson for cosmology?

Hour Exam 1

`www:  Exam Info on Course Website`

`www:  Front Page:  Instructions and Equations`

Any Questions?

Sample Questions

Multiple Choice

An object orbiting the Sun with a semimajor axis of 9 AU has what orbital period?

(a) 3 years
(b) 9 years
(c) 27 years
(d) depends on orbit eccentricity
(e) none of the above

Star A and star B are observed to have the same flux, but the parallax of star A is **larger** than the parallax of star B. Thus the **luminosity** of star A is ________ the luminosity of star B.

(a) larger than
(b) smaller than
(c) the same as
(d) not enough information to answer
(e) none of the above

Short Answer

Sketch the rotation curve observed for our Galaxy. Be sure to:

- label both axes
- indicate the center of the Galaxy
- indicate the visible edge of the Galaxy

Sketch the rotation curve our Galaxy **would** have if all of the matter were in the form of stars. Be sure to label both axes and identify the Galactic center and visible edge.

Explain why the observed rotation curve of our Galaxy gives evidence for dark matter.

Give an example of possible form of dark matter and explain why it meets the requirements to be dark matter.