Astro 350

Lecture 7

Sept. 12, 2012

Announcements:

- *Homework 2* due at start of class Friday
  **Note**: problem 5(a) wording clarified on Monday
- Office hours: Prof–today 1-2pm or by appt; TA tomorrow
- *Discussion 2* due today
- *Discussion 3* on Compass, due next Wednesday

Last time: light and stars

*Q: What is radiation? electromagnetic radiation? examples?*

*Q: What is luminosity $L$? give example using lightbulb?*

*Q: flux or intensity $F$? give example using lightbulb?*

*Q: how to find masses of binary stars? how do they compare to $M_{\rm sun}$?*

# Star Distances and Parsecs

from parallax $p$ find distance

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

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

# Star Luminosity

armed with distances to stars,
can find their luminosities
how?

- measure brightness = intensity or flux $F$
- measure distance $d$
- since $F = L/4\pi d^2$, solve: $L = 4\pi d^2 F$

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 $4 \times 10^{33}$ 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!
typical mass, typical luminosity
note how this fits well into the "Copernican worldview"

# Galaxies: Sweet Home Milky Way

# iClicker Poll: Our Milky Way Galaxy

Milky Way to eye: irregular band of light `www: MW mosaic, closeup of dark lane`

What is the dominant Milky Way light source?

A predominantly gas

B predominantly stars

C roughly equal mix



*Q: MW is band on 2-D sky–what about 3-D space?*

# Our Milky Way Galaxy: Where are we?

Galileo's telescope showed: MW made of stars
eye can't separate, light blends together

MW band in 2-D sky $\rightarrow$ 3-D disk of stars
note similarity with planar concentration of planets in SS

where are we in the disk–near middle or edge?
`www: MW mosaic`
on MW band in sky, stars $\approx$ evenly distributed
*Q: simplest interpretation?* `www: Herschel model (1700's)`
*Q: loophole in the argument?*

clue: dark strips in MW

interstellar space is not empty!

though less dense than the best vacuum that can be made in the laboratory

about 95% of interstellar mass is *gas*–mostly H and He

and about 2% of mass is "stardust"

**dust**: microscopic interstellar solid bodies

made of heavier elements ("metals" = not H, He)

`www: interplanetary dust under microscope`

dusty interstellar gas is like "cosmic smog"
$\rightarrow$ dust absorbs visible light
$\rightarrow$ only see small part of MW disk
this fact only verified in 20th century

But then: How to determine MW structure and size?

H. Shapley (1910's): **globular clusters** of stars
most lie out of disk plane $\rightarrow$ we have unobscured view

*Q: how does sky pattern of GC's tell where we are?*

If we are at MW center:
$\rightarrow$ see GC's evenly spread around the sky

If we are off-center:
$\rightarrow$ see GC's more on one side of sky
$\rightarrow$ that's Galactic "downtown"

`www: observed GC sky distribution`
$\star$ *we are not at the Milky Way center!*

high-tech update:
dust obscures *visible* light, but not longer wavelengths
dust "invisible" if $\lambda \gg$ dust size
so infrared, radio telescopes *can* see all of MW
will see: these confirm we are off-center

# Revolution Revisited

Cosmologist Y. Berra: *It's déjà vu all over again!*

**Copernican Revolution I (17th Century)**:
we're one typical planet among many
  not center of solar system

**Copernican Revolution II (earth 20th Century)**:
we're one typical star among many
  not center of Milky Way Galaxy

... stay tuned for more...

# Observed Milky Way Structure

Milky Way contains about $10^{11} = 100$ billion stars

**I. Disk Components**: most of luminous matter
radius $R \sim 15,000$ pc $= 15$ kpc (kpc = kiloparsec = 1000 pc)
thickness $h \sim 200$ pc at our location: thin!
`www: IRAS full sky: dust. False color, Galactic coords`
`www: DIRBE near-IR image: cool stars`
note–confirms our suburban location!
1. disk contains most stars
2. also dust, gas $\rightarrow$ fuel for star formation

*Disk Structure*
- disk thickest in center, tapers off outward
- disk shows evidence for spiral arms
  $\rightarrow$ we are spiral galaxy! (as in `www: M104`)

## II. Spherical Components

1. bulge at center (old stars, can see in DIRBE image)
2. globular clusters
3. "halo" of old stars

## Milky Way Dynamics

in MW, all objects exert gravity on all others

$\rightarrow$ everything accelerating

$\rightarrow$ everything is in motion

# Milky Way Rotation

measure speeds of stars, gas via Doppler effect
complication: we are moving too

stars orbit MW center
disk stars: $\sim$ circular orbit $\rightarrow$ disk rotates
but disk stars *don't* spin like frisbee (i.e., a solid object)
*Demo*: frisbee: rigid rotation
in time Sun goes around once
stars closer to center go around more than once
stars further out — less than once
$\rightarrow$ "differential rotation"

how measure rotation speeds?
use halo stars, globular clusters (don't rotate)
Sun orbit speed: $v_\odot = 220$ km/s
at our location $R_\odot \simeq 8$ kpc (about halfway out!)

# Milky Way Dynamics

Milky Way stars orbit Galactic center
orbits roughly circular

MW rotation pattern:
plot **rotation curve:** orbit speed vs distance from center

as a warmup:
*Q: rotation curve for points on frisbee (all same period $P$)?*

# iClicker Poll: Solar System Rotation Curve

Rotation curve: plot orbit speed $v$ vs distance $R$

What is the rotation curve shape for solar system objects?

A $v$ increases with increasing $R$

B $v$ constant with increasing $R$

C $v$ decreases with increasing $R$

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*Q: why this trend?*

# Milky Way Rotation Curve

`www: Milky Way rotation curve data`

find $v \sim const$ beyond $R \sim 2$ kpc

"flat rotation curve"

speed stays constant (still flat) out to largest $R$

*even when there are no more stars/gas/dust!*

compare/contrast: solar system rotation curve

*Q: what does the MW/SS difference mean?*