Astro 210
Lecture 32
April 13, 2011

Announcements

- HW 9 due at start of class next time
  instructor office hours: today after class
  TA office hours: tomorrow 10:30-11:30am
- **Solar Observing**: *last day is today!*
  runs until 3:30
  info, report form online

Last time: nuclear fusion in the Sun
hydrogen "burning": $4p \rightarrow {}^4\text{He} + 2\nu + \text{energy}$
confirmed: neutrinos observed
implications:

- Sun a typical star $\rightarrow$ all stars nuclear powered
- a star's nuclear "fuel supply" is hydrogen mass

Mass

Most important parameter of a star!

Q: why is stellar mass hard to determine?

Q: when/how can mass be measured?

For single stars:
mass determination difficult, very indirect

But can find masses for **binary** systems:
two stars orbiting common center of mass
diagram: orbits

measure P, r_1, r_2
get m_1, m_2 from Newton's version of Kepler's 3rd law

$$m_1 + m_2 = \frac{4\pi^2}{G} \frac{r^3}{P^2} \tag{1}$$

and $m_1/m_2 = r_1/r_2$

ω problem: must measure r's *Q: how?*

Types of Binary Stars

visual binary

can see both stars!

`www: visual binary orbit`

eclipsing binary

stars pass in front of each other

can see in light curve:

diagram: light curve $\rightarrow$ get rs from timing of eclipses

spectroscopic binary

periodic Doppler shifts in spectrum

see $\Delta\lambda_1$, $\Delta\lambda_2$

$\rightarrow$ radial velocity $v_r/c = \Delta\lambda/\lambda_0$

then $v_1 = r_1\omega = 2\pi r_1/P$

can solve for r!

iClicker Poll: Stellar Luminosity and Mass

Vote your conscience!

How are a star's luminosity and mass related?

A directly: larger $M \to$ larger L

B inversely: larger $M \to$ smaller L

C no strong dependence: L nearly constant for all M

for many stars find M, $L \to$ plot!

`www:` M `vs` L `-- beware! logarithmic axes`

for *main sequence* stars ("normal" stars)
there is a simple, clear correlation

mass-luminosity relation (main sequence):

$$L \propto M^4 \tag{2}$$

where M is now mass, not magnitude!

Note: this is a rough approximation, not accurate for $M \gtrsim 4M_\odot$

Q: what is L of $0.5M_\odot$ star?

Q: what does this mean for main sequence on HR diagram?

iClicker Poll: Stellar Lifetime

Stars of which mass live longer–$1M_\odot$ or $0.5M_\odot$?

A $1M_\odot$: higher $M \to$ more fuel

B $0.5M_\odot$: lower $L \to$ longer to "burn out"

C effects cancel: lifetimes roughly equal

Stellar Lifespans

From M and L get *lifespan* τ
since energy conservation gives

$$\begin{array}{rccc} E = & L & \times & \tau \\ \text{energy supply (fuel)} = & \text{burn rate} & \times & \text{lifespan} \end{array} \tag{3}$$

thus: $\tau = E/L$

but $E \propto M$: hydrogen mass is thermonuclear fuel

- $\tau = E/L \propto M/M^4 = M^{-3}$
- using solar values $\tau_\odot = \tau(M_\odot) = 10^{10}$ yr, get

$$\tau = 10^{10} \text{ yr} \left(\frac{1 M_\odot}{M}\right)^3 \tag{4}$$

∞ • high mass $\leftrightarrow$ high luminosity $\leftrightarrow$ short life
- low mass $\leftrightarrow$ low luminosity $\leftrightarrow$ long life

Stellar Lifetimes: Implications

Some Facts:

- main sequence mass-lifetime relation:

$$\tau = 10 \text{ billion yr} \left(\frac{1 M_\odot}{M} \right)^3 \tag{5}$$

- age of Sun and solar system: $t_{SS} = 4.5$ billion yr
- age of the Universe (we'll find): $t_0 = 13.7$ billion yr

Q: what's the lifespan of a $0.5 M_\odot$ *star? implications?*
Q: what's the lifespan of a $10 M_\odot$ *star? implications?*
Q: implications for main sequence on HR diagram?

Imagine (for simplicity) that:

- our Galaxy has formed stars at a constant rate throughout the age of the Universe (oversimplified!)

Q: what would this mean for the population of Galactic stars today?

Stellar Lifetimes: Implications

Implications:

- $\tau(0.5 M_\odot) = 80$ billion years $\gg$ age of Universe!
  $\to$ all such stars ever born remain alive today!
- $\tau(10 M_\odot) = 10$ million years $\ll$ age of U., SS
  $\to$ most such stars have come and gone!
  $\to$ any massive stars seen today were recently born

So as our Galaxy makes stars

- low-mass stars live "forever" (but are dim)
- high-mass stars die quickly

$\to$ expect mostly low masses (in a fair sample)
but beware bias – rare, luminous stars easier to see
example of "selection effect"

`www: HR diagram: nearest vs brightest stars`

Theory Building: Stellar Life Cycles

Q: what is involved in making a model of a star's life?

for example, consider a model of the Sun's life

Q: what physics goes in?

Q: what data needed as inputs and/or checks on model outputs?

Q: what kind of predictions can such a solar model make?

The Life and Death of a $1 M_\odot$ Star

Evolution of a $1M_\odot$ Star: Birth

protostar
raw material: H ($\approx 70\%$ of mass), He ($\approx 28\%$), heavy elements ($\approx 2\%$)
in cold molecular cloud
`www: Eagle Nebula`

'free fall" collapse (HW 9)
most material $\rightarrow$ protostar
nonzero angular momentum $\rightarrow$ protoplanetary disk
(see solar system origin notes)

protostar contracts $\rightarrow$ heats

- core $T \uparrow$ until hot enough for nuclear reactions to turn on, then
- H burning starts: heat supply
- gas pressure maintained
- hydrostatic equilibrium achieved $\rightarrow$ star stabilized

$1M_\odot$ Star Mid-Life: "Main Sequence"

"main sequence" = burn H $\rightarrow$ He in core

most of a star's lifespan spent in this phase

Q: how does star core change in composition during this time?
Q: how will the Sun respond to this change?

Evolution of the Sun's Luminosity

in star core: H $\rightarrow$ He "burning"
$\rightarrow$ over time: H "fuel" $\rightarrow$ He "ash"
$\rightarrow$ fuel supply goes down
e.g., today, Sun's core $< 50\%$ H!

how does core respond to H depletion?
- still need to generate nuclear energy
- but with less fuel, have to burn hotter

$\rightarrow$ core T goes up
$\rightarrow$ star responds by *increasing* L!
Q: how would this "move" the Sun on the HR diagram?

Today: sun $\sim 50\%$ brighter than at birth!