Astro 350
Lecture 16
Sept. 30, 2011

Announcements:

- HW4 due now
- HW5 available, due next time
- Hour Exam 1 back next time (mea culpa!)

FYI: Bigshot cosmologist in the house!
Dr. Jonathan Gardner
a lead scientist on James Webb Space Telescope
successor to Hubble

- Public Talk: Tue Oct 4, 7:30pm, 151 Loomis (Physics bldg)
  "A Scientific Revolution: the Hubble and James Webb Space Telescopes"
- Astro Colloquium: Tue Oct 4, 4pm, 134 Astronomy bldg
  "The James Webb Space Telescope"
- informal seminar: Tue Oct 4, 2pm, 134 Astronomy bldg
  "How to get a job working for NASA"

Last time: Milky Way rotation curve and dark matter

Q: what's a rotation curve?
Q: what is the rotation curve of the MW?
Q: how does it tell us there is dark matter?

Q: what is another way to explain the rotation curve without any dark matter at all?
Q: what is attractive about this idea? unattractive?

Alternative Hypothesis: Gravity's Broke!

rotation curve data are what they are
surprise when compared to theory prediction
but theory based on Newtonian gravity theory

and, looking ahead, Einstein's General Relativity gives same prediction

but *theory & data don't agree*

- maybe like 18th Century observations of Uranus' orbit
  $\rightarrow$ keep theory, but need new matter (Neptune)
- or maybe like Kepler's study of Mars' noncircular orbit
  $\rightarrow$ throw out busted theory, get a better one!

▷ if Newton correct on Galactic scales, then DM needed

alternatively: maybe Newton incorrect for Galaxy!

- new "modified" gravity theories have been proposed
  some already ruled out, but some not (yet?)!
- tricky — have to still accurately predict solar system motions
- and will find DM/alt gravity needed beyond Milky Way
  difficult to explain everything with simple mod grav theory
- also: very recent data may rule out
  most modified gravity theories

For most of the course:
we will assume Newton is correct, dark matter exists
but: remember how science works–humility/open mind essential!

my view: dark matter likely to exist
  but unproven till identified

Realm of the Nebulae

"Nebulae" – fluzzy pinwheels or blobs on sky
know for centuries (since telescope) `www: examples`
but are they in MW or beyond it?

key question: distance
Curtis-Shapley debate (1920): *What is the scale of the Universe?*

	H. Shapley	H. Curtis:
MW size	about 10 kpc	about 1 kpc
nebula distances	nearby, inside MW	far, outside MW
nebula sizes	small, like planetary nebulae	large, like our galaxy

turns out: both partially right, partially wrong
to settle the debate: need more data → need distance indicator
e.g., "standard candle"
Q: which is?

Hubble–The Man: Scale of the Universe

recall a **standard candle** is
object with known luminosity ("wattage") L
if know L, measure flux F, then $d = \sqrt{L/4\pi F}$

Edwin Hubble: grew up in Wheaton, college in Chicago
pioneered observations of galaxies

in 1920's: Hubble exploited variable stars: "Cephieds"
`www: animation`
pulsate due to instability in atmosphere
pulsation period related to luminosity
so measure period $\rightarrow$ know $L \rightarrow$ standard candle

Hubble found Cephied in M31 `www: Hubble's discovery image`
$\rightarrow$ established that it is 100's of kpc away
$\rightarrow$ extragalactic! "island universe"
"Realm of the Nebulae"

Galaxies

galaxies fill universe
typical separation $\sim 10^6$ pc $=$ 1 Mpc (megaparsec)
most distant 1000's of Mpc
$\Rightarrow$ galaxies are huge masses of stars

Galaxies sizes range large (like MW) to small "dwarf"
different shapes:

spiral: disk+bulge
gas, dust evident $\rightarrow$ star formation ongoing

elliptical: elongated sphere, no disk
no/very little gas, dust $\rightarrow$ star formation ceased

irregular: no simple geometry
gas, dust present $\rightarrow$ can form stars

Milky Way one of many galaxies $\rightarrow$ a typical spiral

Revolution Re-Revisited

Copernican Revolution I (17th Century):

Earth is one typical planet among many

not center of solar system

Copernican Revolution II (earth 20th Century):

Sun is one typical star among many

not center of Milky Way Galaxy

Copernican Revolution III (1920's):

Milky Way is one typical galaxy among many

Universe much larger than previously thought

... stay tuned for more...

iClicker Poll: Rotation Curves of Other Galaxies

Would like to compare Milky Way rotation curve
to those of other galaxies

Compared to the Milky Way,
measuring the rotation curve of a nearby galaxy is

A easier, but only if the galaxy's disk is seen edge-on

B easier, but only if the galaxy's disk is seen face-on

C always harder

D sorry, can't measure rotation curve of other galaxies

Galaxy Rotation Curves

`www: rotation curves`

Results:

- *all* galaxies show flat rotation curves
  similar to MW – we are not a weirdo!
- flat portion very clearly extends well beyond
  visible matter (stars/gas/dust)

Q: which means?

Galaxies Are Made of Dark Matter

Interpretation:

- *all* galaxies contain large amounts of dark matter!
- in fact, *most* have a *larger* proportion than in MW!

Dark matter fills the Universe!

all galaxies are made of it!

Any successful cosmology theory must

- include dark matter as a key ingredient
- explain what the DM is
- explain why we have so much of it

Galaxy Demographics

Diversity of galaxy shapes, sizes is hint to their origins
$\rightarrow$ very useful to know what is common, what rare

Galaxy Census: Shape ("Morphology")
Roughly: on average, find $\approx 1/3$ elliptical, 1/3 spiral, 1/3 irr
But really: depends on environment
  more ellipticals where galaxies densely packed
  fewer where galaxies sparse
Q: what might this mean?

Galaxy Census: Size (Really: Luminosity)
a wide range in galaxy luminosity & size seen
but clear trend: dwarf galaxies much more numerous
  than large galaxies (like ours!)
although: *visible mass* in large galaxies roughly comparable
  to mass in dwarf galaxies
Q: what might this mean?

Ellipticals numerous where galaxies densely packed
$\rightarrow$ maybe ellipticals come from collisions

Small galaxies more numerous than large
$\rightarrow$ maybe small galaxies made first
combine to form large galaxies

Both trends hint that collisions and mergers
play important role in galaxy evolution
Q: if so–how can we test this?

Evidence for Galaxy Interactions

If galaxy interactions are important and frequent
then we should be able to catch some "in the act"

Interactions are observed:

- ⋆ Milky Way currently "cannibalizing" dwarf galaxies
  which are passing through the disk!
- ⋆ merging galaxies seen, distorted due to mutual gravity
  center of merger $\rightarrow$ gas collides, compressed
  $\rightarrow$ high rate of star formation
- ⋆ starburst galaxies seen: high star formation
  due to recently completed merger?

Cosmology theory must include galaxy interactions!

Relativity

Why Relativity?

Cannot discuss cosmology without relativity!

Why?
cosmology is the history of the universe
  i.e., all space over all time
$\Rightarrow$ need scientific description, understanding of space and time

Relativity is the (modern) scientific theory of space and time

Jumping to the conclusion of the next few classes:
$\star$ the nature of space and time has many possibilities
  and each has measurable consequences
$\star$ the one we live in must be determined scientifically
$\star$ space, time, geometry are *experimental* questions!