

Astro 210  
Lecture 38  
April 25, 2018

Announcements:

- **HW 11: The Final Frontier posted, due 5:00pm Friday**
- Grades: we are catching up! keep checking Moodle

# Galaxies: Sweet Home Milky Way

# 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?*

## iClicker Poll: The Milky Way that Meets the Eye

Vote your conscience!

What's the main source of light in the naked-eye MW?

- A** predominantly gas
- B** predominantly stars
- C** roughly equal mix

# The Milky Way: Our Home Galaxy

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

MW band: a great circle in 2-D sky

→ 3-D **disk of stars**, with the Sun inside the disk

note similarity with planar concentration of planets in SS

*where are we in the disk:*

*near middle or edge?*

www: MW mosaic

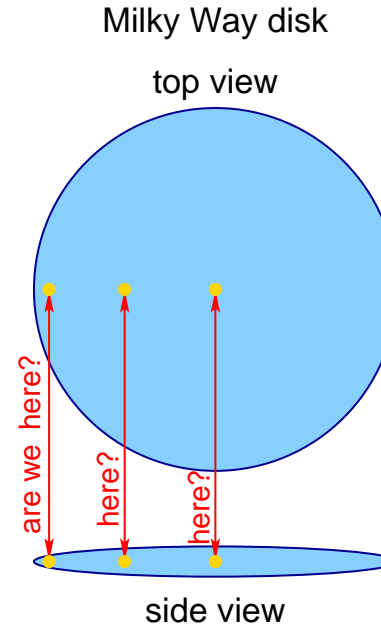
on MW band in optical sky:

*stars  $\approx$  evenly distributed*

*Q: simplest interpretation?*

51 www: Herschel model (1700's)

*Q: loophole in the argument?*



# Finding Our Place in the Milky Way

clue: dark strips in MW

**dust**: absorbs light → only see small part of MW disk  
this fact only verified in 20th century

*But if we can't see through disk:*

*How to determine MW structure and size?*

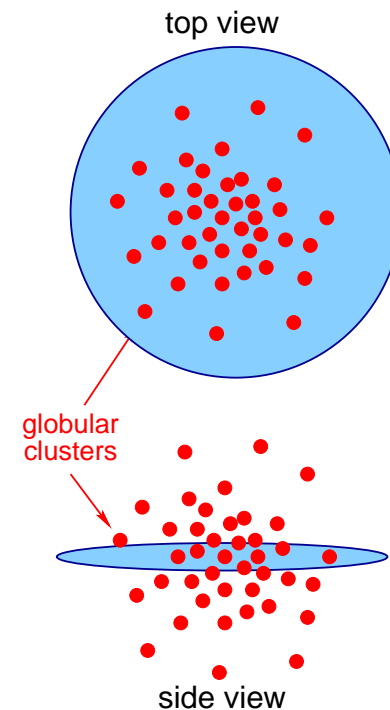
H. Shapley (1910's):

**globular clusters** of stars

most lie **out** of disk plane

→ we have unobscured view

- o *Q: how does GC sky pattern tell where we are?*



# We Are Off-Center

If we are at MW center:

→ see GC's evenly spread around the sky

If we are off-center:

→ see GC's more on one side of sky

→ that's Galactic "downtown"

www: observed GC sky distribution

★ **we are not MW center!**

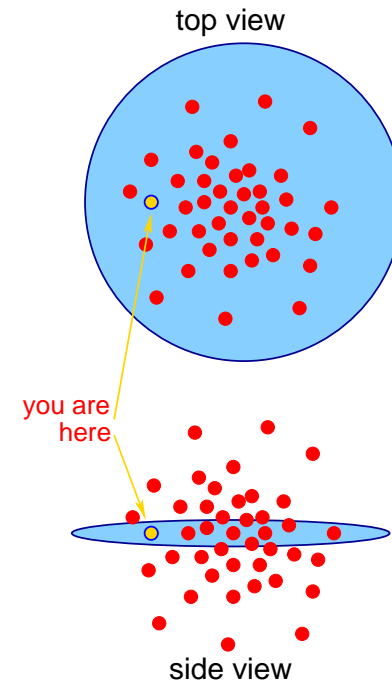
modern update:

*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

**I. Disk Components:** most of luminous matter

www: IRAS full sky: dust. False color, Galactic coordinates

www: DIRBE near-IR image: cool stars

1. *disk contains most Milky Way stars*

roughly  $10^{11} = 100$  billion of them!!

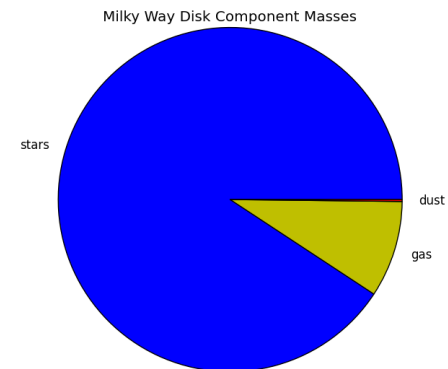
2. *disk contains all MW gas*

(atomic, molecular, ionized)

fuel for new stars:

*star formation occurs in disk*

but total gas mass  $\approx 10\%$  of stellar mass



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3. *disk also contains all dust*

but total dust mass  $\approx 2\%$  of gas mass

## *Milky Way Disk Structure*

radius  $R \sim 15,000$  pc = 15 kpc (kpc = kiloparsec = 1000 pc)

thickness  $h \sim 200$  pc at our location: thin!

- disk thickest in center, tapers off away from center and up from midplane
- disk shows evidence for spiral arms  
→ we are spiral galaxy! (as in www: M104)

## **II. Milky Way Spherical Components**

1. bulge at center (old stars, can see in DIRBE image)  
spherical distribution of stars
2. “halo” of old stars extends from central bulge
3. globular clusters

## Milky Way Dynamics

in MW, all objects exert gravity on all others

→ everything accelerating

→ everything is in motion

*Q: how measure? complications?*

## Milky Way Rotation

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

dis stars and gas orbit MW center

disk stars:  $\sim$  circular orbit  $\rightarrow$  **disk rotates!**

but disk stars *don't* spin like frisbee (i.e., a solid object)

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:** plot orbit speed  $v_{\text{circ}}(R)$  vs orbit radius  $R$

# 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 orbit 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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# Milky Way Rotation Curve

www: MW rotation curve

data:  $v \sim \text{const}$  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  $v = v_{\text{circ}} = \text{const}$

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

→ infer large mass which doesn't glow

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

# Dark Matter

MW mass estimate (rot curves):

$M_{\text{MW}} = 5 - 10 \times 10^{11} M_{\odot}$  total

but stars & gas:  $M_{\star} \simeq 10^{11} M_{\odot}$

→ 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

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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

## Dark Matter: Results to Date

Dark matter identity is still *unknown*

⇒ one of the top questions in all of science!

But we *do know* what dark matter *is not*

- hot gas **X ruled out**
- black holes/white dwarfs/neutron stars **X ruled out**
- neutrinos **X ruled out**
- ★ **exotic particles left over from big bang** *not ruled out*

18 The most exotic possibility is the only one left standing!  
more on this as we discuss cosmology...