Astro 350
Lecture 11
Sept. 16, 2011

Announcements:

- HW3 due now
- HW2 back today
- Good news: no HW next Friday!
- Bad news: Hour Exam 1 next Friday
  info on course website

Last time:

- finished cosmo-workout
  developed scientific tools to apply to Universe
- stars: the source of most (but not all!) cosmic light
- stars have life cycles!
  birth: *Q: where? how?*
  Q: how are stars stabilized against becoming black holes?

Stars and the Sun

a few heliocentric Greeks guessed that the stars are like the Sun, only far away

Newton pushed this further and showed that this is true

Q: how do we know that stars are Suns?
Q: what data is needed for comparison?

Stellar Physical (Turn Head, Cough)

Star Masses

can measure in binary systems: 2 stars in bound orbits

`www: binary star`

recall Kepler/Newton: $GMP^2 = 4\pi a^3$ so

$$M = \frac{4\pi a^3}{GP^2} = \frac{a_{\rm AU}^3}{P_{\rm yr}^2} M_{\rm Sun} \tag{1}$$

result: star masses range $0.1 M_{\rm Sun} \lesssim M_\star \lesssim 100 M_{\rm Sun}$

$\rightarrow$ Sun is in heart of range: a typical star mass-wise

Star Power

power = rate of energy flow or consumption
= energy output/time

$$P = \frac{E}{t} \quad (= dE/dt) \tag{2}$$

light power = light energy outflow: **luminosity**
$\rightarrow$ "star wattage"

iClicker Poll: Naked-Eye Stars

Vote your conscience!

On a clear night, outside of a city,
about how many stars can you see with the naked eye?

A More than the number of people in a packed movie theater

B More than the number of people at sold-out Memorial stadium

C More than the population of Illinois

D More than the population of the Earth

Star Light, Star Bright

to naked eye, in clear sky:
about 6000 (!) stars visible over celestial sphere
$\Rightarrow$ about 3000 at any one night
...but this is just the "tip of the iceberg"

many many more stars exist
but unseen by naked eye

stars appear to have different brightnesses
brightest (other than Sun): Sirius – "dog star"

iClicker Poll: Star Brightness

Vote your conscience!

Stars observable *by the naked eye* appear to have
a wide range of brightnesses

Why?

A they emit similar amounts of light (similar luminosities L), but are at different distances

B they emit very different amounts of light (different L) but are at similar distances

C they emit very different amounts of light (different L) and are also at very different distances

Apparent Brightness vs Luminosity

apparent brightness: what we/scopes actually perceive
energy flow (light power) per area
apparent brightness or **flux** $F = P/A$

consider spherical star: light power output is luminosity L
when observing at distance (radius) R
  light spread over area $A = 4\pi R^2$
so observable flux is

$$F = \frac{L}{4\pi R^2} \tag{3}$$

crucial fact: observed F depends on L but also on R
$\rightarrow$ headlights blinding nearby, tolerable far away

Want to know L, but measure F

to solve $L = 4\pi R^2 F$ need distance R
Q: how measure?

Stellar Distances: Parallax

Recall: Earth orbit $\rightarrow$ shifting viewpoint on stars
$\rightarrow$ nearby stars appear to shift relative to distant stars
diagram: parallax geometry
parallax angle p = shift from midpoint

from parallax angle p can find
distance $d = 1$ AU$/ \tan p$ (exact formula)

but shift very small: p tiny (< 1 arc second $= 1/3600$ degree)
$\rightarrow$ "skinny triangle" law works just fine:
$\tan p \approx p_{\rm radians}$

$$d = \frac{1\ \mathrm{AU}}{p_{\rm radians}} = \frac{200,000\ \mathrm{AU}}{p_{\rm arcsec}} = \frac{1\ \mathrm{parsec}}{p_{\rm arcsec}} \quad (4)$$

Star Distances and Parsecs

from parallax p find distance

$$d = \frac{1 \text{ parsec}}{p_{\text{arcsec}}} \tag{5}$$

- new distance unit: $1\text{parsec} = 1 \text{ pc} = 200,000 \text{ AU}$
- nearest star: $d(\alpha \text{ Cen}) = 1.3 \text{ pc}$
  $\rightarrow$ 1 pc is typical star-star distance in a galaxy
- light travels 1 pc in 3 yrs: $1 \text{ pc} = 3$ light years (lyr)

Star Luminosity

armed with distances to stars,
can find their luminosities

Compare Sun vs star luminosities:

- Sun ($\odot$): $L_\odot = 4\pi (1\ \mathrm{AU})^2 F_\odot = 4 \times 10^{33}$ Watts
  the Sun is a 4×10^{33} Watt lightbulb!
- other stars: luminosity range $10^{-3} L_\odot < L_\star < 10^6 L_\odot$
  huge range, Sun in middle $\rightarrow$ Sun is typical luminosity-wise

$\Rightarrow$ the Sun is a typical star!

Star Stability

recall: stars made of gas, which can be compressed
and always feel inward pull of their own gravity
yet after birth, do not collapse on themselves

Why? stars are *hot* $\rightarrow$ gas pressure high
outward pressure force balances gravity
$\rightarrow$ *hydrostatic equilibrium*

Q: what would happen if the Sun cooled off?
yet the Sun does not cool off–luckily for us!
Q: what does this tell us about the Sun?
hint: compare the Sun and a cup of coffee?

Star Lifespans and Energy Sources

to fight gravity and be stable
the Sun must remain pressurized $\rightarrow$ must remain *hot*
and it does! Sun's T does not change (on human timescales)

but this is strange!
a cup of coffee starts out hot, but cools
  that is, loses heat energy to its environment
yet even though Sun emits energy too, at huge rate L
  still remains hot $\rightarrow$ needs *heat source = energy source*

To maintain luminosity (power output) L

for a *lifespan* τ

a star emits energy $E_{\text{emit}} = L\tau$

but energy conserved: fuel supply must be $E_{\text{fuel}} = E_{\text{emit}} = L\tau$

but since E_{fuel} finite, lifespan $\tau = E/L$ finite

$\rightarrow$ fuel will run out $\rightarrow$ all stars will die!

But what is fuel?

What form of energy in Sun is converted to light & heat?

Q: list all forms of energy in Sun?

Q: how can you tell which is the fuel supply?

we know (from radioactive dating) that

Sun lifetime $\tau_\odot >$ Solar System age $= 4.5$ billon years

But: this requires enormous fuel supply $E_{\text{fuel},\odot} = L_\odot \tau_\odot$

Compare possible Solar energy sources:

- rotational energy (spin down, release KE):
  $\tau_{\text{rot}} = 100$ yr
- chemical energy (make entire Sun from TNT!):
  $\tau_{\text{chem}} = 20,000$ yr
- gravitational energy (contract $\rightarrow$release grav PE)
  $\tau_{\text{grav}} = 20$ million years $= 0.02$ billion years

Q: implications?