Astro 210
Lecture 7
Sept. 11, 2013

Announcements:

- **PS 2 due Friday**
- PS1 returned today–people did well!
- Office hours: today 1–2pm or by appointment
  TA: tomorrow 1–2pm
- ASTR 401: abstracts due next Monday
- Learning names: *Say cheese!*
  identify yourself on Compass, earn easy bonus points

Last time: first look at the Milky Way

Today: exploring the Milky Way

- the observed Milky Way on the 2-D sky
  Q: What is geometry of the sky as observed from Earth?
- our home Galaxy in 3-D space

The Observed Sky: Celestial Sphere

In reality: cosmic objects arranged in 3-D space

But: can't directly tell distance to these objects

no "sense of depth"

So observationally: the sky "flattened" into a 2-D surface $\rightarrow$ we see the Galaxy and Universe in projection: "cosmic roadkill"

sky geometry: spherical

observations measure object direction = angular coordinates on imaginary **celestial sphere**

- fixed, unmoving sphere of infinite radius
- centered on the Earth

Q: star paths during one night, seen from Chambana?

Milky Way: Overview and History

Galileo (1610): first telescope for astronomy
revolutionized our view of the universe, e.g.

- Venus phases ruled out Earth-centered (geocentric) cosmology
- away from Milky Way discovered stars too faint for naked eye
  philosophical problem: what's the use of stars we can't see?

observing Milky Way's light:
  Galileo saw it is *made of stars*

- huge numbers of stars
- very crowded on sky
- individually very faint

eye can't see MW stars individually, light blends together

MW band on 2-D sky is a great circle
Q: what's that?
Q: what does this mean for MW in 3-D space?

Circles of Greatness

great circle: largest possible circle on a sphere

Milky Way band makes great circle on projected 2-D sky
i.e., largest possible circle on celestial sphere

but great circle is intersection of sphere and plane
$\rightarrow$ in 3-D, Milky Way stars are in flattened plane/disk
...and we live inside the disk!

the Sun lives inside the Milky Way disk

Milky Way Pioneers

Why a disk?

Immanuel Kant: gravity + spin (ang. mom.) $\rightarrow$ disk

diagram: collapse to disk

How big is it? Where in the disk do we live?

Sir William Herschel ($\sim$ 1780)

star counts $\rightarrow$ geometric model

Q: how would you do this?

Q: what assumptions needed?

`www: Herschel universe`

Herschel universe:

- Milky Way brightness roughly uniform around sky
- assuming no stars are hidden $\rightarrow$ we are nearly at center!

John Dreyer 1888:
New General Catalogue (NGC) of nebulae.
almost no nebulae within $\pm 15^\circ$ of Galactic plane
"zone of avoidance"

`www: zone of avoidance`

Jacobus Kapteyn 1920's: photographic survey of MW
model: Kapteyn's universe
galaxy size ~ 1000 pc $= 1$ kpc
assumption: stars unobscured: interstellar space empty
but if interstellar matter, starlight can be scattered or absorbed

`www: sunset`

Q: what would this mean for the survey?

Experimentum Crucis

Harlow Shapley 1910's:
used globular clusters of $10^4 - 10^6$ stars
`www: globular cluster`

globular clusters appear all over sky
most lie out of disk plane $\rightarrow$ we have unobscured view

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

center of globular cluster swarm should be MW disk center
Q: why? what if off-center? How would they move?

If we are at MW center:
→ should see GC's evenly spread around the sky: "isotropic"

If we are off-center:
→ should see GC's more on one side of sky: "anisotropic"
→ that's Galactic "downtown"

`www: Shapley's observed GC sky distribution (1918)`
⋆ *we are not at the Milky Way center!*

∞ *Q: How reconcile with off-center location with star counts?*

Strange Things are Afoot at the Circle K

dark bands in MW, zone of avoidance: absorbing medium?

`www: MW optical`

`www: MW zoom`

E. E. Barnard (1907, 1910)

noted "vacancy" on the sky, now called "*dark clouds*"

`www: Barnard's images; modern images of dark clouds`

"It almost seems to me that we are here brought face to face with a phenomenon that may not be explained with our present ideas of the general make-up of the heavens." –Barnard 1907

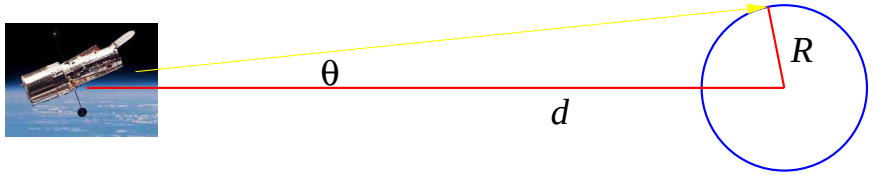
Playing the Trump Card

R. J. Trumpler (1930)
studied open star clusters (bright, newborn stars)
`www: open cluster`
compared open cluster distances measured two ways

angular diameter distance

- assume: all same physical size R
- measure angular size θ on sky
  geometry says $\theta = r/d$

$\Rightarrow$ solve for distance $d_A = R/\theta$



luminosity distance

- assume star luminosities similar from cluster to cluster
  i.e., use cluster stars as *standard candles*: same L
- measure flux F, use inverse square law

$\Rightarrow$ solve for distance $d_L = \sqrt{L/4\pi F}$

iClicker: Absorb This!

Imagine an absorbing medium is spread over interstellar space measure both $d_L = \sqrt{L/4\pi F}$ and $d_A = R/\theta$

What trends should we find?

A $d_L \leq d_A$, and d_L is true distance

B $d_L \geq d_A$, and d_L is true distance

C $d_L \leq d_A$, and d_A is true distance

D $d_L \geq d_A$, and d_A is true distance

E $d_L = d_A$, but neither is true distance

`www: Trumpler's data`

Trumpler found that for distant clusters, $d_L > d_A$
luminosity distance *larger* than angular diameter distance

also found stellar *colors* increasingly *red* with larger distance
Q: possible explanations? implications?

Discovery of the Interstellar Medium

Trumpler: F too small $\rightarrow$ starlight absorbed
$\rightarrow$ interstellar matter exists

interstellar matter mostly gas, but about 1% of mass is **dust**
`www: stardust`
microscopic $r \sim 1\mu = 1000nm$
strongly absorbs light with $\lambda \sim r$
$\rightarrow$ visible, some IR blocked– "in fog"
but more transparent when $\lambda \gg r$ and $\lambda \ll r$
e.g., radio, γ-ray

Also note:
absorption $\rightarrow$ more to picture than meets eye
$\rightarrow$ scale of MW goes up!
$\rightarrow$ Hershel confused by "fog" of dust: we are not at the center!

Celestial Sphere: Coordinate Systems

points on the *sky* specified by 2 coordinates on celestial sphere
points in 3-D space need distance as well

Equatorial Coordinates: based on Earth spin $\vec{S}$
northe celestial pole = direction of $\vec{S}$
points: RA = α, dec = δ
`www: S&G equatorial coordinate diagram`

Q: why is this system useful?
Q: why is this system inconvenient for Galactic studies?
Q: what would be a better choice?