Astro 210

Lecture 38

April 27, 2011

Announcements

- HW 11–last one! due Friday
- **ICES** course evaluation available online
  please fill it out–I *do* read & use results

Last time: changing gears

the Milky Way: our home galaxy

The Milky Way

`www:  MW mosaic`

`www:  MW dust lane closeup`

Milky Way to eye:
irregular band of light

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

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

dust: absorbs 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`
⋆ we are not at MW center!

modern 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 dej/'a 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 roughly $10^{11} = 100$ 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 coordinates`
`www: DIRBE near-IR image: cool stars`
note–confirms our suburban location!
1. disk contains most stars
2. also dust, gas → fuel for star formation

Disk Structure
- disk thickest in center, tapers off outward
- disk shows evidence for spiral arms
  → 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 *Q: how measure? complications?*

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"

rotation curve: measure rotataion speed at all R

iClicker Poll: Rotation Curve Warmup–Solar System

rotation curve: orbit speed v vs orbit distance r from Sun

What's the rotation curve for solar system planets?

A oribt speed v *increases* with increasing distance r

B v roughly *constant* at all r

C v *decreases* with increasing r

D v variation is *random* with r

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www: Solar System rotation curve

Q: why is the result the way it is?

Milky Way Rotation Curve

`www: MW rotation curve`
data: $v \sim const$ beyond $R \sim 2$ kpc

but recall: circular velocity $v_{\text{circ}} = \sqrt{GM/R}$
use to get mass interior to R: $M(R) = v_{\text{circ}}^2 R/G$

so:
1. at $M(R_{\odot} = 8\text{kpc}) \sim 8 \times 10^{10} M_{\odot}$!
2. if $v = v_{\text{circ}} = const$
   then $M \propto R$
   $M(16\text{kpc}) = 2M(8\text{kpc}) = 1.6 \times 10^{11} M_{\odot}$
3. once outside of all mass, $M(R) = M_{\text{tot}}$, and
   $v_{\text{circ}} \propto 1/\sqrt{R}$: not seen!
   mass grows even beyond
   where stars, gas stop
   $\rightarrow$ infer large mass which doesn't glow

Q: what does this imply? what's the alternative?

Dark Matter

MW mass estimate (rot curves):
$M_{\mathrm{MW}} = 5 - 10 \times 10^{11} M_{\odot}$ total
but stars & gas: $M_{\star} \simeq 10^{11} M_{\odot}$
$\rightarrow$ only $10 - 20\%$ of total!
most of MW matter is dark

Milky Way mass mostly **dark matter**

What are possible dark matter forms? – Hints:
▷ matter: must have mass (gravity)
▷ dark: must not glow

Alternative: serious problems with our theory of gravity!
...but this is General Relativity–works spectacularly well
when we can test carefully

Possible Dark Matter Candidates

What is the DM? Unknown (to date). Guesses:

black holes neutron stars white dwarfs "failed stars" – "Jupiters," brown dwarfs	} compact objects

hot $\sim 10^6$K gas (emits X-rays, but not visible light)

neutrinos

exotic particles left over from big bang

iClicker Poll: Dark Matter

Vote your conscience!

Which seems the most likely dark matter candidate?

A hot gas

B black holes/white dwarfs/neutron stars

C neutrinos

D exotic particles left over from big bang