Astro 210

Lecture 39

December 3, 2010

Announcements

- HW 10 due now

  No homework next week! Thanks and congratulations.
- Final Exam: Monday Dec 13, 7–10 pm, here as usual

  `www: info online`
- **ICES** course evaluation available online

  please fill it out–I *do* read & use results
- *check Compass GradeBook scores for accuracy*

Last time: our Milky Way Galaxy

- *Q: basic shape? where are we? how do we know?*
- *Q: rotation curve–what is it? what does it look like? What does it mean?*

Milky Way Galaxy and our Central Black Hole

Does everything orbit the supermassive black hole at the center?
$\rightarrow$ yes, but *not* because of the black hole

total Galaxy mass: $M_{\rm MW} \gtrsim 10^{11} M_\odot$
central black hole: $M_{\rm BH} = 4 \times 10^6 M_\odot \ll M_{\rm MW}$
$\Rightarrow$ black hole is *tiny* fraction of Galactic mass

In fact: high density of *stars* near the center
stellar mass $M_\star(r)$ inside radius r:
$M_\star(r) > M_{\rm BH}$ for $r \gtrsim 2$ pc!
$\rightarrow$ BH only dominates gravity of innermost 2 pc
we are at $r_\odot = 8$ kpc $= 8000$ pc!

So: stars *do* orbit the Galaxy's center
and the black hole does live there
but its gravity is not what keeps us in orbit

Galaxies: Beyond the Milky Way

Edwin Hubble (1920's):
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 structure ("morphology") & star, gas contents

spiral galaxies

- morphology: disk+bulge
- stars in both disk and bulge
- gas, dust evident in disk → ongoing star formation

`www: barred spiral zoom: star formation`

elliptical galaxies

- morphology: elongated sphere, no disk!
- stars in spherical/spheriodal distribution
- no/very little gas, dust!
  → no ongoing star formation–no ingredients!

irregular galaxies

- morphology: no clear, simple shape/symmetry
- stars, gas, and dust all present

`www: HST merging galaxies`

Milky Way one of many galaxies–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...

Motions Within Galaxies

galaxies have (huge) masses
→ each star feels gravity of all other stars
→ all stars are in motion

in spiral galaxies, disk stars in circular orbits around center
in elliptical galaxies, stars in elliptical-like orbits around center
Q: but then how does the galaxy have a spherical shape?

can measure rotation curves for galaxies:
→ in fact, it's easier than measuring our
own Galactic rot curve
Q: what's a rotation curve? what does ours look like?
what does it tell us?

iClicker Poll: Dark Matter in Other Galaxies

Our Galaxy has a "flat" rotation curve $\rightarrow$ dark matter
But what about other galaxies?

Vote your concience!

How common are flat rotation curves and thus dark matter?

A dark matter found in $< 1\%$ of galaxies

B dark matter found in $< 10\%$ of galaxies

C dark matter found in $< 50\%$ of galaxies

D dark matter found in $> 90\%$ of galaxies

If it isn't dark, it doesn't matter!

$\Rightarrow$**All** galaxies have dark matter

Dark matter "halo" much larger than visible galaxy
diagram

and **most** of every galaxy's mass
is in the form of dark matter!

Dark Matter fills Universe!

COSMOLOGY

Structure of the Universe

Galaxy distribution in space:

- small scales: clumpy
- large scales: smooth

`www: 2dF survey and map`

on large scales, Universe is

1. **homogeneous**:
   galaxies fill space with (nearly) uniform density
2. **isotropic**:
   universe looks same in all directions

Q: What's a U that is isotropic but not homogeneous?
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Motions of Galaxies

measure velocity respect to us
i.e., in galaxy spectra, look for shifts in lines

Results:
(almost) all galaxies show redshift
all galaxies move away from us!

Hubble (1929):
galaxy dist, speed related
$v \propto d$, or

$$\boxed{v = Hd} \tag{1}$$

$\rightarrow$ Hubble's law